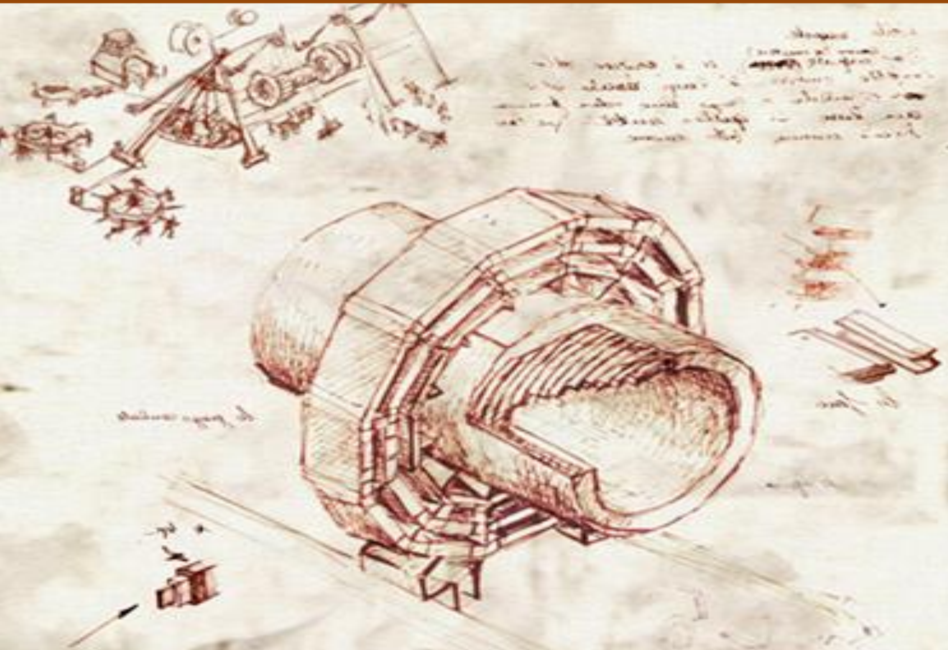
John Adams Institute for Accelerator Science

Imperial College London

Royal Holloway University of London

University of Oxford

Unifying physics of accelerators, lasers and plasma



LHC sketches by Sergio Cittolin (CERN) – used with permission

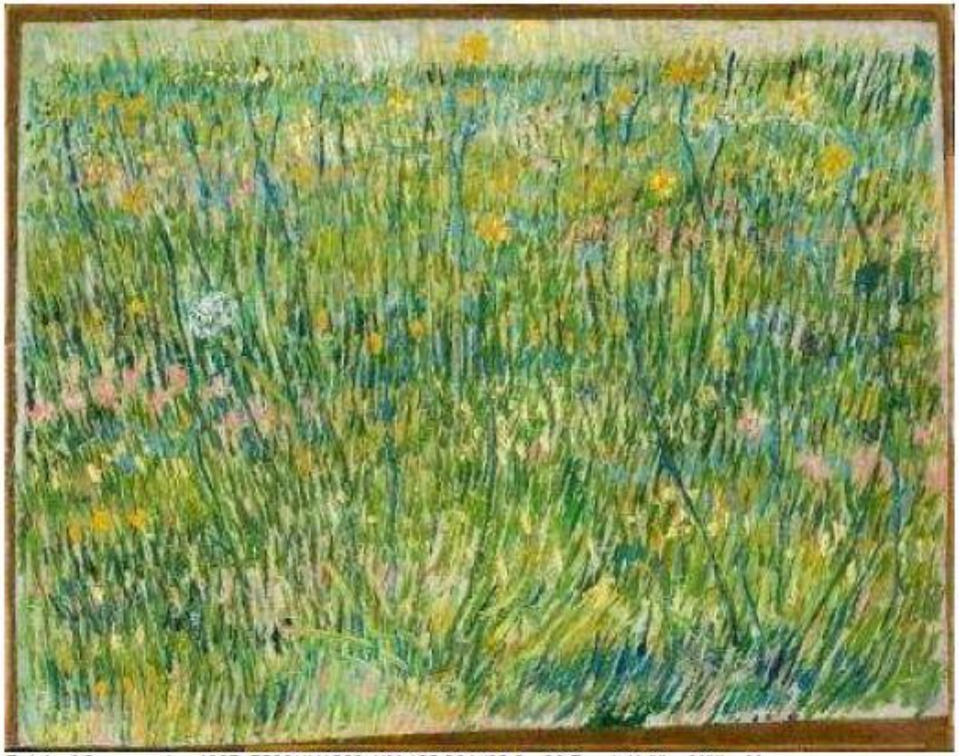
Prof. Andrei A. Seryi
John Adams Institute

Lecture 1: Basics of accelerators and the art of inventiveness

USPAS 2016

June 2016

Accelerators can study art



Patch of Grass, spring 1887, F583/JH1263, KM 105.264 (30,8 x 39,7 cm), Kröller-Müller Museum
(Photo: Rik Klein Gotink)

This painting "Patch of grass" by Vincent van Gogh was the first one analysed by a particle accelerator

It showed a portrait of a woman underneath

http://photon-science.desy.de/news__events/research_highlights/archive/visualizing_a_lost_painting_by_vincent_van_gogh/index_eng.html

Accelerators in archaeology

The interior of samples can be studied using accelerators without destroying them

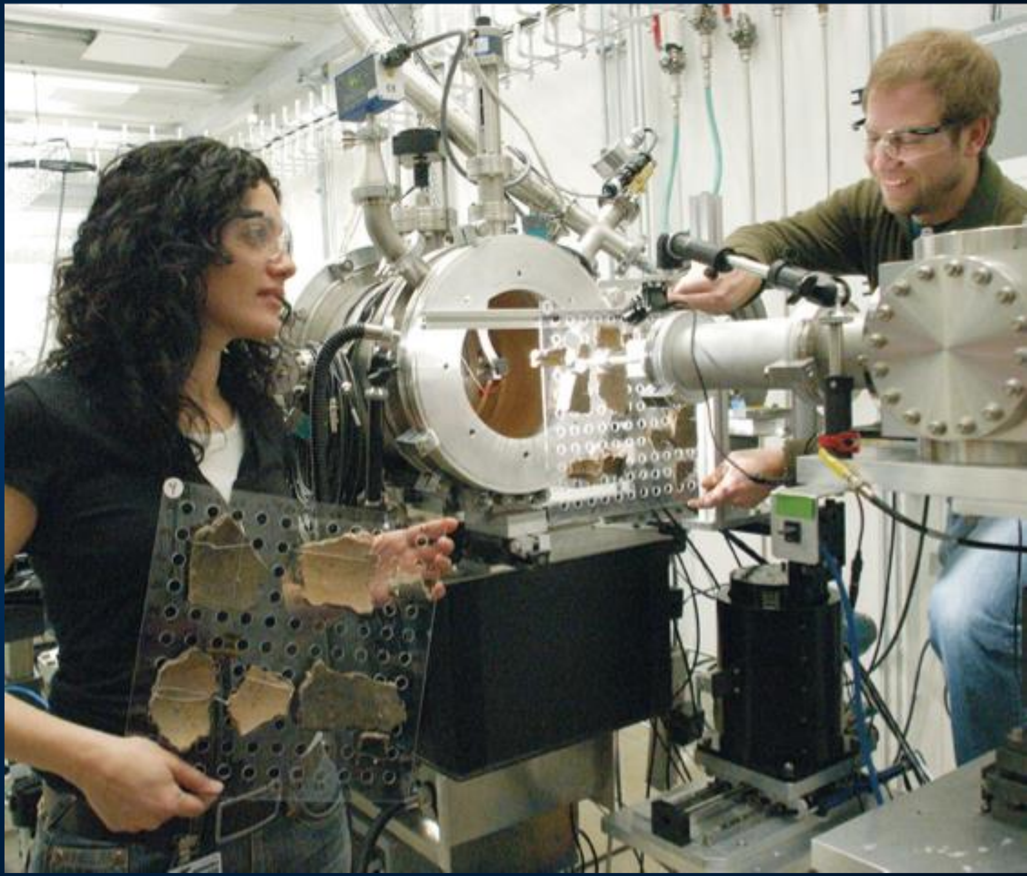


Image: Argonne National Laboratory

Pottery from Armenia, dating back to 1300 BC, is set up for a synchrotron experiment

Particle accelerators can read hidden text

Accelerators can detect the X-ray ‘signature’ of iron in ancient pigments

A written message can be revealed even on a folded manuscript which is too brittle to open

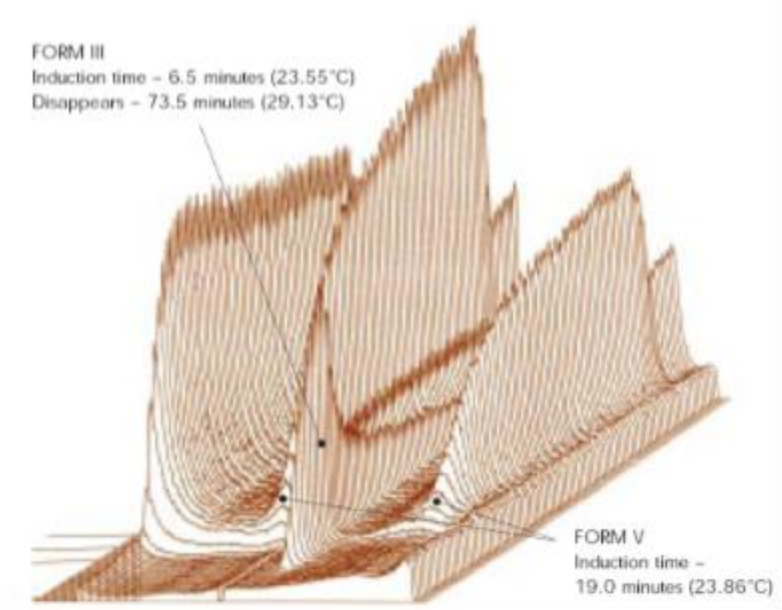
This method has also been used to analyse manuscripts and paintings that have layers of information from different authors

Photo: Graham Davis & Tim Wess

Accelerators can make food taste better

Cadbury used X-rays from a particle accelerator to study how cocoa crystallises

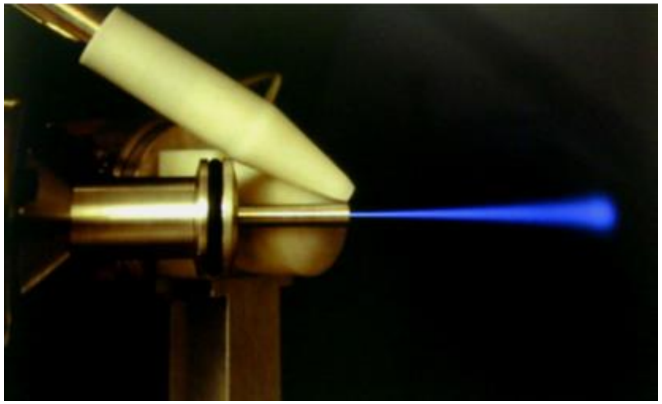
Of the six possible crystal forms, the fifth (form V) produces the best quality chocolate



Accelerators can help spot art forgeries

Ion Beam Analysis shows us the chemical composition of pigments used in paint

This allows art historians to compare them with paints available to artists like Leonardo da Vinci



Accelerators for imaging

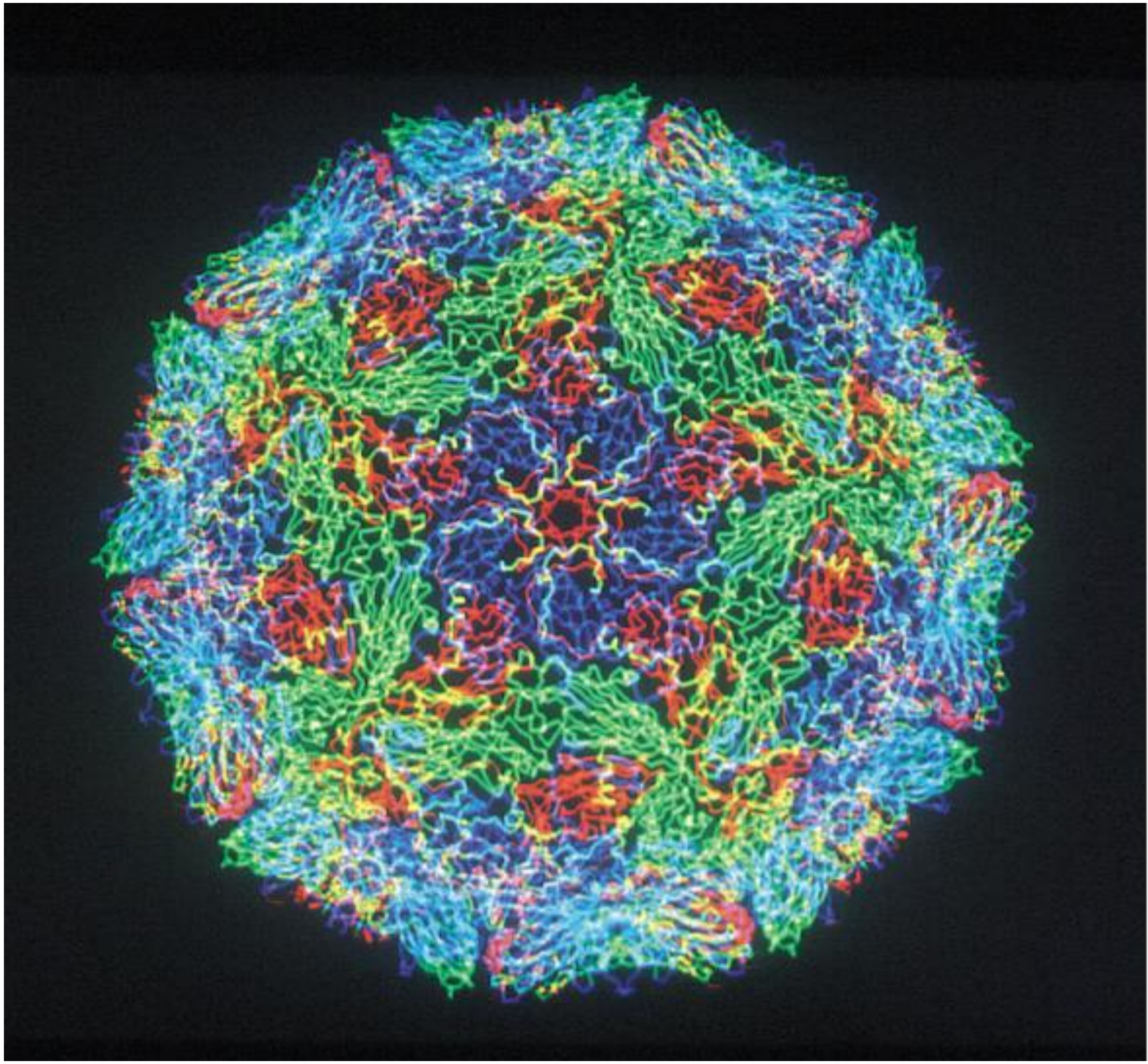
X-rays from electron accelerators produce extremely detailed images

This work helped scientists understand how beetles may have evolved

Image: The Field Museum of Natural History, Chicago, IL; and Argonne National Laboratory

Accelerators can see into viruses

In 1990, a team of scientists from Oxford used the particle accelerator at Daresbury to find the structure of a strain of the foot and mouth virus.



Particle accelerators for medical use

Most of them are used to treat cancer with X-ray beams (radiotherapy)

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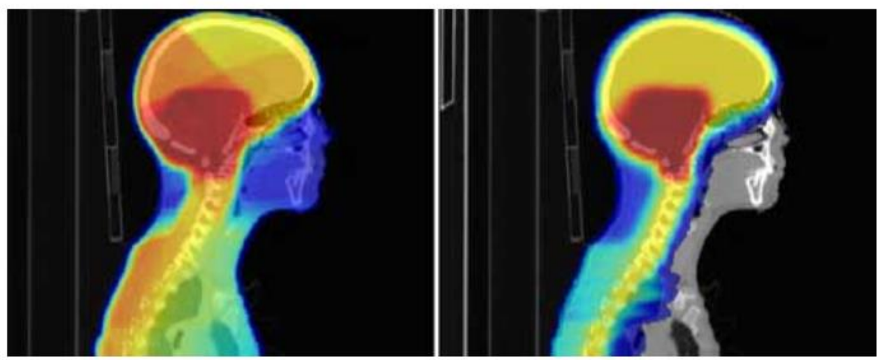
News archive

2014

£110 million for research into personalised cancer treatments

23 October 2014

A new university and business partnership is receiving £35 million of public investment in research to drive innovation and growth.



The funding will support the establishment of the Precision Cancer Medicine Institute (PCMI) at the University of Oxford, in collaboration with Oxford University Hospitals Trust. The PCMI will research a wide range of cancer therapies, including the use of genomics and molecular diagnostics, advanced cancer imaging, trials of new drugs, minimally invasive surgery and proton beam therapy. The project will receive £35 million of funding from the UK Research Partnership Investment Fund (UKRPIF), and has attracted an additional £75 million in private investment.

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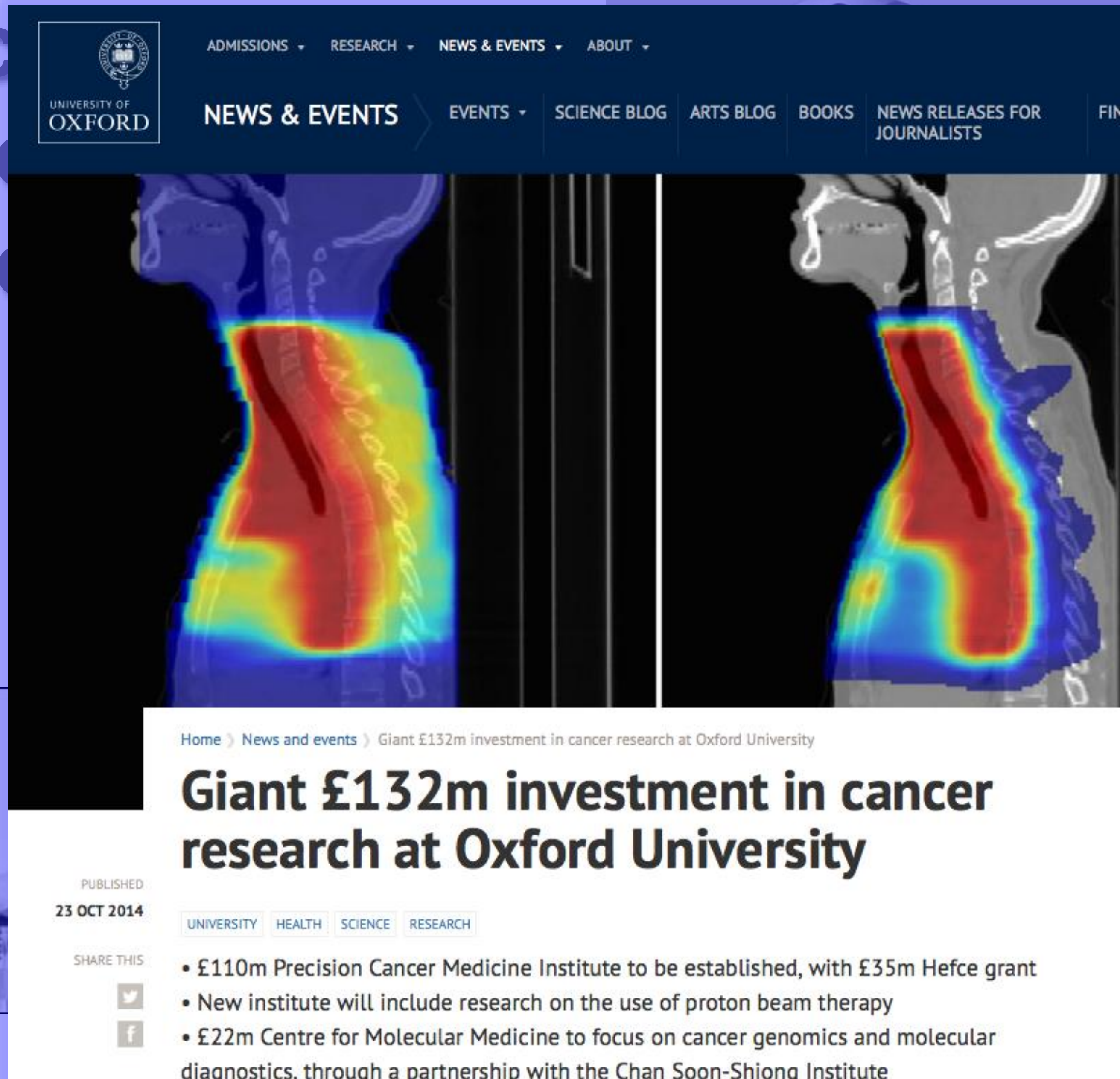

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Giant £132m investment in cancer research at Oxford University

PUBLISHED
23 OCT 2014

UNIVERSITY HEALTH SCIENCE RESEARCH

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- £110m Precision Cancer Medicine Institute to be established, with £35m Hefce grant
- New institute will include research on the use of proton beam therapy
- £22m Centre for Molecular Medicine to focus on cancer genomics and molecular diagnostics, through a partnership with the Chan Soon-Shiong Institute

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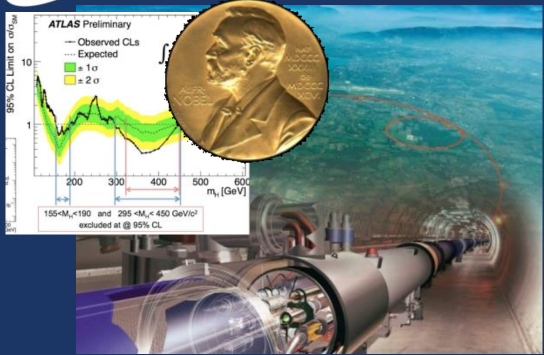
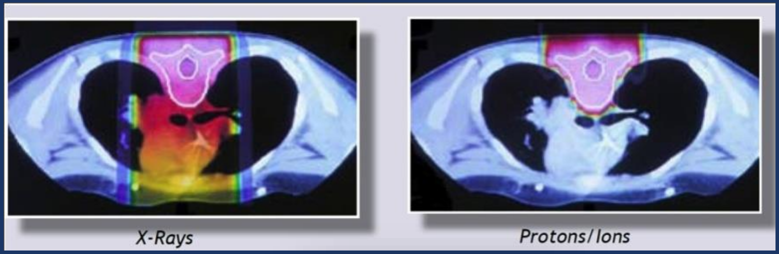
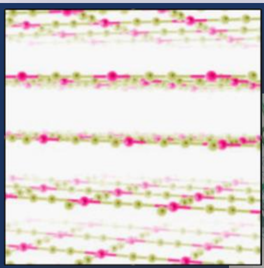
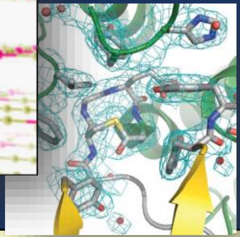
John Adams Institute for Accelerator Science

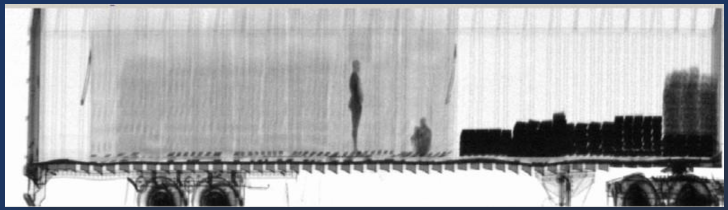
Accelerators for science and society











Accelerators: high energy physics, nuclear physics, healthcare, security, energy, life science, novel materials, industry…

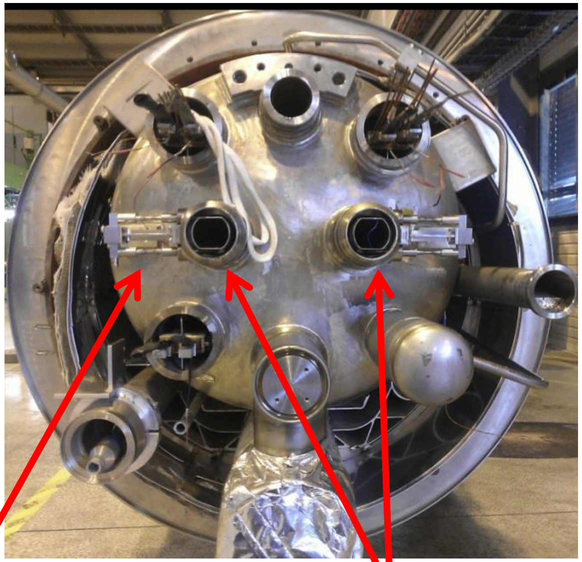
Tens of millions of patients receive accelerator-based diagnoses and treatment each year in hospitals and clinics around the world

All products that are processed, treated, or inspected by particle beams have a collective annual value of more than $500B

The fraction of the Nobel prizes in Physics directly connected to accelerators is about 30%

Accelerators and fundamental discoveries - Large Hadron Collider

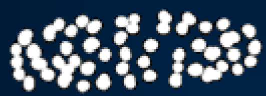
Peter Higgs and Francois Englert,
Nobel prize 2013



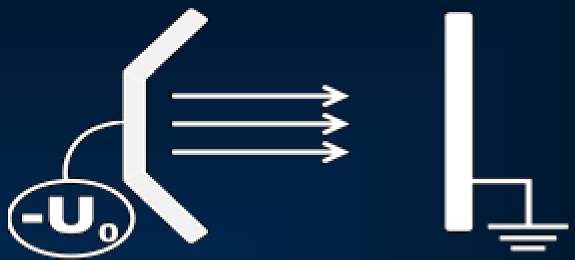
He-II vessel

Beam pipes

Acceleration of what and how



Beam of charged particles

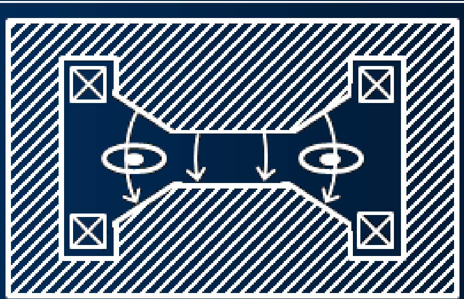


Electrostatic acceleration

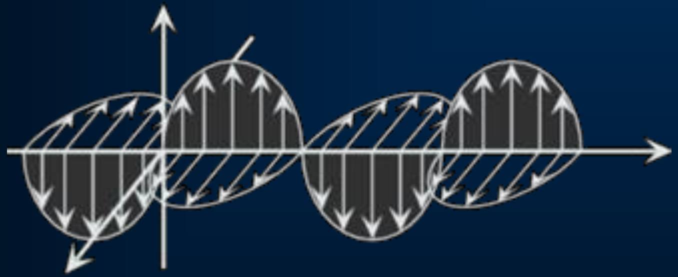
$$\oint \vec{E} \cdot d\vec{l} = -\frac{d}{dt} \int \vec{B} \cdot d\vec{S}$$

Changing B => Curl E

=>



Betatron acceleration

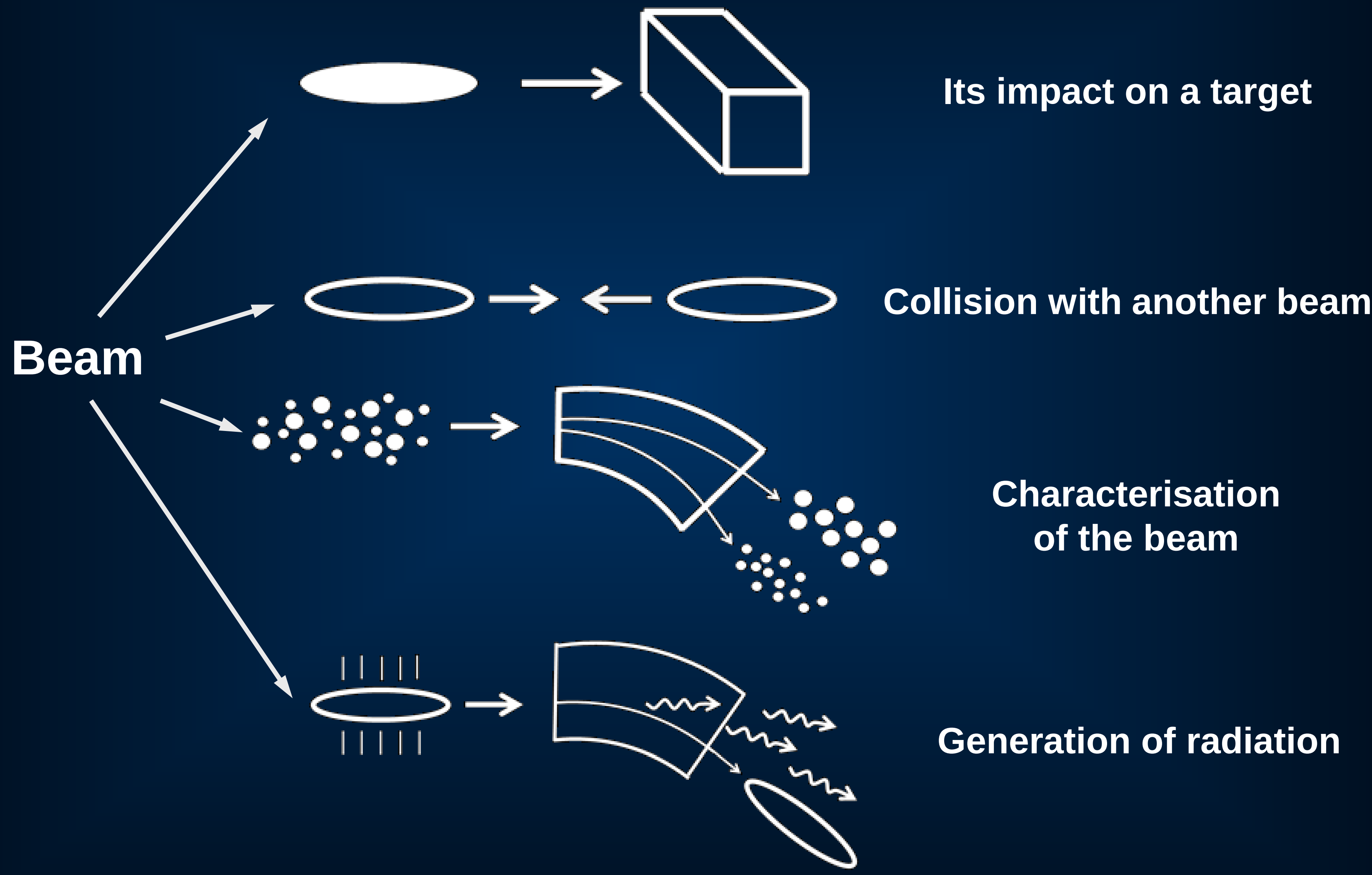


EM wave in space (cannot accelerate)

=>

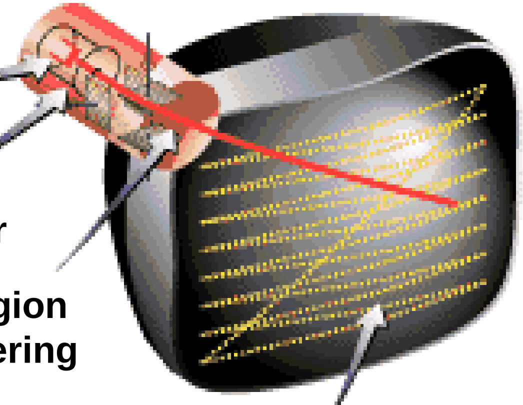
Accelerate with EM wave in structures

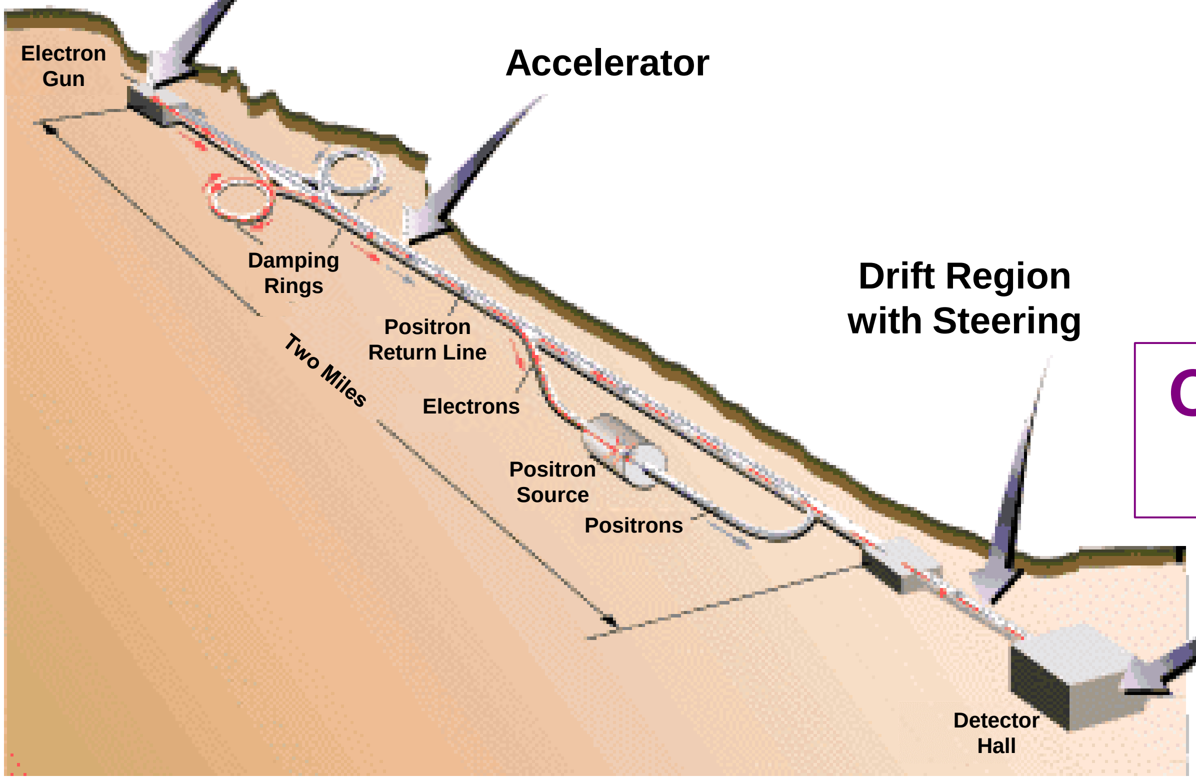
Why accelerate => uses of the beam



Accelerators – similarities in small & large

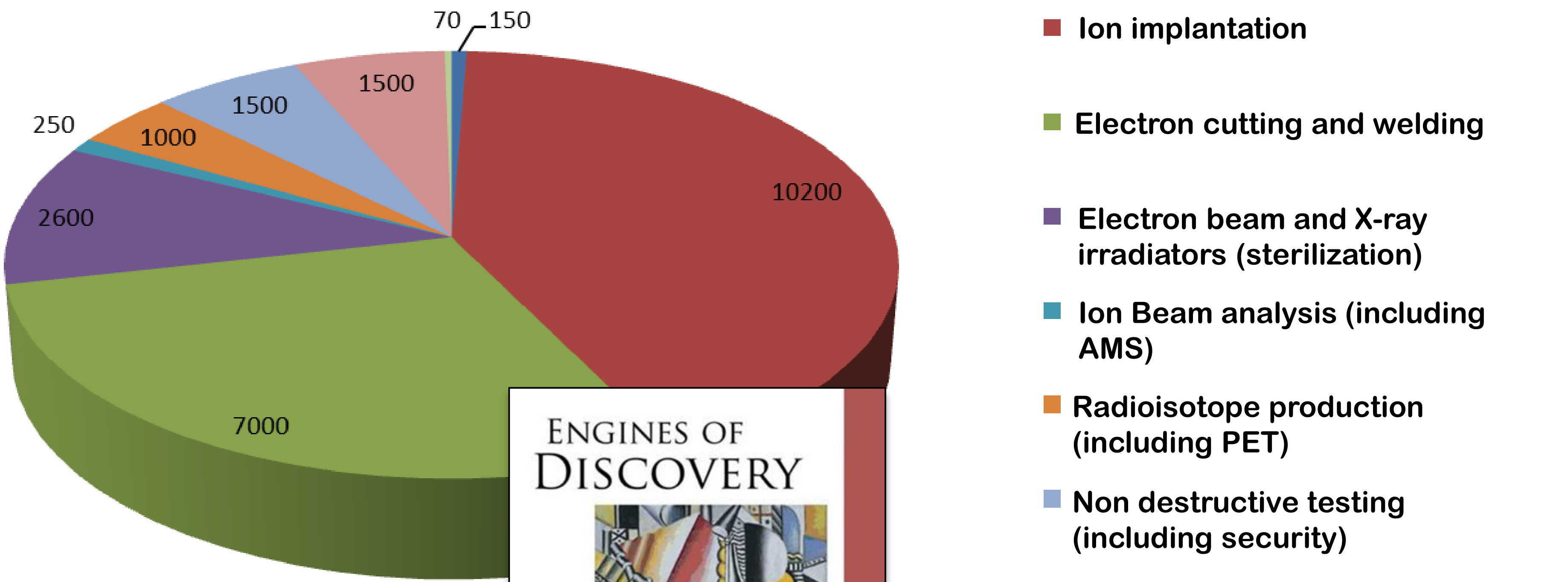
Internal workings of a TV or monitor

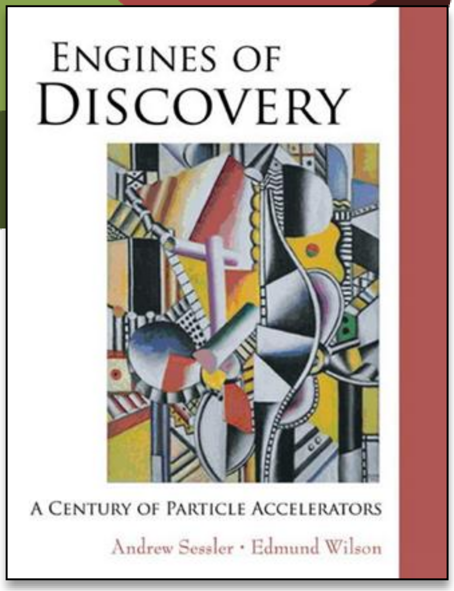




Cutaway view of the Linac

Accelerators in the world >24000





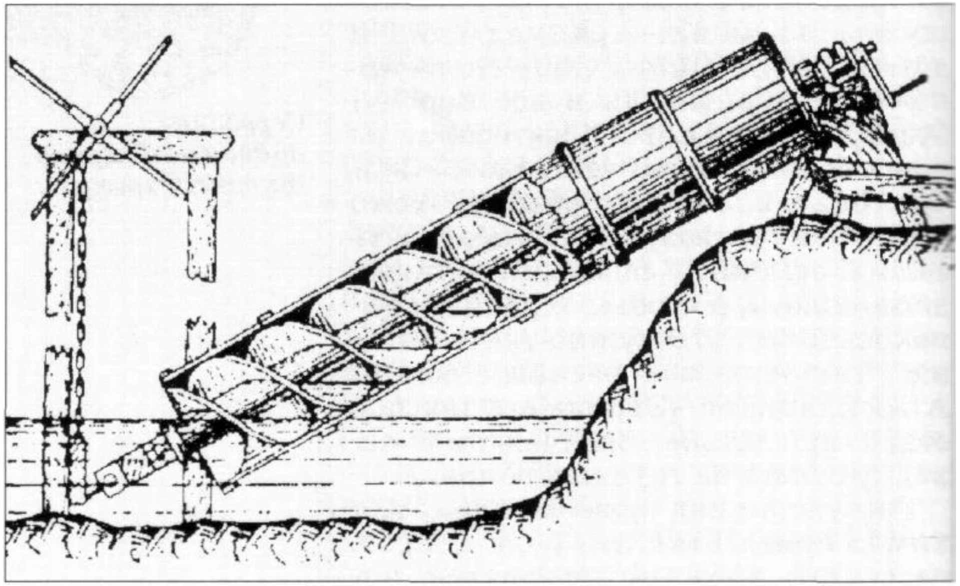
Engines of Discovery.
A Century of Particle Accelerators.
Andrew Sessler, Edmund Wilson

Source (2007):
http://www.worldscientific.com/worldscibooks/10.1142/6272

Accelerator science and inventions…

Accelerator science demonstrates rich history of inventions, often inspired by the nature itself

DNA



Accelerator science and inventions…

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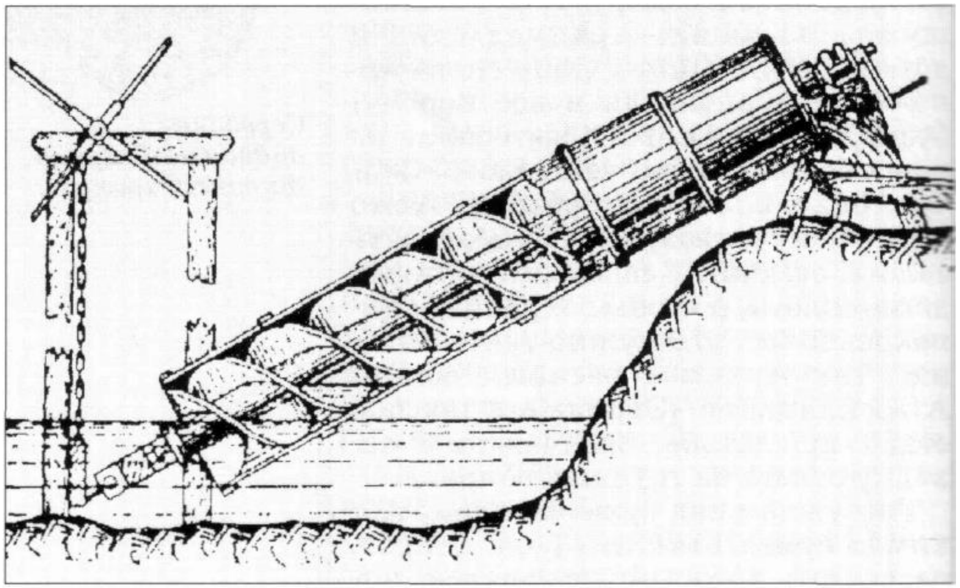
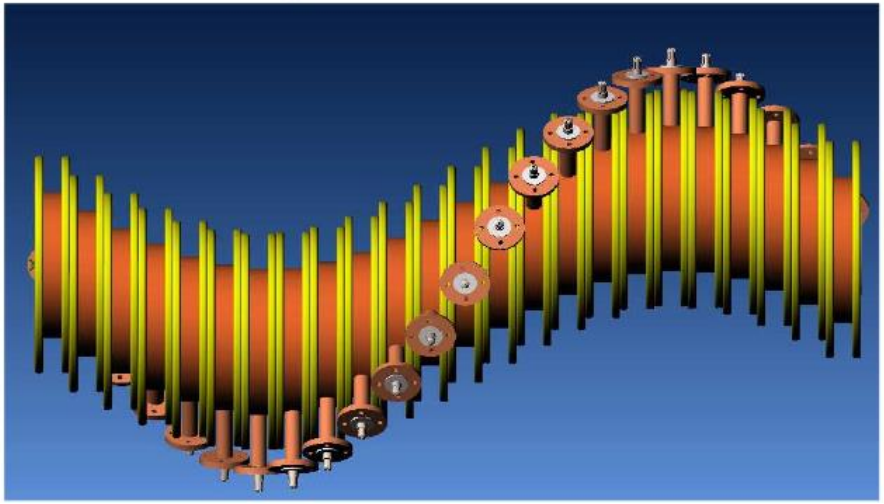


Muon Collider cooling channel … may have been inspired by the shape of DNA



Integrated Helical Solenoid, absorbers and accelerating resonators

Motivation behind inventions

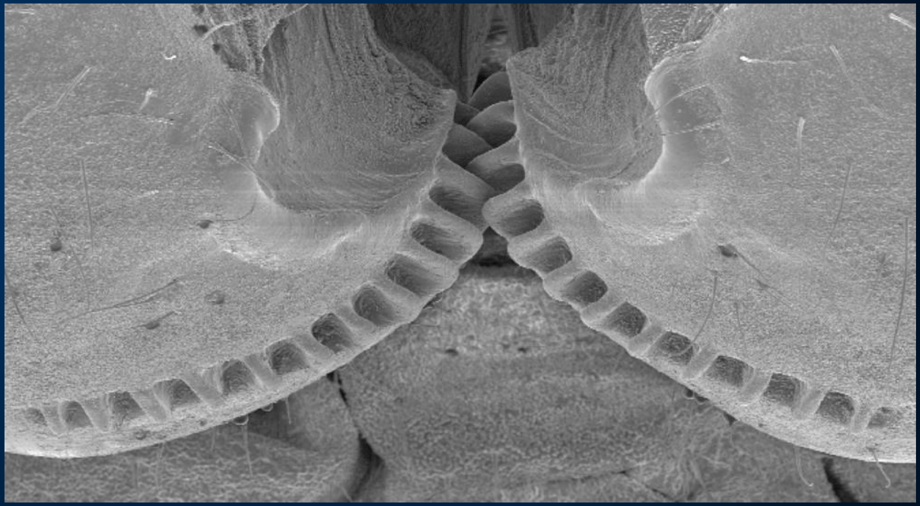
Technical inventions often inspired by nature itself

Were people the inventors of gears?

Motivation behind inventions

Technical inventions often inspired by nature itself (could be)

Were people the inventors of gears?

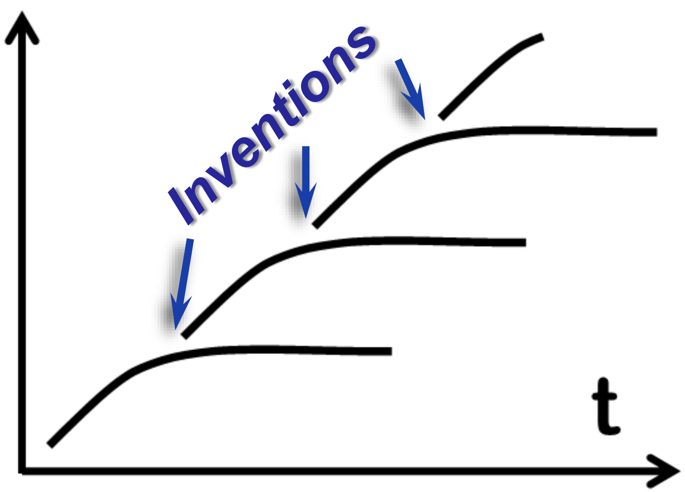


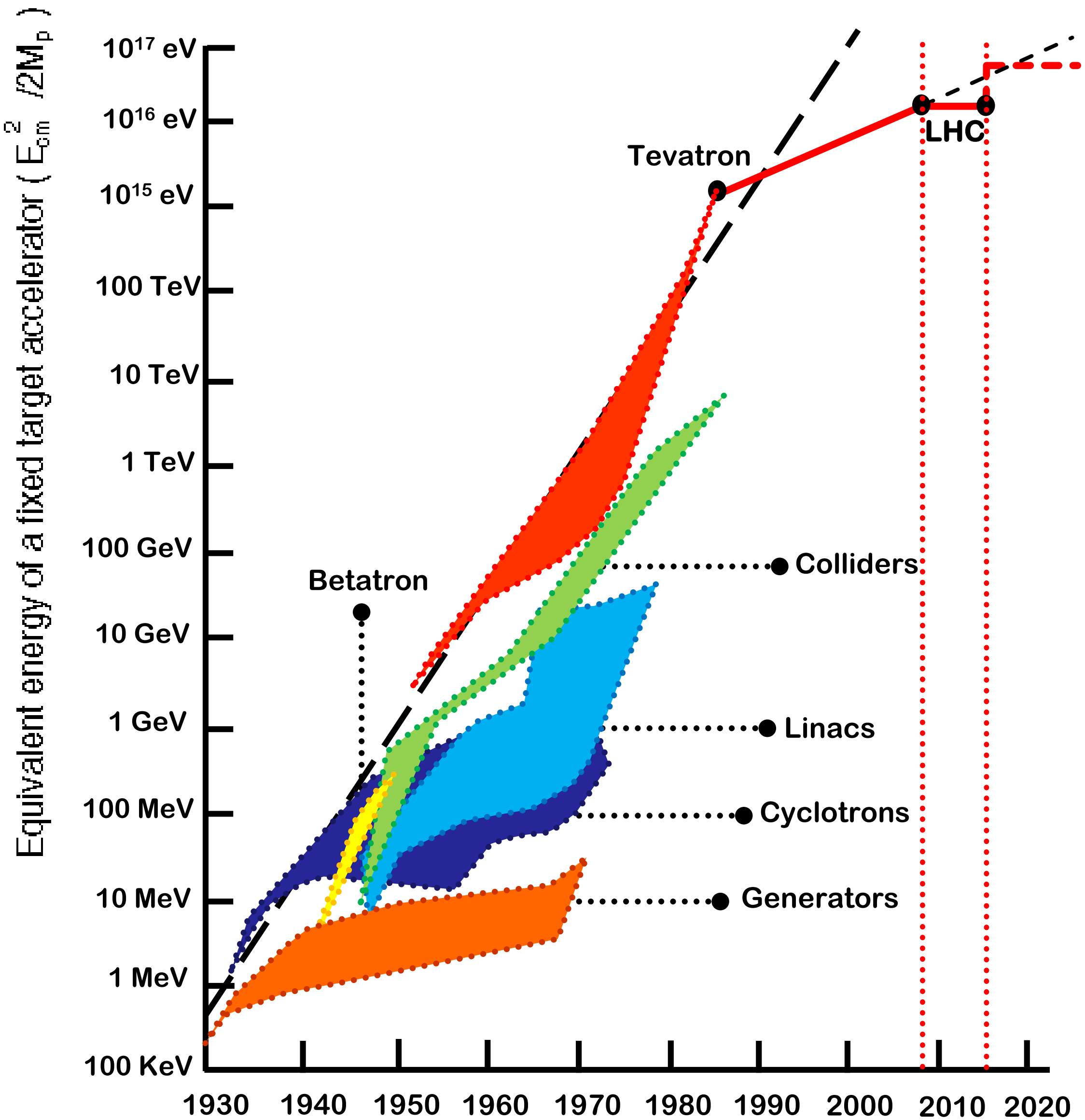
Insects have used them for millions of years!

Interacting Gears Synchronize Propulsive Leg Movements in a Jumping Insect, Science, 13 Sep 2013, M.Burrows, G.Sutton

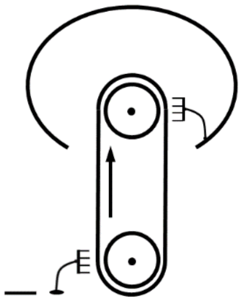
"Livingston plot"

- History of accelerators…
- …and evolution *(and saturation)* of particular technologies of acceleration, and birth of the new technologies *via inventions*

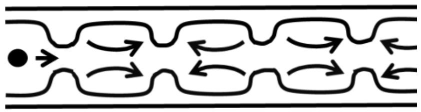




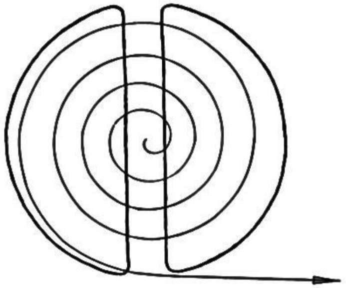
Accelerators – selected inventions



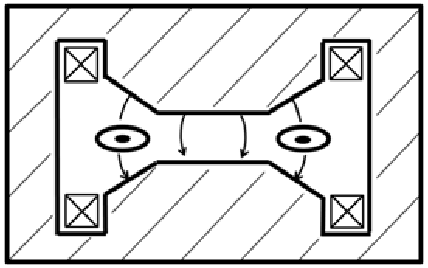
Electrostatic Acc.



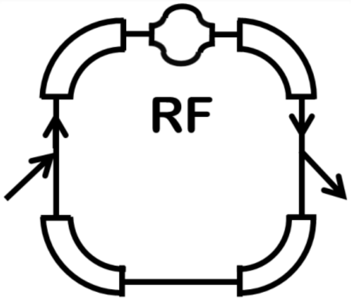
Resonant Linear Acc.



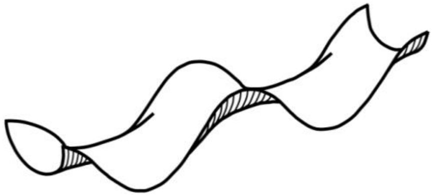
Cyclotron



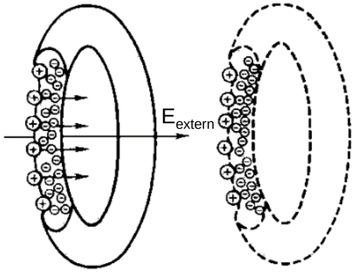
Betatron



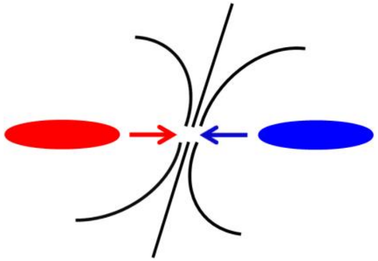
Synchrotron



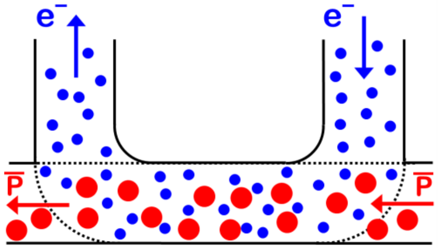
Strong focusing



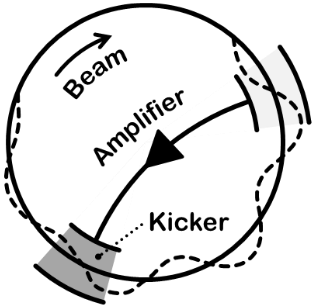
Collective acceleration



Colliders

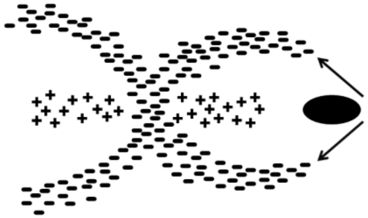


Electron cooling



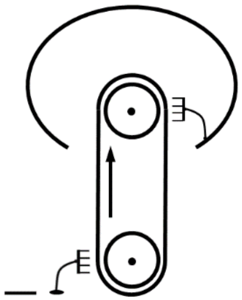
Stochastic cooling

SC magnets and RF

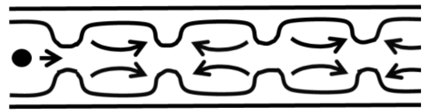


Plasma acceleration

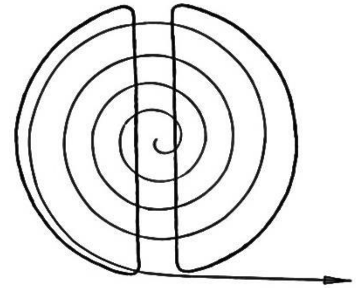
Accelerators – selected inventions



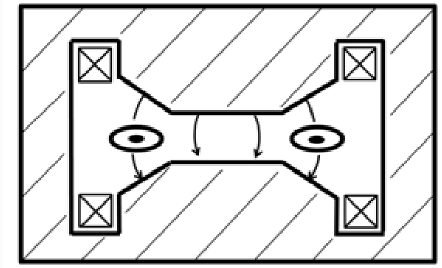
Electrostatic Acc.



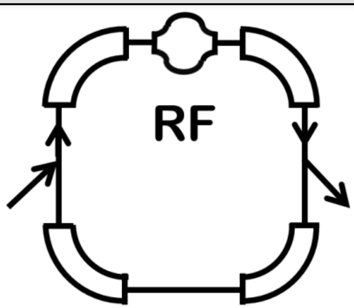
Resonant Linear Acc.



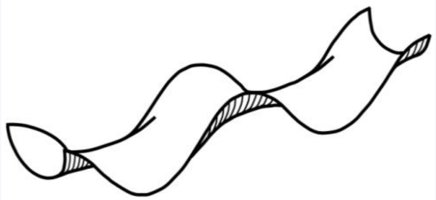
Cyclotron



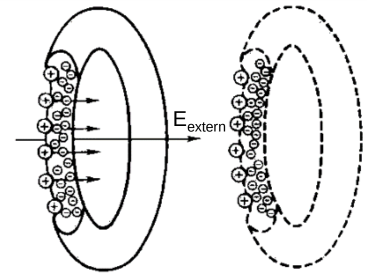
Betatron



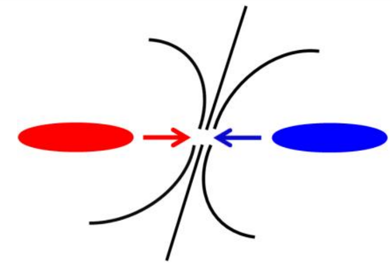
Synchrotron



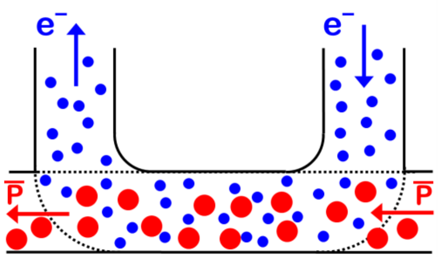
Strong focusing



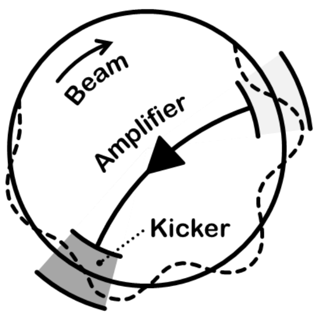
Collective acceleration



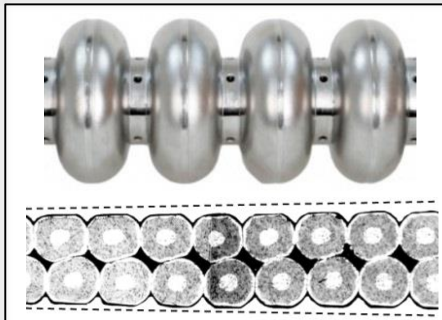
Colliders



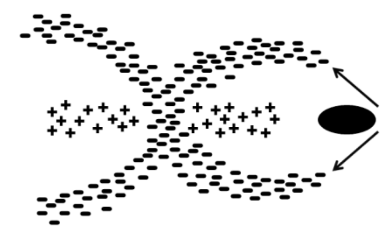
Electron cooling



Stochastic cooling



SC magnets and RF

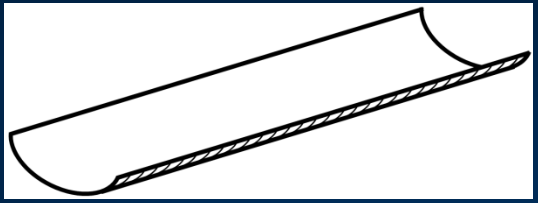


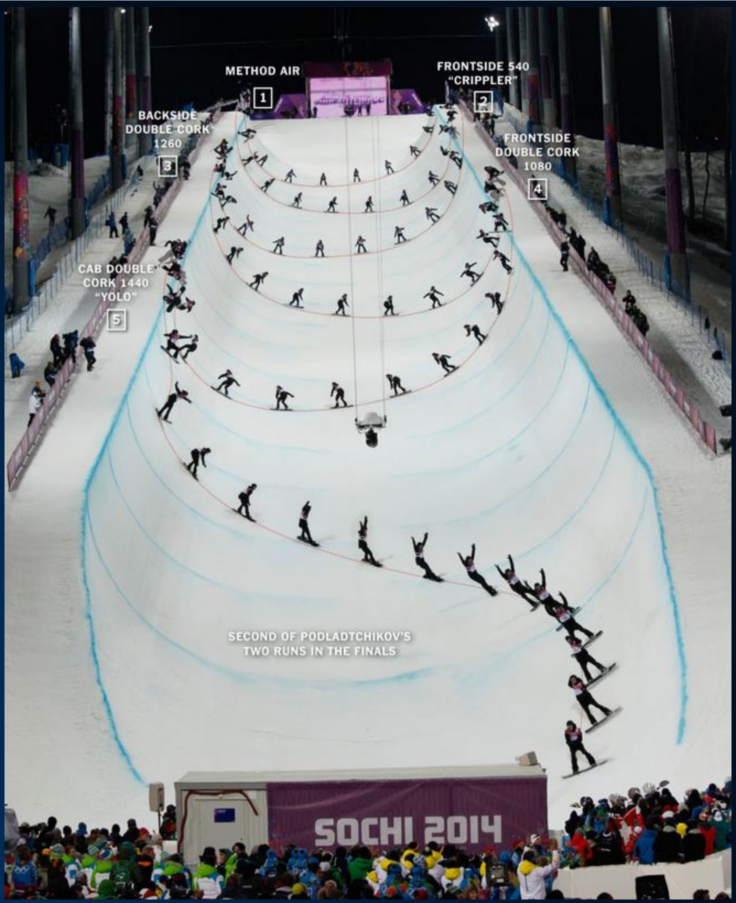
Plasma acceleration

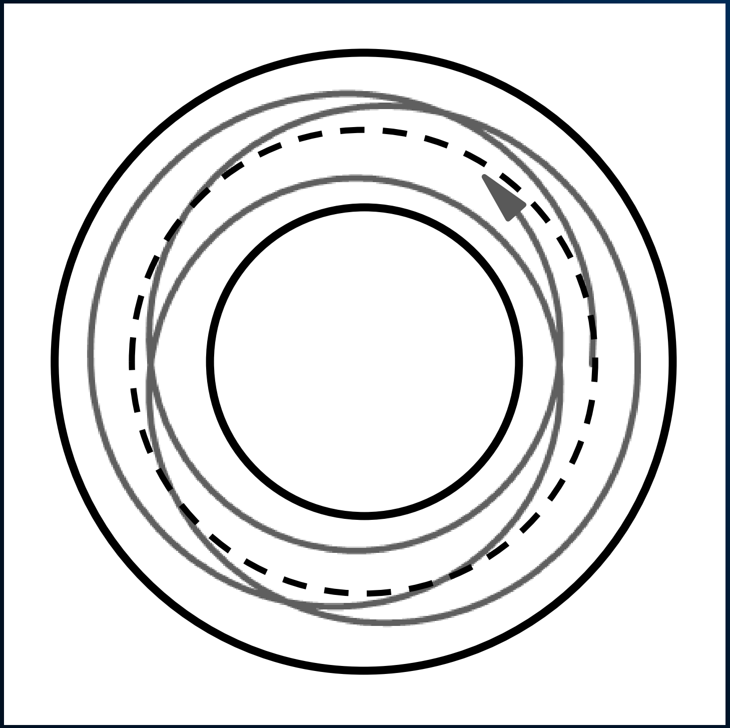
Focusing

Focusing is needed to keep the particle trajectories near the centre

The analogy with the motion in the gutter



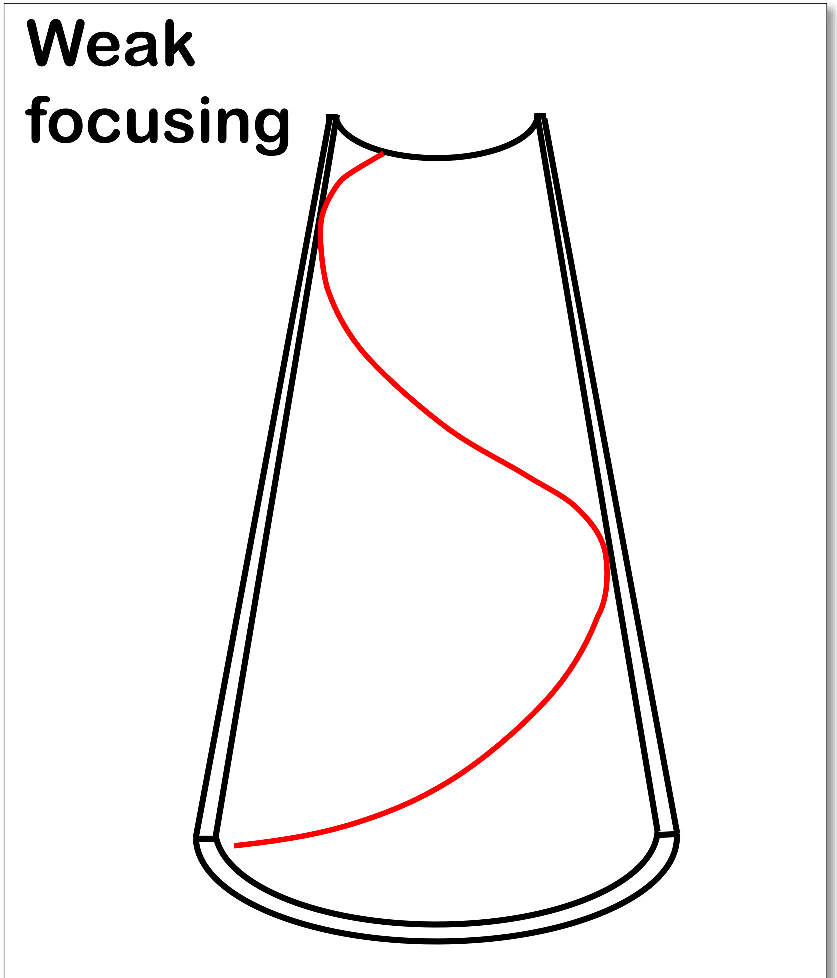


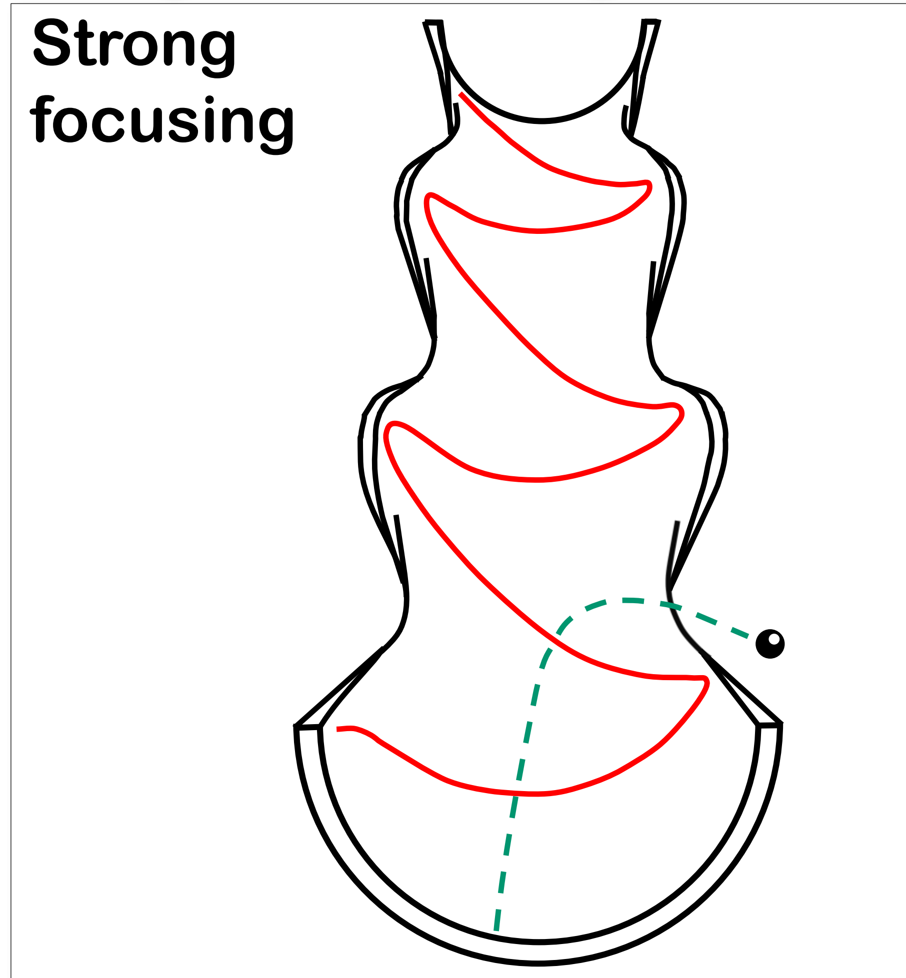


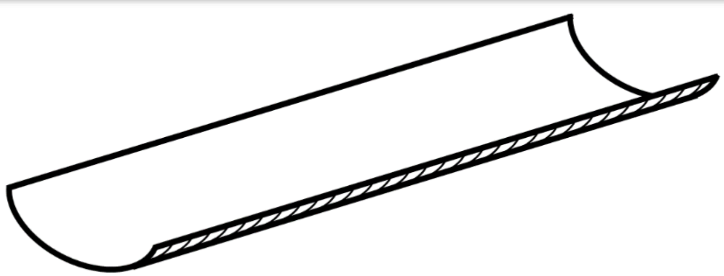
The first accelerators had **weak focusing** with spatial period greater than the perimeter of the accelerator

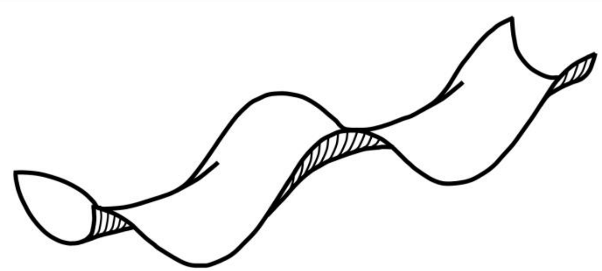
The trajectories of particles in an accelerator with weak focusing

Weak and strong focusing

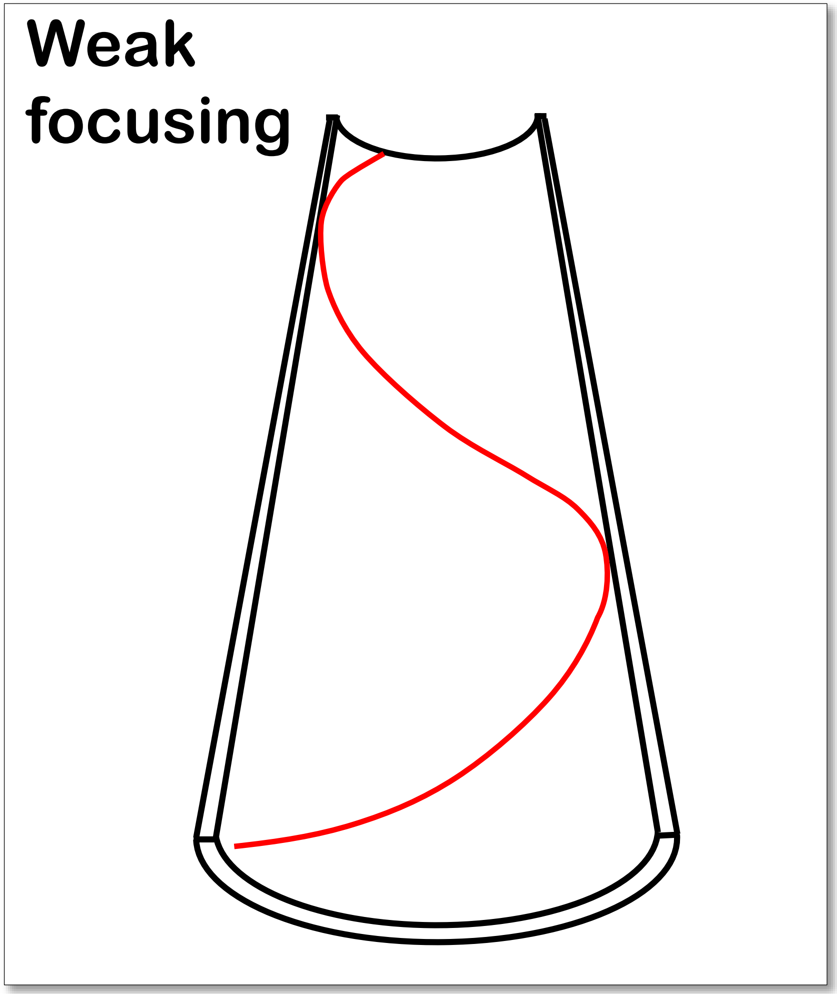


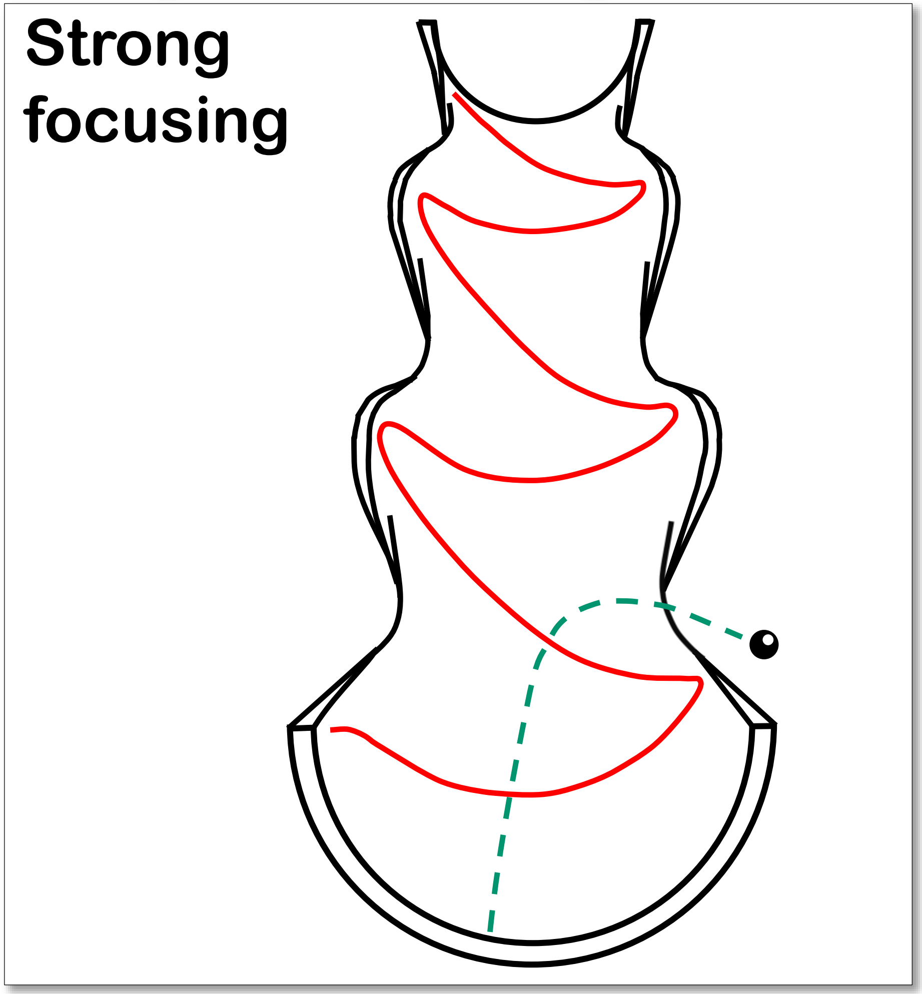


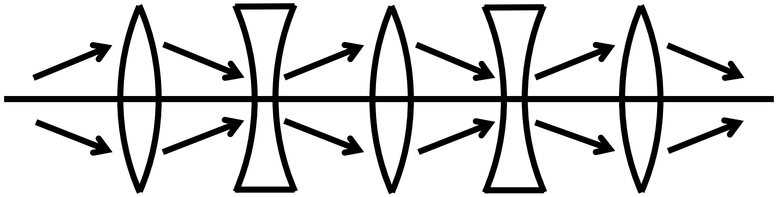




Weak and strong focusing



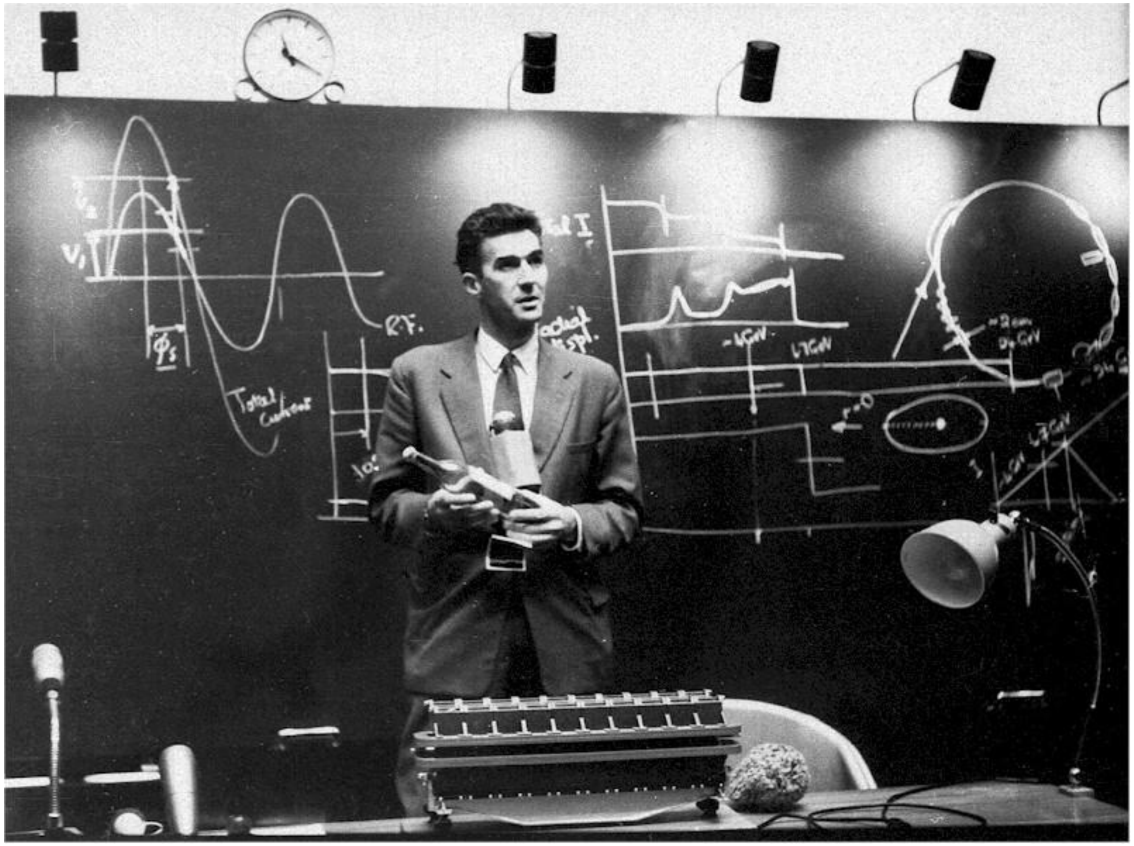




Strong focusing and JA history

John Bertram Adams led the realization of the first strong-focusing proton accelerator.

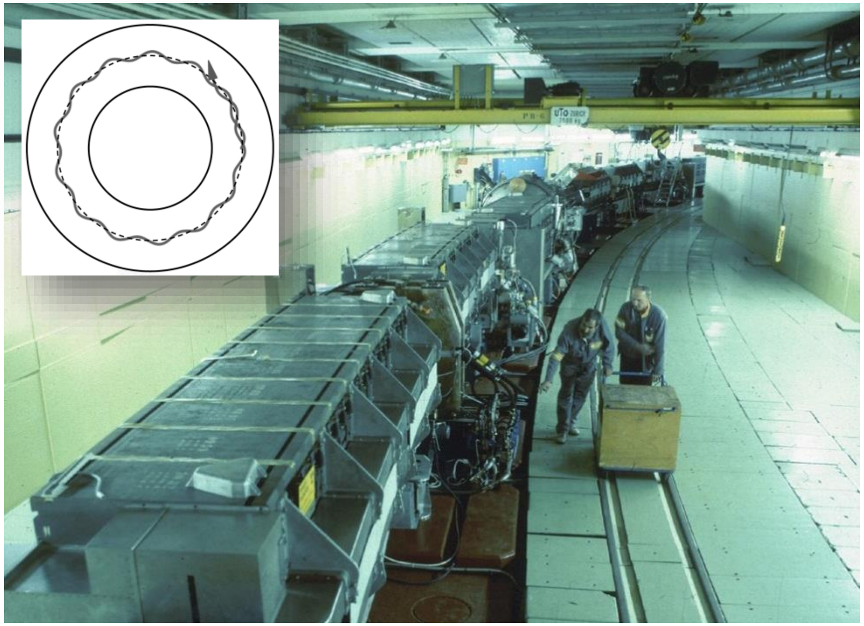
This was the courageous decision – to cancel (in Oct 1952) the already approved 10 GeV weak focusing accelerator for a totally innovative 25 GeV Proton Synchrotron.



On the photo above Sir John Adams is announcing (on 25 Nov 1959) that CERN's PS just reached 24GeV and passed the Dubna's Synchrophasotron world record of 10GeV. This image shows Adams addressing the audience with a token of the victory – a bottled polaroid photograph showing the 24 GeV pulse in the machine ready to be sent back to the Joint Institute for Nuclear Research at Dubna as a sign that CERN had broken Dubna's record of 10 GeV.

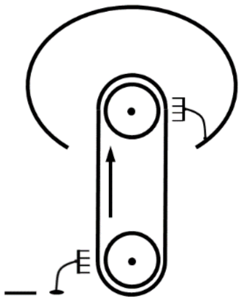
Weak and strong

10 GeV weak-focusing Synchrophasotron built in Dubna in 1957, the biggest and the most powerful for his time. It is ~60m diameter ring, and its magnets weigh 36,000 tons and it was registered in the Guinness Book of Records as the heaviest in the world.

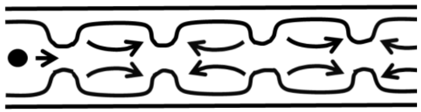


CERN's Proton Synchrotron, the first operating strong-focusing accelerator, reached 24 GeV in 1959. It is a ~200-m diameter ring, weight of magnets 3,800 tons.

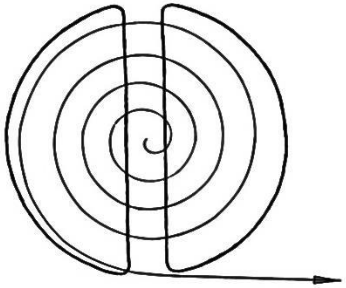
Accelerators – selected inventions



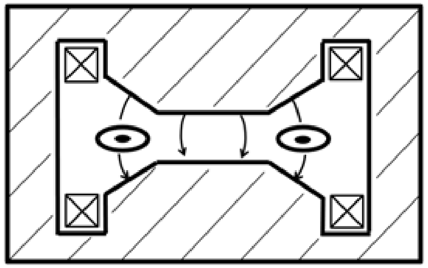
Electrostatic Acc.



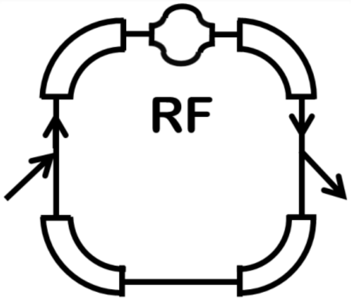
Resonant Linear Acc.



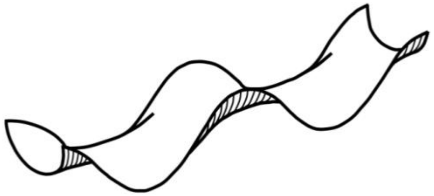
Cyclotron



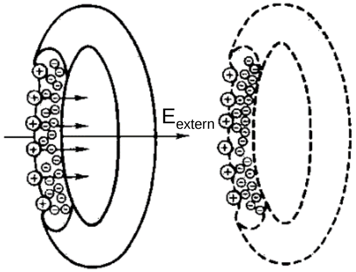
Betatron



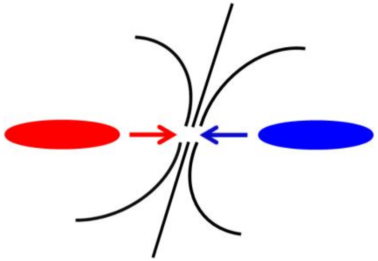
Synchrotron



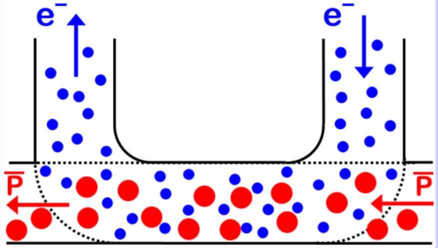
Strong focusing



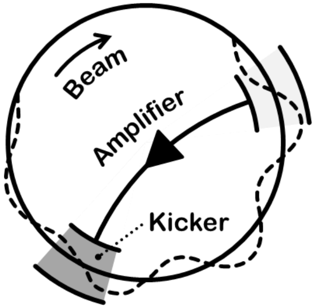
Collective acceleration



Colliders

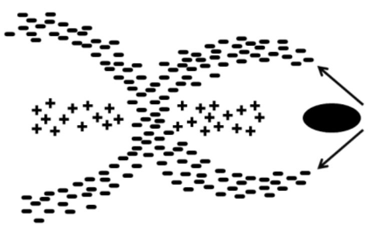


Electron cooling



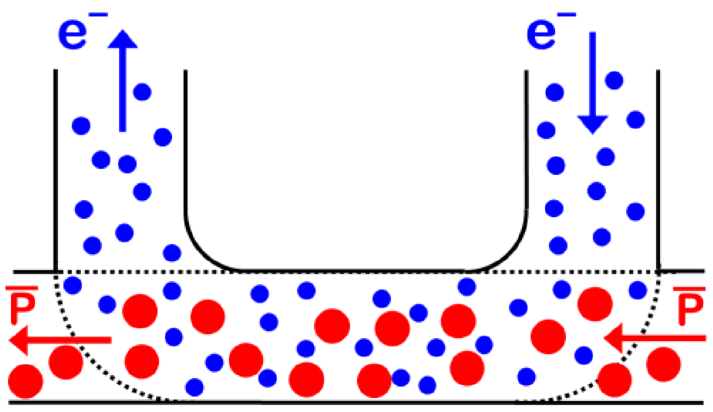
Stochastic cooling

SC magnets and RF



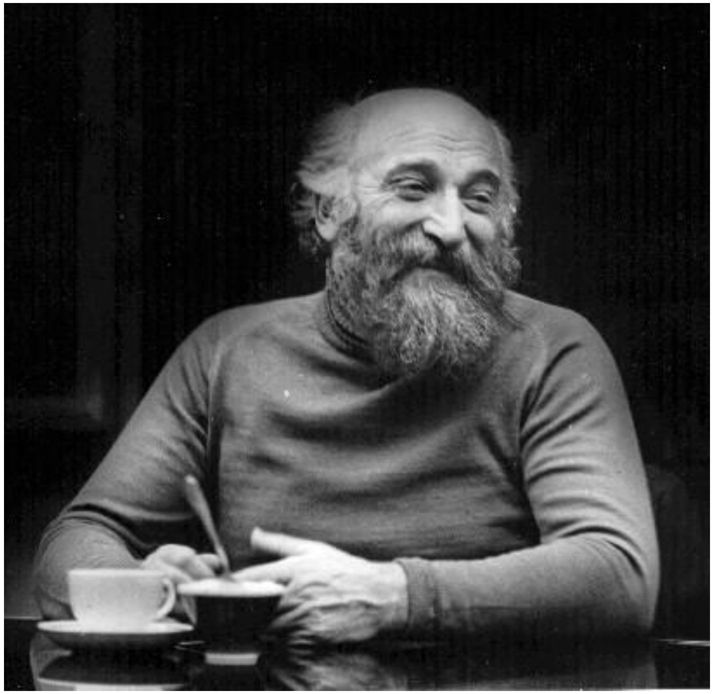
Plasma acceleration

Beam cooling



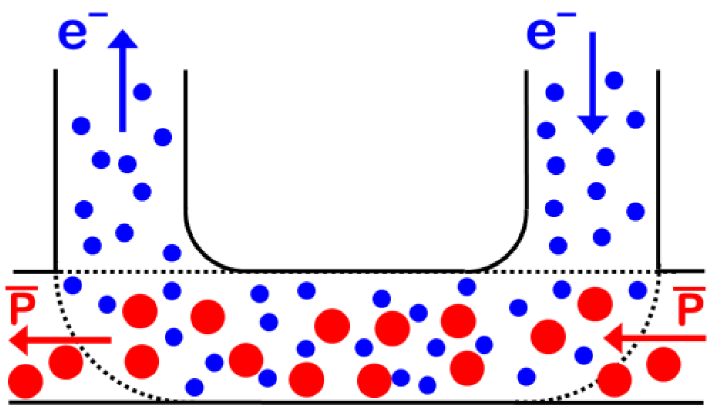
Electron cooling

Cooling is necessary especially for antiparticles such as antiprotons



A.M. Budker - founder and first director of the Institute of Nuclear Physics, Novosibirsk. Author of many inventions in the field of physics, including the idea of electron cooling.

Beam cooling



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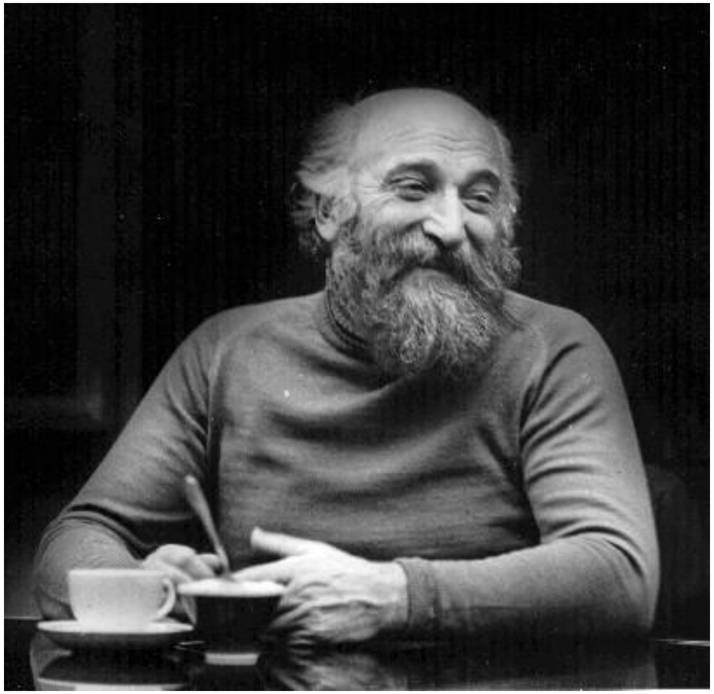

When electron cooling was first proposed, the common opinion was "brilliant idea, but unfortunately non-realistic"

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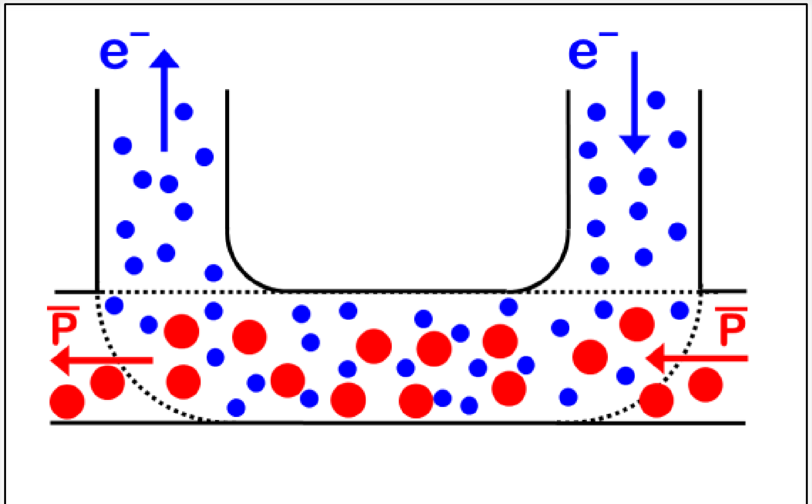
Beam cooling



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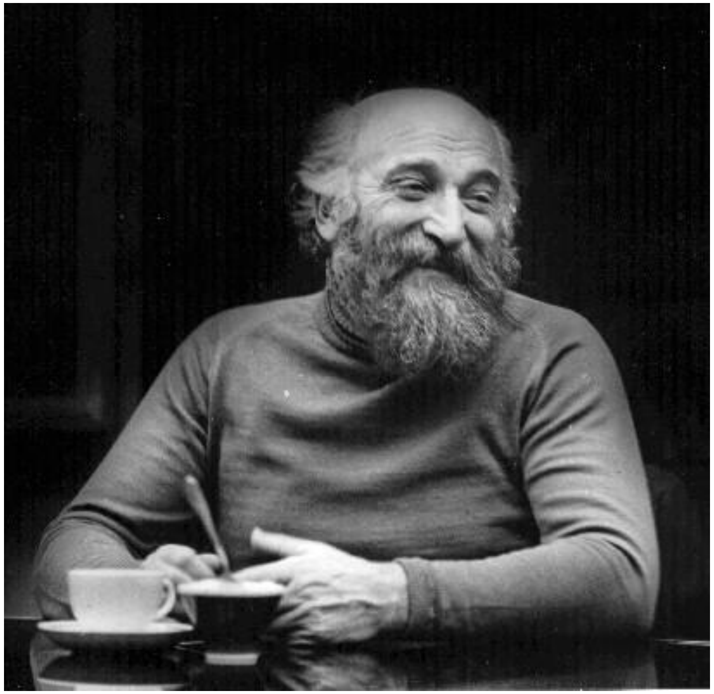
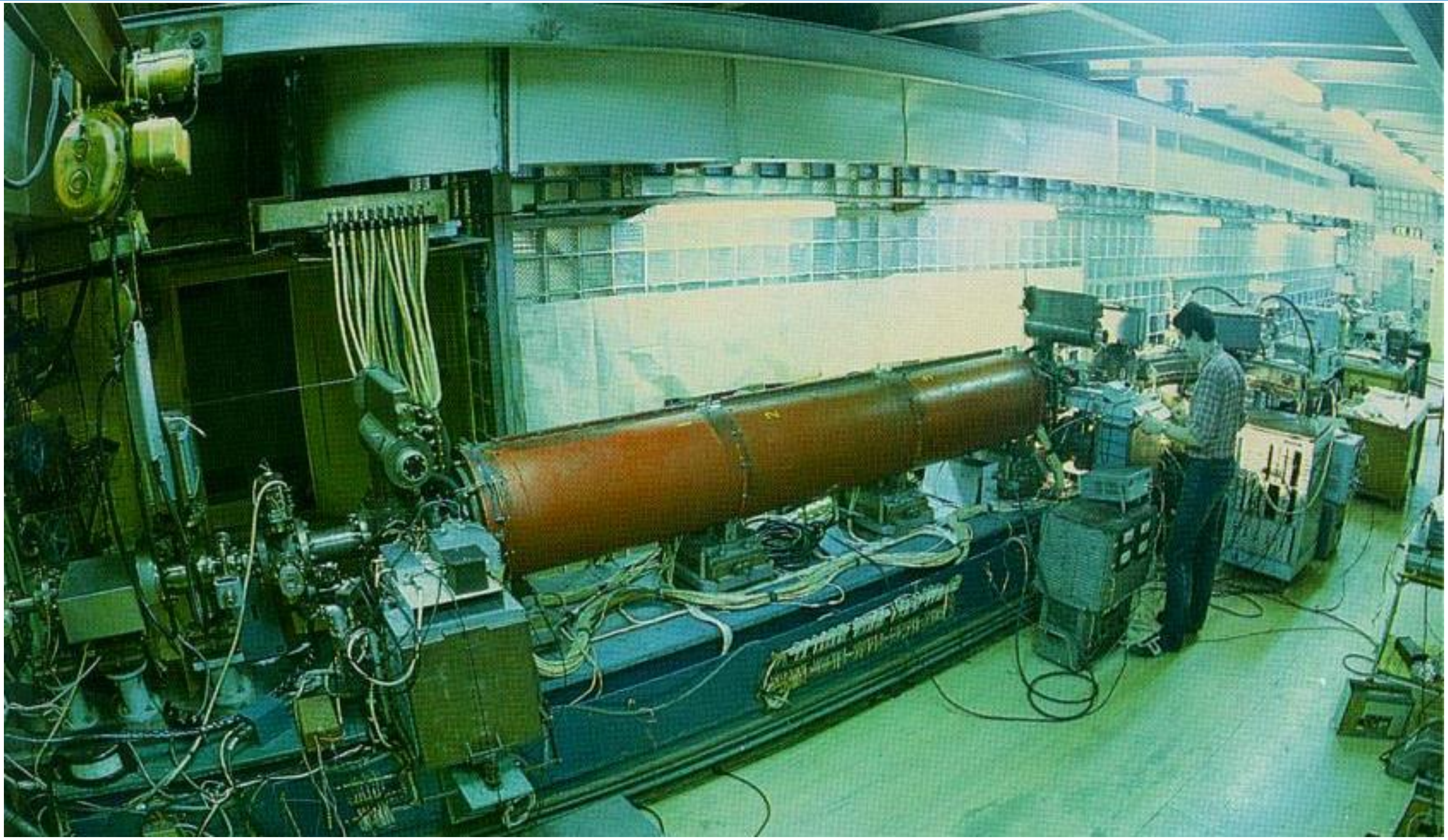


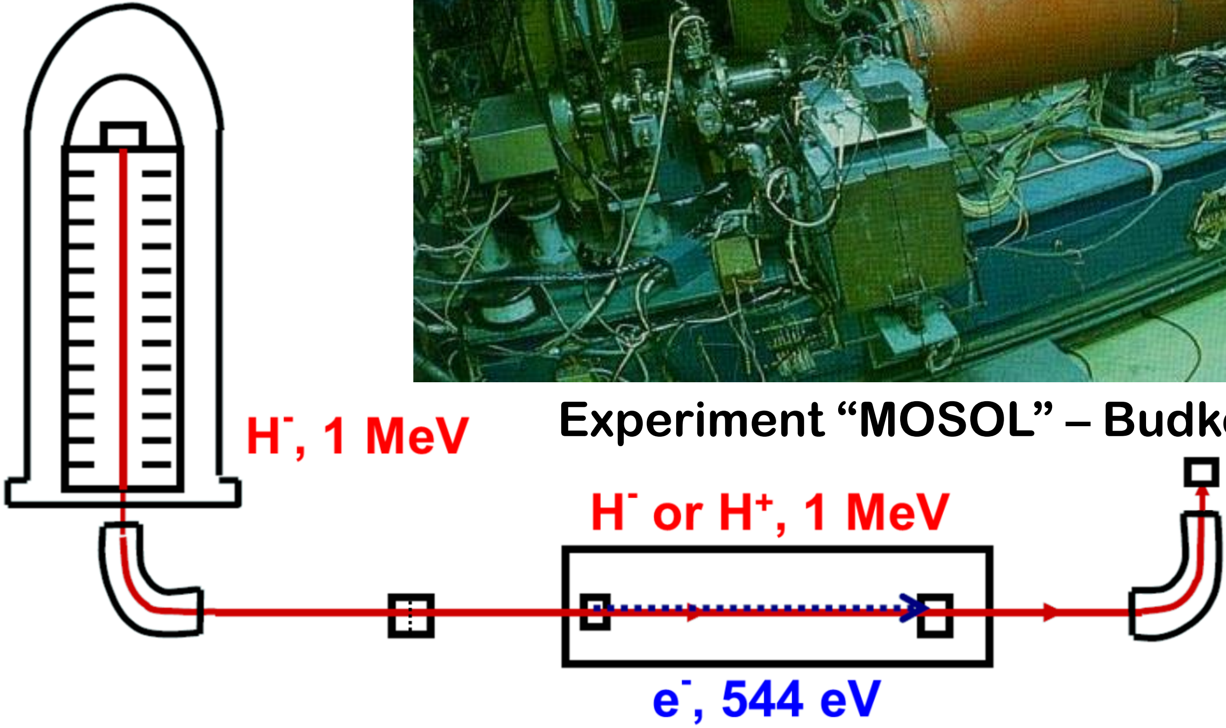
First e-cooler at BINP

A.M. Budker - founder and first director of the Institute of Nuclear Physics, Novosibirsk. Author of many inventions in the field of physics, including the idea of electron cooling.

Single Pass Electron Cooling Experiment

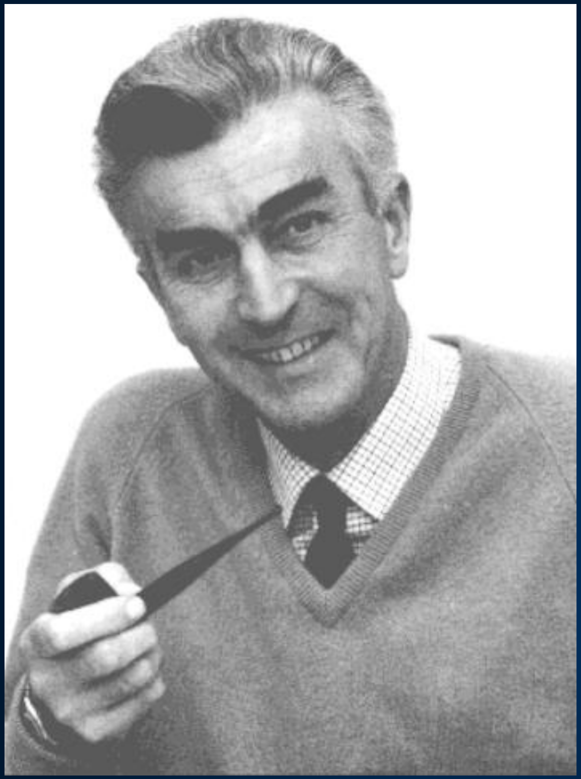


Experiment “MOSOL” – Budker INP, Novosibirsk, ca. 1986

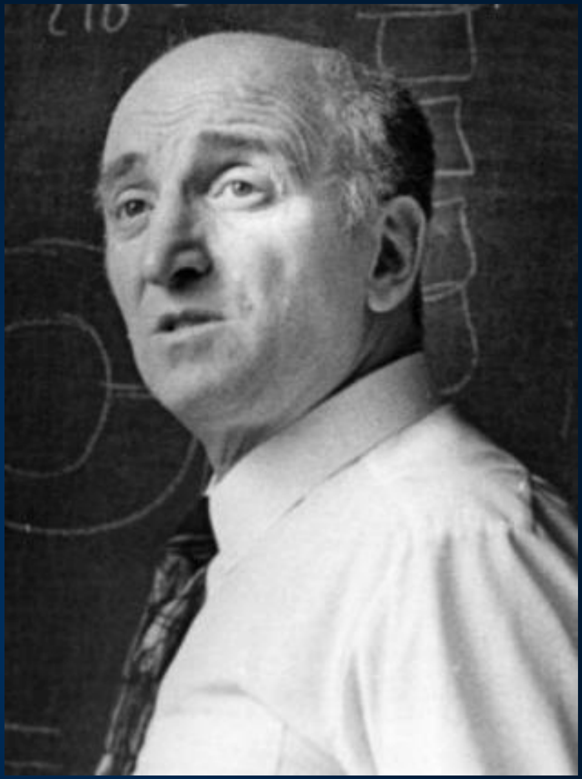


Experiment revealed large difference in cooling force for positive and negative particles

One more connection



Sir John Adams – unique combination of scientific and engineering abilities



A.M. Budker – was once called by Lev Landau a “relativistic engineer”

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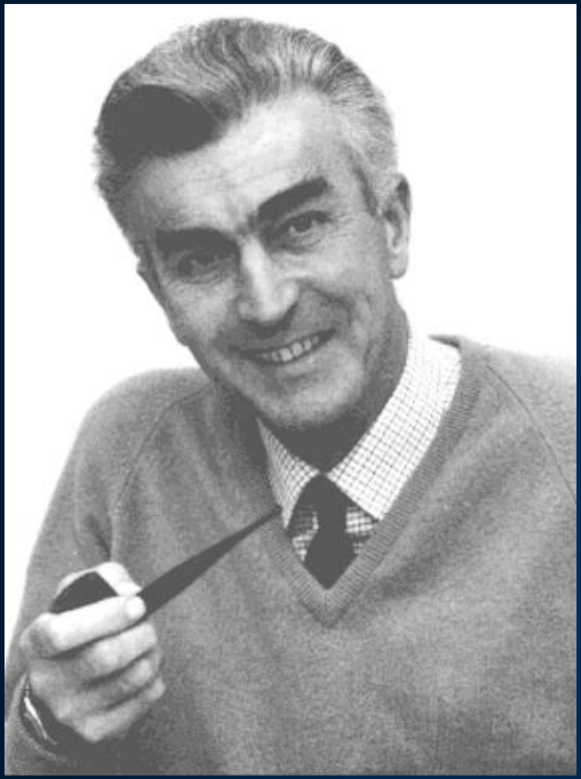

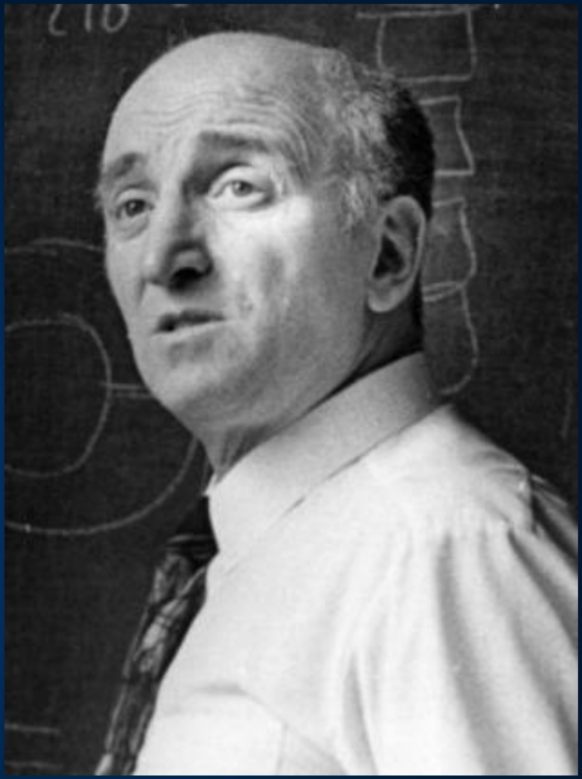

Sir John Adams – unique combination of scientific and engineering abilities

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...and the art of inventiveness that we will also discuss in this lecture came from engineering

How to invent more efficiently?

Forbes

Haydn Shaughnessy, Contributor
I write about enterprise innovation.

TECH | 3/07/2013 @ 6:32AM | 72,570 views

What Makes Samsung Such An Innovative Company?

What was that magic bullet?
…wait a few slides…

But it was [redacted] that became the bedrock of innovation at Samsung. And it was introduced at Samsung by [redacted] whom Samsung had hired into its Seoul Labs in the early 2000s.

In 2003 [redacted] led to 50 new patents for Samsung and in 2004 one project alone, a DVD pick-up innovation, saved Samsung over $100 million. [redacted] is now an obligatory skill set if you want to advance within Samsung.

How to invent – evolution of the methods

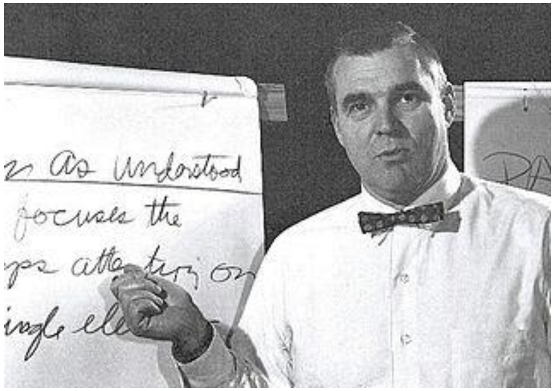
- **Brute-force or exhaustive search**
  - consider any possible ideas
- **Brainstorming**
  - psychological method which helps to solve problems and to invent
  - The main feature of brainstorming – separate the process of idea generation from the process of their critical analysis
  - The method of brainstorming did not meet expectations
    - the absence of feedback, which is the power of the method, is simultaneously its handicap, as feedback is needed for development and adjusting of an idea

Alex Osborn
(1888 – 1966)

The author of brainstorming Alex Osborn introduced the method around 1950s

How to invent – evolution of the methods

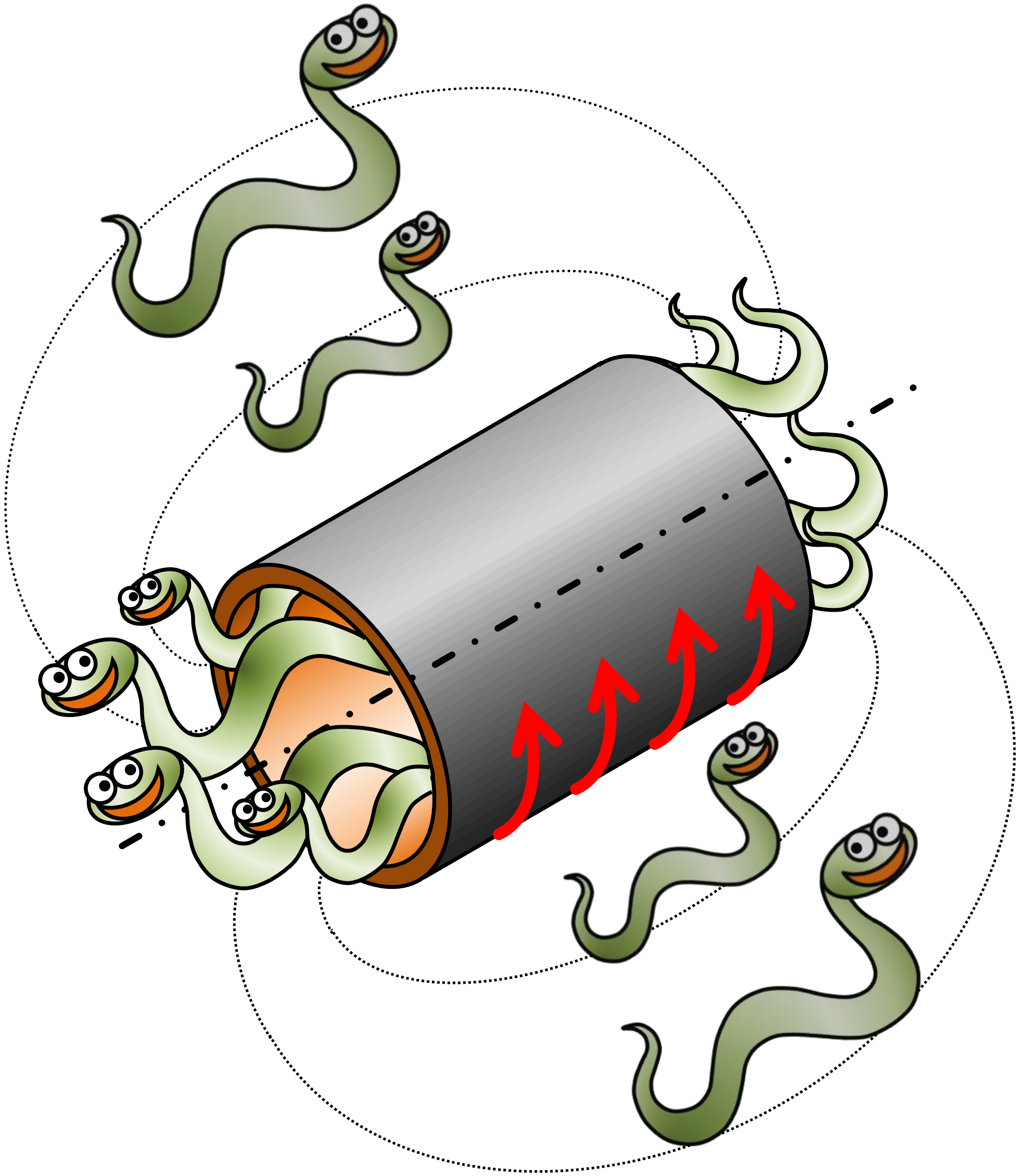
- **Synectics – improved Brainstorming**
- **Features of Synectics:**
  - **Permanent groups for problem solving**
    - **whose members with time become less sensitive to critics and more efficient in problem solving**
  - **Emphasis on the importance to see familiar behind unknown and vice versa**
    - **which should help to solve a new and unfamiliar problem with known methods**
  - **Importance of a fresh view at a problem**
  - **Use of analogies to generate fresh view**
    - **direct (any analogy, e.g. from nature);**
    - **empathic (attempting to look at the problem identifying yourself with the object);**
    - **symbolic (finding a short symbolic description of the problem and the object);**
    - **metaphorical (describing the problem in terms of fairy-tales and legends);**



Attempting to improve brainstorming, George Prince (on the photo) and William Gordon introduced the method of Synectics

Synectics : use of analogies

- Use of analogies to generate fresh view
  - ...
  - empathic (attempting to look at the problem identifying yourself with the object);
  - ...
  - metaphorical (describing the problem in terms of fairy-tales and legends);



How to contain the magnetic flux?

How to invent – evolution of the methods

- Synectics is the limit of what can be achieved, maintaining the brute force method of exhaustive search

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  - Indeed, why one would employ analogies and metaphors and irrational factors in order to come to a natural and universal formula “the action has to happen itself”

How to invent – evolution of the methods

- Synectics is the limit of what can be achieved, maintaining the brute force method of exhaustive search
  - Indeed, why one would employ analogies and metaphors and irrational factors in order to come to a **natural and universal formula "the action has to happen itself"**
  - **One should aim at such formula in any invention, armed with precise identification of physical contradiction – essence of TRIZ**

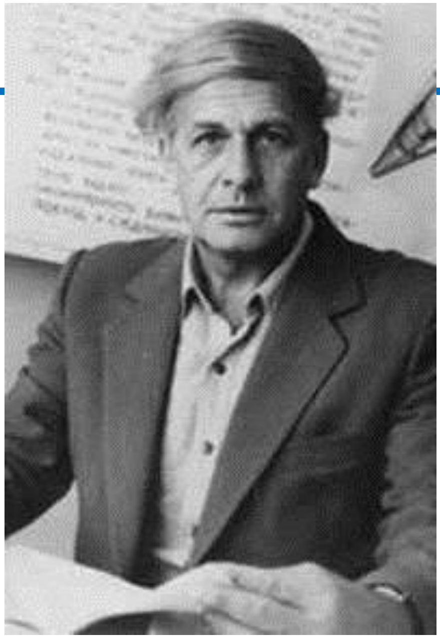
Illustration by Sasha Seraia

How to invent – TRIZ

- **TRIZ – *Teoria Reshenia Izobretatelskikh Zadach***

= Theory of Inventive Problem Solving

- **Developed by Genrikh Altshuller in SU**
  - **Work in patent office in 1946**
  - **Analysed 200000 patents, discovered patterns and identified what makes a patent successful**
  - **Formulated TRIZ in 1956-1985**



Genrikh Altshuller (aka Altov)1926-1998

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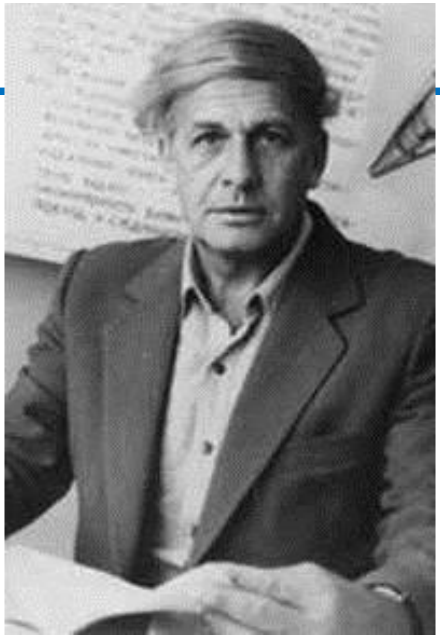

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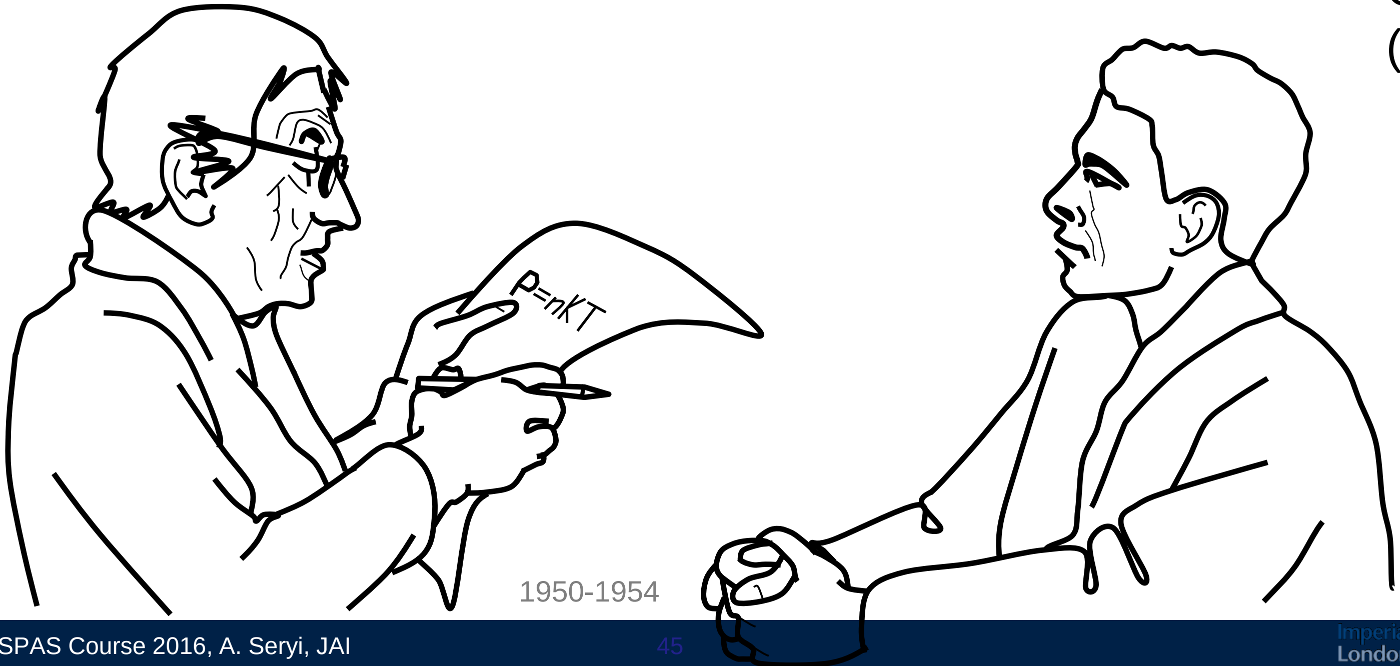
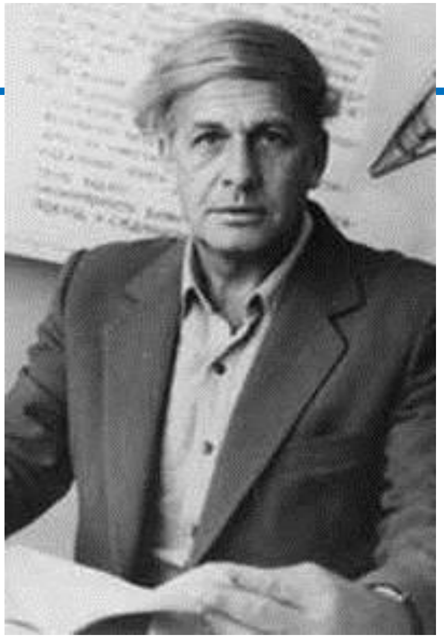


1950-1954

How to invent – TRIZ



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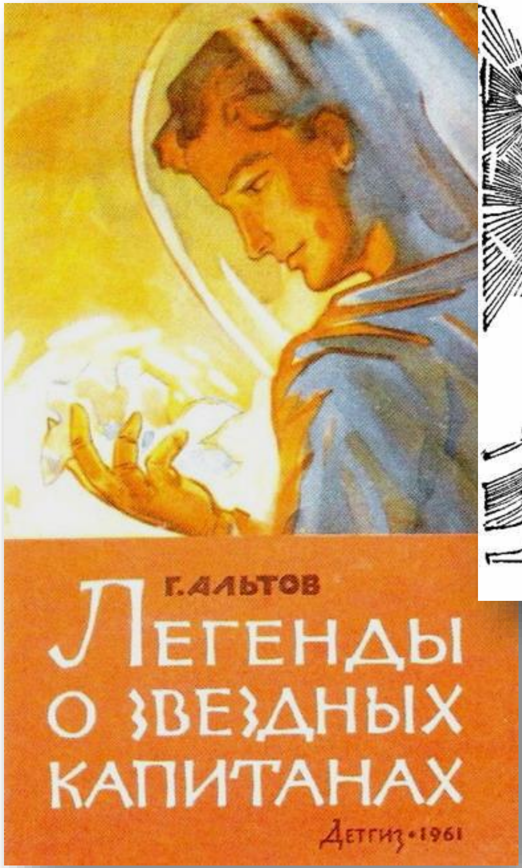

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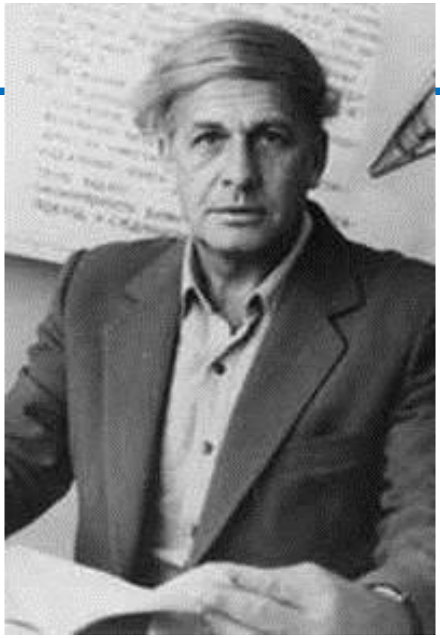

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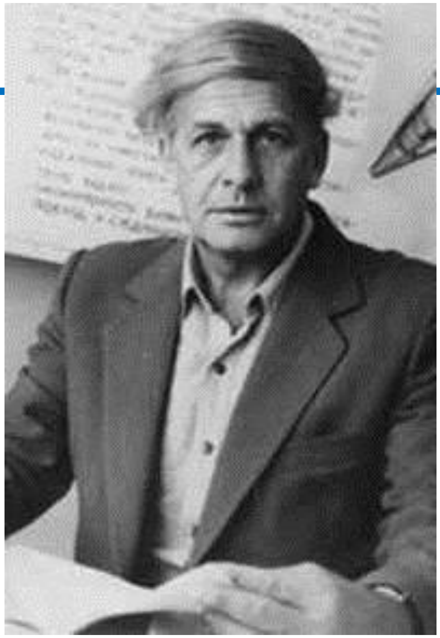

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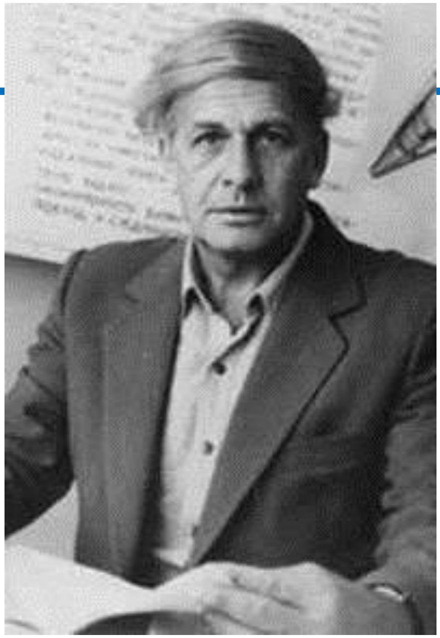

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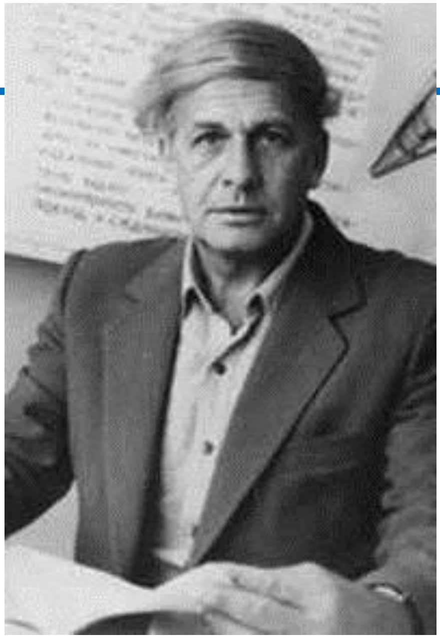

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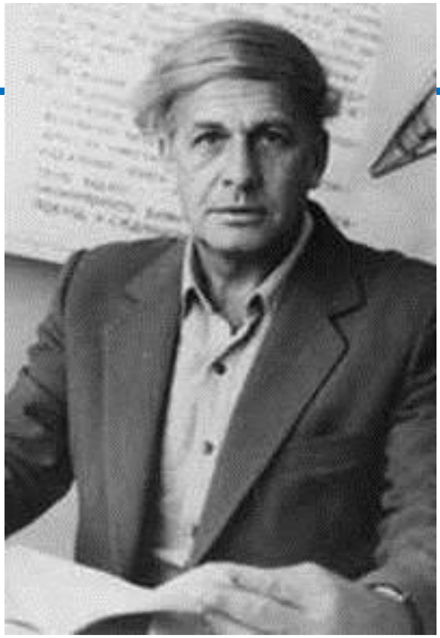

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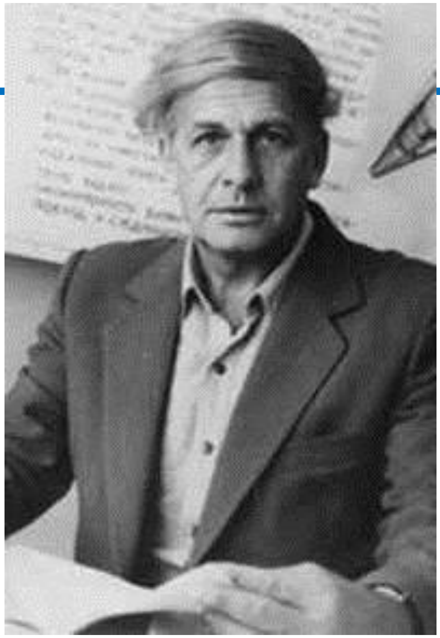

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Forbes

Haydn Shaughnessy, Contributor
I write about enterprise innovation.

TECH | 3/07/2013 @ 6:32AM | 72,570 views

What Makes Samsung Such An Innovative Company?

Why are we interested in this in relation to science?
…wait a few more slides…

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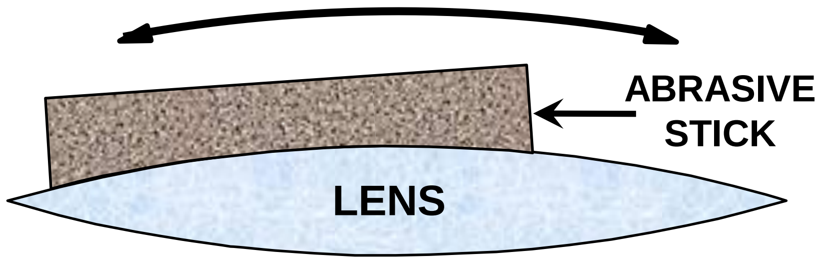
In 2003 TRIZ led to 50 new patents for Samsung and in 2004 one project alone, a DVD pick-up innovation, saved Samsung over $100 million. TRIZ is now an obligatory skill set if you want to advance within Samsung.

TRIZ in action - example



Problem: Lens polished – heat generated. Heat degrades optical properties. Existing cooling methods ineffective, as cannot achieve uniform cooling at each abrasive particle

To be improved: SPEED, What gets worse: TEMPERATURE

Has anyone else solved such contradiction?

1) Define the problem in terms of generic Contradiction parameters

TRIZ Generic Problem

TRIZ Generic Solution

3) Translate generic Inventive Principles into specific solution

Specific Problem

2) Use Contradiction Matrix to obtain relevant Inventive Principles

Specific Solution

Elements of TRIZ contradiction matrix

1. Weight of moving object
2. Weight of stationary object
3. Length of moving object
4. Length of stationary object
5. Area of moving object
6. Area of stationary object
7. Volume of moving object
8. Volume of stationary object
9. Speed
10. Force (Intensity)
11. Stress or pressure
12. Shape
13. Stability of the object
14. Strength
15. Durability of moving object
16. Durability of non moving object
17. Temperature
18. Illumination intensity
19. Use of energy by moving object
20. Use of energy by stationary object
21. Power
22. Loss of Energy
23. Loss of substance
24. Loss of Information
25. Loss of Time
26. Quantity of substance/the
27. Reliability
28. Measurement accuracy
29. Manufacturing precision
30. Object-affected harmful
31. Object-generated harmful
32. Ease of manufacture
33. Ease of operation
34. Ease of repair
35. Adaptability or versatility
36. Device complexity
37. Difficulty of detecting
38. Extent of automation
39. Productivity

Only 39 Matrix parameters!!!

TRIZ Inventive Principles

1. Segmentation
2. Taking out
3. Local quality
4. Asymmetry
5. Merging
6. Universality
7. Russian dolls
8. Anti-weight
9. Preliminary anti-action
10. Preliminary action
11. Beforehand cushioning
12. Equipotentiality
13. "The other way round"
14. Spheroidality - Curvature
15. Dynamics
16. Partial or excessive actions
17. Another dimension
18. Mechanical vibration
19. Periodic action
20. Continuity of useful action
21. Skipping
22. Blessing in disguise
23. Feedback
24. Intermediary
25. Self-service
26. Copying
27. Cheap short-lived objects
28. Mechanics substitution
29. Pneumatics and hydraulics
30. Flexible shells and thin films
31. Porous materials
32. Colour changes
33. Homogeneity
34. Discarding and recovering
35. Parameter changes
36. Phase transitions
37. Thermal expansion
38. Strong oxidants
39. Inert atmosphere
40. Composite materials

Only 40 Principles !!!

TRIZ Principles and Contradiction matrix

For our example with the lens:

Parameter that deteriorates

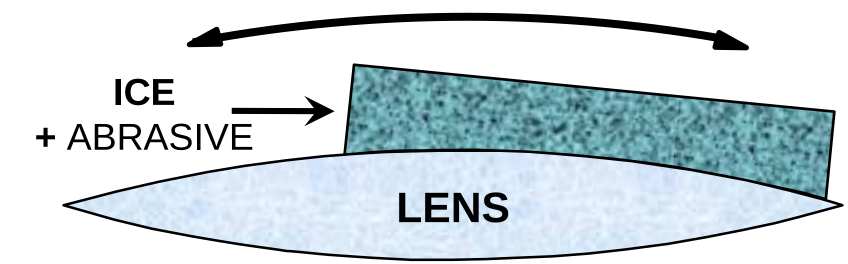
Improving Parameter

	…	9. Speed	…	17. Temperature	…
…					
9. Speed				2, 28, 30, 36	
…					
17. Temperature					
…					

Suggested Principles that have solved similar Contradictions before

TRIZ in action - example

- **Perform lookup* of TRIZ Matrix for this contradiction:**
  - **Improving 9: SPEED without damaging 17: TEMPERATURE**
- **Find Principles to solve this contradiction:**
  - **2. Taking out**
  - **28. Mechanics substitution**
  - **30. Flexible shells and thin films**
  - **<u>36. Phase transitions</u>**
    - **Use phenomena occurring during phase transitions (e.g. volume changes, loss or absorption of heat, etc.).**



Abrasive + Ice - Inventive Principle ‘Phase Transition’

*) E.g. at http://www.triz40.com/

TRIZ Inventive Principles

1. Segm
2. Takir
3. Loca
4. Asym
5. Merg
6. Unive
7. Russian dolls
8. Anti-weight
9. Preliminary anti-action
10. Preliminary action
11. Beforehand cushior
12. Equipotentiality
13. "The other way round"
14. Spheroidality - C vature
15. Dynamics
16. Partial or exces
17. A
18. M
19. P
20. C

27. Cheap short-lived objects
28. Mechanics substitution
29. Pneumatics and hydraulics
32. Colour changes
33. Homogeneity
34. Discarding and recovering
35. Parameter changes
36. Phase transitions

Let's select a couple of principles and try to see if we can recognize them in well-known and familiar things

7. The principle of "Russian dolls"

13. The principle of "The other way round" (or the principle of anti-system)

The principle of “Russian dolls”

Could you give an example of using the principle of “Russian dolls” in everyday life?

The principle of “Russian dolls”

The principle of “Russian dolls”

And what about an example of the application of the principle of “Russian dolls”, for instance ... in philology?

The principle of “Russian dolls”

“This is the house that Jack built”

This is the house that Jack built.

This is the malt
That lay in the house that Jack built.

This is the rat,
That ate the malt
That lay in the house that Jack built.

This is the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

Illustration by Olga Rubtsova (Atroshenko)

This is the maiden all forlorn,
That milked the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the man all tattered and torn,
That kissed the maiden all forlorn,
That milked the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the priest all shaven and shorn,
That married the man all tattered and torn,
That kissed the maiden all forlorn,
That milked the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the cock that crowed in the morn,
That waked the priest all shaven and shorn,
That married the man all tattered and torn,
That kissed the maiden all forlorn,
That milked the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

This is the farmer sowing his corn,
That kept the cock that crowed in the morn,
That waked the priest all shaven and shorn,
That married the man all tattered and torn,
That kissed the maiden all forlorn,
That milked the cow with the crumpled horn,
That tossed the dog,
That worried the cat,
That killed the rat,
That ate the malt
That lay in the house that Jack built.

Mother Goose Rhymes

The principle of “Russian dolls”

“This is the house that Jack built”

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That lay in the house that Jack built.

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That ate the malt
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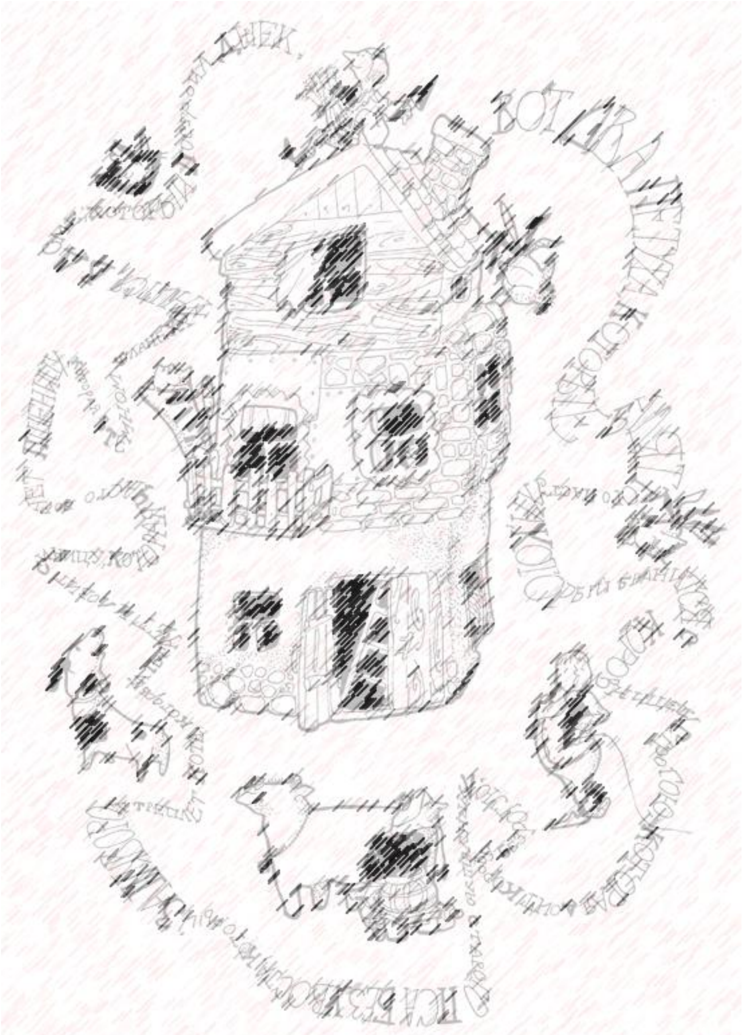

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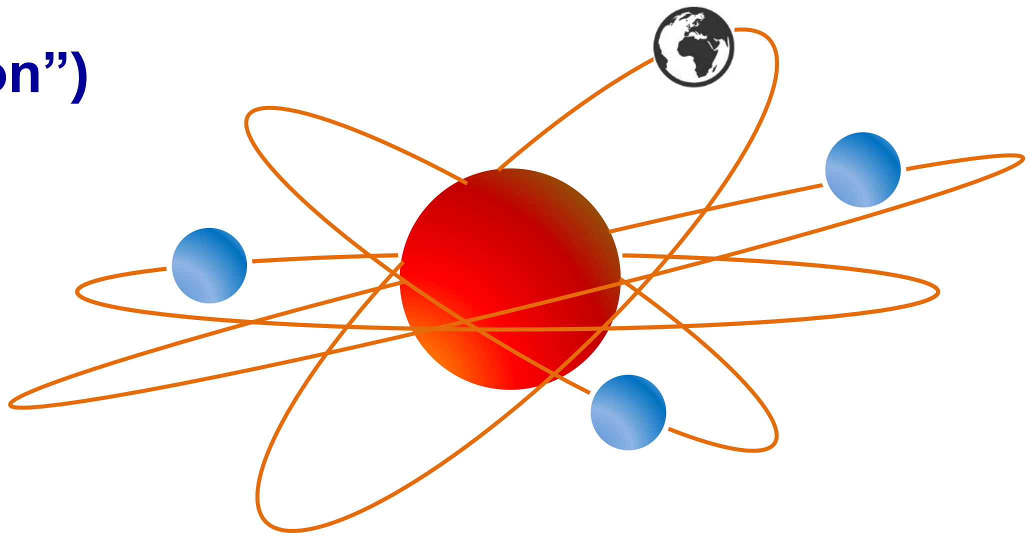
That lay in the house that Jack built.

Mother Goose Rhymes

Is there any example of this principle in science fiction?

The principle of “Russian dolls”

Valery Bryusov – 1920 poem
“Atom” (“The World of Electron”)



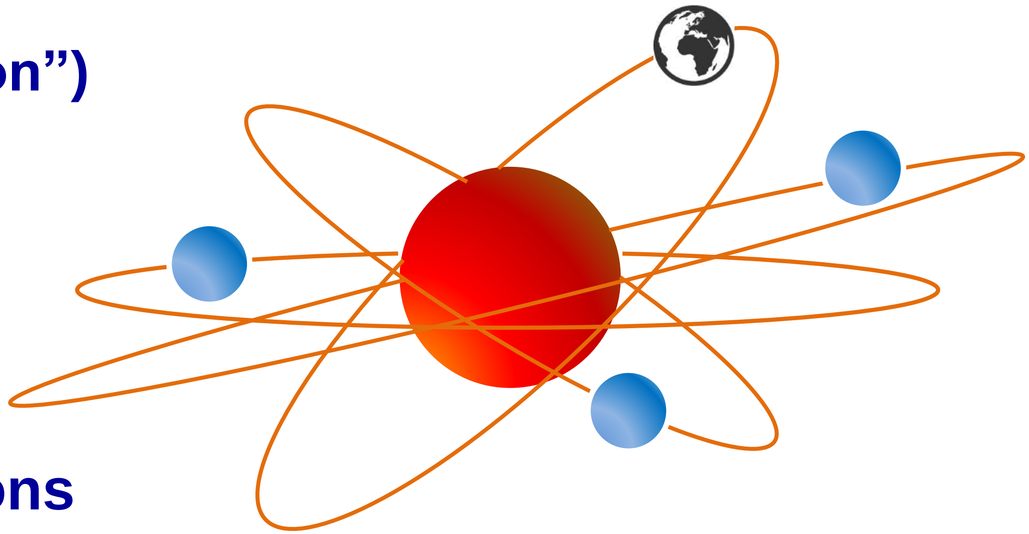
Быть может, эти электроны
Миры, где пять материков,
Искусства, знанья, войны, троны
И память сорока веков!

Ещё, быть может, каждый атом —
Вселенная, где сто планет;
Там — всё, что здесь, в объёме сжатом,
Но также то, чего здесь нет.

…

The principle of "Russian dolls"

Valery Bryusov – 1920 poem
"Atom" ("The World of Electron")



Can you imagine that electrons
Are planets circling their Suns?
Space exploration, wars, elections
And hundreds of computer tongues

…

Remake-translation by A.Seryi

Быть может, эти электроны
Миры, где пять материков,
Искусства, знанья, войны, троны
И память сорока веков!

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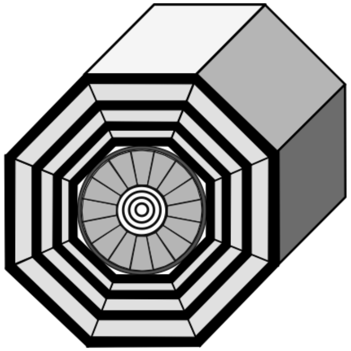
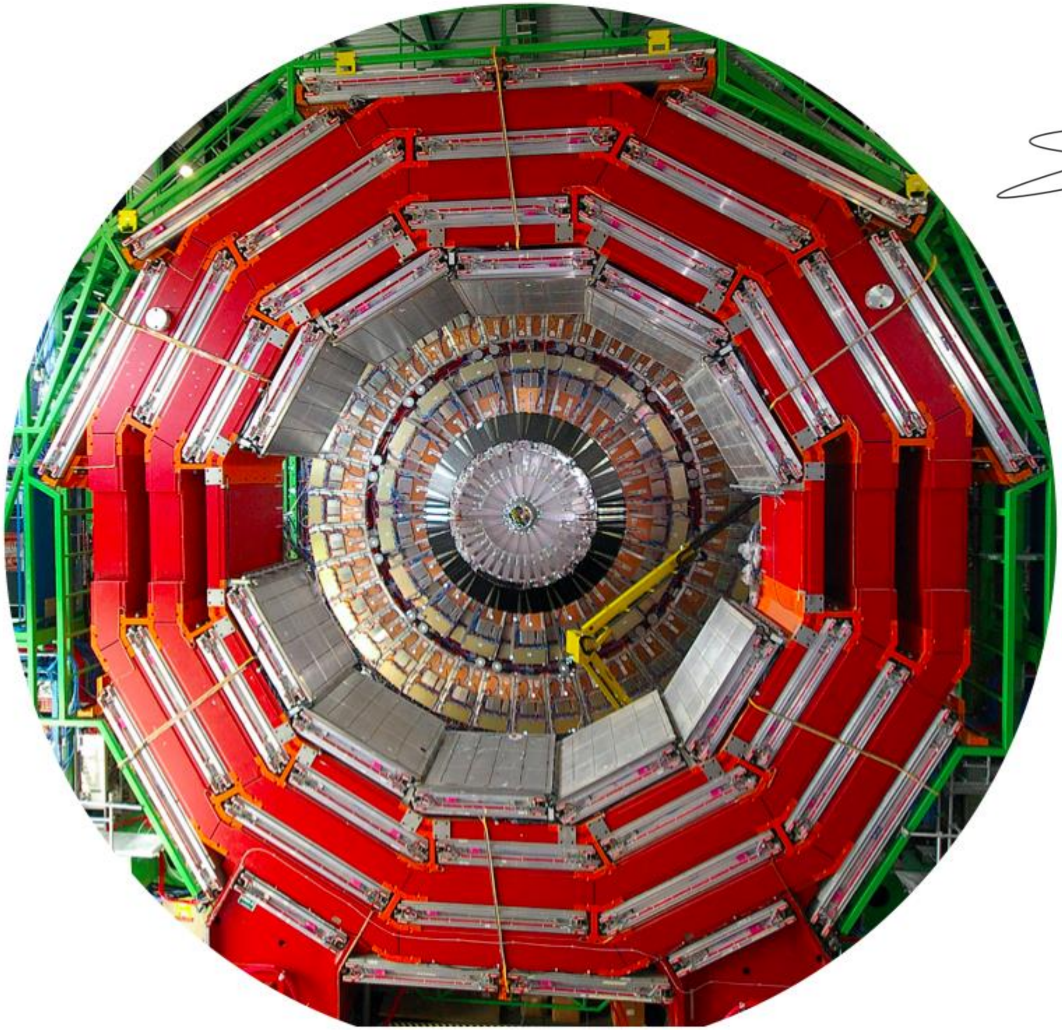
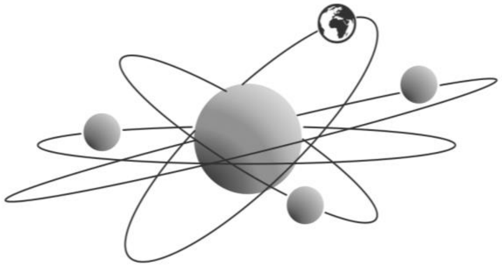
Но также то, чего здесь нет.

…

Is there world inside of an electron?

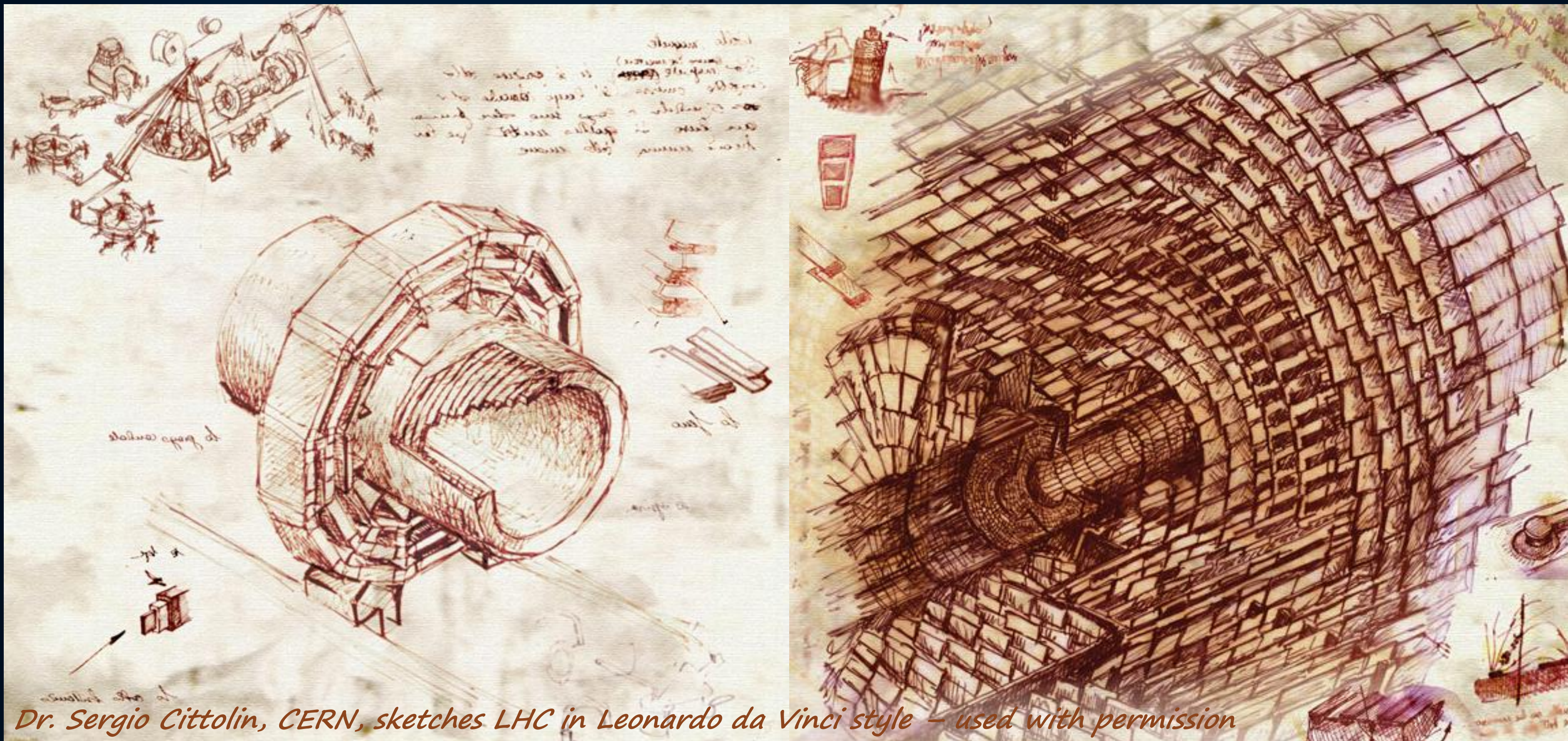






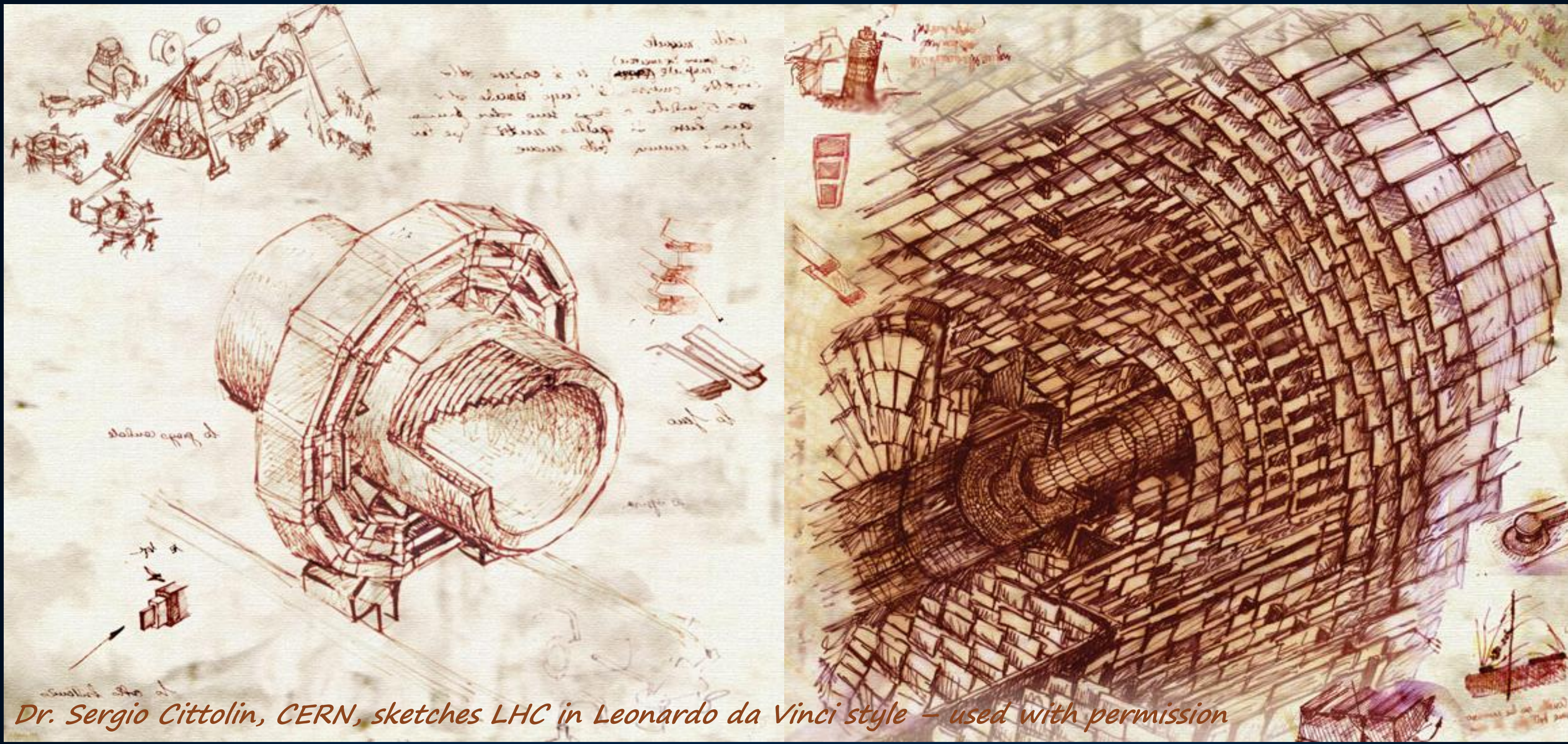
Accelerators and detectors can help to understand whether there is a world inside of an electron

The detectors are arranged just as “Russian dolls”



Dr. Sergio Cittolin, CERN, sketches LHC in Leonardo da Vinci style – used with permission

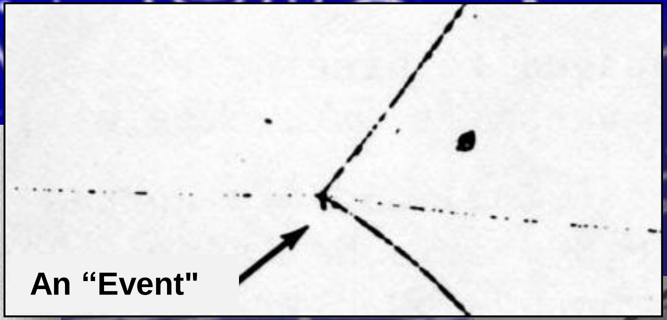
The detectors are arranged just as “Russian dolls”

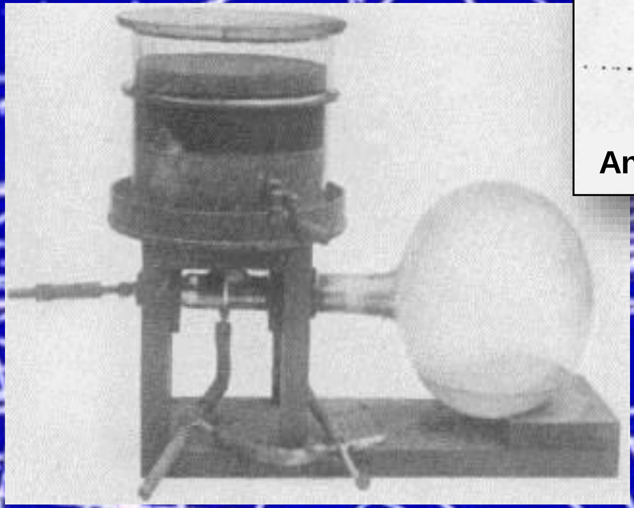


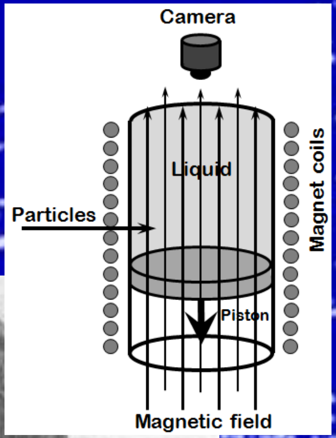
Dr. Sergio Cittolin, CERN, sketches LHC in Leonardo da Vinci style – used with permission

And what were the ones of the first particle detectors?

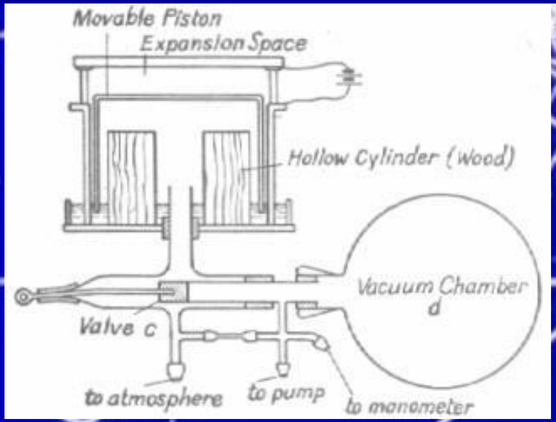
Cloud and bubble chambers







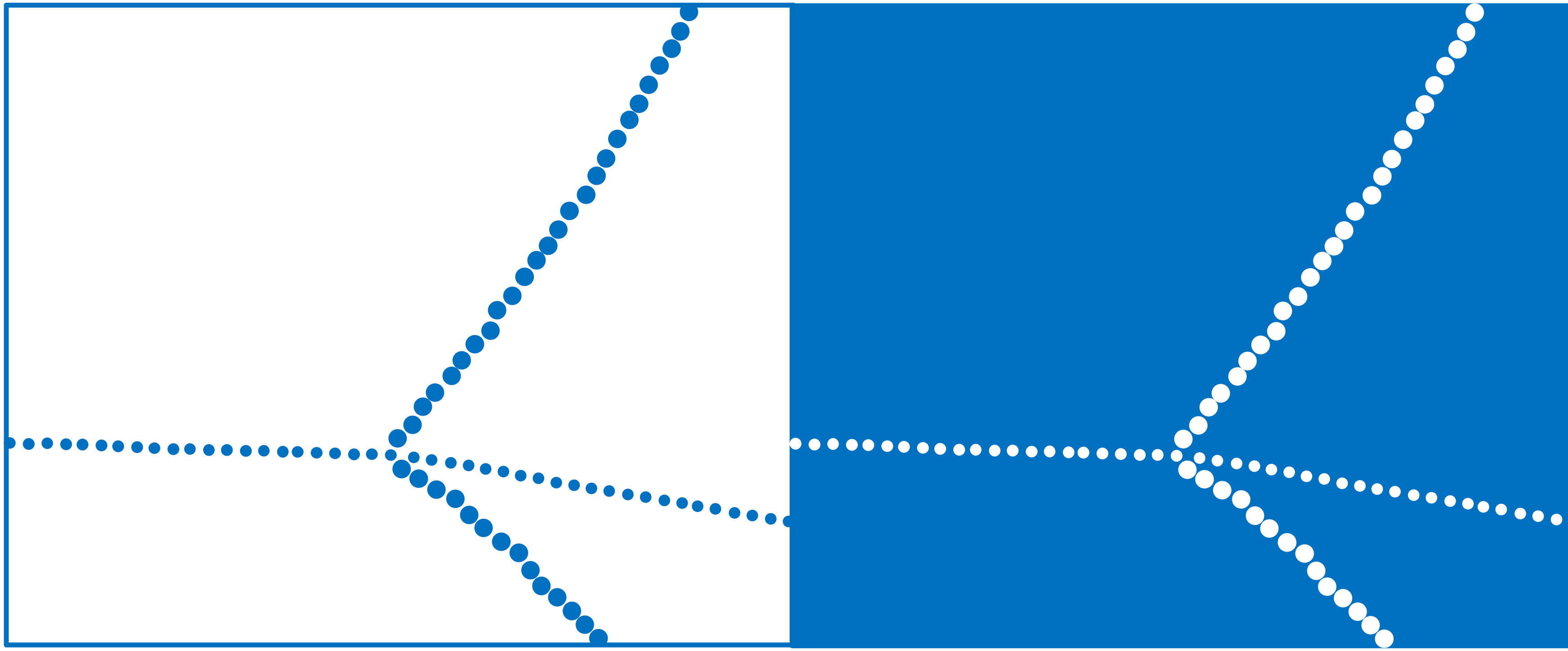
Wilson's Cloud chamber (invented in 1911)



Bubble Chamber (invented in 1952 by D. Glaser – Nobel prize 1960)

On the photo Bubble chamber being installed near Fermilab

Cloud and bubble chambers



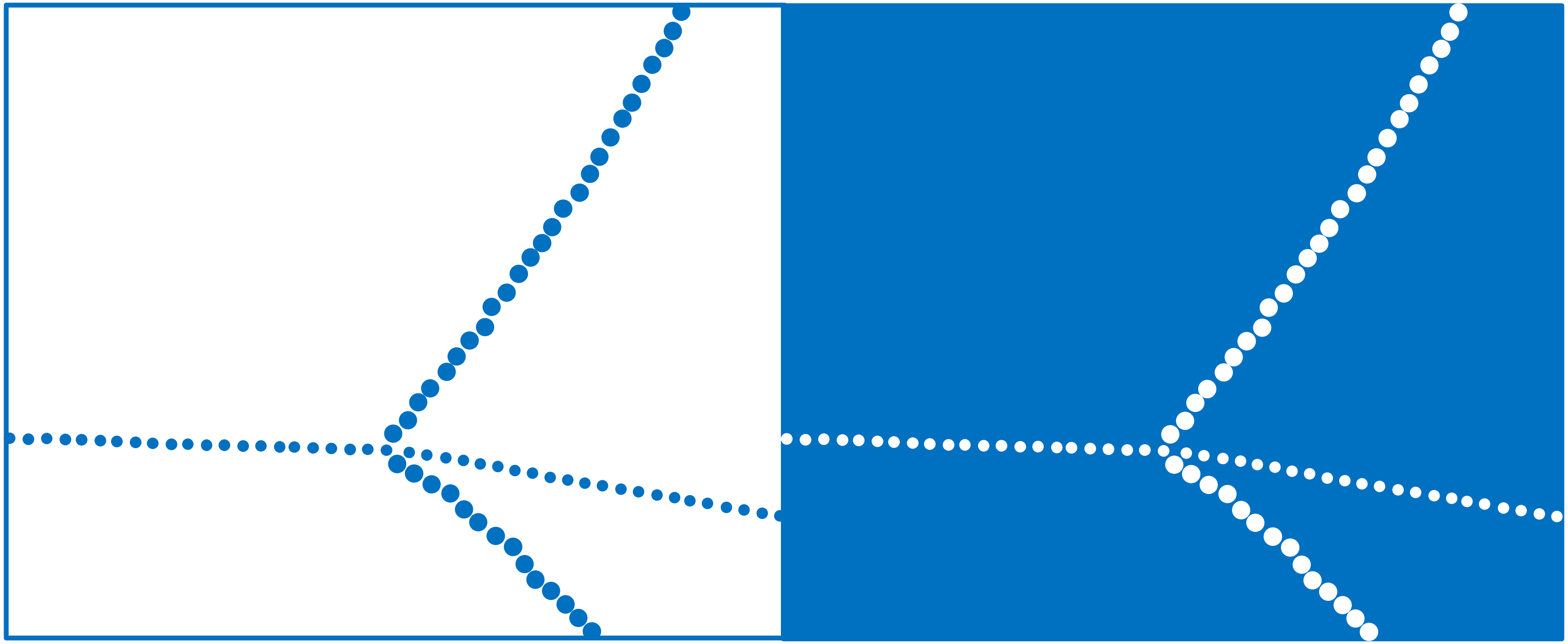
Wilson's Cloud chamber invented in 1911

Glaser's Bubble chamber, invented in 1952

Bubbles of liquid in gas

Bubbles of gas in liquid

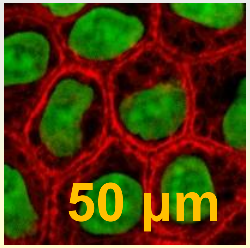
Cloud and bubble chambers



***Wilson's Cloud chamber*, invented in 1911** **Glaser's *Bubble chamber*, invented in 1952**

Cloud chamber and bubble chamber are often mentioned in the TRIZ books with the question - would the invention of the bubble chamber take almost half-a-century if the principle of anti-system had been used?

The structure of matter…



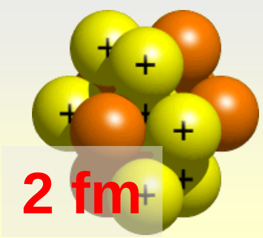
Extra magnification?

CELLS
Twenty per mm

Microscope

x 25 thousand

DNA
Five hundred thousand per mm



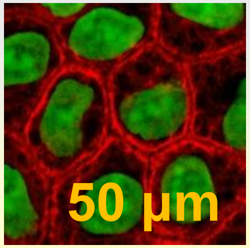
x 1 million

Nucleus
Five hundred billion per mm

x 2 thousand

Quarks
More than one million billion per mm

…use particles



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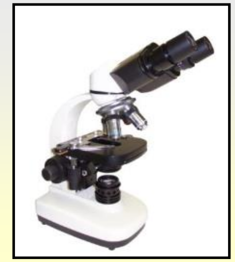
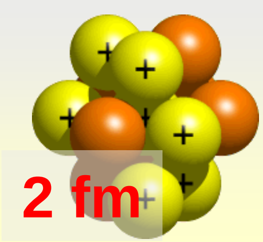


Microscope

x 25 thousand

DNA
Five hundred thousand per mm



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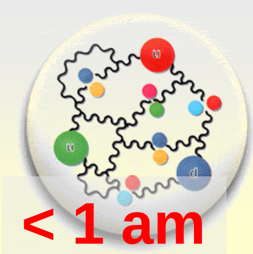


x 2 thousand

Quarks
More than one million billion per mm

Particles & their wave properties

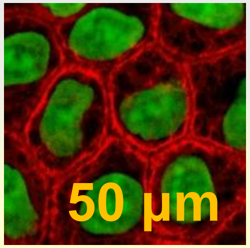
Wavelength corresponding to the particle:

$$\lambda = h/p$$

De Broglie Wavelength — Planck Constant — Momentum

See small? Use particles and increase their energy

…use particle accelerators



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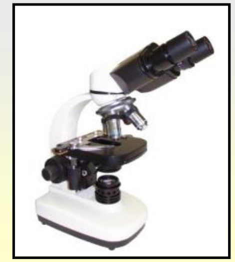

Microscope

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DNA
Five hundred
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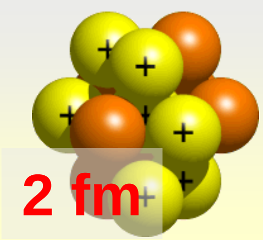
Electron microscope



x 1 million

Nucleus
Five hundred
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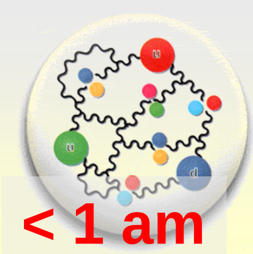
Particle Accelerators



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Quarks
More than one
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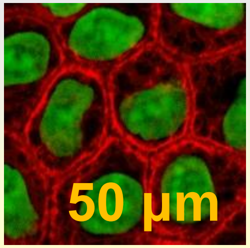
Chemistry Nobel 2014 & inventive principles?



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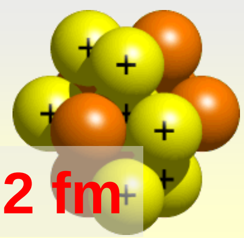

Nucleus
Five hundred
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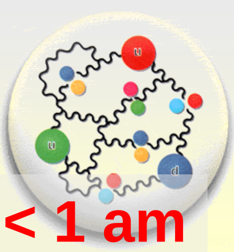
Particle Accelerators

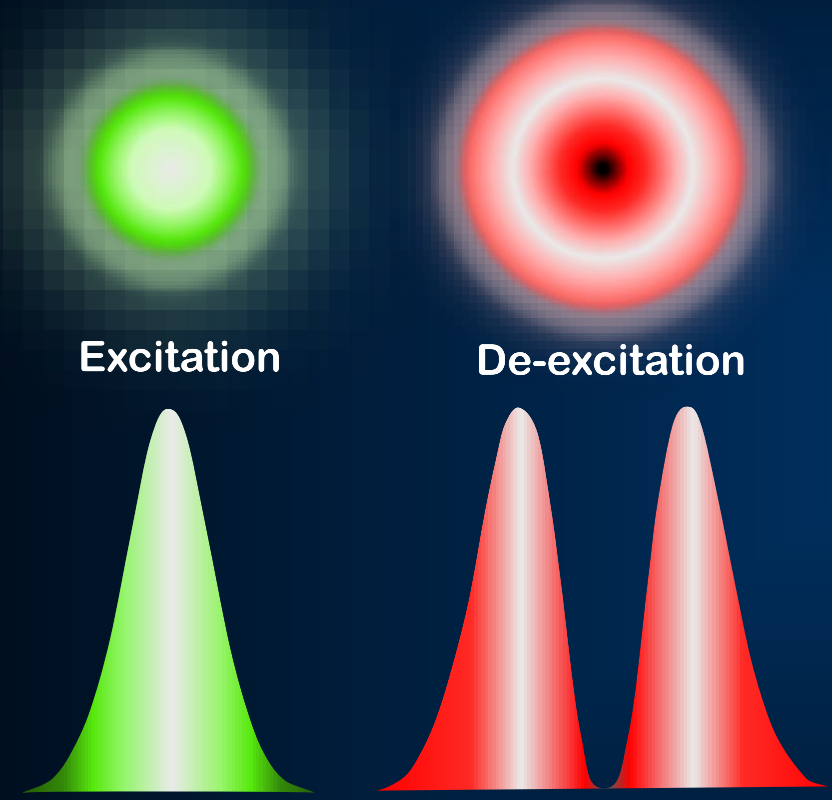
x 2 thousand

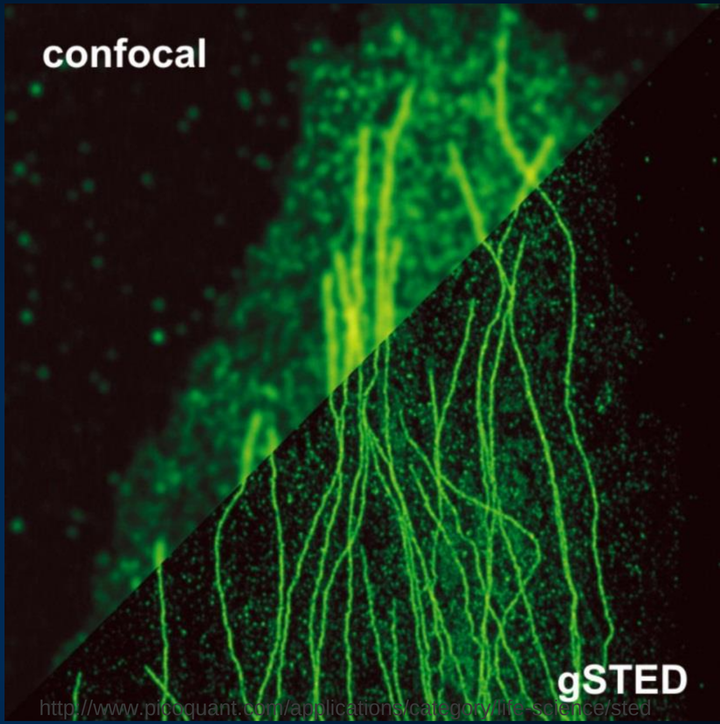


Quarks
More than one
million billion
per mm

Chemistry Nobel 2014 …

Stimulated Emission Depletion microscopy (STED)
Stefan W. Hell

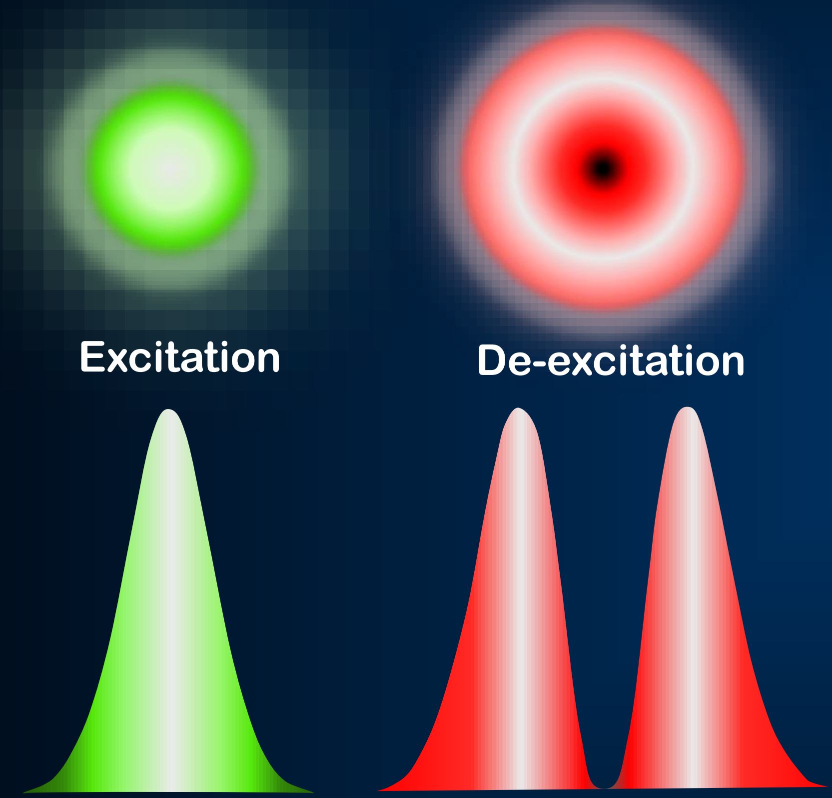


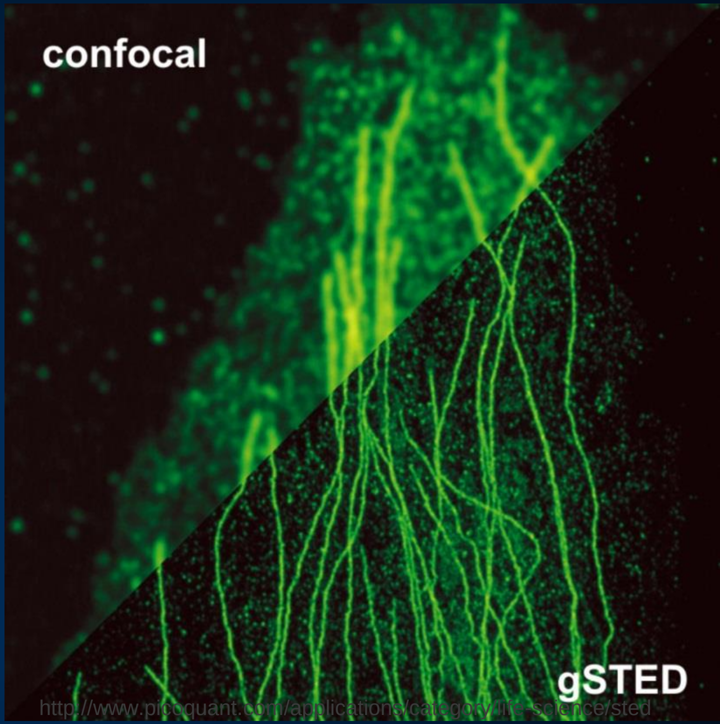


(gated) STED image of Tubulin vs standard confocal image

Chemistry Nobel 2014 & inventive principles

Stimulated Emission Depletion microscopy (STED)
Stefan W. Hell

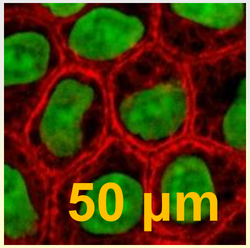




(gated) STED image of Tubulin
vs standard confocal image

From the perspective of TRIZ this is an illustration of the use of the principles of system and anti-system and nested dolls

Colliders & principles of TRIZ



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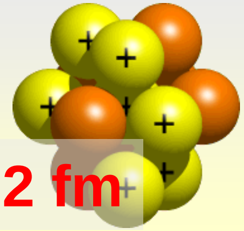


2 fm

x 1 million

Nucleus
Five hundred billion per mm

Particle Accelerators

& Colliders

< 1 am

x 2 thousand

Quarks
More than one million billion per mm

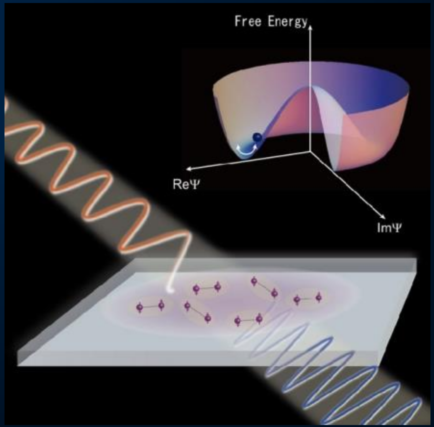
Discovery 2012, Nobel Prize in Physics 2013

The Nobel Prize in Physics 2013 was awarded jointly to François Englert and Peter W. Higgs *"for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle, by the ATLAS and CMS experiments at CERN's Large Hadron Collider".*

Higgs and Superconductivity

"The recent discovery of the Higgs boson has created a lot of excitement … the theoretical proposal of the Higgs mechanism was actually inspired by ideas from condensed matter physics … In 1958, Anderson discussed the appearance of a coherent excited state in superconducting condensates with spontaneously broken symmetry... *On page 1145 of this issue, Matsunaga et al. report direct observation of the Higgs mode in the conventional superconductor niobium nitride (NbN) excited by intense electric field transients*."

Particle physics in a superconductor, A Pashkin & A Leitenstorfer Science 345, 1121 (2014)



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Particle physics in a superconductor, A Pashkin & A Leitenstorfer Science 345, 1121 (2014)

- This shows us that a general conclusion of TRIZ
  - ***"The same Problems and Solutions appear again and again but in different disciplines"***
- is applicable to science too

TRIZ => Science

- **TRIZ was created for engineering**
- **But the method is universal and can be applied to science!**
  - **In particular to Accelerator Science, but not only**

Looking at the world "through the prism of TRIZ" allows us to rethink the familiar things

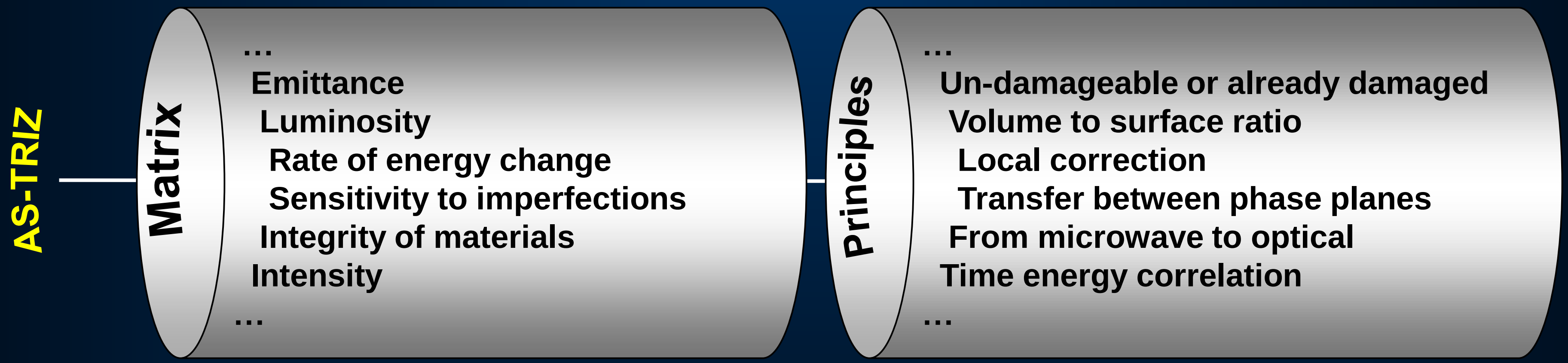
Illustration by Sasha Seraia

TRIZ for Accelerator Science => AS-TRIZ

- TRIZ Contradiction Matrix and Inventive Principles are suitable for engineering disciplines
- To be applicable to Accelerator Science, TRIZ may need to be re-interpreted and extended

TRIZ for Accelerator Science => AS-TRIZ

- TRIZ Contradiction Matrix and Inventive Principles are suitable for engineering disciplines
- To be applicable to Accelerator Science, TRIZ may need to be re-interpreted and extended (extension called Accelerating Science TRIZ or AS-TRIZ)
  - AS-TRIZ Principles and Contradiction Matrix are being developed



Another important reason for creating AS-TRIZ – this will take us through the process of analysing TRIZ, thus helping us to study it proactively

AS-TRIZ

Matrix

- Emittance
- Luminosity
- Rate of energy change
- Sensitivity to imperfections
- Integrity of materials
- Intensity
- …

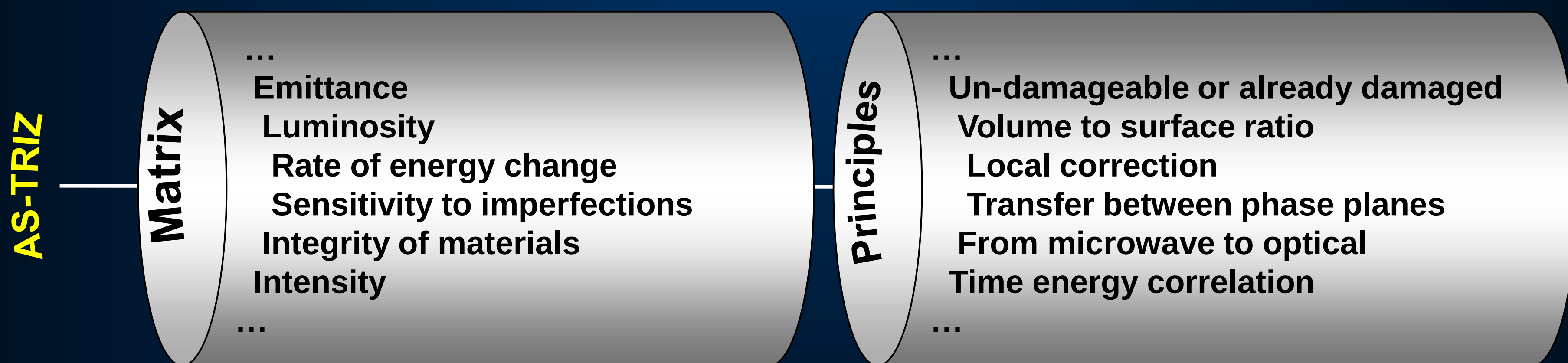
Principles

- Un-damageable or already damaged
- Volume to surface ratio
- Local correction
- Transfer between phase planes
- From microwave to optical
- Time energy correlation
- …

TRIZ for Accelerator Science => AS-TRIZ

- TRIZ Contradiction Matrix and Inventive Principles are suitable for engineering disciplines
- To … be … Accelerating Science TRIZ or AS-TRIZ)
  - AS-TRIZ Principles and Contradiction Matrix are being developed

Accelerating science TRIZ = any area of science can be accelerated using TRIZ

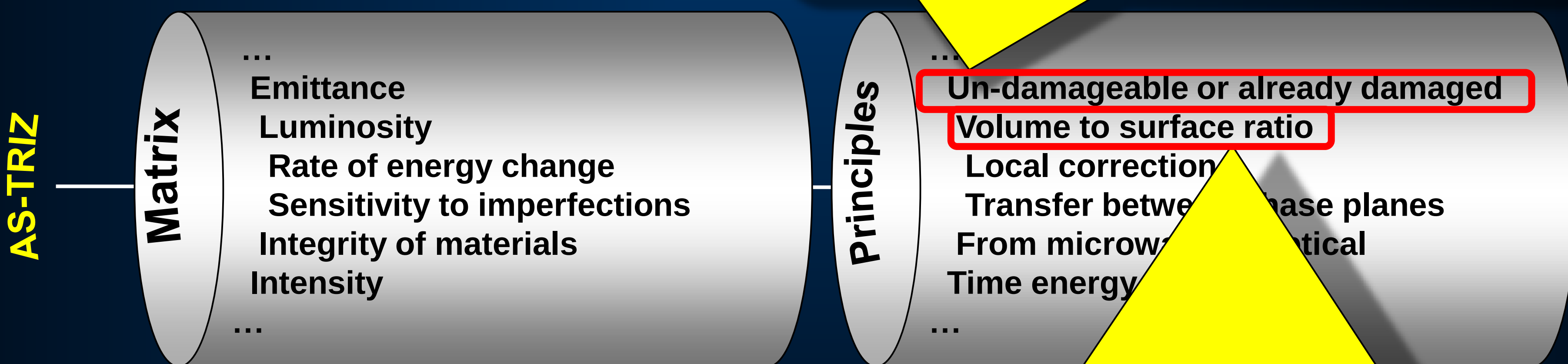


And from the list of the AS-TRIZ principles we shall consider here this pair

suitable for engineering disciplines

- To be applicable to Accelerator Science, TRIZ may need to be re-interpreted and extend
Accelerating Science TRIZ o
  - AS-TRIZ Principles and Contra

3. Using un-damageable or already damaged materials



4. Changing of volume to surface ratio

The principle of changing the volume to surface ratio

The same volume,
but different surface area

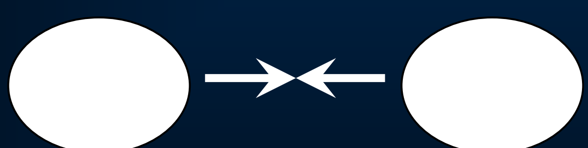
The principle of changing the volume to surface ratio

The same volume,
but different surface area

The principle of changing the volume to surface ratio

The same volume,
but different surface area

The same principle is used in e+e- colliders, where "pancakes" are collided instead of "buns"

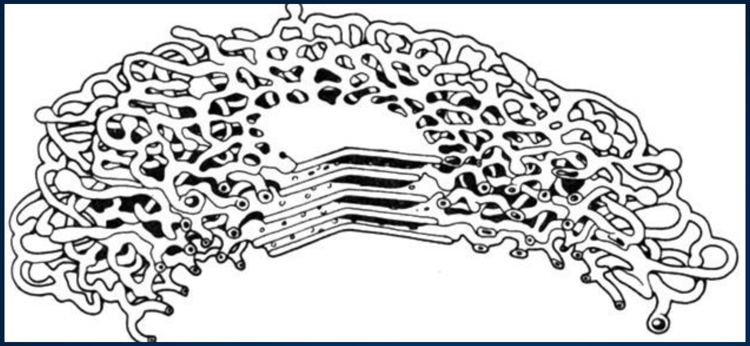


The principle of changing the volume to surface ratio – an example

The same volume, but different surface area and the different amount of information ☺

And could we suggest an example illustrating this principle, for instance, in biology?

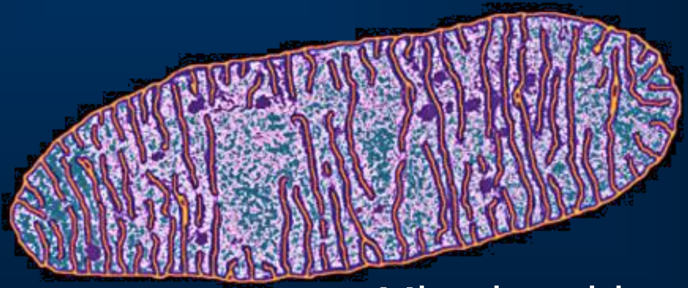
The principle of changing the volume to surface ratio – examples



Golgi Apparatus

Brain

Algae



Mitochondria

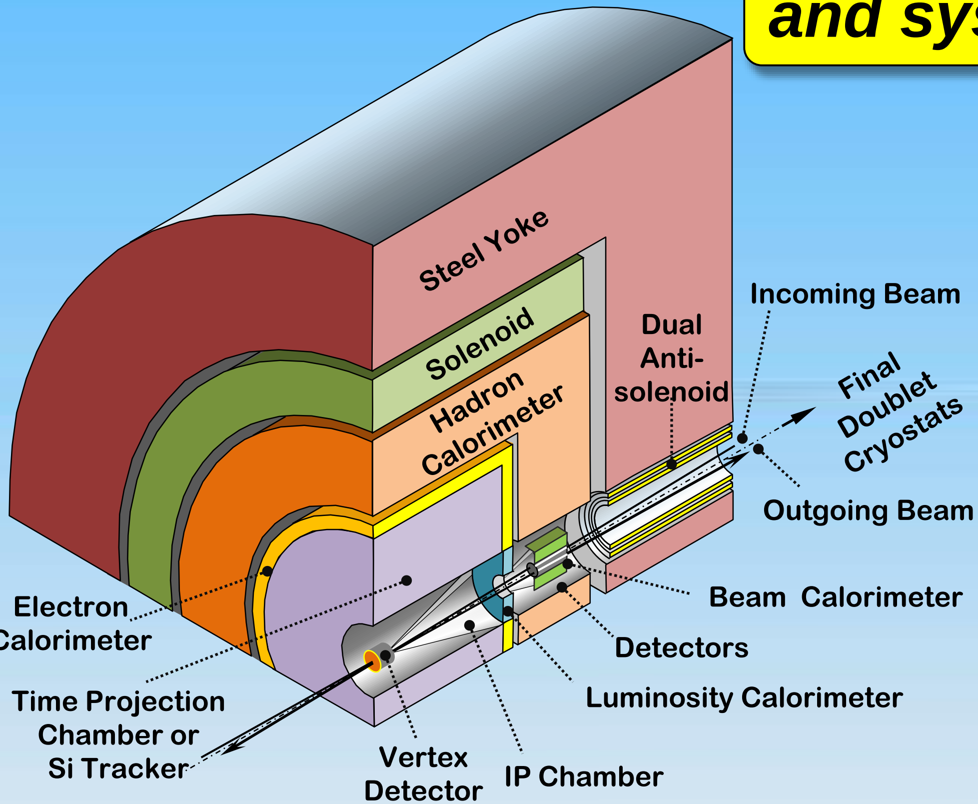
Keeping the same volume but increasing the surface area to enhance the functionality

ILC Interaction Region…

has many examples of TRIZ-like inventions ..

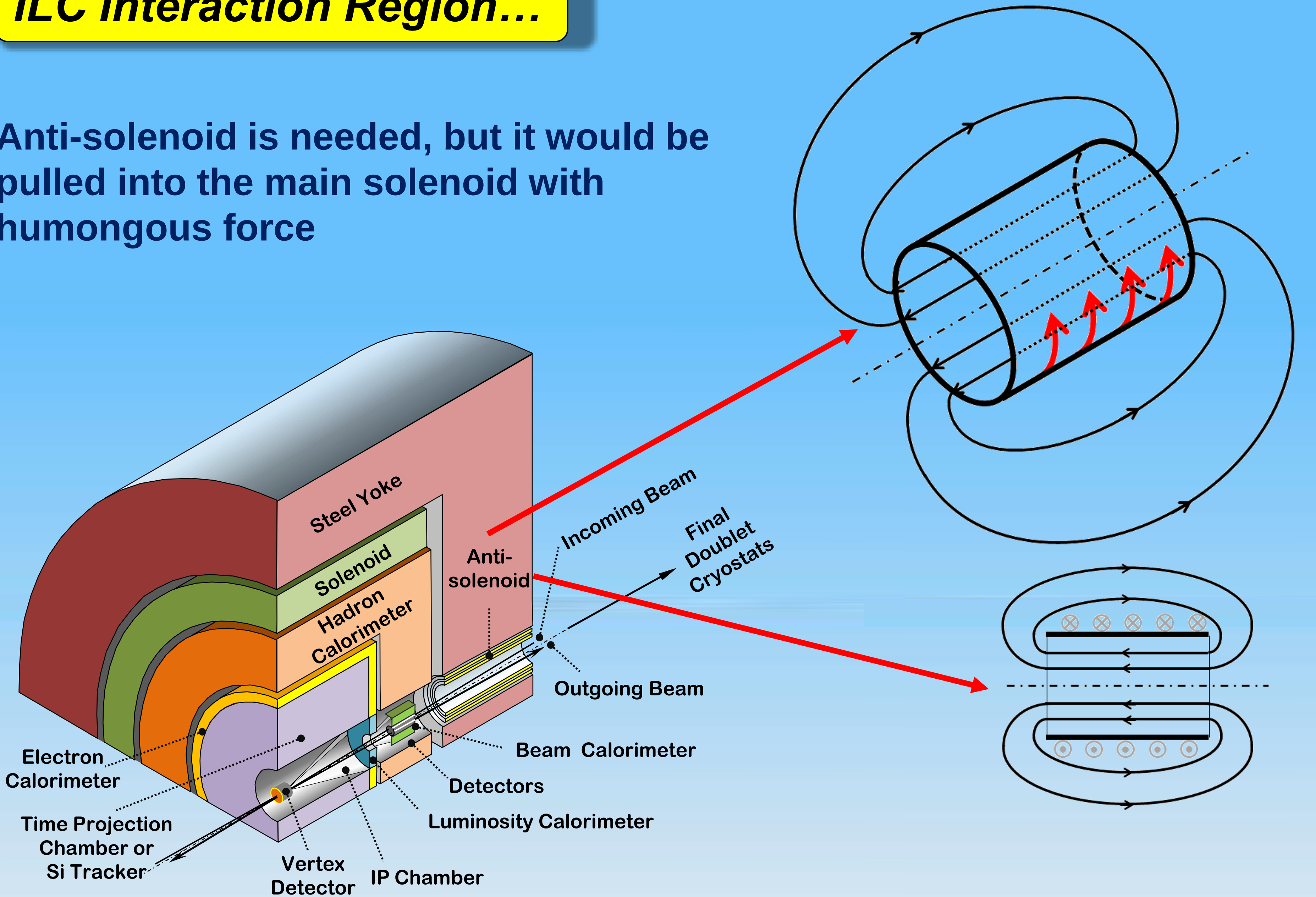
with Russian dolls…

and system-antisystem principles



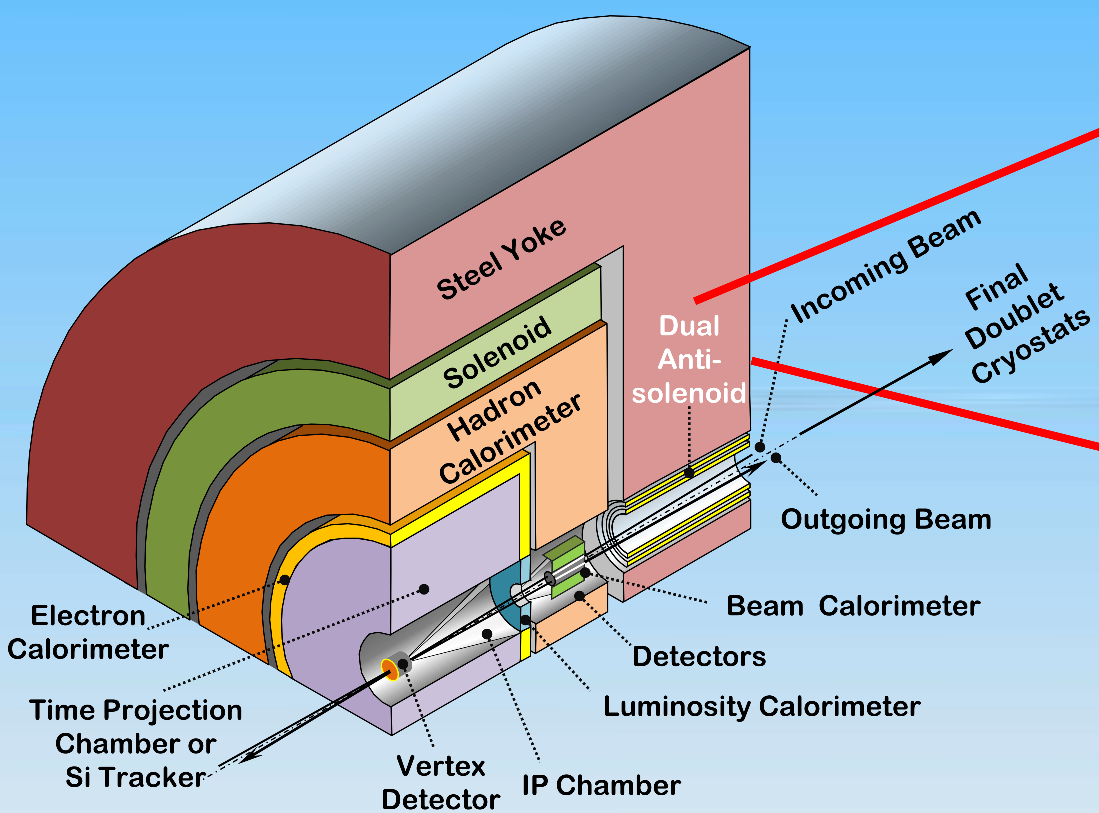
ILC Interaction Region…

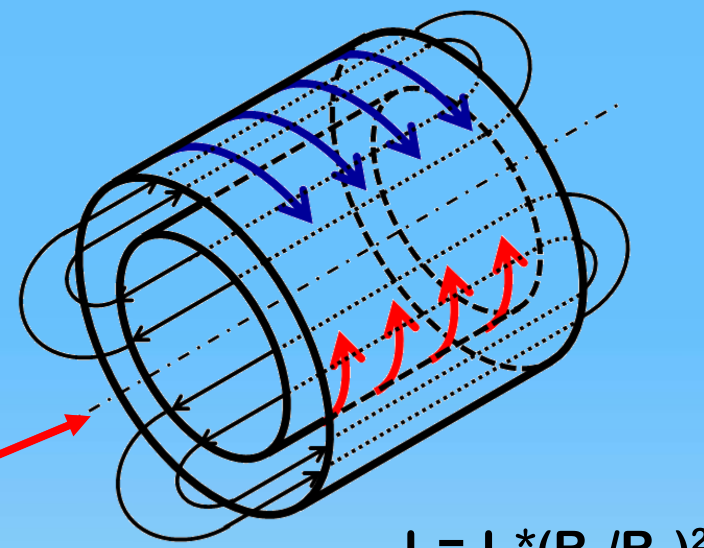
Anti-solenoid is needed, but it would be pulled into the main solenoid with humongous force



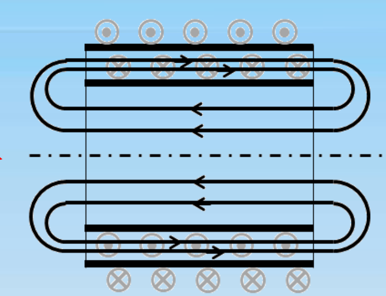
ILC Interaction Region…

Dual anti-solenoid is used, to cancel its external field – this makes it force-neutral





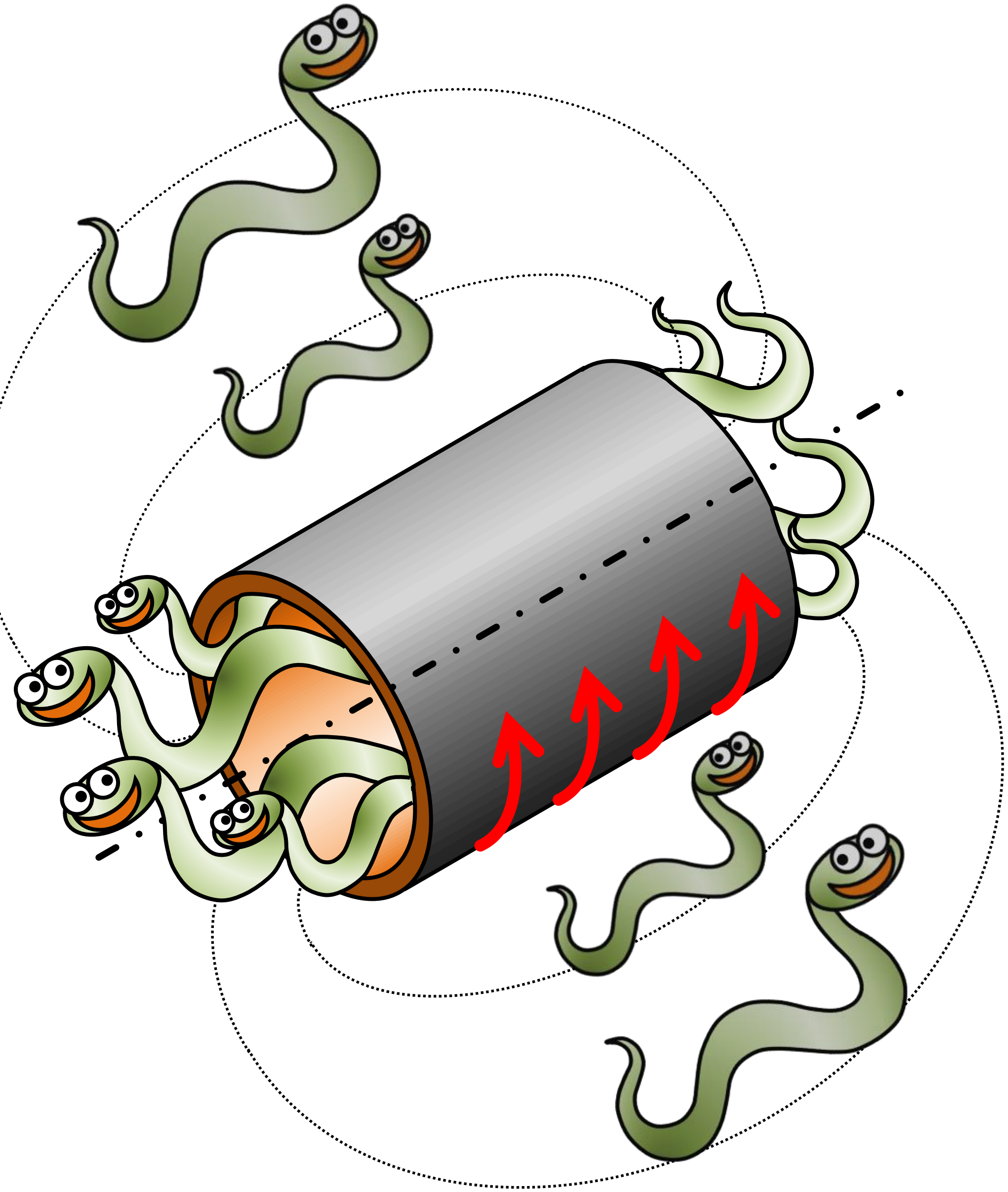
$$I_2=-I_1*(R_1/R_2)^2$$



This is Russian doll & system – anti-system!

Recall synectics and use of analogies

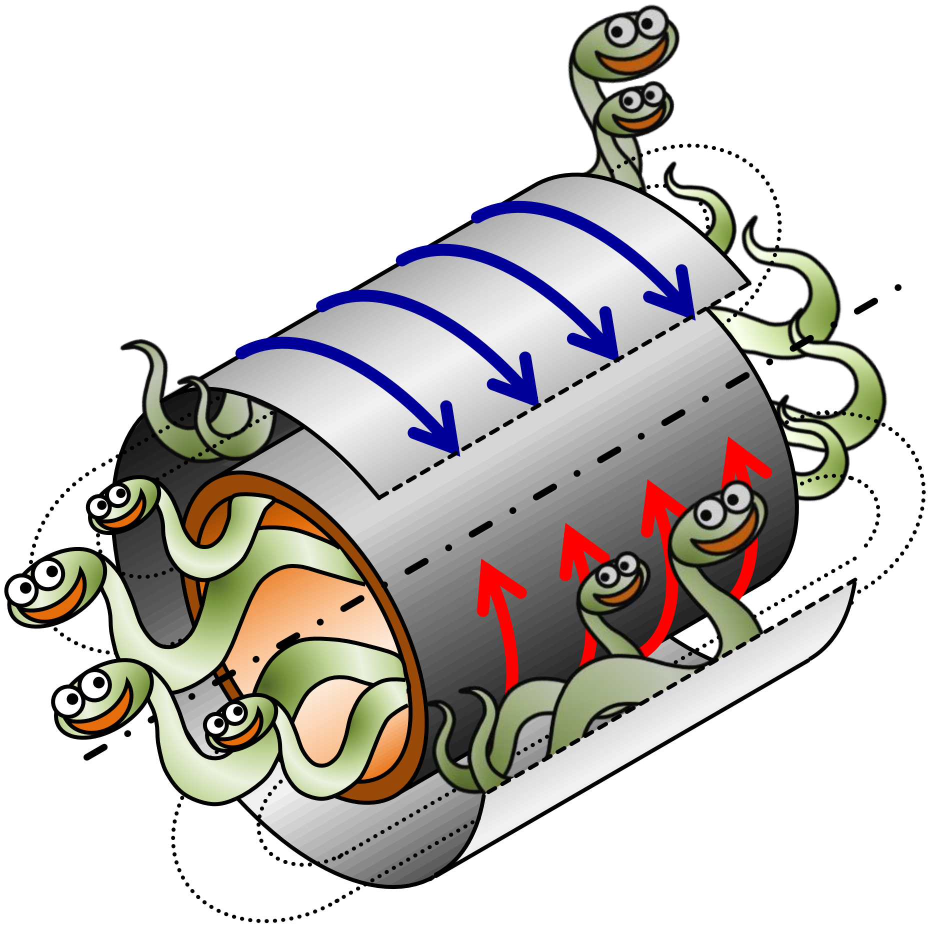
- Use of analogies to generate fresh view
  - …
  - empathic (attempting to look at the problem identifying yourself with the object);
  - …
  - metaphorical (describing the problem in terms of fairy-tales and legends);



How to contain the magnetic flux?

Recall synectics and use of analogies

- Use of analogies to generate fresh view
  - …
  - empathic (attempting to look at the problem identifying yourself with the object);
  - …
  - metaphorical (describing the problem in terms of fairy-tales and legends);

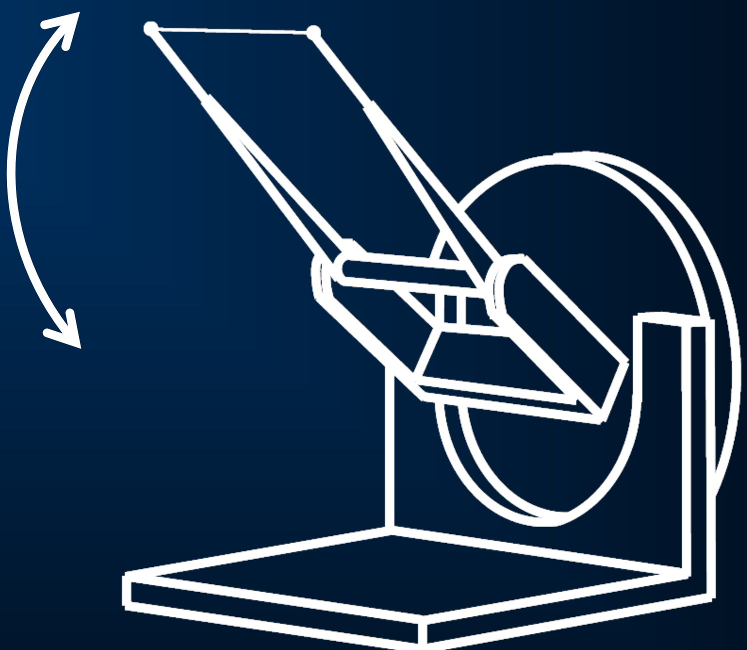


Lasers and beam diagnostics

Lasers are often used to measure parameters of the beams in accelerators

But traditionally "simple" mechanical devices have been used

beam bunches



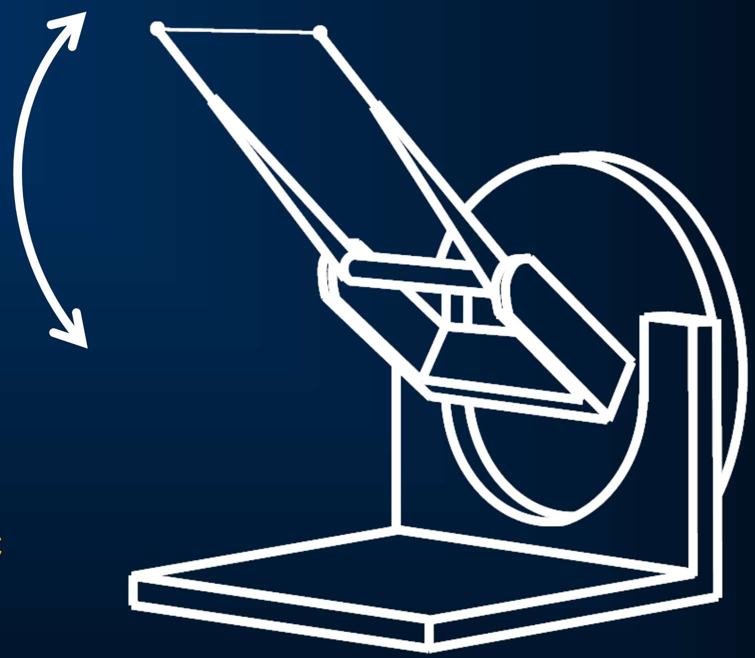
Wires for the beam profile monitor should be very thin ...

Romantic methods in physics

Sometimes thin wires for beam diagnostics were made ...

*"... With a romantic crossbow shooting method * ..."*

beam bunches

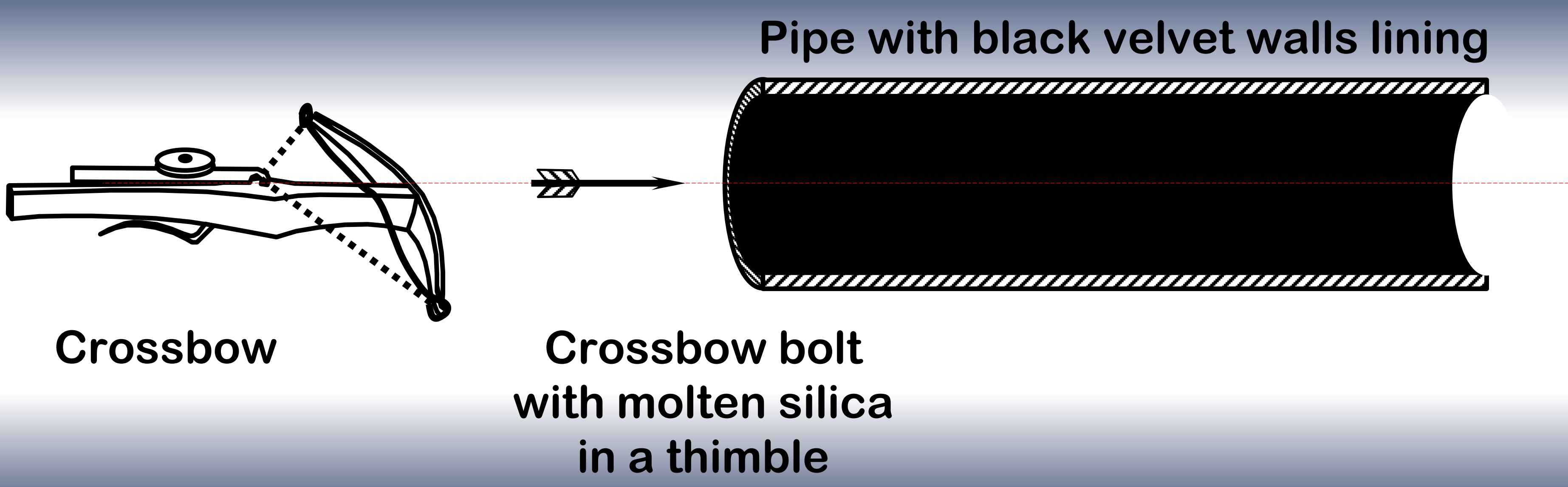


*) from PhD dissertation of V.V.Parkhomchuk (Budker Inst. of Nuclear Physics) - my Scientific Mentor in 1982 - 1986

Romantic methods in physics

Sometimes thin wires for beam diagnostics were made ...

*"... With a romantic crossbow shooting method * ..."*



Romantic methods in physics

Sometimes thin wires for beam diagnostics were made ...

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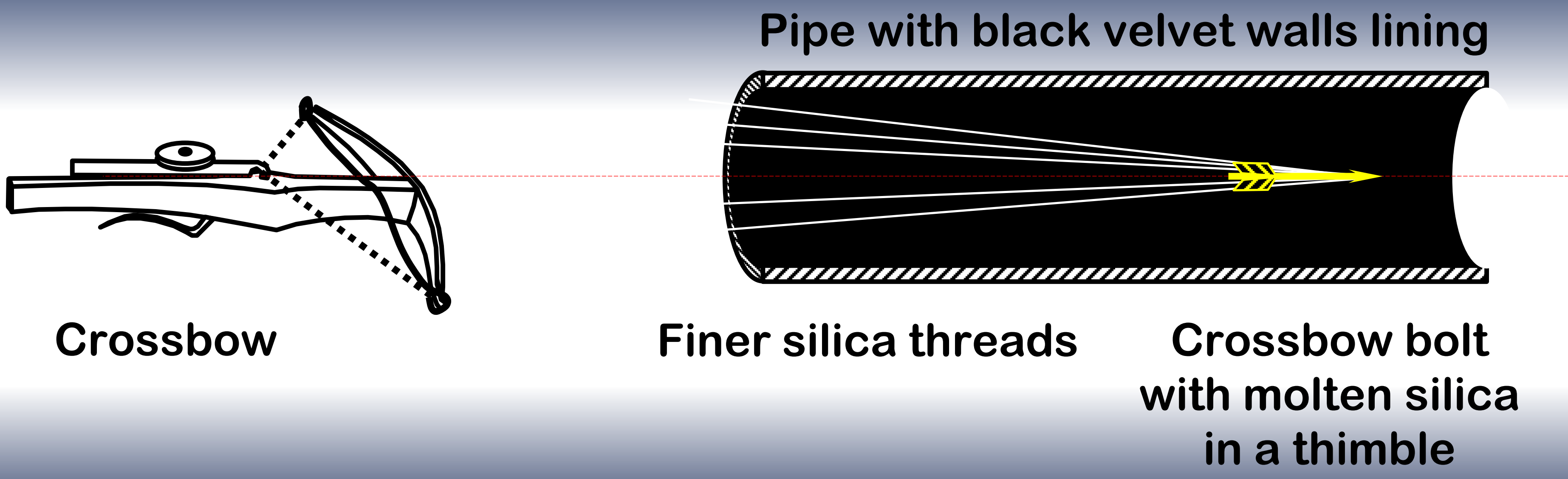
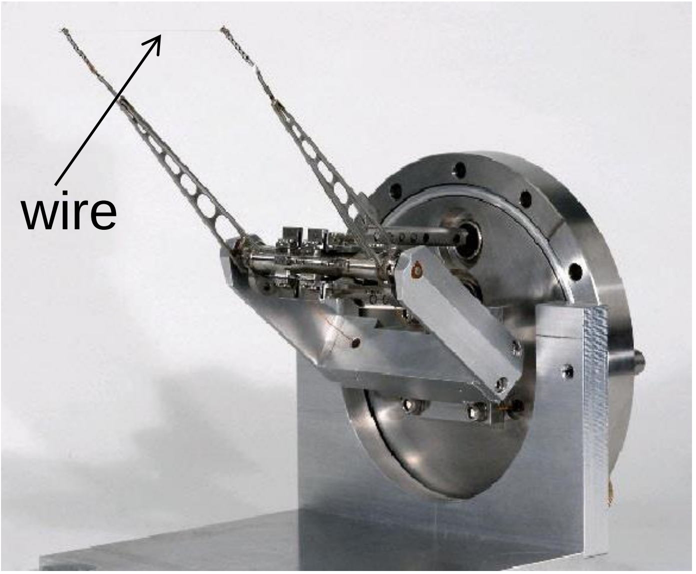


And yet, how laser can help here?



Beam profile monitor with tungsten or carbon wire

Problem:

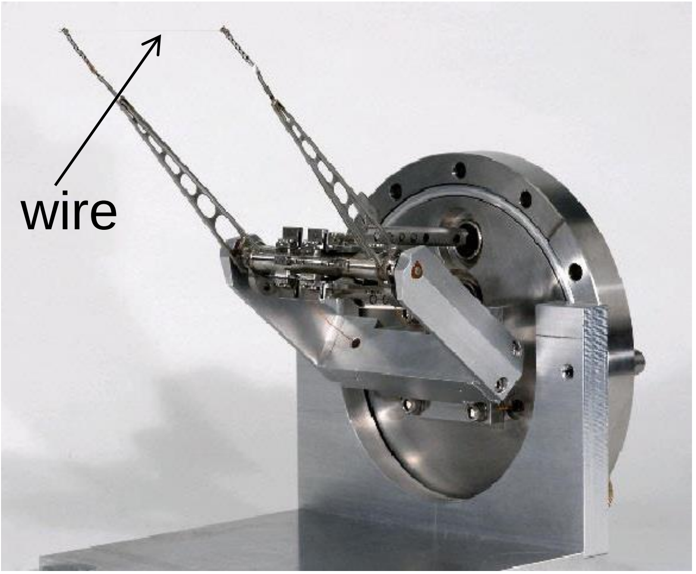
As intensity of the beam increase, the wire get damaged after a single use

Contradiction:

To be improved: INTENSITY

What gets worse: INTEGRITY

And yet, how laser can help here?



Beam profile monitor with tungsten or carbon wire

Problem:

As intensity of the beam increase, the wire get damaged after a single use

Contradiction:

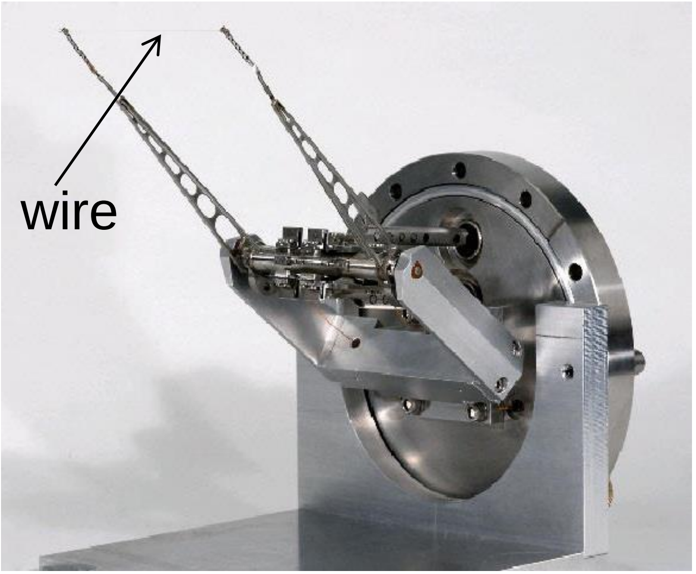
To be improved: INTENSITY

What gets worse: INTEGRITY

We look at the AS-TRIZ matrix:

Improving Parameter	Parameter that deteriorates				
	…	…	9. Integrity	…
…				
6. Intensity			**3, …**	
…				

And yet, how laser can help here?



Beam profile monitor with tungsten or carbon wire

Problem:

As intensity of the beam increase, the wire get damaged after a single use

Contradiction:

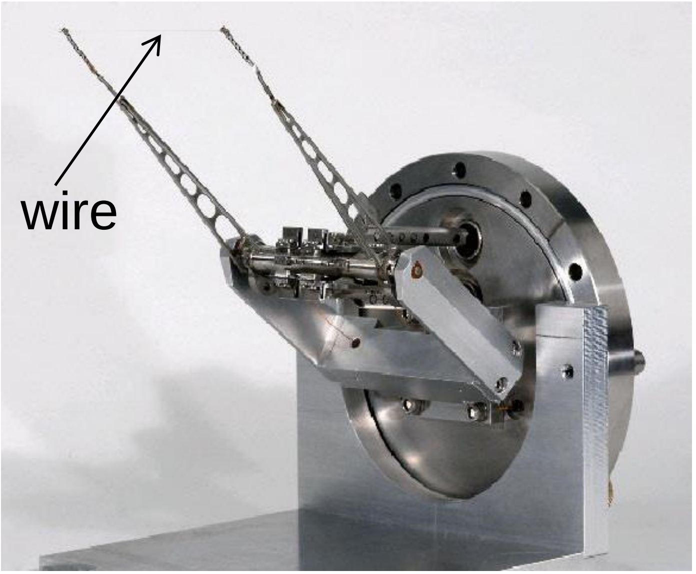
To be improved: INTENSITY

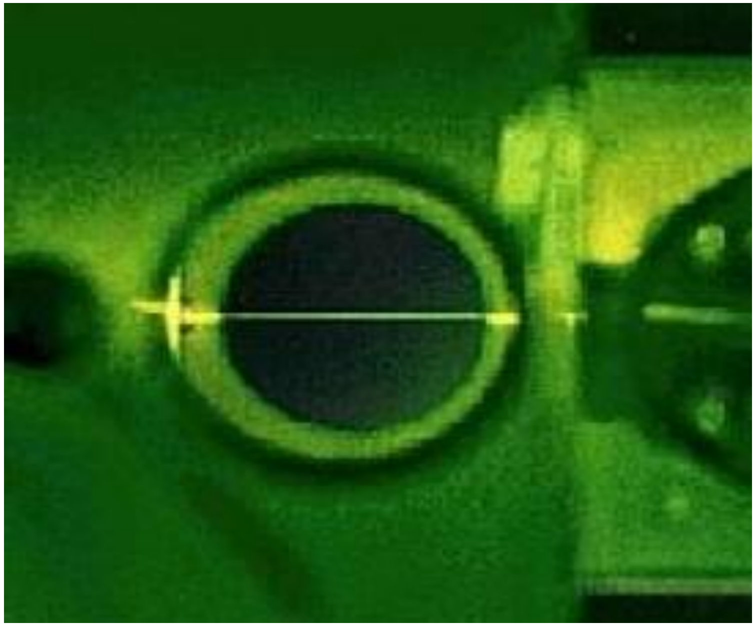
What gets worse: INTEGRITY

And select one of the inventive principles of emerging AS-TRIZ:

- **3: Replace material that can be damaged with other media, which either cannot be damaged (light) or already "damaged" (e.g. plasma)**

Indestructible laser wire!





Beam profile monitor with tungsten or carbon wire

Beam profile monitor with laser beam as the "wire"

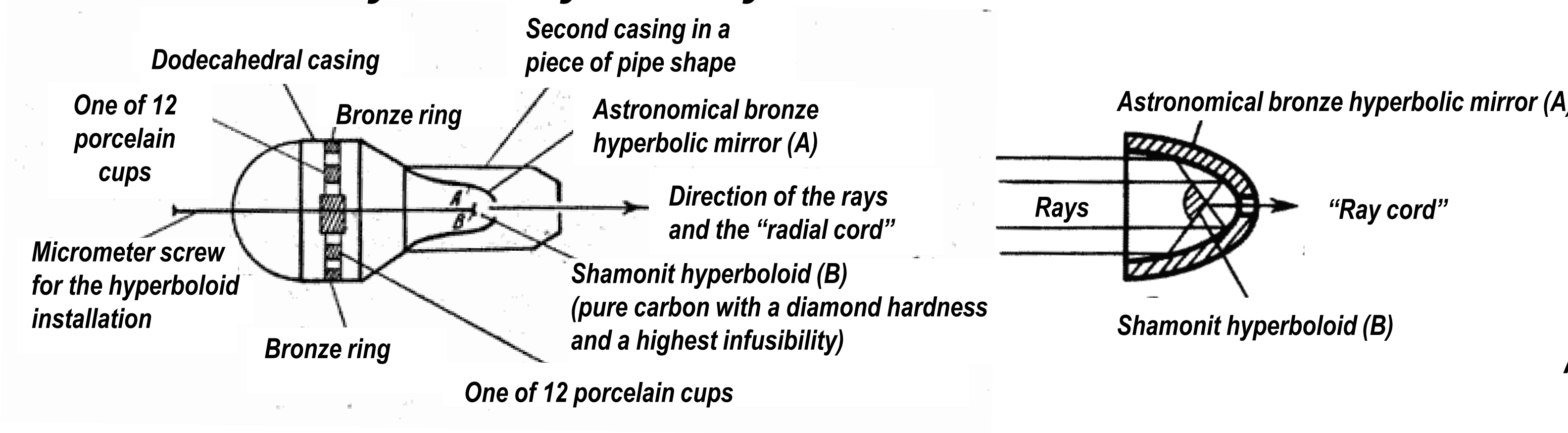
Solution:

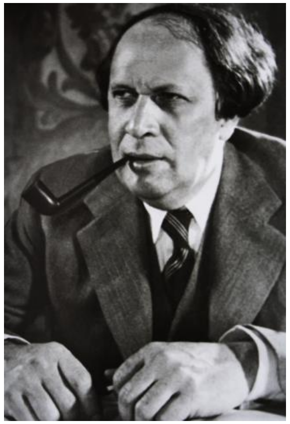
Then we apply this AS-TRIZ inventive principle:

- **3: Replace material that can be damaged with other media, which either cannot be damaged (light) or already "damaged" (e.g. plasma)**

"The Hyperboloid of Engineer Garin"

1926 novel by Aleksey Tolstoy

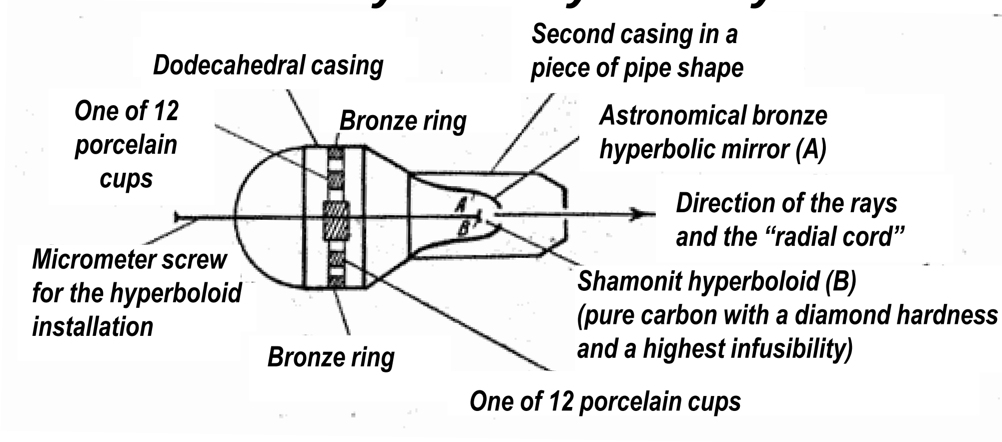


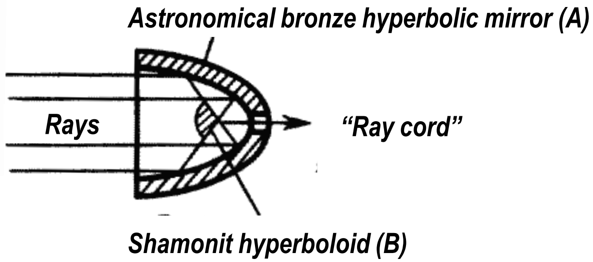


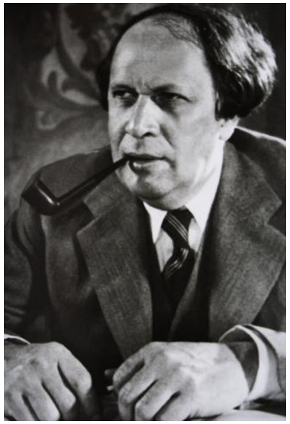
Aleksey Tolstoy

"The Hyperboloid of Engineer Garin"

1926 novel by Aleksey Tolstoy





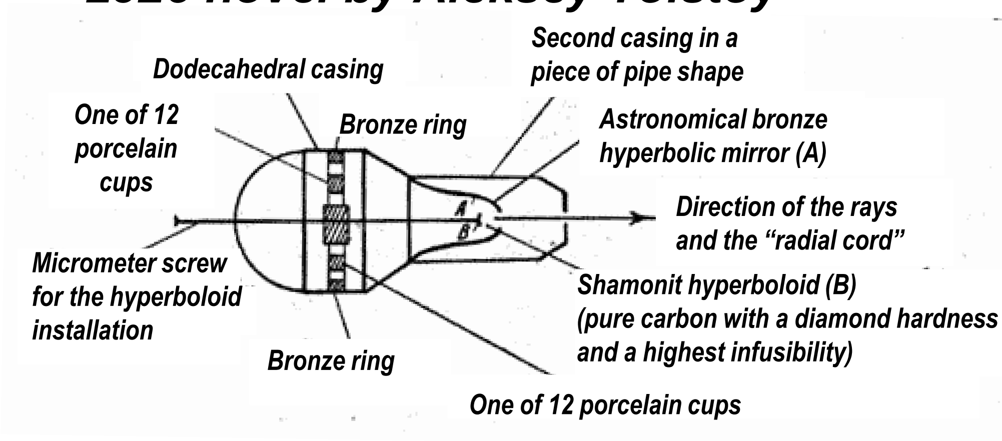

Aleksey Tolstoy

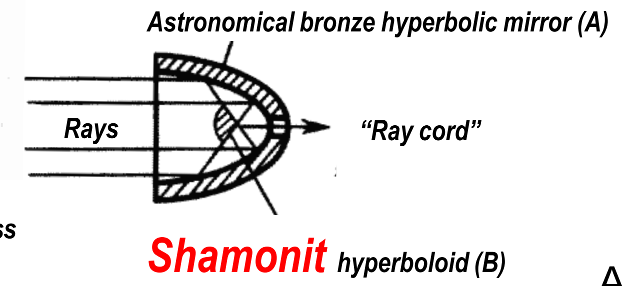
From Tolstoy's novel:

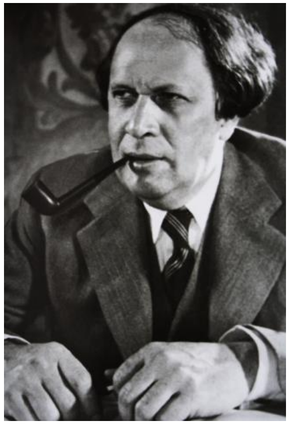
"…Can you imagine what opportunities are opening now? Nothing in the nature can withstand the power of the ray cord - buildings, forts, dreadnoughts, airships, rocks, mountains, the earth's crust - everything could be penetrated, destroyed, cleaved with my beam." Garin suddenly broke off and lifted his head, listening ... "Three cars and eight people," he said in a whisper, "they came after us"…

“The Hyperboloid of Engineer Garin”

1926 novel by Aleksey Tolstoy



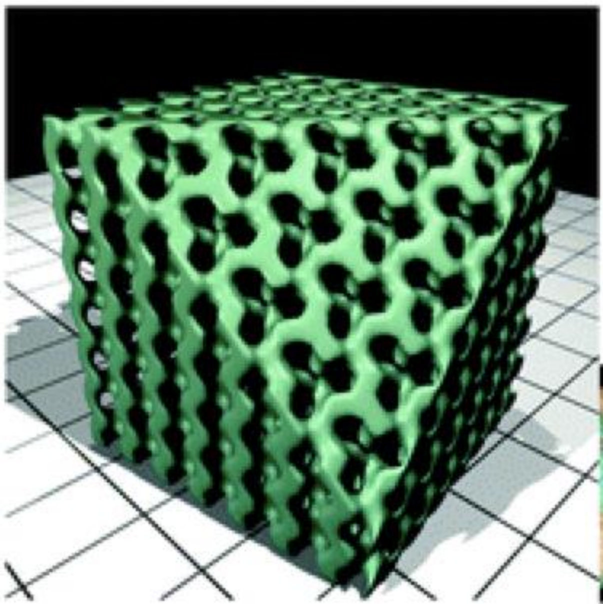


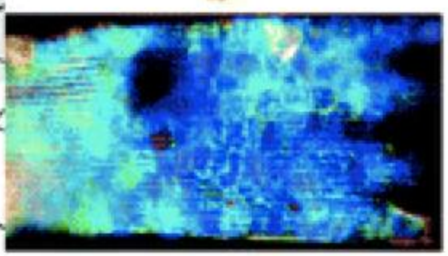


Aleksey Tolstoy

“unobtainium”

Non-existing material



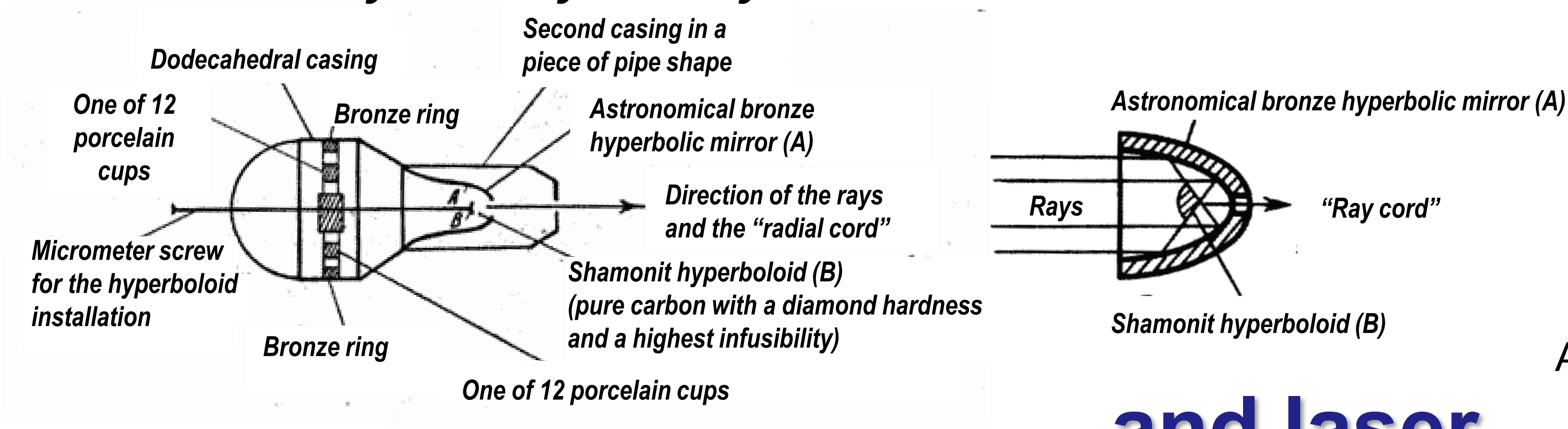


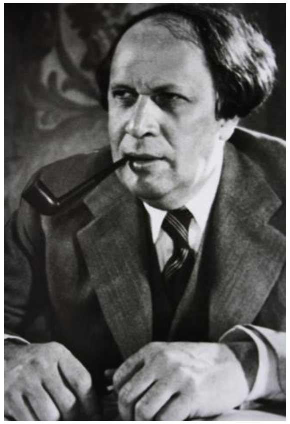
C. Mille, E. Tyrodec, R. Corkery, Chem. Commun., 2011,**47**, 9873-9875

Can shamonit be obtained in the future, as engineered material and inspired by nature, in a similar way how this inorganic chiral 3-D photonic crystals with bicontinuous gyroid structure were replicated from butterfly wings?

“The Hyperboloid of Engineer Garin”

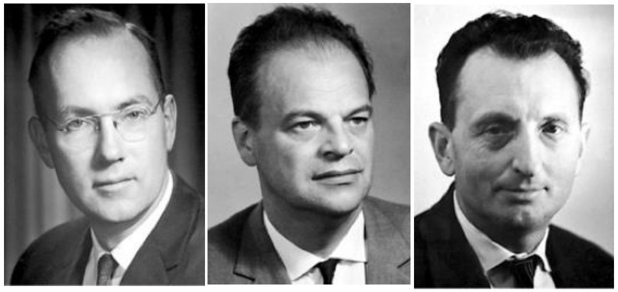
1926 novel by Aleksey Tolstoy





Aleksey Tolstoy

… and laser

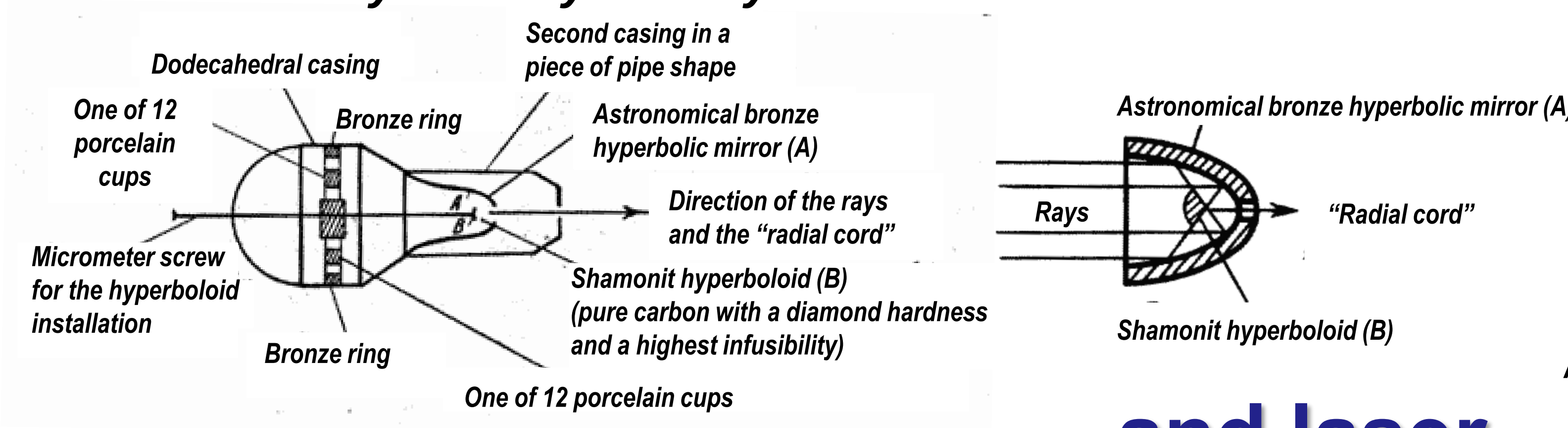


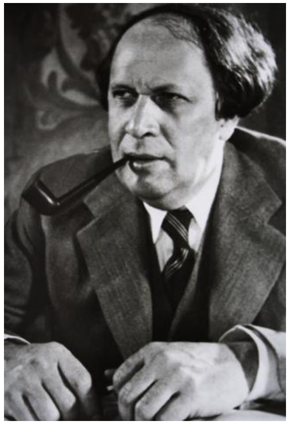
C.Townes N.Basov A. Prokhorov

Nobel Prize in 1964 for the research that led to the development of lasers

“The Hyperboloid of Engineer Garin”

1926 novel by Aleksey Tolstoy





Aleksey Tolstoy

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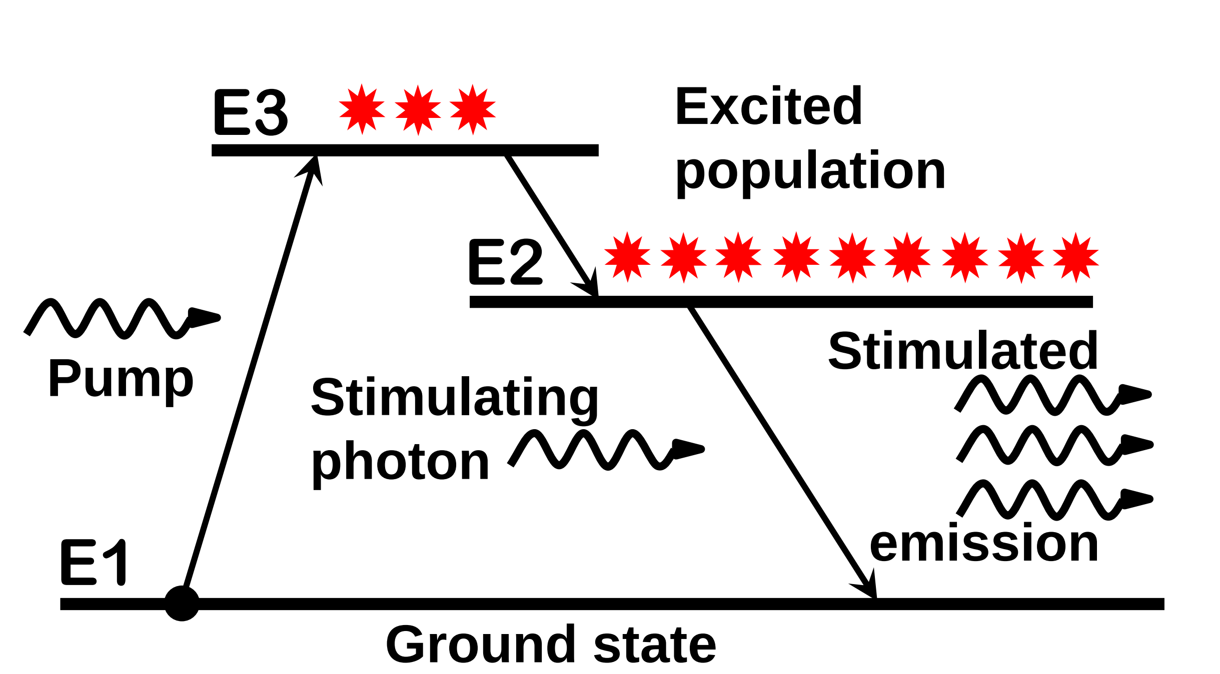

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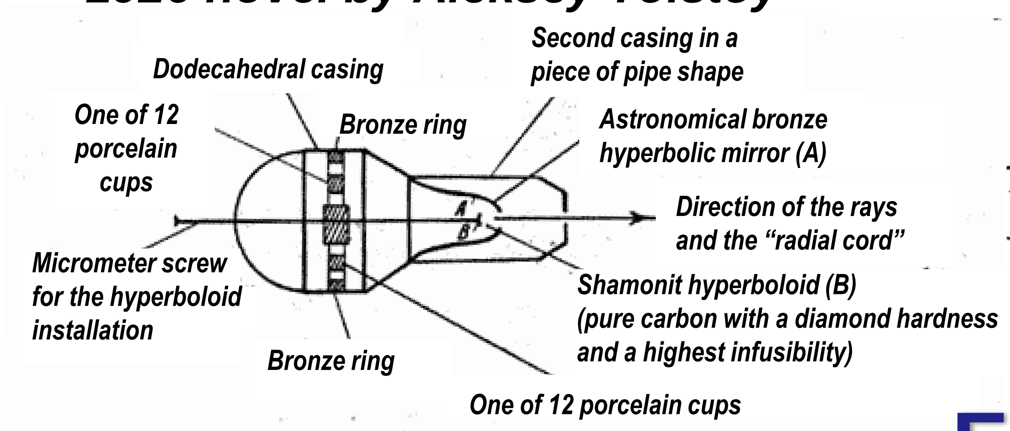
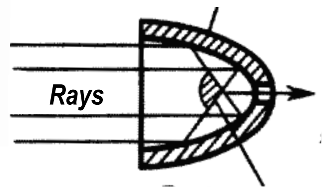
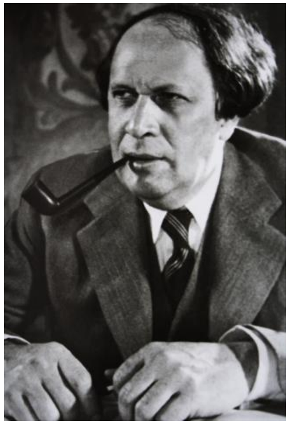
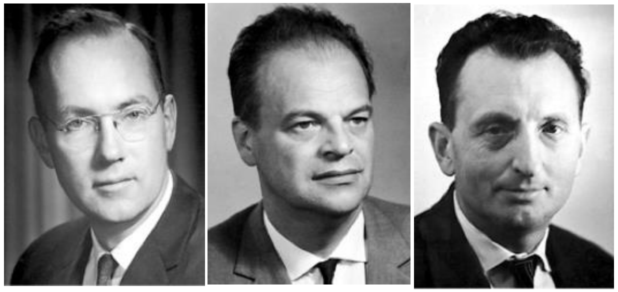






Aleksey Tolstoy

Example: Ruby laser



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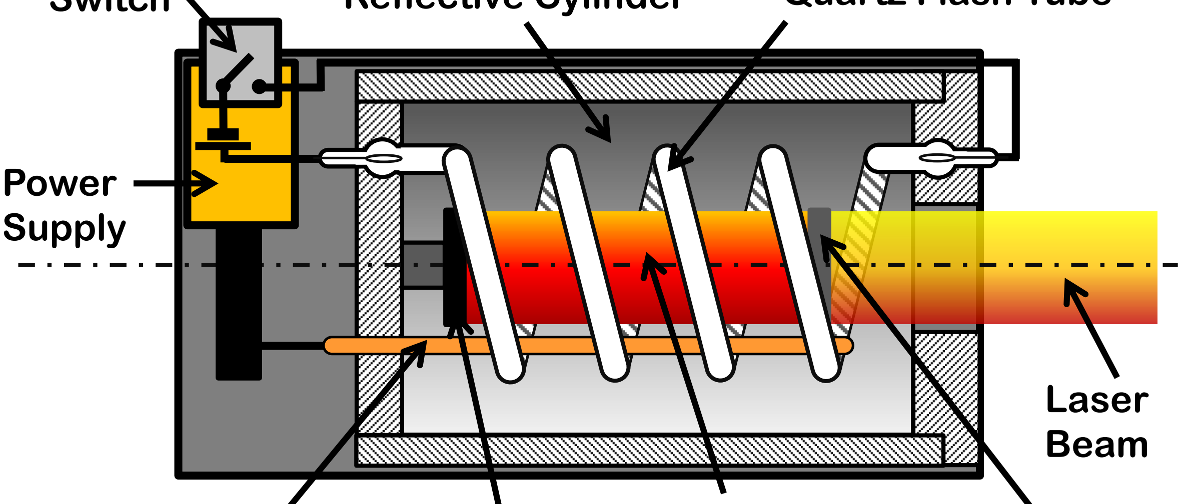
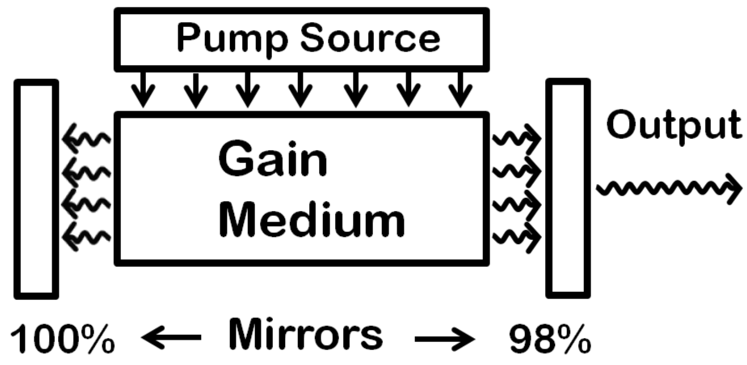
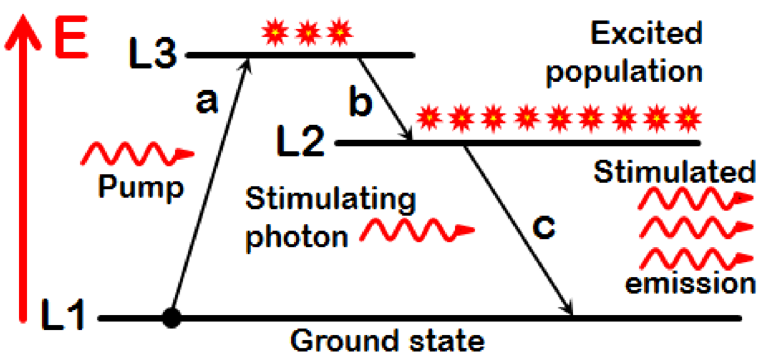


Lasers – scheme & transitions in 3 level laser



Laser scheme



Three level laser

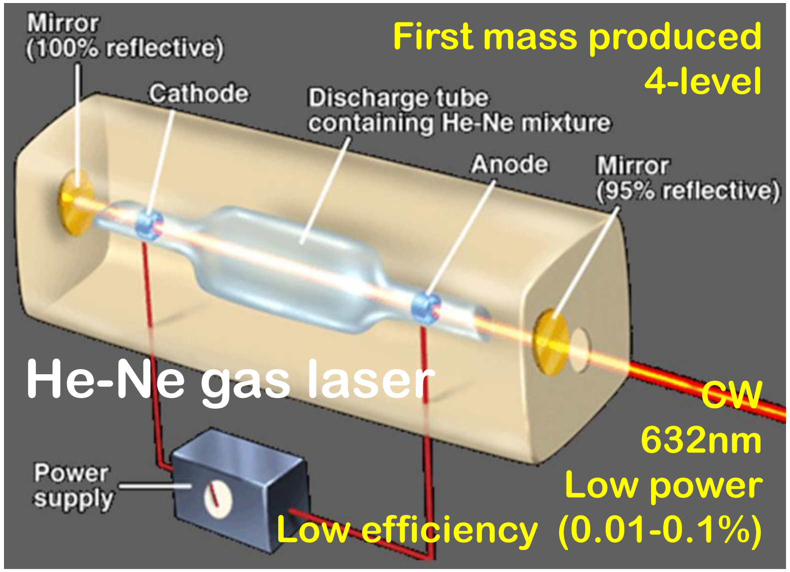
- **Laser components**
  - **Gain Medium (amplifies the light)**
  - **Resonator (gives optical feedback)**
  - **Pump Source (makes population inversion)**

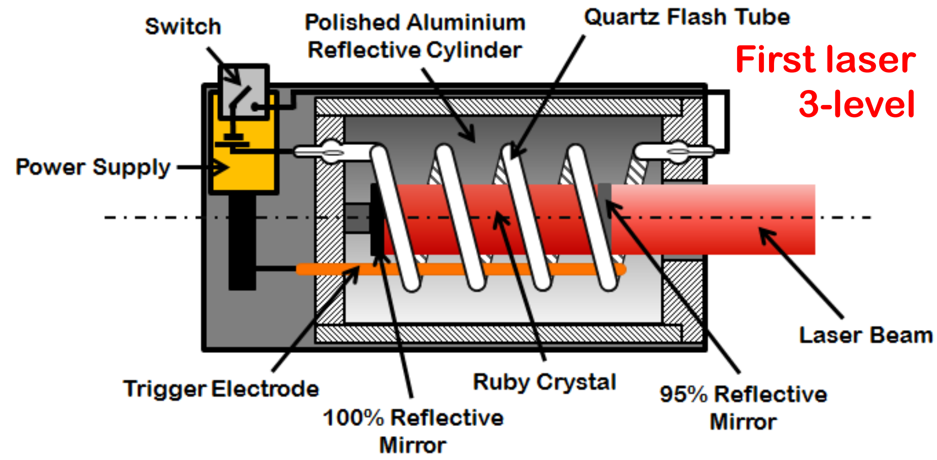
a. **The pump gets population from ground state L1 to the higher energy level L3**

b. **The excited population gets from L3 to L2 through non radiative decay**
   - **The lifetime of L3 is very short and all the population in state L3 decays to state L2**

c. **Stimulated emission from L2 to state L1**
   - **Lifetime of energy state L2 is long => population inversion occurs with respect to state L1**
   - **Once the population inversion is obtained, stimulated emission will give optical gain**

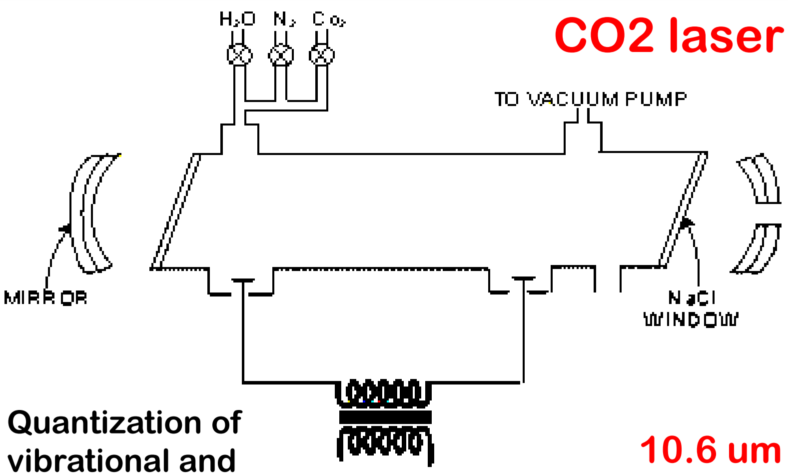
Examples of laser types





Ruby laser
694nm

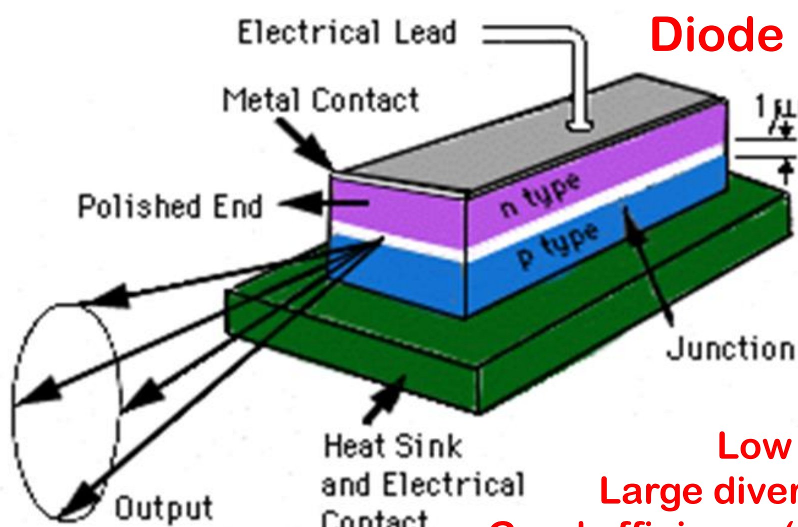
CO2 laser



Quantization of vibrational and rotational states of CO2 molecule

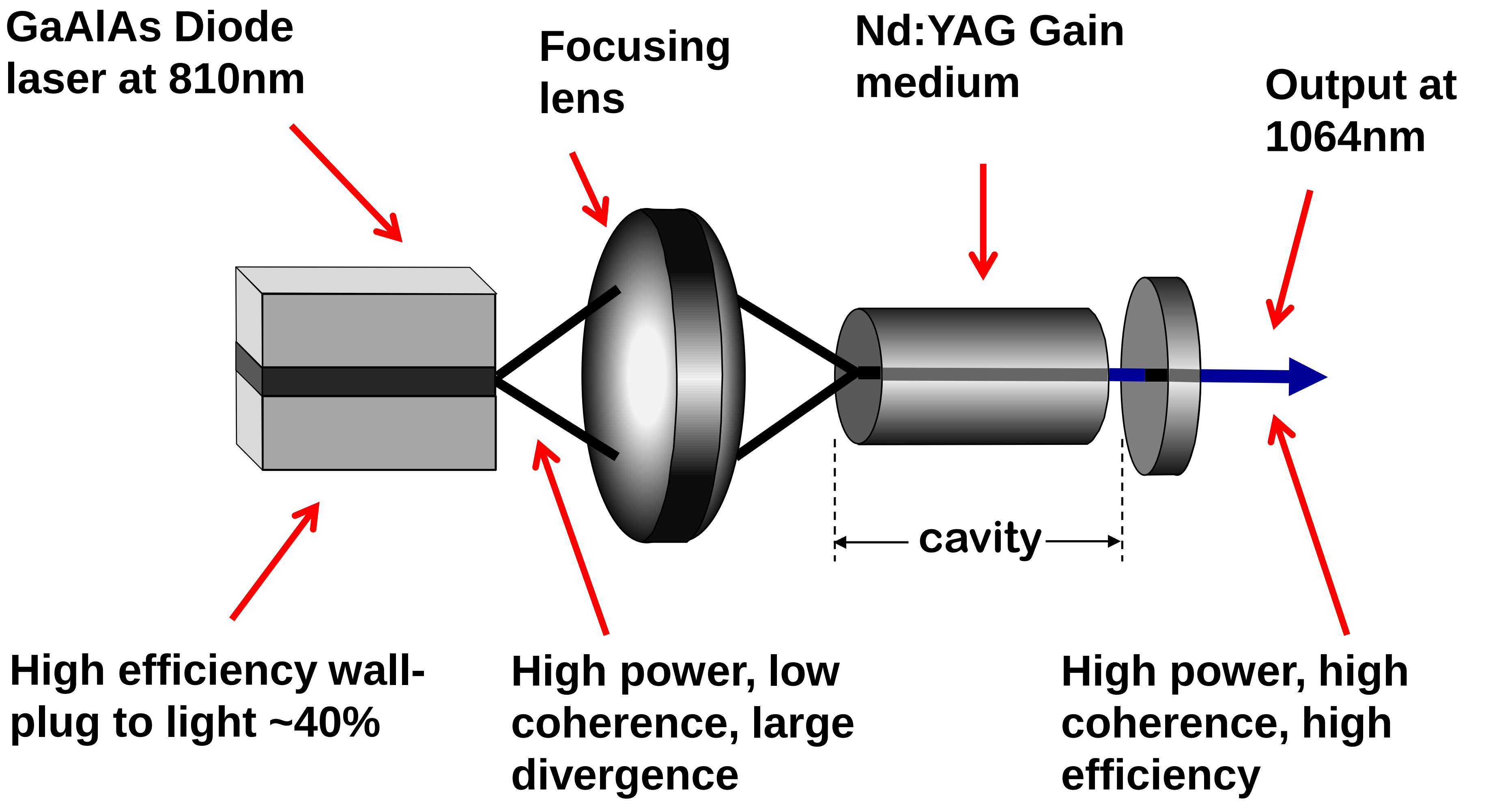
10.6 um
High power, kW in CW
Good efficiency (~ 30%)

Diode laser



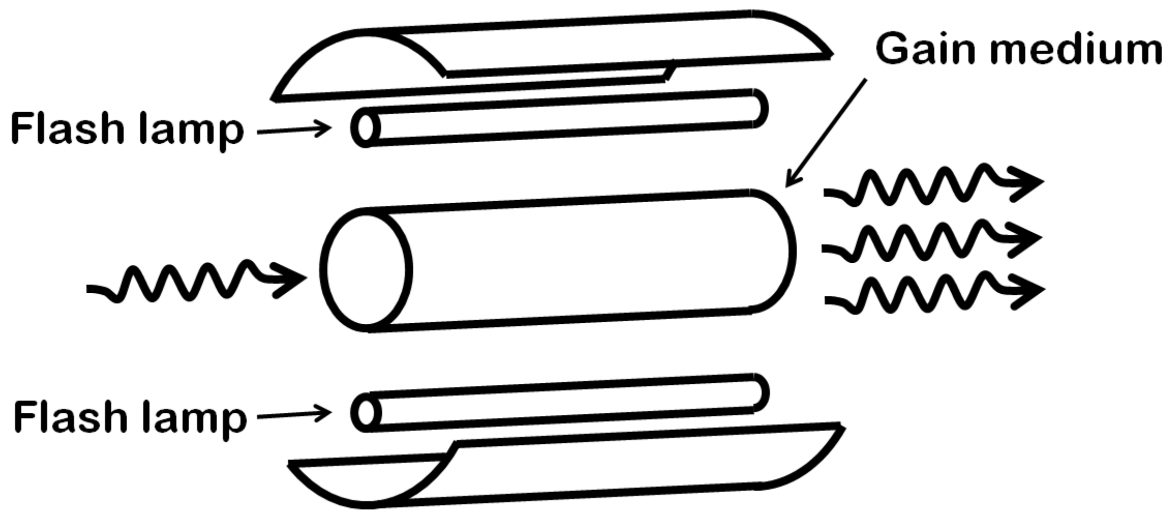
Low power
Large divergence
Good efficiency (~ 40%)

Diode laser – ideal for pumping



Nd:YAG neodymium-doped yttrium aluminium garnet; Nd:Y3Al5O12
Yb:YAG ytterbium-doped …

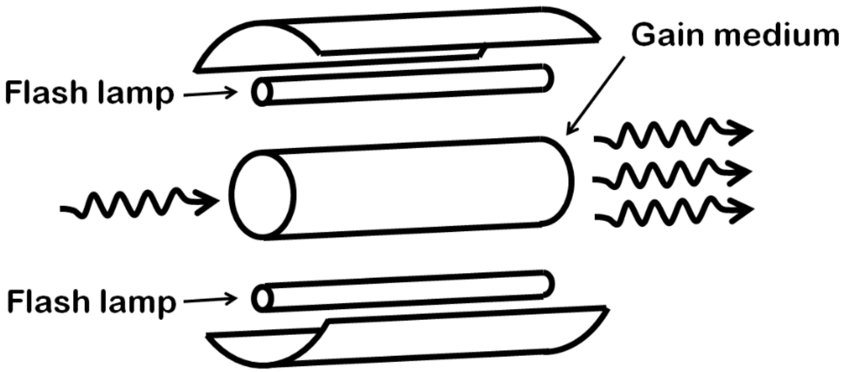
Laser amplifiers



Common principle: gain medium is pumped to produce gain for light at the wavelength of a laser made with the same material as its gain medium

- **Ultra-short and ultra high power – challenges:**
  - **Ultra short – nonlinear effect in the medium**
  - **High power – heating the amplifier medium**
- **These challenges limit rep rate, power and efficiency**
  - **Some of the most powerful lasers fire just once per few hours!**
- **A lot of inventions in the field of light amplification**

Laser rep rate and efficiency



Problem:

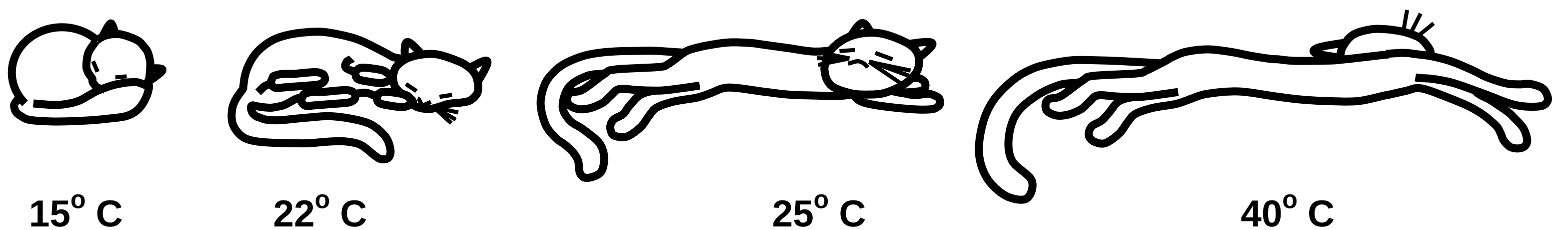
As intensity of the laser light increase, it takes much more time for the media to cool down and be ready for next use

Contradiction:

To be improved: INTENSITY,

What gets worse: REP RATE

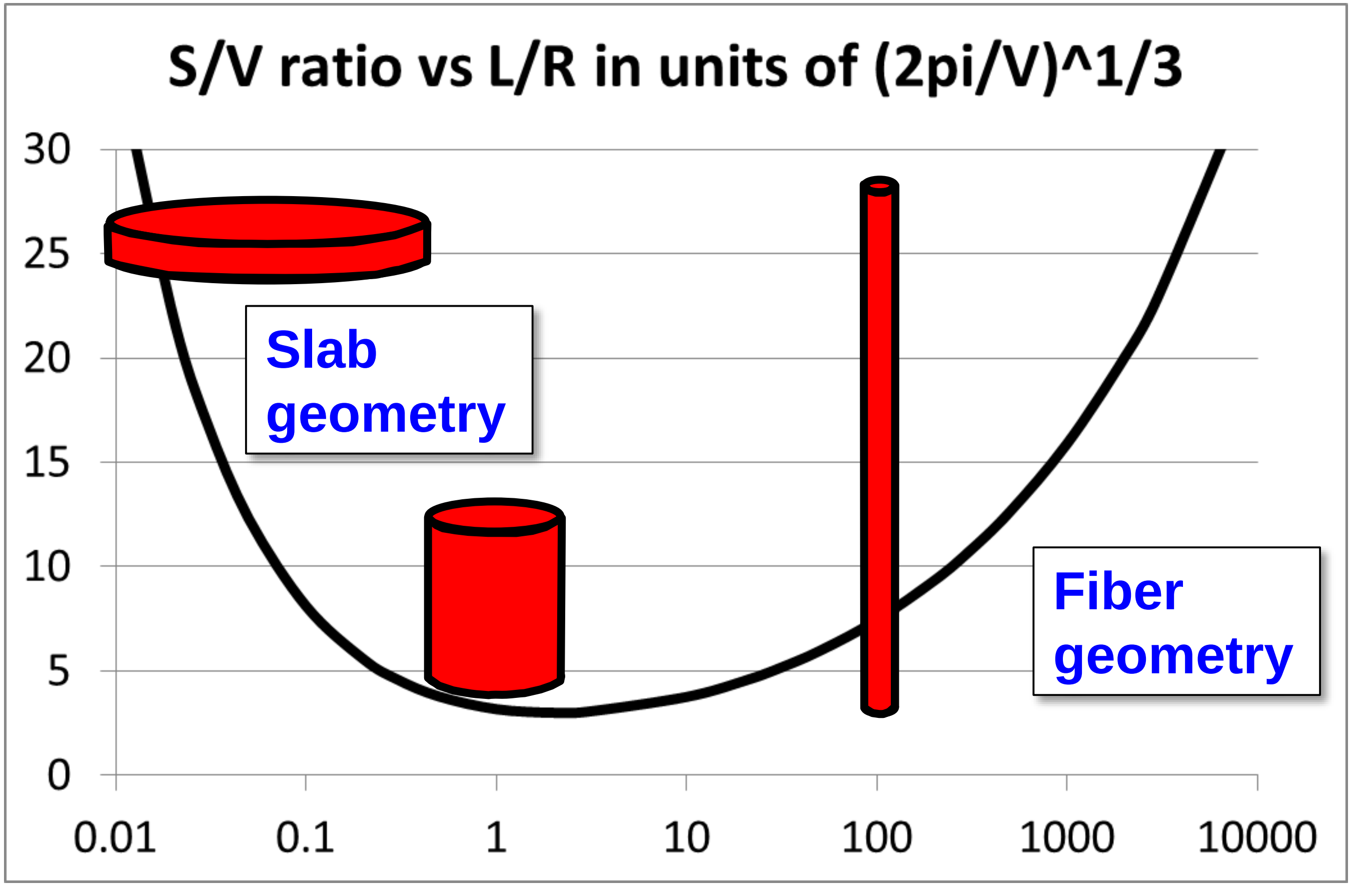
- **A general principle which can solve this can be taken from nature:**
  - **4: Volume to surface ratio – change it to alter the characteristics such as cooling rate, fields of the object, etc**



The cat clearly knows the principle of surface to volume ratio

- **Fiber lasers and Dipole laser technology illustrate this principle**

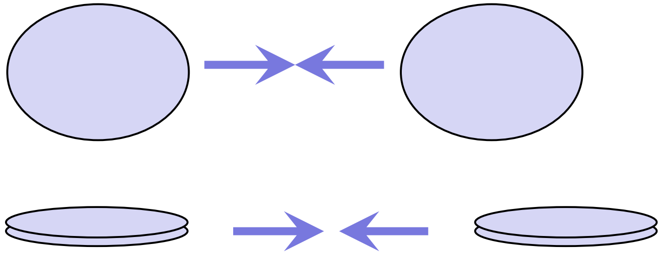
Fiber laser and slab lasers



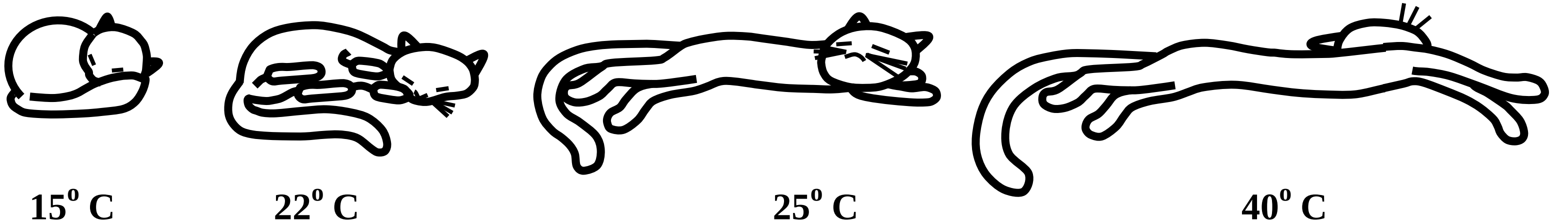
- **Fiber lasers and DiPOLE laser technology use the principle of larger surface to volume ratio**
  - **Possibility of high power, high rep rate, high efficiency**

So, you just saw that

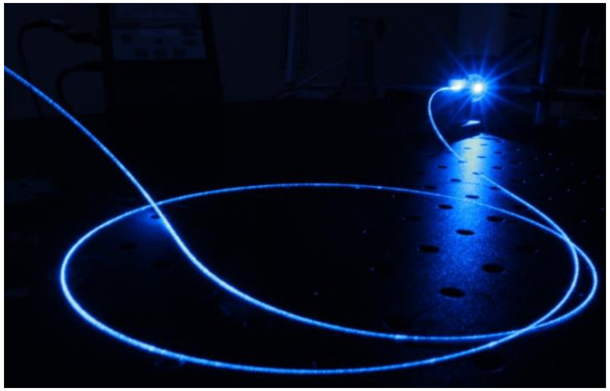
colliding beams…



cats…



The cat intuitively knows the inventive principle of surface to volume ratio

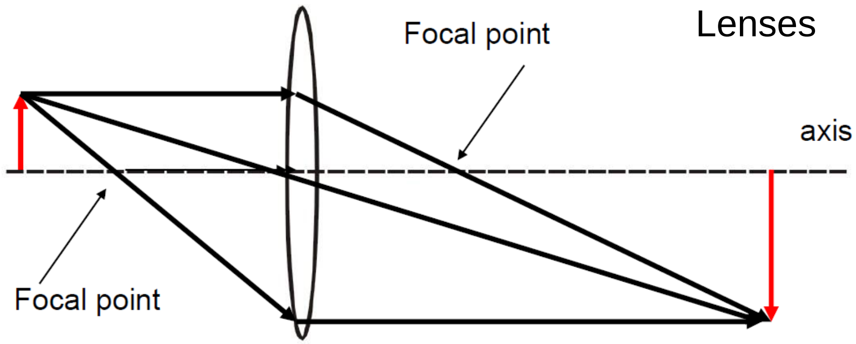


and fibre lasers…

…are <u>connected via TRIZ inventive principles!</u>

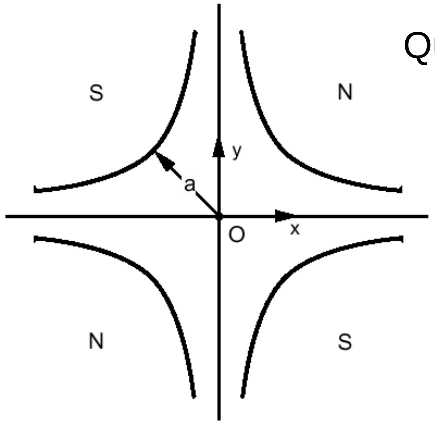
Beam and laser focusing

Lenses



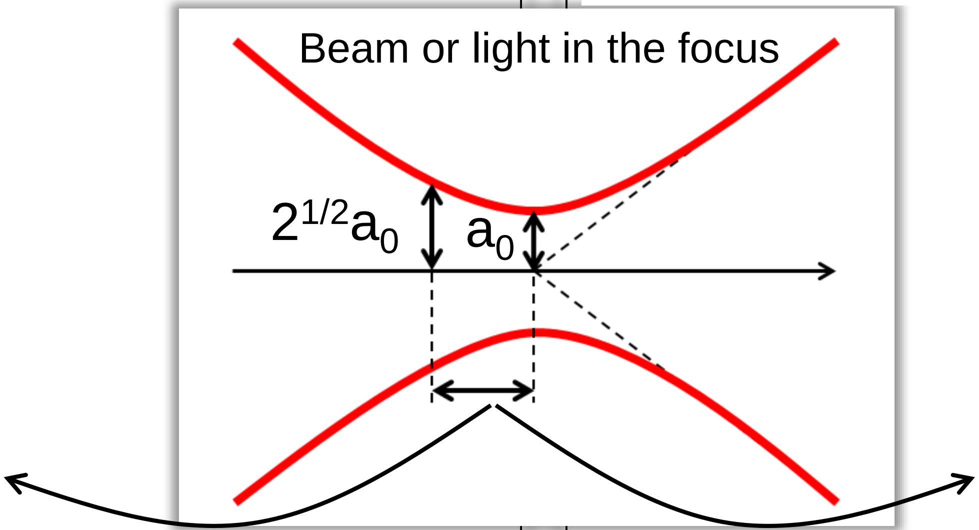
Focus in both planes

Quadrupole magnet



Focus in one plane, defocus in another:

$$x' = x' + G\,x$$
$$y' = y' - G\,y$$



Z_R

Rayleigh length

β_0

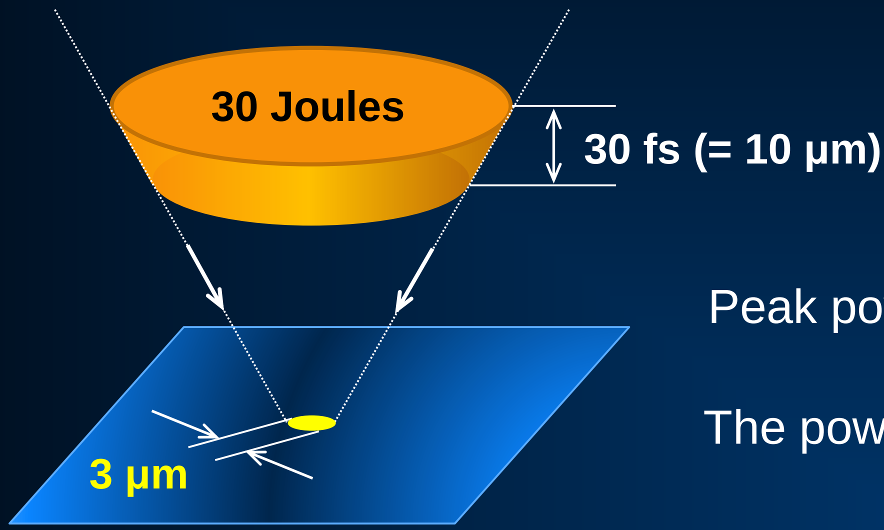
Twiss (beta) function in the focal point

Light focusing lenses or mirrors

Beam focusing w magnets

Contemporary high-power lasers

... are impressive



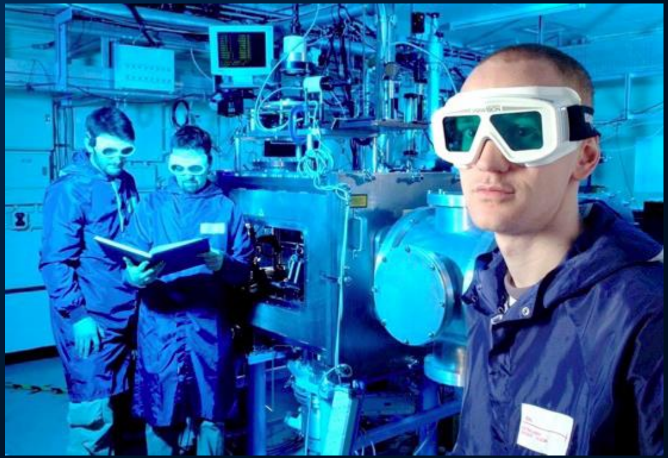
Peak power 10^{15} W

The power density at the focus is 10^{22} W/cm^2

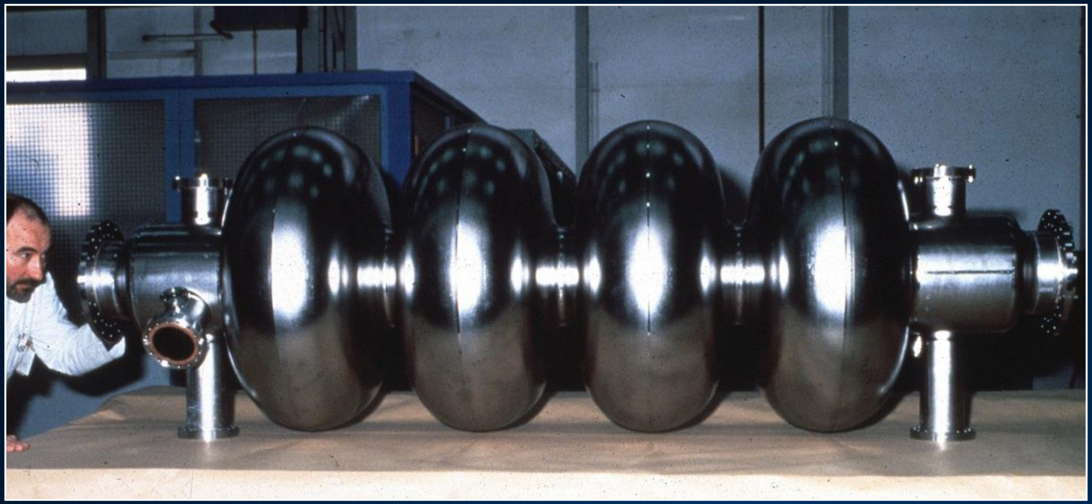
Laser of this power instantly ionizes any substance

Electrons carried along by the field of such a laser instantly become relativistic...

…although conventional resonators usually used for such acceleration



Limits of resonators for acceleration



Superconducting Nb accelerating structures

Conventional, Cu

Problem:
As rate of E change (accelerating gradient) increases, the surface of cavities get damaged by occasional breakdowns

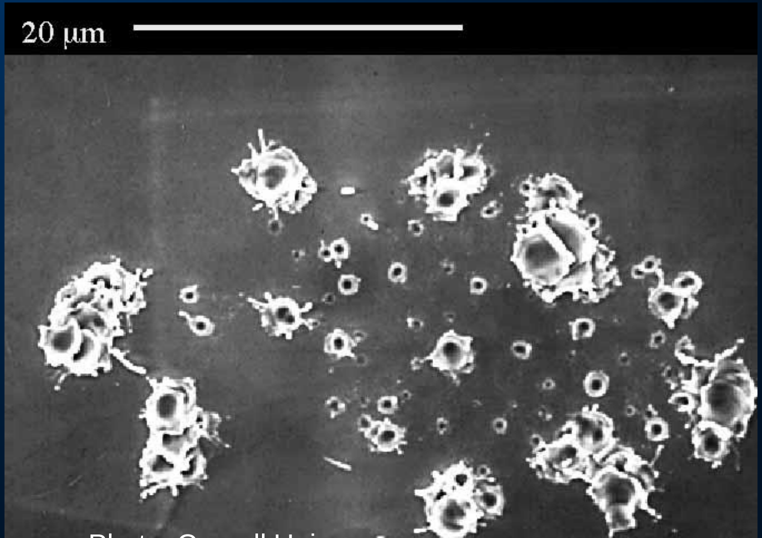
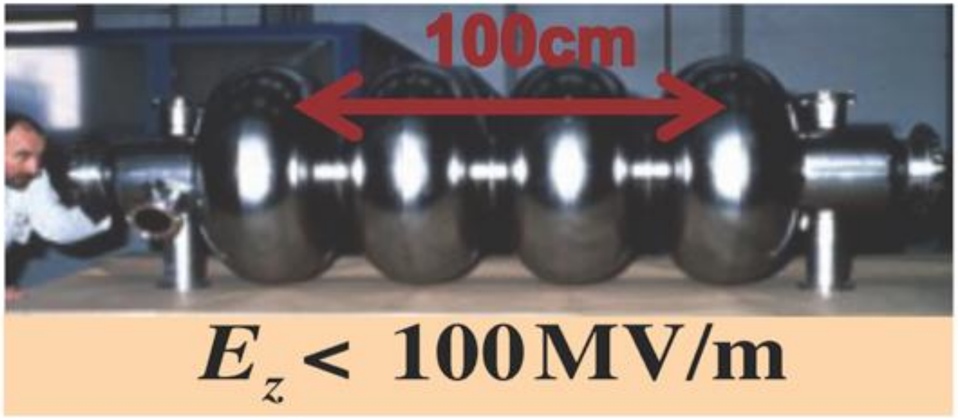


Photo: Cornell Univ.

Lasers and particle acceleration



Accelerating structure, metal (normal conductive or super-conductive)

Problem:

As rate of E change (accelerating gradient) increase, the surface of cavities get damaged by occasional breakdowns

Contradiction:

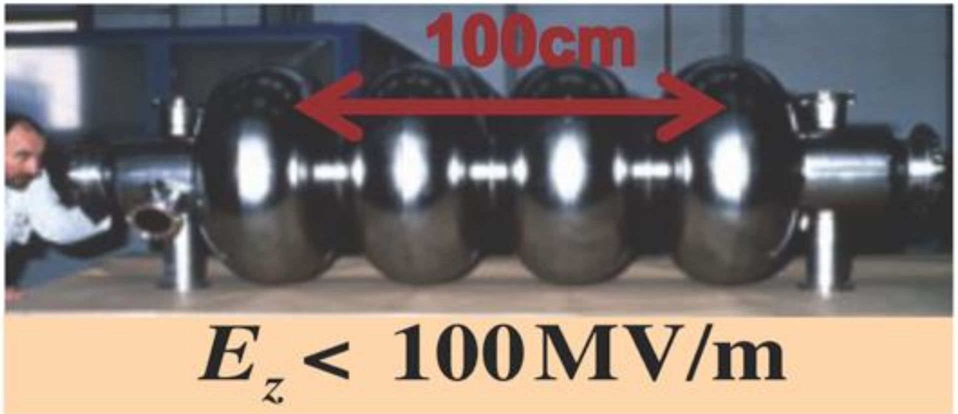
To be improved: Rate of E change

What gets worse: INTEGRITY

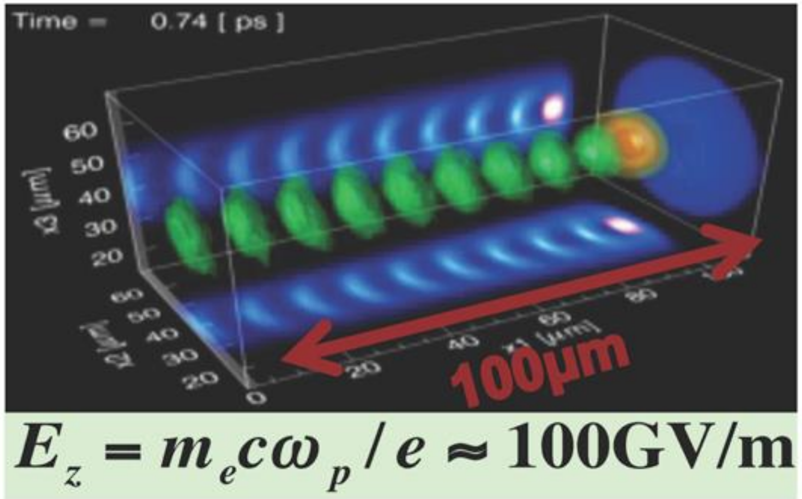
Select one of the inventive principles of emerging AS-TRIZ:

- **3: Replace material that can be damaged with other media, which either cannot be damaged (light) or already "damaged" (e.g. plasma)**

Lasers and particle acceleration



Accelerating structure, metal (normal conductive or super-conductive)



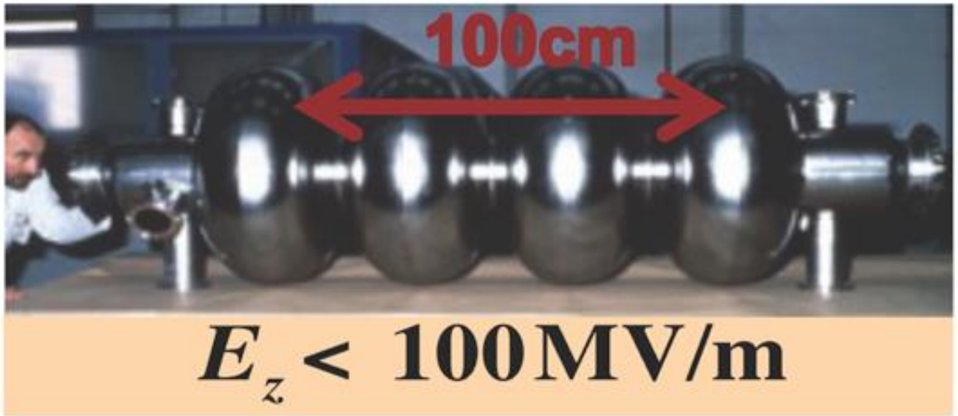
“Accelerating structure” produced on-the-fly in plasma by laser pulse

Solution:

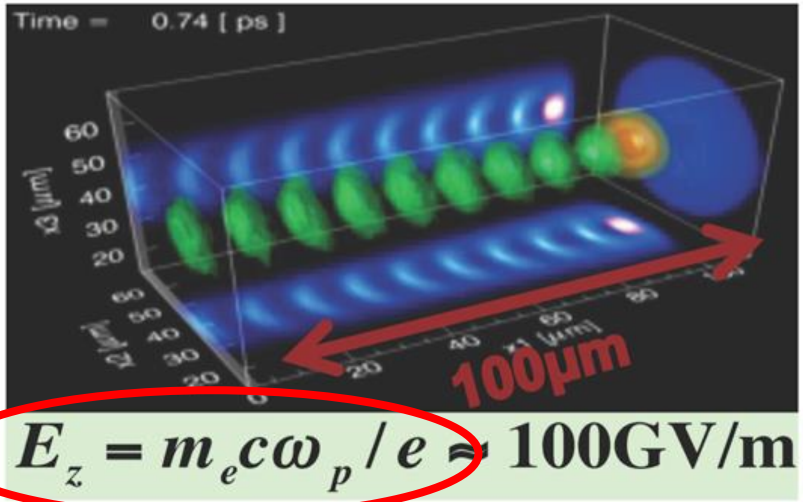
Then apply this inventive AS-TRIZ principle:

- **3: Replace material that can be damaged with other media, which either cannot be damaged (light) or already “damaged” (e.g. plasma)**

Lasers and particle acceleration



Accelerating structure, metal (normal conductive or super-conductive)



“Accelerating structure” produced on-the-fly in plasma by laser pulse

- **We will derive the max possible accelerating field and learn a lot more about these subjects in the next lectures**

Thank you for your attention!