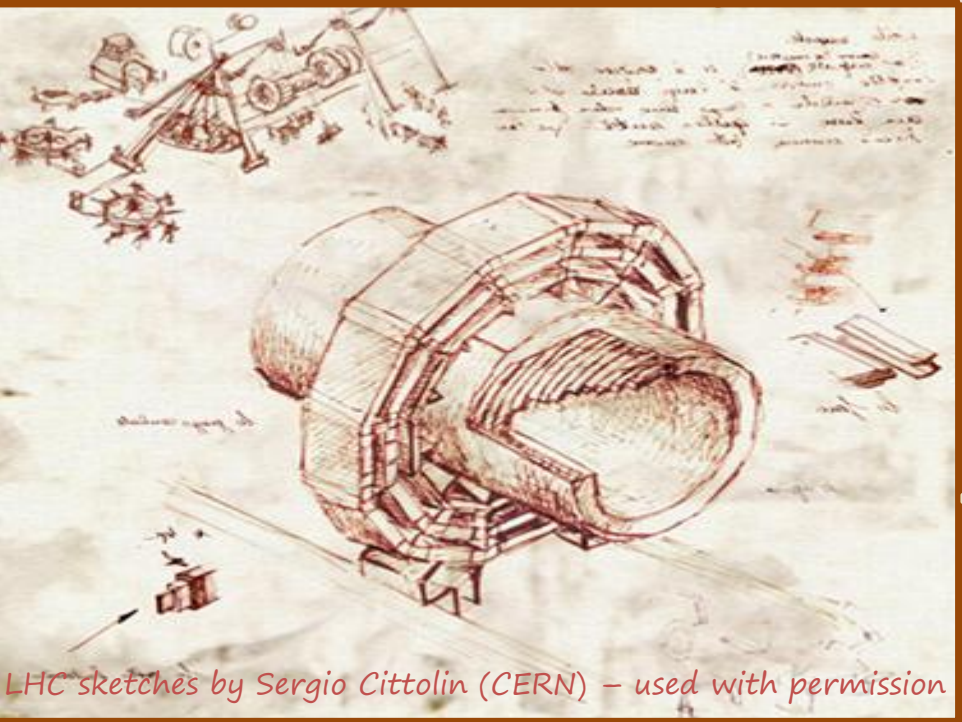
John Adams Institute for Accelerator Science

Unifying physics of accelerators, lasers and plasma



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

Prof. Andrei A. Seryi
John Adams Institute

Lecture 12: Inventions and innovation in science & future directions

USPAS16
June 2016


TRIZ 40 PRINCIPLES

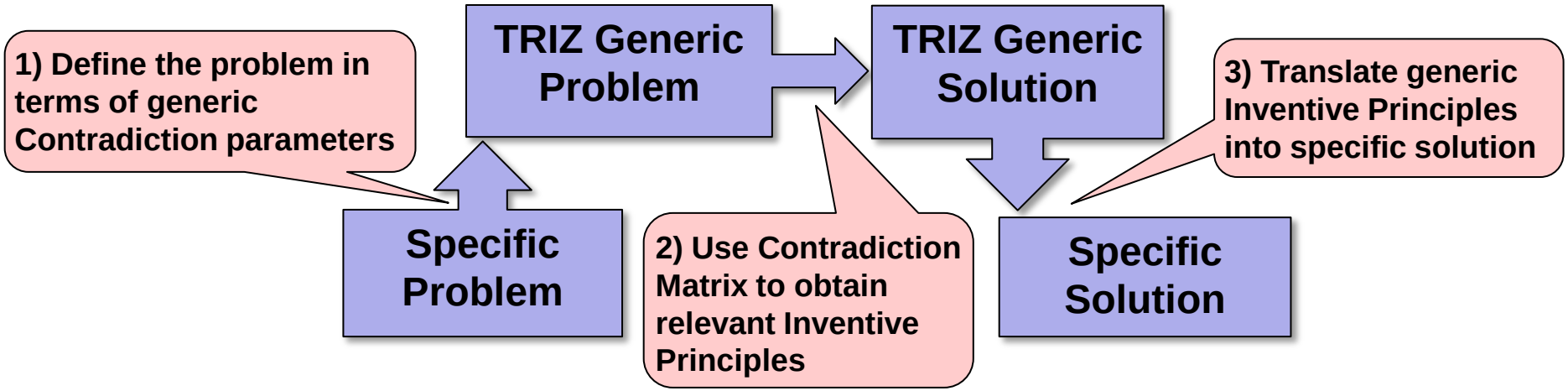

We just opened the door half way
There are more tools in TRIZ arsenal
TRIZ 40 PRINCIPLES
We will look at some of them now

Plan of the lecture

- Trends and principles
- From radars to lasers
- Other tools in TRIZ toolbox
- From idea to practice
- What next for colliders

Recall: How to invent – TRIZ

- **TRIZ = theory of inventive problem solving**
  - Created based on analysis of 200,000 patents
- **Four key discoveries of TRIZ:**
  - The same Problems and Solutions appear again and again but in different industries
  - There is a recognisable Technological Evolution path for all industries
  - Innovative patents, (23% of total) used science/engineering theories outside their own area/industry
  - An Innovative Patent uncovers and solves contradictions
- **TRIZ approach (applicable to Accelerator-Science – AS-TRIZ):**



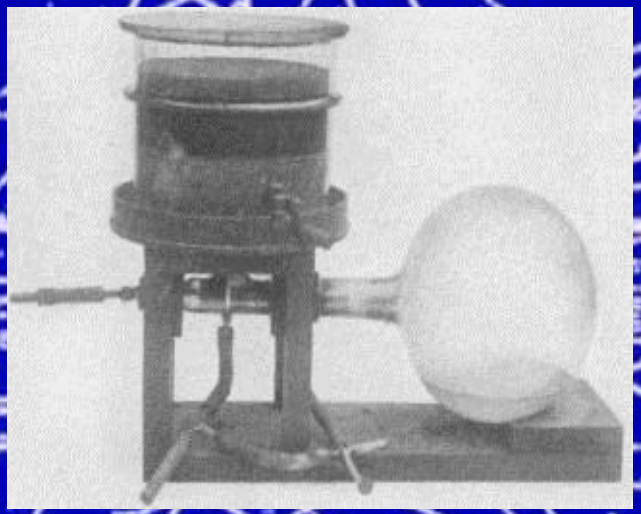
Elements of TRIZ contradiction matrix

1. Weight of moving object
2. Weight of stationary
3. Length of moving object
4. Length of stationary
5. Area of moving object
6. Area of stationary
7. Volume of moving object
8. Volume of stationary
9. Speed
10. Force (Intensity)
11. Stress or pressure
12. Shape
13. Stability of the object
14. Strength
15. Durability of moving obj.
16. Durability of non moving obj.
17. Temperature
18. Illumination intensity
19. Use of energy by moving
20. Use of energy by stationary
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

TRIZ 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

Cloud and bubble chambers

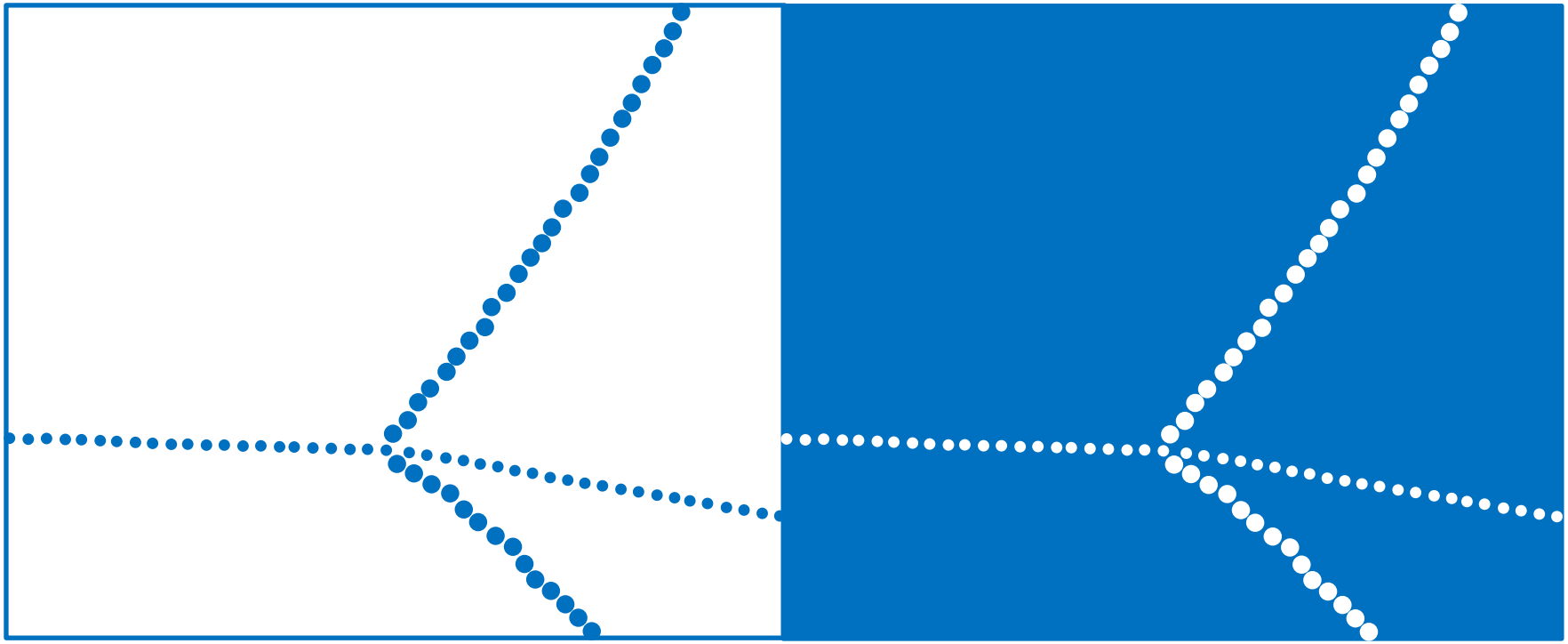


Wilson's Cloud chamber invented in 1911

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

Cloud chamber and bubble chamber are often cited in TRIZ books with a question – could the bubble chamber invention take less than almost half a century if a principle of anti-system were applied?

=> Some of the principles of standard TRIZ are useful for science too
Can you suggest some examples?

Updating: AS-TRIZ matrix and principles

Emerging AS-TRIZ contradiction matrix

1. Energy
2. Rate of energy change
3. Emittance
4. Luminosity
5. Brightness
6. Intensity
7. Efficiency
8. Power
9. Integrity of materials
10. Time duration or length
11. Spatial extent
12. Sensitivity to imperfections
13. Cooling rate

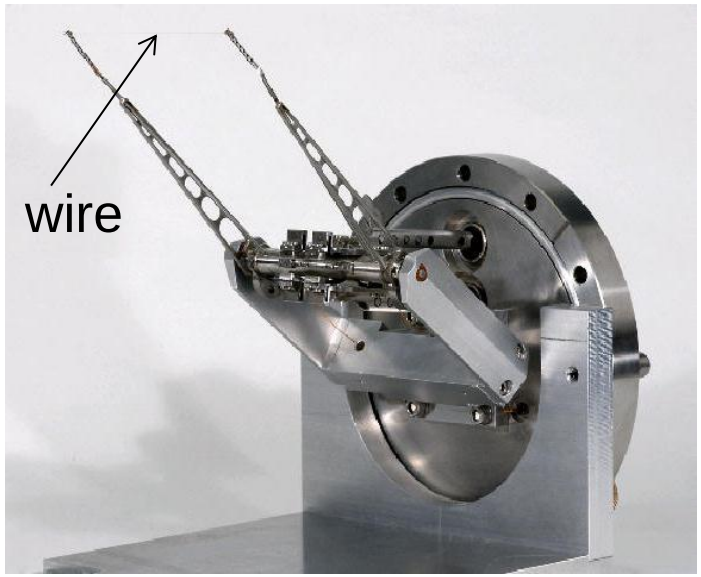
- …

Emerging AS-TRIZ Principles

1. …
2. …
3. Un-damageable or already damaged
4. Volume to surface ratio
5. Local correction
6. Transfer between phase planes
7. From microwave to optical
8. Time energy correlation
9. …

Can TRIZ principles be applicable to science?
Are these AS-TRIZ principles indeed new principles or general trends?

Recall: AS-TRIZ examples



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

Improving Parameter	…	…	9. Integrity	…
…				
2. Rate of E change			3, …	
…				
6. Intensity			3, …	
…				

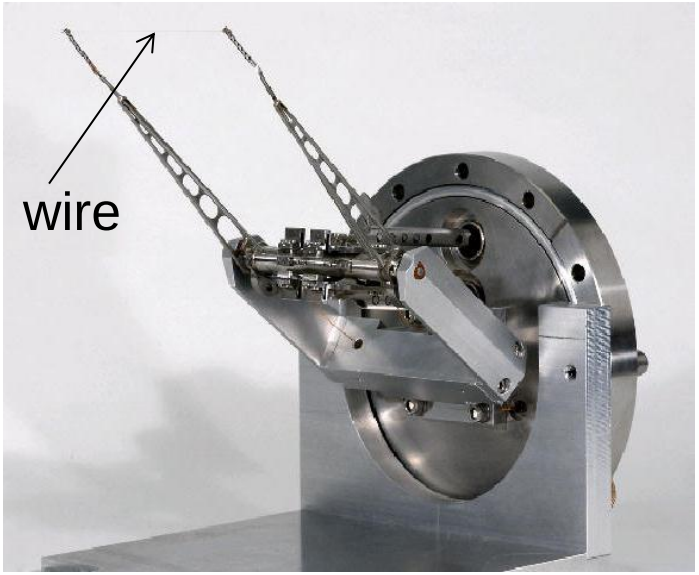
Parameter that deteriorates

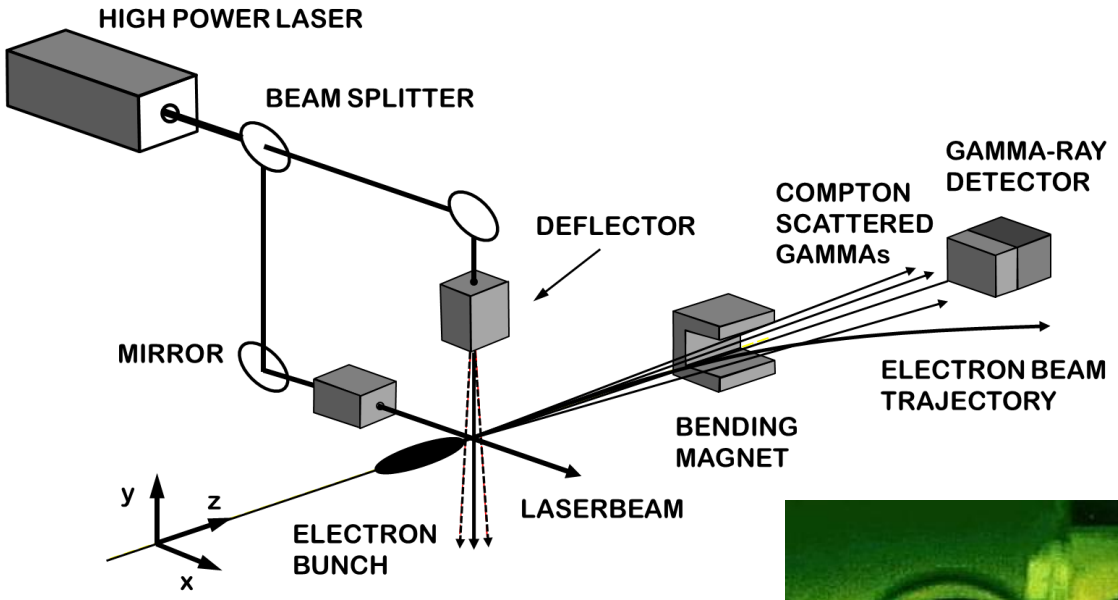
Suggested Principles that have solved similar Contradictions in the past

3: "Un-damageable or already damaged":

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

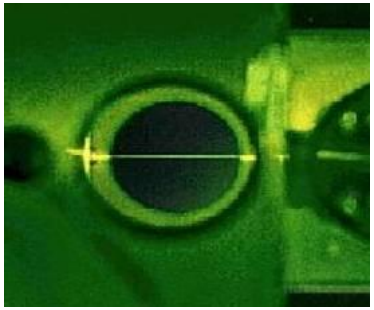
Recall: AS-TRIZ examples





Beam profile monitor with tungsten or carbon wire

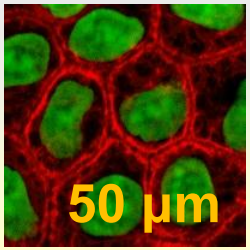
Beam profile monitor with laser beam as the "wire"



Solution:

- **Use AS-TRIZ principles could lead you to this invention faster**
  - **3: Replace material that can be damaged with other media, which either cannot be damaged (light) or already "damaged" (e.g. plasma)**

Chemistry Nobel 2014 & inventive principles?



Extra magnification?

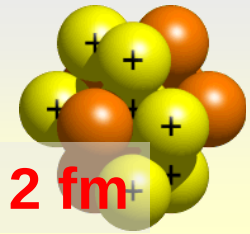
CELLS
Twenty per mm

Microscope

x 25 thousand

DNA
Five hundred thousand per mm

Electron microscope



x 1 million

Nucleus
Five hundred billion per mm

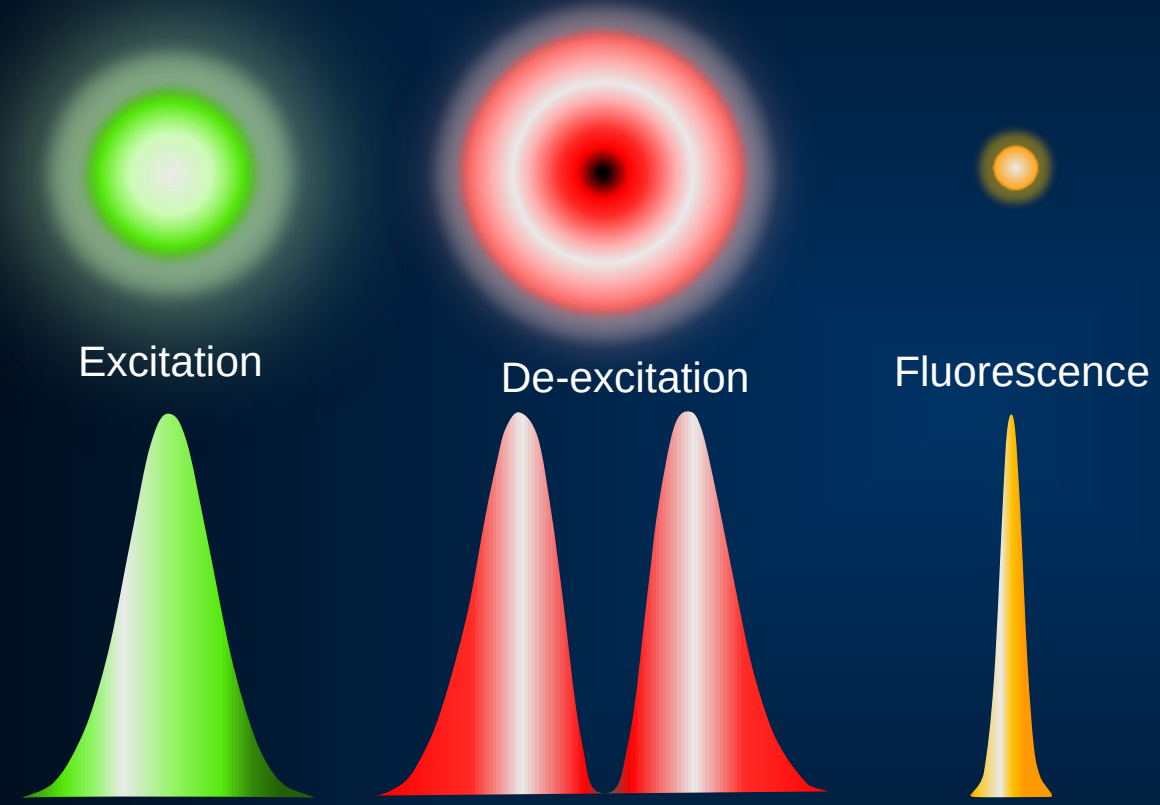
Particle Accelerators

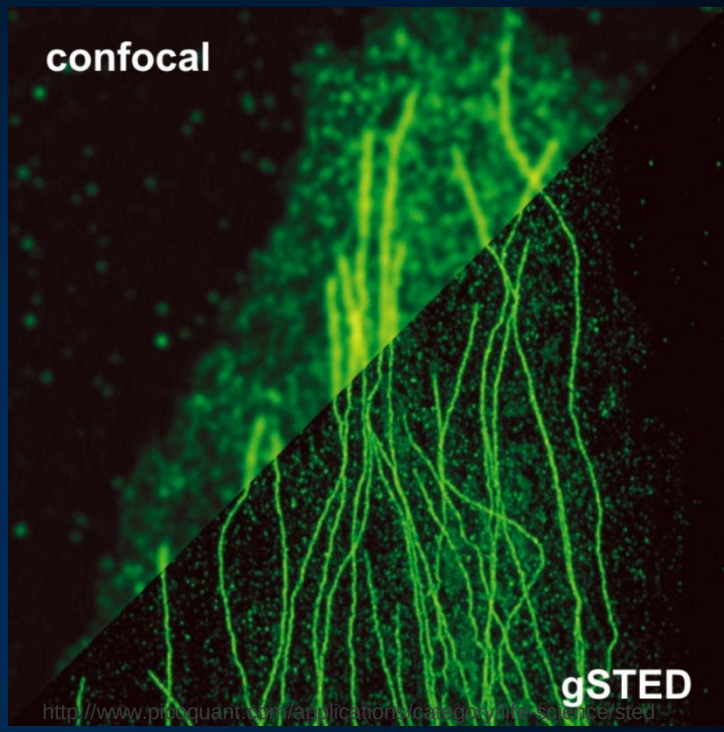
x 2 thousand

Quarks
More than one million billion per mm

Chemistry Nobel 2014 …

Stimulated Emission Depletion microscopy (STED)
Stefan W. Hell

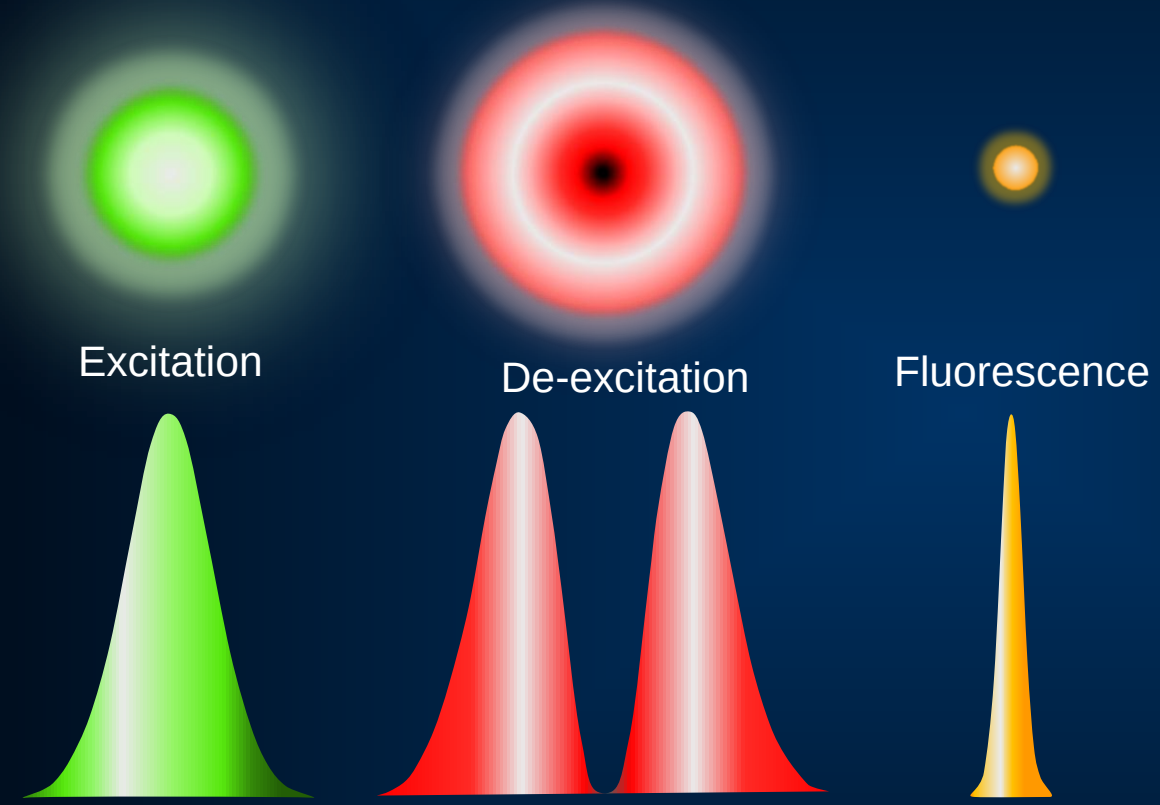


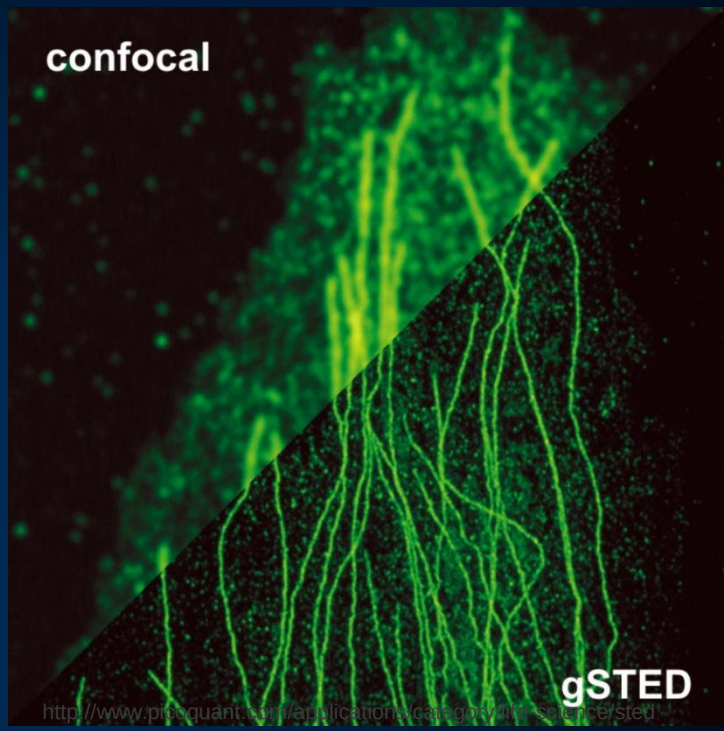


(gated) STED image of Tubulin vs standard confocal image

Chemistry Nobel 2014 & inventive principles

Stimulated Emission Depletion microscopy (STED)
Stefan W. Hell

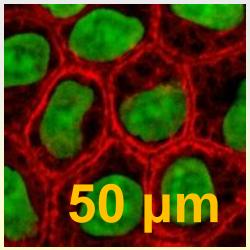




(gated) STED image of Tubulin vs standard confocal image

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



Extra magnification?

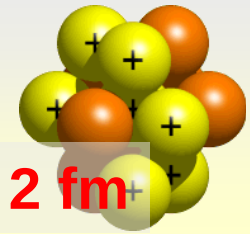
CELLS
Twenty per mm

Microscope

x 25 thousand

DNA
Five hundred thousand per mm

Electron microscope



x 1 million

Nucleus
Five hundred billion per mm

Particle Accelerators

& Colliders

x 2 thousand

Quarks
More than one million billion per mm

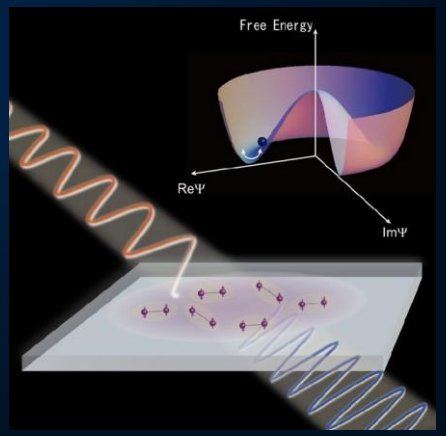
Discovery 2012, Nobel Prize in Physics 2013

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)



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)

- 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

Trends and principles

- **Trends**
  - **General laws of system evolution**
    - **There are just few of them**
- **Principles**
  - **Particular approaches that help to solve contradictions**
    - **There are several dozens of them**

- **Is "From microwave to optical" that we initially identified as Principle indeed a principle or a trend?**

- **Let's look at "standard" TRIZ trends**
- **Let's consider example of invention of CPA in connection to radars**

Laws of technical system evolution (standard TRIZ)

- **Static Laws**
- **Kinematic laws**
- **Dynamic laws**

Laws of technical system evolution (standard TRIZ)

- **Static Laws**
  - **The law of the completeness of the parts of the system**
    - 4 parts: engine, transmission, working unit, control element
  - **The law of energy conductivity of the system**
    - every technical system is a transformer of energy and it should circulate freely and efficiently through its 4 main parts
  - **The law of harmonizing the rhythms of parts of the system**
    - frequencies of periodicity of parts and movements of the system should be in synchronization with each other

Laws of technical system evolution (standard TRIZ)

- **Kinematic laws**
  - **Law of increasing the degree of ideality of the system**
    - ideality is a qualitative ratio between all desirable benefits of the system and its cost or other harmful effects
  - **The law of uneven development of parts of a system**
    - different parts of technical system will evolve differently, leading to the new technical and physical contradictions
  - **The law of transition to a super-system**
    - a system exhausting possibilities of further significant improvement is included in a super-system as one of its parts

Laws of technical system evolution (standard TRIZ)

- **Dynamic laws**
  - **Transition from macro to micro level**
    - development of working organs proceeds initially on a macro and then more and more on a micro level
  - **Increasing involvement of fields in systems**
    - the fields evolve from mechanical fields to electro-magnetic fields

Laws of technical system evolution (standard TRIZ)

- **Static Laws**
  - The law of the completeness of the parts of the system
    - 4 parts: engine, transmission, working unit, control element
  - The law of energy conductivity of the system
    - every technical system is a transformer of energy and it should circulate freely and efficiently through its 4 main parts
  - The law of harmonizing the rhythms of parts of the system
    - frequencies of periodicity of parts and movements of the system should be in synchronization with each other
- **Kinematic laws**
  - Law of increasing the degree of ideality of the system
    - ideality is a qualitative ratio between all desirable benefits of the system and its cost or other harmful effects
  - The law of uneven development of parts of a system
    - different parts of technical system will evolve differently, leading to the new technical and physical contradictions
  - The law of transition to a super-system
    - a system exhausting possibilities of further significant improvement is included in a super-system as one of its parts
- **Dynamic laws**
  - Transition from macro to micro level
    - development of working organs proceeds initially on a macro and then more and more on a micro level
  - Increasing involvement of fields in systems
    - the fields evolve from mechanical fields to electro-magnetic fields

And within EM from RF to Optical?

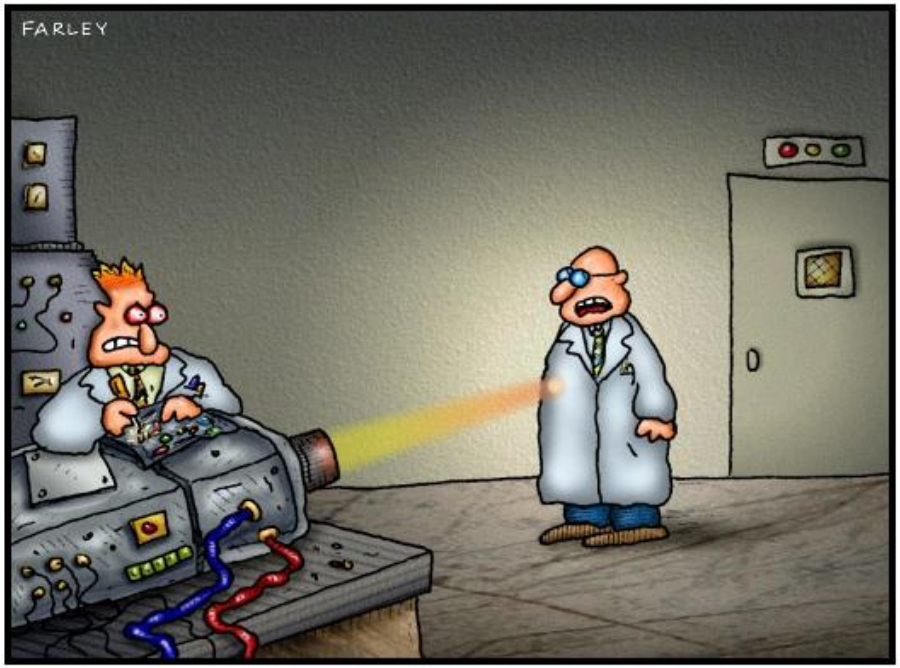
1934 Rumours of German "Death Ray"

"Ray to kill sheep at 100 yards"

Sir Henry Tizard from Air Ministry asked Watson-Watt to investigate

Watson-Watt - "Not possible"

Watson-Watt said: "Well then, if the death ray is not possible, how can we help them?"

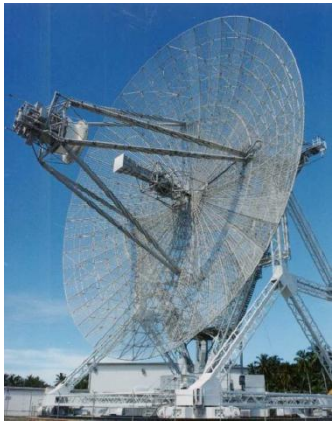


"Heh - some 'Death Ray' ... more like a 'Mild Heat Rash Ray', I'd say."

Only remaining original War time Chain Home tower in Great Baddow, United Kingdom

1935 Watson-Watt develops RDF (Radio-Direction Finding), later to become more familiarly known as

RADAR (RAdio Detection And Ranging)

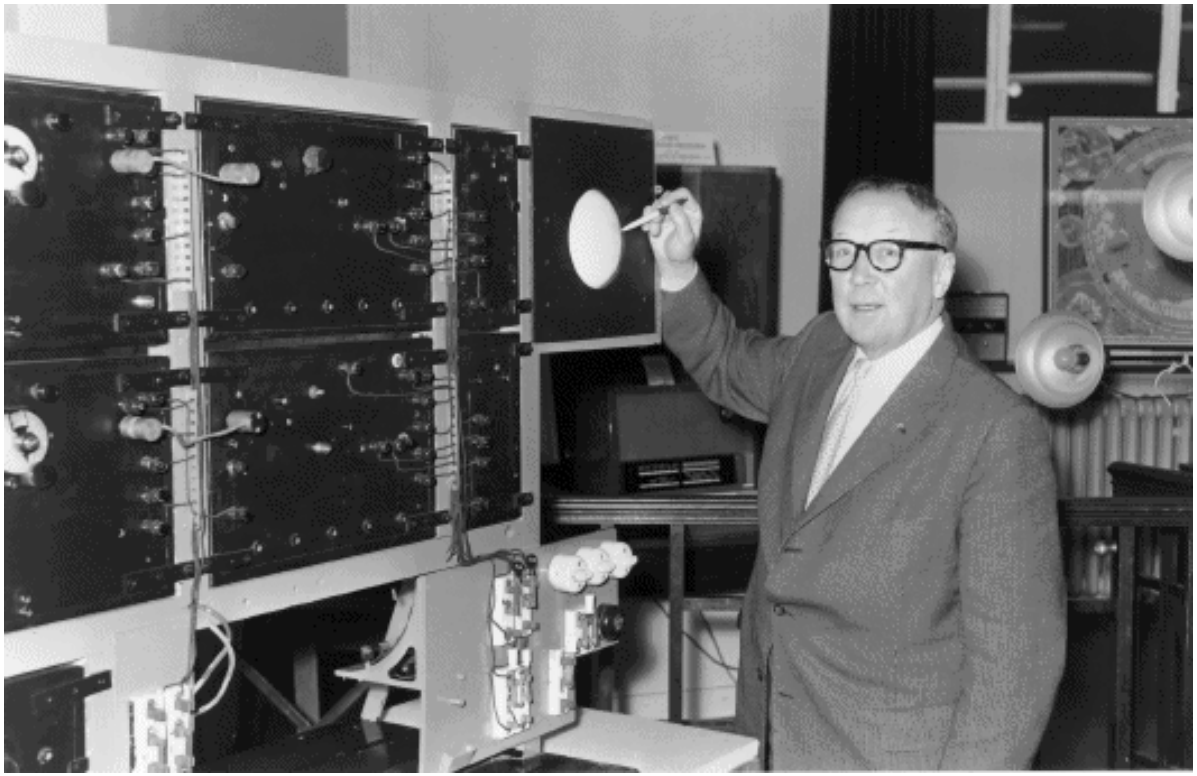


Slide from Bob Bingham, CLF, STFC

Development of Radar

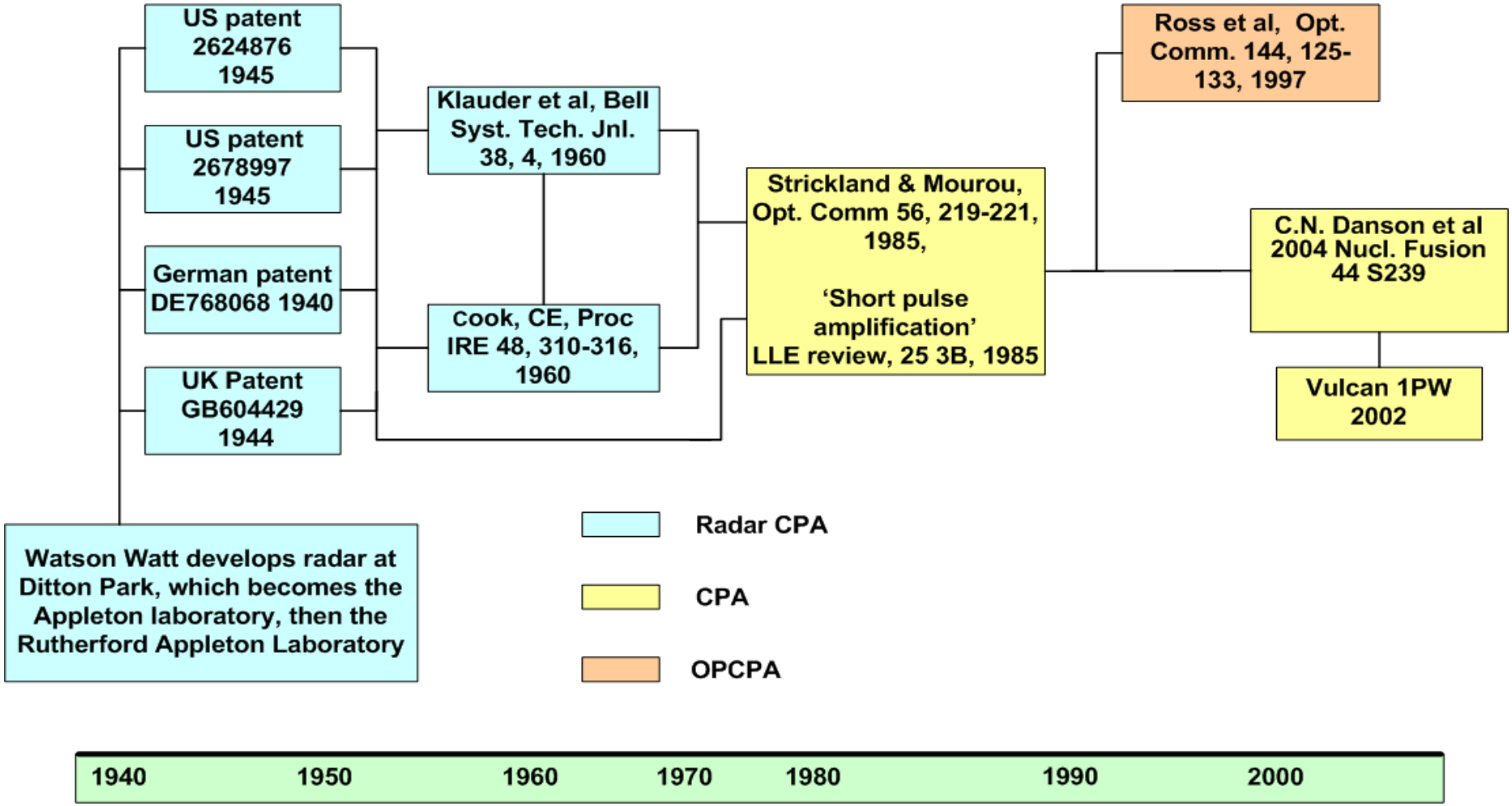
Sir Robert Watson-Watt with the original British Radar Apparatus made at Ditton Park in 1935 this became the Appleton Laboratory Merged with the Rutherford Laboratory to become Rutherford Appleton Laboratory.

This apparatus is now in the London Science Museum.



Slide from Bob Bingham, CLF, STFC

Radar and Laser Amplification

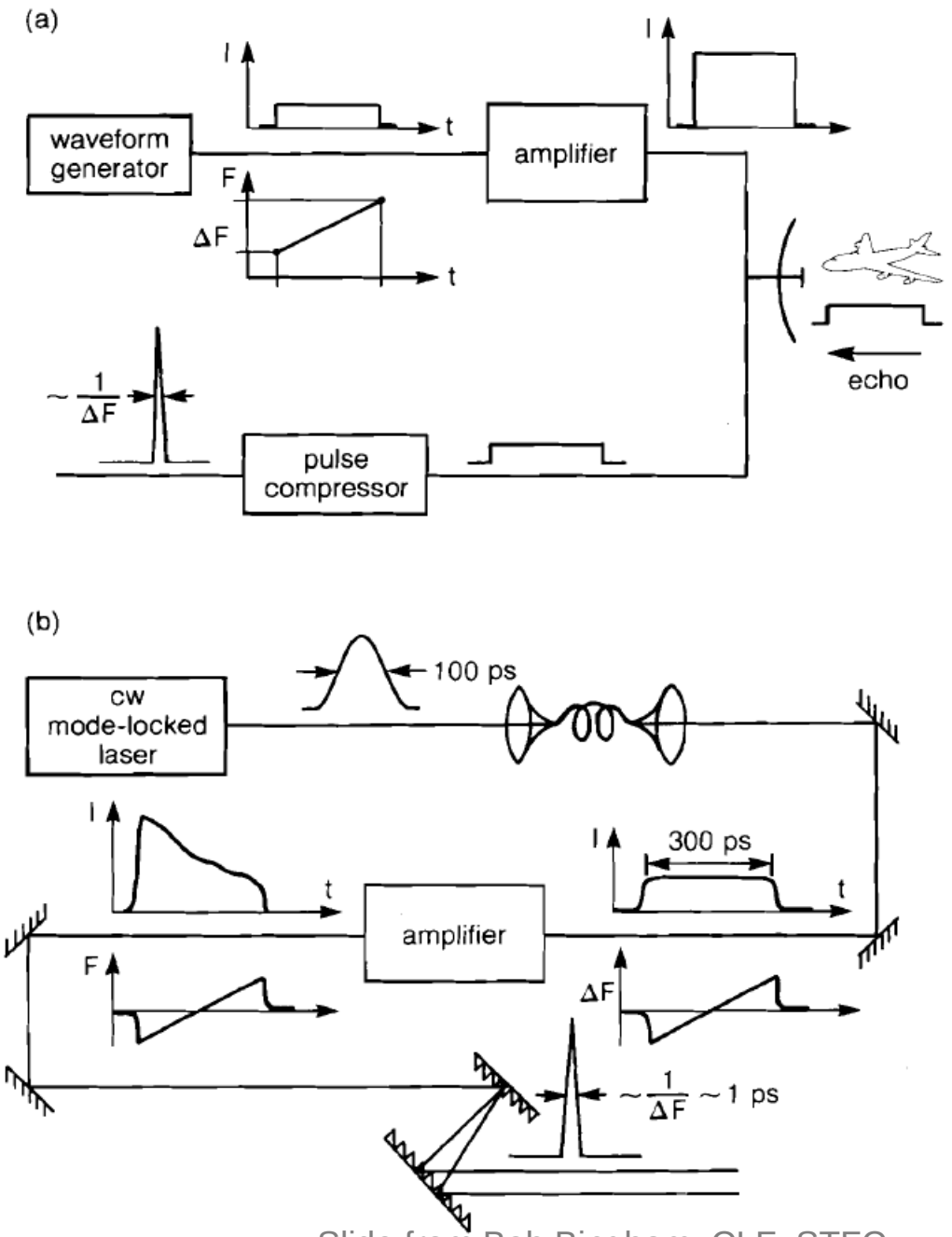


Slide from Bob Bingham, CLF, STFC

Chirped pulse amplification from Radar to Lasers (CPA)

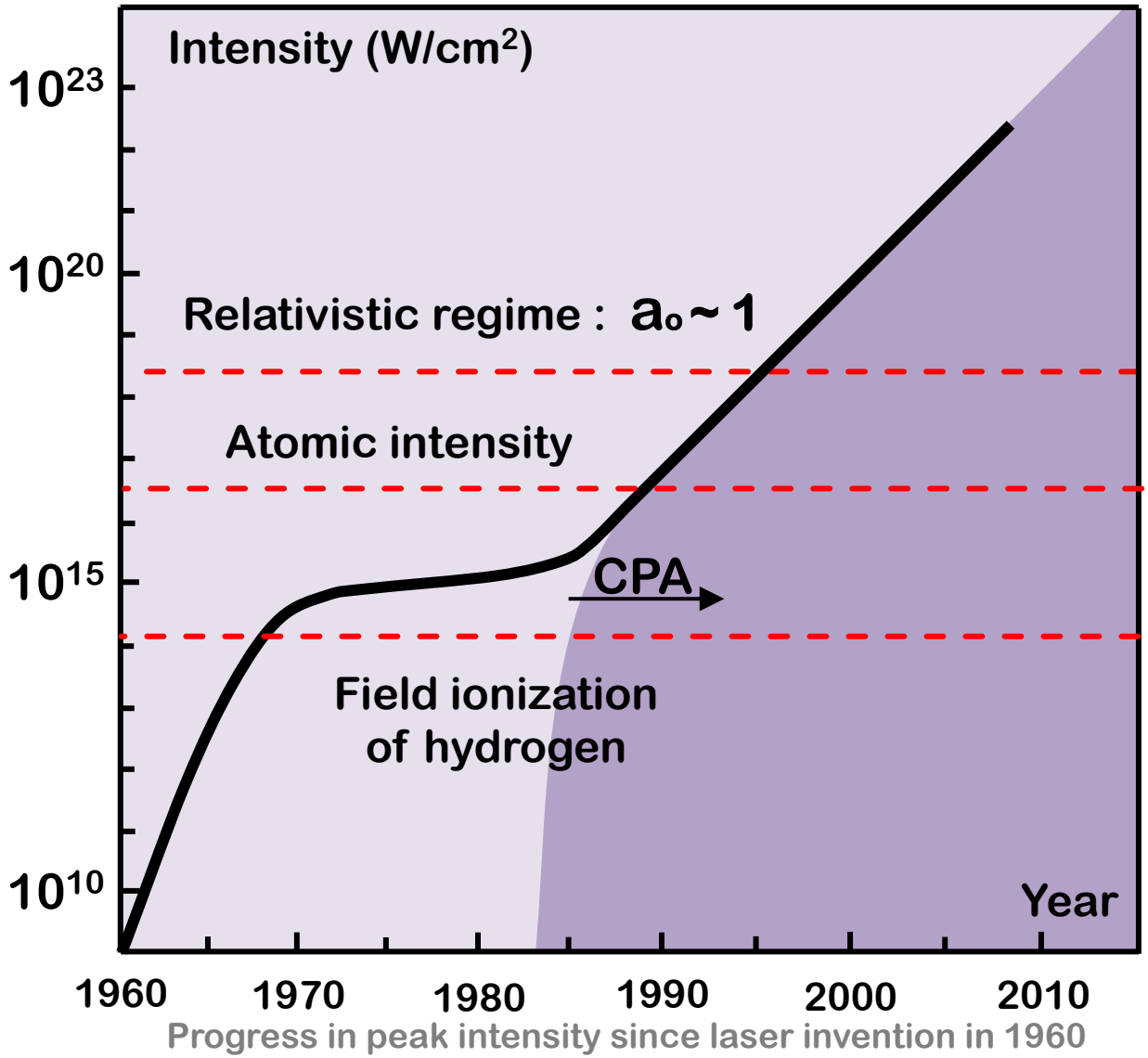
Diagrams taken from early LLE review On the comparison between RADAR chirped pulse amplification from the 1940 onwards upper diagram and laser chirped pulse amplification bottom diagram carried out at the LLE Rochester.

LLE Review 25 3B 1985.



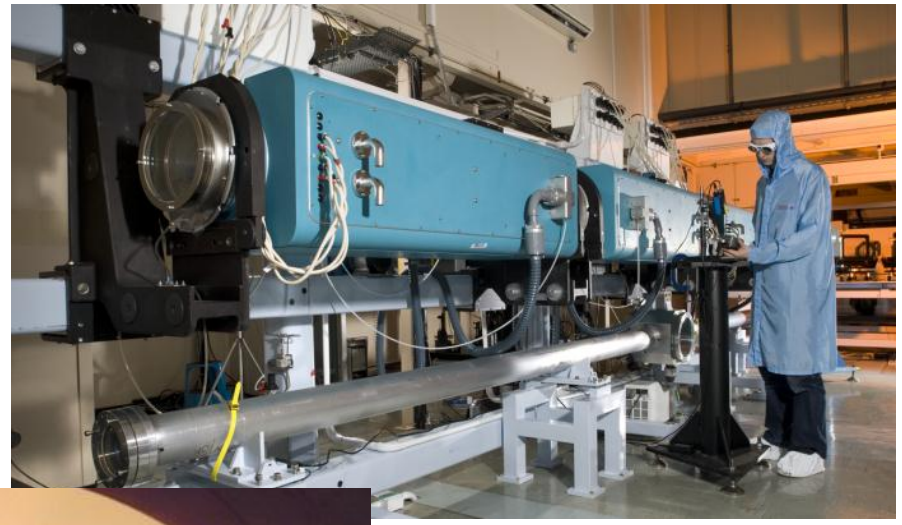
Slide from Bob Bingham, CLF, STFC

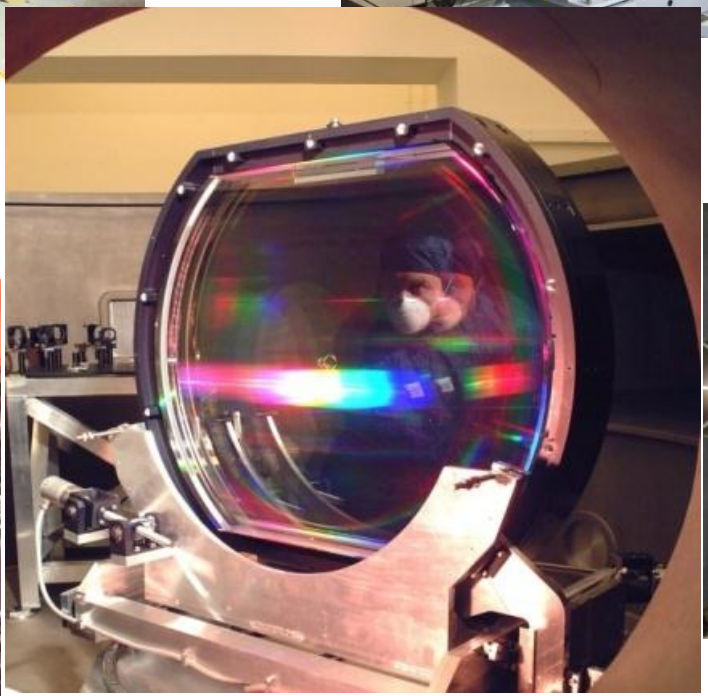
CPA invention: exponential growth of laser power

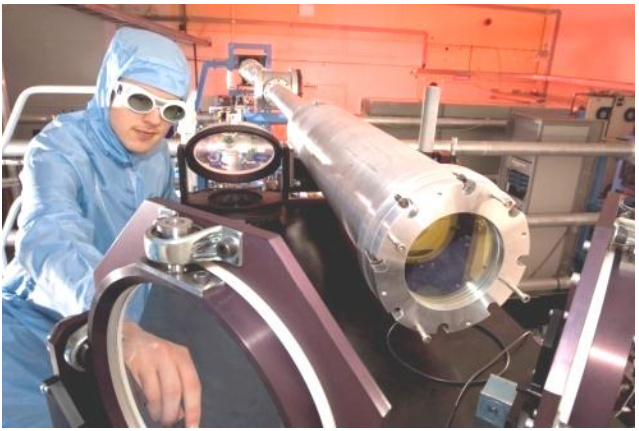


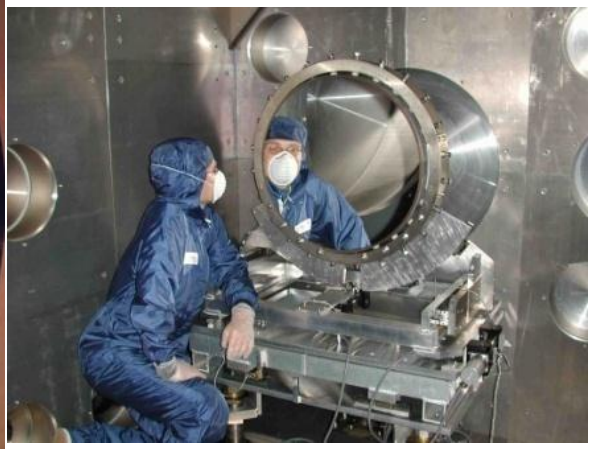
Progress in peak intensity since laser invention in 1960

High Intensity Laser Target Areas









Pictures from Vulcan, Bob Bingham, CLF, STFC

Updating: AS-TRIZ matrix and principles

Emerging AS-TRIZ contradiction matrix

1. Energy
2. Rate of energy change
3. Emittance
4. Luminosity
5. Brightness
6. Intensity
7. Efficiency
8. Power
9. Integrity of materials
10. Time duration or length
11. Spatial extent
12. Sensitivity to imperfections
13. Cooling rate

- …

Emerging AS-TRIZ Principles

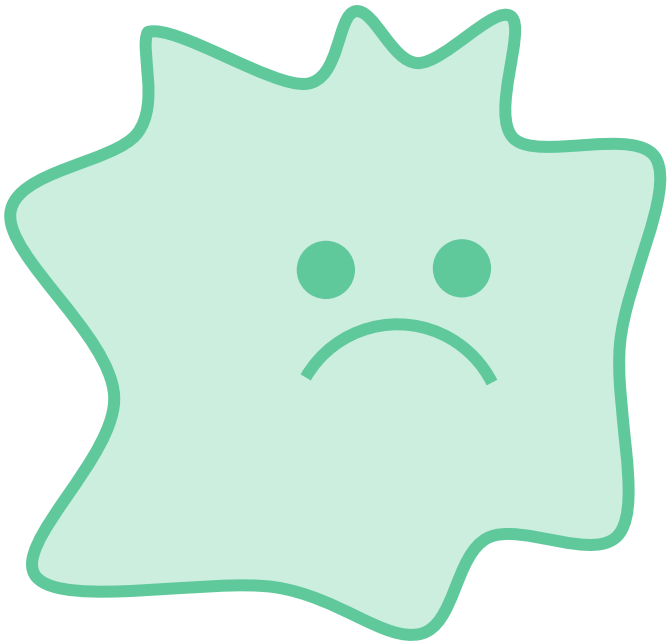
1. …
2. …
3. Un-damageable or already damaged
4. Volume to surface ratio
5. Local correction
6. Transfer between phase planes
7. From microwave to optical
8. Time energy correlation
9. …

So, this is perhaps a general trend, not just a principle

Anyway, any suggestions based on these lectures for the AS-TRIZ matrix and principles?

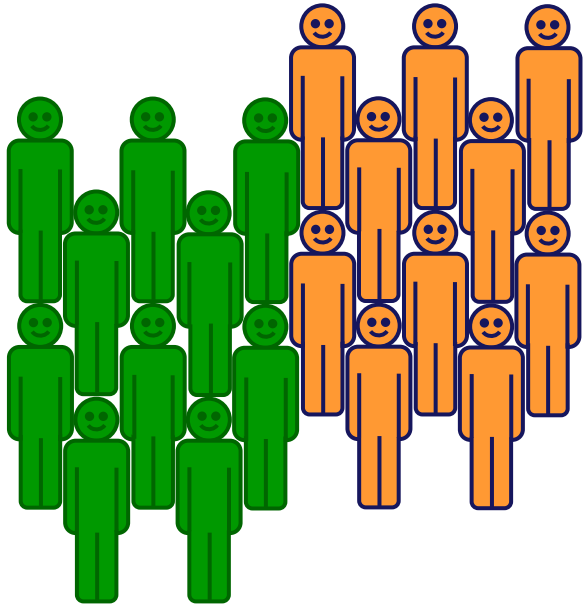
Identifying yourself with an object

- **Remember, we discussed that in Synectics, one of the method was to identify yourself with an object that needs to be improved?**

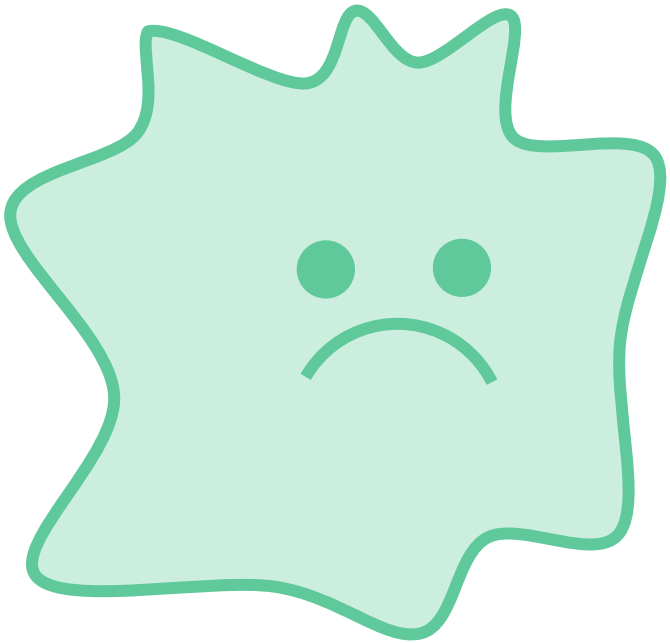


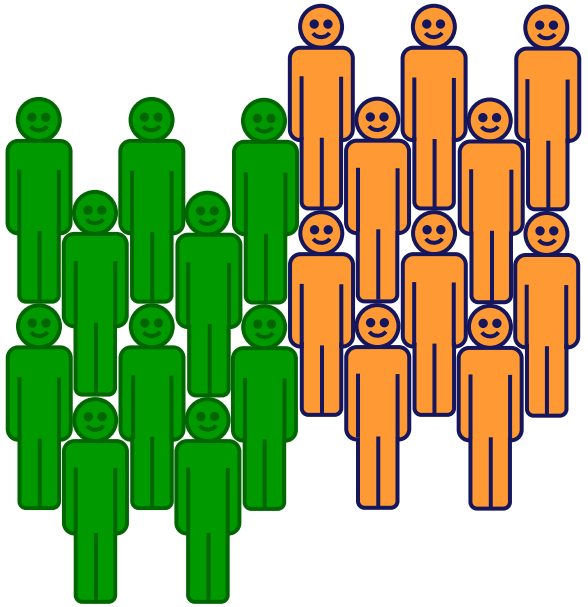
A better approach

- **In TRIZ, instead of identifying yourself with an object, it is sometime useful to imagine that the object consist of many little men – LMM – little men method**

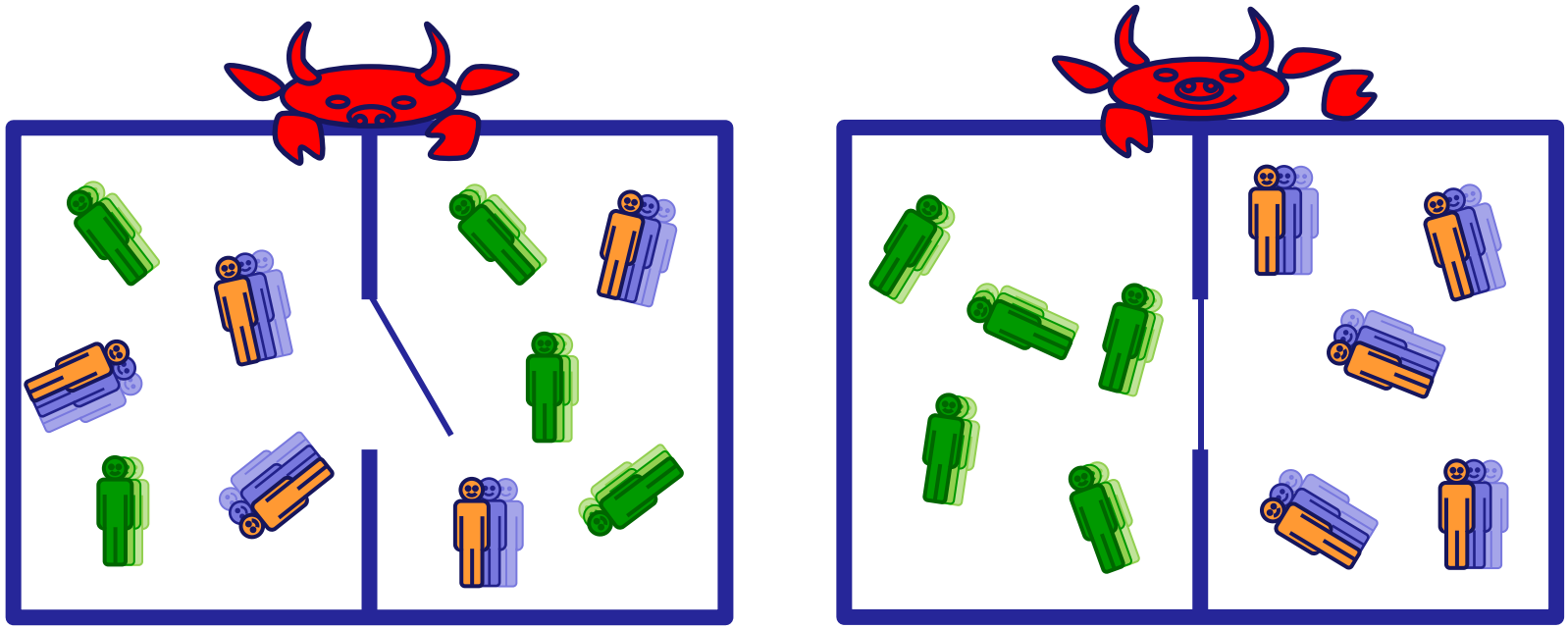


Synectics vs TRIZ



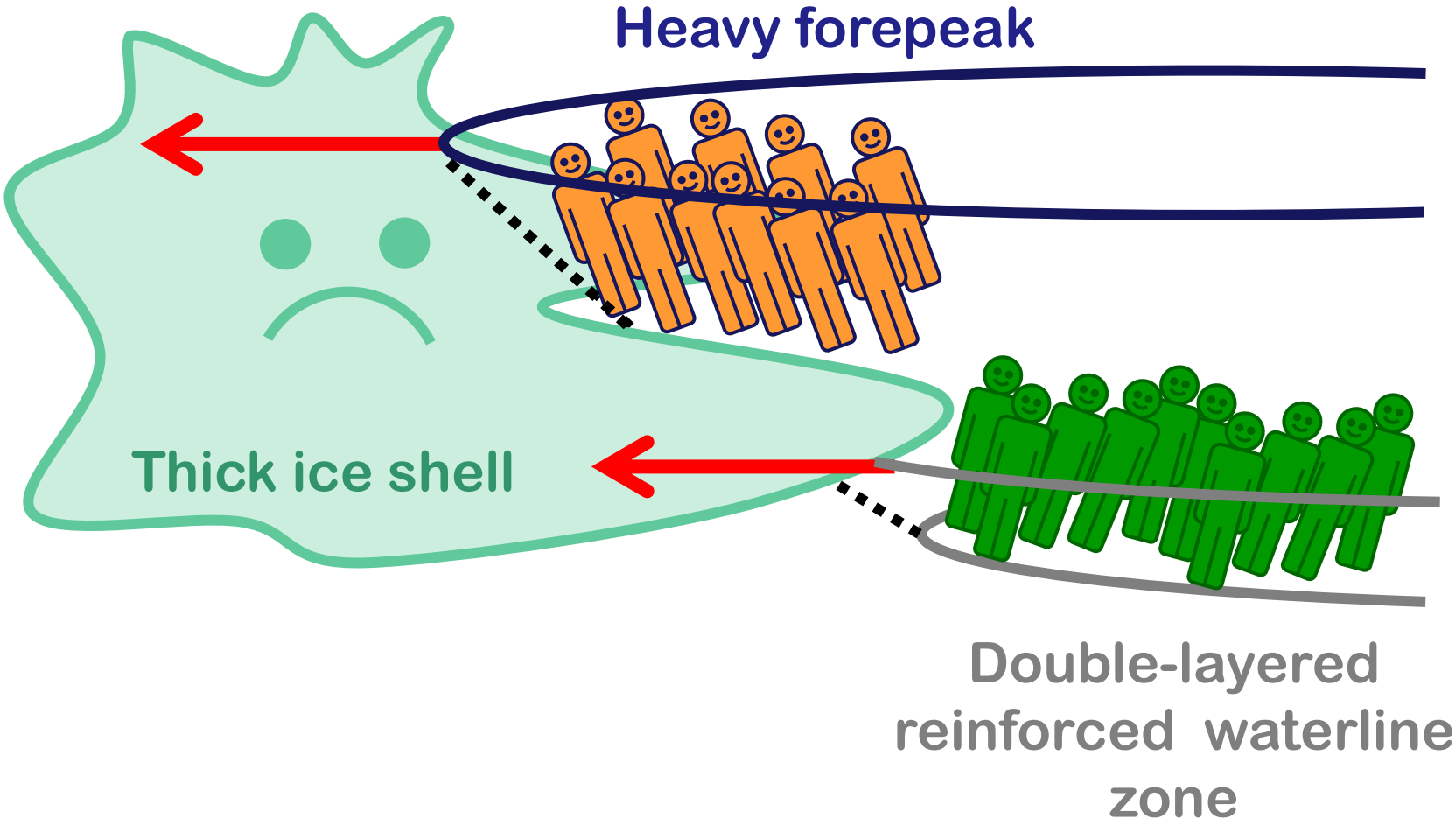


Example of LMM – Maxwell's demon



How to sort molecules? They sort themselves.

Example of LMM method – ice breaker



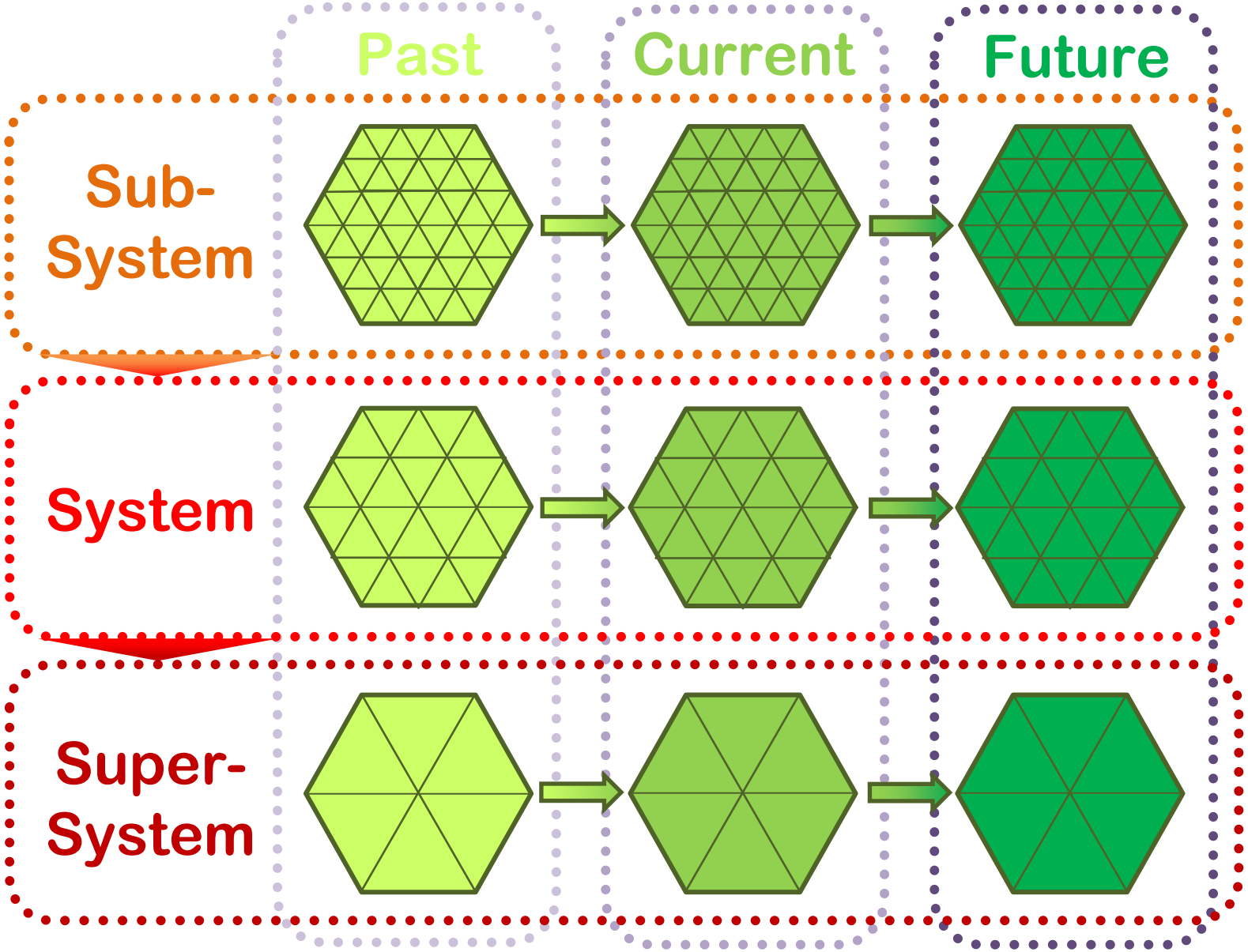
How to cut through ice fast

Understanding where we are

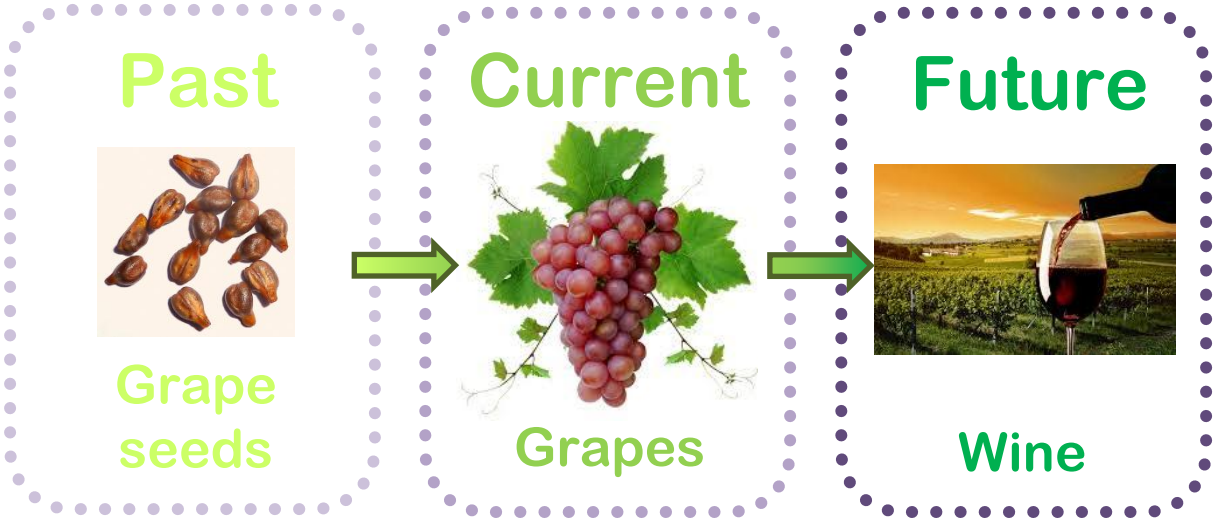
- **In time**
  - **past, now, future**
- **In space**
  - **sub-system, system, super-system**

This helps to understand the context

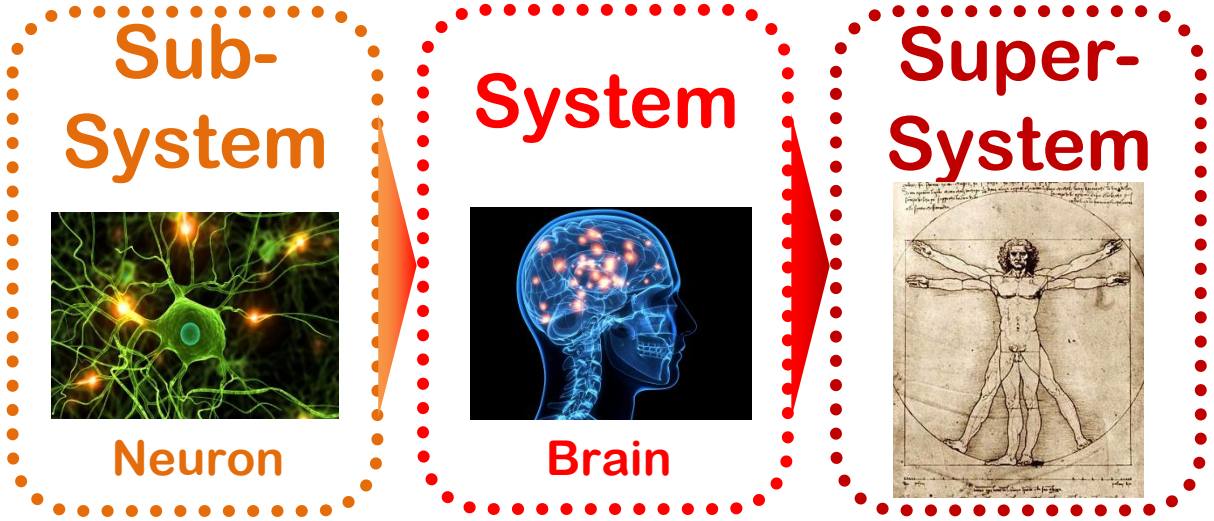
Understanding where we are



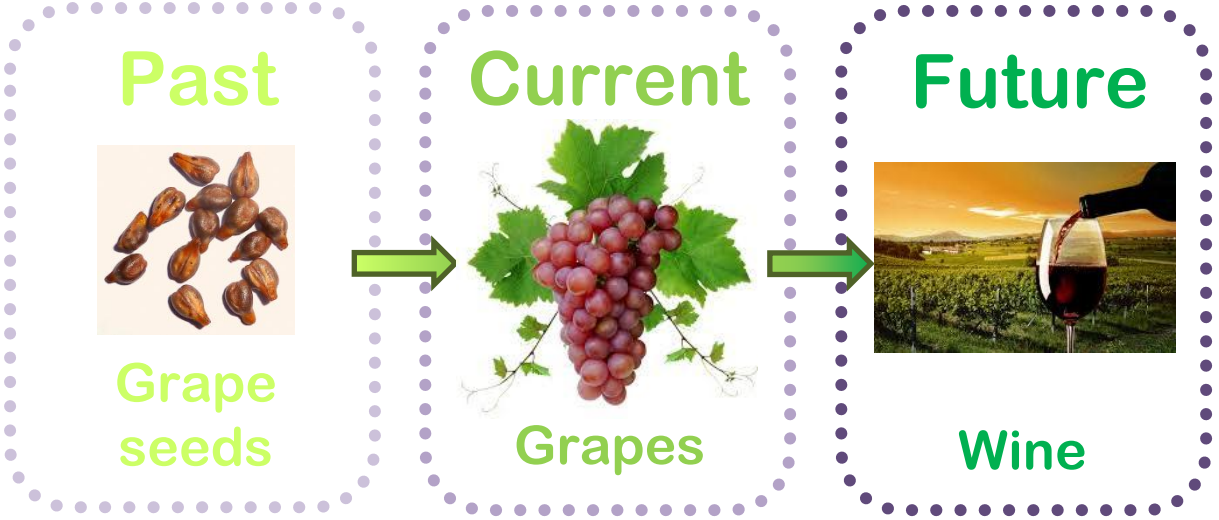
Understanding where we are



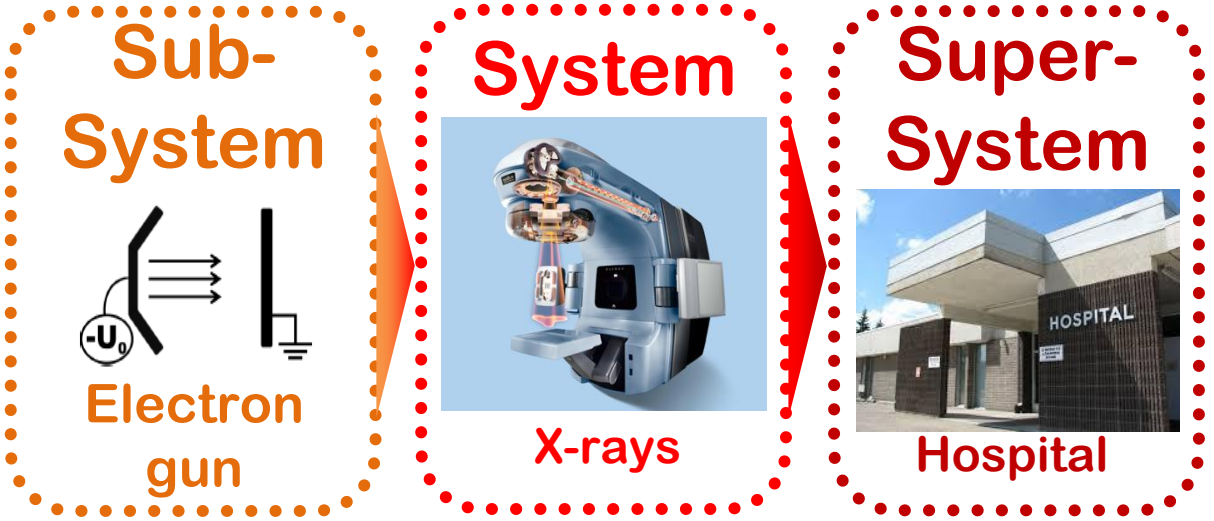
Examples



Understanding where we are



Examples



Other methods in TRIZ toolbox

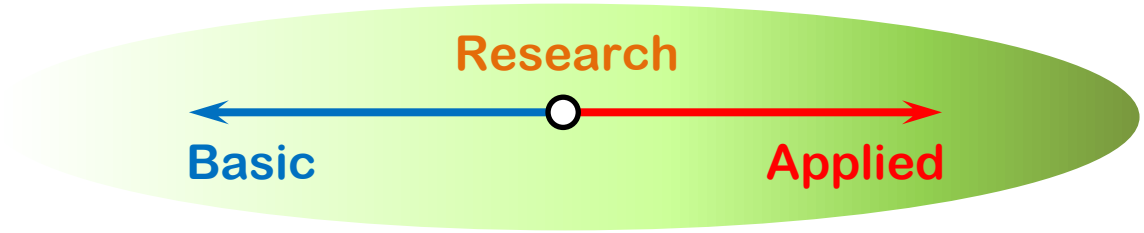
- Defining ideality of a solution
- Defining functions of the system
- Understanding benefits and harms
- TRIZ standard solutions
  - To deal with harms
  - To improve insufficient functions
  - …
- Use TRIZ effects database
- …

- You are encouraged to look at this to develop your skills further

Models of technology transfer

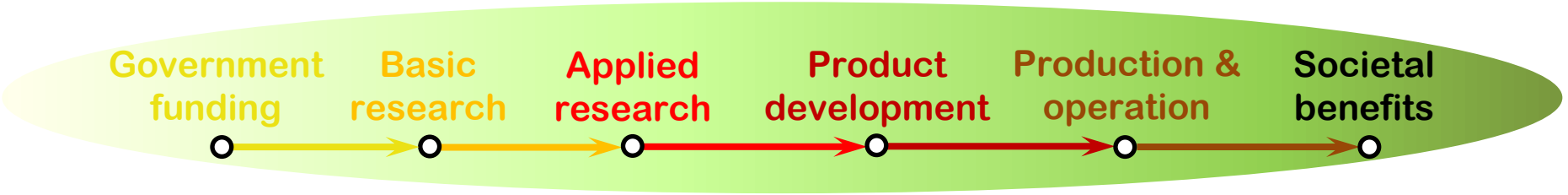
Mechanisms of science impact on society were discussed for many decades now

Vannevar Bush in his 1946 report described 1D or linear model and said that applied research would expel pure research if mixed:



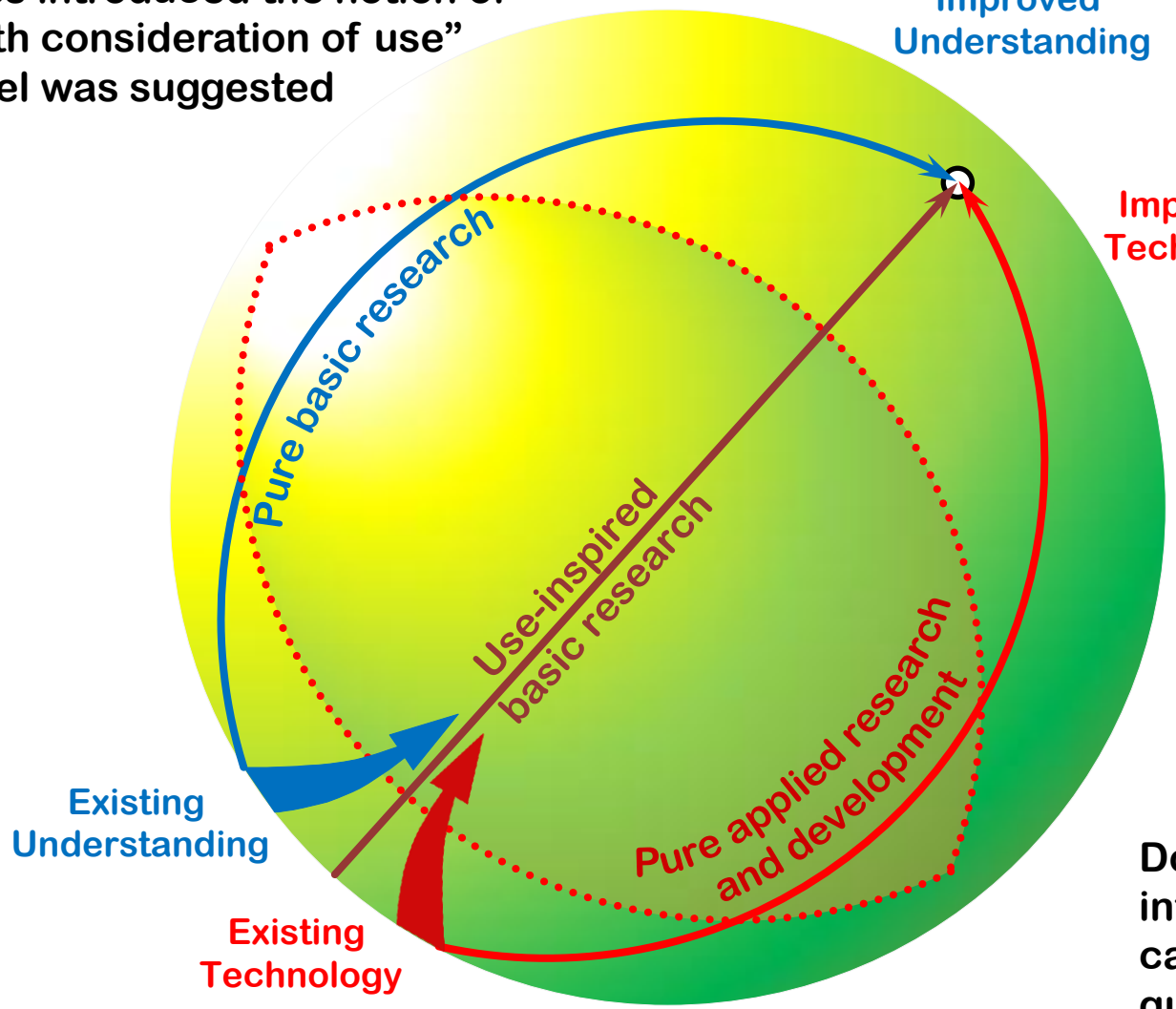
Therefore, according to Vannevar Bush, basic research must be isolated from *considerations of its practical use.*

The 1D linear model of technology transfer thus looks like this pipeline:



Models of technology transfer

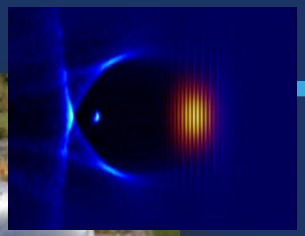
Linear model of Bush was criticized
Donald Stokes introduced the notion of "research with consideration of use"
Revised model was suggested

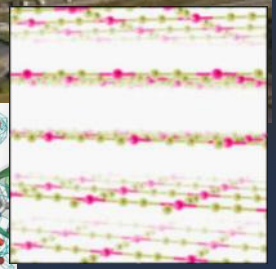


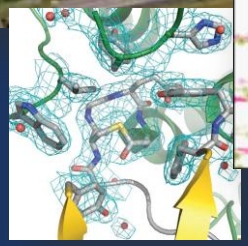
Donald Stokes also introduced the so called "Pasteur quadrant"

John Adams ... lerator Science

Imperial College London | Royal Holloway University of London | University of Oxford







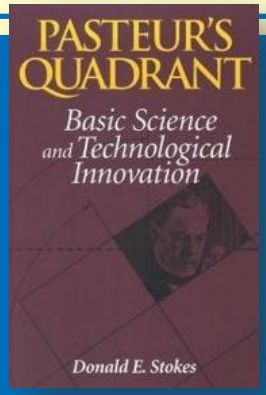
Fundamental knowledge

Consideration of use

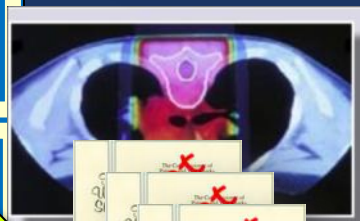
Niels Bohr

Louis Pasteur

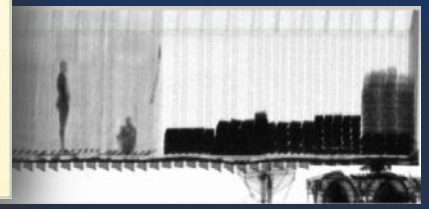
Accelerator Science and Technologies – JAI scope



Thomas Edison



Protons/Ions



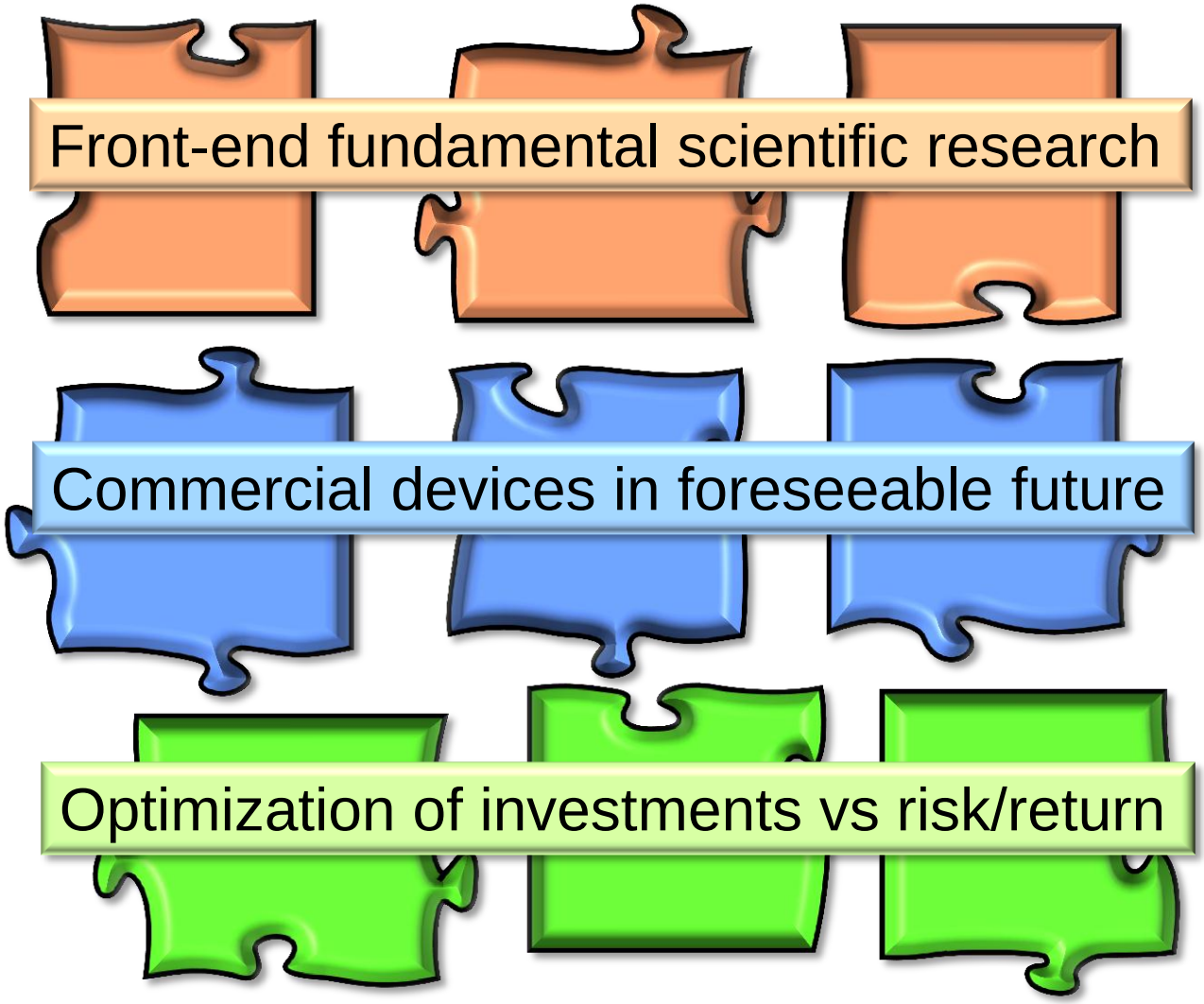
Imperial College London | Royal Holloway University of London | University of Oxford

“Valley of Death”

- A well known challenge – to bring scientific results to industry
- A gap between science result and technological innovation
- This challenge is often referred to “crossing the “Valley of Death”

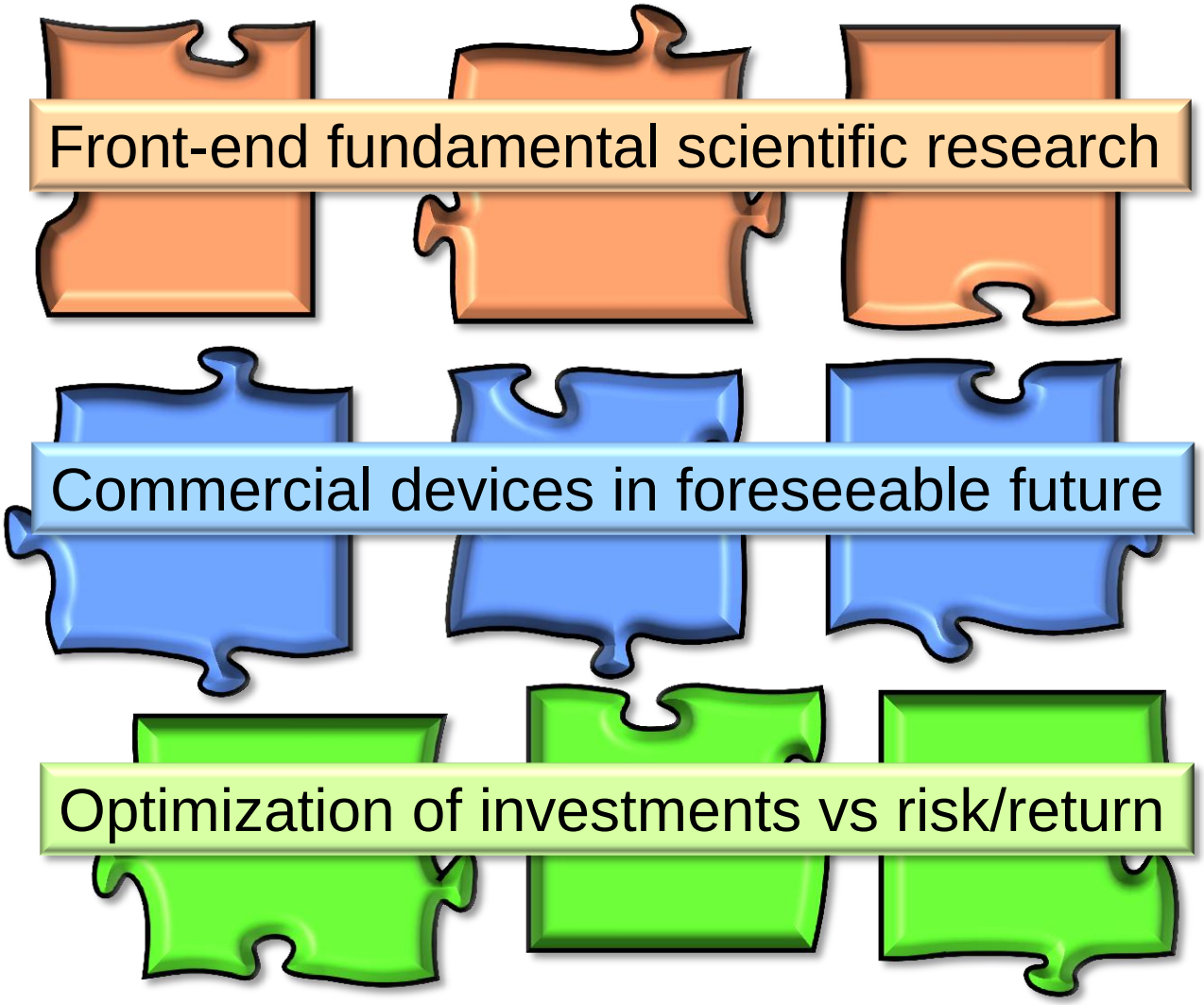
Academia-Industry-Investor puzzle

Different motivations of these three groups complicate the problem



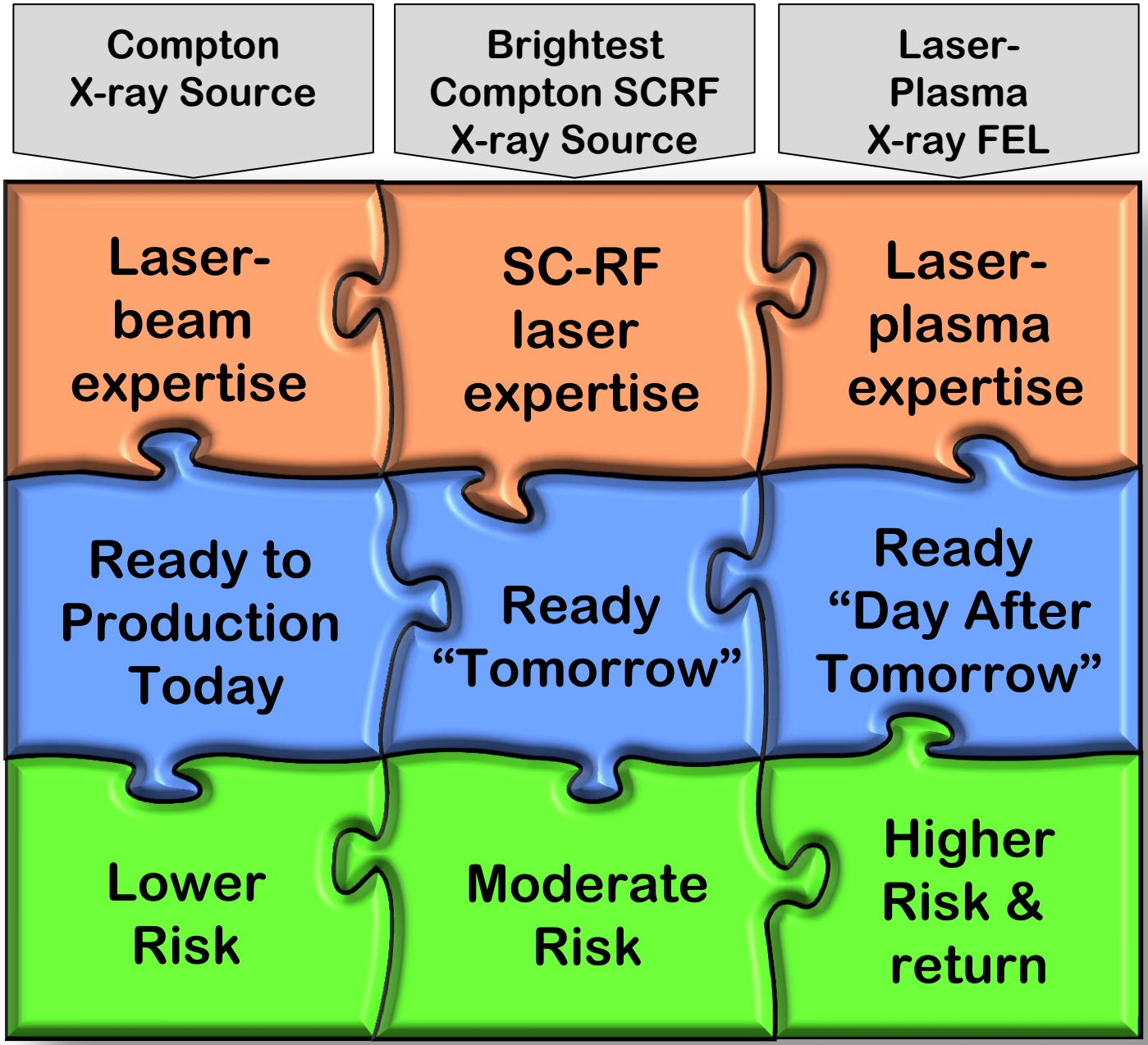
(investor can be government)

Academia-Industry-Investor puzzle



(investor can be government)

Academia-Industry-Investor puzzle solved?



Crossing the “Valley of Death”

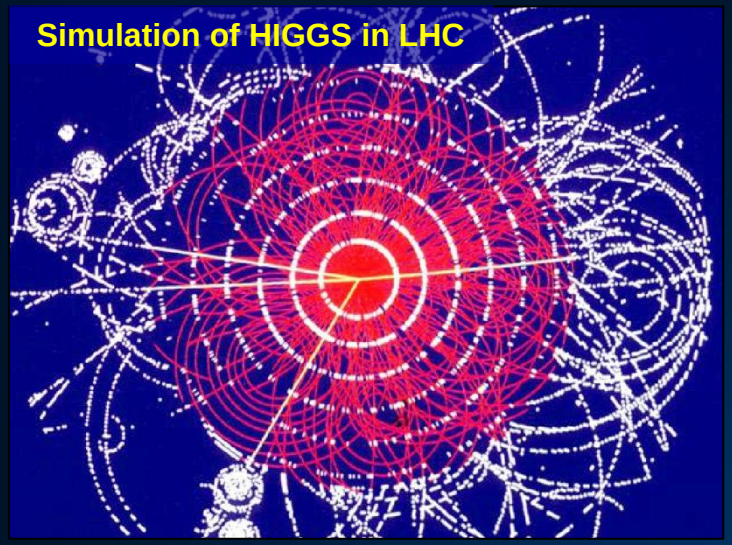
Working on a range of compact X-ray light sources will help crossing the “Valley of Death” between accelerator science and technological innovation

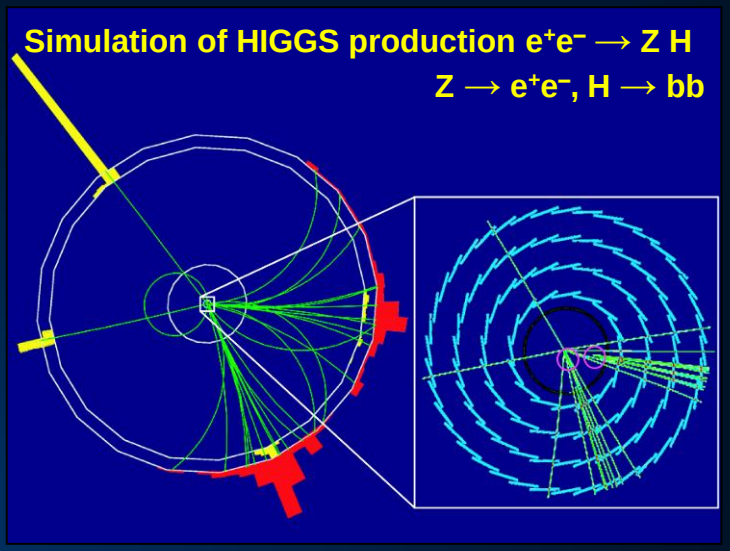
Higgs boson discovered – what's next?

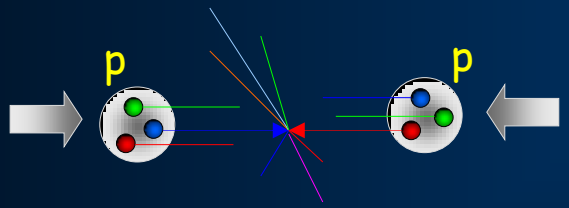
detailed studies…

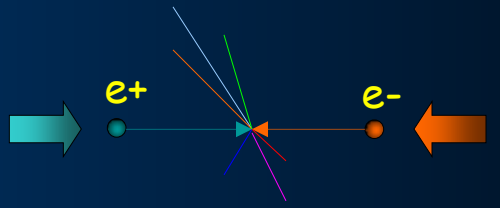
…in the years to come.

Proton-proton and e+e- colliders





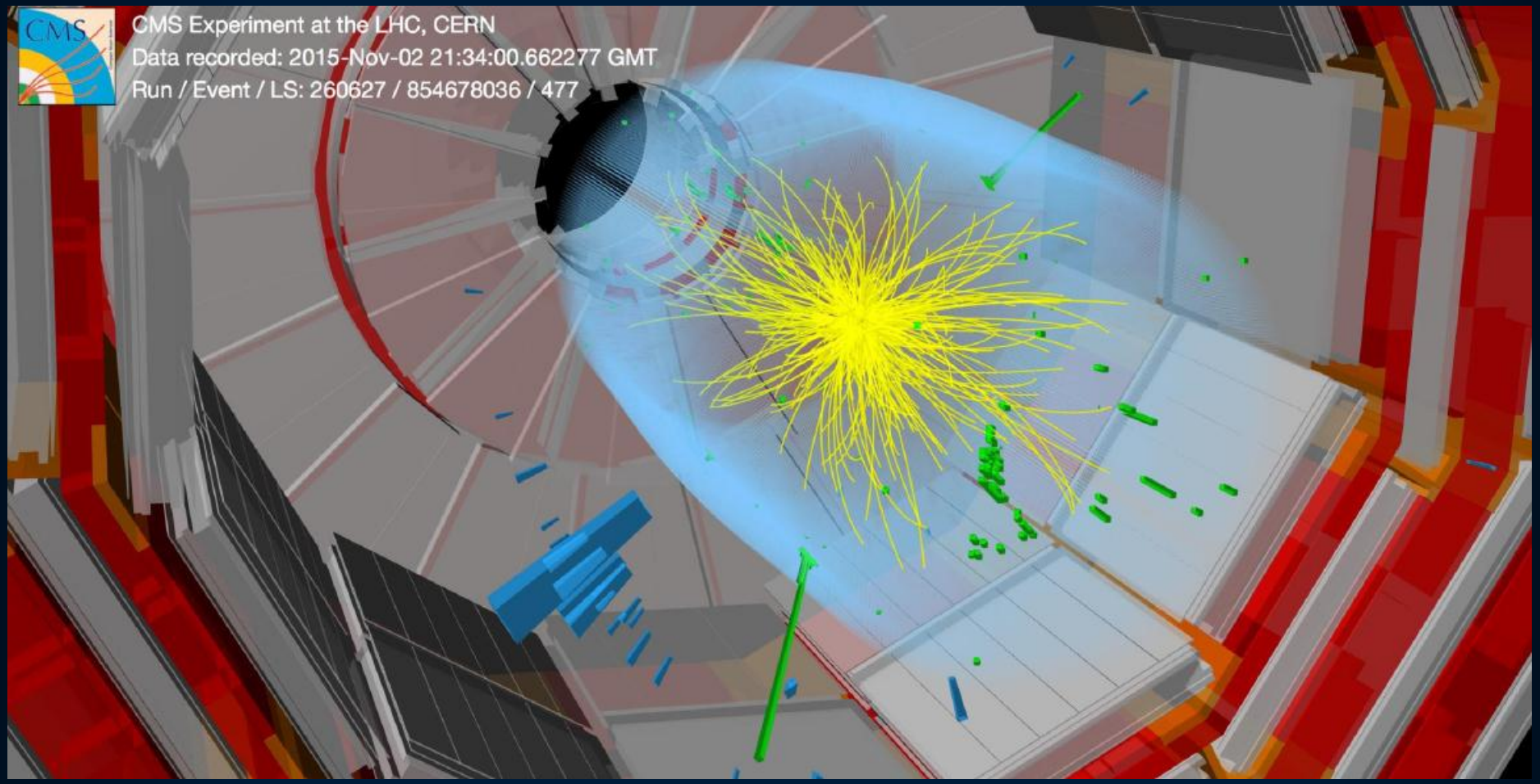




- Hadron collider: frontier of physics
  - Large QCD background
  - not all nucleon energy available in collision
- Lepton collider: precision physics
  - Colliding point like particles
  - well defined initial energy for reaction

Candidate next machine after LHC can be e+e- collider, with energy determined by the Higgs boson mass, aimed at studies of the new physics

Di-photon resonances



If the resonance at 745 GeV seen by CMS and ATLAS will be confirmed, it may become a very important factor defining the future

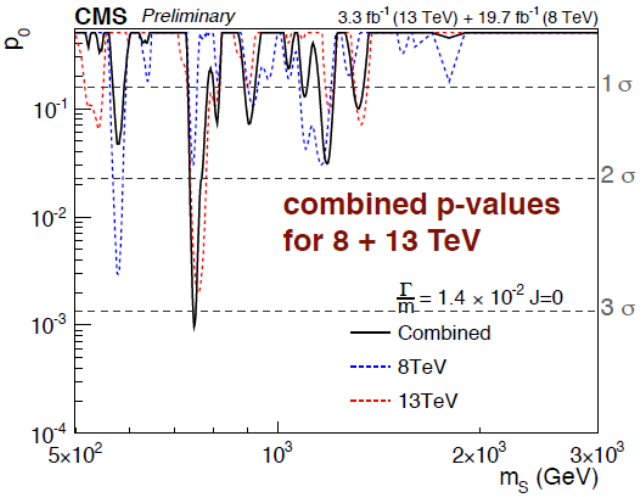
Di-photon resonances

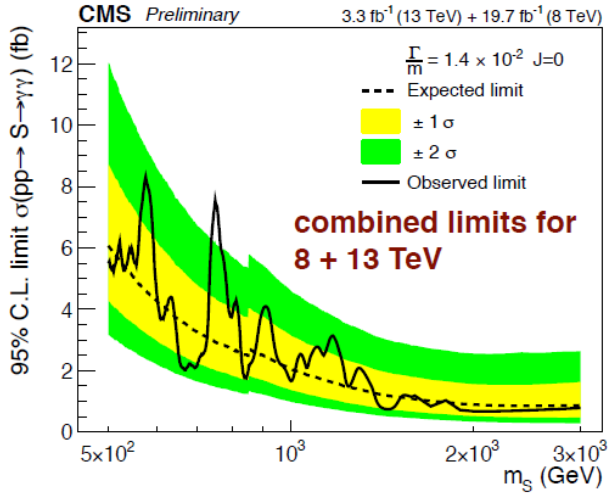
DIPHOTON RESONANCES

[EXO-16-018]

CMS

- Combined 8 TeV + 13 TeV results
  - Largest excess is observed for **750 GeV, spin-0, narrow width**
    - local significance of 3.4σ, 1.6σ after look-elsewhere effect





- Dec '15 result: largest excess at 760 GeV for Γ/M=1.4x10^{-2}
  - local significance of ~3σ, <1.7σ after look-elsewhere effect

If the resonance at 745 GeV seen by CMS and ATLAS will be confirmed, it may become a very important factor defining the future

Di-photon resonances

Di-photons: search for spin-0 resonance

Perform 2D p_0 scan (as function of mass and width of the hypothetical resonance).

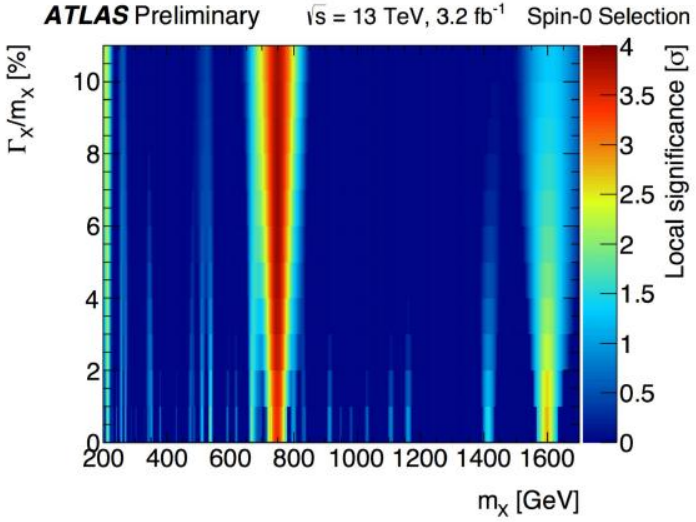
Largest deviation from background-only hypothesis:
near 750 GeV
width ≈ 45 GeV (i.e. 6%)

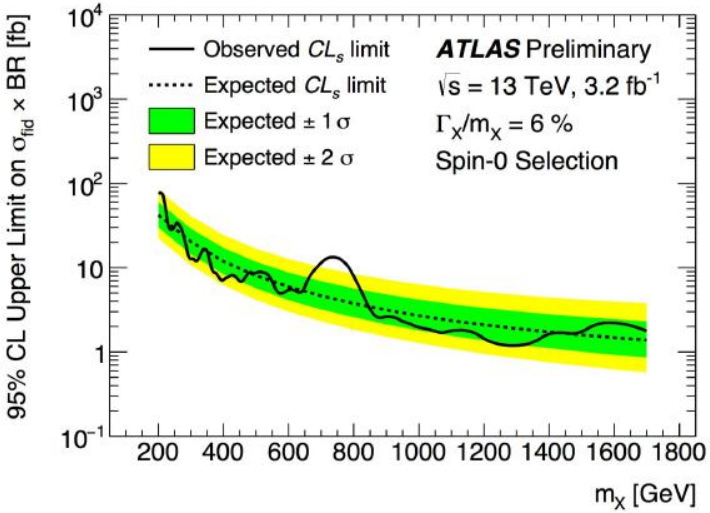
Local significance: 3.9σ
Global significance: 2.0σ

ATLAS-CONF-2016-xxx

Report limits on fiducial cross section as a function of mass hypothesis, for several width hypotheses.

Example shown here: width of 6%





If the resonance at 745 GeV seen by CMS and ATLAS will be confirmed, it may become a very important factor defining the future

Di-photon resonances

Di-photons: search for spin-0 resonance

Perform 2D p_0 scan (as function of mass and width of the hypothetical resonance).

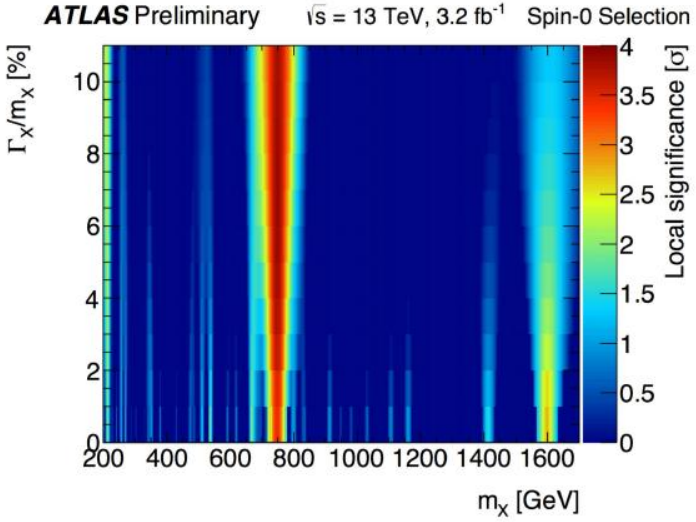
Largest deviation from background-only hypothesis:
near 750 GeV
width ≈ 45 GeV (i.e. 6%)

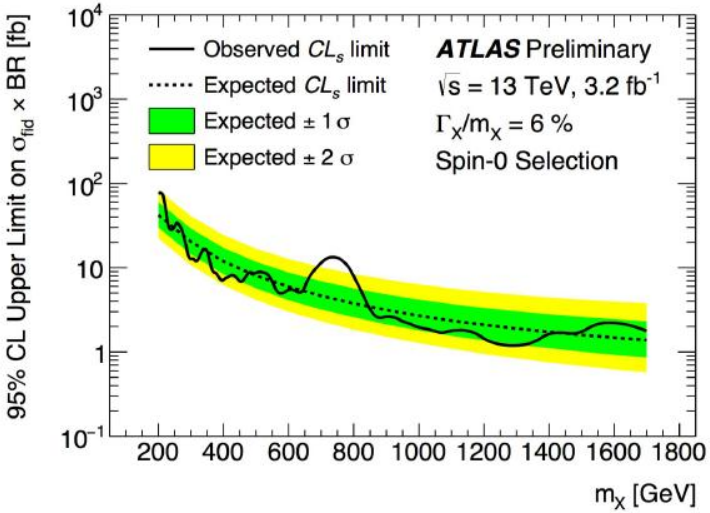
Local significance: 3.9σ
Global significance: 2.0σ

ATLAS-CONF-2016-xxx

Report limits on fiducial cross section as a function of mass hypothesis, for several width hypotheses.

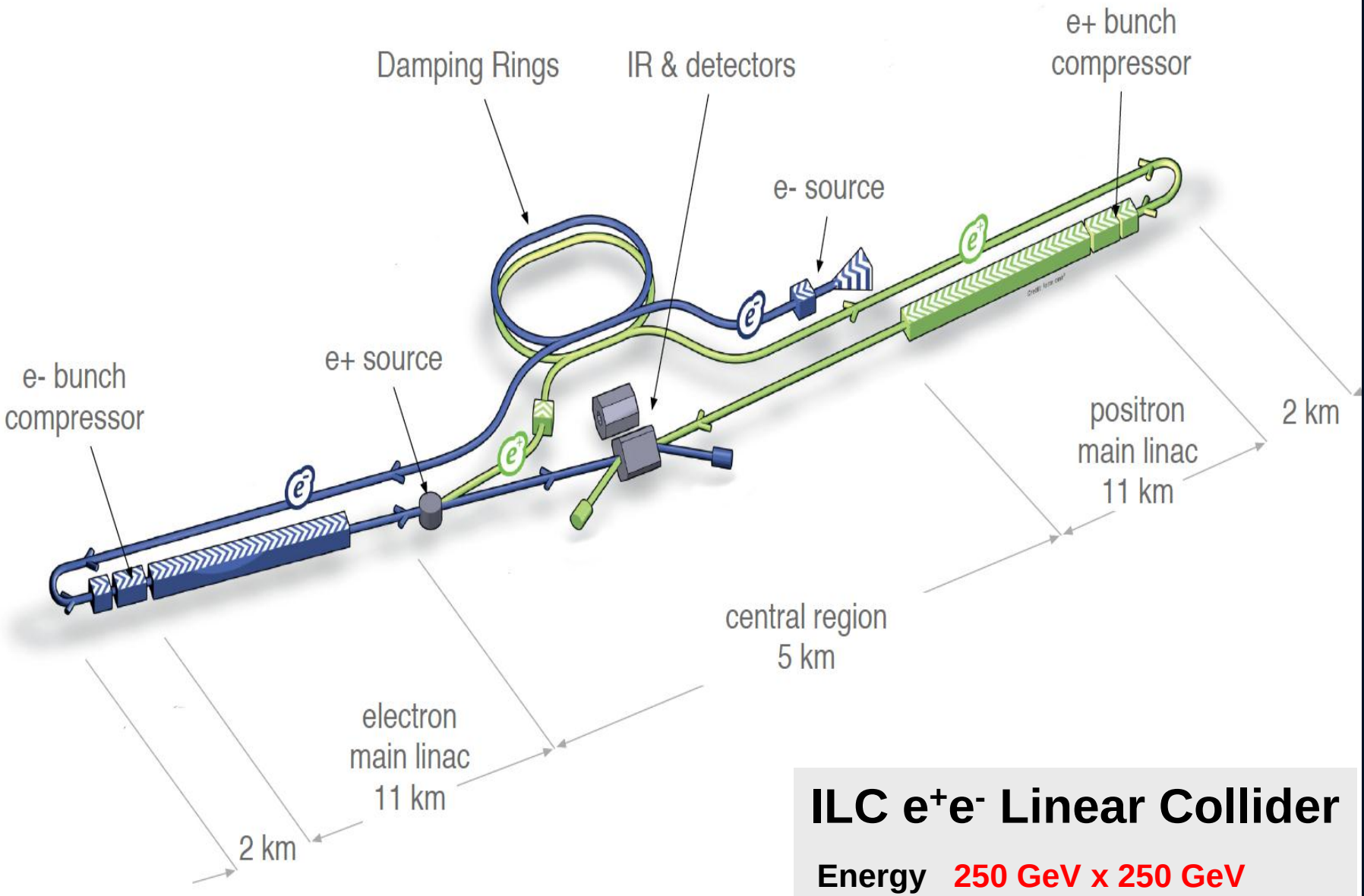
Example shown here: width of 6%





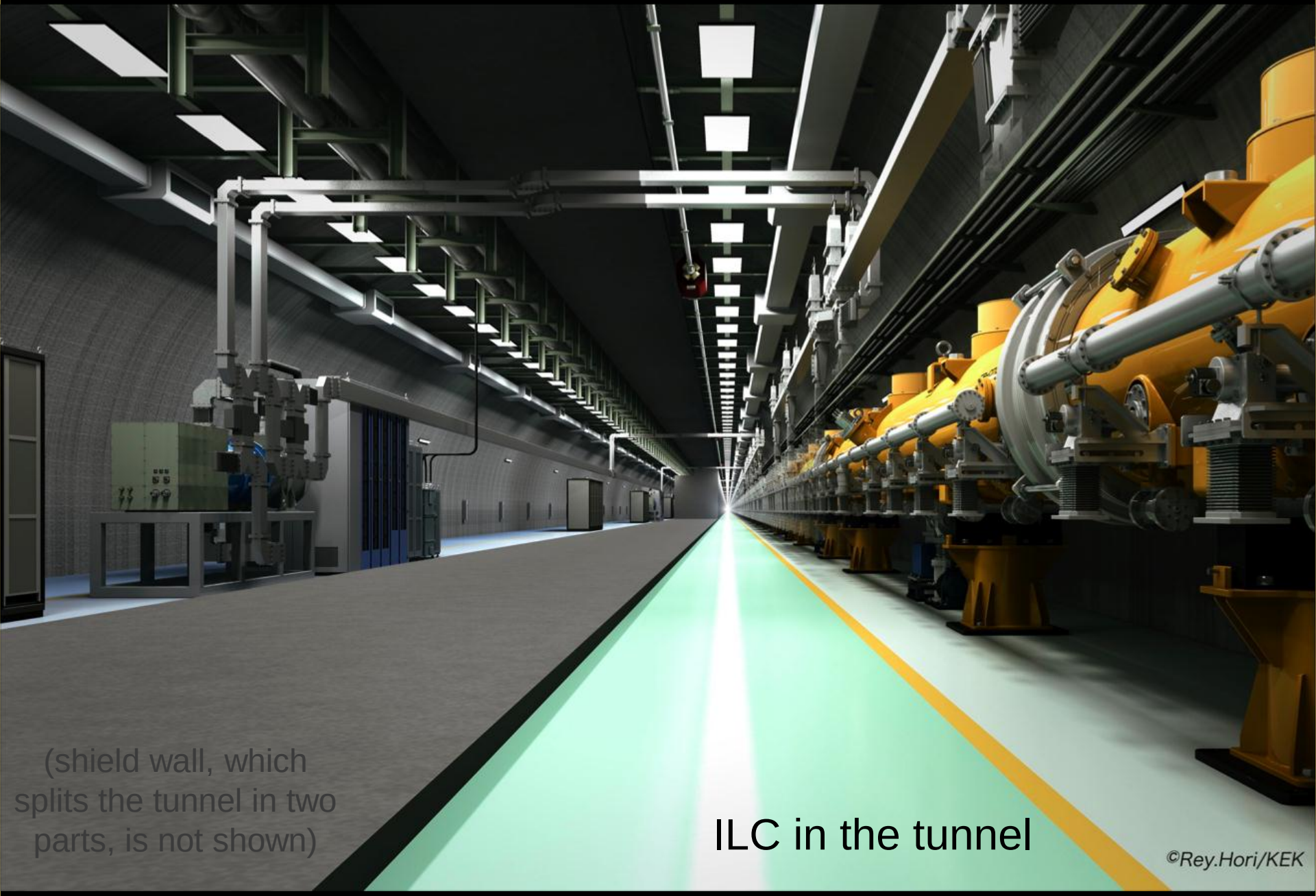
If the resonance at 745 GeV seen by CMS and ATLAS will be confirmed, it may become a very important factor defining the future

International Linear Collider ILC



ILC e^+e^- Linear Collider

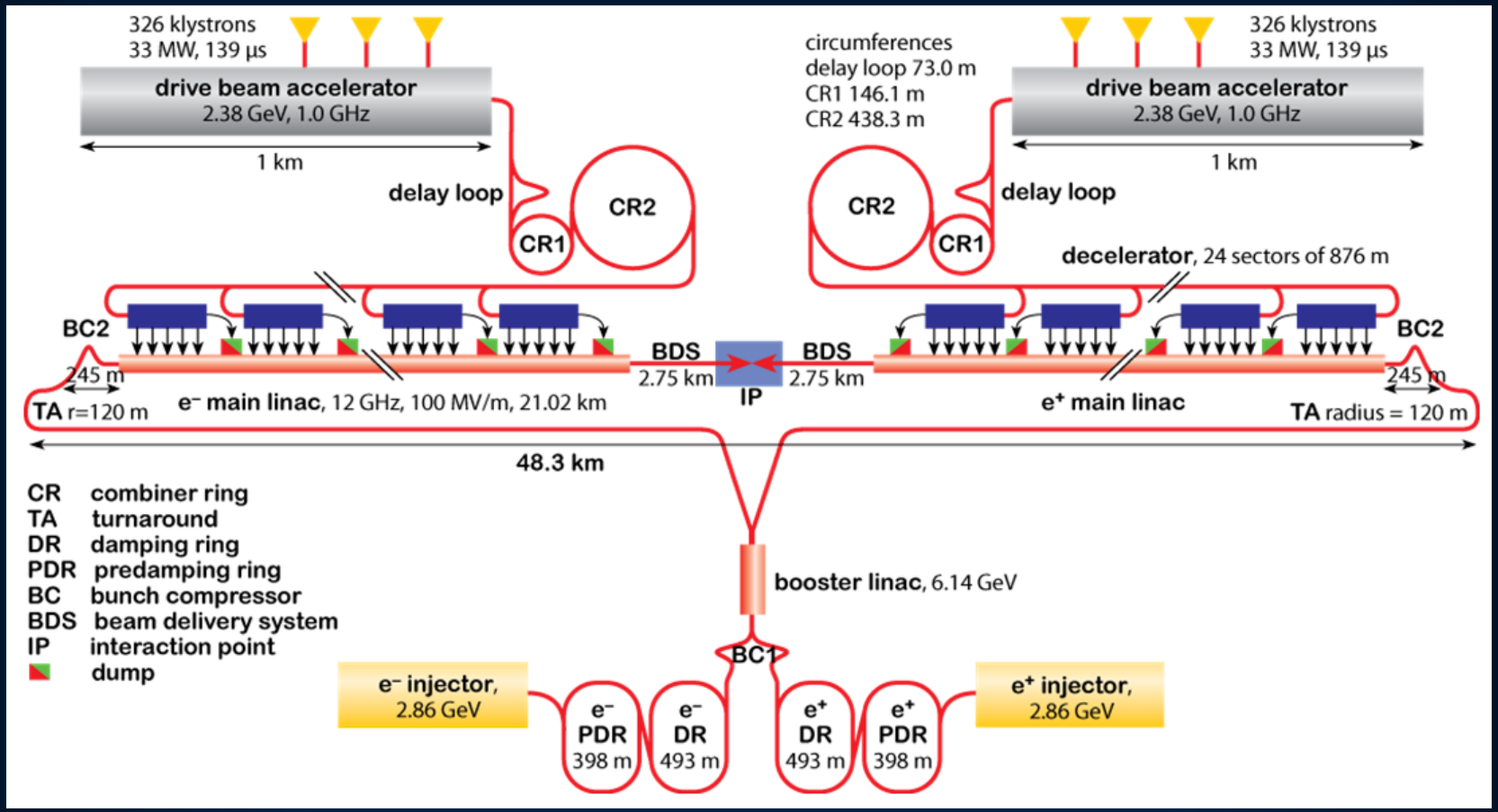
Energy **250 GeV x 250 GeV**


(shield wall, which splits the tunnel in two parts, is not shown)
ILC in the tunnel
©Rey.Hori/KEK

ILC - possibly in Japan

The final decision will be made by the Government of Japan in the coming years

Compact Linear Collider – CLIC



CLIC is now exploring the option of 380 GeV CM (klystron based) for Higgs and top factory
(But may need to look at 750 GeV CM due to di-photon?)

Circular Collider after LHC – CEPC (China)

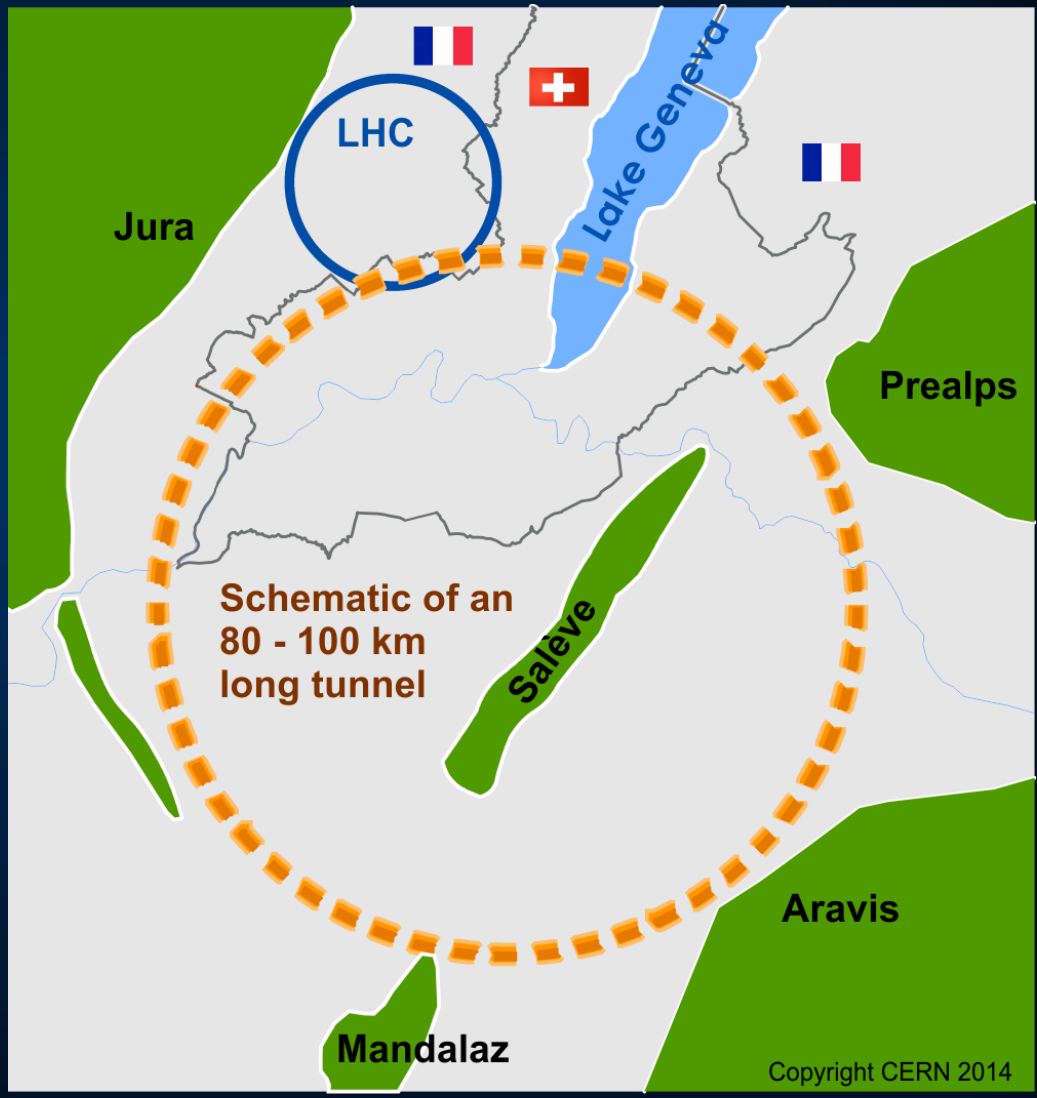
- Circular Collider 50-70 km
- Initially, *e*+-*e*-, and then for protons

- Possible location: Qinhuangdao

Circular Collider after LHC – FCC (CERN)

FCC = Future Circular Collider

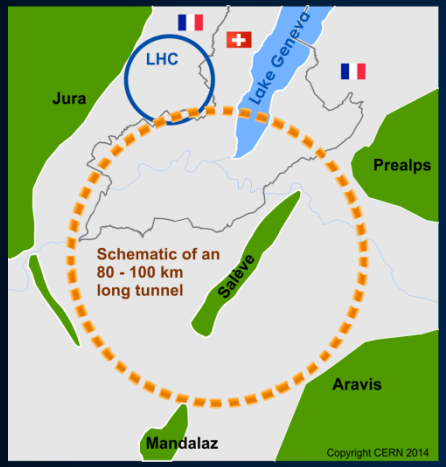
100 km tunnel infrastructure in Geneva area – design driven by pp-collider requirements *with possibility of e+-e- and p-e*



Preliminary parameters (FCC-hh):

CM energy	**100 TeV**
Circumference	**100 km**
Dipole field	**16 Tesla**
Peak Lumi	**5E34 $cm^{-2}s^{-1}$**

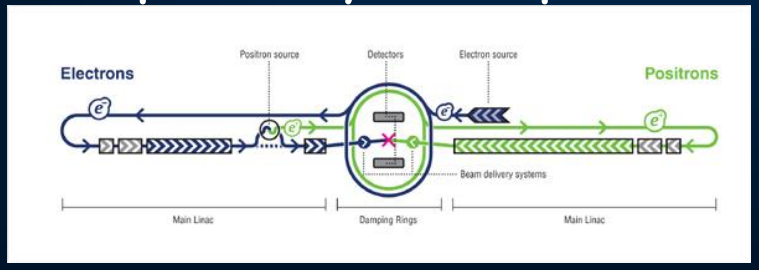
Next e+e- Collider – Circular versus Linear



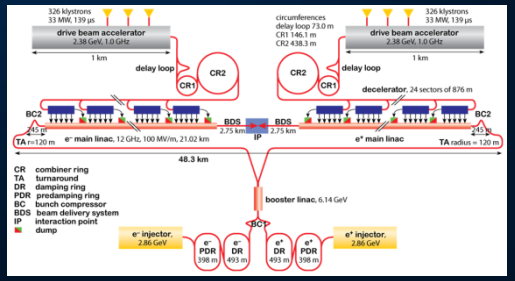
Circular collider FCC (CERN)

Circular collider CEPC (China)

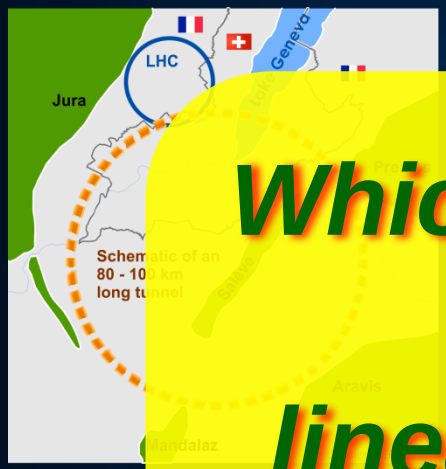
Linear collider ILC (possibly in Japan)

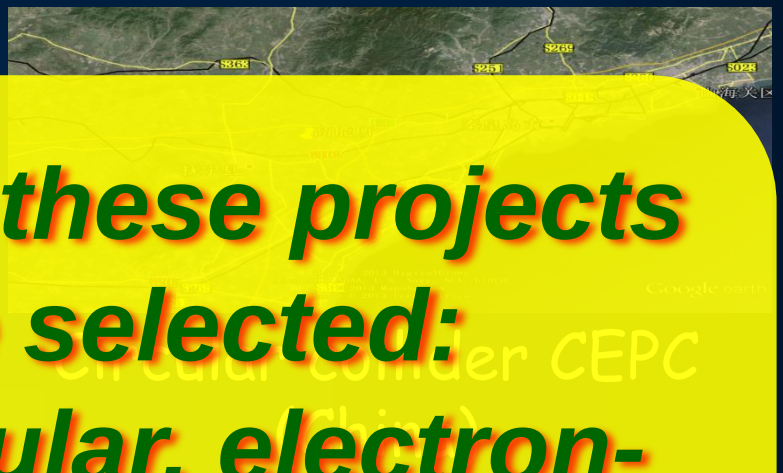


Linear collider CLIC (380 or 750 GeV CM?)

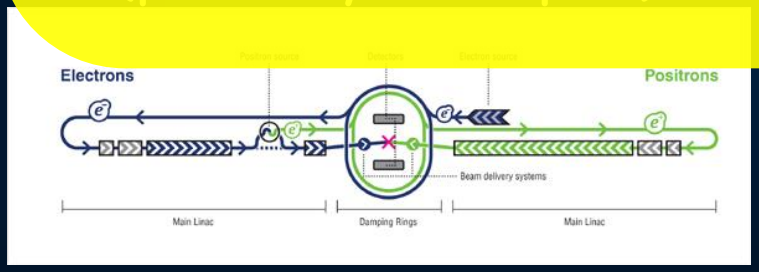


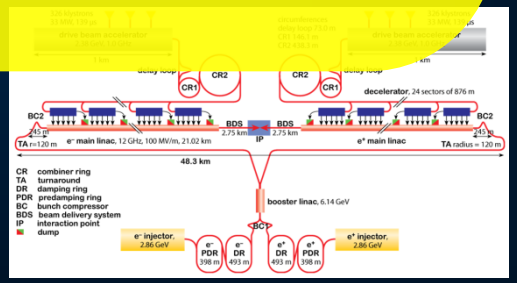
Next e+e- Collider – Circular versus Linear



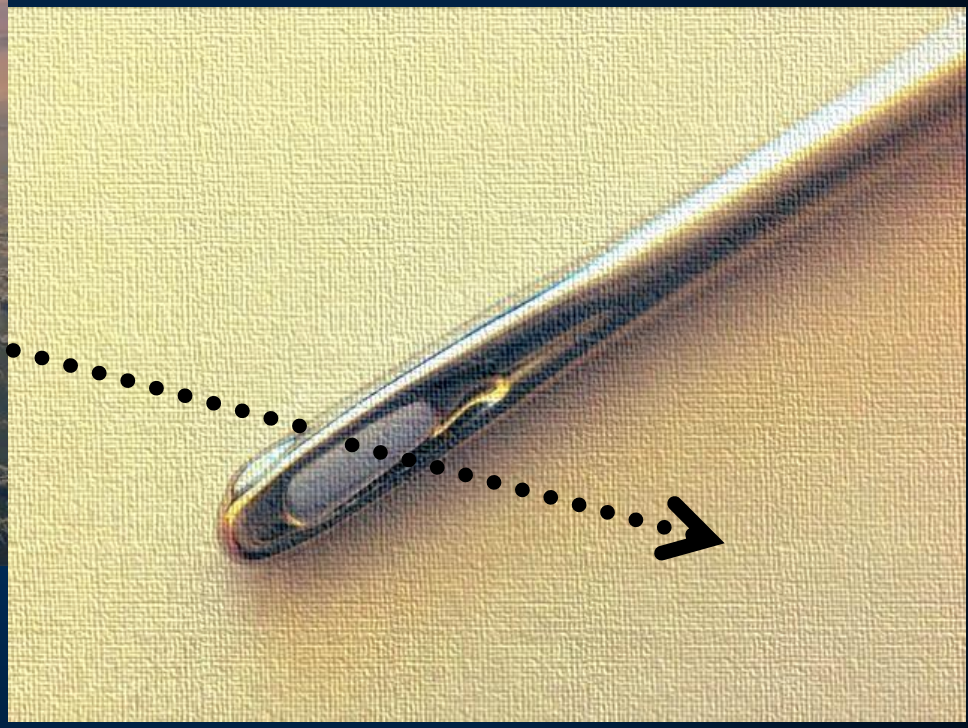


Whichever of these projects would be selected: linear or circular, electron-positron and proton-proton - TRIZ will help implement it



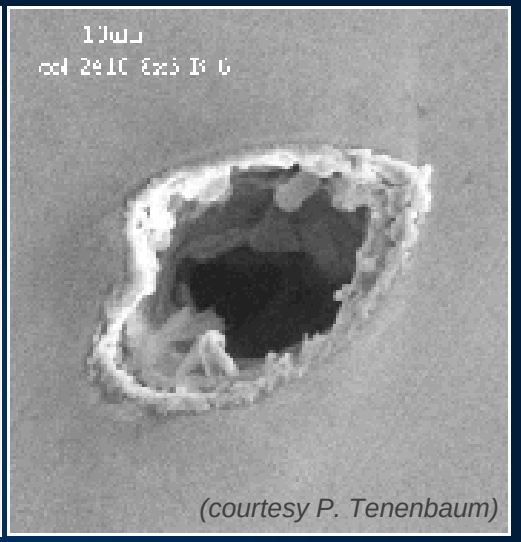


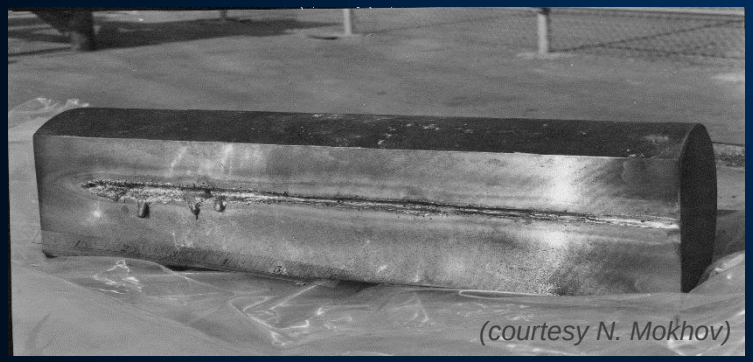
How to pass an Airbus through a needle's eye?

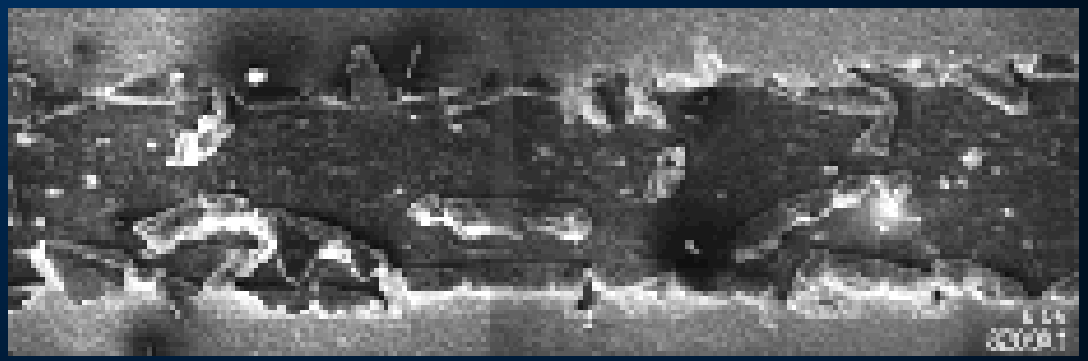


FCC: Energy of each circulating beam above 8GJ (= 1 Airbus 380 at 720km/h)

Examples of damage caused by exposure to the beam



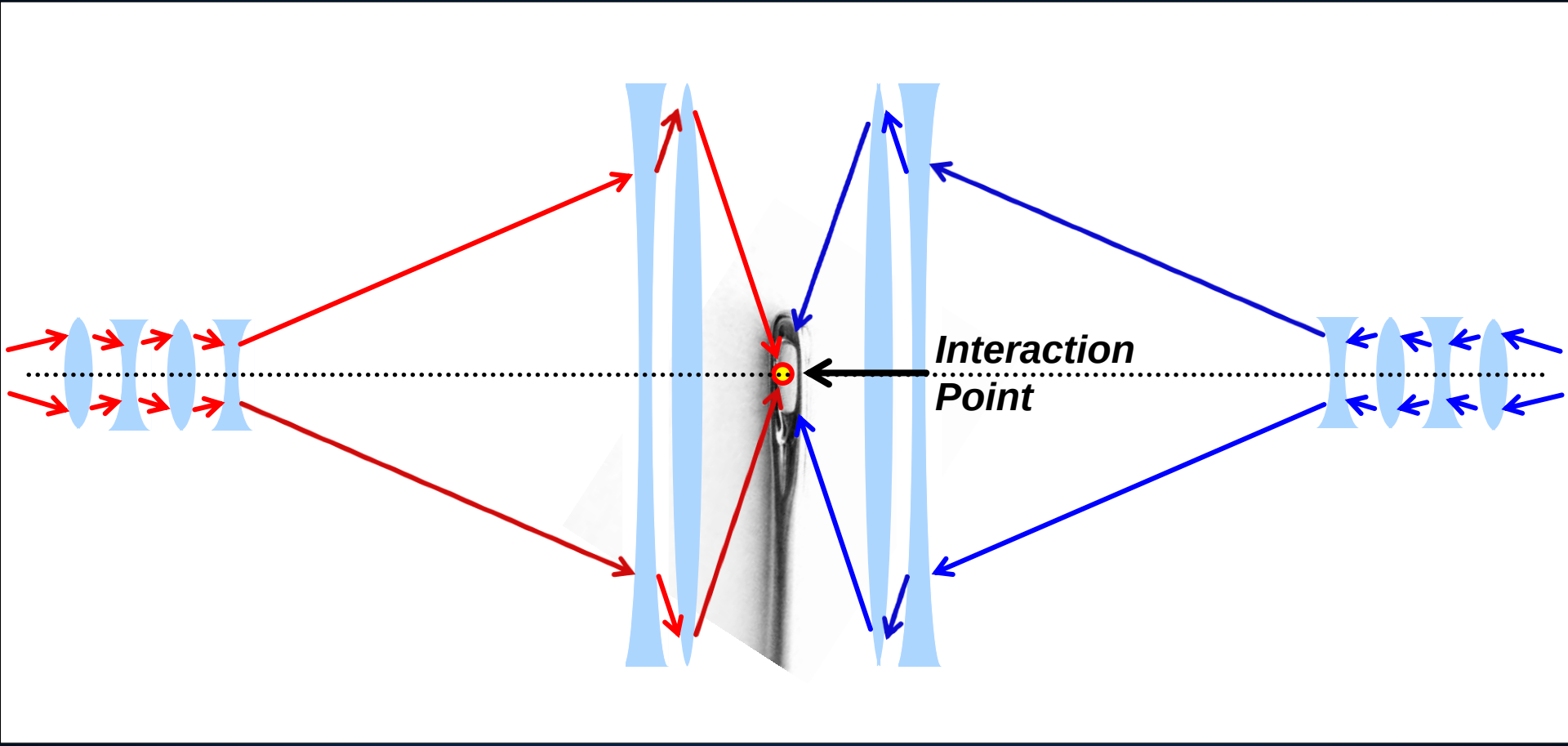




And the damage caused by the beam with energy much less than expected in the FCC!

(materials for slide courtesy R. Assmann and N.Mokhov)

The telescope and the eye of a needle



TRIZ principles help not only focus the colliding beams at the Interaction Point, but also create and improve particle detectors

TRIZ and science: the reason for creating AS-TRIZ is to engage proactively in TRIZ analysis, which help to study it better and feel more closely connected to it

AS-TRIZ

Matrix

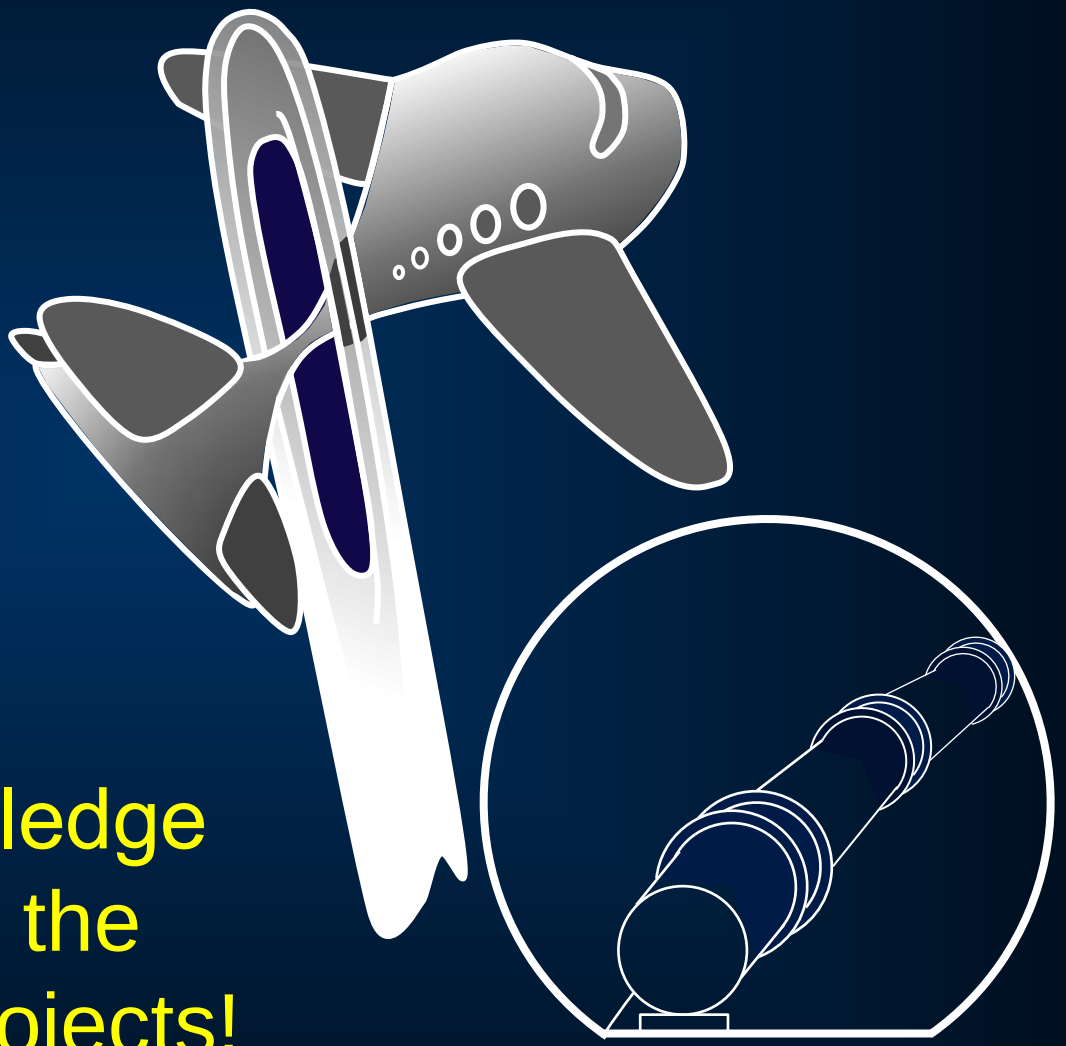
- Luminosity
- Rate of energy change
- Sensitivity to imperfections
- Integrity of materials
- Intensity
- …

Principles

- Volume to surface ratio
- Local correction
- Transfer between phase planes
- From microwave to optical
- Time energy correlation
- …

TRIZ and challenges of the future colliders

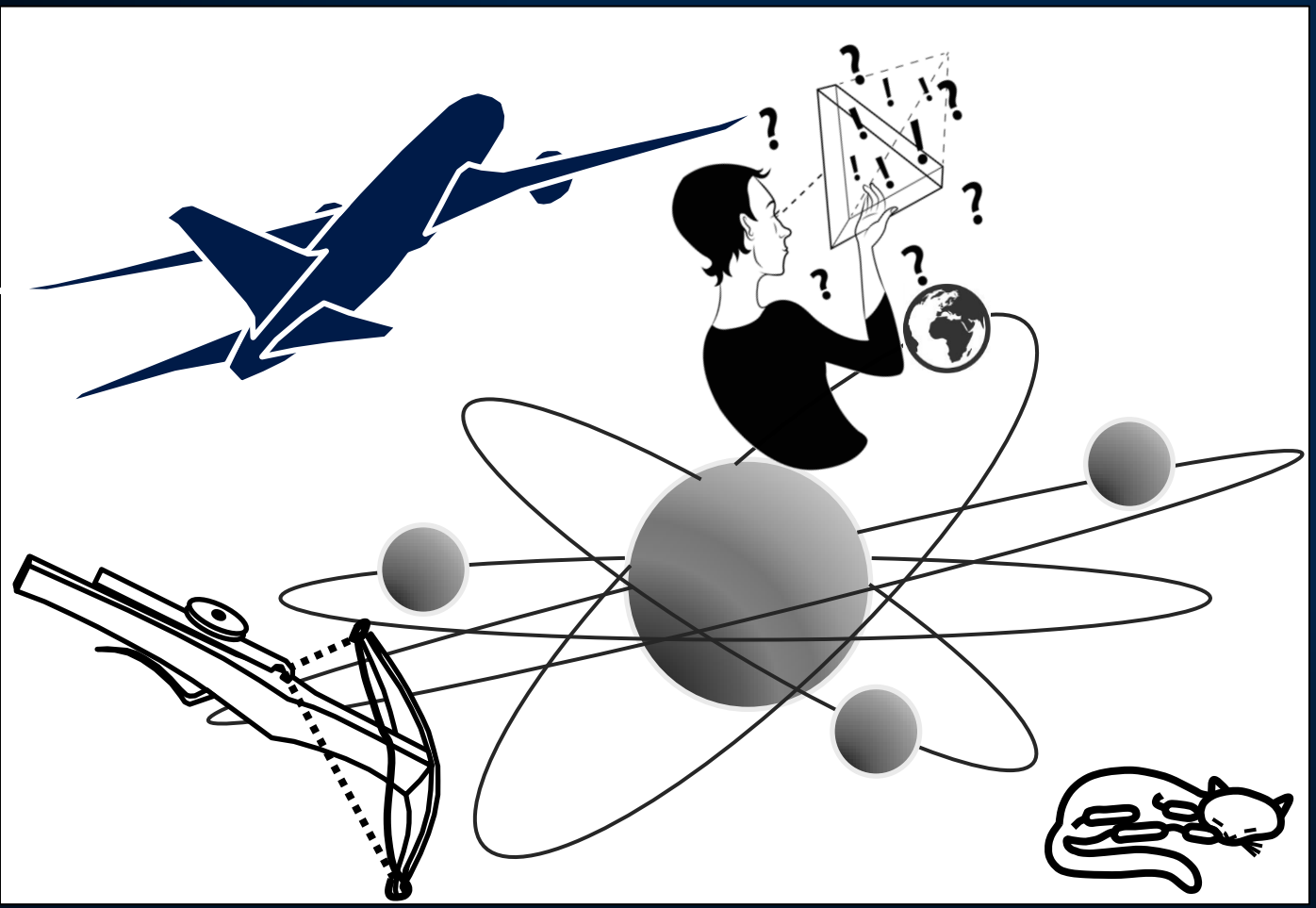
TRIZ methodology can be applied to a new project with a lot of new challenges such as FCC



Let’s apply our knowledge and inventiveness to the challenging future projects!

Thanks to my creative family team!

For many illustrations created for this presentation and for the book



Sasha Seraia

www.sashaseraia.com

Elena Seraia

University of Oxford, Target Discovery Institute

Thank you for your work in this USPAS course!