PARTICLE COLLIDER INTERACTION REGIONS

Backgrounds and Machine-Detector Interface

Lecture 4: Collimation

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OUTLINE

- Collimation Basics
- Multi-Stage Scheme
- Collider Specifics
  - e^+e^-
  - pp
  - $\mu^+\mu^-$
- Novel Techniques
  - Crystals: Channeling, VR and VR radiation
  - Tail Folding with Non-Linear Optics
  - Hollow e-Beam Lens

BEAM COLLIMATION

Beam collimation is mandatory at any high-power accelerator and hadron collider.

Only with a very efficient beam collimation system can one reduce uncontrolled beam losses in the machine to an allowable level,

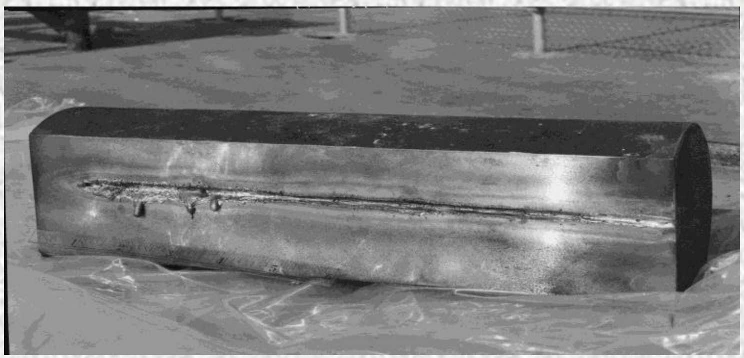
thus protect machine components, detectors and personnel against excessive irradiation, maintain operational reliability over the life of the complex, provide acceptable hands-on maintenance conditions, and reduce the impact of radiation on environment, both at normal operation and accidental conditions.

COLLIMATION COMPLEXITY AND EFFICIENCY

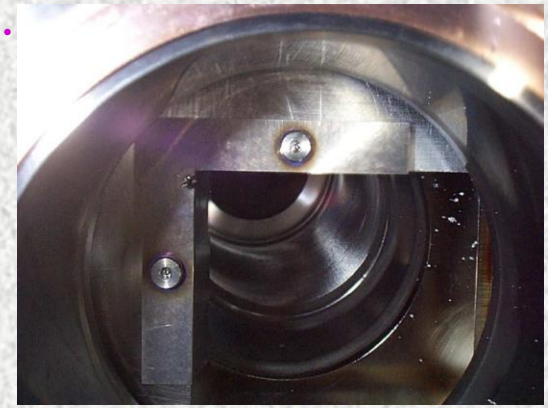
- Tevatron H&V collimators for proton (D49 primary, and E03, F172 and D173 secondary) and pbar (F49 primary, and F48 and D172 secondary) beams along with A01V and A48V for proton abort kicker prefire protection. Collimation efficiency is about 99.9%.
- A brand new Main Injector system consists of a primary collimator and 4 secondary collimators. The achieved efficiency is 99%. **A new approach** with integrated collimator, marble shells and hybrid masks is used.
- LHC Phase I system consists of 112 horizontal, vertical and skew collimators in the ring and SPS-LHC transfer lines. A two-jaw opening at top energy is 3 mm. Surface roughness limit is about 25 μm. A design cleaning efficiency is 99.99%. **A few novelties** have recently been implemented.

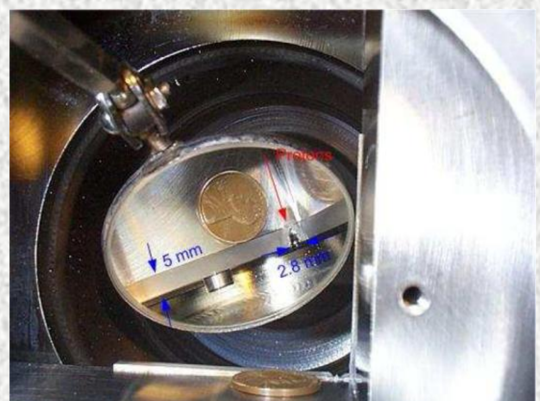
COLLIMATOR AS A LAST LINE OF DEFENSE

All collimators must withstand a predefined fraction of the beam hitting their jaws and - at normal operation - survive for a time long enough to avoid very costly replacements.



0.5-MW, 2-mm diam e-beam, grazing on 60-cm Cu; it took 1.5 s to melt in





2-MJ 1-TeV p-beam drilled a hole in W primary collimator, created a 1-ft groove in SS secondary one, and quenched 2/3 of the ring, all in a few ms. Abort system fired in 10 ms.

TWO-STAGE BEAM COLLIMATION (1)

The system consists of a primary collimator (spoiler, thin scattering target), followed by a few secondary collimators at the appropriate phase advance (locations) in the lattice. The purpose of a spoiler is to increase the amplitude of the betatron oscillations of the halo particles (give them an angular kick) via scattering/interaction in a thin object and thus to increase their impact parameter on secondary collimators.

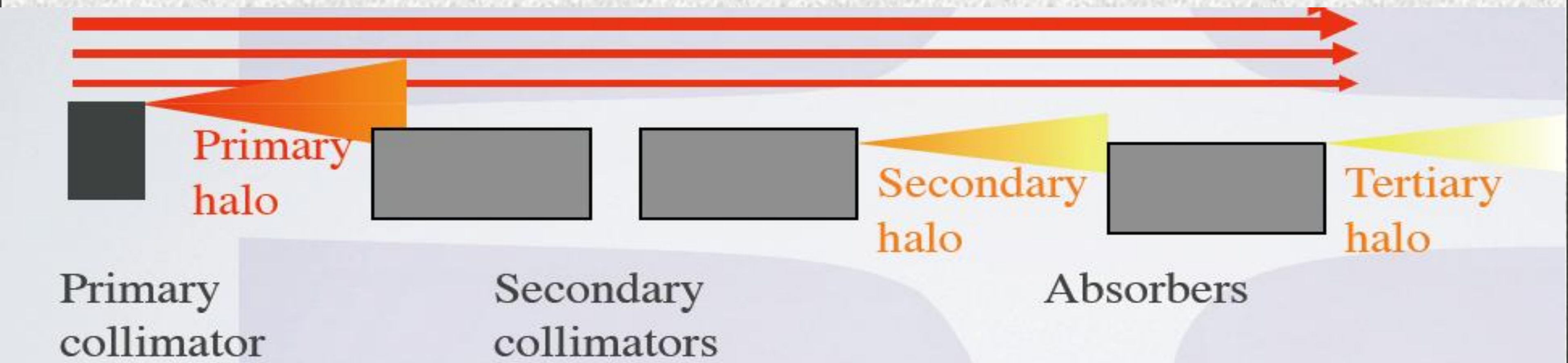
It simply means to start the hadronic/electromagnetic shower earlier and let particles diverge on the way to a downstream massive absorber. One can make the impact parameter on secondary collimators a factor of up to 1000 larger than on primary ones.

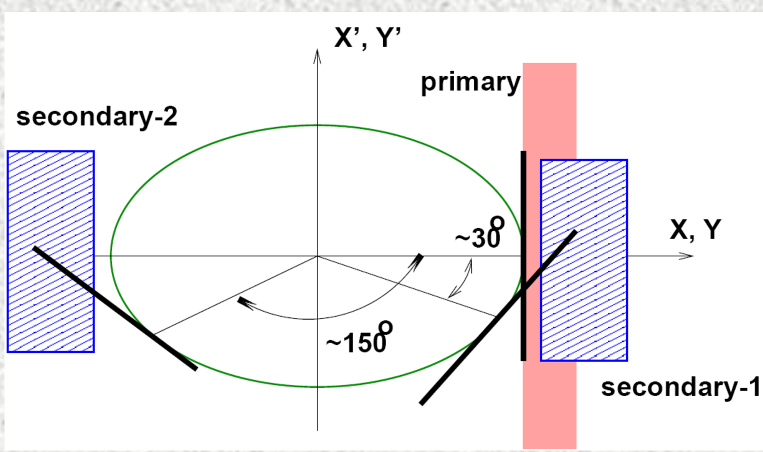
TWO-STAGE BEAM COLLIMATION (2)

This results in a significant increase of the collimation efficiency: substantially lower backgrounds on detectors, beam loss in the lattice, and jaw overheating as well as easier collimator alignment. With such a system, there are only several significant but totally controllable restrictions of the machine aperture, with appropriate radiation shielding in these regions.

MULTI-STAGE COLLIMATION

A common approach is a two-stage system in which a primary collimator is used to increase the betatron oscillation amplitudes of halo particles, thereby increasing their impact parameters on secondary collimators.

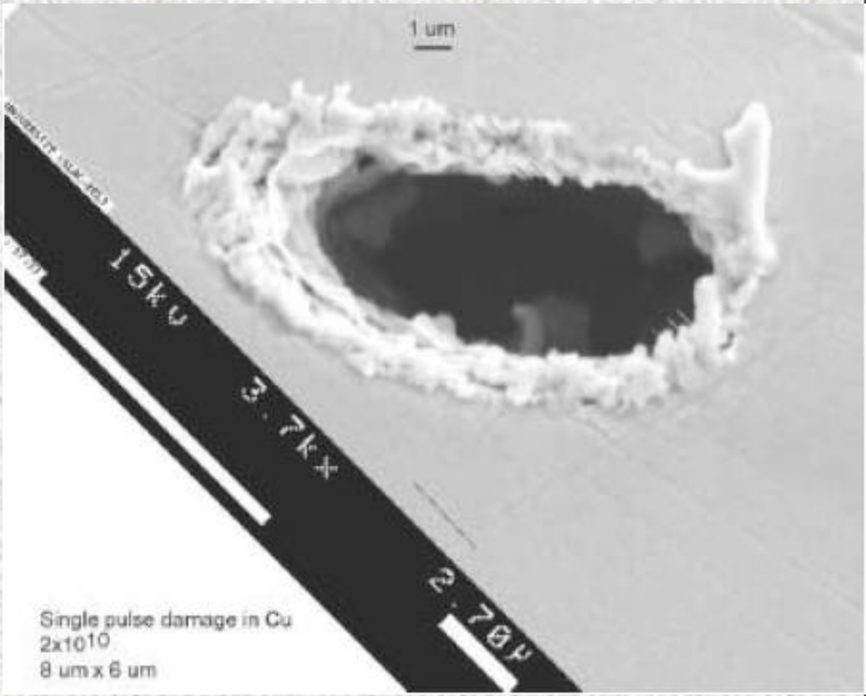




Secondary collimators – horizontal and vertical – located at appropriate phase advances, 1 σ farther from beam axis than the primaries, aligned parallel to beam envelope.

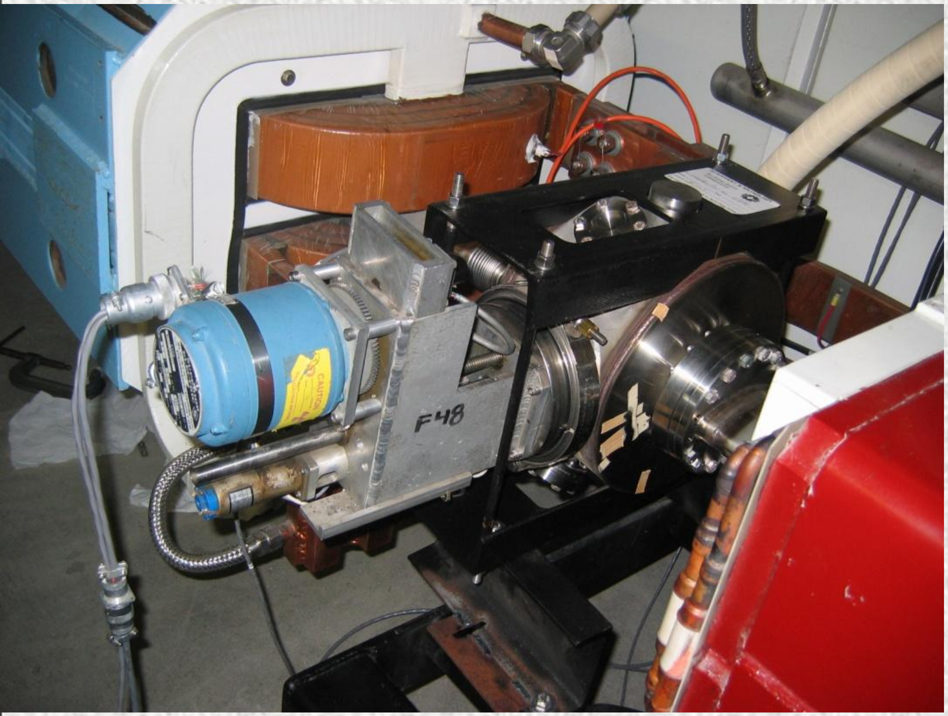
MACHINE PROTECTION & COLLIMATOR DESIGN

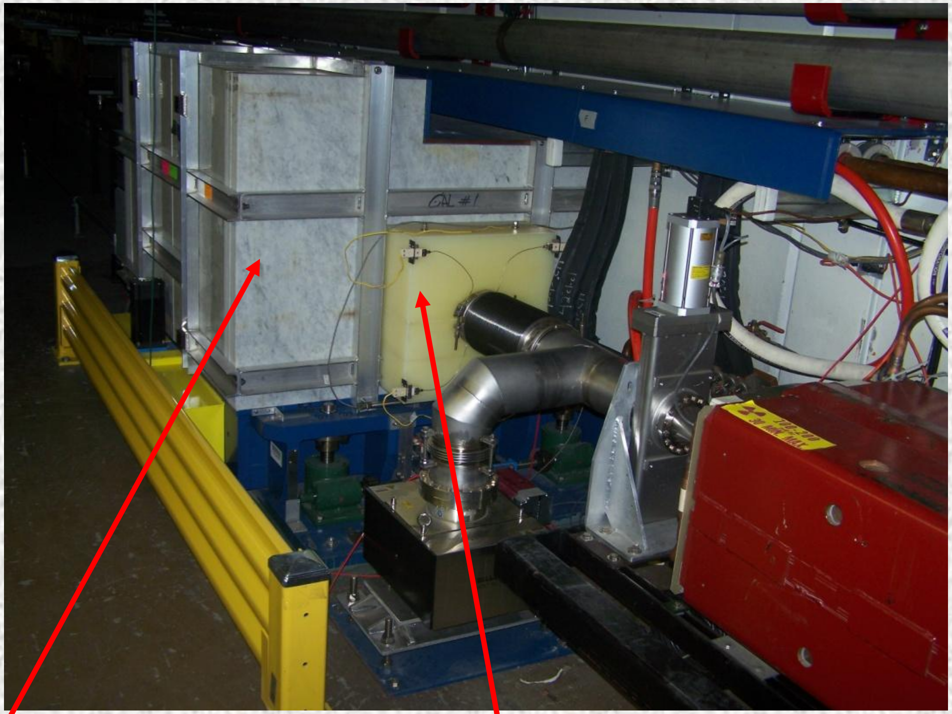
- The beam is very small => single bunch can punch a hole => the need for MPS (machine protection system)
- Damage may be due to
  - electromagnetic shower damage (need several radiation lengths to develop)
  - direct ionization loss (~1.5MeV/g/cm^2 for most materials)
- Mitigation of collimator damage
  - using spoiler-absorber pairs
    - thin (0.5-1 X_0) spoiler followed by thick (~20-30 X_0) absorber
  - increase of beam size at spoilers
  - MPS diverts the beam to emergency extraction as soon as possible



Picture from beam damage experiment at FFTB. The beam was 30GeV, 3-20x10^9 e-, 1mm bunch length, s~45-200um^2. Test sample is Cu, 1.4mm thick. Damage was observed for densities > 7x10^{14}e-/cm^2. Picture is for 6x10^{15}e-/cm^2

MI Primary and Secondary Collimators





0.25-mm tungsten primary collimator MI230

20-ton secondary collimator: 4"x2" aperture, precise radial and vertical motion

Marble shell

Poly mask

MI Steel/Concrete/Marble Masks and Wall

Steel/Concrete mask
to capture outscatter
and neutrons

Steel/Marble mask
to protect downstream
magnets

Concrete wall at 304
to reduce neutrons
on ECOOL

Operational Monitoring of MI Collimation Efficiency

BLM readings (rad/cycle), note three-decade log scale

Loss Time	
Injection end	
Uncaptured	
Later	

94.7% of injected beam accelerated to extraction

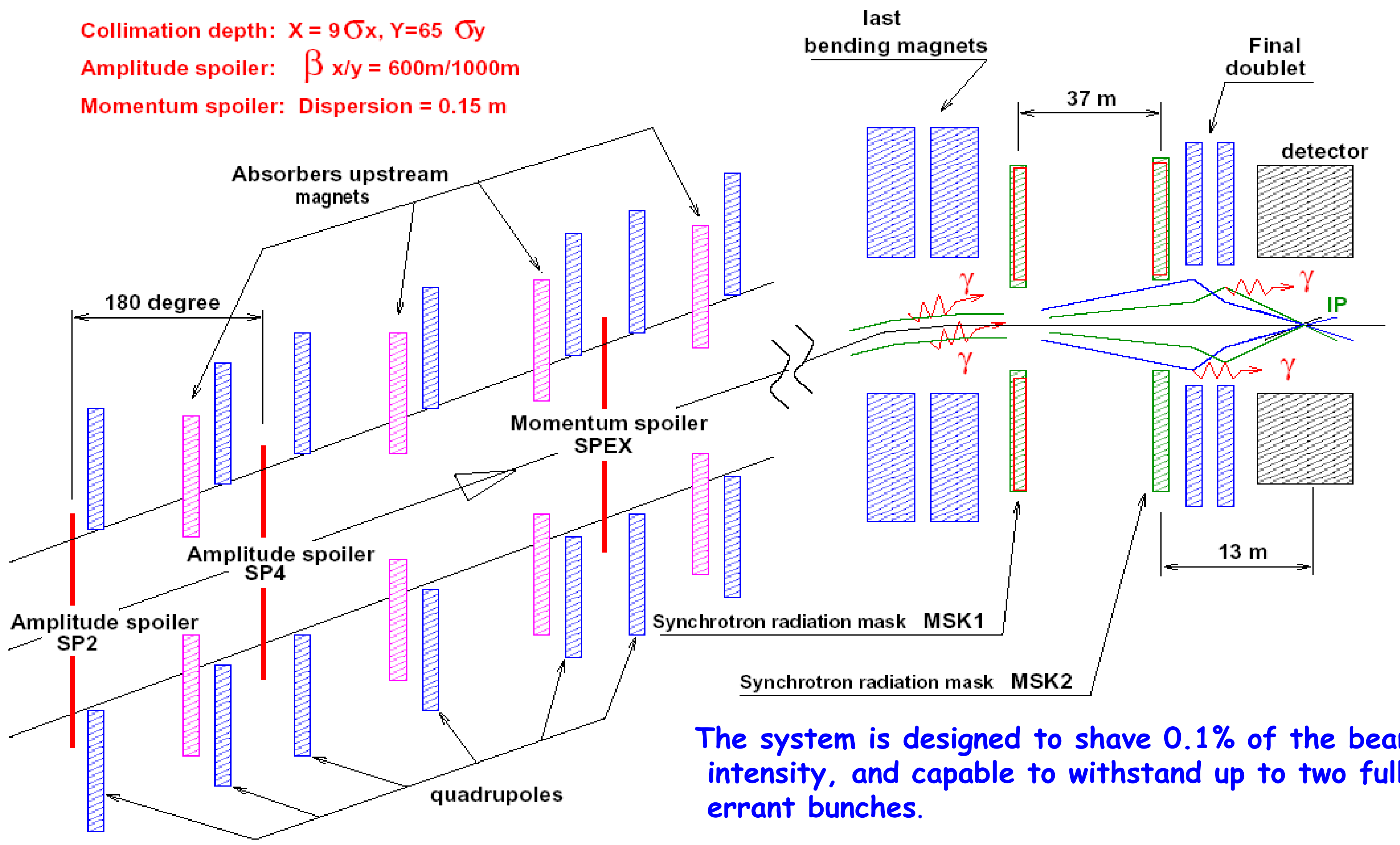
93% of uncaptured beam loss is kept in collimation region plus a few % lost immediately dwnstrm

It is now 99% !

Collider Specifics: e^+e^-

ILC

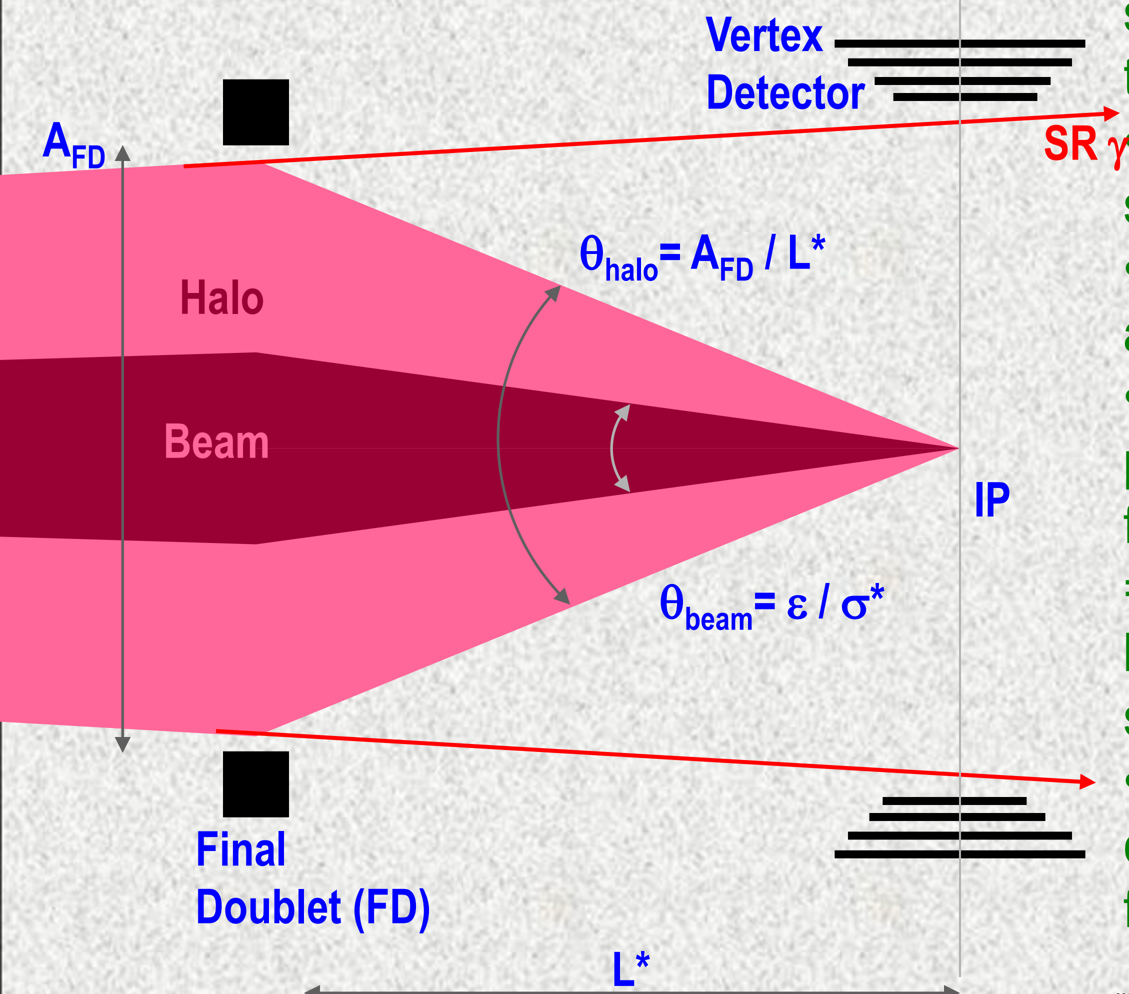
ILC BDS COLLIMATION SYSTEM



The system is designed to shave 0.1% of the beam intensity, and capable to withstand up to two full errant bunches.

BEAM HALO & COLLIMATION (1)

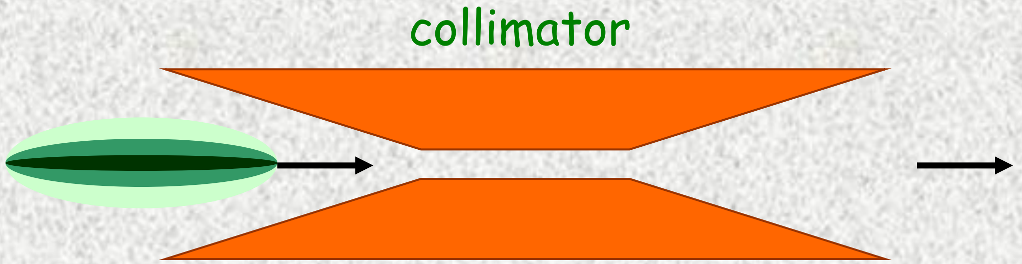
Even if final focus does not generate beam halo itself, the halo may come from upstream and need to be collimated

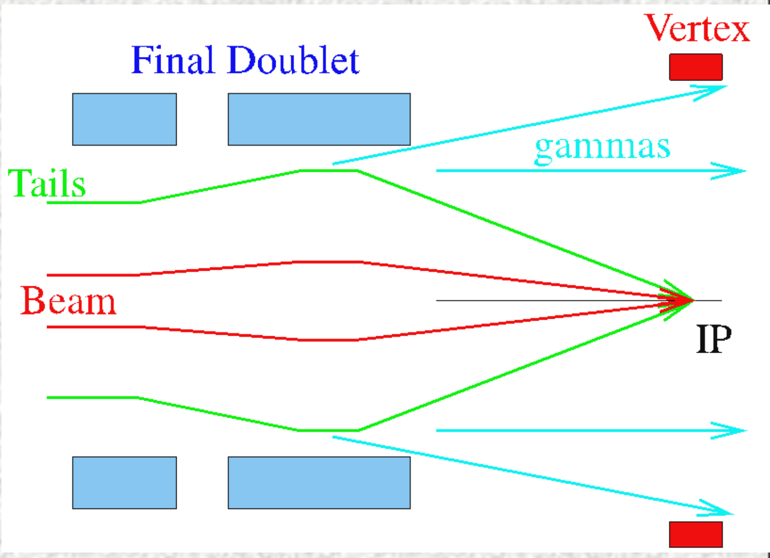


- Halo must be collimated upstream in such a way that SR γ & halo e^{+-} do not touch VX and FD
- => VX aperture needs to be somewhat larger than FD aperture
- Exit aperture is larger than FD or VX aperture
- Beam convergence depends on parameters, the halo convergence is fixed for given geometry
  => $\theta_{halo}/\theta_{beam}$ (collimation depth) becomes tighter with larger L^* or smaller IP beam size
- Tighter collimation => MPS issues, collimation wake-fields, higher muon flux from collimators, etc.

BEAM HALO & COLLIMATION (2)

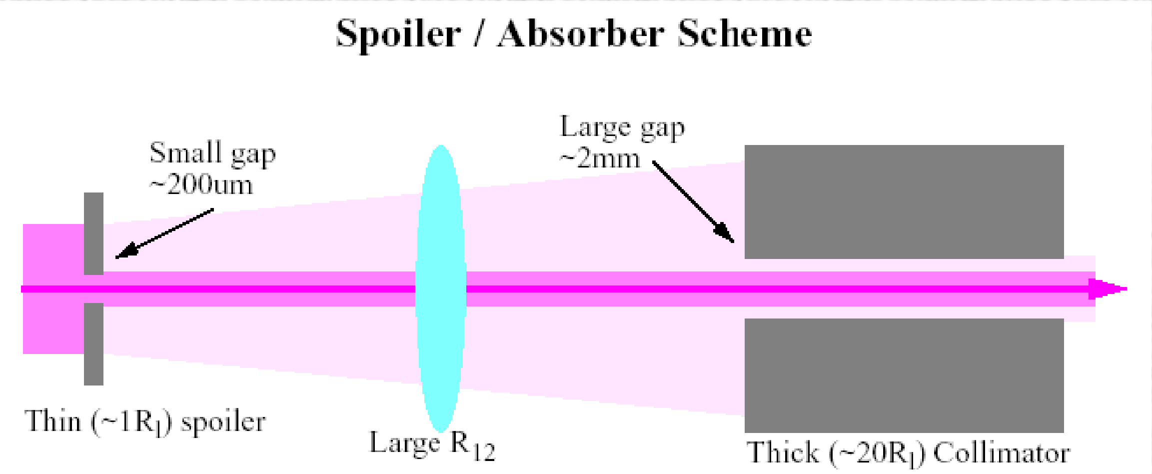
- Collimators have to be placed far from IP, to minimize background
- Ratio of beam/halo size at FD and collimator (placed in "FD phase") remains



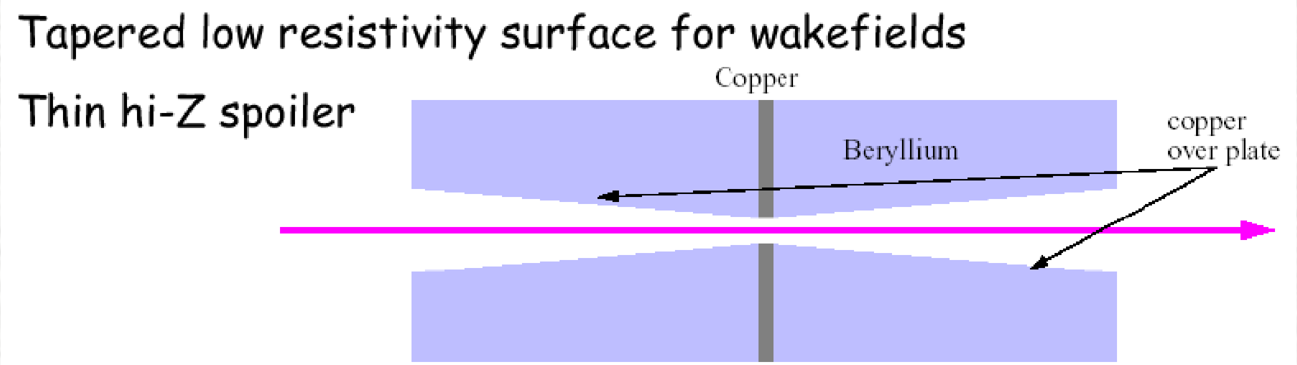


- Collimation depth (esp. in x) can be only ~10 or even less
- It is not unlikely that not only halo (1e-3 – 1e-6 of the beam) but full errant bunch(s) would hit the collimator

SPOILER-ABSORBER & SPOLIER DESIGN

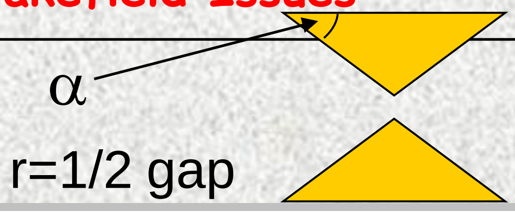
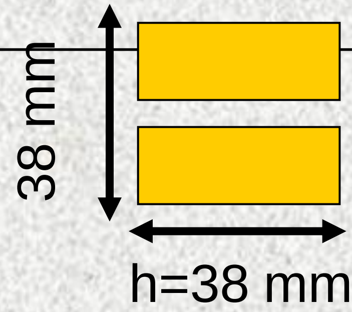
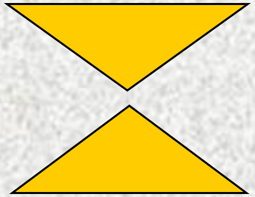
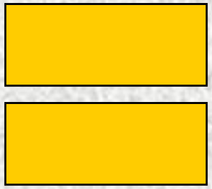
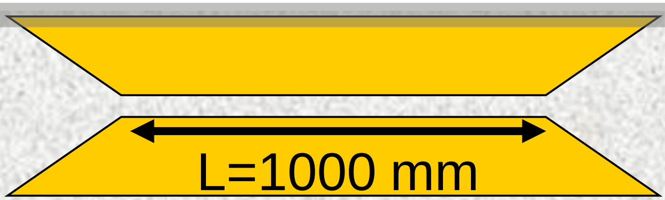
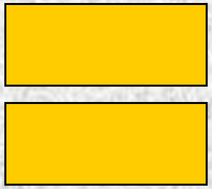
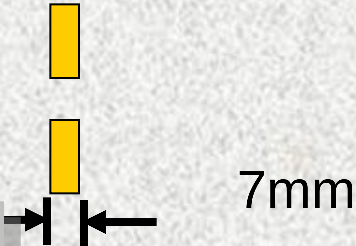
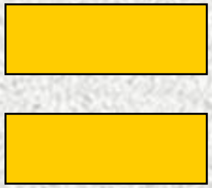


Thin spoiler increases beam divergence and size at the thick absorber already sufficiently large. Absorber is away from the beam and contributes much less to wakefields.



Need the spoiler thickness increase rapidly, but need that surface to increase gradually, to minimize wakefields. The radiation length for Cu X_0=1.43cm and for Be is X_0=35cm. So, Be is invisible to beam in terms of losses. Thin one micron coating over Be provides smooth surface for wakes.

Wakefield Issues

Collim.	Side view	Beam view	
1	 α, r=1/2 gap	 38 mm, h=38 mm	α=324mrad r=2.0mm
2			α=324mrad r=1.4mm
3	 L=1000 mm		α=324mrad r=1.4mm
4	 7mm		$\alpha=\pi/2$rad r=4.0mm

As per last set in Sector 2, commissioning

Extend last set, smaller r, resistive WF in Cu

cf. same r, tapered

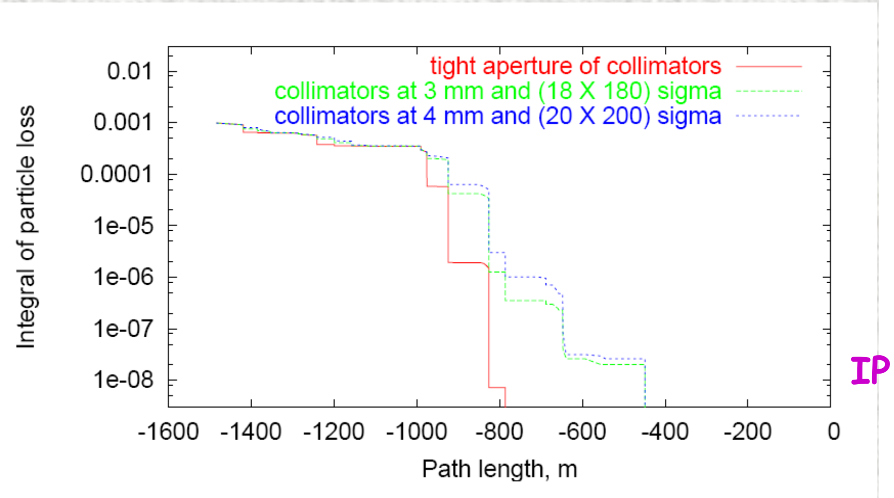
BDS COLLIMATION SYSTEM PARAMETERS

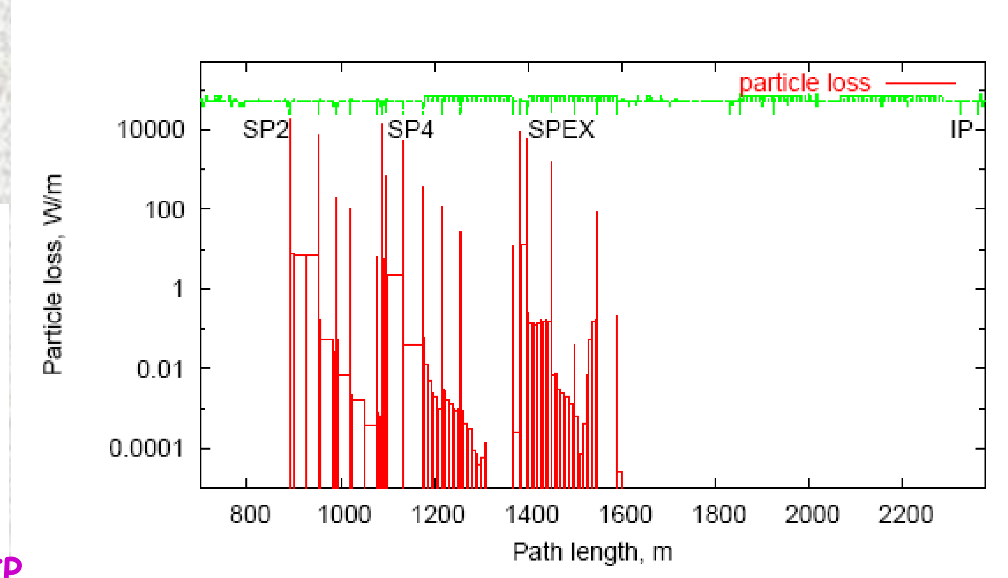
1. Betatron spoilers SP1,SP2 & SP4 in high-beta region at 1582, 1483 and 1286 m from IP, respectively, 0.6 X_0 thick (0.6cm Cu), positioned at $8\sigma_x$ and $65\sigma_y$.
2. Momentum spoiler SPEX in high-dispersion region at 990 m from IP, 1 X_0 thick (3.56cm Ti), at $8\sigma_x$ and $65\sigma_y$.

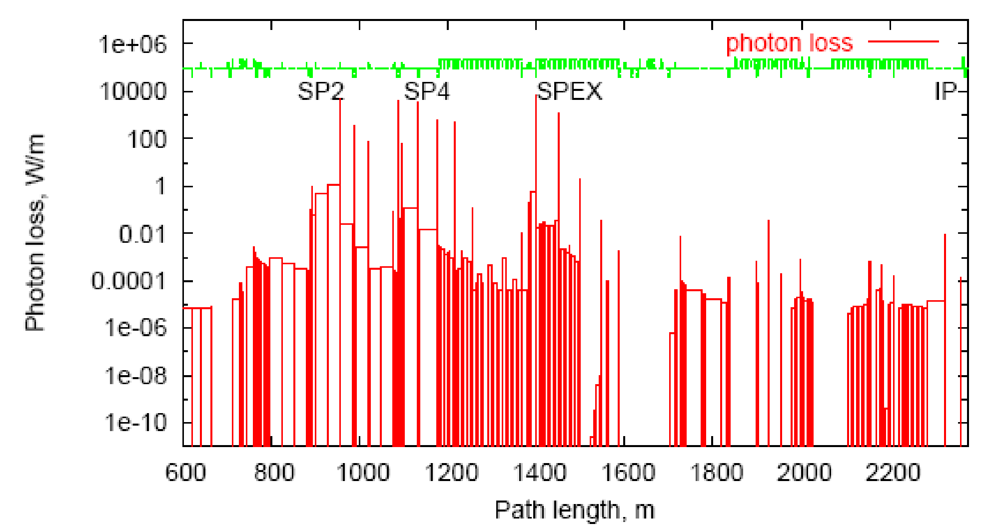
3. Absorbers (secondary collimators) AB1-AB5, at 1500 to 1200 m, 30 X_0 thick (43cm Cu), and ABE, AB7, AB9 & AB10, at 826 to 450 m, 30 X_0 (10.5cm W).
4. Protection collimators PC1-PC11, at 1420 to 785 m, 15 X_0 thick (21.45cm Cu); (it seems they need to be increased to 25-30 X_0).
5. Synchrotron radiation masks MSK1, MSK2, at 50 and 13 m, 30 X_0 thick (10.5cm W).

Last three types are positioned far from the beam at > $16\sigma_x$ and > $150\sigma_y$.

COLLIMATION EFFICIENCY AND BEAM LOSS







Collimation efficiency defined here as a fractional loss of halo charged particles, integrated back starting the IP and normalized to the nominal bunch charge

Collimator Material Damage

- All the possible heat deposition sources guide to instant temperature rise which can be solved by integration of the specific heat equation.
- Heat transfer equation can be solved separately then to get real time dependant temperature distribution between bunches.
- For metals we need to use all the parameters with real dependency of temperature.
- The results of analytical models need to be compared with simulations. ANSYS simulation can be really useful here as it can include phase transformations or melting and possible cracks of material.

Thin Spoiler Material Damage

- Ionization (approximations used for analytical study)
- Main source of heating – ionization with possible correction factor due to electromagnetic shower (1.4 - 2.5)
- Additional information needed for thick structures but not critical for $L<1X_0$ one can apply 2D models
- One can assume instant temperature rise due to a short bunch length in comparison with the heat diffusion
- Then one can get the temperature rise per bunch by integration

$$N_b \frac{dE}{dz} = \int_{T_0}^{T} c_v(T)\,dT \qquad c_v(T) = \frac{9 N_A k_b \rho}{A} \left(\frac{T}{\Theta_d} \right)^2 \int_0^{\Theta_d / T} dx \frac{x^4 e^x}{(e^x - 1)^2}$$

Thin Spoiler Material Damage: heat transfer and limits

Heat transfer should be solved using

$$K(T) = \frac{\pi^2}{2}\left(\frac{k_b}{e}\right)^2 \sigma T \qquad \frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} = \frac{\rho c}{K}\frac{\partial T}{\partial t}$$

Temperature rise limits:

- Temperature should be far enough from melting
- Induced thermal stress should be far enough from leading to cracks and damage. The stress limit is based on tensile strength, modulus of elasticity and coefficient of thermal expansion. Sudden T rise create local stresses. When DT exceeds stress limit, micro-fractures can develop.

$$\sigma_{uts} > \frac{\alpha E \Delta T}{2} \qquad T < T_{melt}$$

Use as an upper limit min{T_{melt}, T_{strees}} (see next page).

Thin Spoiler Damage: simple example

Simple case: thin, no EMS buildup, specific heat is const

$$\Delta T = 1/(\pi\sigma_x\sigma_y) \times (dE/dx)/C_p \times 1.6\times10^{-13} \times 2\times10^{10} \times N_b$$

Spoiler material properties and temperature rise due to a <u>single bunch</u> of 1.25 x 10^{10} electrons within a beam spot with $\sigma_x = \sigma_y = 3.16$ μm.

	Be	C	Al	Ti	Cu	Fe
Radiation Length (cm)	35.7	21.7	9.0	3.7	1.4	1.8
dE/dx_{min} (MeV cm^{-1})	3.1	3.6	4.4	7.2	12.8	11.6
Specific Heat, C_p (J cm^{-3} °C^{-1})	3.3	1.9	2.5	2.4	3.5	3.8
Meltng Point, T_{melt} (°C)	1280	3600	660	1800	1080	1530
Stress Limit, T_{stress} (°C)	150	2500	140	770	180	135
Temperature Rise, ΔT (°C)	2350	4740	4403	7506	9150	7637
$\Delta T / T_{melt}$	1.8	1.3	6.7	4.2	8.5	5.0
$\Delta T / 4T_{stress}$	3.9	0.36	7.9	2.4	12.7	14.1

Direct Hits on Titanium-Alloy Spoilers

Maximum ΔT/ 2×10^{10} bunch at the Hit Location, °C/bunch

Steering Condition	250 GeV Beam Size (μ) σ_x σ_y	Max. Temperature (°C/b) 500 GeV CM	1 TeV CM	Comments
Hit consumable 0.6 rl Ti Betatron spoiler (SP2,4)	28 6	1380	2770	1st bunch fractures or melts Ti alloy
Hit survivable 0.6 rl Ti Betatron spoiler (SP2,4)	111 9	290	560	Survive two bunches at 500 GeV, one bunch at 1 TeV CM
Hit survivable 1.0 rl Ti Energy spoiler (SPE) $\Delta E/E$ = 0.06/0.03 %	104 15 (58 11)	260	720	
Hit AB3 (30 cm copper)	20 1.4	25,000	~60,000	Hopefully very rare occurrence

1. **Ti–6Al–4V alloy – fracture 770 ºC, melt 1800 ºC**
2. **Copper – melt 1080 ºC**

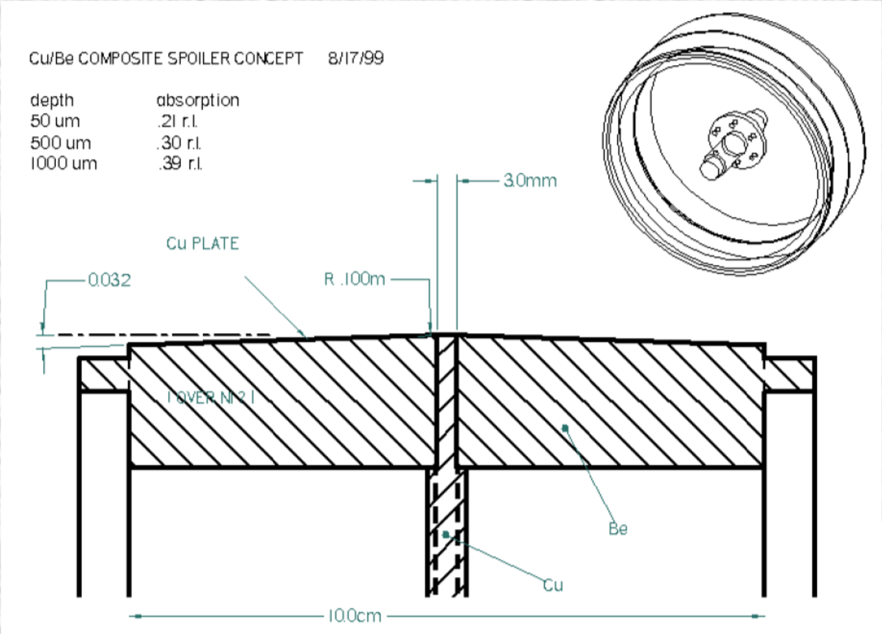
Survivable and Consumable Spoilers

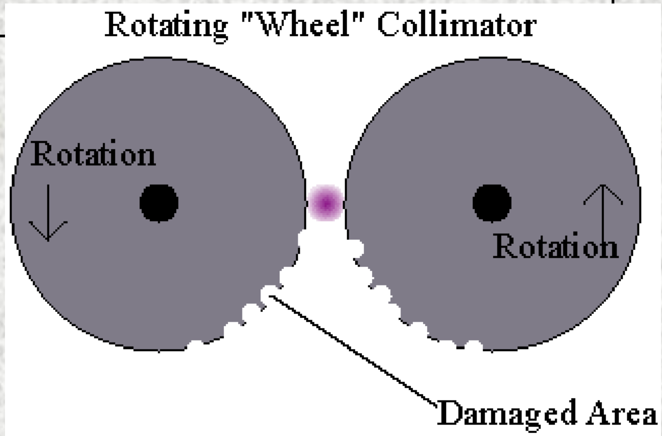
A critical parameter is number of bunches #N that MPS will let through to the spoiler before sending the rest of the train to emergency extraction

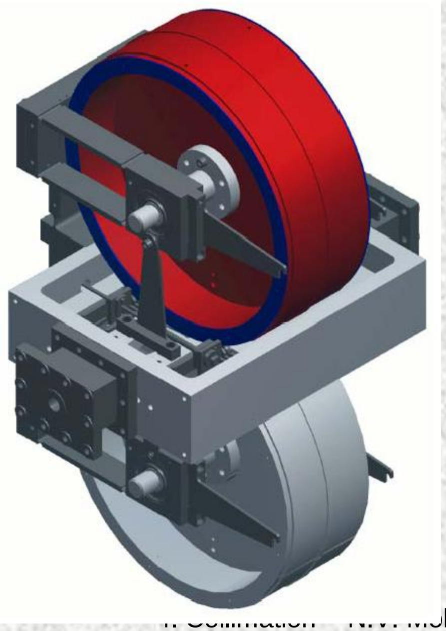
If it is practical to increase the beam size at spoilers so that spoilers survive #N bunches, then they are survivable

Otherwise, spoilers must be consumable or renewable

Renewable Spoilers





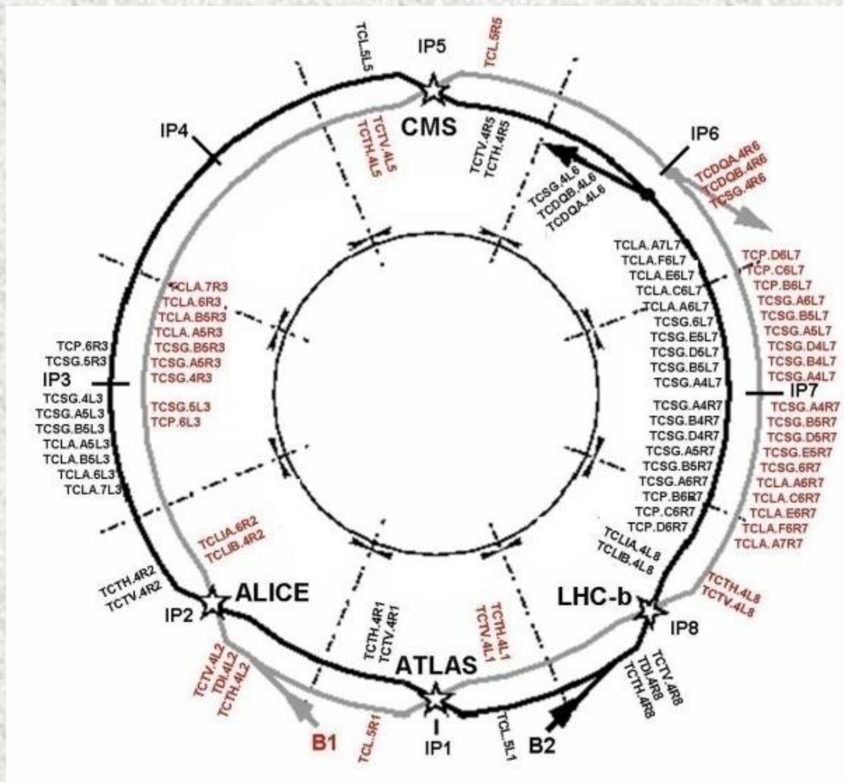


This design was essential for NLC.

This concept is now being applied to LHC collimation.

Specifics: Hadron Colliders

LHC



COLLIMATION AT LHC: 0.5 MW to 5 TW

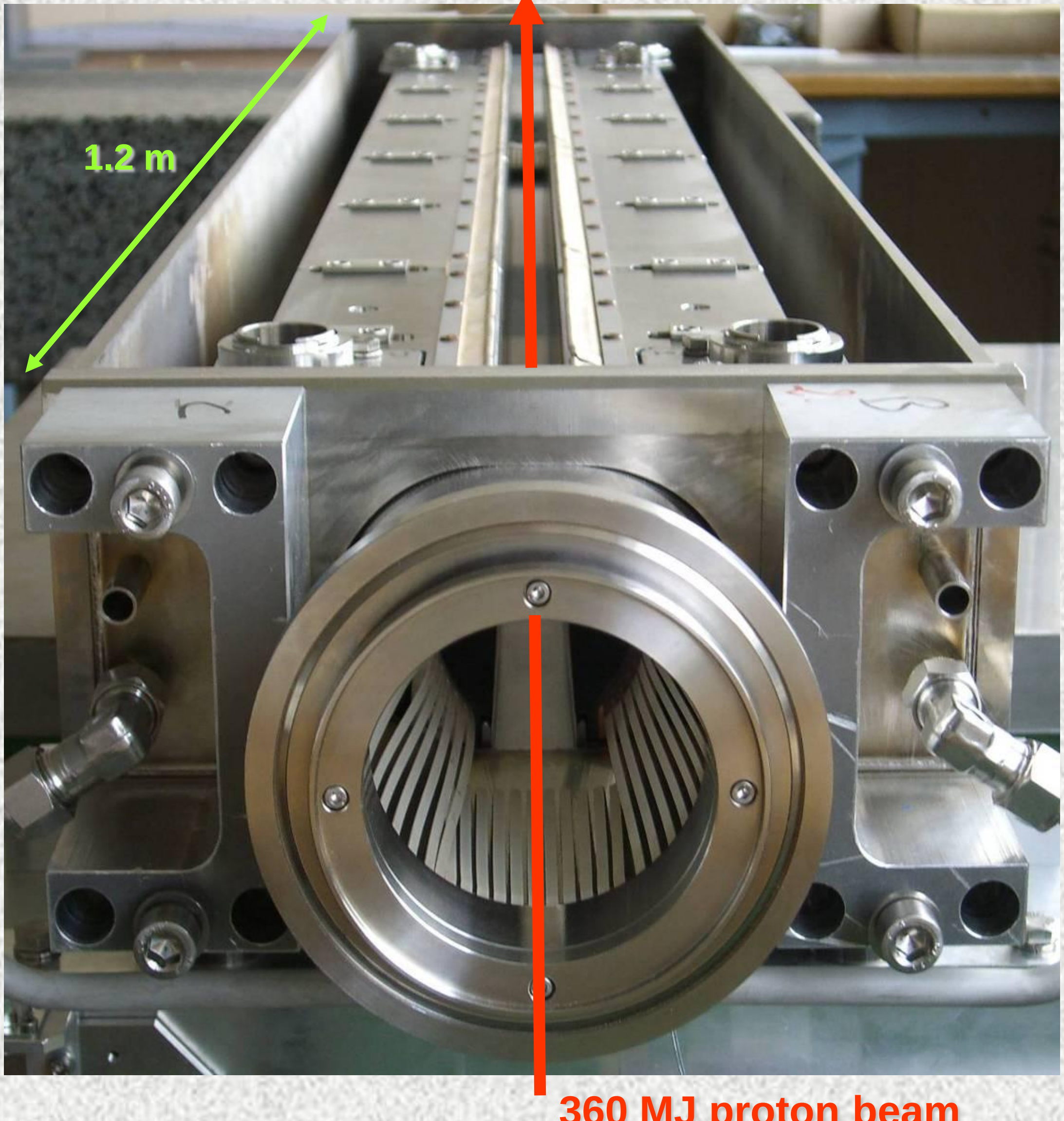
Collimators are the LHC defense against unavoidable losses:

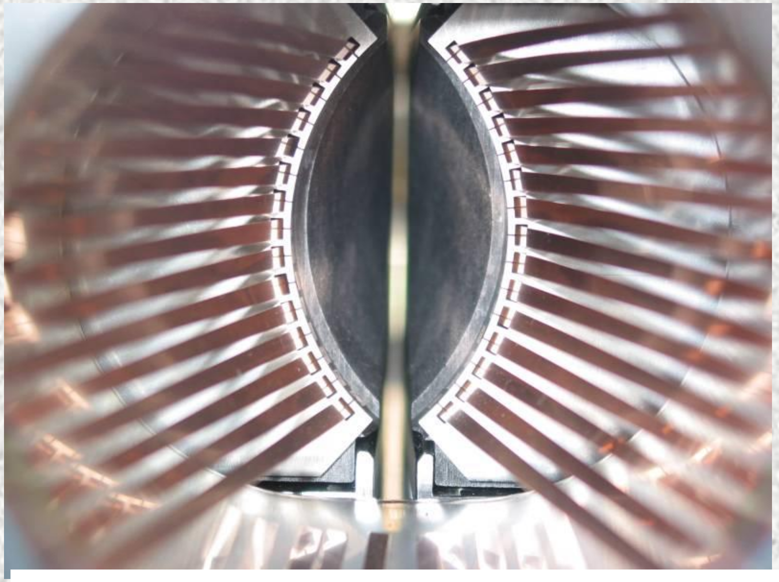
- Irregular fast losses and failures: Passive protection.
- Slow losses: Cleaning and absorption of losses in super-conducting environment.
- Radiation: Managed by collimators.
- Particle physics background: Minimized.

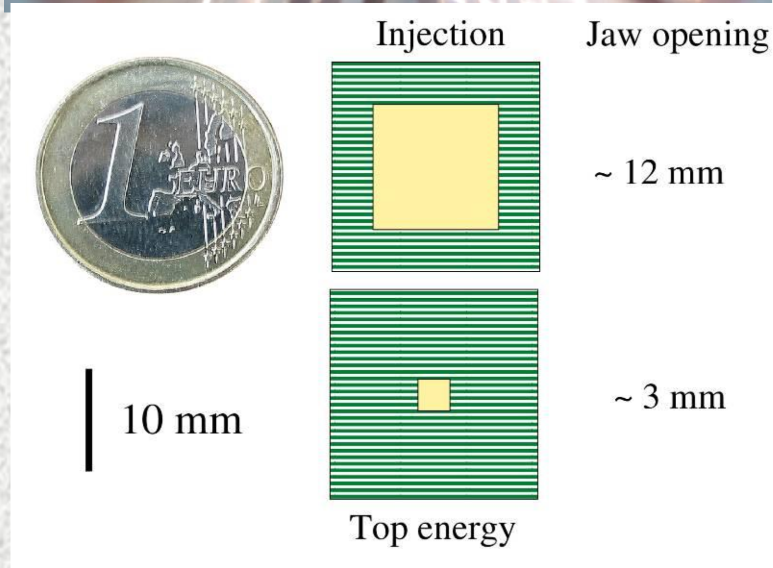
Specified 7 TeV peak beam losses (maximum allowed loss):

Slow:	0.1% of beam per s for 10 s	**0.5 MW**
Transient:	5×10^{-5} of beam in ~10 turns (~1 ms)	**20 MW**
Accidental:	up to 1 MJ in 200 ns into 0.2 mm^2	**5 TW**

LHC Phase I Collimator

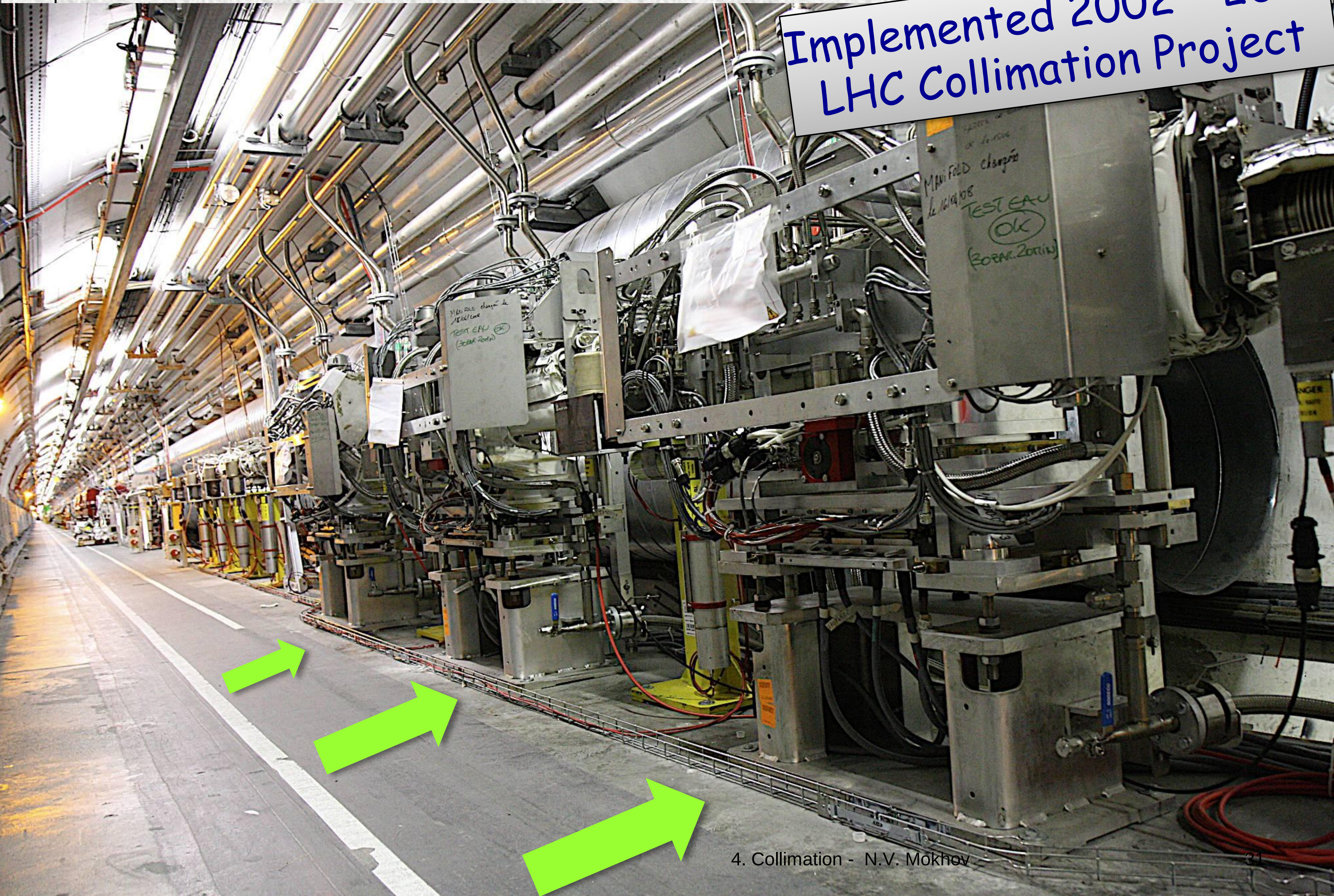




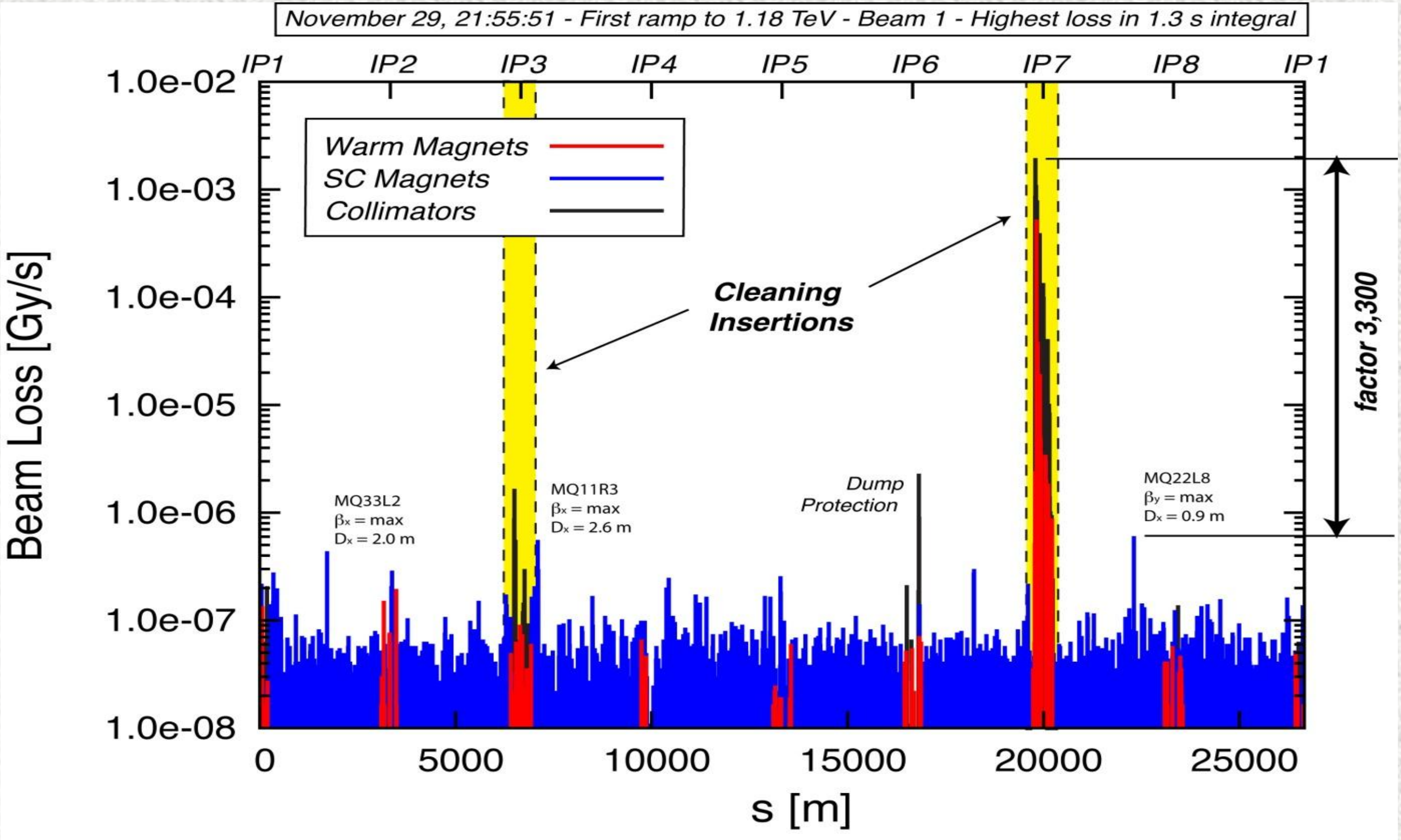


LHC Tunnel: Primary Betatron Collimators

Implemented 2002 - 2009
LHC Collimation Project

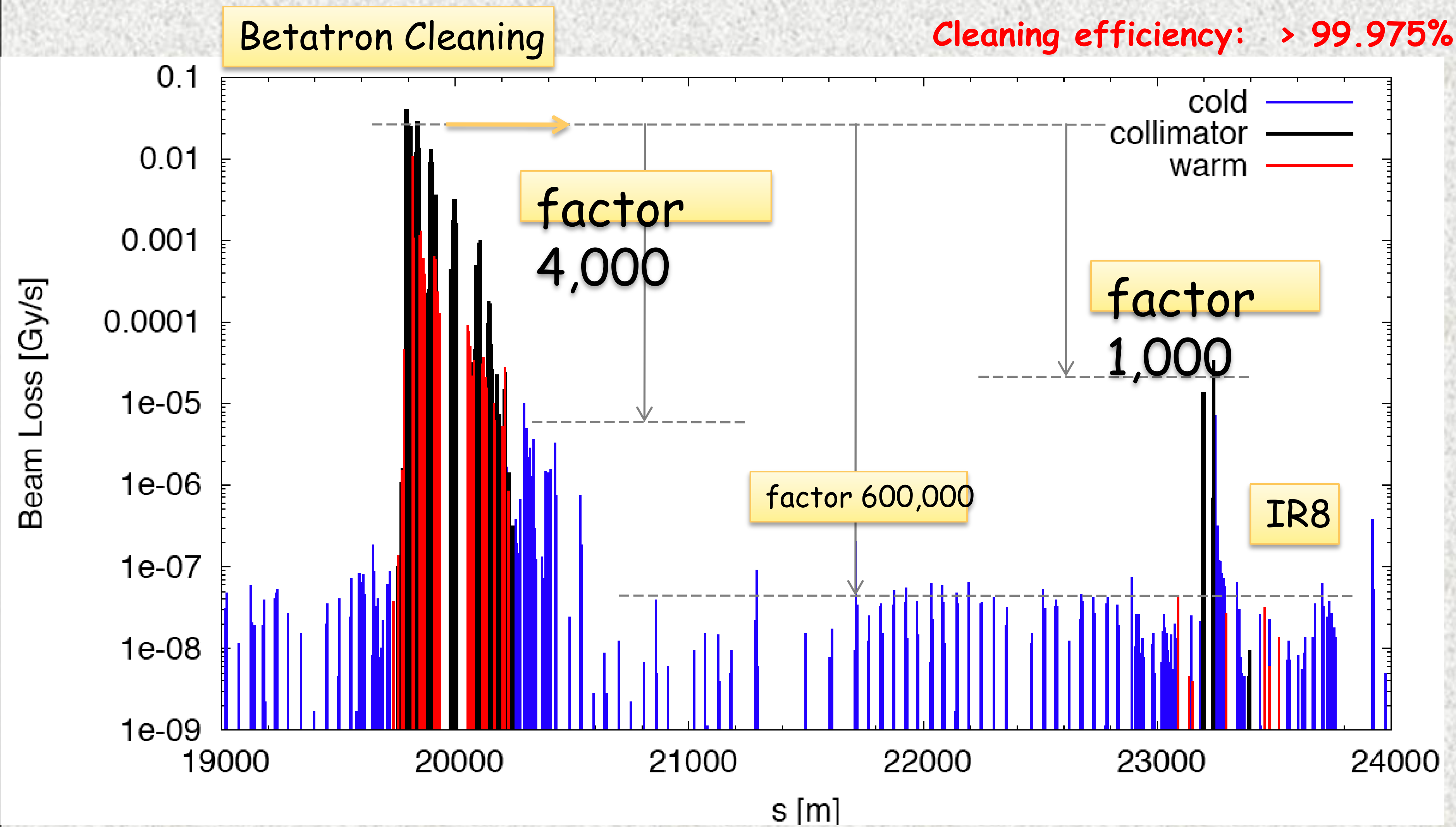


LHC Collimation Performance: First Run at 1.18 TeV



LHC: ε > 99.9% Tevatron: ε ~ 99.9%

LHC: Measured Cleaning at 3.5 TeV



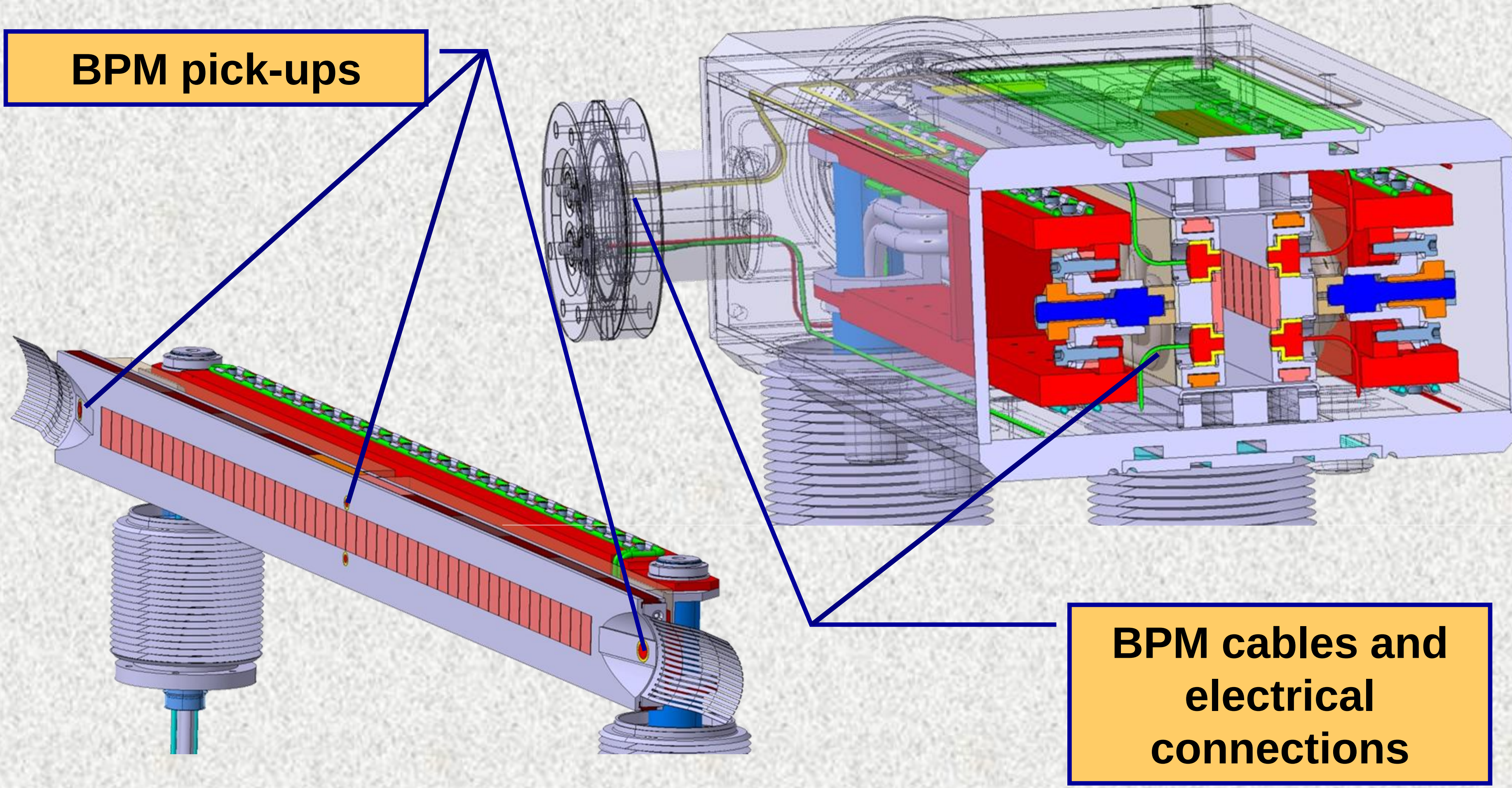
Beam1, vertical beam loss, intermediate settings

PHASE II ADVANCED SECONDARY COLLIMATORS

- Replace CCF secondary collimators with shorter ones (low electrical resistivity, good absorption, flatness, cooling, radiation): copper-based, ceramics or advanced composites.
- Reduction in impedance.
- Non-invasive and fast collimator setup with BPM buttons in jaw.
- Improvement of lifetime for warm magnets and remaining Phase I collimators in cleaning insertions.
- Rotatable collimators for handling damages in-situ.
- Supported construction of TT60 beam test area **HiRadMat**. 2 MJ pulsed beam at ~450 GeV from SPS for accident scenario tests.

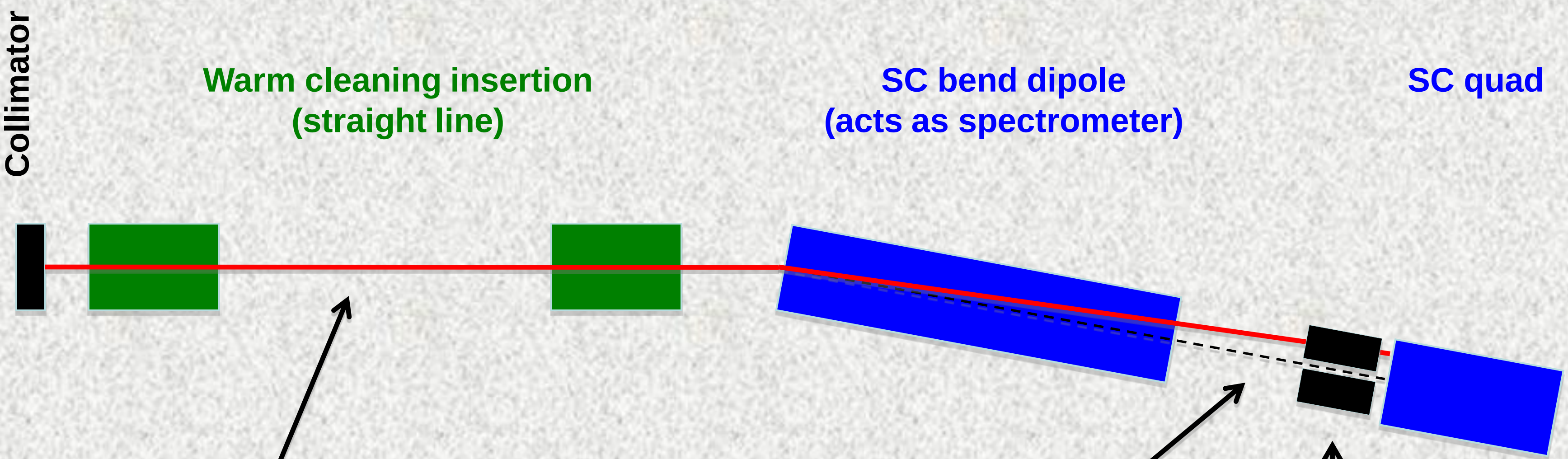
INTEGRATED BPM BUTTONS

Integration of BPMs into the jaw assembly gives a clear advantage for set-up time → Prototyping started at CERN



R. Assmann, CERN

CRYO COLLIMATORS IN DS



Off-momentum particles generated by particle-matter interaction in collimators (SD scattering)

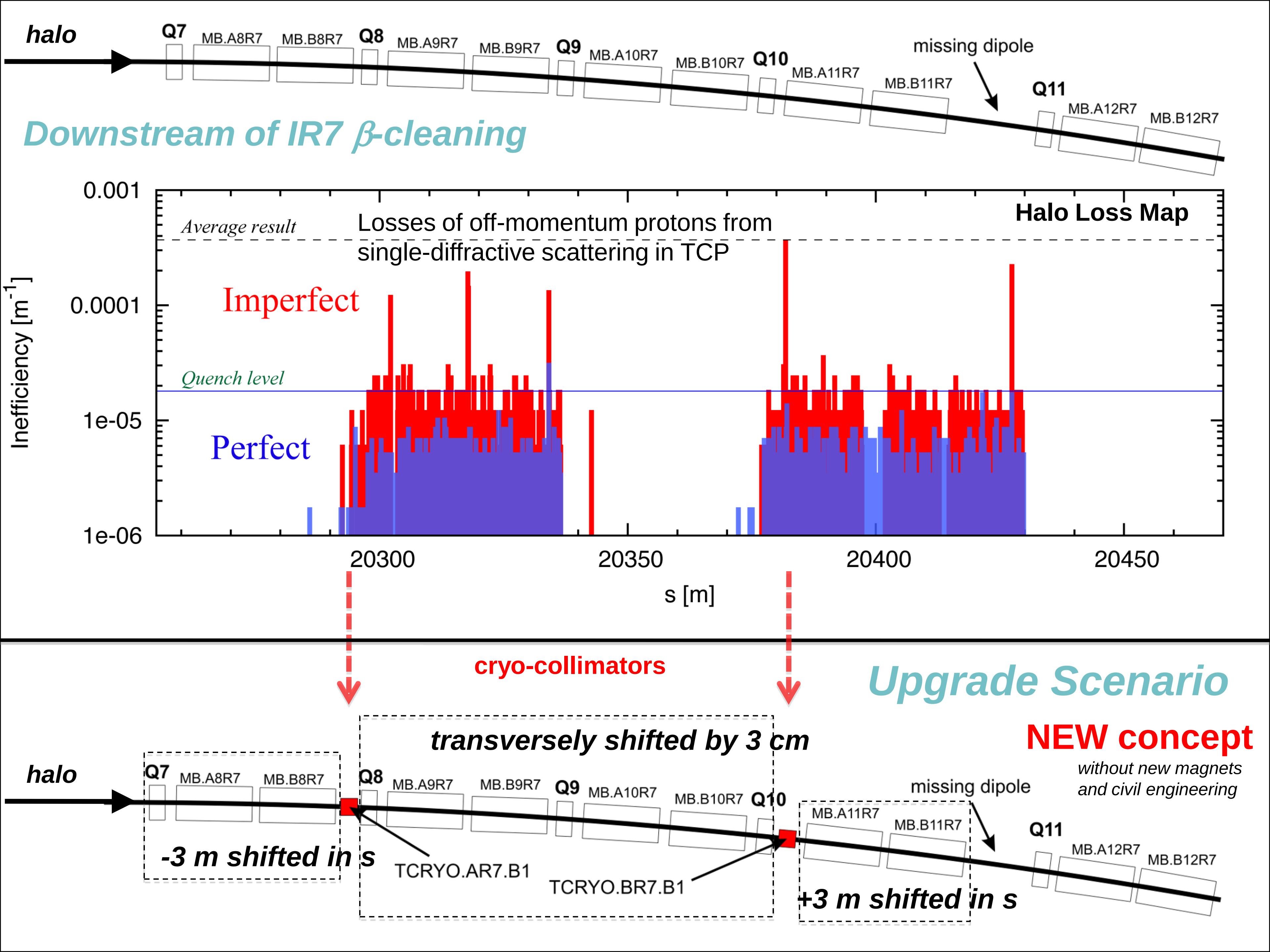
Ideal orbit (on momentum)

+ metallic phase 2 collimators in IR3 and IR7

Add cryogenic collimator, using space left by missing dipole (moving magnets)

Cleaning efficiency improvement by a factor of 15 to 90

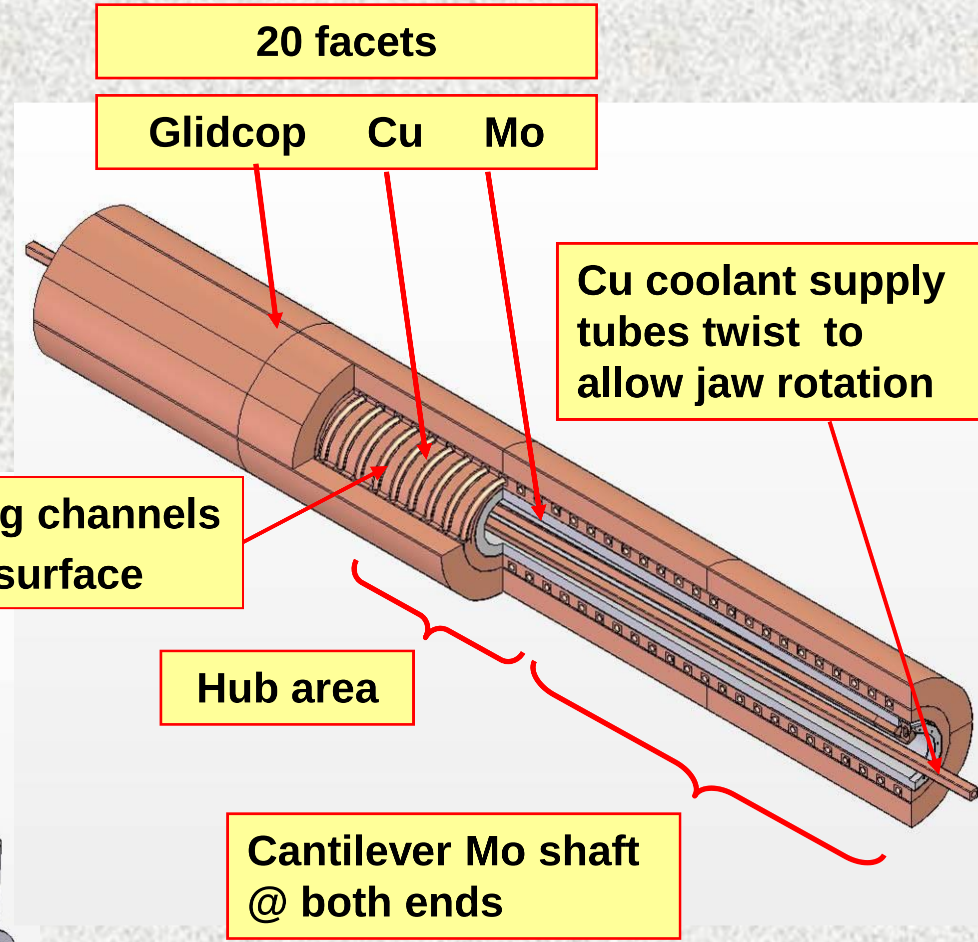
R. Assmann, CERN

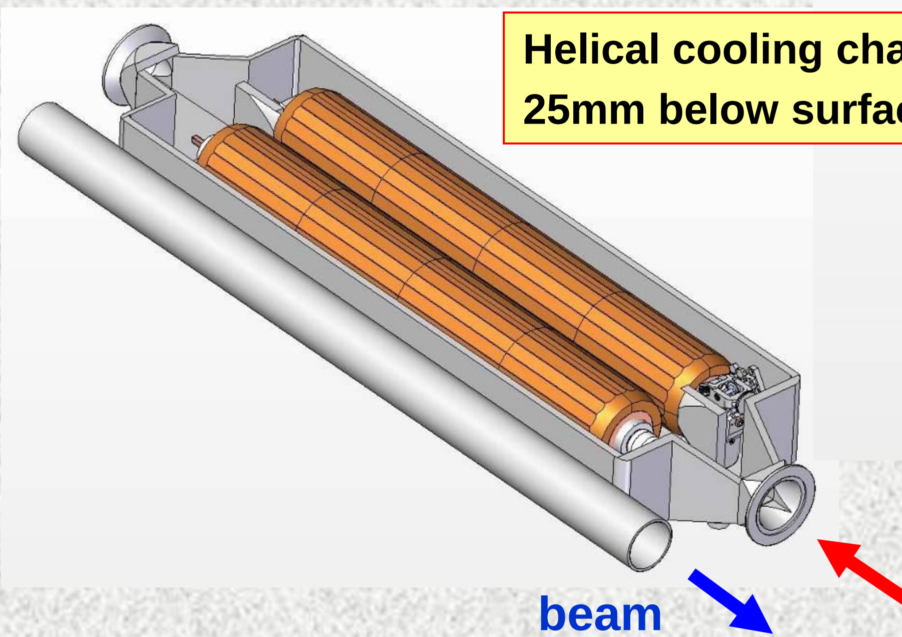


halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
MB.A11R7
MB.B11R7
missing dipole
Q11
MB.A12R7
MB.B12R7
Downstream of IR7 β-cleaning
Halo Loss Map
Average result
Losses of off-momentum protons from single-diffractive scattering in TCP
Imperfect
Perfect
Quench level
Inefficiency [m^-1]
0.001
0.0001
1e-05
1e-06
20300
20350
20400
20450
s [m]
cryo-collimators
Upgrade Scenario
NEW concept
without new magnets and civil engineering
transversely shifted by 3 cm
halo
Q7
MB.A8R7
MB.B8R7
Q8
MB.A9R7
MB.B9R7
Q9
MB.A10R7
MB.B10R7
Q10
missing dipole
MB.A11R7
MB.B11R7
Q11
MB.A12R7
MB.B12R7
-3 m shifted in s
TCRYO.AR7.B1
TCRYO.BR7.B1
+3 m shifted in s

ROTATABLE COLLIMATORS (SLAC)

- **beam spacing: geometrical constraint**
- **Length available 1.47 m flange - flange**
- **Jaw translation mechanism and collimator support base: LHC Phase I**
- **>10 kW per jaw Steady State heat dissipation (material dependent)**





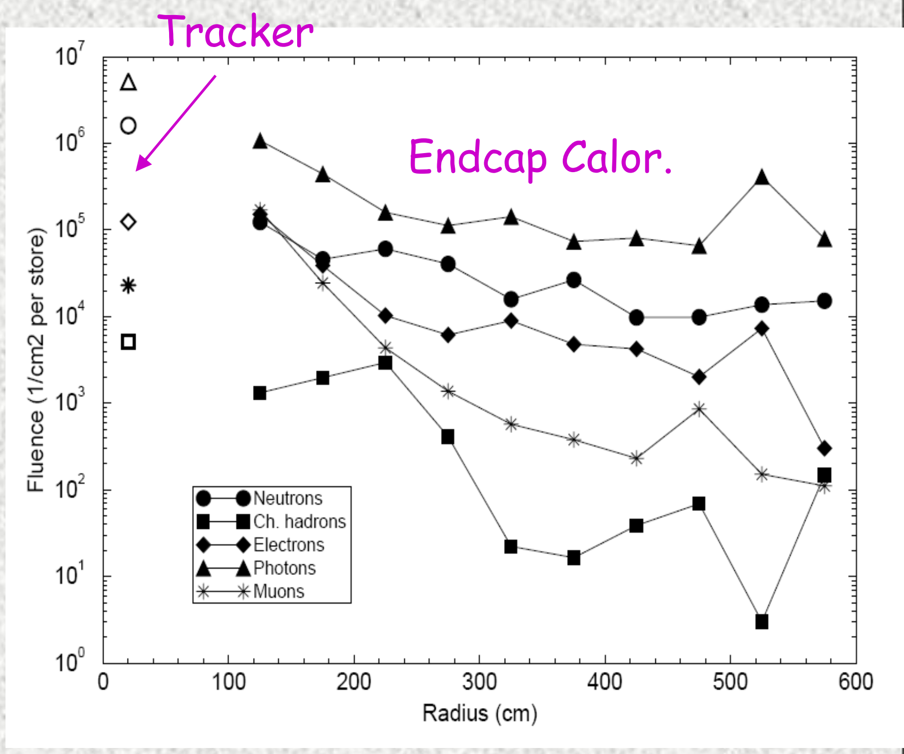
Specifics: Muon Colliders

$$\mu^+\mu^-$$

Muon Beam Halo

It was shown that detector backgrounds originating from beam halo can exceed those from decays in the vicinity of IP. Only with a dedicated beam cleaning system far enough from IP can one mitigate this problem.

Muons injected with large momentum errors or betatron oscillations will be lost within the first few turns. After that, with active scraping, the beam halo generated through beam-gas scattering, resonances and beam-beam interactions at the IP reaches equilibrium and beam losses remain constant throughout the rest of the cycle.



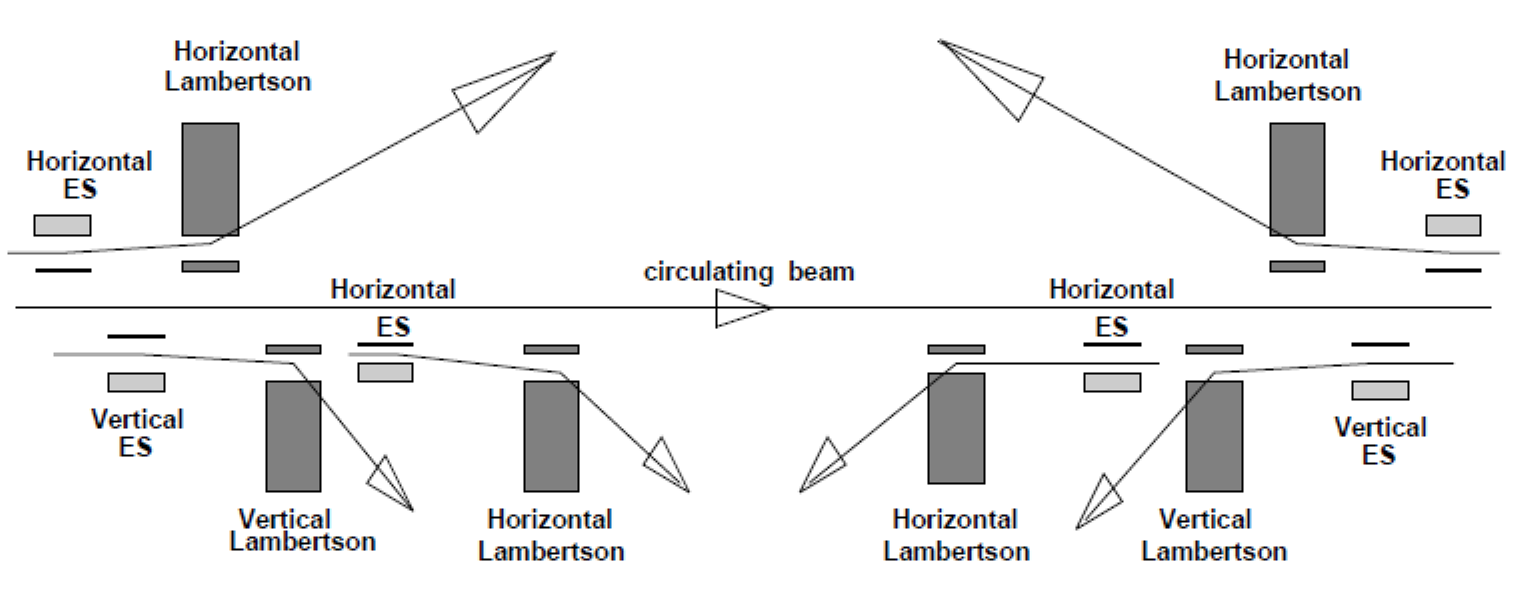
Particle fluxes in detector for 2-TeV beam halo loss (1% per store) at 200m from IP

DEALING WITH MUON BEAM HALO

- For TeV domain, extraction of beam halo with electrostatic deflector reduces loss rate in IR by three orders of magnitude; efficiency of an absorber-based system is much-much lower.

- For 50-GeV muon beam, a five meter long steel absorber does an excellent job, eliminating halo-induced backgrounds in detectors.

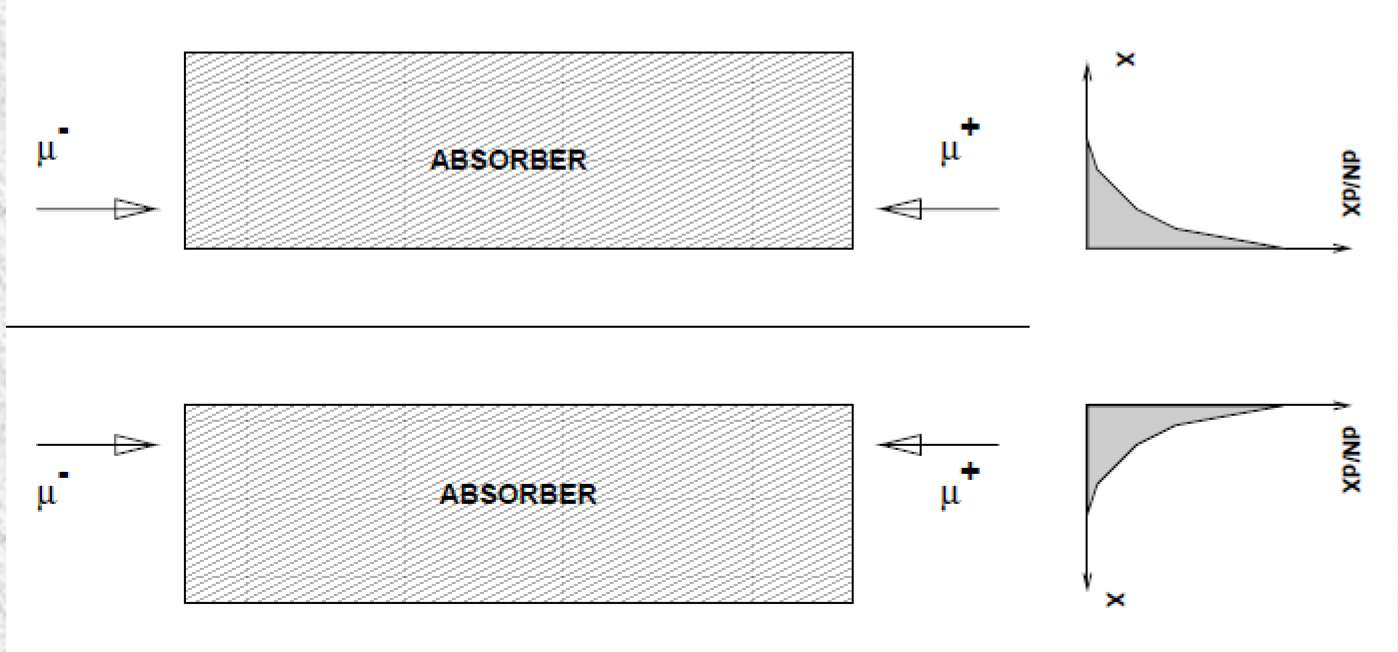
Muon Beam Halo Extraction



A 3-m long electrostatic deflector (Fig. 1) separates muons with amplitudes larger than 3σ and deflects them into a 3-m long Lambertson magnet, which extracts these downwards through a deflection of 17 mrad. A vertical septum magnet is used in the vertical scraping section instead of the Lambertson to keep the direction of extracted beam down. The shaving process lasts for the first few turns. To achieve practical distances and design apertures for the separator/Lambertson combinations, β-functions must reach a kilometer in the 2-TeV case, but only 100 m at 50 GeV. The complete system consists of a vertical scraping section and two horizontal ones for positive and negative momentum scraping (the design is symmetric about the center, so scraping is identical for both μ^+ and μ^-). Always, the halo is extracted down into the ground downstream of the utility section (US).

83% of halo is extracted over the first few turns, with ~8e8 μ's lost in IR, less (but not much) than losses over store from muon beam decays.

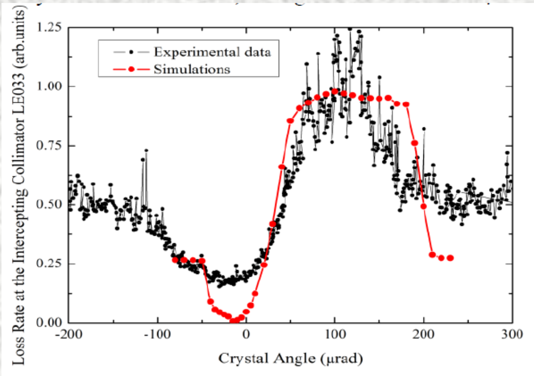
Muon Beam Halo Scraping



At 50-100 GeV, shaving muon halo with a 5-m long steel absorber in a simple compact straight section does an excellent job. Muons loose on average ~10% of their energy and get broad angular and spatial spreads. Therefore, almost all of them are lost in the first 50 m downstream, providing efficiency w.r.t. IR of > 99.9% and manageable dynamic heat load on lattice elements.

NOVEL COLLIMATION TECHNIQUES

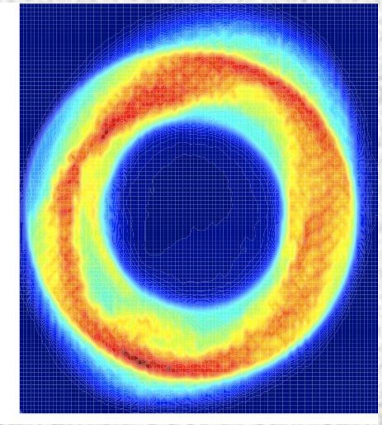
1. **Crystal collimation:** coherent deflection via channeling and multiple volume reflection of halo particles deep into a secondary collimator. Encouraging results at Tevatron and SPS



2. **e^+,e^- beam halo shaving via volume reflection radiation**

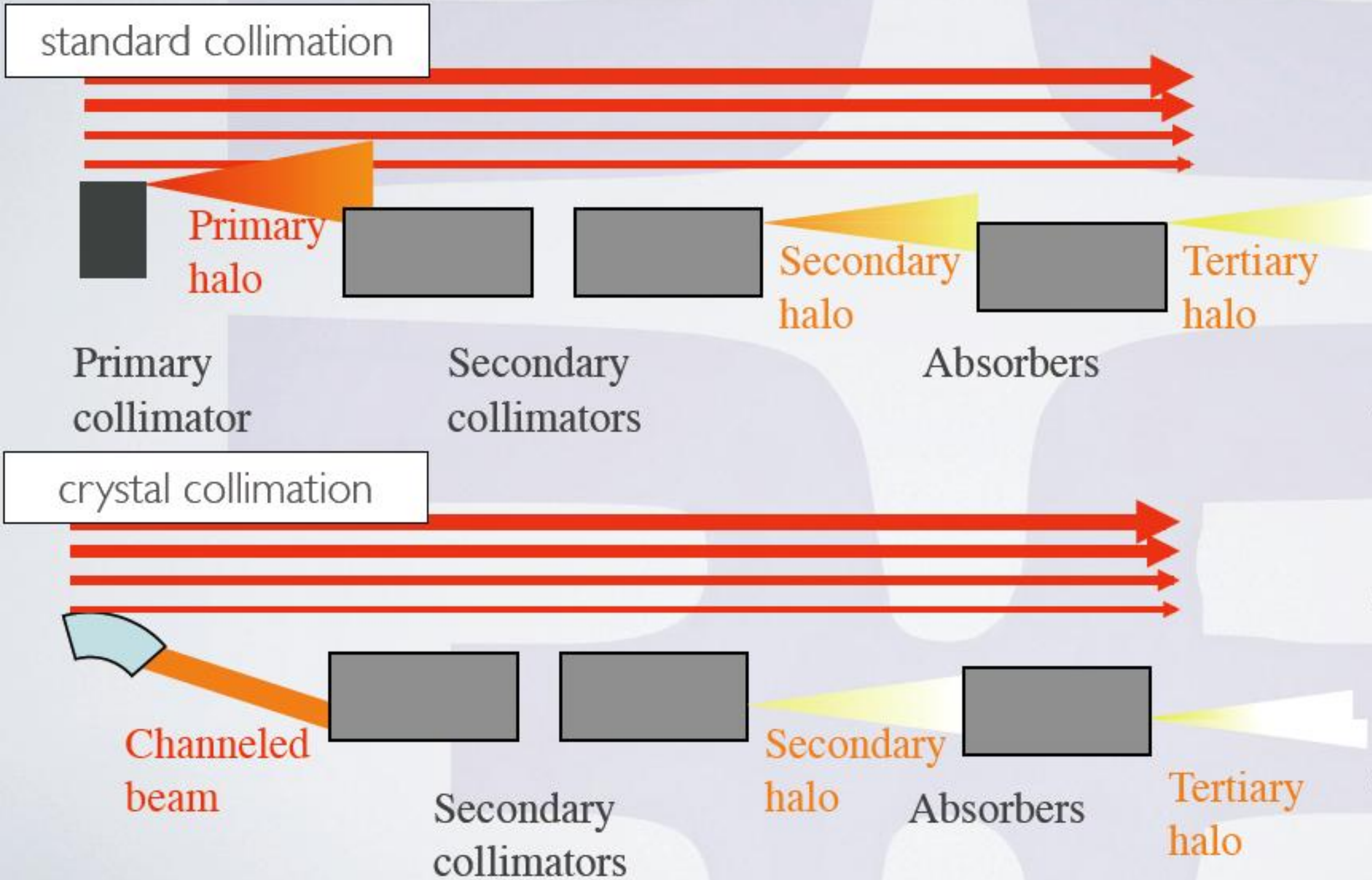
3. **Tail folding** technique

4. **Hollow electron beam** scraper



CRYSTAL COLLIMATION

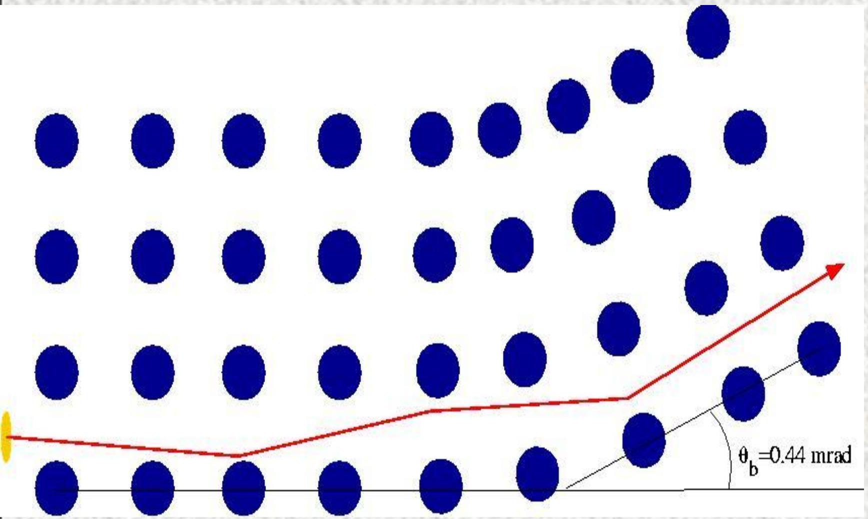
- Bent-crystal channeling is a technique with a potential to increase the beam-halo collimation efficiency at high-energy colliders.

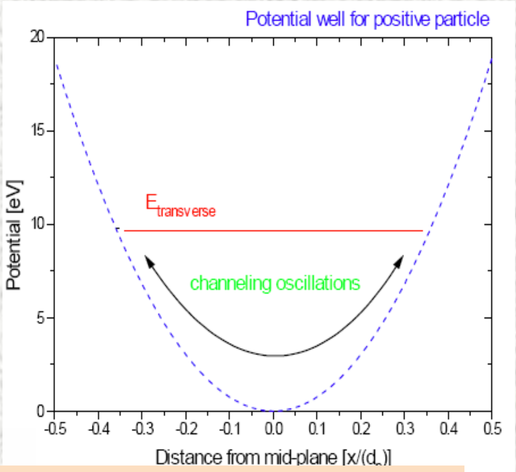


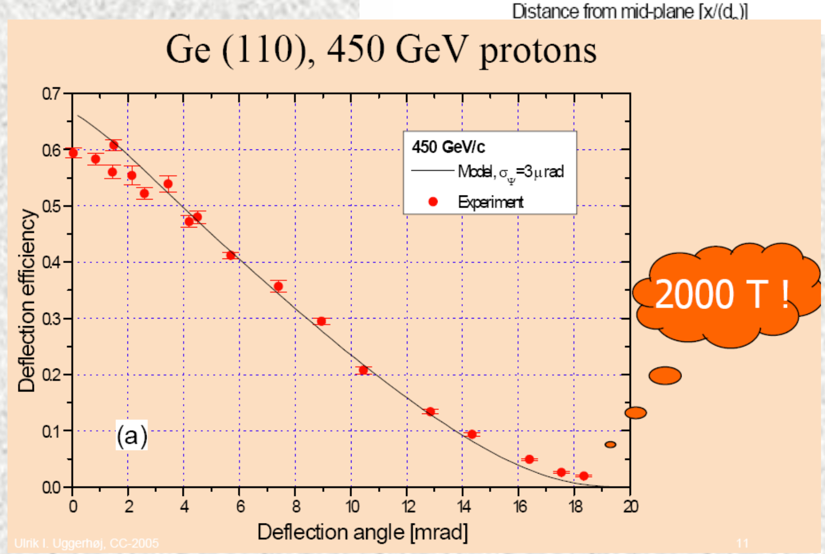
Use the crystal to drive the beam halo deep into a secondary collimator/absorber

- Coherent deviation of the primary halo
- Larger collimation efficiency
- Reduced tertiary halo

CRYSTAL CHANNELING



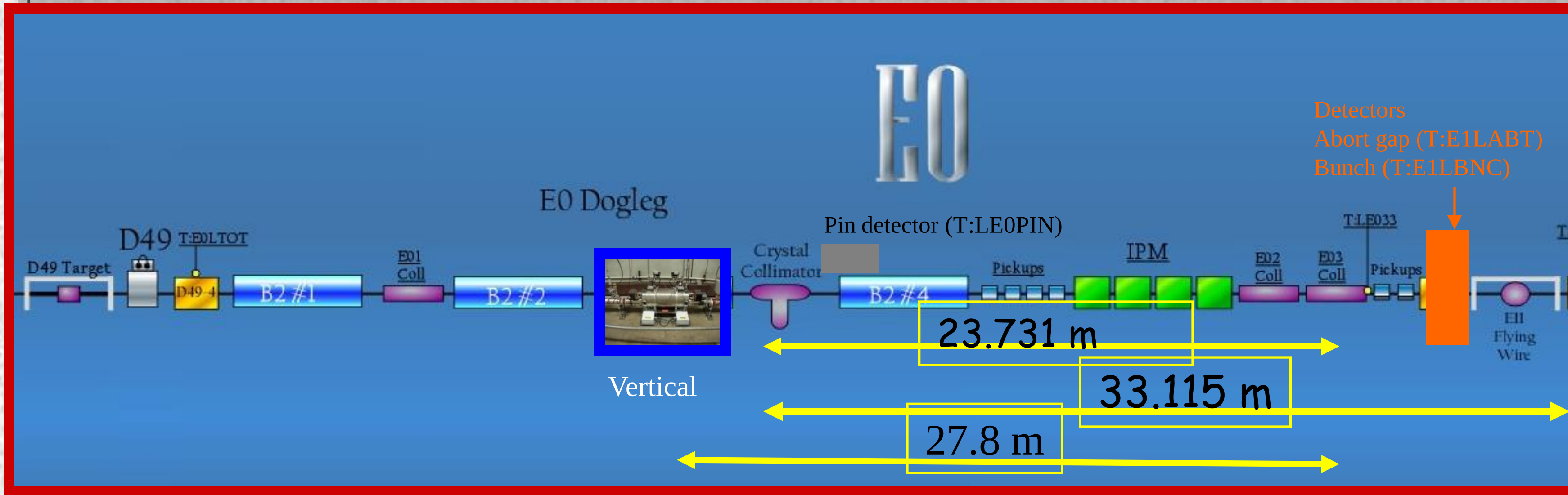




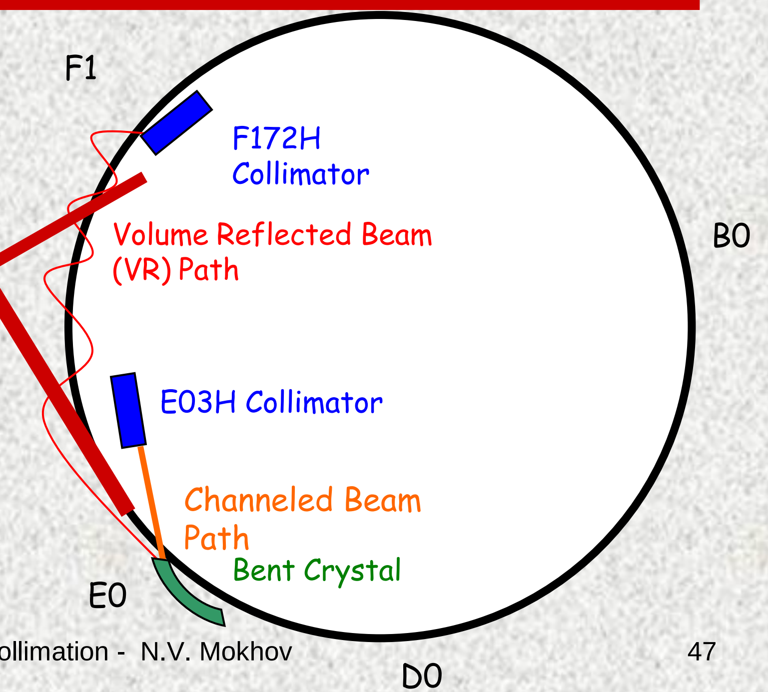
Extremely high interplanar electric fields from screened nuclei (a few GV/cm) allow to bend high-energy beams with very short crystals. Interplanar spacing ~ 2Å.

It was shown at CERN and IHEP that **crystals are heat- and radiation-resistant**. Deflection efficiency deteriorates at about 6%/10^{20} p/cm^2 rate

T980 Setup in Tevatron E0 for 2009-2011



Now able to use 1 or 2 xtals in beam, alternating them without breaking vacuum !



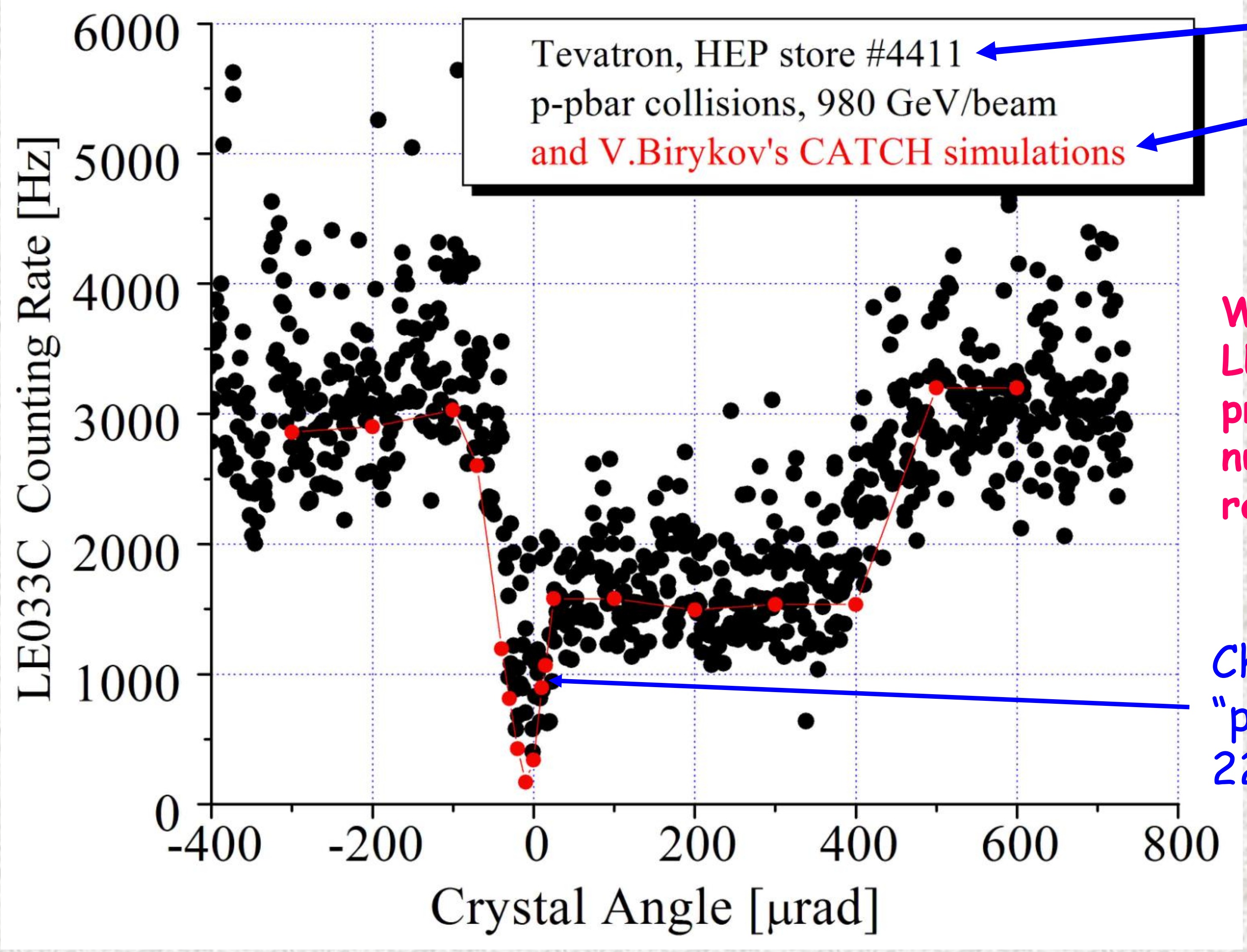
Goniometer Installations

Newly built and installed (Summer 2009) vertical goniometer at E0. It is ~ 4m upstream of the Horizontal one.

It houses (since June 2010) new QM and INFN multi-strip crystal (replacement to IHEP MS and old O-shaped crystals).

Modified horizontal goniometer. Replaced old large miscut positive angle O-shaped crystal with new small negative miscut angle O-shaped during Summer 2009.

980-GEV BEAM CHANNELING: DATA vs THEORY



Oct. 6, 2005
By Dean Still

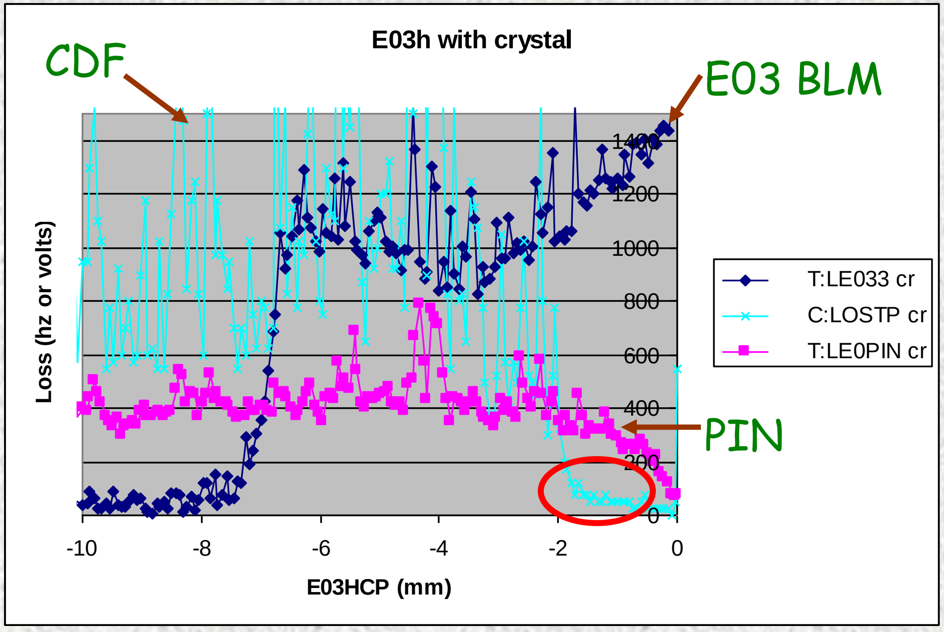
Jan. 31, 2006

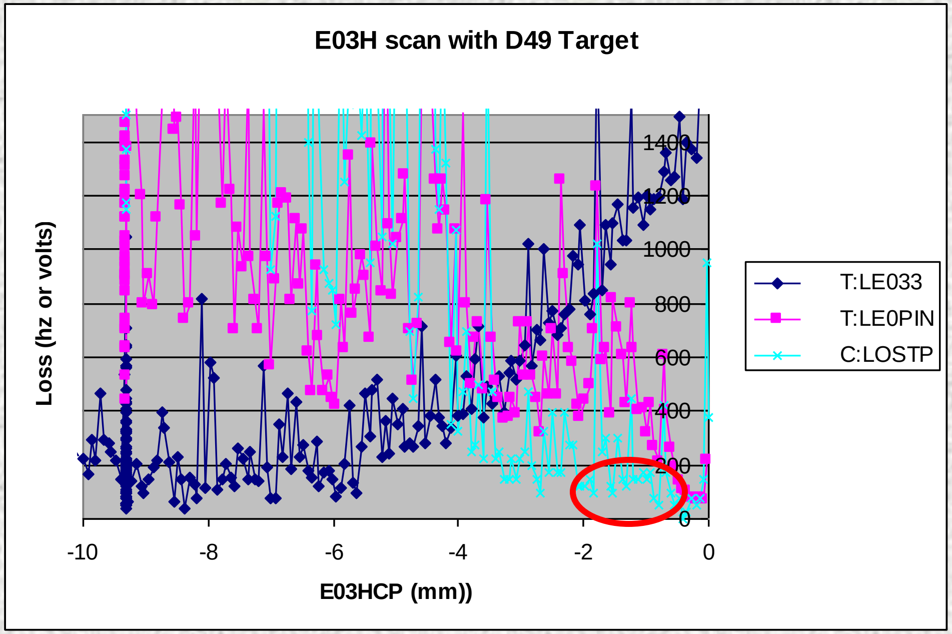
With E03H out, LE033C BLM is proportional to nuclear interact. rate in crystal

Channeled beam "peak" width is 22±4 µrad (rms)

COMPARING EFFECTS OF PROTON HALO LOSSES FOR BENT CRYSTAL AND TUNGSTEN TARGET

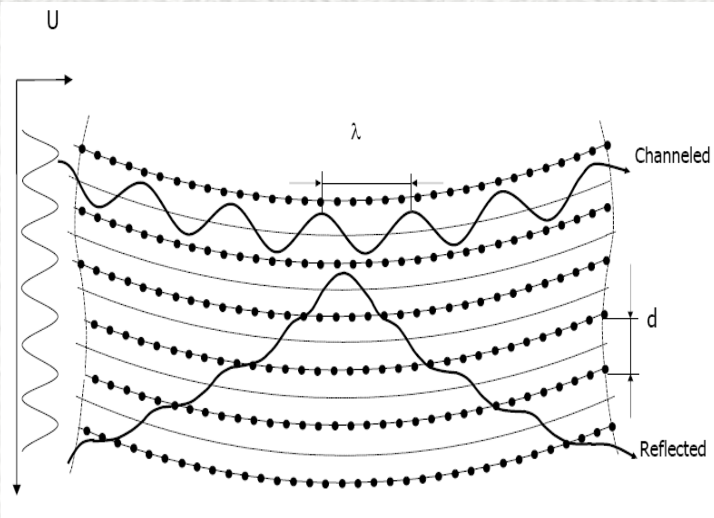
Crystal aligned at peak (118 μrad)



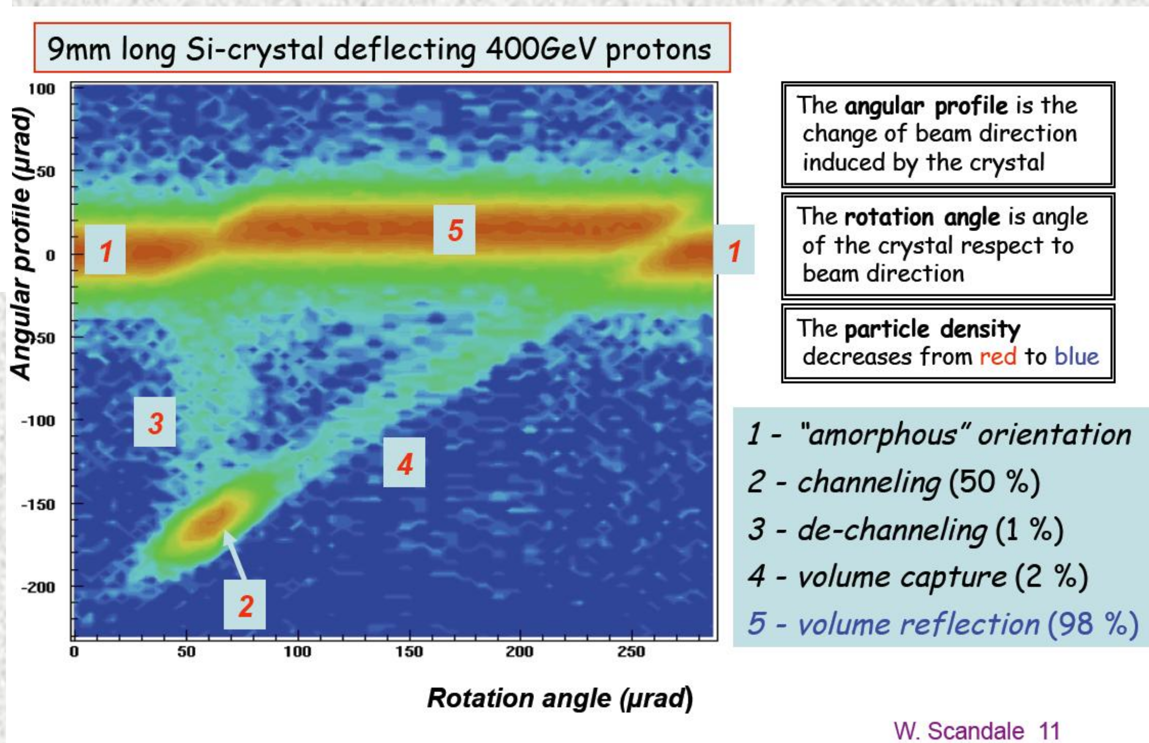


1. Channeled beam is up to 10mm deep on secondary collimator which can remain further from the main beam thus reducing impedance.
2. Almost a factor of 2 reduction of CDF losses.
3. A factor of >5 lower irradiation of downstream components.

VOLUME REFLECTION

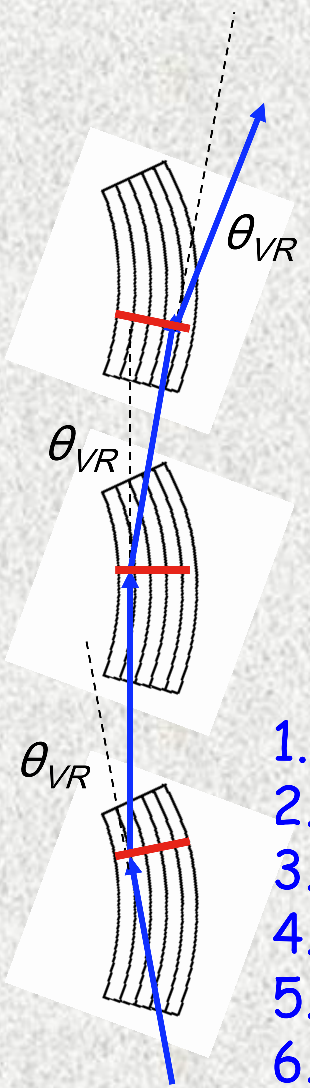


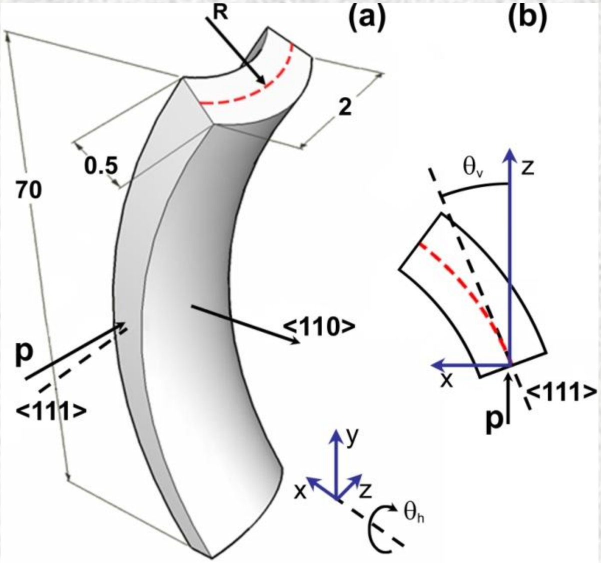
Predicted by Taratin&Vorobiev in 1987.
Recently demonstrated at IHEP & CERN

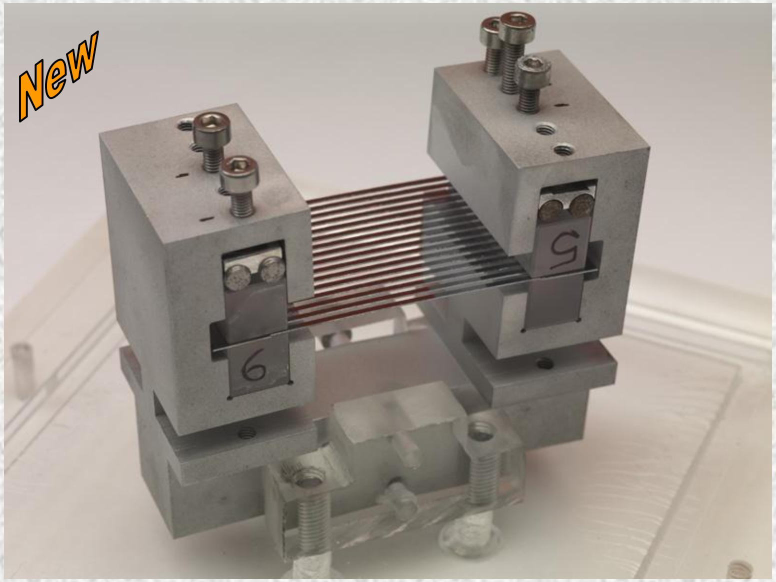


Promising for collimation: acceptance = bent angle (e.g., 400 μrad, to be compared to ~10 μrad for channeling)

New Ferrara Multi-Strip Crystal







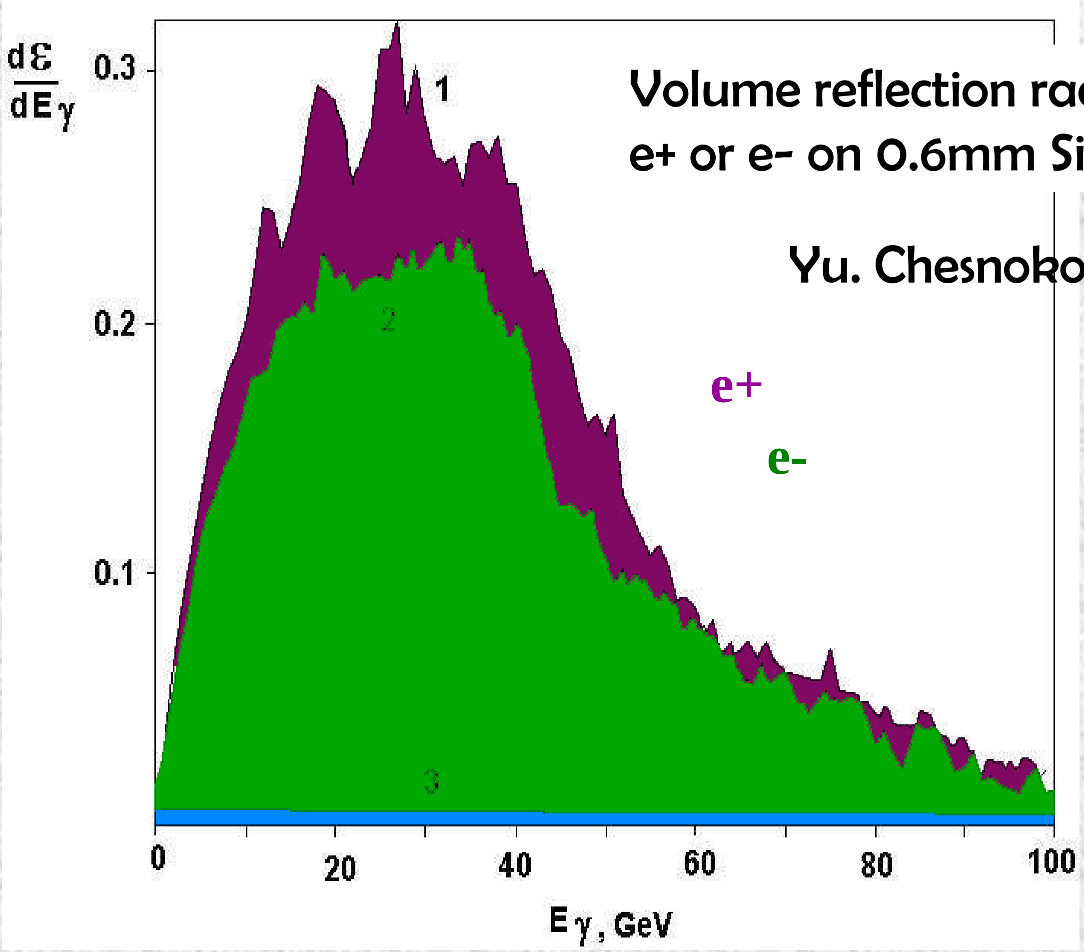
1. Anticlastic curvature radius = 4.2 m
2. Expected acceptance = 80 μrad
3. Number of strips aligned/used = 13
4. Miscut angle was measured as 600 μrad
5. Characterized, tested and installed in vertical goniometer
6. Produced by V. Guidi, Ferrara, INFN

Pixel Telescope Detectors

- Multi-chip modules are of CMS forward pixel production.
- 1x2 cm^2 with a sensitive area 0.8x1.6 cm^2.
- Pixel size 100x150 μm^2, **resolution 7-8 μm**.

- Building 2 detectors
  - 1 installed in front of E03collimator
  - 1 installed in front of F172 collimator
- Consists of 3 telescoping pixels per plane.
- Problems vacuum certifying pixel boards due to baking temperatures.
- Should install ~ December 2010

VOLUME REFLECTION RADIATION



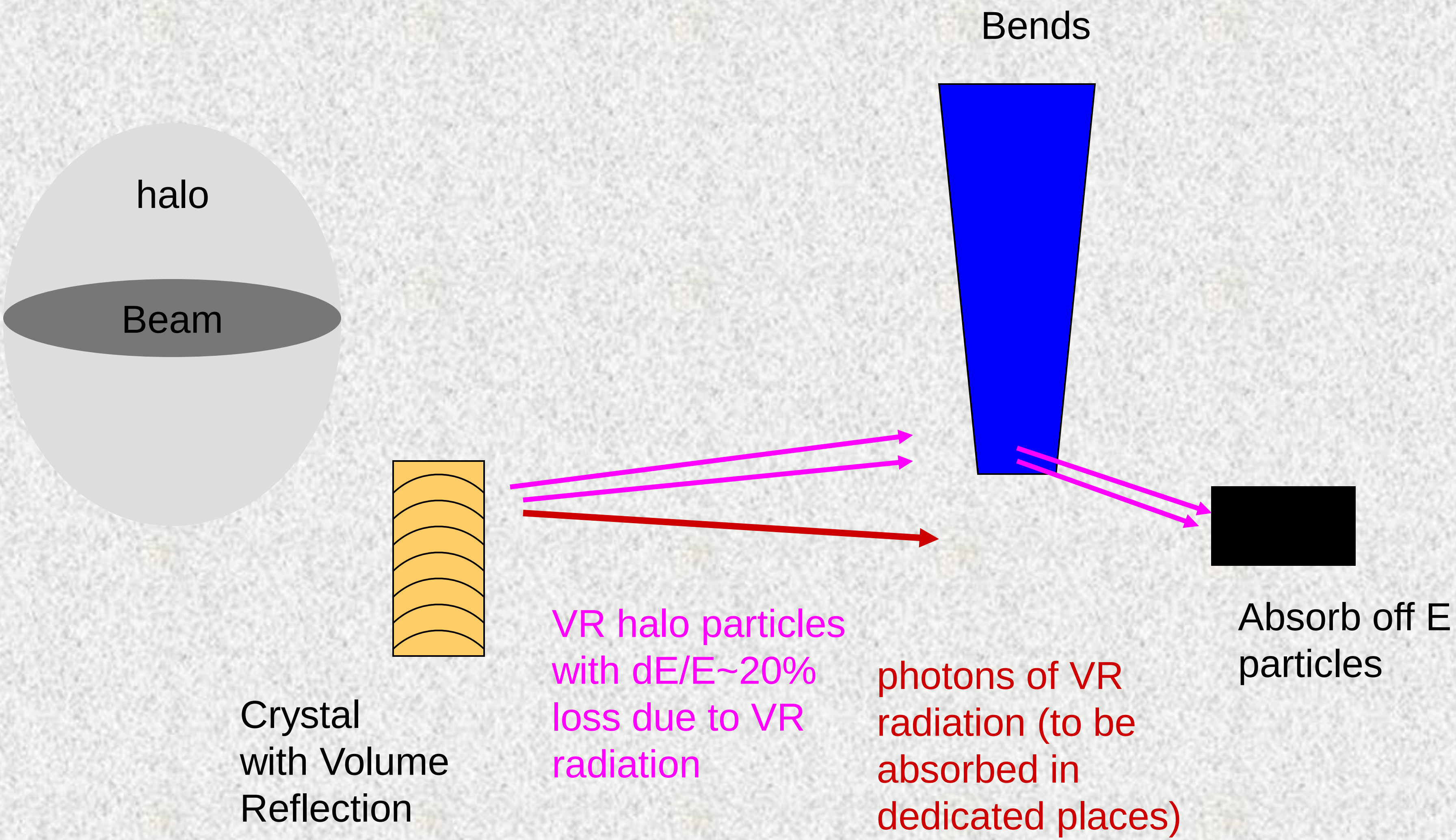
Volume reflection radiation of 200GeV e+ or e- on 0.6mm Si crystal (R_{bend}=10m)

Yu. Chesnokov et al, IHEP 2007-16

Scaling E_γ with E: ~$E^{3/2}$ for E<<10GeV and E^2 for E>>10GeV (Gennady Stupakov)

VR radiation is very similar for both e+ and e-, and has large angular acceptance – it makes this phenomenon good candidate for collimation system of linear collider

e^+ e^- Beam Collimation Based on VR radiation

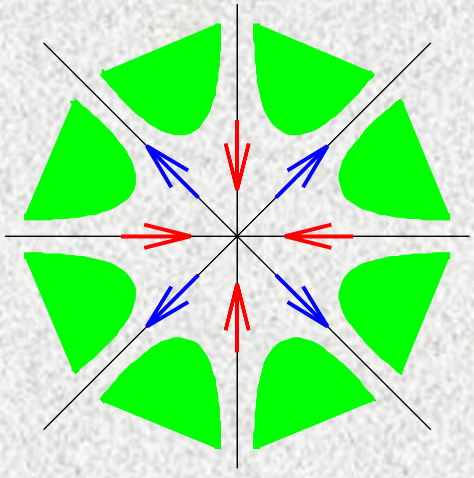


Nonlinear Handling of Beam Tails

- One wants to **focus beam tails** but not to change the core of the beam
  - use **nonlinear** elements

- **Several** nonlinear elements need to be **combined** to provide **focusing in all directions**
  - (analogy with **strong focusing by FODO**)

- **Octupole Doublets (OD)** can be used for **nonlinear tail folding**

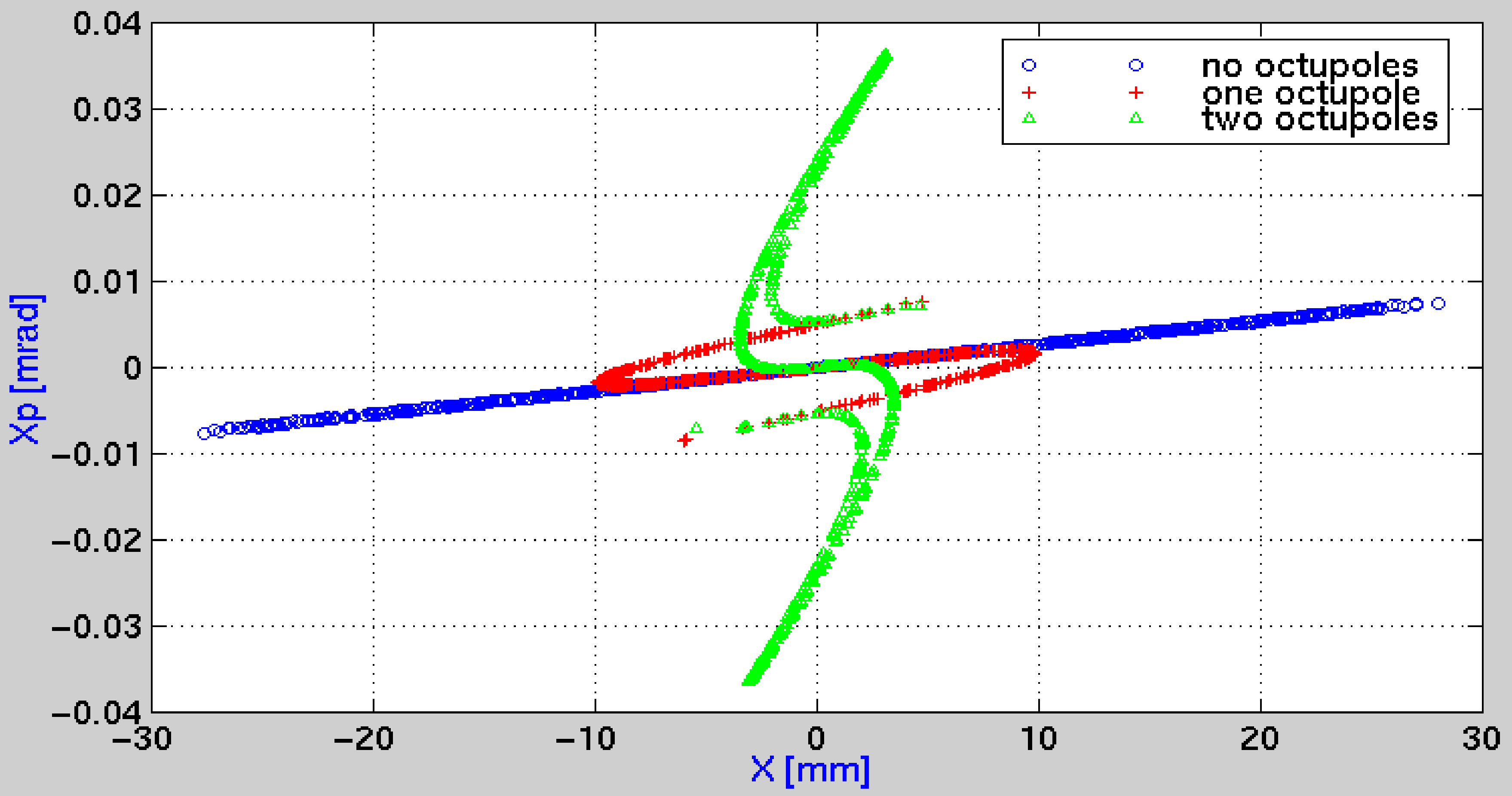


Single octupole focus in planes and defocus on diagonals.

An octupole doublet can focus in all directions !

Courtesy A. Seryi

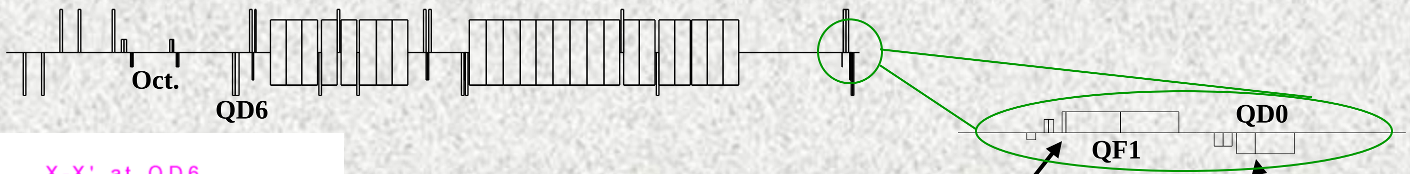
Schematic of Halo Folding with Octupole or OD

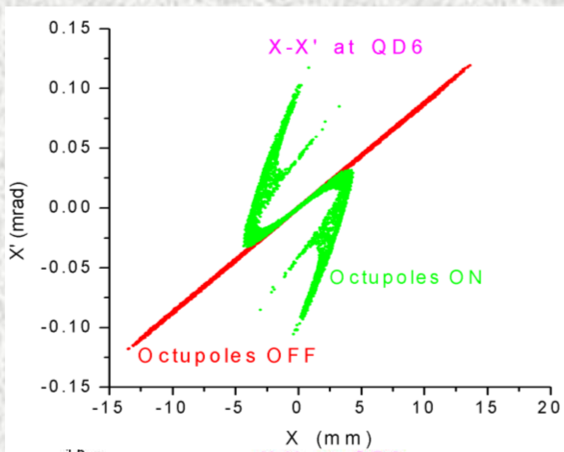


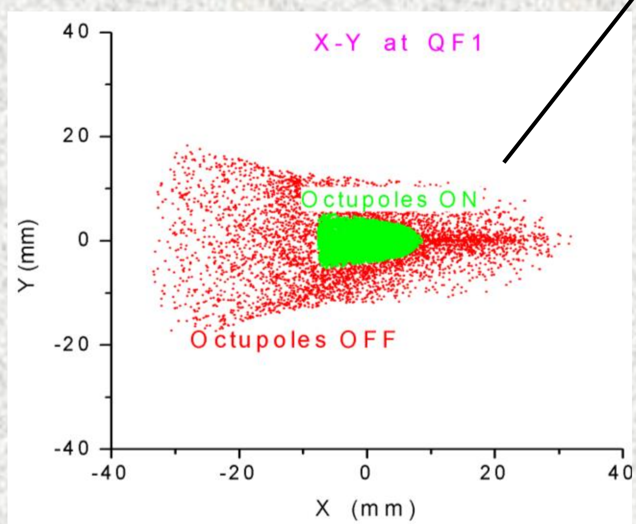
Folding of the horizontal phase space distribution at the entrance of the Final Doublet with one or two octupoles in a "Chebyshev Arrangement".

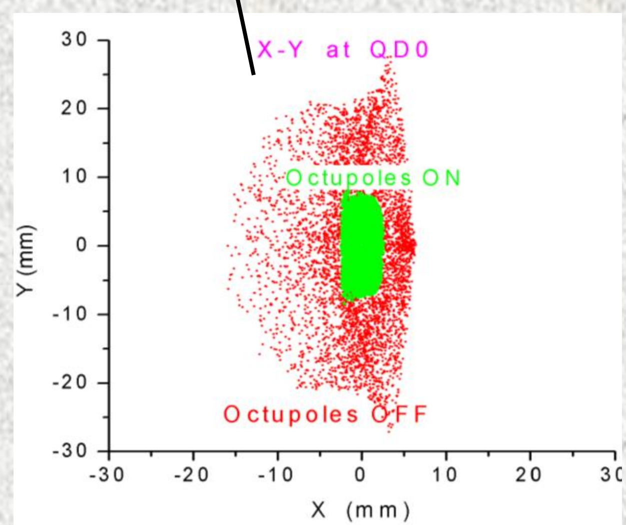
Predicted Tail Folding Effect

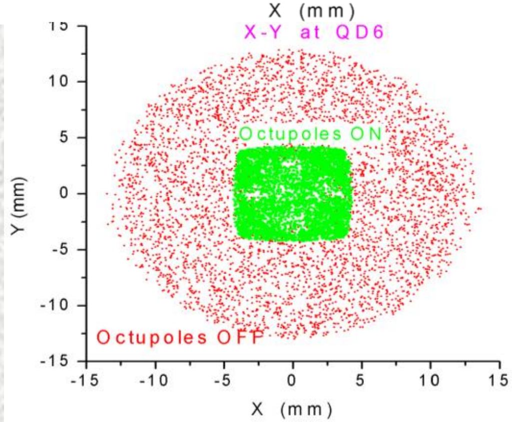
Two octupole doublets give tail folding by ~ 4 times in terms of beam size in FD. This can lead to relaxing collimation requirements by ~ a factor of 4.







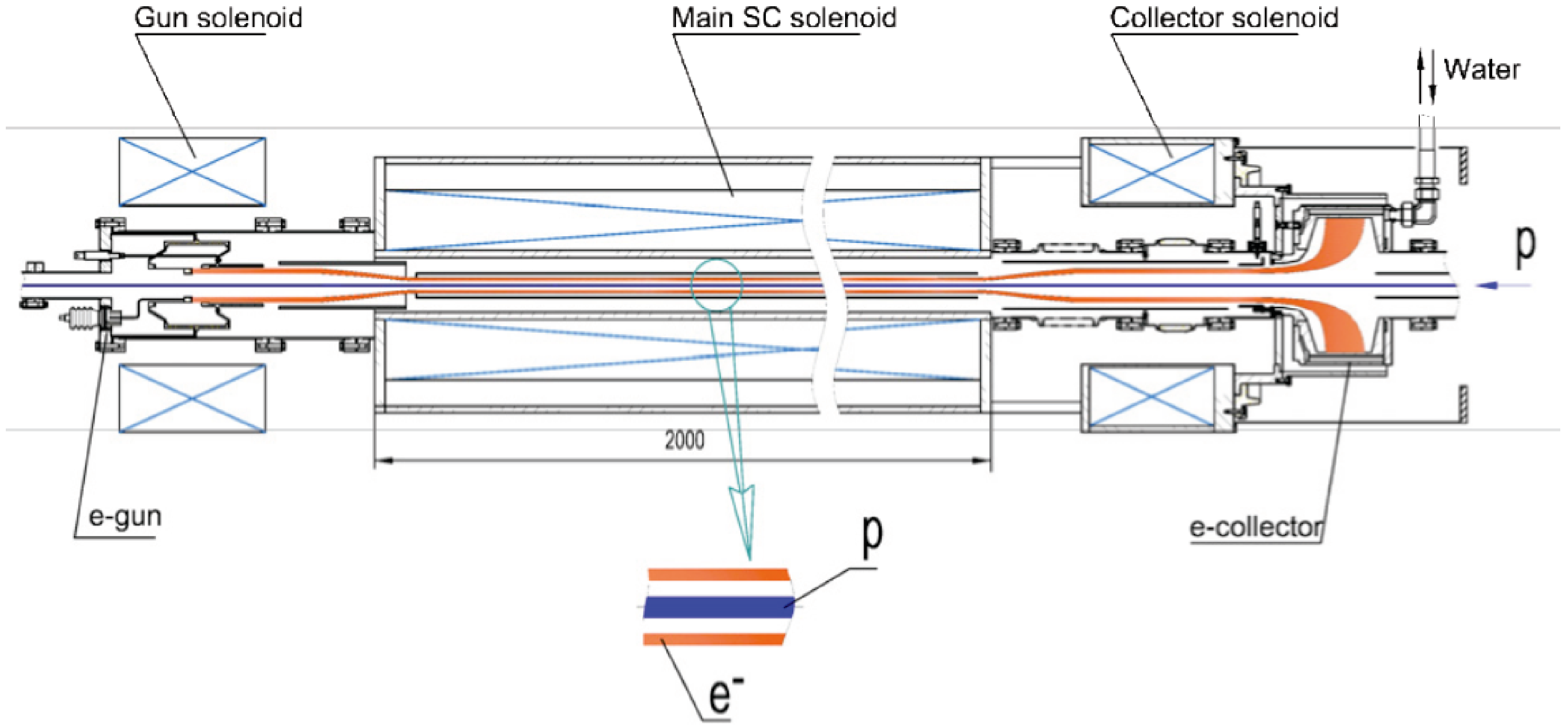




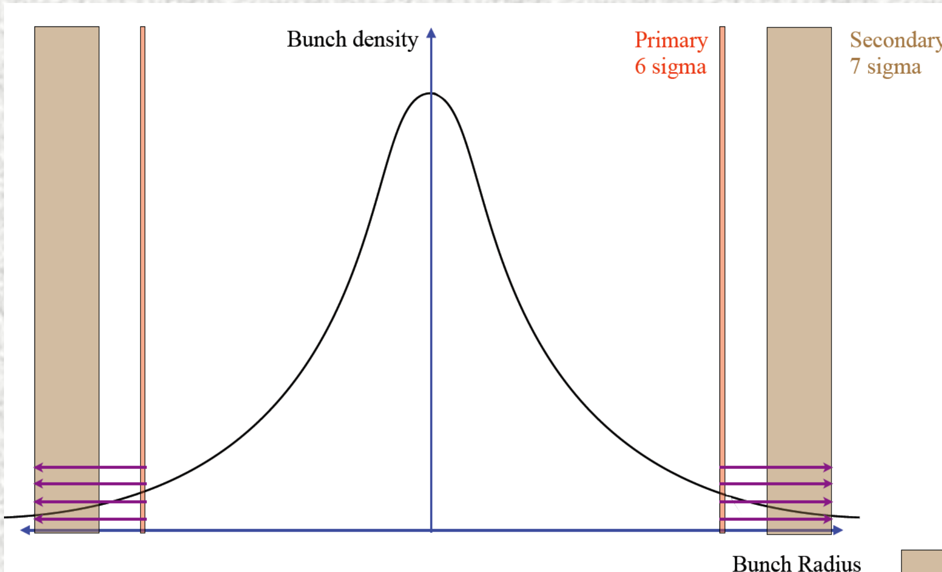
Tail folding by means of two octupole doublets in the new NLC final focus
Input beam has (x,x',y,y') = (14µm,1.2mrad,0.63µm,5.2mrad) in IP units (flat distribution, half width) and ±2% energy spread,
that corresponds approximately to N_σ=(65,65,230,230) sigmas with respect to the nominal NLC beam

HOLLOW ELECTRON LENS

- A Hollow Electron Lens is a hollow cylinder of electrons.
- Inside the cylinder there is no electric field and so particles experience no kick
- Within cylinder and outside particles experience a kick

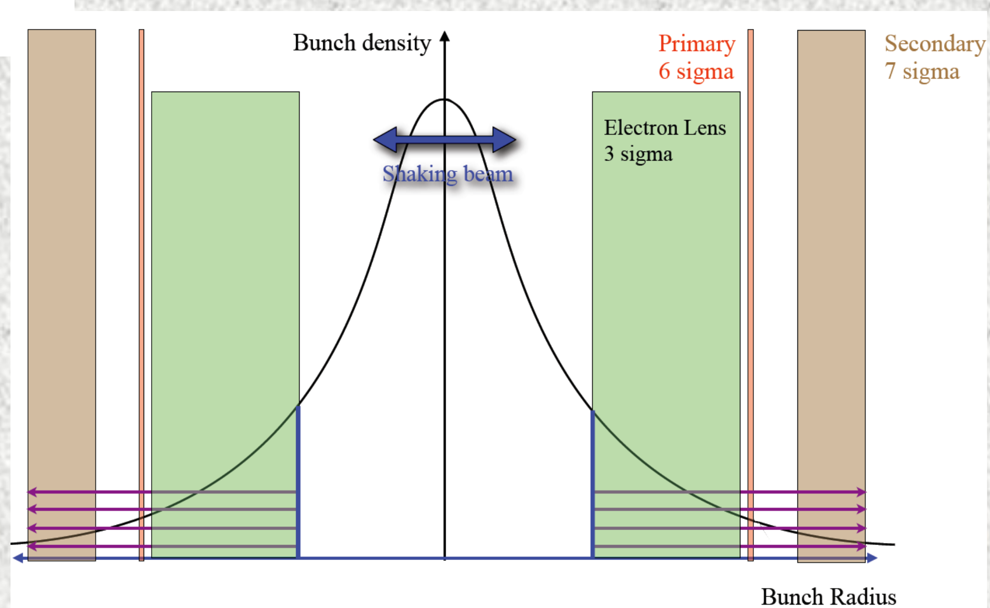


CONVENTIONAL vs HOLLOW LENS COLLIMATION



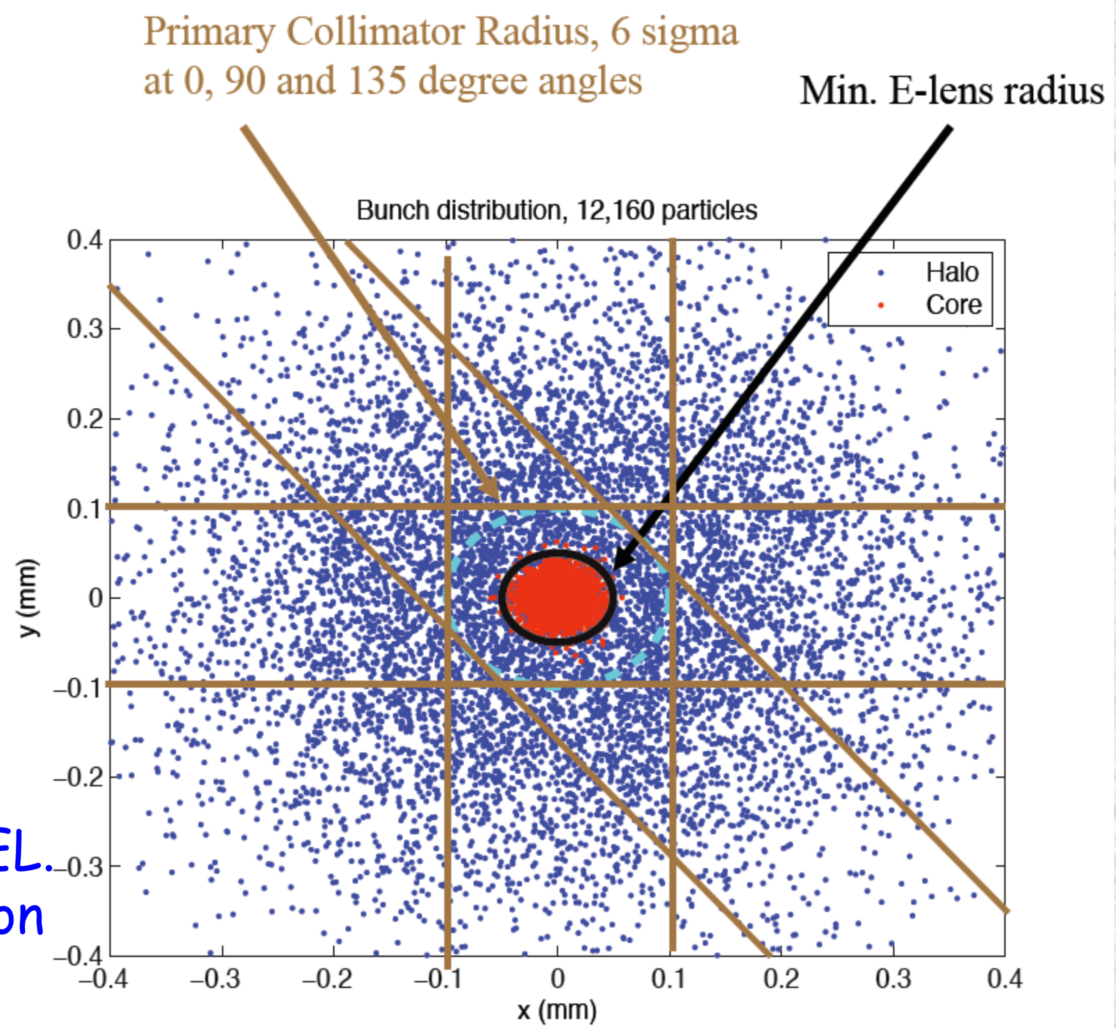
Indestructible non-invasive electron beam at a smaller radius can push halo out, can be used to eliminate loss spikes due to shaking beam and can increase impact parameter of primaries

No material can survive closer than 5 s



BUNCH DISTRIBUTION

- Can model with two Gaussian distributions
  - Core population at nominal emittance
  - Halo populated at 100 times emittance (10x sigma)
  - Halo populated 3 times as much as core
- Everything outside the Primaries should get absorbed within a couple turns
- Between the Electron Lens and primaries is what we are really looking at.
- Beam heating works on a much longer time scale than collimation



Basic parameters similar to TEL.
R&D required on hollow electron gun.
CERN & LARP are supportive.