New Collimation Ideas

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Fermilab

Future Directions
for Accelerator R&D at Fermilab
Lake Geneva, WI
May 11-13, 2009

OUTLINE

- Multi-Stage Scheme Developments
- Crystals: Channeling, VR and VR radiation
- Tail Folding with Non-Linear Optics
- Hollow e-Beam Lens
- Proposed Accelerator R&D

BEAM COLLIMATION

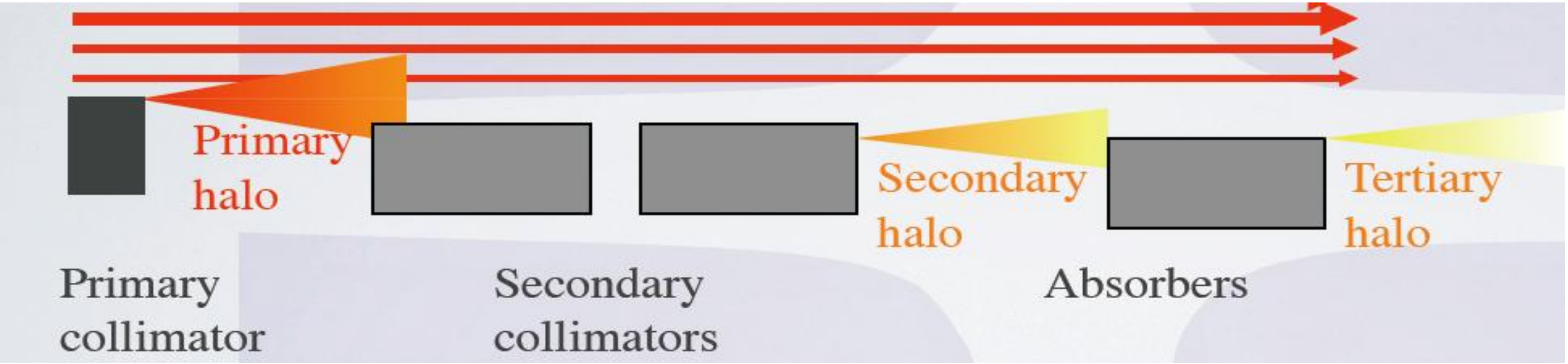
Beam collimation is mandatory at any high-power accelerator and hadron collider.

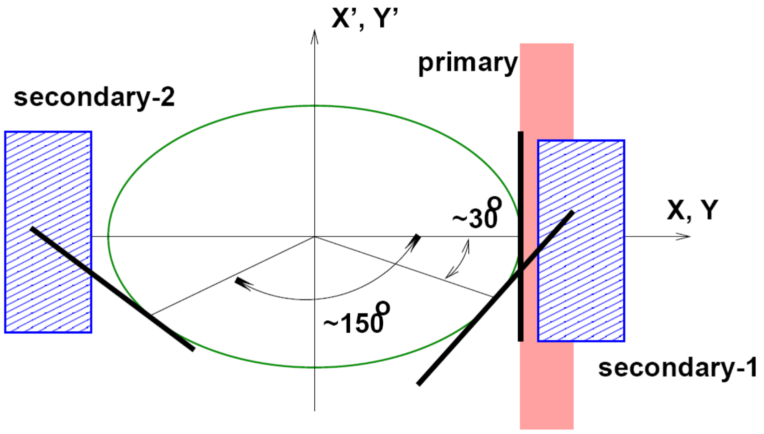
Only with a very efficient beam collimation system can one reduce uncontrolled beam losses in the machine to an allowable level,

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.

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.



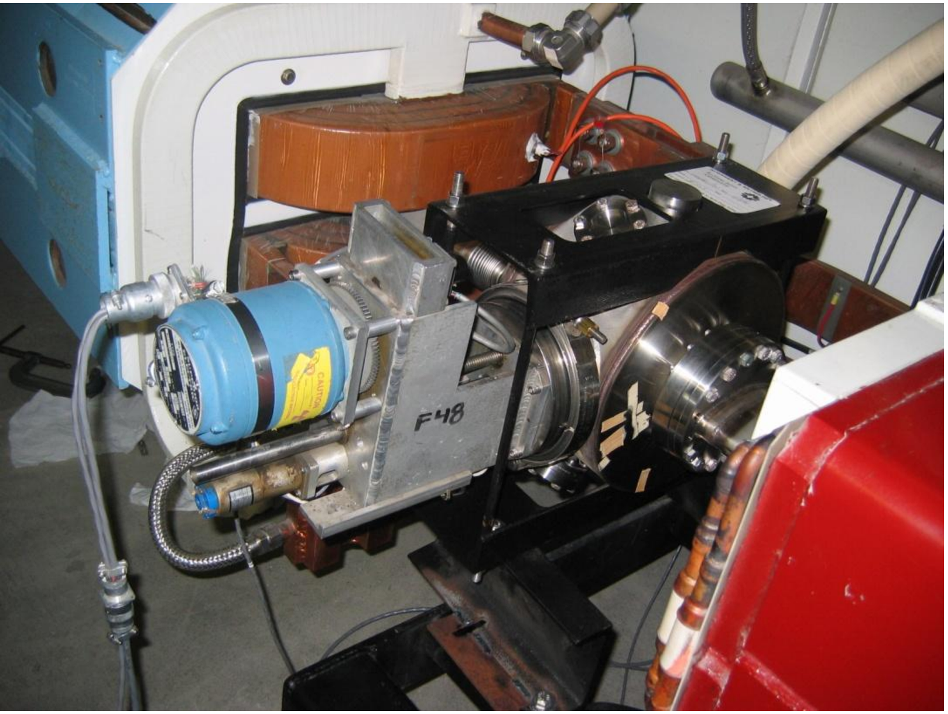


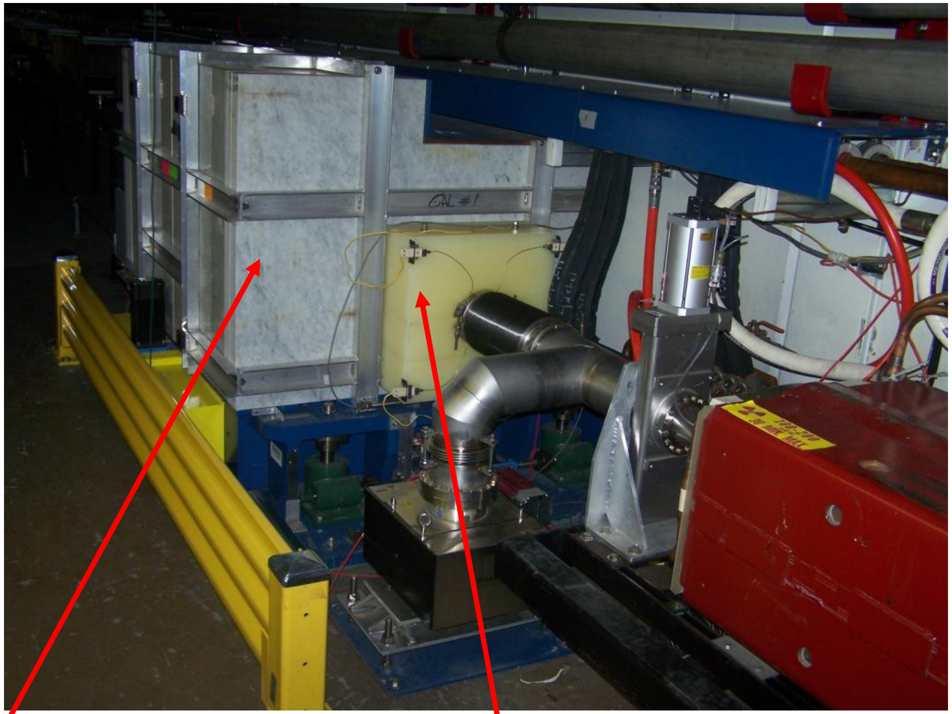
Secondary collimators – horizontal and vertical – located at appropriate phase advances, 1 σ farther from beam axis than the primaries, aligned parallel to beam envelope.

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.

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

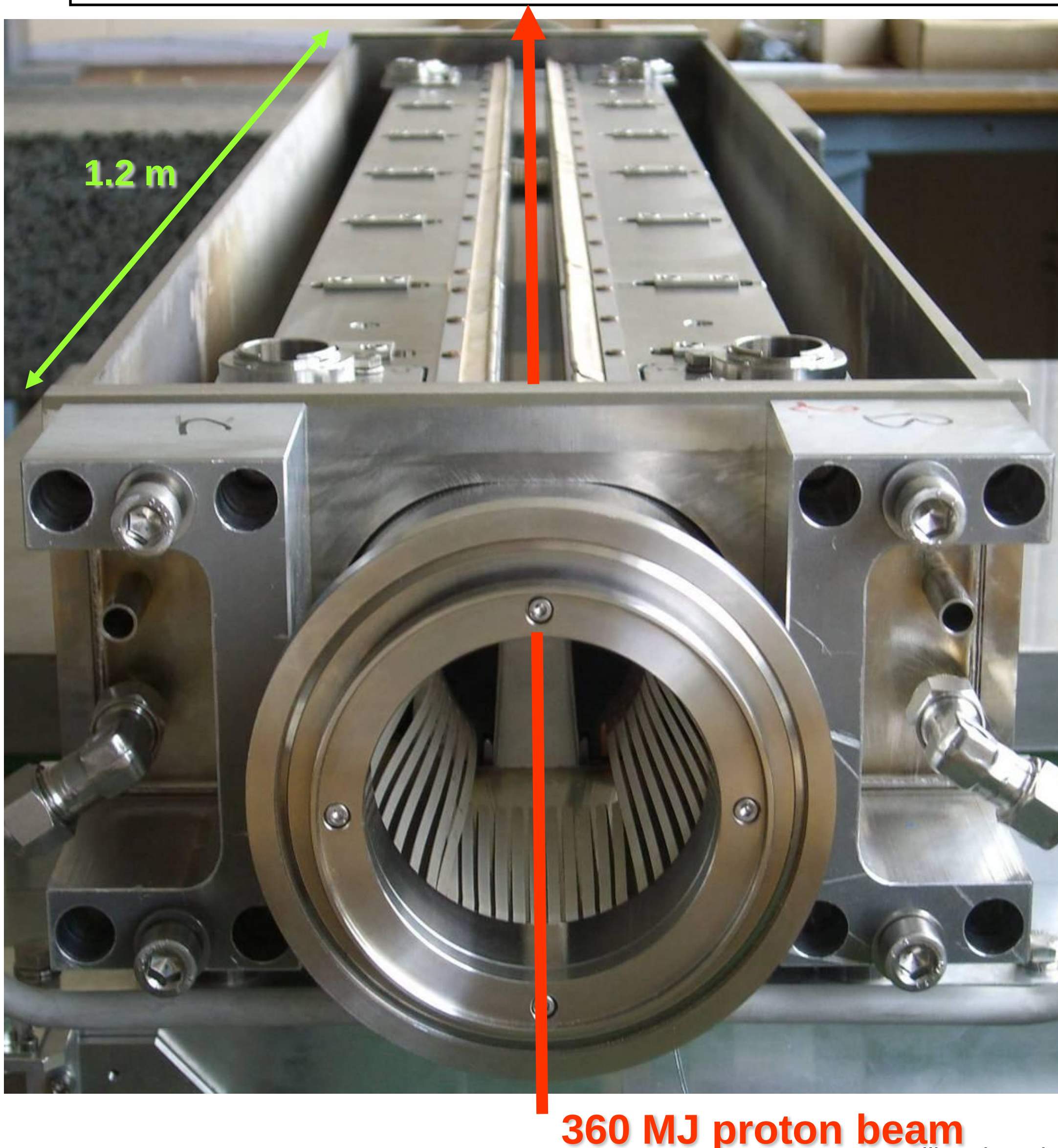
Loss Time	
Injection end	
Uncaptured	
Later	

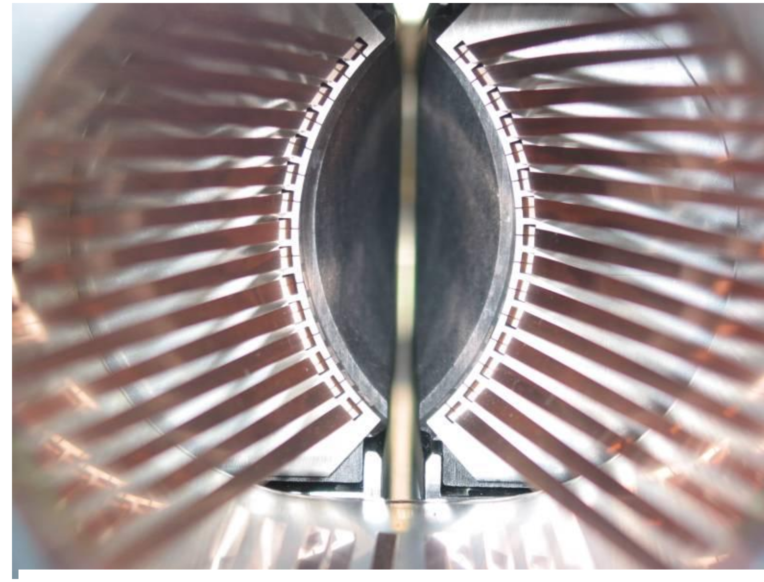
94.7% of injected beam accelerated to extraction

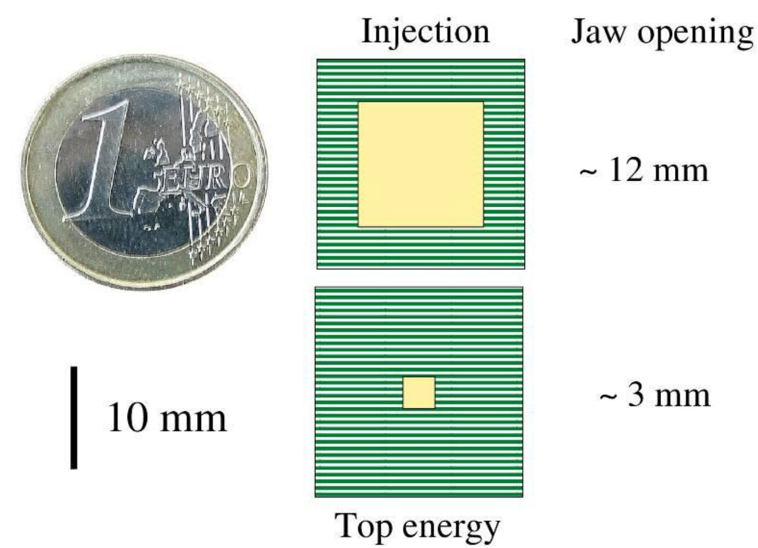
93% of uncaptured beam loss is kept in collimation region plus a few % lost immediately dwnstrm

It is now 99% !

LHC Phase I Collimator







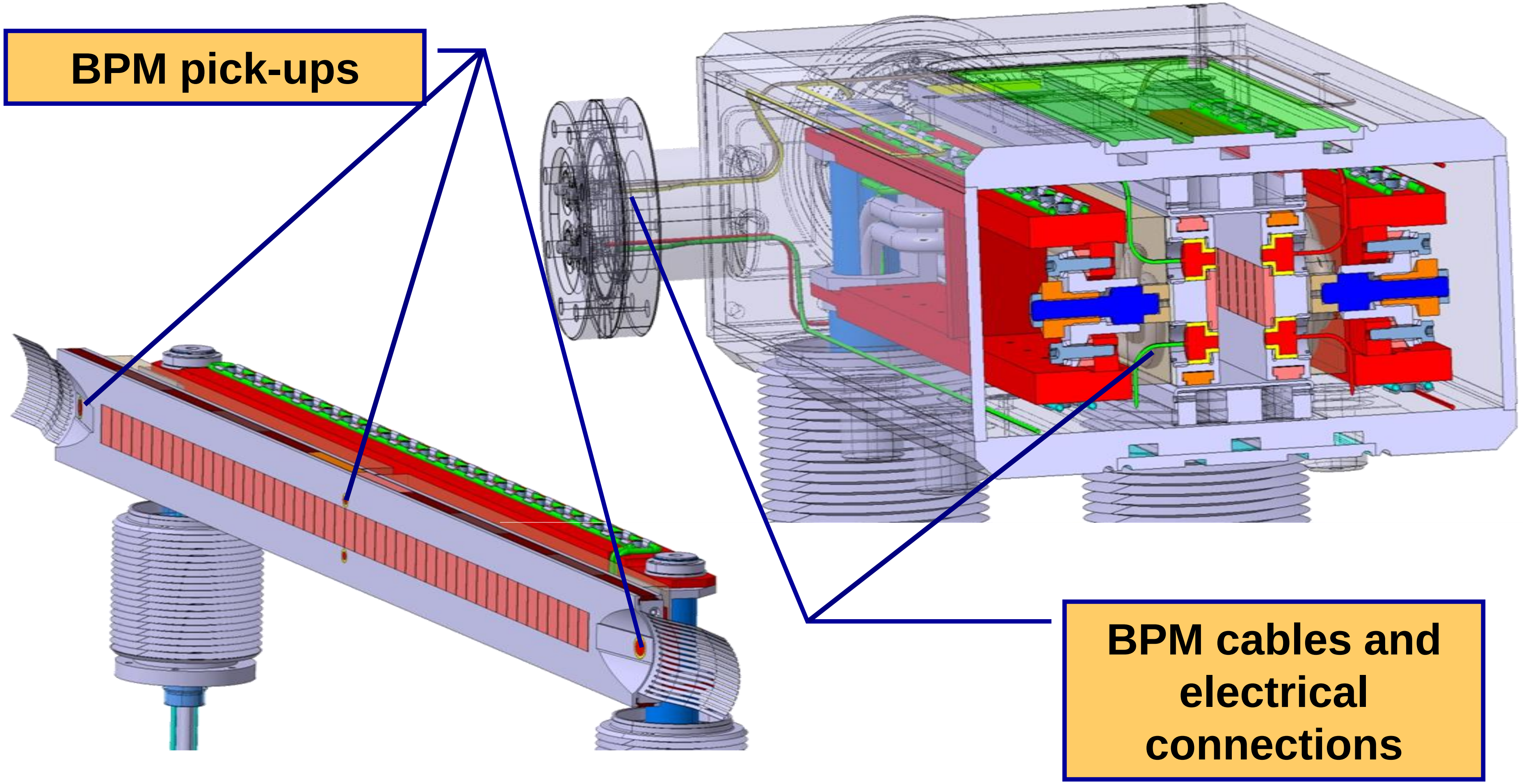
R. Assmann, CERN

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



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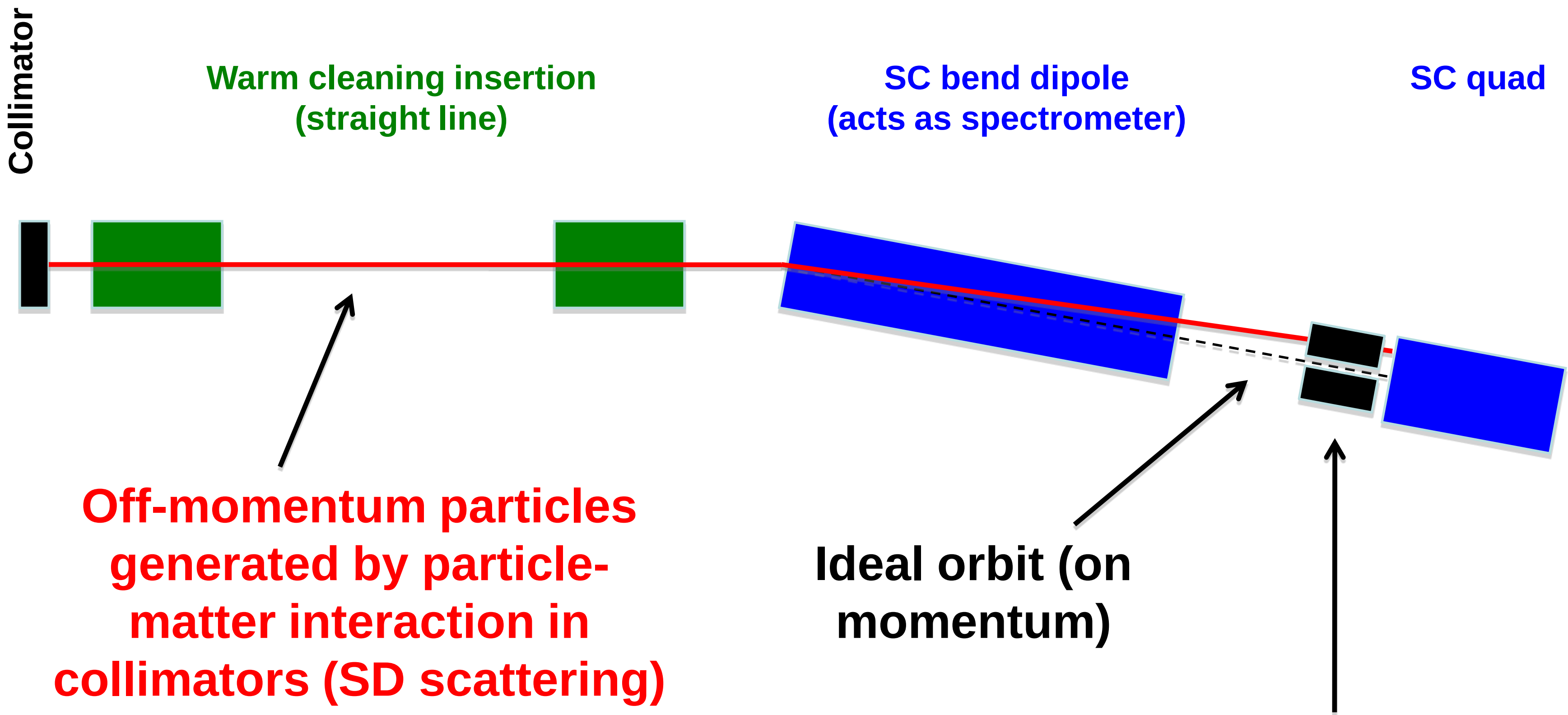
CRYO COLLIMATORS IN DS

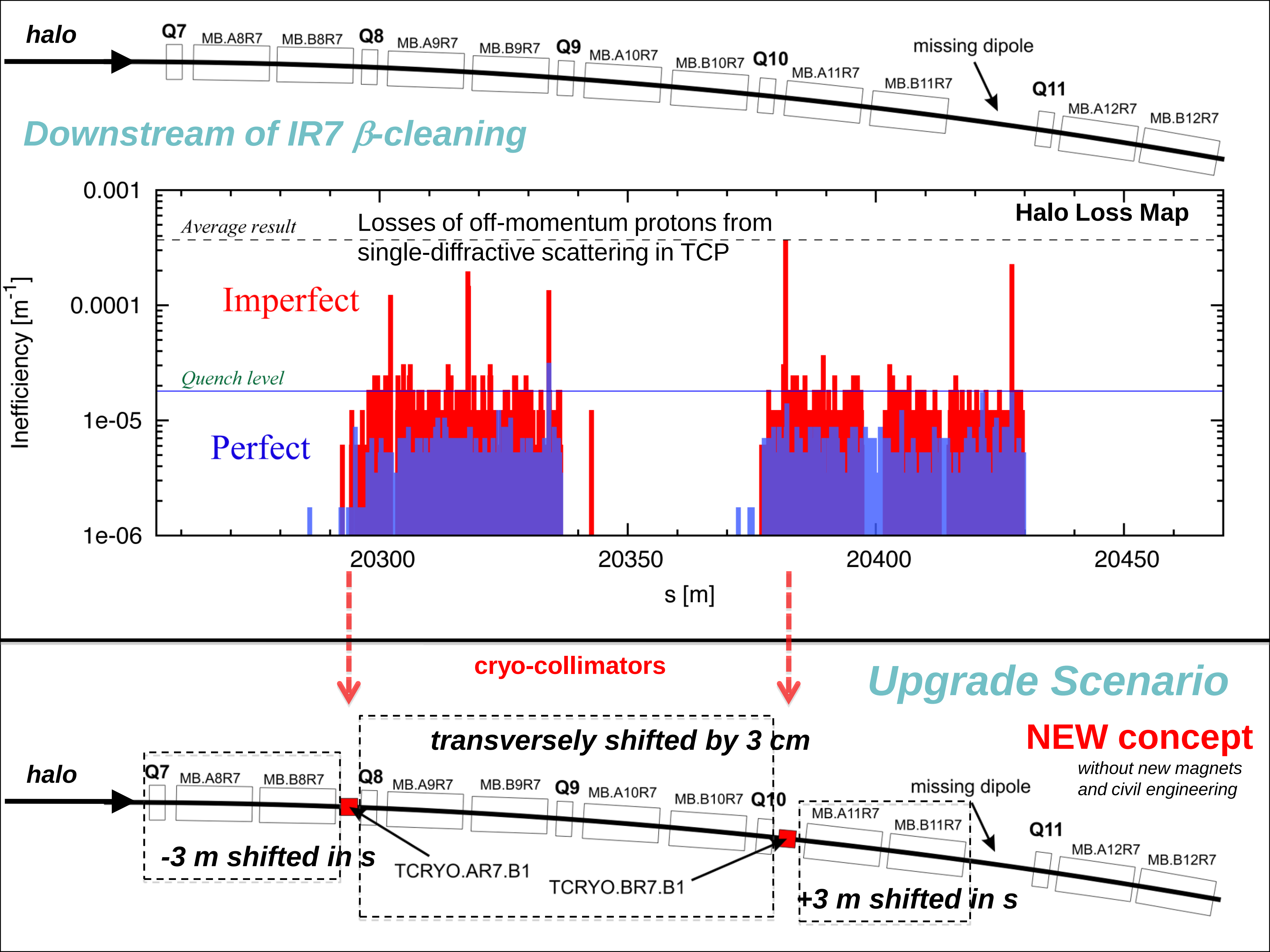


+ metallic phase 2 collimators in IR3 and IR7

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

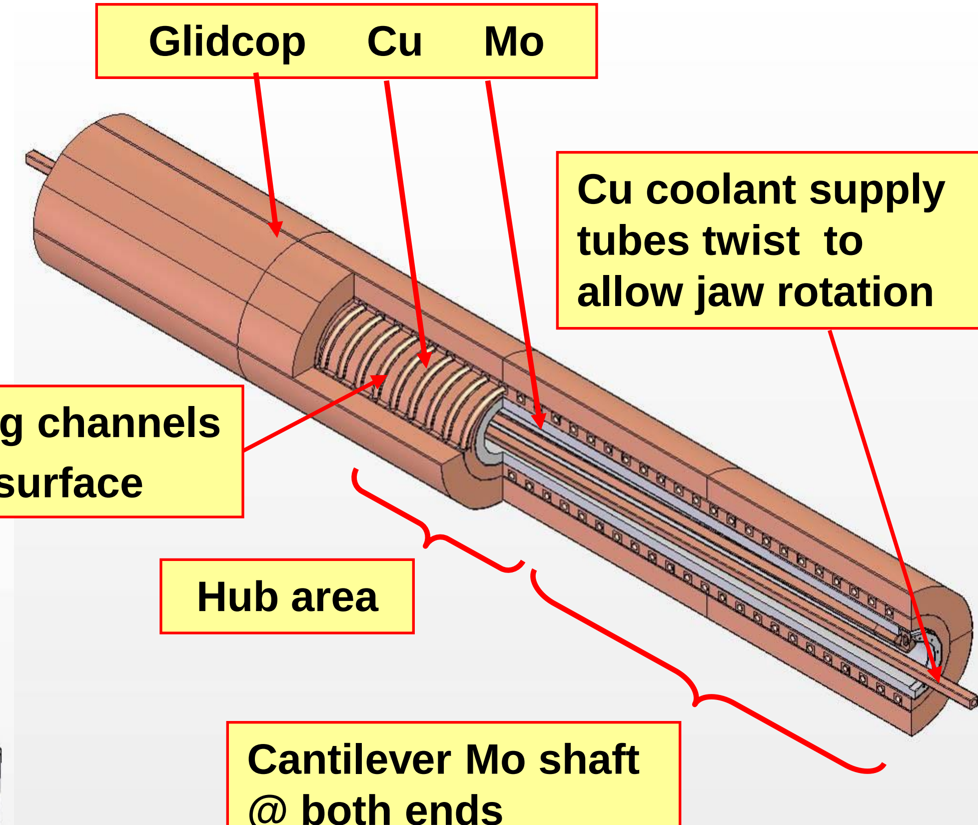
Cleaning efficiency improvement by a factor of 15 to 90

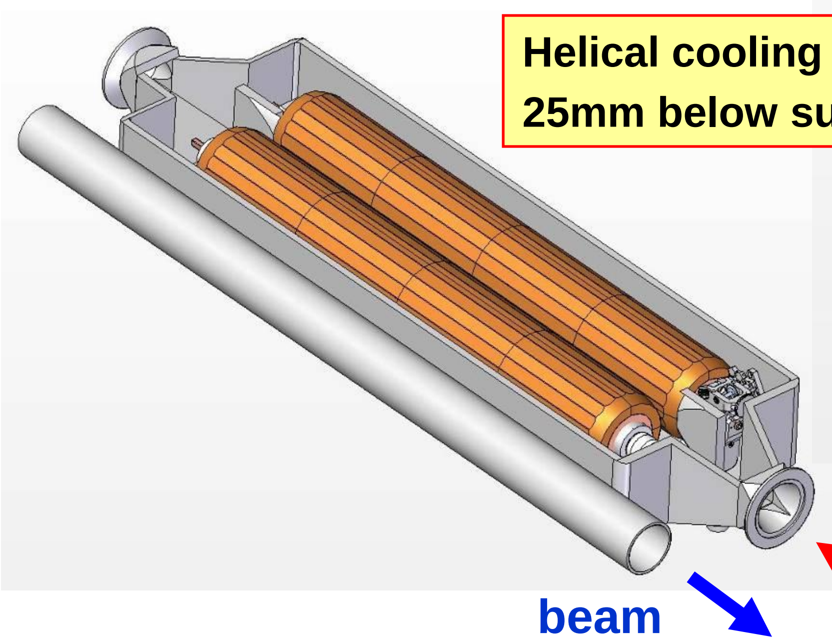
R. Assmann, CERN


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
-3 m shifted in s
+3 m shifted in s
TCRYO.AR7.B1
TCRYO.BR7.B1

ROTATABLE COLLIMATORS (SLAC)

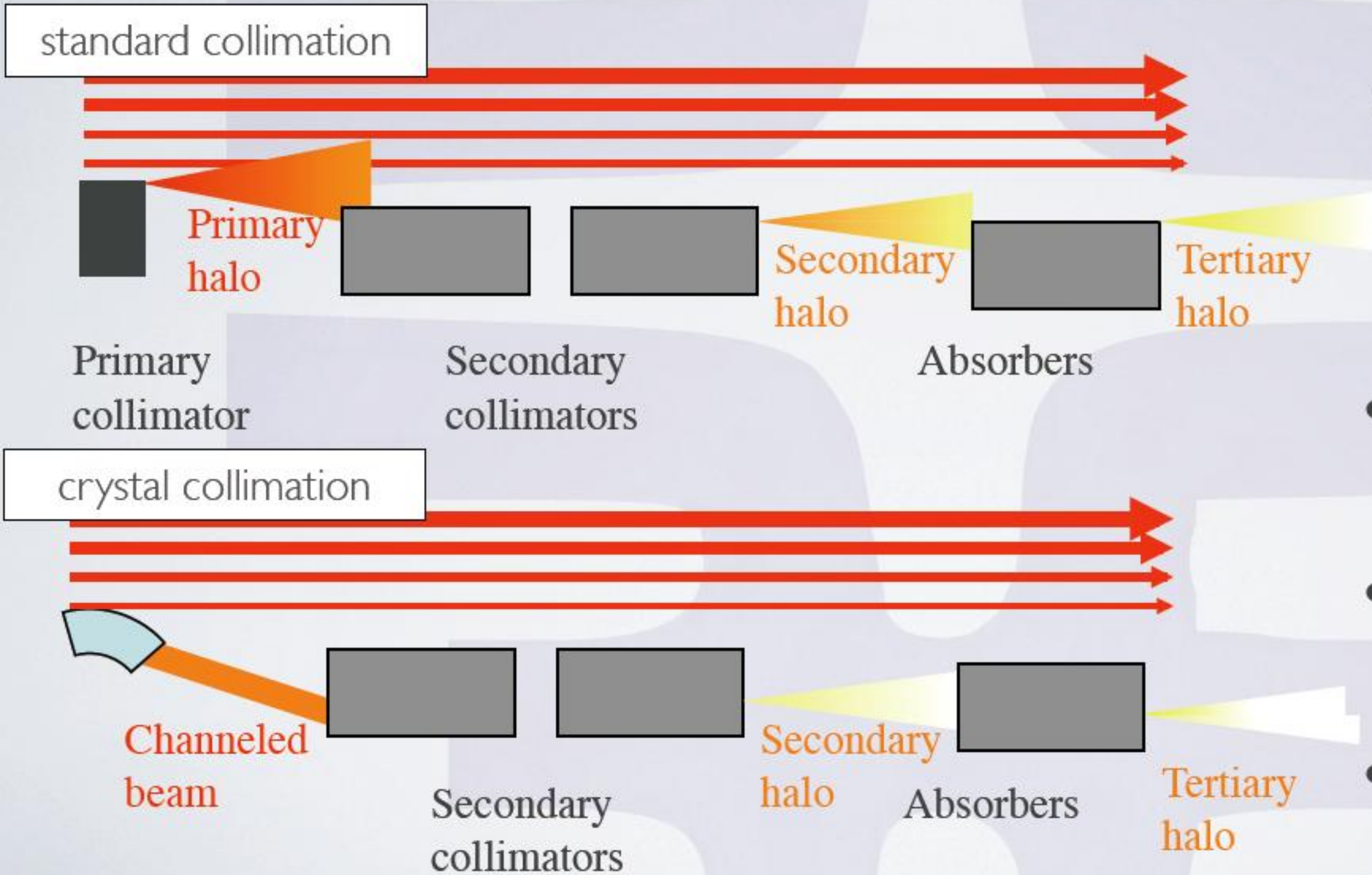
- beam spacing: geometrical constraint
- Length available 1.47 m flange - flange
- Jaw translation mechanism and collimator support base: LHC Phase I
- >10 kW per jaw Steady State heat dissipation (material dependent)





CRYSTAL COLLIMATION

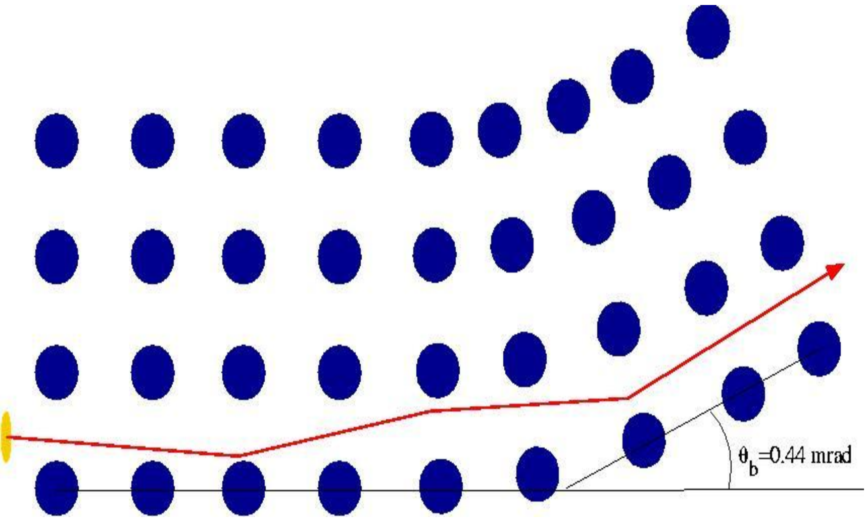
- Bent-crystal channeling is a technique with a potential to increase the beam-halo collimation efficiency at high-energy colliders.

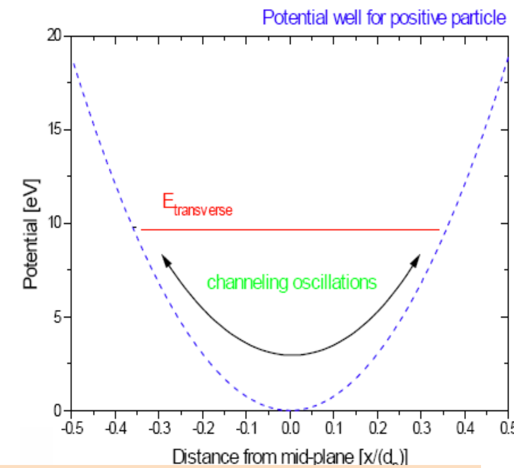


Use the crystal to drive the beam halo deep into a secondary collimator/absorber

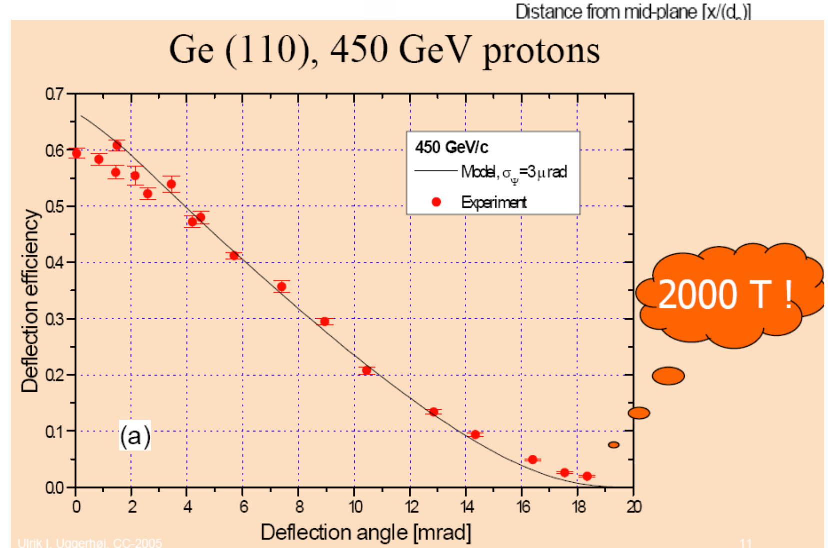
- Coherent deviation of the primary halo
- Larger collimation efficiency
- Reduced tertiary halo

CRYSTAL CHANNELING



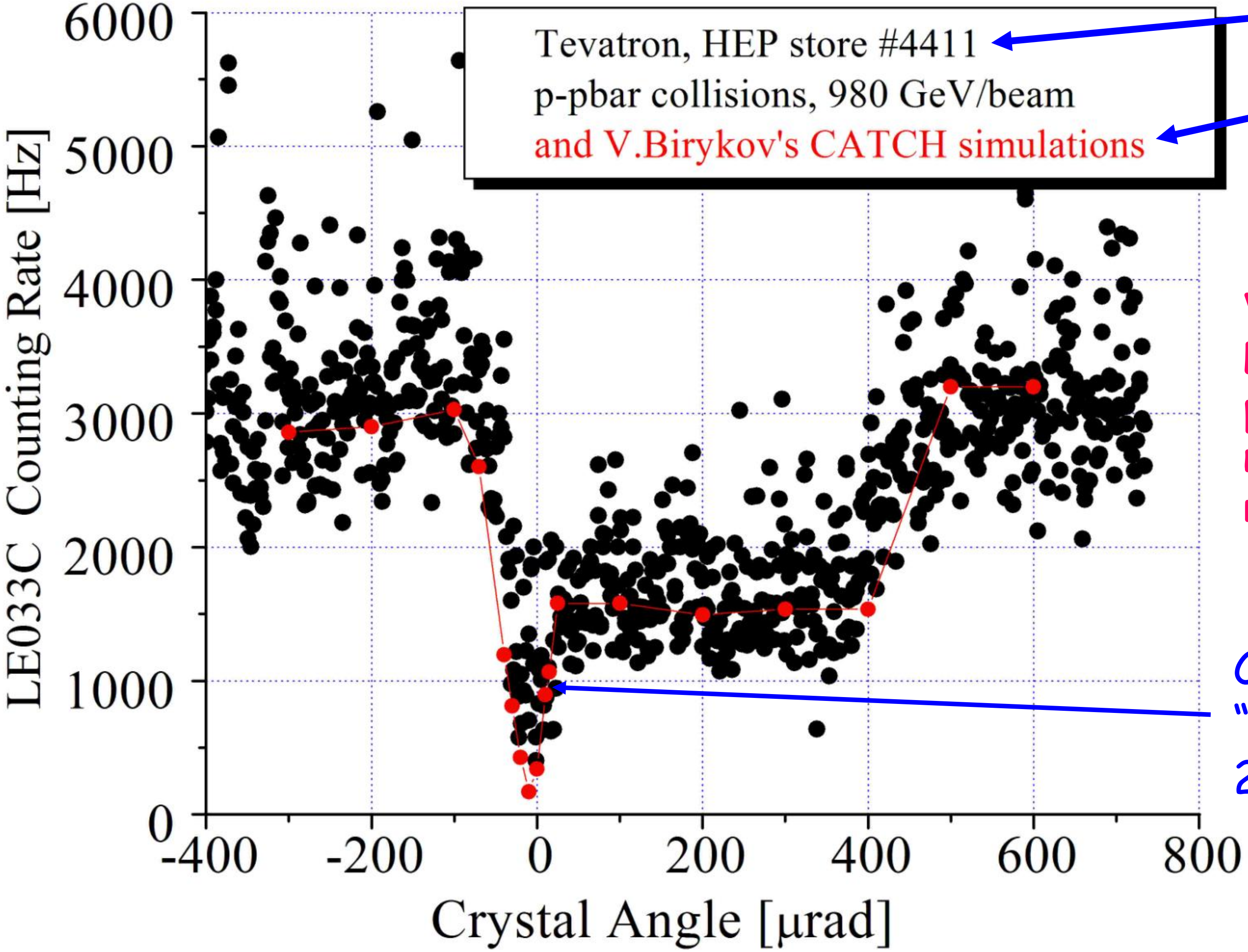


Extremely high interplanar electric fields from screened nuclei (a few GV/cm) allow to bend high-energy beams with very short crystals. Interplanar spacing ~ 2Å.



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

980-GEV BEAM CHANNELING: DATA vs THEORY



Oct. 6, 2005
By Dean Still

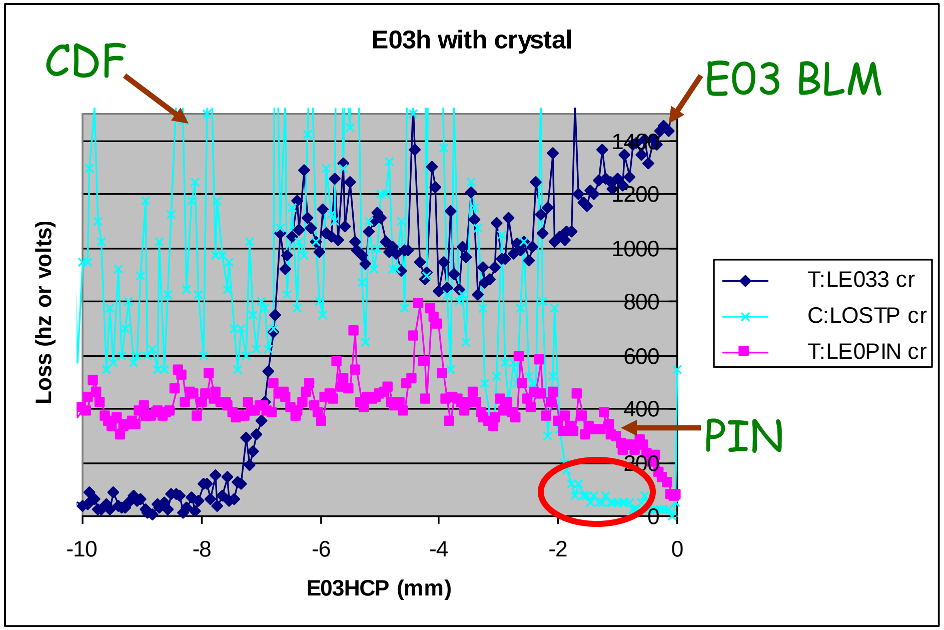
Jan. 31, 2006

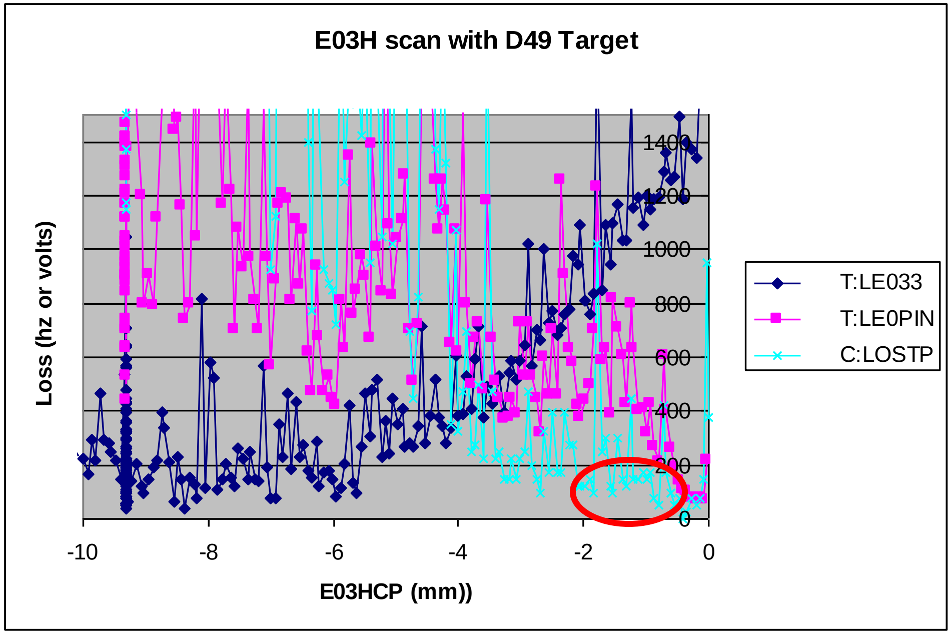
With E03H out, LE033C BLM is proportional to nuclear interact. rate in crystal

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

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

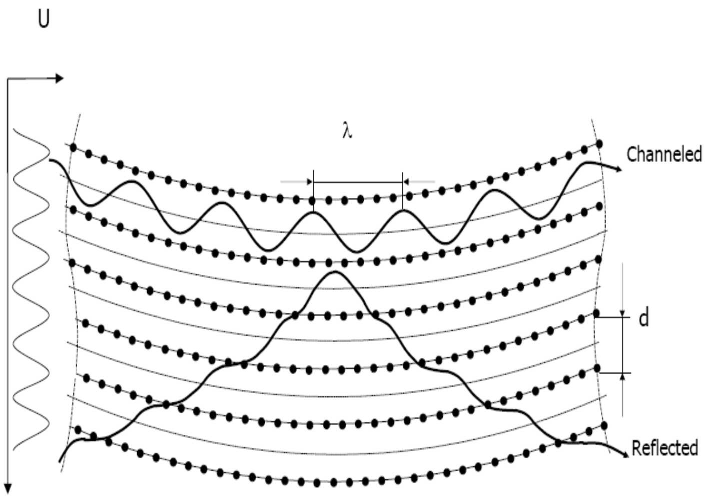
Crystal aligned at peak (118 μrad)



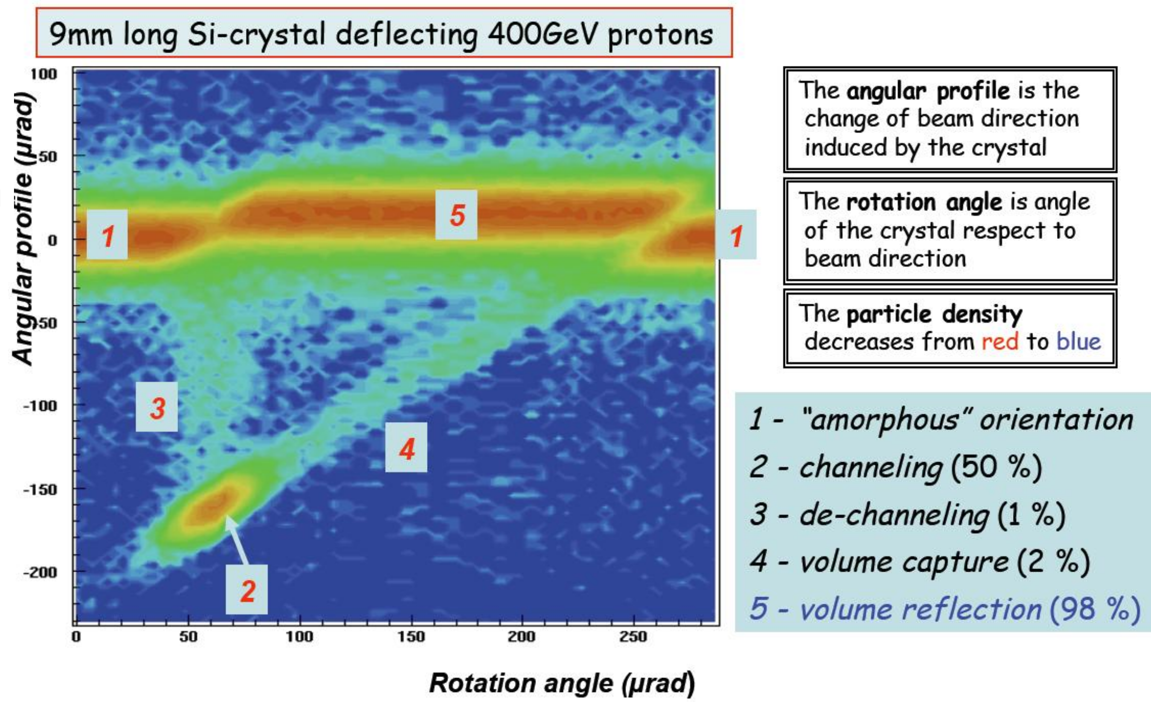


1. Channeled beam is up to 10mm deep on secondary collimator which can remain further from the main beam thus reducing impedance.
2. Almost a factor of 2 reduction of CDF losses.
3. A factor of >5 lower irradiation of downstream components.

VOLUME REFLECTION



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

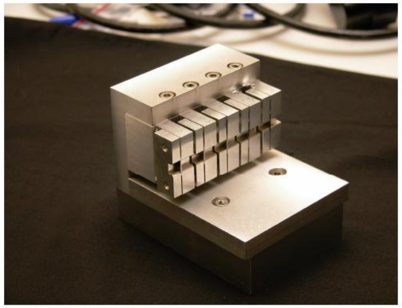


W. Scandale 11

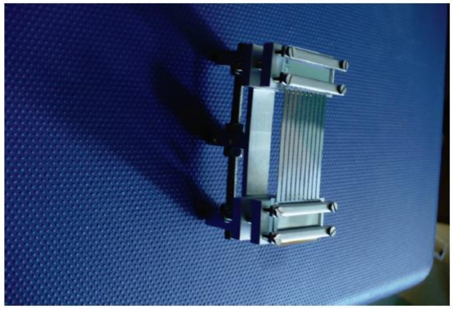
Promising for collimation: acceptance = bent angle
(e.g., 400 μrad, to be compared to ~10 μrad for channeling)

NEW MULTI-STRIP CRYSTALS FOR VR

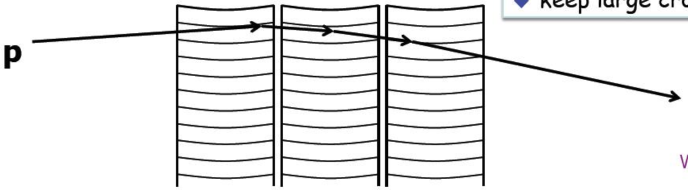
multiheads crystal (PNPI)



multistrip crystal (IHEP and INFN-Ferrara)



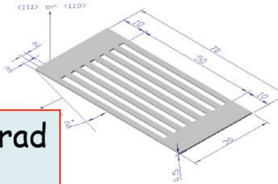
Several consecutive reflections



- enhance the deflection angle
- keep large cross section

W. Scandale 12

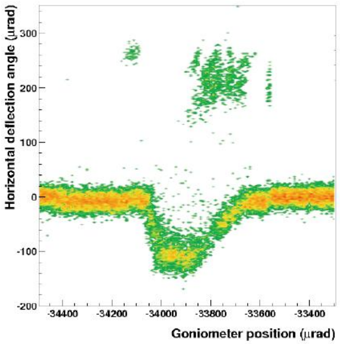
Multi-strips



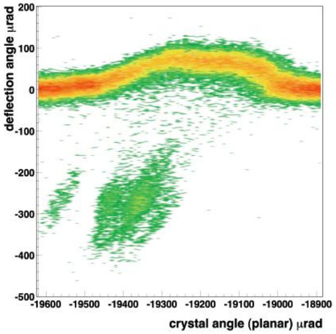
- Volume reflection angle ~100 μrad
- Efficiency ~ 90 %

MST 14 – 400 Gev – R=4.61m

INFN-Ferrara

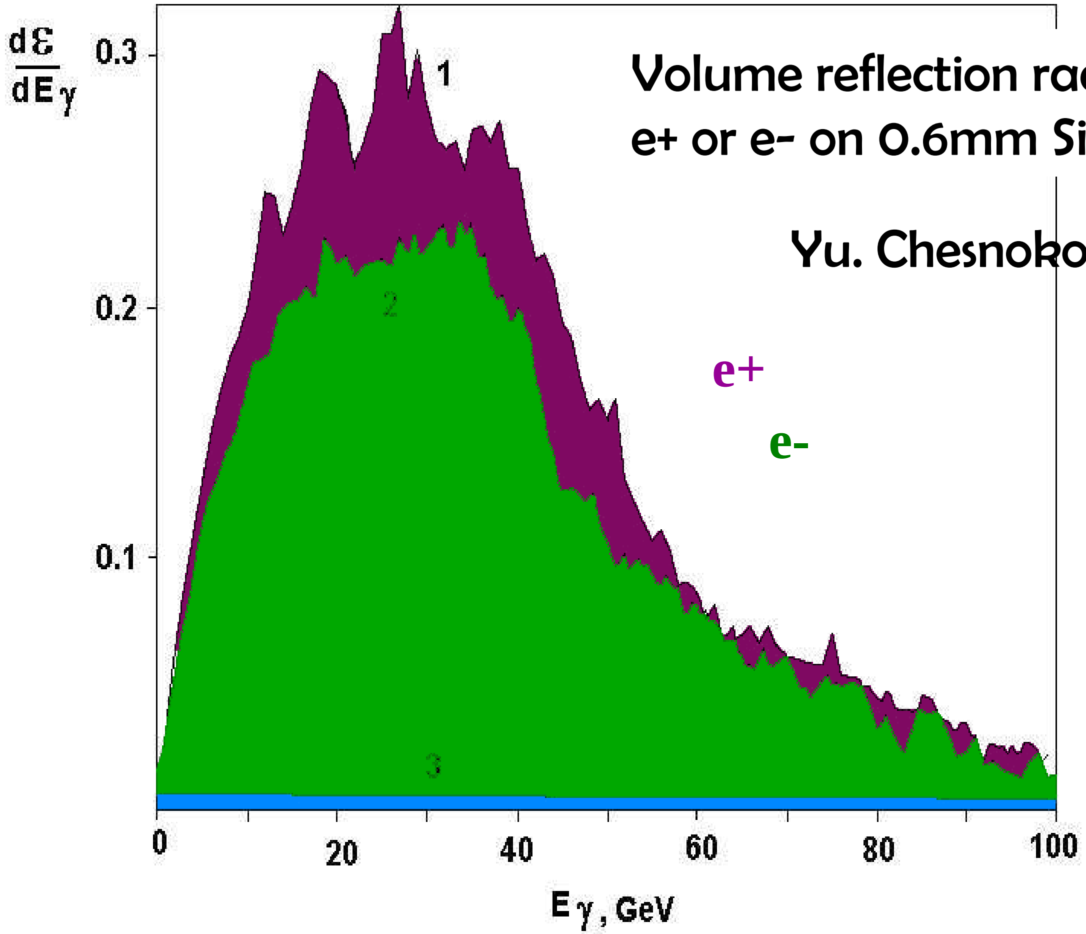


IHEP



Multi-strip is one of the 3 new crystals to be installed in the T-980 new goniometer in the Tevatron this June.

VOLUME REFLECTION RADIATION



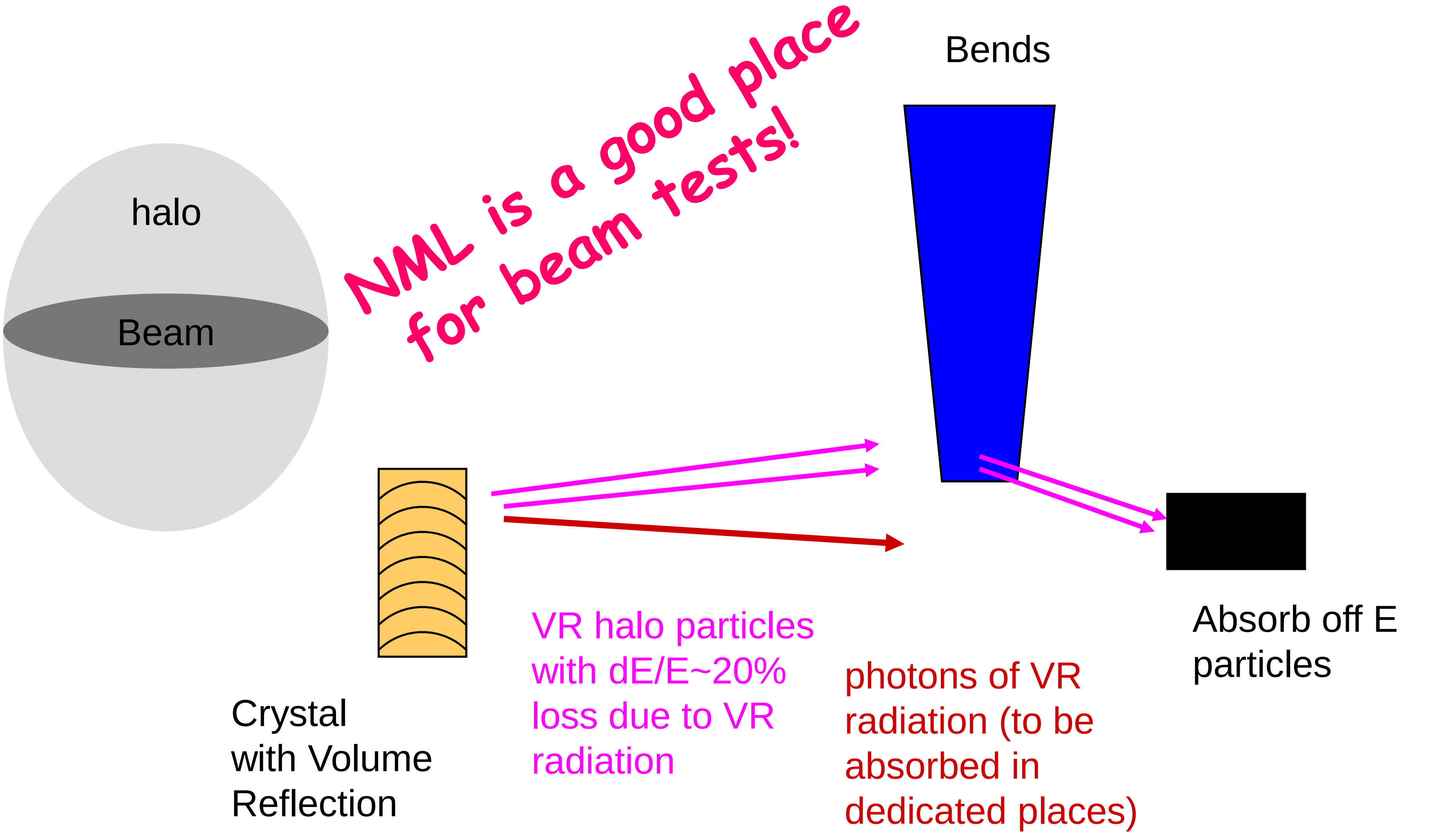
Volume reflection radiation of 200GeV e+ or e- on 0.6mm Si crystal (R_{bend}=10m)

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

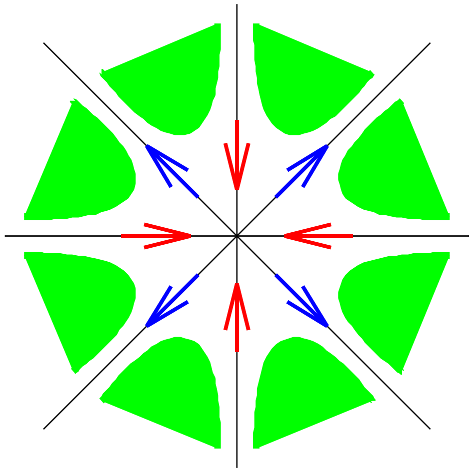


Nonlinear Handling of Beam Tails

- 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**

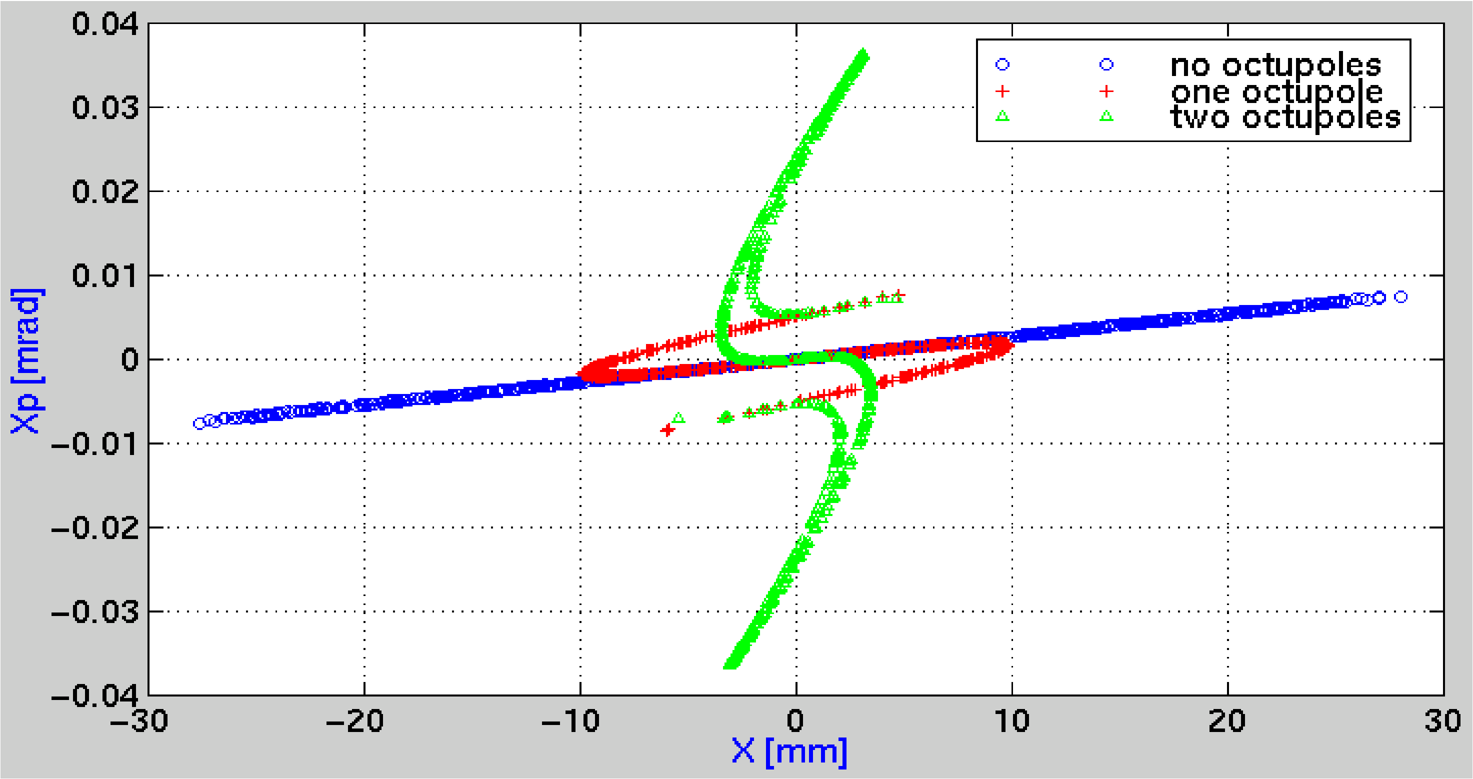


Single octupole focus in planes and defocus on diagonals.

An octupole doublet can focus in all directions !

Courtesy A. Seryi

Schematic of Halo Folding with Octupole or OD



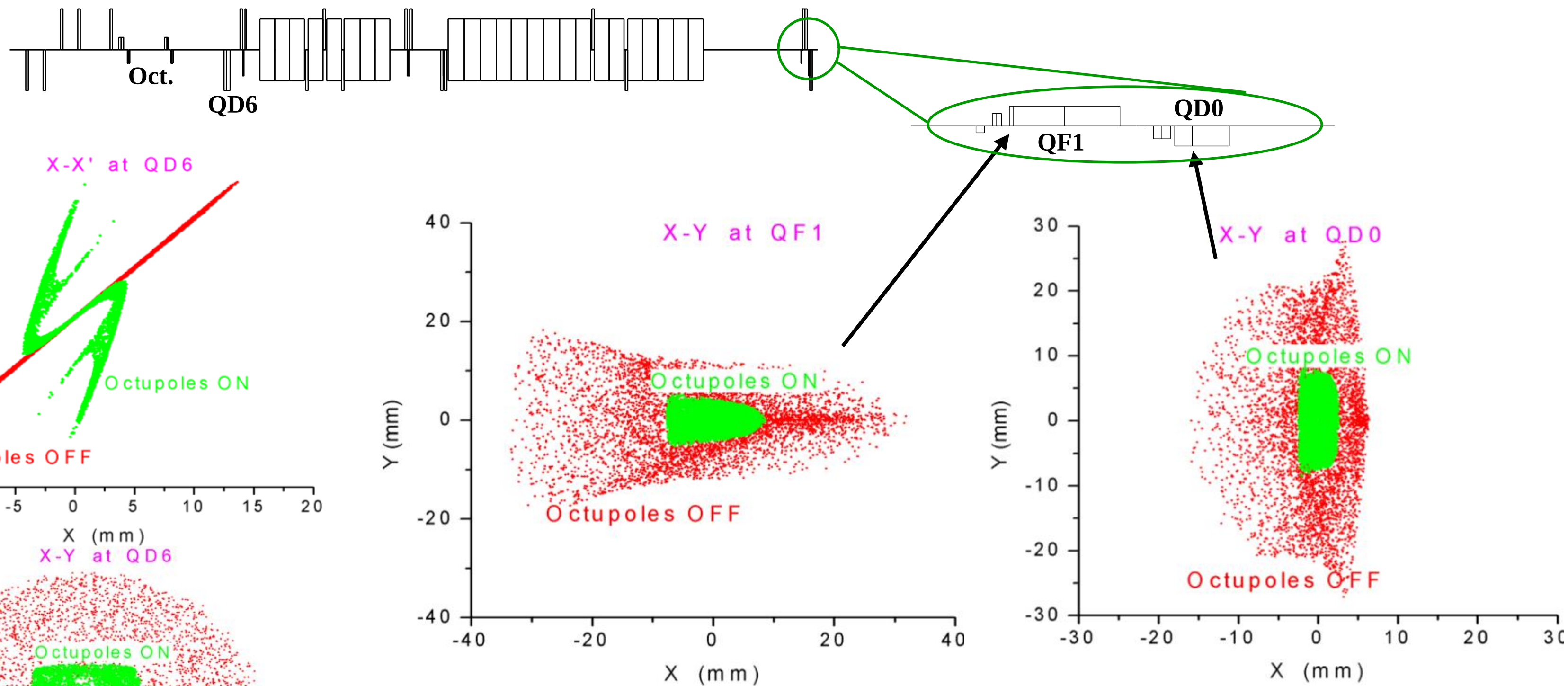
Folding of the horizontal phase space distribution at the entrance of the Final Doublet with one or two octupoles in a "Chebyshev Arrangement"

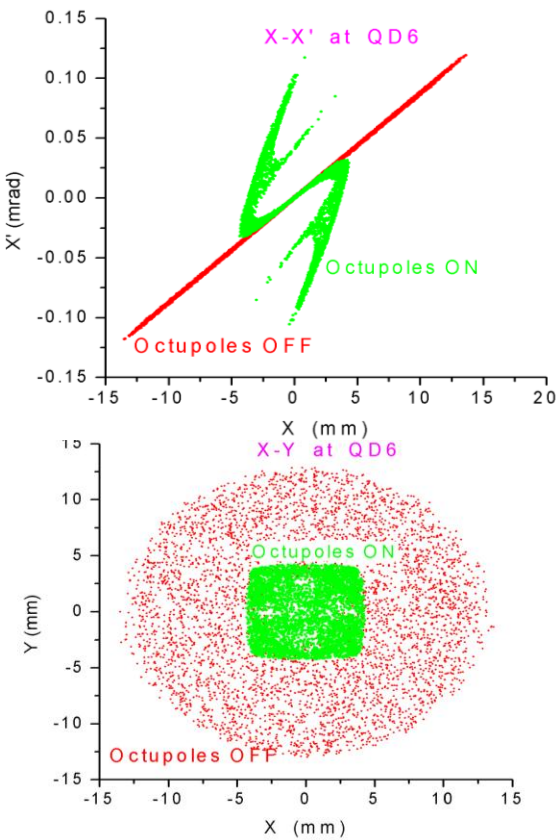
Can we test this at NML?

Courtesy A. Seryi

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.

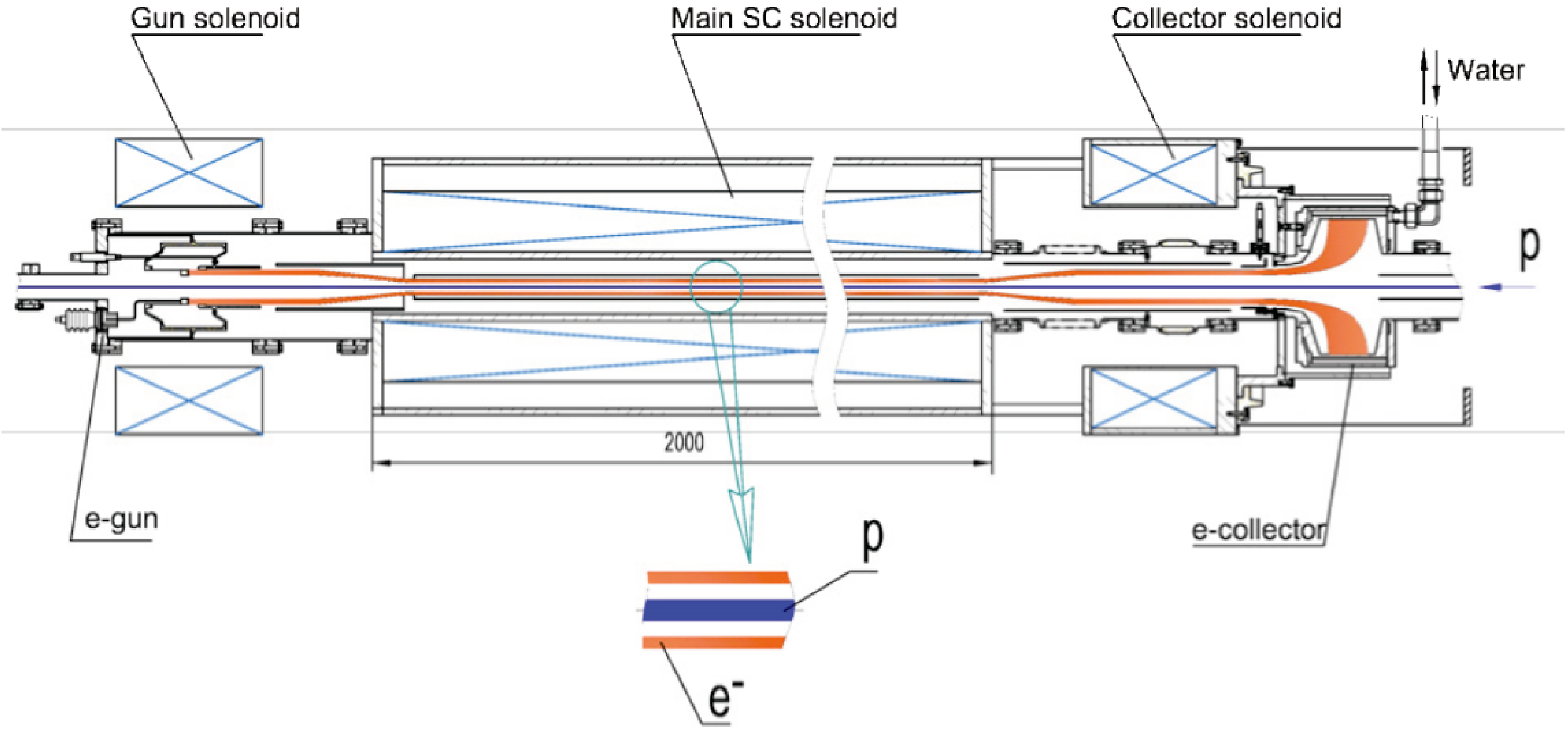




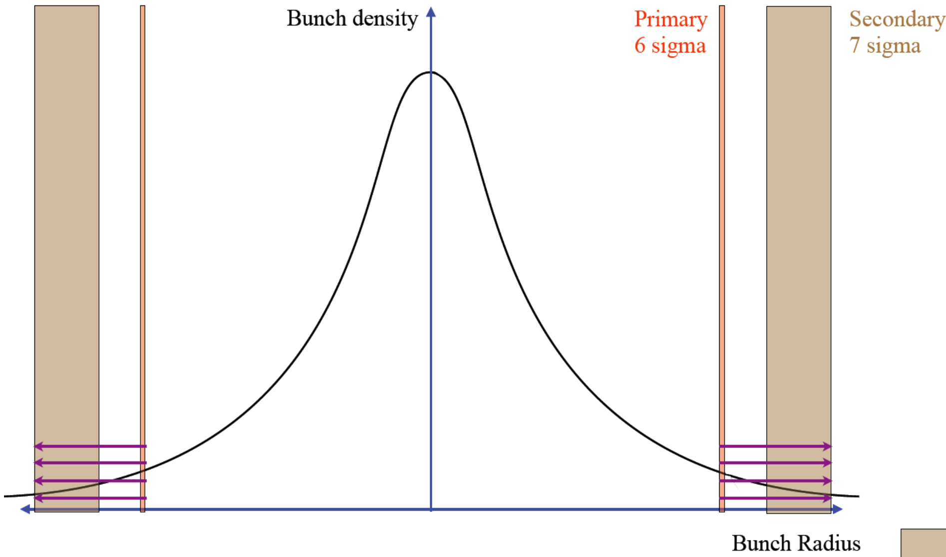
Tail folding by means of two octupole doublets in the new NLC final focus
Input beam has (x,x',y,y') = (14μm,1.2mrad,0.63μm,5.2mrad) in IP units (flat distribution, half width) and ±2% energy spread,
that corresponds approximately to N_σ=(65,65,230,230) sigmas with respect to the nominal NLC beam

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

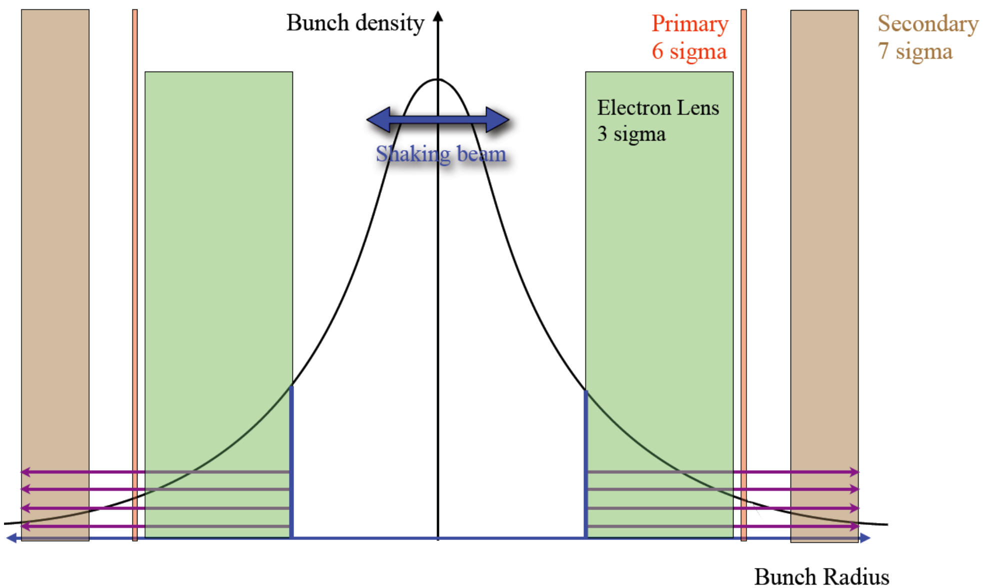


CONVENTIONAL vs HOLLOW LENS COLLIMATION



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

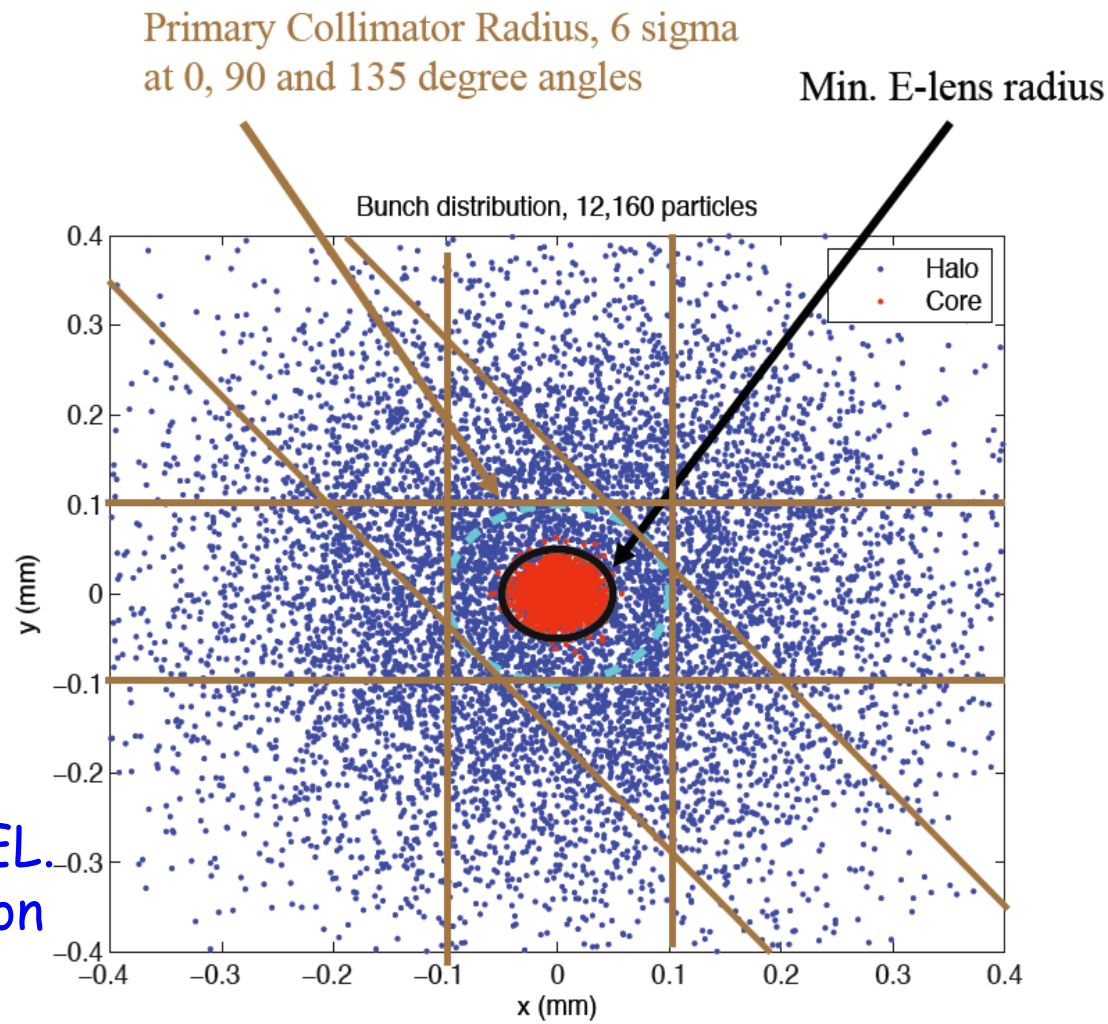
No material can survive closer than 5 s



Courtesy J. Smith

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.

PROPOSED ACCELERATOR R&D

- Continue T-980 crystal collimation experiment at the Tevatron through the end (or even somewhat beyond) of the collider Run II. New advanced goniometer, 3 crystals and enhanced beam diagnostics to be installed this summer. Study potential of large-acceptance VR.
- Hollow e-lens in the Tevatron as a candidate for LHC Phase II collimation.
- Experiment at NML on volume reflection radiation as an interesting possibility for e+ e- beam collimation.
- Experiment at NML on beam tail folding with octupole doublet.
- Materials beam test facility (at Pbar?) for Project X, neutrino factory, muon collider and ADS MW beam needs.