Summary Session Advanced Collimation

CARE-HHH-APD BEAM'07

R. Assmann

Agenda

Session 4 Advanced collimation (16:10 ->18:40)		Chairperson: Ralph Assmann (*CERN*)
16:10	**Collimation issues for the two LHC+ scenarios and future plans** (20') (Slides)	Ralph Assmann (*CERN*)
16:30	**LARP contributions to the LHC phase-2 collimation** (20') (Slides)	Thomas Markiewicz (*SLAC*)
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The Staged LHC Path

	Energy density at collimators (nominal 7 TeV)	**Stored energy in beams**	**Number of LHC collimators**
State-of-the-art in SC colliders (TEVATRON, HERA, …)	**1 MJ/mm²**	**2 MJ**	
Phase 1 LHC collimation	**400 MJ/mm²**	**150 MJ**	**88**
Nominal LHC	**1 GJ/mm²**	**360 MJ**	**122**
Ultimate & upgrade scenarios	**~2 GJ/mm²**	**800 MJ**	**≤ 138**
Limit (avoid damage/quench)	**~50 kJ/mm²**	**~10-30 mJ/cm³**	

Factor > 1000 energy density

Equivalent 80 kg TNT explosive

The LHC Upgrade Scenarios

Scenario	Protons stored	Energy stored	Energy in 200 ns	β*	Peak luminosity
Phase 1 collimation	1.4×10^{14}	**150 MJ**	**0.4 MJ**	0.55 m	0.4×10^{34}
Nominal	3.2×10^{14}	**360 MJ**	**1.0 MJ**	0.55 m	1.0×10^{34}
Ultimate	4.8×10^{14}	**532 MJ**	**2.2 MJ**	0.50 m	2.3×10^{34}
Scenario I	4.8×10^{14}	**532 MJ**	**2.2 MJ**	0.08 m	15.5×10^{34}
Scenario II	6.9×10^{14}	**767 MJ**	**2.3 MJ**	0.25 m	10.7×10^{34}

Improve stability and efficiency!

Address collimator robustness or upgrade beam dump!

Collimation Issues for LHC Upgrade I

- **Higher stored energy** (higher peak losses, higher annual losses, higher activation):
  - Better or same beam stability (upgrade must not reduce beam stability – should be a decision criterion).
  - Better spreading of losses ➔ Operational procedures to avoid local hot spots.
  - Improved collimation efficiency ➔ White paper, LARP, FP7 work.
  - Improved radiation hardness of collimators ➔ White paper, LARP, FP7 work.
  - Improved power absorption ➔ White paper, LARP, FP7 work.
  - Improved local protection or more radiation-hard warm magnets ➔ Experience will show whether needed (less leakage with phase 2).
  - Improved shielding of electronics ➔ Experience will show whether needed.
  - Radiation impact study.
  - Upgrade of beam dump and protection devices.
  - Upgrade of super-conducting link cable in IR3.

Collimation Issues for LHC Upgrade II

- **Higher beam intensity** (intensity dependent effects from collimator-driven LHC impedance):
  - Operation with increased chromaticity.
  - Upgrade of transverse feedback.
  - Operational collimator gaps opened, if efficiency/protection/halo allows to do this.
  - Better conducting collimator jaw material ➔ White paper, LARP, FP7 work.
- **Higher shock beam impact** from irregular dumps:
  - Upgrade of the LHC beam dump to reduce amount of escaping beam.
  - Address collimator robustness ➔ White paper, LARP, FP7 work.

Collimation Issues for LHC Upgrade III

- **<u>Layout, aperture and optics changes</u>** in experimental insertions:
  - Local collimation and protection must be re-evaluated in detail such that tertiary collimation (effect on background) is kept functional.
  - Probably need to rebuild tertiary collimators for ATLAS and CMS.
  - Full simulation of multi-turn halo losses in local aperture, power loads, machine protection and energy deposition is absolutely essential.
  - Full study of halo dynamics with potentially increased off-momentum beta-beat.
  - Collimation request: local triplet masks also for the incoming beam (best possible protection and cleaning)!
- Important not to underestimate the overall effects from local changes in the experimental insertions!

Future Plans

- Powerful LHC collimation system is being installed. Should allow extrapolation in stored energy by factor 100.
- Nevertheless, it can well be that nominal and ultimate LHC intensities already are limited due to beam loss and collimation.
- Work already ongoing or being prepared for phase 2 collimation with support from CERN white paper, LARP and FP7 (if approved):
  - Better efficiency
  - Better radiation hardness
  - Better power absorption
  - Better conducting jaws
  - More robust jaws or in-situ handling of damage
  - Improved operational setup with jaw-internal diagnostics
- No magic bullet ➔ Several improvements together will get us ready for LHC upgrade scenarios!

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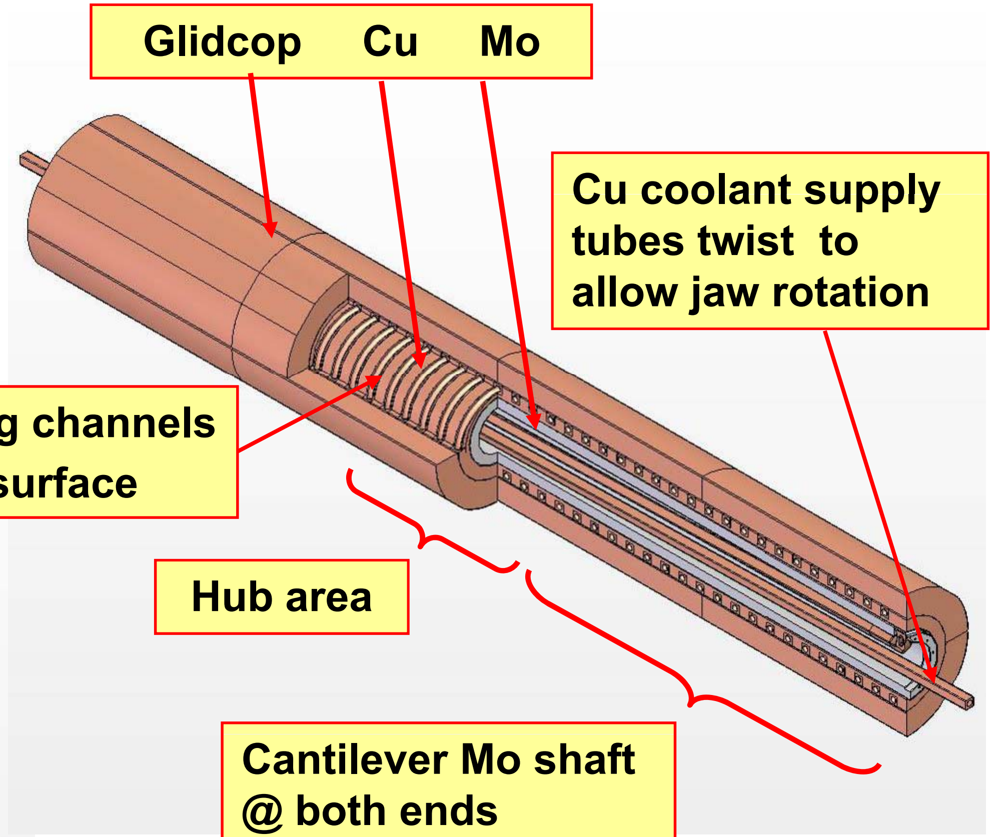
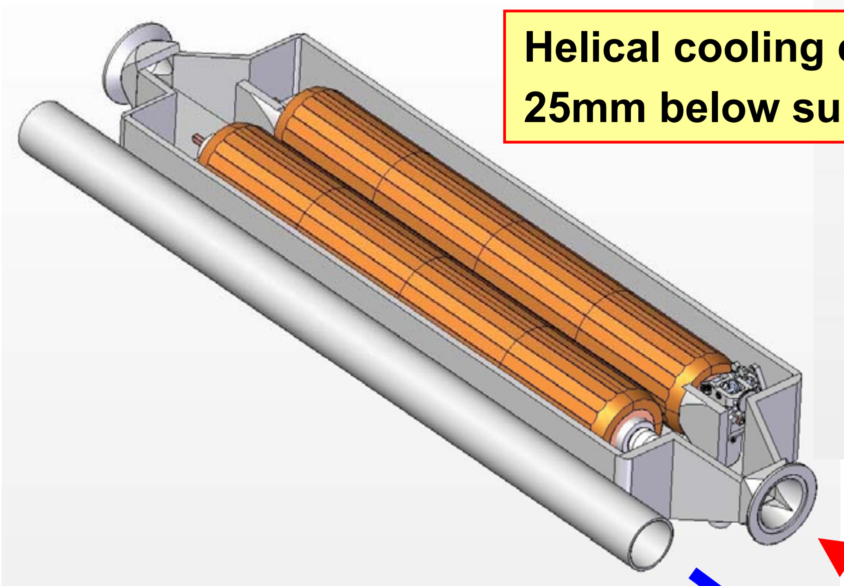
LHC Phase II Base Concept

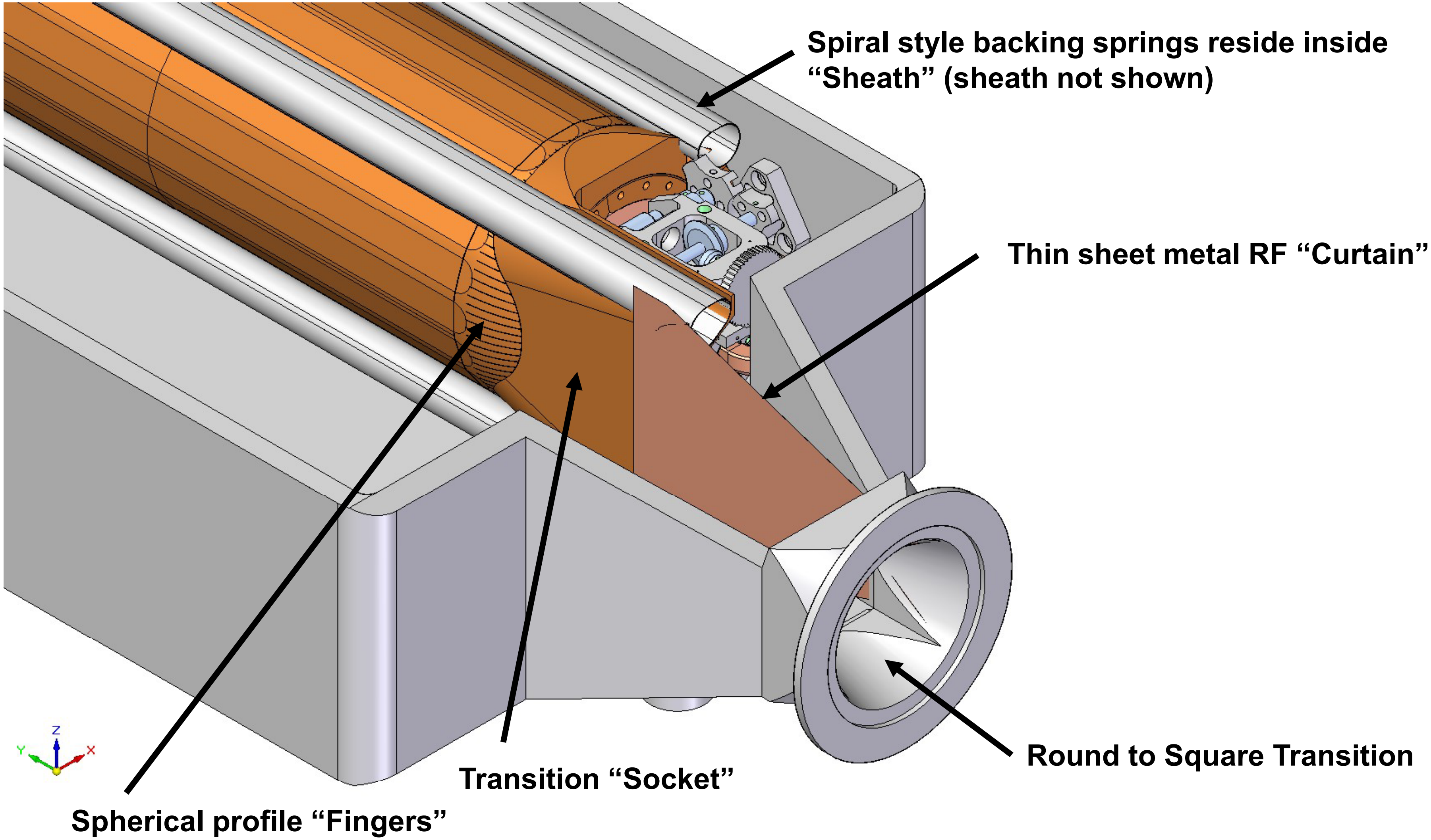
physical constraints
current jaw design

- **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)**

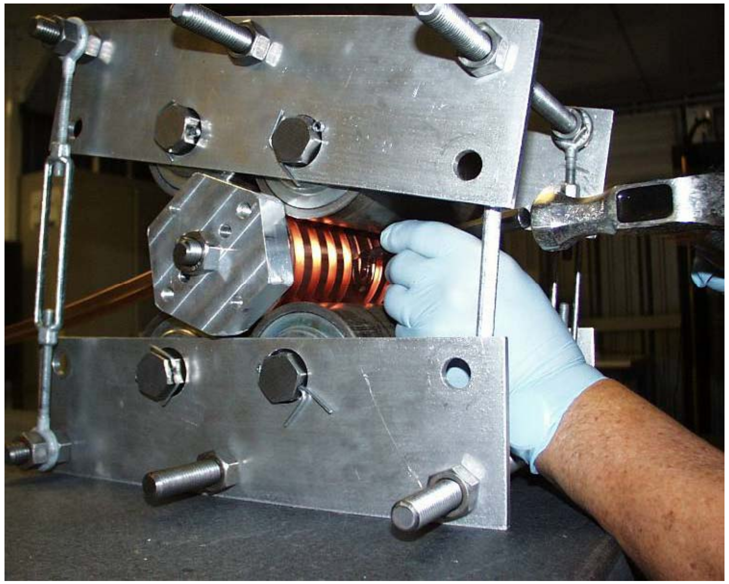




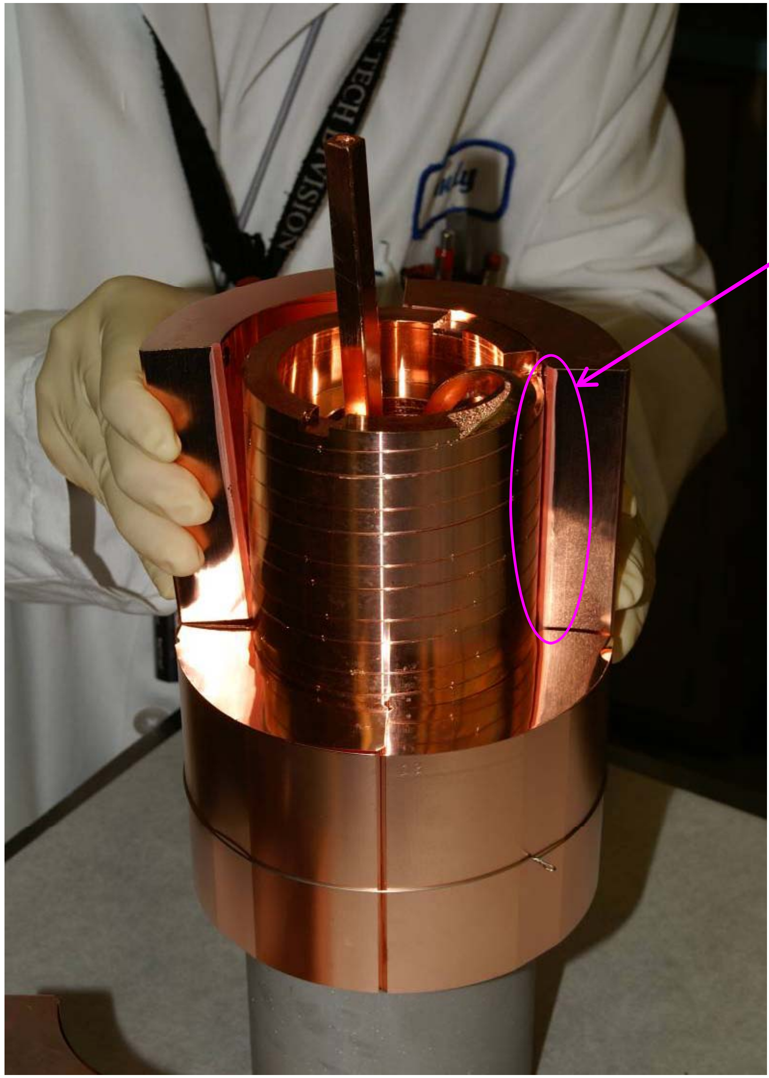
Up Beam end beam side view



Final Wind of First 200mm Copper Mandrel



Braze Test #3: Vacuum tests



3rd Jaw Braze Test Assembly has been vacuum baked at 300 degrees C for 32 hours. Results in slightly lower pressure.

Inclusion of longitudinal grooves in the inner length of jaws for better outgasing

Test Chamber setup similar to previous test.

	Old	New
Baseline	3.2E-9 Torr	2.4E-9 Torr??
w/ jaw assy.	3.7E-9 Torr	3.4E-9 Torr
Presumed jaw assy. pressure	4.5E-10 Torr	10E-10 Torr??
LHC requirement	7.5E-10 Torr	7.5E-10 Torr

Under Investigation...

LARP

LARP Collimator Delivery Schedule

Done	Braze test #1 (short piece) & coil winding procedures/hardware Prep heaters, chillers, measurement sensors & fixtures, DAQ & lab Section Braze test #2 (200mm Cu) and examine –apply lessons Braze test #3 (200mm Cu) – apply lessons learned
	Fab/braze 930mm shaft, mandrel, coil & jaw pieces
2008-01-01	1st full length jaw ready for thermal tests
	Fab 4 shaft supports with bearings & rotation mechanism Fab 2nd 930mm jaw as above with final materials (Glidcop) and equip with rf features, cooling features, motors, etc. Modify 1st jaw or fab a 3rd jaw identical to 2nd jaw, as above Mount 2 jaws in vacuum vessel with external alignment features
2008-09-01	2 full length jaws with full motion control in vacuum tank available for mechanical & vacuum tests in all orientations (“RC1”)
	Modify RC1 as required to meet requirements
2009-01-01	Final prototype (“RC2”) fully operational with final materials, LHC control system-compatible, prototype shipped to CERN to beam test

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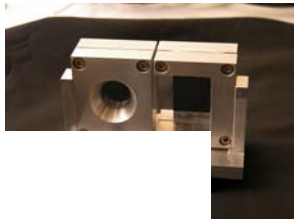
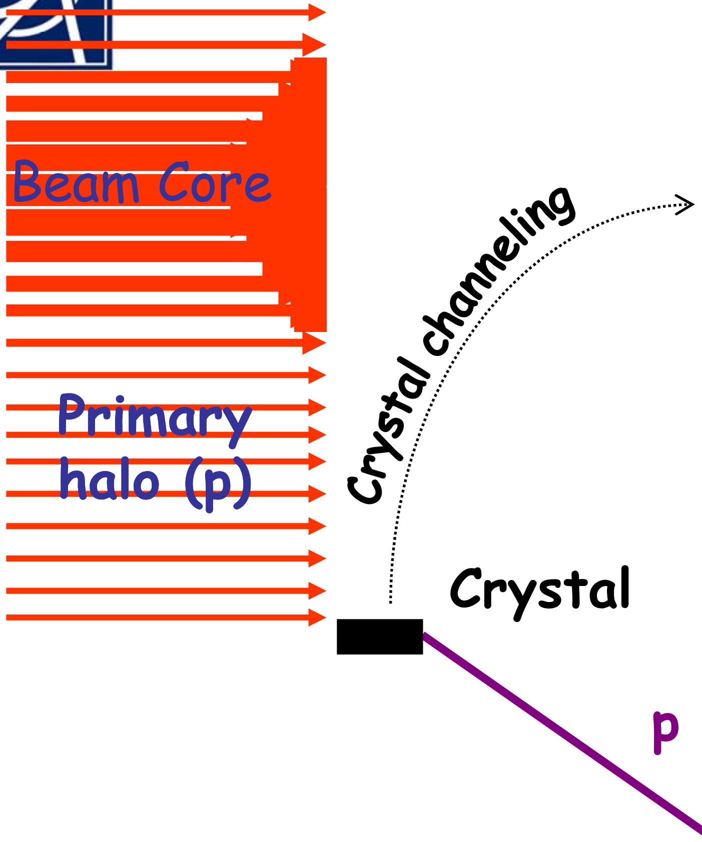
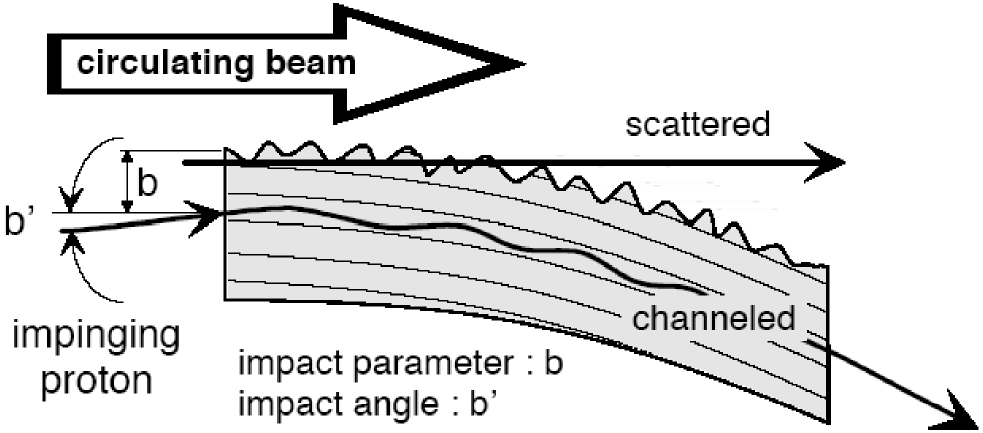
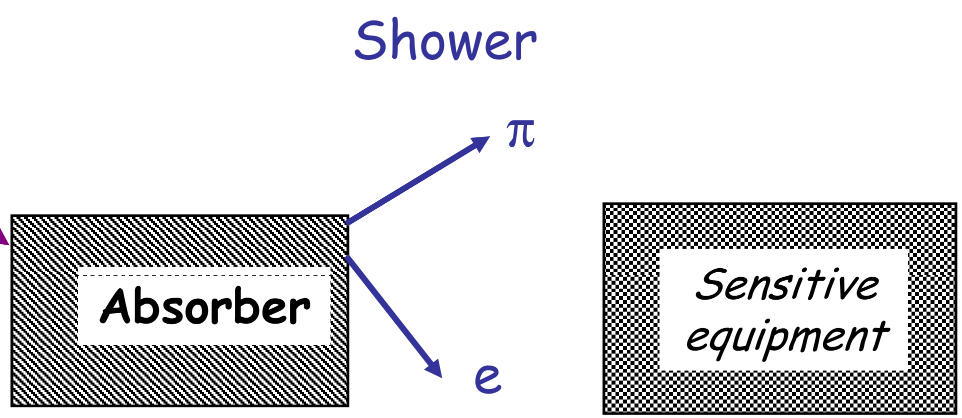
Crystal collimation







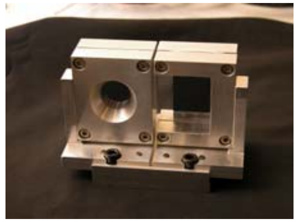
E. Tsyganov & A. Taratin (1991)



- Primary halo directly extracted!
- Much less secondary and tertiary halos
- Larger gap in the secondary collimators

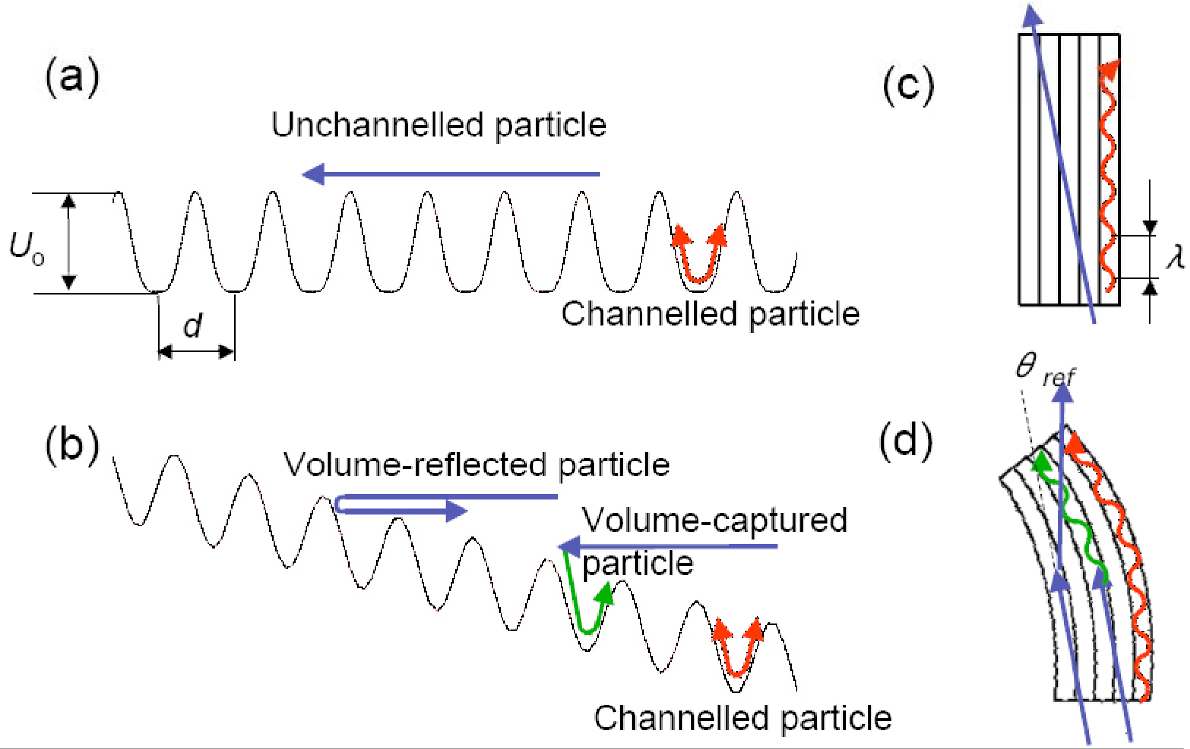
...but not enough data available yet to substantiate the idea...

Particle-crystal interaction



Possible processes:

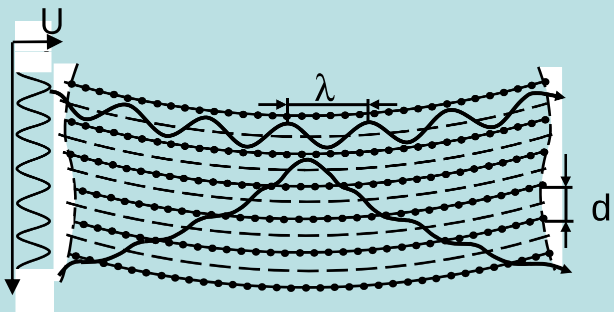
- multiple scattering
- channeling
- volume capture
- de-channeling
- *volume reflection*



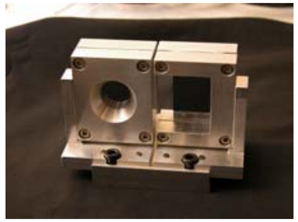
Volume reflection

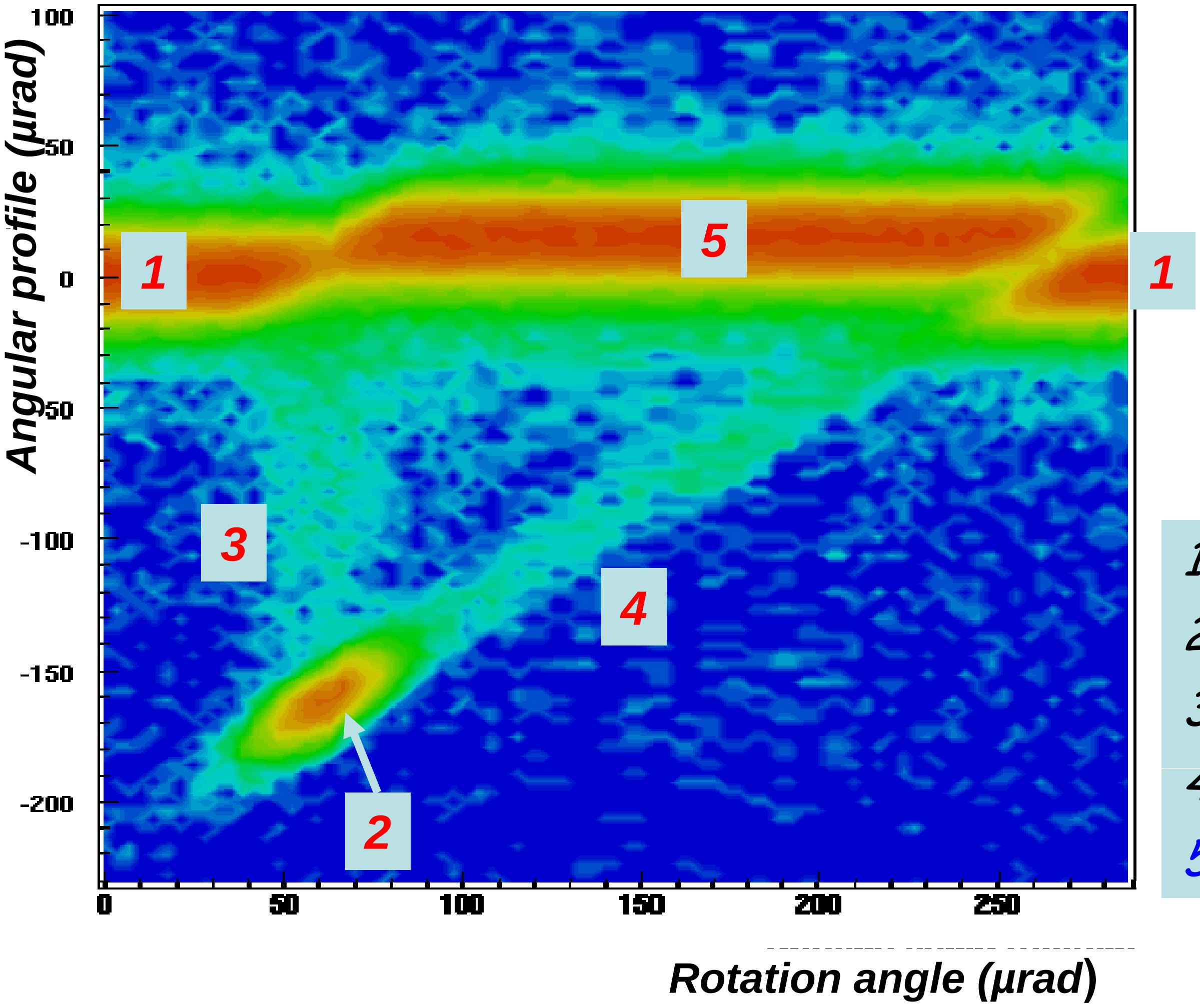
Prediction in 1985-'87 by A.M.Taratin and S.A.Vorobiev,

First observations in 2006 (IHEP - PNPI - CERN)



Angular beam profile as a function of the crystal orientation





The **angular profile** is the change of beam direction induced by the crystal

The **rotation angle** is angle of the crystal respect to beam direction

The **particle density** decreases from red to blue

1 - "amorphous" orientation

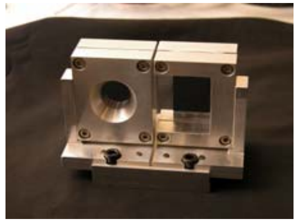
2 - channeling

3 - de-channeling

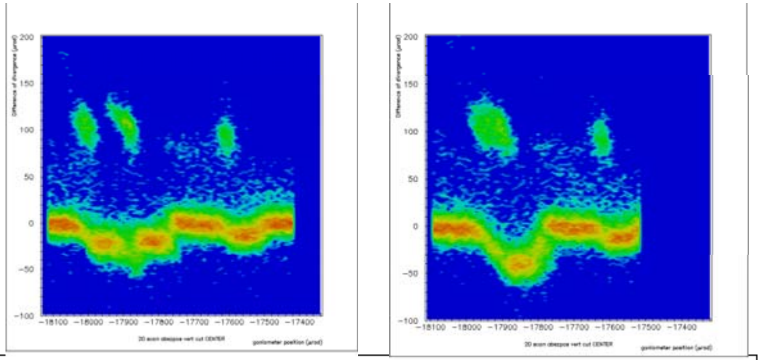
4 - volume capture

5 - volume reflection

Multi Reflection on Quasi-Mosaic Crystals (2)

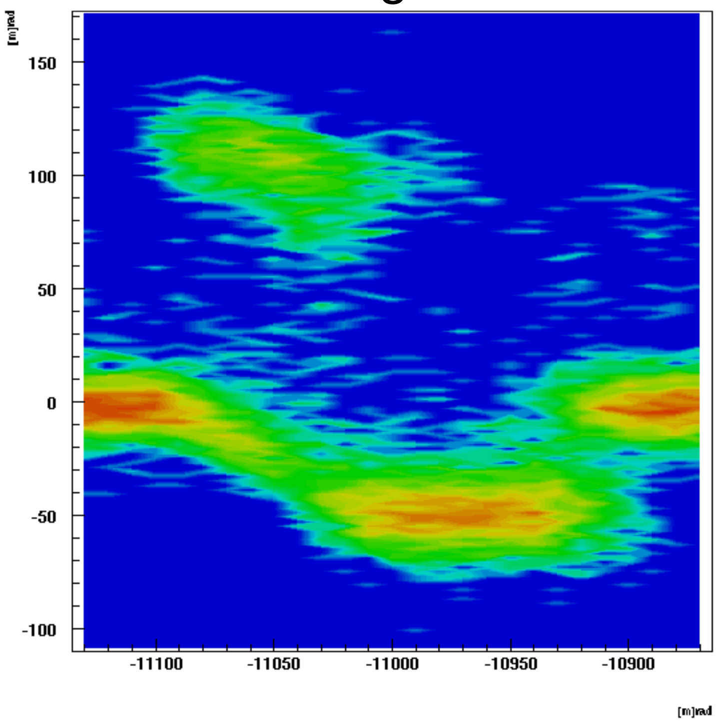


Steps to align the five crystals



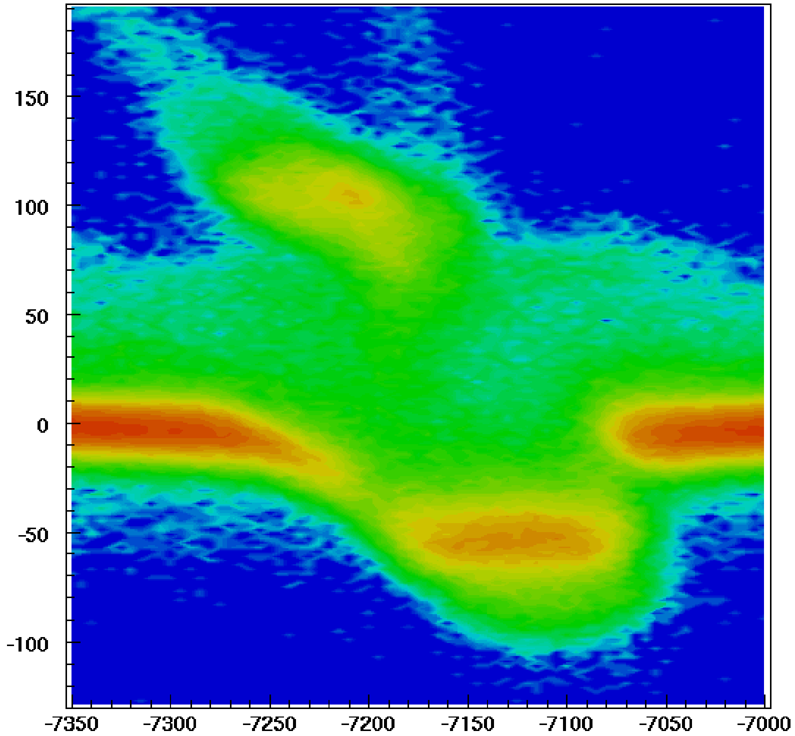
- Volume reflection angle 53 µrad
- Efficiency ≥ 90 %

Best alignment

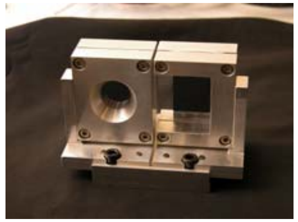


ection on bent

High statistics



Conclusion



- High efficient reflection (and channeling) observed in single pass interaction of high-energy protons with bent crystals (0.5 to 10 mm long)
- Single reflection on a Si bent crystal deflects > 98 % of the incoming 400 Gev p beam by an angle 12÷14 μrad
- Multi-reflections on a sequence of aligned crystals to enhance the reflection angle successfully tested with two and five consecutive crystals.
- Axial channeling observed (scattering enhancement)

Very promising results for application in crystal collimation

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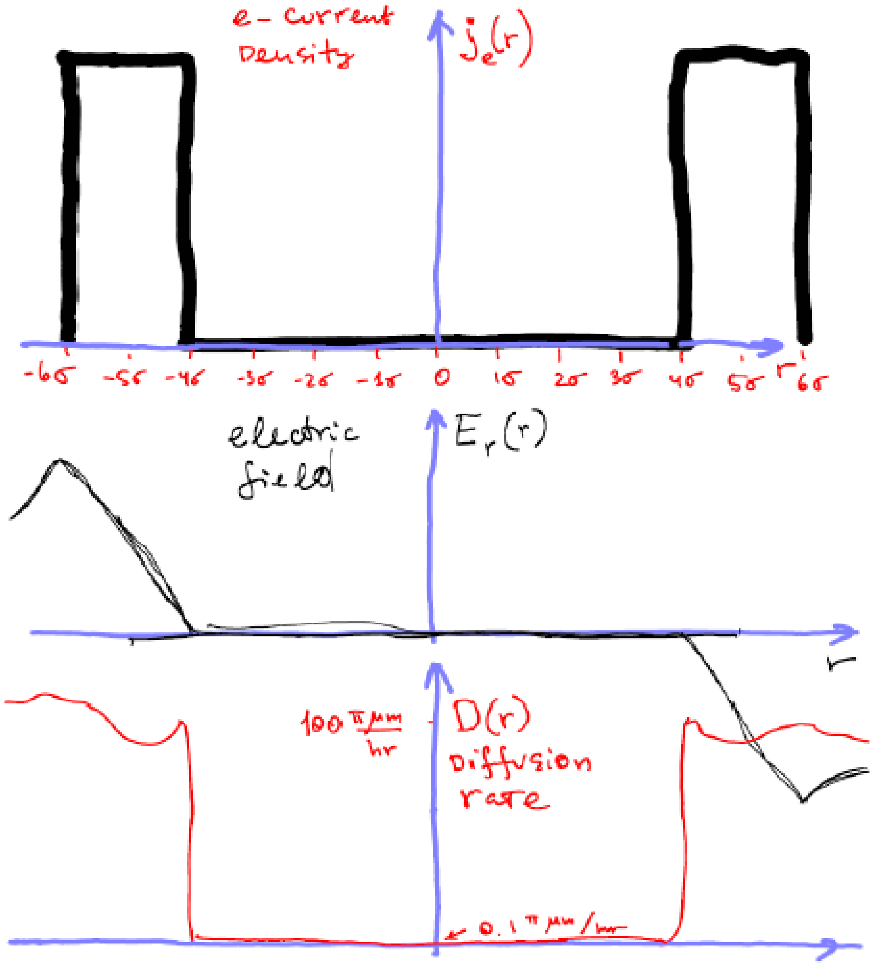
FNAL Experience with TEL

- **Besides it's a B-B-Compensator**
- **TEL can be a great "KILLER"**
  - blow up emittances in controlled fashion
  - drive particles out - randomly or via resonance drive
  - remove unwanted particles, bunches, e.g.:
    - only in between bunches
    - just 1 out of 3000 or satellites only
    - only those with a>5 x Sigma , etc, etc

Hollow Electron Beam as Collimator

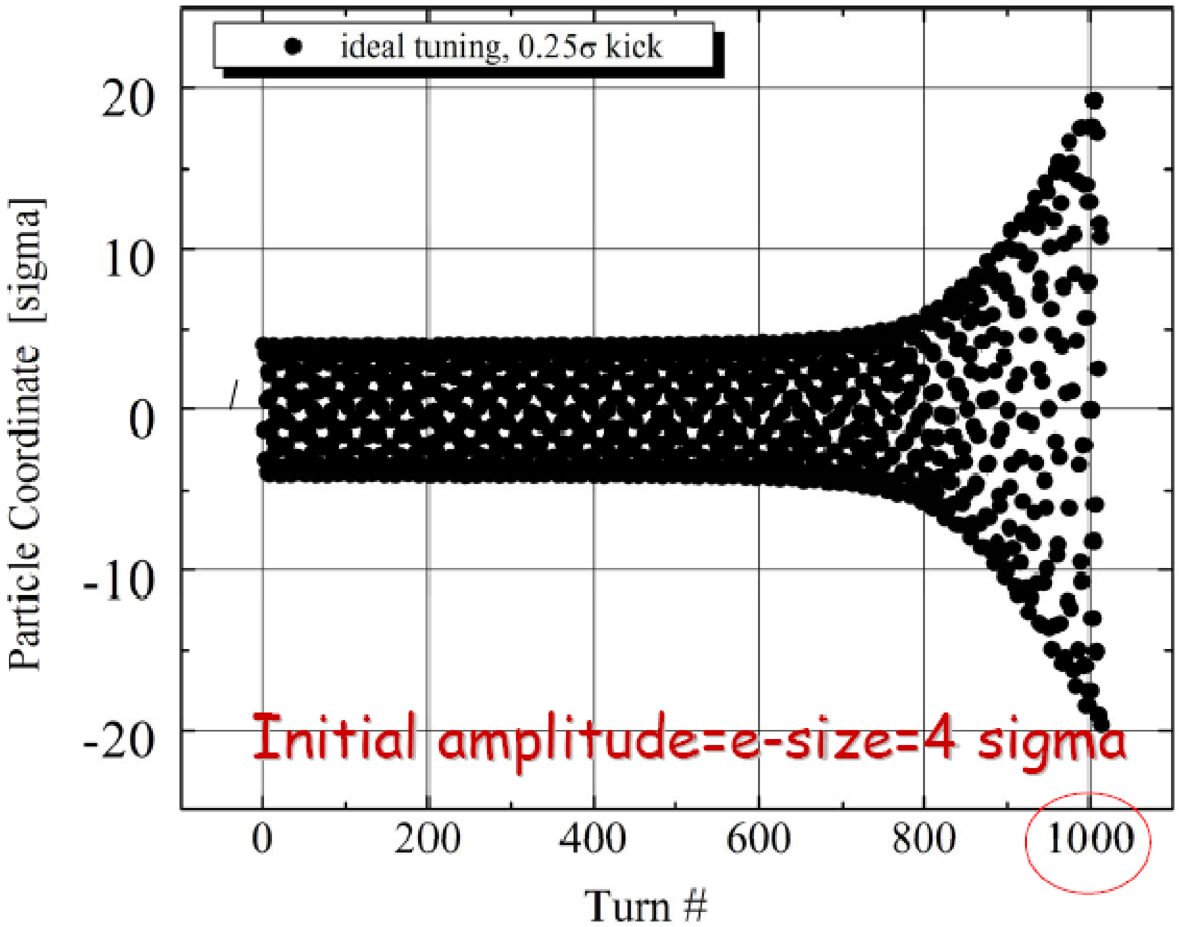


Duffusion enchanced by:

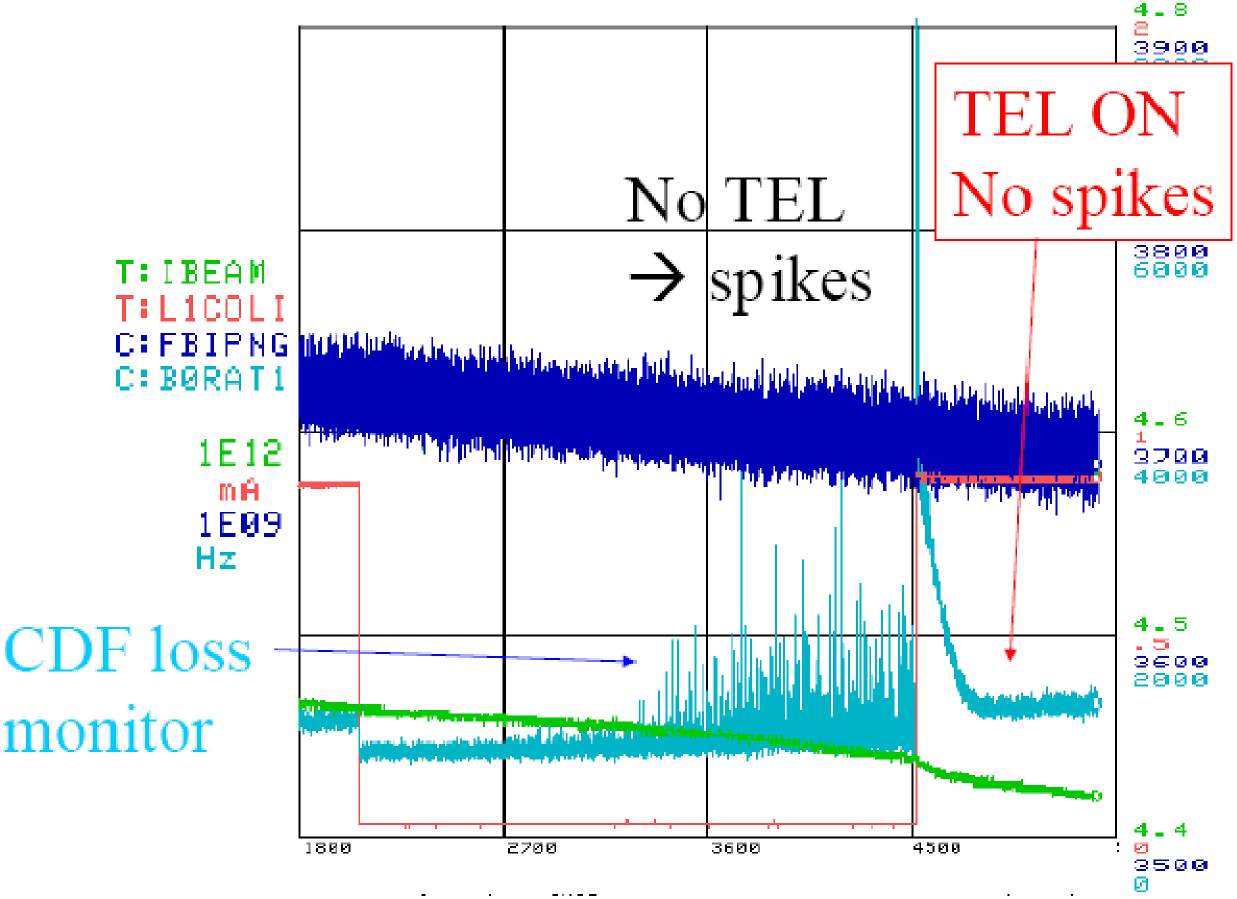
a) by resonant driving at betatron frequency

b) Non-linear fields

Simulated: proton Q=0.31, kick=0.25 sigma



Electron lens collimates "smoothly"



eLens Collimation: "Pro's"

- eLens technology available - TEL
  - Reliability proven by years of operation of Collider
- No nuclear, just EM interaction, can work for ions &protons
- Seems to be strong enough to clean fast
  - Cleaning time (0.1-30 sec) << diffusion time (1000's sec)
- Refreshable, no damage
  - No need of exp(t)ensive damage diagnostics
- Easy size/position control by B-fields, no movers, etc.
- Smooth cleaning (multiturn)
  - No extreme sensitivity to orbit motion
  - No spikes in the loss rates and rad loads on secondaries
- <u>SUMMARY</u>: e-Collimation looks very promising, should be considered in detail, may complement conventional system, is perfect for ions.

Discussion

- LHC(+) collimation issues:
  - Risk associated with **radiation damage to CFC** material.
  - Expected **limitations** for intensity, beam loss rates and LHC performance.
  - **SNS experience supports criticality of collimation** (already facing loss limitations).
  - **Diffusion models** and size of **impact parameter** are crucial.
- SLAC/LARP phase 2 work:
  - **Material** choice for phase 2: Glidcop.
  - Risk when **bending cooling pipes** must take radiation effects into account.
  - Extent of **expected jaw damage** after beam impact.
- Crystals:
  - **Acceptance of crystals** in particle angle.
  - Complements conventional collimation – **surface effects** at crystal.
  - **Radiation-hardness** of crystals.
  - **Experimental program** (CERN, FNAL, …).
- Electron lens:
  - Will **still need efficient collimators**, does not replace them.
  - What **increase in impact parameter** at collimators.
  - Can efficiently **smooth out loss spikes** (solution for possible major LHC issue).
  - Inherently **safe** with collimators still in place.

Conclusion

- Beam loss and collimation issues are challenging and are inspiring new solutions…
- Lively session with plenty of discussion past 6pm.
  - **Thanks to the speakers and the audience for this!**
- The story on collimation at LHC and other high power accelerators (SNS, FAIR, …) is just starting:
  - Lot´s of lessons will be learnt from the beam with the phase 1 LHC collimation system.
  - SNS experience shows this: several loss issues addressed there with high priority.
  - Plenty of new ideas and concepts available for getting full performance reach of the LHC ➔ not just ideas…
  - The advanced ideas are being tested and made to work through hardware prototyping (SLAC/LARP) and beam tests (FNAL/LARP, CERN, crystal collaboration).
- Future work funded through CERN white paper, FP7 and LARP.
- **Session showed that collaboration is really fruitful…**