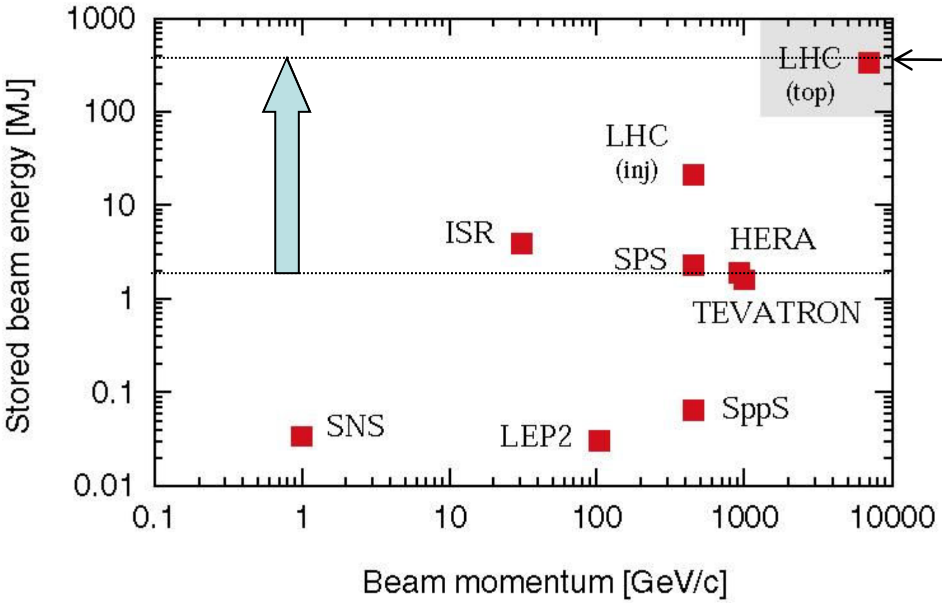
Simulations and Collimation Performance Predictions

A. Rossi on behalf of the CERN/collaboration collimation team

EuCARD 1st ANNUAL MEETING – 13-16 April 2010

The LHC Collimation Challenge



360 MJ

LHC quench limits:

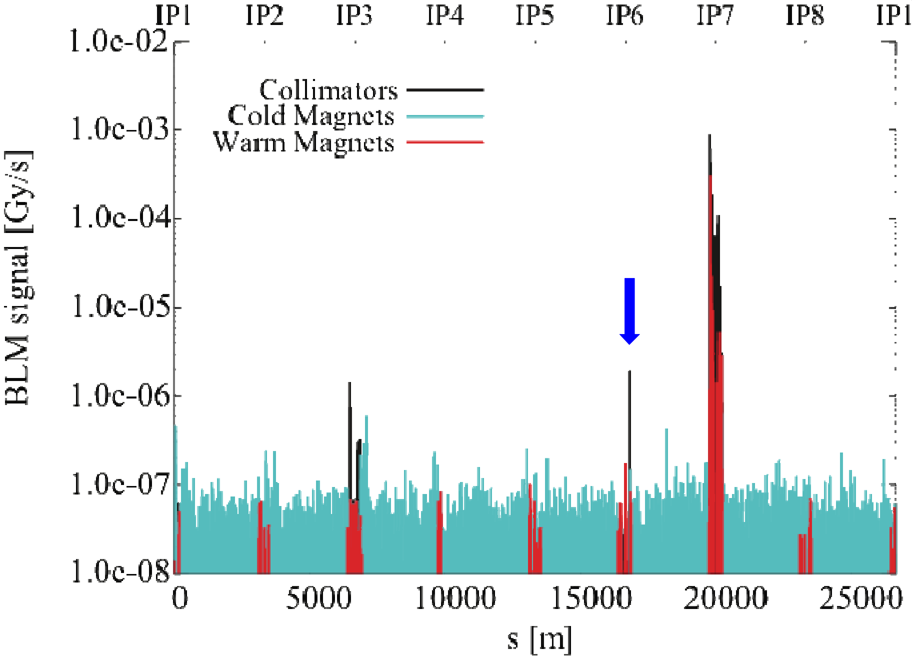
5-30 mJ/cm^3

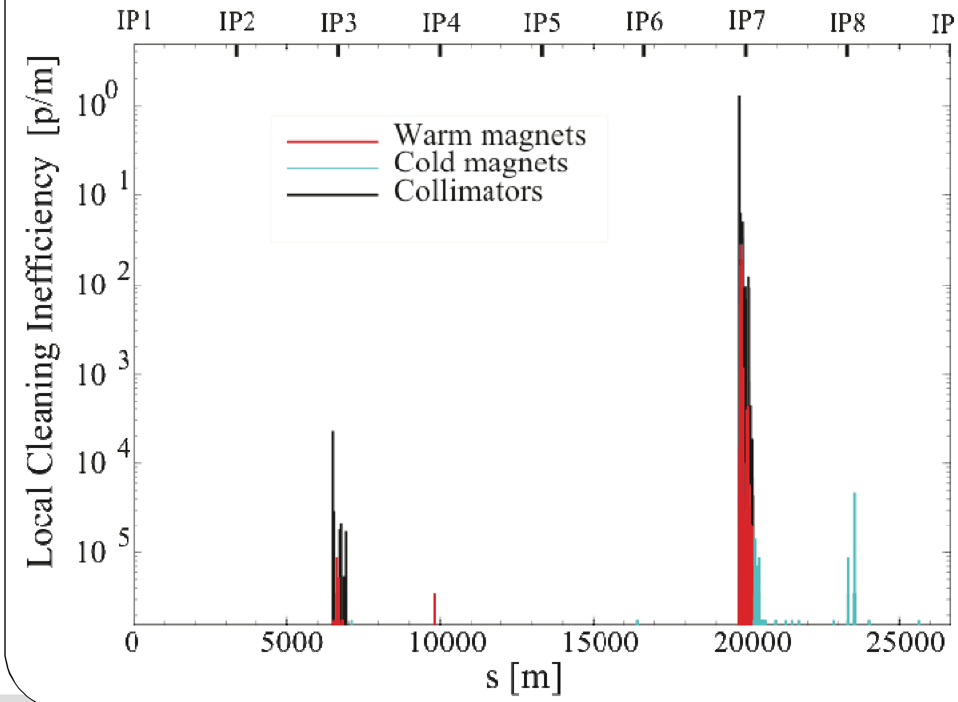
Collimators must clean unavoidable losses and survive expected beam loss…

- A phased approach proposed and approved in 2003:
  - Phase 1 implements for the startup 4-stage cleaning and collimators optimized for maximum robustness (can take full Tevatron beam without damage). **Confirmed by performance**.
  - Phase 2 later implements solution for nominal and ultimate intensity.

Loss Map at 1.18TeV Energy (Coll – Ph 1)

Measured loss map at 1.18TeV for Beam 1
(ramp of December 8th 2009)



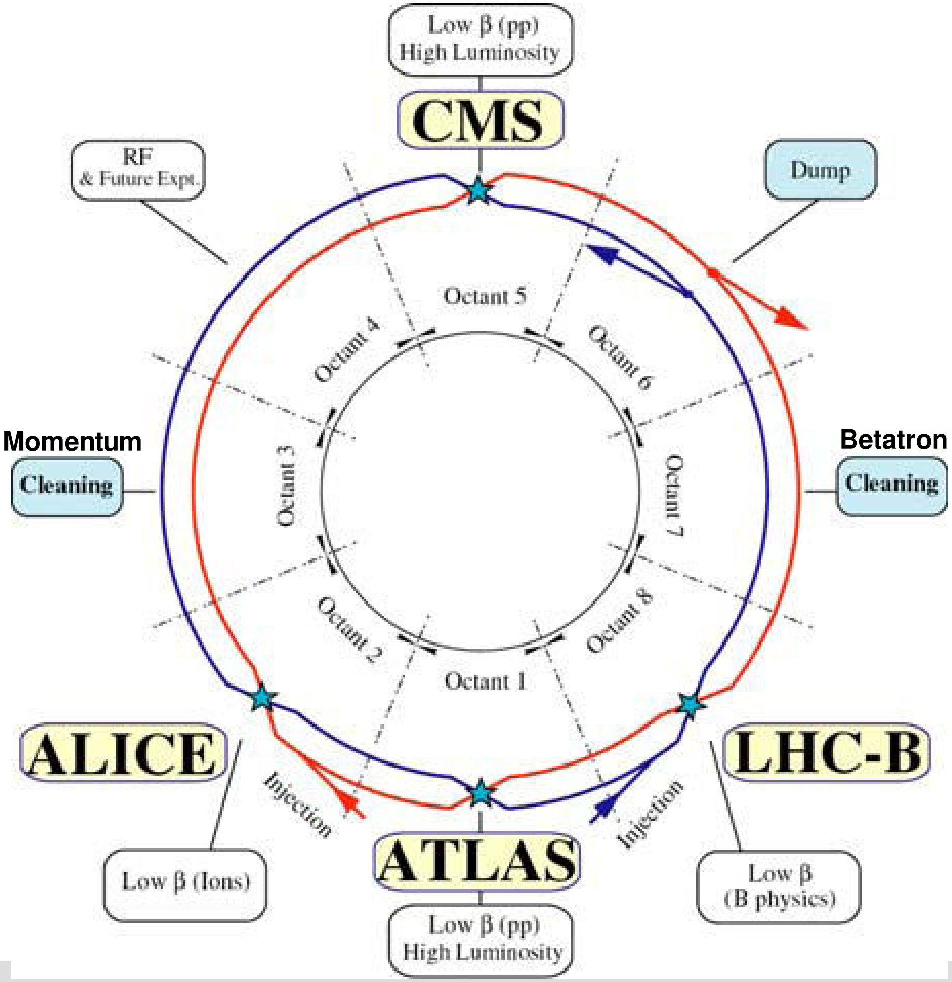


Simulated proton loss map at 1TeV for Beam 1

note that shower development is not included, only primary proton losses.

Collimation Phase 2
as complement to Phase 1

1. Additional secondary collimators and scrapers in the IR3 and IR7 warm regions (already prepared): Cu jaws with higher stopping power and lower impedance
   - CERN white paper
   - SLAC – LARP
   - EuCARD
2. Collimators into super-conducting dispersion suppressors (cryo-collimators) in IR7, IR3 and IR2
   - EuCARD (cryo-coll)
3. Combined Betatron/Momentum Cleaning in IR3



Collimation

- Cleaning inefficiency:

$$\eta(s) = N_{total}(A > \underline{A}) \Big/ \Delta s \cdot N_{abs}(s)$$

Total no. of particles with normalised amplitude > A in Δs

Total no. of particles undergoing inelastic interactions

- Intensity:

Quench limit

$$N_{p\ \max} = \tau R_q / \eta(s)$$

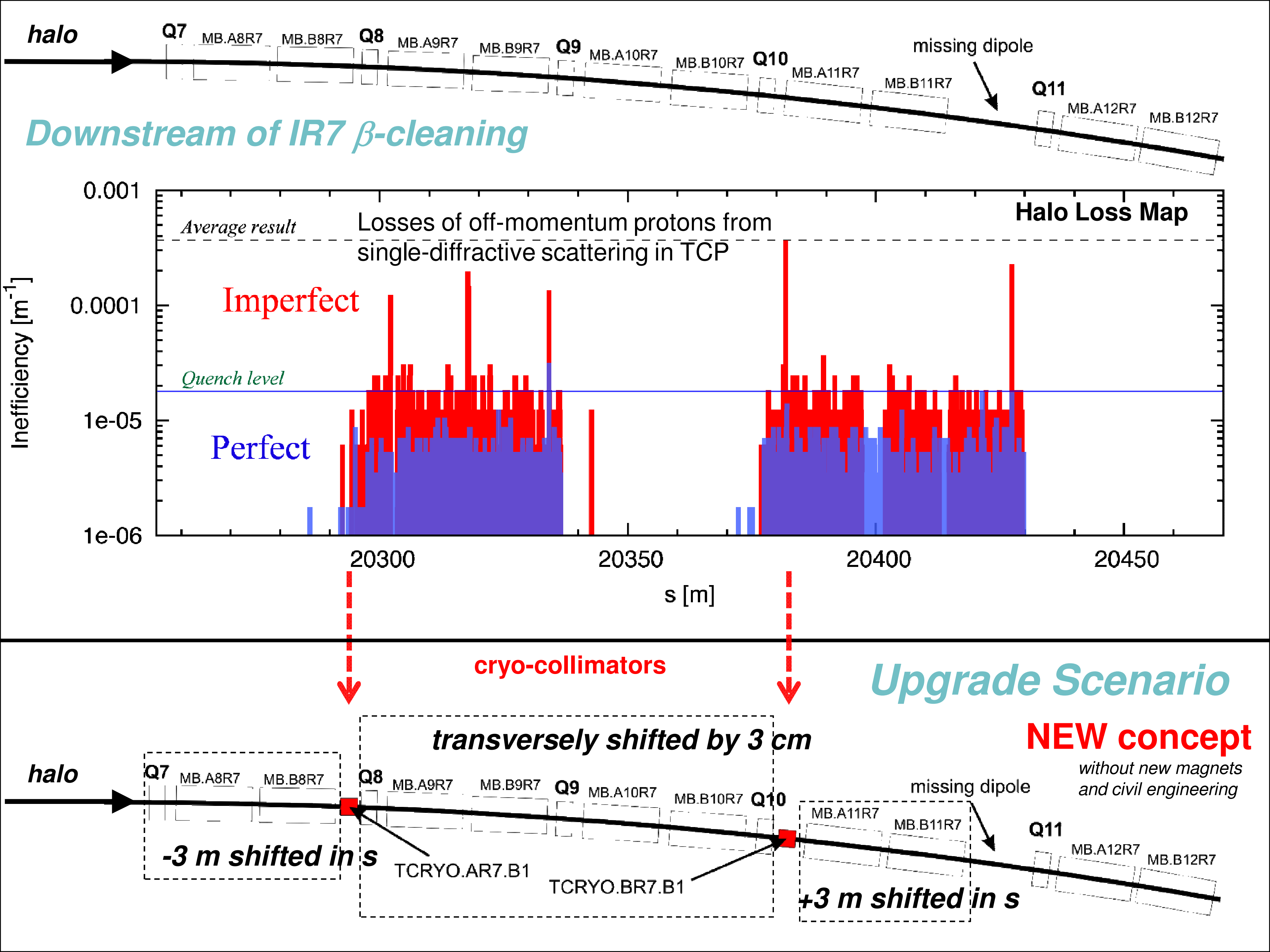
Beam lifetime

R_q = 7.0 × 10^8/p/m/s at 450GeV

R_q = 7.8 × 10^6/p/m/s at 7 TeV

η_c = 7.8 × 10^{-4}/m at 450GeV (for 0.1h and 3.2 × 10^{14} p)

η_c = 1.74 × 10^{-5}/m at 7 TeV (for 0.1h and 3.2 × 10^{14} p)



Downstream of IR7 β-cleaning

Halo Loss Map

Losses of off-momentum protons from single-diffractive scattering in TCP

cryo-collimators

Upgrade Scenario

transversely shifted by 3 cm

NEW concept

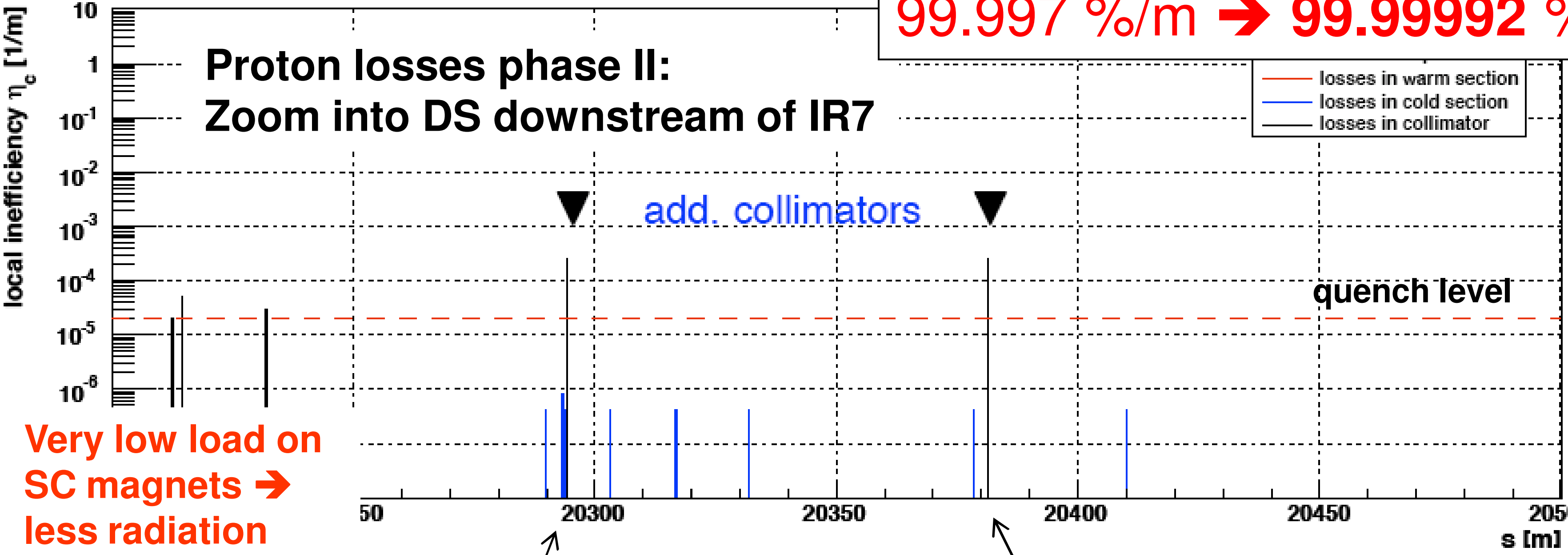
without new magnets and civil engineering

-3 m shifted in s

+3 m shifted in s

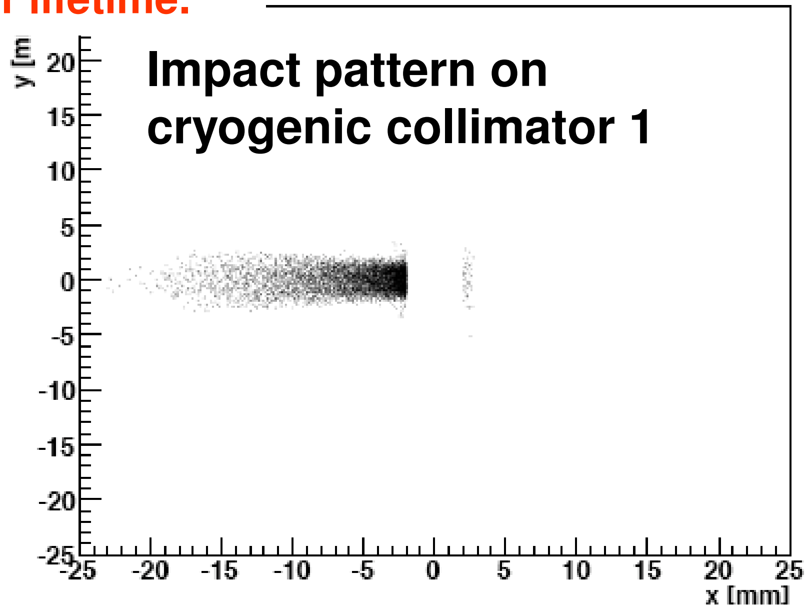
Proton losses phase II: Zoom into DS downstream of IR7

99.997 %/m ➔ **99.99992** %/m

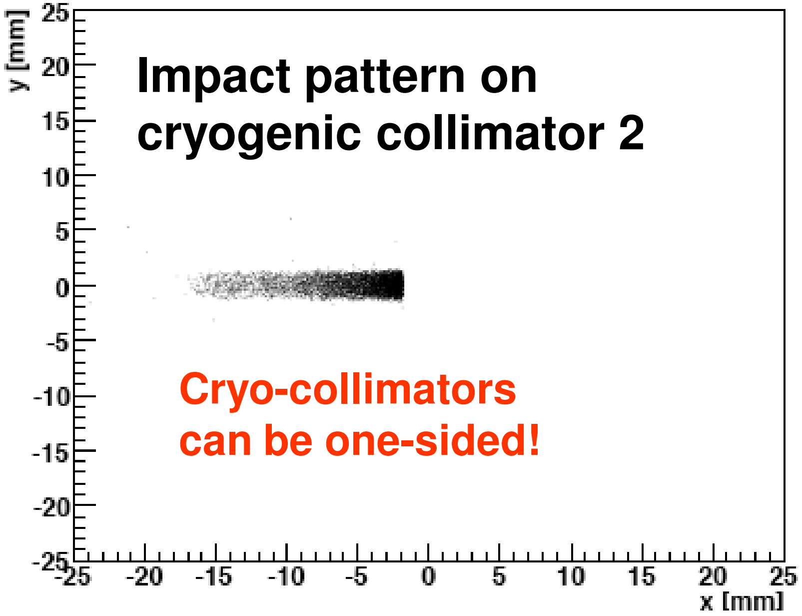


Very low load on SC magnets ➔ less radiation damage, much longer lifetime.

T. Weiler



Impact pattern on cryogenic collimator 1



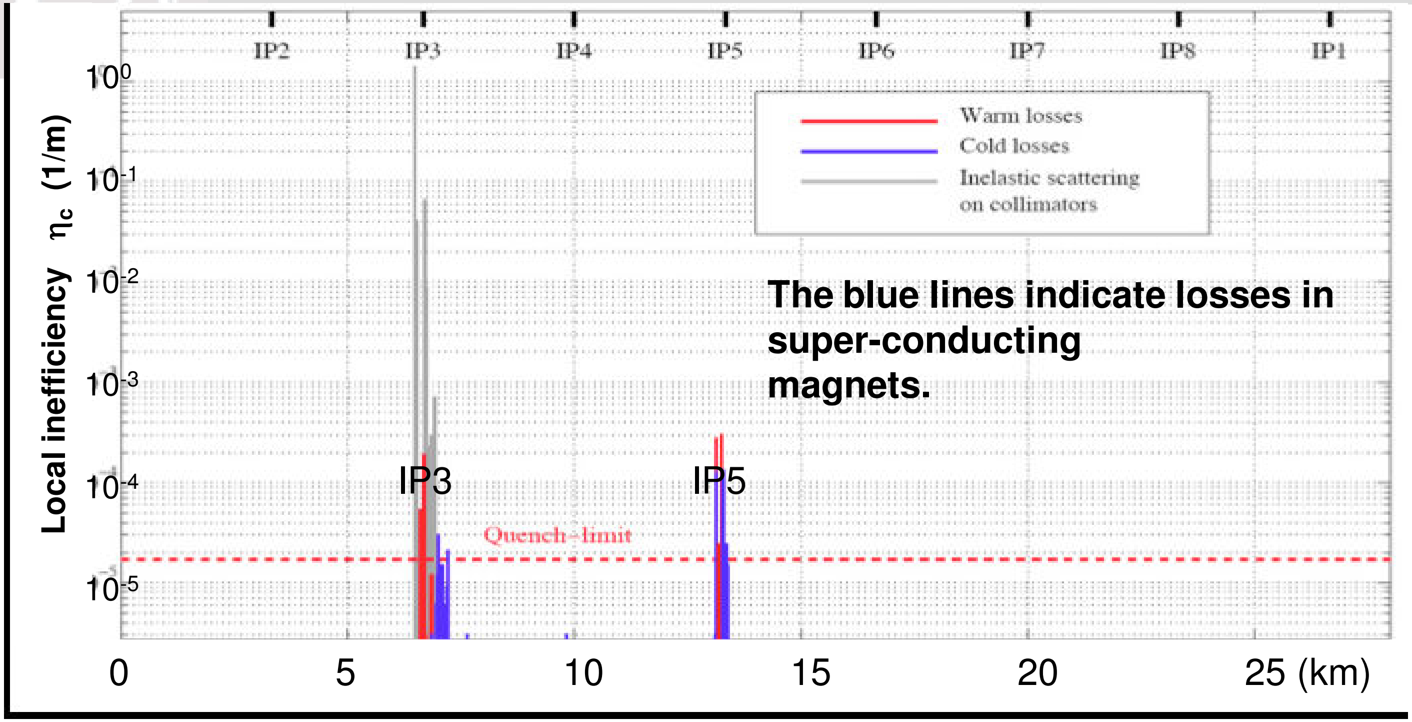
Impact pattern on cryogenic collimator 2

Cryo-collimators can be one-sided!

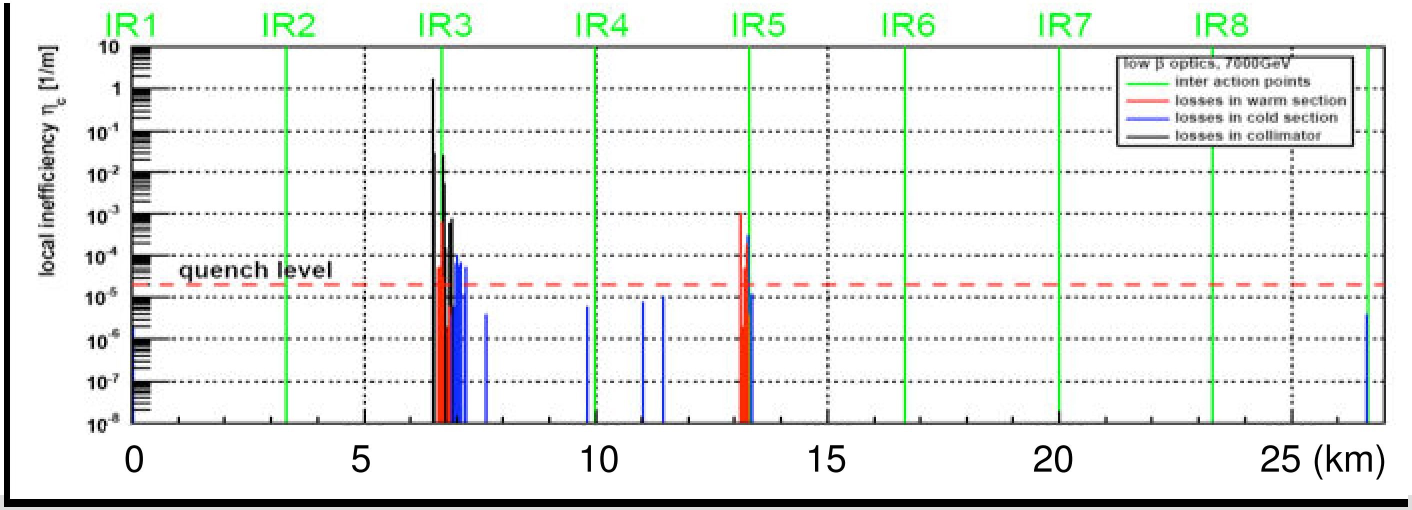
Minimized Plan: First IR3 or IR7?

- If only one IR can be upgraded with cryogenic collimation in 2012, then we prefer IR3 to be done first. Why:
  - IR3 can be used to implement a combined betatron and momentum cleaning system (memo R. Assmann in 7/2008).
  - While we lose efficiency with the combined system, we win with the collimators in the cryogenic dispersion suppressors. Maybe we can get already nominal (simulations ongoing)…
  - SC link cable in IR3 OK for 500 kW losses at primary collimators (nominal). Maybe require additional passive absorbers.
  - LHC collimation with 28 collimators less than now ➔ faster setup and less beam time required. Lower impedance (20 TCP/TCS instead of 38 TCP/TCS)!
  - Limitations with Single Event Upset in IR7 are avoided as losses are relocated to IR3 (100 times less radiation to electronics for same beam loss in IR3).
  - System in IR7 kept operational in case of problems (spare system).
  - Much better flexibility to react to limitations.

Combined Momentum/Betatron Cleaning



The blue lines indicate losses in super-conducting magnets.

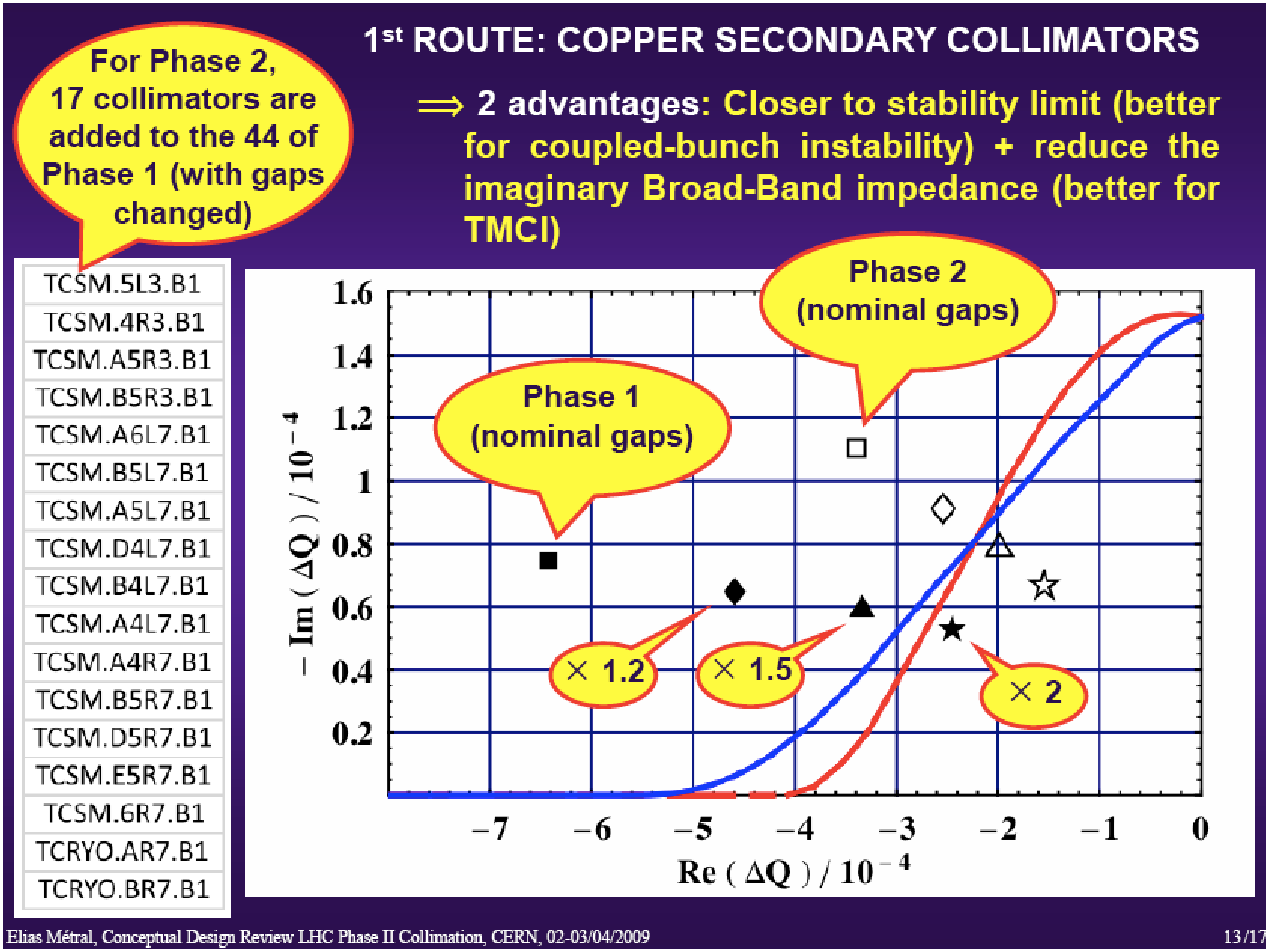


Proton beam loss maps, showing local cleaning inefficiency (leakage) around the ring for horizontal (top) and vertical (bottom) cleaning with a combined IR3 system. A quench level is indicated for nominal LHC intensity and nominal peak loss rate (0.1%/s)

Simulations ongoing to see if we can go to nominal intensity

Results from Th. Weiler studies PAC ‘09

Collimator impedance



1^{st} ROUTE: COPPER SECONDARY COLLIMATORS

⟹ **2 advantages: Closer to stability limit (better for coupled-bunch instability) + reduce the imaginary Broad-Band impedance (better for TMCI)**

For Phase 2, 17 collimators are added to the 44 of Phase 1 (with gaps changed)

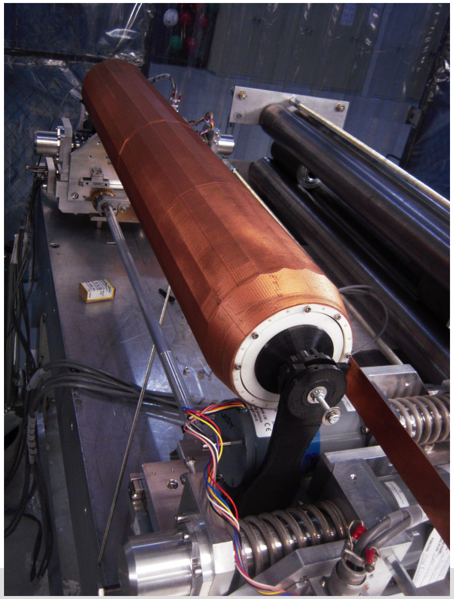
TCSM.5L3.B1
TCSM.4R3.B1
TCSM.A5R3.B1
TCSM.B5R3.B1
TCSM.A6L7.B1
TCSM.B5L7.B1
TCSM.A5L7.B1
TCSM.D4L7.B1
TCSM.B4L7.B1
TCSM.A4L7.B1
TCSM.A4R7.B1
TCSM.B5R7.B1
TCSM.D5R7.B1
TCSM.E5R7.B1
TCSM.6R7.B1
TCRYO.AR7.B1
TCRYO.BR7.B1

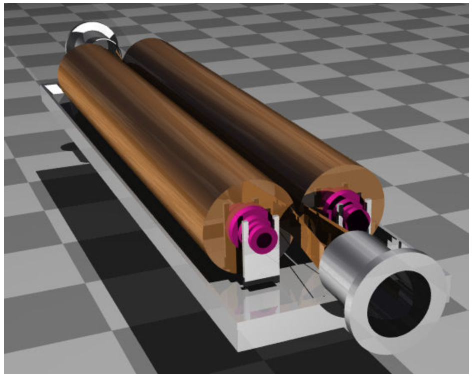
Elias Métral, Conceptual Design Review LHC Phase II Collimation, CERN, 02-03/04/2009 13/17

Energy deposition studies for Phase 2 collimators

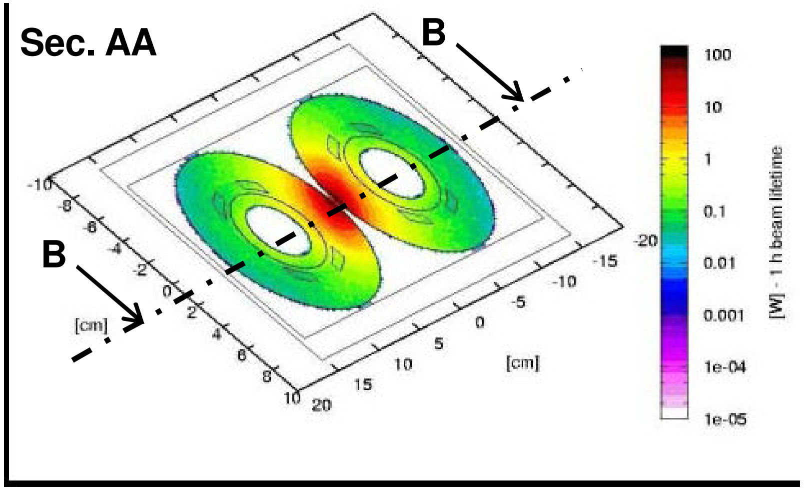
supporting the mechanical integration of prototypes,
e.g. of the Phase II Rotatable Jaw design,
developed by SLAC
in the framework of the LARP collaboration
between CERN and several laboratories in the USA

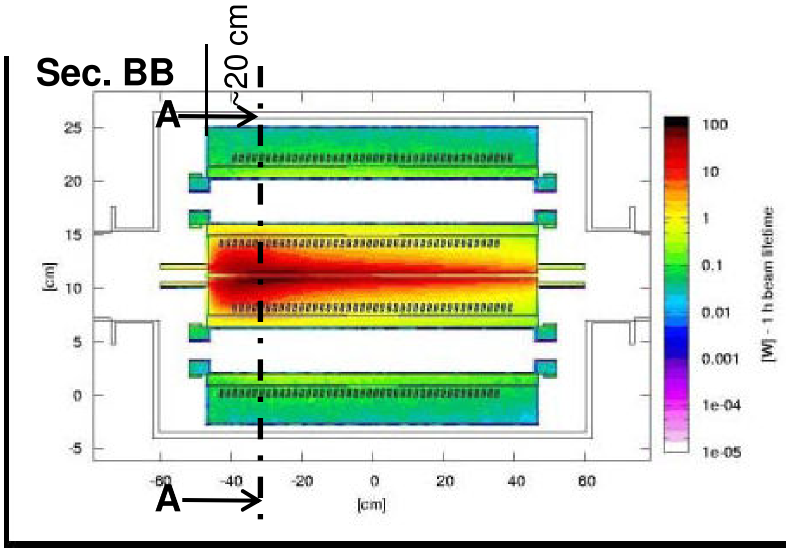
93 cm long Glidcop rotating jaws
(J. Smith et al. EPAC '08)





W – 1 h beam lifetime

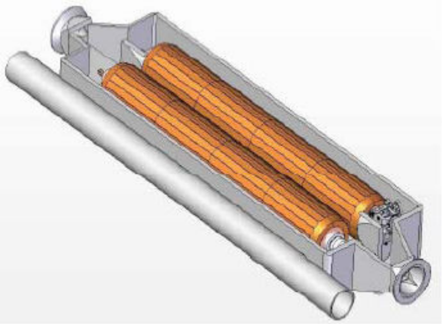




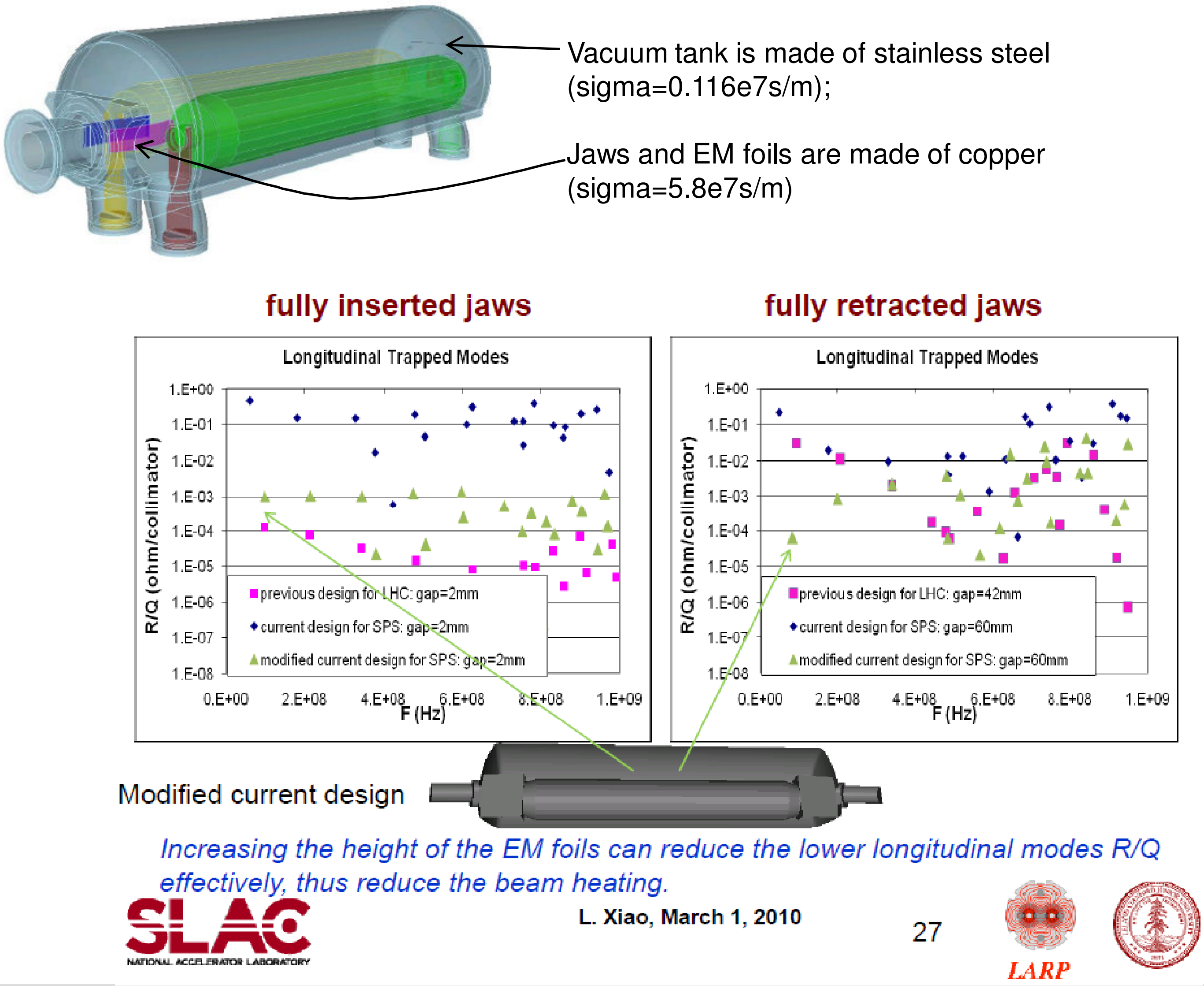
by the CERN FLUKA team

L. Lari et al. EPAC '08

SLAC (LARP collaboration) Trapped Mode Analysis



- Longitudinal TM
- Transverse TM
- Heating Analysis



Vacuum tank is made of stainless steel (sigma=0.116e7s/m);

Jaws and EM foils are made of copper (sigma=5.8e7s/m)

fully inserted jaws

fully retracted jaws

Modified current design

Increasing the height of the EM foils can reduce the lower longitudinal modes R/Q effectively, thus reduce the beam heating.

L. Xiao, March 1, 2010

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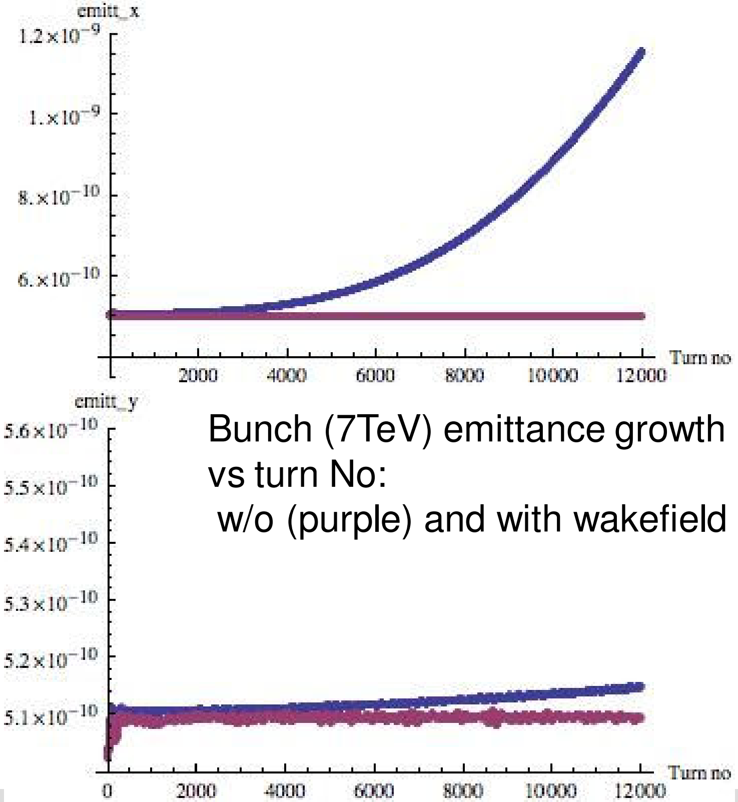
Merlin – a viable tool for LHC collimator studies

- Who: Roger Barlow and Adina Toader (Manchester University), Rob Appleby (CERN), Hywel Owen, James Molson (PhD)
- Why Merlin – by Nick Walker (DESY) : Its c++ design makes it easy to extend and easy to add or modify behaviour and features of particles and components
- Wakefields effects already implemented
- Work on going:
  - Finish implementing scattering in collimators and benchmark against existing used codes for LHC collimation (add SD and Rutherford Scattering)
  - Improve Merlin speed.
  - Study the particle losses due to both scattering and wakefield effects.
  - Study different materials.

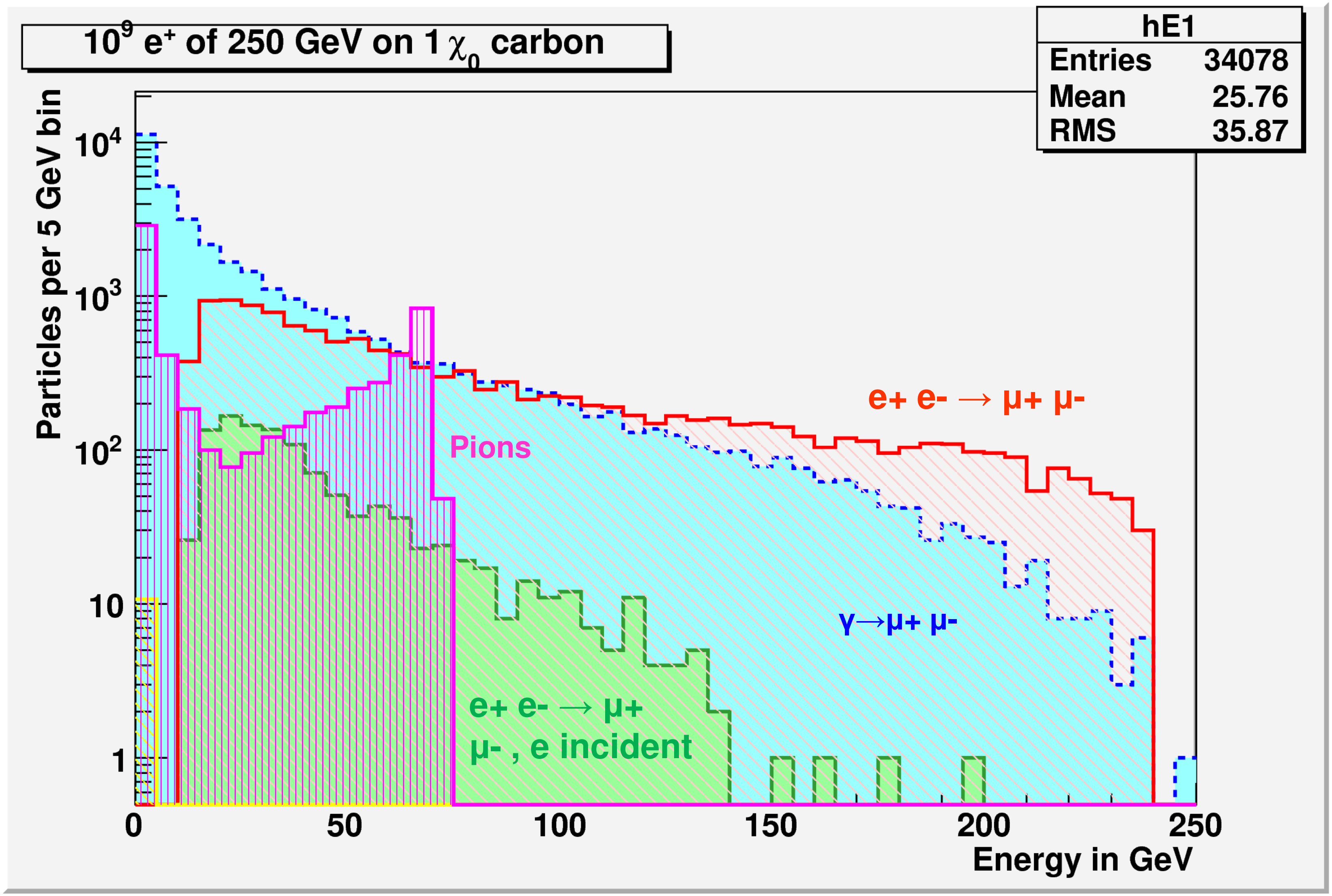


Bunch (7TeV) emittance growth vs turn No:
w/o (purple) and with wakefield

Collimation Backgrounds at LHC and CLIC

- **Lawrence Deacon, Grahame Blair, *John Adams Institute @ RHUL***
- G4 studies :
  - Primary particles from halo distribution file fired into first betatron collimation spoiler
  - All particles above cut-off threshold (energy needed to penetrate iron wall) tracked to IP
- Input spoiler hits from SixTrack (Adriana Rossi), 3.5 TeV beam
- Energy loss maps, to be compare with beam loss monitors data
- Would like to develop G4 models of beam loss monitors
- Seeing particles reaching IP, need to generate more events and increase statistics

CLIC studies: Muon Production



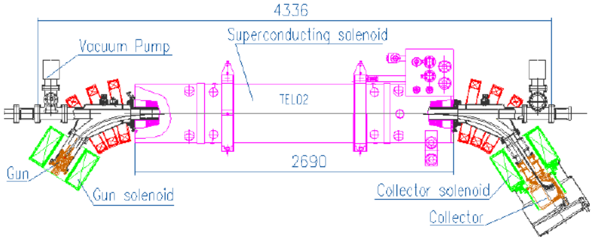
FNAL (LARP collaboration) Hollow electron beam collimator

- Cylindrical, hollow, magnetically confined, pulsed electron beam overlapping with halo and leaving core unperturbed

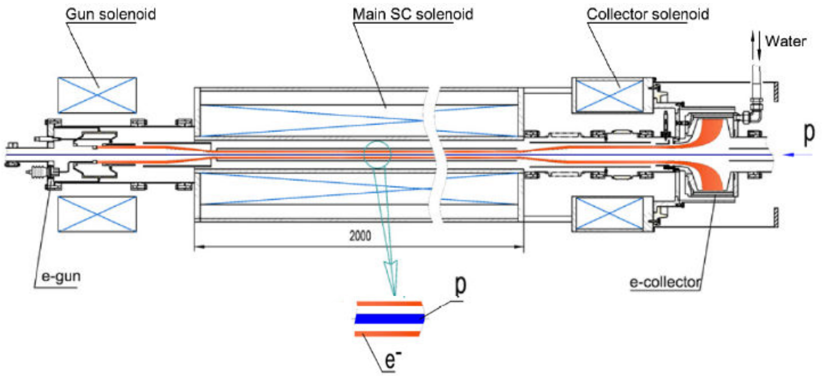
Modeling

kick maps in overlap region
- analytical form ideal case
- 2D from measured profiles Poisson solver
- 3D particle-in-cell `Warp` code, effects of
  - TEL2 bends
  - profile evolution
  - alignment

⇒ **tracking software** with lattice and apertures
- `STRUCT`
- `lifetrac`
- `SixTrack`
- `DMAD`

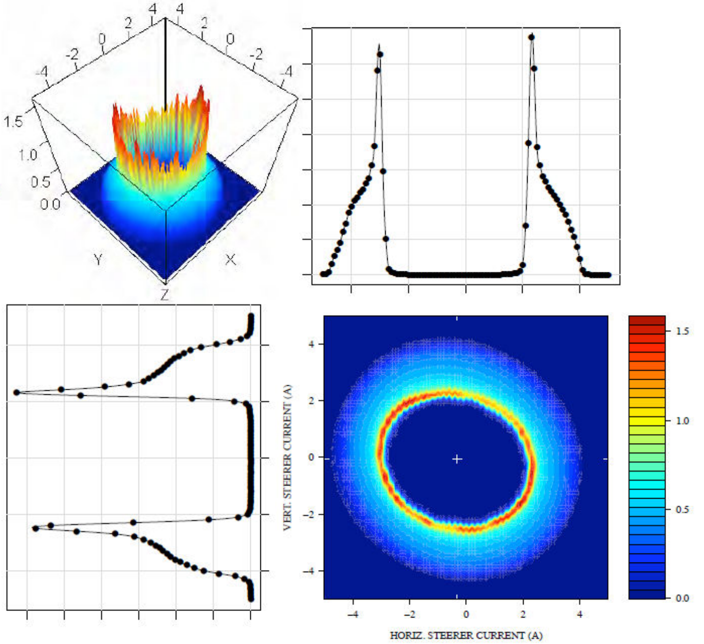


- Modeling:
  - 2D and 3D kick maps from measured distributions
  - performance vs lattice parameters
  - effect of misalignments, field-line ripple, bends



HOLLOW GUN
October 21, 2009

Vacuum: 2×10^{-8} mbar
Filament: 66 W (7.75 A)
Cathode voltage: -0.5 kV
HV PS current: 1.0 mA
Pulse width: 6 us
Rep. period: 0.6 ms
Peak current: 44 mA
Solenoids: 3-3-3 kG



Summary and conclusions

- CERN SixTrack simulations:
  - LHC Phase 1 collimation has been qualitatively confirmed by measurements at 1.18 TeV. Simulations at 450 GeV and 3.5 TeV beam to be compared to data are in progress.
  - LHC Phase 2 Combined Betatron/Momentum Cleaning in IR3 and cryo-collimators: simulations are on going to see if we can go to nominal intensity.
- CERN Impedance simulations being refined and tune shift based measurements are foreseen as benchmark.
- CERN FLUKA simulations to support design:
  - Energy deposition onto collimators.
  - Radiation to equipment.

⟹ **Support in choosing materials and length**

- Manchester University Merlin simulations:
  - Wakefield effect included.
  - Study different materials (including composites).
- John Adams Institute G4 simulations:
  - Collimation Backgrounds at LHC and CLIC.
  - Machine imperfections are being included.