Alternative Dispersion Suppressor Collimation for ALICE

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With contributions from:

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For general background see previous presentations, in particular at COLUSM 1 August 2014
http://indico.cern.ch/event/333525/
Status of DS Collimation for LHC

• Need for DS collimators emerged at Chamonix 2003 but too late to modify original design of cold DS regions

• DS collimators may be needed, with varying degrees of likelihood/urgency, for:
  – Pb-Pb luminosity losses (BFPP, EMD, ...) around ALICE
  – Pb-Pb and p-Pb collimation losses in IR7 and IR3
  – p-p collimation losses in IR7 and IR3
  – Pb-Pb luminosity losses (BFPP, EMD, ...) around ATLAS, CMS
  – p-p luminosity debris around ATLAS, CMS at HL-LHC

• Original solution (moving magnets to make space) dropped in favour of modular scheme, replacing standard MB dipole magnet with (2×11 T dipoles+TCLD) unit, applicable in all potential locations.
  – Synergy with high-field magnet development.

• Following 2013 Collimation Review:
  – First installation (2 TCLD units) foreseen for ALICE Pb-Pb in LS2, subject to confirmation after 2015 Pb-Pb run and tests of bump mitigation techniques
  – Further installations elsewhere in LS3, depending on experience at higher energy and luminosity, quench test results, etc
TCLD absorbs secondary beams from Pb-Pb collisions

Can select additional beams by adjusting the collimator gap.

Example of IR2, deliver full luminosity after ALICE upgrade during LS, quenches likely.
DS collimator installation in IR2

Nominal Beam Line

Magnet to be replaced MB.A10R2

IP2

Modified Sequence

2 × 11T dipole with L = 5.3m
Collimator jaw with L = 1m
DS Collimator locations around ATLAS (or CMS)

Different from IR2 because of QF/QD polarity in dispersion suppressor
Quench Mitigation with Orbit Bumps tested at CMS

R. Bruce et al., Beam losses from ultraperipheral nuclear collisions between 208Pb82+ ions in the Large Hadron Collider and their alleviation, Phys. Rev. ST Accel. Beams 12, 071002 (2009)

Will be operational in 2015 for all experiments.


3-magnet orbit bump with peak amplitude of \( x = -2.6 \text{mm} \) at MQ.11R5.B1

→ Moves BFPP1 beam impact position further downstream, increasing impact angle and spot size.

Orbit bumps could be used to spread out and move the secondary beam losses to a less vulnerable location in order to reduce risk of quench.
Observations during the Experiment

Loss Evolution during Experiment

Losses were gradually reduced with increasing bump amplitude.

At full bump amplitude, highest loss peak on a BLM was reduced by about a factor 10, while the dose on the next downstream BLM increased only by a factor 2. Fully analysed with FLUKA simulations.

Alternative TCLD installation for IR2

• Bump mitigation as in 2011 experiment is less effective in IR2 than in IR1/IR5
  – Some effect predicted in 2009 paper, could be marginally enough, depending on true quench limit, plan to test in 2015
  – Hence IR2 was given priority for possible TCLDs

• Alternative proposed at ColUSM 1 August 2014
  http://indico.cern.ch/event/333525/

• Because of the form of the dispersion function in IR2, there is a possibility that we can combine bumps and an alternative location of the TCLD in the connection cryostat (missing MB)
  – No 11 T magnets required
  – Different but apparently simpler integration
  – Significant orbit bump during luminosity operation!
  – Option to include an additional horizontal corrector beside it.

J.M. Jowett, Collimation Upgrade Meeting, 20/3/2015
Variations of optics, bump and use of available orbit correctors studied (Tom Mertens, next talk). Solution only applicable in IR2.
BFPP loss mitigation prospects - summary

• Run 2:
  – ATLAS and CMS will have about twice design luminosity, some risk of quenches that we can mitigate with bump method (as long planned)
  – ALICE luminosity will be levelled design value, unlikely to cause quenches. Just as well, since the bump mitigation method will not work so well for ALICE.

• Run 3 (after LS2 upgrade of ALICE):
  – Good chance that bumps will still work for ATLAS/CMS. If not, we level, and consider installation DS collimators during LS3.
  – Full luminosity in ALICE, likely to cause quenches, bumps unlikely to help much, use DS collimators installed during LS2.
Conclusions - from LHC Heavy Ion point of view

- Long-term goal of HL-LHC heavy ions: 10 nb\(^{-1}\) Pb-Pb plus various special runs (p-Pb, etc)
  - With all (few) presently planned LIU/HL-LHC heavy-ion luminosity upgrades we expect ~1.2 nb-1/(1 month run) (see RLIUP workshop for details)
  - Confirms need for all upgrades during LS2: to match ALICE upgrade and to approach goal in reasonable time

- As foreseen at 2013 Collimation Review, we are now approaching the decision point for IR2 DS collimator installation.
  - Are we being asked to decide earlier?

- We continue to consider all our options for mitigation of losses from Pb-Pb luminosity.
  - Bumps will be used operationally in 2015. Quench tests vital.

- The alternative TCLD installation proposed in Aug 2014 looks acceptable for ALICE (and only ALICE)
  - Insurance in case 11 T magnets are not available for LS2
  - Could also allow (11 T magnet+TCLD) units to be used elsewhere (IR7?)
  - Or could save costs

- Needed:
  - Integration study for TCLD in connection cryostat
BACKUP SLIDES
Recommendations 1

- The committee strongly encourages the development and prototyping of a 11 T (5.5 m) dipole magnet, and the cyro-bypass/collimator unit.
- Build at least 4 units (1 unit consists of 2 magnets + bypass + collimator) since this would cover 2 possible cases:
  - either 2 units in IR2 for ion operation (and 2 spares), or
  - 4 units in IR7 for proton operation
- For LS2 deployment serial «learning curves» of making coils at CERN and later in EU industries cannot be accommodated. The committee agrees with the early involvement of industrial partners.
- Make full use of knowledge acquired in the Nb$_3$Sn dipole and quadrupole programs to support each other.
Recommendations 3

• Study alternative options to the DS collimators that provide a reduction of the energy deposition by about a factor of 2, possibly sufficient for operation with ions
  – Distributing the energy deposition in the magnet by using dynamic orbit bumps
  – Installation of a thicker beam screen compatible with the aperture inside the vacuum chamber
Recommendations 4

- The quench tests that were performed demonstrate that it is essential to calibrate the complex theoretical models (using particle tracking, hadron shower codes and quench codes) with experimental data.
- Complete the analysis of these tests with the objective of a coherent understanding of the quench limits as a function of loss duration.
- Perform quench tests at high energy, e.g. 6.5 TeV, as soon as possible after the restart of LHC in 2015, including tests with ions.
Steady-state losses during Pb-Pb Collisions in 2011

Bound-free pair production secondary beams from IPs

IBS & Electromagnetic dissociation at IPs, taken up by momentum collimators

Losses from collimation inefficiency, nuclear processes in primary collimators

Total Losses: 3.510E-03 [Gray / s]

Monitors

J.M. Jowett, Collimation Upgrade Meeting, 20/3/2015
Electromagnetic processes in Pb-Pb collisions

BFPP1: $^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{82+} \rightarrow ^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{81+} + \text{e}^+$,
$\sigma = 281 \text{ b}, \quad \delta = 0.01235$

BFPP2: $^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{82+} \rightarrow ^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{80+} + 2\text{e}^+$,
$\sigma \approx 6 \text{ mb}, \quad \delta = 0.02500$

EMD1: $^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{82+} \rightarrow ^{208}\text{Pb}^{82+} + ^{207}\text{Pb}^{82+} + \text{n}$,
$\sigma = 96 \text{ b}, \quad \delta = -0.00485$

EMD2: $^{208}\text{Pb}^{82+} + ^{208}\text{Pb}^{82+} \rightarrow ^{208}\text{Pb}^{82+} + ^{206}\text{Pb}^{82+} + 2\text{n}$,
$\sigma = 29 \text{ b}, \quad \delta = -0.00970$

Each of these makes a secondary beam emerging $\delta = \frac{1 + \Delta m / m_{\text{Pb}}}{1 + \Delta Q / Q} - 1$ from the IP with rigidity change.

Hadronic cross section is 8 b (so much less power in debris).

Discussed since Chamonix 2003 ...

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS
12, 071002 (2009)

Beam losses from ultraperipheral nuclear collisions between $^{208}\text{Pb}^{82+}$ ions in the Large Hadron Collider and their alleviation

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BFPP Beams and Losses in the DS Region in IR2

- $x [m]$, BLM [$10^4$ Gy/s]
- $s [m \text{ from IP2}]$

2011 Pb-Pb operation
Zoom in to loss region
Main losses in DS are due to luminosity

Regular physics fill

From van der Meer scans

J.M. Jowett, Collimation Upgrade Meeting, 20/3/2015
# HL-LHC Performance Goals for Pb-Pb collisions

With upgrade of Pb injectors, etc, indicative parameter goals:

- ALICE upgrade integrated luminosity goal for post-2018 period:
  \[ \int L \, dt = 10 \text{ nb}^{-1} = 10 \times \text{(first phase)} \]
  equivalent to \[ \int L_{NN} \, dt = 0.43 \text{ fb}^{-1} \] nucleon-nucleon luminosity.
- Annual integrated luminosity (1 month run) \( \approx 1.5 \text{ nb}^{-1} \)

Peak luminosity \( L \approx 6 \times 10^{27} \text{ cm}^{-2}\text{s}^{-1} = 6 \times \text{design} \)
- Up to \( k_b = 912 \) bunches with mean intensity \( N_b = 2.2 \times 10^8 \text{ Pb} \).
- Stored energy in beam: \( W \approx 18 \text{ MJ} = 4.8 \times \text{design} \)
- Power in BFPP1 beam: \( P_{BFPP1} = 155 \text{ W} \)
- Power in EMD1 beam: \( P_{EMD1} = 53 \text{ W} \)

ATLAS and CMS also taking luminosity (high burn-off).
- Levelling strategies may reduce peak luminosity but we must aim for high intensity.
- Comparison data: \( p\text{-Pb runs every few years are less demanding from beam-loss point of view} \)

Runs with lighter species (unlikely ?) are not considered here.
Maximum power density in coil at 7 Z TeV:

\[ P = 15.5 \text{ mW/cm}^3 \text{ at design luminosity.} \]

For upgrade luminosity, expect

\[ P \approx 93 \text{ mW/cm}^3 \]

\text{See other talks!}

c.f. quench limit (latest from A. Verweij)

200 mW/cm\(^3\) \text{ at 4 Z TeV}

40-50 mW/cm\(^3\) \text{ at 7 Z TeV}

(higher than used previously)

Nevertheless, expect to quench MB and possibly MQ!

FLUKA studies confirmed recently (next talk).
BFPP mitigation by bumps

• Proposed in R. Bruce et al, Phys Rev STAB, 12, 071002 (2009)

• Apply bump to main beam orbit in loss region, also moves BFPP beam away from impact point, reducing flux, angle of incidence, peak power density.

• Tested opportunistically in 2011 Pb-Pb run gained on BLM signals.

• If truly effective and reliable, and accepted by Machine Protection, could be an alternative to DS collimators.

• May have to rely on this in the period after LS1.
Orbit bump: -2.6 mm at Q11.R5.B1 in steps

12 sigma envelopes from online model

without bump

with bump
Effect on losses

No losses or lifetime drops
Effect on loss pattern

Before

Total Losses: 1.685E-04 [Gray / s]

Bump -2.6 mm

Not enough to create 2\textsuperscript{nd} loss peak
Example of $^{206}$Pb created by EMD2 in primary collimator

- Green rays are ions that almost reach collimator
- Blue rays are $^{206}$Pb rays with rigidity change

"Obvious" solution is to put more collimators here.

Beam pipe in IR7 of LHC
DS collimators in IR7 for heavy ions

- No quench test with ion beams in 2013
- Some results from 2011 only showed that upgraded design intensity is just OK with 1 h lifetimes (questionable?).

- In 2013 p-Pb run, we were forced to raise BLM thresholds to nominal quench limit in squeeze because of losses
  - Pb beams are larger than p beams
  - Partly related to movements of orbit, tight collimators
- Experience after LS1 essential to allow better evaluation of need for DS collimators in IR7. Need to watch this!
- DS collimators very effective for Pb in IR7 (see simulations by G. Bellodi in 2011 Collimation Review).
Bump method to mitigate losses in IR7 (test in 2013)

- Test of B1 horizontal orbit bump in IP7 around Q11.R7 (+2.5 mm), to spread the losses longitudinally,
- It worked, we observe a factor $1.62 \pm 0.04$ gain on the maximum loss peak,
- But losses were reduced at the primary collimator, which should not be influenced, → was there an orbit non closure propagating through the ring?

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