BLM threshold settings for the 2015 Pb-Pb run

Introduction

John Jowett, Michaela Schaumann, Tom Mertens

Numerous contributors to related studies over the years:

A.J. Baltz, S. Klein, J.-B. Jeanneret, A. Morsch, M. Gresham, H. Braun, R. Bruce, S. Gilardoni, G. Bellodi, D. Bocian, J. Wenninger, S. Redaelli, R. Alemany, G.E. Steele, A. Lechner, …

What will be new since the last Pb-Pb run in 2011 ?

- Higher energy (6.37 *Z* TeV) and luminosity
  - Magnets quench more easily
    - How much more easily, the quench level, is our biggest uncertainty
  - More energy in each lost Pb ion
  - Higher direct luminosity losses around experiments
    - Implement mitigation strategy to avoid quenches due to higher energy deposition
  - ALICE experiment will have to level (until upgrade in LS2)
    - Extreme luminosity burn-off regime
    - Luminosity sharing with other experiments
  - Collimation losses in IR7 and IR3 will be higher than from Pb beams in 2011, 2013

Goals

- Deliver maximum integrated luminosity in 2015!
- For HL-LHC heavy ions (after LS2), establish the need for DS Collimators around the experiments and/or in the collimation insertions (as agreed at 2013 Collimation Review)
  - Quench levels of magnets (also data from p-p) – if lower than expected, we may lose some fills at start of physics
  - BLM threshold management (cf p-Pb in 2013)
  - Effectiveness of mitigation by bump methods
  - Quench tests: luminosity and collimation insertions

Electromagnetic and photonuclear processes in Pb-Pb collisions

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

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

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

Each of these makes a secondary beam emerging from the IP with rigidity change

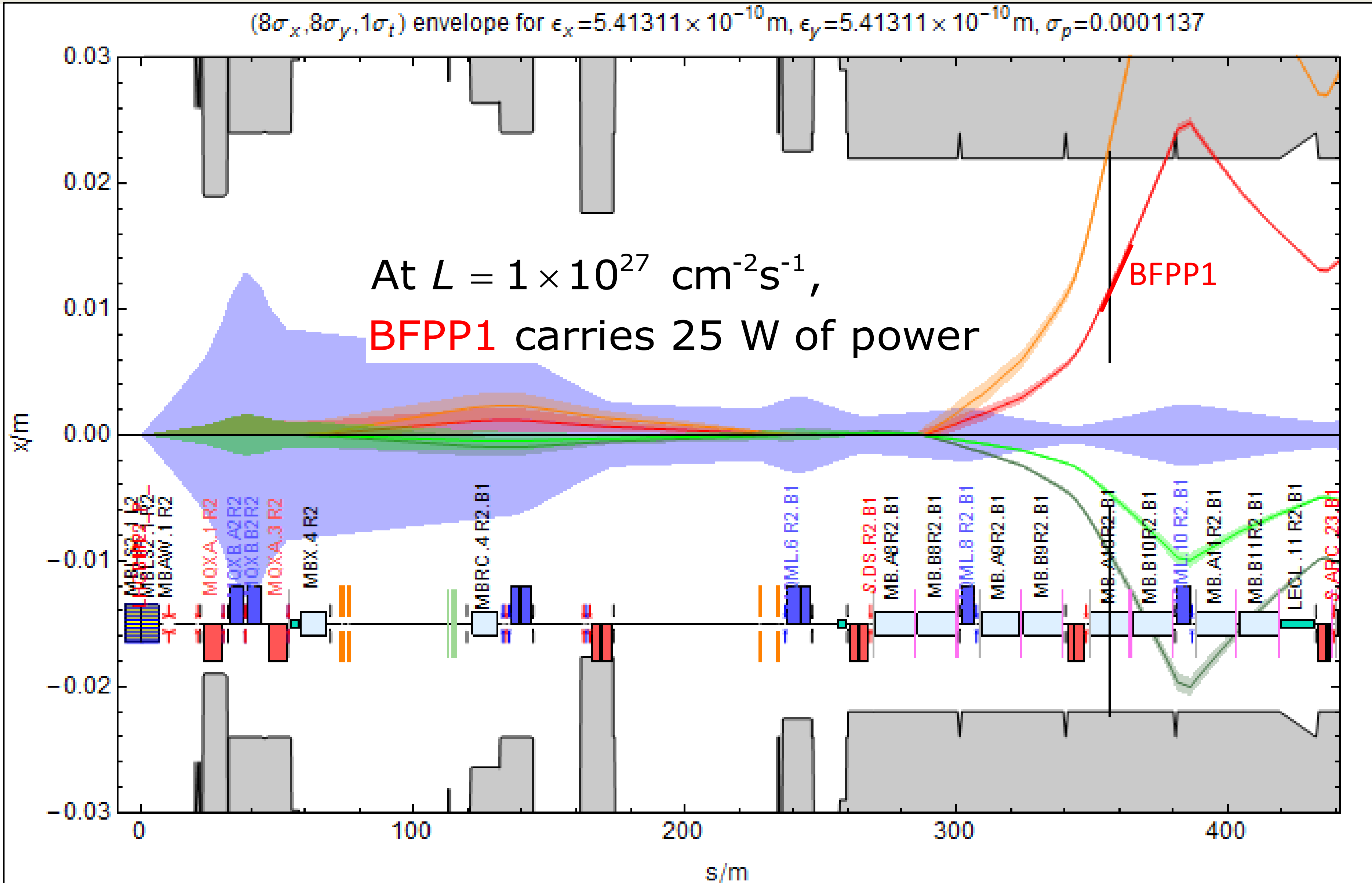
$$\delta = \frac{1 + \Delta m / m_{\text{Pb}}}{1 + \Delta Q / Q} - 1$$

Strong luminosity burn-off of beam intensity.

Discussed for LHC since Chamonix 2003 … see several references.

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

Secondary beams from Beam 1 in IR2 (horizontal plane)



At $L = 1 \times 10^{27}$ cm^{-2}s^{-1},

BFPP1 carries 25 W of power

Power density in superconducting cable

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

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

R. Bruce,[1,*] D. Bocian,[2,1,†] S. Gilardoni,[1] and J. M. Jowett[1]

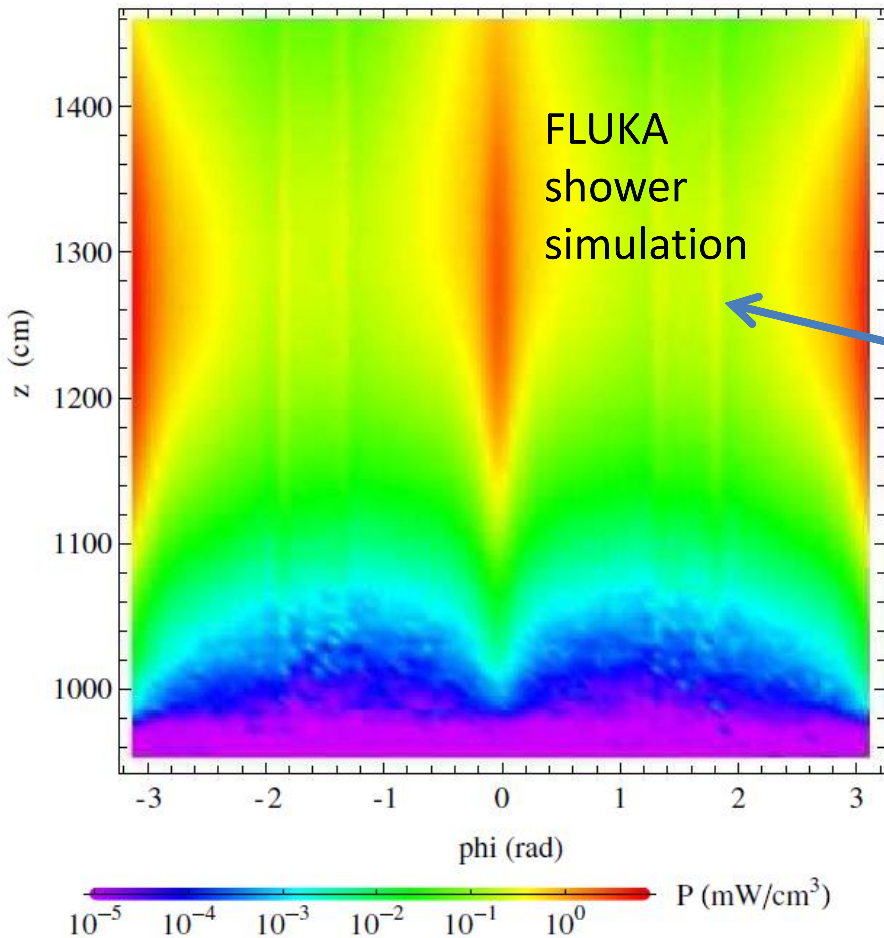


FIG. 7. (Color) The heating power from beam losses caused by BFPP in the inner layer of the coil of an LHC main dipole as simulated with FLUKA. The power density was averaged over the width of the cable and is shown as a function of azimuthal angle ϕ and longitudinal coordinate z, with $z = 0$ in the beginning of the magnet. The beam loss is centered around $z = 1206$ cm and $\phi \approx -3.11$ rad.

Maximum power density in coil at 7 *Z* Te

$P = 15.5$ mW/cm^3 at design luminosity.

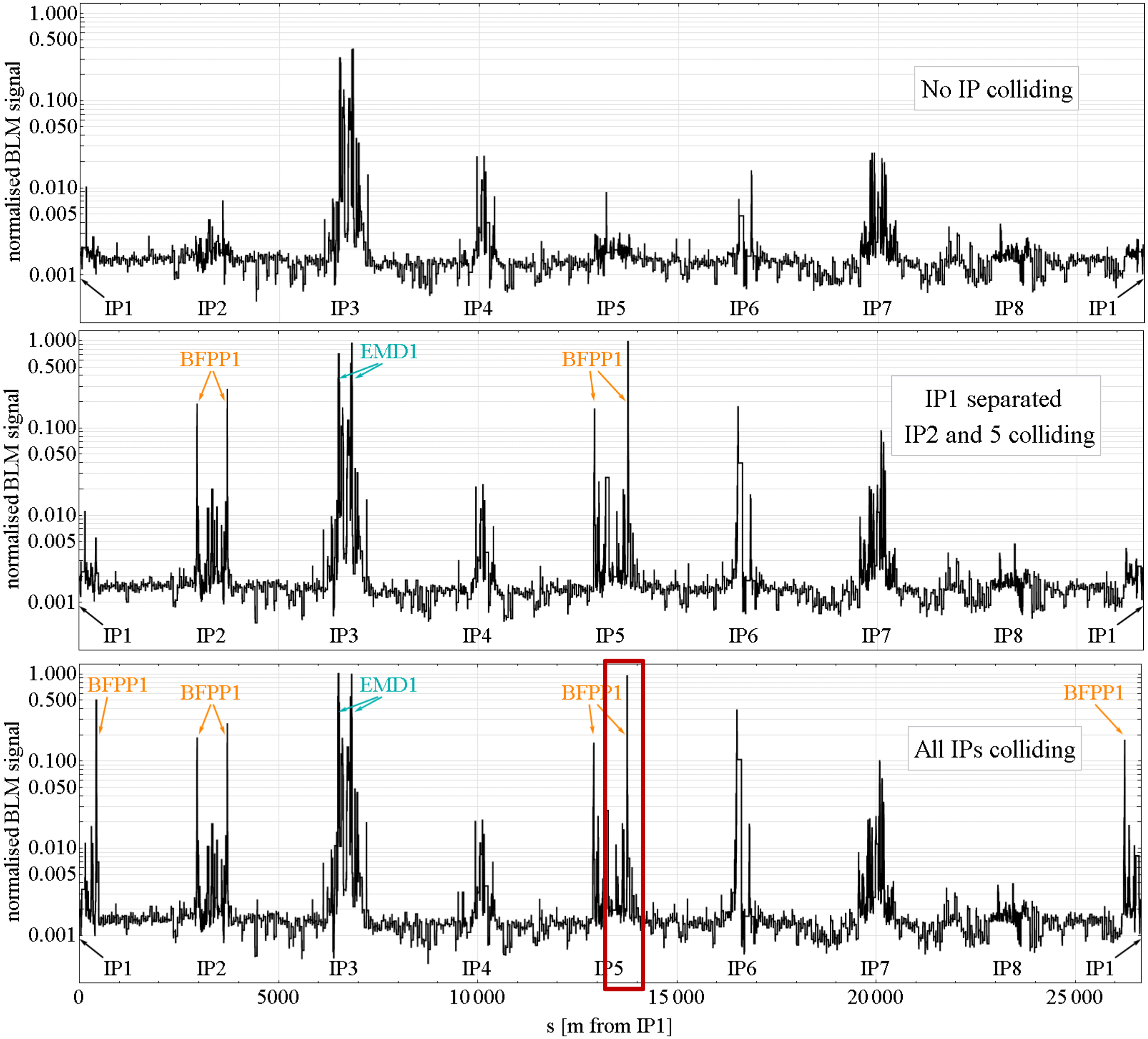
For upgrade luminosity, expect

$P \approx 93$ mW/cm^3

c.f. quench limit

Nevertheless, expect to quench MB and possibly MQ!

BLM Losses in 2011 Pb-Pb



Before collisions

IP1 separated
IP5 and IP2 colliding

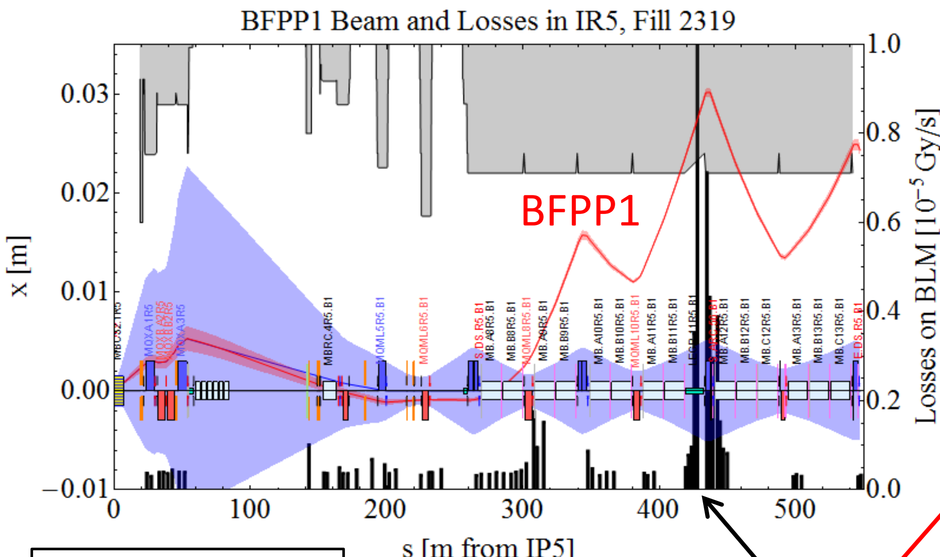
IP1, IP2, IP5 colliding

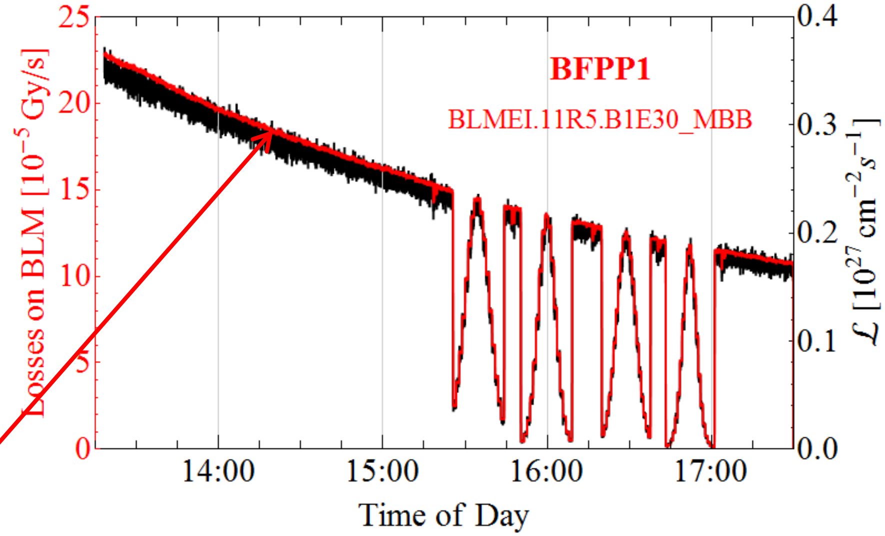
Data normalised to the highest peak in bottom plot.

M. Schaumann

BLM Losses around IP5 in 2011

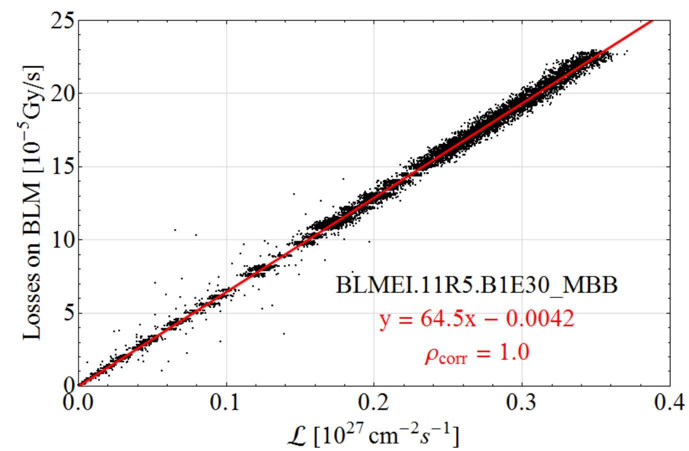
Van der Meer scan





Data of two different fills

BLM with highest signal



Highest losses observed:

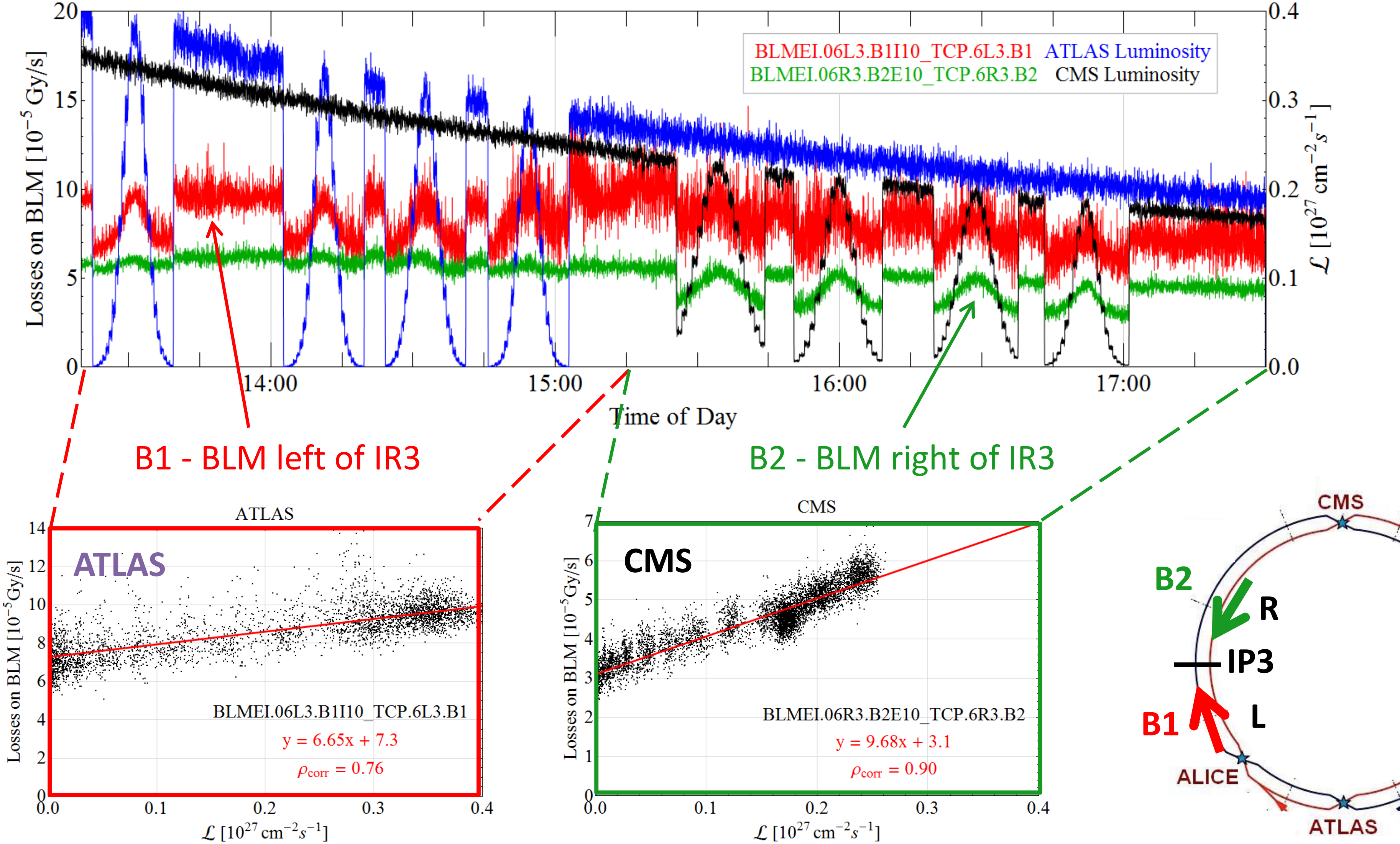
→ Show clear correlation to luminosity.

→ Loss location matches predicted BFPP impact position.

M. Schaumann

EMD Losses in IR3 in 2011 – Momentum Collimation

Selected BLM signals in IR3 compared to **ATLAS** and **CMS** luminosity during VdM Scans



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Quench risk mitigation with Orbit Bumps – Test 2011

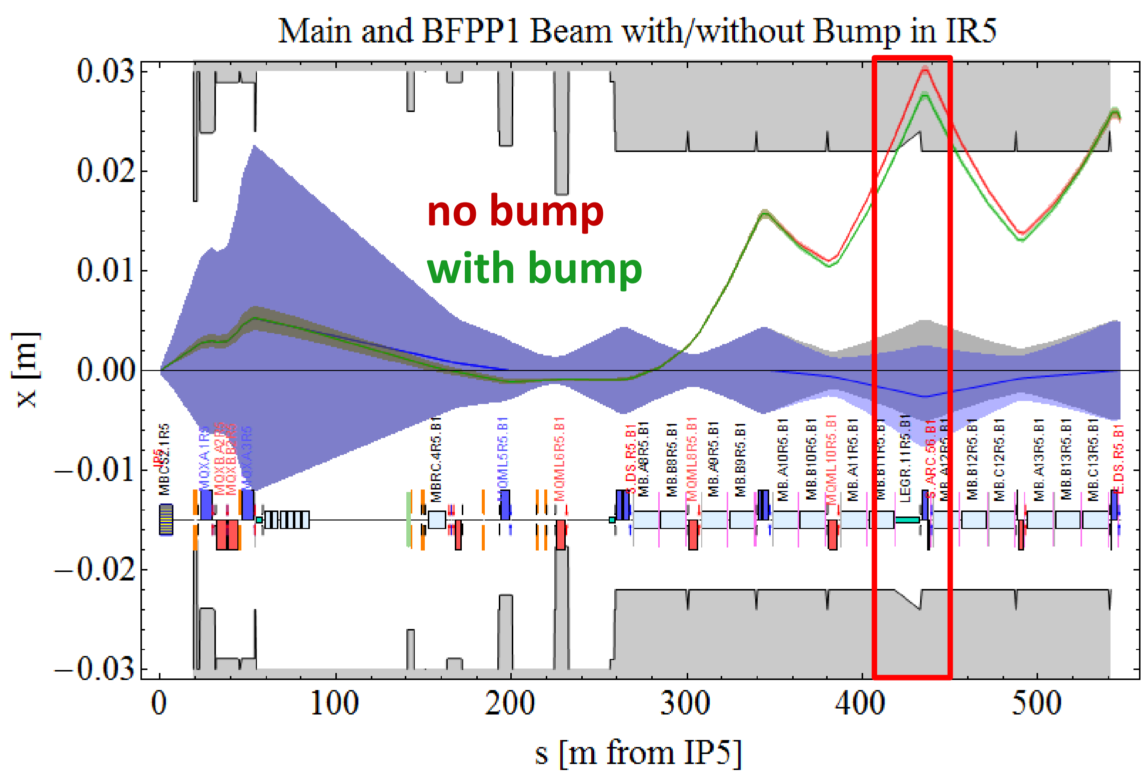
Opportunistic end-of-fill MD (injectors down), became middle-of-fill MD 24/11/2011 – Fill 2319.

Orbit bumps were used to spread out and move the secondary beam losses to a less vulnerable location in order to reduce risk of quench.

Experimental Setup

3-magnet orbit bump with peak amplitude of *x* = -2.6mm at MQ.11R5.B1

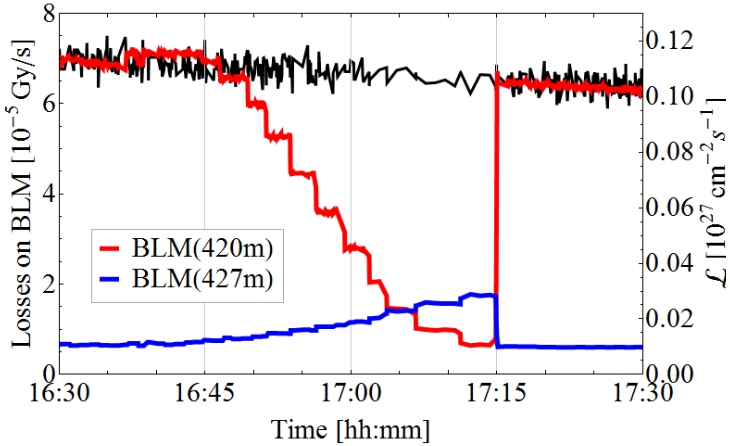
⇒ Moves BFPP1 beam impact position further downstream, increasing impact angle and spot size.



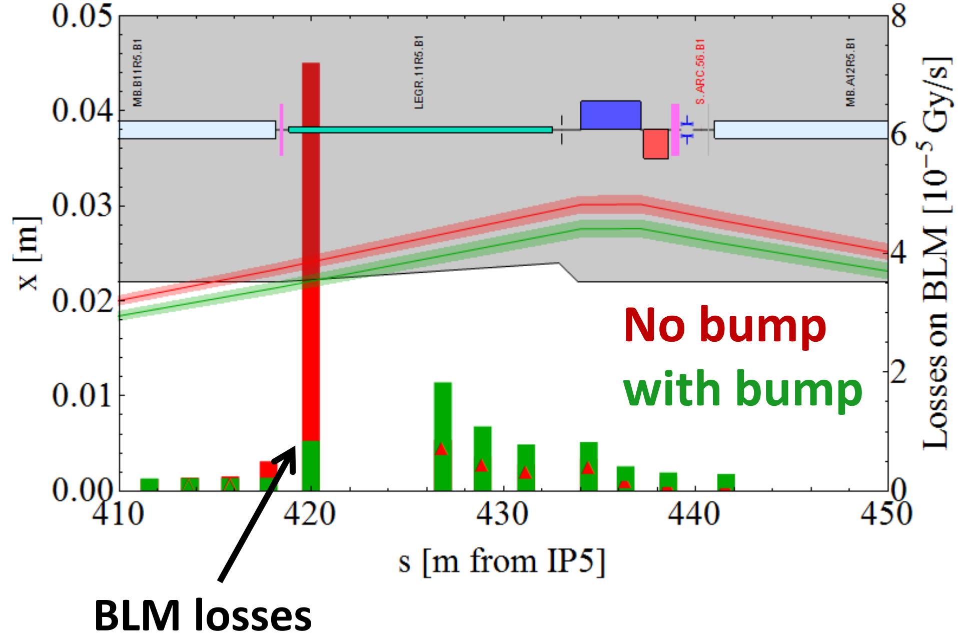
Analysis in M. Schaumann thesis

Direct Observations during the Experiment

Loss Evolution during Experiment



Zoom to impact region



BLM signals gradually reduce with increasing bump amplitude.

At full bump amplitude, highest loss peak is reduced by about a factor 10, while the dose on the subsequent BLM increased only by a factor 2.

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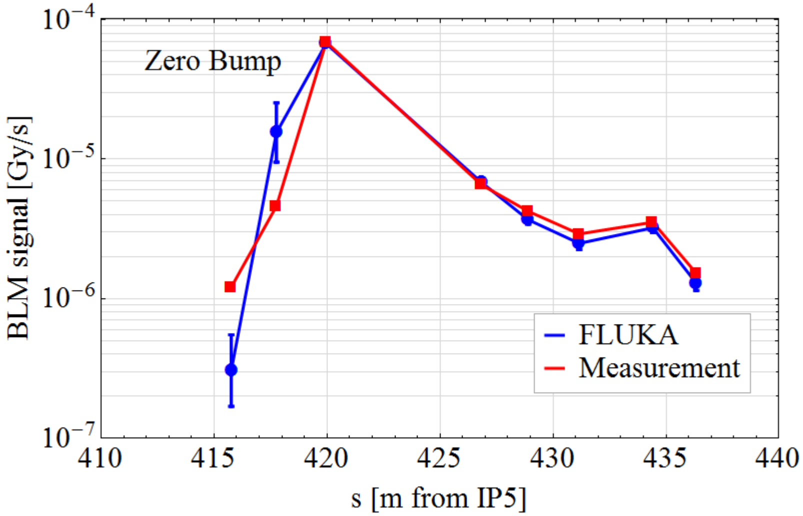
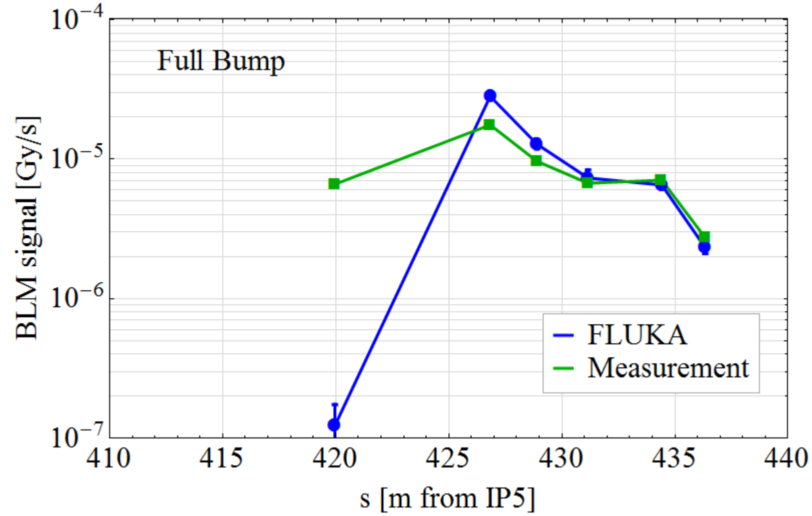
FLUKA Simulations (1)

Simulations performed by A. Lechner, F. Cerutti, N. Shetty and L. Skordis

FLUKA simulated BLM signals compared to measurement





- Good agreement between simulation and data.
- With Bump: beam appears to impact a bit more upstream than calculated.
  - Larger beam pipe radius in FLUKA geometry than used for impact distributions.
  - FLUKA tracks only fully stripped nuclei, but BFPP1 is actually 208Pb81+.
- Absolute emittance crucial for simulation result.

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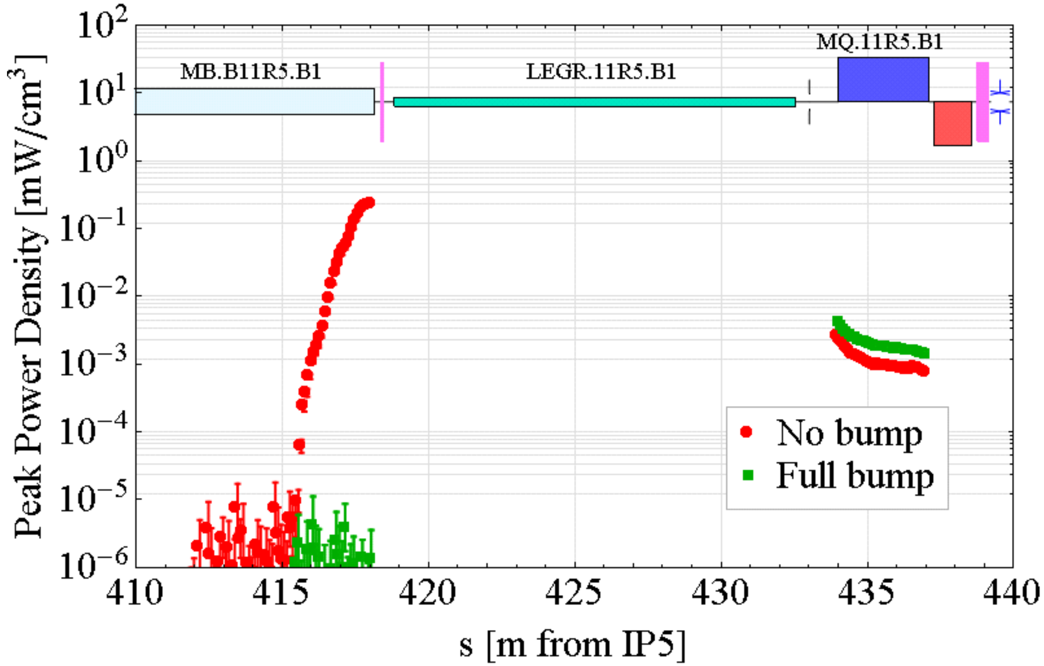
FLUKA Simulations (2)

Simulations performed by A. Lechner, F. Cerutti, N. Shetty and L. Skordis

Peak power density in magnet coils



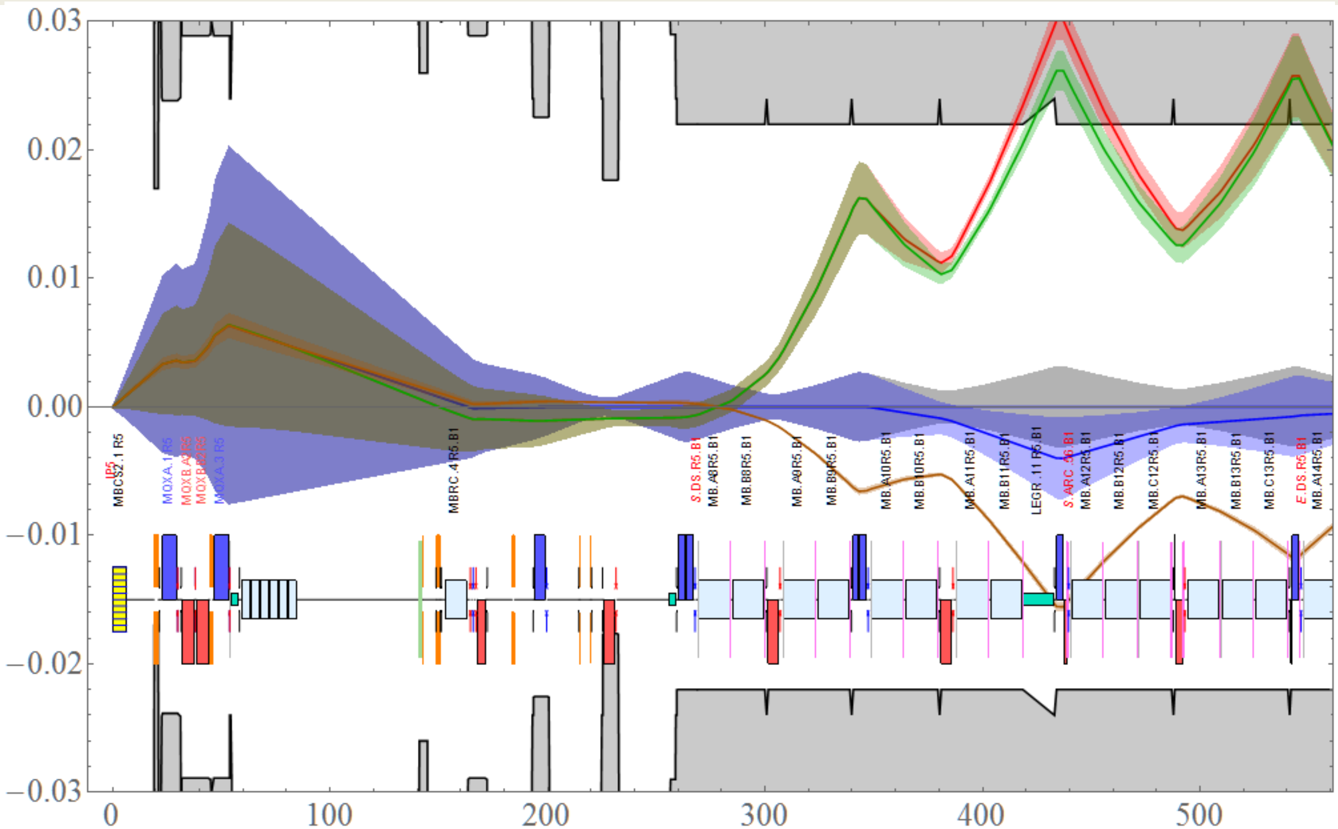
Peak power density in magnet coils is indicator for potential quench.

- No bump: Power density increases until end of the MB.
- With bump: power deposited in the MB is significantly reduced, without dangerously increasing the peak power in the Q11.

Moving the BFPP1 losses to the connection cryostat significantly reduces risk of quenches!

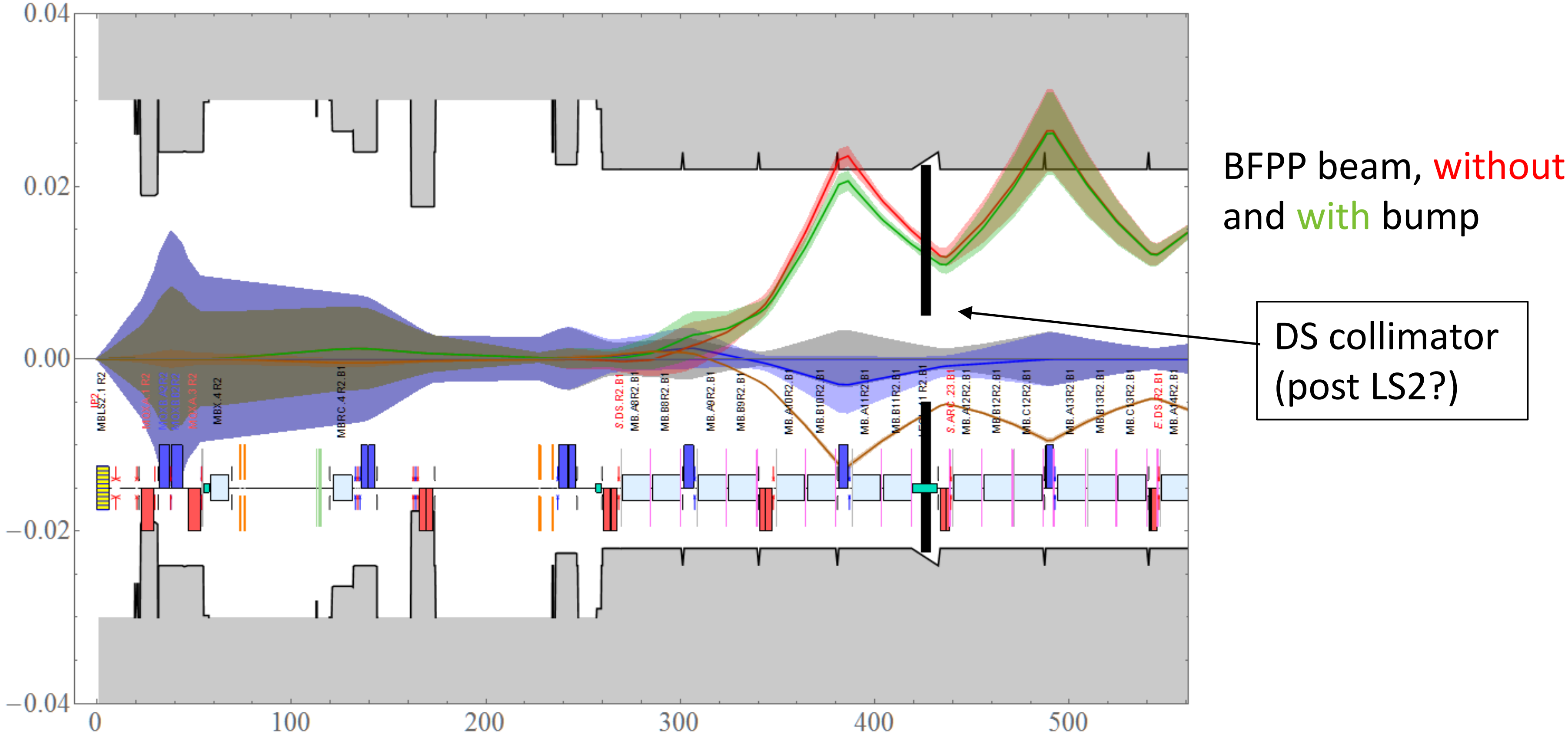
M. Schaumann

Orbit bumps are effective for CMS (or ATLAS)



- Primary loss location close to the connection cryostat - details slightly optics-dependent (this example for 2015 optics with β*=0.6 m)
- Bumps should be set to avoid quenches at the start of physics
- Bumps are well outside TCTs so should be transparent – we do want to change them to see the effects
- Extra BLMs were specifically added for heavy-ion operation in loss region
- Variations of bump possible, uses moderate fraction of available corrector strengths (detailed note about corrector strengths coming soon – Tom Mertens)

Orbit bumps are less effective for ALICE



- IR2 has different quadrupole polarity and dispersion from IR1/IR5
- Primary BFPP loss location is further upstream from connection cryostat
- Bumps can only reduce loss by sending some or all to secondary location in MB before Q12
  - (Unless we put a collimator in connection cryostat - current proposal for LS2)
- With levelled luminosity in ALICE, quenches are unlikely in Run II

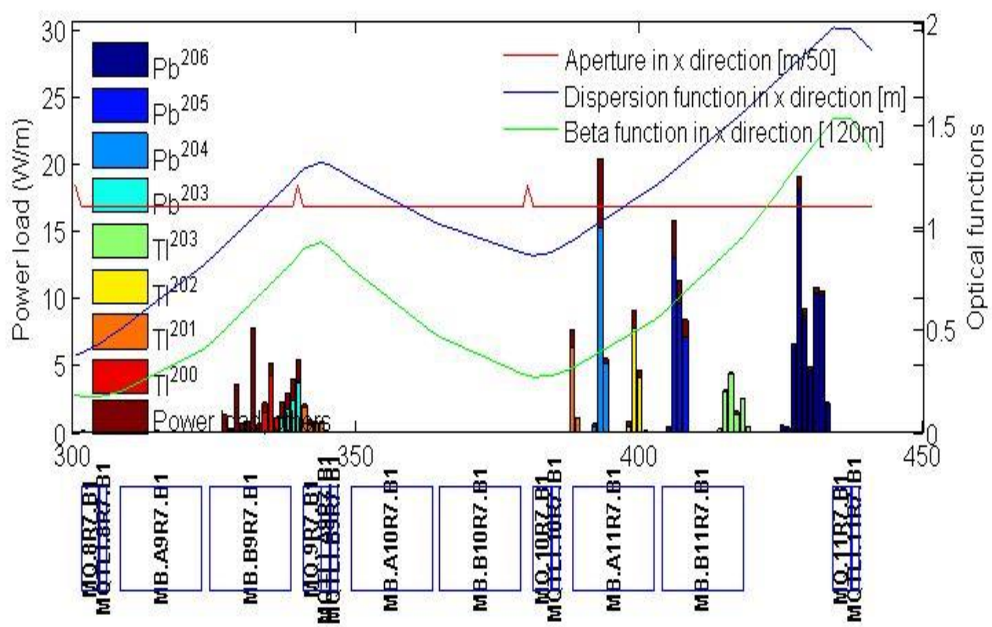
Levelling and mitigation strategy in Run 2

- Before the upgrade (LS2), ALICE luminosity must be levelled at $L = 1 \times 10^{27}$ cm^{-2}s^{-1}
  - Start fills with levelling separation on to avoid exceeding this
- ATLAS and CMS are not limited in peak *L*
  - (Unless BFPP limits peak luminosity by quenches.)
- BFPP mitigation bumps will be set up during first low-luminosity fills (few bunches)
  - Minimise risk of quenches in IR1, IR5 and also IR2
  - Compare BLM signals with expectations from simulations (data in preparation by A. Lechner, T. Mertens).

Collimation Inefficiency

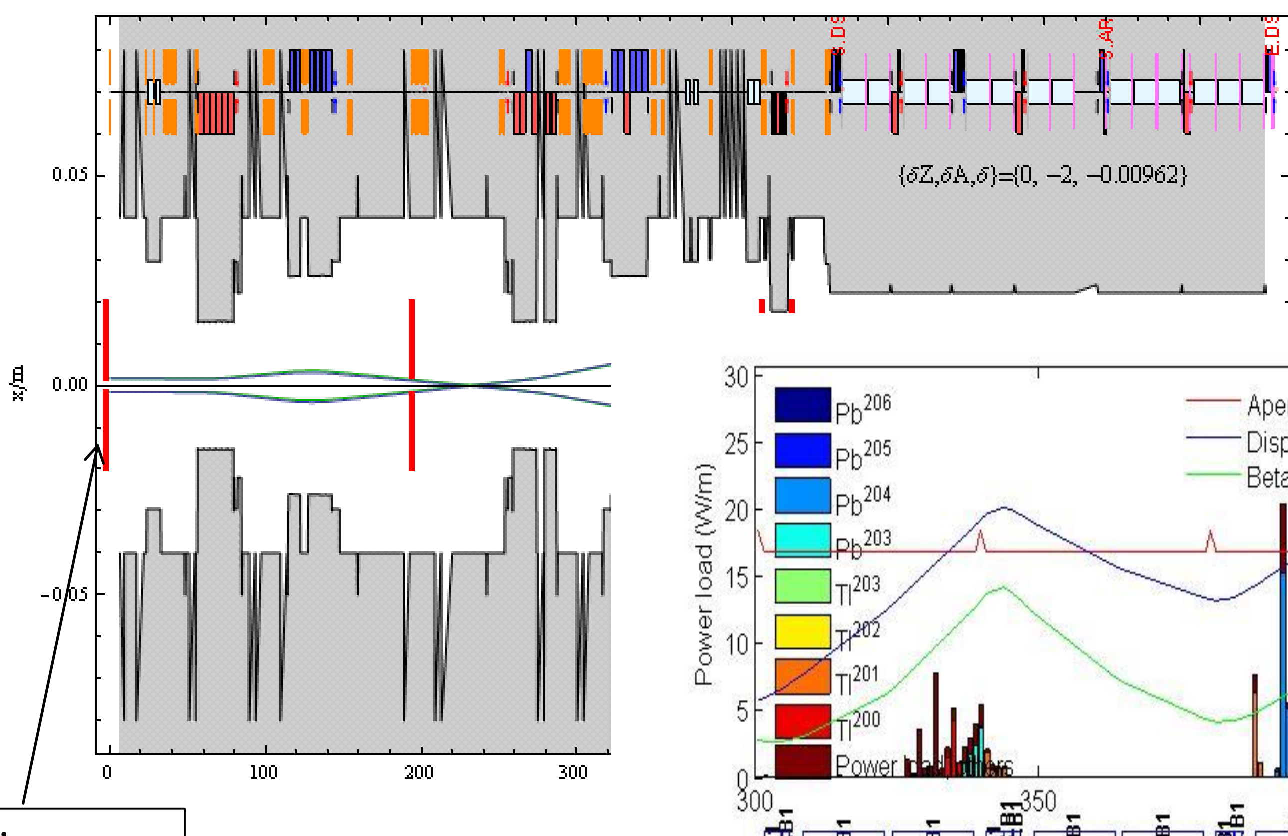
- Discussed extensively in the past
  - Pb nuclei fragment (nuclear or EMD) interacting with carbon of primary collimator – unlike protons
- Mainly a limit on total intensity
  - Some situations (Pb beam sizes larger than p, putting beams into collision, off-momentum p-Pb orbits more critical)
  - Mitigation – some success with bump strategy

New simulations in Sixtrack framework being developed by Pascal Hermes.



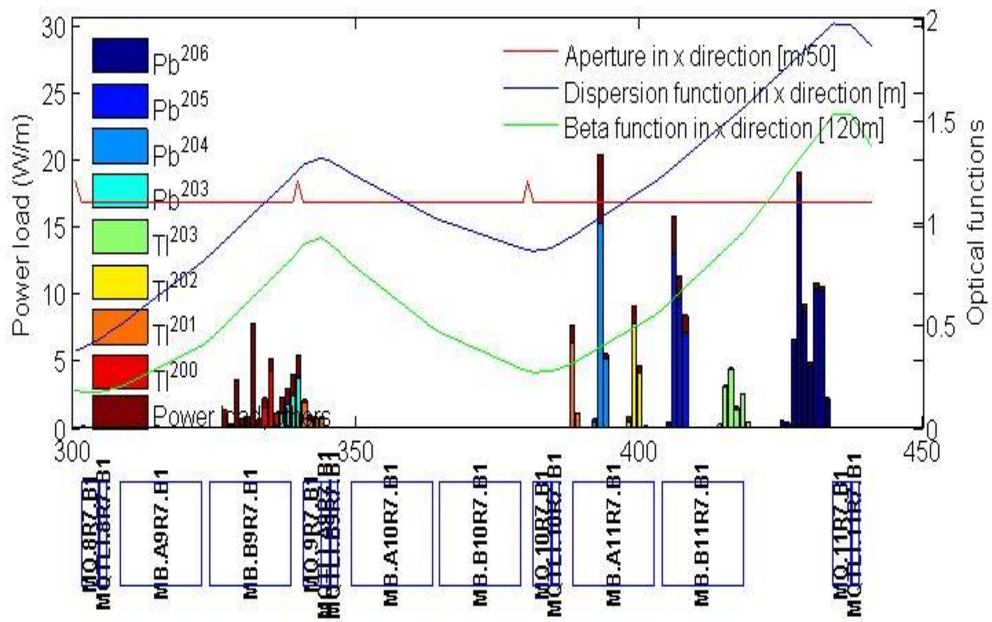
Example of ^{206}Pb created by EMD2 in primary collimator

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



Beam pipe in IR7 of LHC

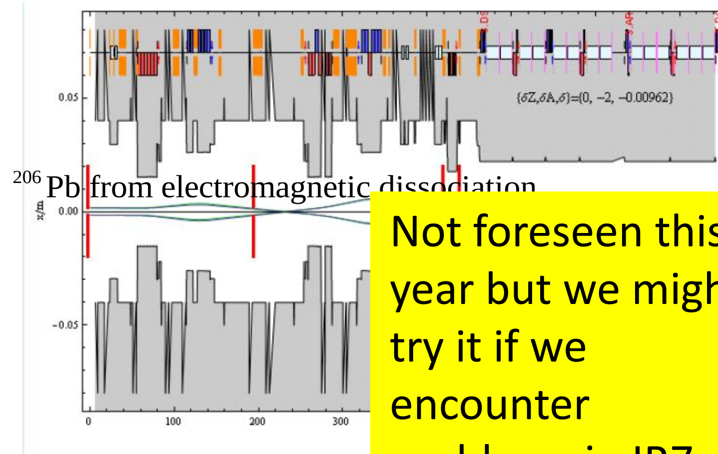
Primary collimator



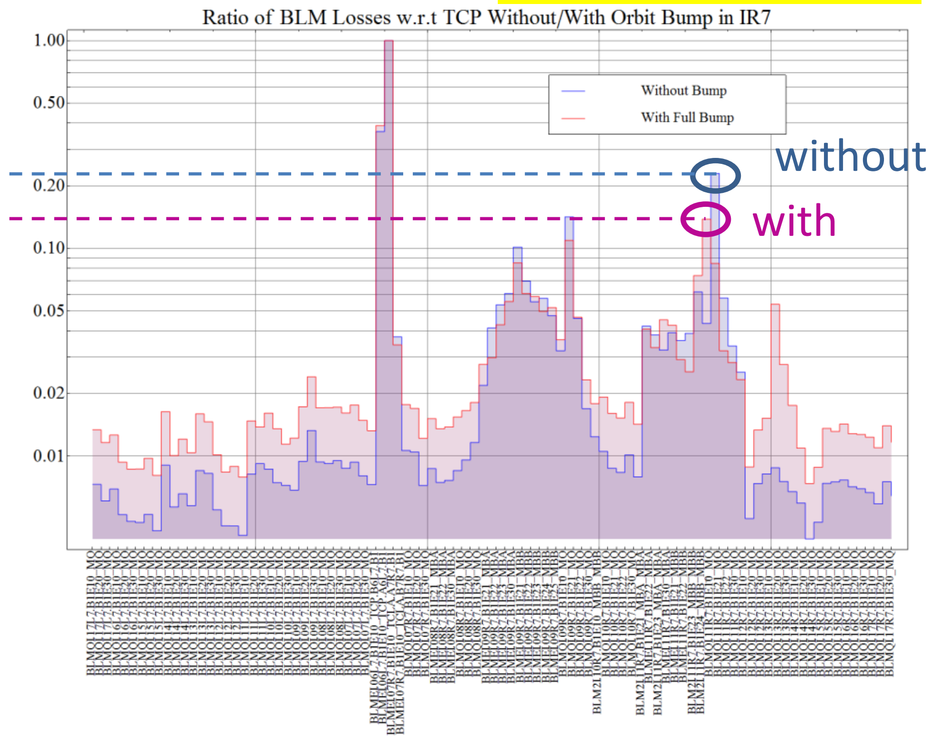
Bump method to mitigate losses in IR7 (test in 2013)

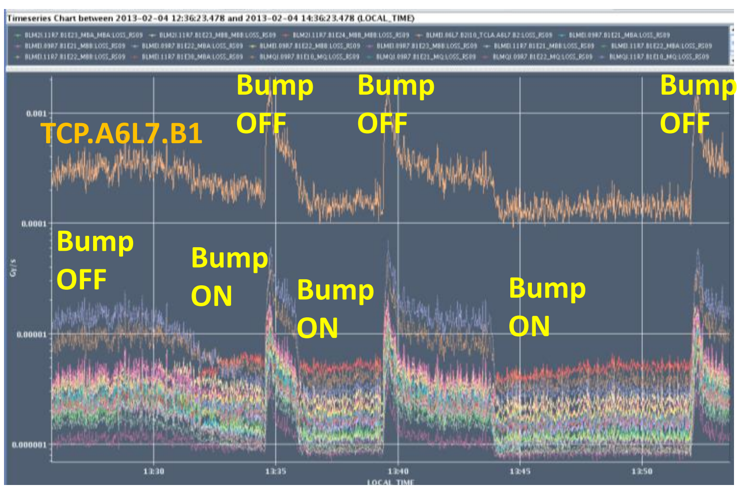
- Test of B1 horizontal orbit bump in IP7 around Q11.R7 (+2.5 mm), to spread the losses longitudinally,
- It worked, we observe a factor **1.62 ± 0.04** gain on the maximum loss peak,
- But losses were reduced at the primary collimator, which should not be influenced, → was there an orbit non closure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

R. Bruce, E.B. Holzer, J. Jowett, S. Redaelli, B. Salvachua, M. Schaumann



Not foreseen this year but we might try it if we encounter problems in IR7.





DS collimators in IR7 for heavy ions

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

ATS/Note/2012/081 MD

2012-10-29

Giulia.Bellodi@cern.ch

Pb ions collimator losses in IR7 DS and quench test at 3.5 Z TeV

G. Bellodi, R W Assmann, R Bruce, B Dehning, E B Holzer, J M Jowett, E Nebot del Busto, L Ponce, S Redaelli, M Sapinski, M Schaumann, R Schmidt, M Solfaroli Camillocci, G Valentino, D Valuch, R Versteegen, J Wenninger, D Wollmann, M Zerlauth /

- 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.

LHC MD304: Collimation quench tests for ions at 6.5 Z TeV

- **MD Contact persons:** P. Hermes, B.Salvachua, S. Redaelli
- **Participants:** Collimation team with BE/BI (BLM), ADT, magnet and MP teams.
- **Time required (hours):** 16
- **Merit:** This study aims at evaluating the quench limits in dispersion suppressor and arc magnets due to Pb ion collimation losses around the betatron cleaning insertion, at assessing maximum intensity reach for RunII, RunIII and HL. These tests also have the immediate outcome of allowing more optimized settings for the operational BLM thresholds. Specifically for ions, important upgrade choices like the production of 11T dipoles depend on the results of such tests.
- **MD procedure link:** See procedure followed in the ion quench tests in 2011: https://espace.cern.ch/be-dep/Lists/IPAC13_new/ Attachments/184/THPEA045.pdf and http://epaper.kek.jp/HB2012/papers/mop245.pdf. The corresponding MP note is also available.
- **Species:** Ions
- **Category:** Normal MD
- **Beam:** Either
- **OP contact person:**
- **Description:**Collimation quench tests for ions are performed by inducing very large beam losses on the primary collimators of IR7 with collimation settings as in standard high-intensity fills for physics. The procedure for ion beams follows what has been already achieved for protons, as in https://cds.cern.ch/record/1708365/files/ CERN-ACC-NOTE-2014-0036.pdf?. Note that in 2011, the ion quench test was performed by exciting the beams with the tune resonance method while we now propose to use the controlled ADT excitations instead.
- **Beam energies:**Flat top

May benefit from previous experience with corresponding proton MD, should be done near end of run.

LHC MD844: BFPP Quench Limit

- **MD Contact persons:** John Jowett
- **Participants:** Michaela Schaumann, Tom Mertens, Anton Lechner, John Jowett
- **Time required (hours):** 4
- **Merit:** Determine the Pb-Pb luminosity at which the BFPP beam induces a quench, important for planning upgrades for HL-LHC. Only necessary if quenches have not already occurred in operation. If quenches still do not occur, the fill can be converted into a physics fill and the time cost will be small.
- **Description:** The operational set up for Pb-Pb physics will include bumps designed to mitigate the risk of quenches. If no quenches occur in operation, we will set up as for a maximum luminosity physics fill and collide in either IP1 or IP5 only (in ADJUST mode). Then we will reduce the bump on L and/or R until a quench occurs. If no quench occurs, it should be possible to repurpose the fill as a physics fill.
- **Species:** Ions
- **Category:** Normal MD
- **Beam:** Both
- **OP contact person:** R. Alemany

Perform near end of run when peak luminosity should be highest.

Try to avoid losses near end of dipole, harder to interpret quench level.

Potentially the most accurate determination of steady-state quench level ?

BLM threshold considerations

- Thresholds in IR7 for collimation losses
  - Lower collimation efficiency, more loss locations
  - Set similarly to protons ?
  - Raise during collimation quench test MD
- Thresholds in BFPP loss regions IR1, IR5, IR2
  - Continuous steady state losses proportional to luminosity
    - Power in luminosity losses cannot fluctuate beyond upper bound
  - Set thresholds “at quench level” in operation ?
  - Raise for BFPP quench test MD

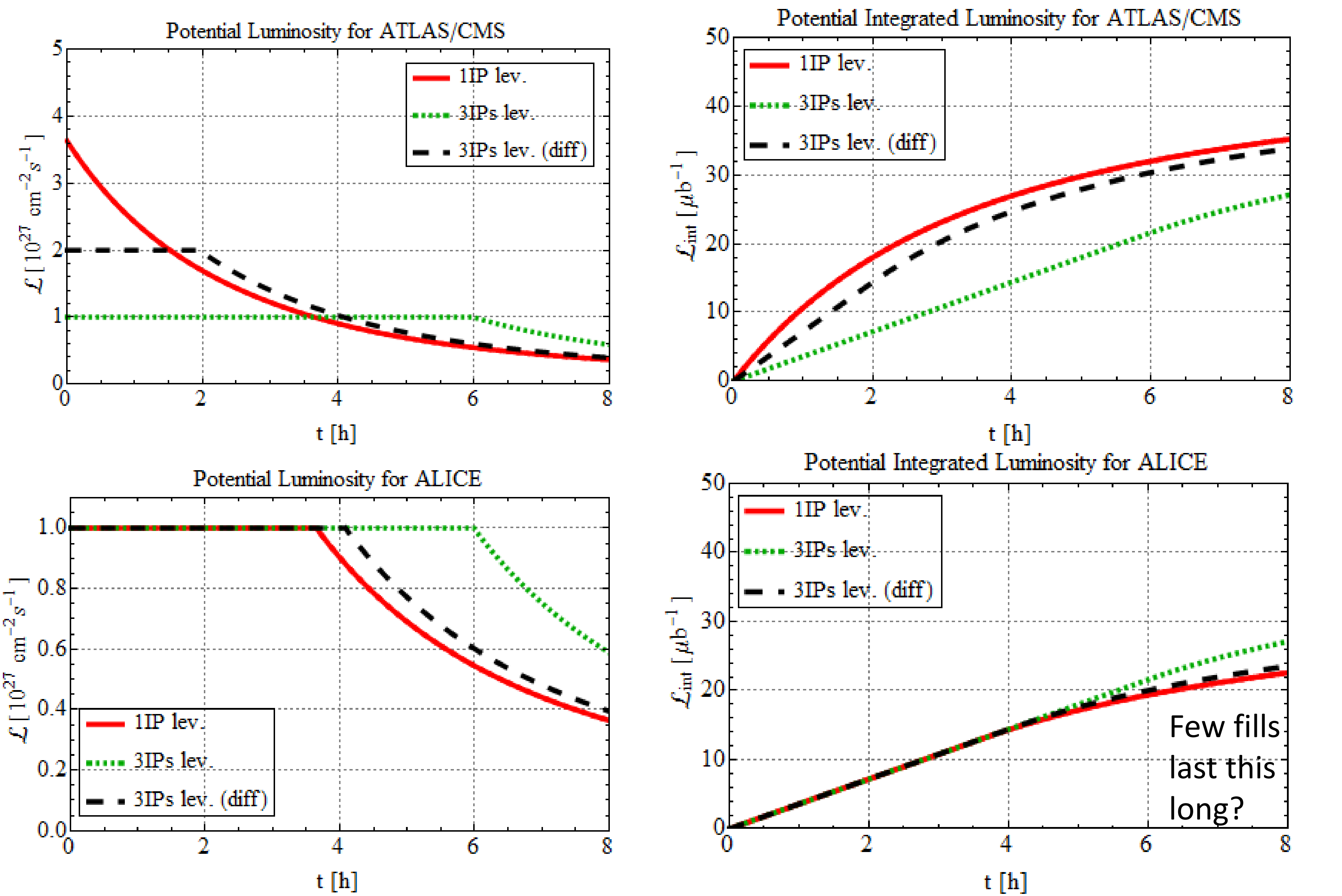
- N.B. we will also try to deliver low luminosity to LHCb
  - Should check loss locations …

Summary

- The 2015 run will be the only Pb-Pb run between 2011 and 2018
  - Important to maximise integrated luminosity
    - Luminosity sharing and levelling
    - Complex run with other new features and requirements
  - Entering new regime beyond design luminosity
    - Some chance of quenches from luminosity in IR7, IR3, IR1, IR5 (IR2?), need to exercise mitigation strategy with orbit bumps
- Decision point for DS collimator installation in LS2
  - Establish need for DS collimators in connection cryostat in IR2
  - Establish need for DS collimators (+11 T magnets) in IR7
- Important to set appropriate BLM thresholds

BACKUP SLIDES

Illustrative levelling options for a very optimistic example fill



Early History

BFPP and other processes contribute to rapid beam intensity decay, A.J. Baltz et al, Phys Rev E, **54**, 4233 (1996)

BFPP can limit luminosity by quenching superconducting magnets in heavy-ion colliders, S. Klein, NIM A **459** (2001) 51

LHC Performance Workshop, Chamonix 2003
Estimates of energy deposition with real LHC magnetic structure and magnets, using older quench limits – concerns about attaining design luminosity.

Discussion of stopping the BFPP secondary beam with collimator – ruled out by engineers as too difficult to modify cryogenic section at that stage of LHC construction (+other crazy ideas …).

HEAVY ION BEAMS IN THE LHC EPAC 2003

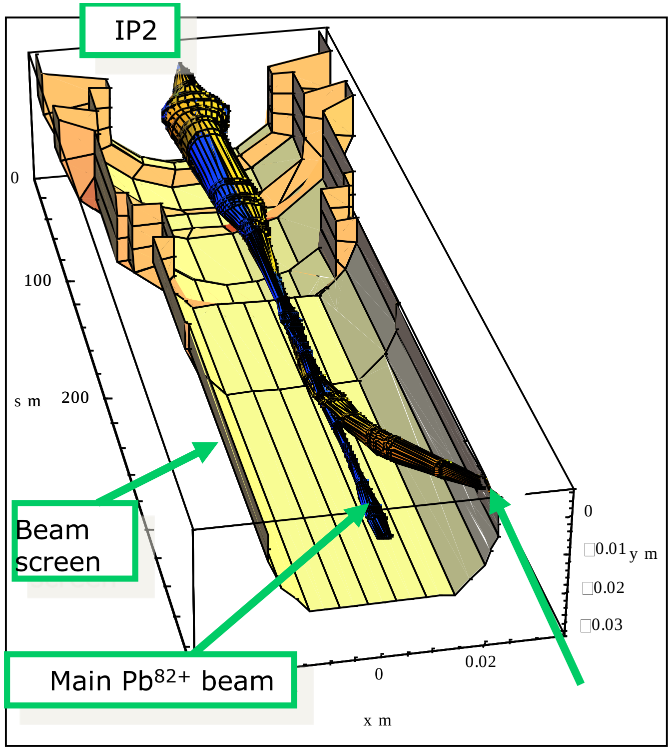
J.M. Jowett, J.-B. Jeanneret, K. Schindl, CERN, Geneva, Switzerland

Luminosity Limit from bound-free pair production

LIMITS TO THE PERFORMANCE OF THE LHC WITH ION BEAMS*

J.M. Jowett#, H.H. Braun, M.I. Gresham*, E. Mahner, A.N. Nicholson, E. Shaposhnikova, CERN, Geneva, Switzerland
I.A. Pshenichnov, INR, Russian Academy of Sciences, Moscow, Russia

EPAC 2004, Chamonix 2004, LHC Design Report



Secondary Pb^{81+} beam (25 W at design luminosity) emerging from IP and impinging on beam screen. Hadronic shower into superconducting coils can quench magnet.

Also new model of luminosity evolution with IBS, radiation damping and luminosity burn-off (earlier work by A. Morsch).

Companion paper (principal author Hans Braun) introduced simulations of heavy ion interactions with collimators.

Distinct EMD process (similar rates) does not form spot on beam pipe

$$^{208}Pb^{82+} + ^{208}Pb^{82+} \xrightarrow{GDR} ^{208}Pb^{82+} + ^{207}Pb^{82+} + n$$

CERN Working Group 2003-2005

Working group in CERN 2003-5 to improve implementation of relevant heavy-ion physics processes in FLUKA Monte-Carlo

PHYSICAL REVIEW SPECIAL TOPICS - ACCELERATORS AND BEAMS **17,** 021006 (2014)

Hadronic and electromagnetic fragmentation of ultrarelativistic heavy ions at LHC

H. H. Braun,[1] A. Fassò,[2] A. Ferrari,[3] J. M. Jowett,[3] P. R. Sala,[4] and G. I. Smirnov[3,5,*]
[1]*Paul Scherrer Institut, 5232 Villigen PSI, Switzerland*
[2]*ELI Beamlines, Prague, Czech Republic*
[3]*CERN, CH-1211 Geneva, Switzerland*
[4]*INFN, Via Celoria 16, 20133 Milano, Italy*
[5]*Laboratory for High Energy Physics, JINR, Dubna, Russia*
(Received 8 July 2013; published 24 February 2014)

Reliable predictions of yields of nuclear fragments produced in electromagnetic dissociation and hadronic fragmentation of ion beams are of great practical importance in analyzing beam losses and interactions with the beam environment at the Large Hadron Collider (LHC) at CERN as well as for estimating radiation effects of galactic cosmic rays on the spacecraft crew and electronic equipment. The model for predicting the fragmentation of relativistic heavy ions is briefly described, and then applied to problems of relevance for LHC. The results are based on the FLUKA code, which includes electromagnetic dissociation physics and DPMJET-III as hadronic event generator. We consider the interaction of fully stripped lead ions with nuclei in the energy range from about one hundred MeV to ultrarelativistic energies. The yields of fragments close in the mass and charge to initial ions are calculated. The approach under discussion provides a good overall description of Pb fragmentation data at 30 and 158A GeV as well as recent LHC data for $\sqrt{s_{\rm NN}} = 2.76$ TeV Pb-Pb interactions. Good agreement with the calculations in the framework of different models is found. This justifies application of the developed simulation technique both at the LHC injection energy of 177A GeV and at its collision energies of 1.38, 1.58, and 2.75A TeV, and gives confidence in the results obtained.

BFPP beam detected at RHIC

RHIC collides Cu-Cu in early 2005 and we realise that BFPP should be detectable.

Rush to RHIC to set up experiment with help of Angelika Drees.

PRL **99,** 144801 (2007) PHYSICAL REVIEW LETTERS week ending 5 OCTOBER 2007

Observations of Beam Losses Due to Bound-Free Pair Production in a Heavy-Ion Collider

R. Bruce,* J. M. Jowett, and S. Gilardoni
CERN, Geneva, Switzerland

A. Drees, W. Fischer, and S. Tepikian
BNL, Upton, New York, USA

S. R. Klein
LBNL, Berkeley, California, USA

(Received 13 June 2007; published 3 October 2007)

We report the first observations of beam losses due to bound-free pair production at the interaction point of a heavy-ion collider. This process is expected to be a major luminosity limit for the CERN Large Hadron Collider when it operates with $^{208}Pb^{82+}$ ions because the localized energy deposition by the lost ions may quench superconducting magnet coils. Measurements were performed at the BNL Relativistic Heavy Ion Collider (RHIC) during operation with 100 GeV/nucleon $^{63}Cu^{29+}$ ions. At RHIC, the rate, energy and magnetic field are low enough so that magnet quenching is not an issue. The hadronic showers produced when the single-electron ions struck the RHIC beam pipe were observed using an array of photodiodes. The measurement confirms the order of magnitude of the theoretical cross section previously calculated by others.

View towards PHENIX

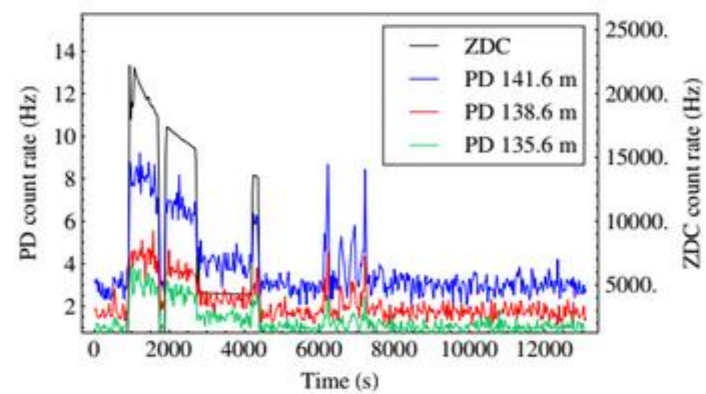


FIG. 4 (color online). Count rates measured on the ZDC luminosity monitors (black, right scale) and the three PDs with the highest signal [shades of gray, left scale (colors online)] during a store with the WPD. The data was binned in 30 sec intervals. A clear correlation between the luminosity and the PD count rates can be seen.