Roadmap for BBLR compensation for HiLumi LHC operation

HS – 22-1-2015
HL-TC

With contributions from:
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Outline

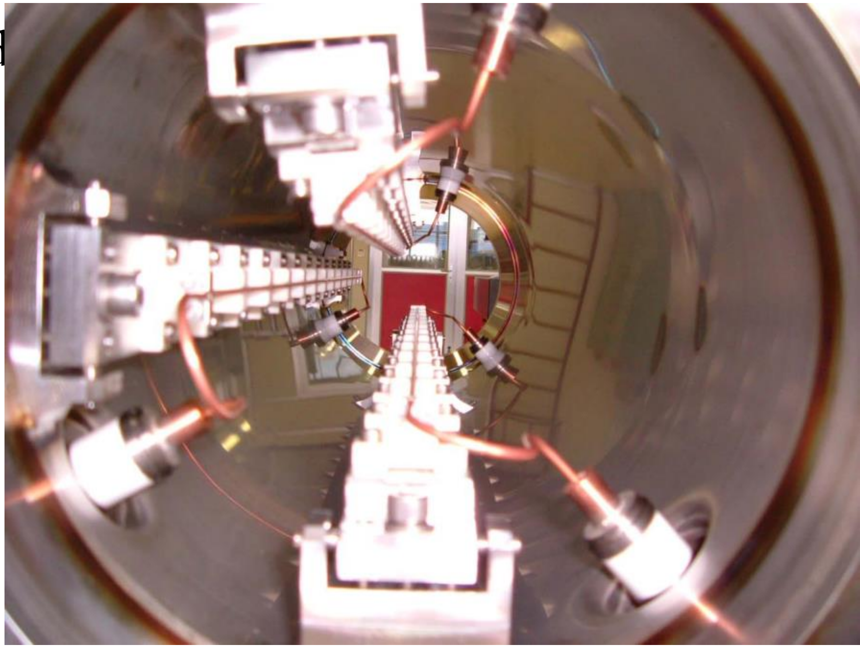
- The project is broken down in four work-packages:

  1) Demonstrator projects before LS2
  (demonstrator installation in collimators, installation winter shutdown 2016-2017)
  2) Related beam instrumentation and beam experiments : 2 D halo monitor, tune spectra
  3) Optimization of parameters for HiLumi
  → done inside HL-WP2
  4) BBLR compensation using e- lenses:
  Try to make this part of a more generic R&D:
  - Low energy e-beams as actuators on hadron beams

1) Demonstrator projects

- Work consists of simulations, a workshop in summer 2015, SPS experiments in 2015/2016, LHC experiments in 2017
  - simulations: Y.Papaphilipou et al, A.Valishev et al.
  Aim: simulate possible beam observables with/without compensation, specify necessary instruments performance
  - workshop: details still to be defined; summer 2015
  aim: bring about 10 people from simulations together with about 10 instrumentation experts…see what is possible
  - SPS experiments: next slide
  - LHC experiments: following slides
- Aim of this work-package is to have end of the year 2017 enough experimental evidence such that BBLR compensation becomes a "construction option" for HL-LHC.

Wires at SPS

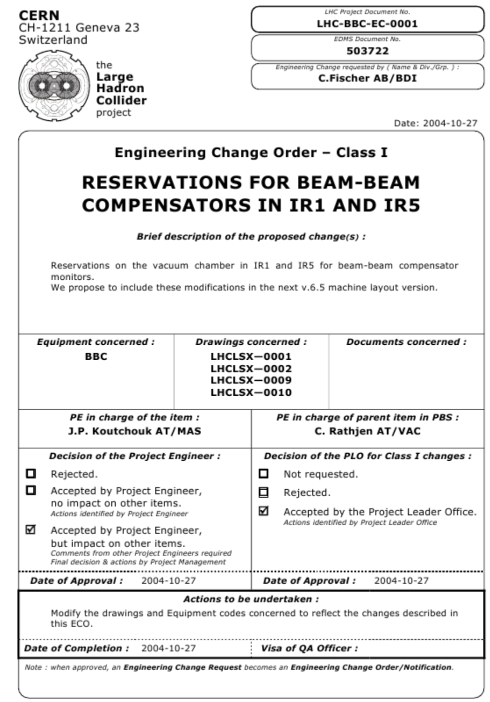


- Two 60cm long 3-wire compensators installed in the CERN SPS
  - Different “crossing” plane and even @ 45deg
- Movable in vertical by +/- 5mm (remote controlled)
- Water cooled
- About equal beta functions in the transverse planes (~50m)
- Separated by phase advance of 3deg (similar between BBC and long range interactions in LHC)
- Powered with integrated DC current of up to 360A m (60 LR collisions in LHC)
- Set-up re-evaluated during 2014 (powering), for MDs in 2015 (benchmarking wire models)
- Effect of wire on orbit, tune, tunes-spread, coupling (alignment), resonance driving terms, beam distribution (tails)
- Can be done at flat bottom in parallel MD cycle with new pulsed power supply
- Beam brought close to the wire with closed bump (to be checked)

Initial Plans: LHC Beam-Beam Compensators I/III

- Reservations around IR1&IR5, LHC-BBC-EC-0001:

	name	Position and longitudinal dimensions
IR1	BBC.4L1	-104.931 m ± 1.5m wrt IP1
	BBC.4R1	104.931 m ± 1.5m wrt IP1
IR5	BBC.4L5	-104.931 m ± 1.5m wrt IP5
	BBC.4R5	104.931 m ± 1.5m wrt IP5


CERN
CH-1211 Geneva 23
Switzerland

the Large Hadron Collider project

LHC Project Document No. LHC-BBC-EC-0001
EDMS Document No. 503722
Engineering Change requested by (Name & Div./Grp.) : C.Fischer AB/BDI

Date: 2004-10-27

Engineering Change Order – Class I

RESERVATIONS FOR BEAM-BEAM COMPENSATORS IN IR1 AND IR5

Brief description of the proposed change(s) :

Reservations on the vacuum chamber in IR1 and IR5 for beam-beam compensator monitors.
We propose to include these modifications in the next v.6.5 machine layout version.

Equipment concerned :	Drawings concerned :	Documents concerned :
BBC	LHCLSX–0001 LHCLSX–0002 LHCLSX–0009 LHCLSX–0010	

PE in charge of the item :	PE in charge of parent item in PBS :
J.P. Koutchouk AT/MAS	C. Rathjen AT/VAC

Decision of the Project Engineer :	Decision of the PLO for Class I changes :
☐ Rejected. ☐ Accepted by Project Engineer, no impact on other items. *Actions identified by Project Engineer* ☑ Accepted by Project Engineer, but impact on other items. *Comments from other Project Engineers required. Final decision & actions by Project Management*	☐ Not requested. ☐ Rejected. ☑ Accepted by the Project Leader Office. *Actions identified by Project Leader Office*
Date of Approval : 2004-10-27	*Date of Approval :* 2004-10-27

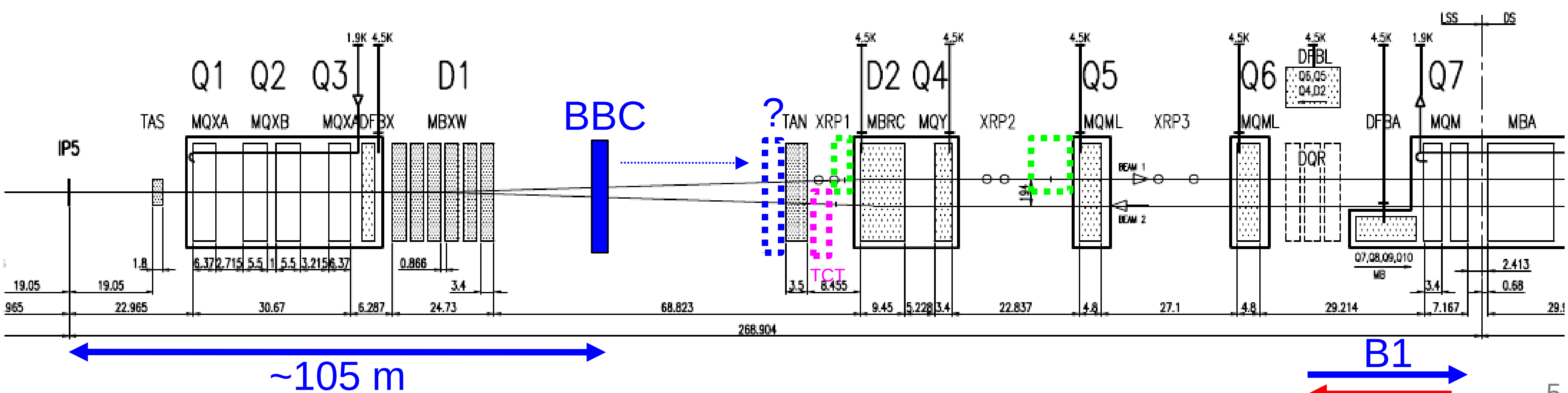
Actions to be undertaken :

Modify the drawings and Equipment codes concerned to reflect the changes described in this ECO.

Date of Completion : 2004-10-27 | *Visa of QA Officer :*

Note : when approved, an ***Engineering Change Request*** *becomes an* ***Engineering Change Order/Notification.***

- Min. LRBB → BBC phase advance: Δμ ≈ 2.6° (→ 3.1°)
- Symmetric beta-function: $\beta_{x/y} \approx$ 1000 m (for β^*= 0.55 m)
- N.B. single vacuum pipe for B1 & B2:
  110 mm full beam separation (only D1 only)
  (→ 165 mm, if shifted more towards TAN)



Status Wire in jaw collimators

- 4 “wire in jaw“ collimators ordered from CINEL. Design finished in late 2014. Delivery during 2015, followed by qualification tests.
  Installation in WS 2016/2017

- Cost covered by HL-LHC

- 2 options:
  1) full compensation of one beam: 1 collimator L&R in IP1 & IP5
  2) compensation of both beams on the ingoing or outgoing side
  = 2 collimators on the same side in IP1 & IP5

  Presently the cabling has been pulled for option 2

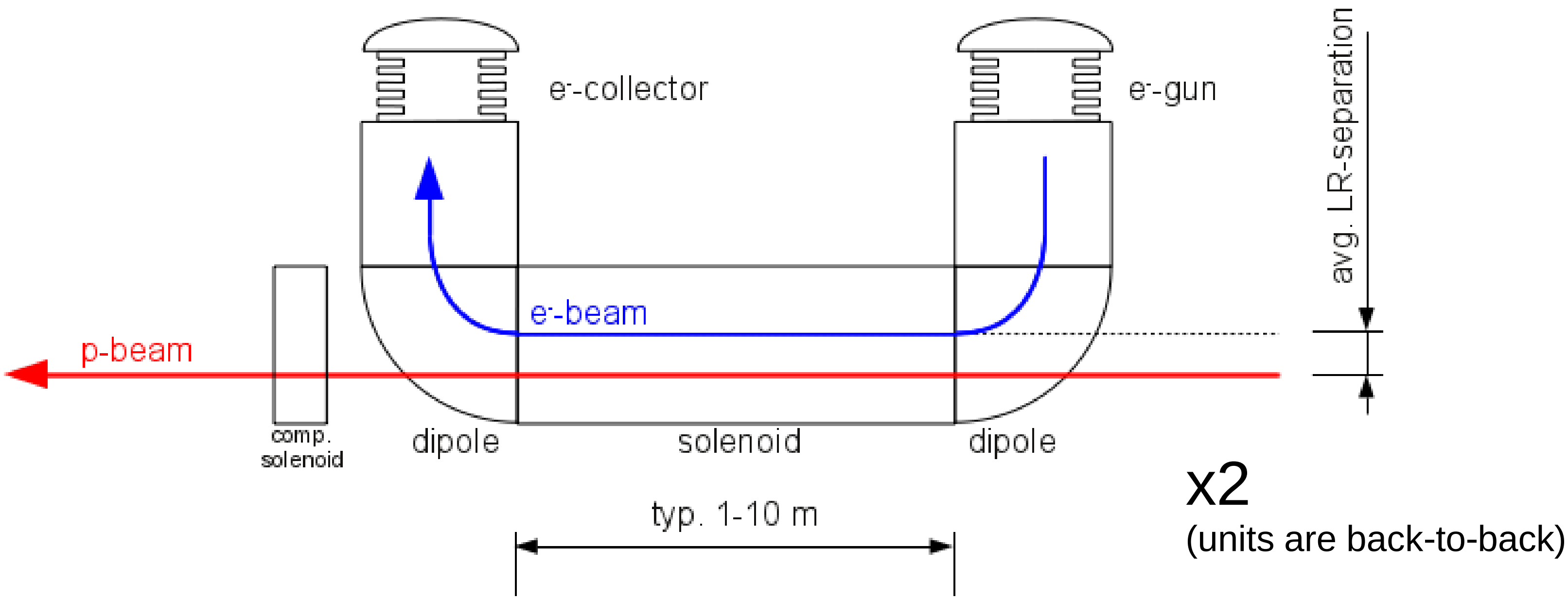
Option 1 is preferable (Yannis dixit) in order to reduce the footprint in tune-space. This needs 4 independent power supplies due to asymmetries in the optics.

One option has to be taken soon.

Experiments to be done in 2017 depend on outcome of SPS studies, on progress of simulations and on available instrumentation.

HL-LHC Option 3: Local e-beam simulating 'wire'-like Field I/II

- E-beam has by-design perfect 'wire' field distribution



- similar to existing e-cooler, (hollow-) e-lenses used at Tevatron & RHIC, however: offset e-beam! → <u>much</u> lower requirements on transverse e-beam parameters (i.e. beam size, profile distribution etc.)
- Still need large solenoid field to stiffen e-beam rigidity
- no solid material close to beam → chance of being MP compatible @6-7σ

Ad 1) workshop

- Exact date and location of this workshop depends on progress on simulations and availability of experts
  → say summer 2015:

- Show simulated observables
- Explain potential of existing instruments
- Understand possible new instruments
- Evaluate experiments
- About 20 participants (FNAL, BNL?, CERN)

2) Instrumentation development (1/2)

- Tune-spectra: nothing done so far; needs simulation effort what can be measured with swept sine wave analysis
- Halo Monitoring:
  a) based on synchrotron light
  b) beam–gas interactions

  a) On the first look challenging due to high energy of LHC beams.
  “ the synchrotron radiation cone (1/gamma) gets so narrow that the beam itself generates a significant diffraction pattern, which overwhelms the potential halo signal)
  - 2 approaches will be tried in collaboration:

  1) Shipment of a coronograph from KEK to CERN and installation of this device onto one BSRT (T. Mitsuhashi et al.)
  Shipment in 2015, installation plans pending.
  Presently optics simulations trying to reduce diffraction fringes by apodisation

Apodisation

Apodisation is a technique used in astronomy for the observation of faint sources close to bright ones, ex. for the observation of exoplanets. It consists in placing an opaque mask with a well-defined attenuation profile in an intermediate image plane. The attenuation profile is optimized to minimize the intensity of the secondary diffraction rings. Due to the complexity of our angular distribution the calculation of the attenuation profile may be complicated. Moreover chromatic dependency on the attenuation factors have to be studied in detail.

2) Instrumentation development (2/2)

- 2) observation of Halo with a high dynamic range camera: A. Fisher (SLAC) et al. + D. Rubin (Cornell).

  The main objectives of this collaboration are:
  - Produce a detailed model of the synchrotron light emission and propagation in HL-LHC (lot of work already done at CERN on this subject)
  - Investigate the possibility of using an apodiser mask in order to reduce the effects of diffraction on the halo measurement.
  - Investigate the different types of high dynamic range (DR) cameras and identify the one better suited for the halo monitor
  - Estimate the performances of an halo monitor based on an apodiser and a high DR camera for LHC and HL-LHC
  - Produce a prototype system and test it on a suitable accelerator (CeSR or light source)
  - Investigate the possible alternative synchrotron light ports in the LHC

This collaboration is presently being defined, not much progress expected in the beginning of this year, CERN experts busy with LHC start-up.

Beam profile measurements based on modern vertex detectors and beam-gas interactions

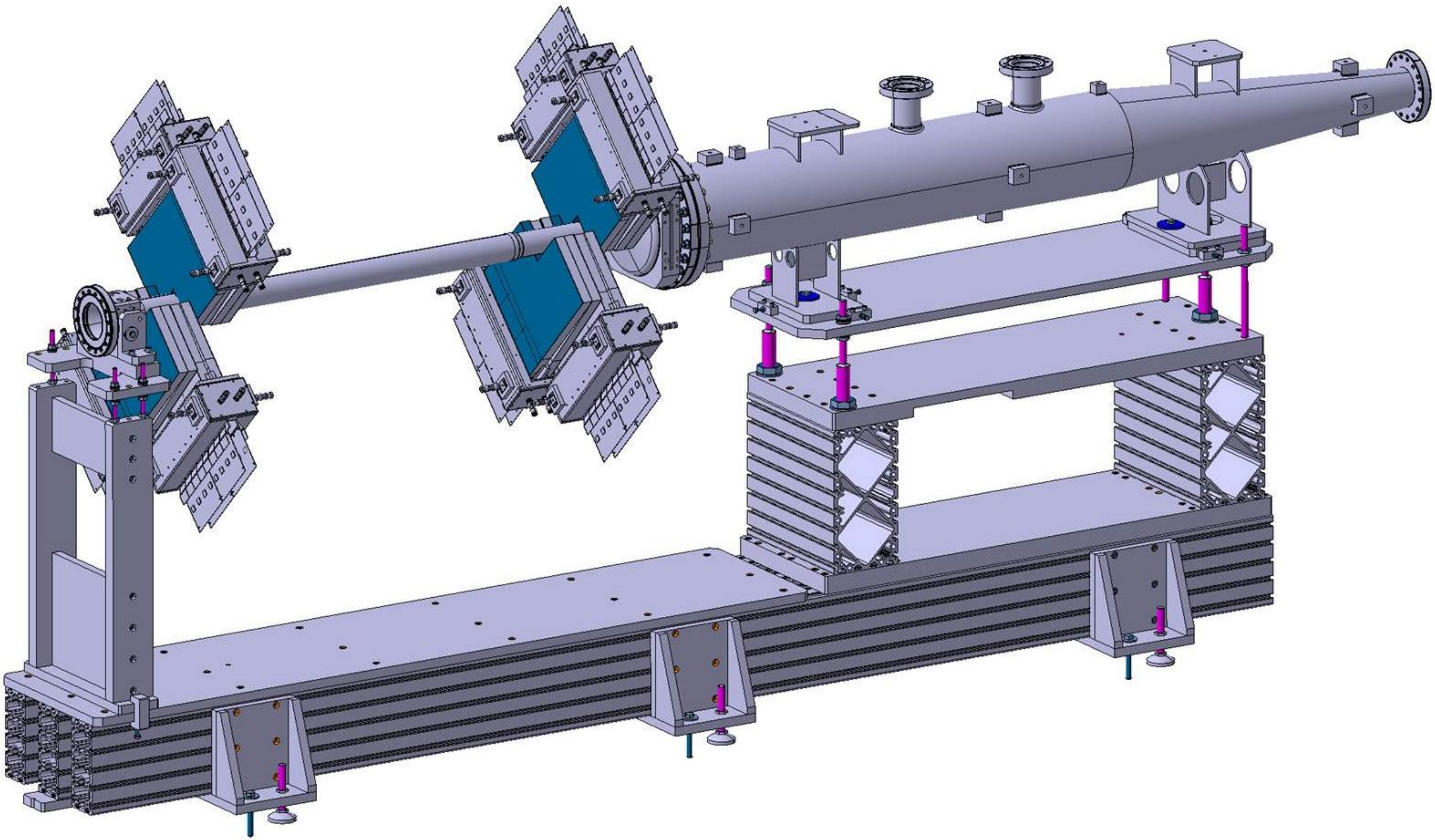
Rhodri Jones (CERN)
SLAC Halo Workshop (IBIC14)

Slides from:

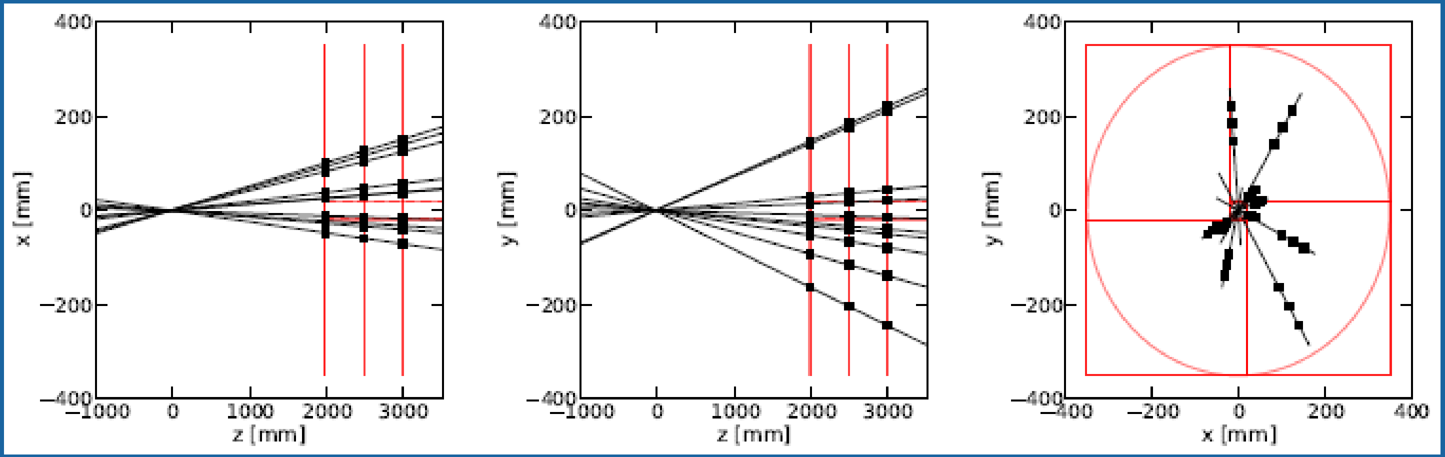
Colin Barschel - TIPP 2014 third international conference on Technology and Instrumentation in Particle Physics

Plamen Hopchev - 9th DITANET Topical Workshop on Non-Invasive Beam Size Measurement for High Brightness Proton and Heavy Ion Accelerators, 16 April 2013

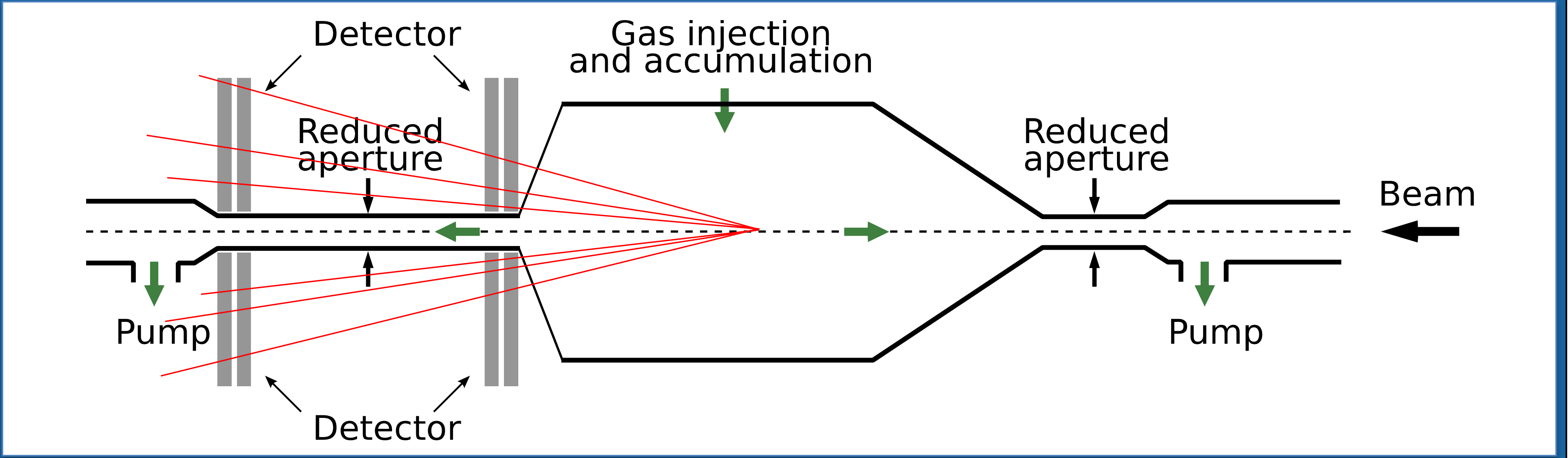
From LHCb to ~~mini LHCb~~ BGV



- As a minimum, need 2 or 3 measuring planes



- Need a dedicated pressure bump



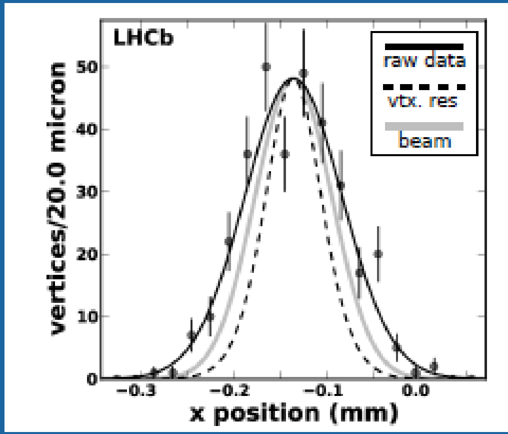
BGV for Halo?

- For a beam with Gaussian transverse shape:

$$\sigma^2_{\mathrm{raw}} = \sigma^2_{\mathrm{beam}} + \sigma^2_{\mathrm{vtx.res}}$$

- When $\delta\sigma_{\mathrm{raw}}/\sigma_{\mathrm{raw}} \to 0$:

$$\frac{\delta\sigma_{\mathrm{beam}}}{\sigma_{\mathrm{beam}}} = \frac{\sigma^2_{\mathrm{vtx.res}}}{\sigma^2_{\mathrm{beam}}} \cdot \frac{\delta\sigma_{\mathrm{vtx.res}}}{\sigma_{\mathrm{vtx.res}}}$$



- No experience with trying to measure the halo at 4-6 sigmas
- Need to deconvolve with tail of vertex resolution
- Beam-gas rate will be orders of magnitude smaller at this radial distance
  - Currently aim at 100Hz beam-gas per nominal bunch.
  - Sampling 0.1% of bunch tail of the bunch ⇒ 0.1 Hz / bunch

Increasing the interaction rate

- Measurement of "average" beam halo possible (2808 bunches)
- Increase the pressure (limited by vacuum interlocks)
  - factor 10 to 100 may be possible for short times
- Combine with gas sheet?

4) R&D on BBLR Compensator implementation post LS3

a) Not part of the HL baseline

b) General consensus that « in jaw wires » not possible
- distance from beam too large
- ideal location for compensator in common beam pipe…second beam has to pass through the collimator jaw

c) Since 2013 proposed to study the replacement of the physical wire by an electron beam:
Presently definition of a collaborative project called:

« Low energy e-beams as actuators on hadron beams »

E- beam applications

- So far:
  - AD, LEIR & ELENA e-cooling (G. Tranquille et al.)
  not further discussed; parameter space is very different, but same people at CERN + common technologies
- Under study
  - LHC beam cleaning (S. Redaelli et al.)
  - LHC BBLR (H. Schmickler et al.)
- Further request:
  - Compensation of space charge effects in SIS18/SIS100 (GSI – FAIR project; P. Spiller et al.)
- Needs a new feasibility study:
  - Compensation of space charge effects in CERN PS, PSB

  https://accelconf.web.cern.ch/accelconf/p07/PAPERS/THPAN074.PDF

GSI has submitted a request to the German BMBF for funding in order to simulate further details of this compensation. CERN is following (and complementing?) these simulations.

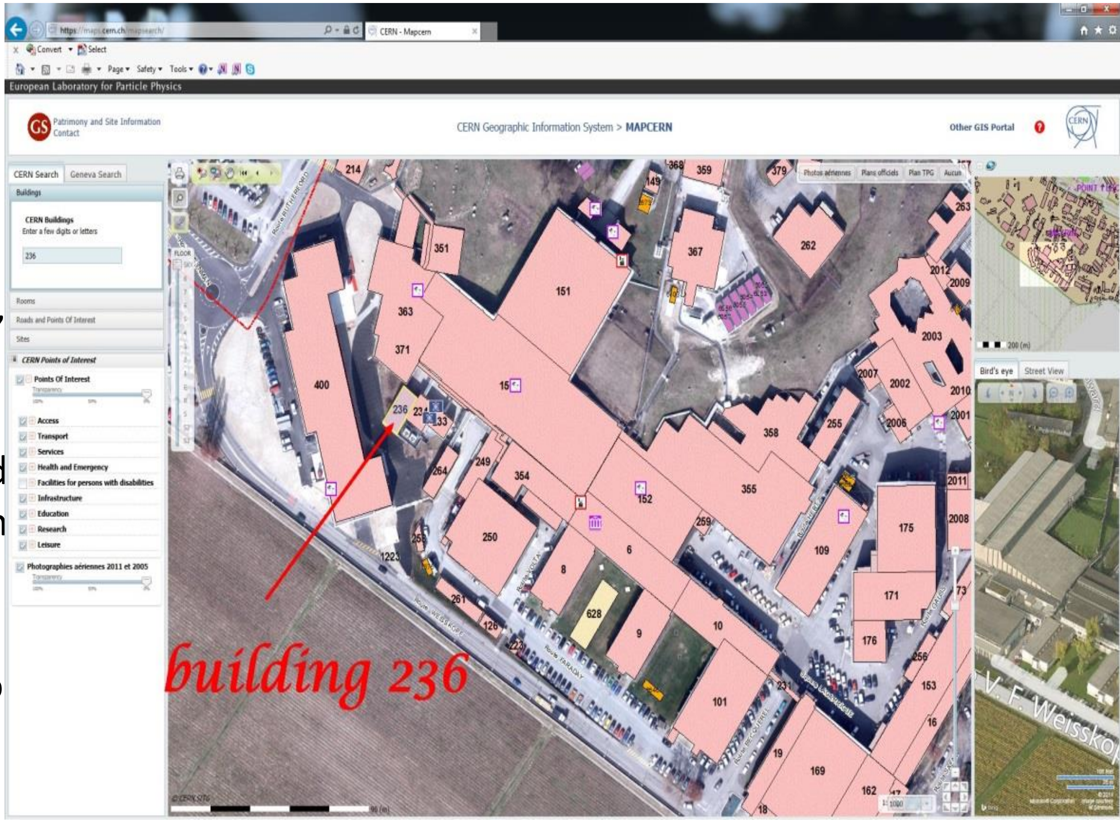
R&D needs

- Increase of intensity of electron beam (presently a few A) by a factor 2 to 5.
- Fast modulation of the (DC) electron beam up to 40 MHz (10% intensity modulation @ LHC for pacman bunches, intensity modulation following bunch shape for space charge compensation)
- Improved diagnostics (e-beam size in the overlap region, overlap of e-beam with p beam)

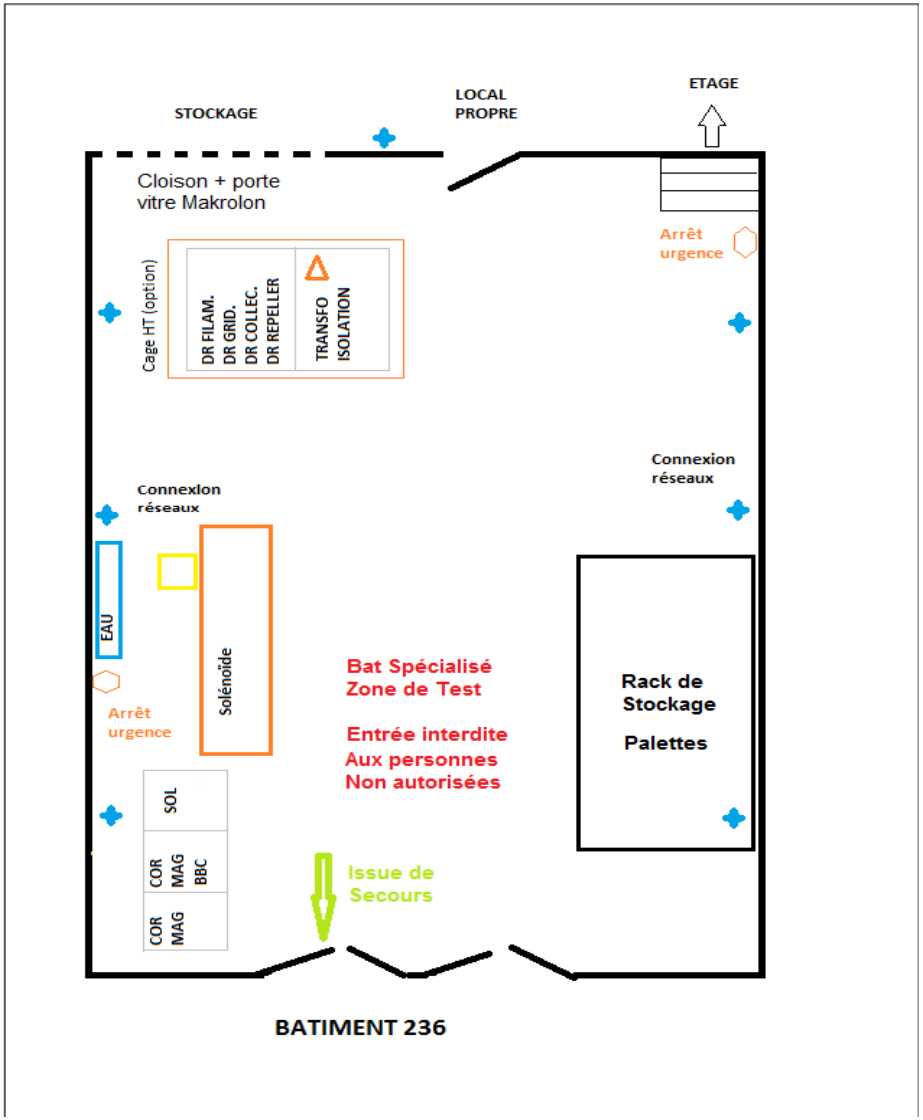
→ CERN will build a test-stand (mainly BE-BI)

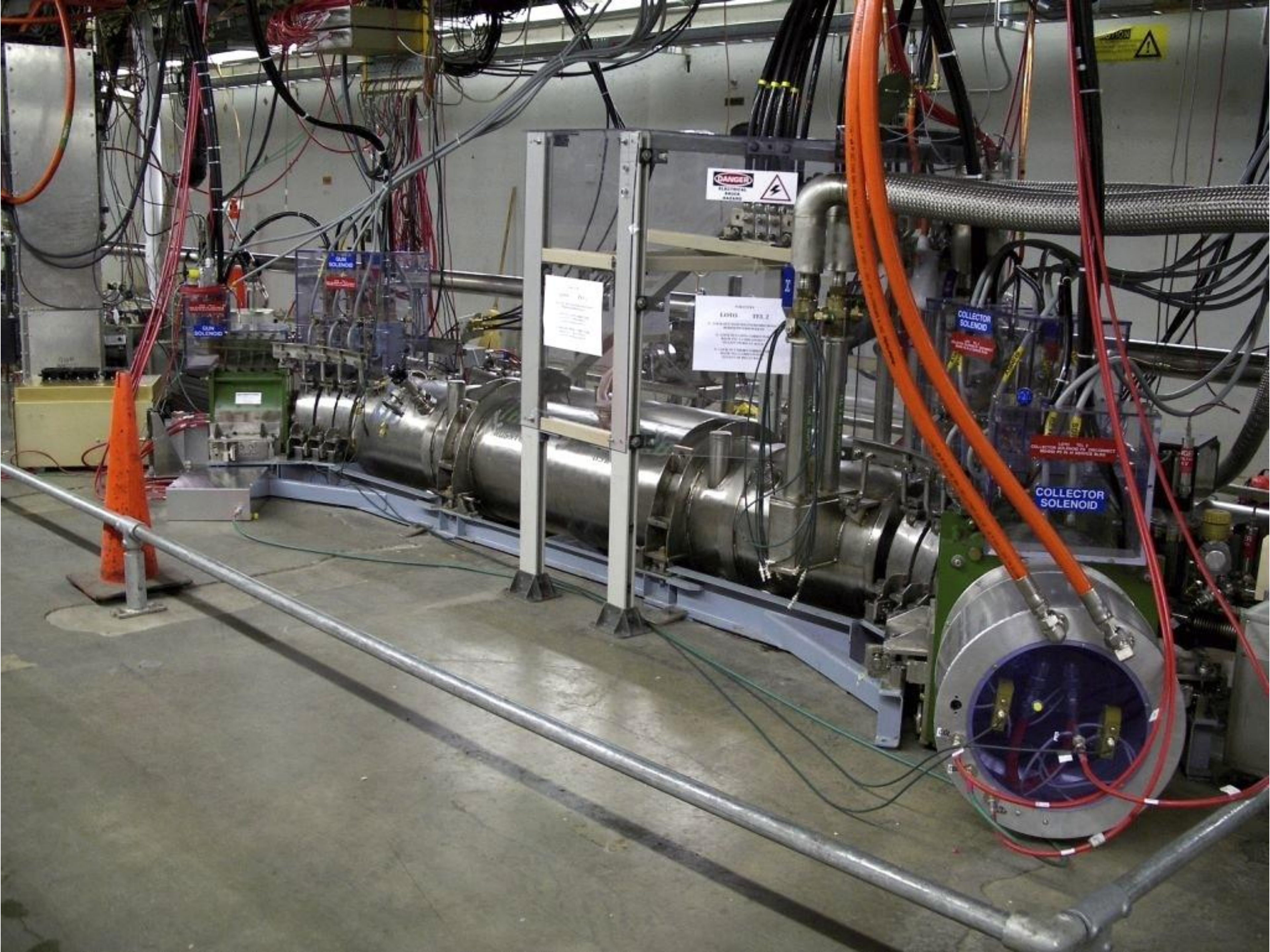
Teststand details

- The BE-BI group has an test-stand for development on electron cooler equipment (LEIR, ELENA) in building 236.
- There is space for an additional test-stand in building 236.
- Such a test stand is a complex system composed of (cryogenic) solenoid magnets, power supplies, electron beam source and collector, vacuum system and diagnostics.
- Instead of building a complete new installation FNAL has agreed to lend the almost complete TEL-2 Tevatron electron lens installation to CERN.
- Presently building 236 is being refurbished and TEL-2 should get to CERN in the second half of the year 2015.



Inside building 236

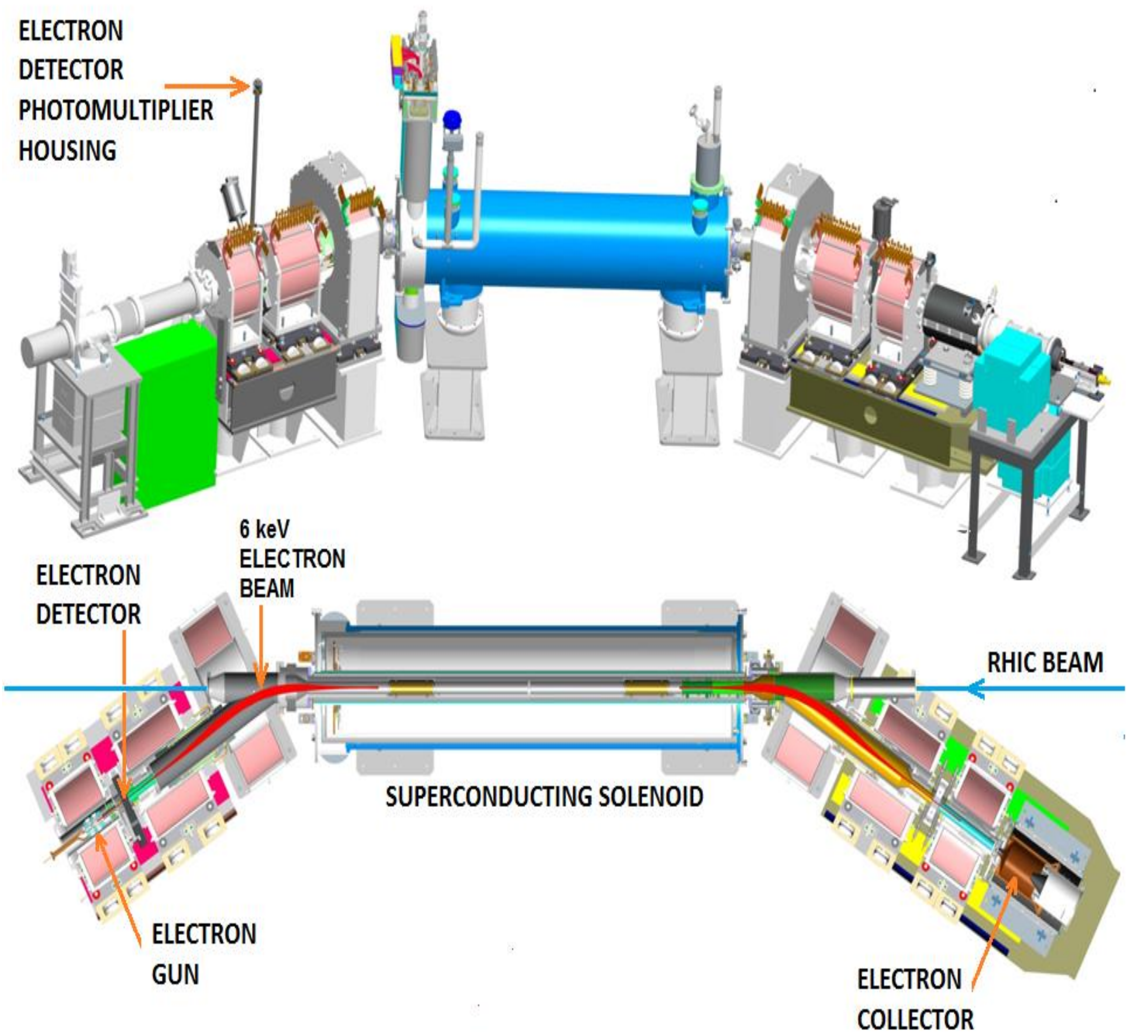



DANGER
GUN SOLENOID
GUN SOLENOID
COLLECTOR SOLENOID
COLLECTOR SOLENOID

Outline of developments to be made

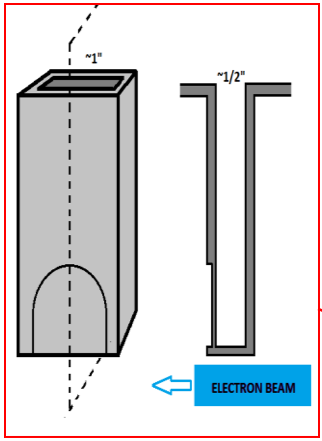
- Pre-requisite: Import the technologies towards CERN engineers. Collaborations with FNAL & GSI
(BNL and COSY to be contacted)
- Increase the electron beam current by a factor two to five.
- Modulate the electron beam intensity by about 10% at 40 MHz; potentially with a low power steering grid.
- Develop an instanteneous beam profile measurement at full beam power. An existing development for the CLIC drive beam (Adam Jeff, Liverpool University) could be adapted to the new geometry : Injection of a gas-curtain and measurement of the beam profile through ionization/fluorescence (2 following slides)

RHIC e-lens showing the location of the electron back-scattering detector (eBSD)

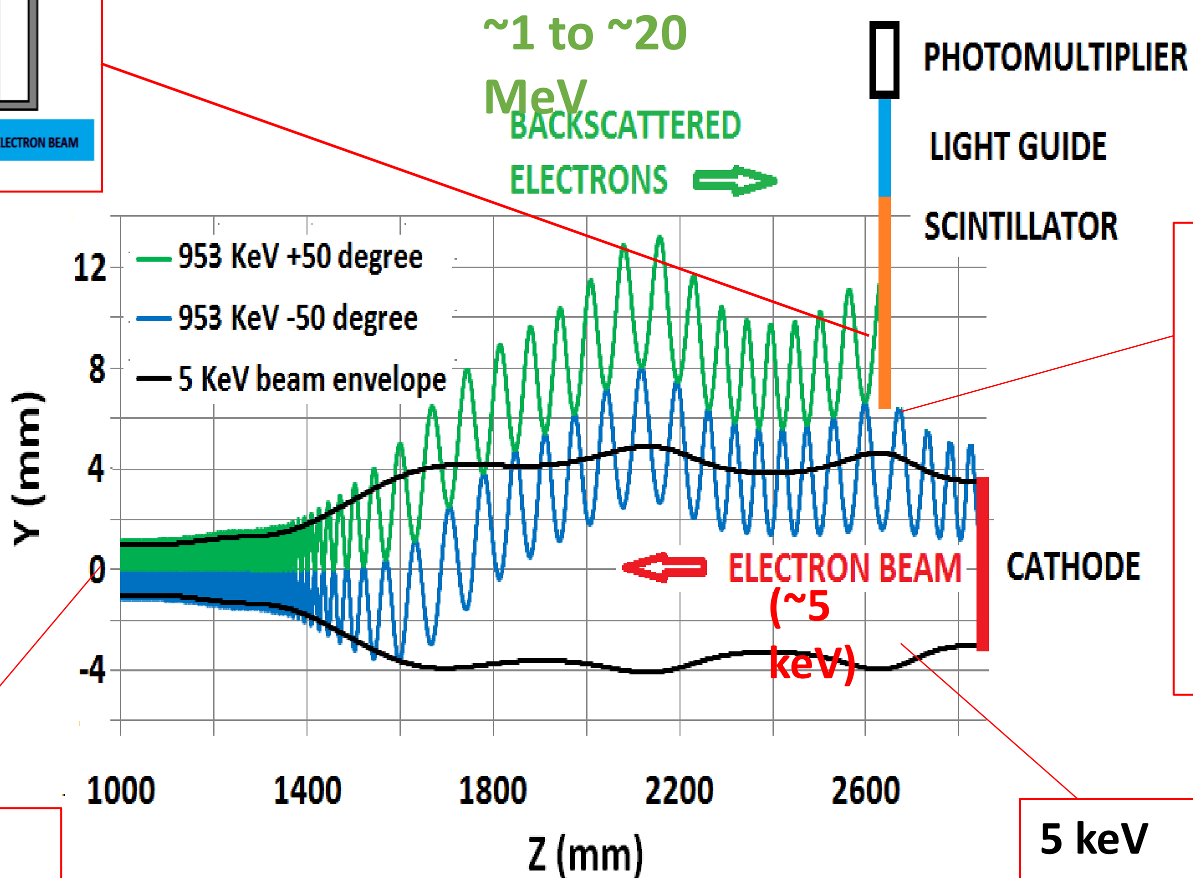


- The beam-beam effect limiting RHIC luminosity will be mitigated with two electron lenses
- The 2 m long electron and proton beams propagating in opposite direction in two ~6T solenoids have a width of ~300 μ rms.
- The misalignment must be < 30 μ for the lenses to work properly.
- Misaligned can do more harm than good.
- BPMs are not quite good enough to guarantee satisfactory alignment.
- We will use electrons backscattered by the protons as the “luminosity signal to achieve alignment
- The system was recently successfully commissioned with 100 GeV/amu Au and ^{3}He beams

Schematic of the detector and of the electron trajectories



The electrons, scattered in small impact parameter collisions with the ions, reach the detector located close to the gun after traversing a thin vacuum window



ION BEAM

The upward trajectory drift is due to the horizontal bend.

End of ~2 m long, 6 T solenoid

5 keV electron beam envelope

Summary

- Not a lot of news
- The construction and installation of the wire in jaw collimators is going on, until WS 2016/2017 the SPS will be our only test bed. Options need to be chosen soon.
- People are concentrating on
  a) refining simulations
  b) preparing advanced diagnostics
- A test stand for e-lenses is prepared at CERN during 2015. Large collaborative interest.
  Funding will only partly come out of HL-LHC, but also (hopefully) from other sources.
- Refined cost schedule in 2 months from now.