Status of Beam Gas Ionization profile monitor for PS

LHC Injectors Upgrade

Mariusz Sapinski,

Oliver Keller, Emiliano Piselli, Bernd Dehning - BE/BI

with input from:
Simone Gilardoni, Dominique Bodart, Rende Steerenberg, Michael Campbell, Xavi llopart

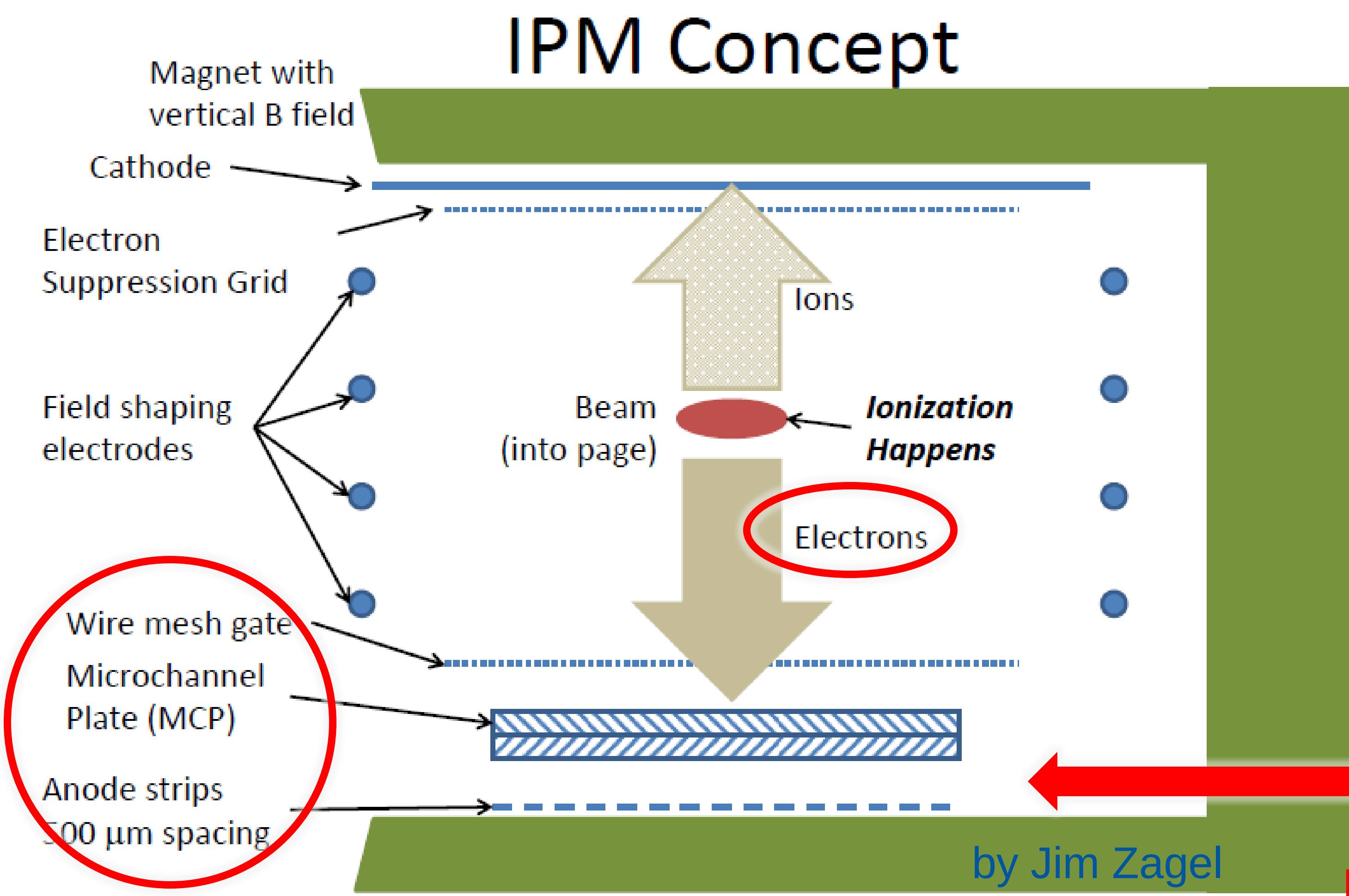
PS LIU meeting, February 11th, 2014

CERN

Outlook

1. Introduction
2. Specification
3. Mechanics
4. Magnetic field
5. High Voltage
6. Readout electronics
7. Location and radiation
8. Timeline and budget

1. Introduction



Readout options:

- optical readout (LHC and SPS)
- anode strips
- **silicon (pix) detector**

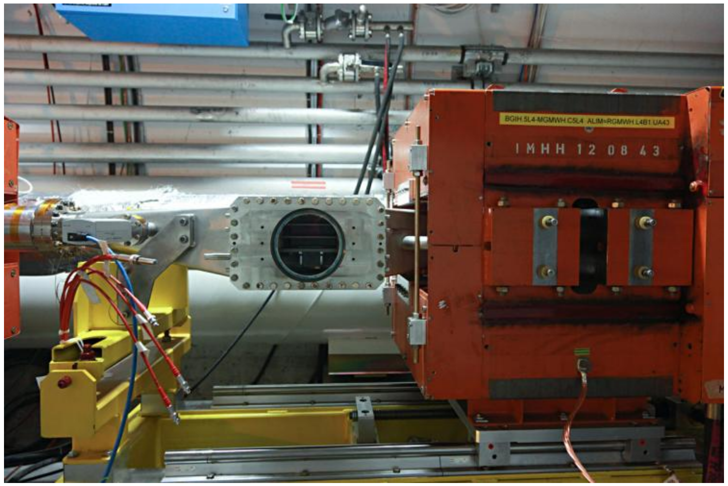
BASELINE

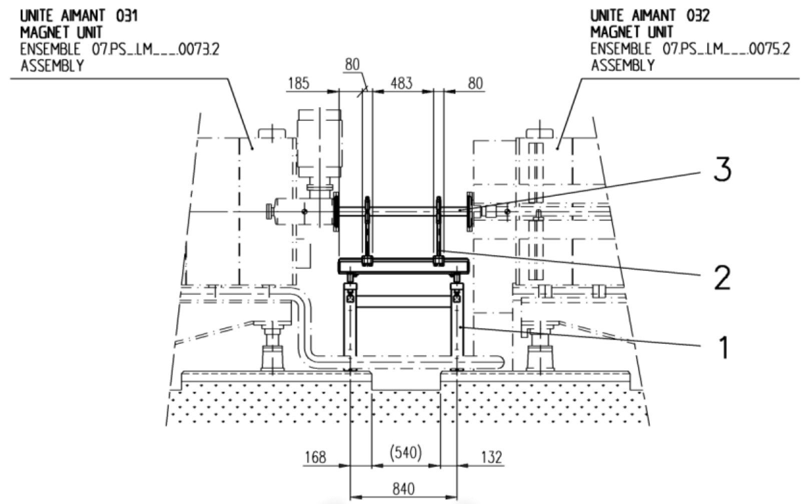
fallback

2. PS BGI basic specification

- Typical beam size: 0.5-5 mm (LHC beams), cover ~ 5 cm
- maximum 72 bunches max, 25 ns bunch spacing
- 10^{12} protons per bunch, 10^{10} Pb^{82+}ions per bunch
- bunch properties change during cycle (splitting, merging)
- Basic mode: continuous measurement during the cycle averaged over all bunches (2.1 s) – 0.1-1 kHz
- Normal mode: continuous bunch-by-bunch measurement during the cycle - 0.1-1 kHz
- Burst more: turn-by-turn measurements (1 turn = 2.1 μs) at chosen moment of the cycle (for about 5000 turns) – 360,000 profiles!

3. Mechanics: entire system





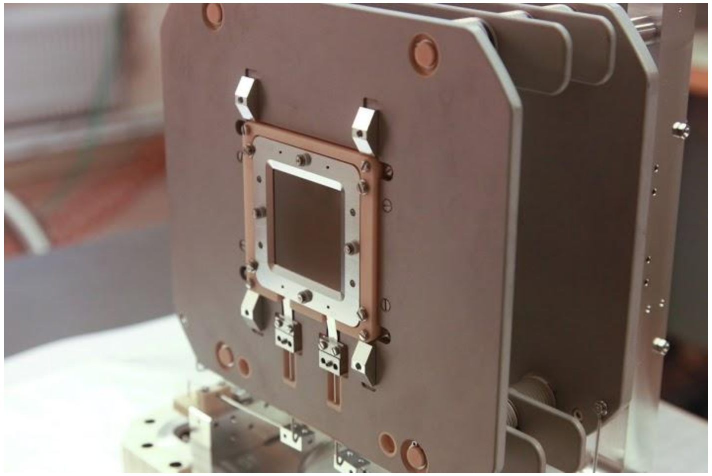
~ 1 m, but with correctors about 3 m

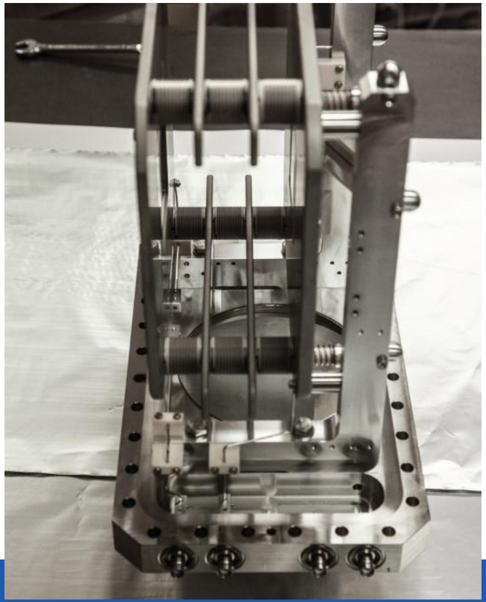
80 cm

We need to find completely different solution where IPM with magnet and corrector magnet fit to ~80 cm.

Detector vacuum chamber length: ~40 cm.

3. Mechanics: HV cage





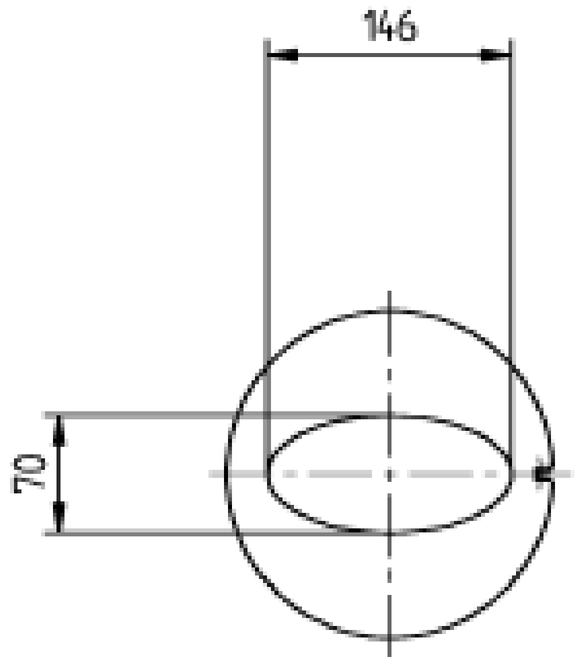
Present LHC/SPS BGI cage is large:

- width 25+3 cm
- length 25 cm
- height 15 cm

Possible reductions:

- length:
  - use shorter detector (5 cm->2 cm)
  - if needed reduce the length further by applying field shaping electrodes along the beam
- width: can decrease if height decreased, argument: good E-field uniformity
- height: 5 cm is used by light extraction system, which we will not have anymore -> height will be determined by required aperture (see next slide) + ~2 cm.

3. Mechanics: horizontal and vertical monitors



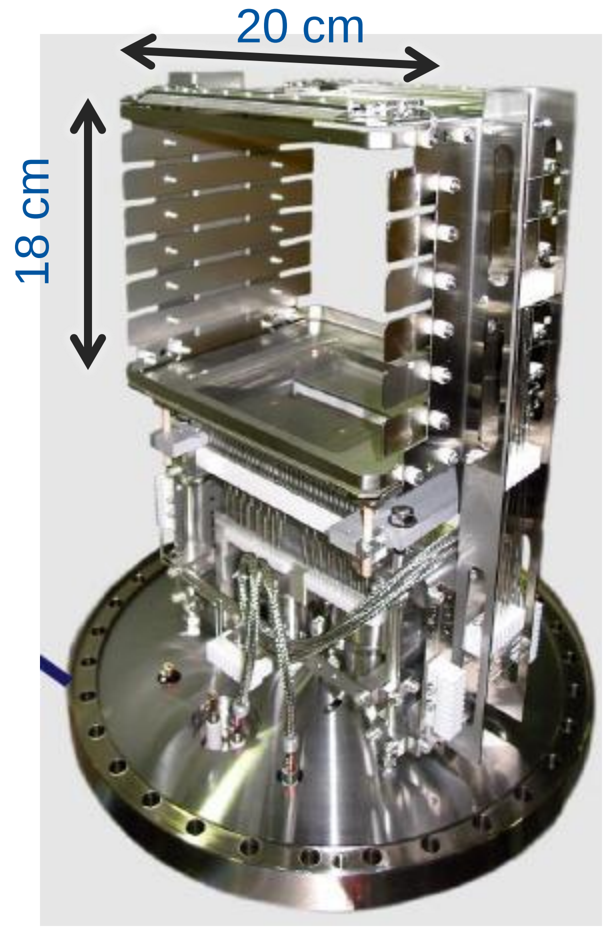
Magnets for vertical IPM may be quite large (like in SPS/LHC!) or reduced field.

Asymetric vacuum chamber:

- Ellipsoidal vacuum chamber - difference between horizontal and vertical axes ~2
- Option 1: construct the same detectors for both planes. Good but:
- $B_{gap}=\mu_0 NI/s_{gap}$ – larger gap equals larger current so larger magnet,
- larger distance between electrodes equals larger surface of electrodes (E-field quality).
- Option 2: adopt HV cages to vacuum chamber dimensions, to some extend modular.

3. Mechanics: conclusions

1. HV cage smaller than in LHC/SPS (at least for horizontal detector)
2. Critical for the cage is optimization for E-field uniformity (simulations)
3. Looking at other designs (GSI, BNL, Fermilab)
4. Tank will be designed once HV cage dimensions are defined
5. No need for viewport.
6. Fast signal transmission - feedthroughs important.
7. One of the investigated options: the PCB with readout chip covered by Liquid Crystal Polymer is at the same time the vacuum chamber wall (good for cooling, space, signal transmission).



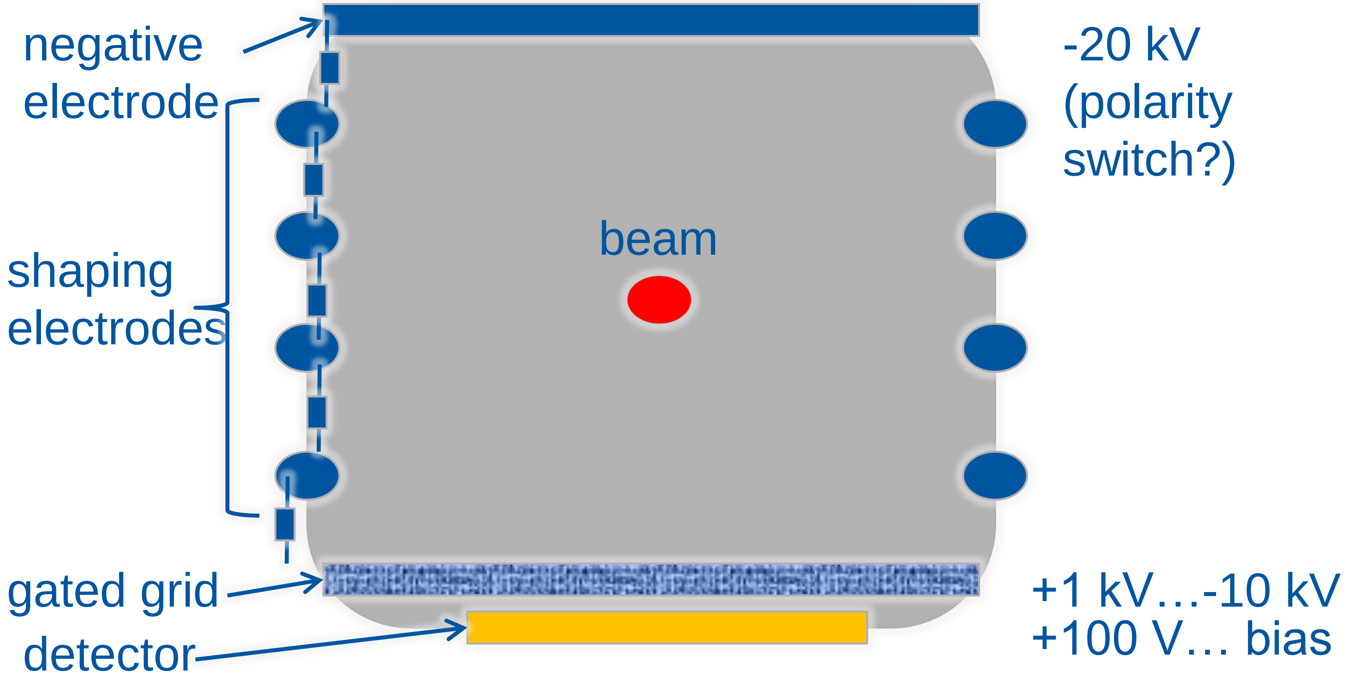
GSI IPM, courtesy T. Giacomini, large height due to large beam size

4. Magnets

1. Need dipoles with 0.2 T field (depending on beam size but also beam brightness – suppression of space charge effect)
2. Good field region very short along the beam (~3 cm)
3. Apertures ~8 cm and ~15 cm (so two types)
4. Iron yoke type magnets.
5. Dominique Bodart will start design when possible (first look soon)
6. Serge Pittet is looking at power converters
7. Need 4 installed magnets (2 magnet with detectors+2correctors)
8. + 2 spares, total 3+3 magnets (2 types)
9. Cost estimate: 150 kchf (power converters included)

5. HV supply

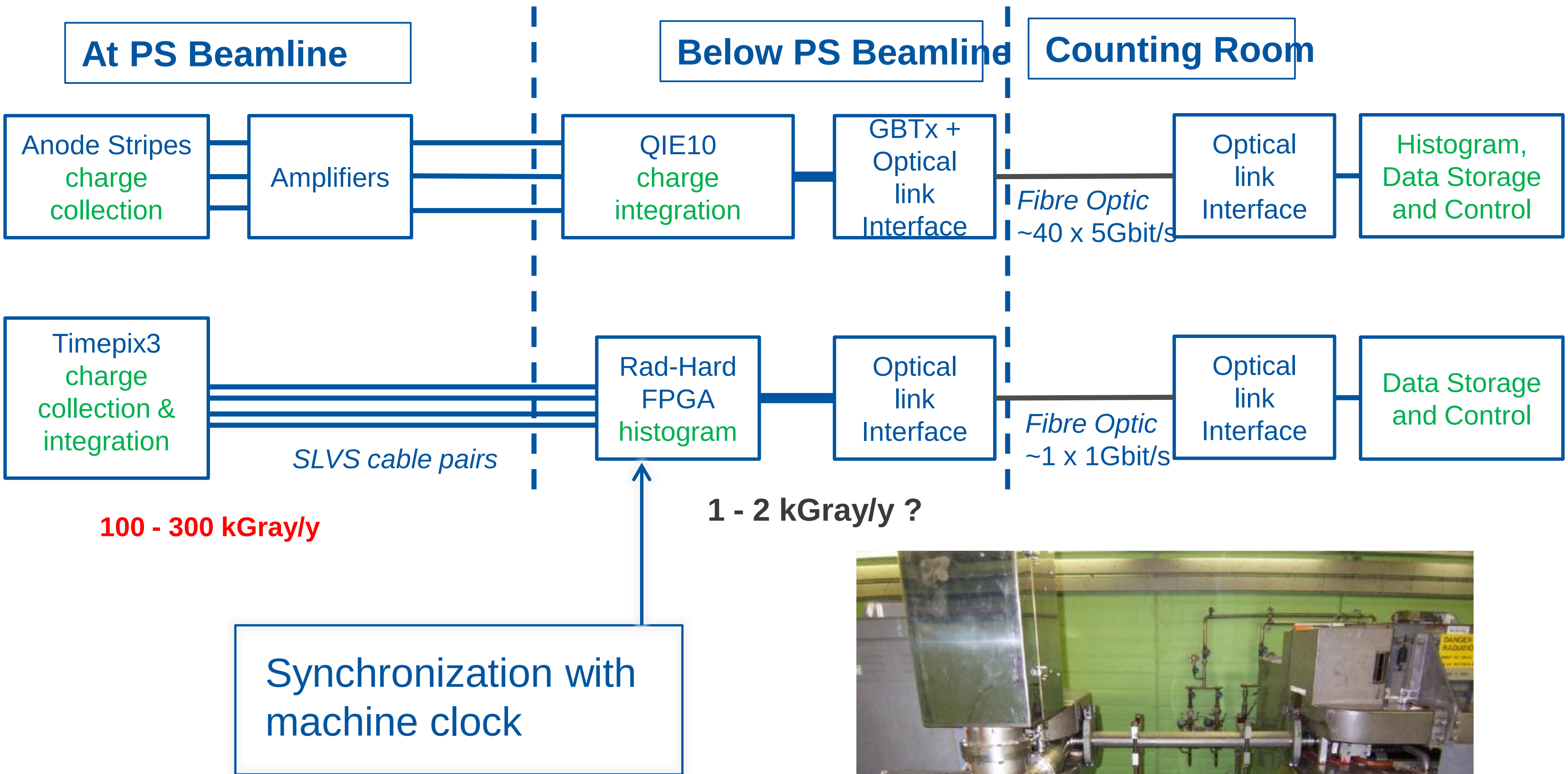
1. Currently: CERN-made system, which works very good but has control issues and is limited to ~ 15 kV
2. Commercial solution is investigated (iseg, CAEN)
3. 20-30 kV needed
4. Probably fast gating (25 ns) needed (depending on detector operation mode)



6. Readout introduction

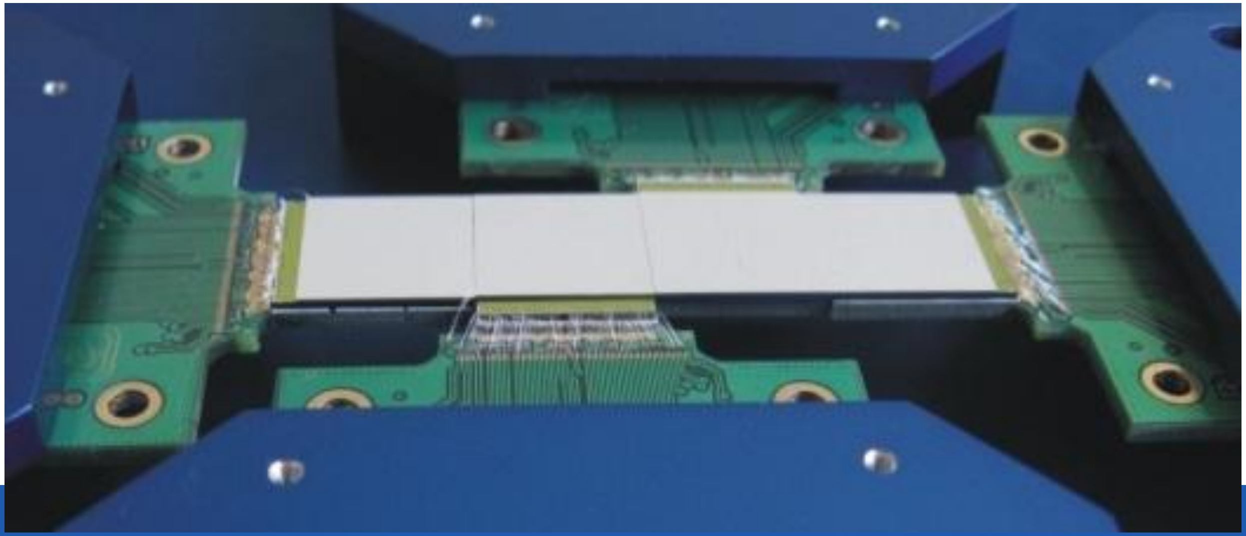
- New idea: use silicon pixel detector bonded to **Timepix3** chip
- Timepix3 is very fast and radiation-hard (MGy in gammas).
- Pixels size: 55 µm x 55 µm – exagerrated for our application (could be 2-3x bigger reducing data flow).
- Silicon readout was never tried before in BGI-type device.
- Experiments (eg. LHCb) plan to use some version of because of its performance and large radiation tolerance.
- Other solutions still followed.
- Following slides are from **Oliver Keller who works on that subject as Technical Student.**

Topological Overview – Basic Variants



Timepix3

- 4 timepix chips *14.08mm = 56.32mm sensor width (max!)
- *8 SLVS links @ 640Mb/s → 5.12 Gb/s per timepix chip: 20.48Gbit/s net in total!*
- *5.12Gbit/s * 4 * 5ms record time = 102.4kbit, possible to store in SRAM of FPGA*
- Readout with FPGA mandatory, due to high data rate (standalone transceiver to slow, e.g. GBTx)
- Readout Options:
- 4 Microsemi IGLOO2 (each 10Gbit Ethernet or 2 VTTx uplink)
  1 Xilinx Virtex7 (8 VTTx uplink, c.f. SPIDR board from NIKHEF)
- Max. Length of timepix3 SLVD outputs, some meters? => to be tested!
- Event-by-event data driven and zero-supressed readout
- Limit max. Hitrate of 80Mhits/s per chip (40Mhits/s/cm2) needed: Gating with HV cathode grid, MCP or similar. Gate voltage with Behlke HV switch.

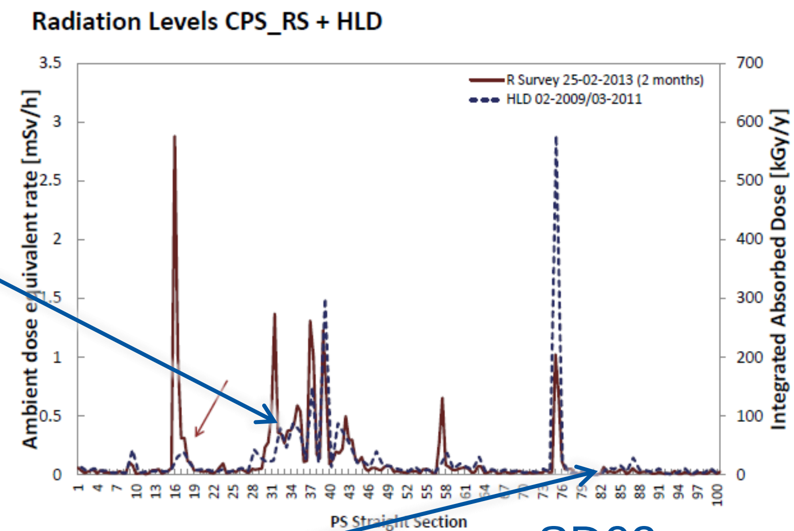


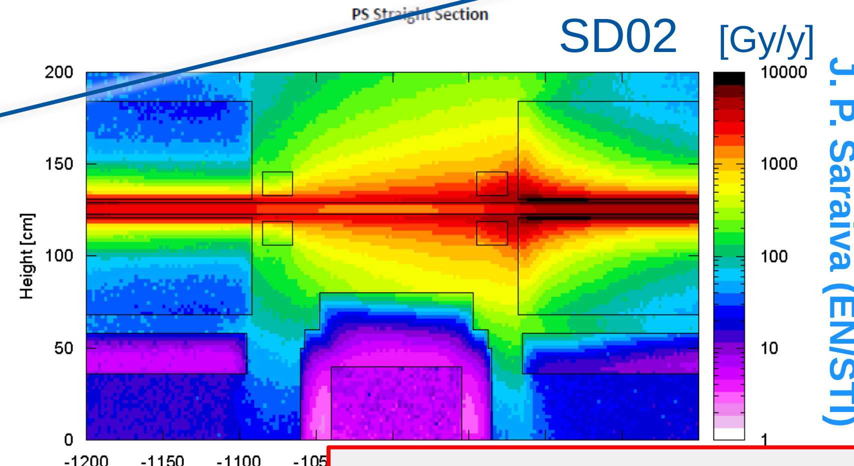
6. Readout status

- Timepix3 is currently being tested by developers.
  Chip/detector assemblies available in several months.
- Ordered previous version (Timepix1) to start playing with it.
- Some parts (optical link) can be used from other BI projects.
- Rad-hard FPGA probably crucial and most expensive part.
  Also a lot of programming/development will be needed here.
- Simulations of response to expected electron rates ongoing.
- Problem with dynamic range (10^3): expected from ~300 to ~300,000 electrons/bunch. To overcome adjust:
  acquisition mode, accelerating voltage, gas pressure, gate HV.

7. Location and radiation

- First location in SD32 and 33 was proposed.
- There is septum in SD31 which needs to be removed, if not -> radiation levels too high.
- Visit: activation 10x higher than in “cold” parts of the ring.
- Plan to investigate SD82.
- Typical dose distribution
- For rad-hard FPGA need to go far (>1 m ?) and probably shield.





Reduction factor: **~10**
with 40 cm of iron shielding

8. Timeline and budget

- ongoing: work on electrical/Silicon readout, magnet simulations, design (or integration of other designs)
- Spring 2014: technical proposal and decision
- Summer 2014-end of 2015: prototype construction
- Winter 2015/2016 installation of prototype
- Budget:
  - feasibility study: 60k (already acquiring equipment)
  - final detectors: ~400k

Summary

- BGI will cover the need of continuous beam emittance measurement in PS.
- Study started. Specs challenging for readout (bbb and tbt).
- Use of Silicon pixel detector with Timepix3 chip fulfills the requirements and allows to get rid of MCP.
- New development: Silicon detector in BGI.
- Different detectors need for horizontal and vertical planes.
- Prototype installation in winter 2015/16.

THANK YOU FOR YOUR ATTENTION

In a few months further developments can be reported.

Backup slides

Introduction

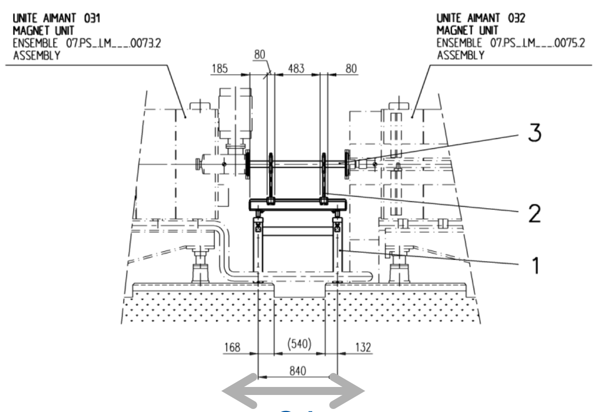
- Beam Gas Ionization monitors (BGI) is a device to measure transverse beam size (and therefore beam emittance) due to ionization of rest gas in the vacuum pipe.
- BGIs operate on many machines, also at CERN: LHC, SPS, LEIR
- Optimizing beam emittance is crucial for HL-LHC.
- Emittance produced in pre-accelerators cannot be improved.
- PS is a machine where a lot of gymnastics with beam is done – many processes can affect emittance.
- Therefore strong need to measure and control emittance in PS.

Choice of principle

- Electron or ions?
  - Fast measurement = electrons.
  - But magnets needed (~0.2 T).
- Optical or electrical or Si pixel readout system?
  - Electrical/Si pixel readout easier fulfills spec.
  - Electrical readout allows to save space (needed by optical mirror) and construct magnets with smaller aperture (impact on cost).
  - Beams are large, no need for optical readout.
  - Probably Si pixels and Timepix chip will allow to get rid of MCP

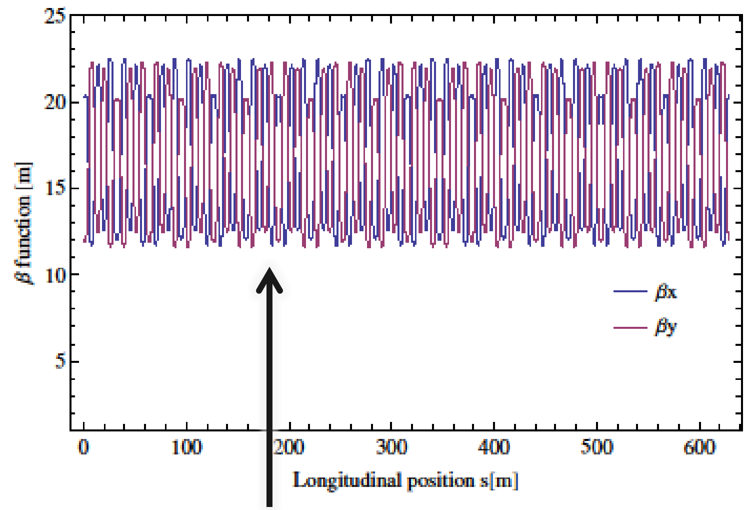
Location

- Horizontal device: SS32
- Vertical device: SS33



~84 cm

SS should be ok for radiation levels once the CT extraction replaced definitely by MTE



SS32

PS BGI and Timepix3

- between 300 and 50000 electrons/bunch (25 ns) generated due to ionization – large dynamic range.
- Electron energy 2-20 keV (adjustable, regulate pixel occupancy).
- Electric “shutter” (wire mesh) to gate on electrons from a chosen bunch only – this will be tricky because of bunch splitting procedure.
- At first look Timepix3 should withstand the radiation in PS.
- Its main advantage over electrical readout (anode strips) is lack of MCP, which suffers from non-uniform gain and ageing.

PS BGI A.D. 1968

THE CPS GAS-IONIZATION BEAM SCANNER

C.D. Johnson and L. Thorndahl
CERN, Geneva, Switzerland

PAC 1969

Summary

A non-destructive beam scanner was installed in the CPS ring early in 1968. Deriving a signal from the electrons liberated by the proton beam from the residual gas in the vacuum chamber and using a crossed el... ...ric and magnetic fields system of electro... ...ction, the scanner gives the projec... ...density distributions in the hori... ...tical planes. Spatial re... ...er than 1 mm.

An importan... ...use of a single collector wh... ...ctrons from a slice of the bea... ...ero equipotential surface. ... ...potential surfaces are arra... ...l to the beam and scanning is ... ...placing these equipotentials ... ...e region of the beam. In parti- ...ero equipotential, which always ...ough the detector, is scanned right ... the beam.

References

1. HORNSTRA, F. and DELUCA, W.H., Non-destructive beam profile detection systems for the ZGS, ANL internal report, 1967

Argonne, 1967

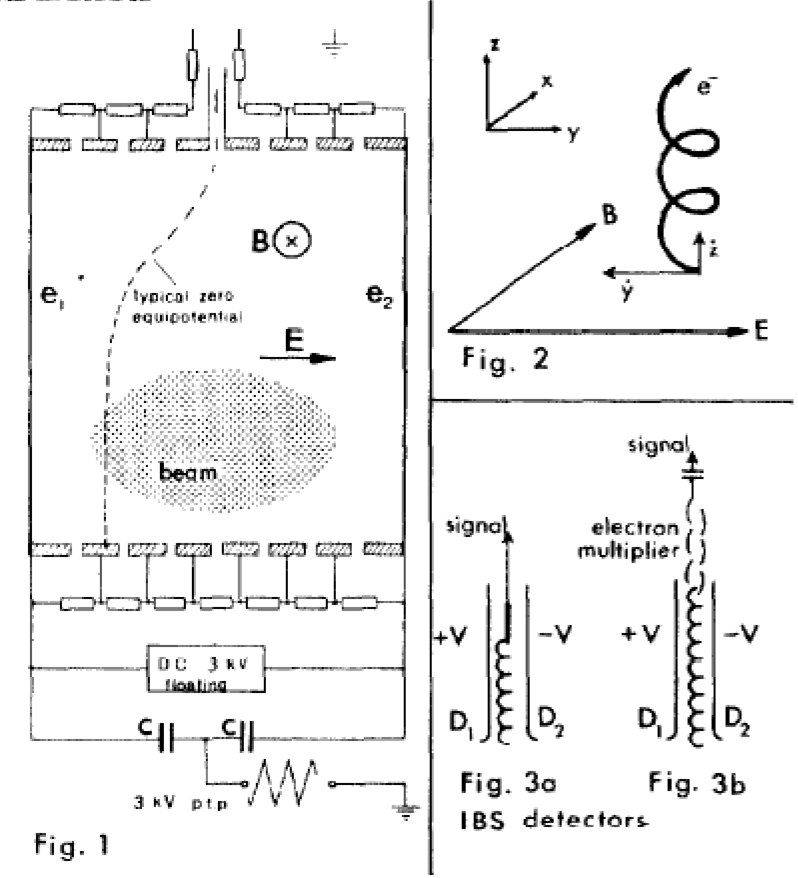


Fig. 1

Fig. 2

Fig. 3a Fig. 3b
IBS detectors

PS beams – examples

beam	SPS ftarget	TOF	EASTA	LHC 25 ns 72 bunches
Injection				
Ek [GeV]	2.0	2.0	2.0	2.0/1.4
Bunch nrb	8	1	1	6
Charges/b	3.1E12	8E12	4E11	1.5E12
Bunch len [ns]	150	190	170	180
εH/V [μm rad]	7.6/5.4	9.2/7.8	1.5/1.5	1.5
Extraction				
Ek [GeV]	14	20	24	26
Bunch nbr	420 (deb)	1	1	72
Charges/b	~5E10	8E12	3.8E11	1.25E11
Bunch len [ns]	5	50	debunched	4
εH/V [μm rad]	11/8	12/10	-	1.5

EDMS 1157752, document in work

Beam specs to be updated after October review of RLIUP.

Magnets

by Dominique Bodart

- Requirement: good field region of 50mm, field 0.2 T
- Iron yoke type corrector magnet
- Number of corrector magnets to close the bump: 1
- 2 types of magnets shall be used because of vacuum chamber shape
- Particular attention on vertical corrector because the aperture needed is 180 mm
- Preliminary study ongoing, 2D simulation show acceptable field homogenity
- Cost 100-200kCHF (for 6 magnets including spares)

Preliminary OP specification:

- Maximum number of bunches: 72
- bunch-by-bunch and turn-by-turn at injection, extraction (maybe transition) for 5-10 ms (5000 turns) – burst mode.
- A sliding window of burst mode.
- No multiplexing (H and V at the same time).
- Beam size: 0.5-60 mm (that is difficult).
- No need during RF bunch splitting/merging – results difficult to interpret in H plane due to large dispersion.
- Normal mode: 100-1000 acquisitions/s (bbb)
- Used mainly for qualification of LHC beams during filling – must work in pulse-to-pulse mode (PPM).

Radiation in SS31 and SS32