Proposal for PS Beam Gas Ionization monitor

LHC Injectors Upgrade

Mariusz Sapinski, Oliver Keller, Bernd Dehning

With input from: Simone Gilardoni, Django Manglunki, Dominique Bodart, Rende Steerenberg, Jose Ferreira, Heiko Damerau and colleagues from GSI, BNL, Fermilab and J-PARC

Design kickoff meeting

June 25th, 2014

CERN

Outlook

1. Basic OP specification
2. Novel readout system,
3. Location:
   - optics, beam sizes,
   - radiation
4. HV cage – overview of existing solutions
   - HV scheme
5. Vacuum chambers
6. Magnets

Basic specification (OP)

- **Typical beam size: σ=0.5-5 mm (LHC beams), cover ~ 5 cm**
- maximum 72 bunches, 25 ns bunch spacing
- 10^{12} protons per bunch, 10^{8} Pb^{54+}ions per bunch
- bunch properties change during cycle (splitting, merging)
- Normal mode:

continuous bunch-by-bunch measurement during cycle - 0.1-1 kHz

- Burst more: turn-by-turn measurements at chosen moment of the cycle

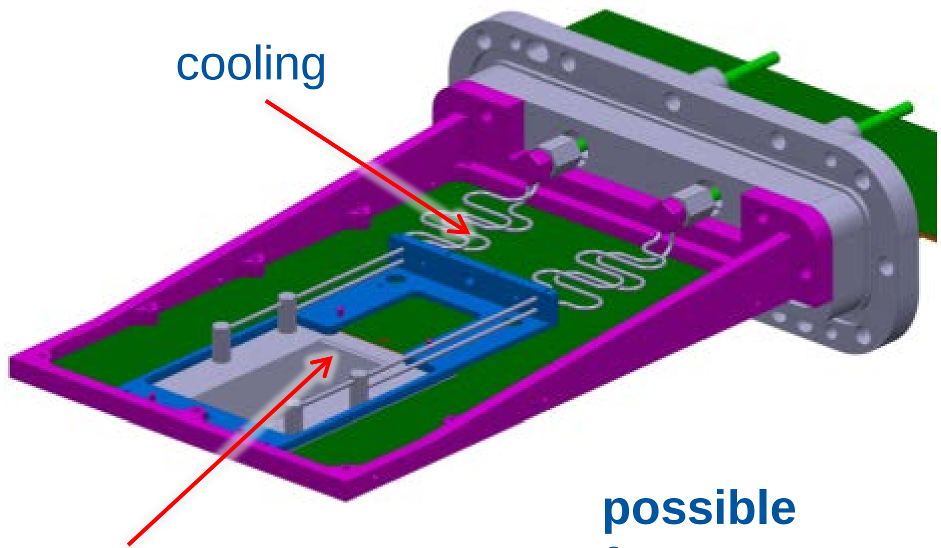
(for about 5000 turns)

- **Independent power supplies and data lines for H/V monitors,**
- cycle-dependent E and B drift fields.
- **Main use: qualification of LHC beams**

Our proposal: silicon pixel detector

- **A lot of developments in the last years – many chips**
- **Recently available multi-purpose Timepix3 fulfills the requirements in terms of readout speed**
- **Sensor size 14x14 mm**

now
– testing Timepix1



possible future

Advantages:

- Well known silicon technology, used more and more frequently in particle physics (VeloPix, TDCpix, etc)
- Radiation-hard.
- Fast – this will be the fastest IPM up to now.
- No need of electron amplification in vacuum (MCPs are fragile and moody)
- Flat – small magnet aperture.
- Early signal digitization - less analog noise

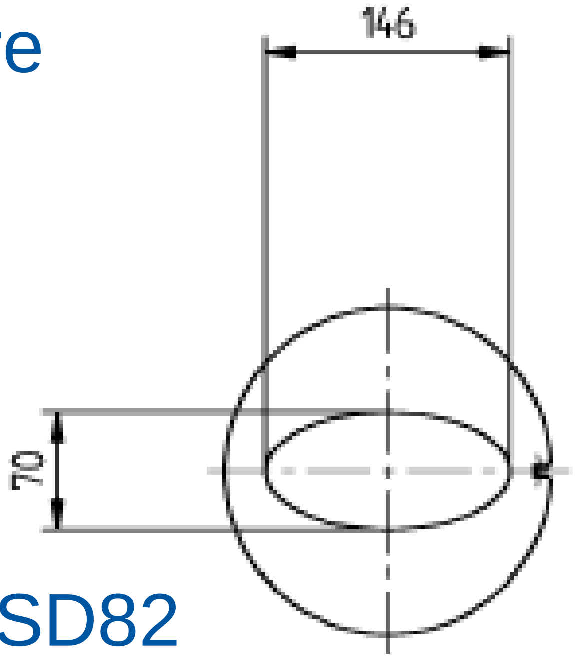
Disadvantage: fragile FPGA 2 meters from the detector.

Initial considerations

Because of vacuum chamber shape horizontal prototype is simpler to construct:

- Magnets with smaller aperture
- Simpler HV cage

Therefore most of initial study done for horizontal monitor.

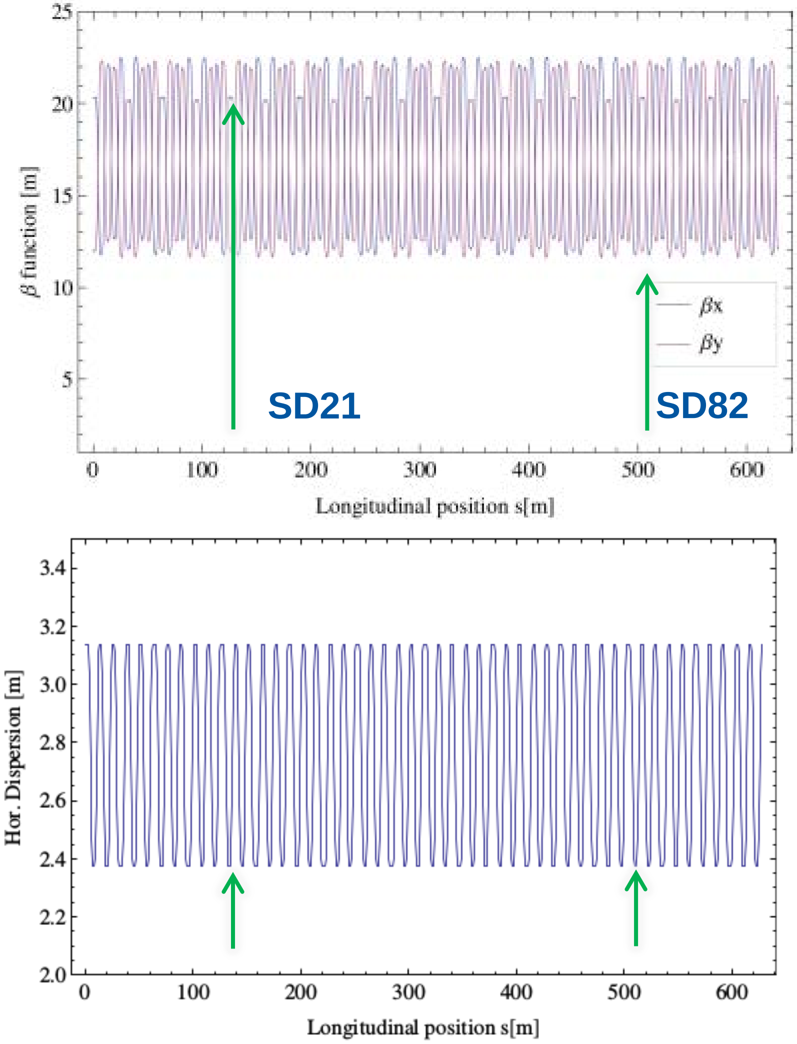


But the location proposed now: SD82

- Small β_{hor}

Location - optics

- Not many sections available!
- Considered: SD31, 33, 35 - large radiation/activation.
- SD82 dcum=510-511 m
- β_x=12m, D=2.4m, B_y=22m
- Another option: SD21, but only if CT kicker removed.
  Large β_x decreases impact of dispersion (dcum 127-128m).
- Other locations still possible – study ongoing, depend on proposed size of the magnet



Post-LS1 LHC beams in PS

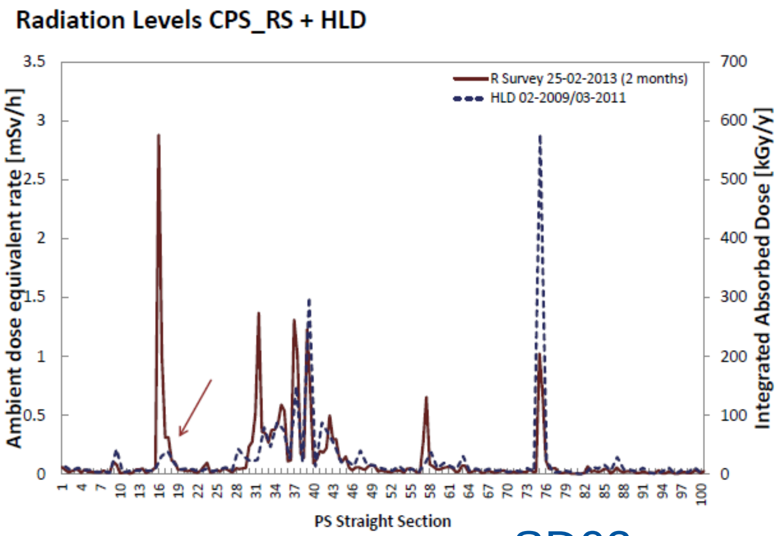
A few examples, for a complete lists: EDMS 1296306, September 2013 β_H=12m

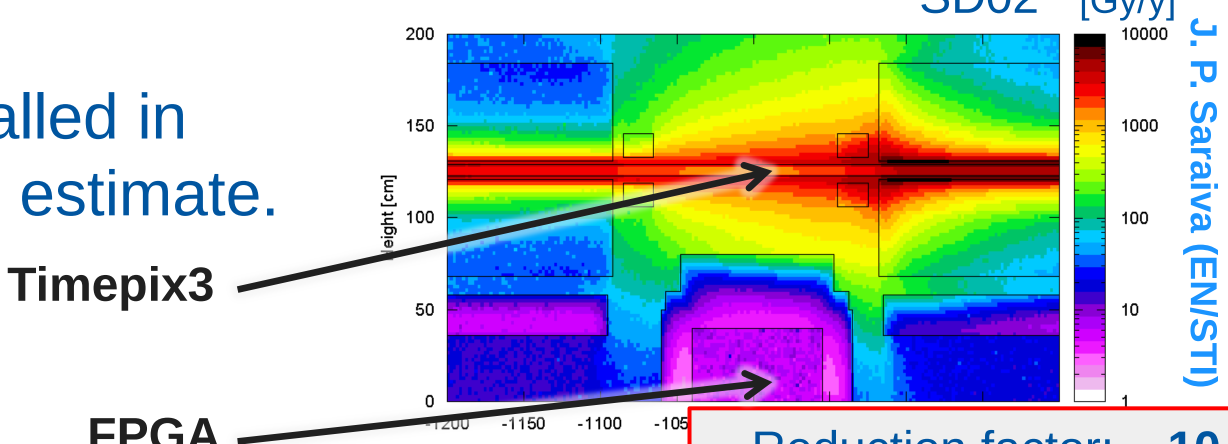
Beam	N (10^{11})	$\varepsilon_{x,y}$ [μm]	E_{Kin} [GeV]	B_l [ns]	Δp/p (10^{-3})	σ_x [mm] D=0	$\sigma_{y,x}$ [mm] D=2.4 m
Standard 50ns inj	11.9	1.48	1.4	180	0.9	**2.8**	**3.5**
extraction	1.89	1.55	25	3	1.5	**0.82**	**3.7**
Standard 25 ns inj	16.84	2.25	1.4	180	0.9	3.3	3.9
Extraction	1.33	2.36	25	3	1.5	1.0	3.7
LIU 50 ns inj	18.95	1.69	2	205	1.0	2.55	3.5
extraction	3.0	1.77	25	3	1.5	0.86	3.7
LIU 25 ns inj	28.07	1.63	2	205	1.5	2.5	4.4
extraction	2.22	1.71	25	3	1.5	0.84	3.7

In horizontal plane the beam size is dispersion-dominated.

Radiation

- The chip is radiation tolerant, FPGA needs shielding.
- FPGA needs to be ~ 1-2m from chip
- FLUKA: shielding reduces dose by 10.
- Radmons installed in SD82 for dose estimate.





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

Location and radmons (prep for installation)

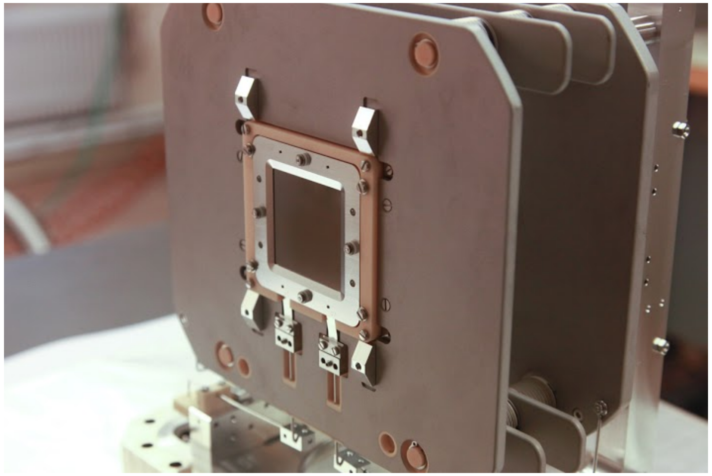
HV cage

- The main detector structure.
- Provides uniform electric field in the area of the detector
- Low impedance – not critical in PS
- In Fermilab they used side electrodes to “clean” electron cloud (gate-off)

HV cage – examples (1)

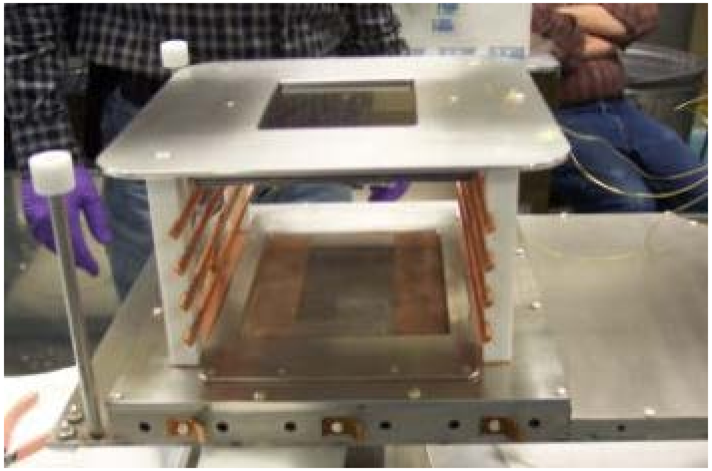
CERN SPS/LHC:

- optical readout
- Design optimized for high-energy machine
- Aperture would fit – partly re-use this design?



FNAL Mark III:

- Well-modeled HV cage
- Standard design



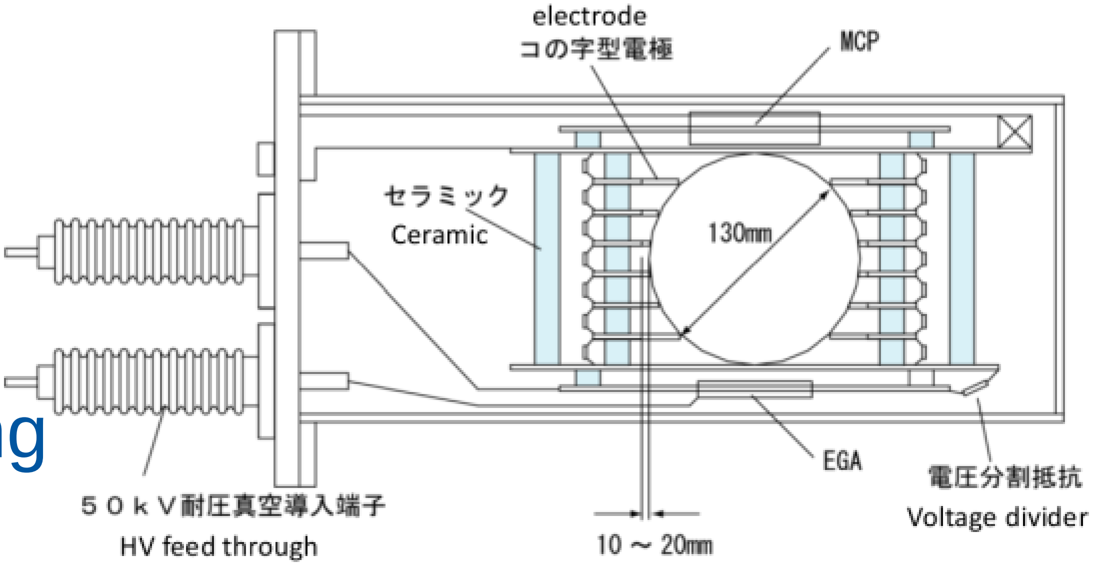
HV cage – examples (2)

GSI:

- large low energy ion beams
- Large aperture, maybe for vertical BGI?

<u>J-PARC (MR):</u>

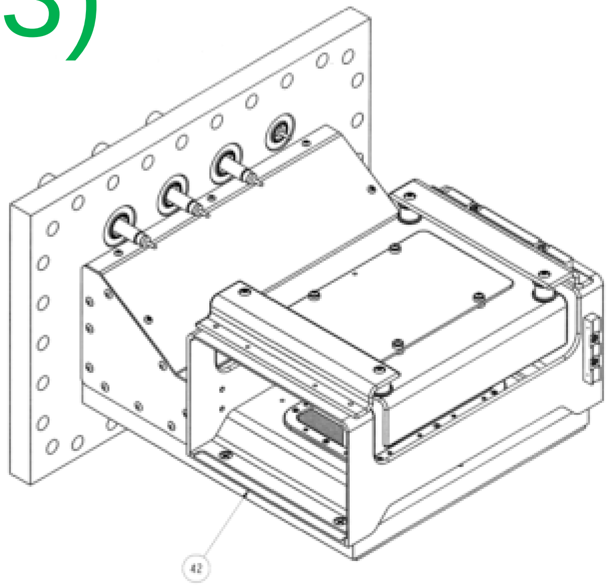
- HV 50 kV
- electrons or ions
- Exotic field-shaping elecrtodes

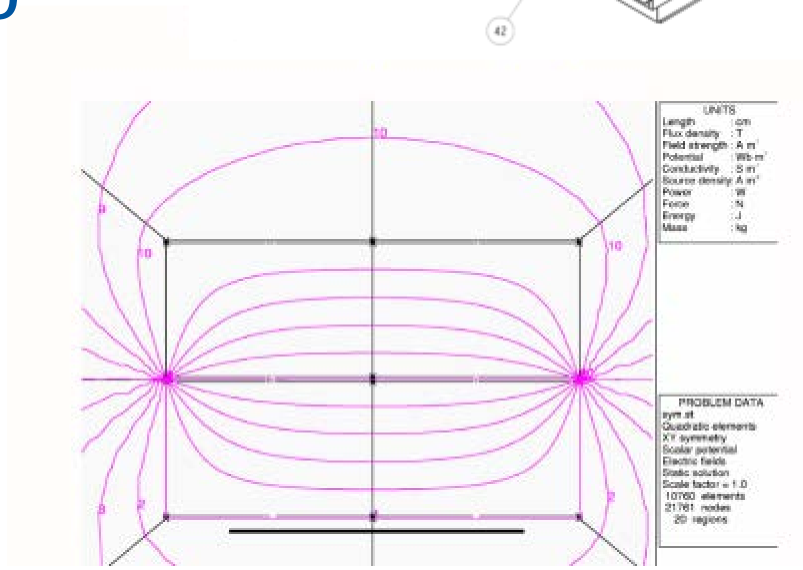


HV cage – examples (3)

<u>BNL:</u>

- Nice compact design
- No side electrodes
- Dimensions similar to PS horizontal
- E-field simulation done but not documented





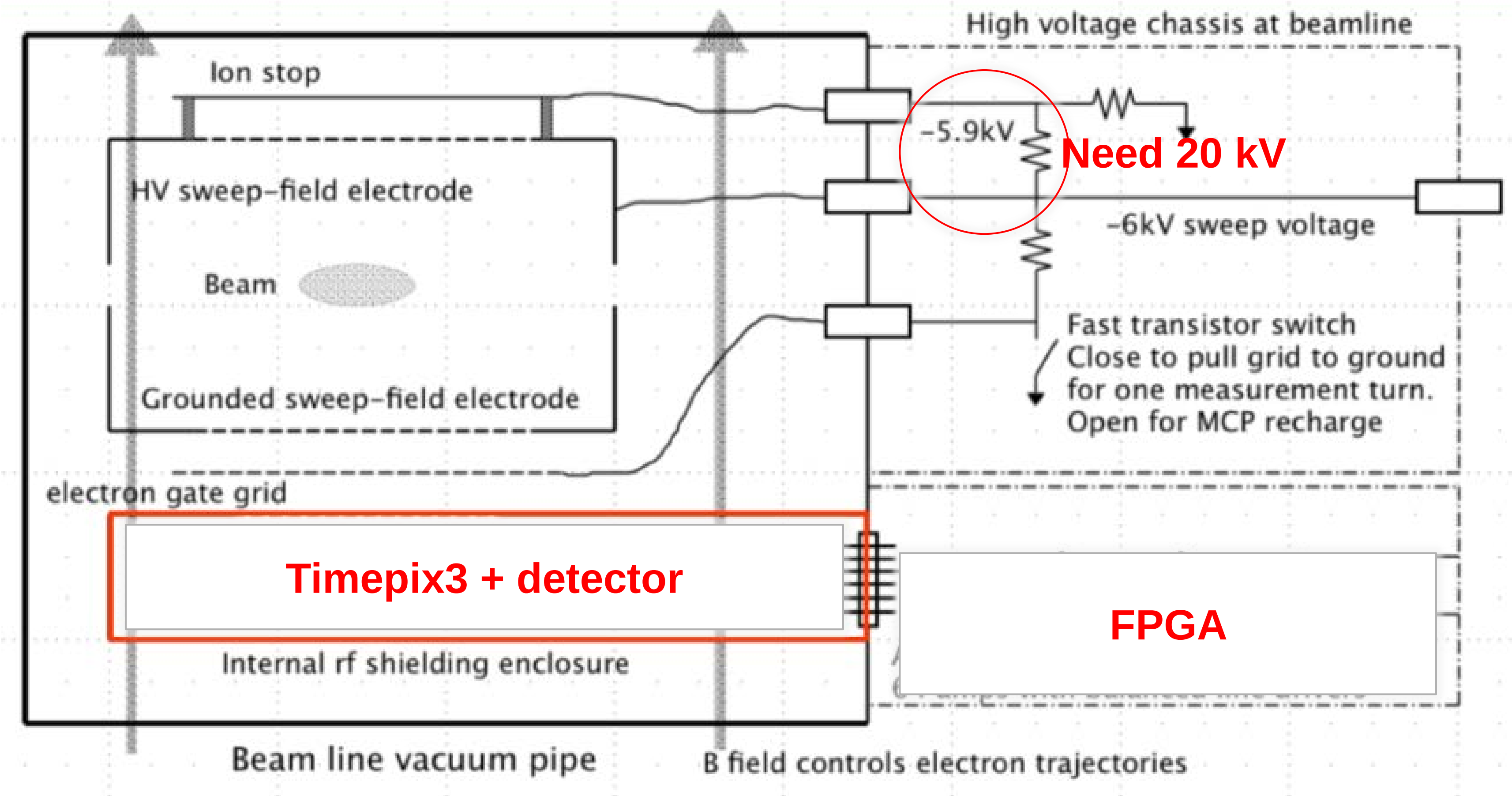
HV cages – comparison

BGI	Aperture [mm]	Width [mm]	Length [mm]	Extraction voltage [kV]
LHC/SPS	80	220	250	4
FNAL mark3	63	203	203	10-30
J-PARC (MR)	130	250	180	50
BNL	**87**	**146**	**211**	**10**
GSI	170	170	160	12
PS hor	**70**	**146**	**tbd**	**20**
PS ver	**146**	**70**	**tbd**	**20**

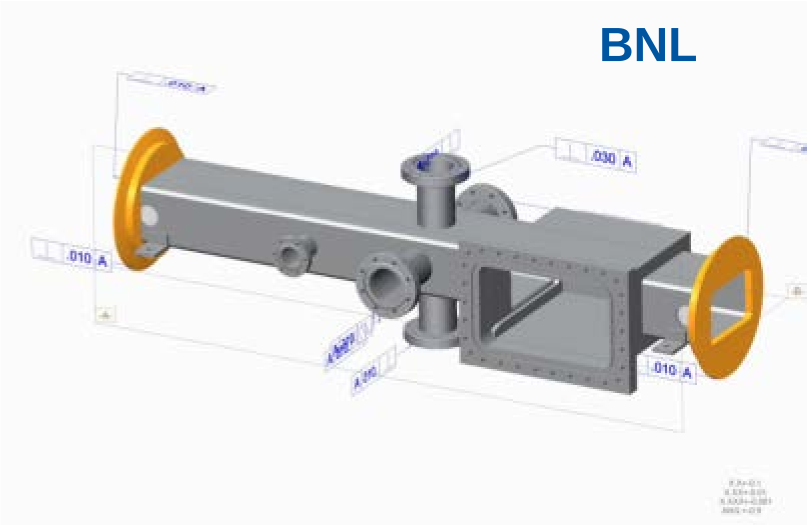
We find BNL solution interesting:

- Simple, tested, nice solutions like honeycomb for RF shielding.
- Size close to PS horizontal monitor.
- EM simulations done long time ago and not well documented
  -> be done soon
- Complete set of tech drawings at CERN, modifications necessary

HV scheme

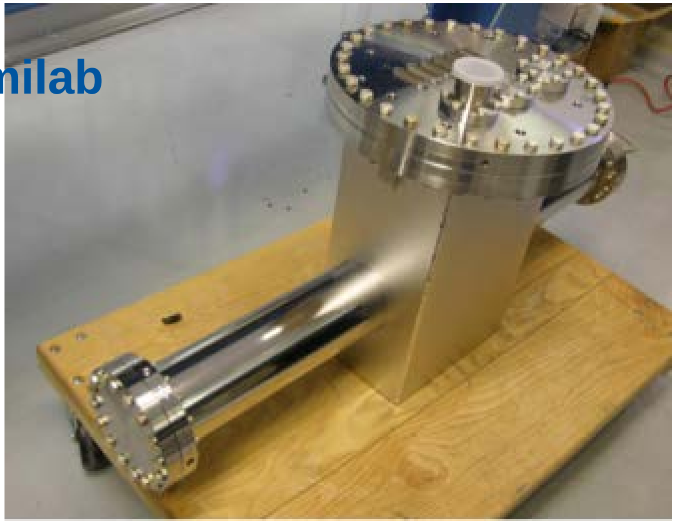

High voltage chassis at beamline
Ion stop
-5.9kV
Need 20 kV
HV sweep-field electrode
-6kV sweep voltage
Beam
Fast transistor switch
Close to pull grid to ground
for one measurement turn.
Open for MCP recharge
Grounded sweep-field electrode
electron gate grid
Timepix3 + detector
FPGA
Internal rf shielding enclosure
Beam line vacuum pipe
B field controls electron trajectories

Vacuum chambers



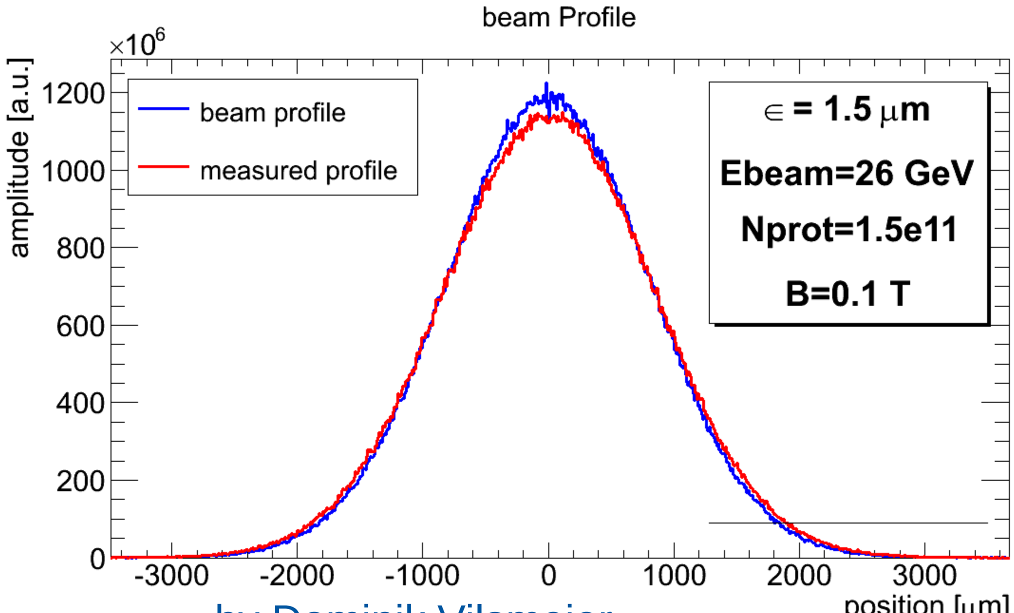
Square or round flange?

Fermilab



Magnets

- Magnet design - vacuum chamber design.
- Good-field region: ~5 cm
- Iron-yoke type corrector magnets (of 2 types (H,V)?)
- Field needed:



by Dominik Vilsmeier

No dispersion
(worst case scenario)

B=0.15 – 0.2 T

Surface electronics

- Building 368
- We will need a rack for PC (data buffering), HV power supplies, machine clock synchronization, slow control

Conclusions

- **We propose Beam Gas Ionization monitor with novel, fast readout scheme**
- Staged development shall be foreseen:
  start with one chip, install more later
- **HV cage solution could be adapted from BNL detector.**
- **or shall we proceed with more standard design?**
- **Shall we develop one or two solutions for H/V?**

Additional resources:

- TWiki:

  https://twiki.cern.ch/twiki/bin/viewauth/PSBGI/WebHome

- Presentation at LIU PS meeting on February 11th, 2014
- Presentation at BI-LIU review on October 3rd, 2013
- Presentations at BI Technical Board on May 15th, 2014

SPARE SLIDES

Choice of measurement principle (I)

Light

Pros:

- Electrical isolation between detector (phosphor) and rest of the structure
- No signal feedthroughs
- Good resolution – small beams

Cons:

- Light extraction system (larger vacuum chamber and magnet aperture)
- Need of extraction window

Electrons/ions

Pros:

- Simpler construction in vacuum
- Smaller vacuum chamber needed

Cons:

- Electrical connections close to beam wakefields

Choice of measurement principle (II)

- Time to reach detector surface:
  electrons 2-3 ns, ions: 400 ns
- Use both: ions for cross-section estimation or signal level estimation to prepare HV?
- Ions have sense for machines with large bunch spacing (no need for magnet) and small bunch charge.
- Electrons – need for magnets.

LHC beams in PS

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

Estimation of ionization rate (I)

- Ionization cross-section:

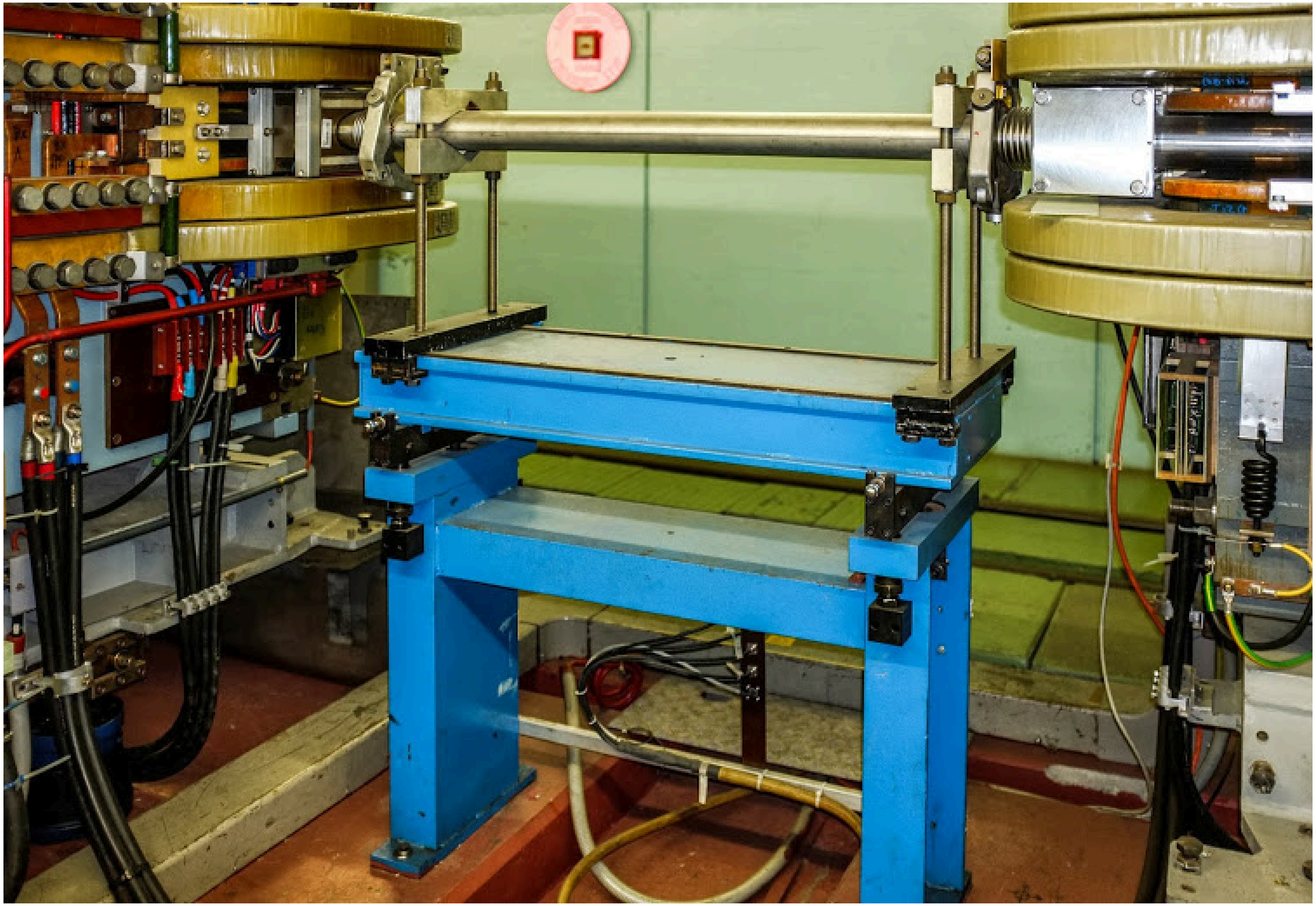
$$\sigma_{ion} = Z^2 \left(\frac{h}{2\pi mc}\right)^2 \beta^{-2} (M^2 x(\beta) + C)$$

- *M,C* – depend on gas type, here assuming Neon
- Typical cross-sections:

particle	p	p	Pb82+	Pb82+
Kin. energy [GeV]	1.4	25	15.02	1227
Cross-section [Mbarn]	0.44	0.56	3700	3300

The cross-section estimations based on Geant4 are 2-3 times lower.

Location



Potential issues

- E-cloud at end of the LHC 25 ns cycle (a few ms before extraction) – there is e-cloud monitor in PS
- Report of low-energy electrons “shielding” the silicon detector surface – need to experiment soon
- Smaller and standard flange (lesson from LHC vacuum problems, but lot of experience now)
- Rest gas temp measurement (?)