UA9 instrumentation

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INFN Roma
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CERN accelerator seminar

Outline

- Description of what we have now in SPS
  - Layout
  - Detectors
    - Beam Loss Monitor, direct beam imaging,…
  - Performances
- Ideas for a possible layout for LHC

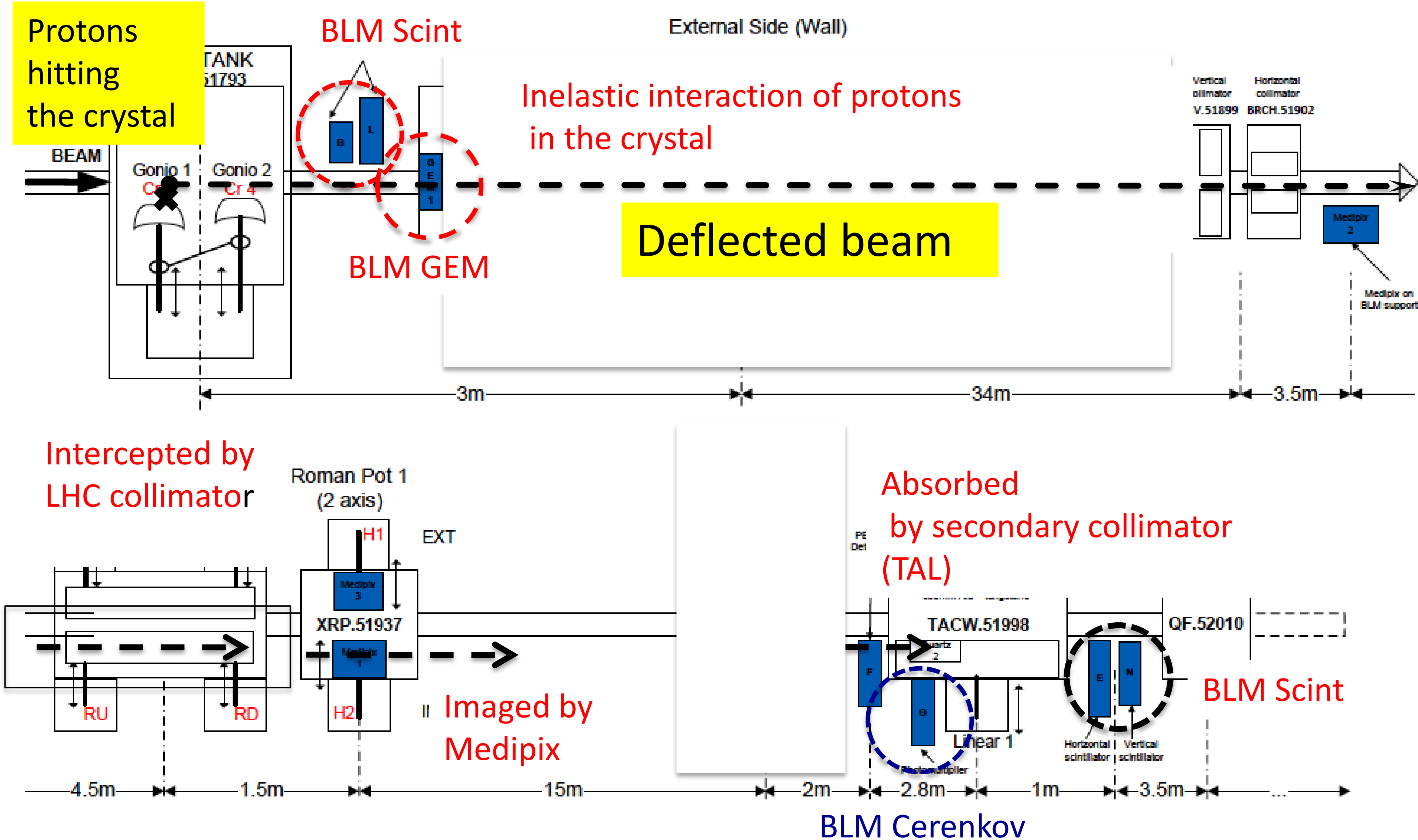
- Current layout in SPS:
  - W. Scandale *et al.*, *JINST* **6** T10002 (2011)

What we measure

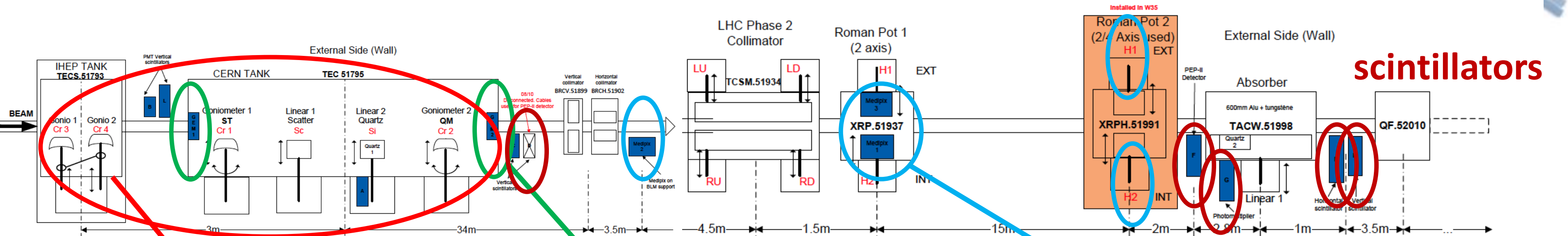
- Detect inelastic interaction secondary products
  - Instrument region ***close to crystal*** or to the ***absorbers/secondary*** collimator where no other BLM available (or BLM dynamic range is not appropriate)
  - ***External*** to vacuum chamber
- Detect channeled beam
  - Measure ch. ***beam profile***
    - ***Check crystal torsional effect, axial channeling…***
  - ***Count channeled particles***
  - Possibly without absorbing the beam or just before beam dump
  - Either in vacuum or in secondary vacuum (Roman Pot)
- Detect leakage around the ring
  - Use accelerator BLM distributed over the whole ring
- Measure beam parameters (current, emittance, orbits, …)
  - Use accelerator devices

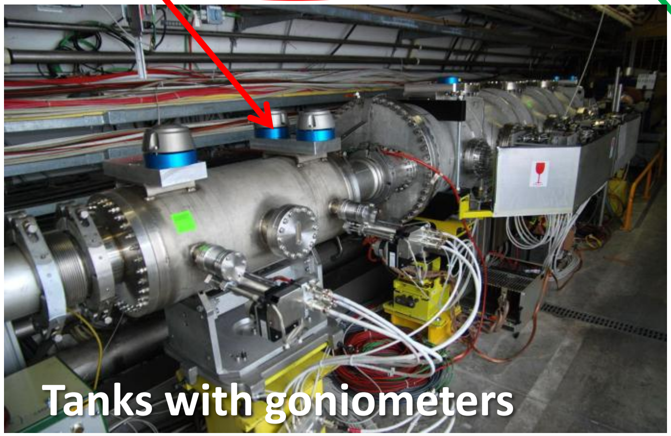
SPS BLM are difficult to use in our experiment (instrumentation, insensitive to low current)
LHC BLM are modern and reliable

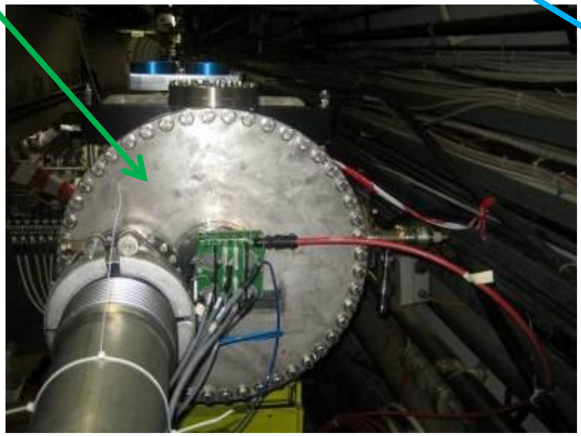
Collimation region

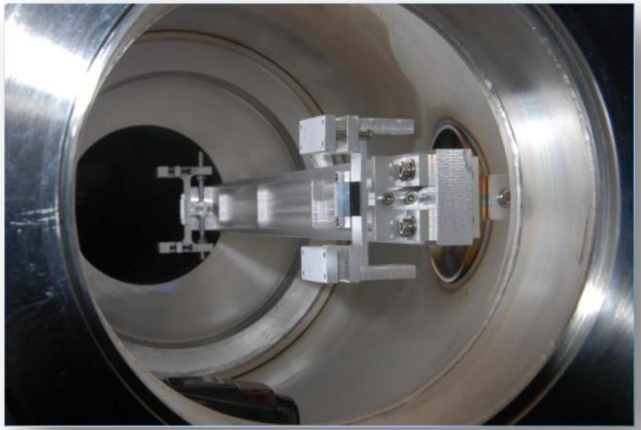


UA9 devices





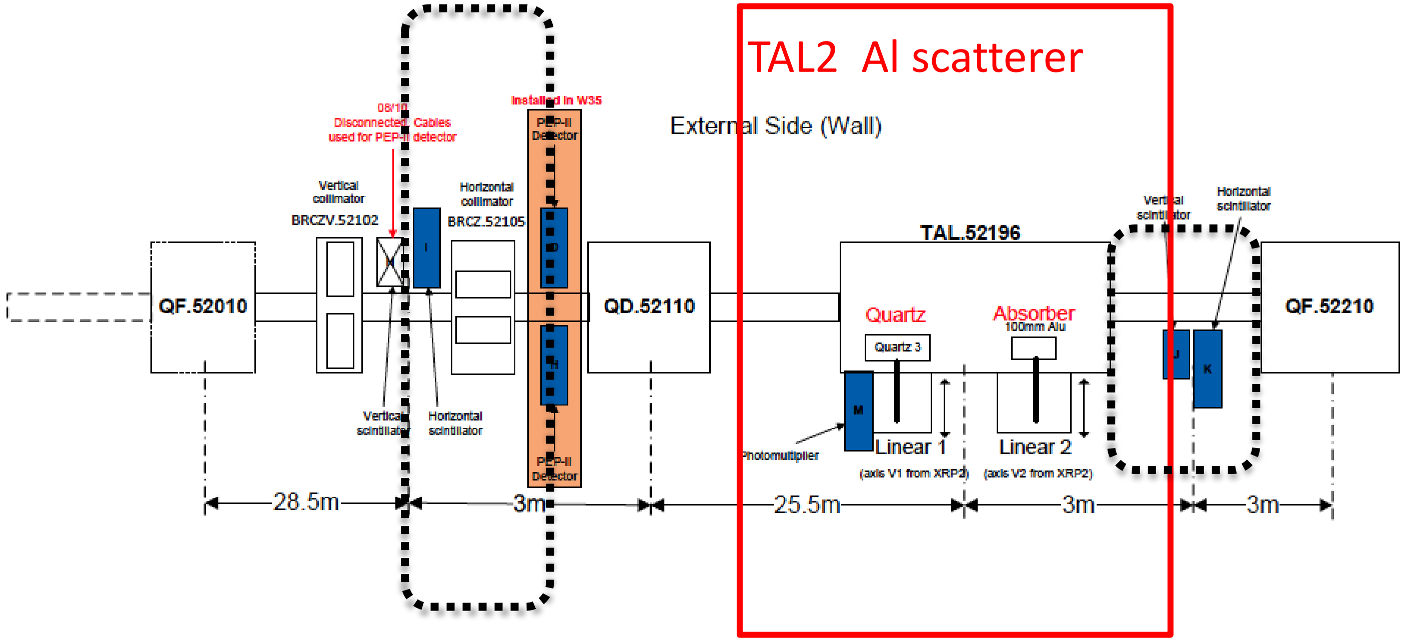




2 Triple GEM detector
at large angle
Active area 10x10 cm^2
128 pads 6x12 mm^2

3 Medipix
in roman pot
Active area 1.4x1.4 cm^2
65536 pads 55x55 μm^2

Dispersive region



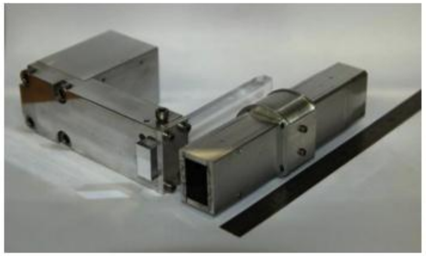
New scatterer + BLM (scint, Cerenkov, ionization ch.)
in highly ***dispersive*** region to detect

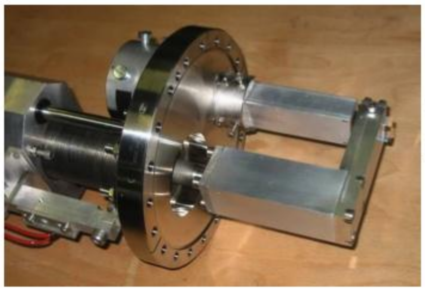
1) **off-momentum particles** (produced in the crystals) which are displaced lateraly
2) any not absorbed secondary halo

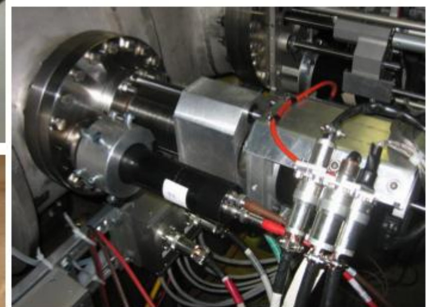
Observe the spray rate as a function of scatterer lateral position

SPS UA9 devices

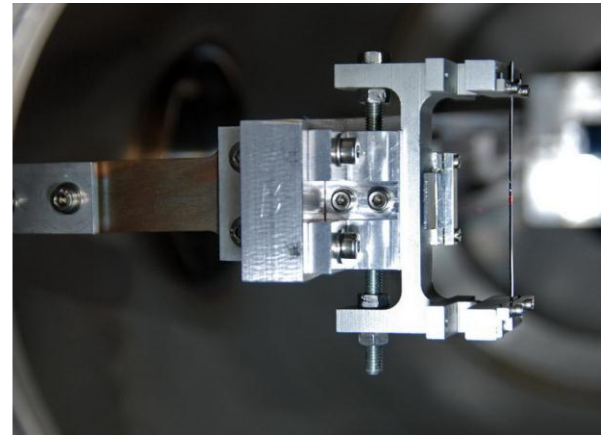
Cherenkov in CERN tank



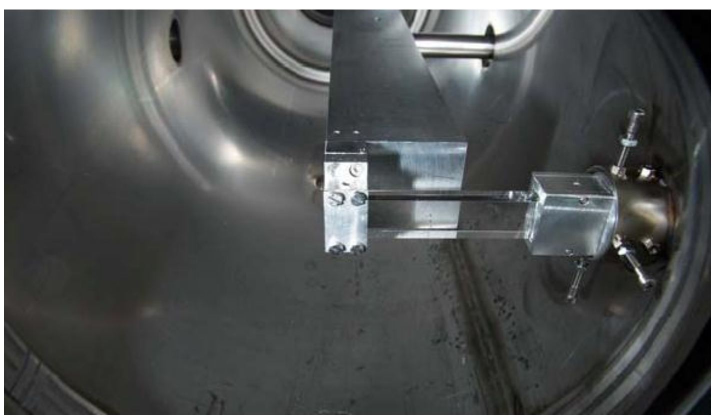




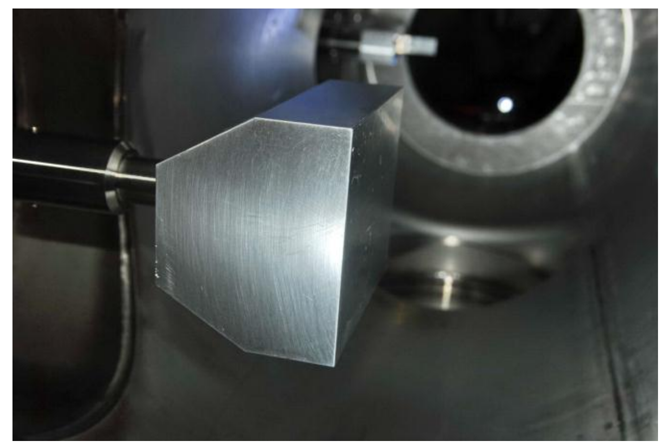
Strip crystal in IHEP tank



TAL absorber & Quartz Cerenkov detector



TAL2 Al scatterer



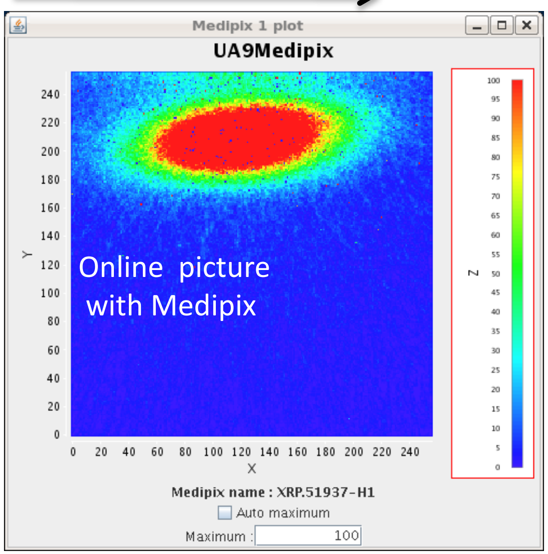
High quality mechanical devices, accurate motion system

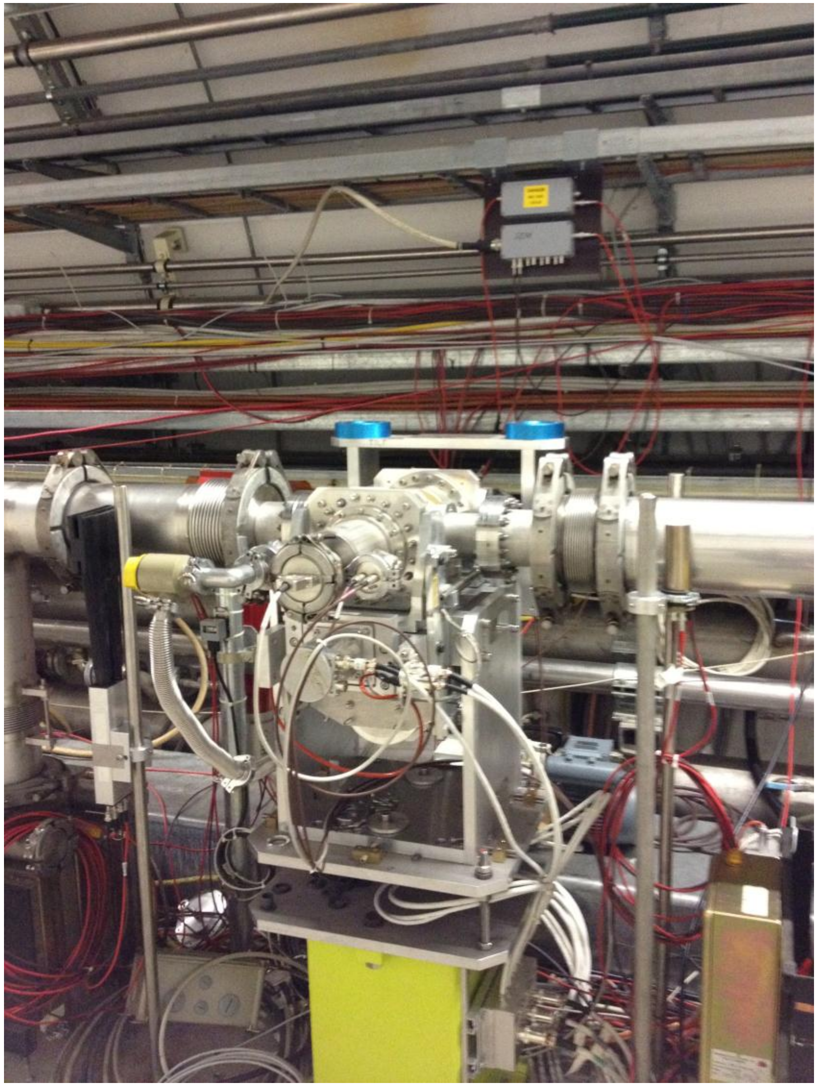
Medipix in Roman pots

- In each pixel count hit (discriminator)
  - Threshold low (mip in Si)
- Limited by DAQ dead time (1 sec)
- Used to ***acquire images of channeled beam***
  - ***Very important to confirm channeling online***
- Relevant to measure channeled beam direction (from centroid) and flux of proton of channeled beam

Vertical displacement

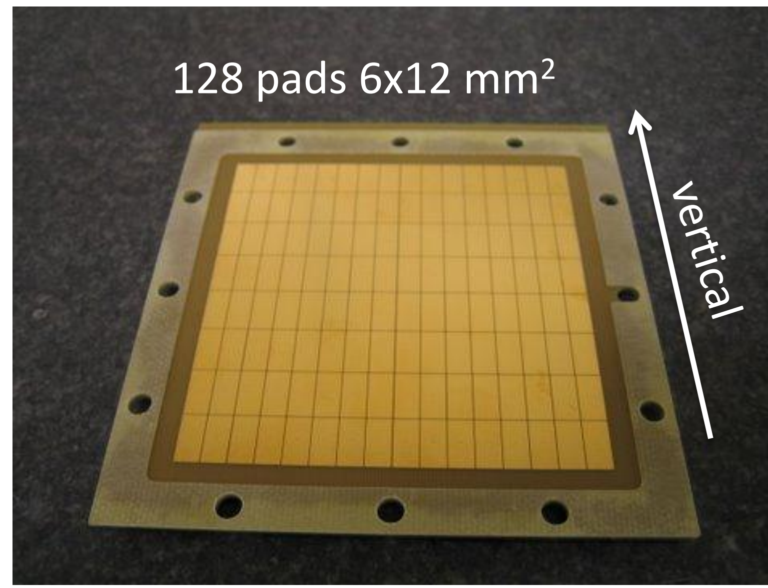
Horizontal displacement





GEM on SPS

- Two GEM mounted on Ex-RD22 tank since 2009
- Operate during UA9 MD, data synchronized with other UA9 BLM



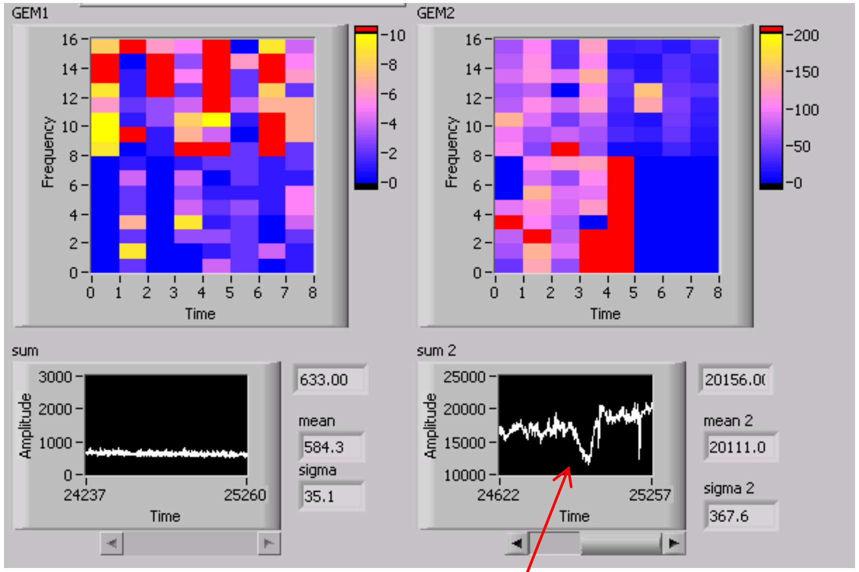
10x10 cm2 active area

Carioca chip on board
DAQ crate remote

Electronics to control
thresholds and LV PS

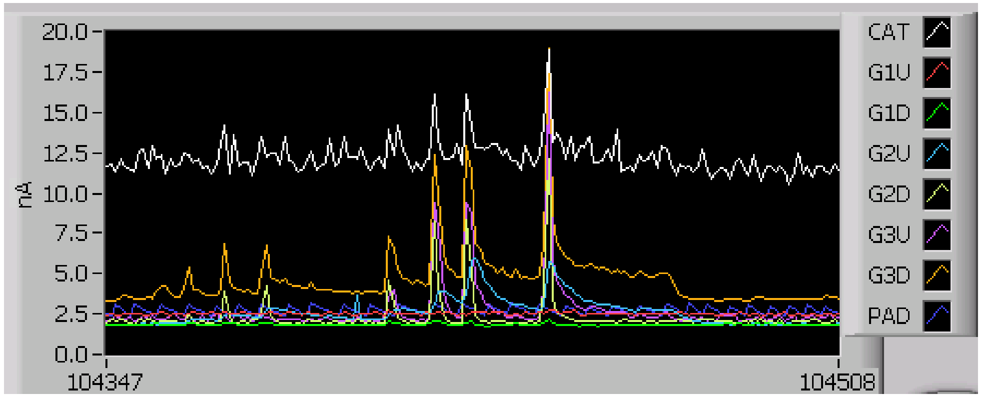
Monitoring with GEMs

The GEM are acquired every second getting an online image of inelastic scattering at large angle



When an angular scan is performed on crystal, a drop appear on the total rate measured by the downstream GEM during the channeling time period.

Nano-amperometer!

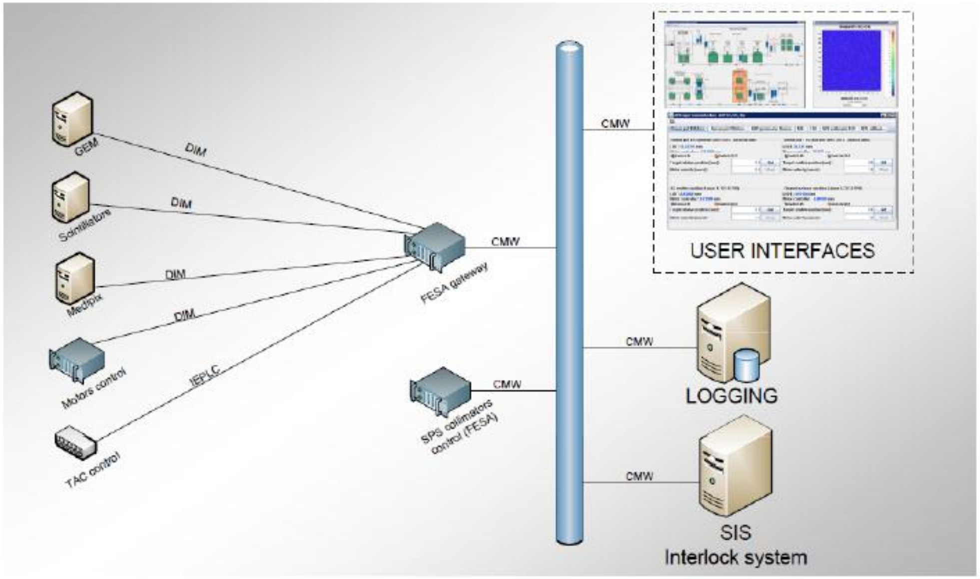


Current vs time.

Also the total current drawn by the GEM chamber is a good measurement of the flux of particles from inelastic interactions.

Very large dynamic range

Data Synchronization



Use of middleware accelerator infrastructure to save data

Every subsystem provide a "measurement" every second

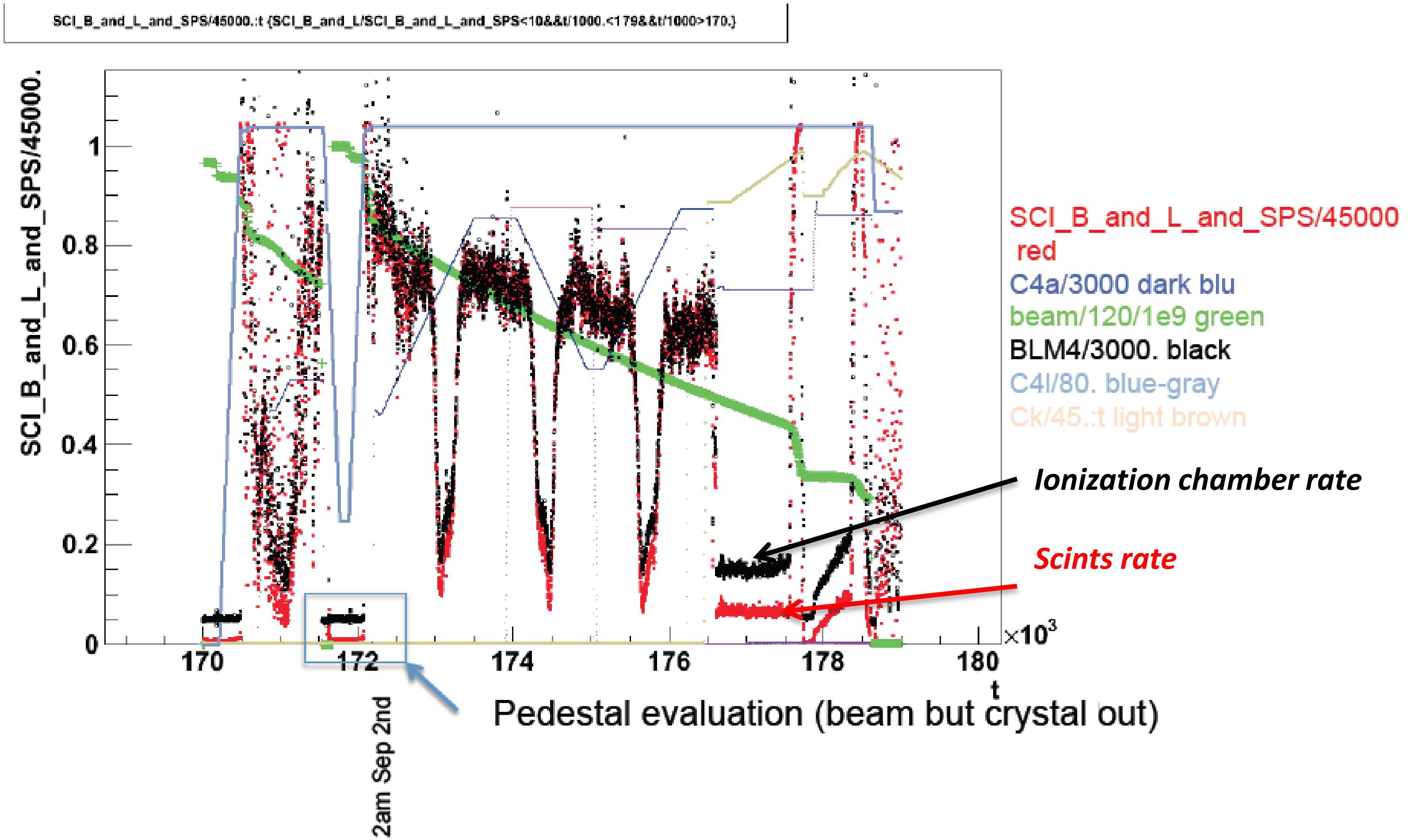
Data are partially available online

More refined analysis can be made offline

Example of different BLMs

Scan night Sep 2nd

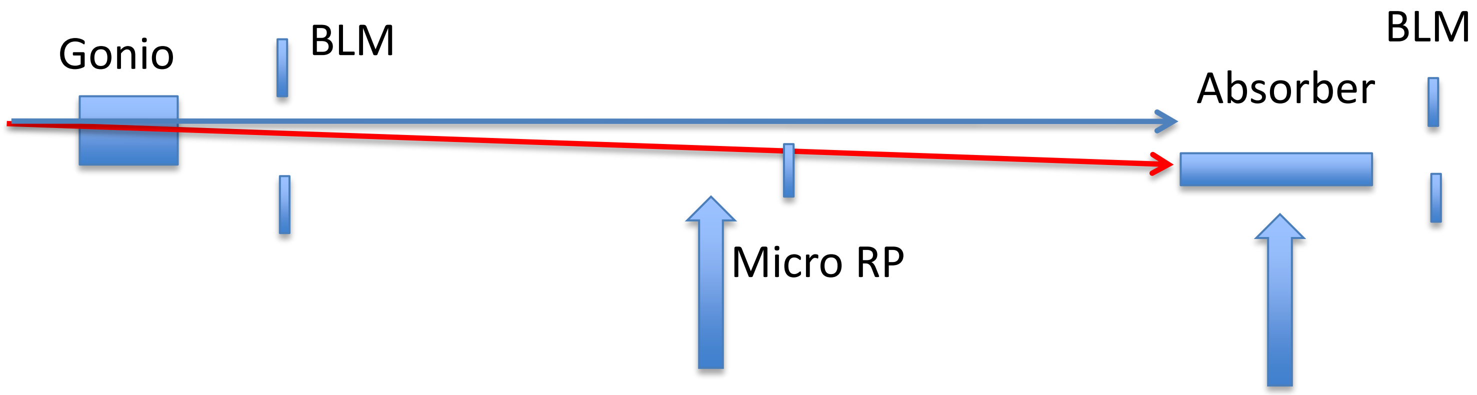
Normalized to "natural" scale for each device



Basic layout for LHC

From SPS UA9 layout experience

- Goniometer
- Special beam line monitor
  - Close to goniometer ahd absorber
  - Sensitive to secondaries
- Micro-RomanPot
  - Intercept channeled particles



I assume standard LHC BLM are much better than standard SPS

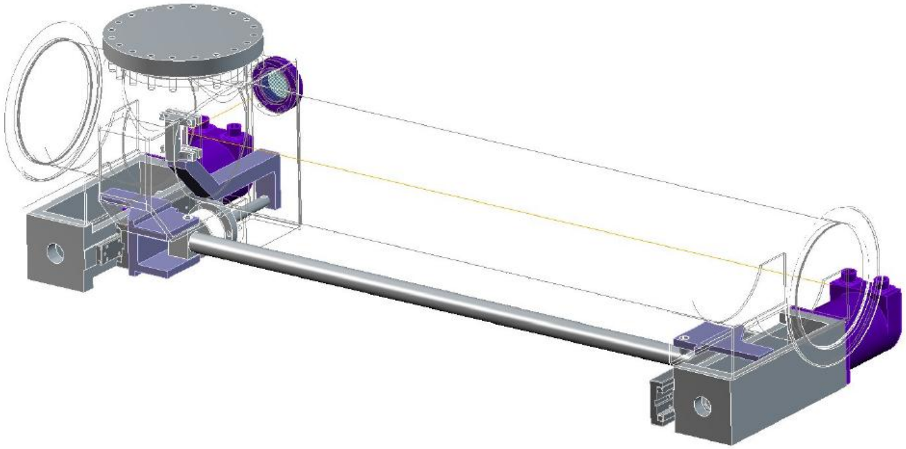
Goniometer spec for LHC

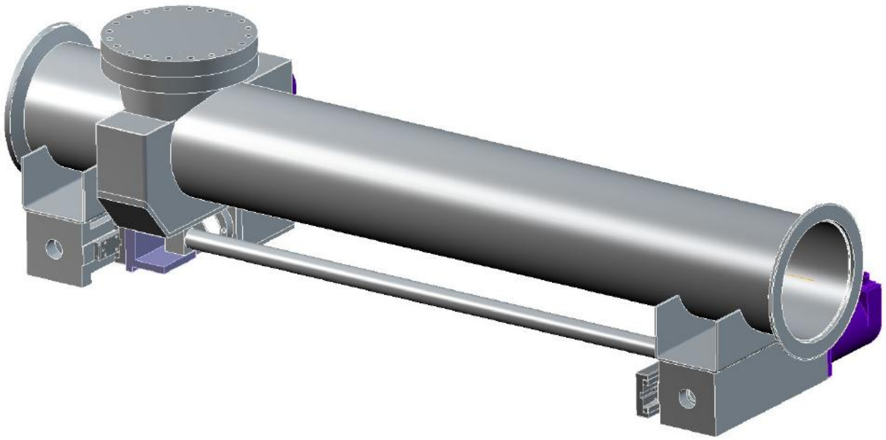
- Total angular range : >10 mrad
- “Resolution”: <0.1 μrad
  - Minimum step of motor
- “Accuracy”: < 1 μrad
  - How precisely the motor goes to a given ang. position
  - Related to channeling critical angle scale

- Maximum tilt inaccuracy: < 1 μrad
  - Linear-angular coupling,…

- Linear resolution: 5 μm
- Total linear range: 40 mm

Goniometer from CINEL srl (Italy)



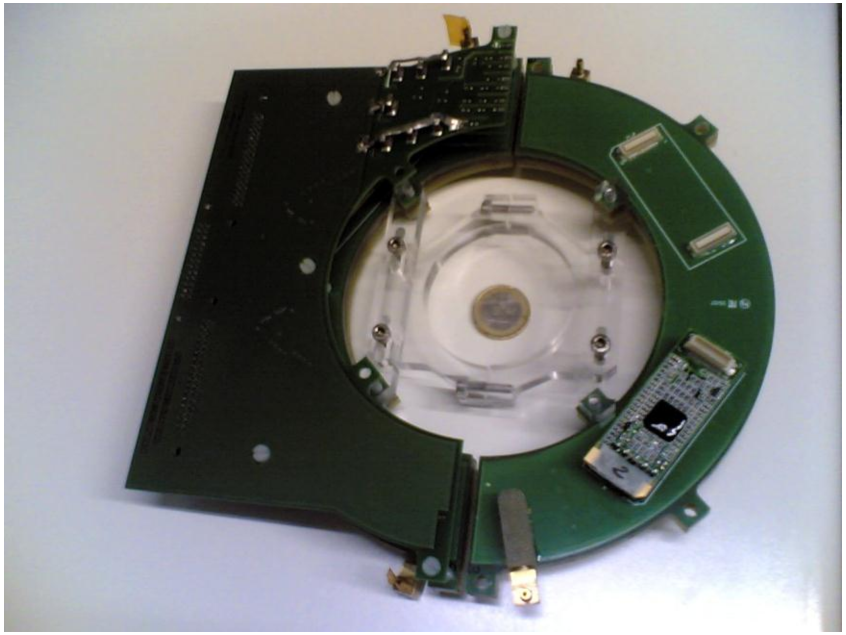


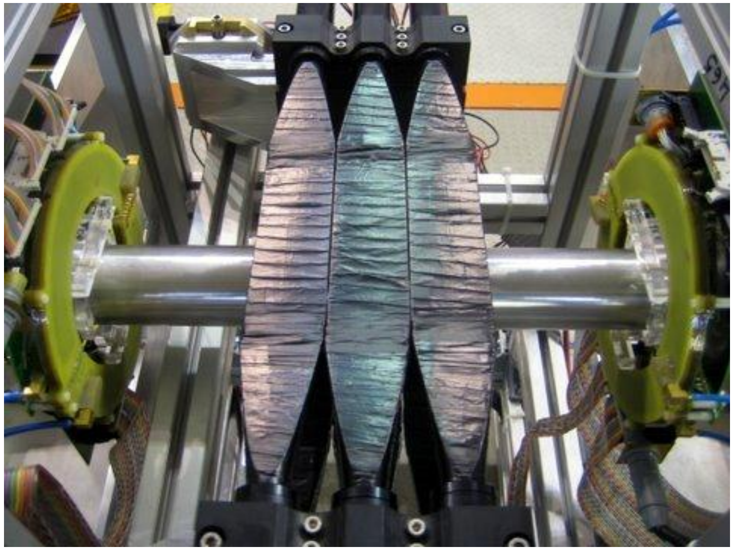
To be built in the next weeks and to be tested on SPS at first

This will be the first critical device for the UA9 LHC setup

Mechanical devices (motors, encoder, etc.) are a very delicate element

BLM close to crystals

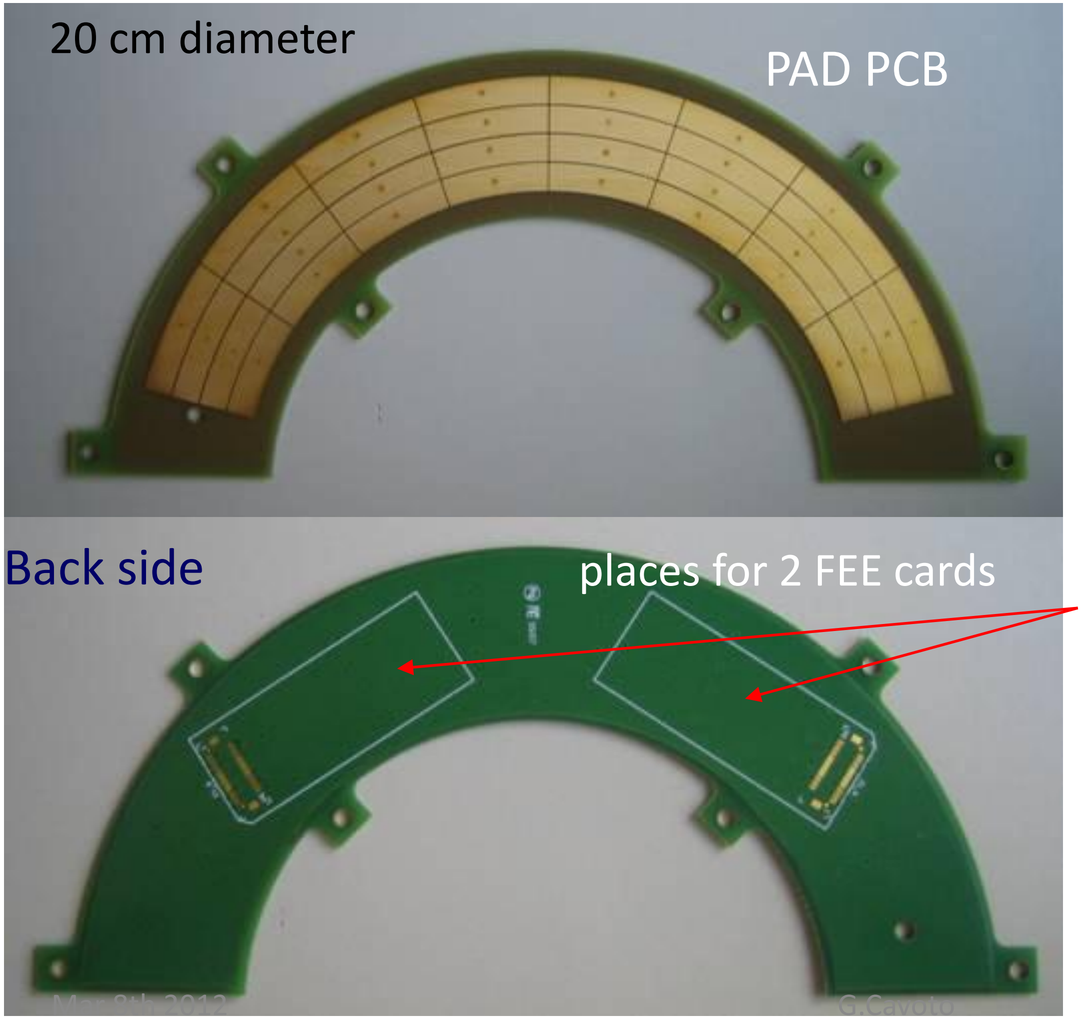




LUMI GEM detector
Dafne (LNF) luminometer

LHC close-to-crystal can be modeled on this

Details on LUMI GEM



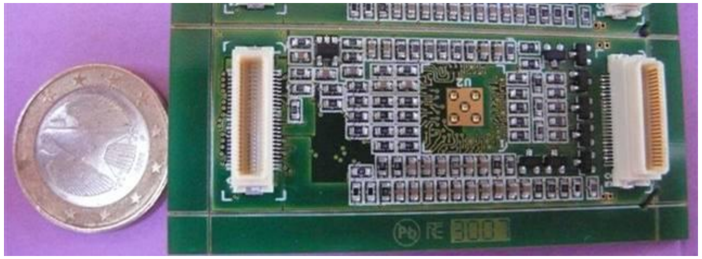
Instrinsically radiation hard detector (No flammable gas)

GEM principle:
Localized electron multiplication can sustain large rate (MHz/cm2)

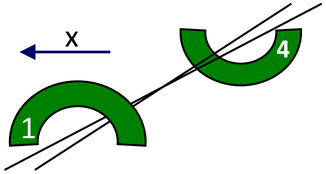
Each pad can count number of m.i.p.'s crossing it.
[threshold well know]

More on GEM BLM

– Electronics Radiation Hard
(Carioca chip, used for LHCb)



- Can be made in several modules
(put at different distances in coincidence)
- Can be made movable
    - (to scan different angles)
- Addition of degrader can make them sensitive to neutron



- Electronics (hit definition) and slow control (thresholds and FE LV PS) in compact FPGA (to be tested in SPS this year)

Detector for RP

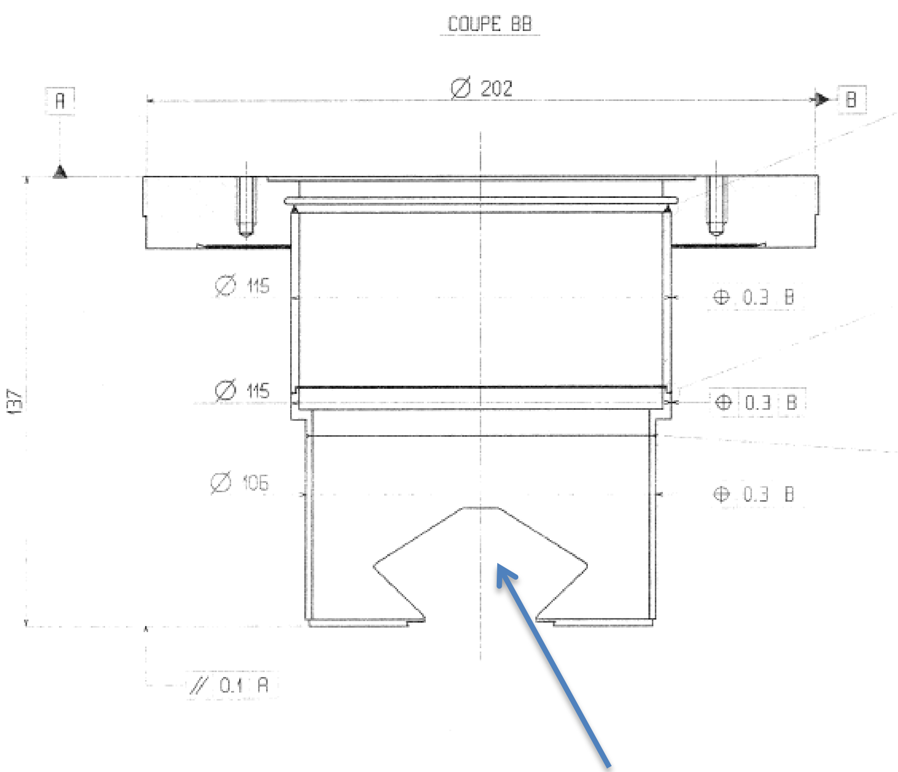
- Intercept channeled protons.
  - » O(100 proton) in few ns [SPS] on a fraction of mm^2 every 43kHz [SPS]
- Should give a signal proportional to crossing protons
  - Good knowledge of calibration and efficiency
  - Not saturate
- Spatial resolution
  - "image" of beam (shape). Not critical
  - If two RP at different machine azimuth: beam direction
- Trigger from machine timing

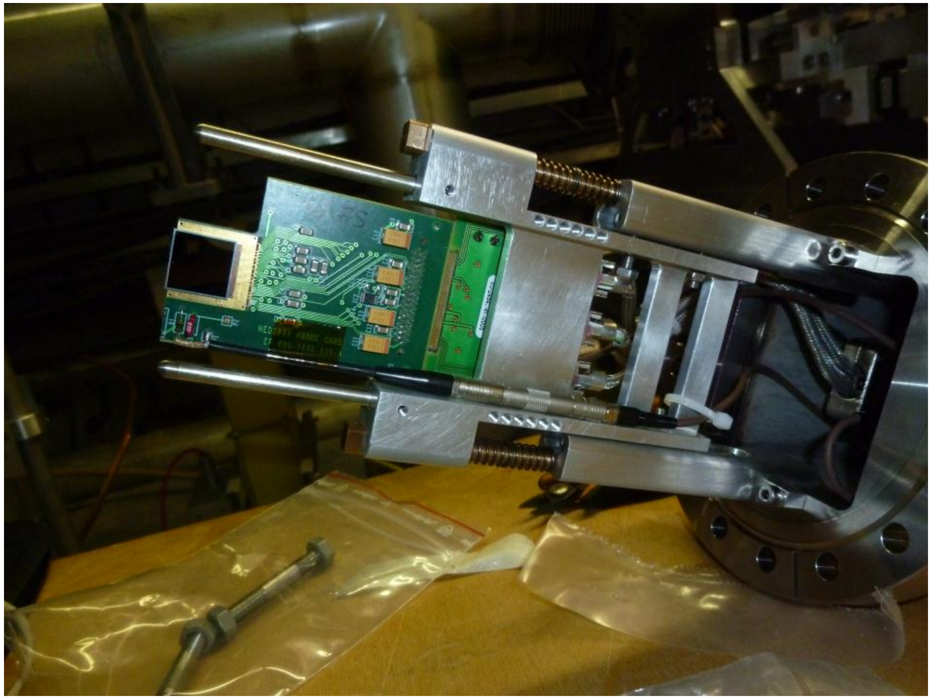
Positive experience with Medipix
Very good spatial resolution
But calibration is not totally understood
Timing is possible but…
Not clear if it can stand high dose

Other more robust Si
MIMOTera ?

Test a scint fiber odoscope in SPS

Roman pot (sec. vacuum)

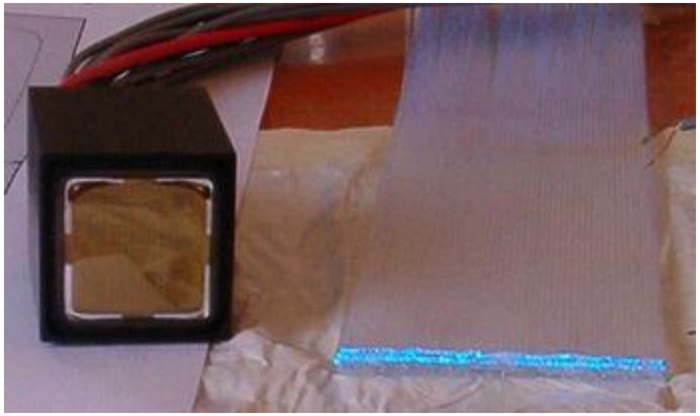




Thin window (200 μm Al thick) where the detector
active region should be placed

Add scintillating fibers in front of Medipix device
(calibration, trigger,…)

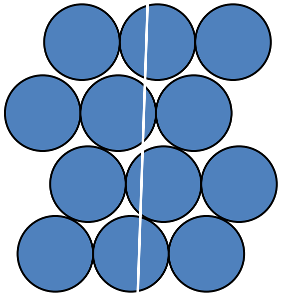
Detector concept



One or **more** layers of fibers:

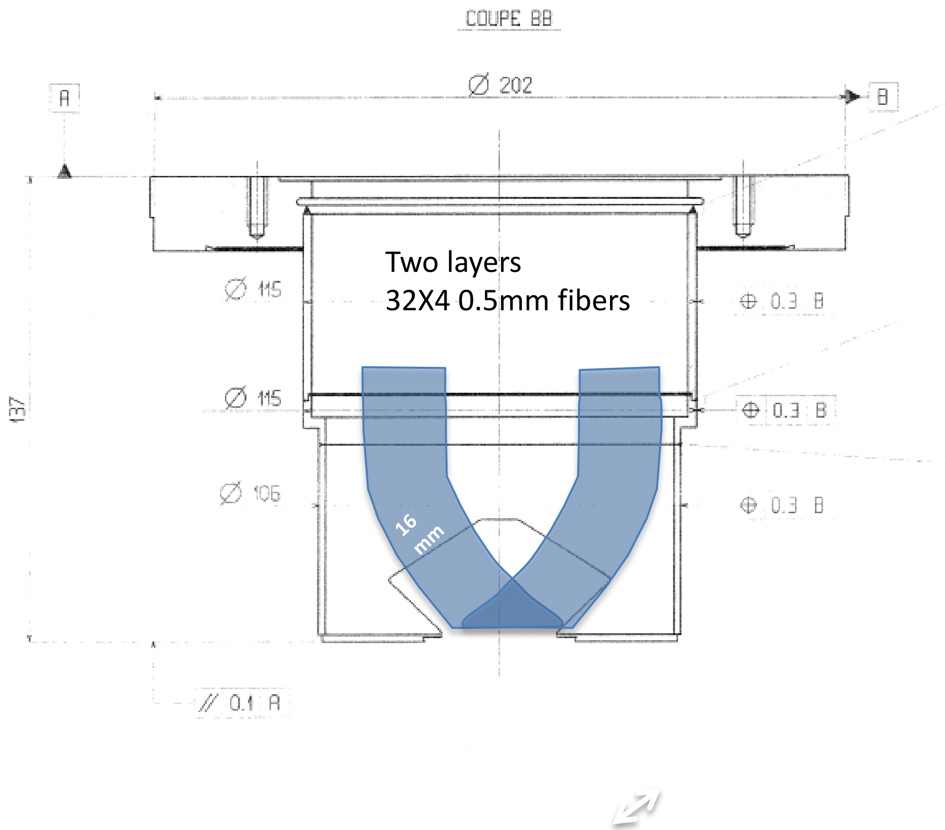
- Plastic (PMMA, polystyrene) fibers:
  - scintillation (blue)
  - $n_{core} \cong 1.6$, $n_{cladding} \cong 1.4$
  - Round or square fibers
  - Diameter/side from **250 μm** to few **mm**

- Quartz (SiO_2) fibers: Cerenkov emission
  - Different cladding materials (silica, hard plastic, PMMA)
  - Core diameter from **100 μm** to **2 mm**



Directly coupled to multi-channel photodetector (e.g. **multi-anode** PMT)

Profilometer



Project at INFN RM, in construction

Two layers of 32x4 0.5 mm fibers

Fibers routed to vacuum-air interface

Hamamatsu MA 64 ch H7546 PMT coupled directly on to vacuum-air interface

Four fiber coupled to a signal photocathode pixel

Need advanced electronics to acquire the signals!!!

Measure pulse height and timing

Some comments

- Collimation tests in SPS were good to understand needs and limits for our instruments.
- We were able to operate various BLMs around the collimation region
- We never achieved a satisfactory system able to count incoming (to crystal) particles and channeled particles
  - Fast electronics to digitize each pulse of a detector would be an important step

Tank-you for your attention

Backup slides

Possible readout

at
A

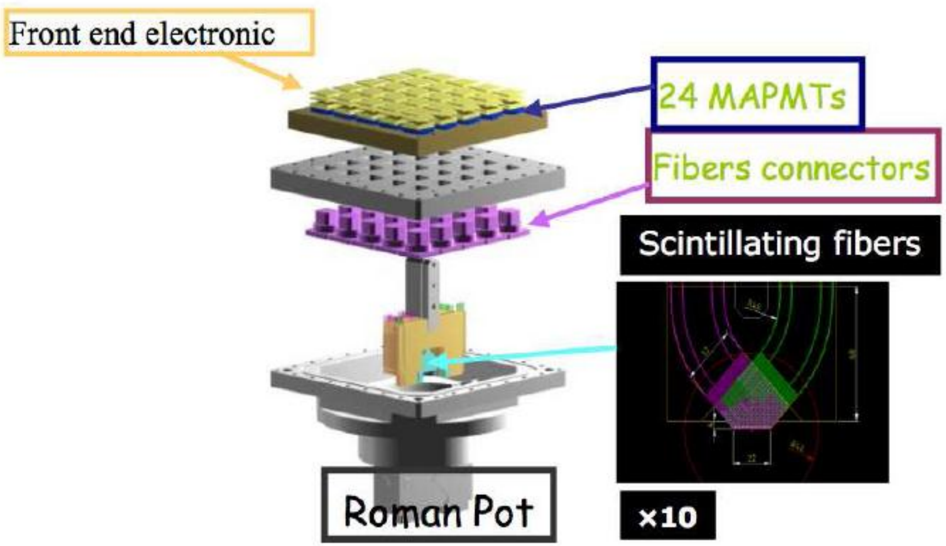


Figure 1. Schematic of a Roman Pot and the front end electronics.

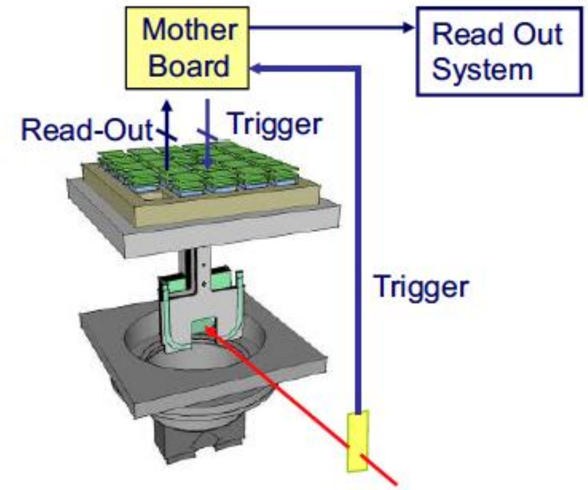
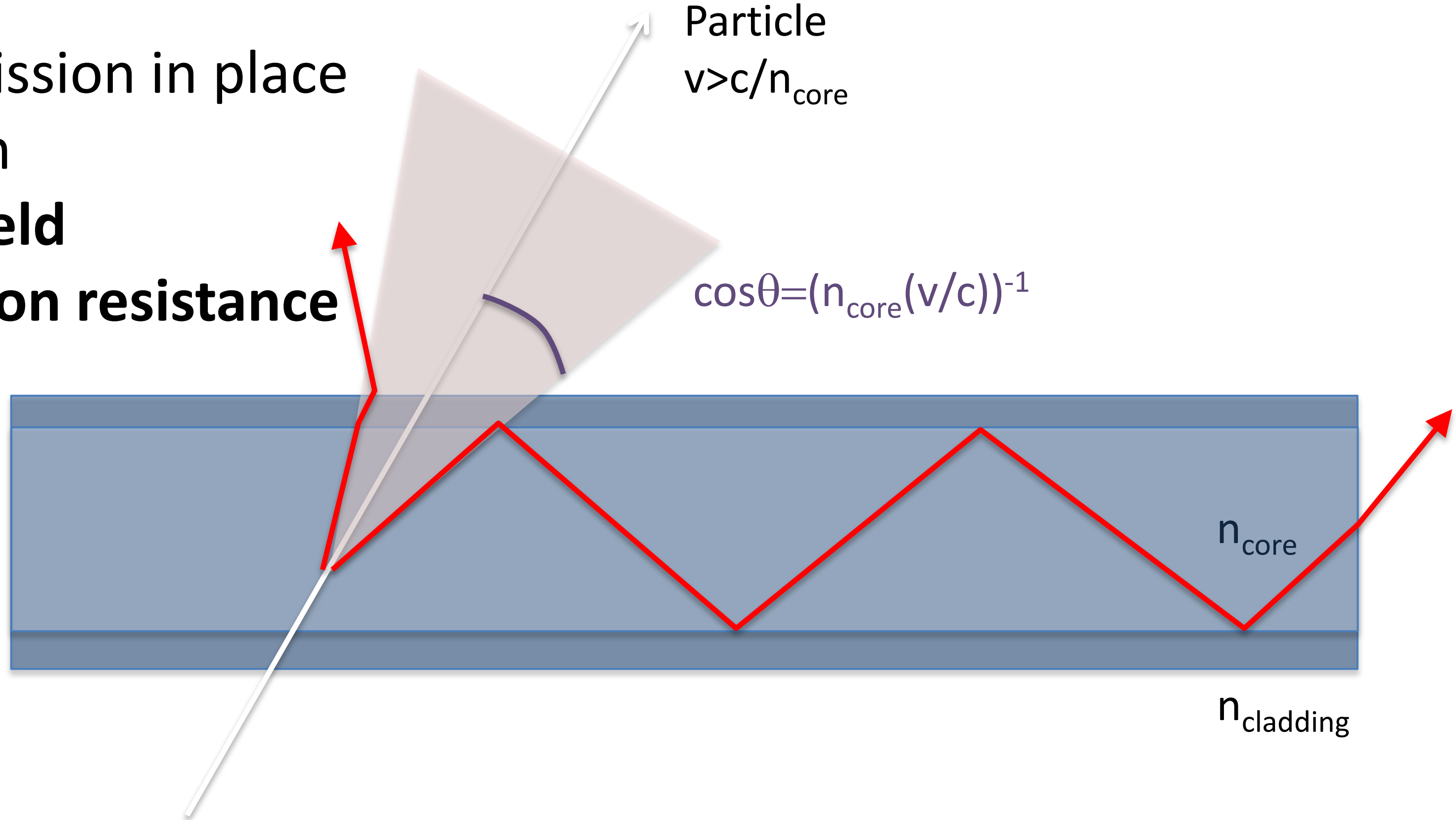


Figure 1. Schematic representation of the ALFA tracker with overlap detectors and read-out electronics above a roman pot. The mother board sends the formatted data to the common ATLAS readout system upon arrival of an L1 trigger signal.

Another possibility…

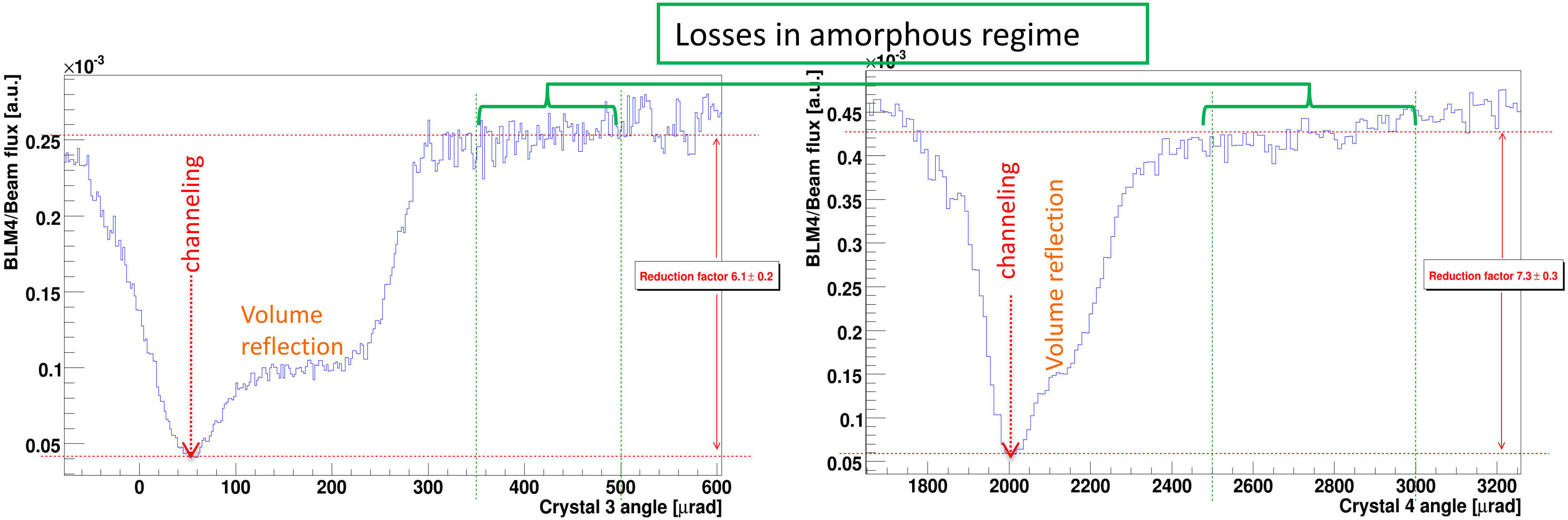
Quartz fibers:

- **Cerenkov** emission in place of scintillation
- lower **light yield**
- Better **radiation resistance**



Angular scans

- <u>Reduction factor</u> of the inelastic losses due to inelastic interactions in channeling versus amorphous orientations.
  - Measured with LHC-BLM and GEM detectors
  - Very reproducible in several scans and fills



Depending on crystals 5 – 9 reduction factor (protons)

NEW: measurement also with Pb ions: 2-4 factor

Still off with respect to simulation

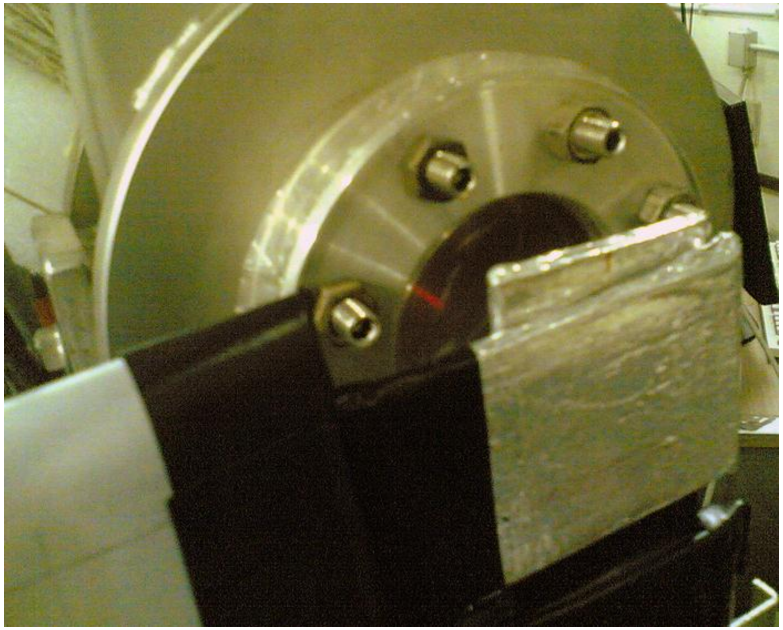
Tools to make progress

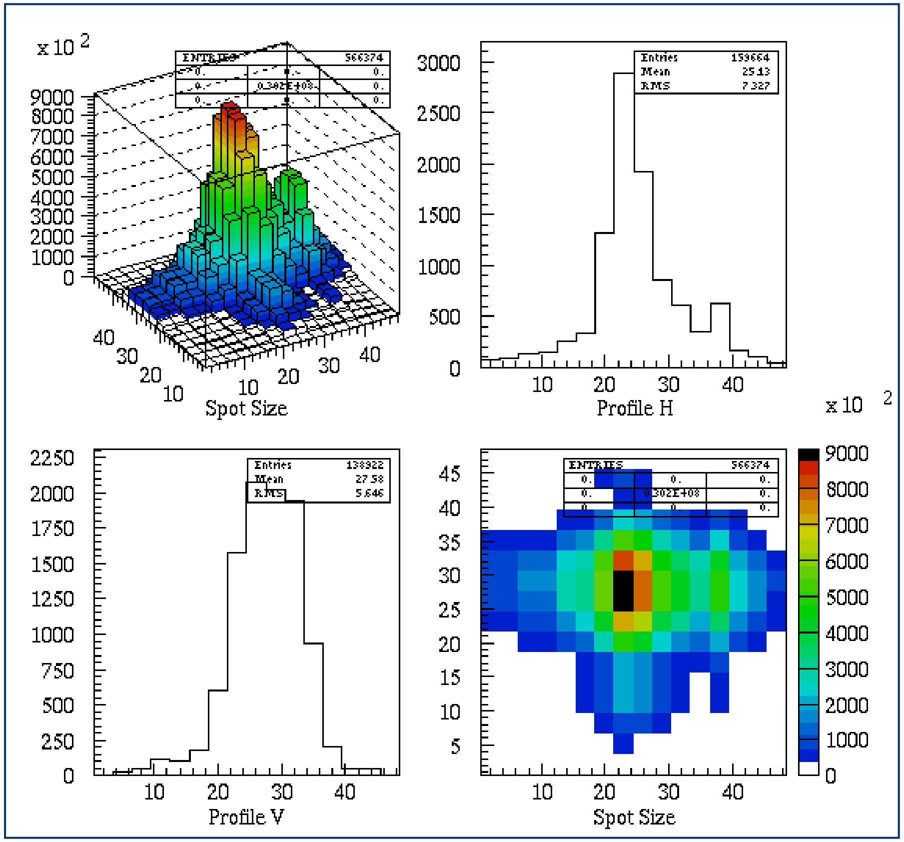
- Simulation.
  - Proton Tracking
  - Aperture model
    - Inelastic interaction
  - Crystal simulation
  - Detector simulation (GEANT4,FLUKA,...)
- Use of mixed tool
  - ICOSIM

Obviously we need this to make a conceptual design (next months?)
A detailed simulation can come later

Scintillating fiber detector

- Fiber detectors (x and y views, 4 layers, 1 mm diameter fibers)
- Working since 2003 at **Frascati BTF**

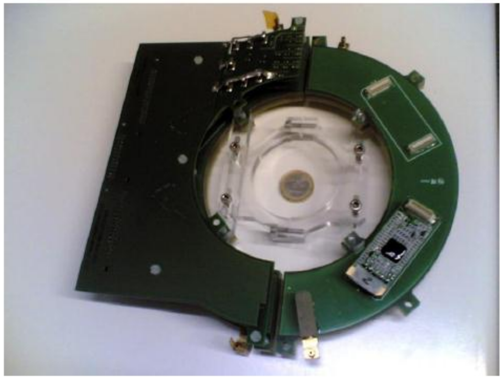


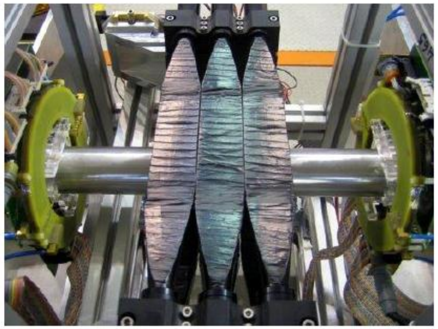


BLM based on GEM

- Sustain high rate (100 KHz/cm2)
  - Limit given by spacing of GEM foil holes
- Linear (sensitive to mip)
- Measure rate on small element (0.5x1cm2 pads)
- Already used in LHCb

New compact DAQ board (see F.Murtas) can avoid problem with long cable





LUMI GEM detector
Dafne (LNF) luminometer

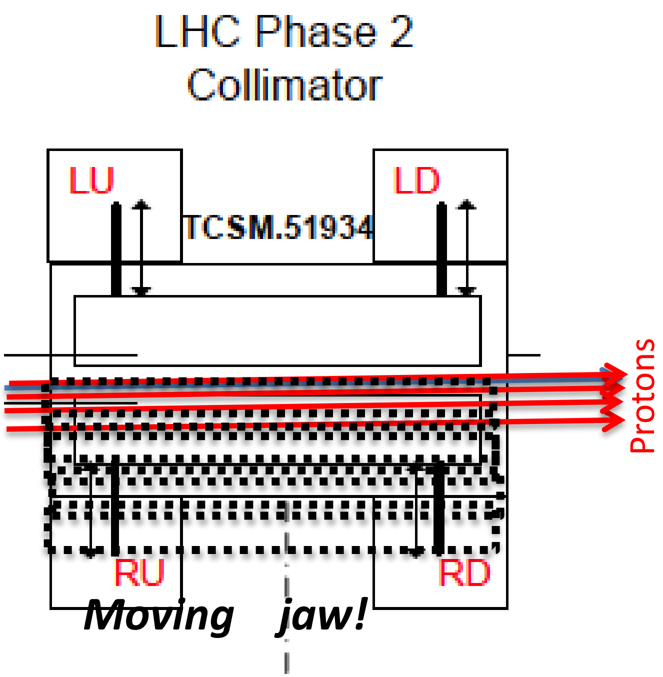
SPS 2010 shows they reproduce standard SPS BLMs.

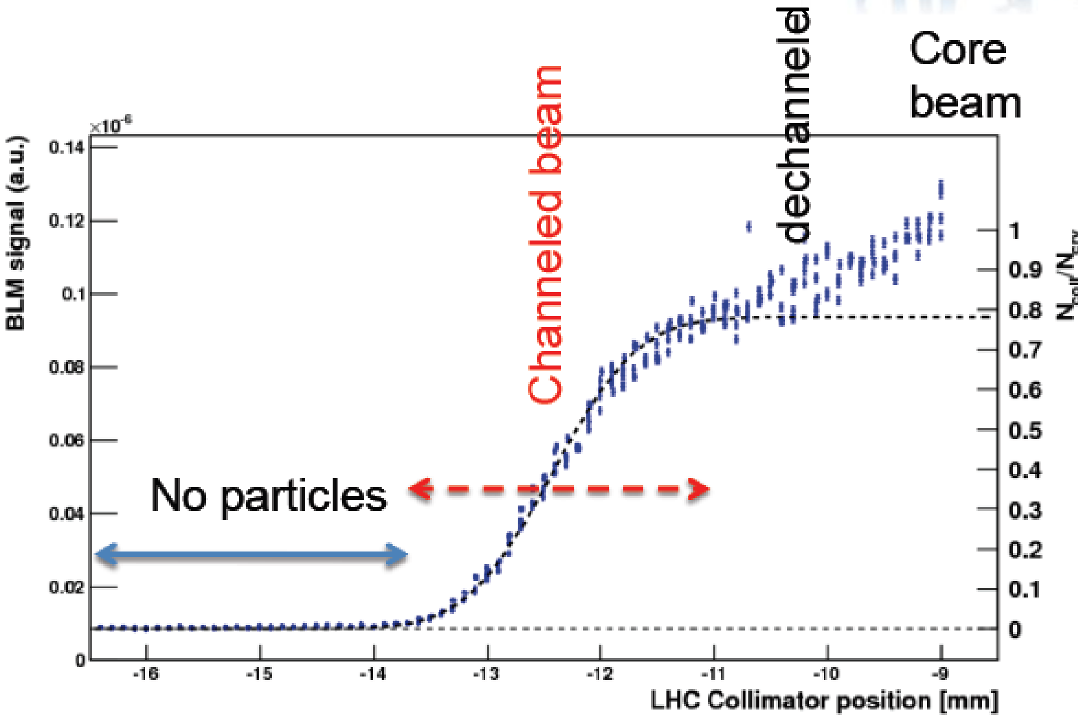
Road-map for a test in LHC

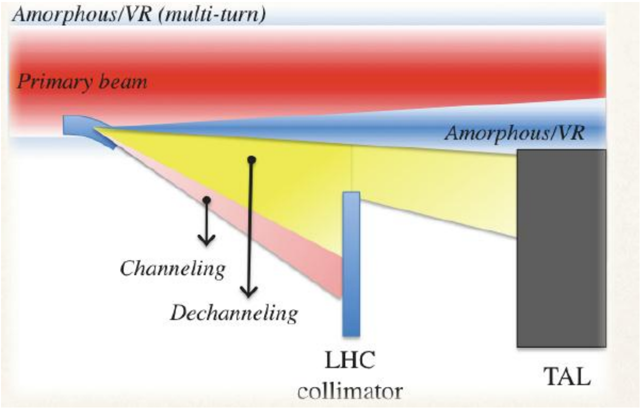
Parameters	Obtained in 2009	Obtained in 2010	Required for LHC	
Channeling efficiency	75	80	90÷95	★★
Nuclear loss reduction	5	5-10	20÷30	★★
Goniometer: angular accuracy [μrad]	30÷40	10	1÷2	★
Crystal bend [μrad]	140÷150	150÷170	50÷100	★★★
Crystal torsion [μrad]	20÷30	0.1÷1 (*)	0.1÷1	★★★
Amorphous layer on crystal	About zero	About zero	About zero	★★
Collimation leakage reduction	-	5	Should be analyzed	★★

(*) On external beam test

LHC collimator scans







Measurement of channeled beam position and width

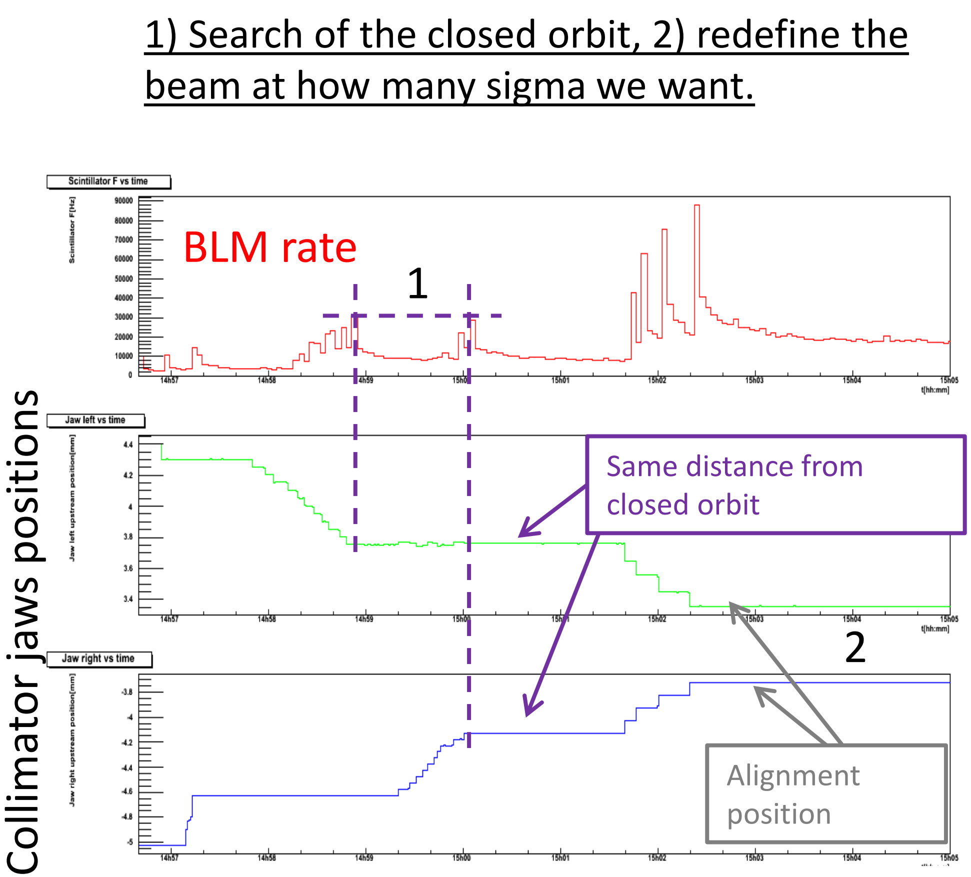
» σ_{beam} **~0.6mm**

Comparison of plateau with core beam

» **Deflection efficiency ~80%,**

Close to expectation (92% and 0.33mm)

Alignment procedure

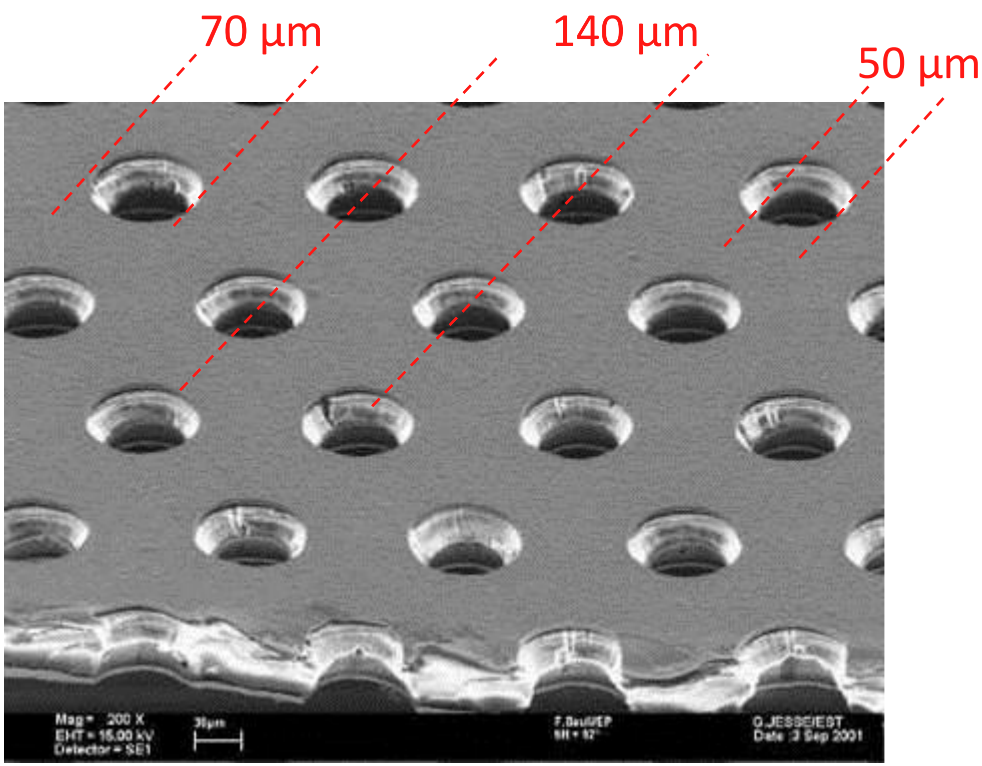


Crystal and all UA9 movable devices are aligned during each fill.

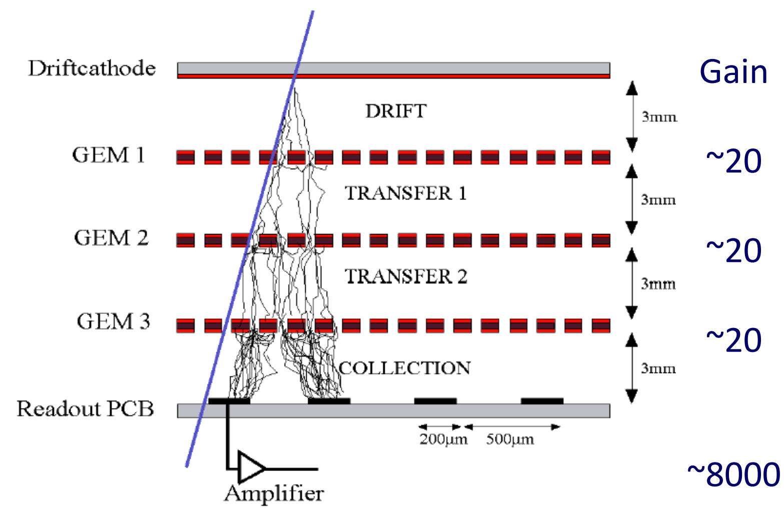
Standard and fast procedure to find channeling configuration and collimation!

Gas Electron Multiplier

A Gas Electron Multiplier (F.Sauli, NIM A386 531 **1997**) is made by 50 μm thick kapton foil, copper clad on each side and perforated by an high surface-density of bi-conical channels;



Triple GEM



Relavant facts for BLM

- Sensitive to secondaries (inelastic interaction)
  - Should be able to detect mips with full efficiency
- On SPS doing test with one bucket filled
  - Bunch length few ns
  - Revol. Frequency 43 kHz
  - Secondary particles arrives “bunched” on the BLM
- Scint BLM are NOT counting secondary
  - If one or more mips crossing scint ALWAYS count one
  - Fully efficient (it is sensitive at low flux) but saturates at rev.freq.
  - Linearity guaranteed for low flux
- Gate with RF signal
  - Very important to reject out of filled bunch particle
  - Need < ns time resolution to distinguish among close bunch (5ns)

Scintillating fiber detector

From LNF BTF test
On similar detectors

Single particle sensitivity, response proportional to number of electrons in beam

≈1 photo-electrons/mm at 50 cm from PMT, 20% quantum efficiency