Operation Experience with the ALICE Silicon Pixel Detector – and Implications for NA62

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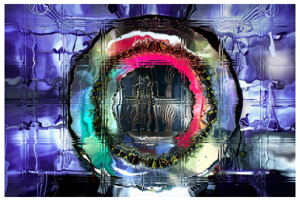
on behalf of the ALICE SPD Project in the ALICE Collaboration

And

On behalf of the Gigatracker Working Group in the NA62 Collaboration

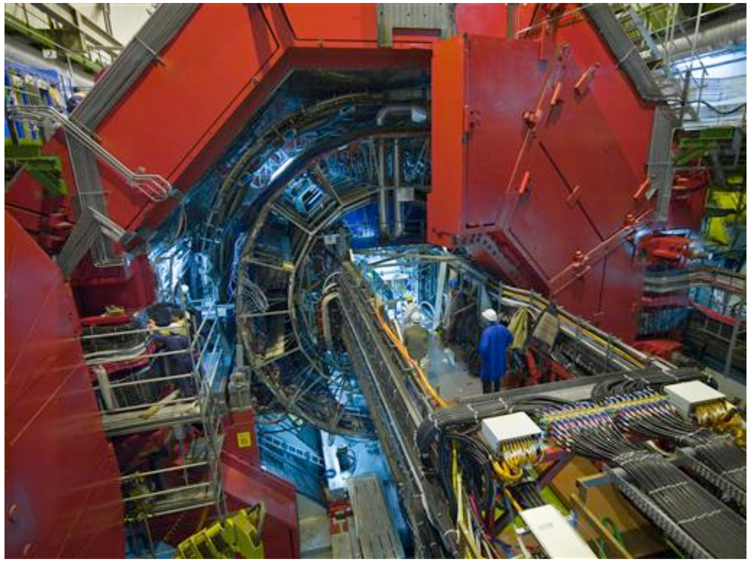


Overview

- The ALICE ITS and SPD
- SPD Installation and Commissioning
  - Standalone tests
  - Cosmic runs
- First Experience with LHC
  - Injection tests 2008
  - Circulating beam 2008
  - Activities in 2009
- Lessons learnt and possible applications for the future: NA62
  - Challenges for NA62
  - Material budget
- Conclusion

The ALICE Experiment

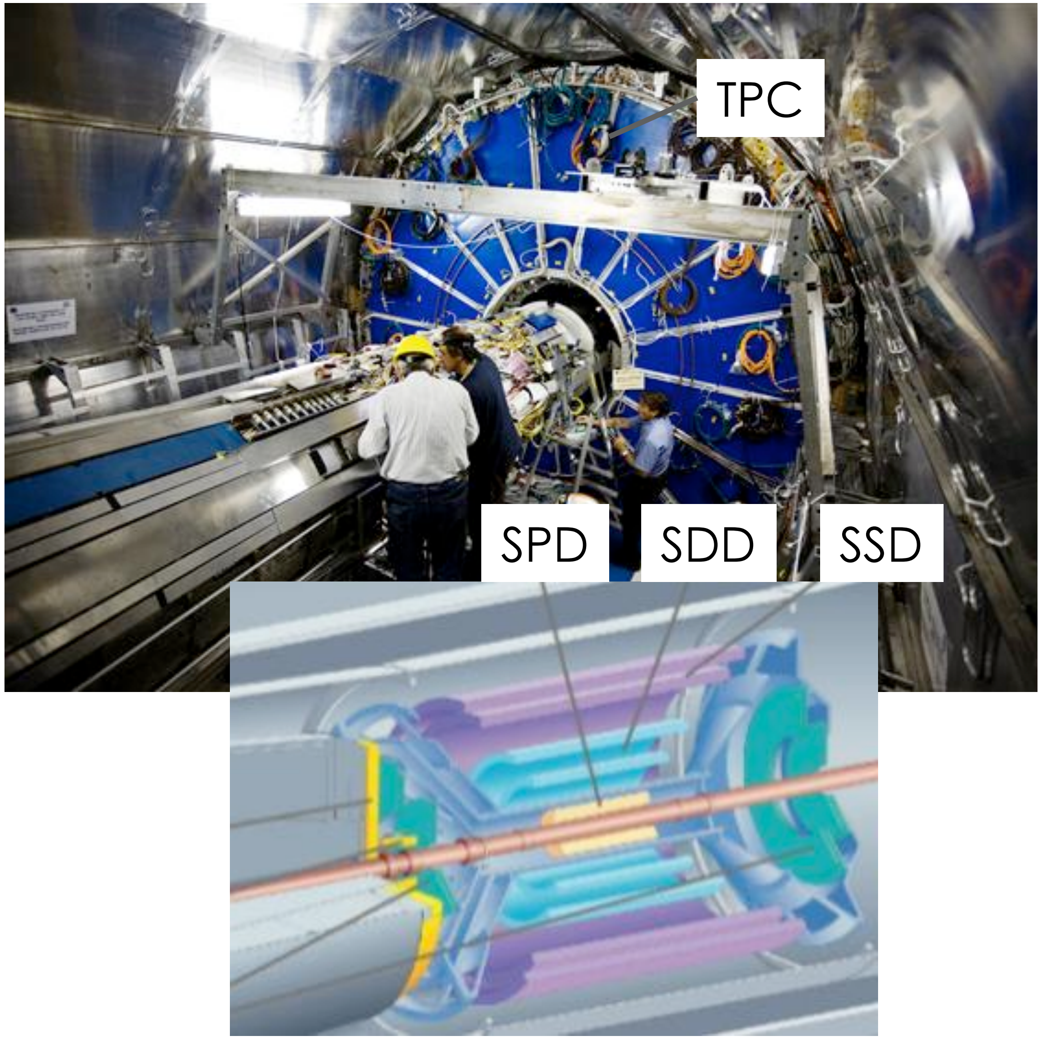
- Designed for ultra-relativistic HI collisions
- Extreme track densities
  - dN/dη ~ 2000 – 8000
  - High granularity detectors with many space points
  - Very low material budget
  - Moderate magnetic field (0.5T)
- Hadron, lepton and photon PID over large momentum range (0.1 GeV/c – 100 GeV/c)



- Lower luminosity and interaction rate wrt ATLAS, CMS
  - 10 kHz (Pb-Pb) – 300kHz (pp)
  - Irraditiation levels after 10 years: 2.5 kGy/3 10^{12} n_{eq} cm^{-2} at innermost layers

The ALICE Inner Tracking System

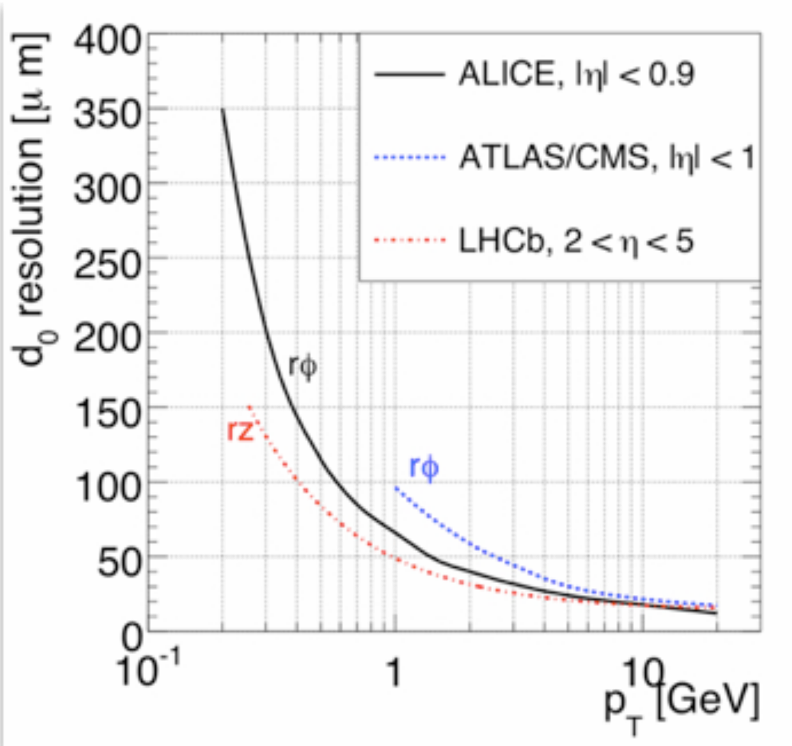
- 6 layers of silicon detectors:
  - 2 layers of pixels (SPD)
  - 2 layers of drift (SDD)
  - 2 layers of ds strips (SSD)
- Radial coverage:
  - Min.: 3.9 cm (SPD 1)
  - Max.: 43 cm (SSD 2)
- dE/dx information in 4 outer layers (SDD, SSD)
- L0 trigger (SPD)



The ALICE Inner Tracking System

- Improve primary vertex reconstruction and momentum resolution
- Secondary vertexing capability (c, b and hyperon decays)
- Track impact parameter resolution
- Tracking and PID of low p_T particles
- Prompt L0 trigger capability (<800 ns)
- Charged particle pseudorapidity distribution

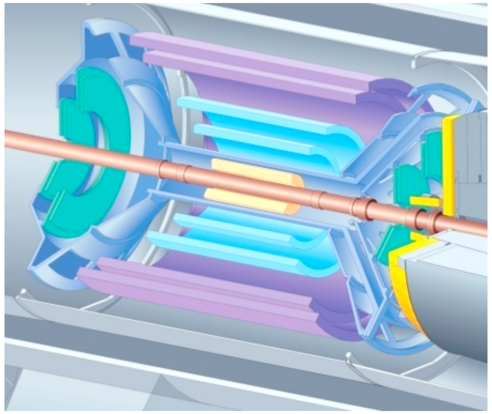
$\sigma_{d0} \cong \sigma_{\text{detector resolution}} \oplus \sigma_{\text{multiple scattering}}$



S.Alekhin et al.
HERA and the LHC - A workshop on the implications of HERA for LHC physics:Proceedings Part B, arXiv:hep-ph/0601013.

The ALICE Inner Tracking System

layer	type	R [cm]	area [m^2]	chan-nels	occu-pancy	$\sigma\_R\phi$	σ_Z
1	pixels SPD	3.9	0.07	3.2 M	2.1	12 μm	100 μm
2		7.6	0.14	6.6 M	0.6		
3	drift SDD	15.0	0.42	43 k	2.5	35 μm	25 μm
4		23.9	0.89	90 k	1		
5	double sided strip SSD	38.0	2.2	1.1 M	4	20 μm	830 μm
6		43.0	2.8	1.5 M	3.3		



low mass: 8 % X_0
SPD 2.3 %
SDD 2.4 %
SSD 1.7 %
structure 1.3 %

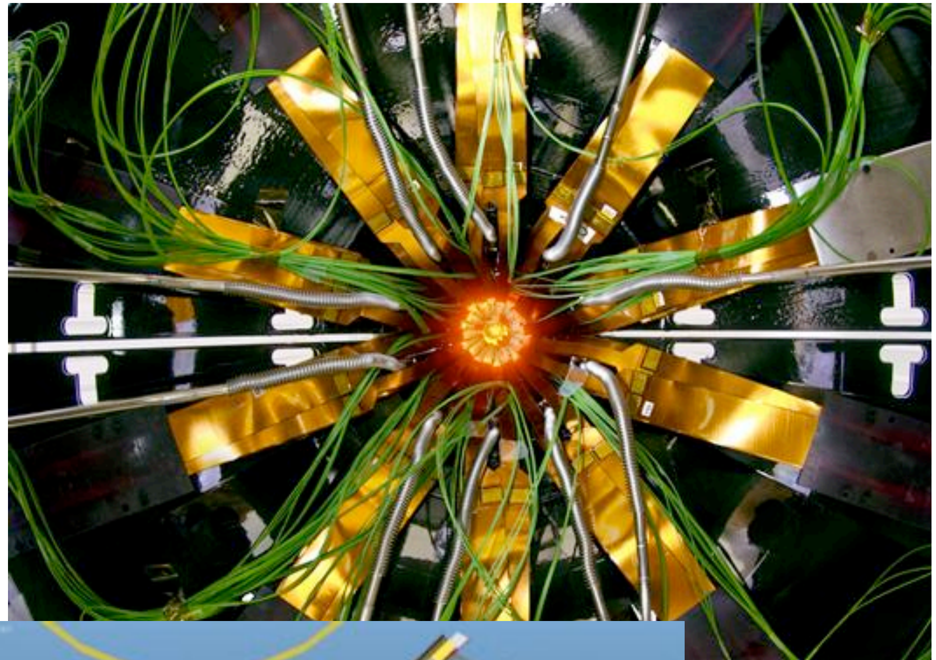
The ALICE Inner Tracking System

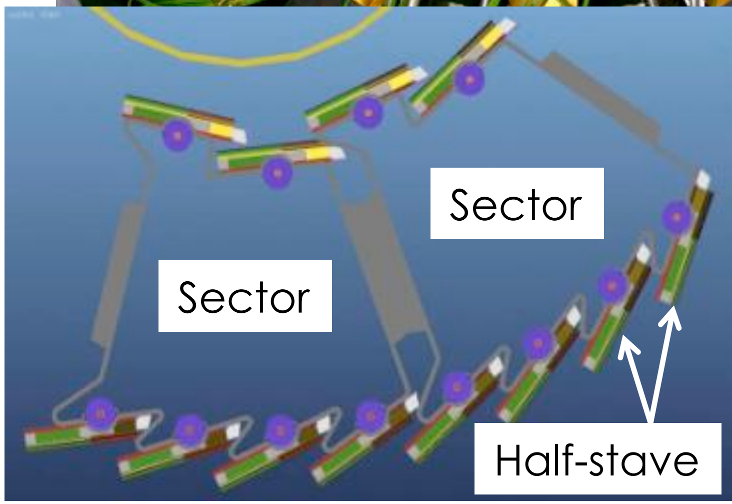
ITS presentations in this conference:

- **G. Aglieri Rinella** - *The ALICE Pixel Trigger system, commissioning and operation* (Wed. 11:15)
- **Francesco Prino** - *Operation the Silicon Drift Detectors of the ALICE Inner Tracking System during cosmic runs* (Wed. 12:05)
- **G.J.L. Nooren** - *Experience with the Silicon Strip Detector of ALICE* (Wed. 12:55)

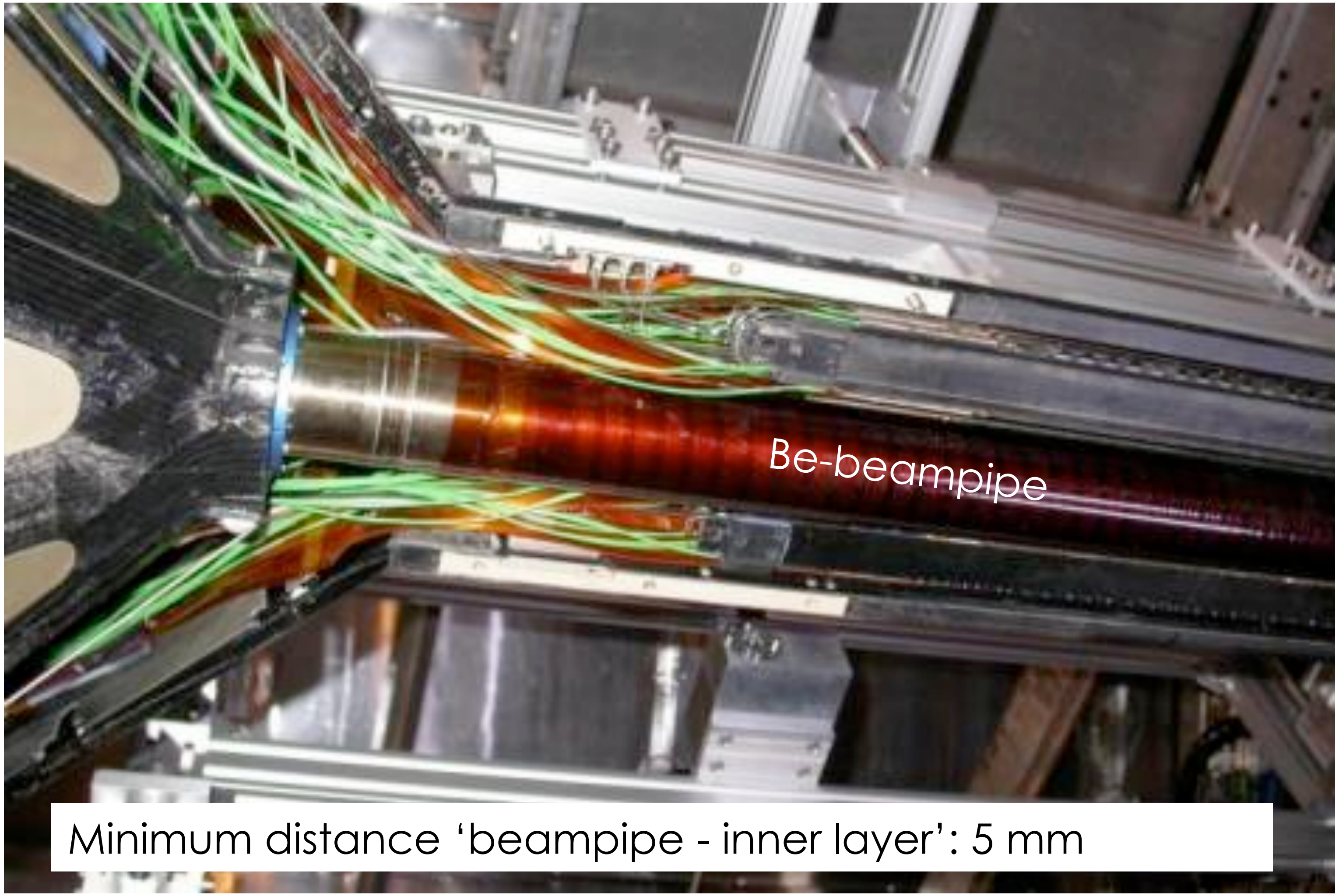
The ALICE SPD

- 2 barrel layers at r=3.9 cm and 7.6 cm built as two half barrels around the beam-pipe (r = 29 mm)
- Light weight support structure (200 µm thick carbon fiber)
- C_4F_{10} evaporative cooling system (1.35 kW power dissipation)
- 120 half-staves, 1200 pixel chips, 9.8 10^6 channels





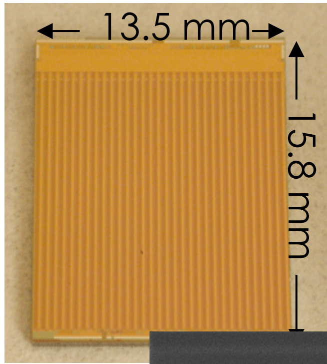
The ALICE SPD

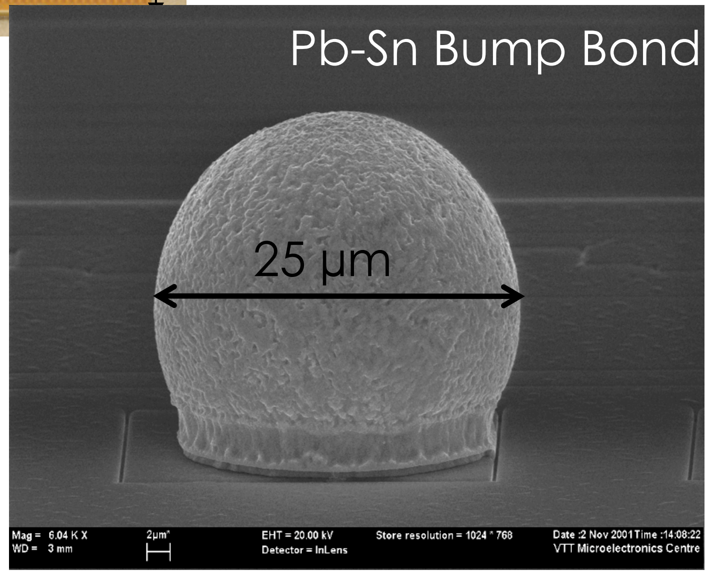


Minimum distance 'beampipe - inner layer': 5 mm

The ALICE SPD

- ALICE1LHCb readout chip
  - Mixed signals, 0.25 µm CMOS, 8192 cells
  - Unique L0 trigger capability *(see talk by Gianluca Aglieri)*
  - Thinned to 150 µm
- Sensor:
  - P-in-n, 70.7 mm x 16.8 mm
  - 200 µm thick
- Flip chip bonding
  - Pb-Sn solder bump bonding
  - 5 readout chips connected to one sensor
  - Reworking process developed: yield 84%
  - Bump yield requirement: >99% (77% ladder yield)
- Material budget 1.14 % X_0 per layer including service connections (multi-layer bus)





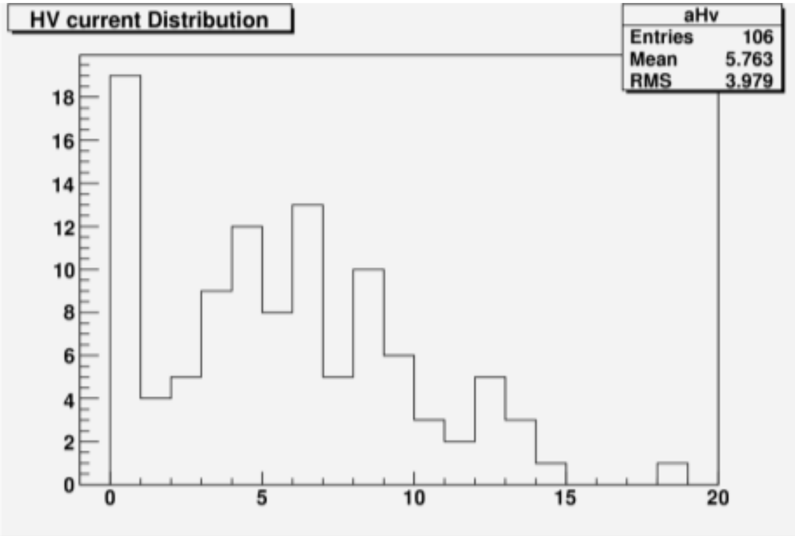
SPD Installation and Commissioning

- The ALICE SPD was pre-commissioned in a clean-room at CERN using the final components for:
  - Readout, DAQ, cooling plant, DCS system, cables, …
- The SPD was installed in the ALICE experiment in June 2007

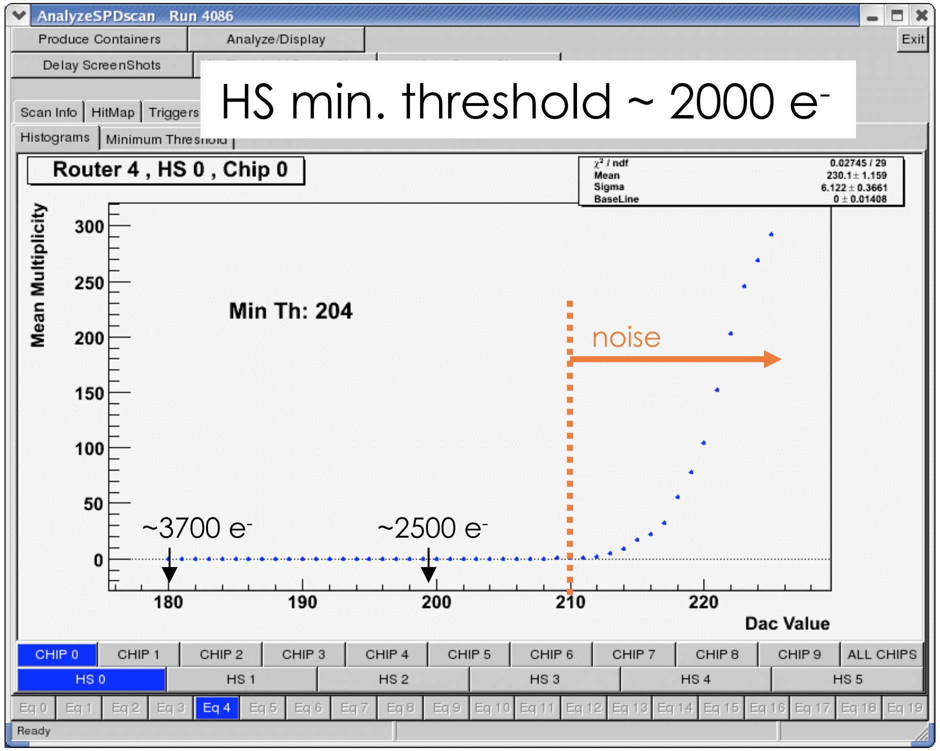
- Standalone calibration (started on fraction of half-staves in 12/2007)

SPD Standalone Tests

- Carried out outside experimental data taking periods
- Examples: Threshold scans, matrix uniformity response, check of noisy and dead pixels, leakage current measurements, temperature checks, …

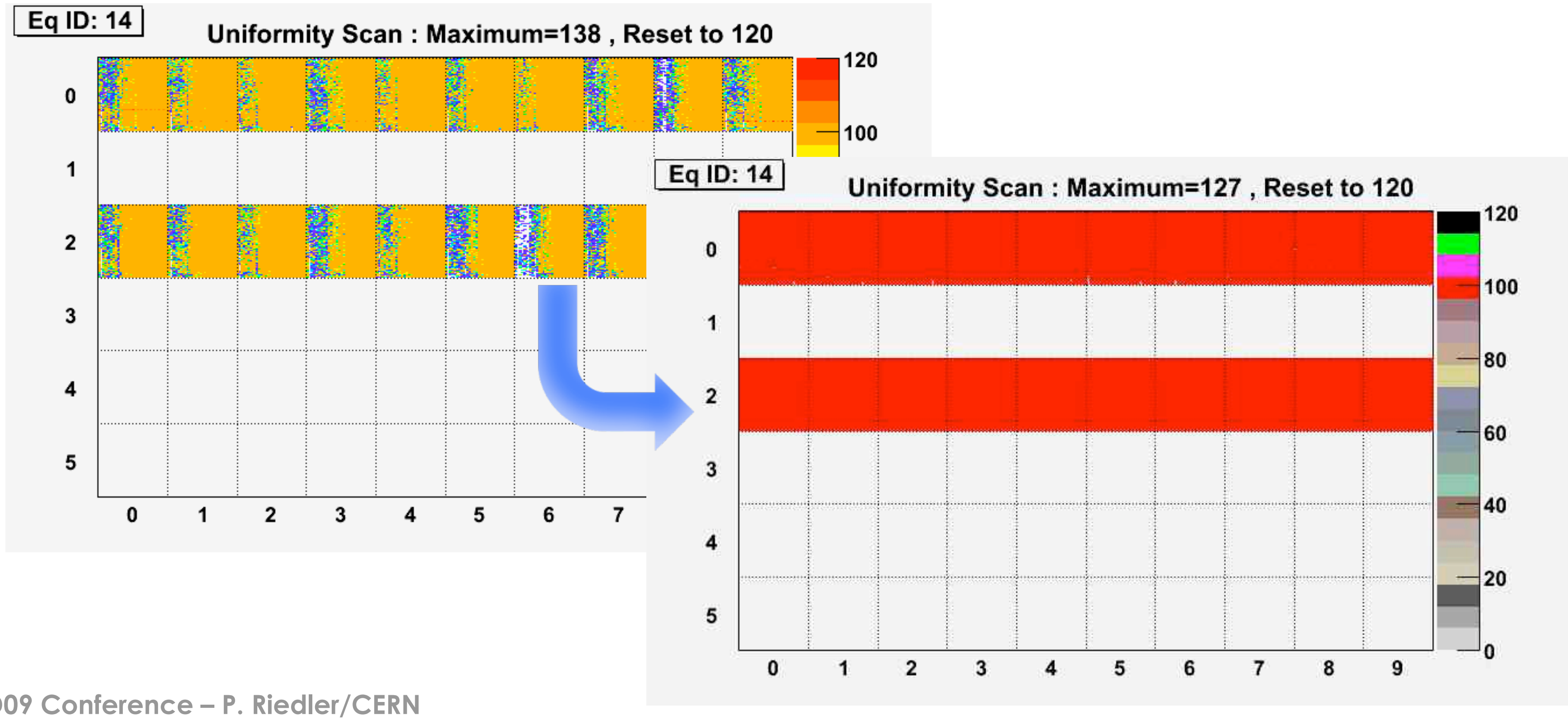


Average leakage current (50V): 5.8 μA (23.8 cm² sensor)



SPD Standalone Tests

- Each chip contains 42 8-bit DACs (1200 chips in total)
- Correct setting of all DACs verified, e.g. matrix uniformity using internal test pulse



Cosmic Runs

- 1st Cosmic Run – Dec. 2007
  - First acquisition tests on a fraction of modules (ongoing installation work on all sub-detectors)
- 2nd Cosmic Run – Feb./Mar. 2008
  - Both sides of the SPD connected, connection commissioning ongoing
  - Calibration tests + first cosmic muons seen in ITS
- 3rd Cosmic Run – Jun./Oct. '08
  - Cosmic runs with Pixel trigger
  - First alignment of the ITS modules + test TPC/ITS track matching
- 4th Cosmic Run (started mid August 2009)

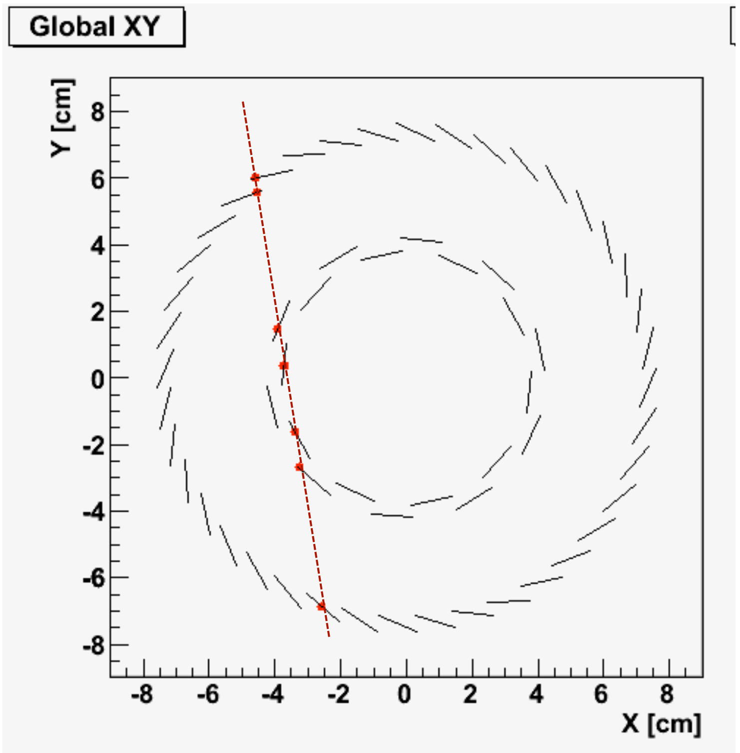
SPD in Cosmic Runs

- 106/120 half-staves - 8.6 M pixels
- Threshold setting: 200 DAC (~2800 e-)
- Missing pixels/half-stave: <0.15%
  - 6488 dead pixels
  - 4096 missing pixels due to wire bonding damage
  - 806 masked noisy pixel
- Detector readout time: ≈ 320 μs
- Detector dead time:
  - 0% up to ≈ 3kHz (multi-event buffering)
  - ≈ 320 μs at 40 MHz trigger rate

SPD in Cosmic Runs

- In 2008 ~10^5 good events collected for alignment using the L0 pixel trigger
  - Event selection: one hit in the outer layer of the top half-barrel in coincidence with one hit in the outer layer of the bottom half-barrel
  - Trigger rate (~0.18 Hz) compatible with simulation and previous measurements taken in L3
  - 65000 events ≥ 3 clusters in SPD
  - 35000 events ≥ 4 clusters in SPD

Online Display



SPD in Cosmic Run

Alignment:

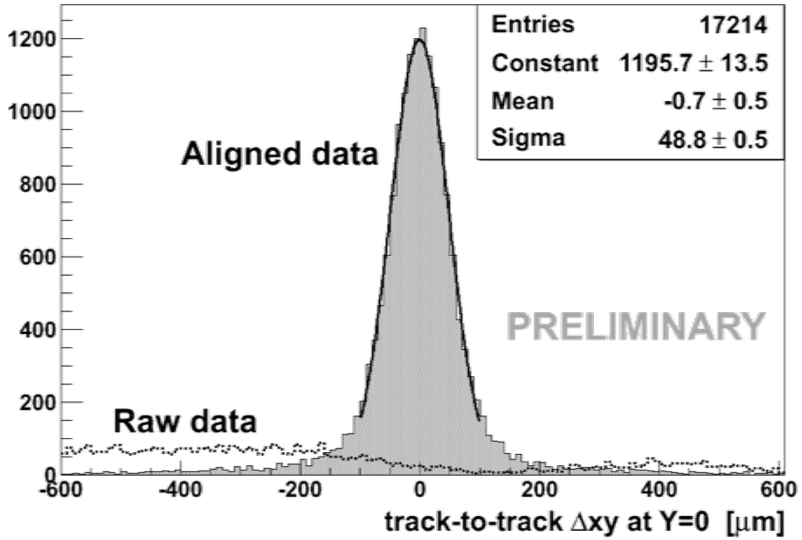
- Two track-based methods to extract the alignment parameters (translations and rotations) of the SPD modules:
  - Global minimization with Millepede (default method)
    - Full ITS alignment SPD+SDD+SSD
  - Iterative approach

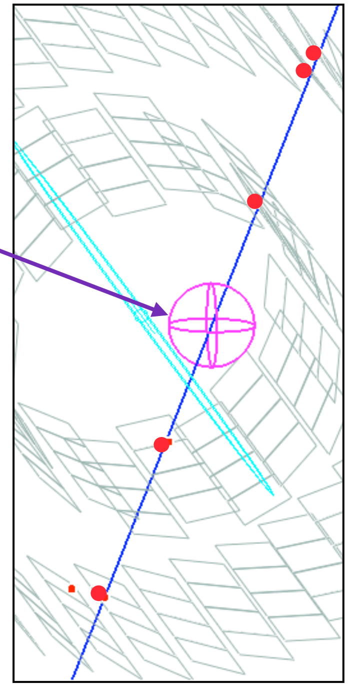
- SPD barrels – 10 sectors – 120 half-staves – 240 sensors

- ITS Standalone tracker adapted for cosmics
  - Pseudo-vertex = point of closest approach between two "tracklets" in top and bottom SPD half-barrels
  - Search for two back-to-back tracks starting from this vertex

SPD in Cosmic Runs

Track-to-track (top vs bottom) distance in transversal plane





SPD only, 2008 B=0 data
A.Dainese

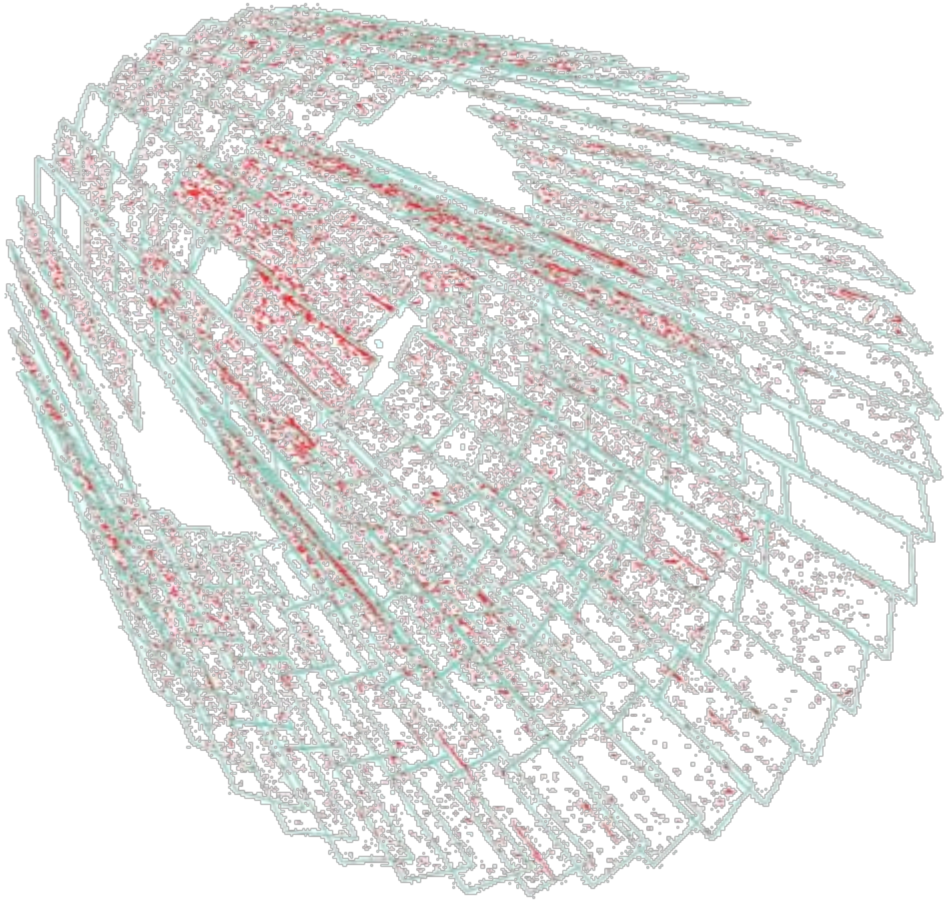
σ = 48 μm (vs. 40 μm in simulation with ideal alignment)

After realignment with cosmics using SPD triggered data and Millepede:

- Effective rφ resolution ~14 μm (nominal detector position resolution rφ 12 μm)

First Experience with LHC

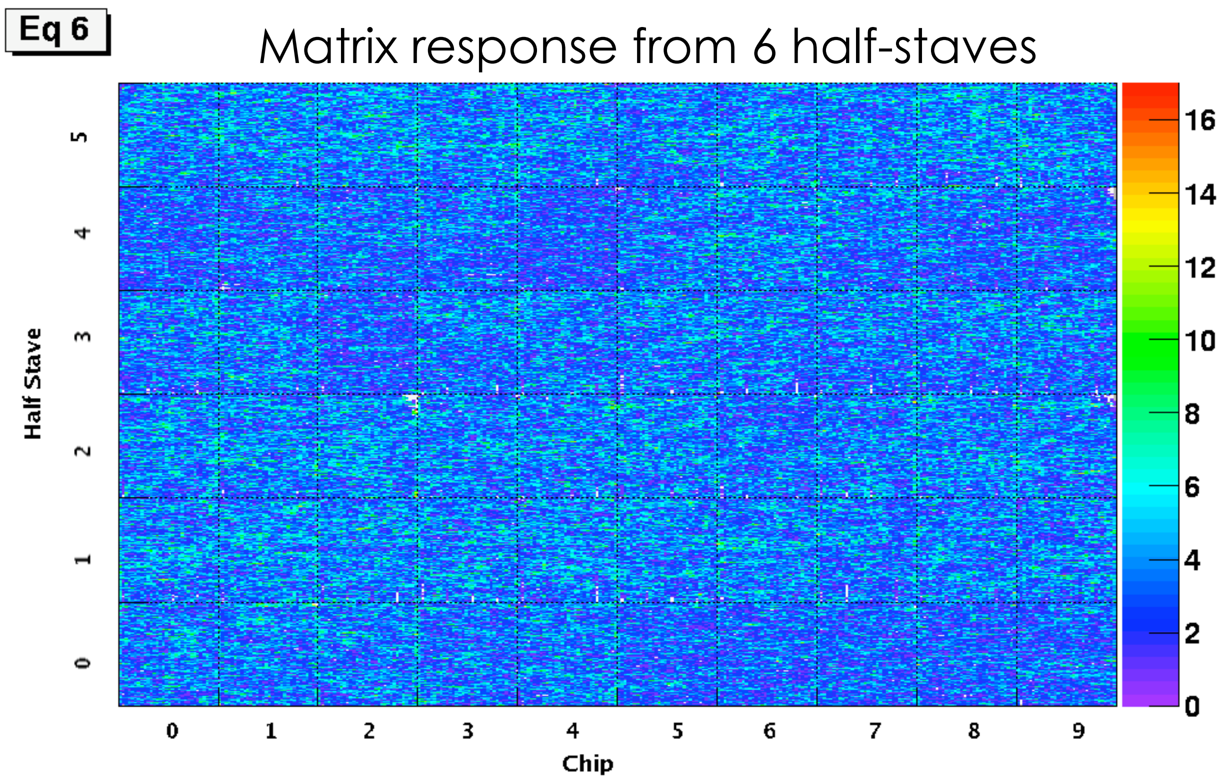
- **June 15, 2008:** during the beam injection test in TI2, the SPD layers in self-triggering mode detected the first "sign of life" of LHC
- Two further injection tests:
  - August 2008
  - July 2009
- SPD participated in all tests (and provided trigger signal)



Longitudinal tracks along one pixel module (~14 cm)

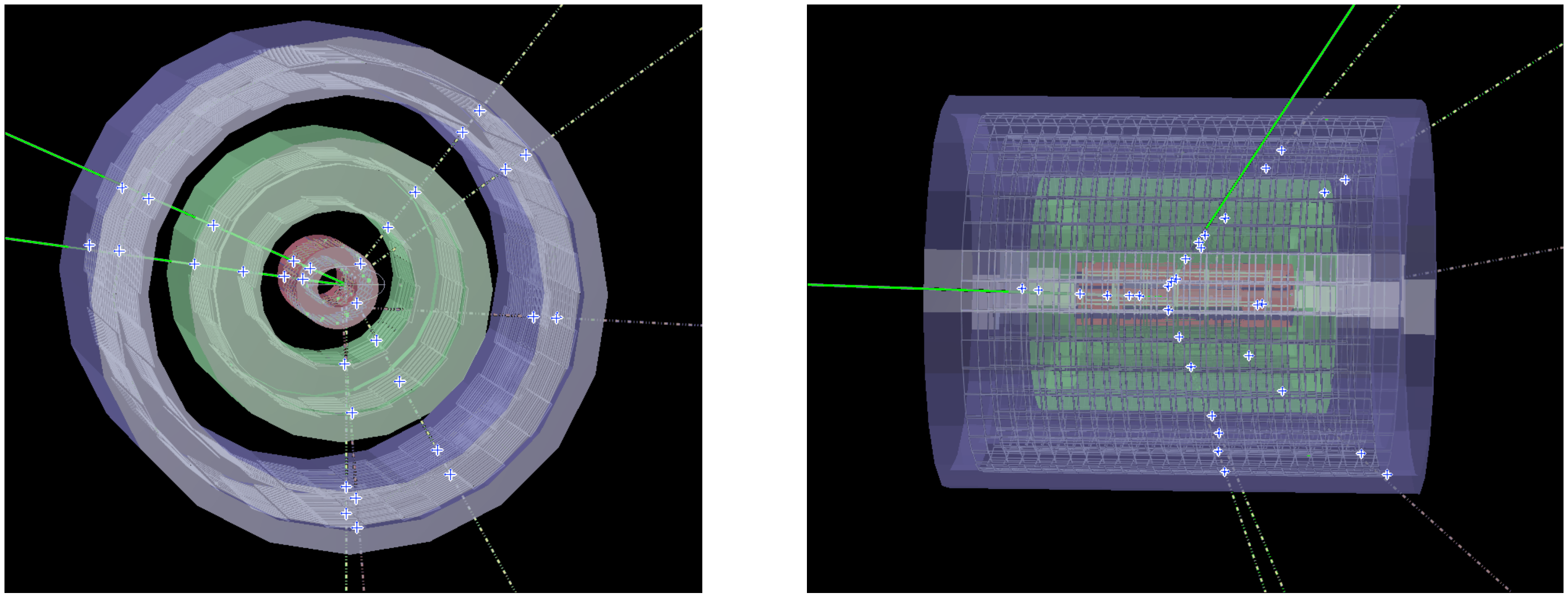
First Experience with LHC

- Accumulated injection tests and cosmic data used to cross-check uniformity response of pixel matrix



First Experience with LHC

- In Sept. 2008 the ITS was ready to record the first collisions in LHC
- First LHC beam-induced interaction was recorded by the ALICE ITS on 11 Sep '08 using the SPD trigger

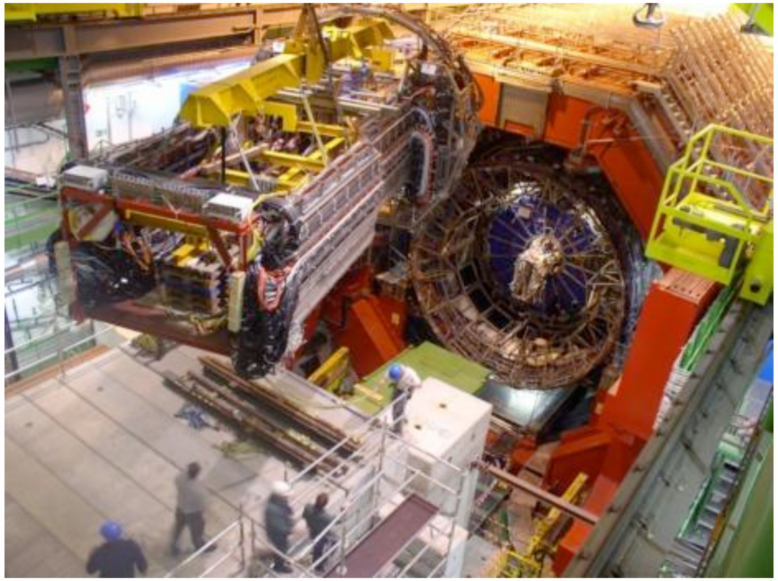


Collision of beam-halo particle with the first pixel layer: 7 reconstructed tracks from common vertex.

Status 2009

- Oct 2008: ALICE has opted for a long shutdown to complete the installation of outer detectors and re-arrange all services (power, optical and cooling) on Side A of the central detectors, including the SPD, to improve access to the TPC electronics.

- Detector operations were resumed after the reconnection of all services in July. Re-commissioning and optimization in progress.

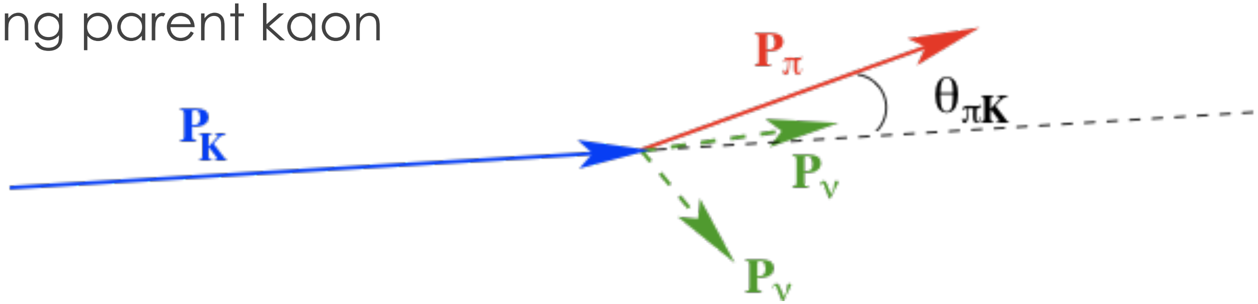


Lessons Learnt

- We have learnt to build a robust low mass detector which performs within expectations and mastered many technical challenges on the way
- Certain aspects have proven to be more challenging than expected, e.g. services in general (optical connections, power supplies, cooling, …)
- Future and upcoming projects which face similar challenges can profit from the experience
- Example presented in the next slides: the NA62 Gigatracker

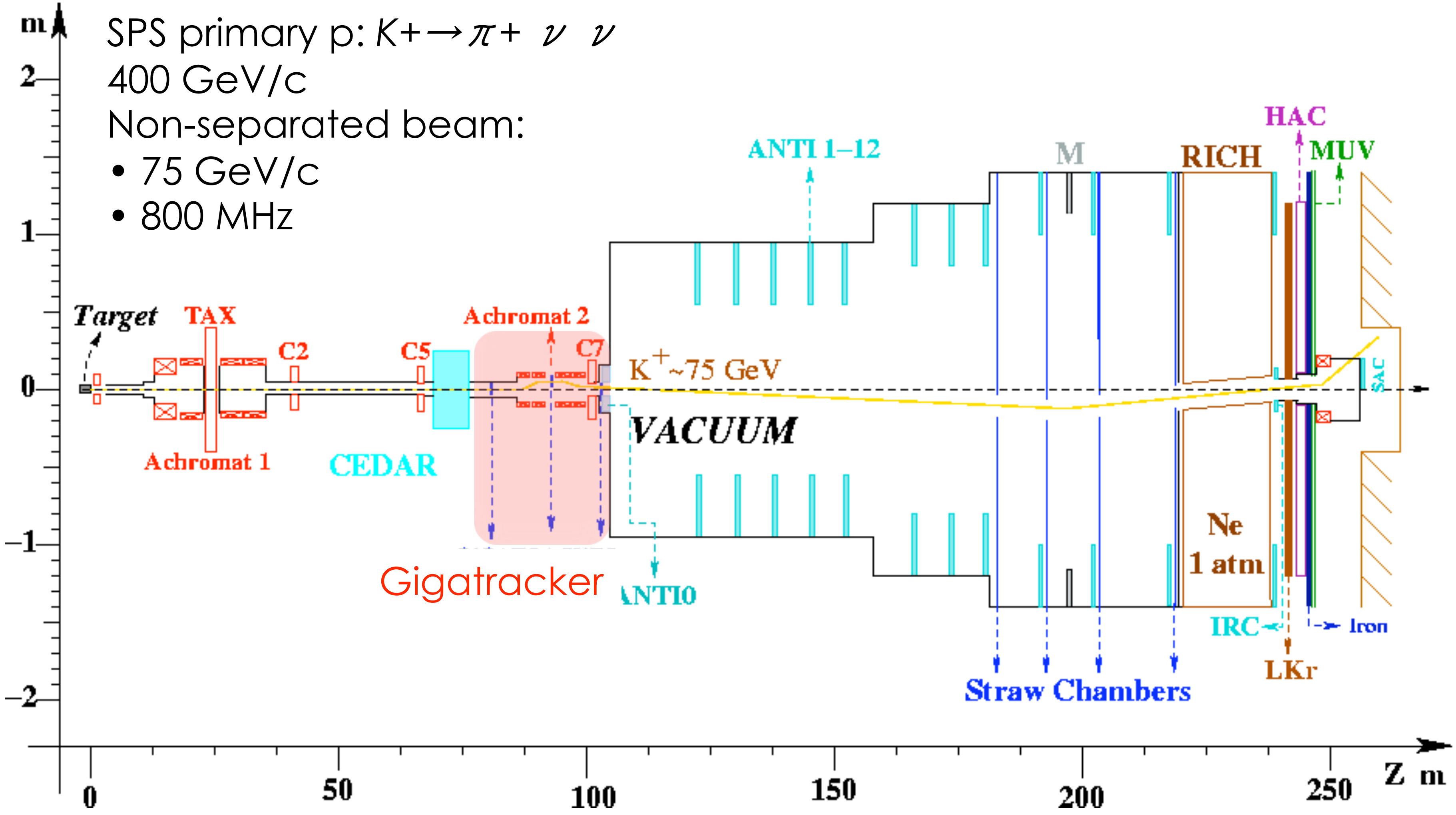
NA62 Experiment

- The NA62 Collaboration aims to measure O(100) $K^+ \rightarrow \pi^+ \nu\nu$ events with ~10% background at the CERN SPS in two years of data taking
- The $K^+ \rightarrow \pi^+ \nu\nu$ decays represent a theoretically clean environment sensitive to new physics
- π /K/p (~6% K+)
- Precise momentum and direction measurement of kaon and pion is of key importance
- Precise timing measurement to associate the outgoing pion to the correct incoming parent kaon



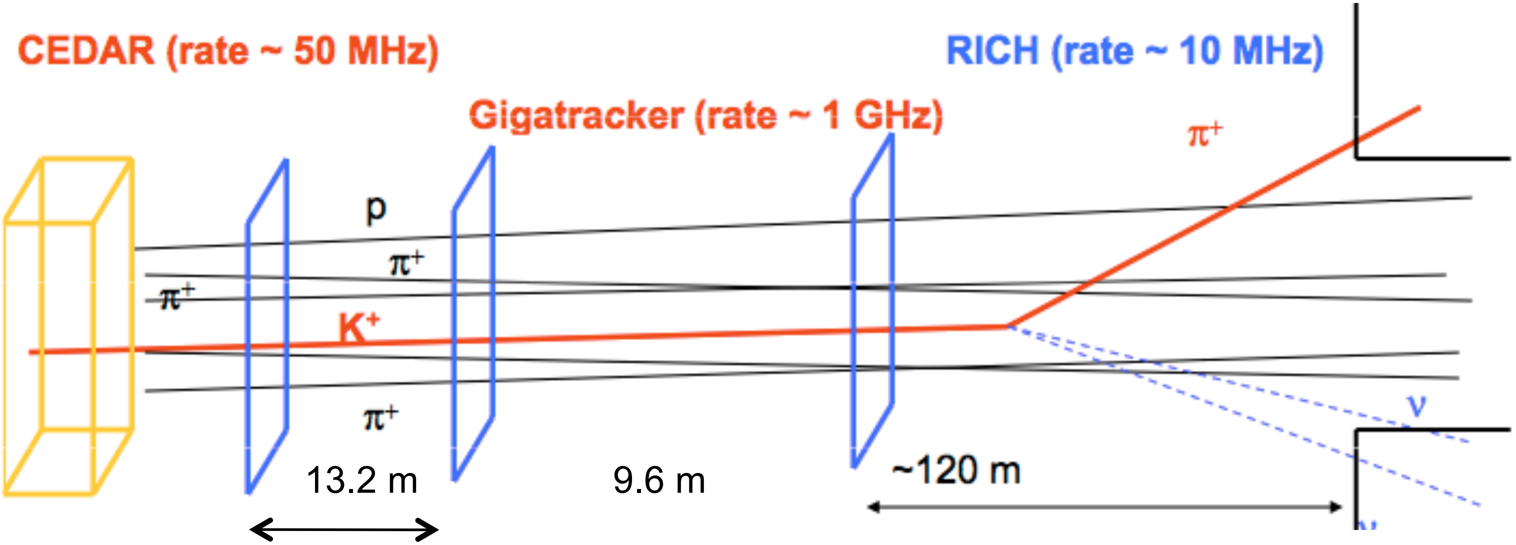
NA62 Detector Layout

SPS primary p: $K+ \rightarrow \pi+ \ \nu \ \nu$
400 GeV/c
Non-separated beam:
- 75 GeV/c
- 800 MHz



Gigatracker

- Beam spectrometer made of 3 stations of hybrid silicon pixel detectors



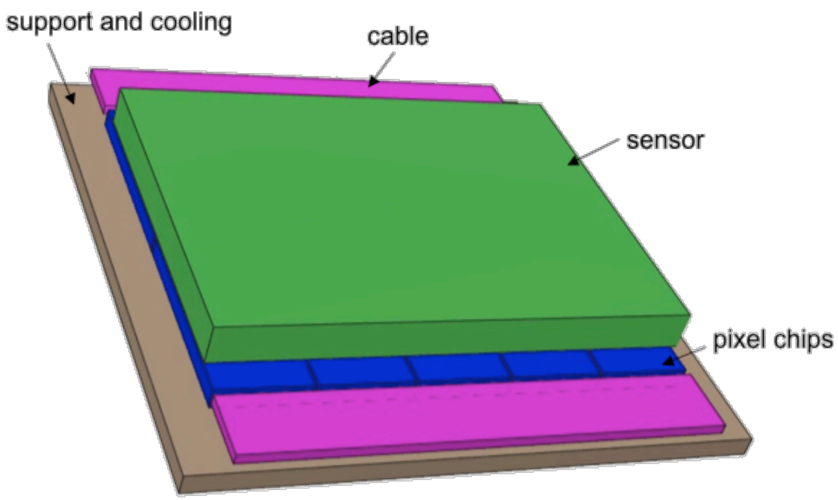
Schematic view – not to scale

Gigatracker Requirements

- Precise momentum and angular track resolution: $\sigma(p)/p$~0.2%, σ_θ ~14 µrad: pixel size: 300 µm x 300 µm
- Precise timing information: $\sigma(t)$~ 150 ps rms on single track
- Material budget per station: 0.5% X_0 to preserve beam divergence for precise downstream measurement and to limit beam hadronic interactions
- Sustain high and non-uniform rate (~1.5 MHz/mm^2 in hot center, ~0.8-1.0 GHz total)
- High fluence levels: ~2 10^{14} n_{eq} cm^{-2} in 100 days (~1 year)
- Operation in beam vacuum to reduce multiple scattering
- Estimated power dissipation per readout chip ~ 2W/cm^2

Gigatracker Layout

- Fixed target configuration: access to each station along the beamline
- One large sensor connected to 2 rows of 5 readout chips via flip chip bonding
- Low mass support structure (carbon fibre)
- Various low mass cooling options under study:
  - Cooling via nitrogen flow to collect power dissipated on the surface
  - Cooling integrated in support, heatsink made of high thermal conducting carbon fiber
  - Micro-channel cooling system



Material Budget

- Material budget is one of the key elements for the success of the Gigatracker

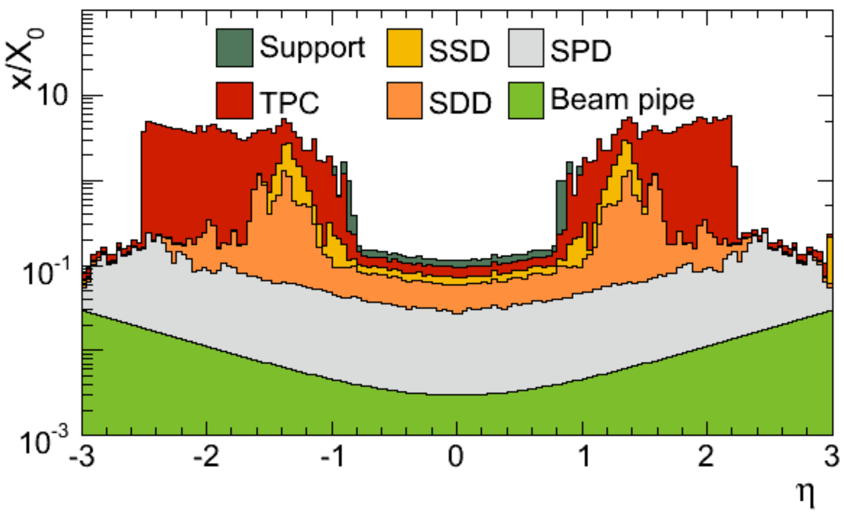
1.14 % X_0 per layer

0.5 % X_0 per station

- The SPD is the lowest mass pixel detector of all LHC experiments
- Target material budget for the Gigatracker is ~ half of what is used in the SPD
- Layout differences: SPD – collider layout, GTK – fixed target layout

Material Budget

- Which components will contribute to the material budget:
  - Sensor
  - Readout chip
  - Support
  - Cooling
  - Connections (cables, wires, etc.)
  - Glue, grease, …



- Each component needs to be optimized to reach the target material budget without compromising the performance

Material Budget

ALICE

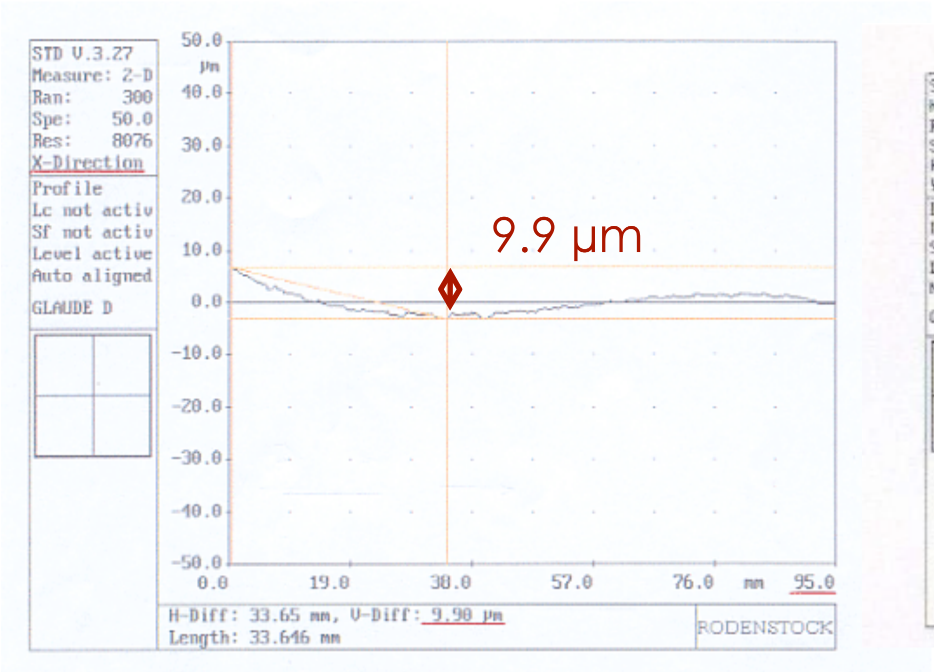
- Sensor $0.21\%\ X_0$
  - thickness: 200 µm
  - Surface: 11.9 cm^2
  - Bow has to be controlled to ensure high bump bonding yield
- Readout chip $0.16\%\ X_0$
  - Thickness: 150 µm
  - Large chip: 13.5 mm x 15.8 mm
  - Thinning process optimized to reduce damage induced stress, losses in processing and to optimize chip flatness

NA62

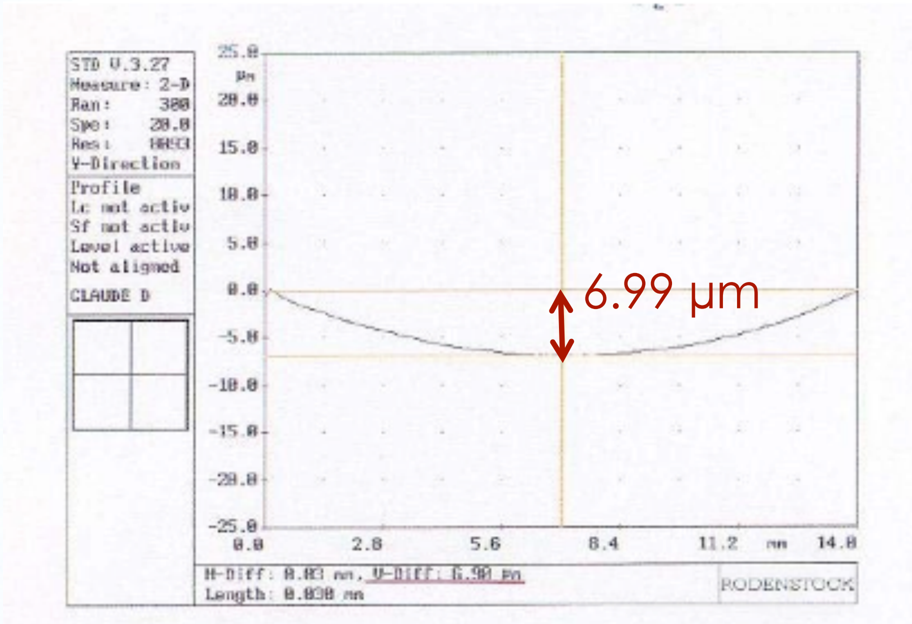
- Sensor
  - Target thickness: 200 µm (signal for timing information!)
  - Surface: 16.2 cm^2
  - One large sensor to use simpler support, avoid dead regions and overlap
- Readout chip $0.11\%\ X_0$
  - Target thickness: <100 µm
  - Large chip: ~19 mm x 12 mm
  - Thinning process needs to be developed and optimized

Material Budget

- Examples from ALICE



Measurement of the sensor flatness along the long side, measured across the center

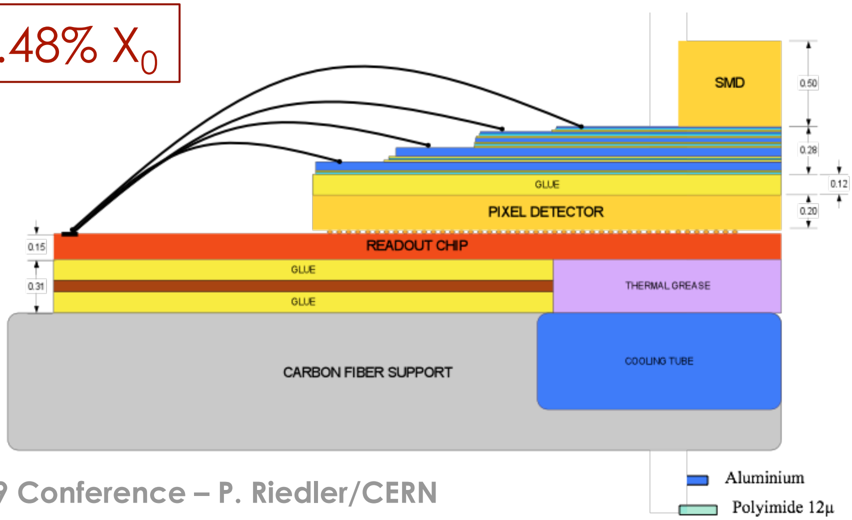


Measurement of the readout chip flatness measured across the center

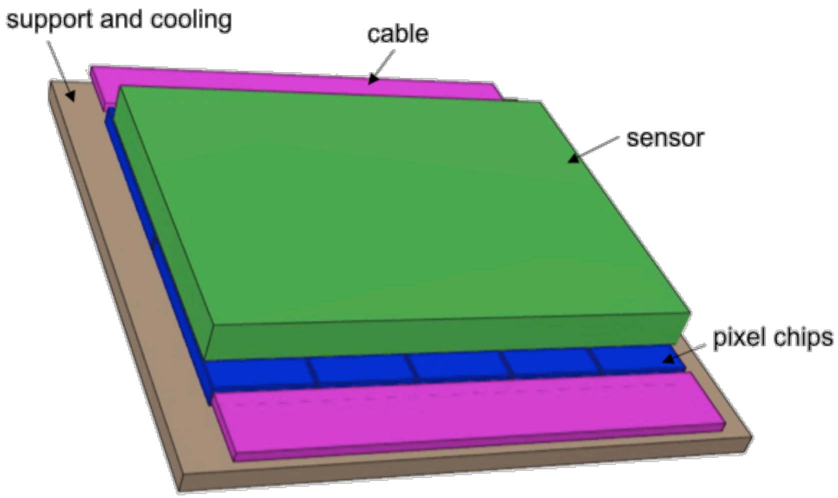
Material Budget

- Connections (cables, etc.)
  - One high density flat cable to connect each pixel chip with the on detector electronics
  - Total thickness: 280 μm
  - Special development using Al and Kapton (several years)

0.48% X_0



- Connections (cables, etc.)
  - Fixed target arrangement allows to place connections outside beam area
  - Caution not to add too much material that can interfere with the beam halo



Conclusion

- The ALICE SPD was successfully commissioned and ready for first beam in 2008
- The SPD participated in several experimental cosmic runs and provided a trigger signal for he L0 trigger decision. Alignment studies using these data have shown to be in good agreement with the simulation
- A long shutdown for re-arrangement of all services allowed to start re-commissioning of the detector in July 2009
- A good experience of building a low mass pixel detector has been gained and new projects, such as the Gigatracker for NA62 can profit from this experience
- The Gigatracker represents a novel pixel detector with very challenging requirements. The R&D activities have already started and first prototypes of readout chips are currently under test