The ALICE Silicon Pixel Detector: Commissioning and Optimization of the Detector Performance

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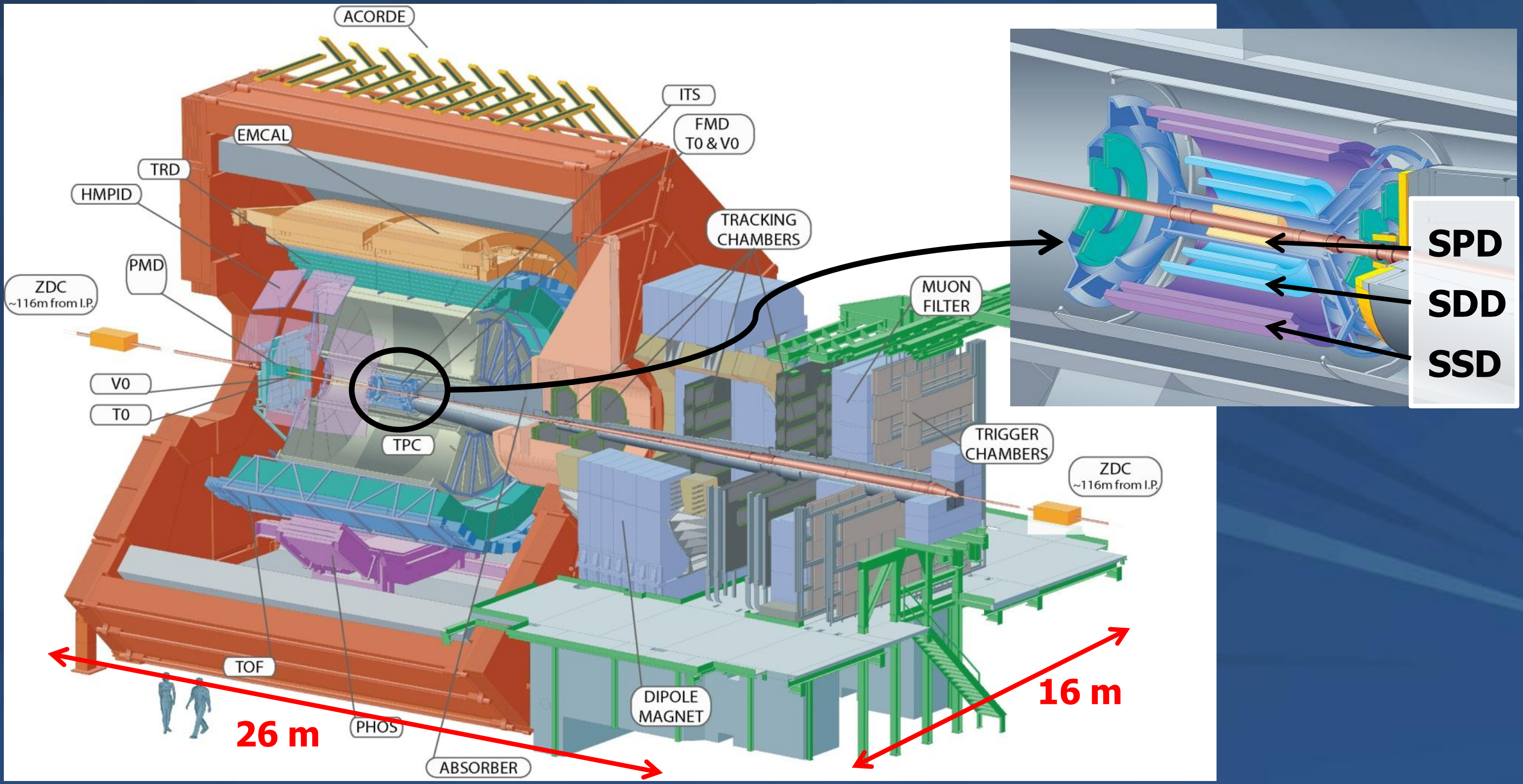
CERN – European Organization for Nuclear Research
on behalf of the SPD project in the ALICE Experiment

ALICE Inner Tracking System

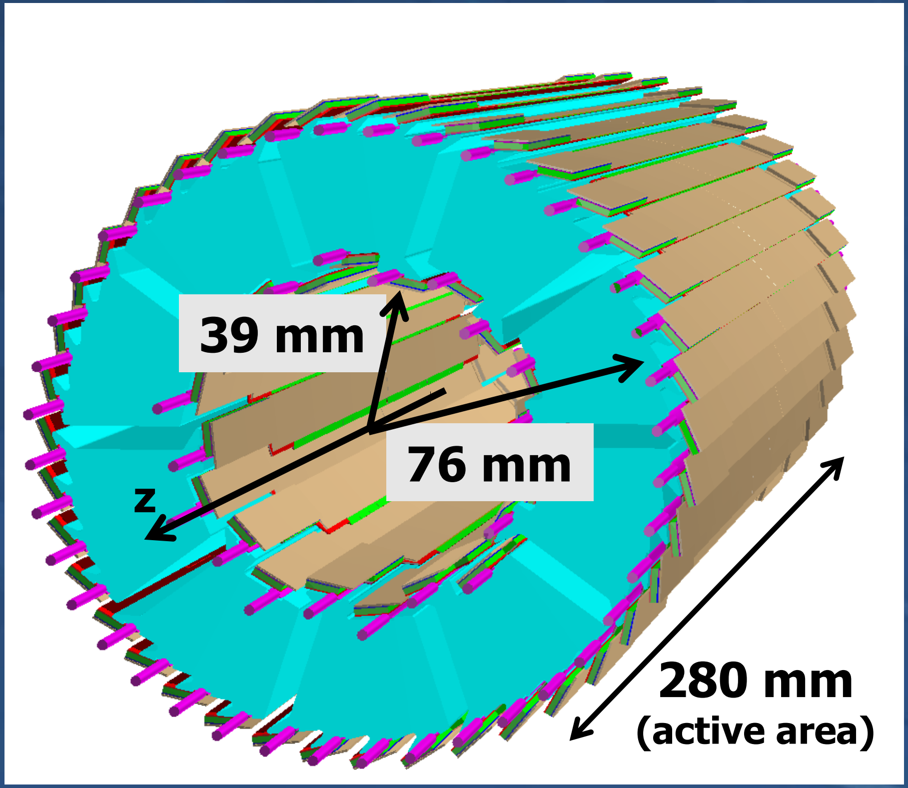
- experiment designed for heavy ion collisions (Pb-Pb @ 2.75+2.75 TeV per nucleon)
- 3 different silicon detector technologies in 6 barrel layers
- Pixels (SPD), Drift (SDD), double sided Strips (SSD)



ALICE Silicon Pixel Detector

REQUIREMENTS

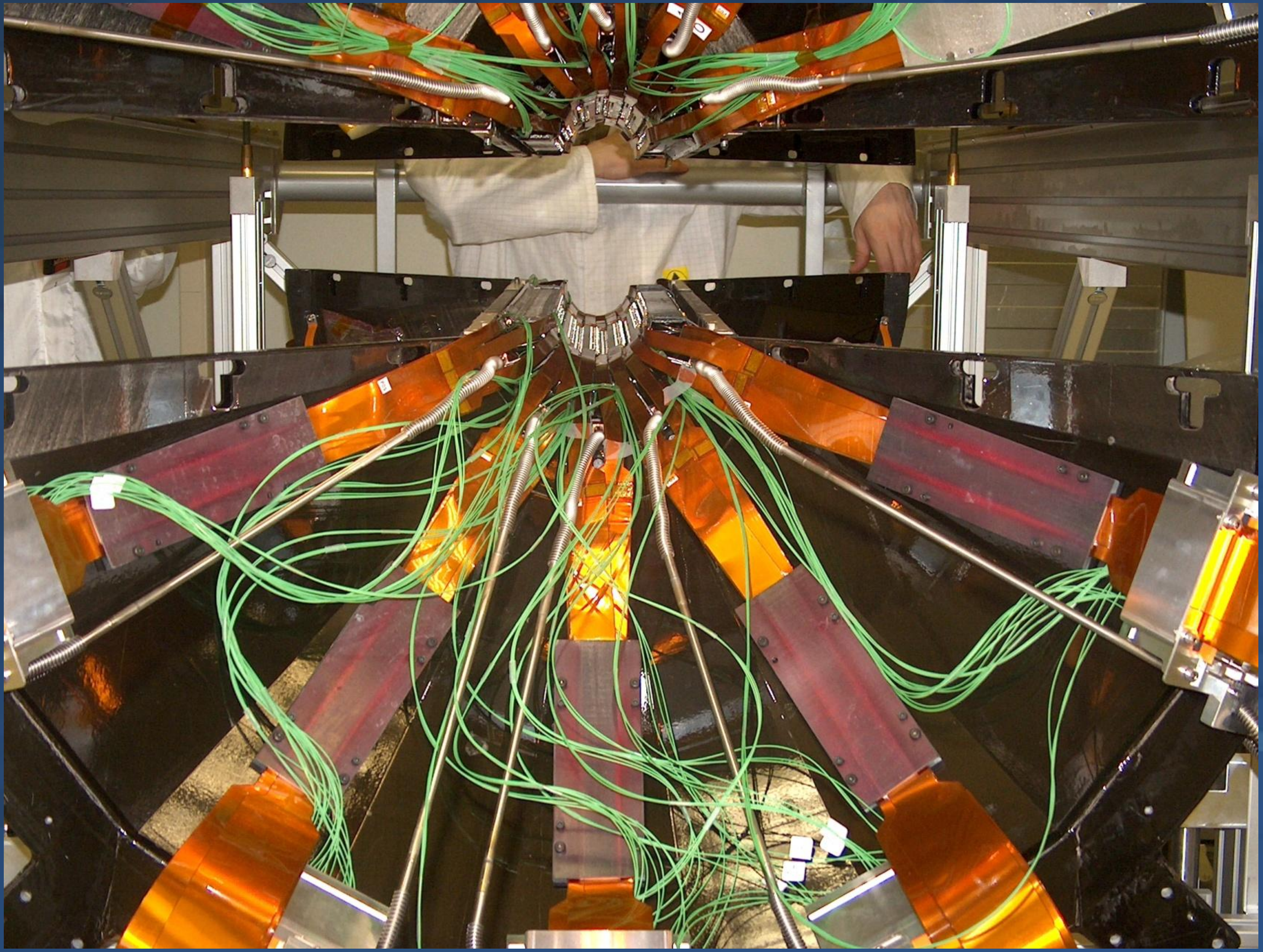
- fast matrix readout (256 μs)
- high detection efficiency (> 99%)
- high spatial precision (~12 μm in the bending plane)
- stringent material budget (~1.1% X_0 per layer)
- prompt signal for L0 trigger



CHARACTERISTICS

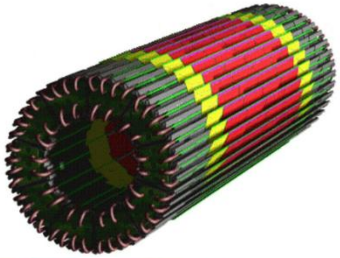
- 2 innermost layers, 0.24 m^2
- ~ 9.8 M readout channels
- pixel size 425 x 50 μm^2 (z x rφ)
- readout chip 0.25 μm CMOS technology
- power consumption ~ 1.35 kW

ALICE Silicon Pixel Detector



ALICE Silicon Pixel Detector

Total SPD components



SPD → 10 sectors | 10 sectors

Sector → 12 half-staves | 120 half-staves

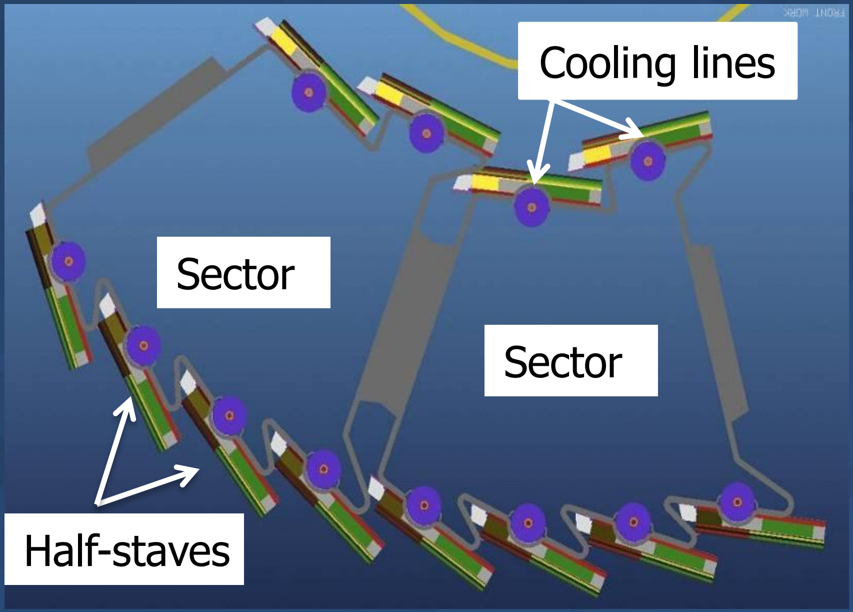
Half-stave → 1 multilayer bus | 120 multilayer buses
→ 1 MCM | 120 MCM
→ 2 ladders | 240 ladders

Ladder → 1 sensor | 240 sensors
→ 5 readout chips | 1200 readout chips

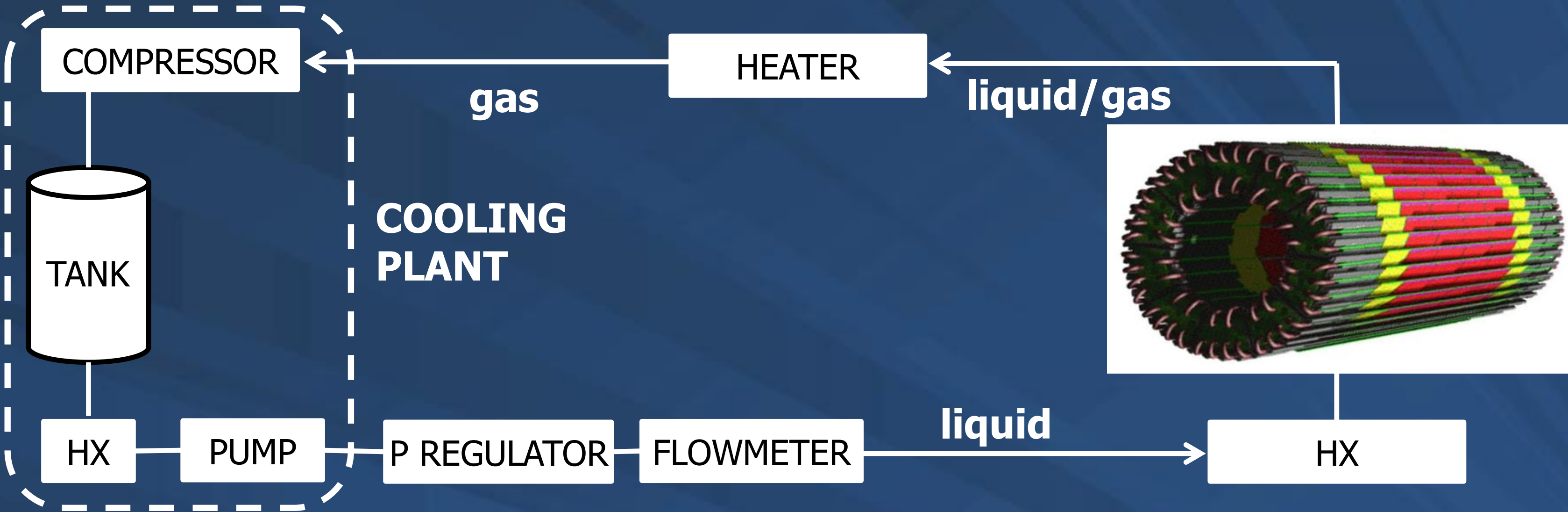
Readout chip → 8192 pixels | ~ 9.8×10^6 pixels

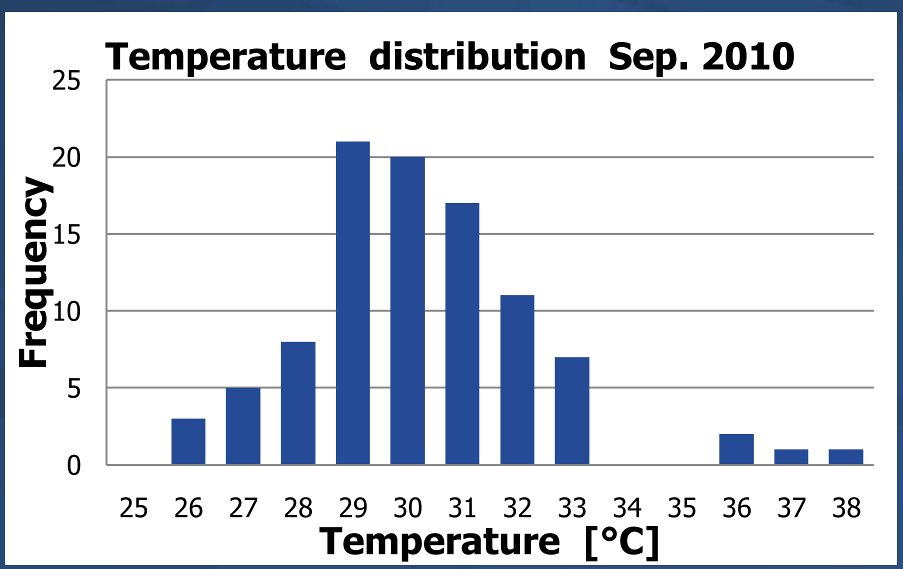
SPD cooling system

- without cooling the SPD temperature would increase ~1°C/s
- evaporative system with C_4F_{10} (dielectric, chemically stable, non toxic)
- capillaries under each half-stave, embedded in the carbon fiber support
- monitoring of T-p at the plant and up/downstream the detector
- control of liquid pressure per line (equivalent to flow)



SPD cooling system



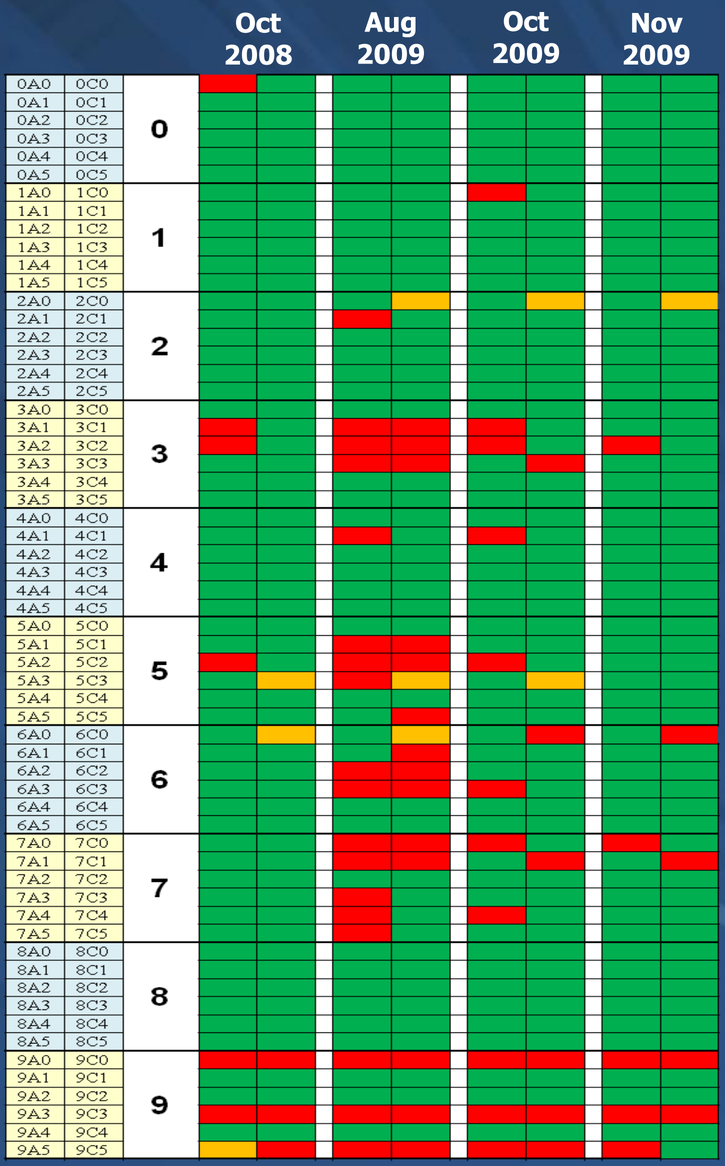


Improvements observed after the tuning of the cooling system

Avg. operating temperature: 29.8 °C

SPD cooling system

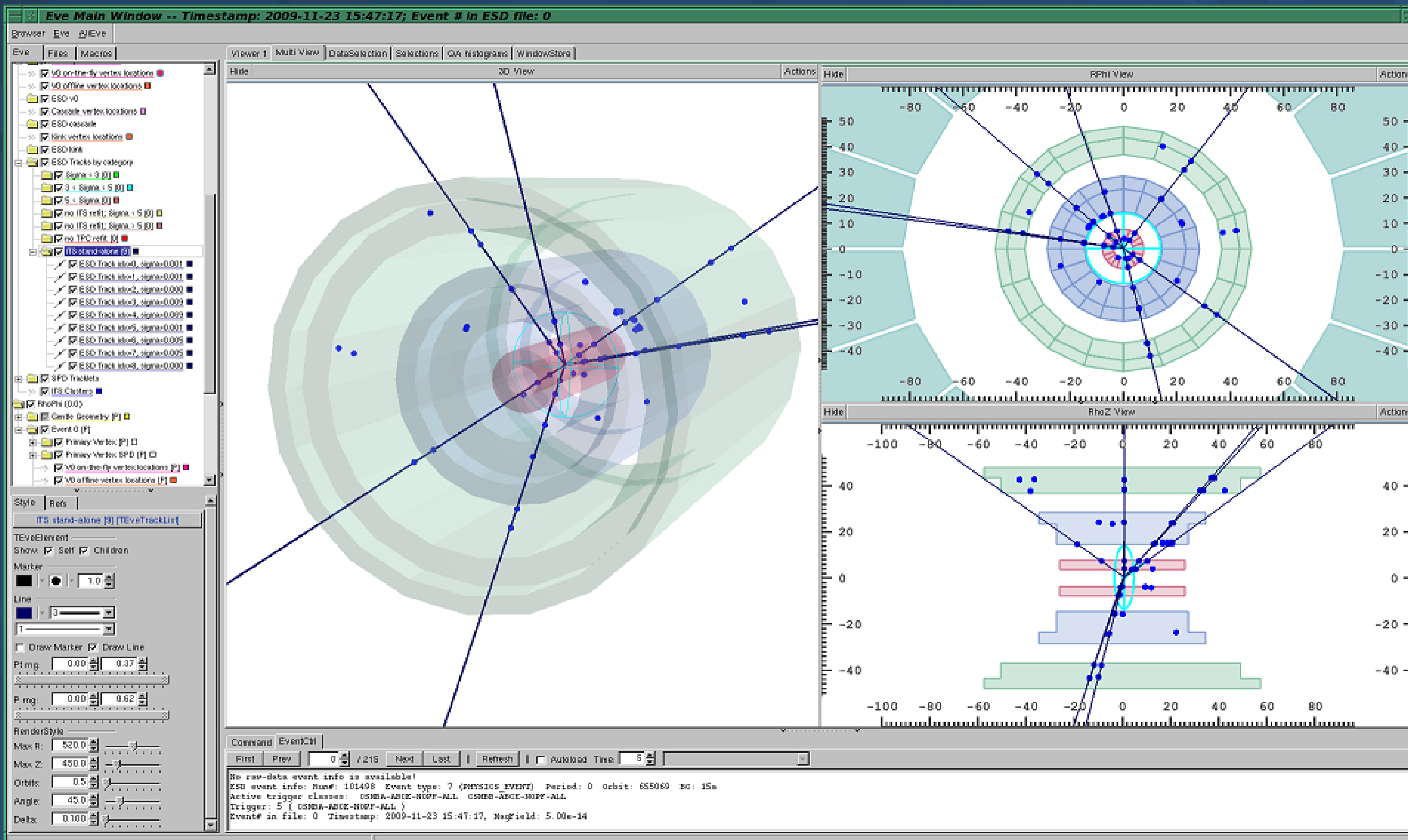
- commissioning started in 2007
- Aug 2009: after long shut-down
  - 85 HS ON (~71%)
  - actions taken:
    - counter-flow-wise cleaning
    - new input lines
    - more T/p monitors on all lines
    - flow gauges
    - per-line liquid pressure control
- Oct 2009:
  - 101 HS ON (~88%)
  - actions taken:
    - installation of subcooling
- Nov 2009:
  - 110 HS ON (~91.7%)
  - to keep the stability ~100 HS from then on



SPD cooling system

… BUT … SPD is performing really well

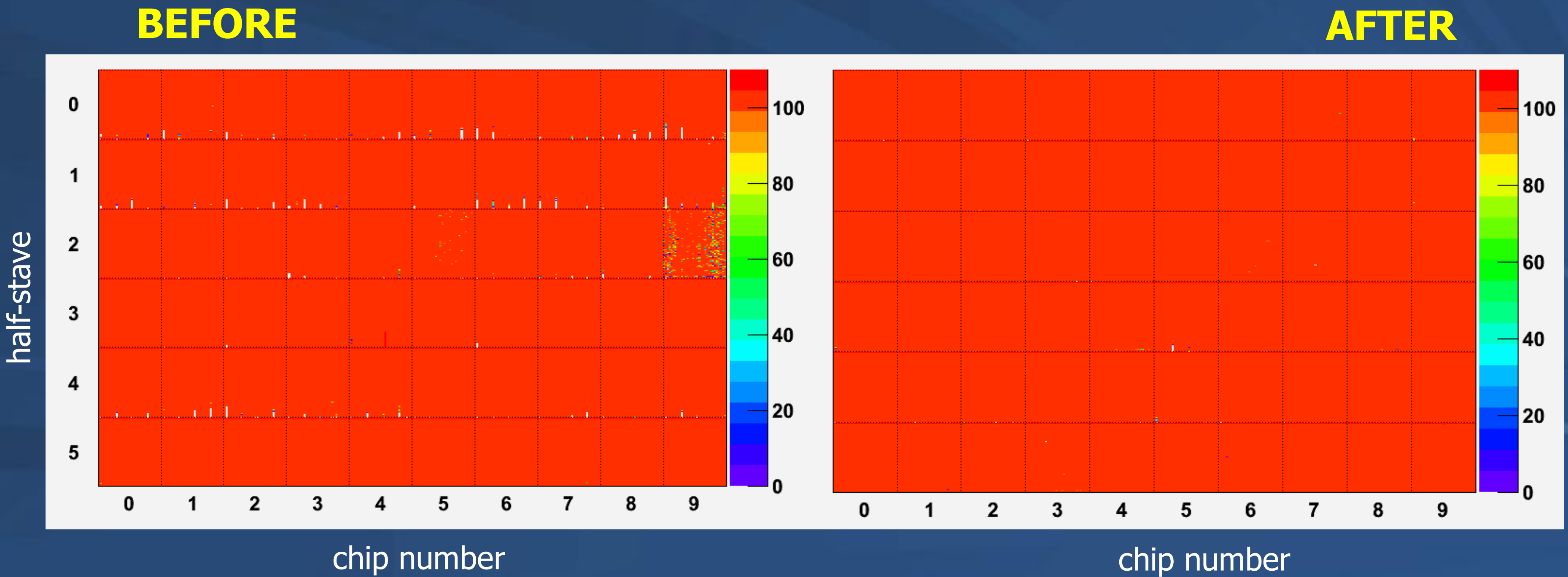
First event @ 900 GeV



Uniformity of chip matrix

- checked noisy/inefficient regions with internal pulser of known amplitude
- injection tests and cosmic data accumulated for cross checking
- noisy pixels: < 0.01 % (masked)

maps obtained with internal pulser
half sector 1 side C

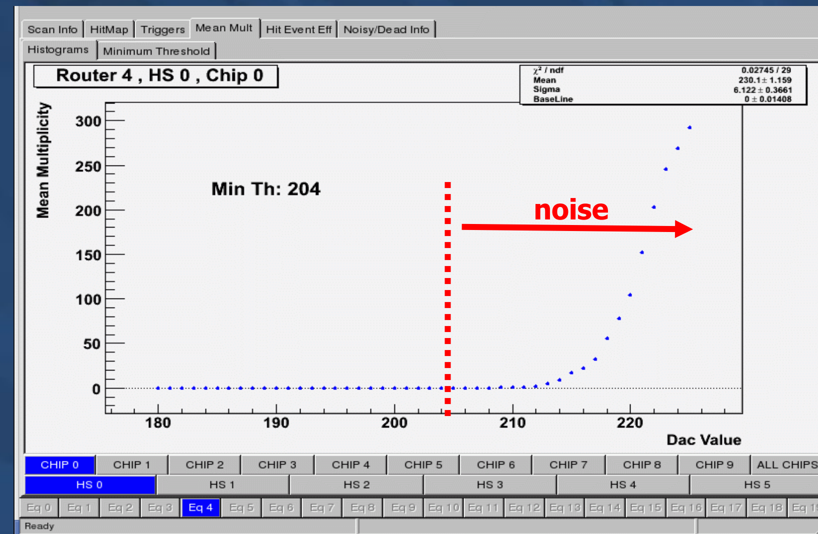


Threshold optimization

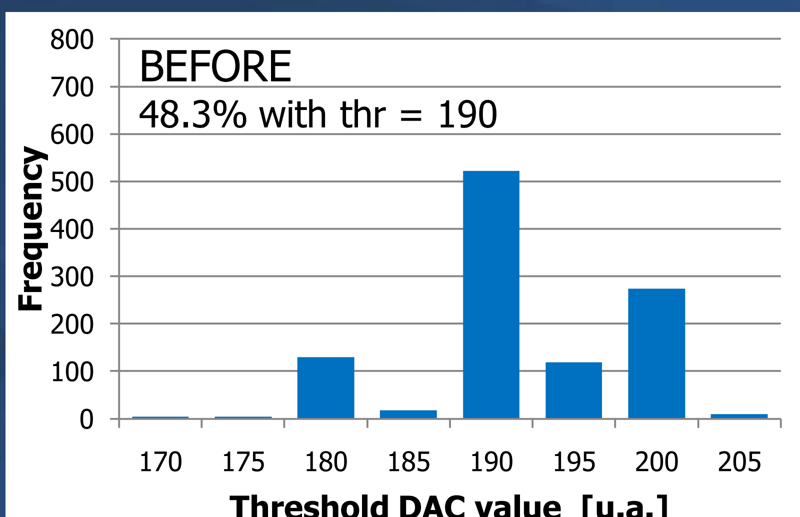
<u>Minimum threshold scan</u>

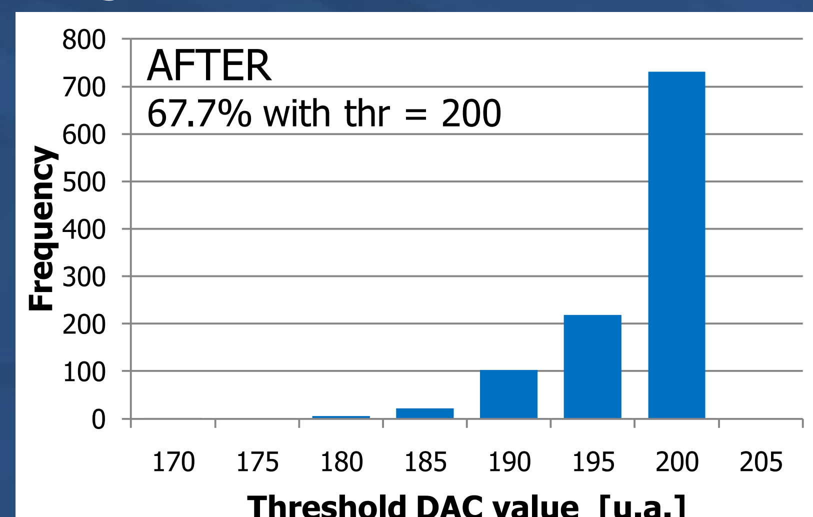
finds the lowest threshold value at which the chip can be operated without noise

- scans trough threshold values
- finds the closest to the noise area
- applies a safety margin (5 steps)



Distribution of threshold settings in the SPD

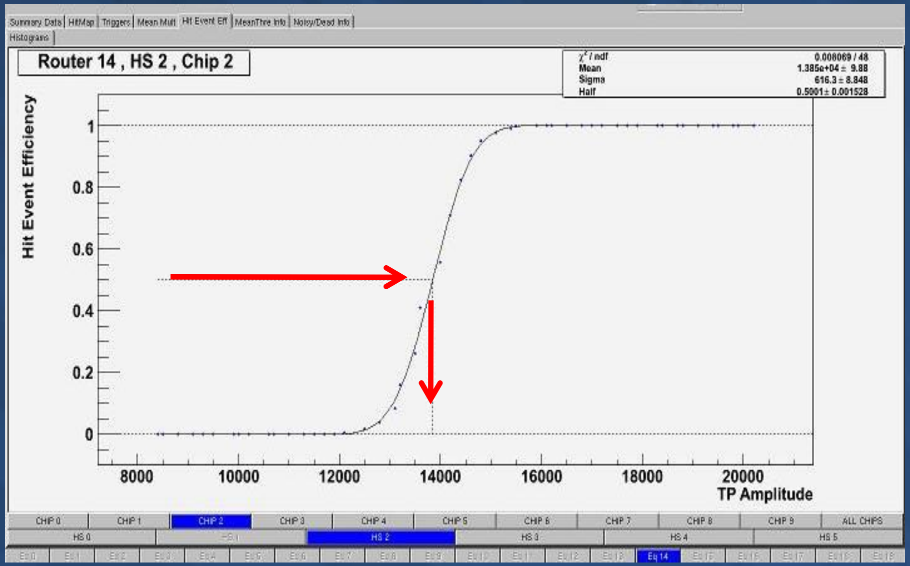




Threshold optimization

<u>Mean threshold scan</u>

- scans through different amplitudes of internal pulser
- determines an S-curve per pixel
- calculates the mean value and sigma per chip



200	195	190	185	180	preVth
551	233	122	28	11	# of chips
30.0	33.0	35.2	37.4	41.3	mean
1.7	1.9	1.9	2.1	1.9	sigma

Threshold optimization

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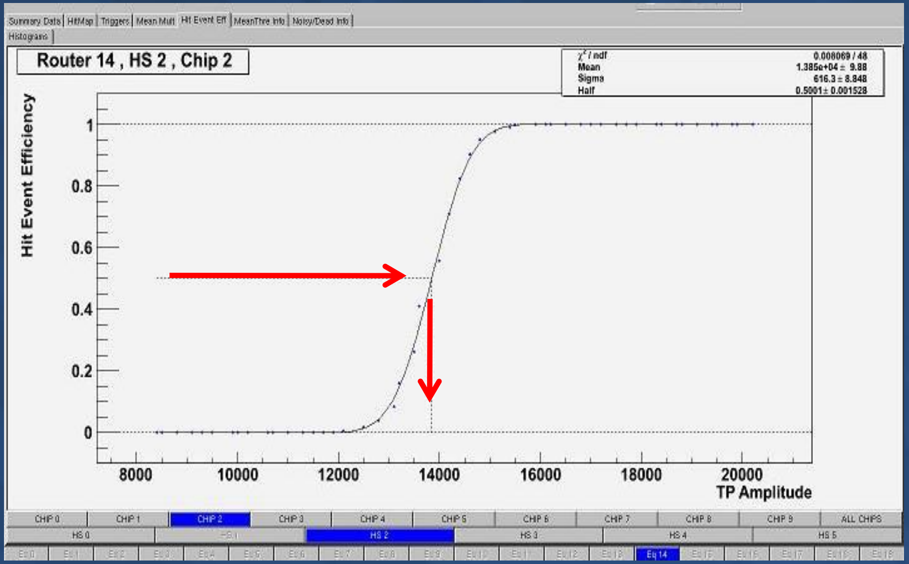
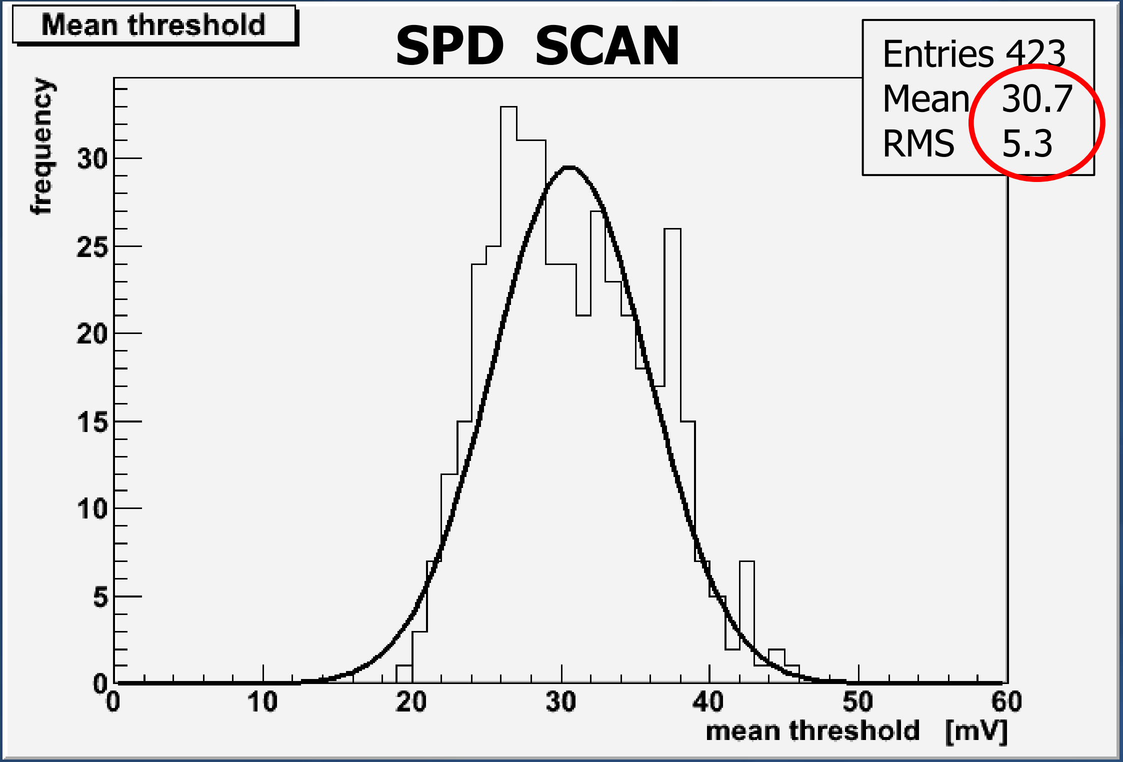


200	195	190	185	180	preVth
551	233	122	28	11	# of chips
1980	2190	2320	2470	2730	mean in electrons
110	120	120	140	120	sigma in electrons

Preliminary conversion: conversion factor of 66 e^-/mV found from tests in the lab

Threshold optimization



SPD scan:

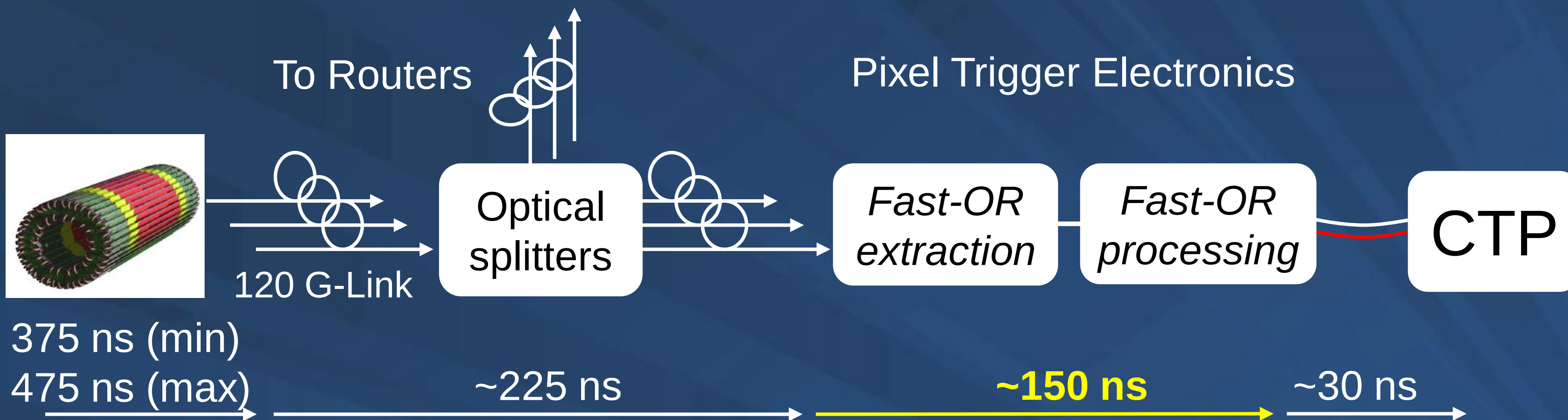
selected only chips with
- threshold = 200 DAC
- preamp = 160 DAC

LAB tests:
- 5 half-staves
- same conditions

LABORATORY:
- mean: 29.7 mV
- RMS: 3.6 mV

Good agreement between the two results

Fast-OR trigger signal



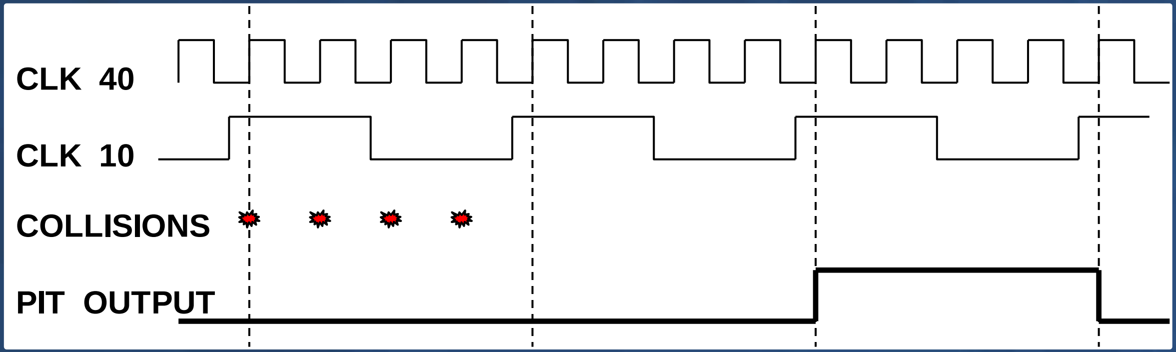
- contributes to the L0 trigger in ALICE
- Fast-OR active on registration of at least 1 hit per chip
- 10 chips/half-stave -> 1200 FO bits every 100 ns on the optical G-Link
- overall latency = 780 ns (min) – 880 ns (max)

- deserialization of data and Fast-OR bits extraction
- processing of the Fast-OR bits
  - up to 10 algorithms executed at the same time (processing time = 25 ns!)
  - minimum bias + multiplicity trigger for p-p collisions
  - centrality trigger for Pb-Pb collisions

Fast-OR efficiency

SPD clock (10 MHz) integrates 4 consecutive BCs

Evaluation of trigger efficiency for the single BCs before/after the SPD clock shift



IF (hit on 1 chip)
ANDIF (FO on same chip) → this chip is efficient

Data from 900 GeV and 7 TeV collisions

	Pos. 1	**Pos. 2**	**Pos. 3**	**Pos. 4**
before	99 %	99 %	99 %	80 %
after	99 %	99 %	99 %	97 %

Last BC position (Pos. 4) is the closest to SPD clock edge -> small jitters can cause inefficiency

Efficiency improved after the SPD clock shift

Fast-OR circuit calibration

Dedicated circuitry in each pixel cell

Required tuning of 5 DACs for every of the 1200 readout chips to

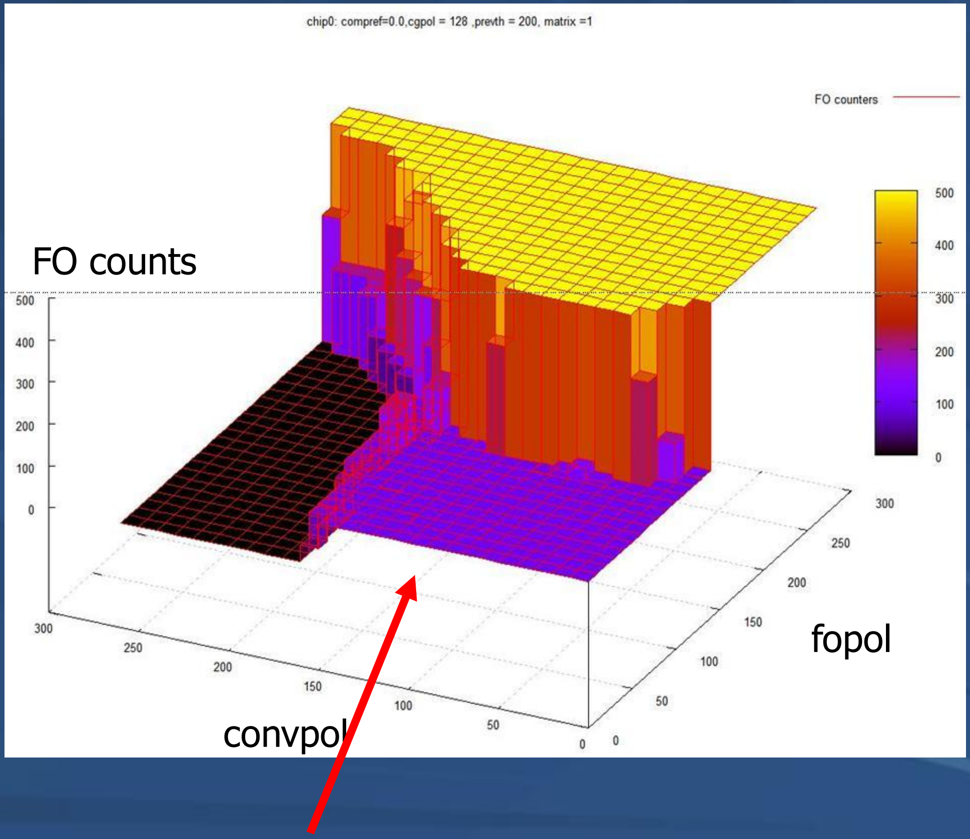
- maximize efficiency
- minimize noise

Automatic calibration procedure

- verifies Fast-OR efficiency in different operating conditions
- scans of the DAC values
- checks of the signal rates
- coordinates SPD readout, control system and PIT operation
- efficiency condition on Fast-OR signal: 100%

Example: 1 chip, central pixel

COMPREF = 0, Pre-VTH = 200



OK -- FO counts = # triggers sent = 100

Cosmic data

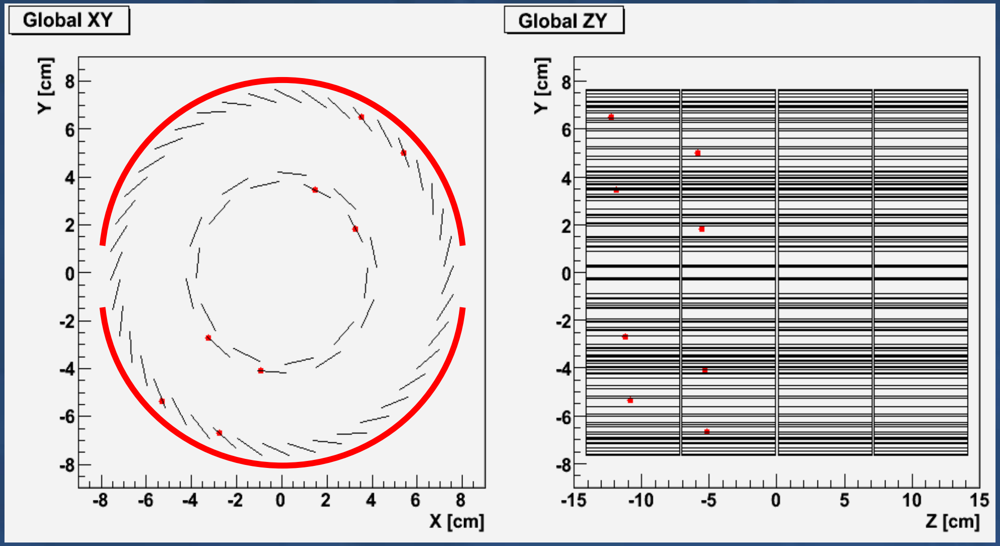
Pixel Trigger used as L0 trigger during ALICE commissioning with cosmic data

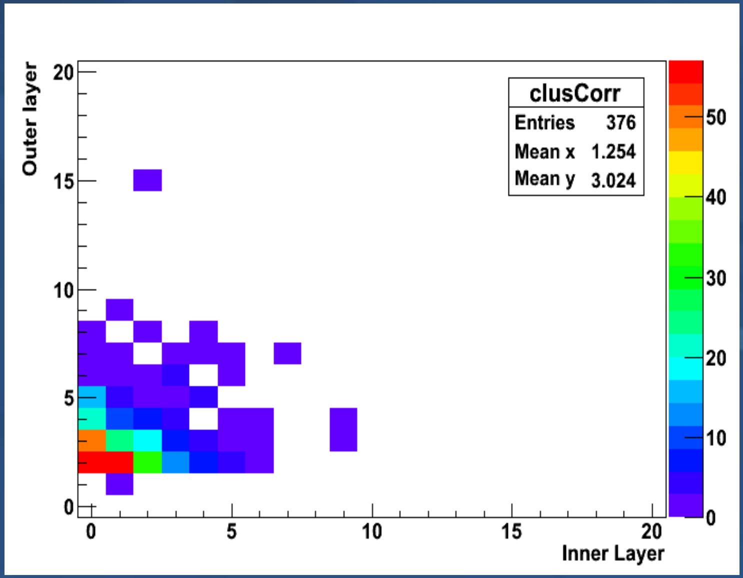
Coincidence algorithm: top/bottom outer layer

Data used for alignment: 100k events with more than 3 clusters on SPD

Rate: 0.18 Hz in agreement with measured flux in the cavern and Monte Carlo simulations

99.6% of events with correct cluster distribution





Cosmic data - alignment

- MillePede2 (global minimization): track-based method to extract the alignment parameters (traslations + rotations) of the 2918 ITS modules
- cosmics acquired with SPD trigger: ~10^5 with B = 0, ~10^4 with B = ±0.5 T
- alignment done matching top-bottom half tracks

expected spread $$\sigma^2_{\Delta x} = 2 * (r^2_{SPD2} + r^2_{SPD1}) / (r_{SPD2} - r_{SPD1})^2 * \sigma^2_{spatial}$$

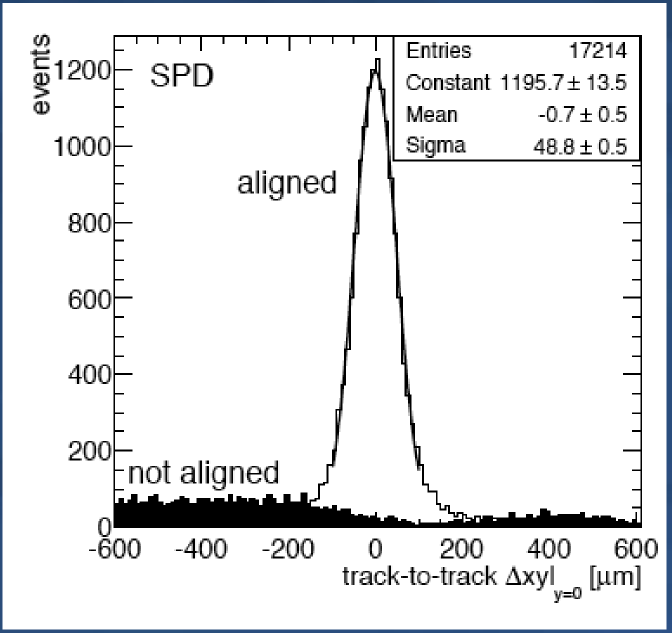
σ = 49 μm

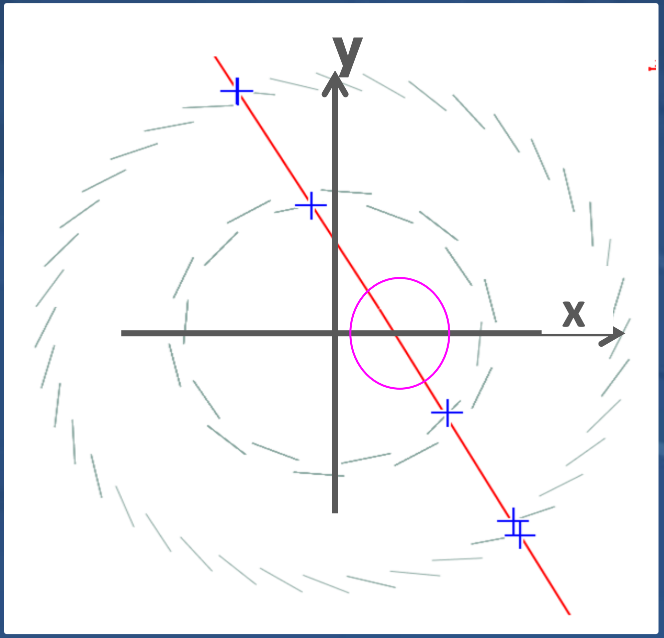
$\sigma_{spatial}$ = 13 μm

$\sigma_{spatial}$ (sim) = 11 μm

⇩

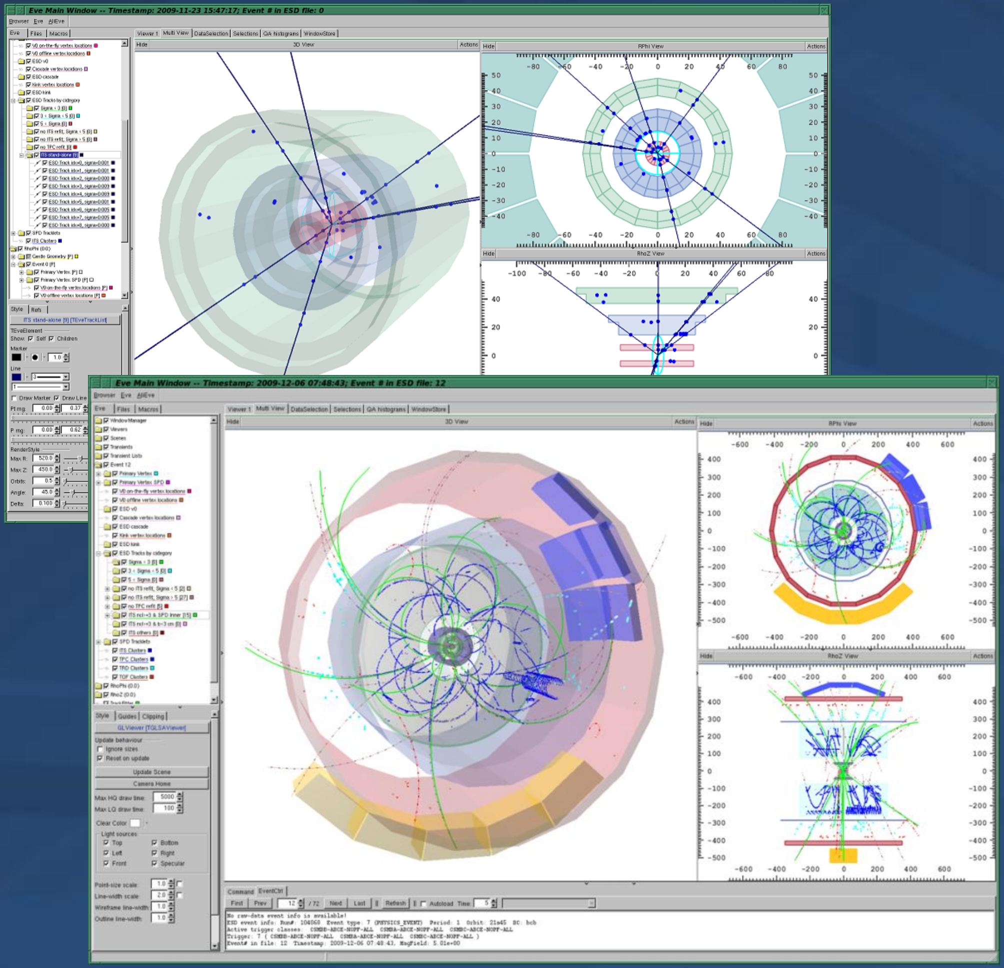
$\sigma_{misal} \approx$ 7 μm





Beam data: first collisions

SPD trigger: minimum bias for 900 GeV
minimum bias + multiplicity for 7 TeV



First LHC paper EPJ C: Vol.65, 1 (2010) based on SPD data and trigger

Now preparation for heavy-ion runs:

- configuration to emulate heavy-ion data size (246 kB/event) by lowering readout thresholds
- tests in the laboratory using internal pulser

Summary

First data with beams collected end of 2009

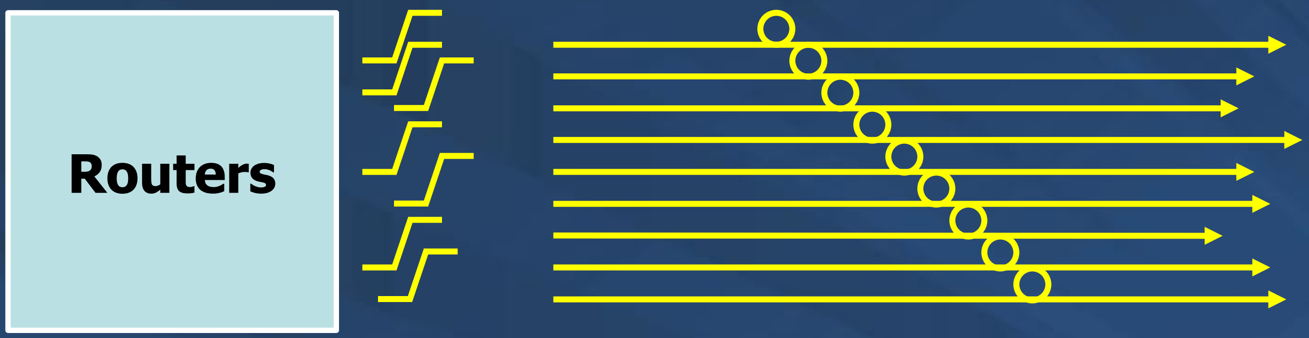
SPD optimization:
- upgrades of the cooling system
- studies on the chip matrix response
- calibration scans on the full detector
- timing studies and adjustments

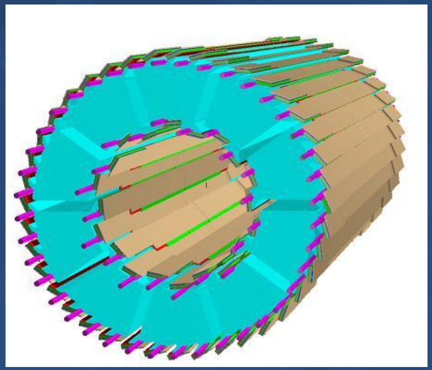
Fast-OR trigger:
- Fast-OR automatic tuning procedure in place
- trigger efficiencies under study
- timing studies and adjustments

Silicon Pixel Detector & Pixel Trigger are successfully providing L0 trigger for the ALICE experiment
- in cosmic runs
- during injection tests and circulating beams

SPD ready for heavy-ion runs

Alignment of SPD clock phases





Clk outputs **Clk fibers (~100m)**

Relative phases of 120 clocks of control units: σ = 0.63 ns
Propagation delays due to 120 optical fibers: σ = 0.90 ns

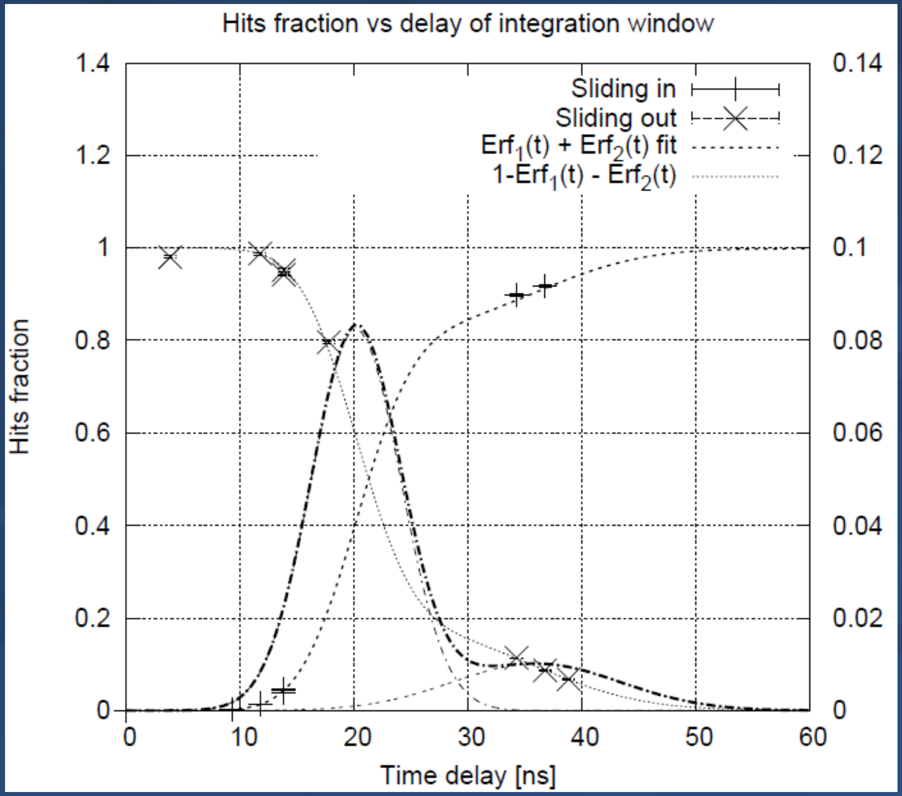
Clock phases at SPD inputs <u>without</u> correction: σ = 1.10 ns

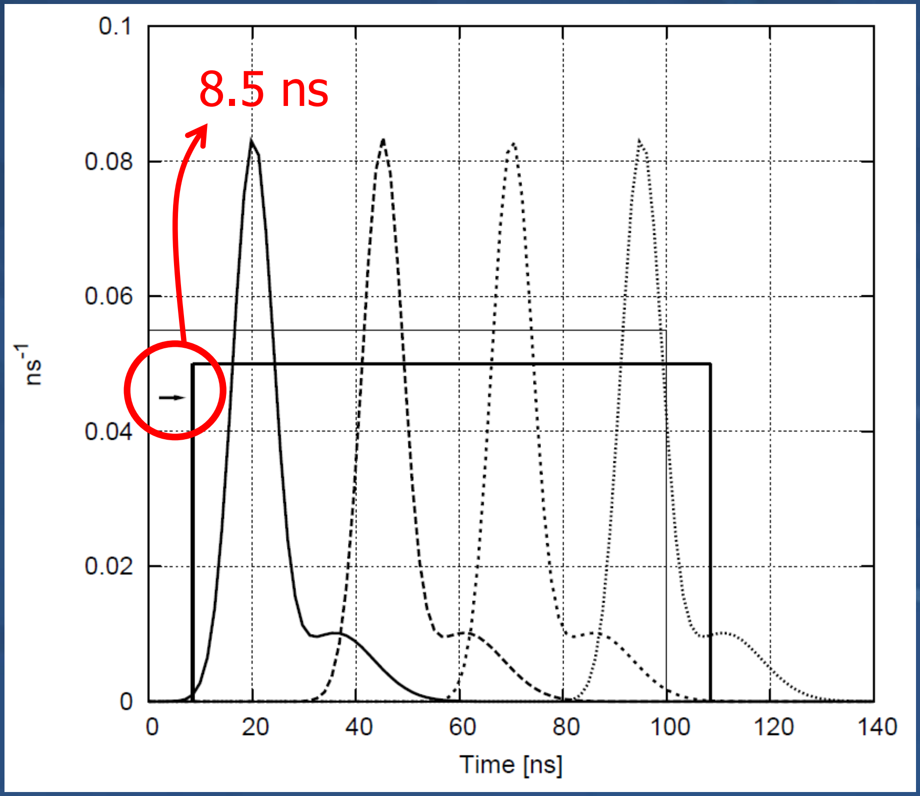
Delays added to the clock transmitters to compensate for differences
Clock phases at SPD inputs <u>with</u> correction: σ = 0.08 ns

SPD clock fine adjustment

Measure time distribution of average number of hits

- using 3.5 TeV colliding beams: single phase of colliding BCs wrt SPD clock
- sliding in/out readout strobe window
- changing delay (multiple of clock cycle and fine delay)
- considering average # hits/event

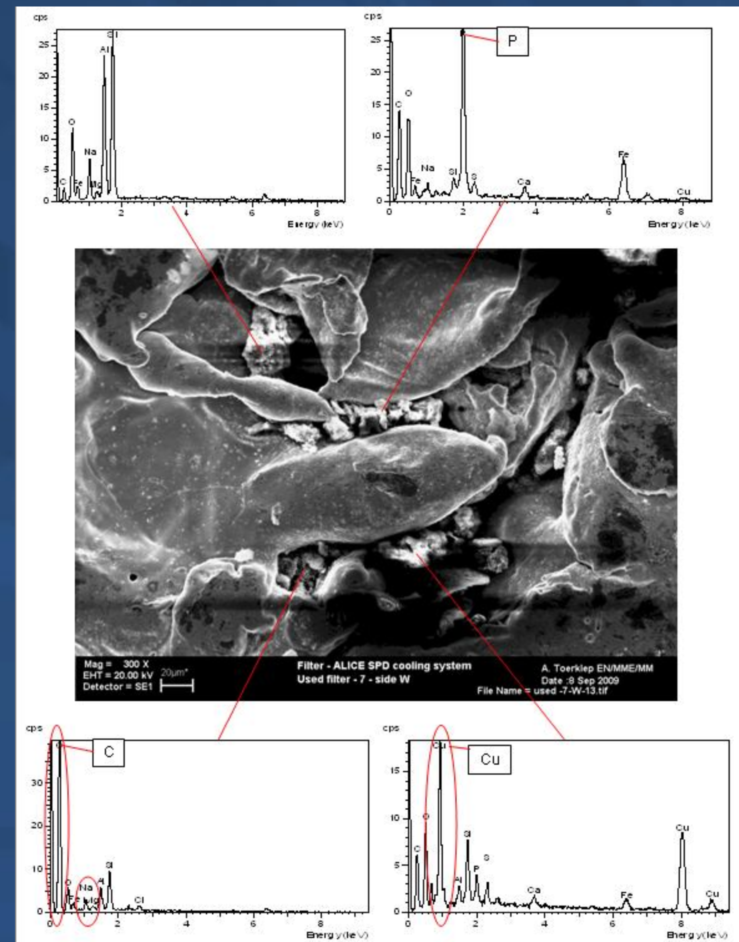




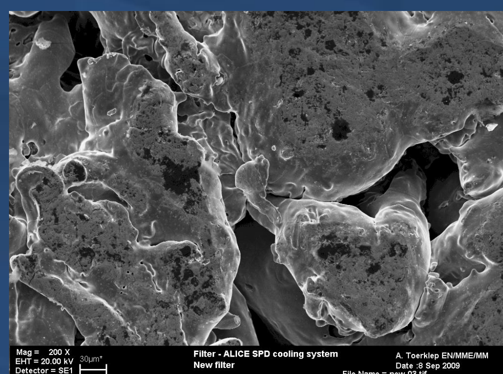
Filters on cooling lines

SEM analysis of microfilters shows clogging, one patch-panel accessible only during long shutdown (need to move TPC)

Used filter

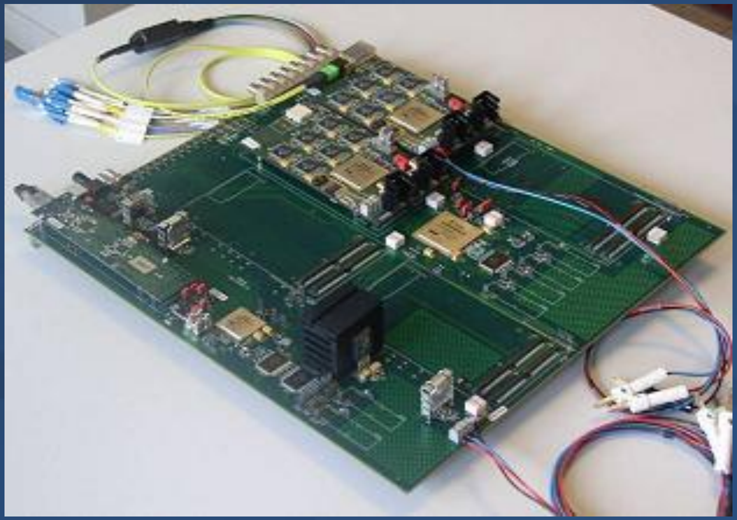


Clean filter



Pixel Trigger characteristics

- contributes to the L0 trigger in ALICE
- based on boolean functions (AND/OR) of the 1200 FO bits
- minimum bias + multiplicity trigger for p-p collisions
- centrality trigger for Pb-Pb collisions
- programmable thresholds on inner/outer layers



Output	Algorithm
1	Minimum Bias
2	High Multiplicity 1
3	High Multiplicity 2
4	High Multiplicity 3
5	High Multiplicity 4
6	Past Future Prot
7	Background(0)
8	Background(1)
9	Background(2)
10	Cosmic