Performance of ALICE silicon tracker detector

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Outline

1. *Introduction*
   - *The ALICE Experiment*
   - *ALICE Inner Tracking System Description*
2. *ITS operations*
   - *Status during LHC Run1*
3. *Physics performance*
   - *Vertexing*
   - *Tracking*
   - *Impact parameter resolution*
   - *Particle identification*
4. *Conclusions*

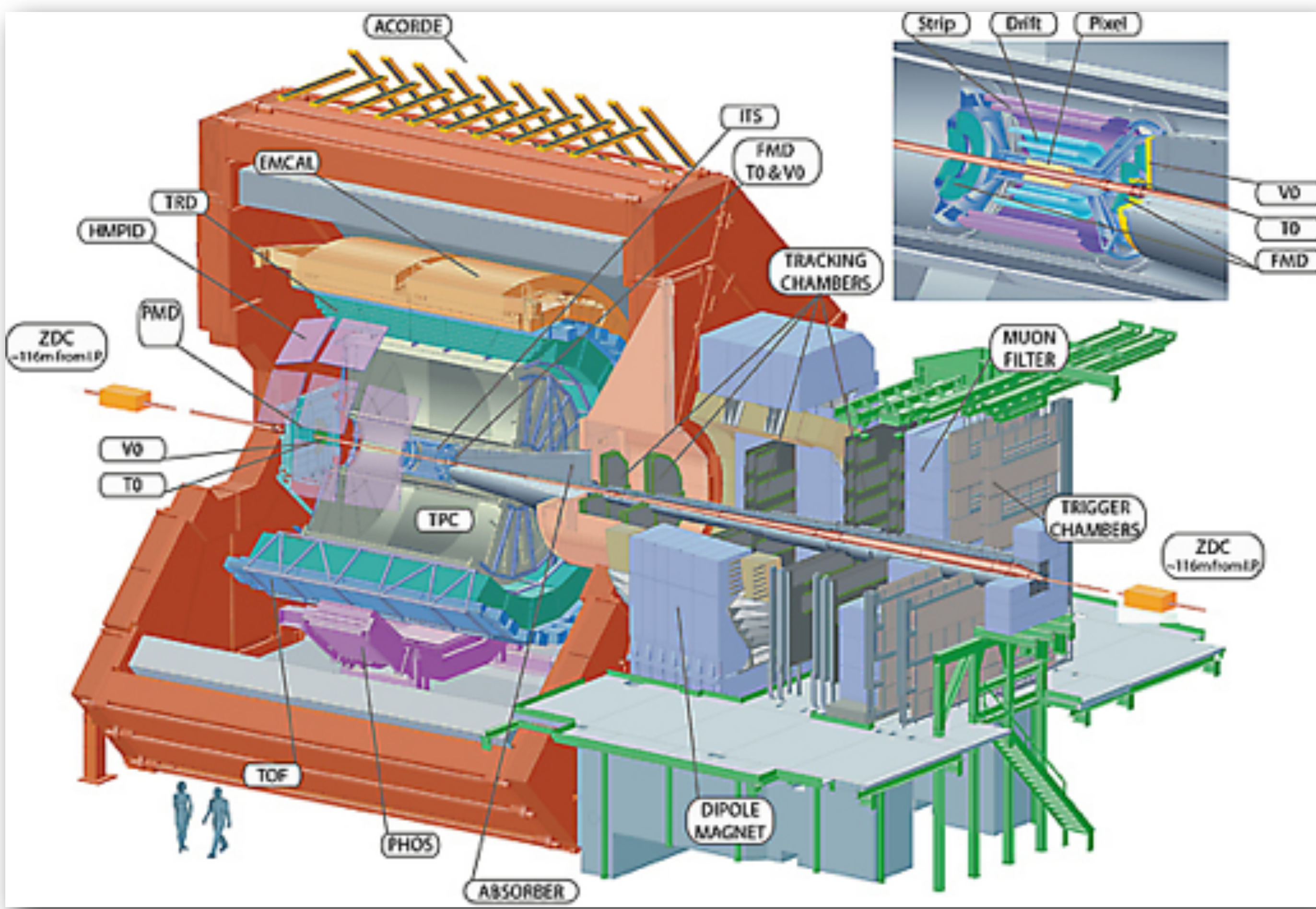
The ALICE detector

Dedicated heavy-ion experiment

- Study the behavior of strongly interacting matter under extreme conditions of high energy density and temperature

Proton-Proton and Proton-Lead collisions

- Reference data for heavy-ion program
- Genuine physics (momentum cutoff < 100 MeV/c, excellent PID, efficient minimum bias trigger)



Main features of the ALICE barrel ($|\eta|<0.9$)

- Robust tracking for heavy-ion environment
  - Mainly 3D hits and up to 150 points along the tracks
- Wide transverse momentum range (100 MeV/c - 100 GeV/c)
  - Low material budget to minimize multiple scattering at low p_T (13% X_0 for ITS+TPC)
  - Large lever arm to guarantee good tracking resolution at high p_T
- Particle Identification in a wide momentum range based on several techniques: dE/dx, time of flight, transition and Cherenkov radiation, calorimetry

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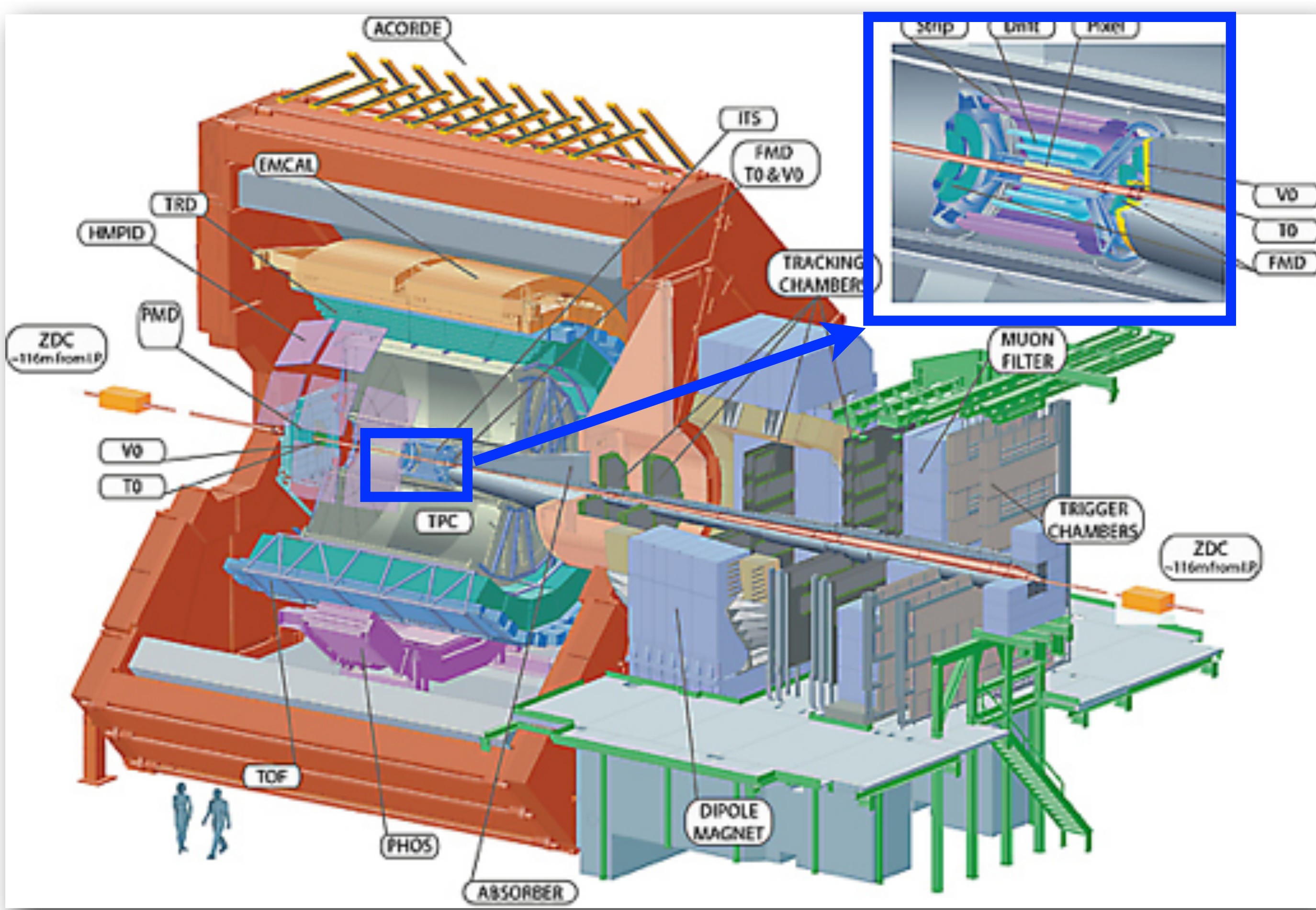

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The ALICE Inner Tracking System

ITS tasks in ALICE

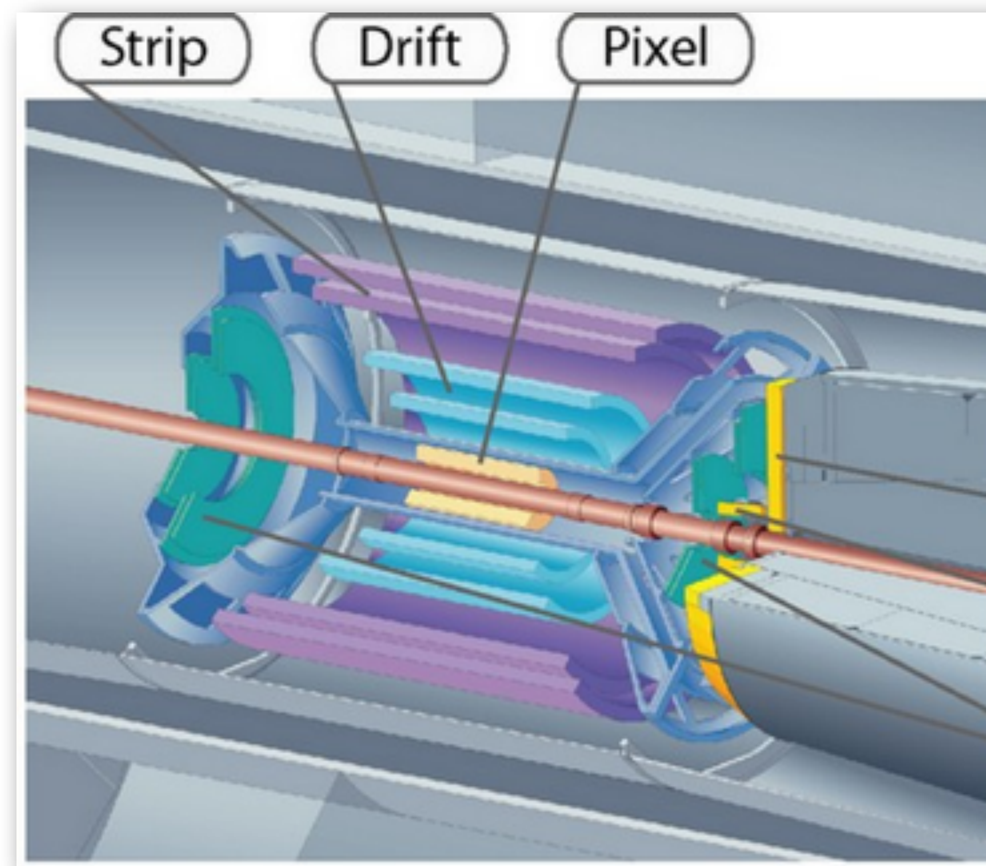
- Secondary vertex reconstruction (c,b decays) with high resolution
- Tracking and PID of low p_T particles, also in standalone
- Improve primary vertex reconstruction, momentum and angle resolution of tracks from outer detectors
- Prompt Level-0 trigger capability < 800 ns (Pixel)
- Measurement of charged particles pseudo-rapidity
- Pileup rejection

ITS requirements

- Capability to handle high particle density
- Good spatial precision
- High efficiency
- High granularity
- Minimize distance of innermost layer from beam axis (mean radius ~3.9 cm)
- Limited material budget
- Analogue information in 4 layers (Drift and Strips) for particle identification in $1/\beta^2$ region via dE/dx

3 different technologies

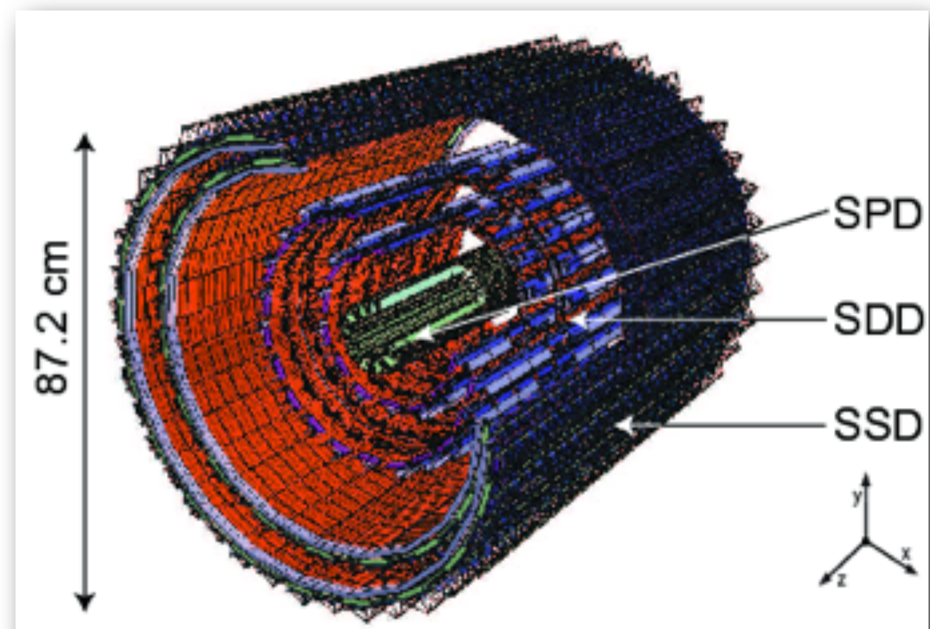
- 2 layers of Silicon Pixel Detector (SPD)
- 2 layers of Silicon Drift Detector (SDD)
- 2 layers of Silicon double-sided microStrip Detector (SSD)



ITS Parameters

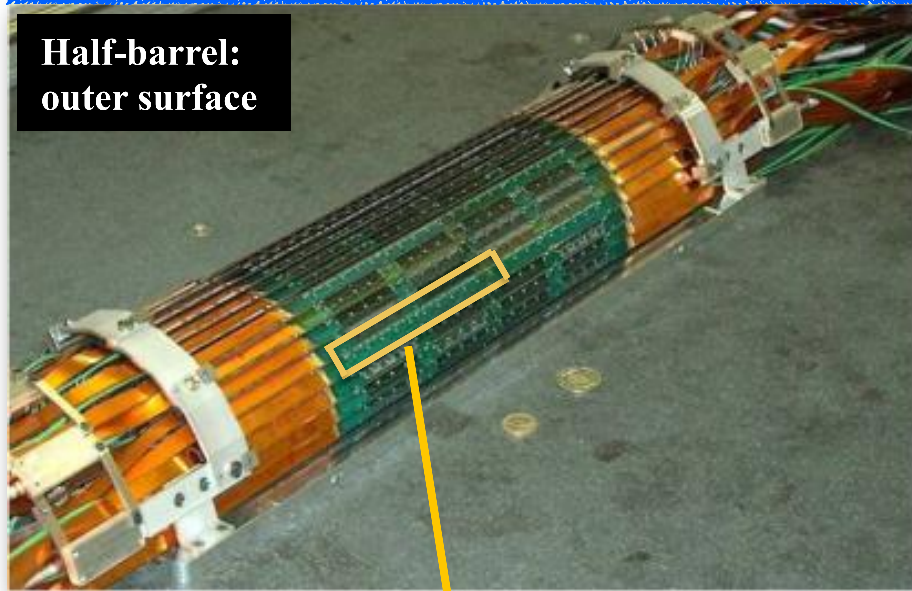
Layer	Det.	Radius (cm)	Length (cm)	Surface (m^2)	Chan.	Spatial precision (mm)		Cell (μm^2)	Max occupancy central PbPb (%)	Power dissipation (W)		Material budget (% X/X_0)
						rφ	z			barrel	end-cap	
1	SPD	3.9	28.2	0.21	9.8M	12	100	50x425	2.1	1.35k	30	1.14
2		7.6	28.2						0.6			1.14
3	SDD	15.0	44.4	1.31	133K	35	25	202x294	2.5	1.06k	1.75k	1.13
4		23.9	59.4						1.0			1.26
5	SSD	38.0	86.2	5.0	2.6M	20	830	95x40000	4.0	850	1.15k	0.83
6		43.0	97.8						3.3			0.86

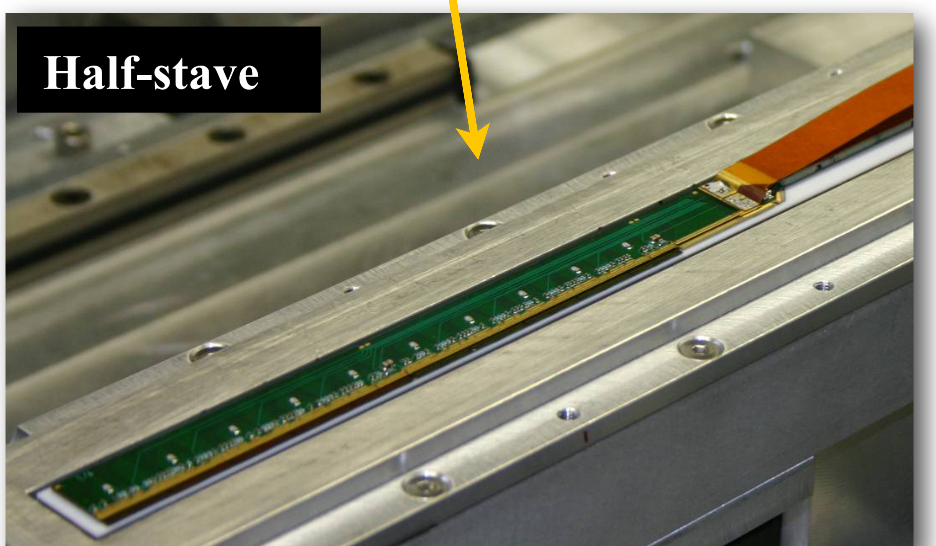
- Radial coverage defined by beam-pipe (inwards) and requirements for track matching with TPC (outwards)
- Max occupancy ~constant in all the layers
- Average material traversed by a straight track perpendicular to the surface is ~1% X_0 per layer

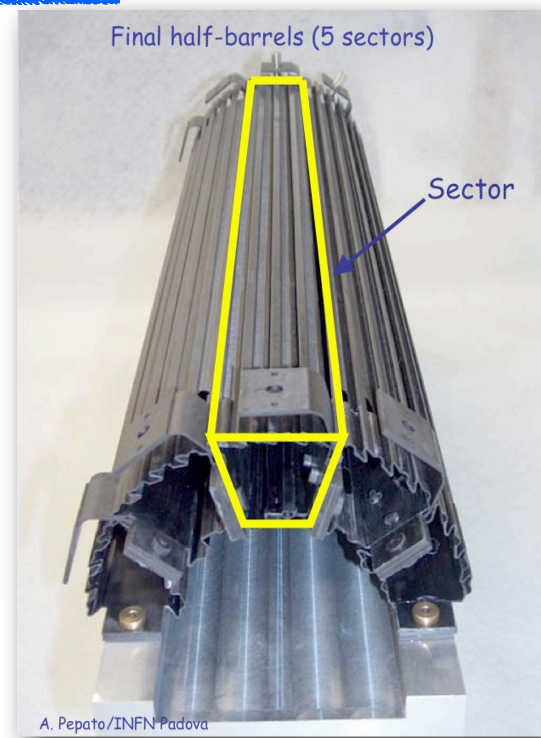


SPD - Silicon Pixel Detector

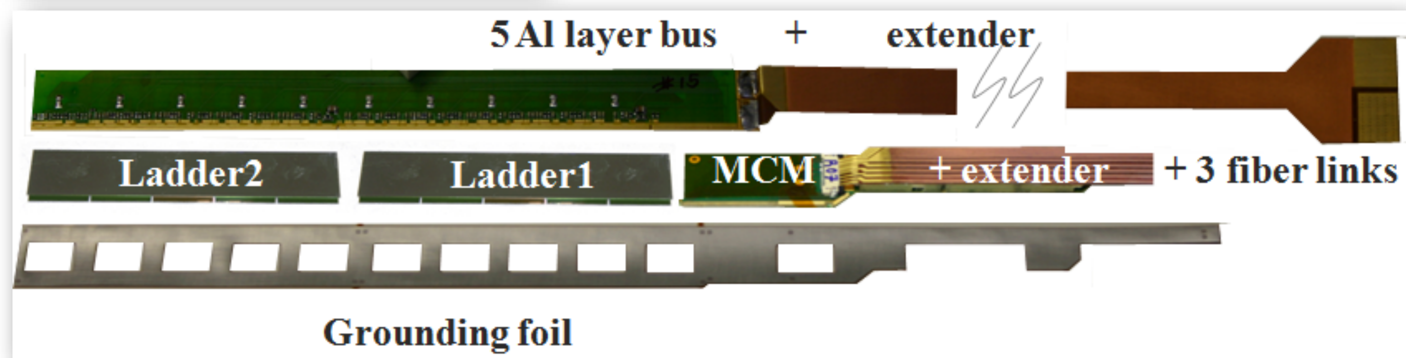
2 layers of pixels grouped in 2 half barrels mounted around the beam pipe





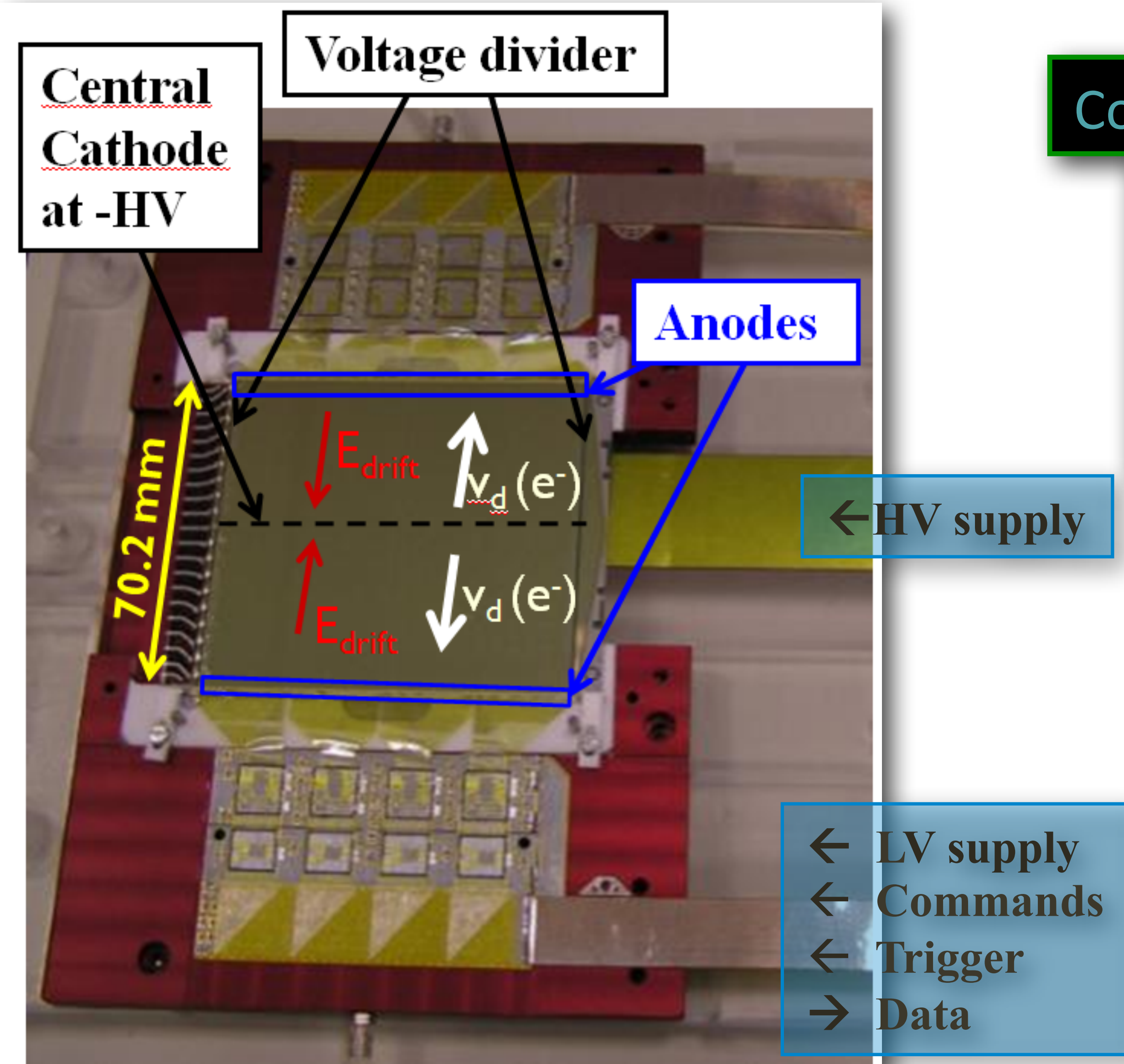


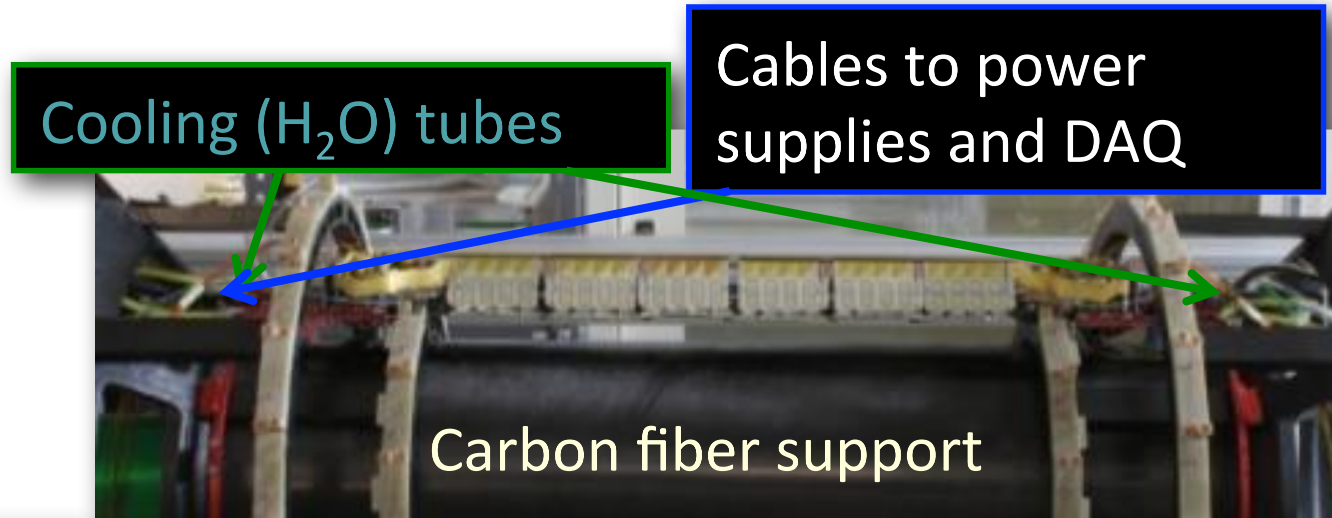
- ✓ 120 half-staves
- ✓ Total surface: ~0.24m^2
- ✓ Power consumption ~1.4kW
- ✓ Evaporative cooling C_4F_{10}
- ✓ Operating at room temperature
- ✓ Fast two-dimensional readout (256μs)
- ✓ L0 trigger capability
- ✓ Material budget per layer ~1% X_0

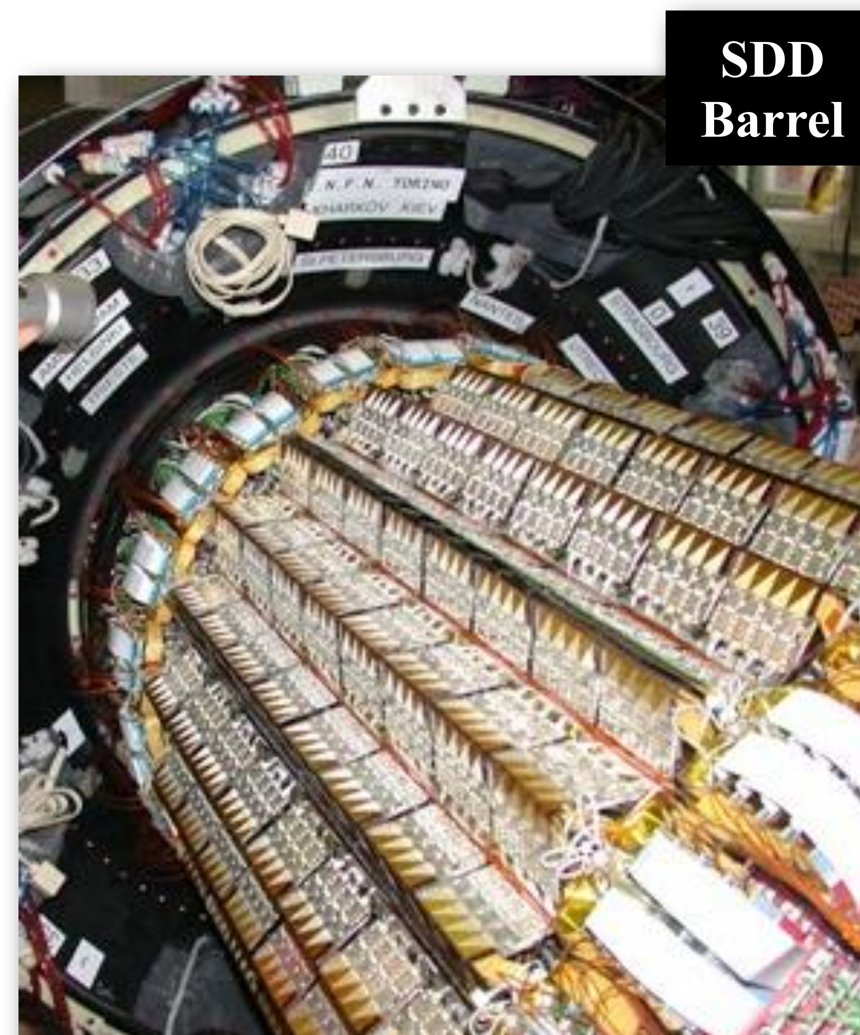


Layer	*Radius (cm)*	*# half-staves*	*Ladders/ half-stave*	*# ladders*
1	3.9	40	2	80
2	7.6	80	2	160

SDD - Silicon Drift Detector



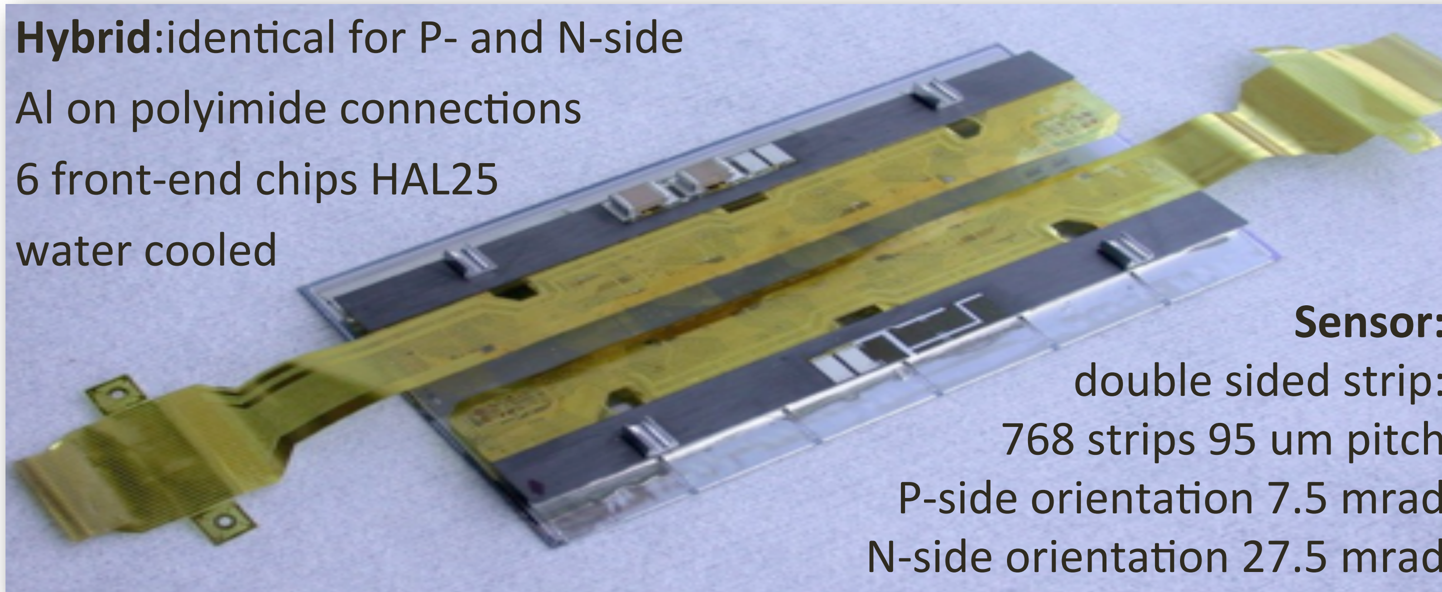




Layer	*Radius (cm)*	*# ladders*	*Mod./ladder*	*# modules*
3	15.0	14	6	87
4	23.9	22	8	176

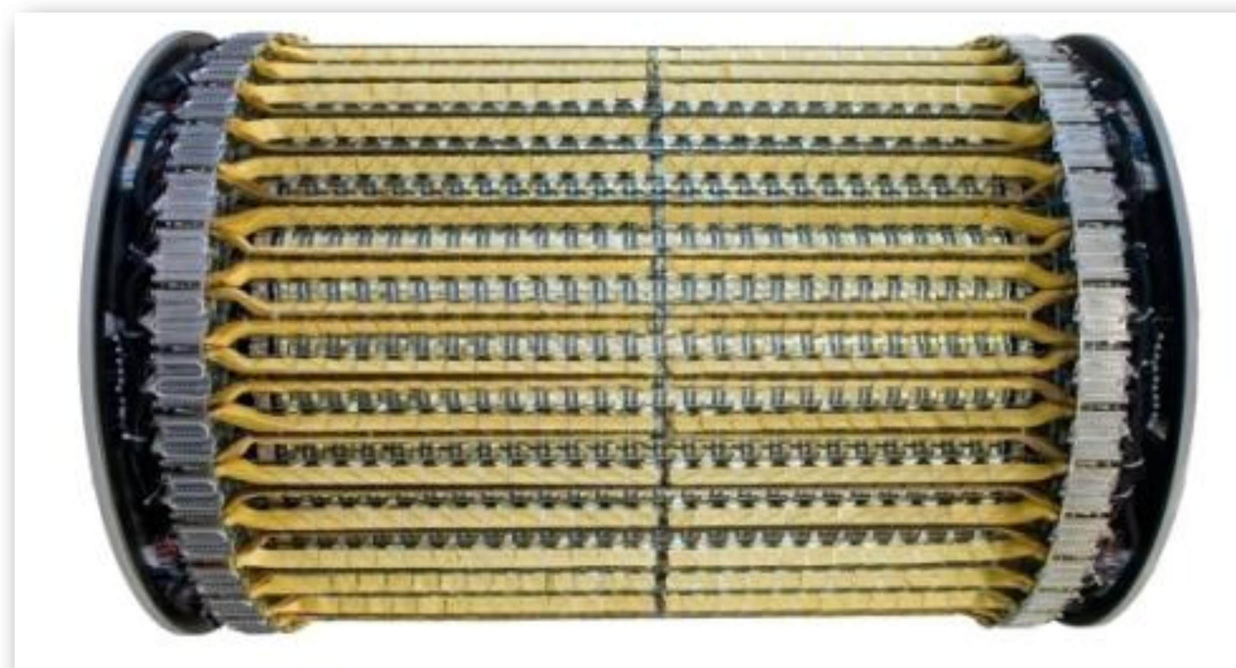
SSD - Silicon Strip Detector

ALICE



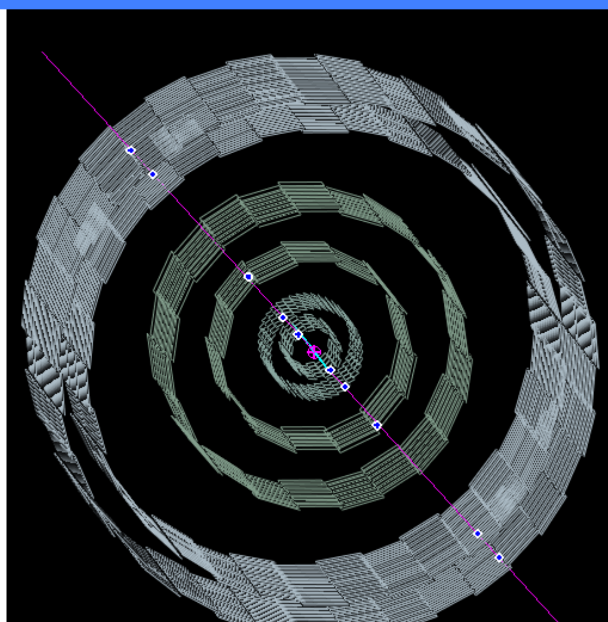
- carbon fibre support
- module pitch: 39.1 mm
- Al on polyimide laddercables

Layer	*Radius (cm)*	*# ladders*	*Mod./ladder*	*# modules*
5	38.0	34	22	748
6	43.0	38	25	950

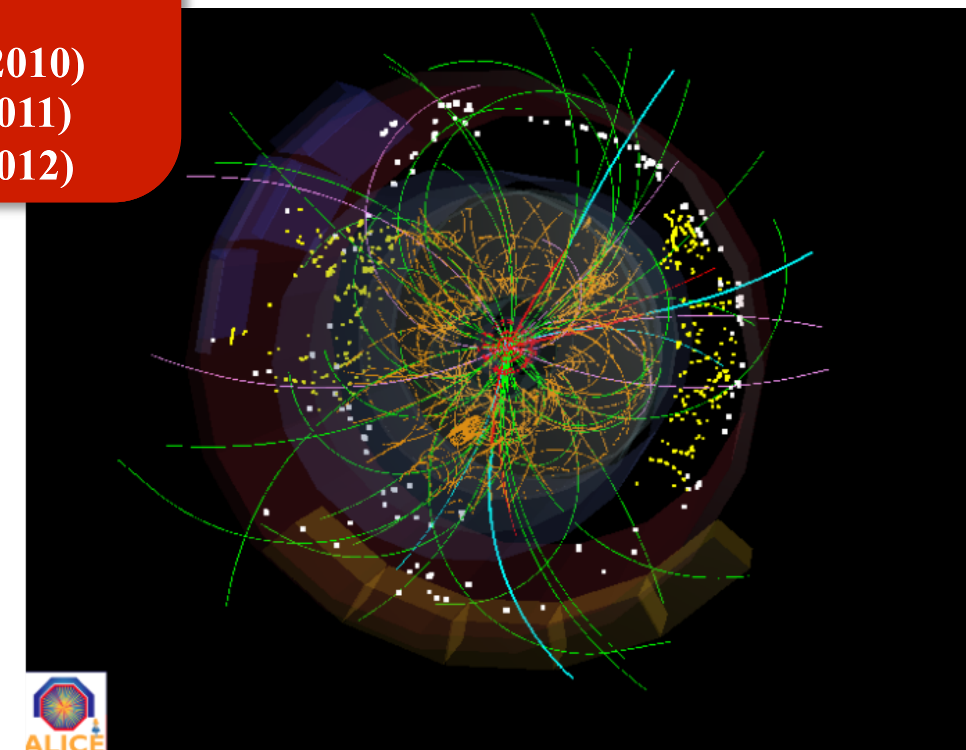


ALICE data-taking

Cosmic (2008)
- ✓ 100 K events in the ITS using the pixel L0 dedicated trigger

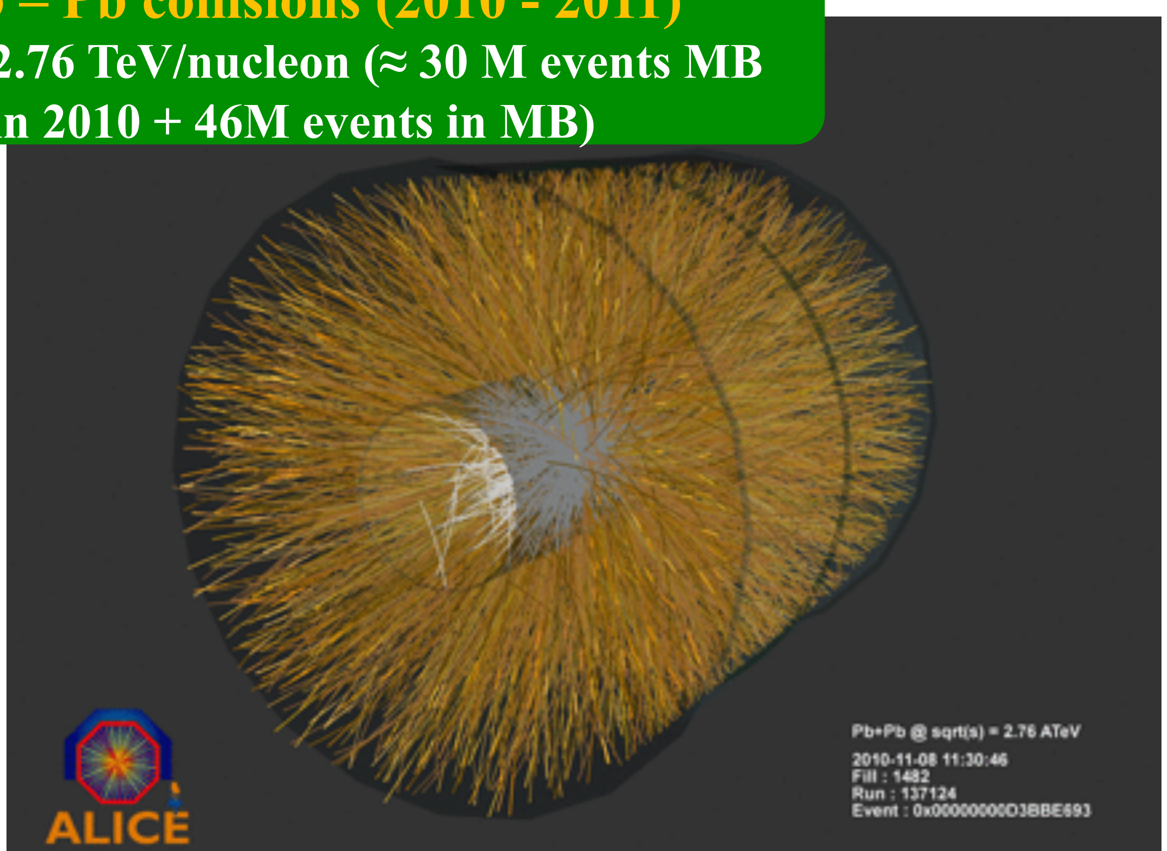


pp collisions (2010 – 2012)
- ✓ 900 GeV (300 K + 8 M events MB)
- ✓ 2.36 TeV (40 K events)
- ✓ 2.76 TeV (70 M events MB)
- ✓ 7 TeV (800 M events MB in 2010)
- ✓ 7 TeV (550 M events MB in 2011)
- ✓ 8 TeV (540 M events MB in 2012)

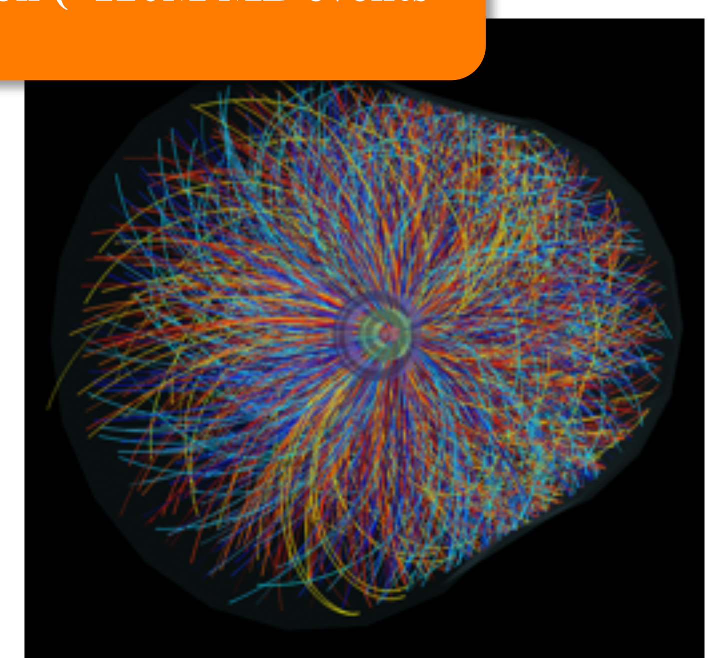


Almost continuous ITS operation between 2010 and 2013 with different colliding systems and at different energies

Pb – Pb collisions (2010 - 2011)
- ✓ 2.76 TeV/nucleon (≈ 30 M events MB in 2010 + 46M events in MB)



p-Pb collisions (2013)
- ✓ 5.02 TeV/nucleon (~120M MB events in 2013)



ALICE Inner Tracking System Operations

ITS Operations

The ITS operates in the experimental area as three independent sub-detectors
➔ specific implementation of the online systems to allow an independent monitor and operation of the each sub-detector

- Specific Detector Control System (DCS) to remotely control the underground hardware: temperatures, HV, LV, FEE electronics
  - In total 4 DCS projects: 3 for each sub-detector + 1 for Pixels Trigger

- Independent data monitoring to online control the quality of the data
  - Prompt spotting of detector de-configurations during data-taking

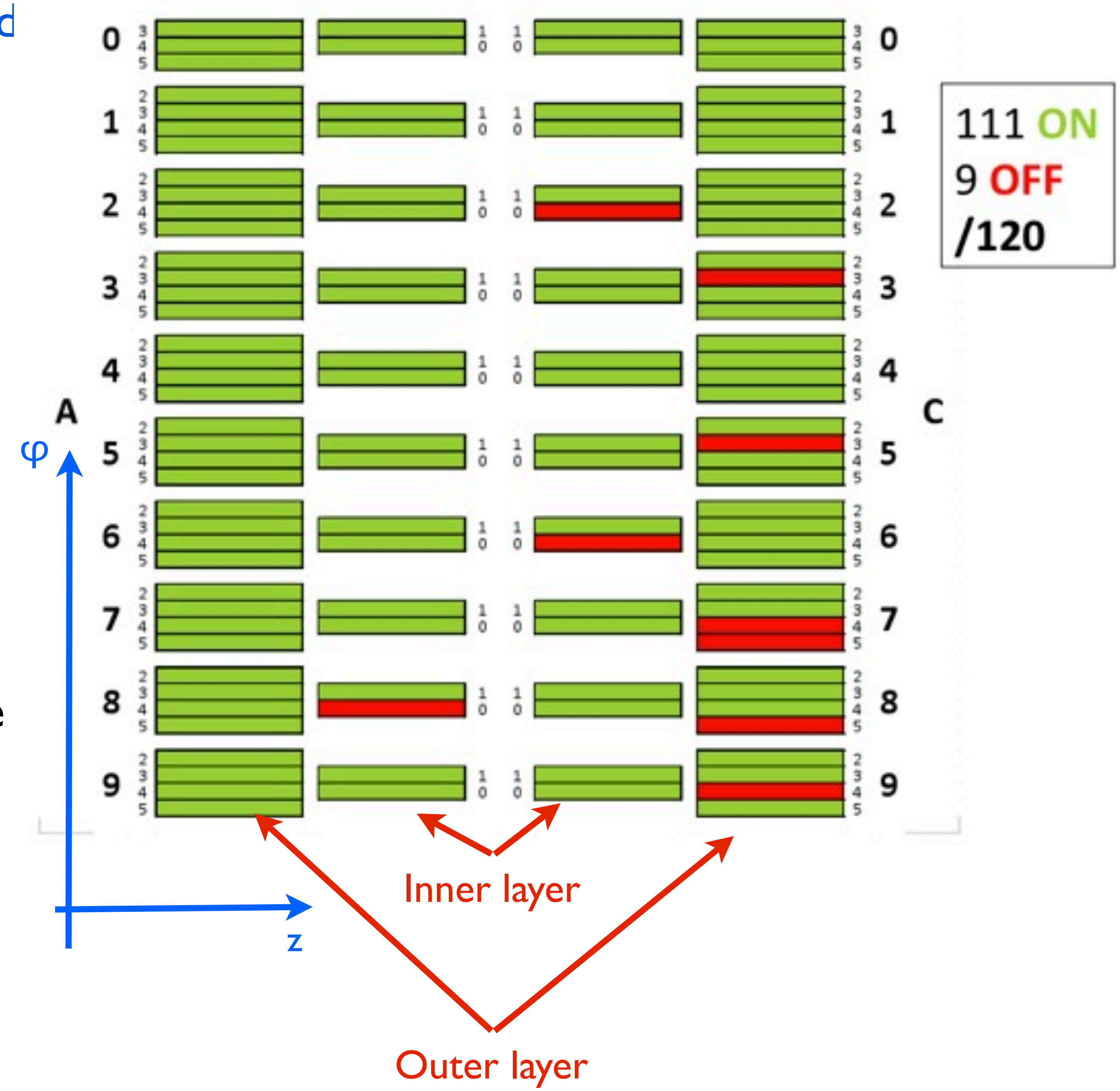
- Independent calibration procedures for each sub-system. In particular, different online calibration strategies developed:
  - SPD: Noisy chips maps
  - SDD: Baseline and Noise, Gain, Drift speed
  - SSD: Baseline and Noise

Detector status: SPD

- 111 Half-Staves (HS) in data-taking and triggering after May 2012
  - High efficiency reached after cooling intervention. Stable configuration.

- Main motivations for excluding HS:
  - Connection problems
  - Configuration not stable

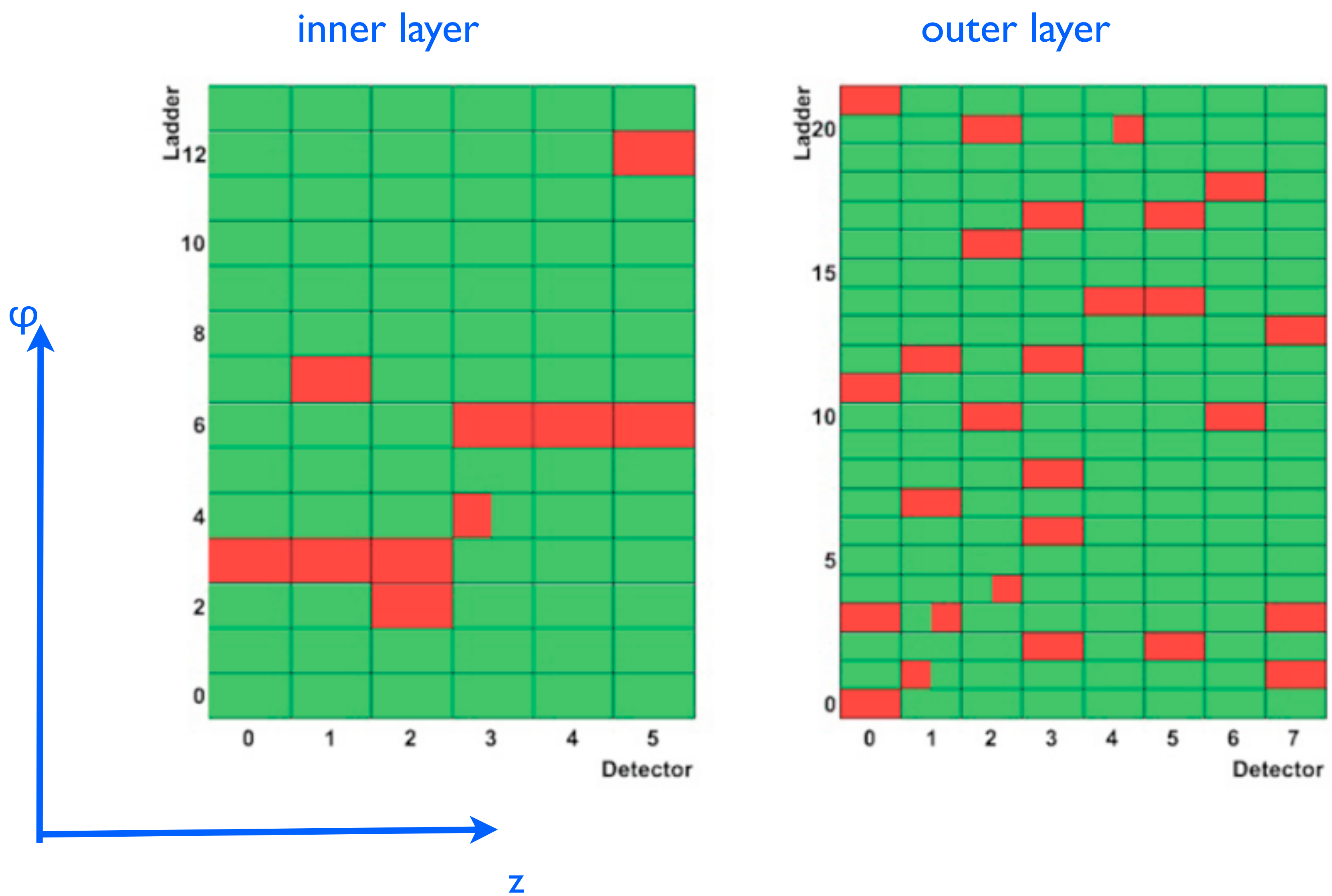
- SPD Calibration
  - Main calibration performed before the beginning of the data taking. Very stable configuration
  - Online calibration based on the research of noisy pixels through dedicated standalone runs or with Detector Algorithms



Detector Status: SDD

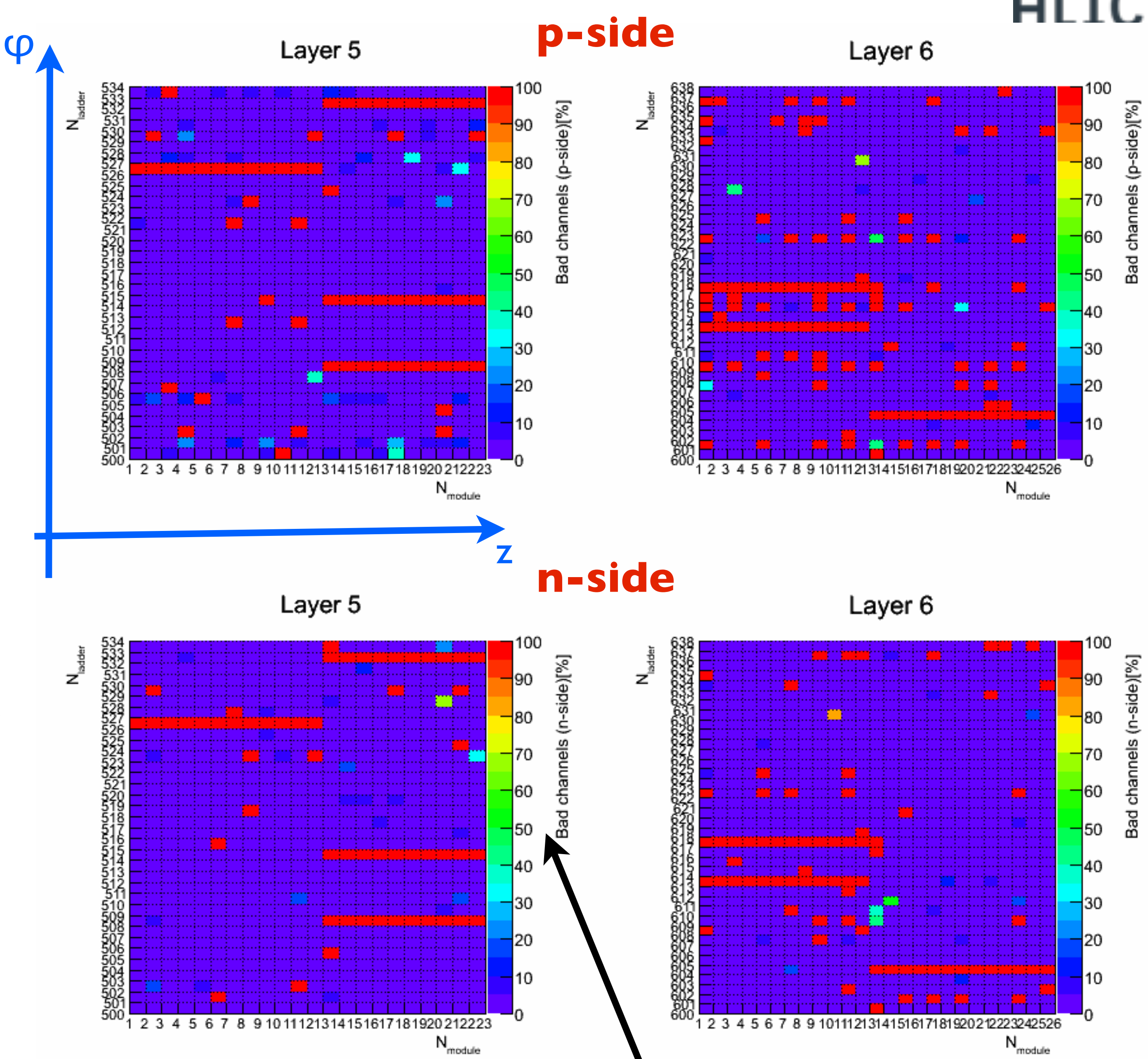
- Fraction of good modules: 86%
    - Fraction of good anodes in good modules: > 98%

- Main motivations for excluding modules:
    - FEE and HV problems



Detector status: SSD

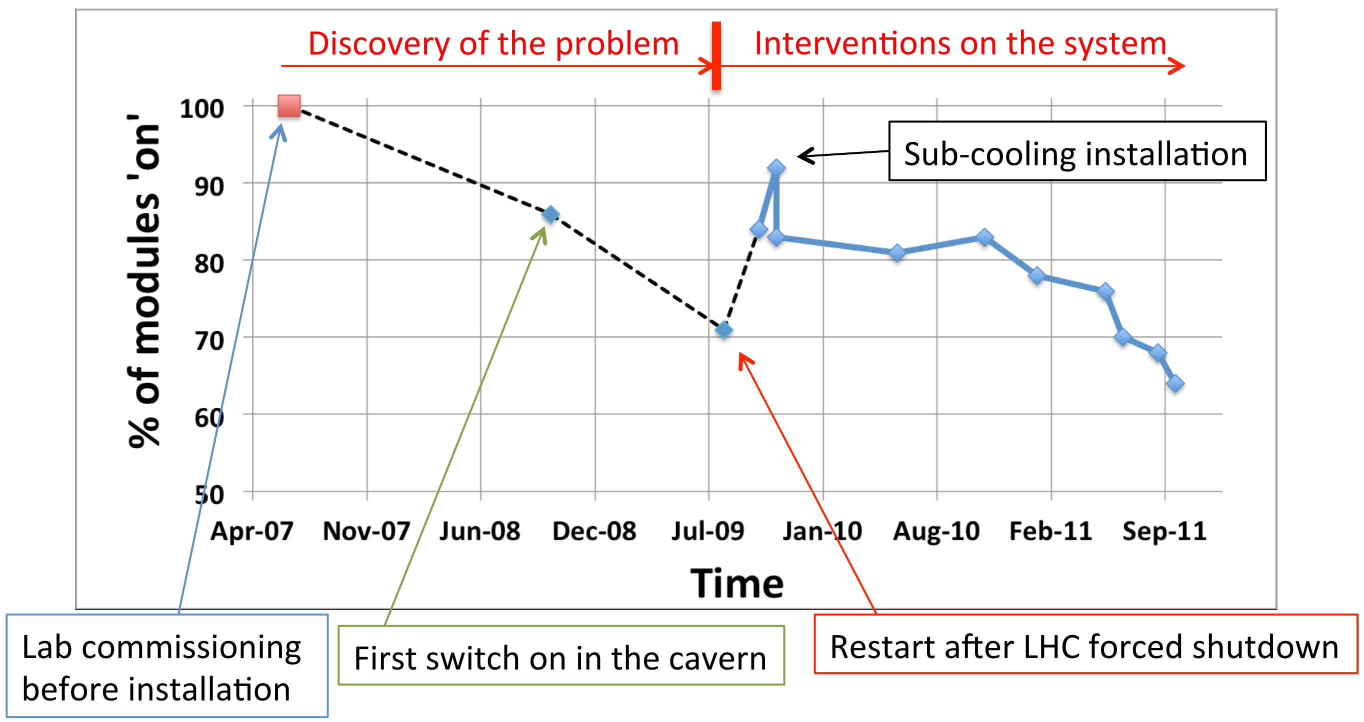
- Active half-ladders: 137/144
    - Active modules: 91%
- Not-active modules:
    - are not operable due to configuration problems
    - are masked due to noisy areas
- Number of active modules depend also from the environmental humidity
    - modules supplied by SINTEF show high current with humidity > 15%. Switched off if humidity is not under control
- Detector Algorithm runs online after standalone runs to search for additional noisy channels

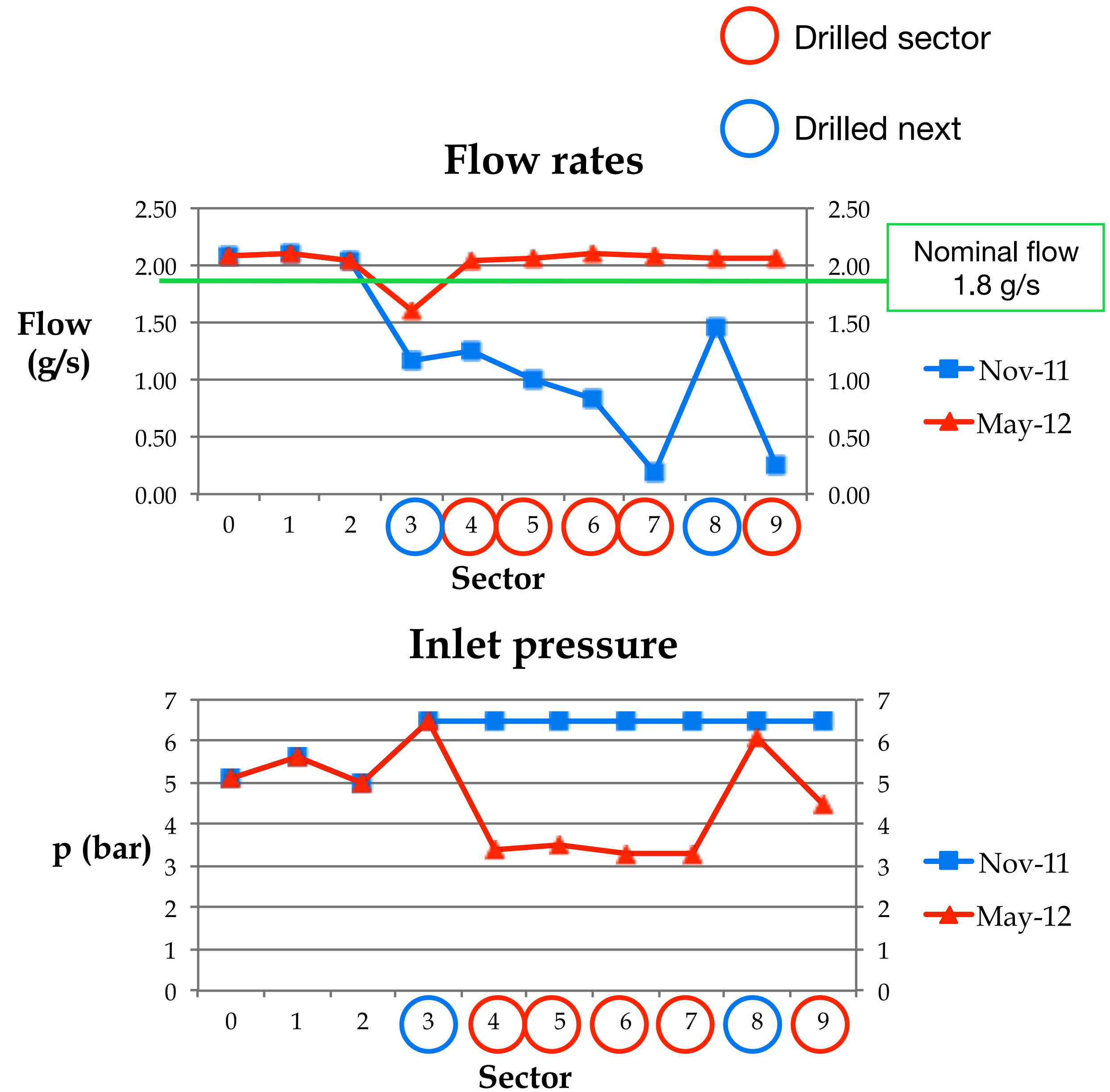


color scale: percentage of bad channels in a module

SPD cooling system issue

- SPD on-detector electronics dissipates 23W per stave (1.35 kW for the whole detector) using the embedded cooling system with C_4F_{10} as cooling liquid
- After the pump the system is split in 10 cooling lines, one for each sector that are recollected before the compressor
- Minimum flow rate to extract the whole power for each sector is 1.8 g/s





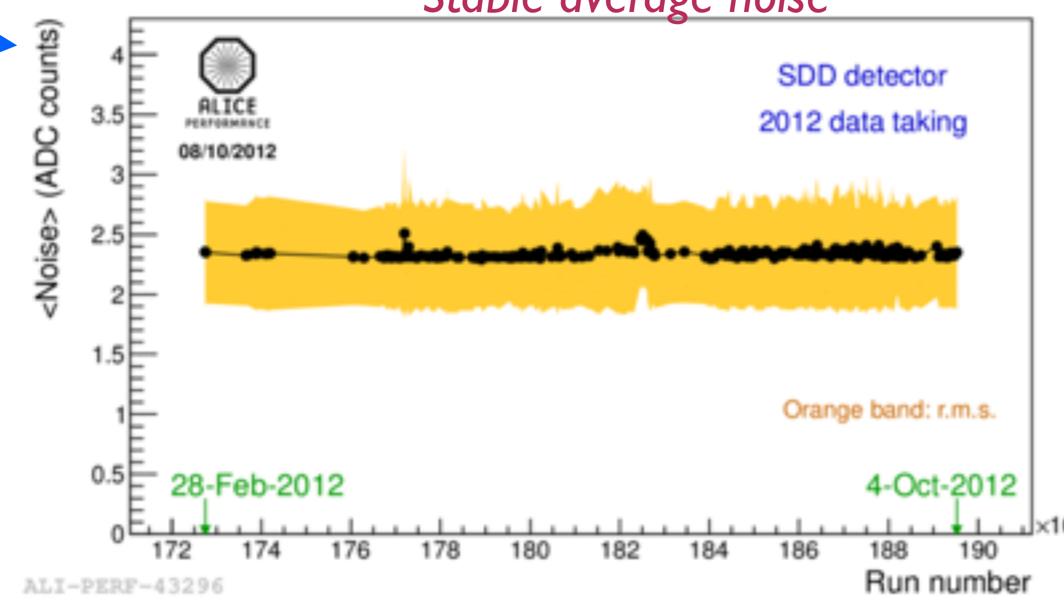
After the intervention 111 Half Staves switched ON

- Many modules OFF for high temperature
- Problem connected with clogging of cooling filters
- Filters not accessible in an easy way
  - difficult drilling procedure prepared and successfully conducted.

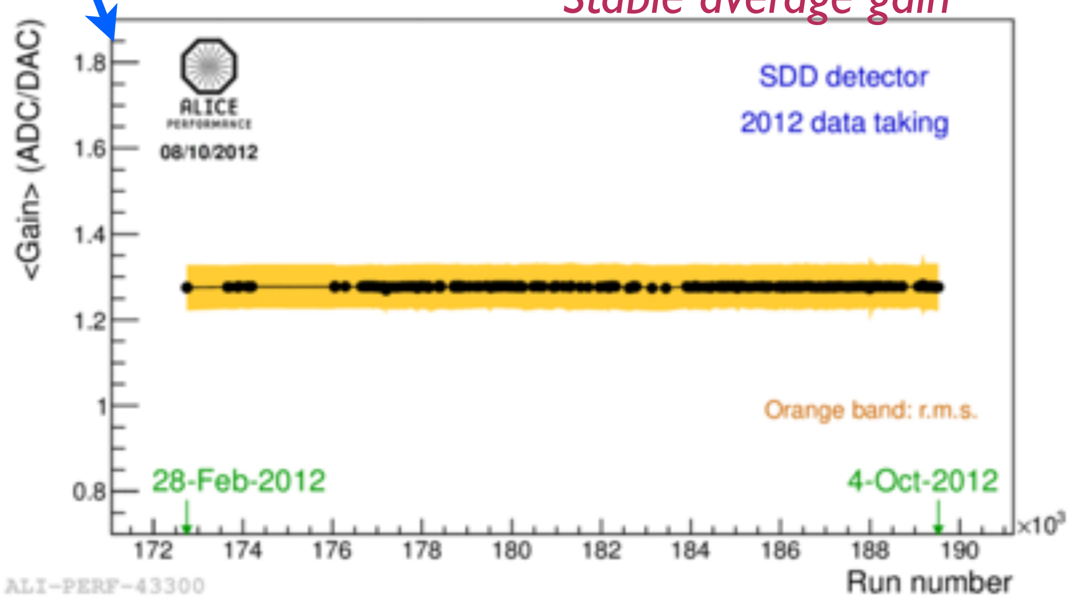
SDD online calibration

1. Baseline and noise
   - Measured at each beam fill
   - Stable behavior over long timescales
   - average noise at ~2.5 ADC counts
2. Gain
   - Measured with pulser standalone runs: test pulse sent to the FE chips

Stable average noise

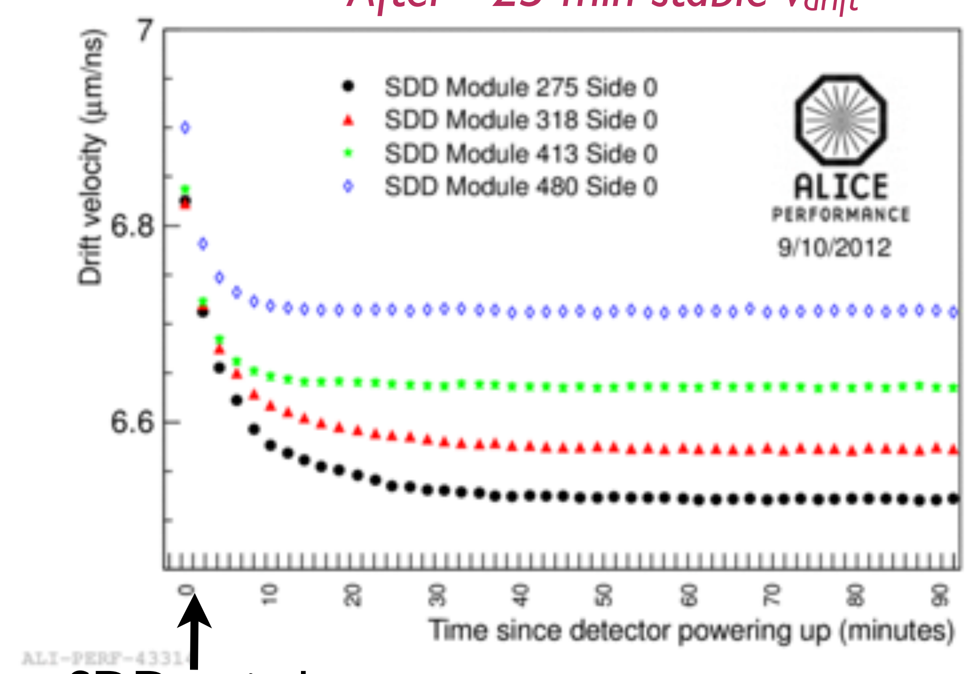


Stable average gain



3. Drift speed measured with MOS Injectors implanted on the detector surface during standalone runs
   - crucial to have a 0.1% precision on drift speed to reach the nominal resolution of 25 microns along the drift region

After ~25 min stable v_{drift}

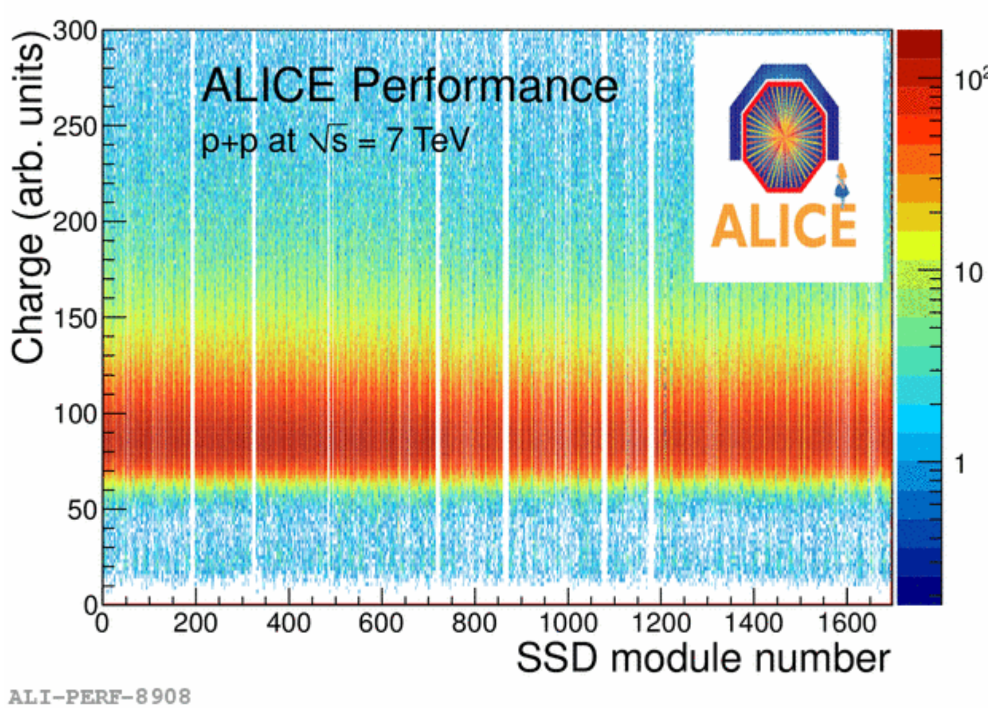


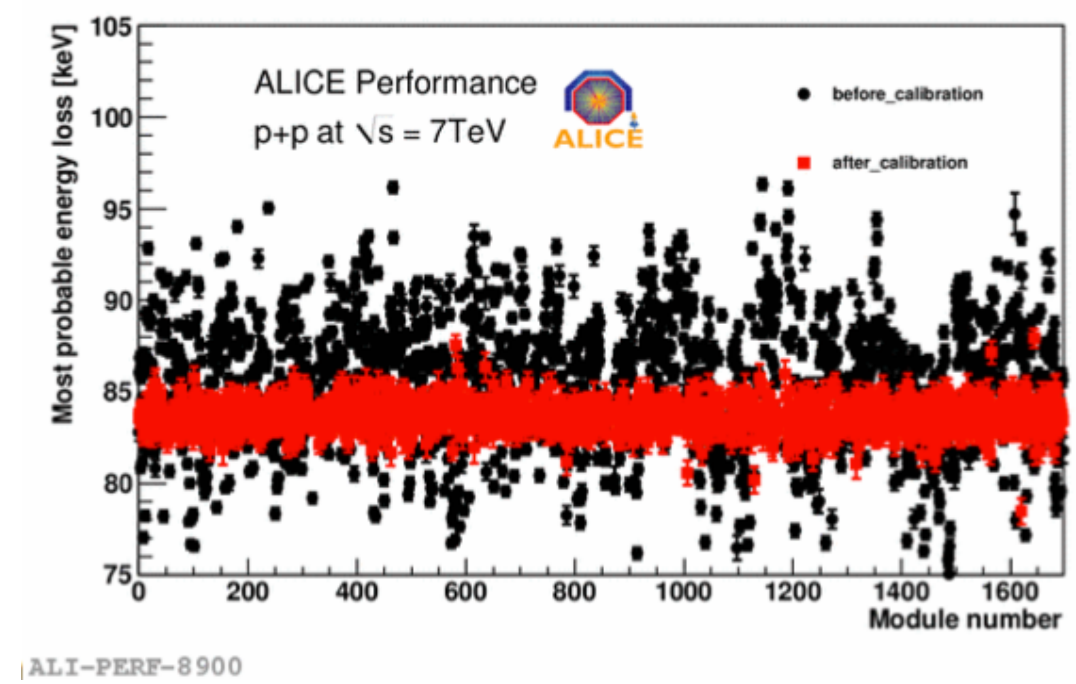
SDD switch on

SSD Calibration

1. Noise and baseline measured during dedicated standalone runs without beam
   - Stable noise distribution vs time
   - Average p-side noise ~2.4 ADC, n-side noise ~3.5 ADC

2. Gain calibration measured from cluster charge distributions obtained from collision data for all the SSD modules
   - MPV value stable within few %
   - Very stable calibration: need to be updated few times per year

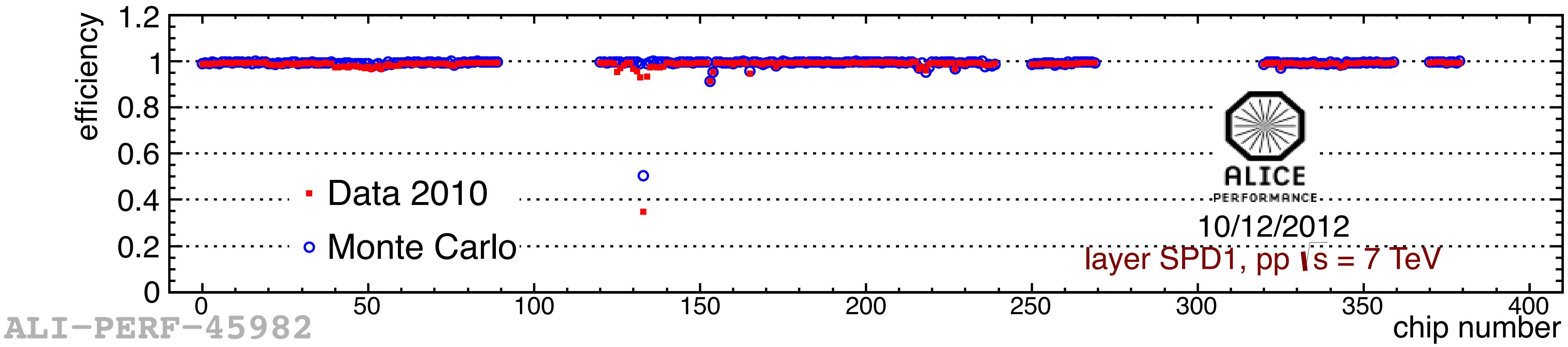


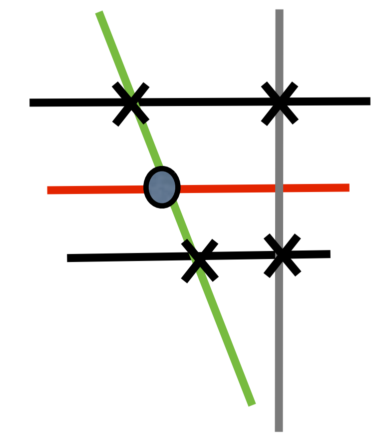


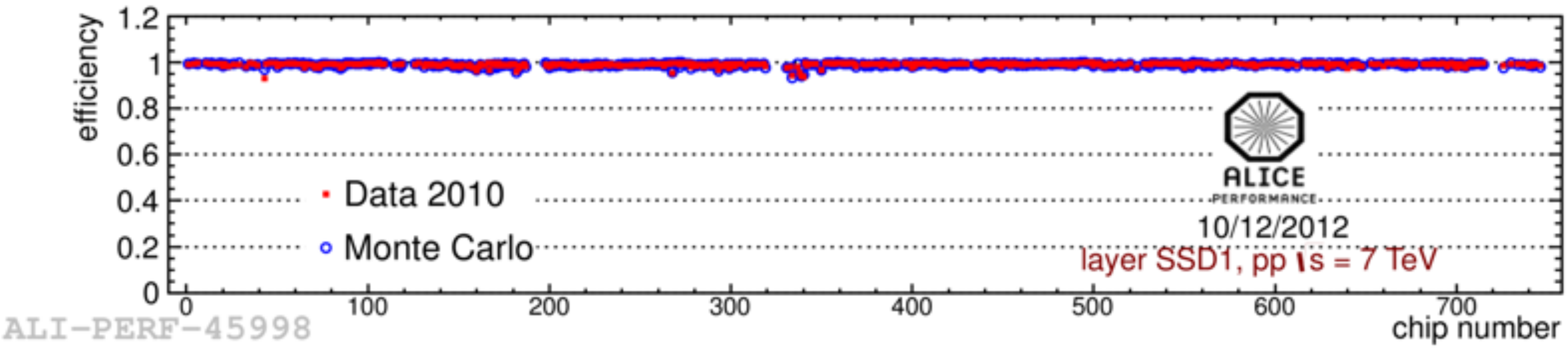
SSD charge released in each module. Each distribution is fitted with a Landau convoluted with an exponential.
First gain calibration with pp data @ 7 TeV and updated regularly

Sensor efficiency measurements

Efficiency = $N_{\text{clusters produced in the module under study}}$ / $N_{\text{total tracks}}$







Sensor efficiency integrated over the active elements of a layer is ~99% for all the 6 layers

Inefficiencies due to:

- inefficiency of the algorithm for the cluster-to track associations
- incomplete hermeticity of the detector, dead areas
- Inefficiency at the level of 0.5 - 1% in good agreement with Monte Carlo

ALICE Inner Tracking System Performance

Vertex reconstruction

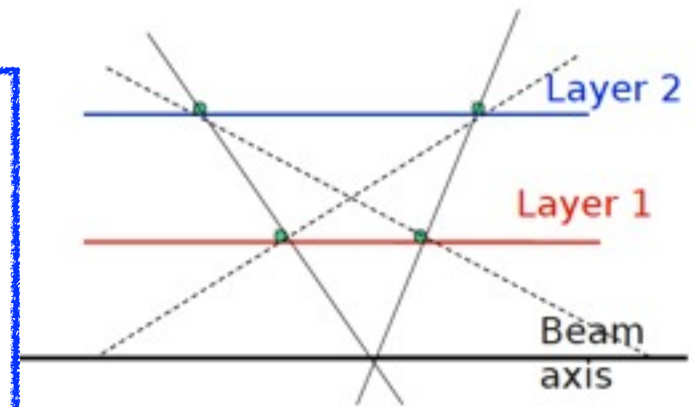
Vertex from ITS

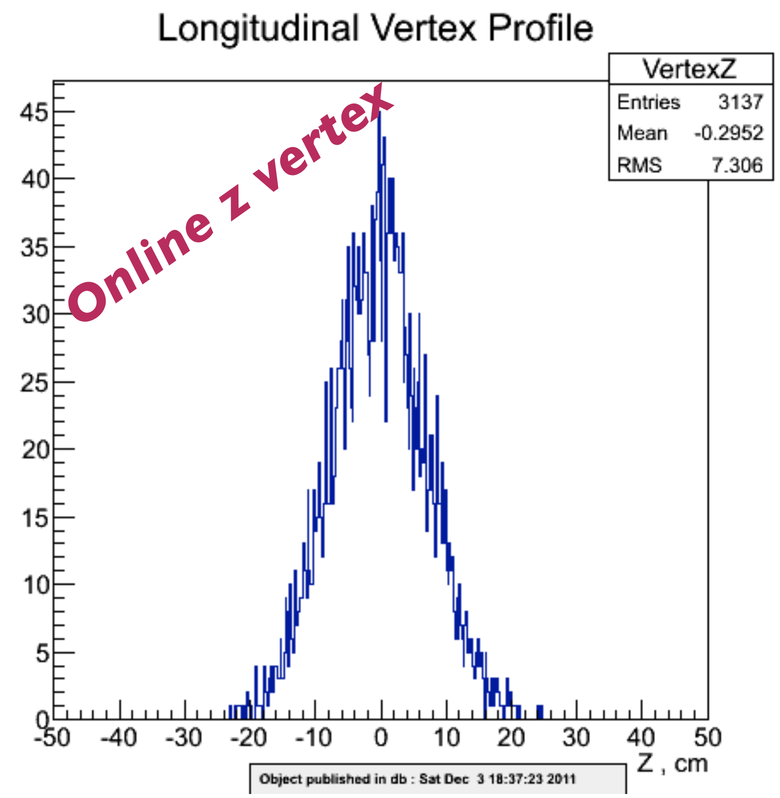
"SPDVertex" from all possible pairs of 2 aligned hits in a fiducial window (in φ, η)

Used to:

- Monitor the interaction diamond position quasi-online
- Initiate barrel and muon arm tracking

High efficiency and poorer resolution





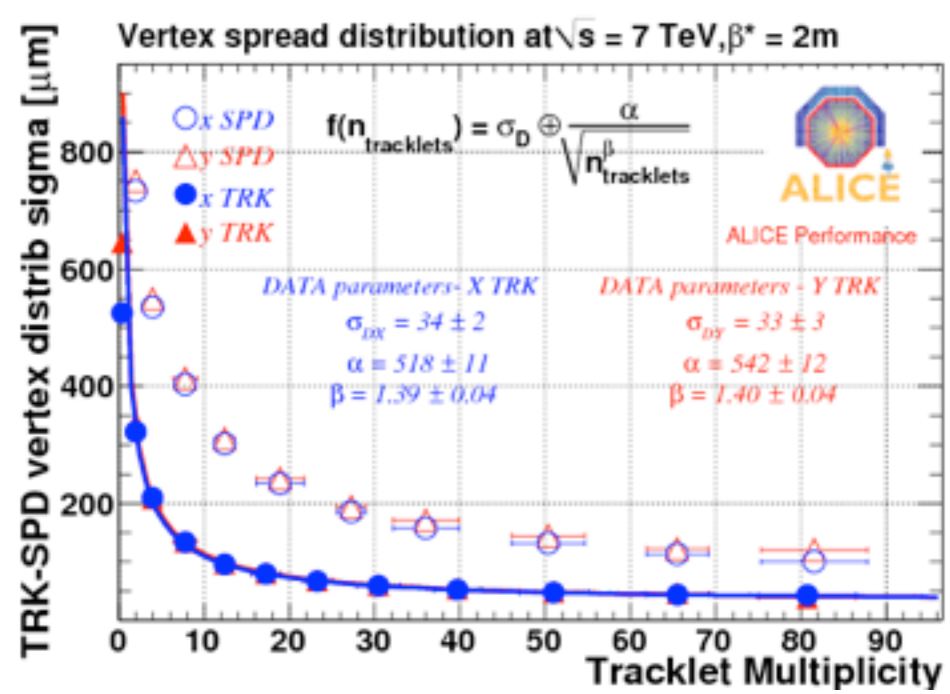
Vertex from reconstructed tracks

Straight line approximation of the reconstructed global tracks in the vicinity of the vertex.

Used to:

- Reconstruct secondary vertices
- Estimate the vertex resolution

Poorer efficiency and high resolution



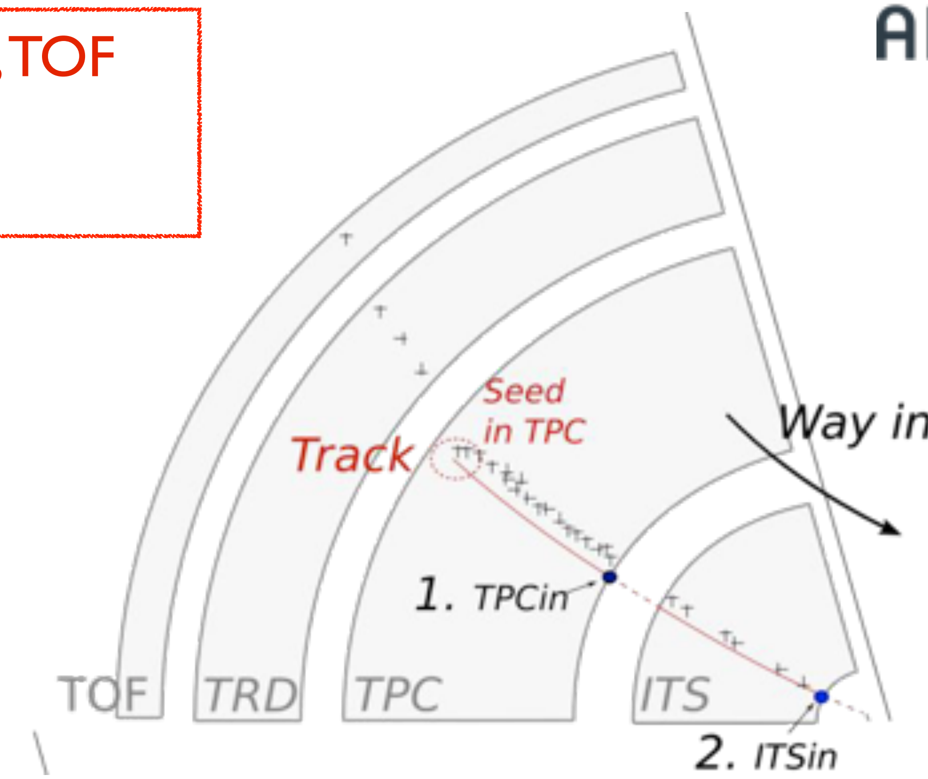
The asymptotic limit estimates the size of the luminous region, seen for the vertices reconstructed with tracks (filled markers).

Tracking strategy and performance

ITS contributes to global tracking together with TPC, TRD, TOF
+
allows for standalone tracking

Global tracking strategy

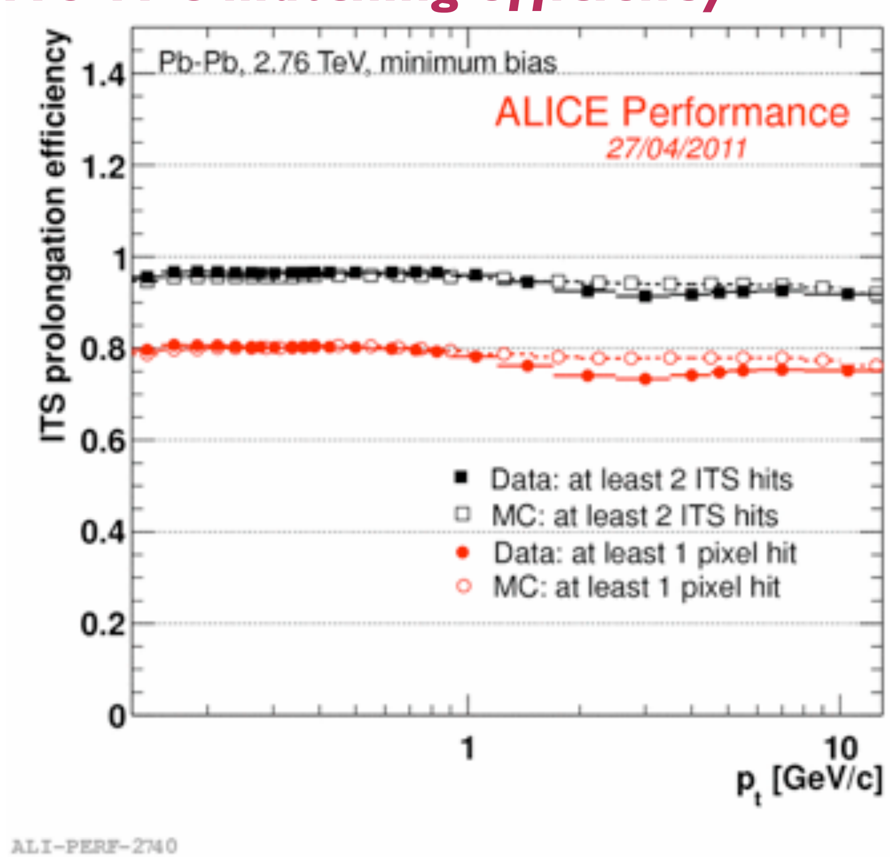
1. Vertex with SPD
2. Seeds in outer part of TPC (lowest track density)
3. Inward tracking from the outer to the inner TPC wall
4. Matching the outer SSD layer and tracking in the ITS
5. Outward tracking from ITS to outer detectors
6. Inward refitting to ITS
7. Refining vertex with optimal resolution (track method)



ITS Standalone tracking

- Recovers hits not previously used in the ITS layers
- Track and identify particles missed by TPC due to p_T cut-off, dead zones between sectors
    1. p_T acceptance extended down to 80-100 MeV/c (for pions)
    2. p_T resolution <~ 6% for a pion in p_T range 200-800 MeV/c

ITS TPC matching efficiency



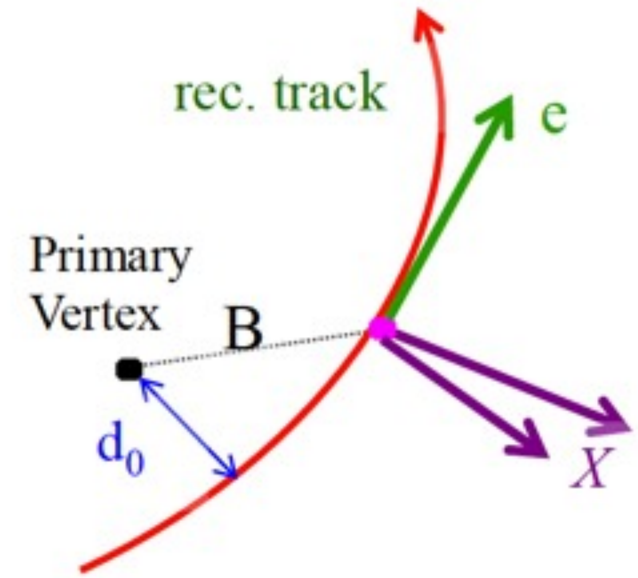
Impact parameter resolution

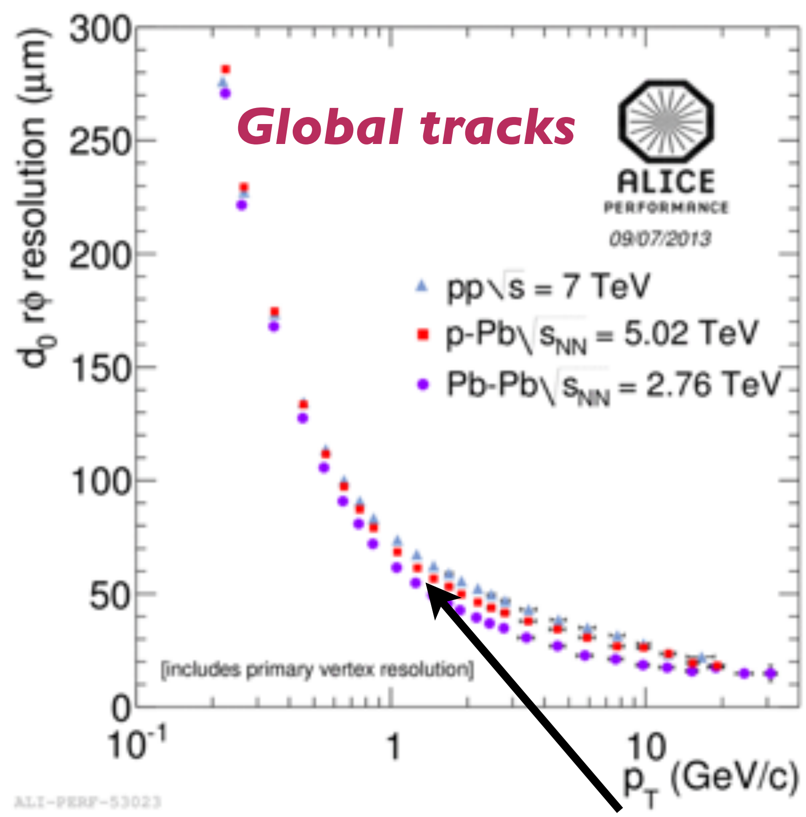
Impact parameter: distance between the track projection and the vertex position reconstruction in the bending plane

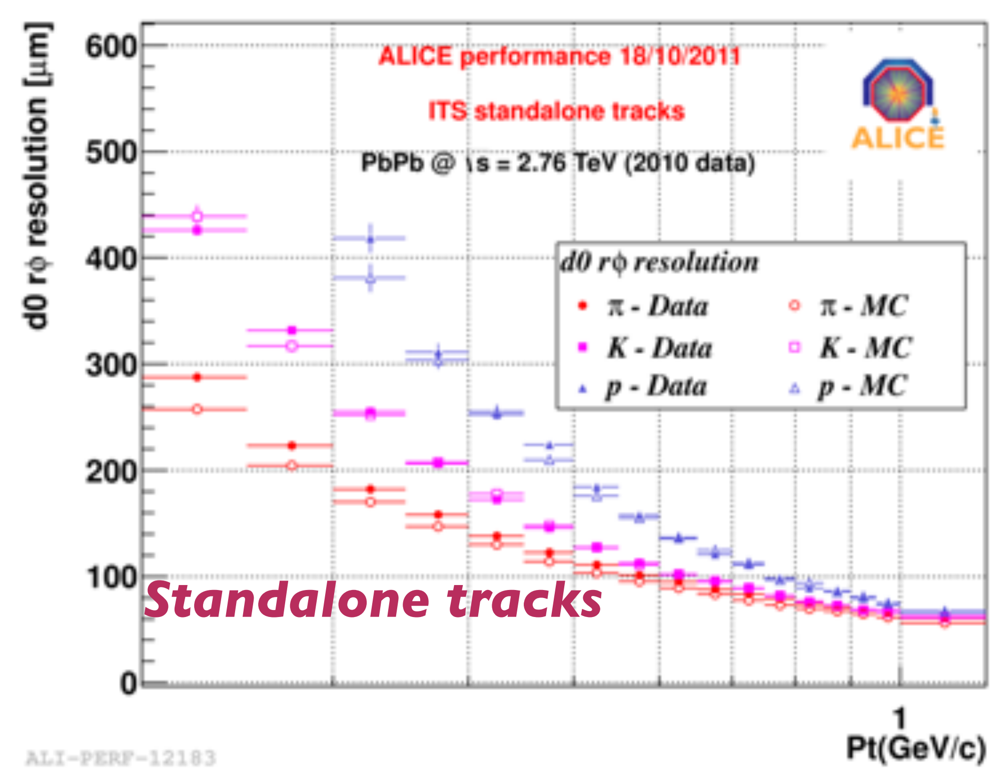
Reference variable to look for secondary tracks from displaced decay vertices (strange, charm, beauty particles)

The material budget influences the performance at low p_T

The point resolution of each layer drives the asymptotic performance



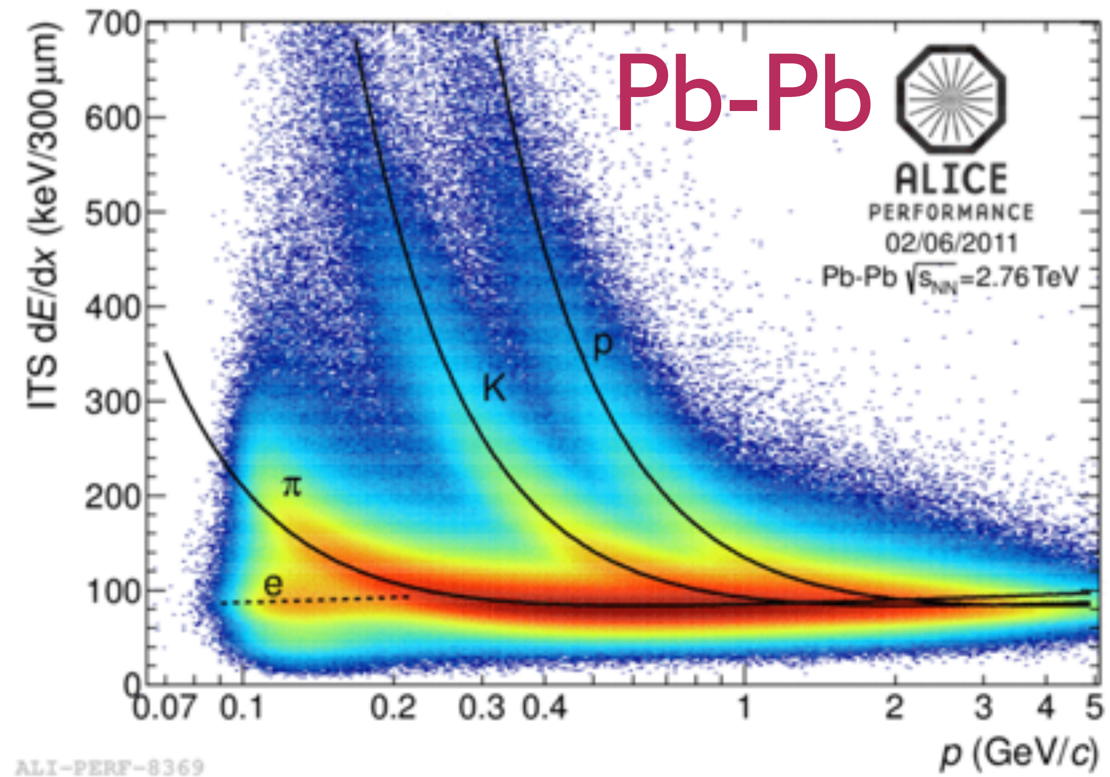




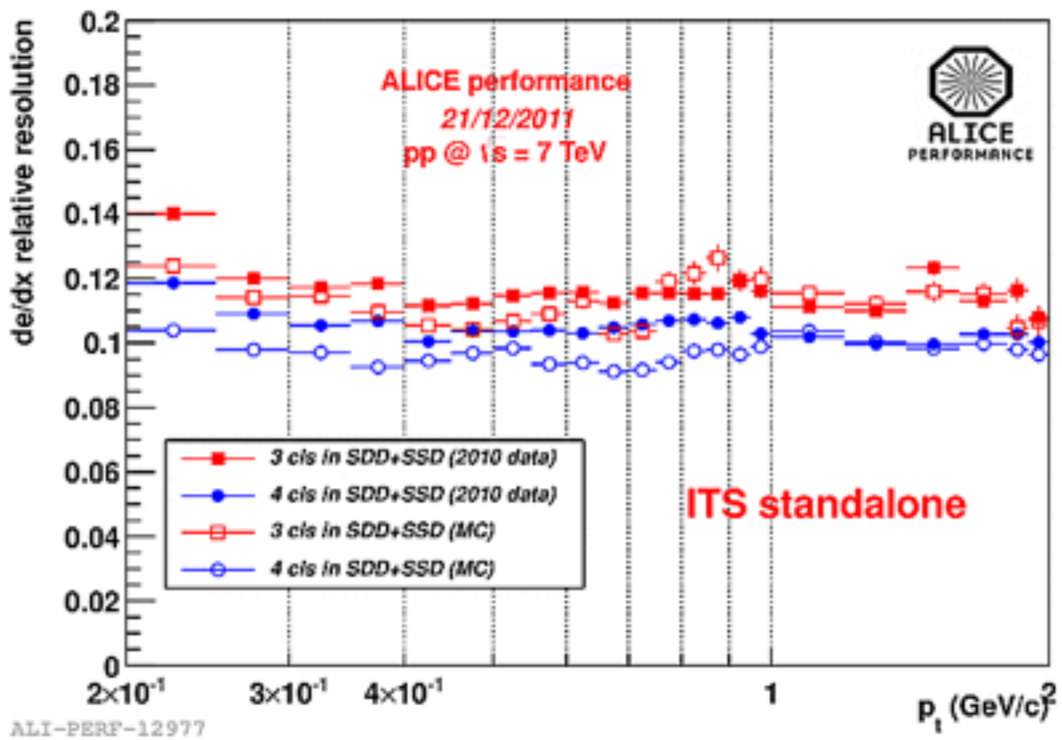
- ~ 60 μm at p_T = 1 GeV/c independent from the colliding system
- Small dependence from the colliding system due to the dependence from the vertex resolution

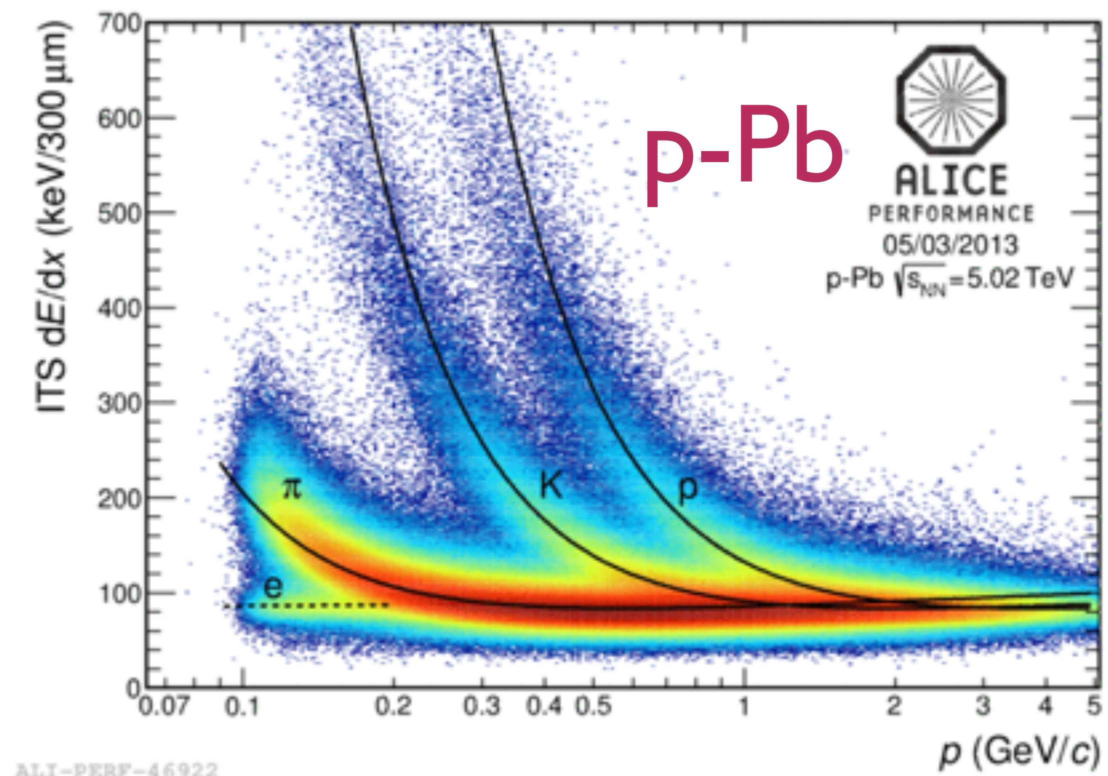
Particle identification

- Analogue read-out of four deposited charge measurements in SDD and SSD
- Up to 4 samples per track, combined via truncated mean: resolution better than 12% achieved
- PID combined with standalone tracking allows to identify charged particles below 100 MeV/c
    - p-K separation up to 1 GeV/c
    - K-π separation up to 450 MeV/c



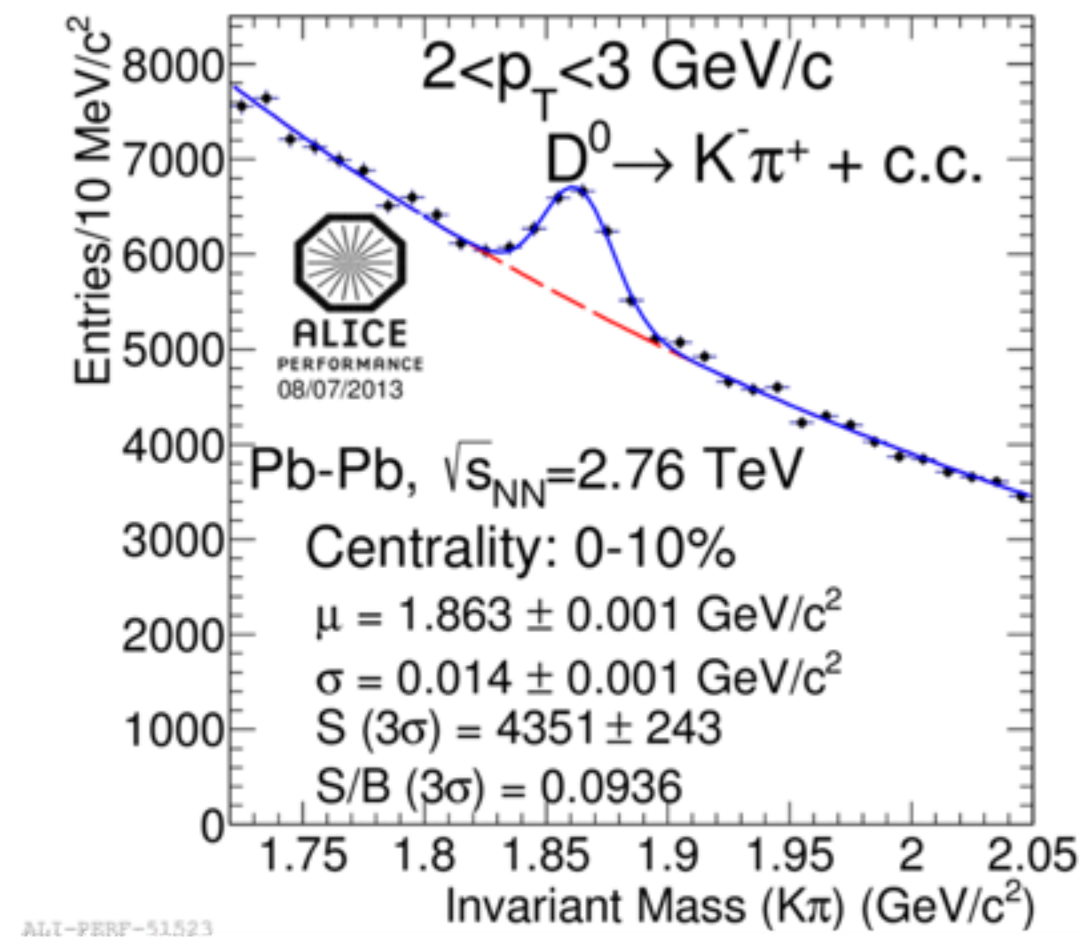
Good performance independently from the colliding system

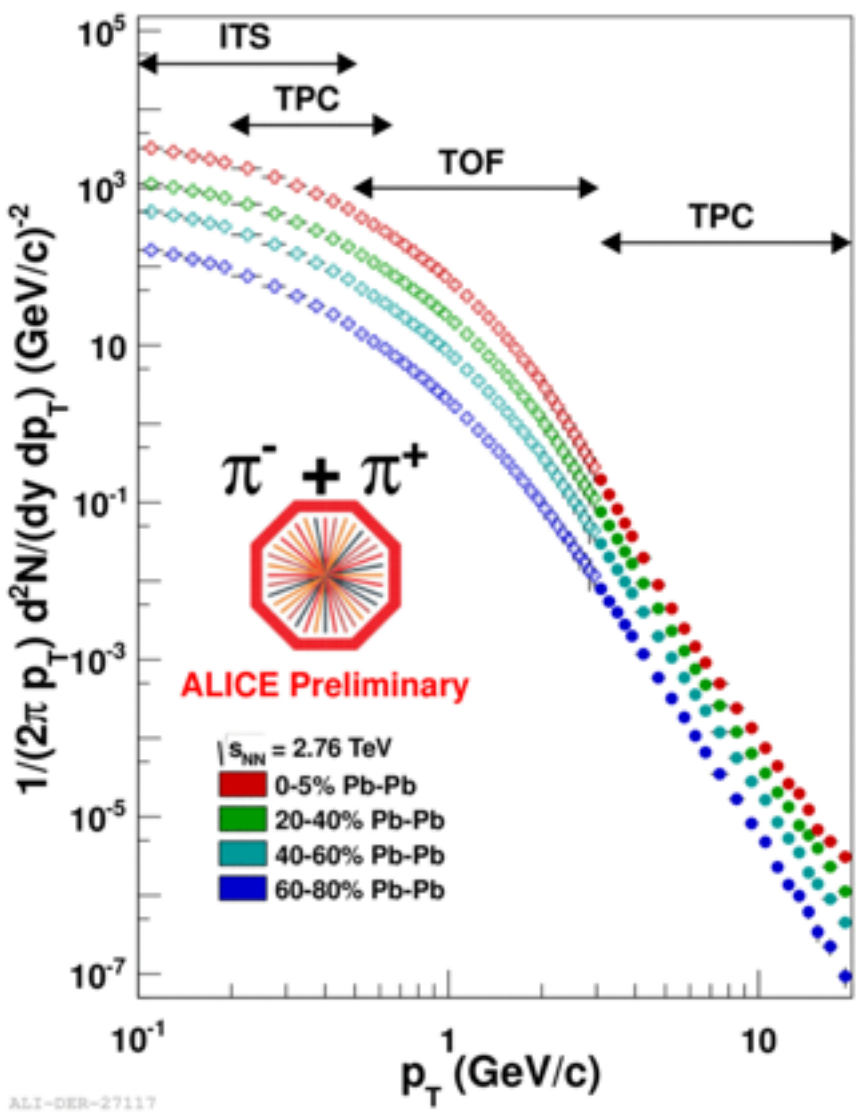




SECONDARY VERTICES RECONSTRUCTION

- Displaced of few 100 μm
- Impact parameter resolution better ~60 μm allows for the second vertex reconstruction





IDENTIFIED PARTICLES SPECTRA

- Combined results of different PID techniques
- Low p_T (down to 100 MeV/c) crucial contribution of ITS standalone tracking and PID
- Reducing extrapolation of the yield down to p_T = 0

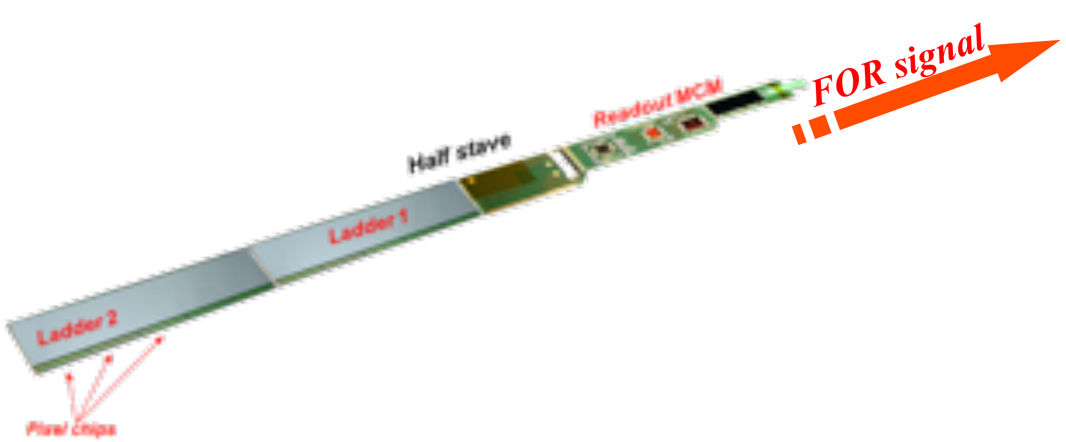
Conclusions

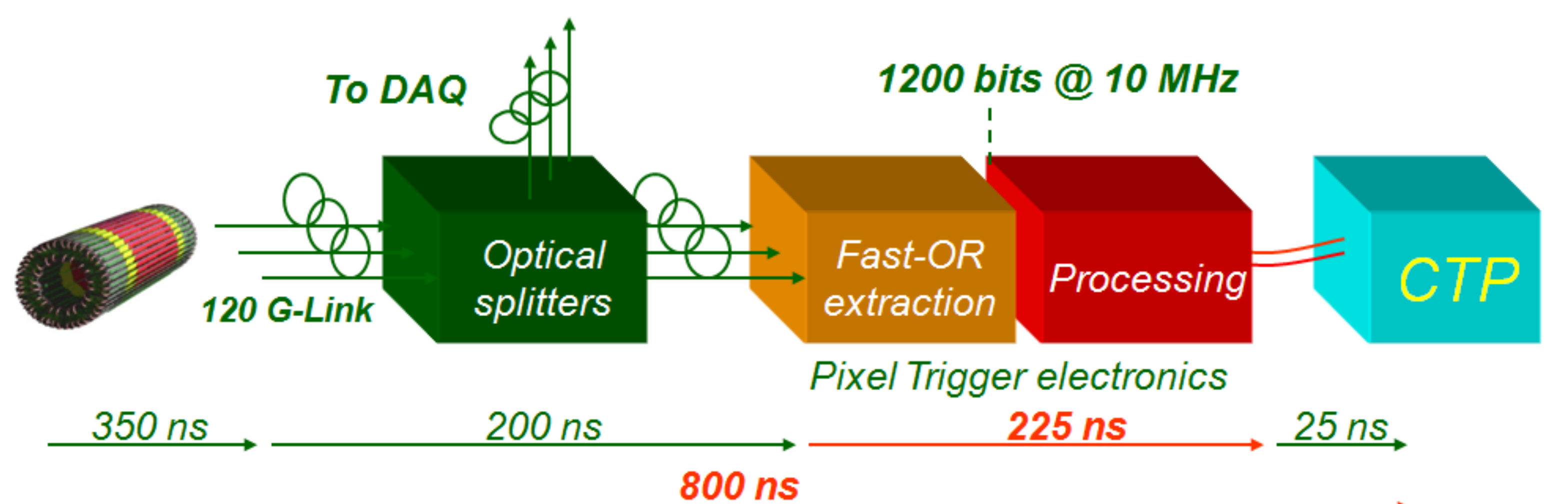
- ALICE Inner Tracking System has been in operation from 2010 to 2013 and participated in pp, p-Pb and Pb-Pb data taking
    - The three subsystems: SPD, SSD, SDD are performing remarkably well and they show a stable behavior
- The performance is well in agreement with the design requirements and is stable with time
    - Standalone capability allows one to track and identify charged particles with momenta down to 100 MeV/c.
    - In addition the particle identification performance allows for the separation of pions, kaons and protons down to very low p_T
    - Impact parameter resolution on ~60 μm for tracks with p_T =1 GeV/c allows the reconstruction of charmed decay secondary vertices
- ALICE ITS is performing very well but improved performance and more intriguing physics results are expected with the upgraded ITS. See **M. Sitta talk**


Back up slides

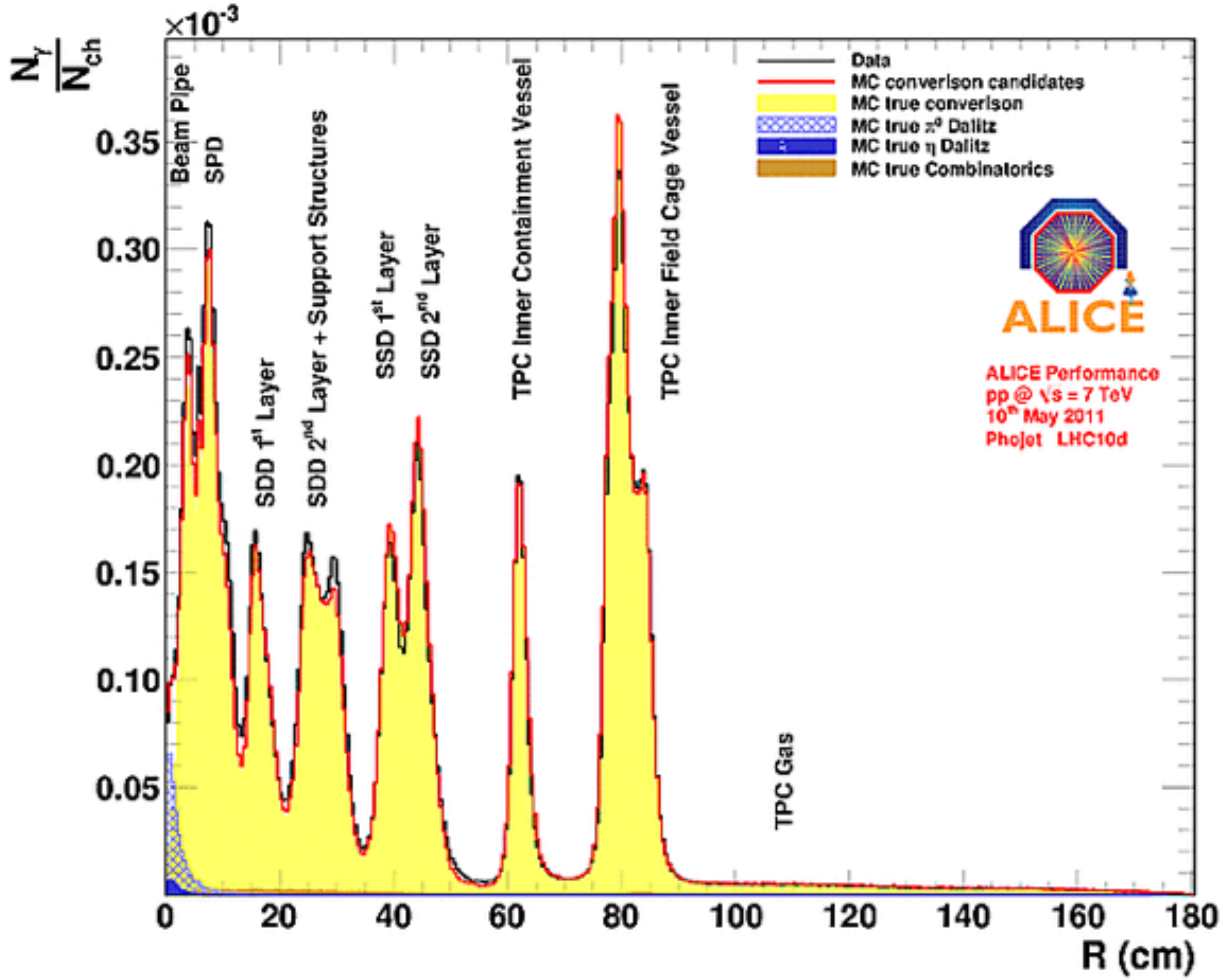
SPD L0 trigger

- Pixel chip prompt Fast-OR
  - Active if at least one pixel hit in the chip map
  - 10 signals in each half-stave (1200 signals in total)
  - Transmitted every 100 ns
- Overall latency constrain 800 ns (CTP)
- Key timing processing are data deserialization and Fast-OR extraction
  - Algorithm processing time < 25 ns
- 10 algorithms provided in parallel: useful for detector commissioning and physics
  - cosmic, minimum bias and multiplicity algorithms
- FPGA remote programmable to guarantee maximum flexibility



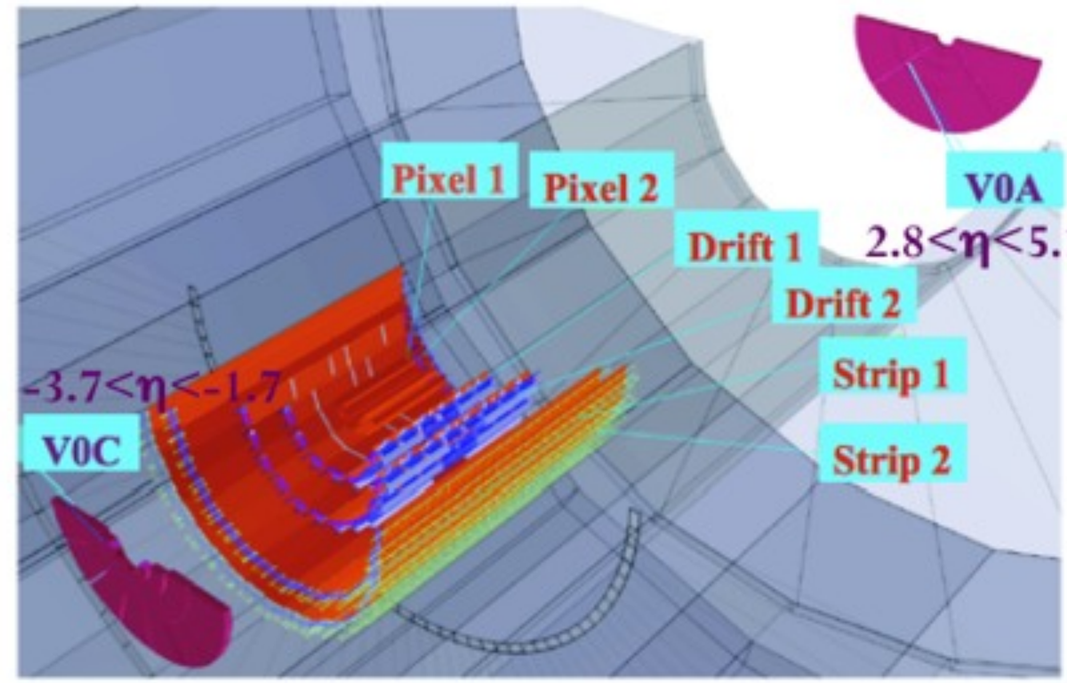


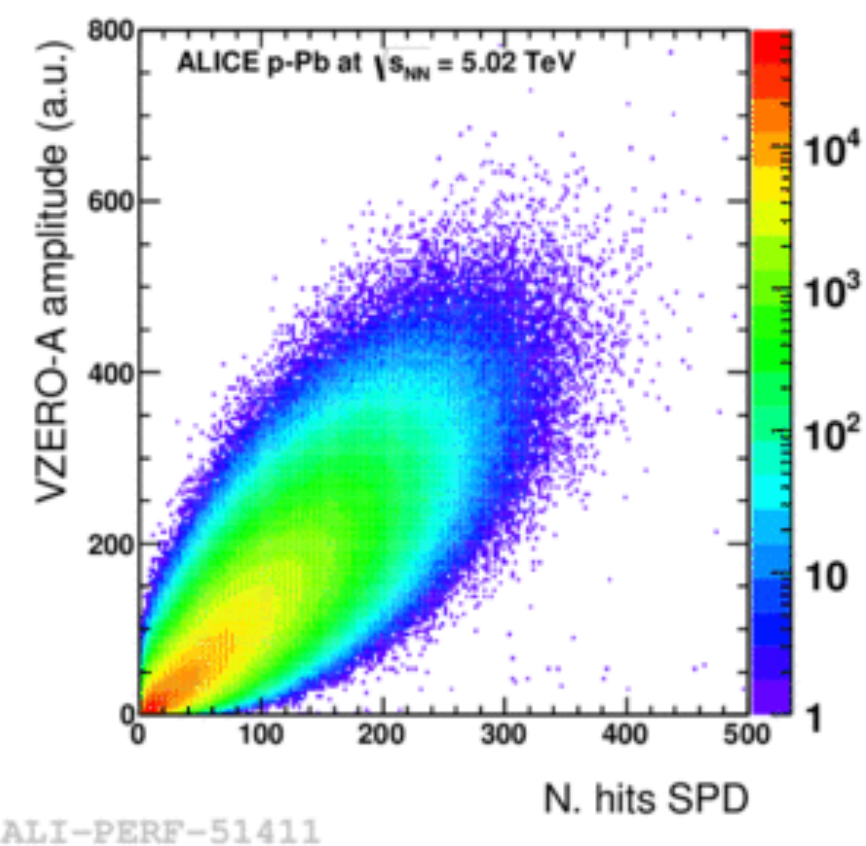
Material description in MC

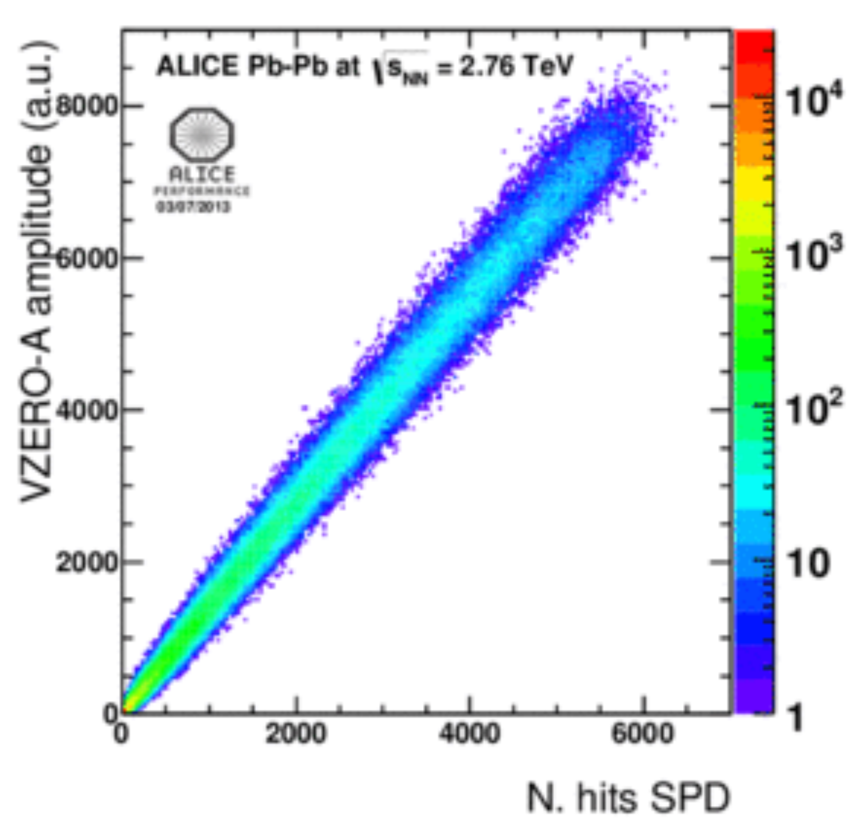


- Radial distribution of photon conversions compared with MC
- Accurate description of material in MC

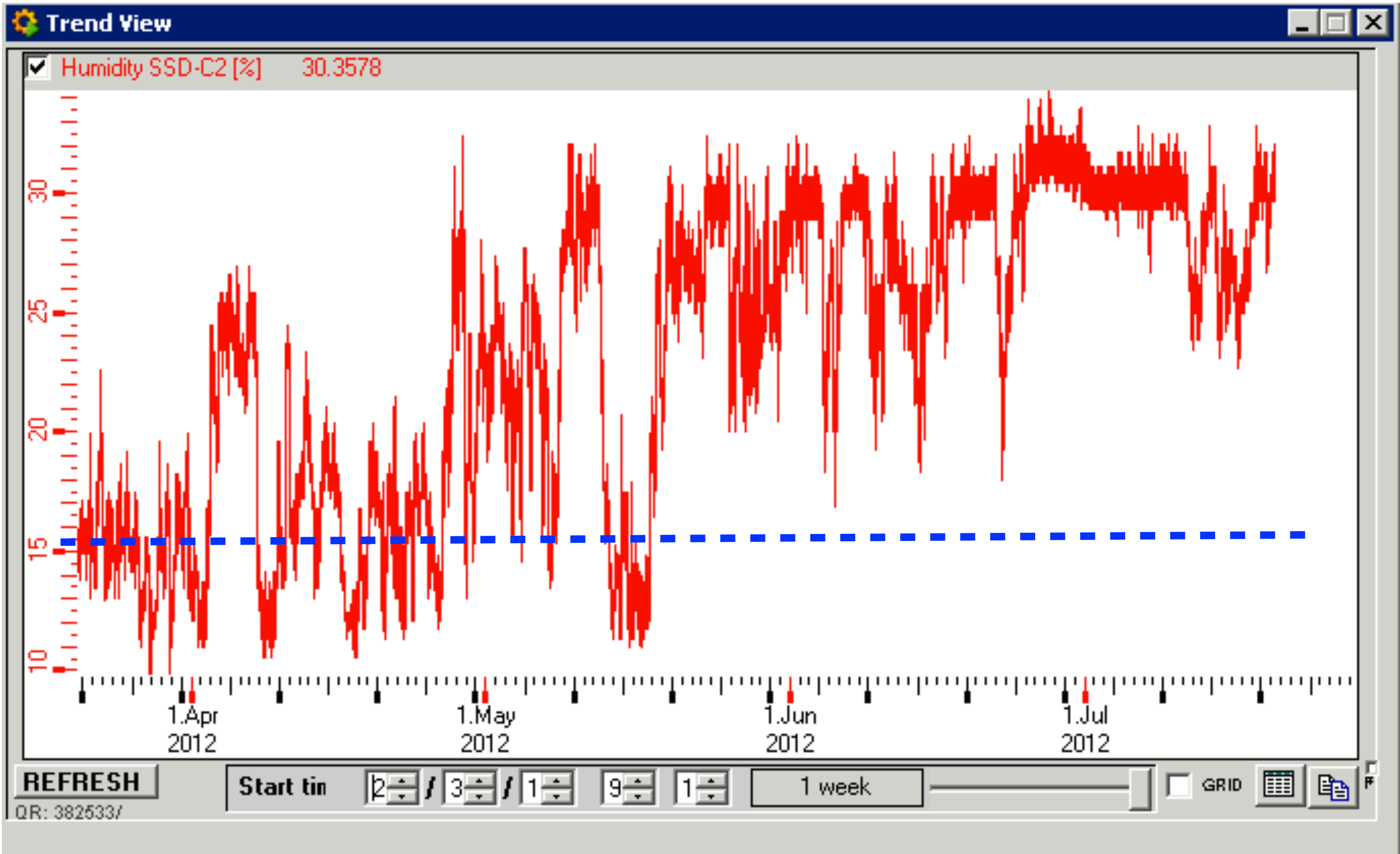
Centrality measurement





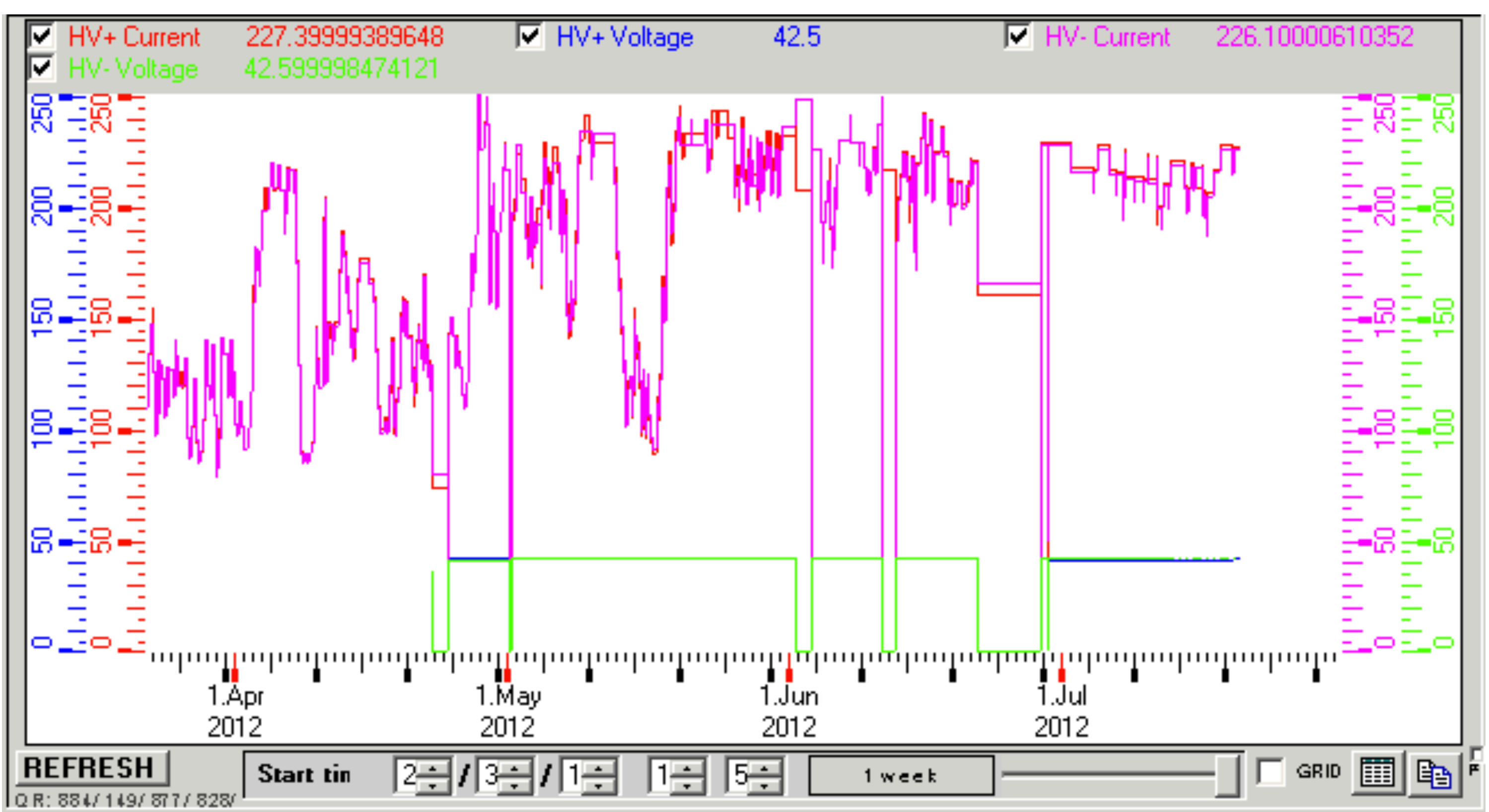


Humidity effect on SSD Sintef ladders



Humidity trend at the entrance of the SSD detector

Optimal RH set is 15%
Long period of operation at high RH (~30%)



Example of leakage current in a SINTEF ladder

Increase from 120 to 220 μA when operating in a high humidity environment @ constant HV applied

Current values goes back at low values when the RH is brought back at 15%.

Alignment strategy

A good alignment is crucial to achieve the required track impact resolution

~2200 modules: more than 13000 parameters to be determined

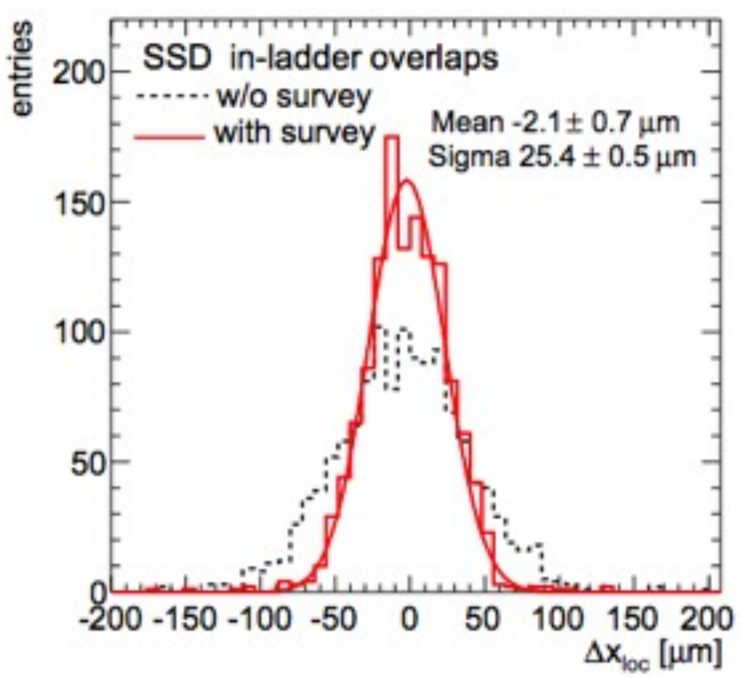
Data sample:

- 100K cosmic tracks collected in 2008 with dedicated pixel Level-0 trigger
- pp data with/without magnetic field

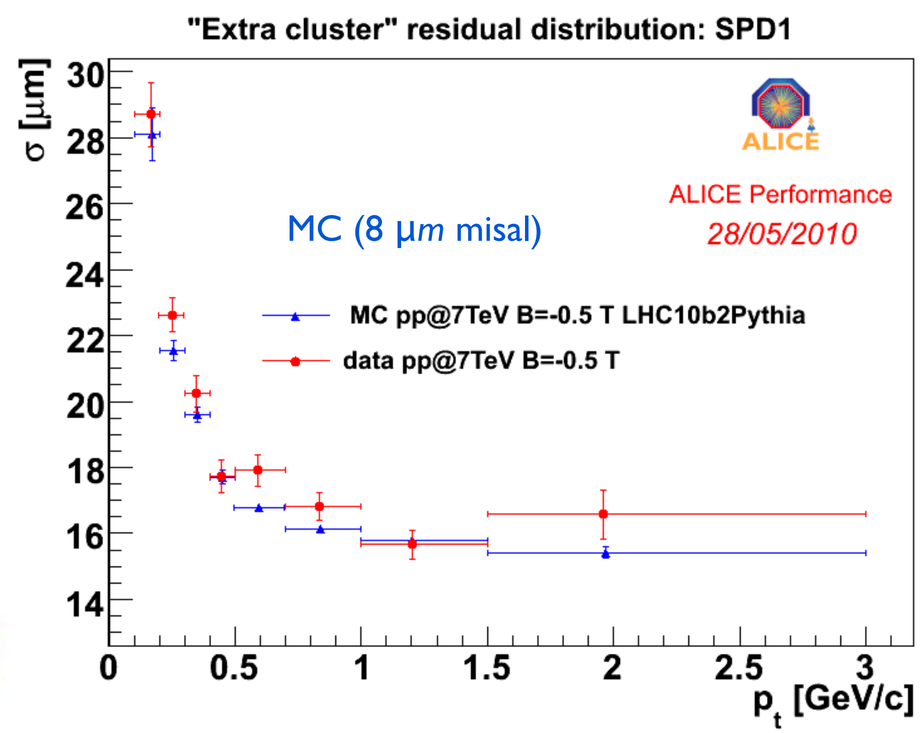
More details in JINST 5, P03003

Strategy:

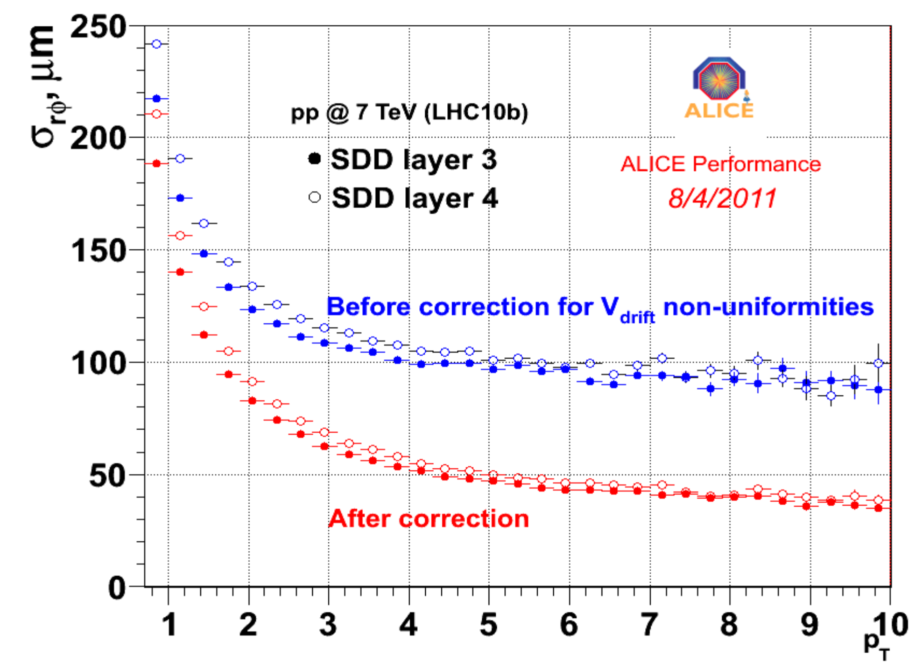
- Validation of survey measurement with cosmic-rays and tracks from pp collisions
- Millepede alignment of SPD and SSD
- Include SDD alignment
    - (longer calibration needed: interplay between alignment, drift velocity, time zero calculation)
- Relative ITS-TPC alignment



SSD: good alignment with survey. Millepede with cosmic used to align SPD barrel wrt SSD



SPD: residual misalignment of about 8 µm after survey and Millepede alignment

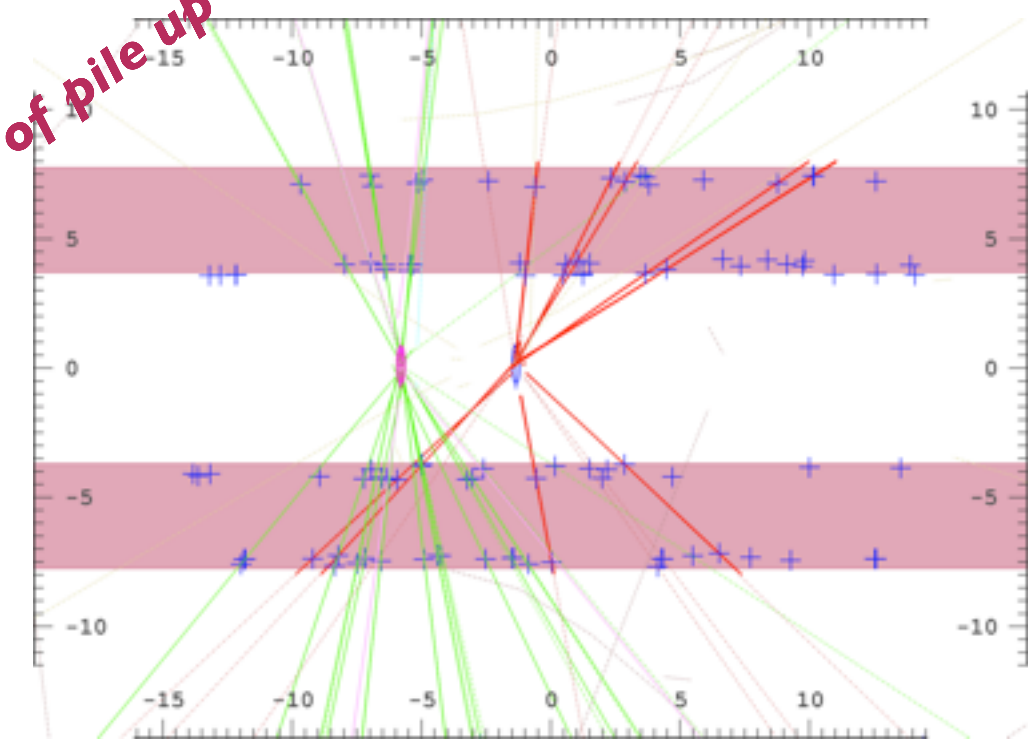


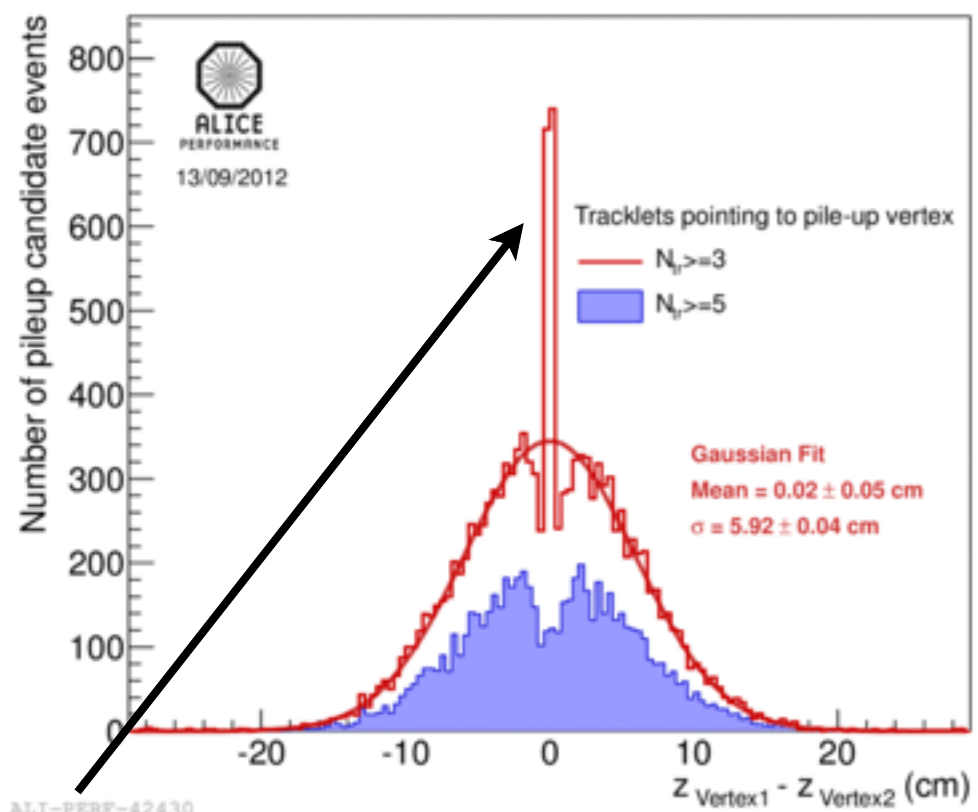
SDD: after correction for non-uniformity and fine tuning of v_{drift} and t_0: track to point residual ~30 µm at high p_T

Pile up detection with SPD

- The SPD can be used to tag pile-up interactions occurring in a time window of 100 ns in pp collisions (4 bunch crossing)
- Tracklets (pair of aligned clusters and a reconstructed vertex) not pointing to the main vertex are used to search for pile-up vertices
- Tagging efficiency is ~ 80% (for vertices separation of 0.8 cm)

Example of pile up vertices

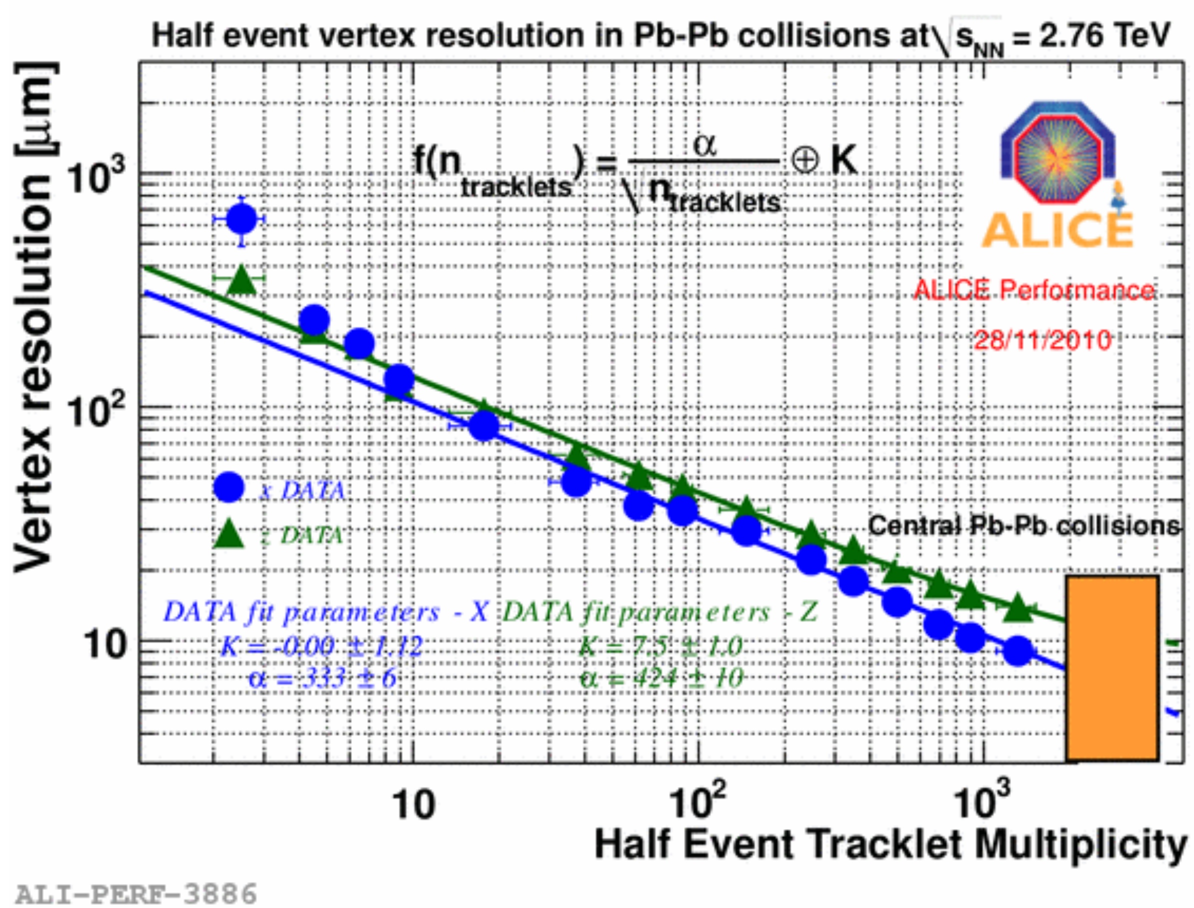




peak at Δz =0 corresponds to false positive. Removed requiring a higher number of tracklets

Vertex resolution

- Method:
  - The track sample is randomly divided into two sub-samples
  - A primary vertex is reconstructed for each sub-sample
  - The resolution is extracted from the sigma of the distribution of the resifdual between the 2 vertices
  - The resolution is extrapolated for the most central (5%) Pb-Pb collisions (orange box)



SPD Cooling System