ALICE ITS: Operational Experience, Performance and Lessons Learned

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on behalf of the **ALICE Collaboration**

The 28th International Workshop on Vertex Detectors,
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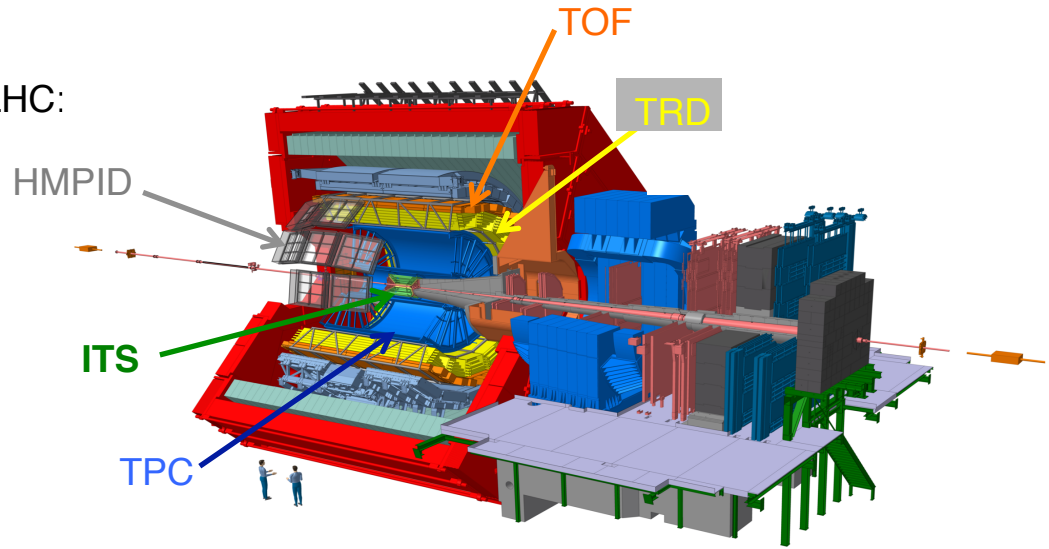
ALICE experiment

- **ALICE** (**A** **L**arge **I**on **C**ollider **E**xperiment) general purpose heavy-ion experiment at the LHC:
  - Strongly interacting matter
  - QGP properties



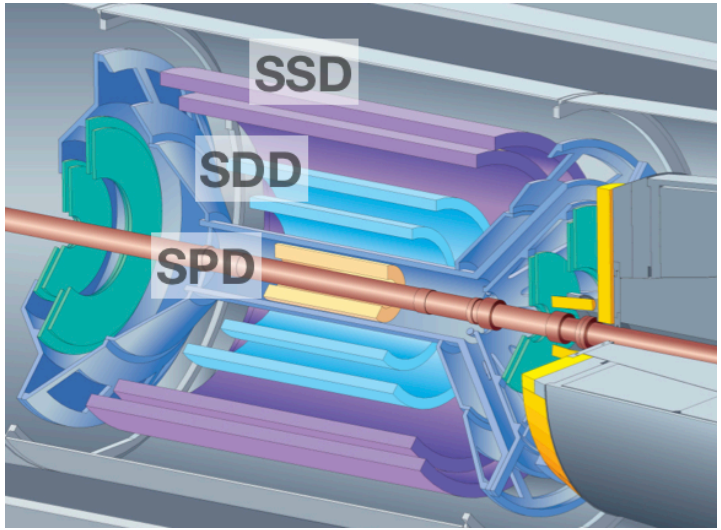
forward muon spectrometer
$-4 < \eta < -2.5$

- **Central Barrel**: pseudorapidity $|\eta| < 0.9$
  - *Tracking* in high density collisions:
    - $dN/d\eta \sim 1600$ in central Pb-Pb
  - *PID* (Particle IDentification):
    - dE/dx : ITS, TPC
    - Time of flight: TOF
    - Transition radiation: TRD
    - Cherenkov radiation: HMPID
  - Low p_T reach: ~ 0.1 GeV/c (p_T : 0.1 – 100 GeV/c)
    - Moderate magnetic field B = 0.5 T
    - Low material budget: (10% X_0 for ITS+TPC)

Inner Tracking System

Six cylindrical layers of silicon sensors

- Silicon Pixel Detector (SPD): two innermost layers
- Silicon Drift Detector (SDD): two intermediate layers
- Silicon Strip Detector (SSD): two outermost layers



Trade-off between track density and available resources

The ITS is optimized for:

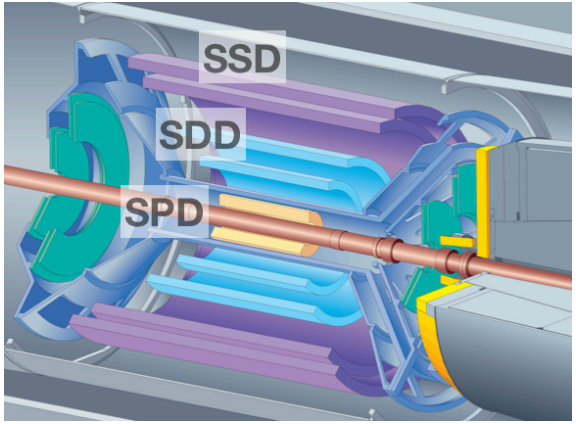
- **primary vertex** reconstruction (resolution better than 100 μm)
- **impact parameter** determination
- separation of primary and **secondary vertices**
- **PID** and **tracking** at low p_T
- **pileup** rejection
- charged-particle **pseudorapidity distribution** determination

Inner Tracking System

- Radial dimensions:
  - from 3.9 cm (close to beam pipe) to 43.0 cm (close to TPC inner wall)

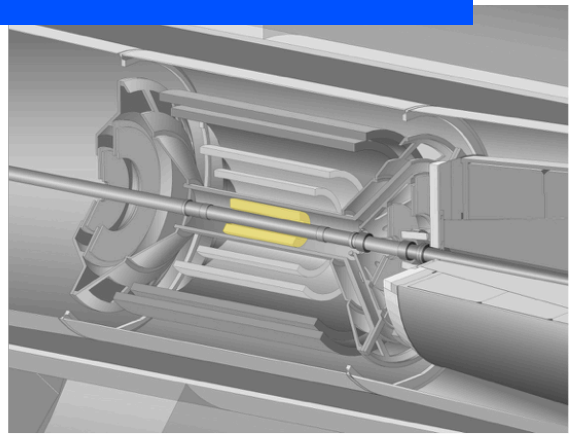
- Material Budget (M.B.):
  - ~ 1% X_0 each layer

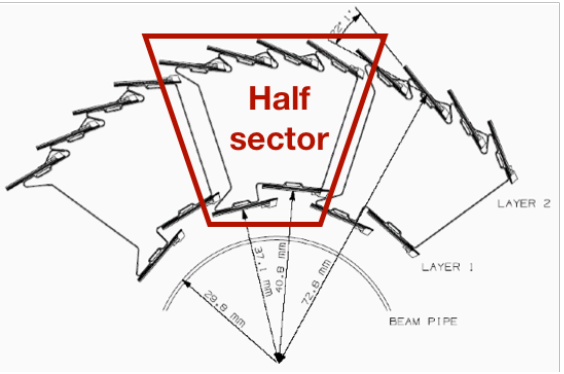
Layer	Det.	Radius (cm)	Length (cm)	Channels	Area (m^2)	Resolution (μm)		M.B. (%X_0)
						rφ	z	
1	SPD	3.9	28.2	3.3 M	0.07	12	100	1.14
2		7.6	28.2	6.6 M	0.14			1.14
3	SDD	15.0	44.4	43 k	0.42	35	25	1.13
4		23.9	59.4	90 k	0.89			1.26
5	SSD	38.0	86.2	1.1 M	2.20	20	830	0.83
6		43.0	97.8	1.5 M	2.80			0.86

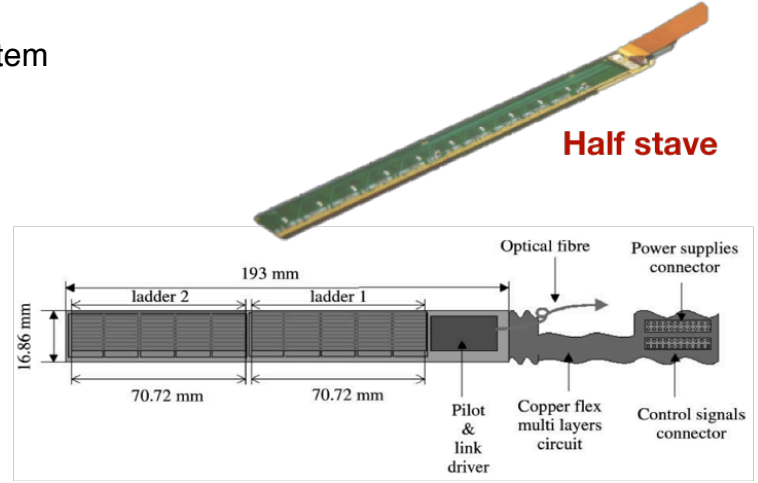


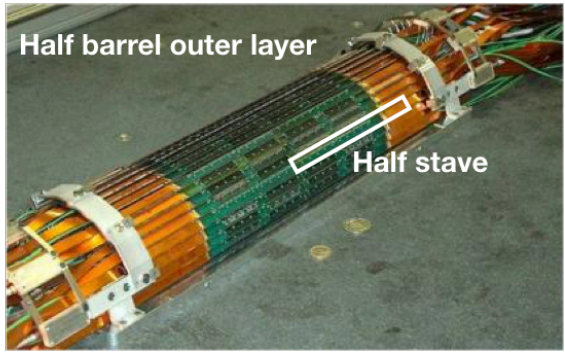
Silicon Pixel Detector

- 120 Half-Stave (HS) modules (40+80), grouped in two Half Barrels
  - each HS contains 2 ladders:
  - 1 sensor (200 μm thick) + 5 readout chips (150 μm thick), bump bonded
  - Hybrid pixel sensors with binary output
  - p^+n reverse biased (50V)
  - cell size 50 µm (rφ) x 425 µm (z) - 256(rφ) x 160(z) cells/sensor
- Each half-barrel divided into 10 half sectors
  - 6 HS: 2 in Layer 1 + 4 in Layer 2
- C_4F_{10} evaporative cooling system



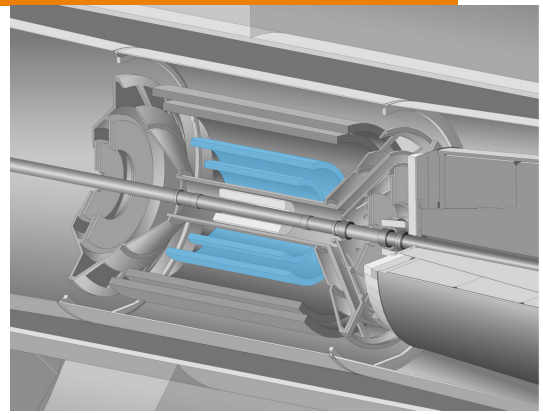


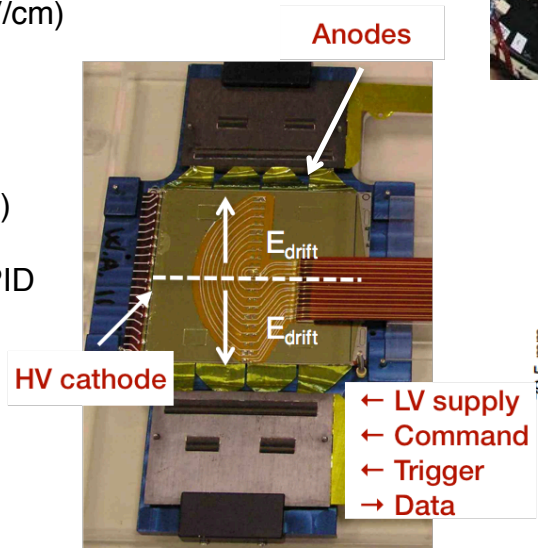


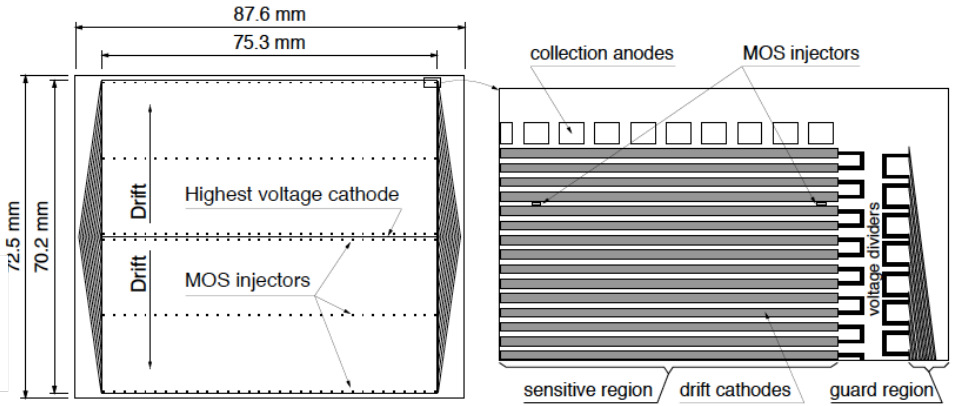


Silicon Drift Detector

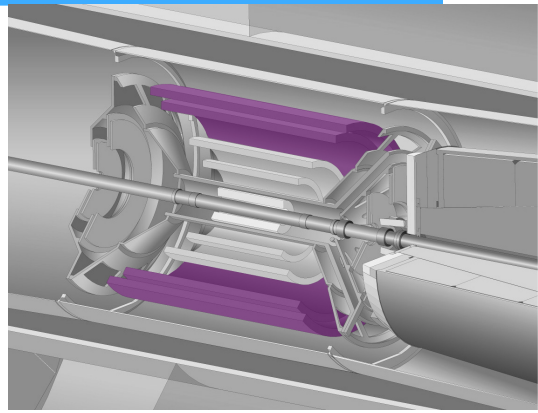
- Two layers, 260 silicon drift modules (300 μm thick)
  - Layer 3: 14 ladders with 6 modules each
  - Layer 4: 22 ladders with 8 modules each
- 2*256 collection anodes (294 μm pitch)
- 2*2*291 p^+ drift cathode strips (120 μm pitch)
- Drift HV: 1.8 kV (E~500 V/cm)
- Drift velocity: 6.7 μm/ns
- MOS Injectors to monitor drift velocity (33*3*2 rows)
- d*E*/d*x* measurement for PID
- Leak-tight water cooling



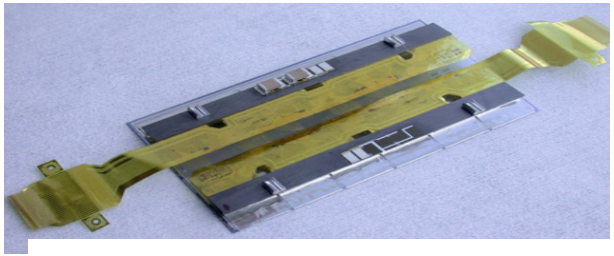




Silicon Strip Detector

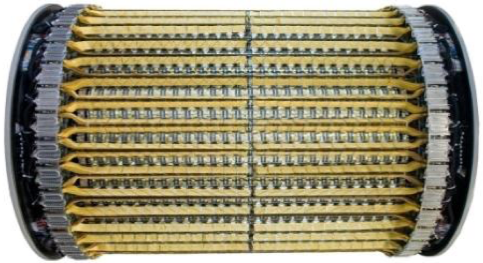


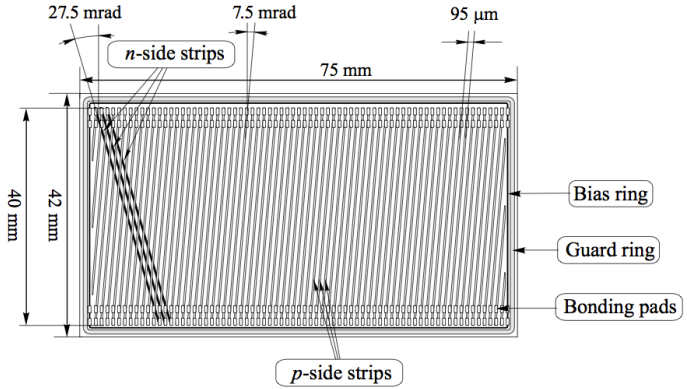
- 1698 silicon strip modules (300 μm thick)
  - Layer 5: 34 ladders with 22 modules each
  - Layer 6: 38 ladders with 25 modules each
- 768 double-sided strip sensors per module:
  - pitch (rφ): 95 μm; length: 40 mm; angle: 35 mrad
- dE/dx measurement for PID
- Leak-tight water cooling system + air dryer system



SSD modules: silicon sensor + 2 hybrids with six HAL25 chips each

SSD barrel



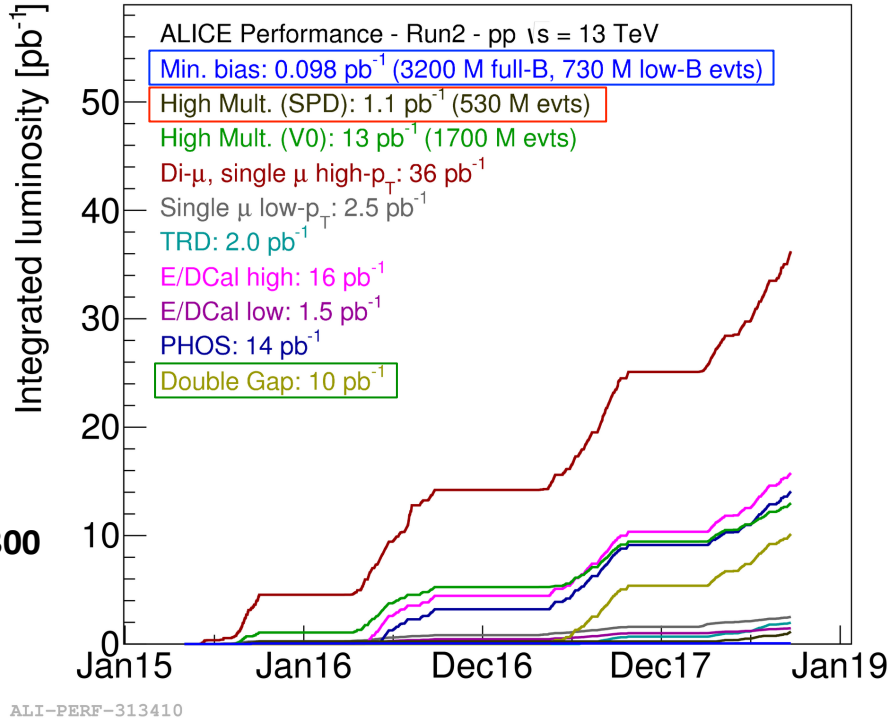


Trigger: SPD

- **L0 Trigger: Minimum Bias**
  - **Fast-OR**: at least one hit in a readout chip
  - INPUT: 1200 bits every 100 ns from SPD to CTP
  - OUTPUT: 10 programmable output based on boolean logic
  - **Maximum latency** at CTP input: 800 ns

- **L0 Trigger: High multiplicity trigger, enrichm. factor ~100**
  - **Fast-OR** signals (100 ns time window)
  - Online beam-gas interaction rejection
  - **Past-future protection**
  - **HM selection**: thresholds on hits in layer 1 and layer 2

- **L0 Trigger: Double Gap diffractive trigger, enrichm. factor ~300**
  - Low-multiplicity events (2-4 tracks)
  - V0 veto
  - **Fast-OR** signal in mid-rapidity region
  - **Topological trigger**:
    - **Opening angle** between two cones
    - Minimum and maximum **number of tracklets**



Detector Control System

- Each detector has its **DCS** to:
  - remotely **control** underground **hardware**
  - apply specific **operation strategies**
  - independent **monitoring** of **operational conditions** and **data quality** (misconfiguration spotted during data taking)

- Each detector has specific security operations for beam injection failures, according to past experience
  - **SPD**: Beam injection or adjustment → reverse bias voltage to 2V (sensor not depleted) and FEE and read-out electronics power-up
  - **SDD**: Beam injection or adjustment → HV and LV off, but readout electronics ready
  - **SSD**: HV and LV always at their nominal value

Experiment Control System

- Each detector has its **ECS** to perform specific operations (stand alone runs, calibrations)
- **Each detector has specific calibration strategy:**
  - **SPD:**
    - Configuration performed once per data taking, followed by tuning
    - Noisy-pixel mask updated when a noisy pixel is detected
    - *online vertex diamond determination*
  - **SDD:**
    - Baseline, noise, gain and drift speed at the beginning of each physics fill, dedicated runs
  - **SSD:**
    - Baseline and noise at the beginning of each physics fill, dedicated calibration runs
- for all detectors, condition data and the online calibration parameters are written in the Offline Condition Data Base (OCDB) at each EoR
- **D**etector **Q**uality **M**onitor and offline **Q**uality **A**ssurance to monitor behavior/performance on run/period basis

Detector Acceptance/Availability

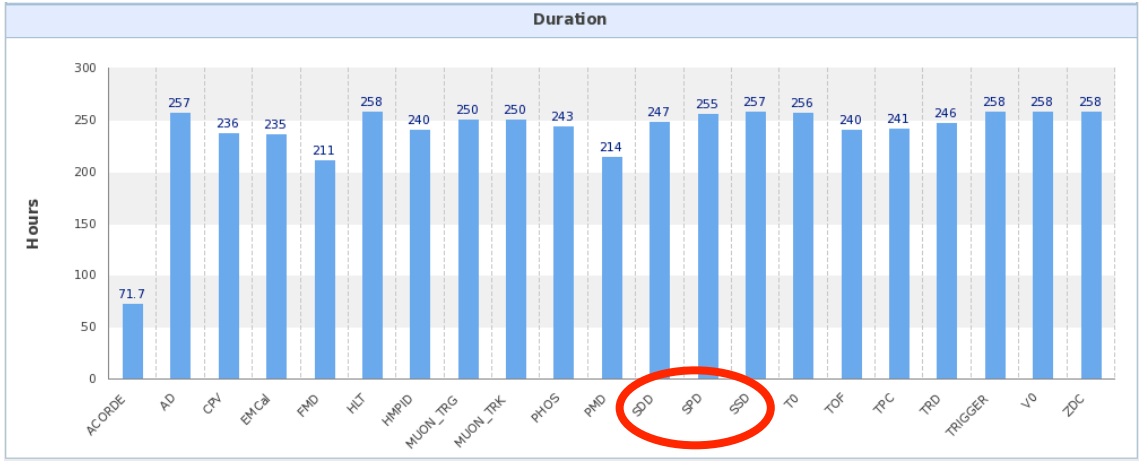
	Acceptance [# of modules]		
	SPD	SDD	SSD
Run1	92%	87%	91%
Run2 (2015-2016)	93%	83%	91%
Run2 (2017)	93%	82%	91%
Run2 (2018)	92%	81%	91%

2018 Pb-Pb run time availability

- SPD: 98.8% (3h out due to hardware problem)
- SDD: 95.7% (100% with central barrel, SDD not included in rare triggers)
- SSD: 99.6% (out only during Electro Magnetic Dissociation runs with SPD, V0 and ZDC only)

SPD: reduced acceptance during Run1 due to cooling system filters clogging solved during LS1

SDD: during installation two HL of layer 3 lost communication; sparse modules: DAQ communication problems.

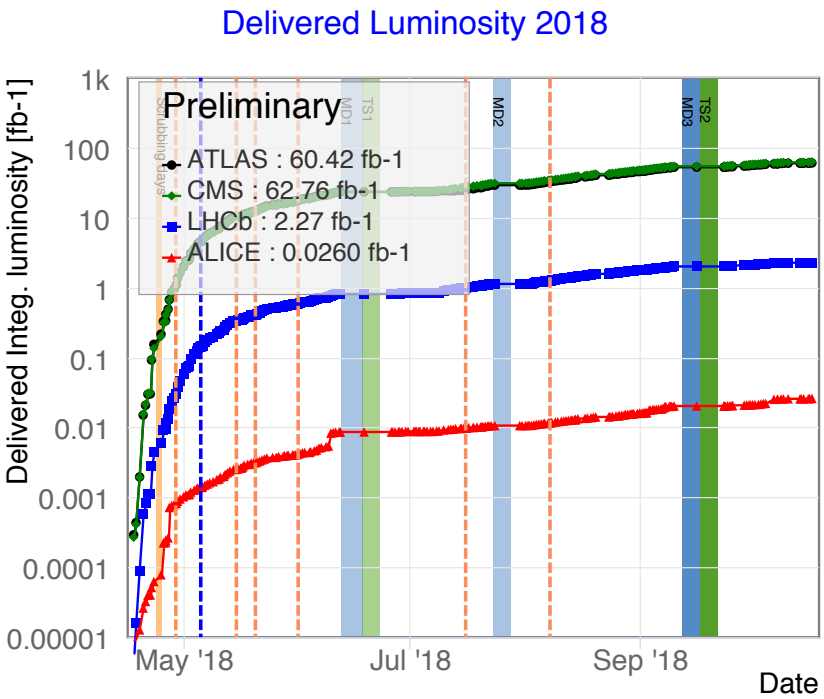


Radiation effects

- ALICE runs at reduced luminosity to cope with TPC read-out rate
  - ALICE luminosity leveled to 2.6 Hz/μbarn
  - the integrated dose of ITS is much lower than the other LHC experiments

Expected integrated dose since LHC startup

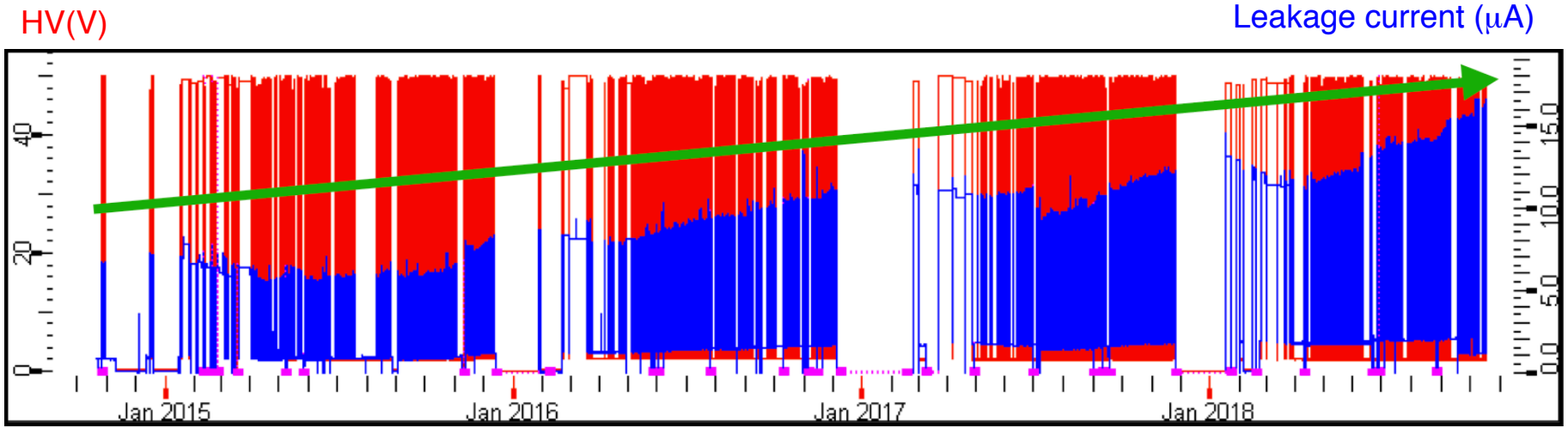
Detector (inner radius)	TID (krad)	1 MeV neq (cm^{-2})
SPD (r = 3.9 cm)	17.4	$2.9\ 10^{11}$
SDD (r = 15 cm)	1.5	$3.6\ 10^{10}$
SSD (r = 38 cm)	0.34	$1.6\ 10^{10}$



No increase in noisy channels and temperature, but increasing leakage current for some SPD Half Staves!

SPD observed effects

- A continuous slight increase of the bulk leakage current was observed for some HSs
  - 8/9 belong to Layer 1 (higher dose)
  - tune current limits before data taking (January & August 2018)

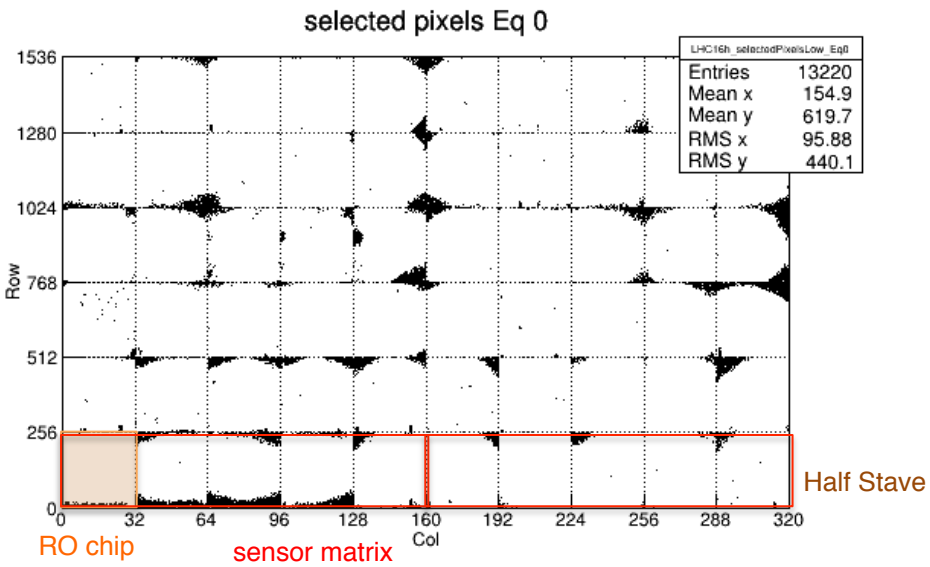


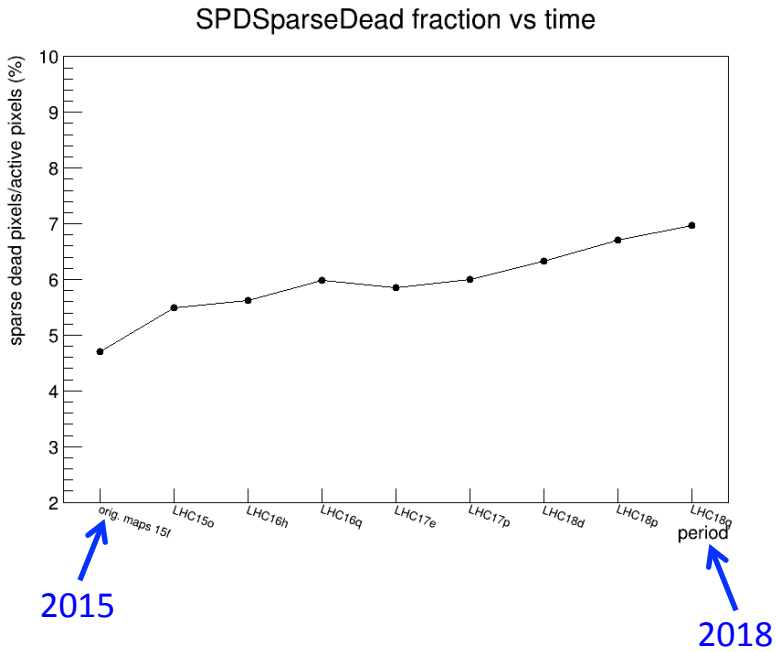
- Stable number of noisy pixels and temperature

- No effects on the performance in terms of detection efficiency and space accuracy

SPD observed effects

- slight increase of the sparse dead pixels fraction
  - mainly at the edges of the readout chips
  - issue of bump bonding breaking
  - mechanical stress, temperature effect, …..



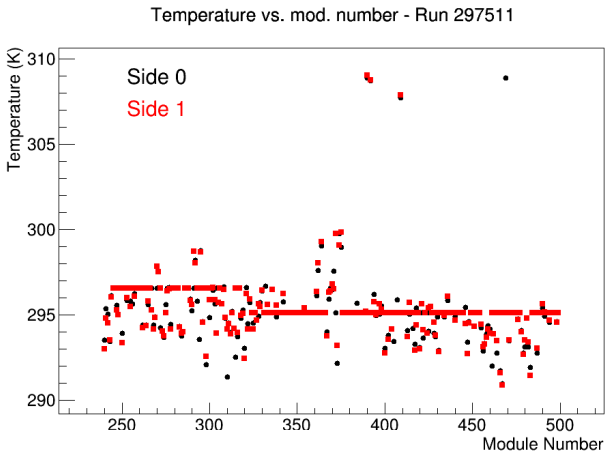


SDD observed effects

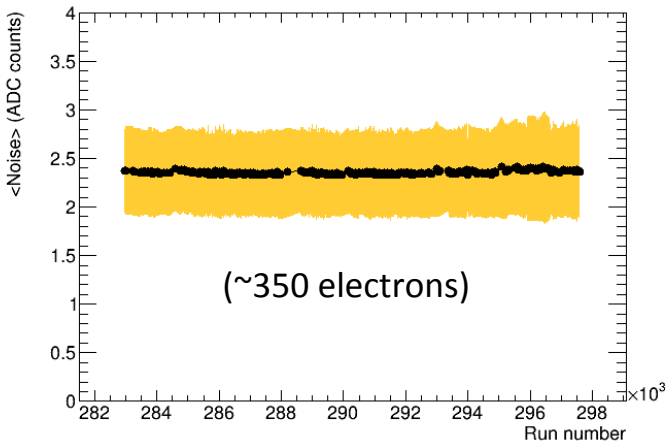
- Stable **drift speed**
  - measured during the **calibration steps** with the **MOS injectors**
  - drift speed depends on **temperature**:

$$v_{drift} \propto T^{-2.4}$$

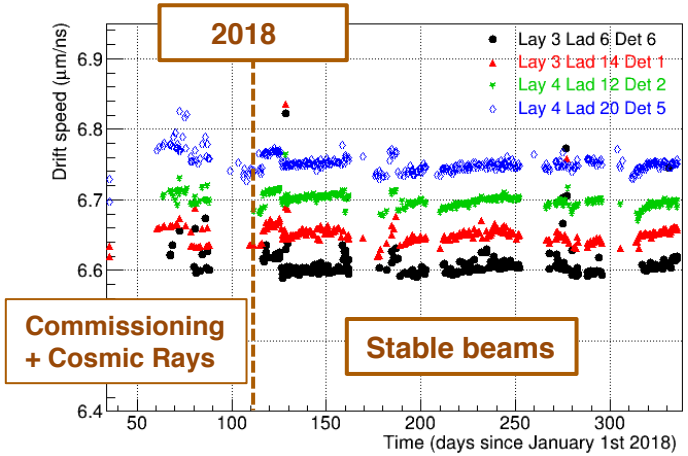
  - 0.8%/K variation at room temperature
  - 0.1% resolution on vdrift to get spatial resolution σ(rφ) = 35 μm



- Noise level is low and stable



~ 1 month

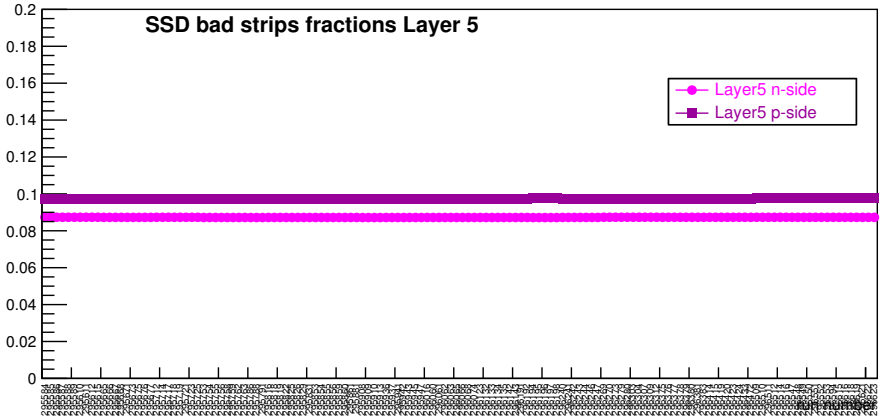


SSD observed effects

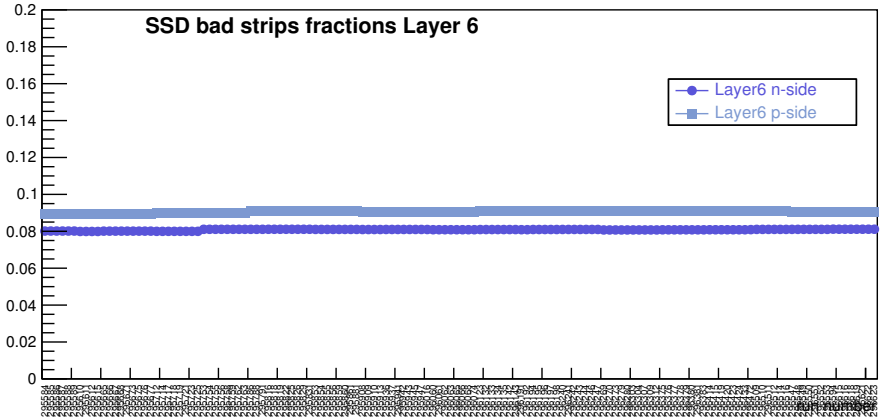
- issues related to humidity of the air coming from ventilation fixed with new ventilation machine (EYETS 2016) and new cooling unit (EYETS 2017) installation

- SSD acceptance stable
  - Minor issue related to JTAGs
    - Solved improving cable connections

- Fraction of bad strips:
  - Layer 5:
    - n-side: 10%
    - p-side: 8.7%
  - Layer 6:
    - n-side: 9.2%
    - p-side: 8.2%



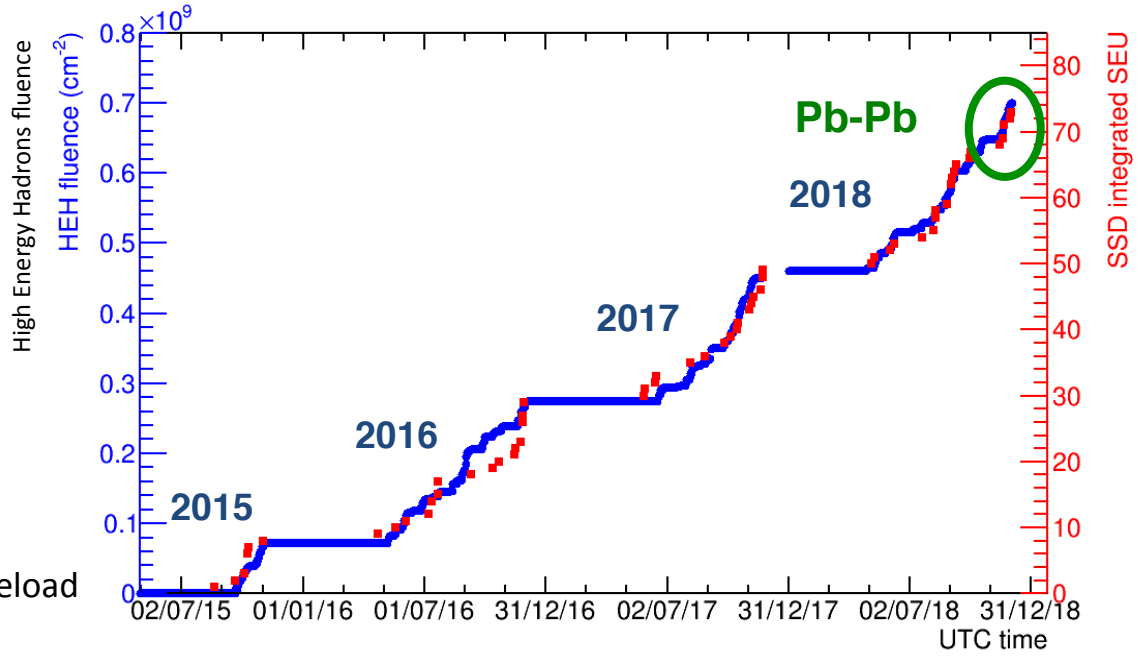
(~2 weeks)



SSD observed effects: Single Event Upset

The Front-End ReadOut Modules (FEROM) are located in the cavern just outside the ALICE solenoid.

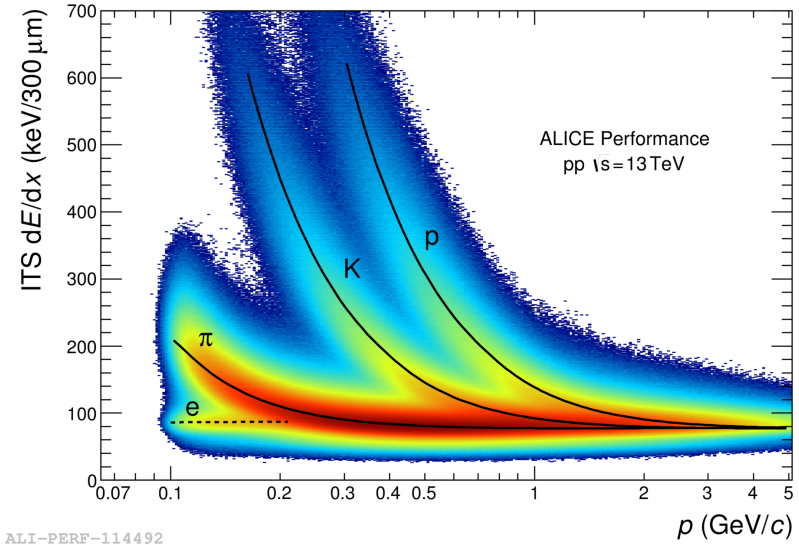
SEU cross section not increased throughout RUN2.

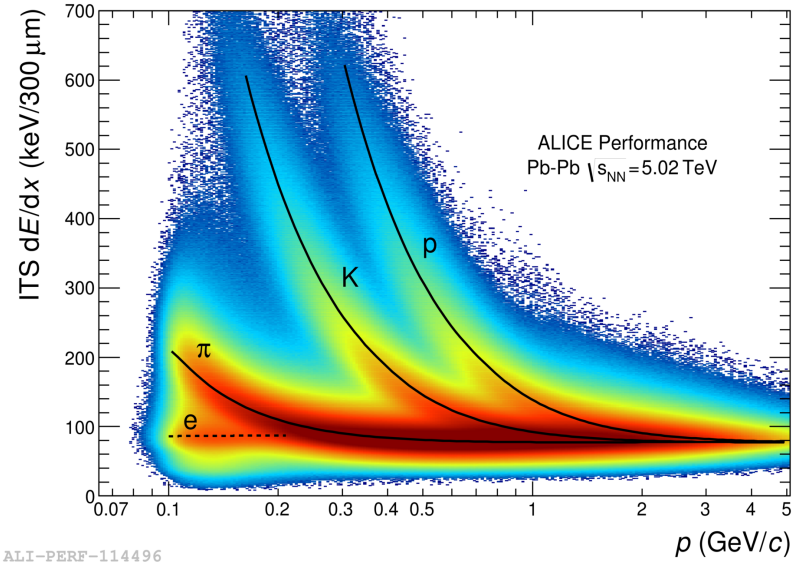


- 7 SEUs in RUN1:
  - radiation tolerant Programmable Read Only Memories
  - firmware upgrade → fast FPGA reload

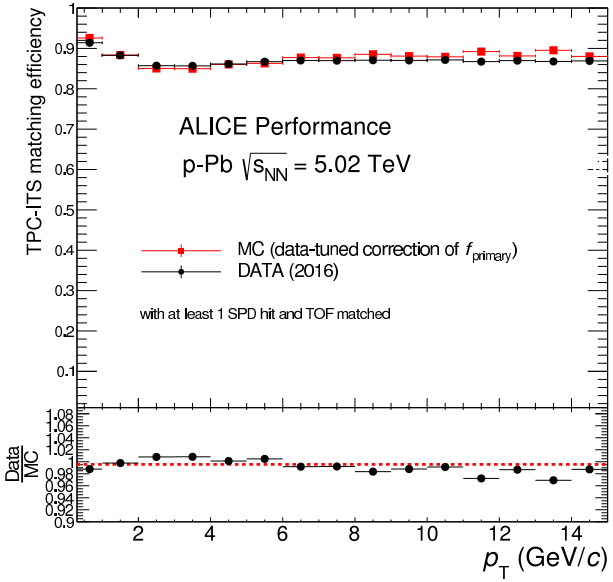
Detector performance

- Particle Identification for pure stand-alone ITS tracks
  - average d*E*/d*x* vs momentum
    - K-π separation in the range 0.1 ÷ 0.45 GeV/*c*
    - K-p separation in the range 0.1 ÷ 1 GeV/*c*



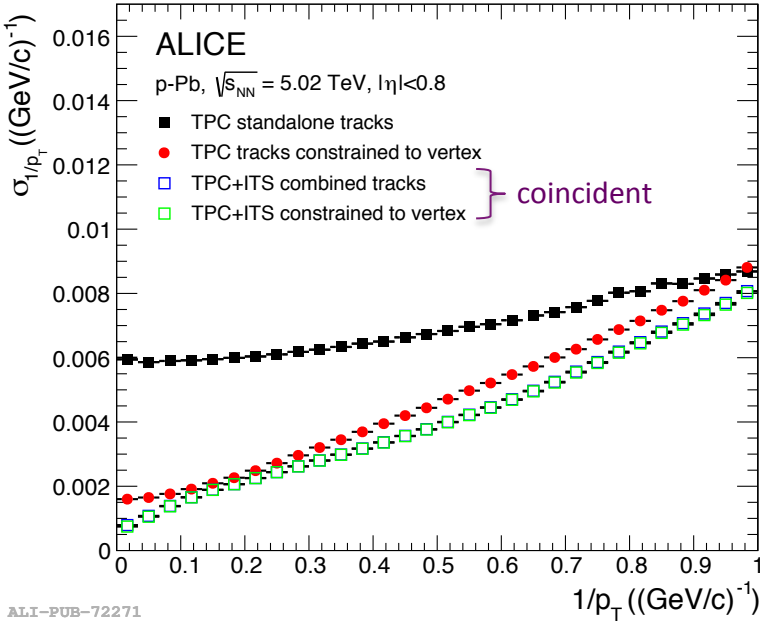


Detector performance



- Excellent ITS-TPC **track matching** performance

Int. J. Mod. Phys. A 29 (2014) 1430044



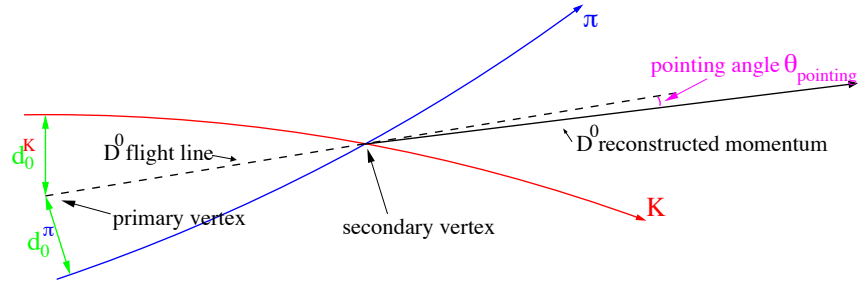
- **Transverse momentum** resolution improved by ITS

$$\frac{\sigma_{p_T}}{p_T} = p_T \, \sigma_{1/p_T}$$

Physics performance

Excellent **impact parameter resolution** (d_0) :

- **σ_{d_0} ~ 60 μm** at p_T = 1 GeV/c
- **Secondary vertex** reconstruction



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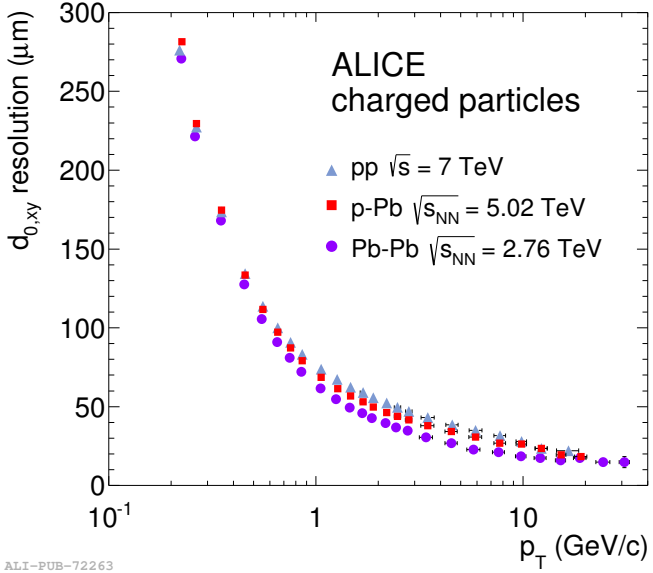
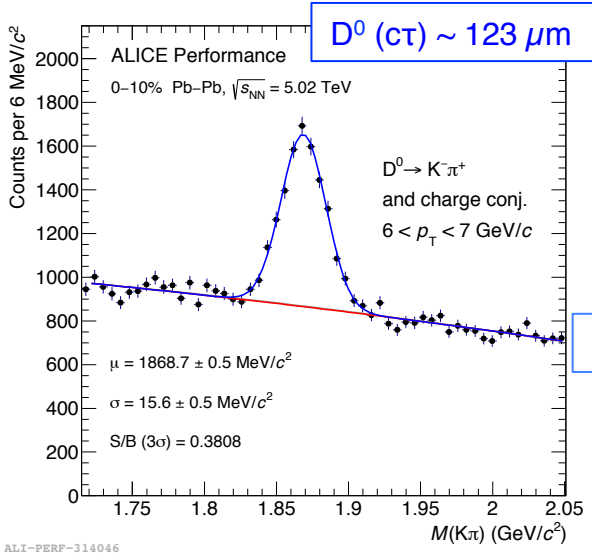
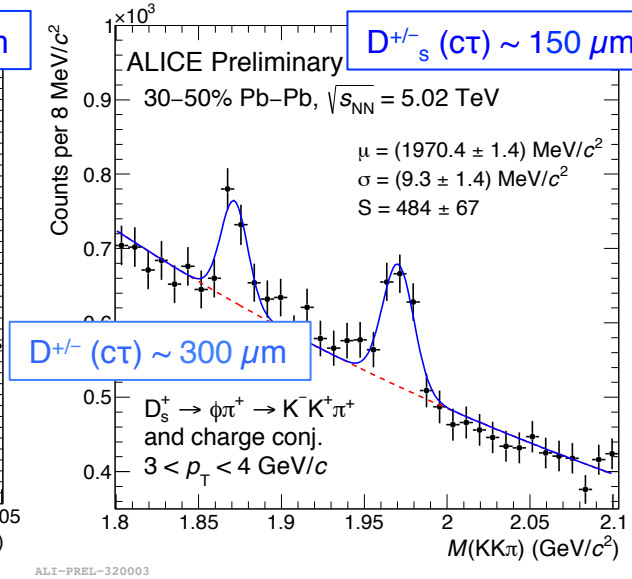






ITS: lessons learned

- SPD+SDD+SSD: successful "co-operation" in Run1 and Run2, excellent performance in vertexing, tracking, PID for low p_T physics

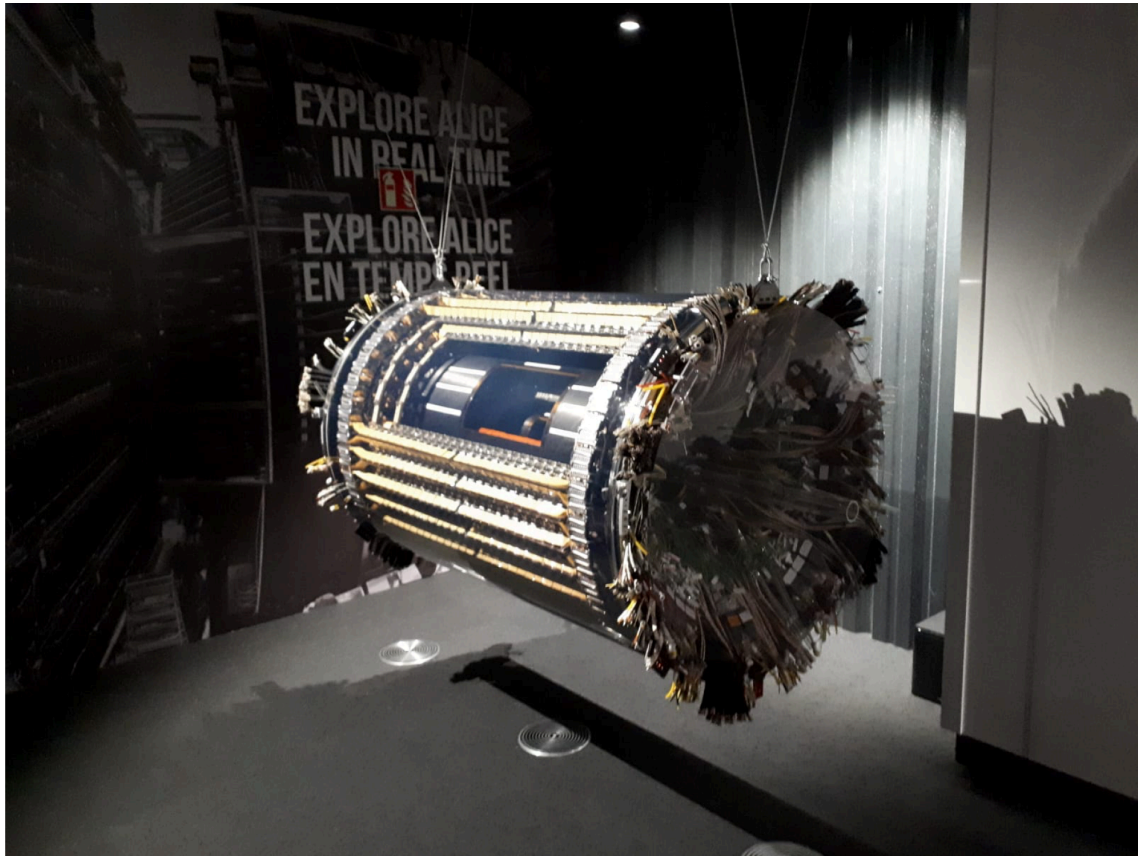
- 3 (sub-) detectors: different features, needs, peculiarities → no standardization

- SPD: lightest vertex detector among LHC experiments, only one to provide L0 trigger signal
  - cooling system issues: positioning of filters
  - it is important to keep under control mechanical and thermal stress (increase of dead pixels due to bump-bonding detachment) → MAPS in ITS2

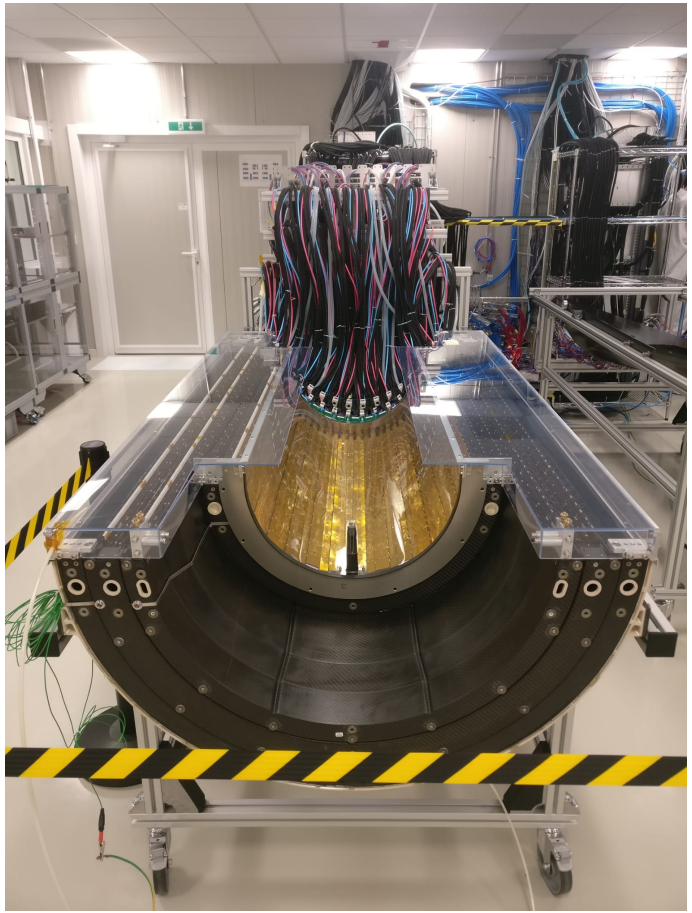
- SDD: ALICE is the only HEP experiment which operated successfully SDD, 2-d readout
  - to precisely calibrate drift speed, plan to have other detectors, based on different technologies, to give precise coordinates in drift direction
  - very effective in determining coordinates along the anode row

- SSD: optimal acceptance performance, best time availability performance during 2018 Pb-Pb
  - it is important to keep under control humidity, SEU …

ITS(1) today …..



… ready for ITS2 !



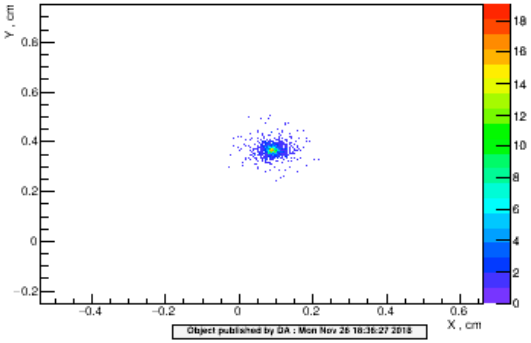
… ready for ITS2 … and beyond !

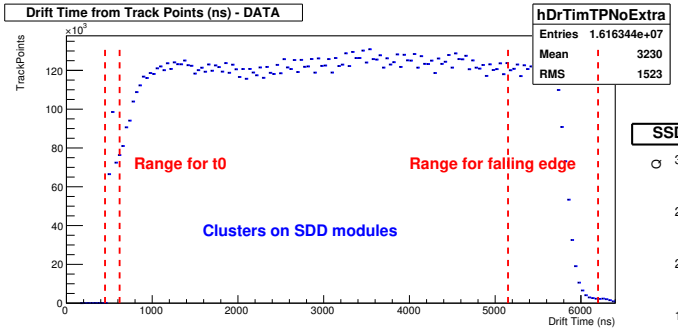
The MAPS-based ITS Upgrade for ALICE
by Giacomo Contin on Monday 14, 15:00

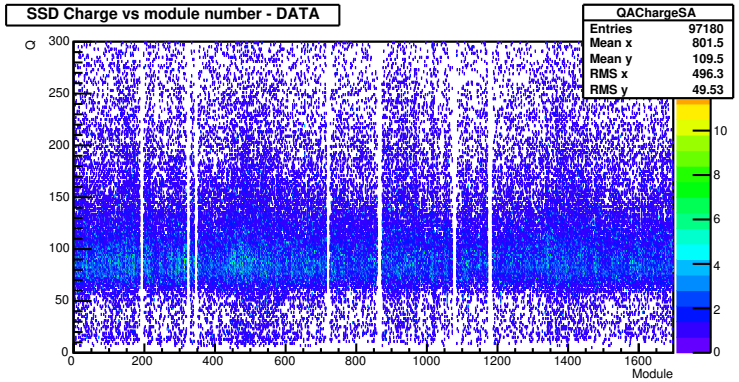
The ALICE ITS Upgrade Readout and Power System
by Pietro Giubilato on Thursday 17, 11:00

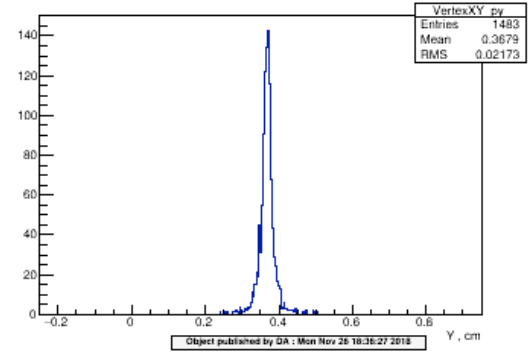
Upgrade of the ALICE ITS in LS3
by Magnus Mager on Thursday 17, 11:30

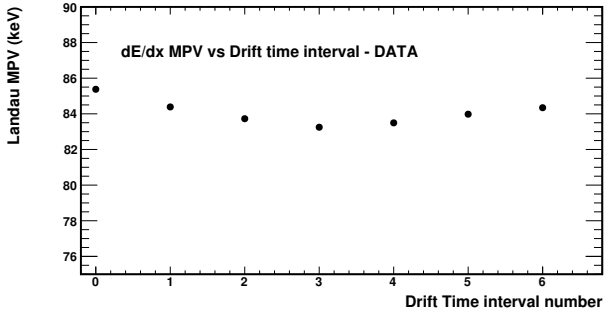
DQM & QA: data quality





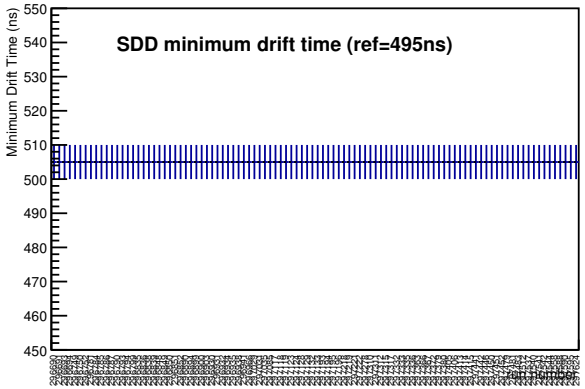


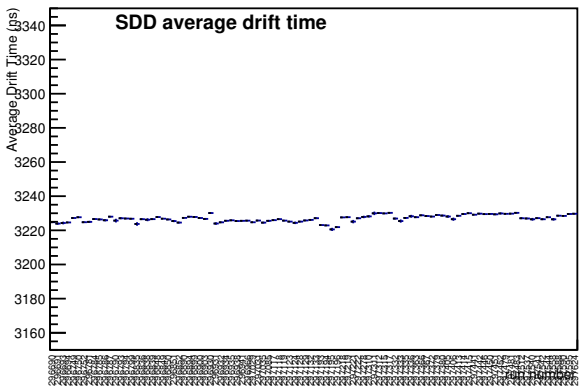


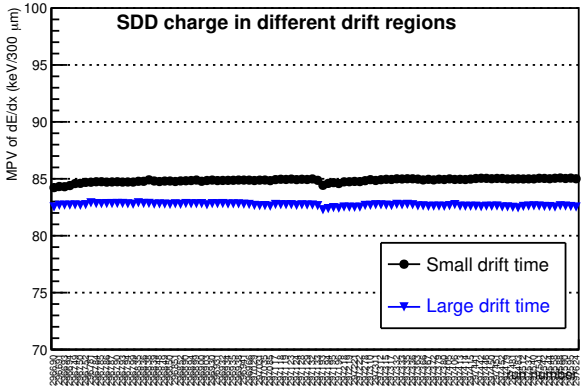


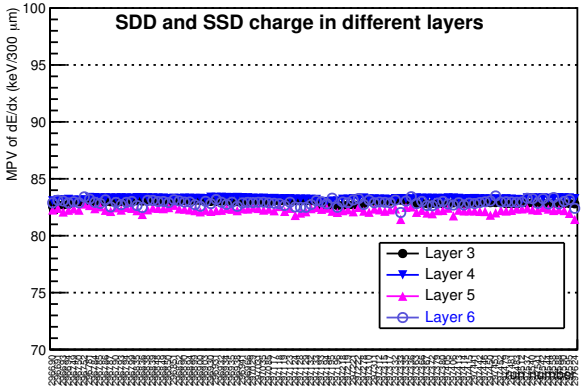
run 297085, LHC18r

DQM & QA: data quality



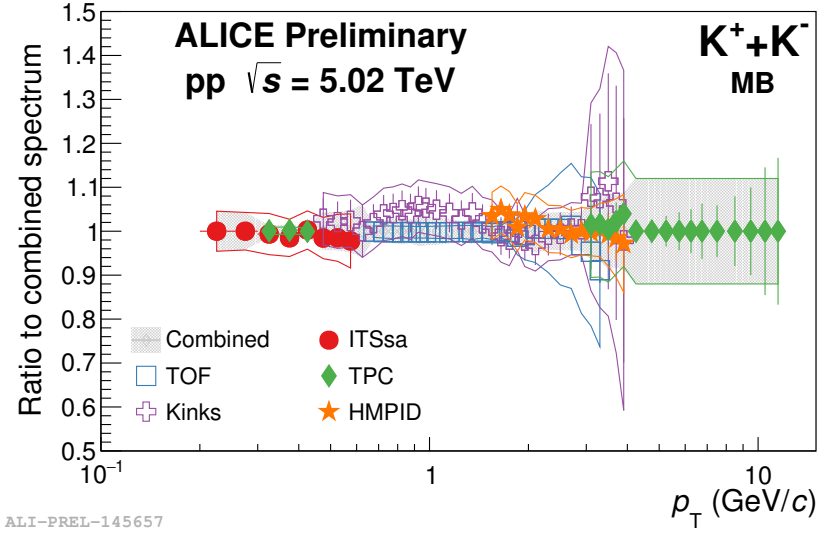


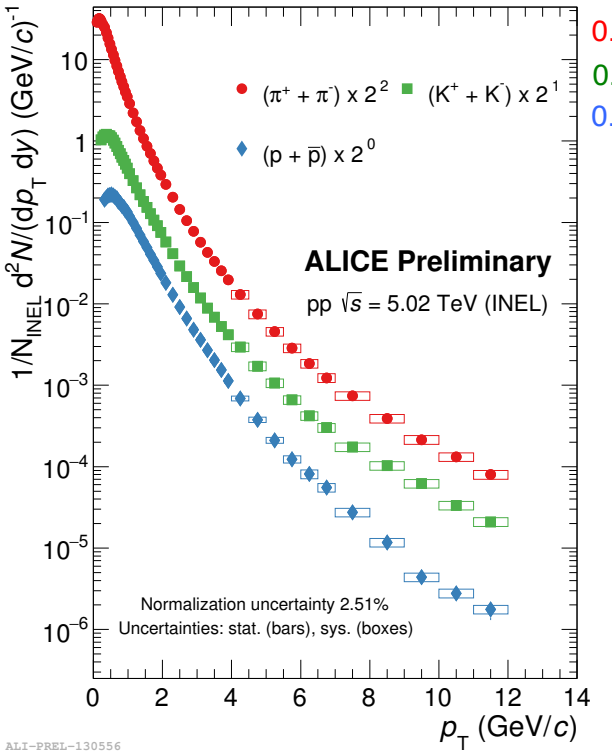




Detector performance

- **ITS stand-alone** algorithm extends the p_T range down to 80÷100 MeV/*c*





0.1 GeV/c
0.2 GeV/c
0.3 GeV/c