Operational experience with the current tracker in ALICE

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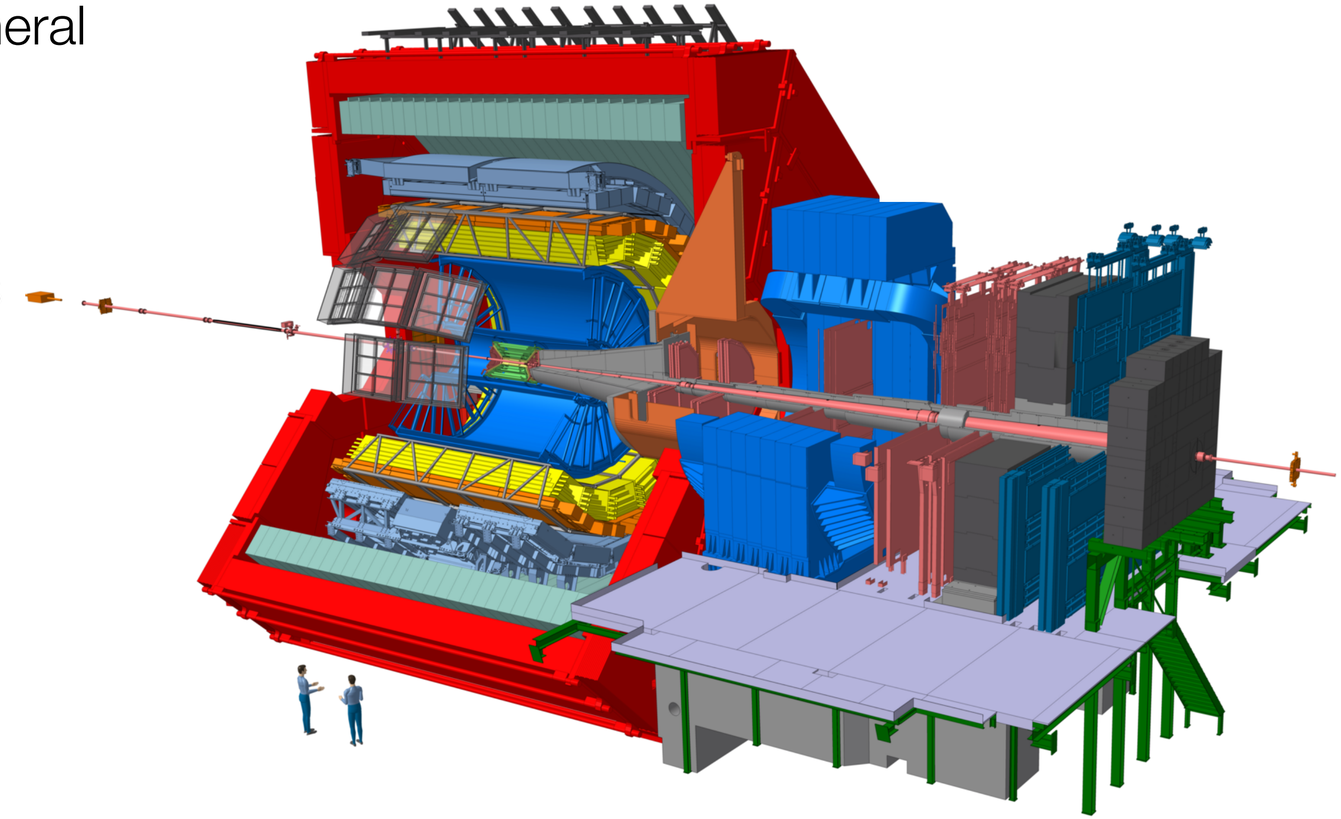
University and INFN - Torino

on behalf of the **ALICE Collaboration**

The 27th International Workshop on Vertex Detectors

The ALICE apparatus

- **ALICE** (**A** **L**arge **I**on **C**ollider **E**xperiment) is a general purpose heavy-ion experiment at the LHC
  - Study of **strongly interacting matter**
  - Study of the **Quark-Gluon Plasma** properties



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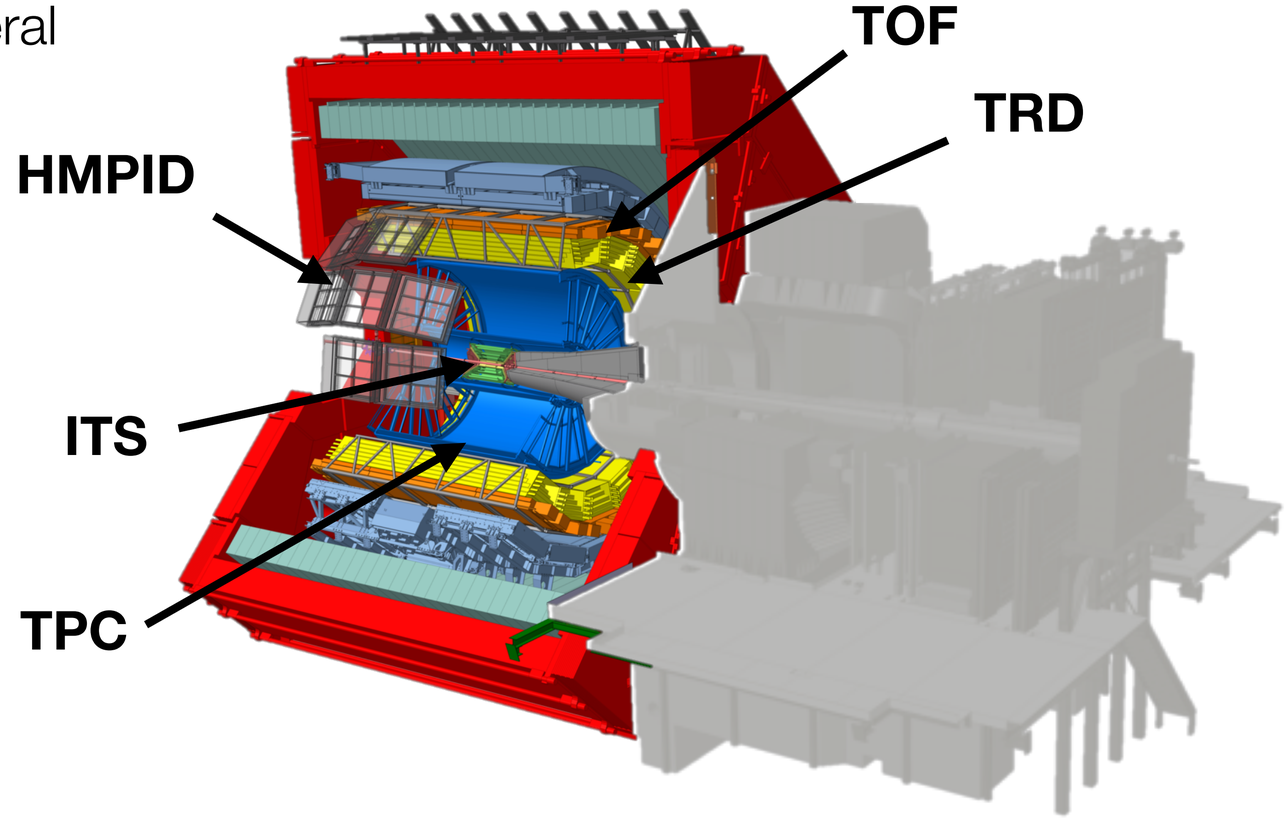
  - Study of **strongly interacting matter**
  - Study of the **Quark-Gluon Plasma** properties
- **Central Barrel**: pseudorapidity $|\eta| < 0.9$
  - **Tracking** in high density collisions:
    - $dN/d\eta \sim 2000$ in central Pb-Pb
  - **PID** (**P**article **ID**entification):
    - dE/dx : ITS, TPC
    - Time of flight: TOF
    - Transition radiation: TRD
    - Cherenkov radiation: HMPID



- **Low p_T reach**: **~ 0.1 GeV/*c***
  - Mild magnetic field B = 0.5 T
  - Low material budget: (10% X_0 for ITS+TPC)

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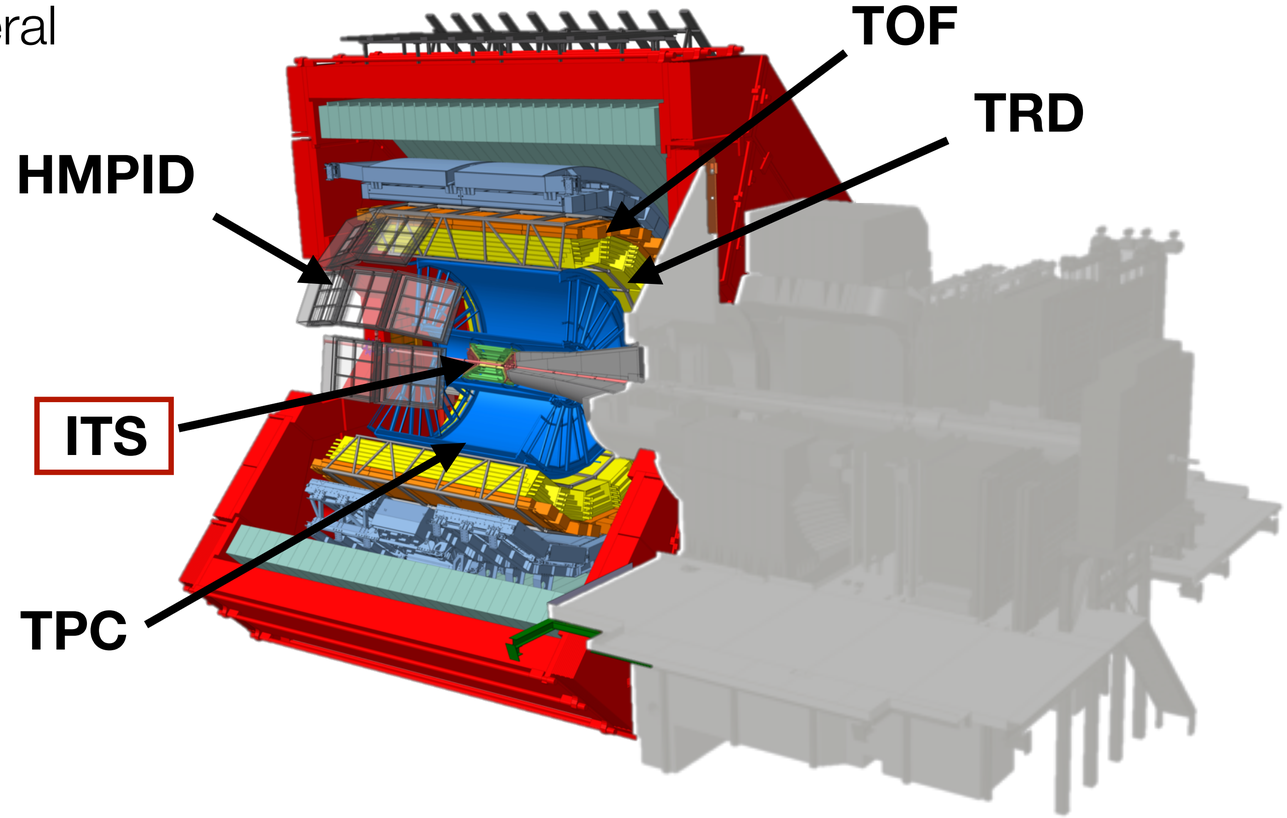

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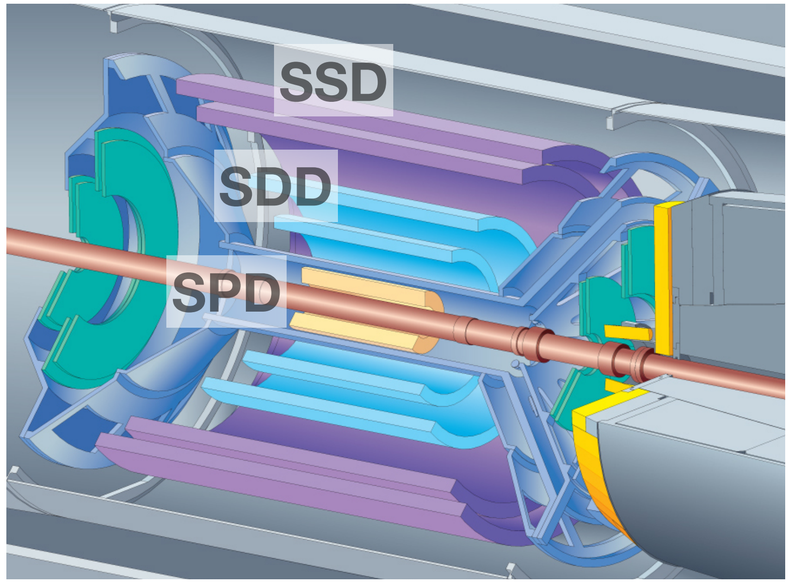
The Inner Tracking System

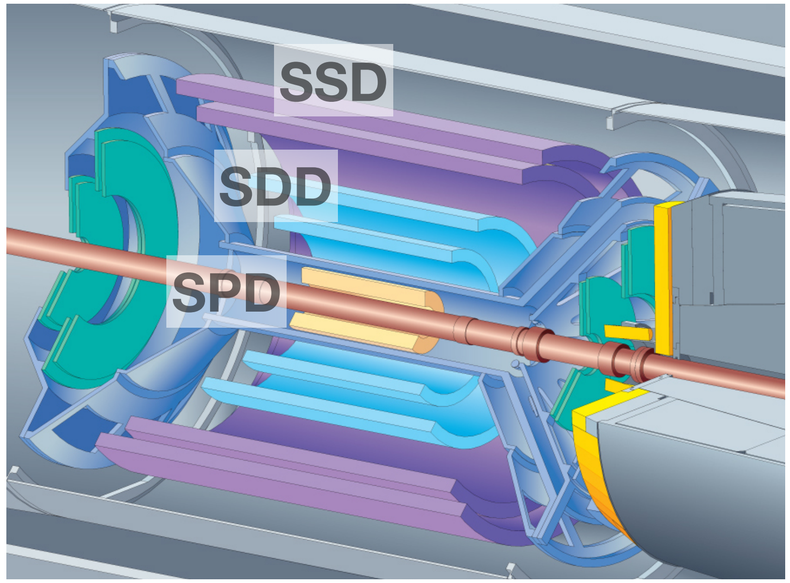
- **Six cylindrical layers** of silicon sensors
  - **S**ilicon **P**ixel **D**etector (**SPD**): the two innermost layers
  - **S**ilicon **D**rift **D**etector (**SDD**): the two intermediate layers
  - **S**ilicon **S**trip **D**etector (**SSD**): the two outermost layers
- The ITS is used for:
  - **primary vertex** reconstruction (resolution better than 100 μm)
  - separation of primary and **secondary vertices**
  - **PID** and **tracking** at low p_T
  - **impact parameter** determination
  - **pileup** rejection
  - charged-particle **pseudorapidity distribution** determination



The Inner Tracking System

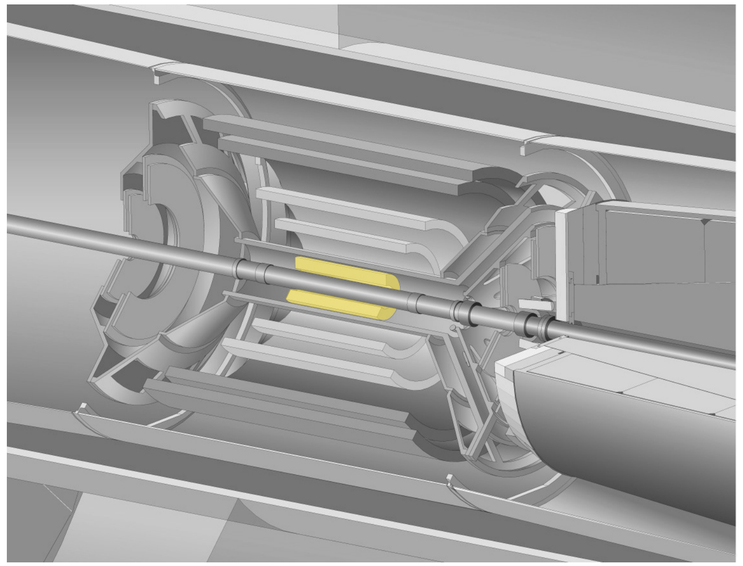
- Radial dimensions:
  - from 3.9 cm (close to beam pipe) to 43.0 cm (close to TPC inner wall)
- Material Budget (M.B.):
  - ~ 1% X_0

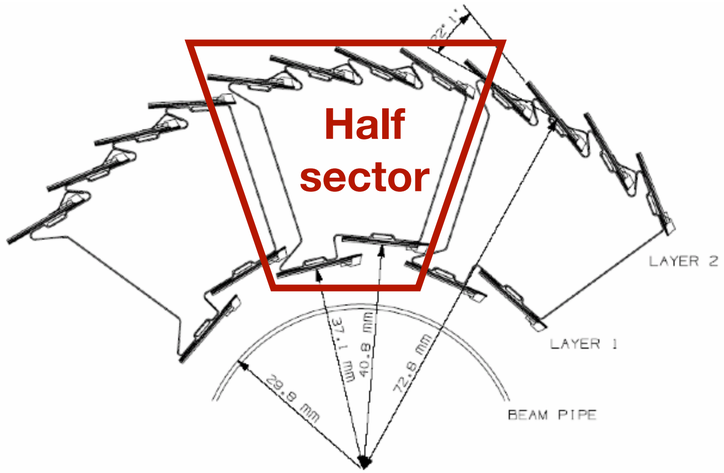
Layer	Det	Radius (cm)	Length (cm)	Channels	Area (m^2)	Resolution (μm)		M.B. (% X_0)
						r_φ	z	
1	SPD	3.9	28.2	3.3 M	0.07	12	100	1.14
2		7.6	28.2	6.5 M	0.14			1.14
3	SDD	15.0	44.4	43 k	0.42	35	25	1.13
4		23.9	59.4	90 k	0.89			1.26
5	SSD	38.0	86.2	1.1 M	2.20	20	830	0.83
6		43.0	97.8	1.5 M	2.80			0.86

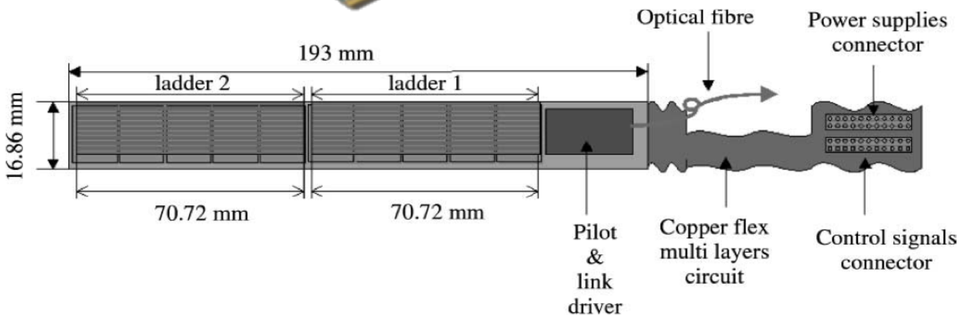


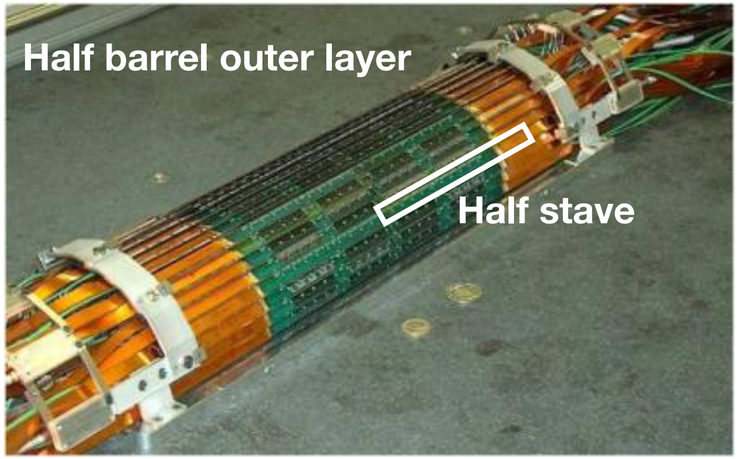
Silicon Pixel Detector (SPD)

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



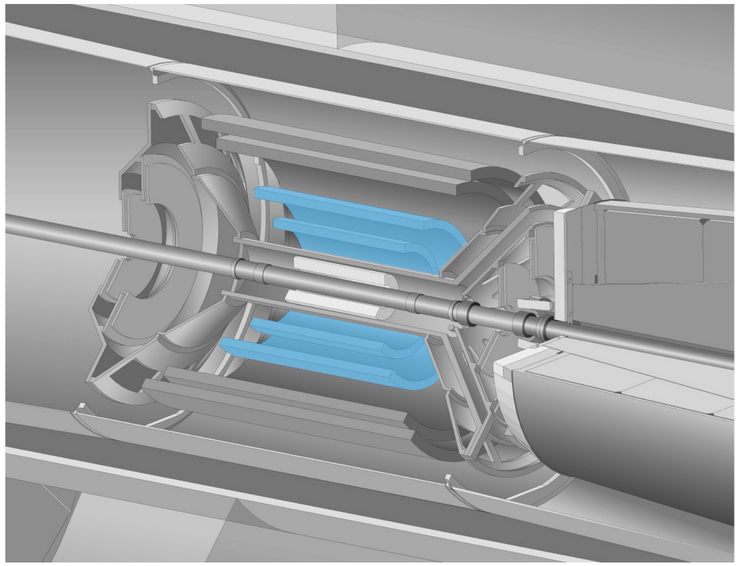


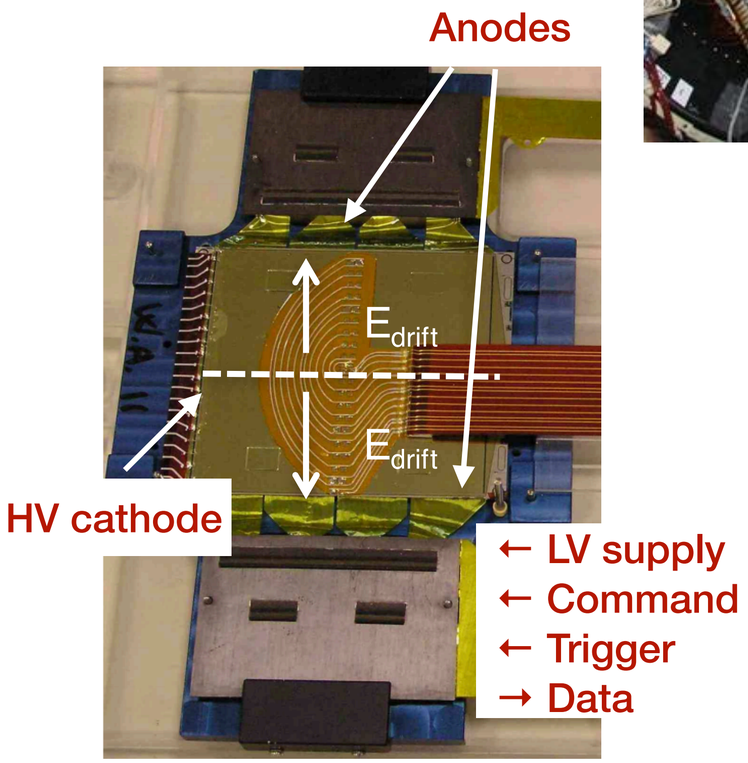


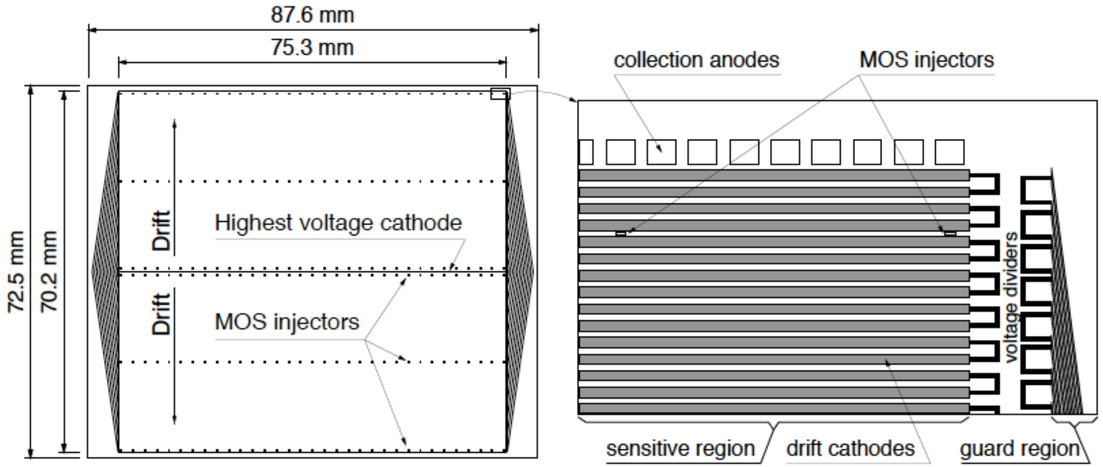


Silicon Drift Detector (SDD)

- Two layers of 260 silicon **drift modules** (300 μm thick)
  - Layer 3: 14 ladders with 6 modules each
  - Layer 4: 22 ladders with 8 modules each
- 512 collection anodes (294 μm pitch)
- Drift **HV**: 1.8 kV
- Drift **velocity**: 6.7 μm/ns
- **dE/dx** measurement for **PID**
- **MOS Injectors** to monitor drift velocity
- Leak-tight **water cooling**

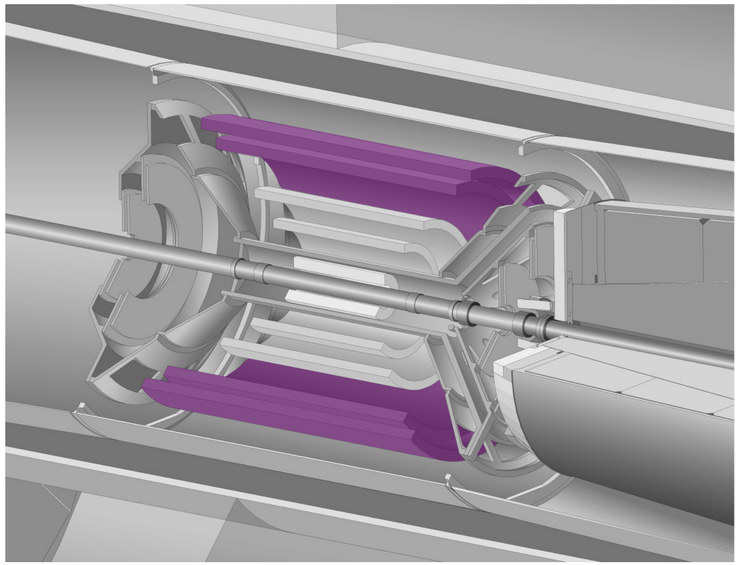




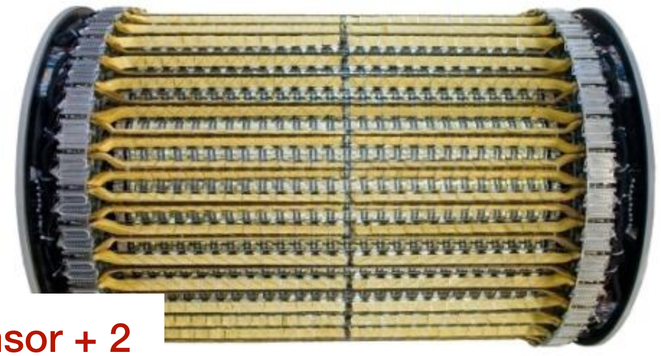


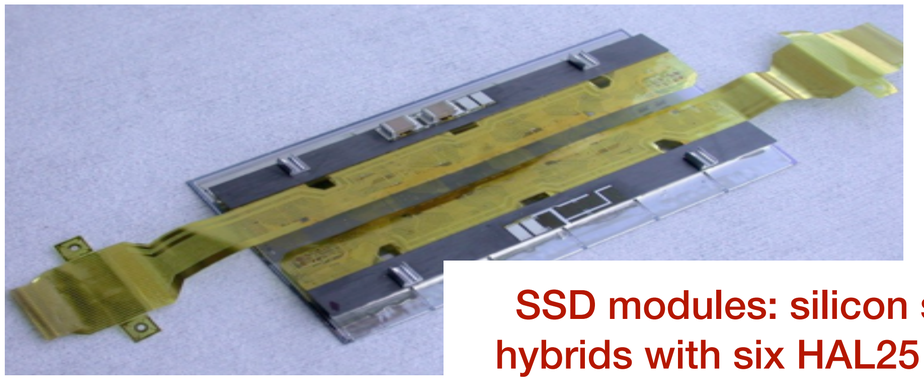
Silicon Strip Detector (SSD)

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

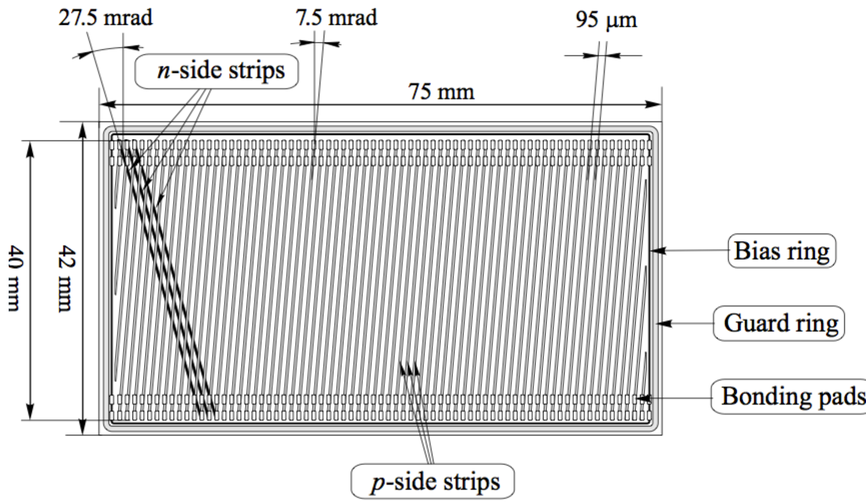


SSD barrel



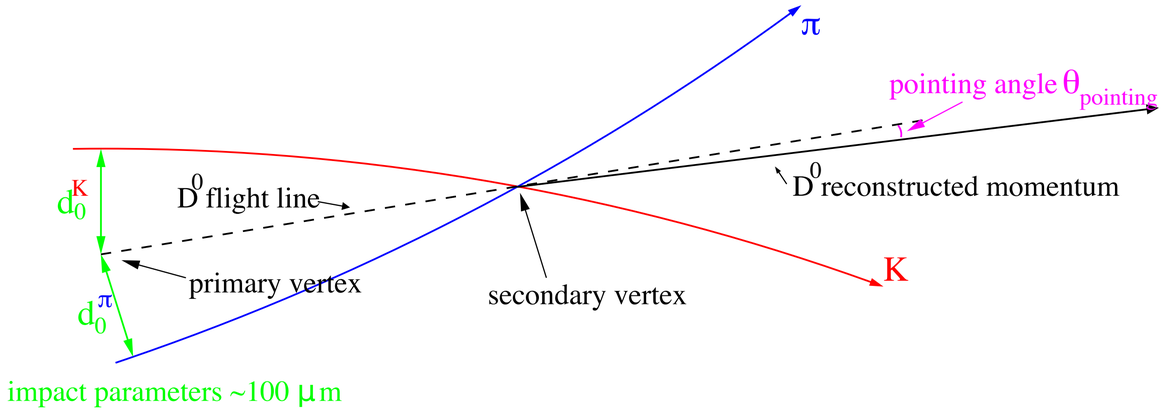


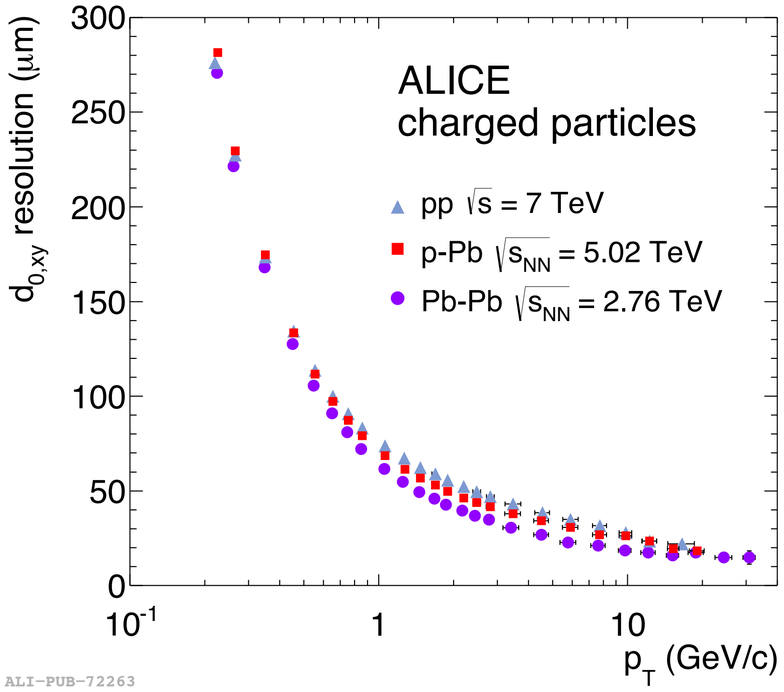
SSD modules: silicon sensor + 2 hybrids with six HAL25 chips each

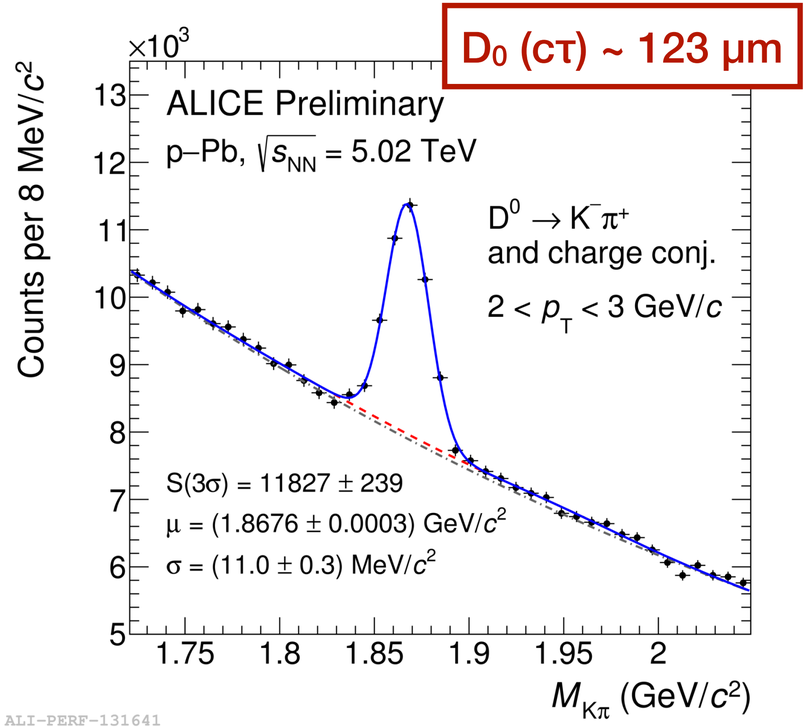


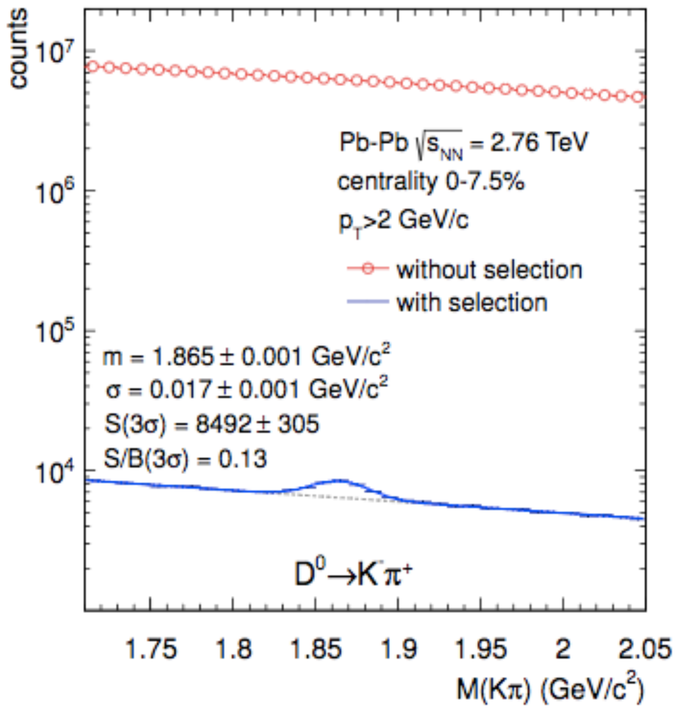
ITS Physics Performance

- Excellent **impact parameter resolution** (d_0) :
  - **σ_{d_0} ~ 60 μm** at p_T = 1 GeV/c
  - **Secondary vertex** reconstruction









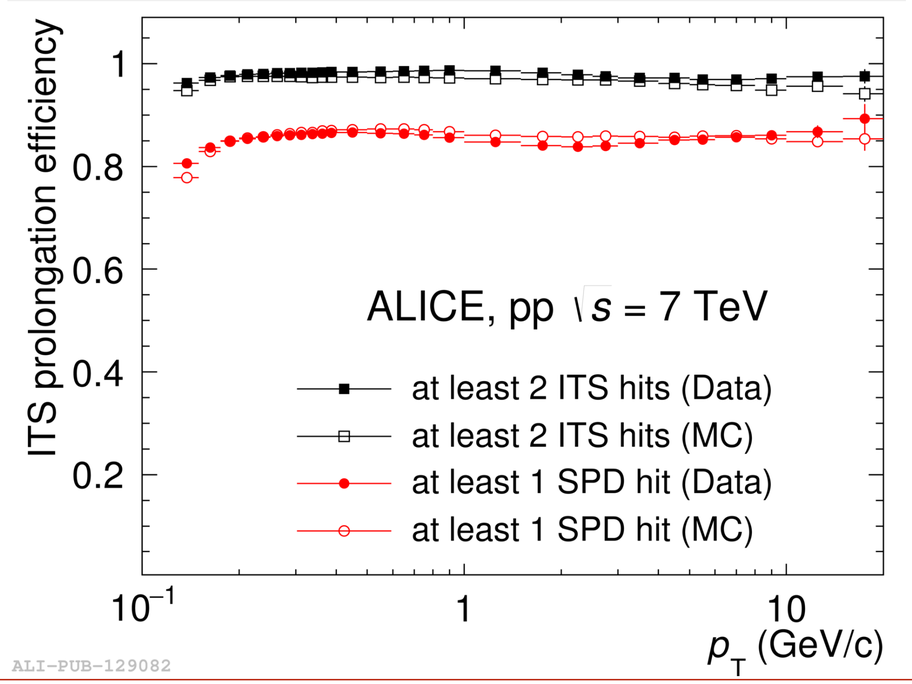
ITS Physics Performance

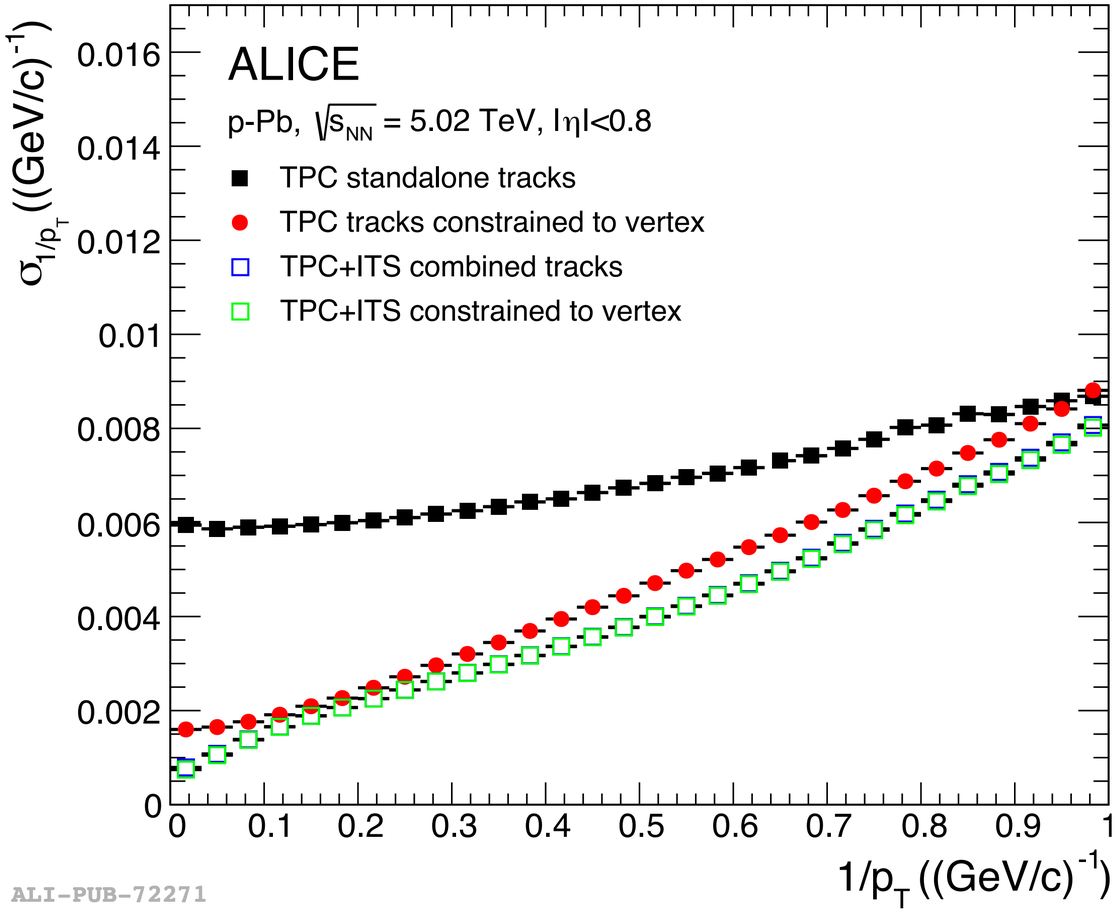
- Excellent **track matching** between ITS and TPC

- Good **transverse momentum resolution**:

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

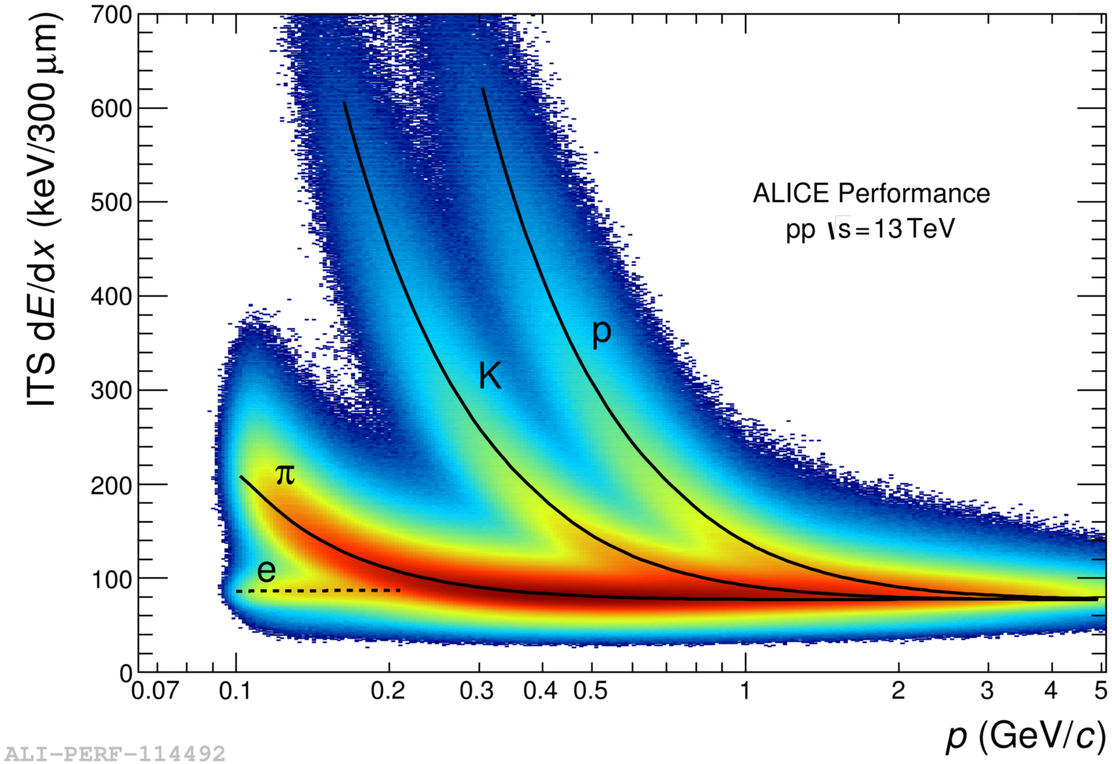
  - **ITS stand-alone** algorithm extends the p_T range down to 80÷100 MeV/*c*

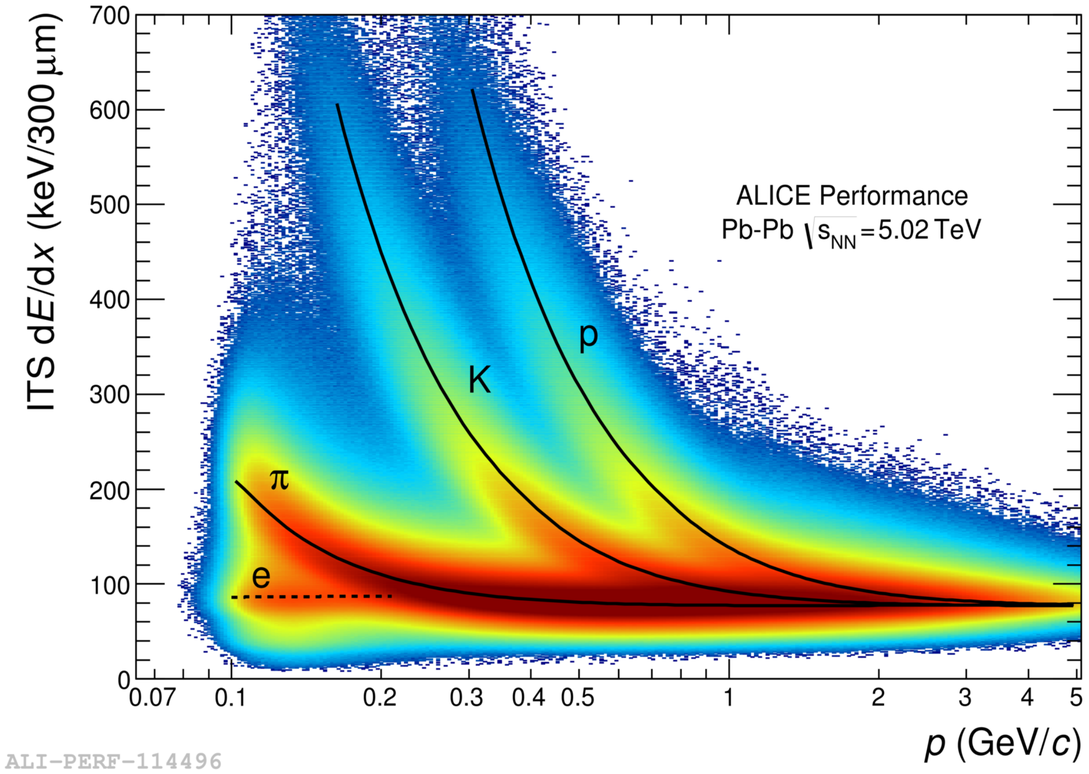




Physics Performance

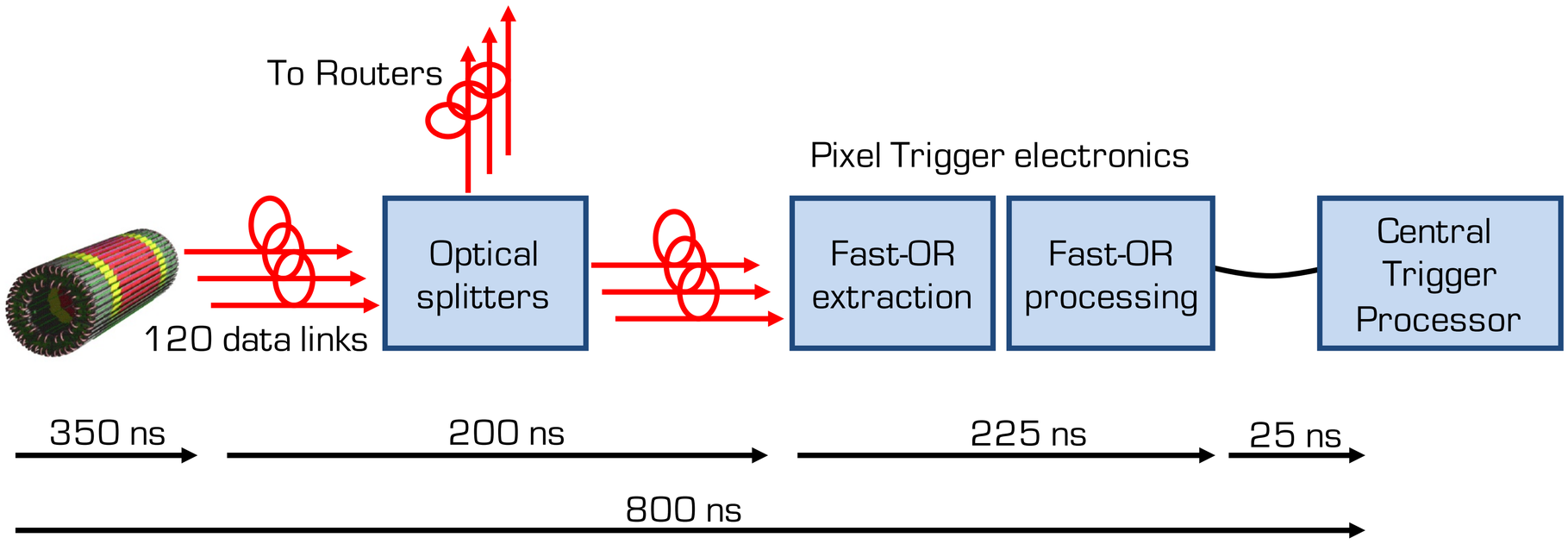
- **PID** for pure stand-alone ITS tracks
  - dE/dx vs momentum
    - K-π separation in the range 0.1 ÷ 0.45 GeV/*c*
    - K-p separation in the range 0.1 ÷ 1 GeV/*c*





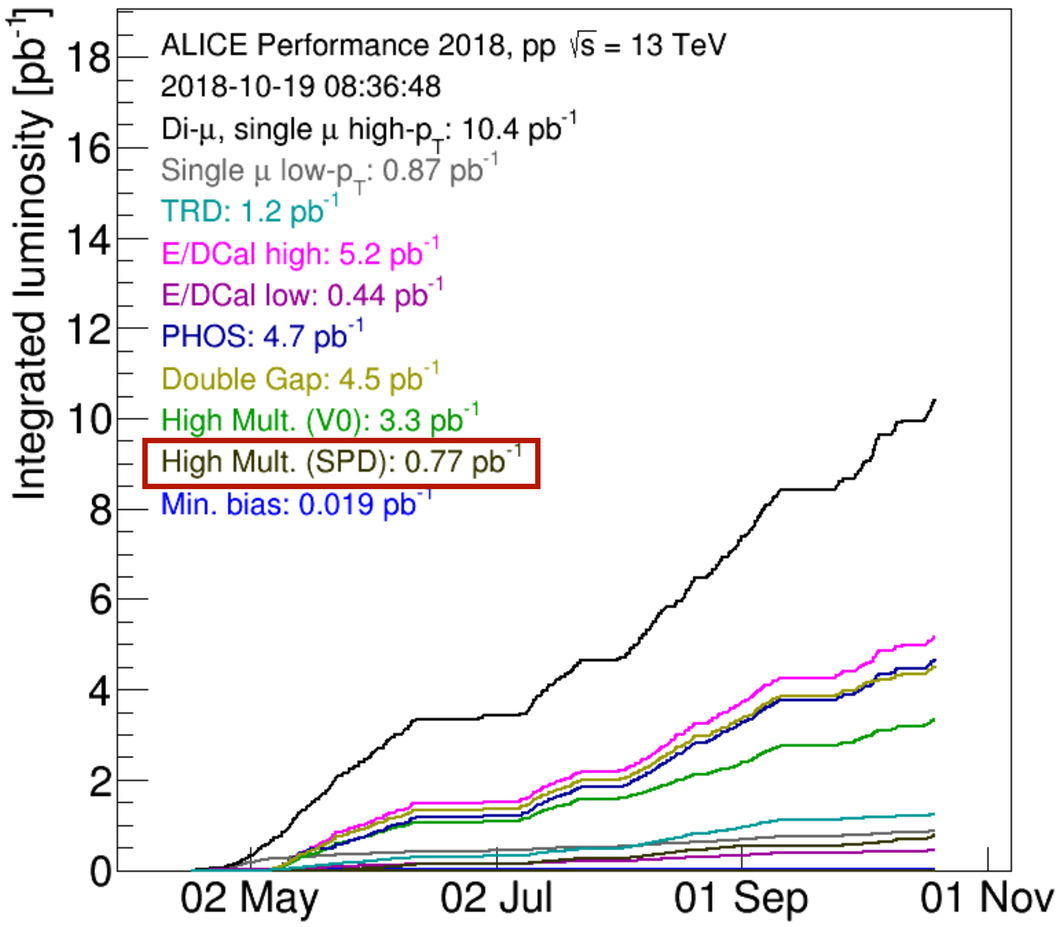
SPD as L0 trigger

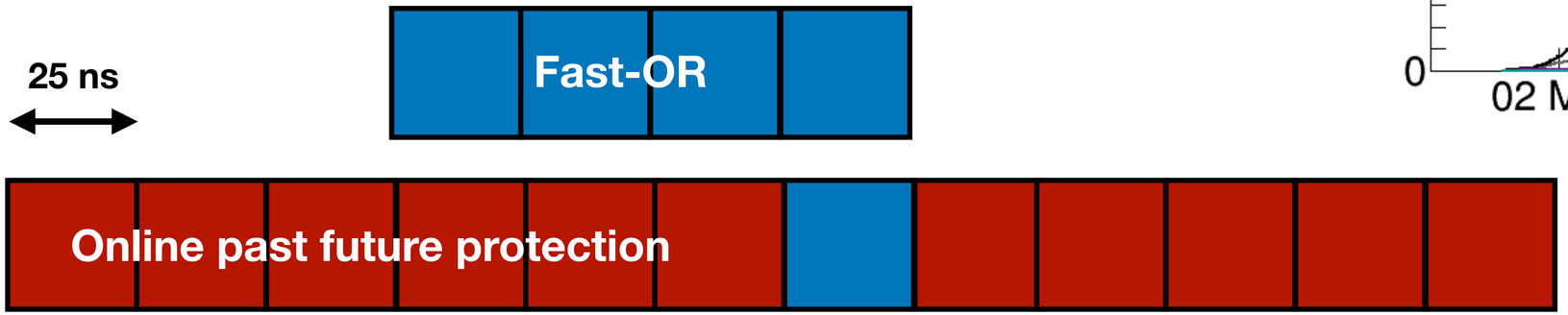
- **First Level Trigger**
  - **Fast-OR**: at least one hit in a readout chip
  - INPUT: 1200 bits every 100 ns from SPD to CTP
  - OUTPUT: 10 programmable output based on boolean logic
- **Maximum latency** at CTP input: 800 ns



SPD - High-Multiplicity trigger

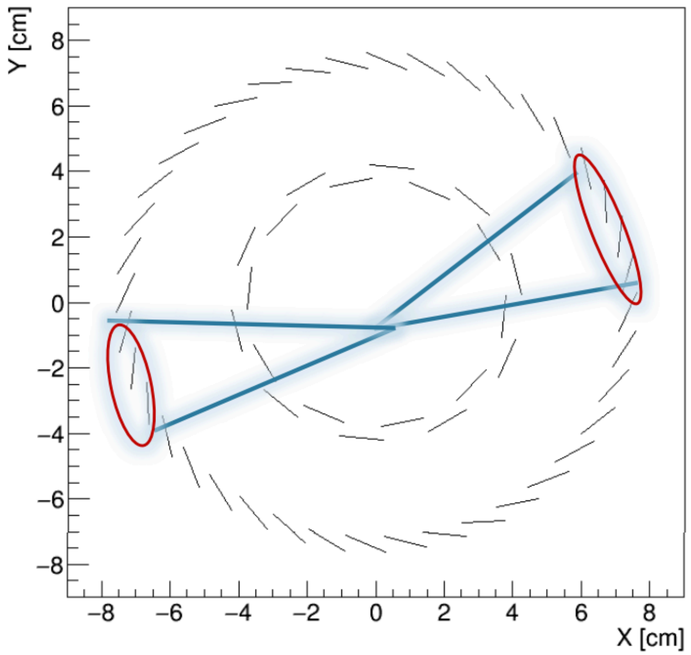
- **Fast-OR** signals (100 ns time window)
- Online beam **background mitigation** with forward rapidity detectors
- Online **Past-future protection**: only events that are alone in the time window (7 bunch crossings)
- **HM selections**:
  - Hits in Layer 1 ≥ threshold 1
  - Hits in Layer 2 ≥ threshold 2

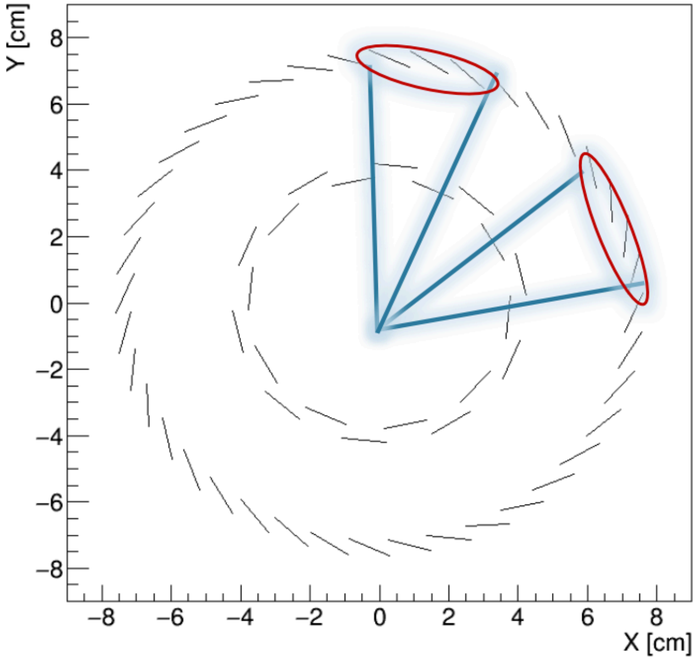


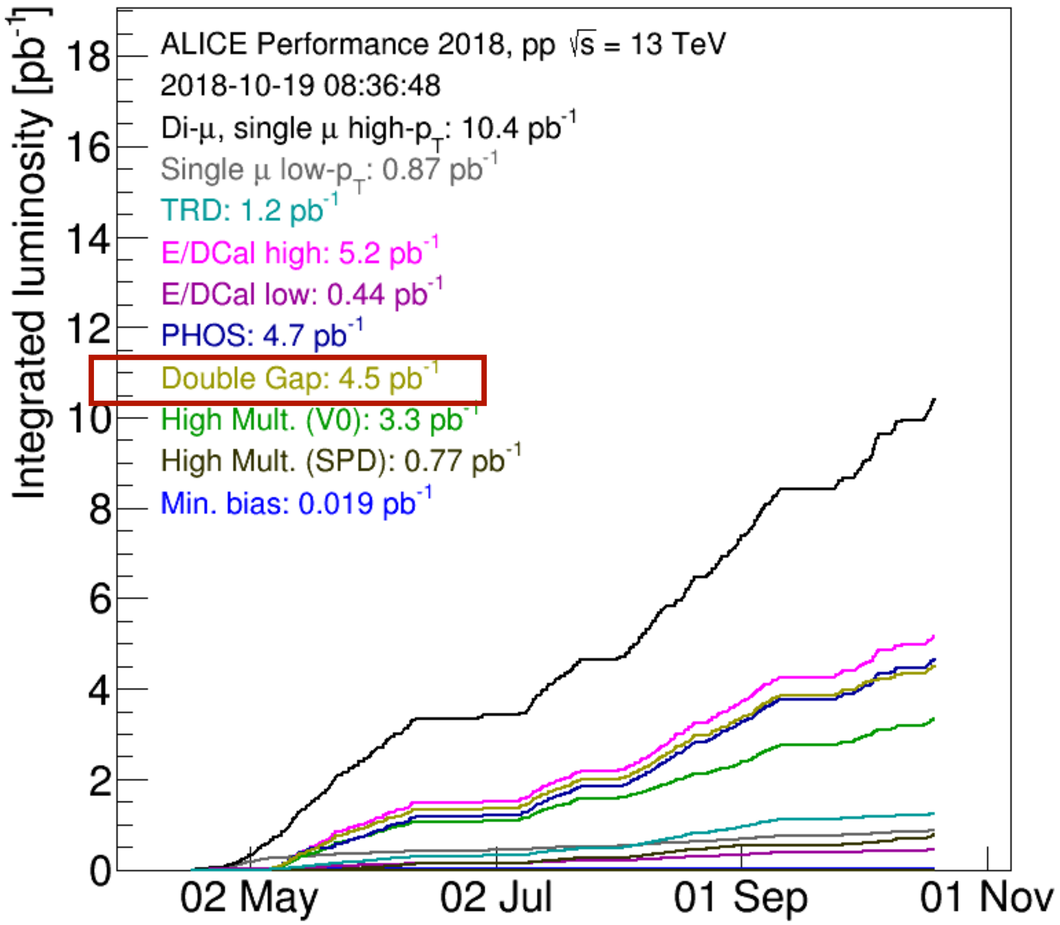


SPD - Double-Gap diffractive trigger

- **Low-multiplicity** events: 2 ÷ 4 tracks
- Veto with forward-rapidity detectors
- Fast-OR signal in mid-rapidity region
- **Topological trigger**:
  - **Opening angle** between the two cones
  - **Minimum** and **maximum** number of **tracklets**



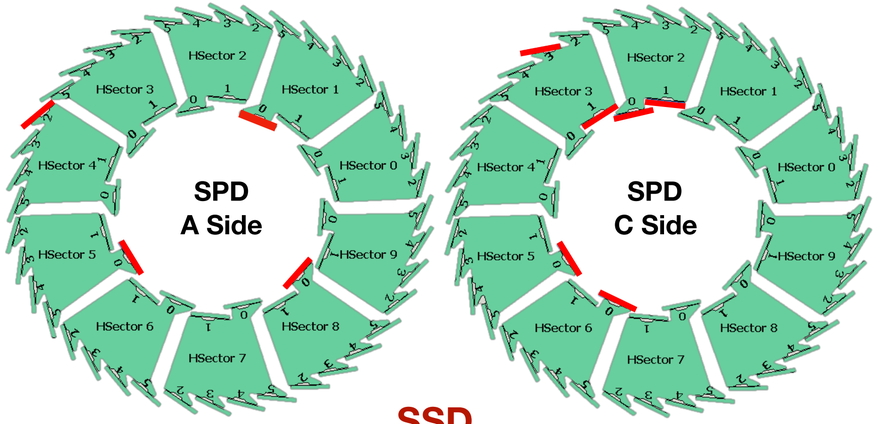




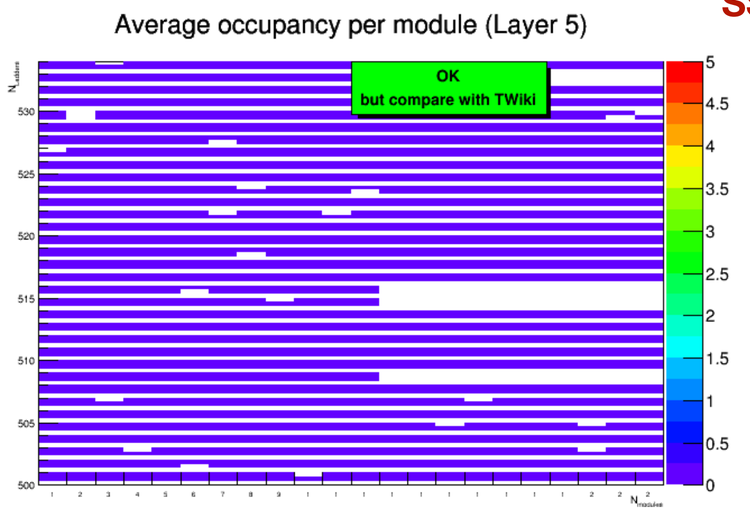
Detector acceptance

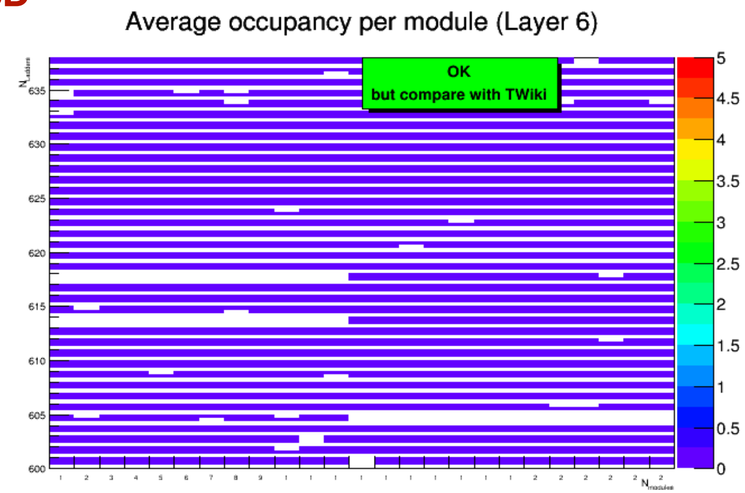
- In some cases the detector acceptance has decreased due to specific problems in the subdetectors
- In Run2 of **active modules** are found to be **stable**:
  - some modules excluded due to HV and readout problems

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

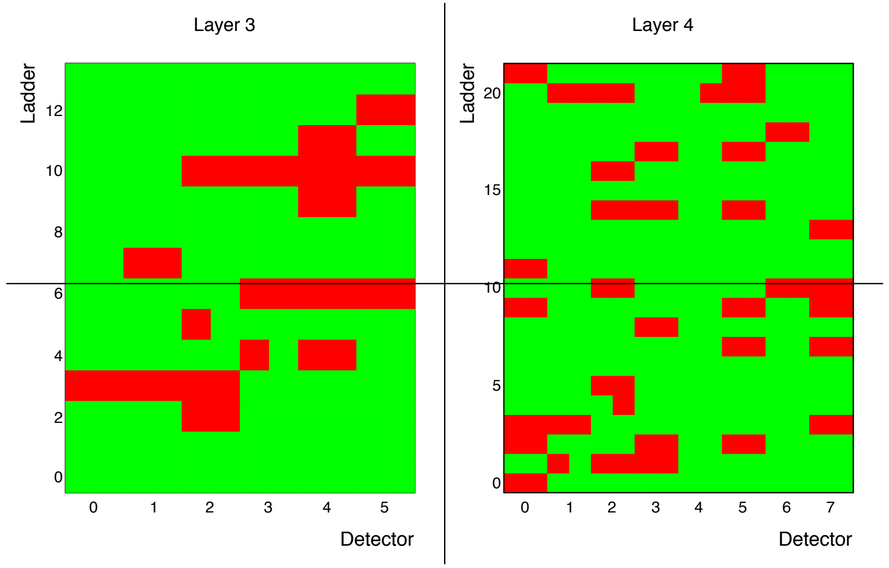


SSD



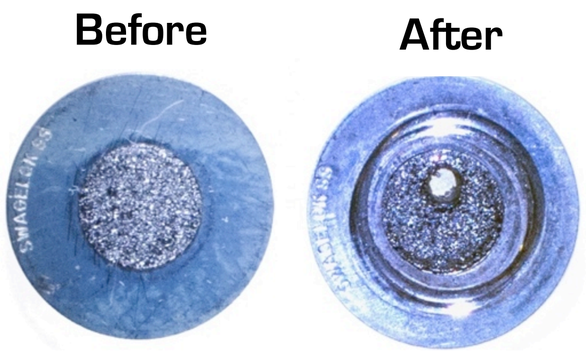


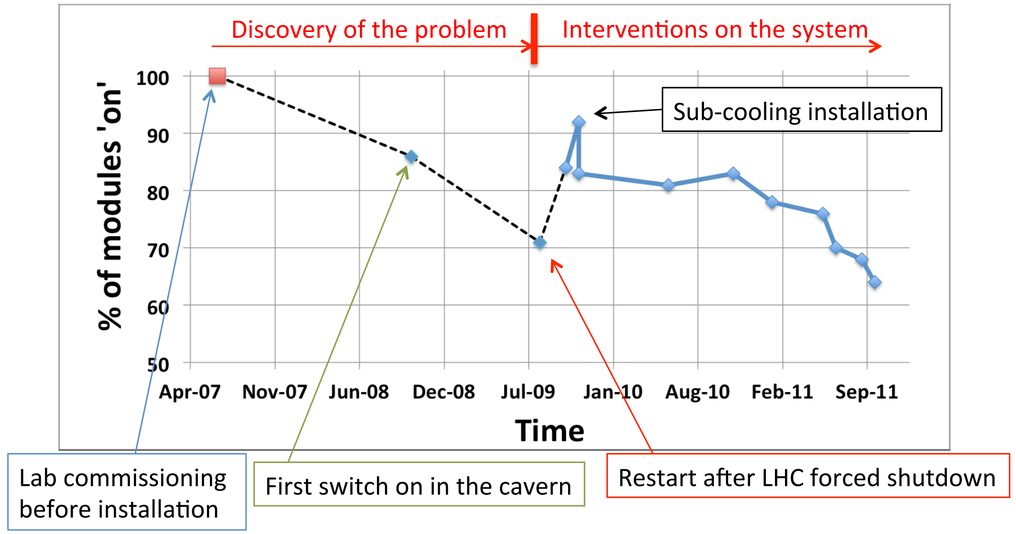
SDD

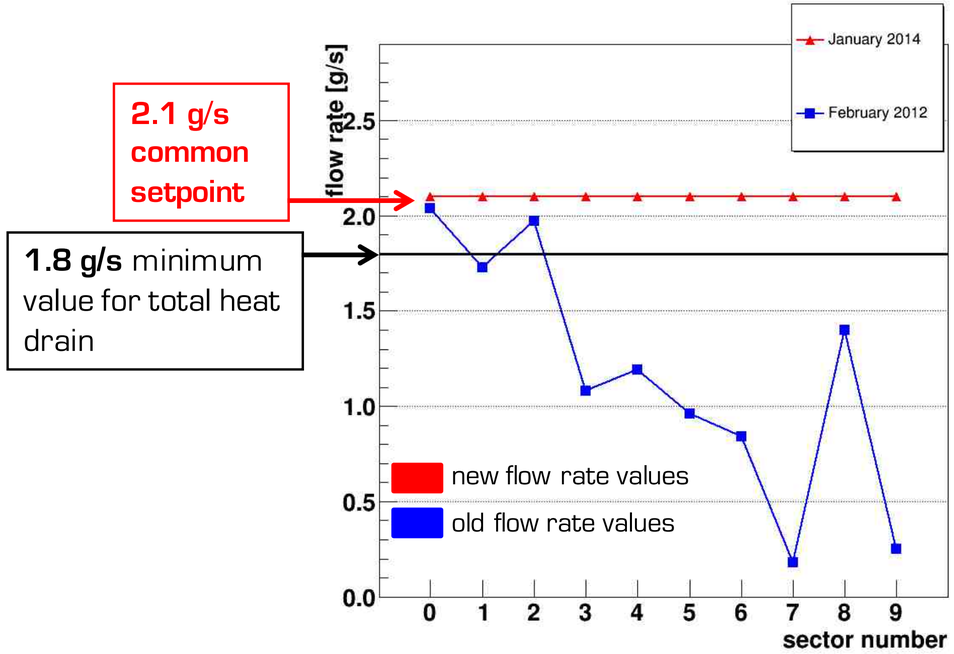


Loss of SPD modules in Run1

- In Run1 SPD suffered some losses due to **cooling problems**
  - The **filters** were **clogged**: they can only be accessed by removing the TPC!”
- The **filters** were **drilled open**, using a cable
  - From February 2012 (63% active modules) to January 2014 (93% active models)
- Since the end of the drilling-campaign the number of modules in acquisition is stable

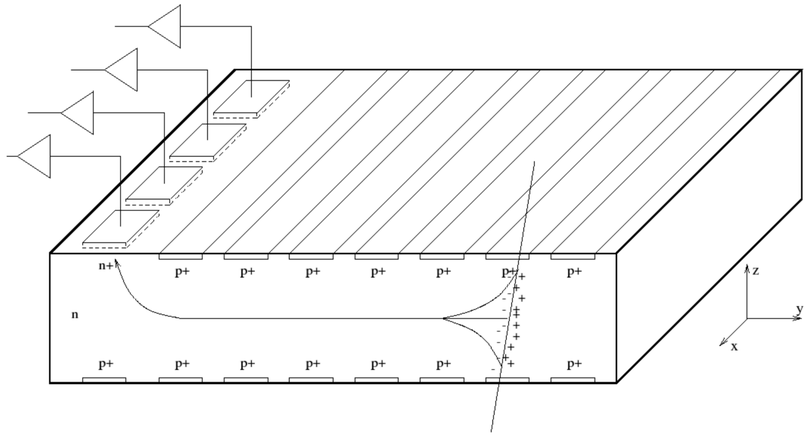


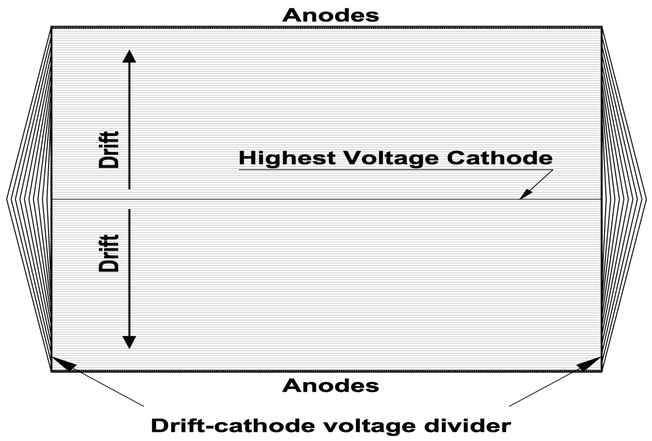




Loss of SDD modules in Run1

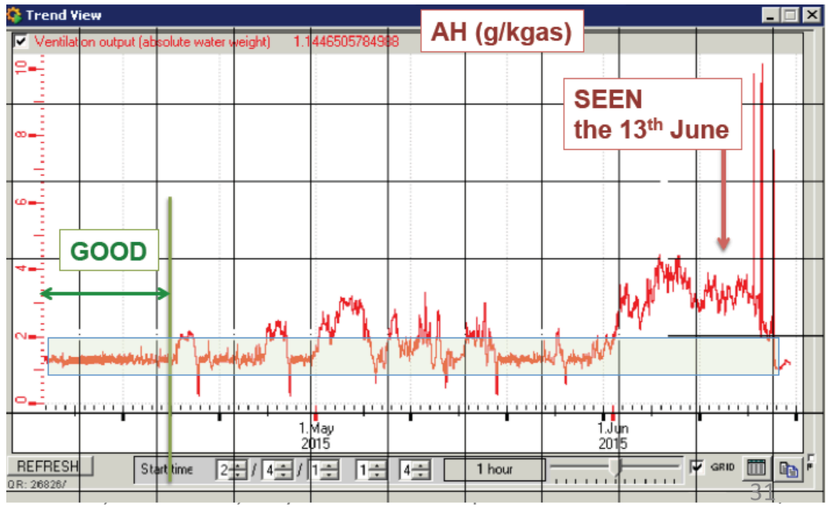
- The SDD suffered many losses during Run1
- During the **installation** of the detector, **one half-ladder** of layer 3 had some problem with the **electronics**
  - Since then we **could not communicate** with these modules
- The **beam** was dumped close to ALICE and **Layer 3** suffered from **high radiation**
  - A lot of MOS injectors were lost
  - Since then, HV and LV are off during INJECTION and ADJUSTMENT

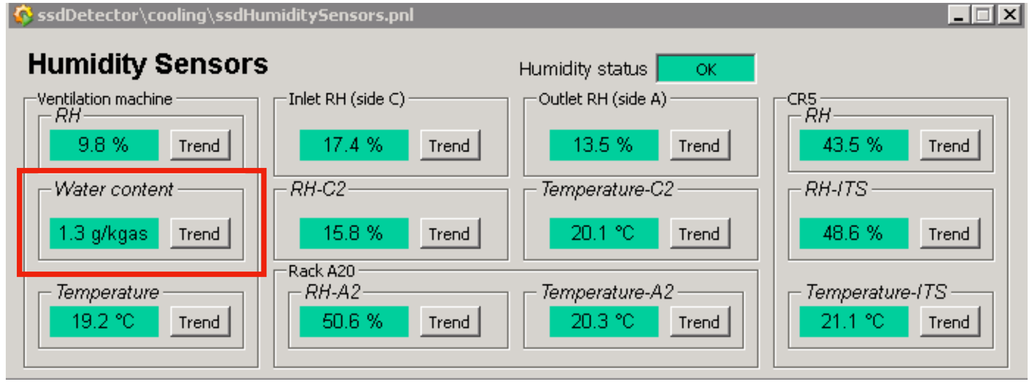




SSD - Air dryer System

- For the SSD the **humidity** is an important factor
  - **Air dryer system** to keep the humidity under control
- In June 2015, a problem with increasing humidity led to **increasing leakage current** → can lead to permanent damages
  - Some interventions on the ventilation machine (DESSICA) to keep the conditions under control till the end of 2015
  - **New machine** (SAMP) installed in April 2016, with following requirements:
    - **Absolute Humidity** (AH) range: 1 to 1.5 g/kgas
    - **Air quality:** Class 1000 (ISO6) filtering stage at the output of the machine
    - **Fixed Flow**: 350 m³/h (100 m³/h to the SSD)





Detector Control System (DCS)

- Each detector has its own **Detector Control System** (DCS) to control remotely the hardware
  - New! Standardisation and completion of high level procedures (related to BEAM SAFE status) for all detectors
- Each detector has specific **security operations**, according to past experience
  - **SPD**
    - Beam injection or adjustment → bias voltage to 2V and sensor not depleted
  - **SDD**
    - Beam injection or adjustment → HV and LV off, but readout electronics ready
      - After the accident with the beam, as precaution
    - New! LV crates can be remotely controlled with remote switch
  - **SSD**
    - HV and LV always at their nominal value → keep the conditions stable

Experiment Control System (ECS)

- Each detector has its own **Experiment Control System** (ECS) to perform specific operations, e.g. **calibration**
- Each detector has specific **calibration strategy**
  - **SPD**
    - Configuration performed only once followed by tuning
    - Noisy-pixel mask updated when a noisy pixel is detected
    - New! Pause And Reset (PAR) procedure implemented
      - To reduce the down time in case of failure
  - **SDD**
    - Baseline, noise, gain and drift speed measured at the beginning of each physics fill with dedicated calibration runs
  - **SSD**
    - Baseline and noise measured at the beginning of each physics fill with dedicated calibration runs

Radiation effects

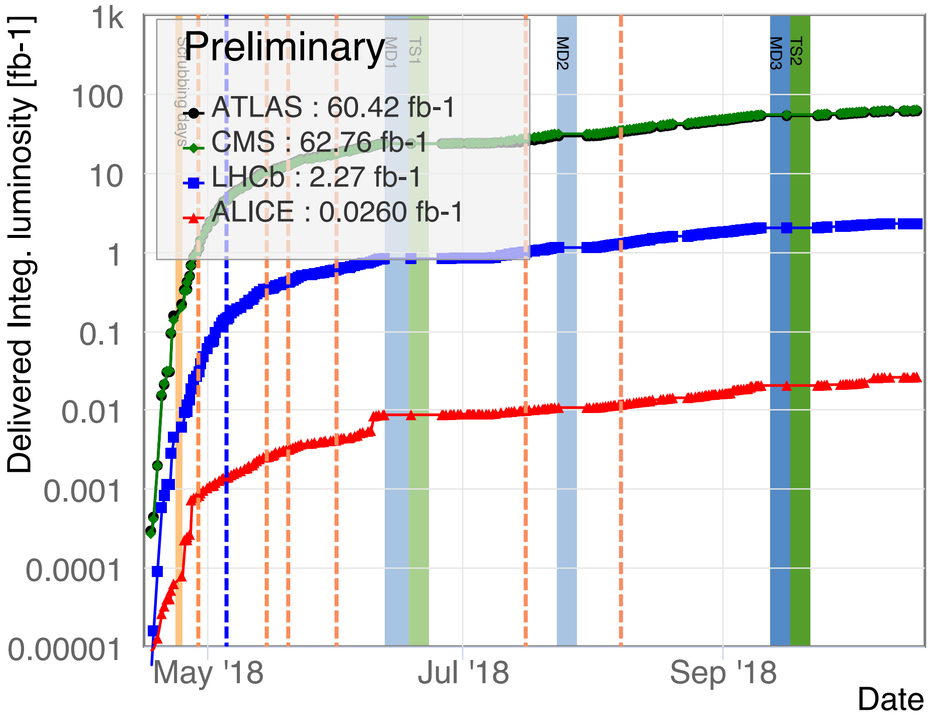
- ALICE runs at reduced
  - the integrated dose of ITS is much lower than the other LHC experiments

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}

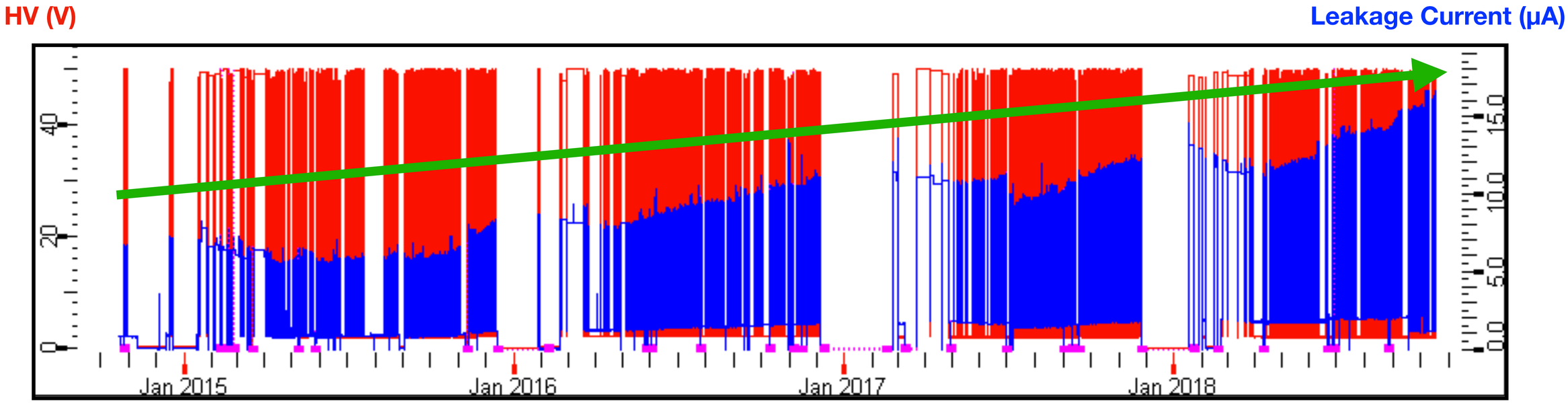
No increase in noisy channels and temperature, but increasing leakage current for some SPD Half Staves!

Delivered Luminosity 2018



SPD operational performances

- A **slight increase** of the **leakage current** has been observed for some HSs
  - 8/9 belong to Layer 1 (higher dose)
- **Stable** number of **noisy pixels** and **temperature**

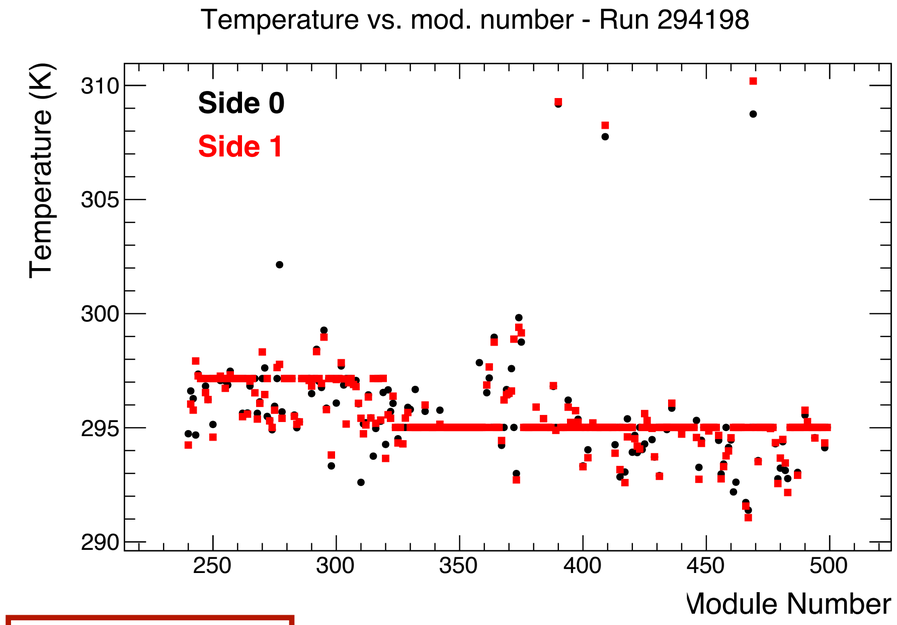


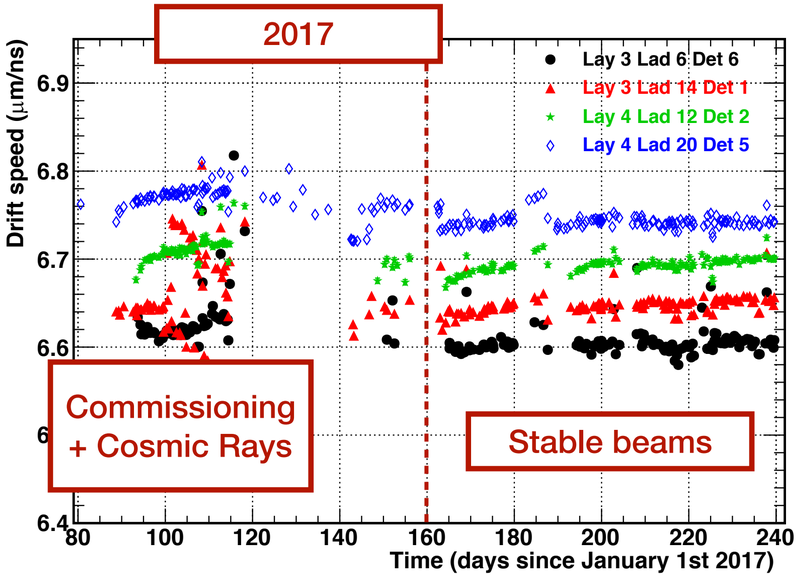
SDD operational performance

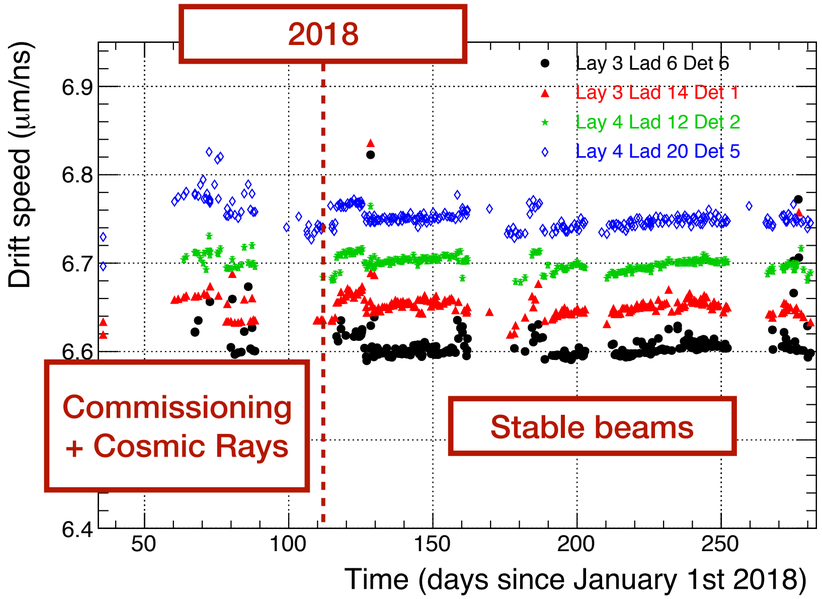
- The **drift speed** is **stable**
  - Measured during the calibration steps with the MOS injectors
  - The drift speed depends on the temperature:

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

  - **0.1% resolution** on $\mathbf{v_{drift}}$ to get the spatial resolution of $\sigma_{r\varphi}$ = 35 μm







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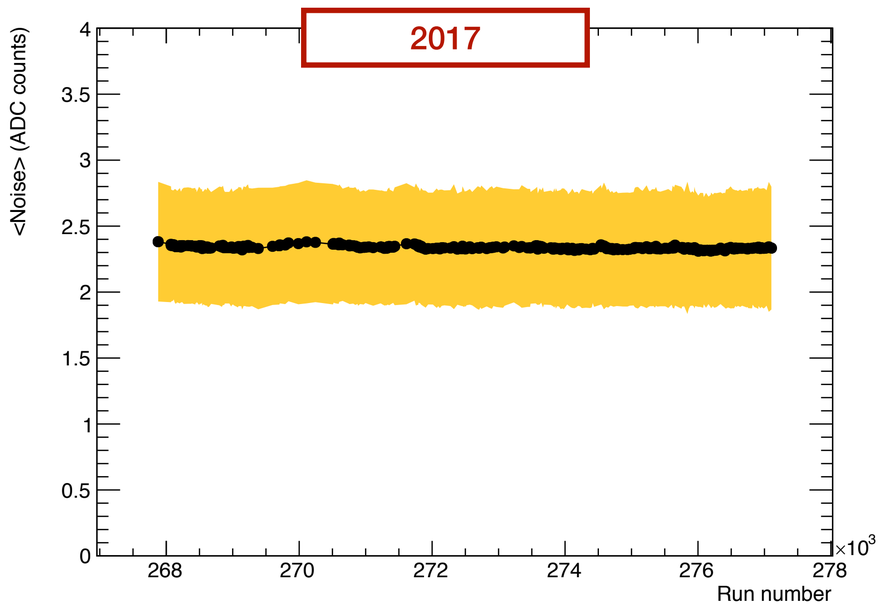
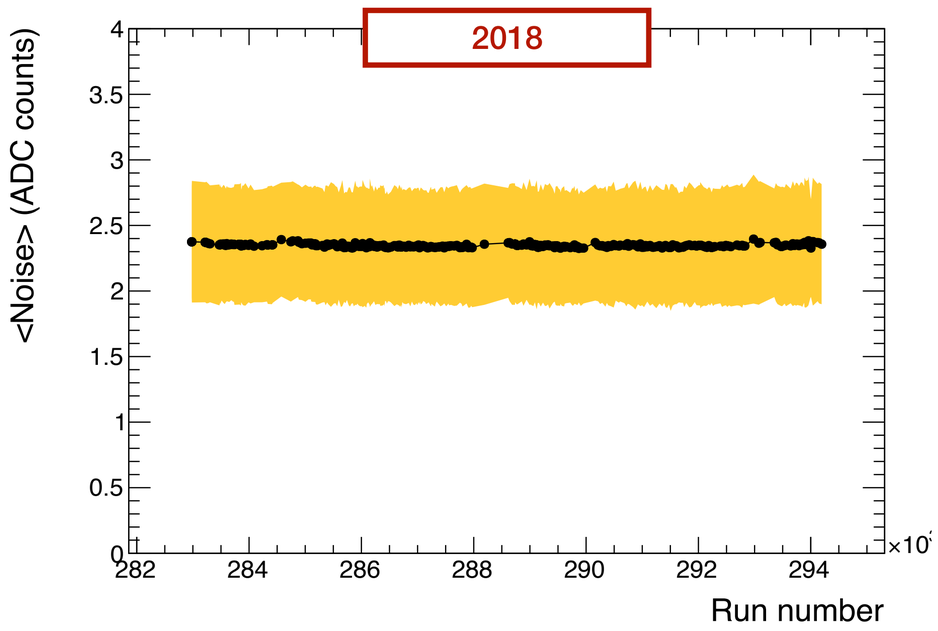
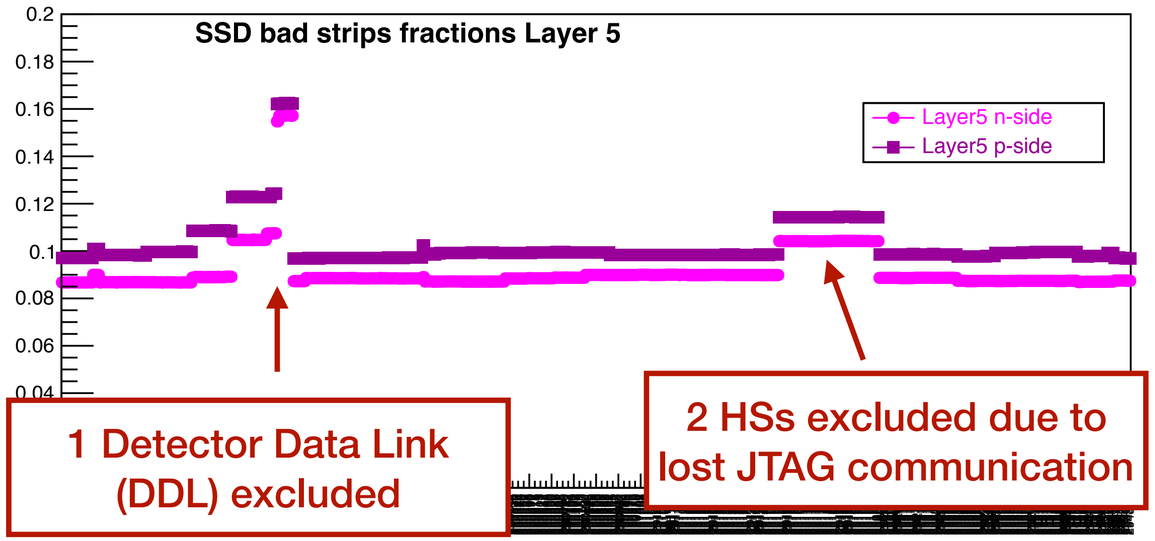
- **Noise** level is **low** and **stable**

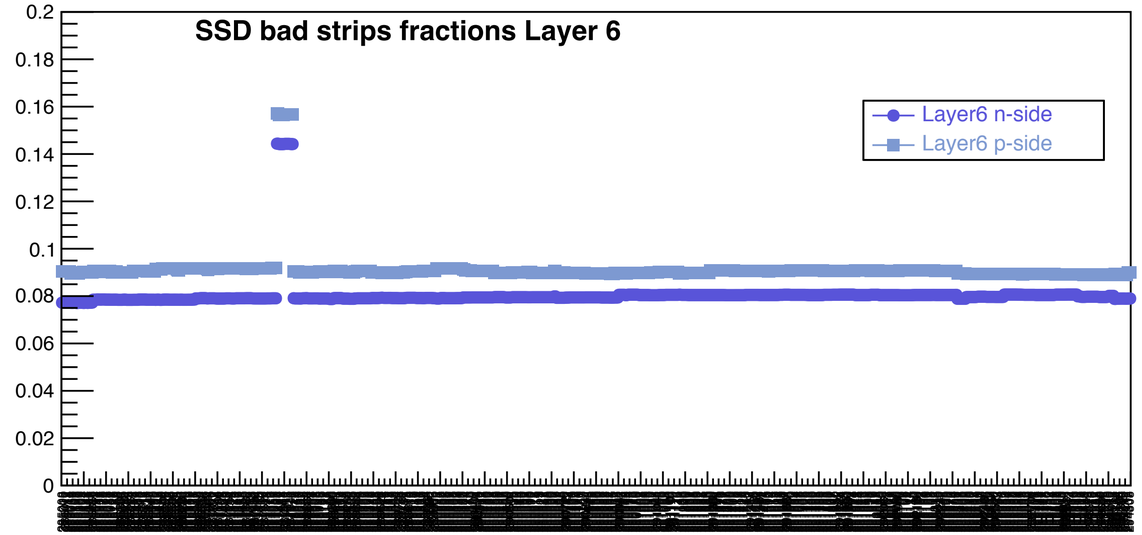




SSD operational experience

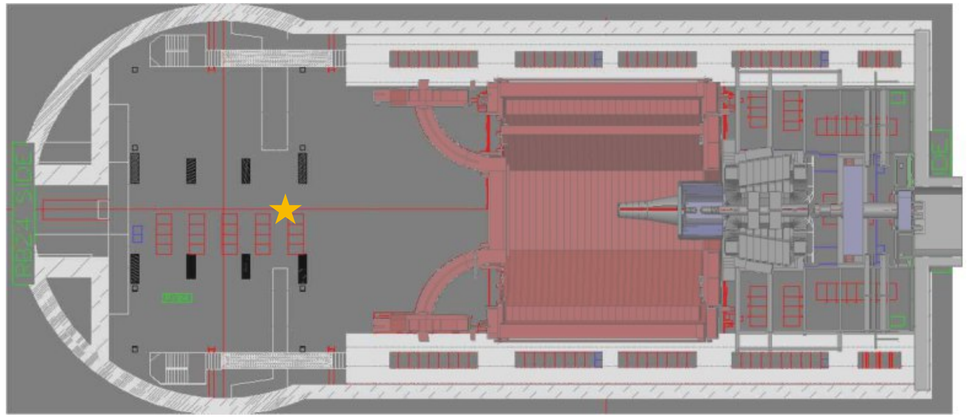
- SSD acceptance **stable**
  - Minor issue related to JTAGs
    - Solved improving cable connections
- Fraction of bad strips:
  - Layer 5:
    - n-side: 10%
    - p-side: 8.7%
  - Layer 6:
    - n-side: 9.2%
    - p-side: 8.2%





SSD – SEU in the FEROM and LV board

- The **F**ront-**E**nd **R**ead**O**ut **M**odules (**FEROM**) are close to the interaction region
  - exposed to radiation, that can change a bit of information (**S**ingle-**E**vent **U**pset)
  - SEU were not expected, due to the presence of a concrete shield



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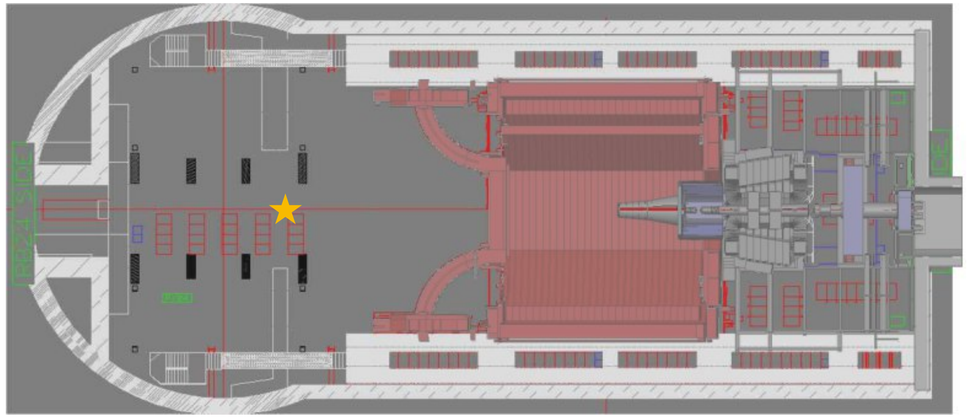
  - Radiation tolerant PROM
  - Firmware upgrade → faster FPGA reload



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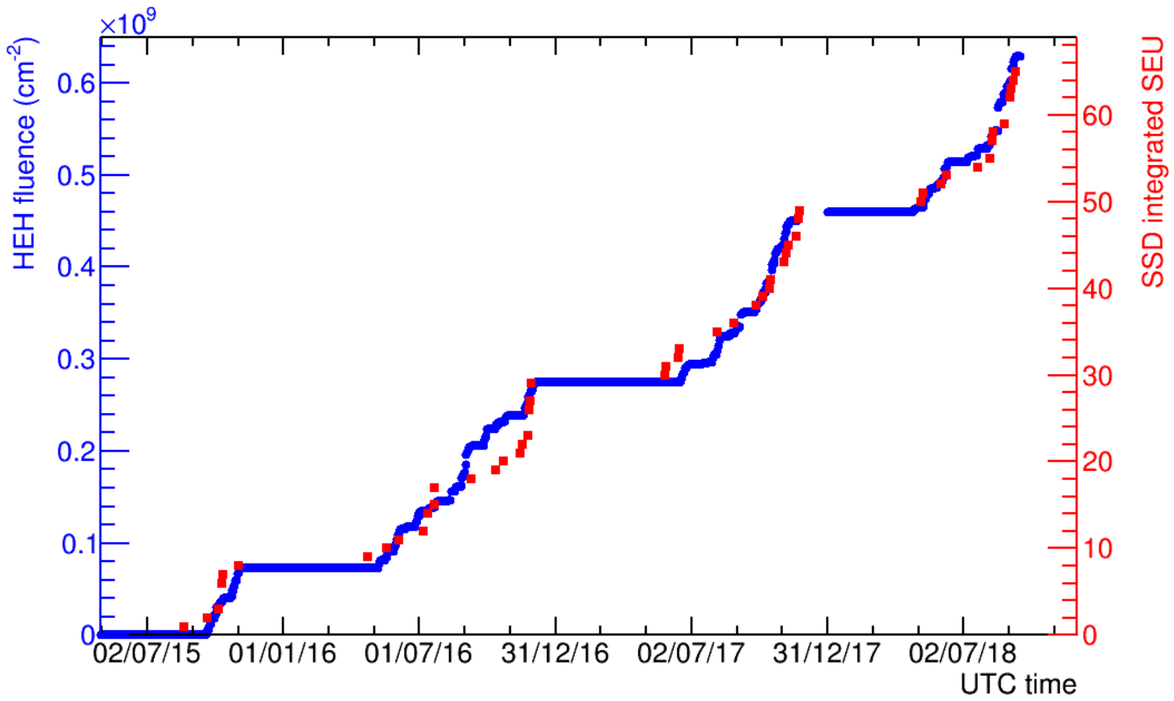
  - SEU were not expected, due to the presence of a concrete shield
- 7 SEUs recorded in **RUN1** → some measures adopted:
  - Radiation tolerant PROM
  - Firmware upgrade → faster FPGA reload
- **SEU** statistic in **RUN2**
  - 2015: 8 (ALICE L_{INT} = 6.8 pb^{-1} (pp) + 433 μb^{-1} (Pb-Pb))
  - 2016: 21 (ALICE L_{INT} = 13.4 pb^{-1} (pp) + 43.3 nb^{-1} (p-Pb))
  - 2017: 20 (ALICE L_{INT} = 19.2 pb^{-1} (pp))
  - **2018: 20 (ALICE L_{INT} ~ 25.4 pb^{-1} (pp))**



Run statistics in 2018

- The ITS was almost always available during the ALICE running time
- ITS caused 10% of the detector-caused End Of Runs (EOR)

Availability	**SPD**	**SDD**	**SSD**
% of 2017 ALICE running time	99.9	99.5	100
% of 2018 ALICE running time	99.6	99.8	99.8

Summary and Conclusions

- The ALICE Inner Tracking System is currently working smoothly, providing a physics performance in agreement with the design requirements.
- In the current year there were no major issues, just ordinary maintenance of the detector.
- The detector is showing some effects of ageing that do not influence the physics performance.
- **During Long Shutdown 2, which will start at the end of this year, the current ITS will be dismissed and completely replaced by a new tracker equipped with 7 monolithic pixel layers:**
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    by Serhiy Senyukov on Tuesday 23, 17:30
  - **Tracking and vertexing in the ALICE experiment at the LHC,**
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Thank you for your attention!