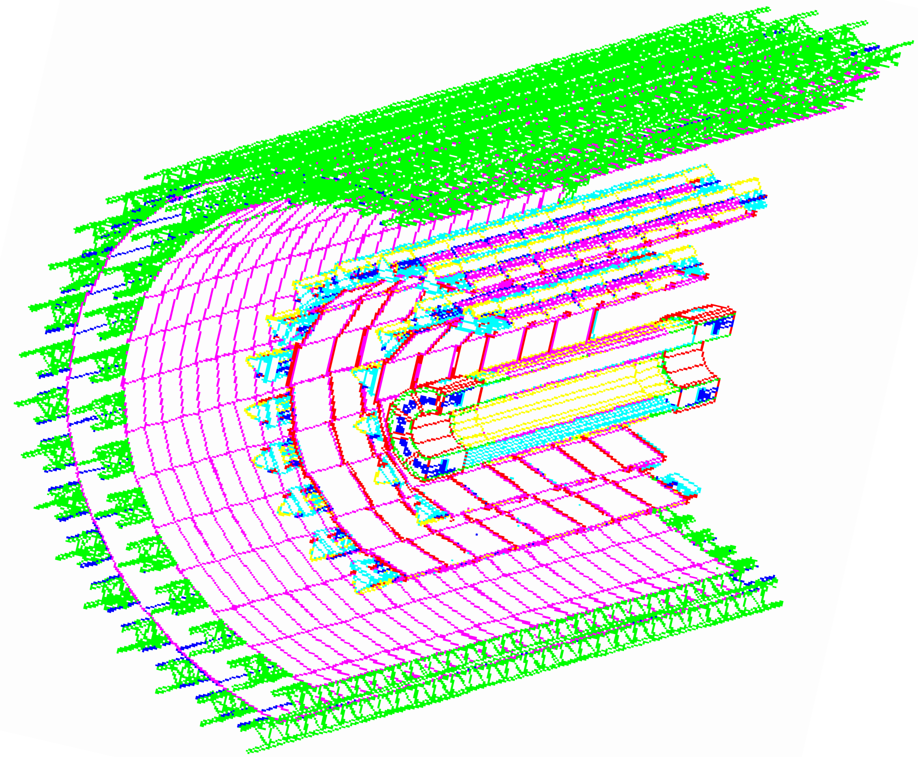
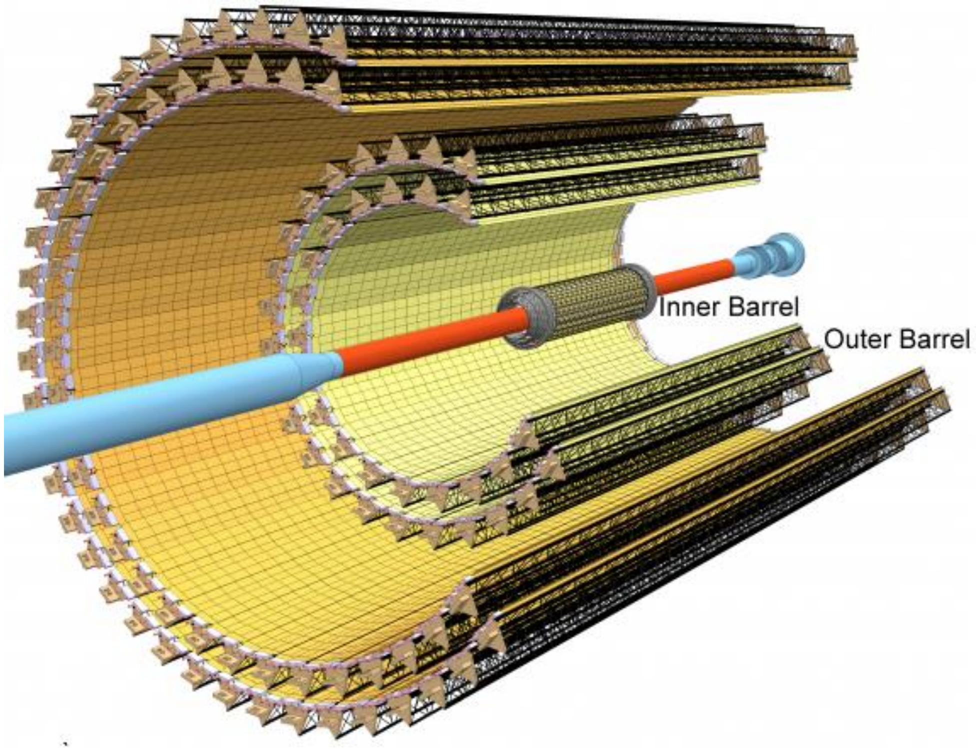




Design of the ALICE ITS then and now: technological evolution

Serhiy Senyukov (CERN)

CERN/LHCC/93-16
LHCC/I 4
1 March 1993

Letter of Intent

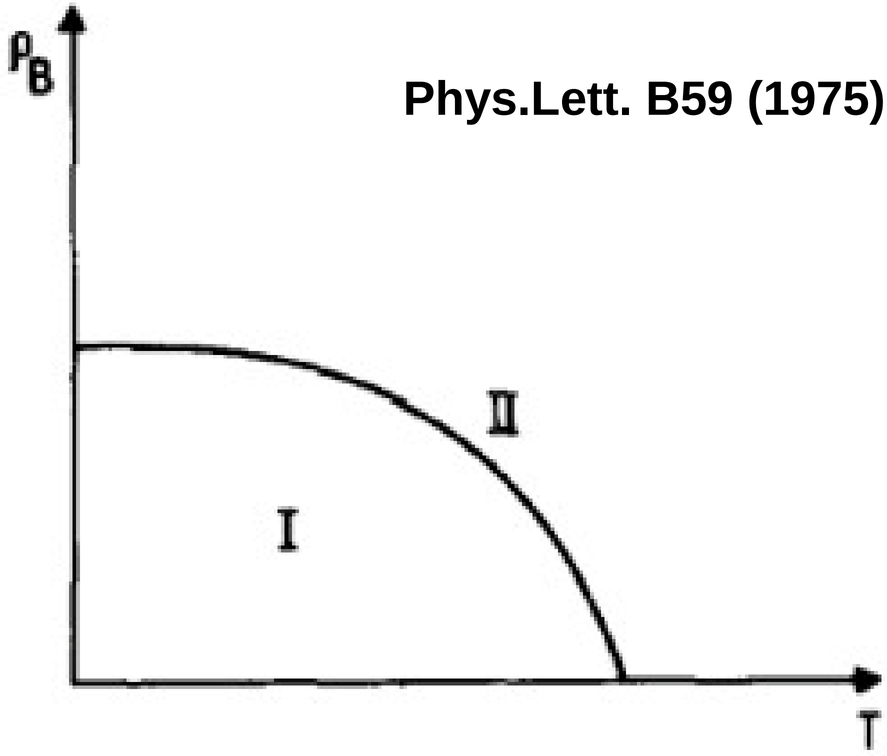
for

A **L**arge **I**on **C**ollider **E**xperiment

Main ALICE goal:
study of quark-gluon plasma (QGP)

the unique physics potential of nucleus–nucleus interactions at LHC energies. Our aim is to study the physics of strongly interacting matter at extreme energy densities, where the formation of a new phase of matter, the quark–gluon plasma, is expected. The existence

Phys.Lett. B59 (1975) 67-69



QGP is studied via probes

- QGP lifetime: 10 fm/c (10^{-23} s)
- Indirect probes are used to access the QGP properties:
  - Photonic
  - Leptonic
  - Hadronic
    - Soft probes – from low-Q processes in QGP
    - Hard probes – from high-Q processes in pre-QGP parton scattering
- Hard probes are penetrating probes
- Tomography of the QGP

Charm quark allows to assess various QGP properties

In-medium energy loss
via nuclear modification factor

Degree of medium thermalisation
via anisotropic flow

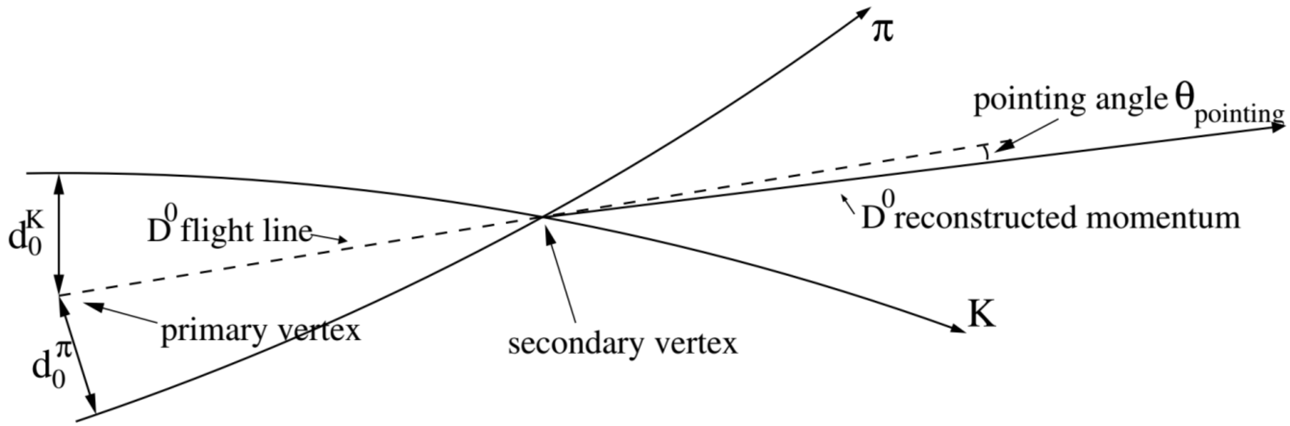
Hadronisation mechanisms
via meson to baryon ratio

All the measurements require wide
momentum range

Open charm hadrons have to be reconstructed

- Charm quark hadronises into open charm mesons and baryons
- Two reconstruction methods
  - Inclusively via semi-leptonic decays
    - Higher branching ratio (6.5 %) but
    - complex photonic background
    - no direct kinematics
    - mix of charm and beauty
  - Exclusively via hadronic decays
    - Lower branching ratio (3.8 %) but
    - direct charm reconstruction
    - high combinatorial background in HI

Topological cuts are used to reduce the background



Distance of the closest approach (DCA) of tracks

Distance between primary and secondary vertices

Pointing angle

Silicon detector is needed for precision tracking in wide p_T range

Proper decay lengths of charmed hadrons:

- D^+ – 312 μm
- D_s – 150 μm
- D^0 – 123 μm
- Λ_c – 60 μm

DCA resolution needed:

- <100 μm for D mesons
- <50 μm for Λ_c baryon

Silicon tracking detector is needed

Tracking precision: spatial resolution × multiple scattering

$$\sigma_{ip} = a \bigoplus \frac{b}{p \cdot (\sin \Theta)^{3/2}}$$

High tracking precision requires:

high spatial resolution = high granularity

AND

low multiple scattering = low material budget

Other conditions have to be satisfied

Geometrical constraints:

- Inner radius: ~4 cm (beam pipe)
- Outer radius: ~45 cm (TPC)

Experimental conditions:

- Particle density: up to ~100 cm^{-2}
- Event rate: 8 kHz (minimum bias trigger)
- Radiation load: up to 270 krad, 3.5×10^{12} n_{eq}/cm^2

Financial conditions:

- Simplicity and low cost

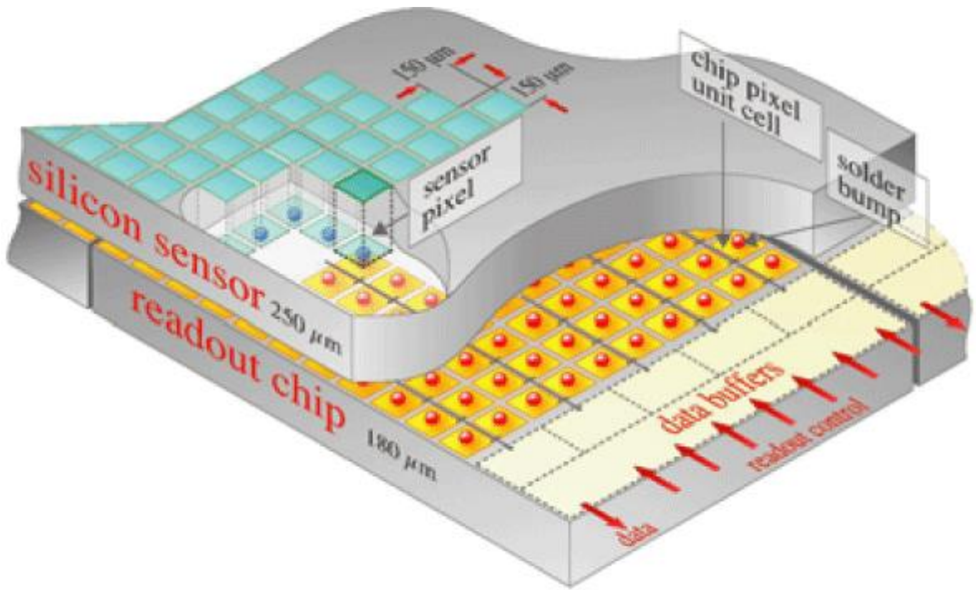
Three technologies available

SPD Silicon Pixel Detectors (SPD)

Silicon Drift Detectors (SDD)

Silicon Strip Detectors (SSD)

Silicon Pixel Detector

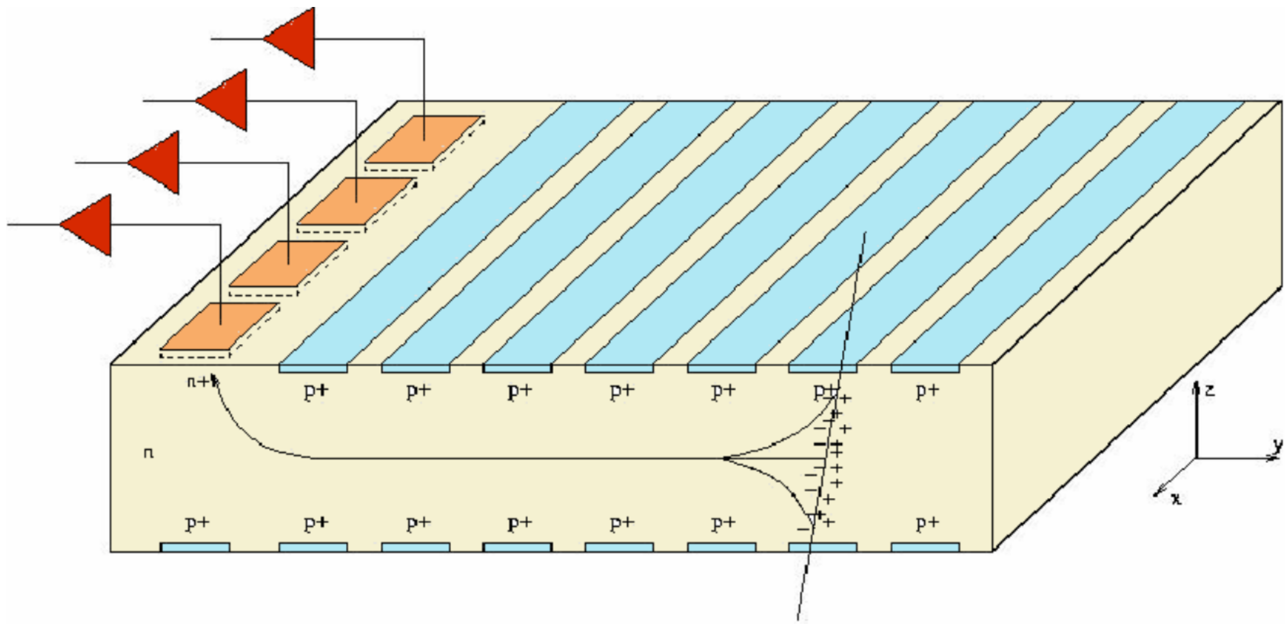


High granularity

High speed

High cost (chip to sensor connection)

Silicon Drift Detector

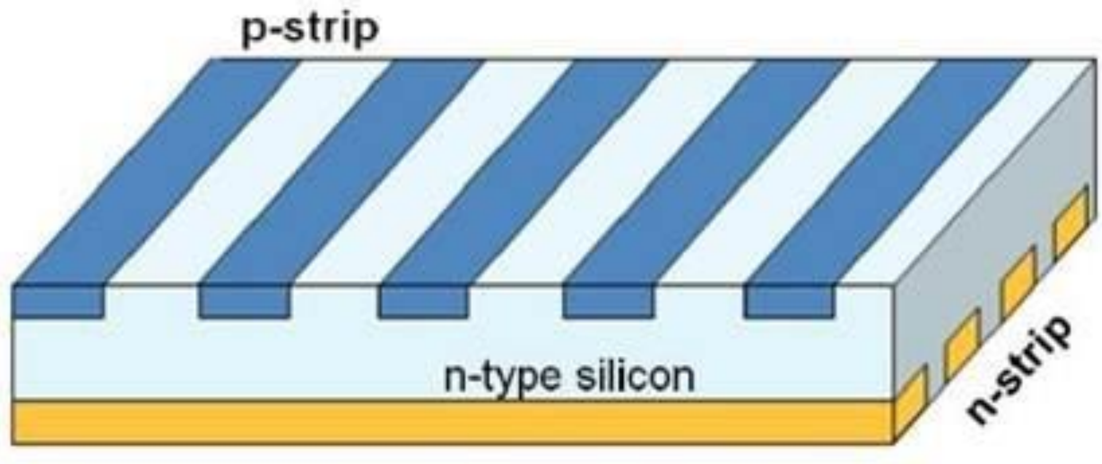


High granularity

Average speed

Average cost

Silicon Strip Detector



Low granularity

High speed

Low cost

Three technologies available

SPD Silicon Pixel Detectors (SPD)

- High granularity
- High speed
- High cost

Silicon Drift Detectors (SDD)

- High granularity
- Average speed
- Average cost

Silicon Strip Detectors (SSD)

- Low granularity
- High speed
- Low cost

Final ITS layout

- Inner layers at 3.9 and 7.6 cm – SPD
  - High granularity is good for highest particle density
  - High speed allows for fast trigger generation
  - High cost is acceptable at small surface
- Intermediate layers at 15 and 23.0 cm – SDD
  - High granularity – intermediate particle density
  - Average speed but compatible with MB rate
  - Average cost is good for intermediate surface
- Outermost layers at 38 and 43 cm – SSD
  - Low granularity is good low particle density
  - High speed is always good
  - Low cost is good for the biggest surface

Modules parameters: trade-off between performance and cost

SPD

Pitch: 50 µm × 425 µm
Resolution: 12 × 100 µm
1-bit readout
Maximum readout rate: 3.3 kHz

SDD

Pitch: 202 µm × 294 µm
Resolution: 35 µm × 25 µm
10-bit readout for dE/dx
Maximum readout rate: ~3 kHz

SSD

Pitch: 95 µm × 40 mm / double-sided
Resolution: 20 µm × 830 µm
11-bit readout for dE/dx
Maximum readout rate: 3.3 kHz

Material budget lowest at LHC

SPD

- Sensor + chips: 200+150 µm
- Aluminum bus + Carbon fiber support
- Total material length per layer: 1.14 % X_0

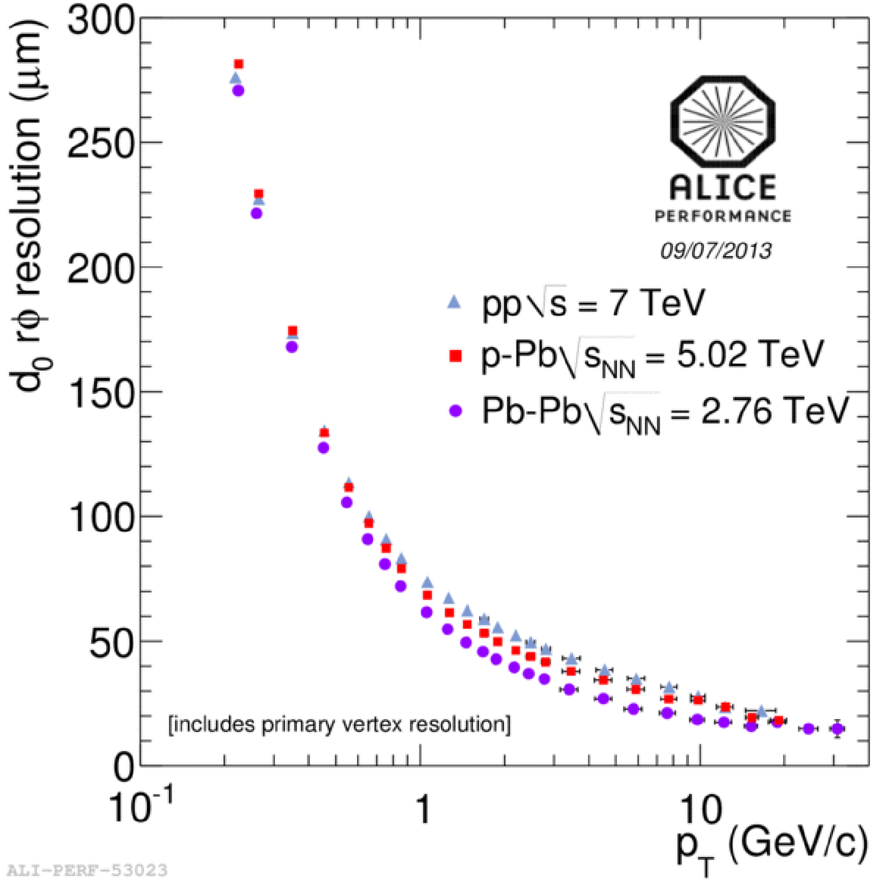
SDD

- Sensor: 300 µm (for dE/dx)
- Aluminum bus + Carbon fiber support
- Total material length per layer: 1.2 % X_0

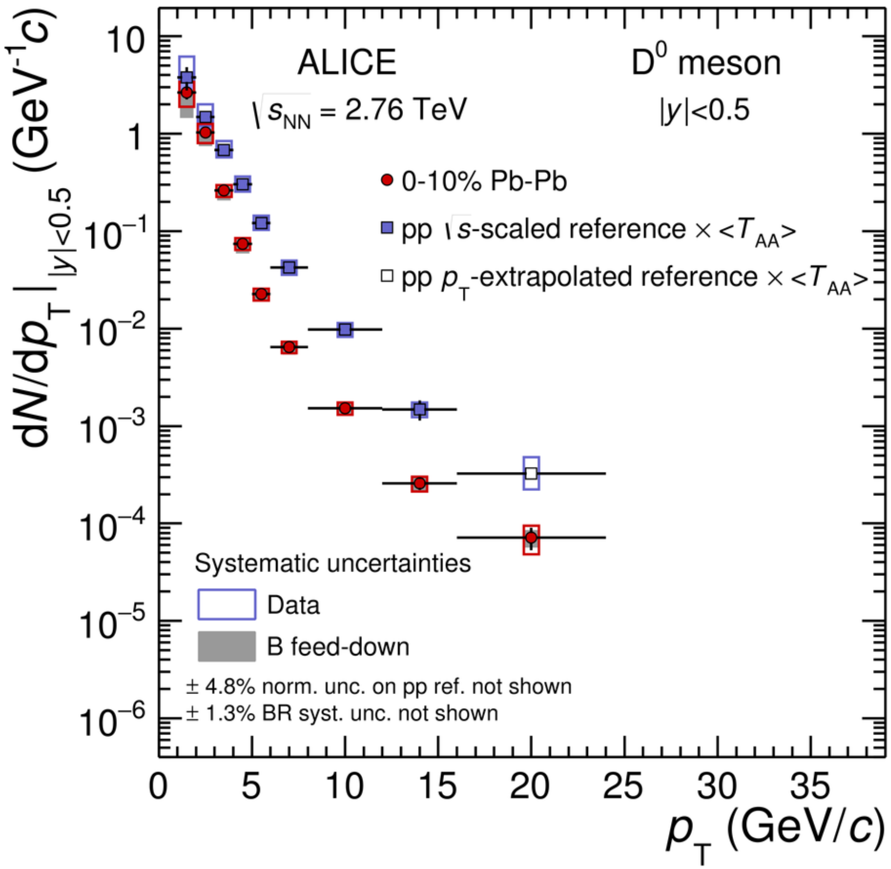
SSD

- Sensor: 300 µm (for dE/dx)
- Aluminum bus + Carbon fiber support
- Total material length per layer: 0.83 % X_0

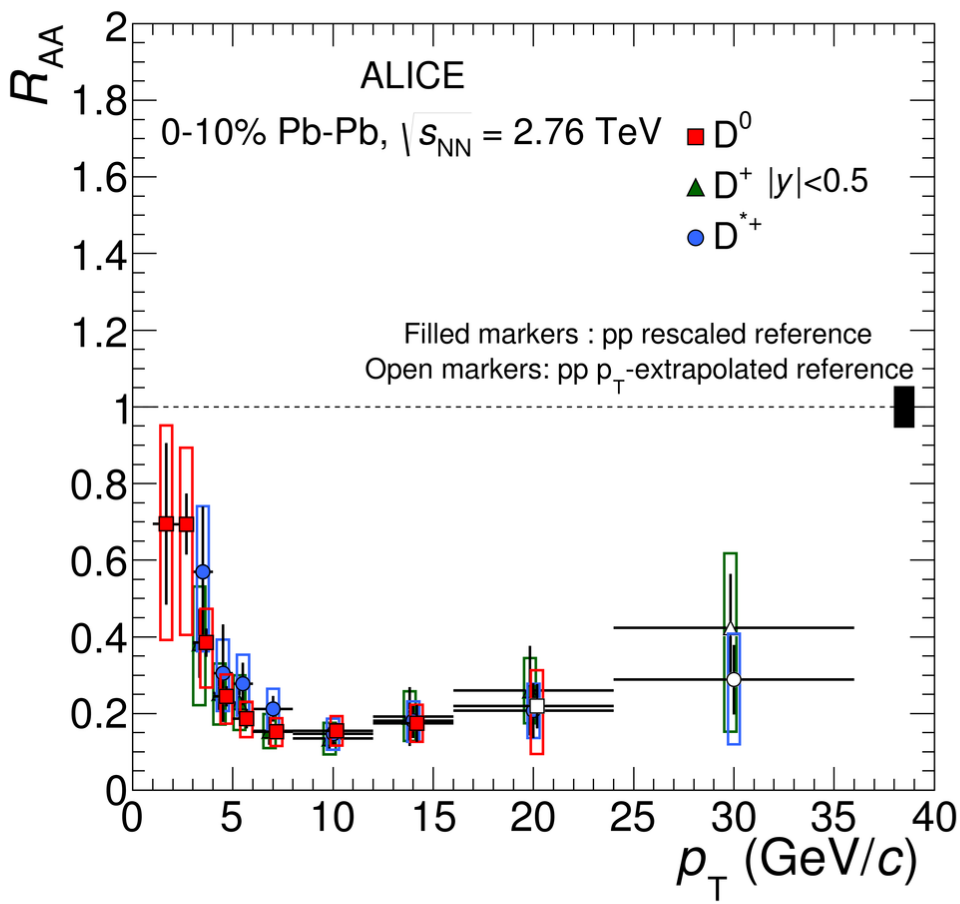
DCA resolution: 60 μm at 1 GeV/c



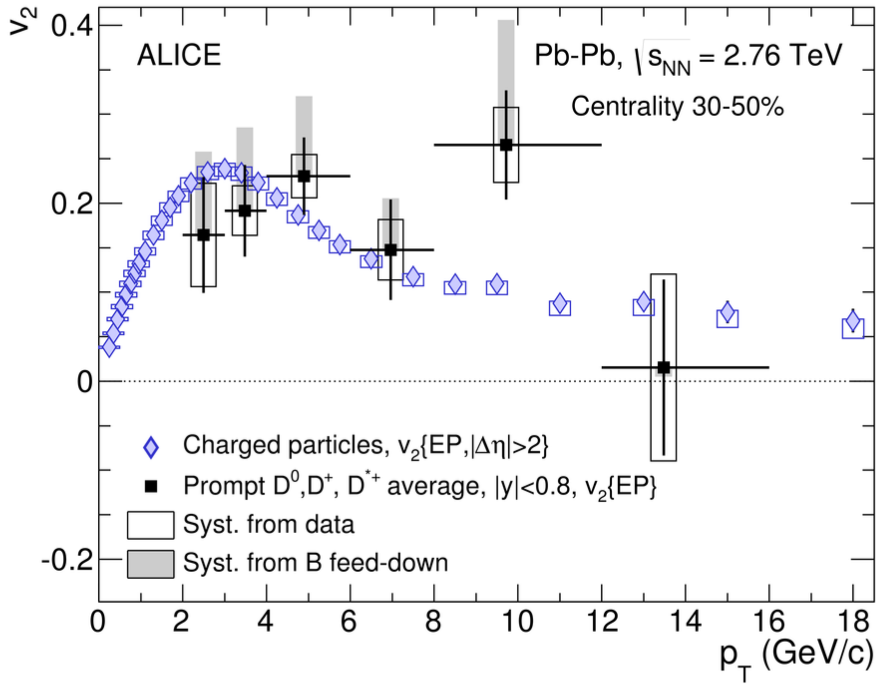
D^0 meson reconstructed for p_T>1 GeV/c in Pb-Pb collisions



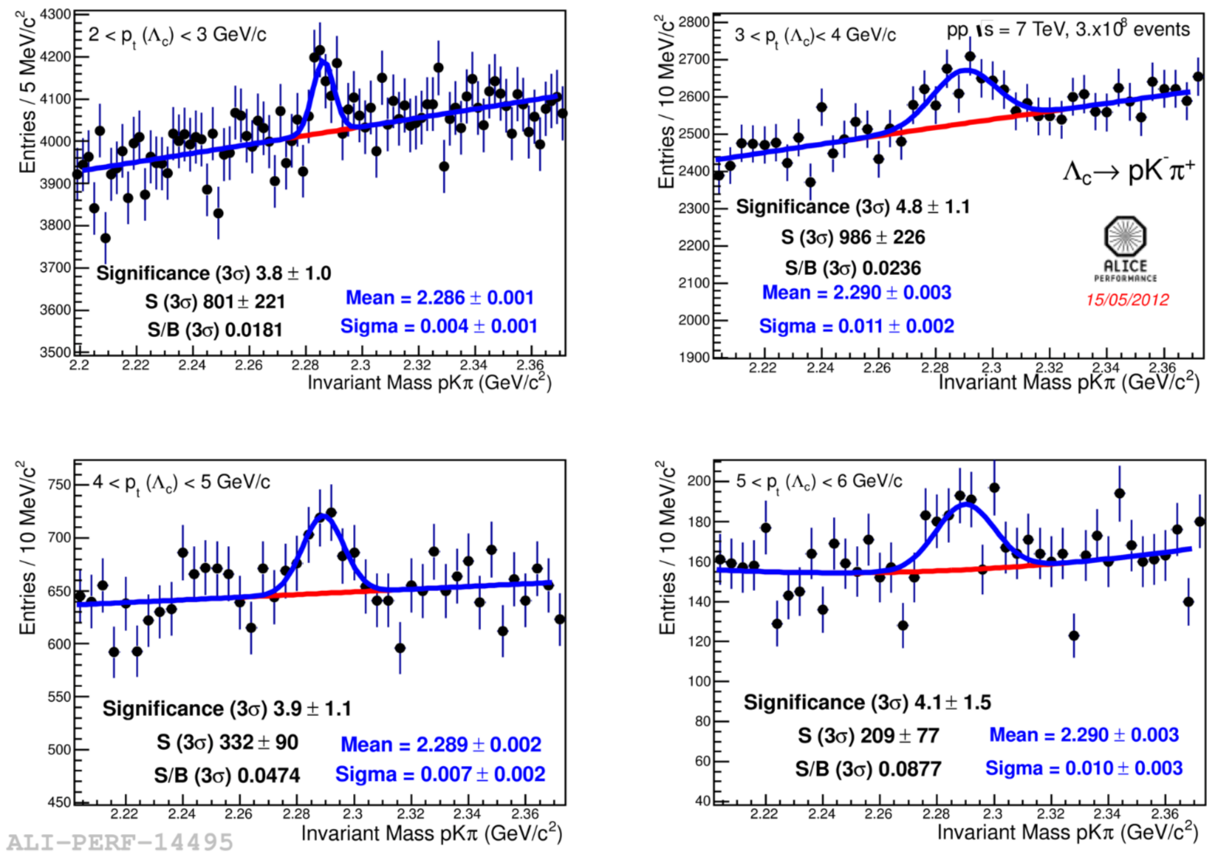
D^0 meson R_{AA} measured for p_T>1 GeV/c in Pb-Pb collisions



D^0 meson v_2 measured for p_T>2 GeV/c in Pb-Pb collisions



Λ_c reconstructed in pp collisions



Λ_c not reconstructed in Pb-Pb collisions

DCA resolution insufficient

Topological cuts inefficient

No way to measure the meson to baryon ratio

Tracking precision has to be improved

Readout rate has to be increased to collect more data

ITS upgrade for higher resolution and readout rate

Higher resolution:

- Innermost layer closer to collision
- Increase detector granularity
- Decrease material budget

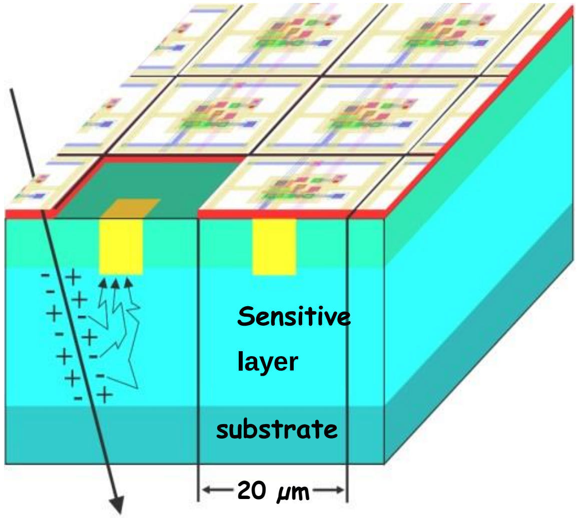
Higher readout rate:

- Remove slow detectors (SDD)
- New readout architecture

Old technologies are still there

- (Hybrid) Silicon Pixel Detectors
  - Pixel size: 50 µm
  - Material budget: ~1% X_0
  - High cost
- Silicon Strip Detectors (SSD)
  - Low granularity (long strips)
  - Analogue readout

A new technology available: CMOS Pixel Sensors (CPS)



Pixel size: 20 μm

Material budget: ~0.3% X_0

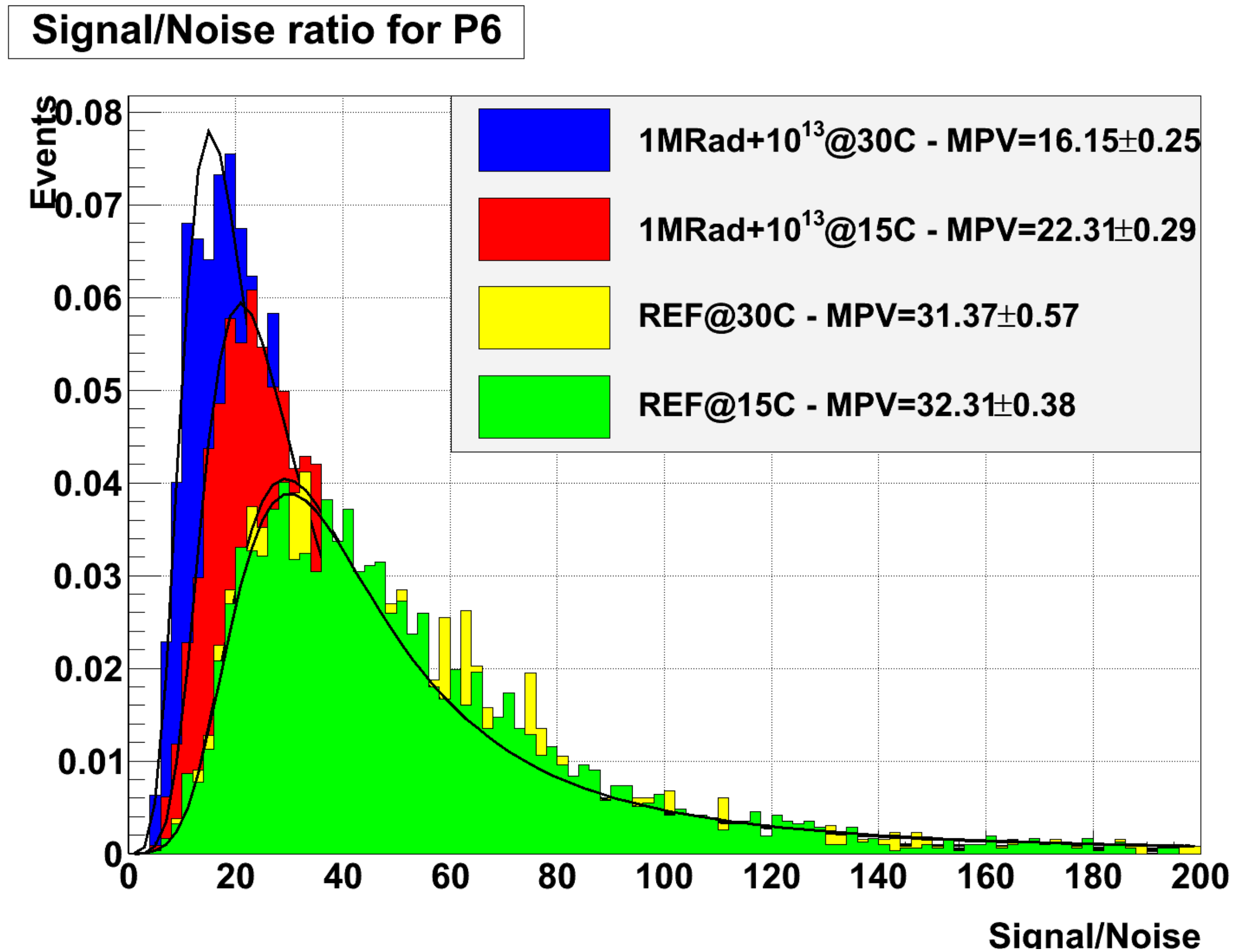
Low cost (CMOS process, no interconnections)

Radiation hardness to be validated

Possible arrangements

- Hybrid SPD
  - Limited performance gain
  - Highest cost – only for inner layers
- Silicon Strip Detectors (SSD)
  - Low granularity – only for outer layers
- CMOS Pixel Sensors (CPS)
  - If radiation hardness proved – very good alternative for hybrid SPD for inner layers
  - Lowest cost – can equip all the layers

CPS radiation hardness validated



2 ITS upgrade layouts considered

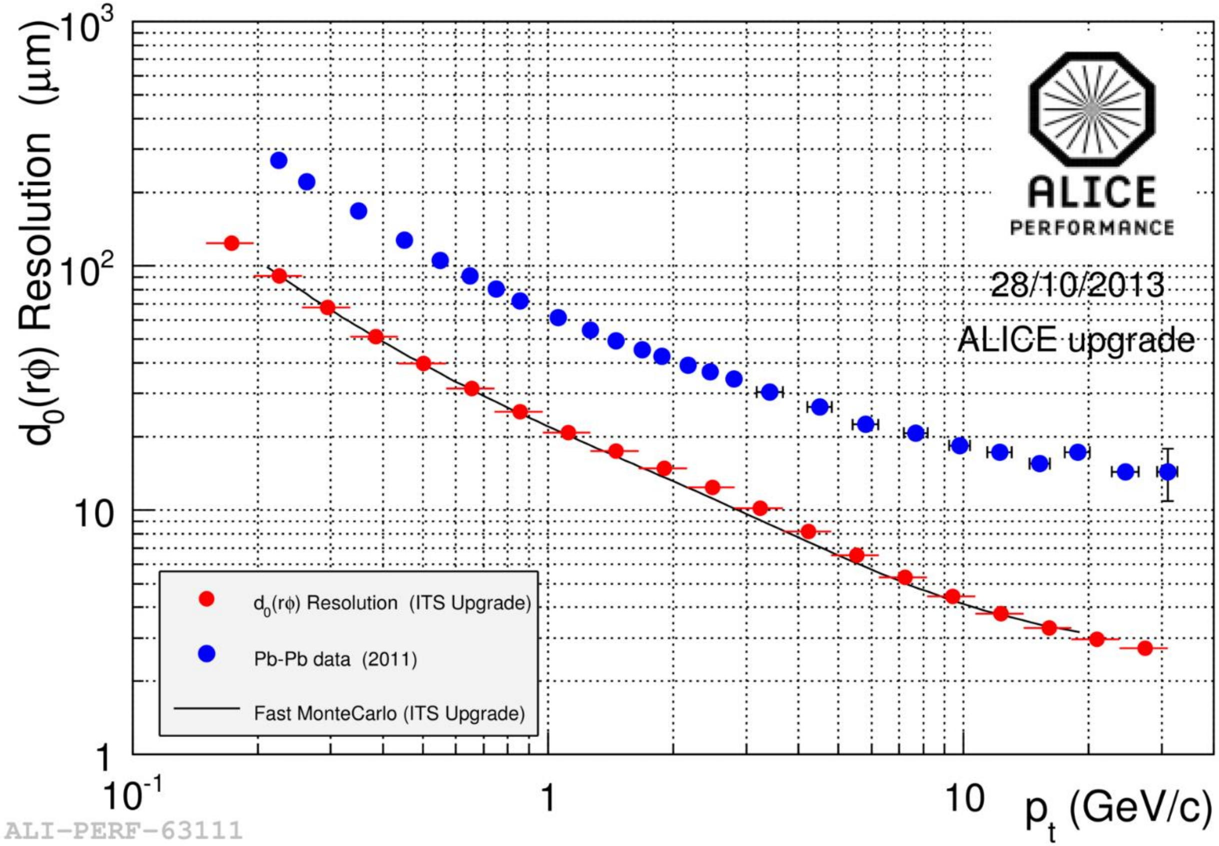
- Radiation hardness of CPS was verified
- Hybrid pixels are excluded
- 2 possible layouts remain:
  - All 7 layers in CPS
    - Lower construction cost
    - No particle identification in ITS
  - 3 inner layers in CPS, 4 outer layers in SSD
    - Analogue readout from SSD for particle identification based on dE/dx
    - Higher construction cost

Final layout: all CPS

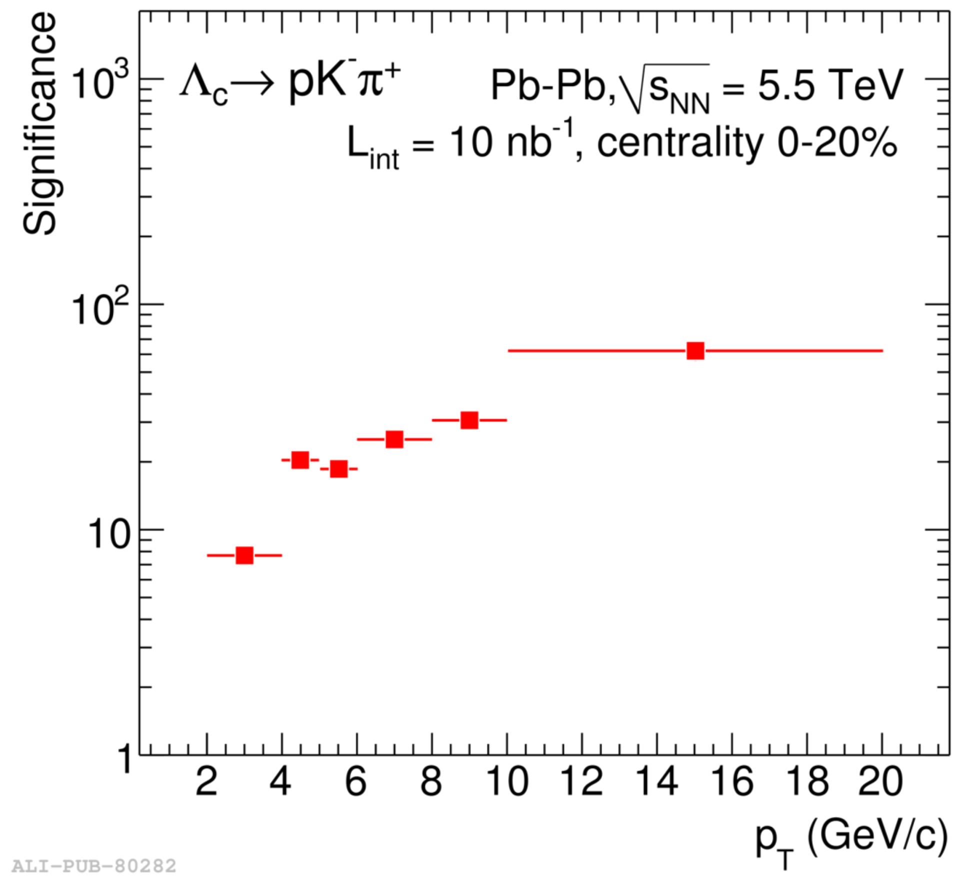
Final layout:

- 7 layers of CPS
- Pitch: 28 µm × 28 µm
- Sensor thickness: 50 µm
- Power consumption: 35 mW/cm^2
- Material budget
  - 3 inner layers: 0.262% X_0 per layer
  - 4 outer layers: 0.813% X_0 per layer
- Maximum readout rate:
  - 100 kHz in Pb-Pb
  - 400 kHz in pp

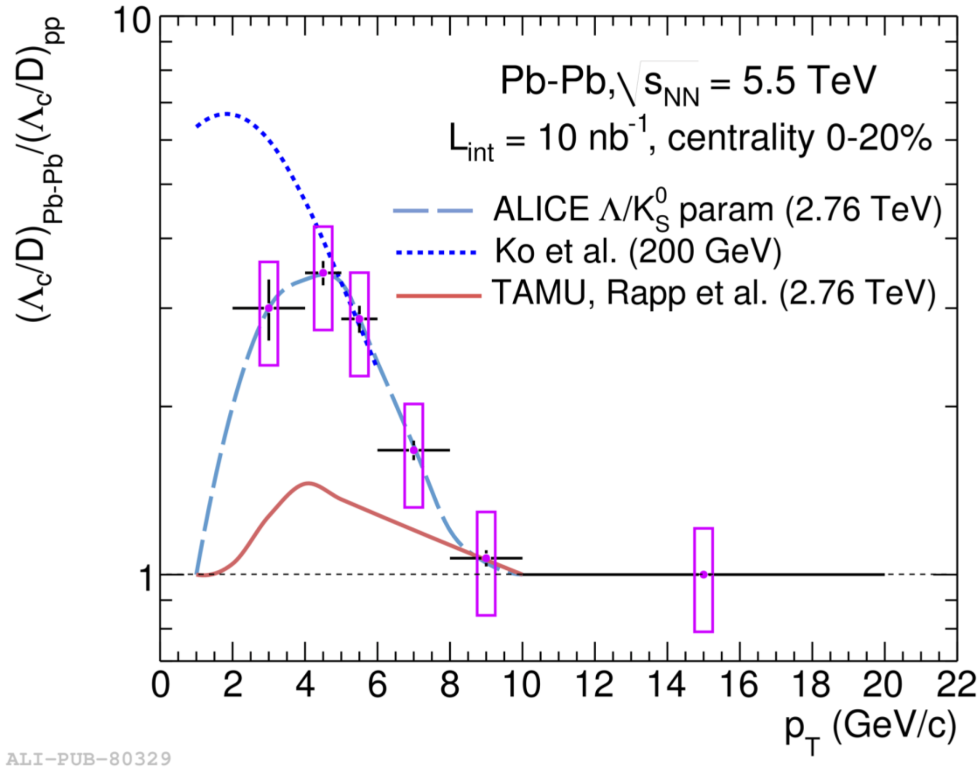
Expected DCA resolution: ~20 µm at 1 GeV/c



Expected to reconstruct Λ_c for p_T>2 GeV/c



Expected to measure Λ_c/D for p_T>2 GeV/c



Development of CPS made this significant improvements possible

Pixel size reduced

- by factor 1.8 in bending plane
- and by factor 16 along beam axis

Readout rate improved by factor 30

Power consumption reduced by factor 14

Material budget reduced by factor 3

Detector DCA resolution improved

- by factor 3 in bending plane
- and by factor 5 along beam axis

Something can still be improved

- Granularity can’t be easily increased at present CMOS feature size.
  - Smaller feature size means higher cost and potentially lower yield.
- Reduction of the material budget can be done
  - Sensor thickness can’t be easily reduced further
  - Cooling and support can be reduced
    - Power consumption optimization
    - Ultra-light detector integration (PLUME, all-silicon layers)

ALICE ITS Super Upgrade?

Let’s speak about it in few years

ALICE