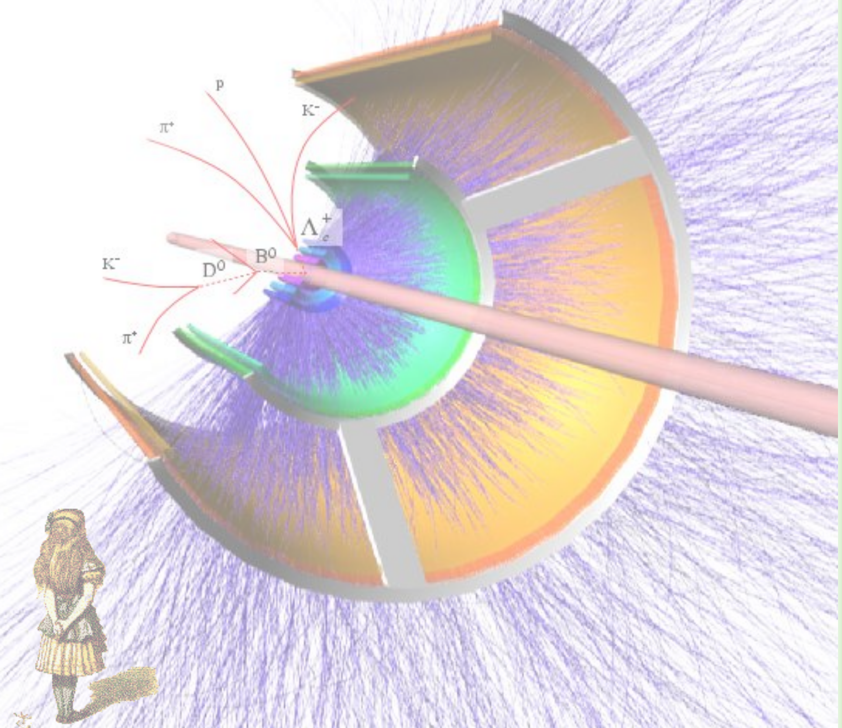
PIXEL2012
Inawashiro, Japan

6th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging, September 3-7, 2012

Upgrade of the ALICE ITS

Details on the Upgrade proposal

Stefan Rossegger
on behalf of the ALICE ITS collaboration
3rd of September, 2011



Overview

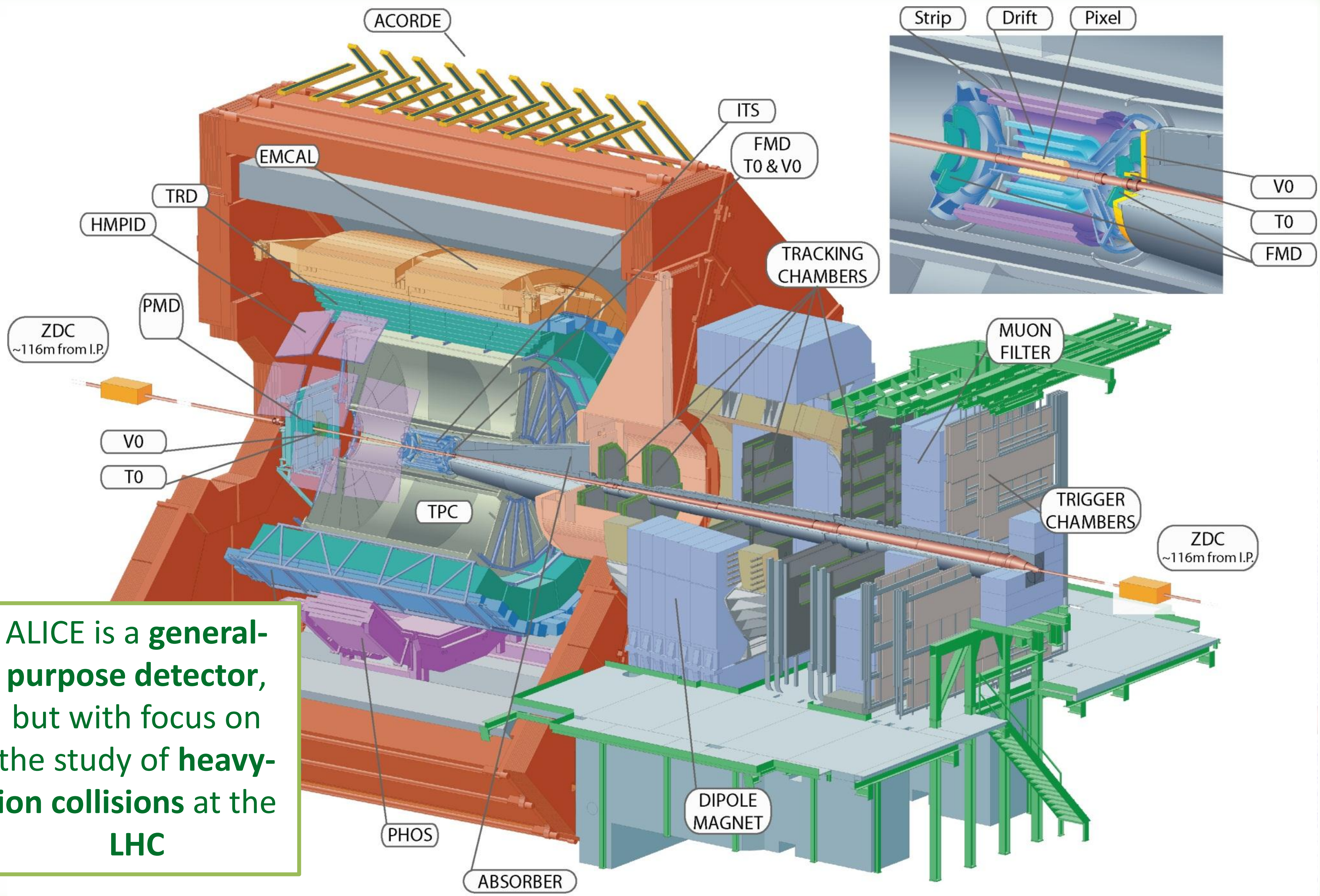
Participating Institutes

OUTLINE

- ALICE at CERN
- Current ITS
  - Design and Performance
- ITS upgrade
  - Motivation
  - Key Improvements
  - Pixel Technologies
  - Mechanical Support
- Timeline

CERN Geneva European Organization for Nuclear Research
China Wuhan Institute of Particle Physics, Central China Normal University (CCNU)
Czech Republic Řež u Prahy Nuclear Physics Institute of the ASCR
France IN2P3 Strasbourg Institut Hubert Curien, Université Louis Pasteur, IN2P3-CNRS
Italy INFN Bari Sezione INFN e Dipartimento dell'Università e del Politecnico di Bari
Italy INFN Cagliari Sezione INFN e Dipartimento di Fisica dell'Università di Cagliari
Italy INFN Catania Sezione INFN e Dipartimento di Fisica dell'Università di Catania
Italy INFN Frascati Laboratori Nazionali di Frascati (LNF)
Italy INFN Legnaro Laboratori Nazionali di Legnaro (LNL)
Italy INFN Padova Sezione INFN e Dipartimento di Fisica e Astronomia dell'Università di Padova
Italy INFN Roma Sezione INFN e Dipartimento di Fisica dell'Università "La Sapienza" di Roma
Italy INFN Torino Sezione INFN e Dipartimento di Fisica dell'Università di Torino
Italy INFN Trieste Sezione INFN e Dipartimento di Fisica dell'Università di Trieste
Korea Seoul Yonsei University
Pakistan Islamabad Faculty of Sciences, COMSATS, Institute of Information Technology
Russia St. Petersburg Institute of Physics, St. Petersburg State University
Slovakia Košice Slovak Academy of Sciences, IEP
UK STFC Birmingham University of Birmingham
UK STFC Warrington STFC Daresbury Laboratory
UK STFC Chilton Rutherford Appleton Laboratory
Ukraine Kharkov Ukrainian Academy of Sciences, KIPT-KFTI
Ukraine Kharkov Scientific Research Technological Institute of Instrument Engineering SRTIIE
Ukraine Kiev Bogolyubov Institute for Theoretical Physics (BITP)

ALICE – A Large Ion Collider Experiment



ALICE is a **general-purpose detector**, but with focus on the study of **heavy-ion collisions** at the **LHC**

ALICE – Detector Upgrade

Motivation

- **Improve tracking and low p_t vertexing** while preserving the excellent particle-identification of the current detector
- **Readout all Pb-Pb** events at an interaction rate of **50 kHz**

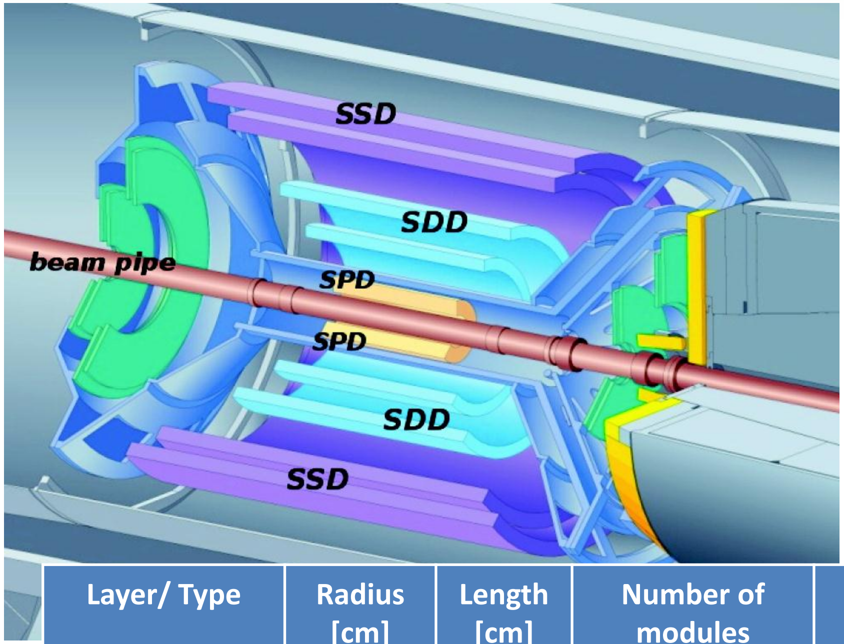
Upgrade targets:

- new, smaller radius, beam pipe
- **new ITS (Inner Tracking System)**
- high-rate upgrade for the readout of the TPC, TRD, TOF, PHOS, Muon-Arm, Online-systems and Trigger detectors

- **Target for installation and commissioning LS2 (2018)**

ALICE ITS (Inner Tracking System)

(current detector)



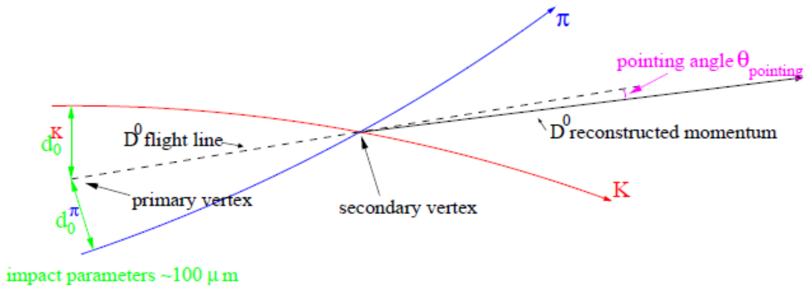
Current ITS consists of 6 concentric barrels of silicon detectors

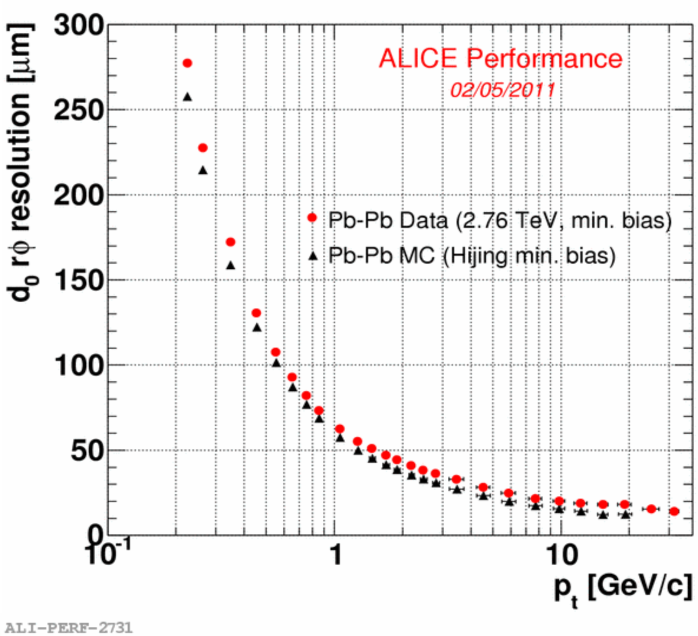
3 different technologies

- 2 layers of silicon **pixel** (SPD)
- 2 layers of silicon **drift** (SDD)
- 2 layers of silicon **strips** (SSD)

Layer/ Type	Radius [cm]	Length [cm]	Number of modules	Active area per module [mm²]	Nom. resolution rϕ x z [μm]	Material budget X/X_0 [%]
Beam pipe	**2.94**	-	-	-	-	0.22
1 / Pixel	**3.9**	28.2	80	12.8 × 70.7	**12 × 100**	**1.14**
2 / Pixel	**7.6**	28.2	160	12.8 × 70.7	**12 × 100**	**1.14**
Thermal Shield	*11.5*	-	-	-	-	*0.65*
3 / Drift	**15.0**	44.4	84	70.2 x 75.3	35 × 25	1.13
4 / Drift	**23.9**	59.4	176	70.2 x 75.3	35 × 25	1.26
Thermal Shield	*31.0*	-	-	-	-	*0.65*
5 / Strip	**38.0**	86.2	748	73.0 x x40.0	30 × 830	0.83
6 / Strip	**43.0**	97.8	950	73.0 x x40.0	20 × 830	0.83

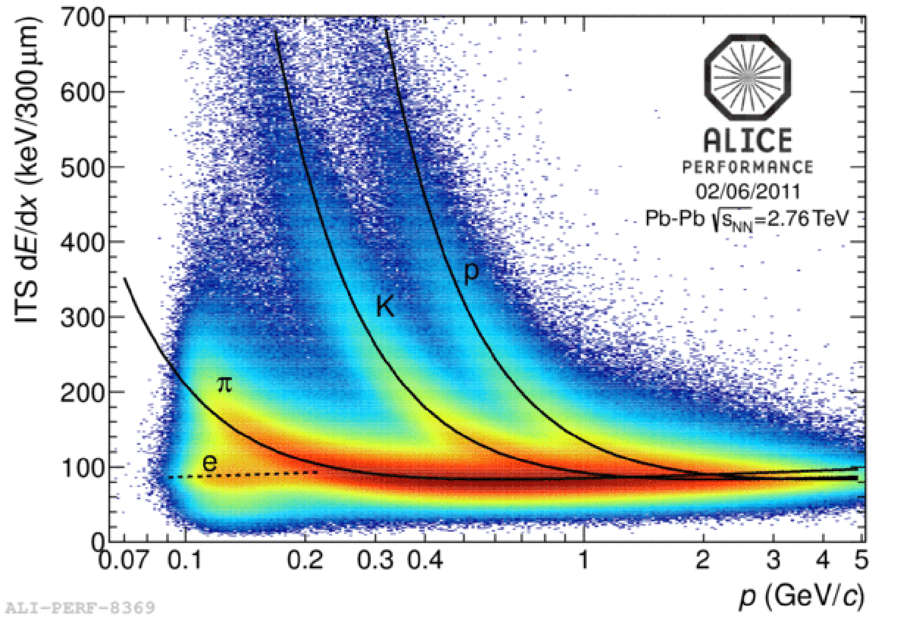
1. **The Identification of secondary vertices** relies on the impact parameter $\mathbf{d_0}$ (in rφ and z)





2. **The PID performance (from SDD & SSD)**

- PID combined with stand-alone tracking allows to identify charged particles below 100 MeV/c
- p-K (3σ) separation up to 1 GeV/c
- π-K (3σ) separation up to 600 MeV/c
- dE/dx resolution of about 10-15% is achieved



ITS Upgrade - Motivation

1. Increase vertex resolution by a factor of ~3

Identification of secondary vertices from decaying charm and beauty

- **increase statistical accuracy** of channels already measured by ALICE e.g. displaced **D^0, J/ψ**
- **measurement of new channels** e.g. charmed baryon Λ_c or more exotic channels like Λ_b
- **measurement of baryon/meson ratios** e.g. charm and beauty (Λ_c/D) (Λ_b/B)

2. Improve tracking efficiency & momentum resolution

3. Improve read-out time

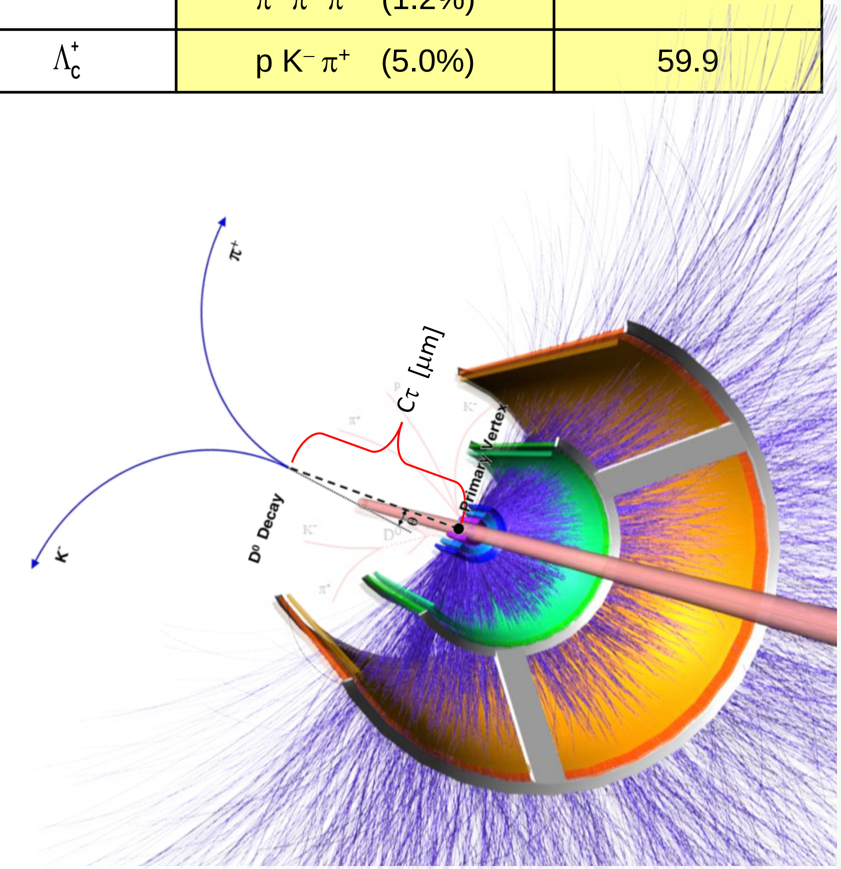
Target: **Pb-Pb min.bias at a rate of 50 kHz**

Current limitation in read-out: ~ 1 kHz (due to SDD)

The ALICE strategy is to readout all data at a rate of 50 kHz (via min.bias Pb-Pb trigger) which will be sent to the Online Systems for processing (first reconstruction and cluster-compression) and later stored on tape

Example - Direct Topological Identification of the Open Charm

Particle	Decay Channel	cτ (μm)
D^0	$K^- \pi^+$ (3.8%)	123
D^+	$K^- \pi^+ \pi^+$ (9.5%)	312
D_s^+	$K^+ K^- \pi^+$ (5.2%) $\pi^+ \pi^+ \pi^-$ (1.2%)	150
Λ_c^+	$p K^- \pi^+$ (5.0%)	59.9



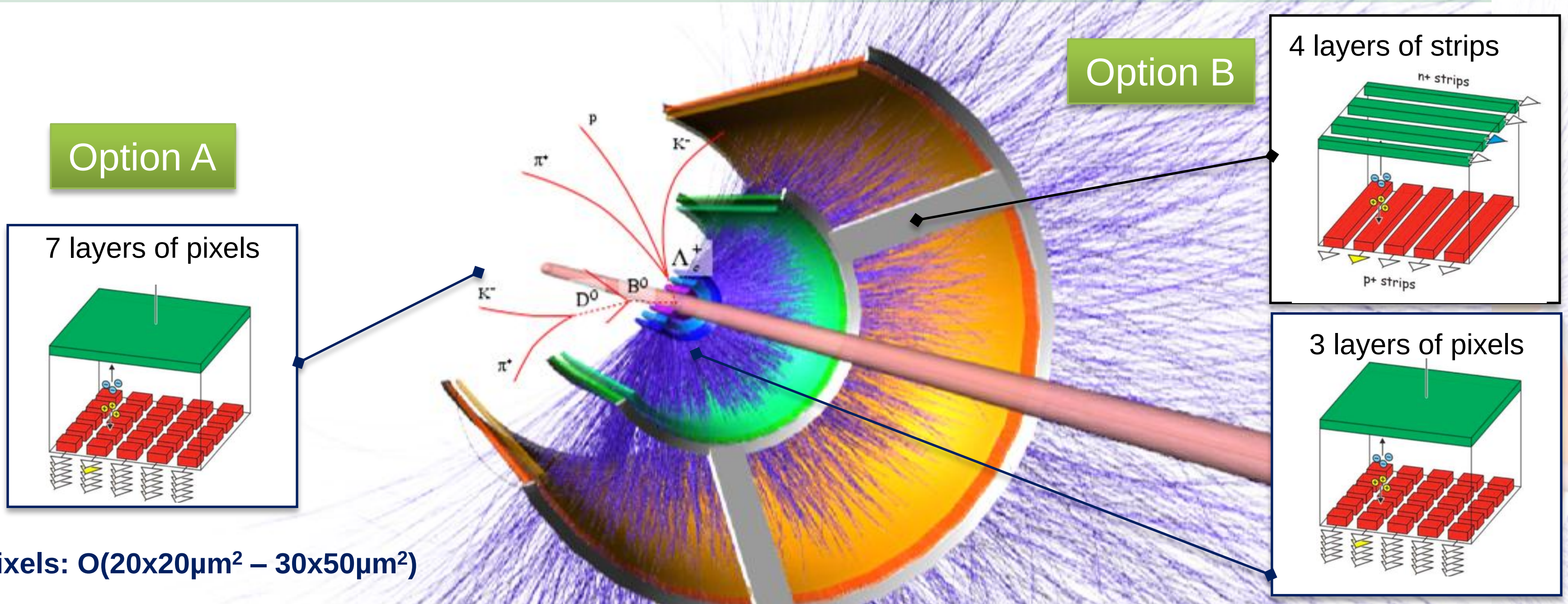
ITS Upgrade - Upgrade Options

Option A: 7 layers of pixel detectors

- better standalone tracking efficiency and momentum resolution
- worse particle identification

Option B: 3 inner layers of pixel detectors and 4 outer layers of strip detectors

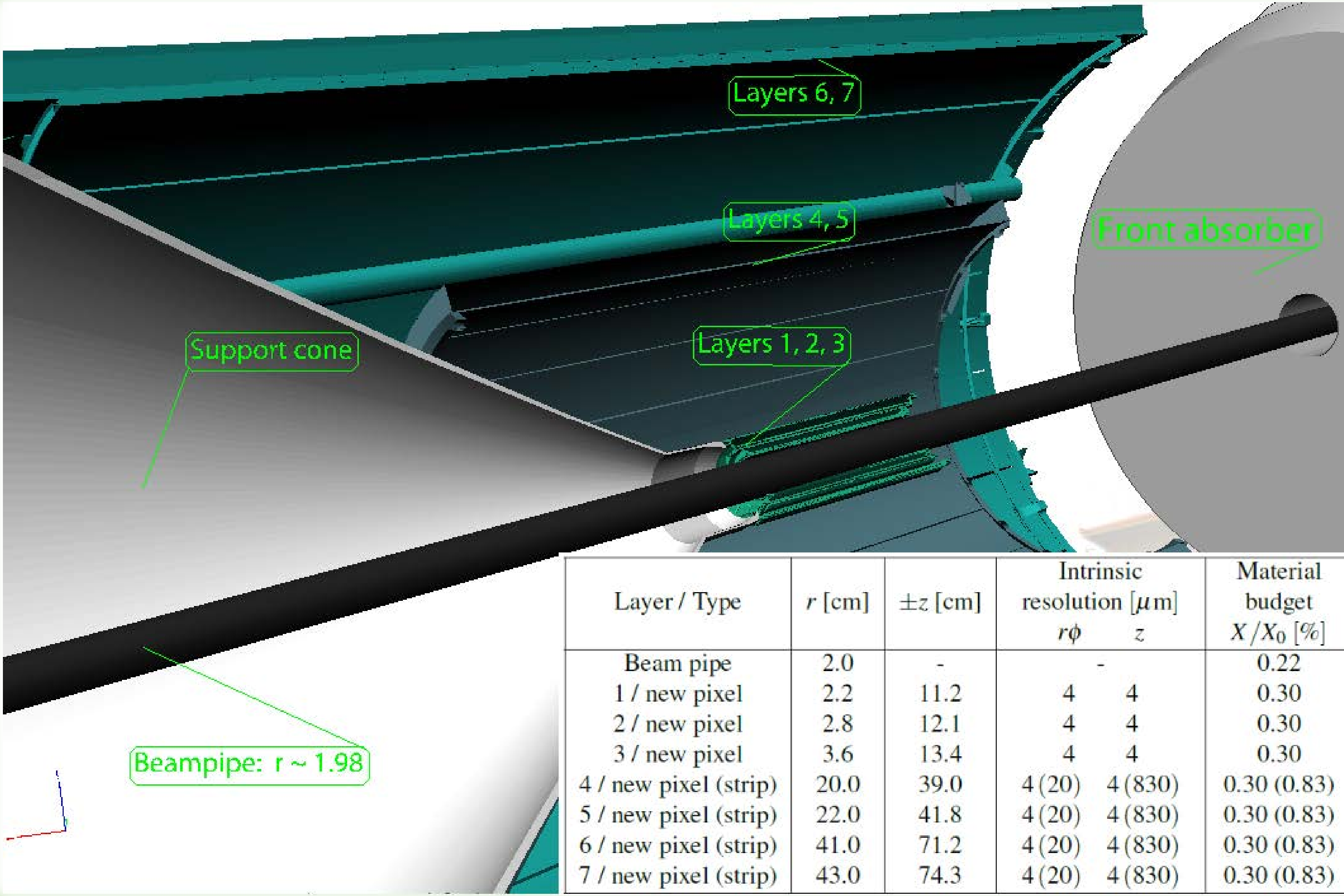
- worse standalone tracking efficiency and momentum resolution
- better particle identification



Pixels: O(20x20μm² – 30x50μm²)

Pixels: O(20x20μm² – 30x50μm²)
Strips: 95μm x 2cm, double sided

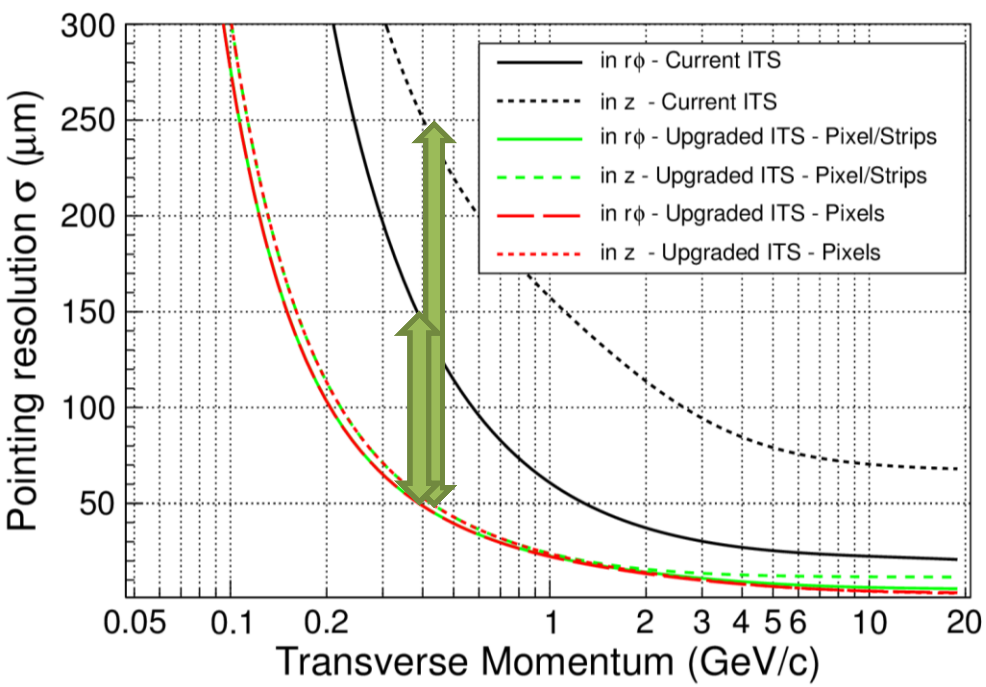
The ITS Upgrade proposal - Conceptual Design

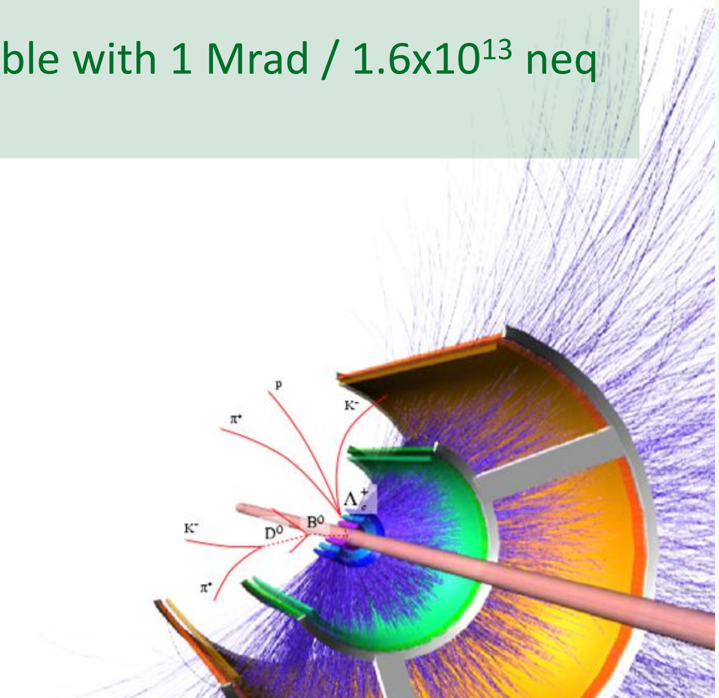


Layer / Type	r [cm]	$\pm z$ [cm]	Intrinsic resolution [μm] $r\phi$	z	Material budget X/X_0 [%]
Beam pipe	2.0	-	-		0.22
1 / new pixel	2.2	11.2	4	4	0.30
2 / new pixel	2.8	12.1	4	4	0.30
3 / new pixel	3.6	13.4	4	4	0.30
4 / new pixel (strip)	20.0	39.0	4 (20)	4 (830)	0.30 (0.83)
5 / new pixel (strip)	22.0	41.8	4 (20)	4 (830)	0.30 (0.83)
6 / new pixel (strip)	41.0	71.2	4 (20)	4 (830)	0.30 (0.83)
7 / new pixel (strip)	43.0	74.3	4 (20)	4 (830)	0.30 (0.83)

ITS Upgrade - key improvements

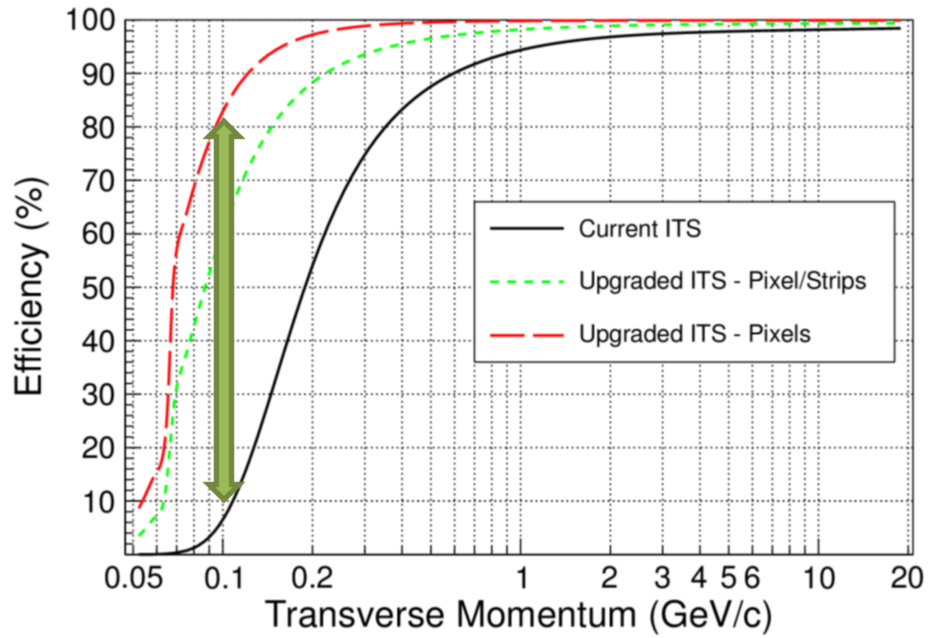
- Add high-resolution pixel layer closer to IP, **r=2.2** cm (⇒ currently r=3.9cm)
- Pixel size ~20-30 μm (rφ,z), **σ(rφ,z) ~4-6 μm** (⇒ currently σ(rφ,z)=(12,100) μm)
- Material budget **0.3-0.5% X0** per layer (⇒ currently ~ 1.14%X0)
- Power consumption **300-500 mW/cm^2**
- Radiation tolerant design (innermost layer) compatible with 1 Mrad / 1.6x10^{13} neq over approximately 5 years

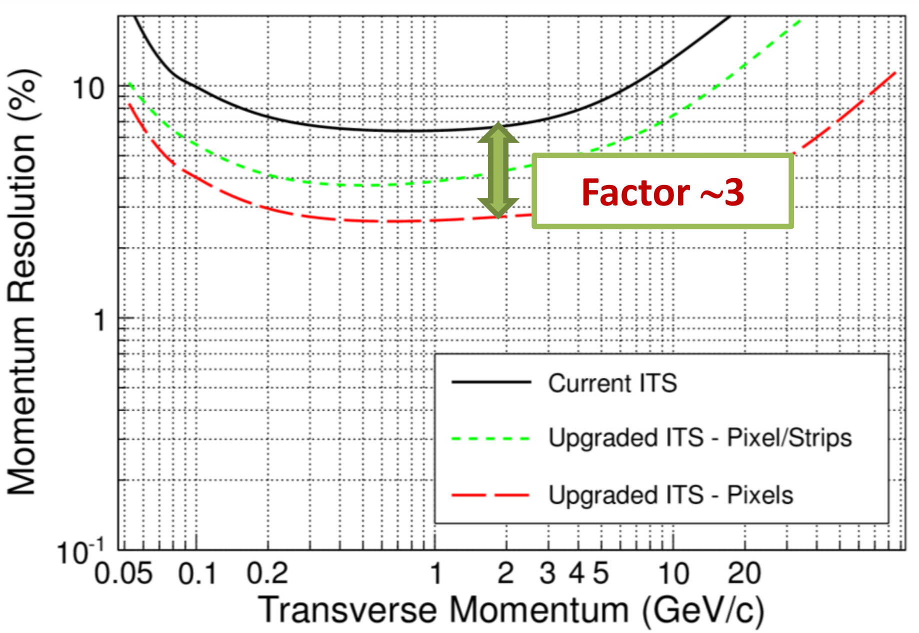




Track resol. improvement by Factor ~3 in rϕ, Factor ~5 in z

ITS Upgrade - key improvements

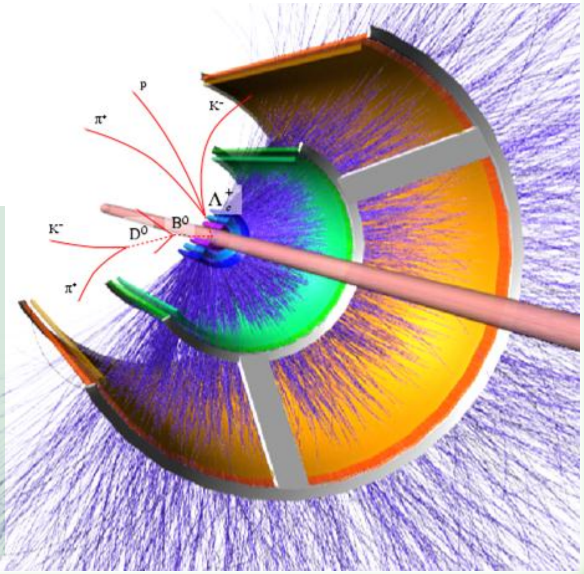




ITS-standalone Rec. efficiency

p_t = 0.1GeV ⇒ ε ~ 83%

- Hit density of approx. 100 tracks/cm^2 in HI collisions
- Up to 7 silicon layers (r=2.2-50 cm) to cover from IP to TPC
- 3 innermost layers made of pixels
- outer 4 layers either pixels or double sided strips



Pixel Technologies: the choices

Key requirements

- Pixel size ~ 20-30 μm (rφ,z) ⇒ **σ(rφ,z) ~ 4-6 μm**
- Material budget **0.3-0.5% X0** per layer
- *Radiation hardness* – 1 Mrad / 1.6x10^{13} neq
- Power consumption 300-500 mW/cm^2
- *Read-out speed – up to 50 kHz*
- *Integration time, cost …*

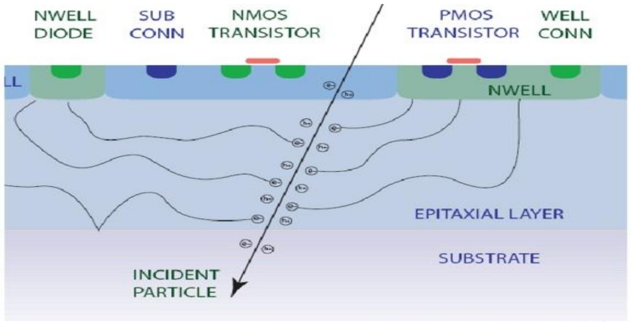


Figure Stanitzki, M. (2010). Nucl. Instr. and Meth. A doi:10.1016/j.nima.2010.11.166

Monolithic pixels

- 1 component, sensing layer included in the CMOS chip
  - *Pros:* material thickness and cost
  - *Cons:* radiation hardness and read-out speed

R&D

Hybrid pixels

- 2 components: CMOS chip and high-resistivity sensor connected via bump bonds
  - *Pros:* radiation hardness and speed
  - *Cons:* material thickness, power and cost

R&D

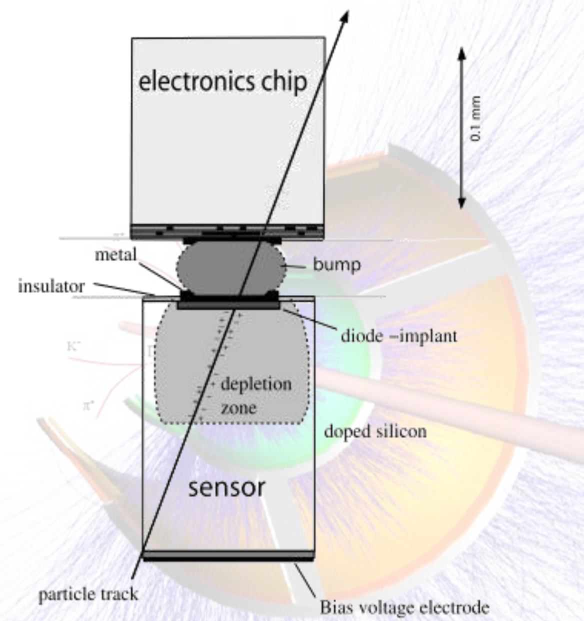


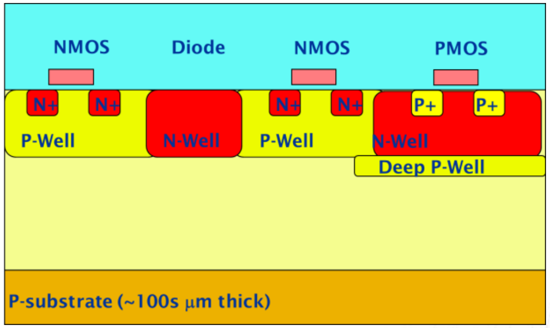
Figure - Rossi, L., Fischer, P., Rohe, T. & Wermes, N. (2006). Berlin: Springer.

Pixel Technologies: the choices

Development for Monolithic Detectors

using Tower/Jazz 0.18 µm CMOS technology …

- Improved **TID resistance** due to smaller technology node
- Available with high resistivity (~1 kΩcm) epitaxial layer up to 18 µm thick
- Quadruple-well technology – deep p-well allow the use of PMOS transistors within the pixel cell without reducing the charge collection efficiency



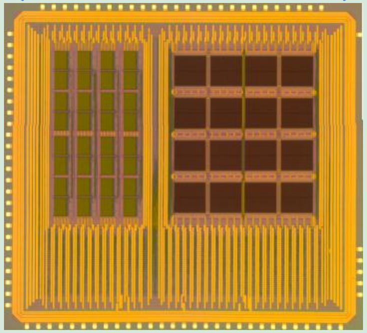
(R. Turchetta – RAL)

Prototype development in 2011/2012

to evaluate radiation tolerance and charge collection efficiency

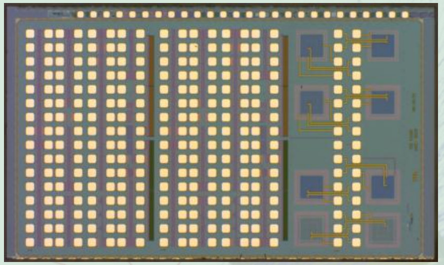
- MIMOSA32
- SEU chip, TID test structures
- test matrices

5.7 mm



SEU chip

2.2 mm



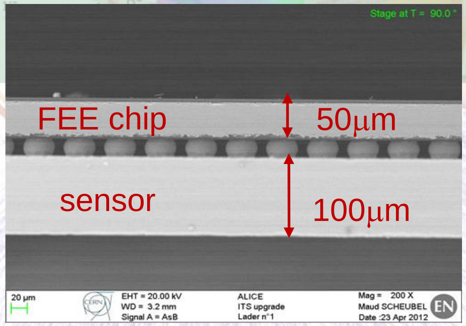
CMOS test structures w/o deep p-well

Breakdown diodes

TID chip

Development for Hybrid Detectors

Edgeless sensors (100µm) + front-end chip (50µm) in 130 nm CMOS



HYBRID (CERN)

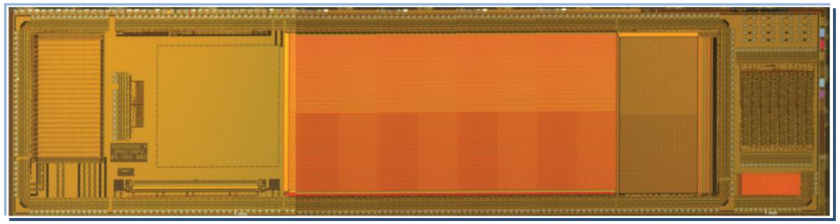
Flipchip-bonding & thinning@ IZM Berlin

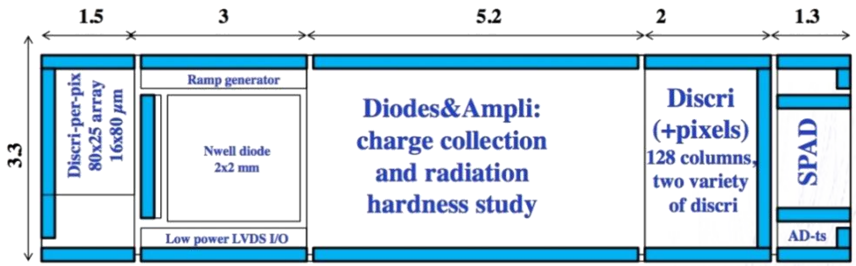
Pixel Technologies: 0.18μm CMOS

MIMOSA 32 (IPHC Strasbourg)

- Digital and analog blocks (2T and 3T structures with various diodes)
- 100 circuits delivered Jan 2012 ✓
- Test with Fe^{55} source ✓
- Irradiation tests (X-ray, neutron) ✓
- Test-Beam on the June 6-11, 2012 ✓

MIMOSA32 chip - circuit (IPHC)



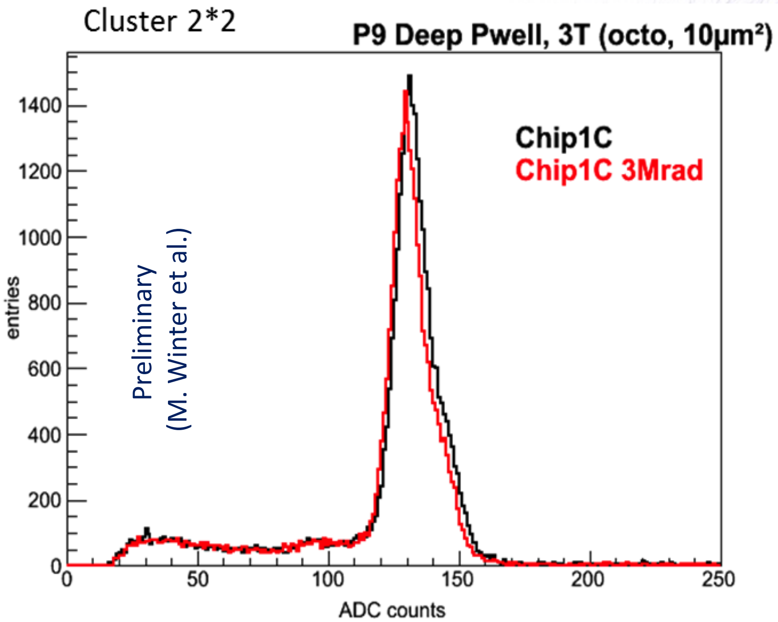


Charge Collection Efficiency (CCE) for 20x20 μm² pixels

– Seed pixel: ~40-50%

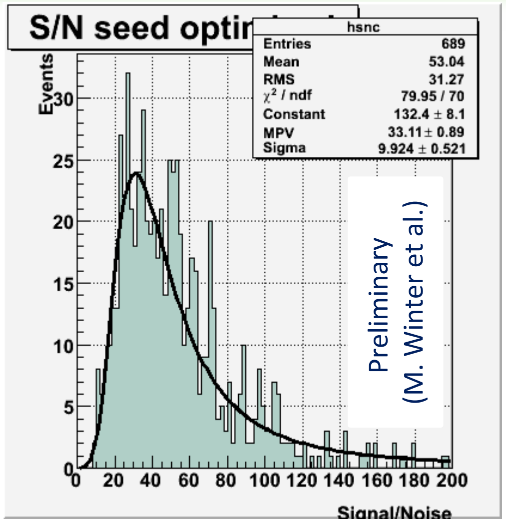
– 2x2 pixel cluster: nearly 100 %

TID test: irradiation to 3 Mrad (X-ray, CERN)



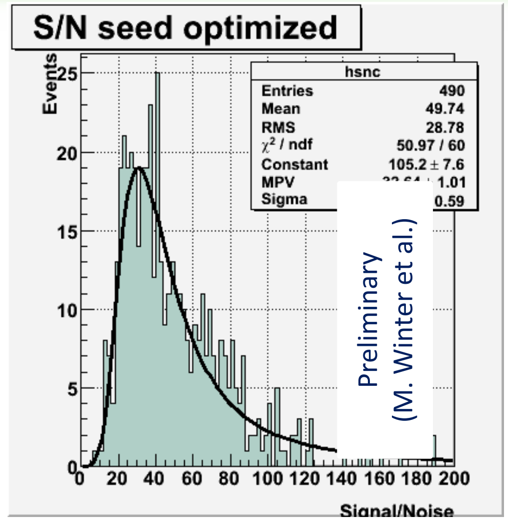
Pixel Technologies: 0.18μm CMOS

Note: 60GeV π^- beam



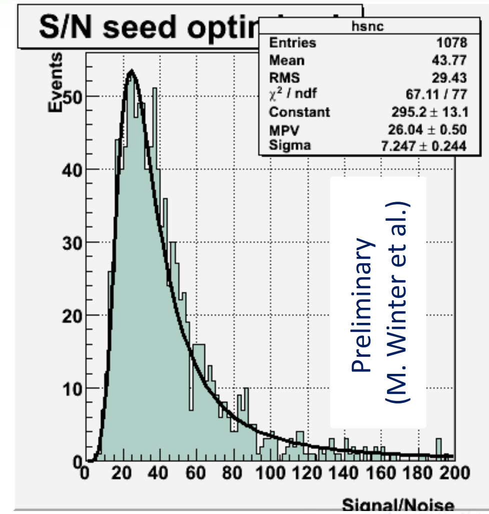
before irradiation

SNR ~ 33.1 ± 0.9



TID (10 keV X-Rays) ~ 3Mrad

SNR ~ 32.3 ± 1.0



10^{13} n_{eq}/cm^2

SNR ~ 26.0 ± 0.5

Summary of first Evaluation of 0.18 µm CMOS technology

- Very low noise (ENC ~ 15-20 e) and good S/N (>25)
- Charge collection almost 100 % for clusters sizes of 2x2
- No significant degradation when irradiated at 3 Mrad, 10^{13} neq

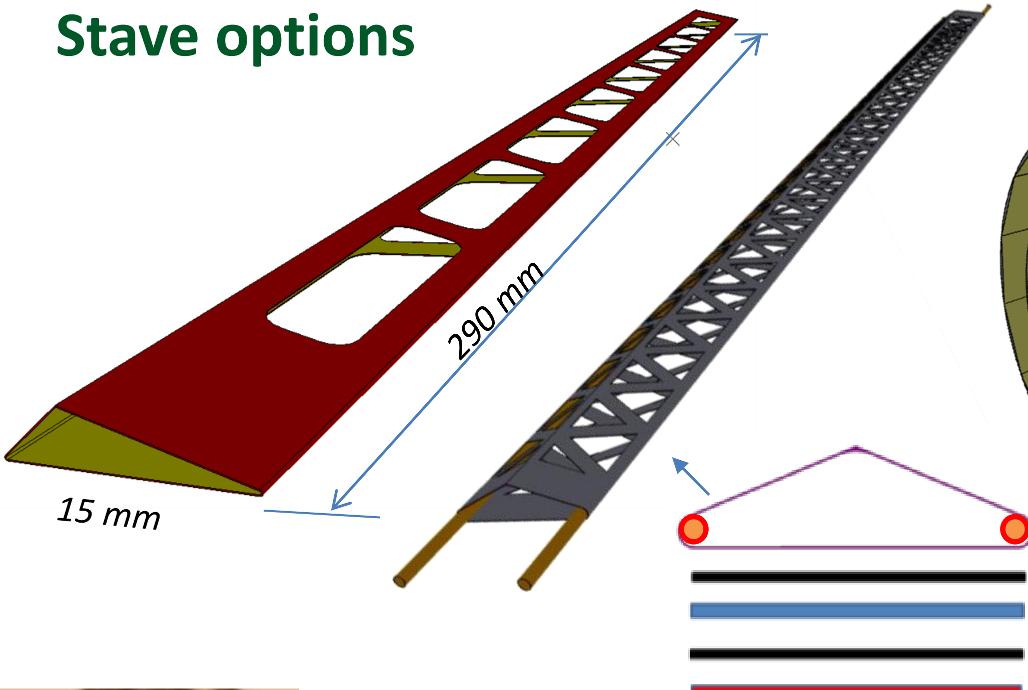
➡ encouraging results

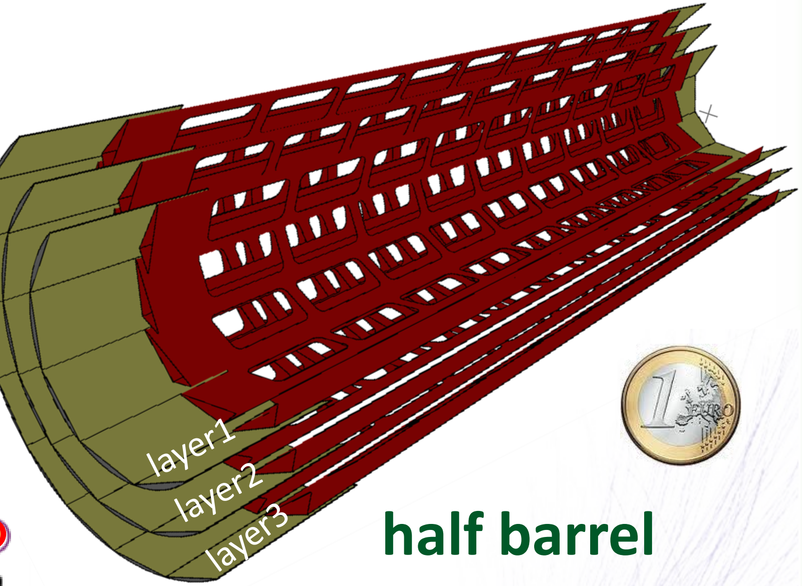
MONALICET1 (CERN/CCNU)

- Single transistors, memories, shift registers
- Delivery early July 2012 ✓ -> irradiation tests and analysis is ongoing

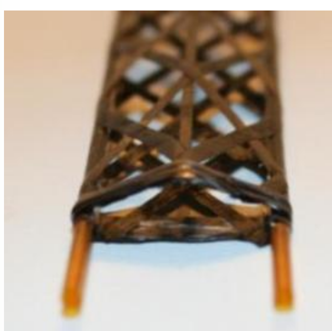
Ultra-light mechanical support structure

Stave options





half barrel



Complete ladder prototype: two mechanical structure and cooling concepts
+ electrical bus + glue
+ dummy silicon

Material	Surface (%)	Tickness (μm)	X_0 (%)	X/X_0 (%)	Contribution to the total X/X_0 (%)
CFRP filament	53	190	25	0.04	15.4
Polyimide Tubes	19	70	28.6	0.005	1.8
Water	19	1450	36.1	0.06	22.7
Glue (CFRP - silicon)	25	100	44.4	0.006	2.2
Silicon	100	50	9.36	0.054	20.5
Glue (silicon - bus)	100	100	44.4	0.022	8.6
Electrical bus	100	-	-	0.075	28.8
Total			≈ 0.26		

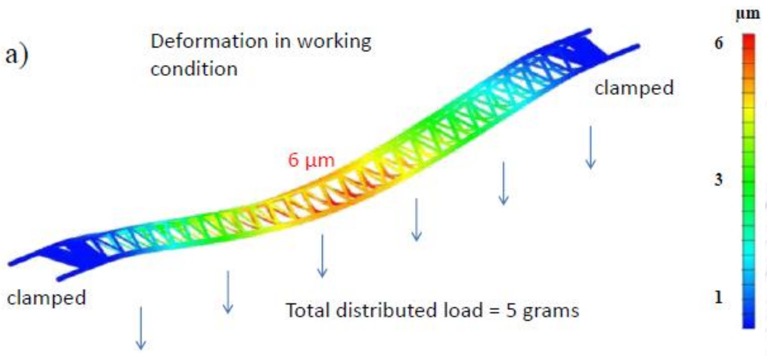
➡ Allows $X/X_0 \leq 0.3\%$

Ongoing R&D …

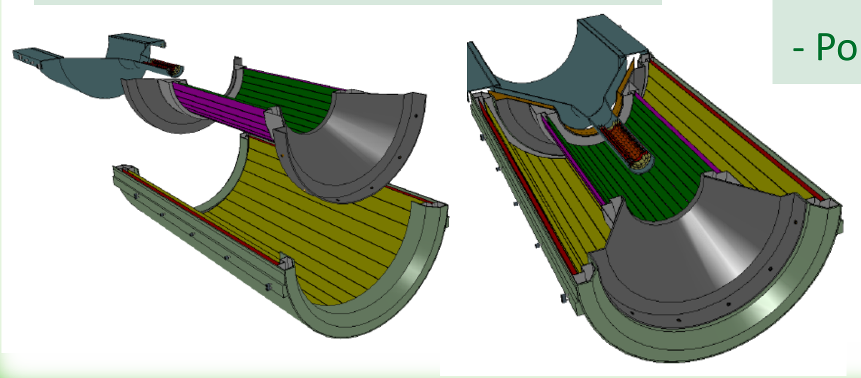
- **Evaluation of different mechanical** structure geometries, composite materials (CFRP) and production processes
- **Several ultra-light mechanical structures (ladders)** for first 3 inner layers have been realized (ladder weight 0.6-1.4 g)

Stiffness tests show **very high mechanical stability**

- Load of 5g : sag < 6mm
- Natural freq. ~600Hz)



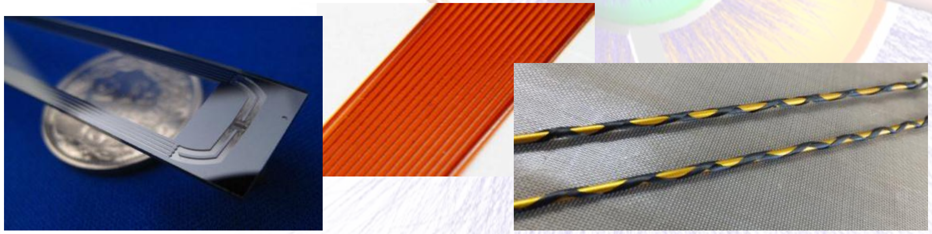
Installation considerations



Surveying several Cooling options

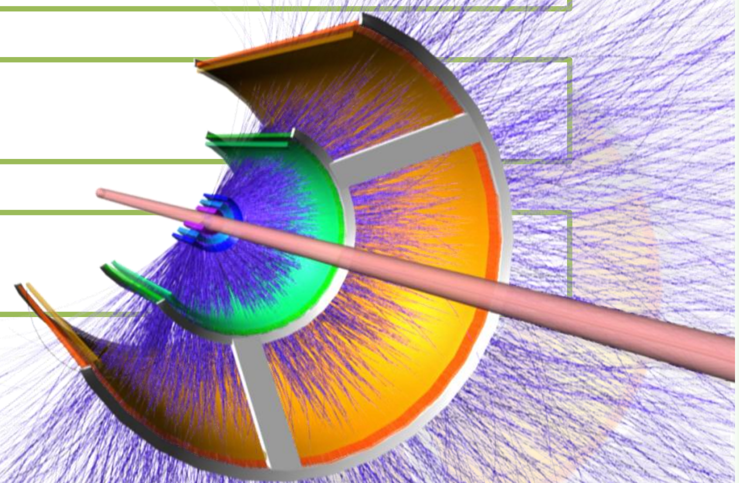
- Silicon micro-channel
- Polyimide micro-channels
- Polyimide tubes

Achieved:
working temp. **< 30 deg**
temp. gradient **< 5 deg**



Timeline of the ITS upgrade project

- 2012 – Finalization of specifications / first prototypes / radiation tests
- 2013 – Selection of technologies and design of mechanics and services
- **2014 – Final Design and validation**
- 2015-2016 – Production /construction and test of detector modules
- 2017 – Assembly and pre-commissioning
- **2018 – Installation in ALICE**



Thanks for your attention

Read-out architectures under study

"In principle, always a trade-of between speed and power consumption"

- **Rolling-Shutter read-out**
  - Pixel matrix is scanned row-by-row
  - 100 μs is achieved by state-of-art sensors
  - Estimate: 25 μs can be achieved at power consumption of < 800 mW/cm²

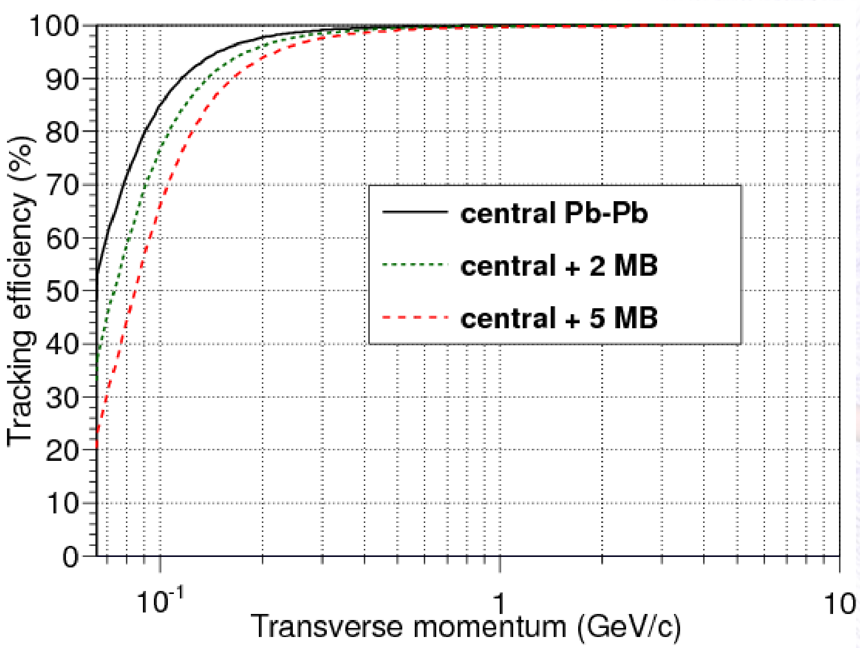
- **Data driven read-out (e.g. via priority encoding)**
  - Only signals above certain threshold transfer data to chip periphery
  - Estimate (assuming 256x512 pixels): 1 μs can be achieved at a power consumption of < 30 mW/cm²

At 50kHz for Pb-Pb, in average

+ 1 pile-up events for 20 μs

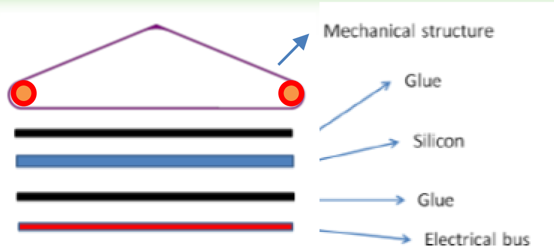
+ 2 pile-up events for 50 μs

If read-out is faster than 20 μs, no significant degradation of tracking efficiency is observed



Backup

R&D on mechanical structure



Ladder prototype equipped with dummy components

Material	Surface (%)	Tickness (μm)	X_0 (%)	X/X_0 (%)	Contribution to the total X/X_0 (%)
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Glue (silicon - bus)	100	100	44.4	0.022	8.6
Electrical bus	100	-	-	0.075	28.8
Total				≈ 0.26	

Backup

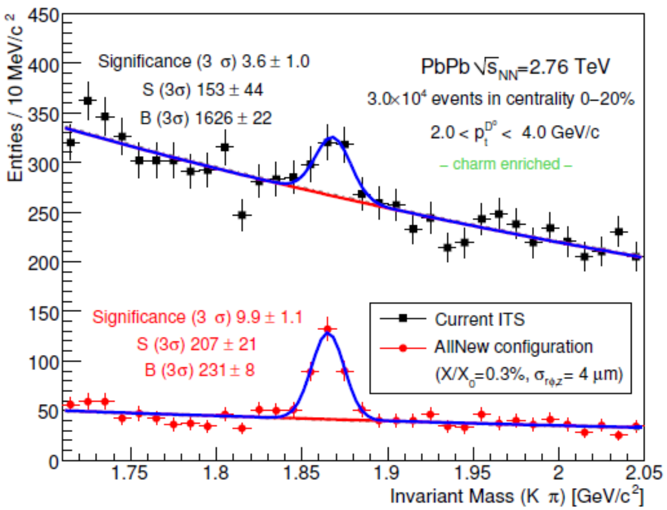
Some examples of physics performance (Λ_c)

Preliminary
(cuts to be optimized)

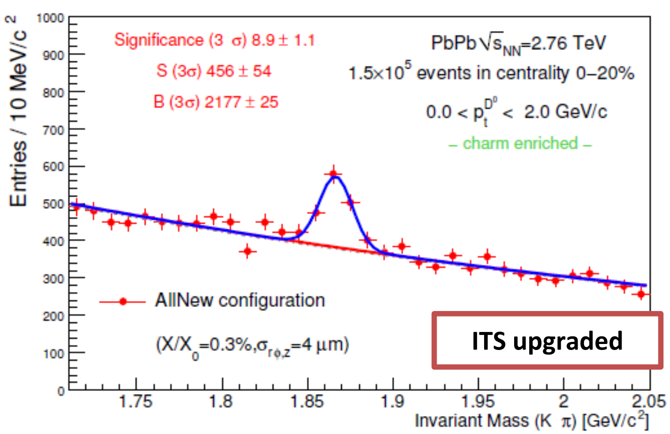
Benchmark channel at very low p_t: $D^0 \rightarrow K\pi$

$\Lambda c \rightarrow pK\pi$ as a benchmark case in Pb-Pb

Factor 25 in background rejection

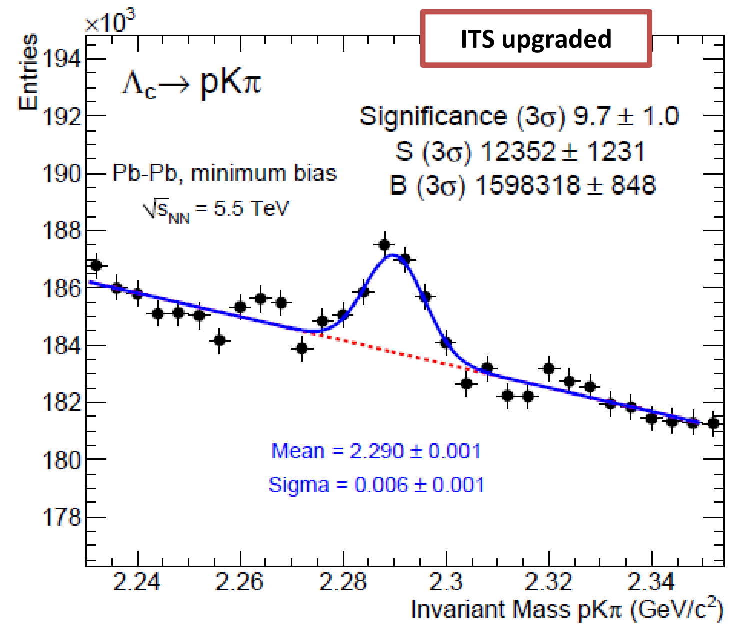


$2.0 < p_t < 4.0$ GeV/c



$p_t < 2.0$ GeV/c

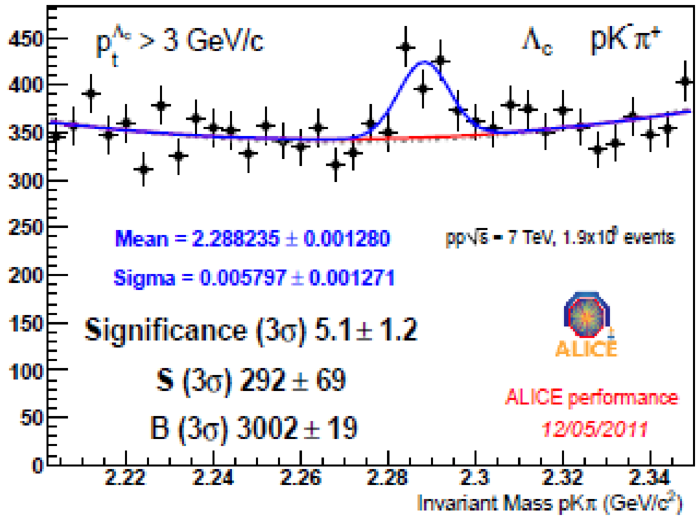
No signal in data with the current ITS in any pt bin



$p_t > 4.0$ GeV/c

$\Lambda_c \rightarrow pK\pi$ as a benchmark case in p-p

Comparison between current and new ITS in the same p_T bin ($p_T > 3$GeV/c)



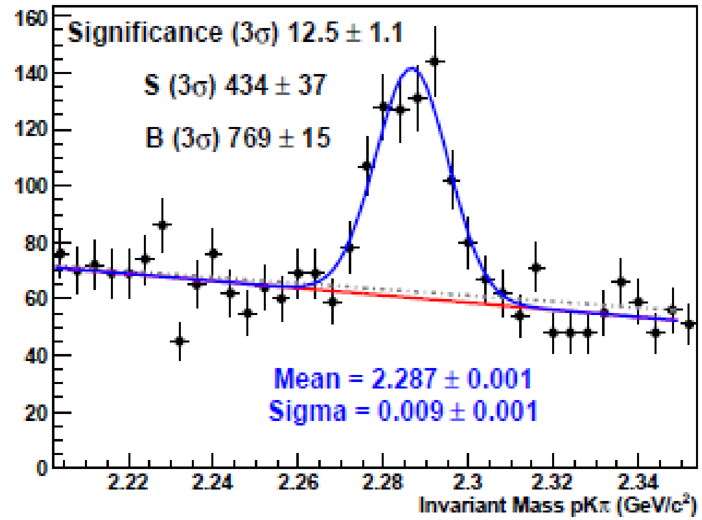


Fig. 1. – Left: Invariant mass spectrum $M[pK\pi]$ in p-p collisions at 7 TeV for $p_T > 3GeV/c^2$ in data. Right: The invariant mass spectrum obtained with the ITS Upgrade in $AllNew-0.3-4\mu\%$ configuration.

D^0 : prompt and from B decays

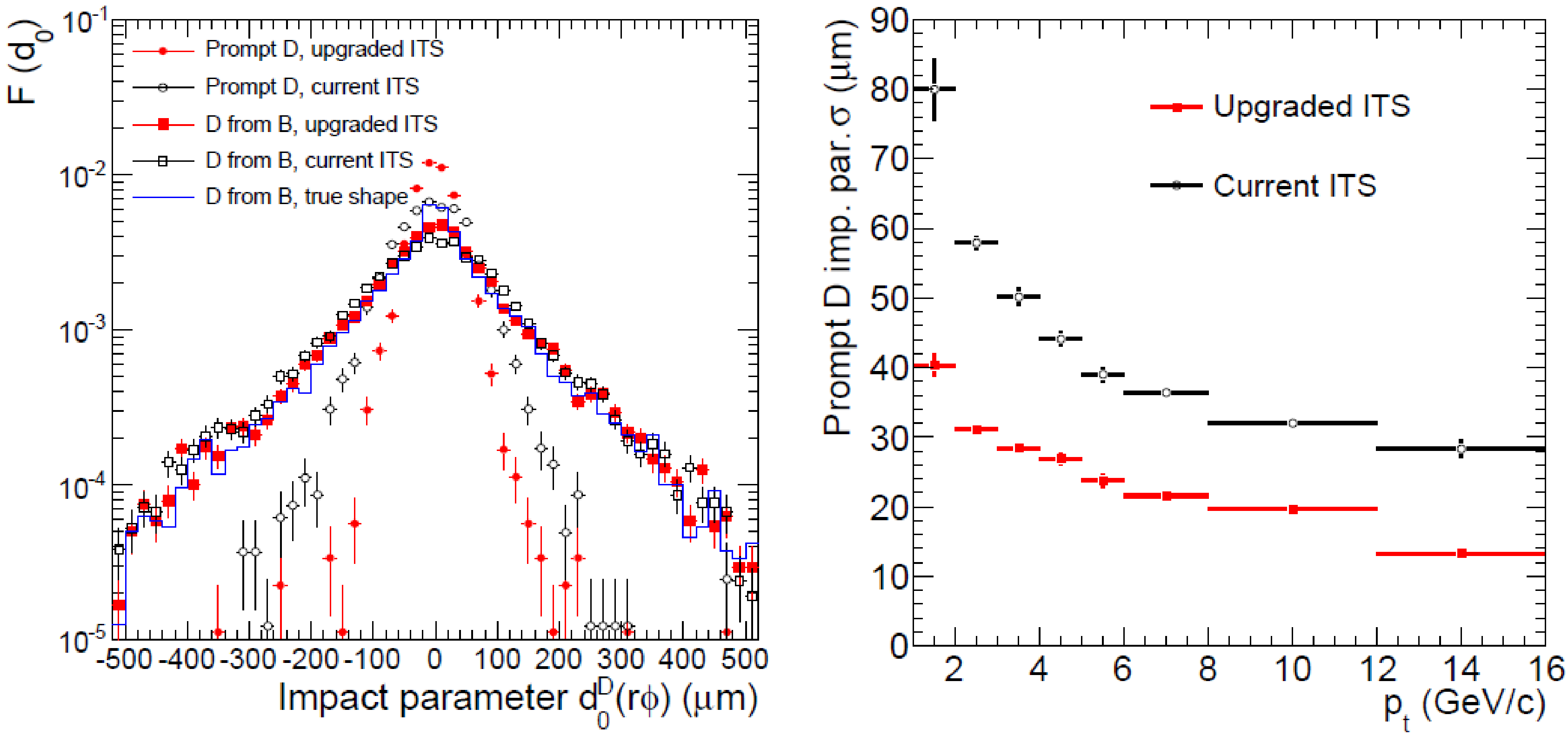


Figure 2.27: D^0 from B decays. Left: comparison of the impact parameter distributions for prompt and secondary D^0 obtained with the current and upgrade ITS configurations in the transverse momentum range $2 < p_t < 3$ GeV/c. Right: sigma of the Gaussian term of the detector resolution function, representing the D^0 impact parameter resolution, for current and upgrade ITS scenarios.