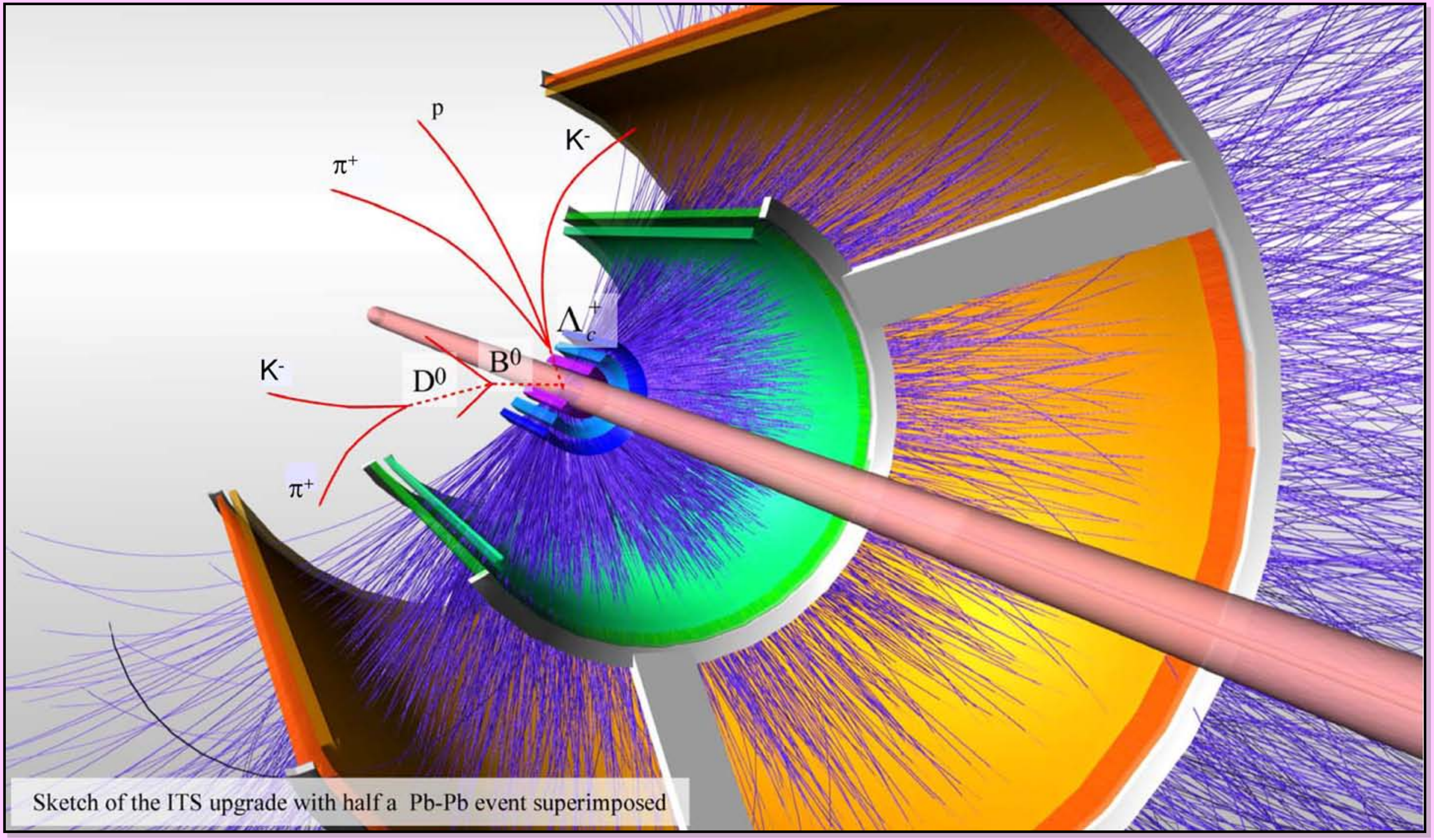
Upgrade of the ALICE ITS



Sketch of the ITS upgrade with half a Pb-Pb event superimposed

Iouri Belikov

ALICE physics plans

Precision measurement of the QGP parameters at $\mu_b = 0$ to fully exploit scientific potential of the LHC – unique in:

- large cross sections for hard probes
- high initial temperature

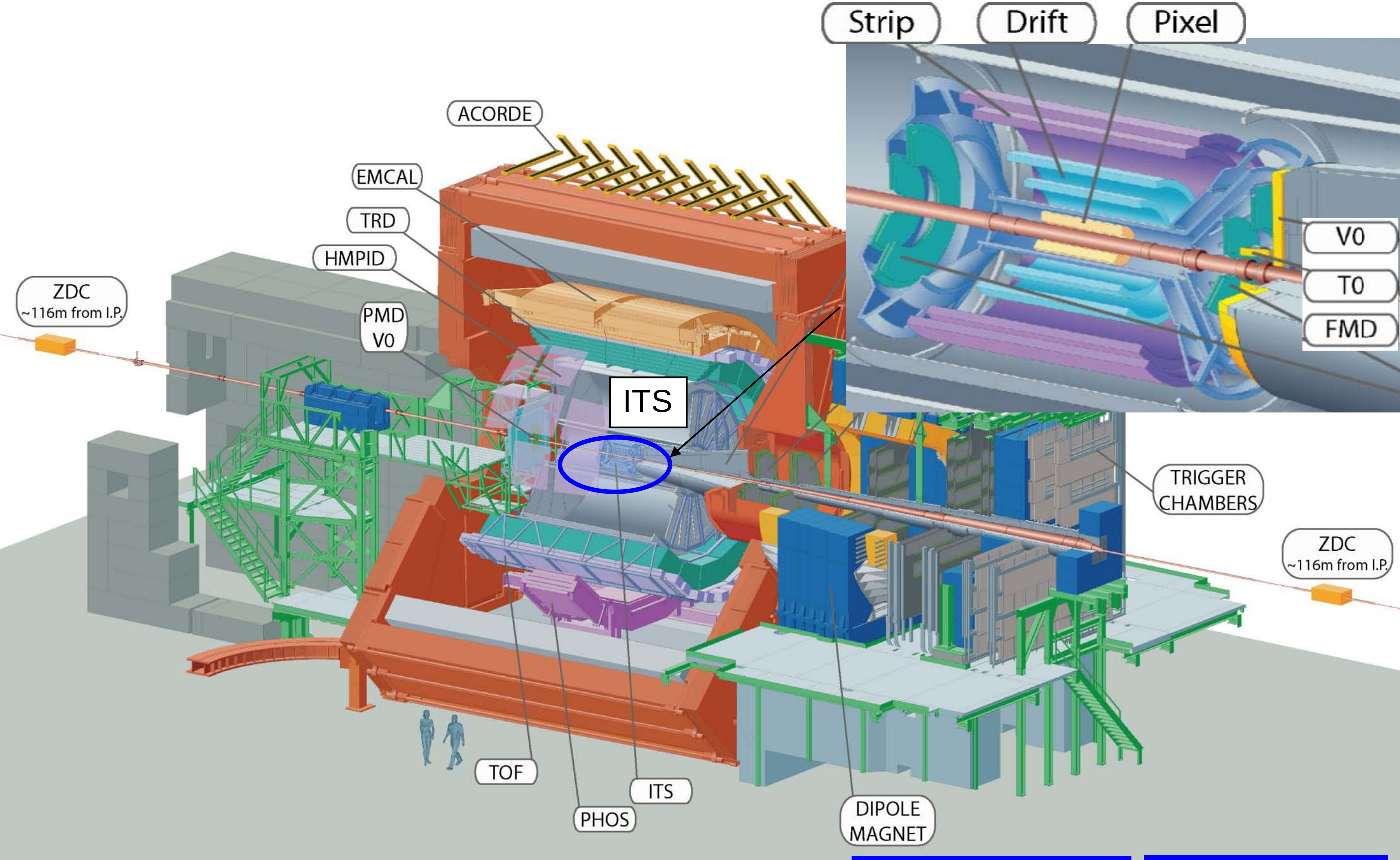
Main physics topics, uniquely accessible with the ALICE detector:

- measurements of heavy-flavour
  - study of QGP properties via transport coefficients (η/s, $\hat{q}$)
  - hadronization mechanisms via baryon/meson ratio
- measurements of low-mass and low-p_T di-leptons
  - study of chiral-symmetry restoration
  - temperature, space-time evolution and equation of state
- J/ψ , ψ', and χ_c states down to zero p_T in wide rapidity range
  - statistical hadronization versus dissociation/recombination

For main physics program: factor > 100 increase in statistics
(maximum readout with present ALICE ~ 500 Hz)
For triggered probes: increase in statistics by factor > 10

ALICE upgrade goals

- High precision measurements of rare probes at low p_T, which cannot be selected with a trigger (large recorded data samples)
- Target:
  - Pb-Pb recorded luminosity $\geq 10\ nb^{-1}$ ➡ 8×10^{10} events
  - pp (reference data) recorded luminosity $\geq 6\ pb^{-1}$ ➡ 1.4×10^{11} events
- Read out all Pb-Pb interactions at a maximum rate of 50kHz (i.e. $L = 6 \times 10^{27}\ cm^{-1}s^{-1}$), with a minimum bias trigger
- Significant improvement of vertexing and tracking capabilities of the detector (especially at low p_T)
- Perform online data reduction based on reconstruction of clusters and tracks (tracking used only to filter out clusters not associated to reconstructed tracks)
- Upgrade of the ALICE offline software
- Everything by after 2018 (LHC 2^{nd} long shutdown)



Detector:
Length: **26** meters
Height: **16** meters
Weight: **10,000** tons

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

Physics motivation for the ITS upgrade

Two main topics:

- thermalization and hadronization of heavy quarks in the medium
  - baryon-to-meson ratio, i.e. Λ_c/D, Λ_b/B
  - azimuthal anisotropy v_2
  - possible thermal charm production?
- in-medium energy loss
  - separately for D and B mesons
  - wide p_T range, and especially low p_T

Significant differences between c and b predicted

Three benchmark analyses presented:

- charm meson production $D^0 \rightarrow K^-\pi^+$
- beauty meson production $B \rightarrow D^0 (\rightarrow K^-\pi^+) + X$
- charm baryon production $\Lambda_c \rightarrow pK^-\pi^+$

New ITS upgrade goals

1. Improve impact parameter resolution by a factor of ~3

- Get closer to IP (position of first layer): 39mm ➡22mm
- Reduce material budget: X/X_0 /layer: ~1.14% ➡ ~ 0.3%
- Reduce pixel size (currently 50μm x 425μm)

  monolithic pixels ➡ O(20μm x 20μm),

  hybrid pixels ➡ state-of-the-art O(50μm x 50μm)

2. High standalone tracking efficiency and p_T resolution

- Increase granularity: 6 layers ➡ 7 layers , reduce pixel size
- Increase radial extension: 39-430 mm ➡ 22– 430(500) mm

3. Fast readout

- Pb-Pb interactions at > 50 kHz, pp interactions at ~ several MHz

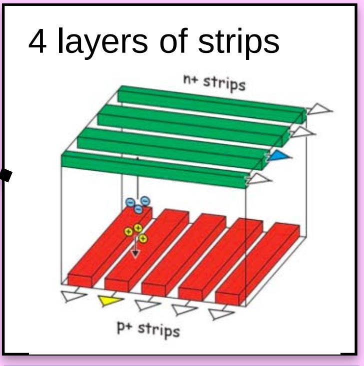
4. Fast insertion/removal for yearly maintenance

- possibility to replace non functioning detector modules during yearly shutdown

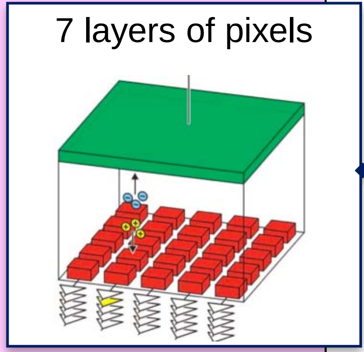
The two ITS upgrade options

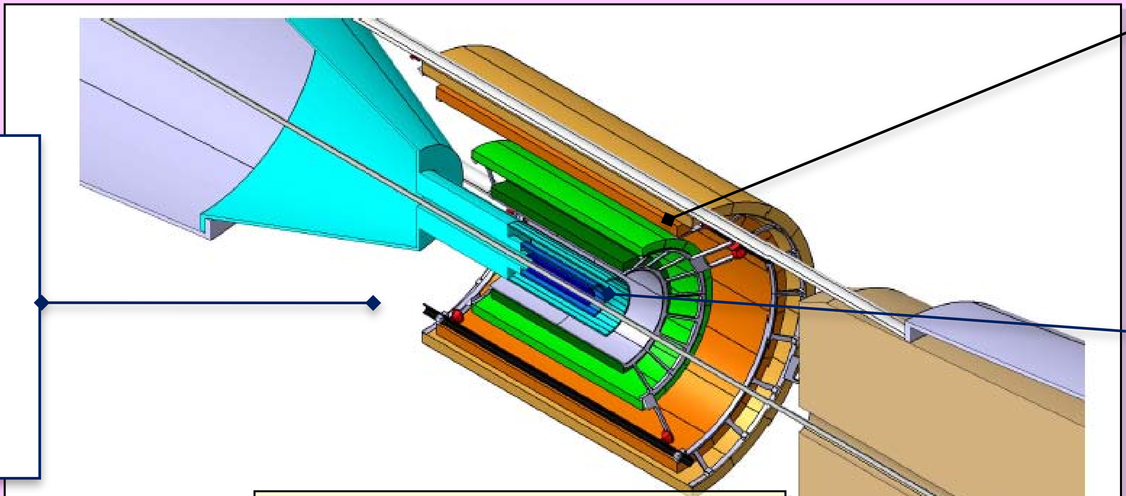
- Option A: 7 layers of pixel detectors:
  - better standalone tracking efficiency and p_T resolution
  - worse PID
- Option B: 3 inner layers of pixel detectors and 4 outer layers of strip detectors:
  - worse standalone tracking efficiency and momentum resolution
  - better PID

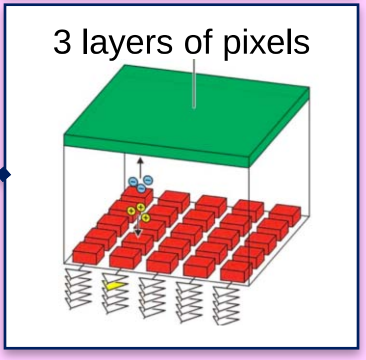
Option B



Option A







Pixels: O (20x20μm² – 50x50μm²)

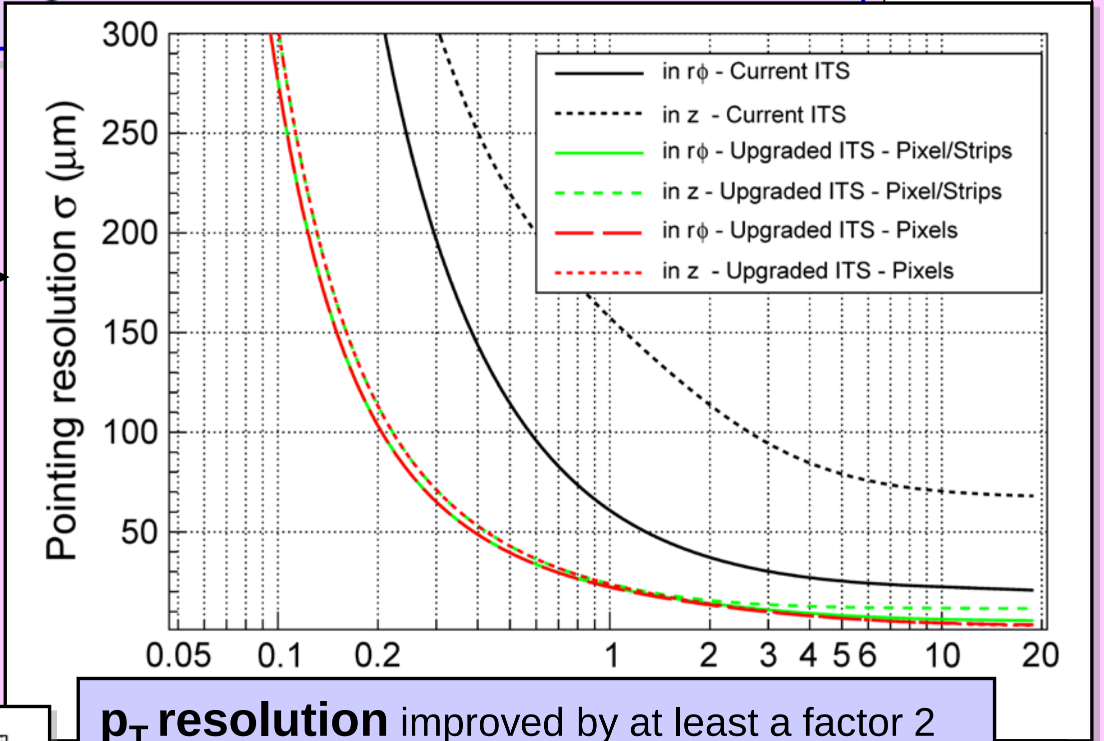
☢ 700 krad/ 10^{13} n_{eq}

Includes safety factor ~ 4

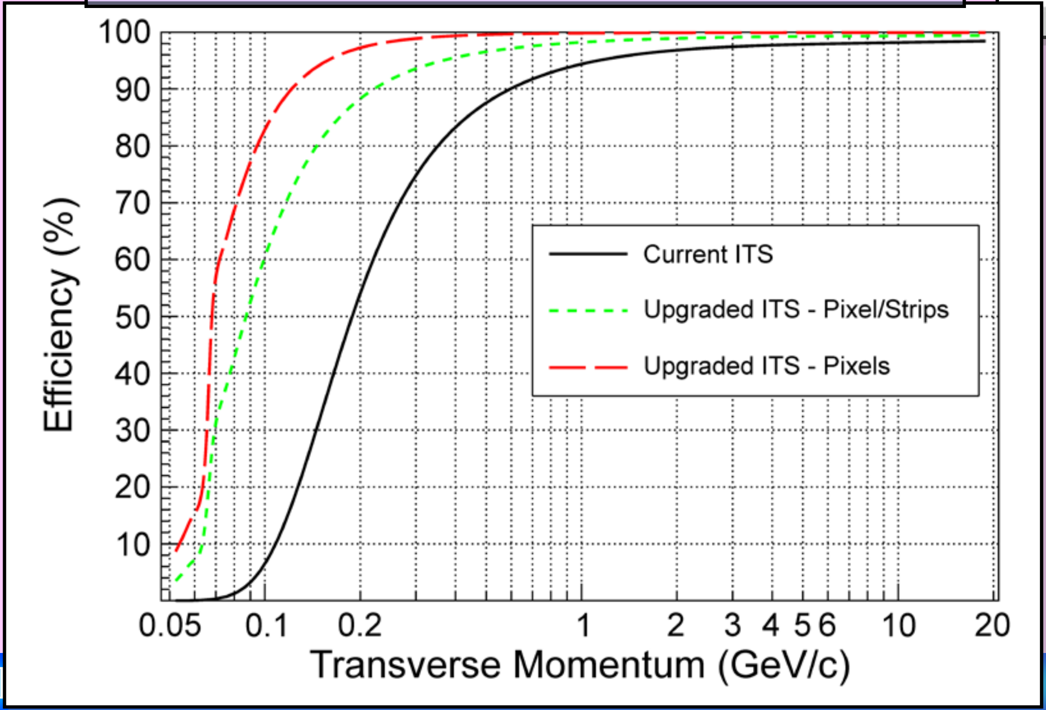
Pixels: O (20x20μm² – 50x50μm²)
Strips: 95 μm x 2 cm, double sided

Simulated performance

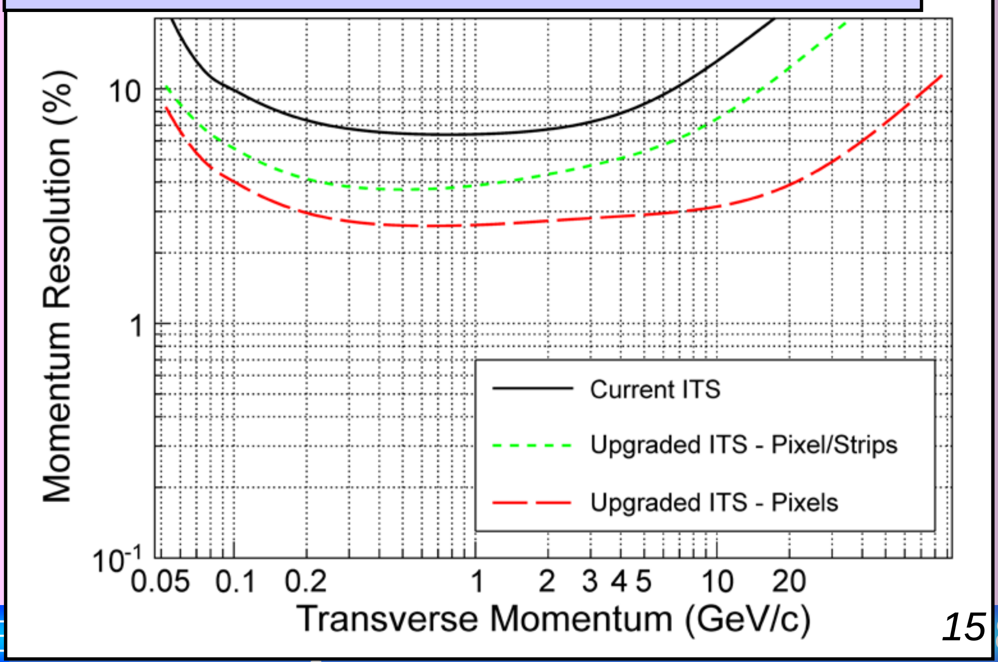
Pointing resolution significantly improved:
- Factor 3 in rφ-plane at 0.5 GeV/c: 120 μm → 40 μm
- Factor 5 along z axis at 0.5 GeV/c: 200 μm → 40 μm



Tracking efficiency significantly improved at low p_T: almost a factor 2 at 0.2 GeV/c

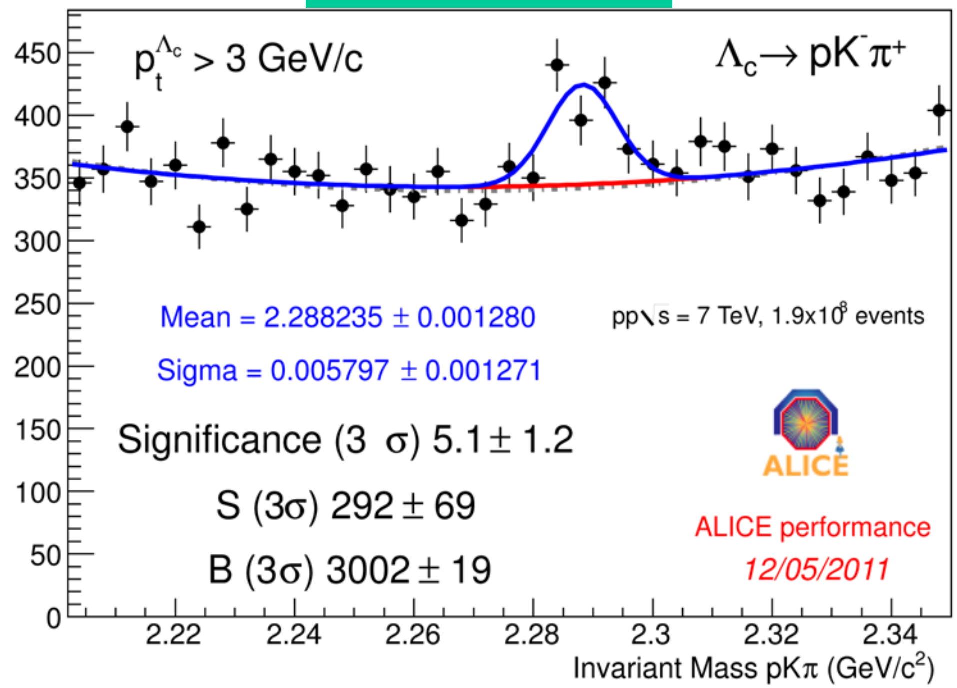


p_T resolution improved by at least a factor 2



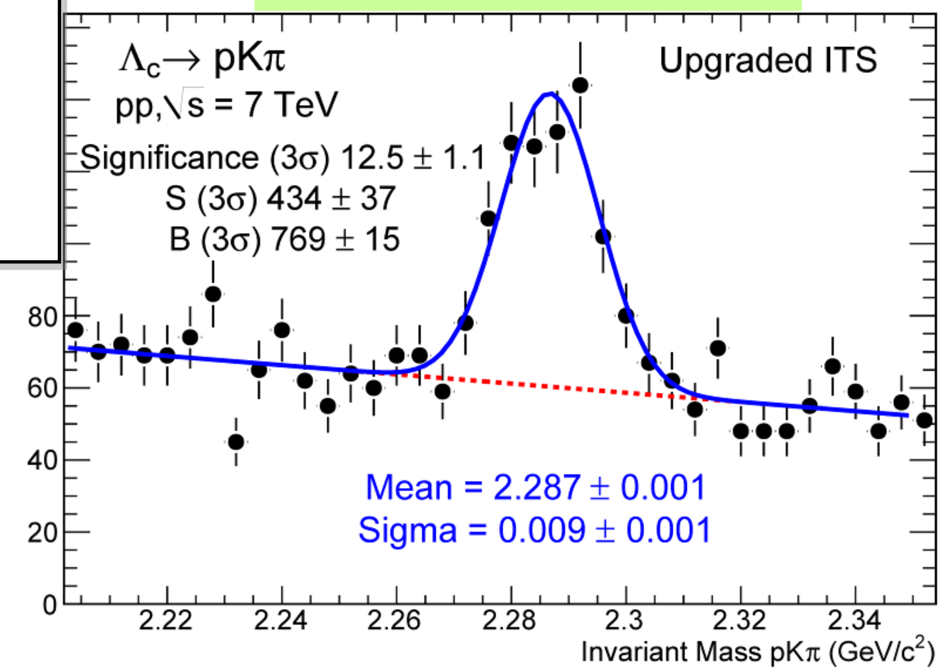
$\Lambda_c \rightarrow pK^-\pi^+$

DATA Current ITS



S/B x 5
Significance x 2.5

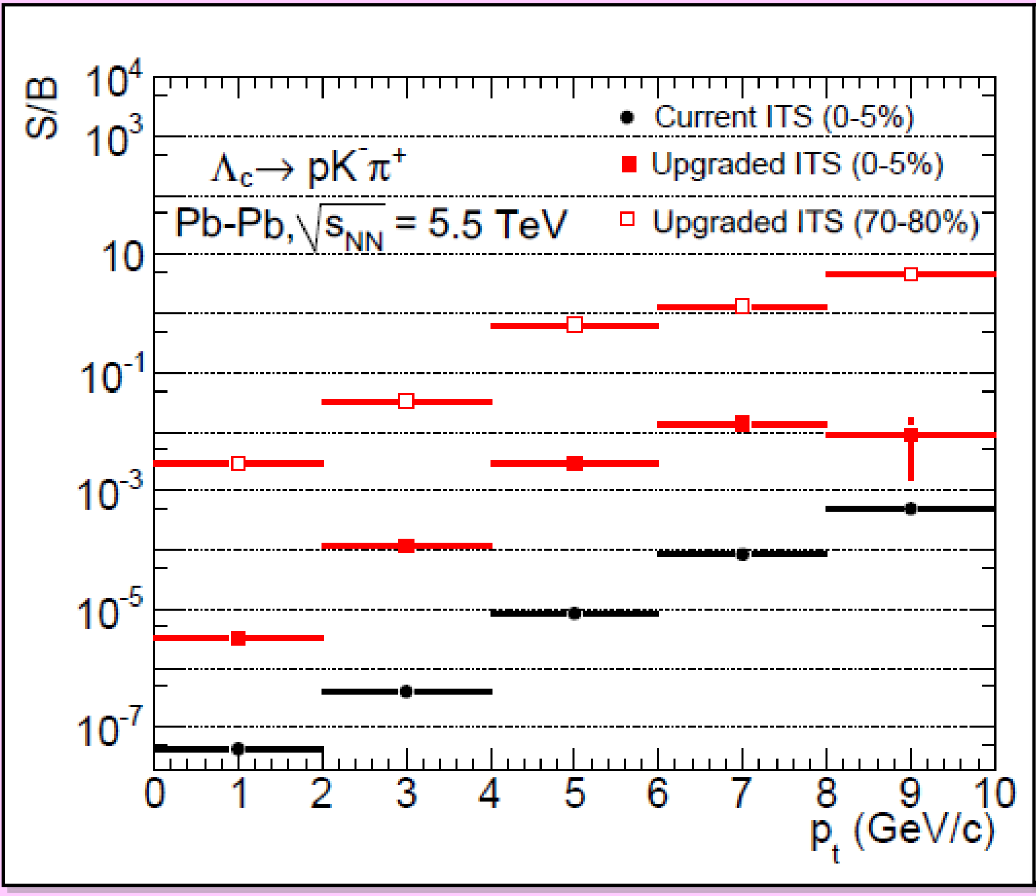
SIMULATION Upgraded ITS

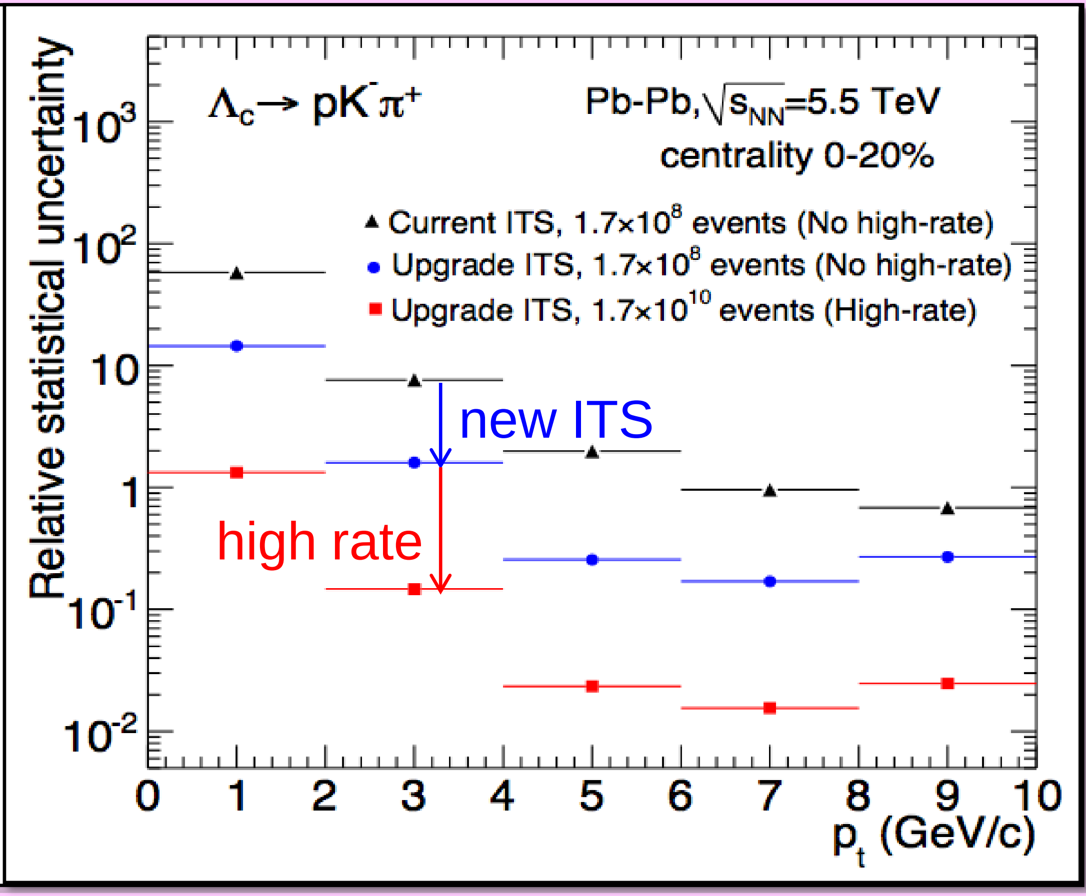


$\Lambda_c \rightarrow pK^-\pi^+$

Signal-to-background ratio

Significance: multiply by ~10^5



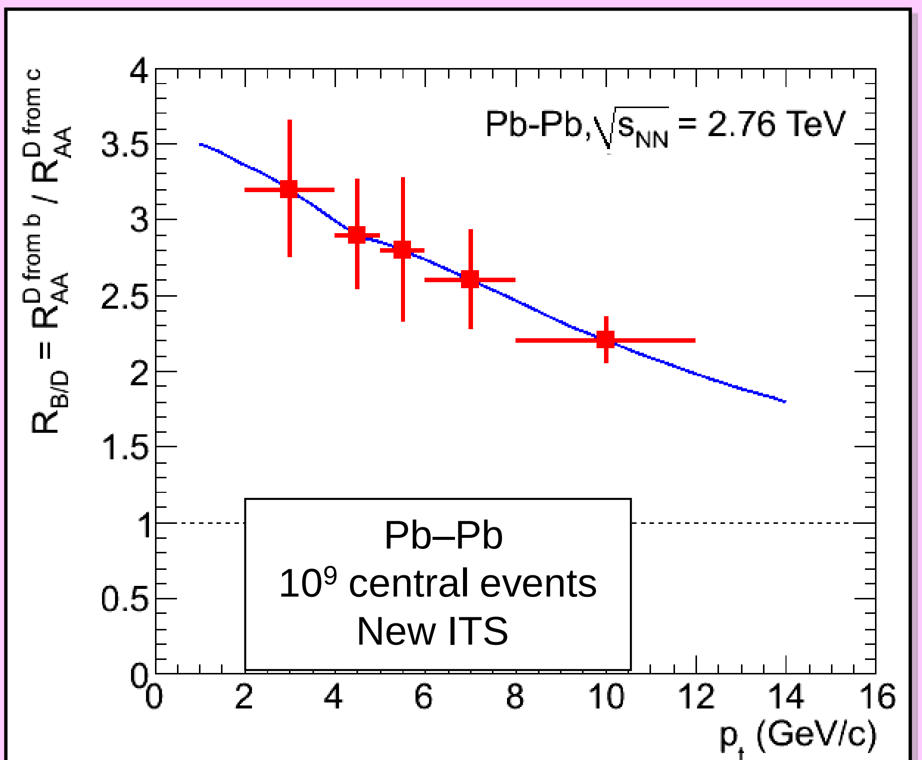


With new ITS: Precision improved by more than two orders of magnitude!
(S/B improvement ~ one order, statistics bring another order)
For Λ_c-baryon measurement -- high statistics necessary

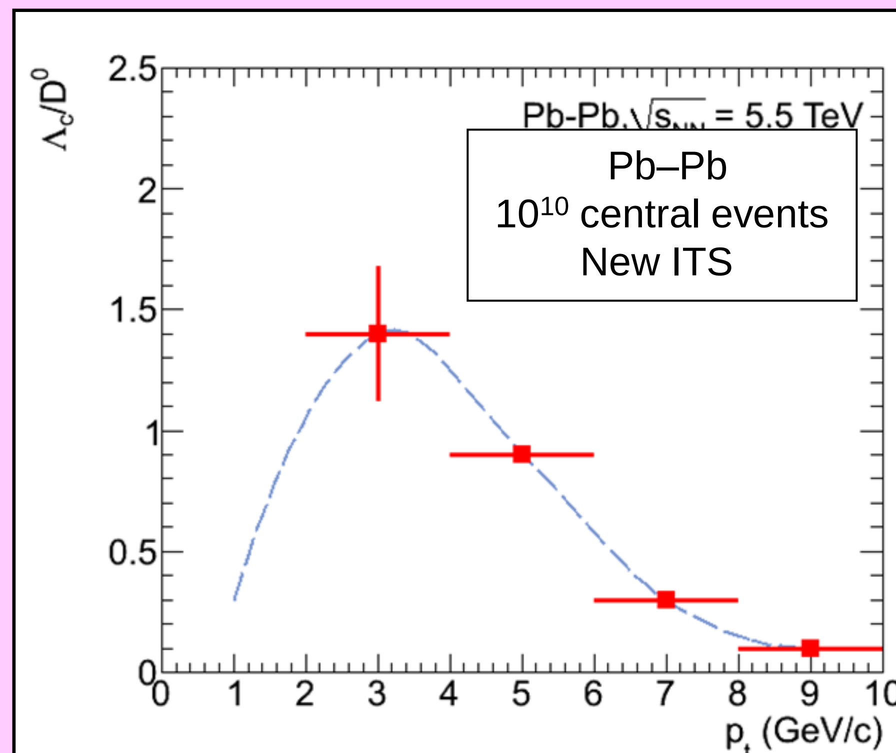
"Physics results"

- beauty via non-prompt $D^0 \to K\pi$ – mass dependence of energy loss
  - needs precision of the new ITS
- Λ_c – charm in-medium hadronization, baryon–meson ratio
  - needs both: new ITS and luminosity ~ 10 nb^{-1}

B/D R_{AA} suppression

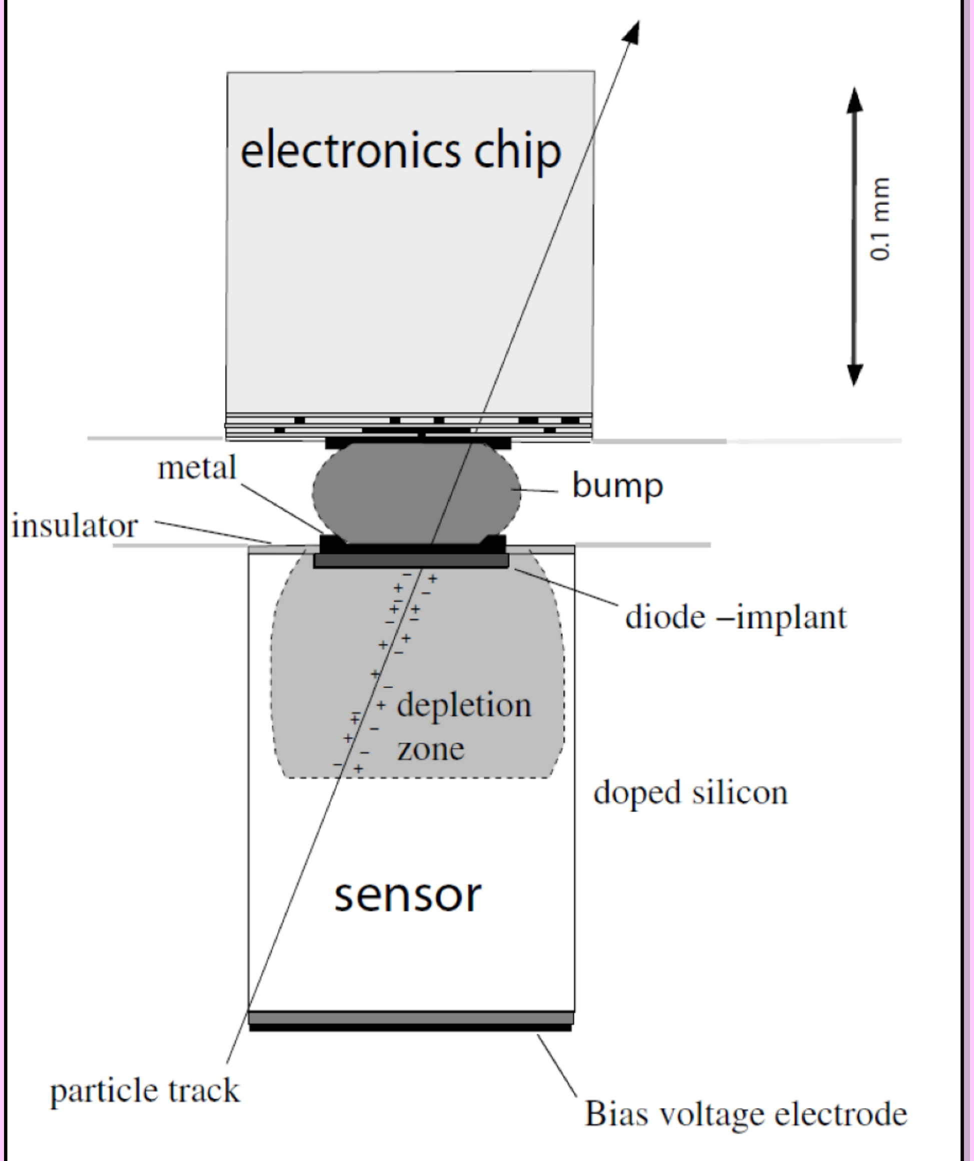


Λ_c/D enhancement

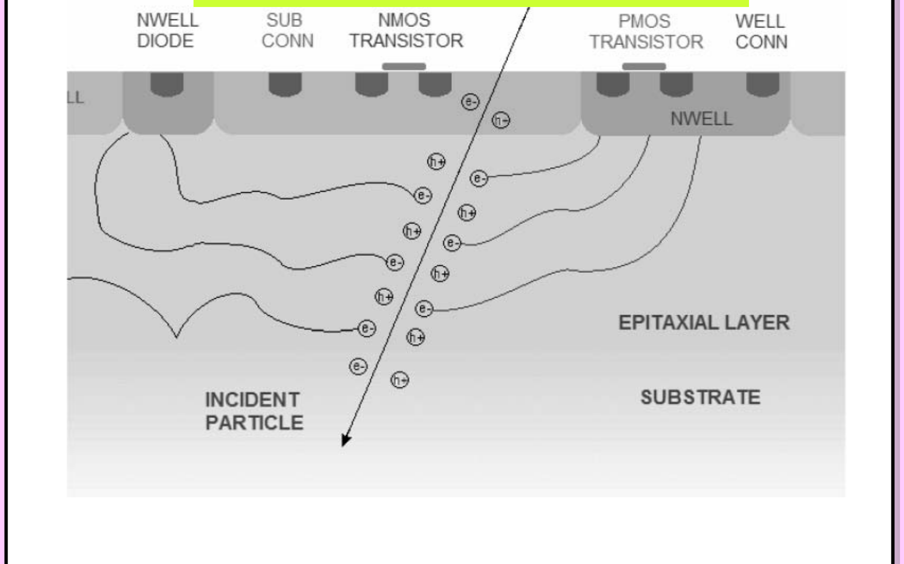


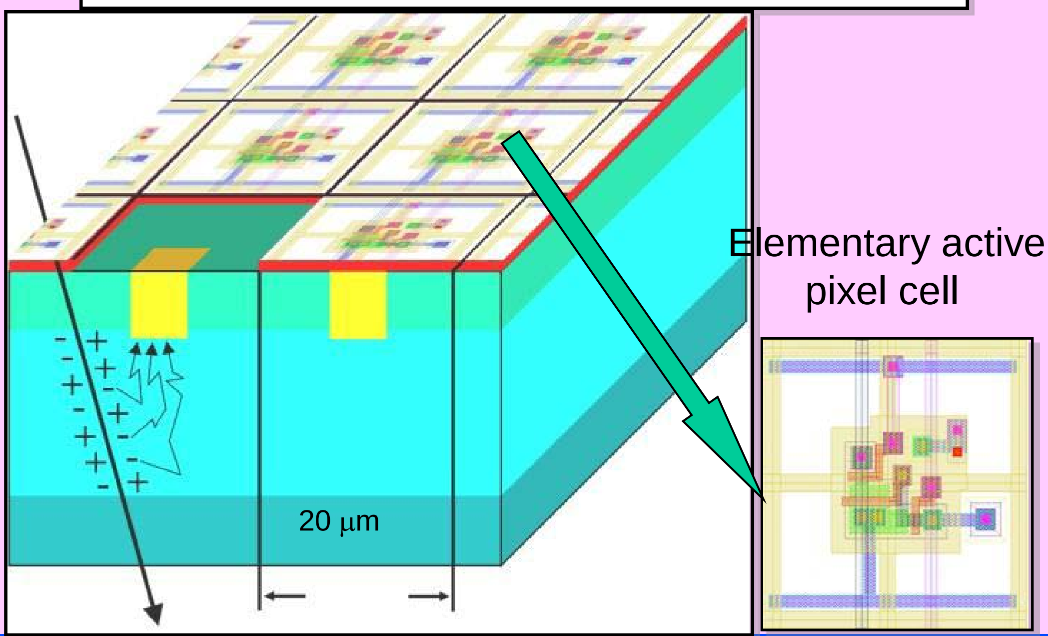
Pixel technologies

Hybrid Pixels



Monolithic Pixels





Pixel technologies

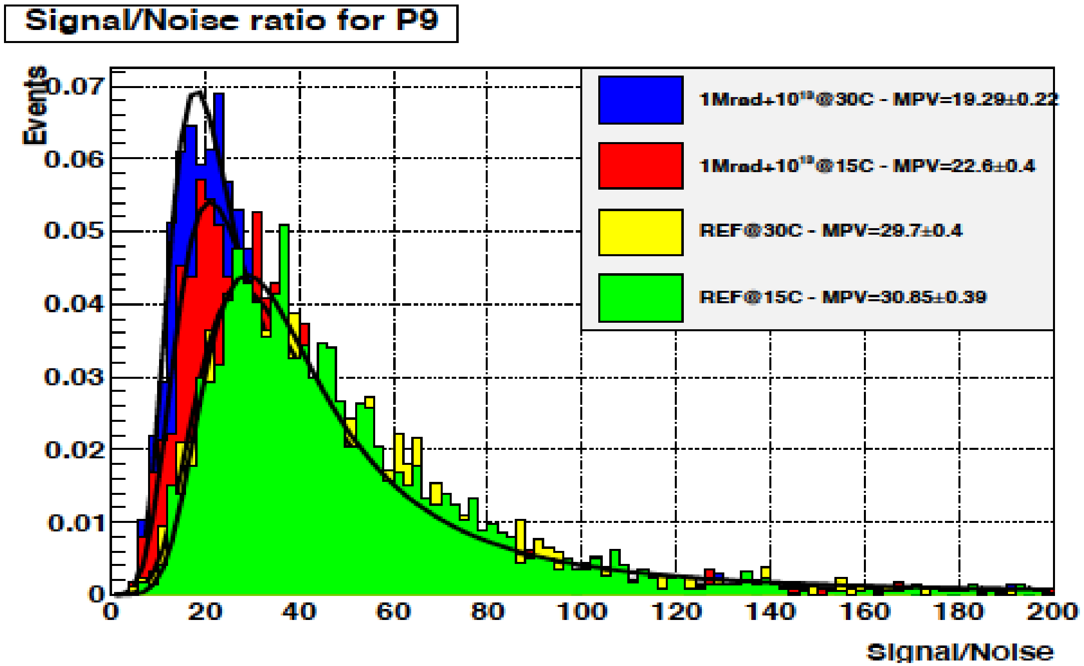
	Hybrid pixels	Monolithic pixels
Granularity	Limited, because of the bump bonding R&D ongoing: state of art 50x50 μm².	Small pixel size (~ 20 x 20 μm²)
Material budget	Two Si-chips limit the minimal material budget. R&D ongoing: thinning of the sensor → 50 μm and of the readout chip → 100 μm	Thin sensor: 50 μm (0.05% X0)
Radiation tolerance	Proven radiation hardness	R&D ongoing: new technology (TOWER/JAZZ CMOS 0.18 μm) Very promissing beam test results
Cost	High, because of the bump bonding	Low

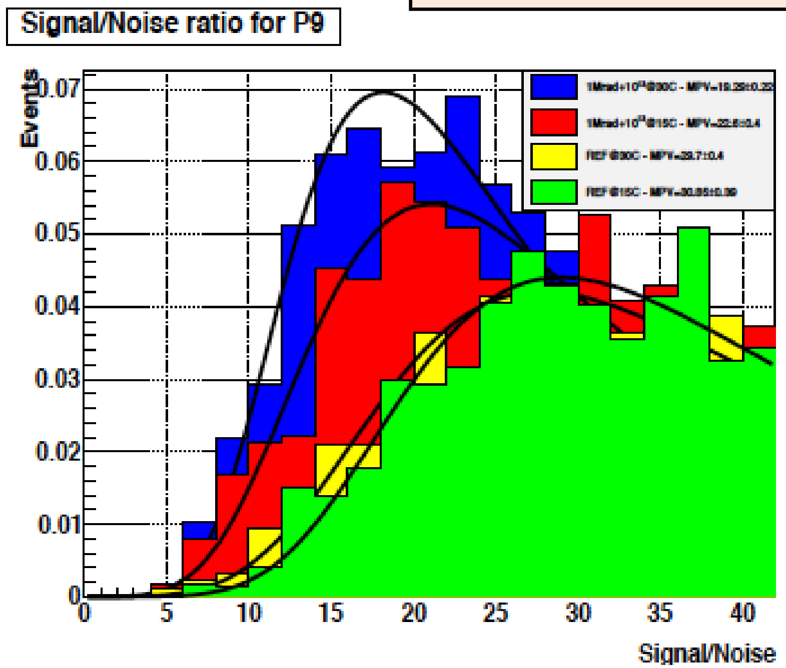
MIMOSA 32 (IPHC) : Characterization at test beam

- **Coolant temperature and radiation dose dependence:**

※ T = 15°C & 30°C ※ Doses: $3\times10^{12}n_{eq}/cm^2$ & 1 MRad$\oplus 1\times10^{13}n_{eq}/cm^2$

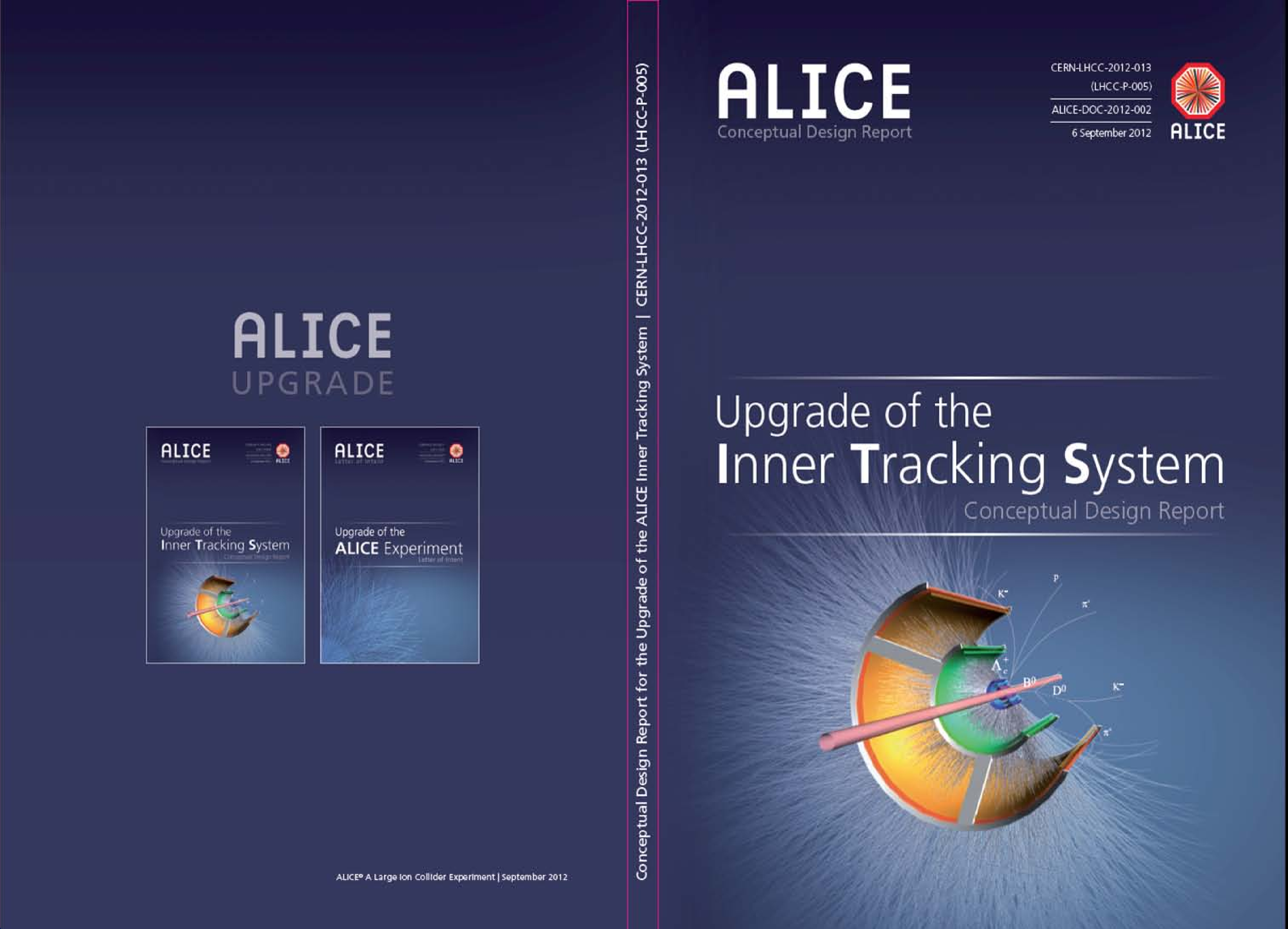
Preliminary (M. Winter et al.)





- **SNR (MPV) and detection efficiency** *(stat. undercainty only)*:

Irradiation Dose	**SNR (MPV)** 15°C	30°C	**Detection efficiency [%]** 15°C	30°C
0	*30.9 ± 0.4*	*29.7 ± 0.4*	*99.91 ± 0.06*	*99.7 ± 0.1*
1 MRad & $1\times10^{13}n_{eq}/cm^2$	*22.6 ± 0.4*	*19.3 ± 0.2*	*99.92 ± 0.08*	*99.87 ± 0.07*


ALICE
UPGRADE
ALICE
Upgrade of the
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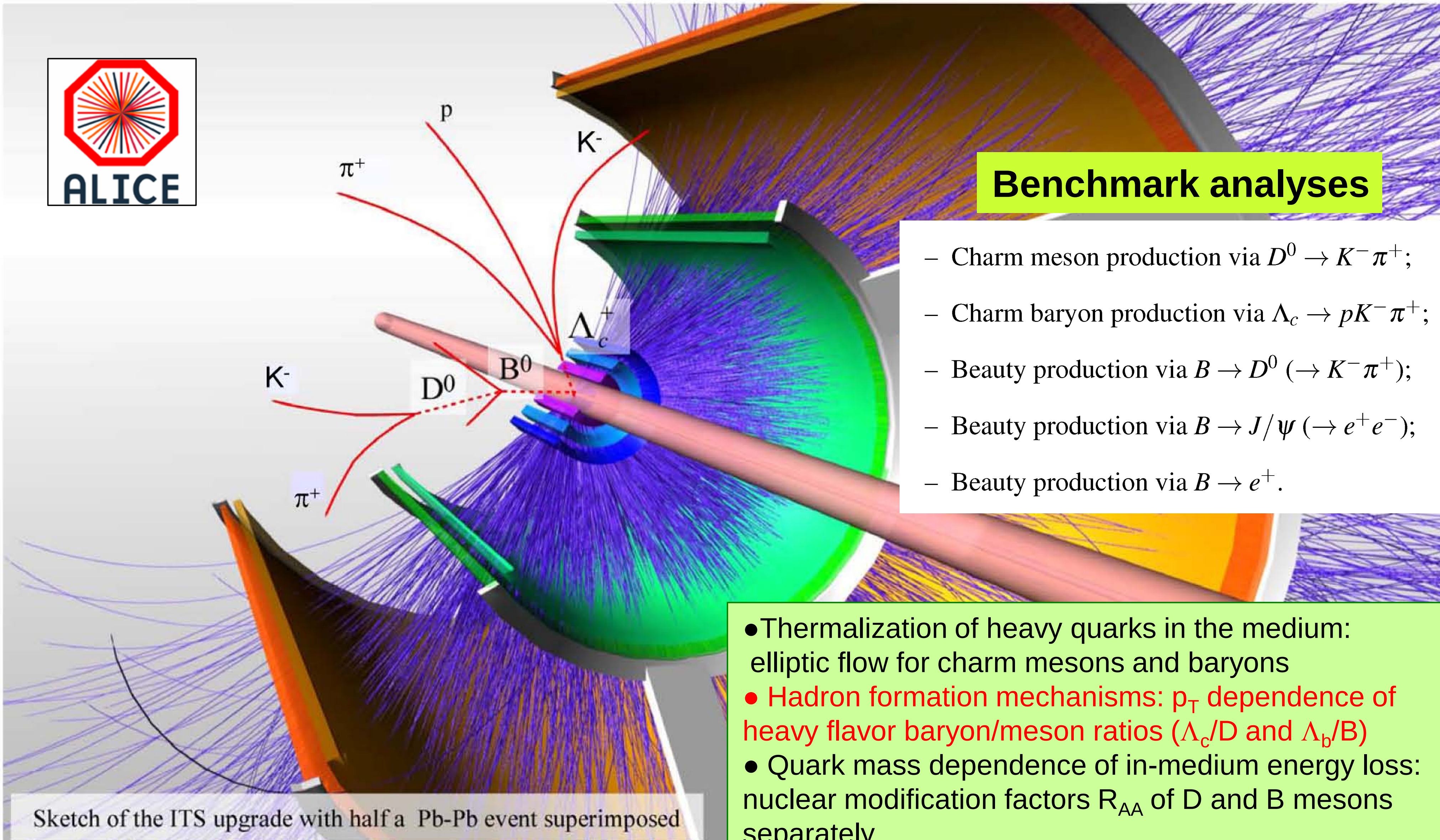
Conceptual Design Report for the Upgrade of the ALICE Inner Tracking System | CERN-LHCC-2012-013 (LHCC-P-005)
ALICE
Conceptual Design Report
CERN-LHCC-2012-013
(LHCC-P-005)
ALICE-DOC-2012-002
6 September 2012
ALICE
Upgrade of the
Inner Tracking System
Conceptual Design Report

Backup slides

Upgrade of the ALICE Inner Tracking System (ITS)



Sketch of the ITS upgrade with half a Pb-Pb event superimposed

Benchmark analyses

- Charm meson production via $D^0 \to K^-\pi^+$;
- Charm baryon production via $\Lambda_c \to pK^-\pi^+$;
- Beauty production via $B \to D^0\ (\to K^-\pi^+)$;
- Beauty production via $B \to J/\psi\ (\to e^+e^-)$;
- Beauty production via $B \to e^+$.

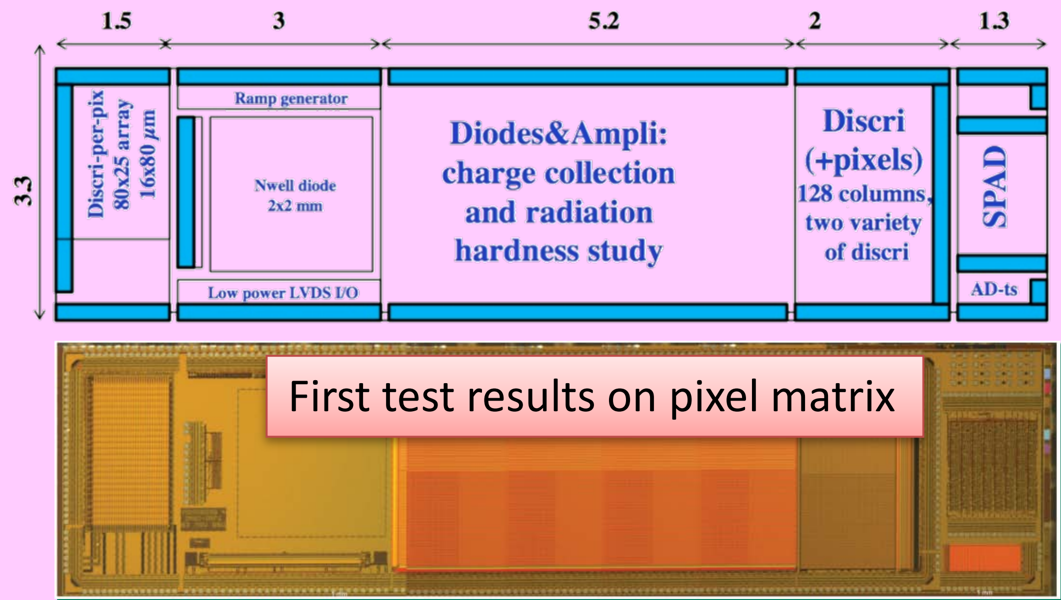
- Thermalization of heavy quarks in the medium: elliptic flow for charm mesons and baryons
- Hadron formation mechanisms: p_T dependence of heavy flavor baryon/meson ratios (Λ_c/D and Λ_b/B)
- Quark mass dependence of in-medium energy loss: nuclear modification factors R_{AA} of D and B mesons separately.

In the perspective of high luminosity PbPb (2018) and the frame of the global reforging of ALICE

Monolithic pixels: Evaluation of Tower/Jazz technogoly

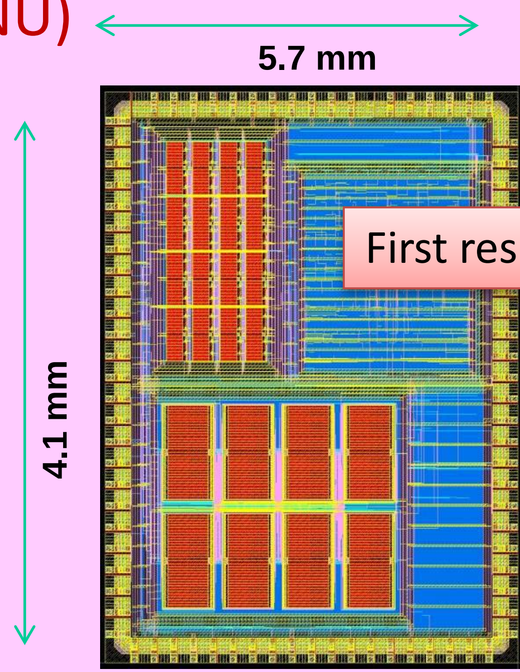
MIMOSA 32 (IPHC Strasbourg)

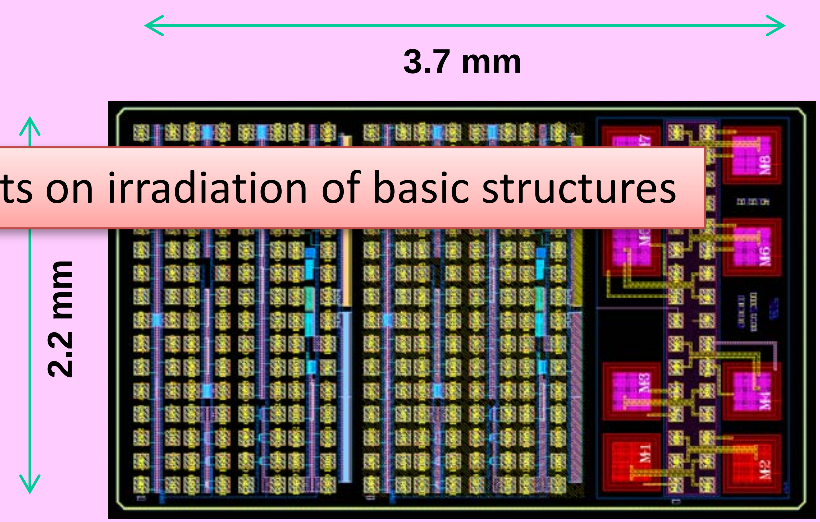
- Digital and analog blocks (2T and 3T structures with various diodes)
- 100 circuits delivered Jan 2012 ✓
- Test with Fe^{55} source ✓
- Irradiation tests (X-ray, neutron) ✓
- Beam-test June 6-11, 2012 ✓



MONALICET1 (CERN/CCNU)

- Single transistors
- Breakdown structures
- Memories
- Digital structures
- Shift register
- Delivery July 2012
- Irradiation test (X-ray) ✓





CMOS test structures w/o deep p-well

Breakdown diodes

ALICE program

- ALICE heavy-ion program approved for ~ 1 nb^{-1}:
  - 2013–14 Long Shutdown 1 (LS1)
    - completion of TRD and CALs
  - 2015 Pb–Pb at $\sqrt{s_{NN}}$ = 5.1 TeV
  - 2016–17 (maybe combined in one year) Pb–Pb at $\sqrt{s_{NN}}$ = 5.5 TeV
  - 2018 Long Shutdown 2 (LS2)
  - 2019 probably Ar–Ar high-luminosity run
  - 2020 p–Pb comparison run at full energy
  - 2021 Pb–Pb run to complete initial ALICE program
  - 2022 Long Shutdown 3 (LS3)

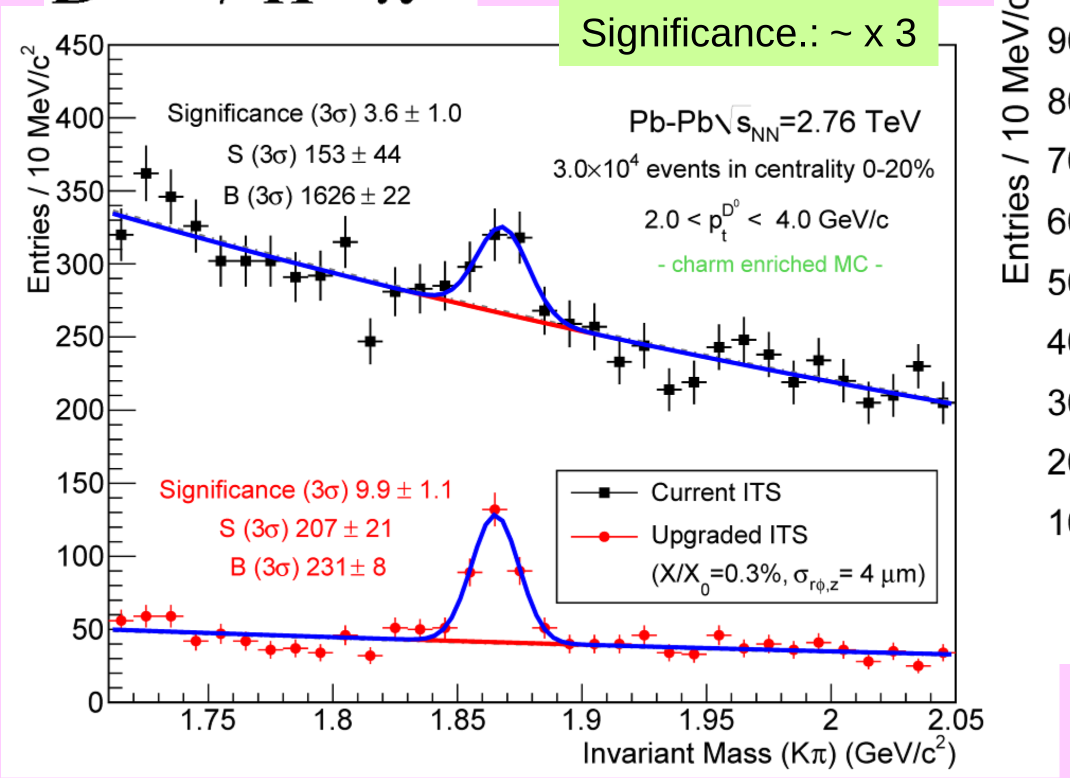
Order/choice of nuclei may change

- This will improve statistical significance of our main results by a factor about 3
  - physics reach extended by the new energy and completion of TRD and CALs

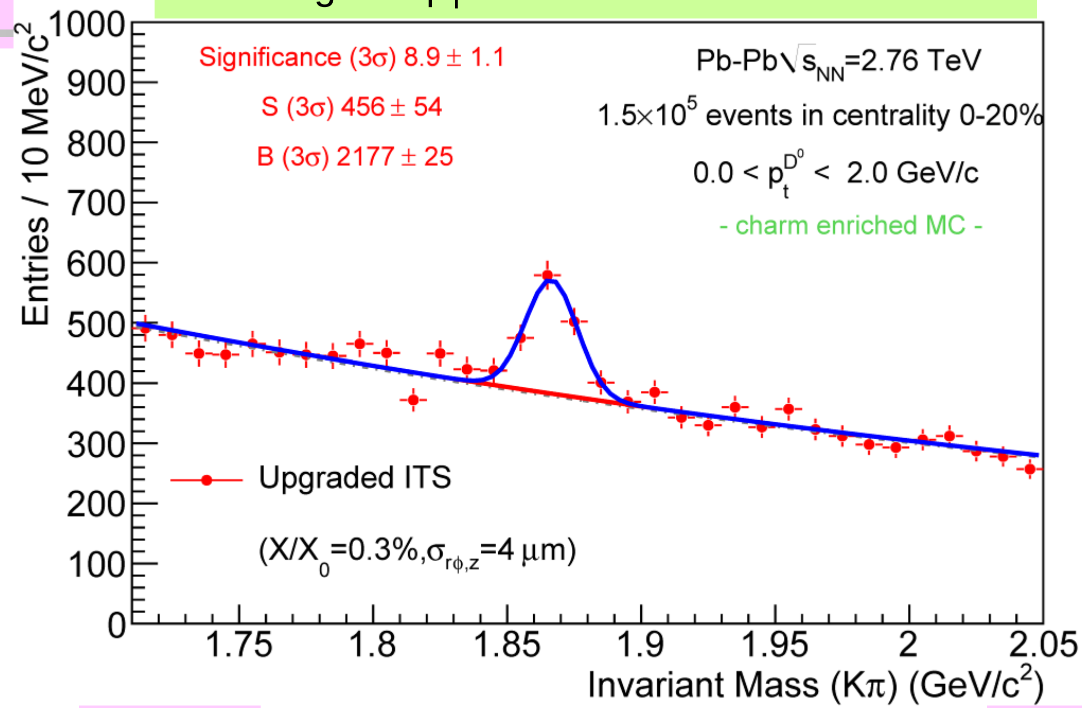
Charm and beauty meson measurement with the upgraded ITS

$D^0 \rightarrow K^- \pi^+$

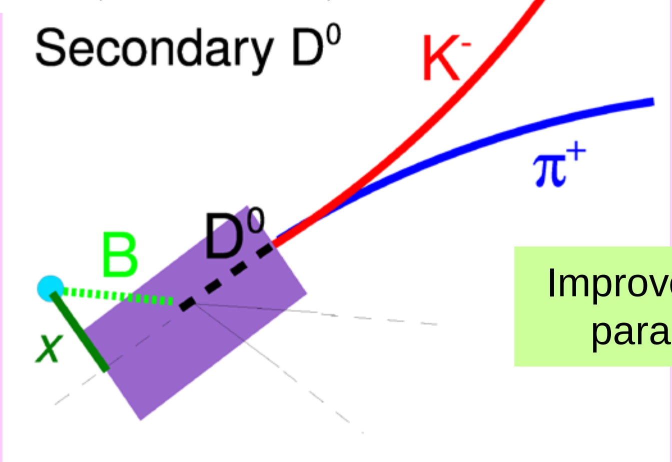
2 < p_T< 4 GeV/c
S/B: ~ x 10
Significance.: ~ x 3



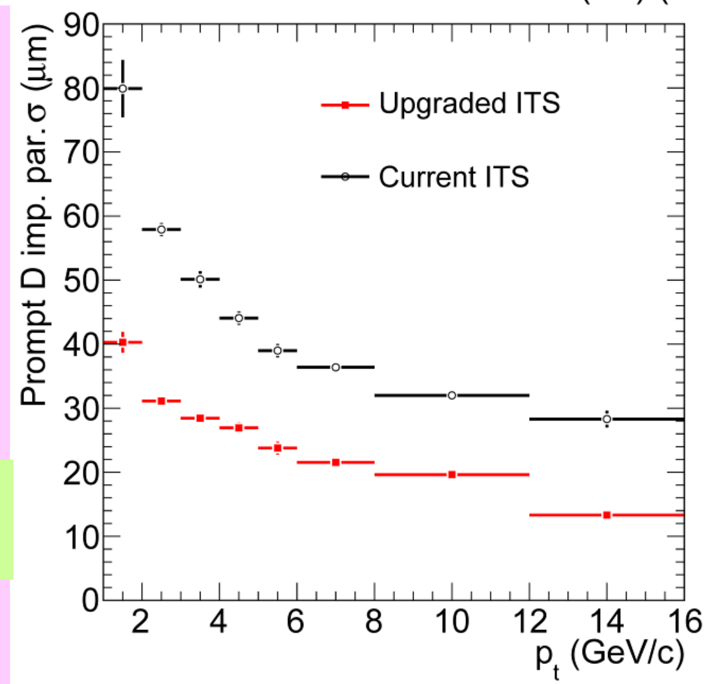
The range 0< p_T< 2 GeV/c becomes accessible



$B \rightarrow D^0 (\rightarrow K^- \pi^+)$



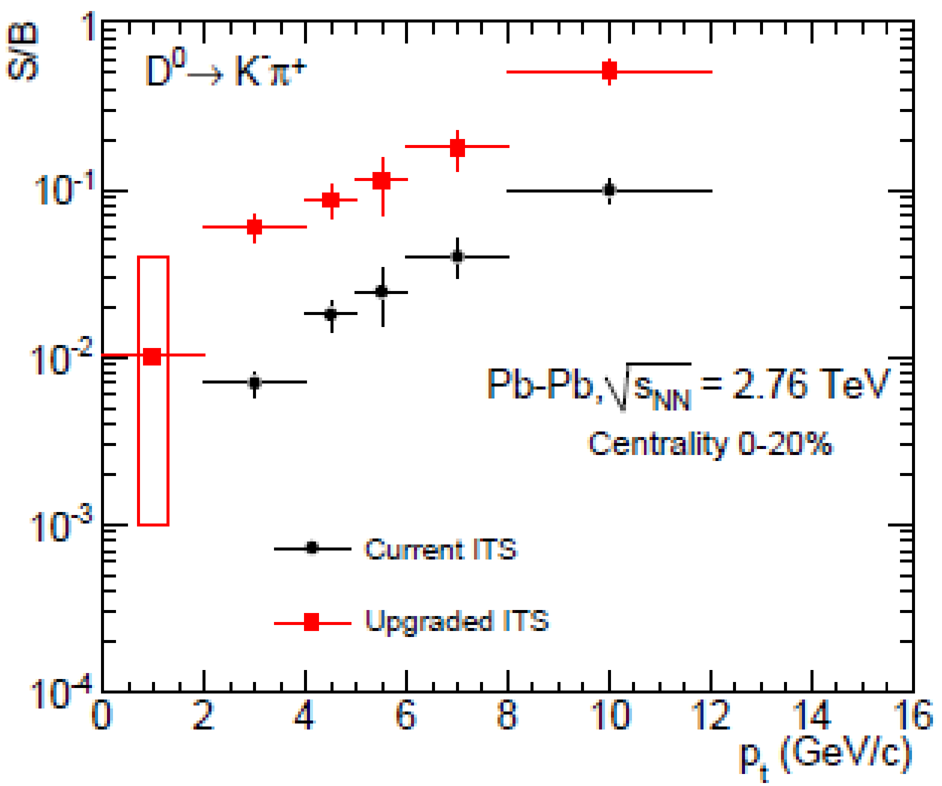
Improvement of D impact parameter resolution

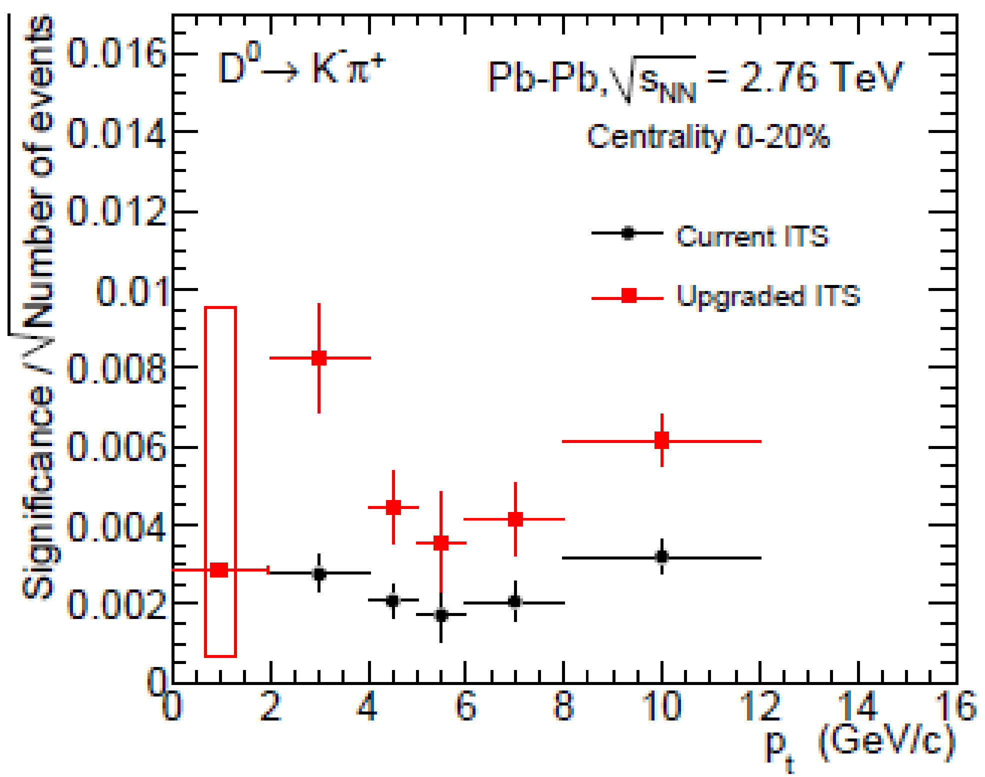


$D^0 \rightarrow K^-\pi^+$

Signal-to-background ratio

Significance: multiply by ~10^5



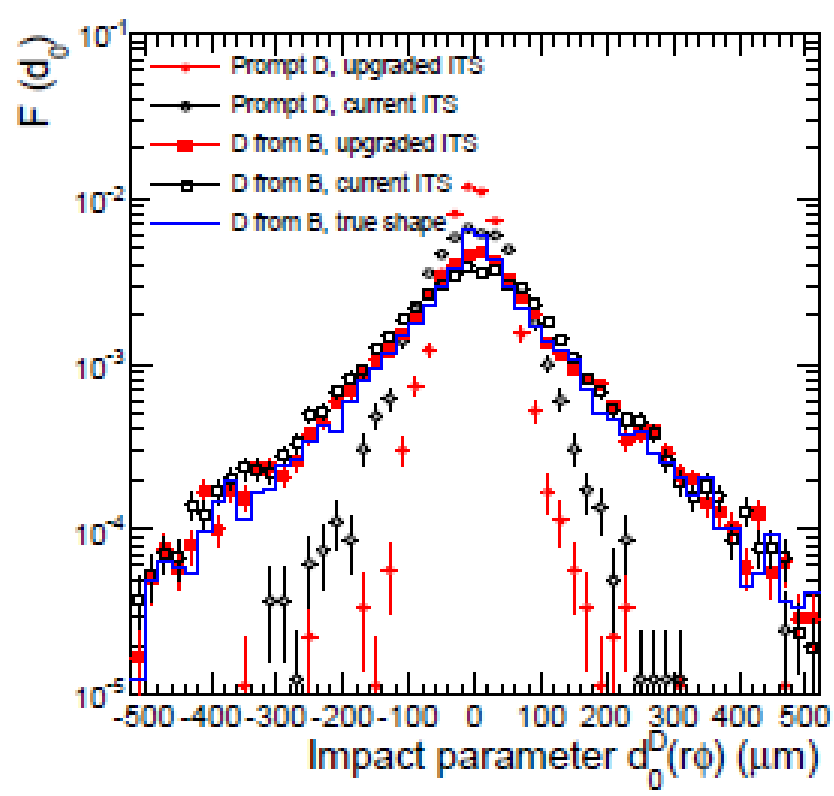


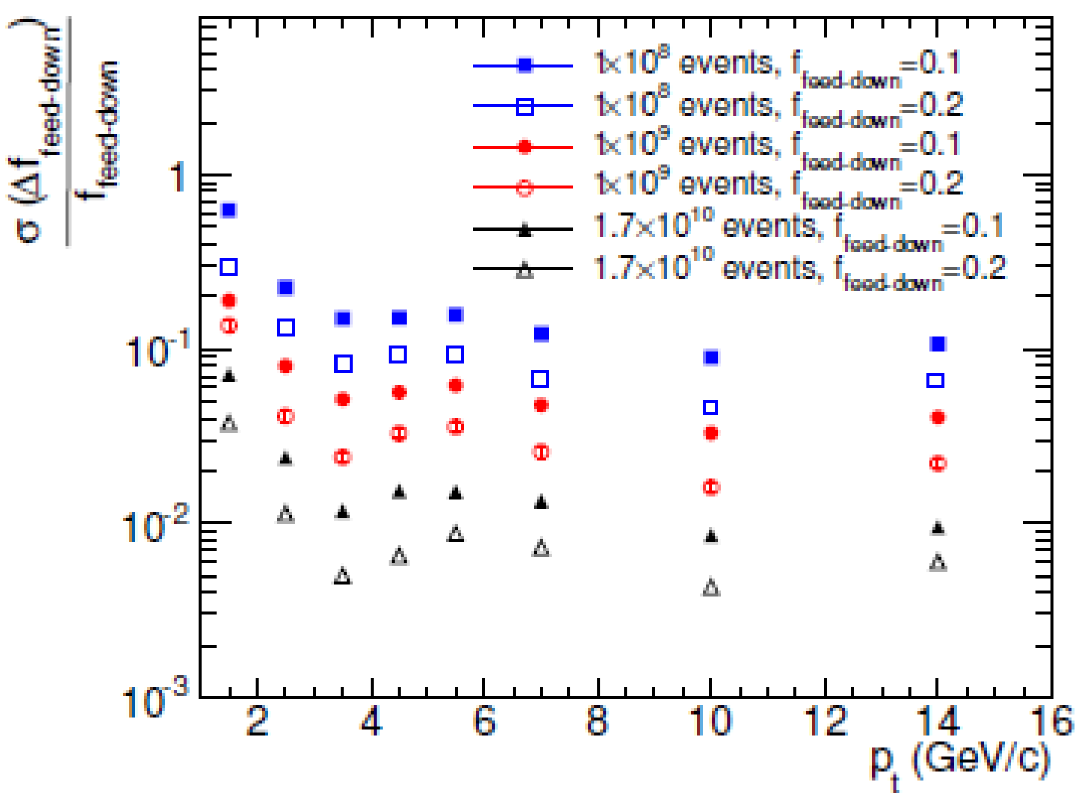
with new ITS: signal-to-background improved by one order of magnitude
significance improved by factor 2–4

$B \to D^0 (\to K^-\pi^+) + X$

Impact parameter distribution for D and B

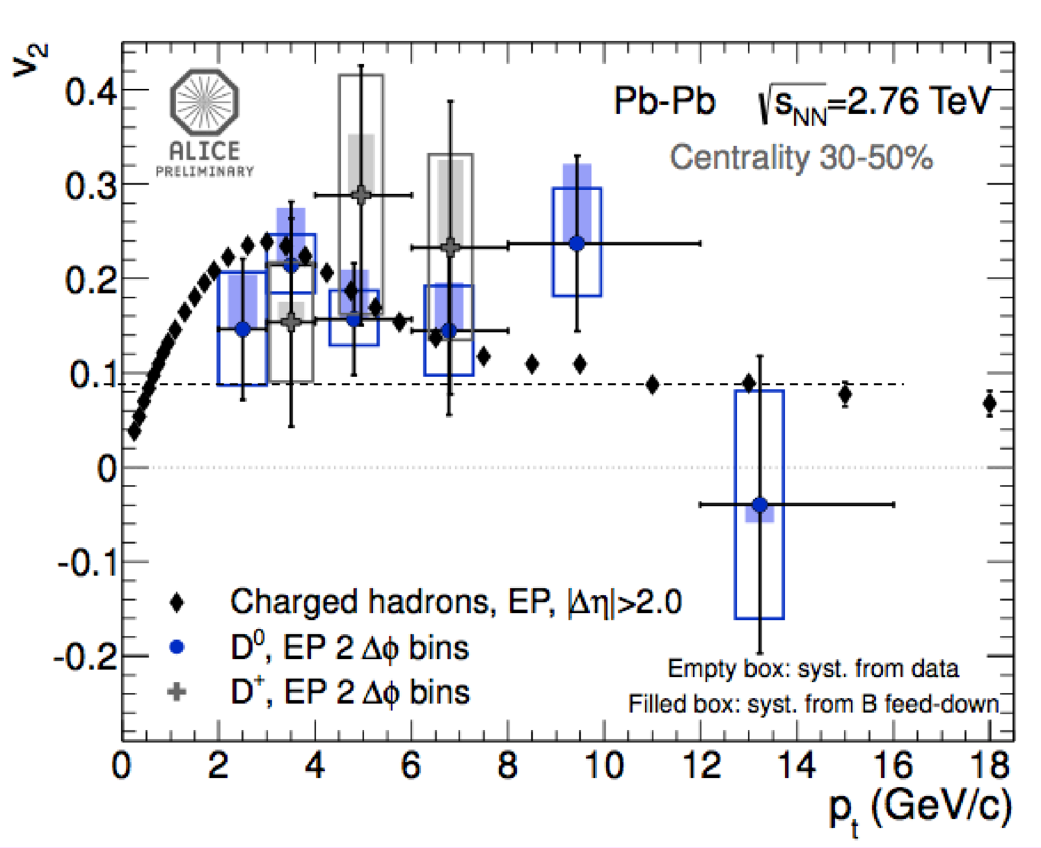
Relative statistical error on B fraction (new ITS)





- Significantly improved resolution for prompt D meson with new ITS
- For B-meson measurement high statistics necessary
- Study of systemic uncertainties presented in LoI

Motivation for elliptic flow



- **New: ALICE preliminary results with full 2011 sample (10^7 events in 30-50%)**
- **Indication of non-zero v_2**
- **But uncertainties are substantial**
- **Factor 3 larger statistics 2015-16 data?**

→ Need precise measurement of v_2 of D and B mesons to answer these questions:

- is v_2 of charm the same as of pions?

- is v_2 of beauty smaller than of charm?

- comparison with models → HQ transport coefficient of QGP

Low-mass dileptons

One of the most fundamental (and difficult) measurements, potentially giving access to:

- chiral-symmetry breaking mechanism by modification of ρ-meson spectral function
- direct photon thermal emission extrapolating to zero dilepton mass
- partonic equation of state studying space–time evolution with invariant-mass and p_T distributions of dileptons

Measurements to be done:

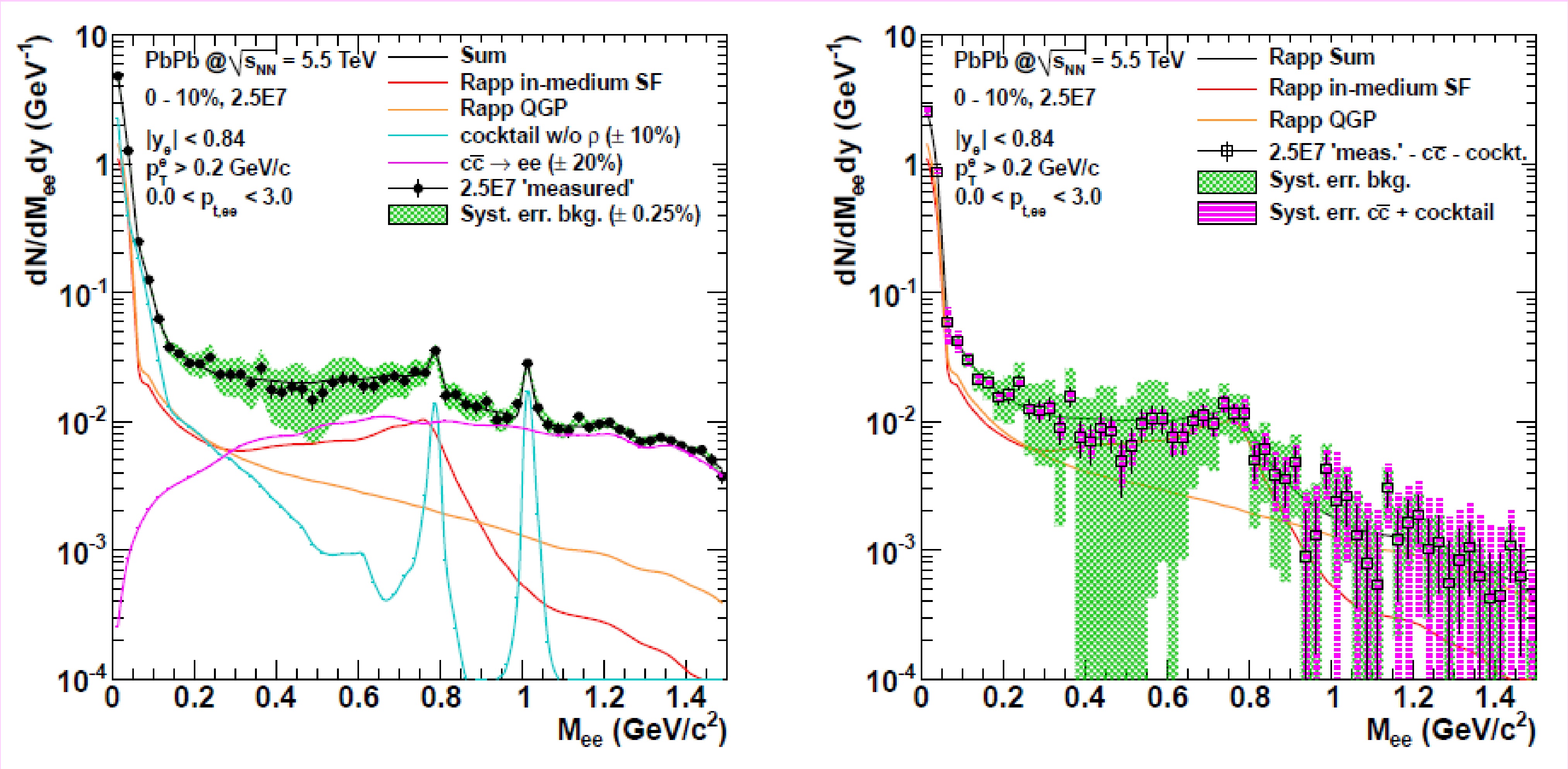
- mapping of dilepton yields in invariant mass and p_T
- elliptic flow of dileptons
- (after experimentally driven subtraction of all backgrounds…)

Need for special run at lower magnetic field (B = 0.2T) to enhance acceptance at low p_T, thus integrated luminosity of 3 nb^{-1} assumed

ALICE dielectrons

inclusive dielectron invariant mass

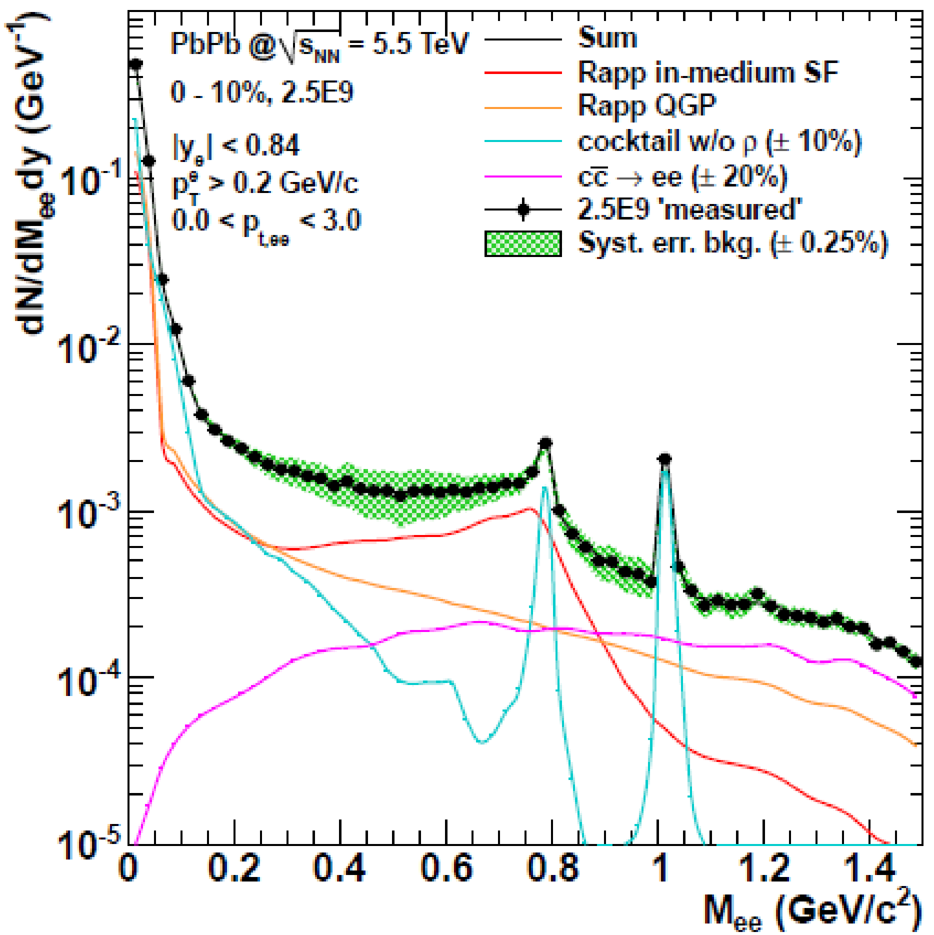
… excess after subtraction



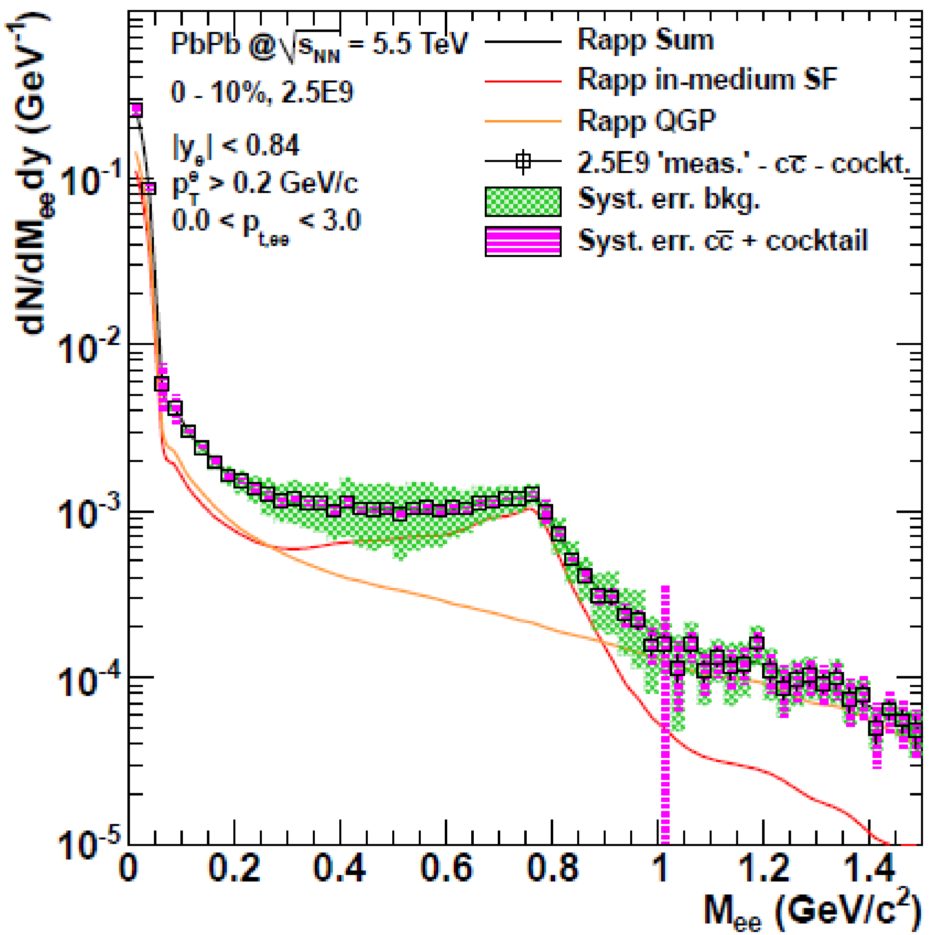
current ITS and event rate, no cut on impact parameter…

ALICE dielectrons

inclusive dielectron invariant mass



… excess after subtraction

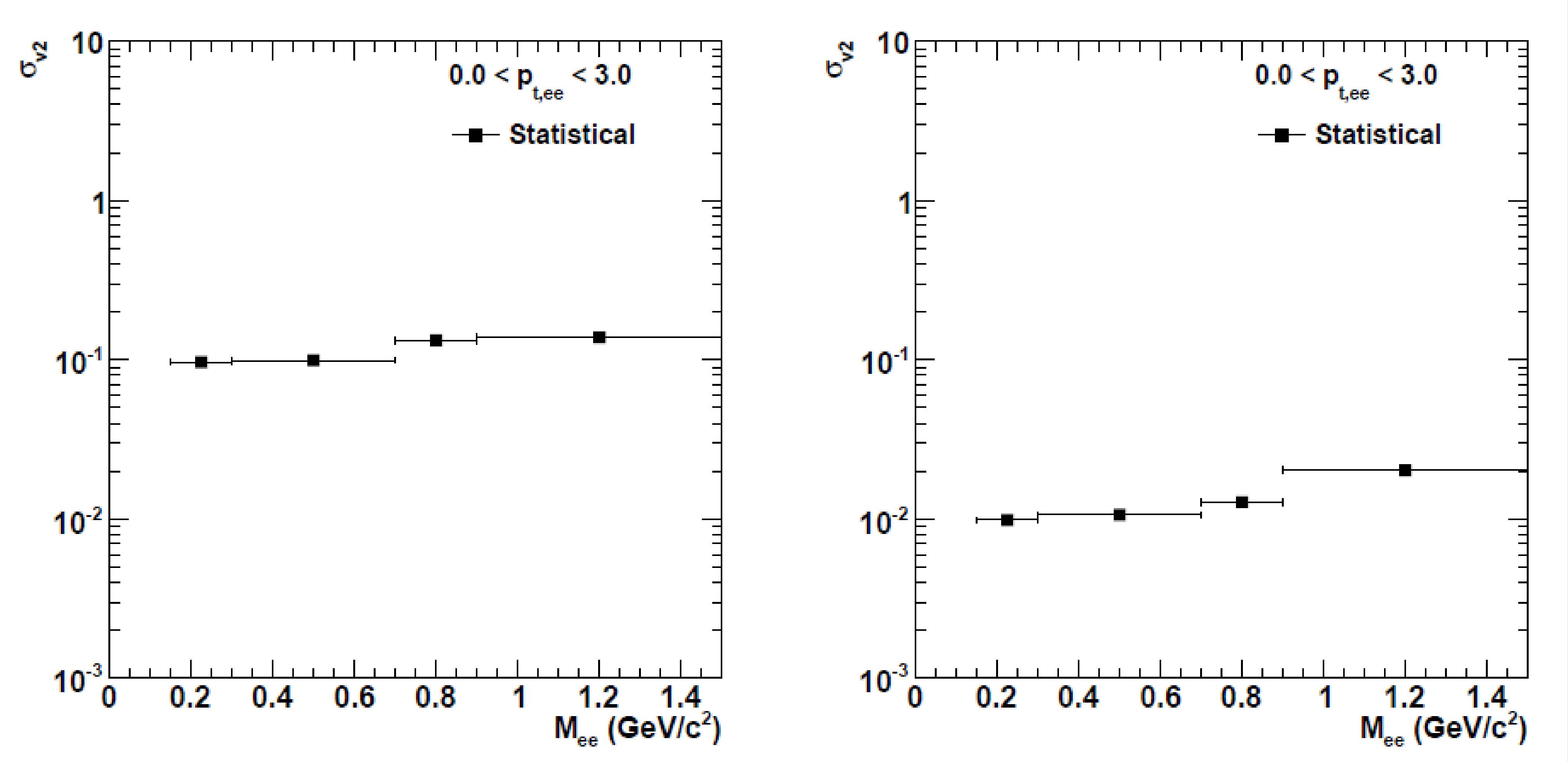


new ITS and high-rate upgrade, with "tight" impact parameter cut…

Dielectron v_2

current ITS, no hight-rate upgrade

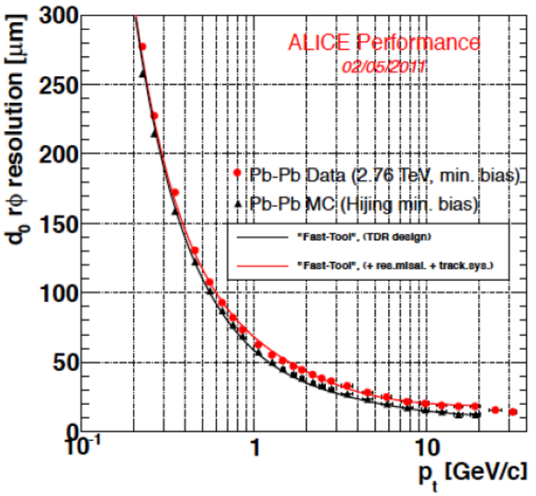
new ITS, high-rate upgrade



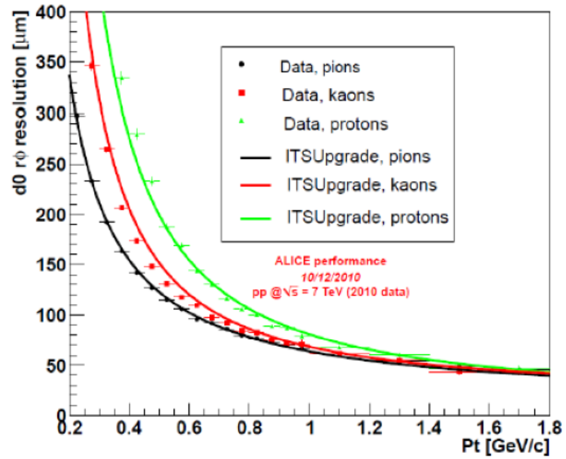
new ITS and high-rate: significant improvement (one order of magnitude)…

Simulation validation

Fast Estimation Tool

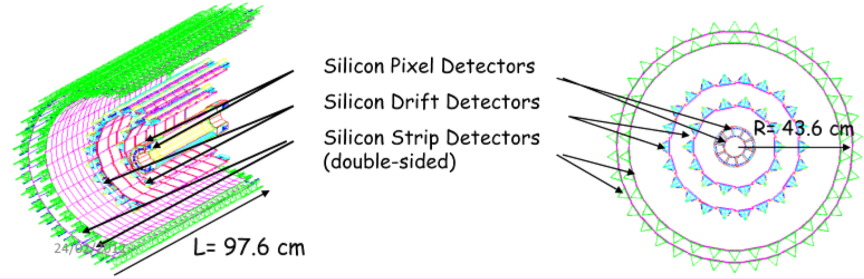


Full Monte Carlo simulation



Present Inner Tracking System (ITS)

Layer	Technology	R (cm)	±z (cm)	Spatial resolution (µm) rϕ	Spatial resolution (µm) z	Material budget X/X_0 (%)	
1	Pixel	4.0	14.1	12	100	1.14	Provide Level 0 trigger (latency < 800 ns)
2	Pixel	7.2	14.1	12	100	1.14	
3	Drift	15.0	22.2	38	28	1.13	
4	Drift	23.9	29.7	38	28	1.26	Provide dE/dx for the particle identification
5	Strip	38.5	43.2	20	830	0.83	
6	Strip	43.6	48.9	20	830	0.83	

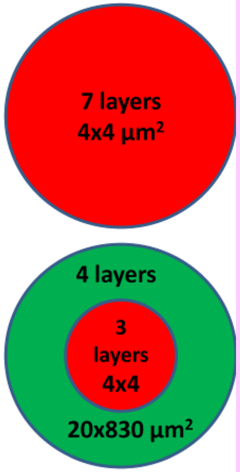


Simulation tools

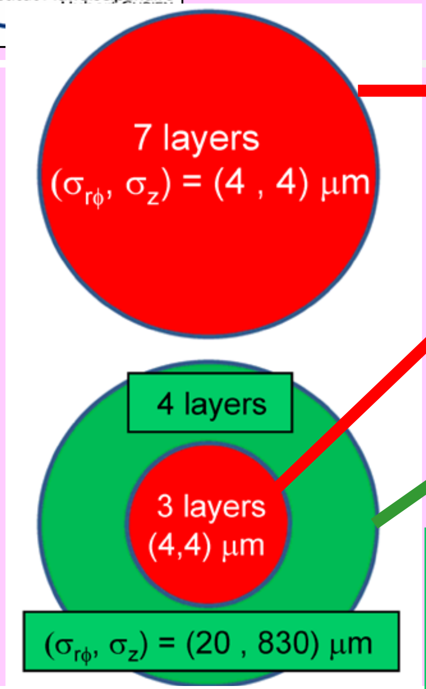
- **Fast Estimation Tool** (FET): “Toy-Model” originally developed by the STAR HFT collaboration which allows to build a simple detector model.
- **Fast MC Tool** : Extension of the FET -> allows to disentangle the performance of the layout from the efficiency of the specific track finding algorithm
- **Full Monte Carlo** : Transport code (geant3) designed to be flexible : the detector segmentation, the number of layers, their radii and material budgets can be set as external parameters of the simulation.

Two basic ITS upgrade scenarios

Layer / Type	R [cm]	±z [cm]	Intrinsic resolution [µm] rϕ	Intrinsic resolution [µm] z	Material budget X/X_0 [%]
Beam pipe	2.0	-	-	-	0.22
1 / pixel	2.2	11.2	4	4	0.3
2 / pixel	2.8	12.1	4	4	0.3
3 / pixel	3.6	13.4	4	4	0.3
4 / pixel (strips)	20.0	39.0	4 (20)	4 (830)	0.3 (0.83)
5 / pixel (strips)	22.0	41.8	4 (20)	4 (830)	0.3 (0.83)
6 / pixel (strips)	41.0	71.2	4 (20)	4 (830)	0.3 (0.83)
7 / pixel (strips)	43.0	74.3	4 (20)	4 (830)	0.3 (0.83)



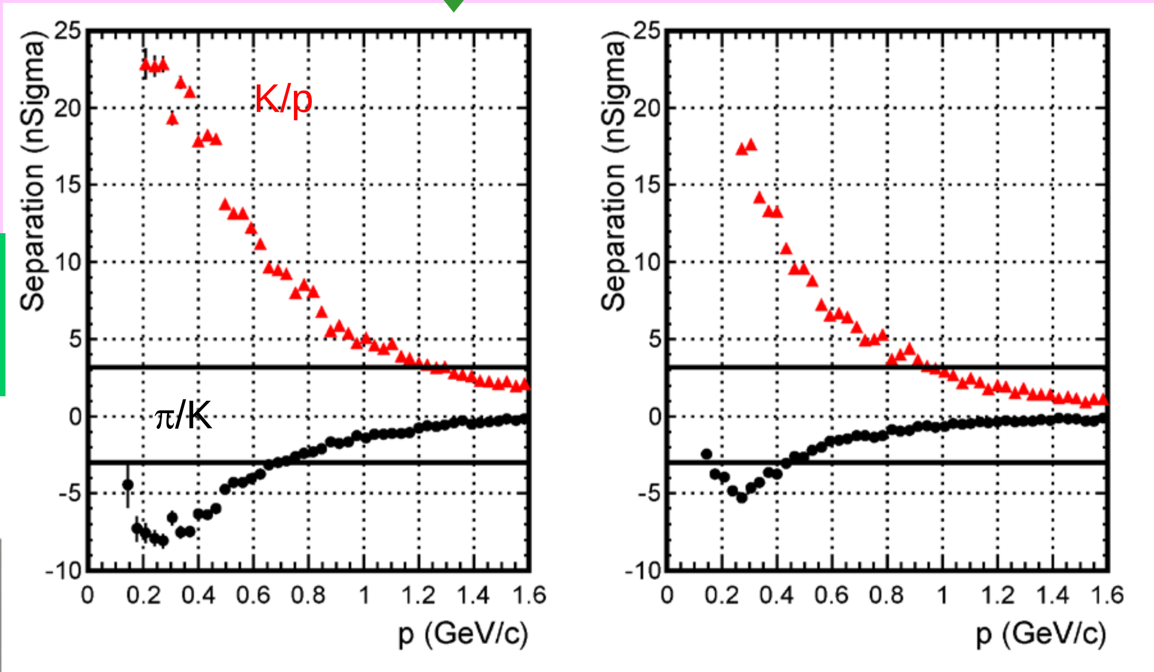
The two Silicon detector technologies



Hybrid and monolithic pixel detectors

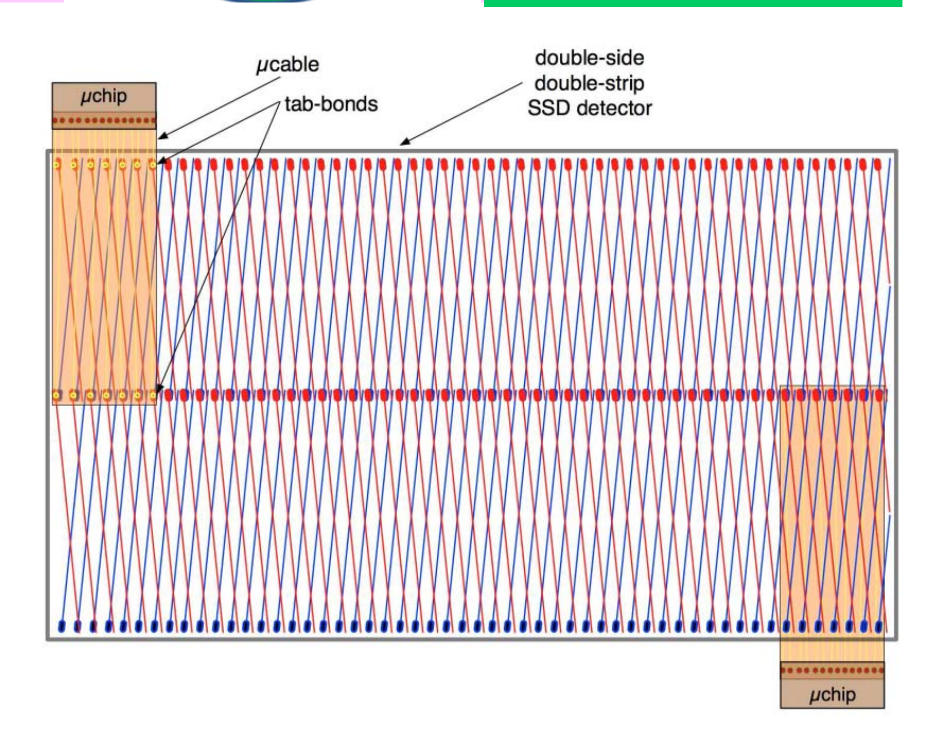
Double sided micro-strip detectors

Improved PID capabilities



3 pixel layers + 4 strip layers (300 μm of Si per layer)

7 Layers of MAPS (active Si thickness per layer: 15 μm)



Well known technology
Sensor based on the existing design
Granularity is adequate for the external layers only

Pixel detector technologies

Several technologies are being considered

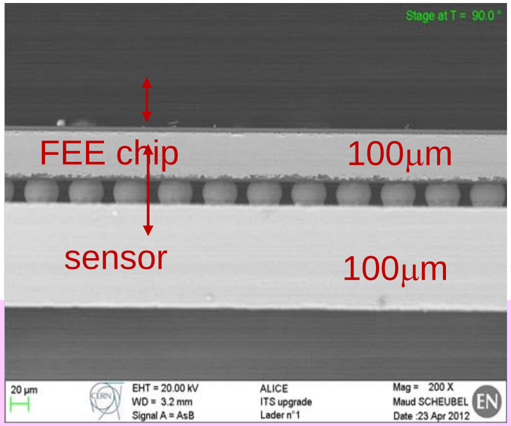
Hybrid pixel detectors

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

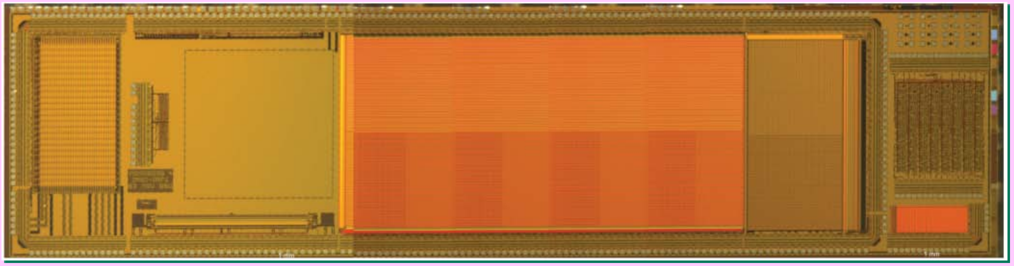
Monolithic pixel detectors

- MIMOSA like in 180 nm CMOS
- INMAPS in 180 nm CMOS → } Tower/Jazz
- LePix in 90nm CMOS — IBM

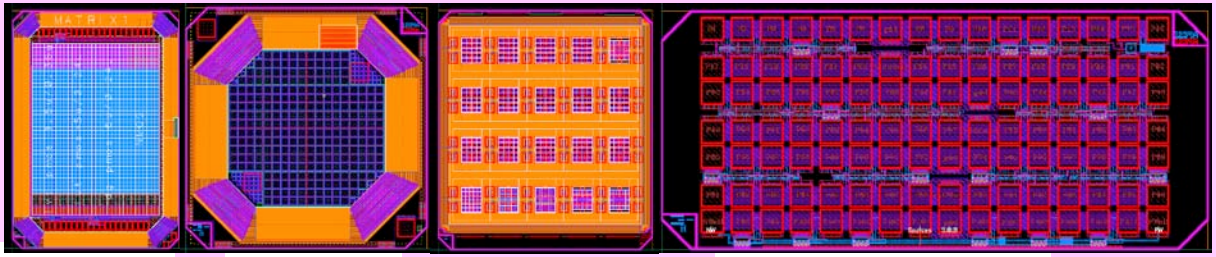
HYBRID (CERN)



MISTRAL prototype circuit (IPHC)

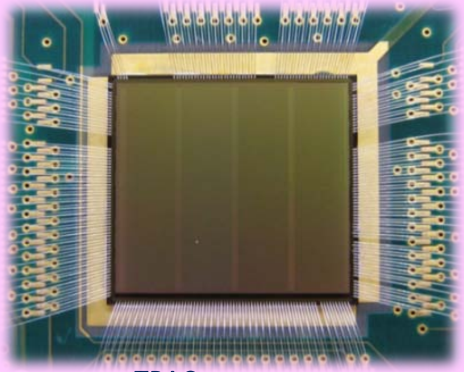


LePIX prototype circuit (CERN)



Matrix1 | Diode | Breakdown test | Transistor test

INMAPS (RAL)



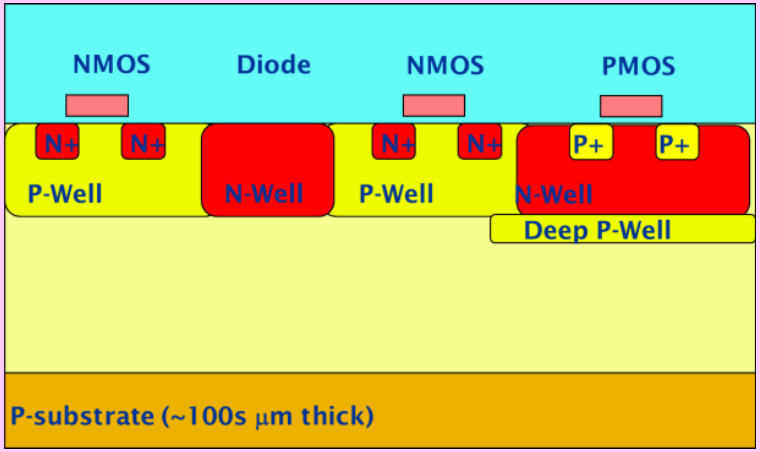
TPAC prototype
50 µm pixel - over 150 CMOS transistors

Monolithic Pixel Detectors
➔possible breakthrough development

TOWERJAZZ

Development for monolithic detectors using Tower/Jazz 0.18 µm CMOS technology:

- Improved TID resistance due to smaller technology node
- Available with high resistivity (~1k Ω•cm) epitaxial layer up to 18 µm
- Special quadruple-well available to shield PMOS transistors (allows in-pixel truly CMOS circuitry)



(R. Turchetta – RAL)

- Study radiation hardness and SEU
- Study charge collection performance

➔

- Design prototype chips in Tower/Jazz 0.18 µm
- Use existing structures (RAL)