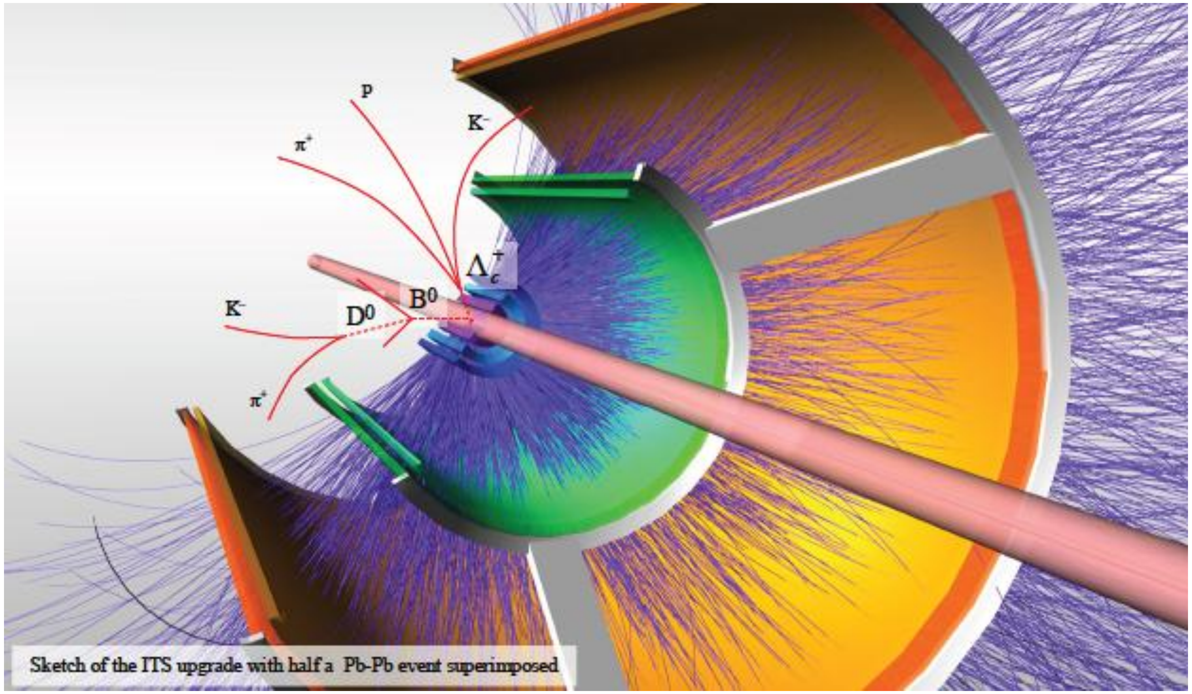
The ALICE ITS Upgrade



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

Roy Lemmon - STFC Daresbury Laboratory, UK
for the ALICE Collaboration

Outline

- physics motivations and strategy
- summary of design goals and detector layout options
- detector performance studies for benchmark channels
- ongoing Technical R&D (very selective)
  - ❑ sensors (MAPS, hybrid, strip)
  - ❑ mechanical structure and detector ladder prototypes
- conclusions

Overall ALICE Upgrade described by Thomas Peitzmann – Parallel 6C

Physics Motivation for ITS Upgrade

1. **Study the thermalization of heavy quarks in the QGP:**
   - Measurement of baryon/meson for charm (Λ_c/D) and possibly for beauty (Λ_b/B)
   - Elliptic flow for B and HF baryons
   - Possible in-medium thermal production of charm quarks (D down to $p_T = 0$)

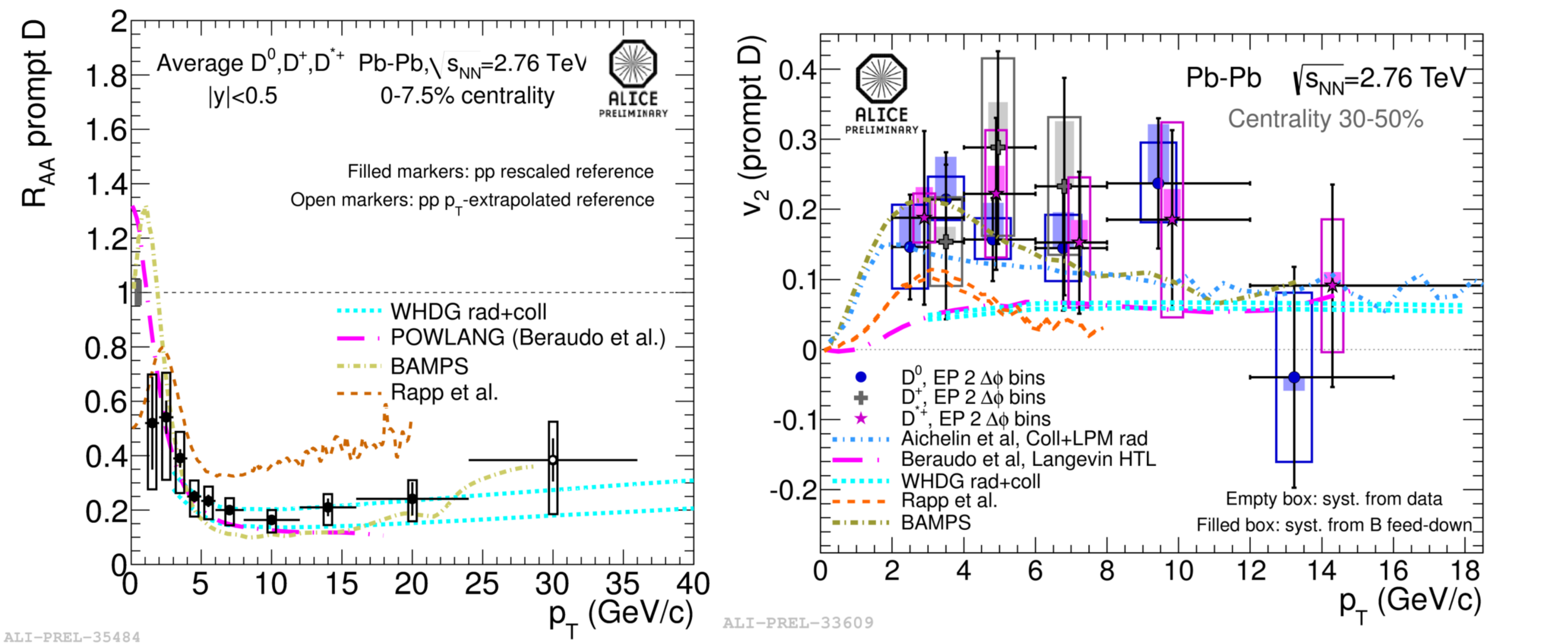
2. **Study of the quark mass dependence of energy loss in the QGP:**
   - Nuclear modification factors R_{AA} of the p_T distribution of D and B mesons separately
     - Beauty via displaced $D^0 \rightarrow K\pi$
     - Beauty via displaced $J/\psi \rightarrow ee$

$$R_{AA}(p_T) = \frac{\text{Yield}_{AA}(p_T)}{\langle N_{bin} \rangle_{AA} \text{Yield}_{pp}(p_T)}$$

3. **Other measurements will also benefit:**
   - e.g. Di-electron measurements
     - Poster by Patrick Reichelt, "Prospects of low-mass di-electron measurements in ALICE with the ITS Upgrade"
   - ...

All measurements to as low p_T as possible, ideally down to $p_T = 0$

R_{AA} and v_2 from 2011 Pb-Pb Run with Current ITS



- **ALICE Heavy Flavour results overview talk by Zaida Conesa del Valle**
- **Increased precision in measurements vital, in particular at low p_T ...**

Design Goals of ITS Upgrade

1. Improve impact parameter resolution by a factor of ~ 3
   - get closer to IP (position of first layer): 39 mm → 22 mm
   - reduce material budget, X/X_0 : ~ 1.14 % → ~ 0.3 %
   - reduce pixel size
     - currently 50 μm x 425 μm
     - monolithic pixels → O(20 μm x 20 μm)
     - hybrid pixels → O(20 μm x 20 μm), state-of-the-art is O(50 μm x 50 μm)

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
   - readout of Pb-Pb interactions at > 50 kHz

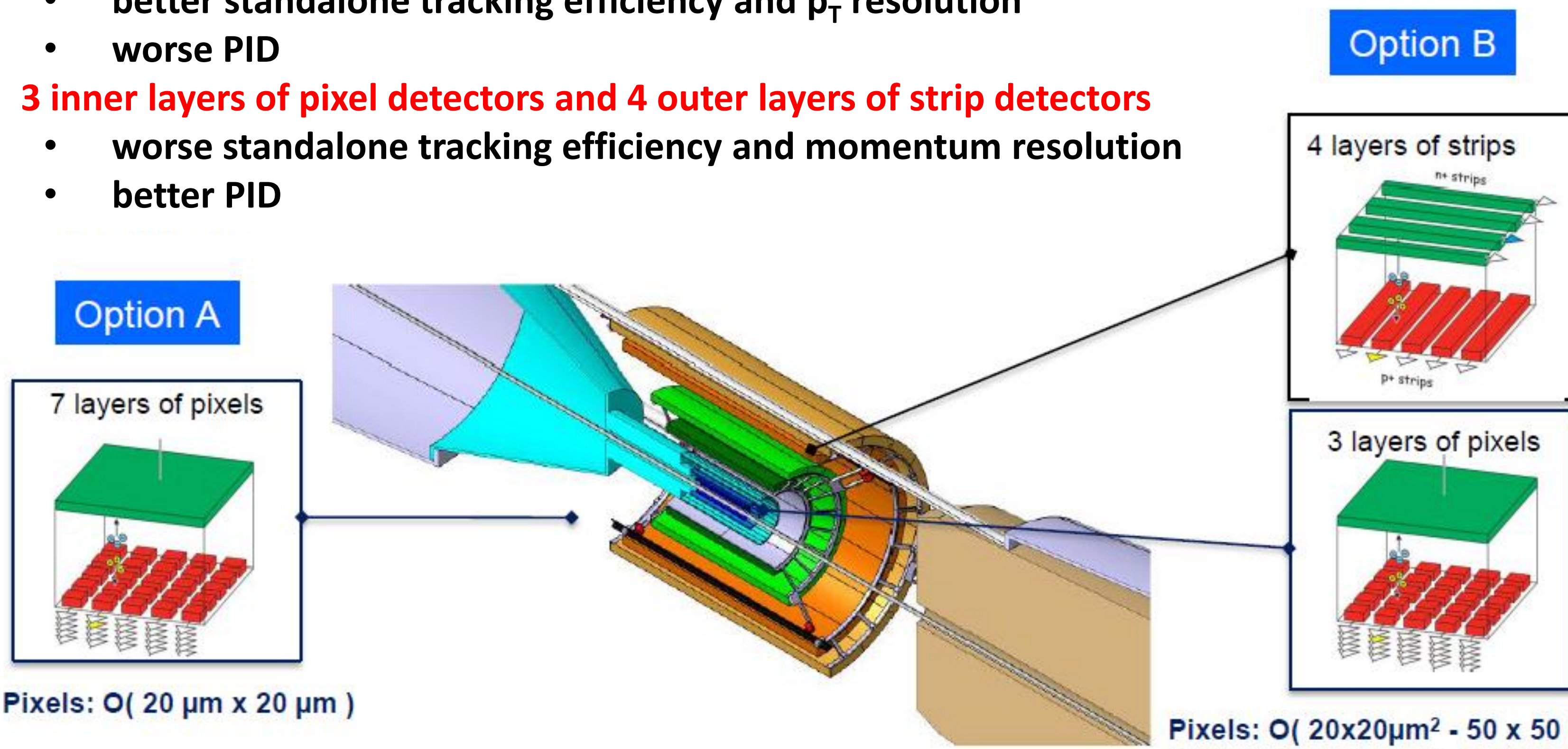
4. Fast insertion/removal for yearly maintenance
   - possibility to replace non-functioning detector modules during yearly shutdown

Upgrade Options

Poster on Sensor R&D – Giacomo Contin

Two design options are being studied:

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



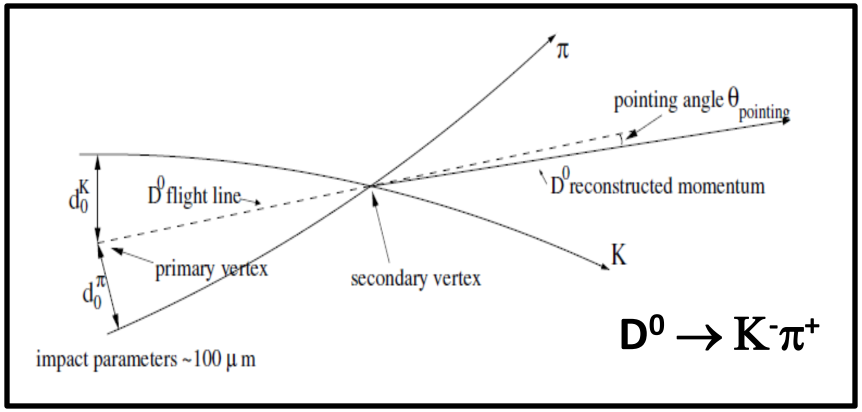
Pixels: O(20 µm x 20 µm)

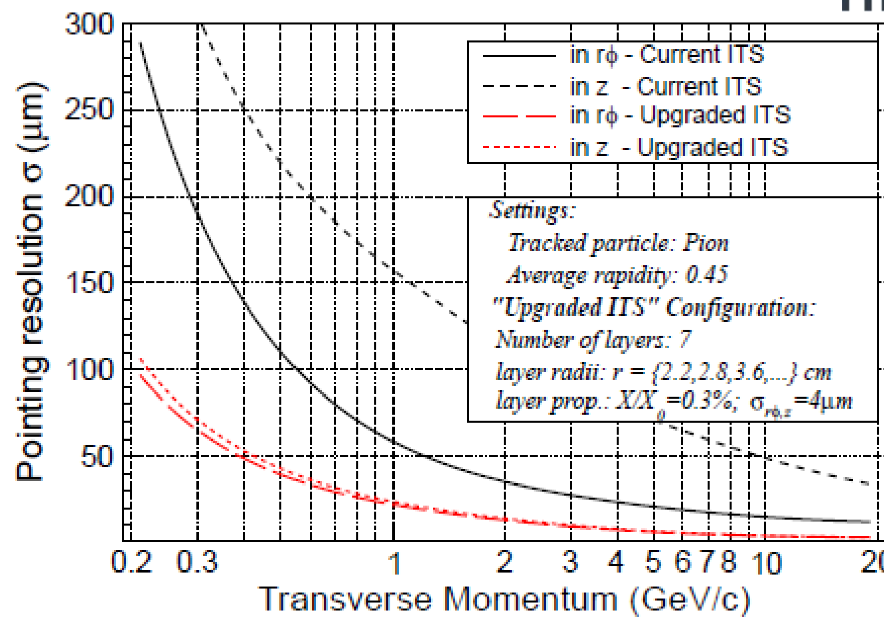
Pixels: O($20 \times 20 \mu m^2$ - $50 \times 50 \mu m^2$)
Strips: 95 µm x 2 cm, double sided

Radiation levels for layer 1:

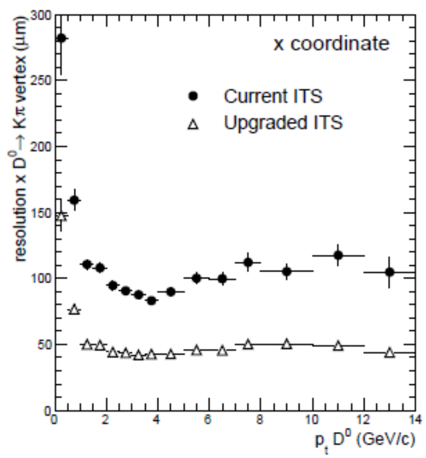
- 1 Mrad/1.6×10^{13} $n_{eq}cm^{-2}$ per year
- with safety factor 4

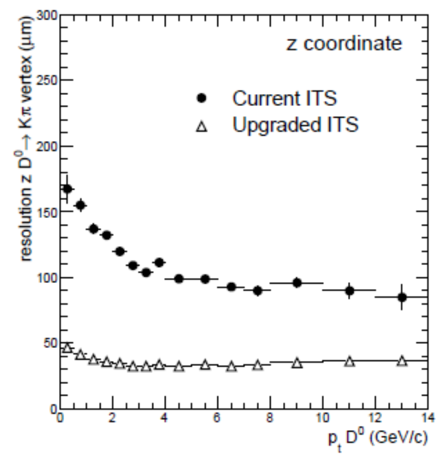
Improvement of Impact Parameter Resolution





Example: secondary vertex resolutions for $D^0 \to K^-\pi^+$

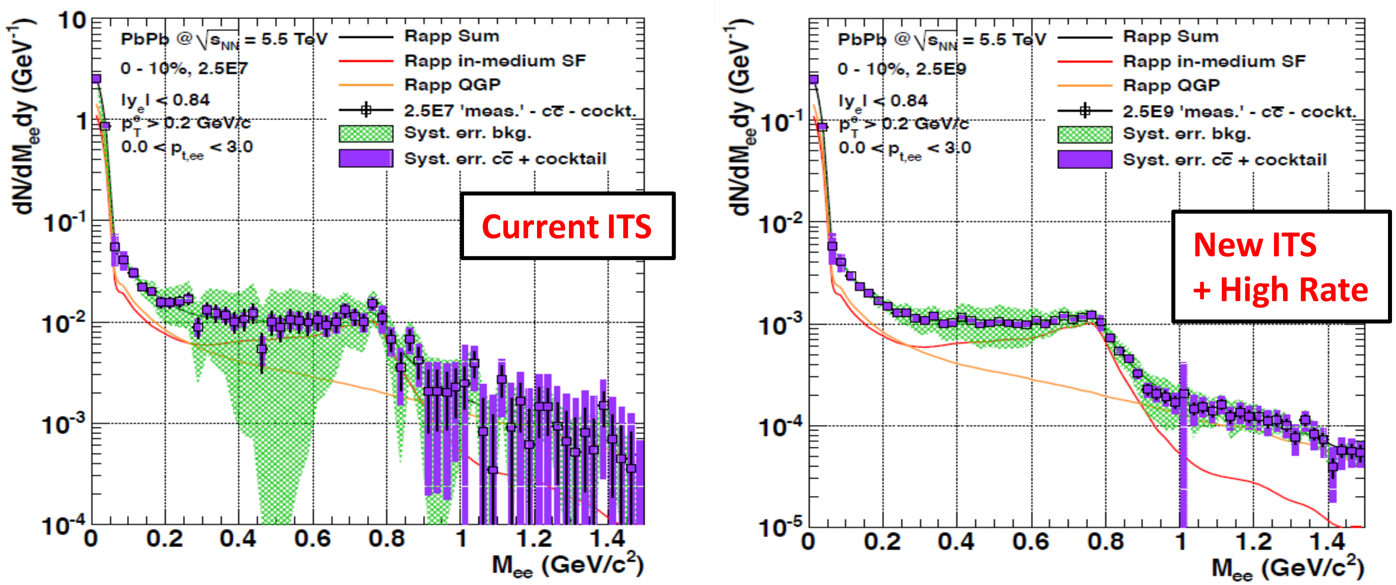




Benchmark Analyses for CDR

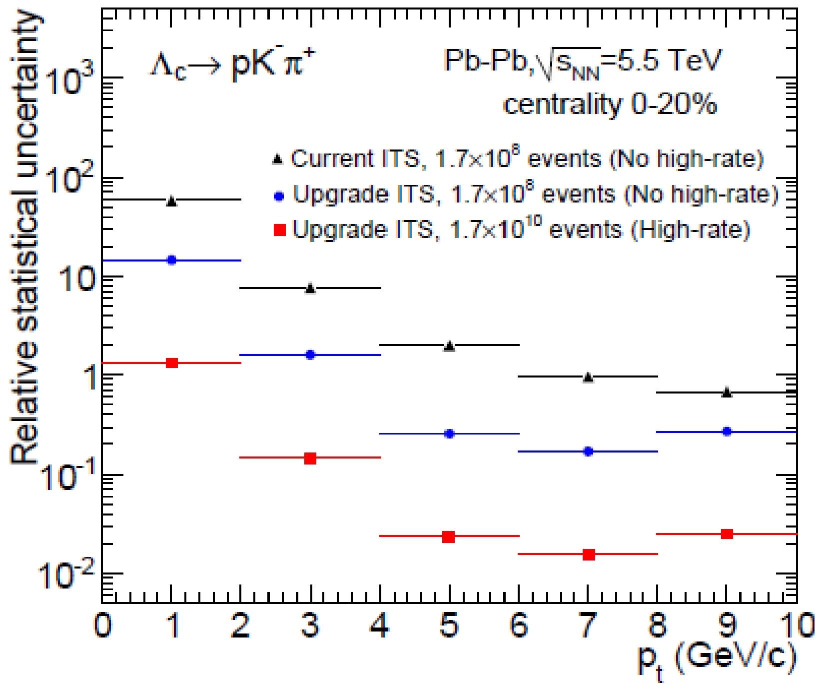
- **Charm meson production via $D^0 \rightarrow K^-\pi^+$**
- **Charm baryon production via $\Lambda_c \rightarrow pK^-\pi^+$**
- **Beauty production via $B \rightarrow D^0 (\rightarrow K^-\pi^+)$**

- **Significant impact of ITS Upgrade on many other areas:**
  - **for example, di-electron measurements: more statistics, more efficient cuts to reduce background**

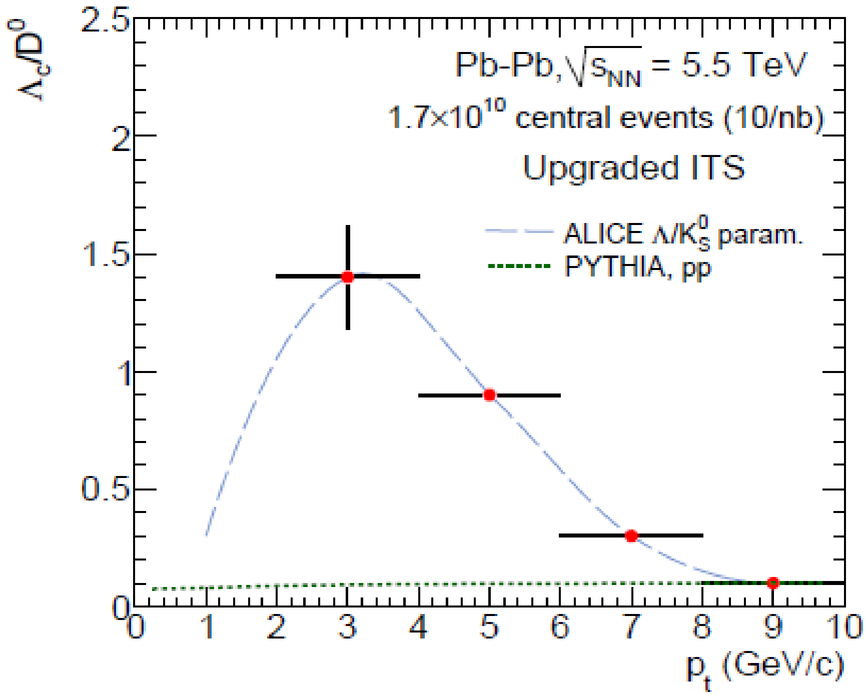


Performance for Charm Meson and Baryons

Charm baryon measurement

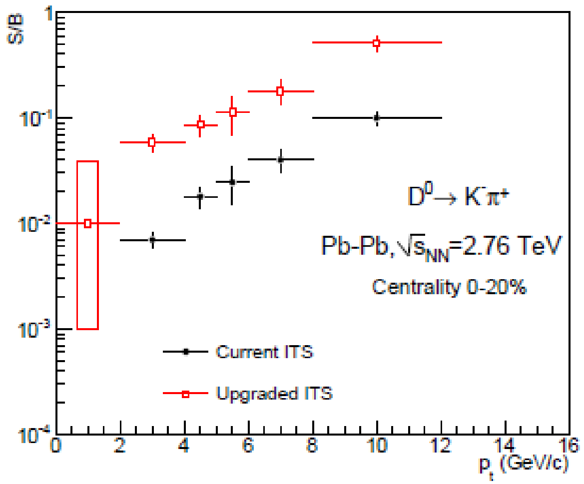


Charm baryon/meson enhancement

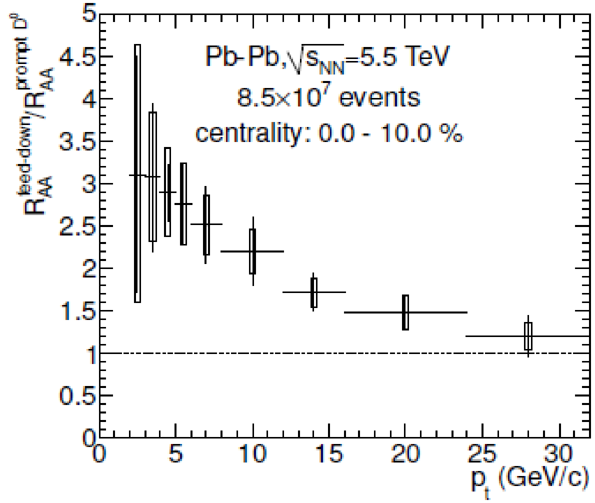


- **Charm meson (e.g. $D^0 \to K^- \pi^+$) and baryon ($\Lambda_c \to pK^- \pi^+$) results shown.**
- **Beauty meson and baryon studies ongoing.**

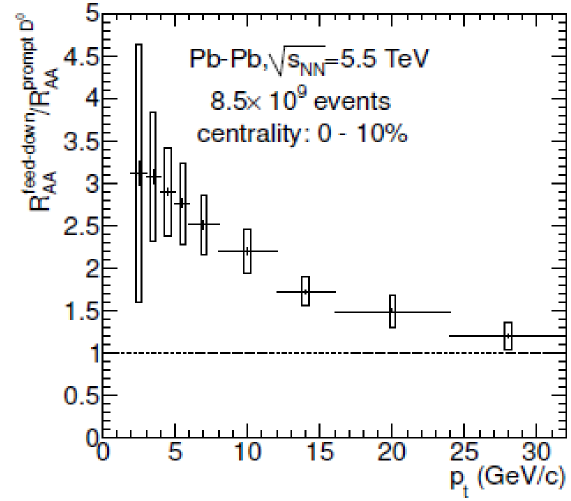
R_{AA} and v_2 of Prompt and Displaced D Mesons

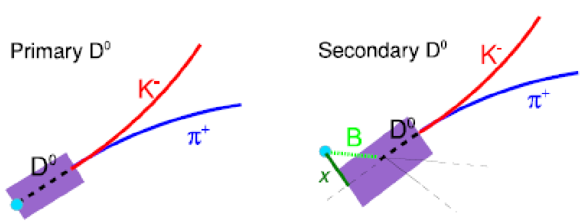


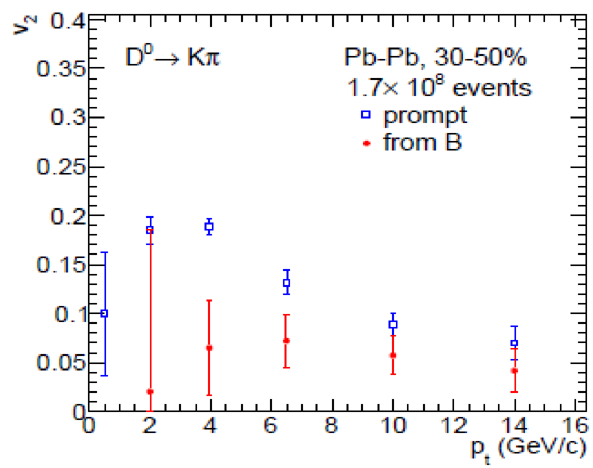
L_{int} = 0.1 nb^{-1}

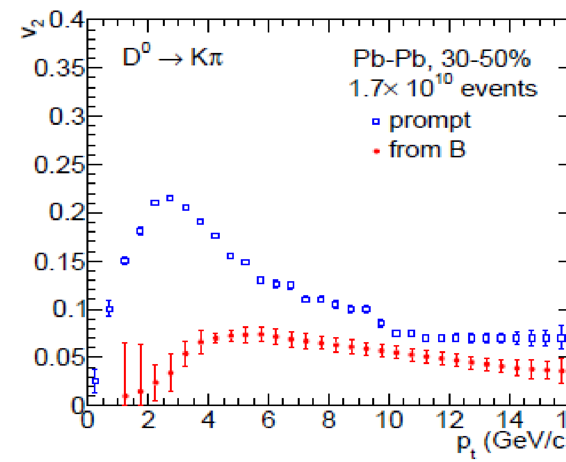


L_{int} = 10 nb^{-1}







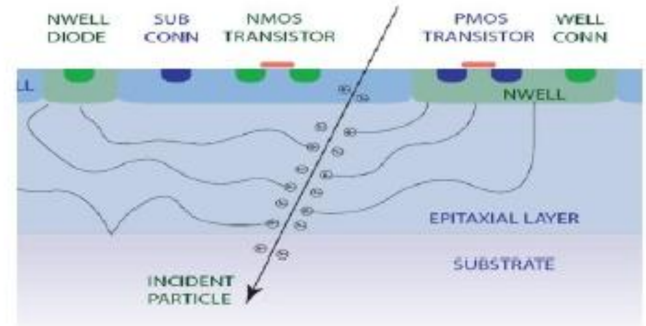


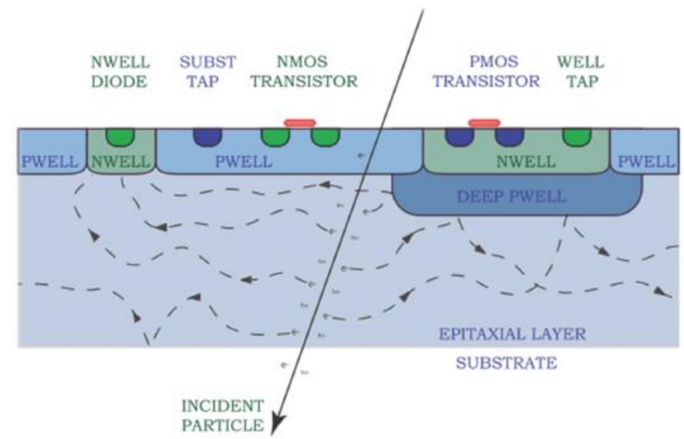
Access to B meson via
$B \to D^0 (\to K^-\pi^+)$

Monolithic Active Pixel Detectors (MAPS)

MAPS features:
- all-in-one: detector-connection-readout
- sensing layer included in CMOS chip
- small pixel size: 20 μm x 20 μm
- small material budget: 50 μm or less

Development for monolithic detectors using Tower/Jazz 0.18 μm CMOS technology:
- improved TID resistance due to smaller technology node
- available with high resistivity (~ 1kΩcm) epitaxial layer up to 18 μm
- special quadruple-well available to shield PMOS transistors (allows in-pixel truly CMOS circuitry)
- study radiation hardness and SEU
- study charge collection performance
- use existing structures/sensors (STFC Rutherford/Daresbury)
- design new prototype chips in Tower/Jazz 0.18 μm (IPHC, CERN, STFC Rutherford/Daresbury)



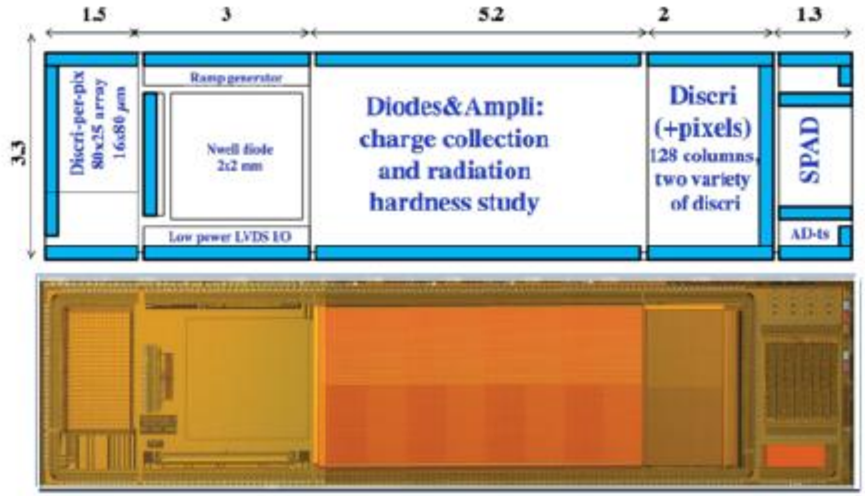


M. Stanitzki et al., Nucl. Instr. Meth. A 650 (2011) 178.

Monolithic Pixels – Evaluation of Tower/Jazz Technology (1)

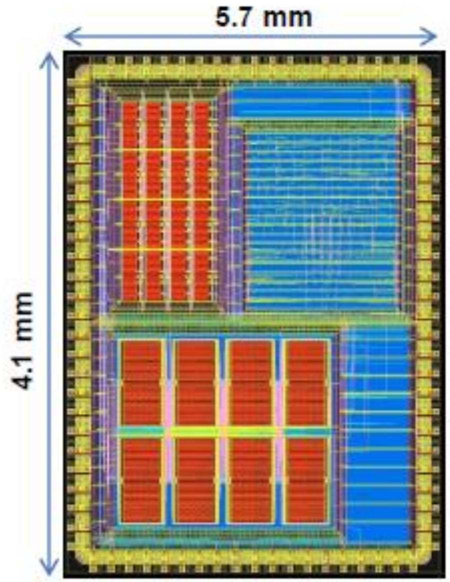
MIMOSA 32 (IPHC)

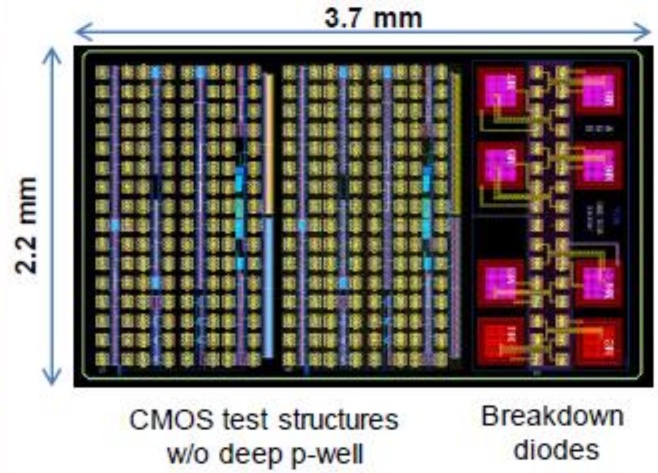
- Digital and analog blocks
- Analog blocks (2T and 3T structures with various diodes)
- Source tests and testbeam
- 100 circuits delivered January 2012



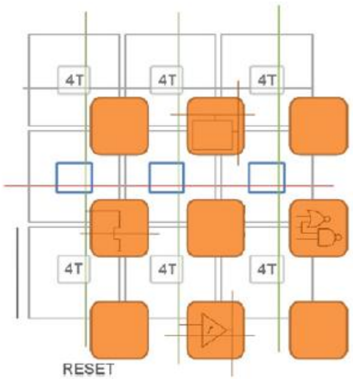
MONALICET1 (CERN/CCNU)

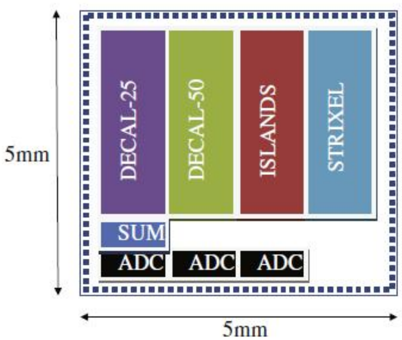
- Single transistors
- Breakdown structures
- Memories
- Digital structures
- Shift register

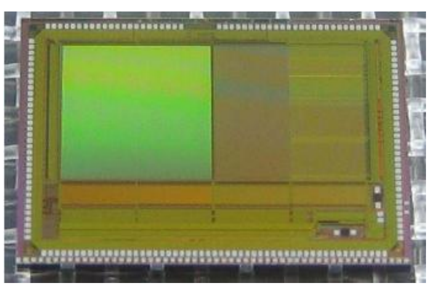




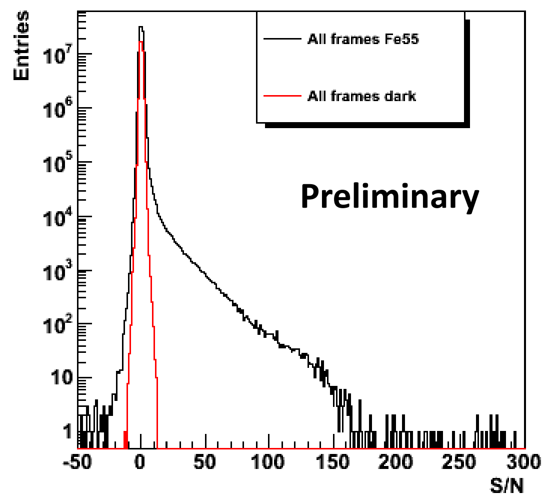
Monolithic Pixels – Evaluation of Tower/Jazz Technology (2)





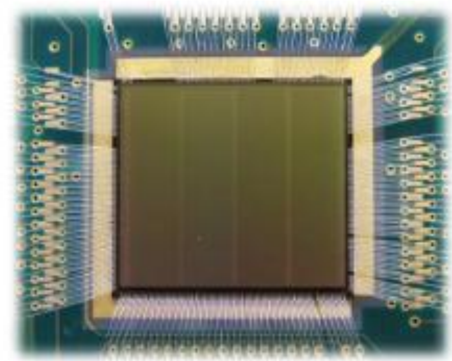


^{55}Fe source measurement

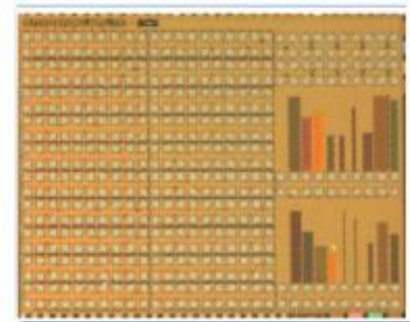


CHERWELL (STFC Rutherford/Daresbury)

- low power, low noise, no inactive area
- rolling shutter architecture, CDS and 4T front end
- 48 columns, 96 pixels per column
- 25 x 25 μm or 50 x 50 μm pixels
- embedded electronic "islands"
- 10-bit ADC either at end of column or in-pixel
- Test beam CERN SPS – November 2012



TPAC prototype
50 μm pixel - over 150 CMOS transistors

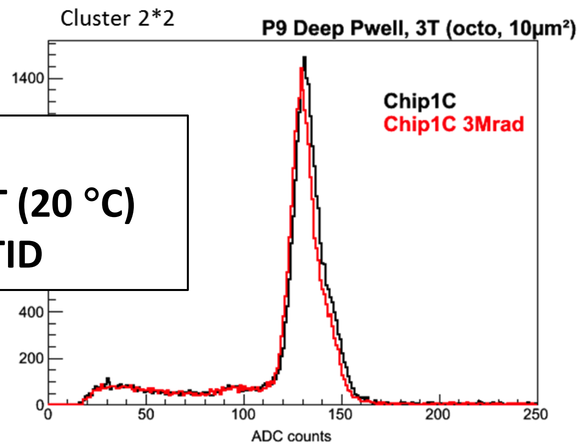


RAL Irradiation test structrues
(Single transistors w/o deep p-well)

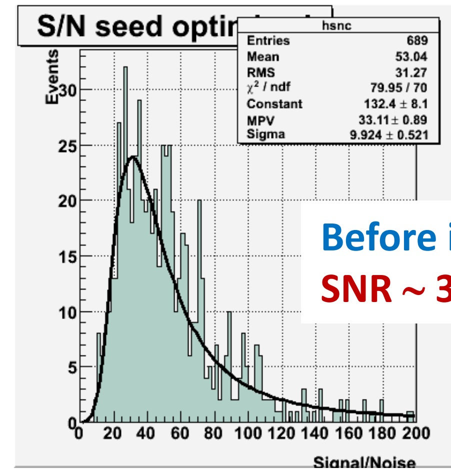
UK Arachnid Collaboration
https://heplnm061.pp.rl.ac.uk/display/arachnid/Home

MIMOSA32 (IPHC) – Characterization at Test Beam

- ^{55}Fe source measurement
- pixel noise ~15-20 e^- at RT (20 °C)
- unchanged after 3 Mrad TID



TID (10 keV X-Rays) ~ 3Mrad

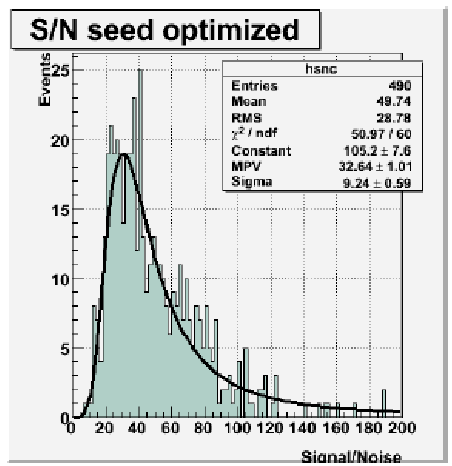


Before irradiation

SNR ~ 33.1 ± 0.9

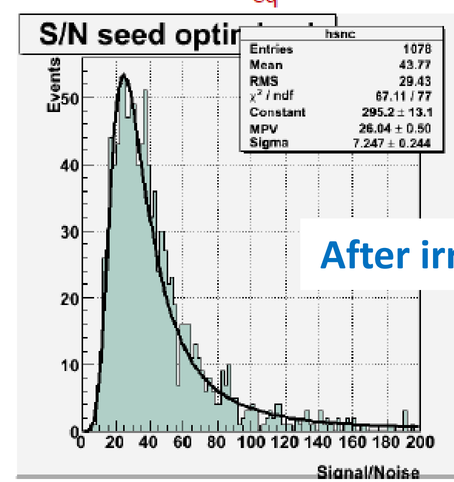
10^{13} n_{eq}/cm^2

Parasitic running on CERN T2-H4 with ~ 60 GeV/c π^- beam



Signal-to-Noise measured with P9 (deep P-well) at T = 15 °C

SNR ~ 32.6 ± 1.0



After irradiation

Signal-to-Noise measured with P9 (deep P-well) at T = 30 °C

SNR ~ 26.0 ± 0.5

Preliminary

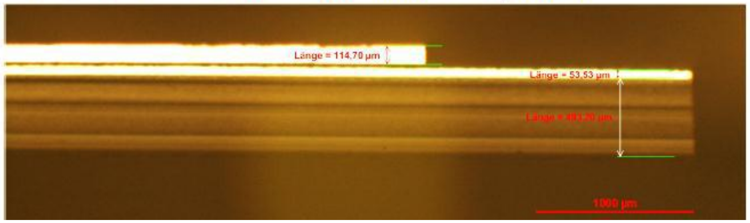
- M. Winter et al., IPHC

Hybrid Pixel and Strip Detector Technologies

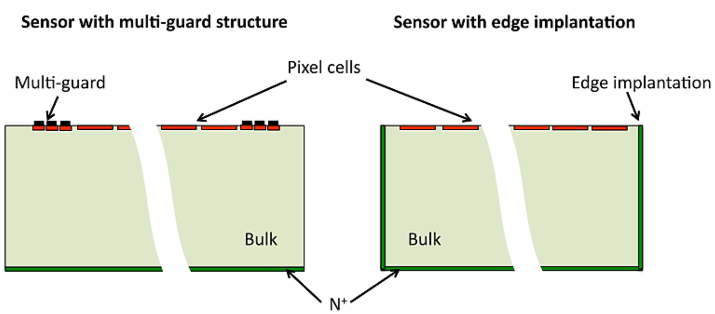
Hybrid Pixels:

- assembly of ultra-thin components
  - 100 µm sensor, 50 µm chip, ~ 0.5% X/X_0

view on module side before carrier chip release:



  - finer pitch bump bonding (30-50 µm)
  - edgeless detectors (inactive region 10-100 µm)
    - reduce inactive region from 600 to 10-100
    - introduce a highly n-doped trench

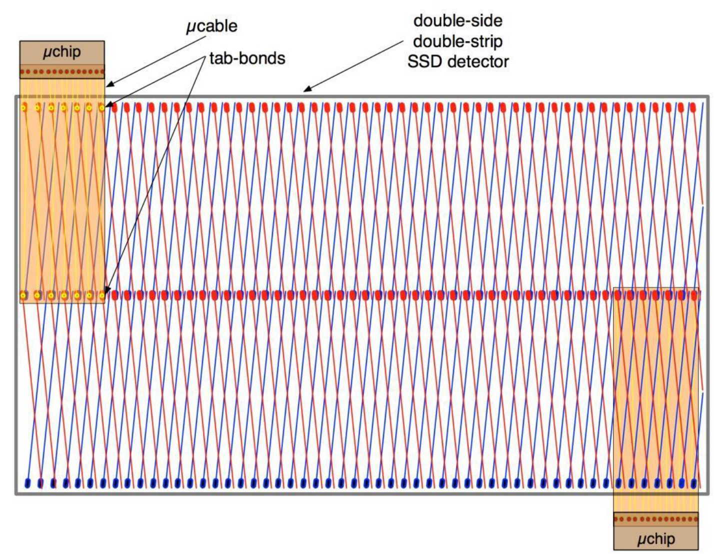


- FEE chip floor plan optimization
  - power/speed optimization

Strip Detectors:

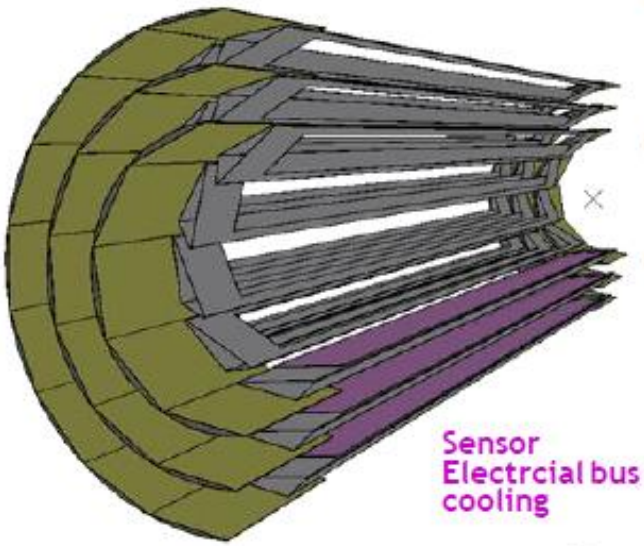
Based on present SSD with shorter strips:

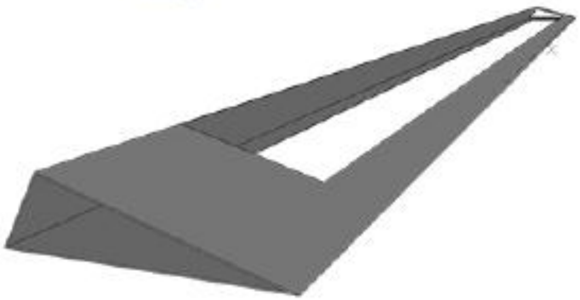
- 300 µm double-sided sensor (7.5 x 4.2 cm)
- 35 mrad stereo-angle between p- and n-side strips
- half cell-size: ~ 95 µm x 20 mm
- higher granularity
- > 95% ghost hit rejection efficiency
- lower strip C: higher S/N

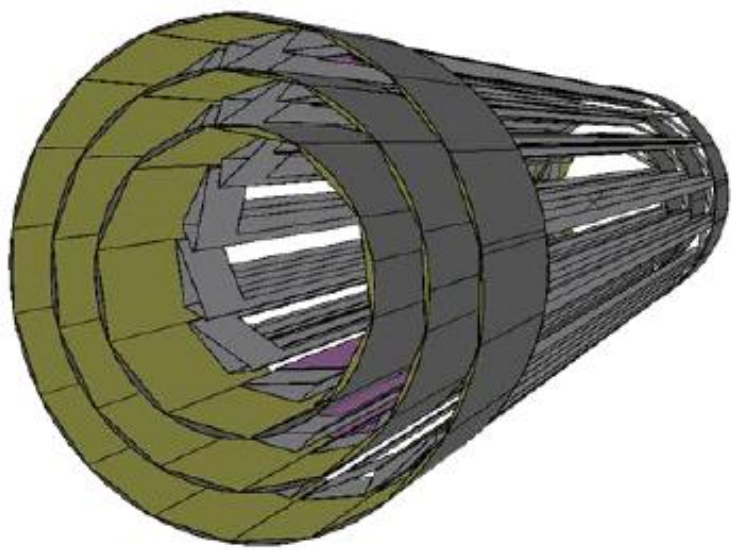


Mechanical Structure - U-light Shell Concept

- Structure based on CFRP with possibility to integrate different cooling concepts (silicon micro-channels, polymide channels)
- Light structure with openings along the sensitive region
- Modularity from stave level can be reduced to half barrel with gain in stiffness and reduction in material

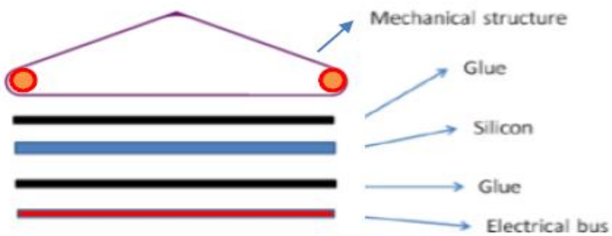




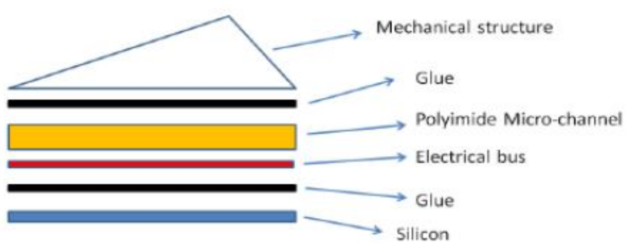


Prototype under construction

R&D on Mechanical Structure



Have shown $X/X_0 \leq 0.30\%$ is achievable



Ladder prototype equipped with dummy components

Conceptual Design Report of ITS Upgrade

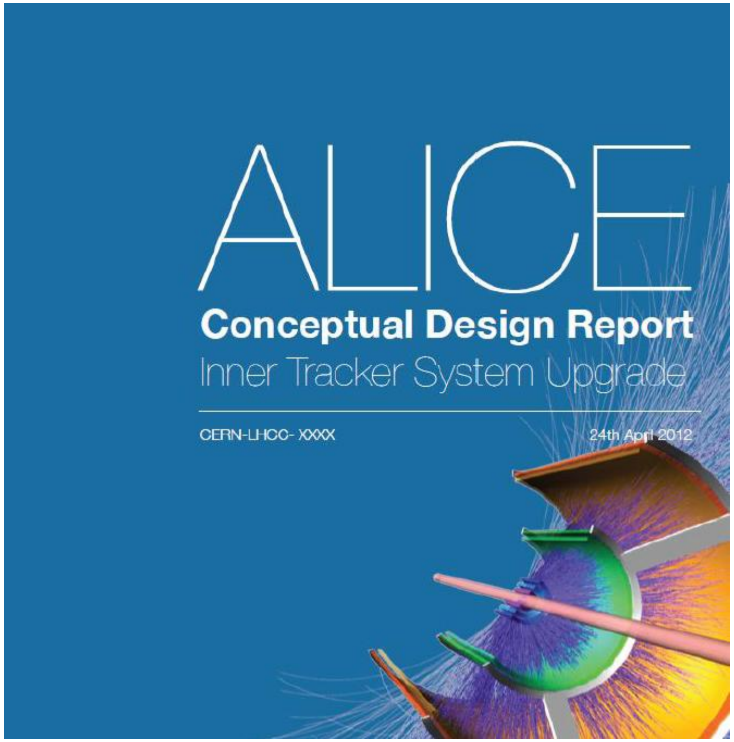
- Full details available in Conceptual Design Report CERN-LHCC-2012-05

- CDR Version 1 published March 2012

- Progress Report June 2012

- Presented to LHCC in March and June 2012 sessions

- Version 2 of CDR with all updates asked for by LHCC will be published in September 2012



Summary

- As part of the ALICE Upgrade, it is proposed to build a new ITS based on 7 silicon layers characterized by:
  - ❑ continuous readout
  - ❑ factor ~3 improvement in impact parameter resolution
  - ❑ very high standalone tracking efficiency down to low pt (> 95% for p_T > 200 MeV/c
  - ❑ fast access (winter shutdown) for maintenance interventions

- Precision measurement of heavy flavour probes to low p_T, etc.

- Aim for installation in ALICE during LHC LS2 in 2018.

- At present in extensive R&D phase. Have shown two highlights:
  - ❑ evaluation of 0.18μm CMOS technology for MAPS sensors.
    - no significant degradation when irradiated at 3 Mrad, 3×10^{13} n_{eq}
  - ❑ mechanical support structure prototypes.
    - several ultra-light mechanical support structure prototypes of first three inner layers have been realized and show $X/X_0 \leq 0.3\%$ is achievable

Backup Slides

Overall ALICE Upgrade Strategy

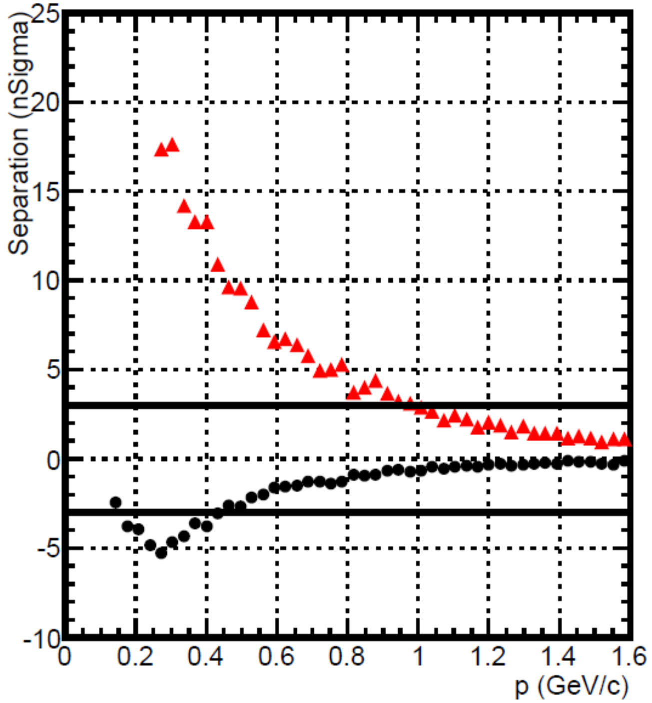
ALICE

ALICE Upgrade described in talk of Thomas Peitzmann:

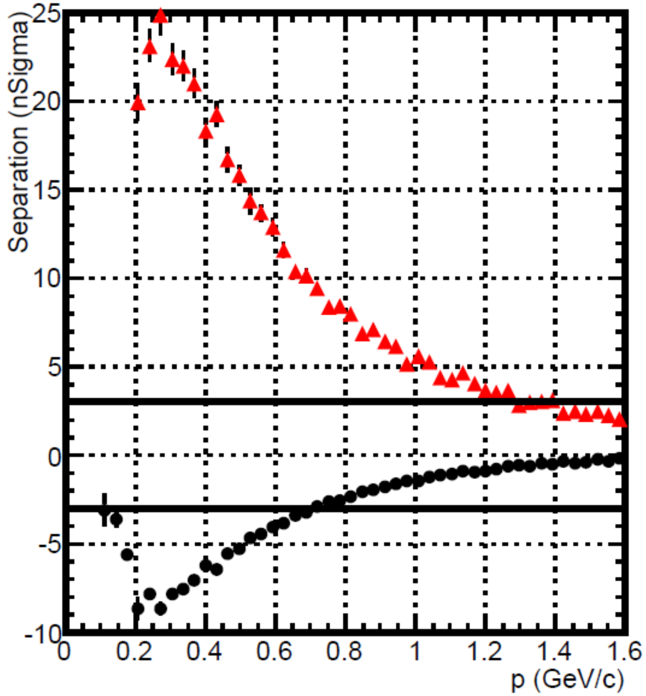
- **inspection of 50 kHz of minimum bias Pb-Pb collisions**
- **factor 100 increase in statistics (for untriggered probes)**
- **collect > 10 nb^{-1} of integrated luminosity**
- **ITS Upgrade fits within this strategy:**
- **50 kHz Pb-Pb collisions inspected with the least possible bias with online event selection based on topological and PID criteria**
- **topological trigger from upgraded ITS**
- **Two High Level Trigger scenarios for the upgrade**
    - **partial event reconstruction: factor of 5 (in use) → rate to tape: 5 kHz**
    - **full event reconstruction: overall data reduction by a factor of 25 → rate to tape: 25 kHz**
    - **min. Bias event size ~ 20MB → ~ 1-4 MB after data reduction**
    - **throughput to mass storage: 20 GB/s**
- **Event rate reduction from 50 kHz to 5kHz (25 kHz) can only be reached with online event reconstruction and selection**

PID Performance of ITS Upgrade Options

7 layers of MAPS (15 µm)

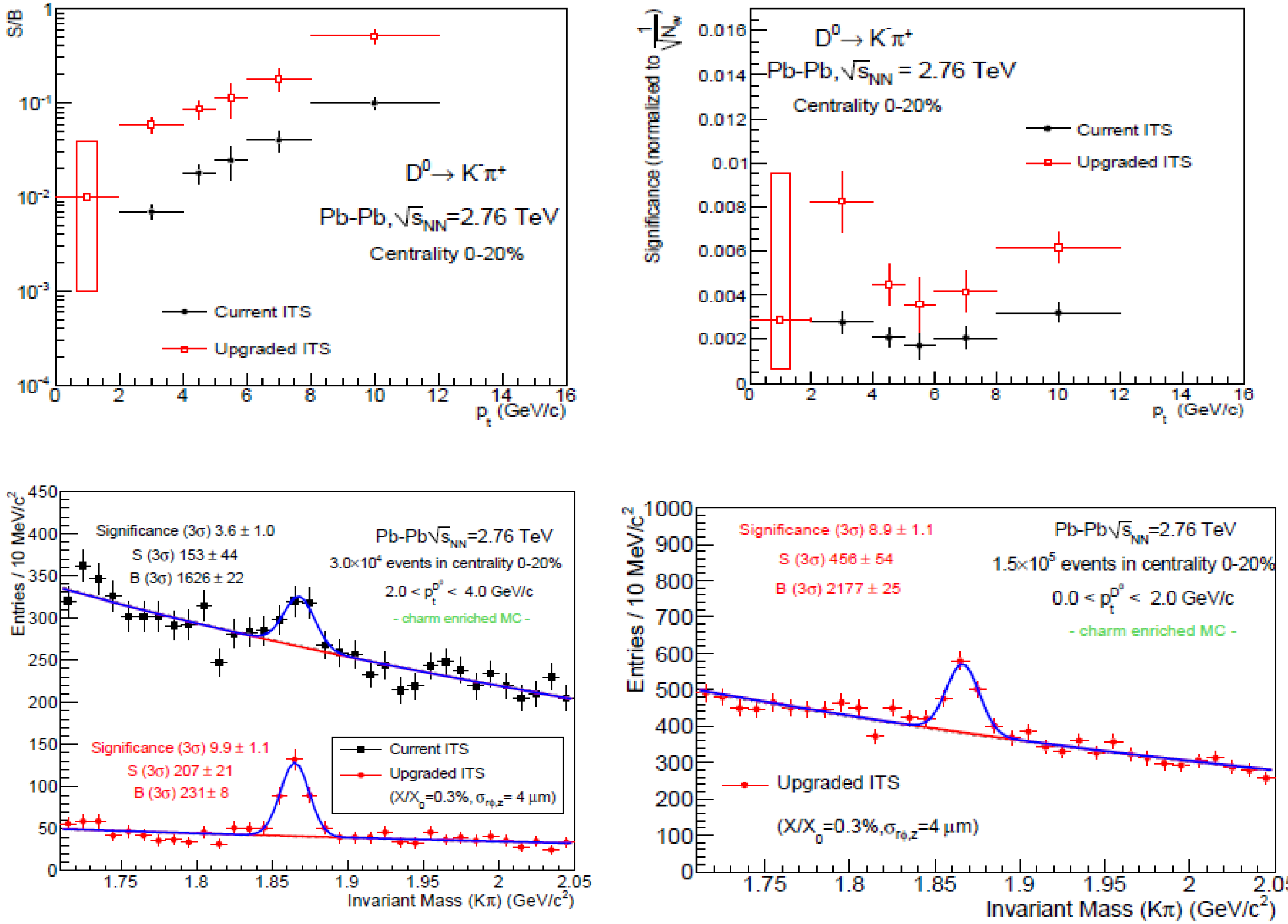


4 layers of hybrid (100 µm)
+ 3 layers of strip (300 µm)

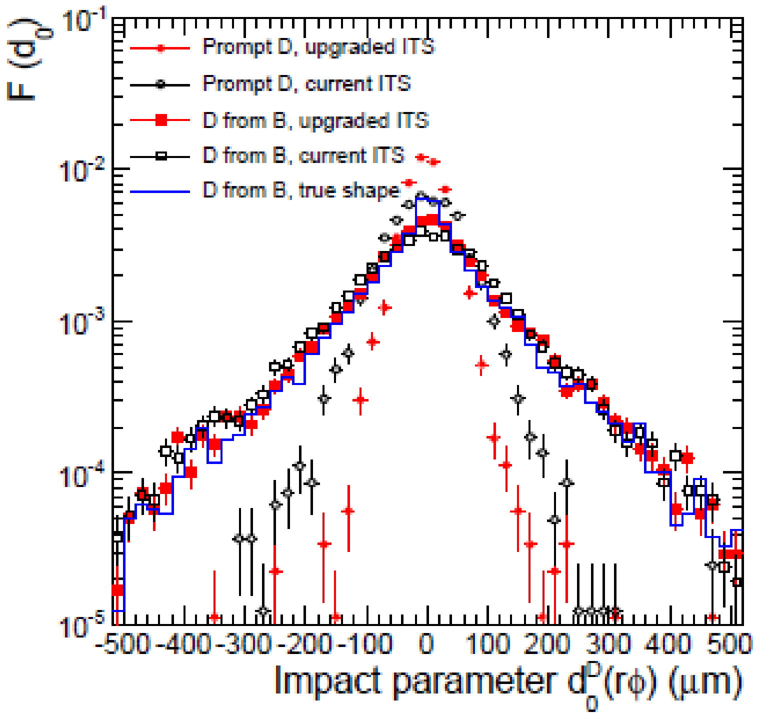


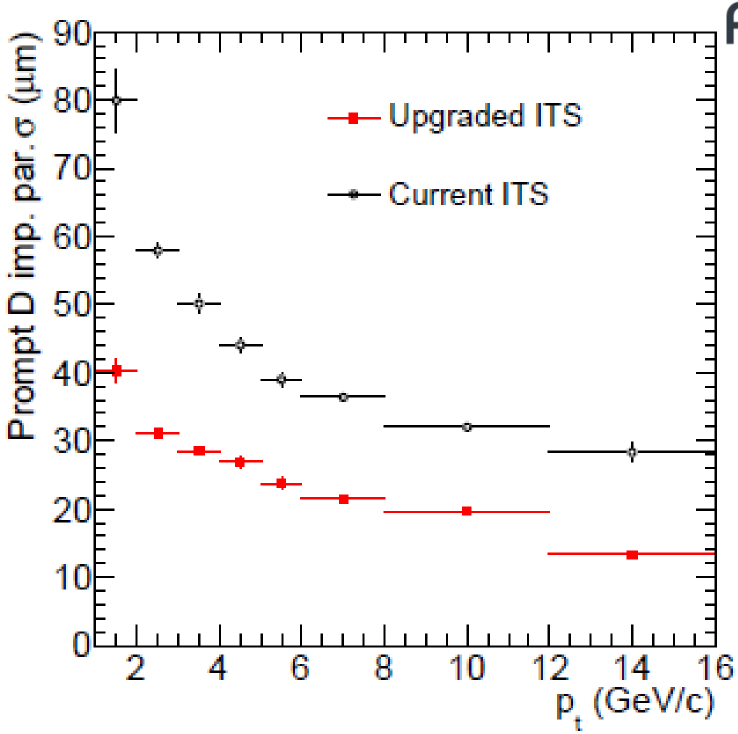
- ● **Pion to kaon separation (units of sigma)**
- ▲ **Proton to kaon separation (units of sigma)**
- — **3 sigma separation**

Performance for $D^0 \rightarrow K^-\pi^+$ for Pb-Pb collisions

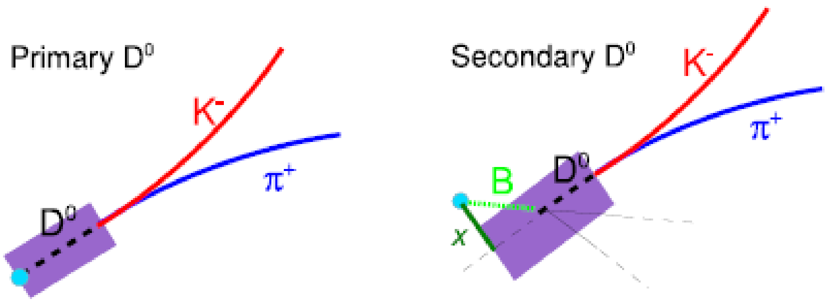


B meson Production via Displaced D^0

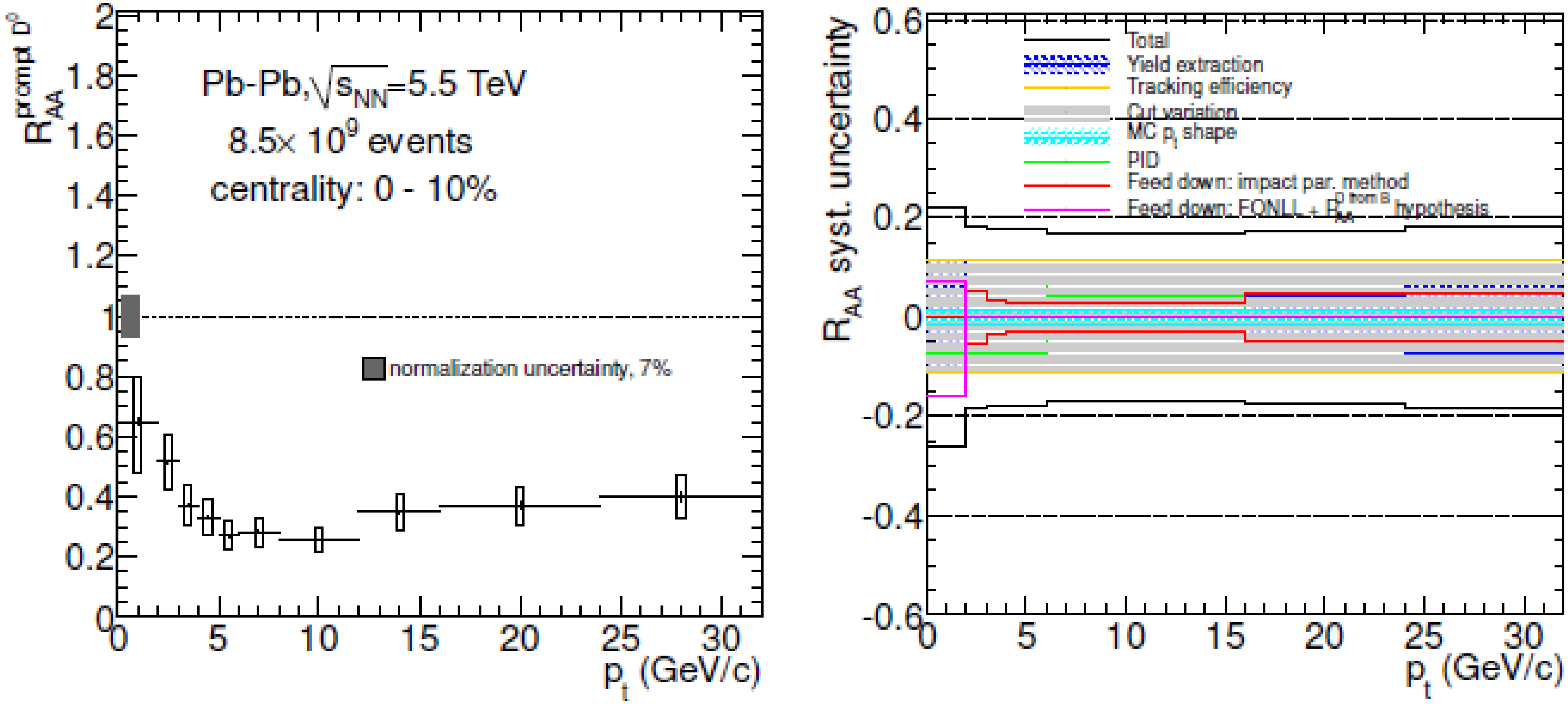




Access to B meson via
$B \rightarrow D^0 (\rightarrow K^-\pi^+)$

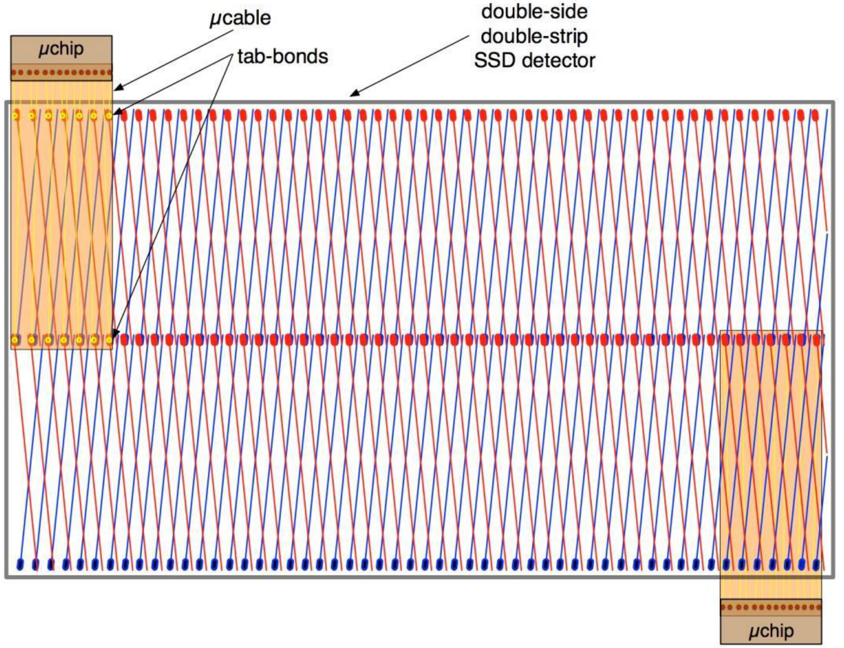


R_{AA} of prompt D^0 Mesons in Central Pb-Pb for $L_{int} = 10nb^{-1}$



Strip Detector Technologies

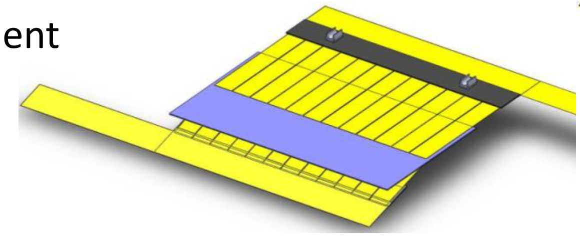
- Based on present SSD with shorter strips:
    - 300 µm double-sided sensor (7.5cm x 4.2 cm)
    - 35 mrad stereo-angle between p- and n-side strips
    - reduced strip length down to 20 mm

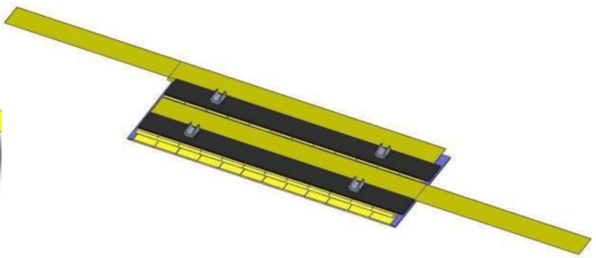


- New design advantages
    - half cell-size: ~ 95 µm x 20 mm
    - higher granularity
    - > 95% ghost hit rejection efficiency
    - lower strip C: higher S/N

- Drawbacks:
    - double number of interconnections
    - bonding at very low pitch
    - Increased power consumption

- R&D activities:
    - small pitch micro-cable development
    - assembly procedure validation

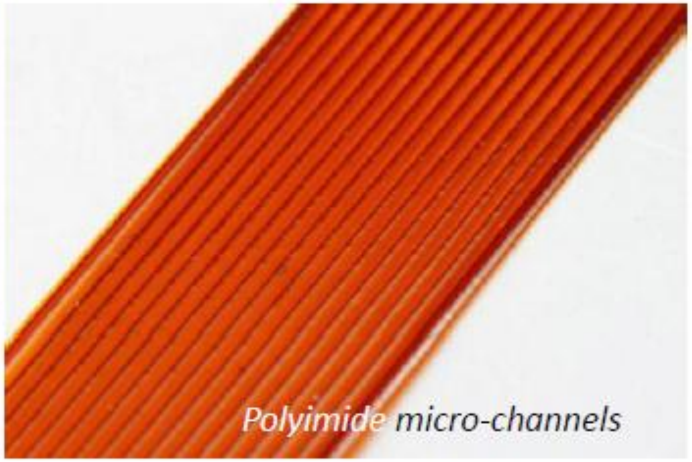




R&D on Mechanical Structure

The Stave Prototypes developed for ITS Layer1,2,3 can be divided in two groups that refer to two of the different cooling concepts under study

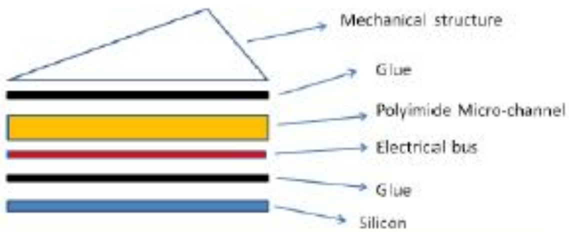
"cold plate"



“cooling pipes"

15

Example: Cold Plate Prototype



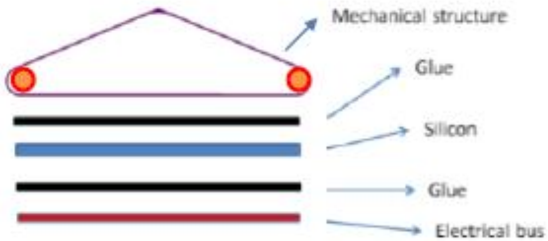
R&D on mechanical structure

Ladder prototype equipped with dummy components

Material	Surface (%)	Tickness (μm)	X_0 (%)	X/X_0 (%)	Contribution to the total X/X_0 (%)
CFRP	22	120	25	0.011	3.5
CFRP	43	240	25	0.043	13.7
Glue (CFRP - microchannel plate)	20	100	44.4	0.005	1.5
Polyimide microchannels walls	21	200	28.6	0.015	4.9
Polyimide microchannels covers	100	100	28.6	0.035	11.6
Water	79	200	36.1	0.044	14.5
Electrical bus	100			0.075	25.0
Glue (bus - silicon)	100	100	44.4	0.022	7.5
Silicon	100	50	9.36	0.054	17.8
Total				$\approx$ 0.30	100

19

Example: Cooling Pipes Prototype



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 (%)
CFRP filament	53	190	25	0.04	15.4
Plyimide 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				**$\approx$ 0.26**	**100**

Project Timeline

ALICE

2012 – 2014	**R&D**
○ **2012**	**finalization of detector specifications** **evaluation of detector technologies (radiation and beam tests** **→ first prototypes of sensors, ASICs and ladders (demonstrators)**
○ **2013**	**selection of technologies and full validation** **engineered prototypes (sensors, ASICs, ladders, data links)** **engineered design for support mechanics and services** **→ Technical Design Report**
○ **2014**	**final design and validation** **start procurement of components**
2015-16	**production, construction and test of detector modules**
2017	**→ assembly and pre-commissioning in clean room**
2018	**→ installation in ALICE**