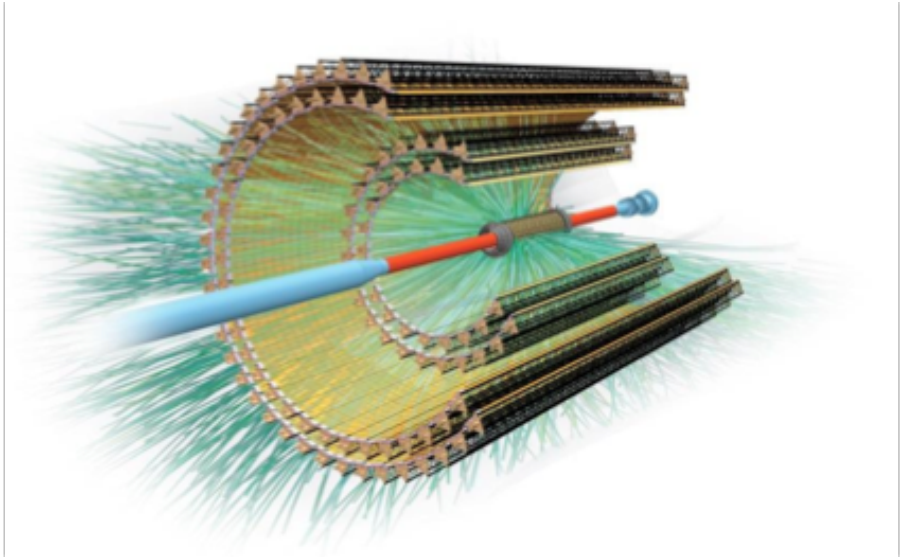
A Large Ion Collider Experiment



Upgrade of the ALICE Inner Tracking System

OUTLINE

- ALICE Upgrade strategy and the ITS project
- Detector and physics performance à la TDR
- Pixel chip technology
- ITS Upgrade activities at Strasbourg

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ALICE UPGRADE STRATEGY

Physics program requires 10 nb^{-1} of integrated luminosity of Pb-Pb collisions wrt. the approved program of 1 nb^{-1}

Physics signals of interest are rare, mostly not triggerable

- Low p_T (below 1 GeV/c), high combinatorial background
- Increase rate capabilities for minimum bias heavy-ion collisions to 50 kHz – 100 kHz

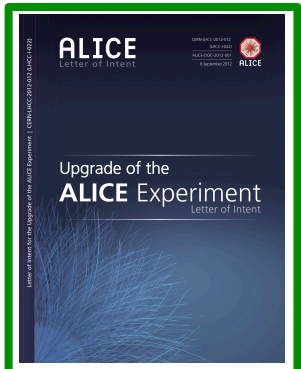
ALICE runs at high luminosity

- Factor 100 increase in statistics (for untriggered probes)
- Requires smaller beam pipe, new detectors: ITS, MFT, upgraded TPC read-out chambers and readout electronics upgrade for other detectors
- New combined online-offline framework: O^2

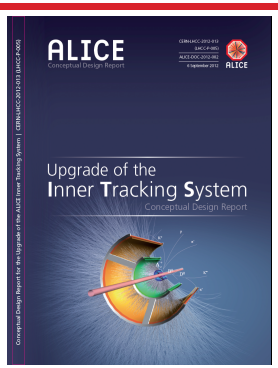
Preserve ALICE uniqueness

- Low p_T measurements and particle identification

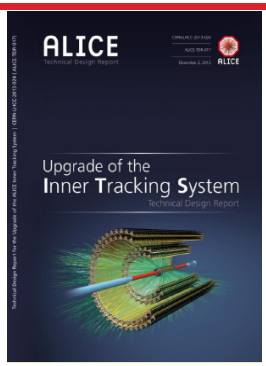
Upgrade in the 2nd LHC Long Shutdown (LS2) 2018/19



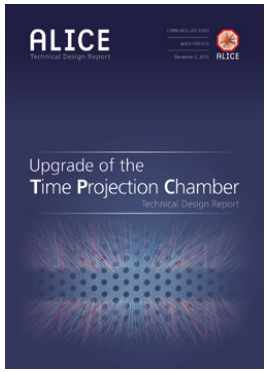
CERNLHCC-2012-012, LHCC-I-022, 2012.



CERN-LHCC-2012-005, LHCC-G-159, 2012.



CERN-LHCC-2013-024 ; ALICE-TDR-017



CERN-LHCC-2013-020 ; ALICE-TDR-016

CERN-LHCC-2013-019 ; ALICE-TDR-015

CERN-LHCC-2013-014 ; LHCC-I-022-ADD-1

Full list and details of upgrade strategy: ALICE LoI, CERN-LHCC-2012-012

MOTIVATION FOR A NEW INNER TRACKING SYSTEM

- Improve impact parameter resolution by factor ≈ 3(5) in r-φ(z)
  - move closer to IP (position of first layer): 39 mm → 22 mm
  - reduce material budget X/X_0 / layer: from ~1.14% …
    … to 0.3% (inner layers) and to 0.8 % (outer layers)
  - reduce pixel size: 50 μm × 425 μm→O(30 μm × 30 μm)
- Improve tracking efficiency and p_T resolution at low p_T
  - increase granularity: 6 layers → 7 layers
- Fast readout (now limited at 1 kHz with full ITS):
  - Pb-Pb: up to 100 kHz
  - pp: several 100 kHz
- Fast insertion/removal
  - possibility to access for yearly maintenance

The new ALICE ITS will fully replace the present ITS !

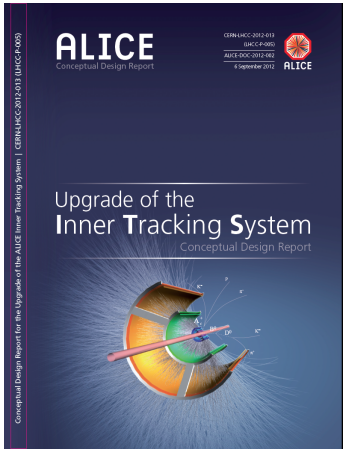
THE ITS UPGRADE PROJECT MILESTONES

- Project approved by LHCC in Sept. 2012
- Technical Design Report approved by LHCC in Dec 2013
- Budget approved by CERN Upgrade Cost Group / Research Board in March 2014

- Decision on pixel chip architecture: Q2 / 2015 (tbc)
- Enter production phase in 2016
- Installation commissioning 2018/2019

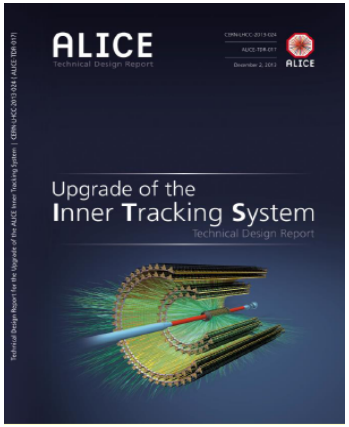
French Institutes (CNRS-IN2P3) in the project:

IPHC+Univ. (Strasbourg), LPSC+Univ. (Grenoble)



CDR

CERN-LHCC-2012-005,
LHCC-G-159, 2012.



TDR

J.Phys. G41
(2014) 087002

CERN-LHCC-2013-024 ;
ALICE-TDR-017

- ALICE Upgrade strategy and the ITS project
- Detector and physics performance à la TDR
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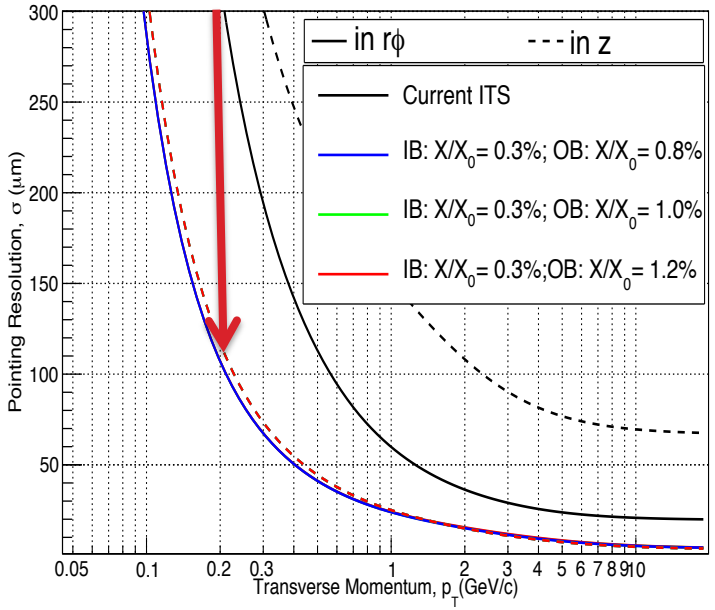
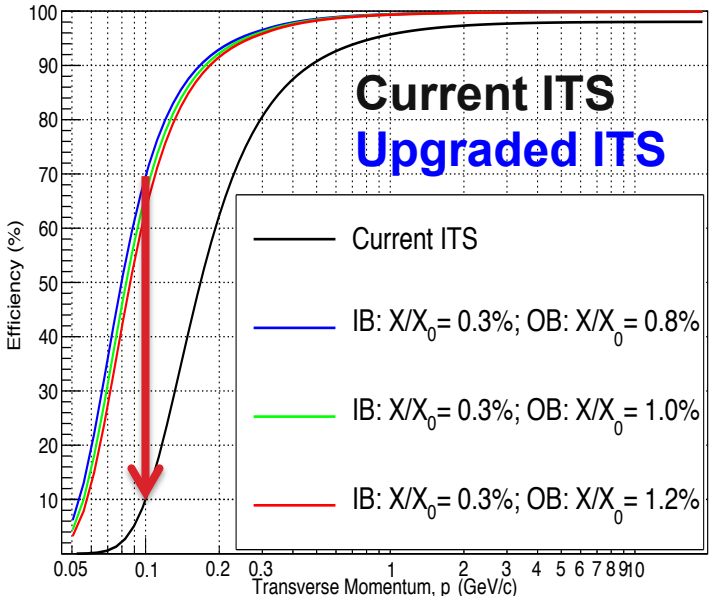
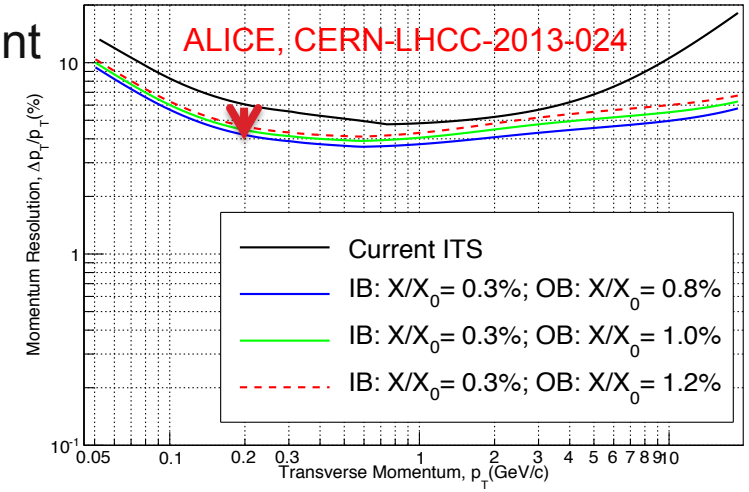
Present and upgraded ITS performance





- Standalone track resolution improvement factor ~3 in rφ and ~ 5 in z
- Standalone tracking efficiency ~ 70 % at p = 100 MeV/c
- Improvement in momentum resolution for standalone tracking



SUMMARY OF ITS UPGRADE PHYSICS REACH (TDR)

Observable	Current, 0.1 nb^{-1}		Upgrade, 10 nb^{-1}	
	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty	$p_{\mathrm{T}}^{\mathrm{min}}$ (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
$\mathrm{D_s}$ meson R_{AA}	4	15 %	< 2	3 %
D meson from B R_{AA}	3	30 %	2	1 %
J/ψ from B R_{AA}	1.5	15 % (p_{T}-int.)	1	5 %
$\mathrm{B^+}$ yield	not accessible		3	10 %
Λ_{c} R_{AA}	not accessible		2	15 %
$\Lambda_{\mathrm{c}}/\mathrm{D^0}$ ratio	not accessible		2	15 %
Λ_{b} yield	not accessible		7	20 %
D meson v_2 ($v_2 = 0.2$)	1	10 %	0	0.2 %
$\mathrm{D_s}$ meson v_2 ($v_2 = 0.2$)	not accessible		< 2	8 %
D from B v_2 ($v_2 = 0.05$)	not accessible		2	8 %
J/ψ from B v_2 ($v_2 = 0.05$)	not accessible		1	60 %
Λ_{c} v_2 ($v_2 = 0.15$)	not accessible		3	20 %
Dielectrons				
Temperature (intermediate mass)	not accessible			10 %
Elliptic flow ($v_2 = 0.1$) [4]	not accessible			10 %
Low-mass spectral function [4]	not accessible		0.3	20 %
Hypernuclei				
$^3_{\Lambda}\mathrm{H}$ yield	2	18 %	2	1.7 %

Pb–Pb collisions for an integrated luminosity of 10 nb^{-1}

Improving precision

Access to new observables

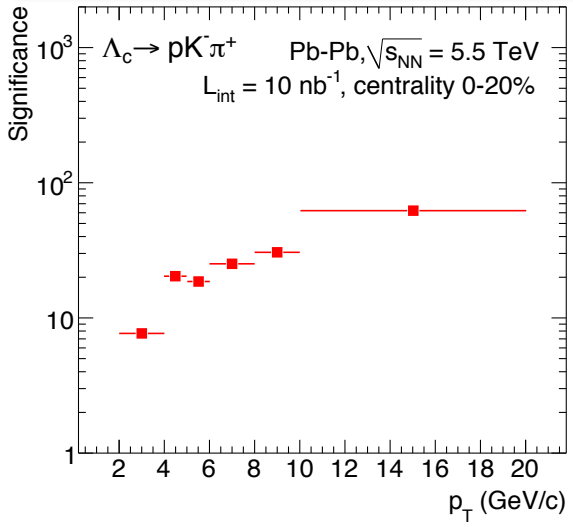
ALICE, CERN-LHCC-2013-024

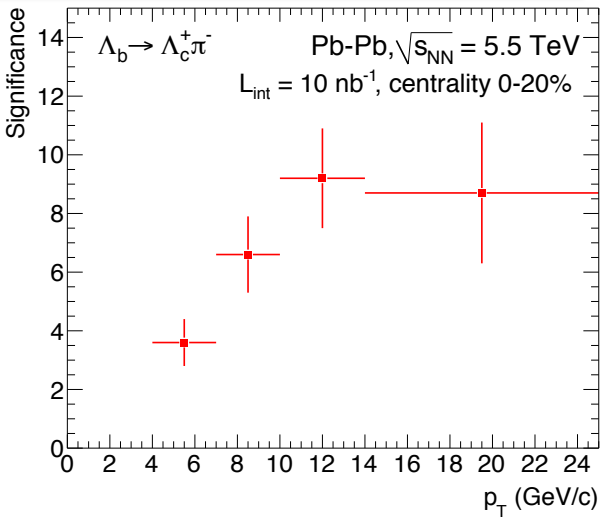
PHYSICS PERFORMANCE, PARTICLE PRODUCTION

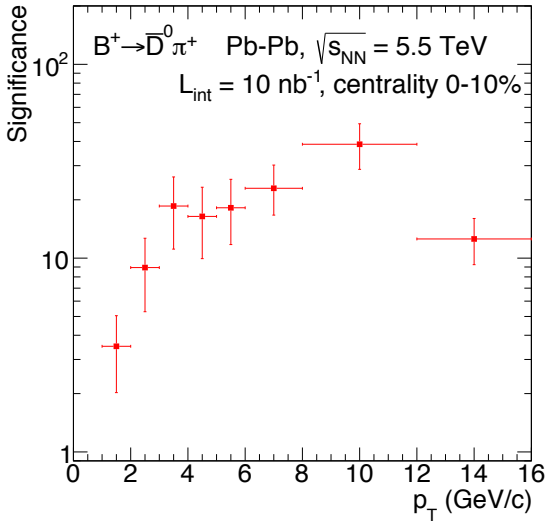
Part.	Yield m.b., 0–10 %	$\mathrm{d}N/\mathrm{d}y\|_{y=0}$ m.b., 0–10 %	$c\tau$ (μm)	decay channel	B.R.
D^0	23, 110	2.3, 11	≈ 120	$\mathrm{K}^-\pi^+$	3.8 %
D^{*+}	9, 44	0.9, 4.4	≈ 0	$\mathrm{D}^0\pi^+$	67.7 %
D_s^+	4.3, 20	0.4, 2.0	≈ 150	$\phi(\to \mathrm{K}^+\mathrm{K}^-)\pi^+$	4.4 %(×49 %)
Λ_c^+	2.9, 14	0.29, 1.4	≈ 60	$\mathrm{pK}^-\pi^+$	5.0 %
				$\mathrm{p}\overline{\mathrm{K}}^0(\mathrm{K}_\mathrm{S}^0 \to \pi^+\pi^-)$	1.15 %(×69.2 %)
				$\Lambda\pi^+(\to \mathrm{p}\pi^-)$	1.1 %(×63.9 %)
B	1.3, 6.2	0.2, 0.9	≈ 500	$\mathrm{J}/\psi(\to \mathrm{e}^+\mathrm{e}^-) + X$	1.2 %(×6 %)
				$\mathrm{D}^0(\to \mathrm{K}^-\pi^+) + X$	60 %(×3.8 %)
				$\mathrm{e}^+ + X$	10.9 %
B^+	0.6, 2.7	0.1, 0.4	≈ 500	$\overline{\mathrm{D}}^0(\to \mathrm{K}^+\pi^-)\pi^+$	0.5 %(×3.8 %)
B^0	0.6, 2.7	0.1, 0.4	≈ 500	$\mathrm{D}^{*-}(\to \mathrm{K}^+\pi^-\pi^-)\pi^+$	0.3 %(×2.6 %)
Λ_b^0	0.1, 0.5	0.015, 0.07	≈ 400	$\Lambda_\mathrm{c}^+(\to \mathrm{pK}^-\pi^+) + \mathrm{e}^- + X$	9.9 %(×5 %)
				$\Lambda_\mathrm{c}^+(\to \mathrm{pK}^-\pi^+) + \pi^-$	0.6 %(×5 %)

Newly accessible heavy baryons/mesons in Pb-Pb collisions

Pb-Pb, 5.5 TeV, Minimum-bias and 0–10 % central collisions, 10 nb^{-1}

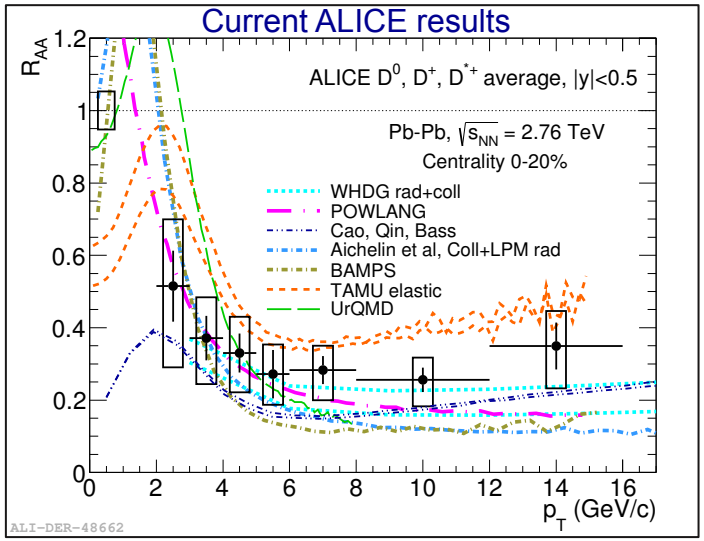






ALICE ITS TDR, CERN-LHCC-2013-024

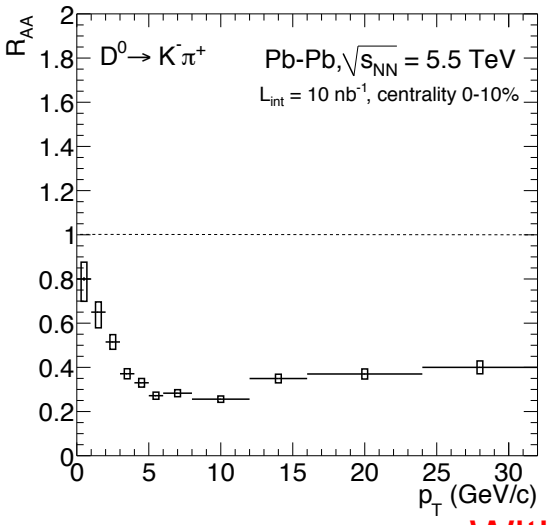
PHYSICS PERFORMANCE, ENERGY LOSS

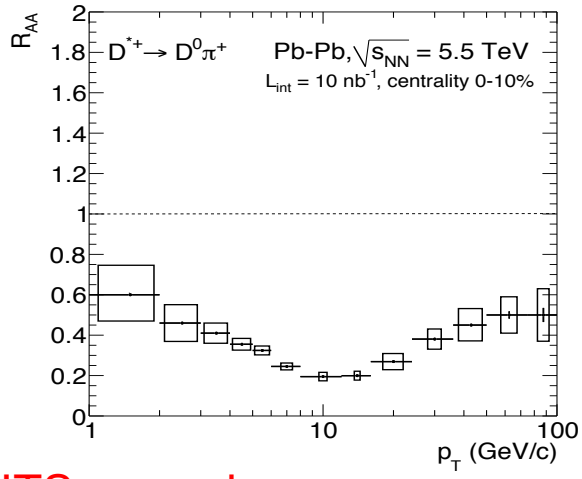


Significant reduction of uncertainties, new heavy baryons/mesons in Pb-Pb collisions

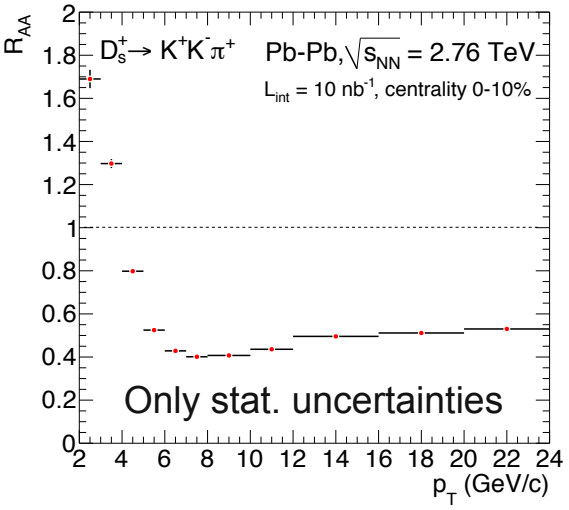
Pb-Pb, 5.5 TeV, 0–10 % central collisions, 10 nb^{-1}

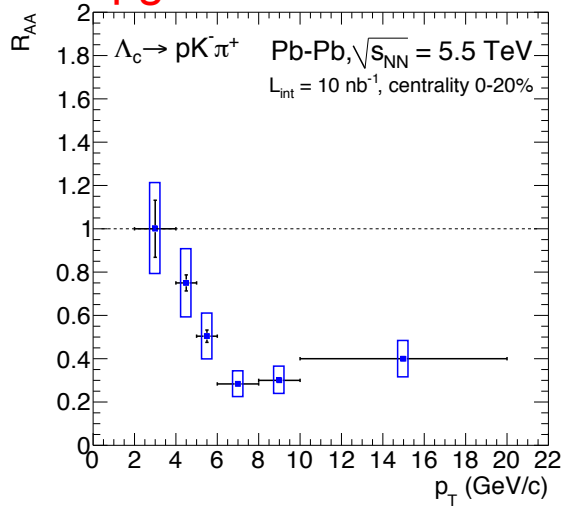
ALICE ITS TDR , CERN-LHCC-2013-024



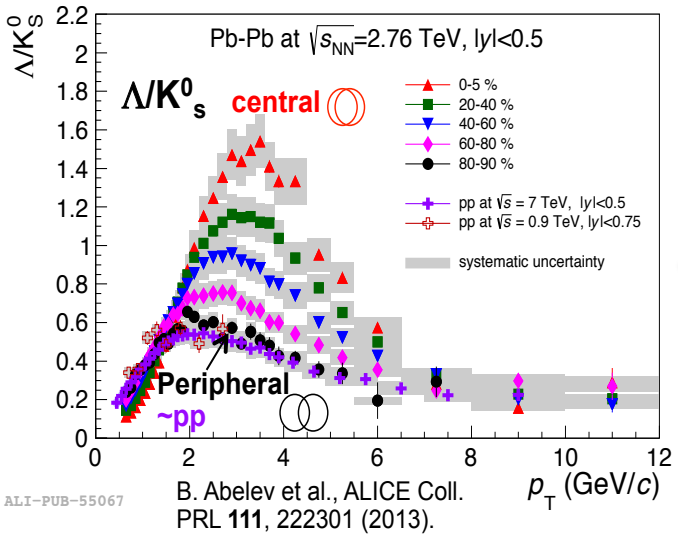


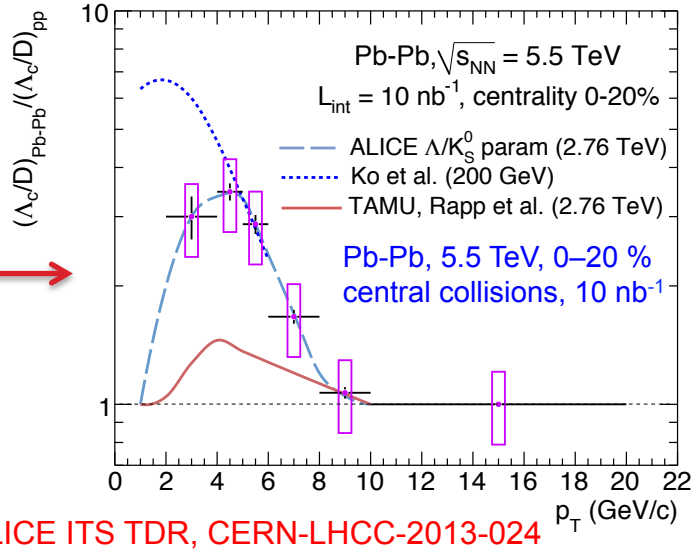
With ITS upgrade





PHYSICS PERFORMANCE, HADRONIZATION, FLOW



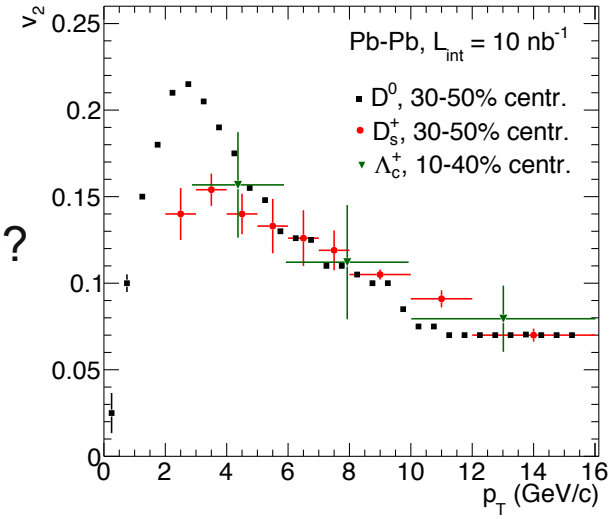


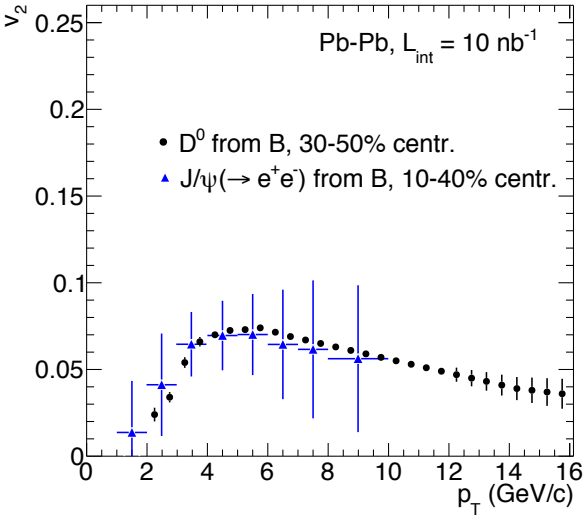
ALICE ITS TDR, CERN-LHCC-2013-024

Investigate possible baryon/meson enhancement …

- radial flow effect?
- hadronization via coalescence?

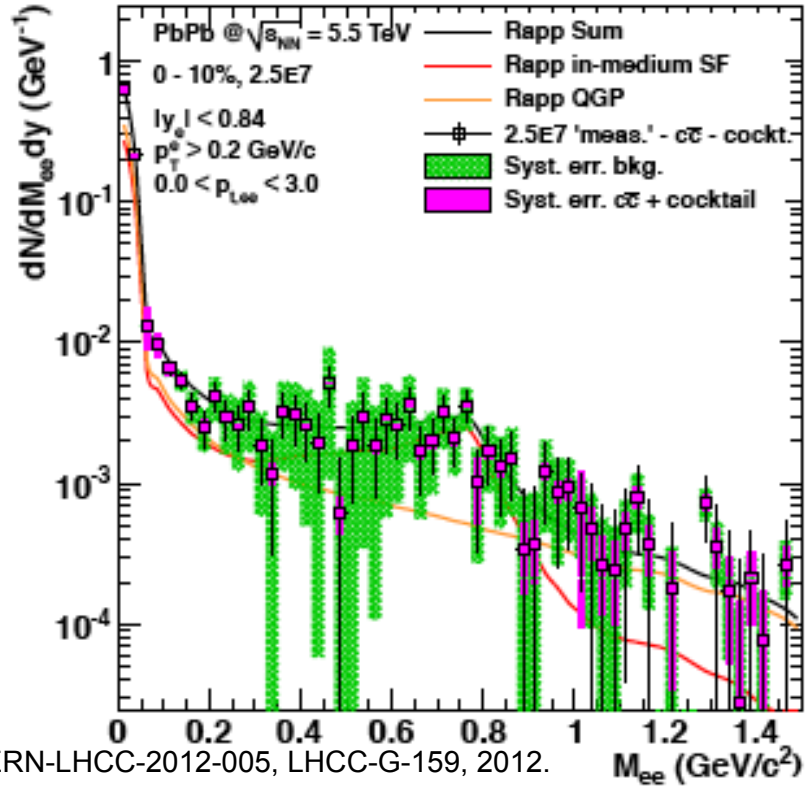
… and access to flow of charmed / beauty hadrons



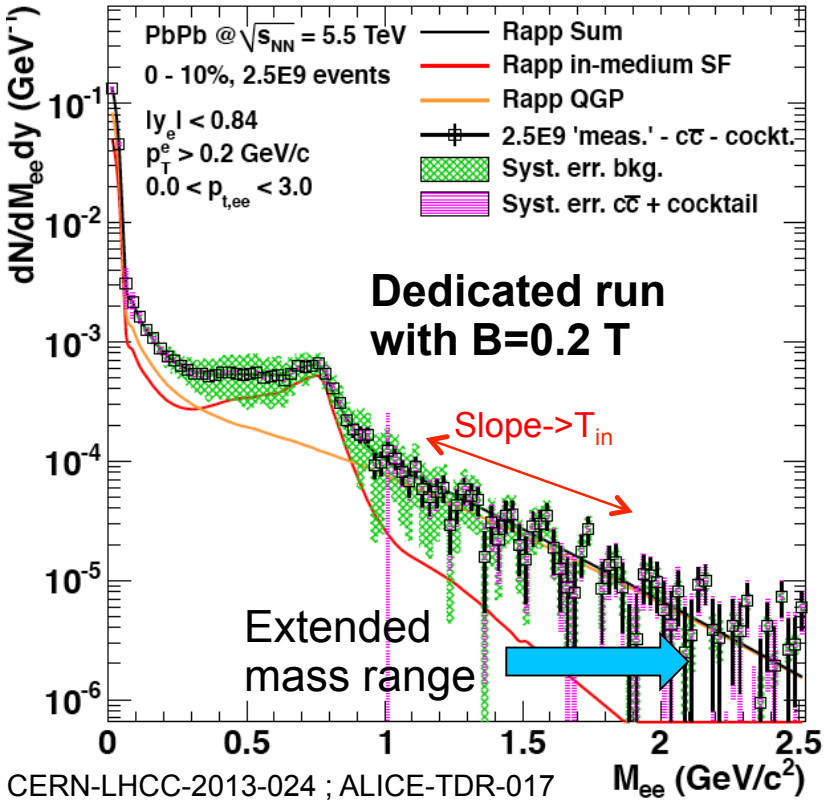


PHYSICS PERFORMANCE, DI-LEPTONS

Excess after background subtraction



CERN-LHCC-2012-005, LHCC-G-159, 2012.



CERN-LHCC-2013-024 ; ALICE-TDR-017

Current ITS and event rate

Upgraded ITS and high rate

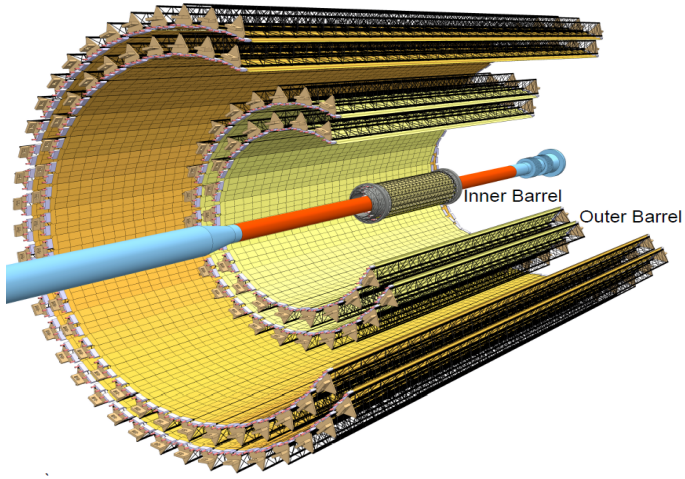
Estimation of the temperature at various phases of system expansion with 10-20% precision (stat.+syst.)

- ALICE Upgrade strategy and the ITS project
- Detector and physics performance à la TDR
- Pixel chip technology
- ITS Upgrade activities at Strasbourg

LAYOUT OF THE UPGRADED ITS

- 7 layers layout:
  - 3 layers of Inner Barrel
  - 4 layers of Outer Barrel

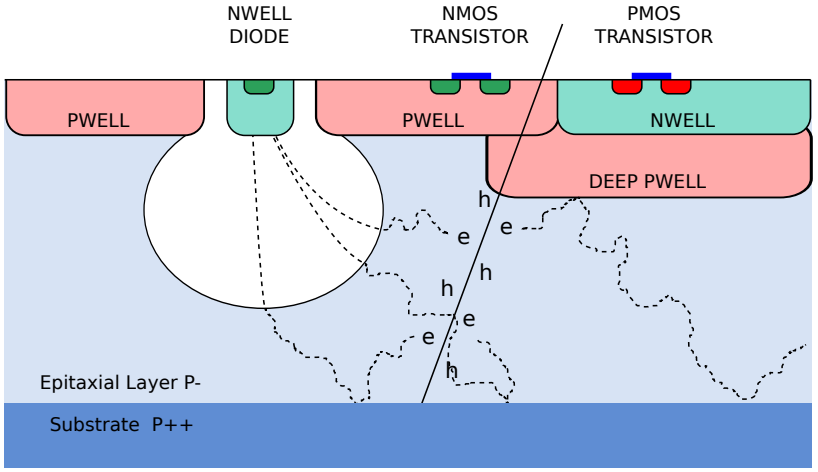
~ 12.5 Gigapixels, binary readout
~ 10 m^2 of silicon



- Radial coverage: 22 mm to 400 mm
- η coverage: $|\eta| \leq 1.22$, for tracks from 90 % most luminous region
- Expected radiation level (innermost layer, including a safety factor 10):
  700 krad (TID) and 1×10^{13} 1 MeV n_{eq} (NIEL)

PIXEL TECHNOLOGY

- Requirements:
  - very thin sensors
  - very high granularity
  - cover large area
  - withstand modest radiation level
- Choice:
  - monolithic silicon pixel sensors using TowerJazz 0.18 µm CMOS Imaging Process
    - high-resistivity (1-6 kΩcm) epitaxial layer on p-type substrate
    - deep p-well to shield PMOS: true CMOS circuitry in the pixel



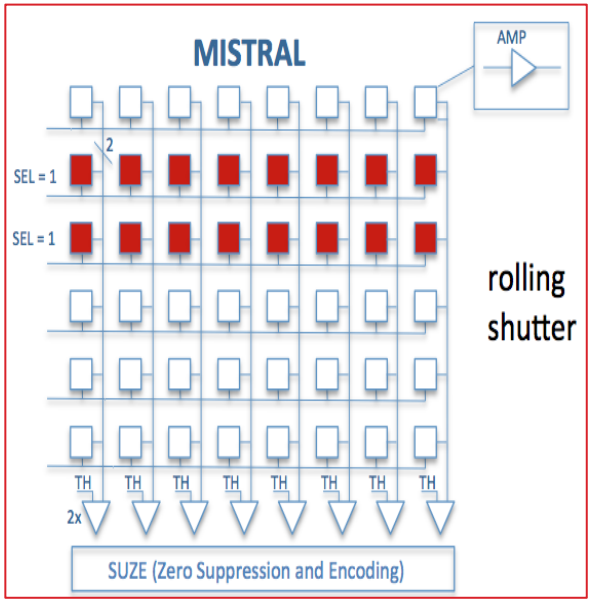
ALICE, CERN-LHCC-2013-024

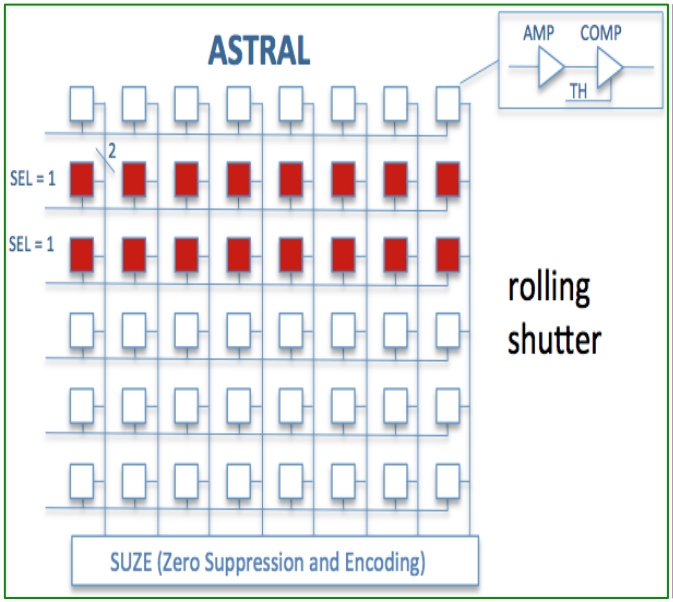
Nwell diode output signal: V ~ Q/C

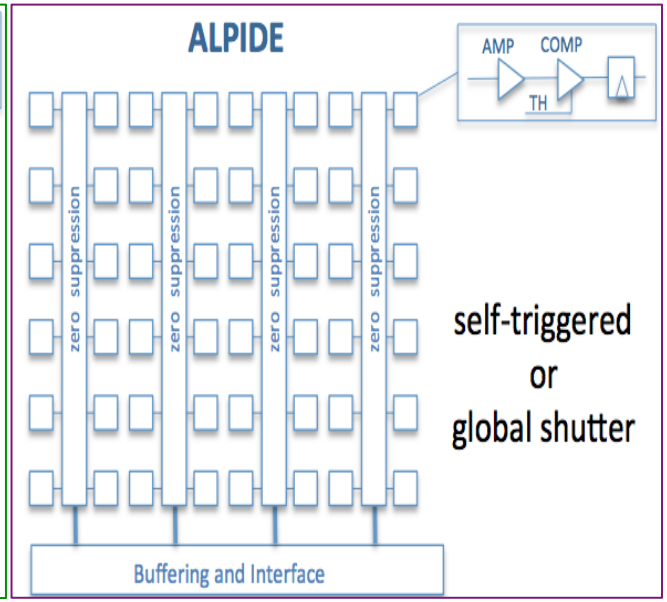
- minimize charge spread over different pixels
- minimize capacitance
- small diode surface (~ 100x smaller than pixel area) and large depletion volume
- Moderate bias voltage on the substrate can increase depletion zone around the Nwell charge collection diode

PIXEL CHIP VERSION UNDER DEVELOPEMENT

ALICE, CERN-LHCC-2013-024







- Three pixel chip architectures under development: MISTRAL / ASTRAL and ALPIDE
- Decision on the ALICE Pixel Chip architecture for the ITS Upgrade: Q2 / 2015 (tbc)

Specifications:

- Chip size: 15 mm x 30 mm
- Pixel pitch: ~ 30 µm
- Si thickness: 50 µm
- Spatial resolution: ~ 5 µm
- Power density: < 100 mW/cm^2
- Integration time: < 30 µs

- ALICE Upgrade strategy and the ITS project
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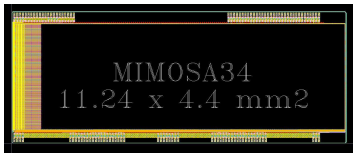
ITS UPGRADE ACTIVITIES IN STRASBOURG

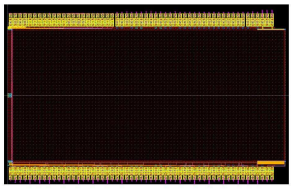
- Pixel chip R&D (PICSEL group)
  - Pixel chip development and test: MISTRAL/ASTRAL
- Outer Barrel module production (ALICE + Micro-techniques groups)
  - Preparation for assembly
- ITS Upgrade software (ALICE group)
  - Framework coordination
  - Standalone reconstruction framework
  - Pixel chip response simulation
- Physics performance analysis (ALICE group)
- Editorial work: ITS Upgrade TDR (ALICE + PICSEL groups)

IPHC: MISTRAL / ASTRAL DEVELOPMENT

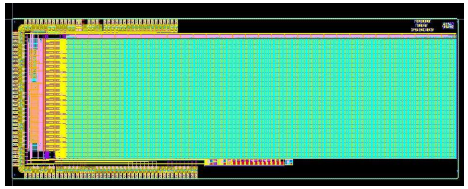
Several small scale prototypes have been realized and characterized …



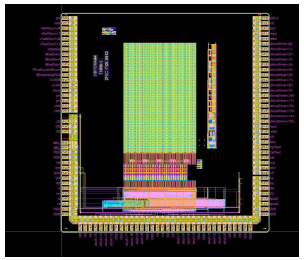
MIMOSA-34



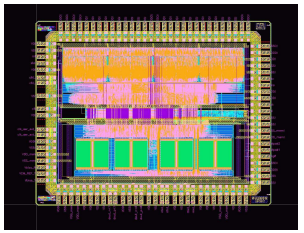
MIMOSA-32FEE



MIMOSA-22THRA



MIMOSA-22THRB

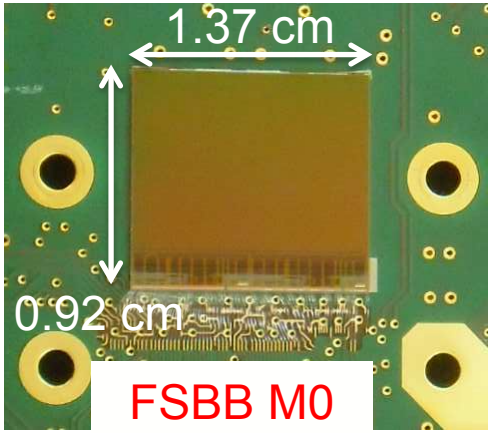


SUZE-02

- sensing node & pixel dimensions
- in-pixel circuitry & end-of-col. discri.
- double-row read-out
- sparsification

… fulfilling the ALICE ITS specifications (SNR, radiation hardness, …)

… and leading to the FSSBs (Full Scale Building Block = 1/3 of a full chip)



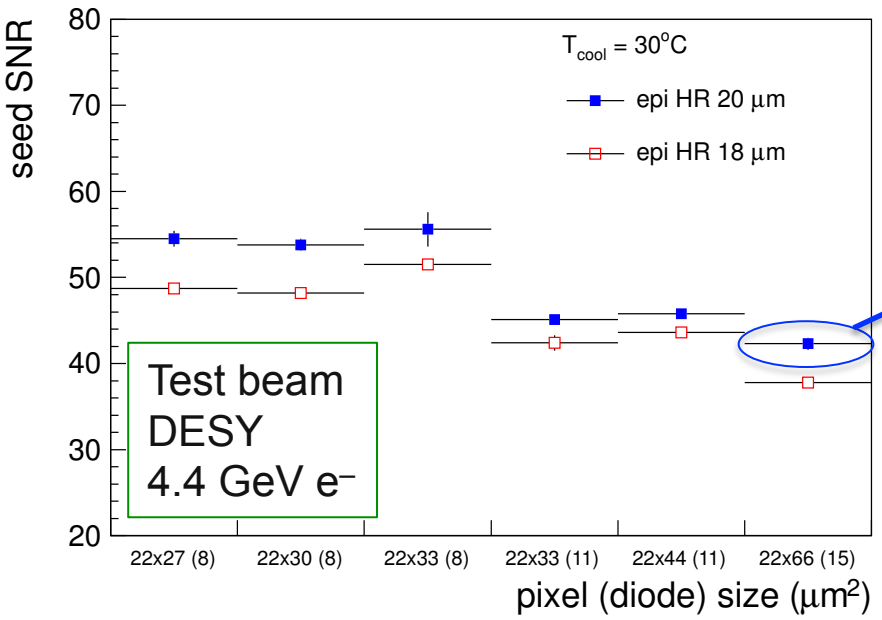
FSBB M0 (MISTRAL)

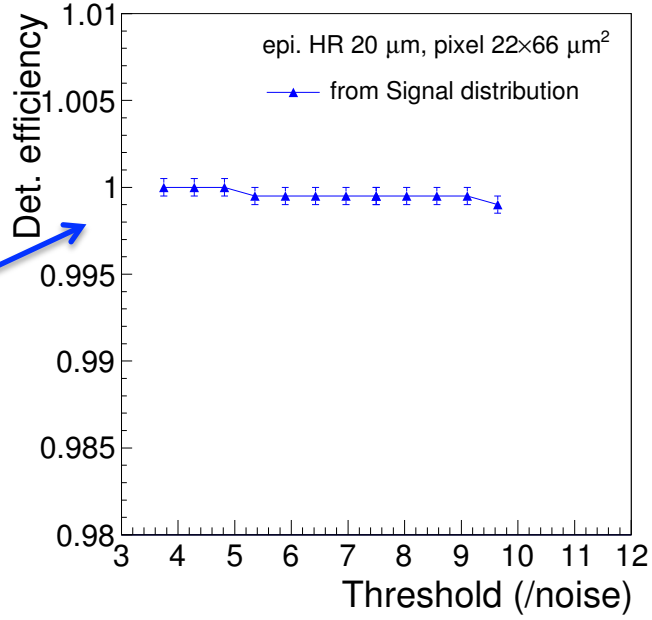
- FSBBs received in late Q2/2014
- Currently characterized in lab:
  - Fabrication yield
  - Uniformity of chips
- Test beam at CERN SPS: Oct 2014

PIXEL CHIP R&D

ASTRAL / MISTRAL – MIMOSA-34

ALICE, CERN-LHCC-2013-024





- Analogue, no in-pixel pre-amplification and CDS circuitry
  - sensing node optimisation: pixel size, epitaxial layer characteristics

CDS: correlated double sampling

- Pixel size varies from 22 × 27 µm² to 22 × 66 µm²
- High detection efficiency even for large 22 × 66 µm² pixels

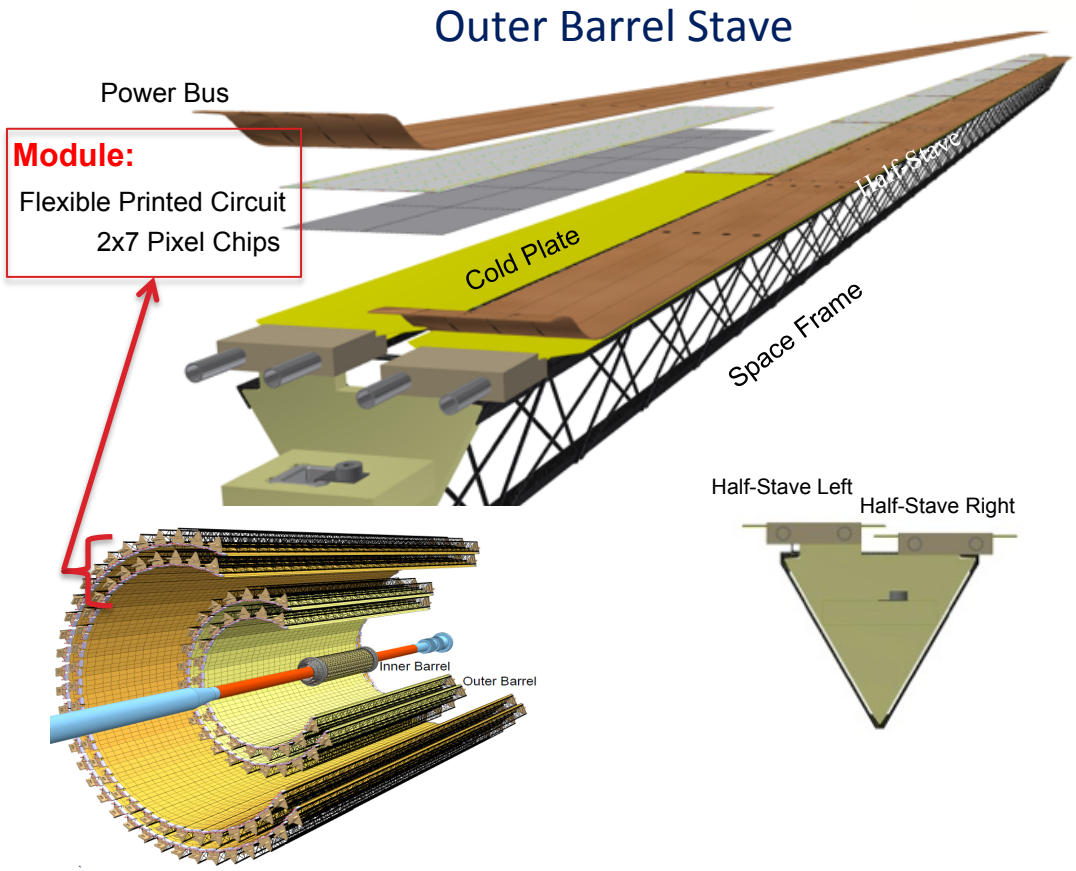
→ Favourable pixel option for Outer Barrel

IPHC: OUTER BARREL MODULE ASSEMBLY

The ITS project identified the following module assembly sites: CERN, LBNL, STFC, CCNU, INFN, IPHC, Korea, Netherlands, Thailand

IPHC is committed to assemble 200-250 out of 1250 modules of the OB

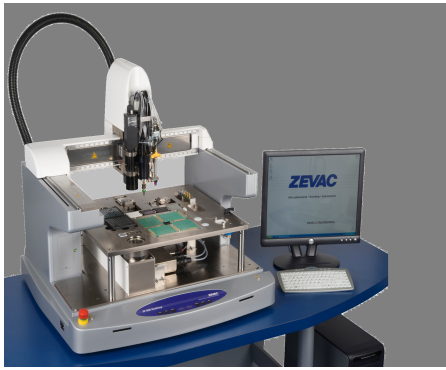
Start of module assembly: 2016, 1 module built and tested / day



IPHC: MODULE ASSEMBLY PREPARATION

2014/06

- Adapt the ALICE module assembly procedure to the local infrastructure
- Improvements: automatic placement and alignment of chips, (interfaced) automatic vacuum control



ZEVAC IP500
(precision ~ 5 µm)

Planned activities for 2014/Q4 - 2015/Q2

- Tools manufacturing at IPHC
- Preparation of positioning and vacuum control protocols
- Dummy module assembly: placement, gluing, soldering / laser soldering training

Planned activities for 2015/Q3 – 2016

- Training on common automatic assembly machine and its procurement
- Start of production in 2016 …

SUMMARY

- The new ALICE ITS with 7 layers of monolithic silicon pixel detectors will be installed during LS2 of the LHC in 2018/19 completely replacing the present ITS

- Full-scale chip prototypes are currently being characterized leading to a decision on the ALICE Pixel Chip architecture for the ITS Upgrade around 2015 / Q2

- ITS Upgrade activities at IPHC: chip R&D, simulation + reconstruction software, physics performance analysis are extended with the preparation for module assembly