ALICE ITS Upgrade

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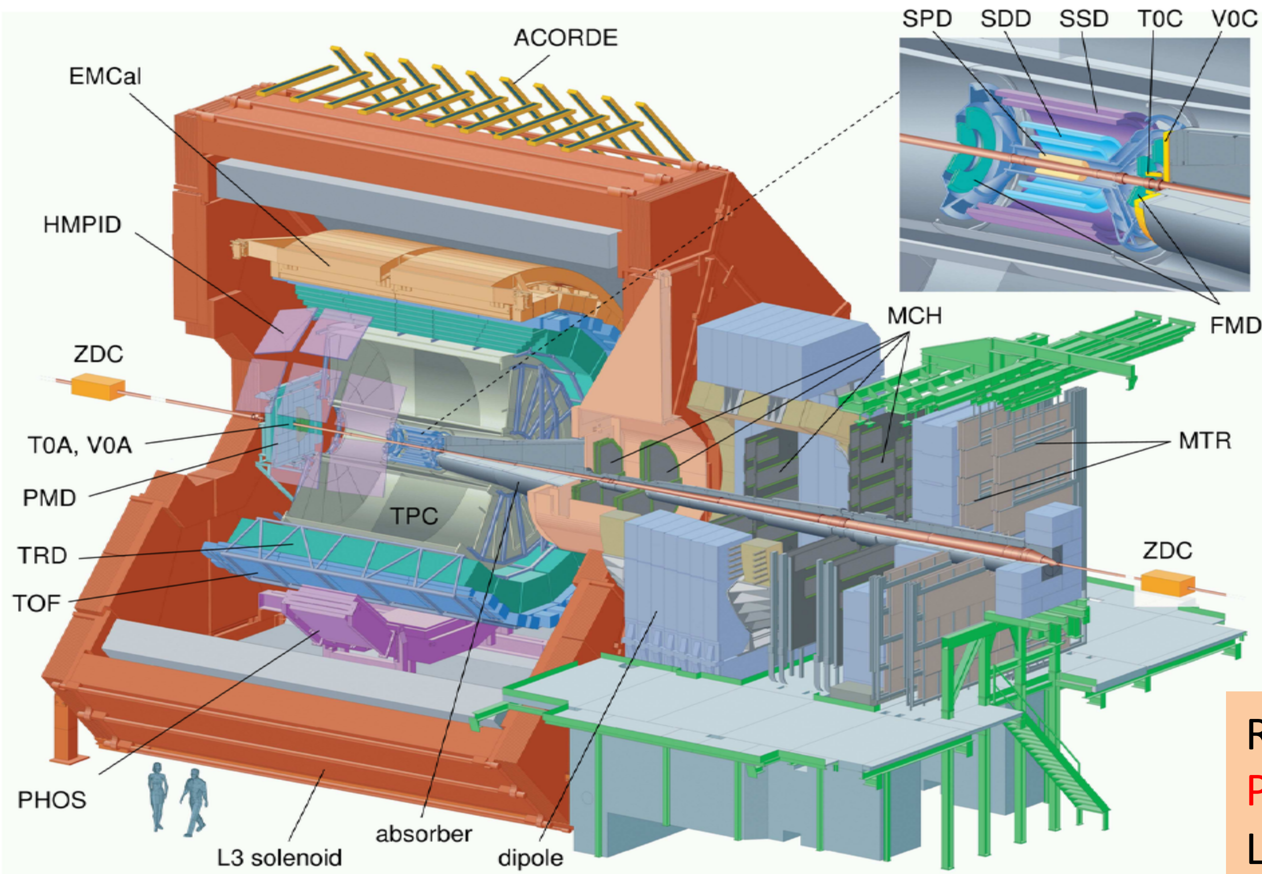
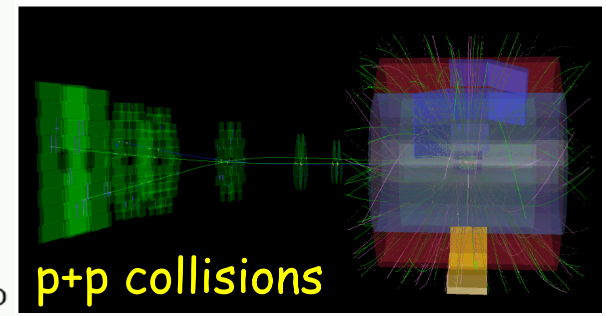
Outline

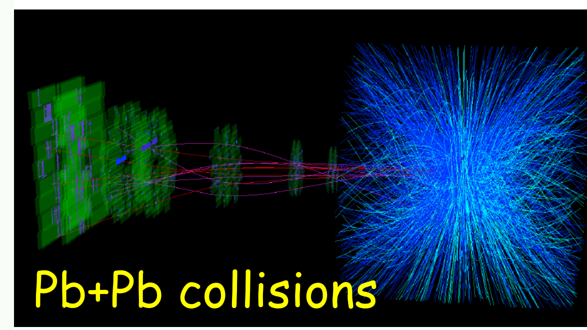
- Introduction
- ALICE ITS Upgrade & Efforts from China
- Summary and Outlook

Introduction – ALICE Experiment at LHC

ALICE (A Large Ion Collider Experiment) is designed to study the physics of strongly interacting matter, and in particular the properties of the Quark-Gluon Plasma (QGP), using proton-proton, proton-nucleus and nucleus-nucleus collisions at the CERN LHC.







Readout rate:
Pb-Pb minimum bias: ~ 1k Hz
Limited by TPC & ITS (SSD).

Introduction – ALICE Upgrade Strategy

The ALICE collaboration prepares a major upgrade for LHC LS2 (2019-2020): High precision measurement of rare probes from high to very low transverse momentum.

Target for upgrade program (Run3 + Run4)

- ✧ Pb-Pb recorded luminosity $\geq 10\ nb^{-1} \rightarrow 8\times10^{10}$ events
- ✧ pp@5.5 TeV recorded luminosity $\geq 6\ pb^{-1} \rightarrow 1.4\times10^{11}$ events

1. Upgrade detectors, readout systems and online systems
   - ✧ Read out all Pb-Pb interactions at a maximum rate of 50 kHz (i.e. $L=6\times10^{27}\ cm^{-2}s^{-1}$), with a minimum bias trigger

     Gain a factor of 100 in statistics over originally approved program (Run1 + Run2)

2. Significant improvement of vertexing and tracking capabilities at low p_T
   - ✧ New silicon trackers (Inner Tracking System, Muon Forward Tracker)

ALICE ITS Upgrade -- Design Objectives

1. Improve impact parameter resolution by a factor of ~3
- Get closer to IP (position of first layer): 39 mm ➡23 mm (layer 0)
- Reduce beam pipe radius: 29mm ➡18.2 mm
- Reduce material budget: ~1.14% ➡ ~ 0.3% (for inner layers)
- Reduce pixel size: 50mm x 425mm ➡ 29 μm x 27 μm

2. Improve tracking efficiency and p_T resolution at low p_T
- Improved integration time: ~10 μs
- Increase granularity and radial extension:
  - 6 layers (2 SPDs + 2 SDDs + 2 SSDs) ➡ 7 pixel layers

3. Fast readout
- readout Pb-Pb interactions > 50 kHz and pp interactions > 200 kHz

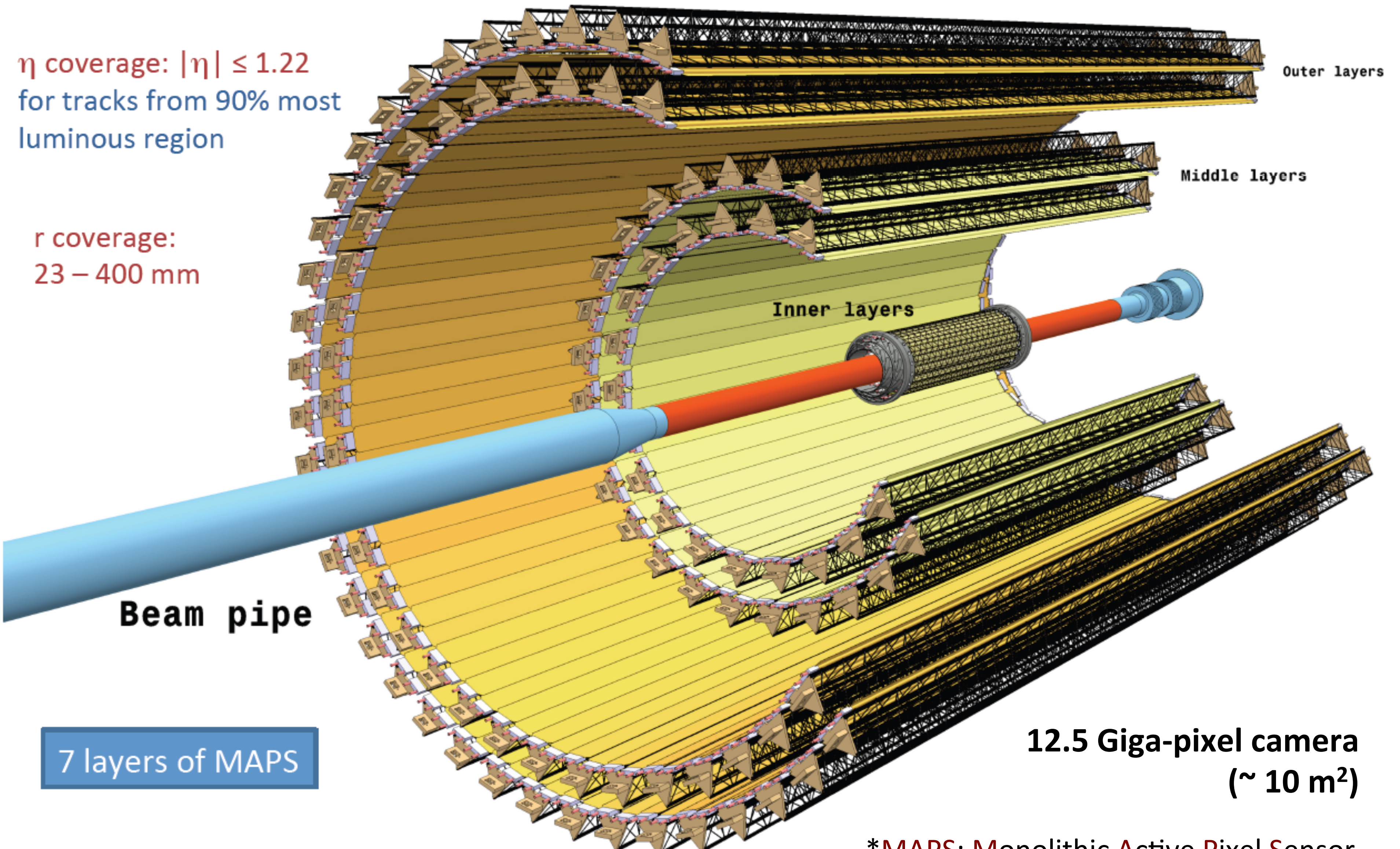
4. Fast insertion/removal for yearly maintenance
- possibility to replace non functioning detector modules during yearly shutdown

5. High radiation tolerance
- TID: 2.7 Mrad, NIEL: 1.7×10^{13} 1 MeV n_{eq} cm^{-2} (safety factor 10)

ALICE ITS Upgrade – The New ITS

η coverage: |η| ≤ 1.22
for tracks from 90% most luminous region

r coverage:
23 – 400 mm

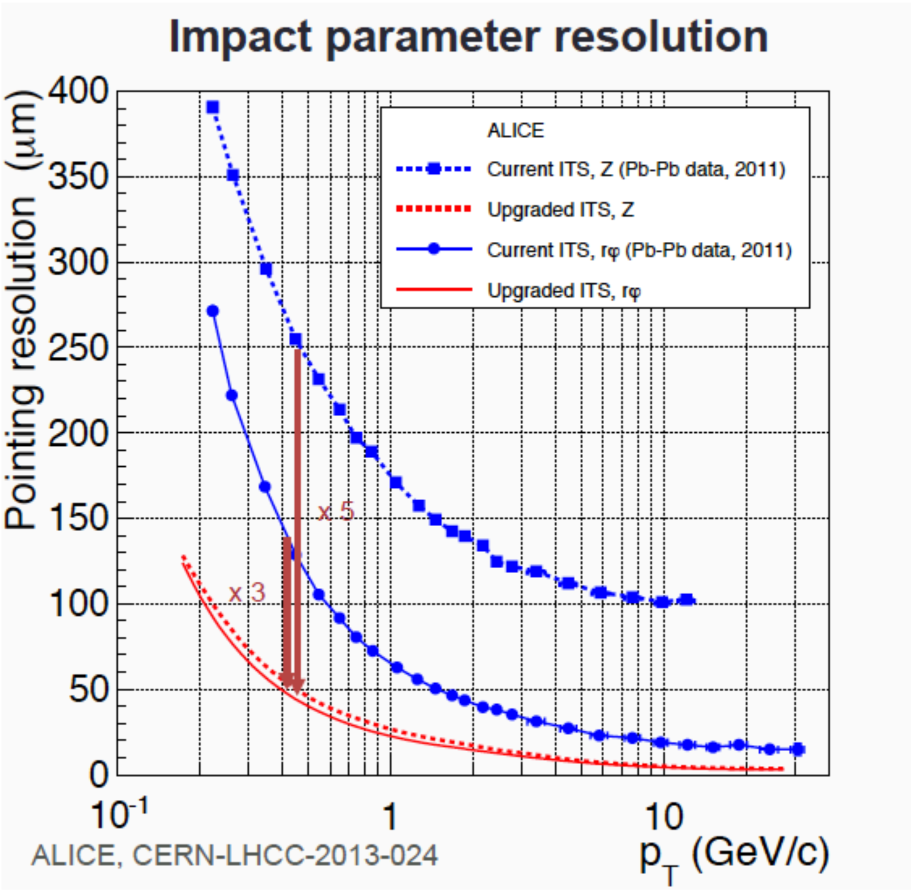


7 layers of MAPS

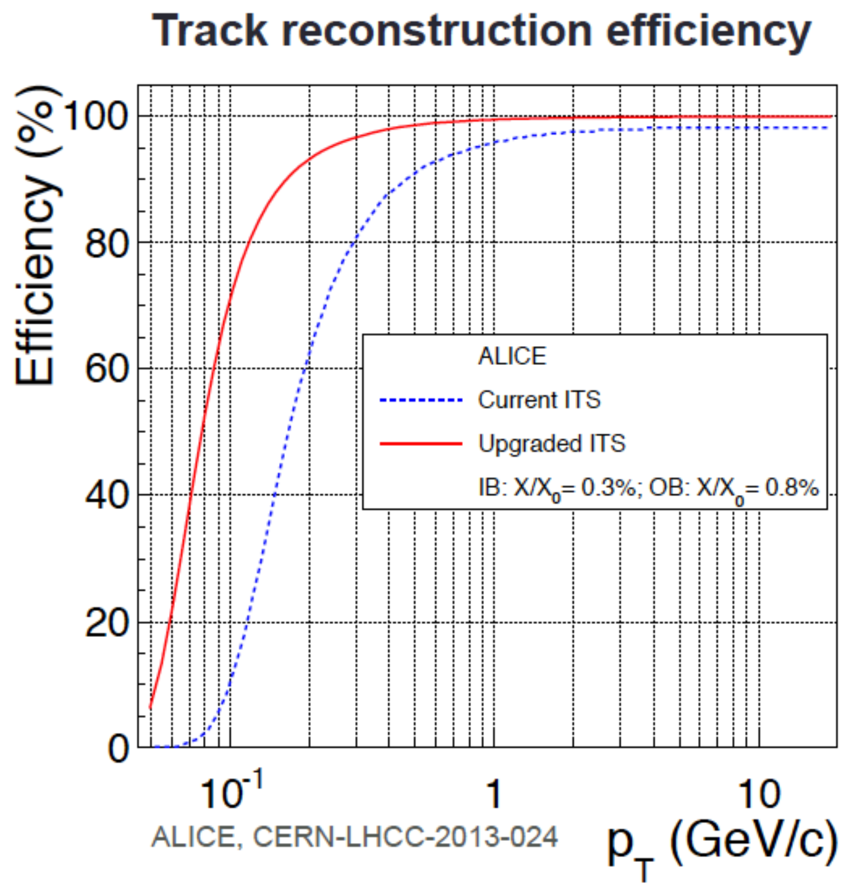
12.5 Giga-pixel camera ($\sim 10\ m^2$)

*MAPS: Monolithic Active Pixel Sensor

ALICE ITS Upgrade – The New ITS Performance (MC)



Improved impact parameter resolution



High standalone tracking efficiency

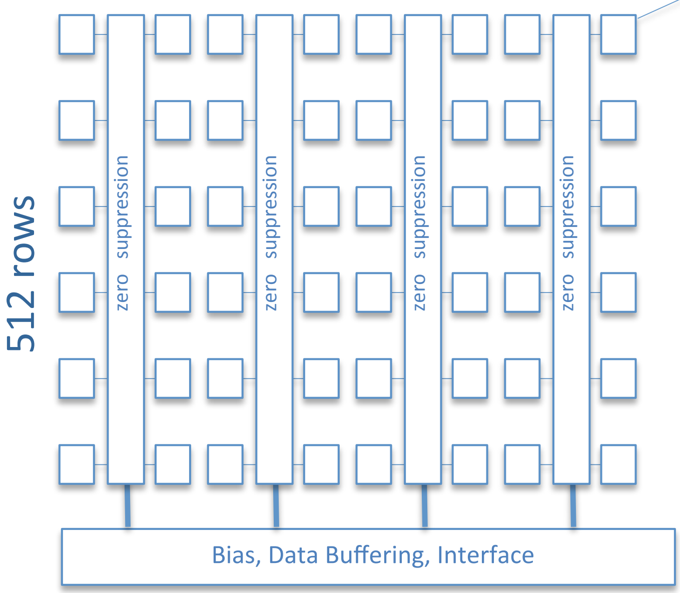
~40 μm at p_T = 0.5 GeV/c

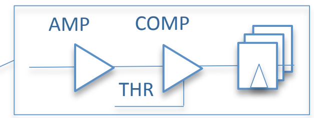
ALICE ITS Upgrade – Physics Reach

Observable	Current, $0.1\,nb^{-1}$		Upgrade, $10\,nb^{-1}$	
	p_T^{min} (GeV/c)	statistical uncertainty	p_T^{min} (GeV/c)	statistical uncertainty
Heavy Flavour				
D meson R_{AA}	1	10 %	0	0.3 %
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 %
B^+ yield	not accessible		2	10 %
Λ_c R_{AA}	not accessible		2	15 %
Λ_c/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 %
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				
$^{3}_{\Lambda}H$ yield	2	18 %	2	1.7 %

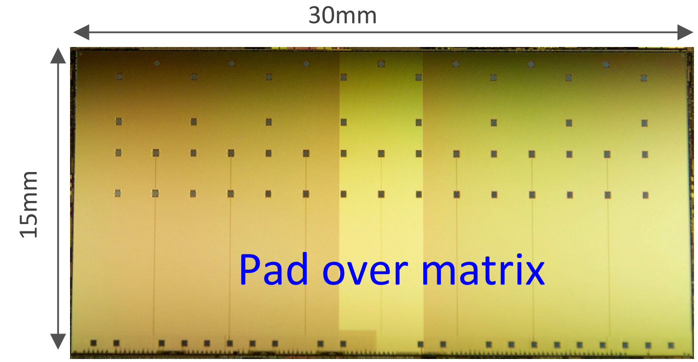
* J. Phys. G(41) 087002

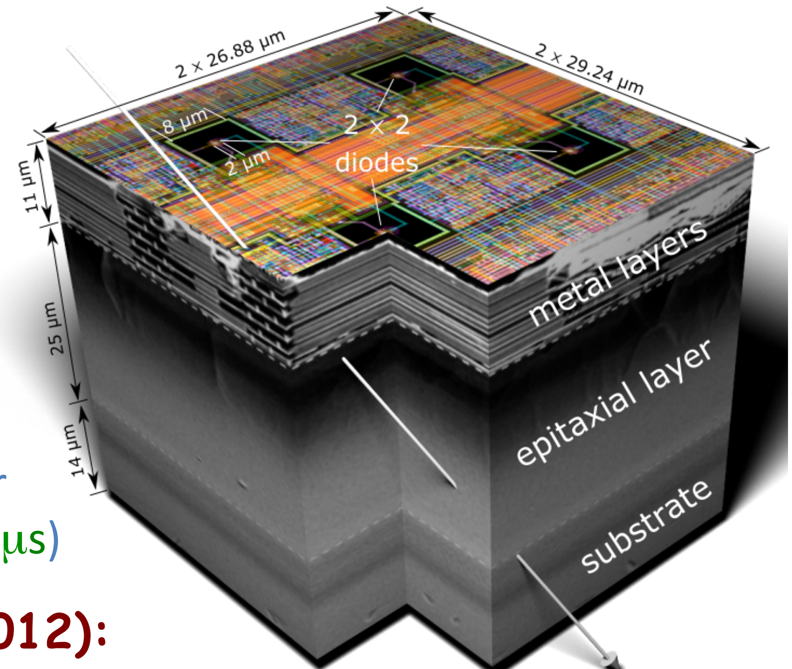
ALICE ITS Upgrade – ALPIDE (ALice PIxel DEtector) Chip





continuous
or
external trigger





- Pixel pitch: 29μm x 27μm
- Ultra-low power (entire chip): < 40mW/cm^2
- Global shutter: triggered acquisition (200 kHz) or continuous (integration time <10μs)

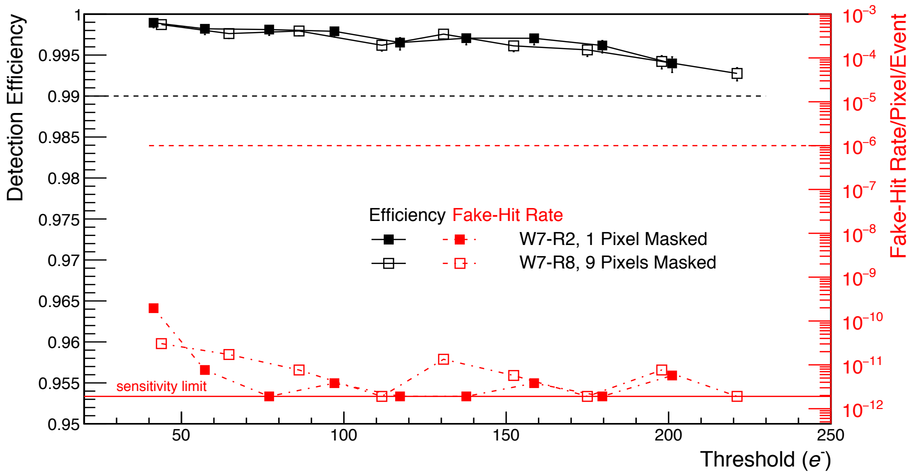
Efforts on chip design from China (Since 2012):

(1) Matrix readout architecture (Dr. P. Yang): lower power, fast readout

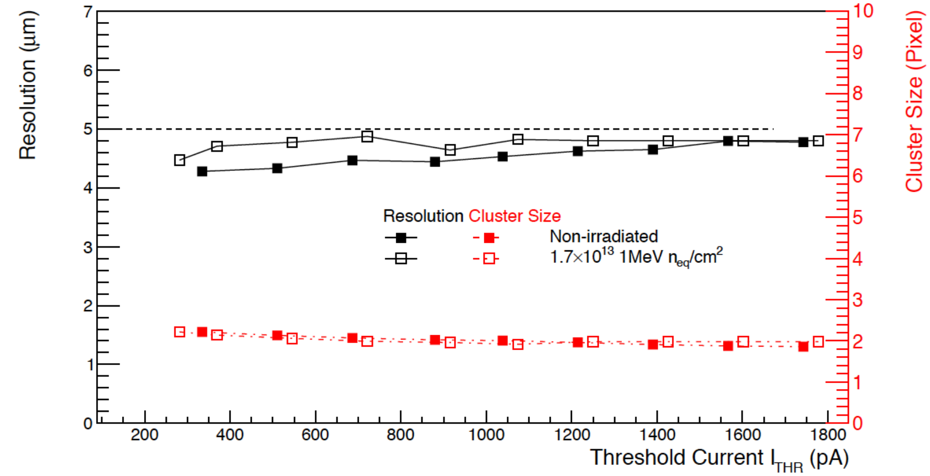
(2) Pixel analog front-end (Dr. C.S. Gao): Charge mis-match reduction, lower noise

ALICE ITS Upgrade – ALPIDE (ALice PIxel Detector) Chip

Detection Efficiency



Spatial resolution

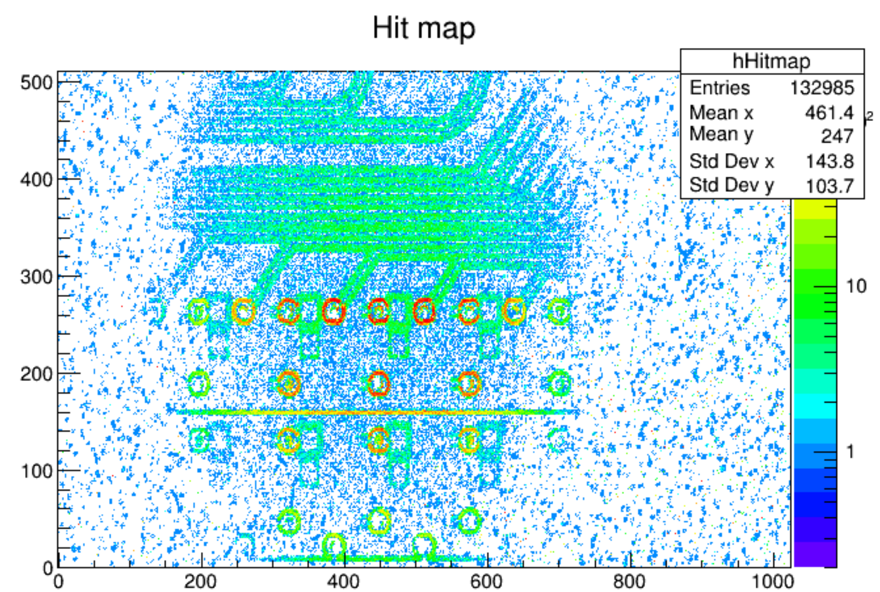


- Spatial resolution: ~ 5 μm (3-D)
- Fake-hit rate: ~10^{-10} pixel/event

Efforts on chip testing from China (Since 2014):

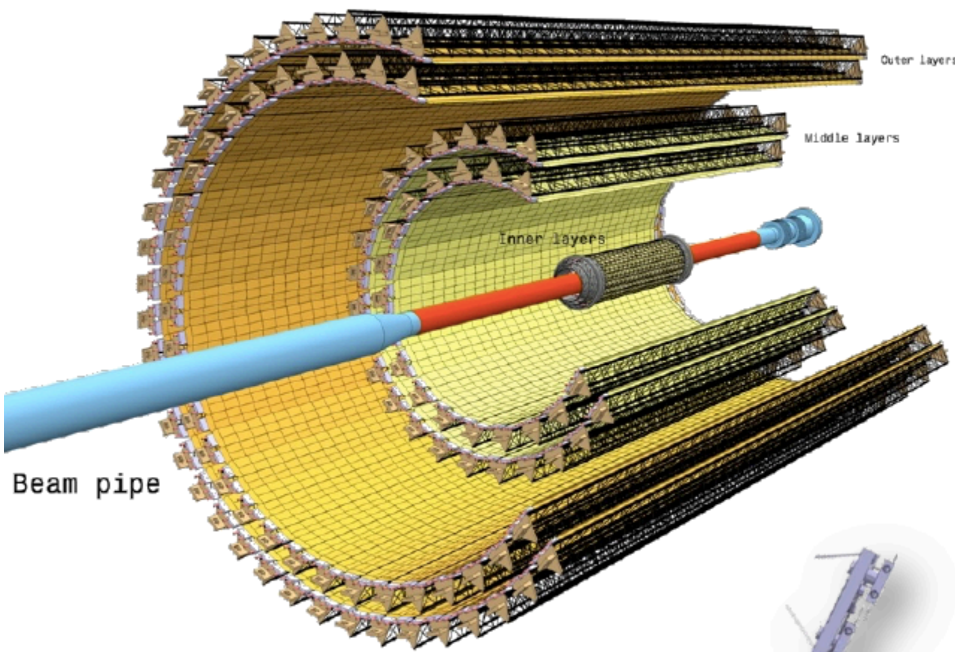
(1) pALPIDE-3 and pALPIDE chip testing at CERN (2 CCNU phD students)

(2) pALPIDE-3 chip testing in China by CCNU-USTC group, and involving in new readout development for ALPIDE



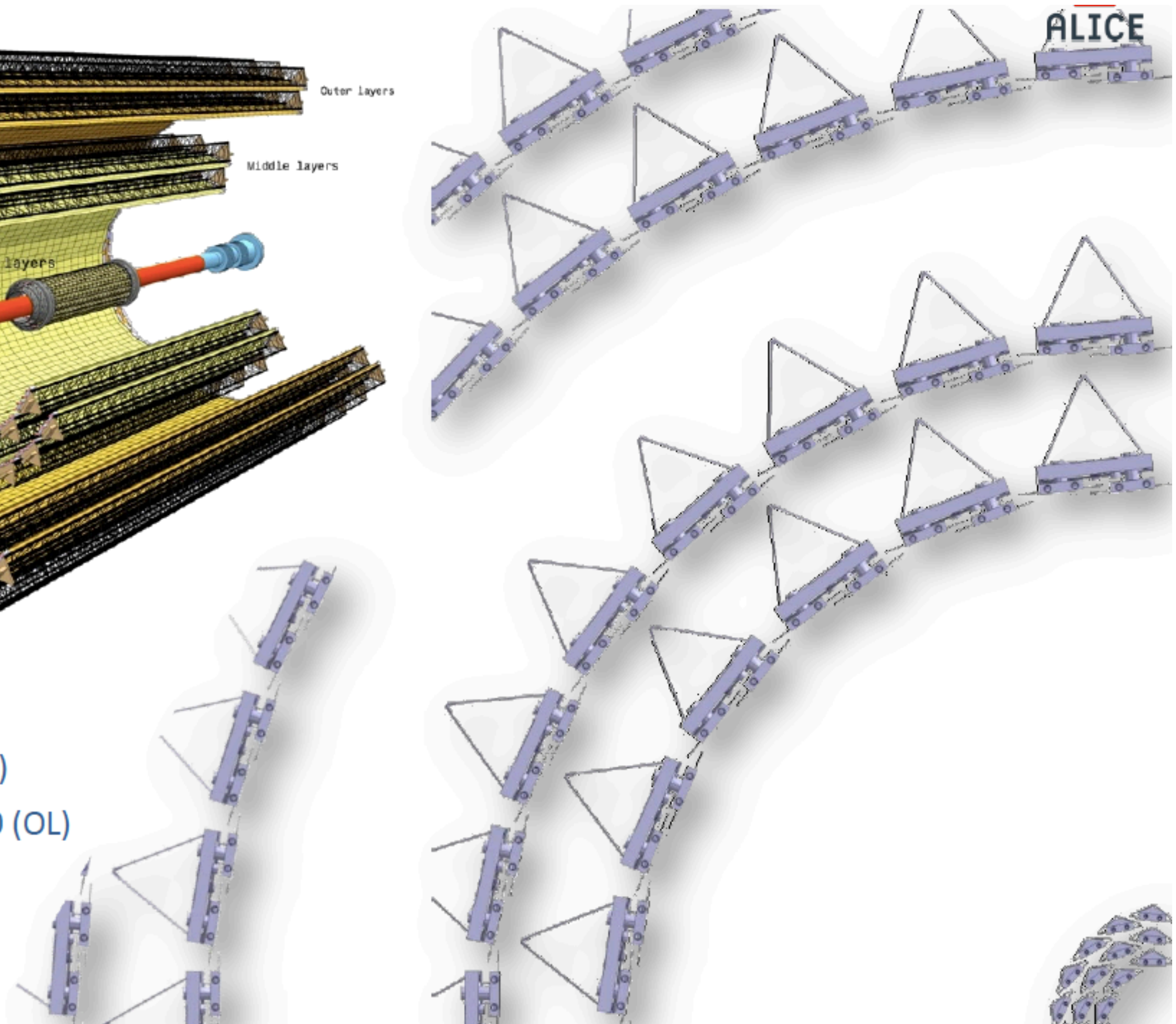
Chip testing in China

ALICE ITS Upgrade – Detector Barrel Staves



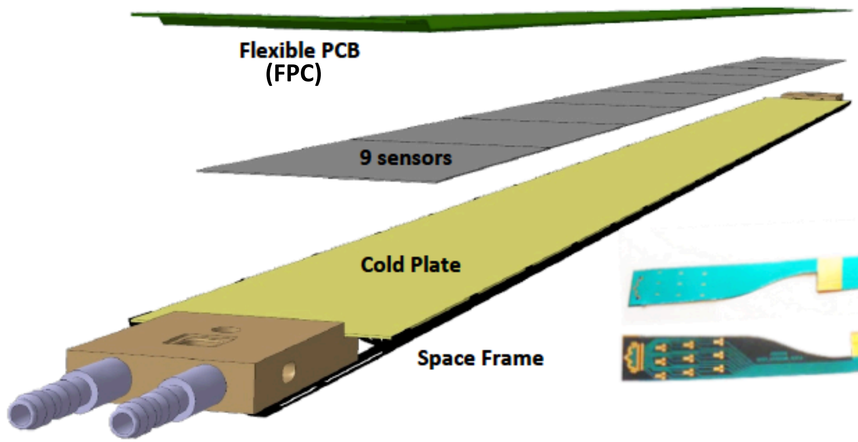
The new ITS consists of

- 7 layers; 3 (IL), 2 (ML), 2(OL)
- 192 staves; 48 (IL), 54 (ML), 90 (OL)

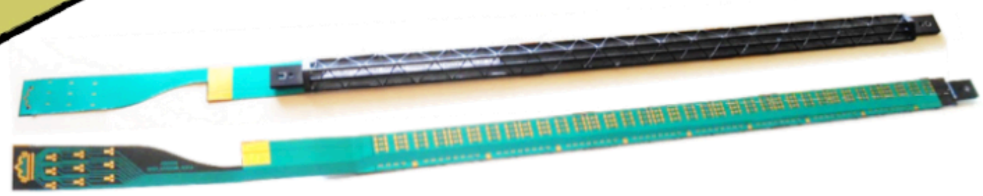


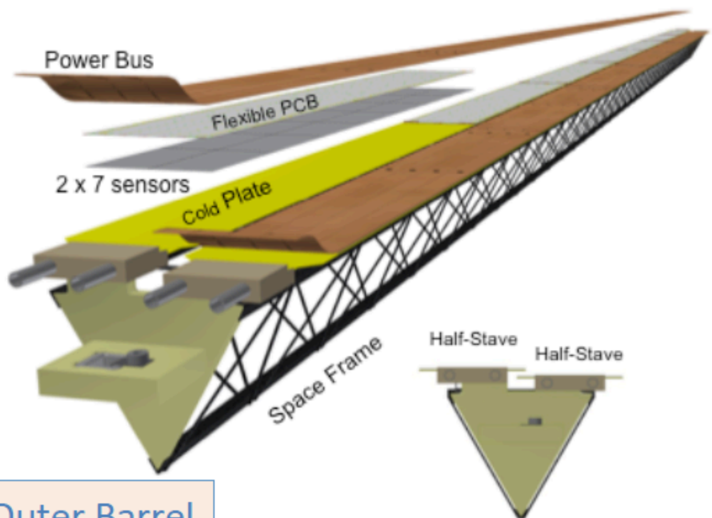
Layer #	6	5	4	3	2	1	0
n. of Staves	48	42	30	24	20	16	12

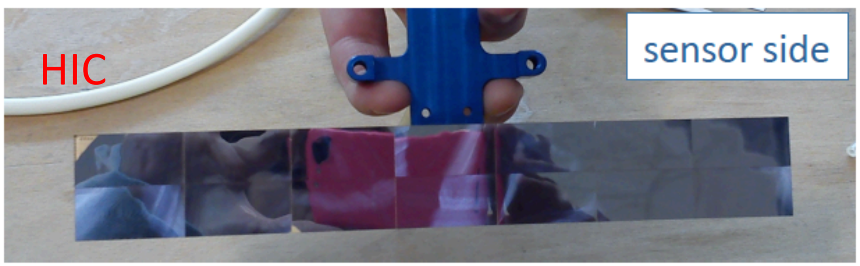
ALICE ITS Upgrade – Barrel Layout

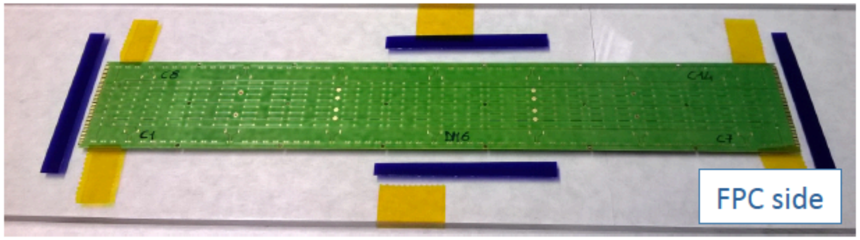


Inner Barrel







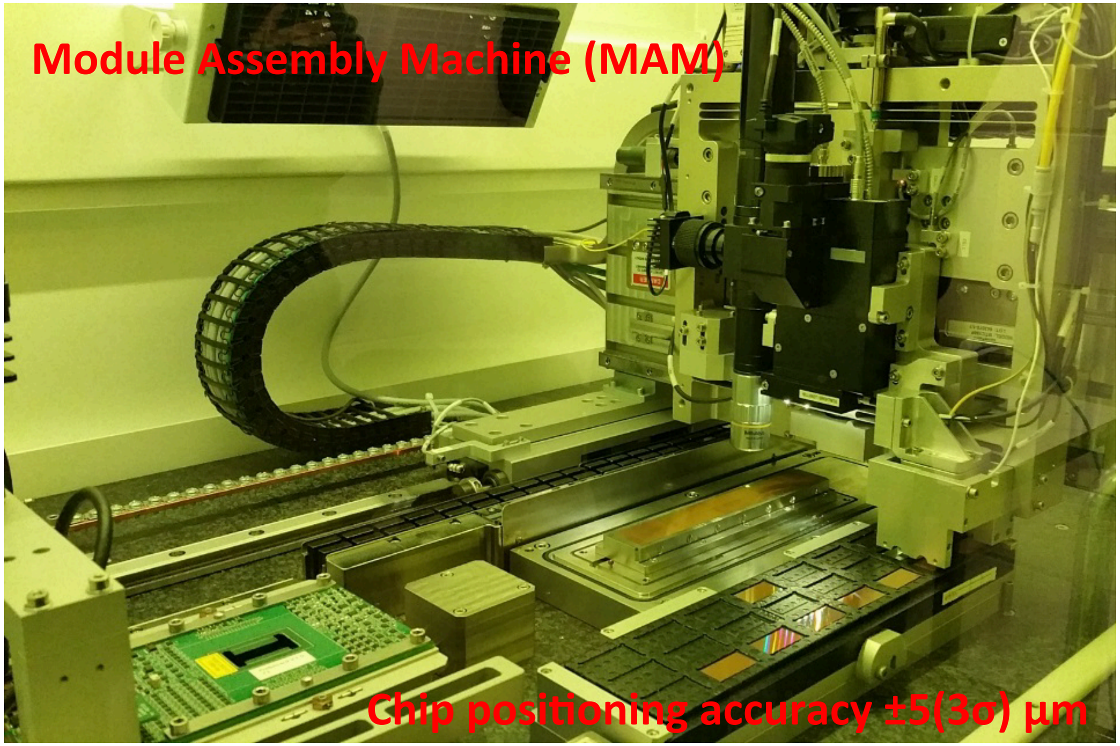


Outer Barrel

HIC (Hybrid Integrated Circuit) module: FPC + 2X7 pixel chips (Outer) or
FPC + 1X9 pixel chips (Inner)

ALICE ITS Upgrade – HIC Assembly

Automated Module Assembly (custom-made machine)

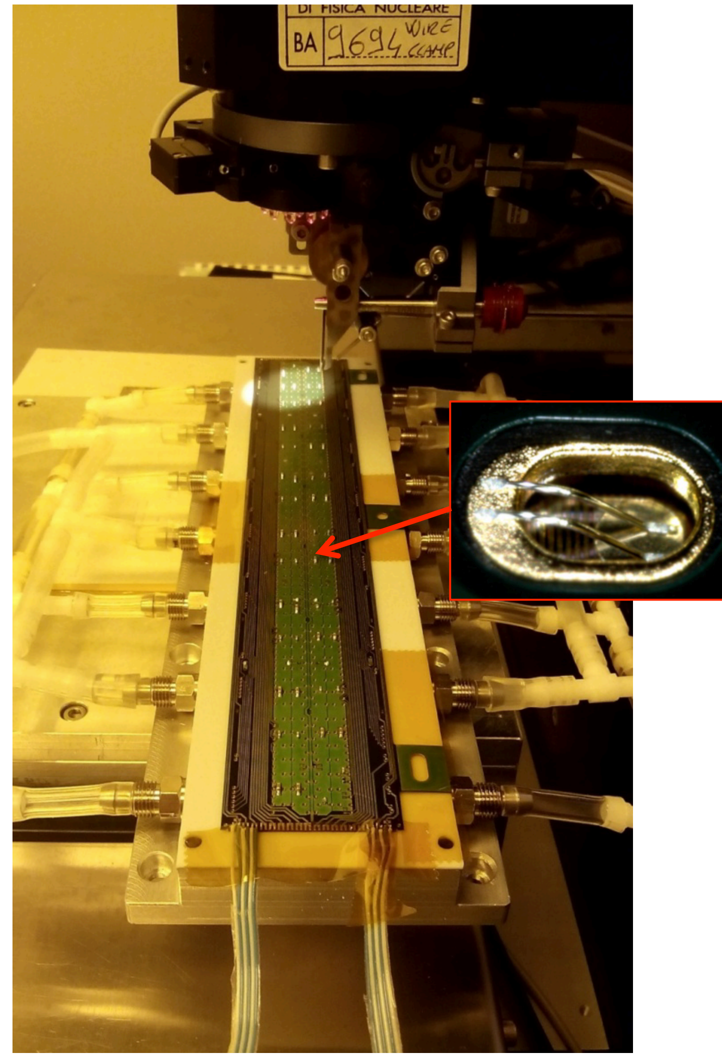


Efforts on HIC module assembly from China (Since 2014, 2 phD students at CERN):

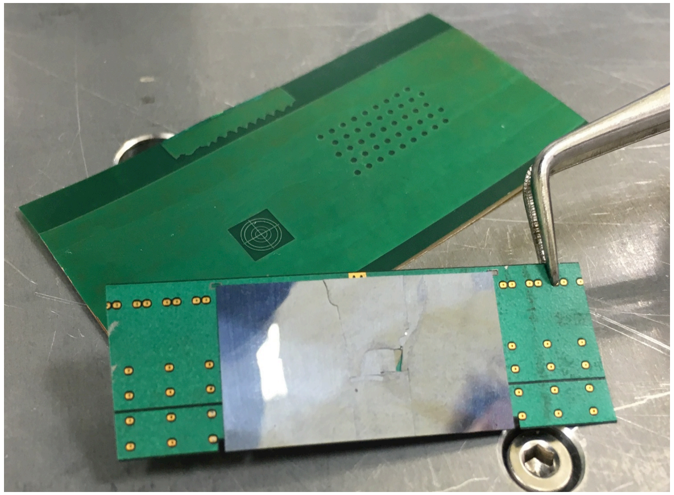
(1) HIC module testing

(2)HIC module assembly training (MAM machine operation, gluing, other procedures)

Electrical Interconnection (Wire Bonding)

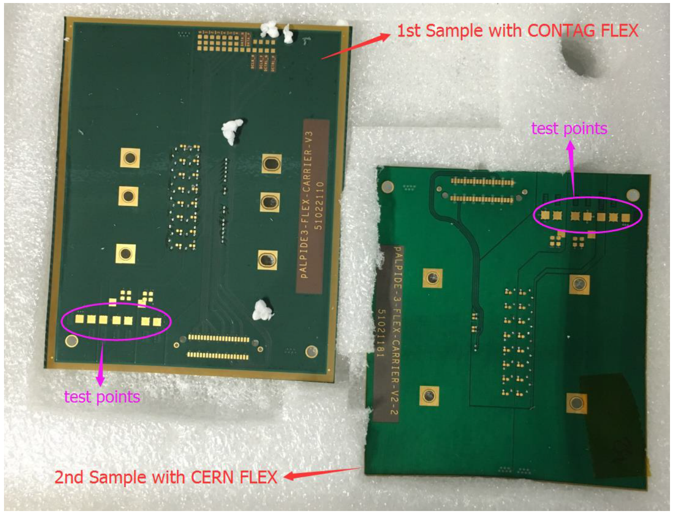


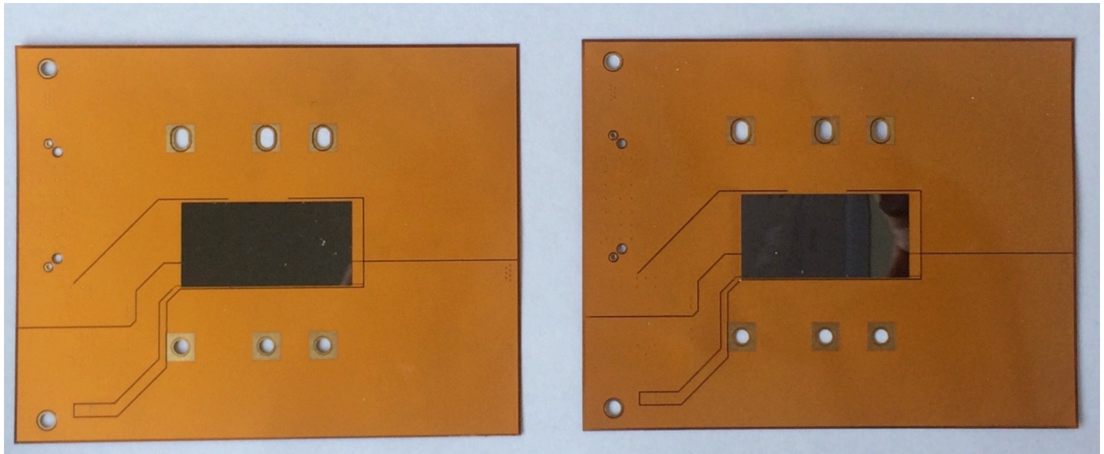
Chip-FPC interconnection R&D at Wuhan (cooperated with a Shenzhen company)



Technical:

- Non-contact heating method (kind of thermal radiation);
- Heating temperature ~300 °C, heating time <1 second;
- solder material is Sn.





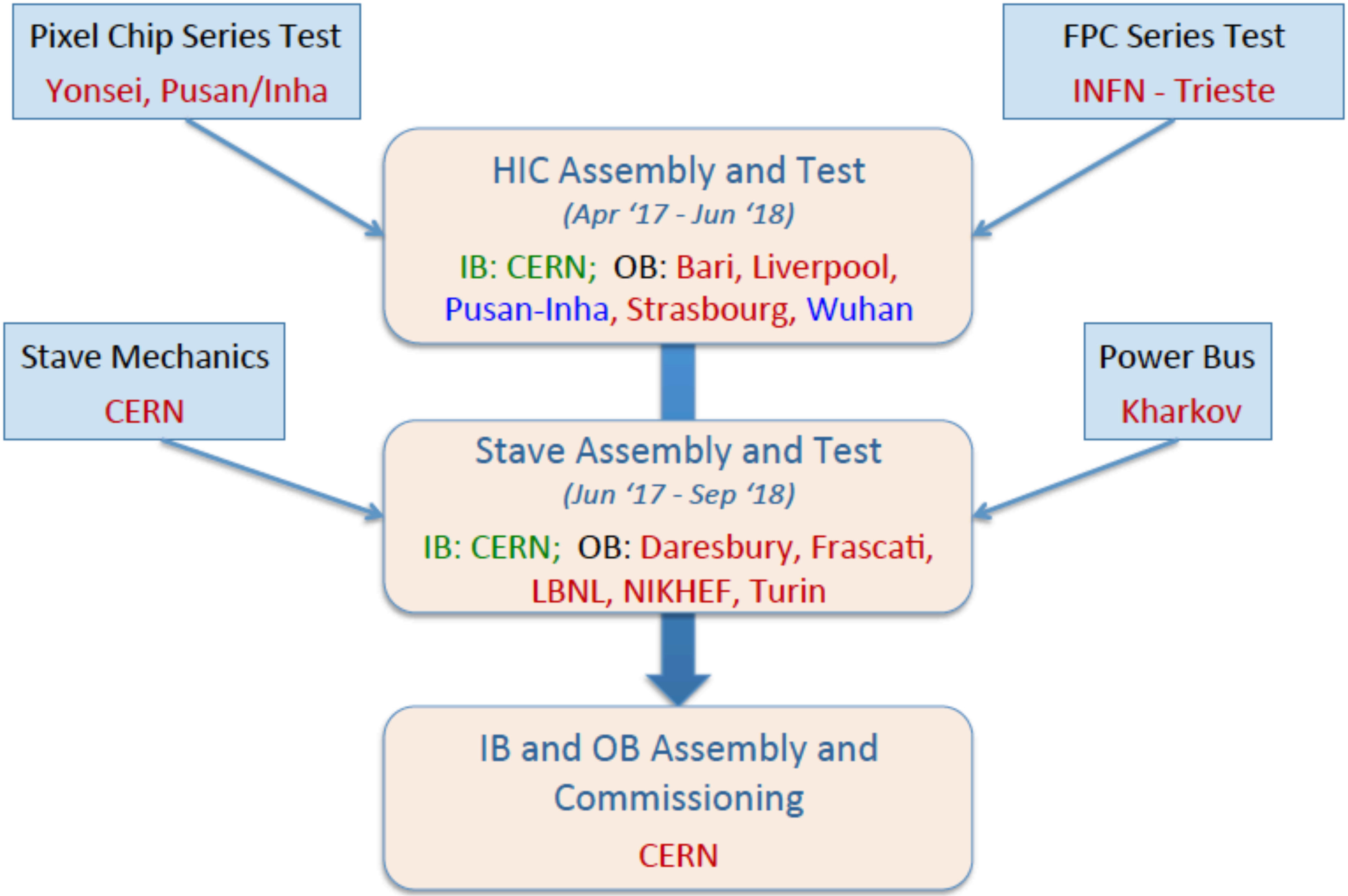
The FPCs were produced in Wuhan using CERN Gerber files

ALICE ITS Upgrade -- OB HIC/Stave Production

Layer	Stave	Half-stave	HIC	Chip
L3	24	48	192	2688
L4	30	60	240	3360
L5	42	84	588	8232
L6	48	96	672	9408
Spares (20%)	11 18	22 36	88 252	1232 3528
Total	**65** **108**	**130** **216**	**2032**	**28448**

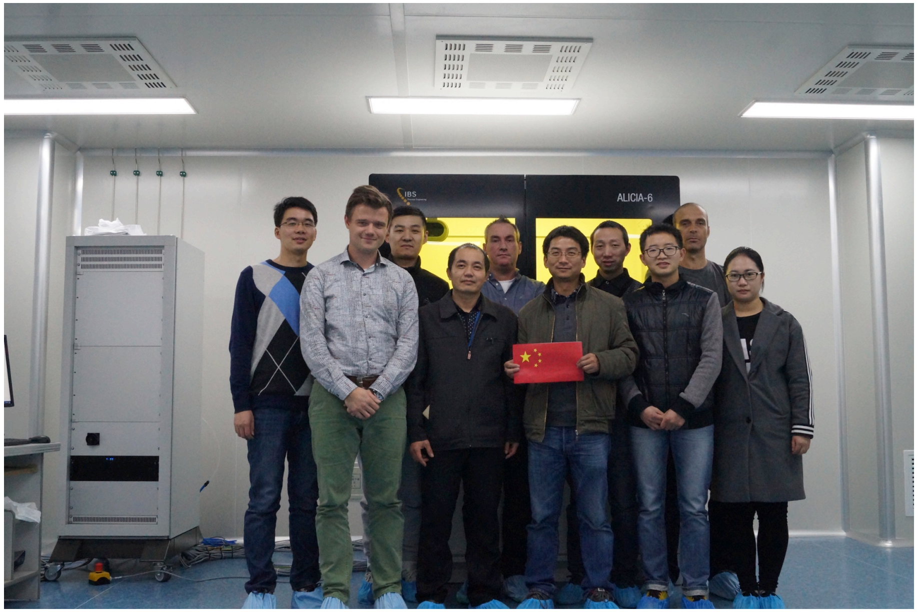
Stave PRR	Mar ‘17
HIC production	Apr ’17 ÷ Jun ‘18
Stave production	Jun ‘17 ÷ Sep ‘18

ALICE ITS Upgrade – HIC and Stave Construction Flow

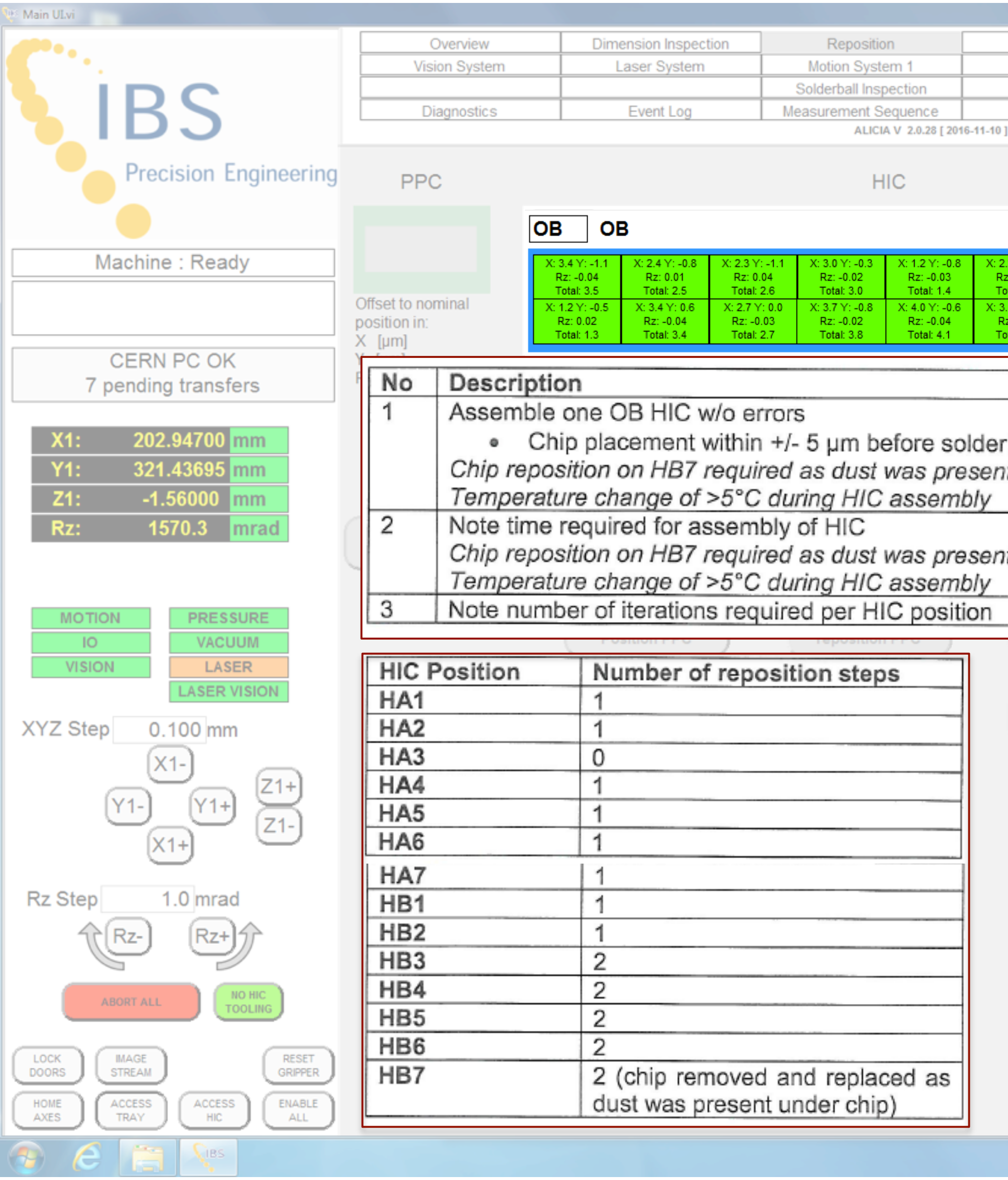


ALICE ITS Upgrade – Preparation at Wuhan for HIC production

- Clean room was tested and accepted at the beginning of November, 2016.
  - ✓ Temperature/humidity controllable
  - ✓ ISO6 area ~ 70 m^2 + ISO7 area ~ 20 m^2
  - ✓ Grounding terminals
  - ✓ Gas supply system (4 channels)
- The clean room has been applied to the MAM site acceptance testing (Nov. 17 ~ 22).
- Technicians and students are trained for MAM operation, and full HIC assembly training will be started in next March.
- Wire-bonding machine procurement is underway.

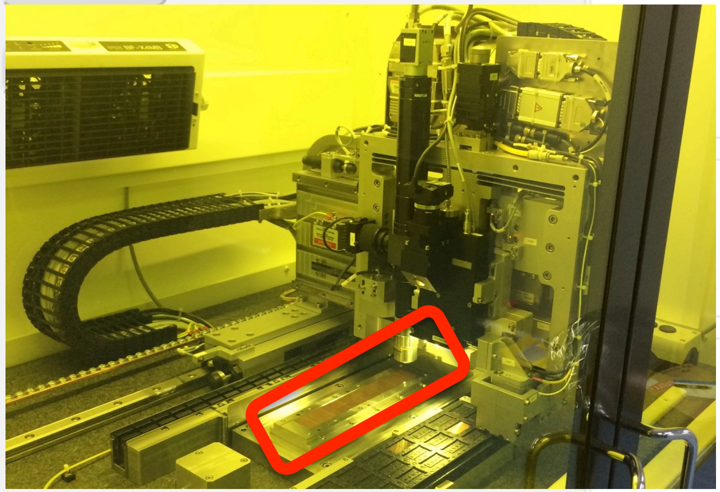


ALICE ITS Upgrade – Preparation at Wuhan for HIC production



No	Description	Pass
1	Assemble one OB HIC w/o errors • Chip placement within +/- 5 µm before soldering *Chip reposition on HB7 required as dust was present on HIC* *Temperature change of >5°C during HIC assembly*	OK
2	Note time required for assembly of HIC *Chip reposition on HB7 required as dust was present on HIC* *Temperature change of >5°C during HIC assembly*	1 hour 30 minutes
3	Note number of iterations required per HIC position	See table below

HIC Position	Number of reposition steps
HA1	1
HA2	1
HA3	0
HA4	1
HA5	1
HA6	1
HA7	1
HB1	1
HB2	1
HB3	2
HB4	2
HB5	2
HB6	2
HB7	2 (chip removed and replaced as dust was present under chip)



Summary and Outlook

- The upgrade of the ALICE ITS will provide excellent tracking capabilities, significantly improving the impact parameter resolution and reading out Pb-Pb events at 50 kHz interaction rate.

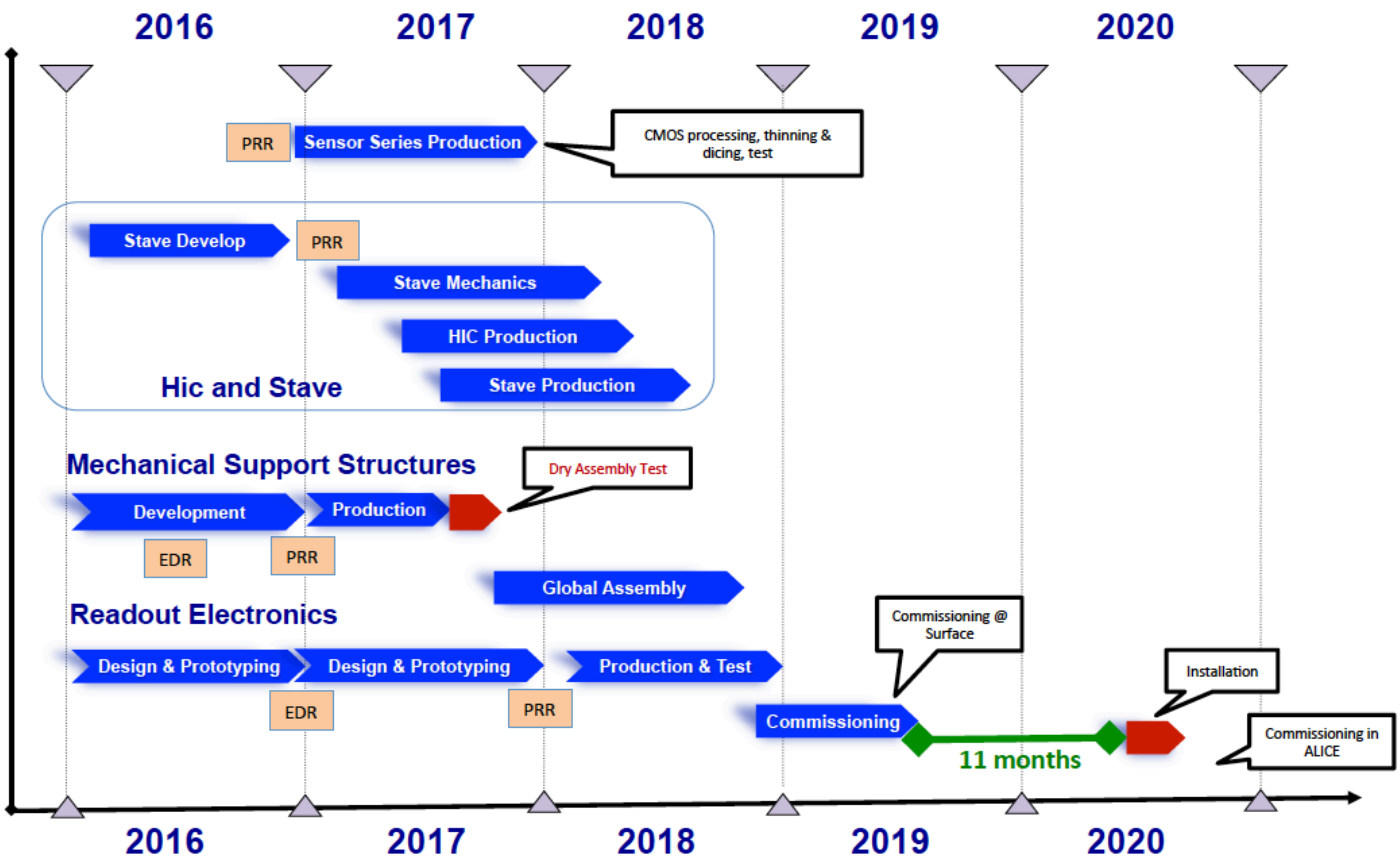
- The new ITS, based on the next generation of MAPS pixel chips, will help to extend the physics reach to new observables and to improve the accuracy of existing ones.

- Preparations in Wuhan are in good shape for the HIC module serious production, which will be started in April, 2017.

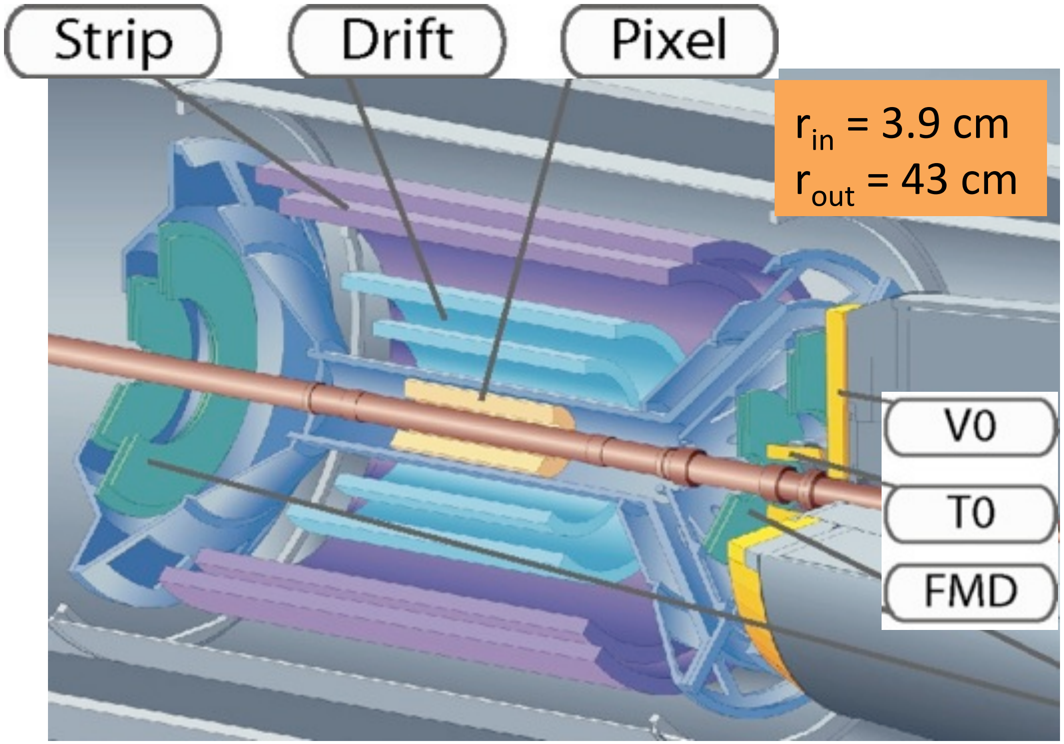
- Production schedule in Wuhan:
  - 406 Outer Barrel modules will be produced in Wuhan
  - ~ 2 HICs/day (1 HIC/day at the beginning of production phase)
  - ~ 250 working days (2 shifts/per day, 5 days for a week)
  - Period since April, 2017 to June, 2018

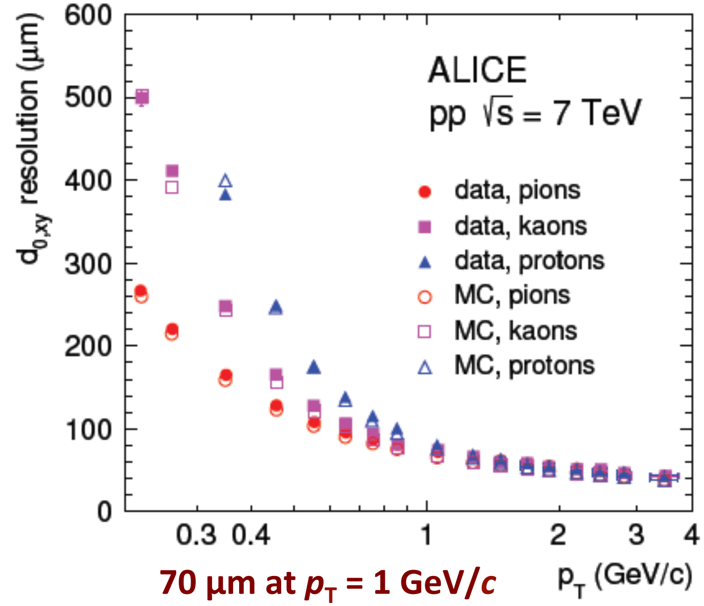
Thanks for your attention!

Overall ITS Planning

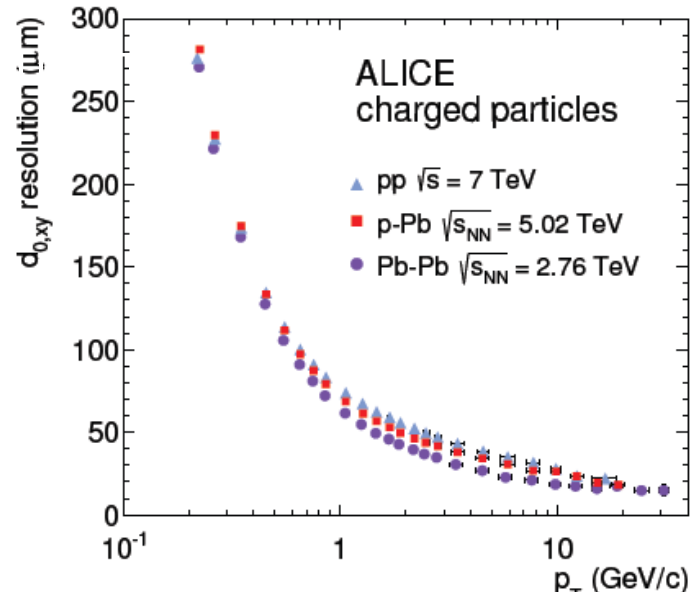


Introduction – the Current ALICE/ITS Detector





70 μm at p_T = 1 GeV/c



ALICE, Int. J. Mod. Phys. A29 (2014) 1430044

The Current ITS:

6 concentric barrels, 3 different technologies

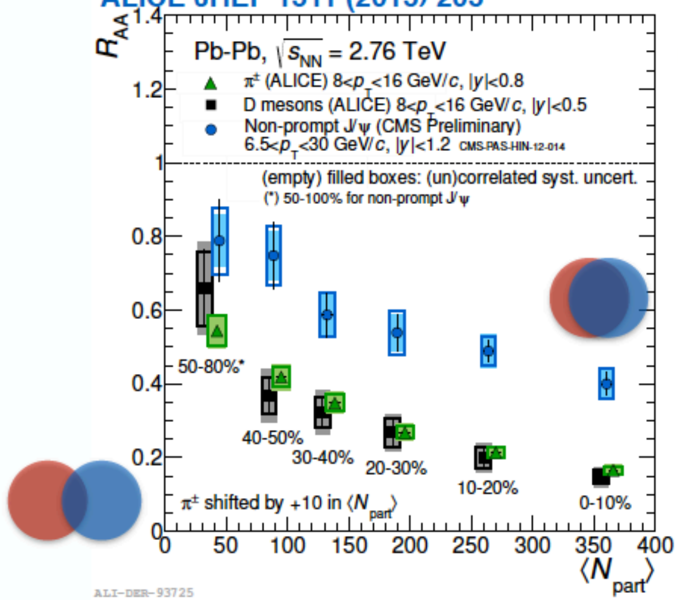
- 2 layers of silicon pixel (SPD)
- 2 layers of silicon drift (SDD)
- 2 layers of silicon strips (SSD)

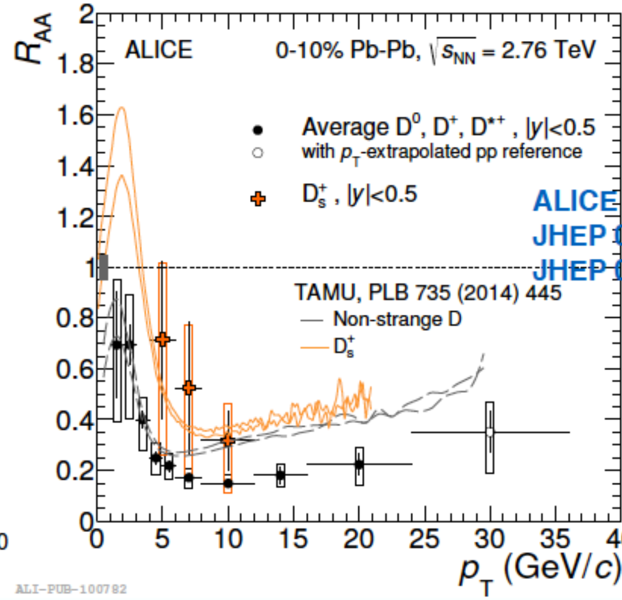
17

R_{AA} of D mesons and non-prompt J/ψ

Talk: A. Dubla, Wuhan hall, Saturday, Sep. 24th 16:00

ALICE JHEP 1511 (2015) 205



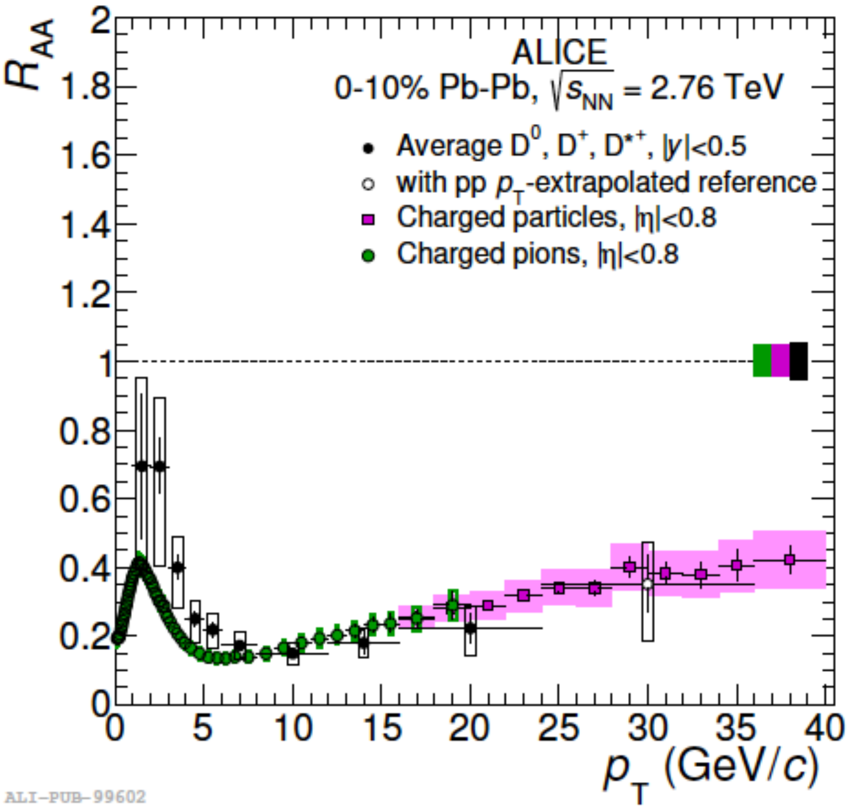


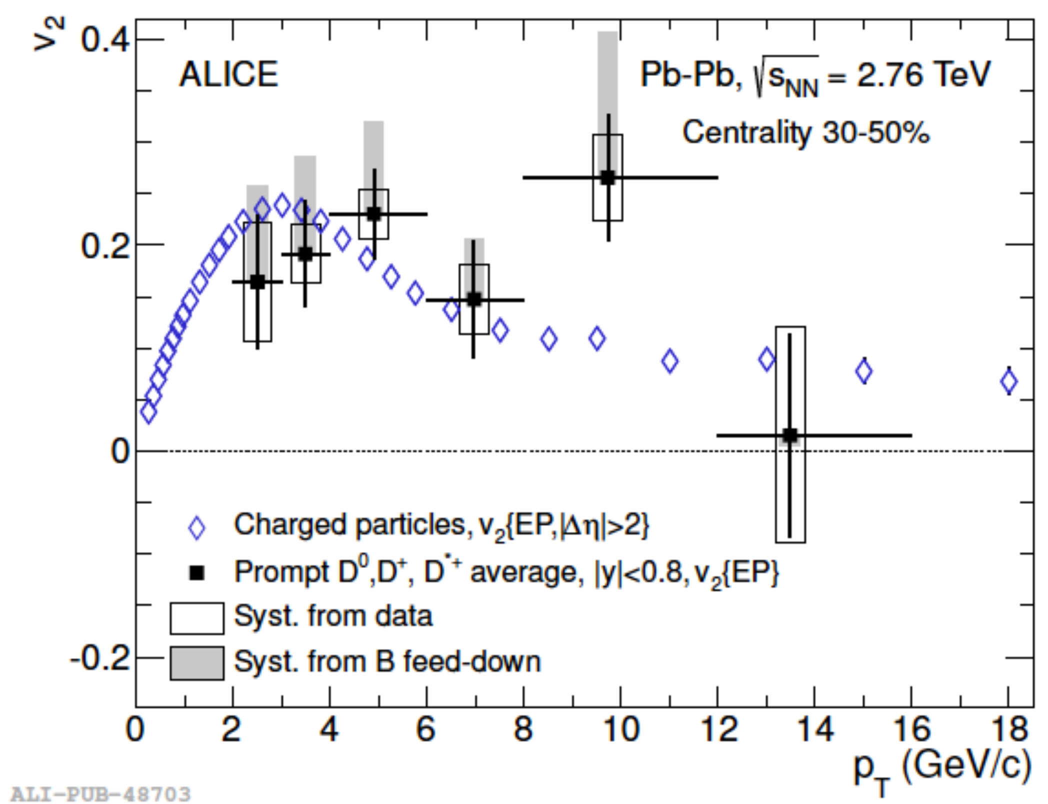
ALICE
JHEP 03 (2016) 081
JHEP 03 (2016) 082

- R_{AA}(D)<R_{AA}(J/ψ←B): $\Delta E_c > \Delta E_b$ — mass dependence of HF energy loss
- R_{AA}(D)≈R_{AA}(π): $\Delta E_c \approx \Delta E_g$(?) or different parton p_T distributions and fragmentation functions
- Charm hadronization through recombination in medium (?) — predicted in models — hint of R_{AA}(D)<R_{AA}(D_s^+) in data — to be confirmed with higher precision measurements

Hard Probes 2016 ALICE Overview X. Zhang

Introduction – Heavy Flavor Measurements at ALICE





- Production of D mesons at lower p_T is less suppressed than light-flavor particles in central Pb+Pb collisions.
- Non-zero v2 is observed for D mesons over a wide p_T range, which is compatible with charged particles.

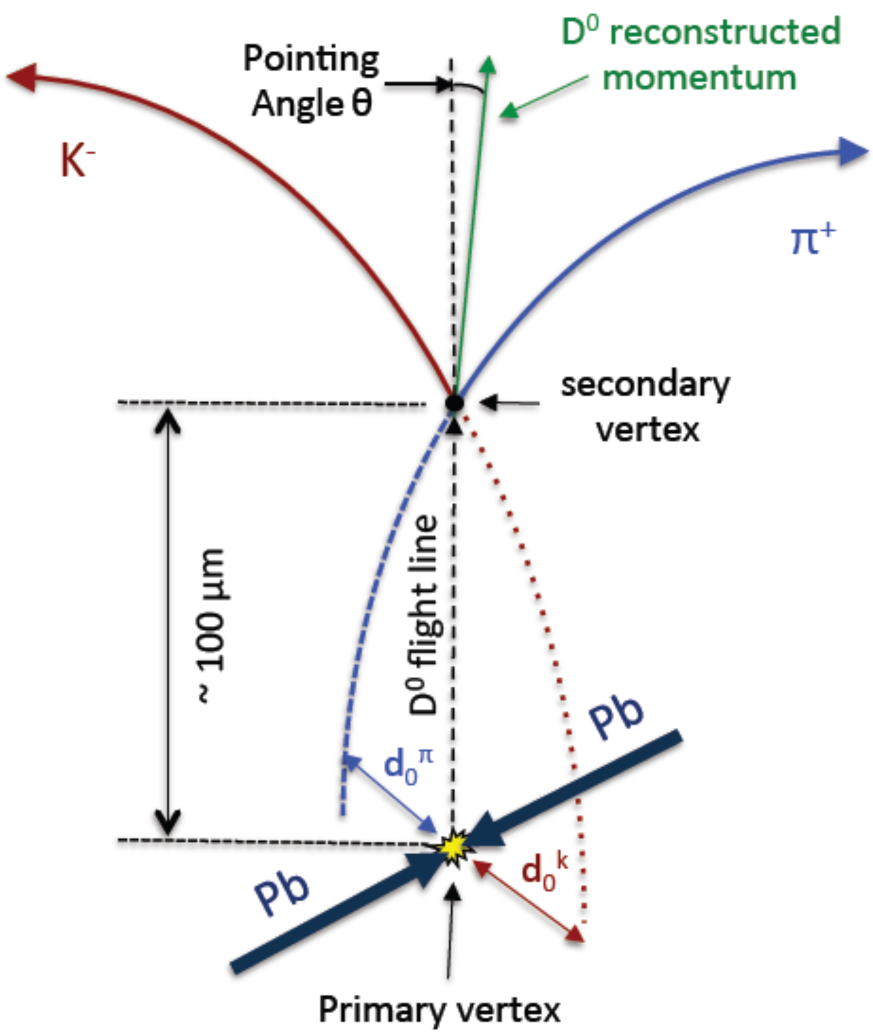
Introduction – Heavy Flavor Measurements at ALICE

- The current statistical and systematic uncertainties do not allow for firm conclusions for some measurements.

- The read-out rate capabilities and space-point precision of the current ITS are not sufficient to perform similar measurements with beauty particles (B-mesons).

Introduction – Heavy Flavor Measurement at ALICE

Example: D^0 meson



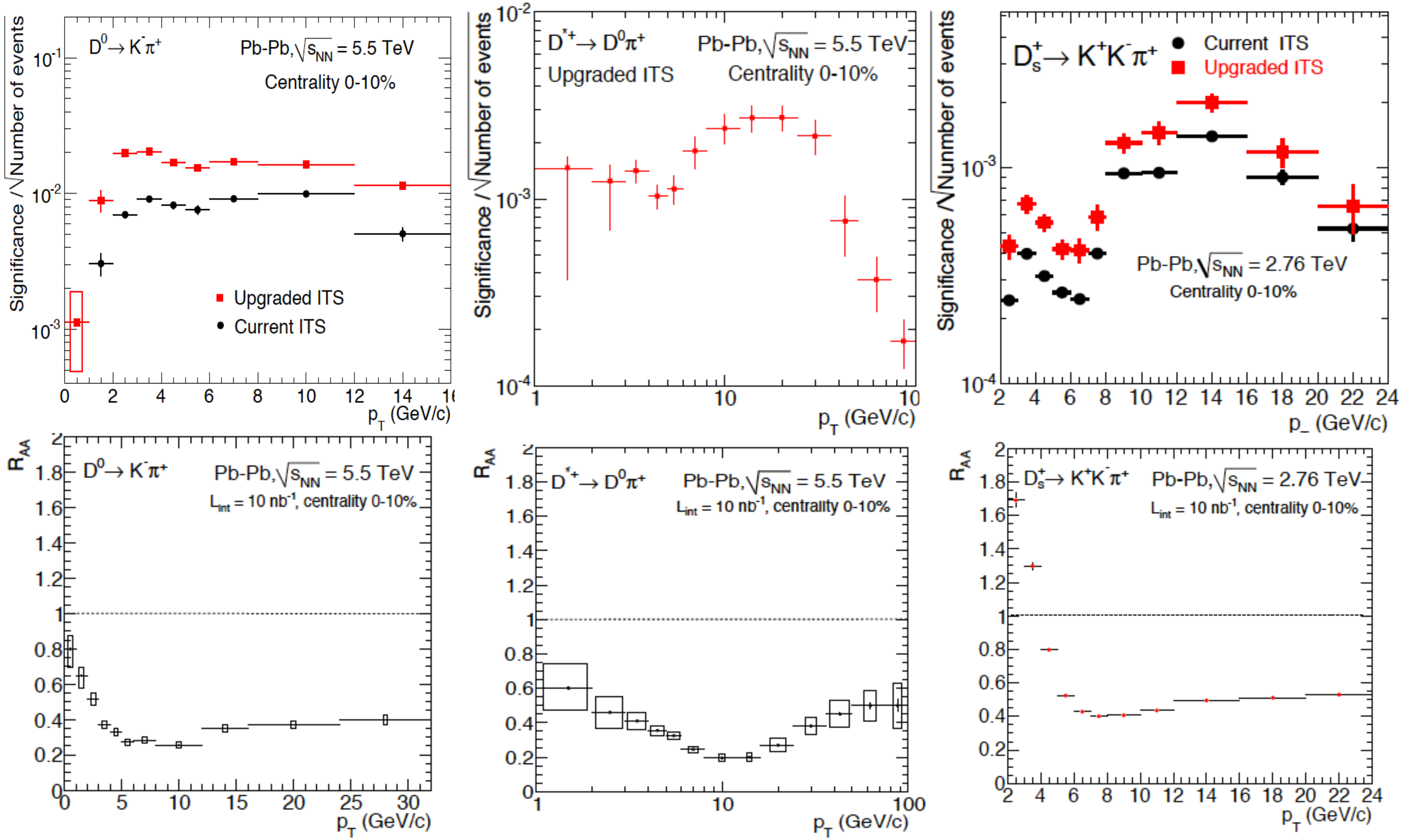
Open charm

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%)	150
Λ_c^+	$p K^- \pi^+$ (5.0%)	60

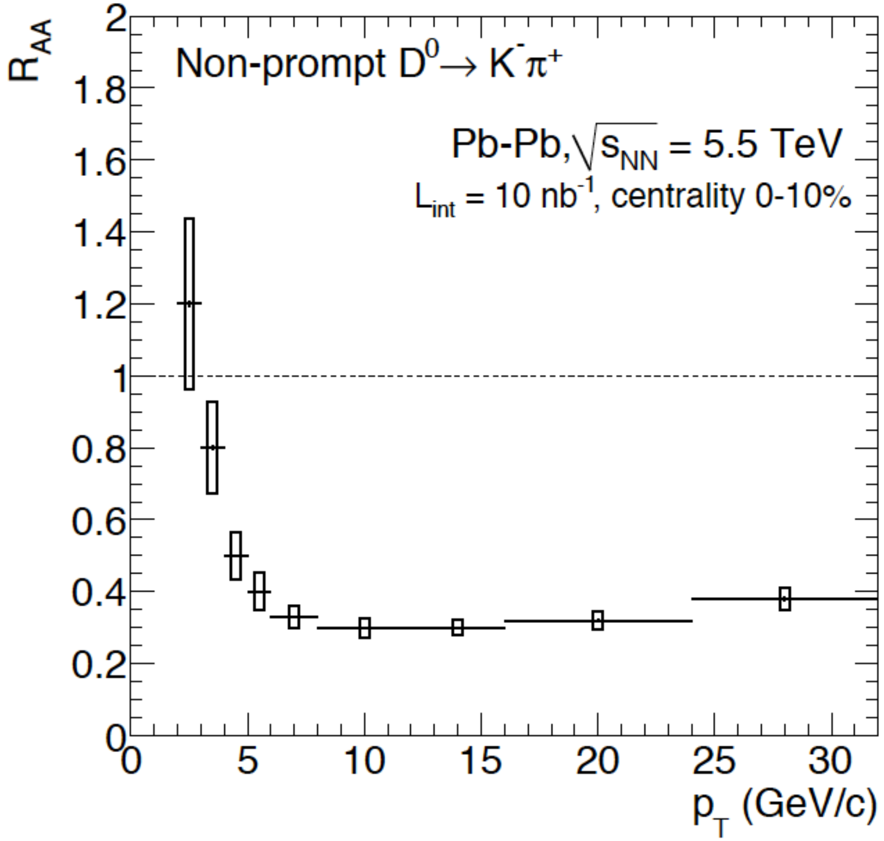
Analysis based on decay topology and invariant mass technique

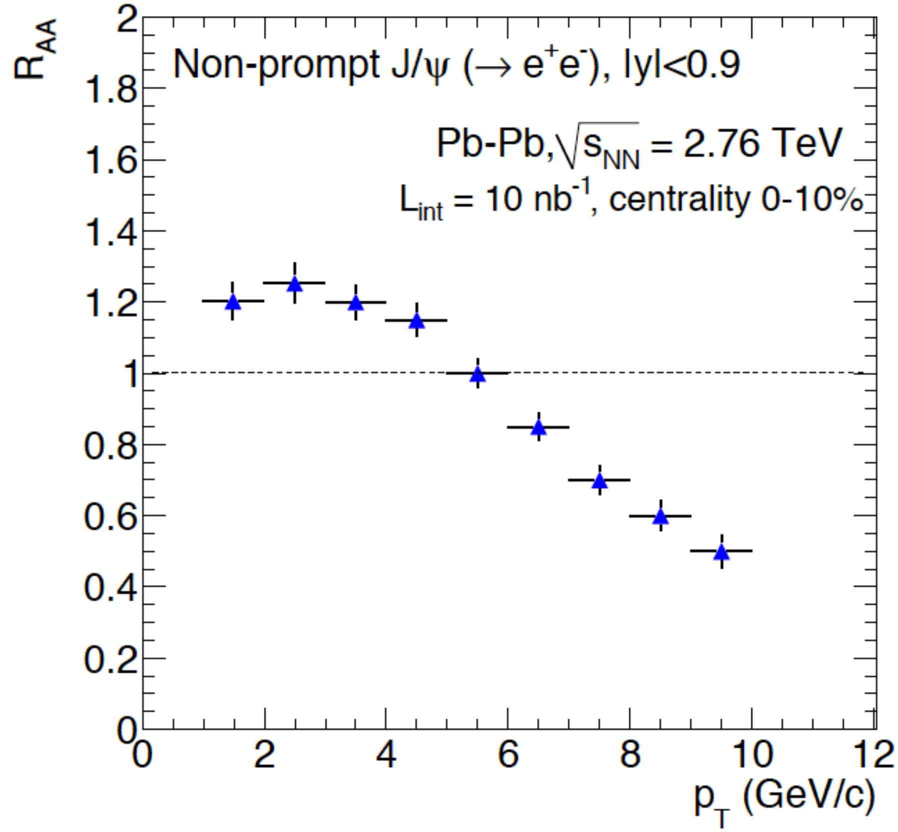
Heavy Flavor Physics Program – Physics Performance

D meson R_{AA}:



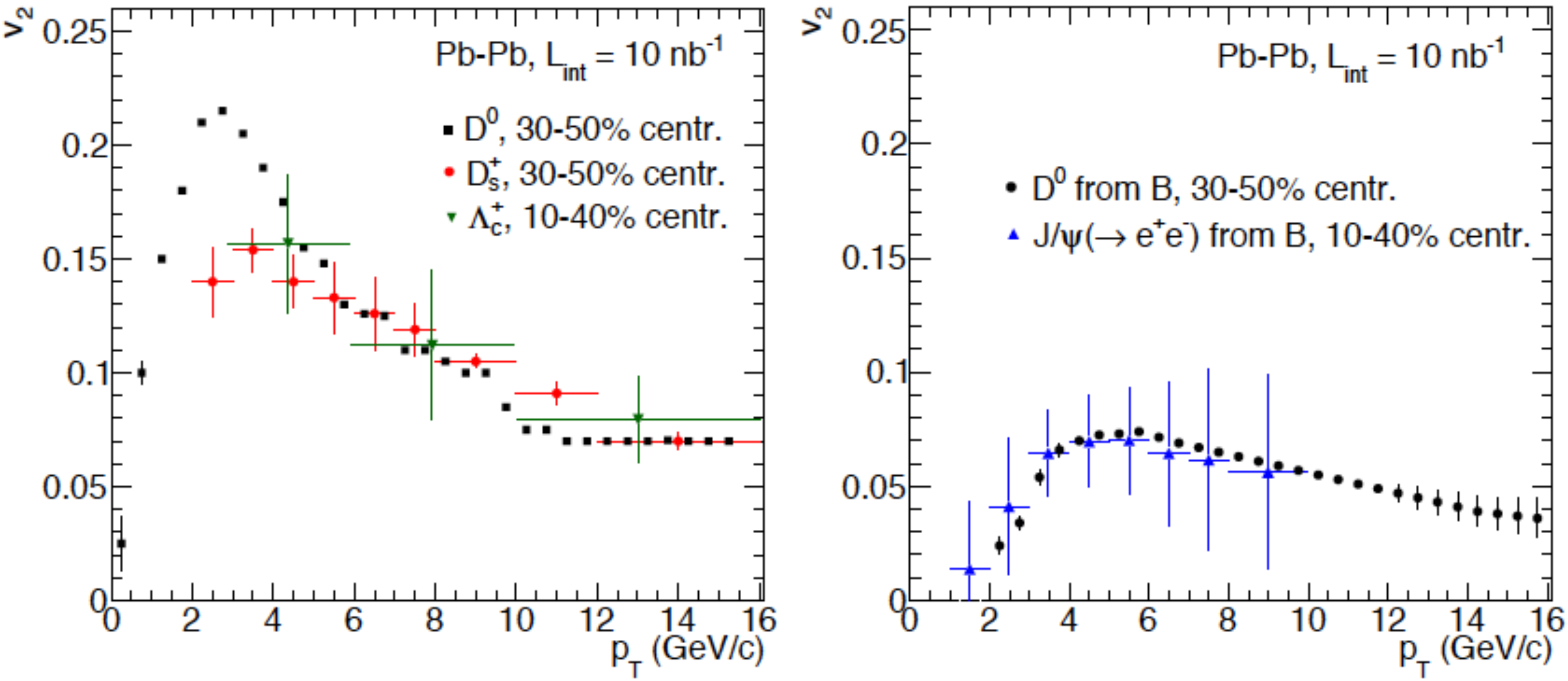
Beauty R_{AA}:





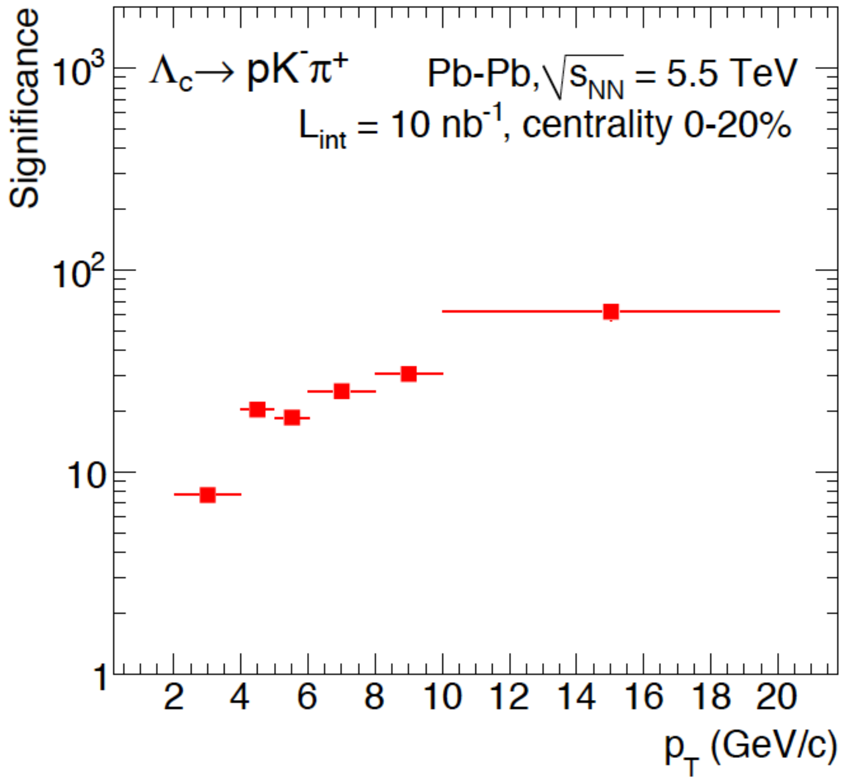
* J. Phys. G(41) 087002

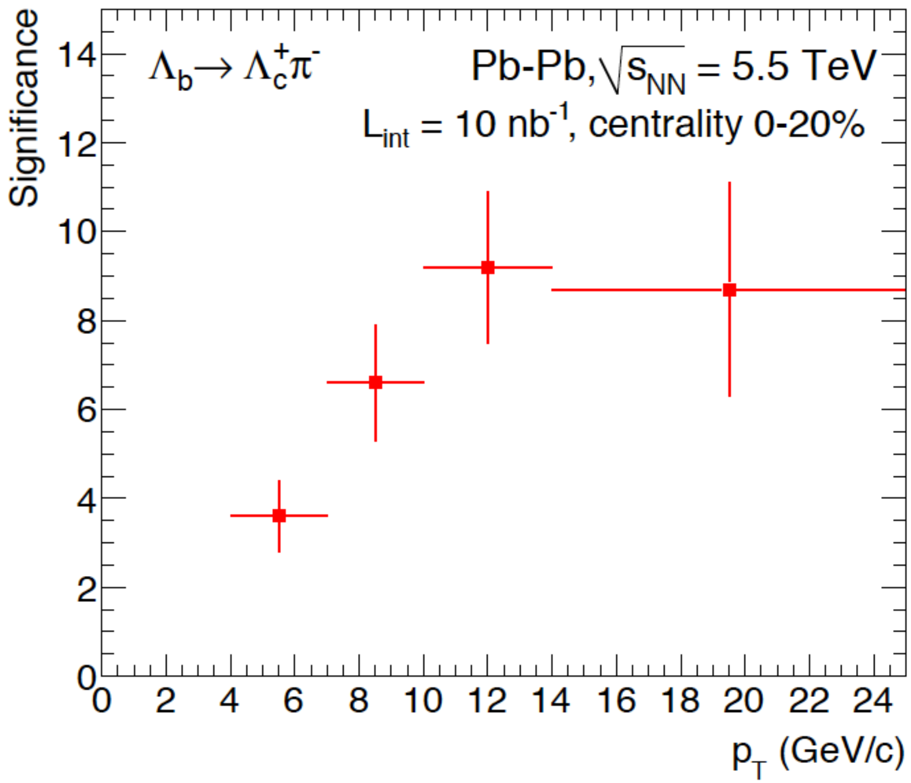
Charm and Beauty v_2:



* J. Phys. G(41) 087002

Heavy flavor baryons:





First measurments of Λ_c in Pb-Pb collisions at LHC

* J. Phys. G(41) 087002

Matrix readout architectures:

Explorer and design new matrix readout architectures other than rolling shutter scheme;

Goals: lower power, fast readout

- Projection readout method

  Four projection dimension can achieve 100% efficiency of data reconstruction for ITS outer layers of hit rate 0.3 hit/cm^2

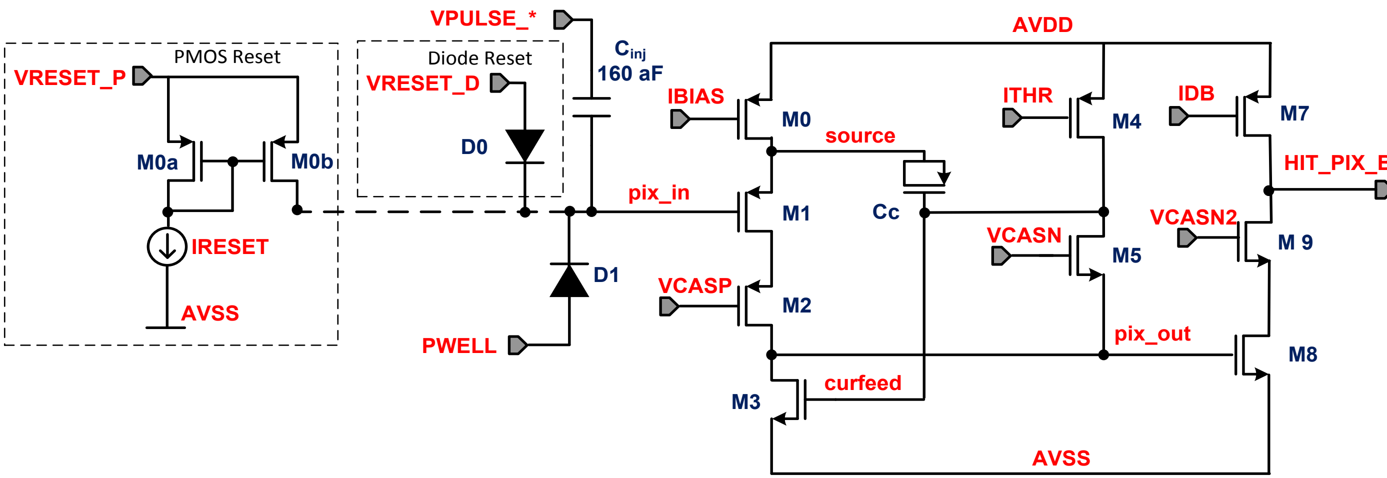
  - Implements the first prototype of OrthoPix
  - Pixel size 10 μm*10 μm, hit density of outer layers, 0.0000012 (cluster size 4).
  - Chip is functional, testing ongoing
- AERD (Address Encoder Reset Decoder) data-driven readout
  - Implements the AERD circuit in pALPIDE-1 /2
  - Zero-suppression: only read out hit pixels, speed 25ns/hit
  - Power consumes 720 pJ/hit

[Costanza, Ping Yang, Cesar, Walter, Gianluca, etc.]

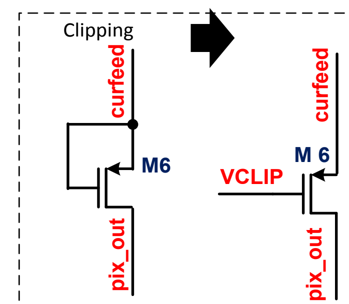
Efforts and Status – ALPIDE Chip Design

Pixel Analog Front End revision and optimization:

- Charge threshold mismatch reduction
  - Device sizing based on Monte Carlo simulation
  - 2nd stage cascode NMOS (M9)
  - Addition of protection diode on MOS gate (reliability issue, no simulation models)



Clipping transistor change



Post-layout Cd = 2.5 fF	Front-end circuit	Charge threshold		Equivalent Noise Charge
		Mean [e]	rms [e]	
	sector4 (pALPIDE-3)	90	2.0	3.3
	sector2 (pALPIDE-2)	107	6.6	4.6

Diode reset, 2 um spacing

Improvements in pALPIDE-3

- Charge threshold -15%
- Mismatch 3.3 times lower
- ENC -30 %

[Walter, Thanu, Chaosong Gao, Daehyeok, Seongjoo, Andrei]

Chip/module testing:

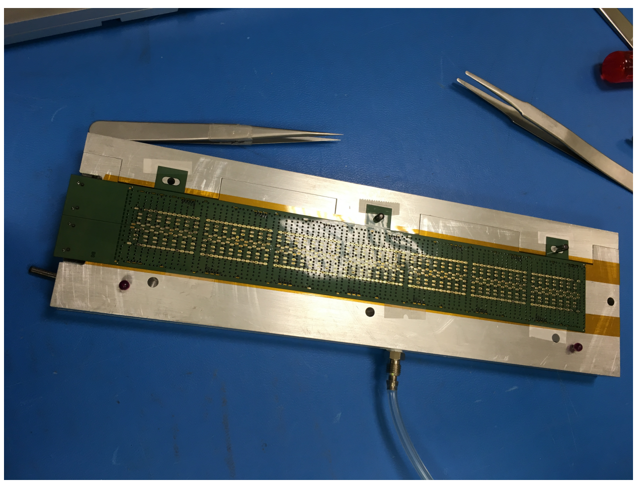
- pALPIDE-3b single chip assembly and carrier board tests
- pALPIDE-3 Multi Event Buffer Noise Occupancy tests
- Measurements on pALPIDE-3b hybrids with power supply defects
- Participated in IB 9-Chip HIC tests
- Participated in the TID chips' behavior test, ran the standard scan and compared the results before/after the irradiation;
- pALPIDE-3b light/dark effect tests
- ALPIDE carrier standard scan
- ALPIDE defective chip check, locate short position and broken pixels;
- Participate in ALPIDE Dynamic Profile test;

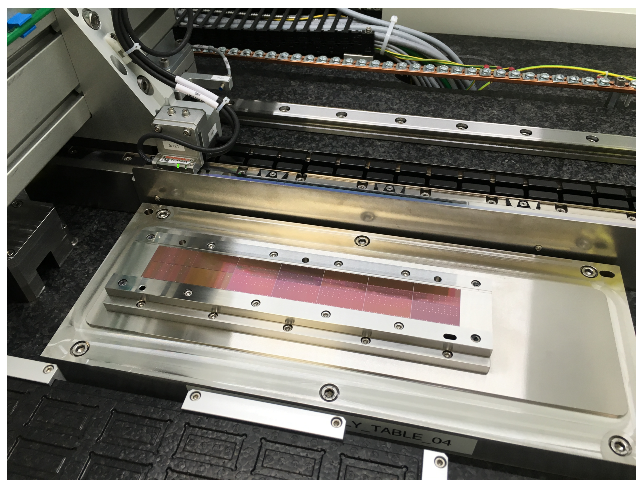
phD students: Mangmang An, Shuguang Zou

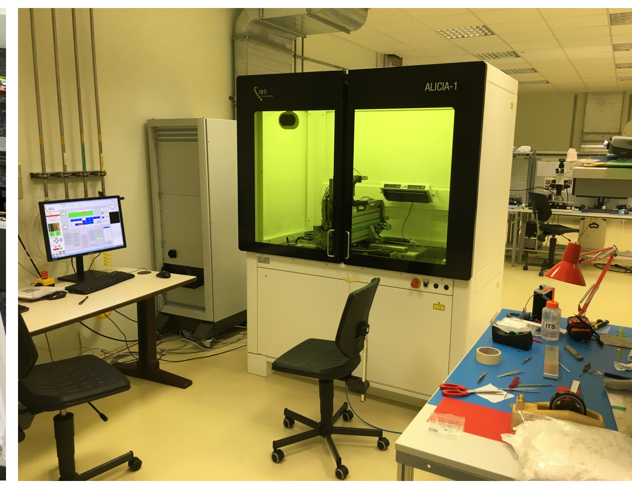
Efforts and Status – HIC Module Assembly Training

Module assembly training:

- Participated in the activities of pALPIDE-3 Single Chip Assembly
- Studied the procedure of single Chip-FPC sample cross slicing/section check;
- Participated in exploring the heat-soldering technology for Chip-FPC and assisted the CCNU group to establish the setup for the ALPIDE test.
- Participated in the Module Assembly Machine (MAM) training, operate the MAM to do the whole procedures of IB/OB module assembly.







phD student: Mangmang An, Shuguang Zou