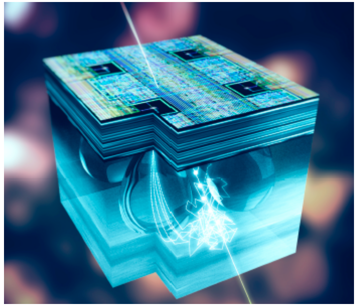
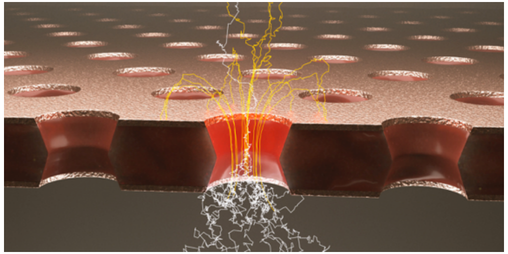
Upgrade of the ALICE central barrel tracking detectors: ITS and TPC



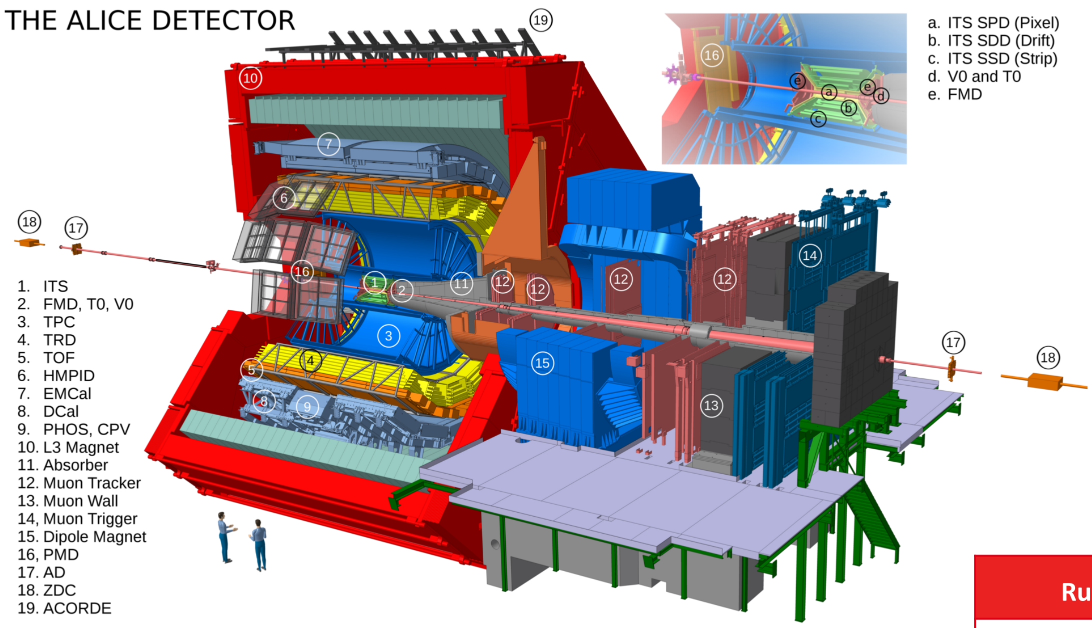


Piotr Gasik

(Technical University of Munich, Excellence Cluster 'Universe')

on behalf of the ALICE Collaboration

ALICE in Run 1 and Run 2



ALICE detector

- Central Barrel: -0.9 < η < 0.9
- Muon spectrometer: -4.0 < η < -2.5
- Forward detectors: trigger, centrality

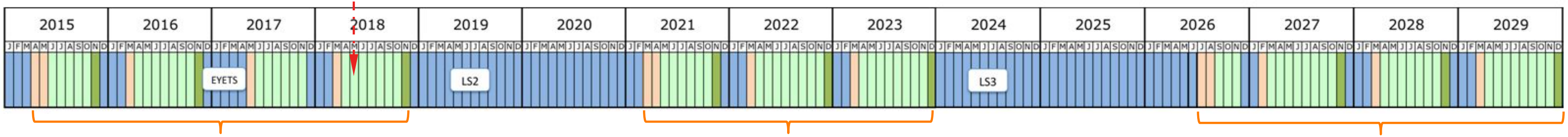
Operation in Run 1 and Run 2

- Tracking and PID in large kinematic range
- High resolution vertex reconstruction

Run 1 (2009 – 2013)
Pb-Pb @ $\sqrt{s_{NN}}$ = 2.76 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV
pp @ $\sqrt{s}$ = 0.9, 2.76, 7, 8 TeV

Run 2 (2015 – 2018)
Pb-Pb @ $\sqrt{s_{NN}}$ = 5.02 TeV Xe-Xe @ $\sqrt{s_{NN}}$ = 5.44 TeV
p-Pb @ $\sqrt{s_{NN}}$ = 5.02, 8.16 TeV
pp @ $\sqrt{s}$ = 5, 13 TeV

Heavy-Ion Collisions at LHC



Run 2: $\mathcal{L}_{\text{Pb-Pb}} = 1.0\ \text{nb}^{-1}$

Run 3: $\mathcal{L}_{\text{Pb-Pb}} = 6.0\ \text{nb}^{-1}$

Run 4: $\mathcal{L}_{\text{Pb-Pb}} = 7.0\ \text{nb}^{-1}$

ALICE strategy for Run 3 + Run 4:

- 50 kHz Pb-Pb interaction rate (now <10 kHz)
- Experiment upgrades (LS2)
- Collect $\mathcal{L}_{\text{Pb-Pb}} > 13\ \text{nb}^{-1}$

"Future prospects for heavy ions at the LHC", **J. Jowett, Tue. 9:00**

ALICE physics goals

- Heavy-flavour mesons and baryons (down to very low p_T) → mechanism of quark-medium interaction
- Charmonium states → dissociation/regeneration as tool to study de-confinement and medium temperature
- Di-leptons from QGP radiation and low-mass vector mesons → χ symmetry restoration, initial temperature and EOS
- High-precision measurement of light and hyper-nuclei → production mechanism and degree of collectivity
- Need MB readout at highest possible rate → no dedicated trigger possible

"The future of high-energy heavy-ion facilities", **J.F. Grosse-Oetringhaus, Sat. 10:00**

ALICE Upgrade Plans

Un-triggered data sample

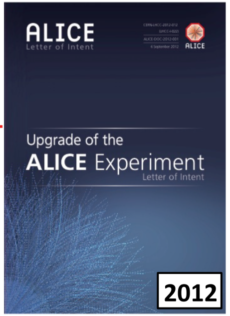
- Write all Pb-Pb interactions at 50 kHz
- Run 3 + Run 4: increase MB sample x50-100 wrt. Run 2

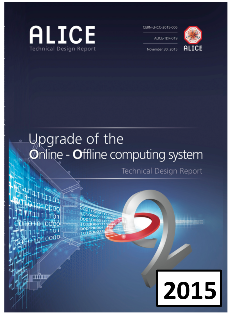
Improve tracking efficiency and resolution at low p_T

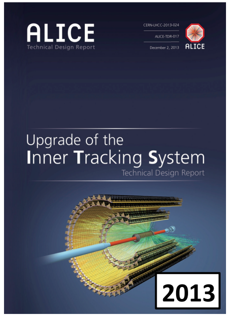
- Increase tracking granularity
- Reduce material thickness
- Minimize the distance to IP

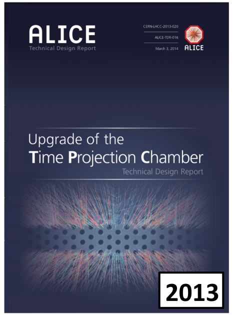
Preserve particle identification (PID)

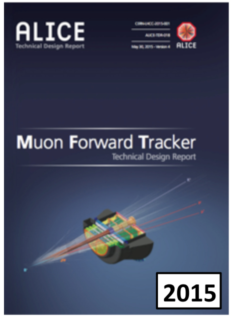
- Consolidate and speed-up main ALICE PID detectors











ALICE in Run 3 and Run 4

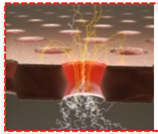
New Inner Tracking System (ITS)

- Complementary Metal-Oxide-Semiconductor (CMOS) Monolithic Active Pixel Sensor (MAPS) technology
- Improved resolution, less material, faster readout

New Muon Forward Tracker (MFT)

- CMOS Pixels, MAPS technology
- Vertex tracker at forward rapidity

S. Siddhanta, Tue. 9:40



New TPC Readout Chambers (ROCs)

- Gas Electron Multiplier (GEM) technology
- New electronics (SAMPA), continuous readout

New Fast Interaction Trigger (FIT) Detector

- Centrality, event plane

I.G. Bearden, Poster 66

FoCal proposal (Run 4)

N. Novitzky, Poster 771

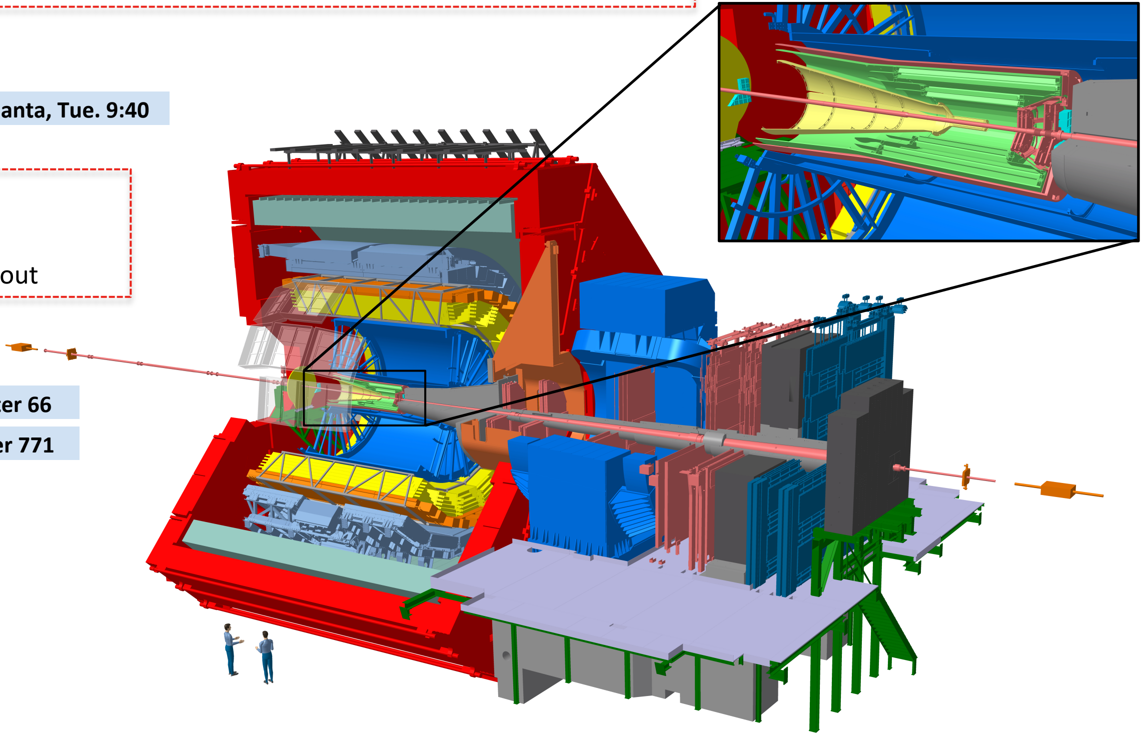
- Measure forward direct photons

Readout upgrade

- TOF, TRD, MUON, ZDC, Calorimeters

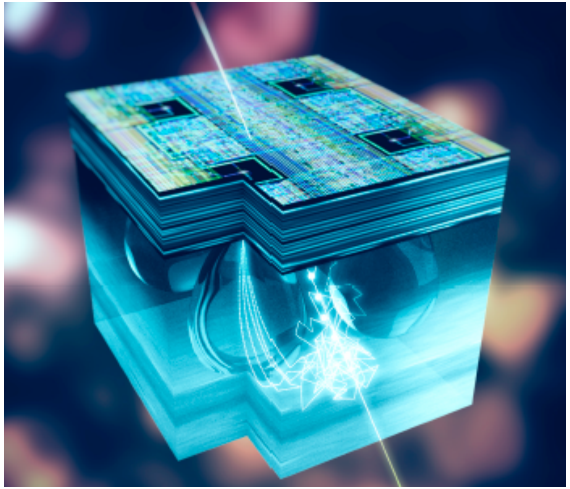
Integrated Online-Offline system (O^2)

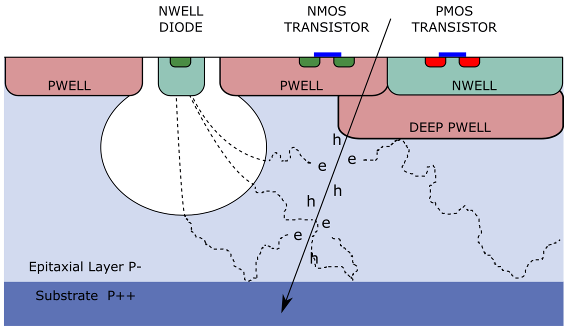
- Record MB Pb-Pb data at 50 kHz



ALICE
Inner Tracking System
upgrade

MAPS – Monolithic Active Pixel Sensor



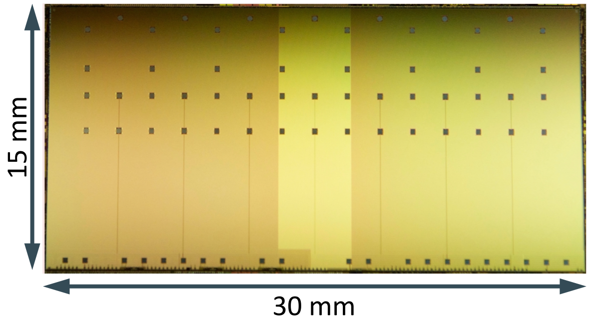


CMOS Monolithic Active Pixel Sensors,

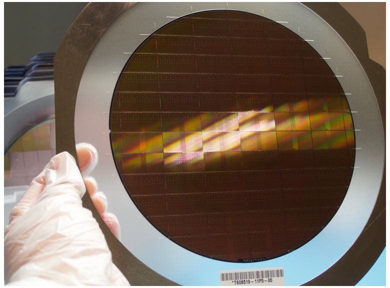
- TowerJazz 180 nm technology
- Primary electron collection efficiency 100%
- Pixel pitch: 29 × 27 μm^2

- **Low power consumption ~40 mW/cm^2**
- **Input capacitance C_{in} = 5 fF**
- **Input charge Q_{in}(MIP) = 1300 e ⟶ V = 40 mV**
- **Spatial resolution 5 μm**
- Event time resolution < 1 μs
- Radiation hardness:
  expected in Run 3 and 4 < 300 krad (< 2.0 × 10^{12} 1 MeV n_{eq}/cm^2)

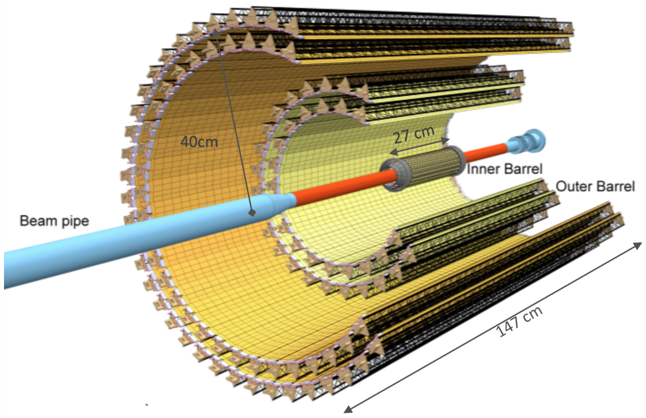
New ITS



ALPIDE (ALICE Pixel Detector)



- Developed for the ALICE upgrade (ITS and MFT)
- 130 000 pixels/cm^2
- Max. particle rate: ~100 MHz/cm^2
- Spatial resolution: ~5 µm
- Thickness: 50 µm for the inner layers
- Fake-hit rate: < 10^{-9} per pixel per event

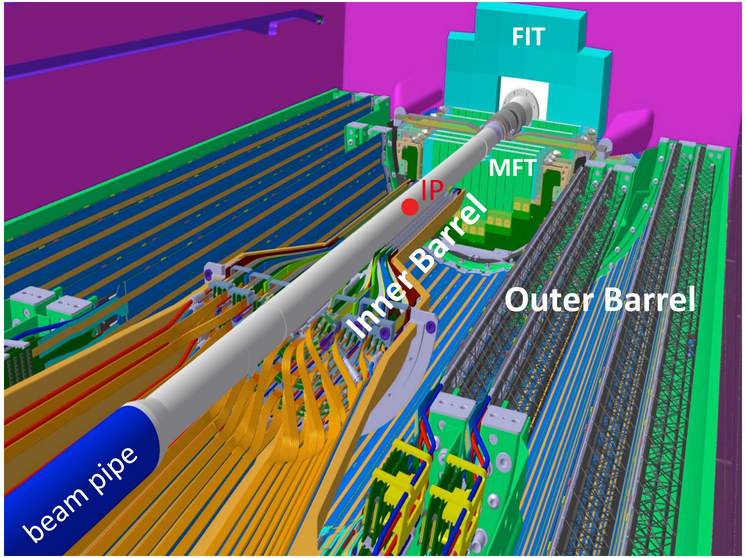


10 m^2 active silicon area, 12.5×10^9 pixels

- Closer to IP: 39 mm ⟶ 22 mm
- Thinner (X_0 for innermost layers): ~1.14 % ⟶ ~0.30 %
- Smaller pixels: 50 × 425 µm^2 ⟶ 27 × 29 µm^2
- Granularity: 20 ch/cm^3 ⟶ 2000 pixels/cm^3
- Readout rate: 1 kHz ⟶ 100 kHz

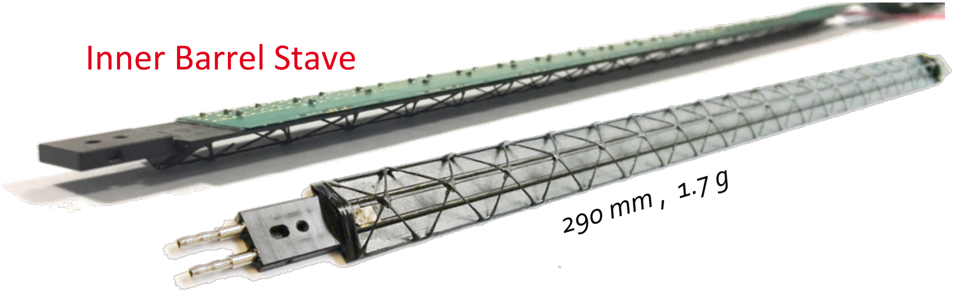
ITS Layout

- 7 layers (inner/middle/outer): 3/2/2
  from R = 22 mm to R = 400 mm
- 192 staves (IL/ML/OL): 48/54/90
- Ultra-lightweight support structure and cooling
- Possible to remove and re-install the detector for maintenance during the yearly shutdowns

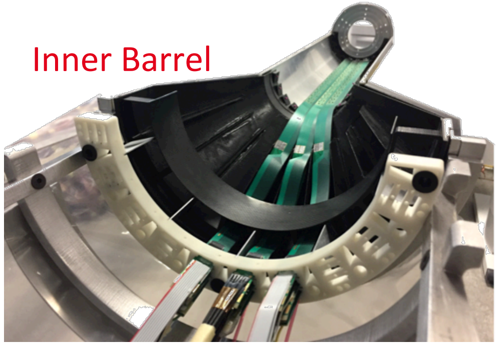


ITS Construction

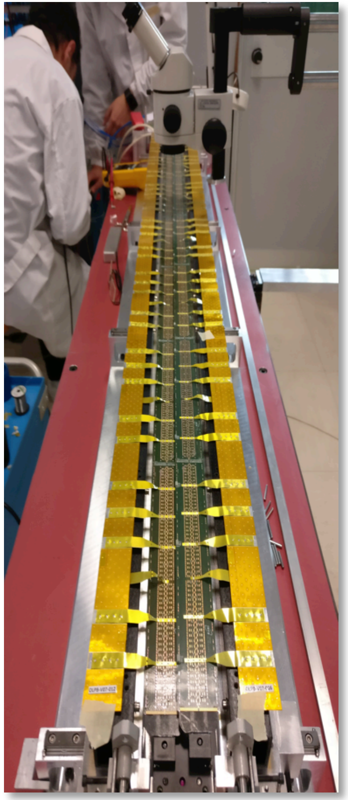
Inner Barrel Stave



Inner Barrel



Outer Barrel Stave



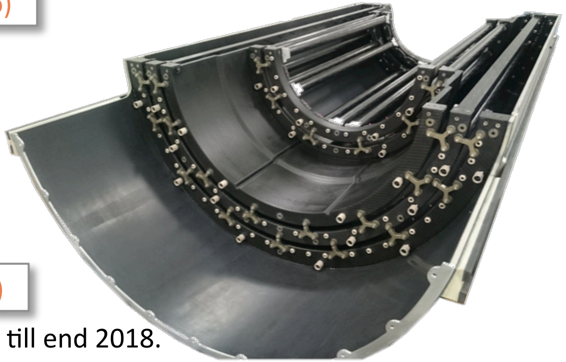
Module Production (CERN, BARI, Liverpool, Pusan, Strasbourg, Wuhan)

- Production is progressing well (20% done) in all sites and will continue till Feb 19
- Production yield 82%, in line with projected value

Stave Production (Berkeley, CERN, Daresbury, Frascati, Nikhef, Torino)

- Production has started in all sites (30 IB staves, 8 OB staves)
- Production will continue till April 2019

Outer Barrel



Mechanics (Berkeley, CERN, Padua)

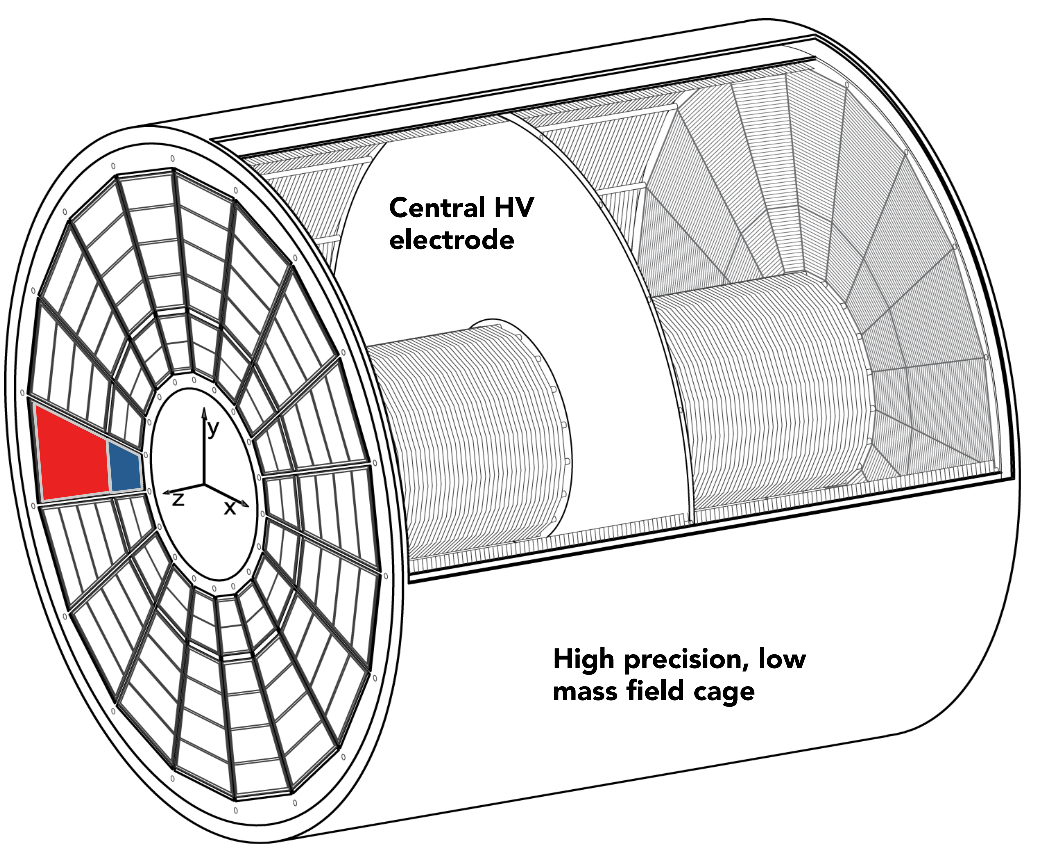
- Construction of all carbon mechanical structures completed

Readout Electronics (Bergen, Berkeley, CERN, Nikhef, Prague, Kosice)

- Development completed. Production has started and will continue till end 2018.

ALICE
Time Projection Chamber upgrade

ALICE TPC

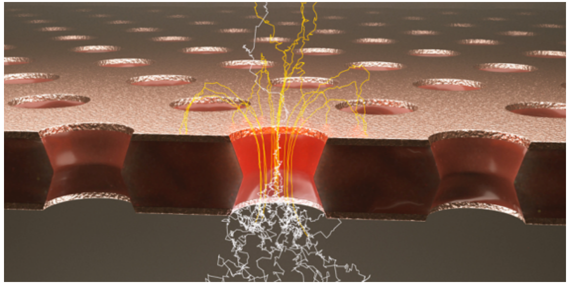


- Diameter: 5 m, length: 5 m
- Gas: Ne-CO_2-N_2, Ar-CO_2
- Max. drift time: ~100 µs
- 18 sectors on each side
- Inner and outer read out chambers: IROC, OROC

- Current detector (Run 1, Run 2):
  - 72 MWPCs
  - ~550 000 readout pads
  - Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
  - Rate limitation: few kHz

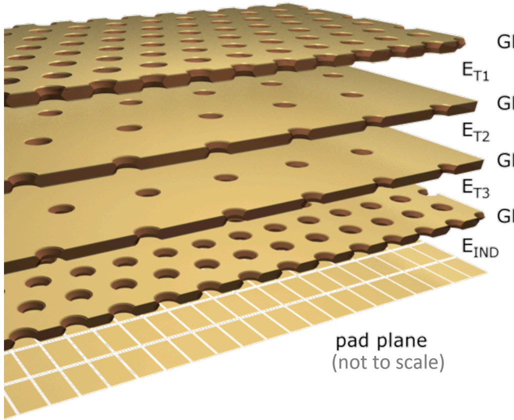
Operate TPC at 50 kHz ⟶ no gating grid

Continuous Readout with GEMs



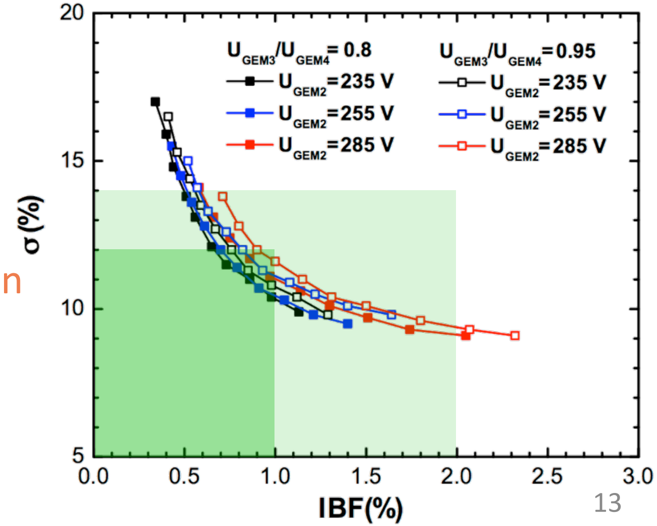
TPC Upgrade requirements:

- Nominal gain = 2000 in Ne-CO_2-N_2 (90-10-5)
- IBF < 1% (ε = 20)
- Energy resolution: σ_E/E < 12% for ^{55}Fe
- Stable operation under LHC Run 3 conditions
- Unprecedented challenges in terms of loads and performance



Baseline solution: 4-GEM stack

- Combination of standard (S) and large pitch (LP) GEM foils
- Highly optimized HV configuration
- Result of intensive R&D



Read-Out Chambers (ROCs)

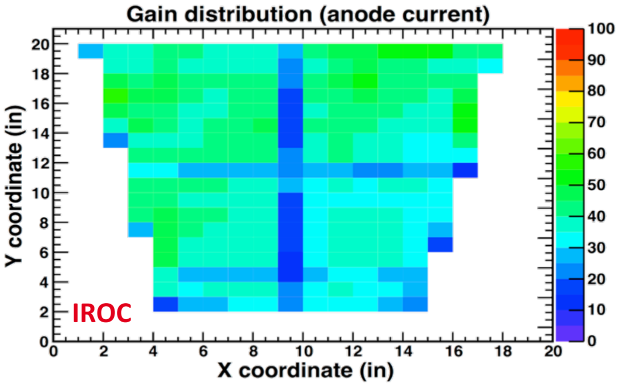
- Production of 40 IROCs and 40 OROCs until September 2018

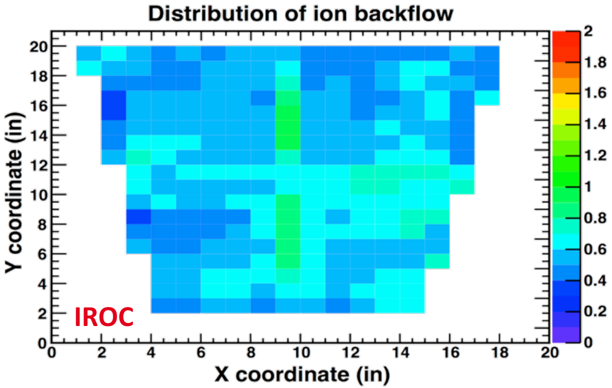
ROC assembly: Yale (IROC), GSI (OROC), HPD Bucharest (OROC); **ROC bodies**: Heidelberg, Frankfurt, UT Knoxville

- Production of 640 GEM foils + spares finishes within the next weeks

GEM QA: CERN, Budapest, Helsinki; **GEM framing**: Munich, Bonn, GSI, Wayne State

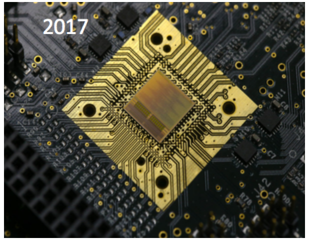
- All chambers thoroughly qualified in terms of:
  - Gas tightness
  - Gain and ion backflow uniformity
  - Stability (long-term irradiation with X-rays)
- Selected chambers tested at the LHC

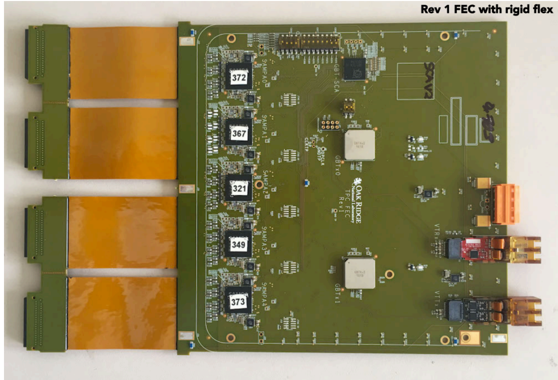


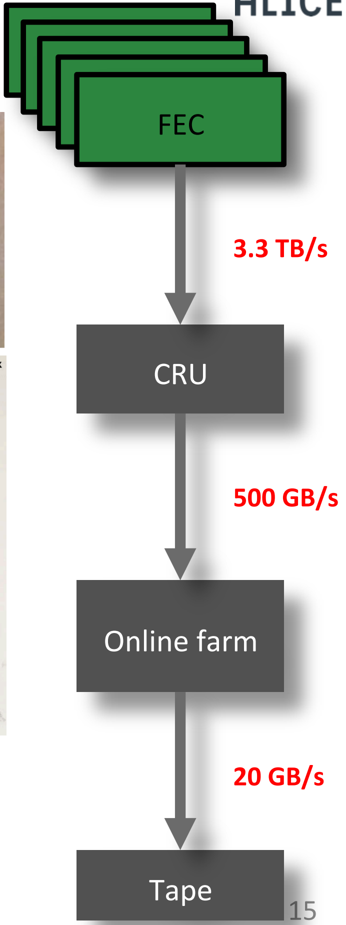


TPC Readout Electronics

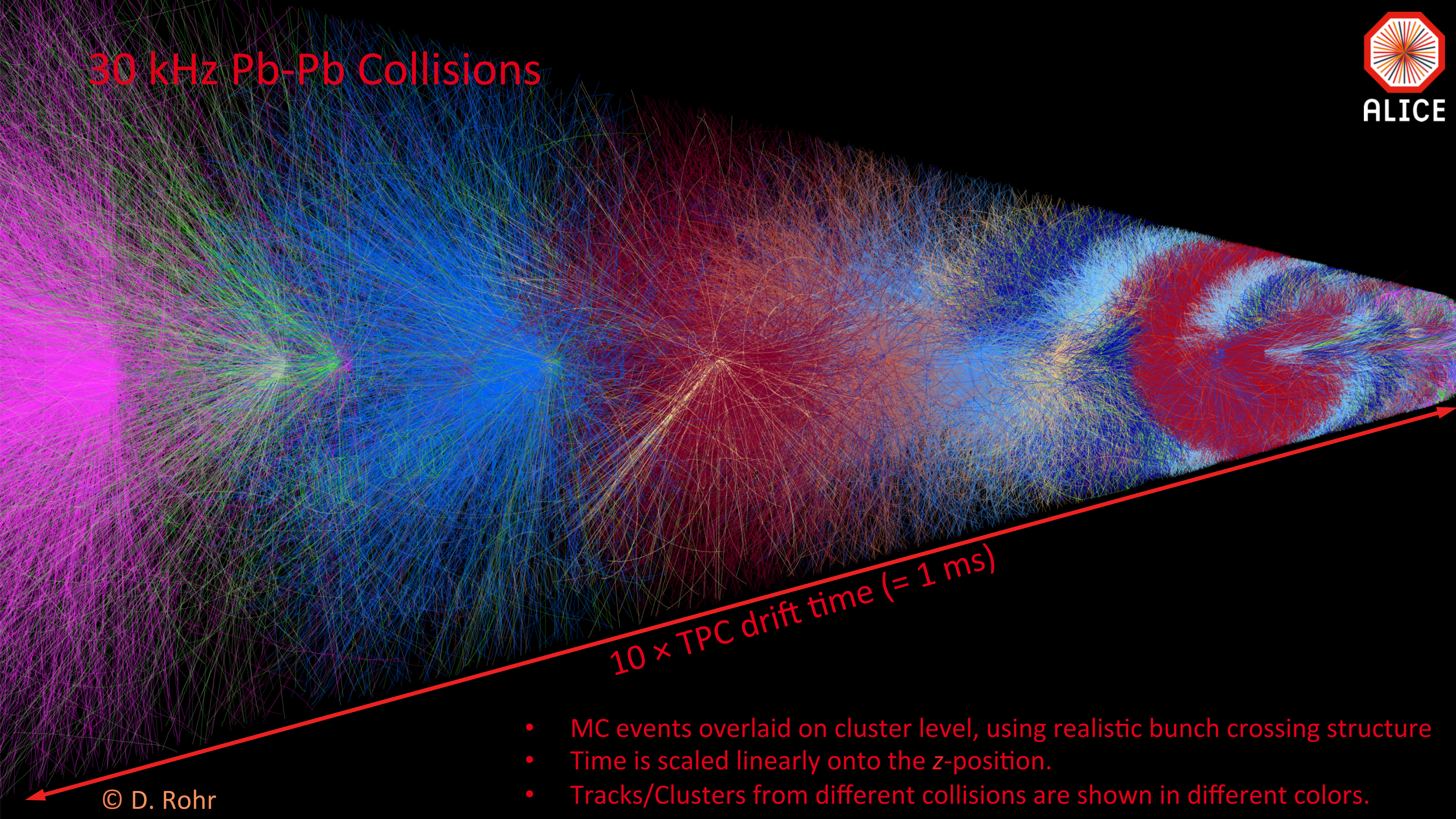
- Newly developed FE **SAMPA** ASIC (130 nm TSMC CMOS)
  - **32 channels (positive or negative input)**
  - PASA preamplifier + 10-bit ADC
  - Programmable conversion gain and peaking times
  - DSP, Memory, High speed e-links
  - **Readout mode: continuous or triggered**
  - **Excellent noise figure of 670 e$^-$**
  - Production and testing until **Sep. 2018**
- Front-End Cards
  - 5 SAMPA chips per FEC (3276 FECs in total)
  - **System continuously digitizes signals at 5 MHz**
  - **All ADC values are read out - 3.28 TB/s**
  - FECs send digitized data over fiber optic links to ALICE Common Readout Units (CRU)
  - Production and testing until **Feb. 2019**



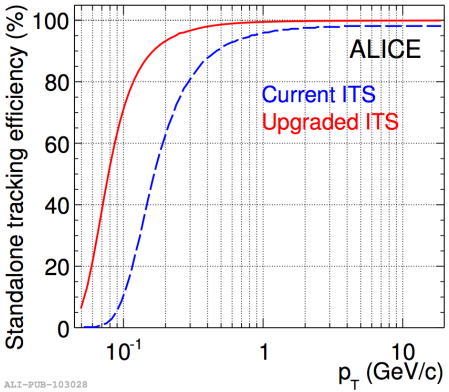


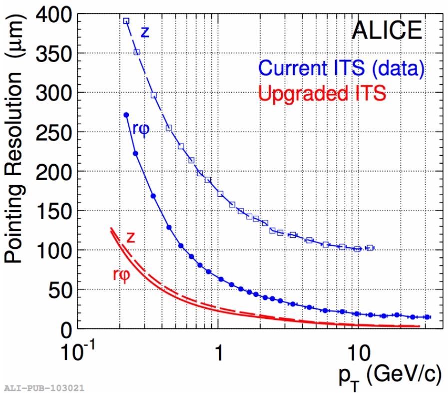


Performance
of the upgraded
ALICE Central Barrel

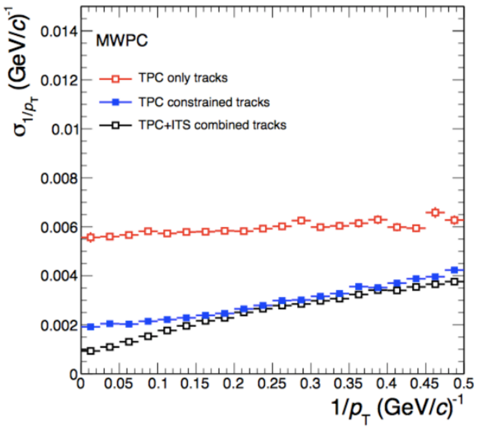

30 kHz Pb-Pb Collisions
ALICE
10 × TPC drift time (= 1 ms)
• MC events overlaid on cluster level, using realistic bunch crossing structure
• Time is scaled linearly onto the z-position.
• Tracks/Clusters from different collisions are shown in different colors.
© D. Rohr

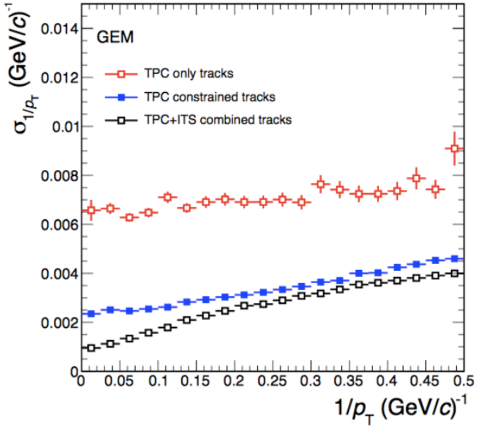
Detector Performance in Run 3 and Run 4





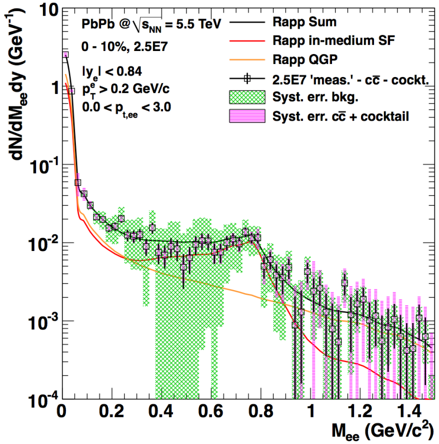
- **New ITS**
  - Improved tracking efficiency
  - Improved tracking resolution
  - Pointing resolution ×3 better in transverse plane (×6 along beam)

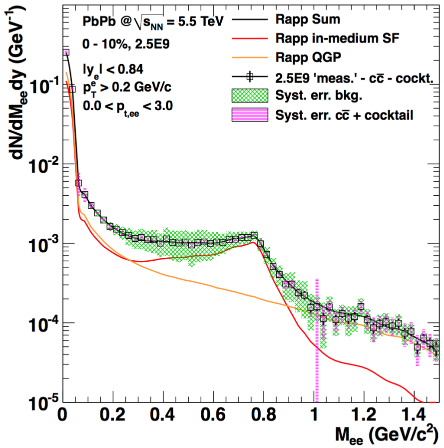




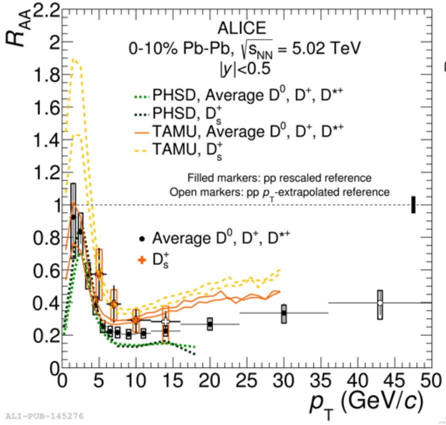
- **New TPC Readout Chambers (GEM):**
  - Preserve momentum resolution for TPC + ITS tracks
  - Preserve particle identification via d*E*/dx (arXiv:1805.03234, submitted to NIM A)

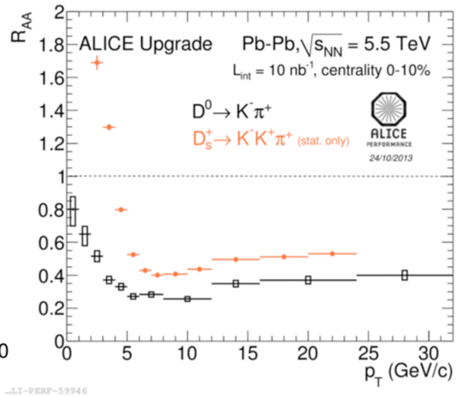
Physics Performance in Run 3 and Run 4





- Low Mass di-electrons
  - Initial temperature from EM radiation
  - Cocktail-subtracted distributions $|\eta| < 0.9$
  - Improved uncertainty figures in Run 3 and 4

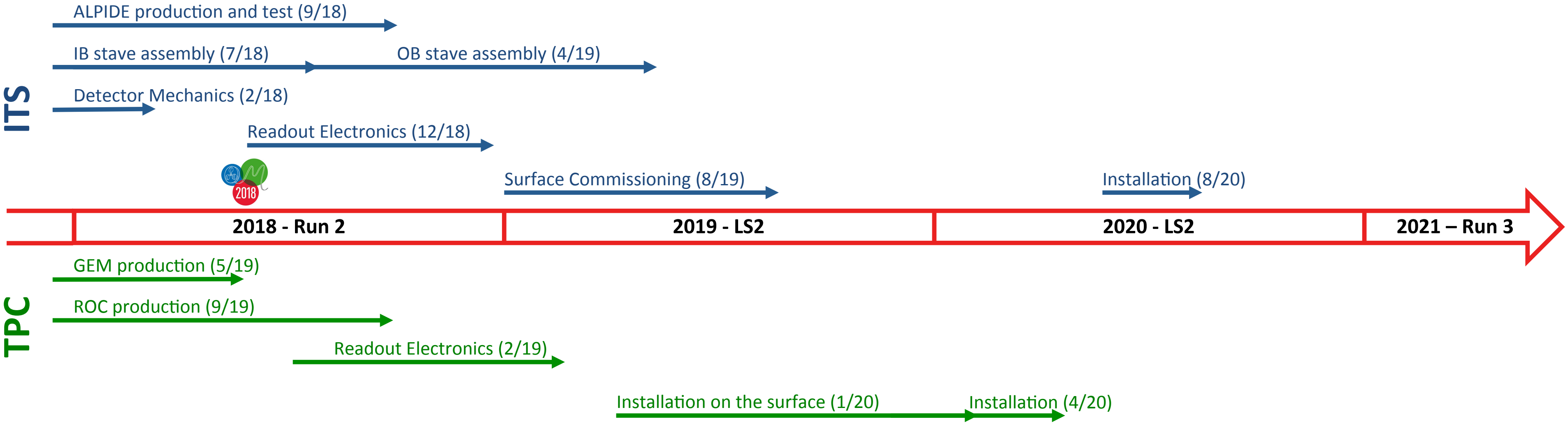




- D^0, D$^+$, D$_s$ production
  - Measure R_{AA} with percent-level precision down to low p_T
  - Precise comparison between strange and non-strange D mesons

Summary and Outlook

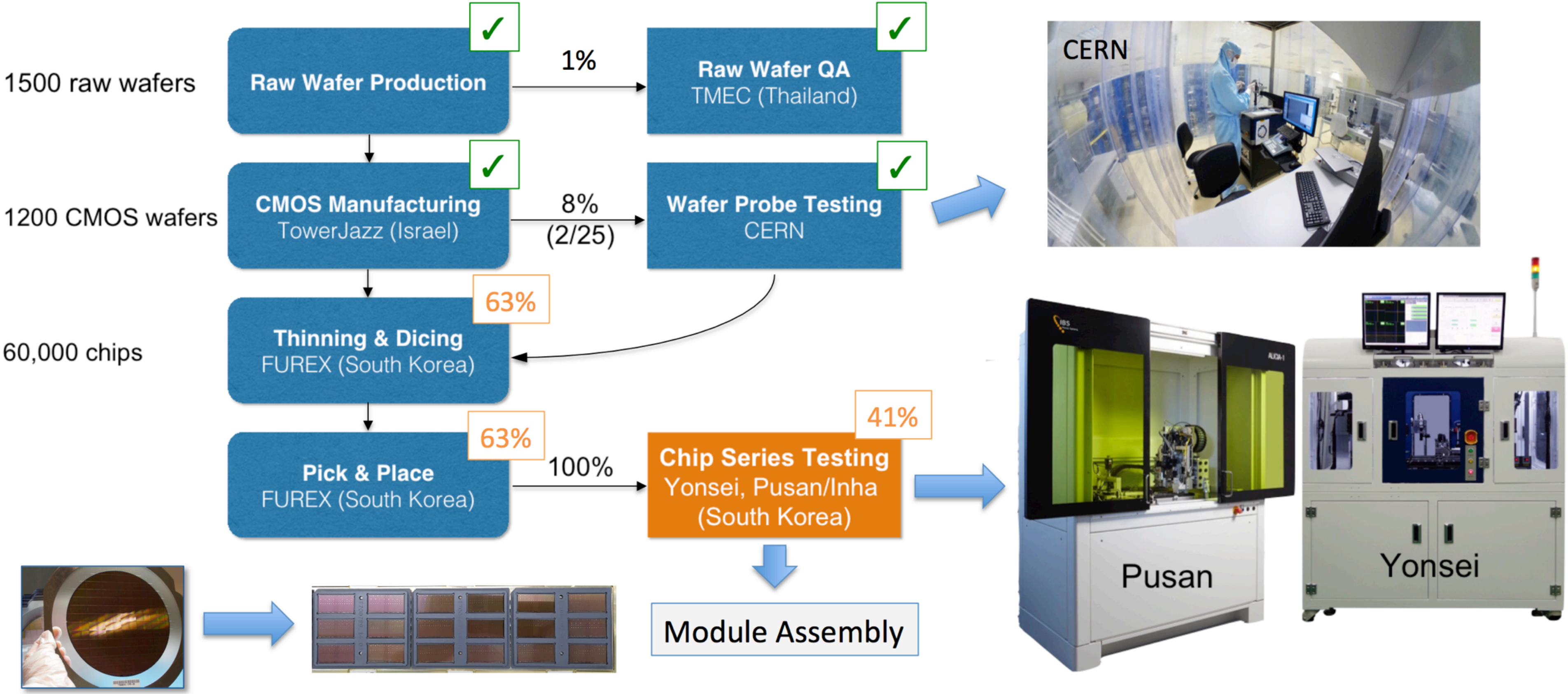
- About 10-fold increase of Pb-Pb delivered luminosity in Run 3 and Run 4
- ALICE will collect all MB events at 50 kHz Pb-Pb collisions, factor 50-100 more than in Run 2
- New ITS based on ALPIDE MAPS sensor will enhance the tracking and vertexing performance
- Upgraded TPC with GEM ROCs will be read out continuously preserving tracking and PID capabilities
- Production of all parts is ongoing, installation during LHC LS2 starts in December 2018
- The central barrel system upgrade (together with HL-LHC) will give access to physics not reachable up to now



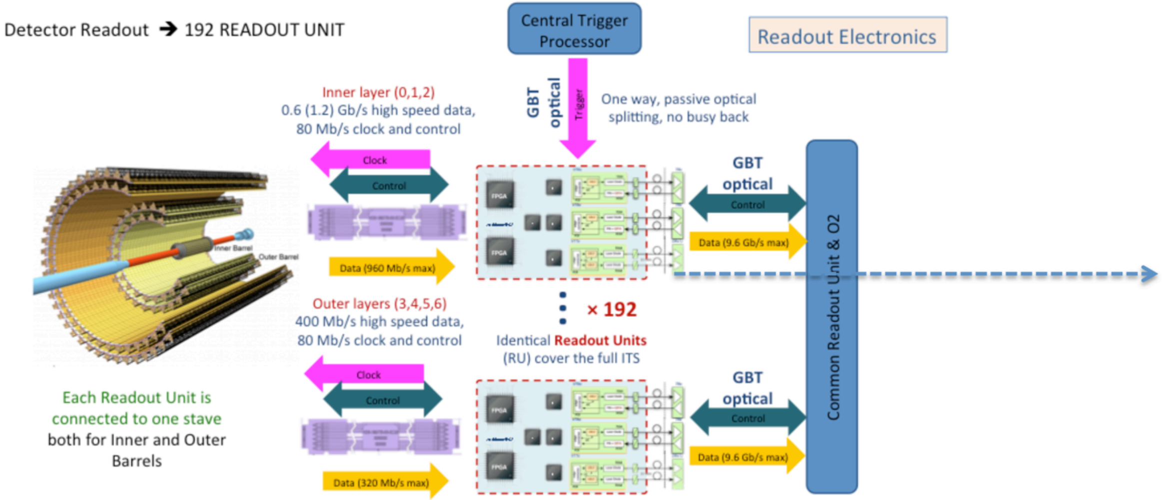
Thank you!

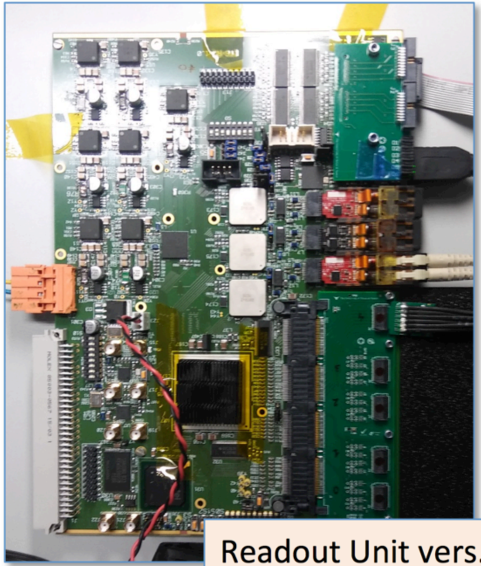
BACKUP SLIDES

ALPIDE Production Status



ITS Readout





Readout Unit vers.1

- 2015-16 Readout Components radiation test and selection (Readout Prototype Board RUv0)
- 2017 System integration (DAQ, trigger, control), integration with services (RUv1)
- 2018 Production May-December (RUv2)

ITS Mechanics

- 7 layers (inner/middle/outer): 3/2/2
  from R = 22 mm to R = 400 mm
- 192 staves (IL/ML/OL): 48/54/90
- Ultra-lightweight support structure and cooling
- Assembly of staves is ongoing
- Inner and Outer Barrel mechanics ready

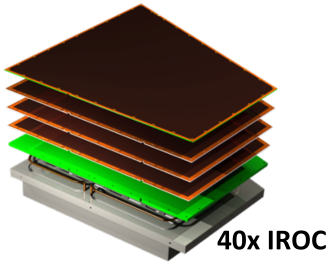
Outer Detector Barrel

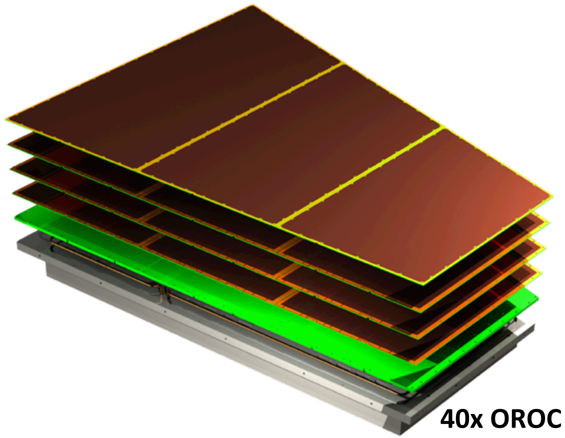
Inner Detector (+Service) Barrel

TPCU production progress

ROC components	Needed	Produced	Fraction
Al-bodies	80	80	100 %
Padplanes	160	160	100 %
FEC connectors	15’000	15’000	100 %
HV cables	1’300	1’300	100 %
GEMs	720 (10% spares)	620	86 %
GEM frames	640	640	100 %

Assembly step	Goal	Assembled	Fraction
Chamber bodies (IROC/OROC)	40/40	27/22	61 %
Padplane + FEC connectors (IROC/OROC)	40/120	40/120	100 %
GEM framing	640	435	68 %
Assembled & Tested ROCs (IROC/OROC)	40/40	19/16	44 %





Tests in ALICE cavern

- Test 2x IROC and 2x OROC at a time
- Chambers are installed in the Miniframe, few meters from the IP
- Installation of the chambers non-trivial
- Tests are performed in the transportation boxes
- Final HV scheme
  (cascaded PS, ammeters, cables, protection resistors, patch boxes)
- Open loop gas system (Ne-CO_2-N_2)
- **2017**: IROC/03 and OROC/PRR successfully operated for more than 200/500 h
- **2018**: 4xROCs, stable operation (100%) since first “stable beam”
- Swap chambers during TSs
- More chambers can be swapped
  in case of long enough access