ALICE Detector Upgrade
during Long Shutdown 2 (LS2)

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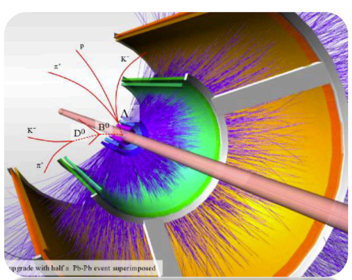
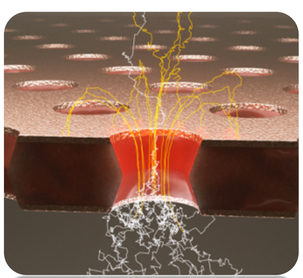
ITS



J.Phys. G41 (2014) 087002

TPC



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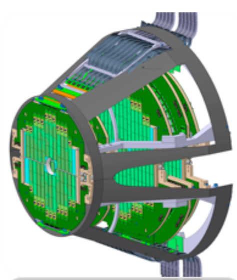
MFT



CERN-LHCC-2015-001

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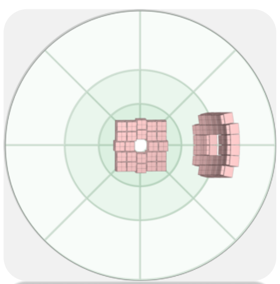
FIT



Readout

TOF, TRD, MUON, ZDC, EMCs

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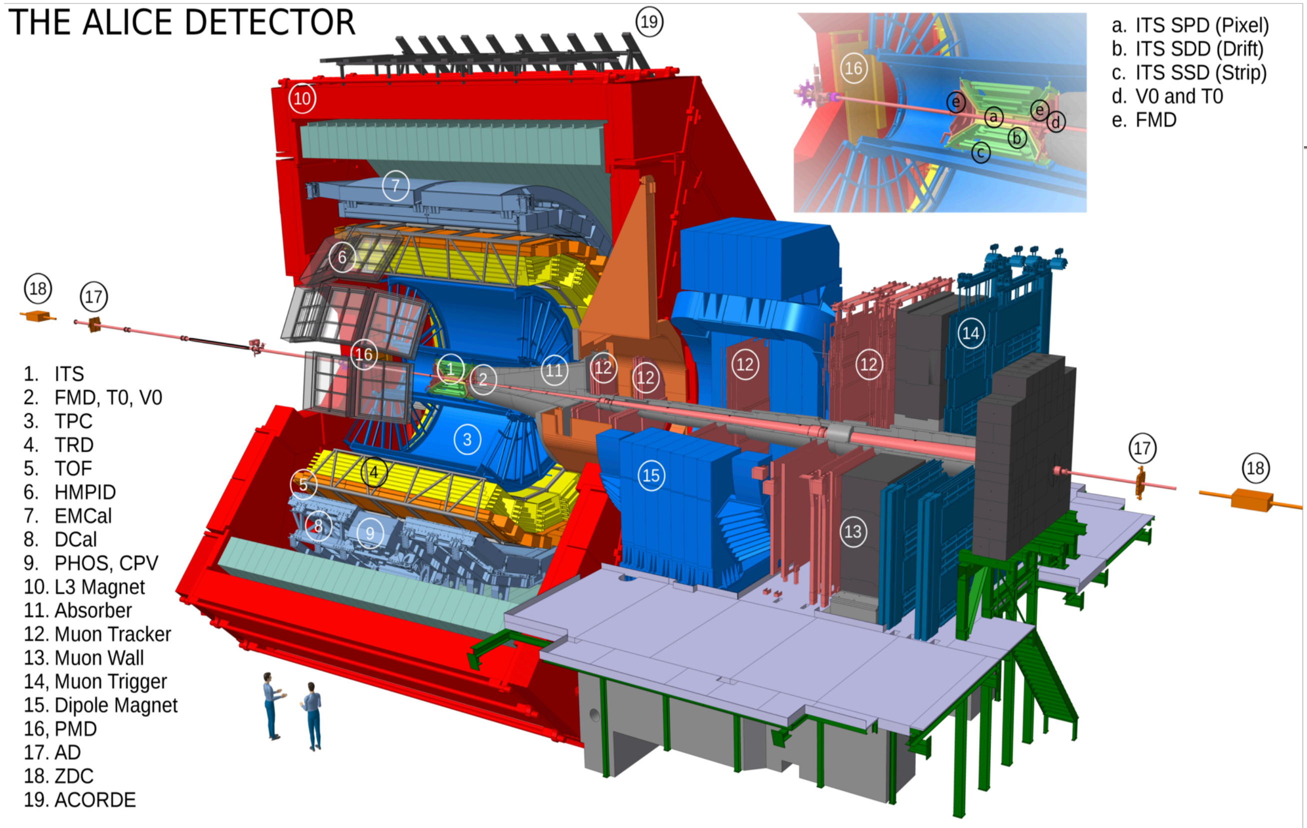
ALICE in Run 1 and Run 2



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

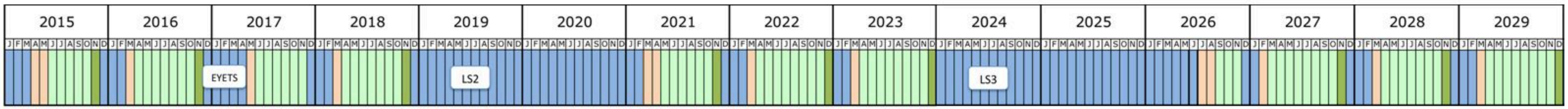
ALICE Detector:

- ✓ Central Barrel: $|\eta| < 0.9$
- ✓ Muon spectrometer: $-4.0 < \eta < -2.5$
- ✓ Forward detectors: trigger, centrality

Operation in Run 1 and Run 2:

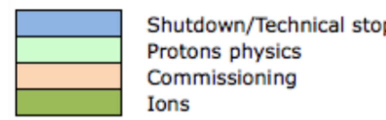
- ✓ Tracking and PID in large kinematic range
- ✓ High resolution vertex reconstruction

ALICE Upgrade Motivations



Run 2: $\mathcal{L}_{Pb\_Pb} = 1.0\ nb^{-1}$ Run 3: $\mathcal{L}_{Pb\_Pb} = 6.0\ nb^{-1}$ Run 4: $\mathcal{L}_{Pb\_Pb} = 7.0\ nb^{-1}$

ALICE strategy for Run 3 + Run 4



- ✓ 50 kHz Pb-Pb interaction rate (current < 10 kHz)
- ✓ Collect $\mathcal{L}_{Pb\_Pb} \geq 13.0\ nb^{-1}$
- ✓ Experiment upgrades during LS2

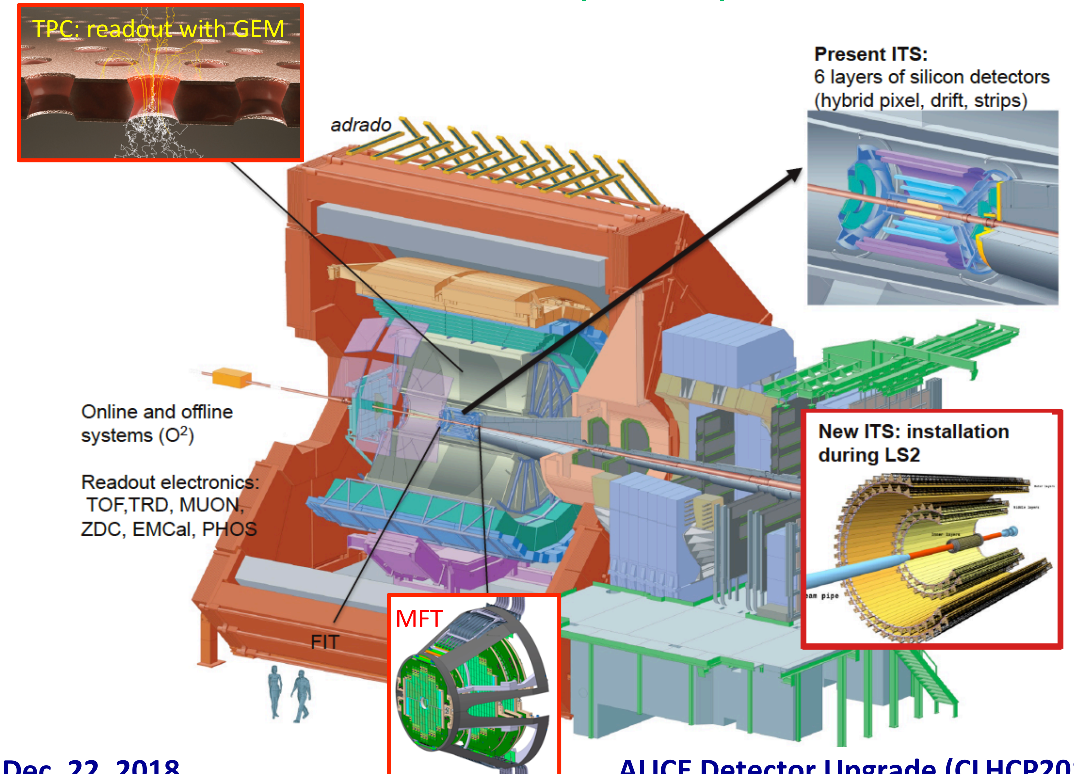
ALICE physics goal → High-precision measurements of QGP properties

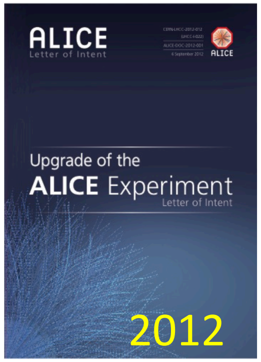
- Heavy-flavour and Quarkonia at very low p_T
  - ❖ Mechanism of quark-medium interactions
  - ❖ Dissociation/regeneration as tool to study de-confinement and medium temperature
- Low-mass vector mesons and low-mass di-leptons
  - ❖ Chiral symmetry restoration, initial temperature and EOS
- High-precision measurement of light nuclei and hyper-nuclei
  - ❖ QGP nucleosynthesis, exotics

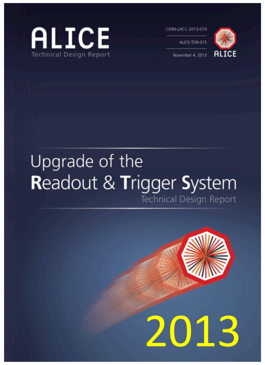
Key ALICE Detector Upgrades during LS2

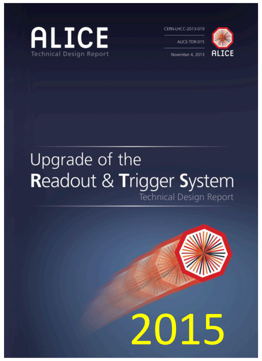
Main detector requirements

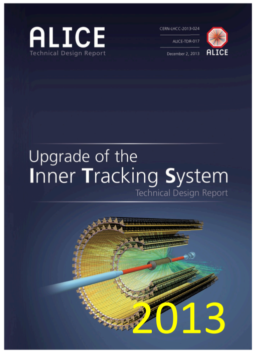
- High tracking efficiency and resolution at low p_T
  - ❖ Increase granularity, reduce material thickness
- High-statistics, un-triggered data sample
  - ❖ Increase readout rate, reduce data size (online data reduction)
- Preserve excellent particle id capabilities
  - ❖ Consolidate and “speed-up” PID detectors

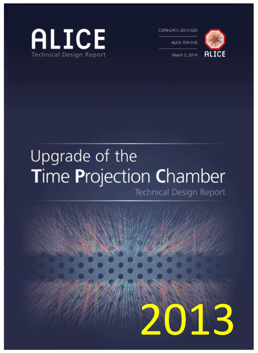


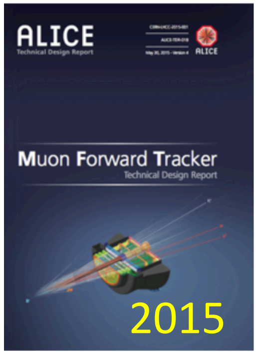












ALICE Inner Tracking System (ITS) Upgrade

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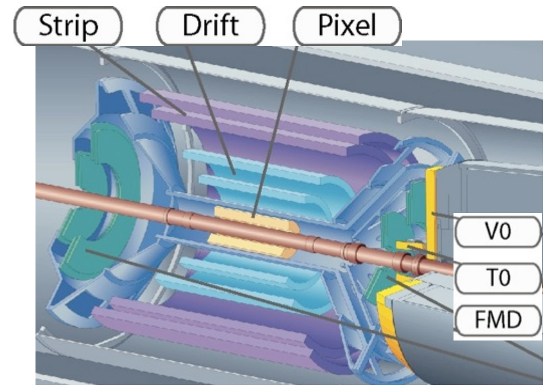
ALICE ITS Upgrade

1. Improve impact parameter resolution by a factor of 3 (5) in $r\varphi$ (z)

- Reduce beam pipe radius: 29mm ➡18.2 mm
- Get closer to IP (position of first layer): 39 mm ➡23 mm (layer 0)
- Reduce material budget: ~1.14% ➡ ~ 0.3% (for inner layers)
- Reduce pixel size: 50mm x 425mm ➡ 29 mm x 27 mm

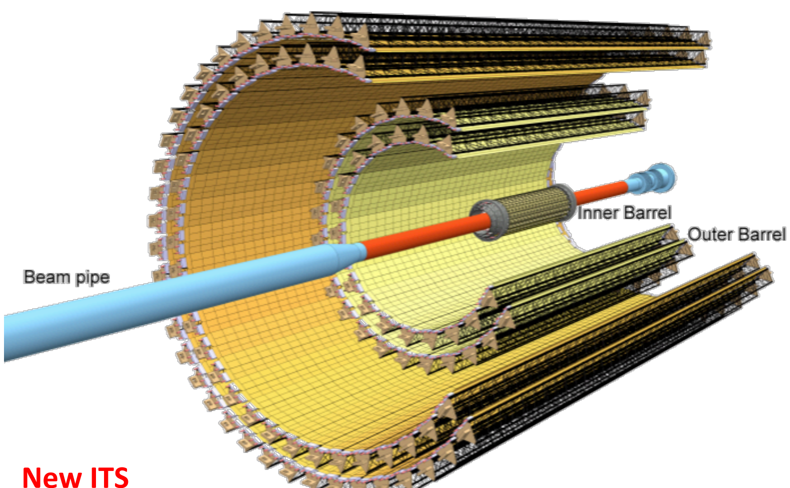


Current ITS

2. Improve tracking efficiency and p_T resolution at low p_T

- Improved integration time: < 10 μs
- Increase granularity and radial extension: 6 layers ➡ 7 MAPS layers

3. Fast readout: 50 kHz @ Pb-Pb



New ITS

7 layers of MAPS (Monolithic Active Pixel Sensor)

12.5G pixels, ~10 m² active area

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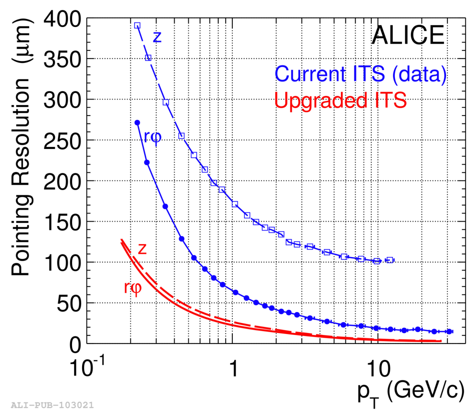
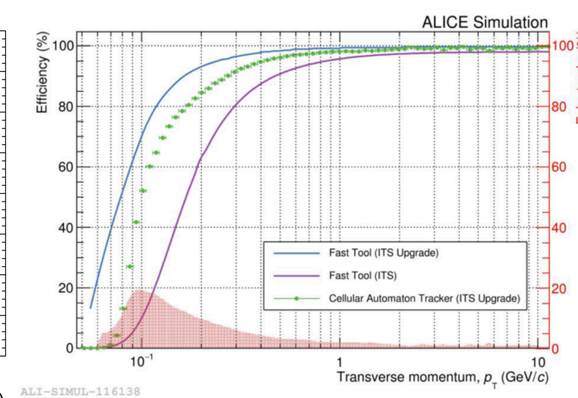
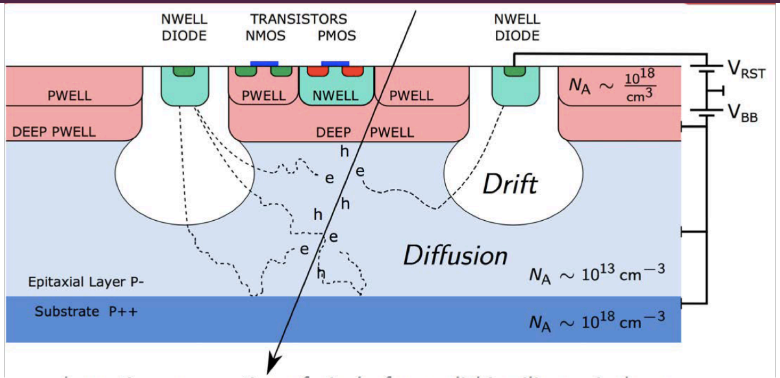


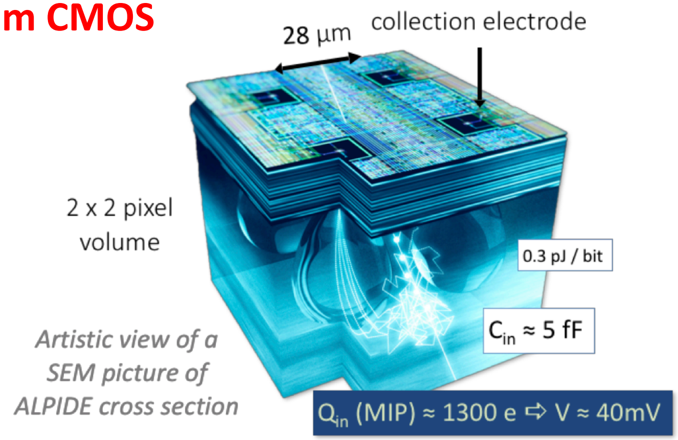


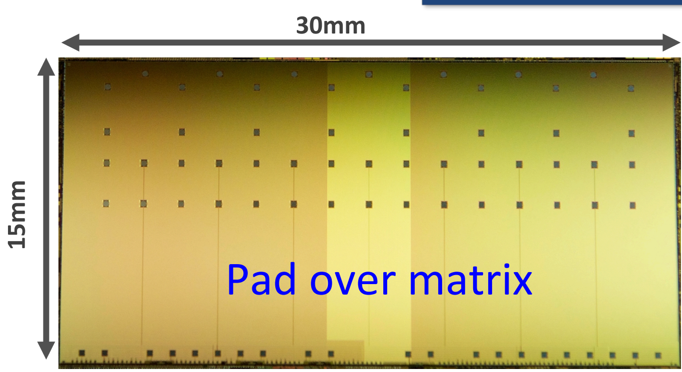
- ✓ Impact parameter resolution of ~40 μm at p_T = 500 MeV/c
- ✓ Tracking efficiency > 95% at p_T = 500 MeV/c

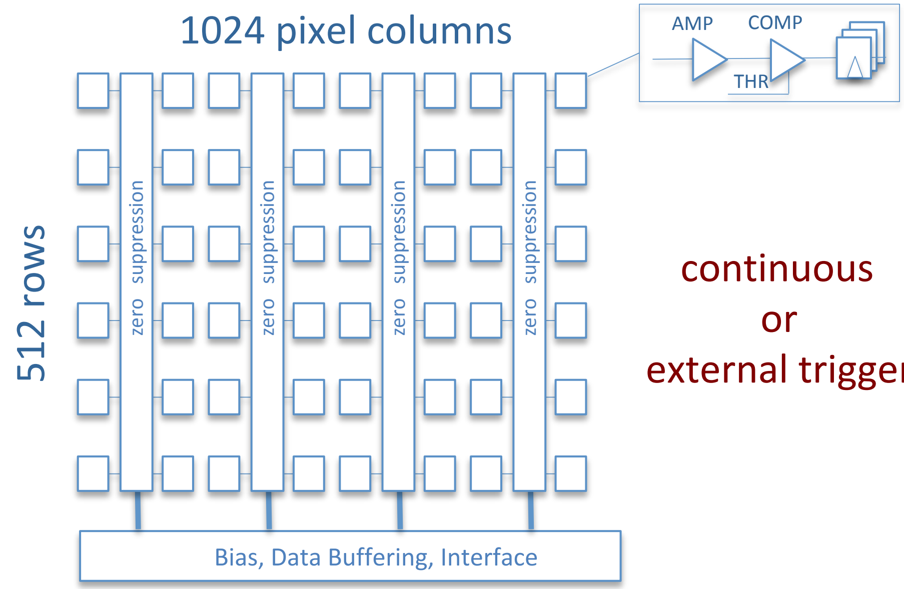
CMOS MAPS – ALICE PIxel Detector (ALPIDE)



MAPS manufactured in Tower-Jazz 180nm CMOS







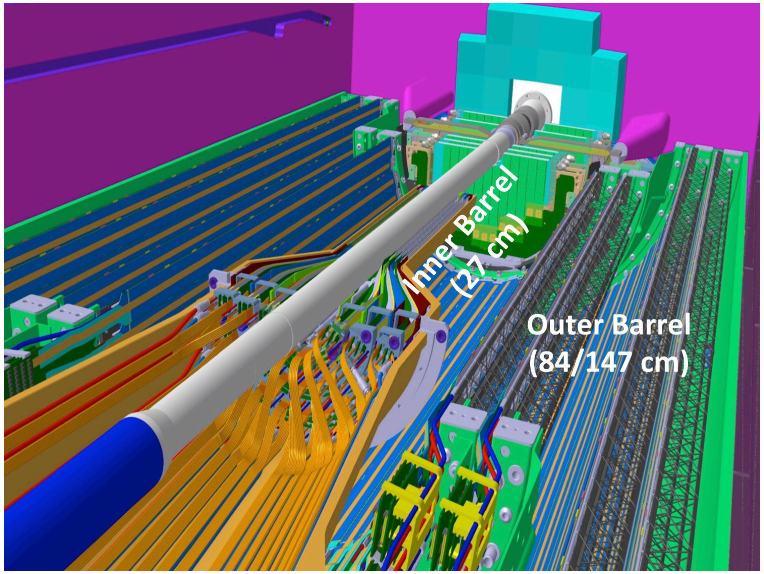
continuous
or
external trigger

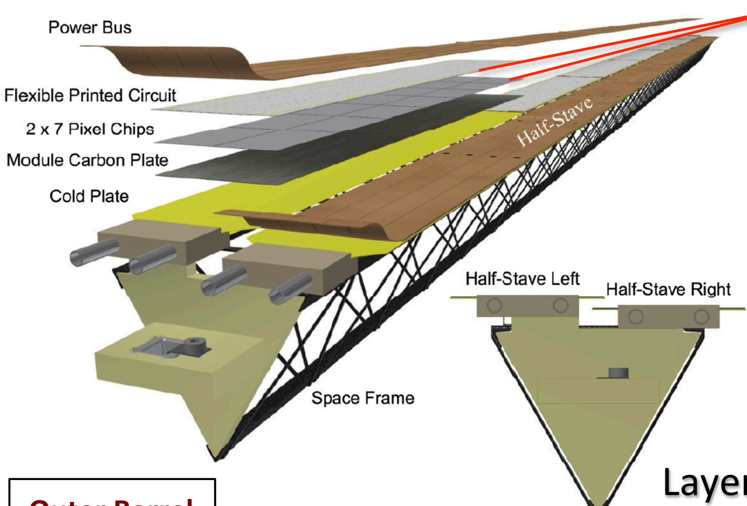
Key Features:

- Dimensions: 30mm x 15mm x 50 (100) µm
- Pixel pitch: 29µm x 27µm
- Spatial resolution: ~ 5 µm (3-D)
- Fake-hit rate: ~10^{-10} pixel/event
- Ultra-low power (entire chip): < 40mW/cm^2
- Global shutter: triggered acquisition (200 kHz) or continuous (integration time <10µs)

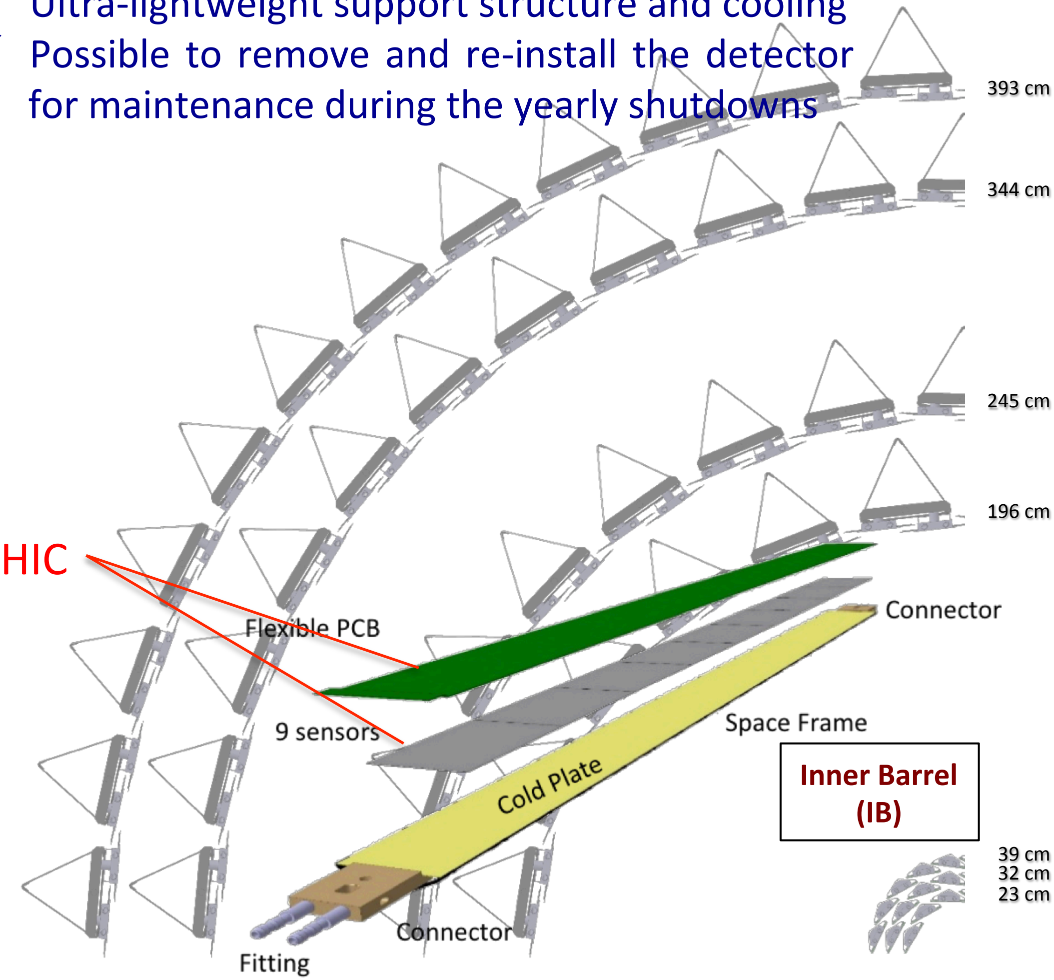
ITS Layout

- ✓ Ultra-lightweight support structure and cooling
- ✓ Possible to remove and re-install the detector for maintenance during the yearly shutdowns





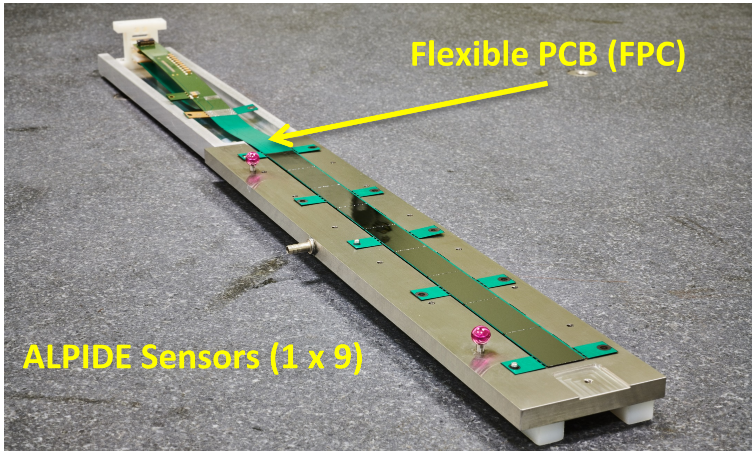
Outer Barrel
(OB)

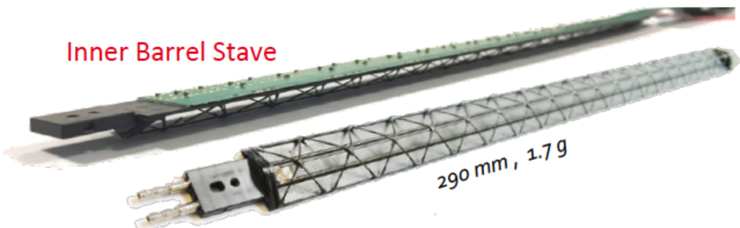


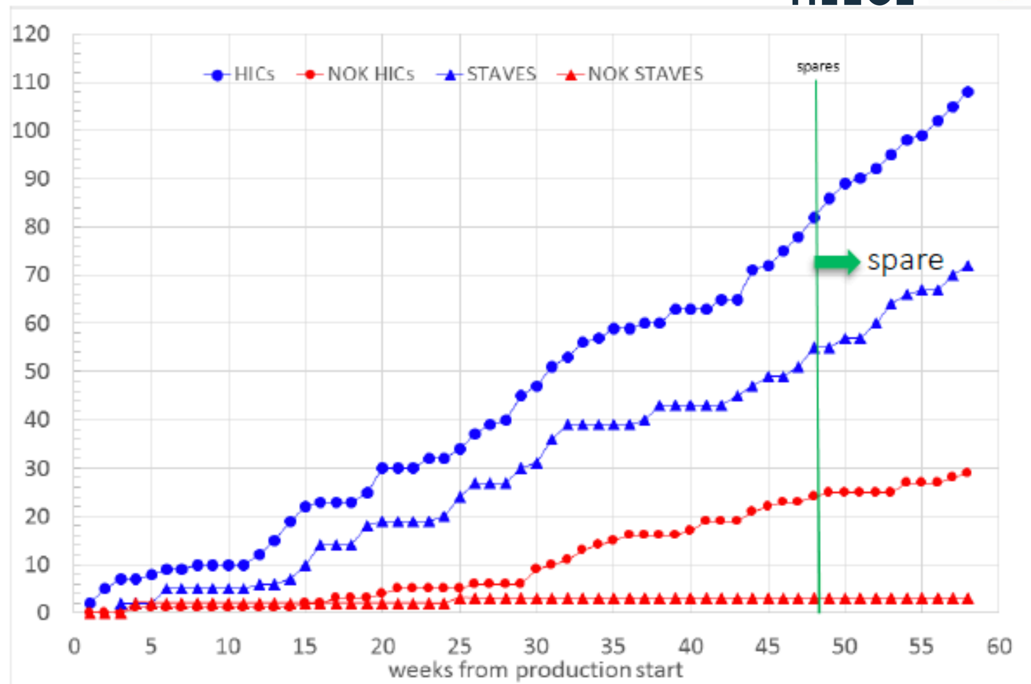
Inner Barrel
(IB)

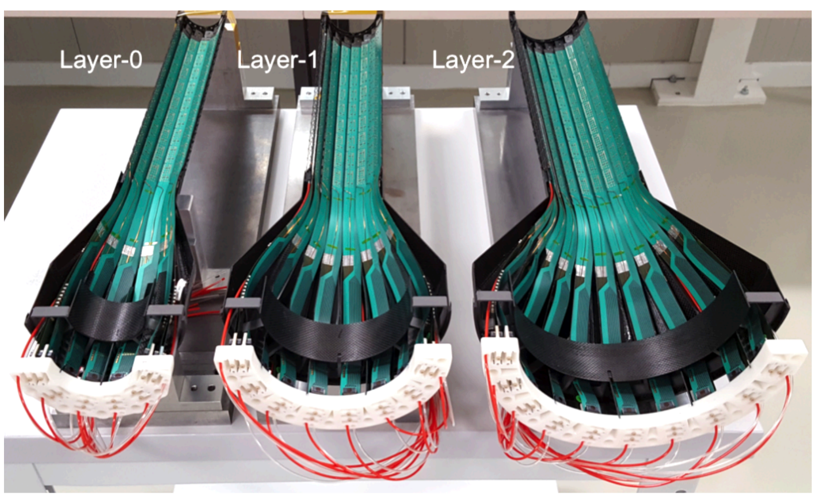
Layer #	6	5	4	3	2	1	0
N. of Stave	48	42	30	24	20	16	12

ITS Construction – Inner Barrel HIC Modules and Staves



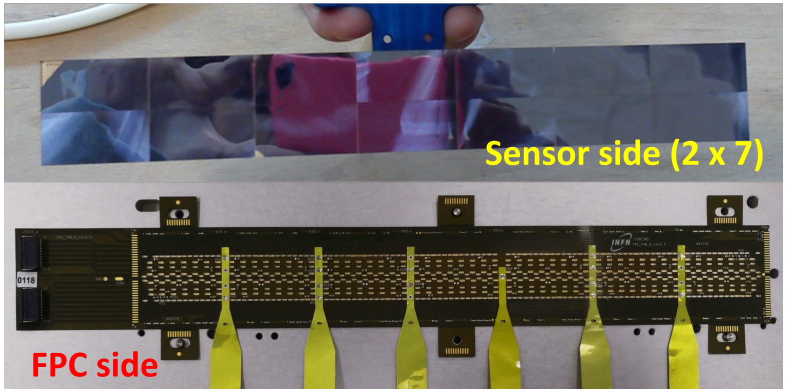


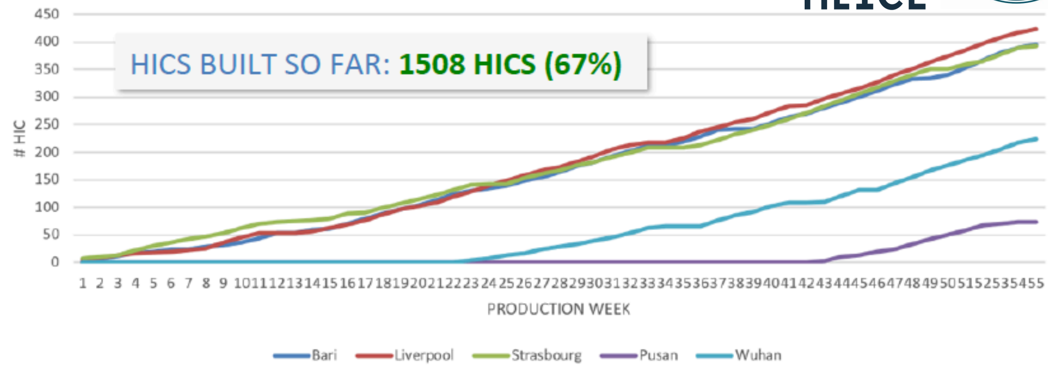


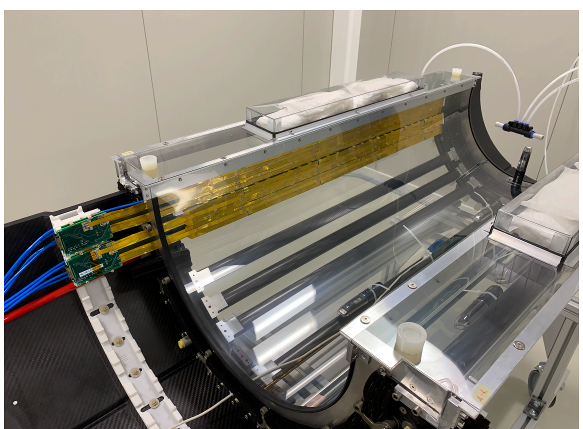


- Inner Barrel Production completed and all layers assembled @ CERN
- Construction of spare staves continues till Jan. 2019. By then:
  - IB-2 Half Barrel
  - 12 additional spares
- The 2nd IB-2 half barrel will be completed at a later stage

ITS Construction – Outer Barrel HIC Modules and Staves







OB HIC Production

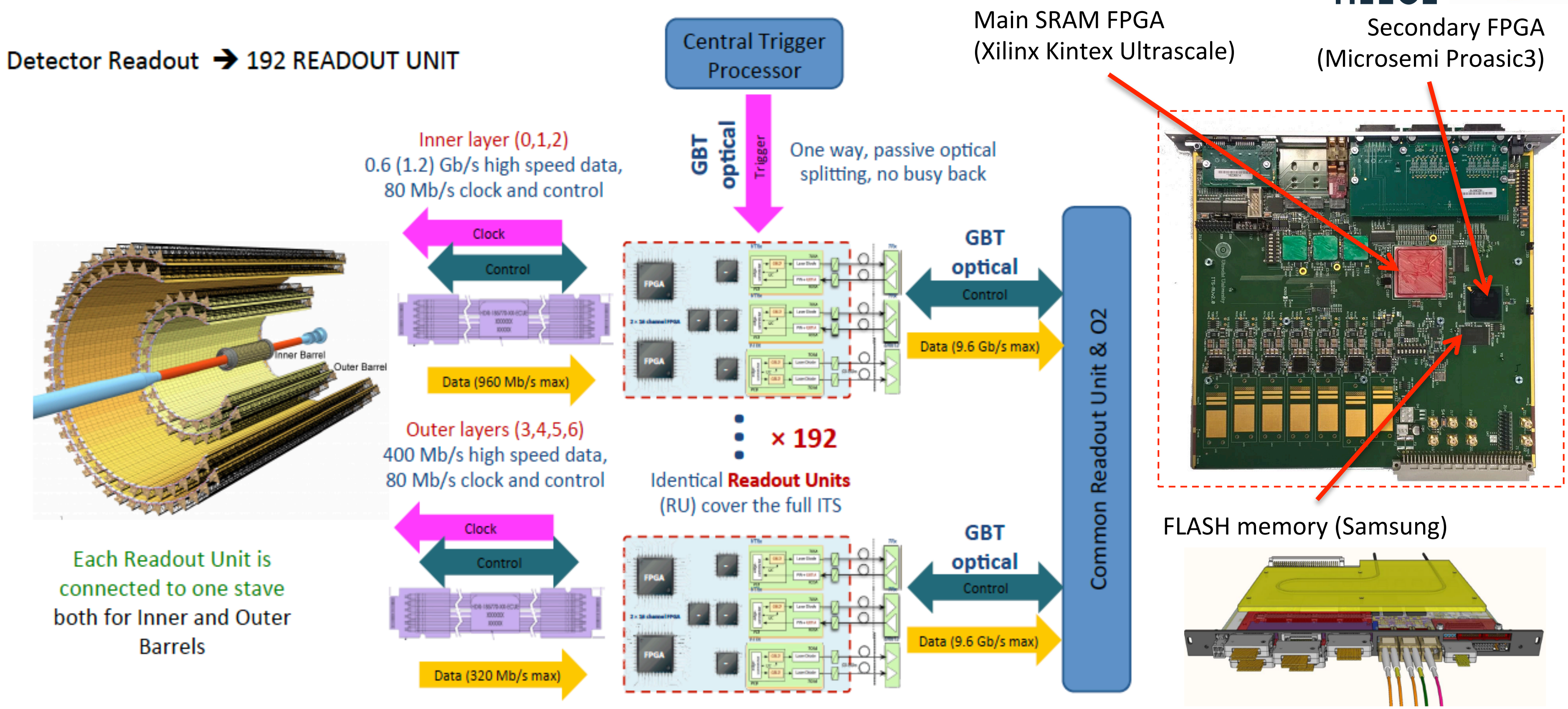
- 2238 HIC modules + 250 spares
- 5 HIC production sites: Bari, Liverpool, Pusan, Strasbourg, Wuhan
- Steady production in Bari, Liverpool, Strasbourg and Wuhan, ramping up in Pusan
- Production end Mar. 2019 (~2 HICs/day/site)
- Production yield stable ~ 84%, well monitored

OB Stave Production

- 90 +10 (OL), 54 + 6 (ML) (# spares in blue)
- 5 stave construction sites: Berkeley, Daresbury, Frascati, Nikhef, Torino
- Production has reached cruise speed in all sites
- 47 OL and 19 ML staves have been built so far

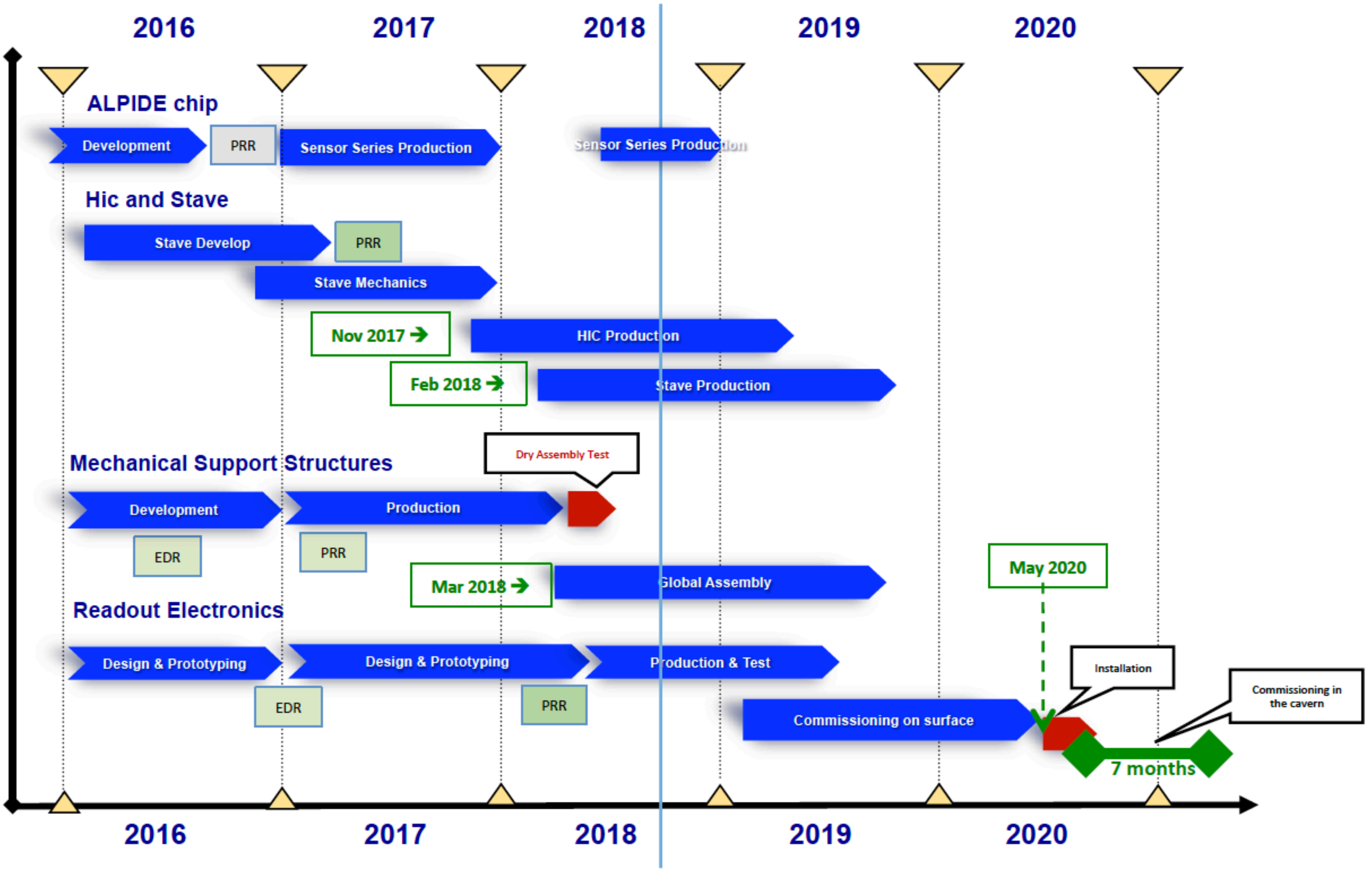
OB Barrel Assembly and Test at CERN

ITS Construction – Readout Electronics



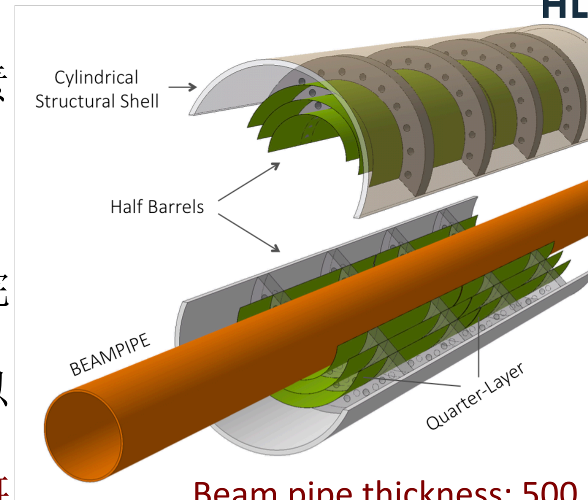
- ITS Frontend Electronics is subdivided into 192 Readout Unit (RU) modules, each connected to and control a stave and optically interfaced to the Common Readout Unit (CRU) and to the Central Trigger Processor (CTP)
- RU distributes trigger and control signals, interface data links to ALICE DAQ, control power supply of chips
- Mass production and testing ongoing (started in Sept 2018, will complete in April 2019)
  - ✓First 20 boards (pre-series) received on 23rd Nov., 2018
  - ✓Qualification tests at CERN (visual inspection and PCB analysis) and NIKHEF (functional test)

ITS Construction – Timeline

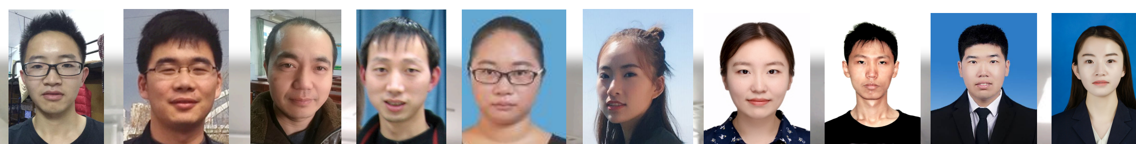


China Effort on the ALICE ITS Upgrade

- 参与LS2期间ALICE/ITS硅像素探测器升级
  - ➢ 参与ITS硅像素芯片设计: (1) 芯片读出结构; (2) 像素模拟前端电子学改进
  - ➢ ITS探测器预研、建造与测试
    - ✓2017年9月份启动预生产
    - ✓2018年4月份启动正式生产，计划于2019年4月完成（生产率为2 模块/天，共建造500个模块）
    - ✓2019年起，开始试运行、刻度、调试等工作，以及重味物理分析方面的工作
- 参与新一代MAPS硅像素探测器ITS3的预研（ALICE Upgrade beyond 2020）



Beam pipe thickness: 500 μm (0.14% X_0)
Sensor thickness: 20 μm (0.03% X_0)



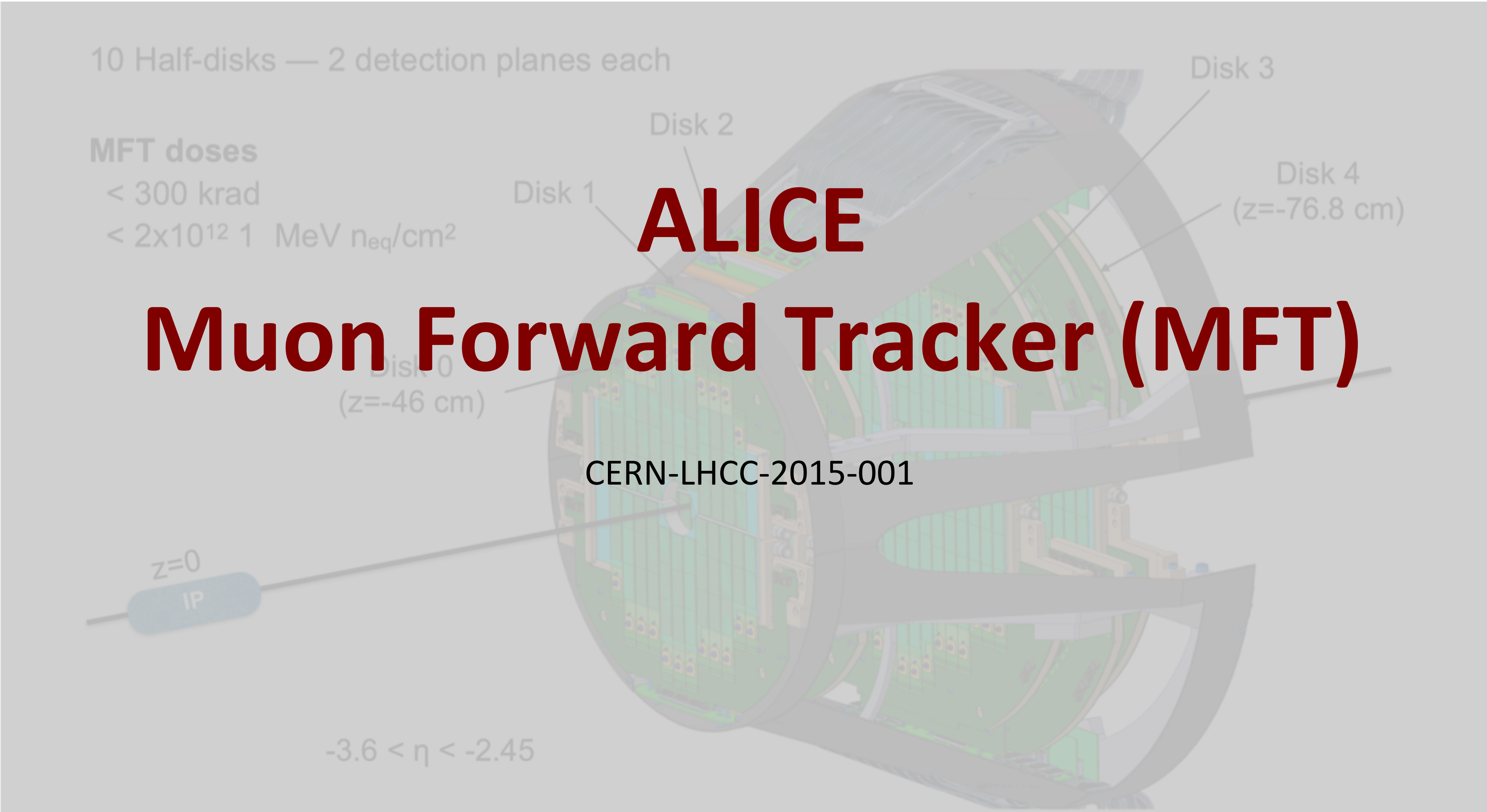
（参与学生与技术员）

千级洁净室 @ 华中师大
（温/湿度可控，约100 平方米）

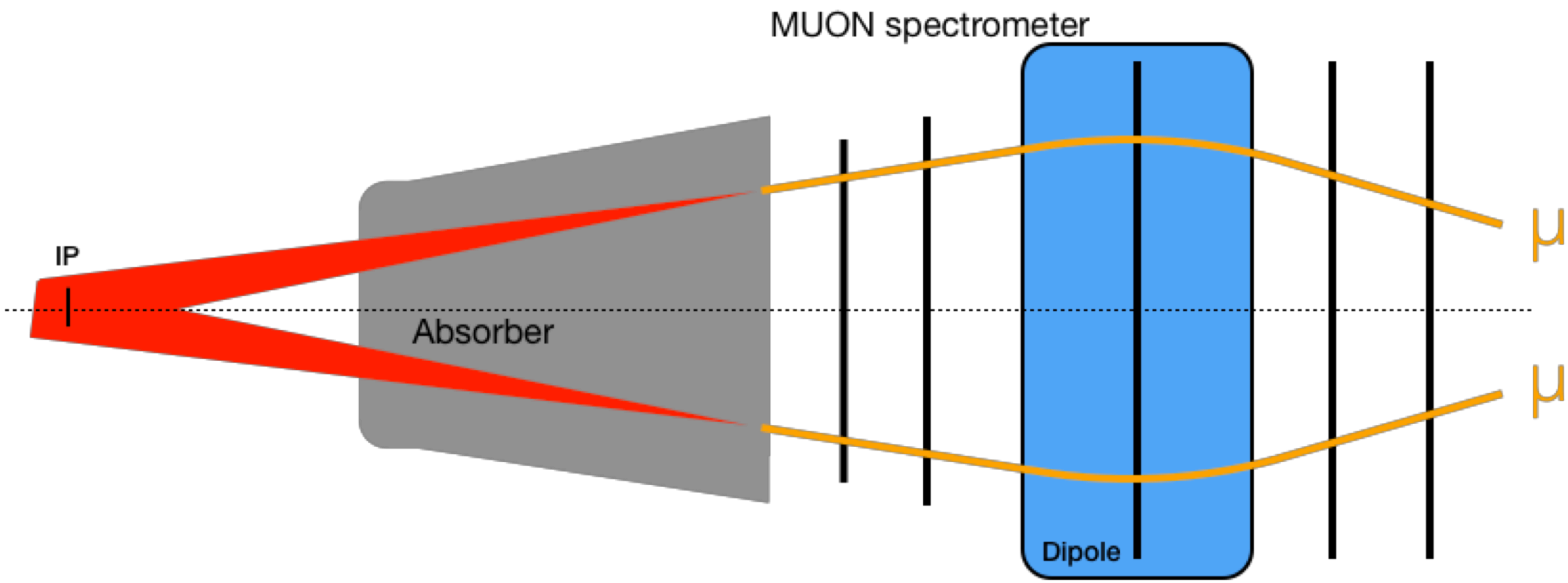
ALICE

Muon Forward Tracker (MFT)

CERN-LHCC-2015-001



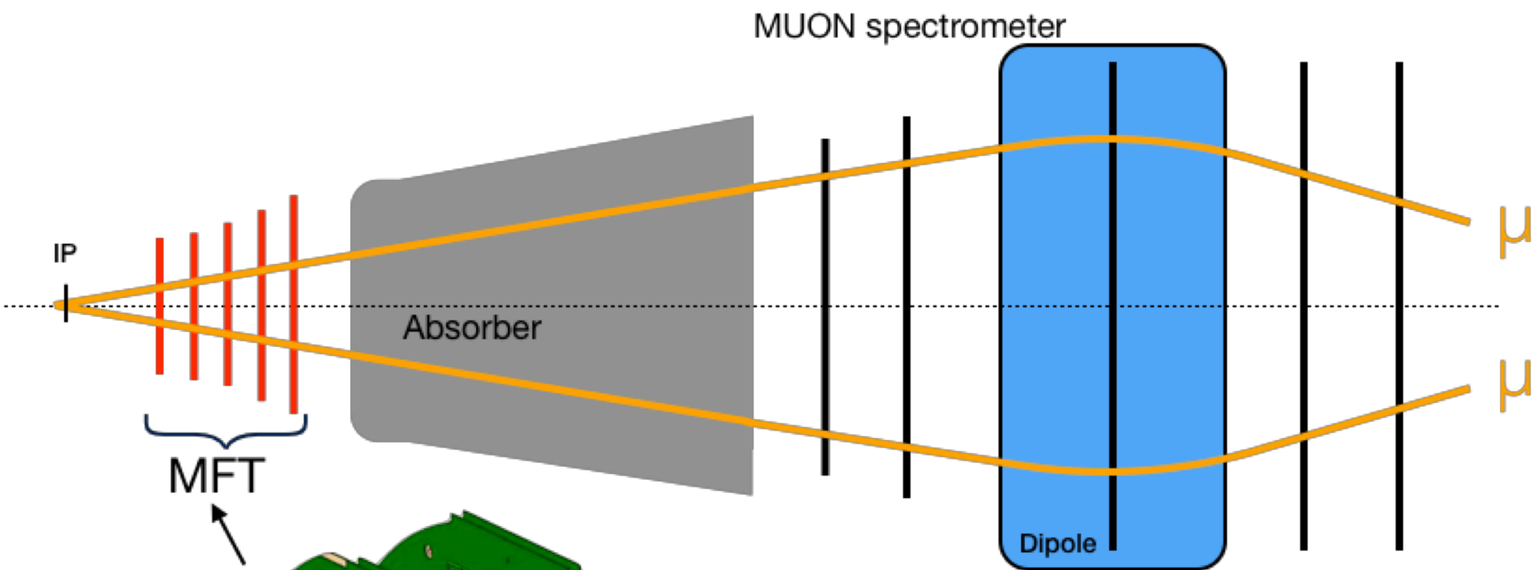
Present MUON Spectrometer

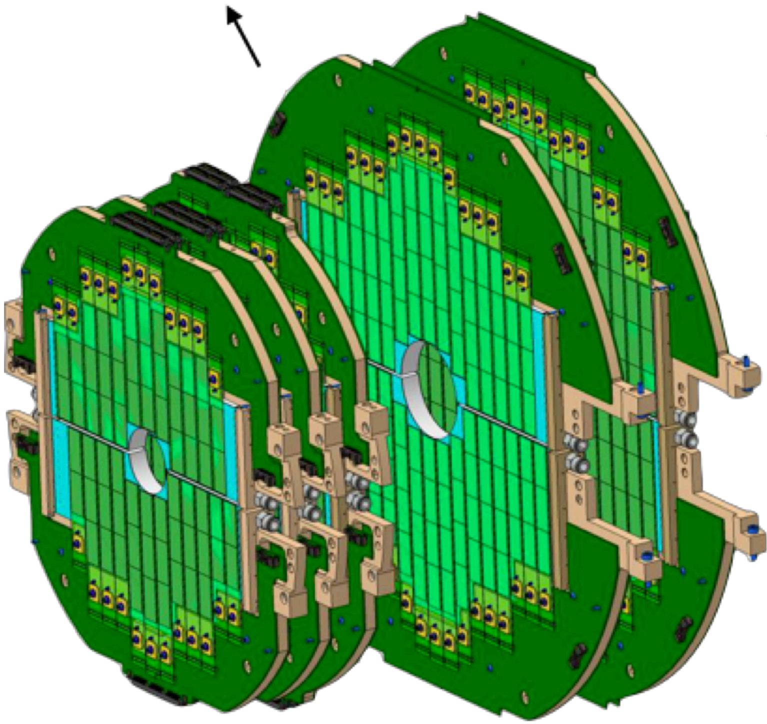


Present MUON spectrometer blurred in muon track extrapolation

- No constraint in the primary vertex region (no charm/beauty separation)

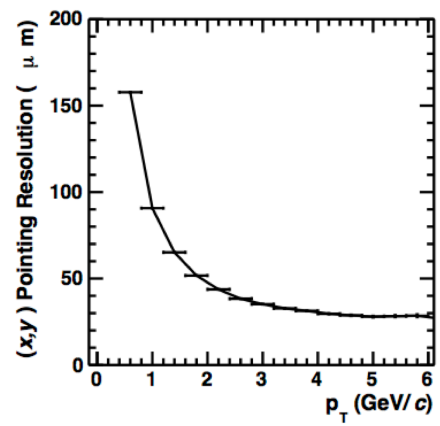
New MFT + MUON Spectrometer



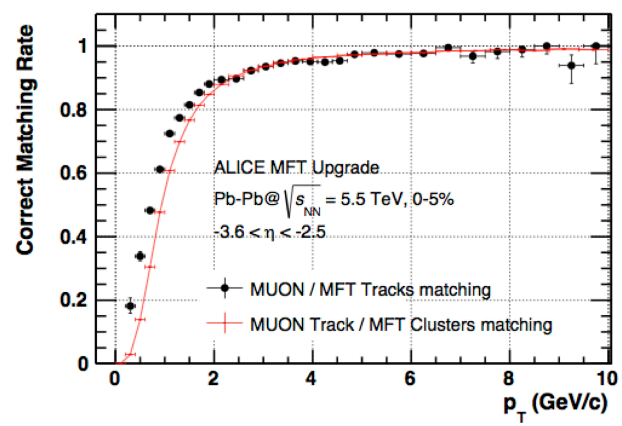


CERN-LHCC-2015-001

Transverse pointing resolution



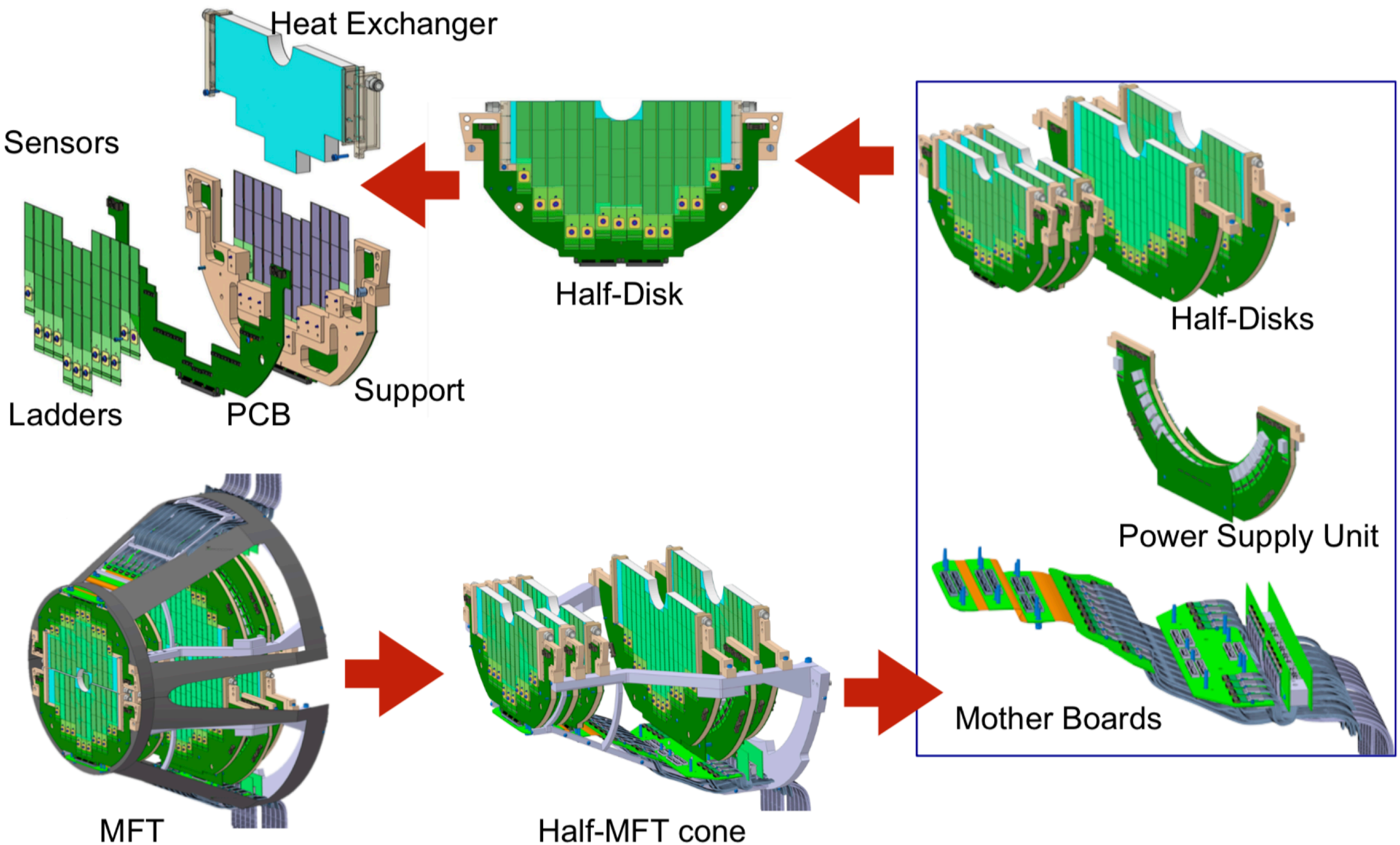
MUON/MFT Matching rate



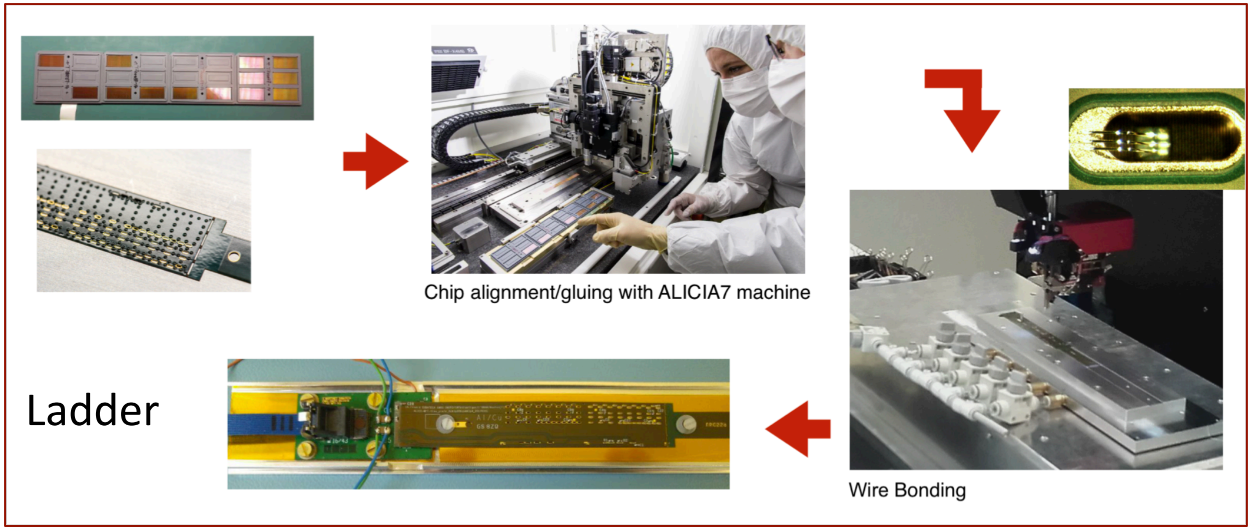
✓ Matching muon tracks to the MFT -> good pointing resolution in the transverse direction

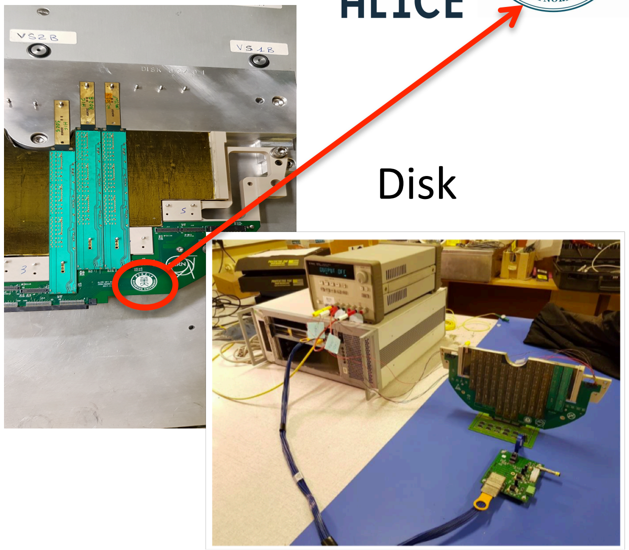
MFT Layout

- 0.4 m^2 active silicon area, 920 MAPS (ALPIDE chip)
- 10 Half-disks, 2 detection planes each



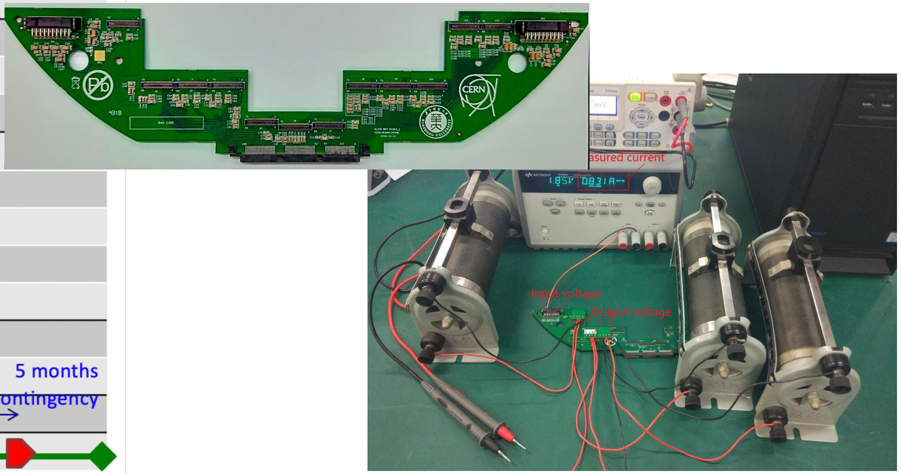
MFT Construction

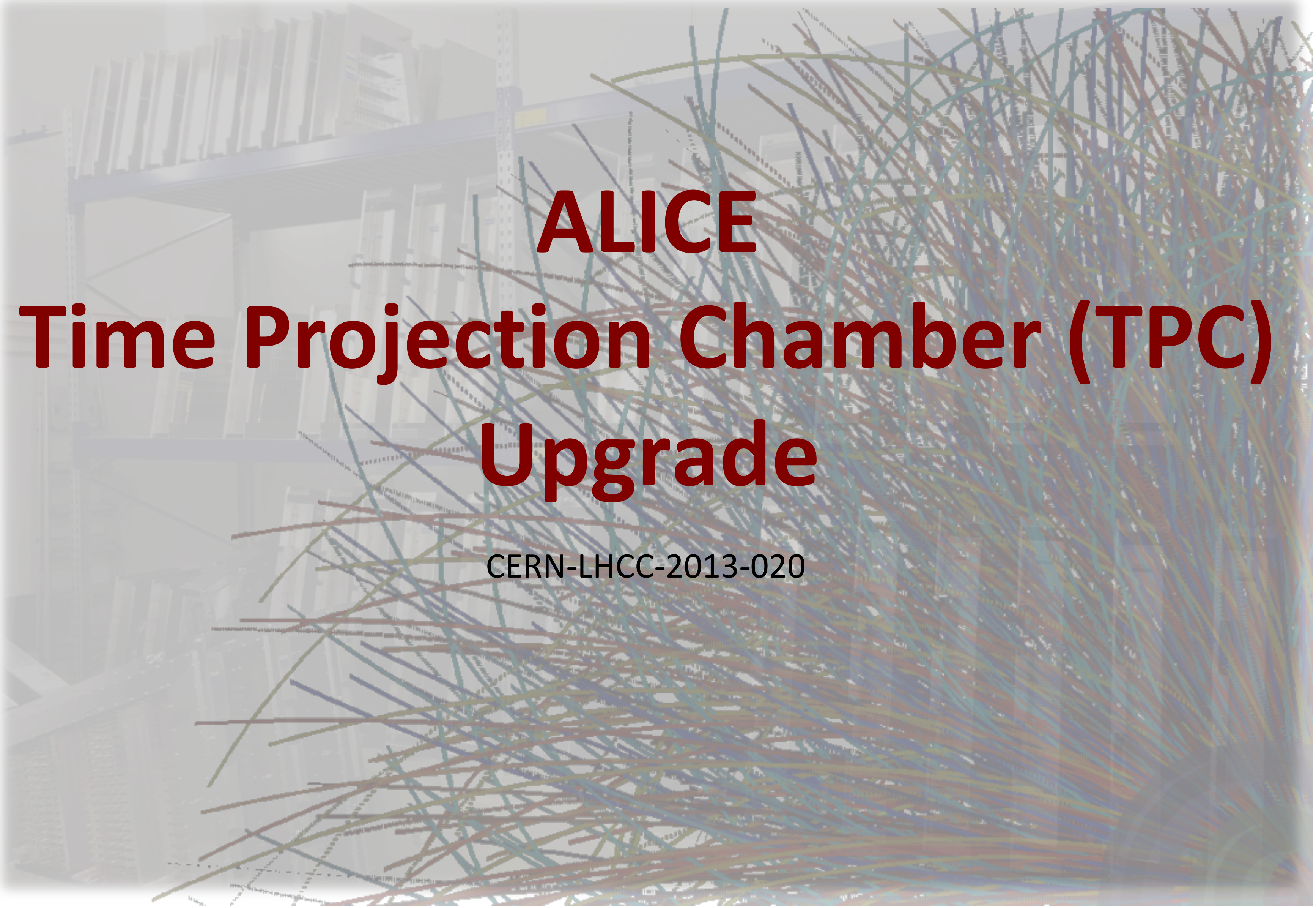




Oct-18	2015	2016	2017	2018	2019	2020
Ladder EDR (30/9/16)						
Ladder PRR (18/10/17)						
FPC production end (03/18)						
Ladder prod. end (7/19)						
Disk EDR (1/2/17)						
Disk PRR (30/1/18)						
Disk prod., assembly, metrology (4/19)						
Cone and barrel EDR (20/6/17)						
Cone and barrel PRR (23/5/18)						
Cone assembly and qualific. end (4/19)						
Barrel structure construction end (01/19)						
Cone integrated inside barrel (5/19)						
RO EDR (13/7/17)						
RO PRR (29/11/18)						5 months
MFT commissioned on surface (11/19)						contingency
MFT installation during LS2 (3/20)						

- China effort on power board design, production and test for all MFT disks
- Pre-production is ongoing

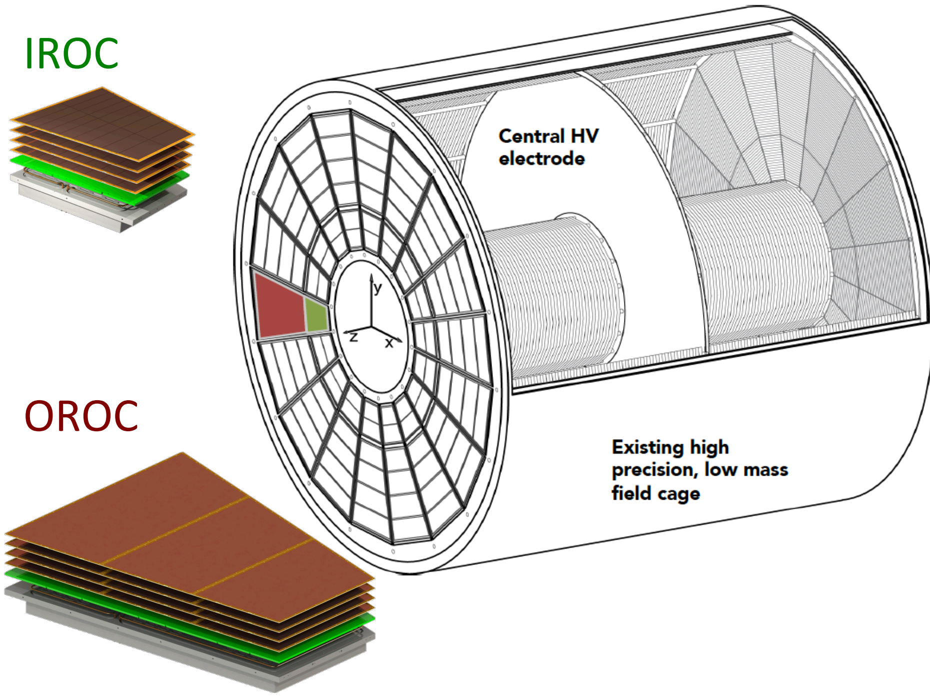


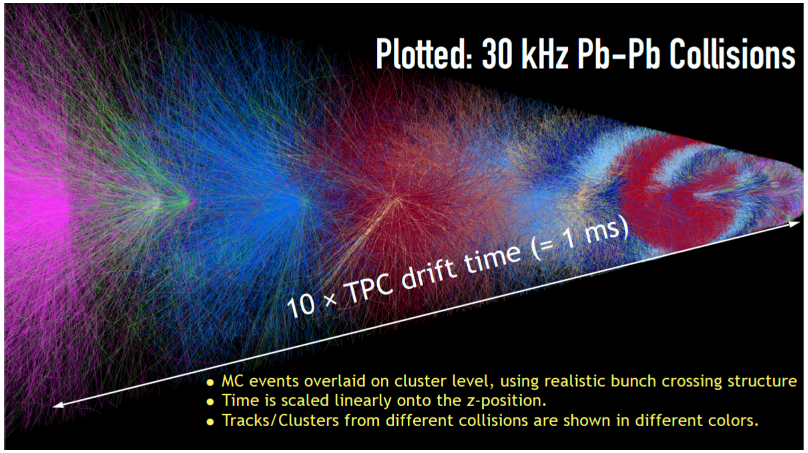


ALICE
Time Projection Chamber (TPC) Upgrade

CERN-LHCC-2013-020

ALICE TPC Upgrade





Current detector (Run 1, Run 2):
- Diameter: 5 m, length: 5 m
- Gas: Ne-CO_2-N_2, Ar-CO_2
- 72 MWPCs, 18 sectors on each side
- ~550 000 readout pads
- Wire gating grid (GG) to minimize Ion Back-Flow (IBF)
- Max drift time: ~ 100 µs
- Rate limitation: few kHz

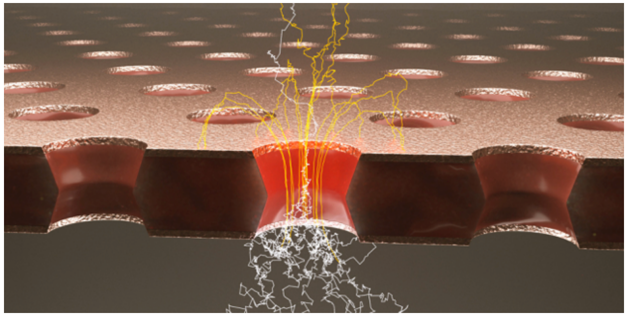
Continuous operation in Run 3:
- 50 kHz Pb–Pb collisions with the goal to inspect them all!
- 100 µs electron drift time in TPC. Average event spacing: ~20 µs → average pileup: 5 events
- Triggered operation does not make sense!
- IBF suppression with gating grid can not work!
- Minimize IBF without the use of a gating grid

→ Continuous readout with GEMs

TPC Continuous Readout with GEMs

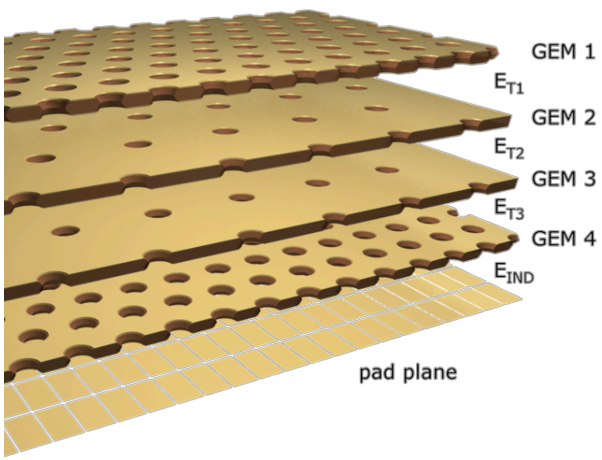
TPC upgrade requirements:

- Nominal gain = 2000 in Ne-CO2-N2 (90-10-5)
- IBF < 1% (ε = 20)
- Energy resolution: $\sigma E/E$ < 12% for ^{55}Fe (X-rays)
- Stable operation under LHC Run 3 conditions
- Unprecedented challenges in terms of loads and performance
- Newly developed Front-End (SAMPA chips) and readout electronics → continuous readout

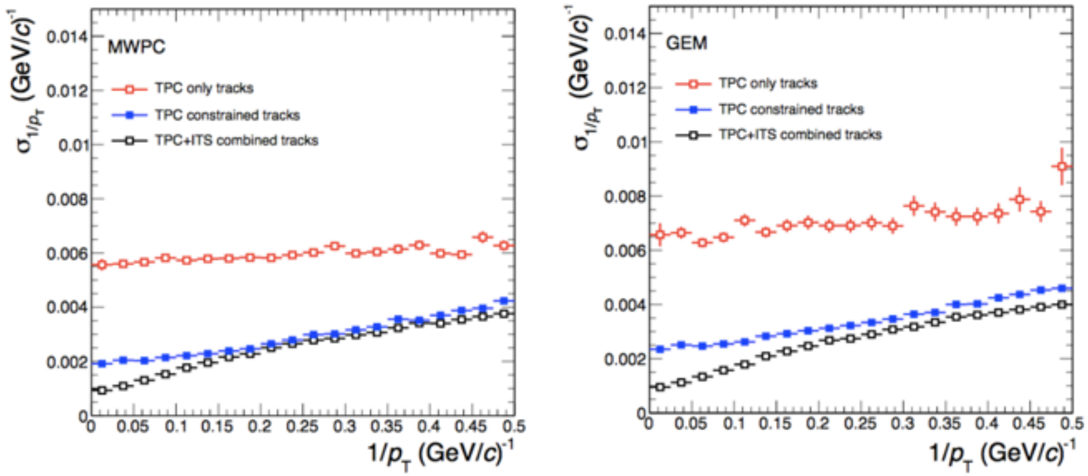


Baseline solution: 4-GEM stack

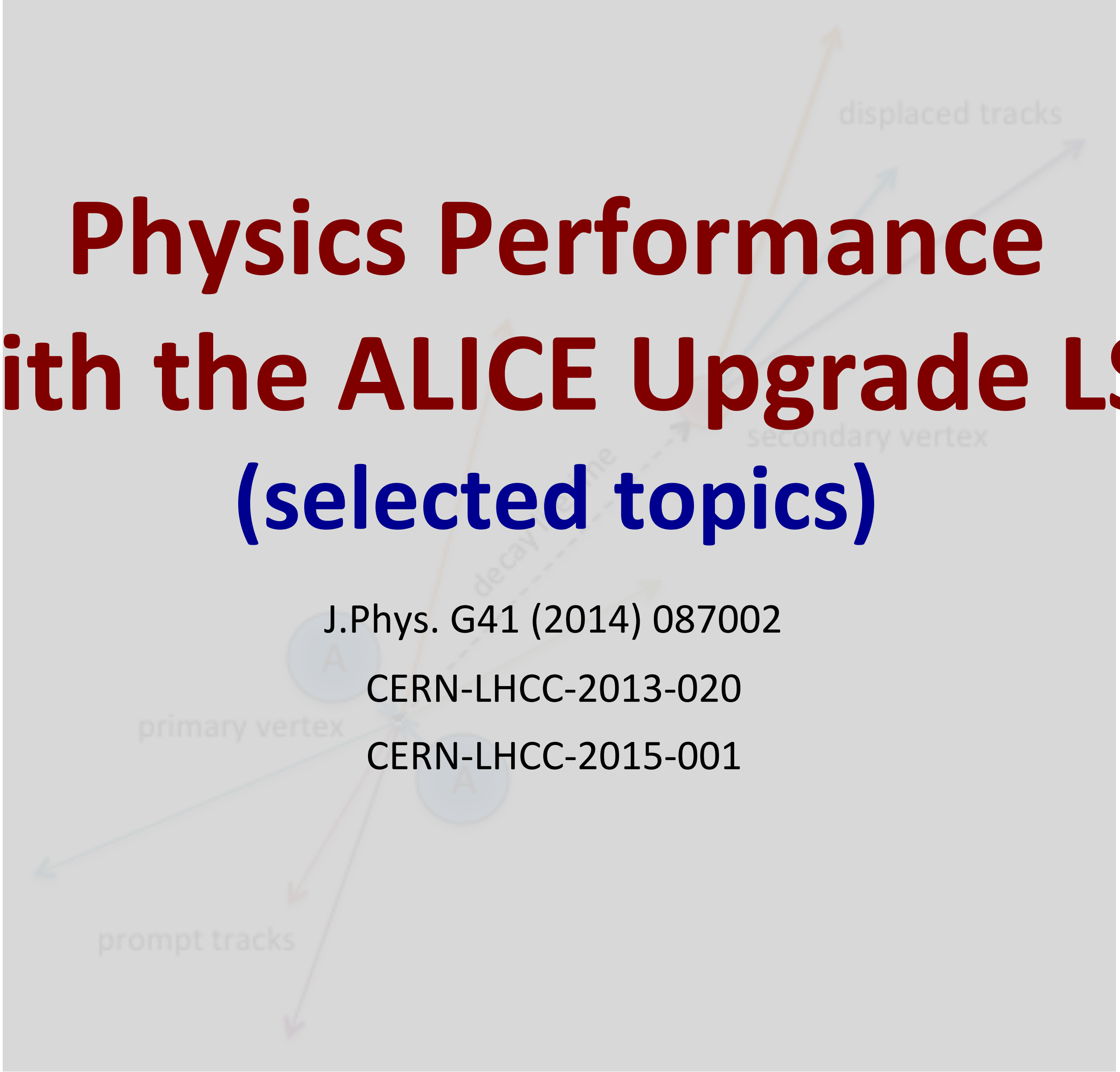
- Combination of standard (S) and large pitch (LP) GEM foils
- Highly optimized HV configuration
- Results of intensive R&D



CERN-LHCC-2013-020



✓ Preserve momentum resolution for TPC + ITS tracks



Physics Performance With the ALICE Upgrade LS2

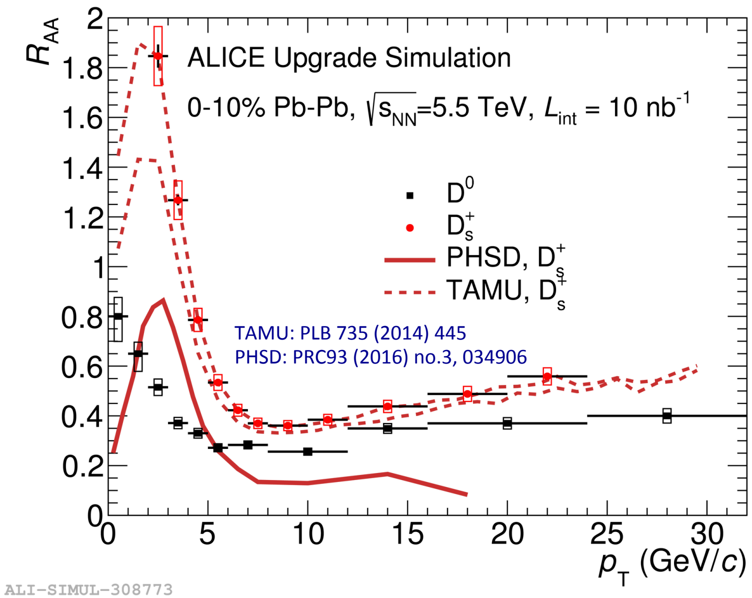
(selected topics)

J.Phys. G41 (2014) 087002

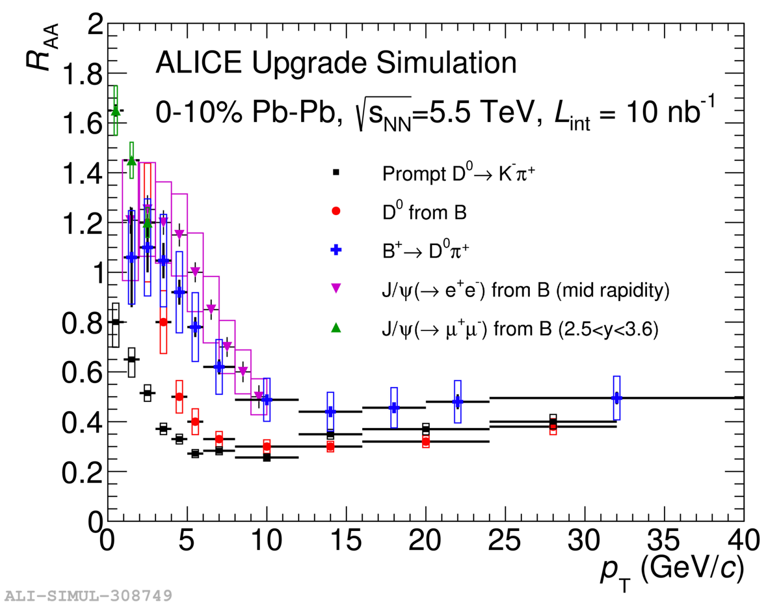
CERN-LHCC-2013-020

CERN-LHCC-2015-001

Physics Performance – D and B-meson Production



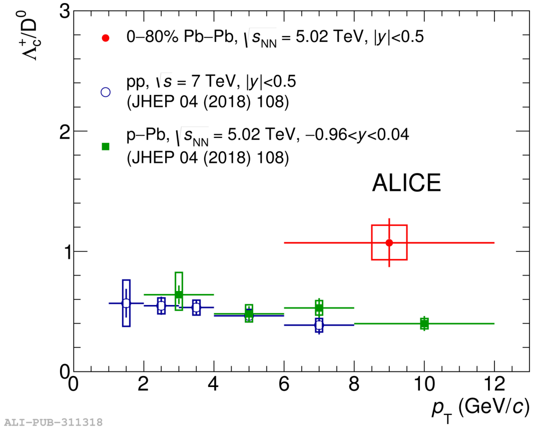
- Significant improvement in the non-strange D-meson production measurement down to $p_T = 0$
- Extend p_T range on D_s-production measurement and low statistical uncertainties
  - access to hadronization mechanisms
  - possibility to disentangle between theoretical models

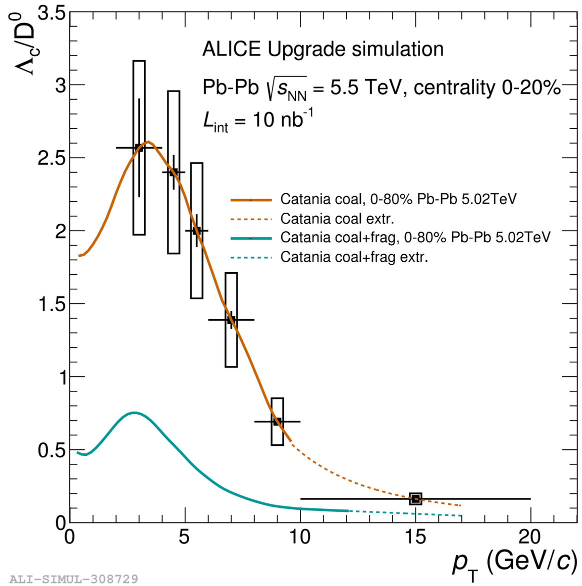


- Full reconstruction of B^+ meson down to 1 GeV/c
- Beauty measurements using both exclusive (non-prompt D^0 and J/ψ) and inclusive decays (B mesons to hadronic decays) at mid and forward rapidity
- Precise R_{AA} allows a quantitative verification of mass dependence energy loss ($\Delta E_{charm} > \Delta E_{beauty}$) and can discriminate between models at low p_T

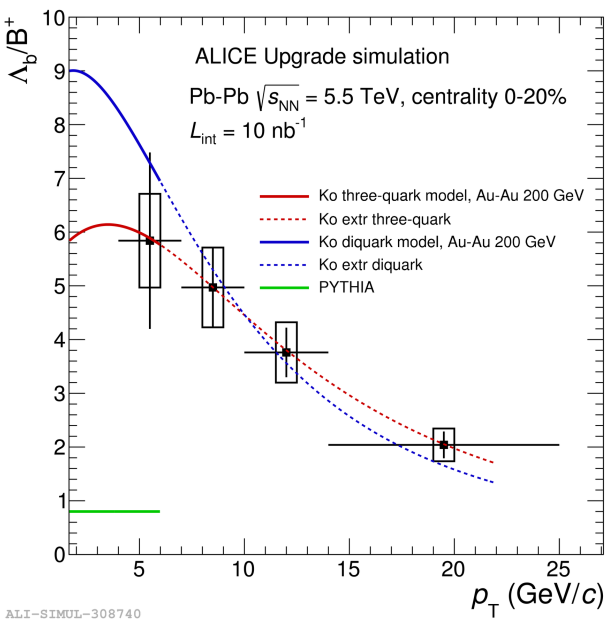
Physics Performance – Baryon-to-meson Ratio

Λ_c/D





- Hints of charm recombination both at RHIC and LHC, very large uncertainty from heavy-ion measurements
- Λ_c/D can discriminate between models at low p_T
- Λ_c measurement possible down to 2 GeV/c in Pb-Pb collisions

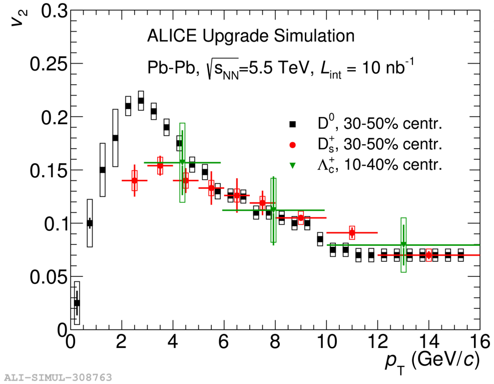


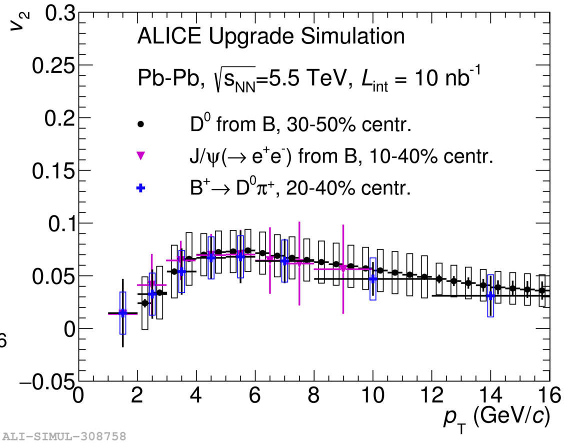
Λ_b/B

- Insight into thermalisation and hadronisation of beauty quarks
- Λ_b measurement possible down to 4 GeV/c in Pb-Pb collisions

Physics Performance – Flow Measurements

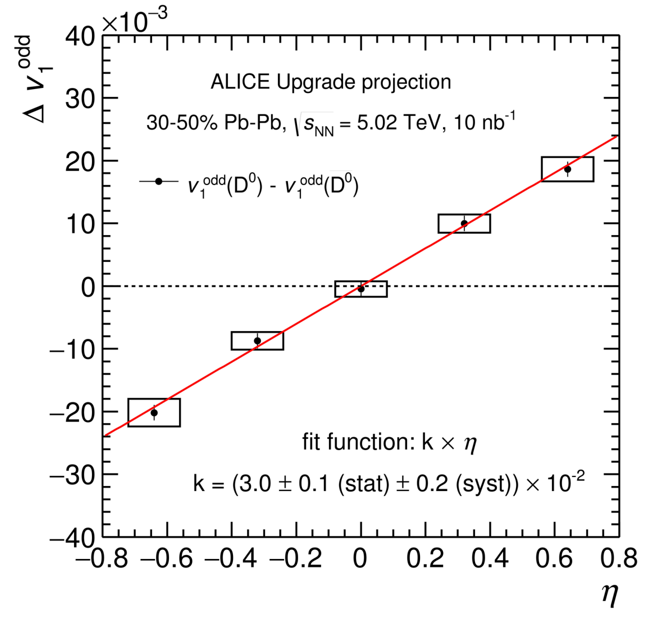
Elliptic flow





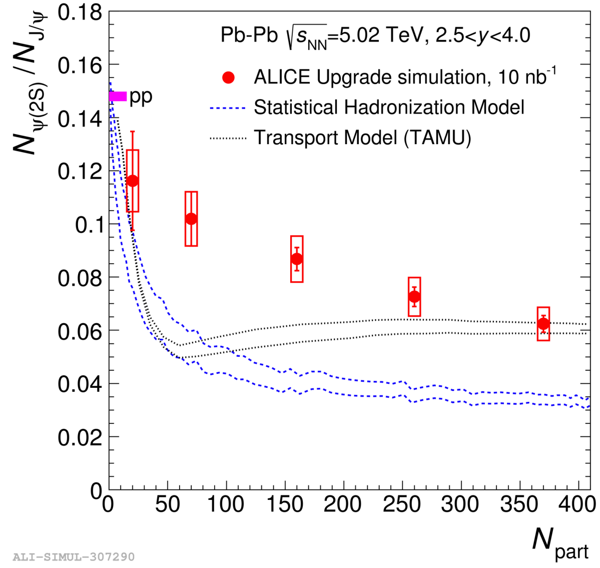
- Elliptic flow of charm and beauty hadrons down to 0 and 1 GeV/*c*, respectively
- Provide the strongest constrain on the c and b quark diffusion coefficients and path-length dependence of the parton energy loss
- More differential measurement will be possible, as v_2 using the Event-Shape-Engineering technique

Directed flow

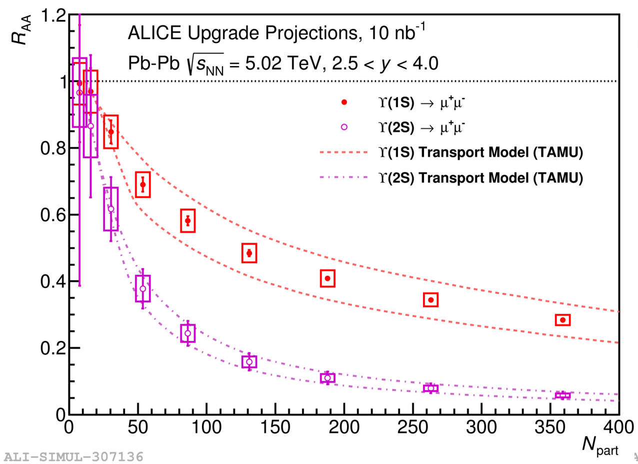


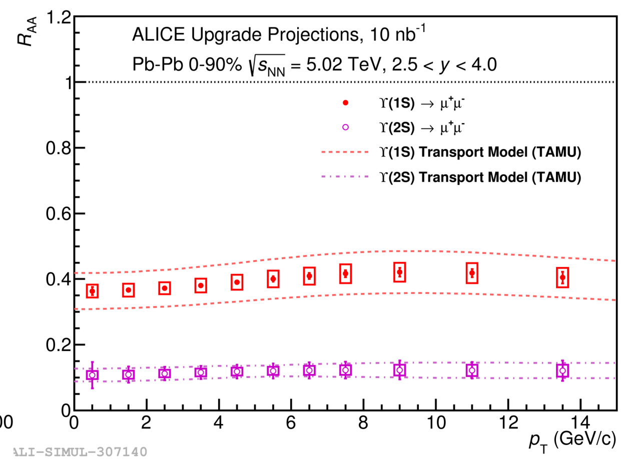
- Magnetic field from moving spectators influence moving charges -> charge-dependent directed flow, asymmetric in rapidity
- Very promising sensitivity to the effect of the early time magnetic field in heavy-ion collisions, can help constrain QGP properties

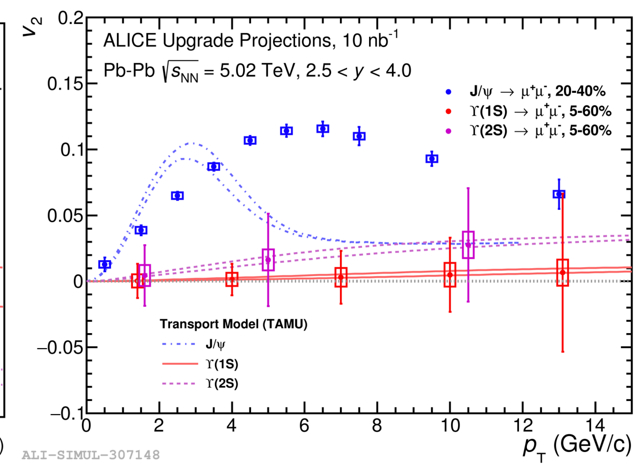
Physics Performance – Quarkonia Measurements



- Assess exited ψ states with small uncertainties and possibility for multi-differential measurements
- Two different scenarios describing charmonium data:
  - ➢ statistical hadronisation model: all ψ generated at hadronisation from deconfined c and c-bar
  - ➢ transport model: interplay between dissociation and recombination from deconfined c-quarks

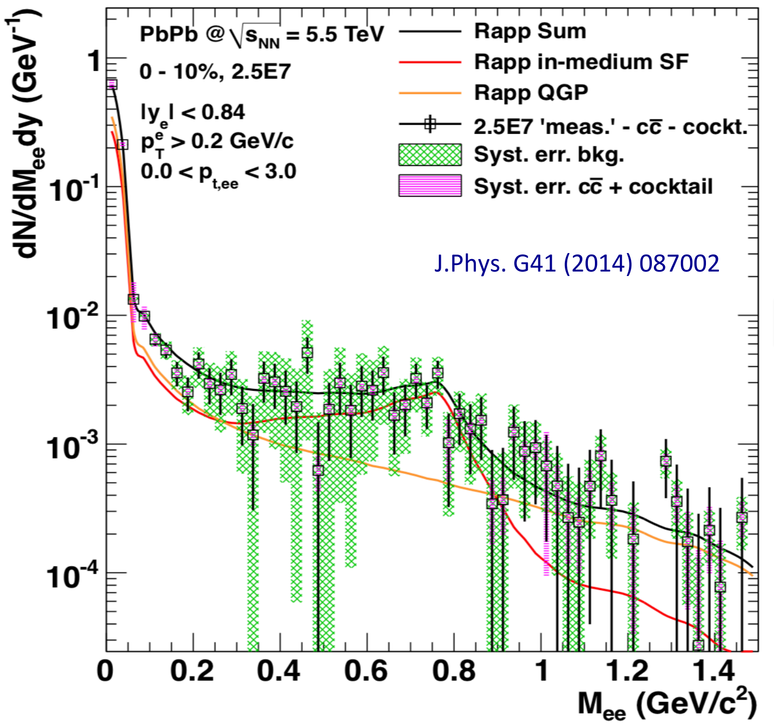


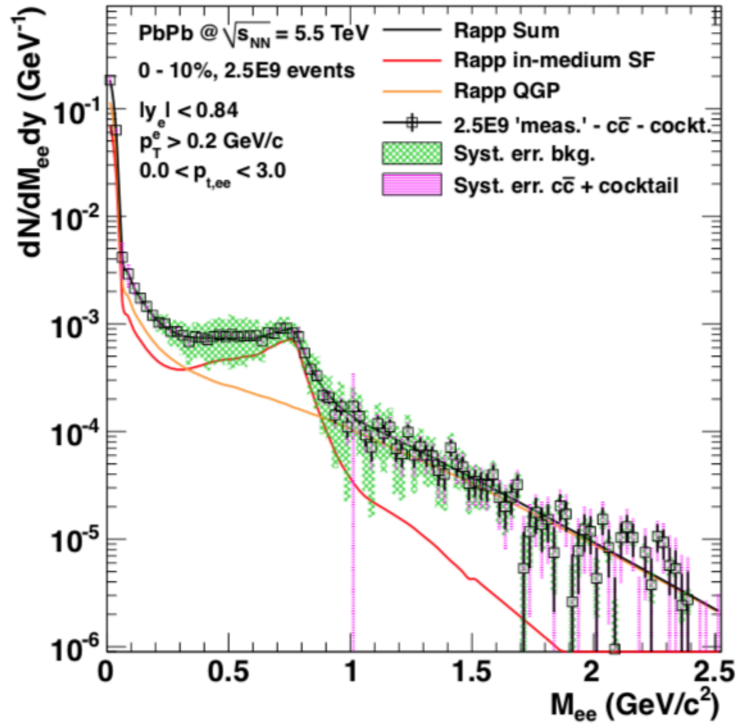




- More differential quarkonia measurements with high precision
- Assess low-p_T and elliptic flow of different Y states

Physics Performance – Low Mass Di-leptons Measurements

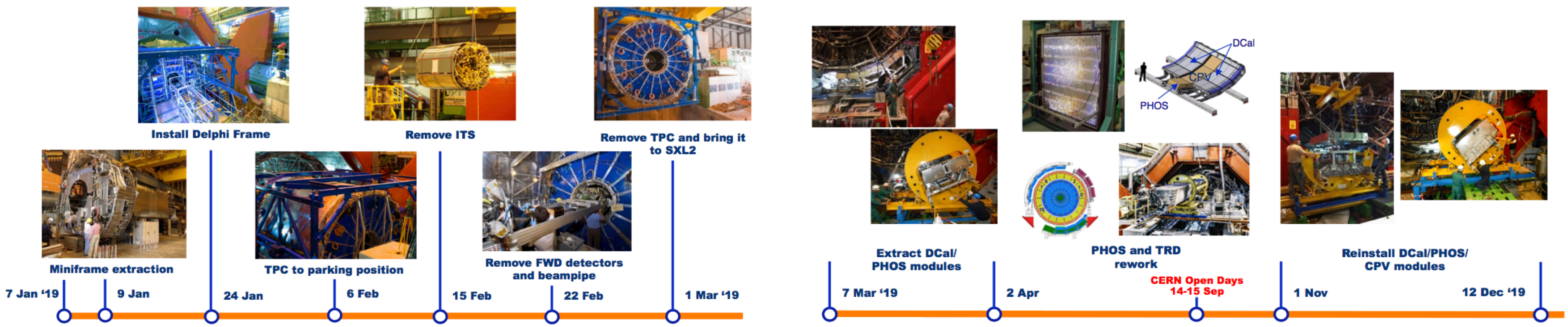


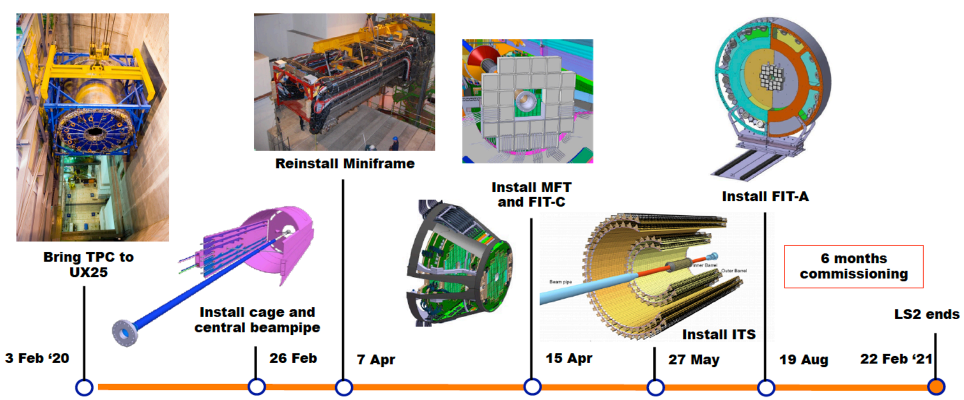


- Low mass di-electrons → Initial temperature from EM radiation
- Up to now difficult to disentangle all the electron-background sources
- After the ALICE upgrade:
  - Cocktail-subtracted distributions $|\eta| < 0.9$
  - Improved uncertainty figures in Run 3 and 4

Summary and Outlook

- The ALICE Upgrade project has successfully completed the R&D phase and it is now in the production/assembly phase -> upgraded detectors
- Enhanced readout capabilities and higher LHC luminosity -> very large statistics
- Production of all parts is ongoing, installation & commissioning during LS2 start in 2019
- The ALICE upgrade will give access to physics not reachable up to now





LS2 is HERE!

Next-Generation HI Experiment at LHC (beyond LS4)

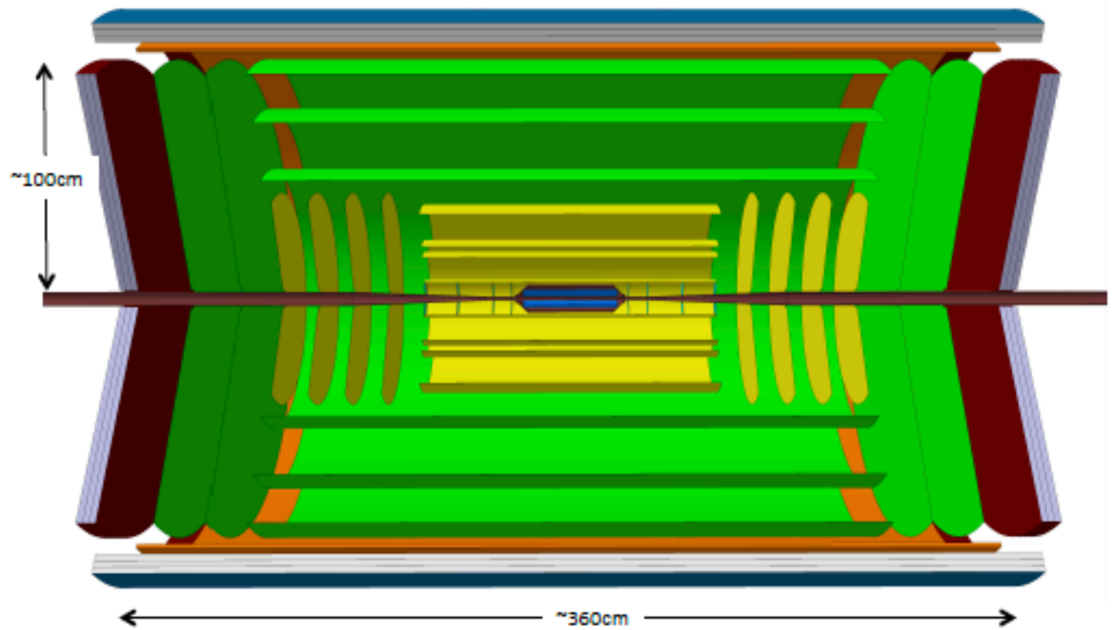
A new experiment based on a "all-silicon" detector

Tracker: ~10 tracking barrel layers (blue, yellow and green) based on CMOS sensors

Hadron ID: TOF with outer silicon layers (orange)

Electron ID: pre-shower (outermost blue layer)

Extended rapidity coverage: **up to 8 rapidity units**
+ FoCal



Preliminary studies

Magnetic Field
- B = 0.5 or 1 T

Spatial resolution
- Innermost 3 layers: $\sigma \sim 1\mu m$
- Outer layers: $\sigma \sim 5\mu m$

Time Measurement
Outermost layer integrates high precision time measurement ($\sigma_t < 30ps$)

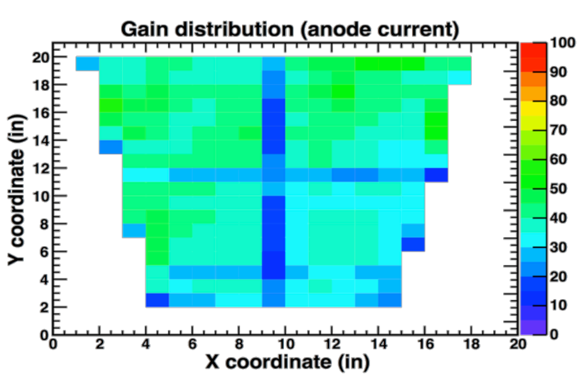
Authors: Luciano, PBM, Federico
https://indico.cern.ch/event/779787/

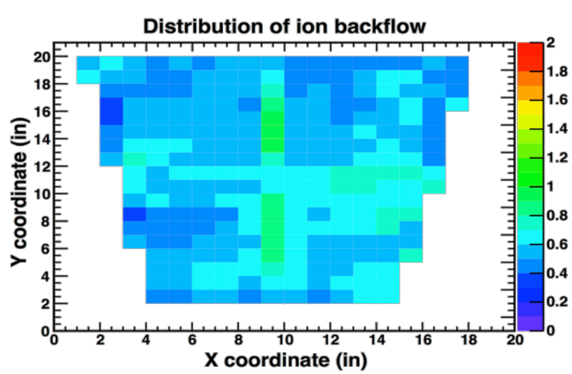
Thanks for your attention!

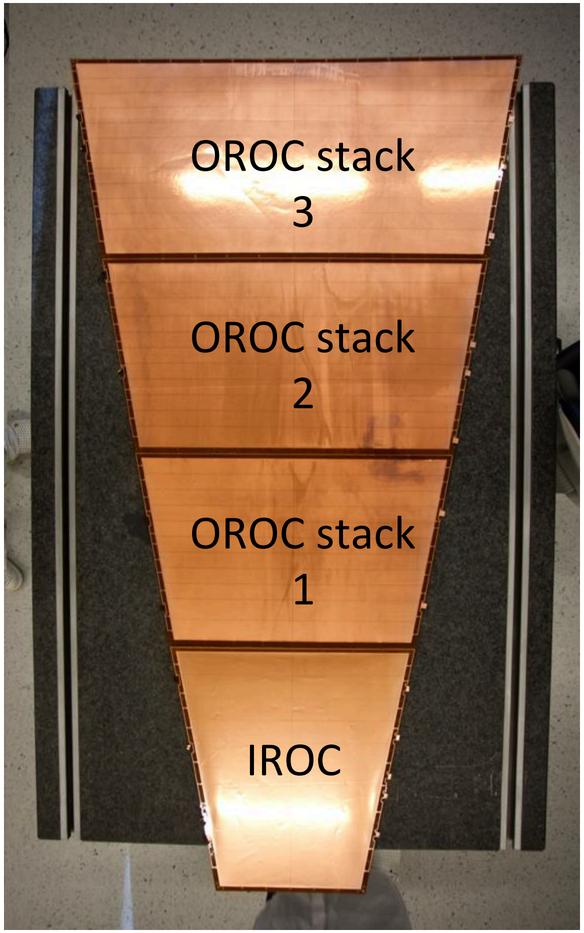
Spare Slides

TPC Construction – GEMs and ROCs

- Production of 40 IROCs and 40 OROCs finishes in Dec. 2018
  - ROC assembly: Yale (IROC), GSI (OROC), HPD Bucharest (OROC)
  - ROC bodies: Heidelberg, Frankfurt, UT Knoxville
- Production of 720 GEM foils + spares finished in May 2018 (yield ~ 90%)
  - 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 ROCs tested at the LHC
  - Noise performance within specs: 1 ADC (= 670 e$^-$)

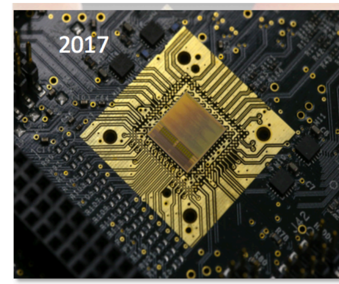






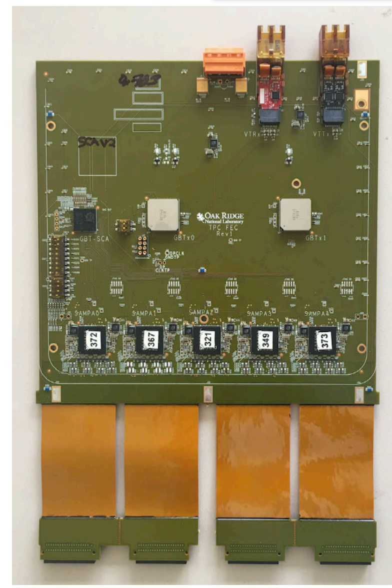
TPC Construction – Readout Electronics

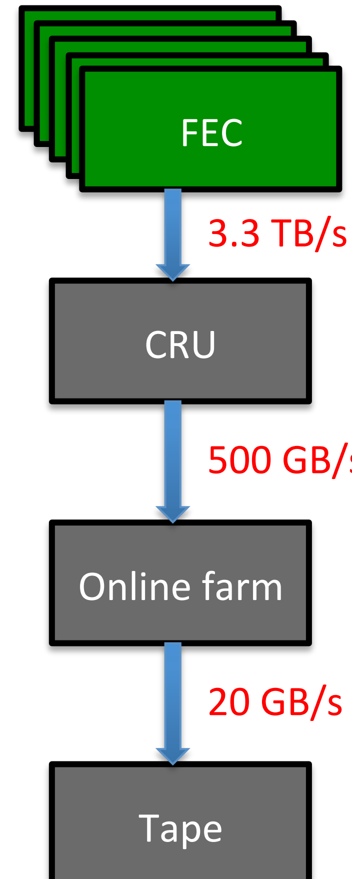
- Newly developed FE SAMPA ASIC (130 nm TSMC CMOS)
  - 32 channels (positive or negative input)
  - PASA preamplifier + 10-bit ADC
  - Programmable conversion gain and peaking times
  - DSP, Memory, High speed e-links
  - Readout mode: continuous or triggered
  - Excellent noise figure of 670 e-
  - Production and testing finished in Sep. 2018



SAMPA Chip
Complete Readout Chain
32 PASA
10-bit 10MHz ADC
DSP + Memory
High-speed e-links

- Front-End Cards (FEC)
  - 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)

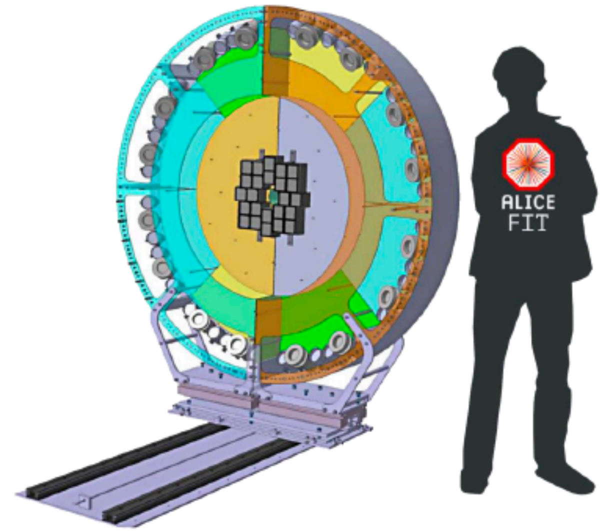


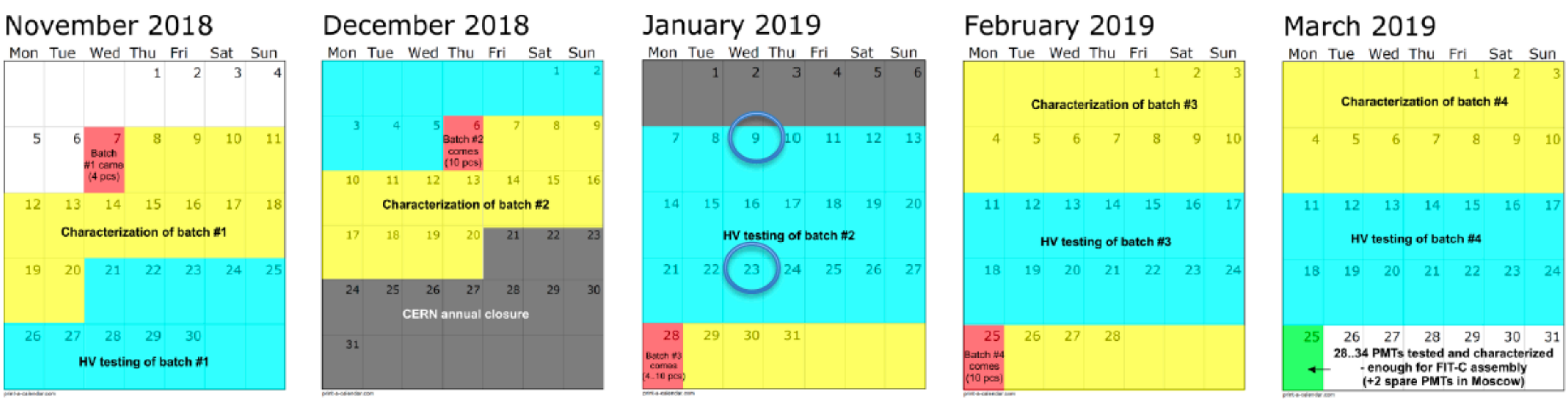


- FEC Production schedule
  - 100 pre-production FECs for sector test will be available in Jan 2019
  - 50% production FECs assembled, tested and received at CERN: 15 Feb 2019
  - 100% production FECs assembled, tested and received at CERN: 15 Apr 2019
  - Start of FEC installation on TPC: 11 Sep 2019
  - FEC production progressing as planned (5 months of contingency)

Remaining agenda for today

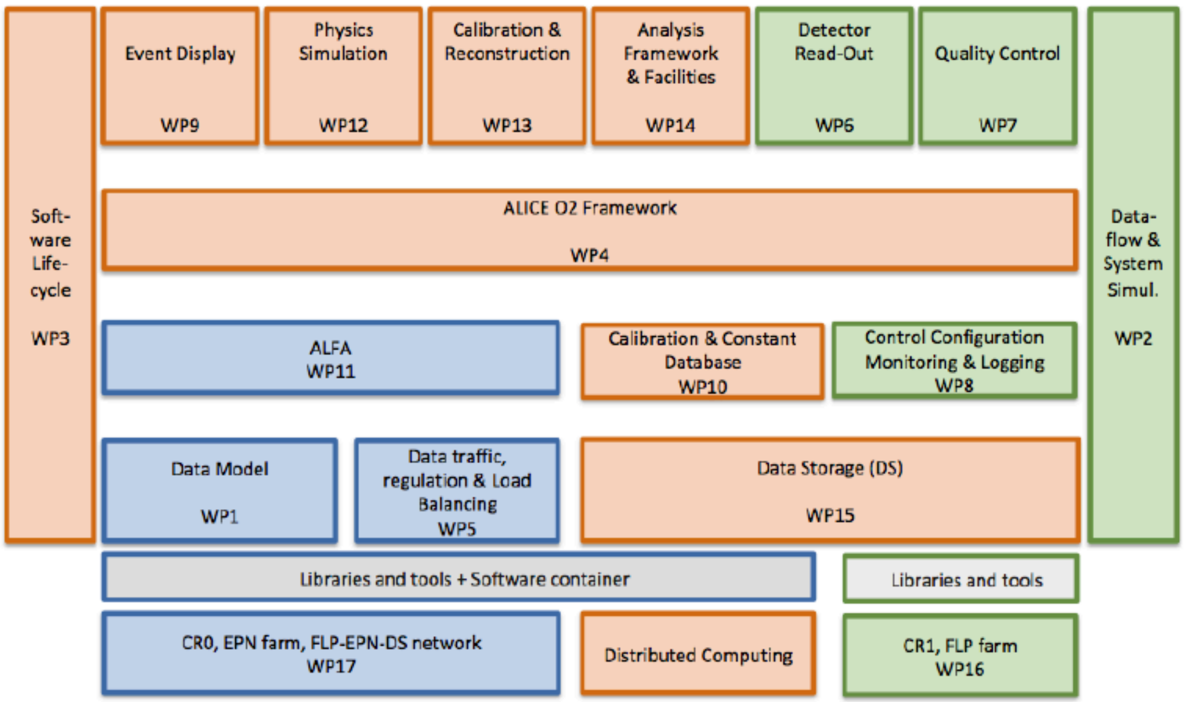
- Update reports
- AOB
  - Because of the Christmas beak at CERN, the next **FIT weekly meeting** will be on **Wednesday**, 9/01/2019, at **15:30 CERN time**
  - The next **FIT Collaboration Meeting** will be on **Wednesday**, 23/01/2019, at **15:30 CERN time**





A Large Ion Collider Experiment

O² is being reorganised



→ 3 separate projects:

- First Level Processors (FLP)
- Event Processing Nodes (EPN)
- Physics and Data Processing (PDP)

details are being finalised

FA | ALICE Week | 10 December 2018 7