A Large Ion Collider Experiment

ALICE

ALICE future upgrades and perspectives

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ALICE

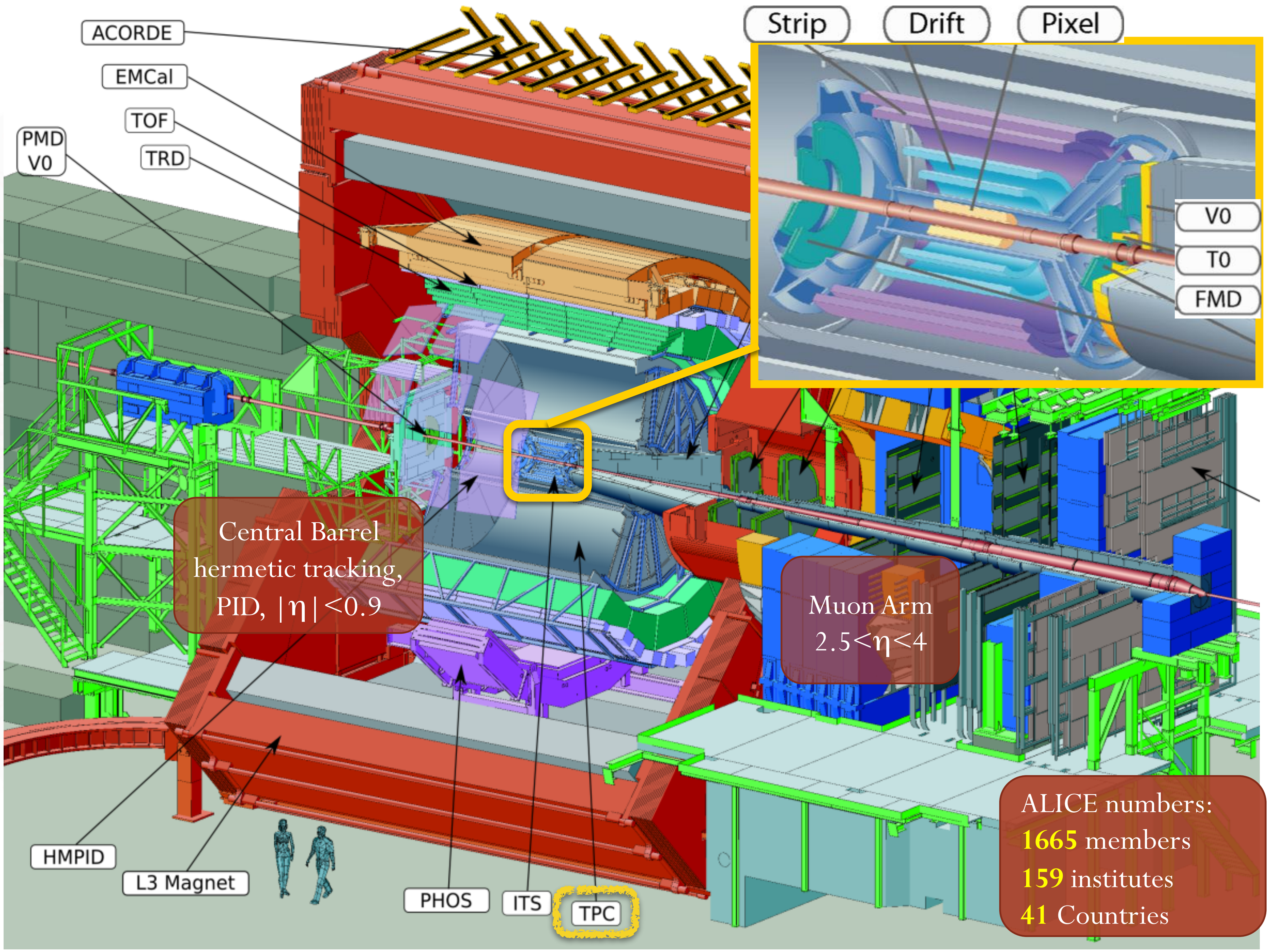
Outline

- ALICE and the LHC schedule
- Running conditions after the next LHC Long Shutdown
- ALICE Upgrade:
  - motivations
  - strategy
- The upgraded detector:
  - new Inner Tracking System (ITS)
  - new Muon Forward Tracker (MFT)
  - Time Projection Chamber (TPC) upgrade
  - Online-Offline (O^2)system.
- Expected physics performance - a personal selection.
- Conclusions

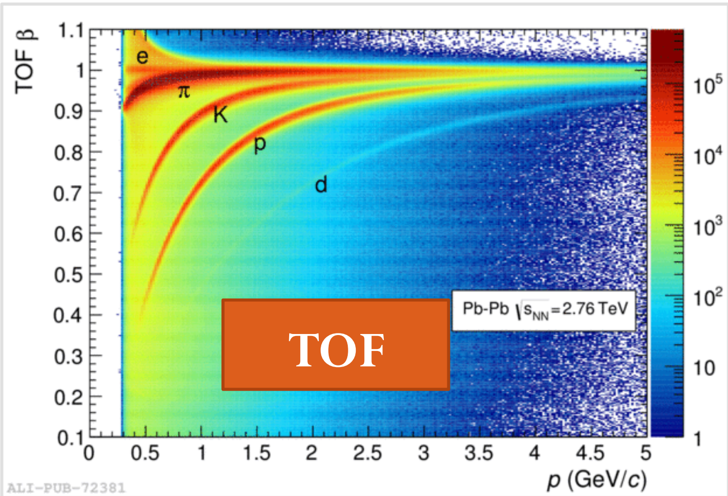
ALICE

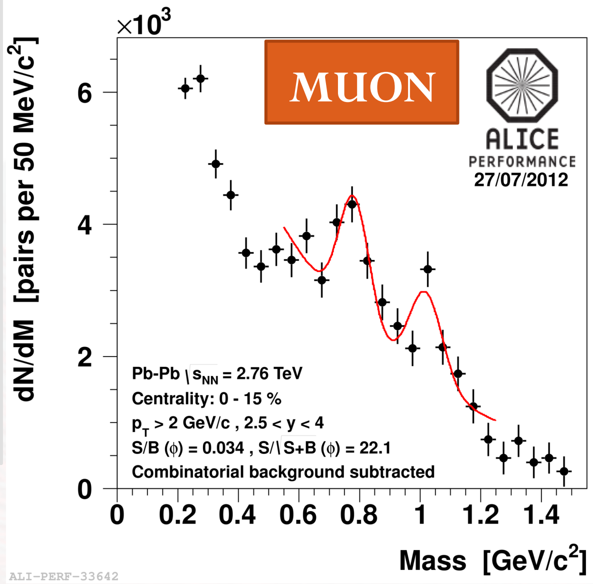
- ALICE is one of the 4 large experiments at the the LHC.
- It was explicitly designed to study **Heavy Ion collisions**.
- ALICE goal: reconstruct and identify charged particles in a central rapidity window to low transverse momentum (p_T~100 MeV/c for pions)
- Central barrel ($|\eta|<1$): tracking (ITS, TPC), PID (TOF,TRD), calorimeters.
- Muon spectrometer: $-4<\eta<-2.5$
- Forward detectors: triggering, centrality, timing.

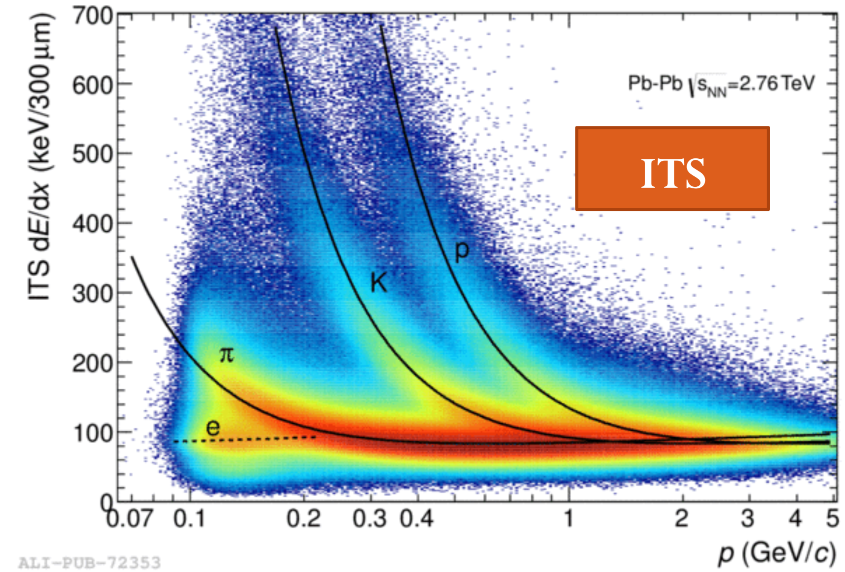
Acronyms:
- ITS - Inner Tracking System
- TPC - Time Projection Chamber
- TOF - Time Of Flight

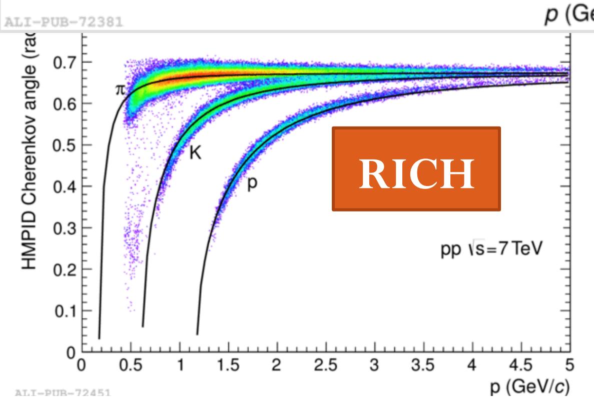


ALICE performance: PID

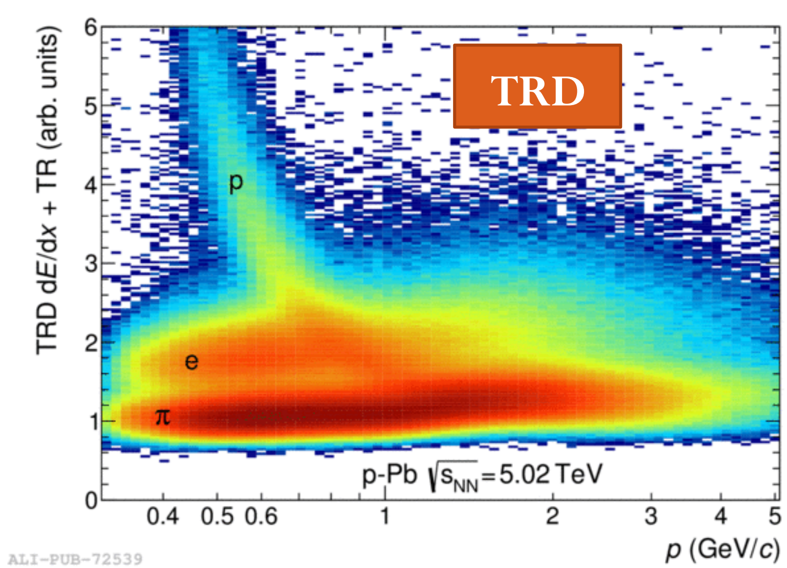


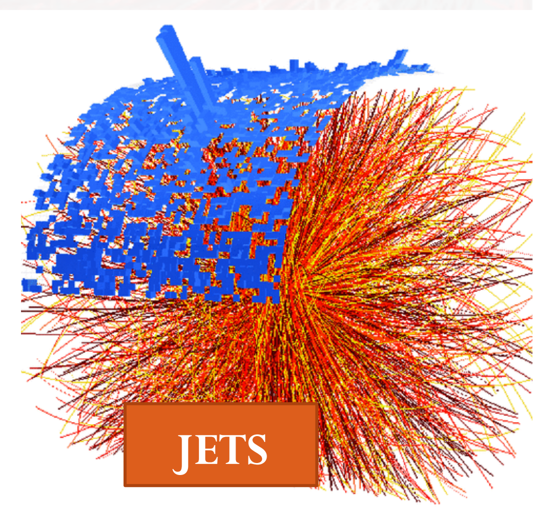


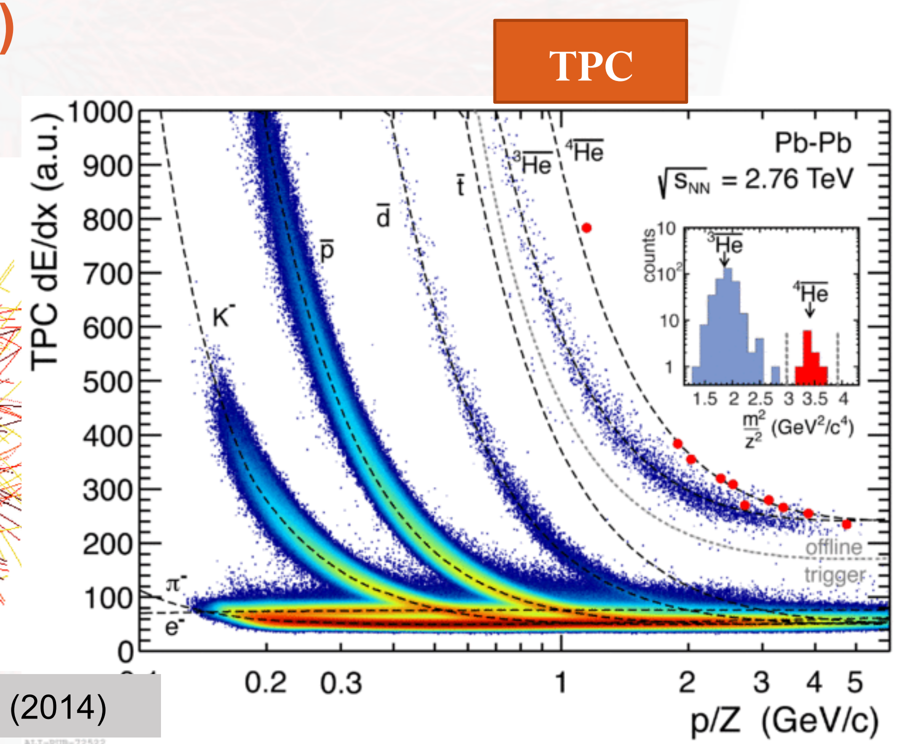




- ✓ Particle identification in a wide momentum range
- ✓ Jets in Pb-Pb (EMCAL)



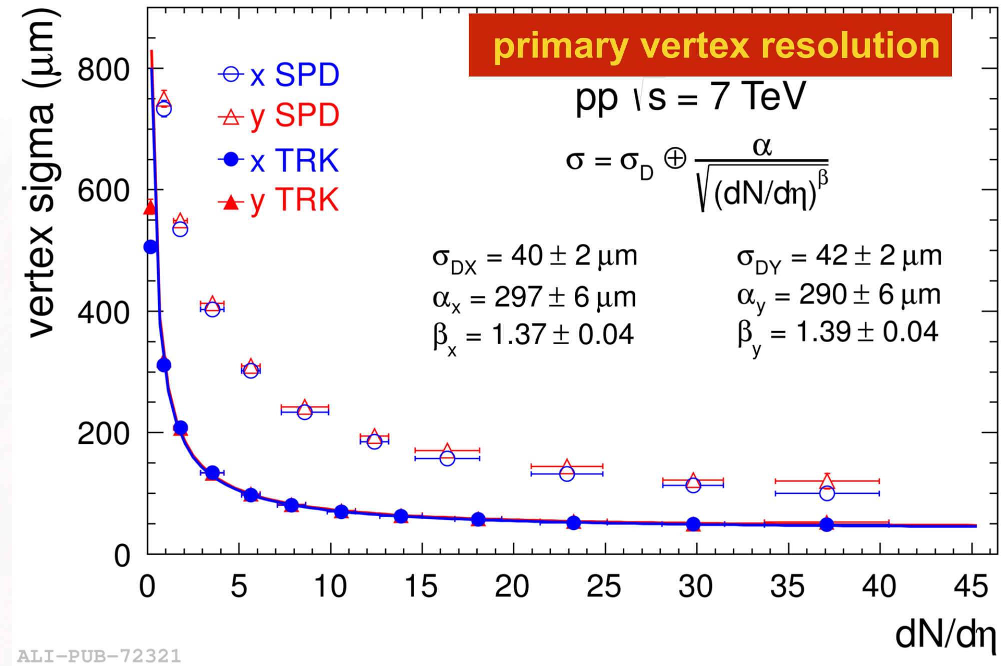


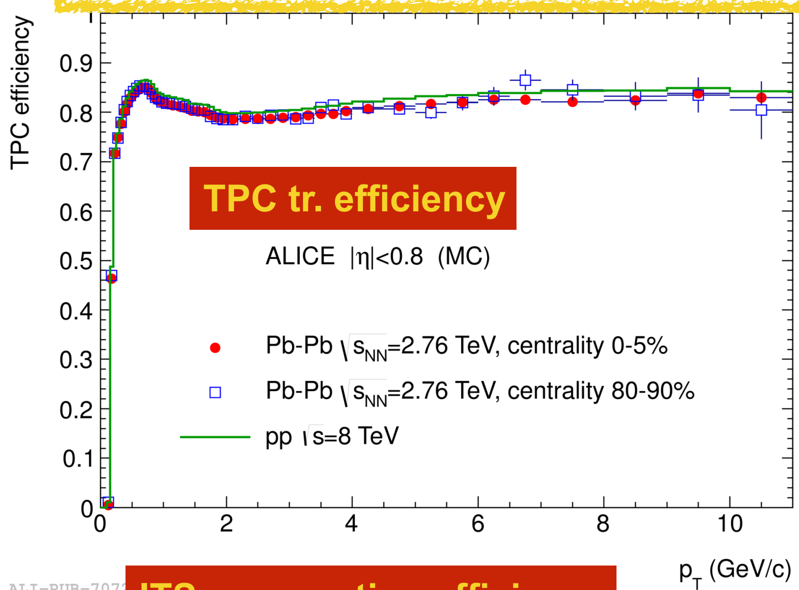


Int. J. Mod. Phys. A 29, 1430044 (2014)

ALICE Performance: vertexing & tracking

- ➡Excellent tracking capabilities
- ➡|η|<0.9 – full azimuthal coverage
- ➡B=0.5 T (solenoidal)
- ➡Key detectors: ITS and TPC
- ➡Good pointing resolution down to low p_T





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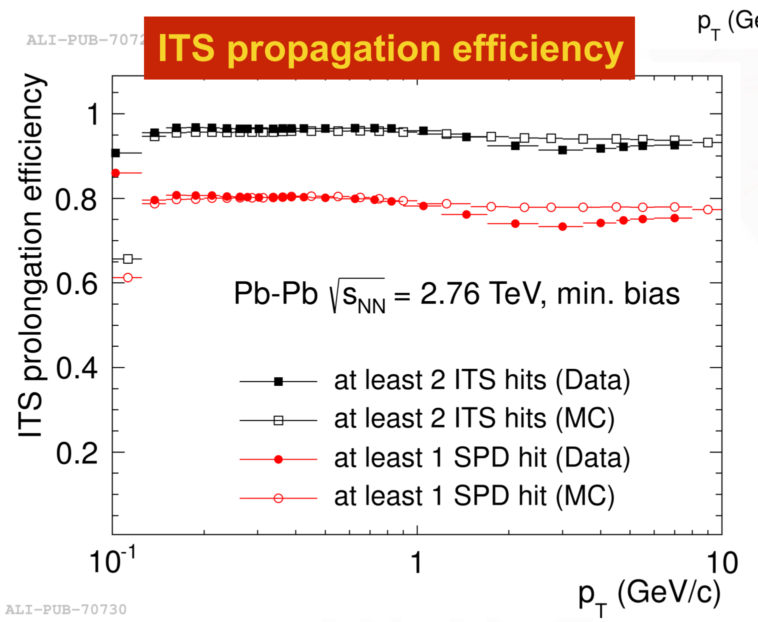
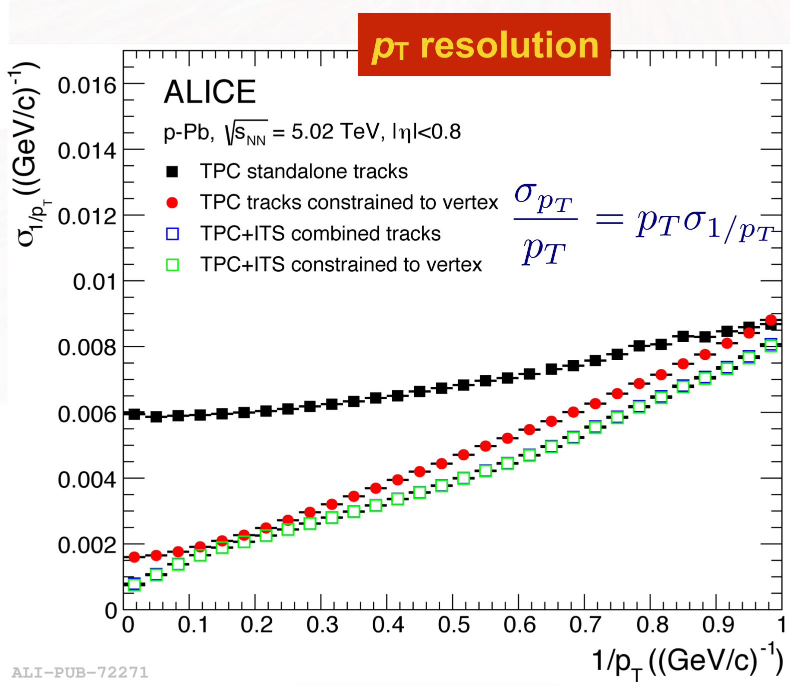
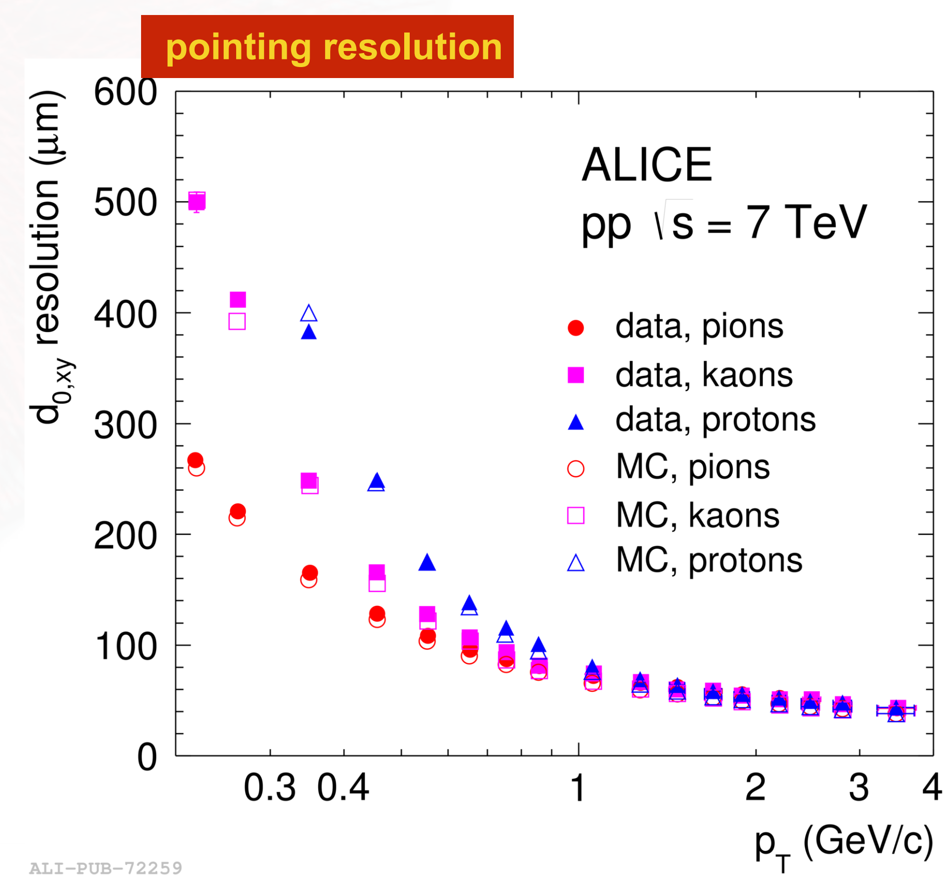
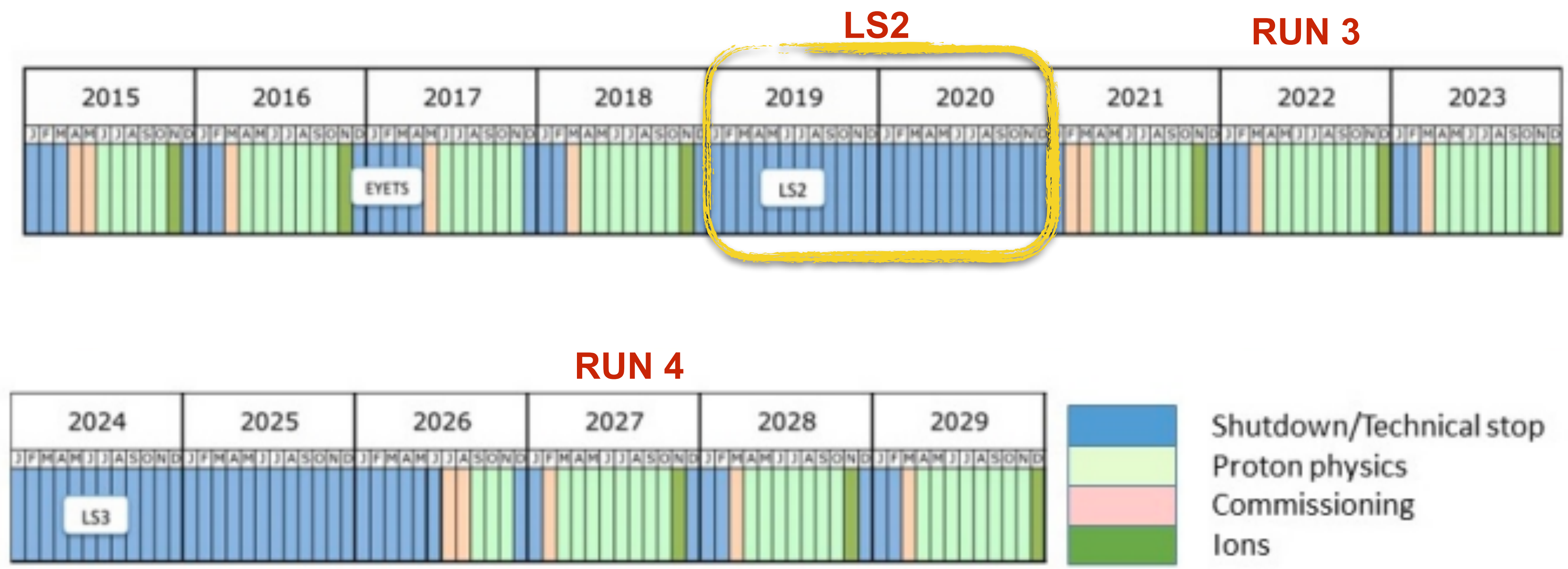






LHC Heavy Ion Program and ALICE upgrade



- The LHC heavy-ion program will extend to Run 3 and Run 4
- High interaction rate: **from 8kHz to 50 kHz** for Pb-Pb $(\mathcal{L} = 6 \times 10^{27}\ \mathrm{cm}^{-2}\mathrm{s}^{-1})$
- Slight energy increase: from $\sqrt{s_{NN}}$=5.02 TeV to $\sqrt{s_{NN}}$=5.5 TeV
- ALICE requested Pb-Pb integrated luminosity: **>10 nb^{-1}** (x100 w.r.t. Run 1)
- **A major detector upgrade has been approved for the LS2 to fully exploit the higher rate and to improve the physics performance**

ALICE Upgrade: physics motivations / 1

- The LHC data confirmed the expectations after the RHIC results:
  - the hot matter created in nucleus-nucleus collisions at the LHC behaves as a **strongly interacting plasma with a very short mean free path.**
  - QGP has the properties of an almost ideal liquid: **radial and elliptic flow**.
  - QCD energy loss in the plasma: **jet quenching, nuclear modification factor**.
- The LHC data brought also **unexpected phenomena like collectivity and strangeness enhancement** in p-Pb and high multiplicity pp collisions.
- With the presently available data, several issues have been addressed, however:
  - there are physics channels that cannot be studied with the present detector.
  - the available integrated luminosity is a limit for rare signals.
- The higher luminosity after LS2 will provide the needed statistics.
- **The purpose of the ALICE upgrade is twofold:**
  - **to exploit the high interaction rate with a MB trigger for low S/B signals.**
  - **to allow for higher precision where needed**

ALICE Upgrade: physics motivations / 2

- ➡ The main physics topics will exploit the **specific** ALICE potentials.
- ➡ ALICE will carry out high precision measurements of rare signals with main focus on the low p_T region:
  - **Charm and beauty hadrons - spectra and flow:**
    - Energy loss of HF in the hot and dense medium produced in AA collisions
    - Thermalization and hadronization mechanisms (coalescence vs fragmentation)
    - Study possible thermal production

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ALICE Upgrade: physics motivations / 2

ALICE

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- **A few examples concerning the Heavy Flavor sector in the next slides**

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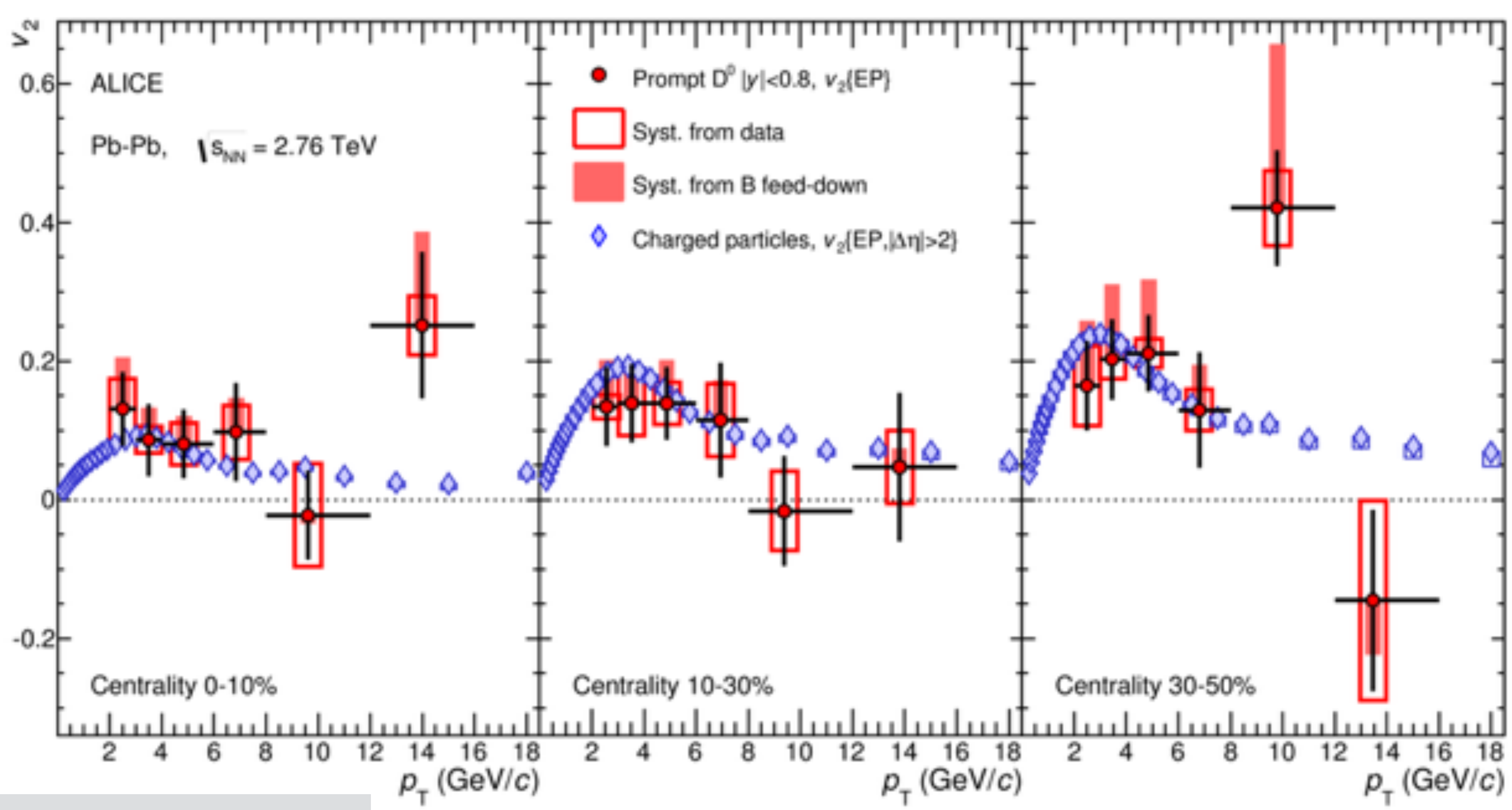
Where higher precision/statistics are needed?

- Open Heavy Flavors are excellent probes for the medium…
- There is evidence that low p_T charm quarks participate in the collective expansion
- **A more precise measurement and higher statistics will allow for a better comparison with light flavor hadrons and with the models.**

Pb-Pb at 2.76 TeV



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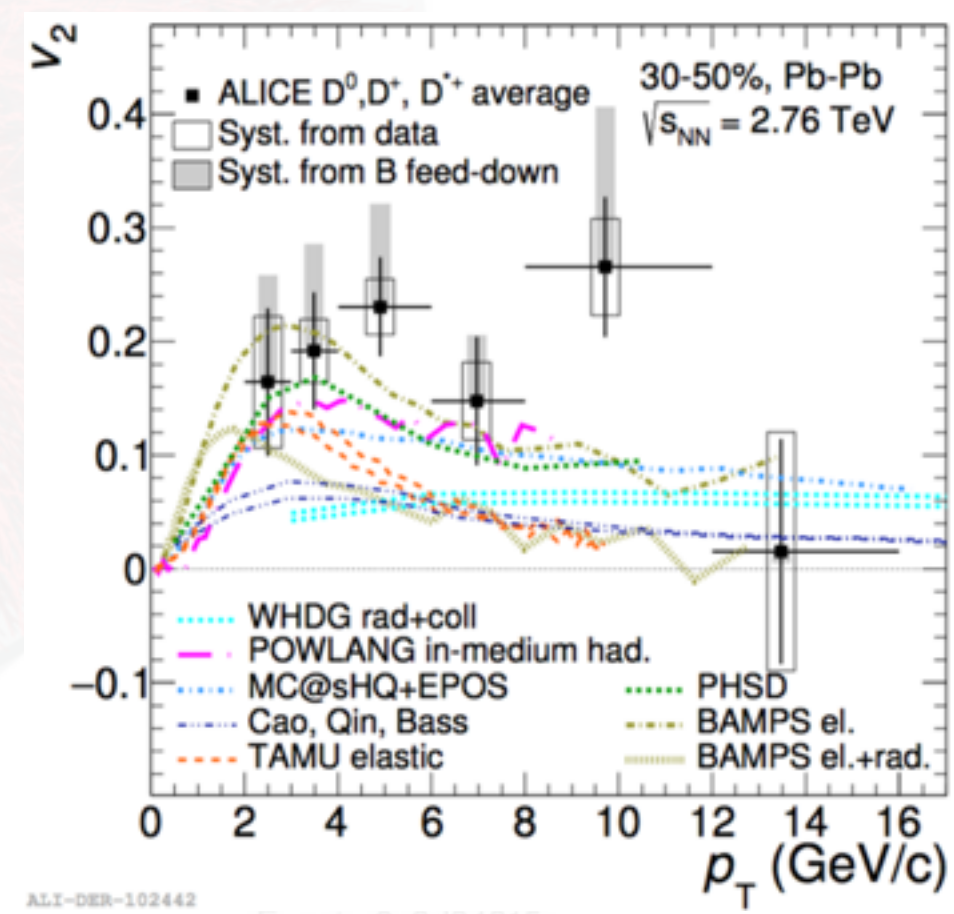

Where higher precision/statistics are needed?

ALICE

- ➡Smaller R_{AA} of D mesons w.r.t. B mesons (J/ψ ← B) as expected from mass-dependent energy loss. **Results are limited to high p_T.**
- ➡R_{AA}(D)≈ R_{AA}(π) . The color charge dependency of energy loss is compensated by the softer fragmentation and p_T spectrum of gluons (M. Djordjevic, Phys. Rev. Lett. 112 (2014) 042302)
- ➡Hints for a R_{AA}(D_s^+)> R_{AA}(D); **if confirmed** it would indicate **charm hadronization through recombination in medium**

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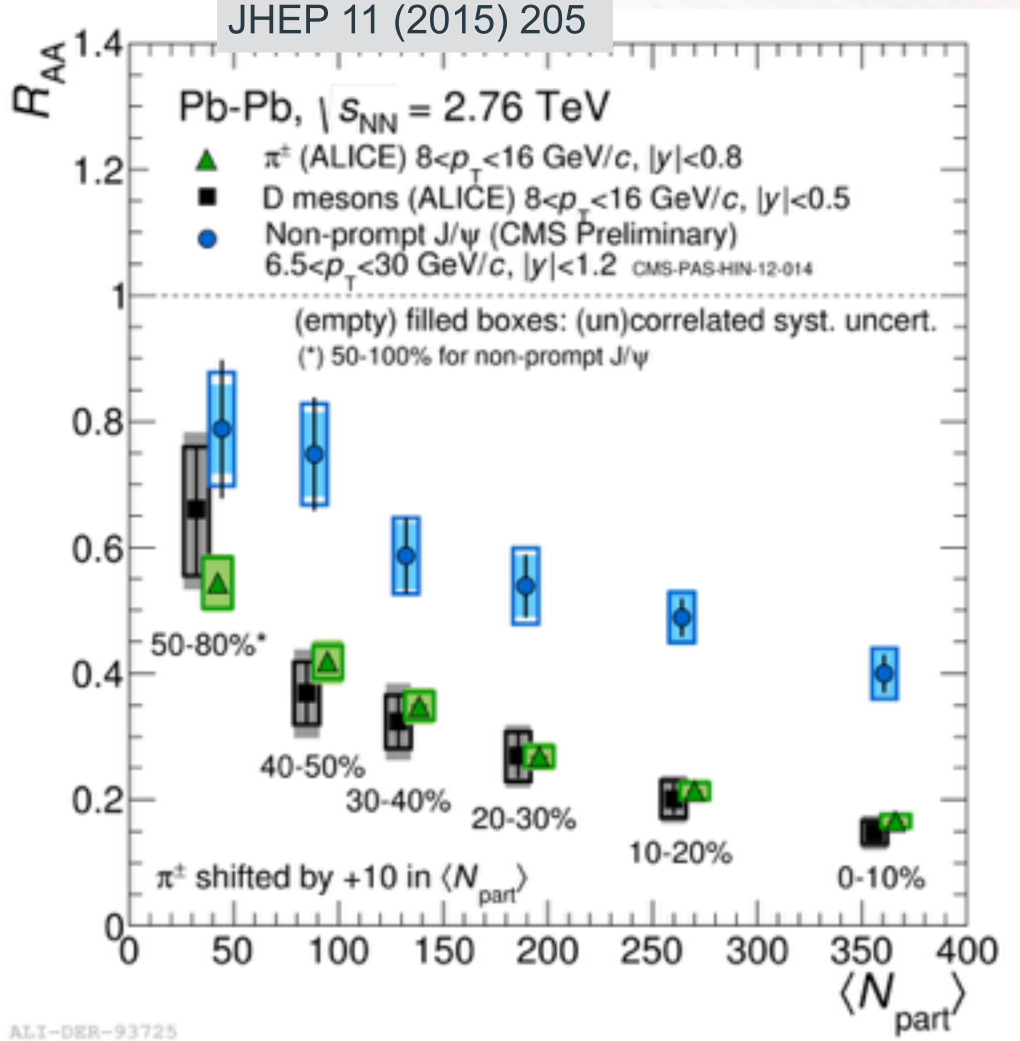
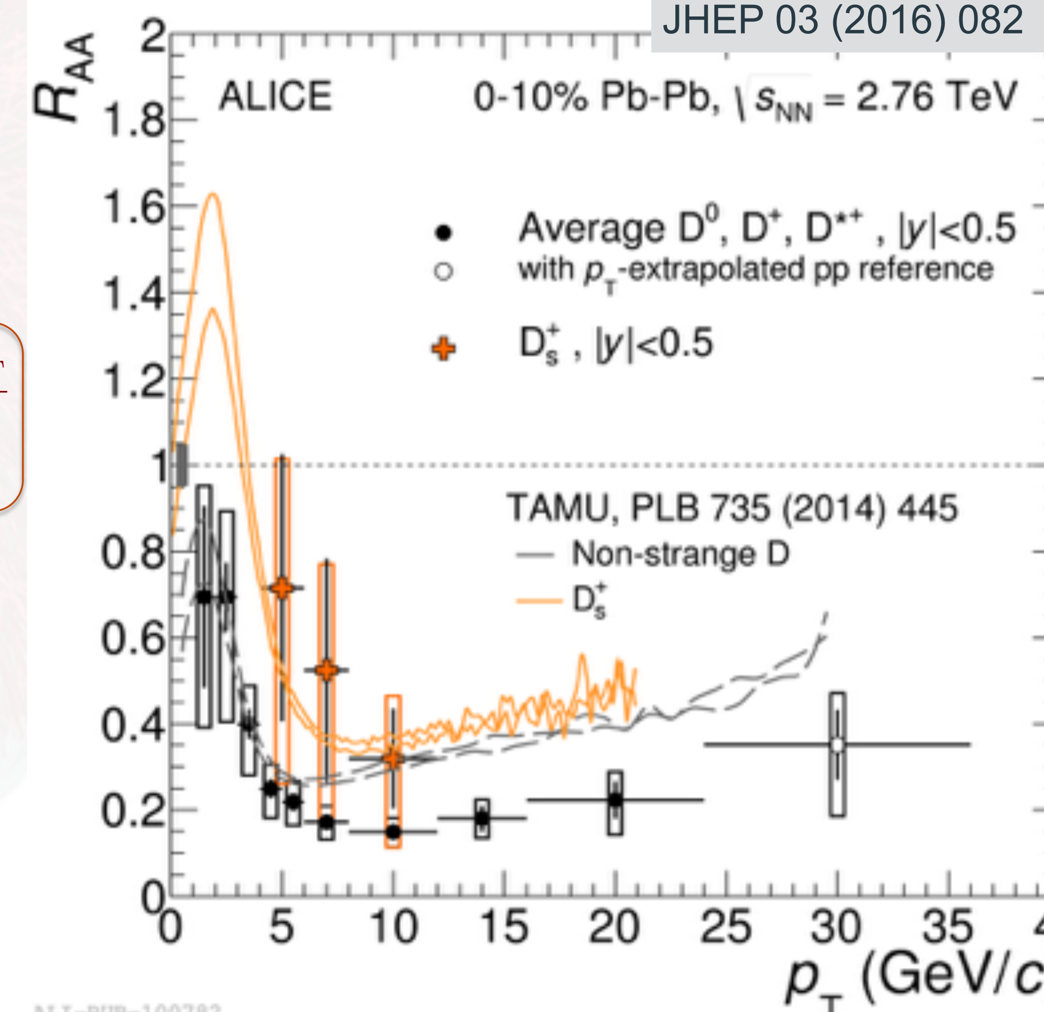


$$R_{AA}(p_T) = \frac{1}{\langle T_{AA} \rangle} \cdot \frac{dN_{AA}/dp_T}{d\sigma_{pp}/dp_T}$$

with $< T_{AA} > \propto < N_{coll} >$

JHEP 03 (2016) 082

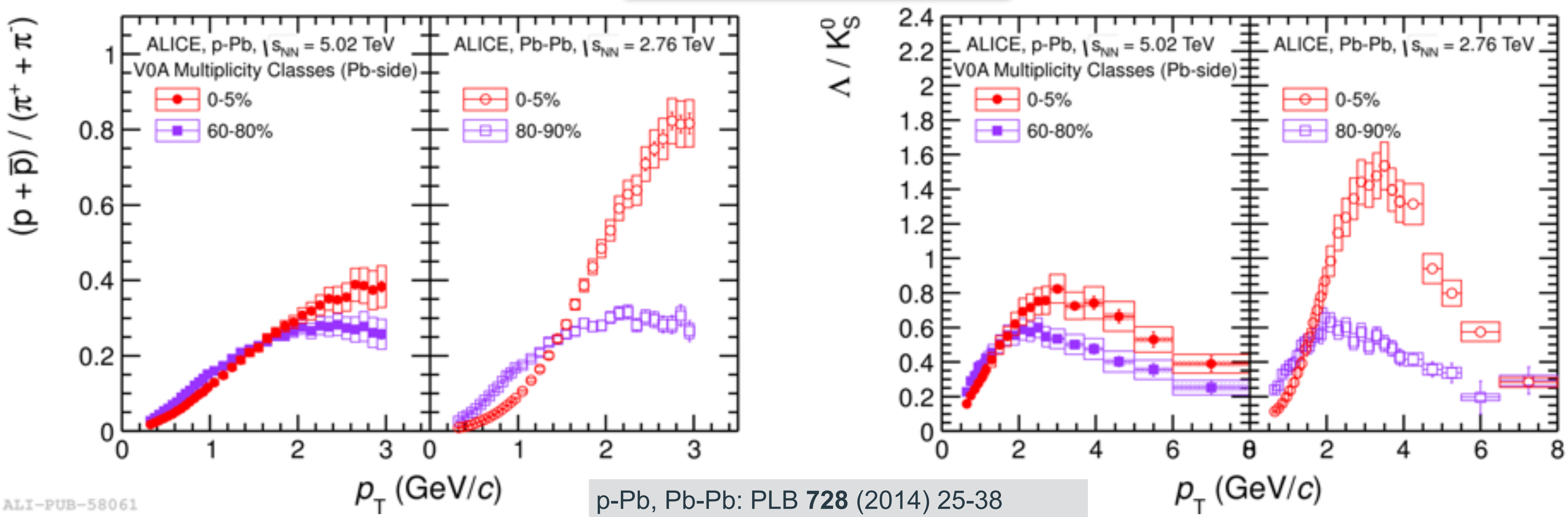


Where higher precision/statistics are needed?

Baryon to meson enhancement

- ➡ Increase from low to high multiplicity collisions in p-Pb and Pb-Pb
- ➡ Trend qualitatively similar in in different colliding systems
- ➡ The enhancement at intermediate p_T can be explained in Pb-Pb by collective flow and/or quark recombinations
- ➡ **Charm and Beauty baryons cannot be reconstructed in Pb-Pb with the present detector**
- ➡ **More generally, direct reconstruction of Beauty is not possible with the present detector**

Baryon to meson ratios



p-Pb, Pb-Pb: PLB **728** (2014) 25-38

ALICE Upgrade: physics motivations / 3

ALICE

➡ ALICE will carry out high precision measurements of rare signals with main focus on the low p_T region:

- **Quarkonia down to p_T~0**
  - wide rapidity range: e.g. $J/\psi \to e^+e^-$ at midrapidity and $J/\psi \to \mu^+\mu^-$ at forward rapidity
  - dissociation and recombination mechanisms in a deconfined medium.
  - **ψ(2S) measurement will help to disentangle the mechanisms at work**
- **Low mass dileptons:**
  - e.m. radiation from the QGP
  - temperature, EOS and space-time evolution
  - chiral symmetry restoration (modification of the spectral function for ρ meson → dileptons).
- **Jets:**
  - quenching and fragmentation
  - PID of jet particle content
  - Heavy Flavour tagging
- **Light nuclei and hypernuclei (e.g. ^{4}He, $^{5}_{\Lambda\Lambda}$H)**

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ALICE Upgrade: strategy

➡ Boundary conditions and requirements:

– very low signal/background ratio for most of the physics signals → **no trigger selection possible**.

– High rate: $\mathcal{L} = 6 \times 10^{27}\, cm^{-2} s^{-1} \Longrightarrow R = 50\, kHz$

– Focus on heavy flavors → improve **track resolution and vertexing**.

– large minimum bias samples required: L_{int}>10 nb^{-1} .

We will have to read out everything

From 1 kHz to 50 kHz

➡ Strategy:

– New **Inner Tracking System** at midrapidity.

– Narrower beam pipe: **from R=29 mm to R=17.2 mm.**

– New **Muon Forward Tracker** in front of the muon absorber.

– New readout chambers for the **TPC**. Readout upgrades for several detectors and the online systems.

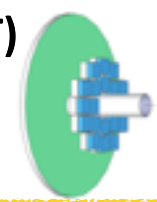
– New Forward Interaction Trigger (**FIT**)

– Integrate Online and Offline (**O^2 project**) → data reconstruction online

New glasses for ALICE

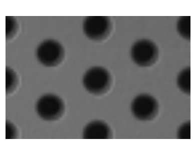
FoCal project (Forward Calorimeter) - Proposal under internal review

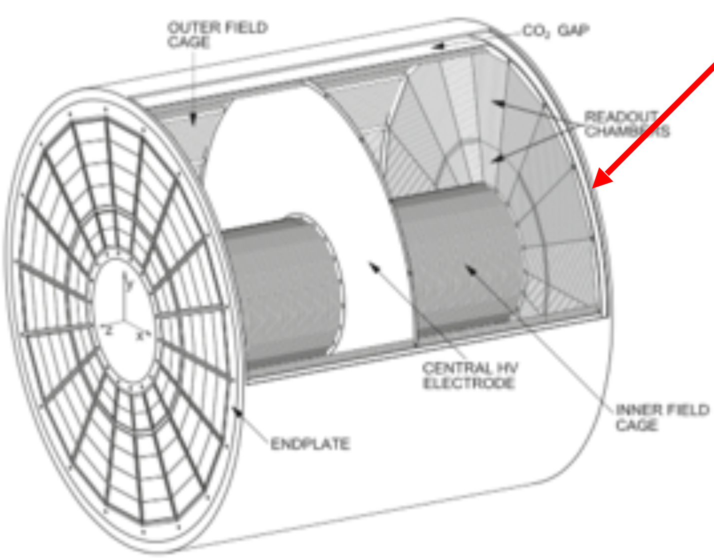
New Forward Interaction Trigger (FIT)

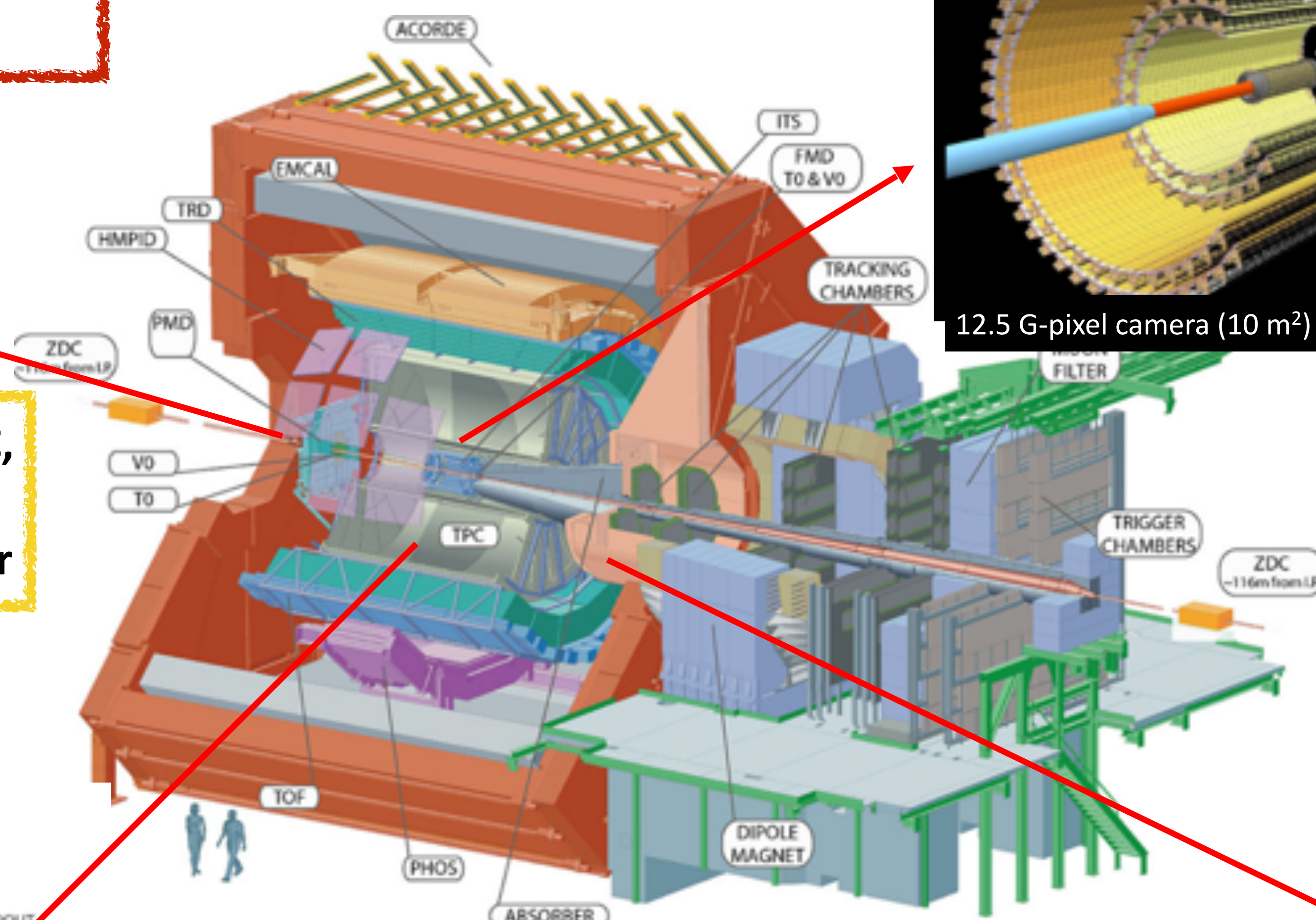


Improved readout for TOF, ZDC, TRD, MUON ARM + new Central Trigger Processor

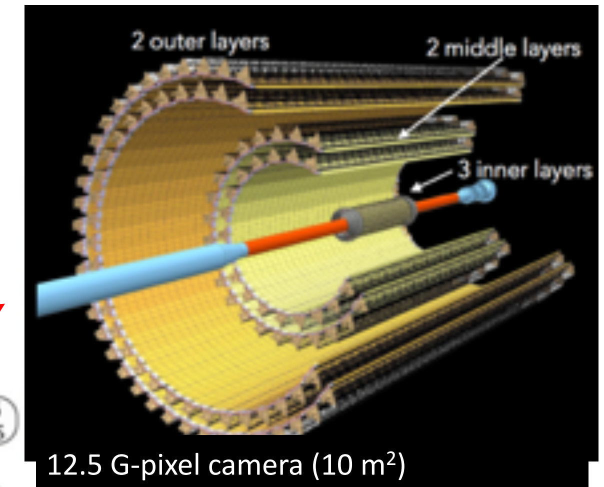
TPC with GEM based readout





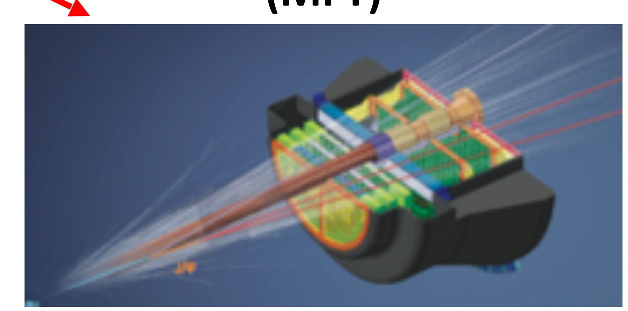


New Inner Tracking System (ITS)



Both based on Monolithic Active Pixel Sensors (MAPS)

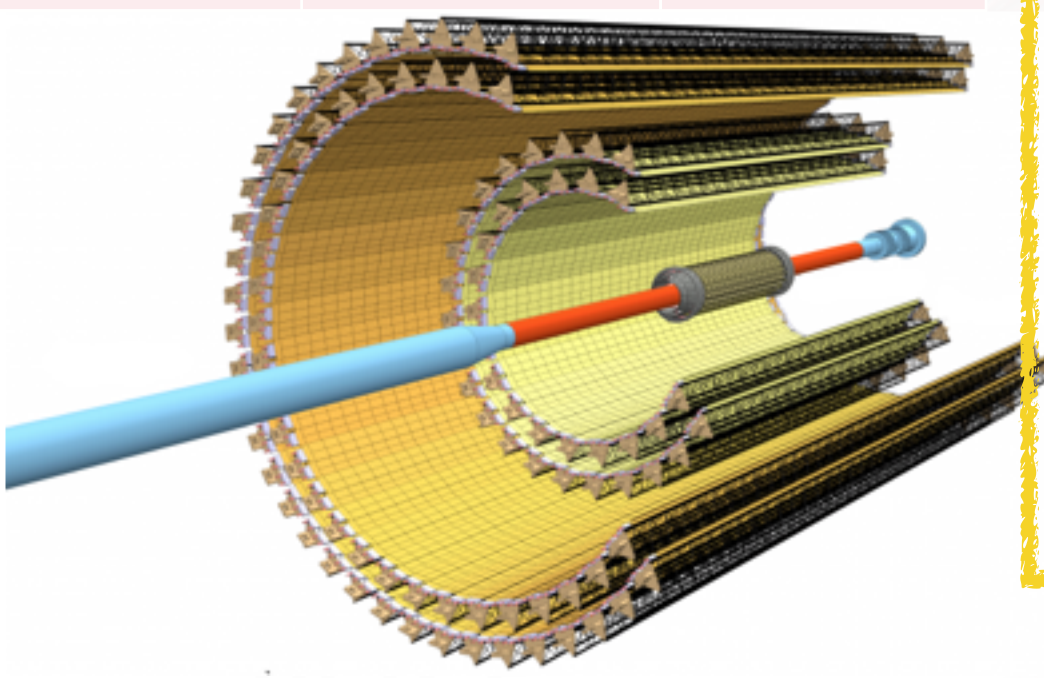
New Muon Forward Tracker (MFT)



New Online+Offline System: O^2

Upgrade of the Inner Tracker

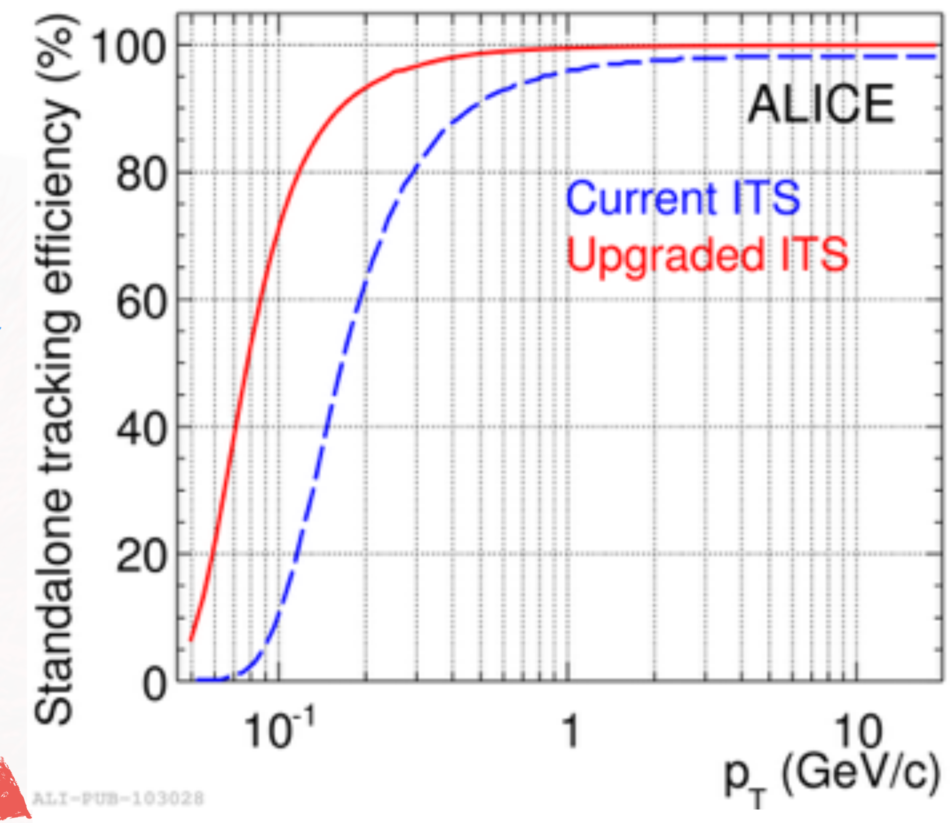
	ITS	ITS UPGRADE
Number of layers	6	7
Rapidity coverage	$\|\eta\|<0.9$	$\|\eta\|<1.5$
Material budget/layer	1.1% X_0	0.3-0.8% X_0
Spatial resolution	12 x 100 μm^2 35 x 20 μm^2 20 x 830 μm^2	5 x 5 μm^2
Max Pb-Pb readout rate	1 kHz	100 kHz

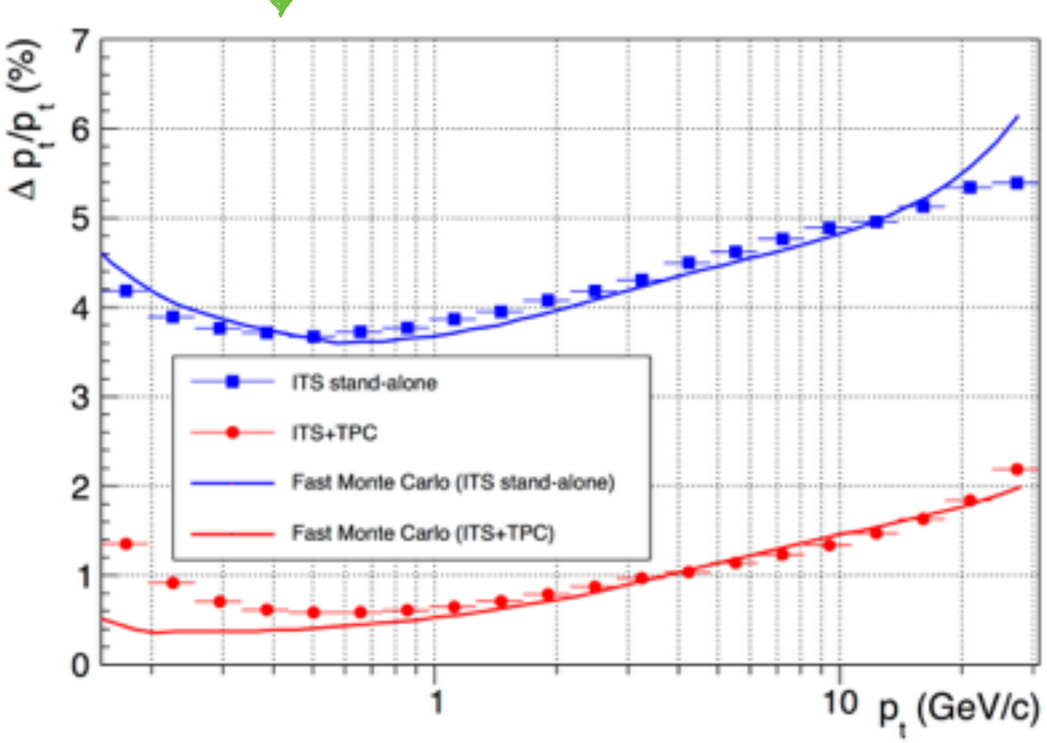


- ➡ **Better pointing resolution by a factor of 3(5) in rφ (z) at p_T=500 MeV/c**
  - innermost layer is closer to the IP: **from 39 mm → 22 mm**
  - reduced material budget: **~0.3% X_0** for the 3 inner layers (**0.8% X_0** for the other 4 layers)
  - reduced pixel size: from 50×425 μm^2 → ~(**30×30 μm^2**)
  - max silicon thickness: **50 µm**
  - **ALPIDE** (**AL**ice **PI**xel **DE**tector) chip → Monolithic Active Pixel Sensors (**MAPS**) in TowerJazz 0.18 µm CMOS technology.
- **Better tracking efficiency and p_T resolution at low p_T**
  - thanks to the higher resolution and to the additional layer
- ➡ **Faster readout**
- ➡ **Accessible for maintenance during winter shutdowns**

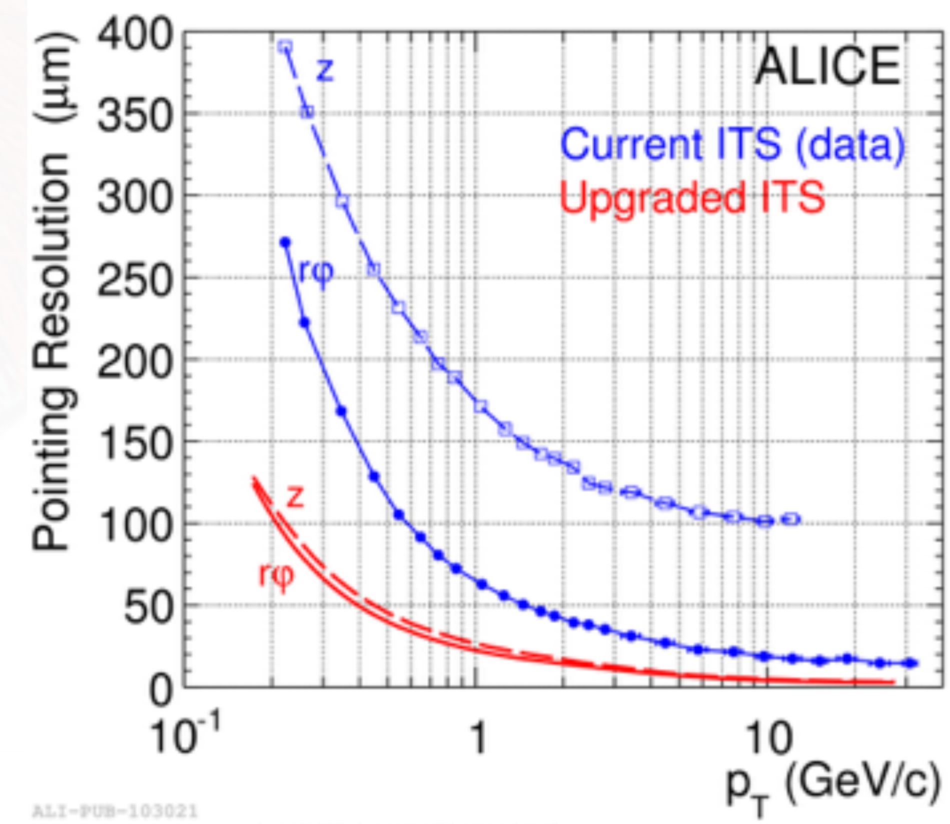
Upgrade of the Inner Tracker

- Expected performance of the new ITS :
  - – tracking efficiency
  - – impact parameter resolution
  - – transverse momentum resolution

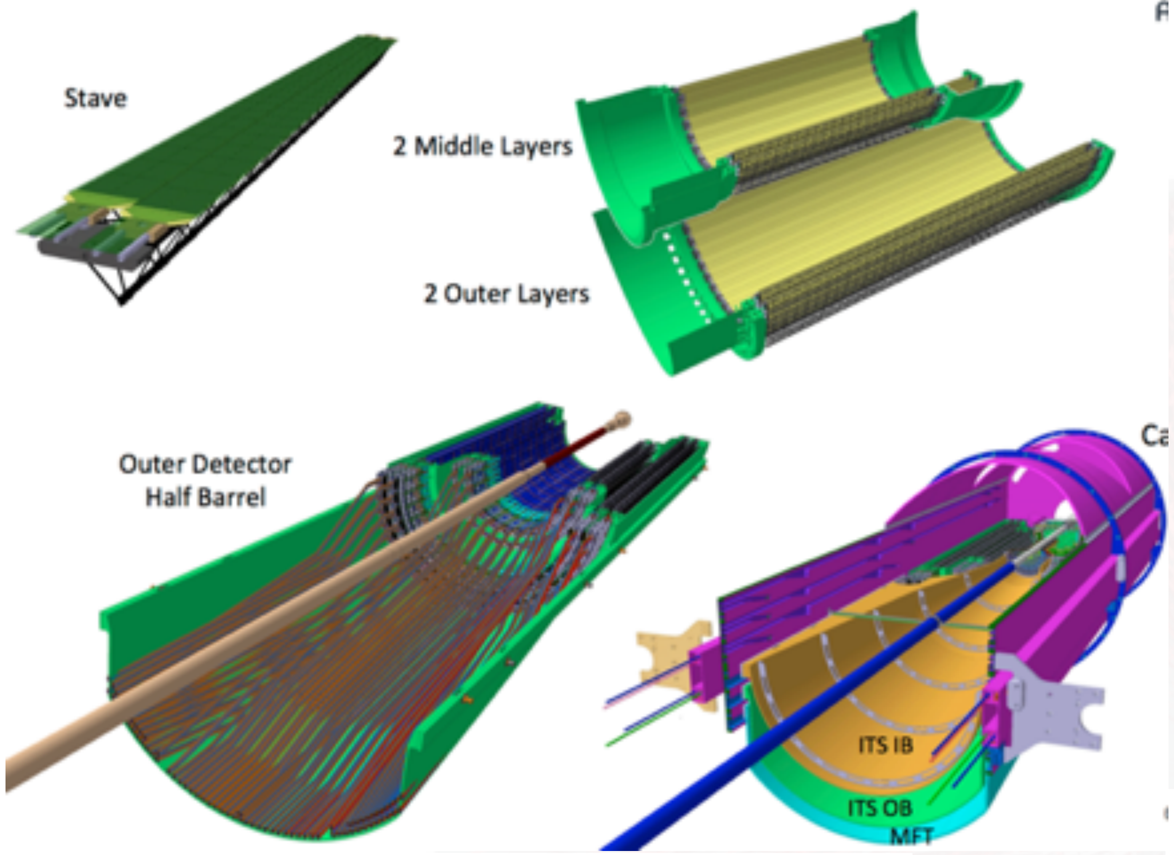


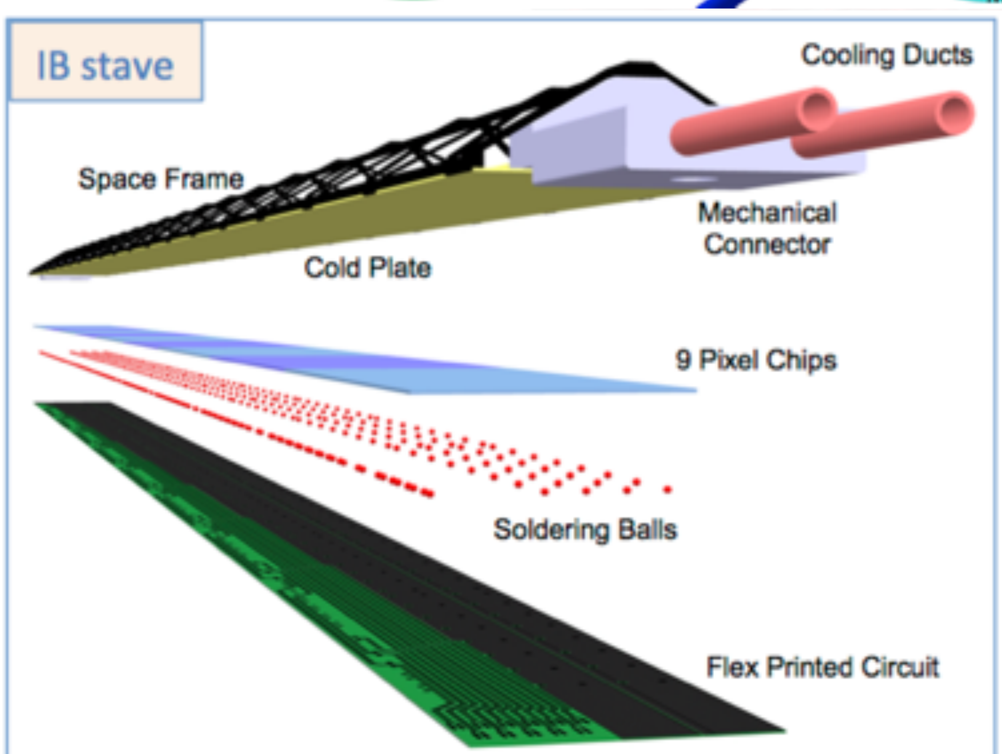


CERN-LHCC-2013-024 ;
ALICE-TDR-017

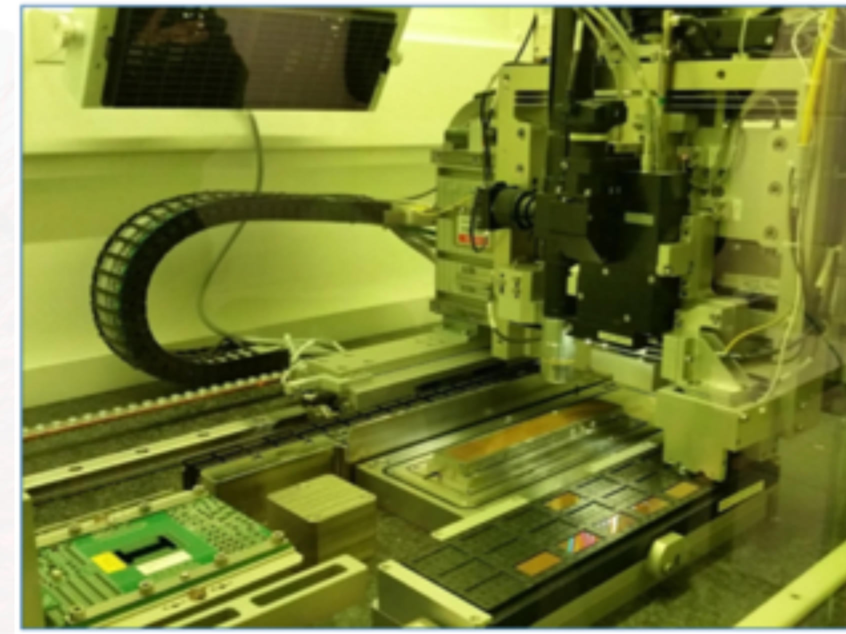


The ITSU building phase will start soon





Module assembly machines

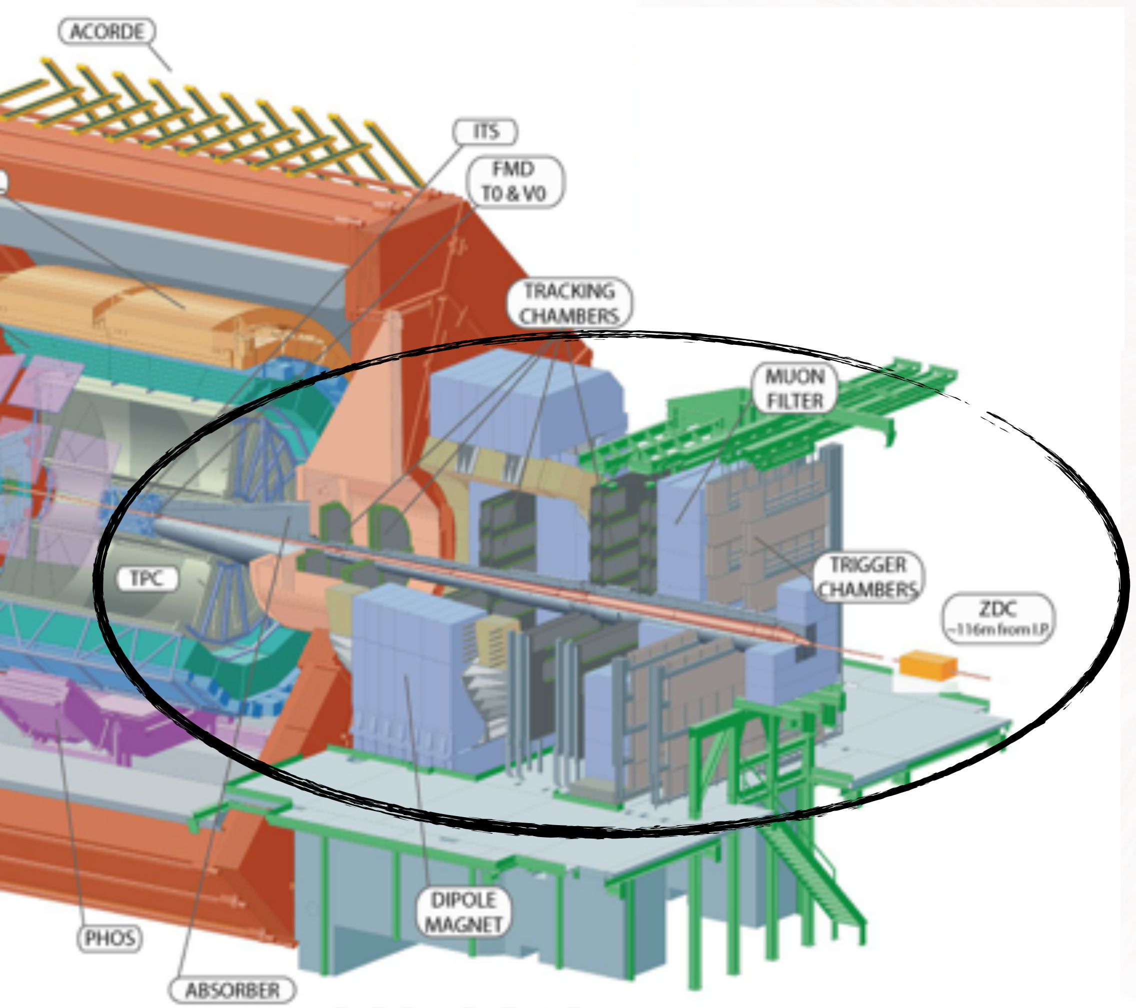


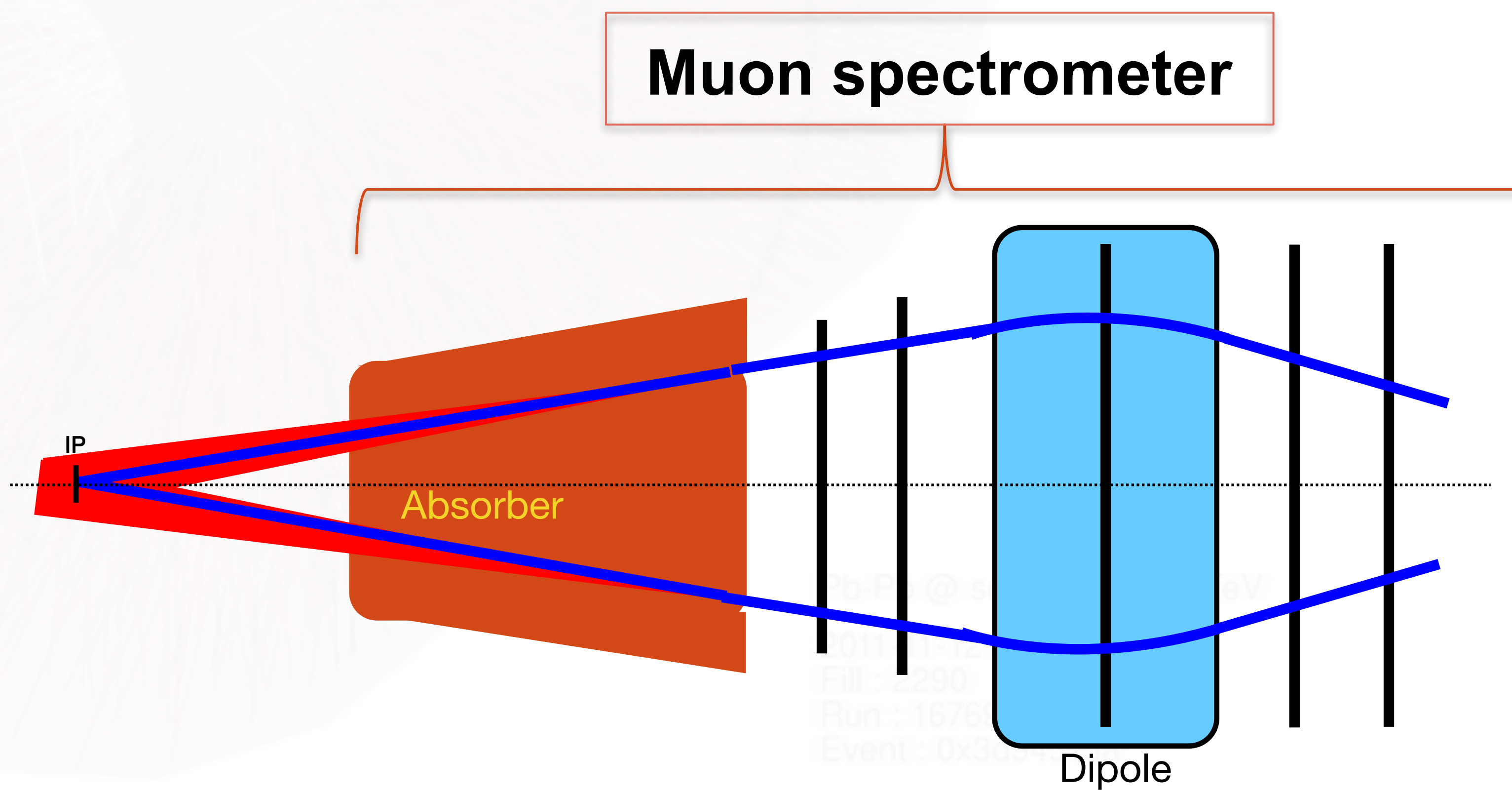
ITS IB staves

Production:
-n. 31 units produced

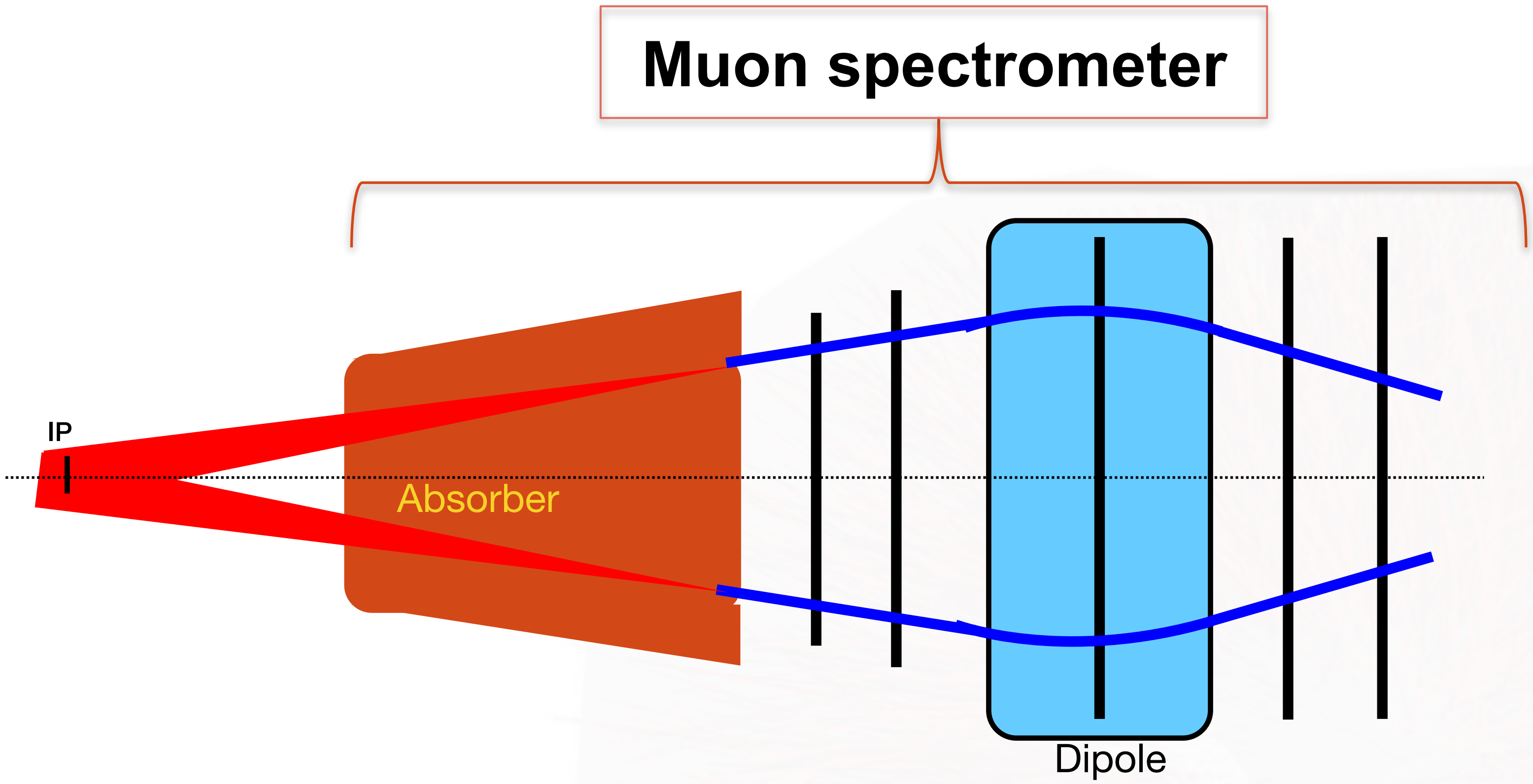
The Muon spectrometer

- ALICE muon spectrometer is located in the forward region: **$-4<\eta<-2.5$** .
- The extrapolation of the muon tracks candidates to the interaction diamond is affected by the presence of the absorber.
- This has a negative effect on the reconstruction of the kinematics and on the possibility to separate prompt and displaced muons





The new Muon Forward Tracker (MFT)



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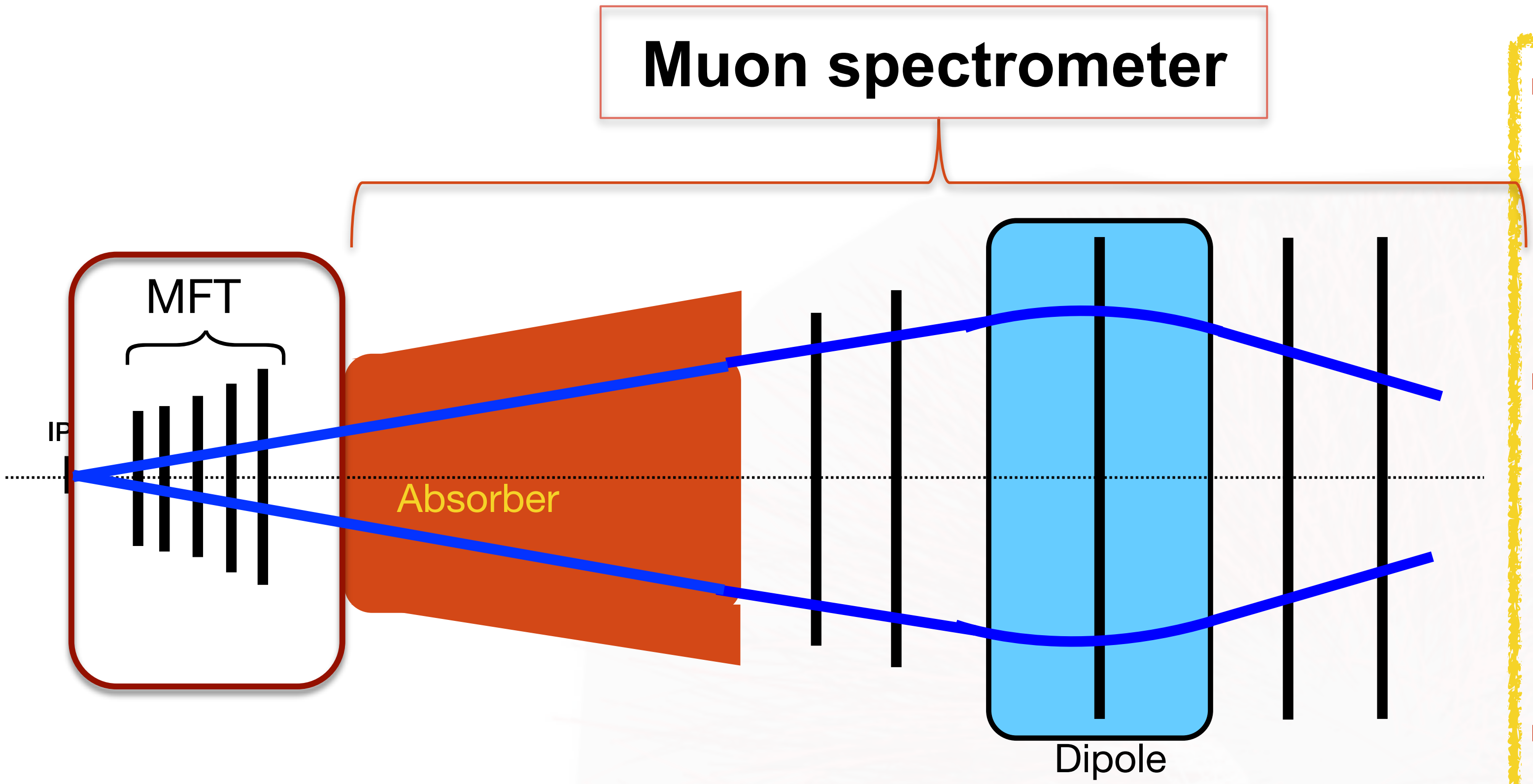
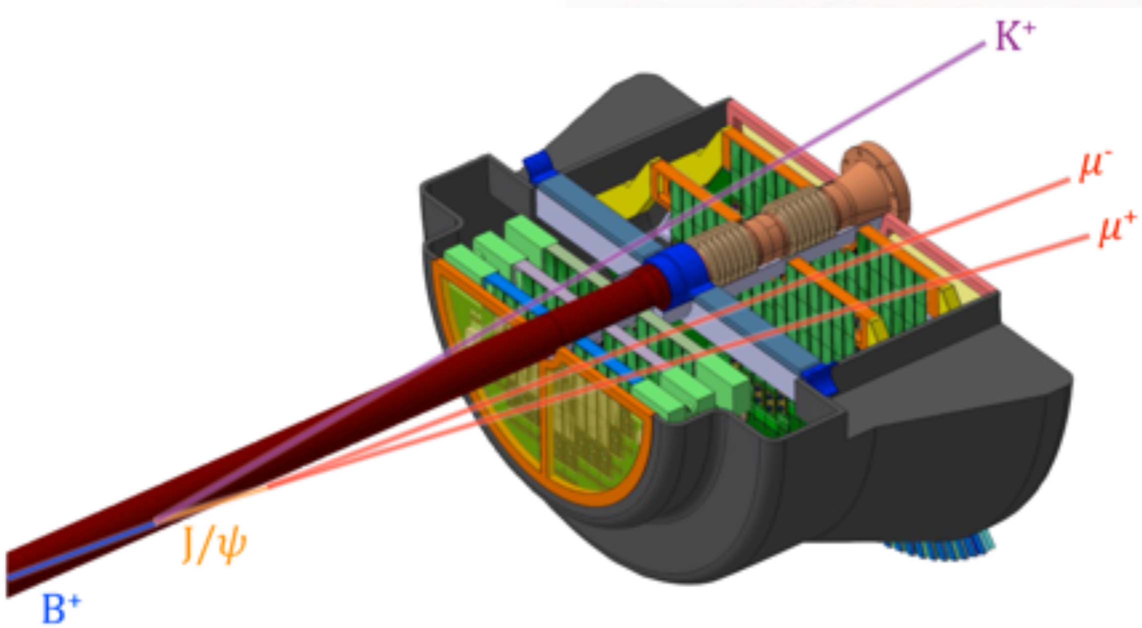


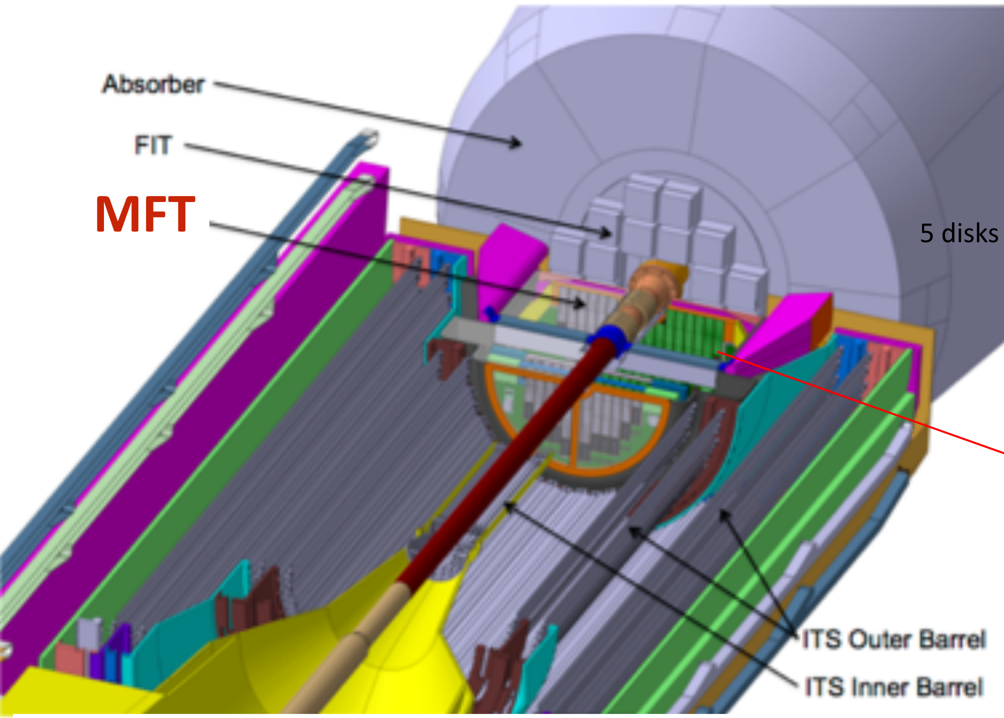


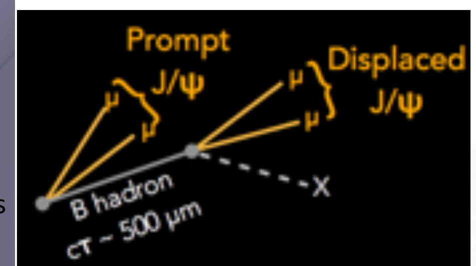
- The extrapolated muon tracks are matched with tracks reconstructed with the MFT

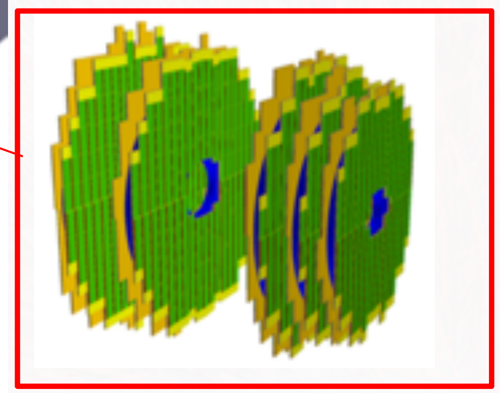
PHYSICS GOALS

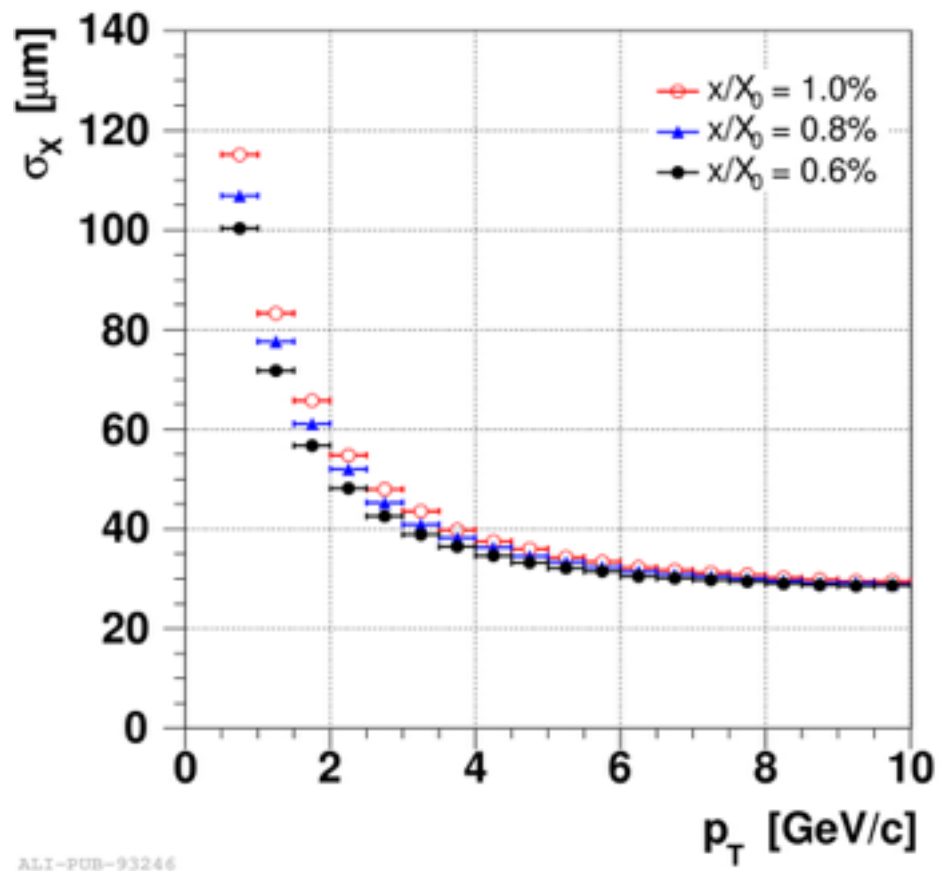
- **Open Heavy Flavors**
  - Charm measurement down to p_T=1 GeV/c (single μ channel)
  - Beauty measurement down to p_T=0 (non prompt J/ψ)
- **Prompt charmonium production**
  - prompt/non prompt J/ψ separation down to p_T=0
  - ψ(2S) in central Pb-Pb collisions down to p_T=0
- **Low mass dimuons**
  - improved mass resolution (low mass resonances)
- **Event plane measurement and azimuthal correlation at forward rapidity**

The new Muon Forward Tracker (MFT)









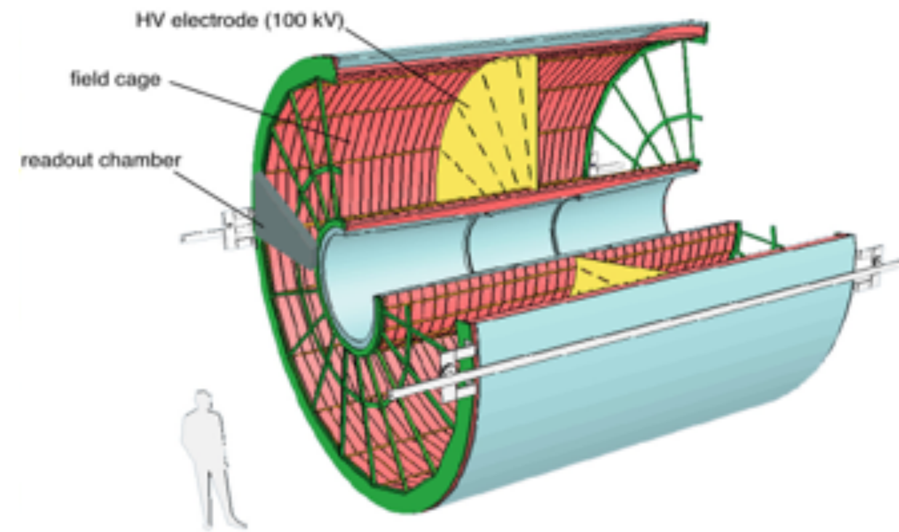
CERN-LHCC-2015-001

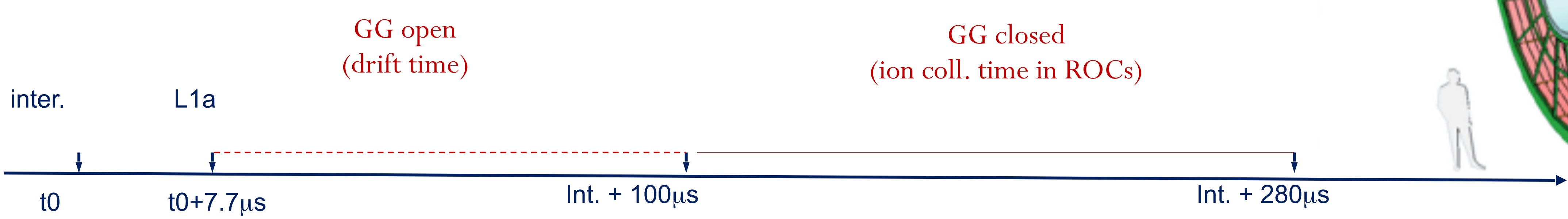
- 5 planes of MAPS ALPIDE silicon pixel sensors
  - **same chip used in the ITS**
- Placed in front of the absorber:
  - -76.8 cm < z < -46 cm
- $-3.6 < \eta < -2.45$
- $X/X_0 = 0.6\%$
- Inner radius of the disk constrained by the beam pipe: 2.5 cm ÷ 3.92
- Outer radius: 9.26 cm ÷ 14.35 cm
- 896 sensors

Time Projection Chamber: present limitations

➡ **gating grid of readout MWPCs closed to avoid ion feedback**
- Limit space charge to tolerable level
- Effective dead time ~280 μs, maximum readout rate: 3.5 kHz

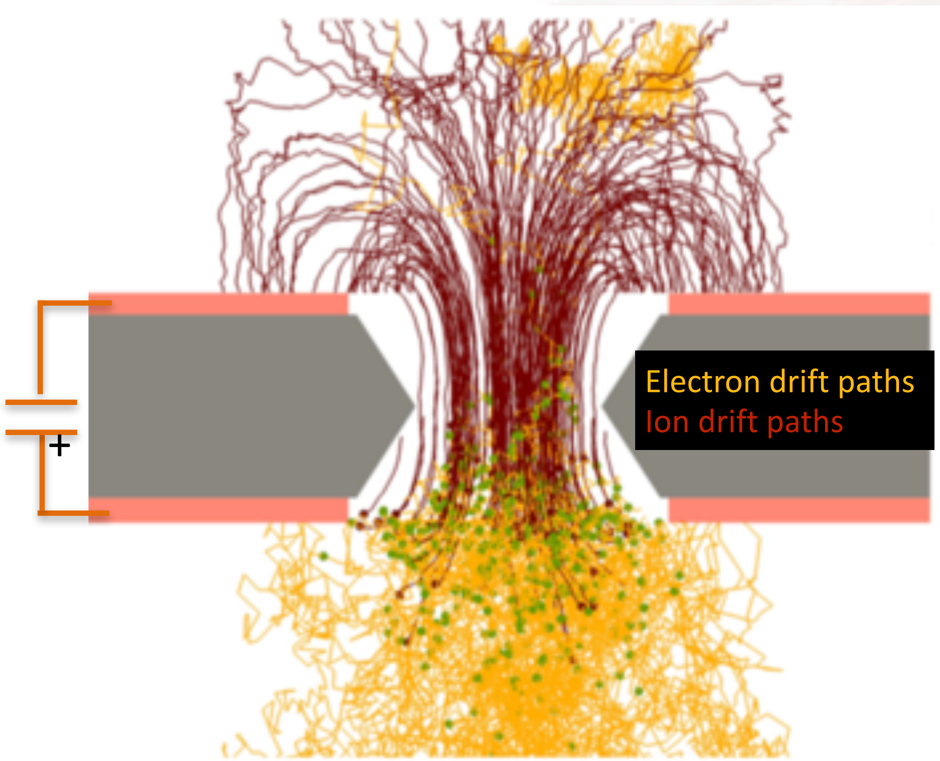
➡ **alternative: gating grid always open**
- Ion feedback ~10^3 x primary ions generated in drift volume
- Large space charge effects (of the order of electrical field)
  - Space point distortions (at 50 kHz) of order of 1 m – not tolerable!!

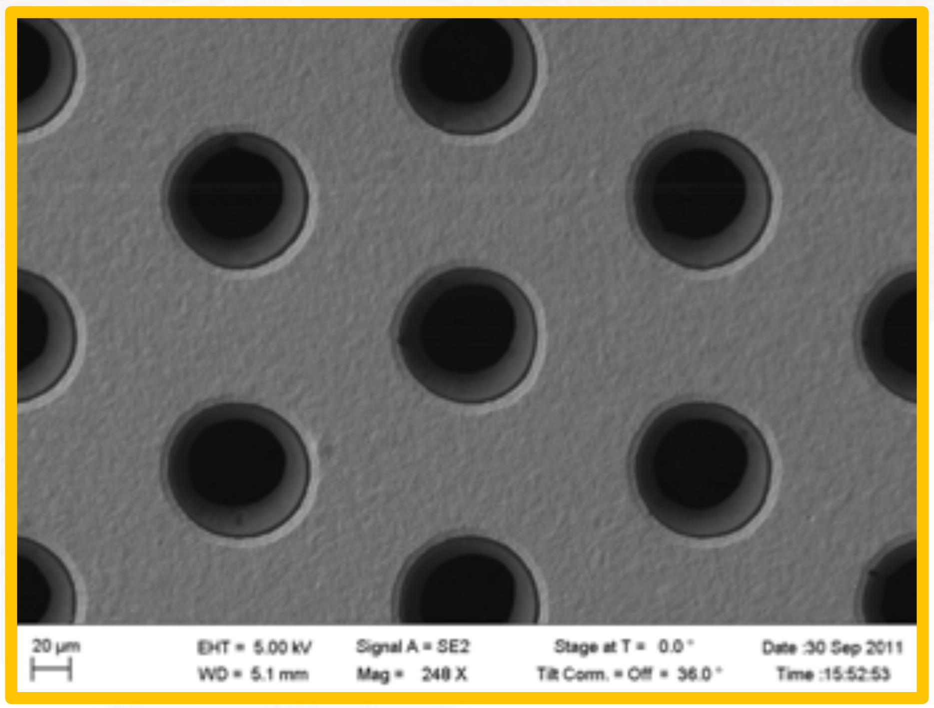


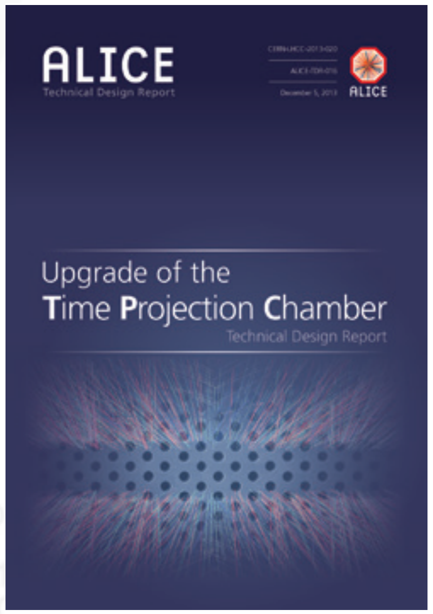


TPC Upgrade

- **Goal**
  - Operate at 50 kHz preserving the present tracking and PID performance
- **Upgrade**
  - **Continuous readout** → redesign TPC FE and Readout electronic systems
  - **No gating** → with MWPC this would lead to massive space-charge distortions
  - To reduce ion back flow at high rate, MWPCs will be replaced with a readout based on **GEM (Gas Electron Multiplier)**





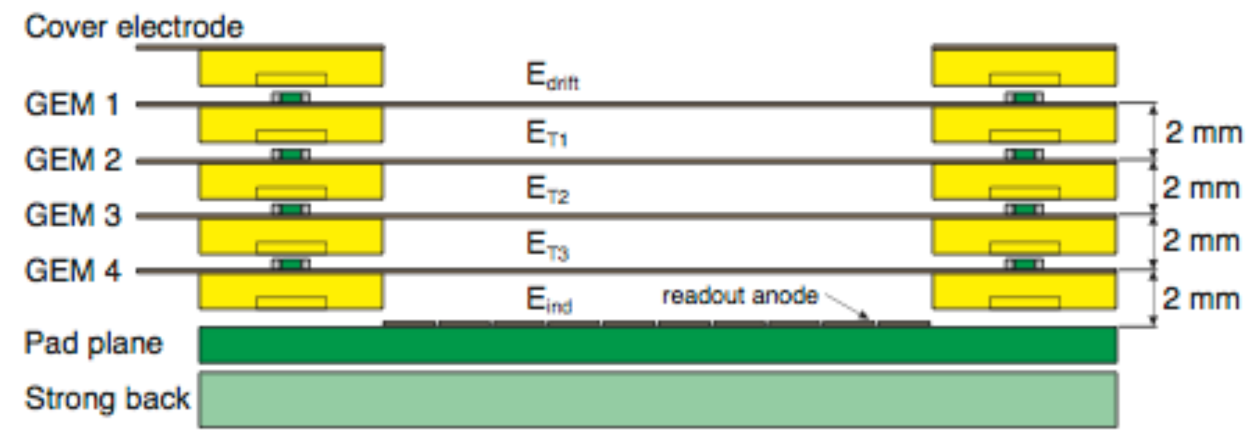


CERN-LHCC-2013-020 ; ALICE-TDR-016

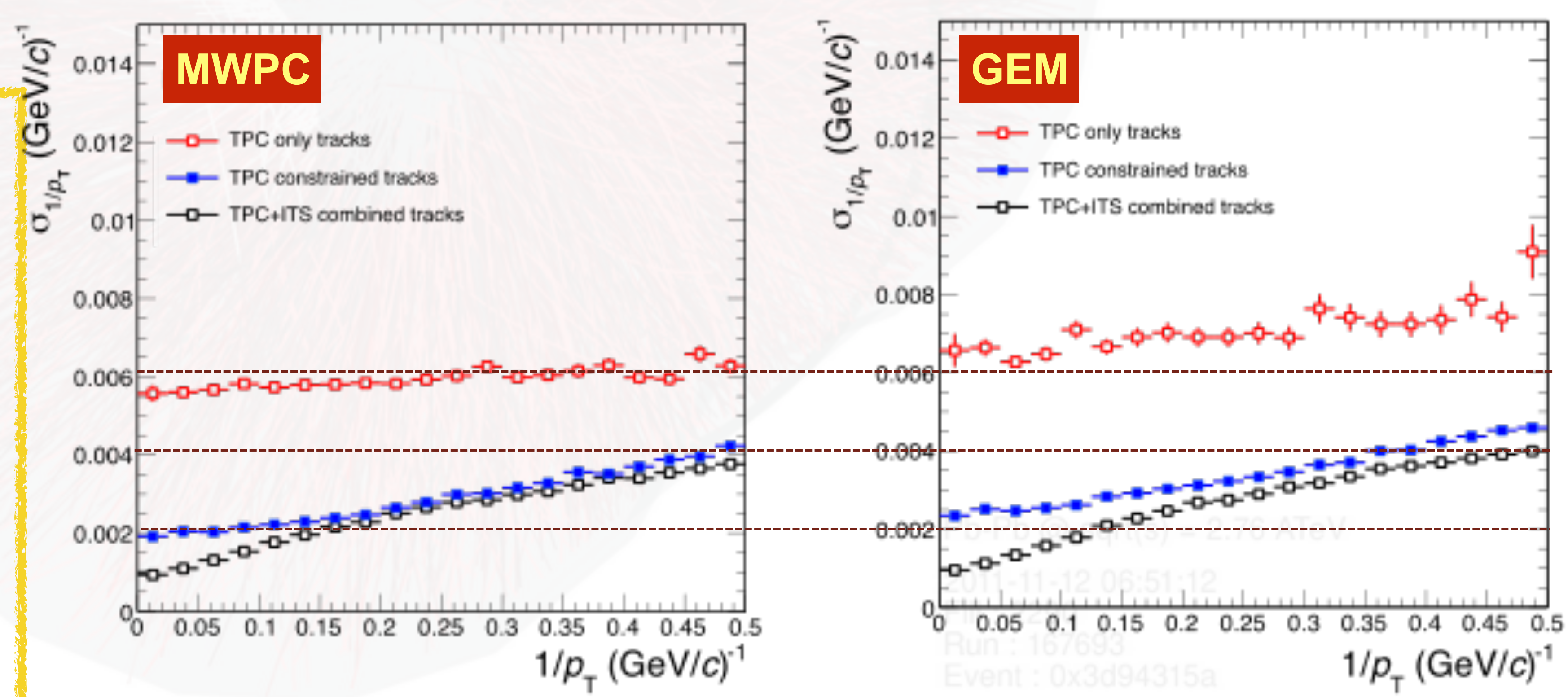
ALICE

TPC Upgrade: expected performance

- **Technical baseline choice:**
  - stack of 4 GEM foils
  - Ion Back Flow < 1% at gain 2000
  - dE/dx resolution <12% for ^{55}Fe
- **Preproduction: after summer 2016**



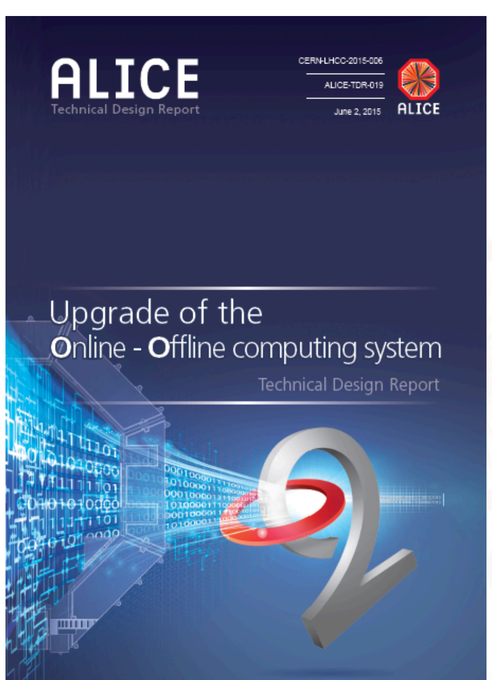
- Tracking resolution preserved
- Slight deterioration when only TPC is used
- Correction for space-charge effects via ITS-TRD matching:
  - successfully used in Run 2
- **Full recovery when tracks are matched with the ITS**



ALICE Upgrade: the O^2 system

- The expected data rate for Pb-Pb collisions at 50 kHz is ~1.1 TB/s
- The TPC alone accounts for 1 TB/s
- The O^2 project aims to integrate in a single infrastructure the present DAQ, HLT and Offline (for the reconstruction part) systems

Detector	Average event size (MB)	Data rate for Pb-Pb @ 50 kHz (GB/s)
TPC	20.7	1012
ITS	0.8	40
TRD	0.5	20
MFT	0.2	10
Others	0.3	12.2
Total	**22,5**	**1094,2**



- The data volume coming from the detectors must be substantially reduced before sending the data to the mass storage.
- Online processing is the only option
- The computing strategy must rely on a heterogeneous architecture to match the interaction rate:
  - » ~250 FLP worker nodes (First Level Processors) equipped with FPGA
  - » ~1500 EPN worker nodes (Event Processing Nodes) equipped with GPU
  - » yearly amount of data (2020, 2021): 54 PB

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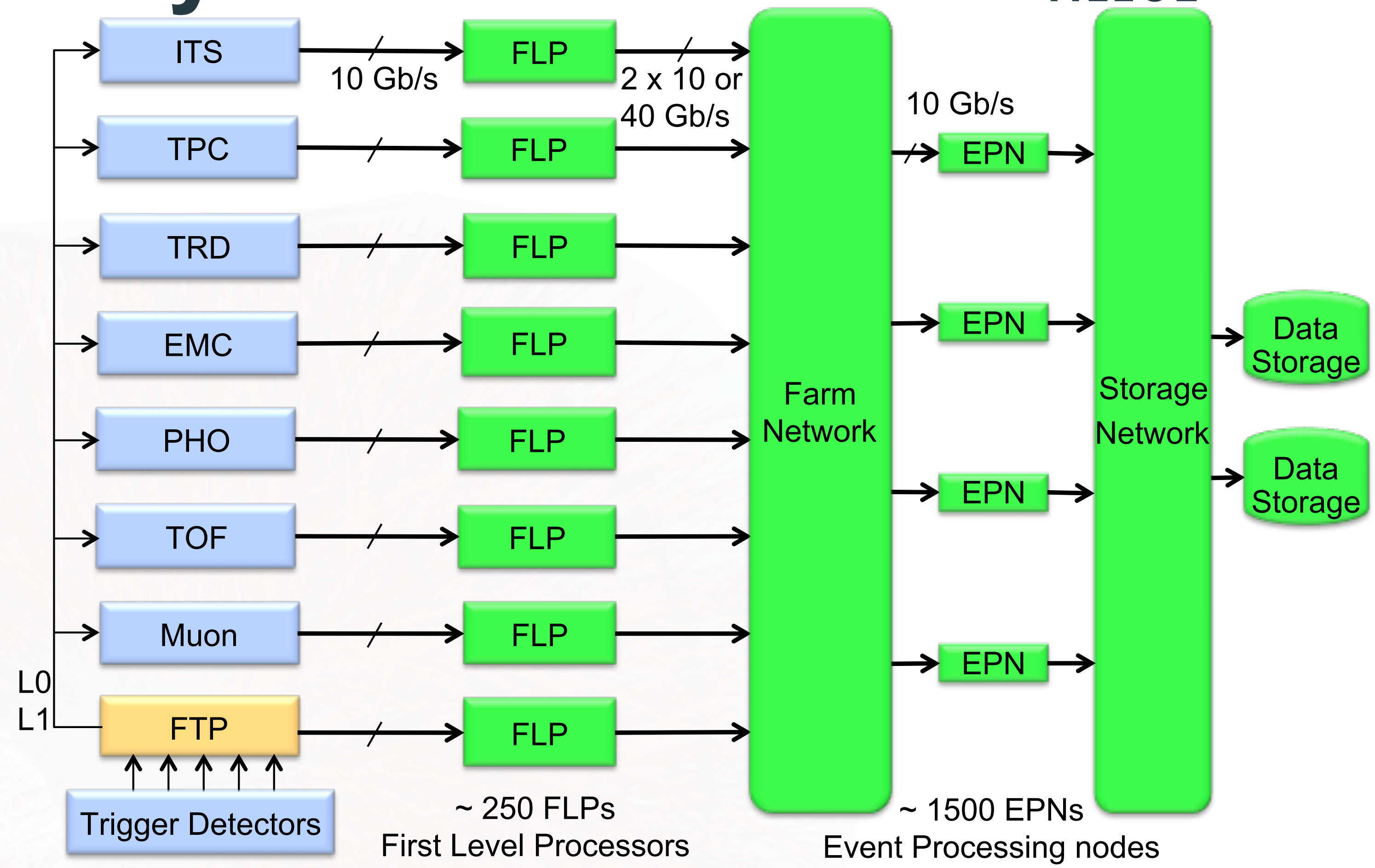

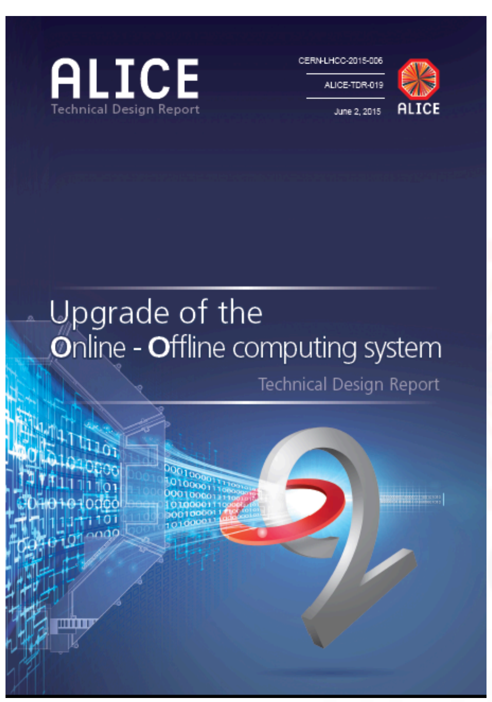

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Online data volume reduction

- The impressive reduction factor that can be obtained for the TPC is based on:
  - zero suppression
  - clustering and compression
  - removal of clusters non associated to interesting particle tracks (e.g. very low momentum electrons)
  - data format optimization
- Largely based on the present High Level Trigger results

Still uncertainties for the ITS:

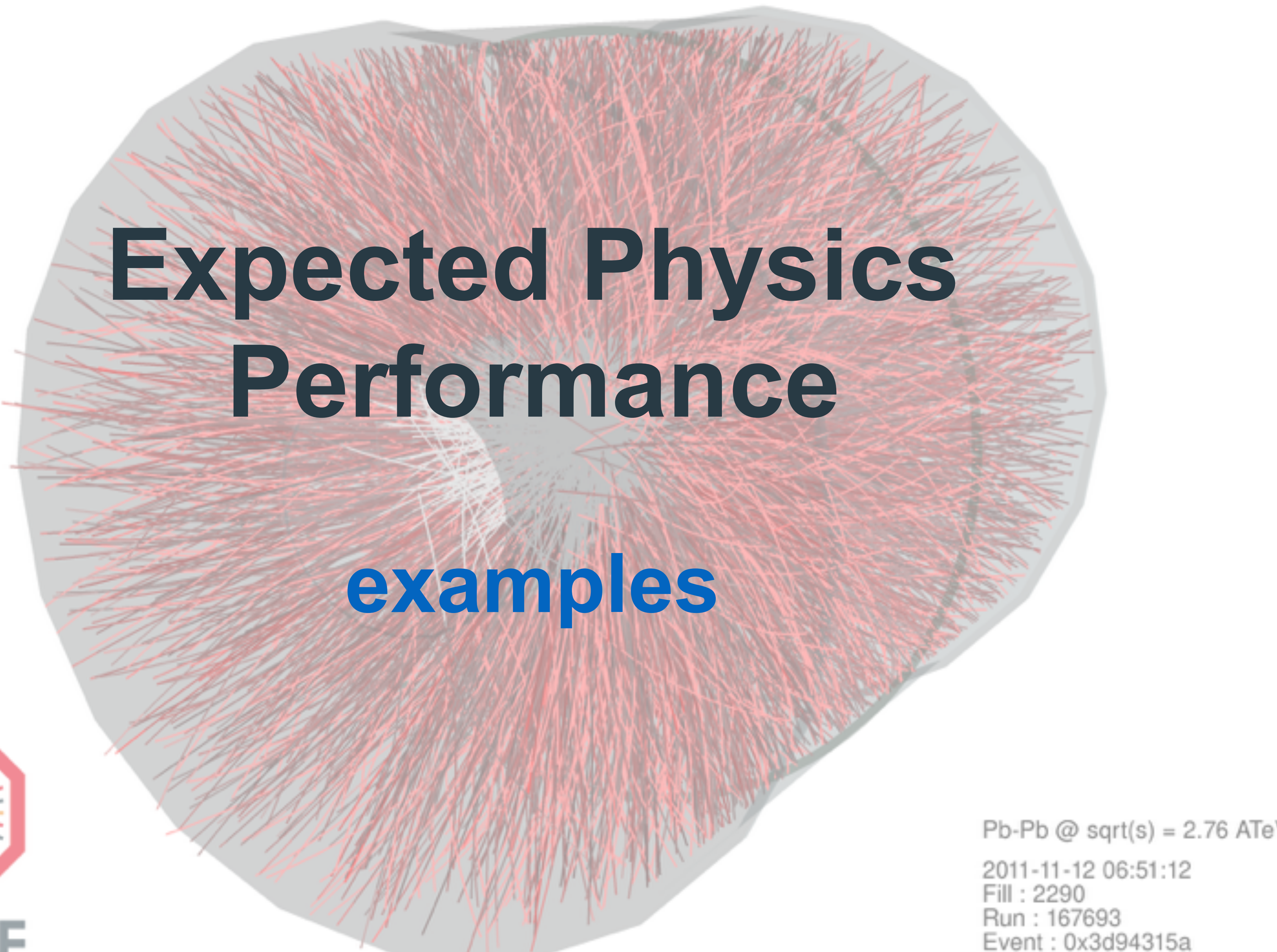
» The contribution from noisy clusters is unknown: here a pessimistic estimate of a probability of **10^{-5} per pixel** has been made

» If full synchronous reconstruction will be feasible a higher reduction factor will be achieved (noise removal)

Detector	Data rate for Pb-Pb @ 50 kHz (GB/s)	Compressed data rate (GB/s)	Data reduction
TPC	1012	50	20.2
ITS	40	26 (8)	1.5 (5)
TRD	20	3	6.7
MFT	10	5	2
Total	**1082**	**84 (66)**	**12.9 (16.4)**

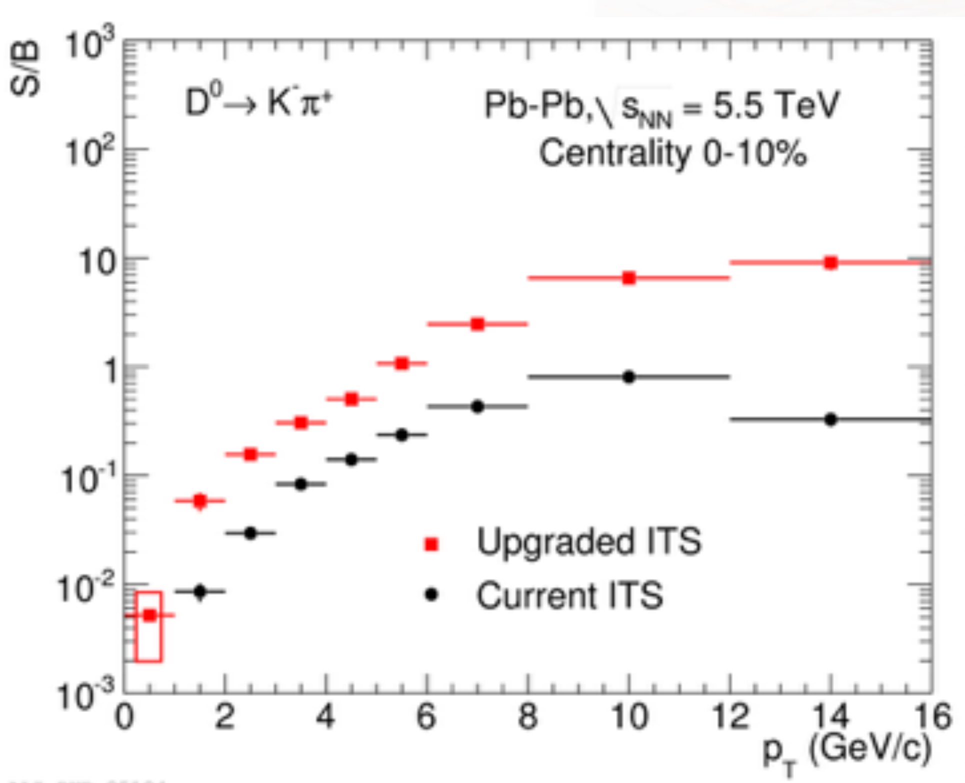
Expected Physics Performance

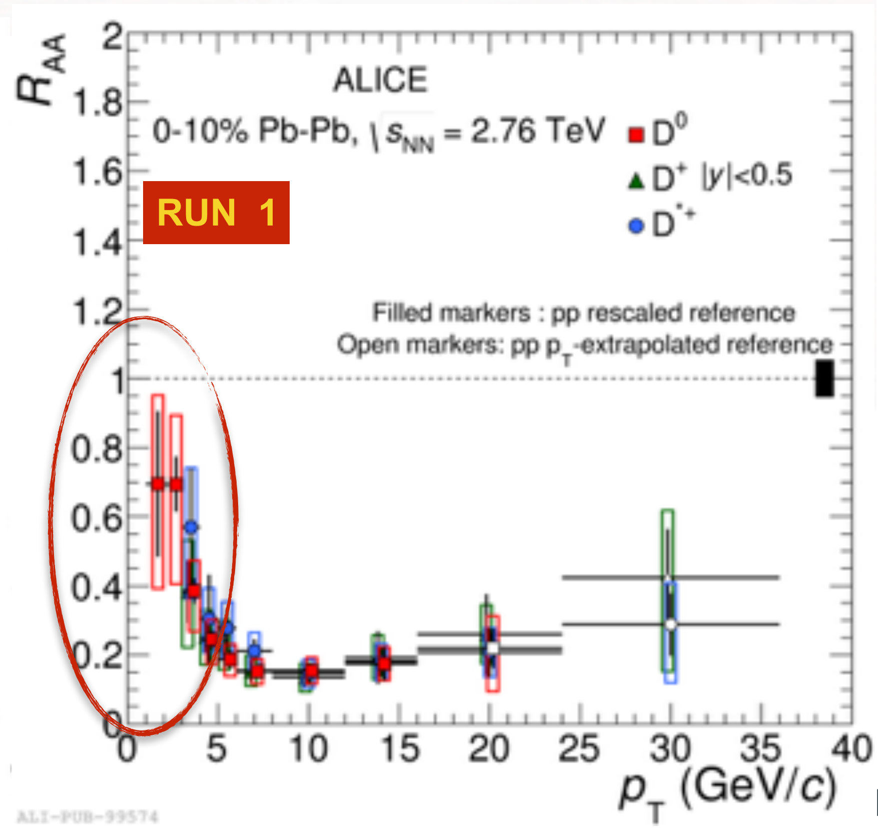
examples

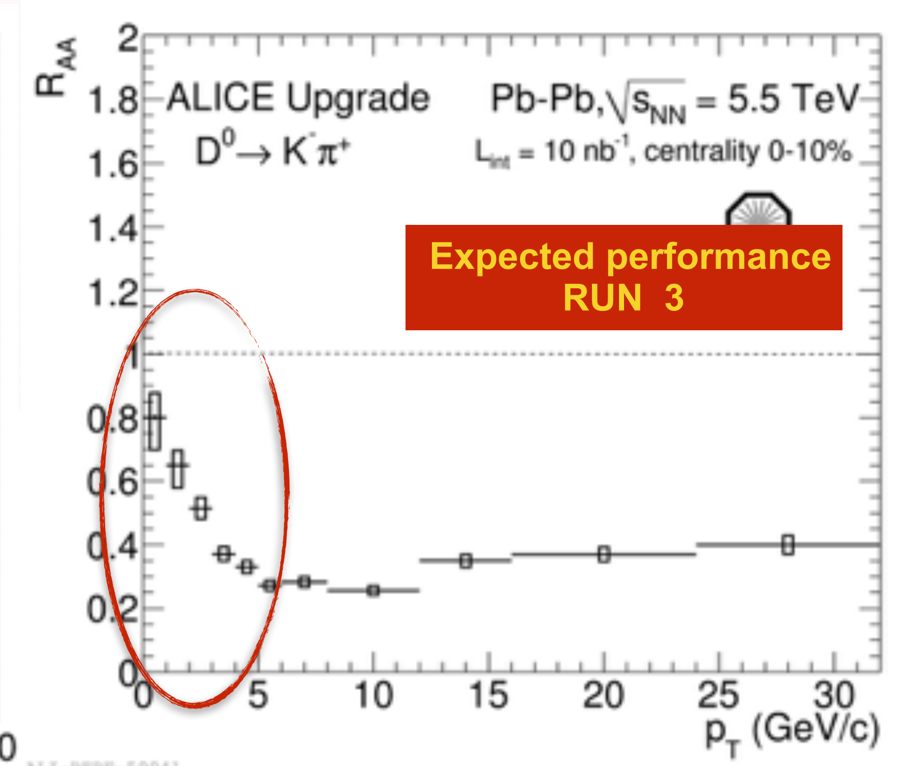


$D^0 \rightarrow K^-\pi^+$

- ➡ Basic benchmark for all open charm studies in their hadronic decay channels.
- ➡ Run 1 results for R_{AA}: large systematic uncertainties at low p_T
- ➡ With the upgrade
  - – comparable efficiency for signal extraction
  - – background rejection improved by a factor of **4-5 for p_T >2 GeV/c** and almost by a **factor of 10 for p_T <2 GeV/c**
  - – Expected significance for L_{int}=10 nb^{-1} **larger than 50** for 10% most central Pb-Pb collisions in the range **0< p_T <1 GeV/c**
  - – important **reduction of systematic uncertainties** due to the easier signal extraction and to the direct Beauty feed-down corrections



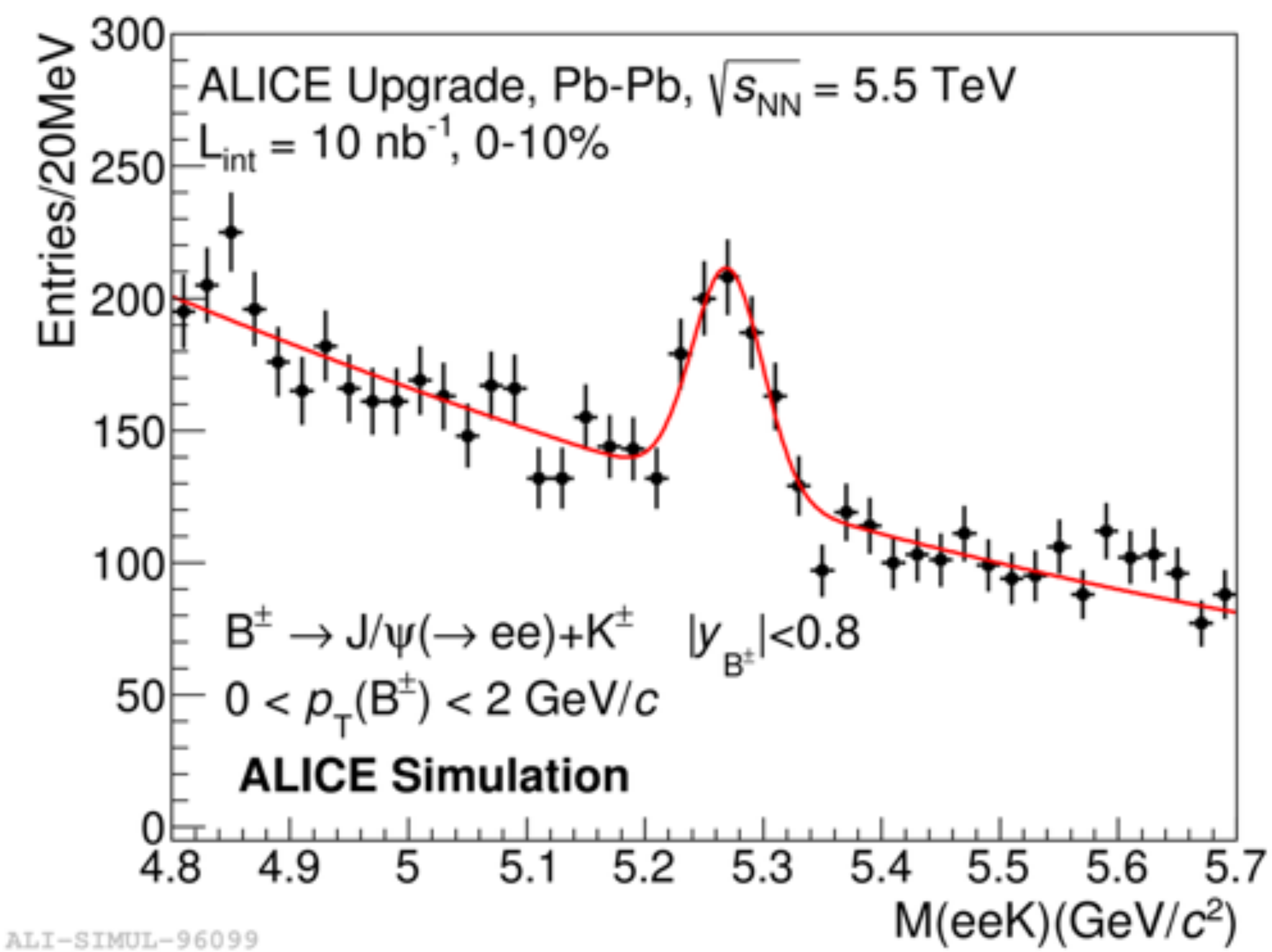


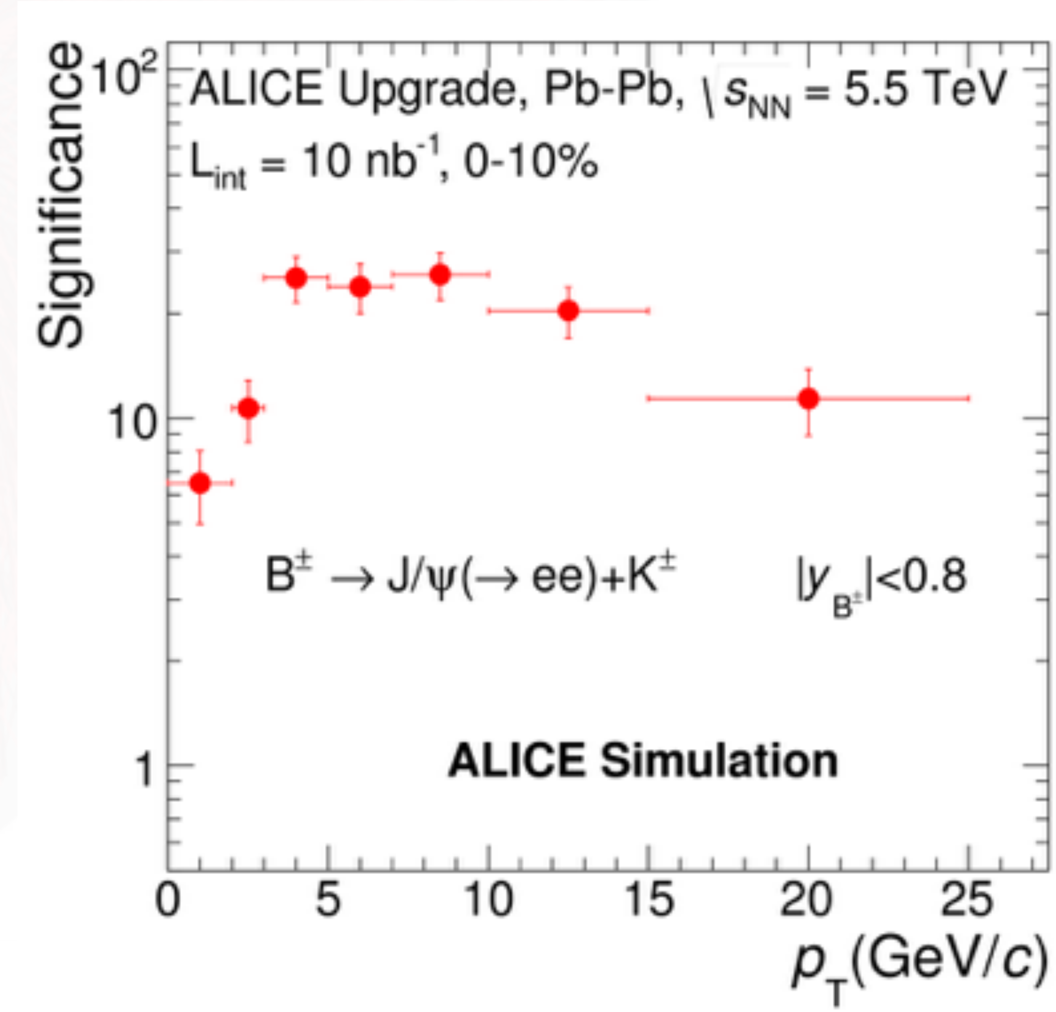


Exclusive beauty reconstruction

- ➡ Access to beauty at low p_T will be achieved via
  - –inclusive channels:
    - displaced J/ψ
    - displaced D mesons
    - muons/electrons from B semi-leptonic decays
  - – exclusive channels:
    - **$B^+ \rightarrow J/\psi\ (\rightarrow ee)K^+$**

Exclusive reconstruction down to p_T=0





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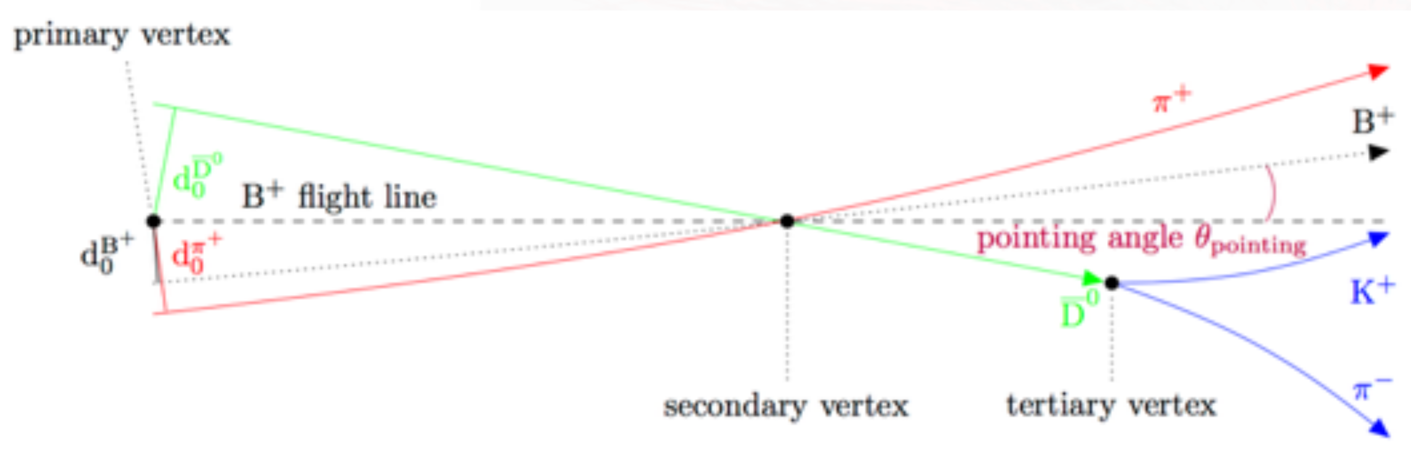
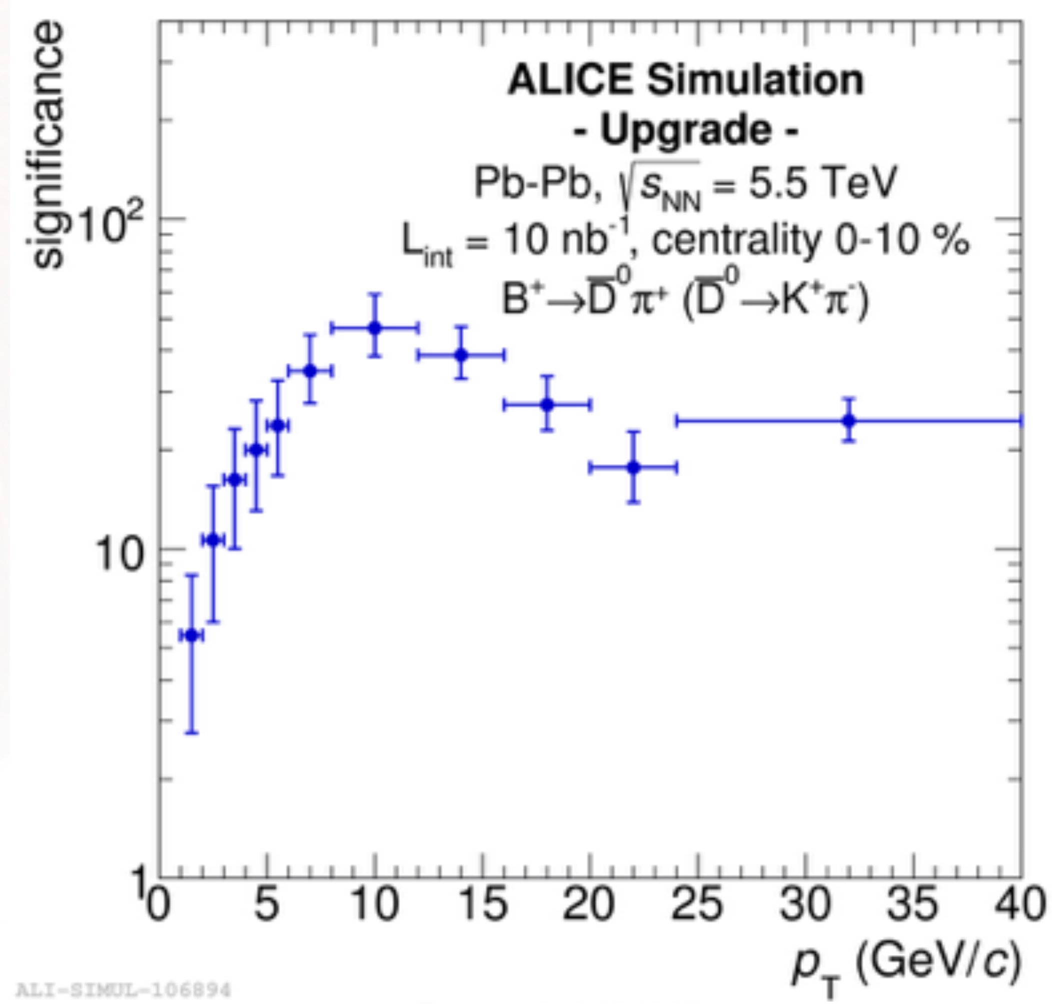
  - exclusive channels:
    - **$B^+ \to D^0(\to K\pi)\pi^+$** Exclusive reconstruction down to p_T=2 GeV/c



This study requires the simulation of a very large Pb-Pb sample ~100M events (to have enough background statistics)
→ **Driving motivation for the development of a fast MC tool,** that reduces the simulation time by factor ~10^3



ALICE

Exclusive beauty reconstruction

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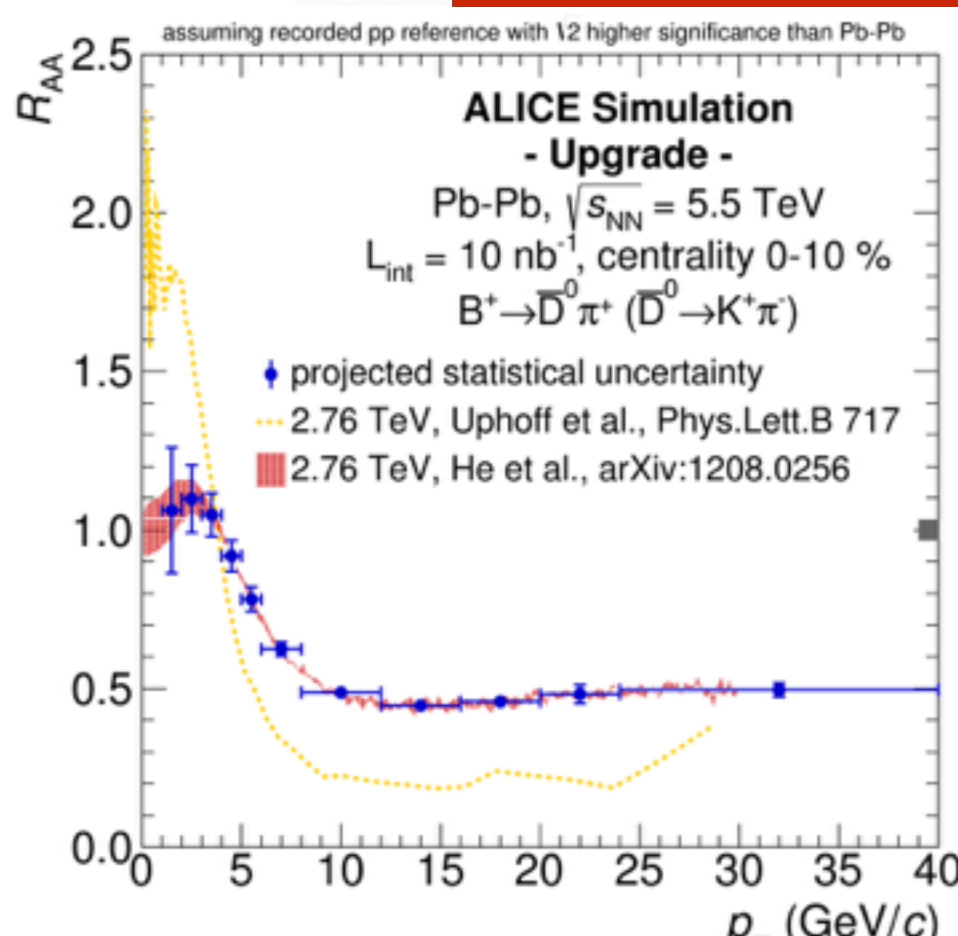
– inclusive channels:

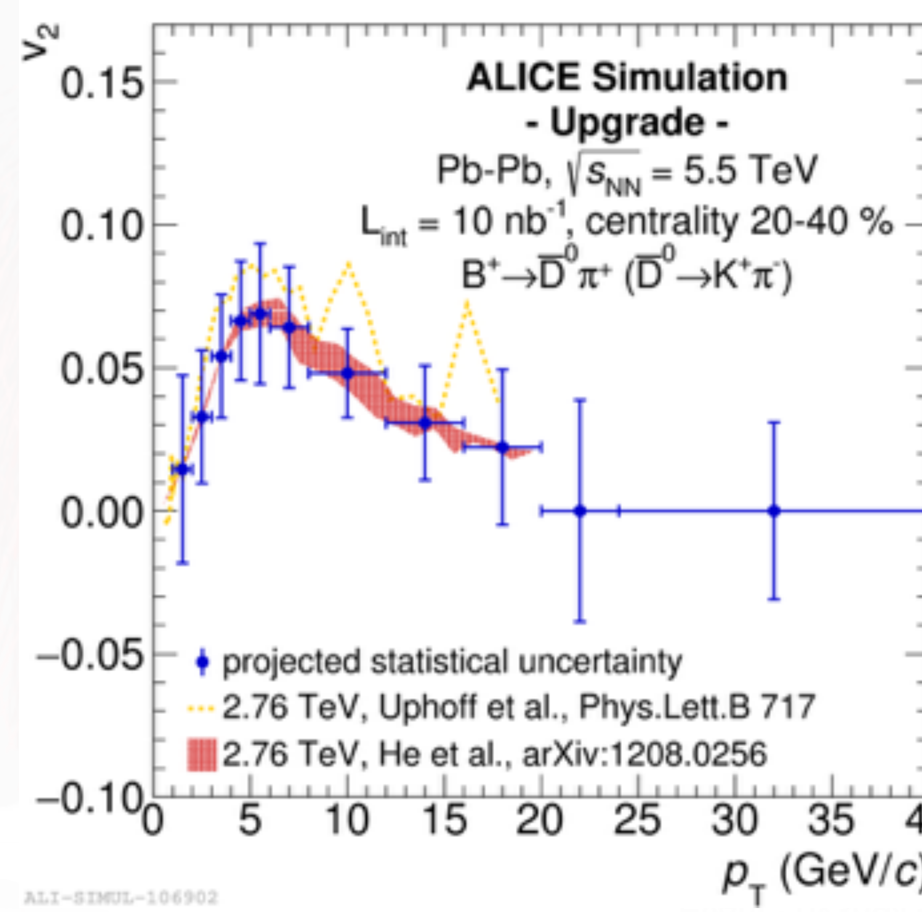
- displaced J/ψ
- displaced D mesons
- muons/electrons from B semi-leptonic decays

– exclusive channels:

- **$B^+ \rightarrow D^0(\rightarrow K\pi)\pi^+$** Exclusive reconstruction down to p_T=2 GeV/c

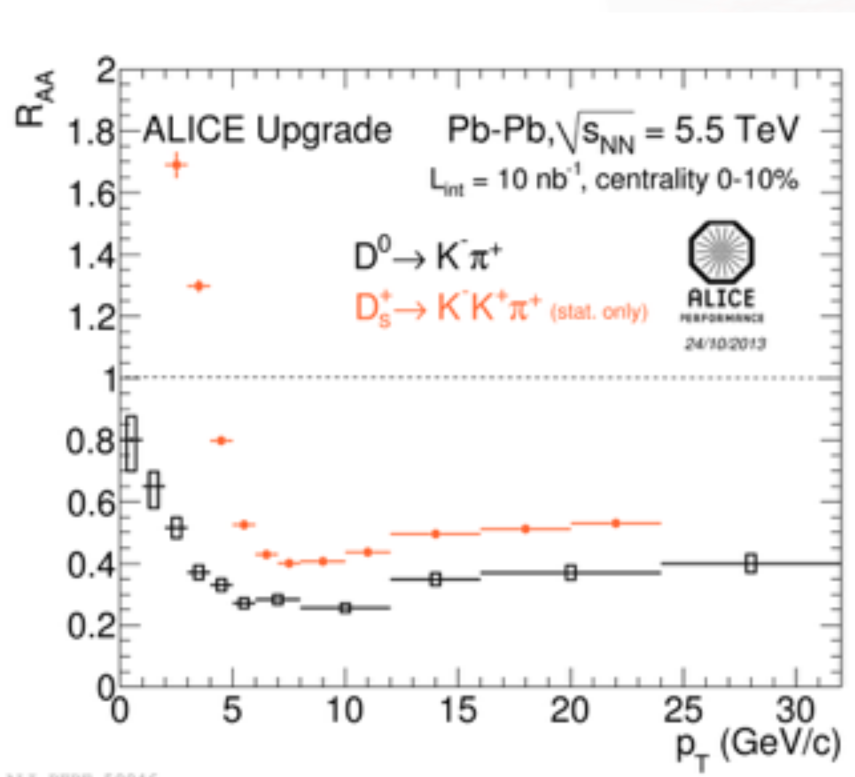
Sensitivity to Beauty R_{AA} and v_2 (elliptic flow)

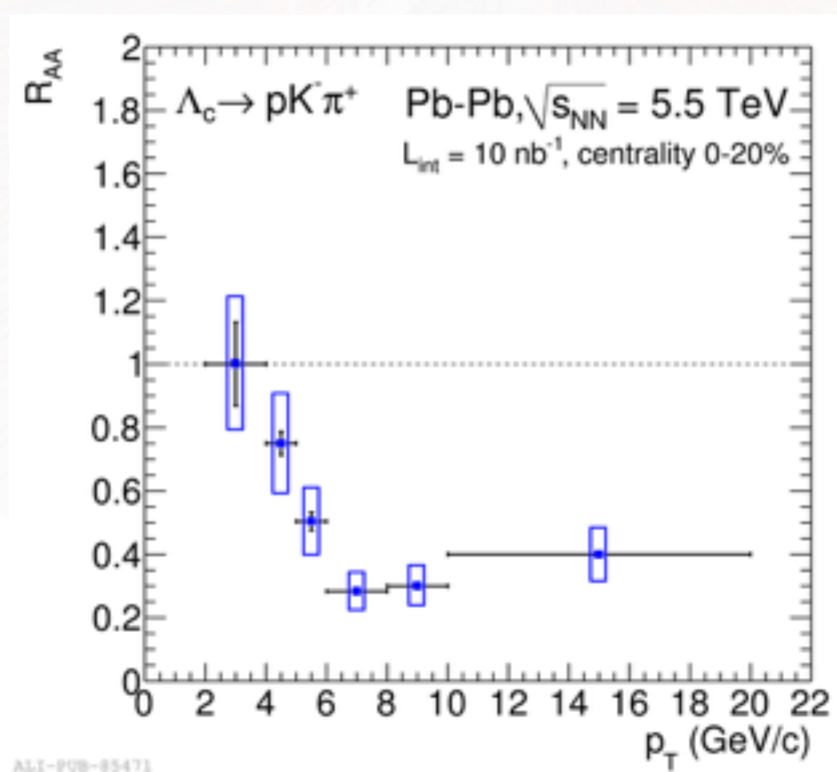


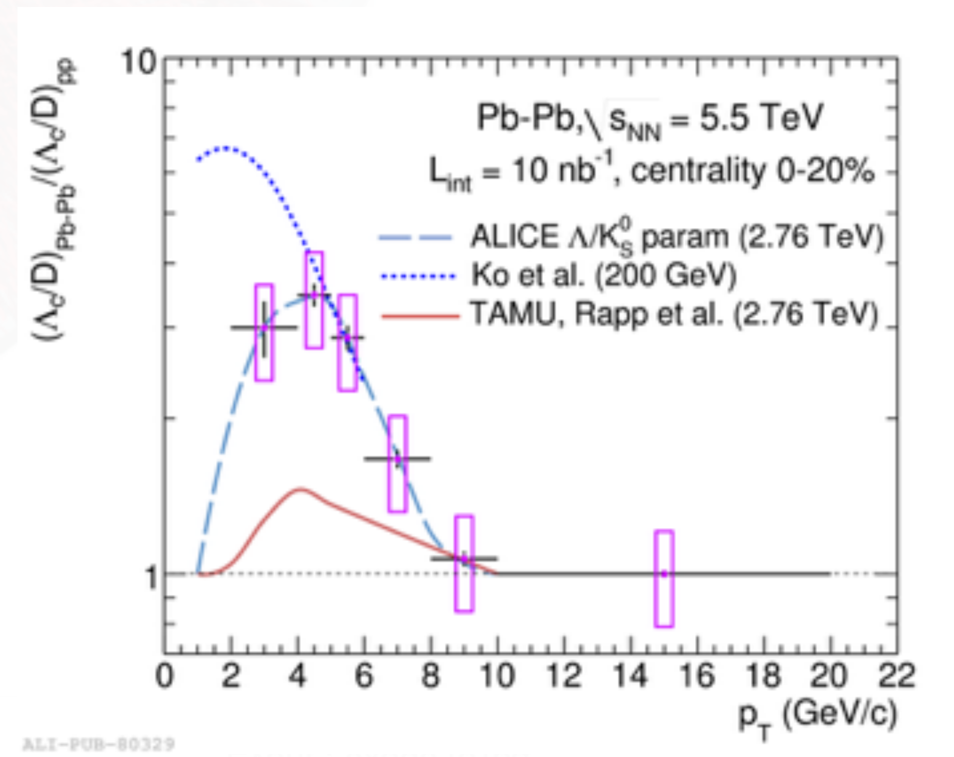


Heavy flavor baryons - In medium hadronization

- ➡ Heavy Flavor baryons (**Λ_c but also Λ_b**) will be accessible in Pb-Pb collisions.
- ➡ Hints that charm could recombine in the QGP from LHC Run 1 data
  - – e.g. reduced suppression of D_s interpreted ad **in medium hadronization** given the higher quark s abundance in QGP.
- ➡ In Run 3: **precise measurements of HF mesons and baryons**
  - – **$\Lambda_c \rightarrow pK^- \pi^+$** is a very challenging measurement: **cτ=60 μm - B.R. ~5%**
  - – discrimination among different models of hadronization by measuring baryon/ meson ratios





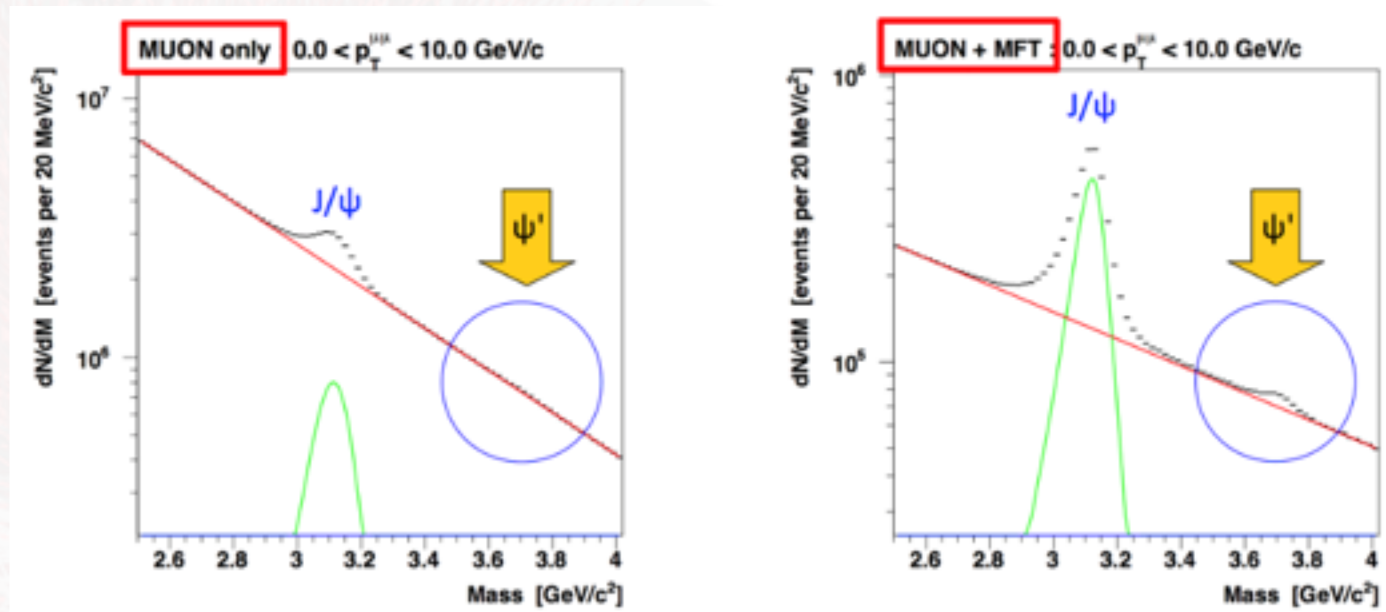


Charmonium and low mass dileptons in ALICE

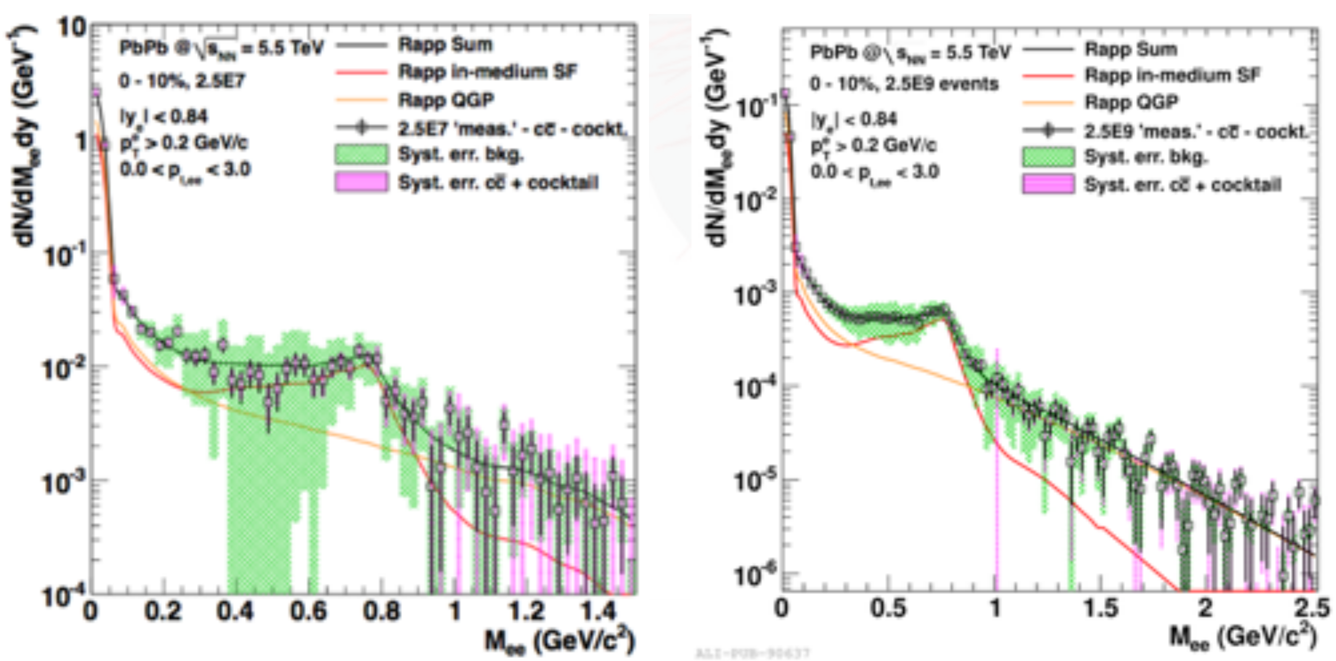
Improved discrimination of prompt/displaced dileptons both in the central barrel (upgraded ITS) and in the forward region (thanks to the MFT)

$\mu^+\mu^-$

- ➡Isolation of forward prompt J/ψ, not possible without the MFT
- ➡S/B ratio for **ψ(2S)** in central Pb-Pb improved **by a factor of 6-7**



PRESENT PERFORMANCE | **UPGRADE**



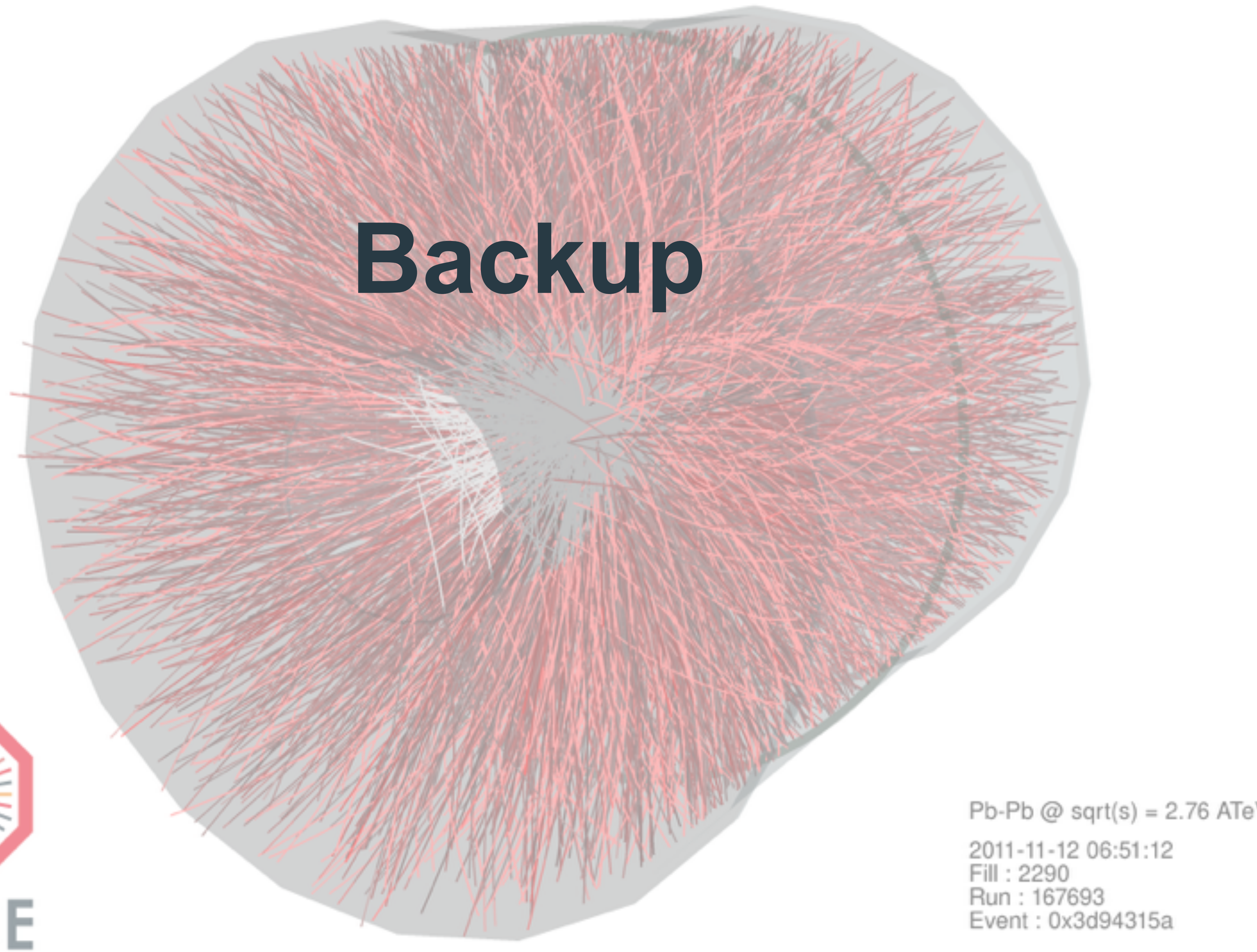
e^+e^-

- ➡ dielectron spectrum after subtracting combinatorial background and dielectric from known sources (cocktail with, ω,Φ and semileptonic decays of hadrons, but not the ρ meson)
- ➡Isolation of medium-modified ρ meson
- ➡ thermal radiation from QGP

Conclusions

- ➡ In the LHC Long Shutdown 2 (2018-19) ALICE will undergo a major upgrade:
  - **tracking and vertexing precision** will be significantly improved both at mid and forward rapidities thanks to a **new Inner Tracking System** and a **new Muon Forward Tracker**
  - readout rate at 50 kHz in Pb-Pb (**50× increase** w.r.t. the present value)
  - the online and offline systems will be unified and deeply reorganized (**O^2 project**)
- ➡ A comprehensive physics program for ALICE in the LHC Run 3 has been finalized in the last years, during the preparation of the Technical Design Reports.
- ➡ The **R&D phase is ending in 2016** and the production/construction will be carried out in 2017/18
- ➡ The purpose of the upgrade is to carry out precision studies of observables extending the p_T reach as close as possible to zero. Main probes:
  - **Heavy Flavors**
  - **dileptons**
- ➡ A Forward Calorimeter with focus on saturation physics is presently under discussion

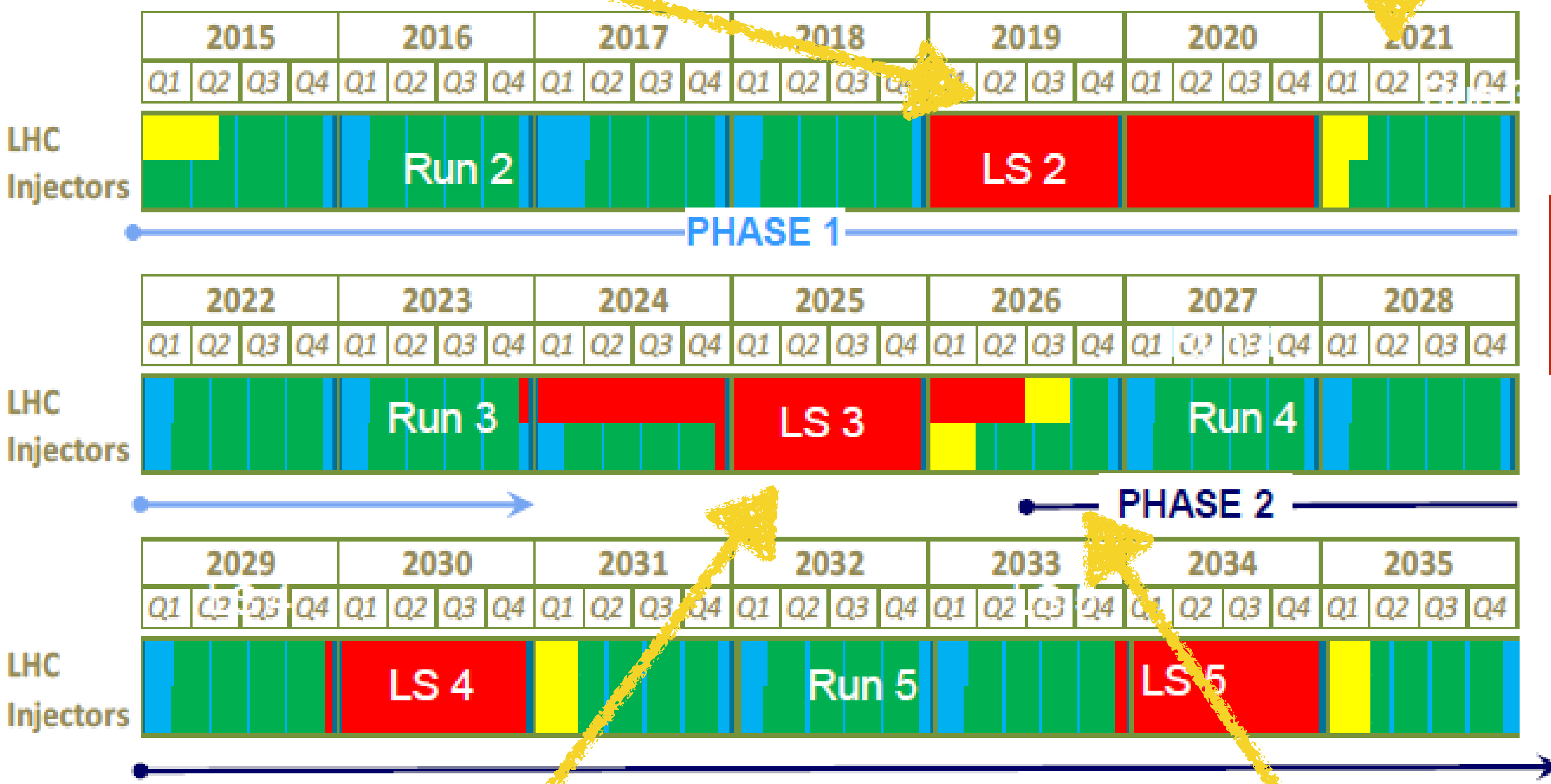
Backup


Pb-Pb @ sqrt(s) = 2.76 ATeV
2011-11-12 06:51:12
Fill : 2290
Run : 167693
Event : 0x3d94315a

LHC expected schedule

PHASE I Upgrade
ALICE, LHCb major upgrade
ATLAS, CMS ‚minor' upgrade

Heavy Ion Luminosity
from 10^{27} to 7 x10^{27}



Pb-Pb:
L_{int}=10 nb^{-1} requested for Run3 and Run 4

PHASE II Upgrade
ATLAS, CMS major upgrade

HL-LHC, pp luminosity
from 10^{34} (peak) to 5 x10^{34} (levelled)

ALICE

LHC expected schedule

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ALICE, LHCb major upgrade
ATLAS, CMS ‚minor' upgrade

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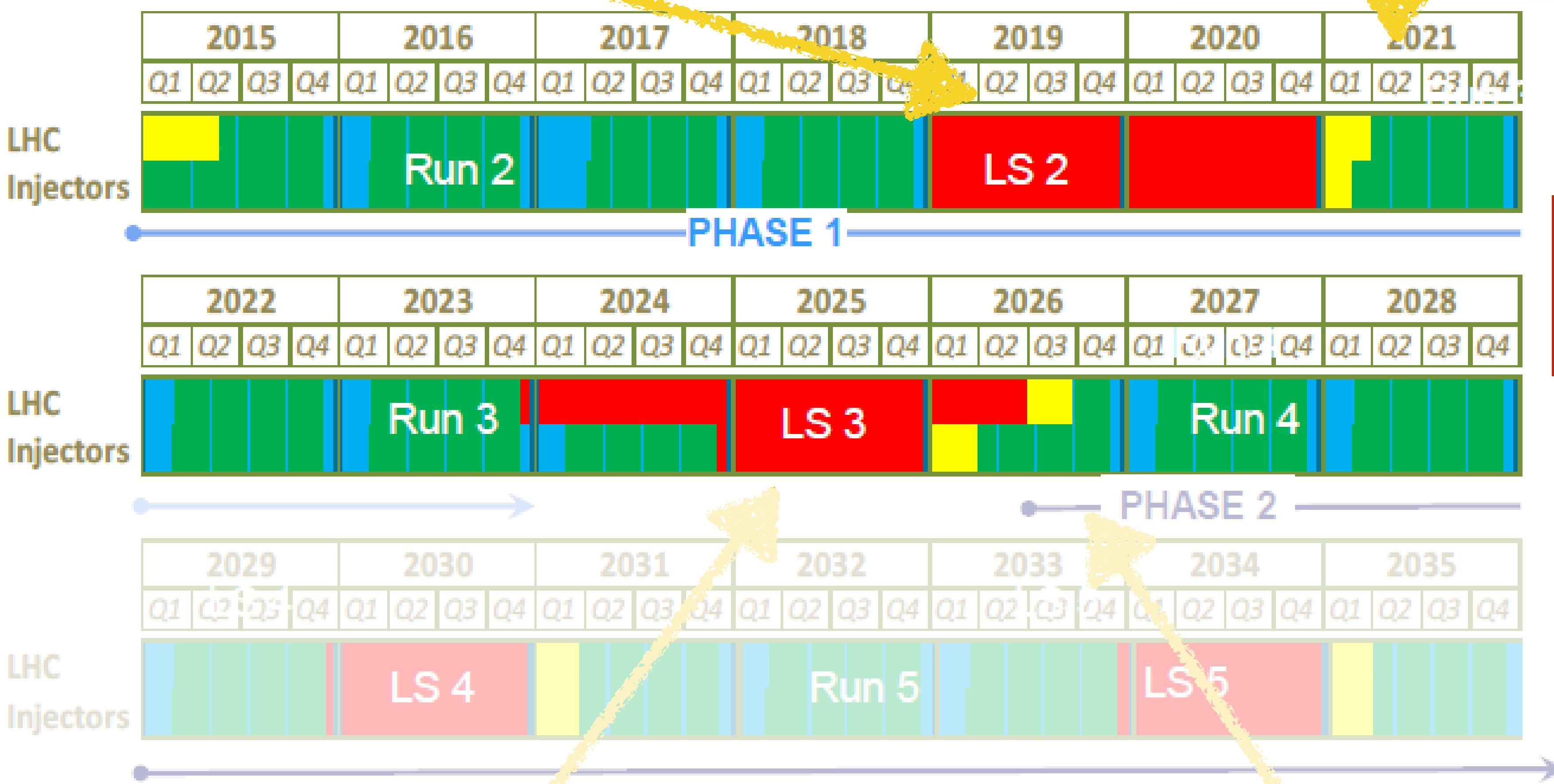

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PHASE II Upgrade
ATLAS, CMS major upgrade

HL-LHC, pp luminosity from 10^{34} (peak) to 5×10^{34} (levelled)

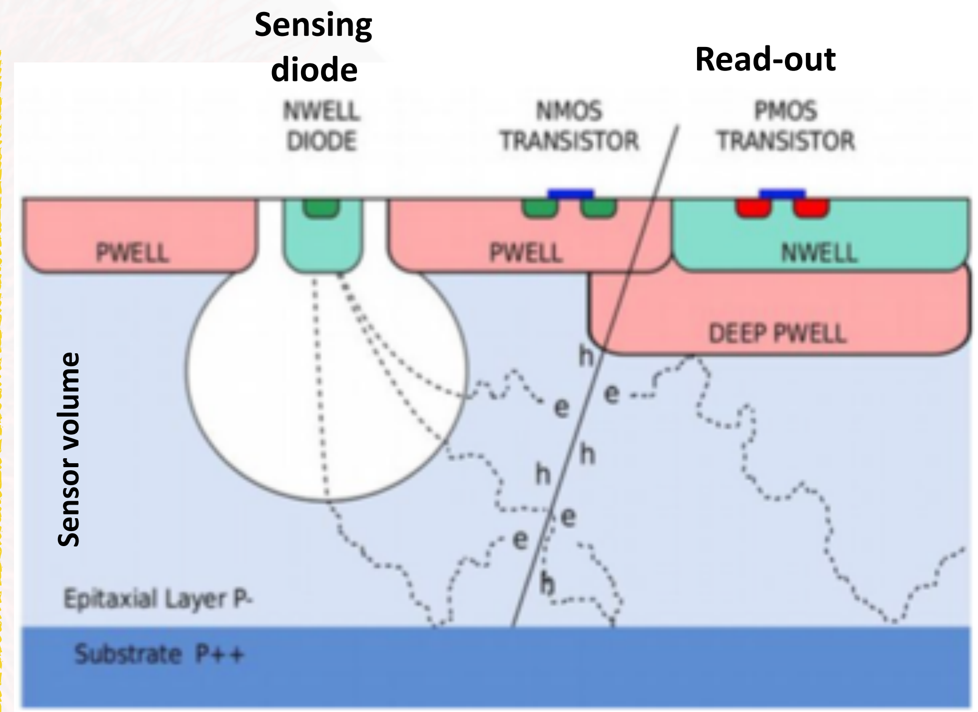
MAPS: Monolithic Active Pixel Sensors

MAPS attractive technology for ALICE due to:

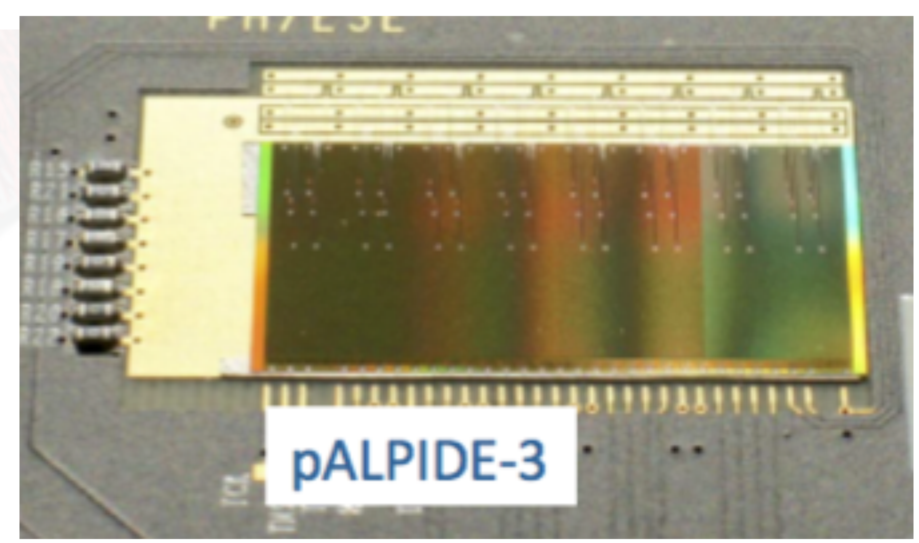
- Reduction of material budget (sensor&readout integrated) 350 μm→50-100 μm/layer
- Limited radiation tolerance and moderate readout time: still fitting for ALICE (700 krad foreseen for innermost layer)!

ALICE baseline: MAPS using CMOS 0.18 μm technology (TowerJazz)

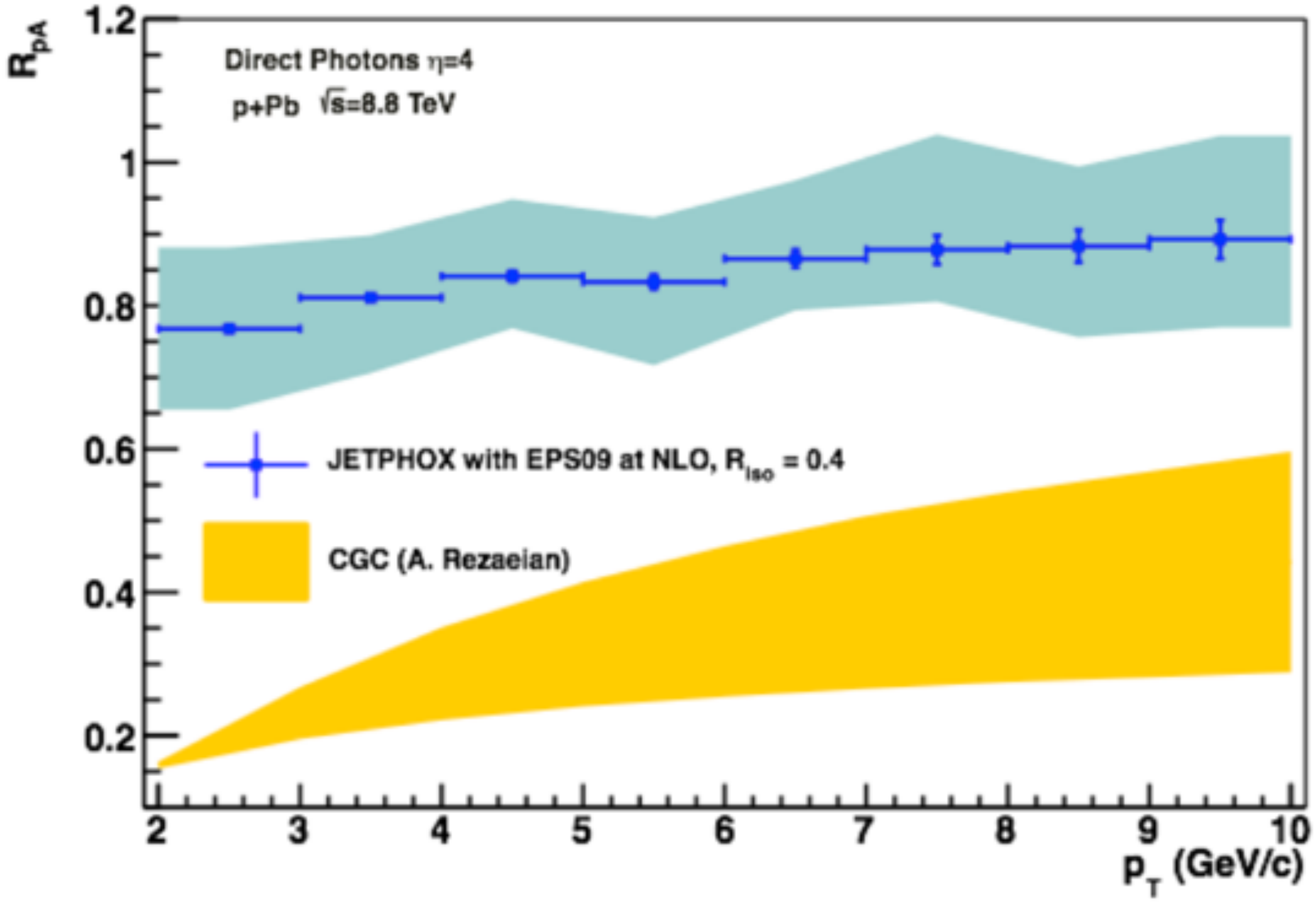
Pixel pitch ~ 30 μm x 30 μm
High resistivity epitaxial layer (>1 kΩ)
PMOS transistor for readout on top of deep p-well
- PMOS/NMOS in the same pixel cell
- deep p-well junction reflects signal electrons
- signal collected by the sensing diode only



Final version of MAPS chip (ALPIDE = ALICE Pixel Detector) **July 2016**
(after 3 prototype runs) →start production end of the year
29 μm x 27 μm pixel pitch
Power consumption: 40 mW/cm^2
Efficiency > 99%
Noise probability: < 10^{-6}



Gluon saturation with forward photons

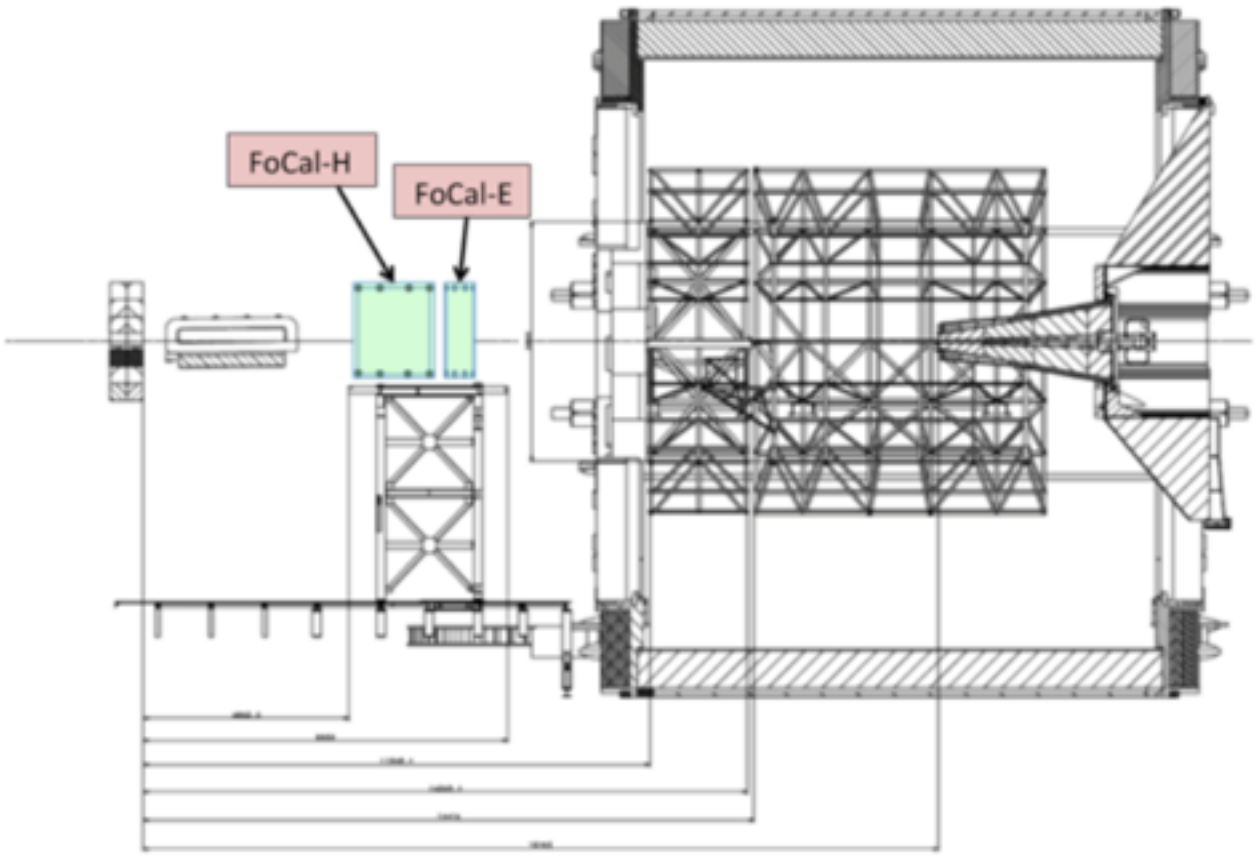


two scenarios for forward γ production in p+A at LHC:

- normal nuclear effects
  linear evolution, shadowing
- saturation/CGC
  running coupling BK evolution

- strong suppression in direct γ R_{pA}
  - clean signal for isolated photons
- signals expected at forward η, low-intermediate p_T

FoCal



electromagnetic calorimeter for γ and π^0 measurement

preferred scenario:

- at $z \approx 7$m (outside magnet)
  $3.3 < \eta < 5.3$
  (space to add hadr. calorimeter)

under internal discussion
possible installation in LS3

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, granularity $\approx$ 1mm²

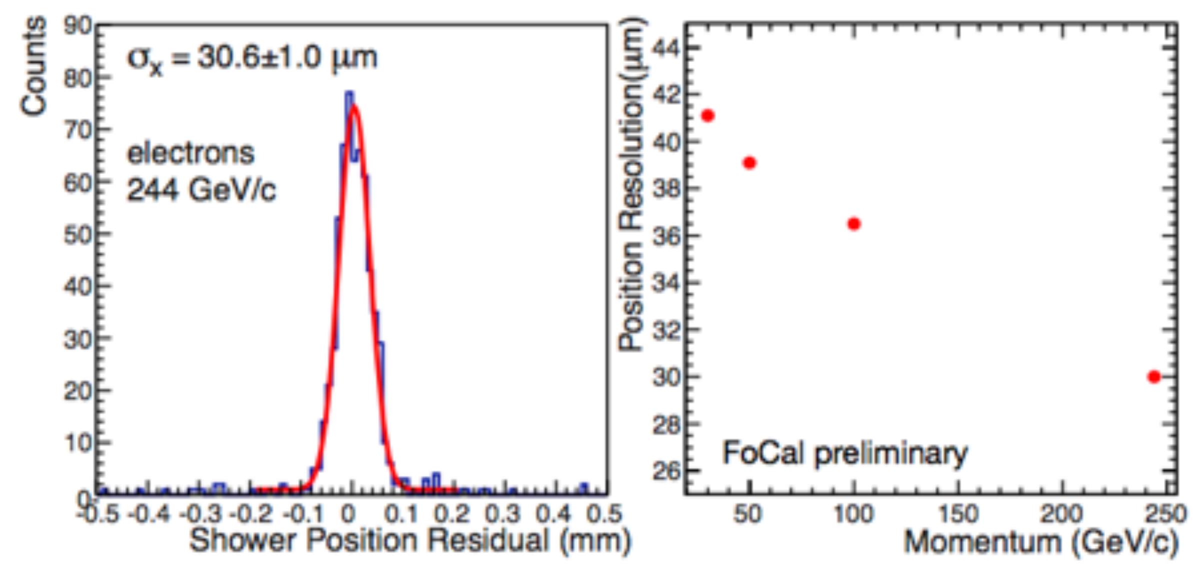
FoCal: R&D

- main challenge: separate γ/π^0 at high energy
- need small Molière radius, high-granularity read-out
  - Si-W calorimeter, granularity ≈ 1mm2

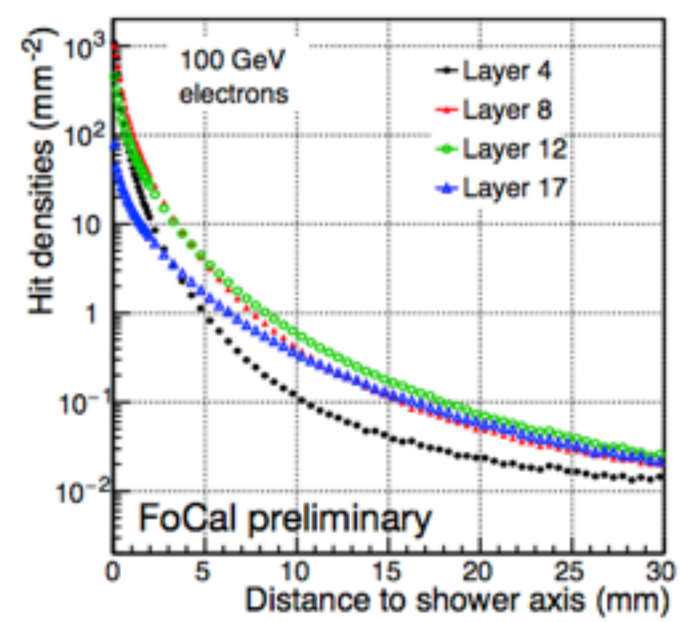
prototype of Si/W calorimeter with CMOS pixel sensors (synergy with ITS)
collaborating in CALICE

30µm pixel pitch
very small Moliere radius
$R_M \approx 11$mm
can provide unprecedented two-shower separation

shower position resolution



lateral profiles of electron showers



measurement of two showers