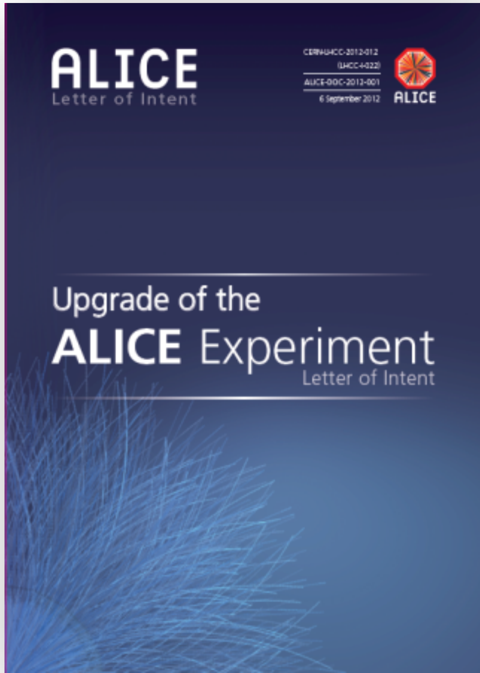
ALICE Upgrade Program

David Silvermyr (Lund)
for the ALICE collaboration

Outline

- Upgrade Motivation: Key Observables
- The ALICE detector now
- ALICE Upgrade Strategy: ITS, TPC, MFT, O^2, …
- Expected Performance
- Summary/Outlook

ALICE upgrade
Letter of Intent



CERN-LHCC-2012-12

Goals

Motivation: QGP precision studies
High precision measurements of rare probes from low to high transverse momentum

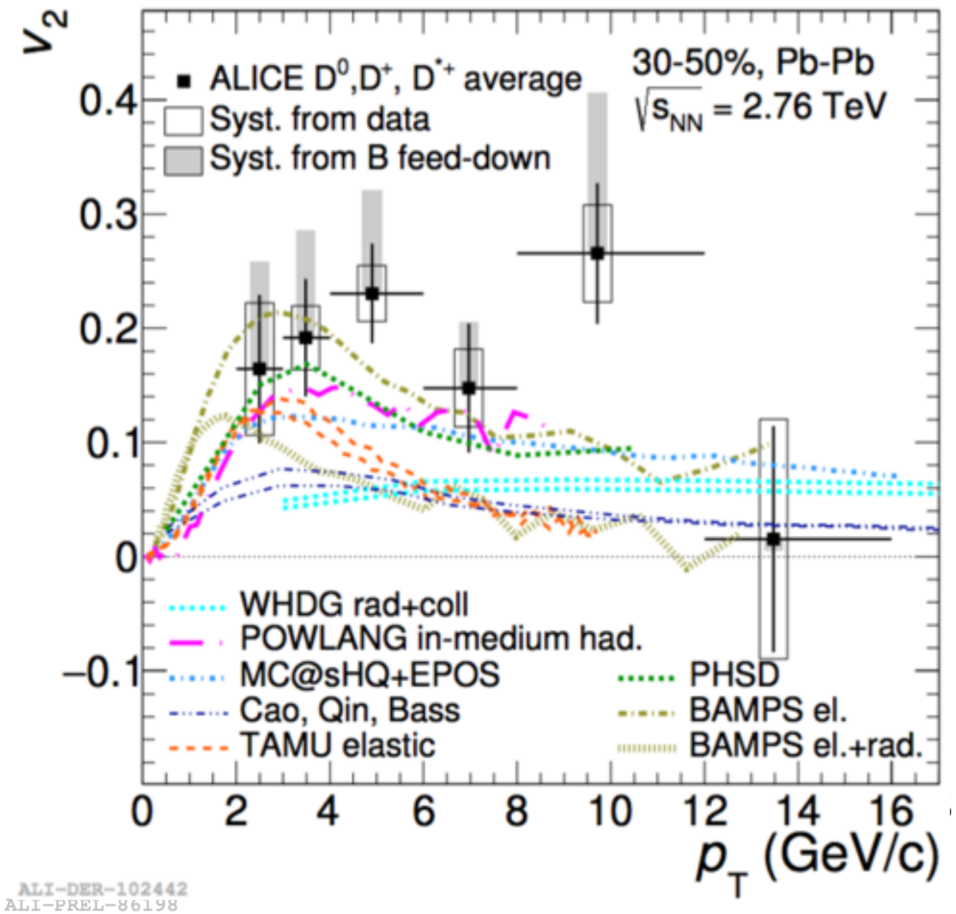
Requirements:
- Excellent tracking efficiency and resolution at low p_T
- Large statistics
- PID capability (even at high rate)

"Semi-hard" Observables

- Significant changes in many observables at intermediate p_T (from soft to hard regions): interesting regime for heavy-ion vs pp comparisons

- Not as easy to trigger on though…

- Key Observables:
  - charm production
    - hydro-dynamics
    - charm quark energy loss / jet quenching
    - J/ψ suppression
  - thermal photons at low and intermediate p_T

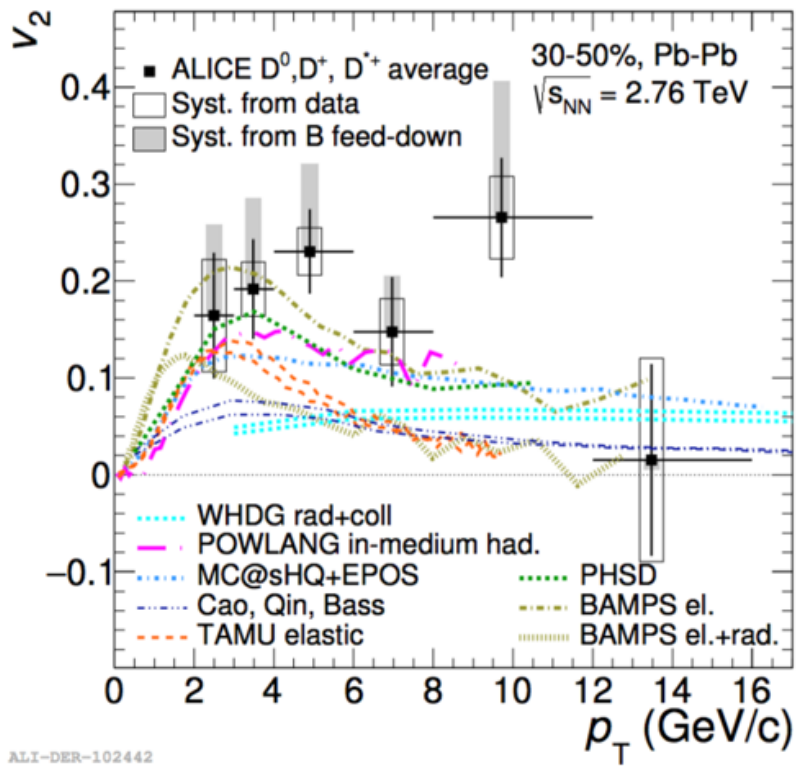


Motivation: Need to Understand QGP Better

Open heavy flavor: good probes of the hot medium ...

- Heavy quarks take part in collective expansion
- Still challenging to see expected hierarchy in energy losses
- Distinguish between b/c energy losses is limited to high p_T
- No access in Pb-Pb to charm (and beauty) baryons → baryon/meson ratio for light flavor only

PRC 90 034904 (2014) PRL 111 102301 (2013)



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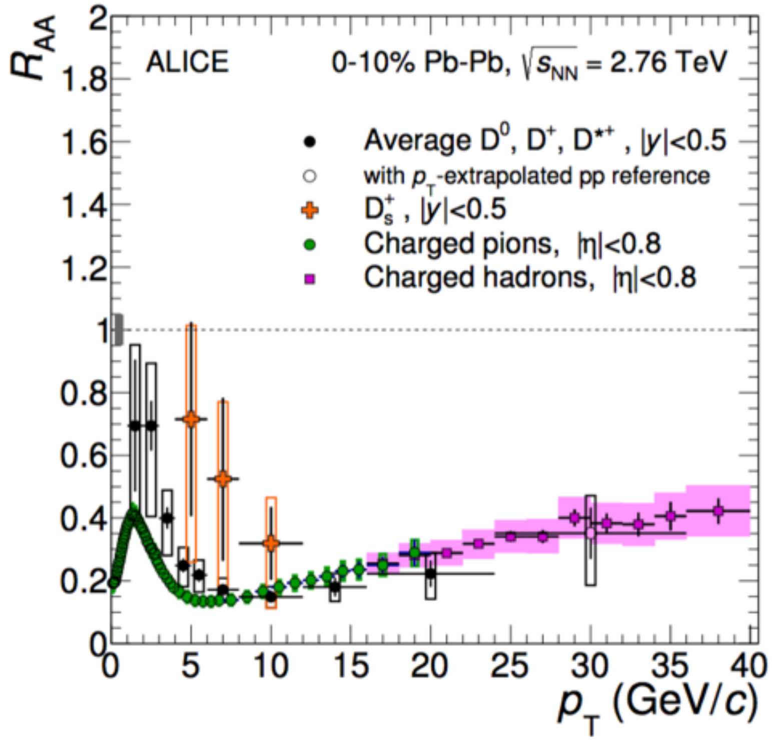
JHEP 03 (2016) 081 JHEP 03 (2016) 082



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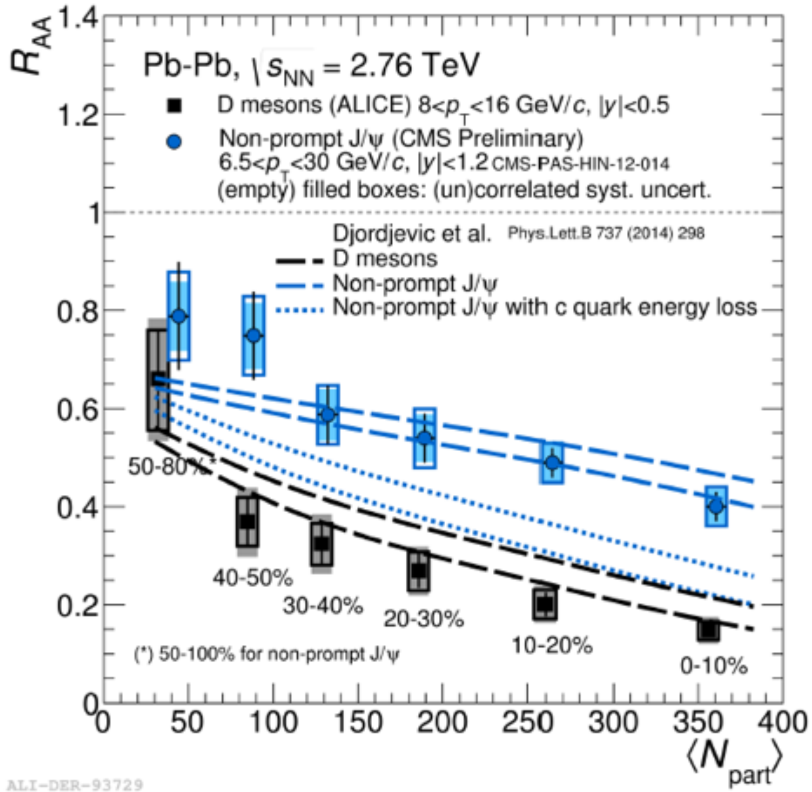
JHEP 11 (2015) 205



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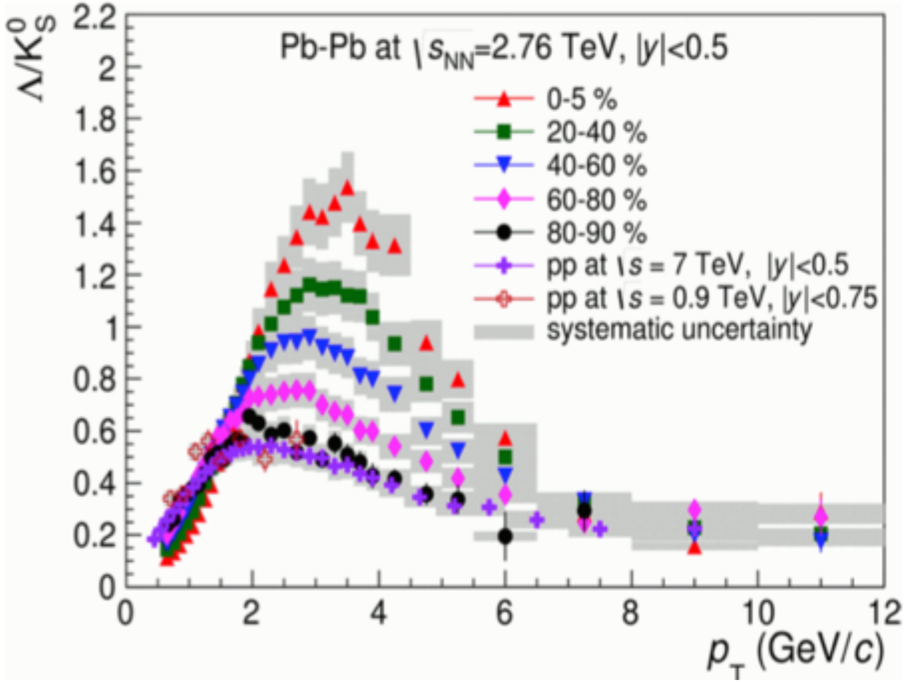
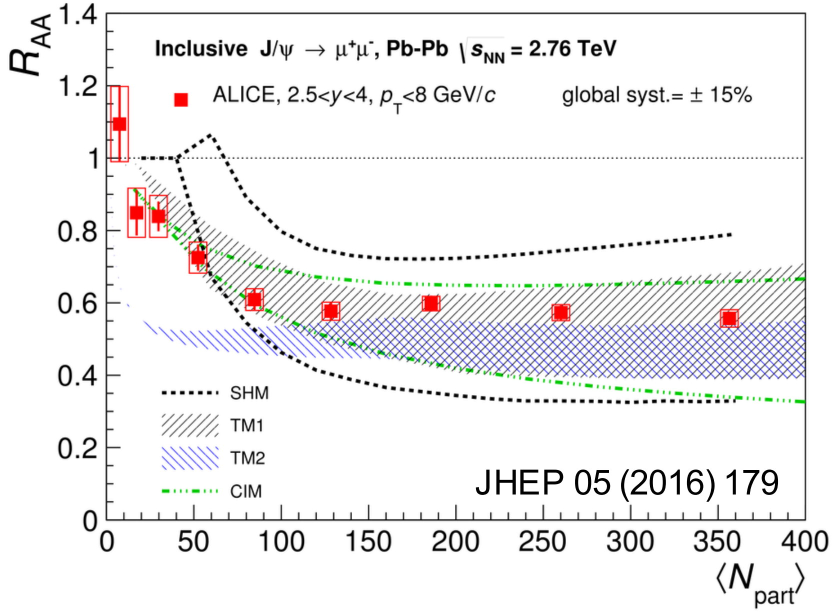
PRL 111, 222301(2013)



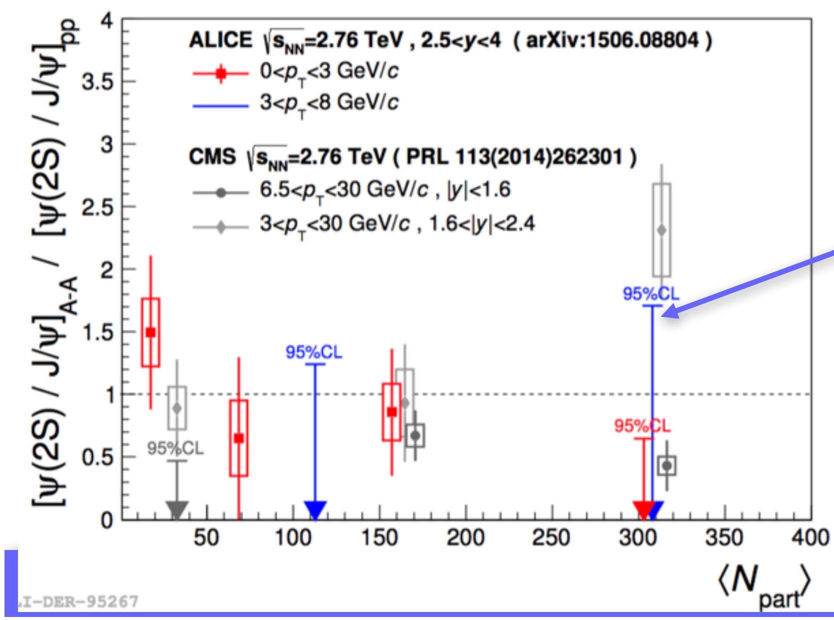
Quarkonia: Hadronize or Recombine?



Reduced suppression with respect to RHIC
Theoretical models which include ~50% of the low-p_T J/ψ via recombination describe LHC data

→ theor. uncertainties linked to total $\sigma_{c\bar{c}}$ + CNM effects

→ recombination contributes mainly at **low p_T**



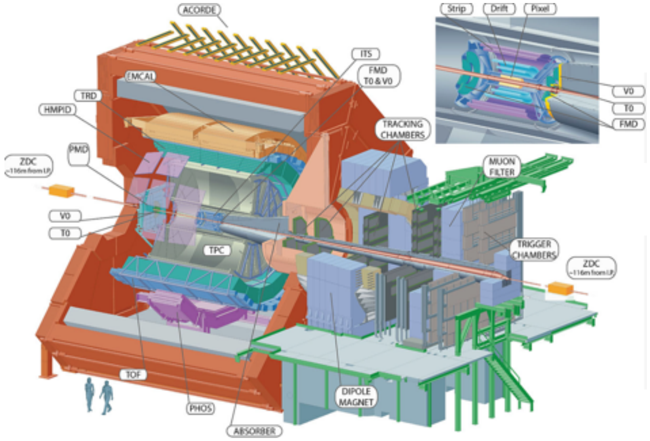
Statistical hadronization or kinetic recombination?

- ***ψ*(2S)** can help to disentangle mechanisms at work
- Double ratio has less dependency on $\sigma_{c\bar{c}}$
- CMS/ALICE measurements showed some tensions

  → Precision must be improved

ALICE Upgrade Strategy

Finding our optimal path forward…



- Study the thermalization of partons in the QGP, with focus on charm and beauty quarks at low p_T
  → secondary vertices → improve inner tracker

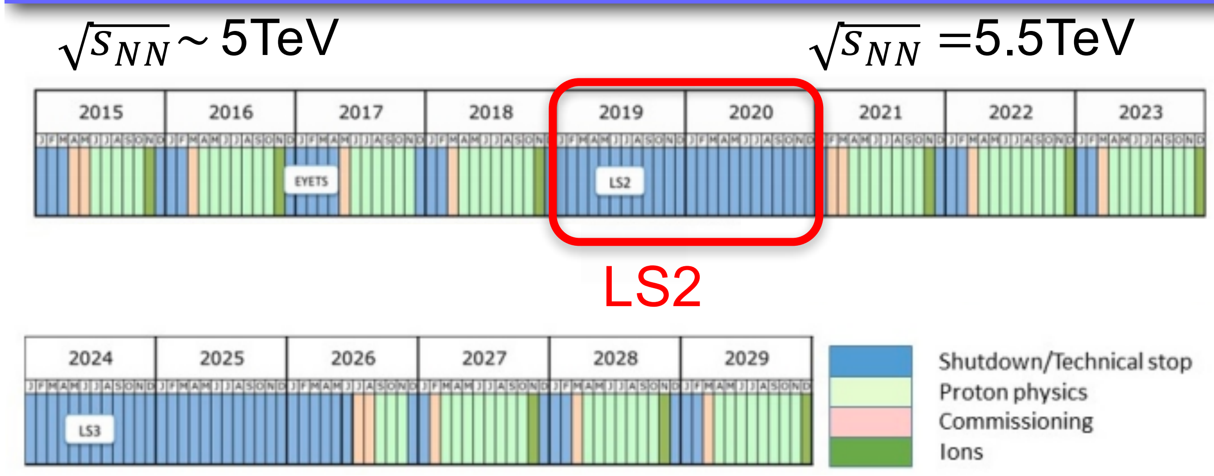
- Low-momentum charmonia dissociation (and regeneration?) to study deconfinement and medium temperature
- Production of thermal photons and low-mass dileptons emitted by QGP to study initial temperature and equation of state of the medium
  → exploit ALICE low p_T reach, PID capabilities, improve vertexing and readout rate → improve inner tracker and readout upgrade of the rest of ALICE

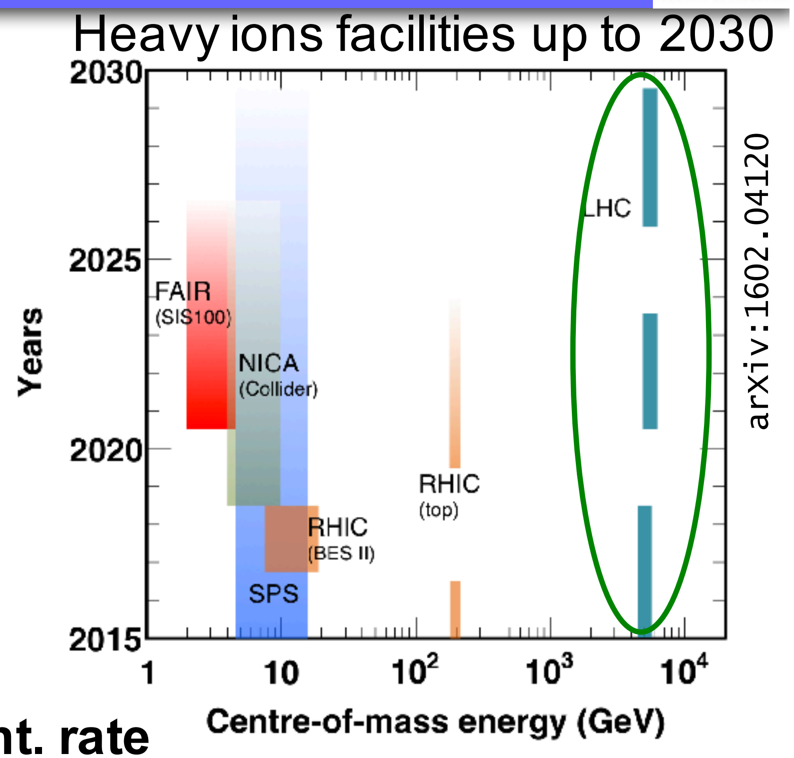
- Precision study of light nuclei and hyper-nuclei

All this cannot be selected at trigger level (very large combinatorial background) → read out everything!

Move from <1 kHz to 50 kHz in Pb-Pb!

LHC Schedule

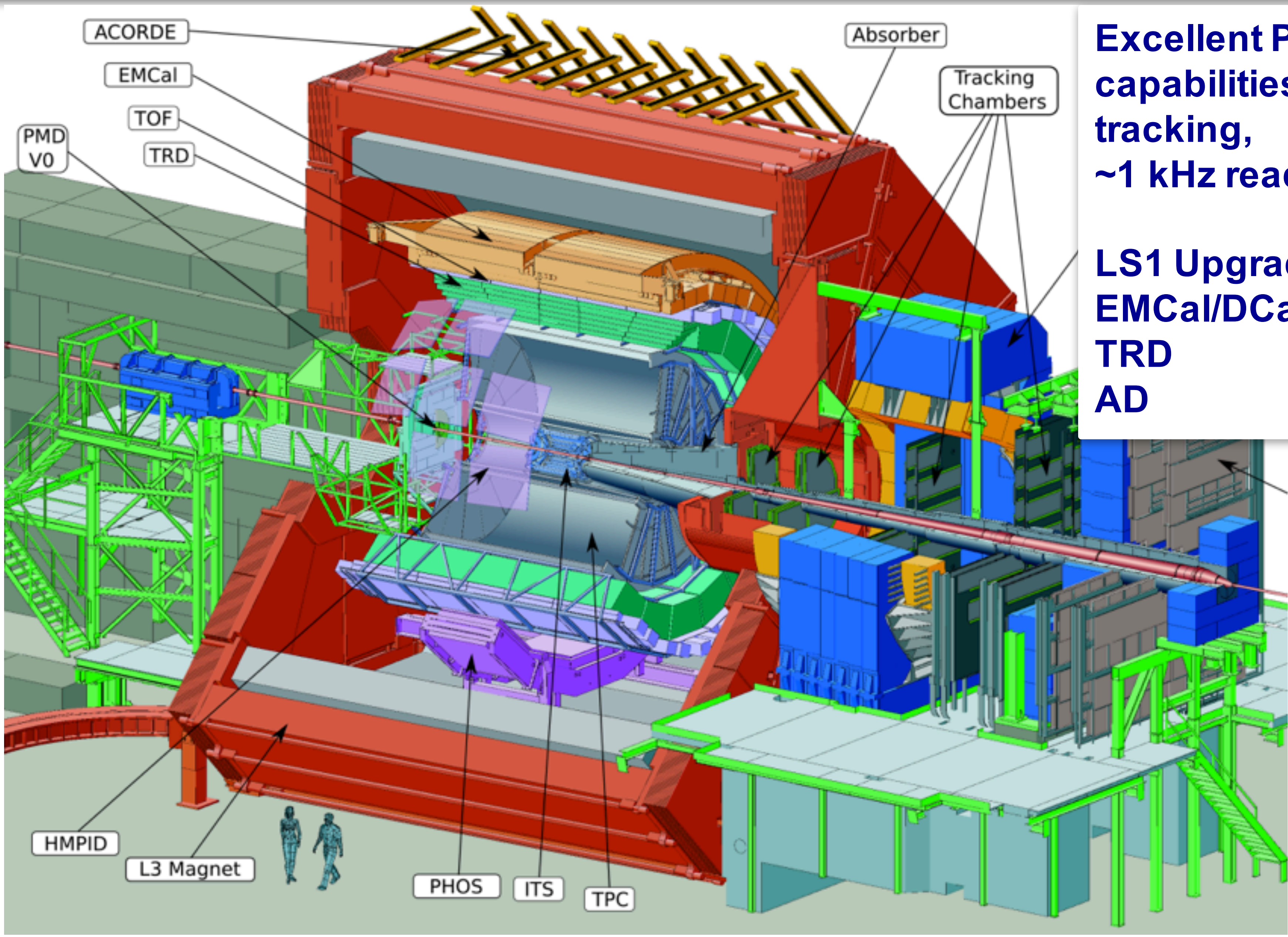




- L_{int} 10^{27} $cm^{-2}s^{-1}$ → (goal) 6 10^{27} $cm^{-2}s^{-1}$ → **50 KHz int. rate** (thanks to LHC team!)
- In addition to Pb-Pb: p-Pb and pp at relevant energies
- ALICE request: 10 nb^{-1} Pb-Pb at B=0.5 T (+ 3 nb^{-1} at B=0.2 T)

LHC operates at higher energies and at vanishing baryon chemical potential
→ best suited for measurement of QGP properties
→ abundance of calculable QCD processes (heavy quarks)

The ALICE Detector Now



Excellent PID capabilities, tracking, ~1 kHz readout

LS1 Upgrades:
EMCal/DCal/PHOS
TRD
AD

ALICE Upgrade: LS2

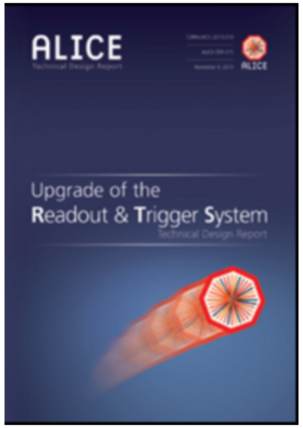
- The ALICE LS2 upgrade plans:
  - new, high-resolution, low-material Inner Tracking System (ITS)
  - upgrade of Time Projection Chamber (TPC)
  - new silicon telescope in front of hadron absorber in the acceptance of the Muon Spectrometer (Muon Forward Tracker, MFT)
  - upgrade of the online systems (O^2)
  - upgrade of the forward trigger detectors (FIT) and ZDC
  - upgrade of read-out electronics of: TRD, TOF and Muon Spectrometer
  - upgrade of the offline reconstruction and analysis framework

Collection of ALICE upgrade TDRs

CERN-LHCC-2013-024

CERN-LHCC-2012-012

CERN-LHCC-2015-021

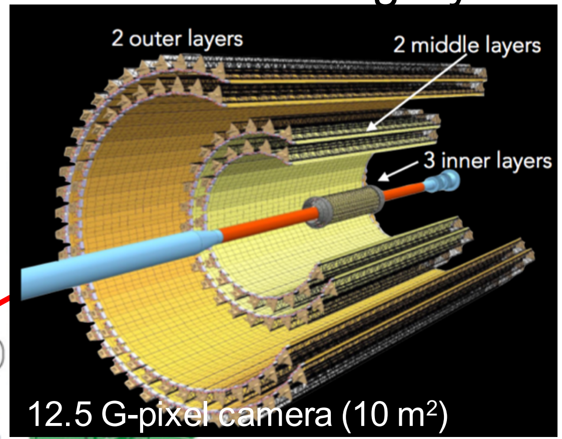


CERN-LHCC-2013-019

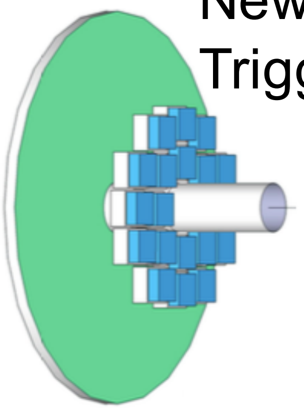
CERN-LHCC-2015-006

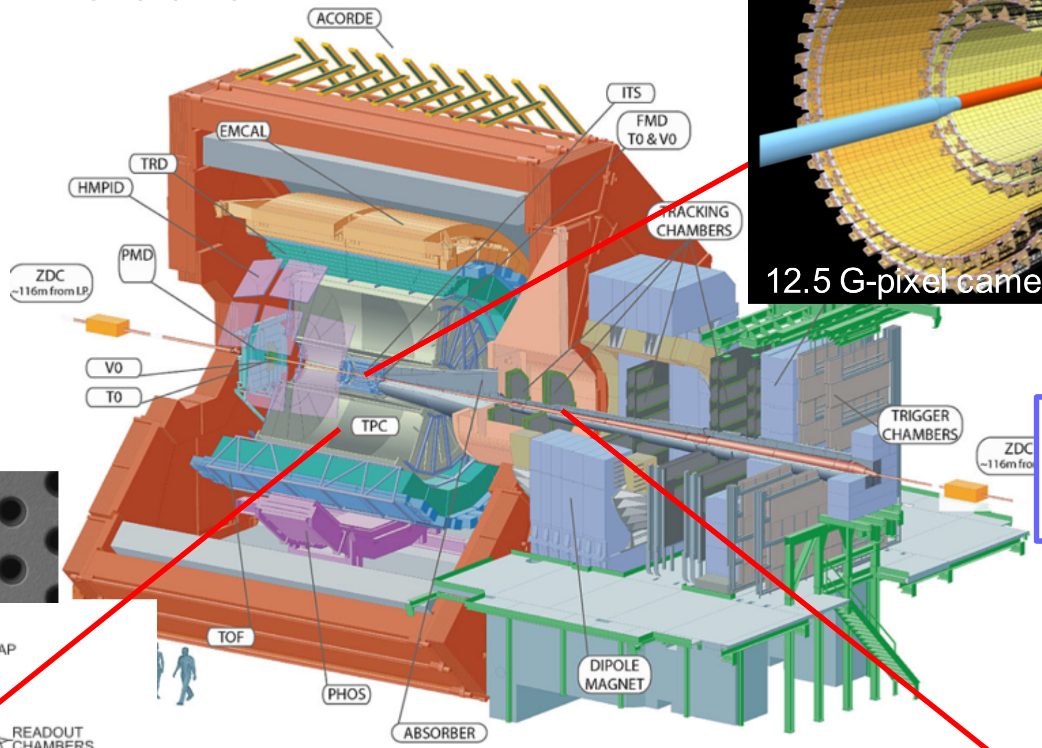
ALICE Upgrade: LS2

New Inner Tracking System (ITS)

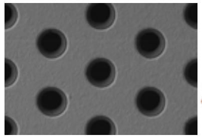


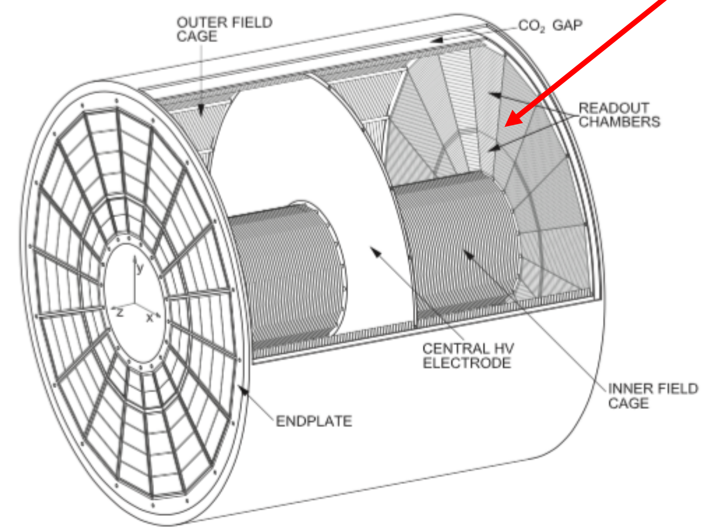
New Forward Interaction Trigger (FIT)





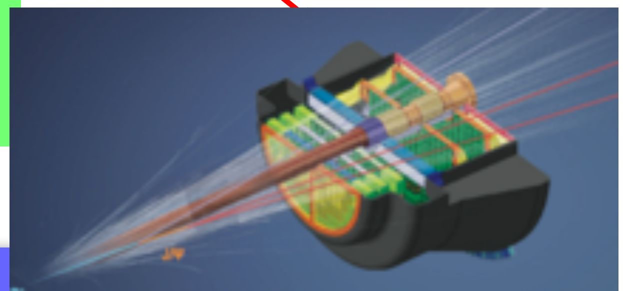
TPC with GEM based readout





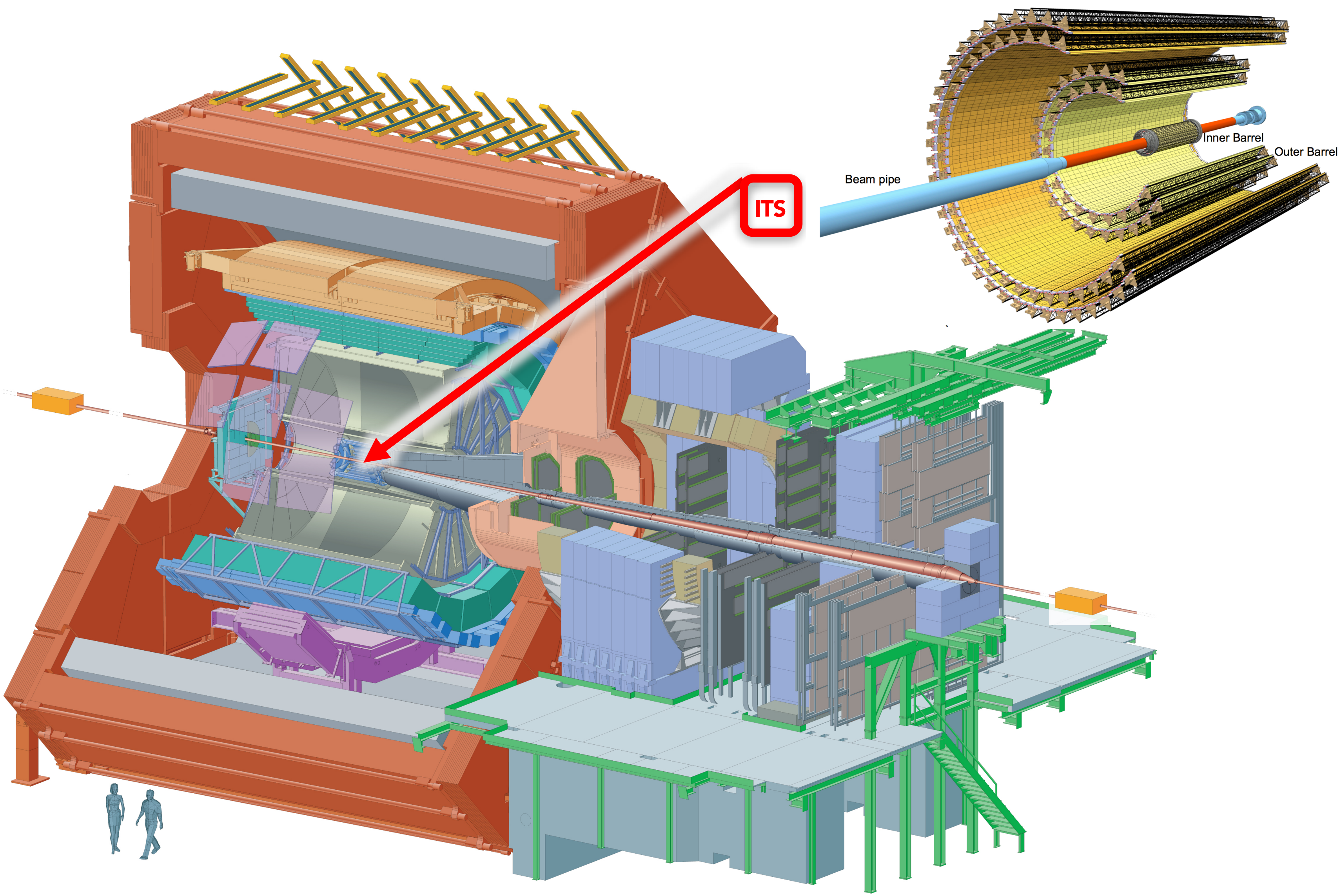
Both based on Monolithic Active Pixel Sensors (MAPS)

New Muon Forward Tracker (MFT)

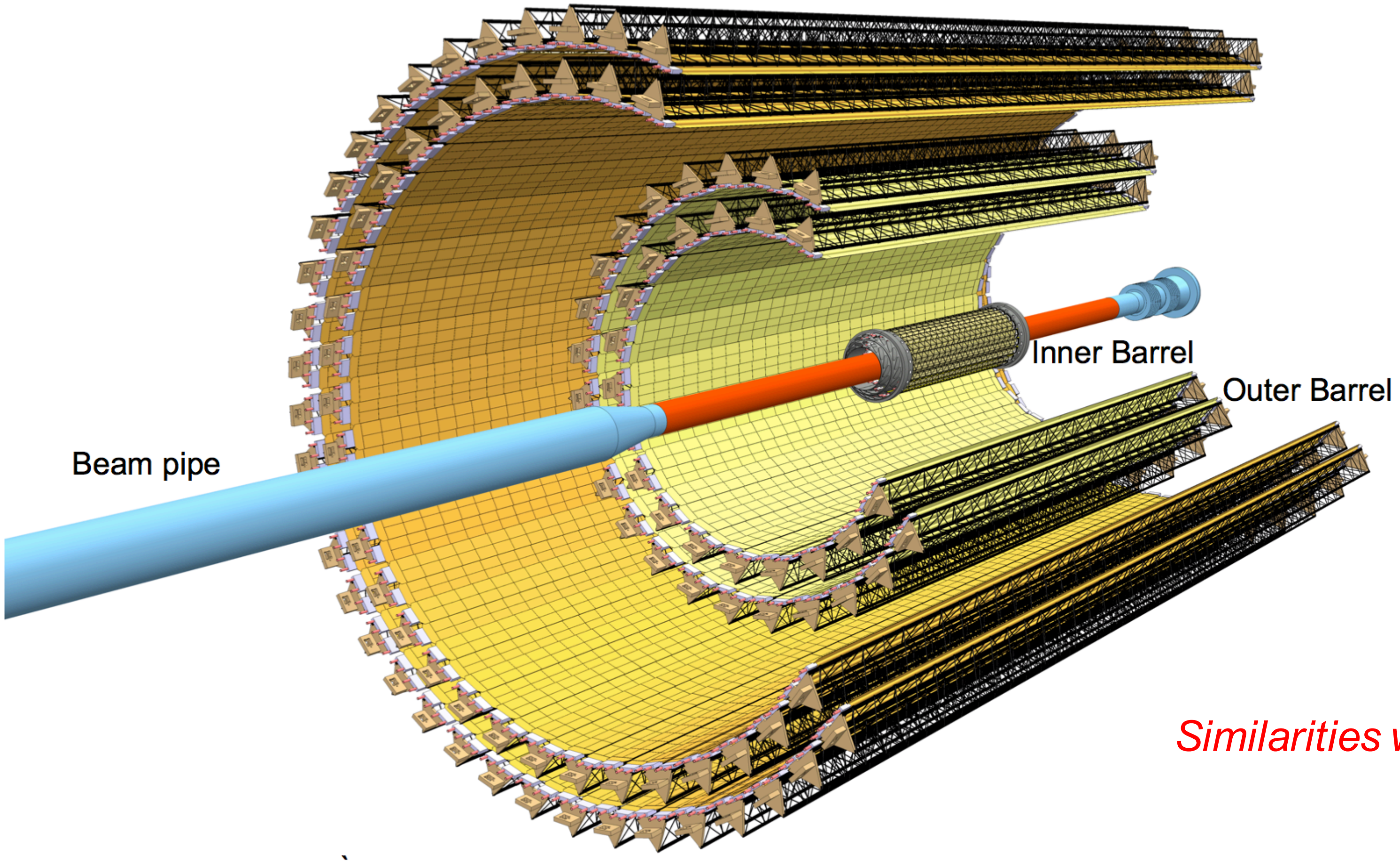


+ improved readout for TOF, ZDC, TRD, MUON ARM
+ new Central Trigger Processor
+ new DAQ/Offline architecture

ALICE ITS Upgrade



New ITS Layout



12.5 Gpixels

Area: ~10m^{2},

Inner Barrel: 3 layers;

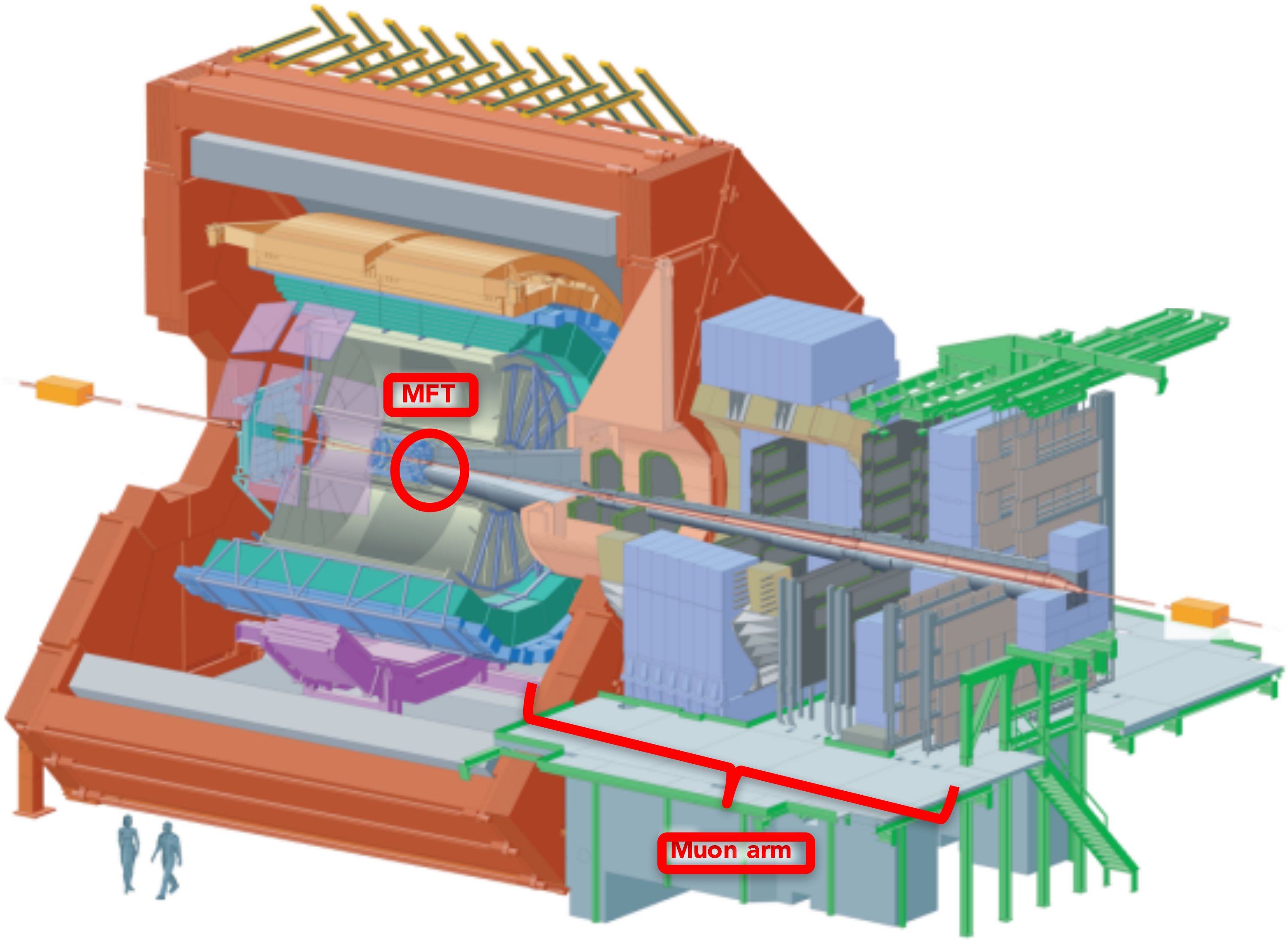
Outer Barrel: 2+2 layers;

Same technology for IB & OB

$|\eta| \leq 1.5$

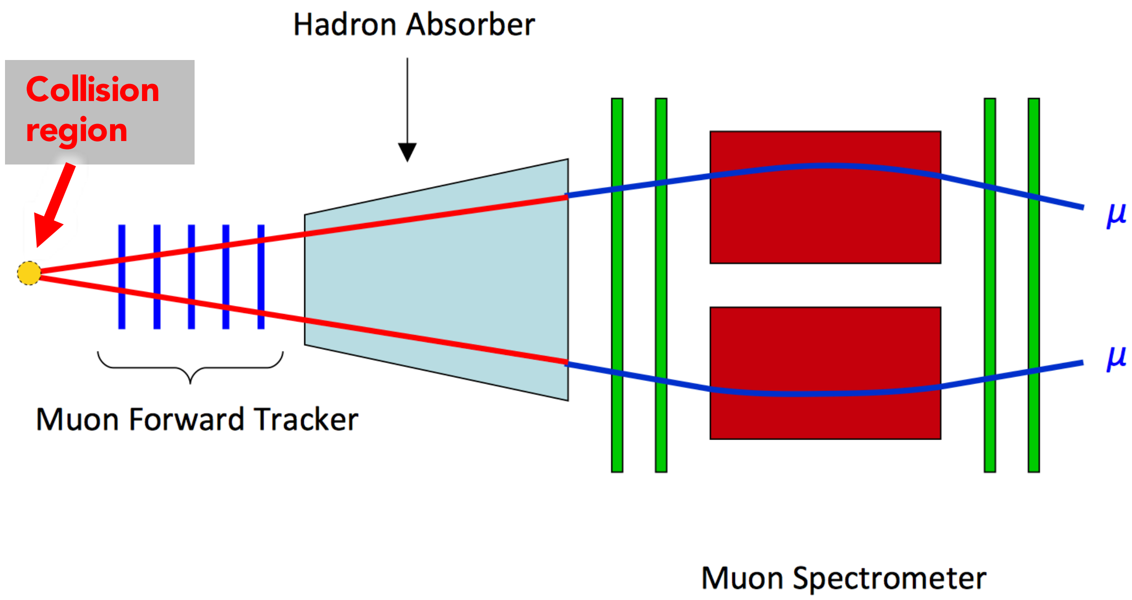
Similarities with STAR HFT project

ALICE MFT Upgrade

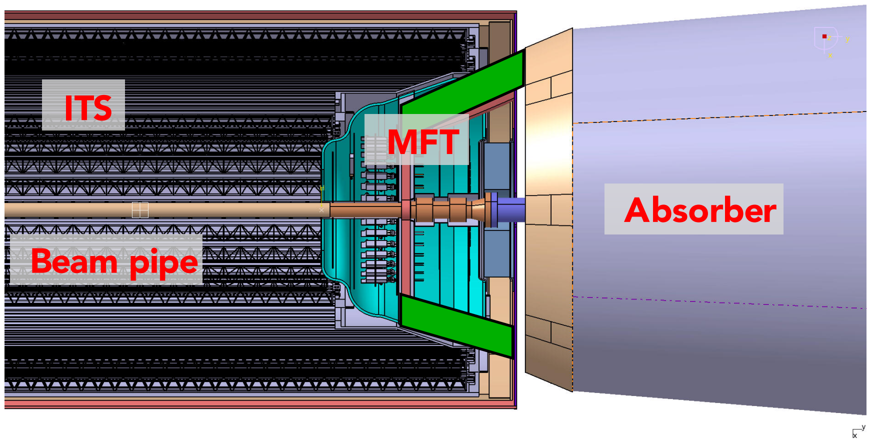


MFT Concept

- ALICE muon arm: detect muons in forward **range** **$-4.0 < \eta < -2.5$**
- Muon Forward Tracker (MFT) design objectives: Increase pointing accuracy for the muon tracks, in particular at low p_T
- Implementation: silicon telescope in front of the hadron absorber

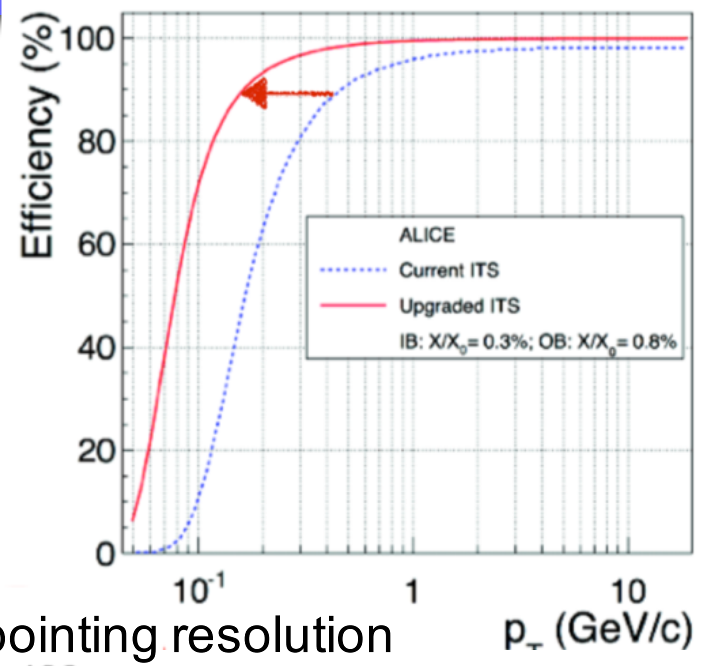


Similarities with PHENIX FVTX project

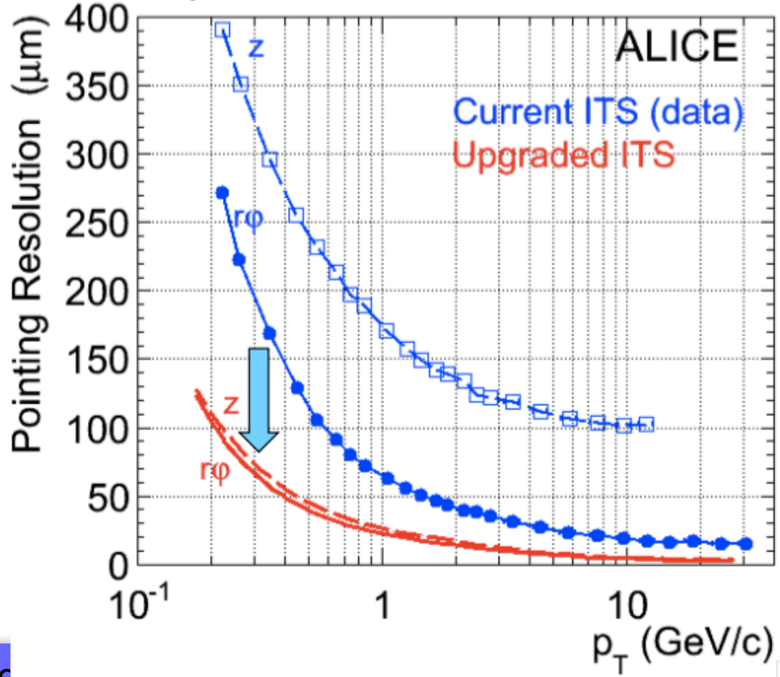


Inner Tracker Upgrade

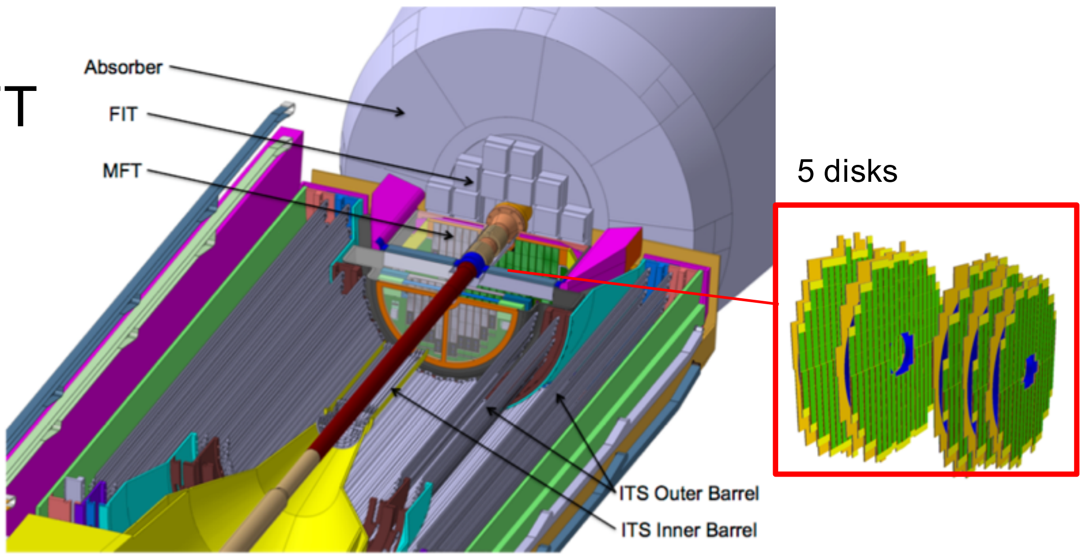
	ITS	ITS UPGRADE	MFT
# layers	6	7	5
Rapidity coverage	$\lvert\eta\rvert<0.9$	$\lvert\eta\rvert<1.5$	$-3.6<\eta<-2.4$
r_{min}	3.9 cm	2.3 cm	/
Material budget per layer	1.1% X_0	0.3 - 1% X_0	0.6%X_0
Spatial resolution	12 x 100 μm^2 35 x 20 μm^2 20 x 830 μm^2	~5 x 5 μm^2	~5 x 5 μm^2
Max Pb-Pb readout rate	1 kHz	100 kHz	100 kHz



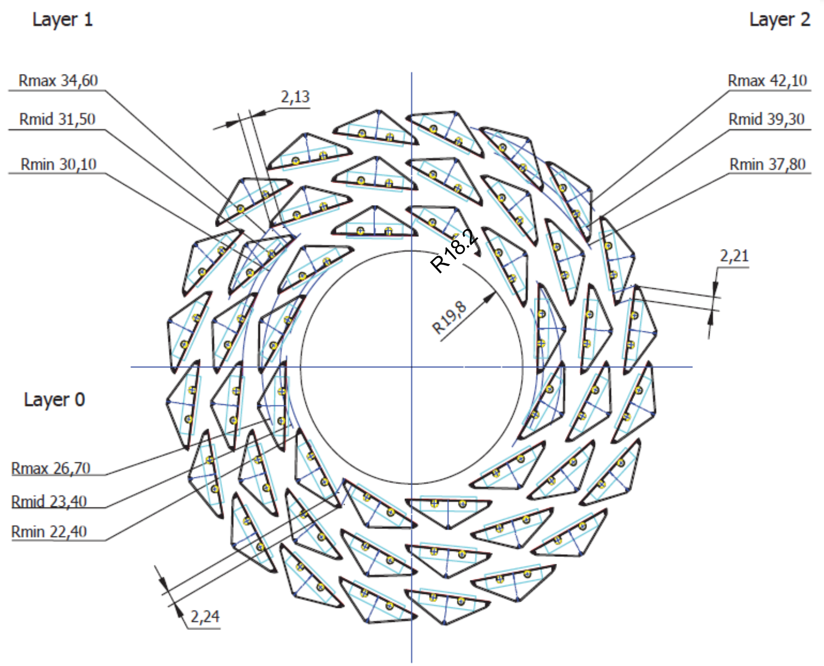
ITS pointing resolution

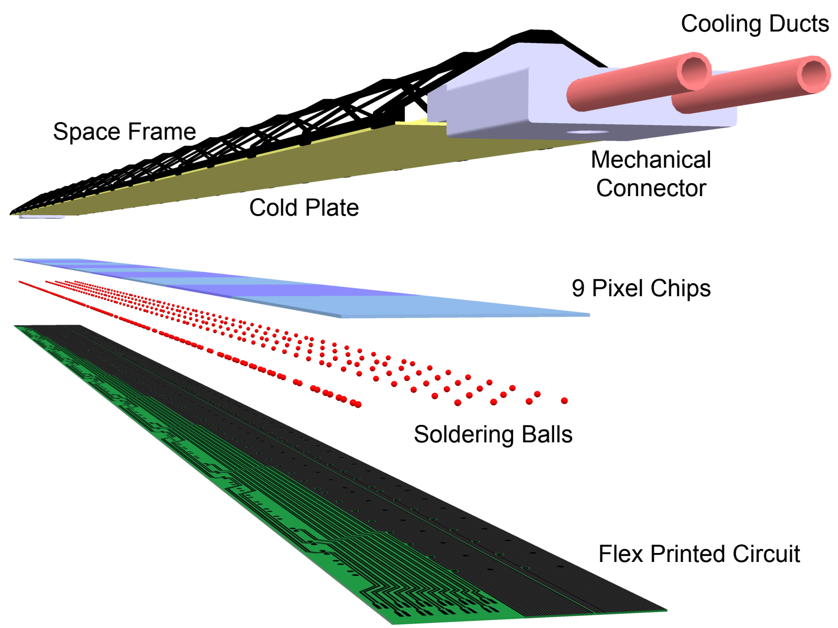


MFT



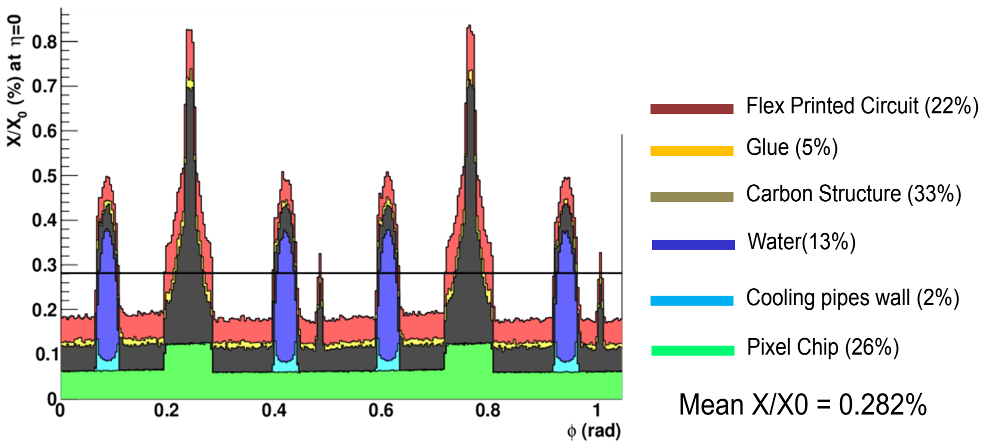
Inner Barrel

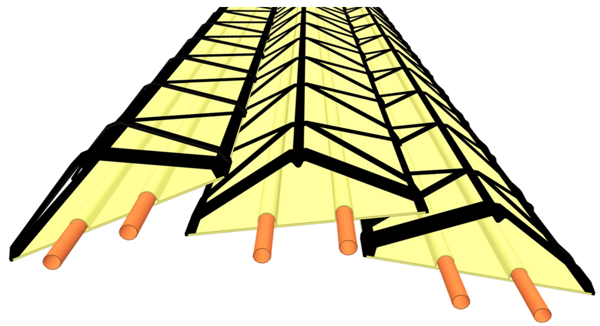


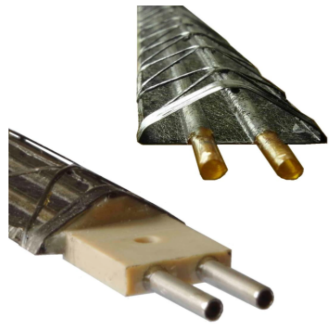


Material budget: ~ 0.3 % X_0 per layer

Inner Barrel Stave







Monolithic Active Pixel Sensors

MAPS attractive technology for ALICE due to:

- Reduction of material budget (sensor&readout integrated) 350 μm → 50-100 μm/layer
- Radiation tolerance and moderate read-out time fitting ALICE needs

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

Pixel pitch ~ 30 μm x 30 μm

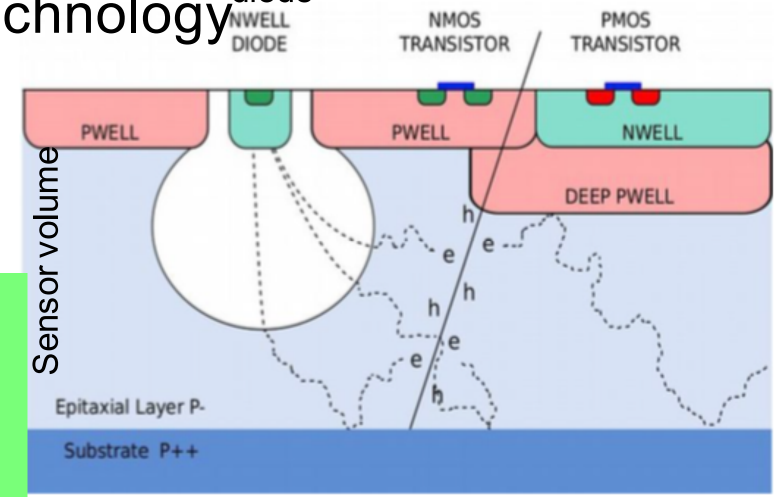
Final version of MAPS chip (ALPIDE = ALICE Pixel Detector) due July 2016 (after 3 prototype runs)
→ start production end of the year

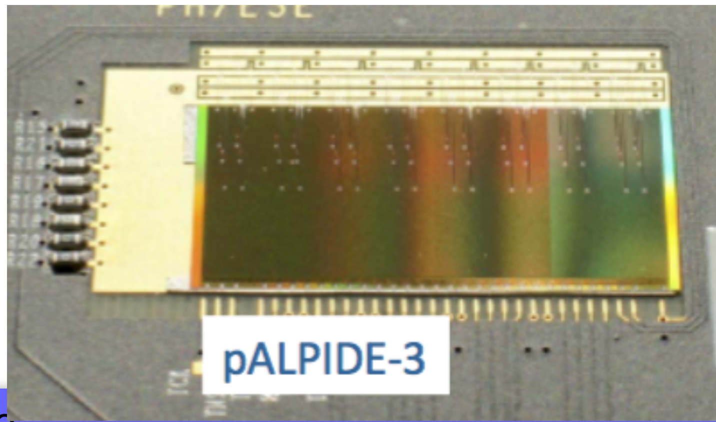
Power consumption: <100 mW/cm^2
Efficiency > 99%
Noise probability: < 10^{-6}

Non-Ionizing Energy Loss: 1.7 × 10^{13} 1 MeV neq /cm2
Total Ionizing Dose: 2.7 Mrad for IB, 100 krad for OB

Sensing diode

Read-out

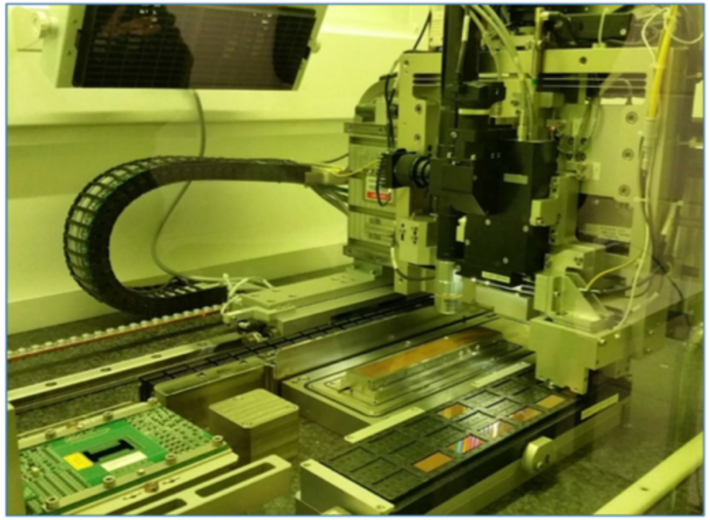


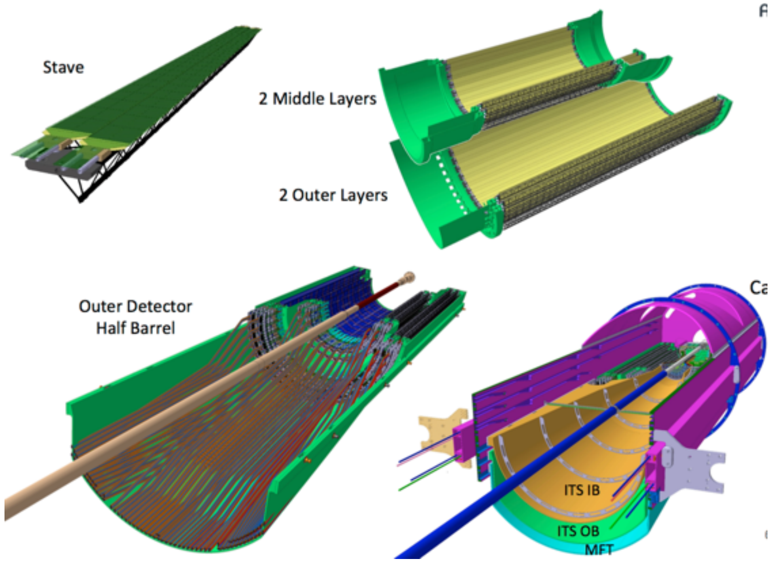


From plots & drawings to pictures

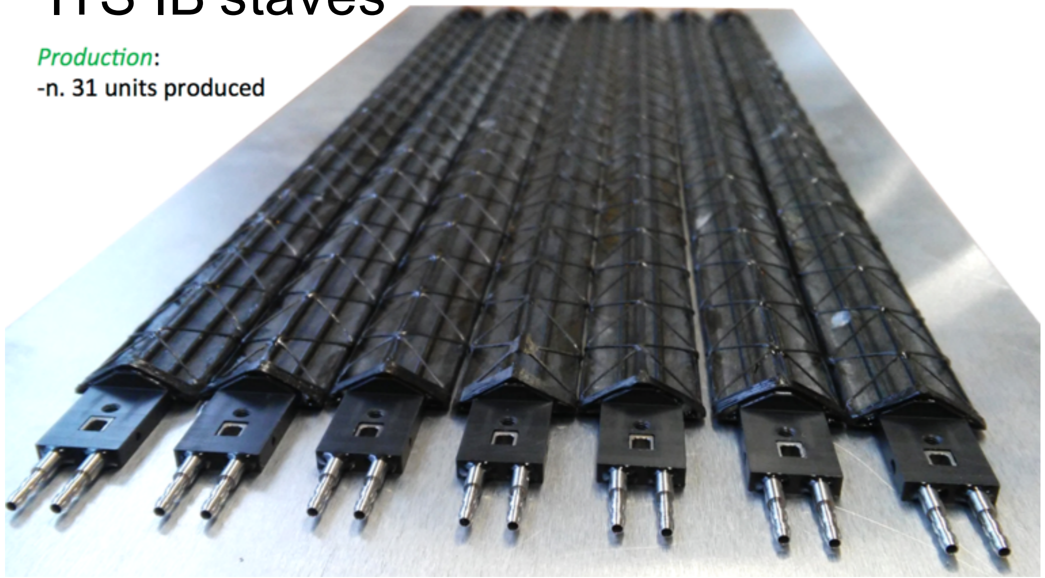
MFT disk # 1: PCB + support

Module assembly machines

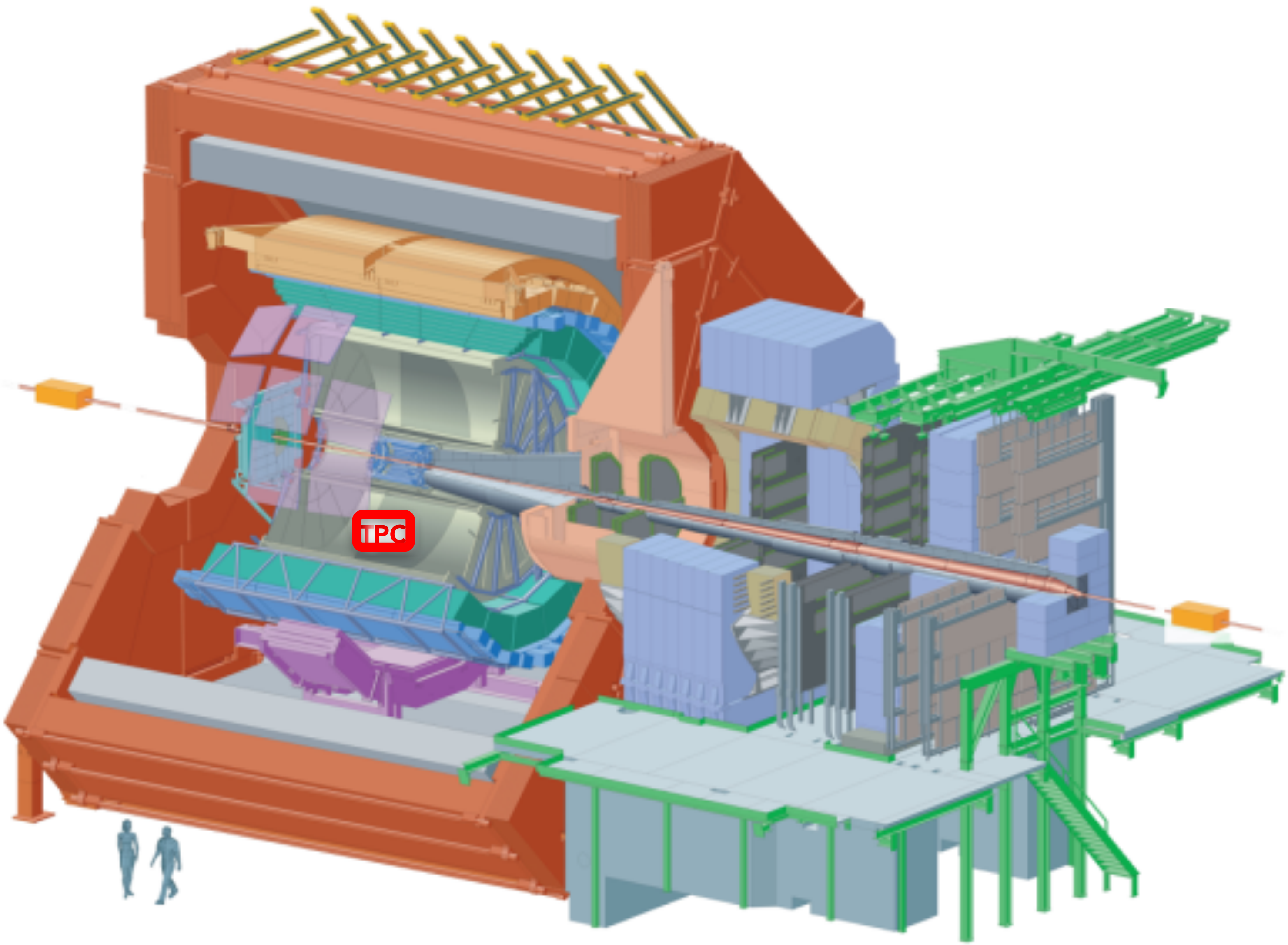




ITS IB staves

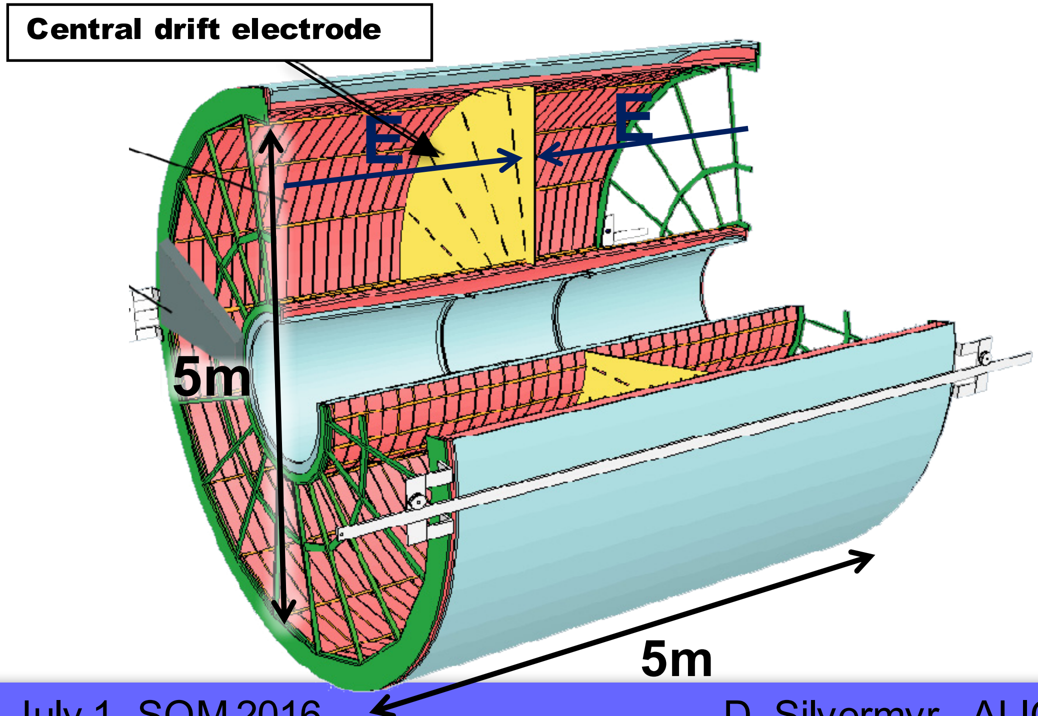


ALICE TPC Upgrade

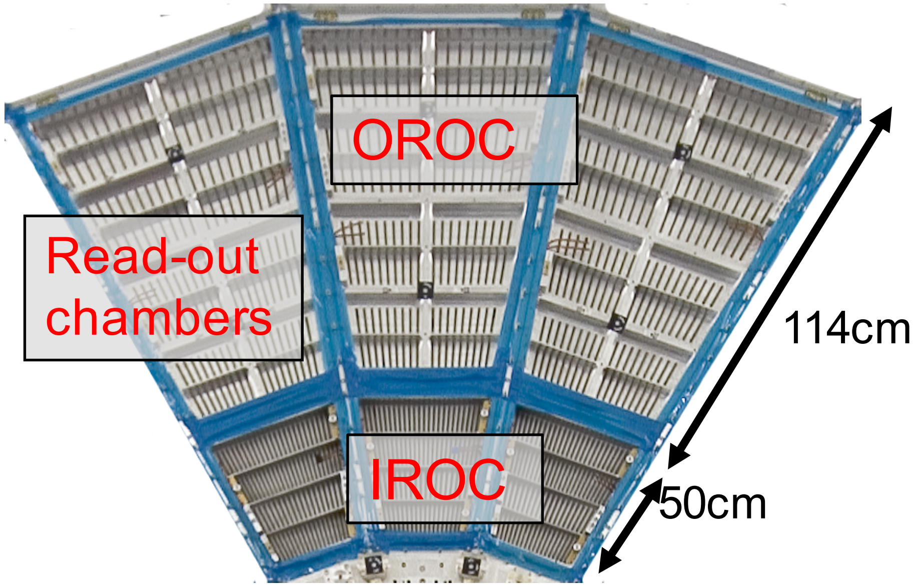


TPC Overview

- Diameter: 5 m, length: 5 m
- Acceptance: $|\eta| < 0.9$, $\Delta\phi = 2\pi$
- Gas: $Ne\text{-}CO_2$ in Run1,
  $Ar\text{-}CO_2$ in Run2
- Drift field = 400V/cm
  - Diffusion: $\sigma_T \approx \sigma_L \approx 0.2$ mm/$\sqrt{cm}$
  - $v_d \approx 2.7$ cm/μs, max. drift time: 92 μs

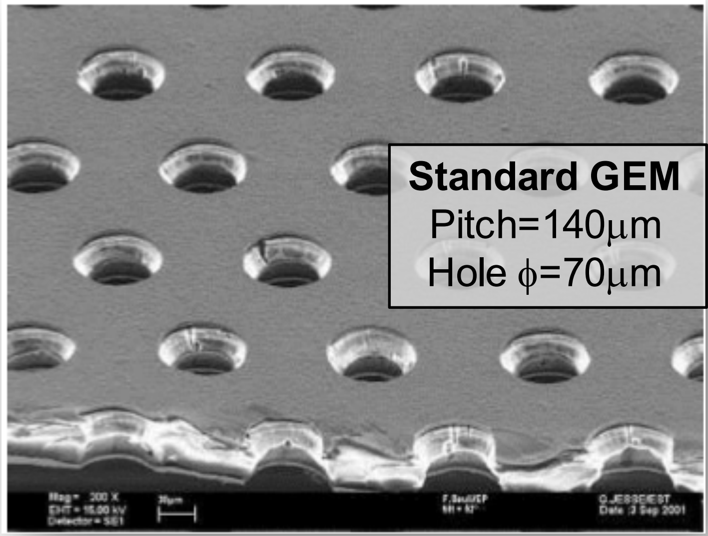


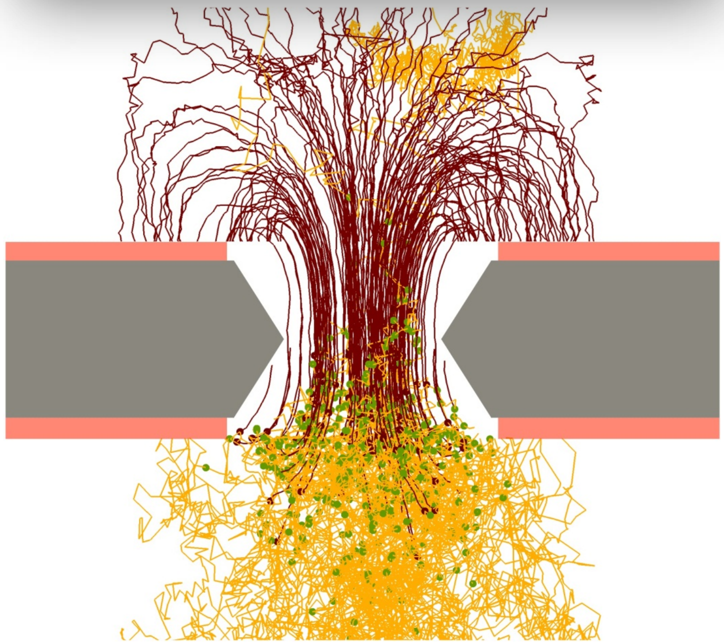
- **Read-out Chambers: Total = 36 × 2**
  - **outer (OROC): 18 × 2**
  - **inner (IROC): 18 × 2**
- **Pad sizes: 4 × 7.5 mm², 6 × 10 (15) mm²**
- **Channel number: 557 568**
- **In Run1 & Run2: MWPC + gating grid operation**
  - **Present rate limitation: few kHz**



TPC Upgrade Objectives

- Main objective: Retain physics performance in high rate operation
  - continuous read-out of Pb-Pb events at 50 kHz collision rate
- Operation of MWPC without gating grid would lead to massive space-charge distortions due to back-drifting ions
- Instead: Continuous read-out with micro-pattern gaseous detectors (GEMs)
- Advantages:
  - reduced ion backflow (IBF)
  - high rate capability
  - no long ion tail





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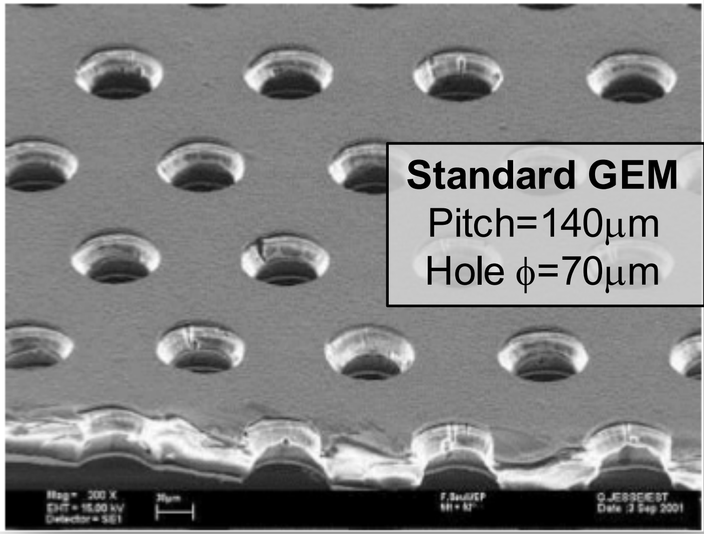
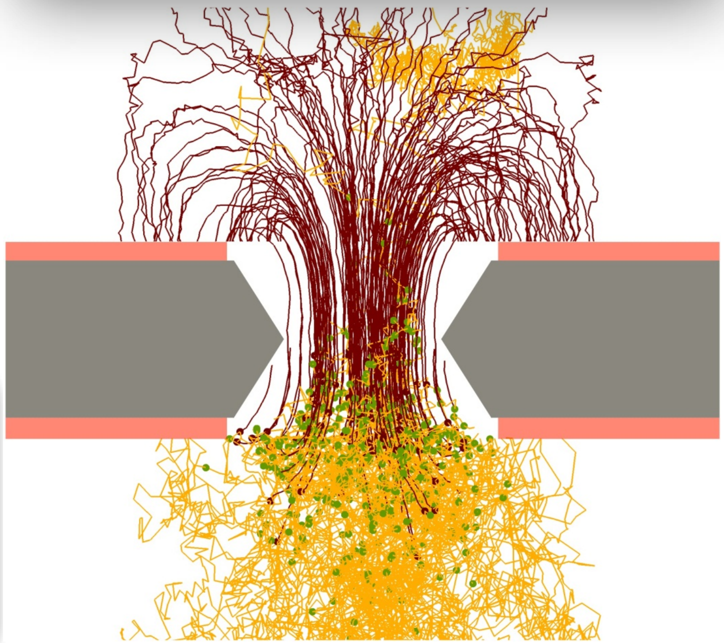
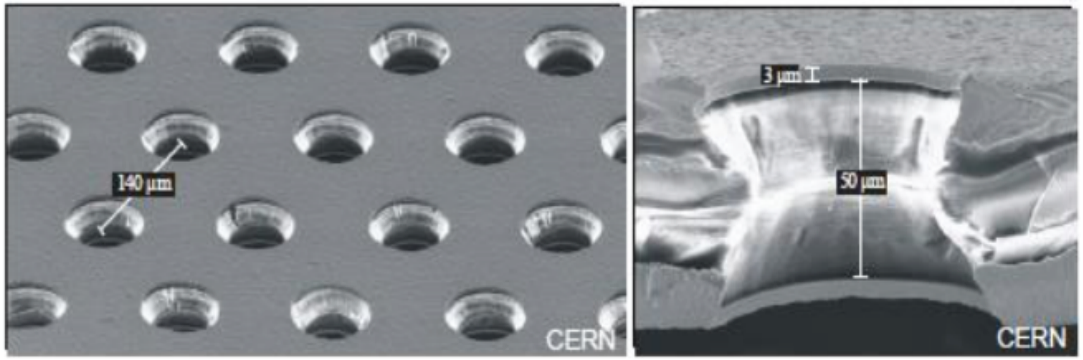
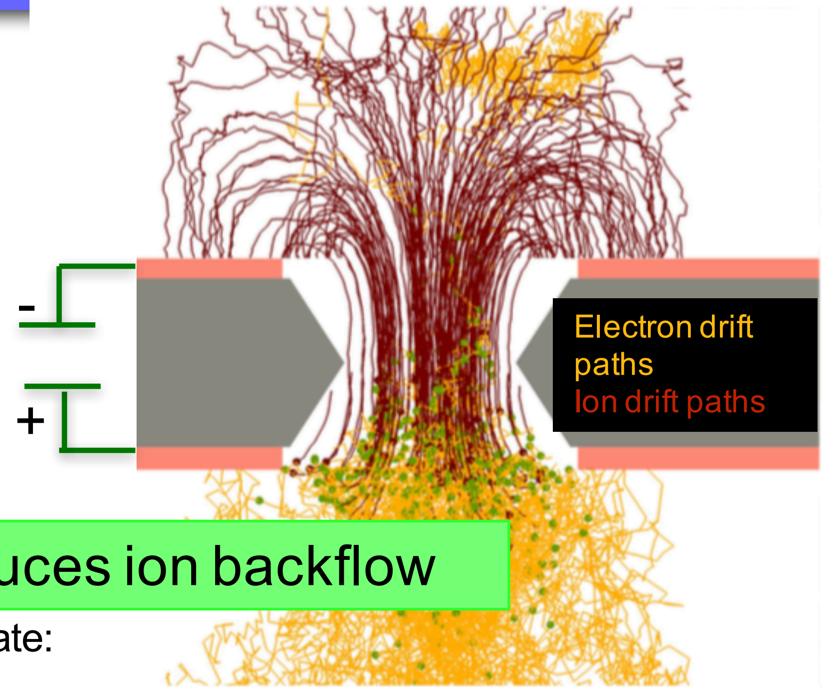
  - high rate capability
  - no long ion tail
- Requirements for read-out system:
  - **IBF < 1% at gain 2000**
  - **d*E*/dx resolution < 12% for ^{55}Fe**
  - **Stable operation under LHC conditions**





Collect Large Statistics with the TPC

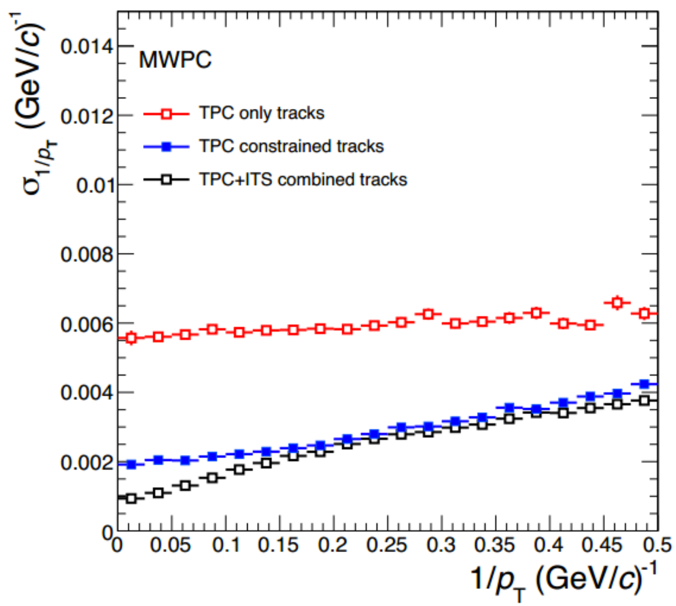


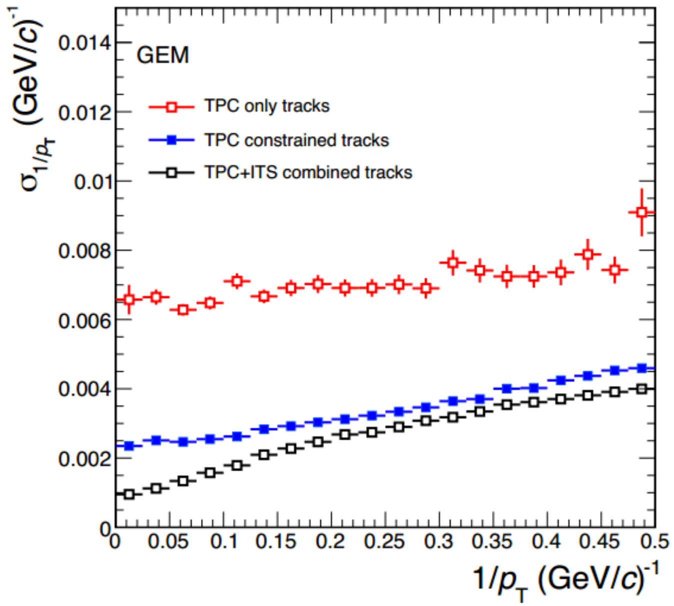


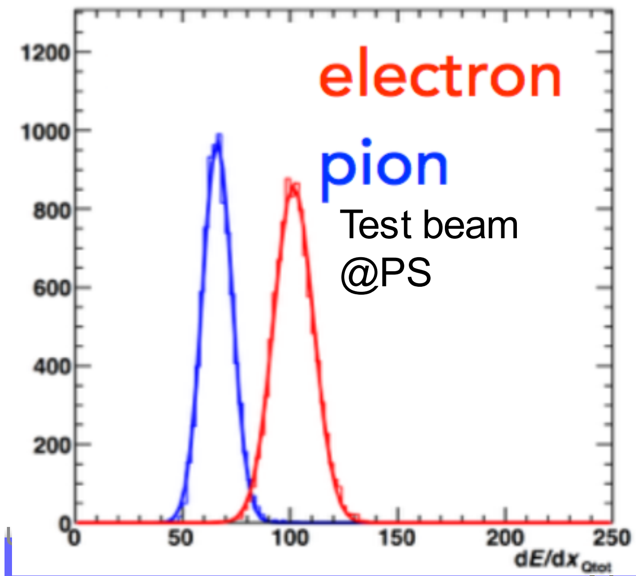
GEM (Gas Electron Multiplier) technology reduces ion backflow

With GEM TPC continuous readout possible @Pb-Pb interaction rate:
50 kHz, preserving tracking, p resolution and PID capabilities

TPC TDR: CERN-LHCC-2012-012

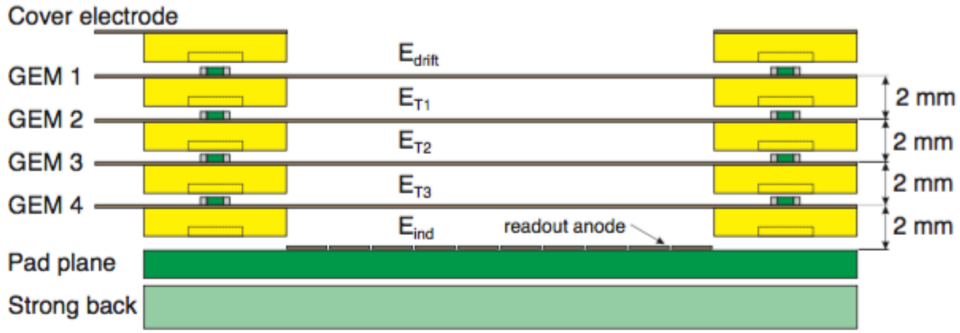


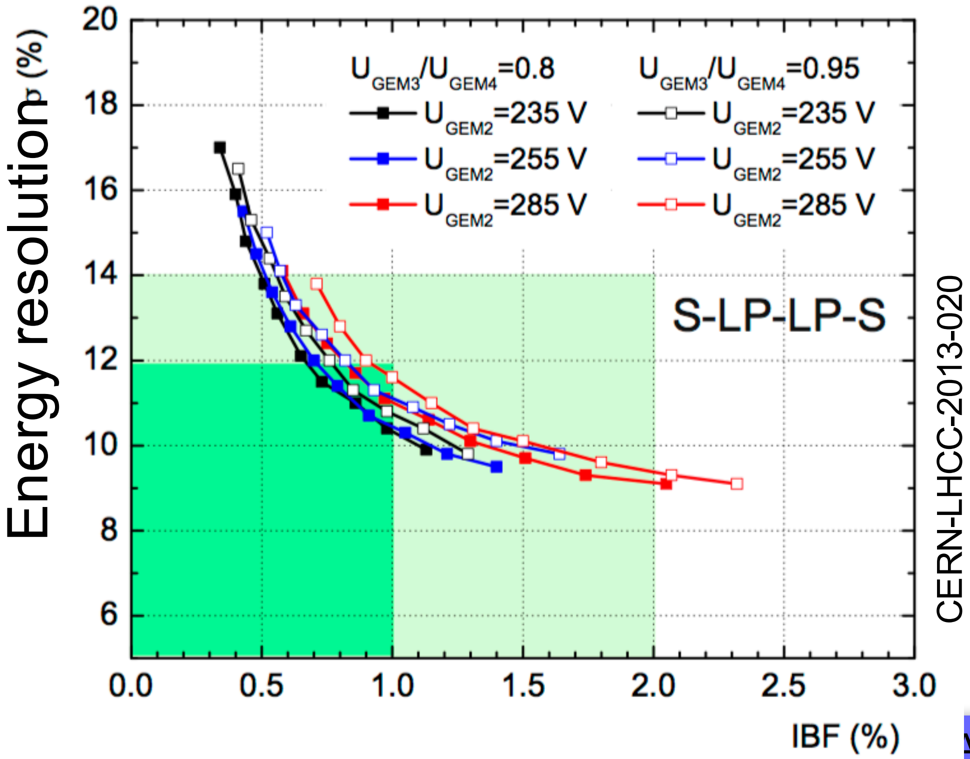


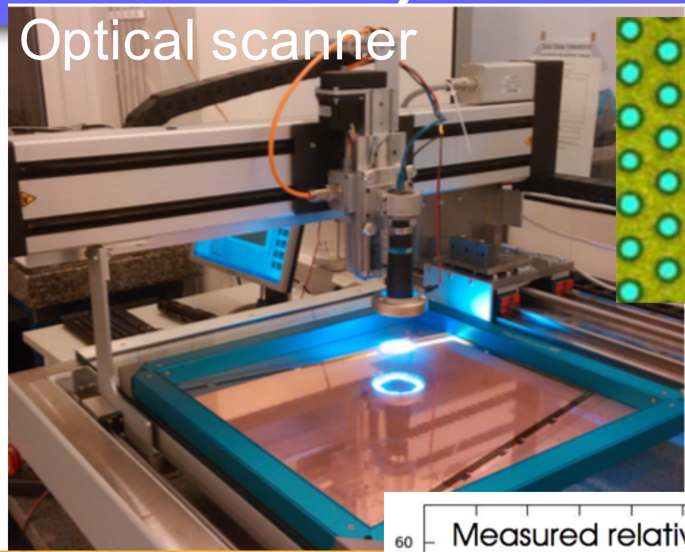


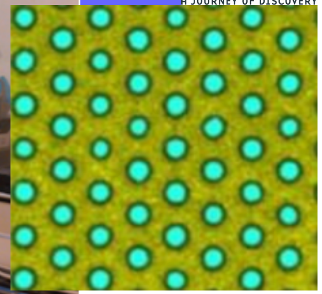
R&D Work (and Pictures…)

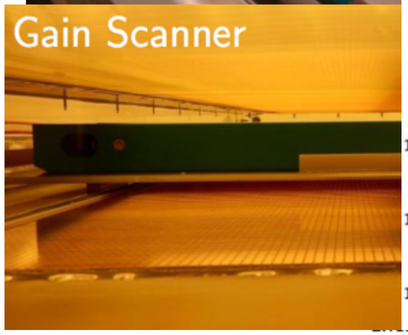
To effectively reduce IBF a GEM stack is needed
→ 4 GEM scheme with optimization of holes

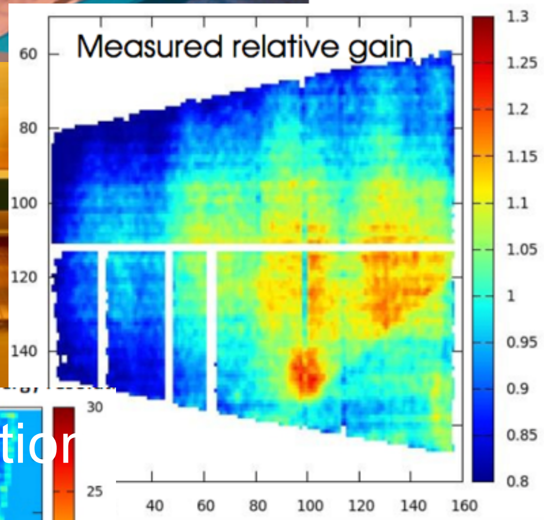


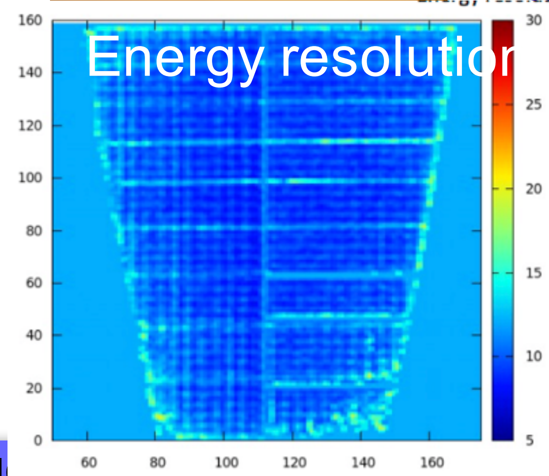












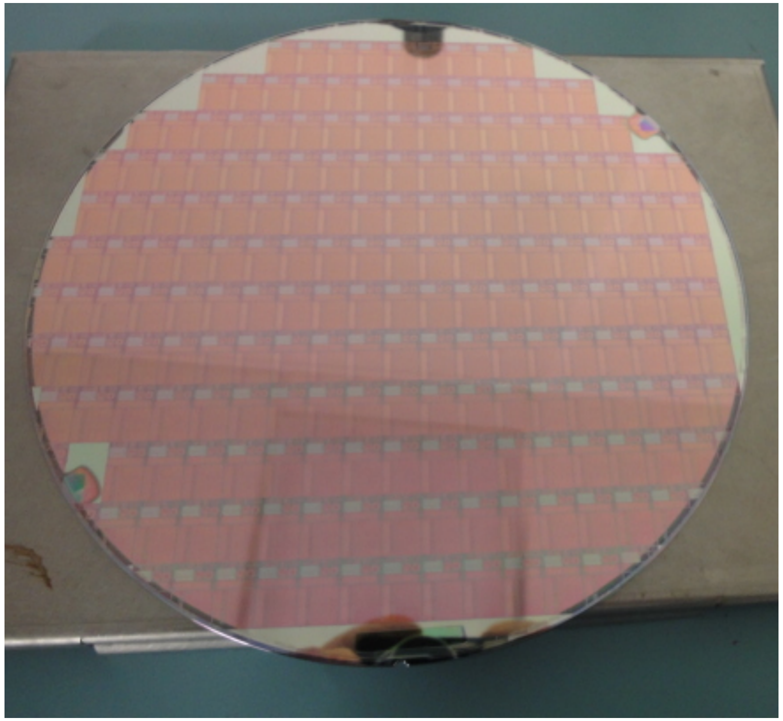
Pre-production to be launched after Summer 2016

Read-out ASIC: SAMPA

- Integrate functionality of present preamplifier / shaper and ALTRO chip. To be used by TPC & Muon Chambers (MCH)
  - Pos/ neg. polarity
  - continuous / triggered read-out

Interest also e.g. from STAR iTPC project

- **MPW2 testing starting now!**



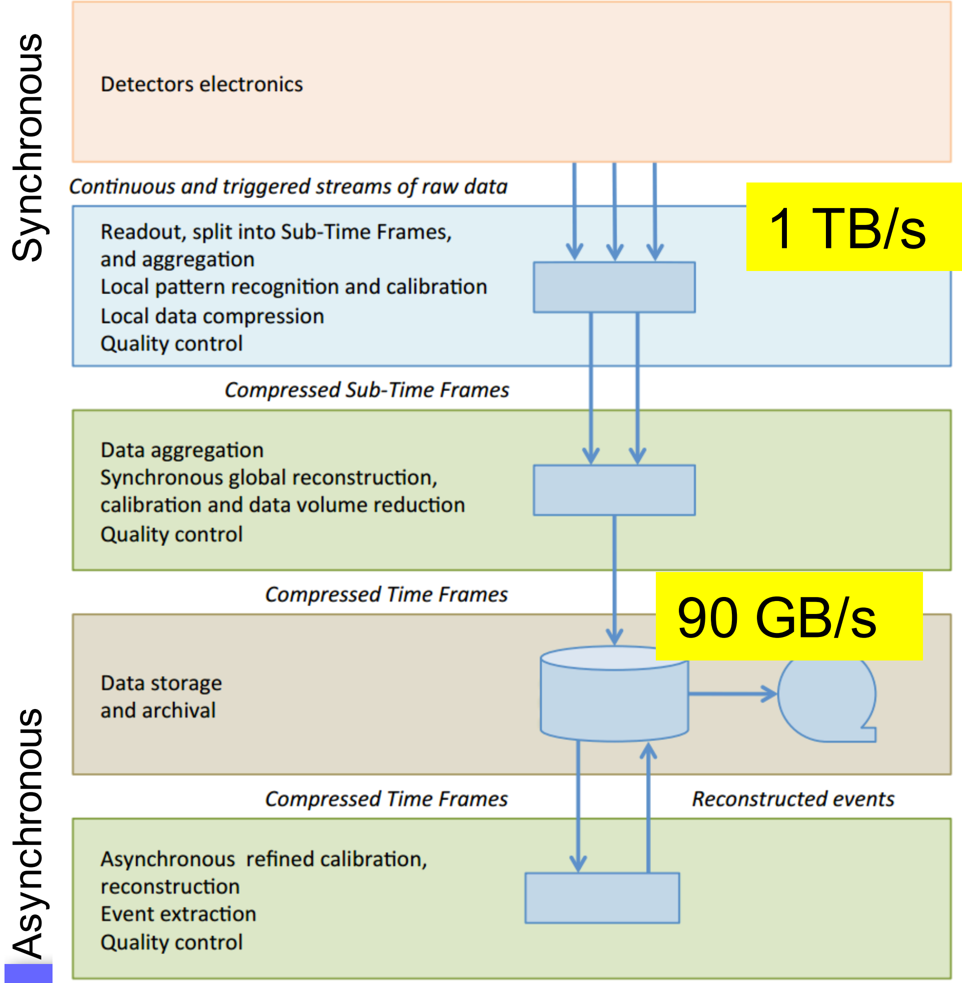
O^2: Adapt Online & Offline

The challenges:

Target luminosity implies 1 TB/s
→ Data reduction is key
→ Online calibration needed

The new infrastructure

O^2: new ALICE facility
100 k CPU cores
60 PB of storage



- Data transfer in continuous mode fashion or by using minimum bias trigger
- Local compression (i.e. for TPC cluster finding)
- Online calibration & global reconstruction replace original raw data with compressed data

The O^2 system will perform calibration and reconstruction **concurrently** with data taking

Online Systems

- Two reconstruction stages are carried out on the O^2 computing farm
  - first reconstruction stage (aimed at data reduction) online
  - second reconstruction stage (aimed at obtaining final performance) asynchronous
- Data bandwidth:

Detector	Input to Online System (GByte/s)	Peak Output to Local Data Storage (GByte/s)	Avg. output to computing center (GByte/s)
TPC	1000	50.0	8.0
TRD	81.5	10.0	1.6
ITS	40	10.0	1.6
Others	25	12.5	2.0
Total	1146.5	82.5	13.2

- LHC luminosity variation during fill and efficiency taken into account for average output to computing center

Expected performance

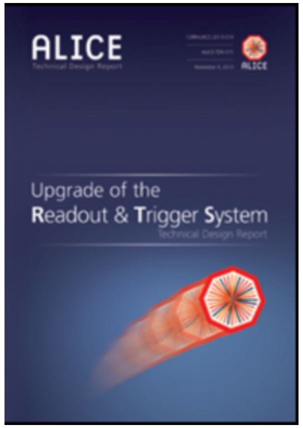
- Reduction of uncertainties for charm
- Separation between beauty and charm
- Full reconstruction of B decays
- Measurements of heavy-flavor baryons
- Low mass di-leptons: e^+e^- (barrel) and $\mu^+\mu^-$ (MFT)
- ψ(2S) → discrimination between models of recombination
- and more…. (light nuclei)

All results with $\mathcal{L}_{int}$=10 nb^{-1} achievable only via the five joint ALICE upgrade projects

CERN-LHCC-2013-024

CERN-LHCC-2012-012

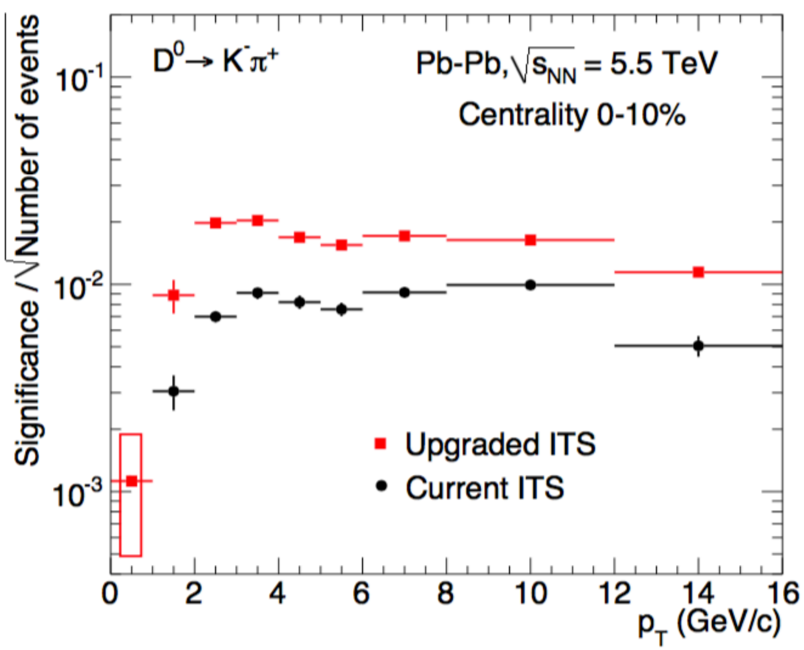
CERN-LHCC-2015-021

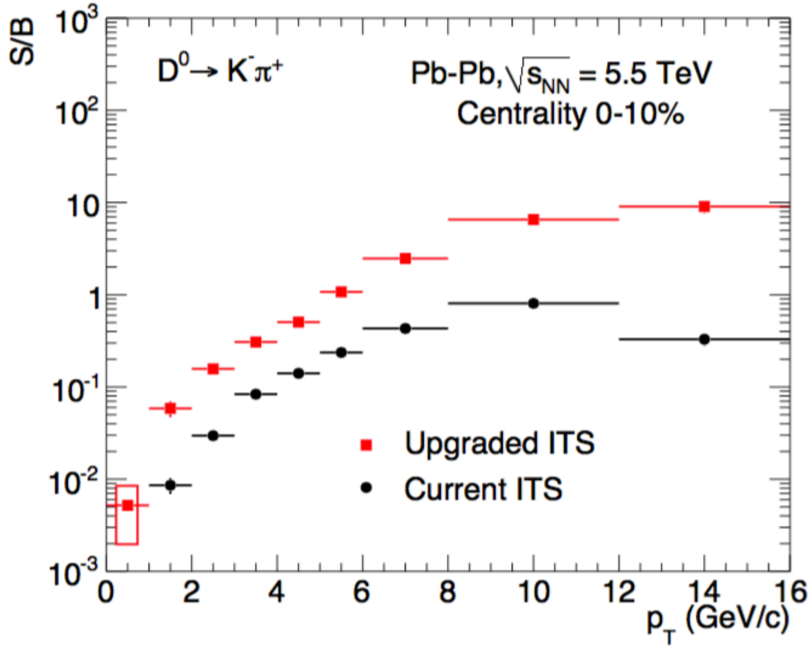


CERN-LHCC-2013-019

CERN-LHCC-2015-006

D^0 as reference candle for charm





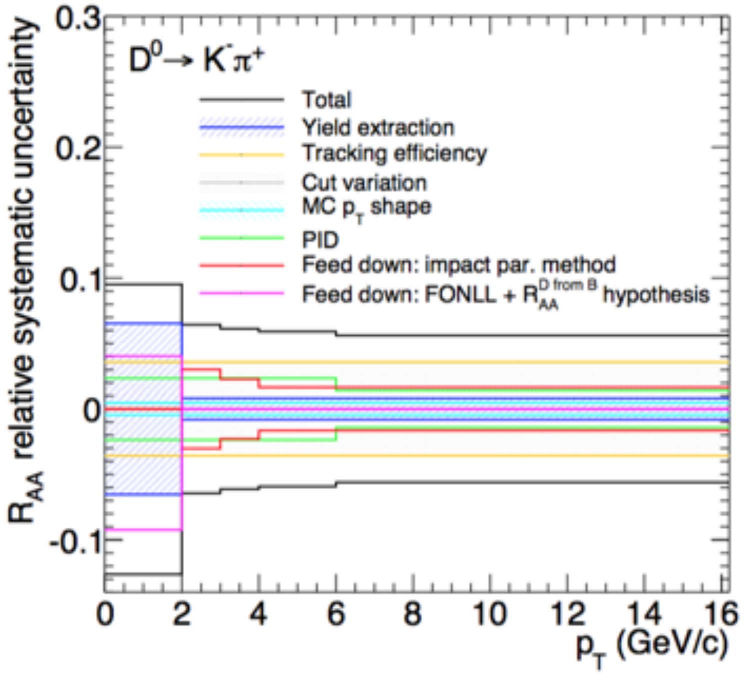
Background down by factor 5

For $\mathcal{L}_{int}$=10 nb^{-1} number of events **8 x 10⁹**

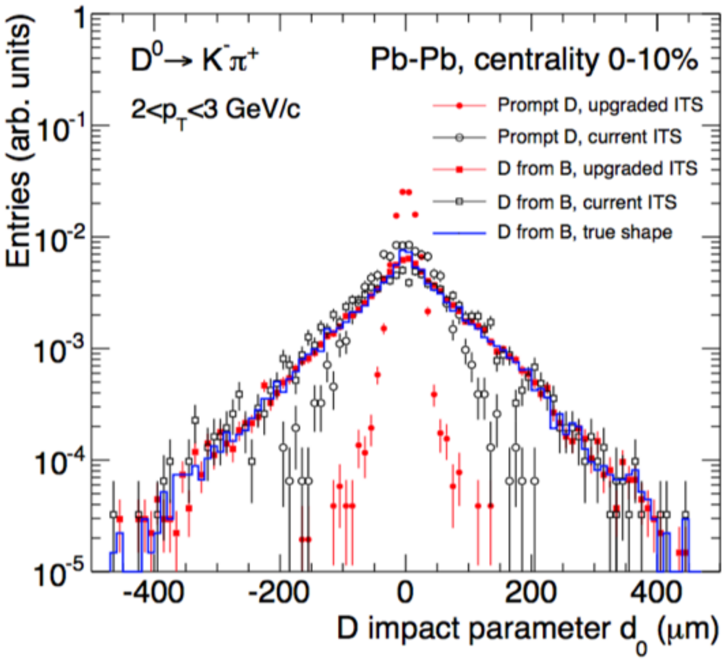
→ Significance 50 for p_T< 1GeV/c (and 1000 at high p_T)

Systematics improvement due to:

- Easier signal extraction
- "direct" feed-down correction → Compare with current 12% in JHEP 11(2015) 205!



Separation between charm and beauty



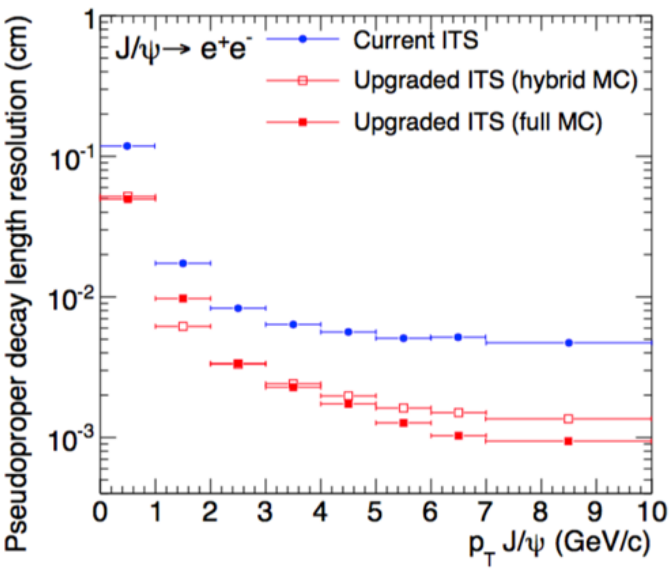
B.R.(B → D^0 + X) ~60%

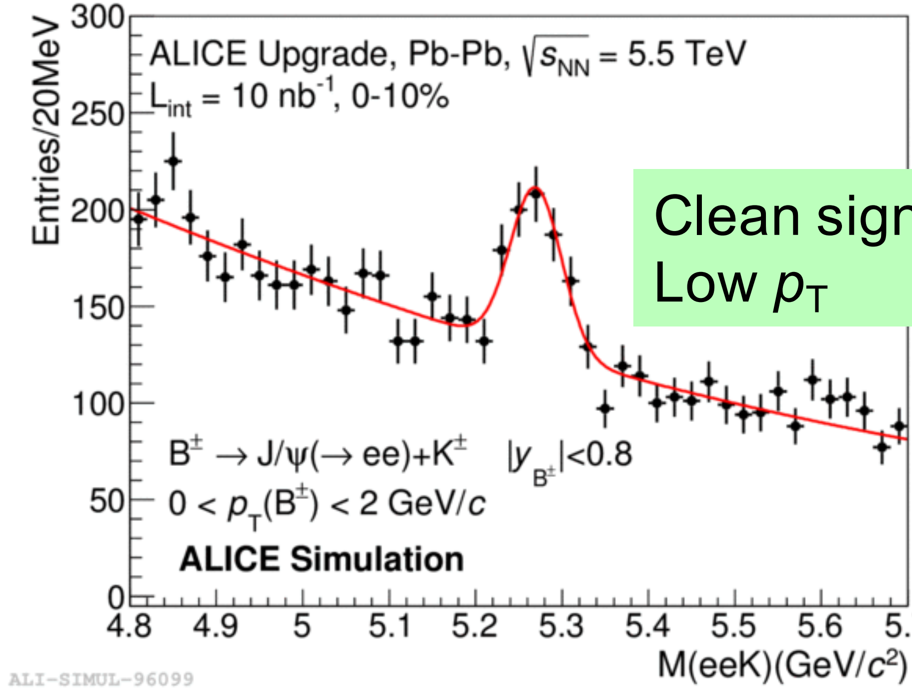
B: cτ ~ 460-490 μm → exploit DCA shape

Upgraded ITS: resolution improves by factor 3

→ Better separation of the two components

This is also valid for displaced J/ψ, e.g. for the study of B→J/ψ (→e^+e^-) + K

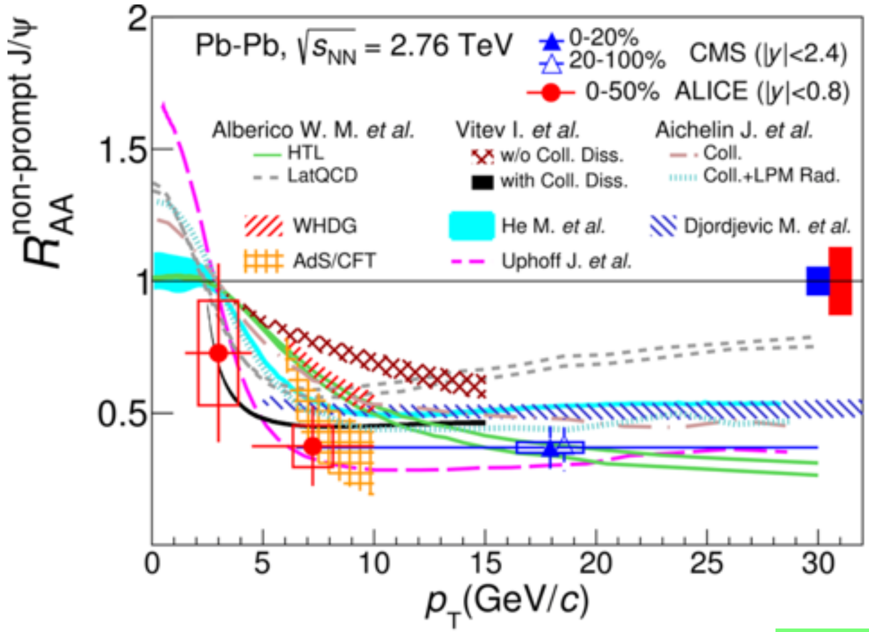


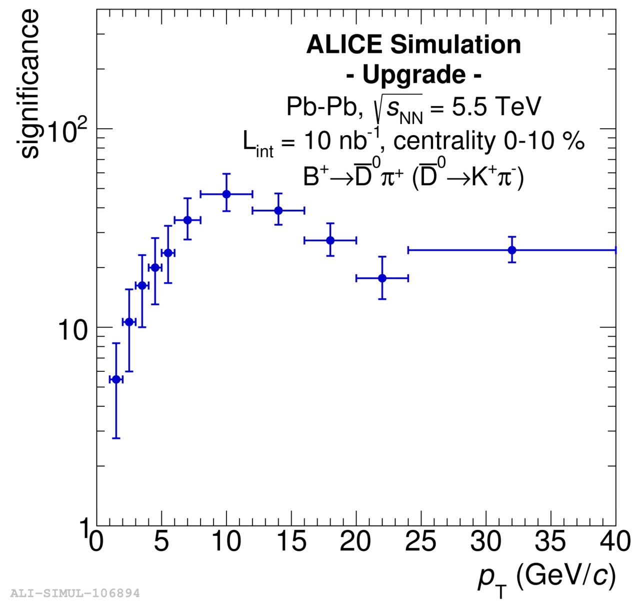


Clean signal
Low p_T

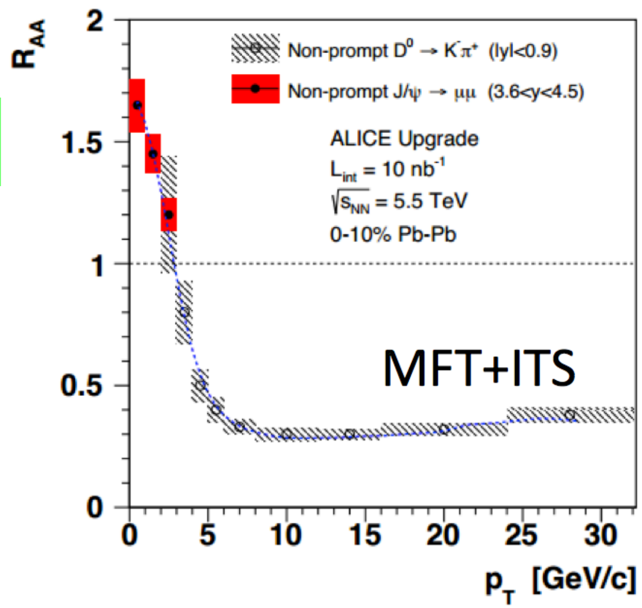
From run 1 to run 3-4: beauty

What can we see? JHEP 07 (2015) 051





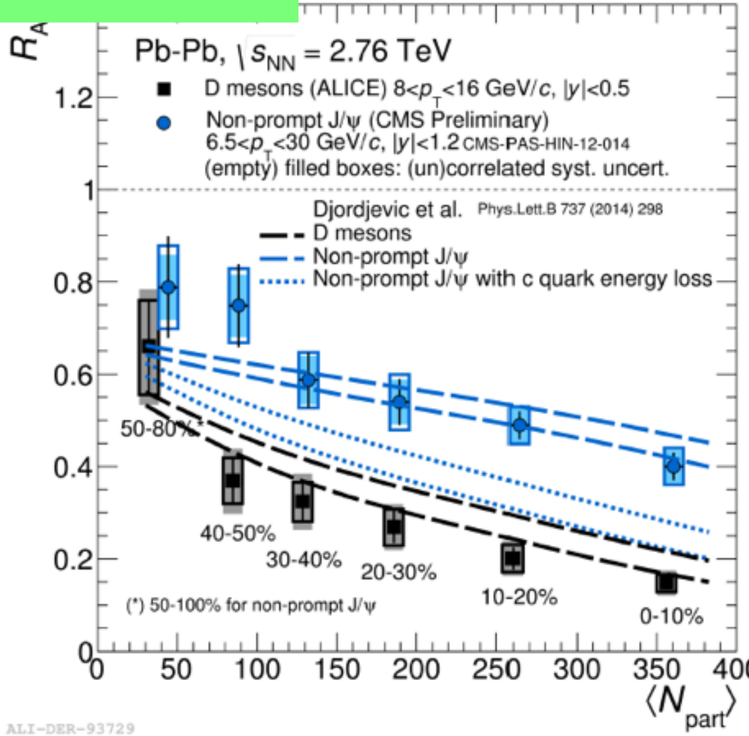
Upgraded ITS |y|<0.9

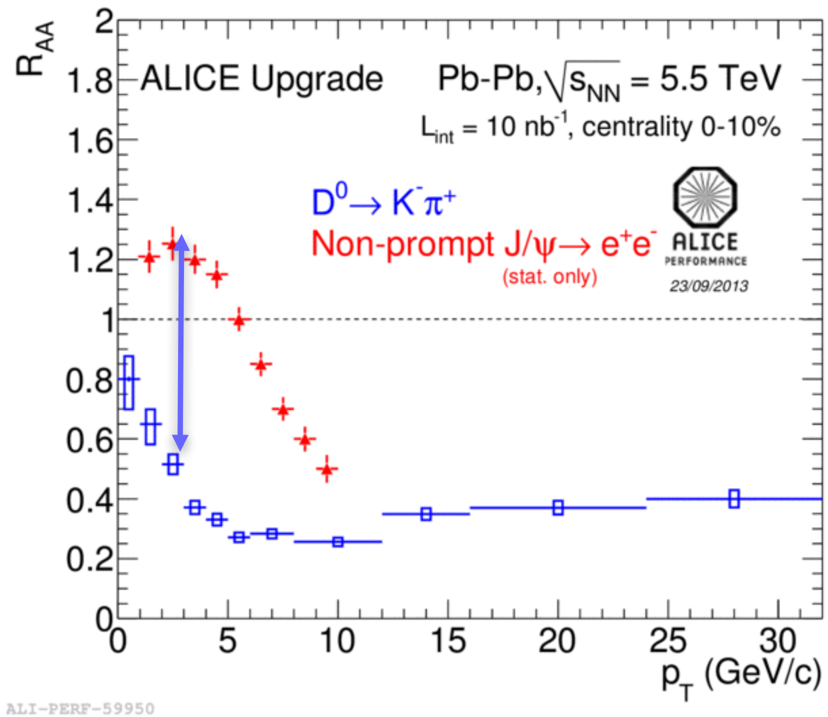


- New channel opened (B) + much larger precision on R_{AA} (both via displaced J/ψ and non prompt D^0)
- The study of non prompt J/ψ in $\mu^+\mu^-$ channel key tool to measure B down to zero p_T

Beauty and charm energy loss

Reminder:





Move from "first clear indication of $\Delta E_c > \Delta E_b$"
to test quantitative description as a function of p_T

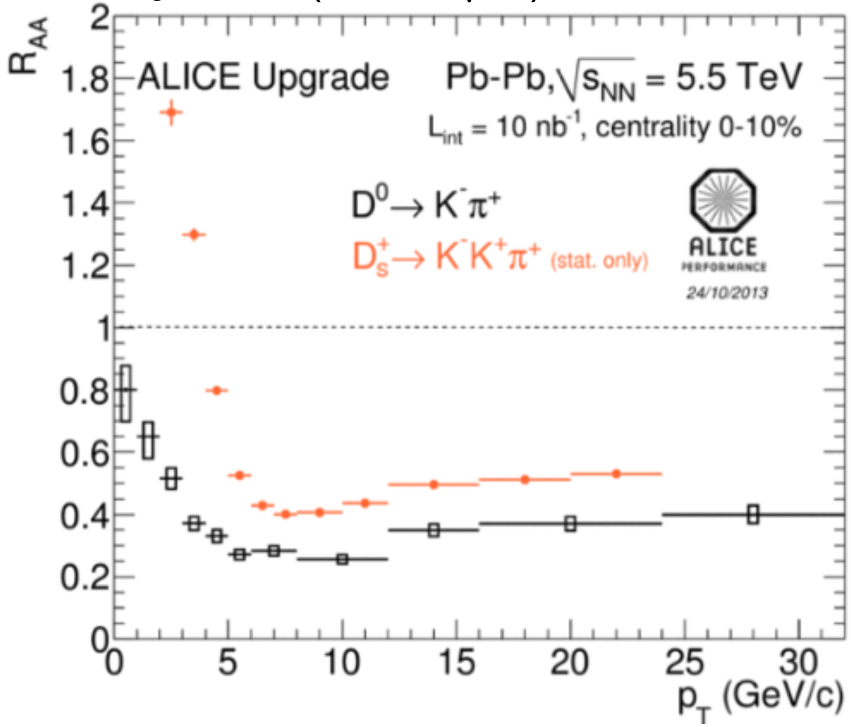
Physics Letters B 519 (2001) 199–206

Heavy-quark colorimetry of QCD matter

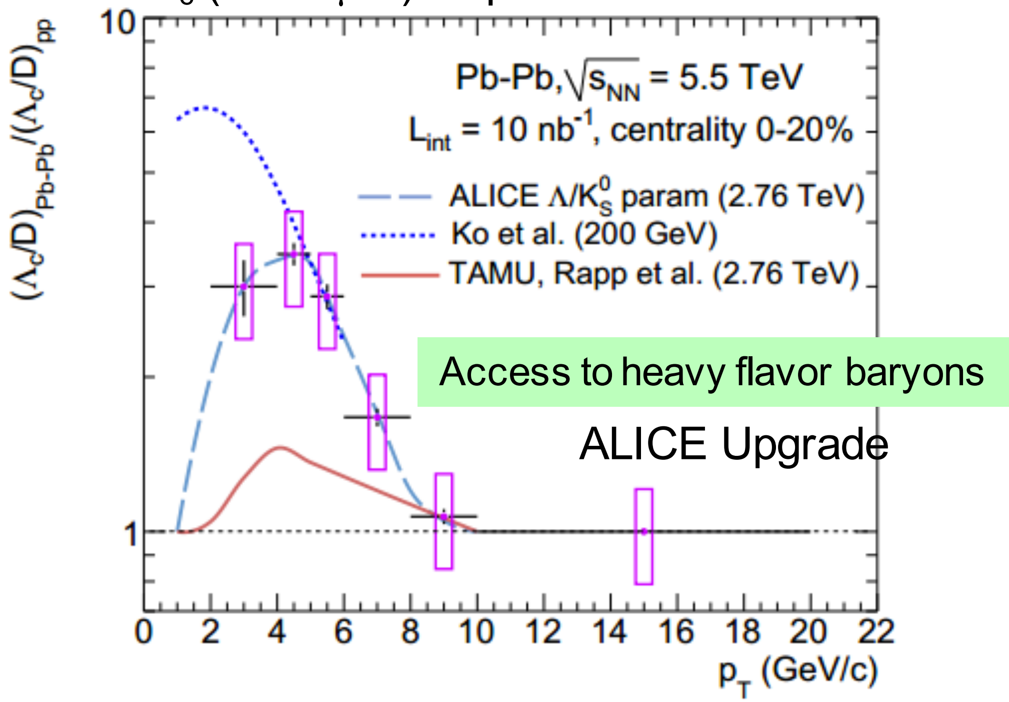
Yu.L. Dokshitzer [a], D.E. Kharzeev [a,b]

Hadrochemistry: heavy flavor

$D_s \rightarrow KK\pi$ ($c\tau$ 150 μm)



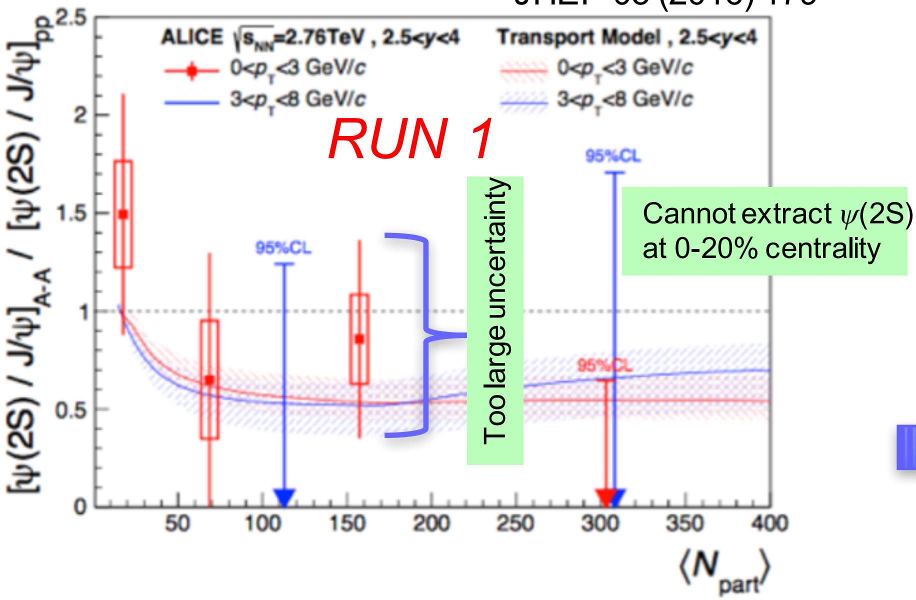
Λ_c ($c\tau$ 60 μm) → $pK\pi$

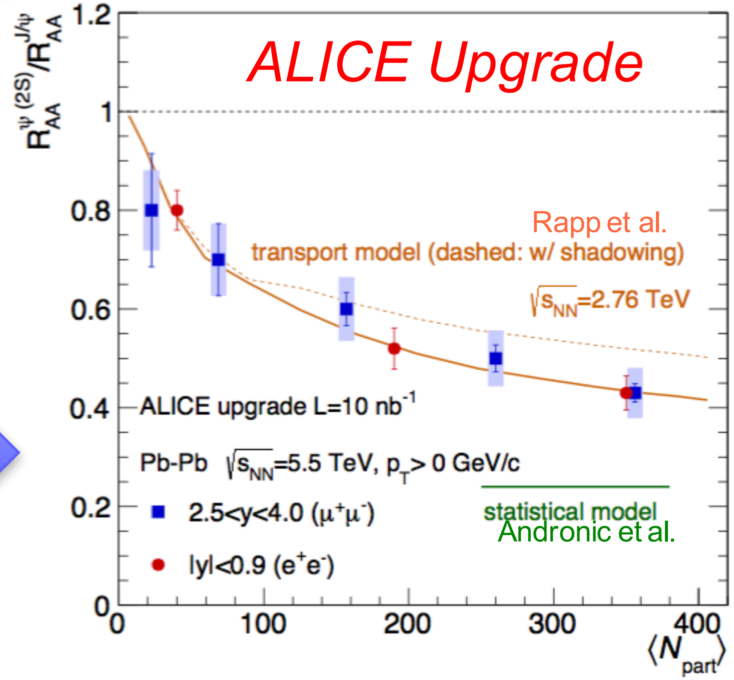


- In QGP higher s abundance → D_s enhanced if charm hadrons form predominantly in in-medium hadronization (Rafelski et al., Rapp et al.)
- Λ_c for the first time accessible in Pb-Pb.
- Discrimination among different models of hadronization (thermal vs coalescence). In-medium recombination → Λ_c/D^0 increases at intermediate momenta (Ko et al., Rapp et al., Greco et al.)

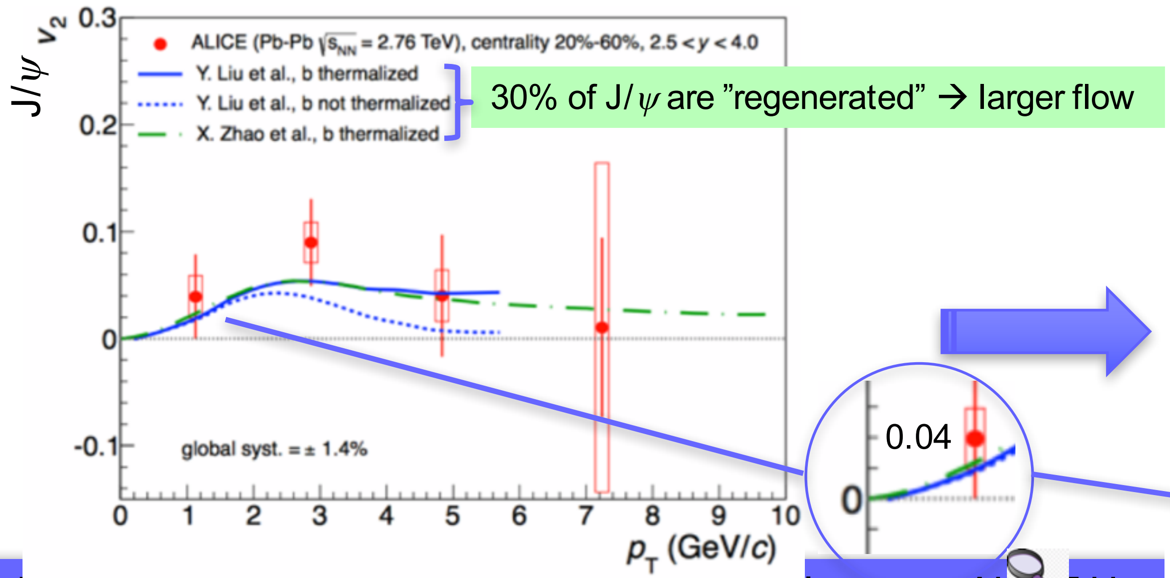
Charmonium: deconfined charm quarks in the QGP phase?

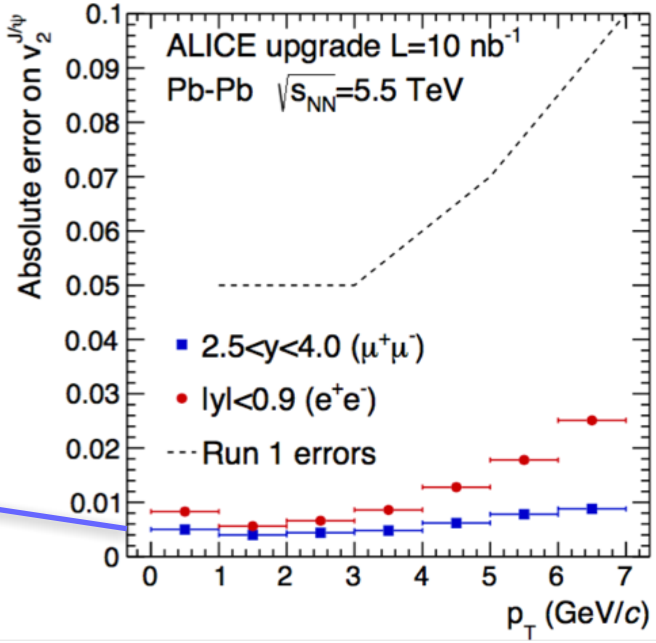
JHEP 05 (2016) 179





PRL 111, 162301 (2013)



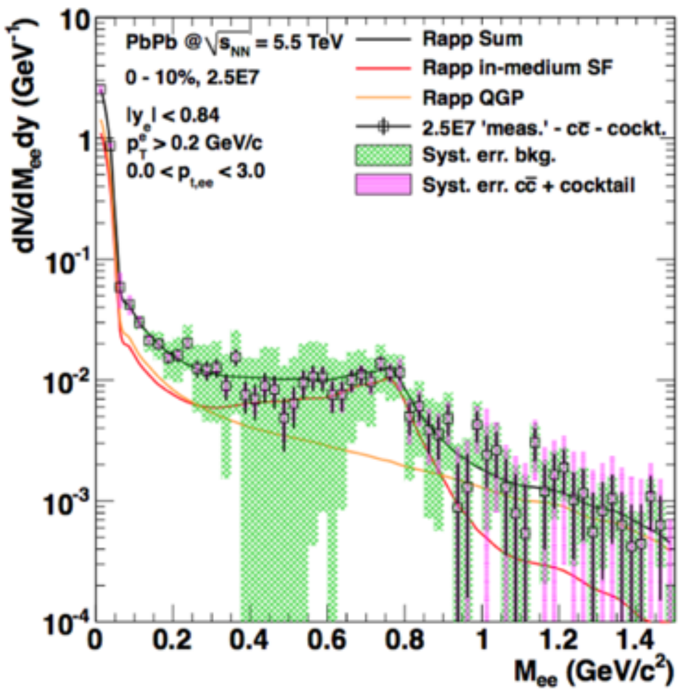


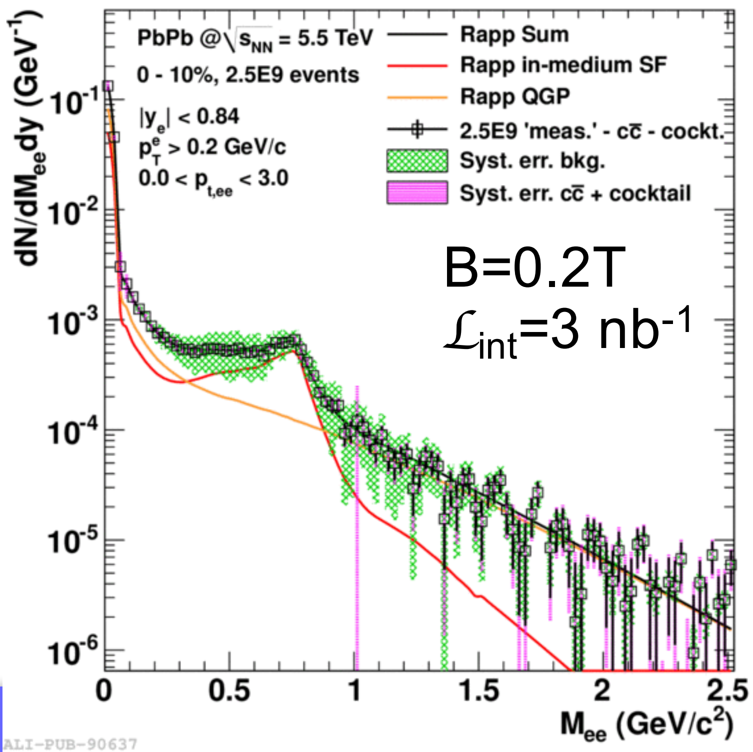
Low mass di-leptons

- Dileptons carry temperature information from the initial phase
- Temperature can be extracted via $\frac{dN}{dM_{ee}} \propto \exp\left(-{}^{M_{ee}}/_{T_{fit}}\right)$
- Statistical error on the slope < 10% for M_{ee}

- ITS and MUON+MFT enable $\mathbf{M_{ee}}$ and $M_{\mu\mu}$ studies
- ITS reduced thickness reduces conversion probability
- High rate + low B → increase electron acceptance / use PID
- ITS/MFT spatial resolution → reject charm decays

Ref. Model: Rapp et al.,NPA 806 333 (2008)





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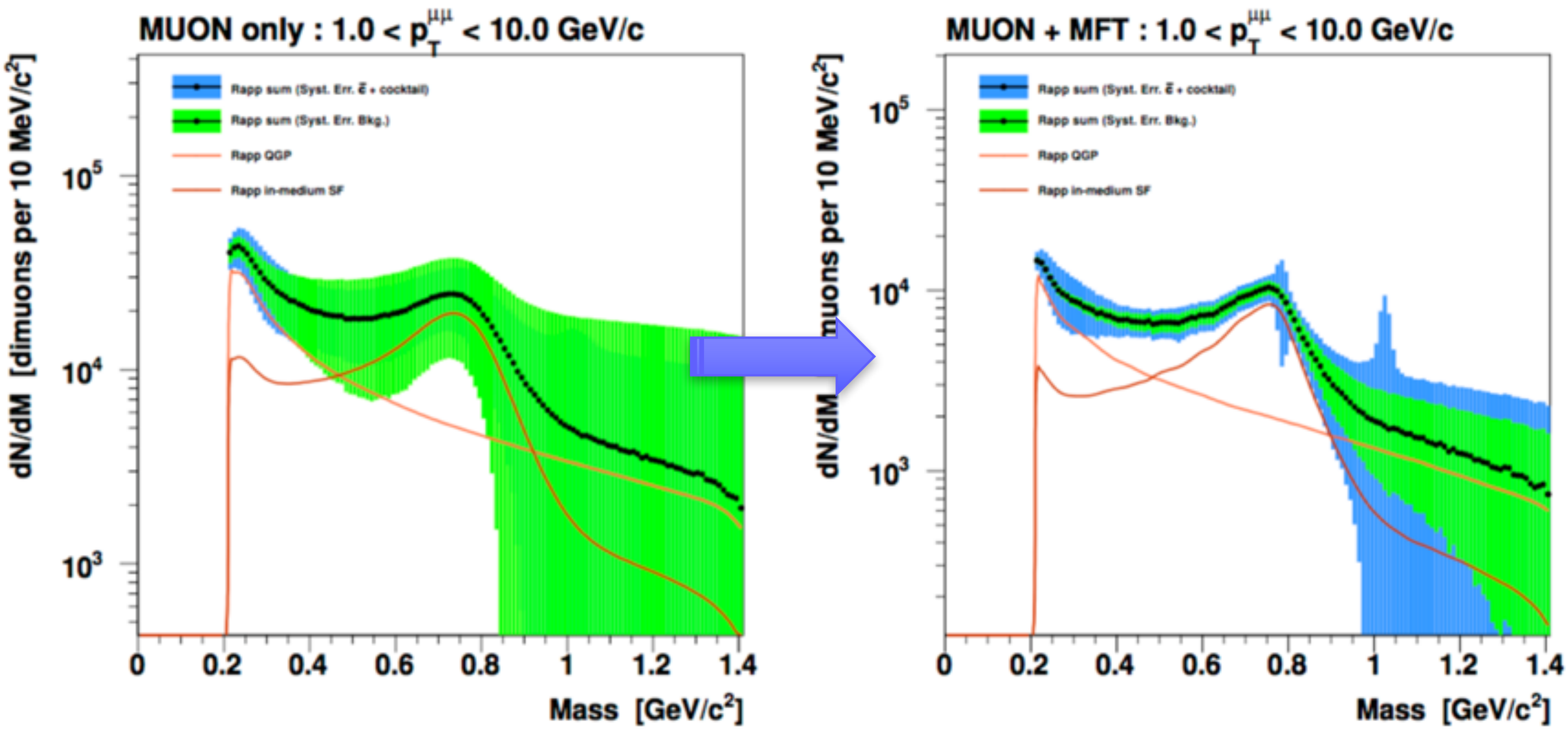
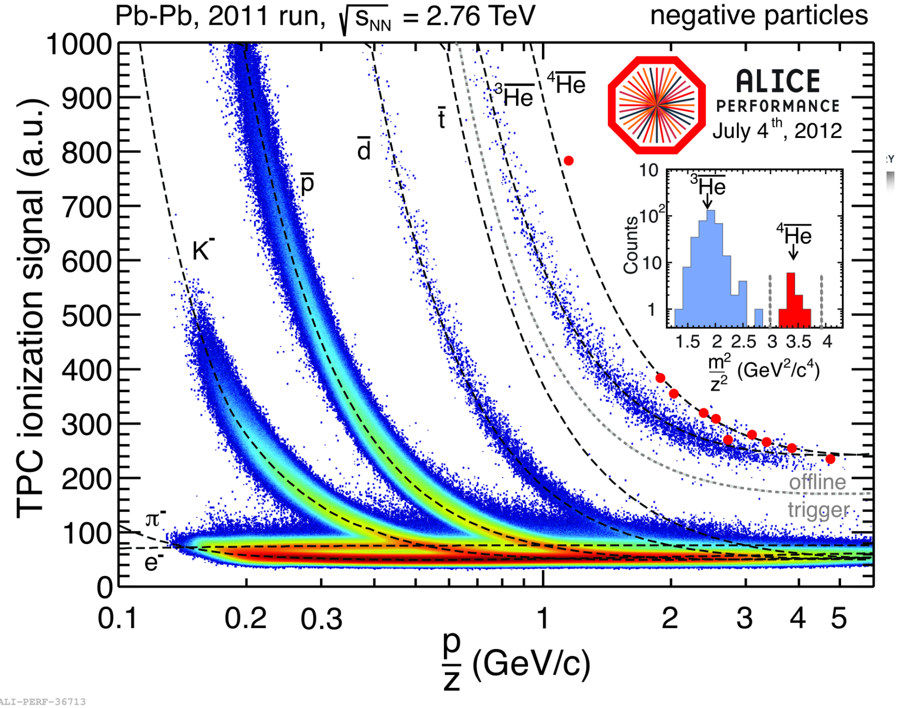


Hyper-Nuclei



- (anti-)(hyper-)nuclei are rarely produced: each additional nucleon leads to reduction of the yield by a factor of about 300!

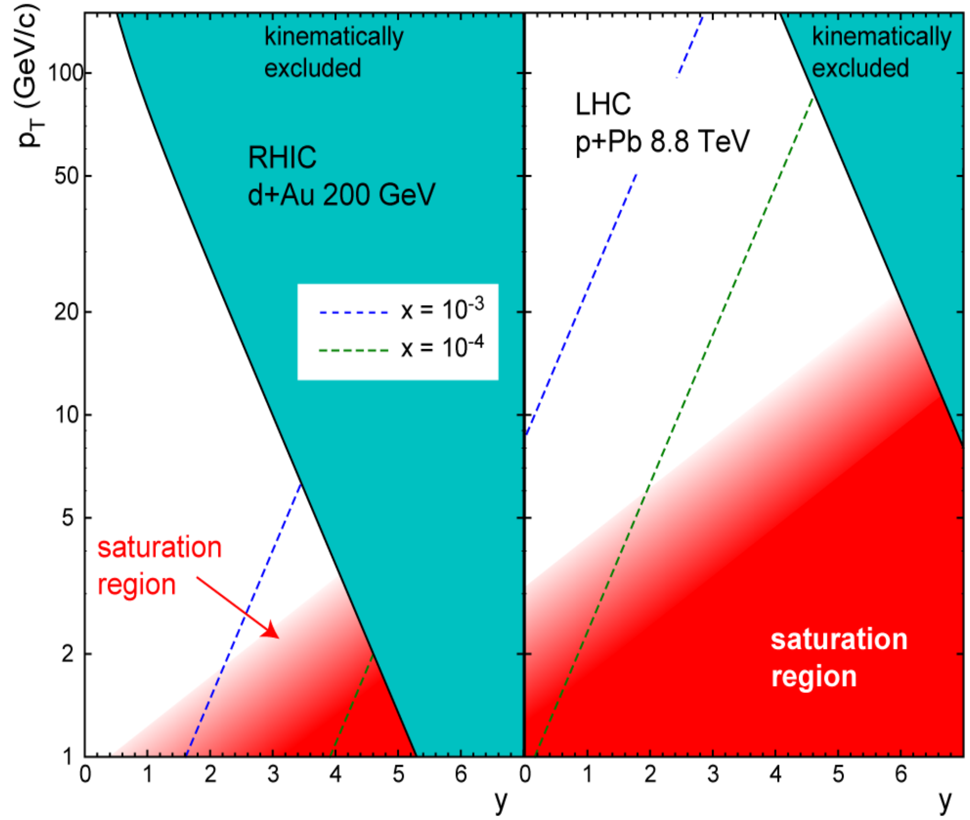
- 10 anti-alpha candidates were detected in LHC Run 1.

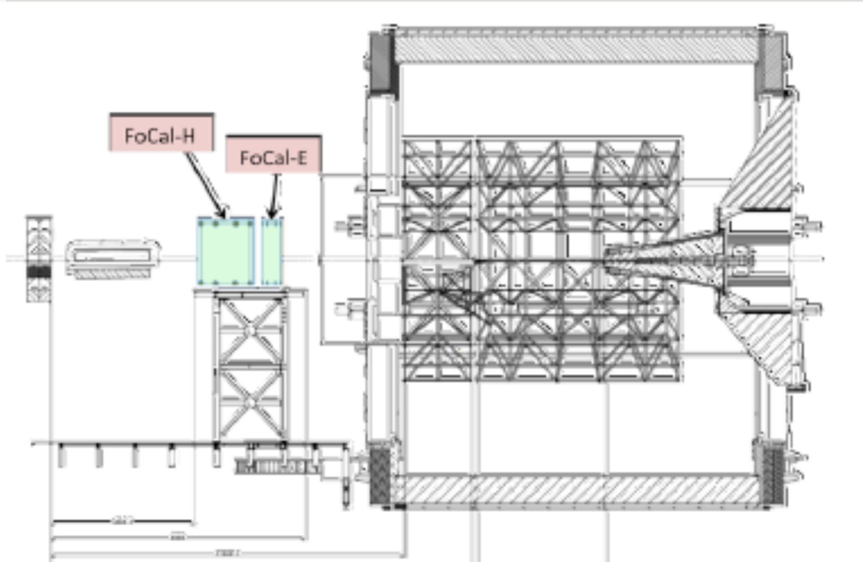
- All the physics which is done in Run1 and Run2 for A = 2 and A = 3 (hyper-)nuclei will be done for A = 4 in Run3.

Particle	Yield
Anti-alpha $^4\overline{\mathrm{He}}$	3.0×10^4
Anti-hypertriton $^3_{\bar{\Lambda}}\overline{\mathrm{H}}$ $(\bar{\Lambda}\bar{p}\bar{n})$	3.0×10^5
$^4_{\bar{\Lambda}}\overline{\mathrm{H}}$ $(\bar{\Lambda}\bar{p}\bar{n}\bar{n})$	8.0×10^2
$^5_{\bar{\Lambda}}\overline{\mathrm{H}}$ $(\bar{\Lambda}\bar{p}\bar{n}\bar{n}\bar{n})$	3.0
$^4_{\bar{\Lambda}\bar{\Lambda}}\overline{\mathrm{H}}$ $(\bar{\Lambda}\bar{\Lambda}\bar{p}\bar{n})$	3.4×10^1
$^5_{\bar{\Lambda}\bar{\Lambda}}\overline{\mathrm{H}}$ $(\bar{\Lambda}\bar{\Lambda}\bar{p}\bar{n}\bar{n})$	0.2

Particle yields (including reconstruction efficiency) for 10^{10} central Pb-Pb collisions from ALICE upgrade LOI.

LS3: FoCal?





Flagship measurements of direct γ R_{pA} (and R_{AA}) at forward rapidities η ~ 3-5

Low *x* (large y): large gluon density

Gluon density also increases with A, and with beam energy

New regime at LHC:
Strong fields, particularly at large rapidities

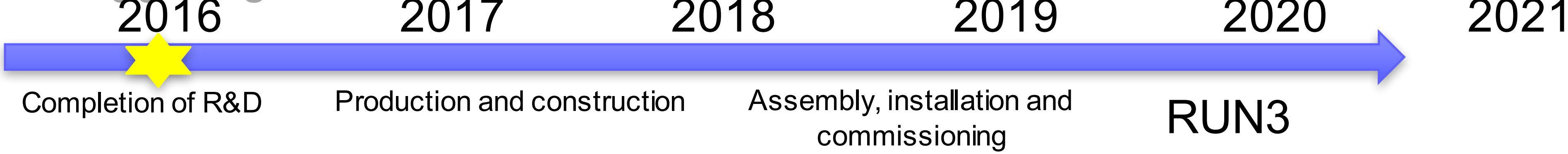
Forward Calorimeter proposal (γ, π^0 measurements) under internal discussion

Summary

ALICE has a comprehensive upgrade programme starting to move into its implementation phase

LS2 (2019-2020) is a major ALICE upgrade:

- Improved tracking precision (ITS+MFT) at low p_T mid/fwd y
- Readout at 50 kHz in Pb-Pb via TPC (+ readout upgrade)
- New paradigm for Online/Offline operations
- New triggering detector



- It will extend ALICE life cycle well beyond 2020. First Pb-Pb physics data in 5 years from now.
- The upgrade strategy is oriented **to explore low and intermediate p_T observables** to study QGP properties in particular using **heavy flavor probes** and **invariant mass di-leptons**
- The ALICE upgrade physics programme is **unique and complementary** (so… unique strengths!) with respect to other observables studied by other LHC detectors.