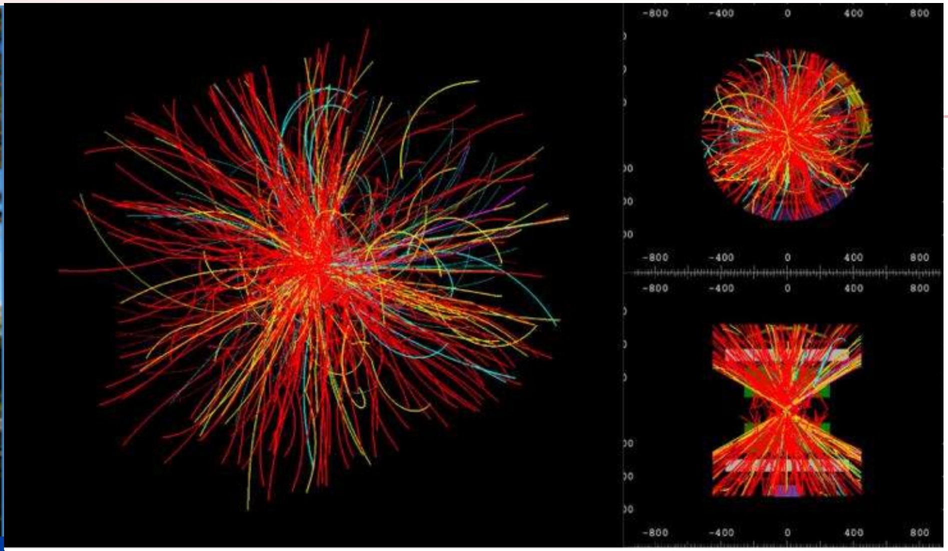
ALICE upgrade plans and potential



P. Antonioli
INFN – Bologna (Italy)
On behalf of the ALICE Collaboration

What is an upgrade?

1903

1951

2016

The Wonderland didn't change. It is what we want to explore since the beginning. But with 2016 movie upgrade we can see it better probably....

What in this talk?

Observables we would like to see and current limitations

Upgrade strategy: where/how to improve the detector?

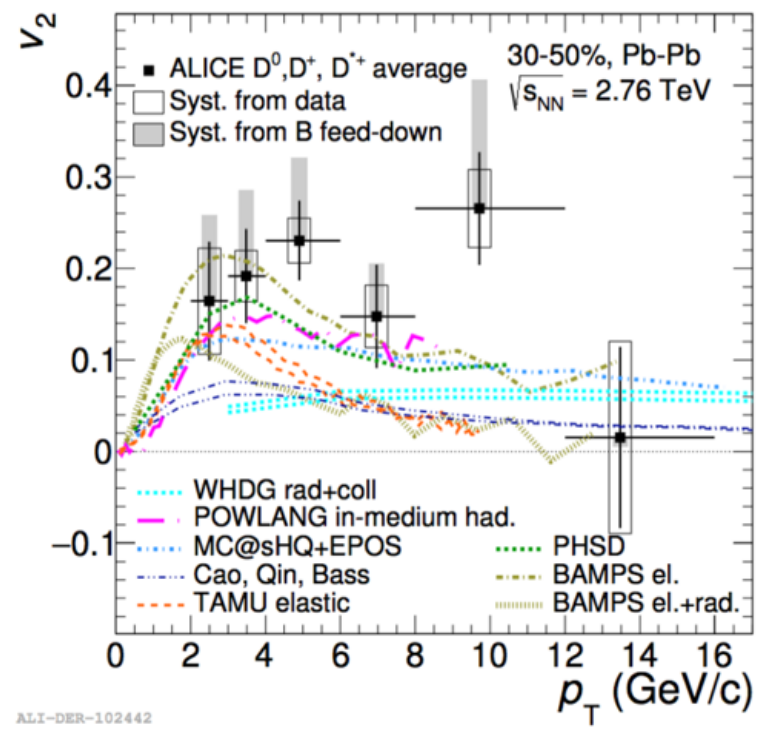
Expected performance and physics outputs

Where do we need more details to understand QGP?

- RHIC "picture" of the created hot matter confirmed @ LHC: "a strongly-coupled plasma with very short mean free path"
- QGP as a near perfect liquid: radial & elliptic flow
- QCD energy loss in the QGP
- Evidence of collectivity and strangeness enhancement in high multiplicity events in pp and p-Pb remains a puzzle

Open heavy flavor: good probes of the hot medium but…

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



- 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

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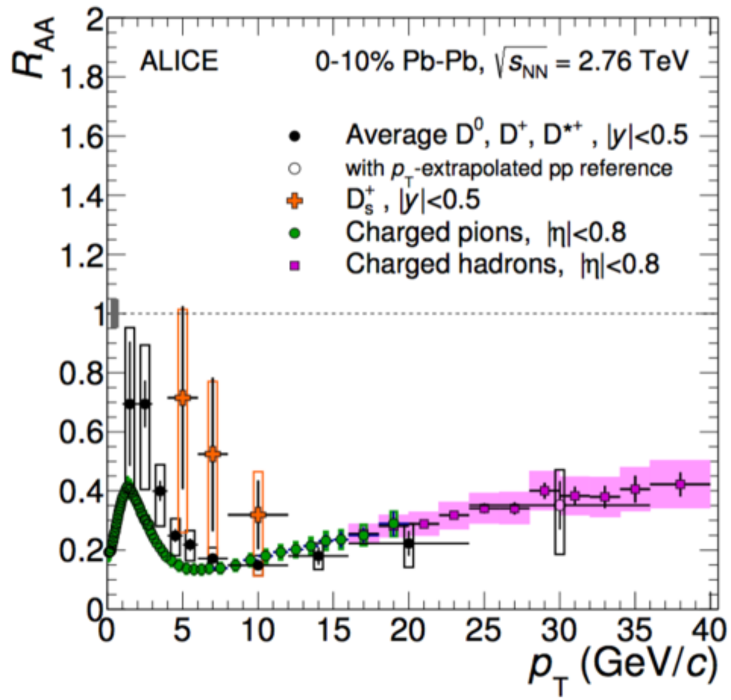
JHEP 03 (2016) 081 JHEP 03 (2016) 082



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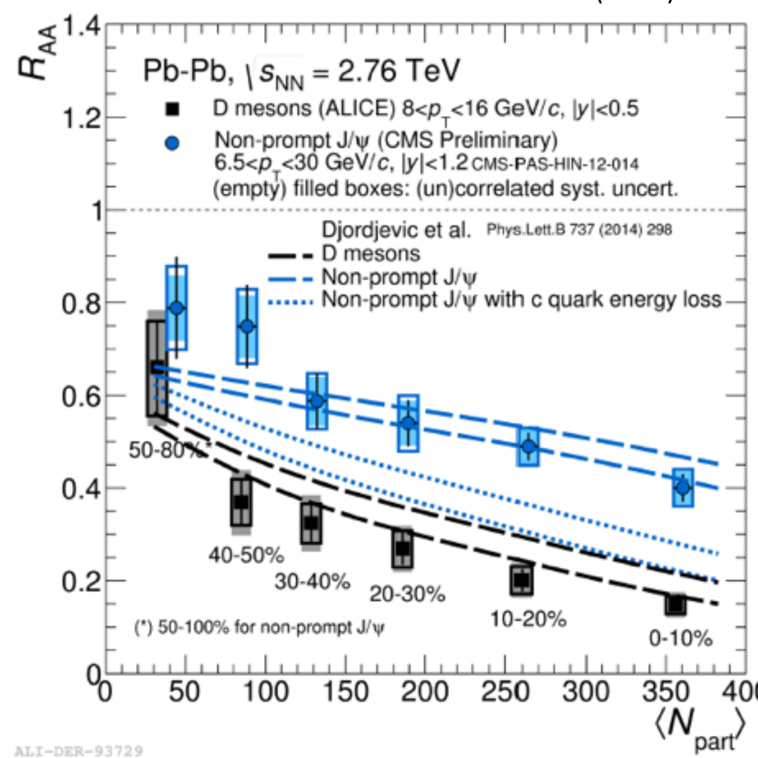
JHEP 11 (2015) 205



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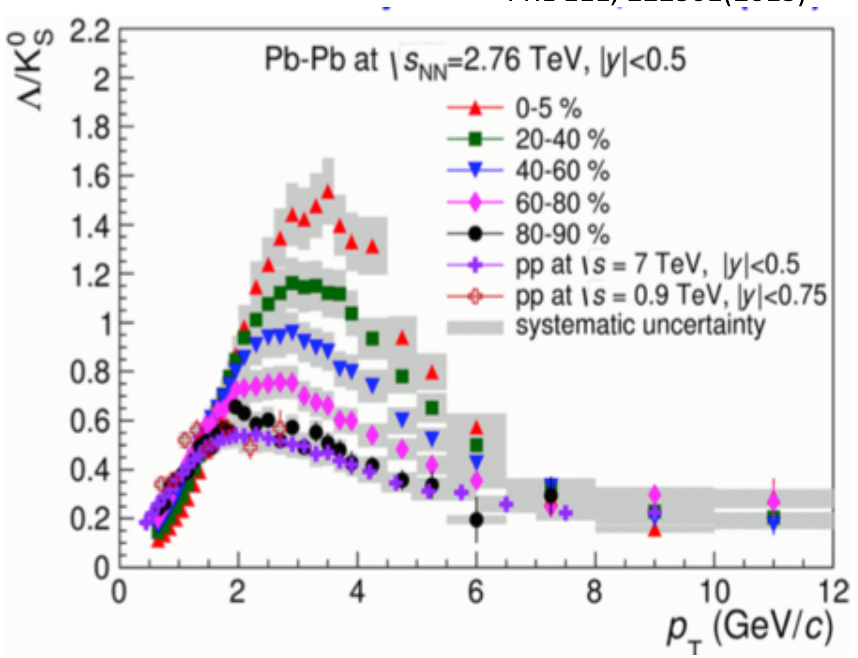
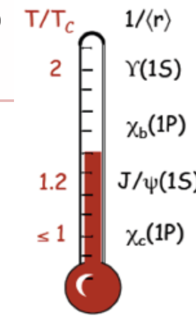
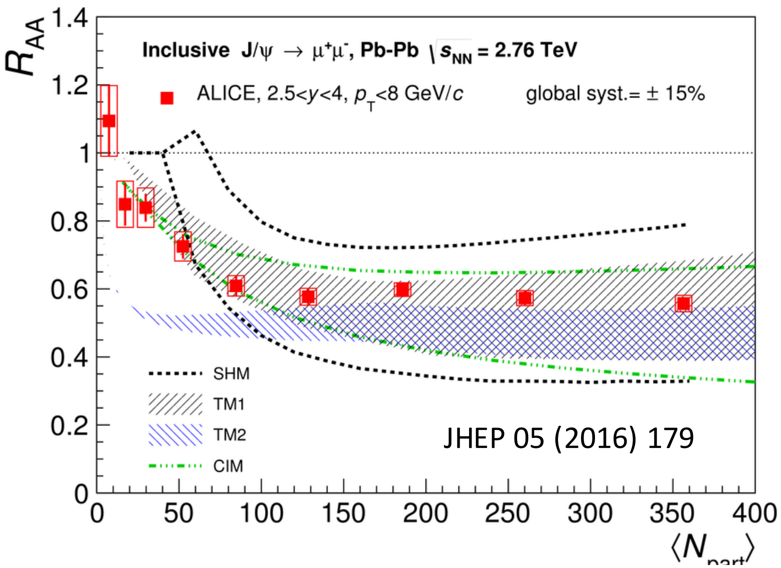
PRL 111, 222301(2013)



Quarkonia: hadronize or recombine?



- J/ψ suppression QGP "smoking gun": quarkonia states melting as a plasma thermometer
- Higher $\sqrt{s_{NN}}$ increases heavy quark production → possibility of recombination

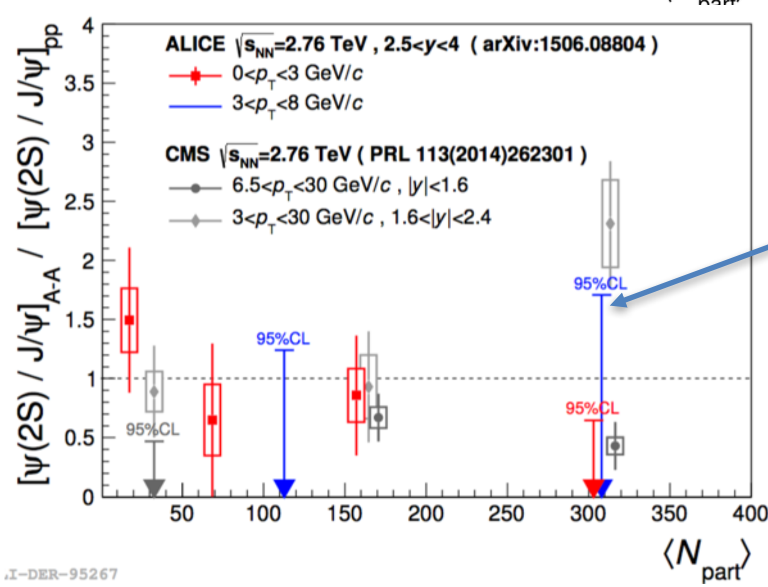


Reduced suppression with respect to RHIC

Theoretical models which include ~50% of the low-p_T J/ψ via recombination describe 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 mechanism at work
- Double ratio has less dependency on $\sigma_{c\bar{c}}$
- CMS/ALICE measurements showed some tensions

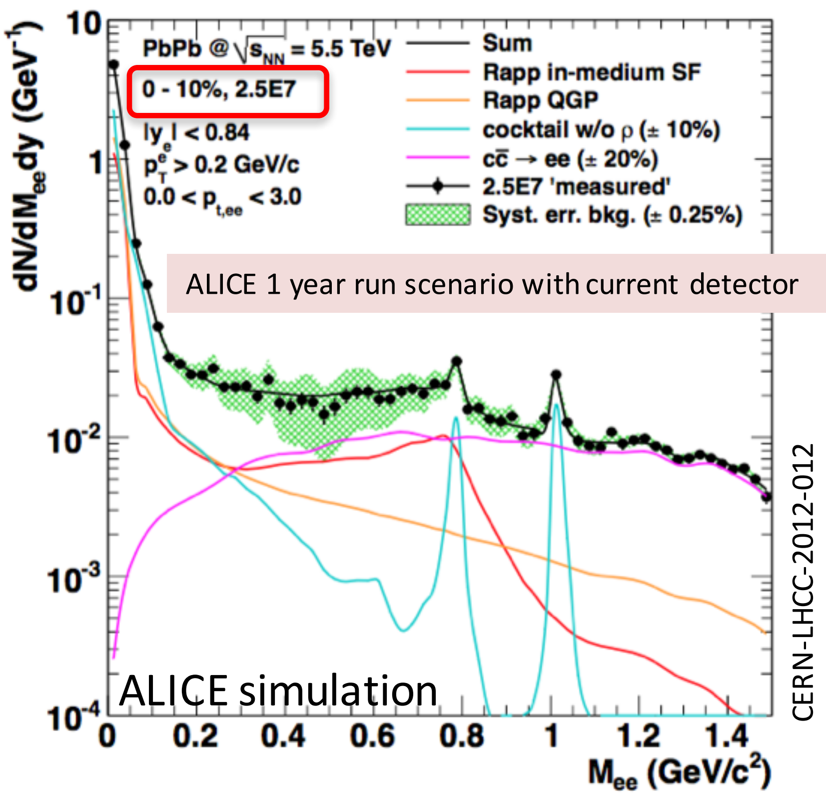
→ Precision must be improved

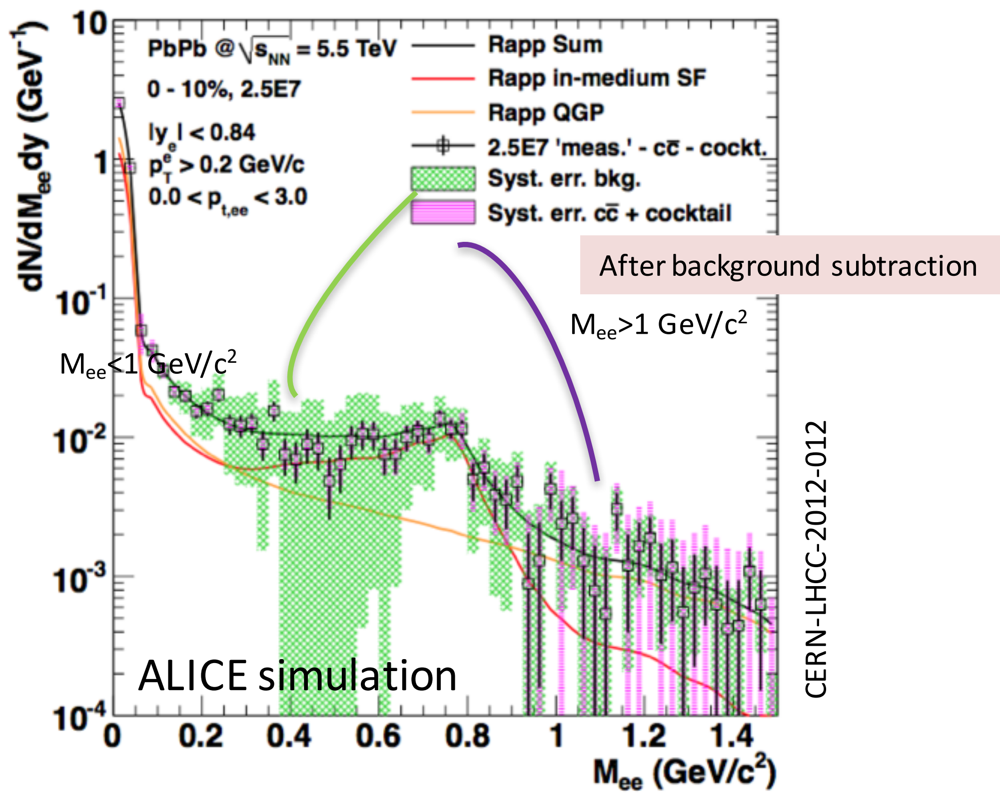
Low mass di-leptons

- EM radiation is produced at all stages of the collision →
  - leptons don't interact →
    - spectrum retains information of the entire system evolution!
- Temperature dependence encoded in invariant mass spectrum
- Space-time evolution of the system

What can we see with the current detector?

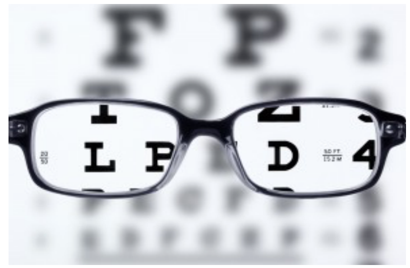
M_{ee} as measurement but…
- insufficient statistics
- Systematics (comb.subtr. and c subtr.) dominate
- DCA cuts with current resolution don't help

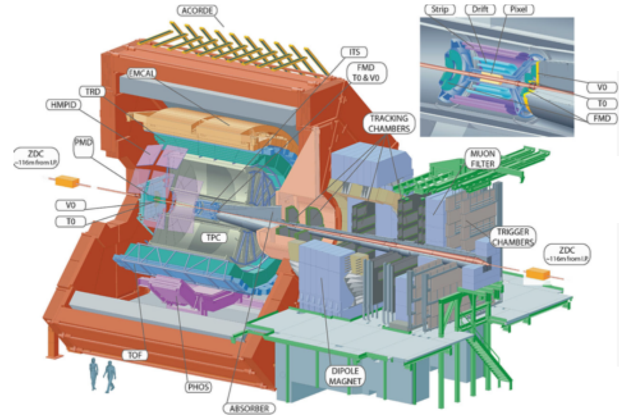




Design a strategy to better see…

Our starting glasses are ALICE sub-detectors…
how can we improve them?





- 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 low p_T reach & PID / DCA cuts → again inner tracker
- Precision study of light nuclei and hyper-nuclei

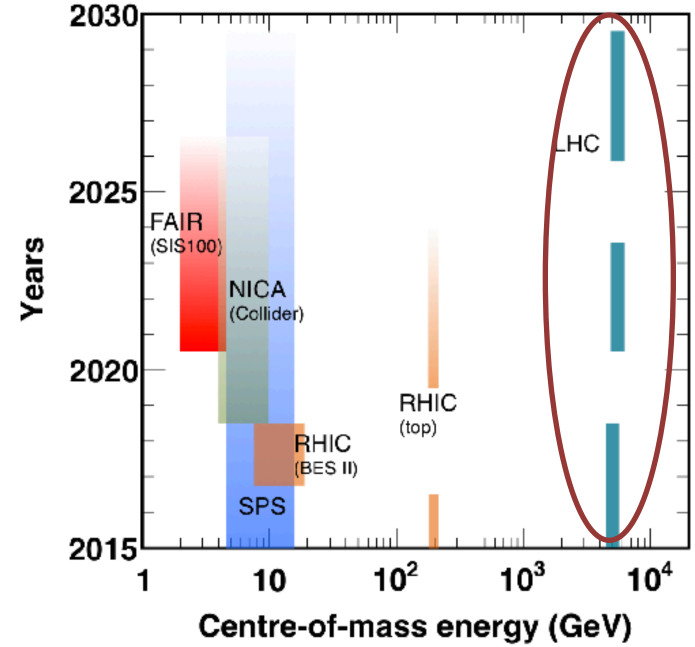
All this cannot be selected at trigger level (very large combinatorial background) → read out everything!

Move from 1 kHz to 50 kHz in PbPb!

When?

$\sqrt{s_{NN}}$~ 5TeV $\sqrt{s_{NN}}$ =5.5TeV

Heavy ions facilities up to 2030



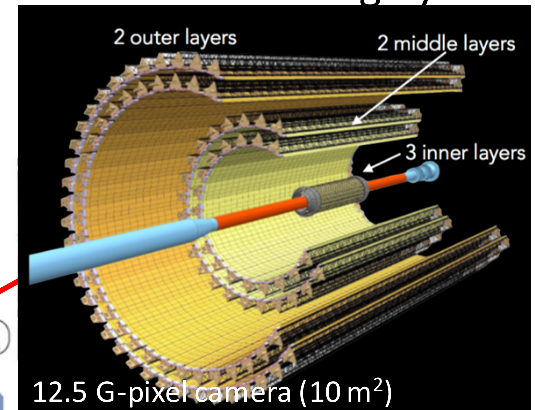
arxiv:1602.04120

- L_{int} 10^{27} $cm^{-2}s^{-1}$ → (goal) 6 10^{27} $cm^{-2}s^{-1}$ → **50 KHz int. rate** (LHC collimators upgrade)
- Besides Pb-Pb, p-Pb and pp at $\sqrt{s}$=5.5 TeV
- ALICE request: 10 nb^{-1} at B=0.5 T (+ 3 nb^{-1} at B=0.2 T)

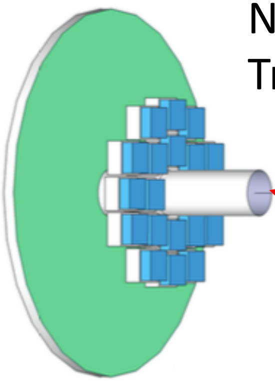
LHC operates at higher energies and at vanishing baryon chemical potential
→ best suited for measurement of QGP properties
→ abundance of calculable QCD processes (heavy quarks)

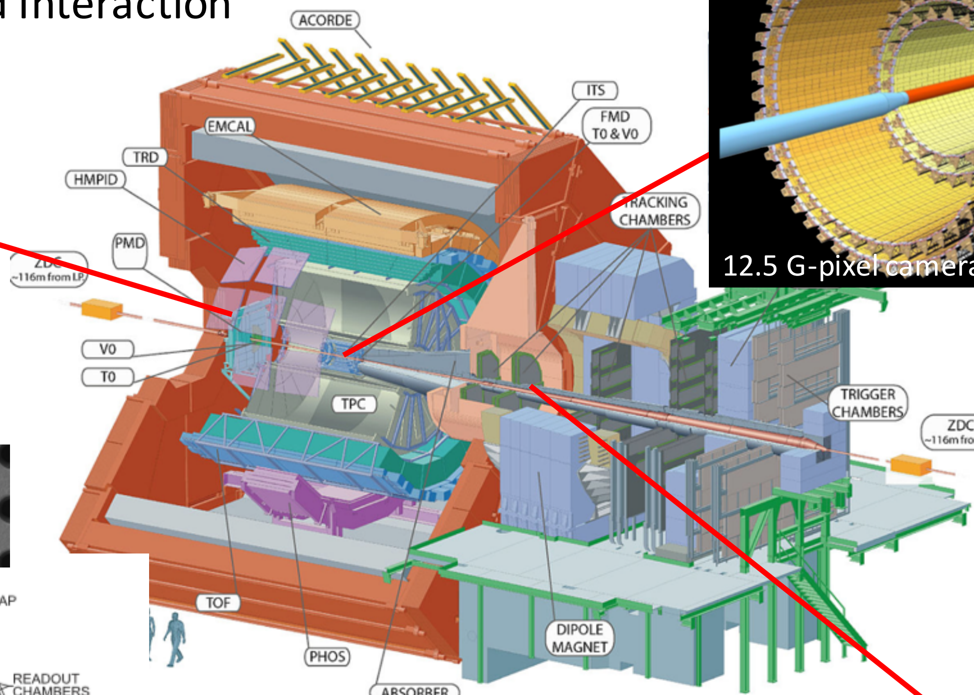
ALICE upgrade: new glasses

New Inner Tracking System (ITS)



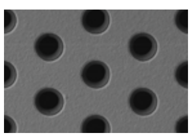
New Forward Interaction Trigger (FIT)

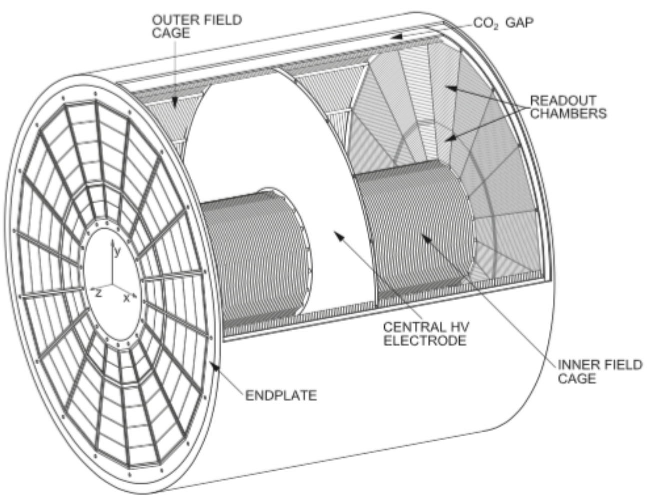




Both based on Monolithic Active Pixel Sensors (MAPS)

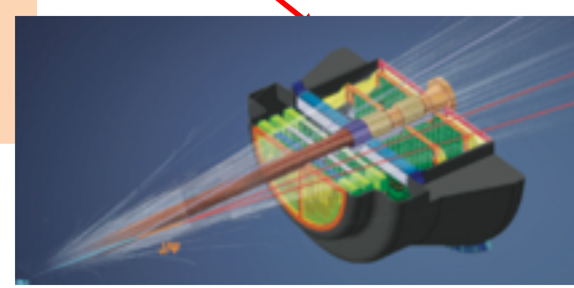
TPC with GEM based readout





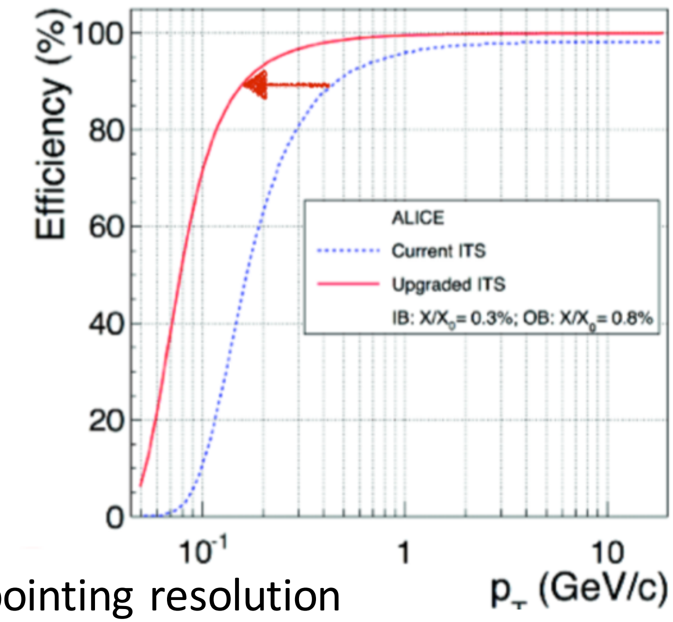
New Muon Forward Tracker (MFT)

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

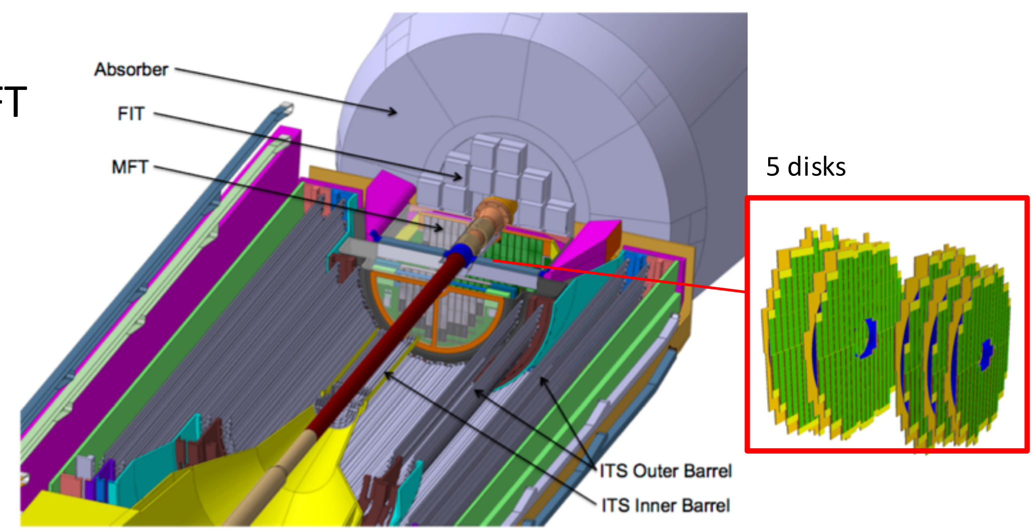


Upgrade the inner tracker

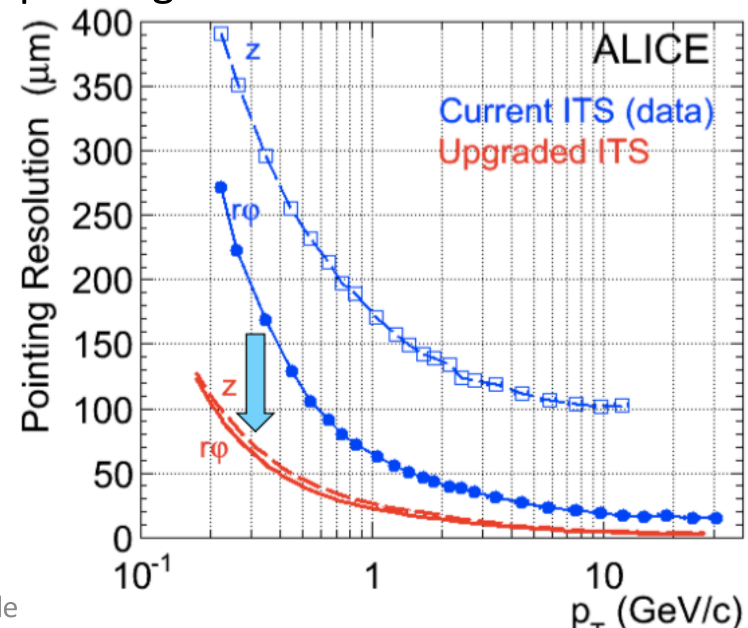
	ITS	ITS UPGRADE	MFT
# layers	6	7	5
Rapidity coverage	$\|\eta\|<0.9$	$\|\eta\|<1.5$	$-3.6<\eta<-2.4$
r_{min}	3.9 cm	2.3 cm	/
Material budget per layer	1.1% X_0	0.3-0.8% X_0	0.6%X_0
Spatial resolution	12 x 100 μm^2 35 x 20 μm^2 20 x 830 μm^2	~5 x 5 μm^2	~5 x 5 μm^2
Max Pb-Pb readout rate	1 kHz	100 kHz	100 kHz



MFT



ITS pointing resolution



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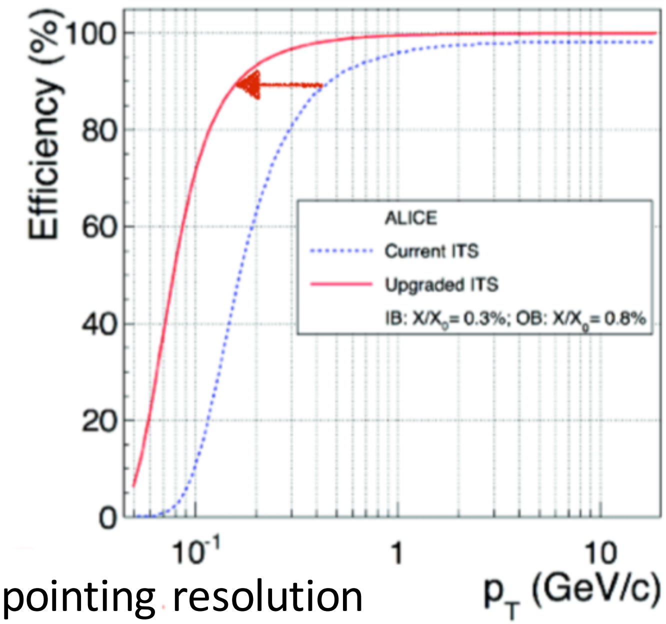
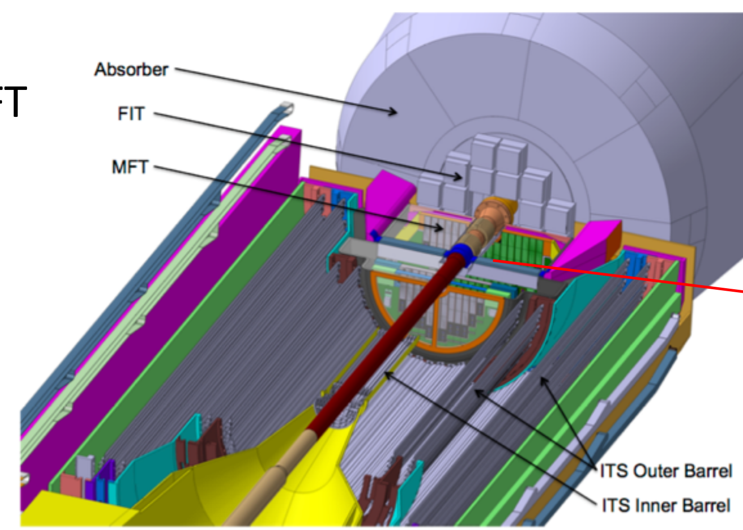
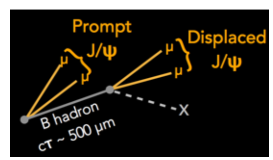
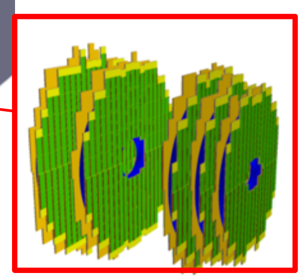


MFT

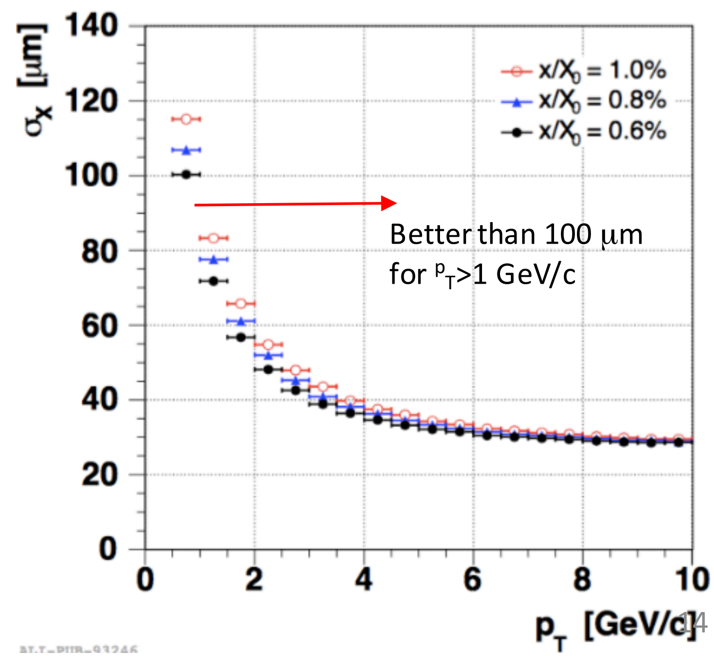




5 disks



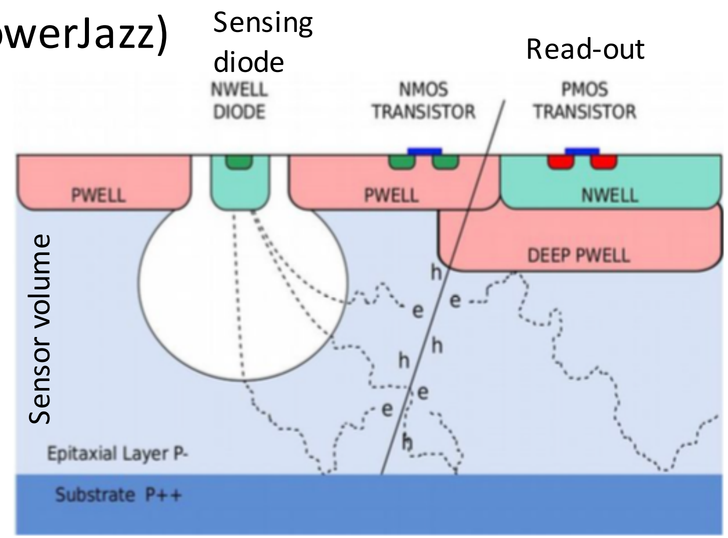
MFT pointing resolution



Monolithic Active Pixel Sensors

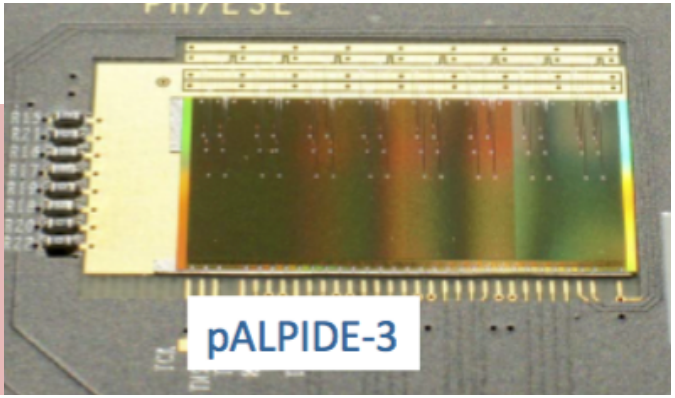
MAPS attractive technology for ALICE due to:
- Reduction of material budget (sensor&readout integrated) 350 μm→50-100 μm/layer
- Limited radiation tolerance and moderate readout time: still fitting for ALICE (700 krad foreseen for innermost layer)!

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

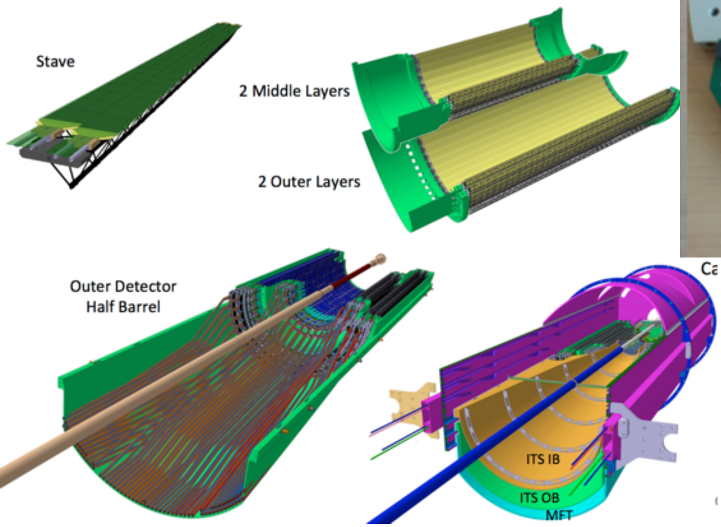


Pixel pitch ~ 30 μm x 30 μm
High resistivity (>1 kΩ) epitaxial layer
PMOS transistor for readout on top of deep p-well
- PMOS/NMOS in the same pixel cell
- deep p-well junction reflects signal electrons
- signal collected by the sensing diode only

Final version of MAPS chip (ALPIDE = ALICE Pixel Detector) due 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}

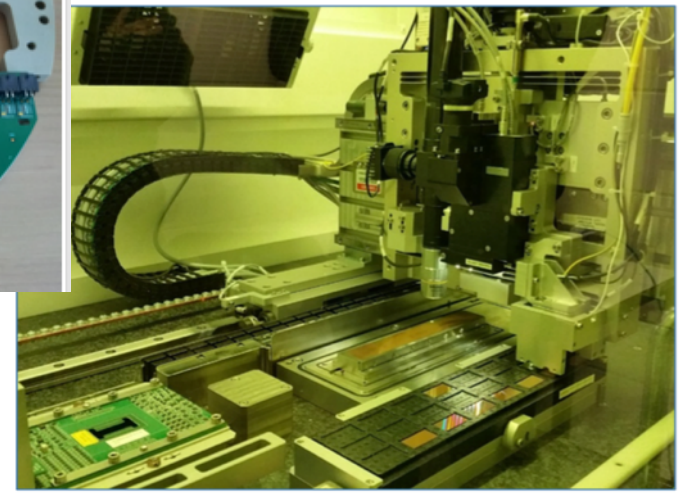


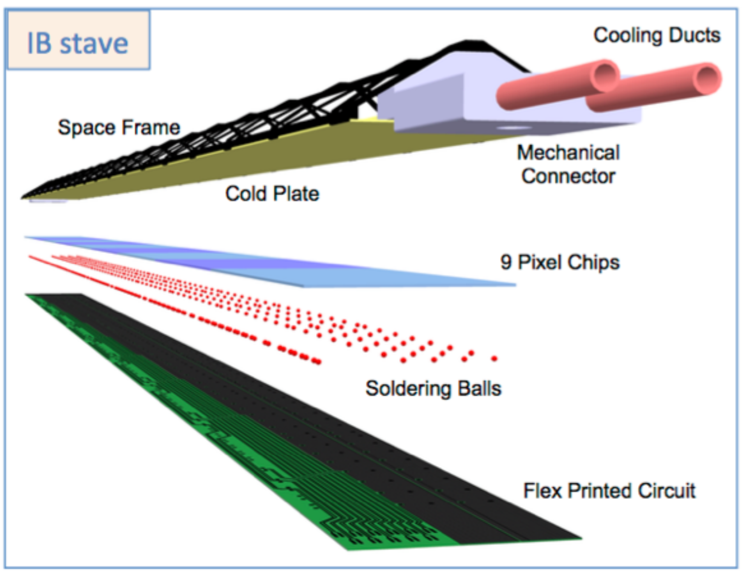
From plots & drawings to pictures



MFT disk # 1: PCB + support

Module assembly machines



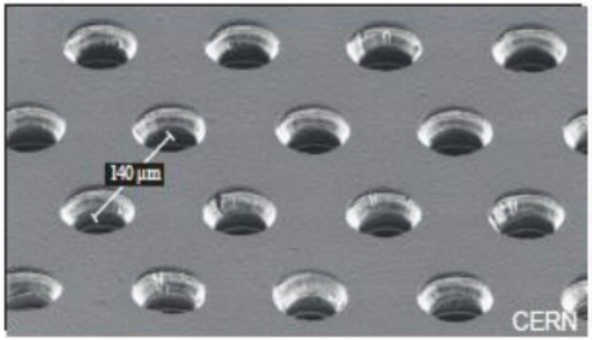


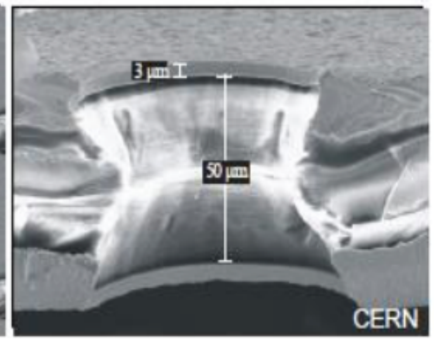
ITS IB staves

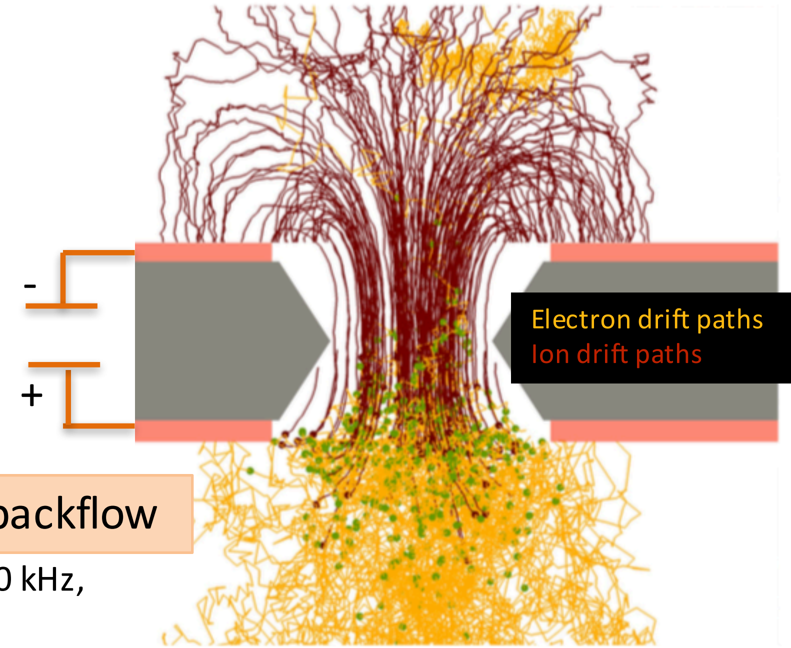
Production:
-n. 31 units produced

Collect large statistics with the TPC

Current MWPC readout limits event readout rate to ~ 3 kHz (ALICE TPC operated with active ion Gating Grid. Readout time (100 μs) + GG closure time (200 μs))



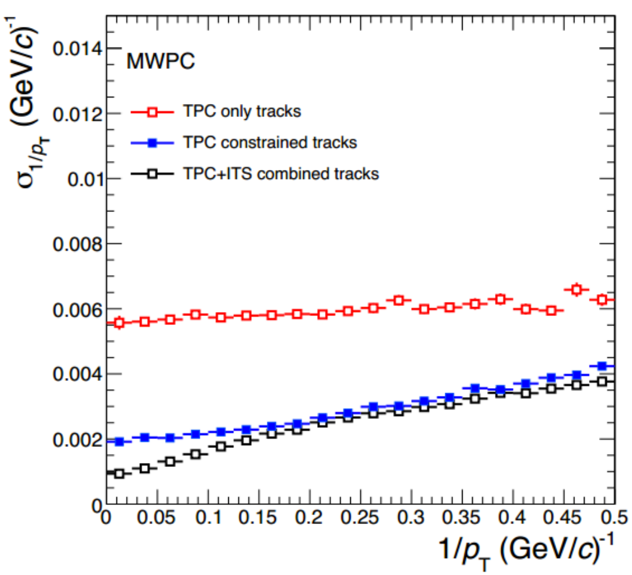


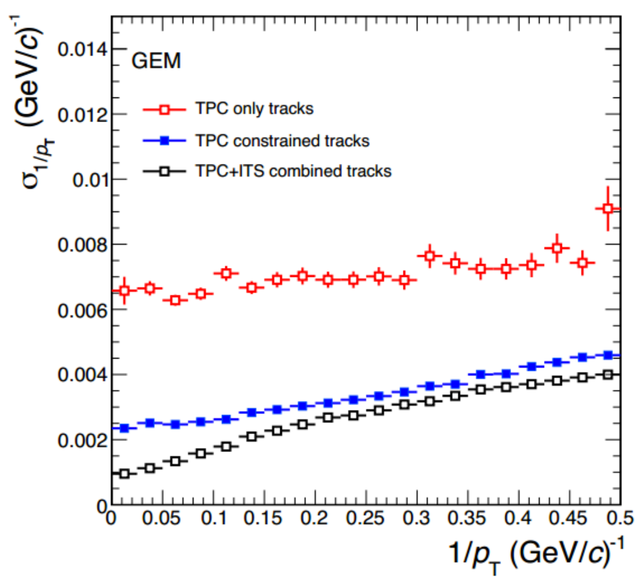


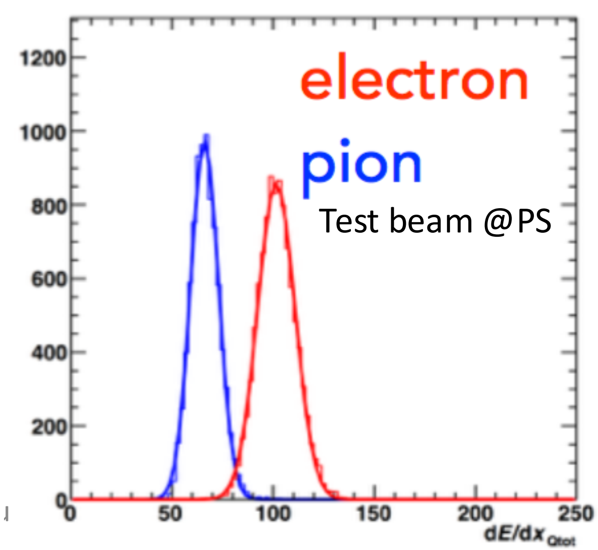
GEM (Gas Electron Multiplier) technology reduces ion backflow

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

TCP TDR: CERN-LHCC-2012-012



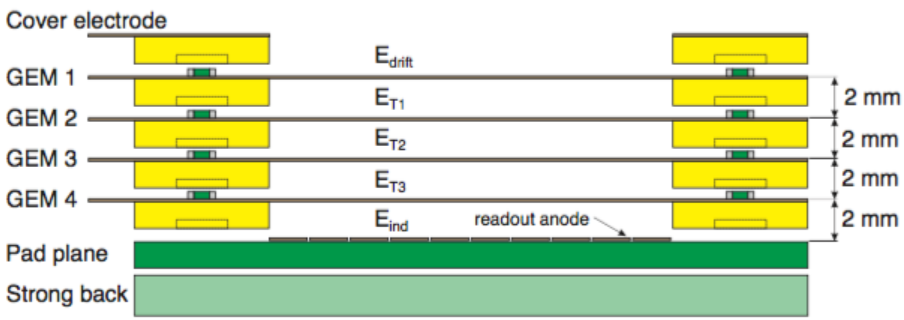


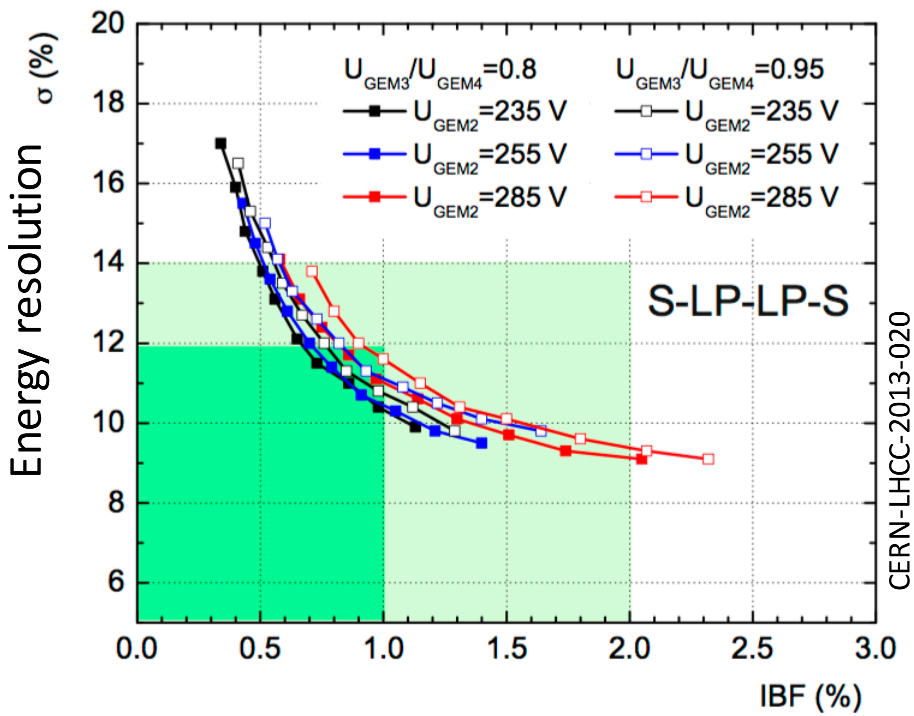


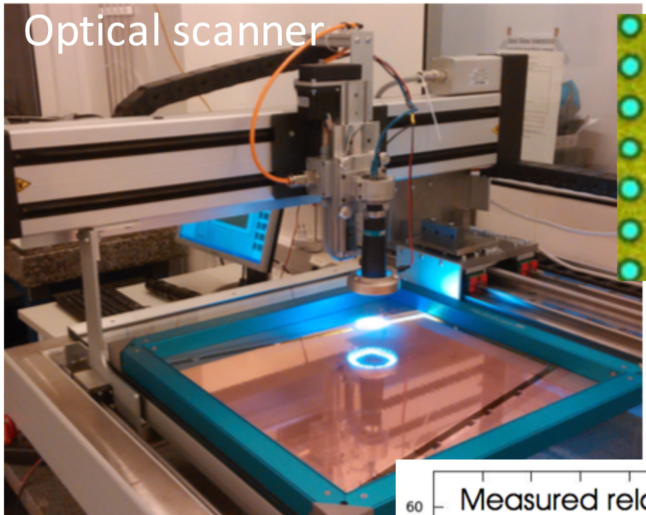
R&D work (and pictures…)

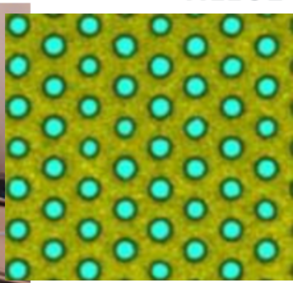
To effectively reduce IBF a GEM stack is needed

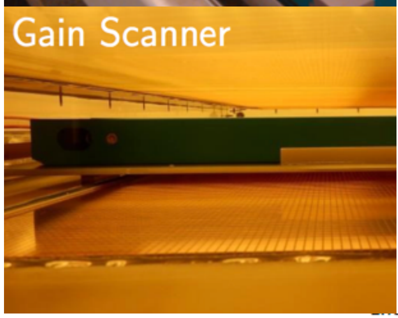
→ 4 GEM scheme with optimization of holes

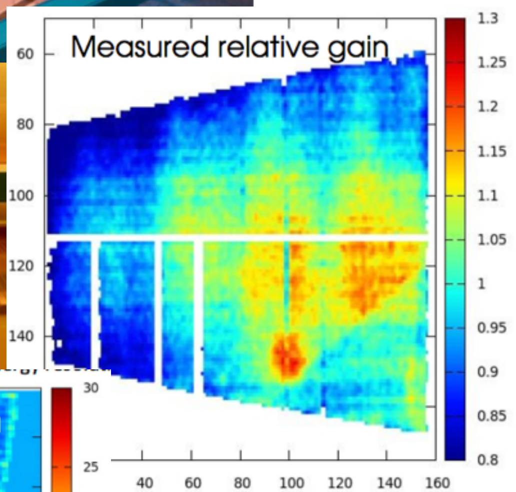


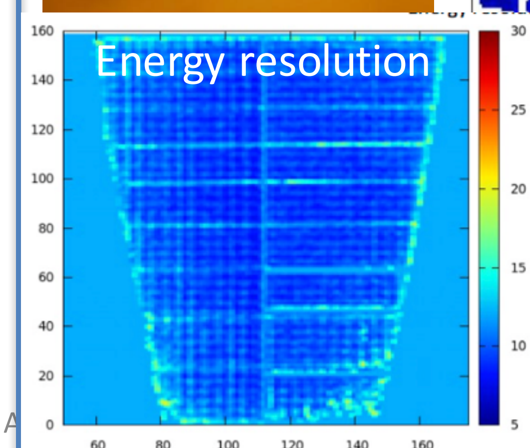












Pre-production to be launched after Summer 2016

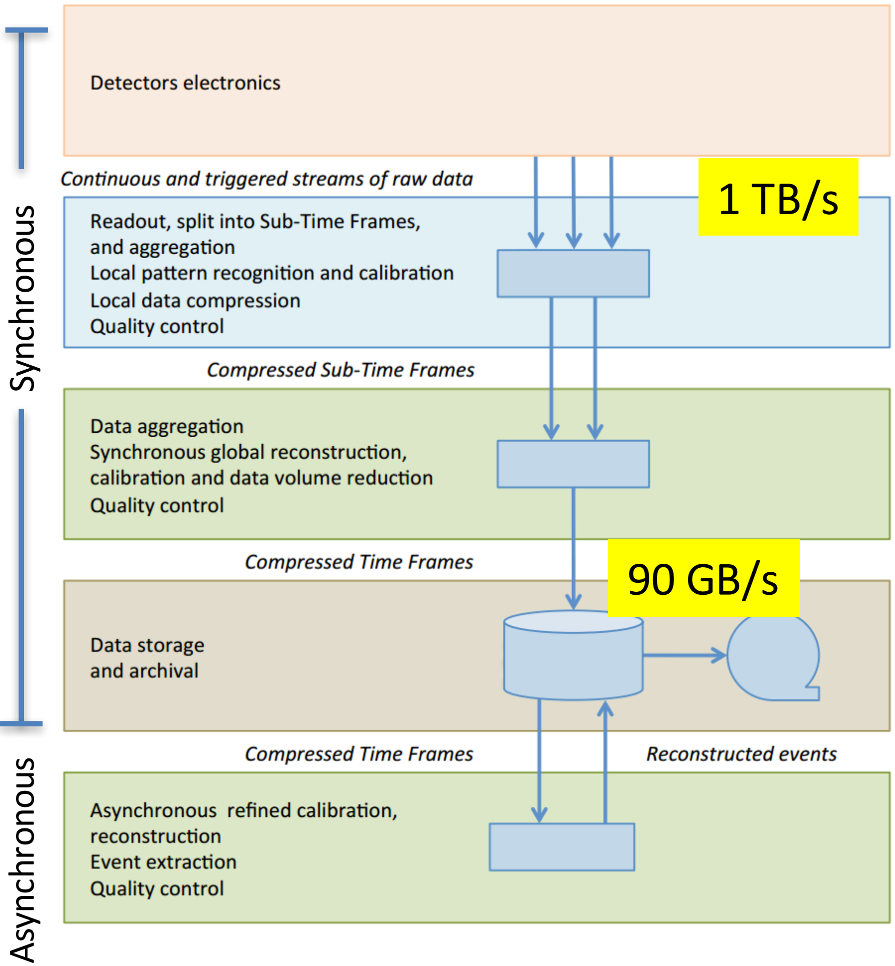
O^2: adapt online & offline

The challenges:

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

The new infrastructure

O^2: new facility @ LHC Point 2
100 k CPU cores
60 PB of storage



- Data transfer in continuous mode fashion or by using minimum bias trigger
- Dedicated time markers used to 'chop' data in Time Frames to be inspected
- 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

Expected performance

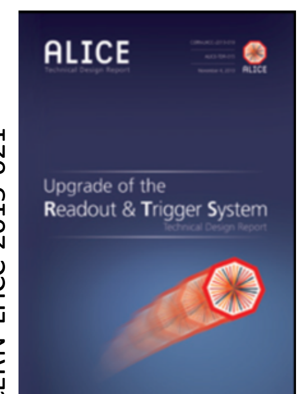
- Reduction of uncertainties for charm
- Separation between beauty and charm
- Full reconstruction of B decays
- Measurements of heavy-flavor baryons
- Low mass di-leptons: e^+e^- (barrel) and $\mu^+\mu^-$ (MFT)
- Ψ(2S) → discrimination between models of recombination
- and more…. (light nuclei)

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

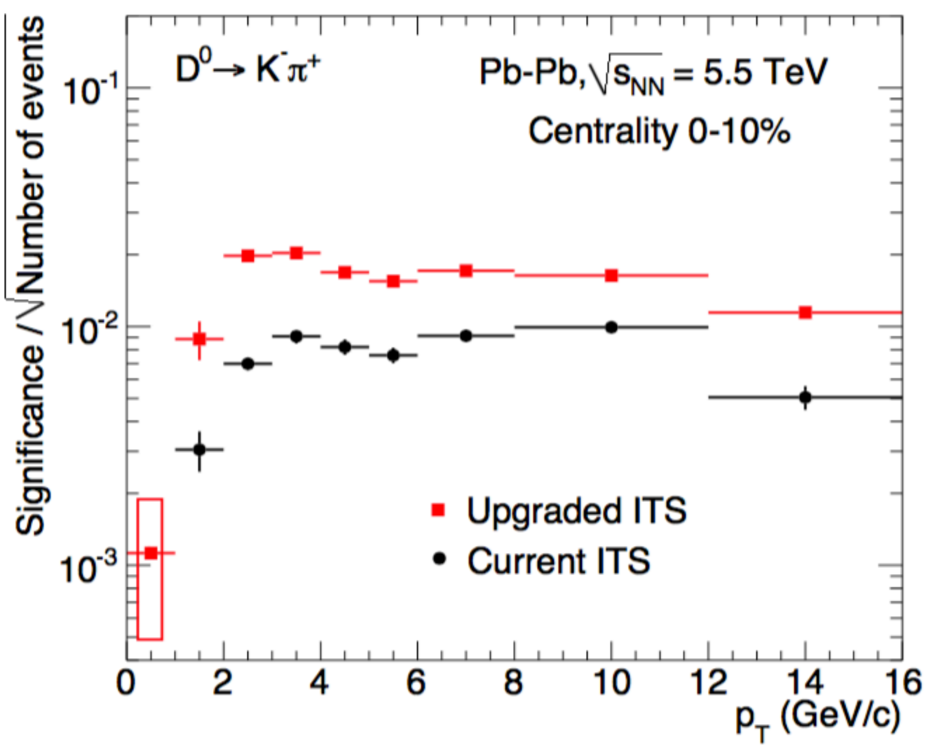
CERN-LHCC-2015-021

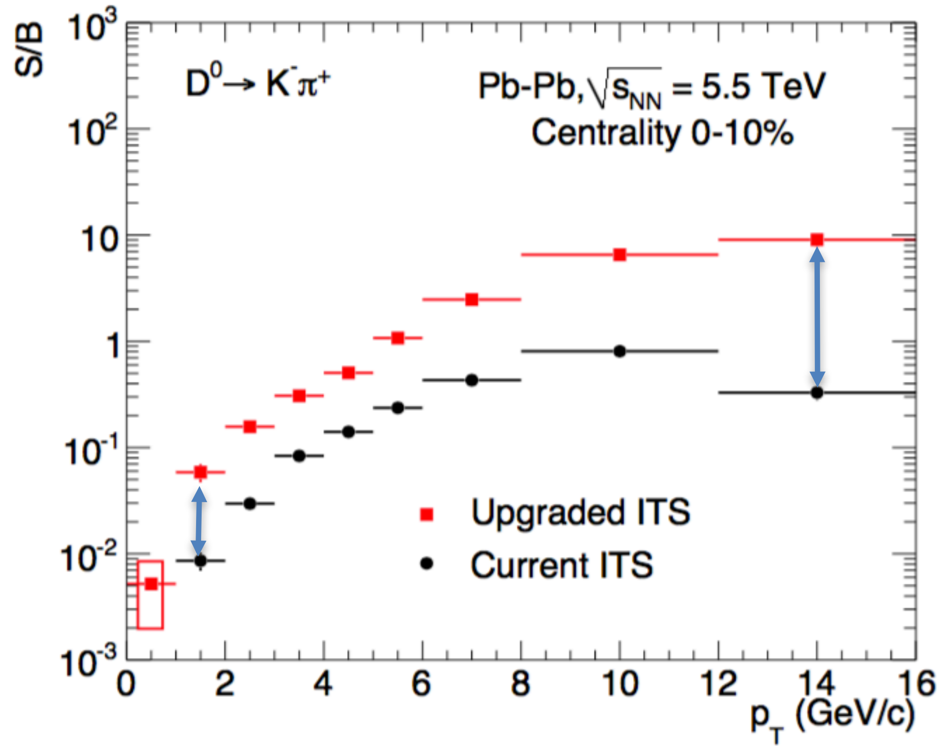


CERN-LHCC-2013-019

CERN-LHCC-2015-006

D^0 as reference candle for charm





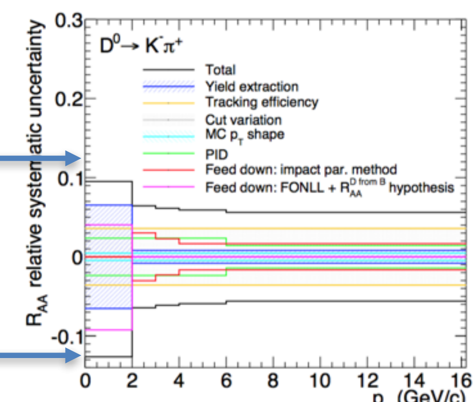
For $\mathcal{L}_{int}$=10 nb^{-1} number of events **8 x 10^9**
→ Significance 50 for p_T< 1GeV (and 1000 at high p_T)

Background down by factor 5 - 10

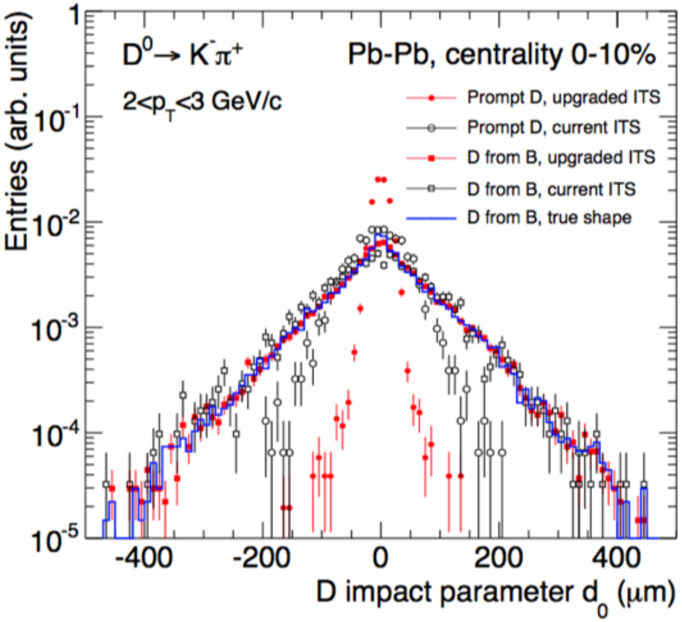
Systematics improvement due to:

- Easier signal extraction
- "direct" feed-down correction →

Compare with current 12% in JHEP 11(2015) 205!



Separation between charm and beauty

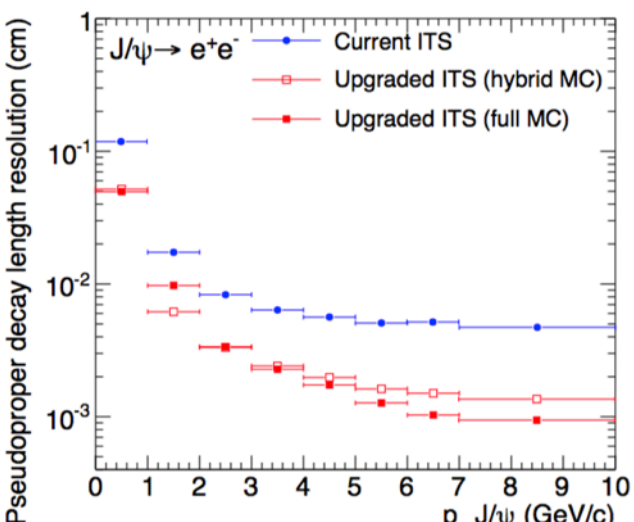


B.R.(B → D^0 + X) ~60%

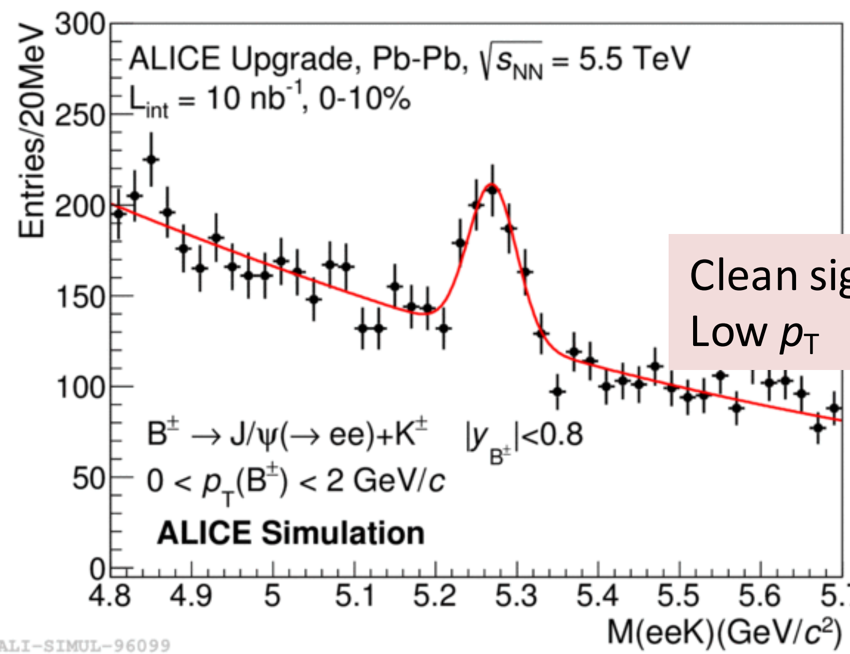
B: cτ ~ 460-490 mm → exploit impact parameter shape

With upgraded ITS resolution improves by factor 3

→ Better separation of the two components

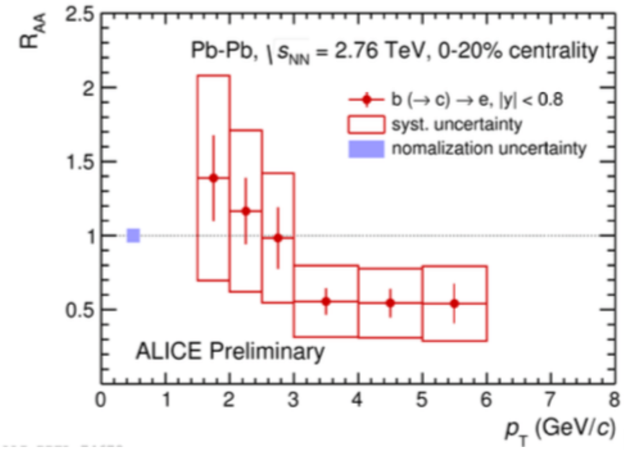


This is also valid for displaced J/ψ → opens in the barrel for the study of B→J/ψ (→e^+e^-) + K



Clean signal
Low p_T

From run 1 to run 3-4… beauty looks better



Can we see something?

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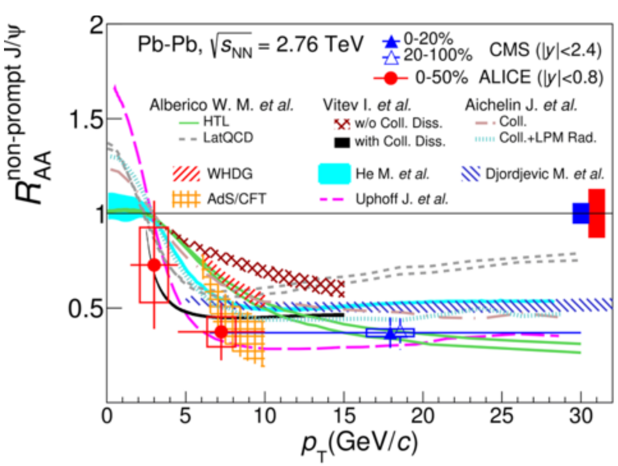
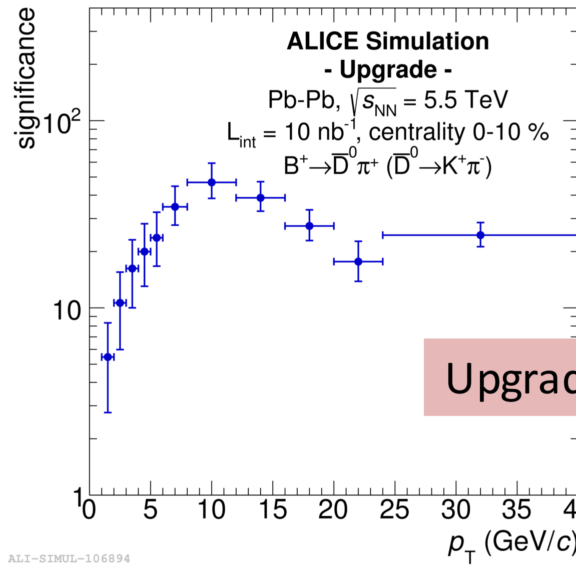
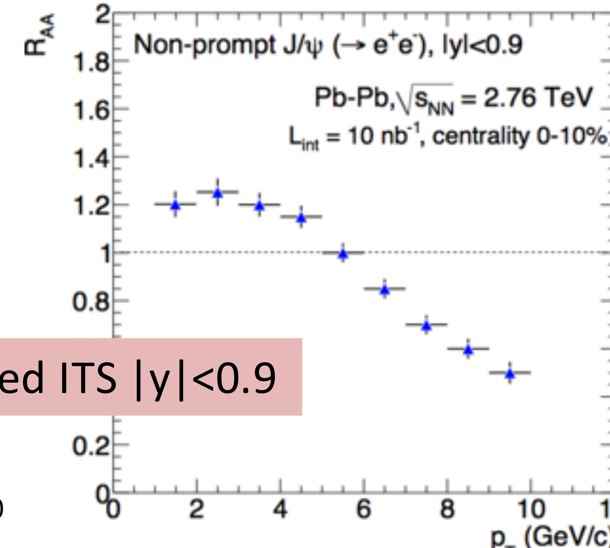
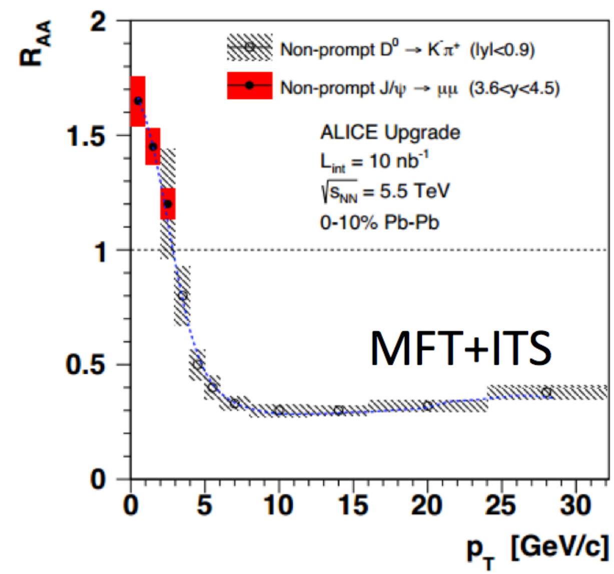






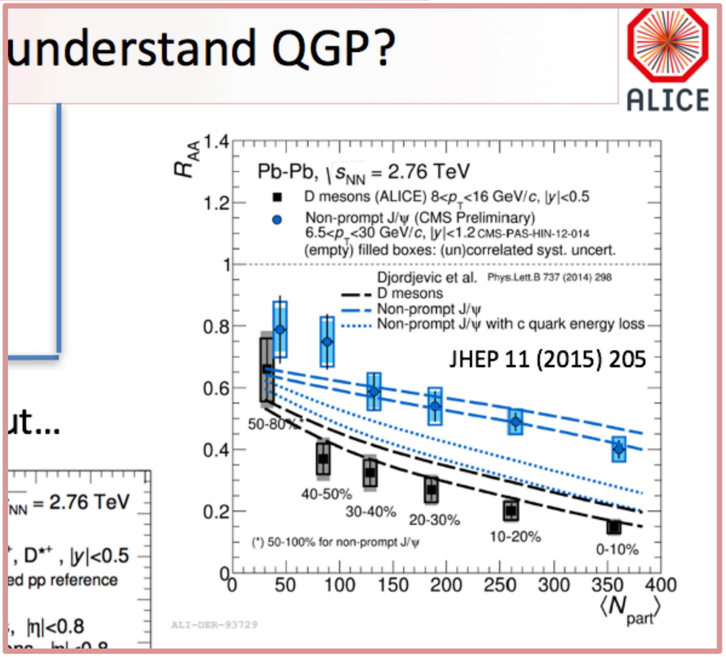
Upgraded ITS |y|<0.9

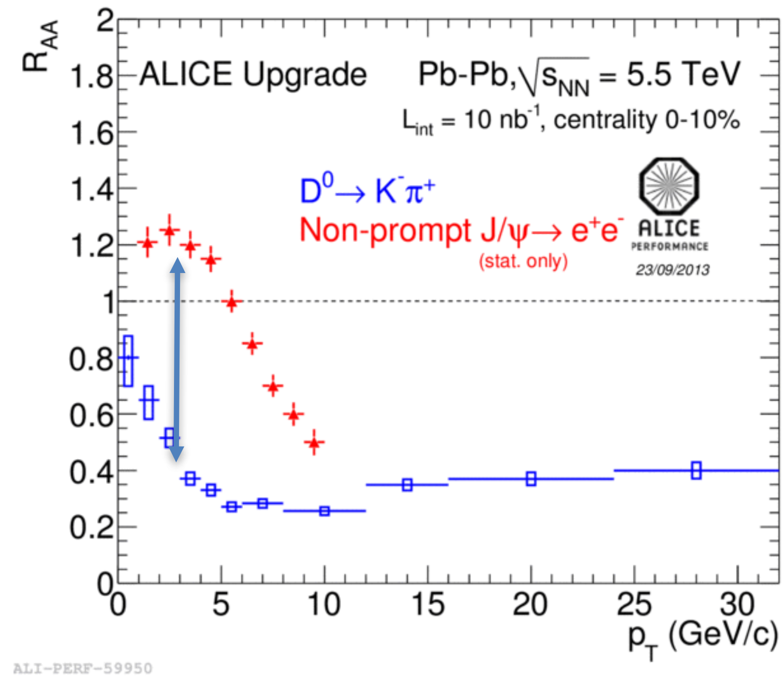
- New channel opened (B) + much larger precision on R_{AA} (both via displaced J/ψ and non prompt D^0)
- The study of non prompt J/ψ in $\mu^+\mu^-$ channel key tool to measure B down to zero p_T



Beauty and charm energy loss

Remember slide # 4





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

Soft gluon irradiation / dead-cone effect

$$dP = \frac{\alpha_s C_F}{\pi} \frac{d\omega}{\omega} \frac{k_\perp^2\, dk_\perp^2}{(k_\perp^2 + \omega^2\theta_0^2)^2}, \qquad \theta_0 \equiv \frac{M}{E},$$

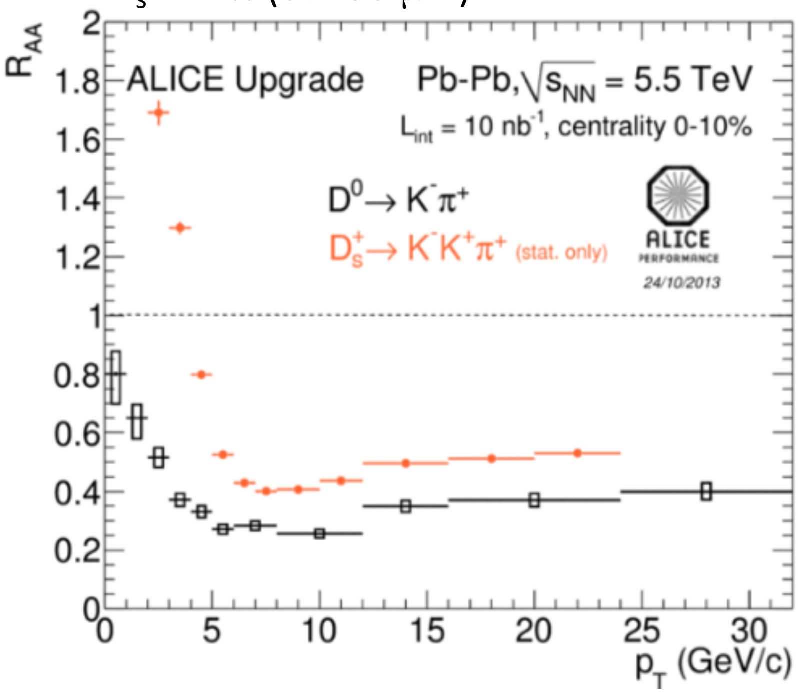
Physics Letters B 519 (2001) 199–206

Heavy-quark colorimetry of QCD matter

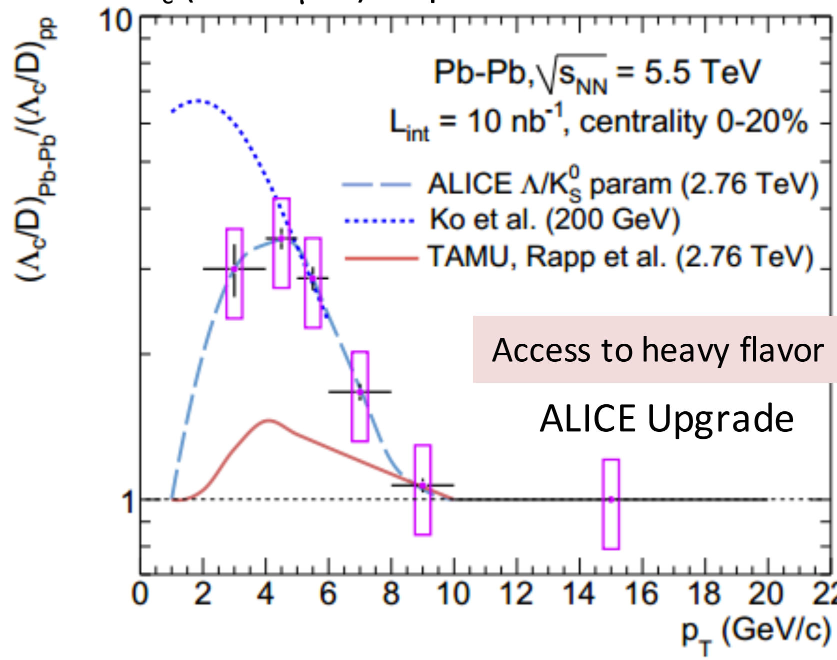
Yu.L. Dokshitzer[a], D.E. Kharzeev[a,b]

Hadrochemistry: in medium hadronization for heavy flavor?

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



Λ_c ($c\tau$ 60 μm) → $pK\pi$



Access to heavy flavor baryons

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

Charmonium: deconfined charm quarks in the QGP phase?

RUN 1

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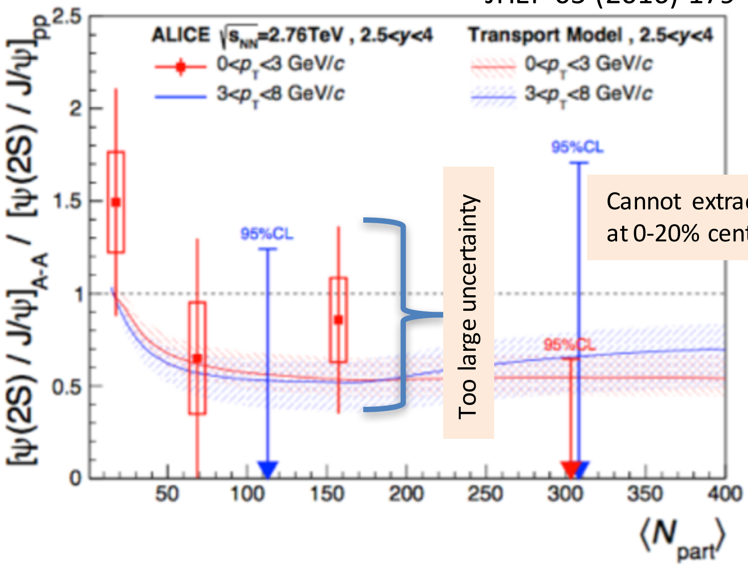
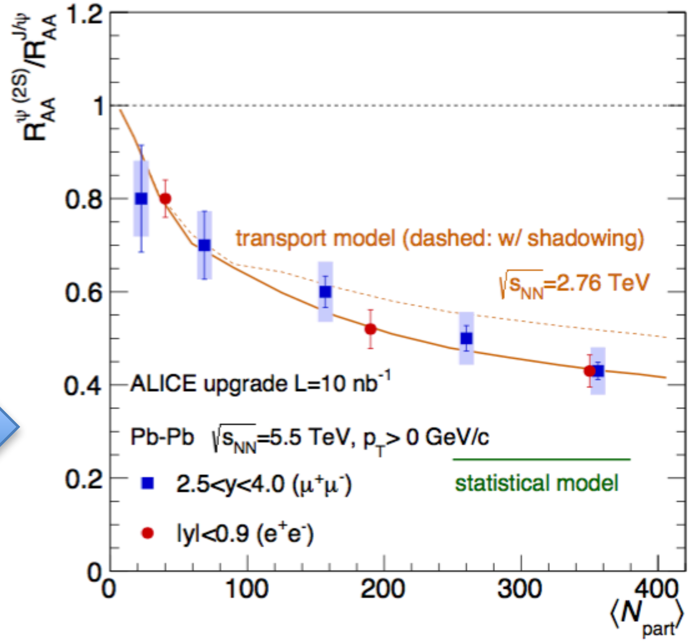


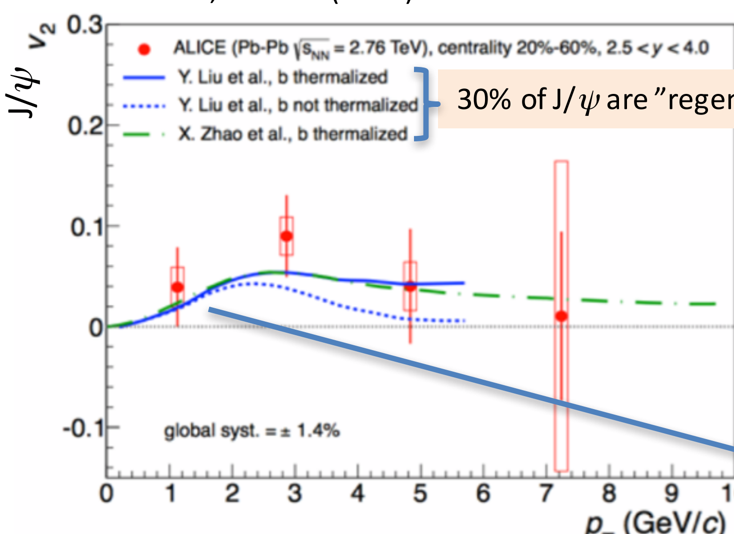
Too large uncertainty

Cannot extract ψ(2S) at 0-20% centrality

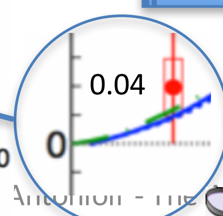
ALICE Upgrade

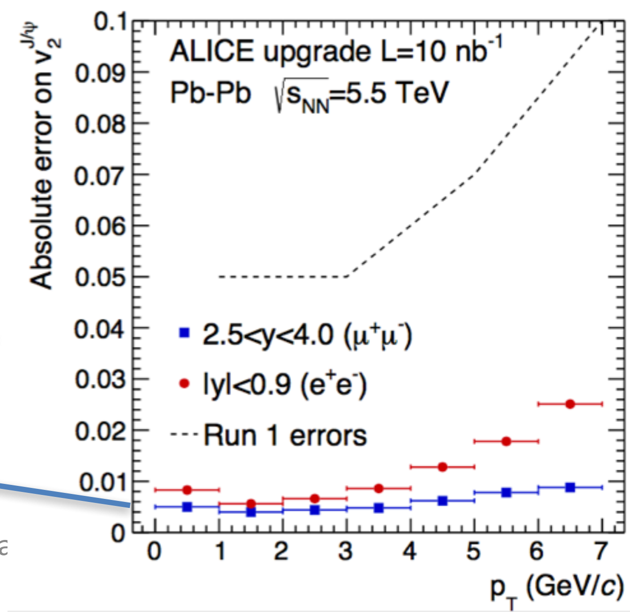


PRL 111, 162301 (2013)



30% of J/ψ are "regenerated" → larger flow

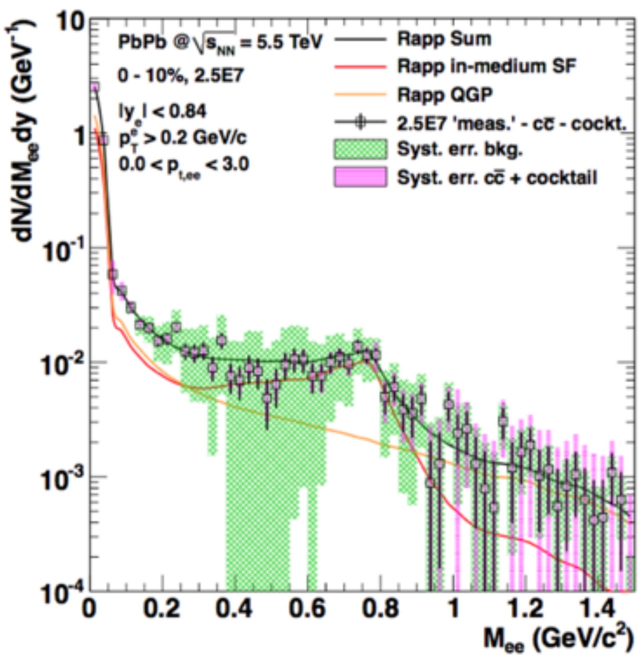


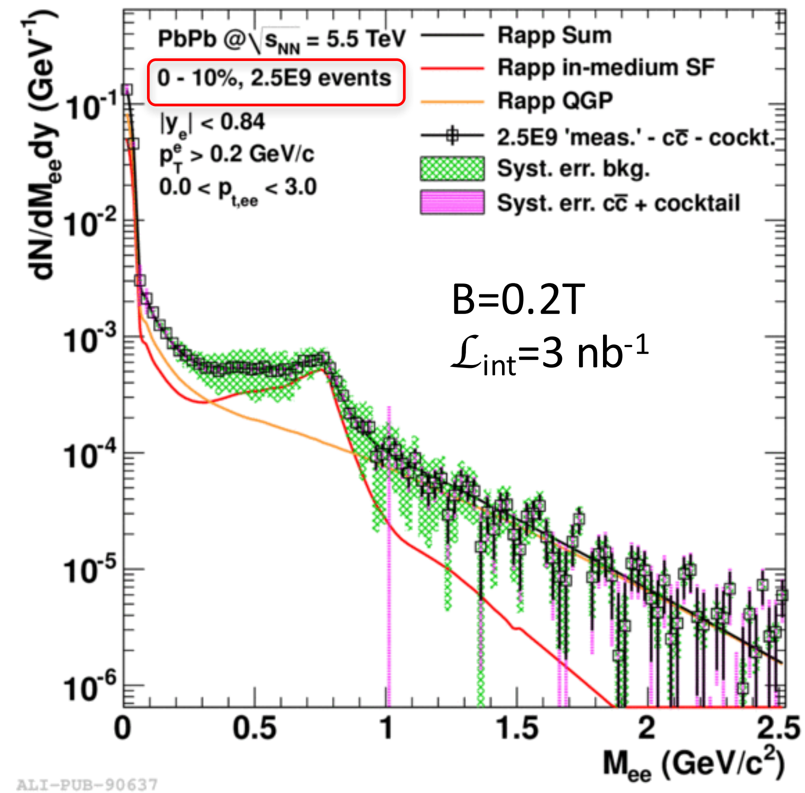


Low mass di-leptons

- ITS and MUON+MFT enable $\mathbf{M_{ee}}$ and $M_{\mu\mu}$ studies
- ITS reduced thickness reduces conversion
- 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)





- 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}

Low mass di-leptons

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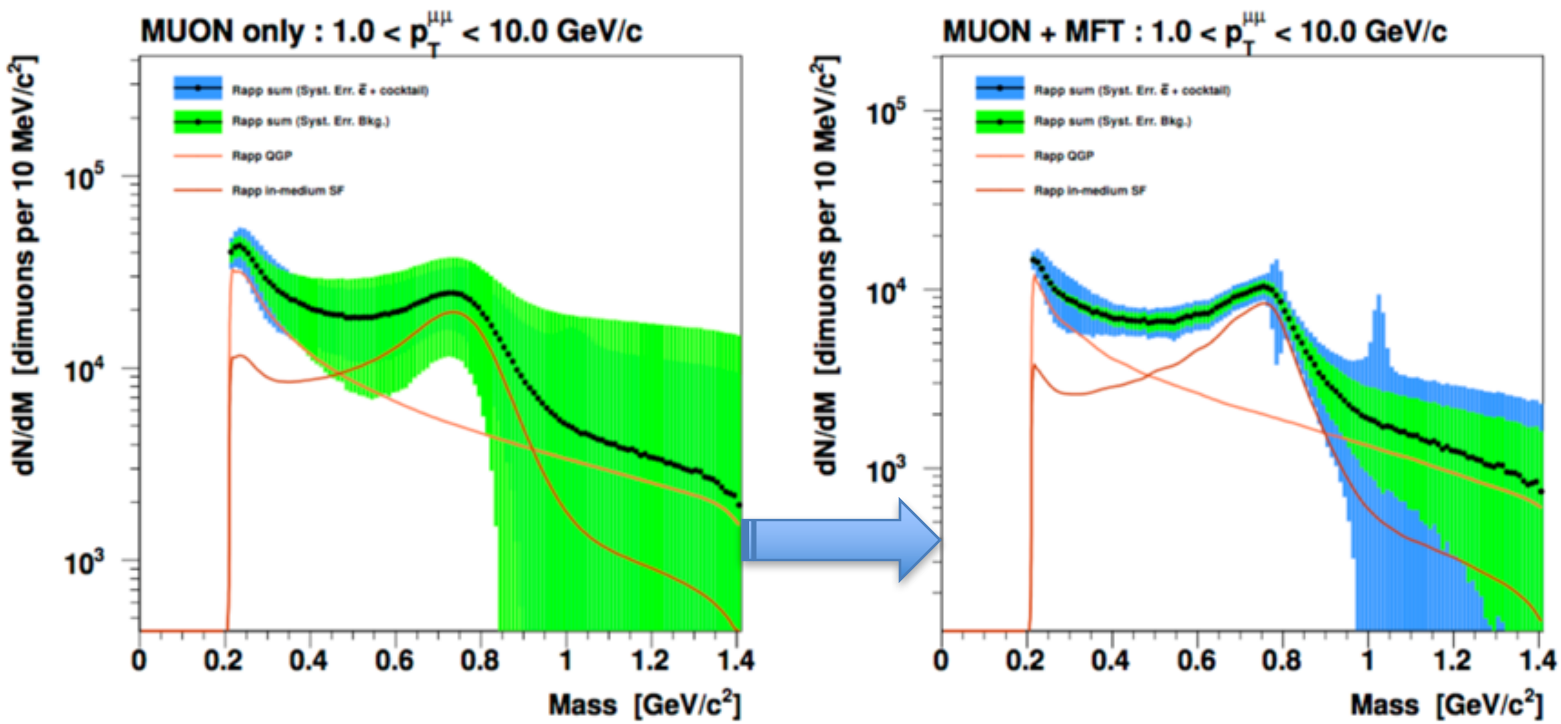

Summary

ALICE has a comprehensive upgrade programme starting to move in 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 PbPb via TPC (+ readout upgrade)
- New paradigm for Online/Offline operations
- New triggering detector

2016 | 2017 | 2018 | 2019 | 2020 | 2021

Completion of R&D | Production and construction | Assembly, installation and commissioning | RUN3

- It will extend ALICE life cycle up to 2029. First PbPb physics data in 5 years from now.
- The upgrade strategy is oriented **to explore low 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.
- A Forward Calorimeter (to be installed during LS3) with focus on saturation physics also under discussion

(*) See A. Uras talk @LHCP2016, "Heavy ions at HL-LHC" [parallel Friday 17]