ALICE upgrade programme

(Программа модернизации АЛИЦЕ)

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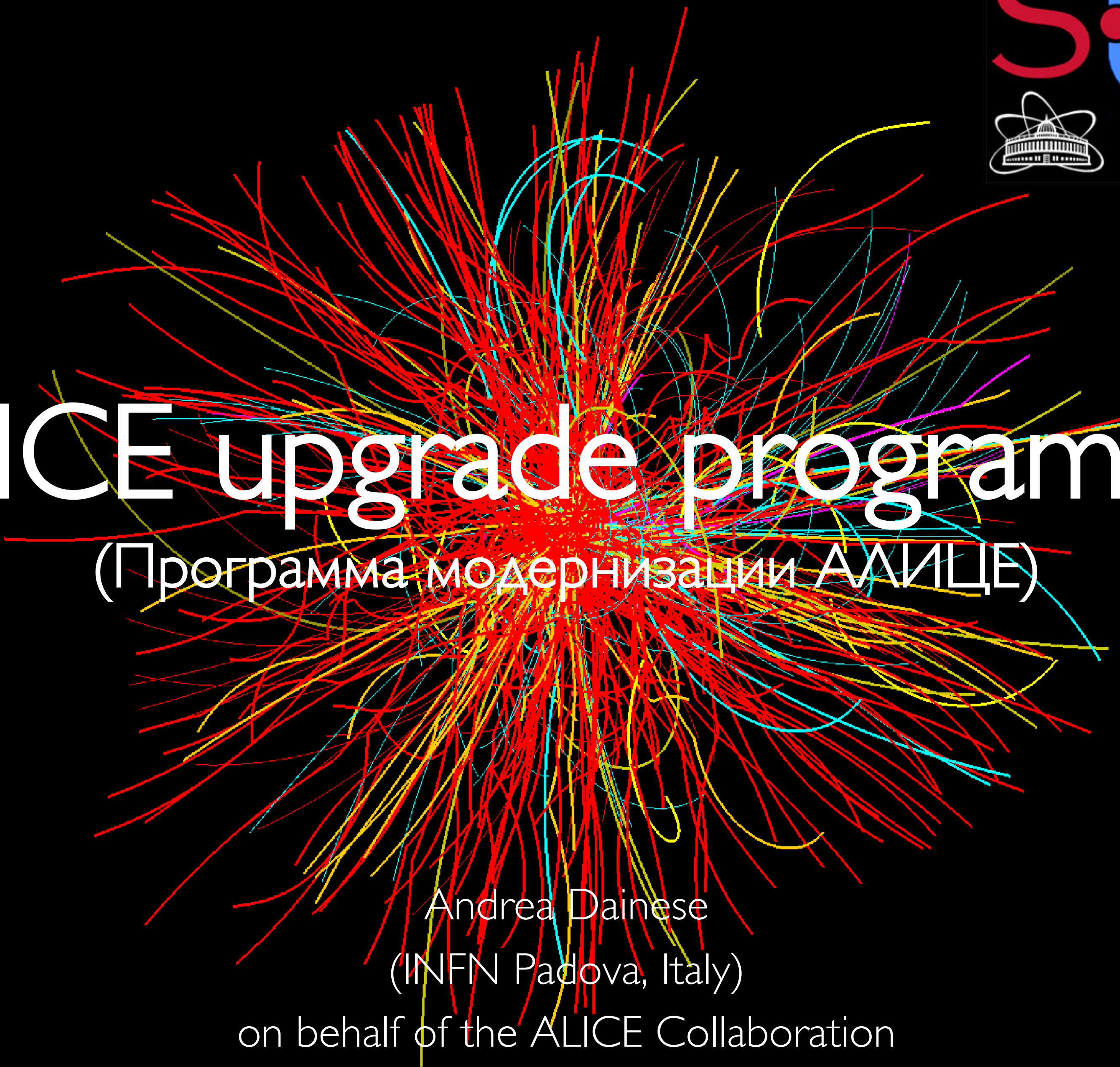
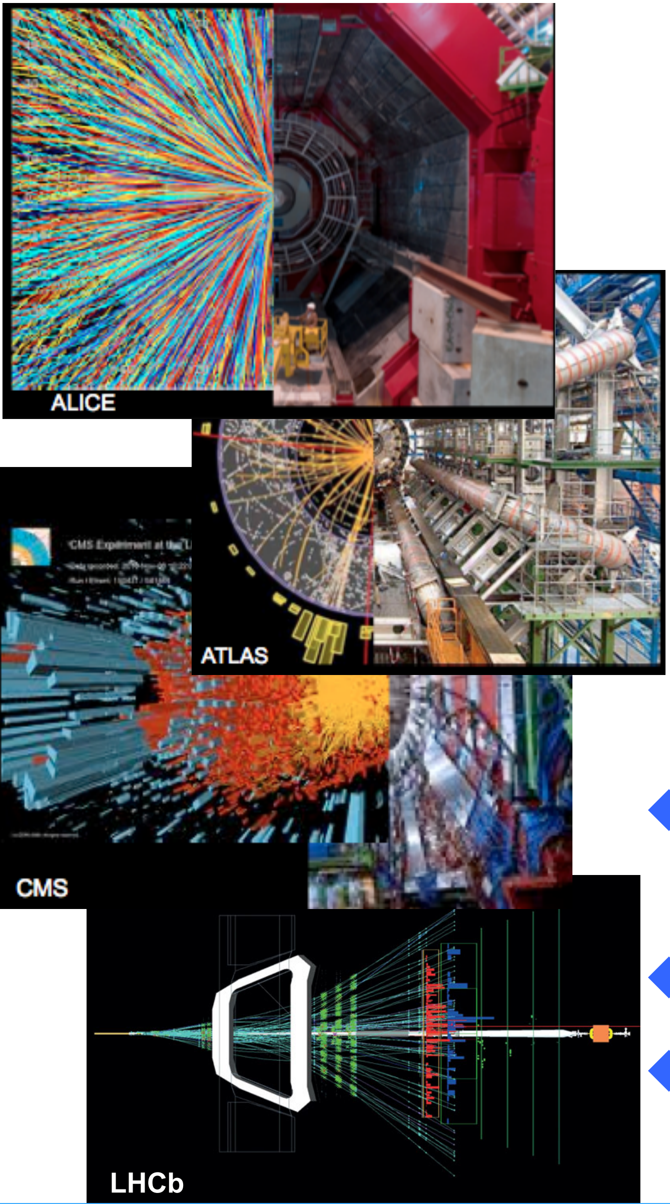
on behalf of the ALICE Collaboration



Outline

- Future of the LHC heavy ion programme
- ALICE upgrade goals and strategy
- Overview of detector upgrades
- Selected physics items: present status and prospects with the upgrade
  - Open heavy flavour
  - Charmonium
  - Low-mass di-leptons
  - Light nuclei
- Outlook: FoCal project study

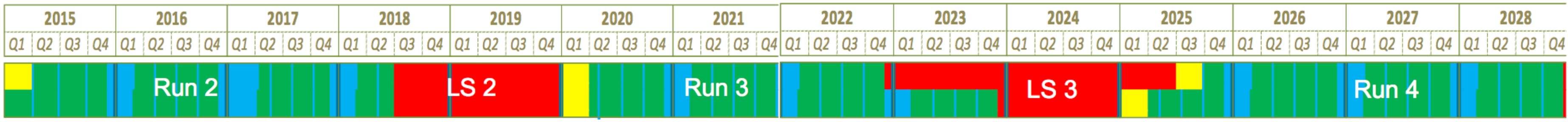
Heavy Ions at the LHC: Run 1



year	system	$\sqrt{s_{NN}}$ (TeV)	L_{int}
2010	**Pb-Pb**	**2.76**	**~ 10 μb^{-1}**
2011	pp	2.76	~ 250 nb^{-1}
2011	**Pb-Pb**	**2.76**	**~ 150 μb^{-1}**
2013	p-Pb	5.02	~ 30 nb^{-1}
2013	pp	2.76	~ 5 pb^{-1}

- 2011 Pb-Pb run already reached nominal luminosity: 5x10^{26}
- First p-Pb run (with all four large exp's)
- Two short pp reference runs at Pb-Pb $\sqrt{s}$

Timeline of future HI runs at the LHC



Pb-Pb L_{int}: R-2 ~1/nb R-3 ~7/nb R-4 ~7/nb

- **Run 2:** Pb-Pb ~1-2/nb, at $\sqrt{s_{NN}}$ ~ 5 TeV, 1 p-Pb run (5 or 8 TeV), short pp reference runs ~5 TeV
- **LS2 (2018-19):** *[most likely postponed to 2019-20]*
  - LHC collimator upgrades: target Pb-Pb L ~ 6×10^{27} $cm^{-2}s^{-1}$ (i.e. 50 kHz int. rate)
  - Major ALICE upgrade (important upgrades, relevant for HI, also for ATLAS, CMS and LHCb)
- **Runs 3+4 (2020-28):**
  - Exp's request: >10/nb Pb-Pb 5.5 TeV (ALICE: 10/nb at 0.5T + 3/nb at 0.2T)
    → x100 larger min. bias sample for ALICE wrt Run 2 (~10^{11} events)
    → x10 larger rare trigger sample for ATLAS/CMS wrt Run 2
  - + p-Pb high lumi, pp ref. 5.5 TeV, possibly light ions (e.g. Ar-Ar)

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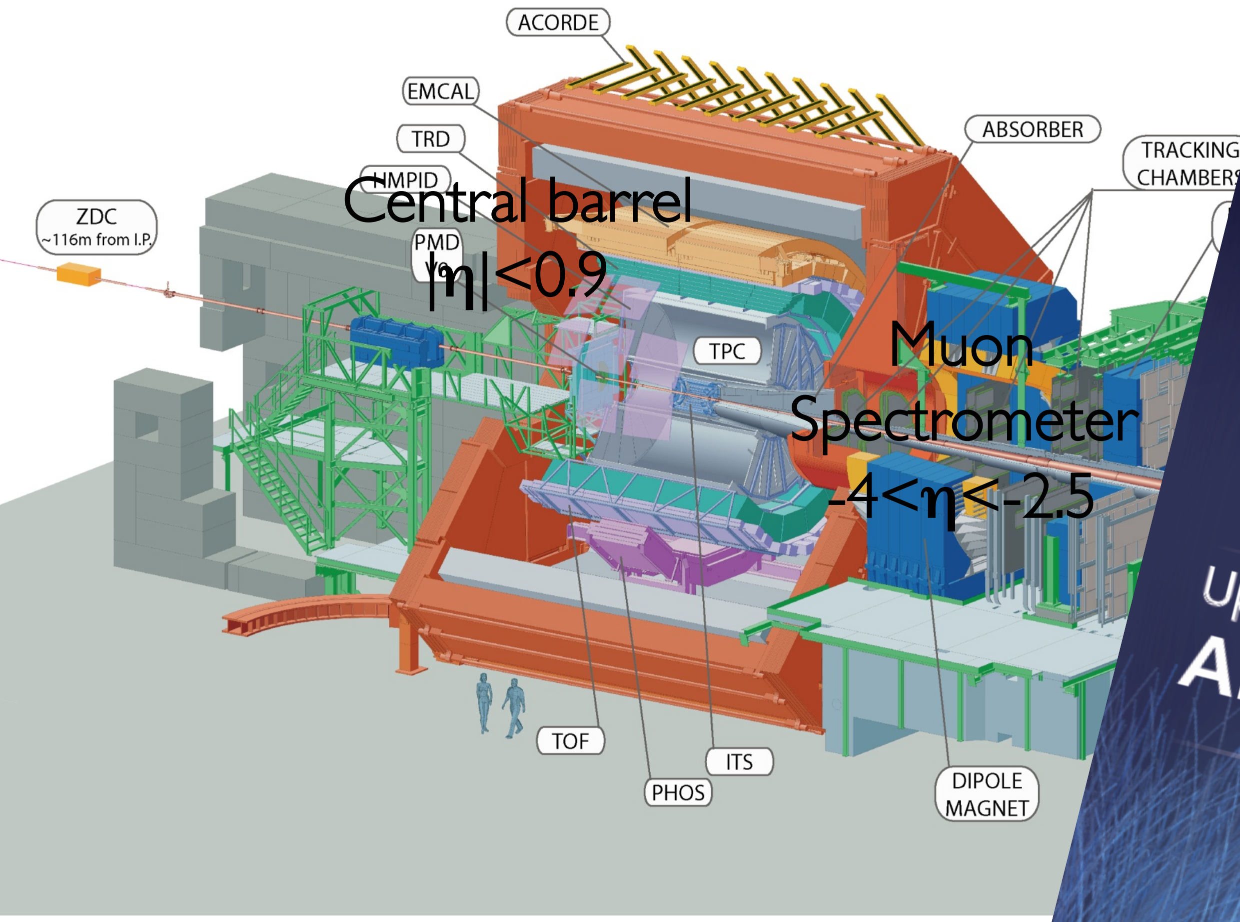
ALICE detector and its upgrade

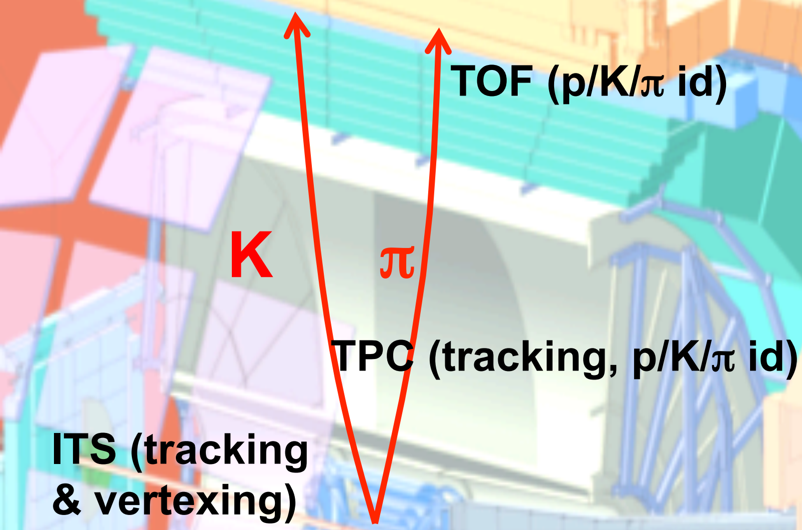


http://cdsweb.cern.ch/record/1475243
http://cdsweb.cern.ch/record/1592659

ALICE Upgrade:
(selected) physics questions & observables

1. **Characterise mechanisms of quark-medium interaction**
   → **Heavy flavour dynamics and hadronisation at low p_T**
2. **Charmonia regeneration as tool to study deconfinement**
   → **Charmonia down to zero p_T**
3. **Chiral symmetry and QGP temperature at LHC**
   → **Vector mesons and virtual thermal photons via di-leptons**
4. **Production of light nuclei from the QGP**
   → **Precise measurement of light nuclei and hyper-nuclei**

Heavy flavour: requirements



Currently, in Pb-Pb:

$D^0 \rightarrow K\pi$

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

$D^* \rightarrow D^0\pi$

$D_s \rightarrow KK\pi$ (limited)

HF $\rightarrow$ e/μ +X

B $\rightarrow$ e / J/ψ +X (limited)

Goals for upgrade:

Precision! $p_T \rightarrow 0$!

B $\rightarrow$ D^0+X

B $\rightarrow$ J/ψ+X

B $\rightarrow$ e/μ +X

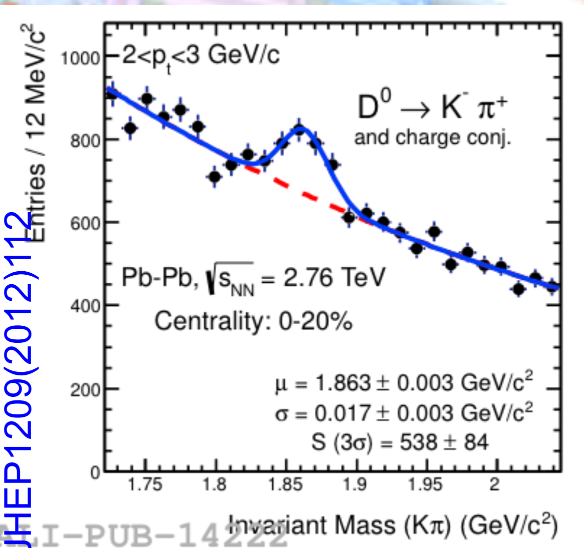
$\Lambda_c \rightarrow pK\pi$

$\Lambda_b \rightarrow \Lambda_c\pi$

General features:

Decay at few 100 μm from interaction point

Large combinatorial background → low signal/background → no dedicated trigger



JHEP1209(2012)112

Requirements:

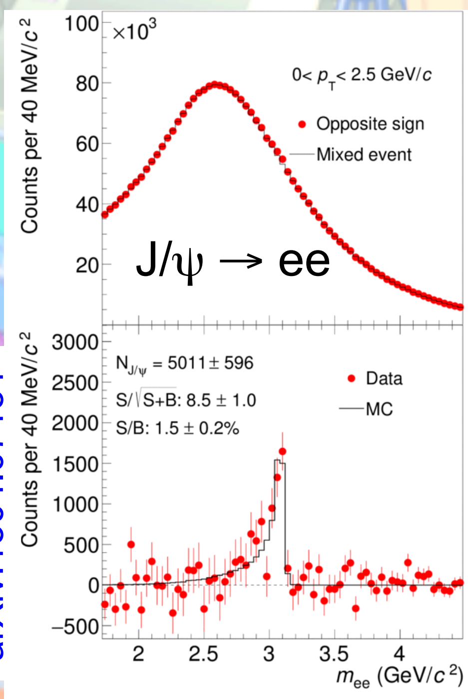
- **Vertexing resolution**
- **Preserve particle identification**
- **Large statistics (no dedicated trigger)**

Charmonium: requirements

e
e
μ
μ

ITS, TPC (tracking)
TPC, TRD, TOF (id)

MUON (tracking,id)



arXiv:1504.07151

Currently, in Pb-Pb:
Incl. $J/\psi \rightarrow \mu\mu$
$\psi' \rightarrow \mu\mu$ (limited)
Incl. $J/\psi \rightarrow ee$ (limited)
$B \rightarrow J/\psi \rightarrow ee$ (limited)
Goals for upgrade:
Precision!
$\psi' \rightarrow ee$
Direct J/ψ
$B \rightarrow J/\psi+X$ ($\mu\mu$ and ee)

General features:

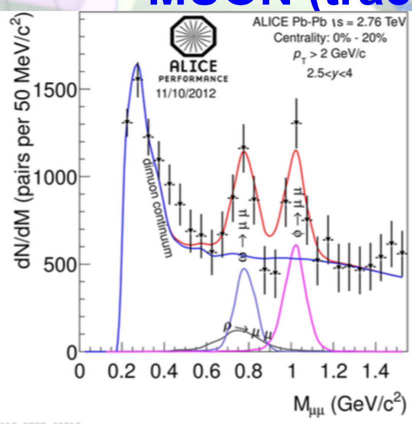
B decay few 100 μm from interaction point

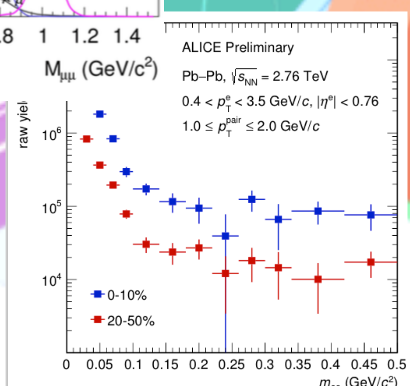
Large combinatorial background in ee channel → low signal/background → no dedicated trigger

Requirements:
- **Vertexing resolution**
- **Preserve particle identification**
- **Large statistics (no dedicated trigger)**

Low-mass di-leptons: requirements

e
e
ITS, TPC (tracking)
TPC, TRD, TOF (id)
μ
μ
MUON (tracking,id)





Currently, in Pb-Pb: very small S/B, high-mass region not accessible
Goals for upgrade:
ρ → ee
ρ → μμ
γ* → ee
γ* → μμ

General features:

Electrons and muons with very low momentum

Large background from heavy flavour decays

Large combinatorial background → low signal/background → no dedicated trigger

Requirements:

- **Tracking efficiency at low p_T**
- **Vertexing resolution**
- **Preserve particle identification**
- **Large statistics (no dedicated trigger)**

ALICE Upgrade: summary of requirements

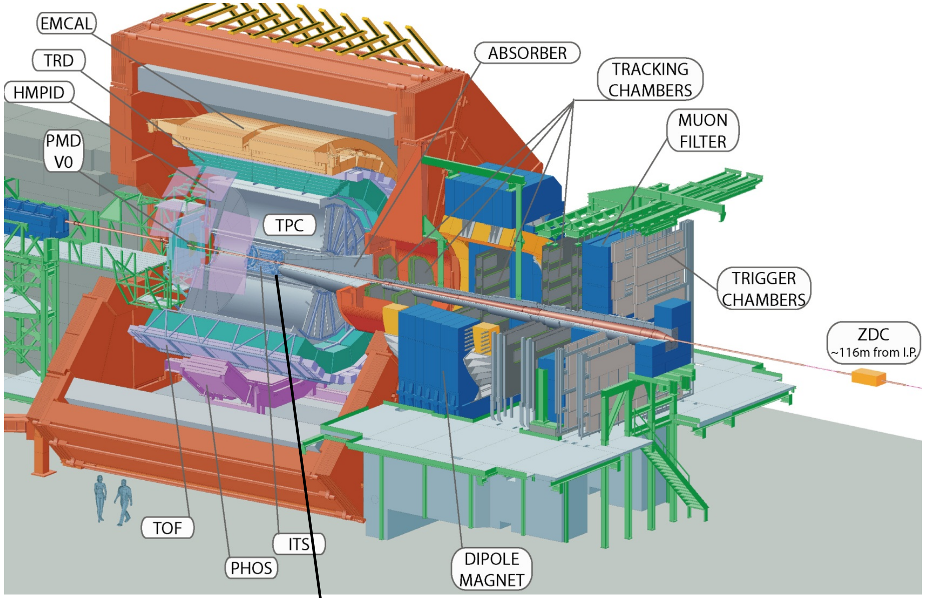
- Tracking efficiency and resolution at low p_T
  → increase tracking granularity, reduce material thickness

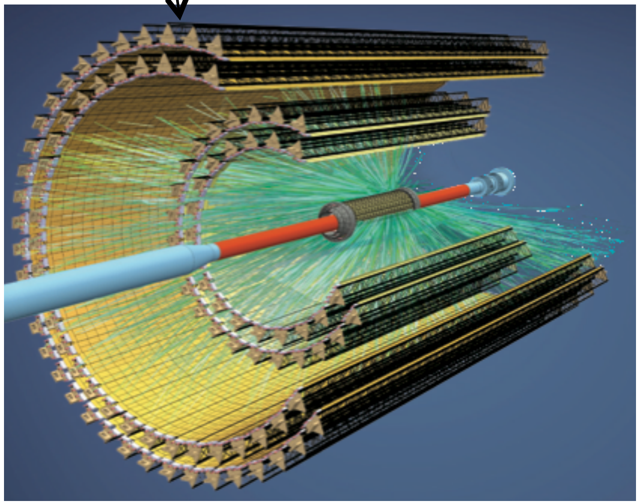
- Large statistics (no dedicated trigger)
  → increase readout rate, reduce data size (online compression)

- Preserve particle identification
  → consolidate and "speed-up" the PID detectors

ALICE Upgrade: strategy

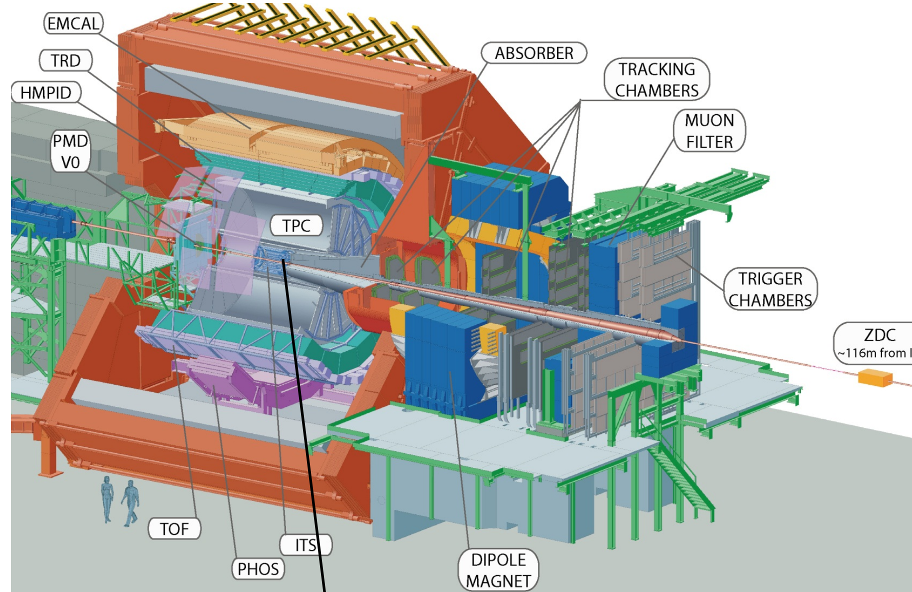
- New Inner Tracking System (ITS)
  - Improved resolution, less material, faster readout

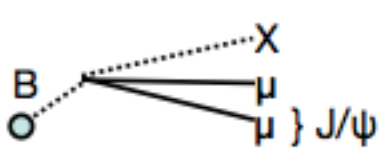


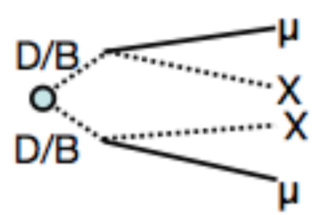


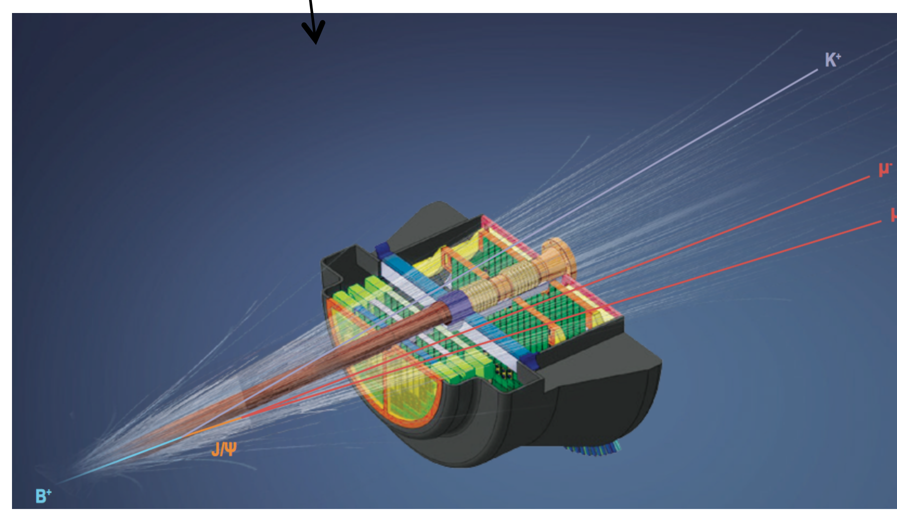
ALICE Upgrade: strategy

- New Inner Tracking System (ITS)
  - Improved resolution, less material, faster readout
- New Forward Muon Tracker (MFT)
  - HF vertices also at forward rapidity



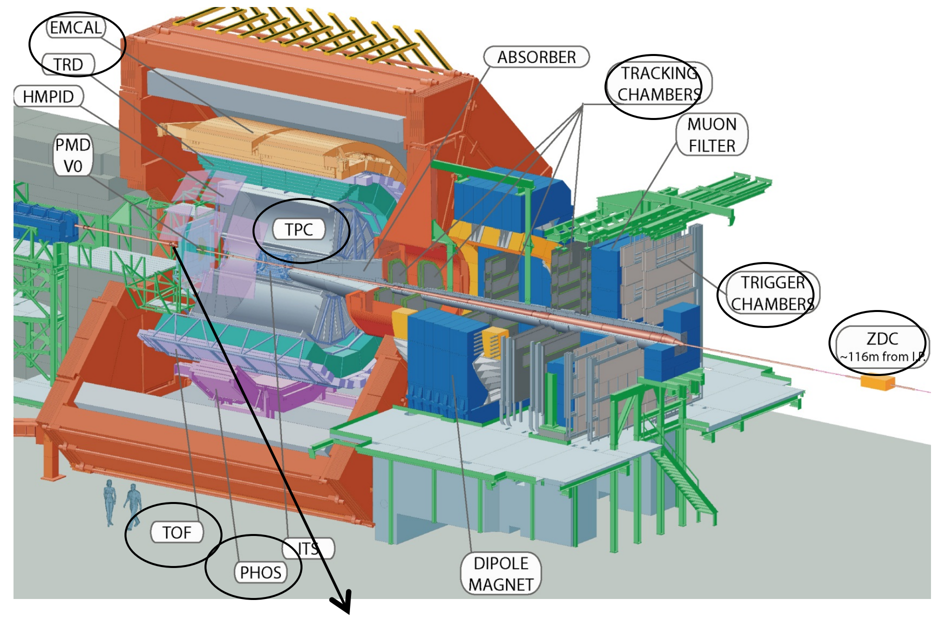


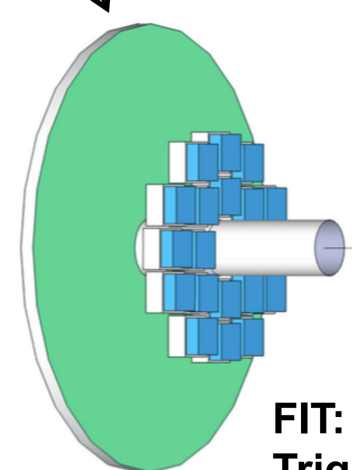




ALICE Upgrade: strategy

- New Inner Tracking System (ITS)
  - Improved resolution, less material, faster readout
- New Forward Muon Tracker (MFT)
  - HF vertices also at forward rapidity
- Upgraded read-out for TPC, TOF, TRD, MUON, ZDC, EMCal, PHOS, new trigger detector (FIT), integrated Online-Offline system (O^2)
  - Record minimum-bias Pb-Pb data at 50 kHz (currently <0.5 kHz)





FIT: Fast Interaction Trigger

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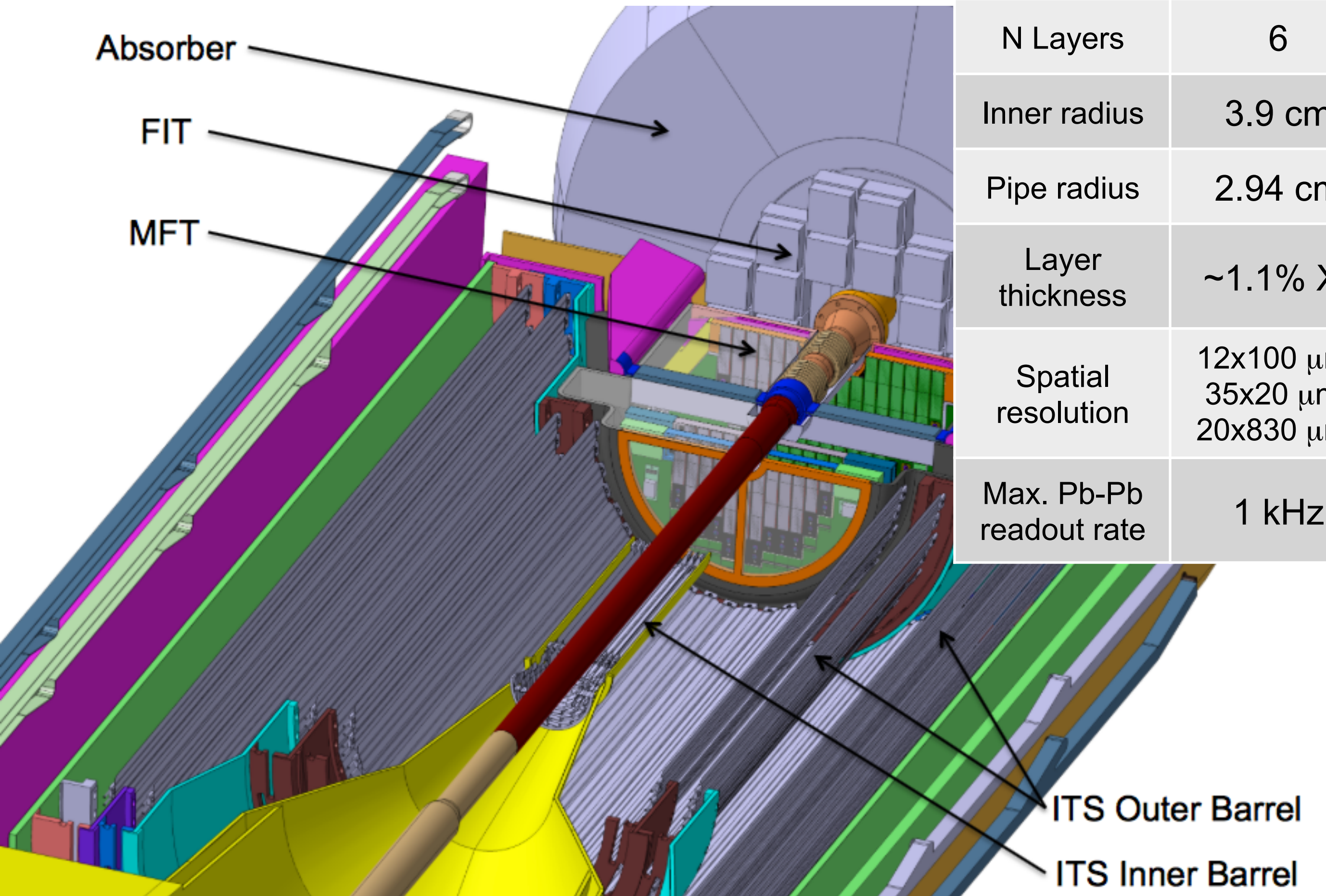
New all-pixel trackers: ITS and MFT

- Both trackers fully based on Monolithic Active Pixel Sensors (MAPS)

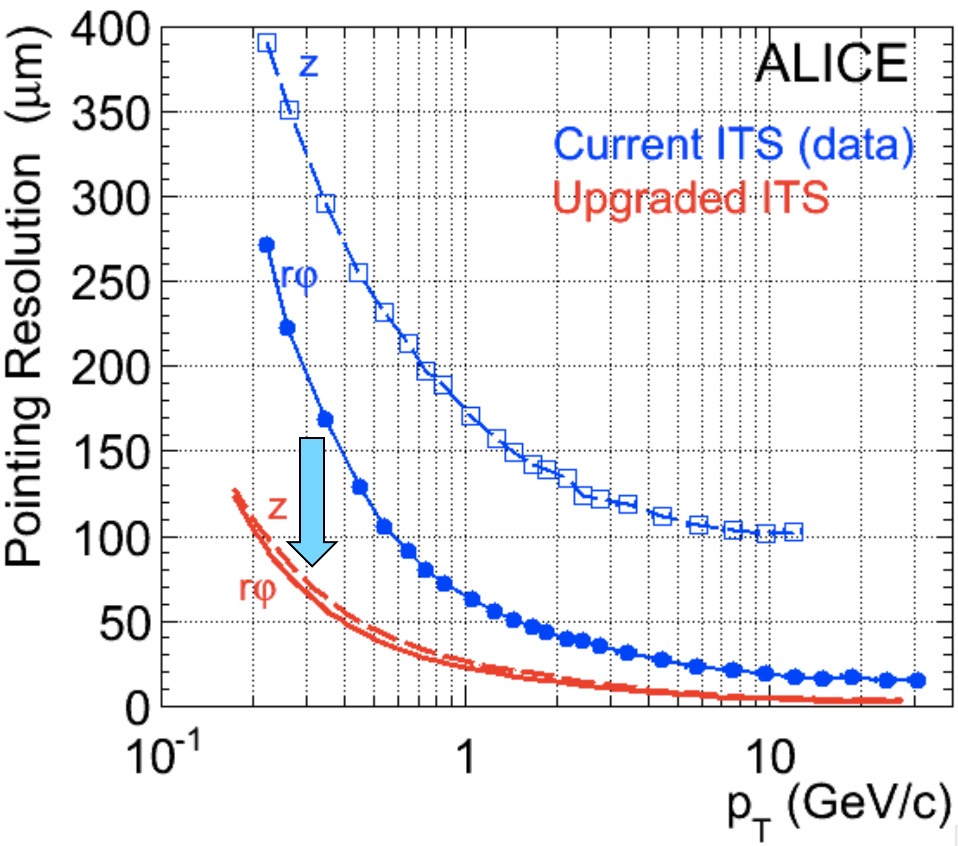
	Pres. ITS	New ITS	MFT
Acceptance	$\|\eta\|<0.9$	$\|\eta\|<1.5$	$-3.6<\eta<-2.3$
N Layers	6	7	5
Inner radius	3.9 cm	2.3 cm	/
Pipe radius	2.94 cm	1.86 cm	/
Layer thickness	~1.1% X_0	0.3-0.8% X_0	0.6% X_0
Spatial resolution	12x100 μm^2 35x20 μm^2 20x830 μm^2	~5x5 μm^2	~5x5 μm^2
Max. Pb-Pb readout rate	1 kHz	100 kHz	100 kHz



ITS: CERN-LHCC-2013-024
MFT: CERN-LHCC-2015-001

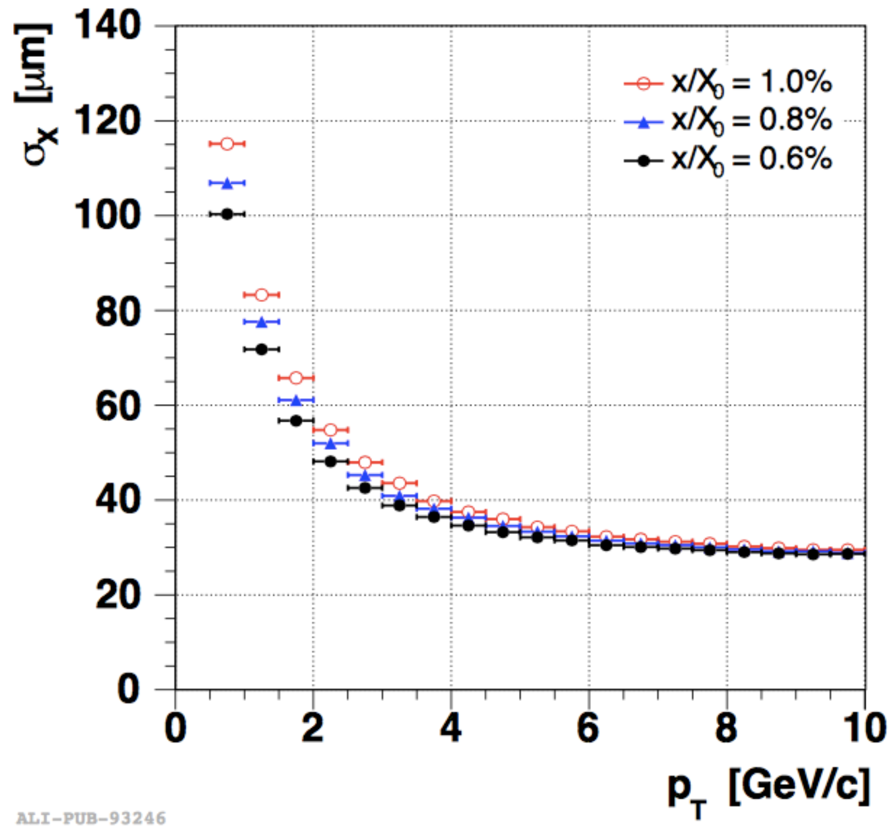
Tracking precision

ITS: pointing resolution x3 better in transverse plane (x6 along beam)



Adapted from CERN-LHCC-2013-024

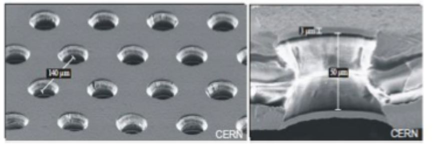
MFT: pointing resolution better than 100 μm for $p_T > 1$ GeV/c



CERN-LHCC-2015-001

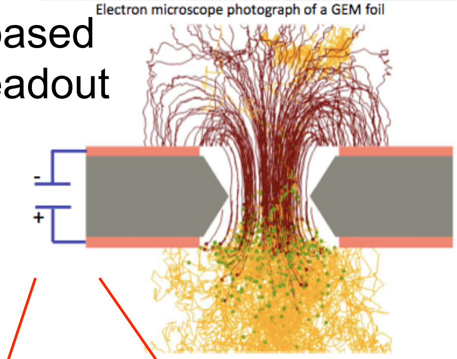
TPC with GEM readout chambers

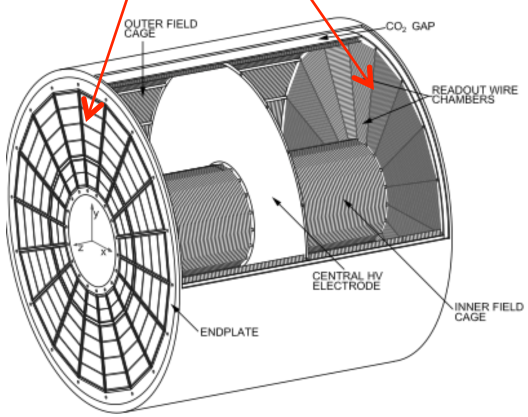
- Current MWPC: readout limited by ion backflow
- New readout chambers (GEM): readout up to 50 kHz
  - preserve momentum resolution for TPC + ITS tracks
  - preserve particle identification via dE/dx

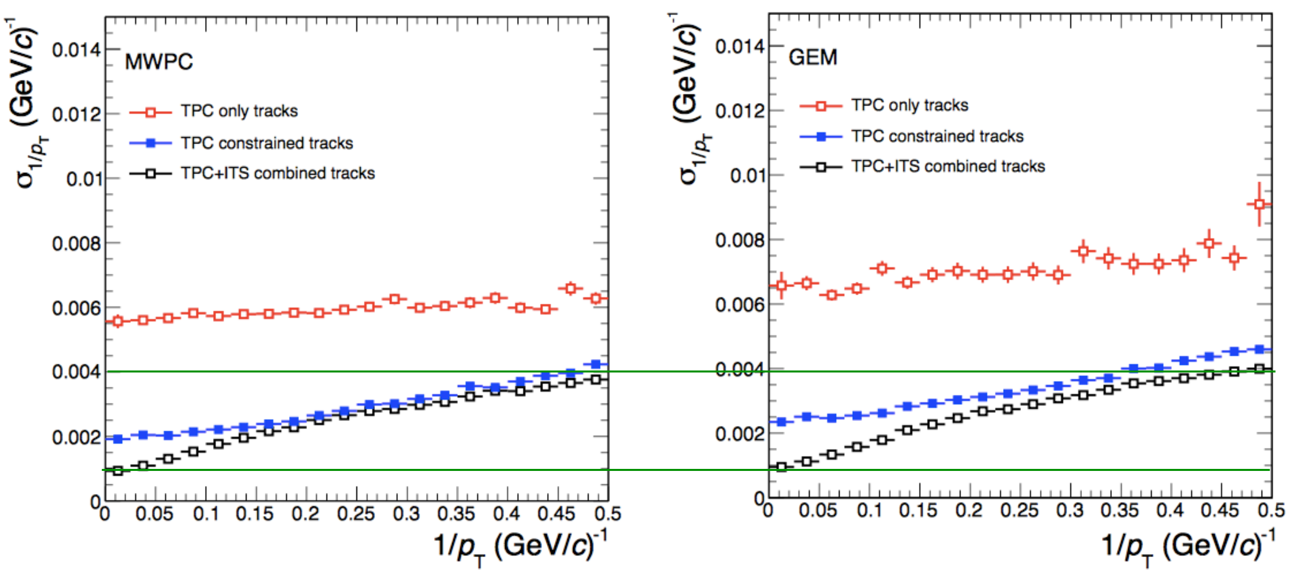


Electron microscope photograph of a GEM foil

GEM-based TPC readout







CERN-LHCC-2013-020

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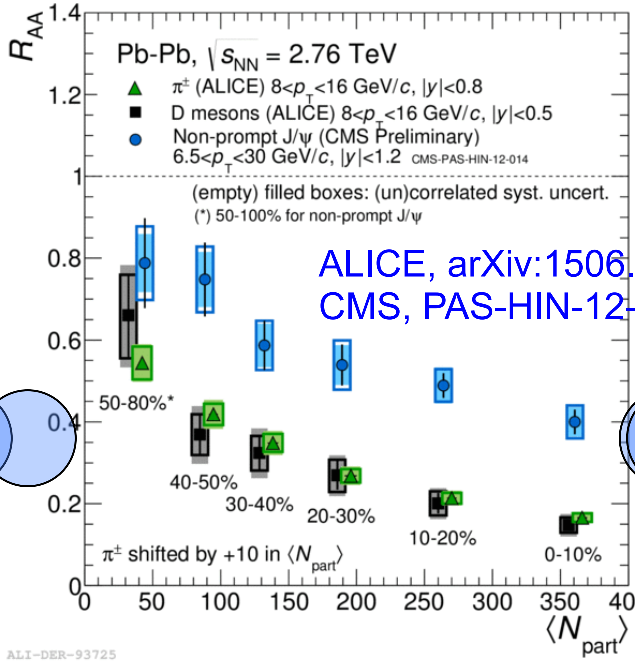
4. **Production of "light" nuclei from the QGP**
   → **Precise measurement of light nuclei and hyper-nuclei**

Heavy flavour R_{AA} and v_2: Run I

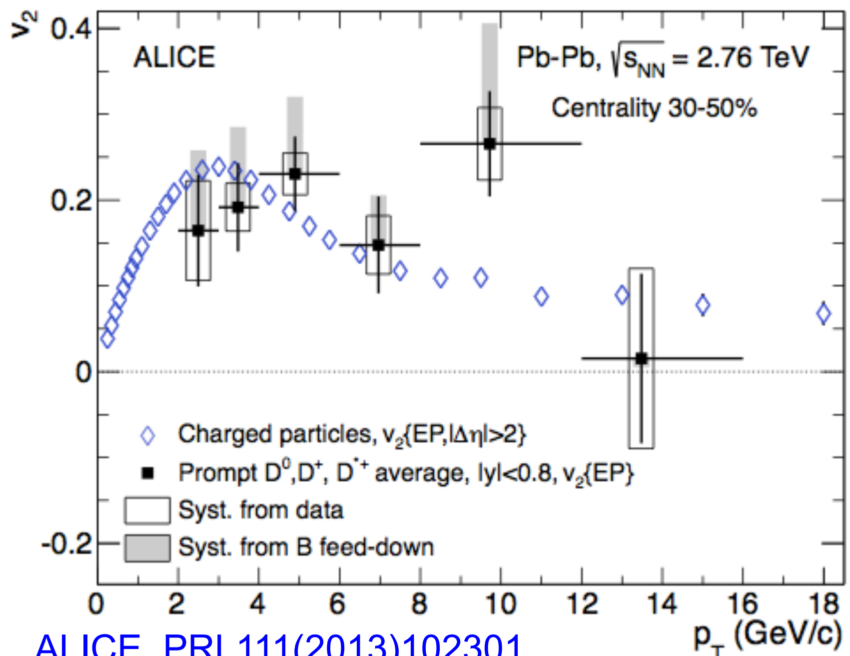
- First indication of mass dependence of energy loss:

  R_{AA}^{B} (CMS) > R_{AA}^{D} (ALICE)



Limited to high p_T (~10 GeV/c) and sizeable uncertainties in centrality dependence

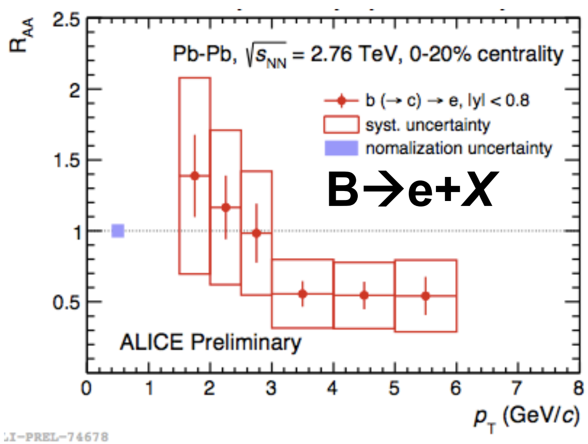
- Charm hadrons have v_2>0
- Heavy quark flow? Role of hadronization?

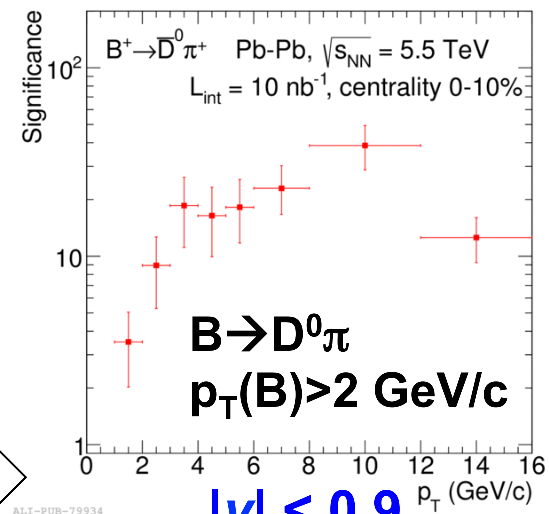


ALICE, PRL111(2013)102301

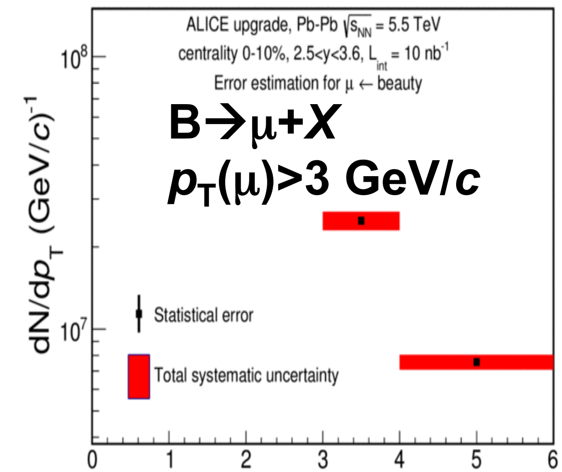
Sizeable uncertainties for charm and no separate measurement for beauty

Beauty in ALICE: Run 1 vs. Upgrade

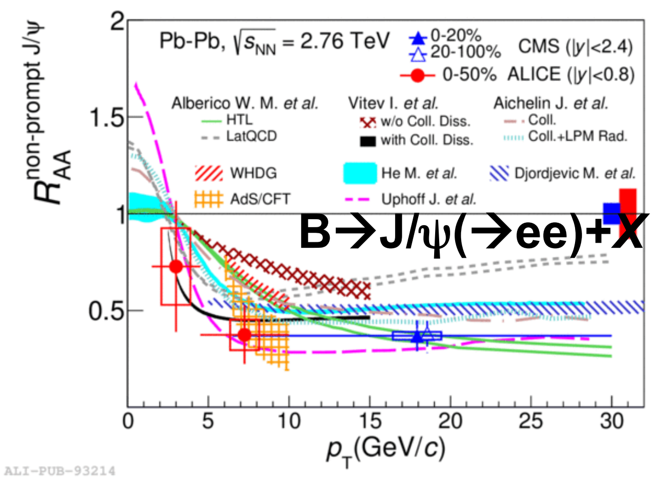




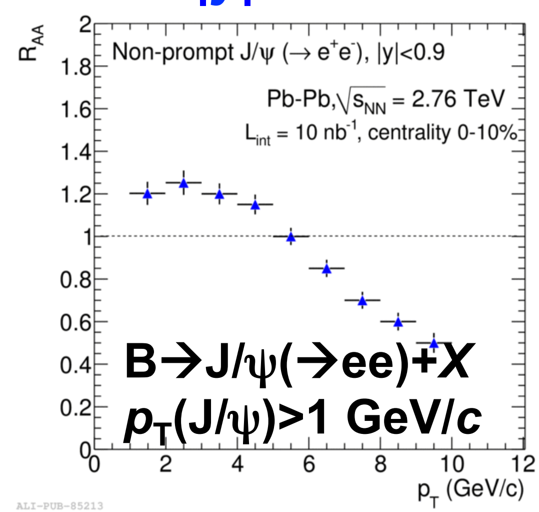
|y| < 0.9

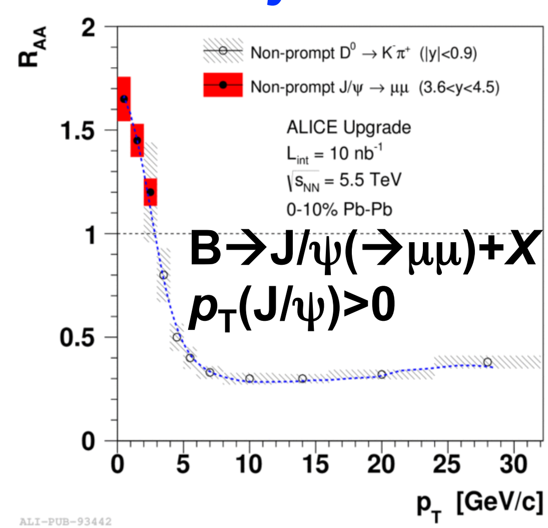


2.5 < y < 3.6



ALICE, arXiv:1504.07151

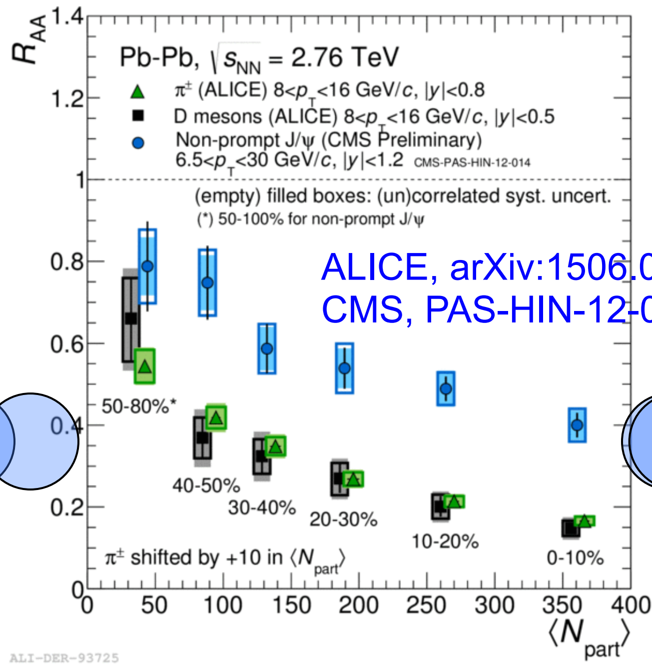




ALICE, CERN-LHCC-2013-024, CERN-LHCC-2015-001

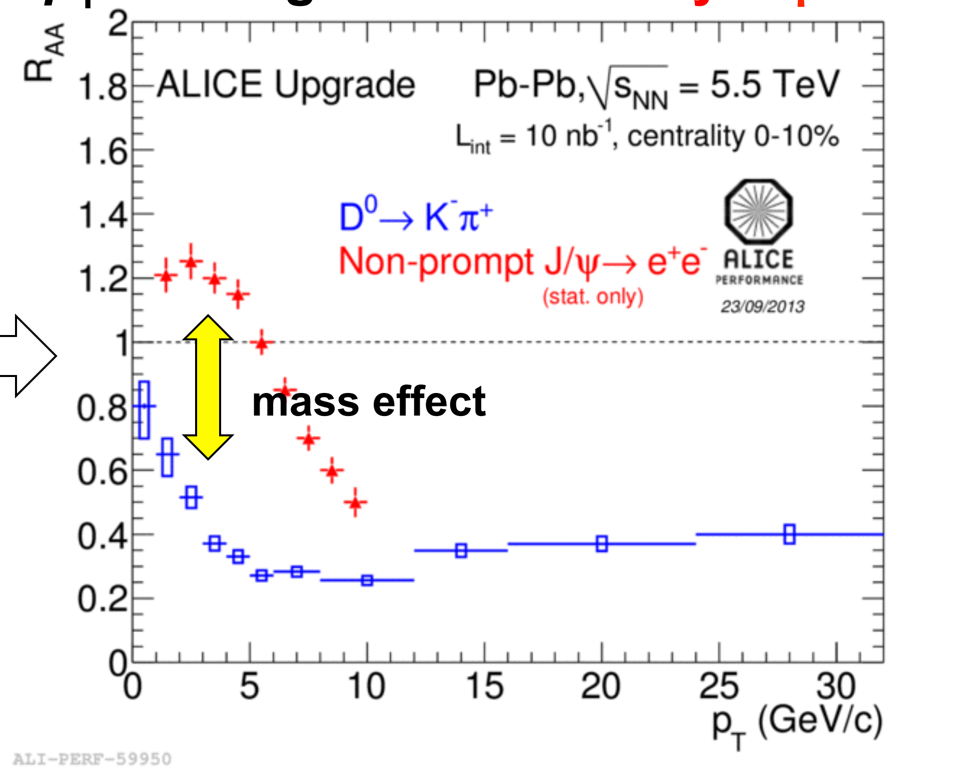
Heavy flavour R_{AA}: Run I vs. Upgrade

Present data at p_T~10 GeV/*c*



ALICE, arXiv:1506.06604
CMS, PAS-HIN-12-014

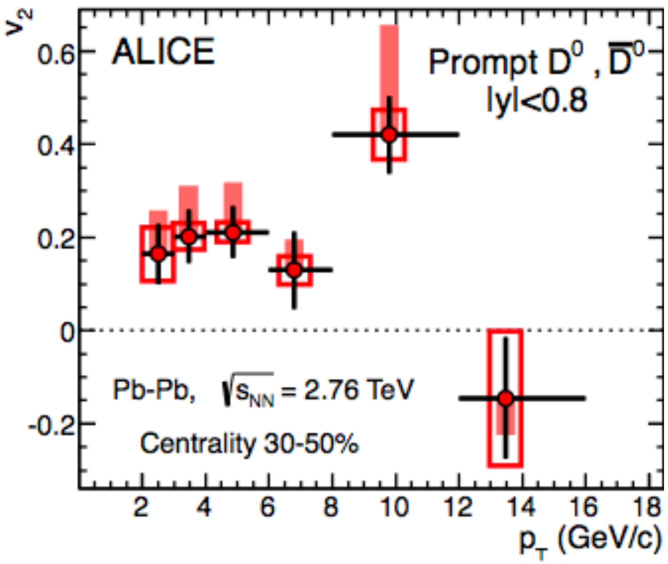
Upgrade: Charm and beauty R_{AA} down to p_T~0 using D^0 and B-decay J/ψ



ALICE, CERN-LHCC-2013-024

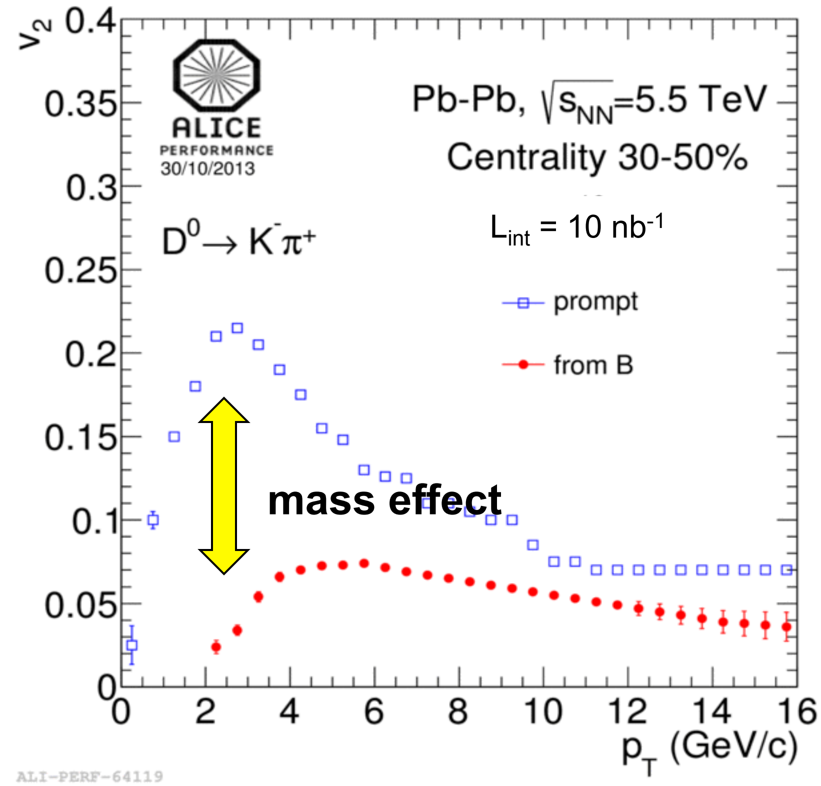
Heavy flavour v_2: Run 1 vs. Upgrade

Present data on charm v_2



ALICE, PRL 111 (2013) 102301

Upgrade: Charm and beauty v_2 down to p_T~0 using prompt and B-decay D^0

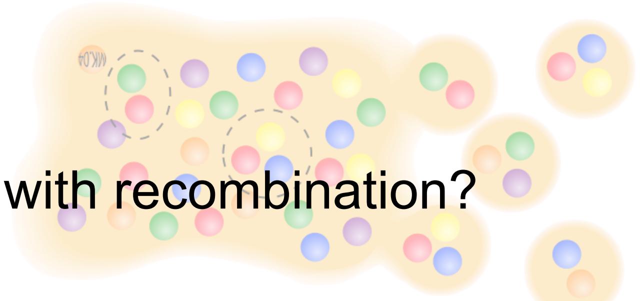


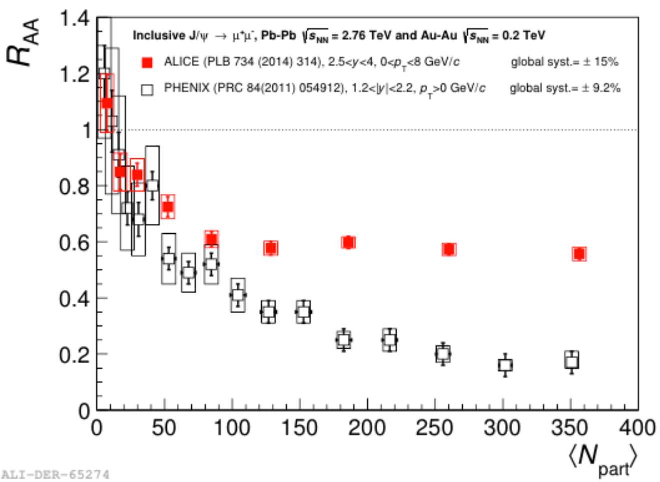
ALICE, CERN-LHCC-2013-024

Input values from BAMPS model:
C. Greiner et al. arXiv:1205.4945

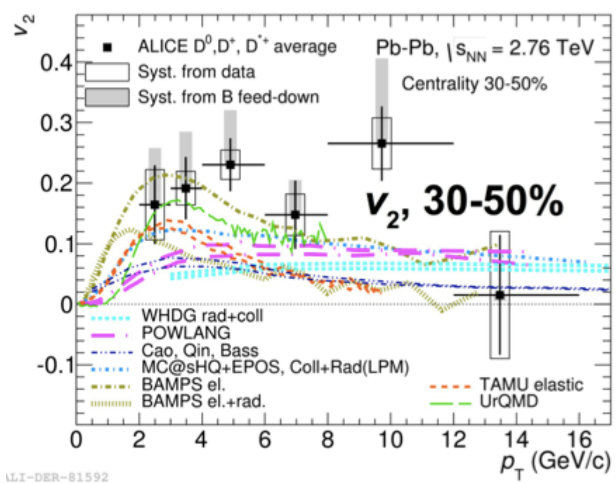
In-medium heavy-flavour hadronization?

- From LHC Run 1 data, some hints that charm *could* recombine in the medium:
  - J/ψ R_{AA} (and v_2) at low p_T
  - D v_2 (LHC) and D R_{AA} (RHIC) better described with recombination?
  - D_s R_{AA} (central value) larger than D R_{AA}?

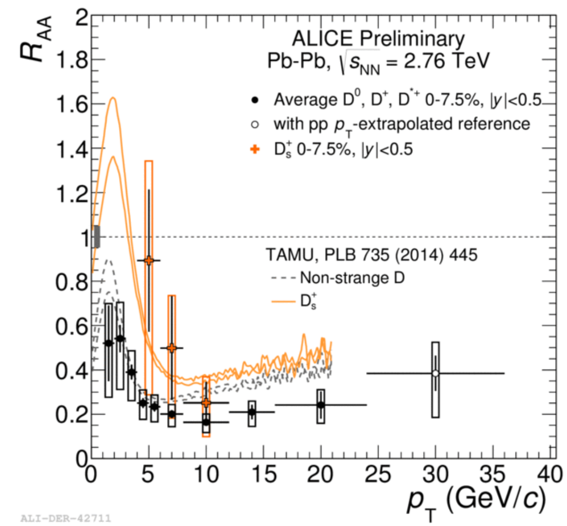




ALICE, PLB734 (2014) 314

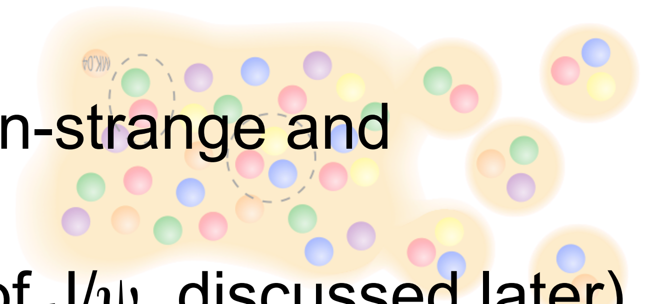


ALICE, PRC90 (2014) 034904

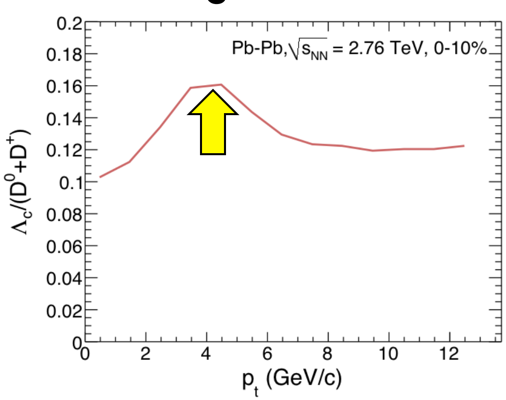


In-medium heavy-flavour hadronization?

- From LHC Run 1 data, some hints that charm *could* recombine in the medium
  - → Precise measurements of HF mesons (non-strange and strange) and baryons
  - → Precise measurements of their v_2 (+ that of J/ψ, discussed later)

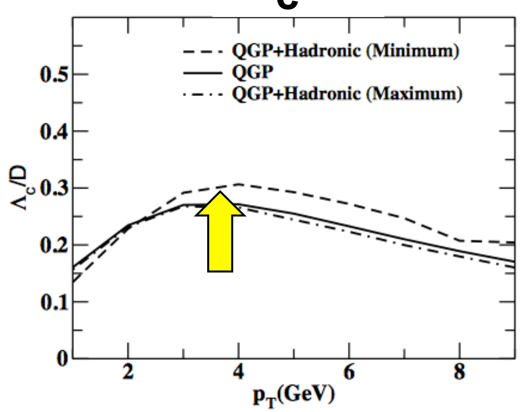


Λ_c/D



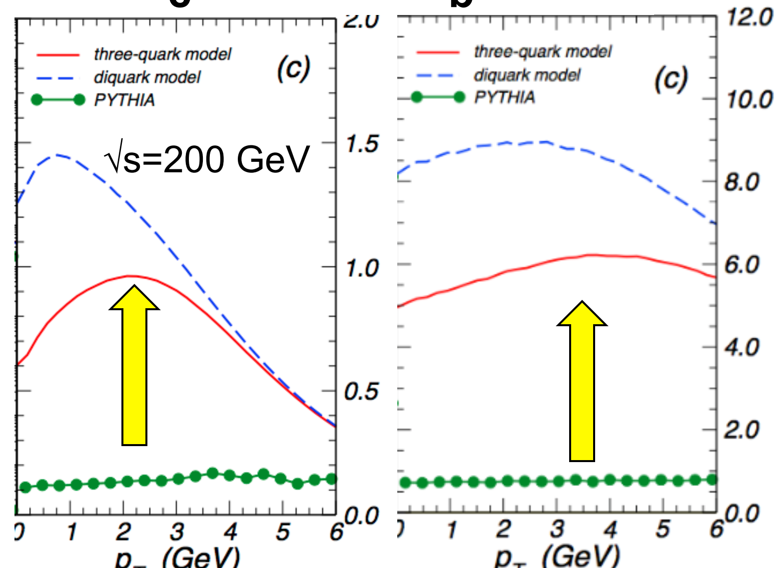
Rapp et al., based on PRL110 (2013)

Λ_c/D



Greco et al. PRD90 (2014)

Λ_c/D and Λ_b/B

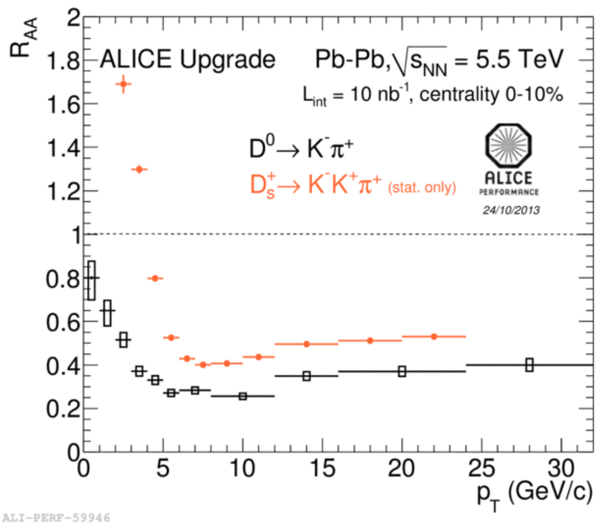


Ko et al. PRC79 (2008)

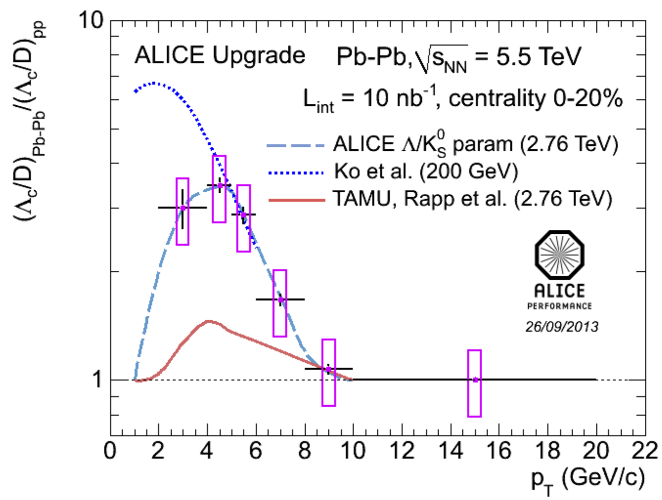
HF "hadrochemistry": Upgrade

- $\Lambda_c \rightarrow pK\pi$ and $D_s \rightarrow KK\pi$ ($c\tau$=60 and 150 μm) will be measured with good precision for p_T>2 GeV/c
- $\Lambda_b \rightarrow \Lambda_c\pi$ ($c\tau$=450 μm) accessible for p_T>7 GeV/c

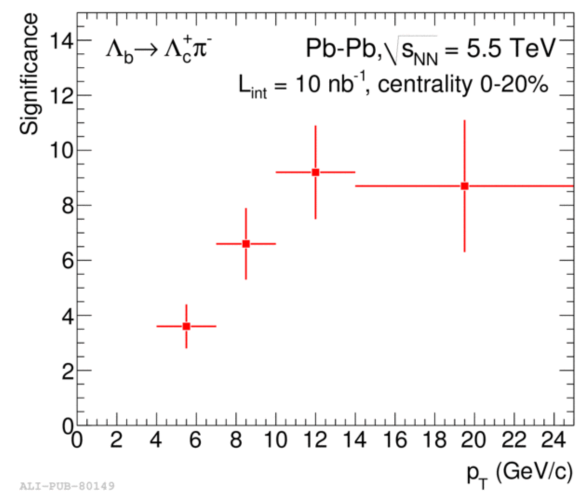
D^0 and D_s R_{AA}



Λ_c/D "enhancement"



Λ_b significance



ALICE, CERN-LHCC-2013-024

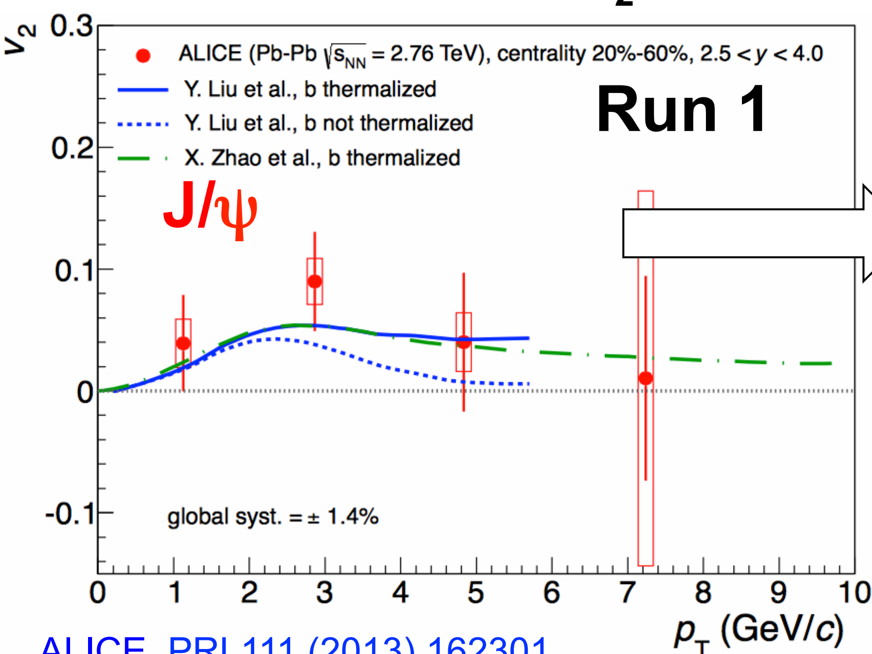
ALICE Upgrade:
(selected) physics questions & observables

1. Characterise mechanisms of quark-medium interaction
   → Heavy flavour dynamics and hadronisation at low p_T
2. **Charmonia regeneration as tool to study deconfinement**
   → **Charmonia down to zero p_T**
3. Chiral symmetry and QGP temperature at LHC
   → Vector mesons and virtual thermal photons via di-leptons
4. Production of "light" nuclei from the QGP
   → Precise measurement of light nuclei and hyper-nuclei

Low-p_T charmonium: Run 1 vs. Upgrade

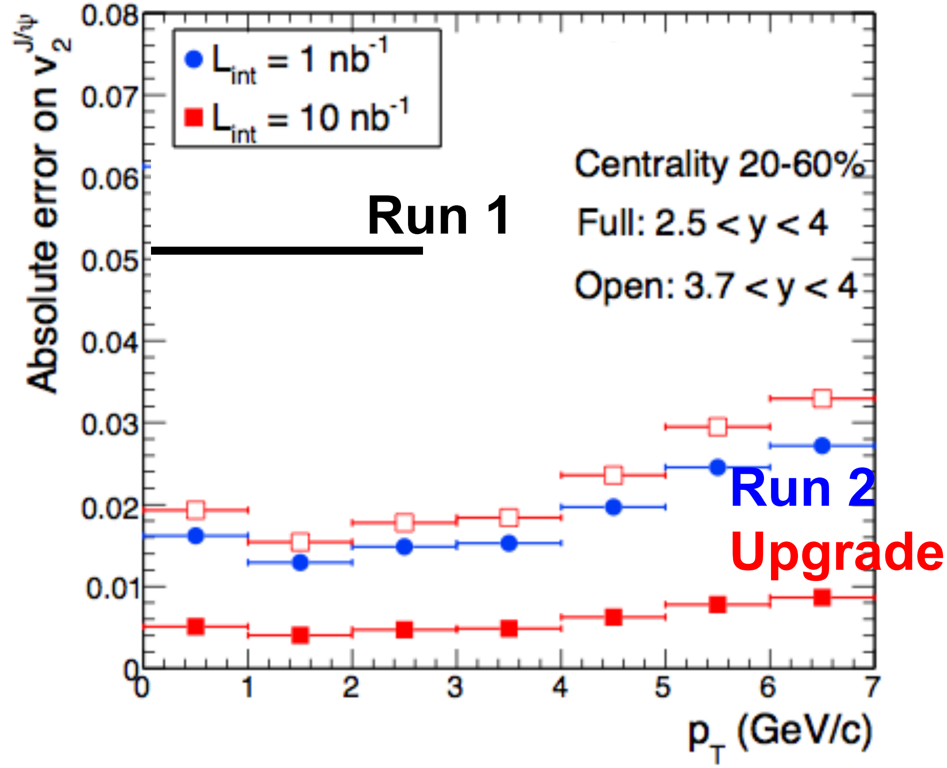
- Is J/ψ v_2 consistent with that of D mesons in a regeneration scenario?
- J/ψ v_2 with expected precision better than 0.005 (x10 better than in Run-1), also for *prompt* J/ψ (more direct comparison with models)

Run 1: hint of v_2>0



ALICE, PRL111 (2013) 162301

Upgrade: x10 better precision



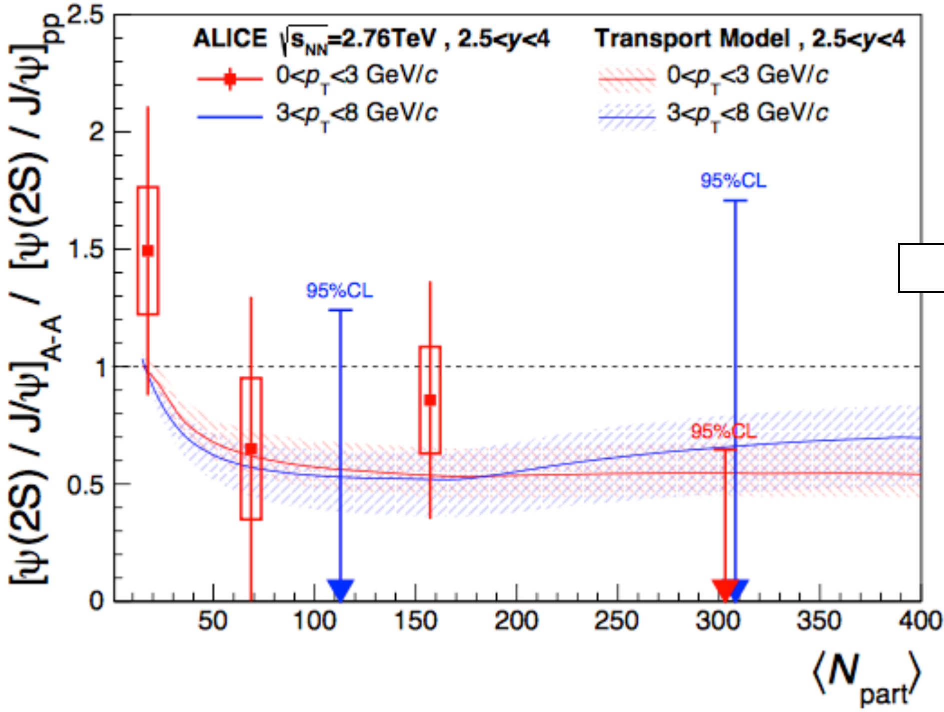
CERN-LHCC-2012-012

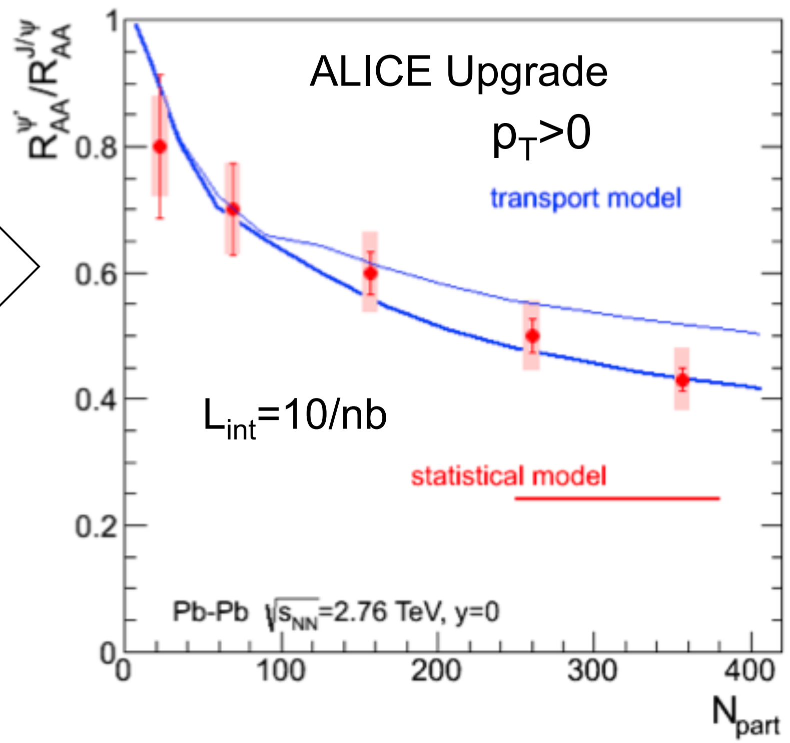
Low-p_T charmonium: Run I vs. Upgrade

- Low-p_T ψ'/ψ could allow to discriminate between models of recombination (transport vs. statistical)

$R_{AA}(\psi')/R_{AA}(\psi)$

Run 1: limited precision, no central coll. **Upgrade: p_T>0, precision <10%**





ALICE, arXiv:1506.08804

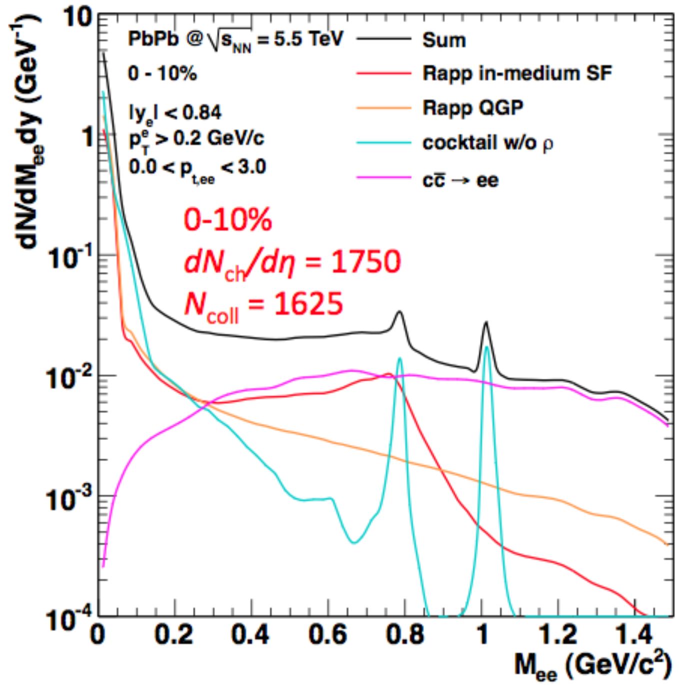
ALICE, CERN-LHCC-2013-014

ALICE Upgrade: (selected) physics questions & observables

1. Characterise mechanisms of quark-medium interaction
   → Heavy flavour dynamics and hadronisation at low p_T
2. Charmonia regeneration as tool to study deconfinement
   → Charmonia down to zero p_T
3. **Chiral symmetry and QGP temperature at LHC**
   → **Vector mesons and virtual thermal photons via di-leptons**
4. Production of "light" nuclei from the QGP
   → Precise measurement of light nuclei and hyper-nuclei

ρ spectral function and thermal radiation via "low-mass" di-leptons

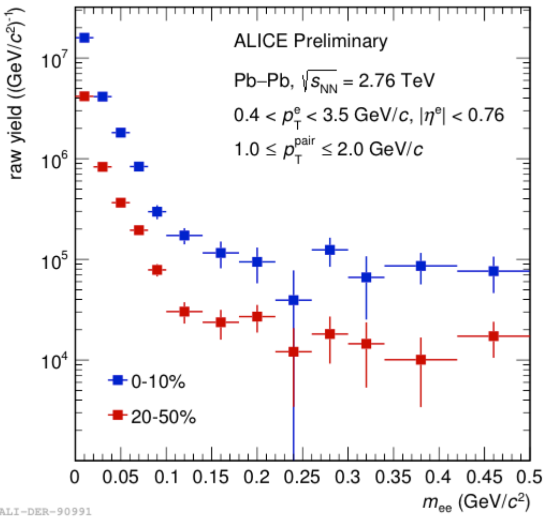
Di-lepton signals:
- Vector mesons (ρ) → l^+l^-
- QGP radiation $\gamma/\gamma^* \rightarrow l^+l^-$

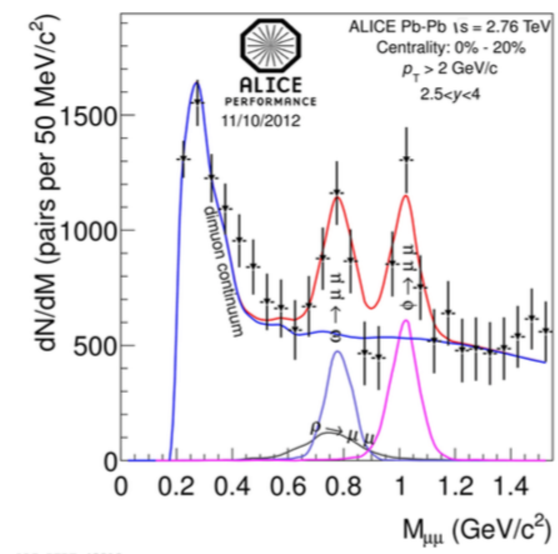


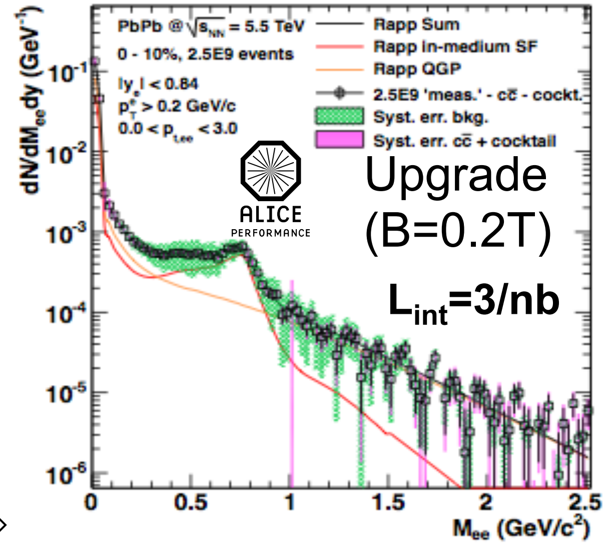
Very large combinatorial background:
- Conversions in the material (for ee)
- π/K decays (for μμ)
- Charm decays

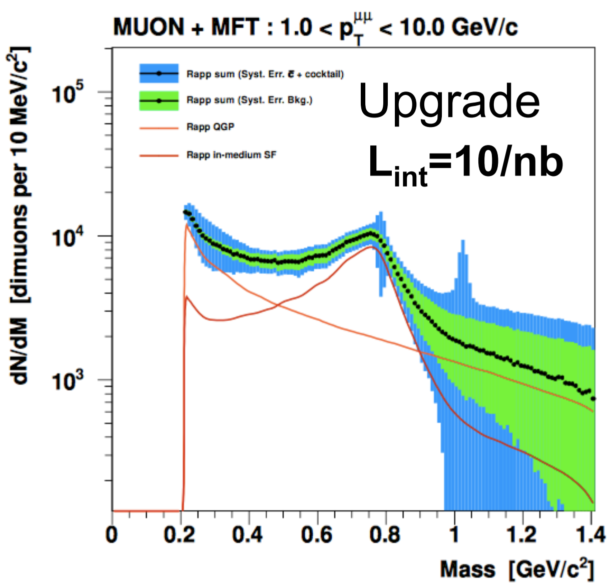
Benefits of the upgrade:
- ITS reduced thickness → less conversions
- ITS tracking efficiency → measure conversions
- ITS/MFT resol → reject charm→e/μ and π/K→μ
- High rate → statistical significance x10
  → dedicated low-field run for optimal electron acceptance at low p_T

Di-leptons: Run 1 vs. Upgrade









Both ee and μμ: good sensitivity to ρ spectral function in both channels

ee, IMR: measurement of thermal radiation inv. slope with ~10% precision

CERN-LHCC-2012-012
CERN-LHCC-2013-014

ALICE Upgrade: (selected) physics questions & observables

1. Characterise mechanisms of quark-medium interaction
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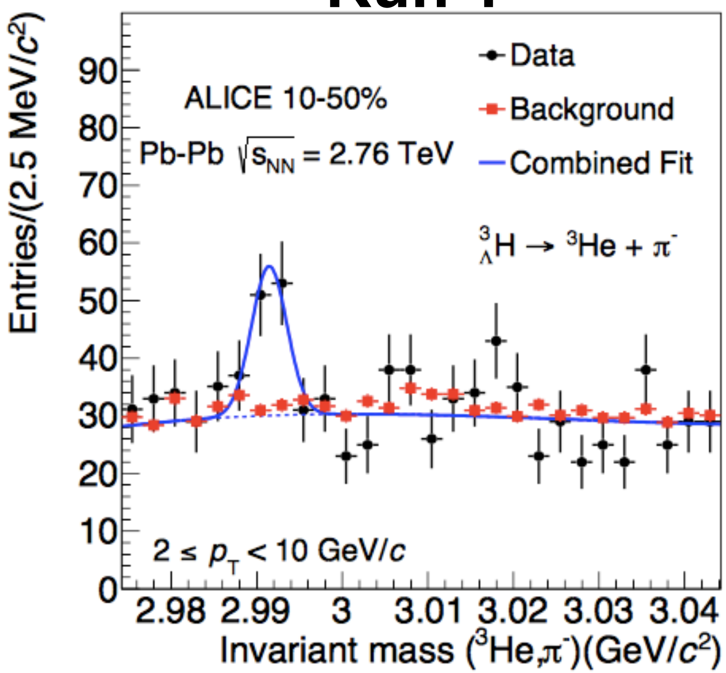
   → **Precise measurement of light nuclei and hyper-nuclei**

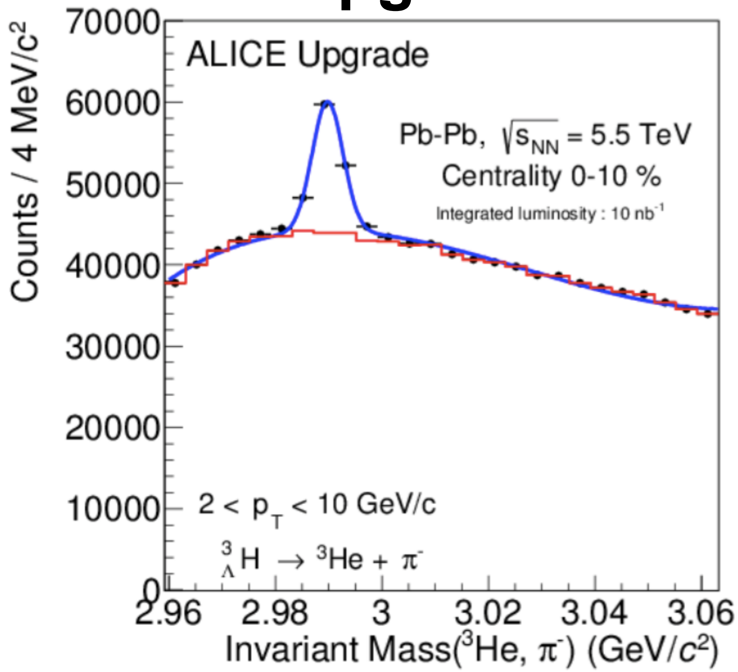
Example: Hypertriton, Run 1 vs. Upgrade

- Production of light nuclei and hyper-nuclei in AA is sensitive to QGP hadronisation mechanisms: statistical hadronisation vs. coalescence of nucleons and Λ's

Run 1



Upgrade



ALICE, arXiv:1506.08453

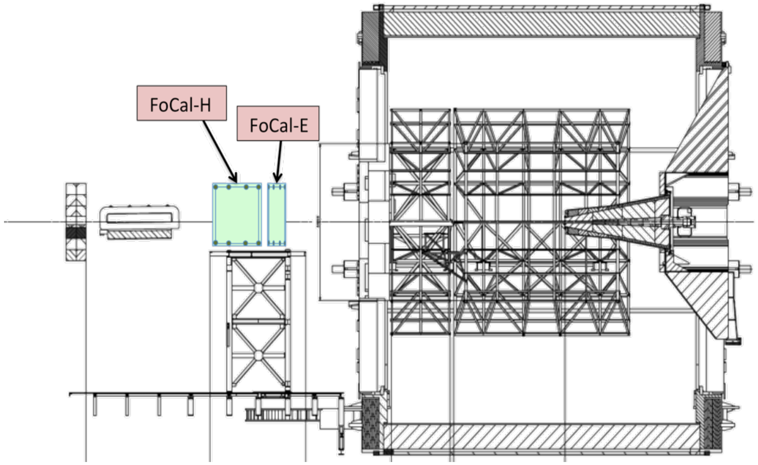
ALICE, CERN-LHCC-2013-024

Outline

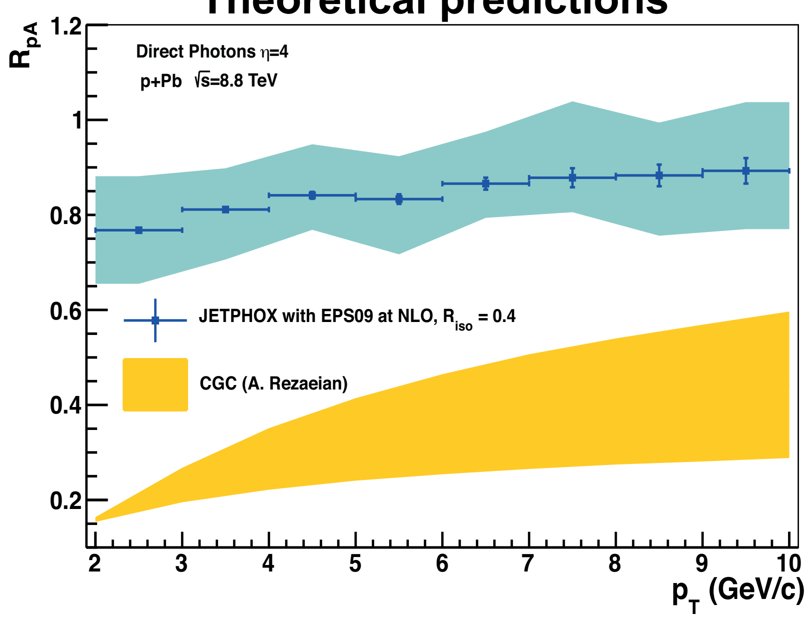
- Future of the LHC heavy ion programme
- ALICE upgrade goals and strategy
- Overview of detector upgrades
- Selected physics items: present status and prospects with the upgrade
  - Open heavy flavour
  - Charmonium
  - Low-mass di-leptons
  - Light nuclei
- Outlook: FoCal project study

Study for a forward calorimeter in ALICE

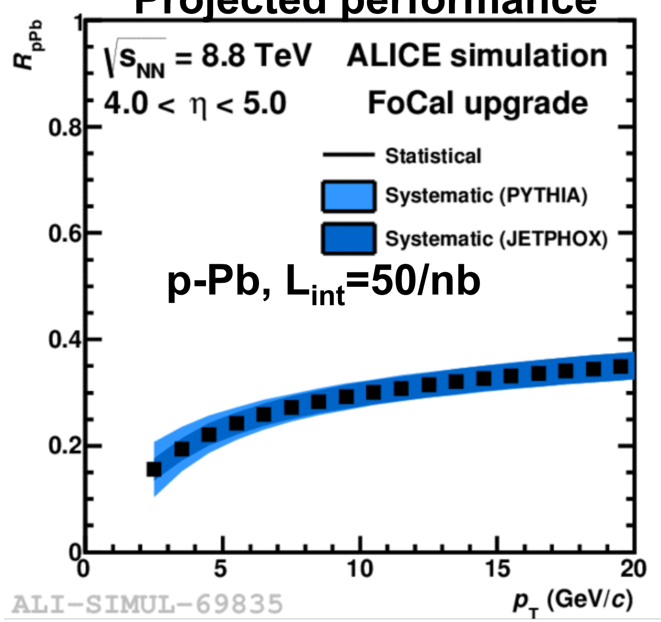
- FoCal: R&D for a high-granularity calorimeter at η~3-5 with focus on saturation physics studies
  - Possible installation during LS3
- Benchmark measurement: direct photons η~4-5 in p-Pb ($x \sim 10^{-5}$)
  - Sensitive to Shadowing vs. Saturation



Theoretical predictions



Projected performance



Summary

- Major ALICE upgrade in 2018-19
  - Increase tracking precision at low p_T at mid and forward y
  - Enable readout rate of 50 kHz in Pb-Pb
  - Min-bias sample x100 larger than that foreseen in Run-2

- Unique programme extending to the late 2020s

- Focus on rare –and high background– probes and their interaction with the medium (HF, charmonium, di-leptons)

- Ongoing study for further upgrade aimed at forward physics

Спасибо !

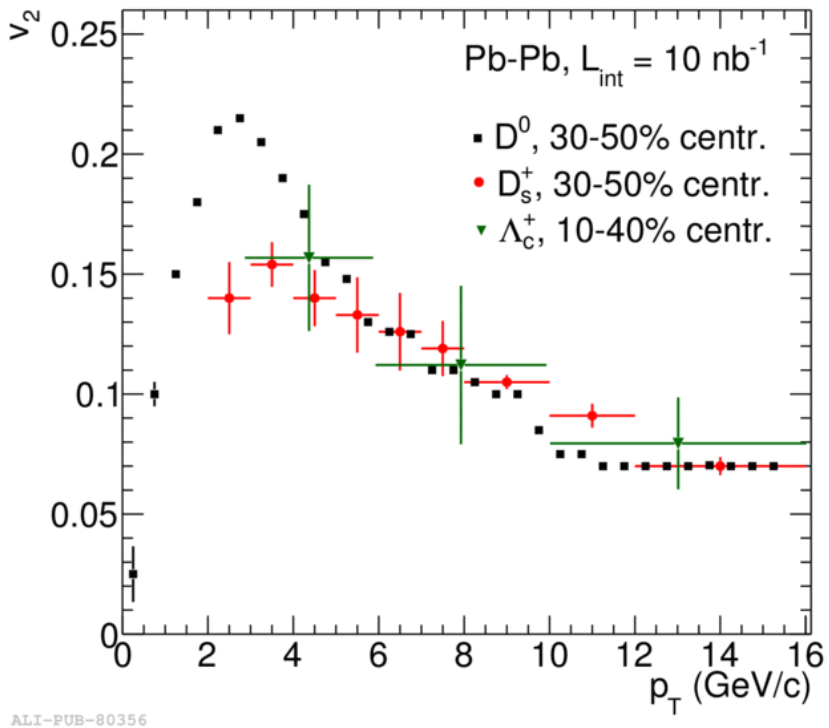
Run:225000
Timestamp:2015-06-03 09:21:39(UTC)
Colliding system:p-p
Energy: 13 TeV

EXTRA SLIDES

HF "hadrochemistry": Upgrade

- $\Lambda_c \rightarrow pK\pi$ and $D_s \rightarrow KK\pi$ ($c\tau$=60 and 150 μm) will be measured with good precision for p_T>2 GeV/c
- $\Lambda_b \rightarrow \Lambda_c\pi$ ($c\tau$=450 μm) accessible for p_T>7 GeV/c

D^0, D_s, Λ_c v_2



ALICE, CERN-LHCC-2013-024

ATLAS, CMS, LHCb: upgrades most relevant to HI

- ATLAS
  - Additional pixel layer (LS1), then new tracker (LS3): tracking and b-tag
  - Fast tracking trigger (LS2): high-multiplicity tracking
  - Calorimeter and muon upgrades (LS2): electron, γ, muon triggers
- CMS
  - Upgrade of trigger and DAQ, L1 calorimeter trigger (LS1): enables L1 rejection at 95%, e.g. (after LS2) from 50 kHz to <3 kHz (HLT input)
  - New pixel tracker (YES15-16), then new tracker (LS3): tracking and b-tag
  - Extension of forward muon system (LS2): muon acceptance
  - Upgrade forward calorimeter (LS3): forward jets in HI
- LHCb (LS2)
  - New trackers (pixel, strip, scintillating fiber)
  - Readout upgrade: up 40 MHz (pp) → exploit full p-Pb luminosity