A Large Ion Collider Experiment

Perspectives of the ALICE Central Barrel Upgrade

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HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

BMBF Forschungsschwerpunkt ALICE Experiment 201

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EMMI

Outline

- Future Heavy-Ion Program of ALICE
- ALICE Central Barrel Upgrade
- Future Measurements on Heavy-Flavor Probes and Charmonium
- Summary and Outlook

ALICE Upgrade Strategy for Runs 3 + 4

2013 — Long Shutdown I:
Detector completion (ALICE) and upgrades (ATLAS)

2018 — Long Shutdown II:
Significant detector upgrades ALICE, ATLAS, CMS, LHCb

2015 — Run 2:
~1 nb^{-1} Pb-Pb at $\sqrt{s_{NN}}$=5.5 TeV
reference data pp and p-Pb

2020 — Runs 3 + 4:
ALICE target luminosity:
- $L^{mb} \geq 10\ nb^{-1}$
- $6 \times 10^{27}\ cm^{-2}s^{-1}$
- Maximum rate (high-rate upgrade):
  50 kHz (Pb-Pb)
  200 kHz (pp)

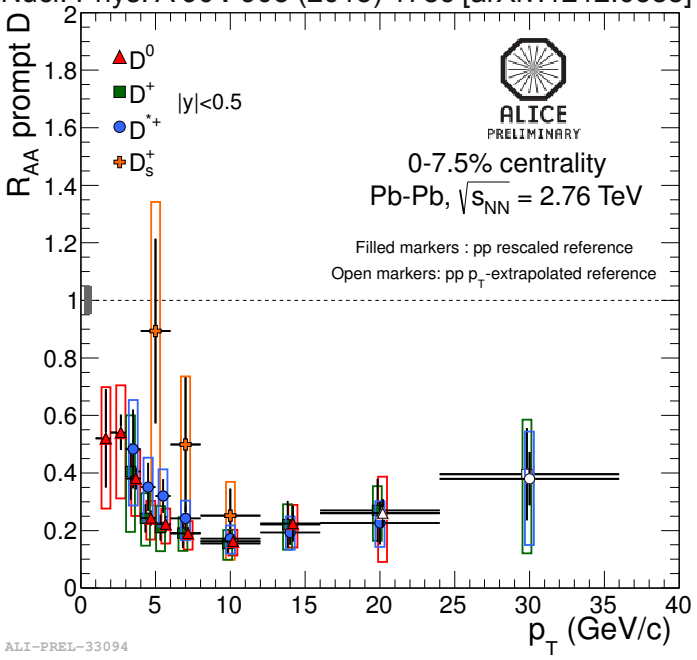
1. **Improved vertexing and tracking**
   - **New Inner Tracking System (ITS)**
   - **TPC Upgrade with GEMs**
   - Muon Forward Tracker (MFT)
2. **Fast data readout**
   - Upgrade of readout and online systems

Heavy Flavors Charmonia
Heavy Nuclei **low p_T** EM radiation
Precision Jet measurements

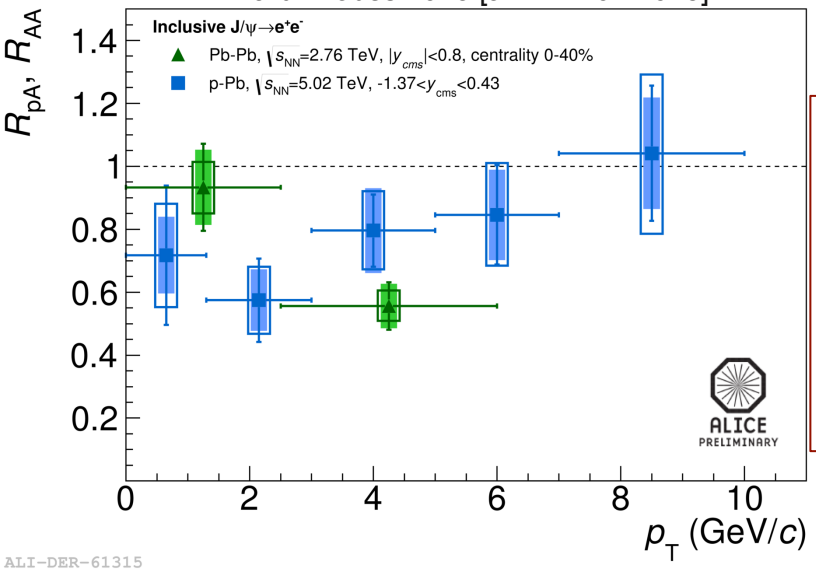
Heavy Flavor and Charmonium Measurements in ALICE

- ALICE has unique *particle identification* and *vertexing* capabilities at the LHC
- Study heavy-flavor interactions with the strongly-interacting medium
  - D^0, D^+, D_S^+, D^{*+}, Λ_c & heavy-flavor decay electrons and muons
- Quarkonium production
  - J/ψ(1S) and ψ(2S) (central and forward)

Nucl. Phys. A **904-905** (2013) 178c [arXiv:1212.0385]



Hard-Probes 2013 [arXiv:1404.1615]



Runs 3 + 4

→ Precision measurements of nuclear modification factor, collective flow, correlations, **down to lowest p_T**

→ Charmed mesons down to zero p_T

→ Beauty via non-prompt D^0 (J/ψ)

→ Full reconstruction of B mesons, Λ_c & Λ_b

→ J/ψ v_2, excited charmonia, mid-rapidiy spectrum

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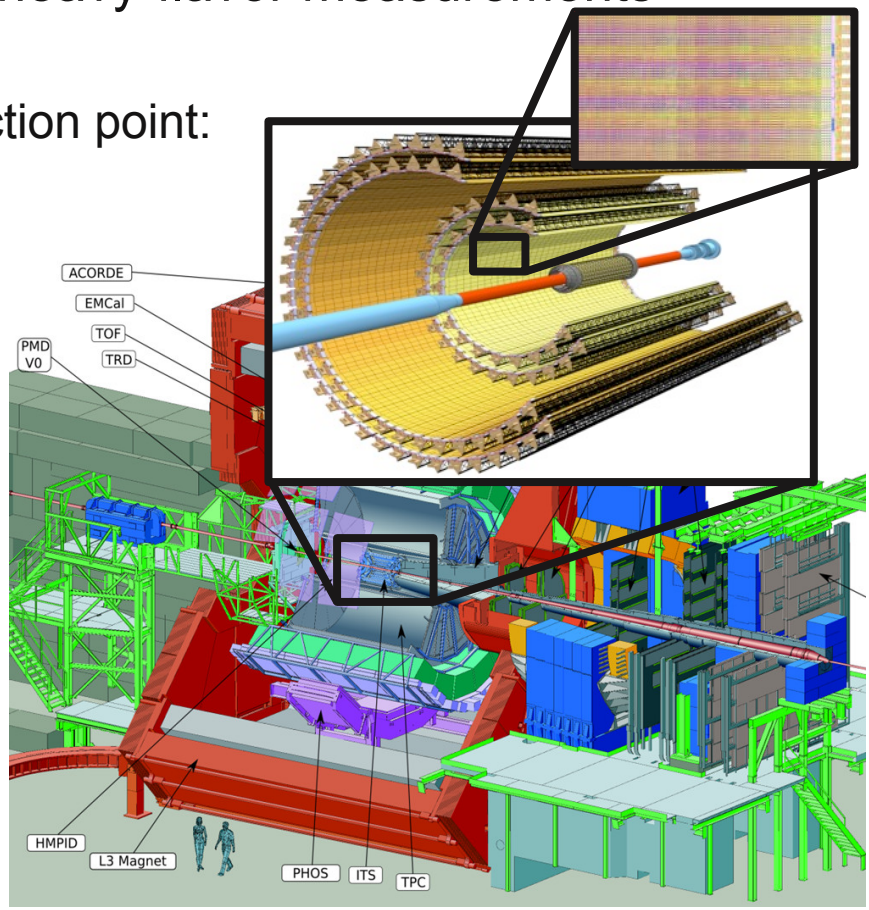
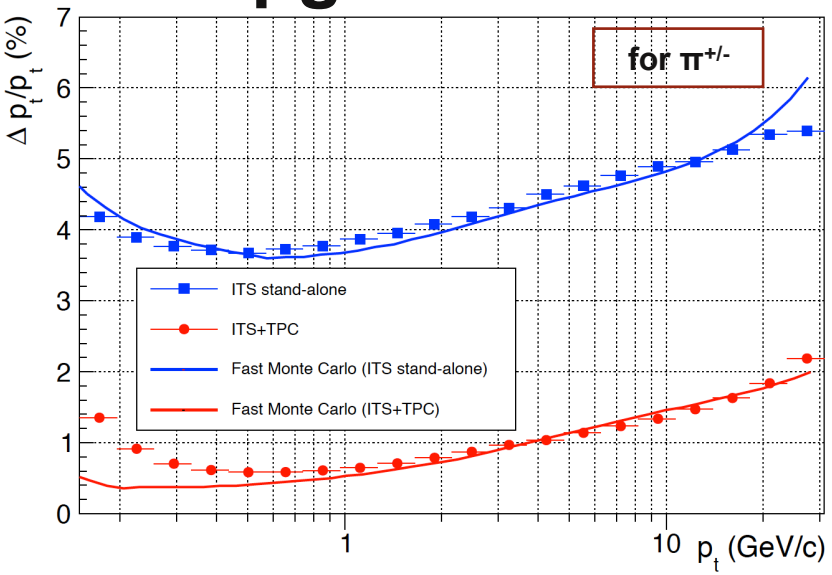
A Large Ion Collider Experiment – Upgrade of the Inner Tracking System (ITS)

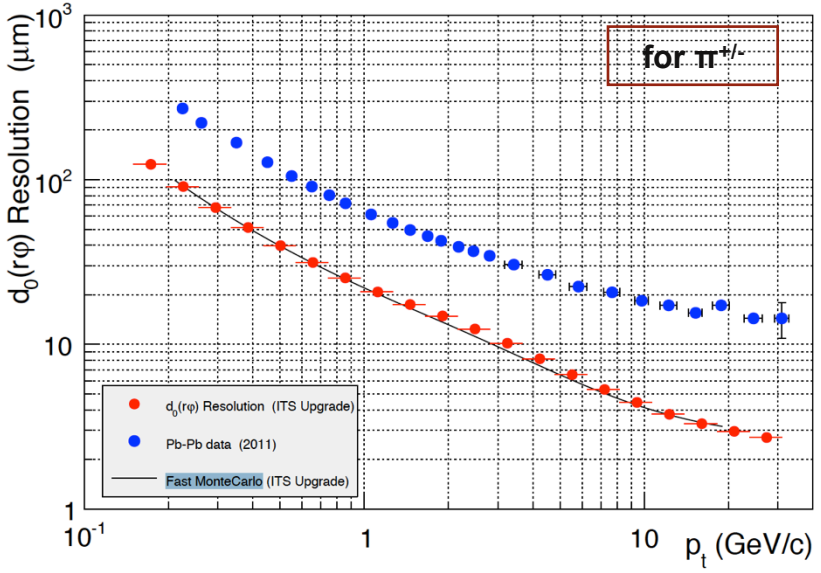
Crucial for secondary vertex detection in heavy-flavor measurements

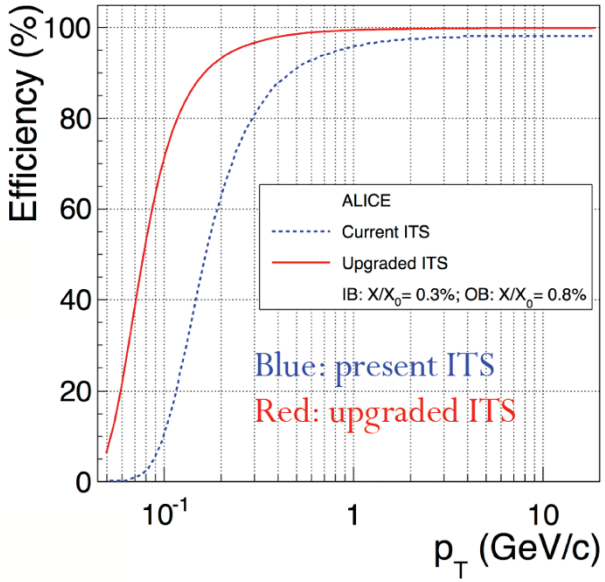
1. **Improved impact parameter resolution**
   - First reconstruction layer closer to interaction point:
     39 mm → 22 mm
   - Ultra low material budget (x/X_0) per layer:
     1.14 % → 0.3 – 0.9 %
   - New pixel technology & reduced pixel size
     Monolithic Active Pixel Sensors
     50 x 425 μm² → O(30 x 30 μm²)
2. **Improved tracking efficiency and p_T resolution**
   - Increased number of channels:
     6 → 7 layers & all pixels
3. **Fast data readout of each interaction**
   - **1 kHz → Up to 50 kHz in Pb–Pb collisions**
4. **Accessible for possible maintenance during yearly shutdowns**



ITS Upgrade Performance







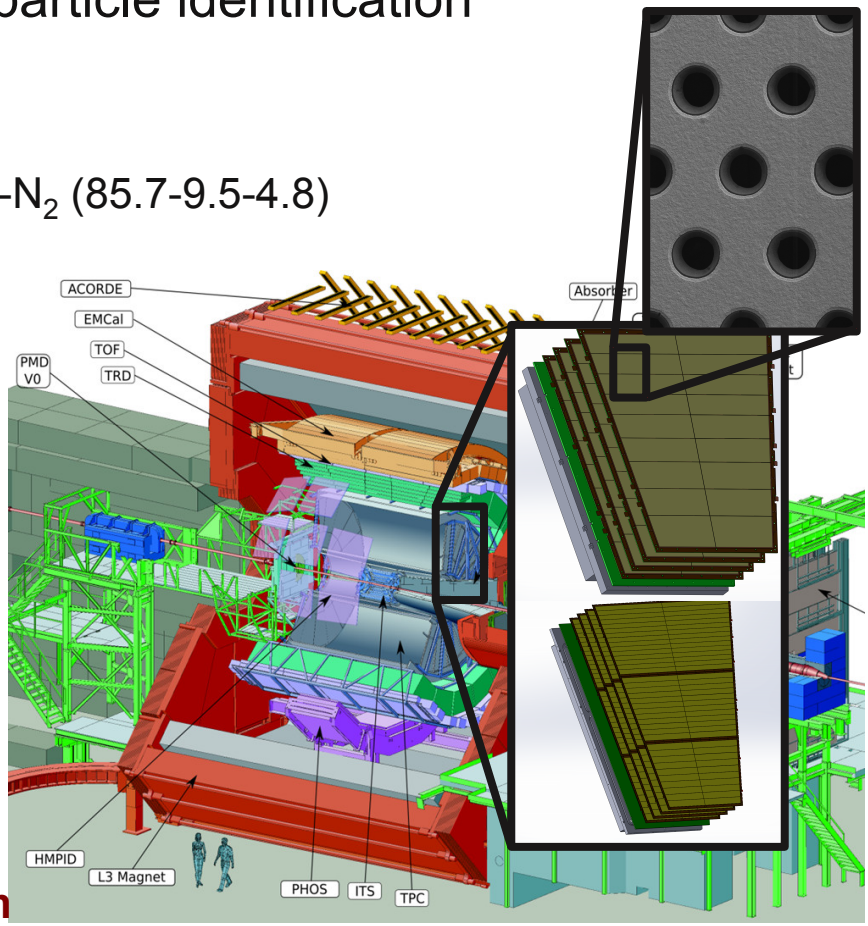
At 400 MeV/*c*

- **~ 4 %** momentum resolution
- **~ 50 µm** pointing resolution
- **~ 98 %** efficiency

A Large Ion Collider Experiment – Upgrade of the Time Projection Chamber (TPC)

Crucial for charged-particle tracking and particle identification

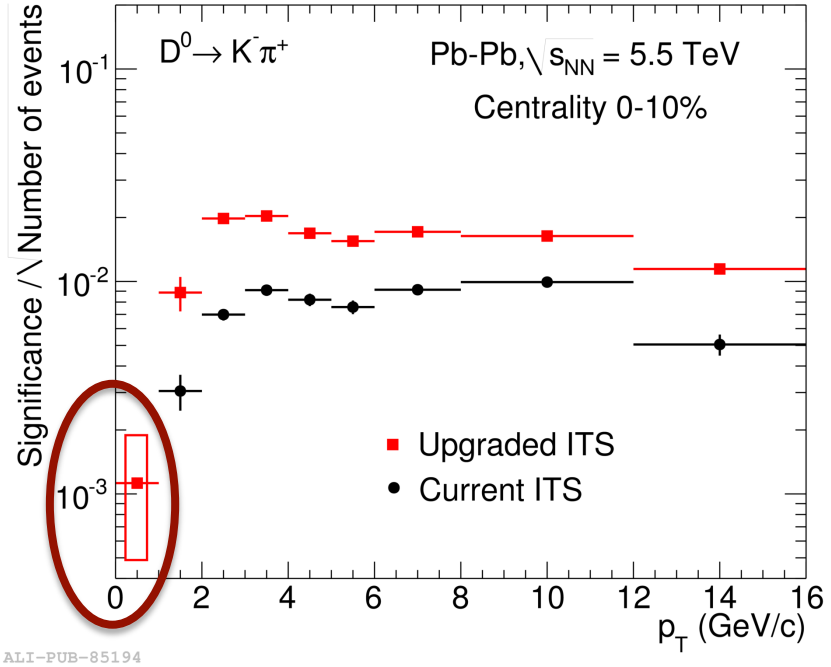
1. **New readout chambers**
   - Based on **Gas Electron Multipliers** (GEMs)
   - Ion backflow **< 1 % at gain of 2000** in Ne-CO_2-N_2 (85.7-9.5-4.8)
2. **Continuous readout scheme**
   - **Continuous readout**
   - Front-end noise around 670*e*
3. **Online data reduction**
   - Based on cluster finding + track association
   - **Data compression of ~20**
4. **Preserve current performance**
   - Momentum and d*E*/d*x* resolution
   - **Local energy resolution < 12 % (at 5.9 keV)**
   - **Correct space charge distortions to the order of intrinsic spatial resolution ~200 µm**
5. **Reuse of existing hardware**

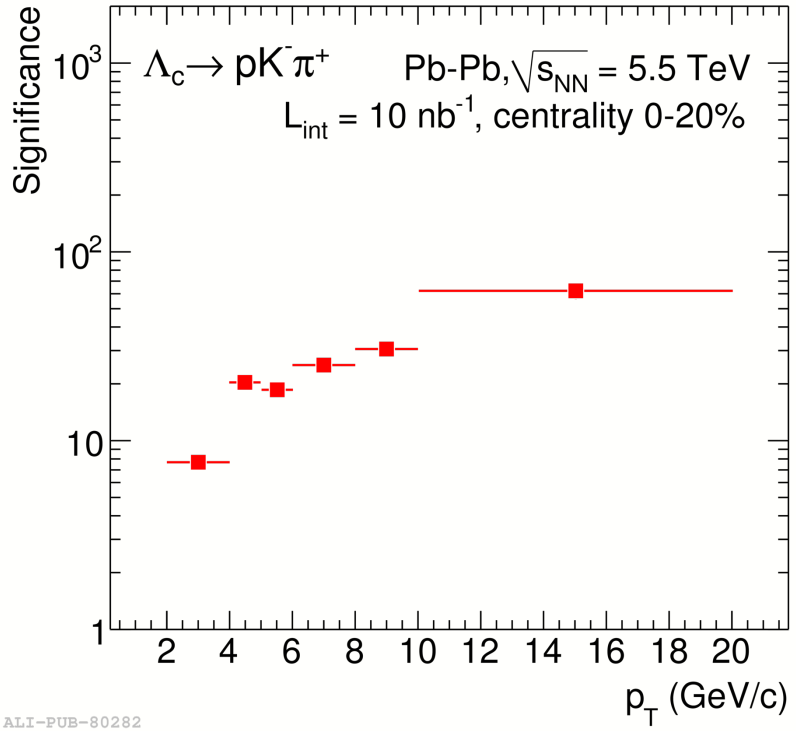


Charmed Meson & Baryon Reconstruction as Benchmark

Dedicated simulations with current and new ITS detector

- D^0 topological selection similar to 2010 Pb-Pb data analysis → efficiency from simulation
- HIJING background scaled to match data and collision energy
- ~10 fold background rejection for $p_T < 2$ GeV/c



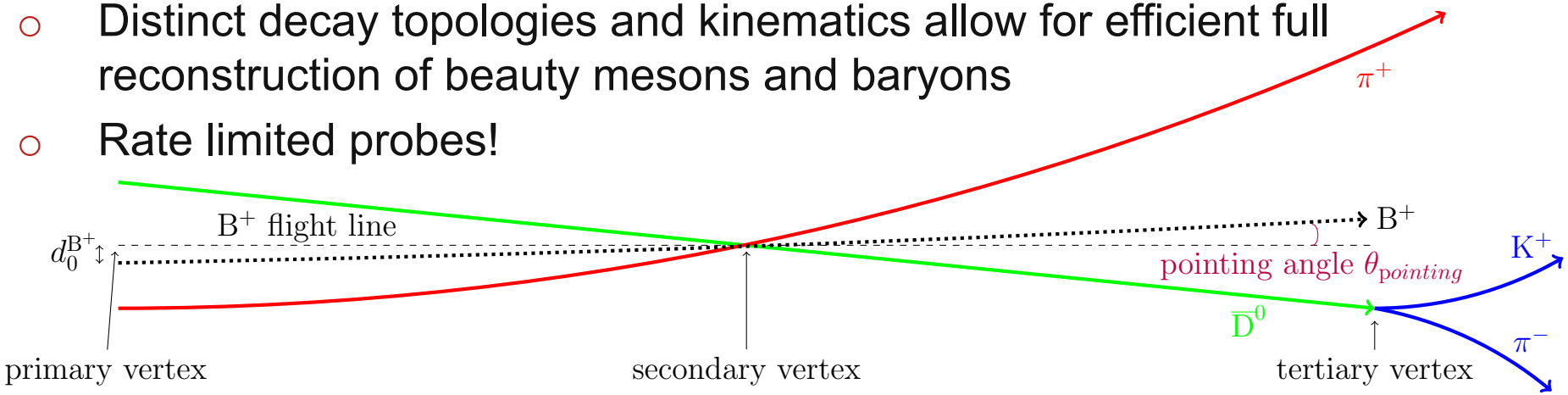


- Λ_c reconstruction requires excellent spatial resolution ($c\tau \approx 60$ μm) and PID capabilities
- Dedicated combinatorial & correlated background analysis
- Significant measurement for $p_T > 2$ GeV/c

New Measurements in the Beauty Sector

Full kinematic reconstruction of beauty mesons and baryons

- Distinct decay topologies and kinematics allow for efficient full reconstruction of beauty mesons and baryons
- Rate limited probes!



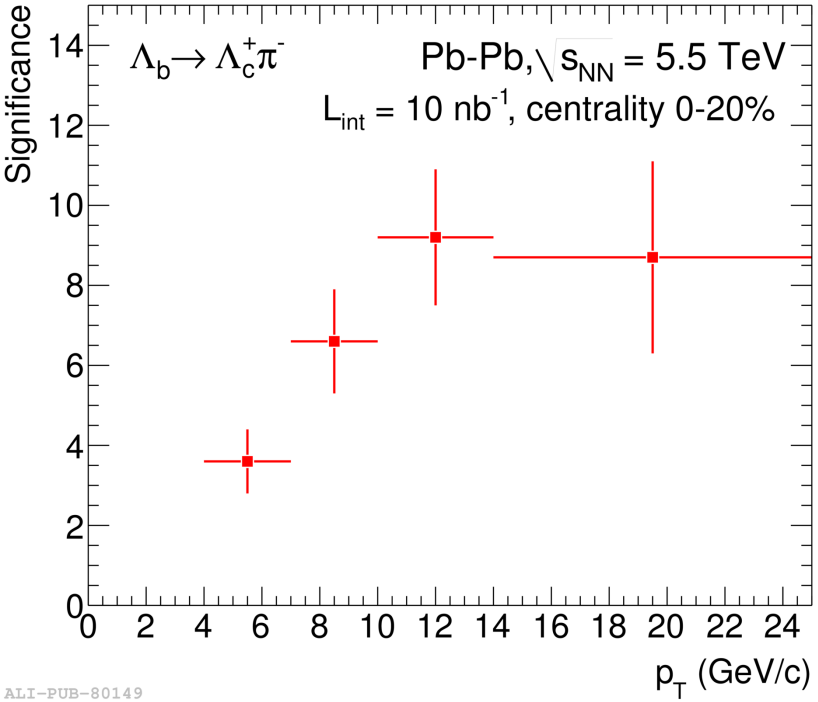
	$B^- \rightarrow D^0\pi^-$ ($D^0 \rightarrow K^-\pi^+$)	$\Lambda_b^0 \rightarrow \Lambda_c^+\pi^-$ ($\Lambda_c^+ \rightarrow pK^-\pi^+$)
Invariant mass	*5.29 GeV/c^2*	*5.62 GeV/c^2*
Mean decay length	*491.4 ± 1.2 μm*	*435.3 ± 3.9 μm*
Combined branching ratio	*(1.87 ± 0.06) x 10^{-4}*	*($2.85^{+2.13}_{-1.49}$) x 10^{-4}*
Most efficient selection criteria:	*$\cos(\theta_{pointing})$, L^D/σ, p_T^π, p_T^D, d_0^B*	*$\cos(\theta_{pointing})$, L^Λ/σ, $d0^\Lambda$ x $d0^\pi$*

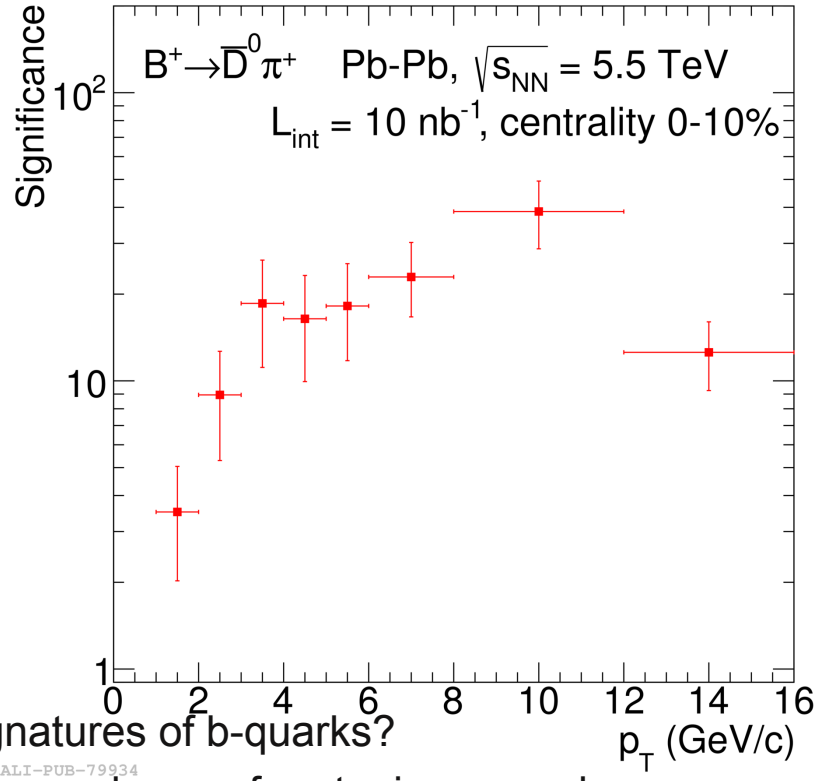
New Measurements in the Beauty Sector

Dedicated simulations for new ITS detector

- Binary scaling of $\sigma_{b\bar{b}}$ from FONLL calculations
- Track rotation method for combinatorial background generation
- Model uncertainties & systematic uncertainties from track rotations

→ Significant, new measurements down to low p_T





- Flow signatures of b-quarks?
- Flavor dependence of partonic energy loss ($R_{AA}^{b} > R_{AA}^{c} > R_{AA}^{u/d}$)?

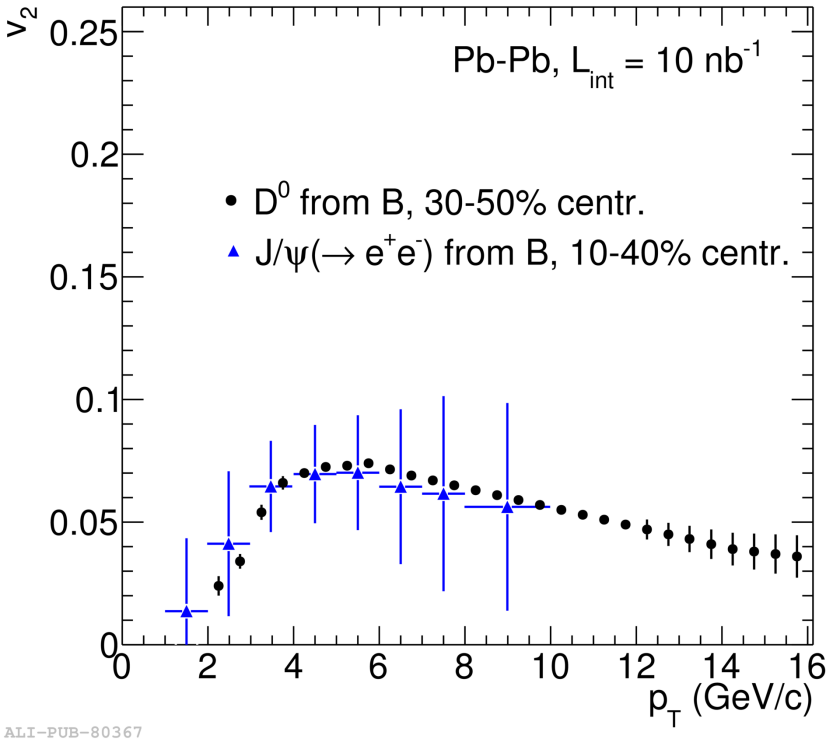
→ Determine expected sensitivity

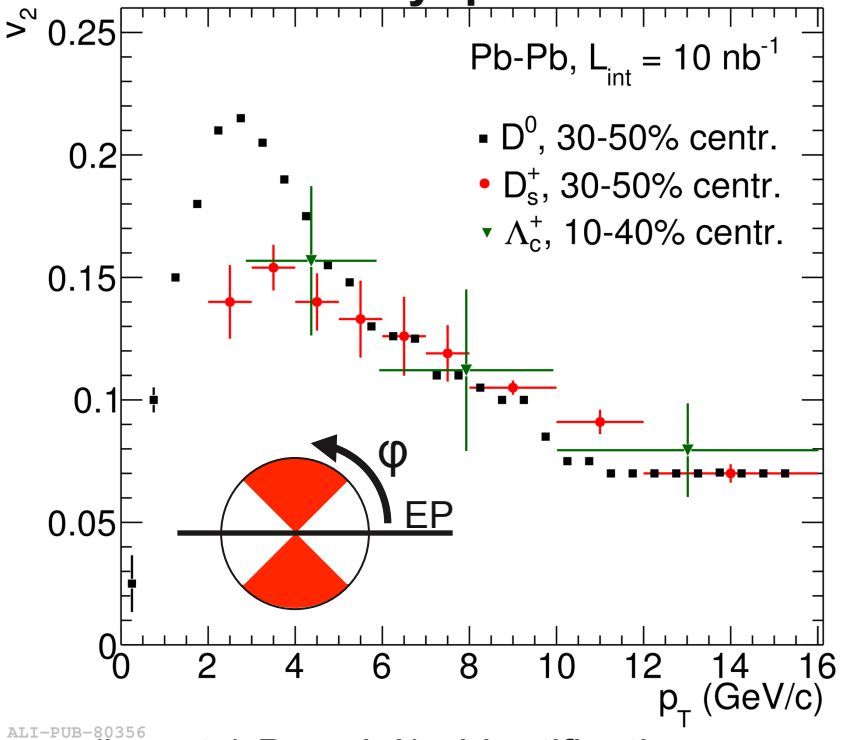
→ Further channels ($B^0, B^+ \rightarrow D^* K^+, B^+ \rightarrow J/\psi K^+ (J/\psi \rightarrow e^+e^-)$)

Heavy Flavor Azimuthal Anisotropy

Measure of interactions between thermal QGP bulk & heavy quarks

- Systematic uncertainties expected to be small as yield extraction and correlation uncertainties mostly cancel in v_2 ratio
- Future measurement very sensitive to v_2 signatures for charmed mesons and baryons





ALI-PUB-80356

- Non-prompt (beauty) D and J/ψ identification via fits to impact parameter and pseudoproper decay length
- 10 – 40 %: Optimal choice for statistics-limited measurements (expected signal yields and number of events largest)

ALI-PUB-80367

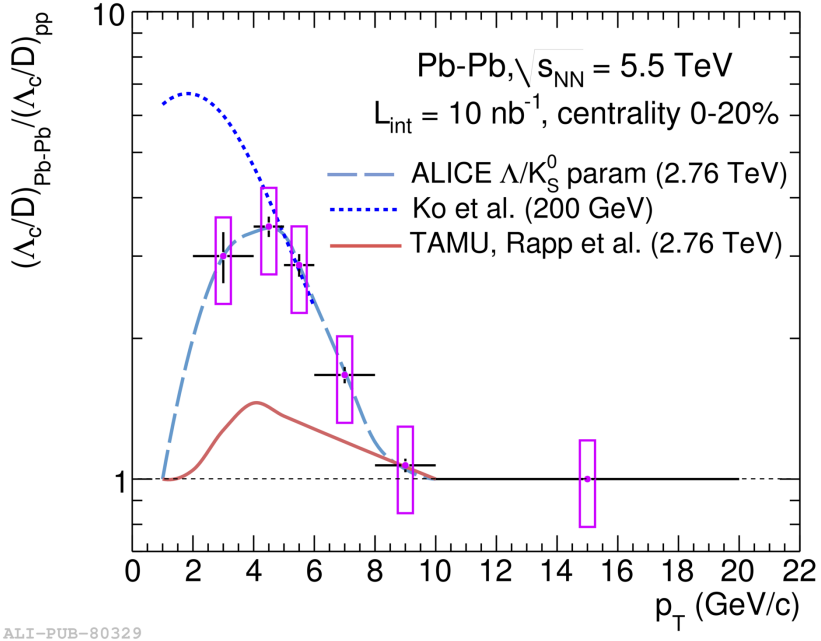
Heavy Flavor Nuclear Modification Factor

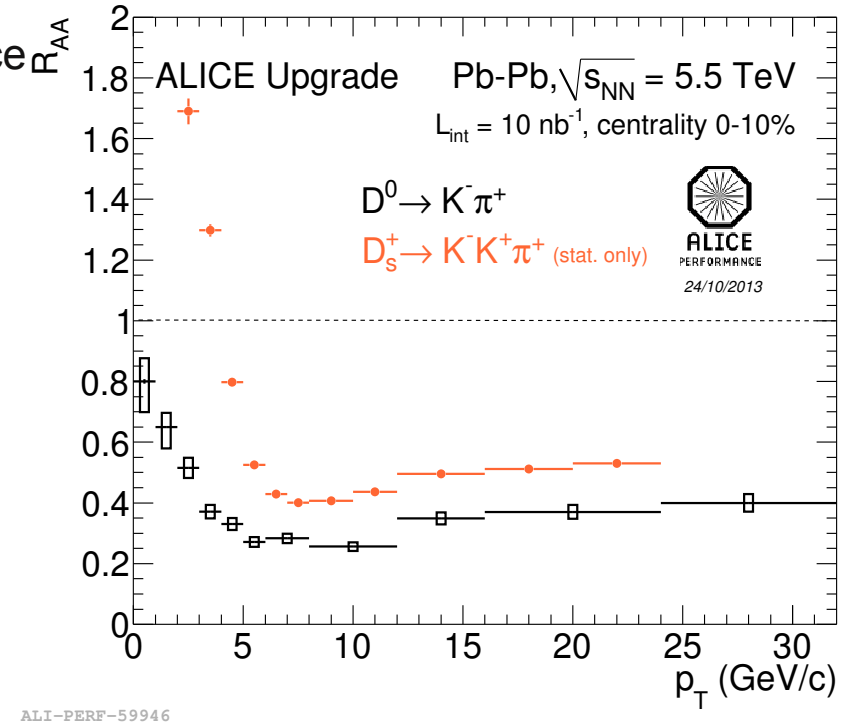
Direct handle on heavy quark energy loss, its color charge dependence,…

- Assume statistical uncertainties of the pp reference are negligible compared to Pb-Pb
- Systematic uncertainties partially cancel (tracking and cut selection efficiency)
- **High precision measurements**

→ high-p_T heavy quarks shifted to low momenta?

→ Thermalization in the system?





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- Highly sensitive measurement on Baryon/Meson Ratios

→ Can clearly distinguish between models

→ Coalescence, thermal models, …

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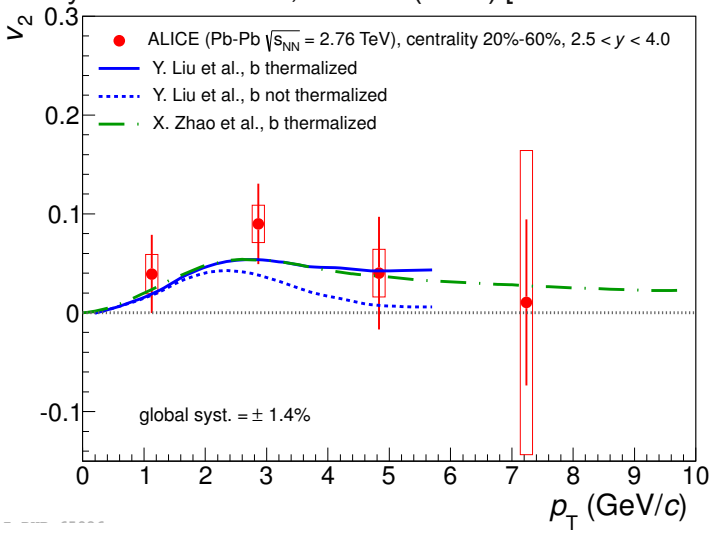
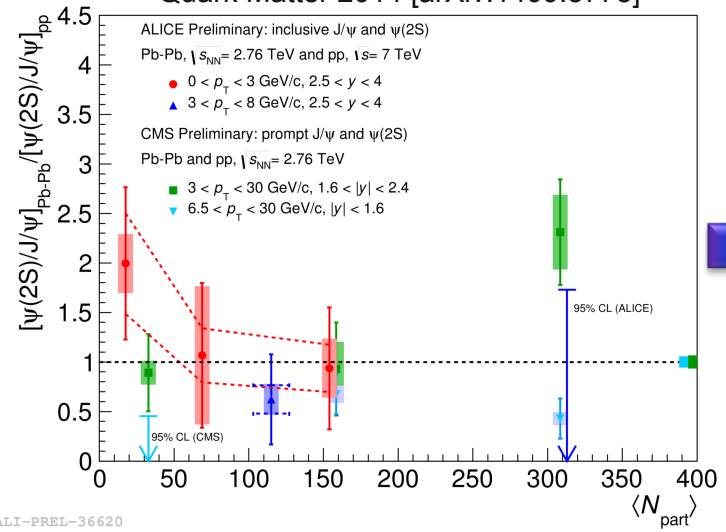
Prospect on Charmonium Measurements

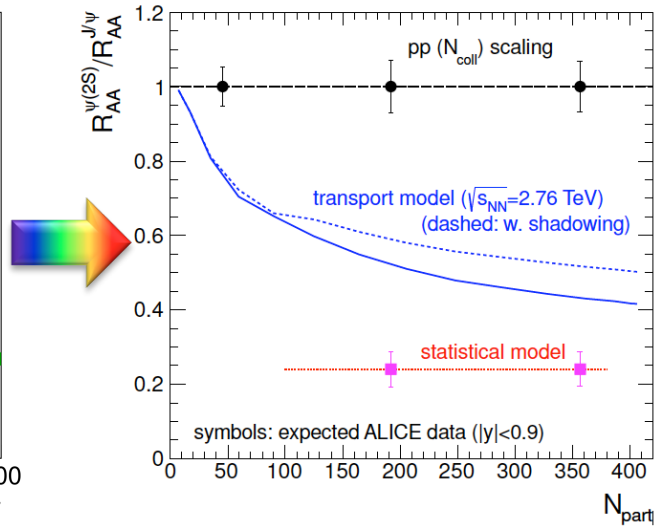
- Good agreement between R_{AA} of ALICE and CMS (high p_T)
- v_2 measurement of J/ψ hints non-zero value
  → Recombination $c\bar{c}$ pairs?
- Tension between ψ(2S) production between ALICE and CMS
  → Statistical hadronization, kinetic transport?

Phys. Rev. Lett. **111**, 162301 (2013) [arXiv:1303.5880]



Quark Matter 2014 [arXiv:1409.5778]





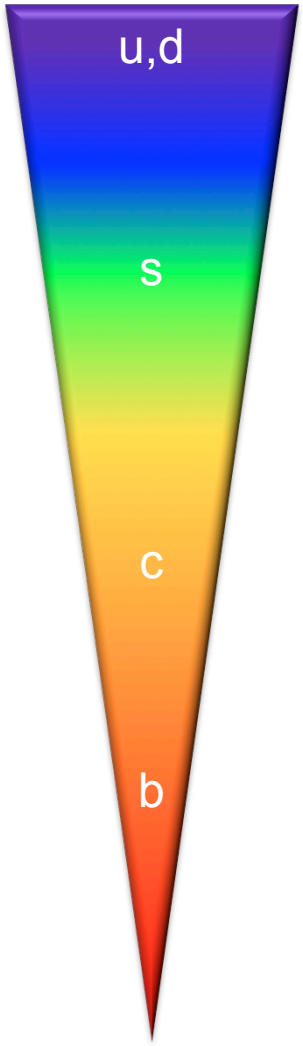
High-precision measurements of charm production cross section down to zero p_T over wide y range

ALI-PREL-36620

ALICE

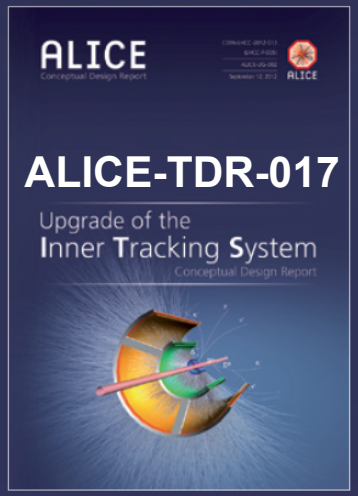
Summary & Outlook

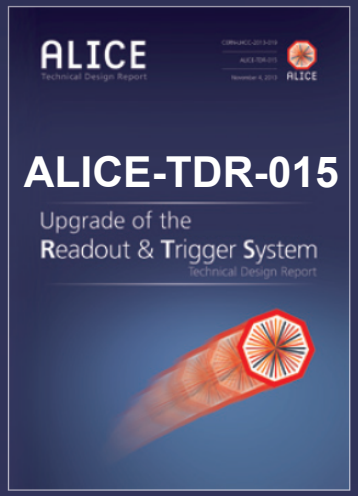
- New detectors will be installed in the ALICE central barrel before LHC Run 3 in 2020
  - → New Inner Tracking System
  - → New GEM-based TPC readout chambers
  - → New Muon Forward Tracker
  - → New fast data readout
  - → New Fast Interaction Trigger detector (FIT)
- High precision measurements in the charm sector to $p_T = 0$ GeV/c
- New and unique measurements exploring rare probes of beauty sector

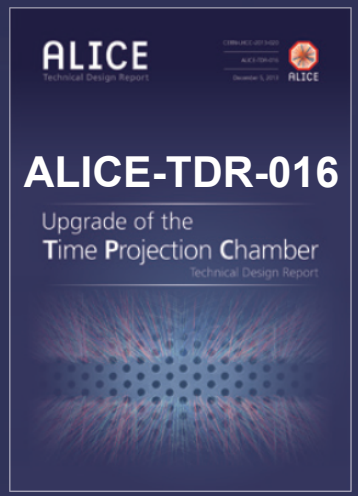


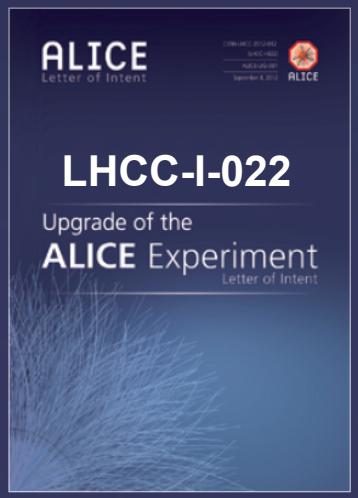
Thank you!

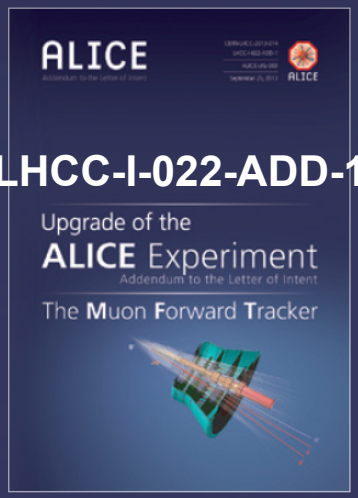
References


ALICE
ALICE-TDR-017
Upgrade of the
Inner Tracking System
Conceptual Design Report


ALICE
ALICE-TDR-015
Upgrade of the
Readout & Trigger System
Technical Design Report


ALICE
ALICE-TDR-016
Upgrade of the
Time Projection Chamber
Technical Design Report


ALICE
LHCC-I-022
Upgrade of the
ALICE Experiment
Letter of Intent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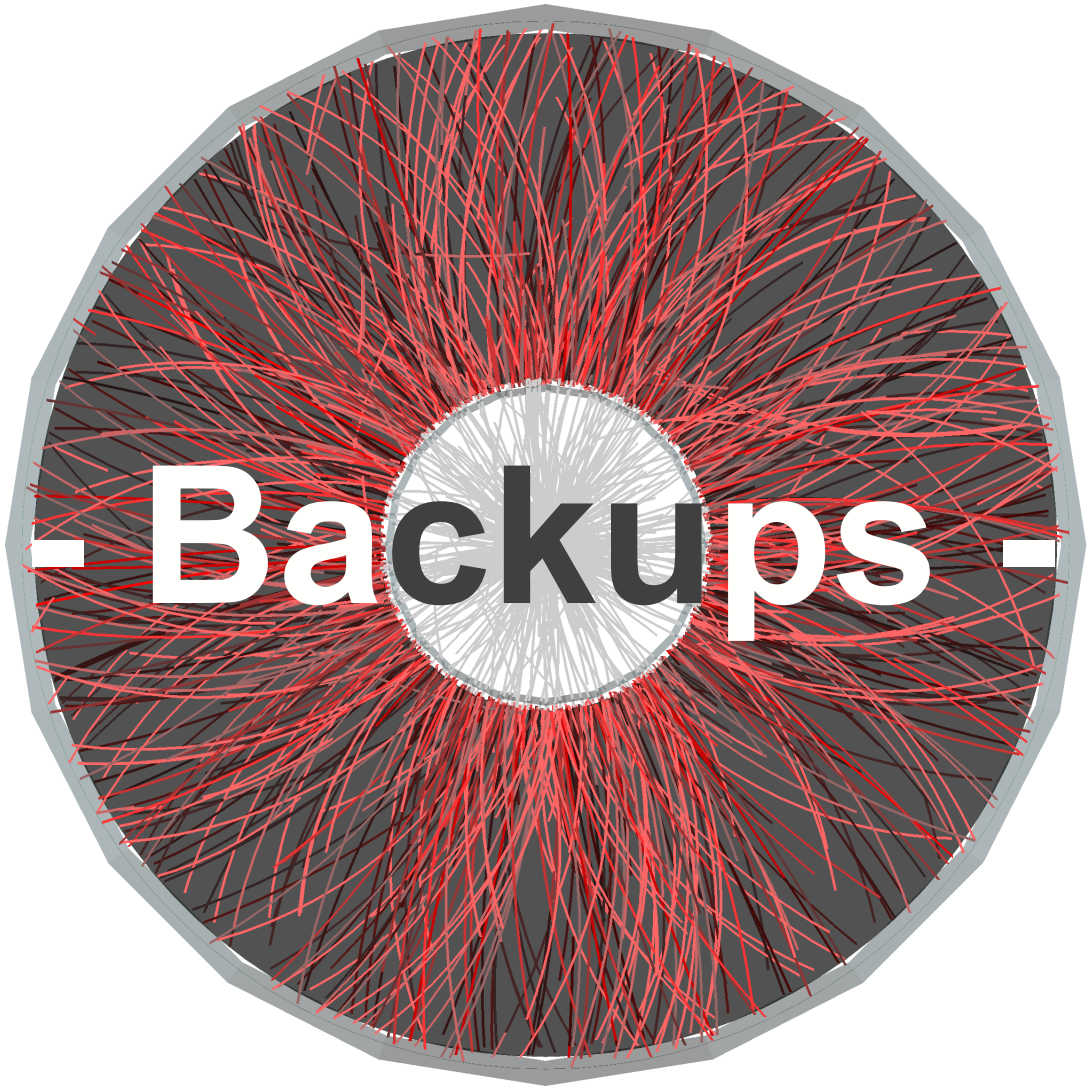
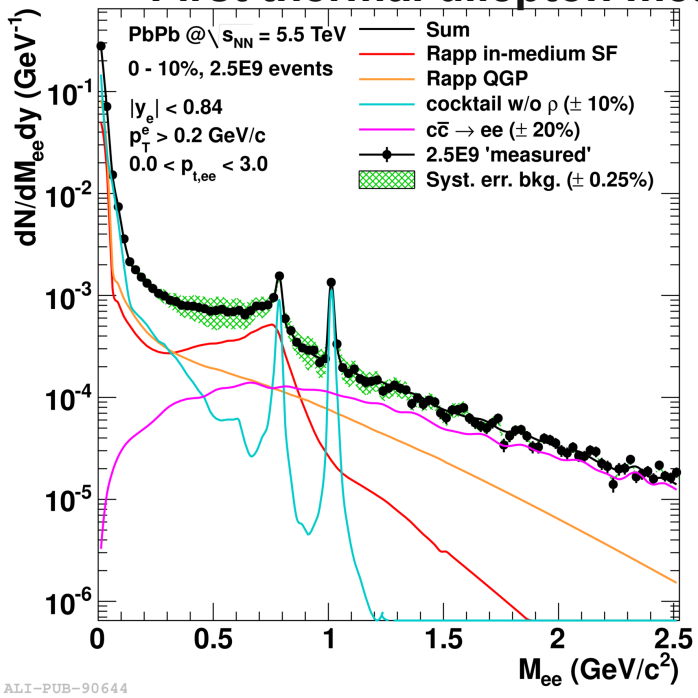
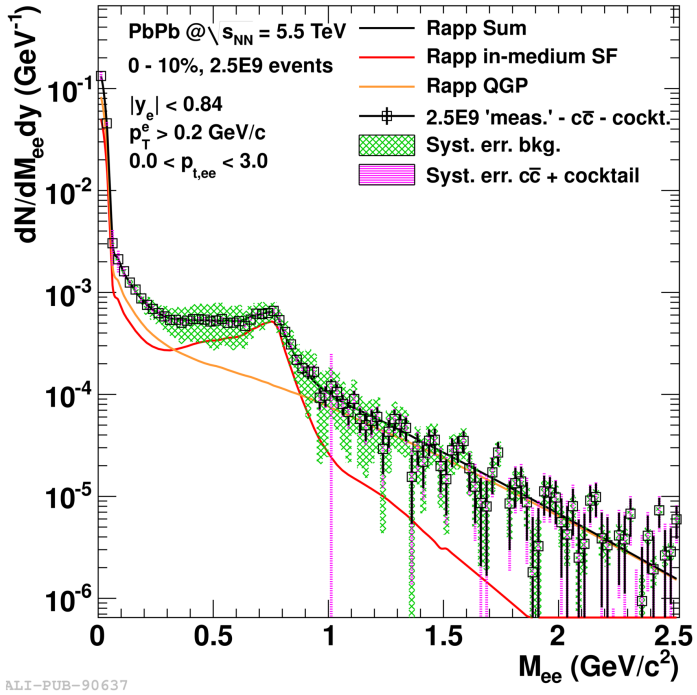
Upgrade of the
ALICE Experiment
Addendum to the Letter of Intent
The Muon Forward Tracker


- Backups -

Low-mass Dielectrons

First thermal dilepton measurement in Pb-Pb collisions at the LHC





→ Requires $L_{int} \approx 3 nb^{-1}$ with low B field at 0.2 T

- Spectrum of electromagnetic radiation yields information of the entire system evolution
- → **Requires ultra-low material budget and high statistics data**
- With Upgraded ITS detector:
  - → e^- measurement down to $p_T \geq 0.05$ GeV/c
  - → Background rejection via impact parameter selection