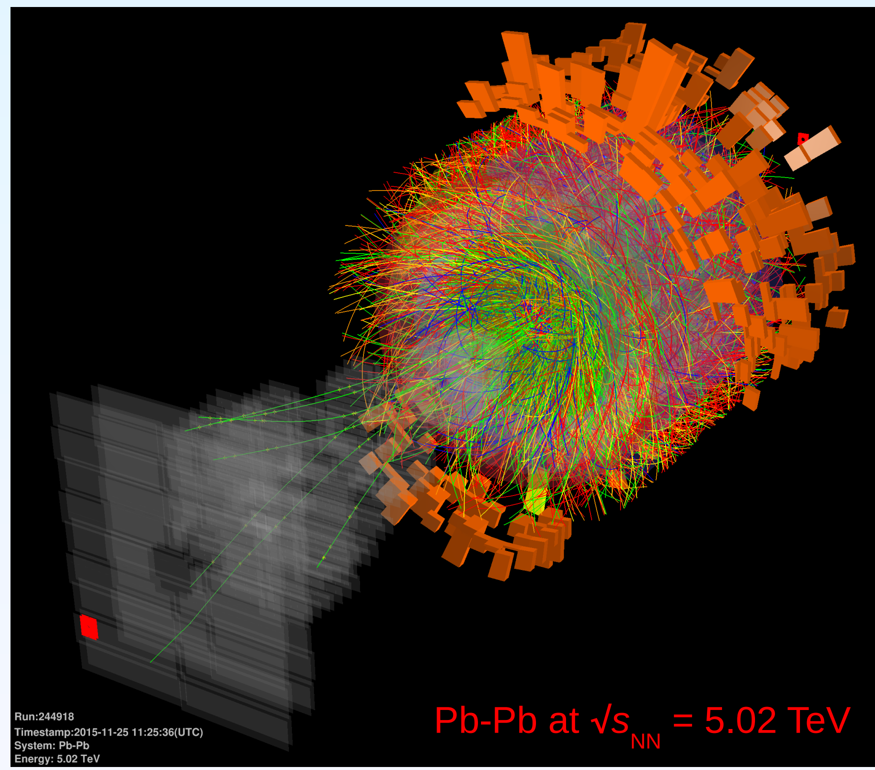
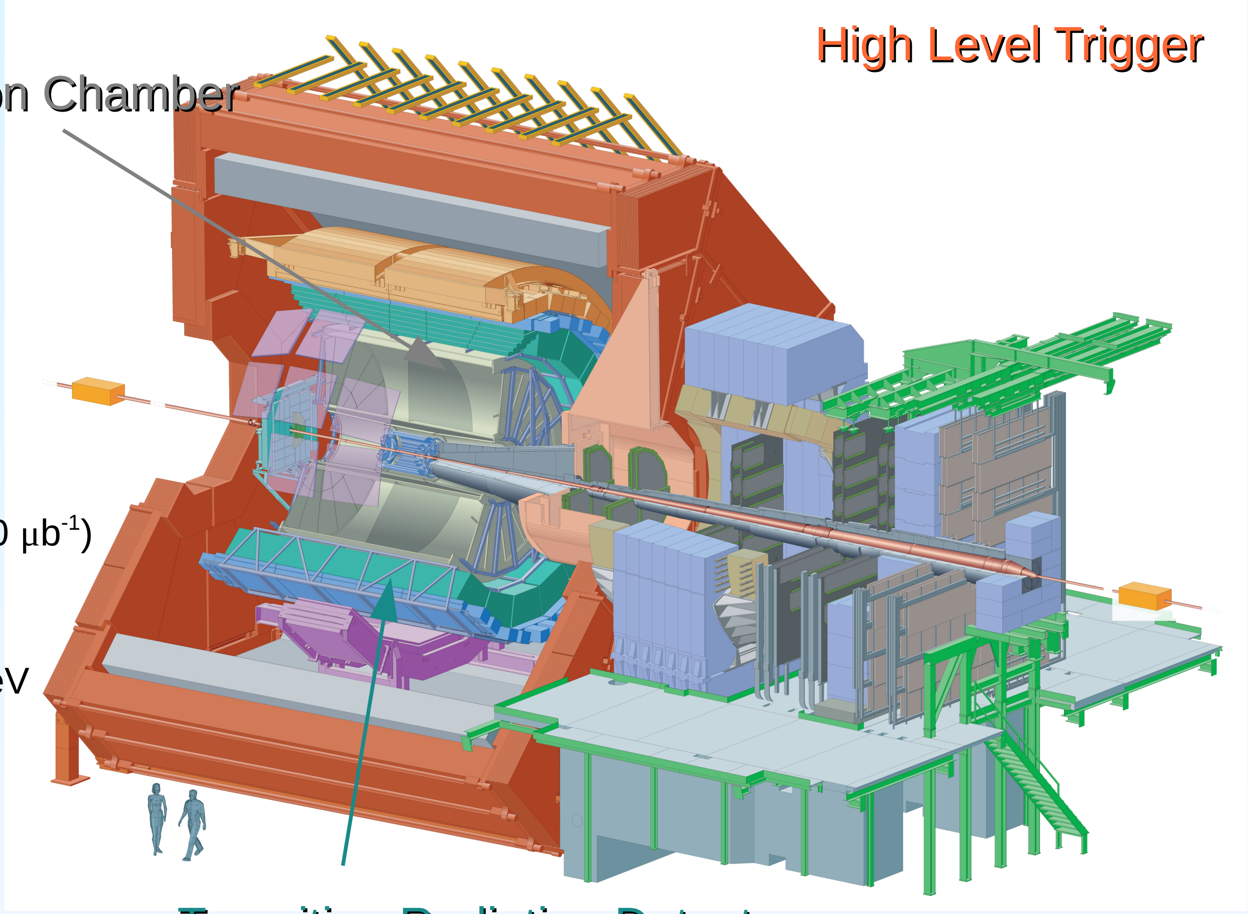
ALICE Resultate und Upgrade

Yvonne Pachmayer, Universität Heidelberg

BMBF Forschungsschwerpunkt
ALICE Experiment 201



ALICE Apparatus



- **Data sets**
  - Run 1 (2009-2013)
    - Pb-Pb at 2.76 TeV
      (2010: ~10 μb^{-1} , 2011: ~150 μb^{-1})
    - p-Pb at 5.02 TeV
    - pp at 0.9, 2.36, 2.76, 7, 8 TeV
  - Run 2 (2015)
    - Pb-Pb at 5.02 TeV
    - pp at 0.9, 5.02, 13 TeV

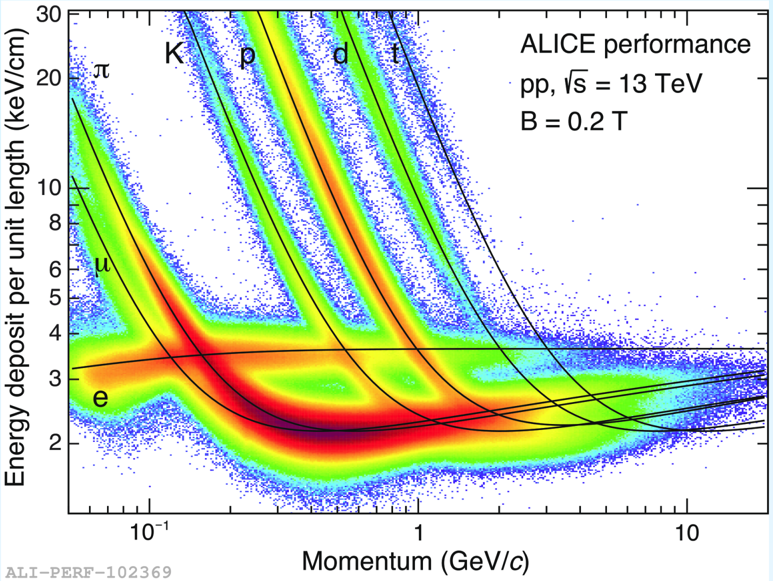
German Contributions

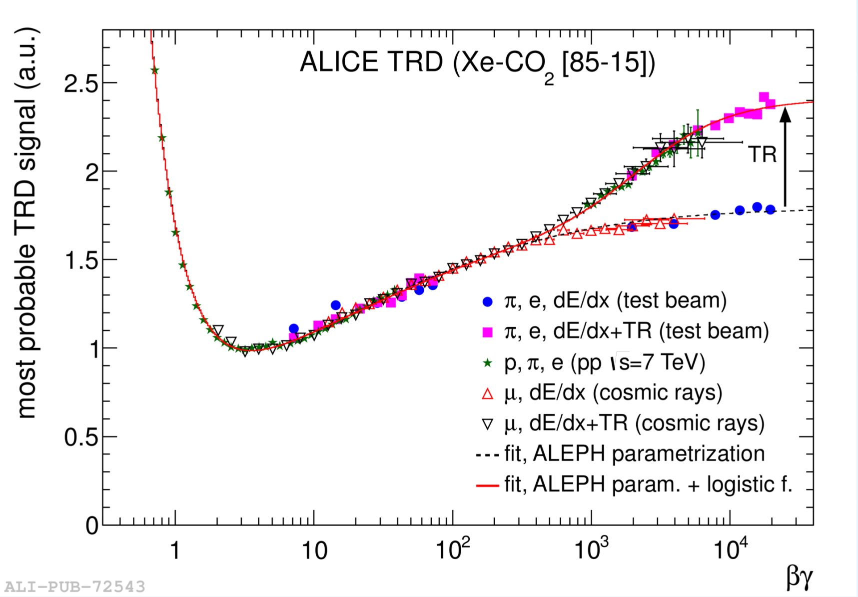
- **TPC: H. Appelshäuser (U Frankfurt, PL), C. Garabatos (GSI, DPL), C. Lippmann (GSI, TC)**
- **TRD: J. Stachel (U Heidelberg, PL), J. Wessels (U Münster, DPL), J. Mercado (U Heidelberg, TC)**
- **HLT: V. Lindenstruth (U Frankfurt, PL), M. Krzewicki (U Frankfurt, DPL/TC), T. Alt (U Frankfurt, DTC)**

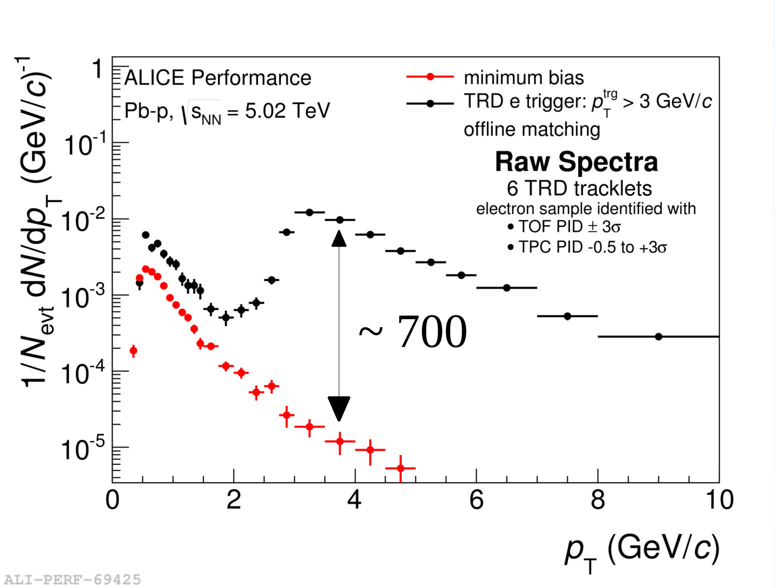
- **Collaboration Board Chair: P. Braun-Munzinger (GSI/EMMI)**
- **Deputy Spokesperson: J. Wessels (U Münster)**

- **BMBF Forschungsschwerpunkt 201-ALICE:**
  - GSI/EMMI
  - Universität Heidelberg
  - Universität Frankfurt
  - Universität Münster
  - Universität Tübingen
  - Technische Universität München
  - Universität Bonn (associate, transfer to full membership in December)
  - FIAS Frankfurt
  - FH Worms, FH Köln

Detector Performance

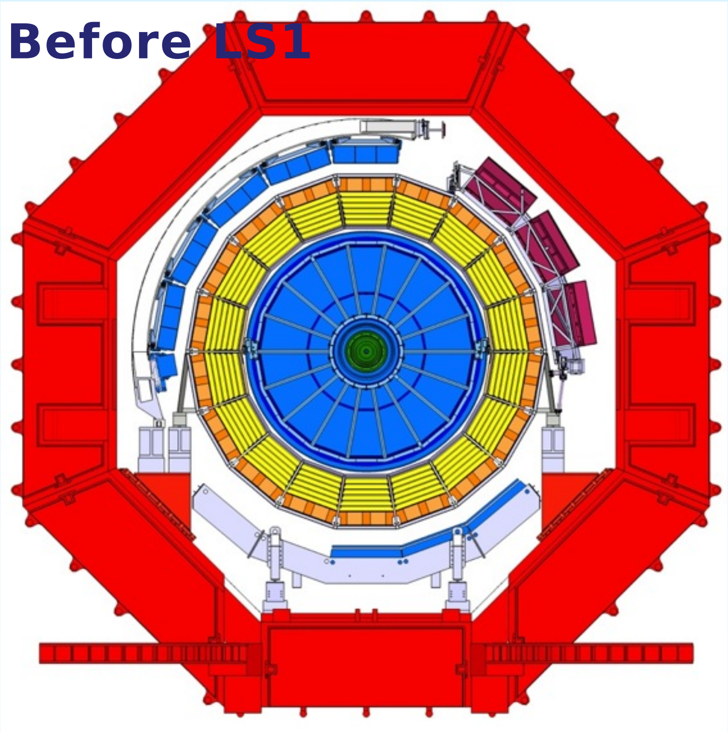


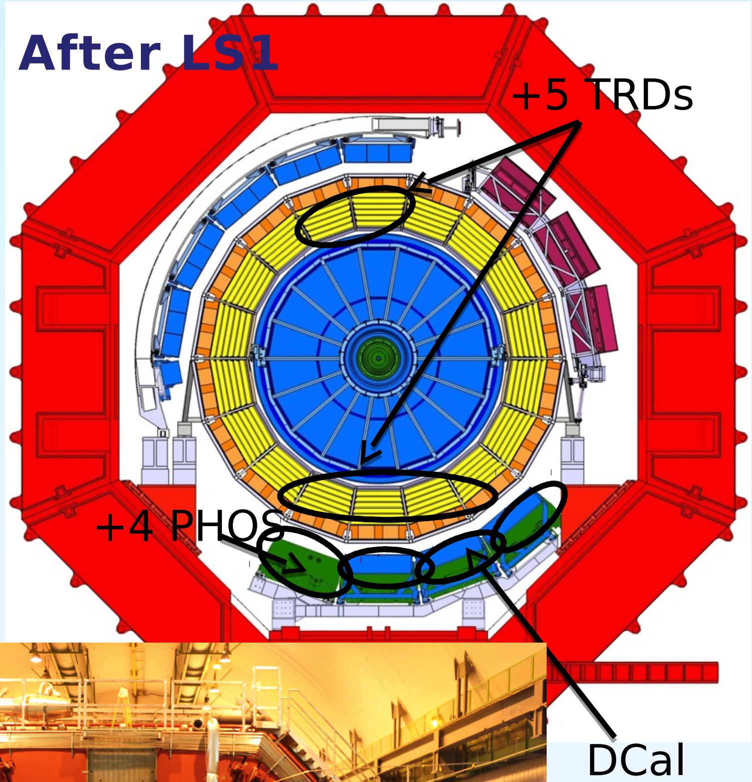




- **Leading contributions to**
  - Tracking (GSI)
  - Calibration (U Frankfurt)
  - Particle identification (U Frankfurt, U Heidelberg, U Tübingen)
  - TRD trigger (U Heidelberg, U Münster)
- **Offline Coordinators:**
  - TPC: K. Schweda (GSI), TRD: C. Blume (U Frankfurt)

Long Shutdown 1





- **LS 1 installation**
  - 5 TRD supermodules
  - TRD read-out upgrade
    DDL → DDL2 (2.125 Gbit/s → 4 Gbit/s)
  - TPC: gas mixture changed to Ar:CO_2
  - HLT
    - New farm
    - Hardware acceleration: FPGA+ GPU

Impact on Physics Results

- **Physics Working Group Conveners (2/16): R. Averbeck (GSI), K. Reygers (U Heidelberg)**
- **Editorial Board Chair: H. Oeschler until May 2014 (U Heidelberg)**
- **Editorial Board Member: Y. Pachmayer (U Heidelberg)**
- **Conference Committee Member: C. Klein-Bösing (U Münster)**

- **Active membership in paper committees and internal review committees**
- **Supported by the Tier2 center (GSI)**

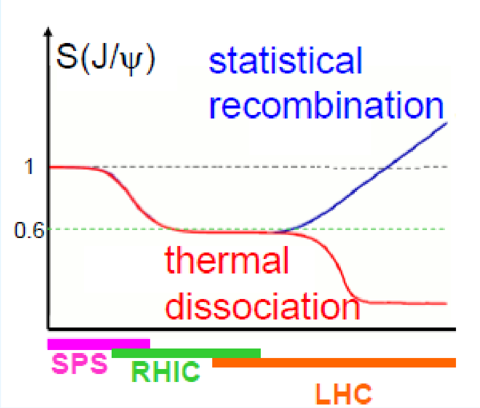
- **Publications in 2014/15 published and submitted: 58**
  - Pb-Pb: 31; p-Pb: 18
  - Phys. Lett. B: 11, Nature: 1
  - Citations: 1508 (3 Dec 2015)

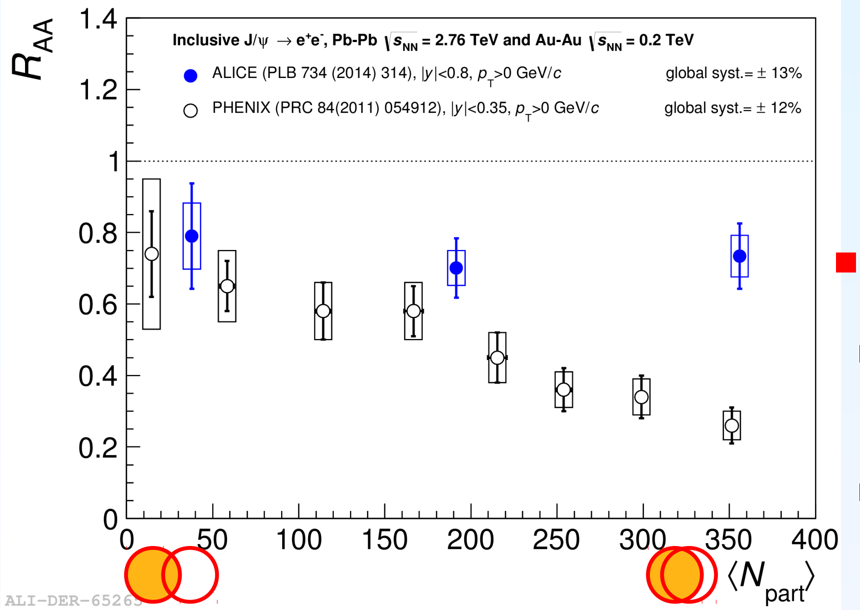
J/ψ in Pb-Pb Collisions

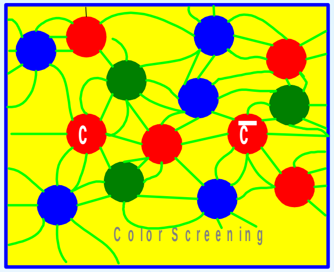
$$R_{PbPb}(p_T) = \frac{1}{\langle T_{PbPb} \rangle} \times \frac{dN_{PbPb}/dp_T}{d\sigma_{pp}/dp_T}$$

Cold nuclear matter effects
+ hot nuclear matter effects
(related to the Quark-Gluon Plasma)

Elementary collision
No nuclear matter effects







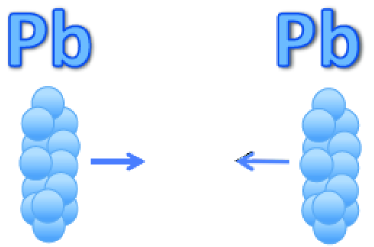
J/ψ Meson ($c\bar{c}$)

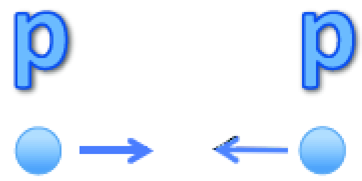
- Original idea (1986): J/ψ suppression via colour screening discussed as probe of de-confinement
- Quark-Gluon Plasma screens all charmonia, but charmonium production takes place at the phase boundary

ALICE: Phys. Lett. B 734 (2014) 314
PHENIX: Phys. Rev. Lett. 98 (2007) 232301;
Phys. Rev. C 84 (2011) 054912; Phys. Rev. C (2005) 049901

Matsui, Satz PLB 178 (1986)
Braun-Munzinger, Stachel PLB 490 (2000)
Thews et al. PRC 62 (2000)

J/ψ in Pb-Pb Collisions





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

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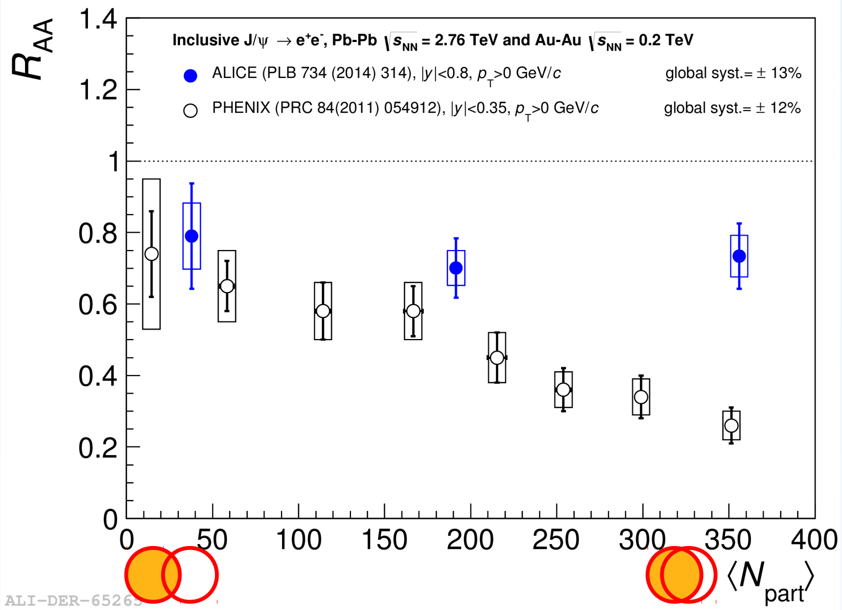

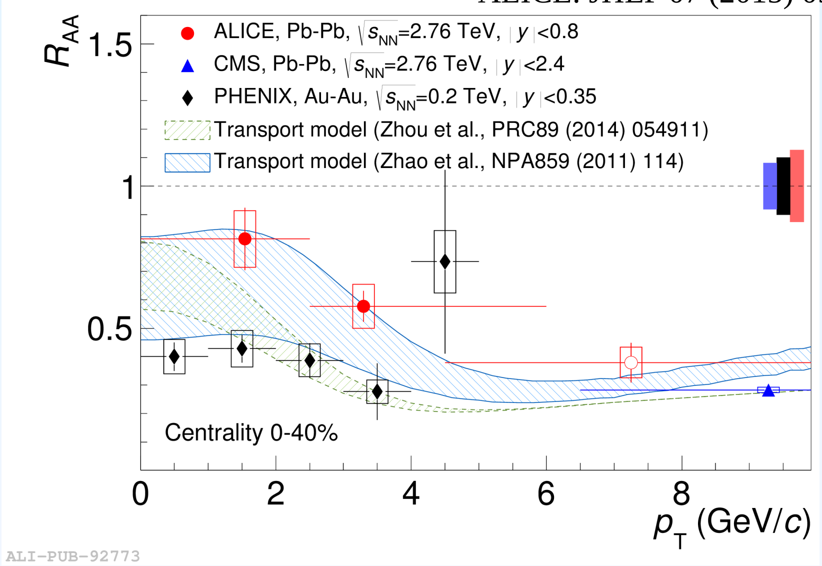

ALICE: Phys. Lett. B 734 (2014) 314
PHENIX: Phys. Rev. Lett. 98 (2007) 232301;
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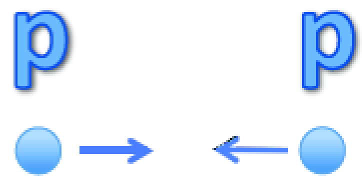
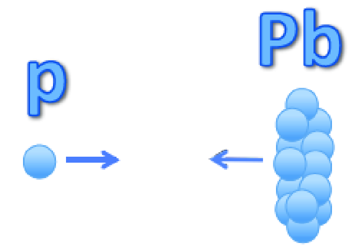
→ J/ψ regeneration

J/ψ in p-Pb Collisions

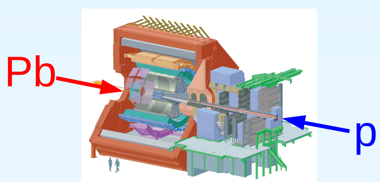




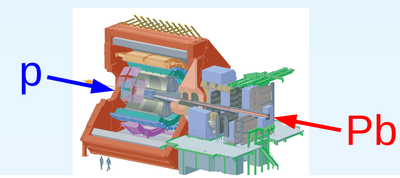
Elementary collision
No nuclear matter effects

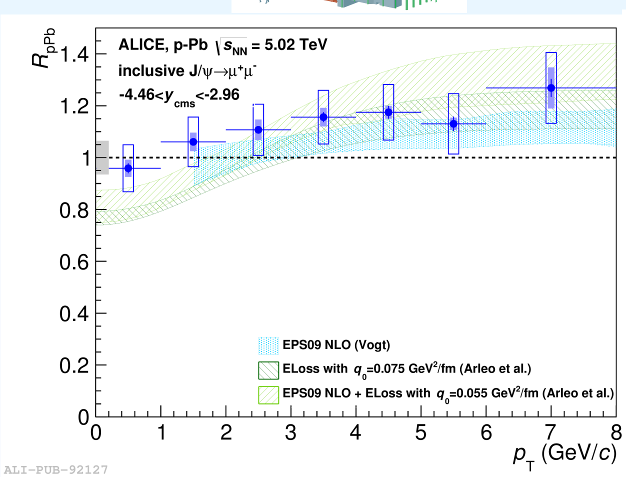
Cold nuclear matter effects -
without Quark-Gluon Plasma

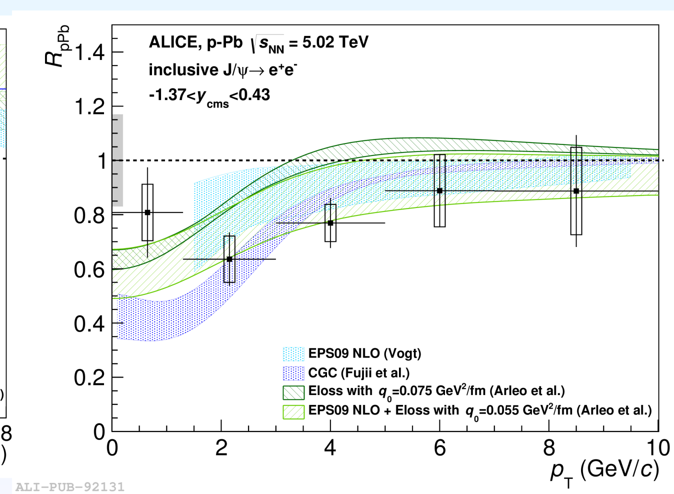
ALICE: JHEP 06 (2015) 055

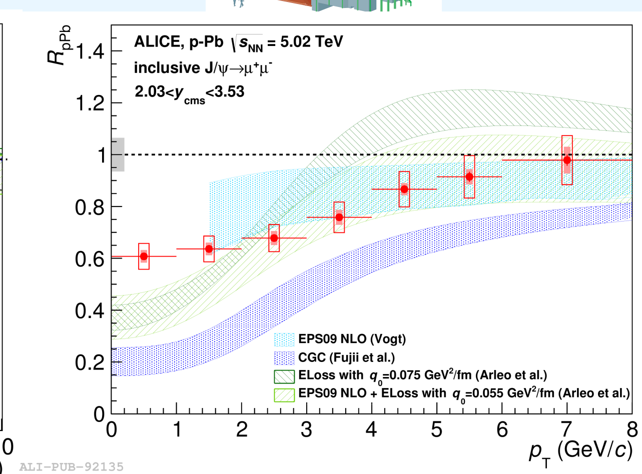


Mid-rapidity p ⟶⟵ Pb

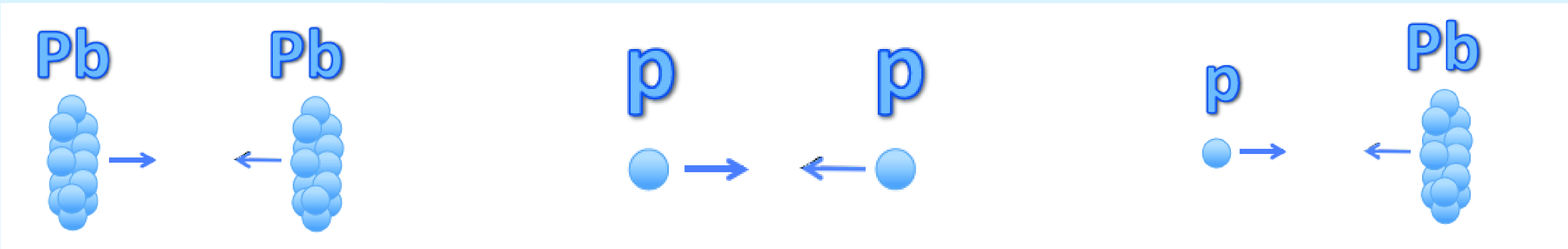








J/ψ in p-Pb and Pb-Pb Collisions



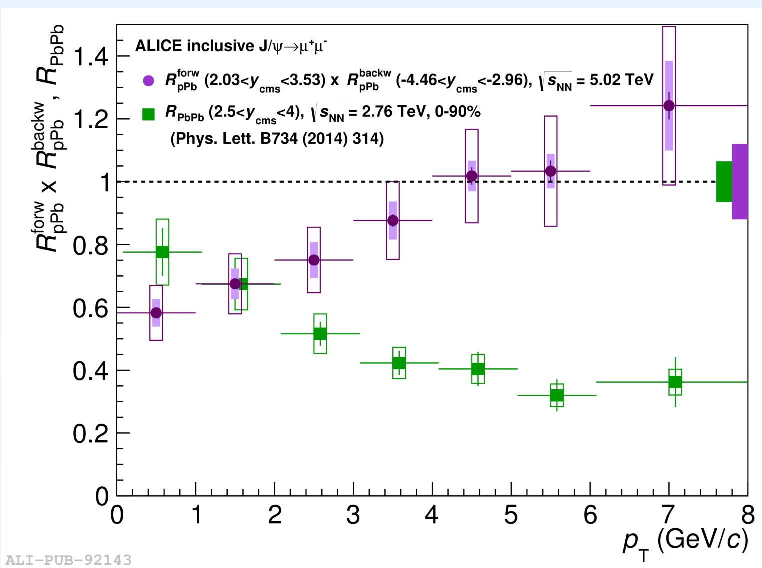
Cold nuclear matter effects
+ hot nuclear matter effects
(related to the Quark-Gluon Plasma)

Elementary collision
No nuclear matter effects

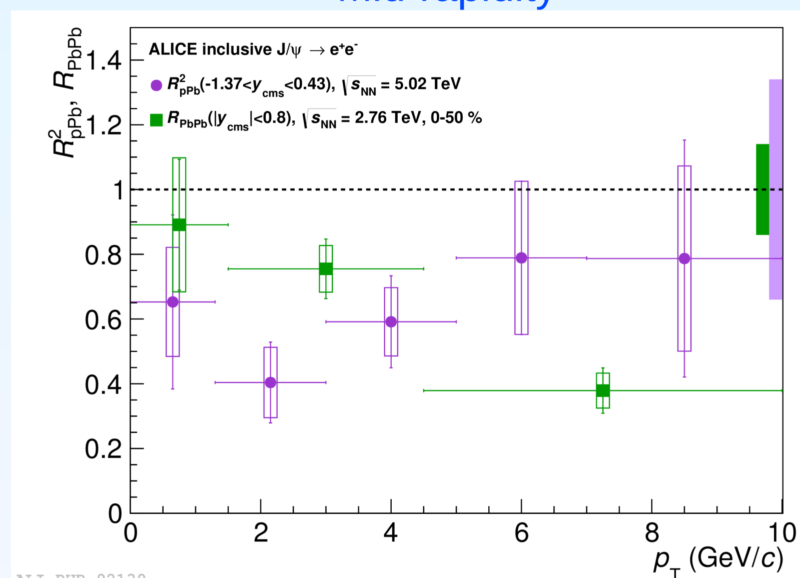
Cold nuclear matter effects -
without Quark-Gluon Plasma

Backward rapidity & Forward rapidity

ALICE: JHEP 06 (2015) 055



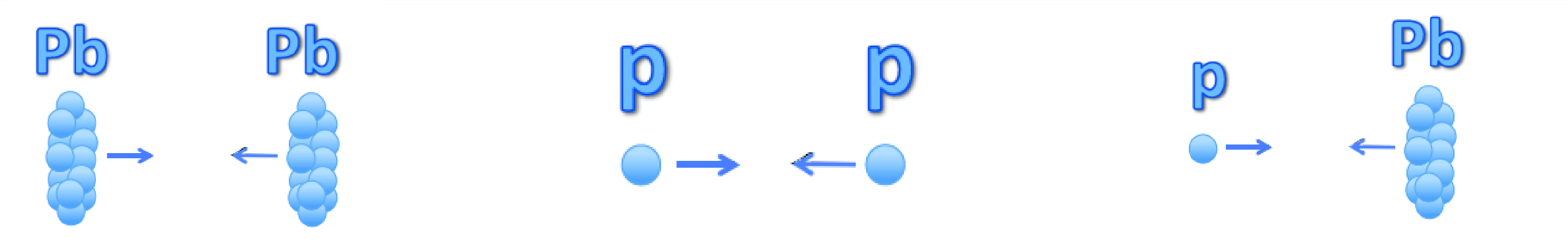
Mid-rapidity



- **Assuming 2 → 1 kinematics + factorization of nuclear effect** (only nPDF as nucl. effects in pA)

→ J/ψ regeneration

J/ψ in p-Pb Collisions



Cold nuclear matter effects
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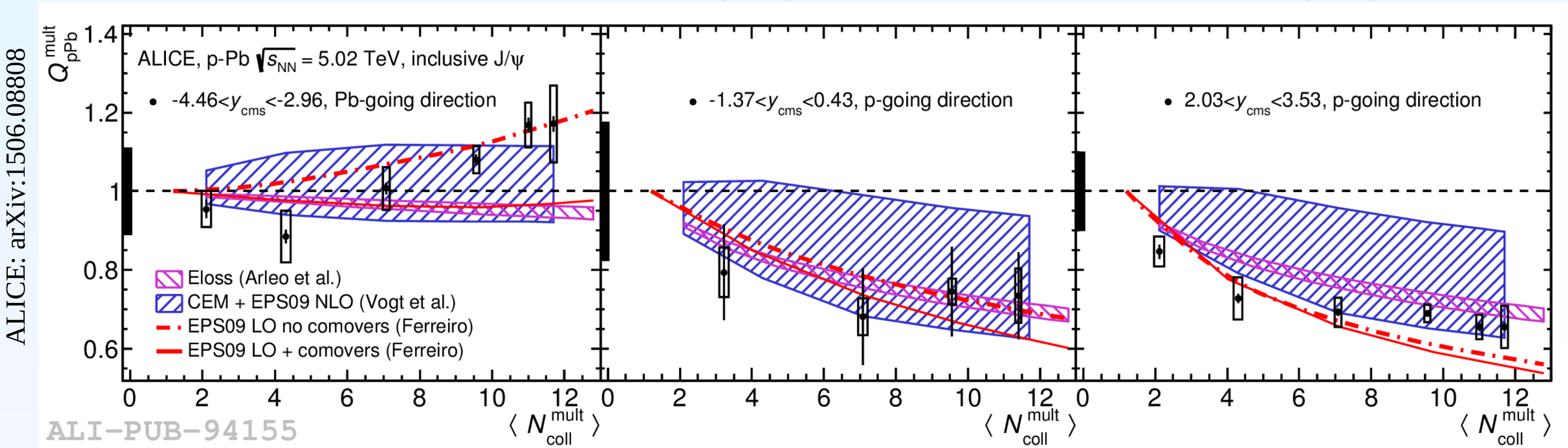
Elementary collision
No nuclear matter effects

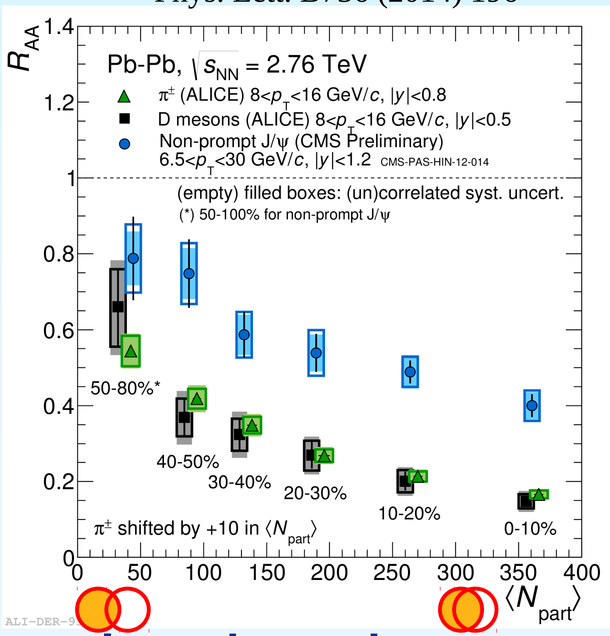
Cold nuclear matter effects -
without Quark-Gluon Plasma

Backward rapidity **Pb→ ←p** Mid-rapidity **p → ← Pb** Forward rapidity **p → ← Pb**

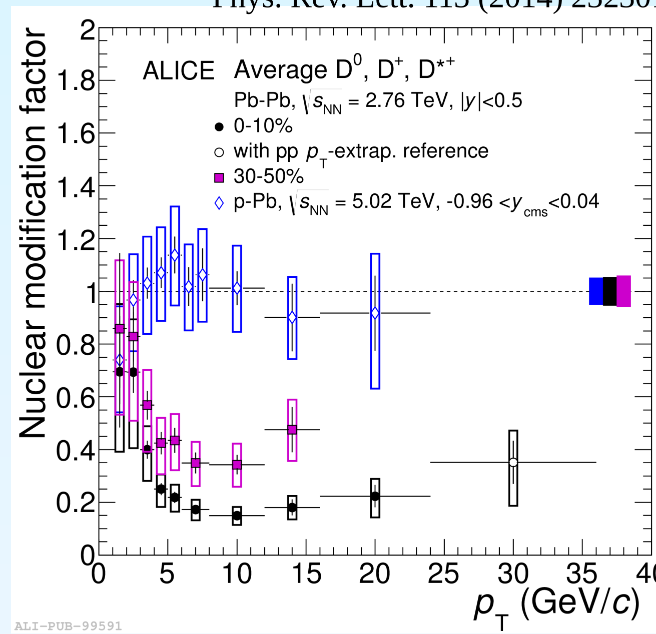


Heavy-Flavour Production in p-Pb and Pb-Pb Collisions

ALICE: arXiv:1506.06604, Phys. Lett. B736 (2014) 196



ALICE: arXiv:1509.06888, Phys. Rev. Lett. 113 (2014) 232301



- **Energy loss depends on**
  - Properties of the medium (gluon densities, size)
  - Properties of the probe (color charge, mass)
    - Mass dependence:
      Gluon radiation is suppressed for angles $\theta < M_Q/E_Q$
- **Expected behaviour: $\Delta E_g > \Delta E_{charm} > \Delta E_{beauty}$**

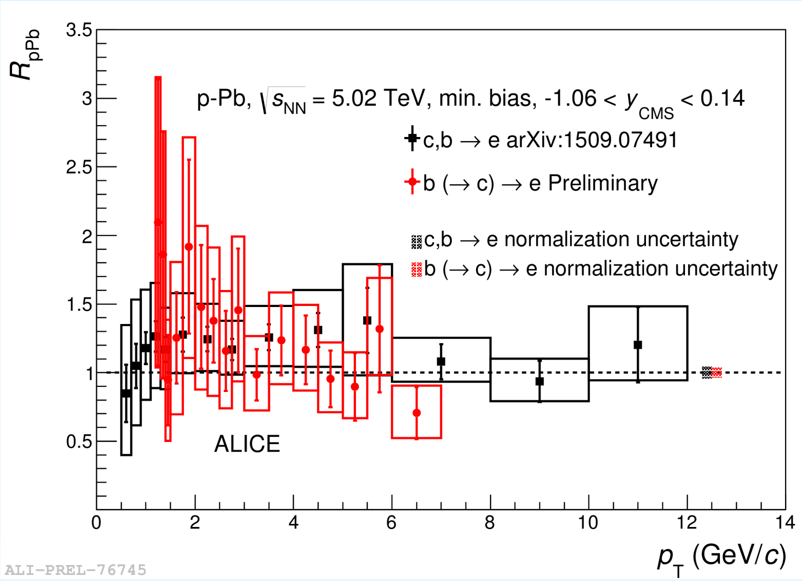
  → R_{AA} (light hadrons) < R_{AA} (D) < R_{AA} (B)

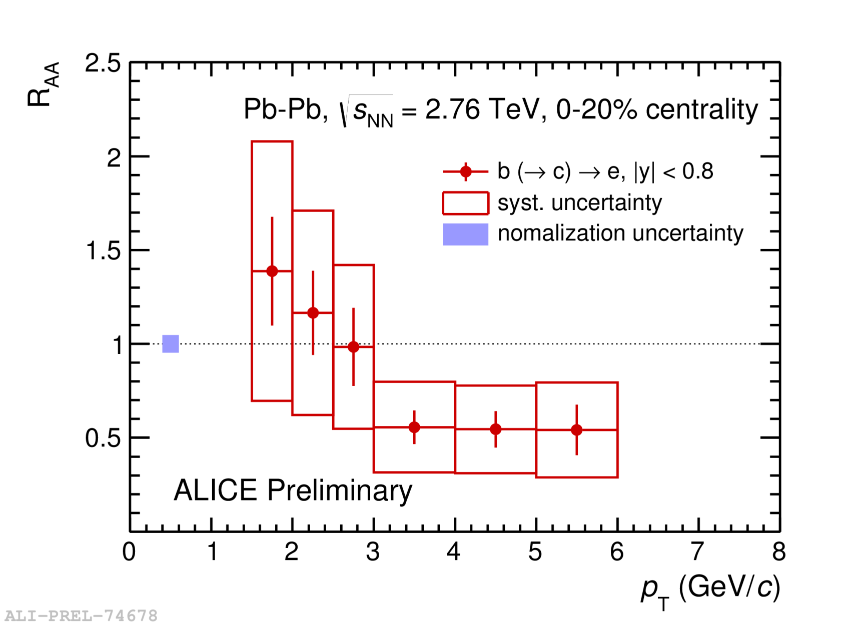
→ R_{AA} (π) and R_{AA} (D) compatible within uncertainties

→ Suppression in Pb-Pb is a final state effect

Heavy-Flavour Production in p-Pb and Pb-Pb Collisions

ALICE: arXiv:1509.07491





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- **Expected behaviour: $\Delta E_g > \Delta E_{charm} > \Delta E_{beauty}$**

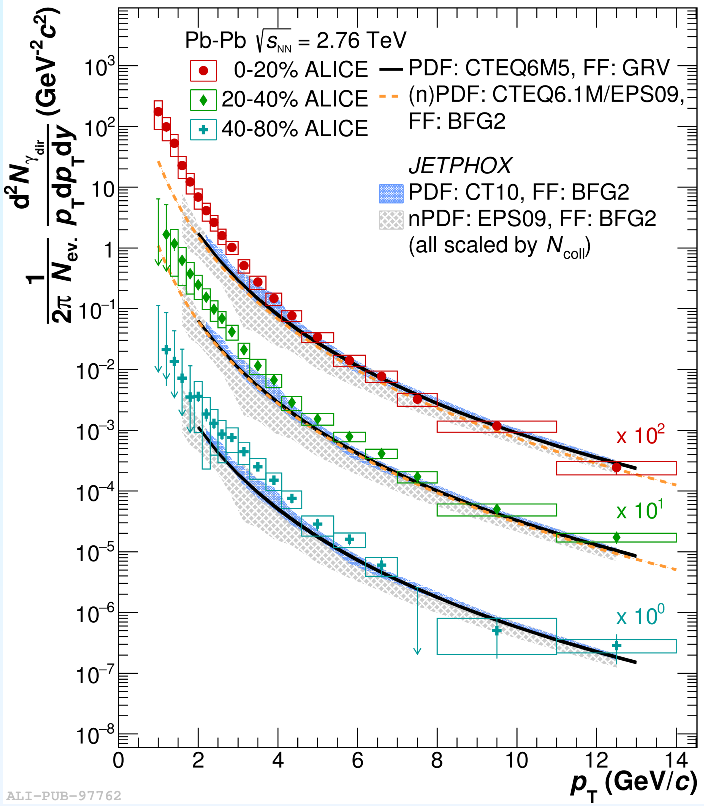
  → R_{AA} (light hadrons) < R_{AA} (D) < R_{AA} (B)

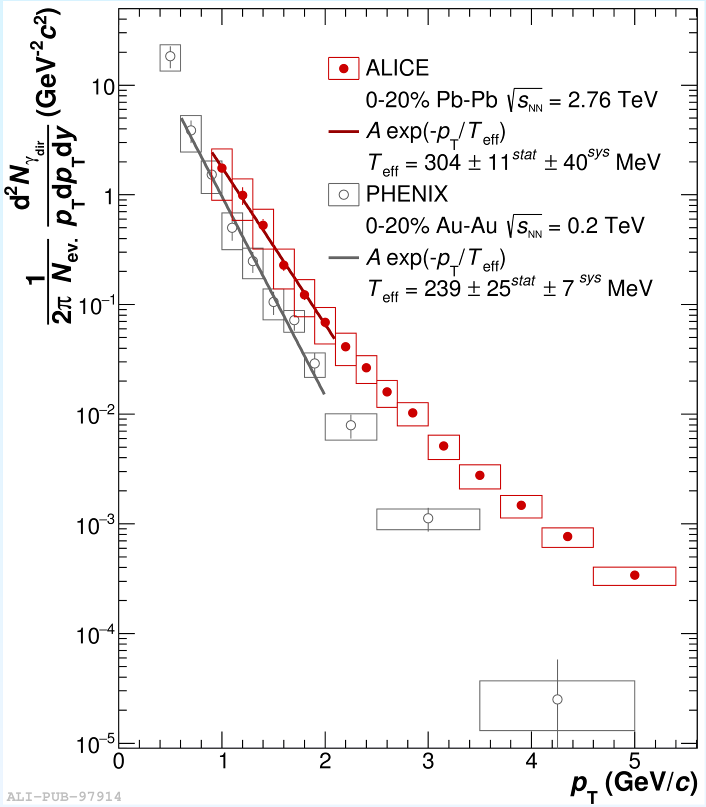
→ Suppression in Pb-Pb is a final state effect

→ Profit from full TRD in Run2

Direct Photons in Pb-Pb

ALICE: arXiv:1509.07324

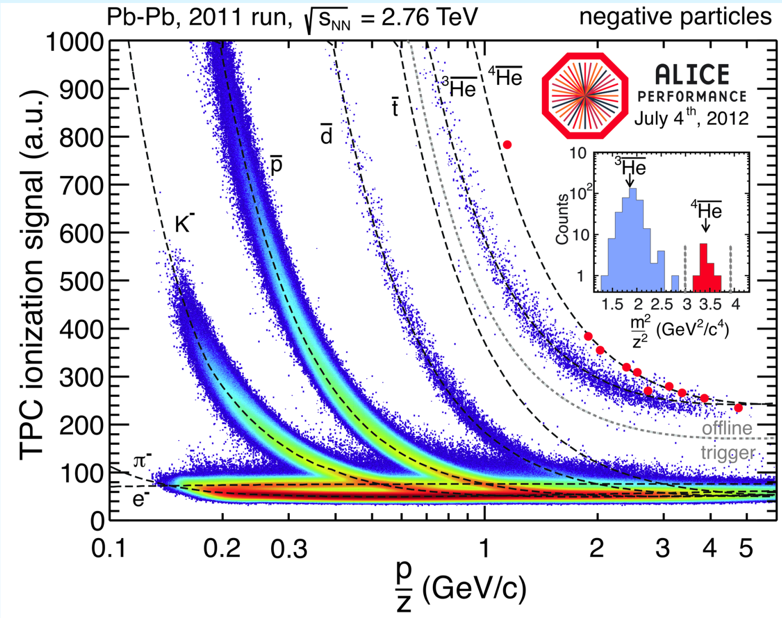


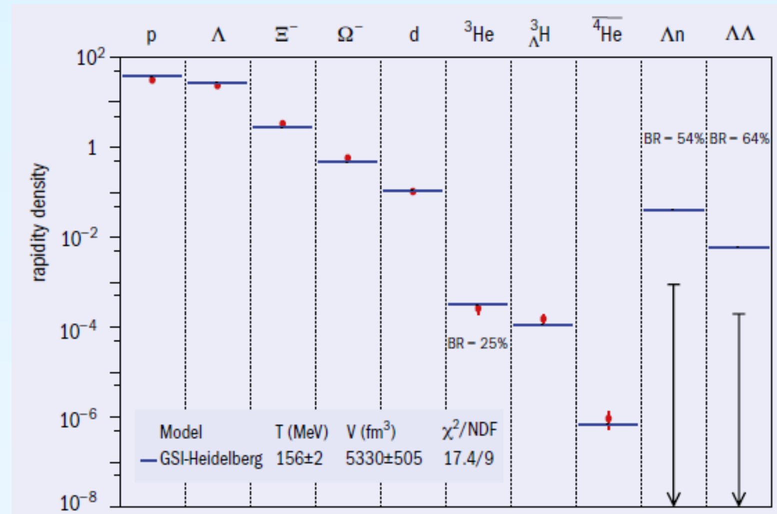


- **2.6σ excess in low p_T in 0-20% central**
- **T_{eff} = 304 ± 11 ± 40 MeV (30% larger than at RHIC)**
  - Higher initial energy or stronger radial flow

Light (anti)(hyper)nuclei production in Pb-Pb Collisions

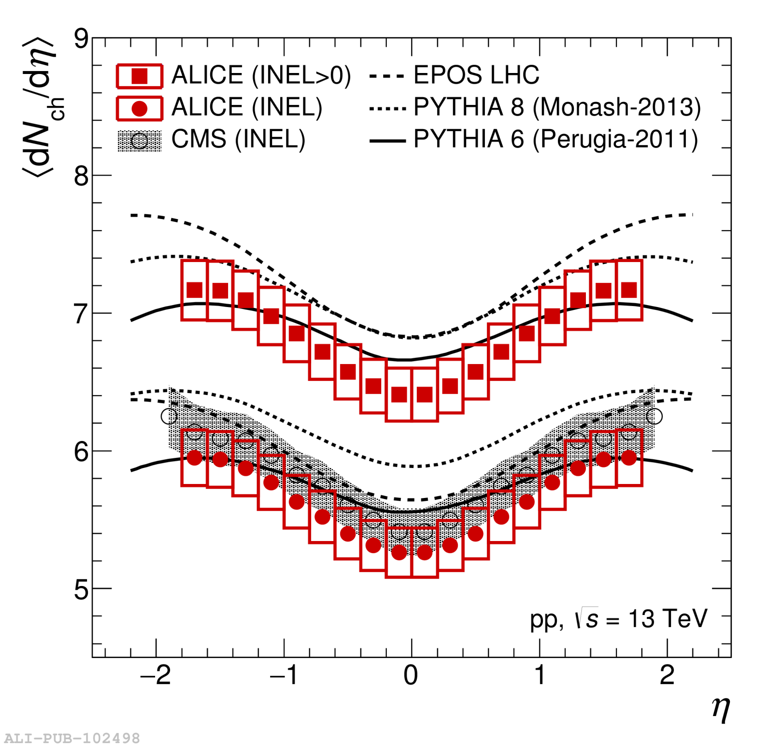
ALICE: CERN Courier, September 2015
Braun-Munzinger, Stachel J Phys. G 28 (2002)
Andronic et al. Phys. Lett. B 697 (2011)

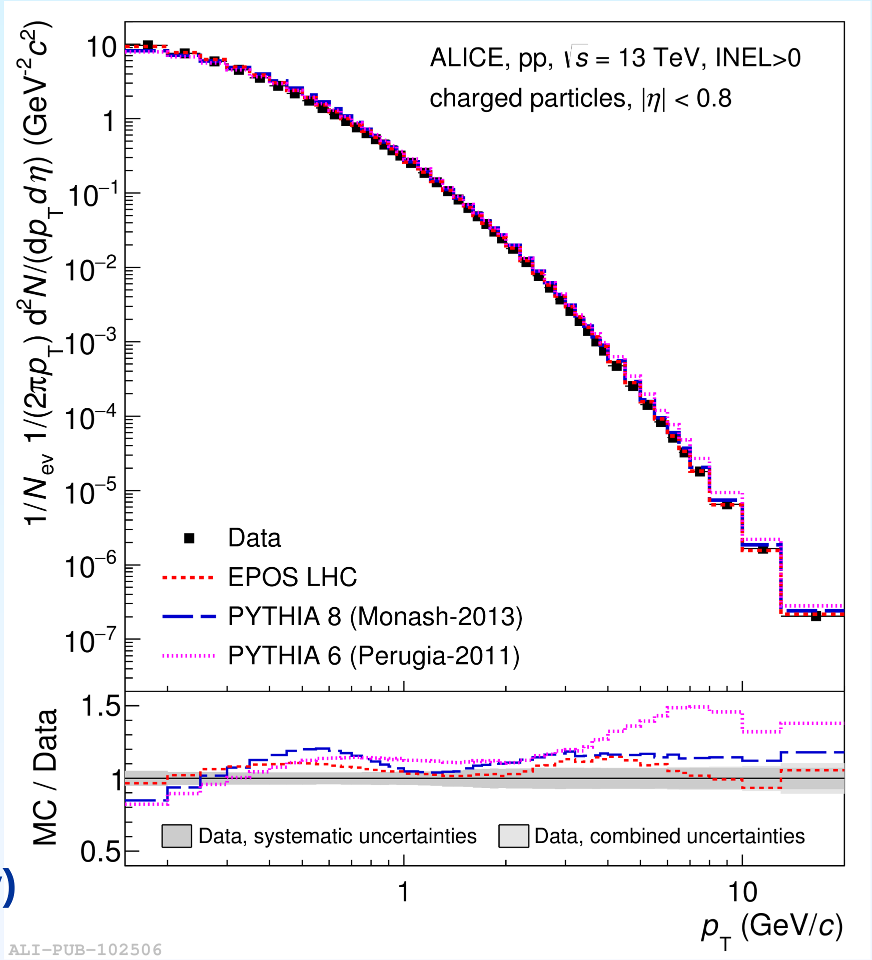




- **Yields can be interpreted in terms of statistical (thermal) model with a common chemical freeze-out temperature: T_{chem} = 156 ± 2 MeV**
  - Also true for loosely bound deuterons and hypertritons
- **Upper limits for Λn bound state and H-Dibaryon are significantly lower than all predicting models (thermal and coalescence)**

Run 2: pp 13 TeV data





- **pp at 13 TeV June until November 2015**
- **Minimum bias, high luminosity running with rare triggers (muon, high multiplicity)**
- **First results**
  - Charged-particle density distribution
  - Charged-particle yields vs. p_T

Run 2
Near-term measurements

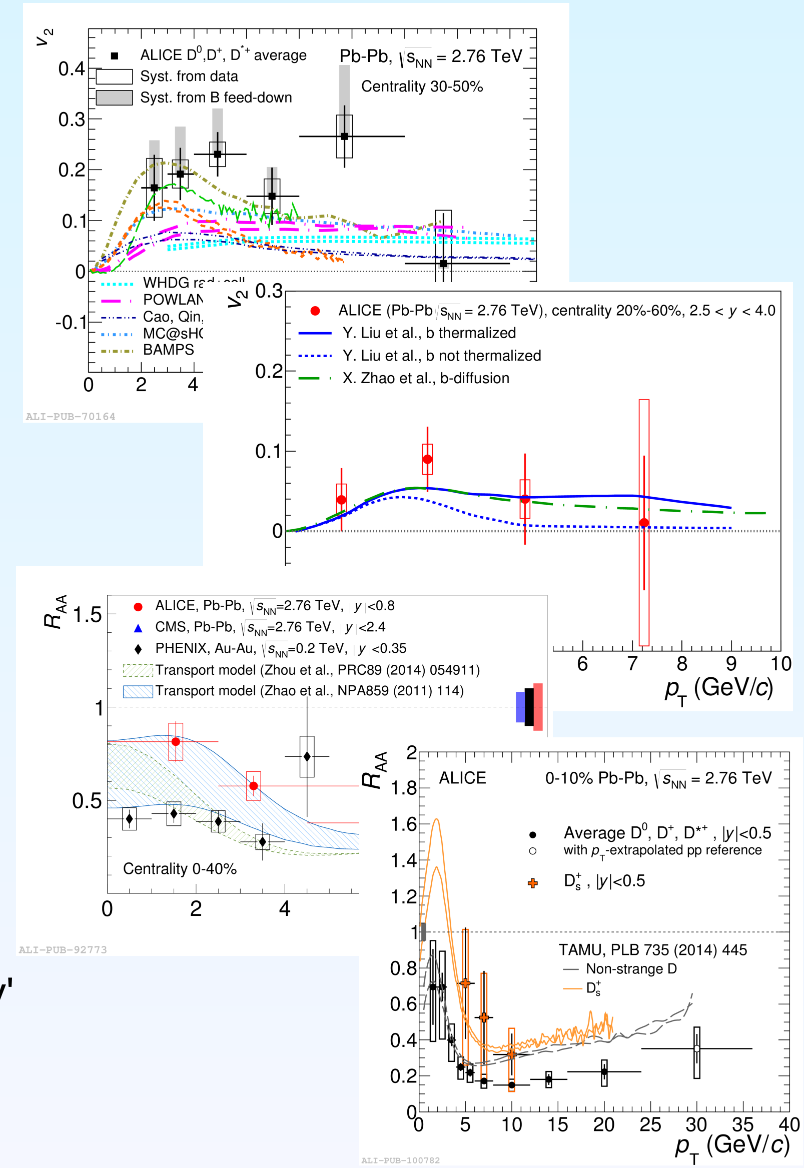
ALICE

Data sets

- Pb-Pb at $\sqrt{s}_{NN}$ = 5.02 TeV ~1 nb^{-1}
- 1 p-Pb run, pp reference

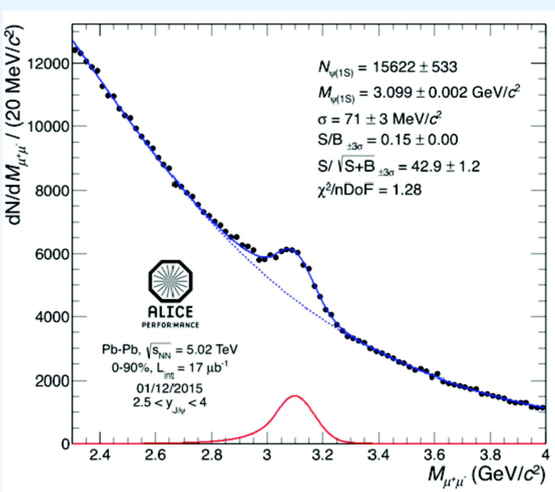
Physics objectives

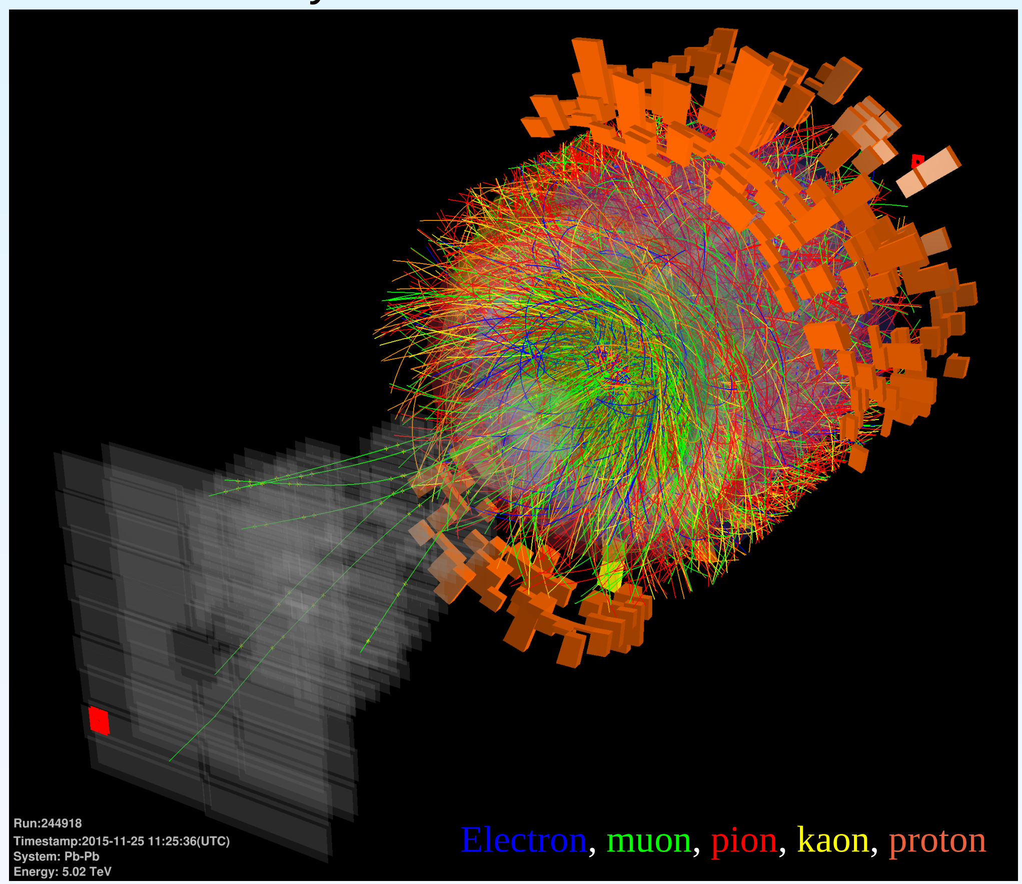
- Improved precision and differential studies
- Transport properties of the medium in different classes of events
- 'Collectivity' and coherence in large and small systems
- Jet quenching within QGP
- Heavy-flavour suppression and flow
- Quarkonia re-combination and flow
- Hard processes vs. event 'activity' and 'geometry'
- Photo-production of particles



Heavy Ions 2015

- **pp reference run at √*s* = 5.02 TeV**
  - Precious reference data for Pb-Pb (2015) and p-Pb (2013)
  - High ALICE data taking and operational efficiency
- **Pb-Pb $\sqrt{s_{NN}}$ = 5.02 TeV**
  - Design luminosity reached
  - 1000 Hz/b → 16 GB/s readout, 6 GB/s on disk after HLT compression

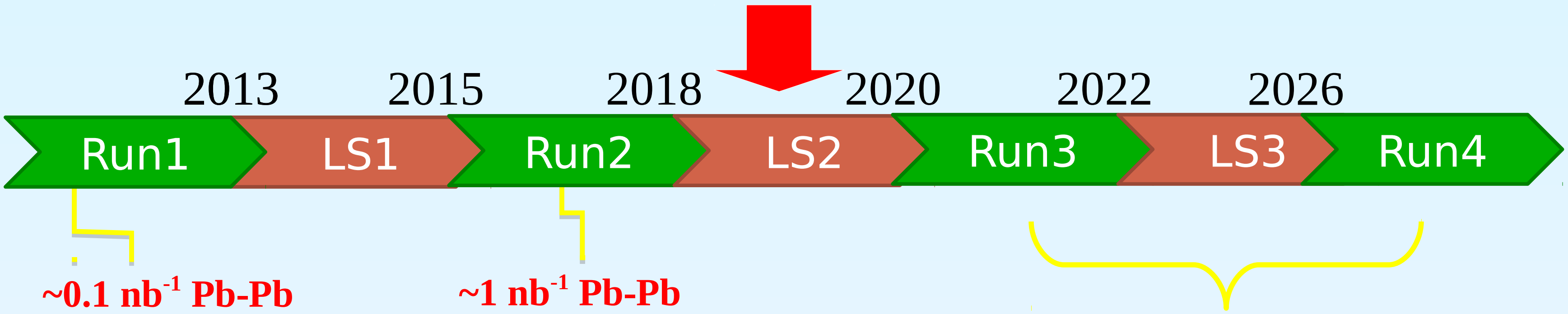




(Long-term) Opportunities
Heavy-ion program extended to Run 3 and Run 4

LS = Long Shutdown

ALICE Upgrade



~0.1 nb^{-1} Pb-Pb
pp, p-Pb

~1 nb^{-1} Pb-Pb
pp, p-Pb

>10 nb^{-1} Pb-Pb
(2.85 nb^{-1} low magnetic field)
6 pb^{-1} pp
50 nb^{-1} p-Pb

- **LS 2: ALICE Upgrade**
- **Run 3 + Run 4:**
  - Pb-Pb >10 nb^{-1} at $\sqrt{s_{NN}}$ ~ 5.5 TeV
  - LHC target luminosity: 6 x 10^{27} cm^{-2} s^{-1} → R = 50 kHz

ALICE Physics Goals for Run3 and Run4

Probe	Physics	Measurement
Heavy-flavor (charm & bottom)	Thermalization, equation of state (EoS), transport coefficient, energy los	v_2 and R_{AA}
Quarkonia (J/ψ, ψ')	Producti	, and R_{AA}
Low mass di-leptons		and R_{AA}, vector ectral function
Jet Probes		ntation n, heavy flavor in jets, γ-jet correlation
Heavy nuclear state	e bound , anti-hyper nucleus, H-Dibaryon	Yield

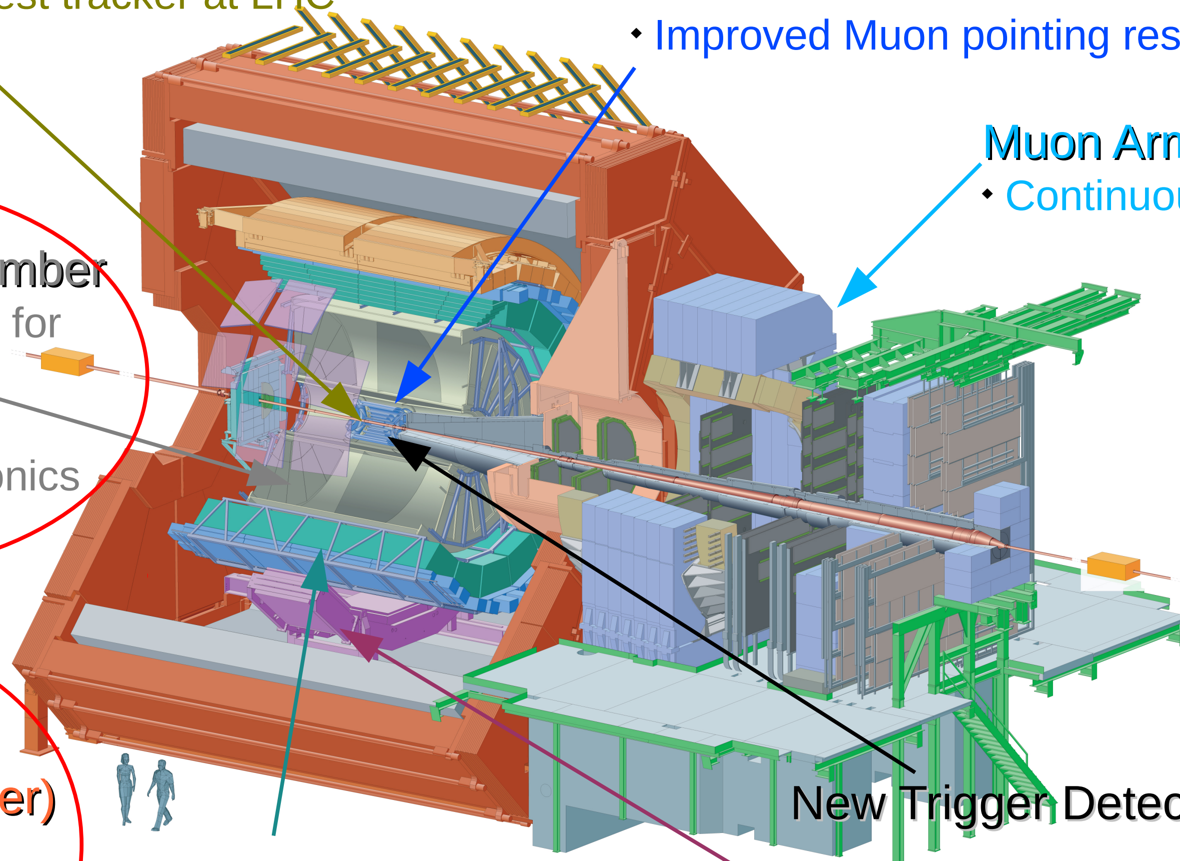
- **Precision measurements down to low p_T**
- **Minimum bias trigger selection**
- **Data taking at high rates: 50 kHz Pb-Pb**
- **Large statistics data sample**
- **Preserve excellent particle identification capabilities**
- **Enhance low-momentum vertexing and tracking capabilities**

→ Complementarity in comparison to ATLAS and CMS

ALICE Upgrade

New Inner Tracking System
- New pixel technology
- Less material → thinnest tracker at LHC

Muon Forward Tracker (MFT)
- New silicon tracker
- Improved Muon pointing resolution



Muon Arm
- Continuous Readout

Time Projection Chamber
- New GEM technology for readout chambers
- Continuous readout
- Faster readout electronics

New Trigger Detectors (FIT)

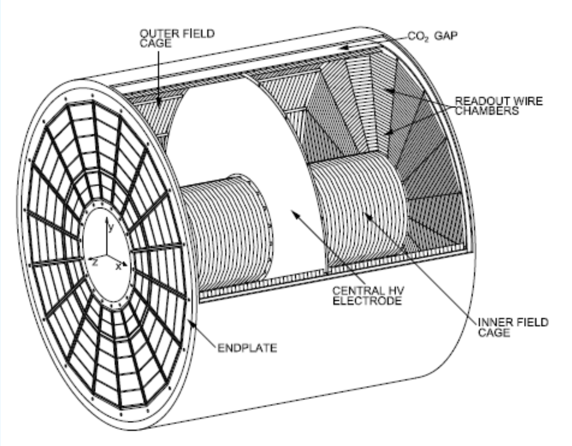
Data Acquisition, O^2 (High Level Trigger)
- New architecture
- On-line tracking & data compression
- 50 kHz Pb-Pb event rate

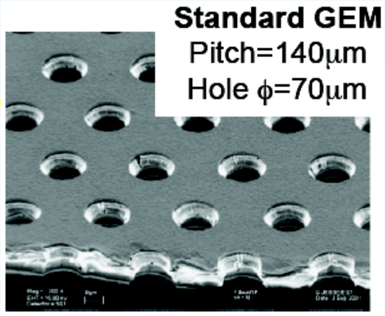
Time-Of-Flight Detector, Transition Radiation Detector
- Faster Readout

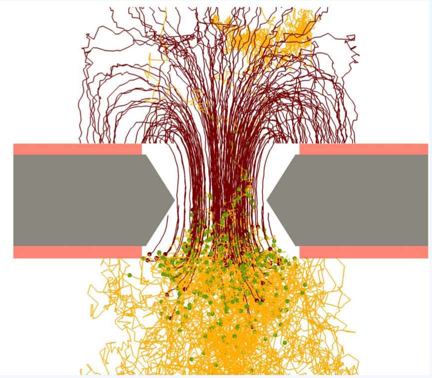
Calorimeters, HMPID
- Readout electronics

Upgrade Time Projection Chamber

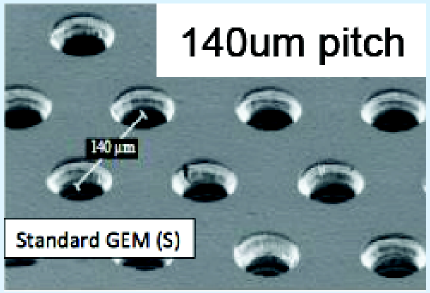
- **Current TPC**
  - Gating grid of readout of MWPCs closed to avoid ion feedback (IFB) and keep space charge at tolerable levels
  - Effective dead time ~280 μs, maximum effective readout rate 3.5 kHz
- **Upgrade TPC**
  - Continuous readout with Gas Electron Multiplier (GEM)
    - GEM has advantages in:
      - Reduction of ion backflow (IBF)
      - High rate capability
      - No ion tail
    - Requirement
      - IBF < 1% at Gain = 2000
      - d*E*/d*x* resolution from Run 1,2 must be preserved
      - Stable operation under LHC condition
      - New electronics (neg. polarity)
      - Novel calibration and online reconstruction schemes

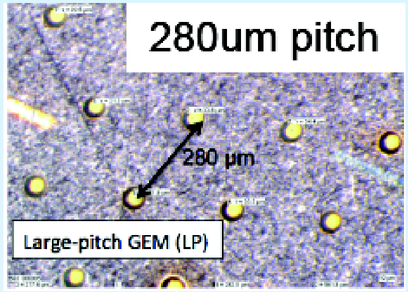




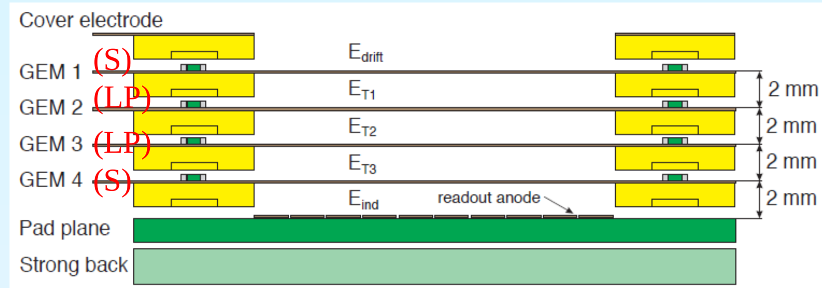


Baseline solution: 4 GEM setup

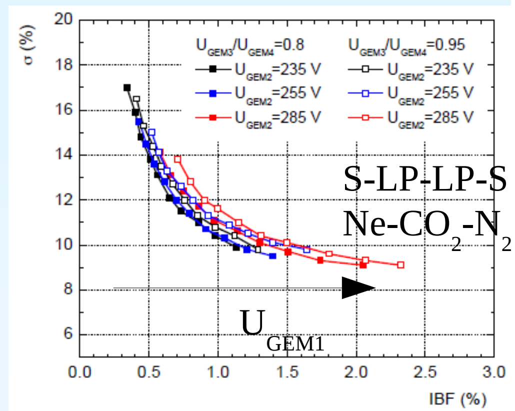


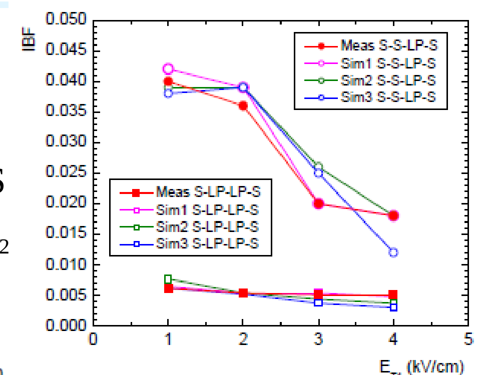


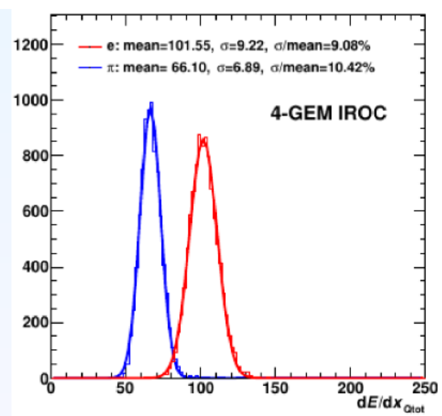
ALICE: CERN-LHCC-2013-020, CERN-LHCC-2015-002



- **IBF and resolution studies**
  - 0.6-0.8% IBF at σ(5.9keV) ~ 12%
  - IBF quantitatively well described by simulations
- **Prototype test beam at PS (CERN)**
  - Good e/π separation
  - $\sigma_{dE/dx}$/<d*E*/dx> ~ 10.5% comparable to current TPC resolution (~9.5% with IROC)
- **Momentum resolution – performance of current TPC preserved**







ALICE O^2 Project

The Upgrade of the ALICE Online and Offline Computing

- **50.000 collisions per second, each ~20 MByte**
  → ~1.1 TByte/s data input
- **Detectors in continuous & triggered read-out mode**
- **Data reduction by on-line reconstruction and compression**
- **Storage of only reconstruction results, discard raw data**
- **Combined DAQ/HLT/off-line farm (O2)**
- **Subsequent reconstruction passes for physics on farm**

Detectors	Input to On-line System (GByte/s)	Peak Output to Local Data Storage (GByte/s)	Avg. Output to Computing Center (GByte/s)
TPC	1000	50.	8.
TRD	81.5	10.	1.6
ITS	40.	10.	1.6
Others	25.	12.5	2.
Total	1146.5	82.5	13.2

German Contributions to the Upgrade Project

- TPC: H. Appelshäuser (U Frankfurt, PL), C. Garabatos (GSI, DPL), C. Lippmann (GSI, TC)
- HLT Upgrade: V. Lindenstruth (U Frankfurt, PL), T. Kolleger (GSI, TC)
- Involved groups:
  - GSI/EMMI
  - Universität Heidelberg
  - Universität Frankfurt
  - Universität Münster
  - Universität Tübingen
  - Technische Universität München
  - Universität Bonn
  - FH Worms

Contributions to the TPC Upgrade Project

- GEM frames
- Chamber assembly
- Electronics development
- Online calibration and reconstruction
- Integration, commissioning and testing

Status TPC Upgrade Project

- Full-size 4-GEM
- GEM foils test and QA
- Electronics tests
- Engineering Design Review
  - Chamber assembly
  - HV
  - Etc.

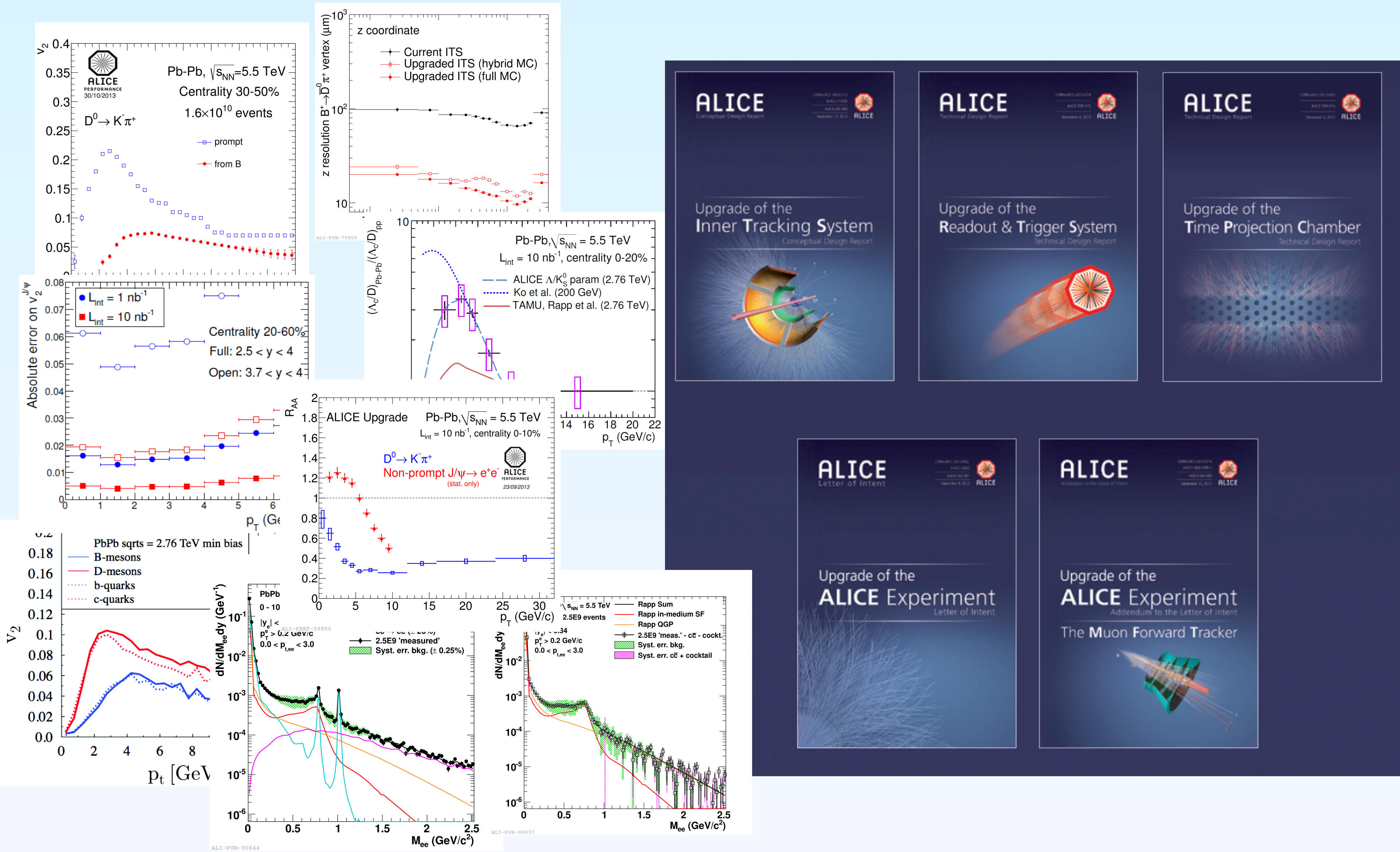
Conclusion

- **Rich physics harvest of LHC Run 1**

- **Smooth start into Run 2**
- **Exiting results to come → stay tuned**

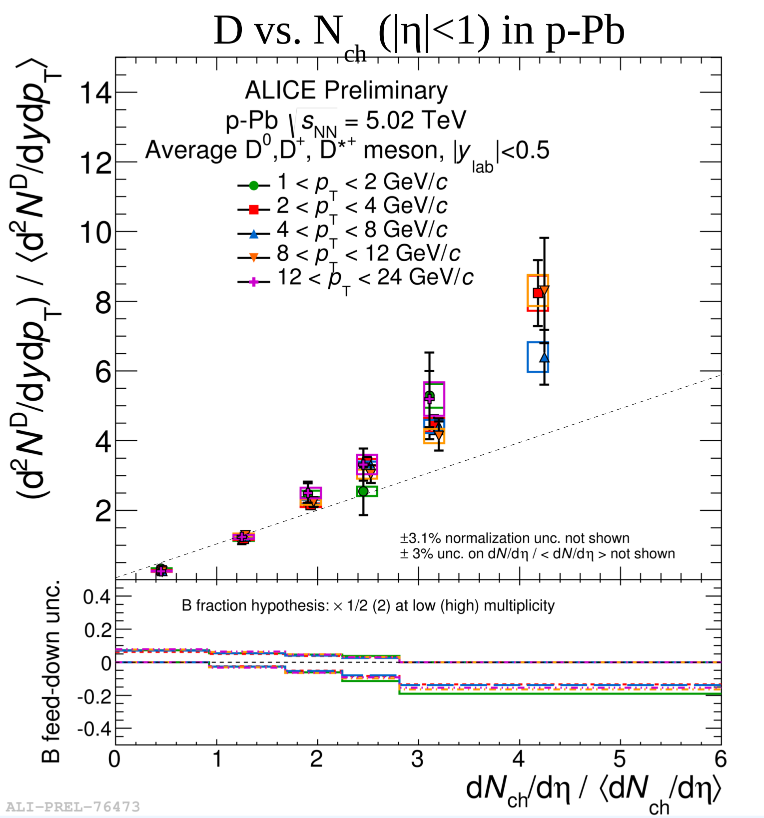
- **Major detector upgrade during LS2 to exploit the high collision rate expected for the LHC Run 3**
- **ALICE has a strong and unique program for precision QGP studies in Run 3**
  - Focus on rare probes and their interaction with the QGP
  - Extending to the late 2020s

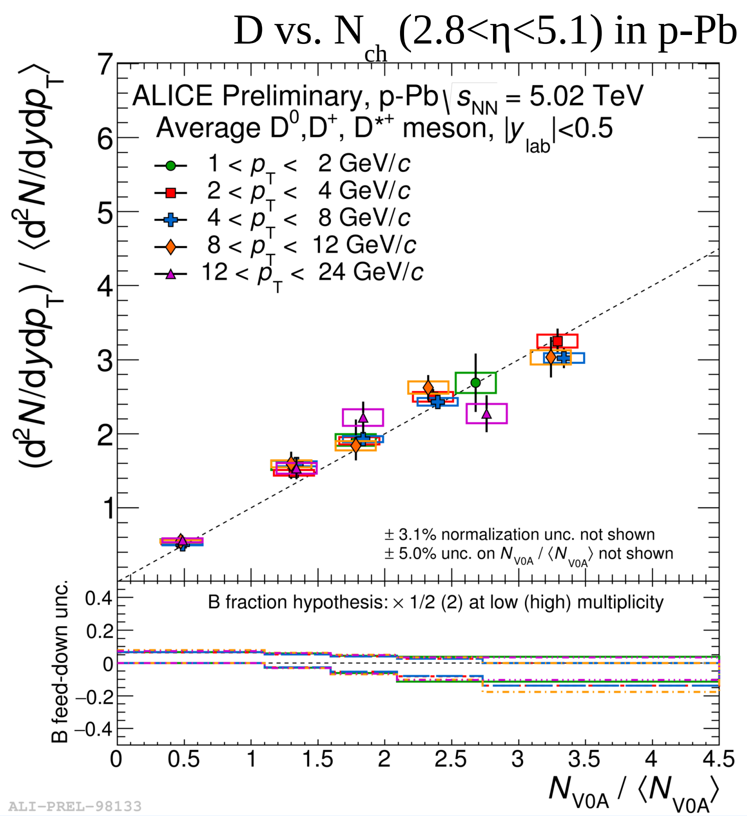
ALICE Upgrade and Physics Opportunities



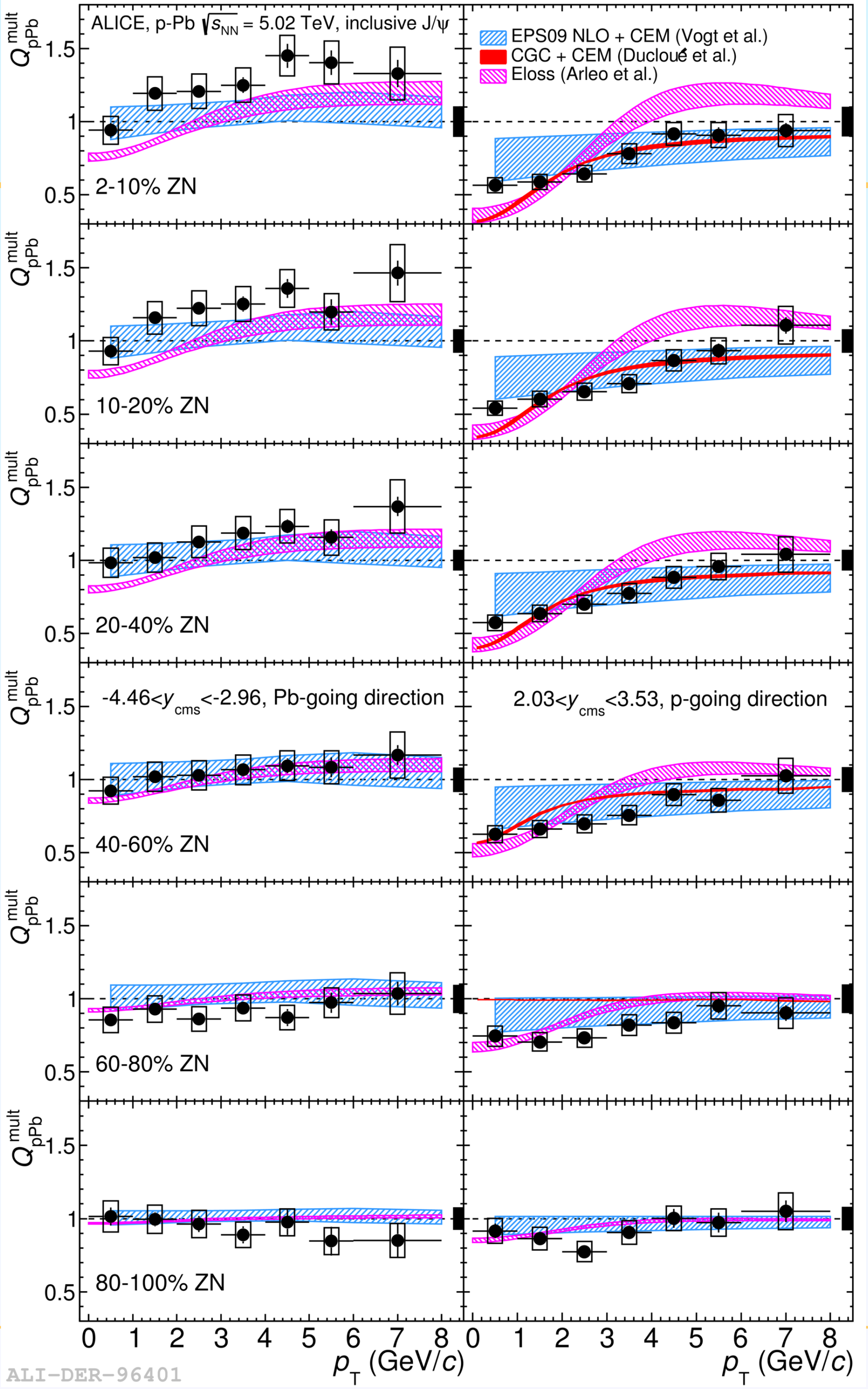
Back-Up

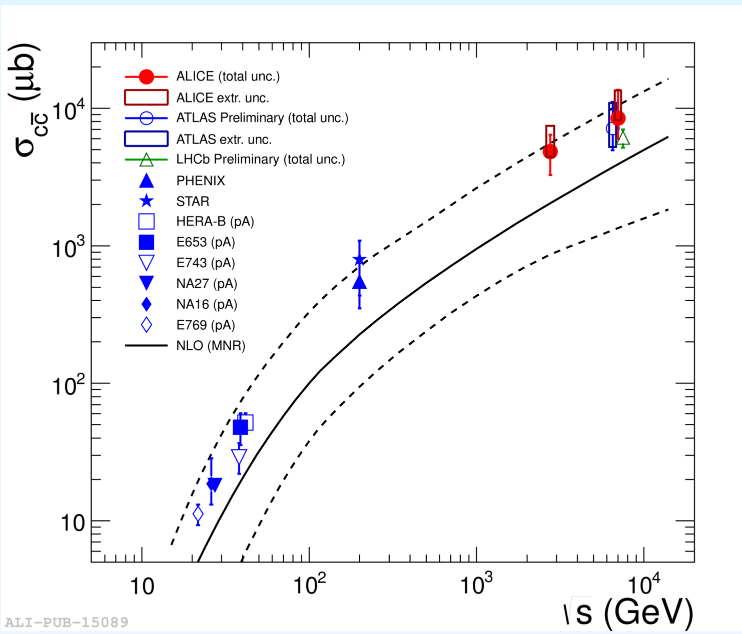
Heavy-Flavour Production in p-Pb
Event Activities in p-Pb

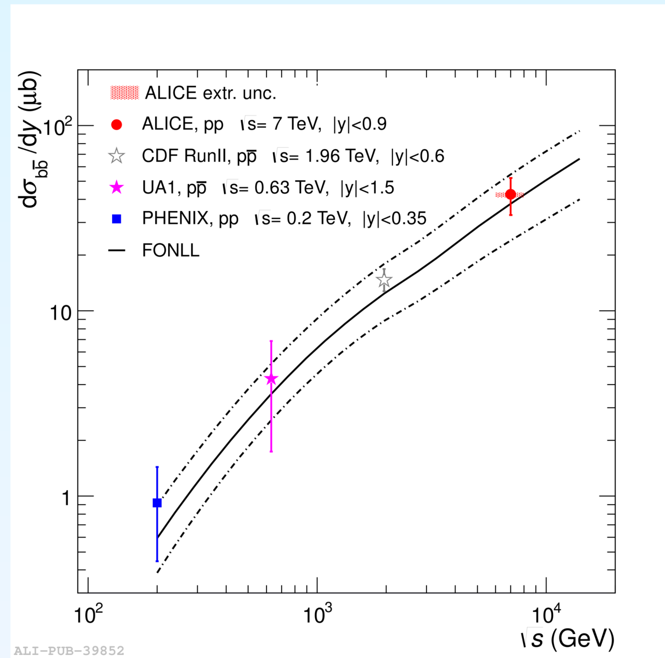




- **Self-normalised yield vs. multiplicity from two estimators**
  - Tracklets in SPD (|η|<1) and backward (Pb-going) multiplicity in V0A (2.8<η<5.1)
- **Faster-than-linear increase with N_{ch} (|η|<1)**
- **Linear increase in measured multiplicity with V0A estimator.**
  - Consistent with mid-rapidity result in measured multiplicity interval


ALICE, p-Pb $\sqrt{s_{NN}}$ = 5.02 TeV, inclusive J/ψ
EPS09 NLO + CEM (Vogt et al.)
CGC + CEM (Ducloué et al.)
Eloss (Arleo et al.)
2-10% ZN
10-20% ZN
20-40% ZN
-4.46<y_{cms}<-2.96, Pb-going direction
2.03<y_{cms}<3.53, p-going direction
40-60% ZN
60-80% ZN
80-100% ZN
Q_{pPb}^{mult}
p_T (GeV/c)
ALI-DER-96401


ALICE (total unc.)
ALICE extr. unc.
ATLAS Preliminary (total unc.)
ATLAS extr. unc.
LHCb Preliminary (total unc.)
PHENIX
STAR
HERA-B (pA)
E653 (pA)
E743 (pA)
NA27 (pA)
NA16 (pA)
E769 (pA)
NLO (MNR)
$\sigma_{c\bar{c}}$ (μb)
10^4
10^3
10^2
10
$\sqrt{s}$ (GeV)
ALI-PUB-15089


ALICE extr. unc.
ALICE, pp $\sqrt{s}$= 7 TeV, |y|<0.9
CDF RunII, $p\bar{p}$ $\sqrt{s}$= 1.96 TeV, |y|<0.6
UA1, $p\bar{p}$ $\sqrt{s}$= 0.63 TeV, |y|<1.5
PHENIX, pp $\sqrt{s}$= 0.2 TeV, |y|<0.35
FONLL
$d\sigma_{b\bar{b}}/dy$ (μb)
10^2
10
1
10^3
10^4
$\sqrt{s}$ (GeV)
ALI-PUB-39852