Strangeness in Quark Matter

JINR-Dubna (Russia)

July 6-11, 2015

Low-mass dimuon measurements in pp, p-Pb and Pb-Pb collisions with ALICE at the LHC

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ALICE Lyon group @ IPNL

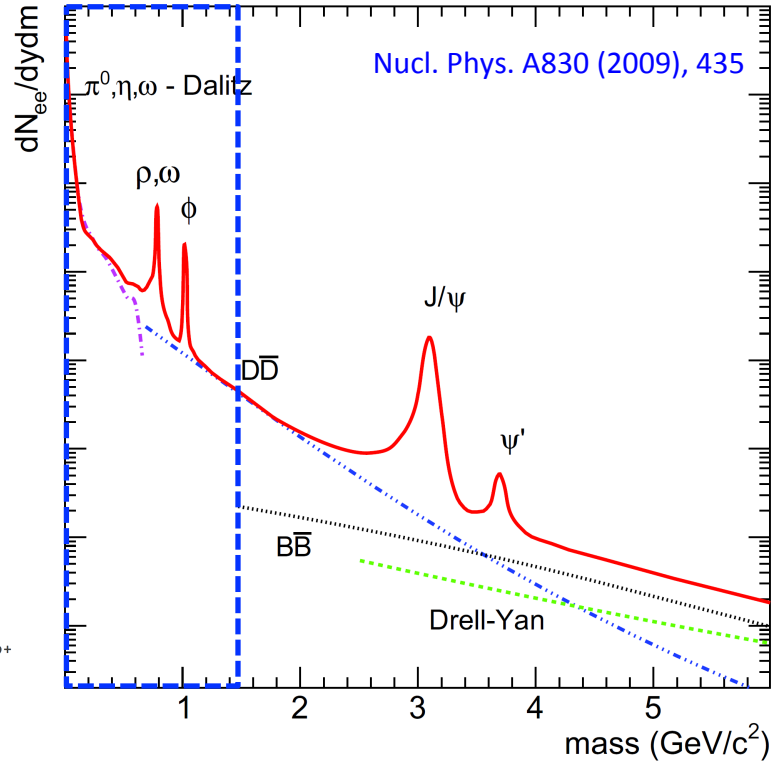
ALICE

Low-Mass Dilepton Physics

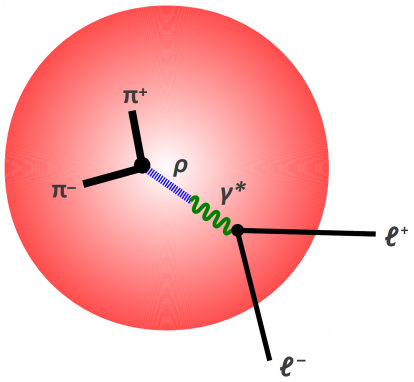
Low-mass dilepton production in AA collisions → key information on the hot and dense state of strongly-interacting matter produced in high-energy nucleus-nucleus collisions

Insight on **non-perturbative QCD**:

- Strangeness production investigated via ϕ meson production
- In-medium modifications of hadron properties accessed through ρ spectral function: possible link to chiral symmetry restoration



Dileptons (dielectrons, dimuons) → Negligible final-state effects



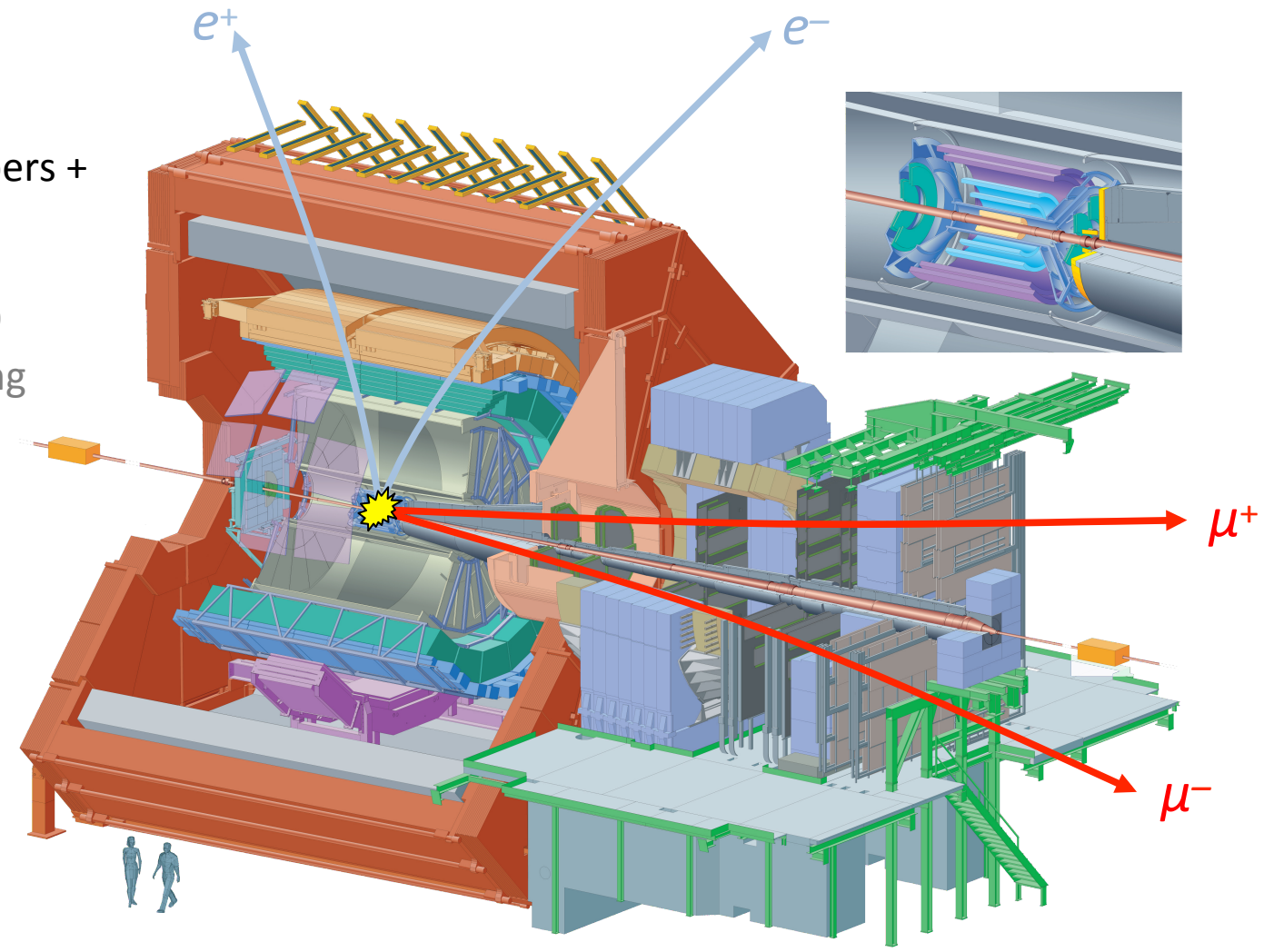
Measurements in pp and p-A collisions → Soft particle production in Cold Nuclear Matter, needed reference for correctly interpreting heavy-ion observations

Measuring Dileptons in ALICE

- **Dimuons** ⟶ **$2.5 < \eta < 4$**
  Muon Arm: Tracking Chambers + Muon Trigger

- **Dielectrons** ⟶ **$|\eta| < 0.9$**
  Central Barrel: Inner Tracking System + Time Projection Chamber + Time Of Flight

See talk by M. Ozdemir



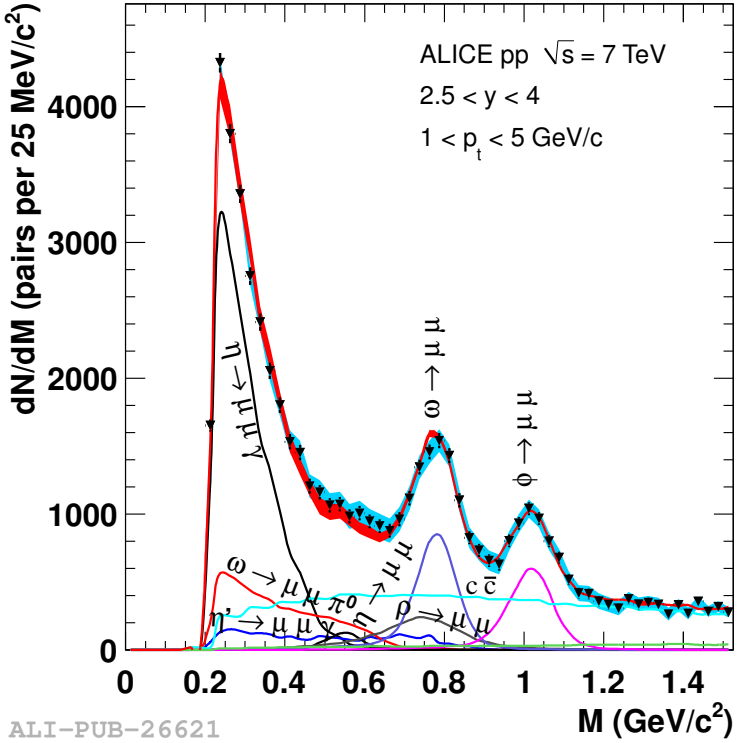
- pp collisions at **2.76 TeV**, **7 TeV** [⟶ PLB 710 (2012) 557
- p-Pb collisions at **5.02 TeV** per nucleon pair
- Pb-Pb collisions at **2.76 TeV** per nucleon pair

pp results at 7 and 2.76 TeV

Low-Mass Dimuons in pp at $\sqrt{s}$ = 7 and 2.76 TeV

- Low-Mass Dimuon Spectrum: **good agreement between signal and MC**
- **p_T-differential cross sections measured for ω and ϕ mesons** ⟶ reference for the interpolation at ≈ 5 TeV energy
- **ϕ meson** ⟶ PYTHIA tunes Perugia0 and Perugia11 underestimate the data by about a factor 2 both at 2.76 and 7 TeV

$\sqrt{s}$ = 7 TeV



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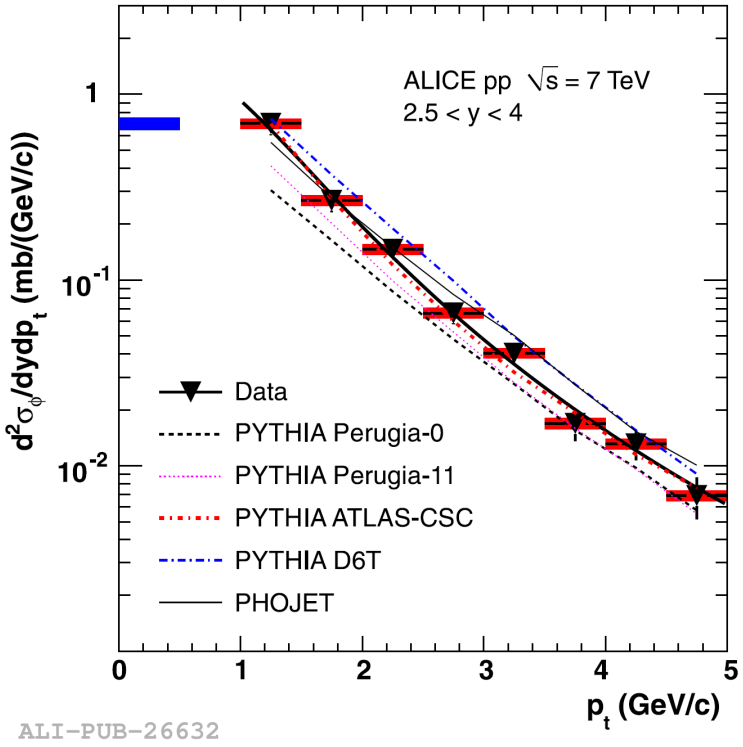

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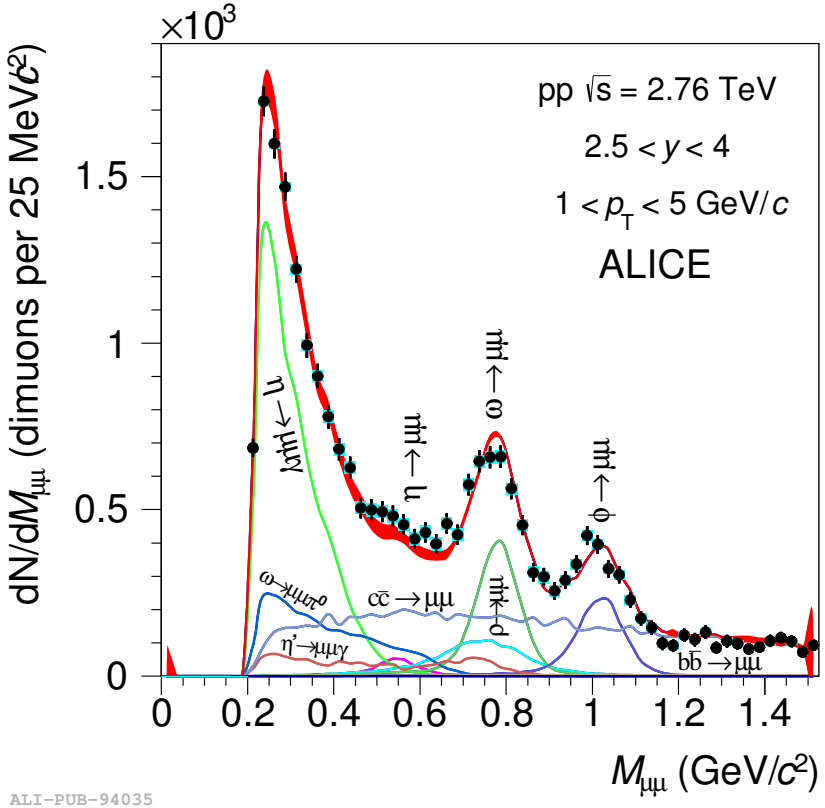
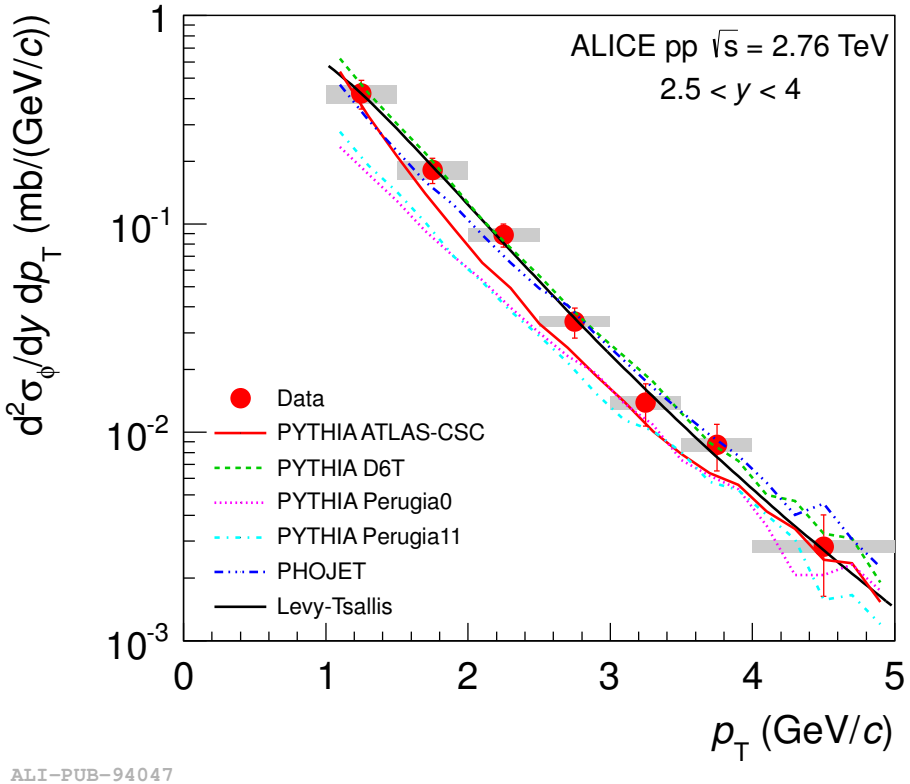
$\sqrt{s}$ = 2.76 TeV



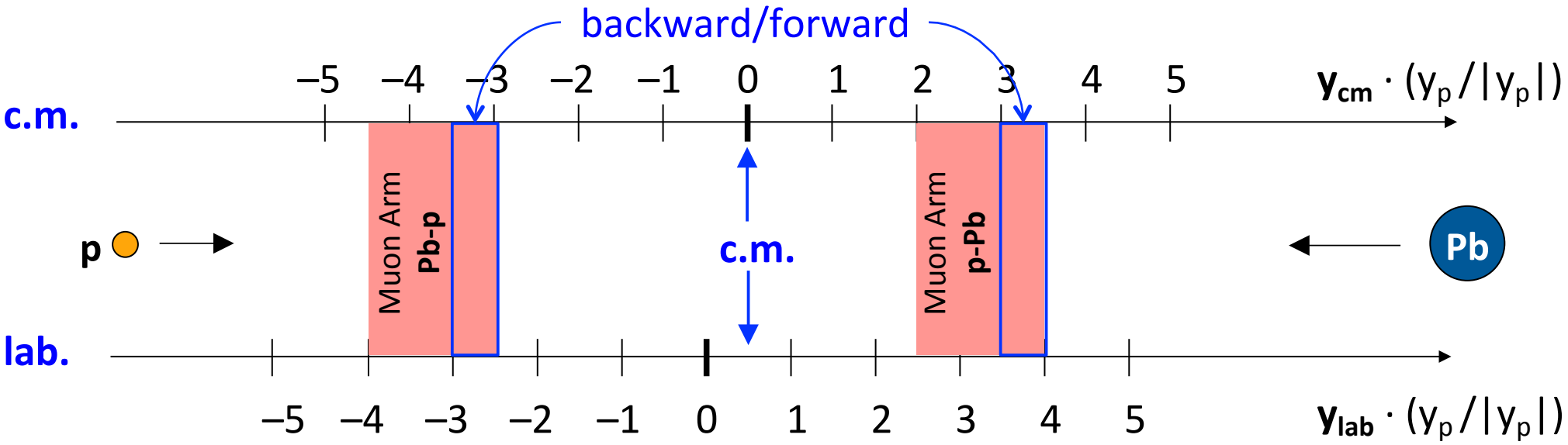
arXiv:1506.09206



p-Pb results at 5.02 TeV

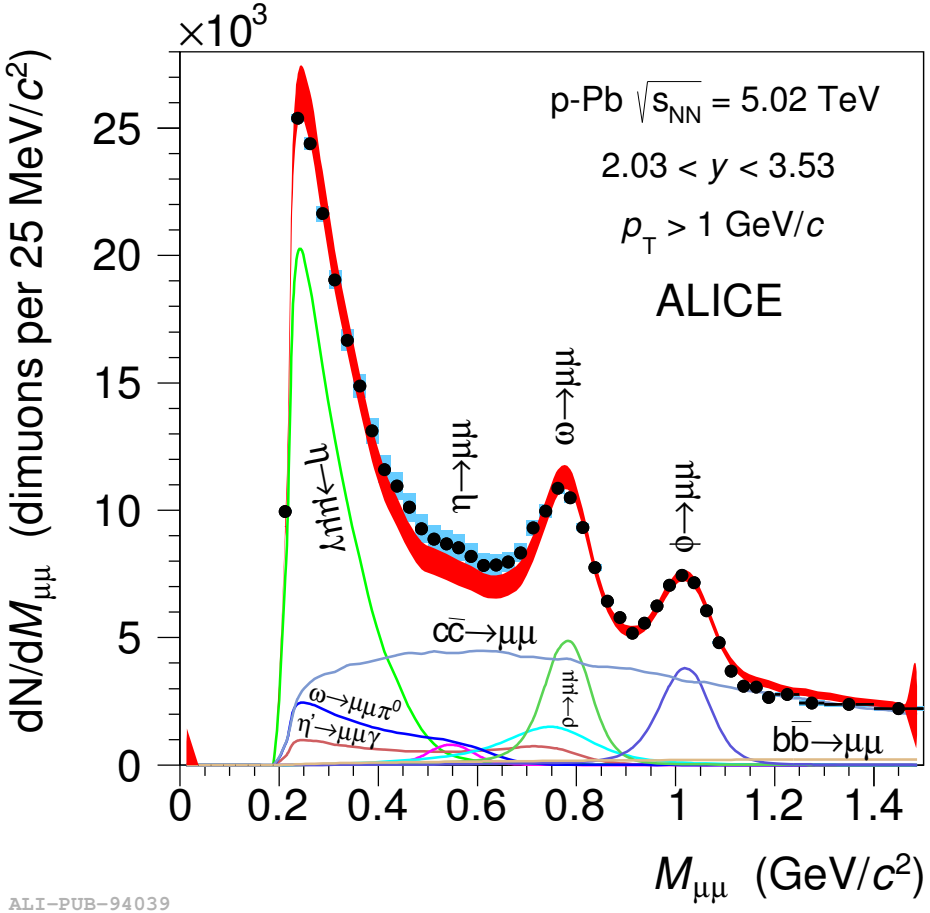
Low-Mass Dimuons in p-Pb at $\sqrt{s_{NN}}$ = 5.02 TeV

- **LHC p-Pb run in 2013: nearly 11 nb^{-1} integrated luminosity for dimuon triggers**
- LHC provides different energies for p (4 TeV) and Pb (1.58 × A TeV) beams ⟶ **c.m. moves with rapidity +0.46 in the laboratory**
- **Asymmetric system** ⟶ interest in looking both forward and backward hemispheres with the Muon Arm ($2.5 < y_{lab} < 4.0$): switch from p-Pb to Pb-p (much easier than flipping the Muon Arm!)
- Direct forward/backward comparisons only available in $2.96 < |y_{cm}| < 3.53$



Hadron Cocktail Fits

- Favorable dimuon trigger scheme: **acceptance down to dimuon p_T = 1 GeV/c**
- **Fair agreement between data and hadronic cocktail + open heavy flavors**
- **Focus on ϕ meson**: systematics on signal extraction within 7%



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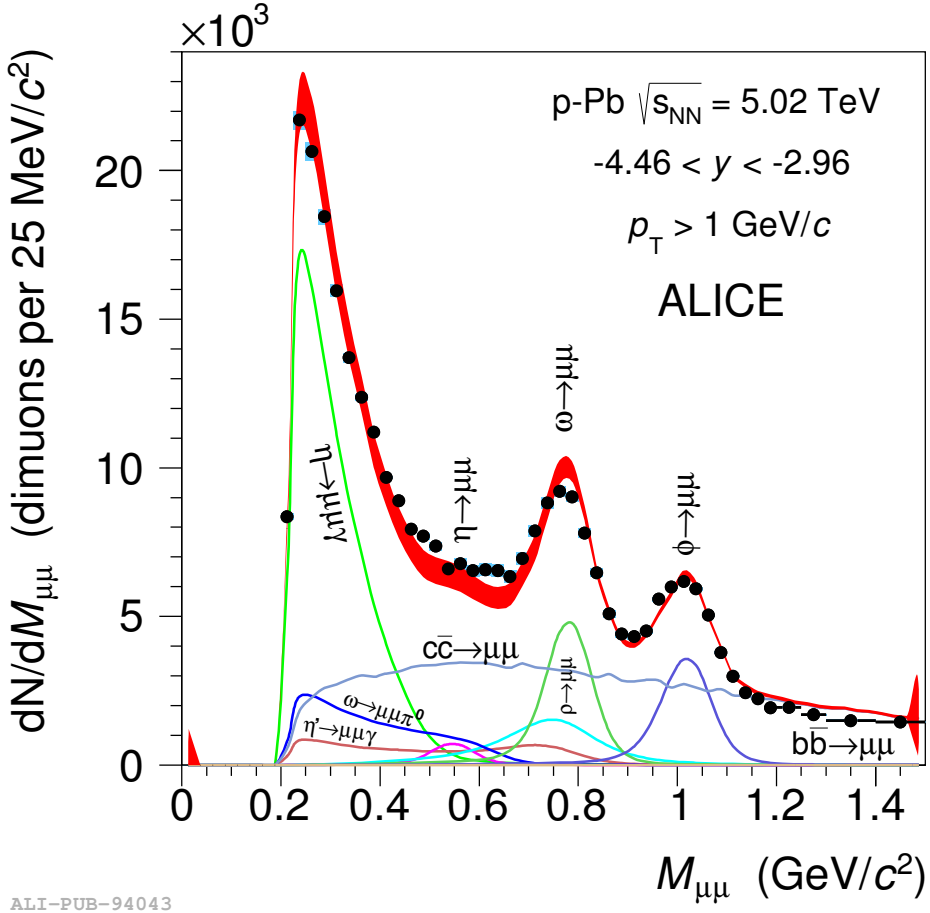
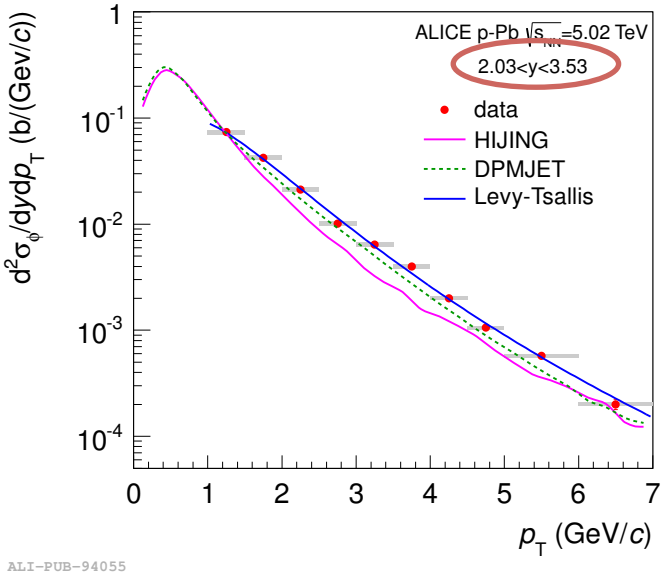
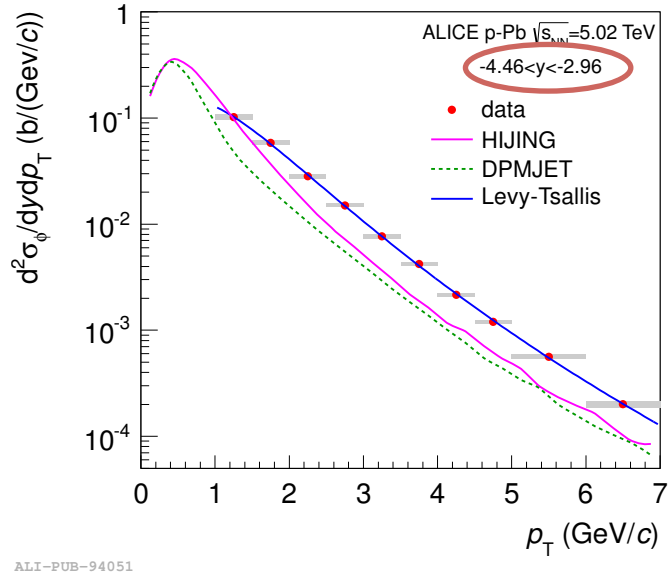


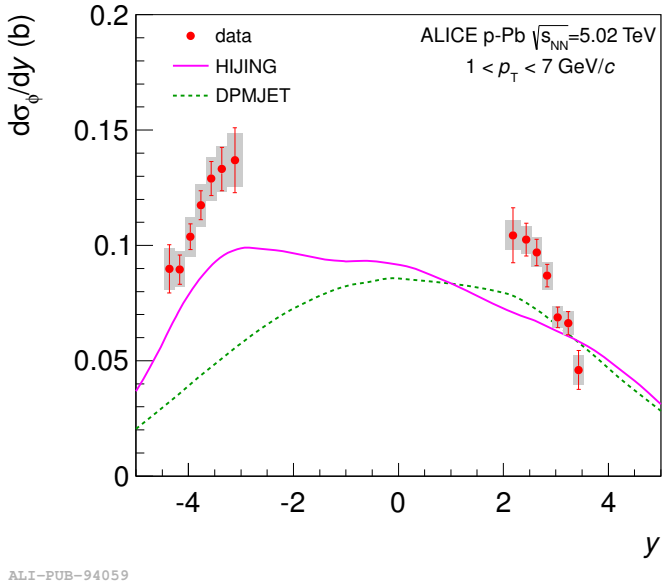
ϕ Meson Cross Section vs p_T and Rapidity

- **Transverse momentum dependence** of ϕ meson cross section: **compatible trends** in the proton- and Pb-going directions
- **Rapidity dependence** of ϕ meson cross section: **clear asymmetry** between the proton- and Pb-going directions. Expected from soft particle measurements at LHC and RHIC
- **Predictions from HIJING and DPMJET:** large deviations from the data, especially for the cross section normalization in the backward region and the description of the rapidity dependence in both the forward and backward regions

arXiv:1506.09206







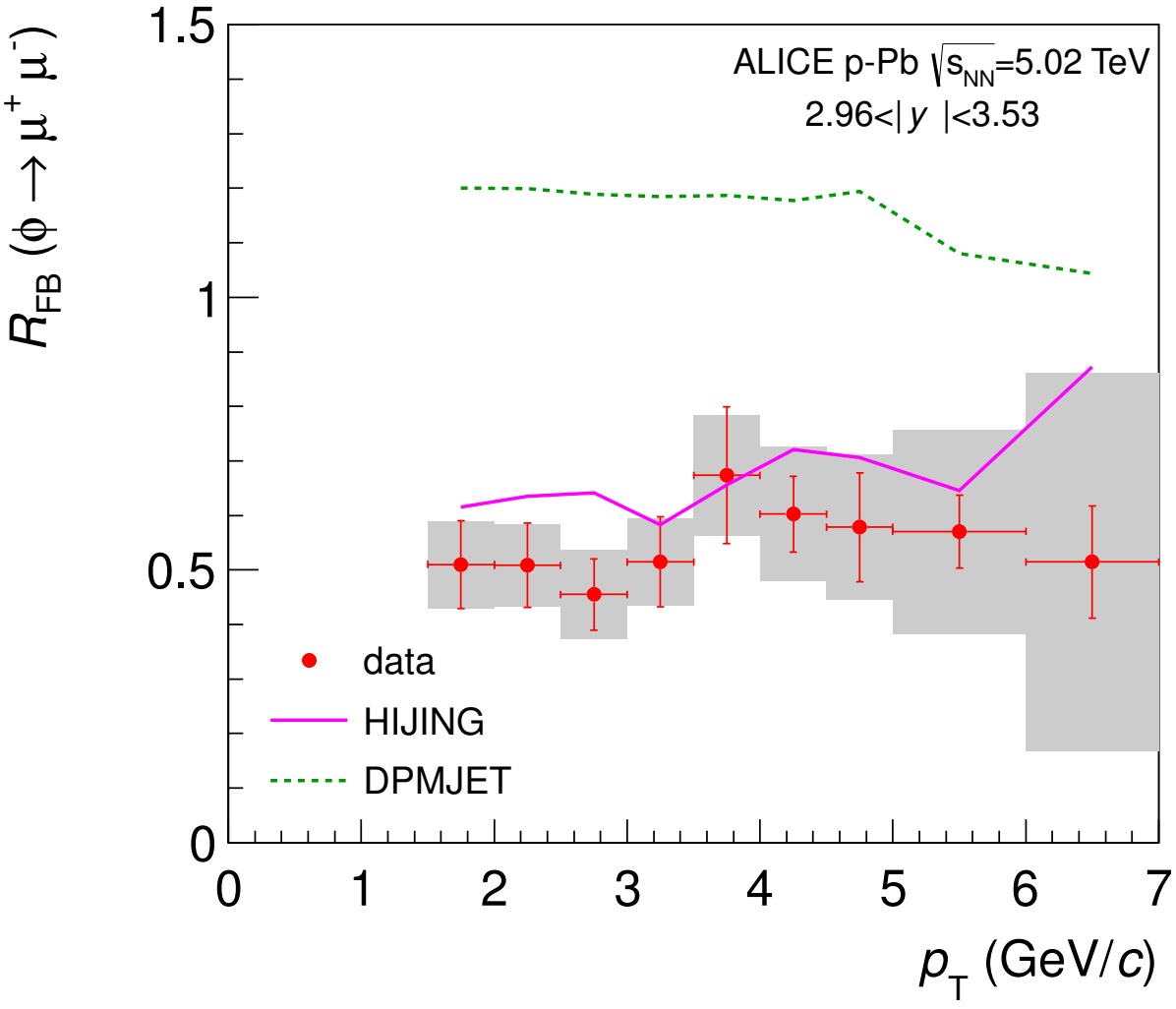
Forward/Backward Ratio

- **Defined as:**

$$R_{\mathrm{FB}} = \sigma_\phi(\Delta y)/\sigma_\phi(-\Delta y)$$

- A good way to compare forward and backward production is to **measure the yields in the common c.m. rapidity range: 2.96 < |*y*| < 3.54**

- **No dependence with p_T within uncertainties.** Differences in the observed yields at forward and backward rapidities → related to the known asymmetries in soft-particle production



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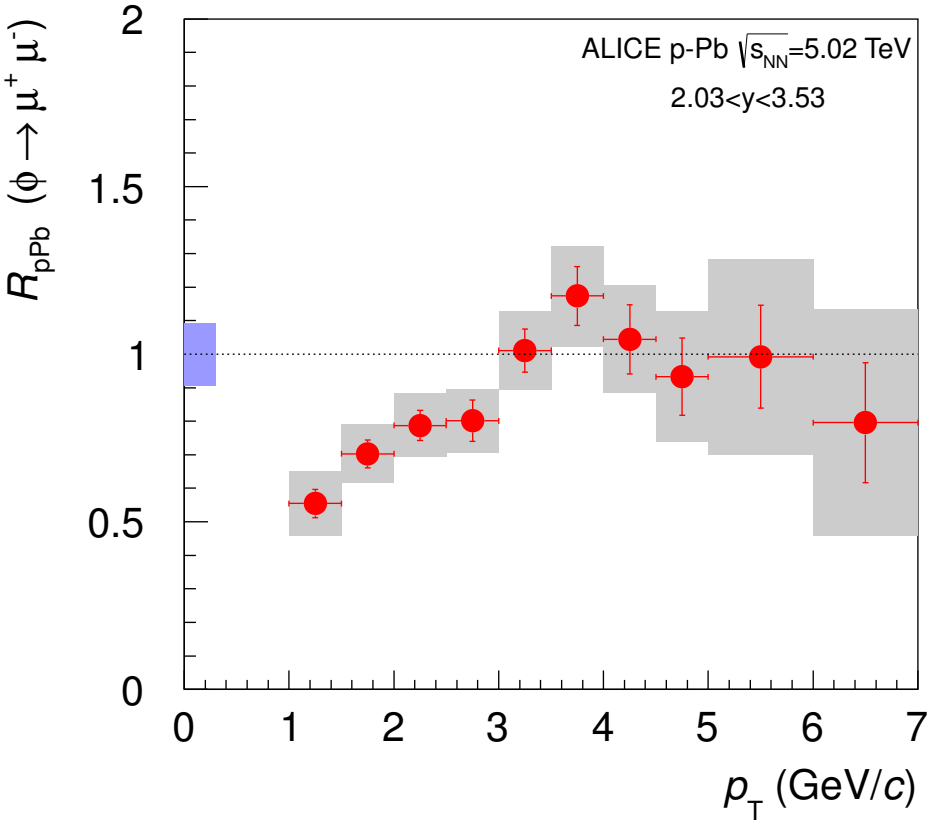
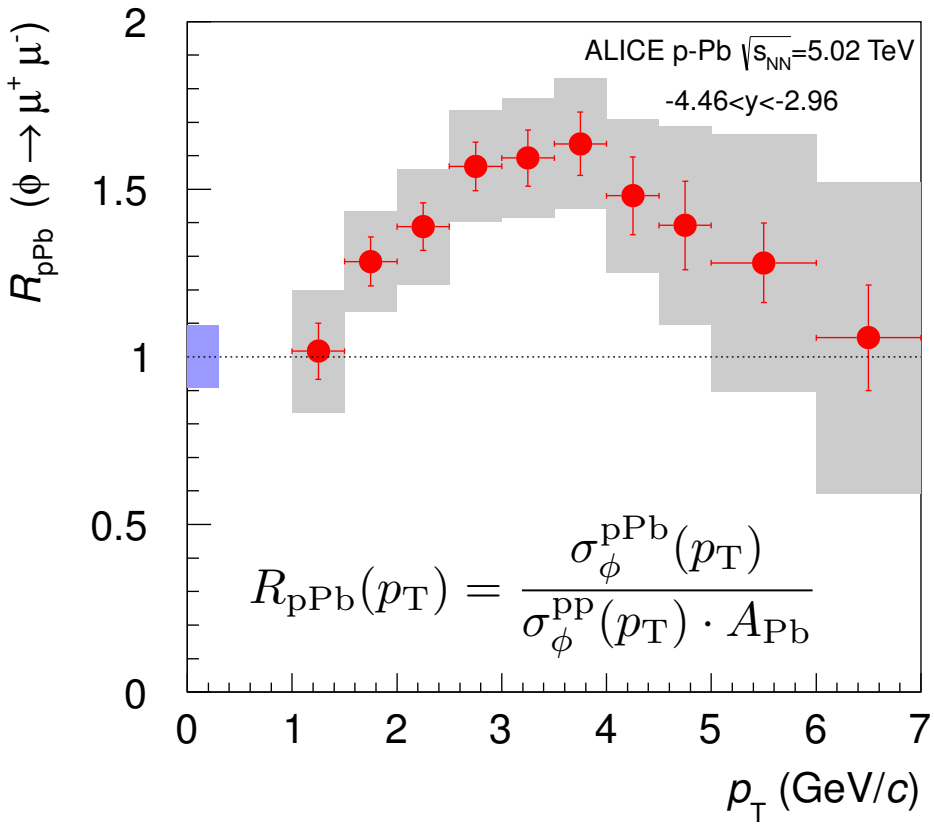
ALI-PUB-94063

R_{pPb} at Forward and Backward Rapidity

- ***R_{pPb}* vs p_T for the ϕ meson at forward** (p-going) **and backward** (Pb-going) rapidities: ***R_{pPb}* larger for backward rapidities**, but similar trends vs p_T

- R_{pPb} enhancement at backward rapidity for p_T = 3-4 GeV/c. Cronin-like initial-state effect or hint for flow? Specific model predictions are needed!





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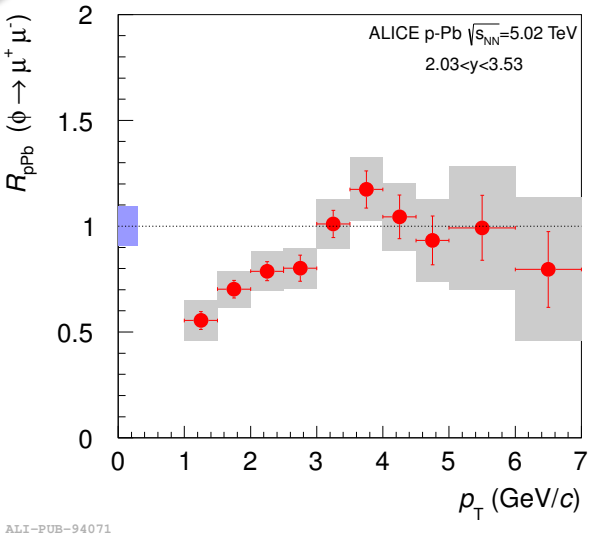
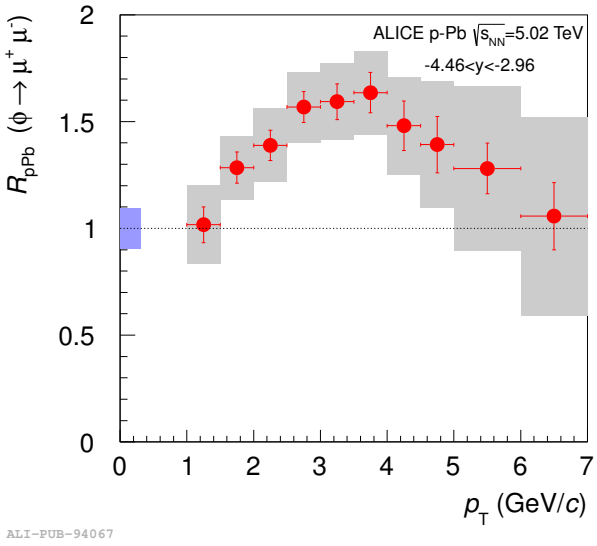
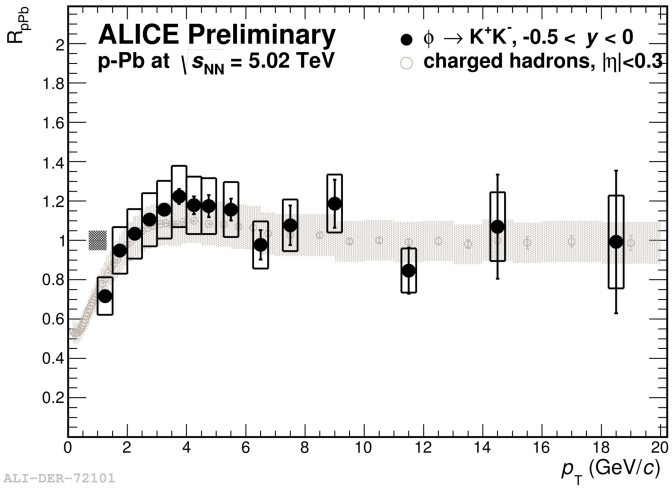
R_{pPb} at Forward and Backward Rapidity



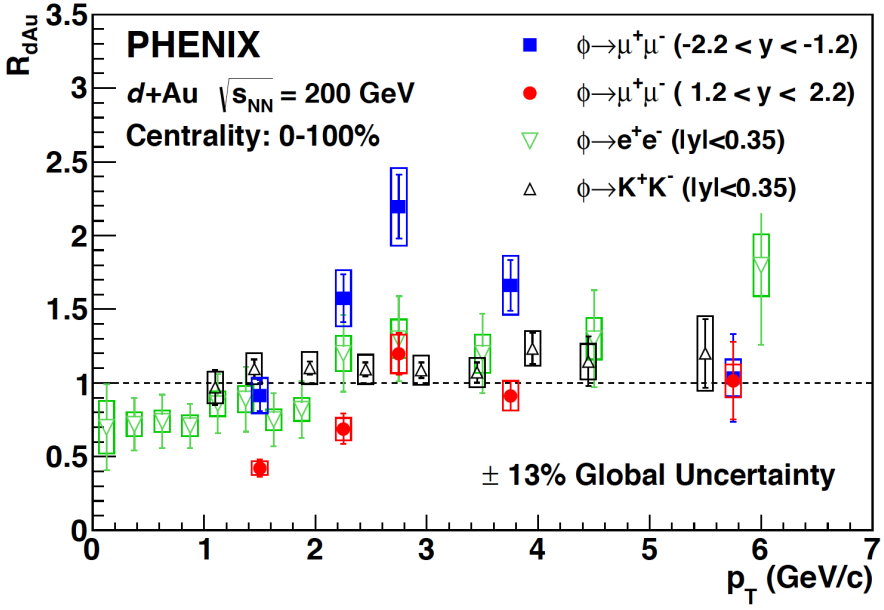




- Results on ϕ-meson R_{dAu} at RHIC ⟶ **same trend observed for the ϕ-meson R_{pPb} in ALICE,** both for the **p_T-dependence** and the **rapidity evolution**

- **Mid-rapidity data** seem to sit between the forward- and backward-rapidity results, both in ALICE and PHENIX

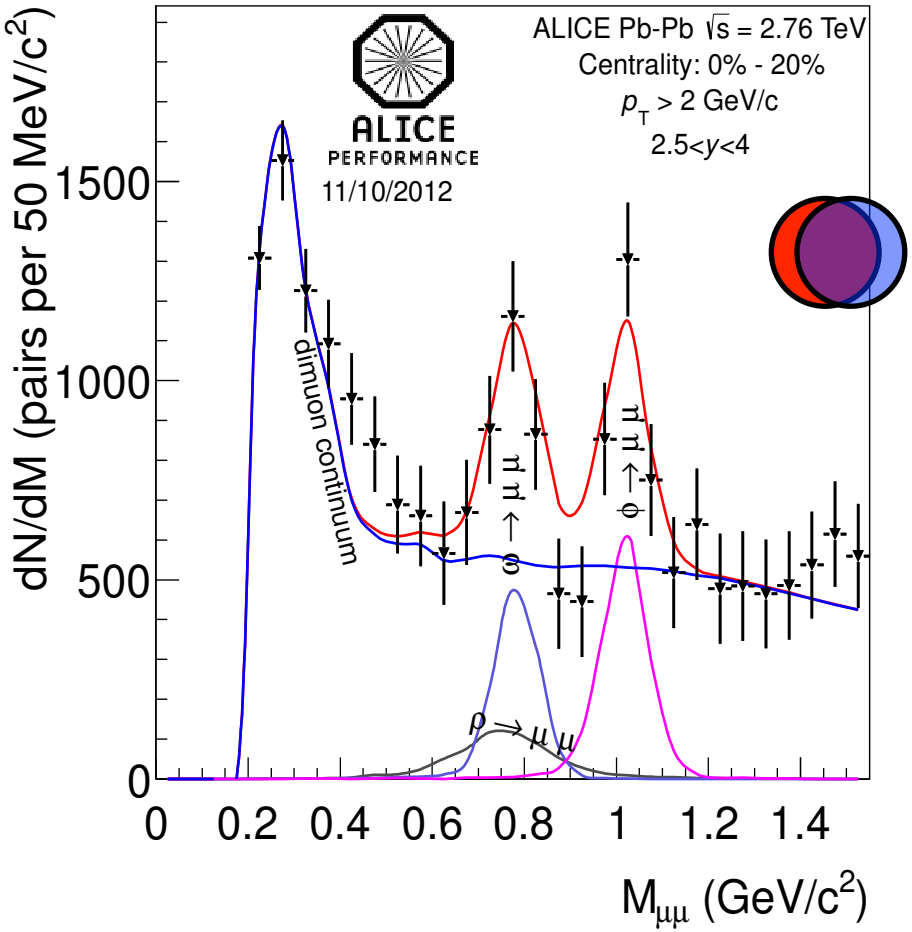
arXiv:1506.08181

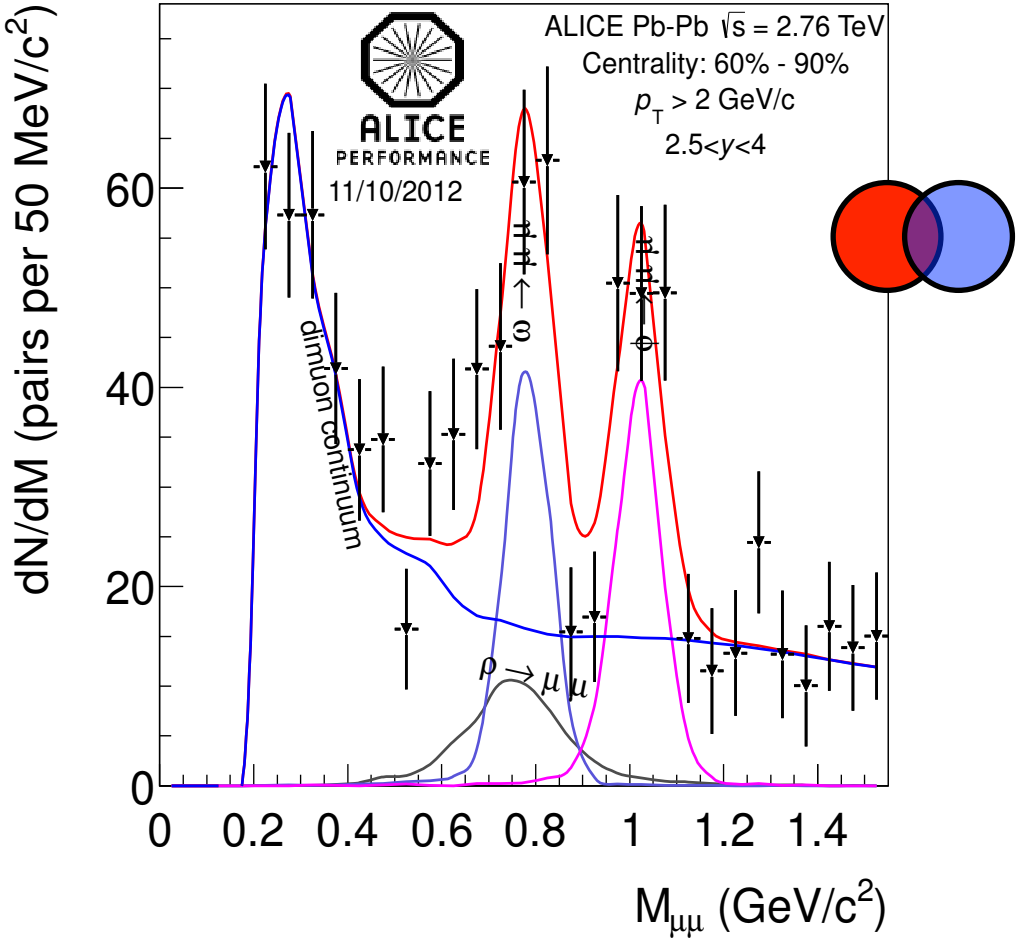


Pb-Pb results at 2.76 TeV

Low-Mass Dimuons in Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

- **ρ/ω and ϕ signals can be extracted w.r.t. continuum** (open charm/beauty and Dalitz decays). The large statistical uncertainties do not allow a precision study of the underlying continuum





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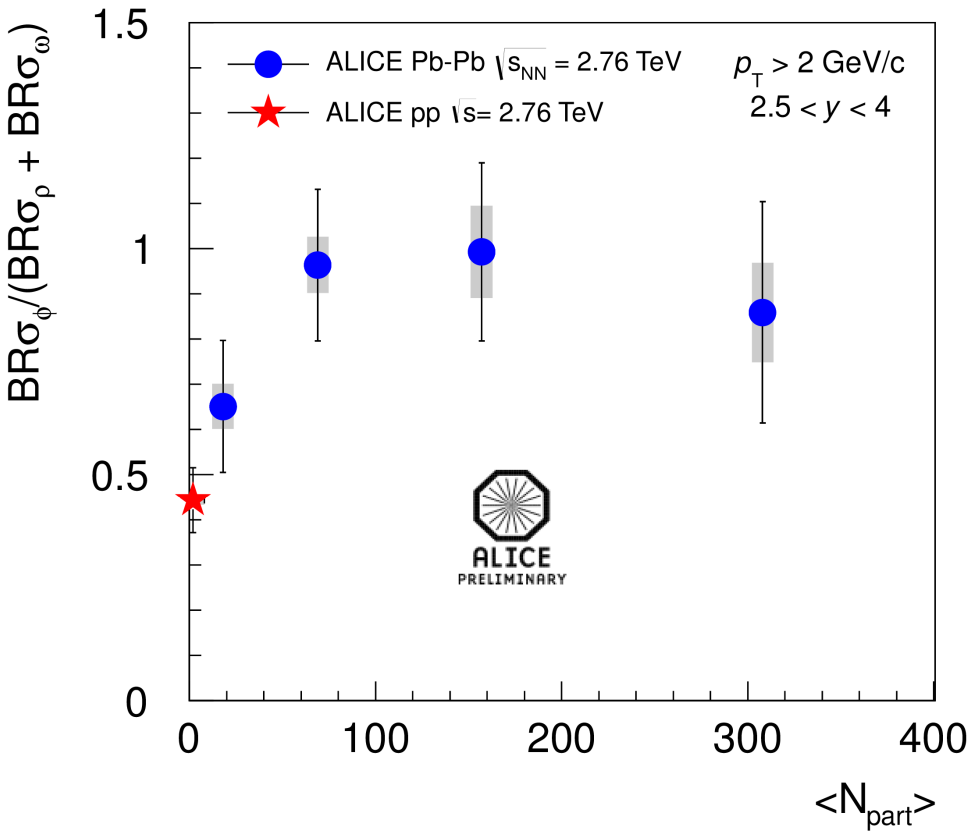
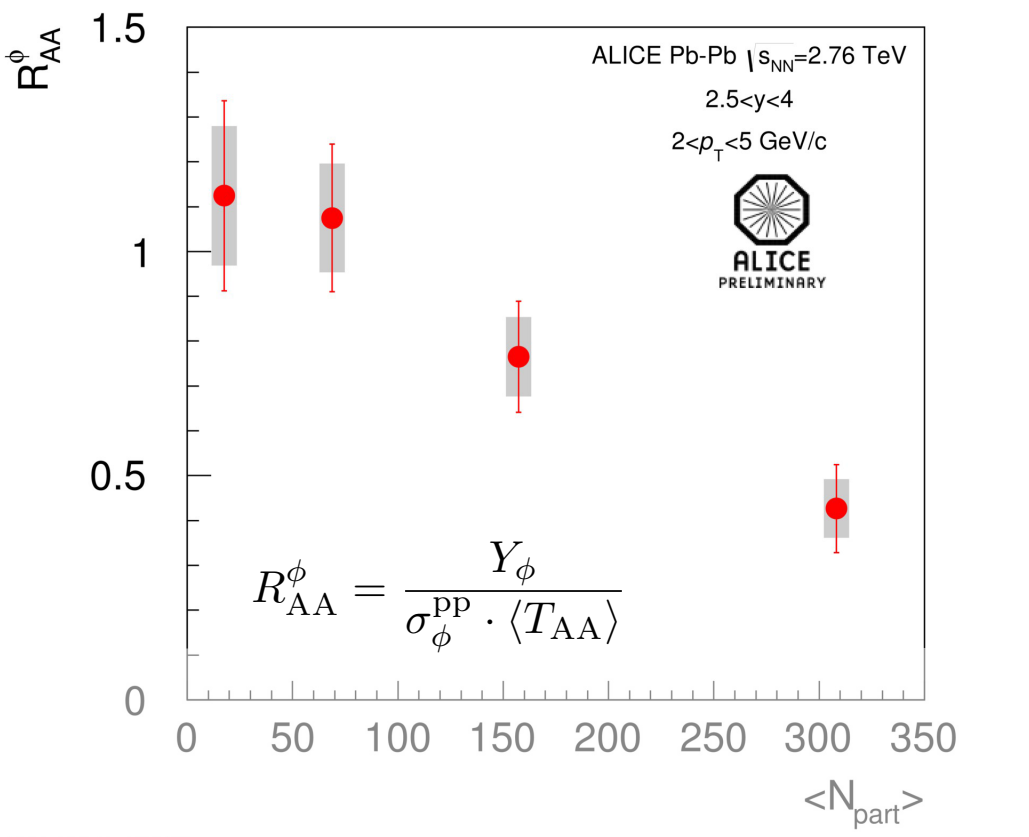
Low-Mass Dimuons in Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

- **ϕ/(ρ+ω) increases with respect to pp collisions:** ratio tends to **saturate** from semiperipheral to central collisions

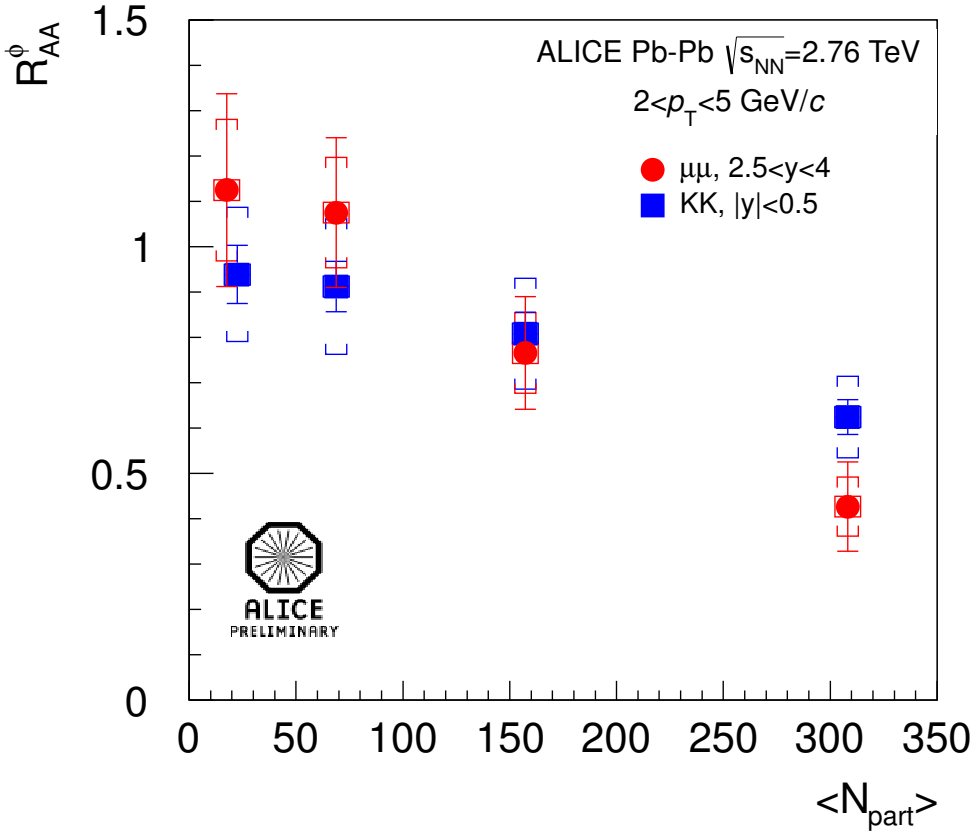
- ***R*$_{AA}$ measured for the ϕ meson vs centrality:** compatible with unity for peripheral collisions, suppressed going toward central collisions



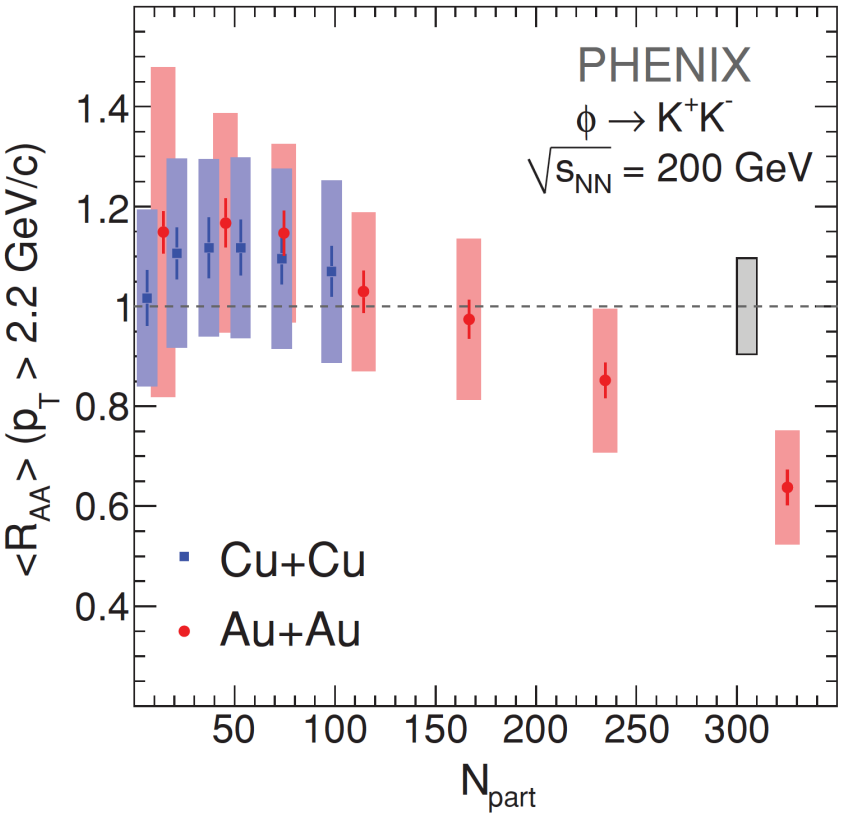


Low-Mass Dimuons in Pb-Pb at $\sqrt{s_{NN}}$ = 2.76 TeV

- Comparison with ϕ measurements in the KK channel in ALICE ⟶ **different shapes for R_{AA} vs centrality at mid- and forward rapidity**
- **Similar trend** as found for $R_{AA}(\phi)$ at mid-rapidity in Au-Au at 200 GeV by PHENIX



Phys. Rev. C 83 (2011) 024909



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Summary

- **pp collisions:** low-mass dimuon spectrum successfully described by the hadronic cocktail both at 2.76 and 7 TeV: baseline for Pb-Pb and p-Pb

- **p-Pb collisions:** forward/backward asymmetry observed for the ϕ meson, flat vs p_T , not well reproduced by models. **Measurement of the nuclear modification factor R_{pPb} peaked at p_T = 3-4 GeV/c at backward rapidity.** No prediction available from theoretical models: interpretation in terms of initial-state (Cronin-like) or final-state (flow-like) effect still pending

- **Pb-Pb at 2.76 TeV**: R_{AA} dimuon measurement available for the ϕ meson, although in a small p_T range. Suppression observed with increasing centrality, down to R_{AA} = 0.5

Backup Slides

Dilepton Physics

Probing full evolution of collisions, with negligible final-state interactions

High Mass Region (M > 3 GeV/c²)

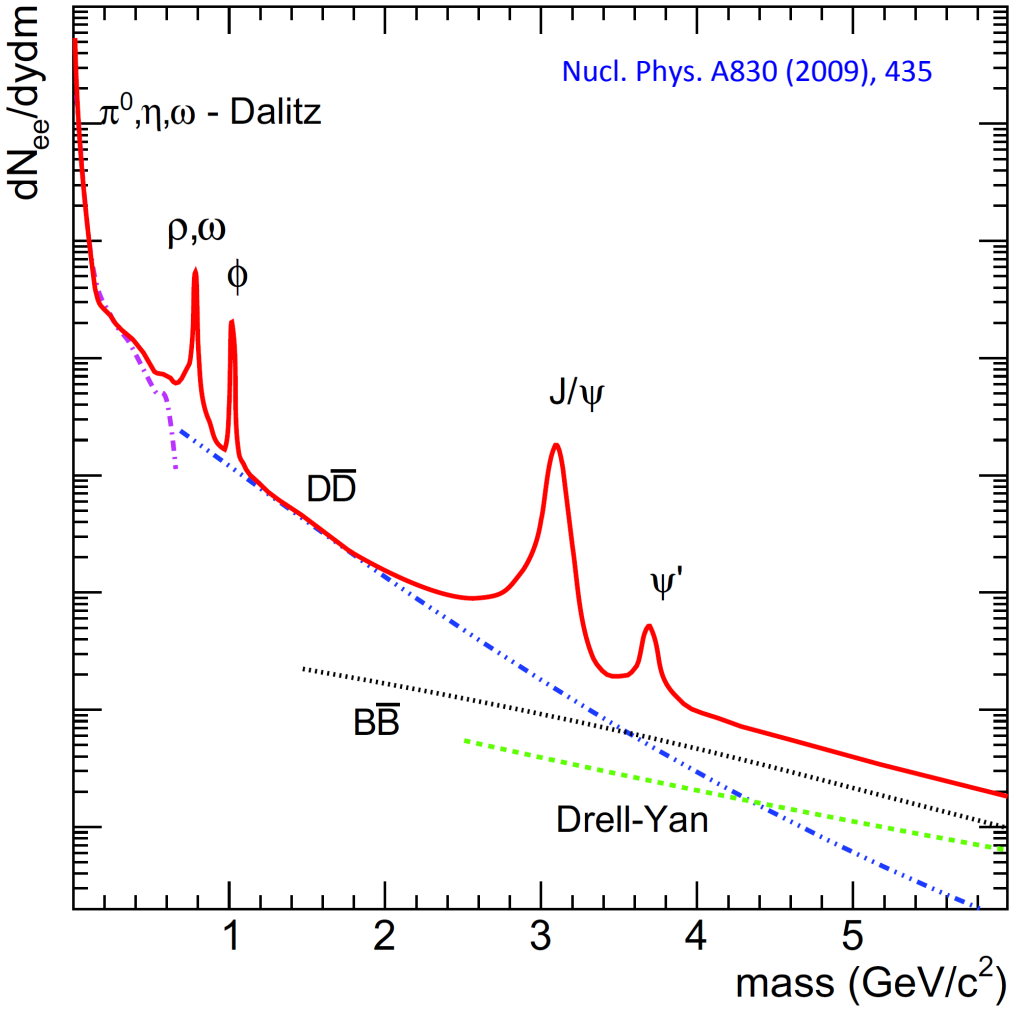
- Primordial emission, Drell-Yan
- Quarkonia and open heavy flavors (mostly beauty)

Intermediate Mass Region (1 < M < 3 GeV/c²)

- Thermal radiation from QGP
- Open heavy flavors (mostly charm)

Low Mass Region (M < 1 GeV/c²)

- Dalitz and 2-body decays of light narrow resonances close to freeze-out (light flavors)
- Thermal emission dominantly hadronic (from a hadron gas), mediated by the broad vector meson ρ in the form $\pi\pi \rightarrow \rho \rightarrow \ell\ell$



pp Reference at 5.02 TeV

- **Reference yield in pp collisions is needed** to evaluate the nuclear modification factor. **However, no pp measurement is available at 5.02 TeV**

- Starting from the measured p_T-differential cross sections measured in pp at 2.76 TeV and at 7 TeV, **we interpolate at 5.02 TeV**. Various hypotheses for the interpolating function ⟶ systematic uncertainty (up to 40% at p_T = 6-7 GeV/c!!)

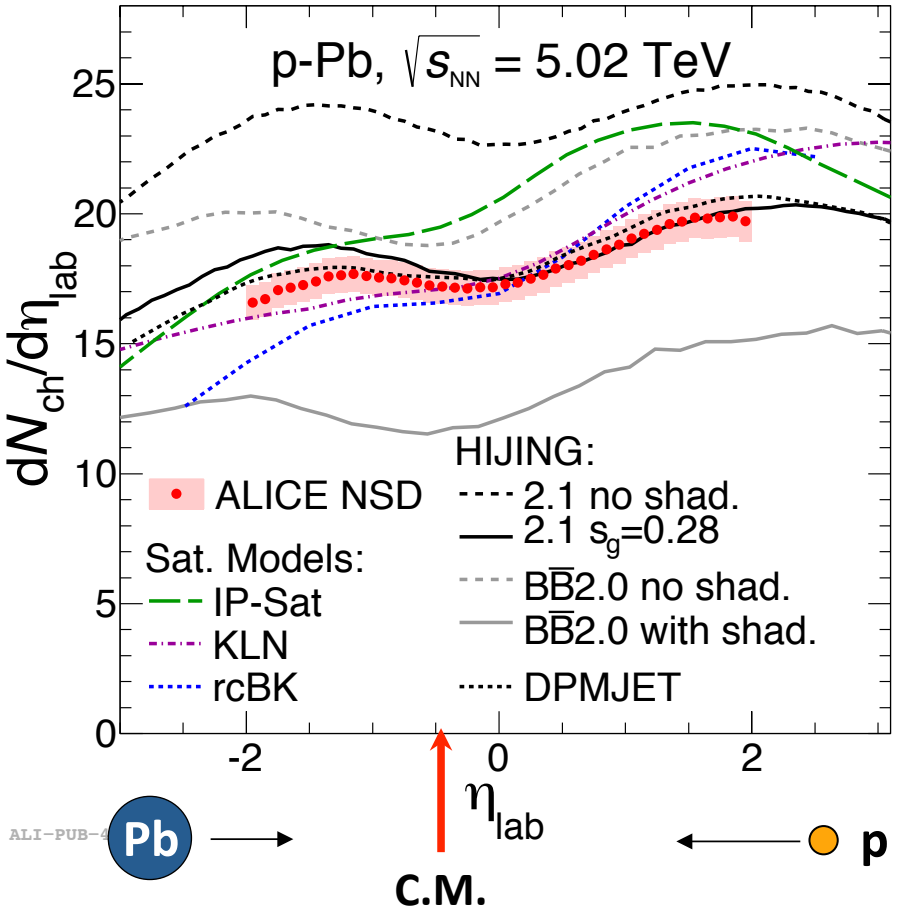
- **Resulting interpolated distribution is parameterized** ⟶ get rid of bin-to-bin fluctuations and extend to the full p_T range accessible in p-Pb

- Obtained in this way, the reference is relative to the nominal Muon Arm acceptance ($2.5 < y_{lab} < 4.0$) ⟶ **MC models allow a translation to the two rapidity regions covered in the analysis**

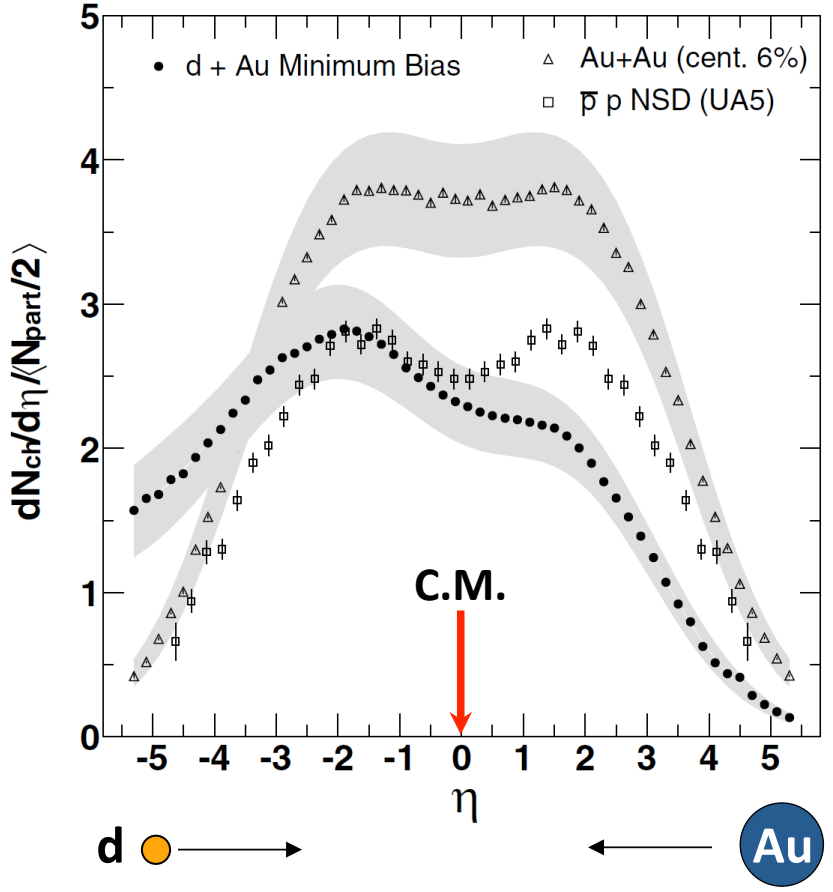
Forward vs Backward

- **ϕ yield larger at backward rapidity (Pb hemisphere) than at forward rapidity (proton's hemisphere)**: expected from soft particle production measurements

ALICE Coll. Phys. Rev. Lett. 110, 032301 (2013)

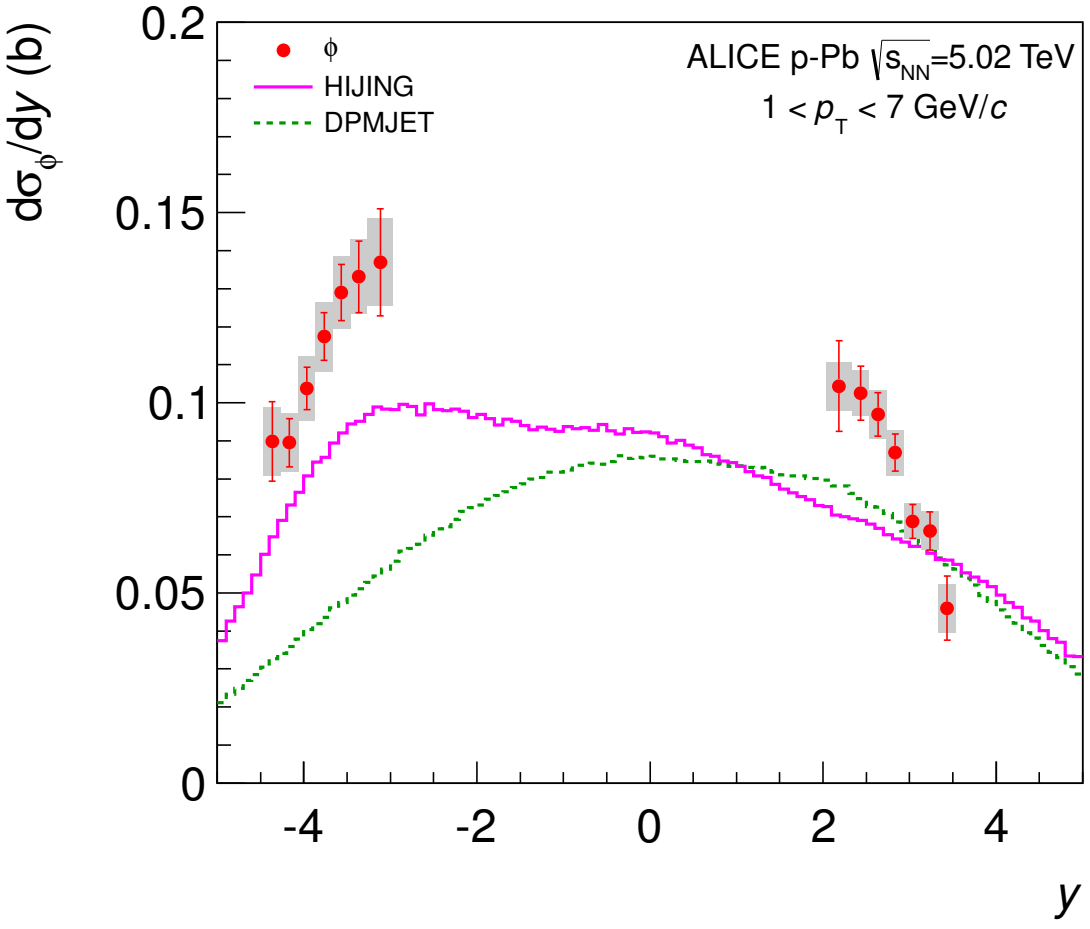


PHOBOS Coll. Phys. Rev. Lett. 93, 082301 (2004)



ϕ Meson y-differential Cross Section

- **ϕ yield** measurement ranging from the Pb to the proton fragmentation regions. First measurement of soft particle production at forward rapidity at the LHC



- **Extension** of soft particle production measurement in p-Pb at mid-rapidity (see next slide)
- Data compared to HIJING model predictions (which best described results at mid-rapidity)
- Models cannot describe the observed rapidity dependence of **ϕ yield**:
  - **Forward/backward asymmetry** not well reproduced
  - Normalization underestimated