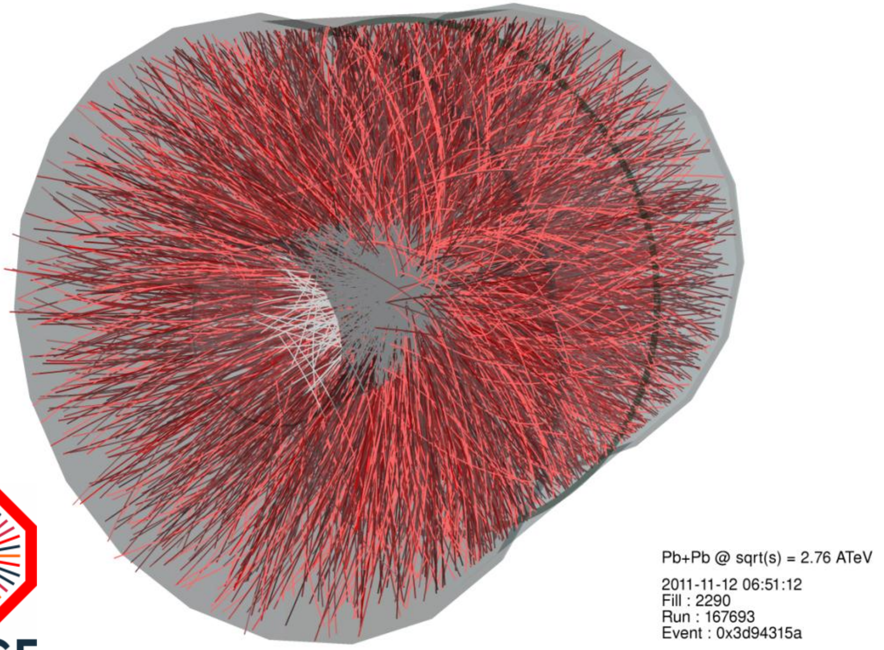
ALICE status and plans



ALICE

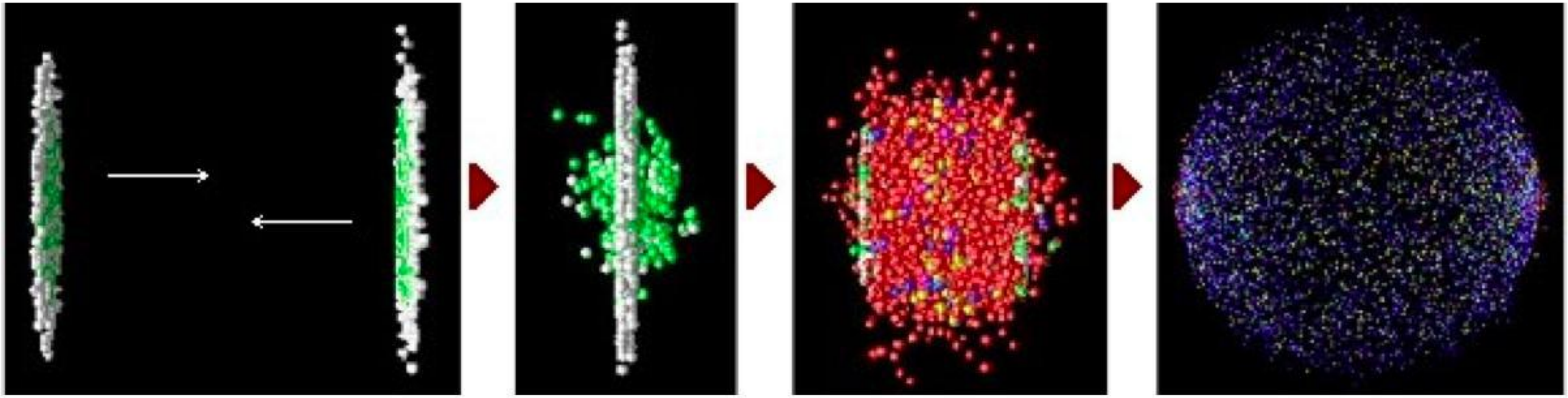
Evgeny Kryshen
(Petersburg Nuclear Physics Institute)
for the ALICE collaboration

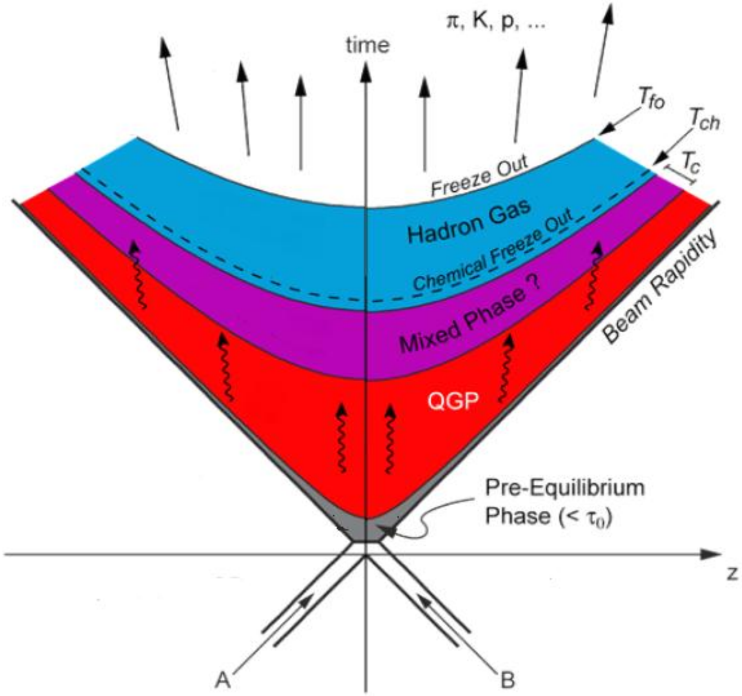
LHC on the March, Protvino, 20-22 November 2012

Contents

- ALICE motivation, layout and data taking overview
- Recent ALICE results
  - Identified particle spectra
  - Anisotropic flow
  - Particle correlations
  - Heavy flavours
  - Quarkonia
  - pA highlights
- Plans and upgrade perspectives
- Conclusions

Physics motivation



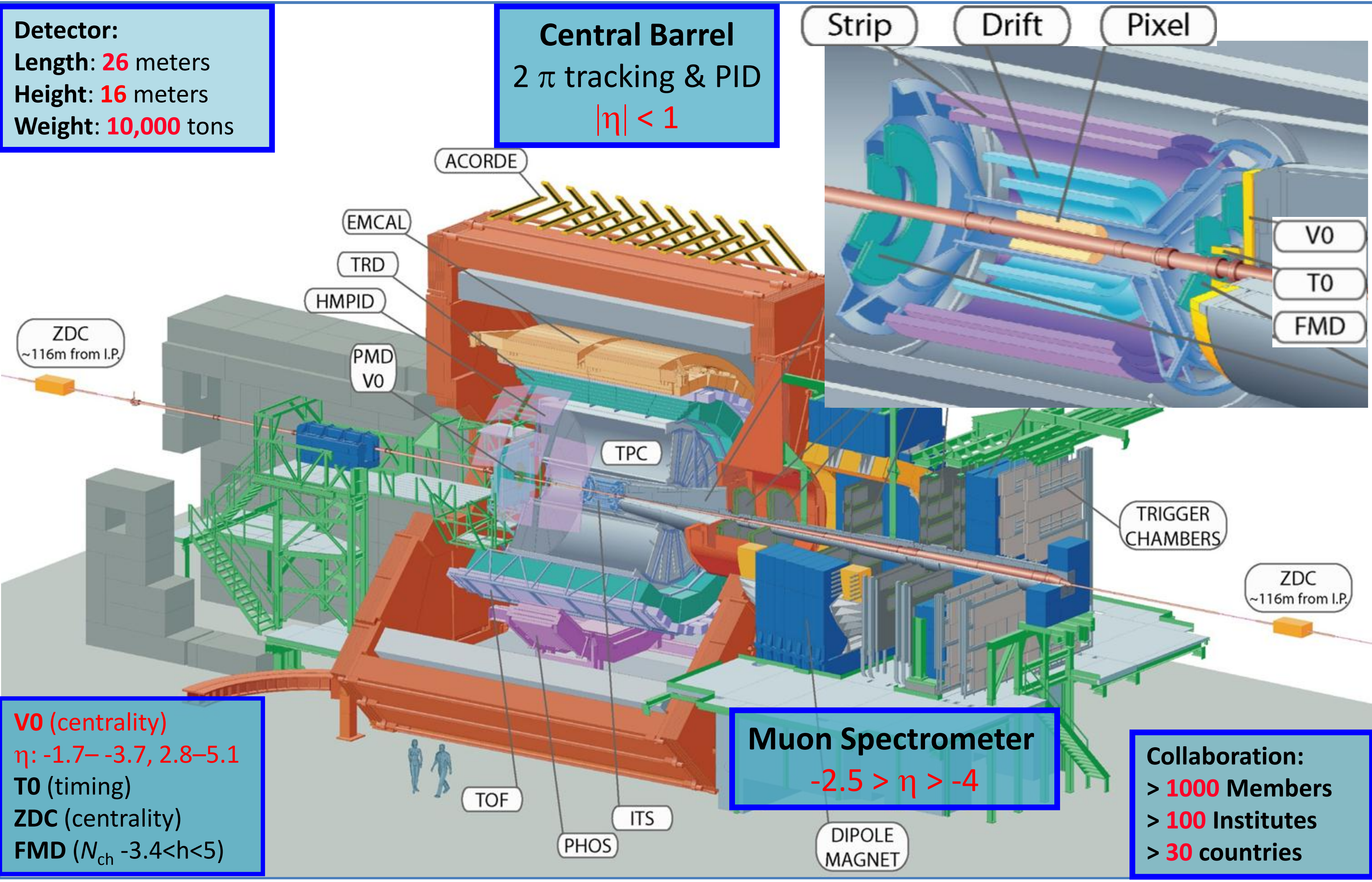


- Goal: study nuclear matter at extreme conditions of temperature and density
- Heavy ion collisions studied since SPS & RHIC eras
- Produced QCD matter initially thought as weakly interacting gas of quarks and gluons but …
- found as strongly interacting matter:
  - short mean free path
  - high collectivity and flows
  - large parton energy-loss
  - almost perfect liquid

ALICE experimental setup

Detector:
Length: 26 meters
Height: 16 meters
Weight: 10,000 tons

Central Barrel
2 π tracking & PID
$|\eta| < 1$

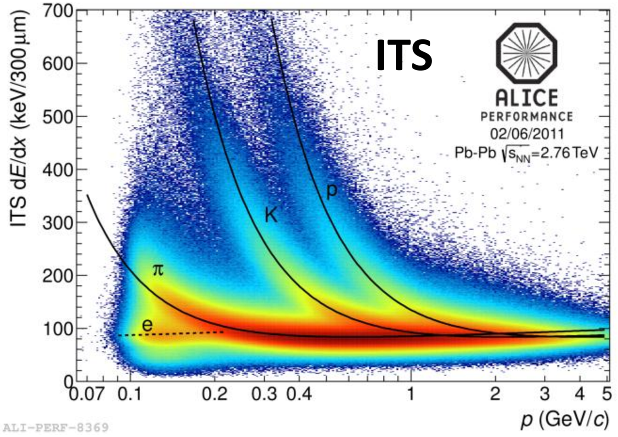


V0 (centrality)
η: -1.7– -3.7, 2.8–5.1
T0 (timing)
ZDC (centrality)
FMD (N_{ch} -3.4<h<5)

Muon Spectrometer
$-2.5 > \eta > -4$

Collaboration:
> 1000 Members
> 100 Institutes
> 30 countries

PID, vertexing and tracking capabilities



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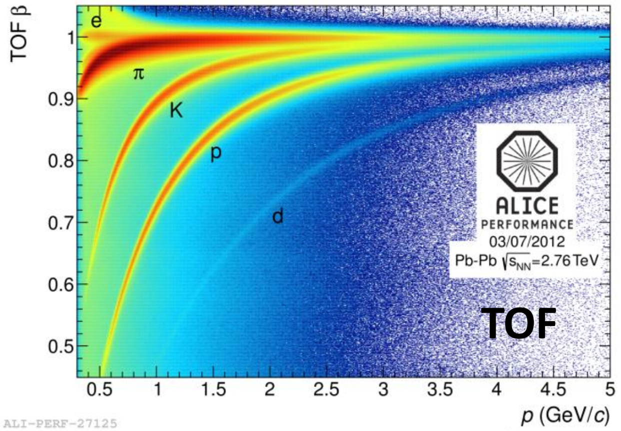

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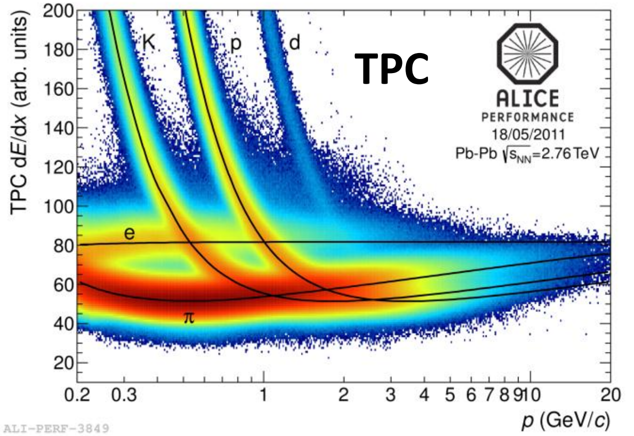

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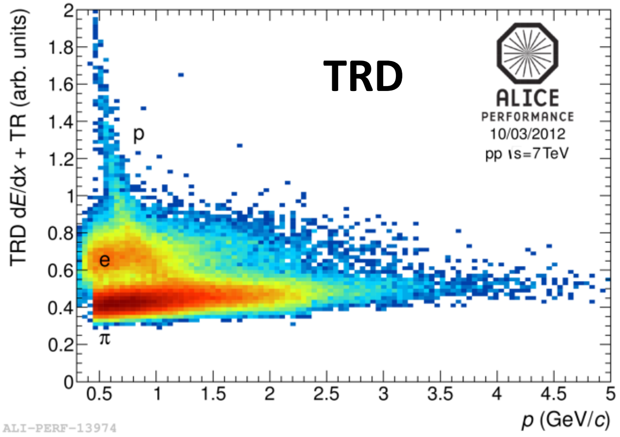

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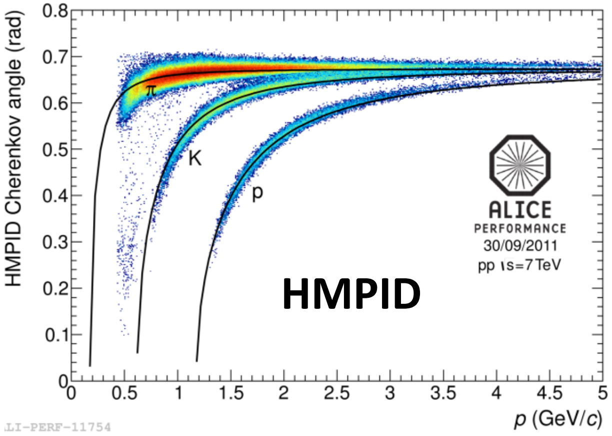

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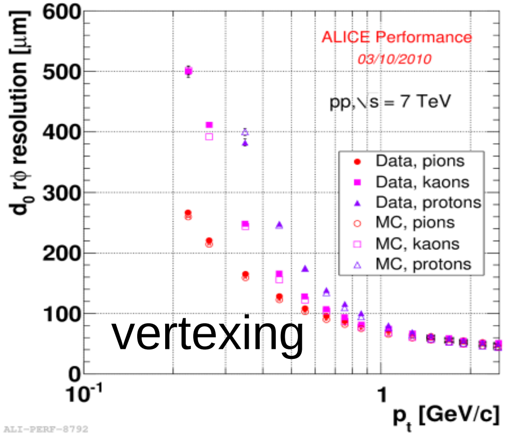


ALI-PERF-8792

- particle identification (practically all known techniques)
- extremely low-mass tracker ~ 10% of X_0
- excellent vertexing capability
- efficient low-momentum tracking – down to ~ 100 MeV/*c*

ALICE Data taking history

system	$\sqrt{s_{NN}}$ (TeV)	run year	min. bias (centrality)	rare triggers, ∫Ldt
p-p	7	2010	800M	17 μb^{-1}**
p-p	7	2011	800M	2 pb^{-1}
p-p	2.76	2011	70M	20 nb^{-1}
p-p	8	2012	500M *	5 pb^{-1} *
Pb-Pb	2.76	2010	30M	4 μb^{-1} **
Pb-Pb	2.76	2011	9M (65M)	80 μb^{-1}
p-Pb	5.02	2012	1.8M	0.9 μb^{-1}

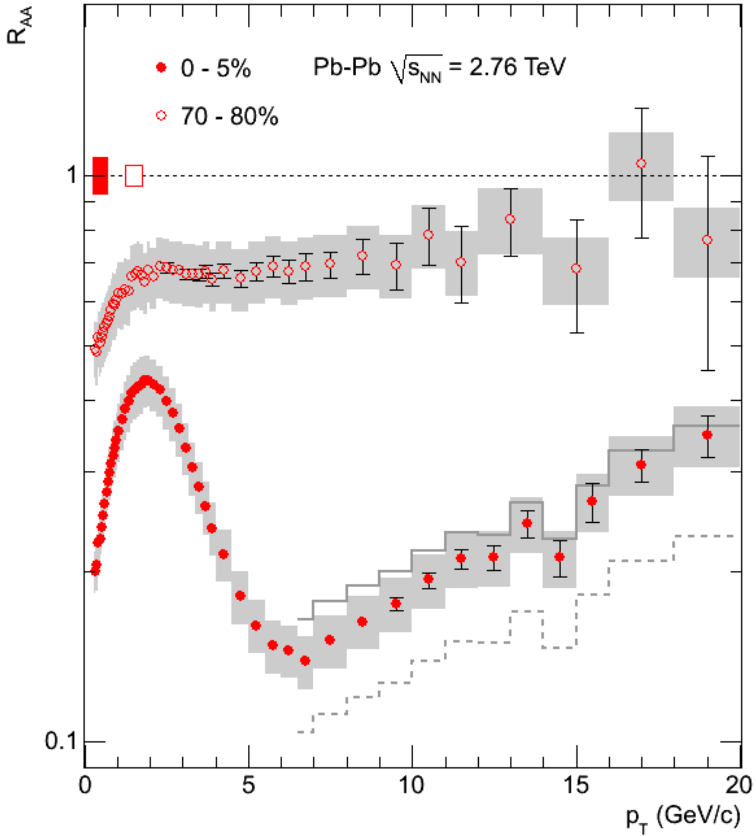
* statistics for p-p 2012 is “planned”

** no rare trigger used, value corresponds to min. bias

- 2009-10: commissioning & the first data
- 2011: - long p-p run with p-p at 7 TeV
  - 1 month of Pb-Pb run, already above nominal luminosity
- 2012: - long p-p run at 8 TeV
  - 1 day p-Pb pilot run
- 2013 (plan): p-Pb, Pb-p measurements (above 30 nb^{-1} expected)

Identified particle spectra

Motivation



ALICE, Phys. Lett. B696, 30 (2011)

yield in Pb-Pb

$$R_{AA}(p_T) = \frac{\boxed{(1/N_{evt}^{AA})\, d^2N_{ch}^{AA}/d\eta\, dp_T}}{\langle N_{coll}\rangle \boxed{(1/N_{evt}^{pp})\, d^2N_{ch}^{pp}/d\eta\, dp_T}}$$

yield in pp

Interesting results on charged particle spectra in Pb-Pb collisions without Particle Identification (PID). Example: R_{AA} as function of p_T

Next step is to study 3 regimes of p_T and their particle species dependence:

Low: p_T < 3-4 GeV/*c*

- Bulk properties and collective radial flow

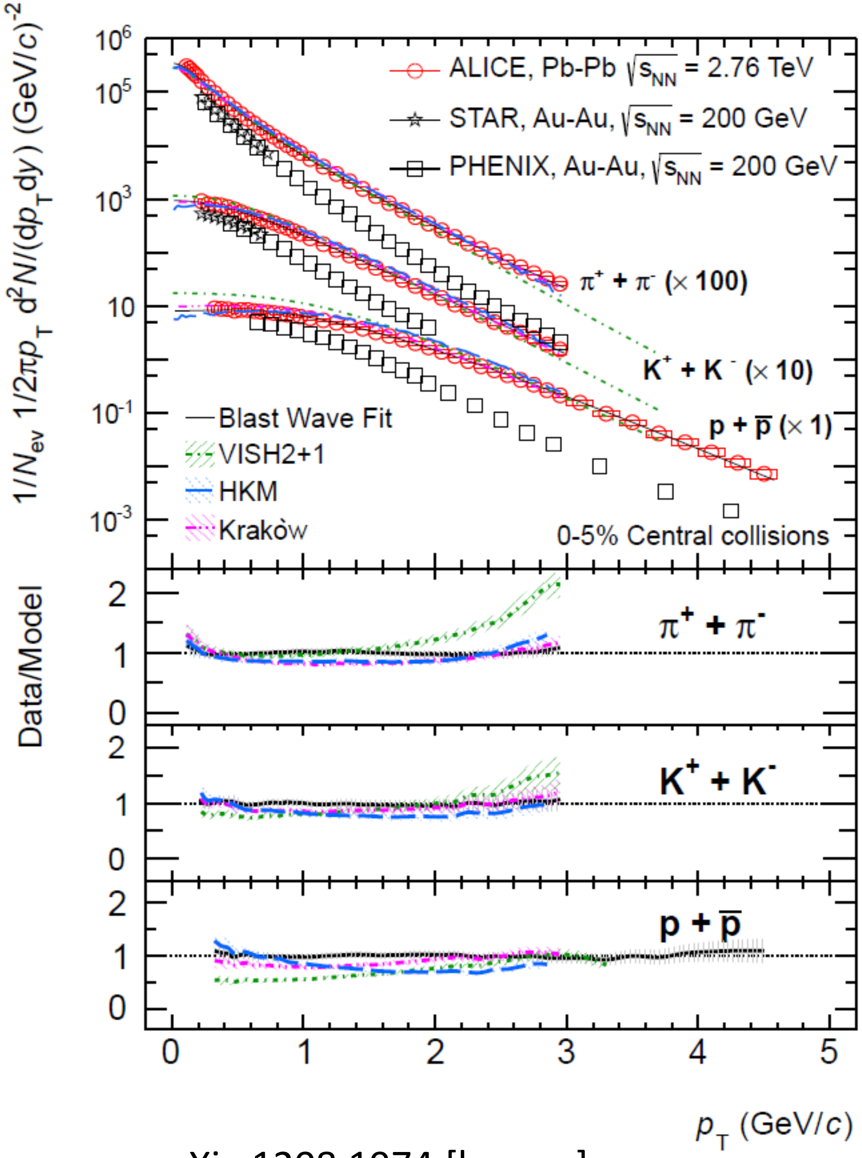
Intermediate: 3 < p_T < 7 GeV/*c*

- Test of valence quark scaling
- Anomalous baryon enhancement and coalescence

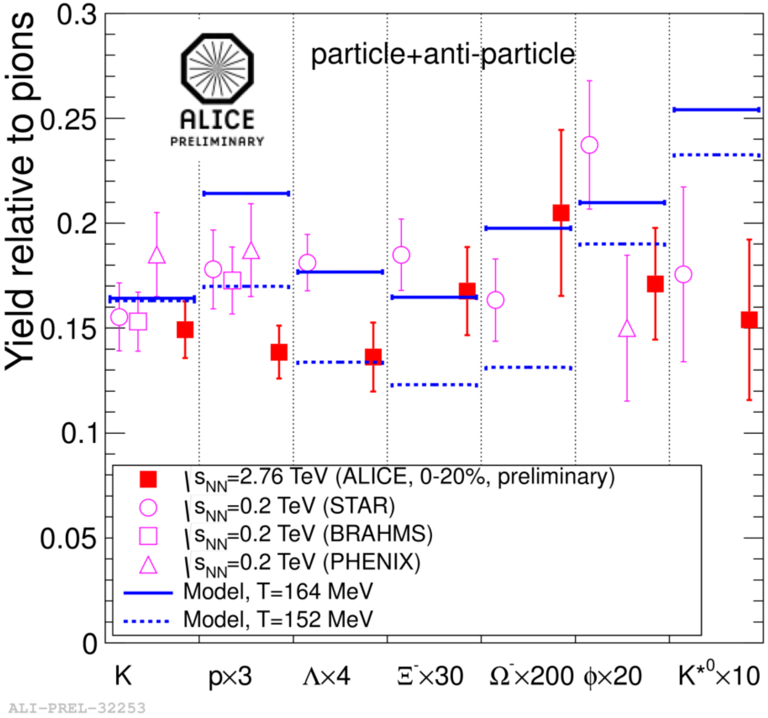
High: p_T > 7 GeV/*c*

- Search for medium modification of fragmentation functions

Low p_T particle production

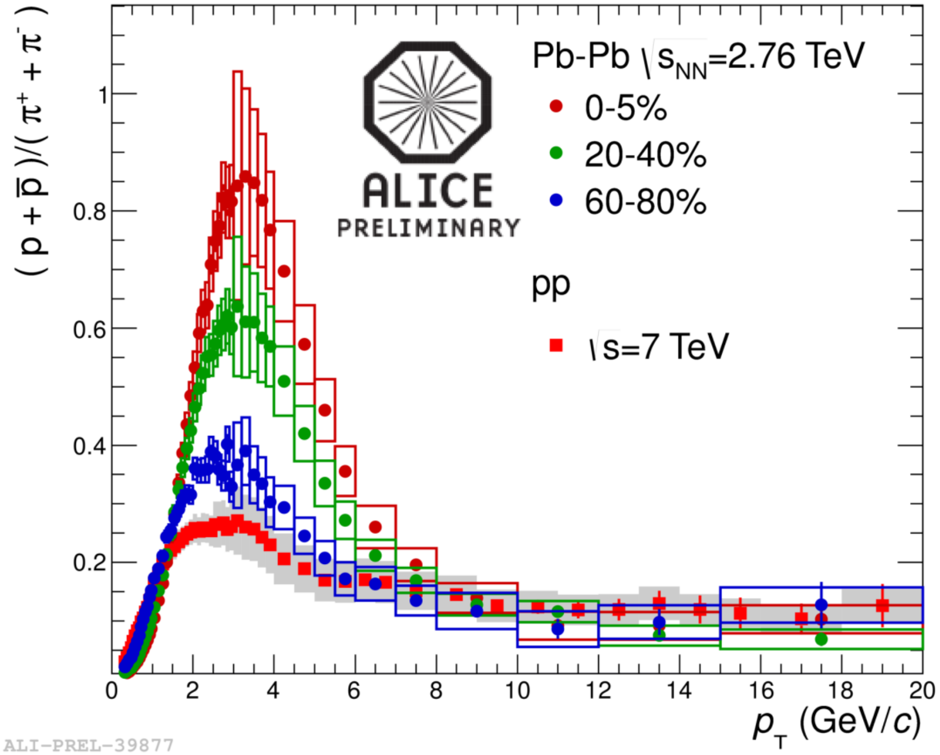


arXiv:1208.1974 [hep-ex]



- Predicted temperature T = 164 MeV
- Thermal fit: T = 152 MeV (χ^2/ndf = 40/9)
- Ξ and Ω significantly higher than statistical model
- p/π and Λ/ π ratios at LHC lower than at RHIC
  Hadronic re-interactions?
  F.Becattini et al. 1201.6349,
  J.Steinheimer et al. 1203.5302

Baryon-to-meson ratio: p/π



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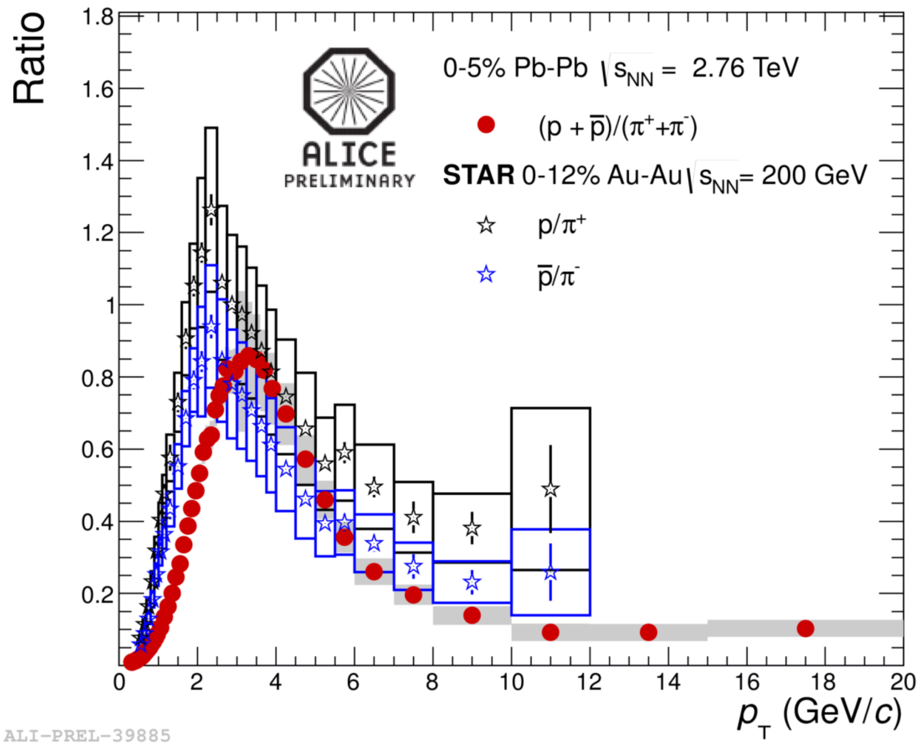
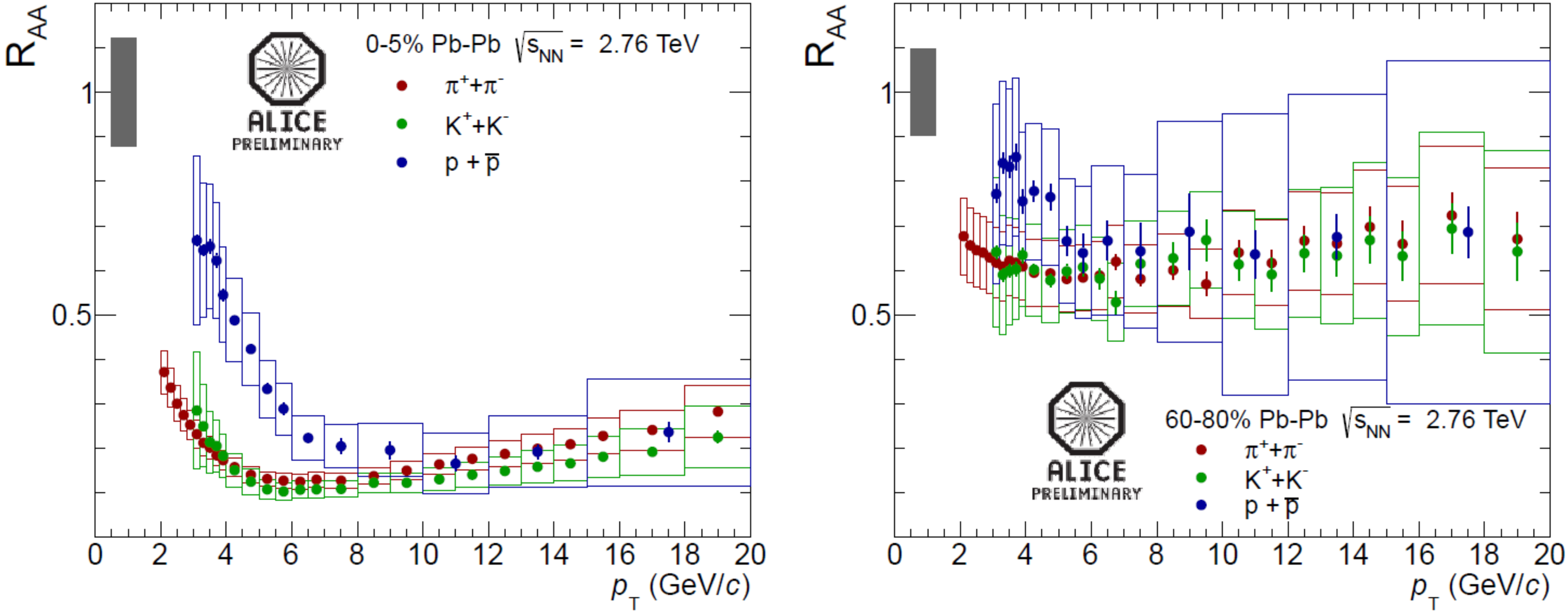


ALI-PREL-39885

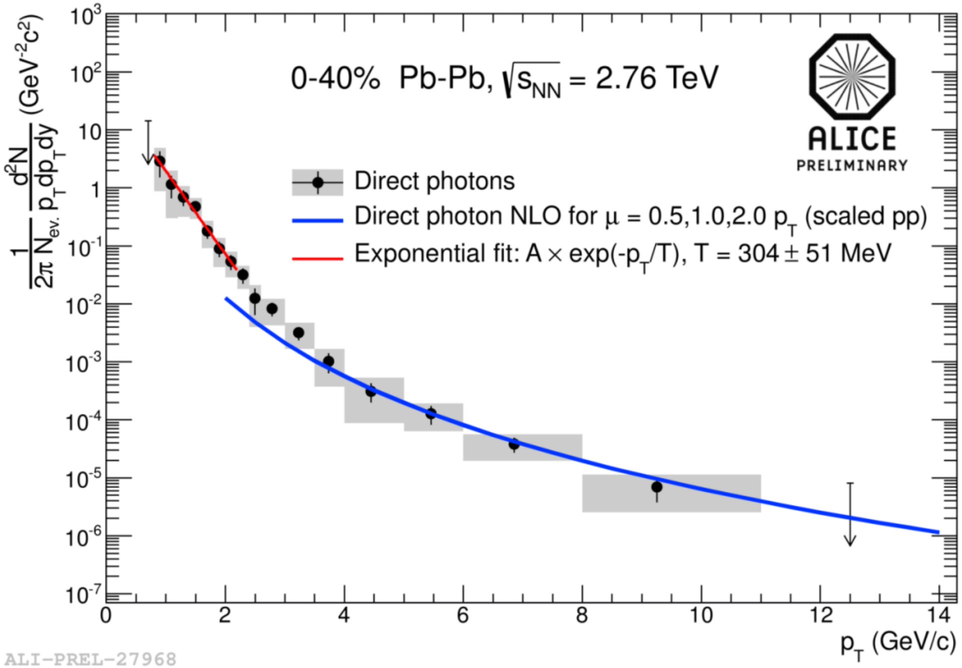
- p/π ratio at p_T ≈ 3 GeV/*c* in 0–5% central Pb-Pb collisions factor ~3 higher than in pp
- the maximum of the ratio is shifted to higher p_T with respect to RHIC measurements
- at p_T above ~ 10 GeV/*c* back to the “normal” pp value
- recombination – radial flow?

Identified particles R_{AA}



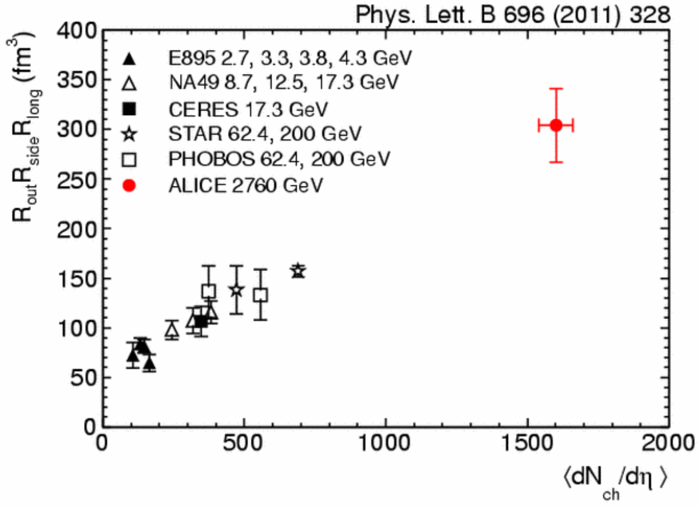
- Strong suppression confirming previous measurements for non-identified particles
- For p_T below ~ 7 GeV/c:
  - $R_{AA}(\pi) < R_{AA}(h^{\pm})$
  - $R_{AA}(K) \approx R_{AA}(h^{\pm})$
  - $R_{AA}(p) > R_{AA}(h^{\pm})$
- At higher p_T: R_{AA} are compatible → medium does not significantly affect the fragmentation.

Direct photon production



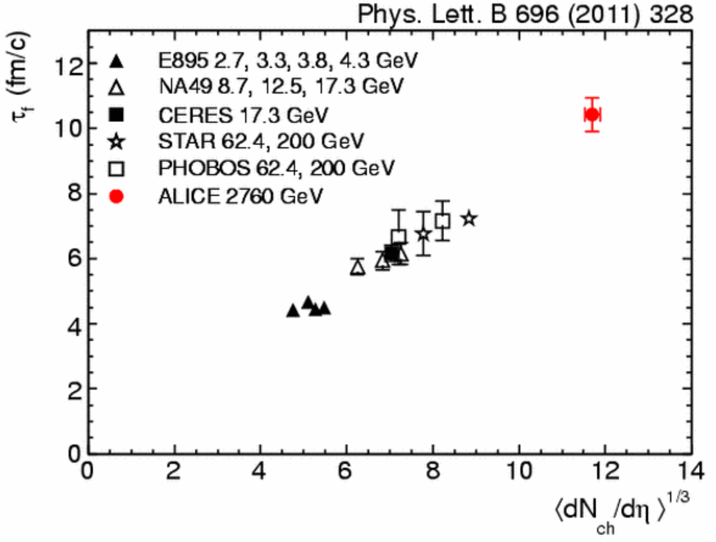
ALI-PREL-27968

2 x volume at RHIC



ALI-PUB-174

+30% lifetime



ALI-PUB-181

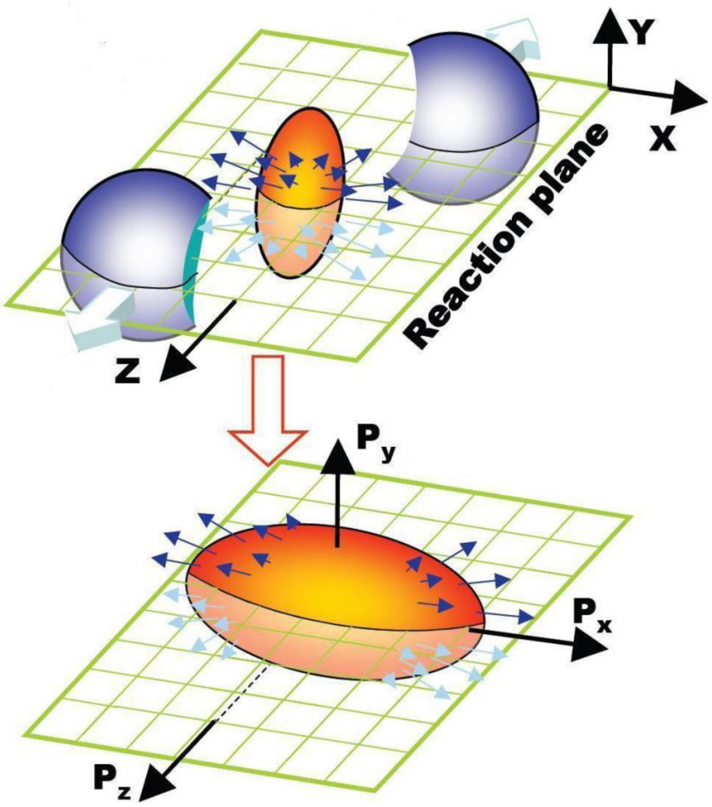
- Low-p_T direct photons probe the early temperature
- ALICE: T = 304 ± 51 MeV
  (for 0–40% Pb–Pb at √s=2.76 TeV, p_T < 2.2 GeV/c)
- PHENIX: T = 221 ± 19 ± 19 MeV
  (for 0–20% Au–Au at √s=200 GeV, p_T < 2 GeV/c)
- p_T > 4 GeV/c agreement with N_{coll}-scaled NLO

arXiv:1210.5958 [nucl-ex]

Anisotropic flow

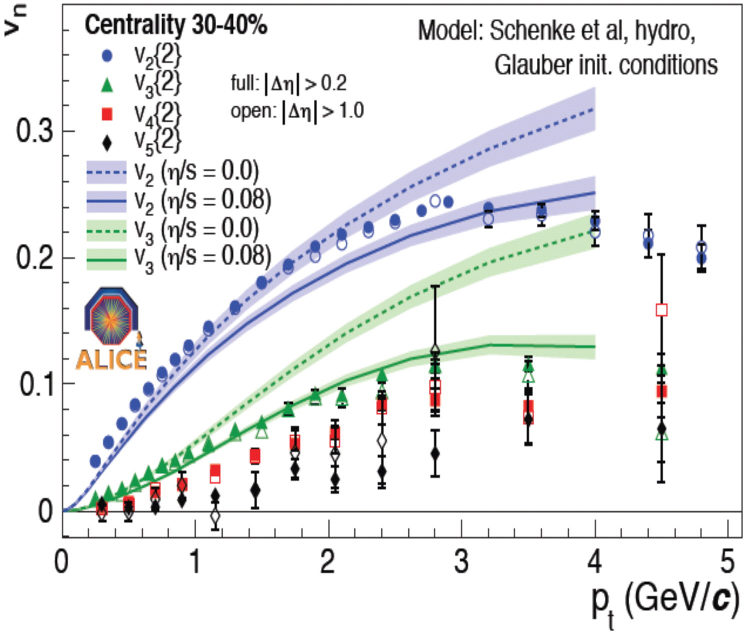
Anisotropic flow

Spatial asymmetry transforms into momentum space:



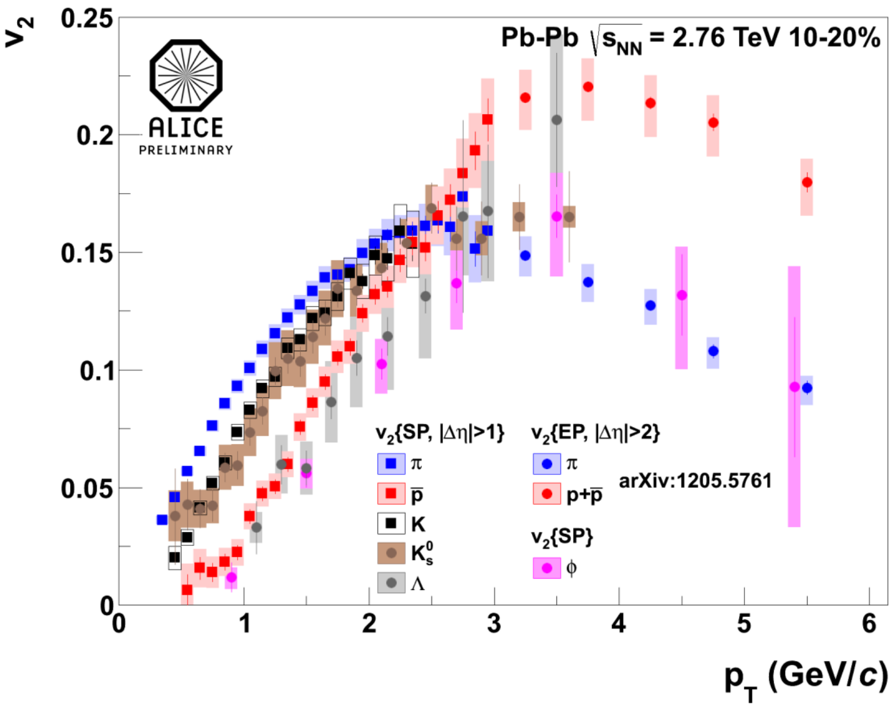
$$\frac{dN}{d(\varphi_i-\Psi_n)} \sim 1 + 2\sum_{n=1} v_n \cos[n(\varphi_i-\Psi_n)]$$

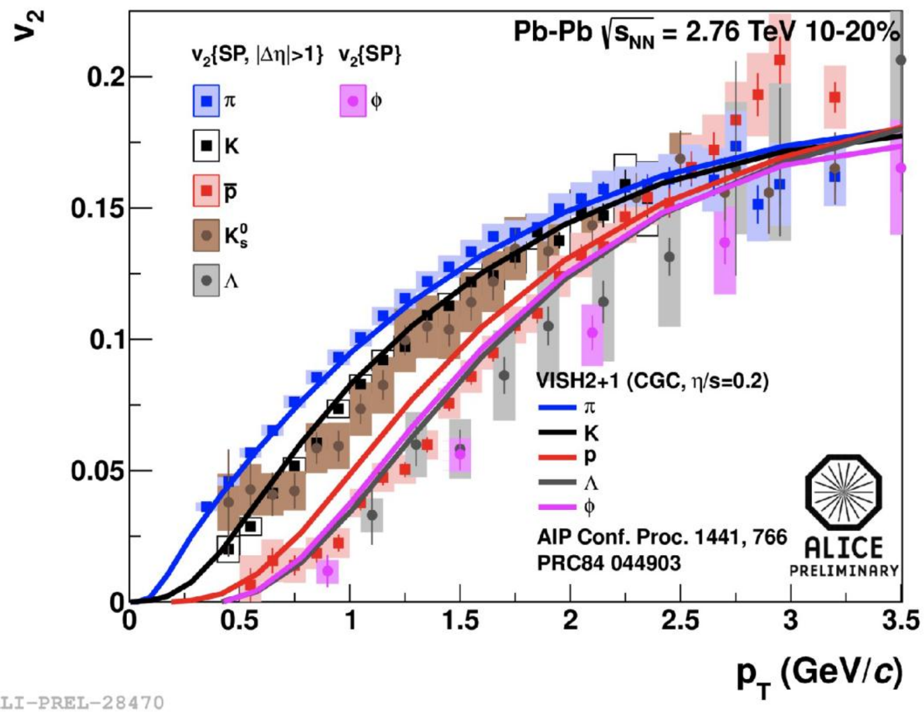
Phys. Rev. Lett. 107, 032301 (2011)



- Anisotropic flow of identified particles is sensitive to the partonic degrees of freedom at the early times of a heavy-ion collision
- flow vs. transverse momentum allows to quantify:
  - rate of hydrodynamic radial expansion
  - properties of the deconfined phase
  - details of hadronization mechanism

Identified particle v_2

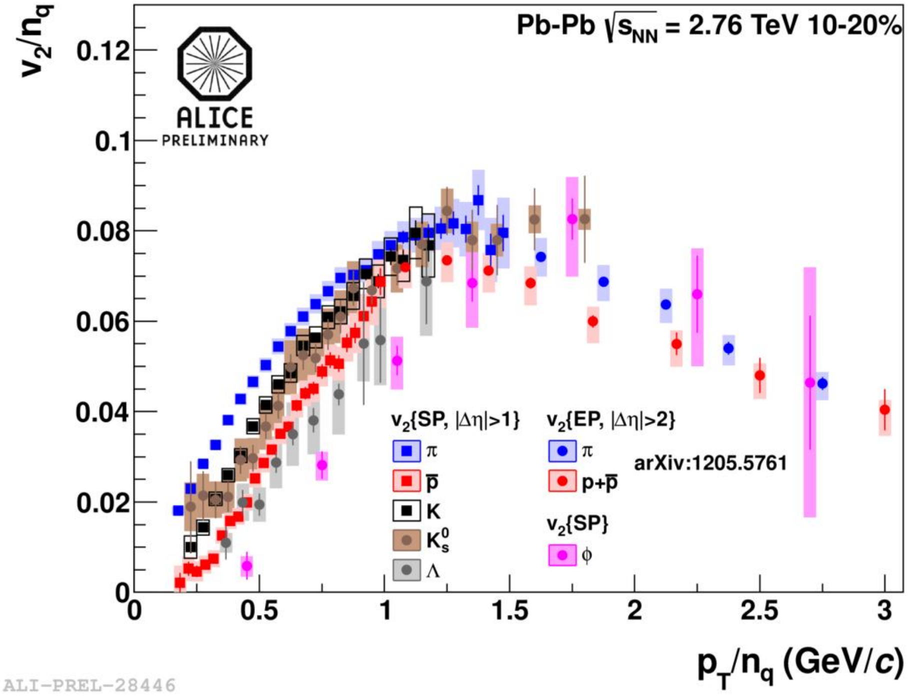


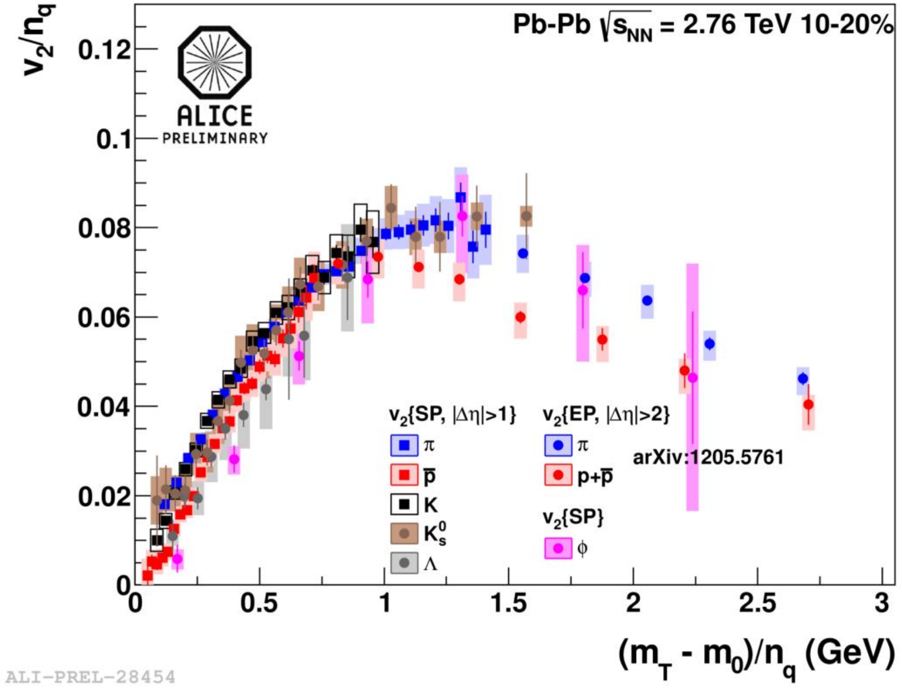


ALI-PREL-28470

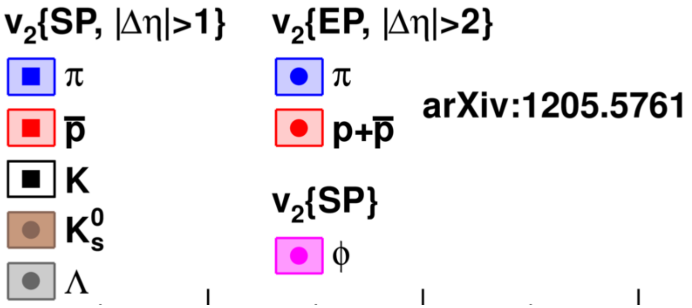
- Mass ordering observed at low p_T for π, p, K±, K^0_s, Λ, ϕ and (not shown) Ξ, Ω
- ϕ-meson follows mass dependence at $p_T < 3$ GeV/c and “meson band” at higher p_T
- Overall qualitative agreement with viscous hydro calculations at low p_T
- Adding hadronic rescattering phase improves the agreement:
  Heinz et al., AIP Conf Proc 1441, 766 (2012)

Identified-particle v_2: NCQ scaling

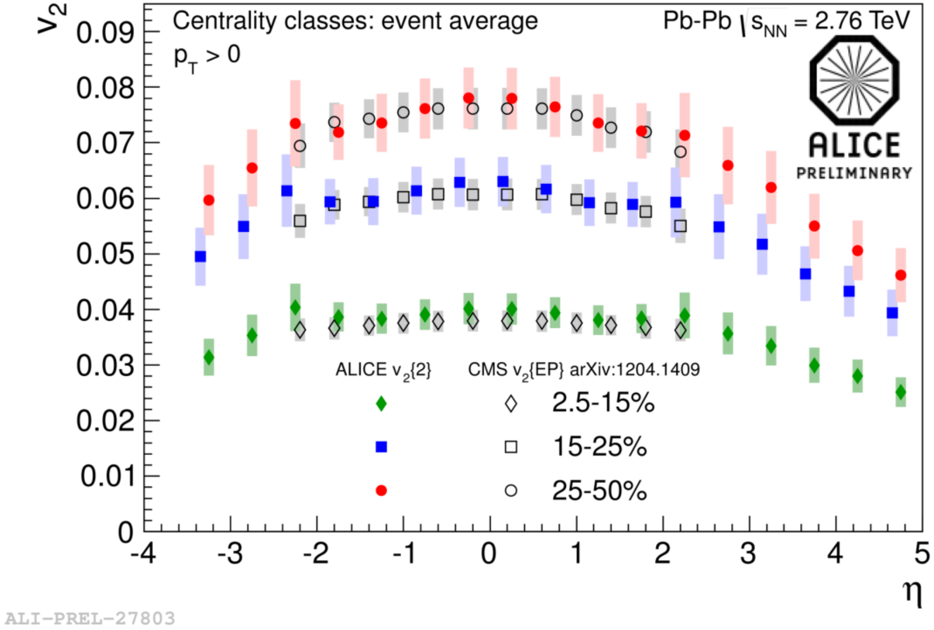


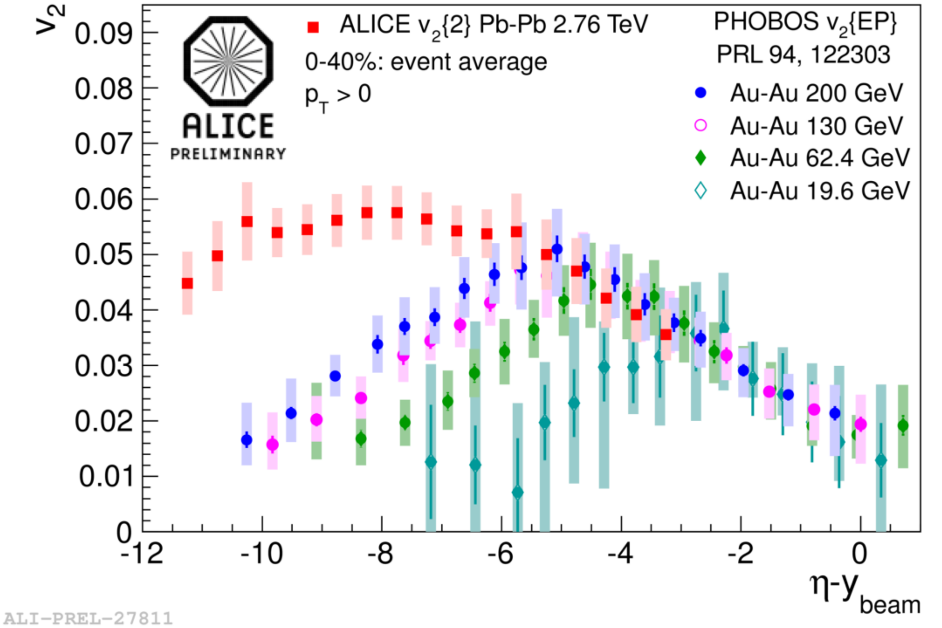


- scaling off by 10-20% at high p_T (where mass is negligible)



v_2 and v_3 versus η

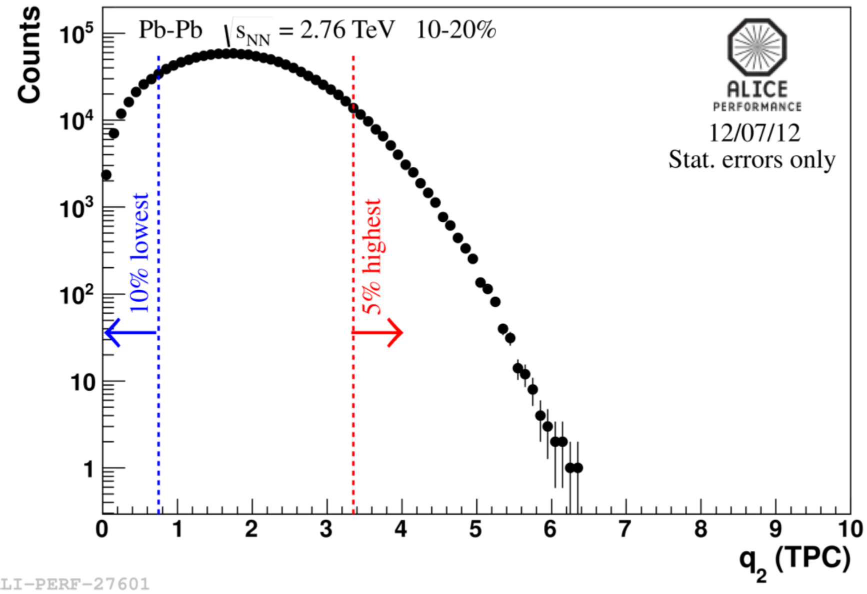




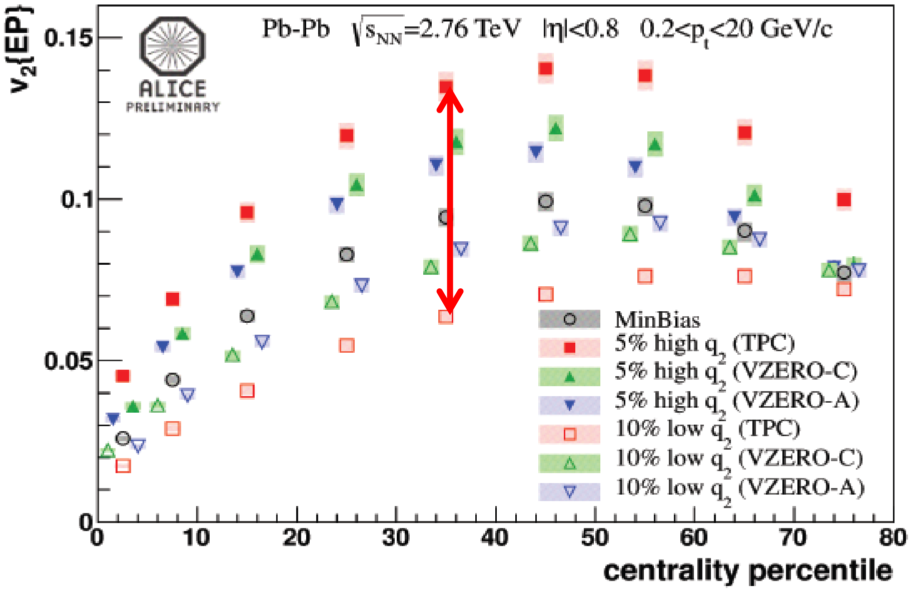
- v_3 sensitive to initial state fluctuations
- v_2 and v_3 measurements extended up to η = 5
- observed plateau in pseudorapidity (|η| < 2)
- very good agreement between ALICE and CMS for v_2 in |η| < 2.4
- consistent with longitudinal scaling in η – y_{beam} with PHOBOS data

Event Shape Engineering

New tool towards better understanding of elliptic flow



ALI-PERF-27601



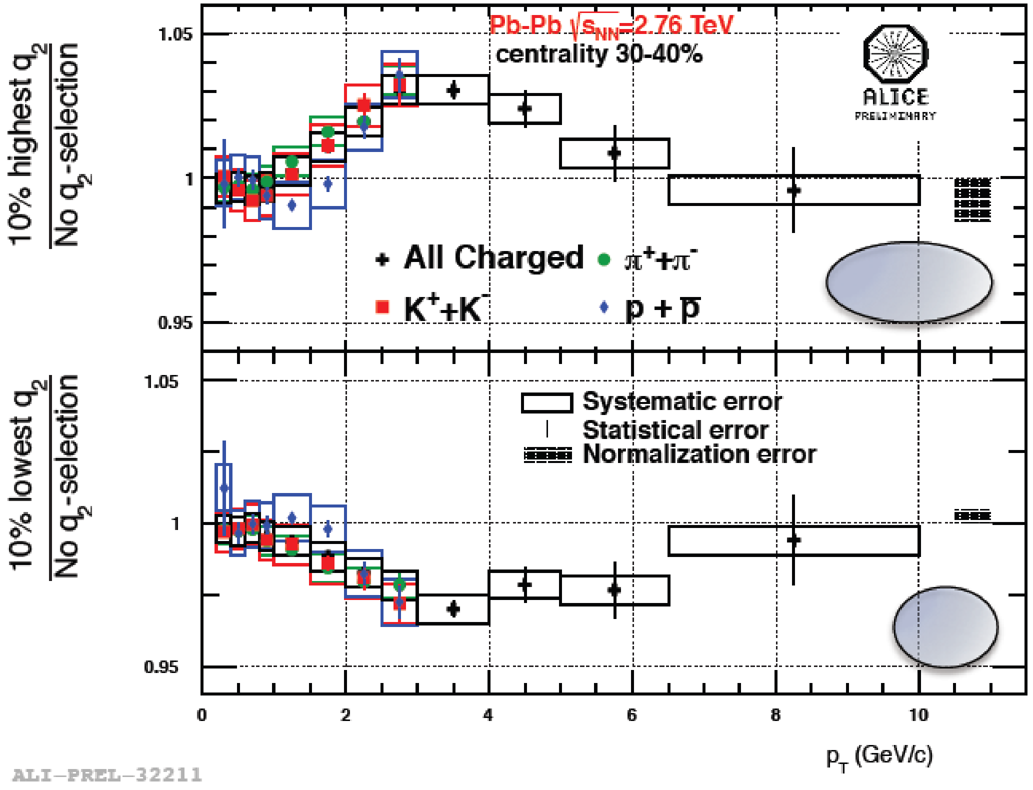
$$Q_{n,x} = \sum_{i=1}^{M} \cos n\varphi_i$$

$$Q_{n,y} = \sum_{i=1}^{M} \sin n\varphi_i$$

$$q_n = Q_n/\sqrt{M}$$

- At fixed centrality large flow fluctuations
- v_2 splits by factor of two for semi-central events (30–50%)

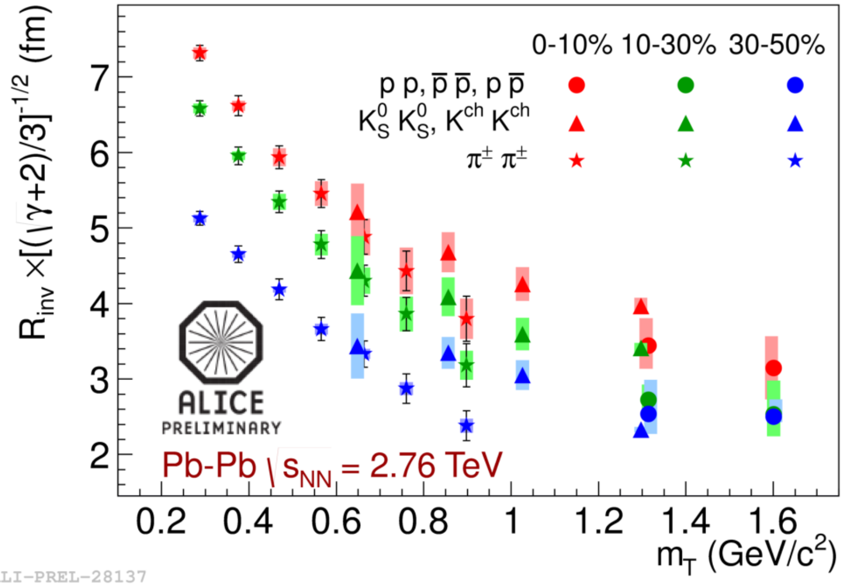
Event Shape Engineering: example



- Modification of the p_T spectrum: large q_2 → harder spectrum
- Hint of mass ordering?
- Are v_2 and radial flow correlated?

Correlations and femtoscopy

Baryon femtoscopy



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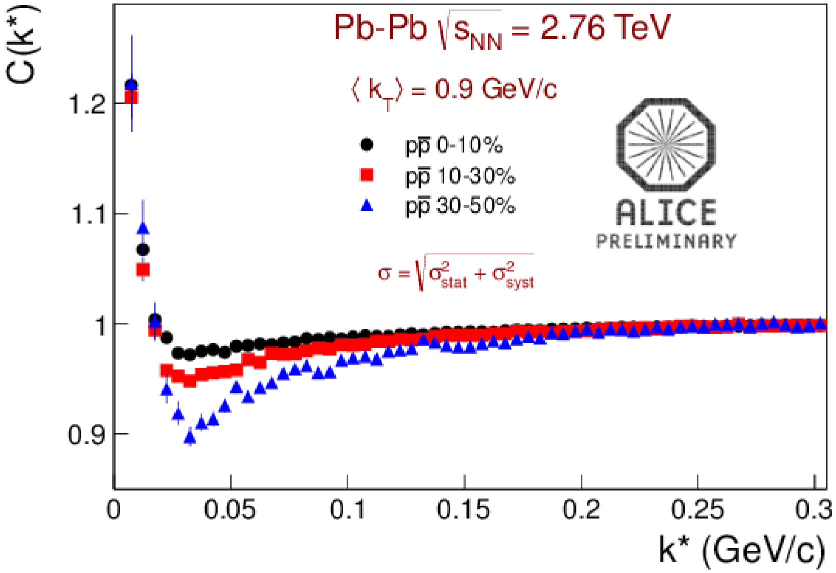
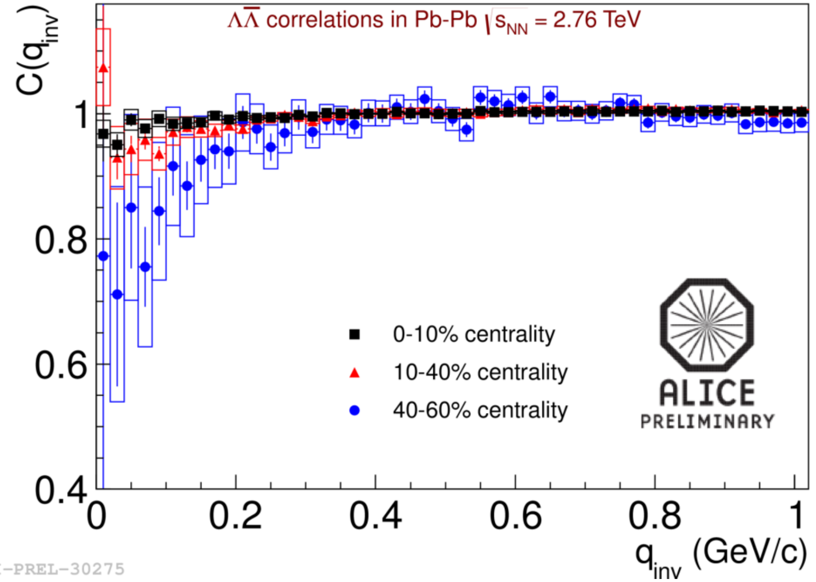


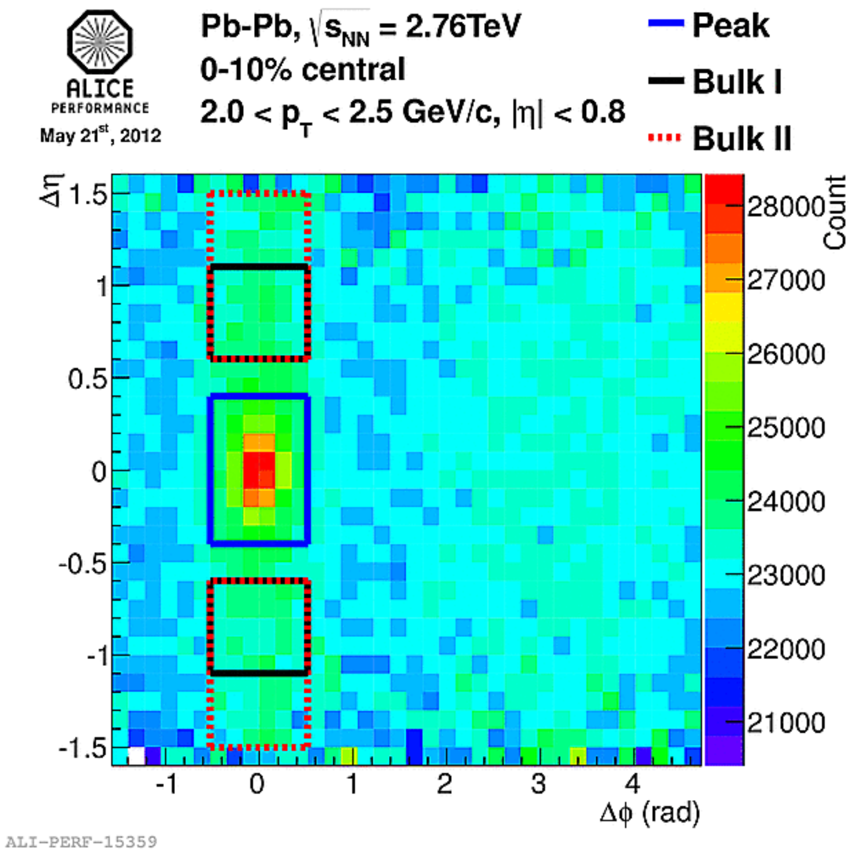
- Observe m_T-scaling of homogeneity length for all particle species
  → consistent with hydrodynamics

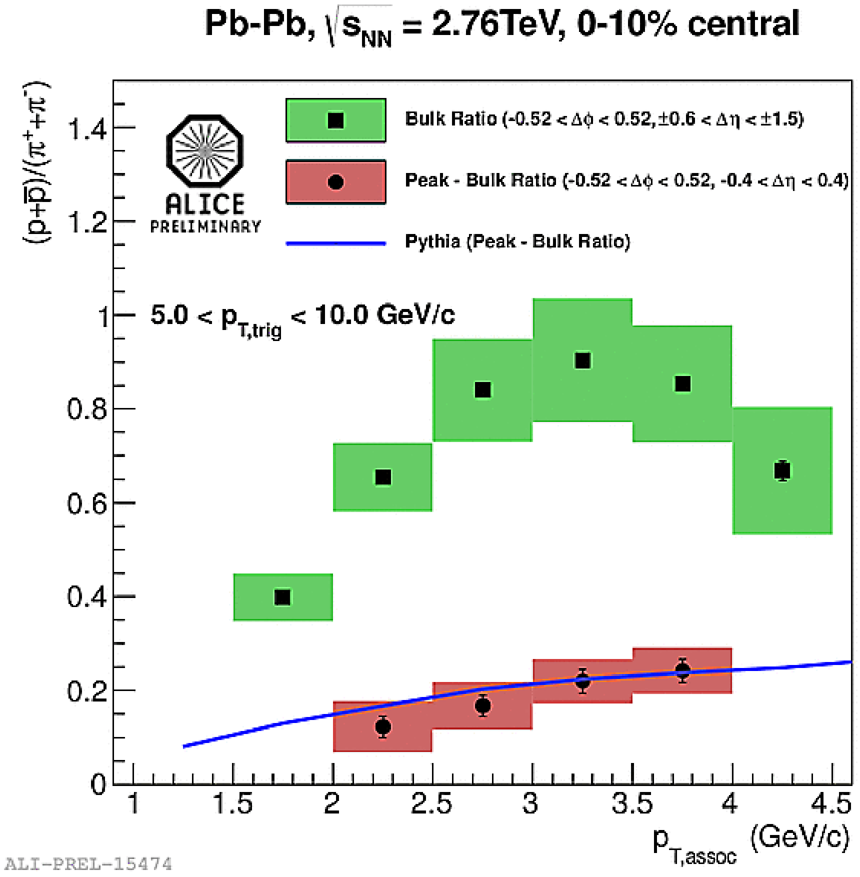
- Baryon–antibaryon correlation function has large contribution from final state interaction
  → measurement of annihilation cross section



ALI-PREL-30275

PID in jet structures





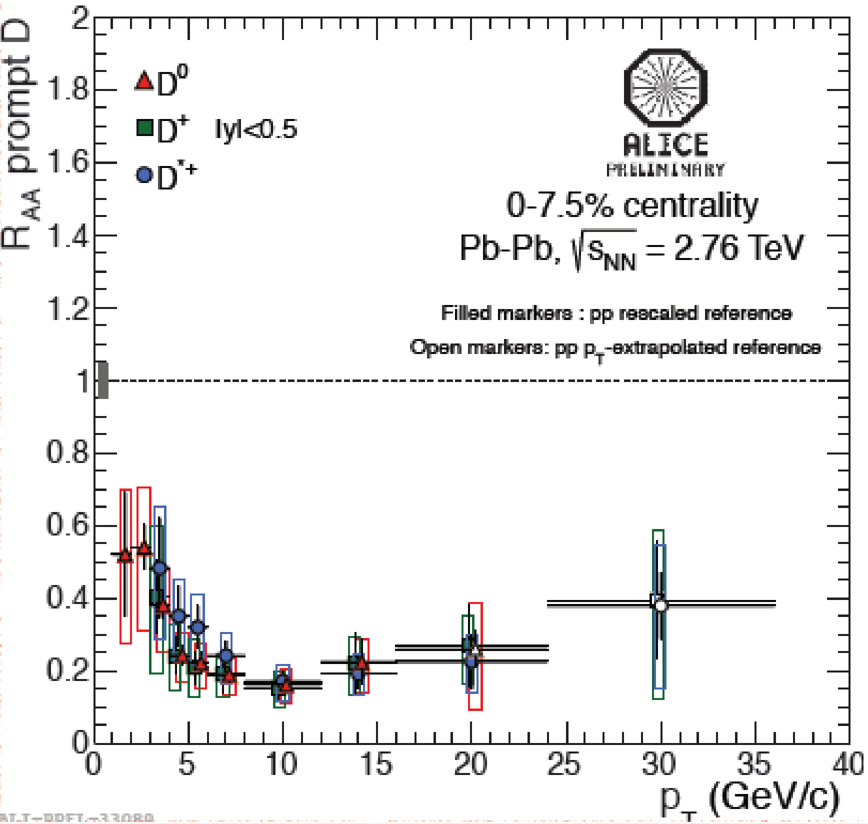
- Near-side peak (after bulk subtraction): p/π ratio compatible with that of pp (PYTHIA)
→ No significant modification of jet fragmentation chemistry
- Bulk region: p/π ratio strongly enhanced – compatible with overall baryon enhancement
→ Baryon enhancement is from the bulk, not from jets

Heavy flavour highlights

(see dedicated talk by R.Bailhache)

D meson R_{AA}

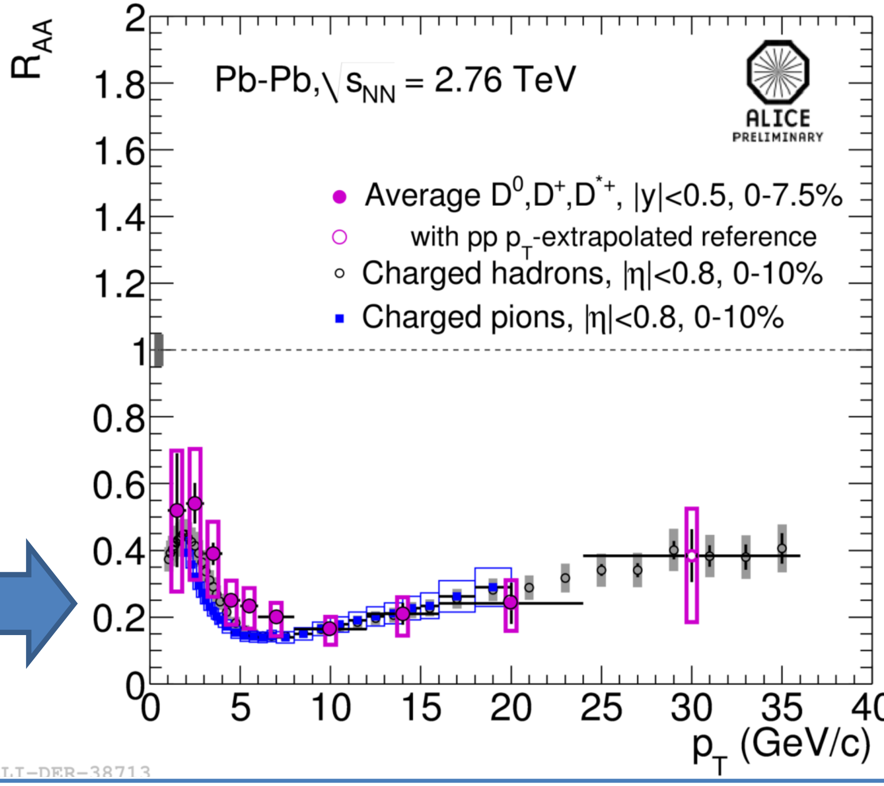
JHEP 1209 (2012) 112



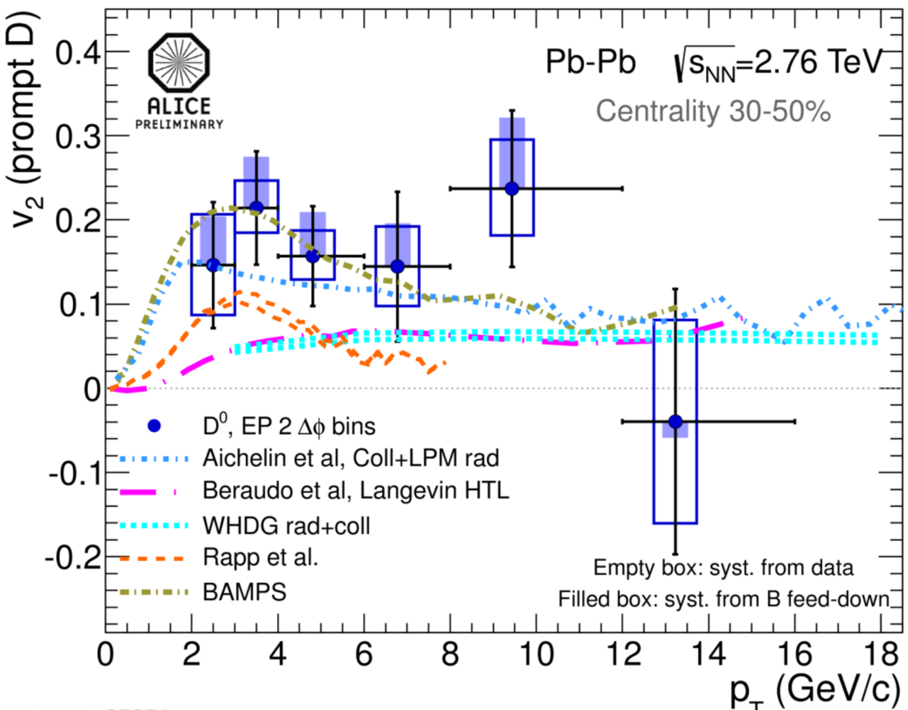
- D^0, D^+ and D^{*+} R_{AA} compatible within uncertainties.
- Suppression up to a factor 5 at p_T~ 10 GeV/c.

Average D-meson R_{AA}:

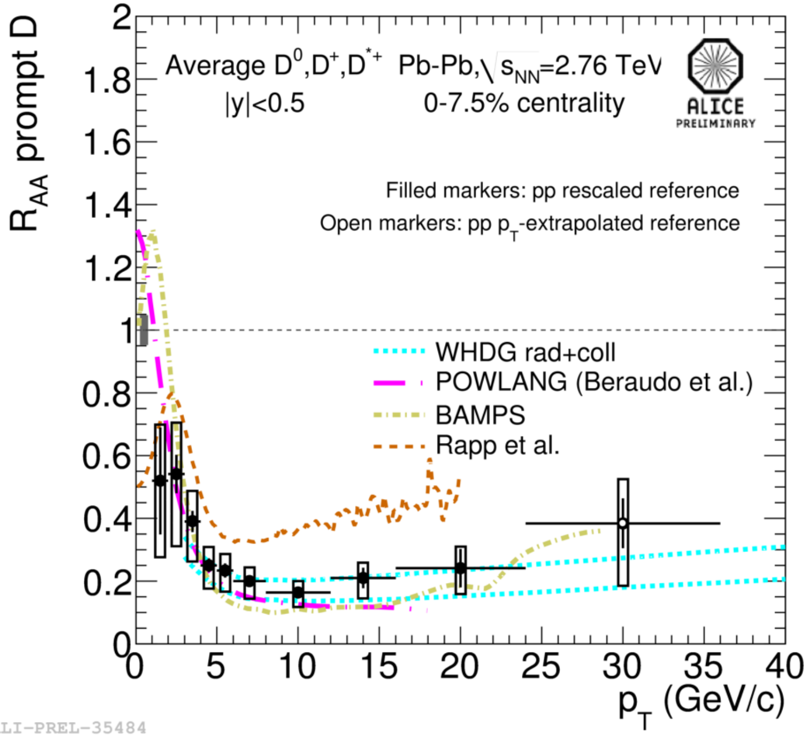
- – p_T < 8 GeV/*c* hint of slightly less suppression than for light hadrons
- – p_T > 8 GeV/*c* both (all) very similar: no indication of colour charge dependence



D meson v_2



ALI-PREL-27254



ALI-PREL-35484

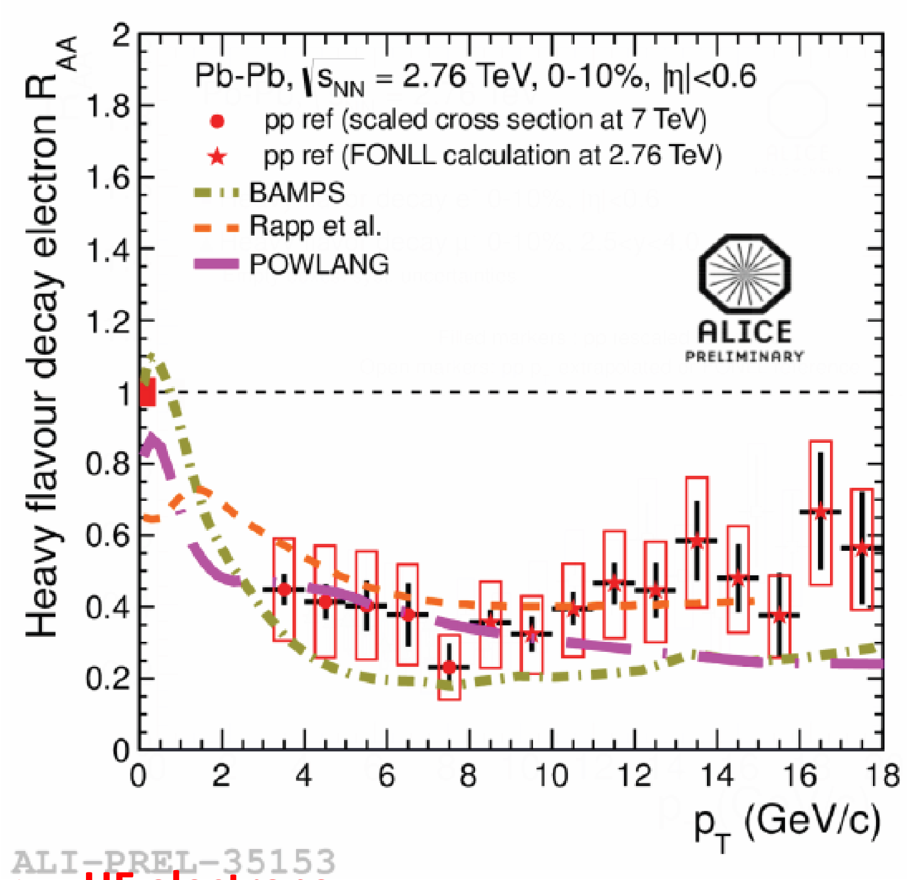
Non-zero D-meson elliptic flow observed:

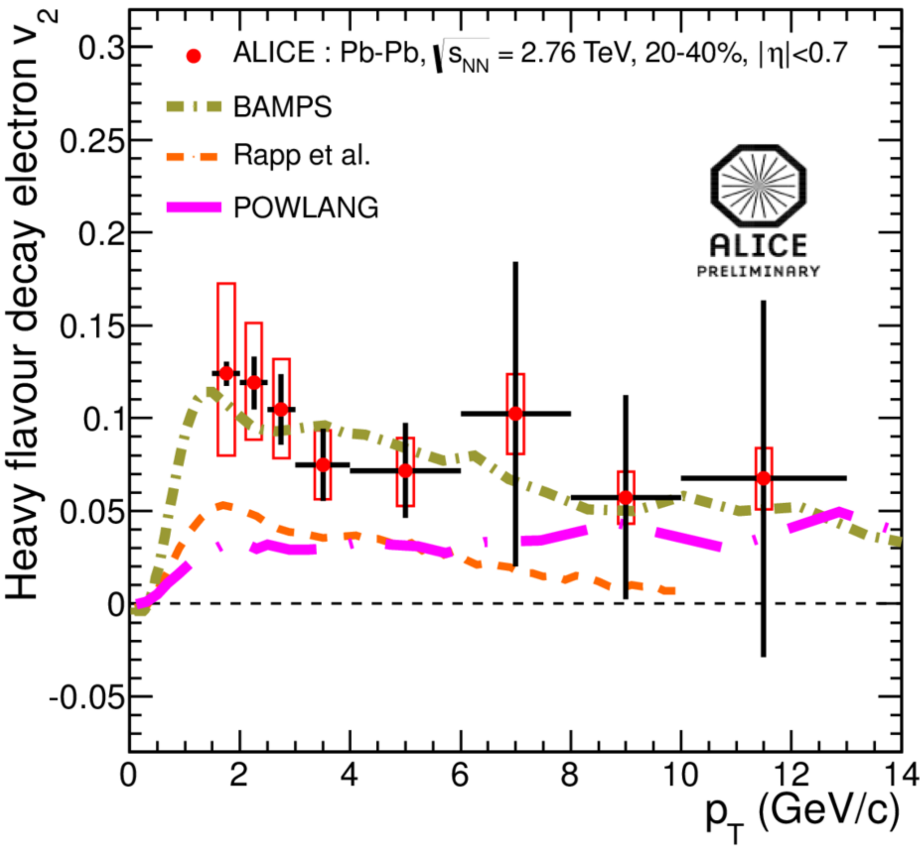
- consistent among D-meson species (D^0, D^+, D^{*+})
- comparable to v_2 of light hadrons

Simultaneous description of R_{AA} and v_2 – strong constraint to transport models

→ c-quark transport coefficient in medium

Heavy flavour e(μ) R_{AA} & v_2



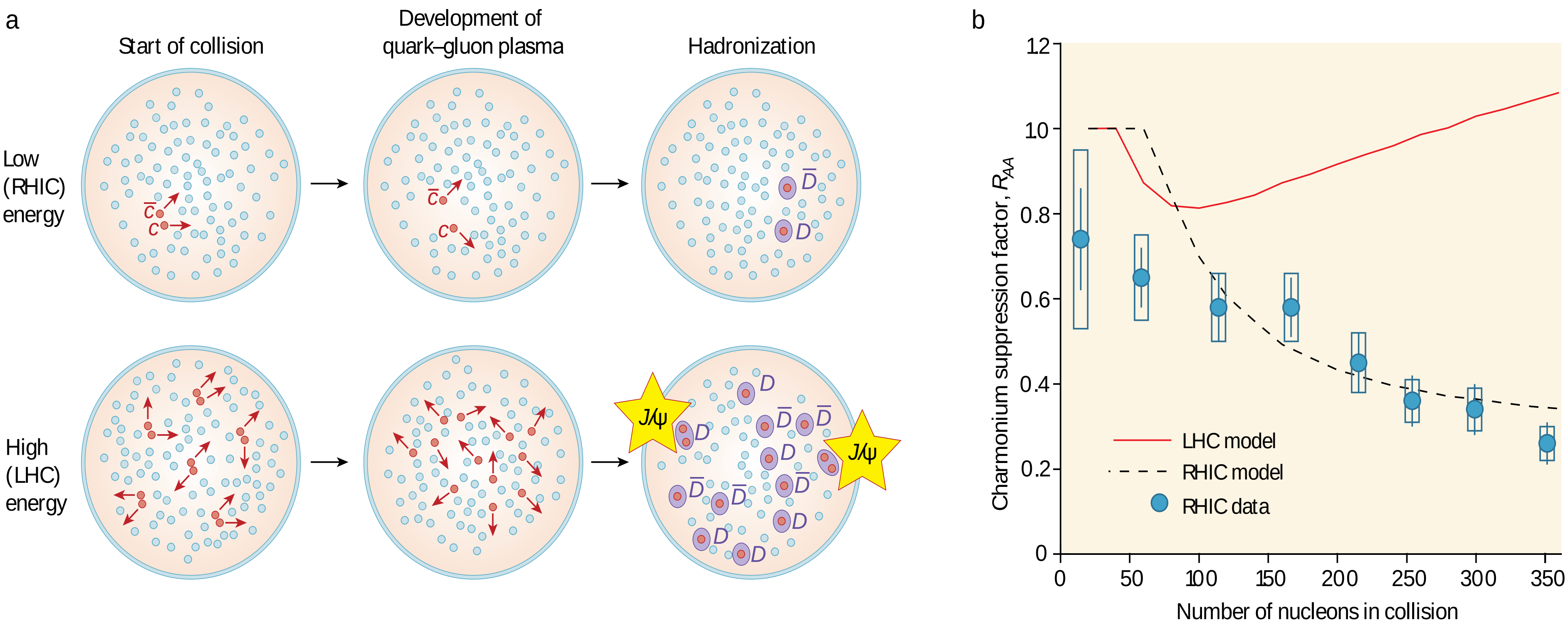


- **HF electrons:**
  - strong suppression up to p_T 18 GeV/c in 0–10% centrality
  - non-zero v_2 in 20–40% centrality class
- **HF muons:** suppression in forward region very similar to that of electrons
- Simultaneous measurement of R_{AA} and $v_2 \rightarrow$ constrains transport models

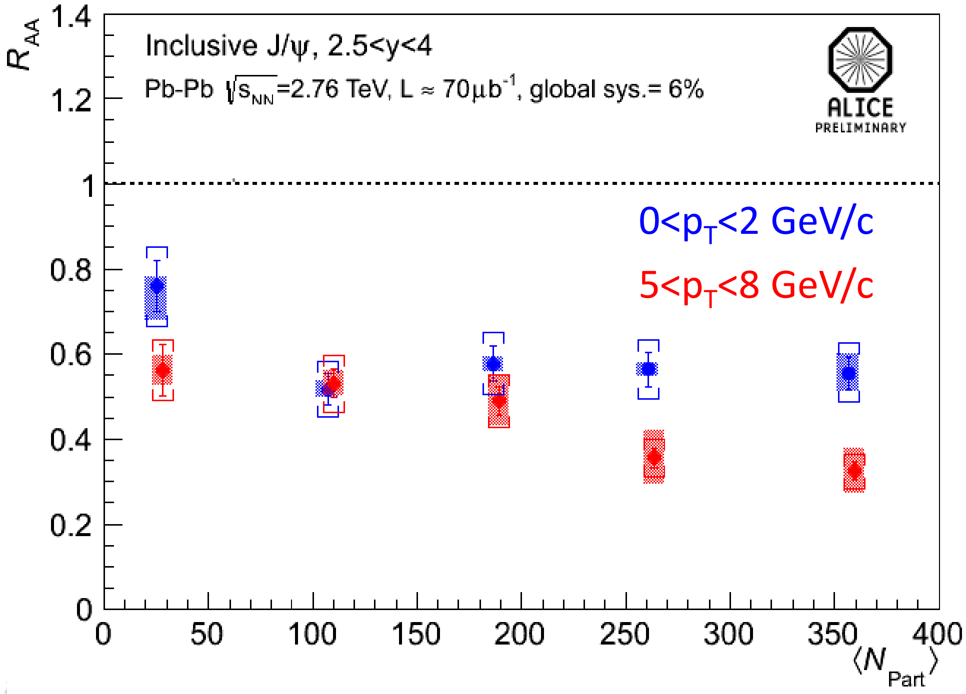
Quarkonia

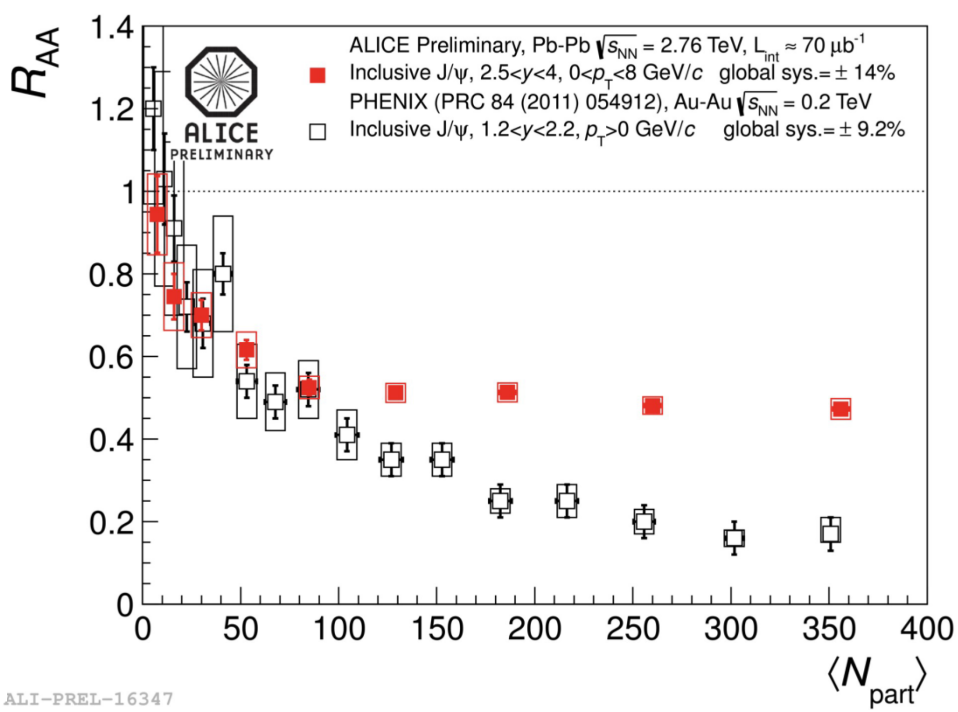
Quarkonia: suppression or enhancement?

- **SPS & RHIC energies:** Quarkonia suppression via colour screening
  → probe of deconfinement (Matsui and Satz, PLB 178, 416 (1986))
- **LHC energies :** Enhancement via (re)generation of quarkonia, due to the large heavy-quark multiplicity (A. Andronic et al., PLB 571, 36 (2003))



J/ψ R_{AA} vs centrality



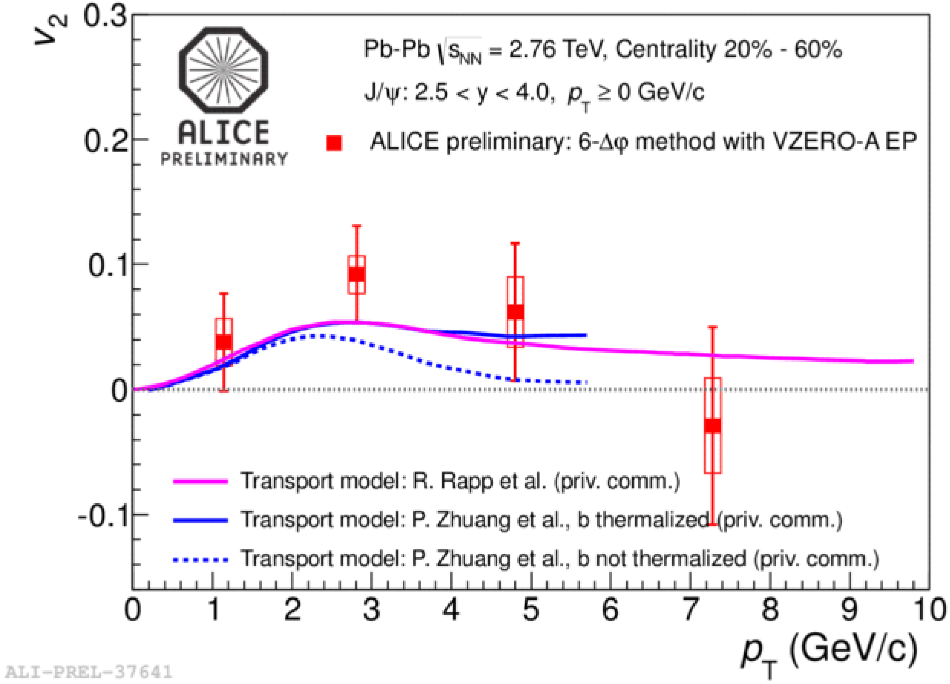


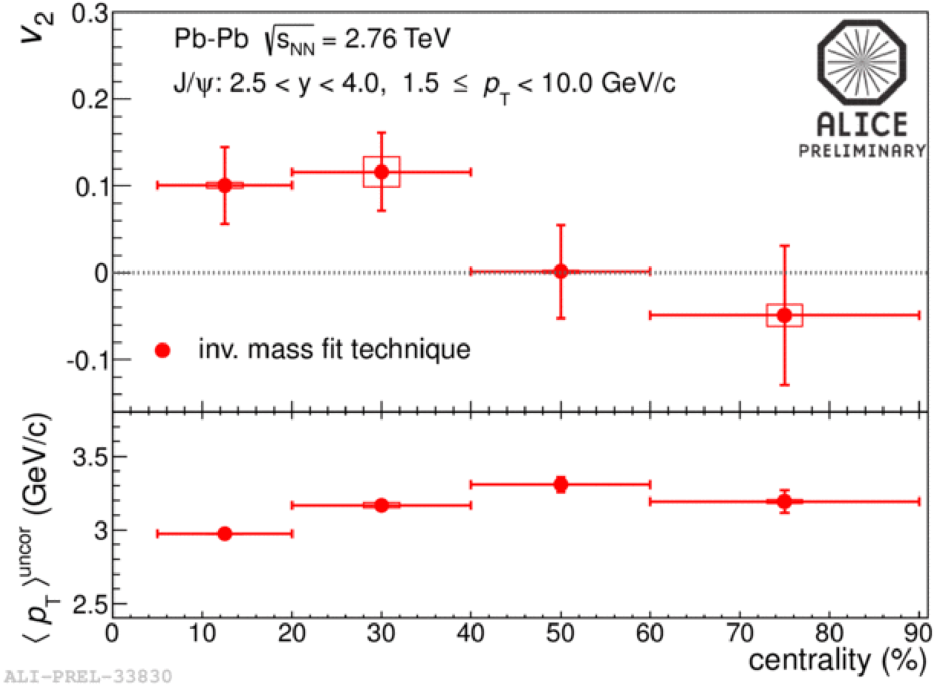
- Centrality dependence of the nuclear modification factor studied at both central and forward rapidities
- At forward *y*, R_{AA} flattens for $N_{part} \geq 100$
- At LHC less suppression than at RHIC, weaker centrality dependence
- at low p_T (< 2 GeV/*c*) less suppression than at high p_T, especially in more central collisions
- Indication of J/ψ regeneration at low p_T ?

Phys. Rev. Lett. 109, 072301 (2012)

J/ψ v_2

The contribution of J/ψ from recombination should lead to a significant elliptic flow signal at LHC energy

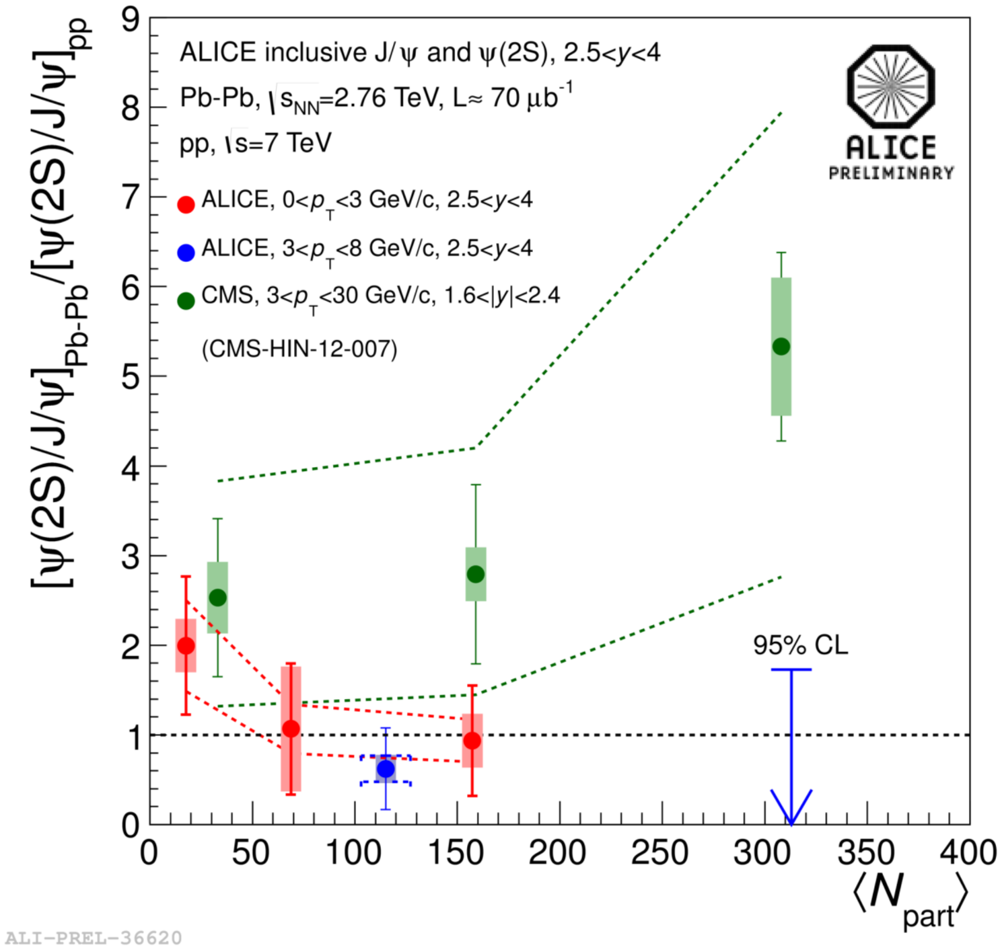




- STAR: v_2 compatible with zero everywhere
- ALICE: hint for non-zero v_2
- Significance up to 3.5 σ

- Qualitative agreement with transport models including regeneration

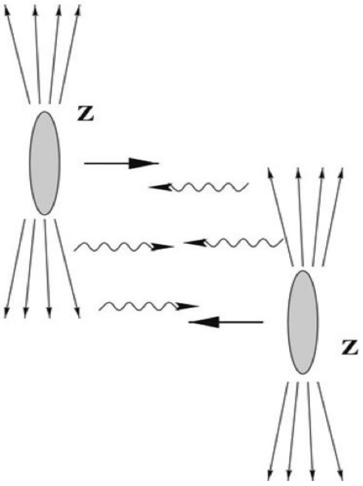
ψ’ and J/ψ

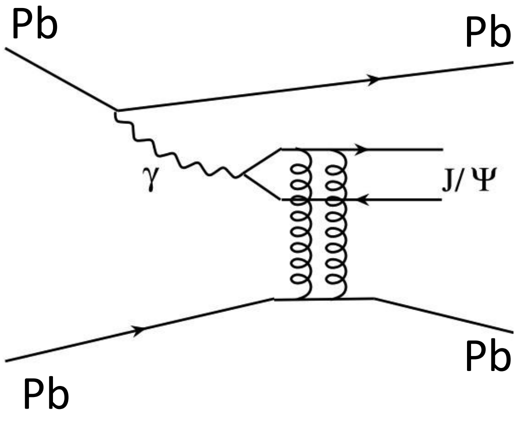


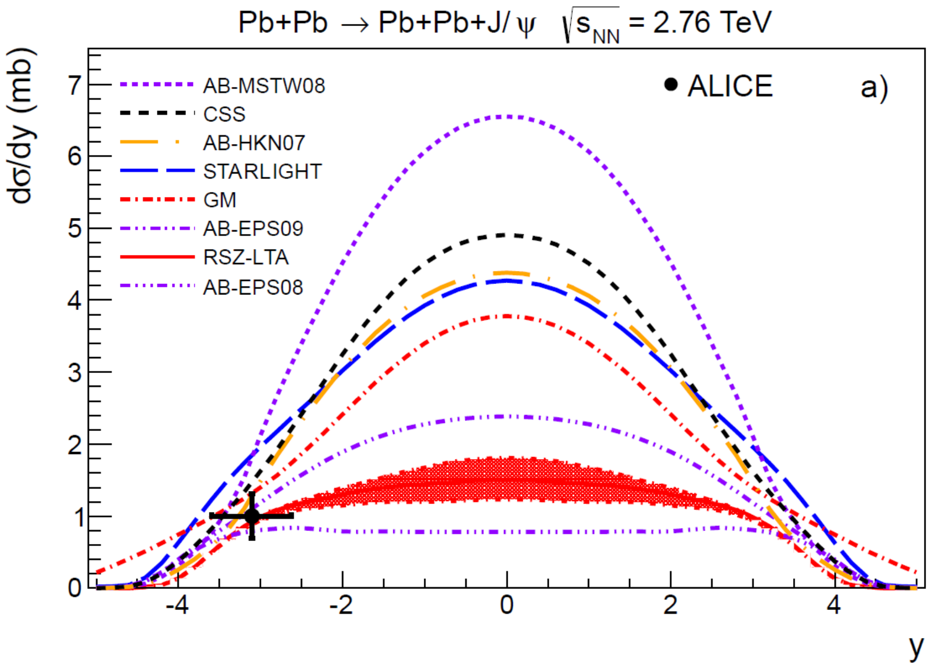
- Study the ψ(2S) yield normalized to the J/ψ one in Pb-Pb and in pp: $[\psi(2S)/J/\psi]_{Pb\text{-}Pb} / [\psi(2S)/J/\psi]_{pp}$
- Use $\sqrt{s}$ = 7 TeV pp data as a reference (small $\sqrt{s}$- and *y*-dependence accounted for in the systematic uncertainty)
- Large statistics and systematic errors prevent a firm conclusion on the ψ(2S) enhancement or suppression versus centrality
- Exclude large enhancement in central collisions
- Large enhancement observed by CMS at p_T above 3GeV/*c* not confirmed

CMS-PAS-HIN-12-007
R. Arnaldi (ALICE) QM2012

J/ψ in ultraperipheral collisions



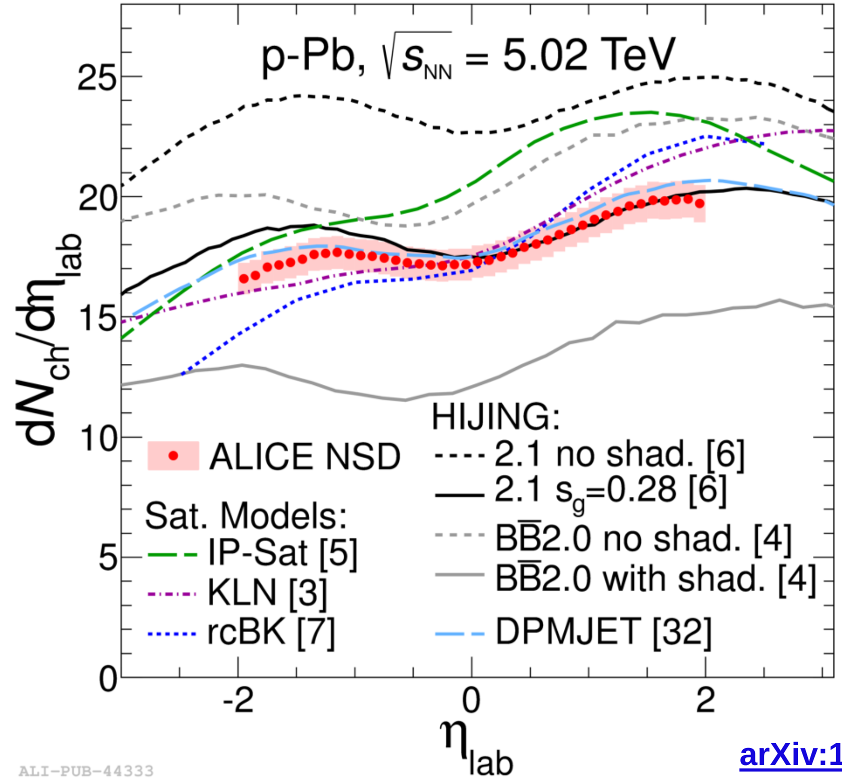




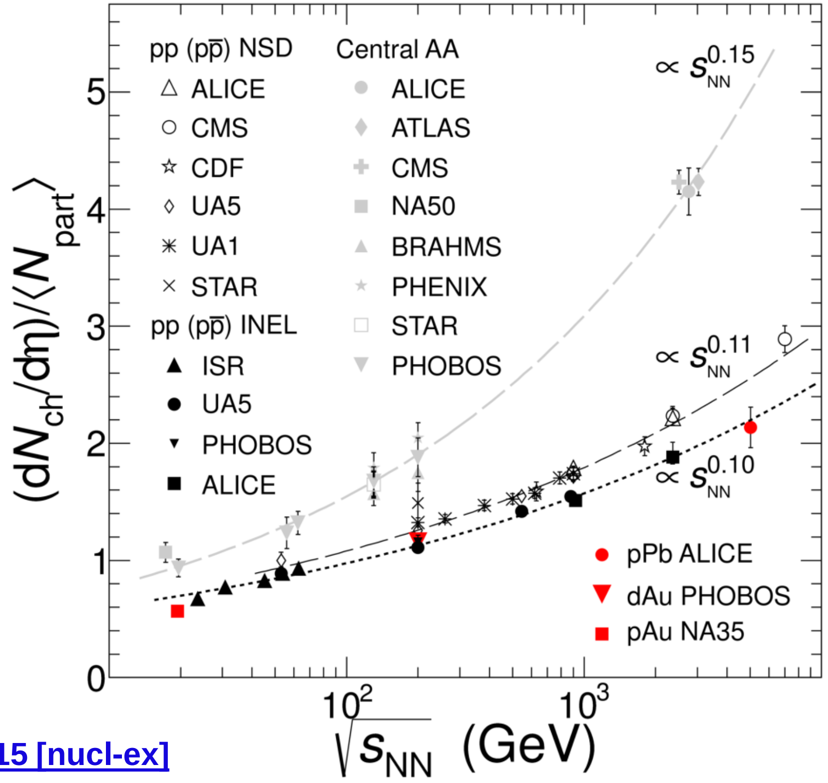
- Ultra-peripheral (UPC) heavy-ion collisions: impact parameter b larger than sum of the two radii 2R
  → hadronic interactions strongly suppressed
- high photon flux ~ Z^2
  → high σ for γ-induced reactions
- LO pQCD: coherent J/ψ cross section proportional to the squared nuclear gluon density:
  → unique tool to probe nuclear gluon shadowing at low x
- Data in good agreement with pQCD models which include gluon shadowing
- See dedicated talk by C. Mayer

pA highlights

$dN_{ch}/d\eta$ in p-Pb collisions

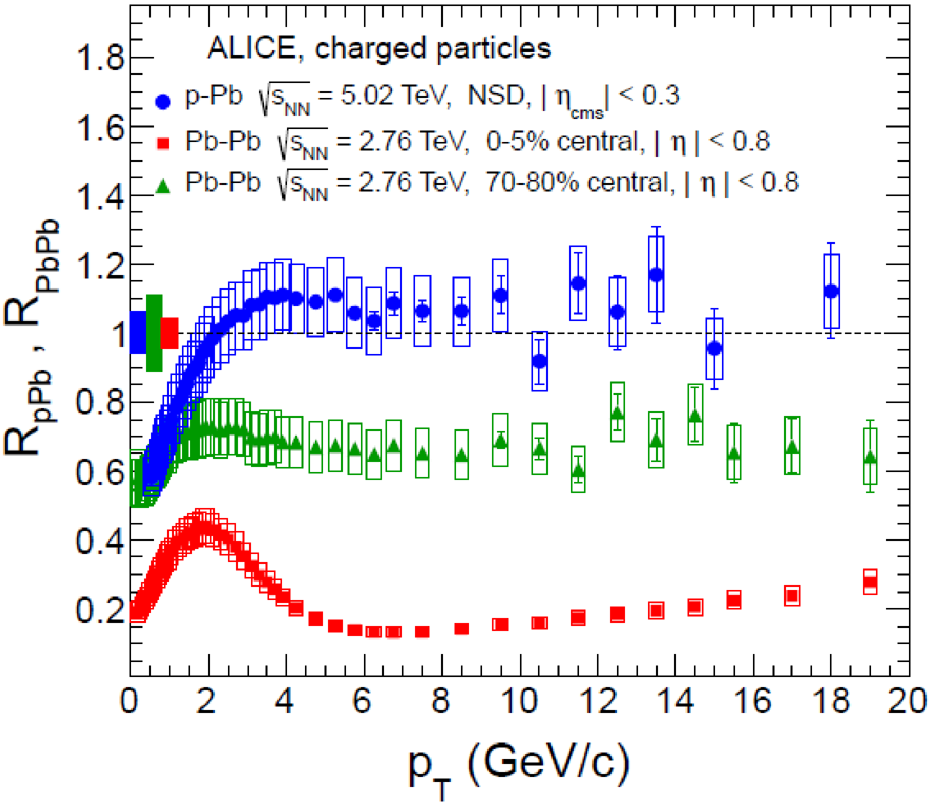


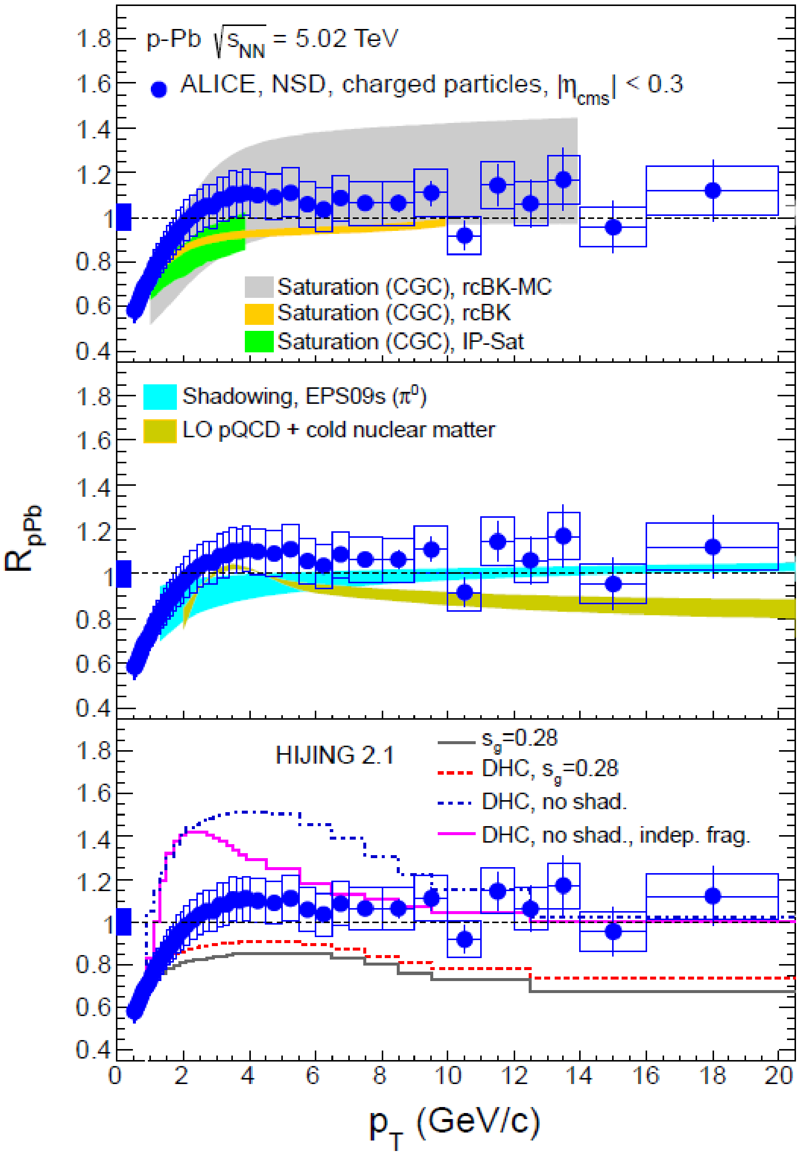
[arXiv:1210.3615 [nucl-ex]](https://arxiv.org/abs/1210.3615)



- pA crucial to discriminate between initial (cold nuclear matter) effects and QGP dynamics
- p-Pb at LHC → probe nuclear wave-function at low *x* → nuclear gluon shadowing
- gluon saturation models: steeper η_{lab} dependence than the data
- HIJING (with shadowing) and DPMJET: describe the η-shape rather well
- mid-rapidity ⟨Npart⟩ normalized $\langle dN_{ch}/d\eta\rangle$ p-Pb similar trend to pp

Charged particle R_{pA}





- consistent with unity for p_T > 2 GeV/c
- the strong suppression observed in Pb-Pb is NOT an initial-state but hot QCD matter effect

arXiv:1210.4520 [nucl-ex]

Plans and upgrade perspectives

LHC and ALICE schedule

LHC Phase 0

- 2010-11: long run with p-p collisions at 7 TeV, 1 month/year Pb-Pb
- 2012: long run with p-p at 8 TeV ⇦ **we are here**
- 2013: 1 month p-Pb control measurement

LHC LS1 (long shutdown 1)

- 2013-14: LHC consolidation and training
  ALICE detector completion and upgrades

LHC Phase 1

- 2015-17: p-p and Pb-Pb at full energy (+ probably Ar+Ar, p-Pb)
  start ALICE upgrade during last p-p run before LS2 (optional)

LHC LS2

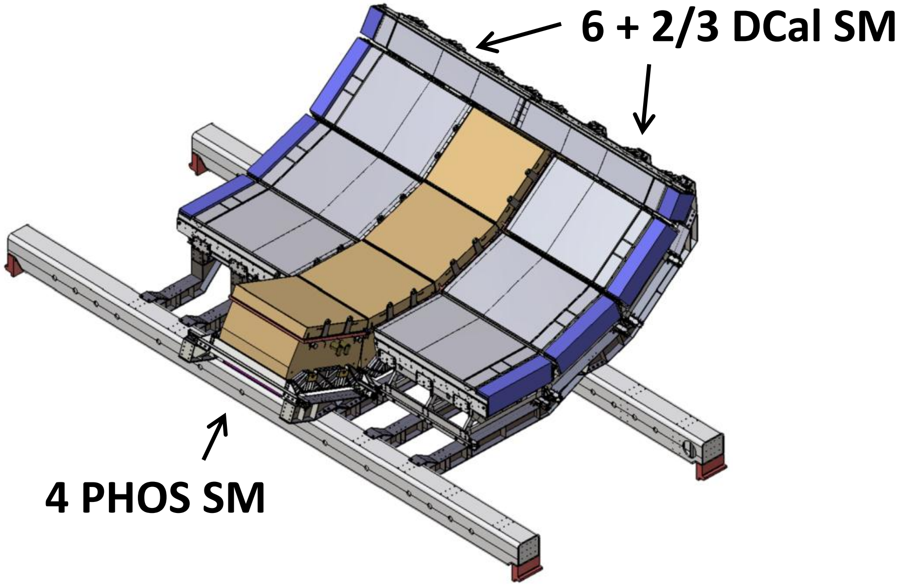
- 2018: LHC luminosity upgrades
  ALICE detector upgrades

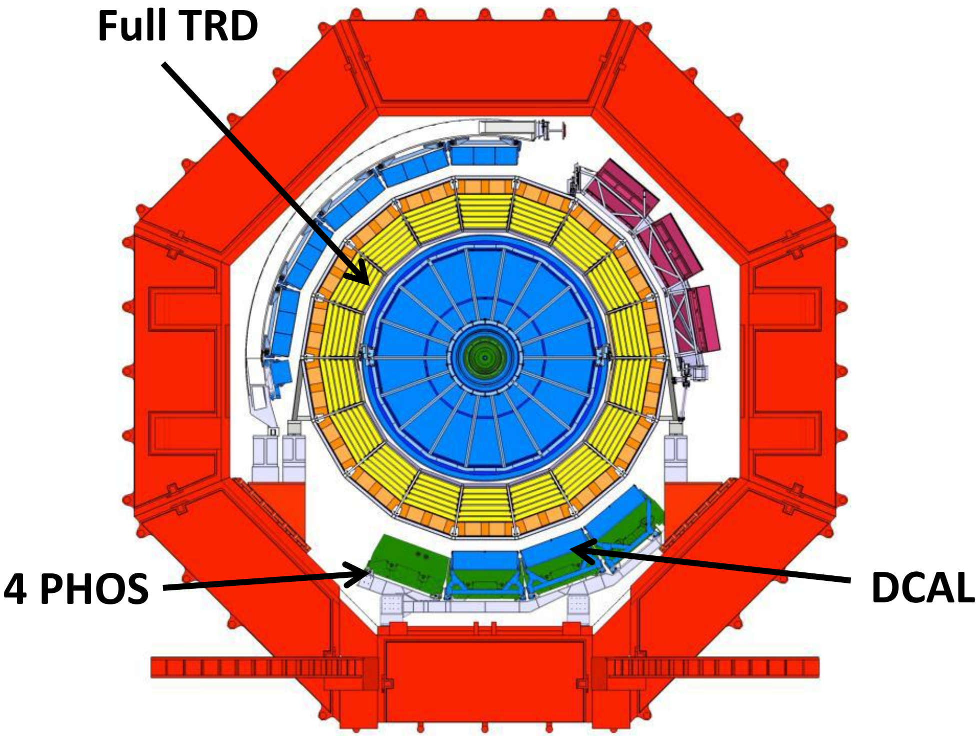
LHC Phase 2

- 2019-22: p-p and Pb-Pb at full energy at High-Luminosity LHC

ALICE LS1 upgrade

- complete **PHOS** (PWO)
- complete **TRD**
- consolidate jet capability by introducing **EMCal (DCAL)** at opposite position to the current EMCal





ALICE LS2 upgrade strategy

LoI completed and endorsed by LHCC

Goal: multi-dimensional, low p_T observables with unprecedented stat. and syst. accuracy:

- Record 100 times more statistics: (10 nb^{-1}), O(10^{10}) central collisions
  - LHC rate after upgrade up to 50 kHz Pb-Pb (i.e. L ~ $6x10^{27}$ $cm^{-1}s^{-1}$ … factor 10 more)
  - present ALICE: < 500Hz at 50% trigger dead time
    → in realistic trigger setup, only 10% of min.bias can be recorded
  - need to record all minimum bias (pipeline, continuous readout) … no trigger!
  - requires high-rate upgrade for the detectors (including MWPC → GEMs in TPC)
  - requires new DAQ and HLT systems
- Improve vertexing and tracking at low p_T:
  - new, smaller radius beam pipe
  - new inner tracker (ITS)

Plan:

- run 6 years with upgraded detector, i.e. until 2026
- including low B-field run & p-A control run

Also extending physics scope is under discussion:

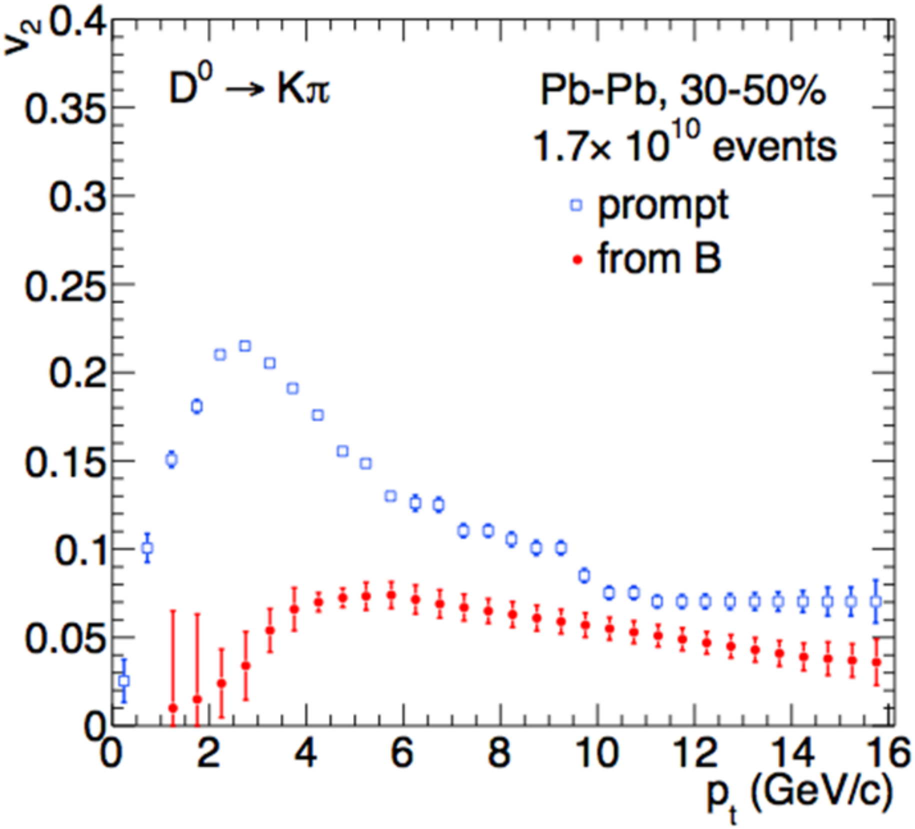
- VHMPID: new high momentum PID capabilities
- MFT: b-tagging for J/ψ, low-mass di-muons
- FoCAL: low-x physics with identified γ/π^0

ALICE physics perspectives

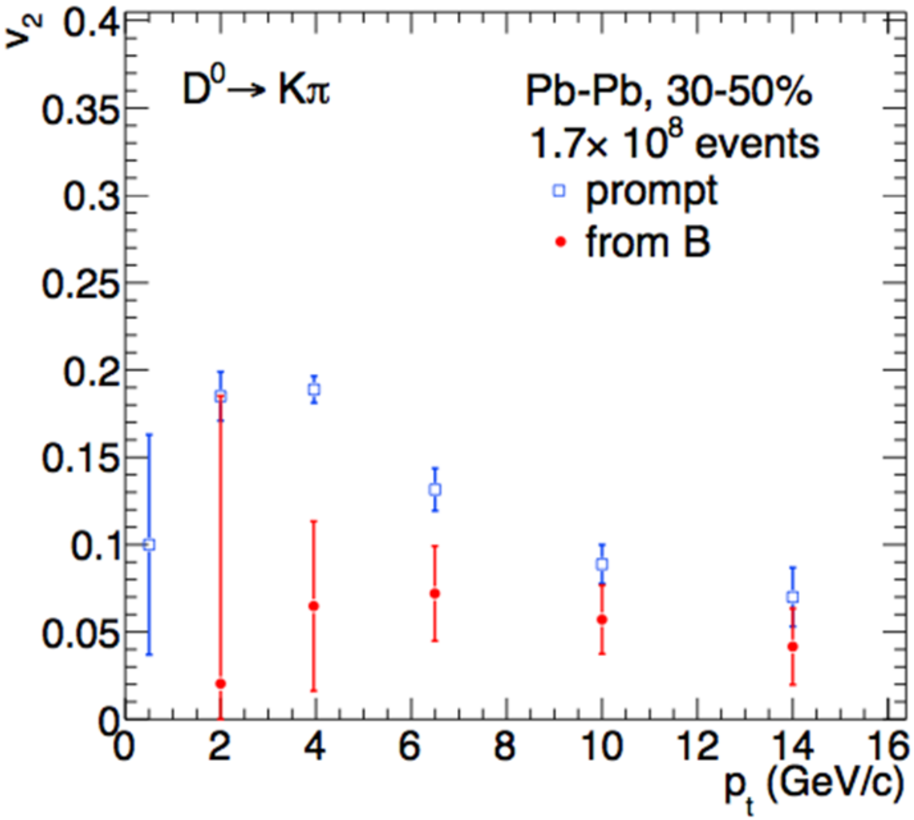
		Status as of today	Reachable for approved	Reach with the upgrade
Bulk production	light flavours, v_2, HBT	quantitative	precision	precision
Intermediate p_t	v_2, correlations, baryon-meson	quantitative	precision	precision
High-p_t – jets	R_{AA}, correlations, jet fragm.	quantitative	precision	precision
	heavy-flavour in jets		hint	quantitative
	PID fragmentation	hint	quantitative	precision
Heavy flavour	D-mesons, R_{AA}	quantitative	🟩	precision
	D-meson v_2	hint	🟥	precision
	beauty, D_s	hint	quantitative	precision
	charm baryons		hint	Quantitative
Charmonia	J/ψ forward, R_{AA}	quantitative	precision	Precision
	J/ψ v_2	hint	quantitative	precision
	ψ', χ_c			quantitative
	J/ψ central, Υ family	hint	quantitative	precision
Dileptons – γ	virtual γ	hint	🟥	quantitative
	ρ-meson			quantitative
Heavy nuclei	hyper(anti)nuclei, H-dibaryon	hint	quantitative	precision

Example: Heavy-flavour v_2

High rate, new ITS



No high rate, new ITS



- need >> 1 nb^{-1} for precise measurement of charm and beauty v_2
- systematic uncertainties and corrections mostly cancel in v_2
- Other key measurements: Λ_b, Ξ_c, B decays, virtual γ, ψ', χ_c, tagged jets…

Conclusions

- ALICE is obtaining a wealth of physics results from the first two LHC heavy-ion runs:
    - bulk, soft probes: spectra and flow of identified particles, thermal photons
    - high-p_T probes: jet fragmentation, particle-type dependent correlations
    - heavy-flavour physics: suppression and flow of D mesons, leptons, J/ψ
    - Low-x physics with exclusive J/ψ measurements

- Entering the precision measurement era:
    - First studies of cold nuclear matter effects with p–Pb collisions, more next year
    - Pb-Pb collisions at higher energy with complete approved ALICE detector

- Long-term upgrade strategy for high-luminosity LHC:
    - ambitious physics programme
    - require improved vertexing and tracking
    - and high-rate capability for all subdetectors