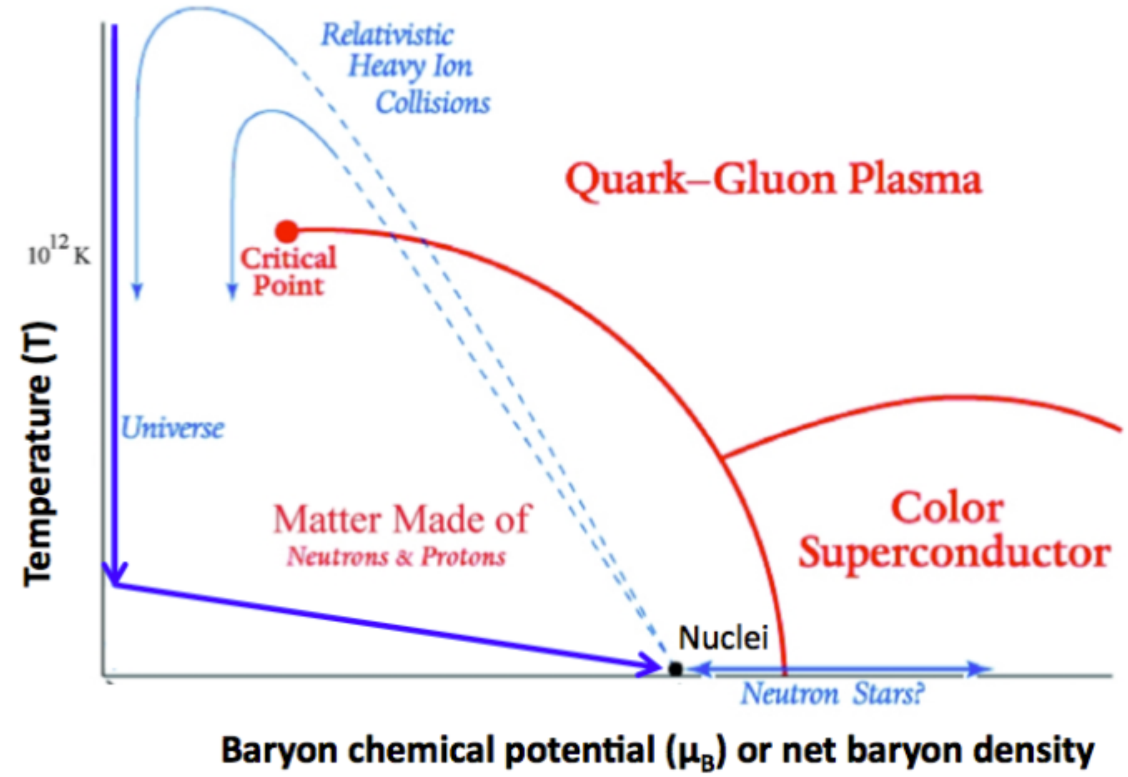
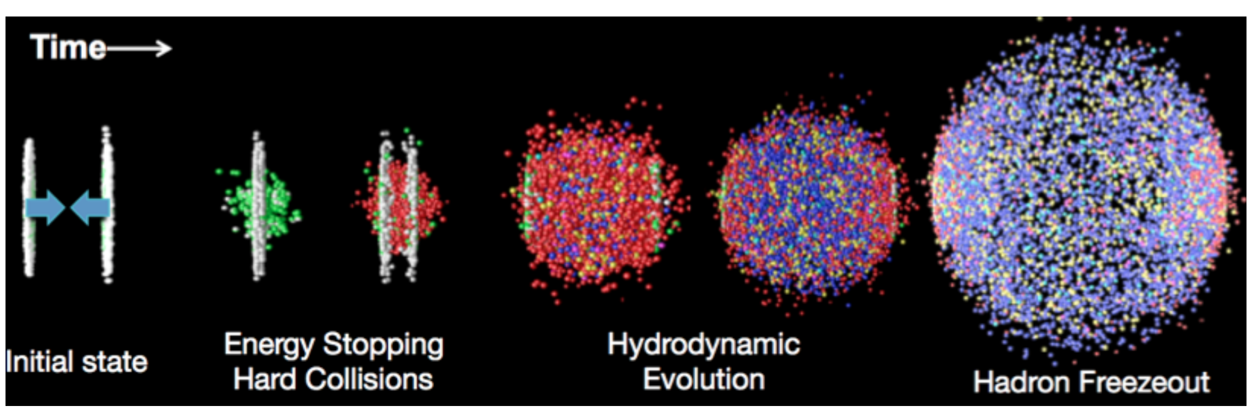
ALICE and some of her (dutch) wonders

Davide Caffarri (NIKHEF),
for the ALICE NL group

Quark Gluon Plasma in Heavy-Ion collisions

- QCD predicts a novel state of nuclear matter: a **strongly interacting, deconfined medium** (QGP).
- High energy heavy-ion collisions allow a large energy in a small volume and produce a "fireball" of hot matter
- Evidence of QGP already at CERN-SPS and BNL-RHIC experiments.





- At the LHC:
  - **precise characterization of QGP parameters,**
  - **investigation of novel QCD related effects** (QCD chiral imbalance, collectivity in small systems, strongest magnetic field)

How to investigate the QGP at LHC?

- Precise characterization of the **macroscopic QGP properties**
  - QGP “source” with **global quantities and collective behaviour**
  - Temperature, viscosity, diffusion coefficients, …

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  - Saturation effects, nuclear-PDF modifications?

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today's focus

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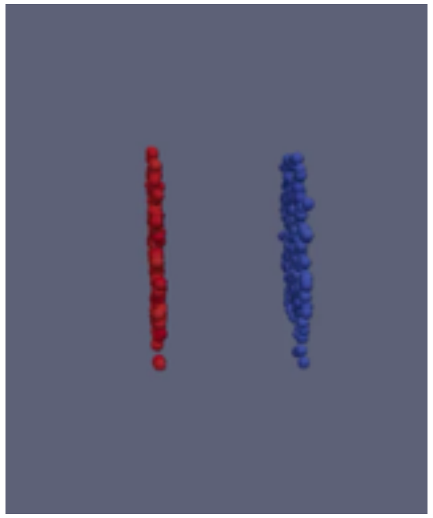
Heavy-ion collisions evolution

Heavy ions

τ ~ 0



Before the collisions
Nuclear PDF modified due to the high quarks and gluons density?

Heavy-ion collisions evolution

Heavy ions
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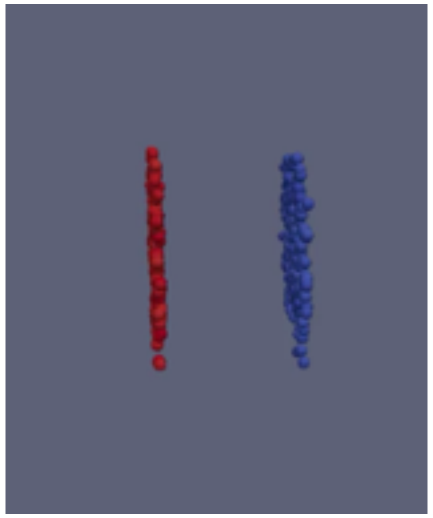

QGP
τ ~ 1 fm/c

Hard scatterings
Partons with high energy and virtuality are produced
Production can be studied using pQCD approach

QGP formation
Hot and dense matter made of deconfined and interacting partons

Heavy-ion collisions evolution

Heavy ions
τ ~ 0

QGP
τ ~ 1 fm/c

QGP
τ ~ 5 fm/c

QGP behaves like a perfect liquid
Approximated with hydrodynamical calculations of an expanding fluid
System can be described with global variables:
- $\eta/s, \zeta/s$ (shear and bulk viscosity over entropy density)
- temperature of the source

Heavy-ion collisions evolution

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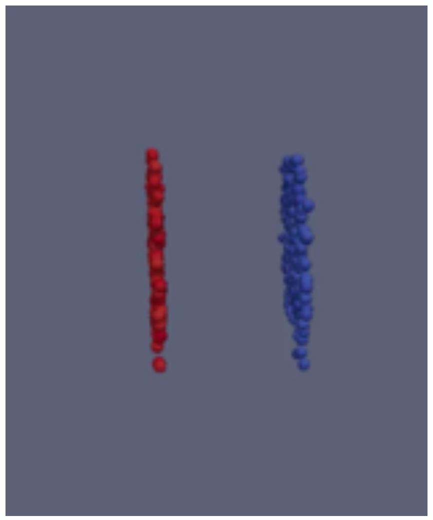

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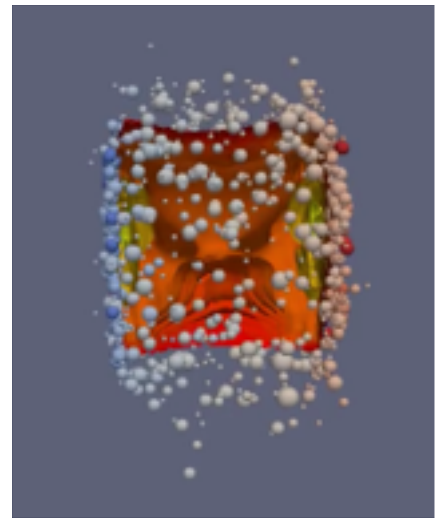
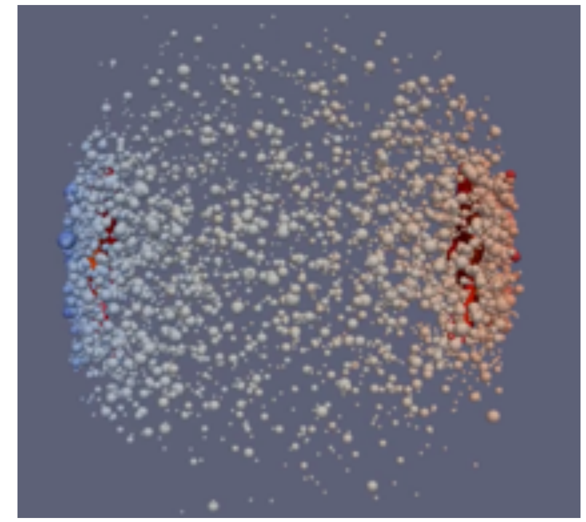


Hadrons
τ > 10 fm/c



Transition from QGP phase to hadron gas.
Hadronization and hadronic phase interactions to be taken into account.

Heavy-ion collisions evolution

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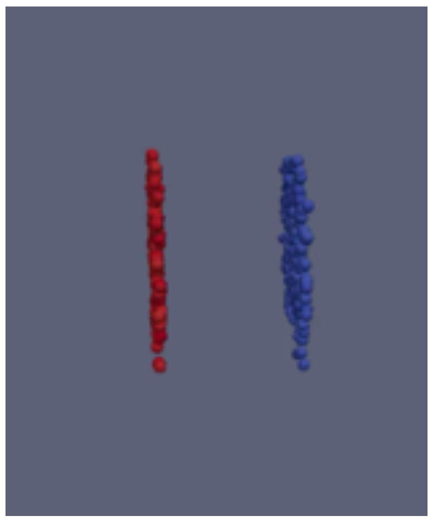

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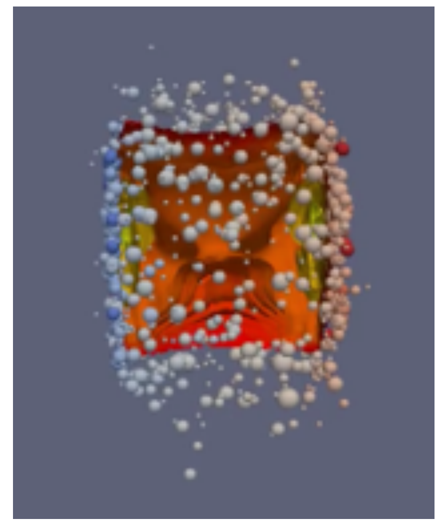

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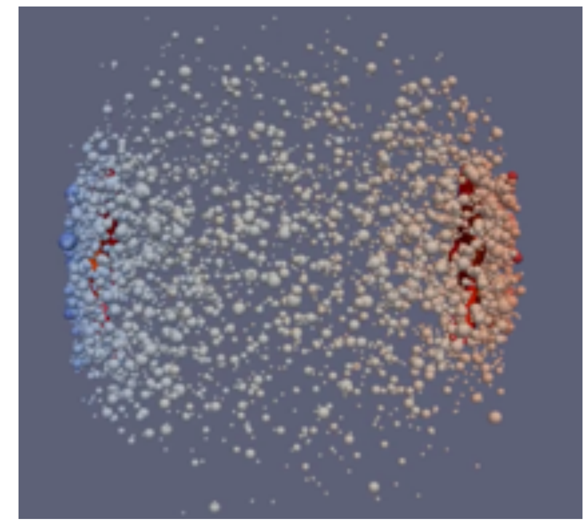
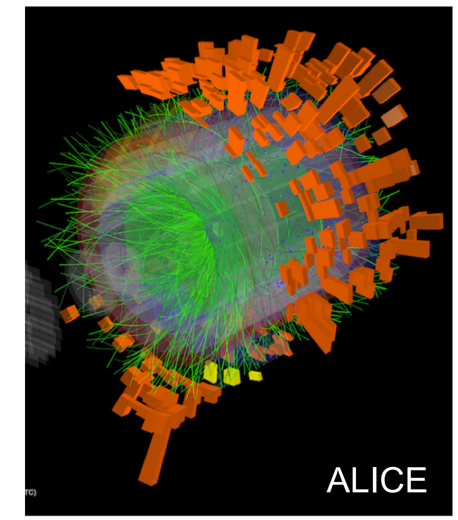


Detection
τ > 10 pm/c



No direct observation of the QGP is possible
Rely on detected particles as “probes”
Study the event-by-event properties, fluctuations and correlations between all particles.

Heavy-ion collisions evolution

Heavy ions
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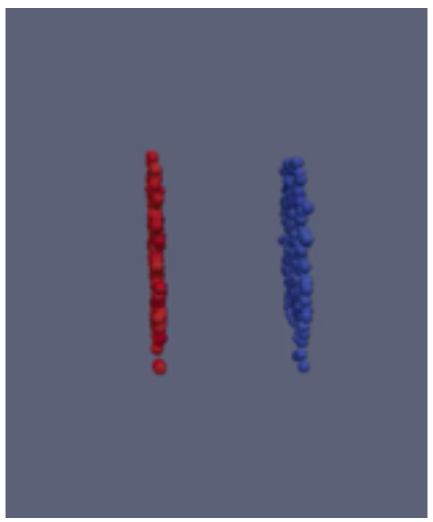

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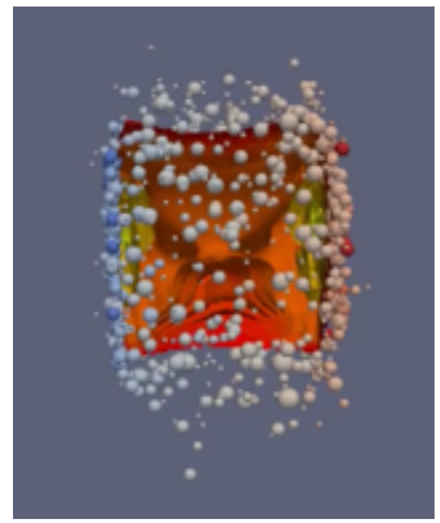

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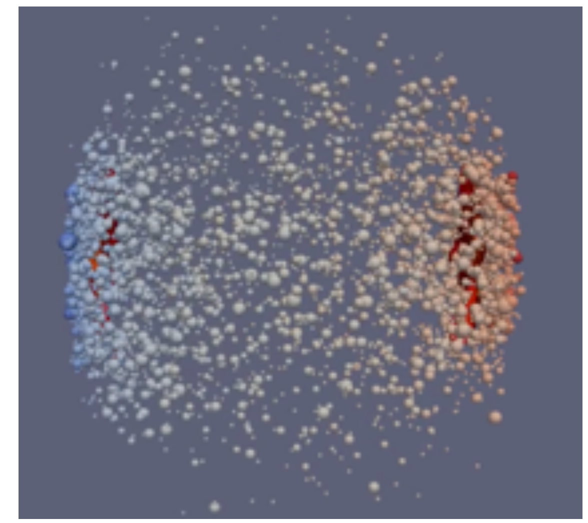

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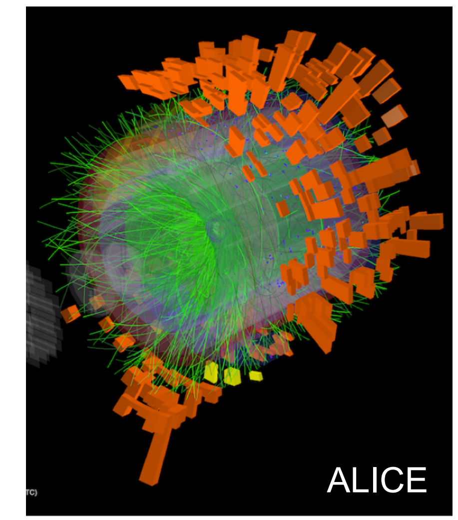
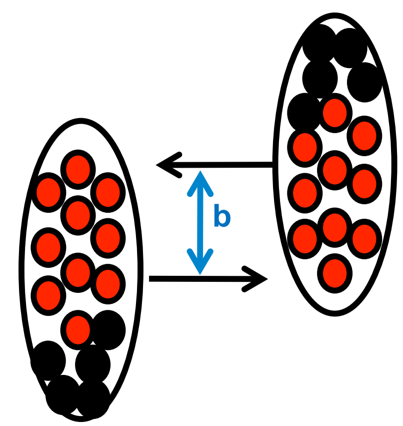
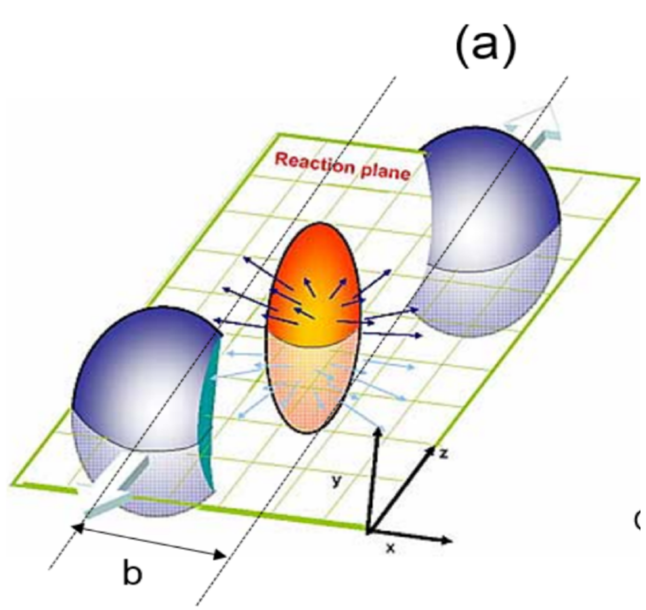


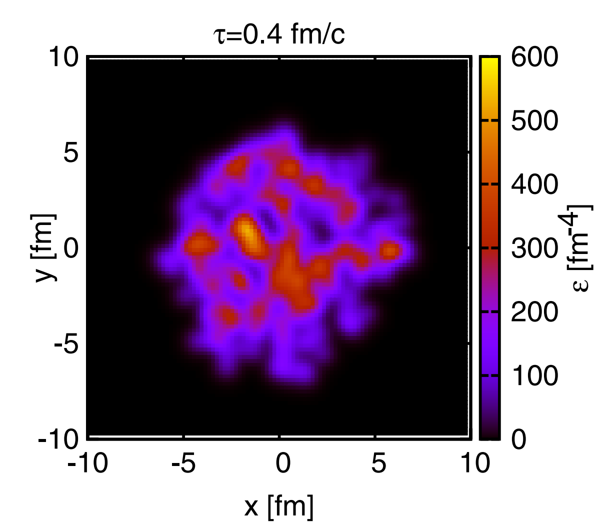
Centrality,
Related particle multiplicity produced in the collisions,
Number of participants nucleons in the collisions.



collision geometry,



... and it's fluctuations.



B. Schenke et al., PRL 106 (2011) 042301

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- Precise characterization of the **macroscopic QGP properties**
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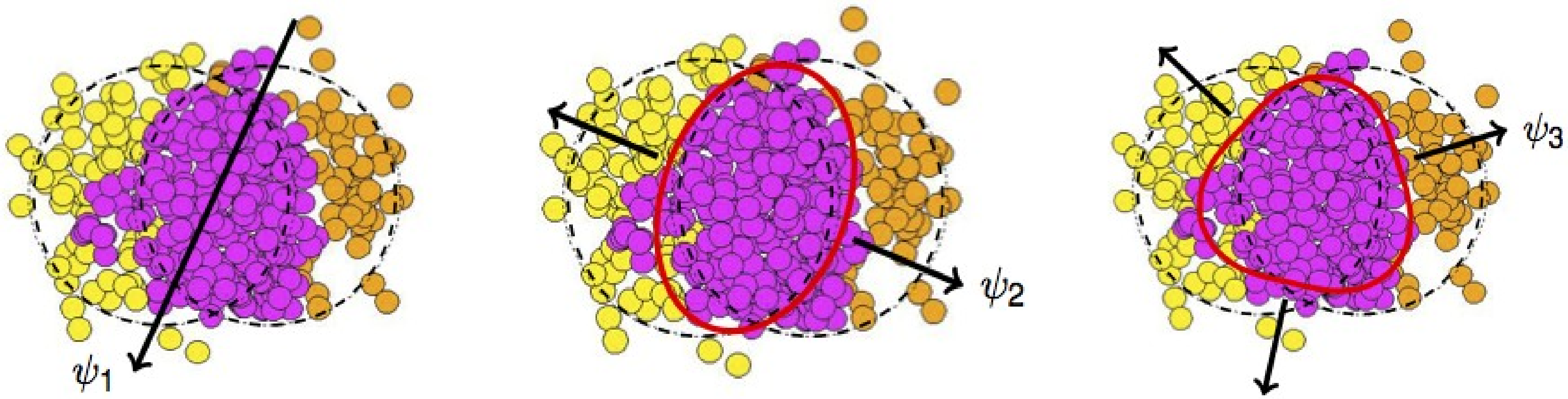
Azimuthal Anisotropies

- **Spatial anisotropies** induce **pressure gradients** that push particles with different velocities



- **More** and **faster** particles are seen in the symmetry planes (ψ_n) directions.
  - **Particle azimuthal distributions** measured wrt symmetry planes → Fourier series

Flow coefficients

$$v_n = \langle \cos(n(\varphi - \Psi_n)) \rangle$$

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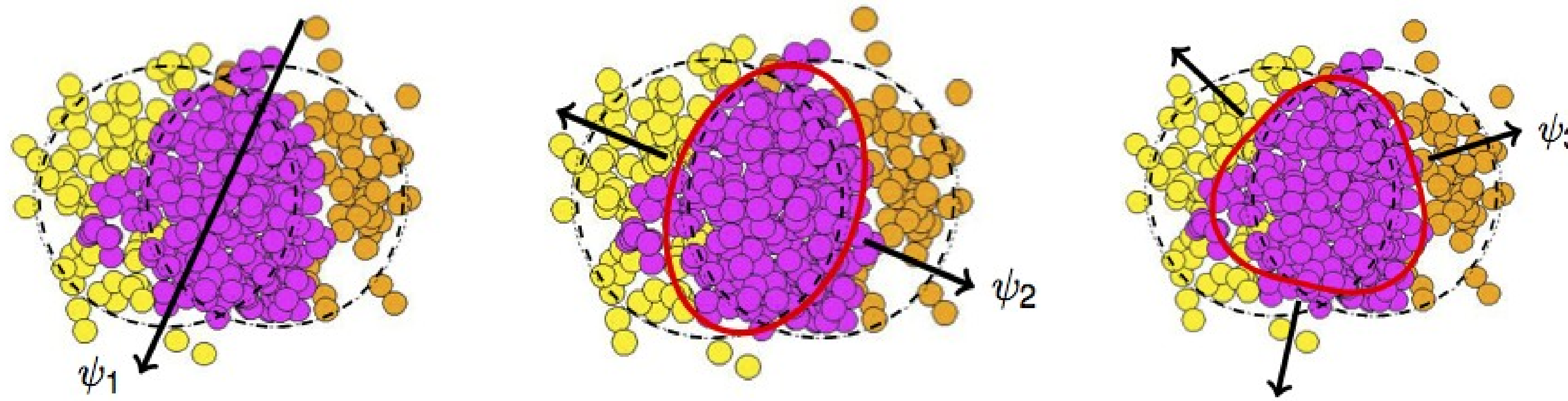

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Flow coefficients

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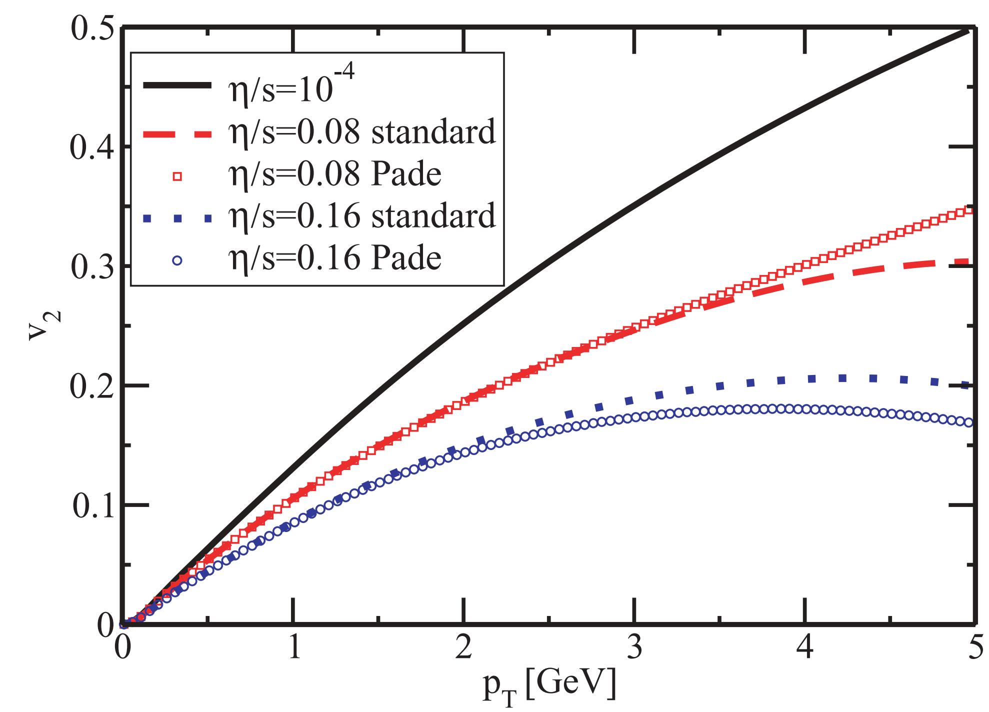
- Investigation of QGP shear viscosity over entropy density (*η/s*)
  - Friction effects of fluid elements
  - Perfect liquid → *η/s* ~ 0
  - Investigation of the *η/s* (*T*)

M. Luzum, P. Romatschke PRC 78 (2008) 034915
Erratum PRC 79 (2009) 039903

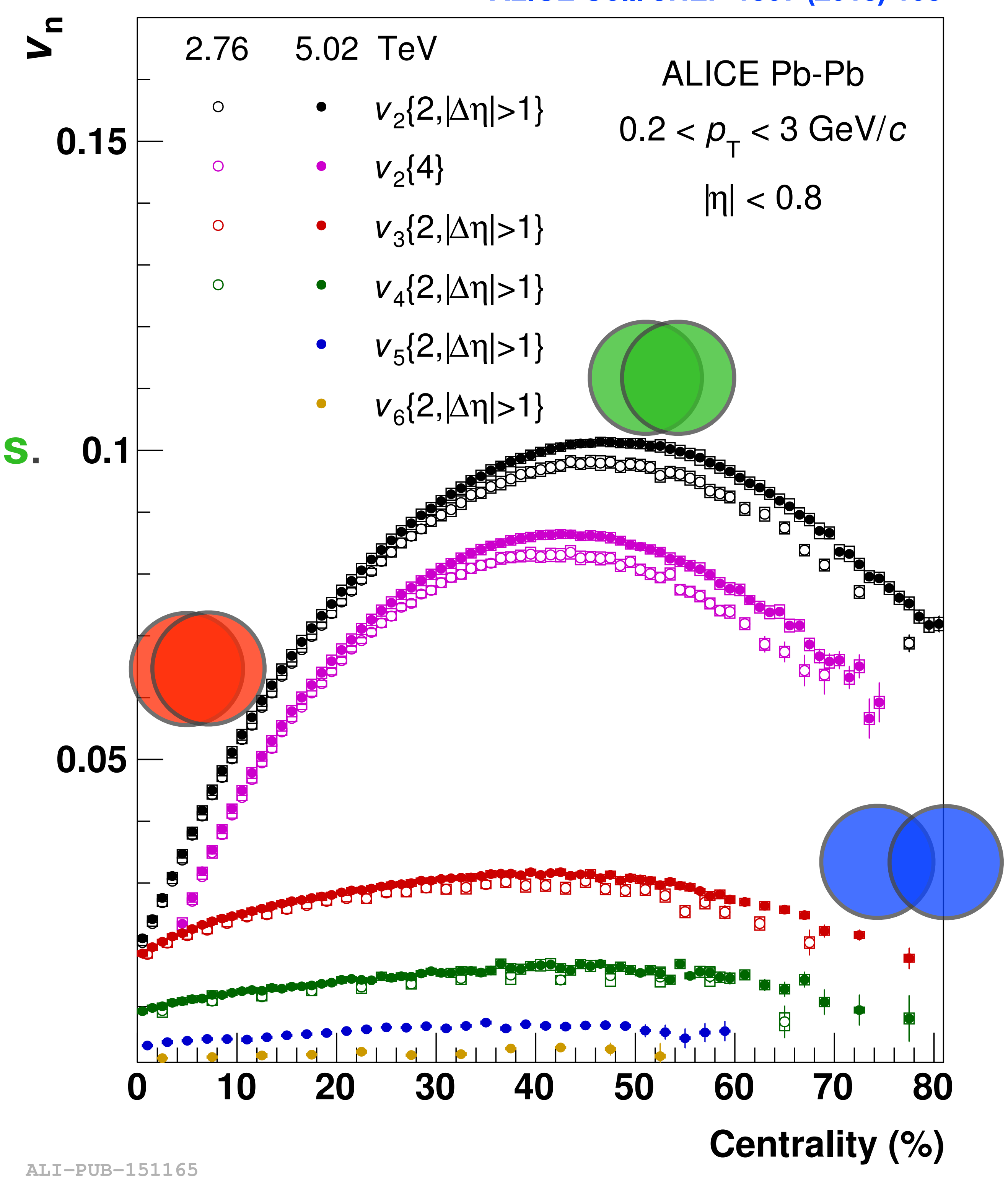


Charge particles flow coefficients

- Centrality dependence of flow coefficients for charged hadrons in 0.2 <p_T < 3.0 GeV/c
  - **Up to v_6 > 0** coefficients measured
  - **Very high precision** reached

- **Strong increase of v_2 harmonic** contribution in **semi-central collisions**.
- Collective effects coming from **different contributions of different harmonics** to different centralities

ALICE Coll. JHEP 1807 (2018) 103



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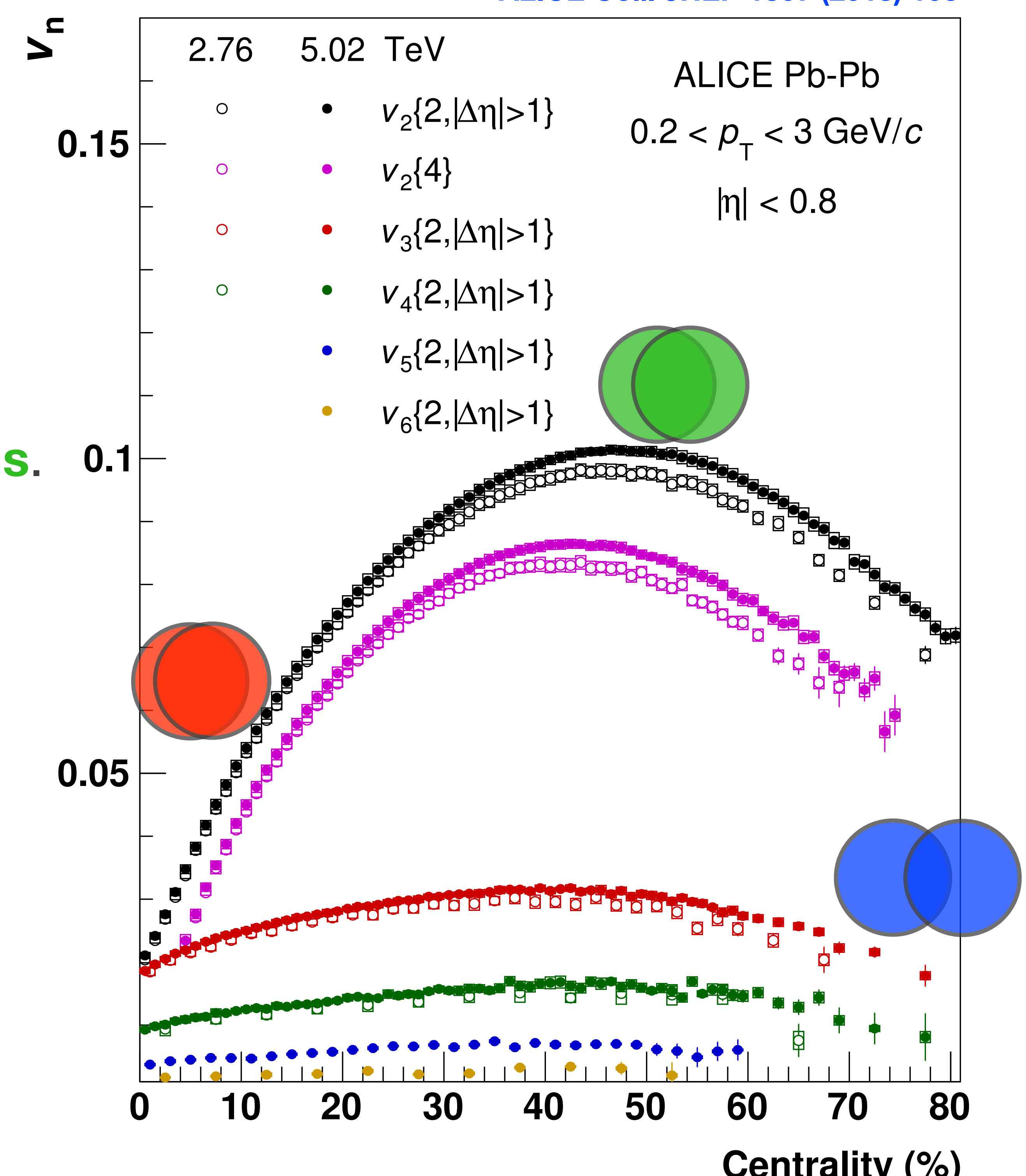
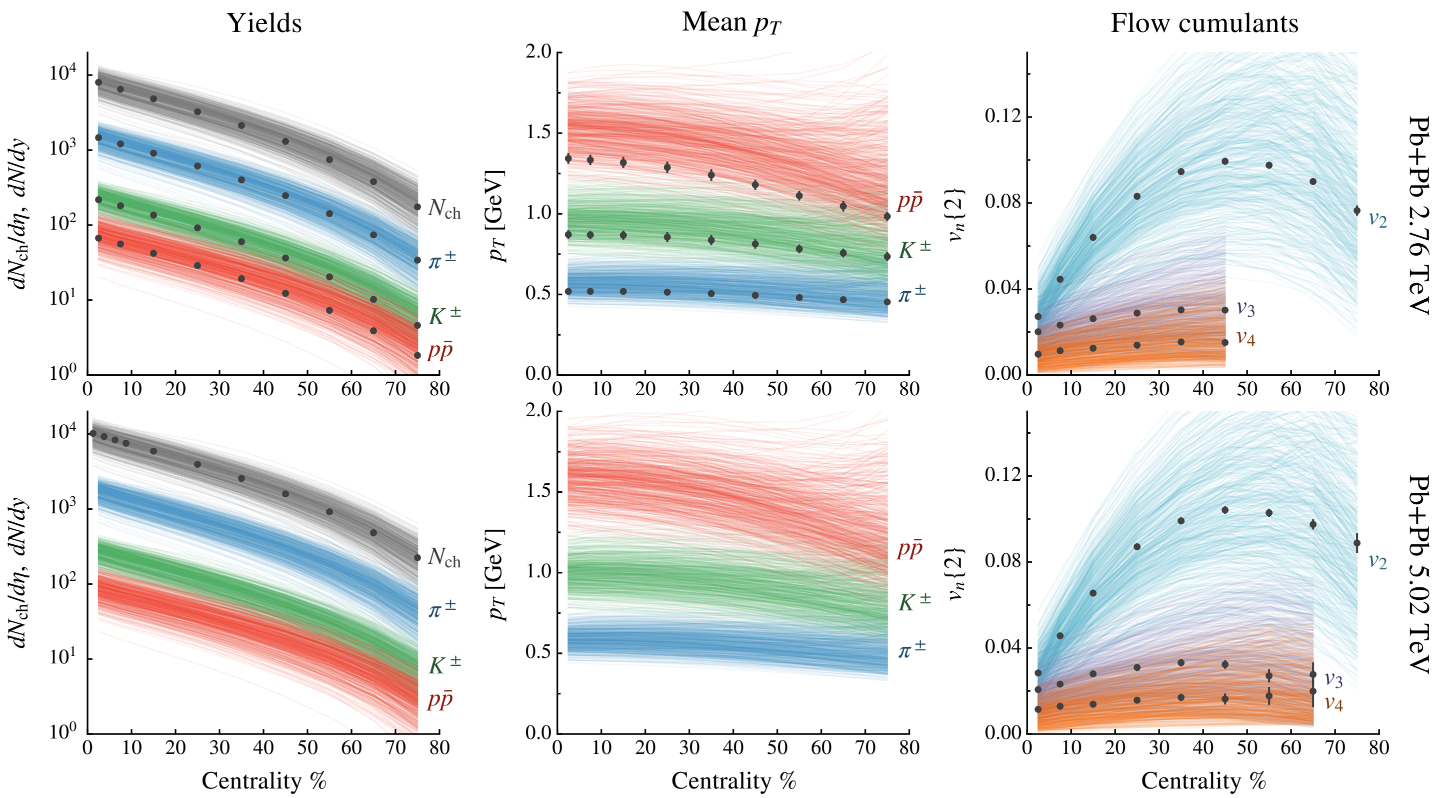
Collective effects arise from the non-trivial interplay of different collision geometries and initial state fluctuations.

ALICE Coll. JHEP 1807 (2018) 103



Determining QGP properties with measurements

- ALICE results used as input for a Bayesian model-to-data analysis to constrain QGP parameters
- Simulation of experimental observables with a sub-set of significant parameters



S. Bass et al. Nucl.Phys A, 967 (2017) 67-73, J. S. Moreland et al 1808.02106

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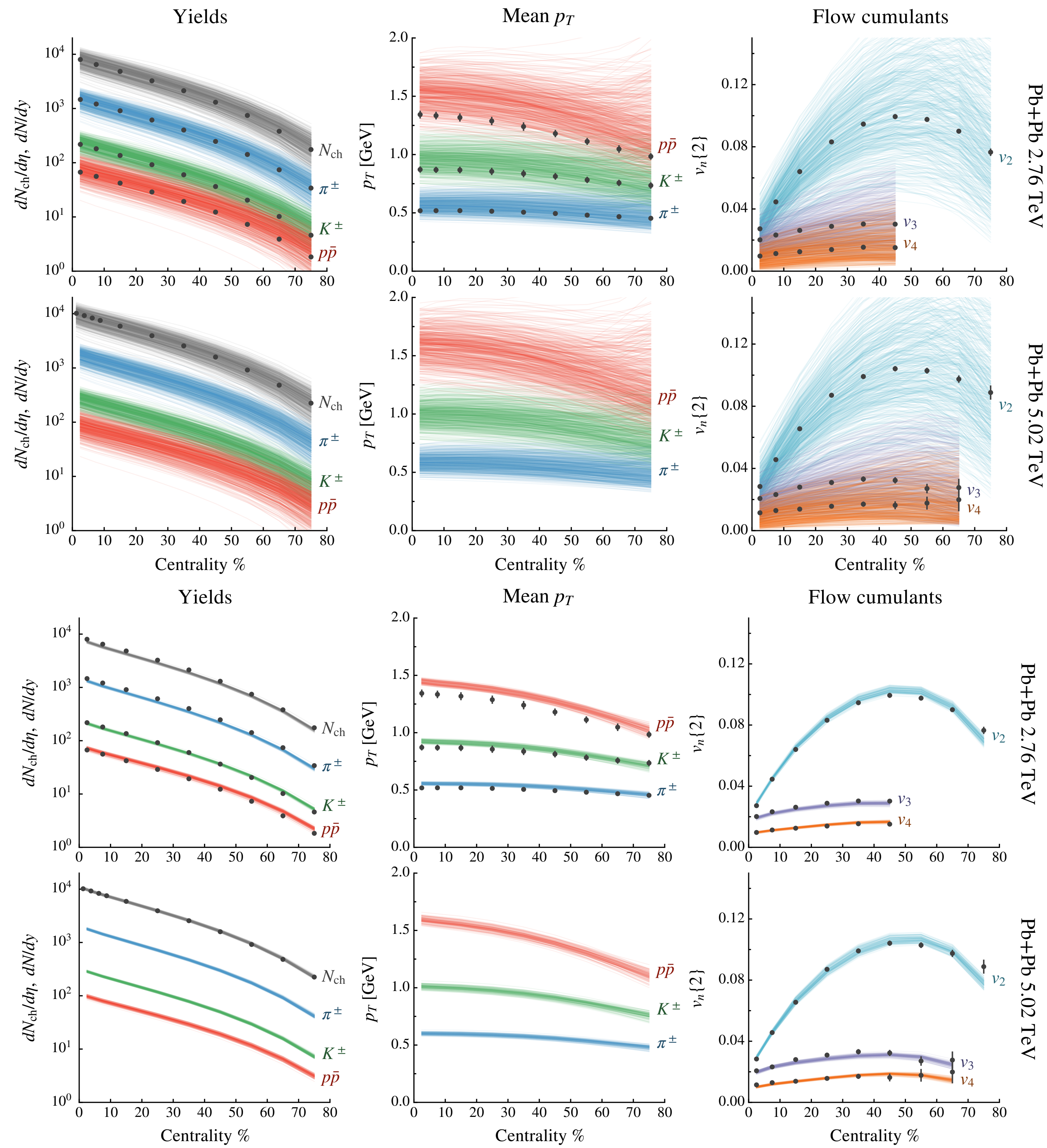

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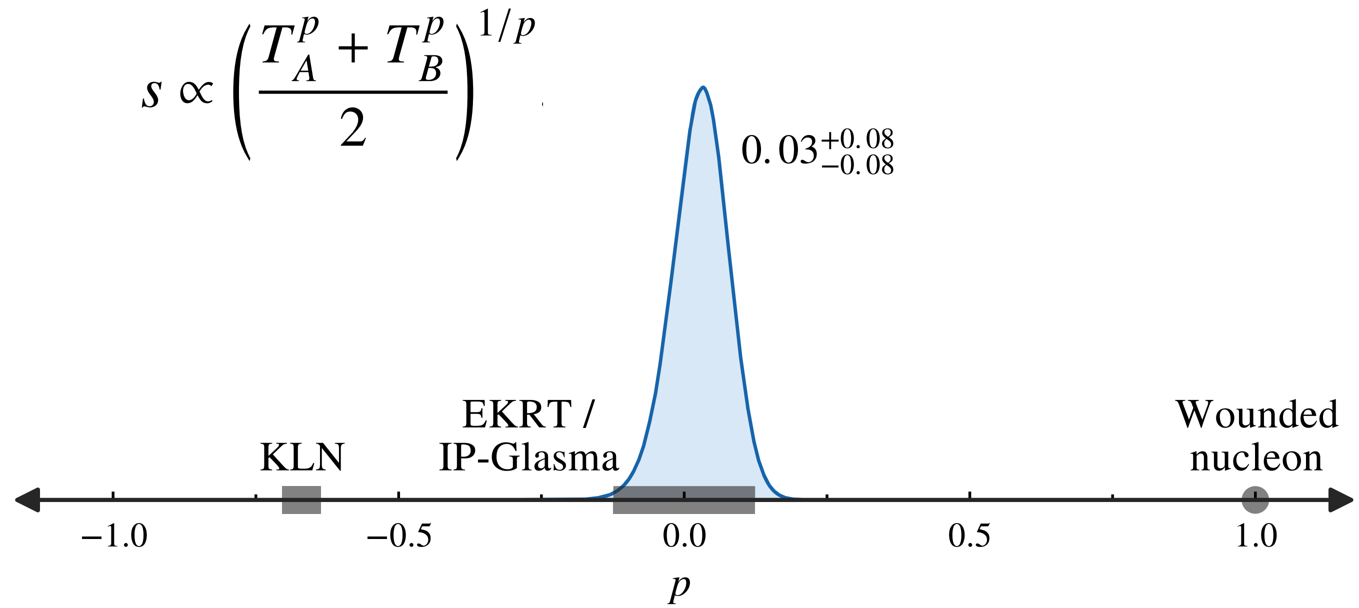
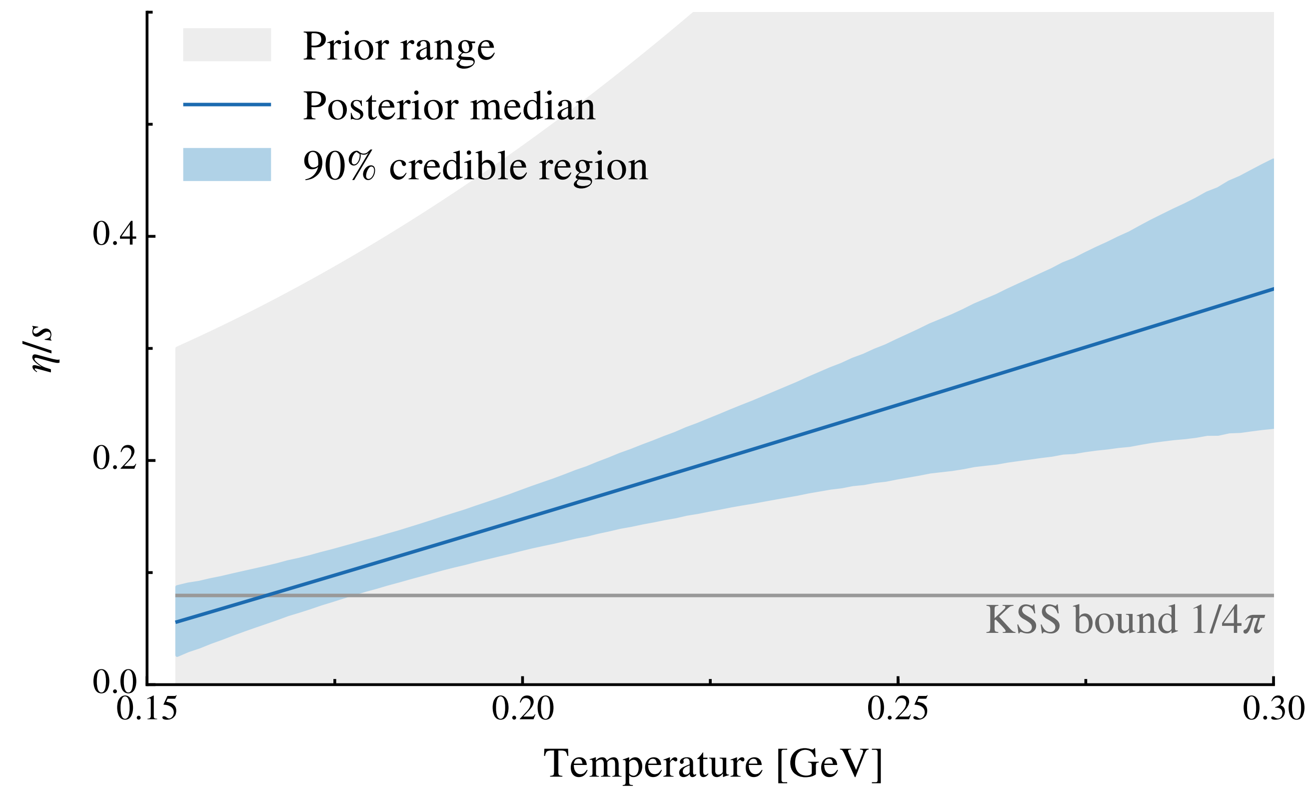


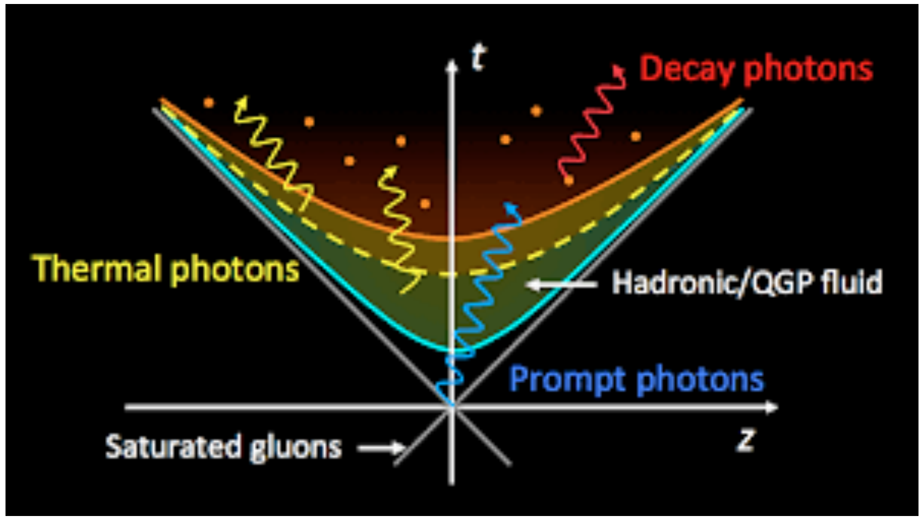


Constraining initial conditions and extraction of η/s(T) using this multi-observable statistical method with high precision ALICE data

S. Bass et al. Nucl.Phys A, 967 (2017) 67-73

Direct γ v_2

- Direct γ:
  - emitted in hard scatterings and by the QGP during its evolution
  - not interacting with the medium constituents
  - spectrum depends on medium properties (T, expansion velocity)



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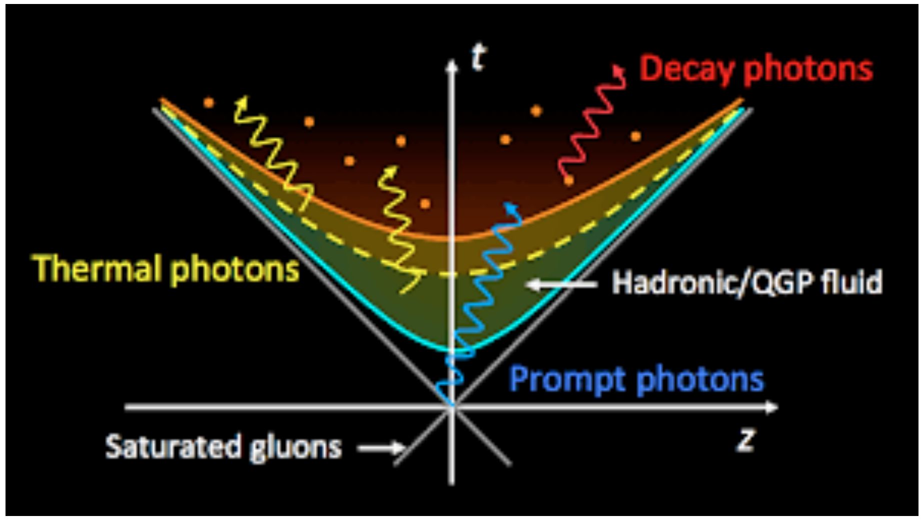
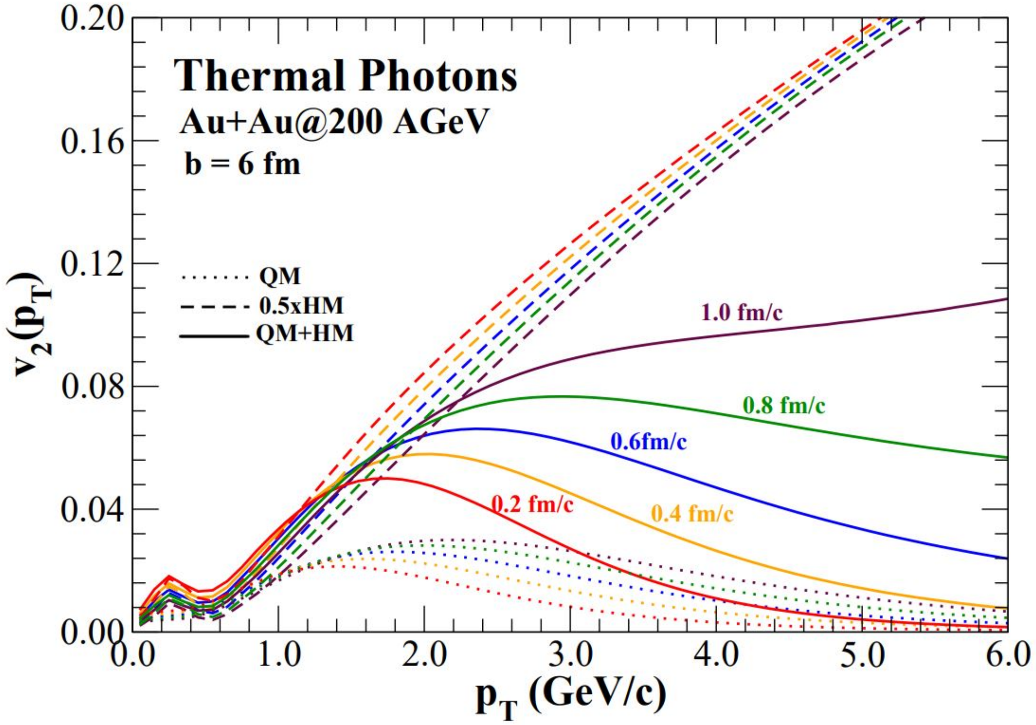


R. Chatterjee, D. K. Srivastava Nucl. Phys. A830 (2009) 503



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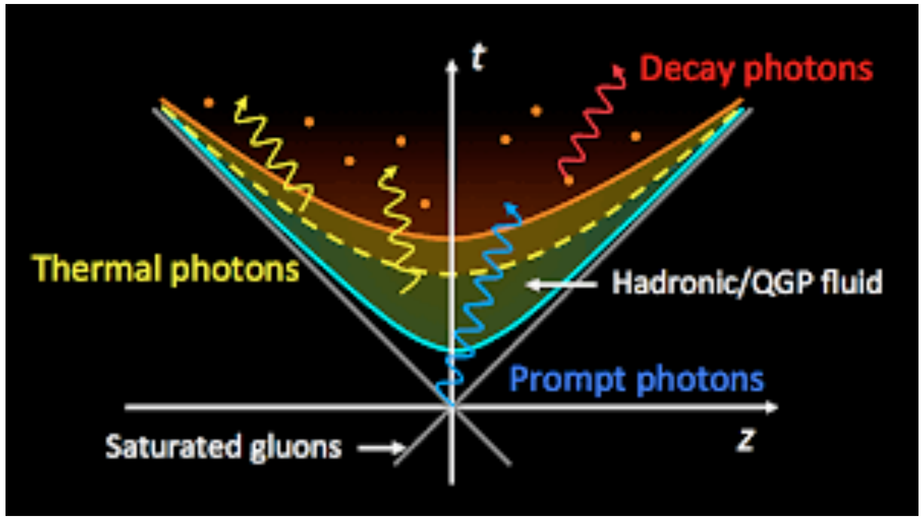

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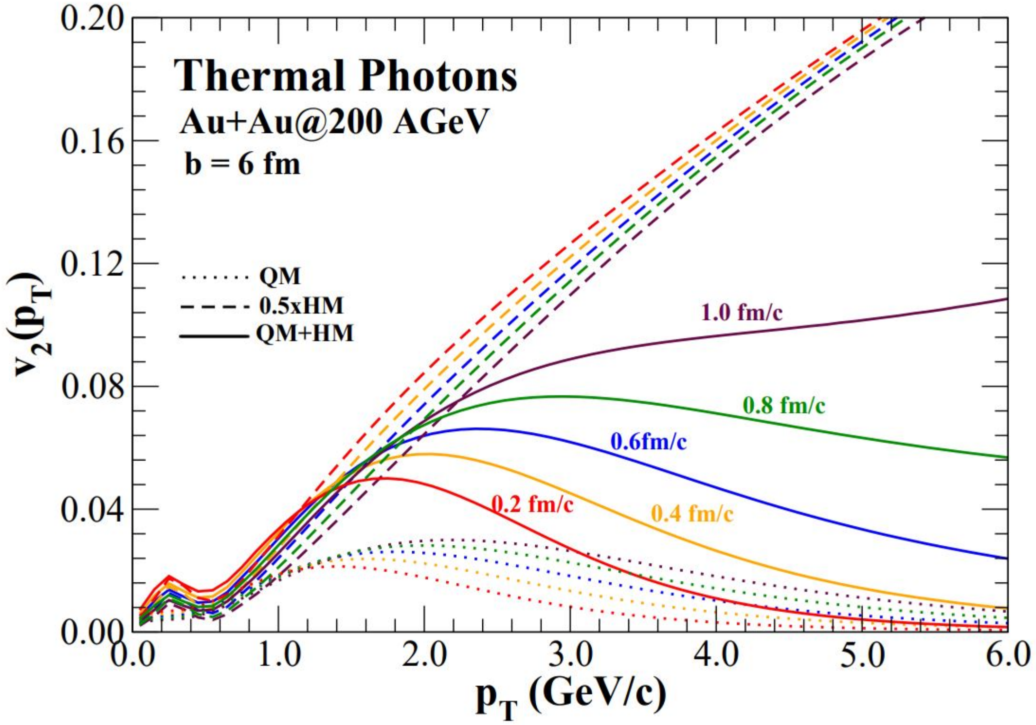


Later emitted photons develop larger v_2

Extract direct photon yields

$$\gamma_{direct} = \gamma_{incl} - \gamma_{decay} = \left(1 - \frac{1}{R_\gamma}\right) \cdot \gamma_{incl}$$

$$R_\gamma = \frac{\gamma_{incl}}{\gamma_{decay}}$$

Calculation of the direct photons v_2

$$v_2^{\gamma,\mathrm{dir}} = \frac{R_\gamma \; v_2^{\gamma,\mathrm{inc}} - v_2^{\gamma,\mathrm{dec}}}{R_\gamma - 1}$$

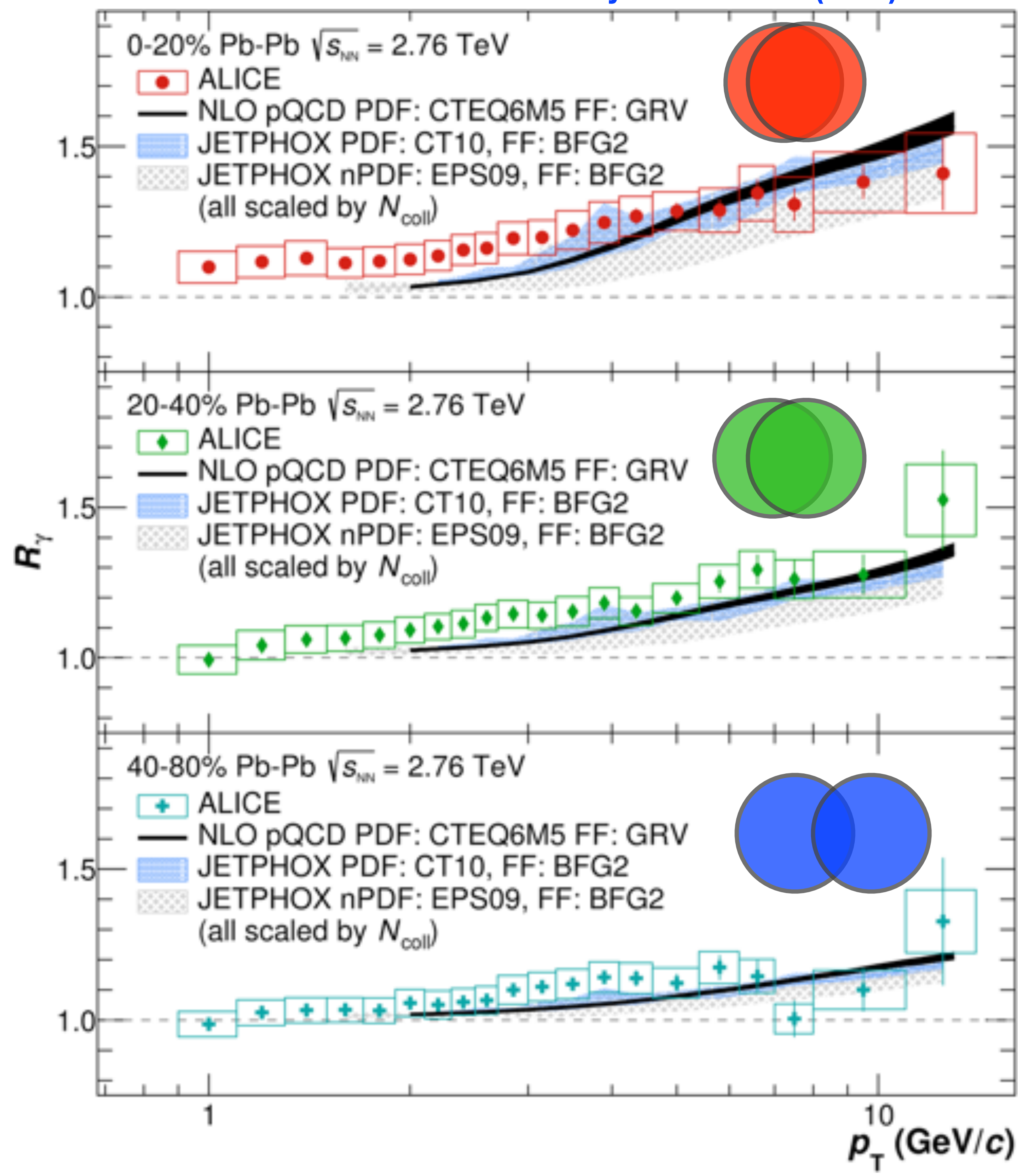
Direct γ v_2

- Measurement of $\mathbf{R_\gamma}$ factor in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

$$R_\gamma = \frac{\gamma_{incl}}{\gamma_{decay}}$$

- Only ~ 10% of inclusive γ are direct ones.
- Measurement of $v_2^{\gamma,incl}$ measured with two-particles correlations method
- Calculation of the $v_2^{\gamma,decay}$ using simulation with cocktail of decay particles (π^0, η, …)

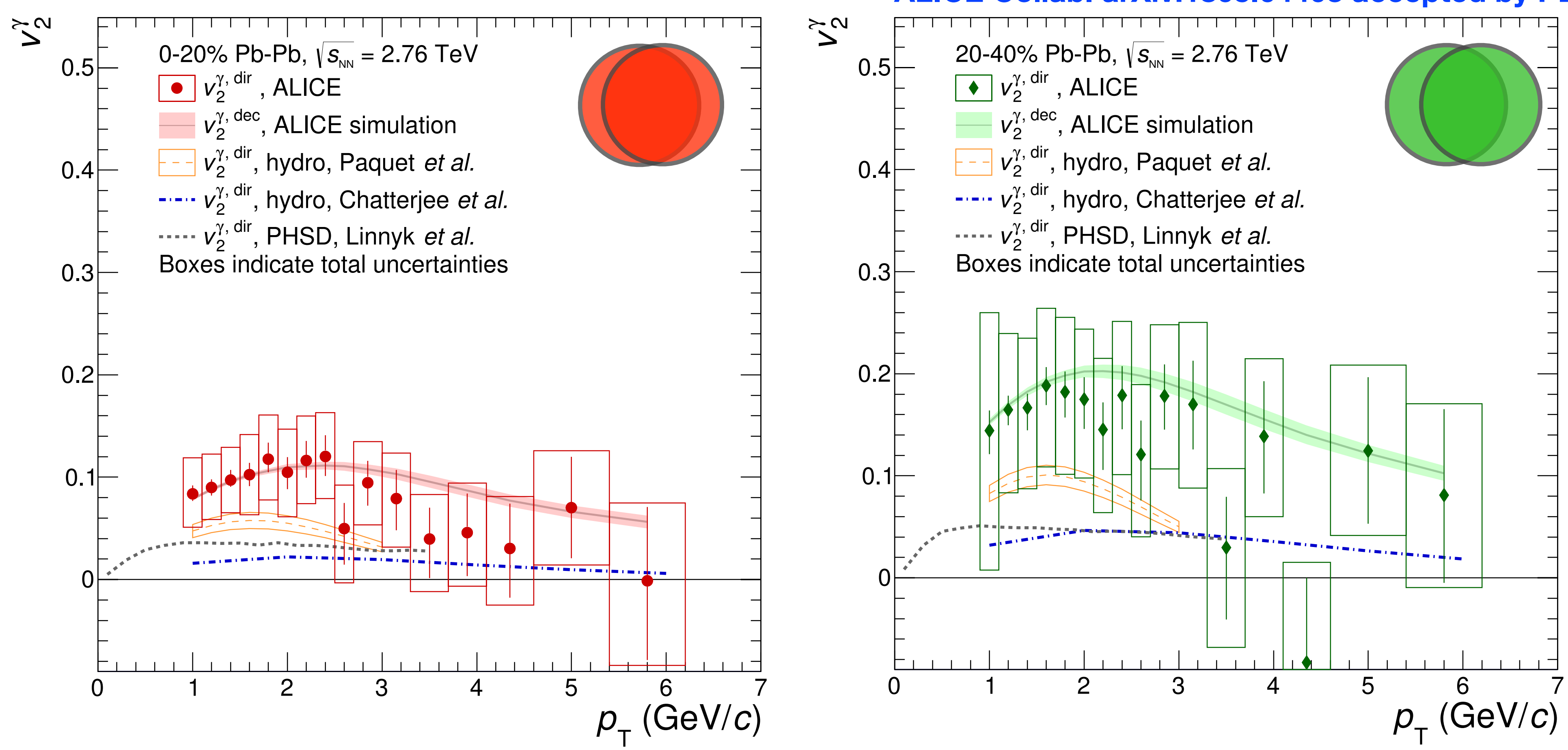
ALICE Collab. Phys. Lett. B 754 (2016) 235-248



Direct γ v_2

- Final results obtained by employing a Baysian approach given the small fraction of direct γ.
- Non - zero direct γ flow (significance 1.4-1.0 σ)
- Results tend to be higher than the model predictions
- Similar values as observed at PHENIX.

ALICE Collab. arXiv:1805.04403 accepted by PLB



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First measurement of $v_2^{\gamma,dir}$ at the LHC. More data needed to improve our R_γ factor estimate.

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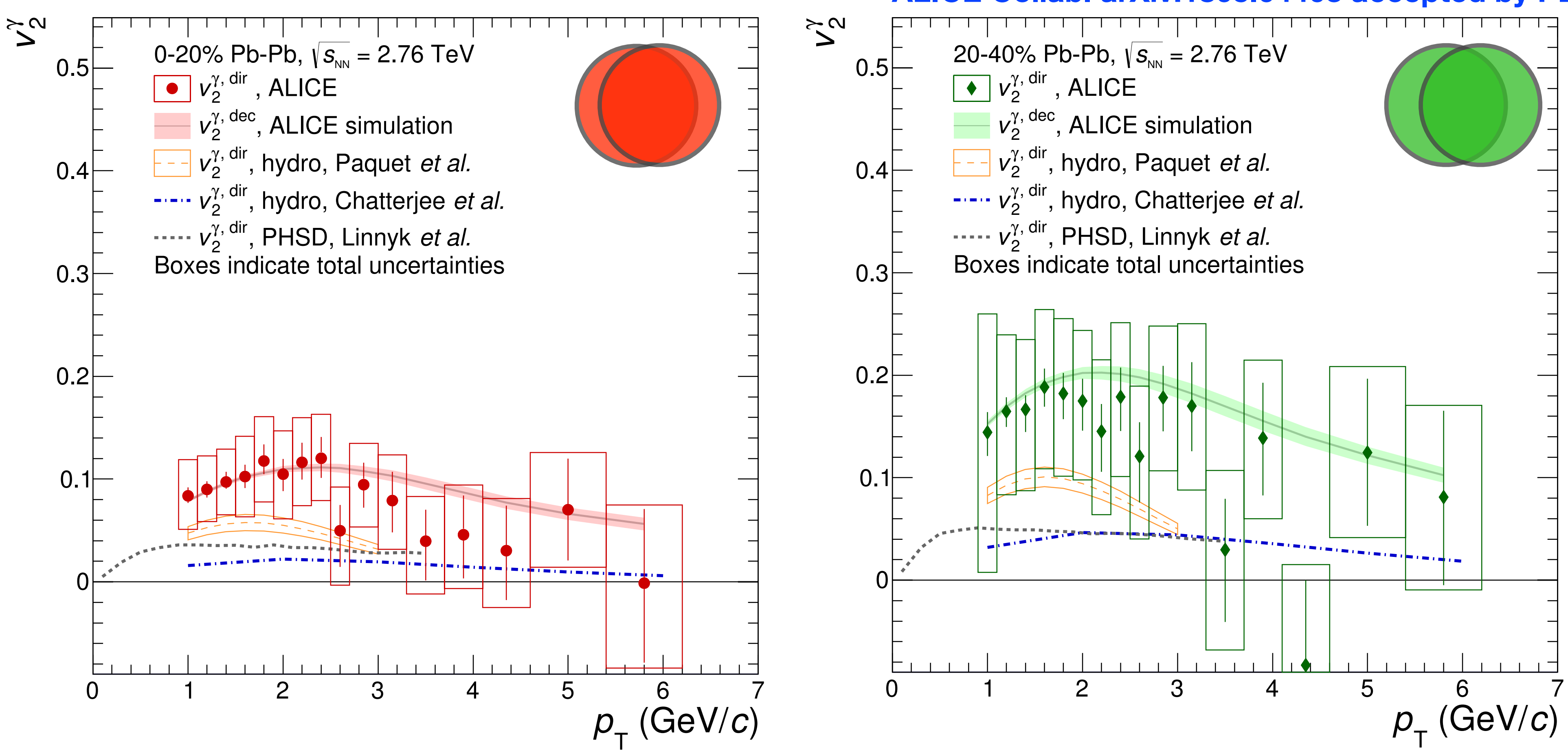
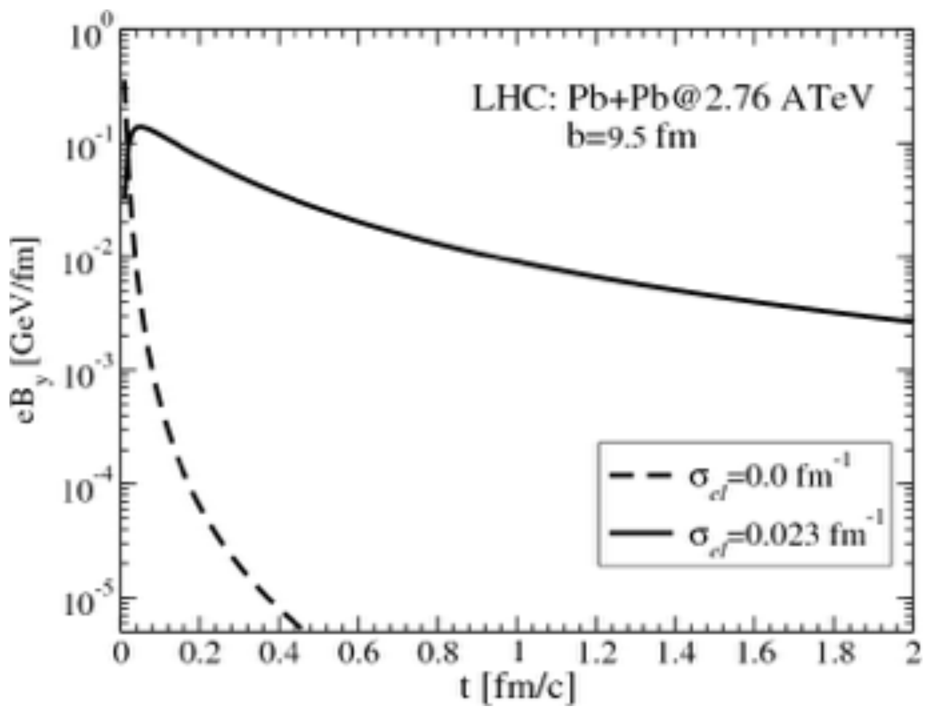


Probing the strongest magnetic field

U. Gursoy, D. Kharzeev and K. Rajagopal Phys. Rev. C 89, 054905 (2014)

- Constraint the properties of high magnetic field created in heavy-ions collisions before investigating more complex effects (as Chiral Magnetic Effects, …)

- B parameters:
  - almost no constraint from theory
  - related to QGP properties (conductivity, vorticity, …)



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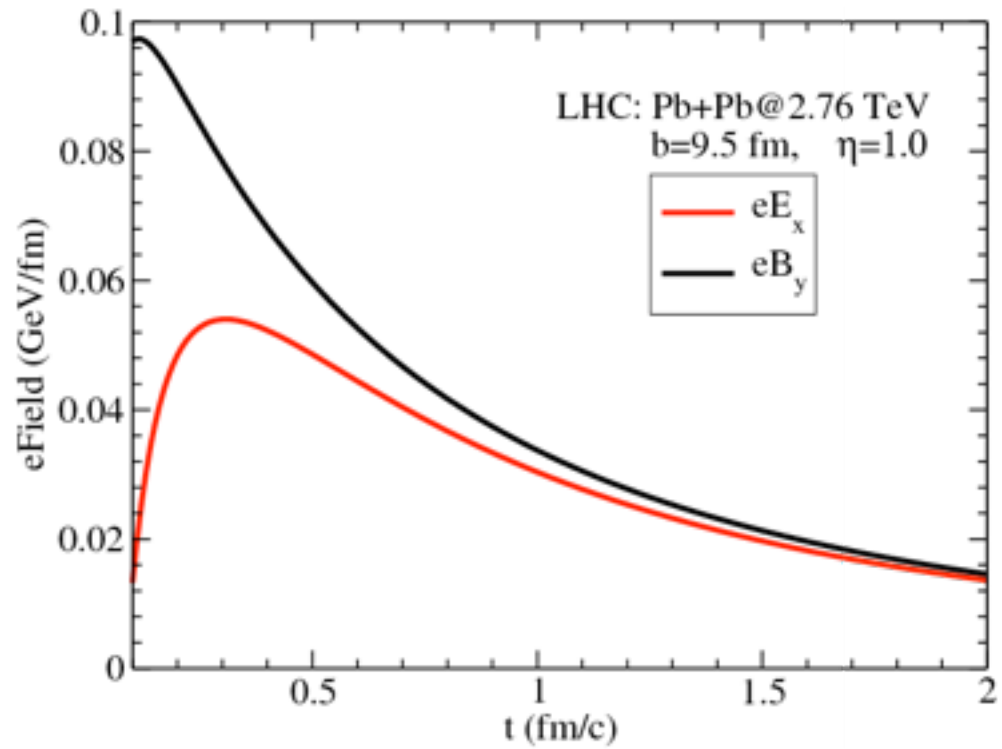
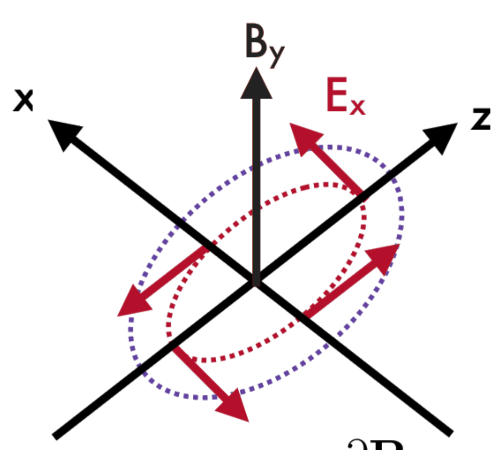


- B parameters:
  - almost no constraint from theory
  - related to QGP properties (conductivity, vorticity, …)

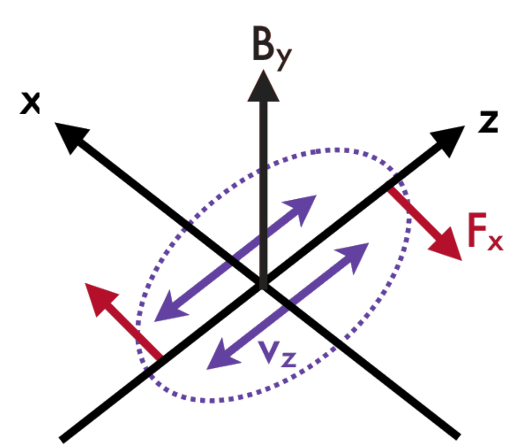
- Two competing effects:
  - Faraday effect - Electric field induced by decreasing magnetic field vs time (spectators)
  - Hall effect - Lorentz force induced by moving charges (QGP expansion)

Faraday effect



$$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

Hall effect

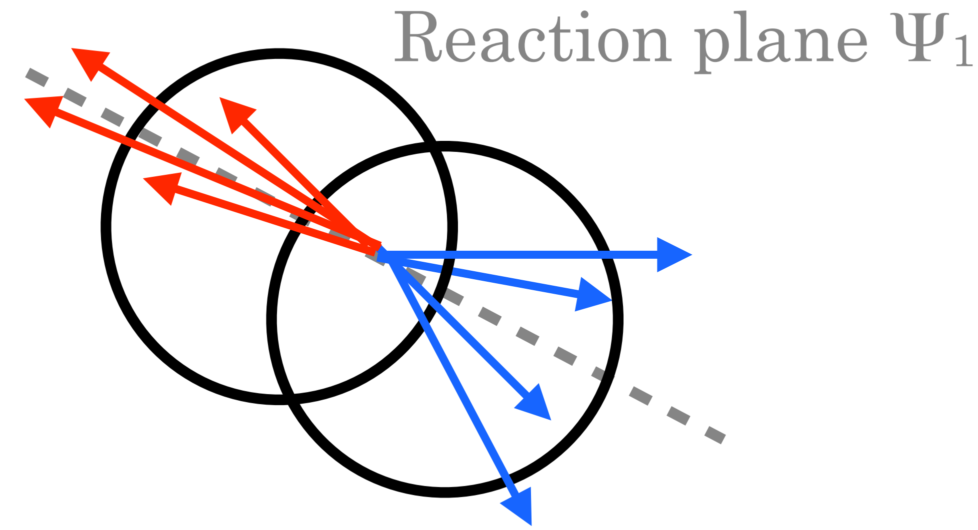


$$\mathbf{F} = q\,\mathbf{v} \times \mathbf{B}$$

Charge-dependent v_1

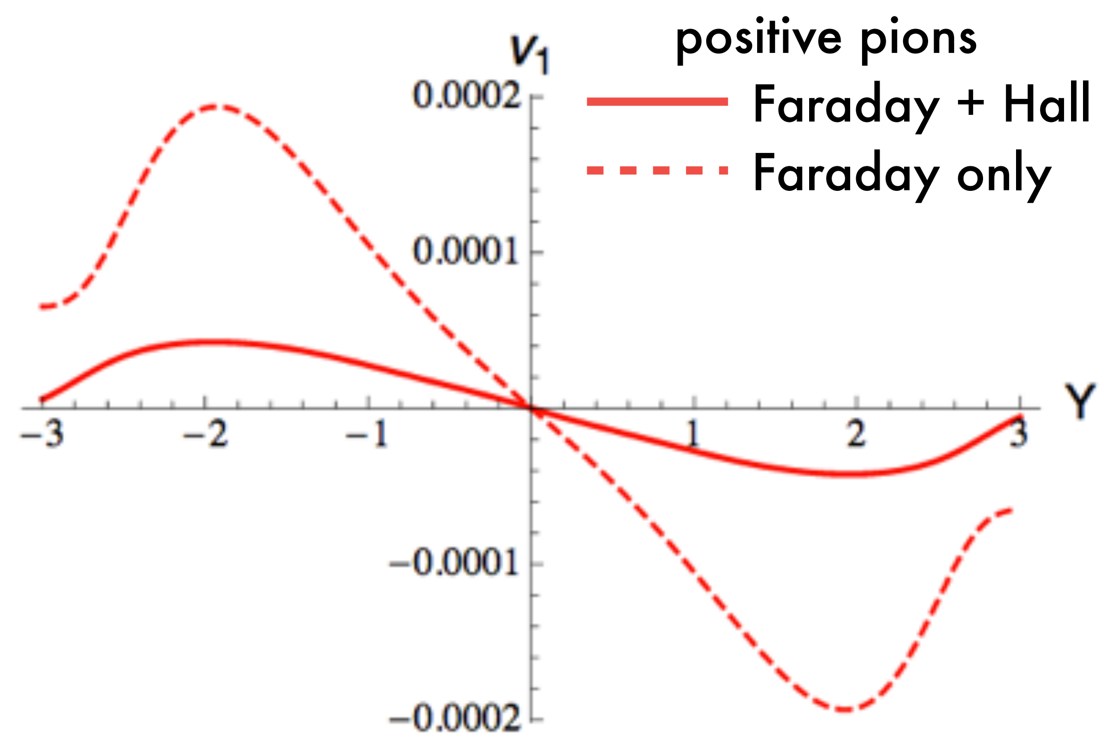
- v_1 measures the asymmetry of particles produced in the same and opposite direction of the collisions impact parameter

$$v_1^{\mathrm{odd}} = \frac{1}{2}(v_1^{(y>0)} - v_1^{(y<0)})$$



- Expected different v_1 for positive and negative particles vs rapidity

$$v_1(+,\eta) = -v_1(+,-\eta) = v_1(-,-\eta) = -v_1(-,\eta),$$



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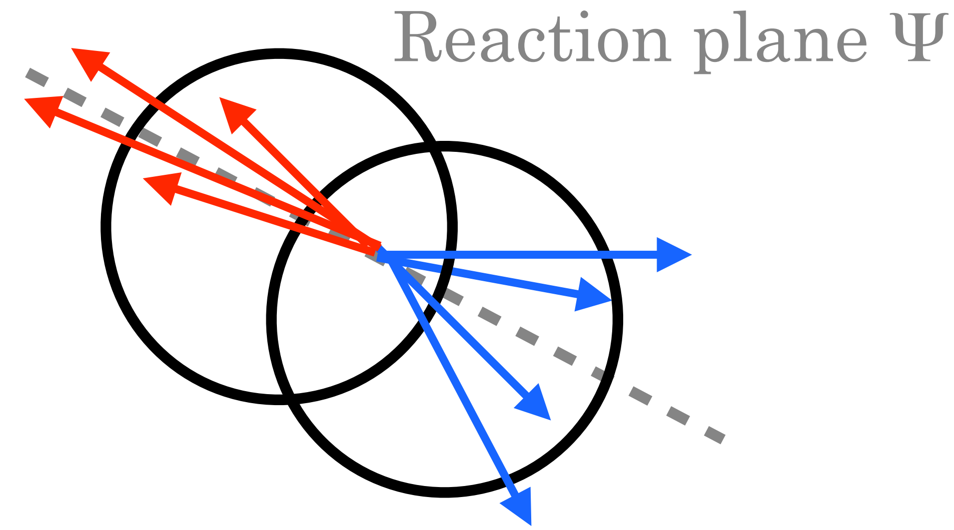

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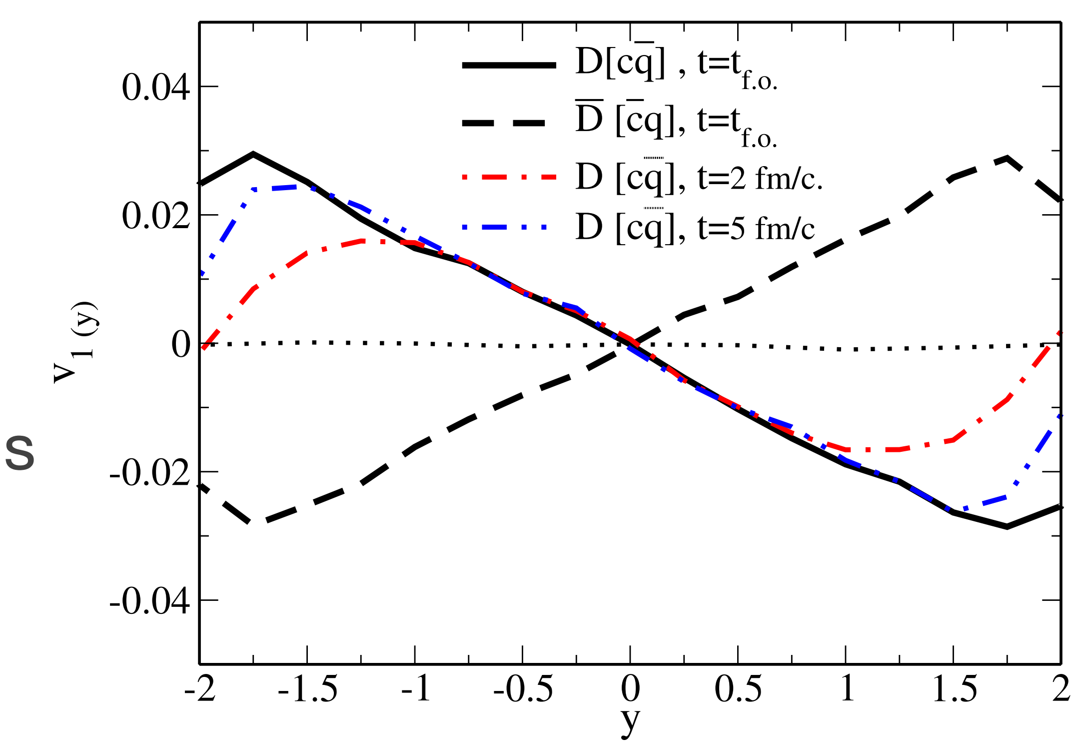
$$v_1(+,\eta) = -v_1(+,-\eta) = v_1(-,-\eta) = -v_1(-,\eta),$$

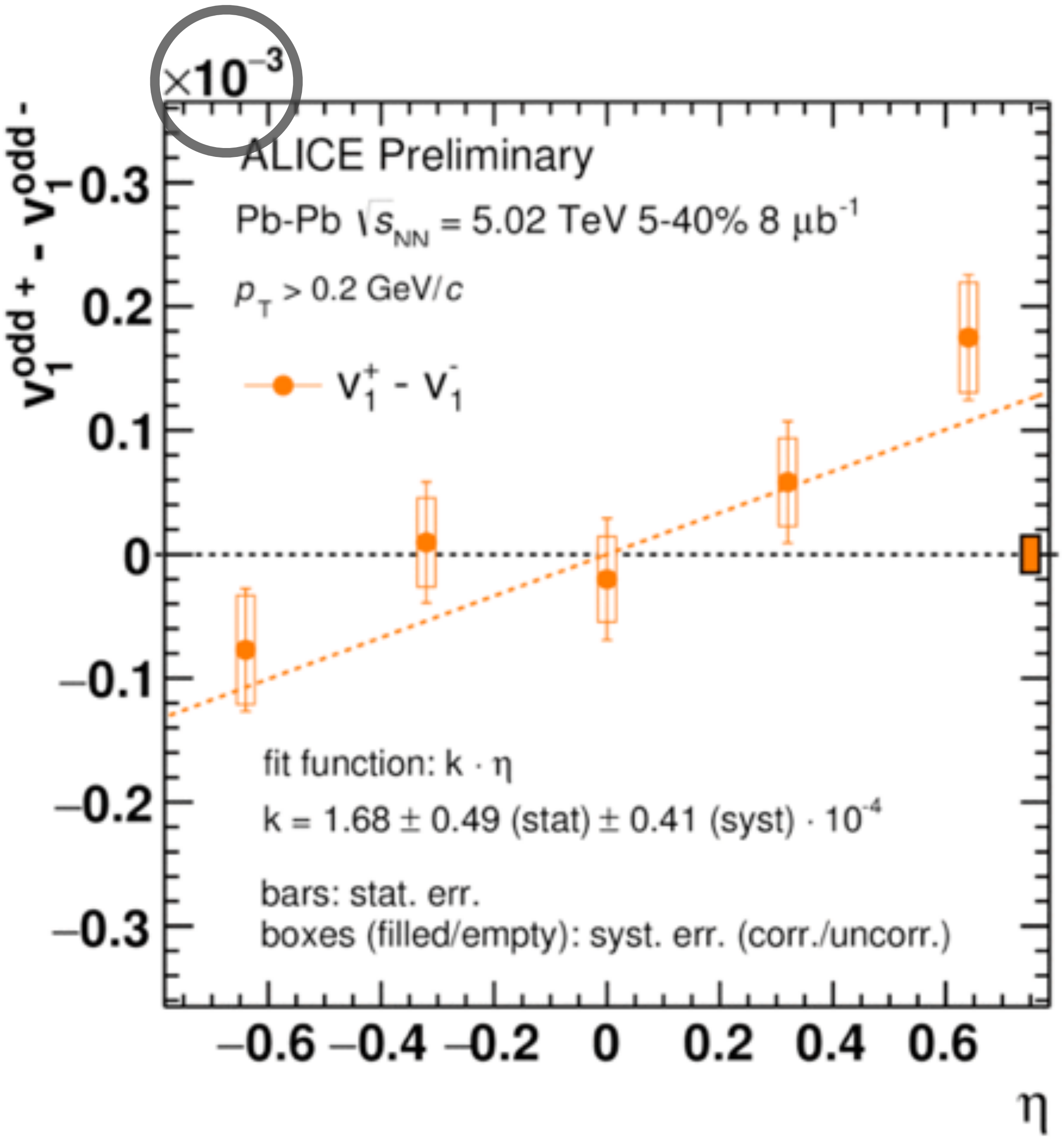
- Charm formation time is comparable to maximum B
  - Expected larger effect than light hadrons

K. Das et al, PLB 768 (2017) 260-264



$\Delta v_1^{odd} = v_1^{odd}(+) - v_1^{odd}(-)$

- **Hint (2.6σ) of non-zero slope** for $\Delta v_1^{odd} = v_1^{odd}(+) - v_1^{odd}(-)$



ALI-PREL-129689

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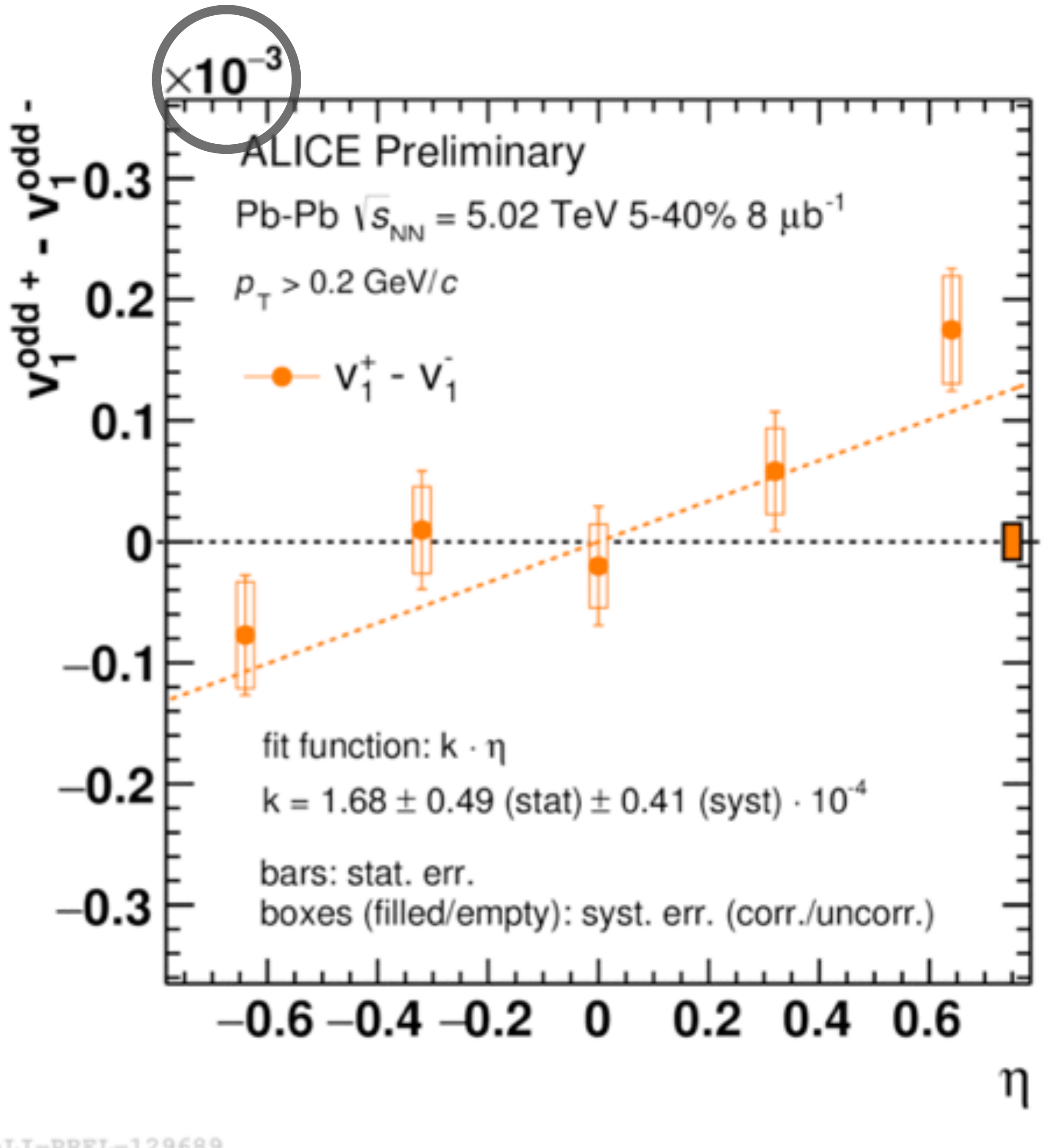

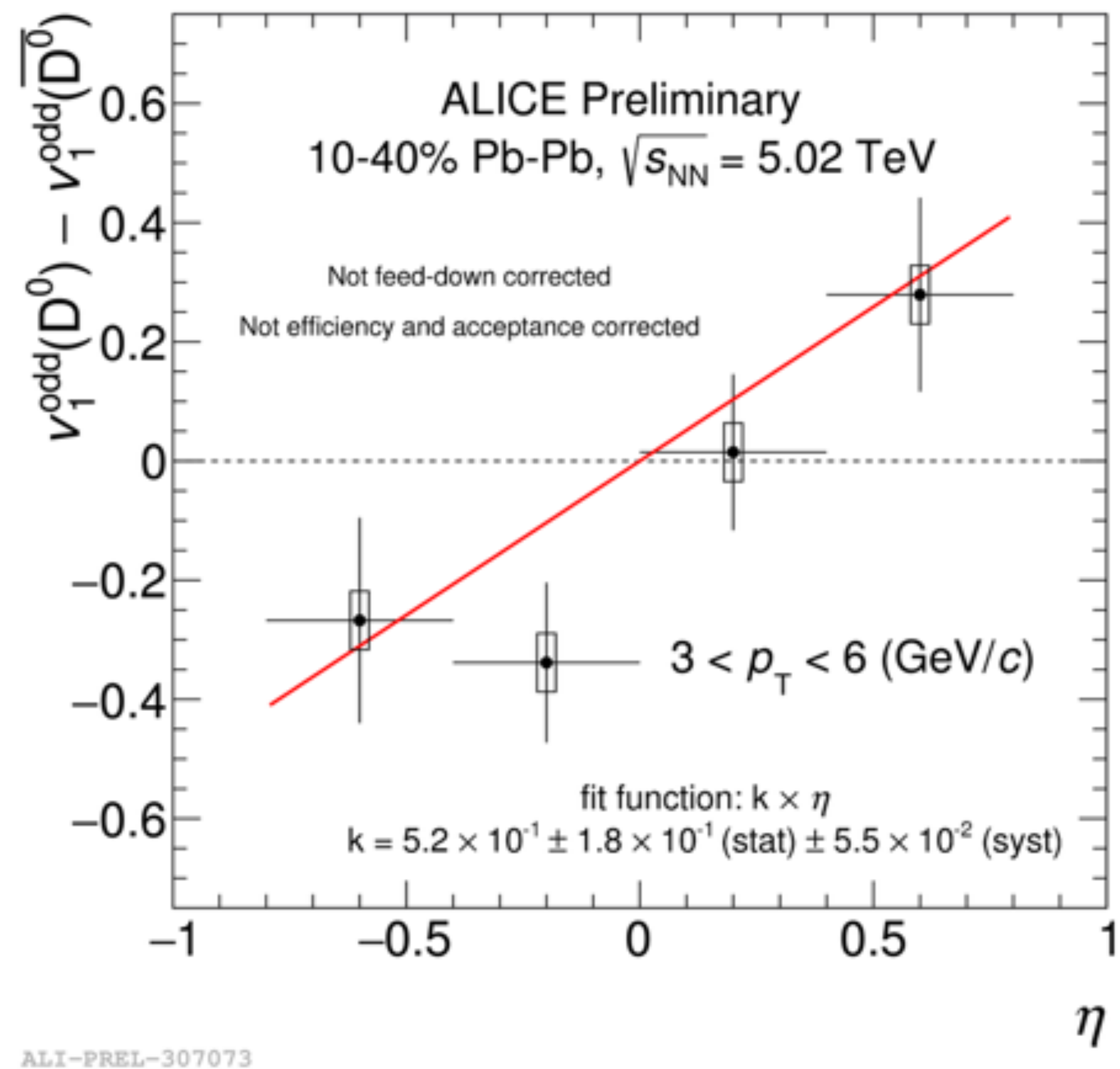

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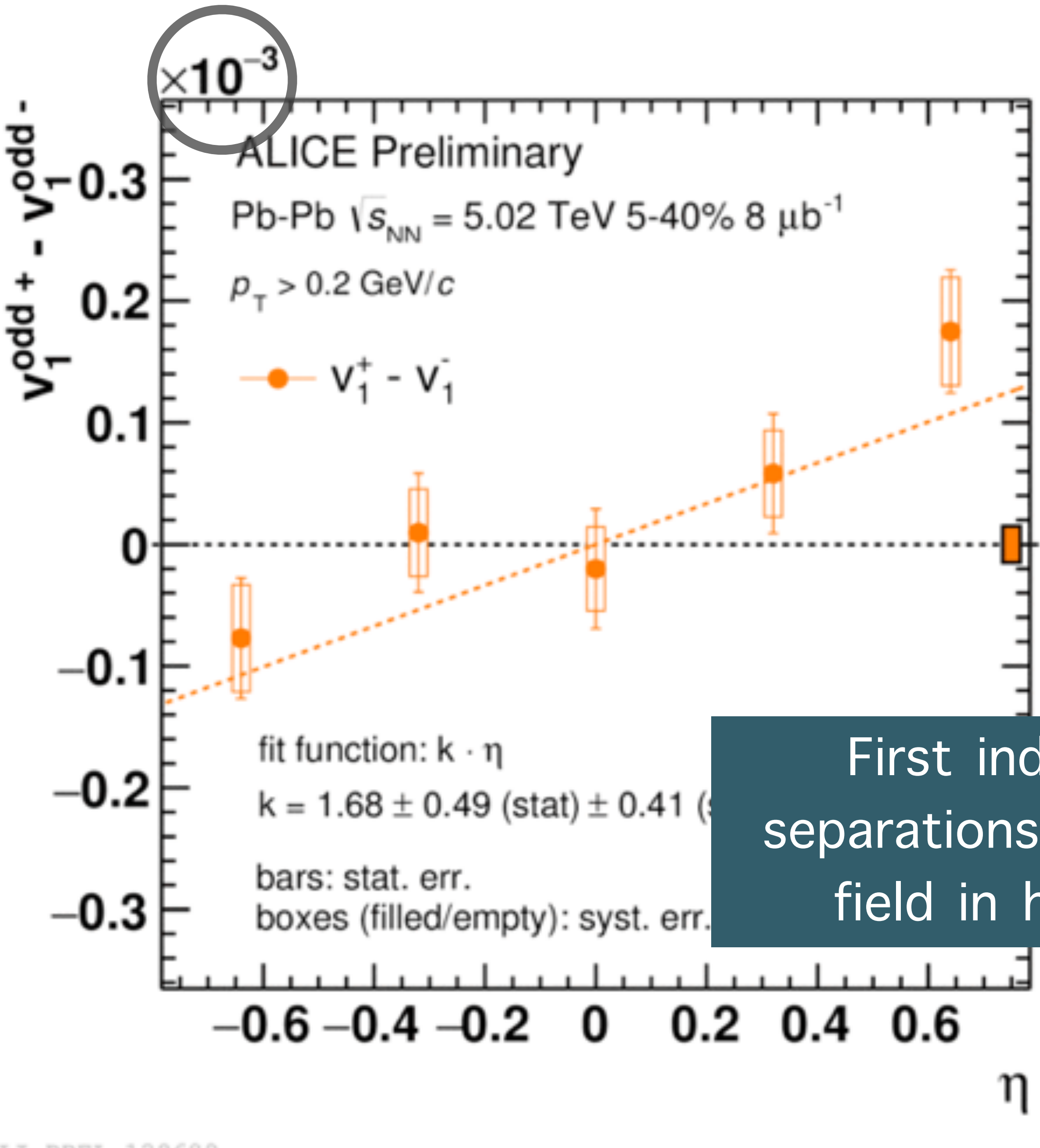
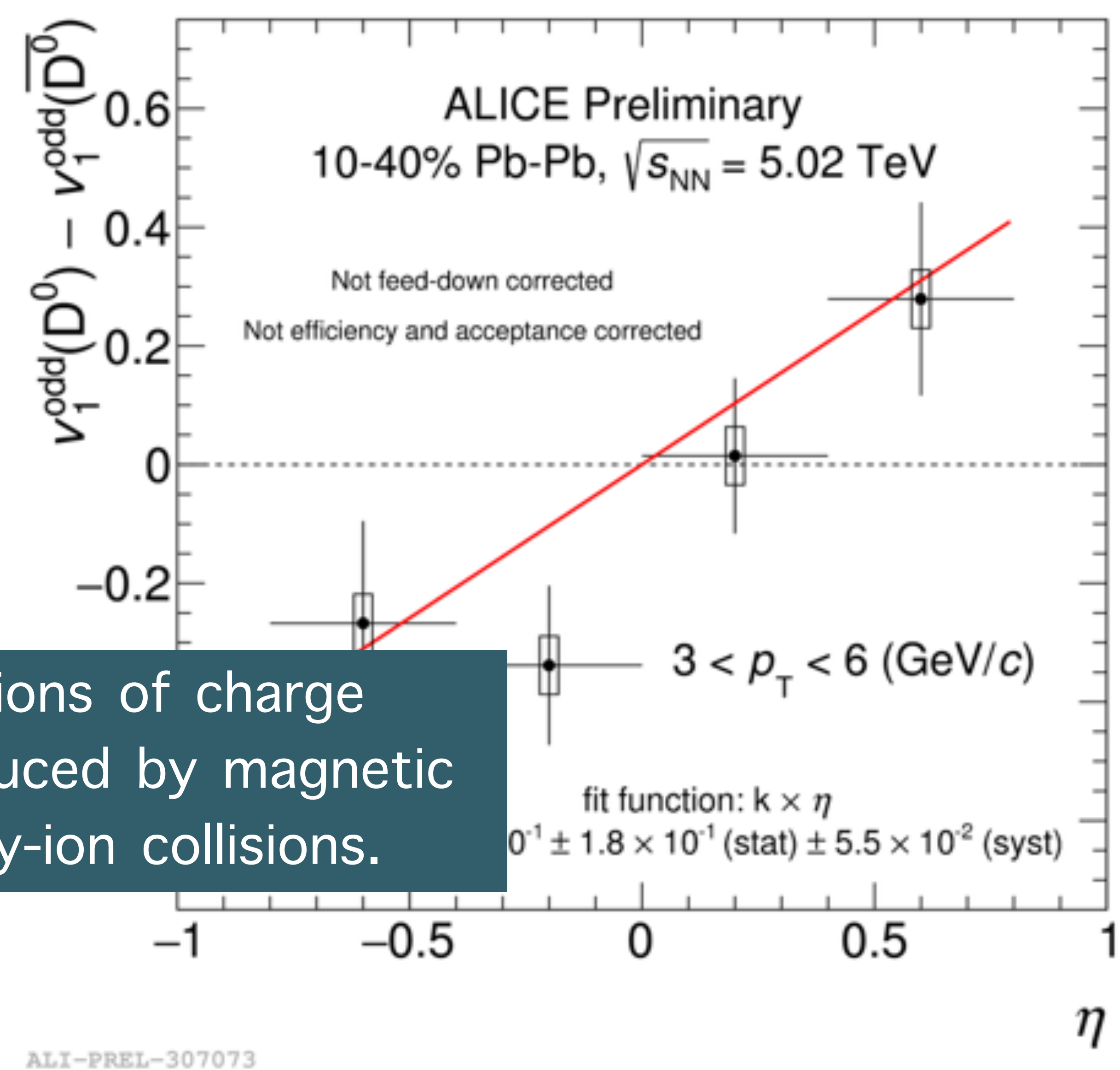




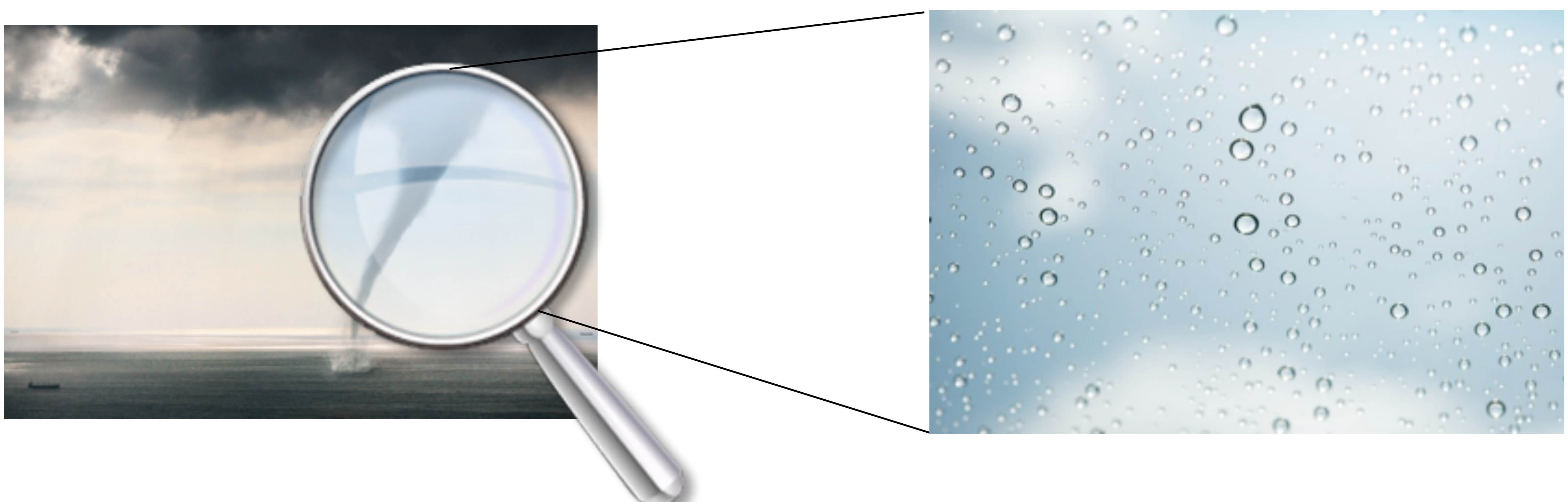
First indications of charge separations induced by magnetic field in heavy-ion collisions.

How to investigate the QGP at LHC?

(aka: the outline of my talk)

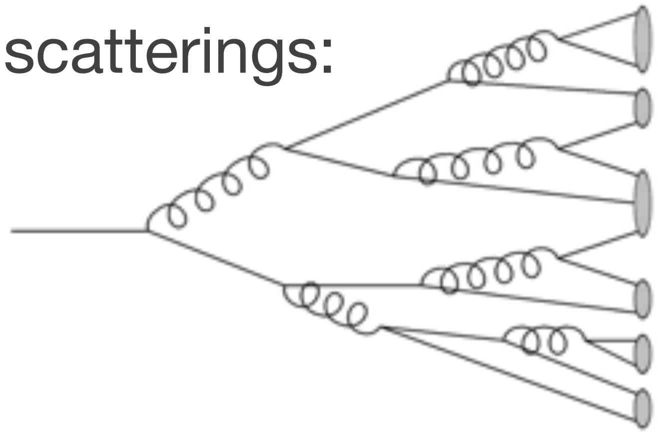
- Precise characterization of the macroscopic QGP properties
  - QGP "source" characterized by global quantities and collective behaviors
  - Temperature, viscosity, diffusion coefficients, …

- **How microscopic parton dynamics build the QGP properties**
  - Investigate effective constituents of QGP
  - Study how QCD processes are affected by the medium: QCD splitting, color coherence, hadron formation



Parton energy loss

- High-p_T and virtuality partons are produced in initial hard scatterings:
  - virtuality evolution through parton shower,
  - hadronisation at Λ_{QCD} scale.



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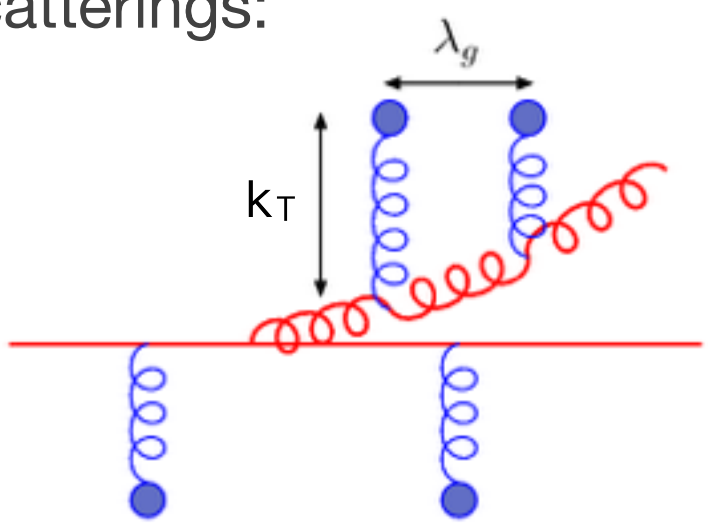
- Hard partons traverse the QGP and lose energy while passing through it: “Gluon bremsstrahlung effect”
  - Decoherence effect of gluon wave function due to multiple inelastic scatterings



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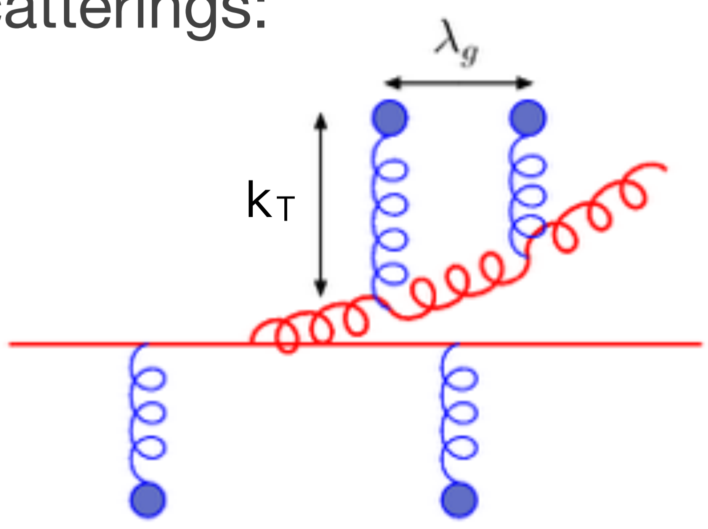

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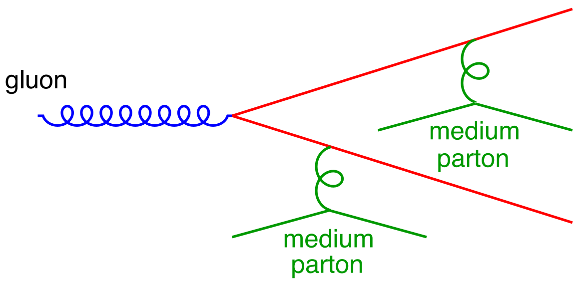
Nuclear modification factor

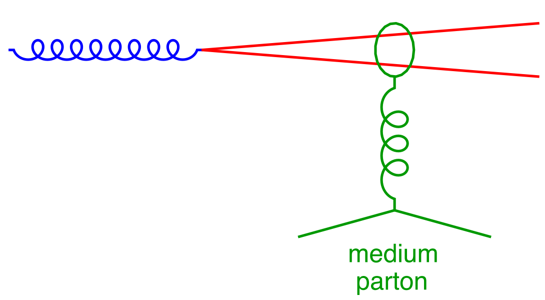
$$R_{AA}(p_T) = \frac{1}{< N_{coll} >} \times \frac{d^2N_{AA}/dp_T d\eta}{d^2N_{pp}/dp_T d\eta}$$

- Energy radiated related to QCD effects and medium properties:
  - **Casimir factor**
  - **Mass** of the high-pT parton (charm and beauty quarks loose less energy?)
  - **Medium characteristics** (density of scattering centers, interaction strength)
  - **Colour coherence effects**?

incoherent



coherent



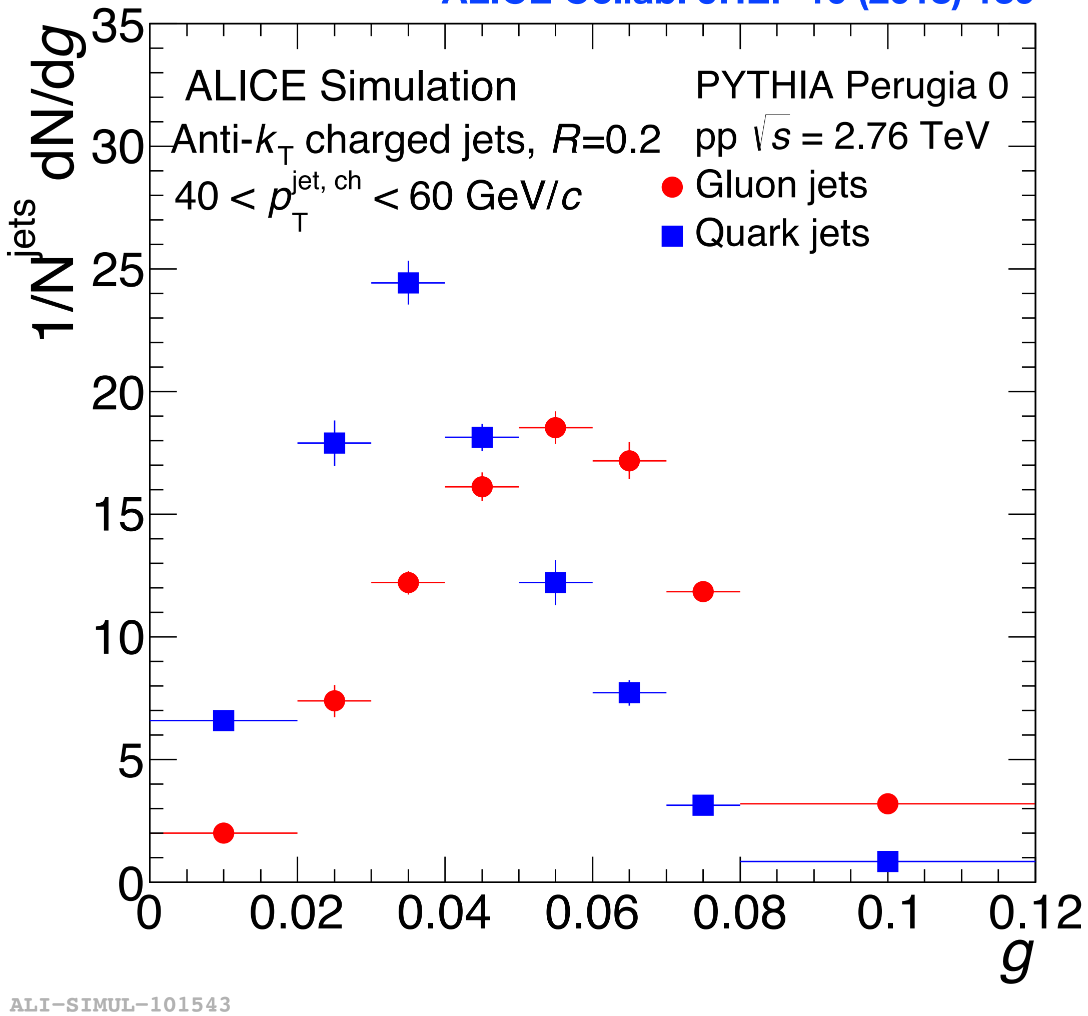
Jet shapes measurements

- Jet shapes are observables built combining different information coming from the properties of the jet
- Shape built as a jet-by-jet function of the jet constituents 4-momenta

- **Radial moment (*g*)**:
  - Measures the momentum re-distribution of jet constituents weighted by their distance from the jet axis

$$g = \sum_{i \in \mathrm{jet}} \frac{p_{\mathrm{T}}^{i}}{p_{\mathrm{T}}^{\mathrm{jet}}} |r_i|$$

ALICE Collab. JHEP 10 (2018) 139



J. Gallicchio, M.D. Schwartz, PRL 107 (2011) 172001

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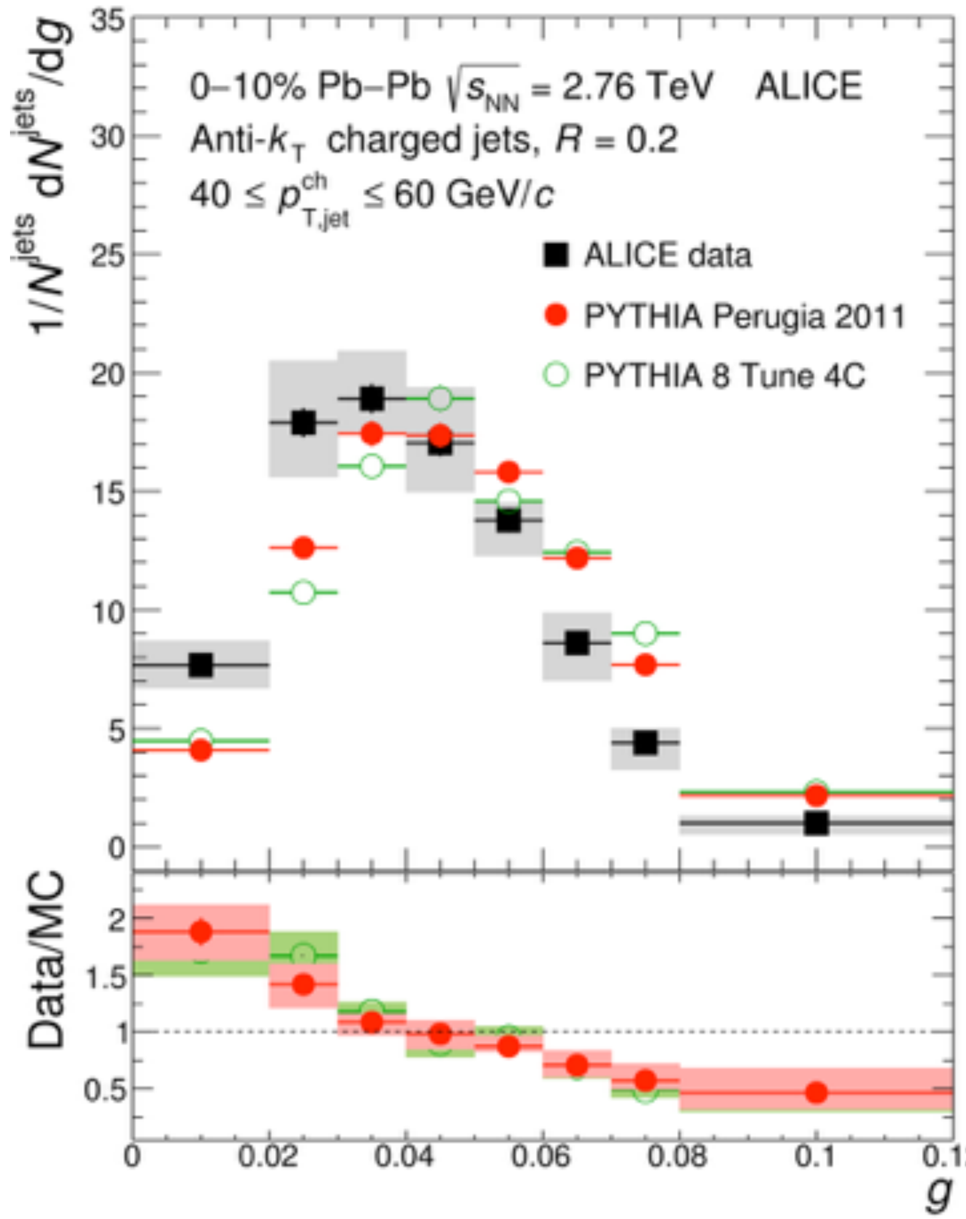
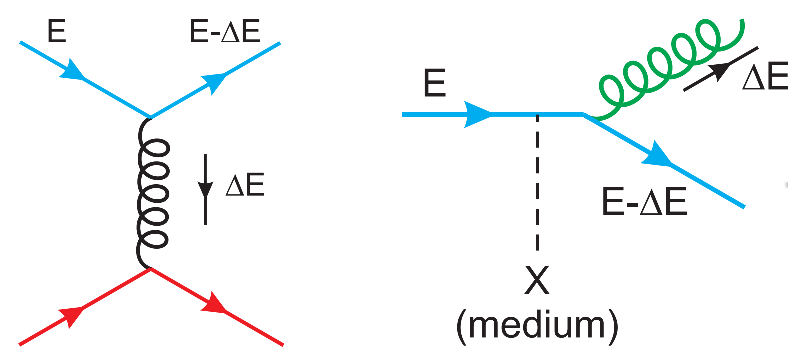


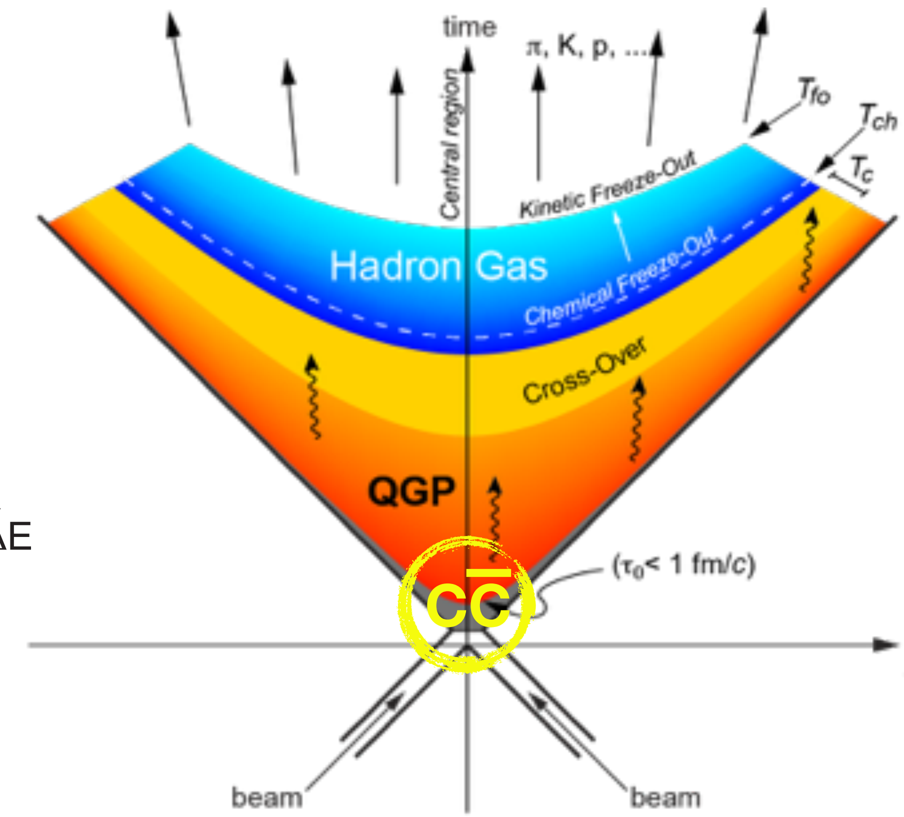
Jet shapes favour more collimated and harder fragmentation in Pb-Pb than pp collisions.

J. Gallicchio, M.D. Schwartz, PRL 107 (2011) 172001

Heavy-flavour in Pb-Pb collisions

- **Heavy-flavor quarks** (charm and beauty)
  - mainly produced in **hard scattering**,
  - can probe the **entire evolution of the QGP**,
    $t_{\mathrm{prod}} \sim \hbar/4m_{c(b)} \sim 0.05\ (0.01)\ \mathrm{fm}/c$ vs $t_{\mathrm{QGP}} \sim 0.1\text{-}1\ \mathrm{fm}/c$
  - interact with medium constituents via
    - elastic scatterings,
    - gluon radiations





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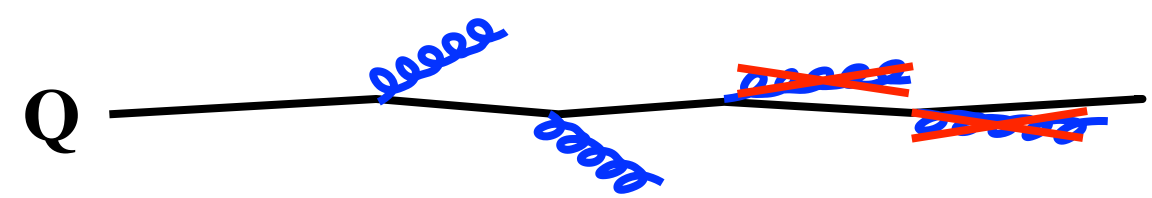


Gluonsstrahlung probability

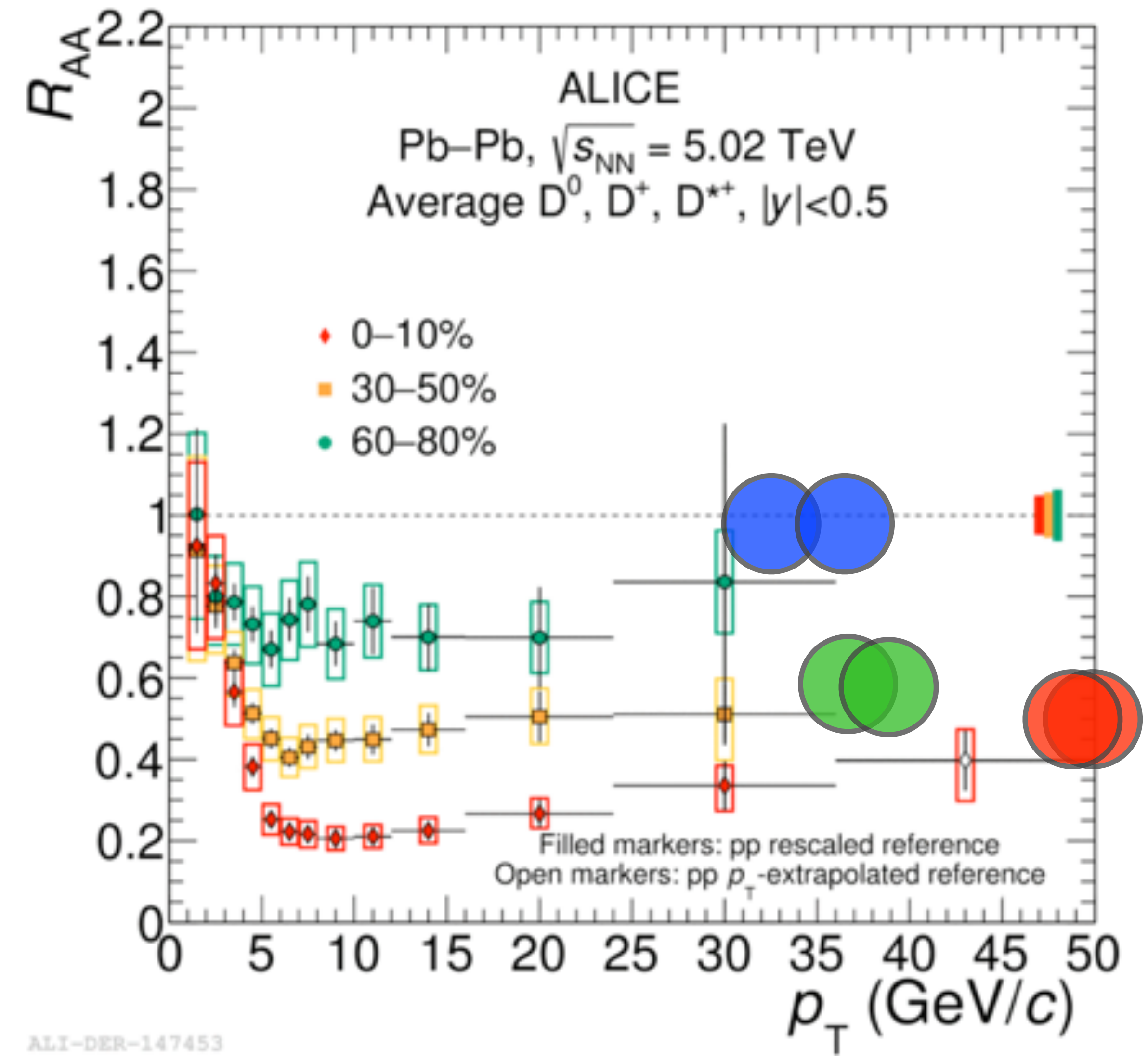
$$\propto \frac{1}{[\theta^2 + (m_Q / E_Q)^2]^2}$$

Dokshitzer, Khoze, Troyan, JPG 17 (1991) 1602.
Dokshitzer and Kharzeev, PLB 519 (2001) 199.

Heavy-flavour hadrons

- High precision measurements obtained with 2015 Pb-Pb data.
- Strong suppression observed for D mesons in central collisions

ALICE Collab. arXiv:1804.09083 submitted to JHEP



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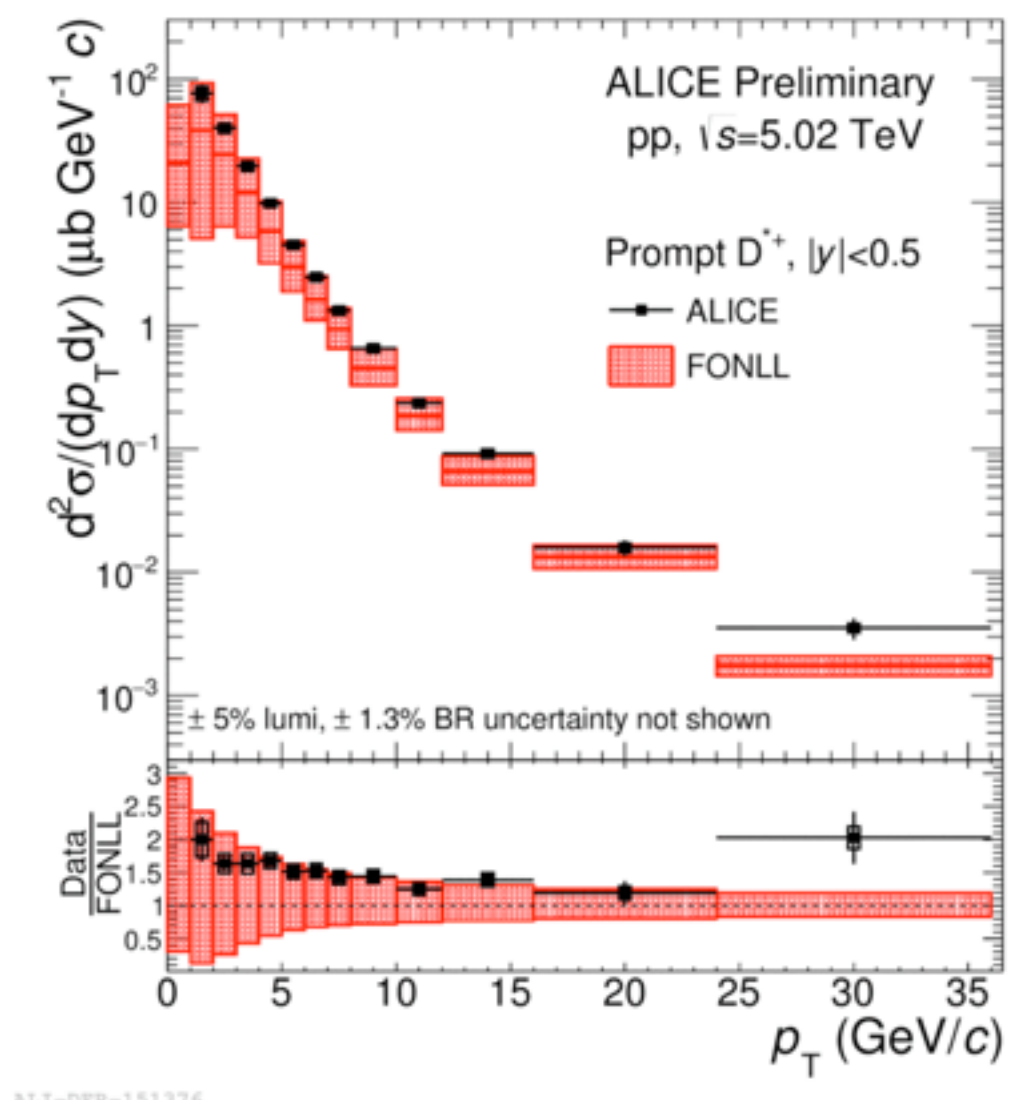

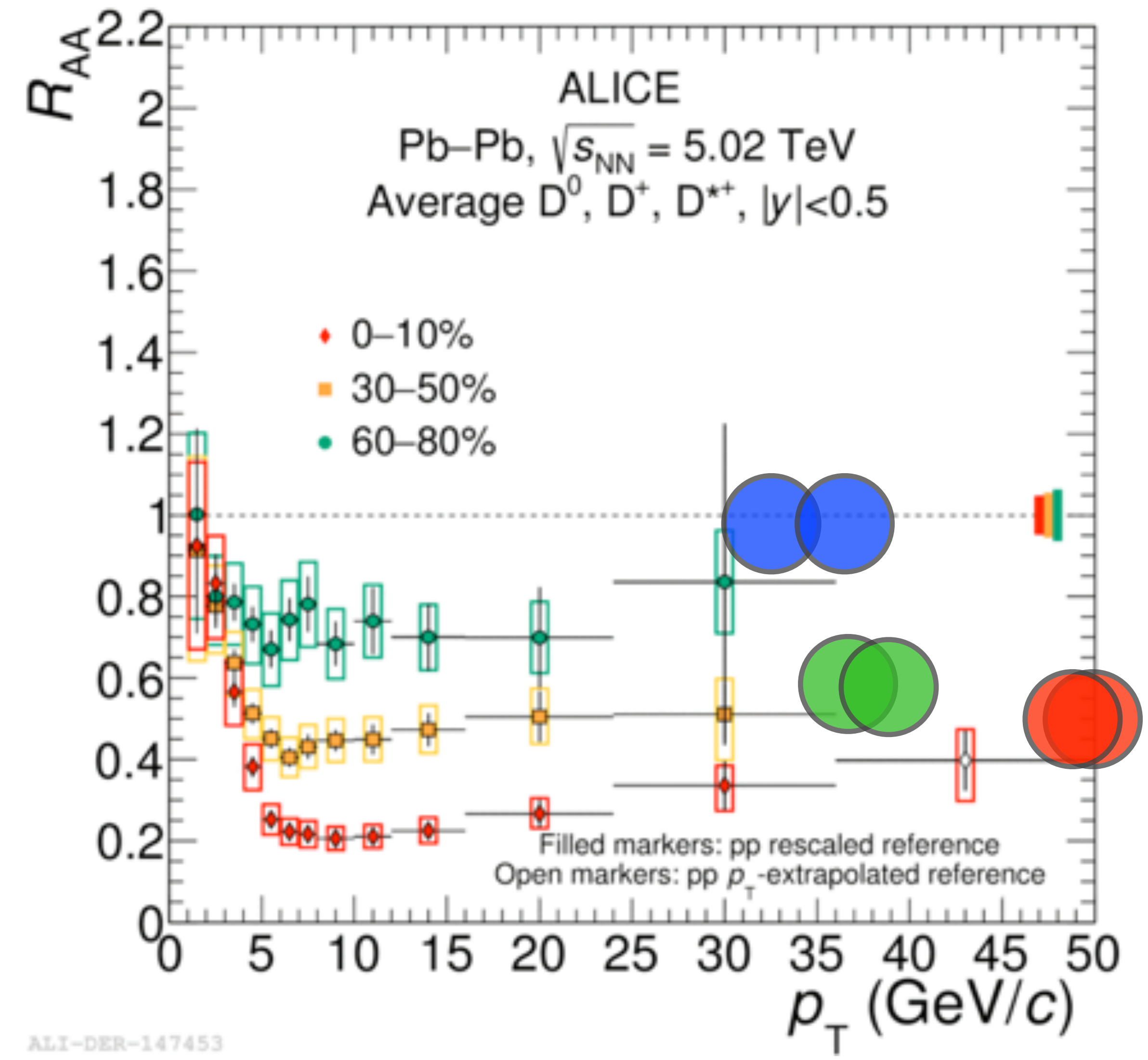

- New more precise results will be achieved with 2018 Pb-Pb data and new **pp reference measured** with special pp run in 2017 at the same energy

Heavy-flavour jets

- **Complementary to heavy-flavour hadron** measurements to investigate:
  - Flavour dependence of jet quenching / splitting effects.
  - Modification of heavy-quark fragmentation
  - Heavy-flavour jet properties

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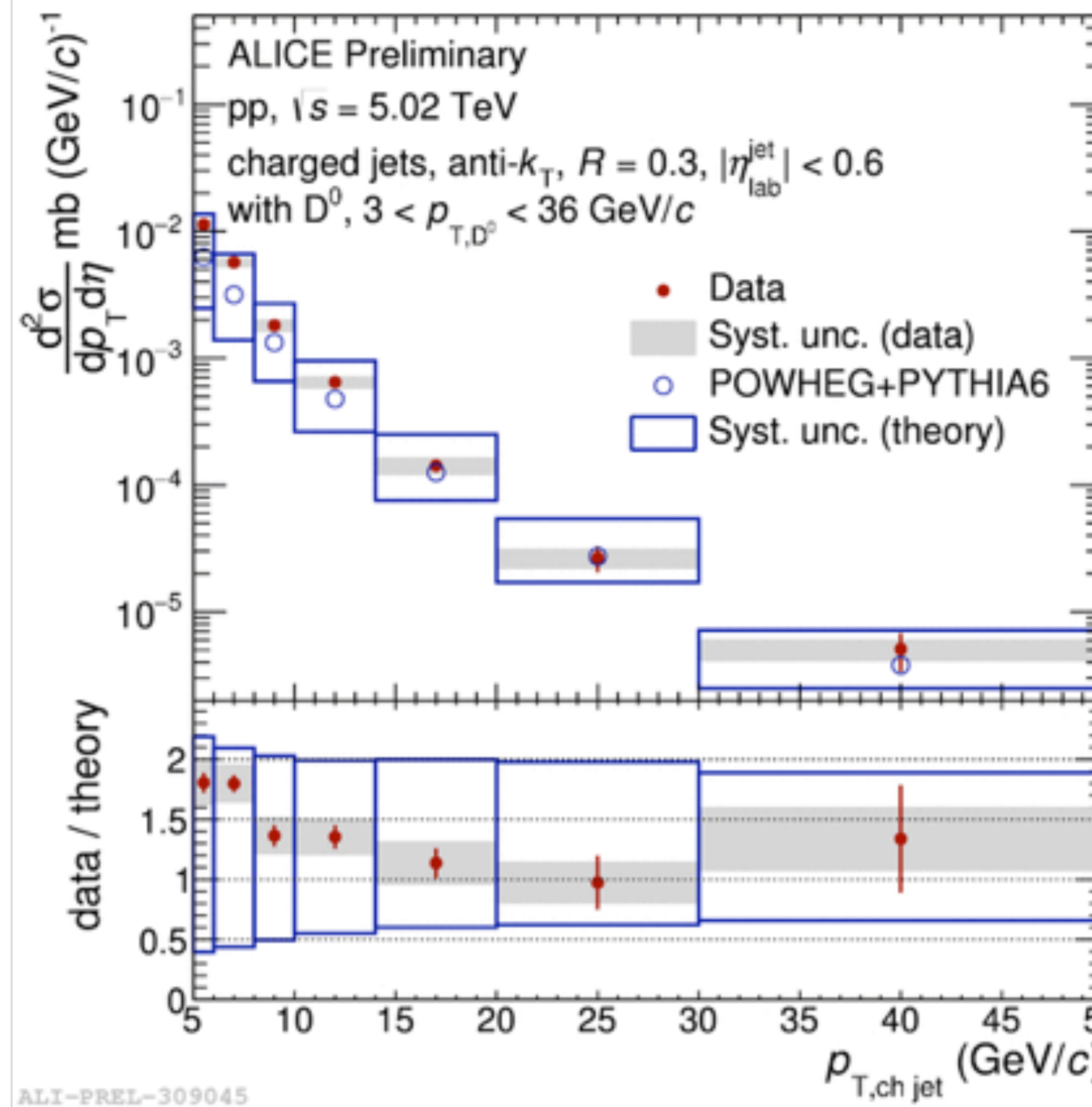
  - charged jets with D meson (p_T > 3 GeV/c) as one of the constituents
  - Charged jets, anti-kT with R=0.3, 0.4 with **p_T > 5 GeV/c.**

- **Cross section** and **jet momentum fraction** in agreement with NLO pQCD **POWHEG + PYTHIA6 calculations** for both pp and p-Pb collisions



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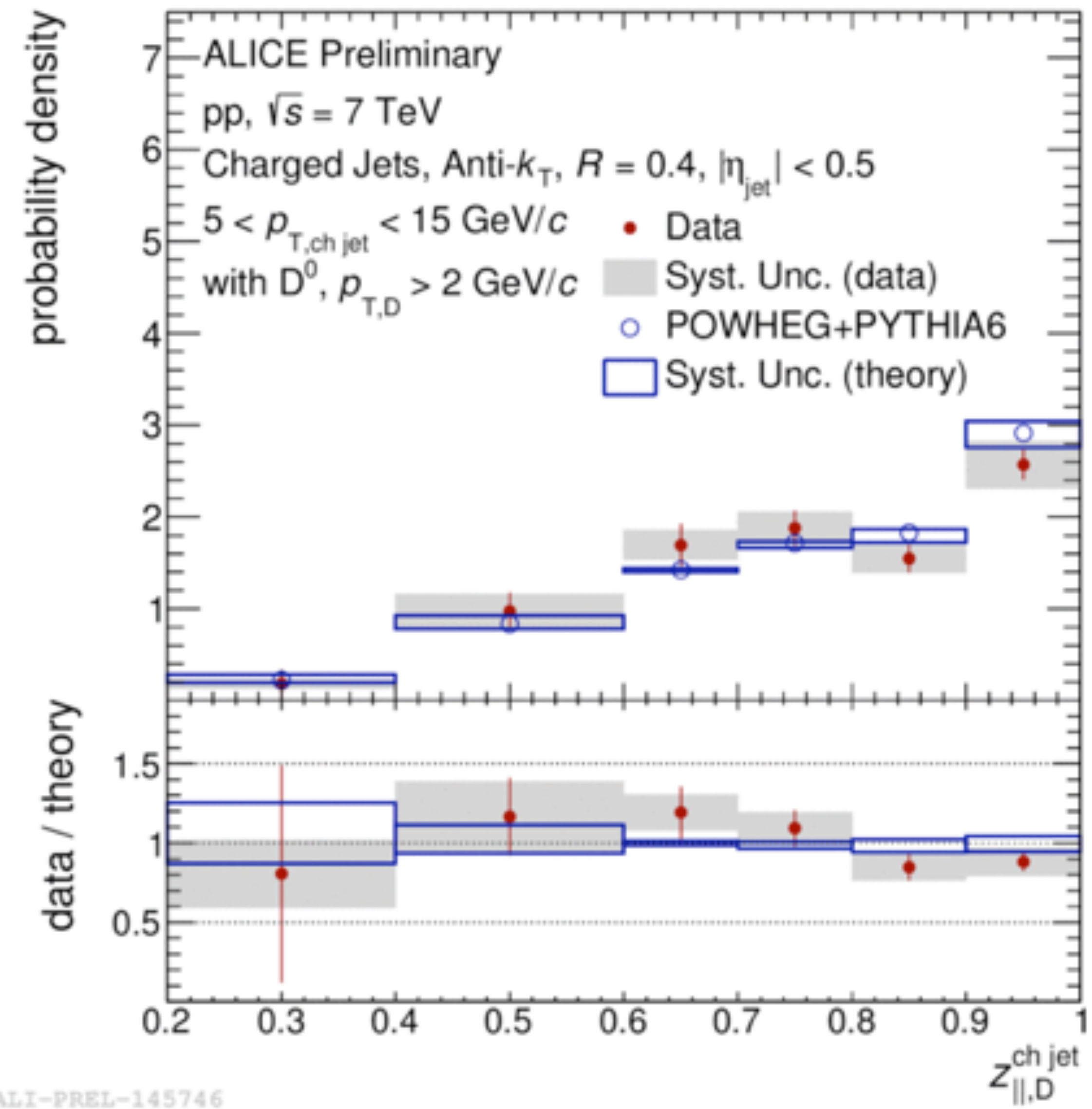


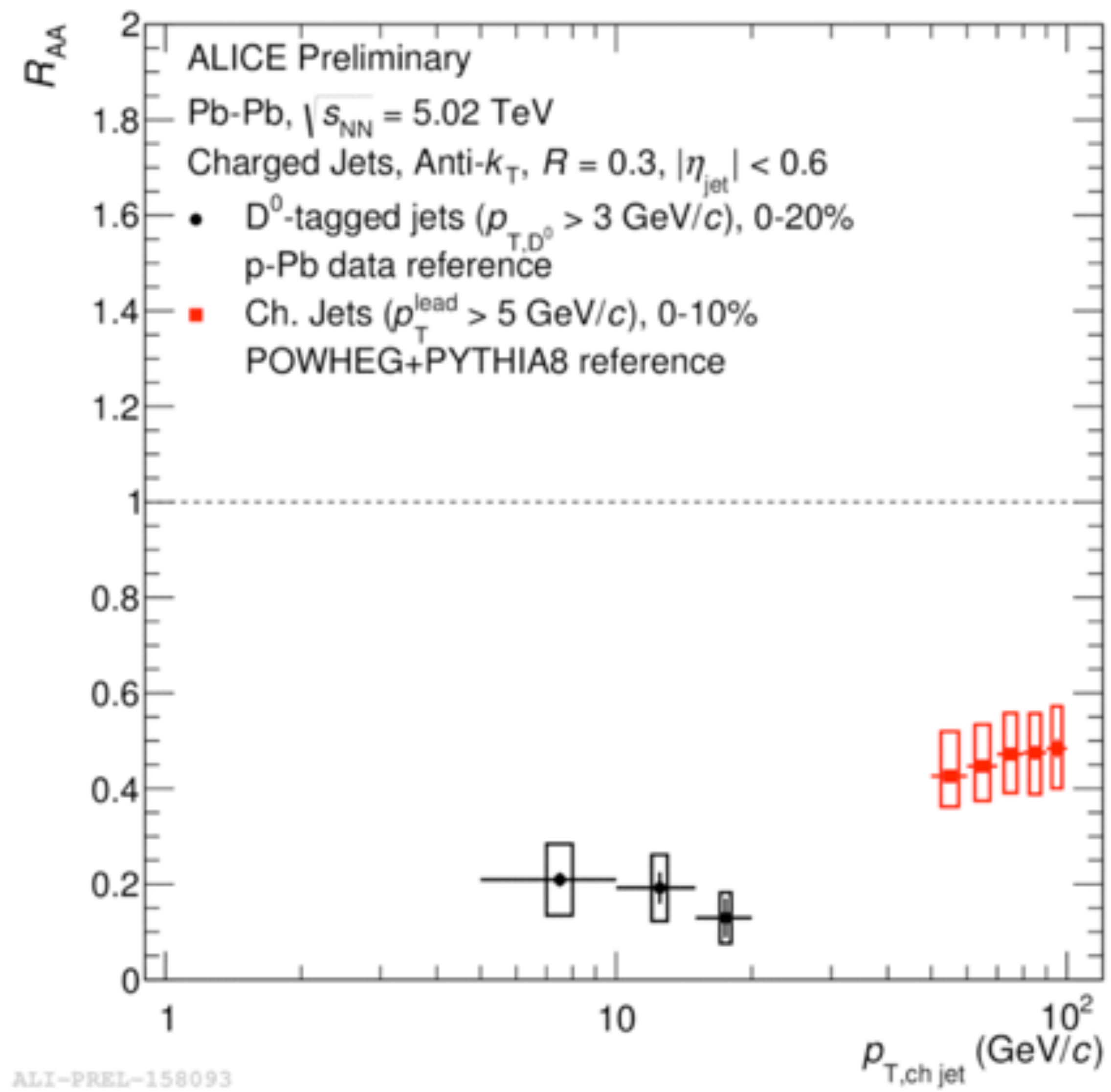
$$z_{||} = \frac{\vec{p}_{jet} \cdot \vec{p}_D}{\vec{p}_{jet} \cdot \vec{p}_{jet}}$$

Heavy-flavour jets in Pb-Pb collisions

- **Strong suppression observed for D^0 tagged jets in central Pb-Pb collisions**

$$R_{AA}(p_T) = \frac{1}{< N_{coll} >} \times \frac{d^2 N_{AA}/dp_T d\eta}{d^2 N_{pp}/dp_T d\eta}$$

- **Lowest p_T measurement for jet physics in Pb-Pb collisions achieved so far**
- Stronger suppression than **inclusive jets?**



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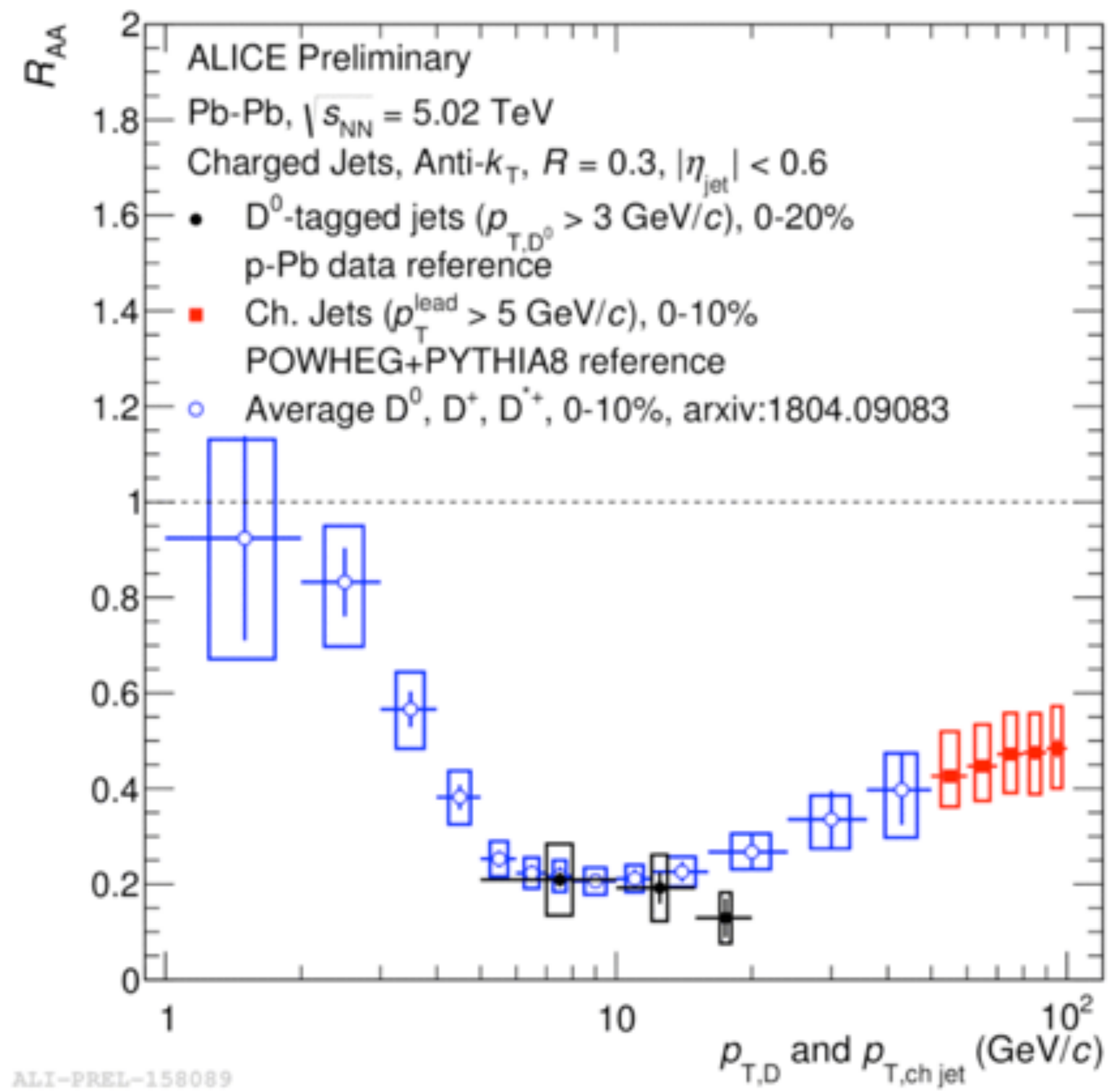

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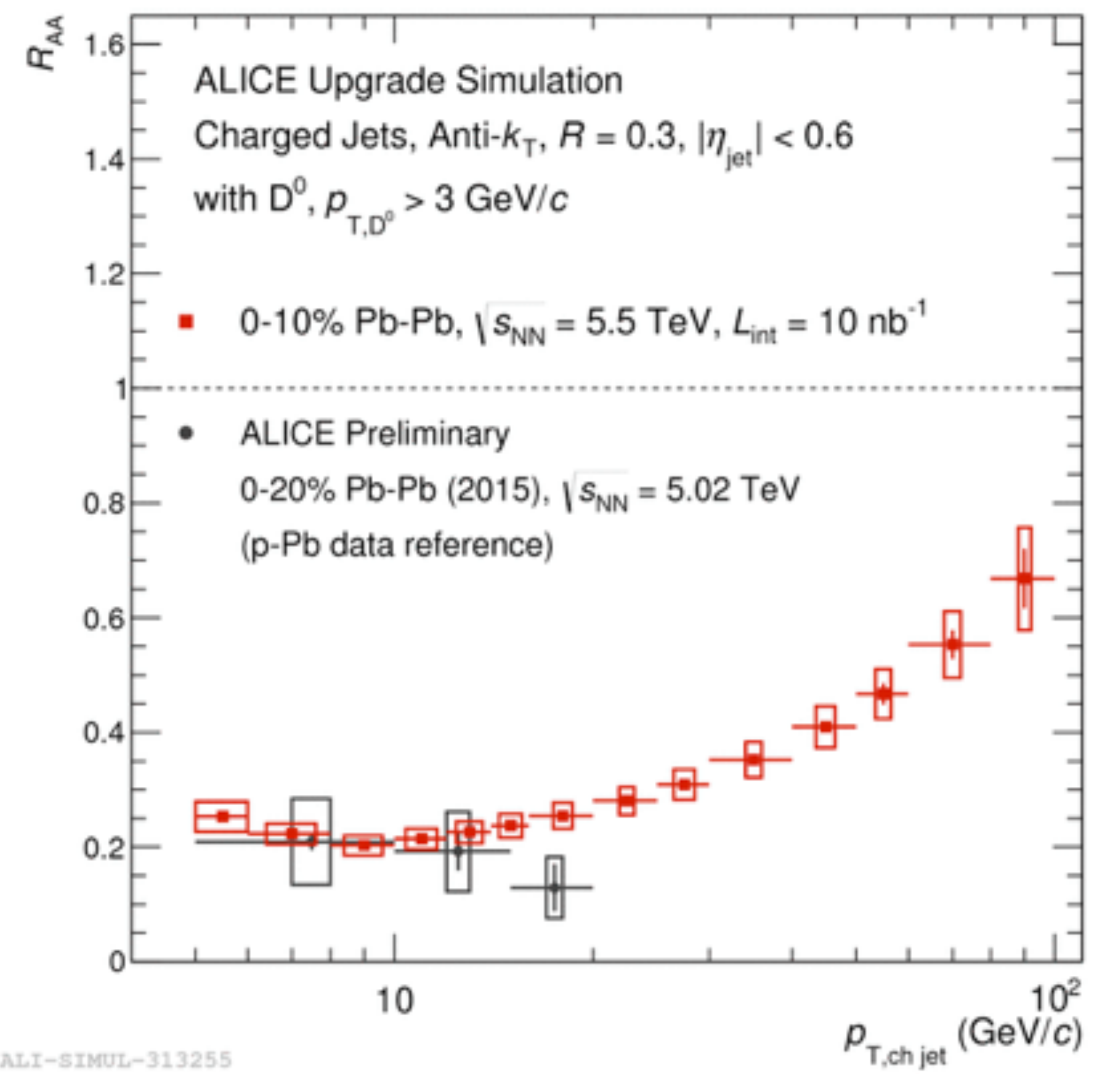
- Lowest p_T measurement for jet physics in Pb-Pb collisions achieved so far
- Stronger suppression than **inclusive jets?**
- Similar suppression observed for **D mesons**
- First promising measurement that will be repeated with Pb-Pb 2018 data and Run3 and 4 data.

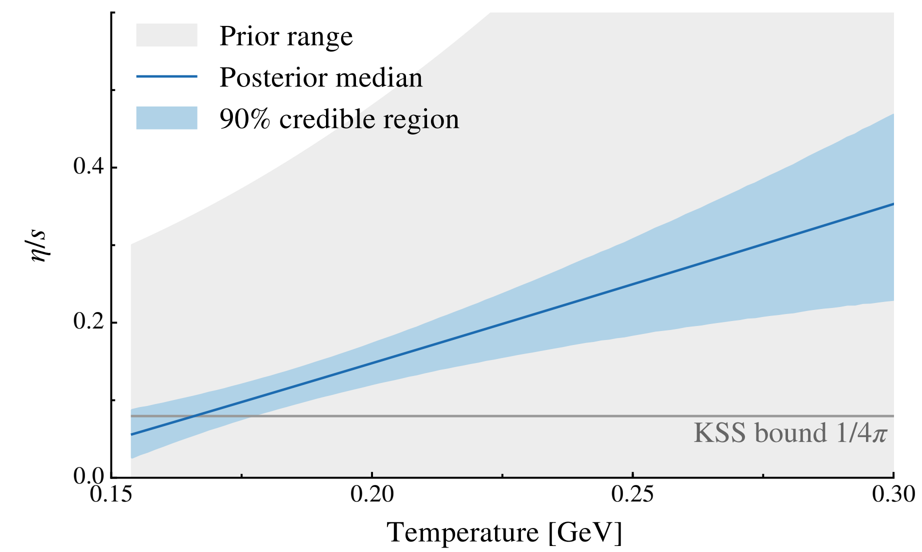
Projections for yellow report
High density QCD at LHC WG5



More complex and differential measurements in order to investigate microscopic properties of QGP

Conclusions

- High precision data starts to constraint global QGP properties



Conclusions

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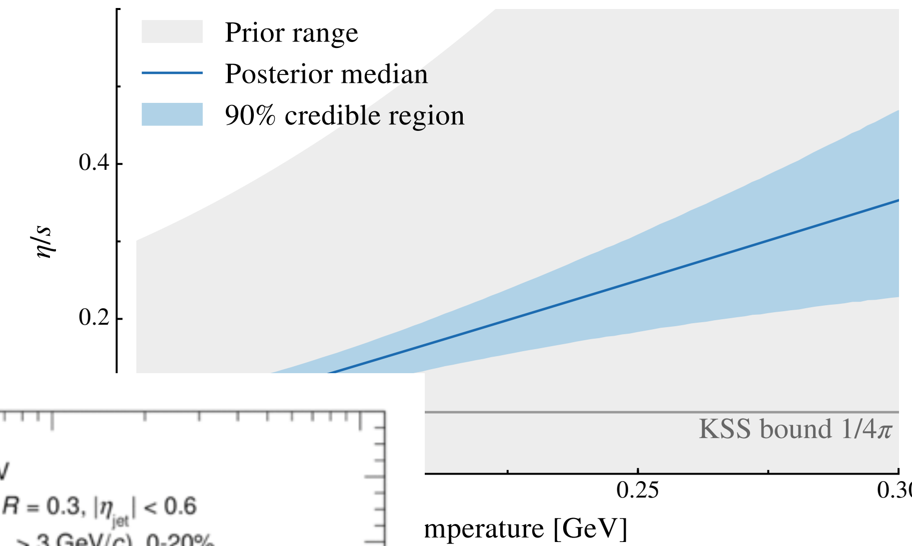
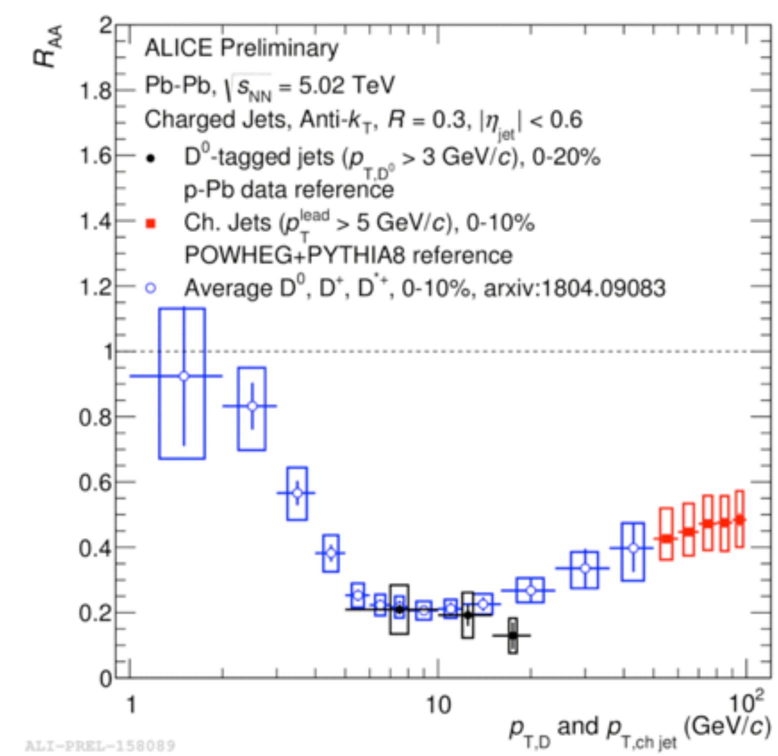
- New and more differential observables are being used to understand the microscopic dynamics of the QGP





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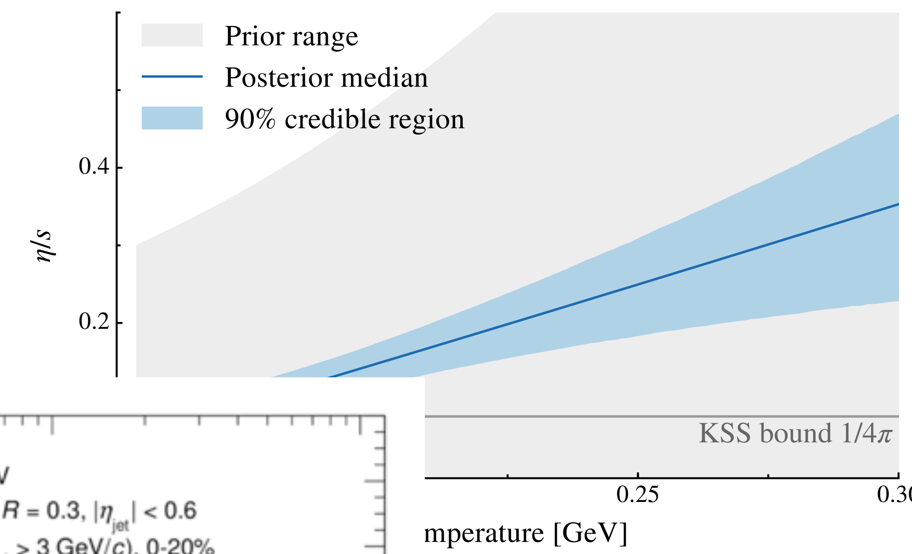
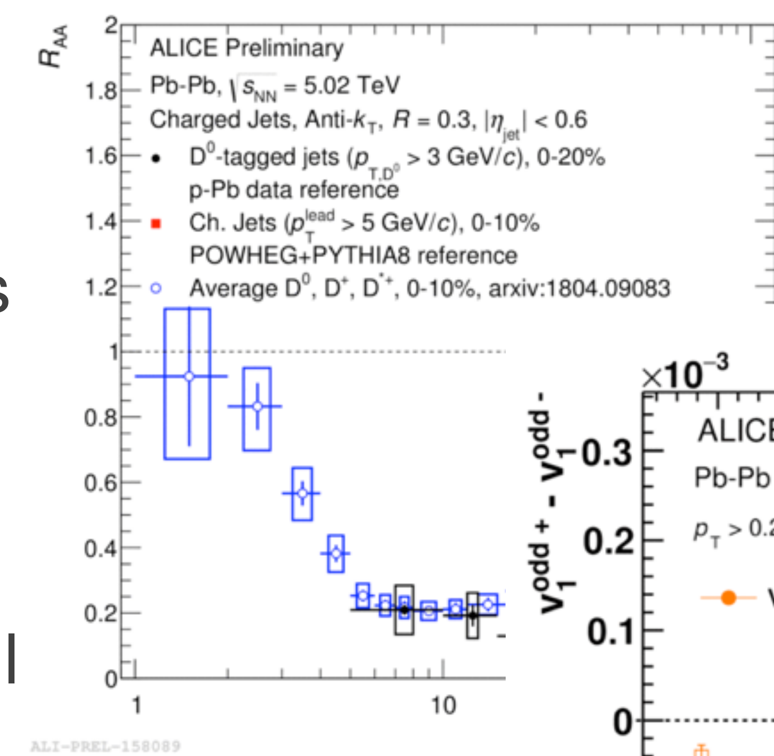
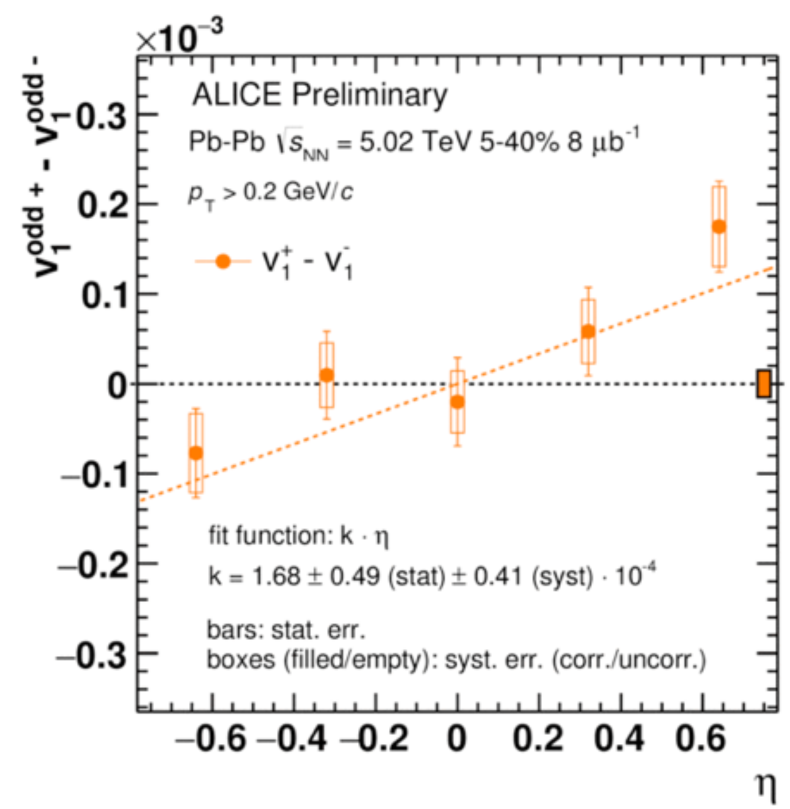
- Investigations of novel QCD effects not only related to heavy-ions physics are ongoing

- Full Run2 high statistic samples will allow new and more precise measurements

- Run3 and Run4 will bring x100 larger statistics than Run2 and upgraded detector.







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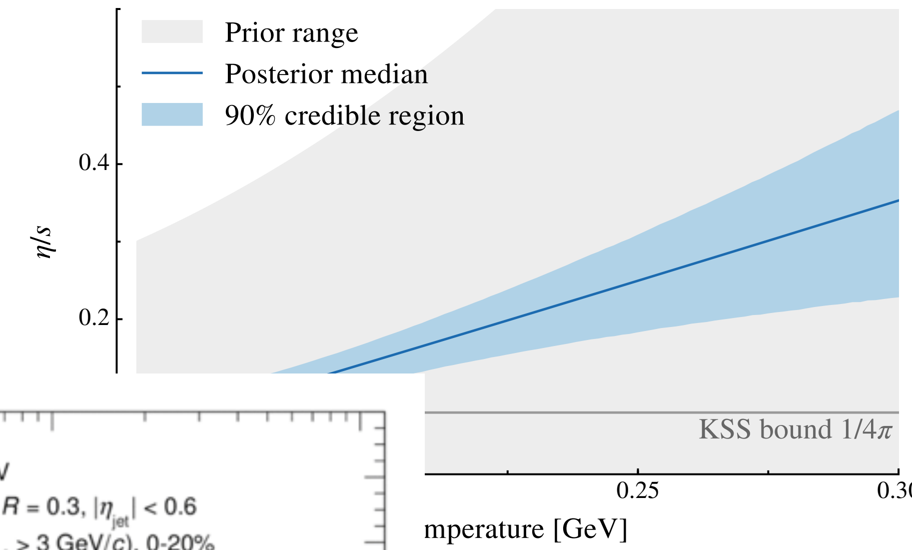
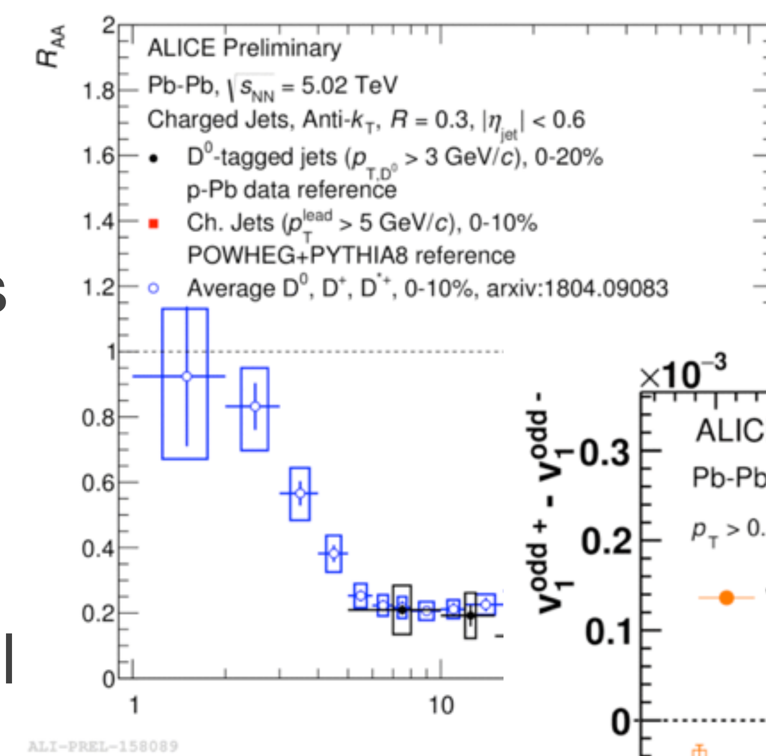
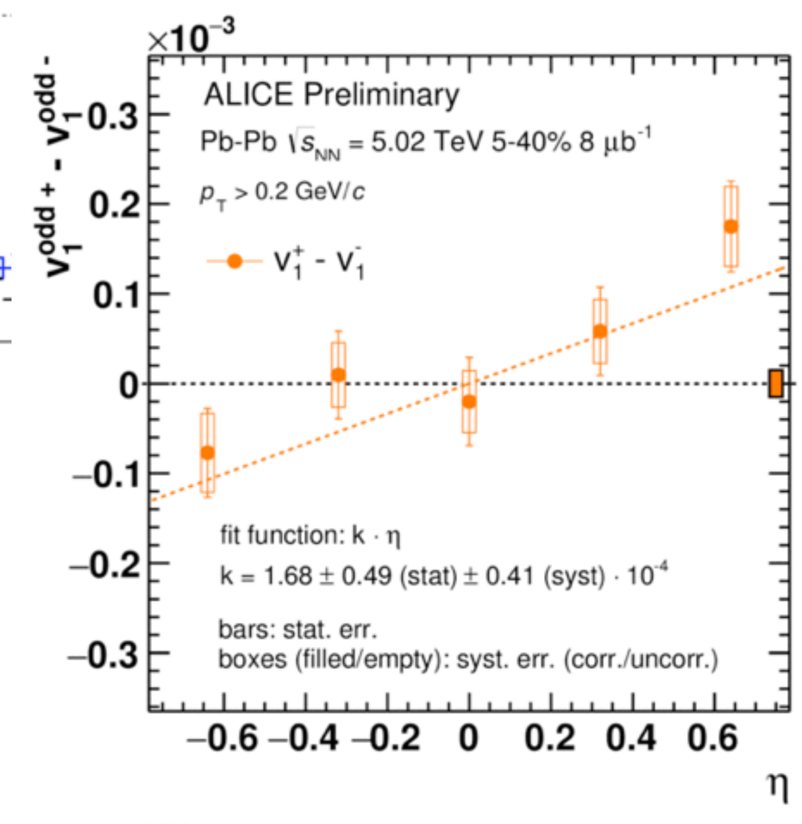


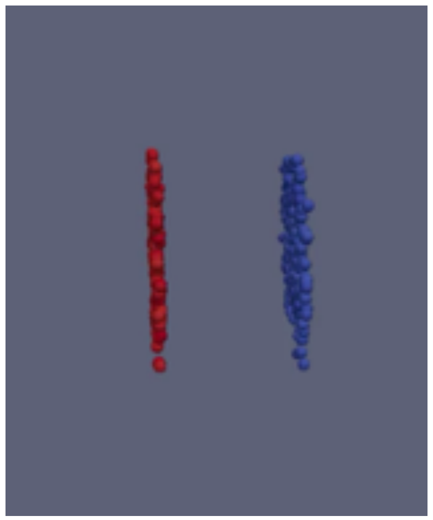




Back up slides

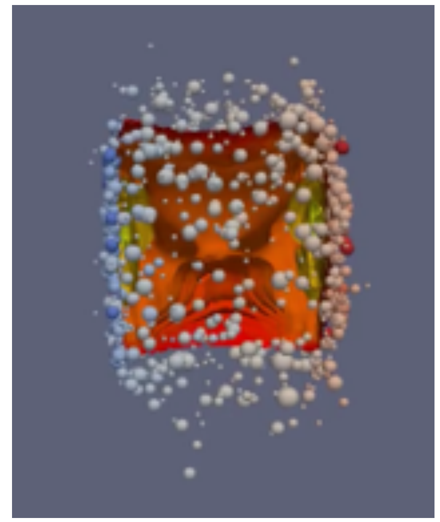
Heavy-ion collisions evolution

Heavy ions
τ ~ 0

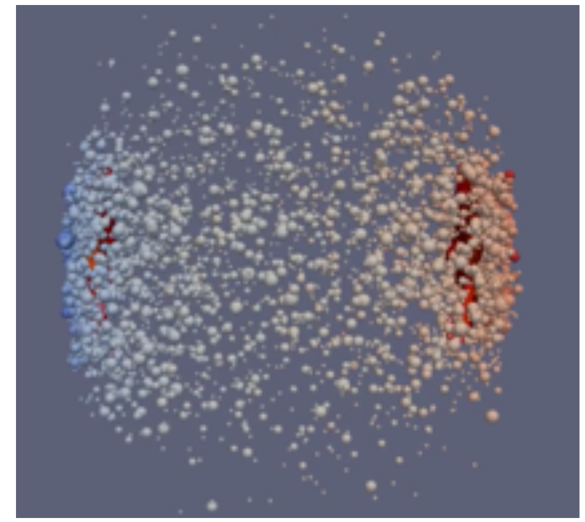


QGP
τ ~ 1 fm/c

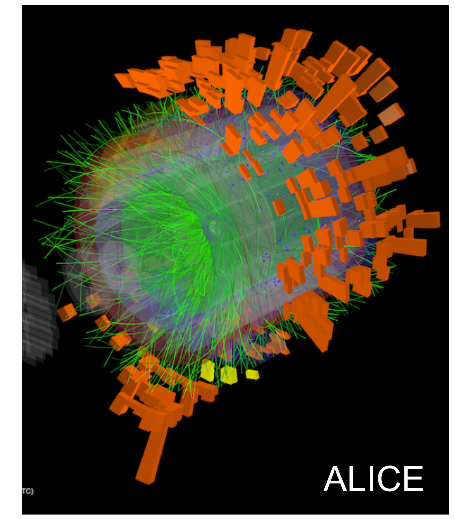
QGP
τ ~ 5 fm/c



Hadrons
τ > 10 fm/c

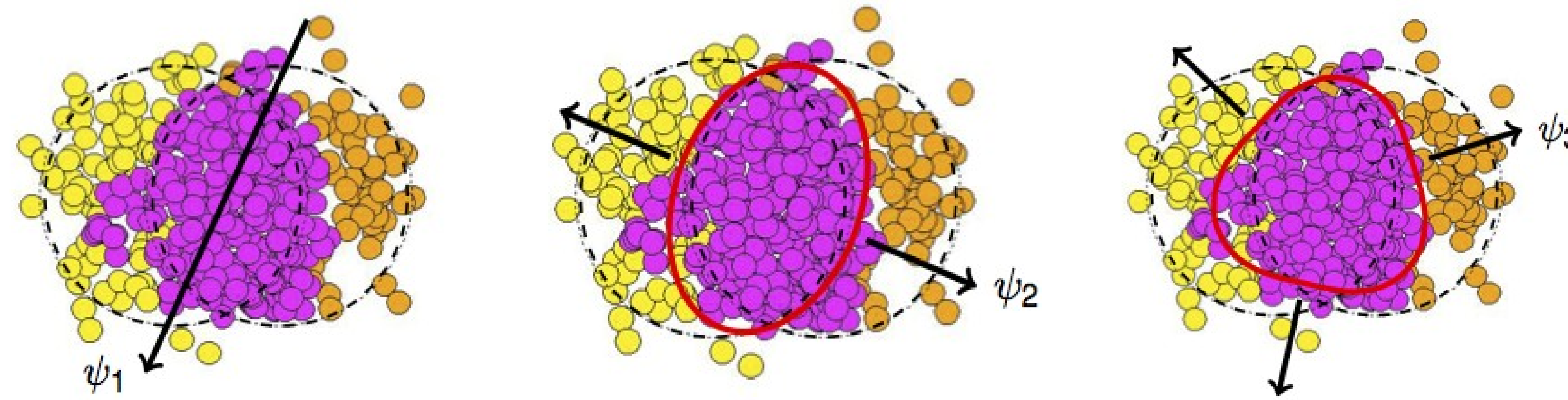


Detection
τ > 10 pm/c



Azimuthal Anisotropies

- **Spatial anisotropies** induce **pressure gradients** that push particles with different velocities



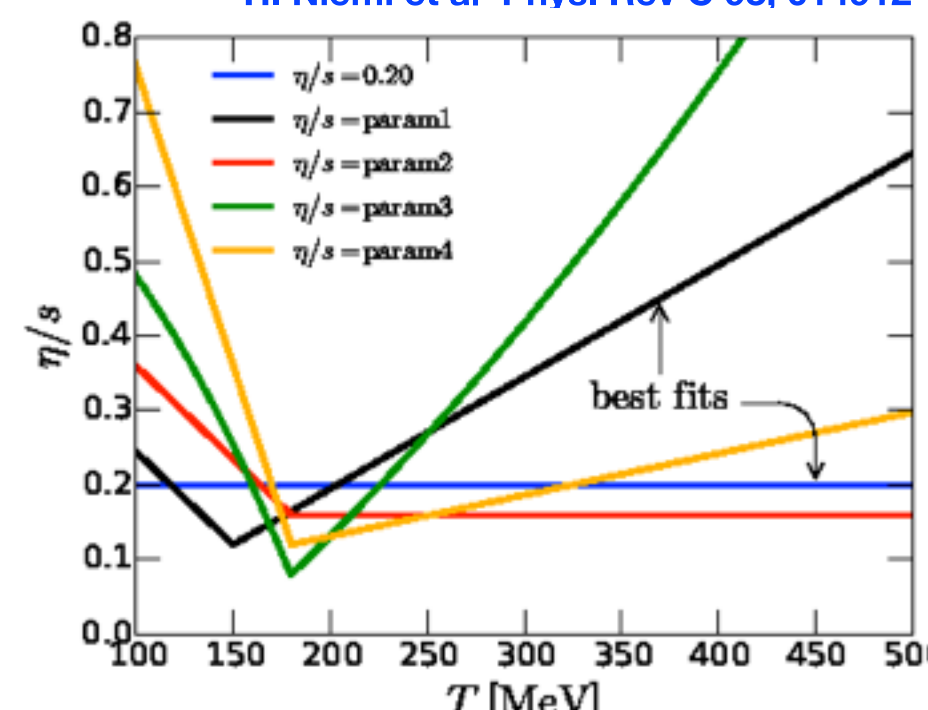
- **More** and **faster** particles are seen in the symmetry planes (ψ_n) directions.
  - **Particle azimuthal distributions** measured wrt symmetry planes → Fourier series

Flow coefficients

$$v_n = \langle \cos(n(\varphi - \Psi_n)) \rangle$$

- Investigation of QGP shear viscosity (η/s)
  - Friction effects of fluid elements
  - Perfect liquid → $\eta/s = 0$
  - Investigation of the η/s (T)

H. Niemi et al Phys. Rev C 93, 014912

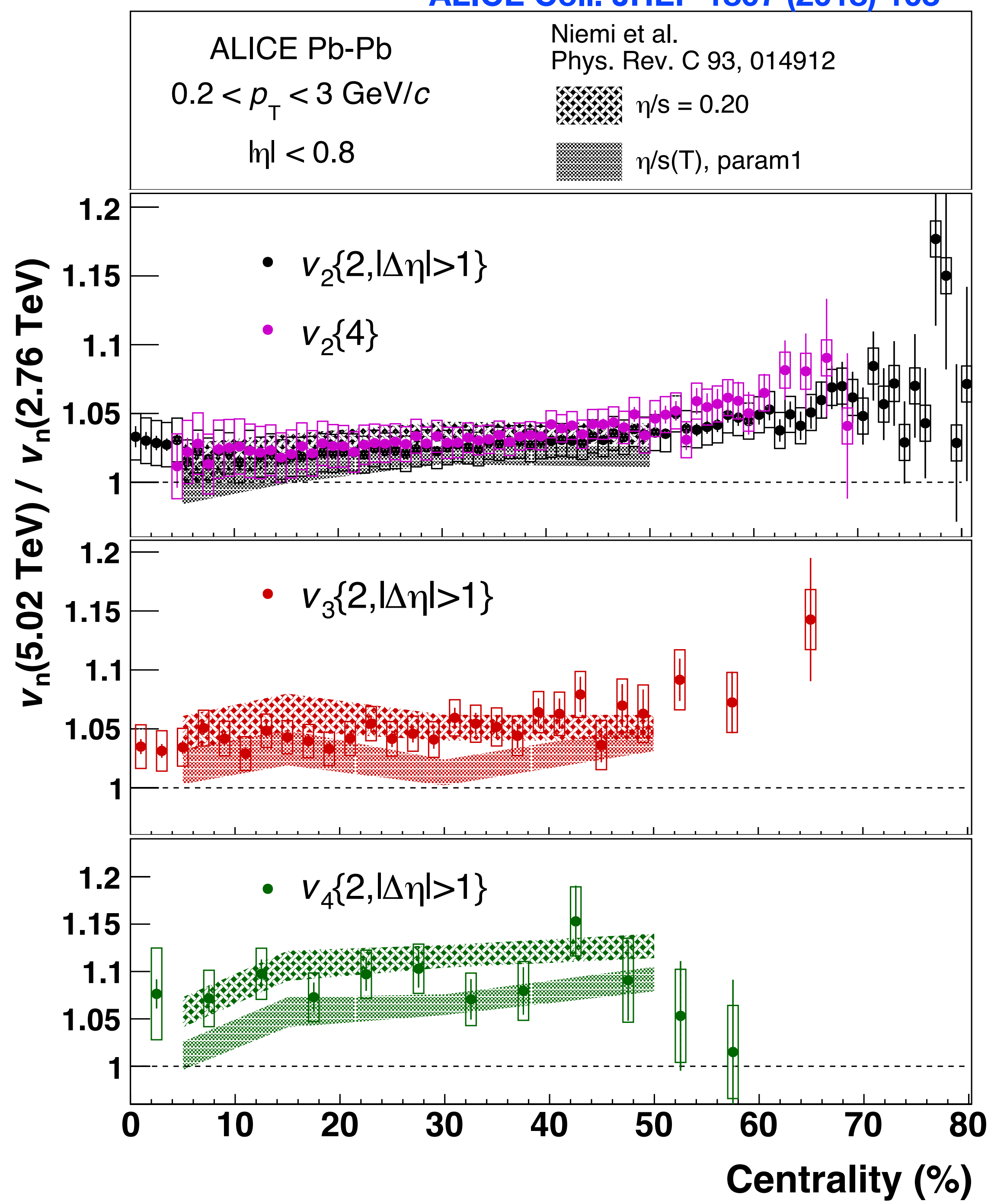


Charge particles flow coefficients

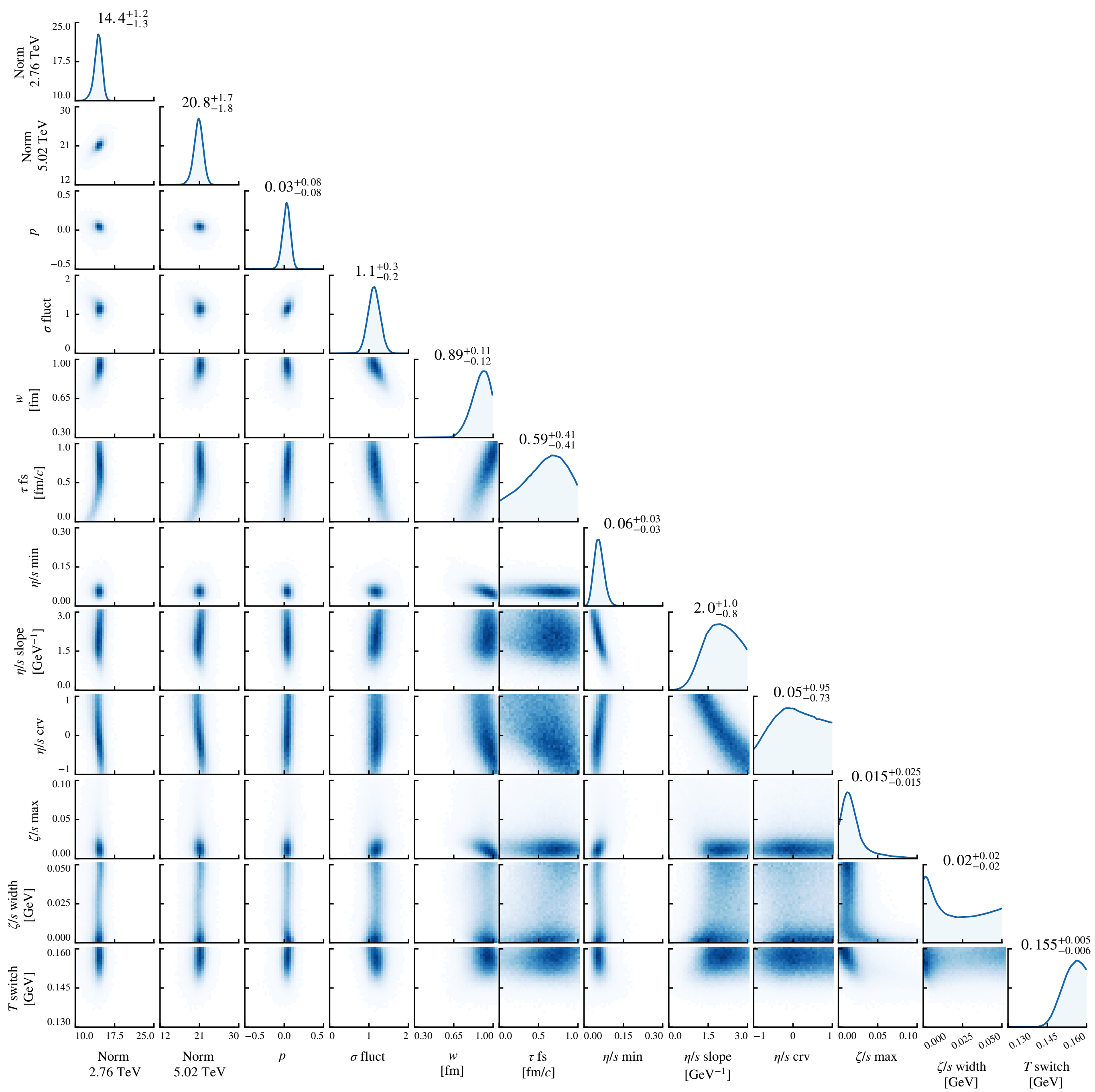
- Centrality dependence of flow coefficients for charged hadrons in $0.2 < p_T < 3.0$ GeV/c
  - Up to $v_6 > 0$ coefficients measured
  - Strong increase of v_2 harmonic contribution in semi-central collisions.
  - Collective effects coming from different contributions $v_2 \sim v_3$ in central collisions.

- 2-10% higher flow found at higher collision energy ($\sqrt{s_{NN}}$ = 2.76 to 5.02 TeV)
- Ratio of the two energies sensitive to different trend of η/s (T)
- Similar p-values for the two favorite $\eta/s(T)$ scenarios

ALICE Coll. JHEP 1807 (2018) 103



Baysian statistical analysis



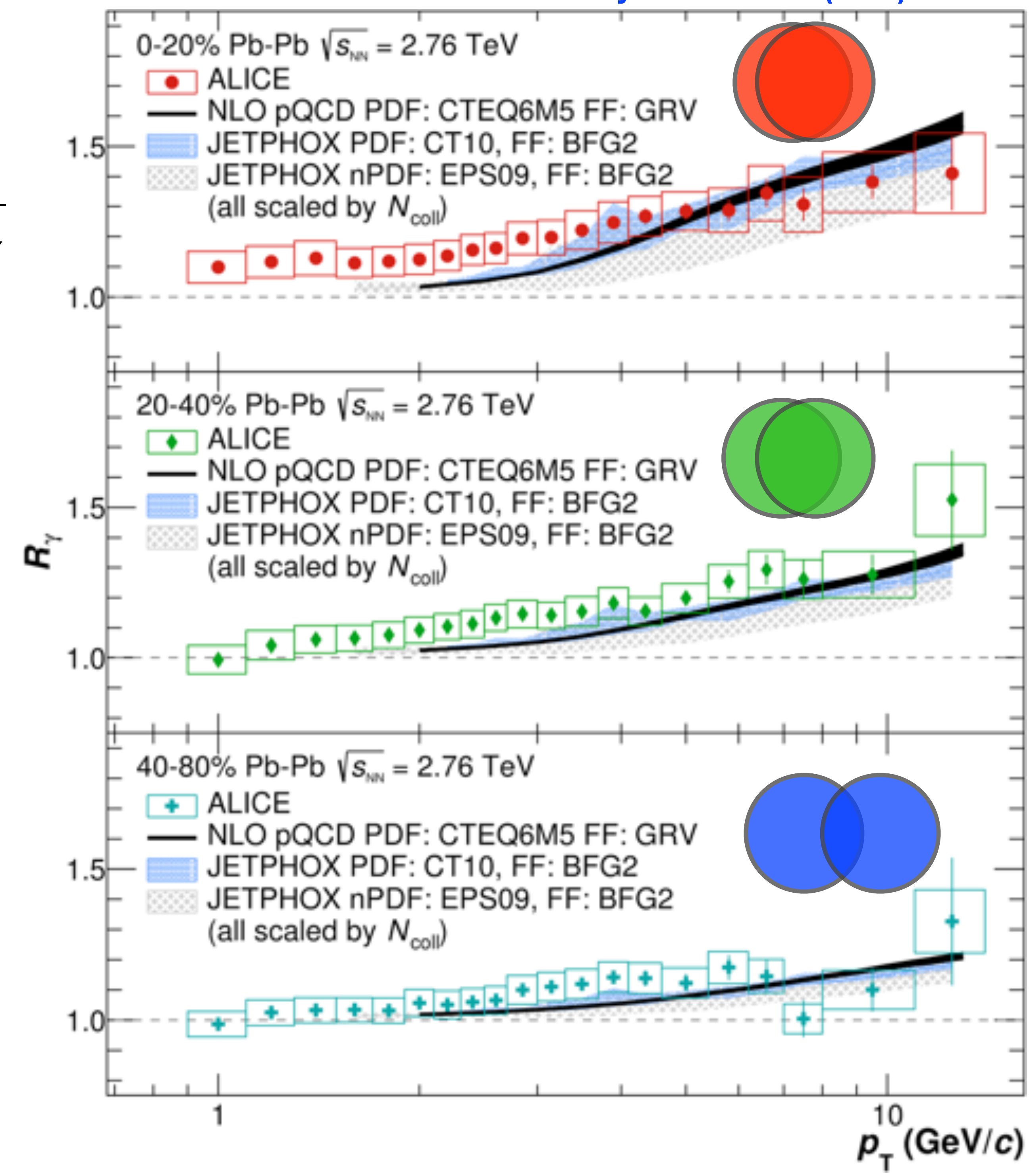
Direct ɣ v_2

- Measurement of $\mathbf{R}_{\gamma}$ factor in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV

$$R_{\gamma} = \frac{\gamma_{incl}}{\gamma_{decay}}$$

- Only ~ 10% of inclusive ɣ are direct ones.

ALICE Collab. Phys. Lett. B 754 (2016) 235-248



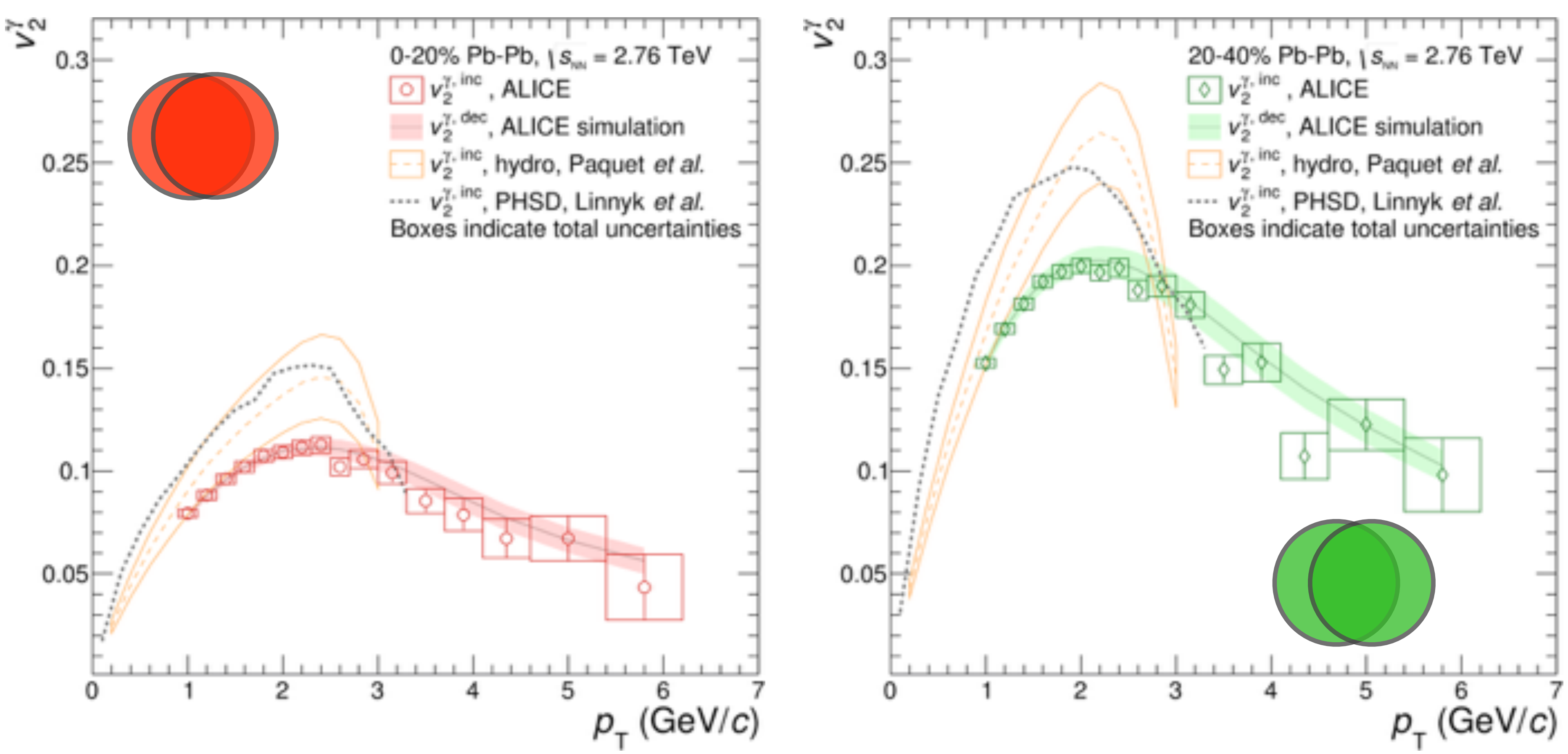
Direct γ v_2

- Measurement of **R_γ** factor in Pb-Pb collisions at $\sqrt{s_{NN}}$ = 2.76 TeV for three centrality classes

$$R_\gamma = \frac{\gamma_{incl}}{\gamma_{decay}}$$

- Only ~ 10% of inclusive γ are direct ones.

ALICE Collab. arXiv:1805.04403 accepted by PLB



Direct γ v_2

- Final results obtained by employing a Baysian approach given the small fraction of direct γ.
- Non - zero direct γ flow (significance 1.4-1.0 σ)
- Similar values as observed at PHENIX.

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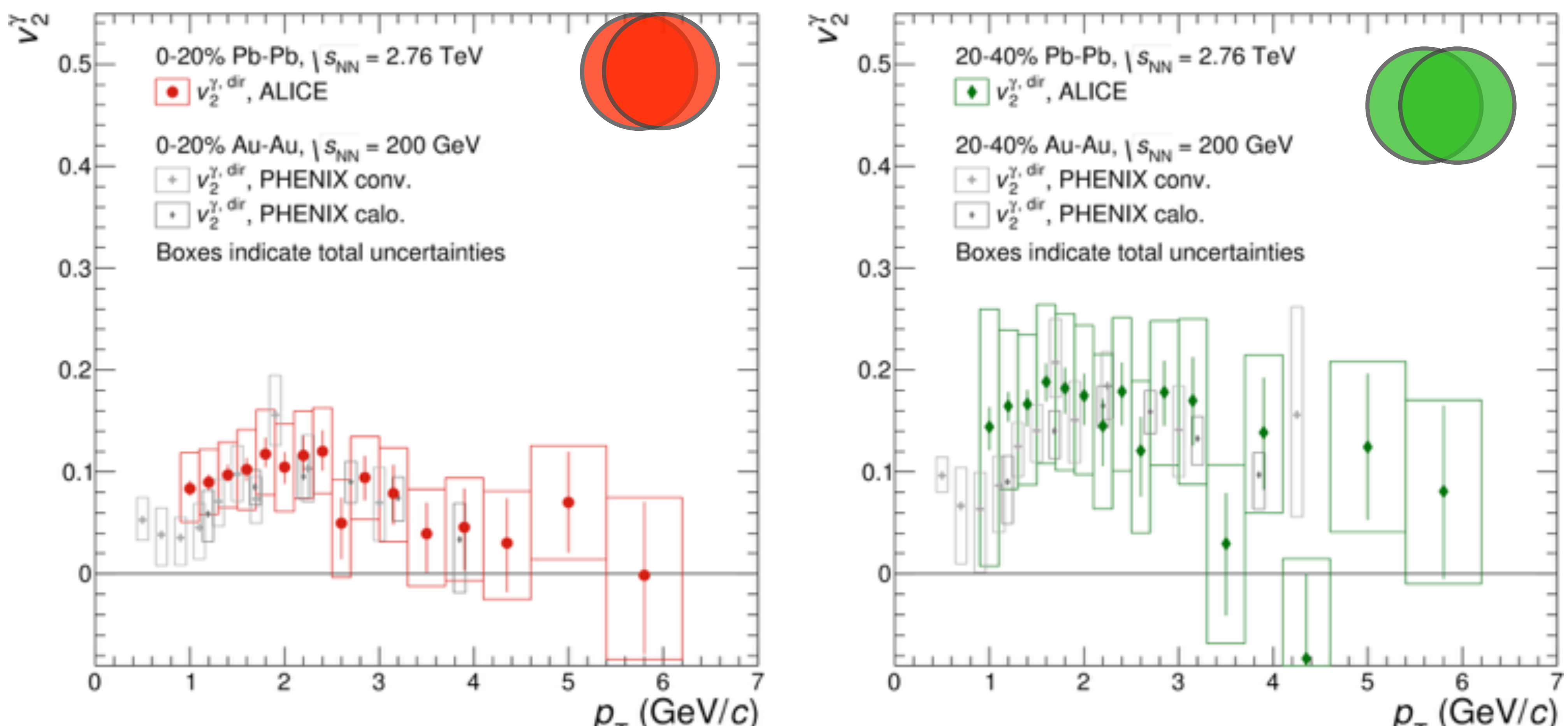

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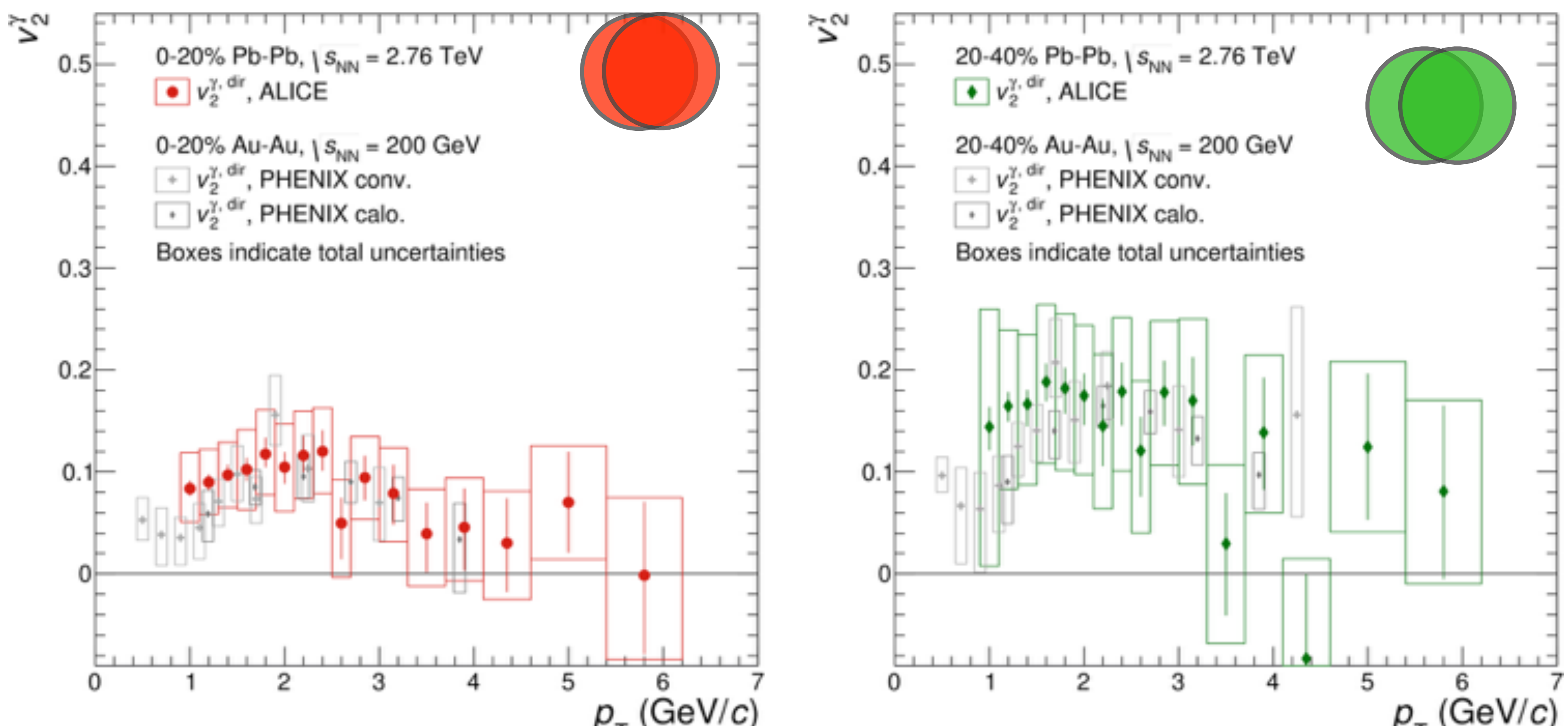
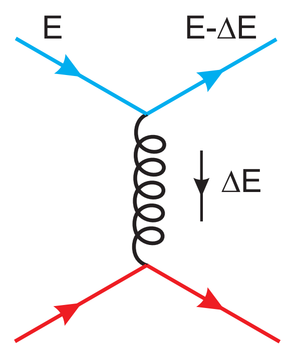
- Similar values as observed at PHENIX.

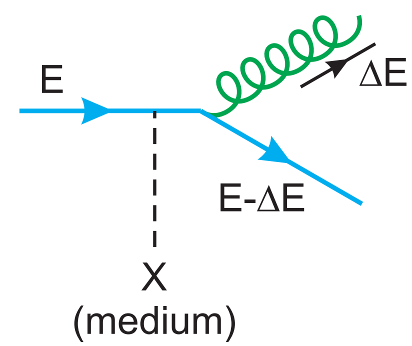
ALICE Collab. arXiv:1805.04403 accepted by PLB

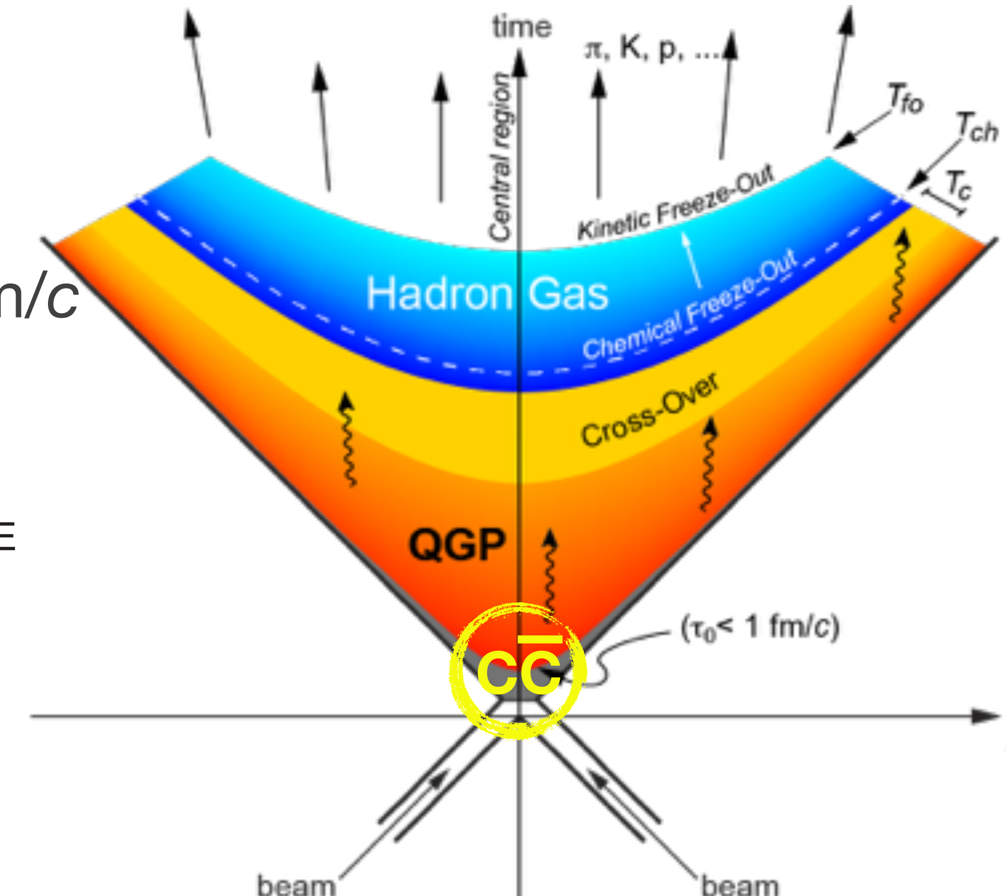


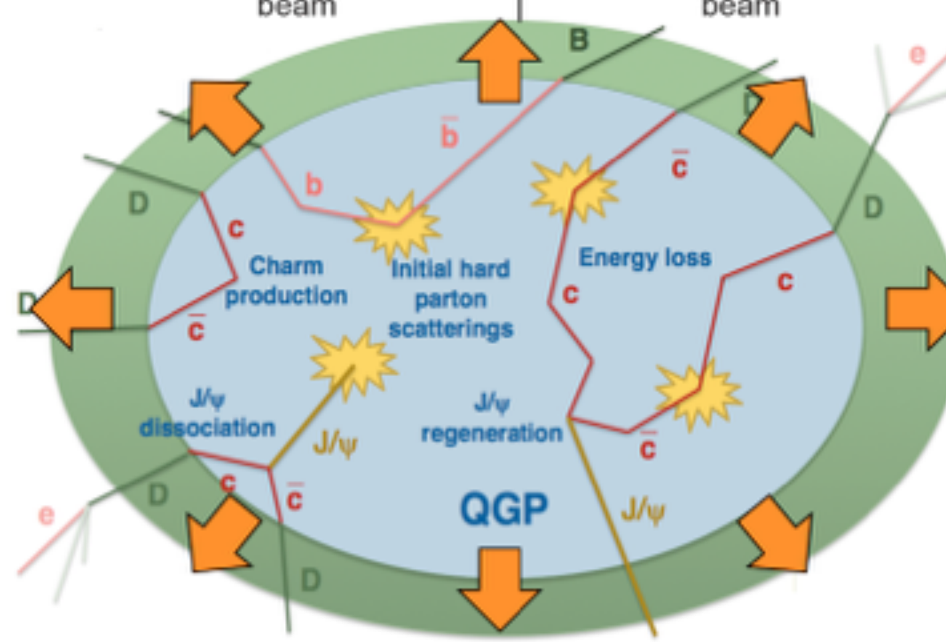
Heavy quarks flow coefficients

- **Heavy-flavor quarks** (charm and beauty)
  - mainly produced in **hard scattering**,
  - can probe the **entire evolution of the QGP**,
    $t_{prod} \sim \hbar/4m_{c(b)} \sim 0.05\ (0.01)\ fm/c$ vs $t_{QGP} \sim 0.1\text{-}1\ fm/c$
  - interact with medium constituents via
    - elastic scatterings,
    - gluon radiations







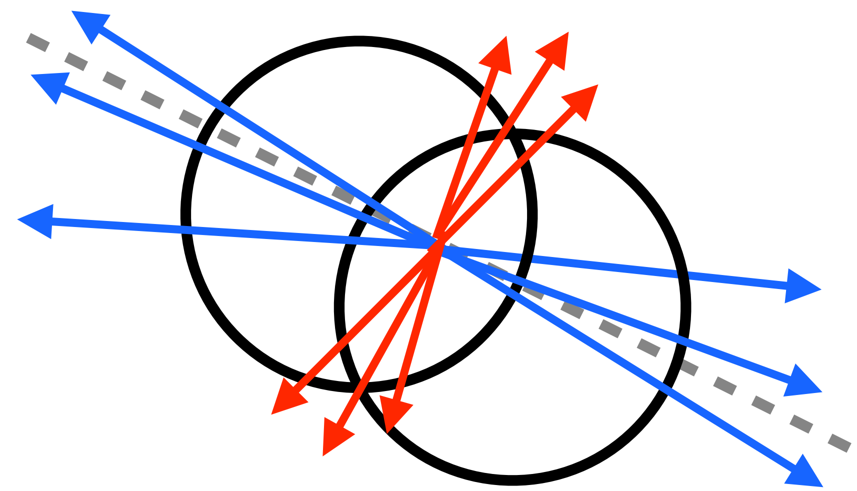


- Anisotropic flow coefficients for charmed mesons used to study:
  - charm quark thermalization → participation in the collective medium expansion ?
  - charm diffusion coefficient
  - path dependence of the energy loss in the QGP ?
  - magnetic field produced in heavy-ion collisions ?

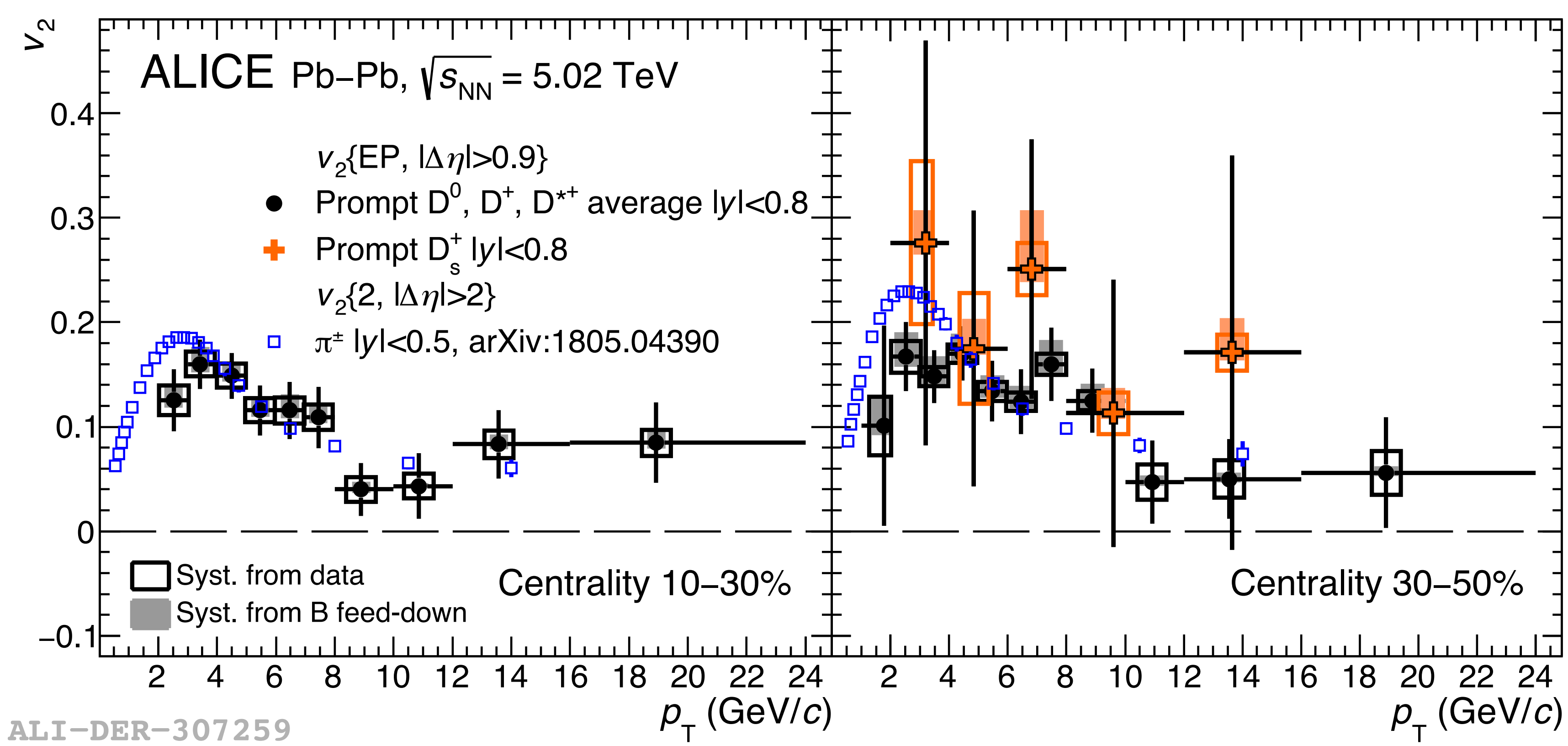
Heavy-flavour v_2

- Difference in the yields of D mesons produced **in-plane** and **out-of-plane**

$$v_2 = \frac{1}{R_2}\frac{\pi}{4}\frac{N_{IN} - N_{OUT}}{N_{IN} + N_{OUT}}$$



- **v_2 (D)** ≈ **v_2 (π)** for $p_T > 4$ GeV/c for both centrality classes
- **v_2 (D)** < **v_2(π)** for $p_T < 4$ GeV/c ?
- Is the light-flavor quark responsible for v_2 (D)?



ALICE Coll, arXiv:1809.09371, submitted to JHEP
ALICE Coll. PRL 120 (2018) 102301

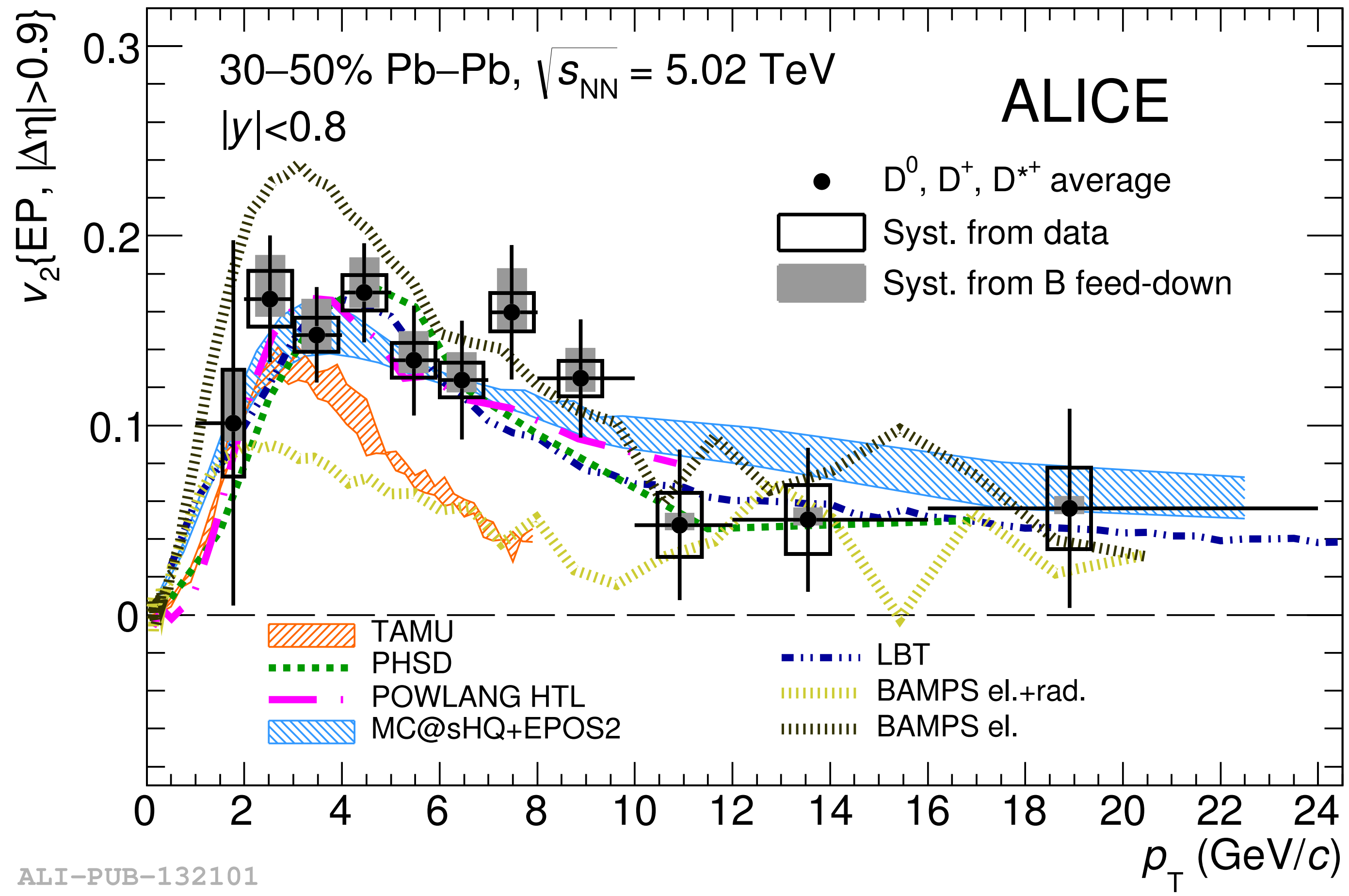
Comparison with models

ALICE Coll. PRL 120 (2018) 102301

- Comparison with theoretical calculations that include hydrodynamical model for the QGP expansion.

- Models implement
  - recombination effects
  - collisional energy loss
  - radiative energy loss

- Non-trivial interplay of these effects needed to fairly reproduce the results.



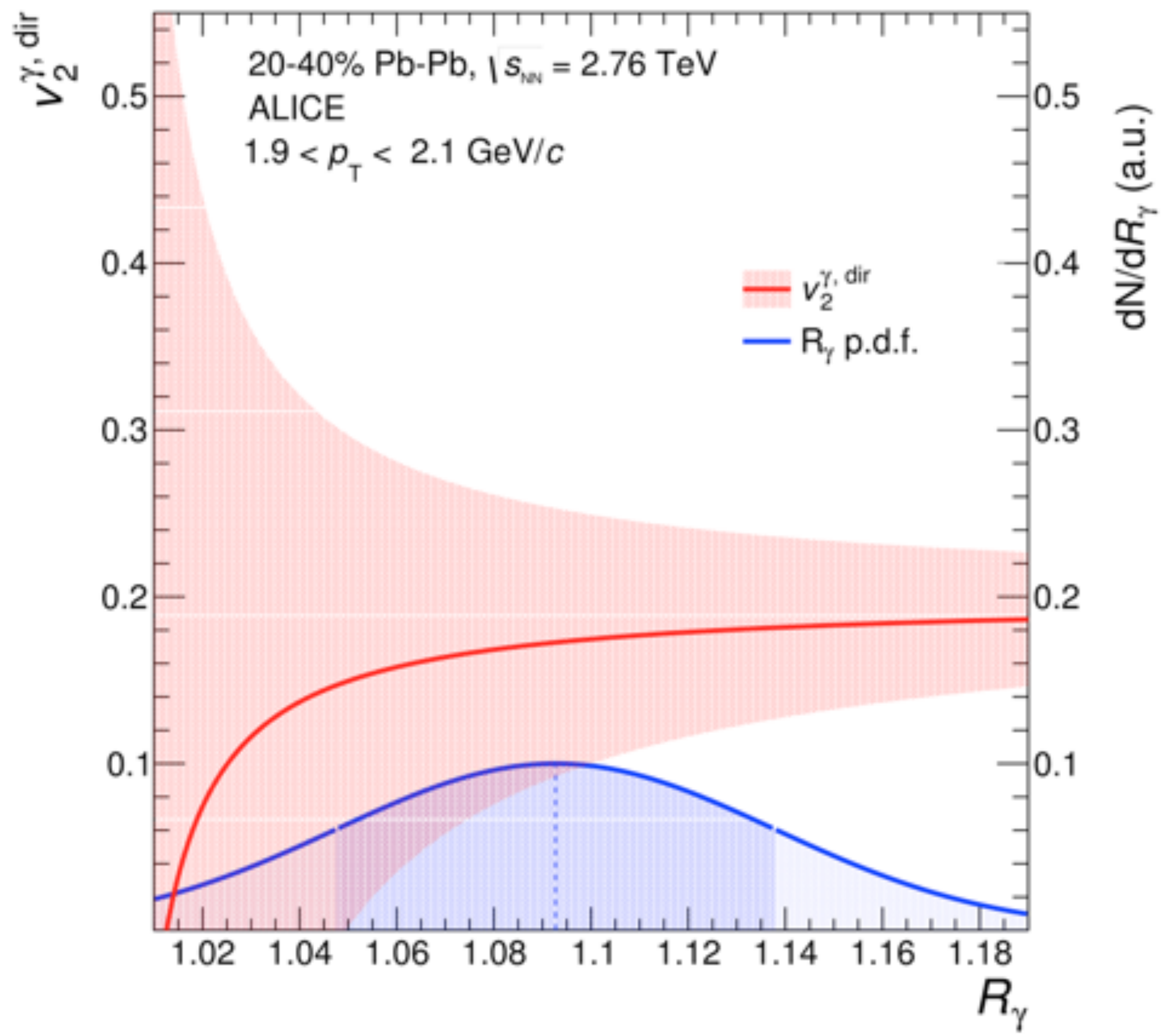
- For models with χ^2/NDF < 1: $1.5 < 2\pi T_c D_s < 7$ at $T_c \approx$ 155 MeV

- Heavy-flavor spatial diffusion coefficient evaluated from χ^2 test in 2< p_T< 8 GeV/c given the improved precision of the measurement.

$$\tau_{\mathrm{charm}} = \frac{m_{\mathrm{charm}}}{T} D_s(T) \sim 3 - 14 \ \mathrm{fm/c}$$

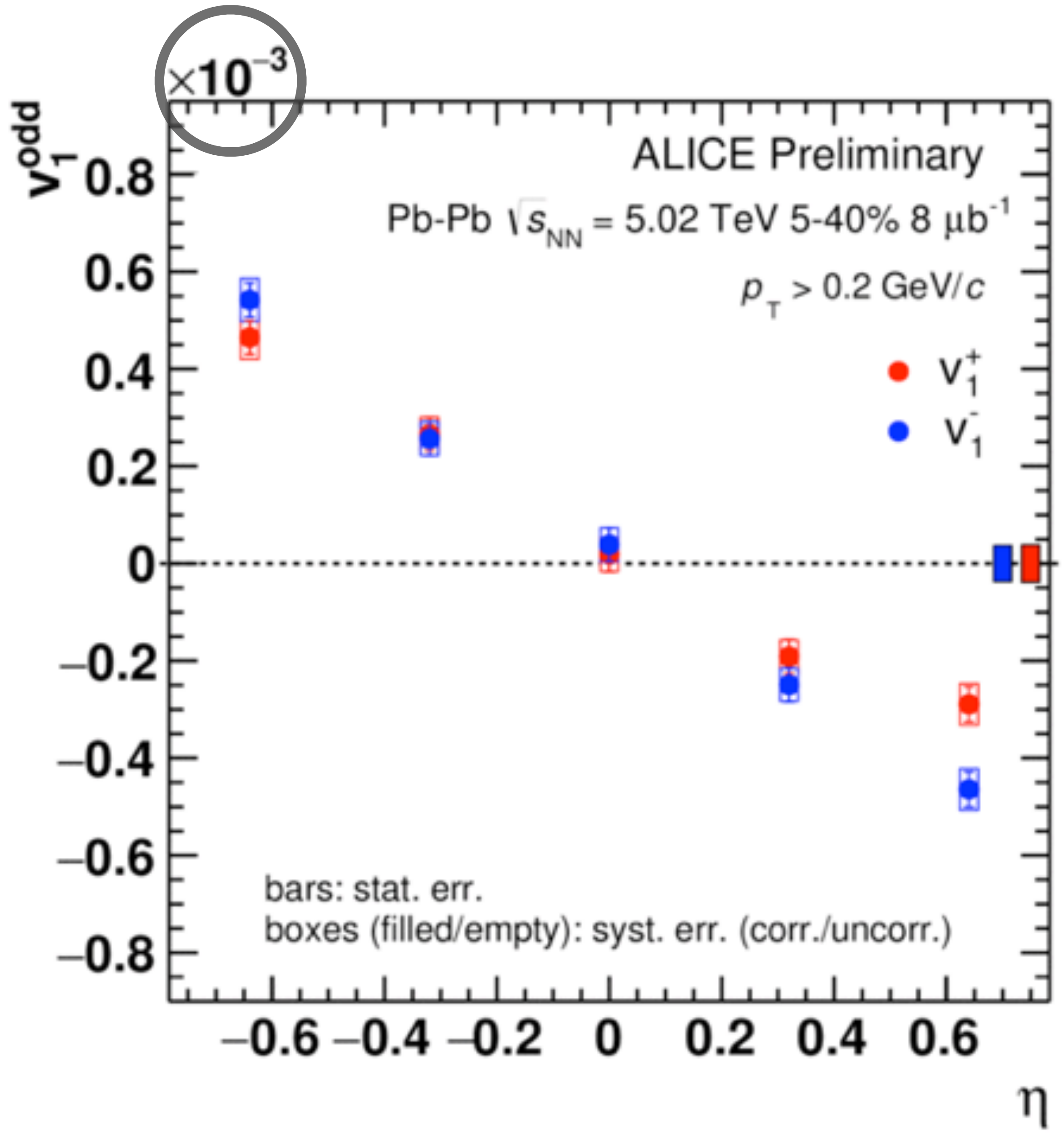
Direct γ v_2

- The small significance of the direct photon excess in R_γ impact the $v_2^{\gamma,dir}$ significance
- A bayesian method is used to extract the probability distribution to observe a certain set of measured values given the true valu

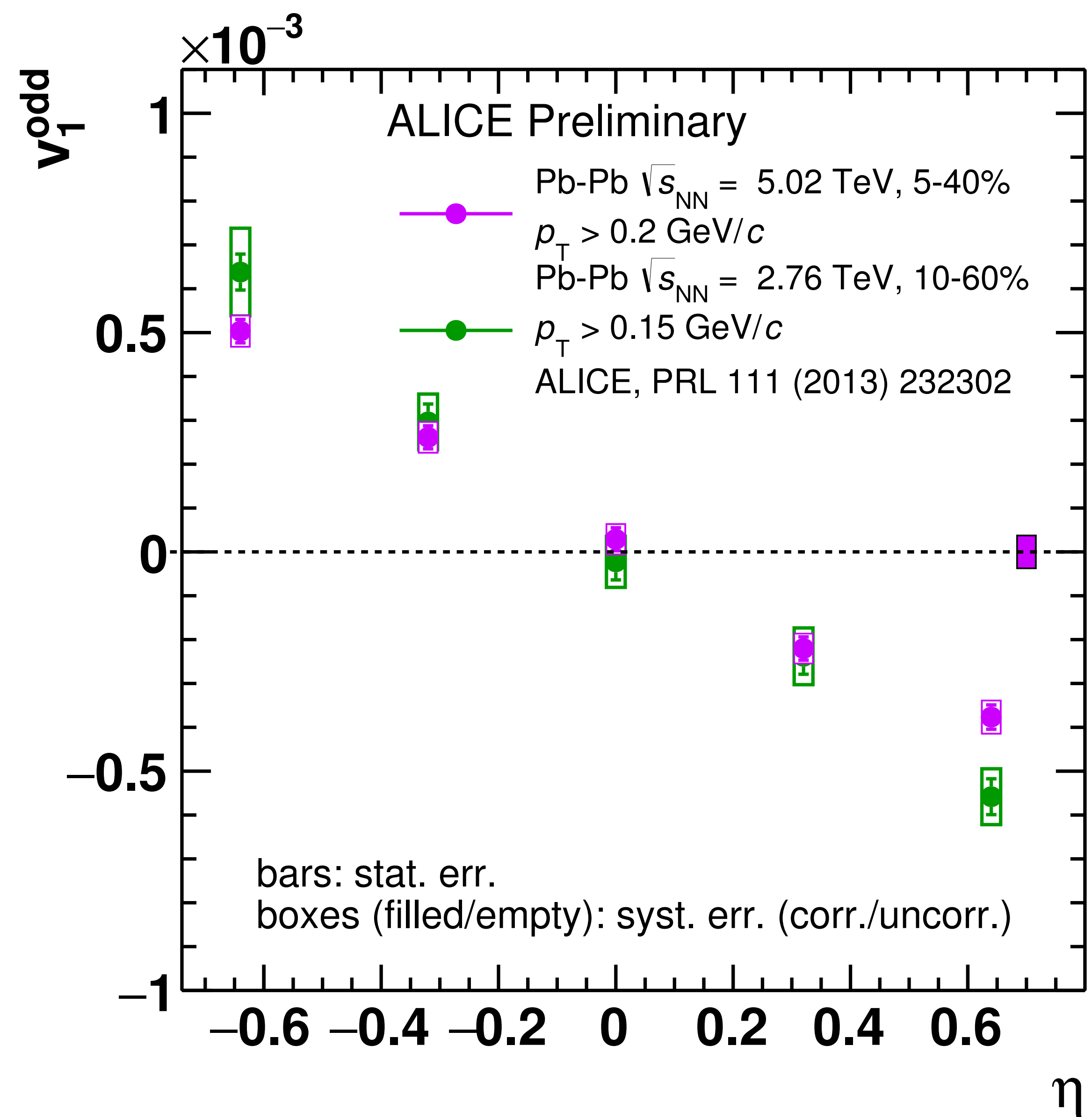


Charge-dependent v_1

- First measurement performed with charged hadrons $p_T > 0.2$ GeV/c for 10-40% centrality class.



ALI-PREL-129681



ALI-PREL-130184

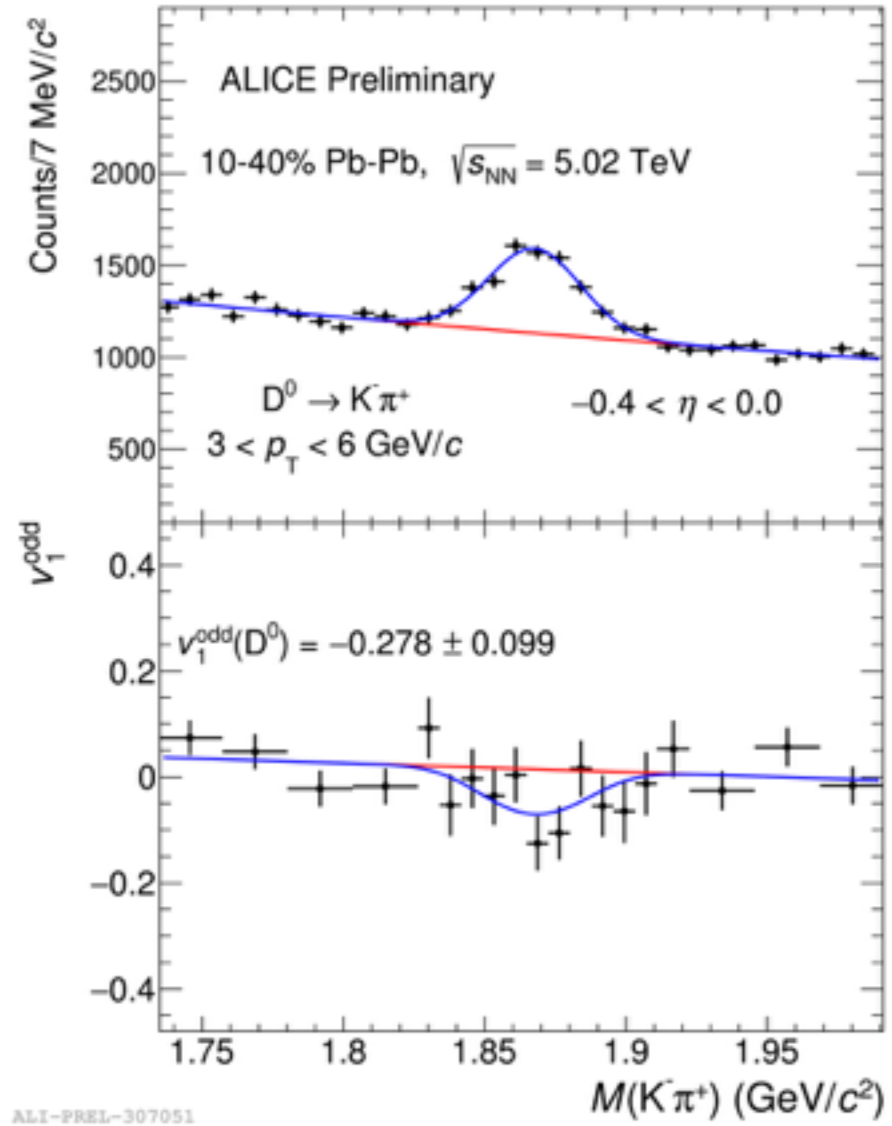
Charge-dependent directed flow

- Directed flow measured with the scalar-product method.
- Spectator plane reconstructed
  - with Zero Degree Calorimeter $|\eta| > 8.8$
  - for two rapidity sides A, C

$$v_1\{\mathrm{A,C}\} = \frac{\langle \vec{u}_1 \cdot \vec{Q}_1^{\mathrm{A,C}} \rangle}{\sqrt{\langle \vec{Q}_1^{\mathrm{A}} \cdot \vec{Q}_1^{\mathrm{C}} \rangle}}$$

$$v_1^{\mathrm{odd}} = \frac{1}{2}(v_1\{A\} - v_1\{C\})$$

- D-meson v_1 measured with a simultaneous fit of v_1 and invariant mass (considering background and signal regions) separately for D^0 and $\overline{D^0}$



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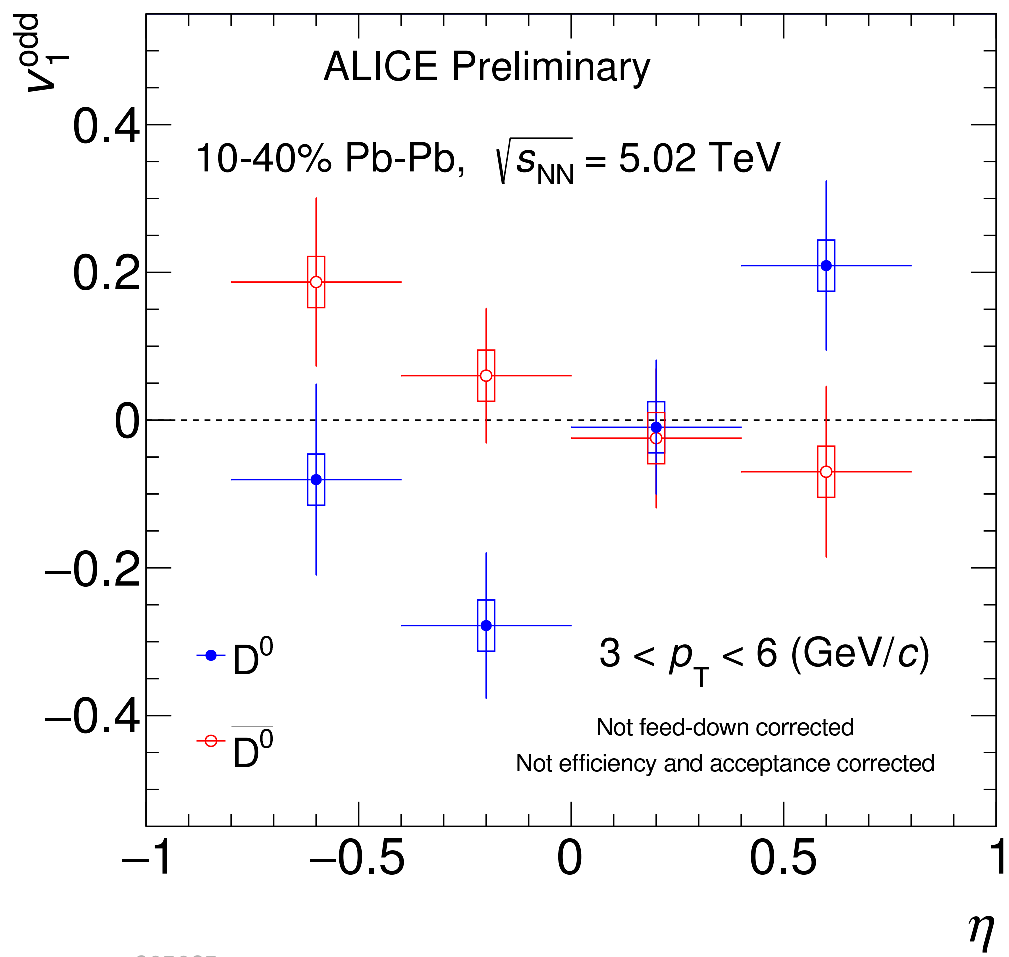
- D-meson v_1 measured with a simultaneous fit of v_1 and invariant mass (considering background and signal regions) separately for D^0 and $\overline{D^0}$
- Hint of opposite trend for v_1^{odd} vs η for D^0 and $\overline{D^0}$ with $3 < p_T < 6$ GeV/*c* in the 10-40% centrality class



ALI-PREL-307087

Charge-dependent directed flow

$$v_1\{A,C\} = \frac{\langle \vec{u}_1 \cdot \vec{Q}_1^{A,C} \rangle}{\sqrt{\langle \vec{Q}_1^{A} \cdot \vec{Q}_1^{C} \rangle}}$$

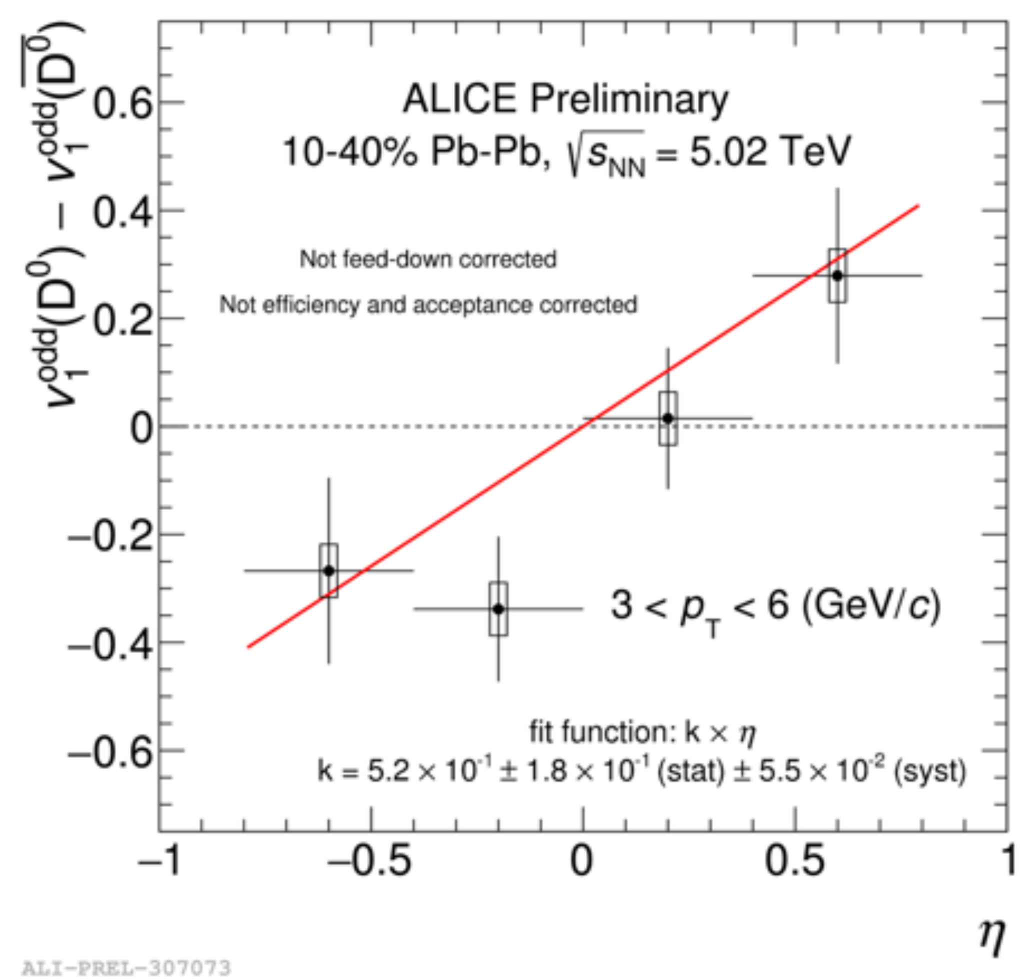
$$v_1^{odd} = \frac{1}{2}(v_1\{A\} - v_1\{C\})$$

- Directed flow measured with the scalar-product method.
- Spectator plane reconstructed
  - with Zero Degree Calorimeter $|\eta| > 8.8$
  - for two rapidity sides A, C

- D-meson v_1 measured with a simultaneous fit of v_1 and invariant mass (considering background and signal regions) separately for D^0 and $\overline{D^0}$

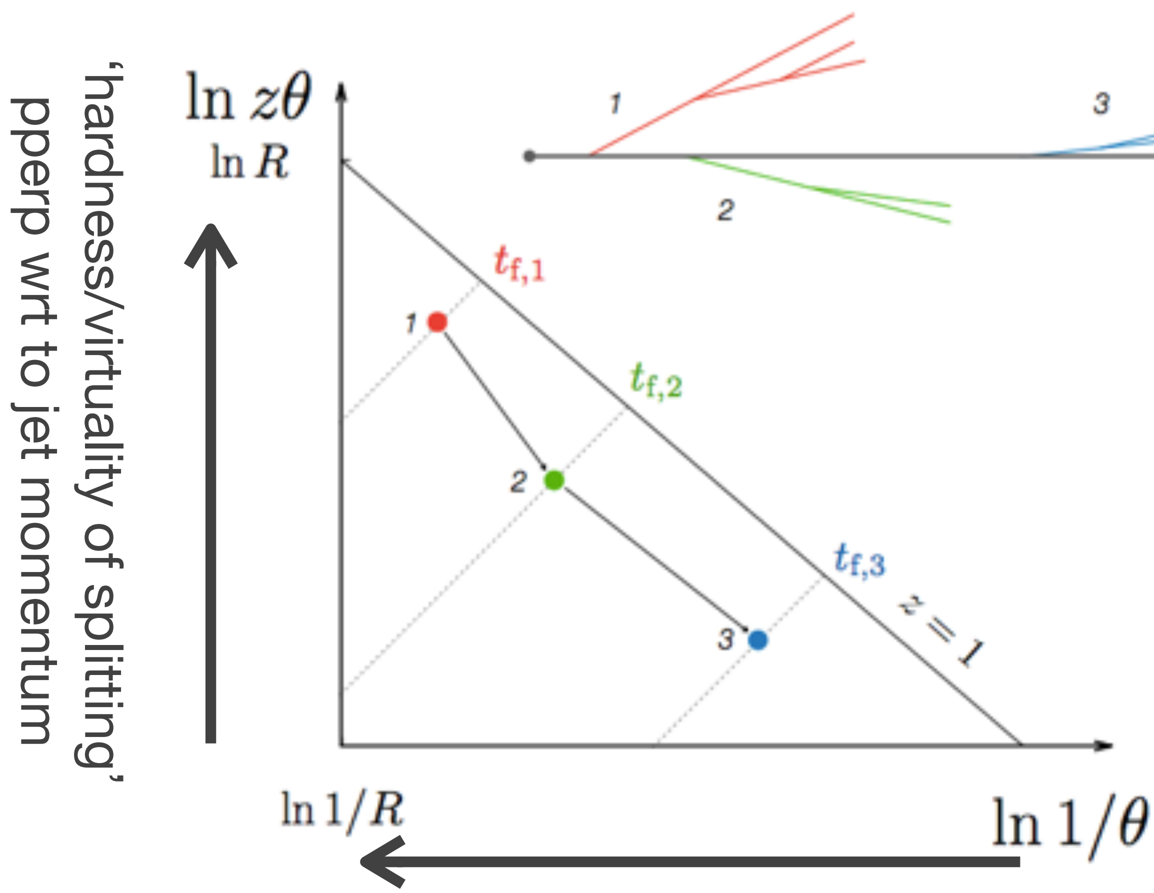
- Hint of opposite trend for v_1^{odd} vs η for D^0 and $\overline{D^0}$ with $3 < p_T < 6$ GeV/c in the 10-40% centrality class

- Hint of positive slope (2.7σ) for $\Delta v_1^{odd} = v_1^{odd}(D^0) - v_1^{odd}(\overline{D^0})$ in $3 < p_T < 6$ GeV/c
- Similar effects observed for v_1^{odd}(had), smaller effect expected



Jet shapes measurements

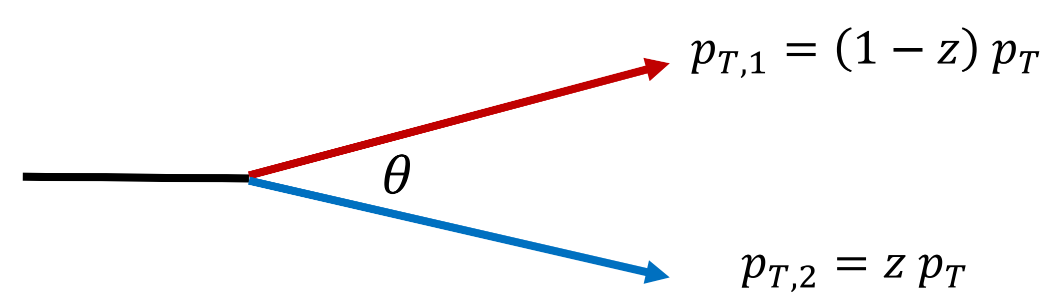
- Jet shapes are observables built combining different information coming from the properties of the jet
- Shape defined considering the jet clustering history in order to reconstruct the different splittings



Angle between prongs

- **Soft drop subjet momentum balance (z_g)**
  - Momentum balance of the two hard sub-jets.
  - Correlated with distance between the two sub-jets (ϑ)

$$z_g = \frac{\min(p_{T,1}, p_{T,2})}{p_{T,1} + p_{T,2}},$$



Jet shapes measurements

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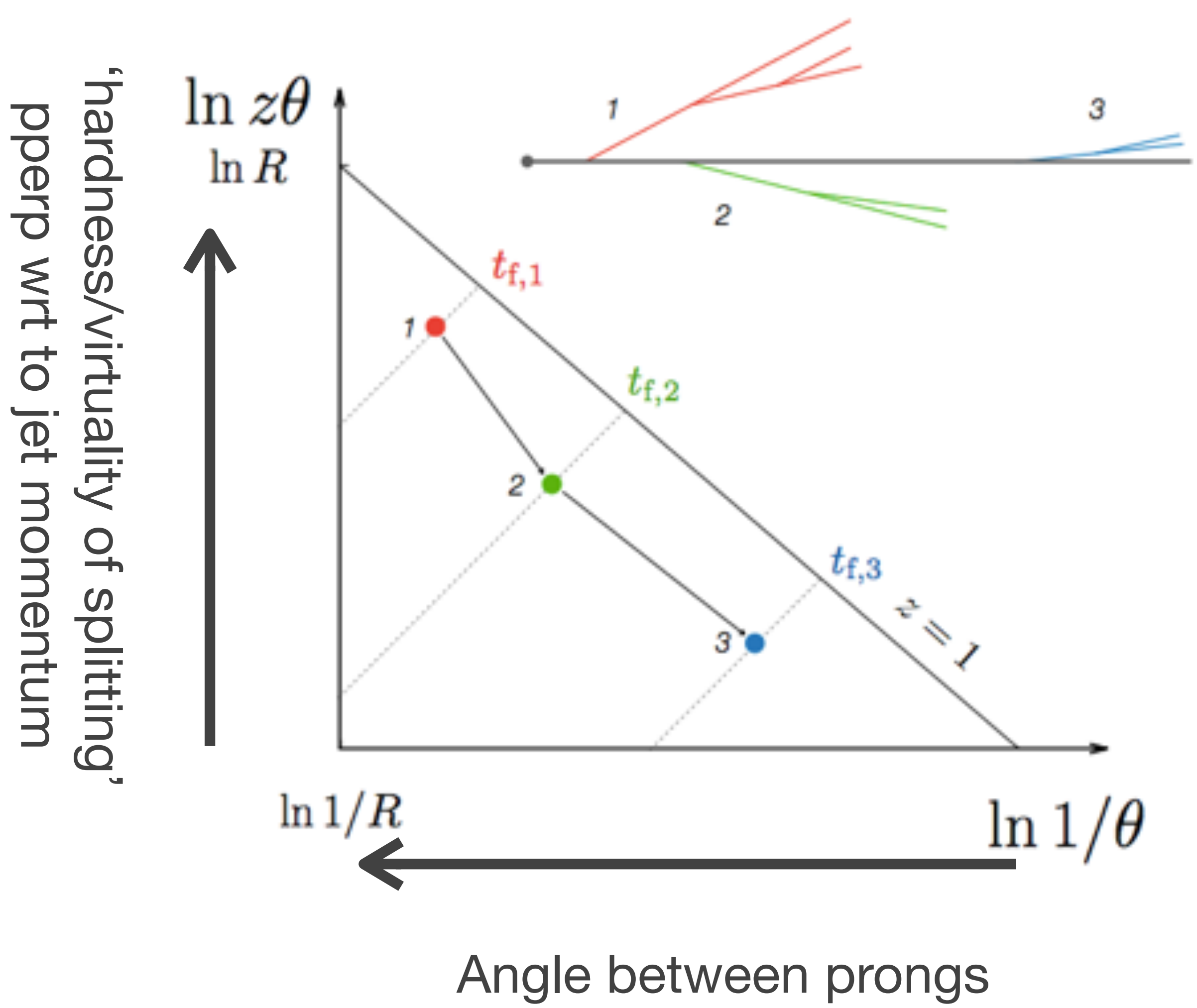
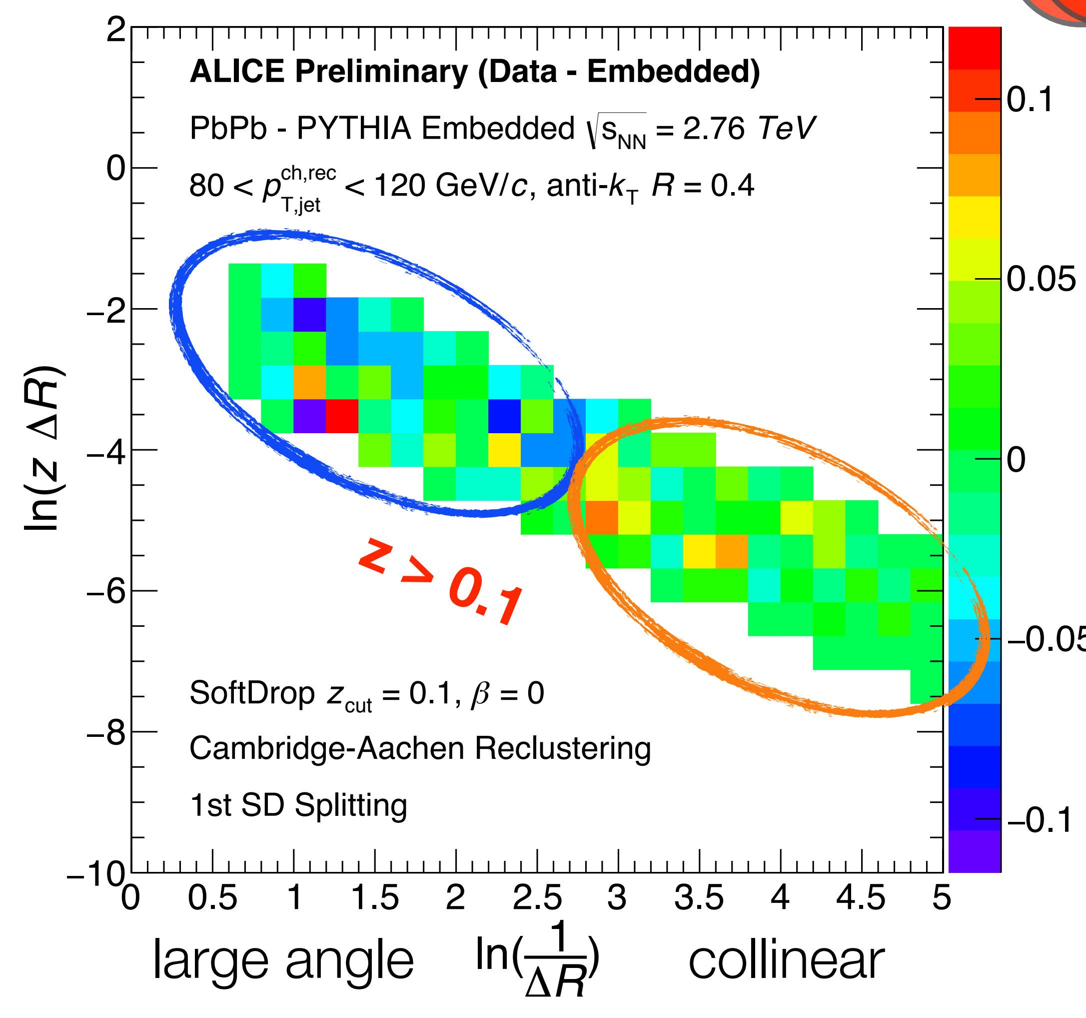
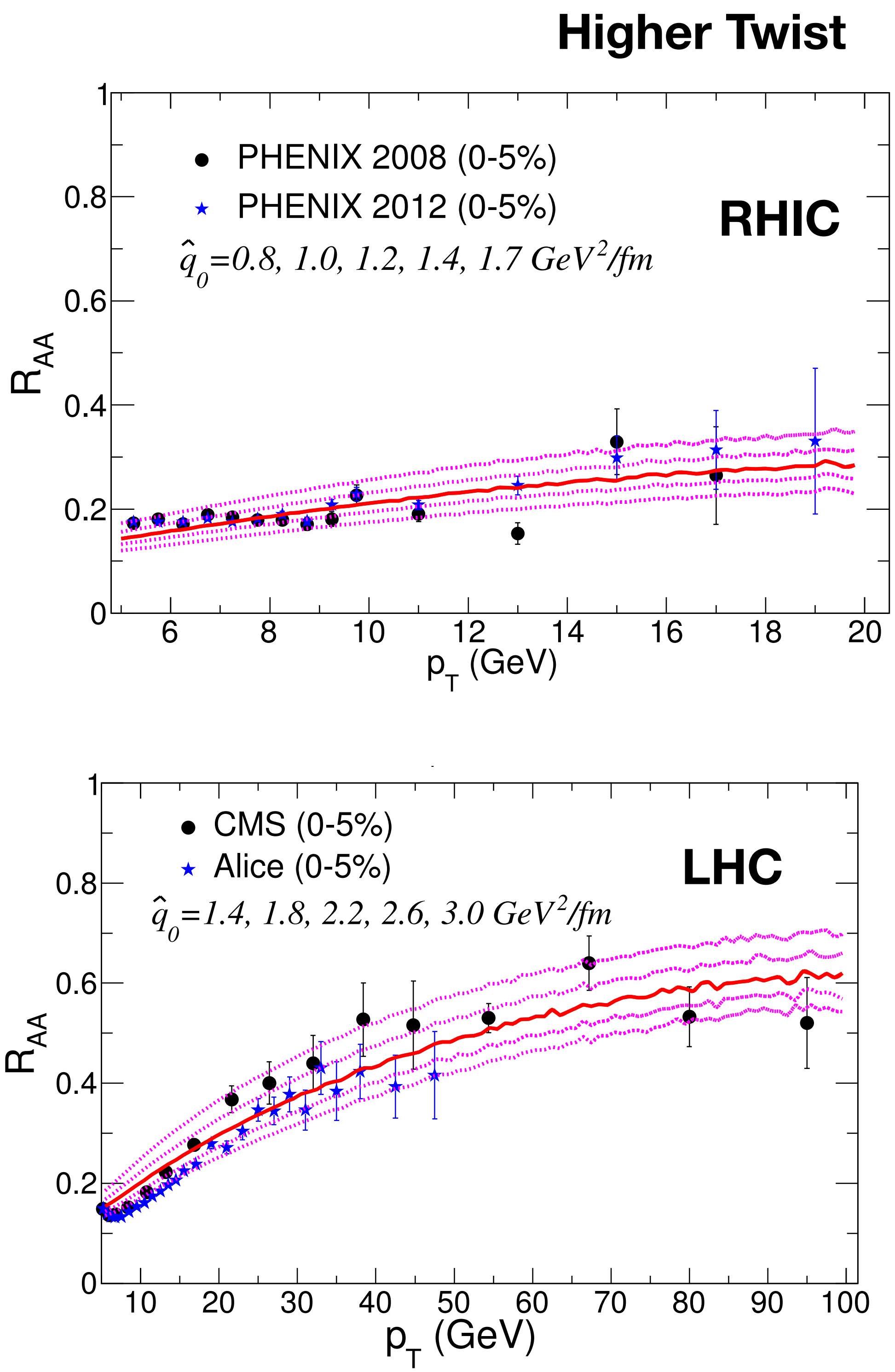
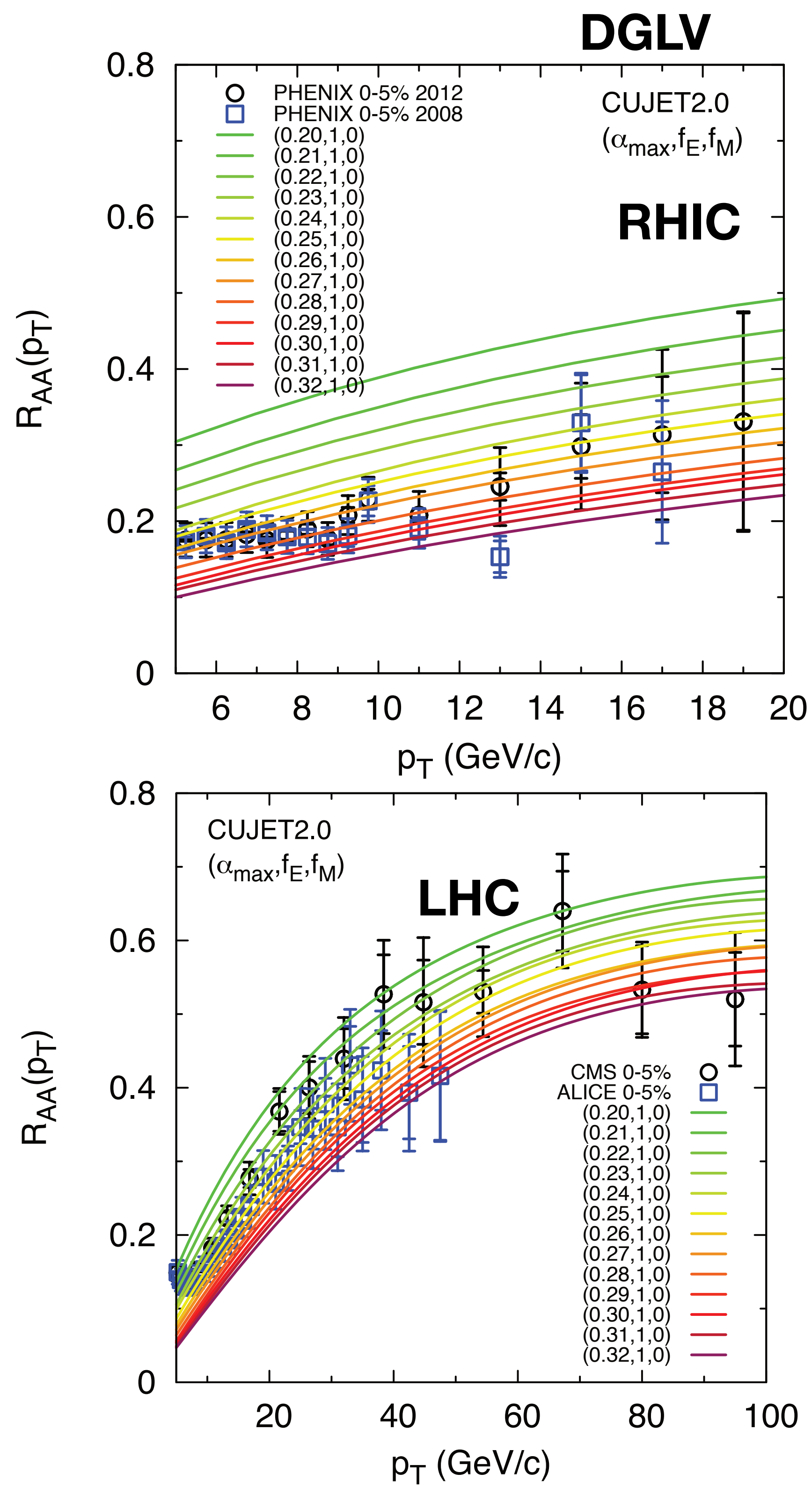




suppression at large angle
enhancement for collinear splitting

Extraction of qhat





Systematic comparison of energy loss models with R_{AA} data

Medium Model by Hydro (2+1D, 3+1D)

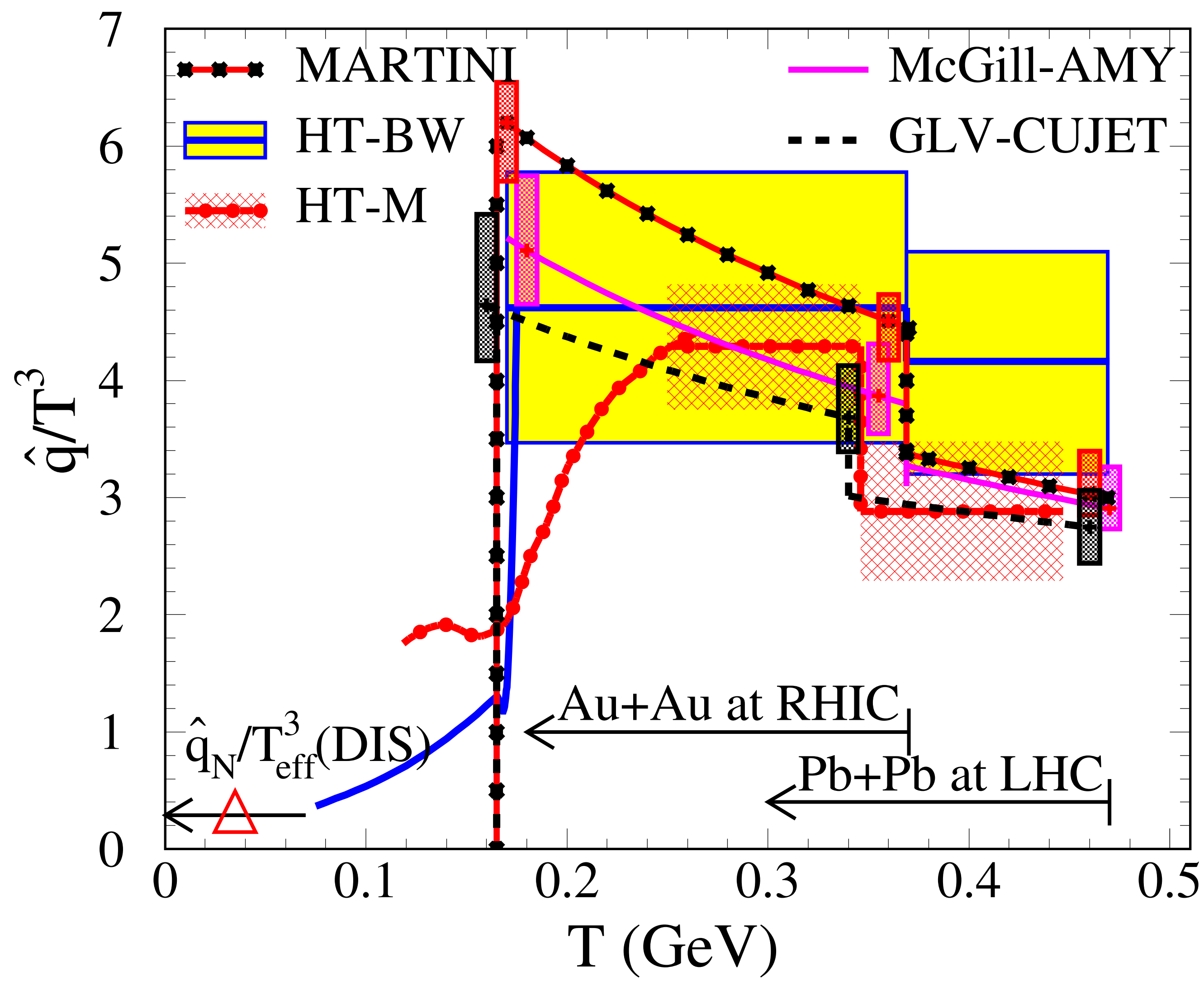
Extraction of qhat

- qhat extracted for 5 different models
- Range of different parameters considered as theoretical uncertainties
- Only the R_{AA} of charged hadrons at both energies is used to fit the data

$$\frac{\hat{q}}{T^3} \approx \begin{cases} 4.6 \pm 1.2 & \text{at RHIC,} \\ 3.7 \pm 1.4 & \text{at LHC,} \end{cases}$$

$$\hat{q} \approx \begin{cases} 1.2 \pm 0.3 \\ 1.9 \pm 0.7 \end{cases} \text{GeV}^2/\text{fm at} \begin{array}{l} \text{T=370 MeV,} \\ \text{T=470 MeV,} \end{array}$$

for a 10 GeV quark jet at $\tau_0 = 0.6$ fm/c assuming a gas of quarks and gluons (partonic degrees of freedom)



How to investigate the QGP at LHC?

- Precise characterization of the macroscopic QGP properties
  - QGP "source" characterized by global quantities and collective behaviors
  - Temperature, viscosity, diffusion coefficients, …

- How microscopic parton dynamics build the QGP properties
  - Investigate effective constituents of QGP
  - Study how QCD processes are affected by the medium: QCD splitting, color coherence, hadron formation

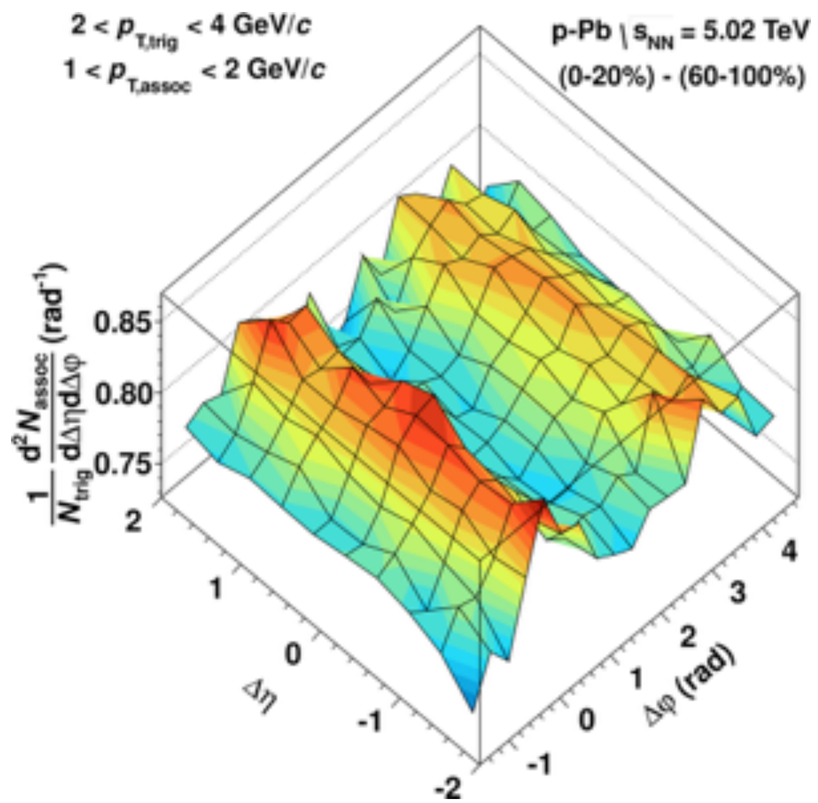
- Probing partonic content in the nuclei
  - Study of saturation effects, nPDF modifications

- **Investigations of "Pb-Pb like" effects in small collisions systems.**
- **Collectivity? Initial state fluctuations? Other QCD effects?**

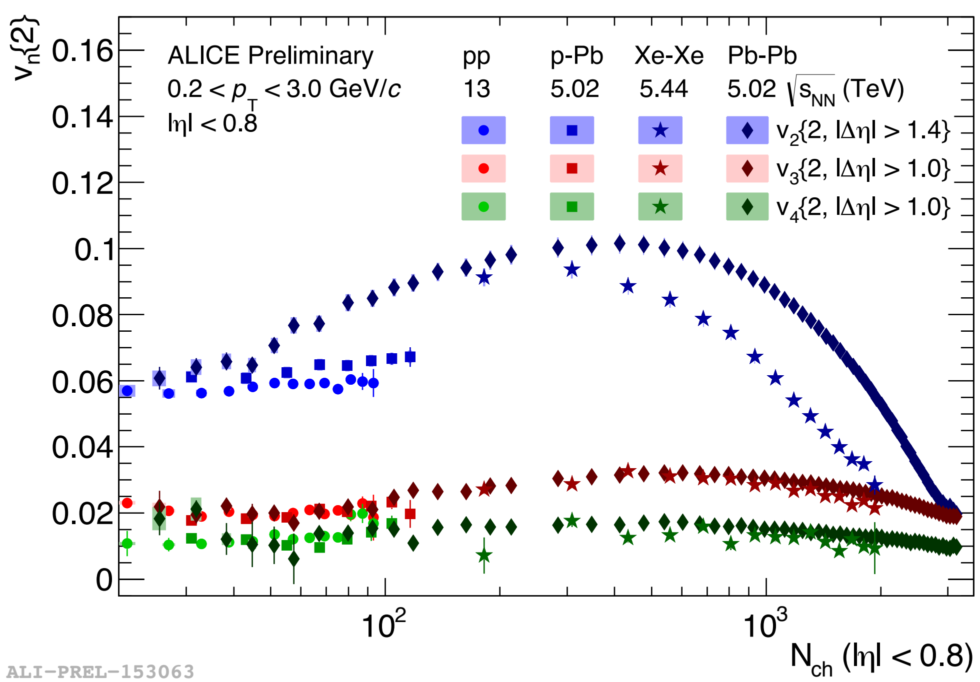
“Flow-like” effects in small systems?

- In high-multiplicity p-Pb and pp collisions observed:
- Collective structures in 2-particle correlations
- v_n coefficients > 0

ALICE Collab. Phys. Lett. B 719 (2013) 29-41



- QGP droplets in high-multiplicity events? Other QCD effects?

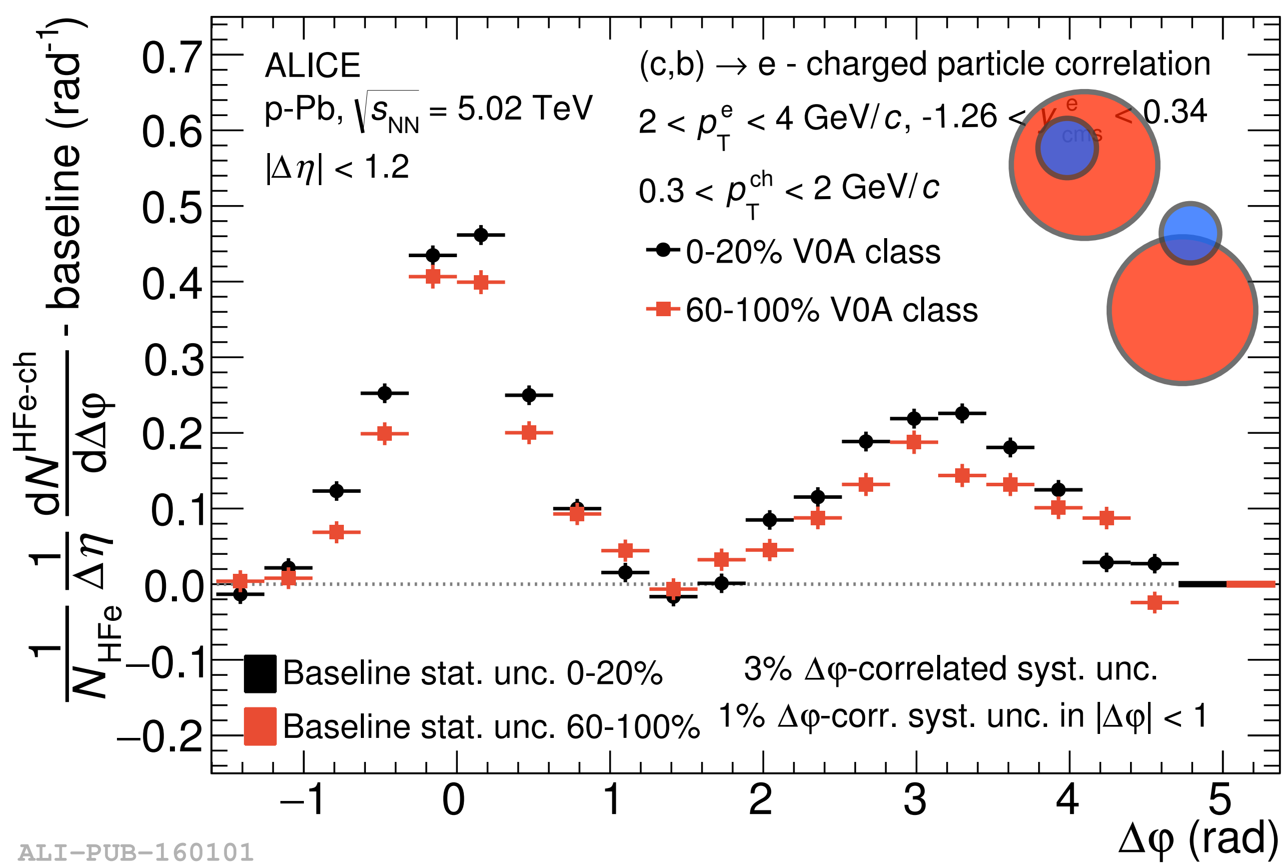


HF-e v_2 with two particles correlations

- "Flow-like" effects in the heavy flavor sector investigated with HF electron - hadron correlations

- Analysis performed in two bins of multiplicity : **0-20%** and **60-100%**
- Modification observed in both near and away side structures

ALICE Coll, arXiv:1805.04367, submitted to PRL

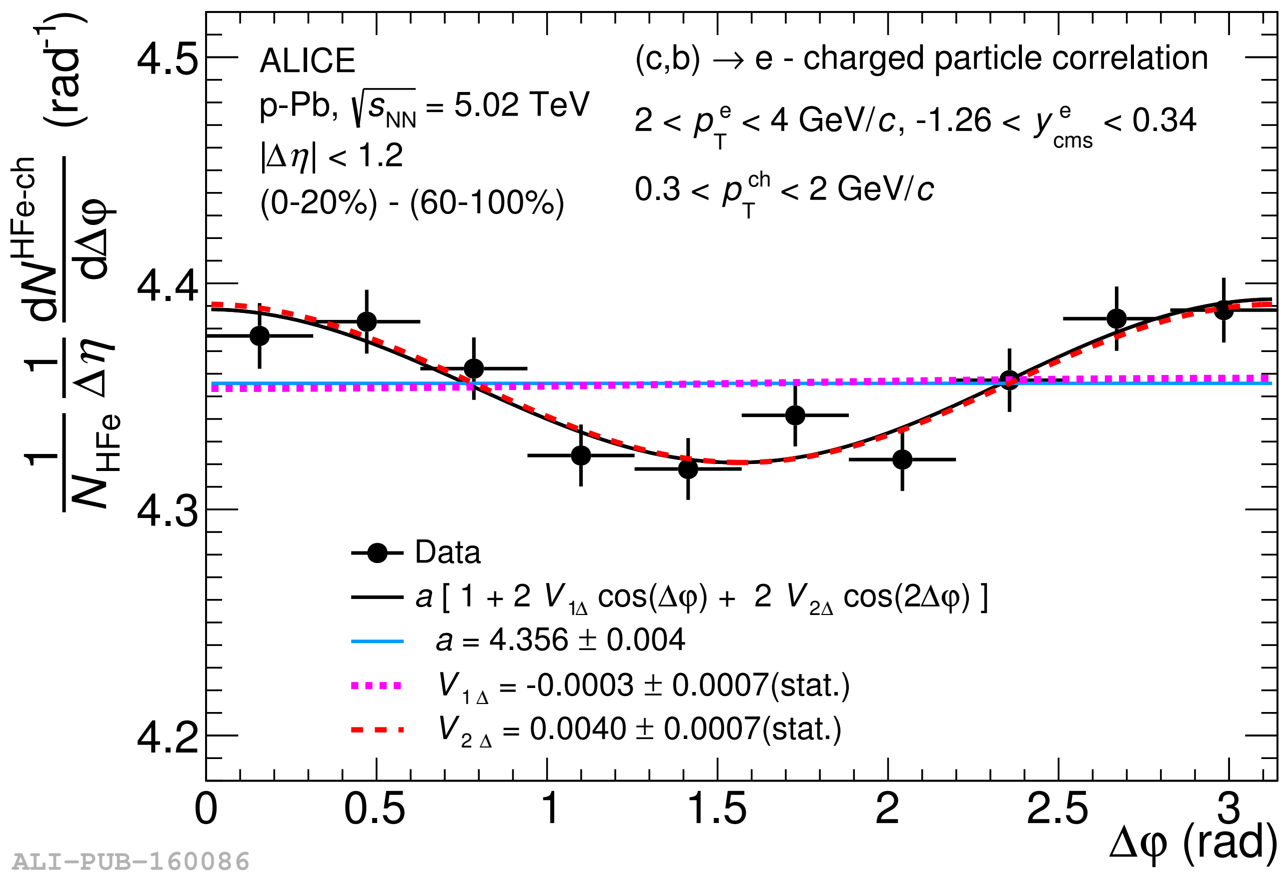


HF-e v_2 with two particles correlations

- Heavy-flavour electron-hadron correlation to study flow-like effects in p-Pb collisions.
- Focus on the low-momenta and Δφ projection of the correlation function

- Analysis performed in two bins of multiplicity : **0-20%** and **60-100%**
- Modification observed in both near and away side structures
- Modulation effect present !

ALICE Coll, arXiv:1805.04367, submitted to PRL



HF-e v_2 with two particles correlations

- Heavy-flavour electron-hadron correlation to study flow-like effects in p-Pb collisions.
- Focus on the low-momenta and $\Delta\varphi$ projection of the correlation function

- Analysis performed in two bins of multiplicity : **0-20%** and **60-100%**
- Modification observed in both near and away side structures
- Modulation effect present !
  - **$v_2^{hfe} \sim 0.07$**
  - 5.1σ effects in $1.5 < p_T < 4$ GeV/c
  - smaller than **charged particles**
  - Collective effects? Initial or final cold nuclear matter effects?
  - Many options still on the market, one of main discussion in HI and pp community

ALICE Coll, arXiv:1805.04367, submitted to PRL