J/ψ elliptic flow in pp collisions at 13 TeV in ALICE

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Forming the QGP and studying it

Study of Quark-Gluon Plasma (QGP)

- Deconfined state of matter
- Freely-roaming color charges

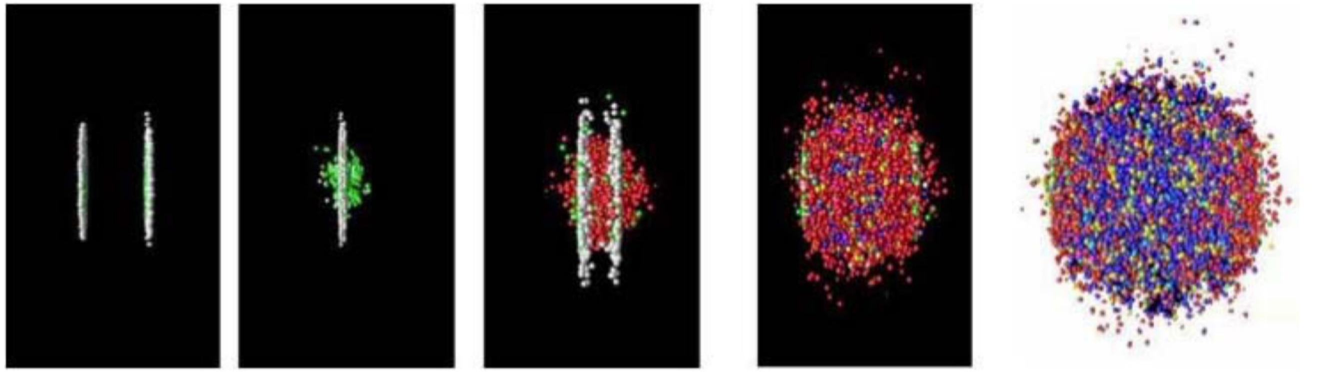
Formation through Heavy-ion collisions

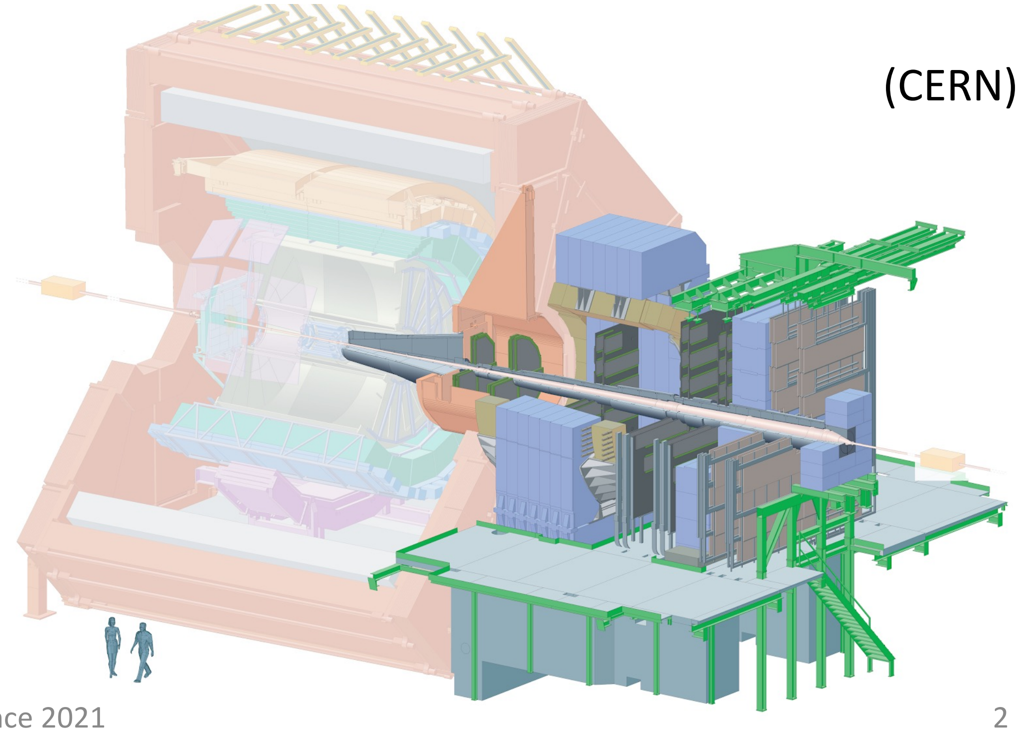
Pb-Pb ⇒ Formation of QGP
Pb-p, p-p ⇒ Reference (Cold Nuclear Matter (CNM) effects, assume no QGP formation)

What to look at ?

Focus on quarkonium ($Q\bar{Q}$)

Formed before the QGP
Influenced by color charges
Insight on QGP properties (e.g. Temperature)



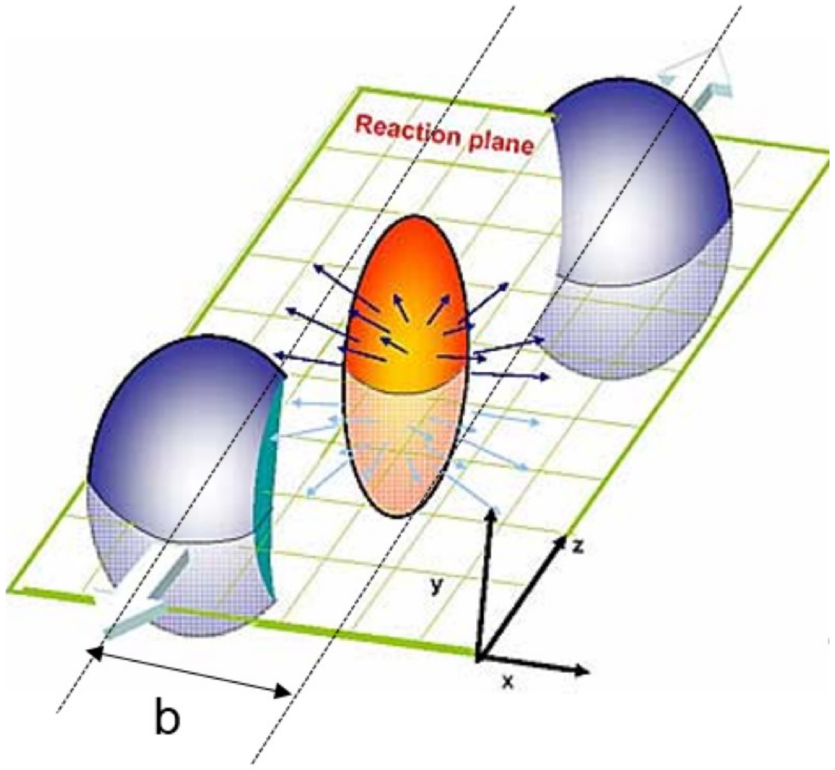


(CERN)

What is flow ?

In Heavy-ion collisions, anisotropic collision region

- Anisotropies in momentum distribution
- Long-range correlations of produced particles



Taken from Universe, 2017

[arXiv:nucl-ex/9805001]

Azimuthal correlations of particles quantified by Fourier coefficients in ϕ angle distribution (wrt event plane if large multiplicity), or 2-particle correlations (in smaller systems)

$$\frac{dN}{d\phi} = \left\langle \frac{dN}{d\phi} \right\rangle \left(1 + \sum_n 2v_n \cos[n(\phi - \Psi_n)] \right)$$

$$\frac{dN^{pairs}}{d\Delta\phi} \propto (1 + \sum_{n=1}^{\infty} 2v_n^2 \cos(n\Delta\phi)).$$

v_2 (elliptic) related to the initial geometry of the collision
v_3 (triangular) related to fluctuations

Flow is a signature of QGP formation as it shows collective behaviours

Constrains theoretical models

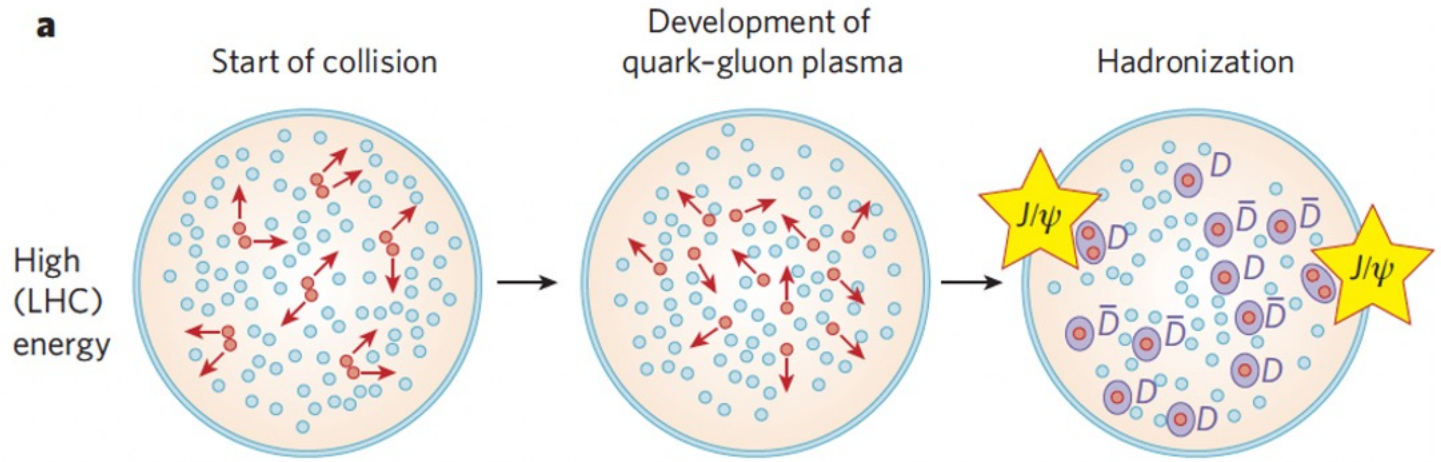
Explaining the J/ψ flow

Final State effects

Flow is **acquired through QGP evolution** (geometry-related)

Two sources for the J/ψ flow:

- (Re)combination of charm quarks (flow inheritence)
  - At freeze-out
  - Dynamic transport model
- Path-length dependent suppression (primary J/ψ)



[*Nature* **448,** 302–309 (2007)]

Pb-Pb, J/ψ regenerates

Pb-Pb ALICE (Run2, inclusive, 5.02 TeV)

[arXiv:2005.14518]

Higher energy than RHIC: more c and thermalisation of c

Comparison to transport model (TAMU, X. Du et al.)

(which reproduces nicely R_{AA} behaviour)

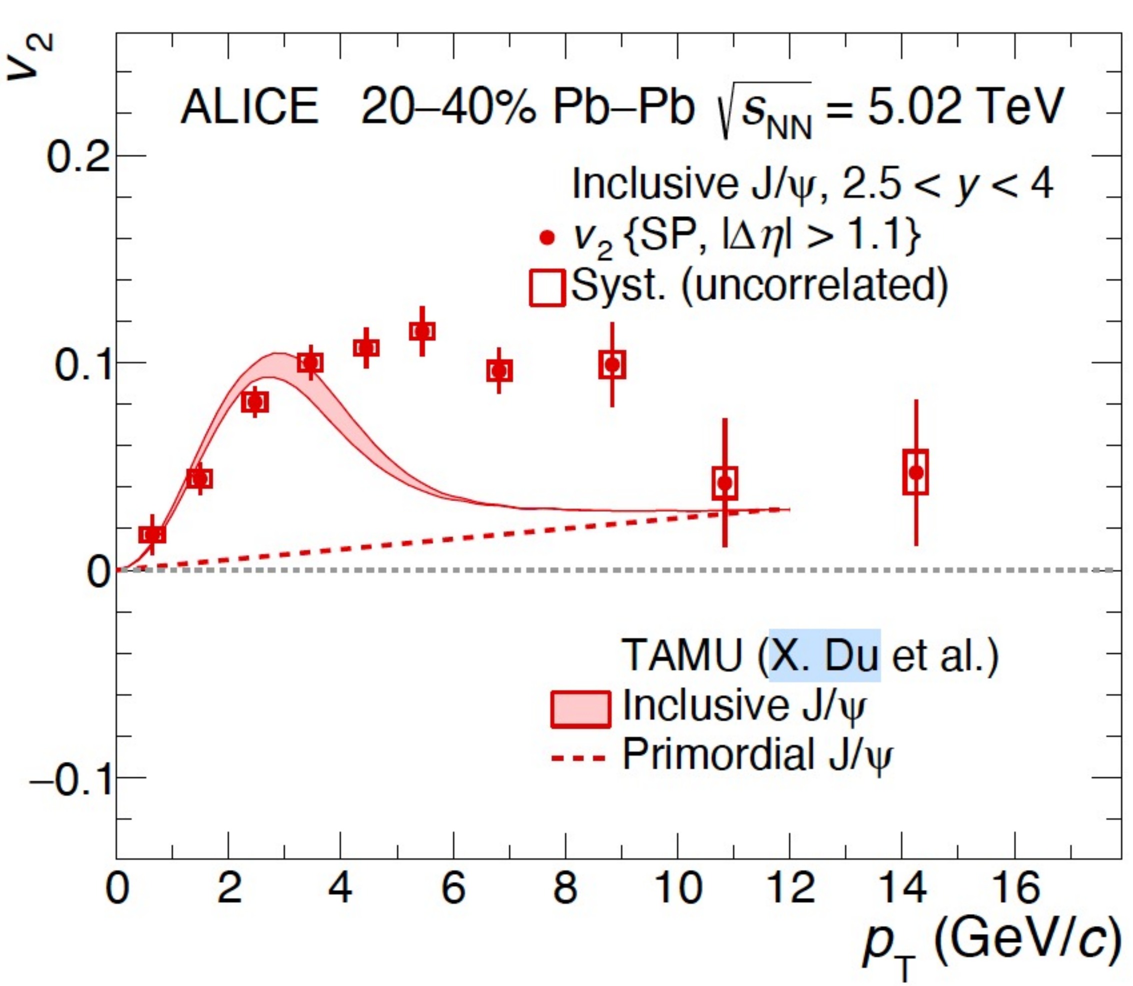
Strong tensions at mid- p_T but some coherent features:

- Increase at low- p_T (recombined c quarks)
- Decrease at high- p_T (less recombination)
- Non-0 asymptote (only path-length dependence in primordial J/ψ bring a small v_2)

Data (low- p_T) shows that J/ψ regenerates

Bad description of the p_T-dependence at mid-p_T

- Missing mechanism ?

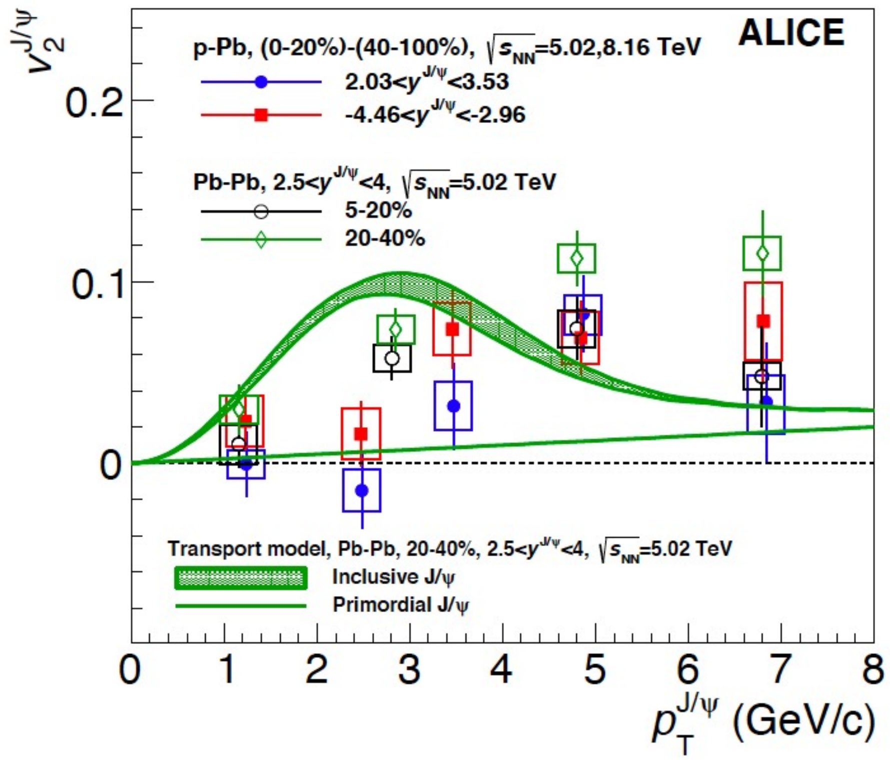


p-Pb, exploration of smaller systems

ALICE (Run2, inclusive, 5.02 and 8.16 TeV)

[arXiv:1709.06807]

- $v_{2,J/\psi} > 0$ ($> 5\sigma$) for $3 < p_T < 6$ GeV/c
- Values in p-Pb close to Pb-Pb, suggests common mechanism
- Low-p_T v_2 compatible with 0 : barely any recombination in p-Pb
- Should be no sizeable v_2 from path-length dependence

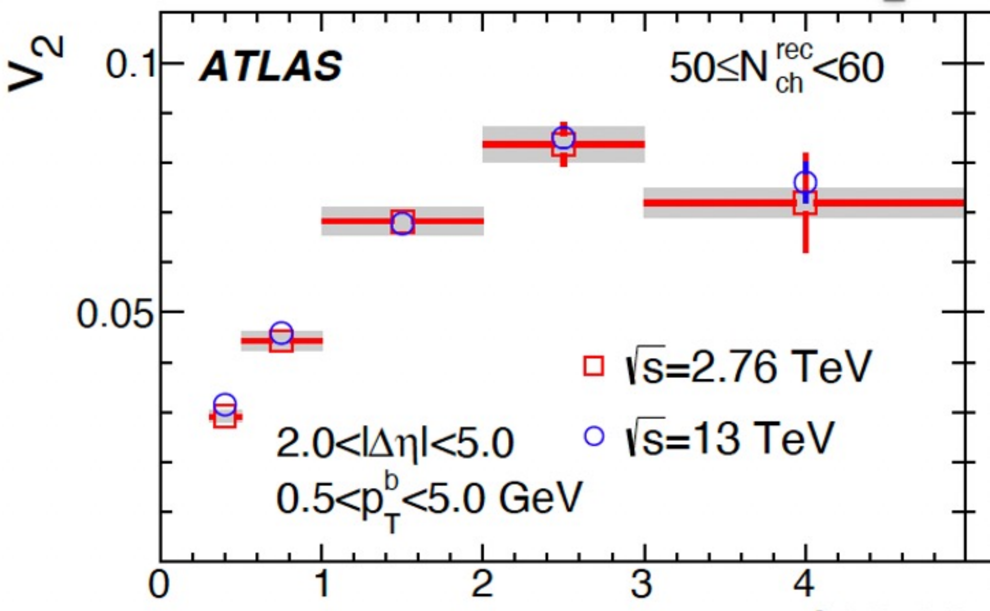


Hints in p-p

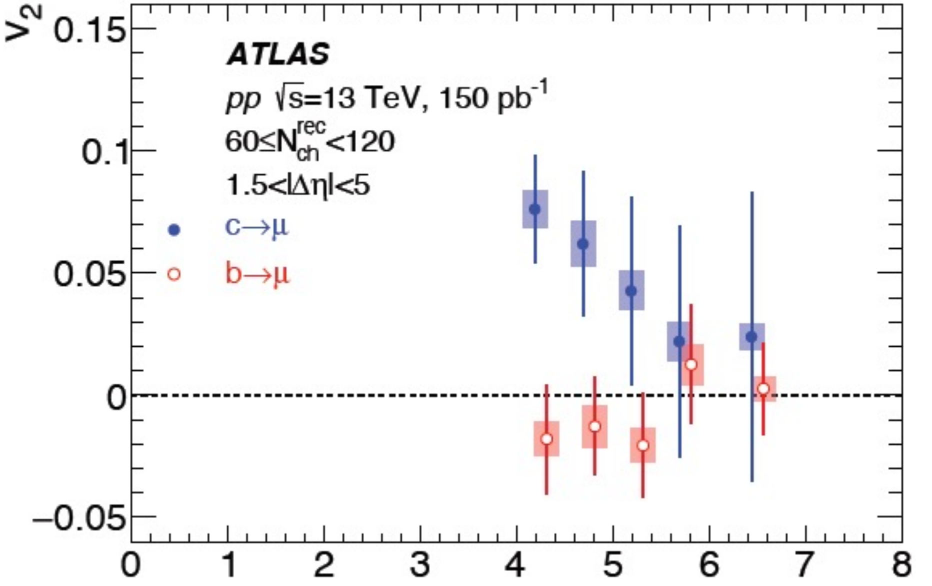
- Charged particles v_2 (ATLAS, CMS)
- Similar trend with p-A and A-A collisions
  - Similar mechanism ?

- c and b through muon decay (ATLAS)
- b-hadrons v_2 consistent with 0
- c-hadrons $v_2 > 0$. Is c flowing or are only lighter quarks flowing ?

Need to study J/ψ p-p flow to determine if c flows or not !



[arXiv:1509.04776]



[arXiv:1909.01650]

Analysis procedure (from p-Pb analysis) 1/2

- Separate high and low multiplicity collisions (“central” and “peripheral”)
  - Make pairs of particles: dimuon-tracklet or tracklet-tracklet

(tracklet: charged particle track in the central barrel, whereas J/ψ observed through dimuon decay in forward spectrometer)

  - Measure particle correlations with respect to Δη (pseudorapidity) and $\Delta\phi$ (azimuthal angle)

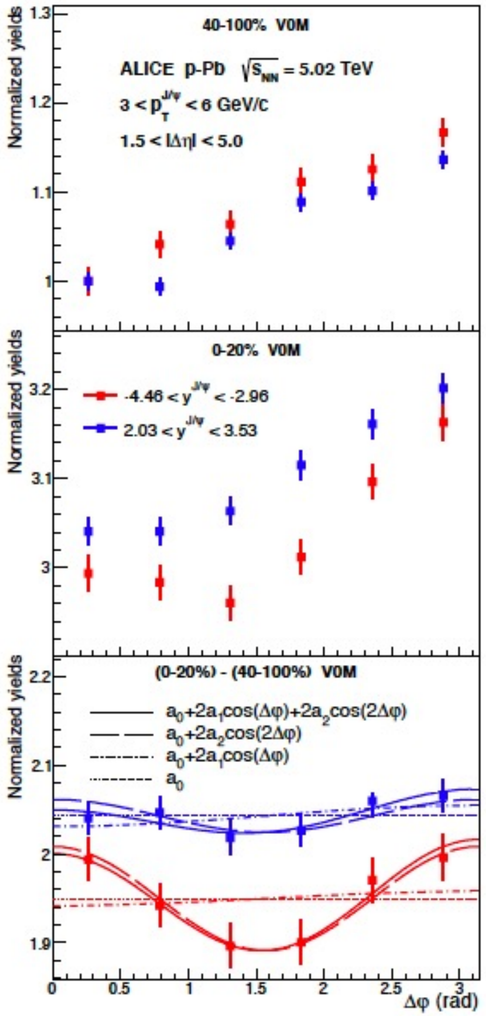
  - Compute “per trigger yields”*

$$* \quad Y^i(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu}, \Delta\varphi, \Delta\eta) = \frac{1}{N^i_{\mathrm{trig}}(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu})} \frac{\mathrm{d}^2 N^i_{\mathrm{assoc}}(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu})}{\mathrm{d}\Delta\varphi \mathrm{d}\Delta\eta}$$

$$= \frac{1}{N^i_{\mathrm{trig}}(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu})} \frac{SE^i(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu}, \Delta\varphi, \Delta\eta)}{ME^i(z_{\mathrm{vtx}}, M_{\mu\mu}, p_{\mathrm{T}}^{\mu\mu}, \Delta\varphi, \Delta\eta)},$$

Number of associated particle pairs found in a bin of Δη, $\Delta\phi$, z_{vertex}, invariant mass, p_t, centrality

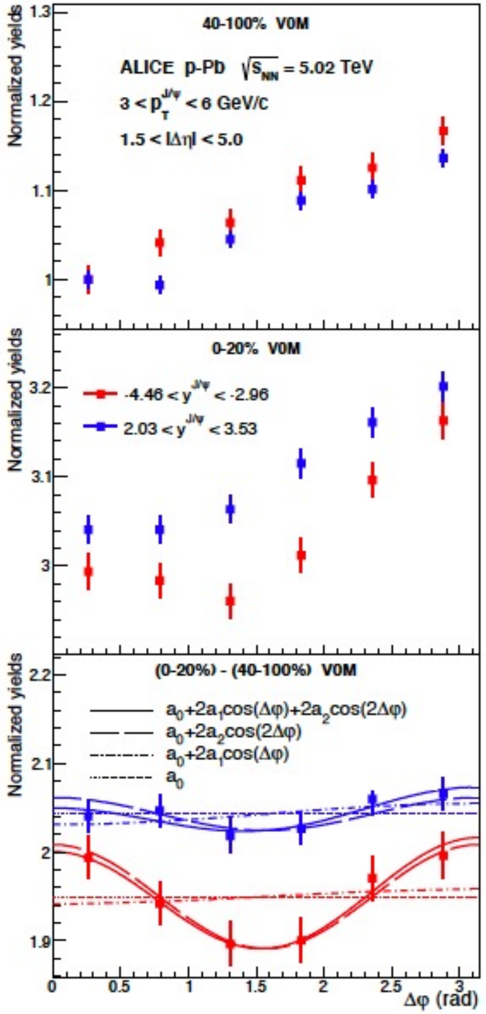
Number of reference particles triggered on in a bin of z_{vertex}, invariant mass, p_t, centrality



ALICE, p-Pb publication [arXiv:1709.06807]

Analysis procedure (from p-Pb analysis) 2/2

- Getting rid of non-flow effects (eg. Jets)
  - Suppose non-flow is centrality independent
  - Subtract Central and Peripheral yields to get rid of non flow-effects
  - Fourier analysis of subtracted Yields $\frac{dN^{pairs}}{d\Delta\phi} \propto (1 + \sum_{n=1}^{\infty} 2v_n^2 \cos(n\Delta\phi)).$
  - Measure $V_{2,tracklet-J/\psi} = v_{2,J/\psi} * v_{2,tracklet}$
  - Measure $V_{2,tracklet-tracklet} = v_{2,tracklet}^2$
  - Deduce $v_{2,J/\psi} = \frac{V_{2,tracklet-J/\psi}}{\sqrt{V_{2,tracklets}}}$

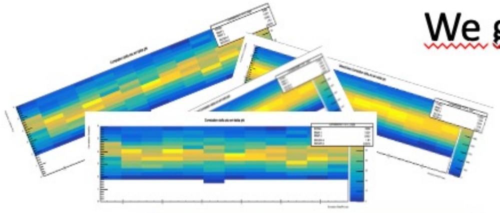


ALICE, p-Pb publication [arXiv:1709.06807]

Step by step

From Correlations to Yields

We get rid of the z_{vertex}, the detector acceptance, and the Δη dependencies



Correlations SE and ME

- Δη and $\Delta\phi$
- Bins of C, mass, p_t, z_{vertex}

Normalisation of ME

Summation on z_{vertex}

- Project SE and ME on $\Delta\phi$ axis
- Divide and sum over z_{vertex}

Yields

- Wrt $\Delta\phi$
- Bins of C, mass, p_t

– Each $M_{ijk}(\Delta\phi, \Delta\eta)$ is projected on the $\Delta\eta$ axis. The normalization factor is then obtained as the maximum value of $M_{ijk}(\Delta\eta)$. This method is quite similar to the one used in the muon-hadron correlation analysis. It is the default one used in the present analysis;

2. "Summing method 2". In the second method of combining z_{vertex} bins the Y_{ijk} yields are obtained in the following way. First, each $S_{ijk}(\Delta\phi, \Delta\eta)$ and $M_{ijk}(\Delta\phi, \Delta\eta)$ are projected on the $\Delta\phi$ axis by summing within the chosen range of $\Delta\eta$. The, the per-trigger yields are obtained as:

$$Y_{ik}(\Delta\phi) = \frac{1}{\sum_j N_{\text{trig}}^{ijk}} \sum_j \frac{S_{ijk}(\Delta\phi)}{M_{ijk}(\Delta\phi)} \quad (5)$$

From Yields to V_2 Methods pPb-like (dimuon-tkl)

- To get from Yields to V_2 there are 2 steps:
  - **Separating signal** and background (on mass dependent plots)
  - **Subtracting** central and peripheral and extracting **Fourier** coefficients (on $\Delta\phi$ dependent plots)

Do these steps in either order

Method 1: Yields wrt mass ($\Delta\phi$ bins) > **Extract** Signal Yield wrt $\Delta\phi$ > **Subtract** Central and Peripheral > Fourier

Method 2: Yields wrt $\Delta\phi$ (Mass bins) > **Subtract** Central and Peripheral > Fourier wrt mass > **Extract** Signal V_2

Various methods of V2 extraction

- pPb-like - $Fourier\ analysis\ of\ \boldsymbol{Y_C - Y_P}$
- ZYAM – Similar to pPb but the baselines are subtracted from the yields

$$Fourier\ analysis\ of\ (\boldsymbol{Y_C - B_C}) - (\boldsymbol{Y_P - B_P})$$

(similar to p-Pb, just changes the calculations to get to V_2)

Template fits: $\boldsymbol{Y_C = A(ridge) + F * Peripheral\ yields}$

- Template fit – ATLAS (preferred) [PRL – 116,172301 (2016)]
  - G is a fixed parameter to ensure the integrals on both side of the equation are the same

$$Fit\ of\ \boldsymbol{Y_C = G(1 + 2v_{2,2}\cos(2\Delta\phi)) + F * Y_P}$$

Assumption that v_1 is non flow that you suppress using the F factor

- Template fit + Peripheral ZYAM – ATLAS (biased) [PRL – 116,172301 (2016)]

$$Fit\ of\ \boldsymbol{Y_C = G(1 + 2v_{2,2}\cos(2\Delta\phi)) + F * (Y_P - B_P)}$$

- Template fit - by Quentin and Cvetan

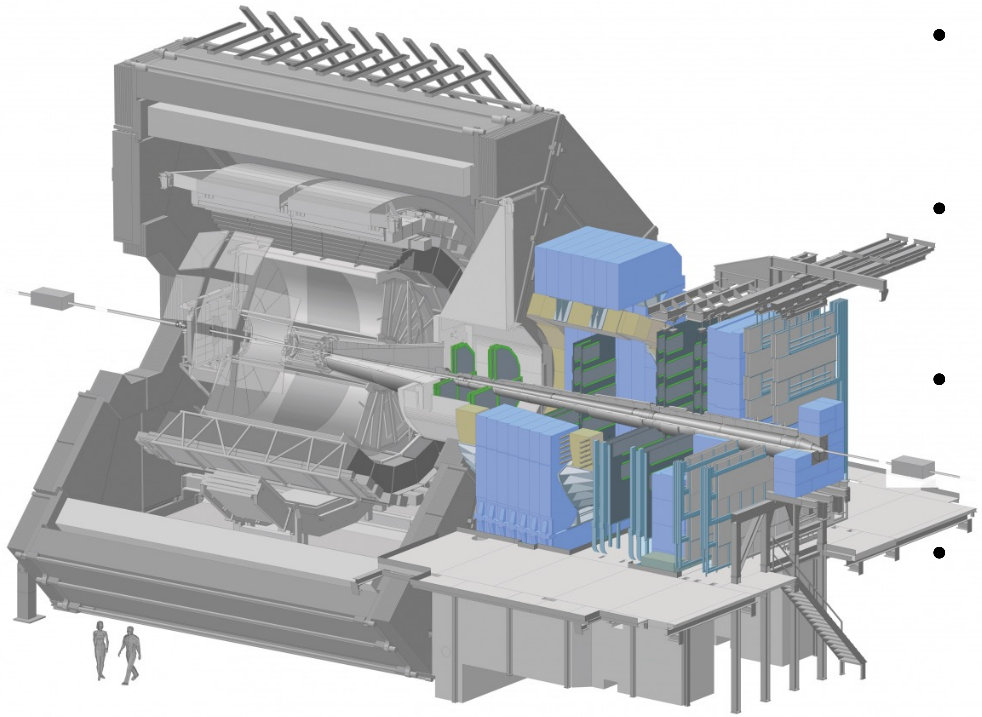
$$Fit\ of\ \boldsymbol{Y_C = B_C(1 + 2v_{2,2}\cos(2\Delta\phi)) + F * (Y_P - B_P)}$$

Outlook on J/ψ flow pp analysis

- Understand why the ATLAS Template fit gives an outlier result
- Use other centrality estimators to define centrality classes and see how it impacts the values
- Do checks using p-Pb data and ALICE results, and cumulants computation
- Do the whole systematics study (signal extraction, summation methods, normalisations, centrality classes, binnings)

Quality Control (QC) and Muon Spectrometer Commissioning

Commissioning ALICE Muon Spectrometer



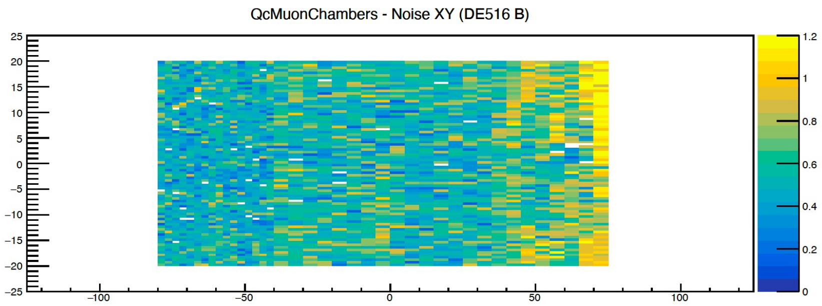
- Forward detector
  (-4 < y < -2.5)
- Front absorber and trigger chambers
- 5 stations of 2 detection chambers each
- A dipole magnet (3 T.m) for p_T identification

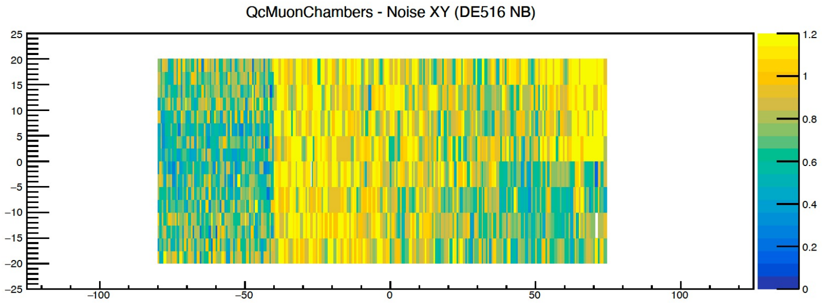
Electronics and readout being upgraded within ALICE Upgrade during LS2 (up until next year)
MCH needs to be commissioned (installation and quality control of the detectors)

Quality Control

- During commissioning: Checking noise and pedestals levels of the detectors
- During Run 3: Monitoring various observables to ensure proper functionning of the detectors

Interesting observables to monitor



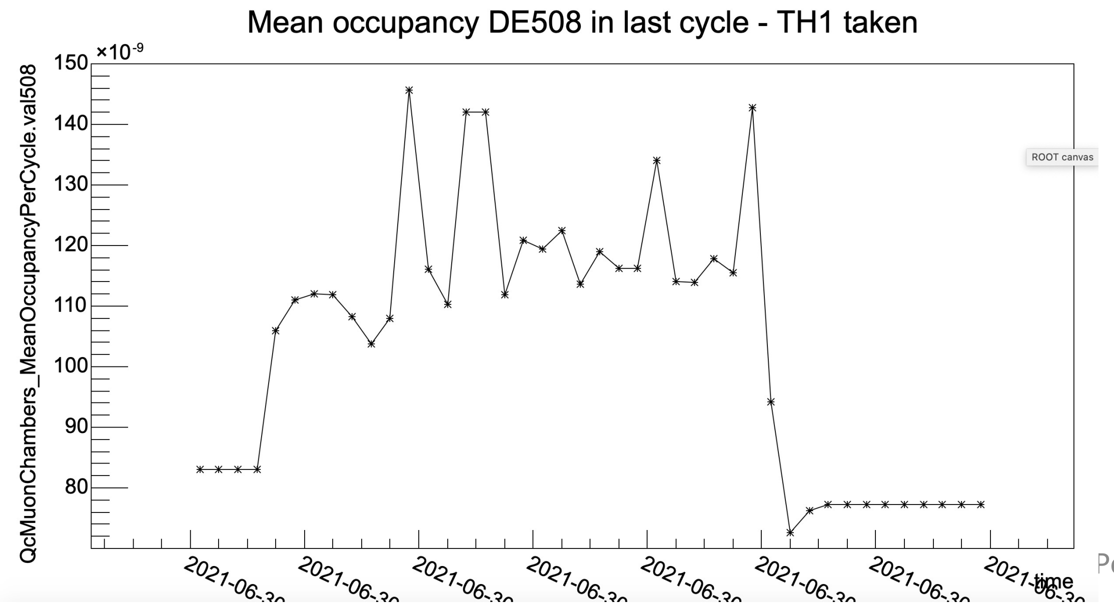


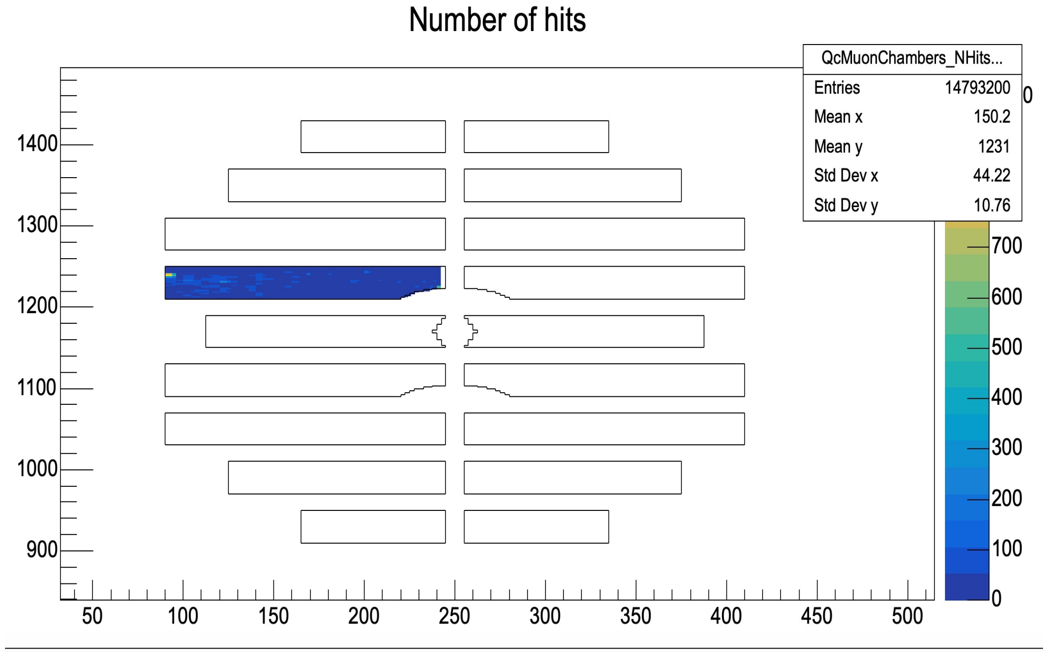
During commissioning:

- Runs on noise data
- Displays the noise and pedestal values of each channel
- Check: identification of noisy channels (info to be sent to mask them)

During Run 3:

- Error checker (check readout errors on raw data)
- Monitor detector occupancy, efficiency, deposited charge
- Trending of values over time





Conclusion

Analysis (J/ψ v_2 in pp)

Searching for collective behaviour in small systems
Ongoing work (checks, systematics, etc.)

MCH Commissioning

Ongoing work on Quality Control development

- Development of tasks and tools to monitor the detectors
- Used for noise and pedestal studies and for Run 3 data taking

Work on clustering algorithms

- Porting of simple algorithms
- Checks on Test Beam data
- Ongoing work in the collaboration to develop more complex clusterings and improve the results

Thank you for your attention !