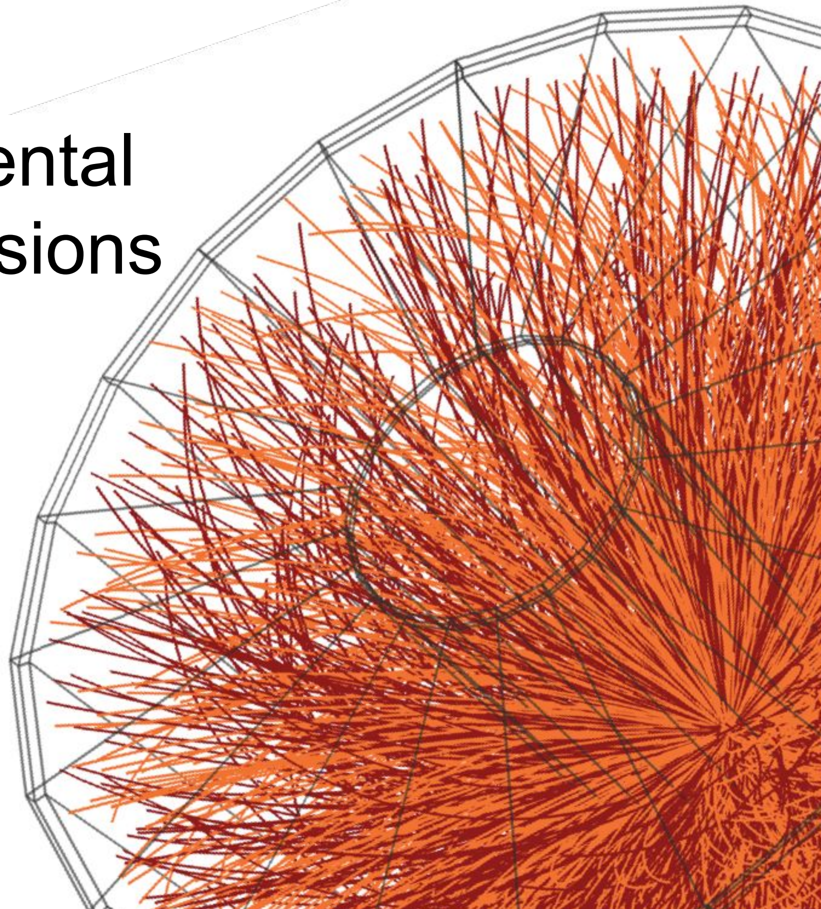
Understanding biases in experimental multiplicity estimations for pp collisions at the LHC

Adrian Nassirpour

Sejong University

ATHIC 2025
Gopalpur
Jan 15th, 2025



A bit of a disclaimer

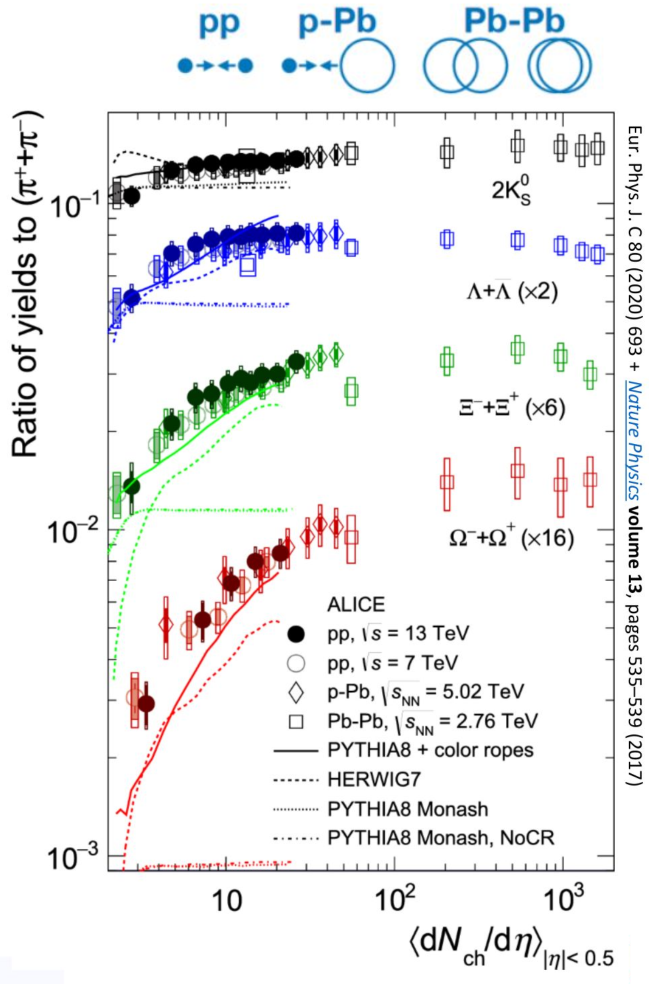
- This talk will not be particularly groundbreaking…
  - No new results will be shown.

- This talk is more intended to be a PSA
  - Idea is to create grounds for discussion

Strangeness Enhancement

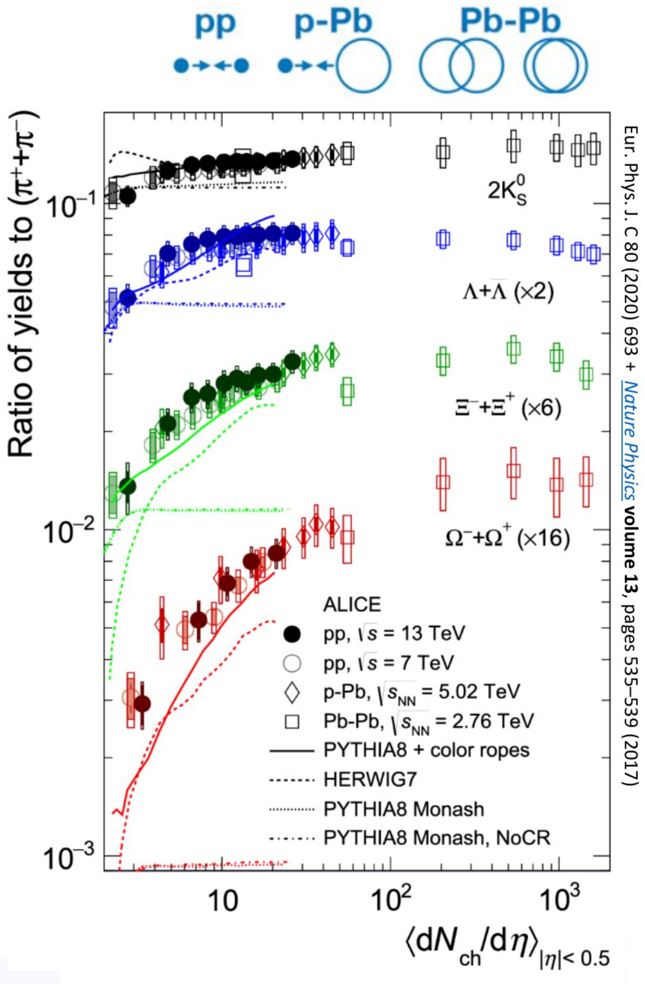
- One of the first suggested QGP observables:

  an abundance of strange hadrons



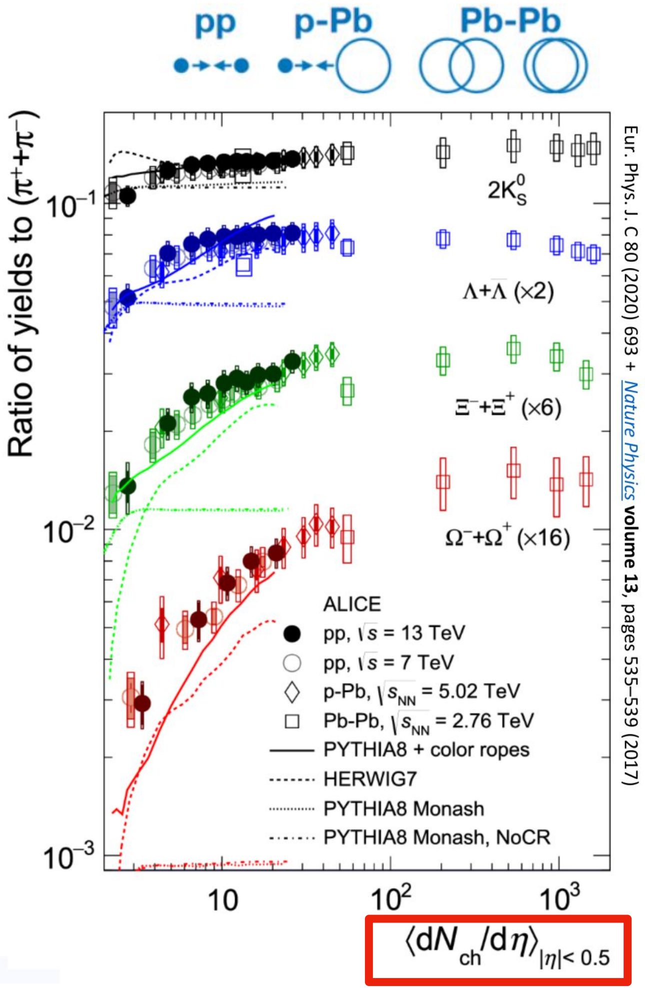
Strangeness Enhancement

- One of the first suggested QGP observables: **an abundance of strange hadrons**
- For now, I'm not interested in discussion the physics persay…
  - Instead: let's focus on the x-axis



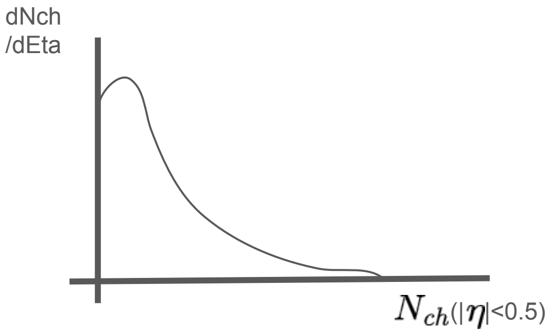
Strangeness Enhancement

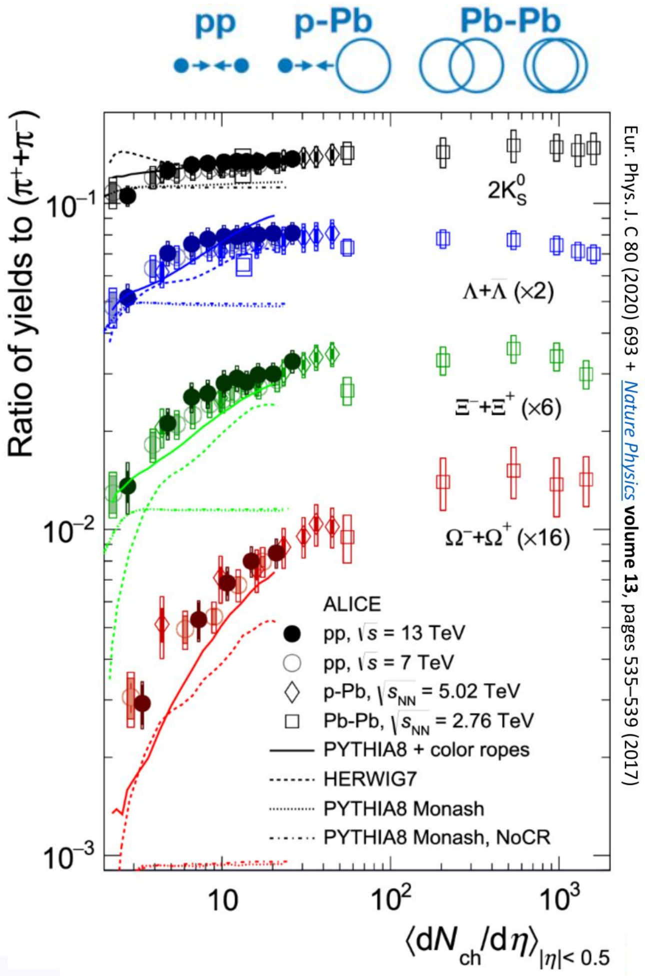
- One of the first suggested QGP observables: **an abundance of strange hadrons**
- For now, I'm not interested in discussion the physics persay…
  - Instead: let's focus on the x-axis
- How many people here understand this?
  - In particular, people not from ALICE?



Multiplicity Selections

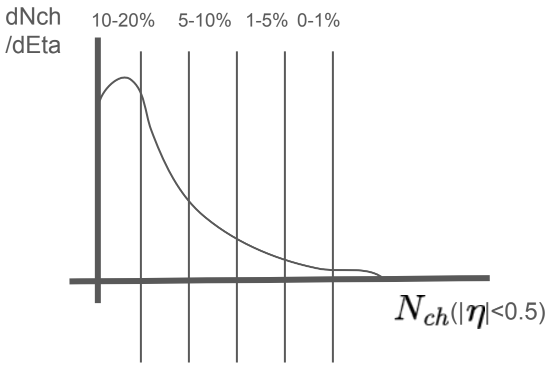
- Intuitive approach
  - Simply the number of charged particles measured at midrapidity

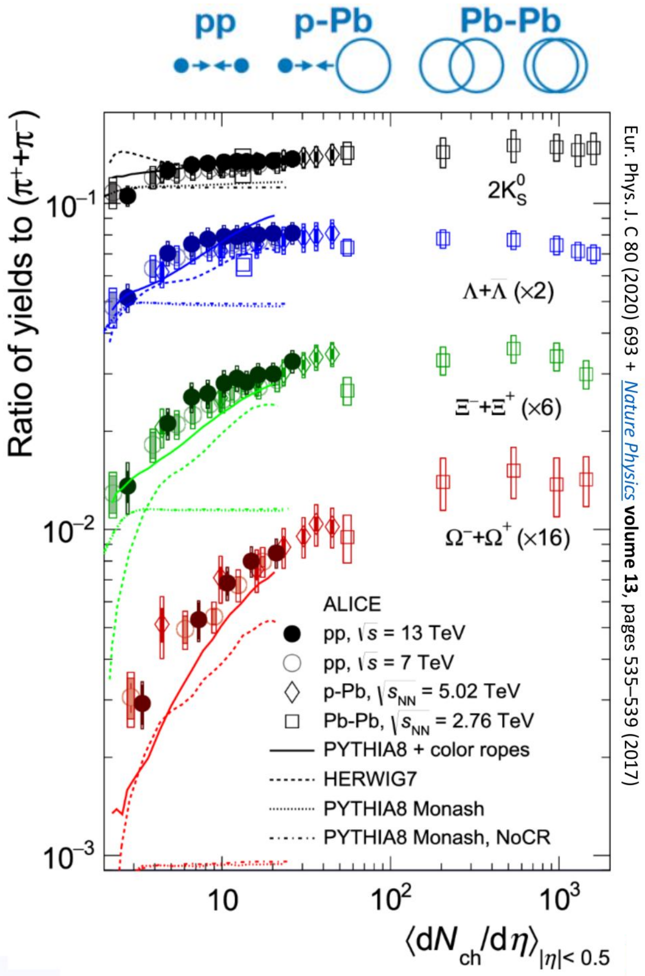




Multiplicity Selections

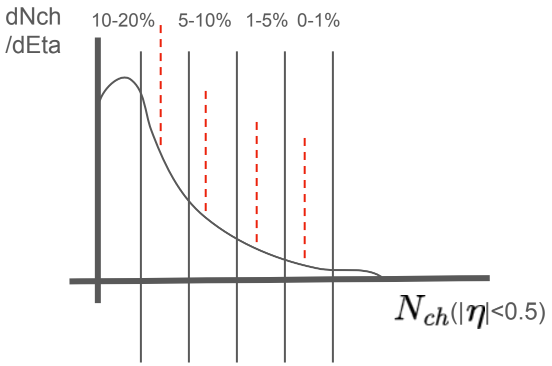
- Intuitive approach
  - Simply the number of charged particles measured at midrapidity

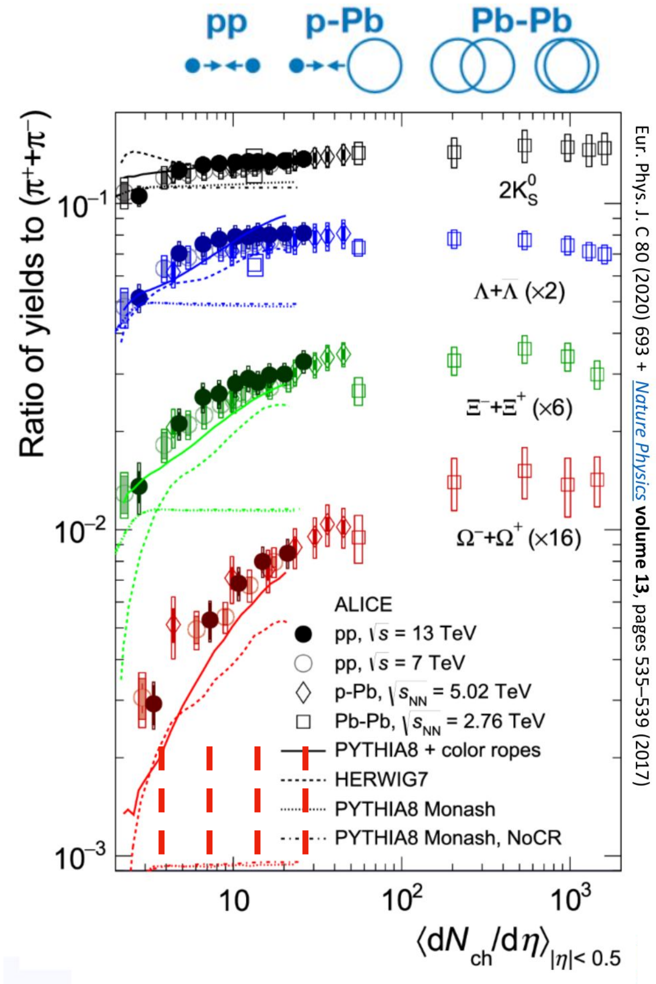




Multiplicity Selections

- Intuitive approach
  - Simply the number of charged particles measured at midrapidity

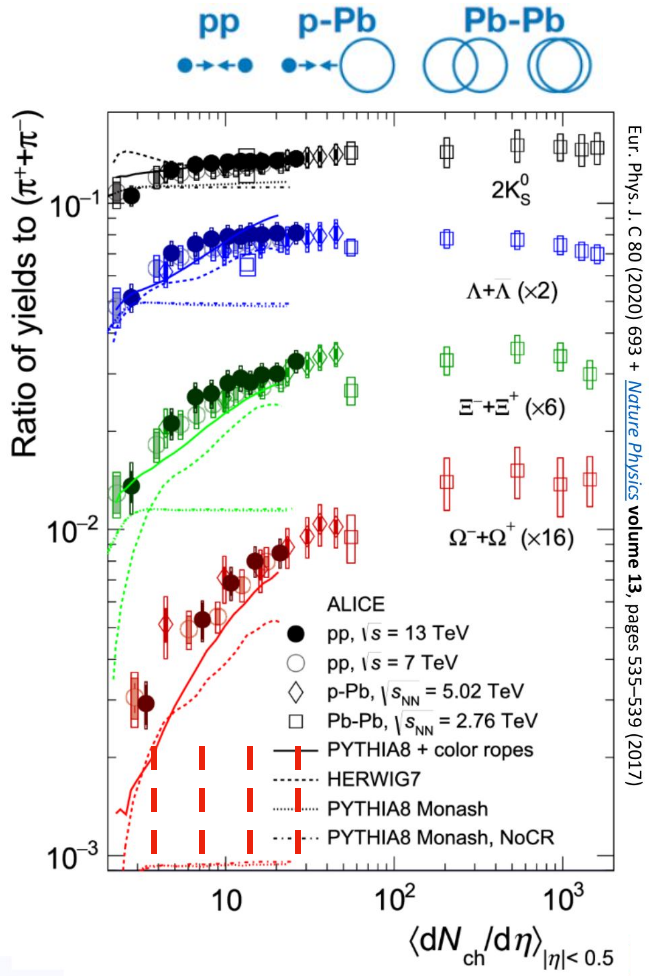




Multiplicity Selections

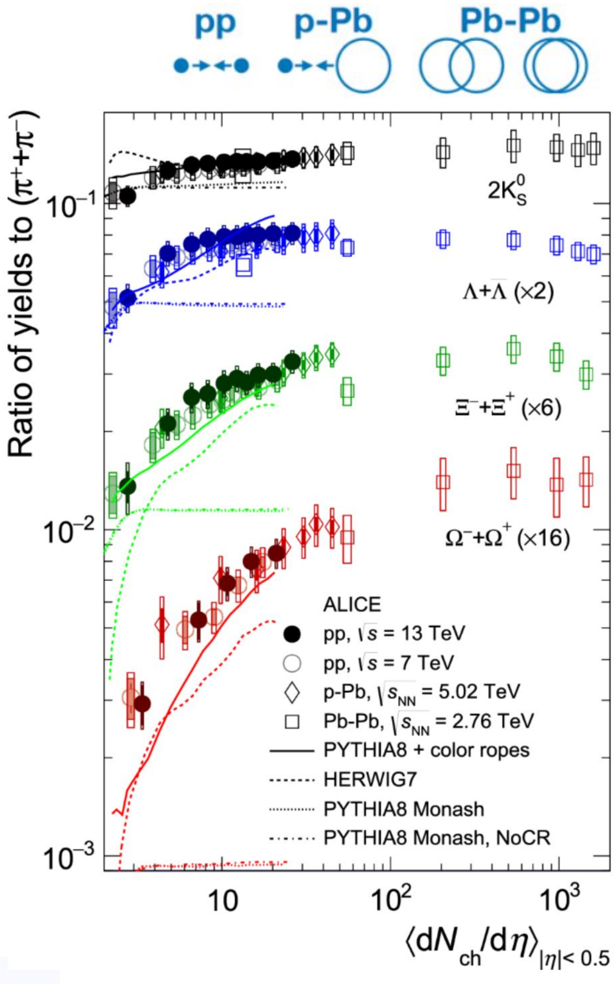
- Intuitive approach
  - Simply the number of charged particles measured at midrapidity

THIS IS WRONG



Multiplicity Selections

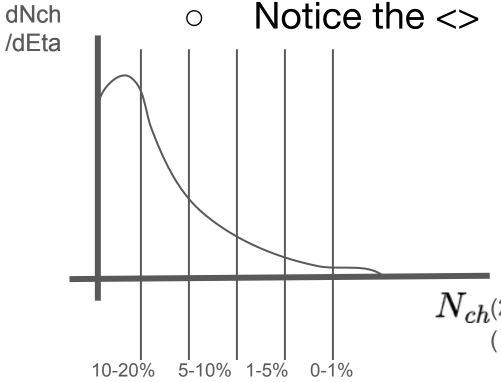
- Intuitive approach
  - Simply the number of charged particles measured at midrapidity
- Less intuitive approach
  - Notice the <>



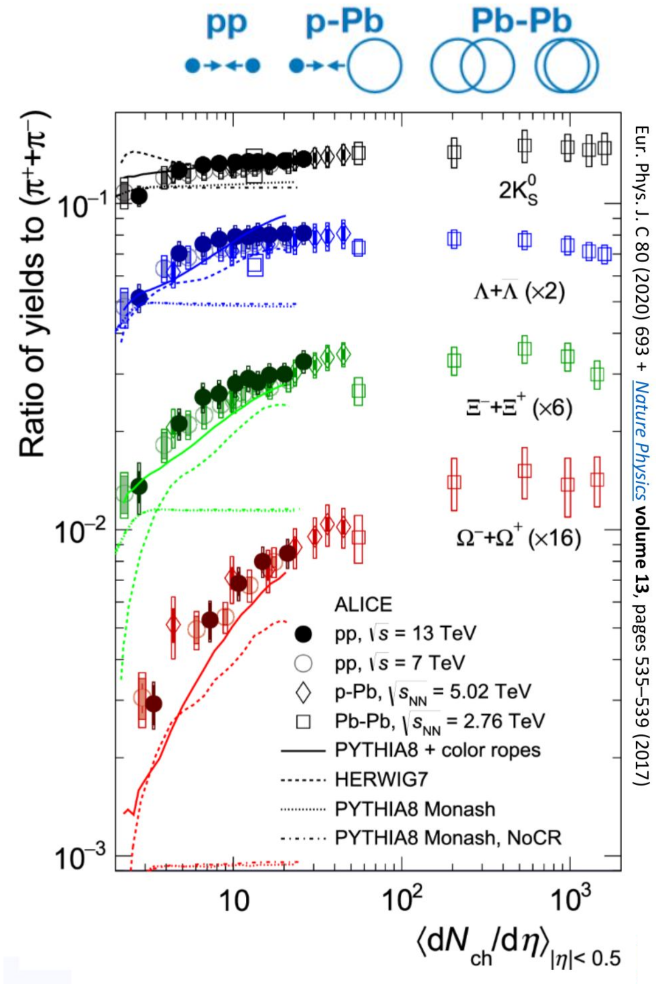
Eur. Phys. J. C 80 (2020) 693 + *Nature Physics* **volume 13**, pages 535–539 (2017)

Multiplicity Selections

- Intuitive approach
  - Simply the number of charged particles measured at midrapidity
- Less intuitive approach
  - Notice the <>

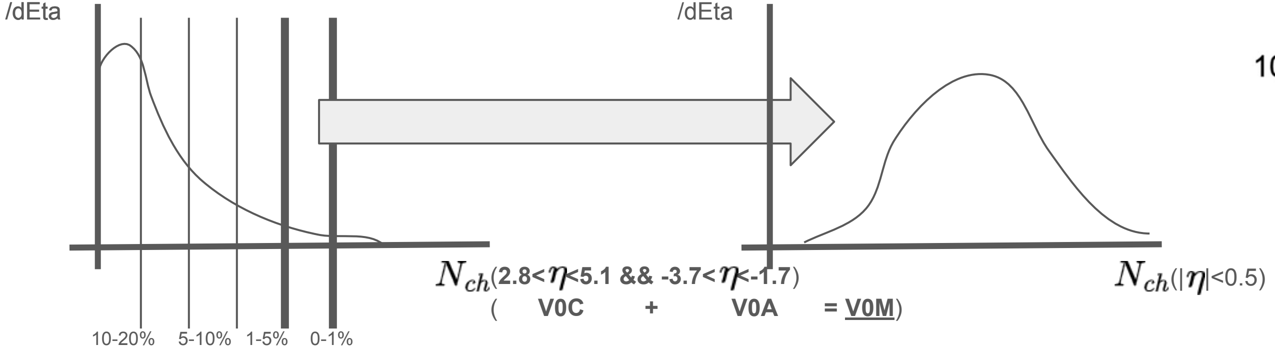


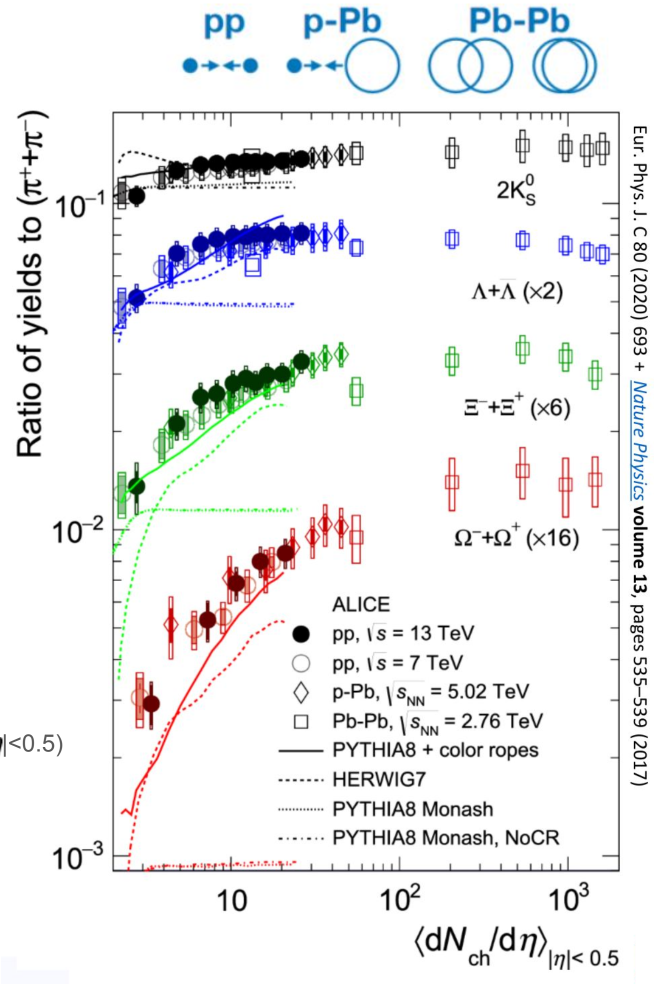
N_{ch}(2.8<η<5.1 && -3.7<η<-1.7)
(V0C + V0A = V0M)



Multiplicity Selections

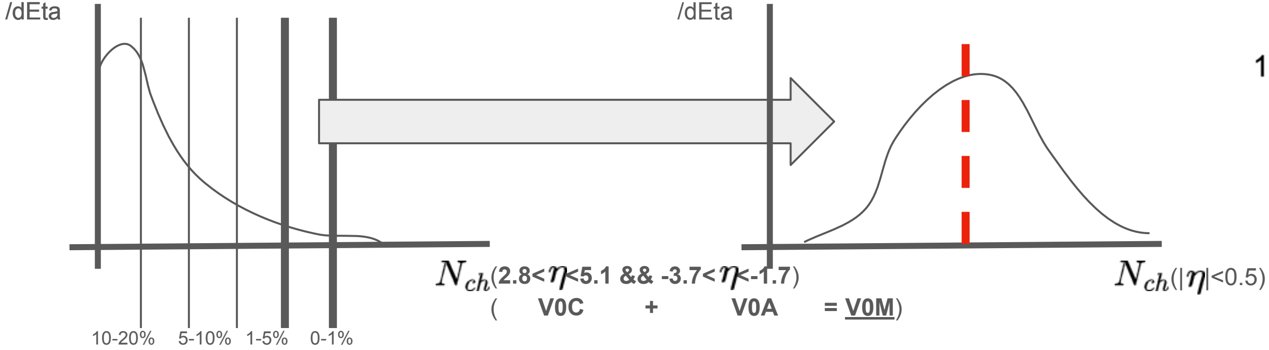
- Intuitive approach
  - Simply the number of charged particles measured at midrapidity
- Less intuitive approach
  - Notice the <>

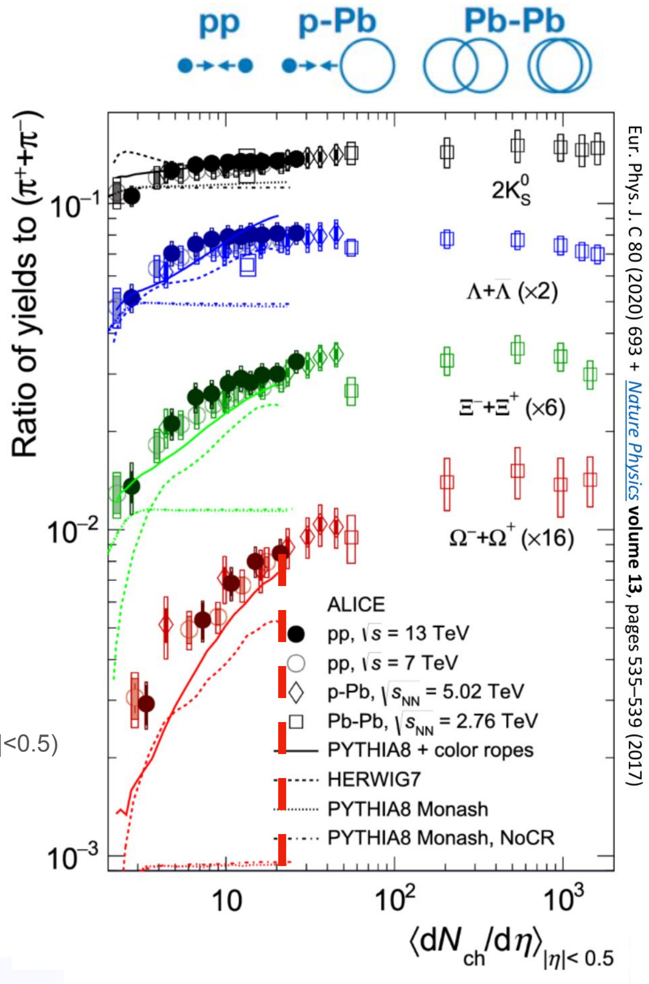




Multiplicity Selections

- Intuitive approach
  - Simply the number of charged particles measured at midrapidity
- Less intuitive approach
  - Notice the <>

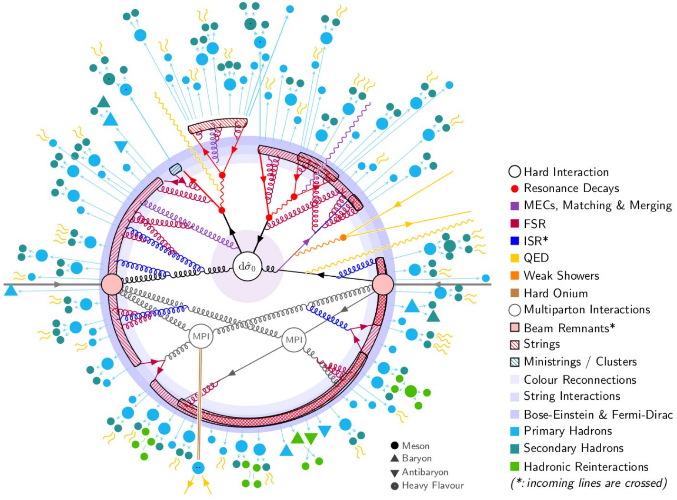


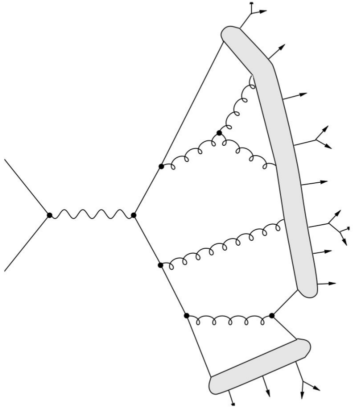


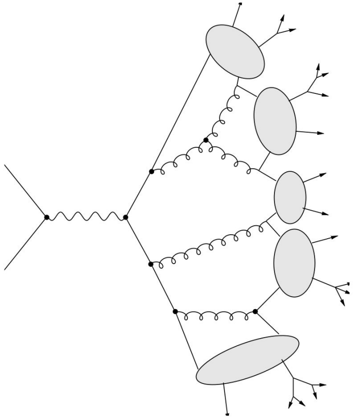
Multiplicity Selections

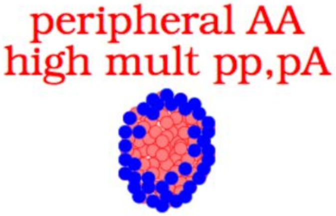
- But why is this done?

- Autocorrelations: Local fluctuations (jets) bias toward your multiplicity region
  - Depending on your phenomenology; pp collisions are complicated….
  - Combination of correlated vs. uncorrelated production









Multiplicity Selections

- But why is this done?

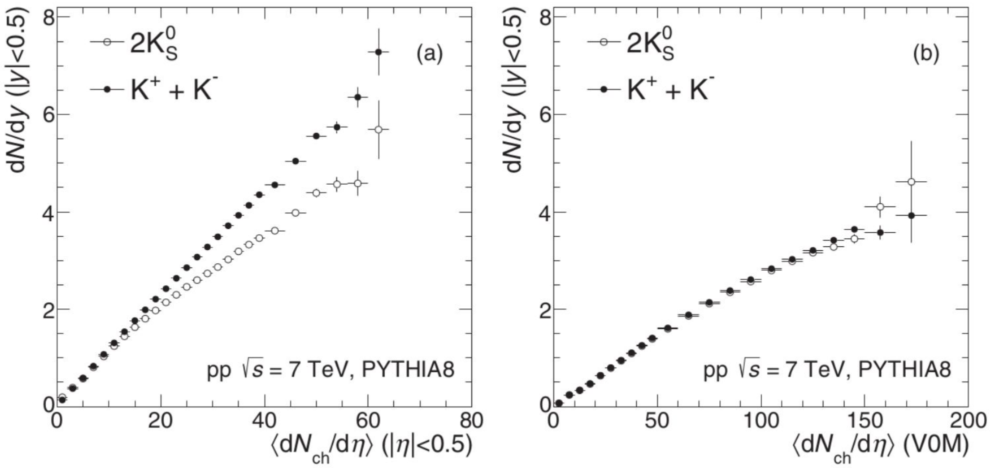
- Autocorrelations: Local fluctuations (jets) bias toward your multiplicity region
  - Depending on your phenomenology; pp collisions are complicated….
  - Combination of correlated vs. uncorrelated production

- Charged particle bias:

  Hadrochemistry is uneven

- The jury is in: V0M is superior?

Phys. Rev. C 99, 024906 (2019), 1807.11321



Main takeaway

- Main takeaway from this talk:
  - If your multiplicity is produced from multiple processes which fluctuate…
  - …you cannot select multiplicity in an unbiased way!!
    - Simply not possible

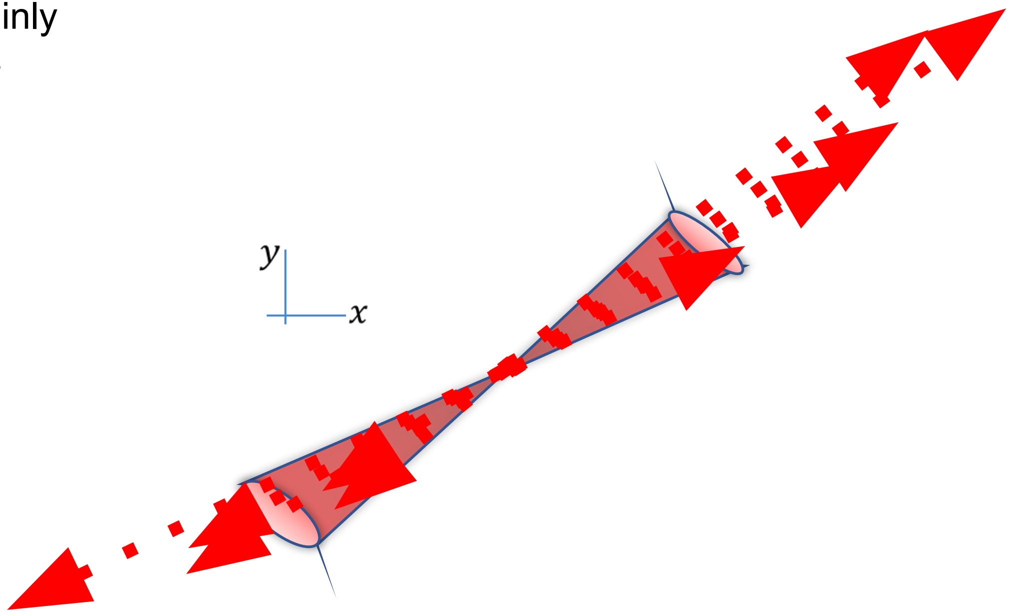
- Name of the game: UNDERSTAND the biases, and use it to your advantage
  - These “biases” can constrain physics; might not be trivially correlated
  - Likewise for V0M, it is not perfect in this sense

Controlling the fluctuations: Transverse Spherocity

- Idea is to classify high-multiplicity events based on event topology

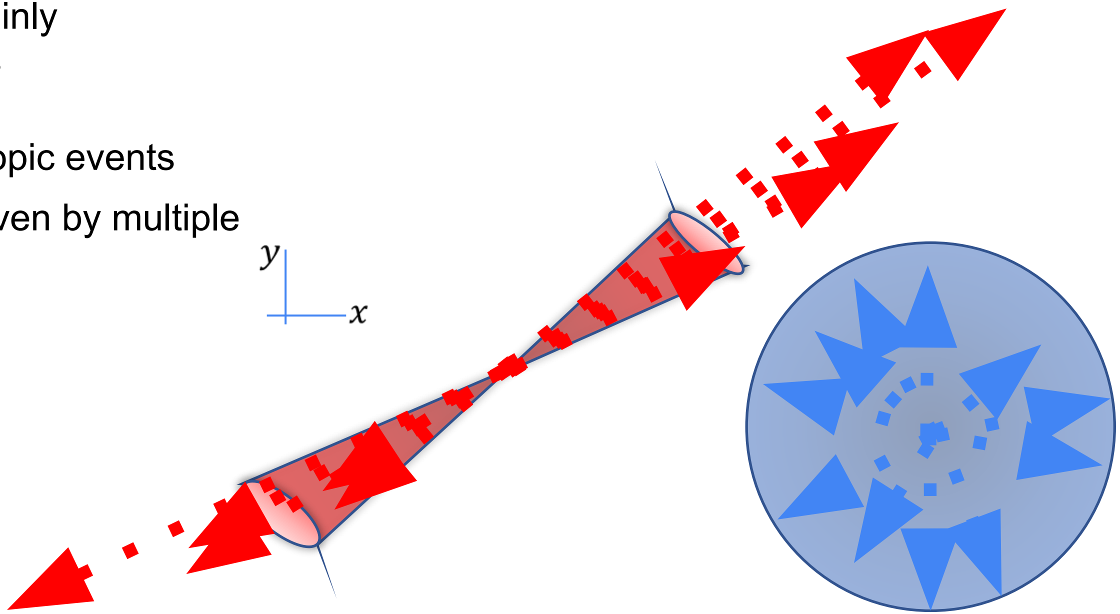
Controlling the fluctuations: Transverse Spherocity

- Idea is to classify high-multiplicity events based on event topology
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics



Controlling the fluctuations: Transverse Spherocity

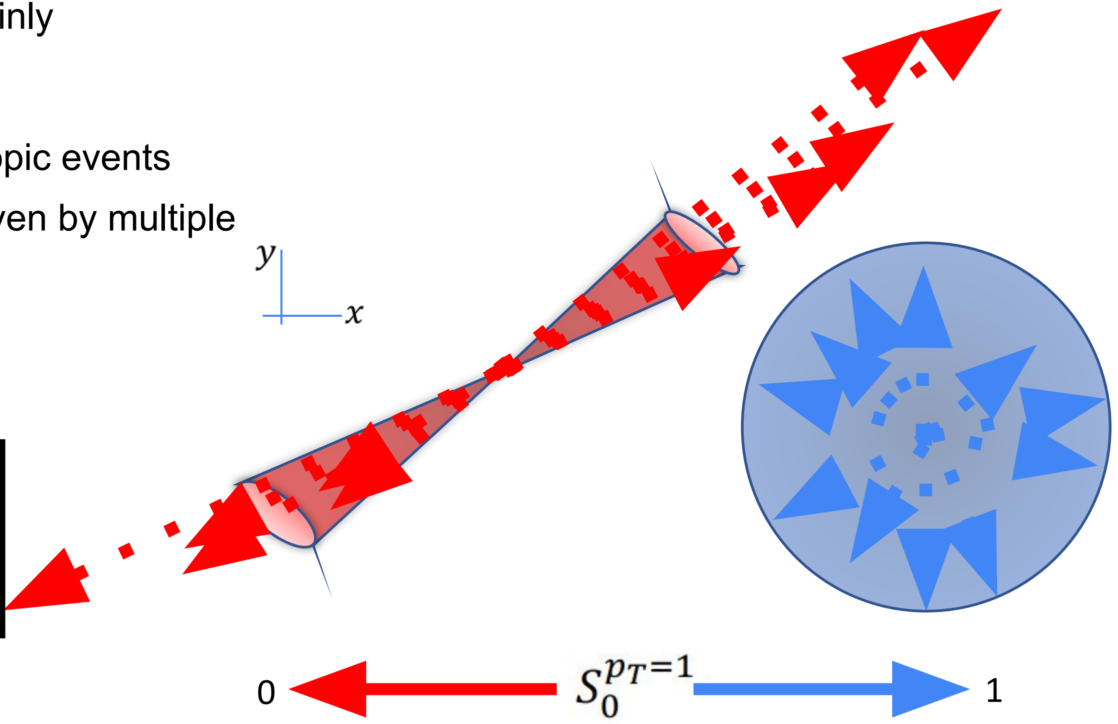
- Idea is to classify high-multiplicity events based on event topology
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions



Controlling the fluctuations: Transverse Spherocity

- Idea is to classify high-multiplicity events based on event topology
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}} \right)$$

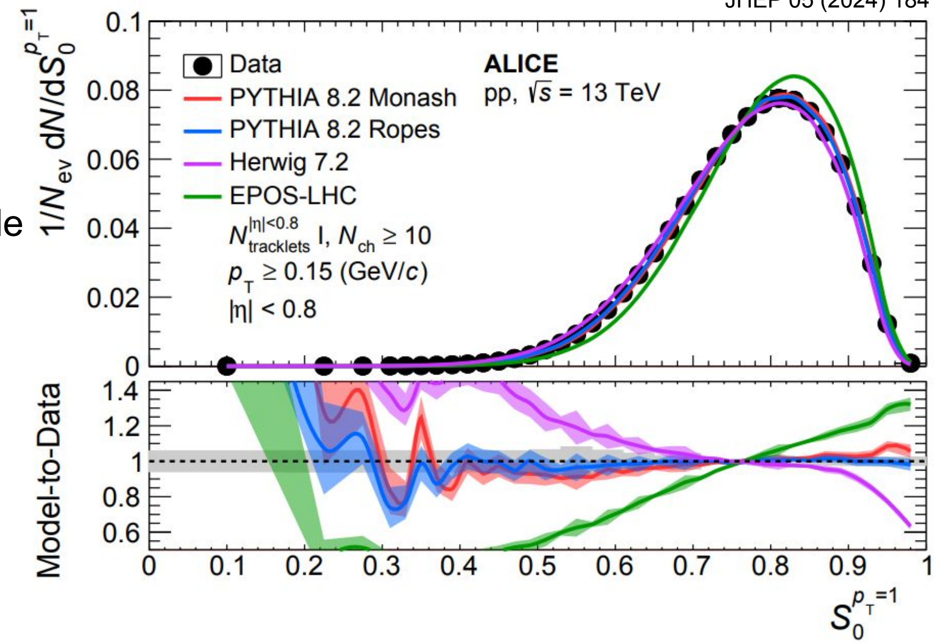


Controlling the fluctuations: Transverse Spherocity

- Idea is to classify high-multiplicity events based on event topology
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions

$$S_0^{p_T=1} = \frac{\pi^2}{4}\min_{\hat{n}}\left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}}\right)$$

JHEP 05 (2024) 184



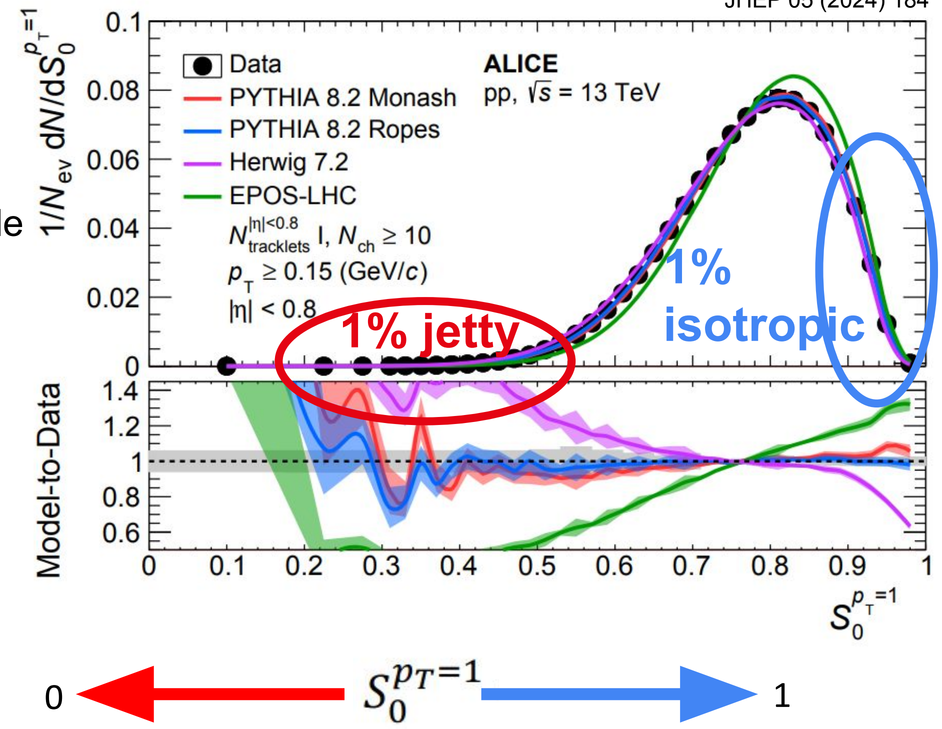
0 ← $S_0^{p_T=1}$ → 1

Controlling the fluctuations: Transverse Spherocity

- Idea is to classify high-multiplicity events based on event topology
  - **Jetty:** Back-to-Back "jet-like" events
    - Particle production mainly driven by hard physics
  - **Isotropic:** Azimuthally isotropic events
    - Particle production driven by multiple softer collisions

$$S_0^{p_T=1} = \frac{\pi^2}{4} \min_{\hat{n}} \left(\sum_i \frac{|\widehat{p_{\mathrm{T},i}} \times \hat{n}|}{N_{\mathrm{trk}}} \right)$$

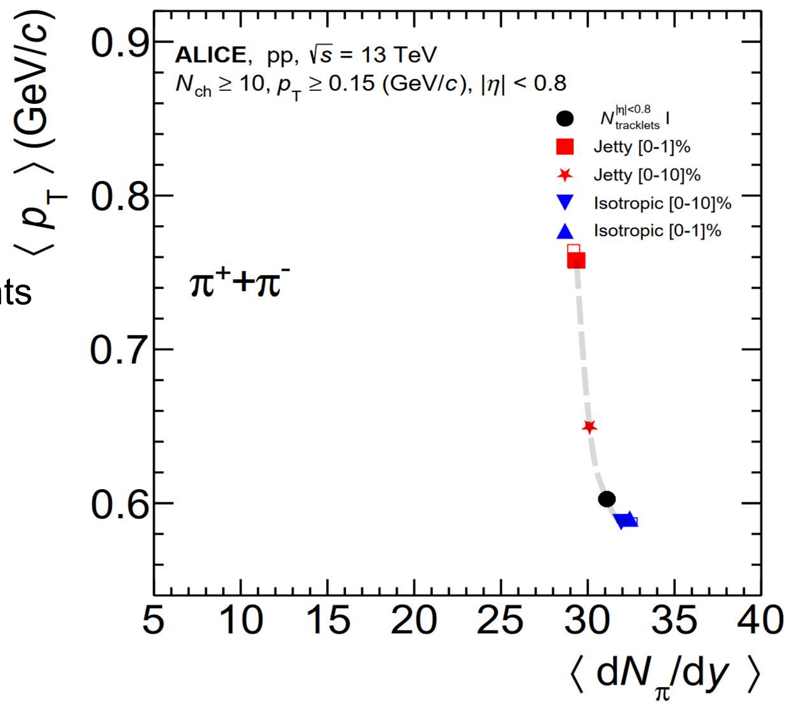
JHEP 05 (2024) 184



Controlling the fluctuations: Transverse Spherocity

- This topological selection can be used with a multiplicity selection to “control” the physics selection
  - With a midrapidity multiplicity selection
    - Large shift in <p_T>
    - Very small (~10%) shift in yield
    - Our jet-like selection is able to capture events that are significantly harder than average

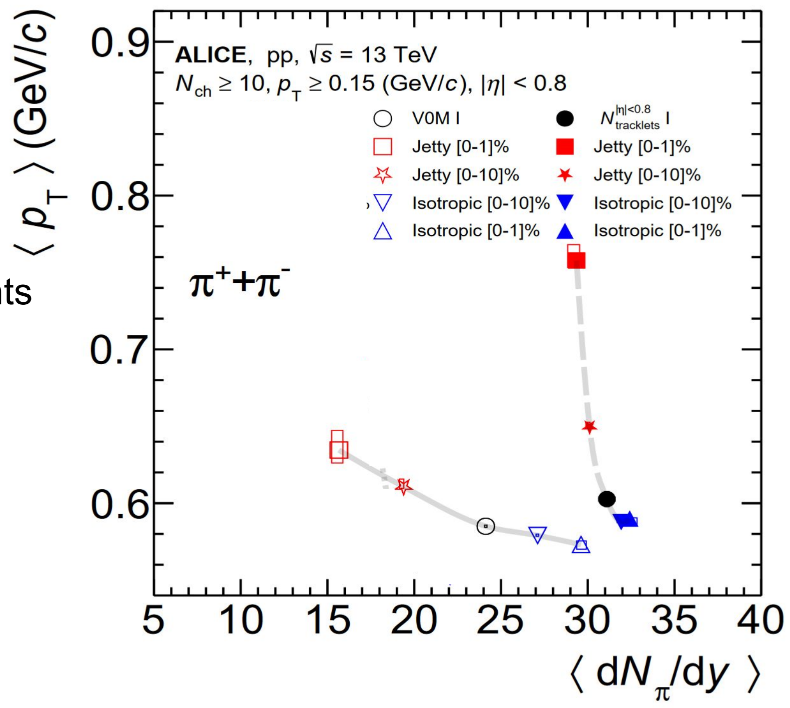
JHEP 05 (2024) 184



Controlling the fluctuations: Transverse Spherocity

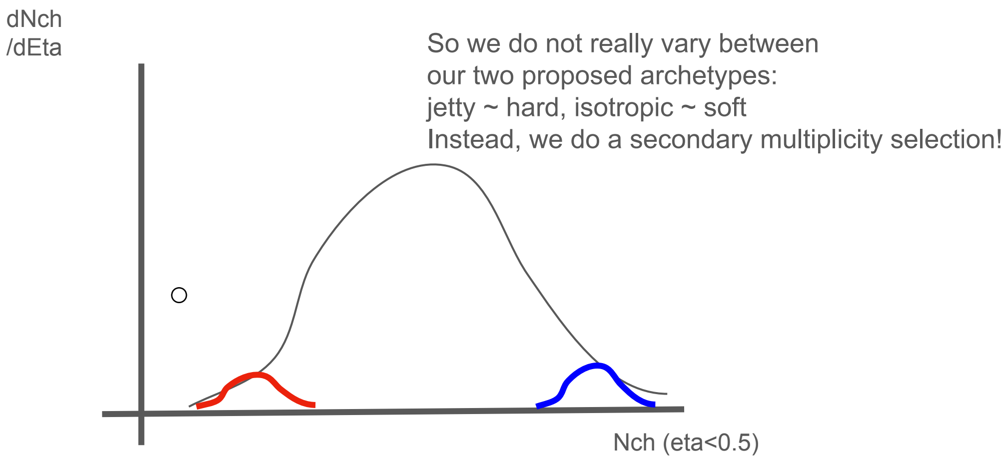
- This topological selection can be used with a multiplicity selection to “control” the physics selection
  - With a midrapidity multiplicity selection
    - Large shift in <p_T>
    - Very small (~10%) shift in yield
    - Our jet-like selection is able to capture events that are significantly harder than average
  - With a forward rapidity multiplicity selection
    - Now we get the opposite!

JHEP 05 (2024) 184

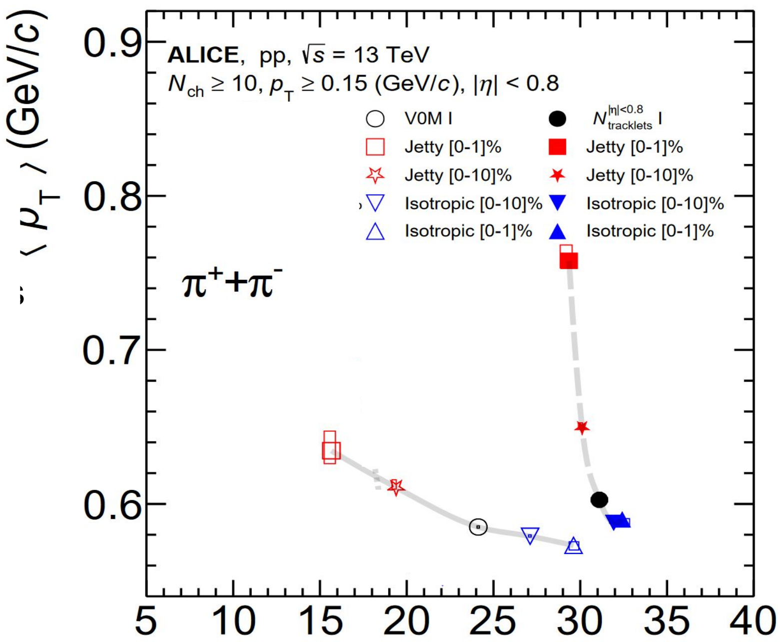


Controlling the fluctuations: Transverse Spherocity

- This topological selection can be used with a multiplicity selection to "control" the physics selection
  - With a midrapidity multiplicity selection
    - Large shift in <p_T>
  -



JHEP 05 (2024) 184

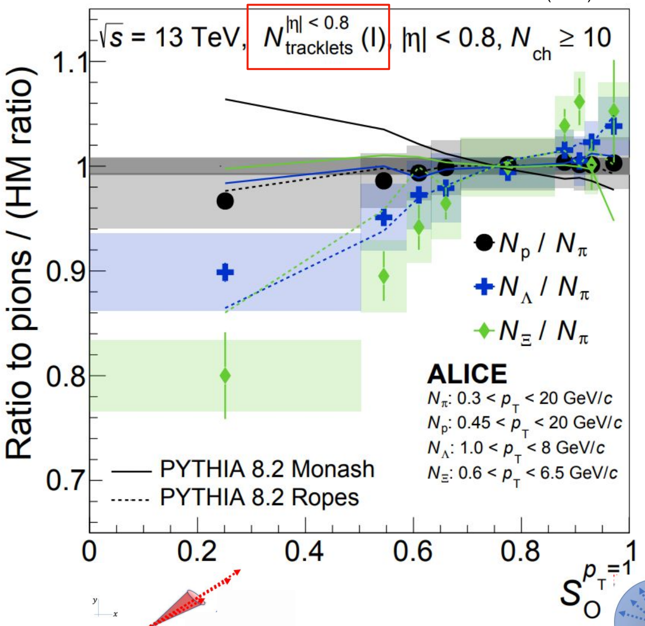


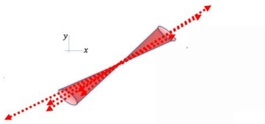
We can control the hardness by in this case using midrapidity multiplicity ⟨ dN_π/dy ⟩

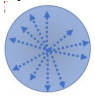
Controlling the fluctuations: Transverse Spherocity

- This observation also directly affects the secondary physics measurements
  - Using midrapidity multiplicity
    - Significant suppression of jet-like yields

JHEP 05 (2024) 184







Controlling the fluctuations: Transverse Spherocity

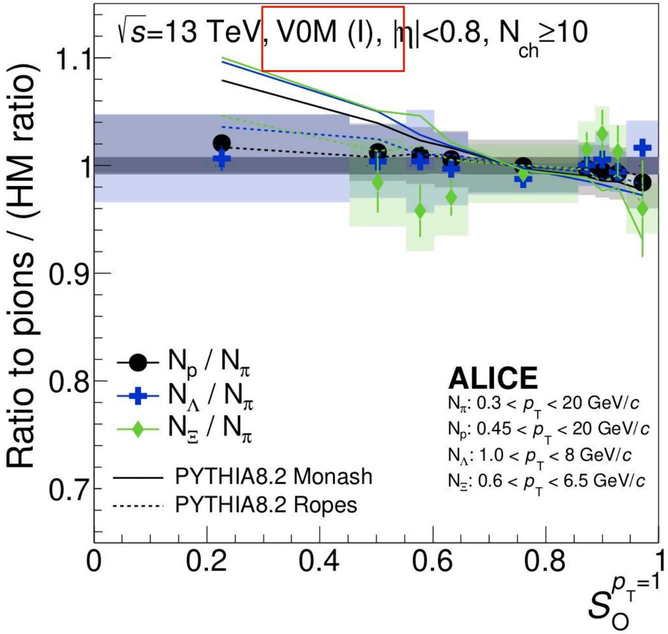
- This observation also directly affects the secondary physics measurements
  - Using midrapidity multiplicity
    - Significant suppression of jet-like yields

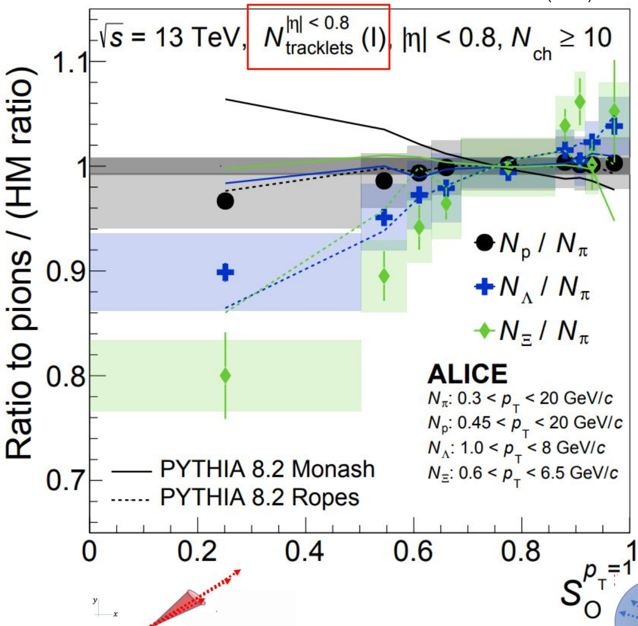
- Scaling is removed when using V0M!

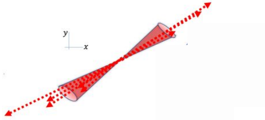
V0M: MPI Scaling (more of the same)

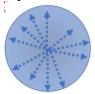
Midrapidity: Contrast between different physics processes

JHEP 05 (2024) 184





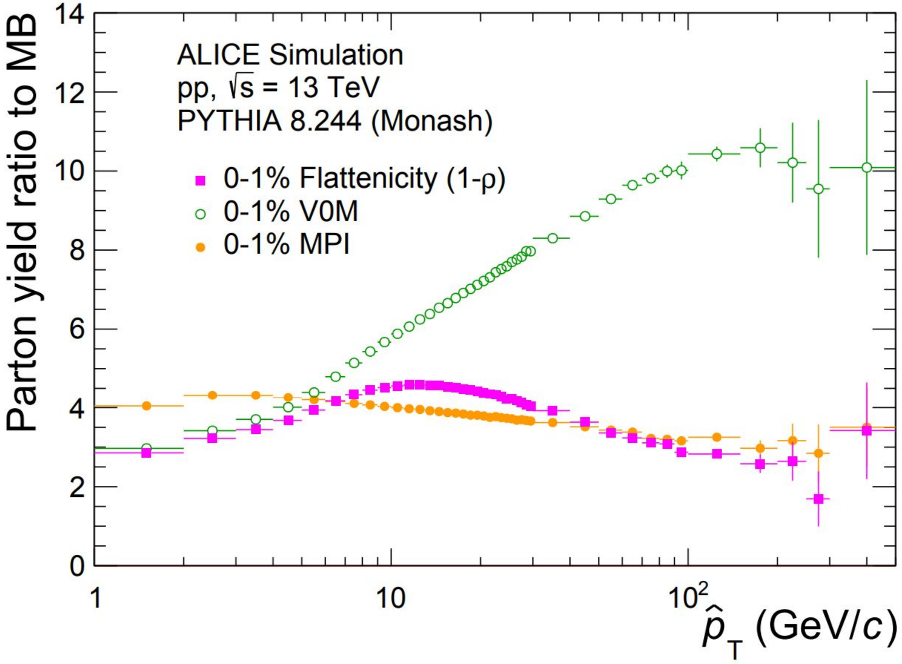




More observables: Flattenicity

- Instead of contrasting different processes, we can dial into one
  - Fully bias into the MPI scaling as modelled in PYTHIA
    - Can act as a direct proxy for MPI

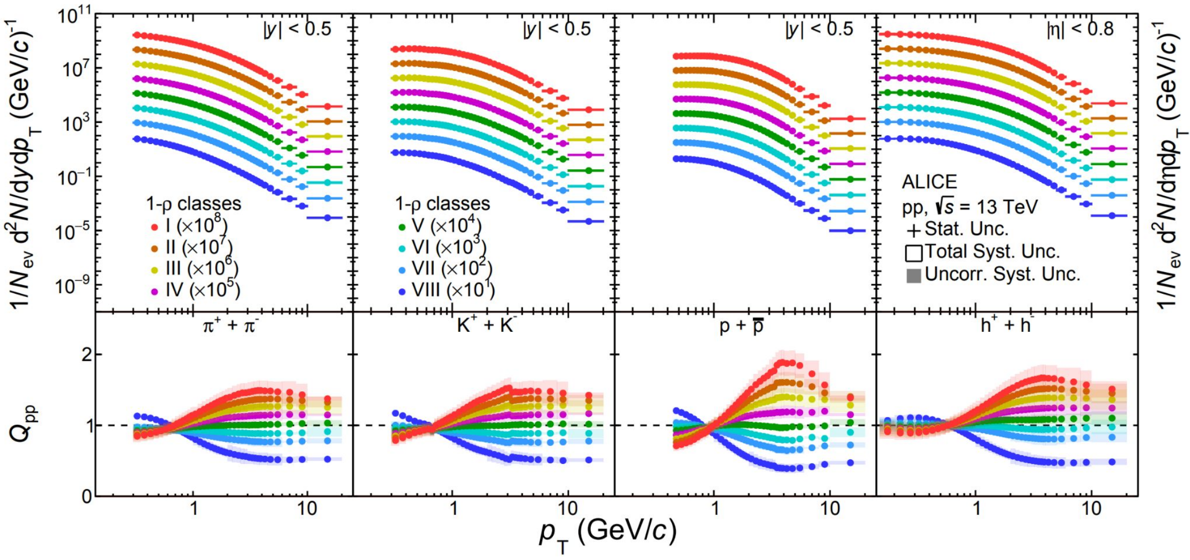
arXiv:2407.20037



More observables: Flattenicity

- Instead of contrasting different processes, we can dial into one
  - Fully bias into the MPI scaling as modelled in PYTHIA
    - Can act as a direct proxy for MPI
  - Novel features in the spectra: bump at intermediate pT

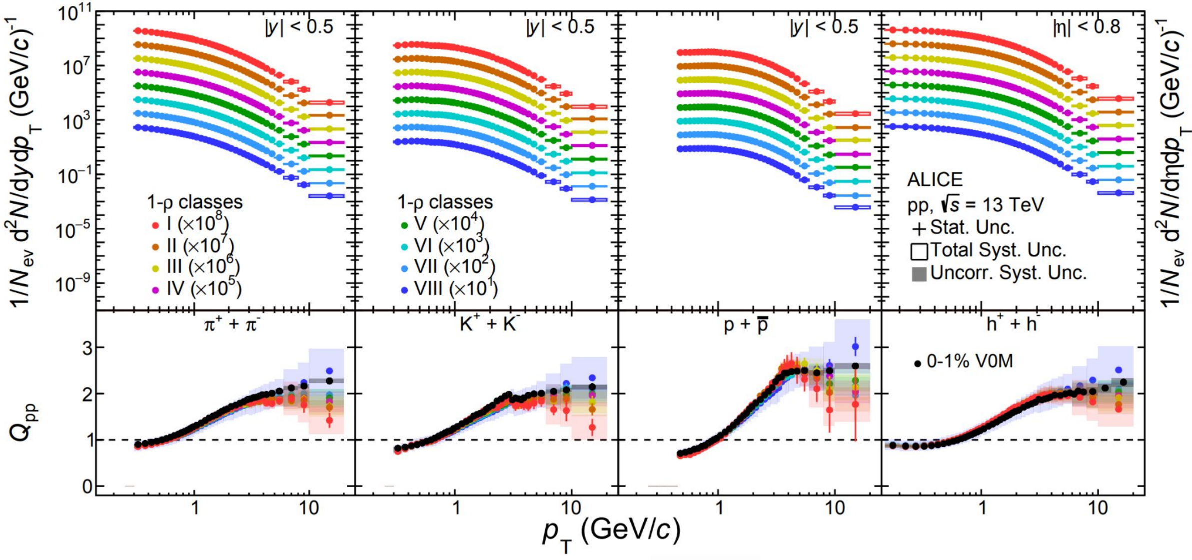
arXiv:2407.20037



More observables: Flattenicity

- Instead of contrasting different processes, we can dial into one
  - Fully bias into the MPI scaling as modelled in PYTHIA
    - Can act as a direct proxy for MPI
  - Novel features in the spectra: bump at intermediate pT
  - However, cannot co-exist with V0M selection

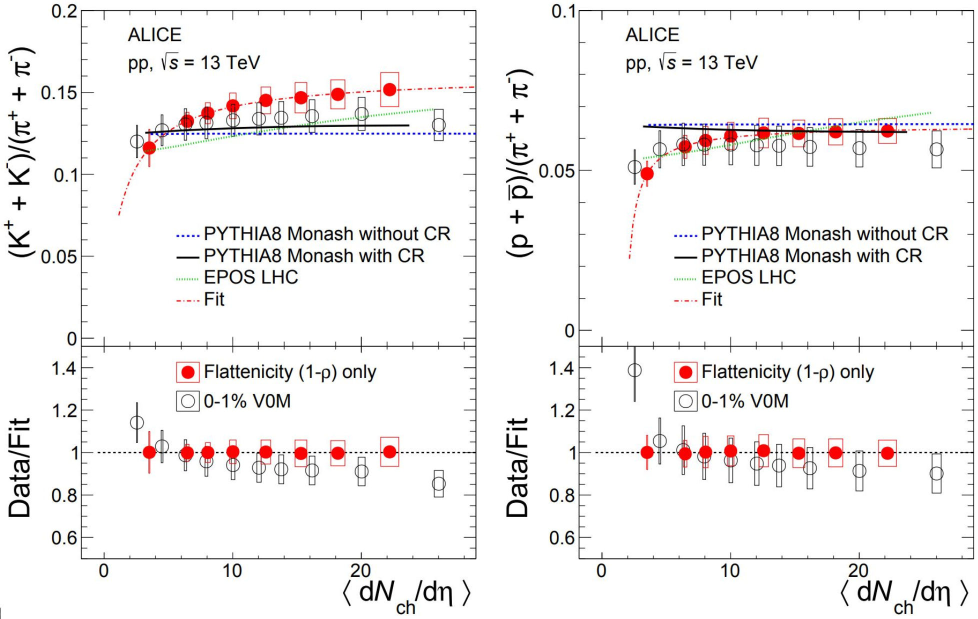
arXiv:2407.20037



More observables: Flattenicity

- Instead of contrasting different processes, we can dial into one
  - Fully bias into the MPI scaling as modelled in PYTHIA
    - Can act as a direct proxy for MPI
  - Novel features in the spectra: bump at intermediate pT
  - However, cannot co-exist with V0M selection
  - Integrated quantities showcase very weak effect
- This is intuitive to understand: We bias away from hard processes - loses interplay

arXiv:2407.20037

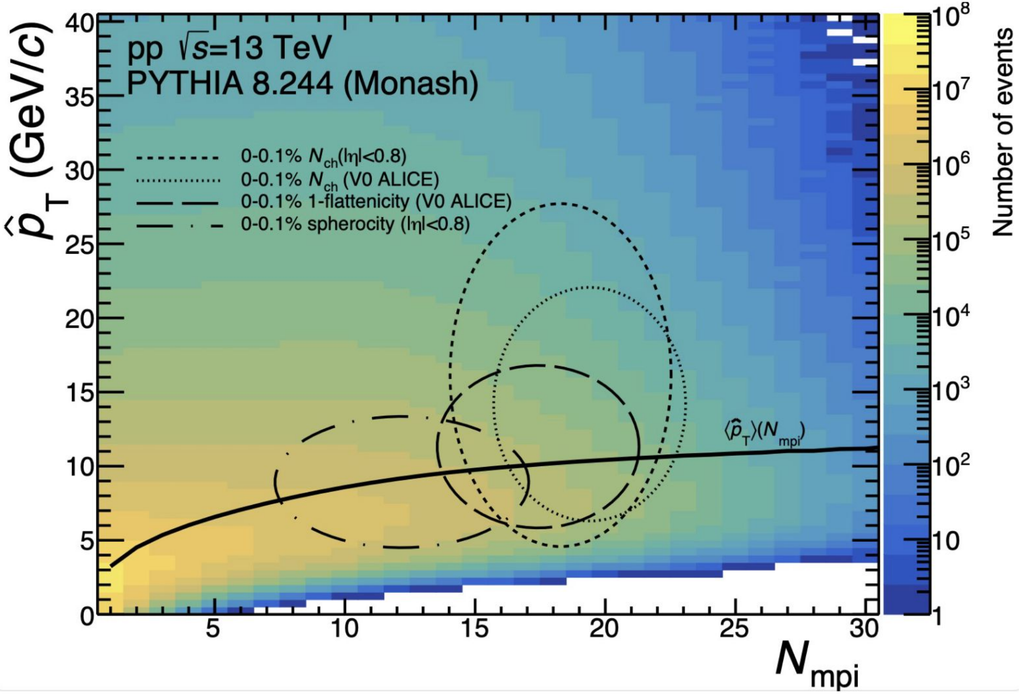


Summary and Outlook

- Many, many other observables to re-examine in this lens
  - Underlying event activity, correlations, etc etc

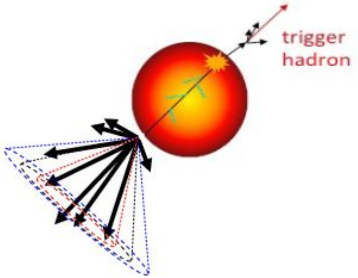
- Important to note that none of these selections are “better”

- Raises the important question: How do we compare with different experiments?
  - Important to understand the biases, and the correlations produced through fluctuations



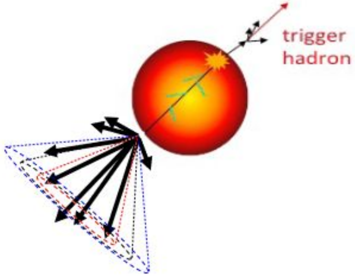
BACKUP

Di-jet Acoplenarity



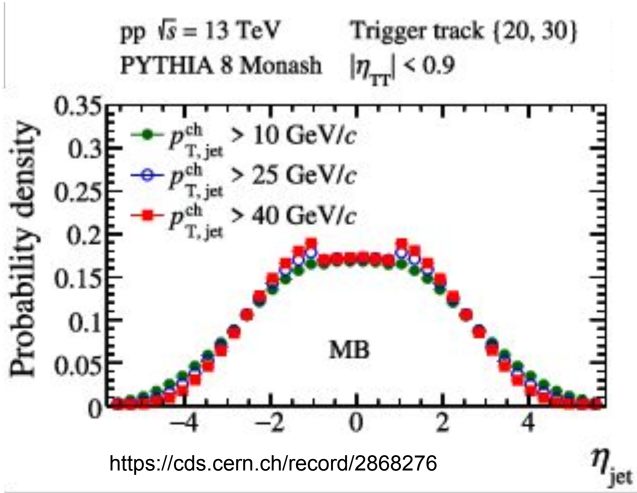
- Semi-inclusive jets
  - A charged trigger track is chosen
  - Jet finding reclustering is then performed in the opposite direction (pi/2) of this jet

Di-jet Acoplenarity



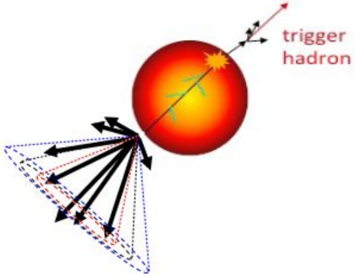
- Semi-inclusive jets
  - A charged trigger track is chosen
  - Jet finding reclustering is then performed in the opposite direction (pi/2) of this jet

- Probability densities of jet location changes if asking for V0M multiplicity!



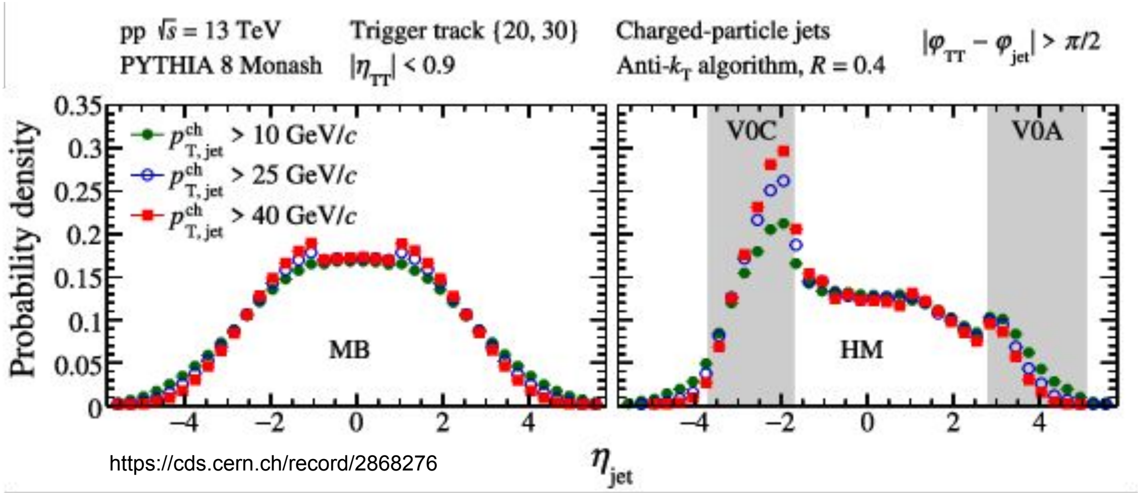
https://cds.cern.ch/record/2868276

Di-jet Acoplenarity



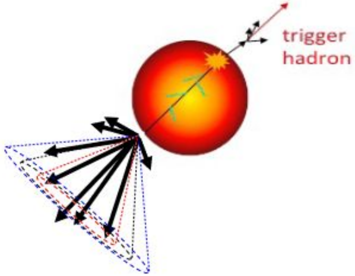
- Semi-inclusive jets
  - A charged trigger track is chosen
  - Jet finding reclustering is then performed in the opposite direction (pi/2) of this jet

- Probability densities of jet location changes if asking for V0M multiplicity!
  - V0M requirement will slowly kink the jet toward the larger (V0C) of the two scintillators!



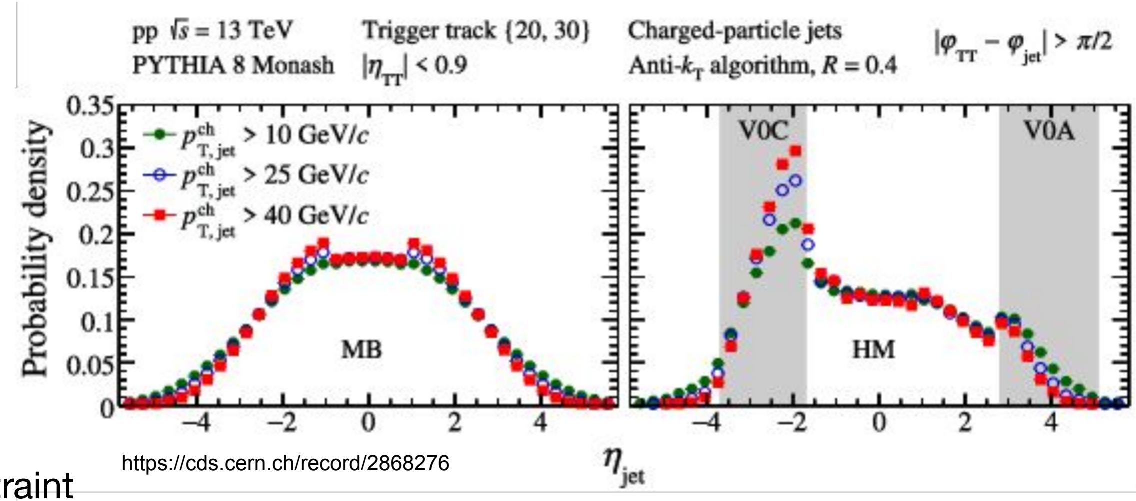
https://cds.cern.ch/record/2868276

Di-jet Acoplenarity



- Semi-inclusive jets
  - A charged trigger track is chosen
  - Jet finding reclustering is then performed in the opposite direction (pi/2) of this jet

- Probability densities of jet location changes if asking for V0M multiplicity!
  - V0M requirement will slowly kink the jet toward the larger (V0C) of the two scintillators!
    - THIS IS NOT A DETECTOR EFFECT
      - Consequence of multiplicity constraint

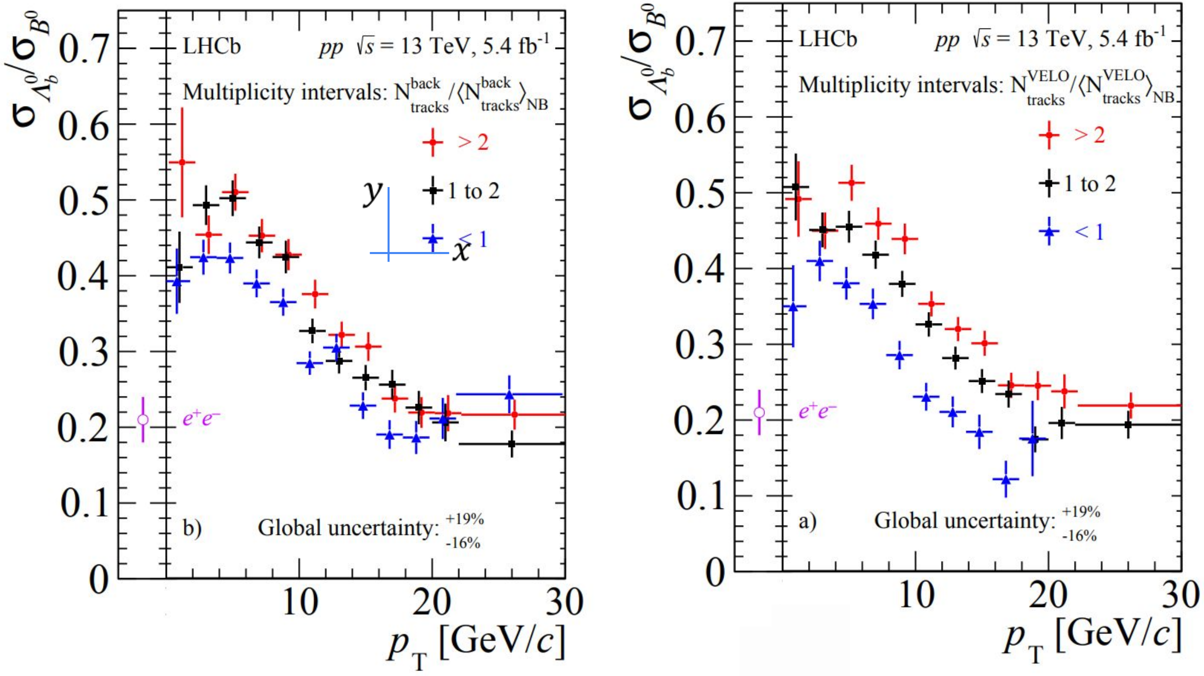


https://cds.cern.ch/record/2868276

Controlling the fluctuations: Transverse Spherocity

- This observation also directly affects the secondary physics measurements
  - Using midrapidity multiplicity
    - Significant suppression of jet-like yields

https://cds.cern.ch/record/2877050/



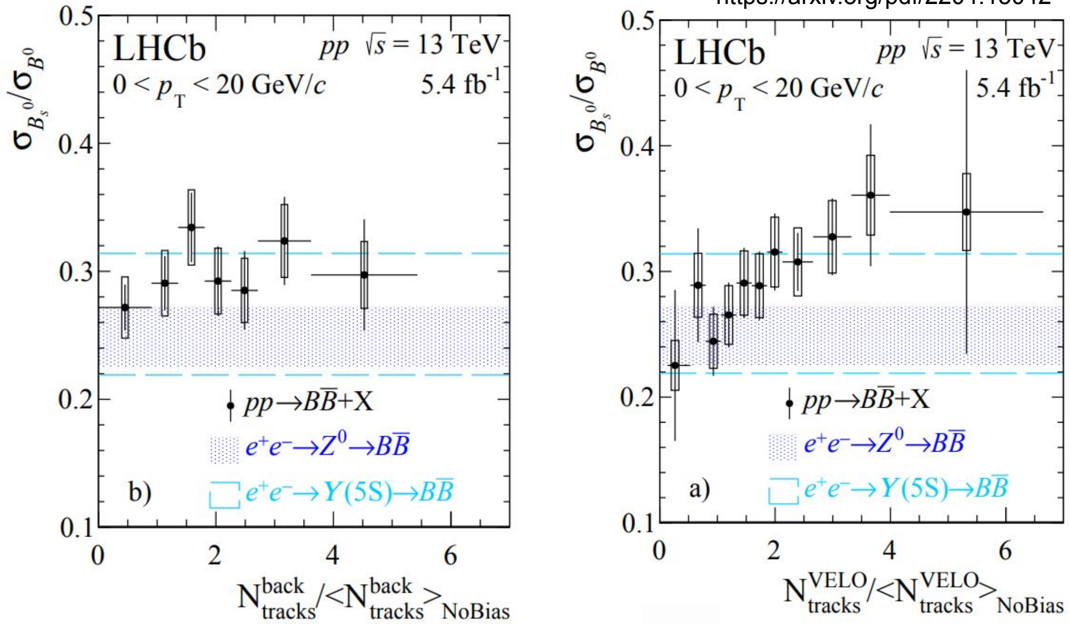
- Scaling
  is removed
  when using
  V0M!

Curiously, similar effects are observed for other experiments

Controlling the fluctuations: Transverse Spherocity

- This observation also directly affects the secondary physics measurements
  - Using midrapidity multiplicity
    - Significant suppression of jet-like yields

https://arxiv.org/pdf/2204.13042

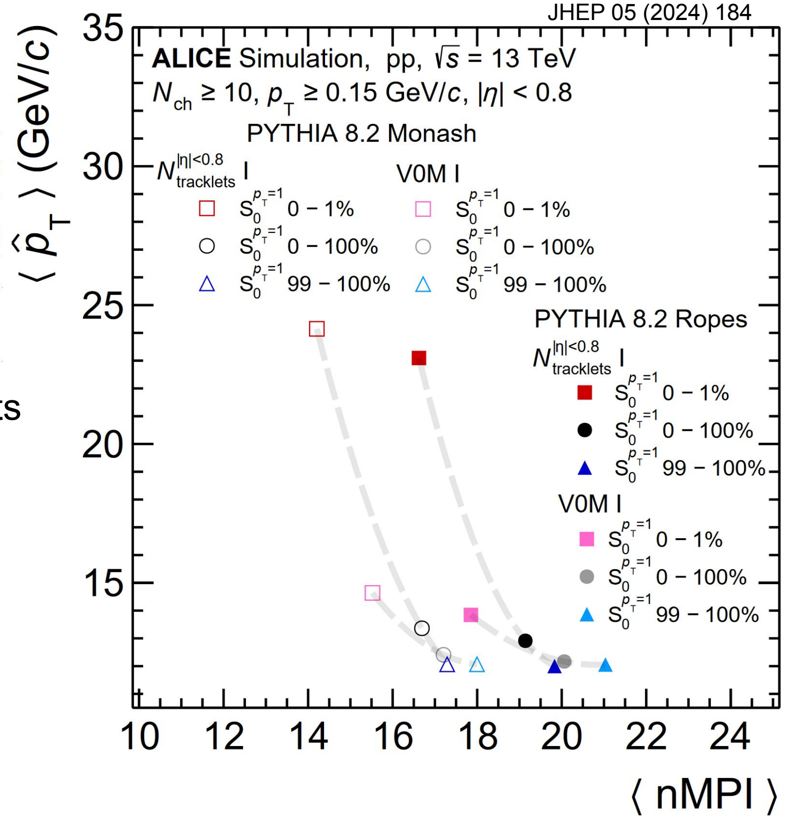


- Scaling is removed when using V0M!

Curiously, similar effects are observed for other experiments

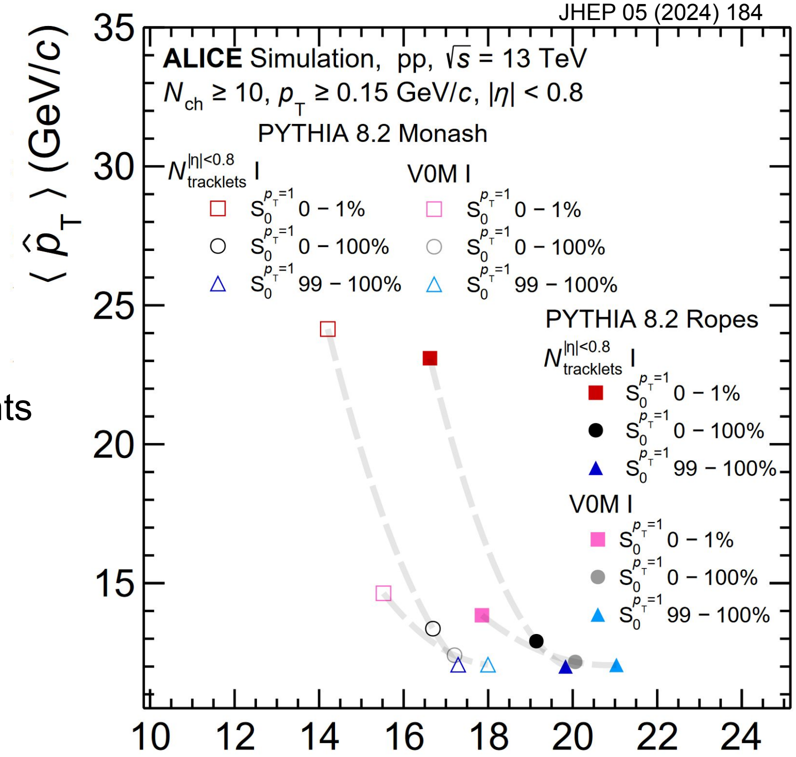
Controlling the fluctuations: Transverse Spherocity

- This topological selection can be used with a multiplicity selection to "control" the physics selection
  - With a midrapidity multiplicity selection
    - Large shift in <pT>
    - Very small (~10%) shift in yield
    - Our jet-like selection is able to capture events that are significantly harder than average
  - With a forward rapidity multiplicity selection
    - Now we get the opposite!
    - Also confirmed by MC



Controlling the fluctuations: Transverse Spherocity

- This topological selection can be used with a multiplicity selection to “control” the physics selection
  - With a midrapidity multiplicity selection
    - Large shift in <pT>
    - Very small (~10%) shift in yield
    - Our jet-like selection is able to capture events that are significantly harder than average
  - With a forward rapidity multiplicity selection
    - Now we get the opposite!
    - Also confirmed by MC



We can control the hardness by in this case using midrapidity multiplicity

⟨ nMPI ⟩