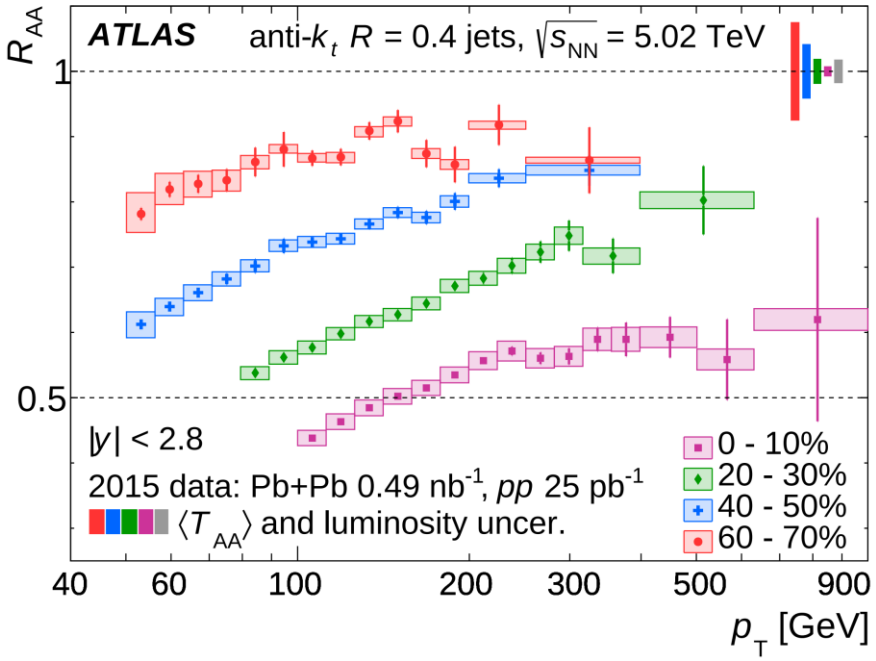
Measurements of the Azimuthal Anisotropy of Jets and High-p_T Charged Particles in Pb+Pb Collisions with the ATLAS Detector

Xiaoning Wang for the ATLAS Collaboration

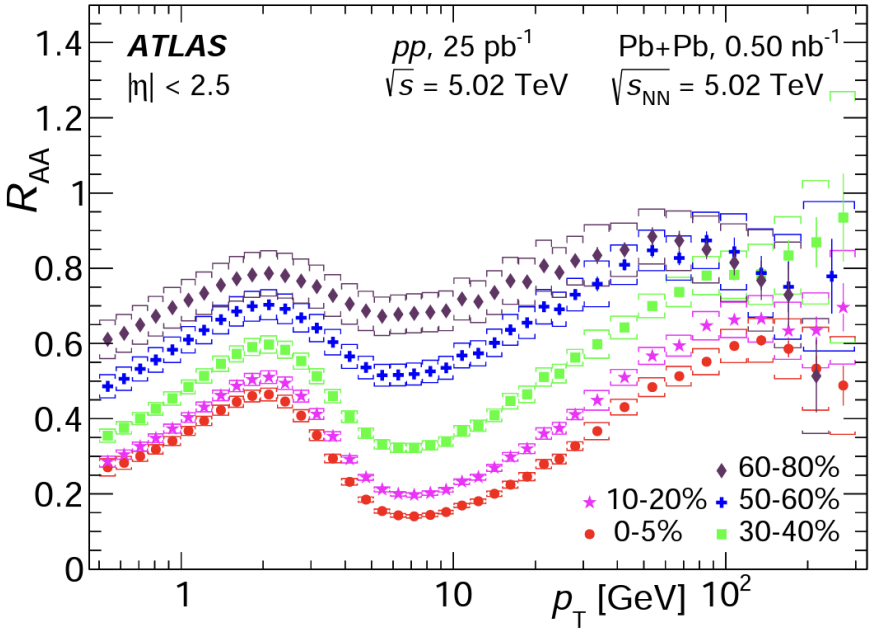
March 28, 2023

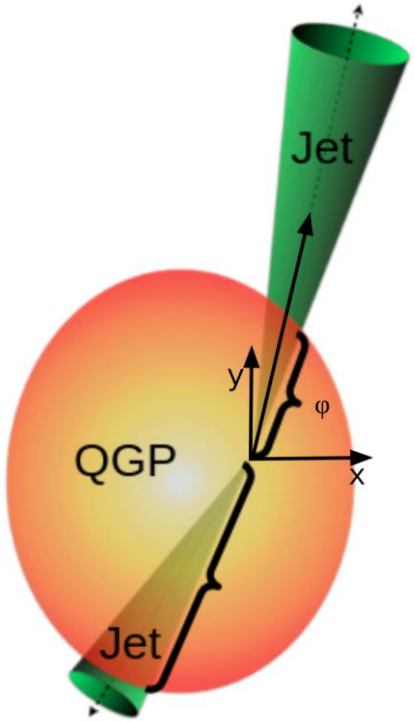
Energy Loss Anisotropy

Phys.Lett.B 790 (2019) 108-128
e-Print: arXiv:1805.05635



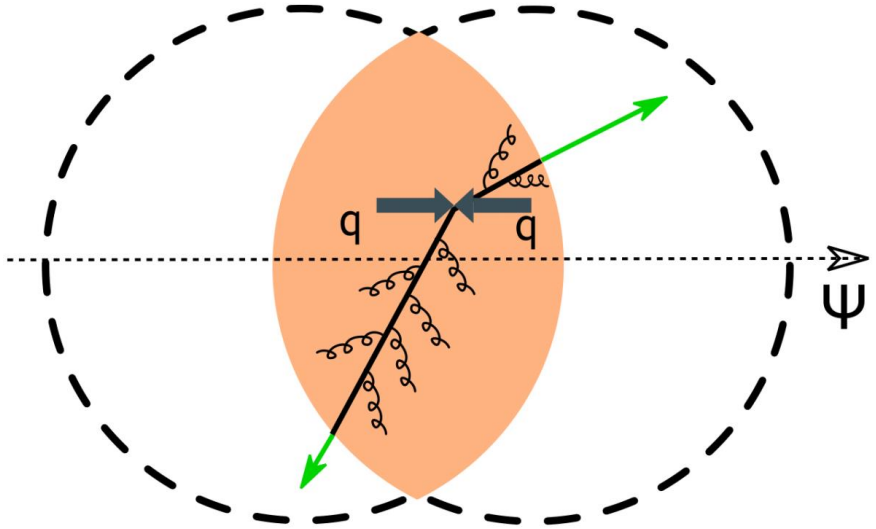
CERN-EP-2022-221
e-Print: arXiv:2211.15257





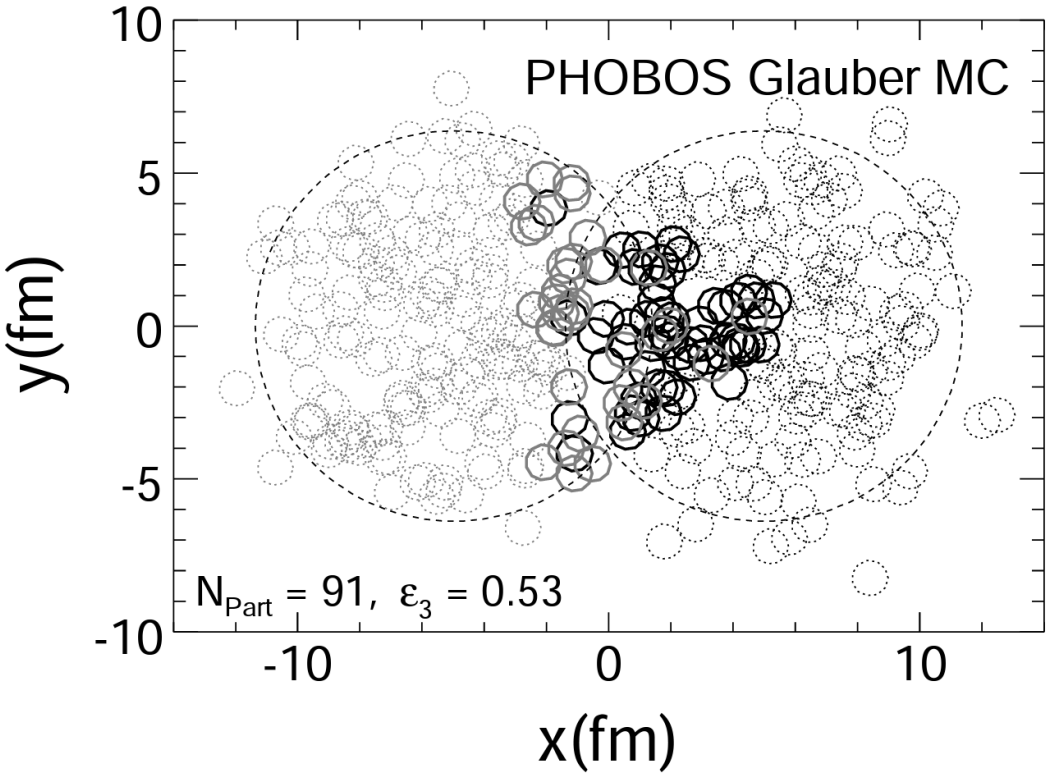
- Shown through observables like jets (left) and tracks (right) R_{AA}, hard scattered partons lose energy when traversing through QGP.
- What's the mechanism of this energy loss? What path length dependence does it have? What's the role of fluctuations?

Azimuthal Anisotropies Measurements



$$\frac{dN}{d\phi} \propto 1 + 2\sum_{n=1}^{\infty} v_n \cos(n(\phi_i - \Psi_n))$$

Phys.Rev.C 81 (2010) 054905
e-Print: arXiv:1003.0194



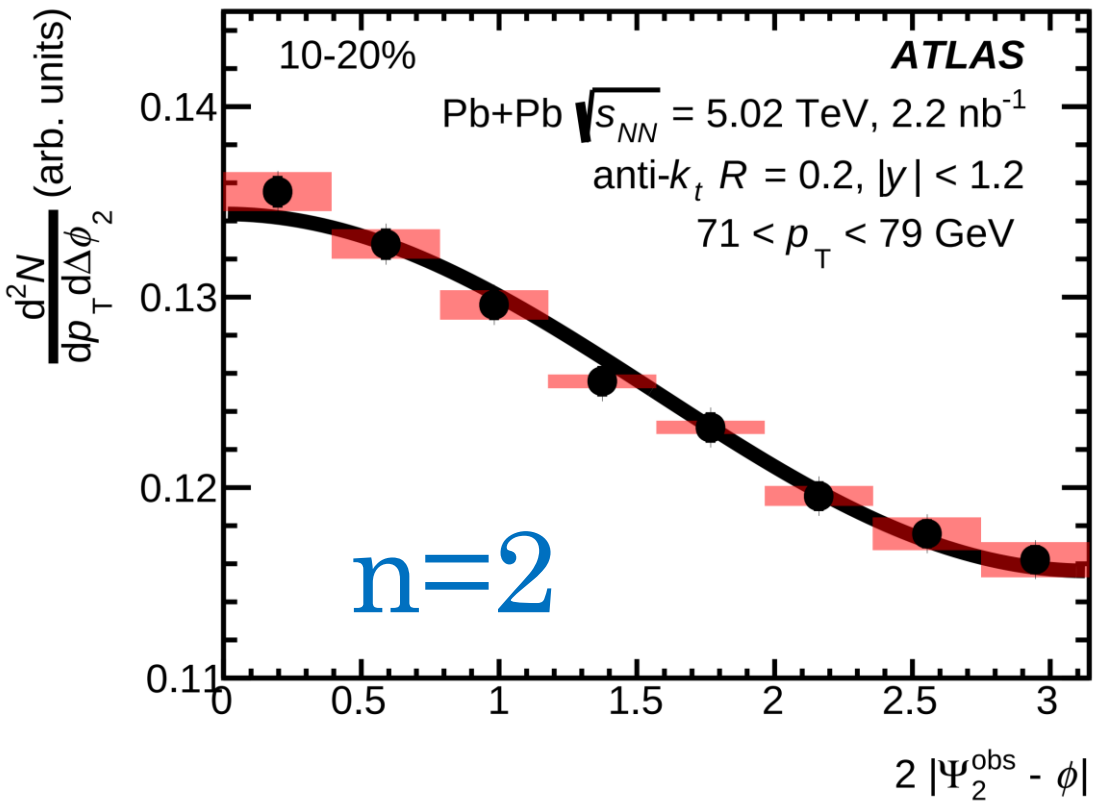
- v_n is sensitive to the path-length dependence of energy loss to QGP
  - Modeling of high-p_T particle production requires both initial geometry and energy loss mechanism
  - v_2 can be explained by almond shaped QGP
  - $v_{n>2}$ can give insights on role of fluctuations

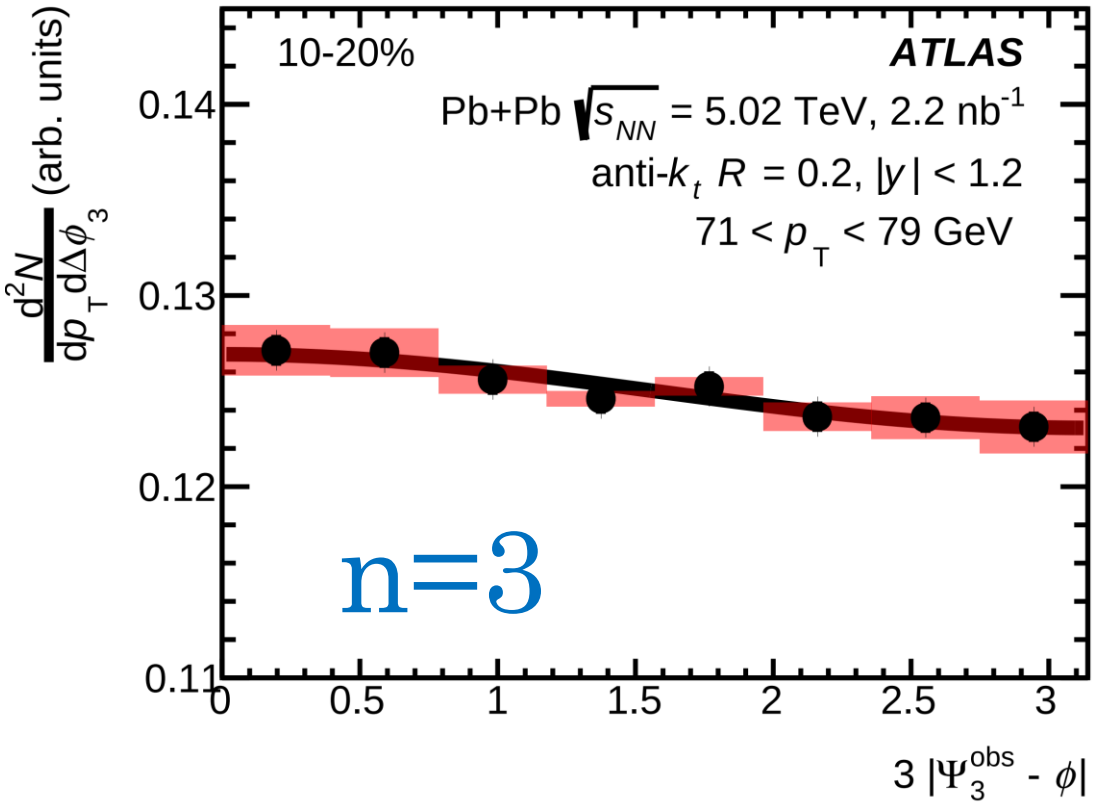
Probes of Hard Sector Energy Loss

- Jet v_n in $|y| < 1.2$
  - Jet as hard sector probes for short-distance QGP interactions
  - v_n of jet yield with respect to n-th order event plane
  - **Published ATLAS result with Run II data:**
    - ***Phys.Rev.C* 105 (2022) 6, 064903**

- High-p_T charged particle v_n in $|\eta| < 2.5$
  - High-p_T particles as proxy of jet as a follow up to jet v_n measurements.
  - More statistics with number of particles, more flexible ways of suppressing non-flow.
  - **NEW preliminary ATLAS result with Run II data:**
    - **ATLAS-CONF-2023-007**

Jet v_n with Event Plane Method

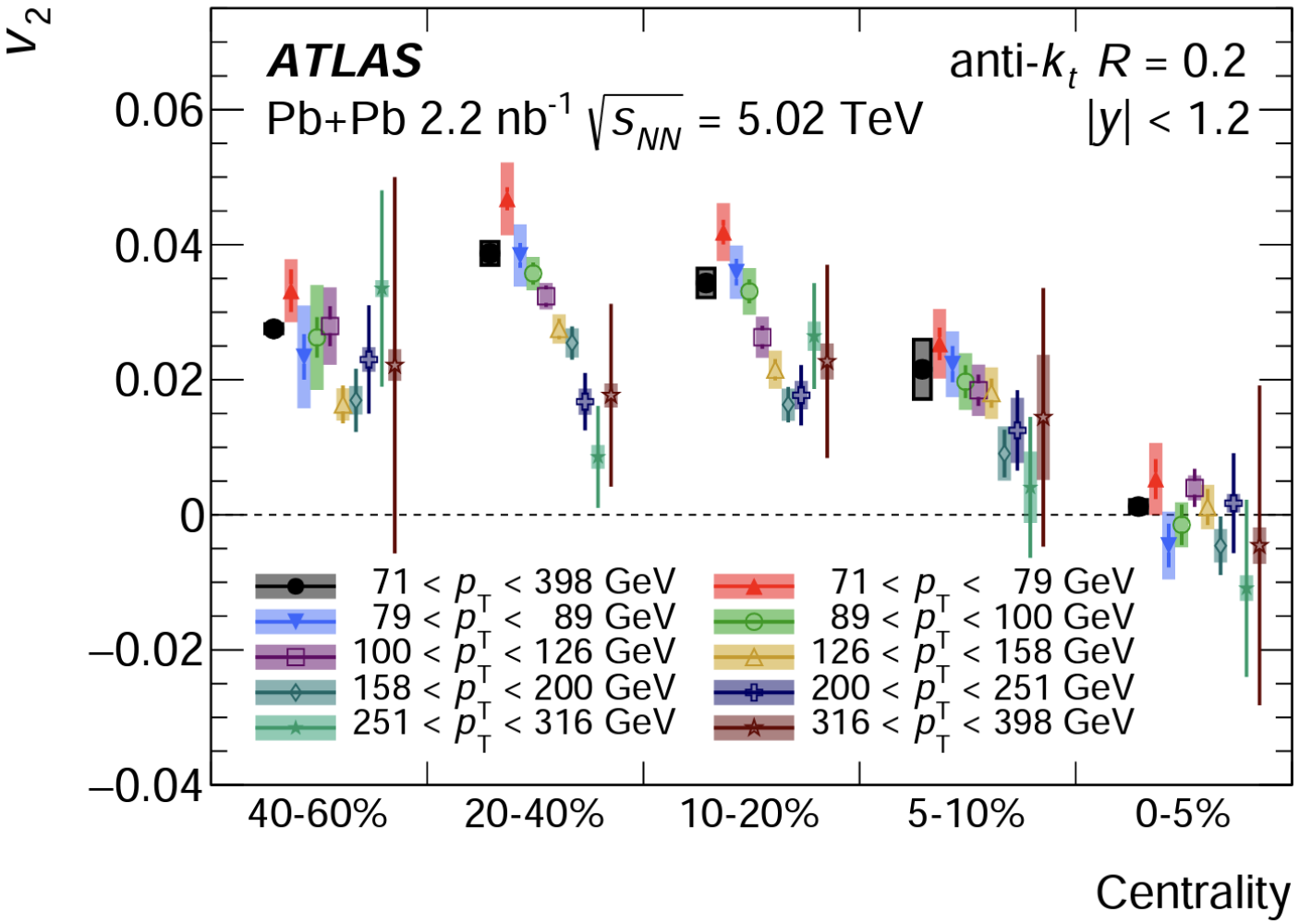




- Measure Ψ_n^{obs}, and $n\Delta\phi = n|\phi - \Psi_n|$ in bins of p_T and centrality
- n=2, 3, 4 were measured
- Yields are unfolded in p_T and $\Delta\phi$
- Fit sinusoidal curve to extract v_n

Phys.Rev.C 105 (2022) 6, 064903
e-Print: arXiv: 2111.06606

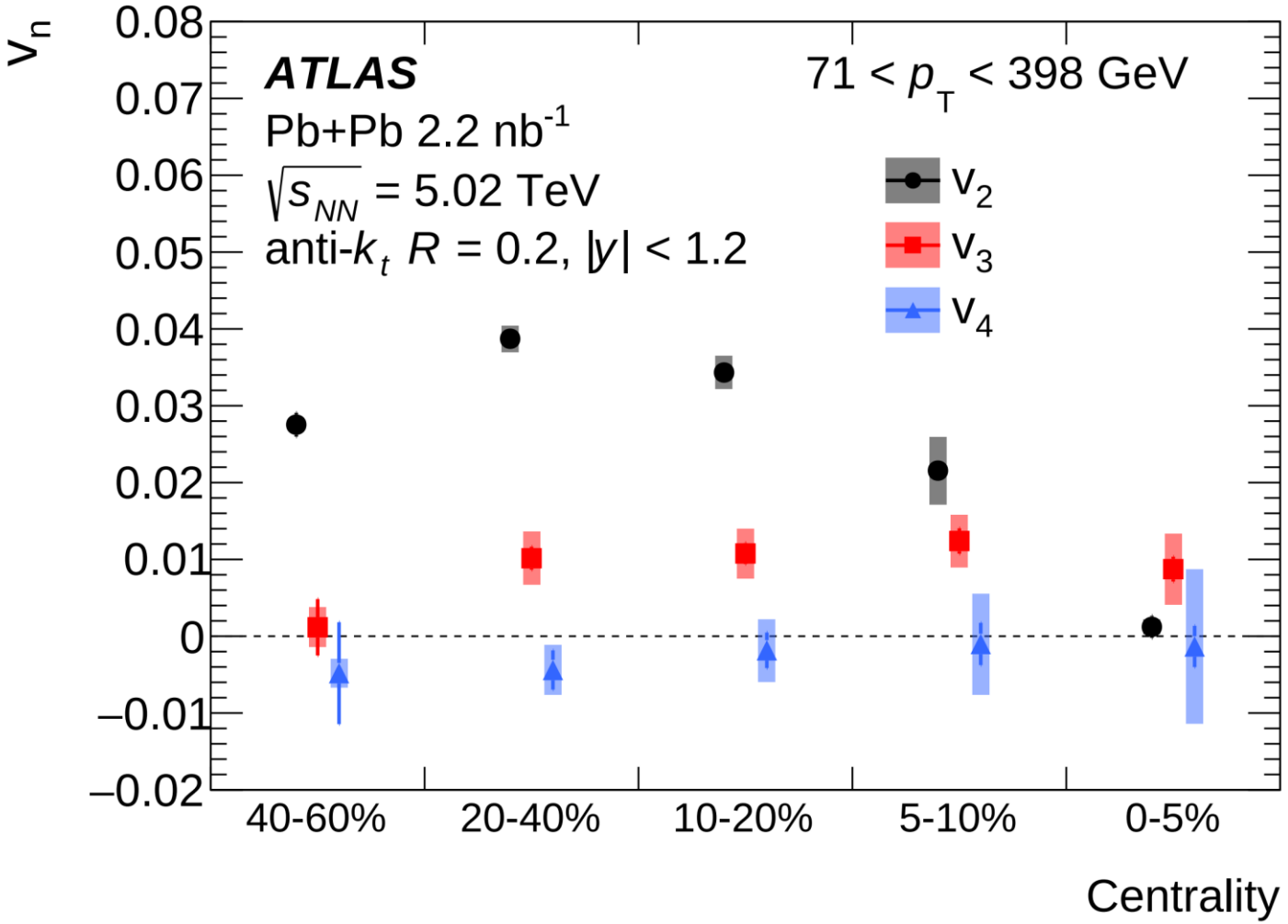
Jet v_2 Results



- The v_2 values are consistent with zero in the most central collisions, and positive for all other centrality bins for inclusive p_T.
- v_2 shows a decreasing trend with p_T in the mid-central collisions

Phys.Rev.C 105 (2022) 6, 064903
e-Print: arXiv: 2111.06606

Jet v_2-v_4 Results

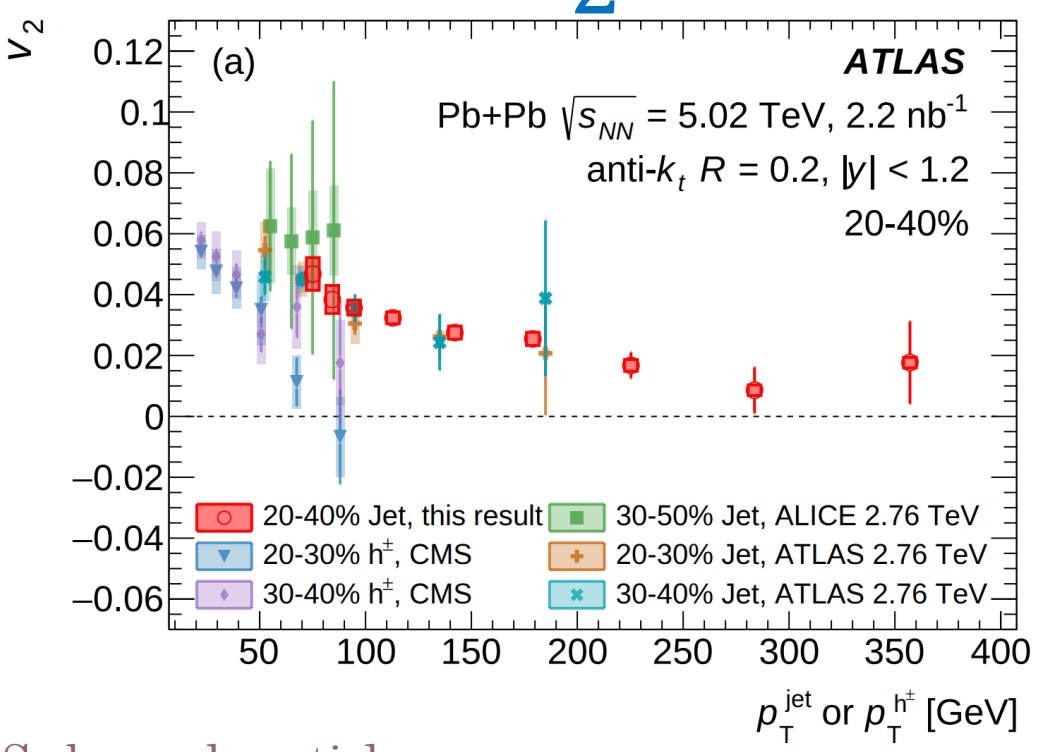


- Non-zero v_2 with strong centrality dependence
- Non-zero v_3 for 0%-40% range at ~1%
- No evidence of non-zero v_4

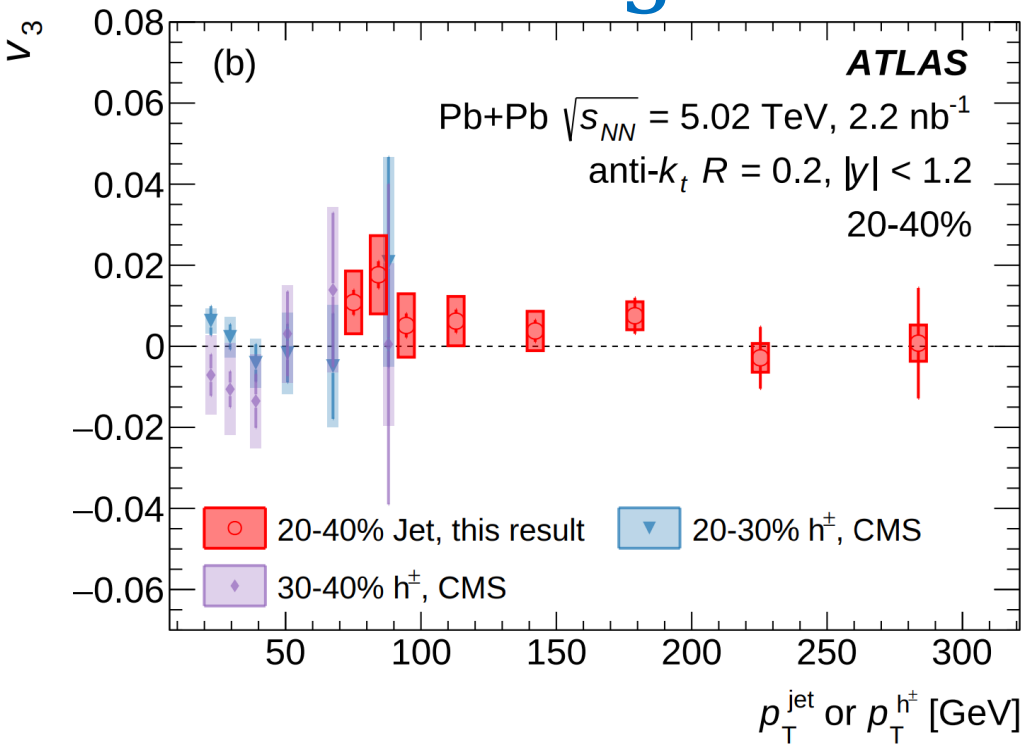
Phys.Rev.C 105 (2022) 6, 064903
e-Print: arXiv: 2111.06606

Comparison to other v_n Results

v_2



v_3



CMS charged particle:

Phys.Lett.B 776 (2018) 195-216, e-Print: arXiv:1702.00630

ATLAS 2.76 TeV Jet:

Phys.Rev.Lett. 111 (2013) 15, 152301, e-Print: arXiv:1306.6469

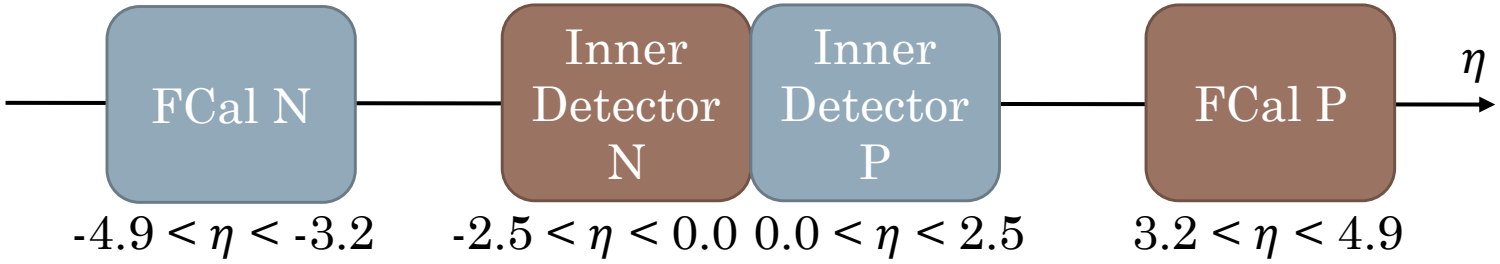
ALICE 2.76 TeV Jet:

Phys.Lett.B 753 (2016) 511-525 , e-Print: arXiv:1509.07334

Phys.Rev.C 105 (2022) 6, 064903

e-Print: arXiv: 2111.06606

High-p_T Track v_n with Scalar Product (SP) Method



- Events are divided into sub-events by pseudo-rapidity range
- v_n of particle yields is measured with respect to a sub-event plane of large η gap (3.2)
  - Suppresses non-flow correlations from resonance decay, particles of same jet, etc.
- **Extended previous measurements to higher p_T with 2018 dataset!**
  - **Sampled full luminosity in high-p_T region with jet triggers**

- *More about SP Method:*
  - *Explanation of method* Phys.Rev.C 87 (2013) 4, 044907, e-Print: arXiv: 1209.2323
  - *ATLAS 2015 SP method measurement* Eur.Phys.J.C 78 (2018) 12, 997, e-Print: arXiv: 1808.03951

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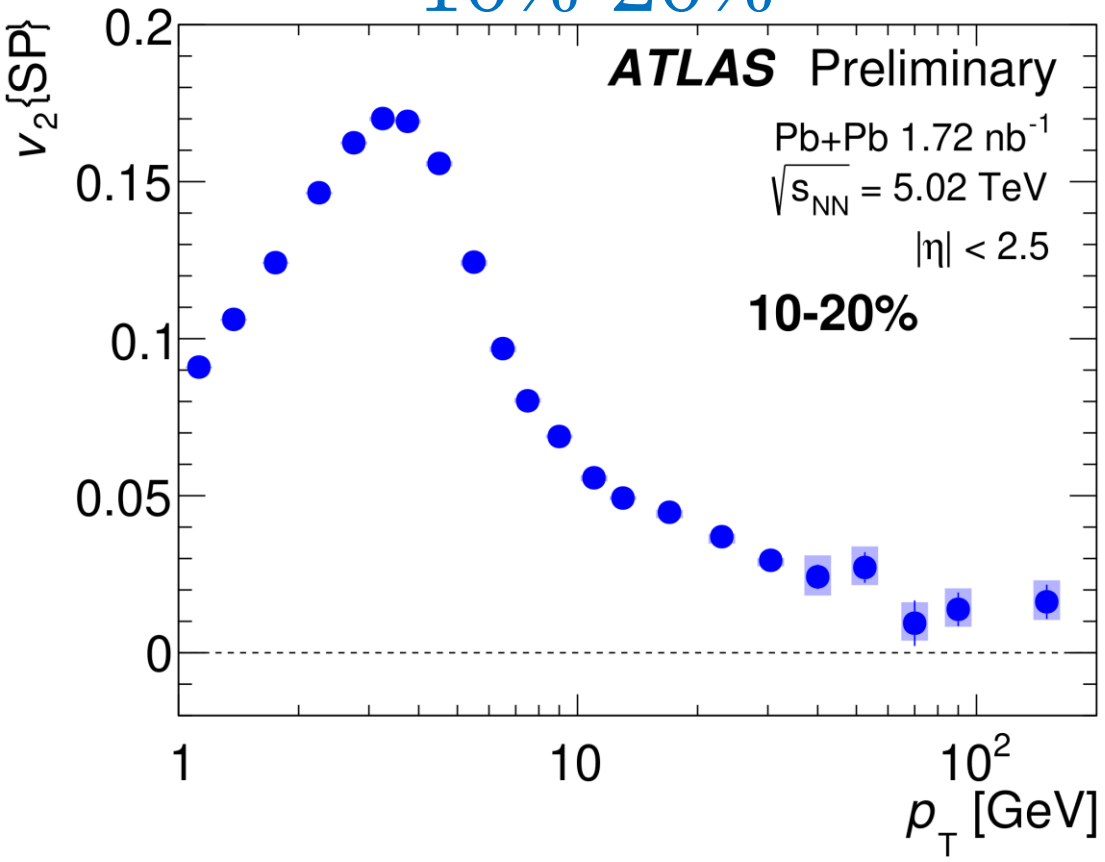
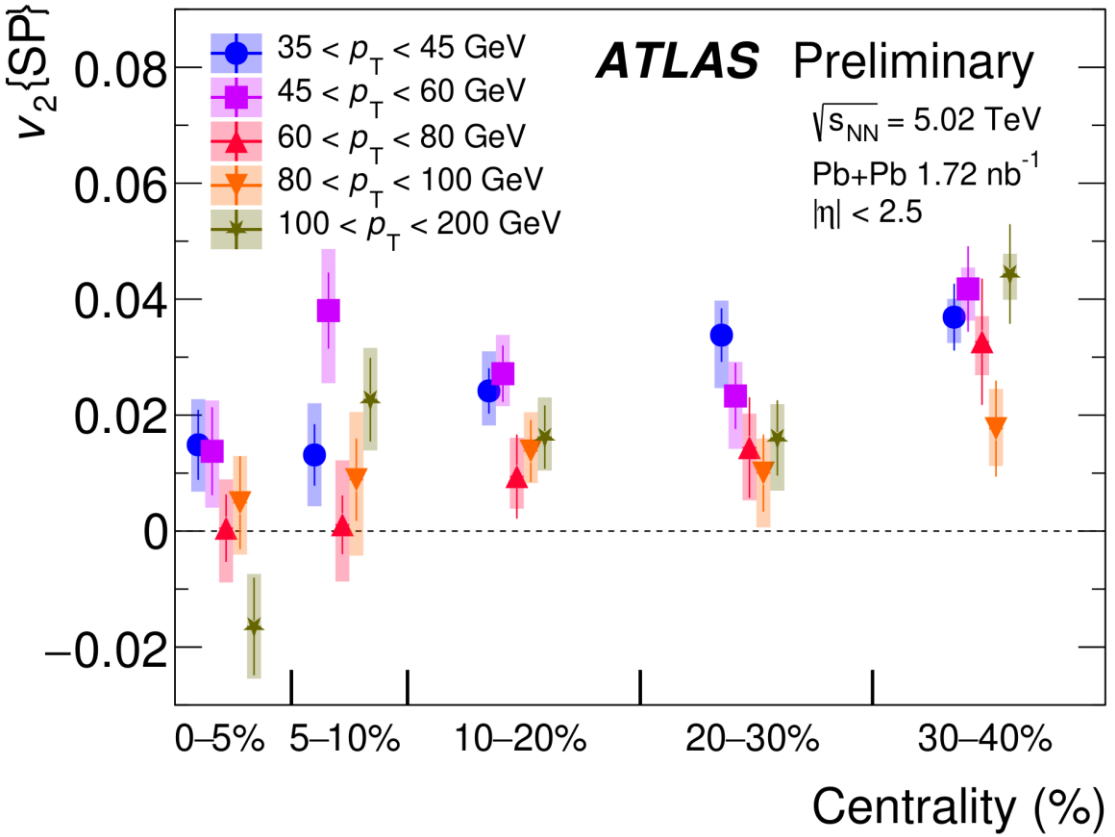
Track v_2 Results

10%-20%



0%-40%



- Non-zero v_2 up to 200 GeV for most centrality bins

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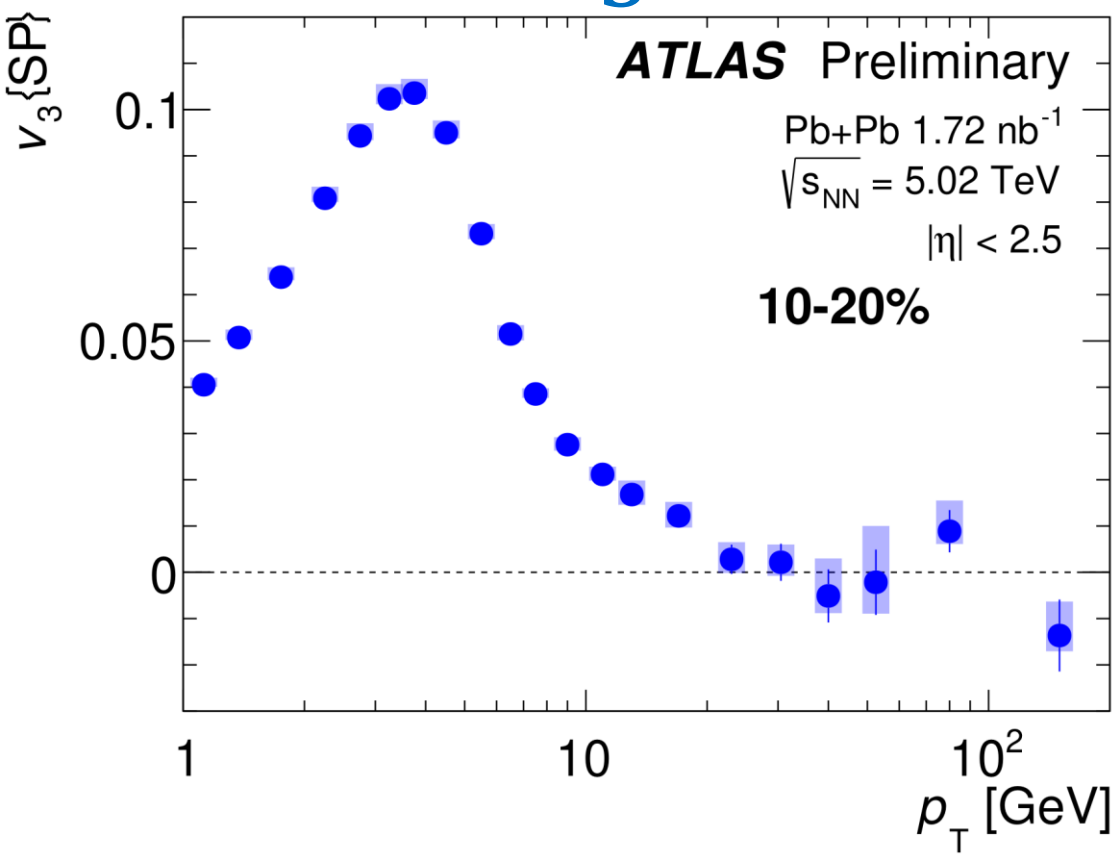
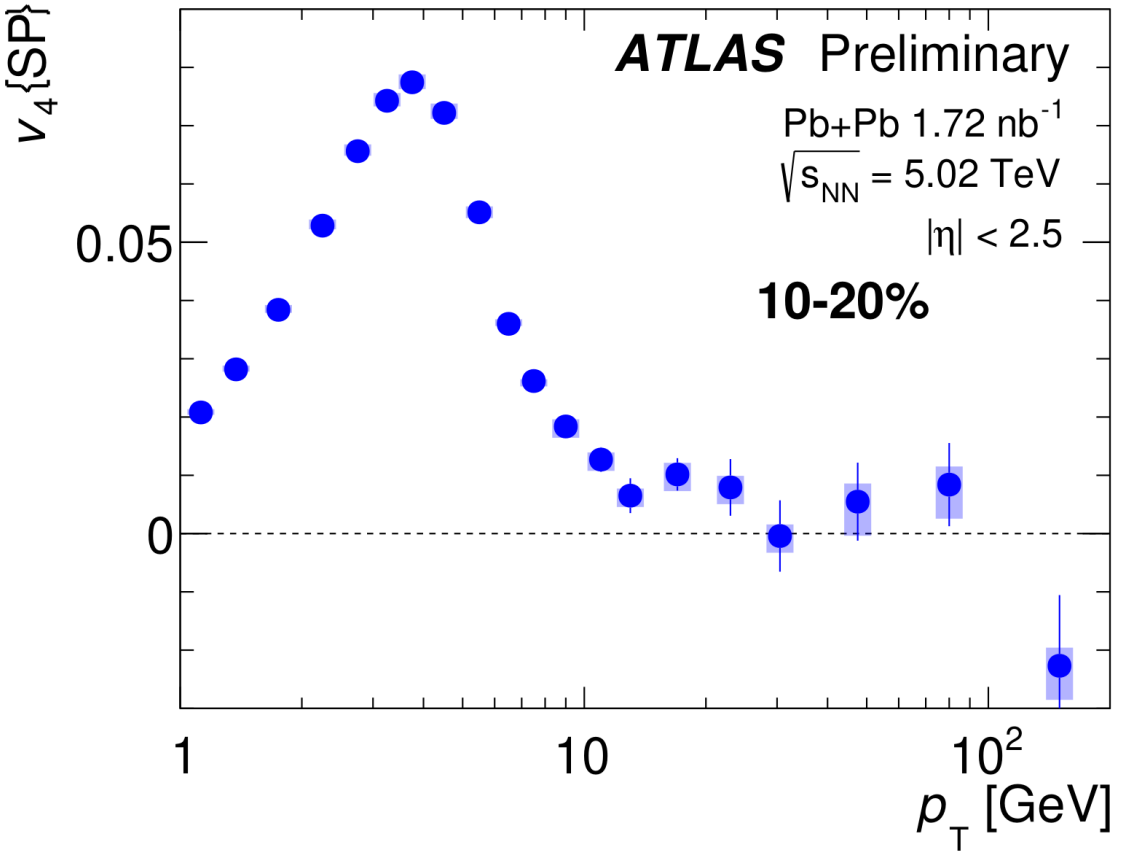
Track v_3 and v_4 Results

v_3



v_4



- No evidence of non-zero v_3 and v_4 in range $|\eta| < 2.5$ for all centrality range (see back-up for other centrality) at high p_T.

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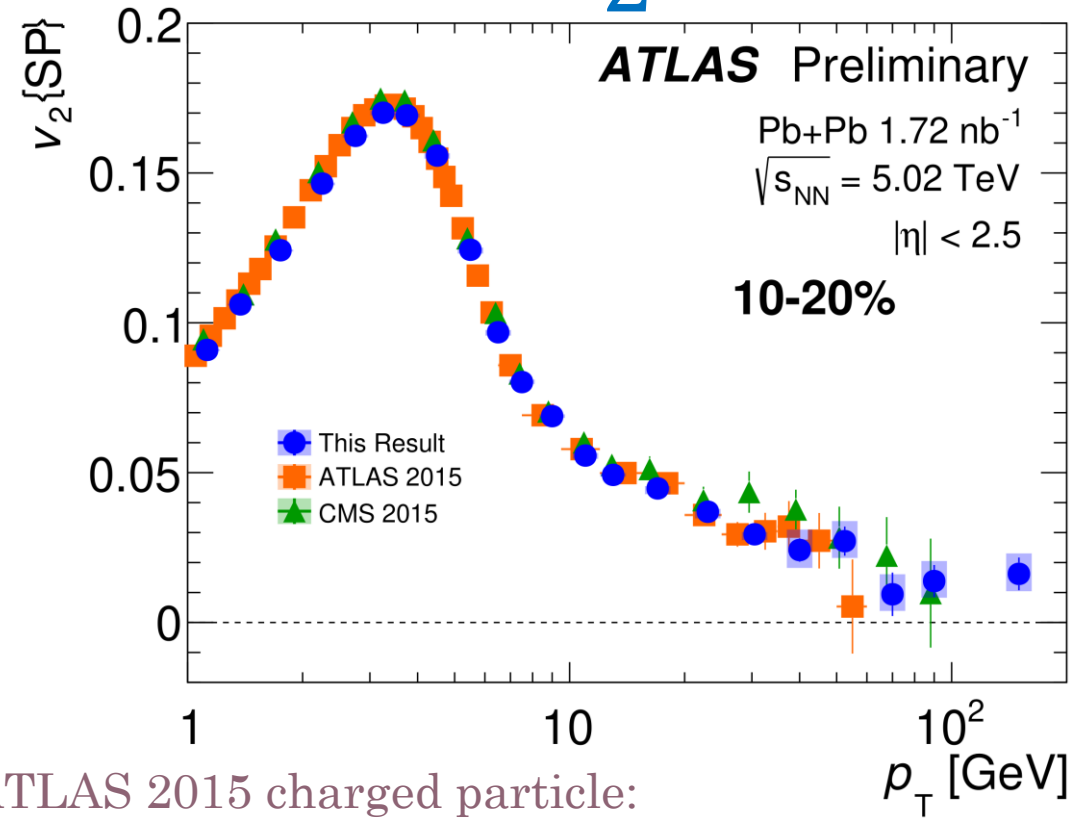
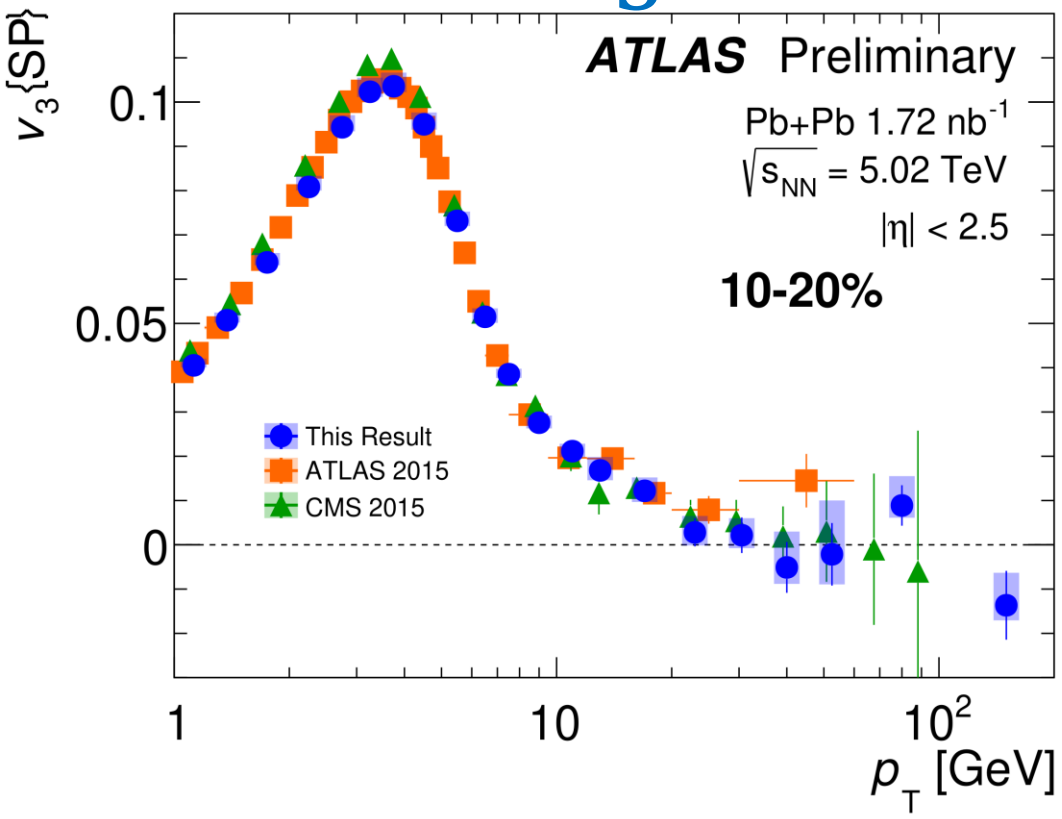
Comparison to other Track v_n Result

v_2



v_3



ATLAS 2015 charged particle:
Eur.Phys.J.C 78 (2018) 12, 997,
e-Print: arXiv: 1808.03951

CMS 2015 charged particle:
Phys.Lett.B 776 (2018) 195-216,
e-Print: arXiv:1702.00630

- Consistent with previous results in overlapped p_T range for v_2-v_4 (v_3, v_4 in back-up)
- ***Extended measurements to 200 GeV!!***

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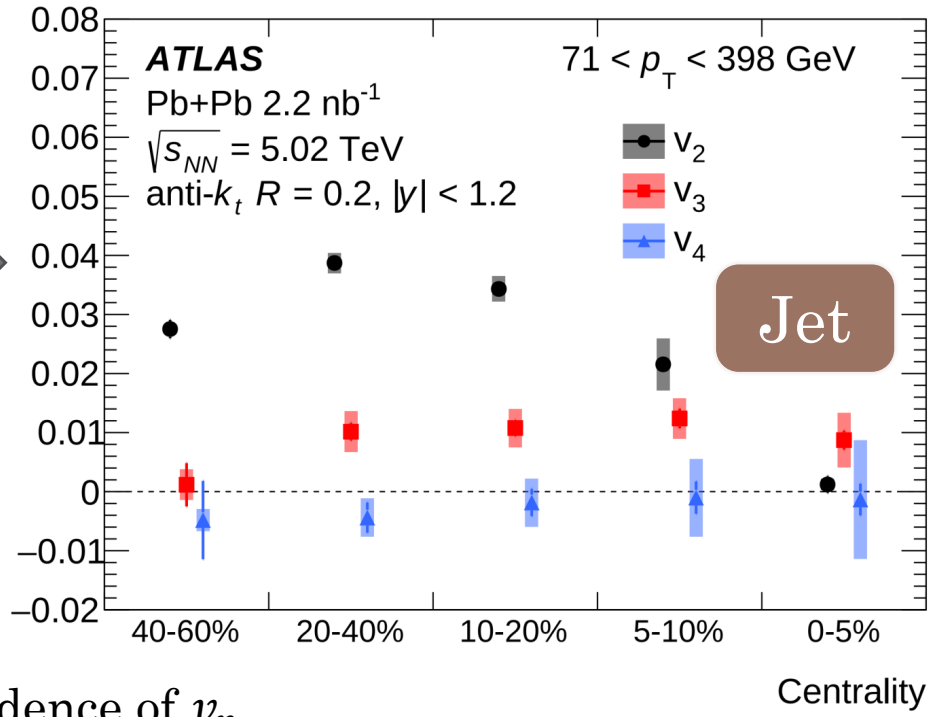
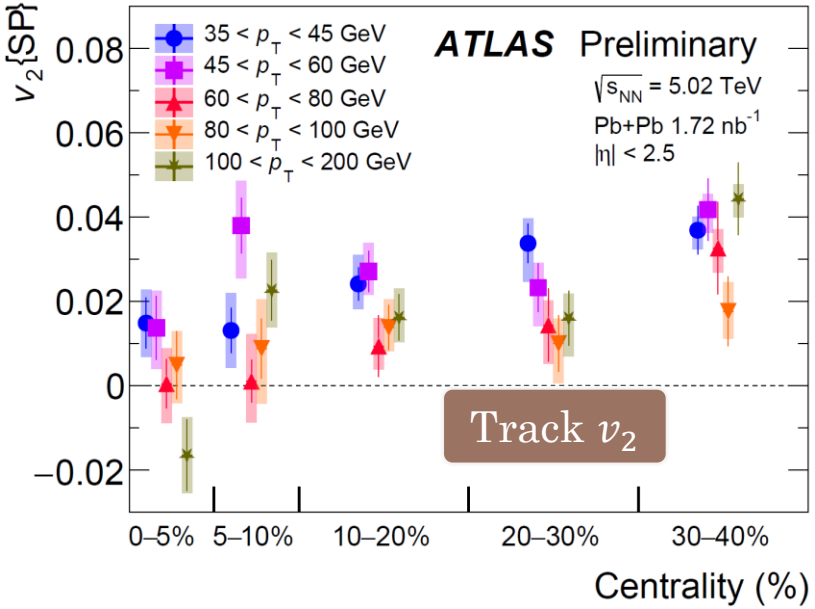
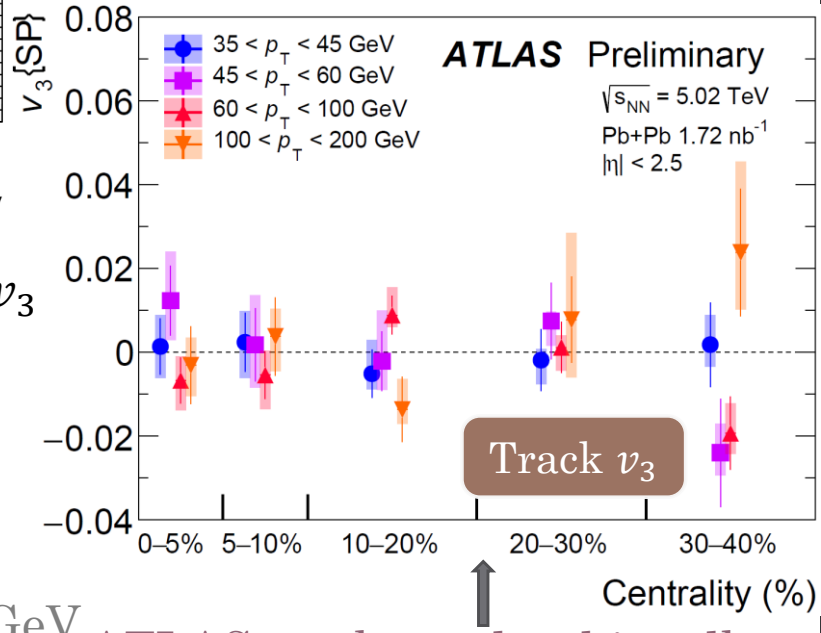
Xiaoning Wang

Understanding Different Probes

ATLAS Jet Results This talk:
Phys.Rev.C 105 (2022) 6, 064903
e-Print: arXiv: 2111.066061



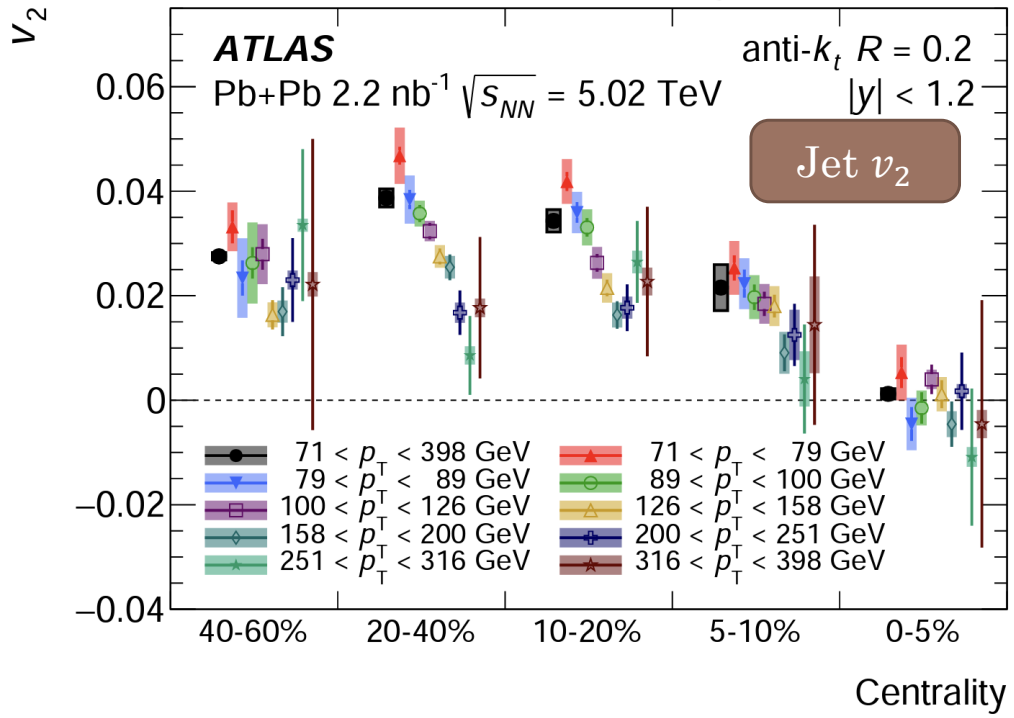


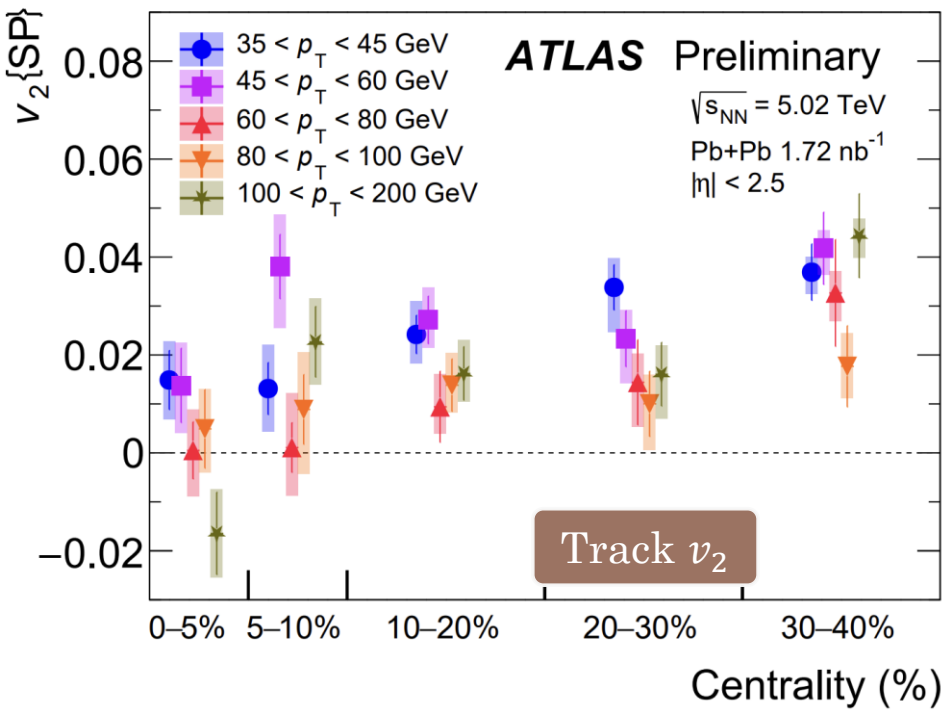


- Similar centrality dependence of v_n
  - Strong centrality dependence for v_2, no obvious dependence for v_3 and v_4
  - Different pseudo-rapidity range, different results
- Different mapping of p_T
- 2018 dataset has enabled us to extend greatly in p_T range to 200 GeV
  - More measurements can be done!

ATLAS track results this talk:
ATLAS-CONF-2023-007

Understanding Different Probes





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ATLAS Jet Results This talk:
Phys.Rev.C 105 (2022) 6, 064903,
e-Print: arXiv: 2111.06606
ATLAS track results this talk:
ATLAS-CONF-2023-007

Understanding Different Probes

ATLAS track results this talk:
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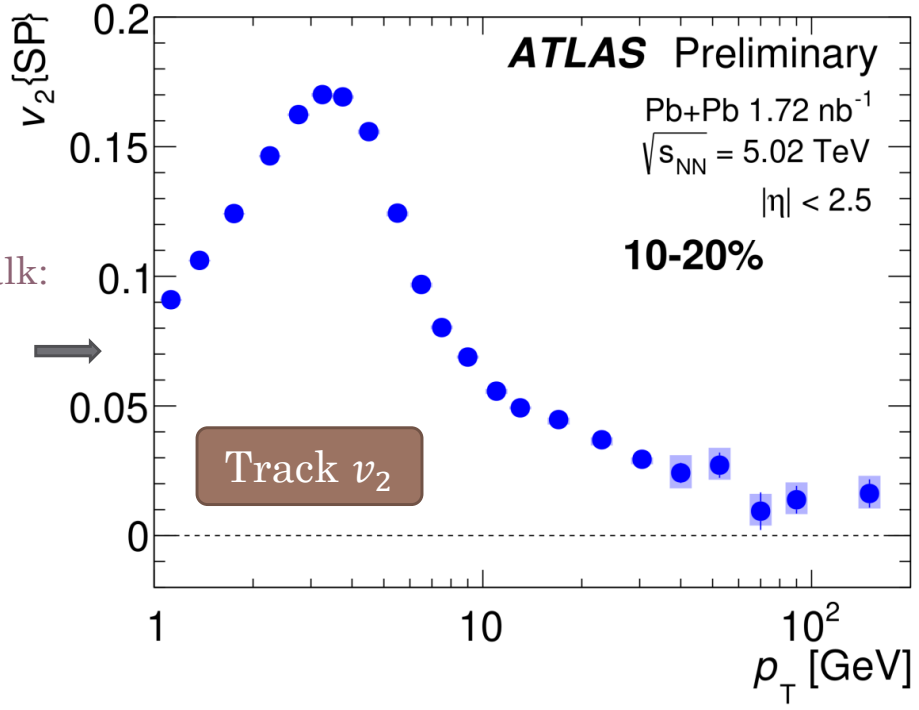

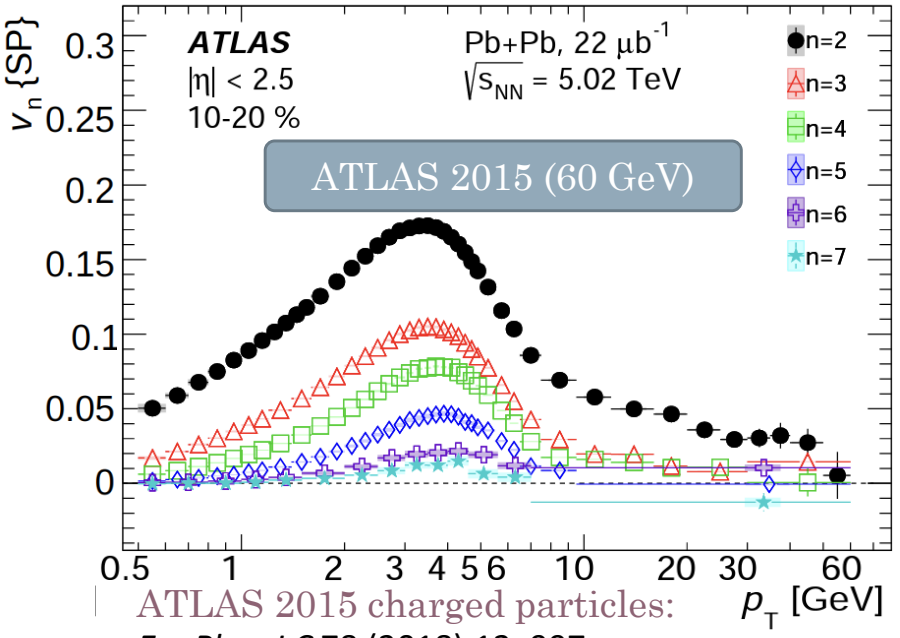

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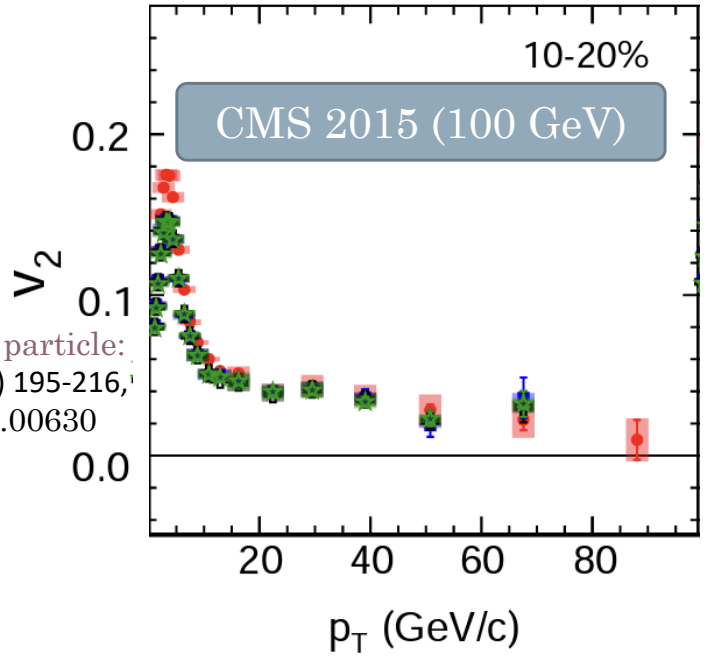
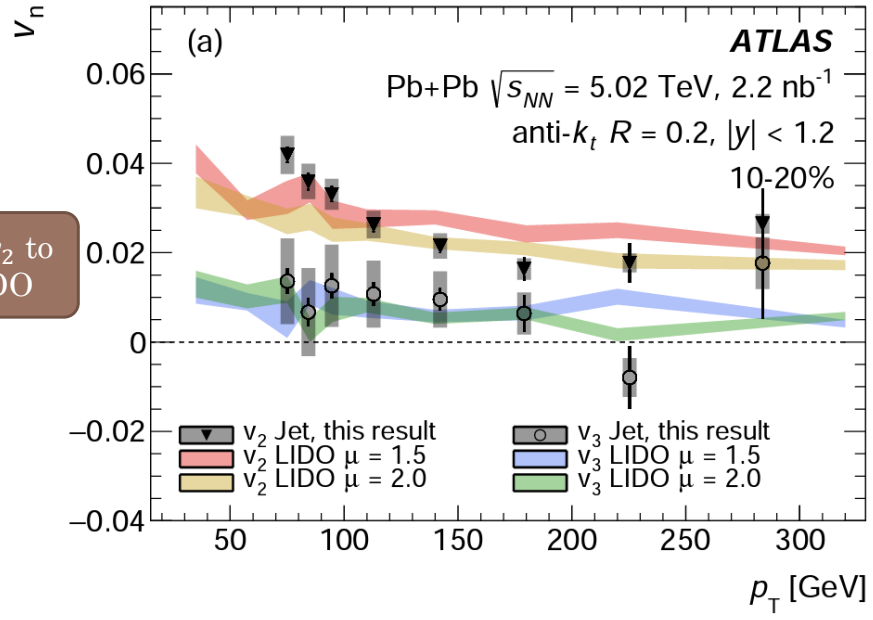


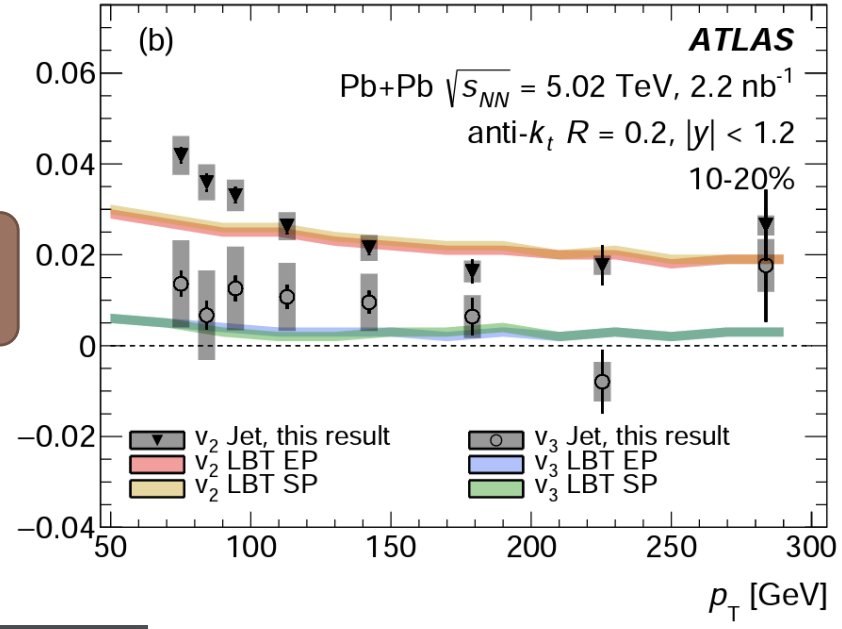
CMS 2015 charged particle:
Phys.Lett.B 776 (2018) 195-216,
e-Print: arXiv:1702.00630

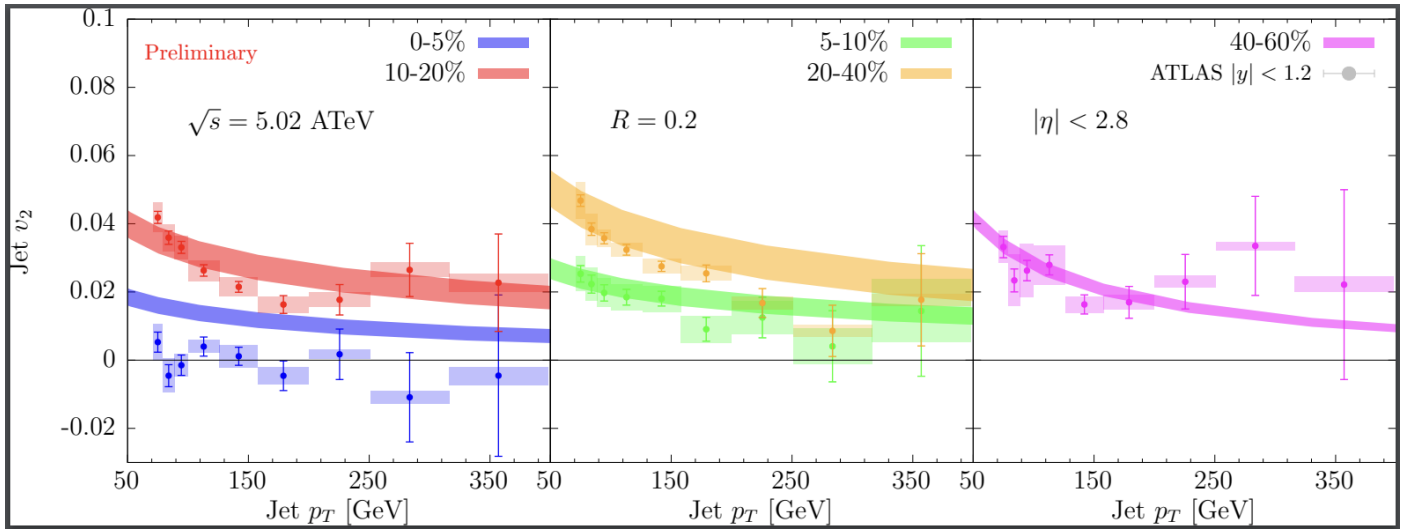
Theoretical Comparisons

Jet v_2 to LIDO



Jet v_n to LBT





- Looking forward to theoretical calculations for charged particles!

v_n Jet, this result:
Phys.Rev.C 105 (2022) 6, 064903, arXiv: 2111.06606

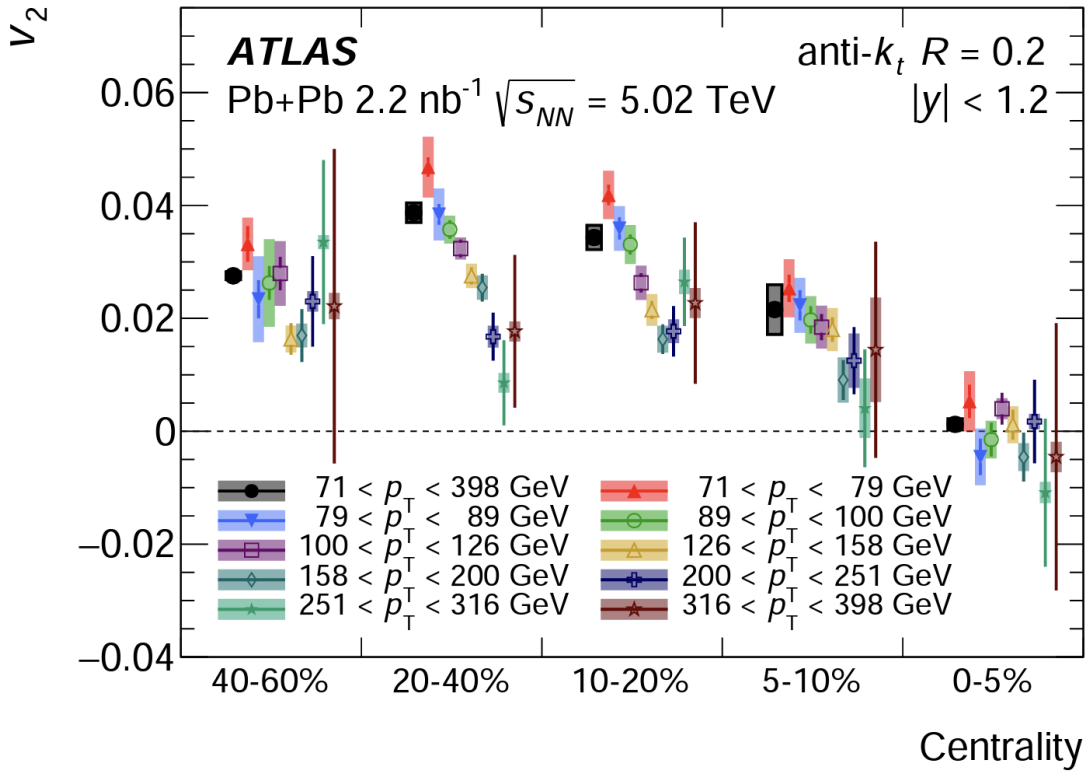
LIDO:
JHEP 05 (2021) 041, arXiv: 2010.13680

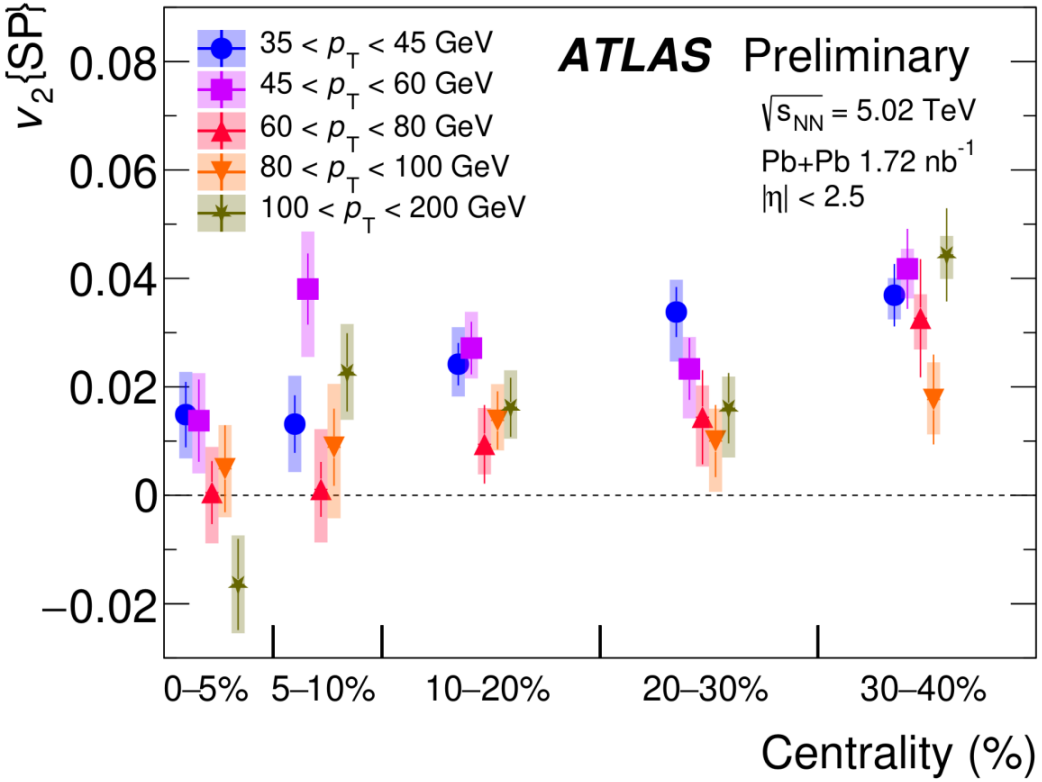
LBT Models:
Nucl.Phys.A 982 (2019) 635-638, arXiv:1811.08975
Phys.Rev.C 99 (2019) 5, 054911, arXiv:1809.02525
Phys.Rev.C 91 (2015) 054908, arXiv:1503.03313

Theoretical Paper quoting this result:
Phys.Rev.C 106 (2022) 4, 044904, arXiv: 2201.08408
arXiv: 2208.02061

Talk:
Mehtar-Tani et. al
Dr Konrad Tywoniuk, 29 Mar 2023, 15:00

Summary



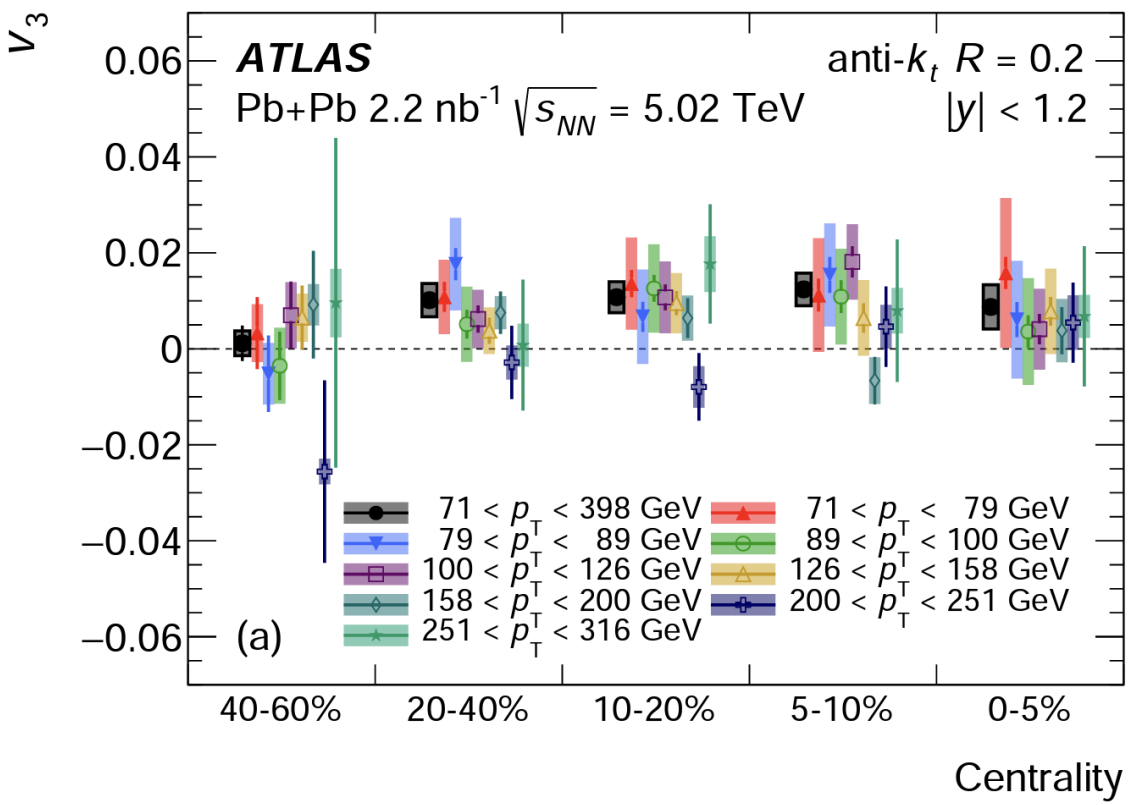


- **Extended the p_T range** of current measurements of energy loss anisotropies in hard sector using jets and charged particles.
- Non-zero v_3 measured by jet result in high p_T, charged particles with wider pseudo-rapidity range see v_3 consistent with zero. Measurements of v_4 are consistent with zero.
- **More measurements feasible** with good statistics of 2018 Run II data with ATLAS!
- ATLAS heavy-ions public results: https://twiki.cern.ch/twiki/bin/view/AtlasPublic/HeavyIonsPublicResults

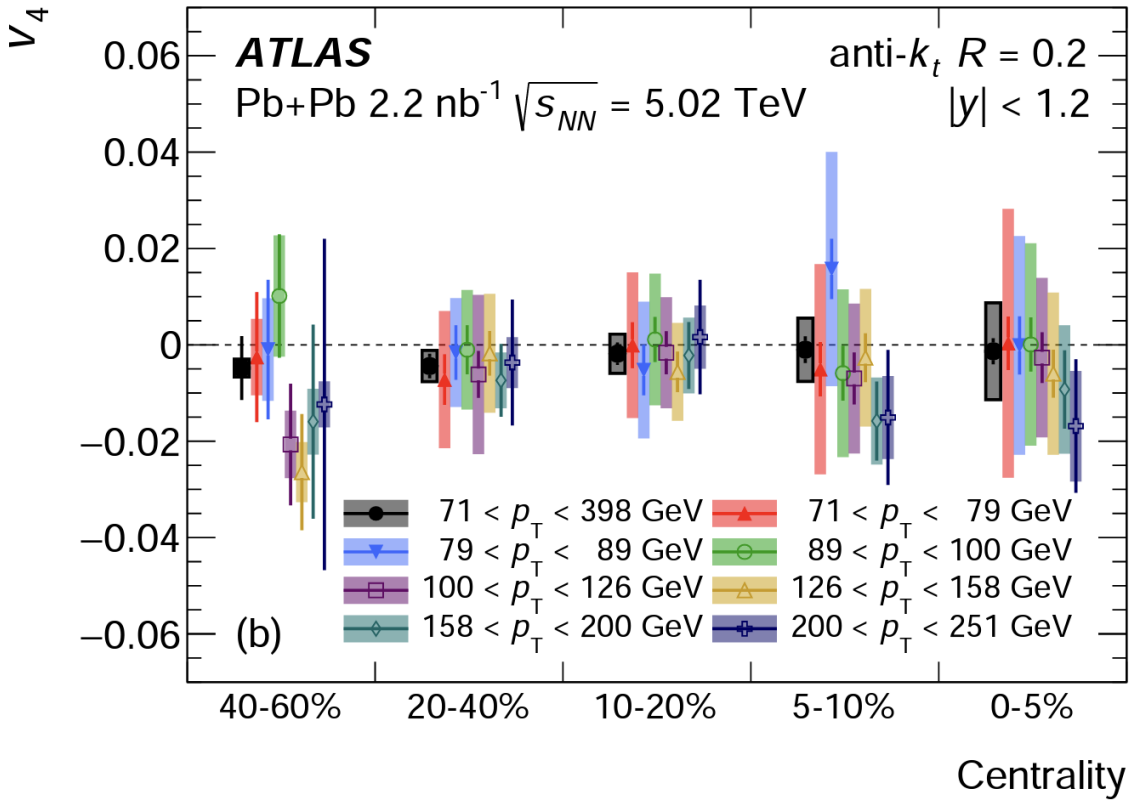
Back-up

Jet v_3 and v_4 Results

v_3



v_4



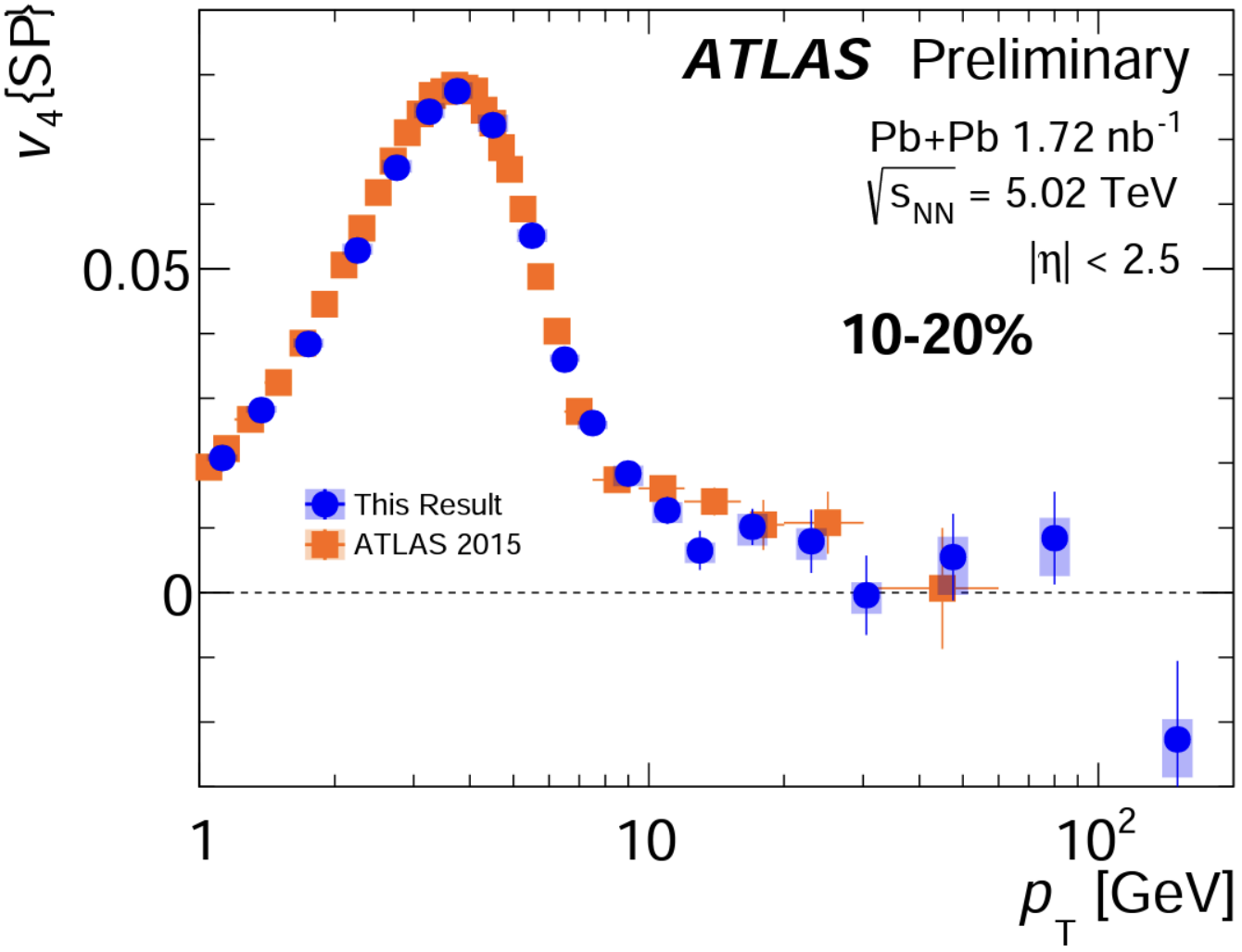
- Non-zero v_3 for centrality bin 0-40%.
- No evidence of non-zero v_4 for all centrality bins.

Phys.Rev.C 105 (2022) 6, 064903
e-Print: arXiv: 2111.06606

Details of SP Method

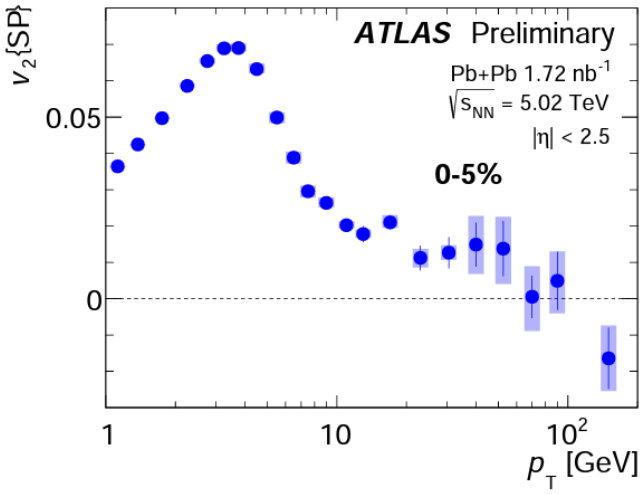
- Flow vectors are computed for each subevent
  - Negative and positive FCal with calorimeter tower energy ($Q^{N|P}$)
  - Negative and positive inner detector with tracks ($q_{n,j}$)
- Final Formula:
  - $v_n\{SP\} = Re\ \frac{\left\langle q_{n,j}^{*} Q_n^{N|P} \right\rangle}{\sqrt{\langle Q_n^{N*} Q_n^{P} \rangle}}$

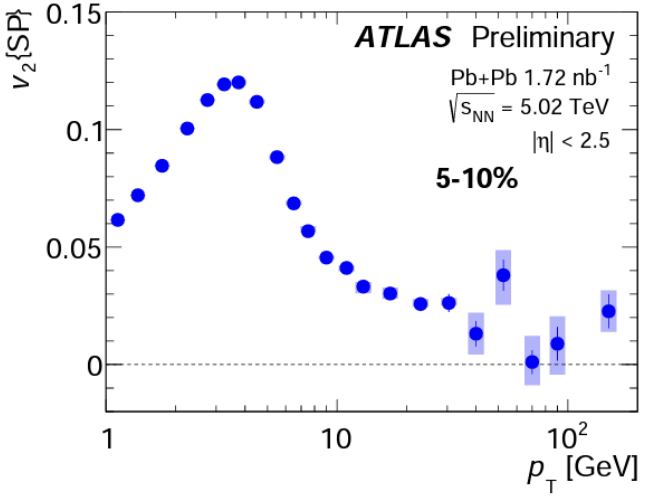
Comparison to 2015 ATLAS SP Method Track v_4 Result

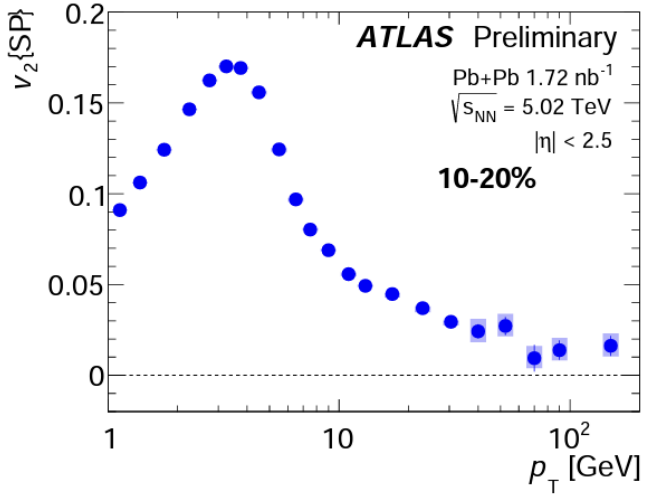


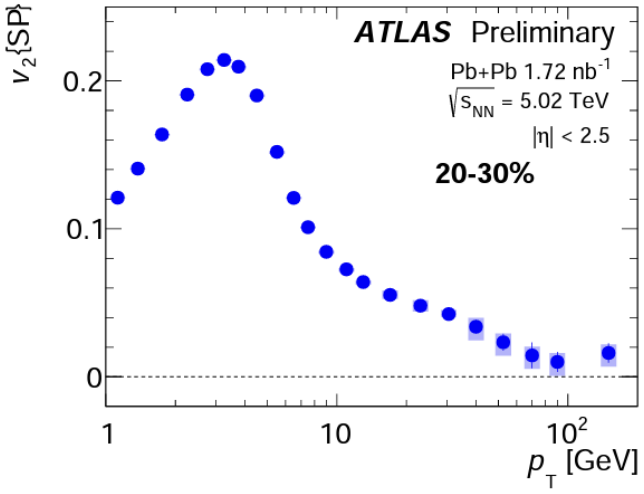
ATLAS-COM-CONF-2023-005

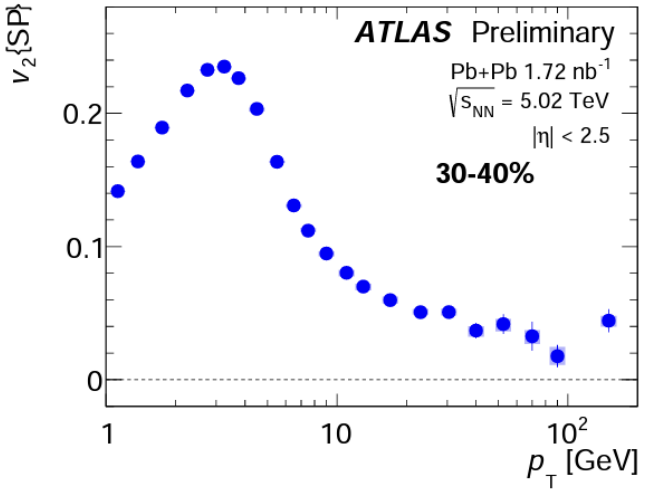
Other v_2 Centrality



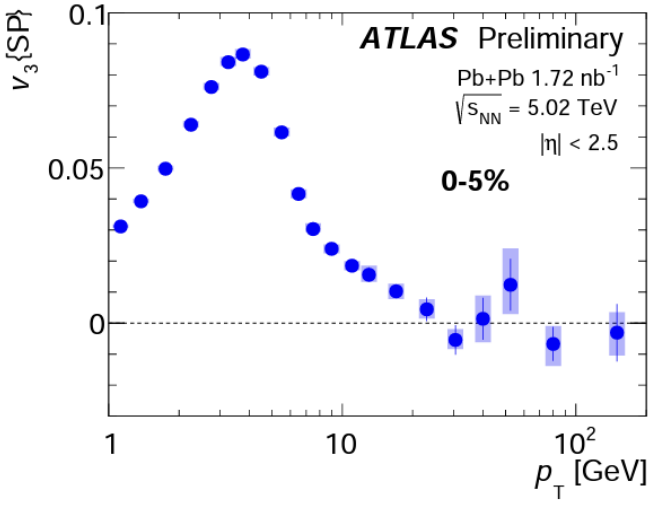


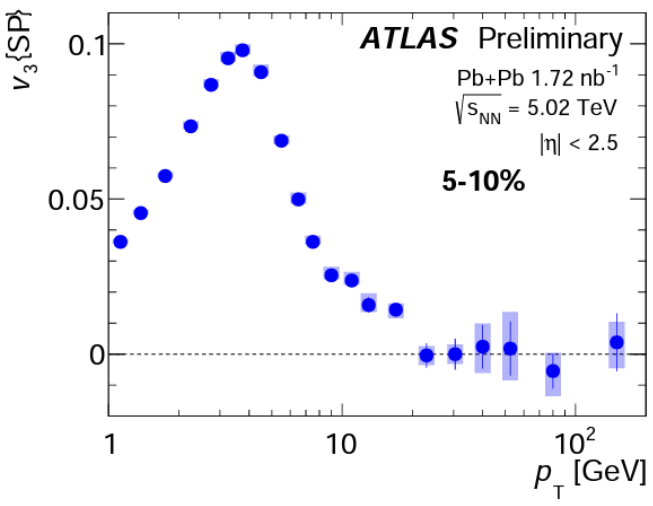


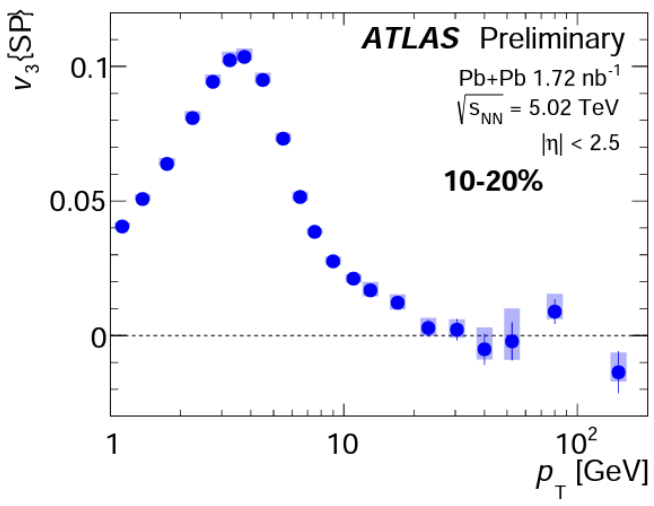


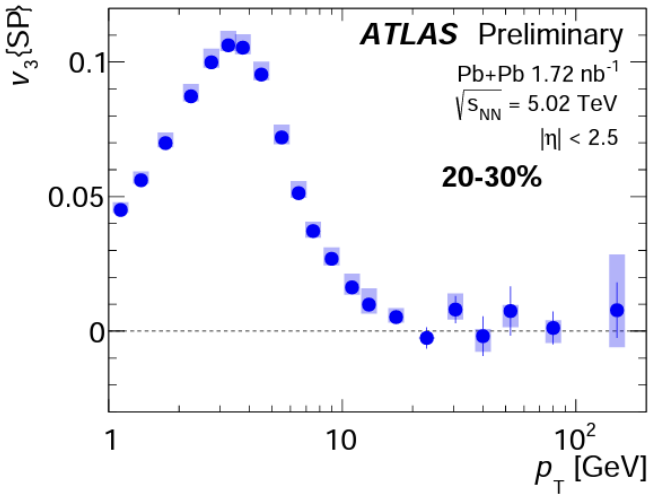


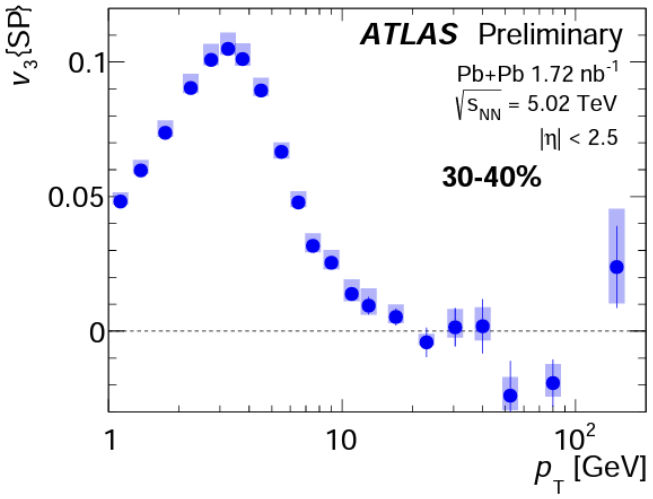
Other v_3 Centrality



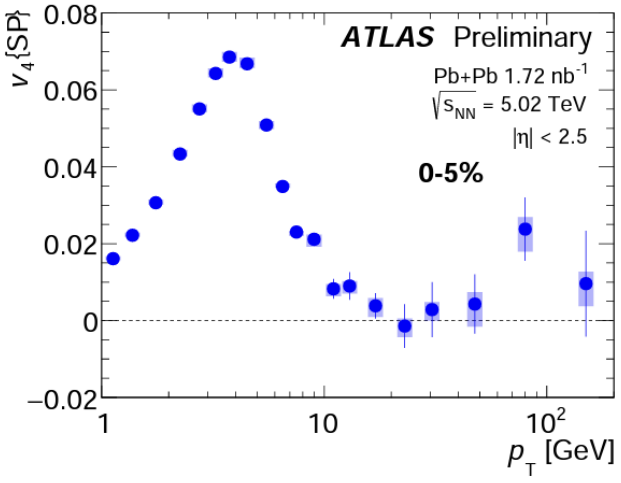


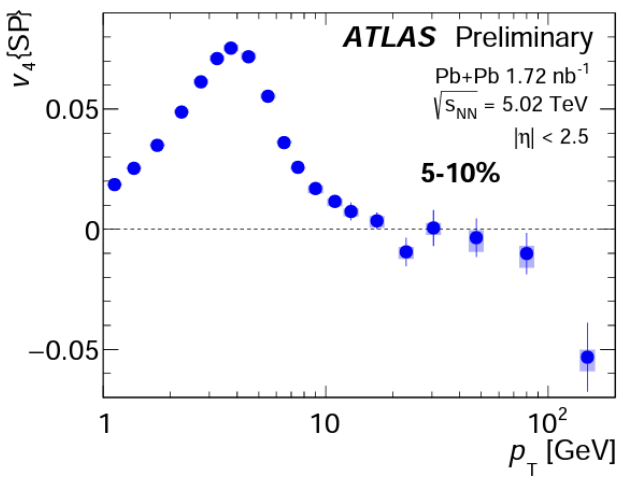


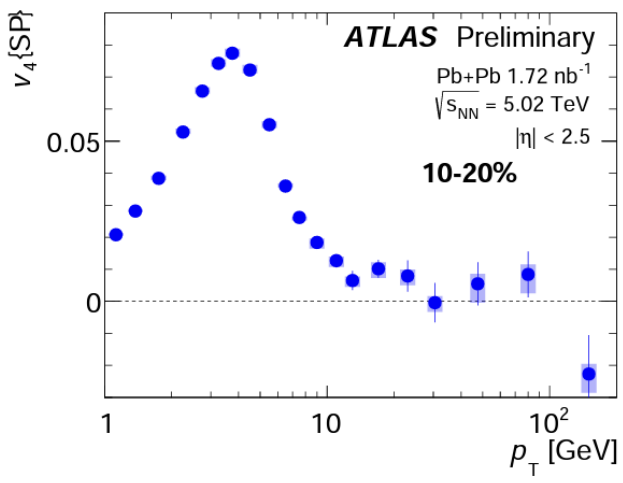


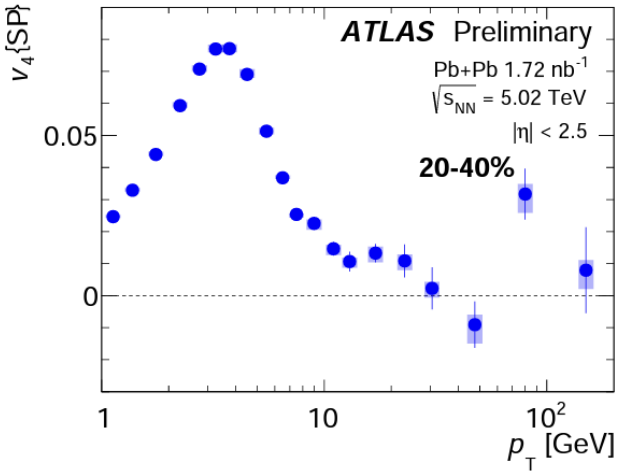


Other v_4 Centrality

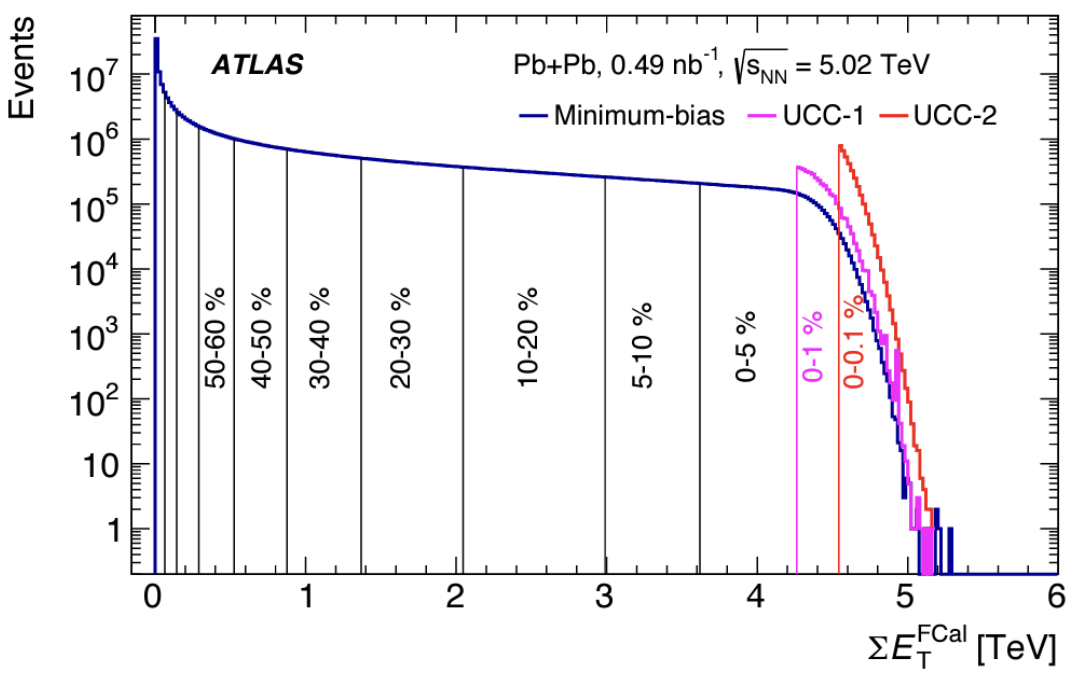


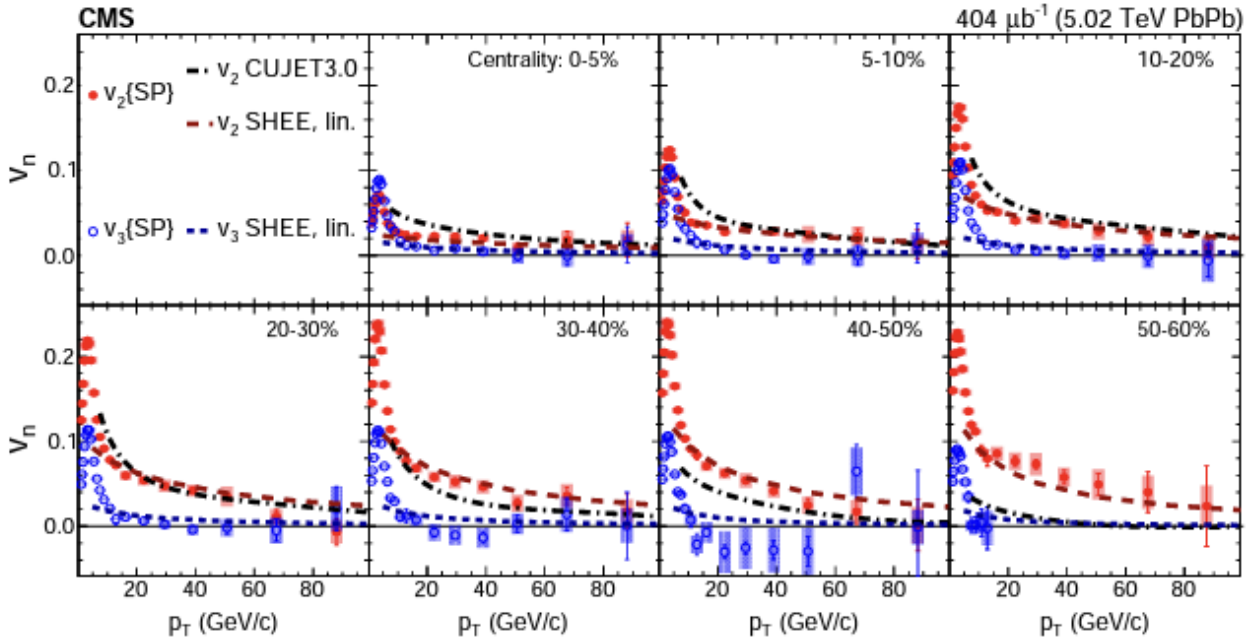






Luminosity Comparisons





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