Searches for the ridge in DIS and e^+e^-

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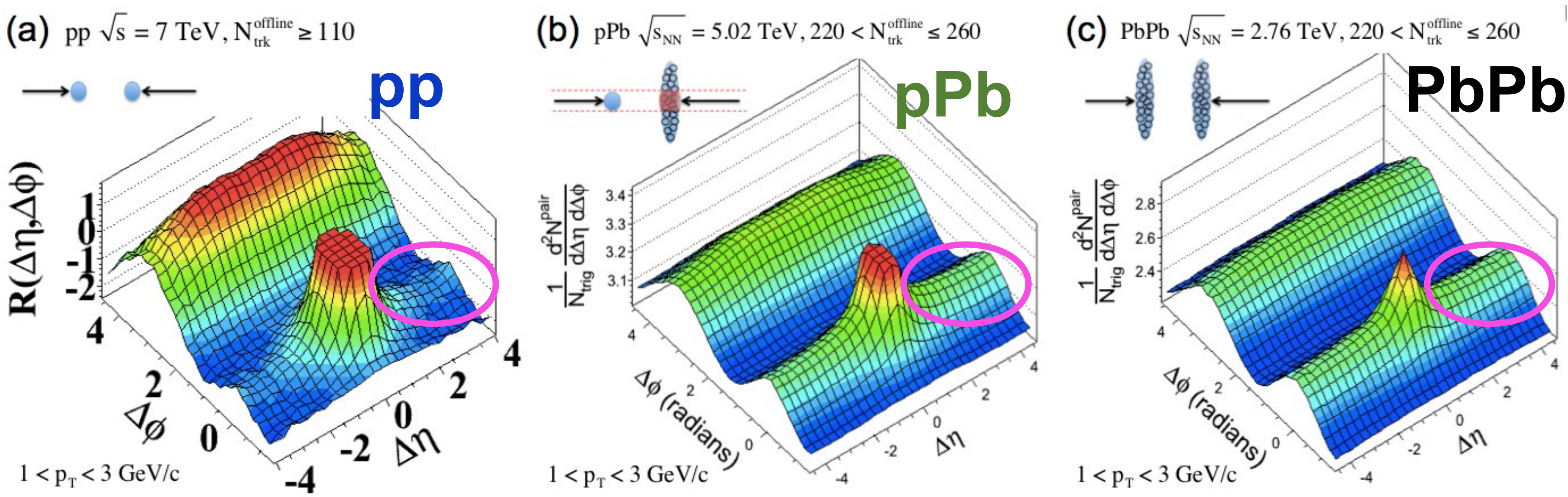
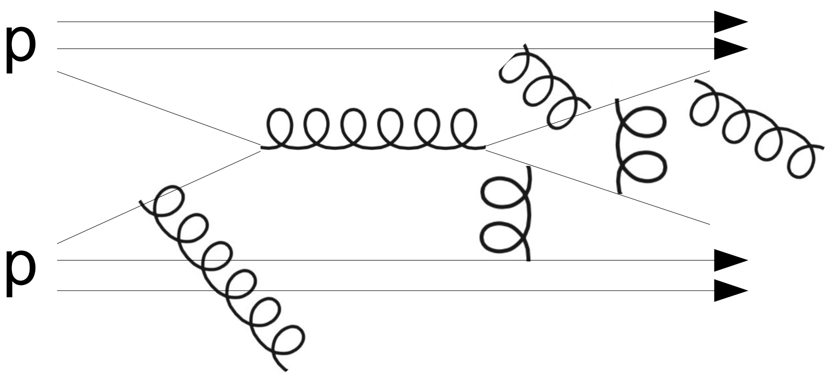
DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA ·

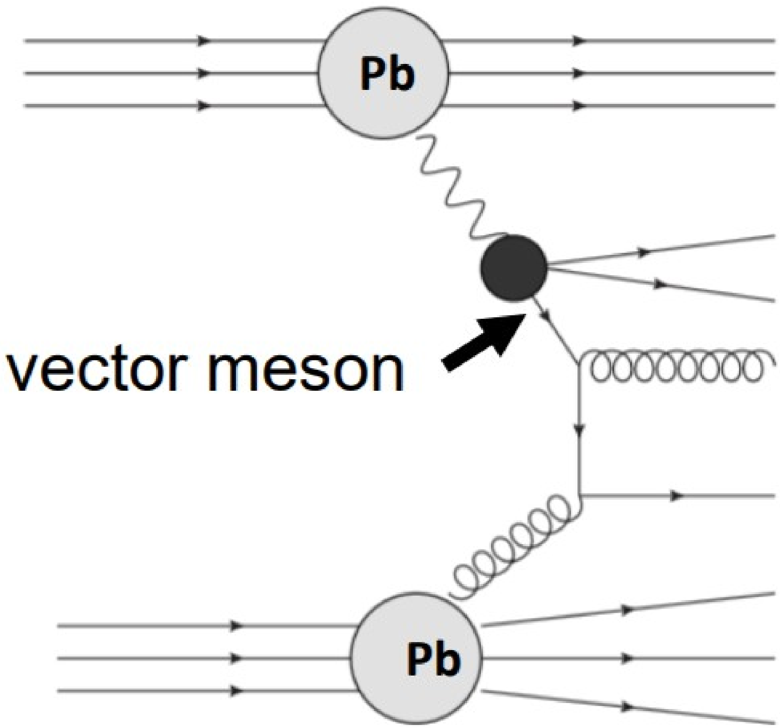
Introduction

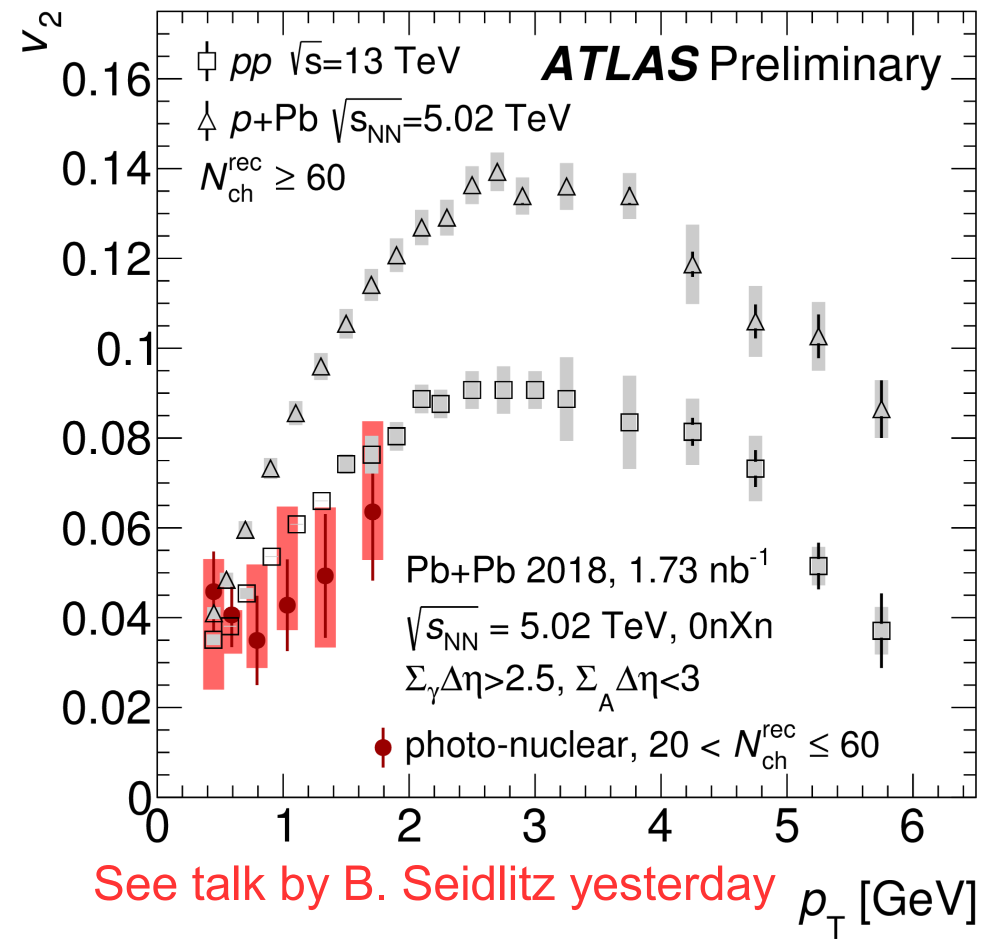


- Origin of ridge in small systems still uncertain
  - Initial state effect (CGC)
  - Flowing mini Quark Gluon Plasma
  - MPIs
  - “Escape” mechanism
- Complications from complexity of hadronic events
  - Hadron structure
  - Gluon ISR
  - Beam remnants
- Can we simplify the system?



v_2 in UPC





See talk by B. Seidlitz yesterday

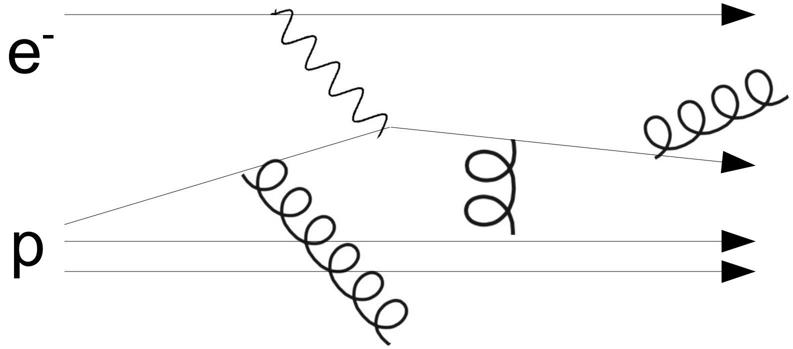
- Nonzero v_2 seen in γA collisions!

- Dominated by resolved photon interactions
- No direct control over initial photon energy
  - Large range of effective collision energies

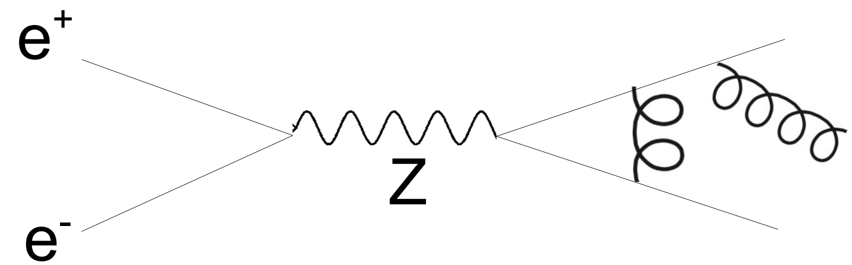
- At higher Q^2, can control kinematics and interaction process better
  - Does v_2 persist in DIS region?

DIS and e^+e^- collisions

Deep Inelastic Scattering



e^+e^- Annihilations



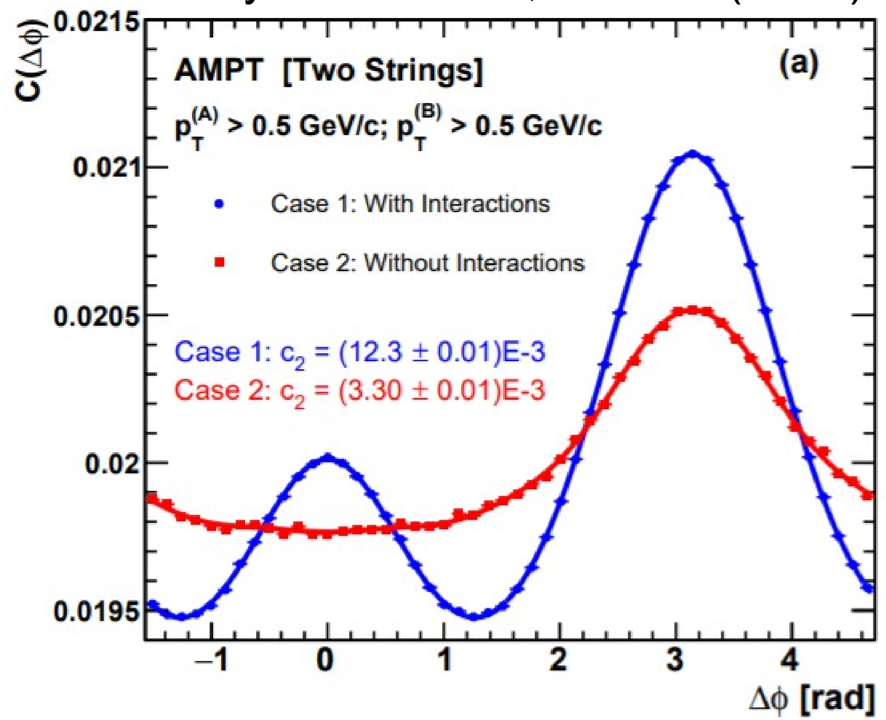
- Study high-multiplicity events with well-defined initial conditions

- Control systems to study
  - parton fragmentation
  - proton structure
  - hadronization and rescattering

- DIS: Use electron to tag Q^2, x
- e^+e^-: Use clean decay of $Z \rightarrow q\bar{q}$

- Suggested that ridge could be in e^+e^-

Phys. Rev. C 97, 024909 (2018)



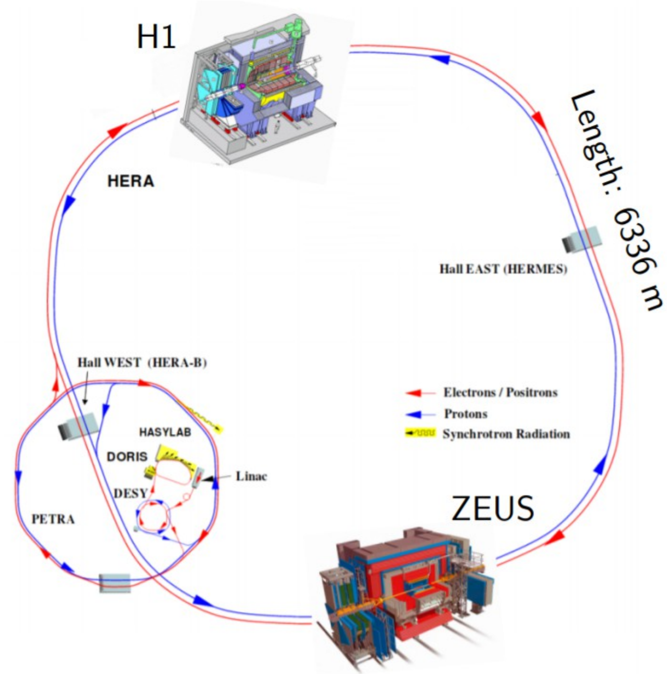
HERA DIS Data

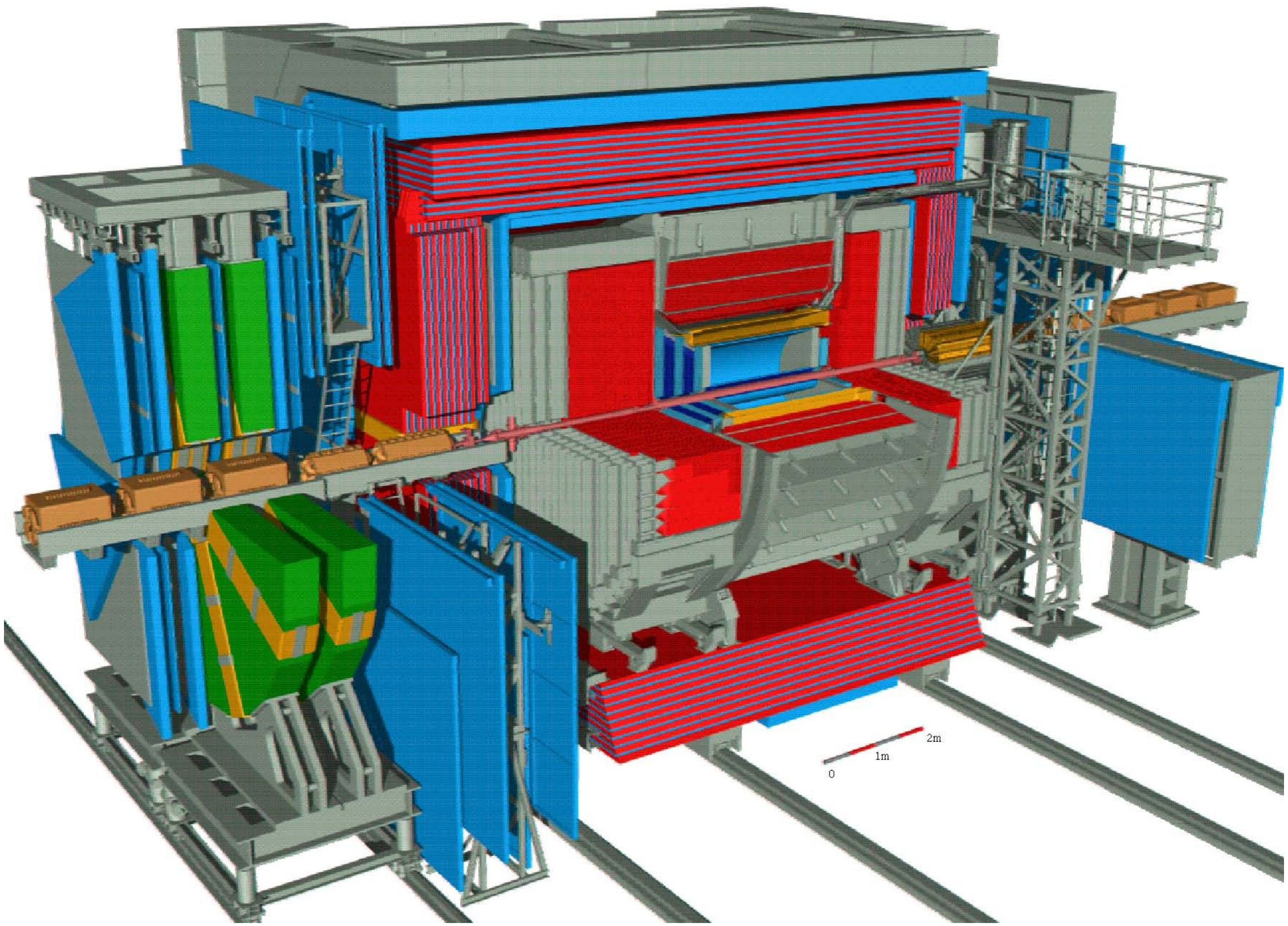
Based on results from the ZEUS Collaboration

QM 2018 talk

HERA and ZEUS

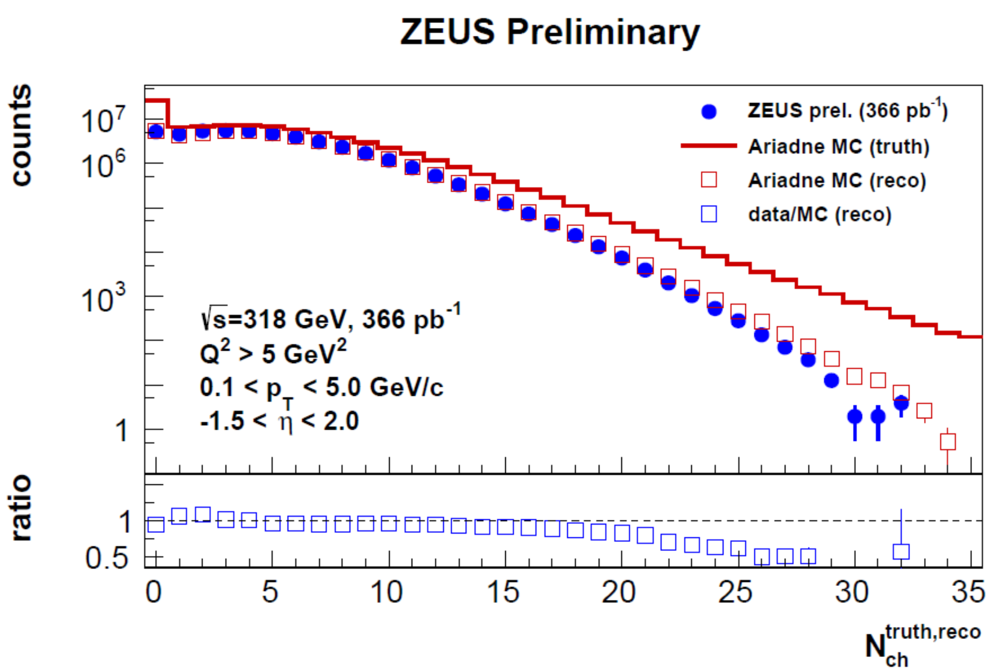
- HERA ran from 1992-2007
- 27.6 GeV electron/positron
- 920 GeV proton
  - $\sqrt{s}$ = 318 GeV

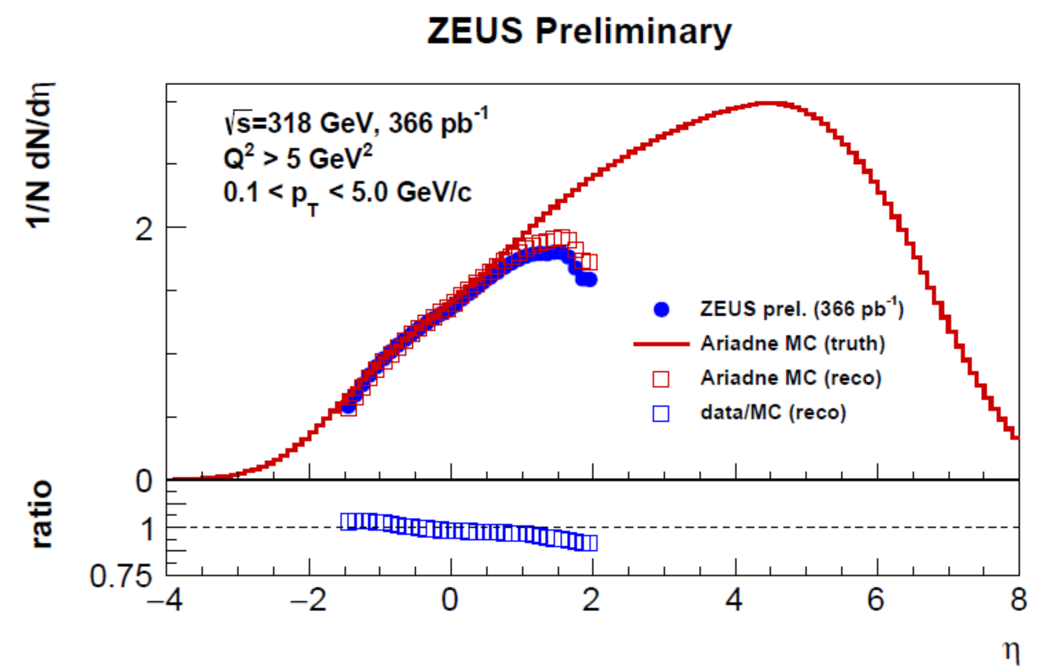




- Tracking:
  - Microvertex tracker
  - Outer drift chamber
  - Forward straw tracker
- DIS events, $\mathbf{Q^2 > 5\ GeV^2}$
- $E_e > 10$ GeV
- 46M events

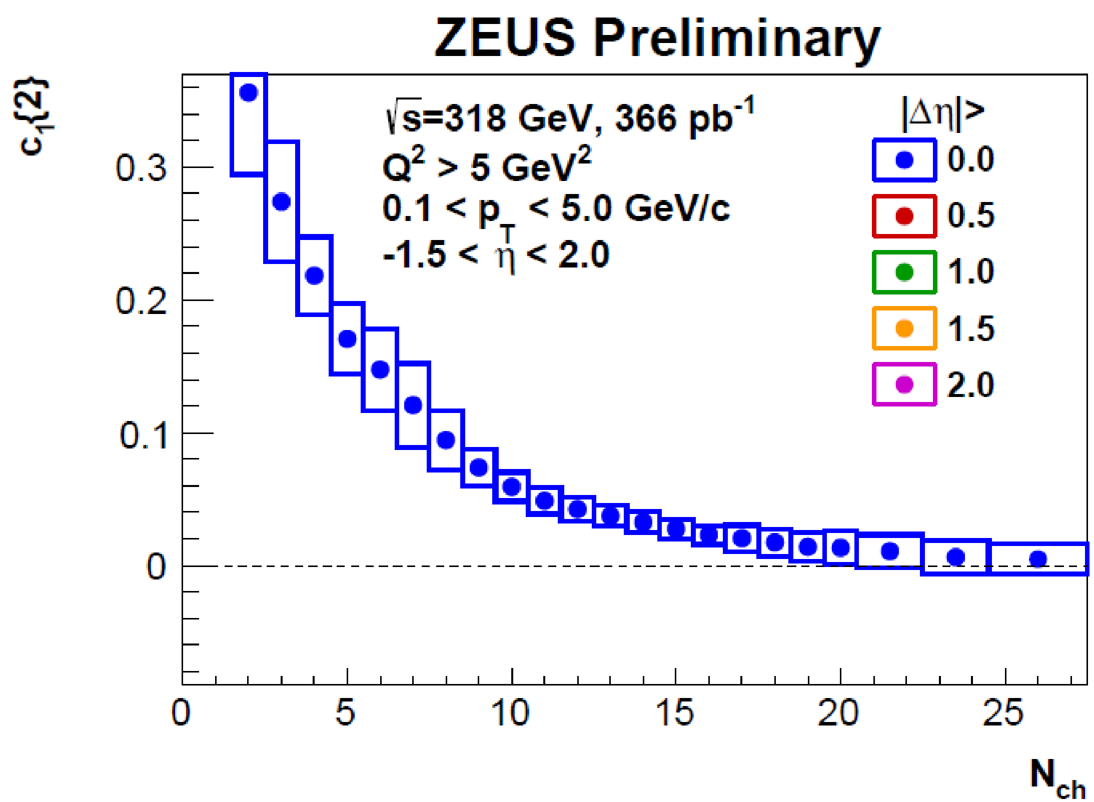
Multiplicity Distribution





- ZEUS tracker covers
  - $-1.5 < \eta < 2.0$
  - $0.1 < p_T < 5.0$ GeV/c
- Only samples one side of η distribution
- Up to $N_{trk} = 30$
- Interesting to revisit with larger acceptance/different beam energy
  - Synergy with EIC / VHEeP / LHeC plans?

$c_1\{2\}$



$$c_n\{2\} = \langle\langle 2 \rangle\rangle = \langle\langle e^{in(\phi_\alpha - \phi_\beta)} \rangle\rangle$$

$$N_{ch} = \sum w_{eff} \;\; w_\varphi$$

- Cumulant method used
  - Measures $c_n\{2\}$
- N_{ch} is weighted track sum
- Large N_{ch} dependence observed for inclusive tracks

$c_1\{2\}$

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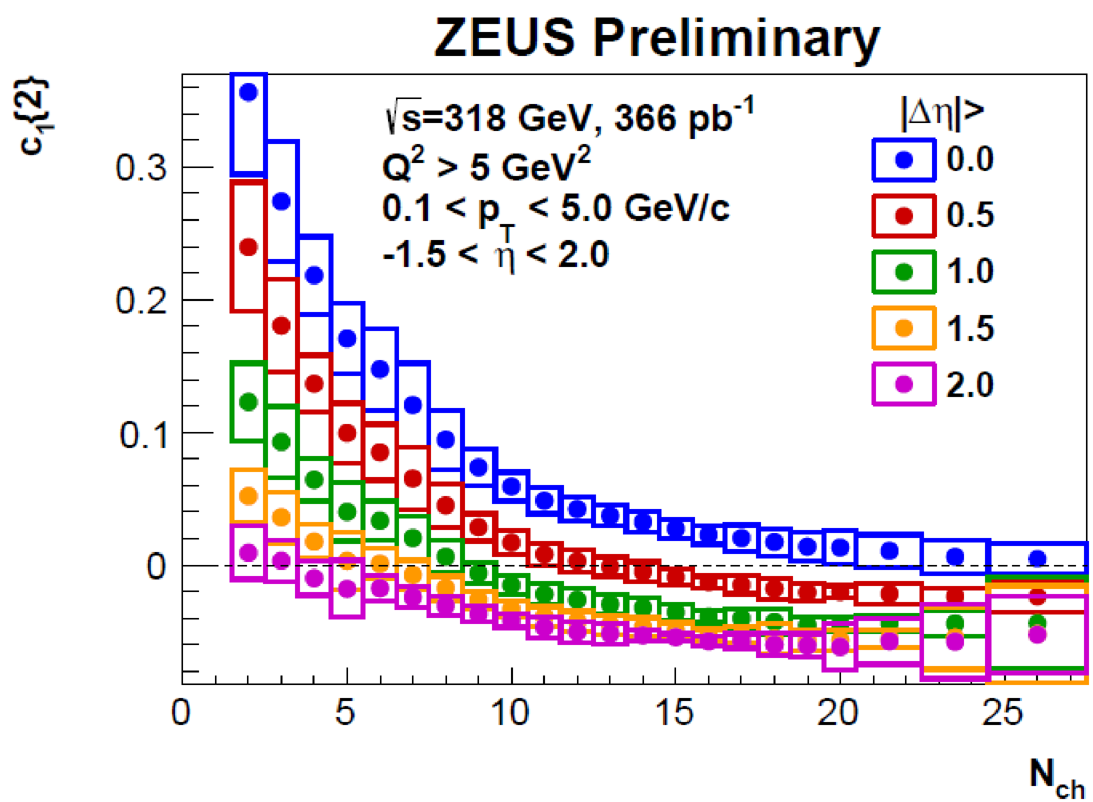
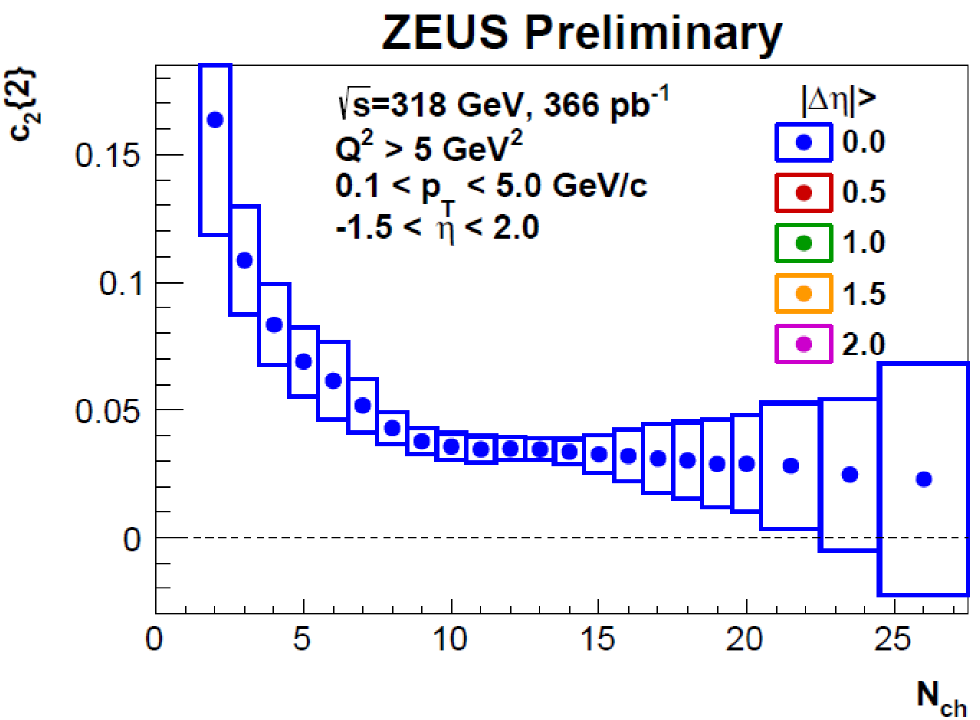
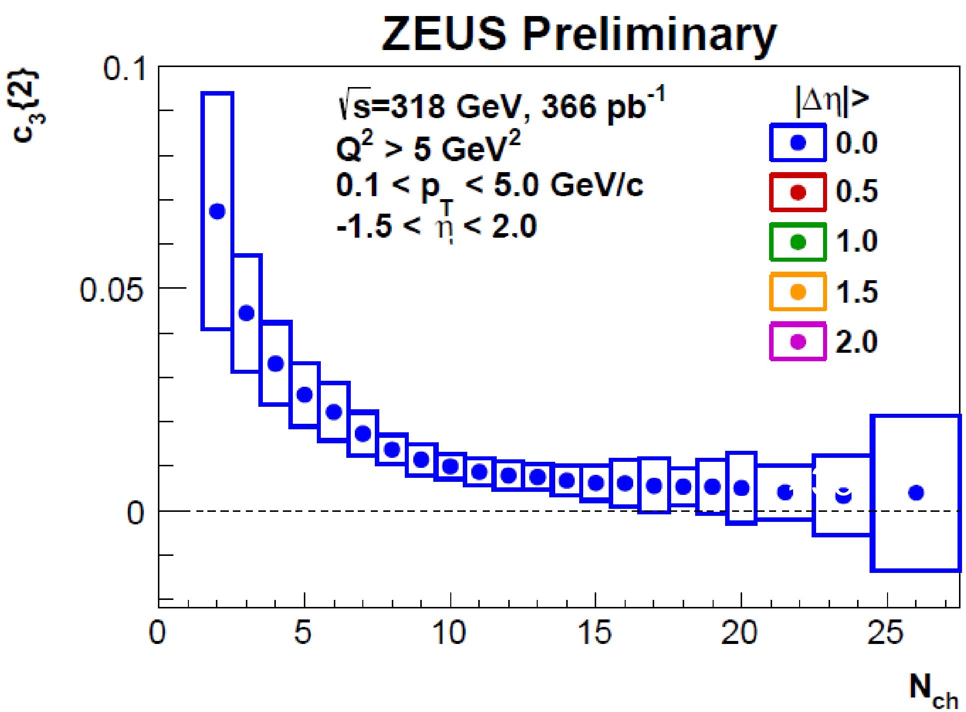


- Cumulant method used
  - Measures $c_n\{2\}$
- N_{ch} is weighted track sum
- Large N_{ch} dependence observed for inclusive tracks

- Applying η gap causes $c_1\{2\}$ to cross 0
  - Conservation of momentum in DIS

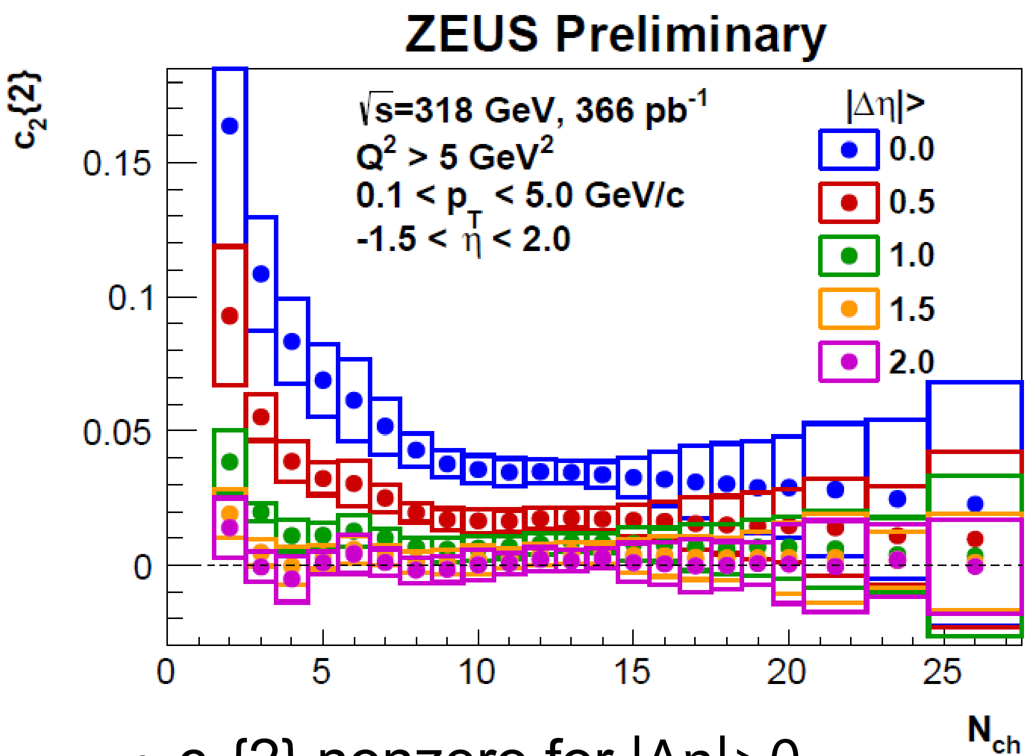
$c_2\{2\}$ and $c_3\{2\}$

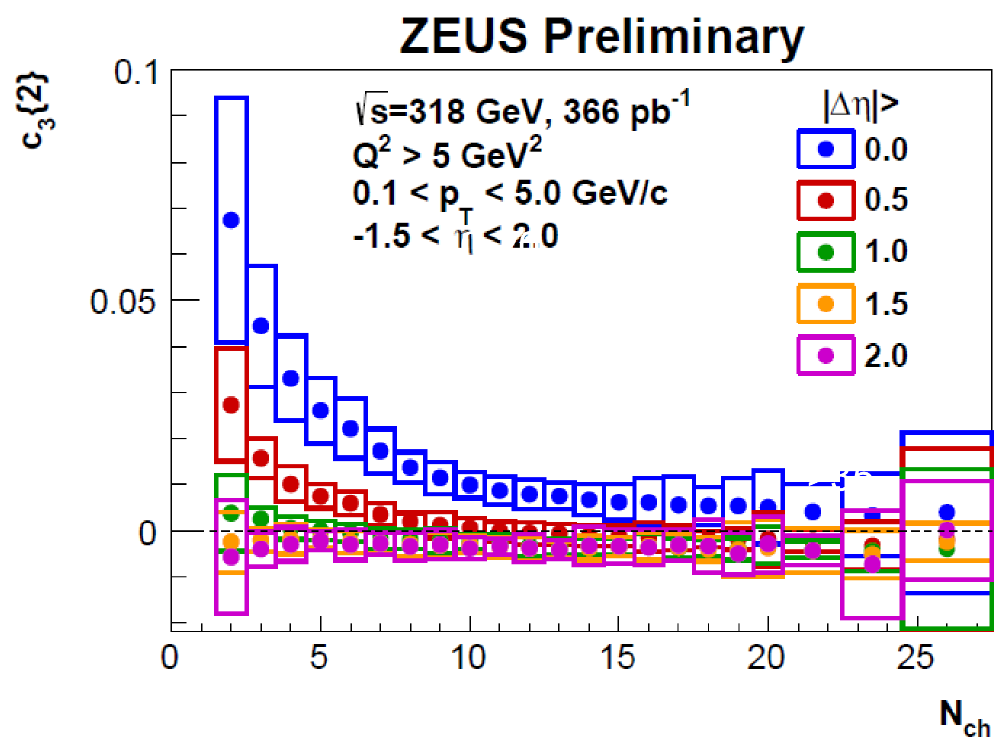




- $c_2\{2\}$ nonzero for $|\Delta\eta|>0$
- $c_3\{2\}$ slightly above 0 large at N_{ch}

$c_2\{2\}$ and $c_3\{2\}$



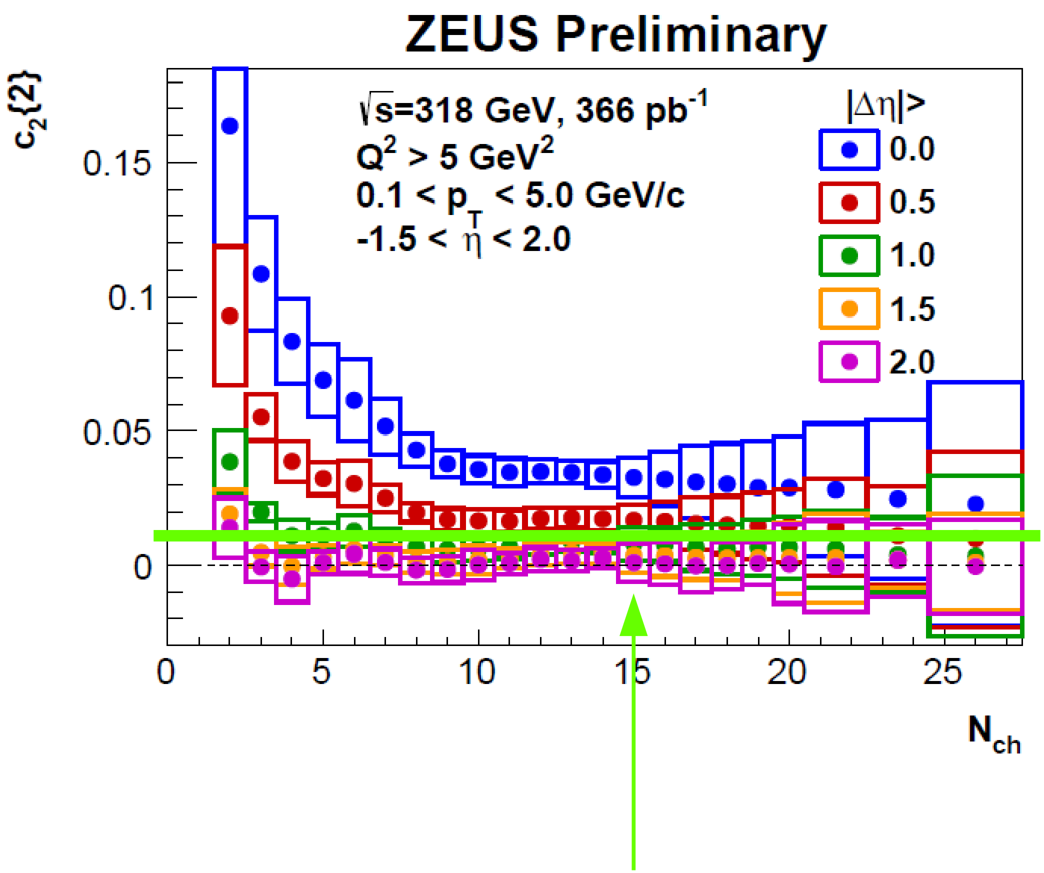


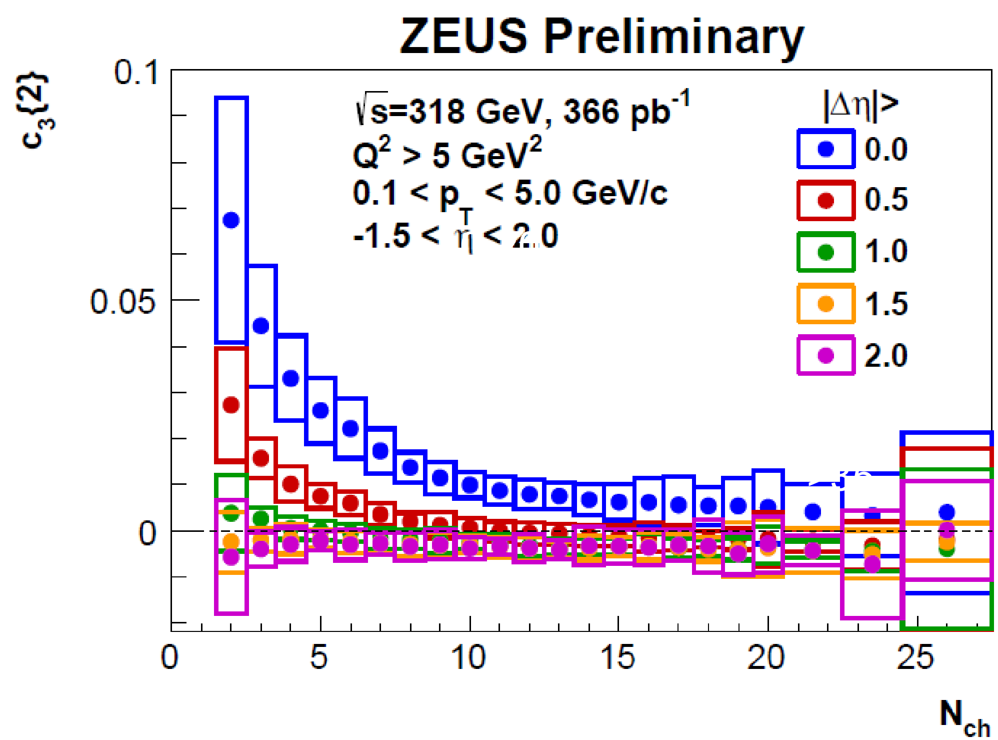
- $c_2\{2\}$ nonzero for $|\Delta\eta|>0$
- $c_3\{2\}$ slightly above 0 large at N_{ch}

- Vanish when η gap is required!
- Statistics become poor for large η gap

- Similar results for $c_4\{2\}$

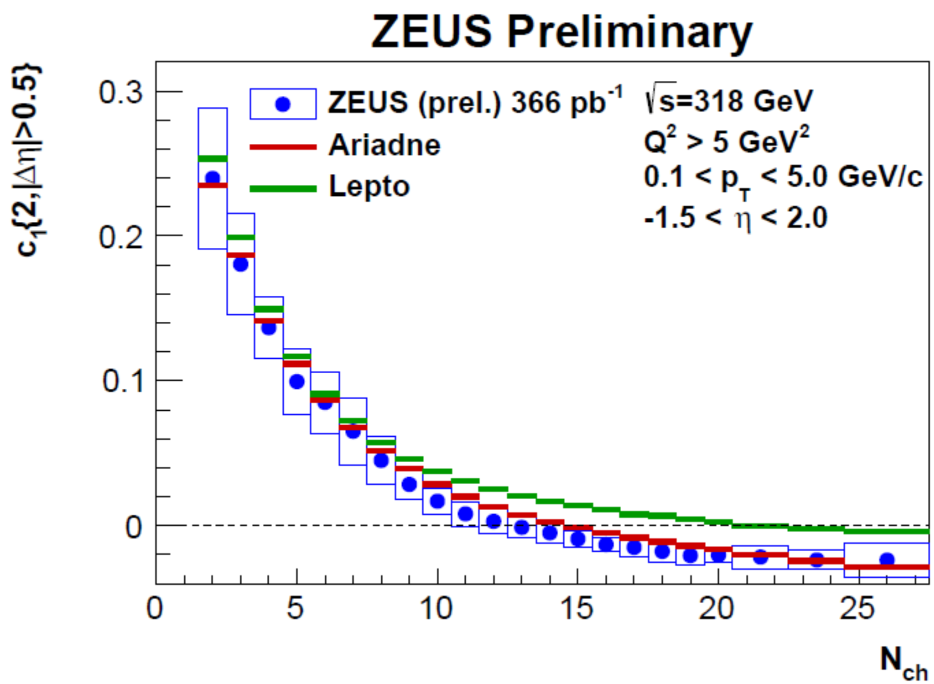
$c_2\{2\}$ and $c_3\{2\}$

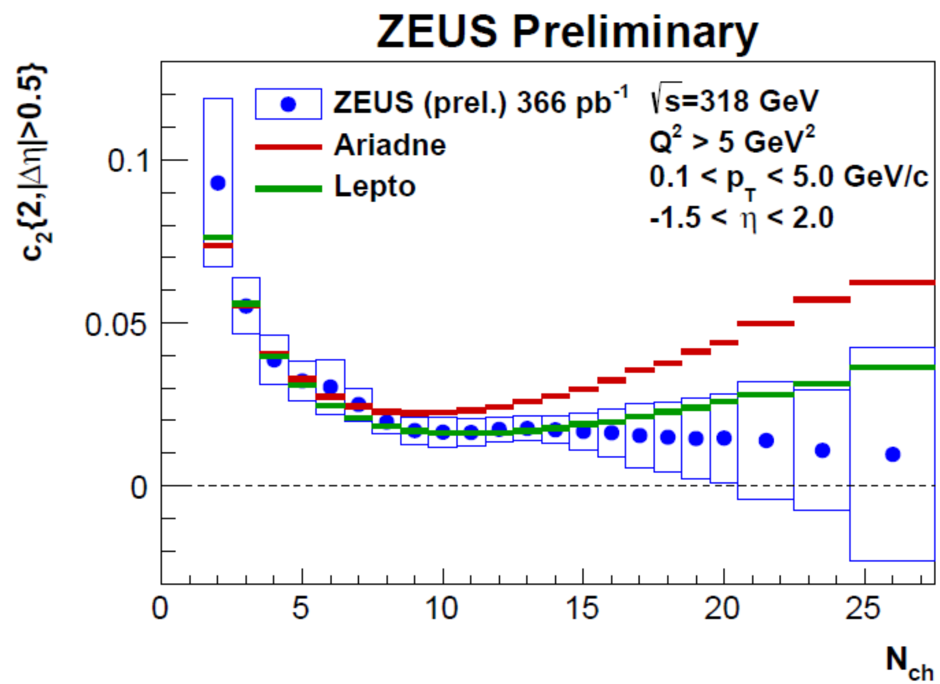




- $c_2\{2\} < 0.01$ at $N_{ch} = 15$ implies $v_2 < 0.1$
  - Still room for small v_2 signal, especially at high multiplicity
- No strong evidence for 'flow-like' effect in the probed N_{ch} range

Comparisons to MC





- Data ($|\Delta\eta|>0.5$) compared to Ariadne and Lepto generators
- Both describe data for $N_{ch}<8$

- $c_1\{2\}$ better described by Ariadne
- $c_2\{2\}$ better described by Lepto

- Multiplicity-dependent measurements can still constrain MC

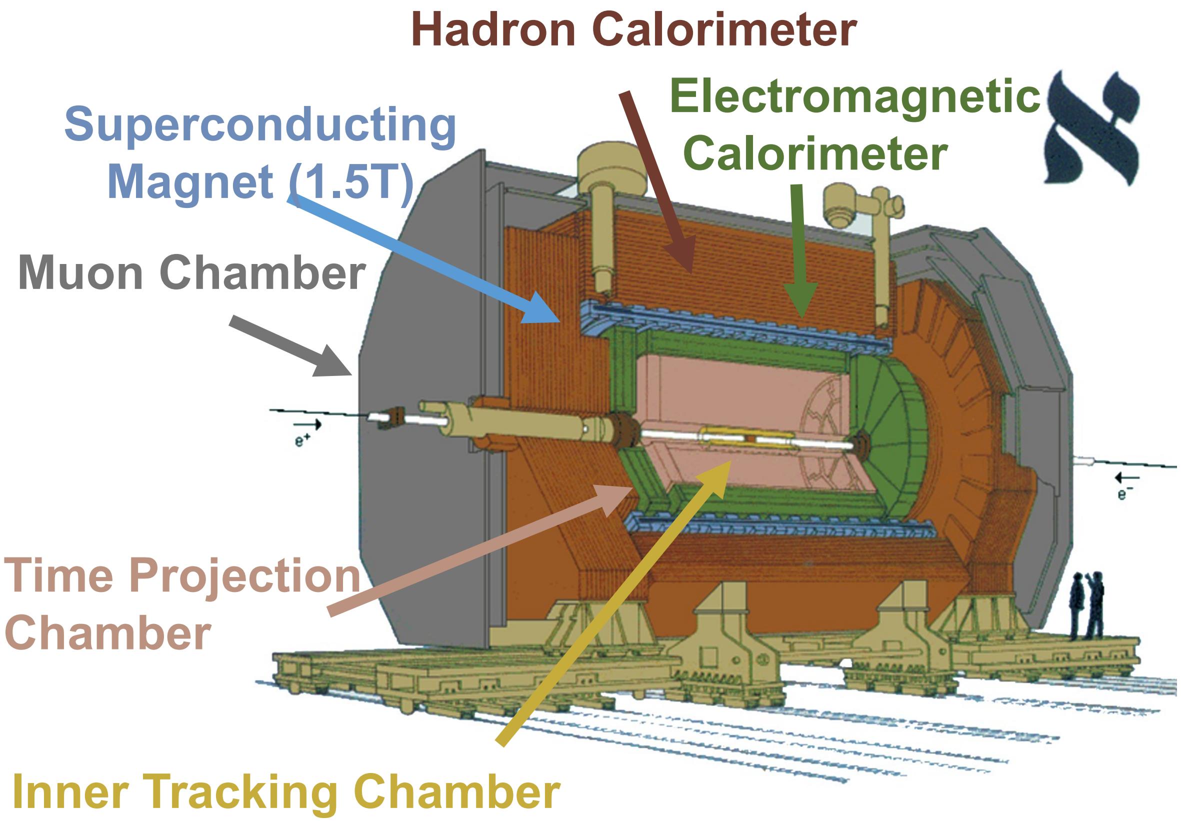
LEP e^+e^- Data

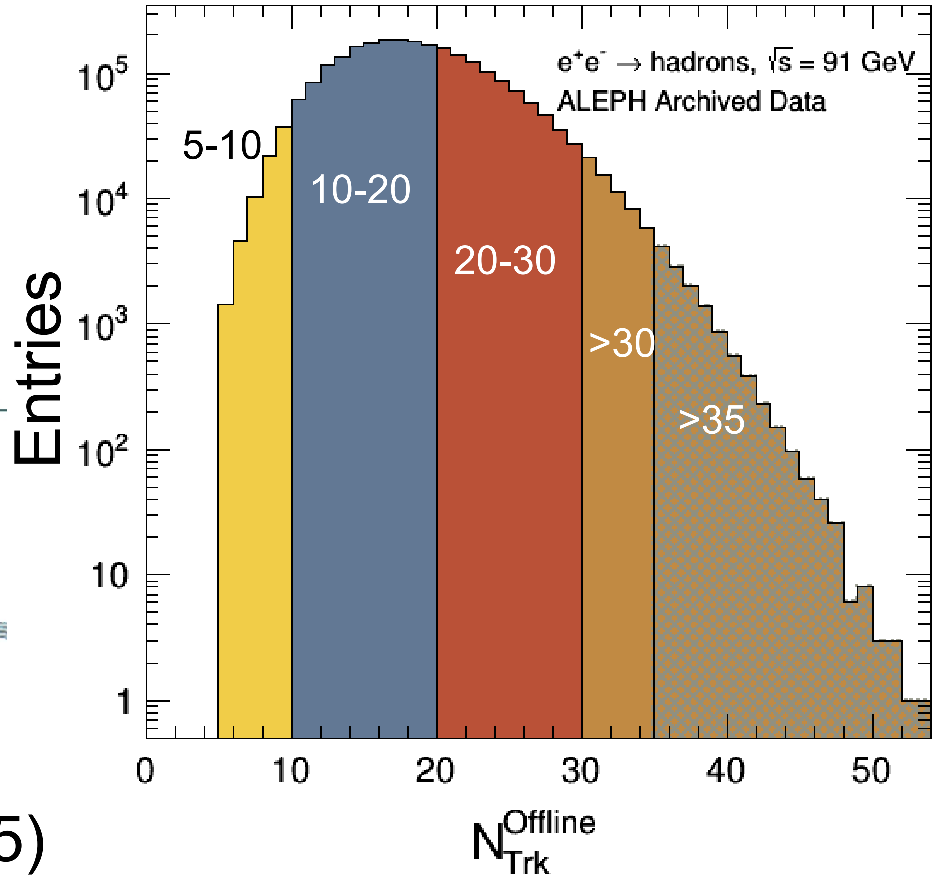
Based on analysis of archived ALEPH data

Anthony Badea,[1] Austin Baty,[1] Paoti Chang,[2] Gian Michele Innocenti,[1] Marcello Maggi,[3] Christopher McGinn,[1] Michael Peters,[1] Tzu-An Sheng,[2] Jesse Thaler,[1] and Yen-Jie Lee[1,*]

Arxiv:1906.00489
(Submitted to PRL)

The ALEPH Detector

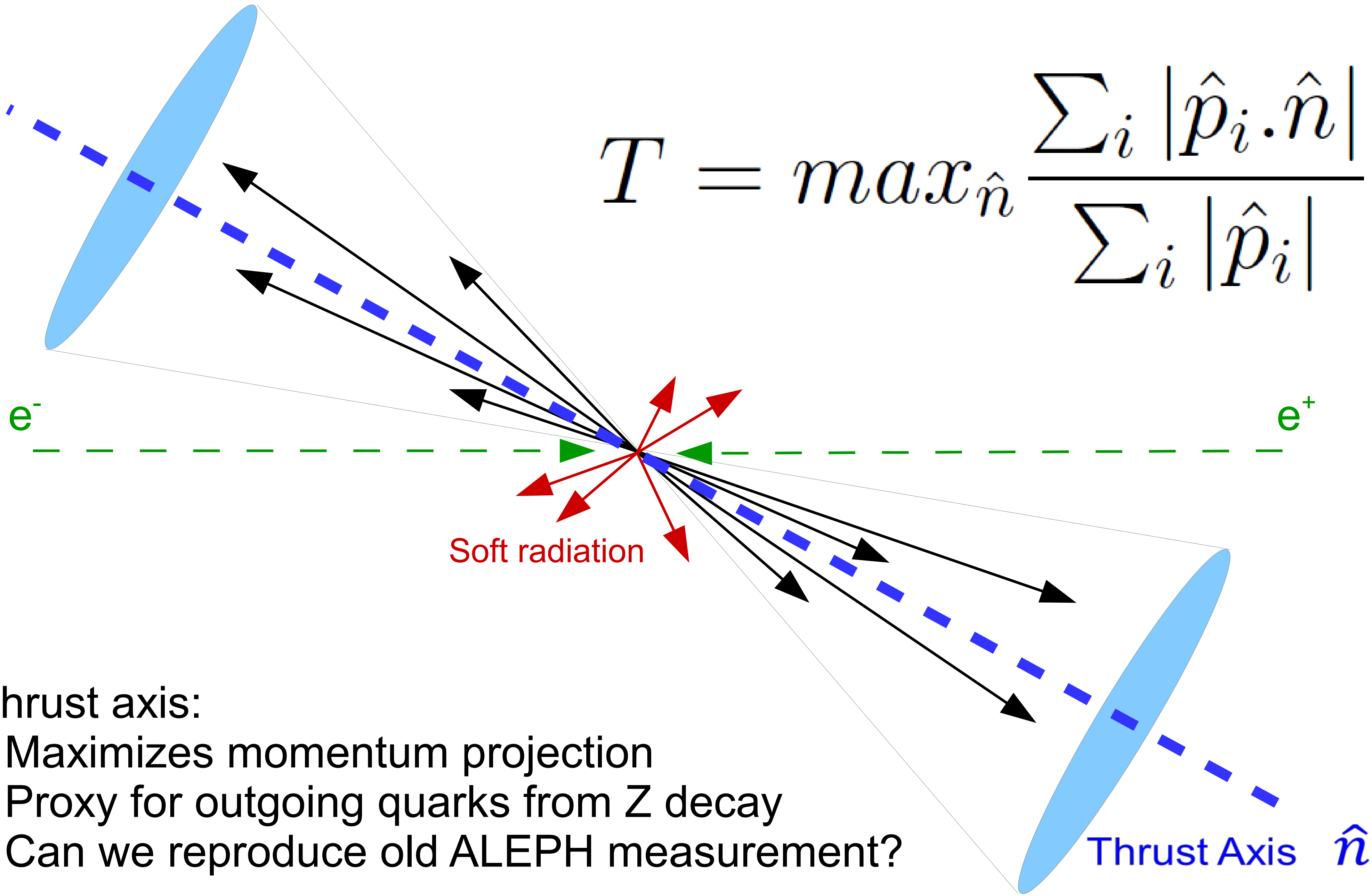




- LEP1 e^+e^- data at 91 GeV (1991-1995)
- Data archived as list of energy-flow objects
- Multiplicities up to 50
  - p_T>0.2 GeV and $|\eta|$<1.74
- Calorimeters used for event shape variables

Thrust Axis definition

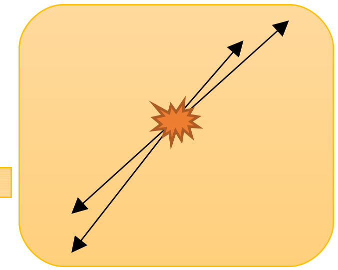
$$T = max_{\hat{n}} \frac{\sum_i |\hat{p}_i . \hat{n}|}{\sum_i |\hat{p}_i|}$$

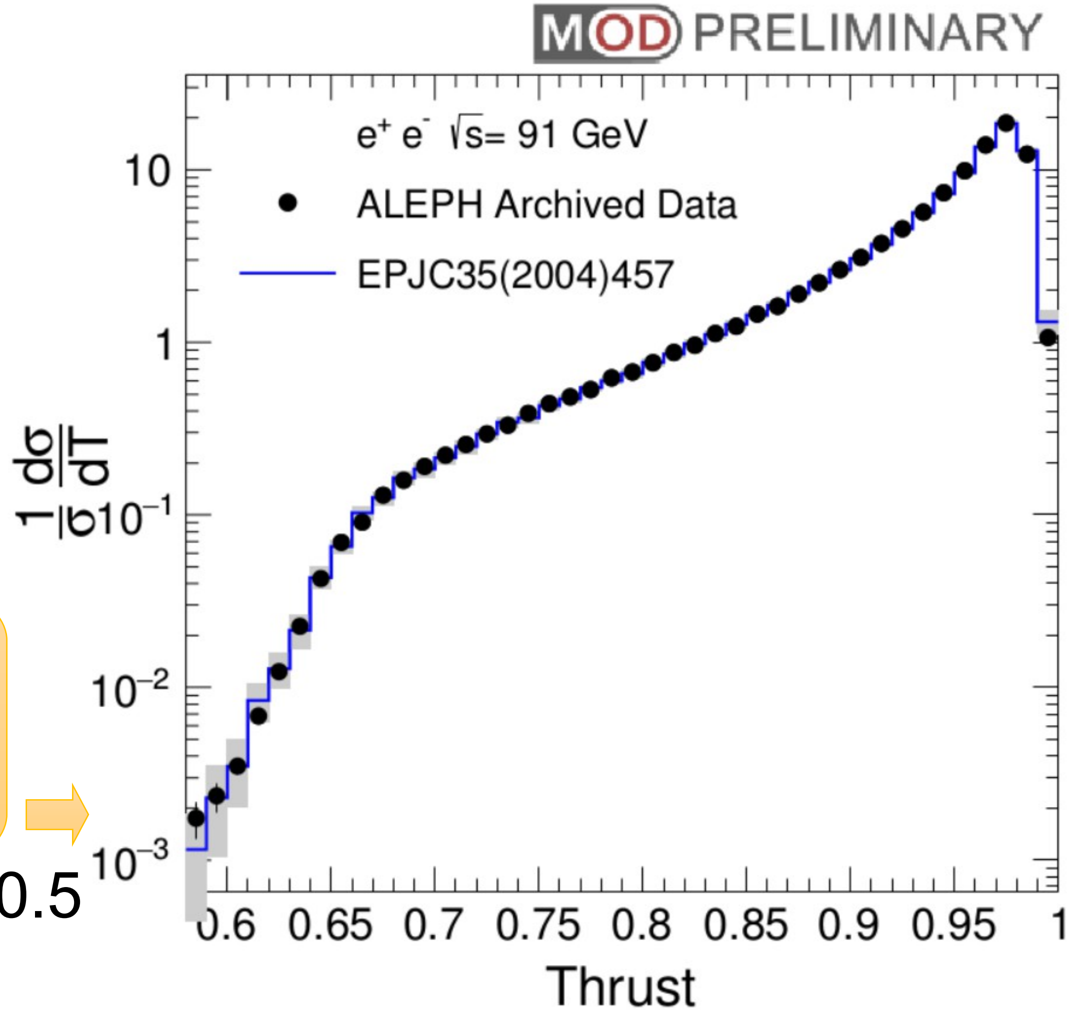


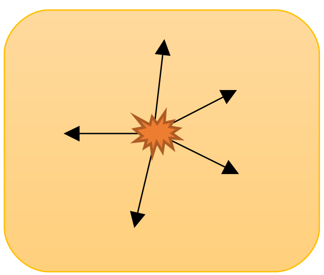
- Thrust axis:
  - Maximizes momentum projection
  - Proxy for outgoing quarks from Z decay
  - Can we reproduce old ALEPH measurement?

Unfolded Thrust Distribution

Pencil-like: T~1



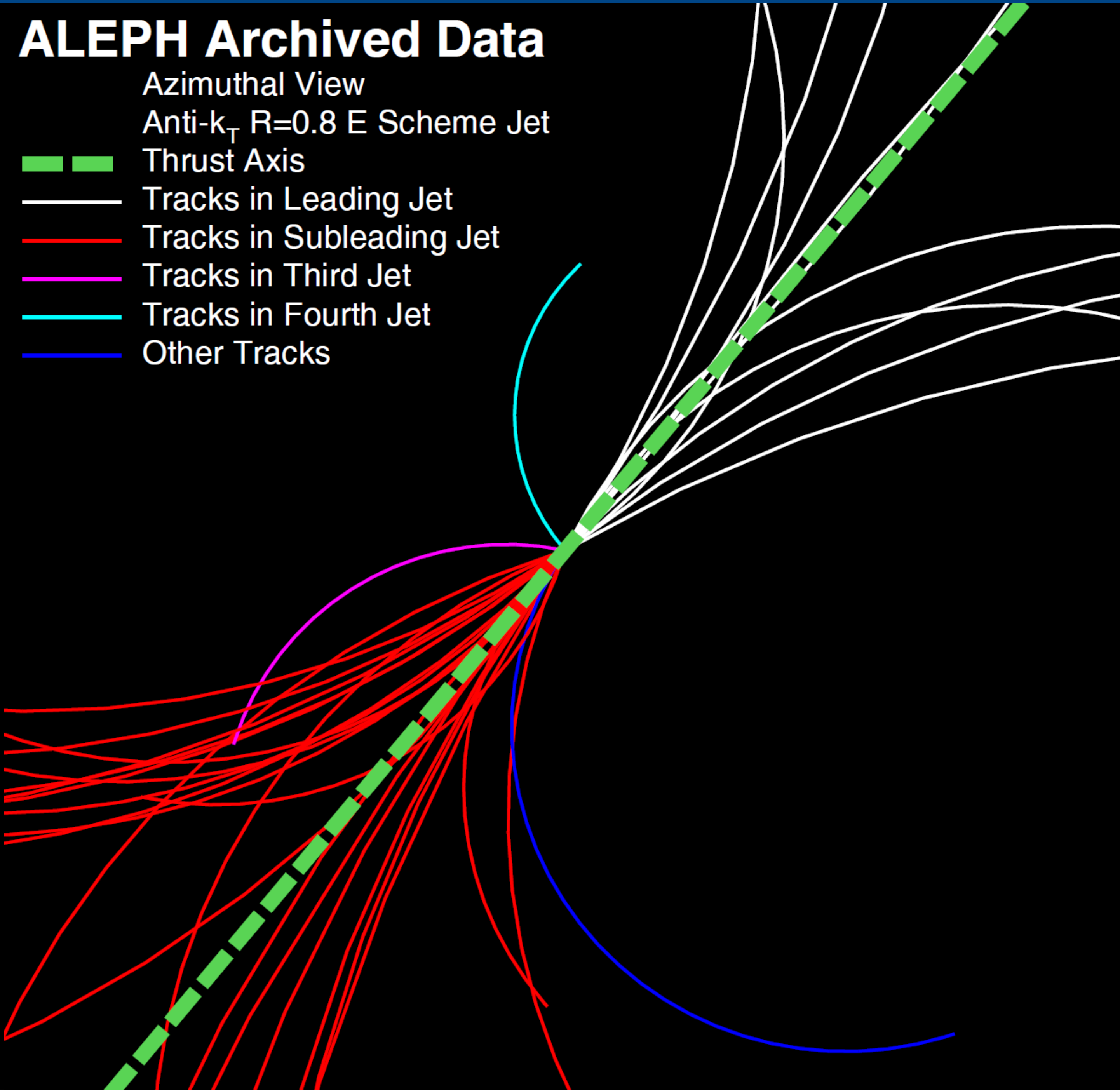




Spherical: T~0.5

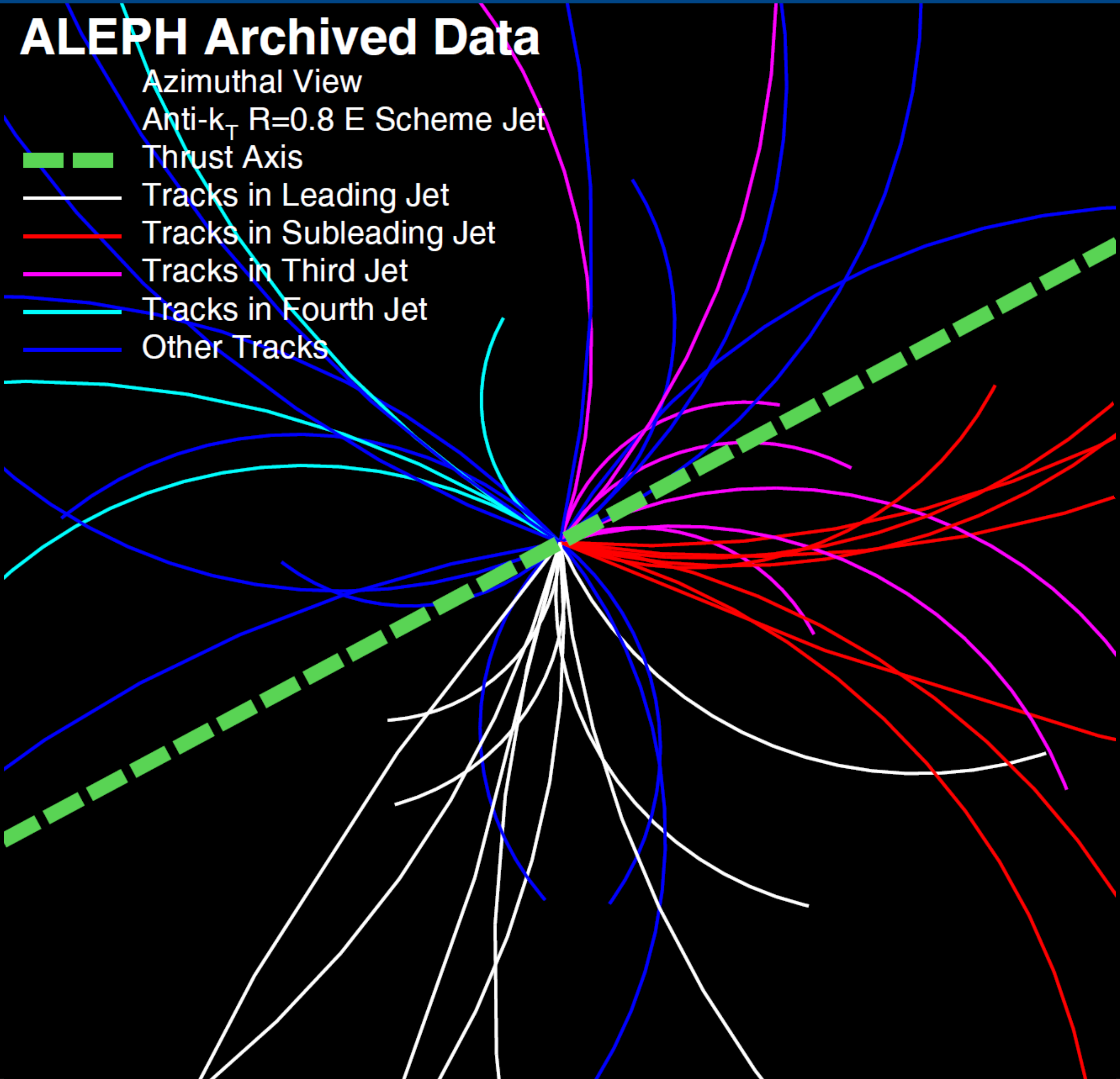
- Reproduced existing measurements with archived data!
- Most events are dijet-like
- But what about high-multiplicity events?

High Multiplicity e^+e^- Event (1)



39 tracks
T = 0.98

High Multiplicity e^+e^- Event (2)

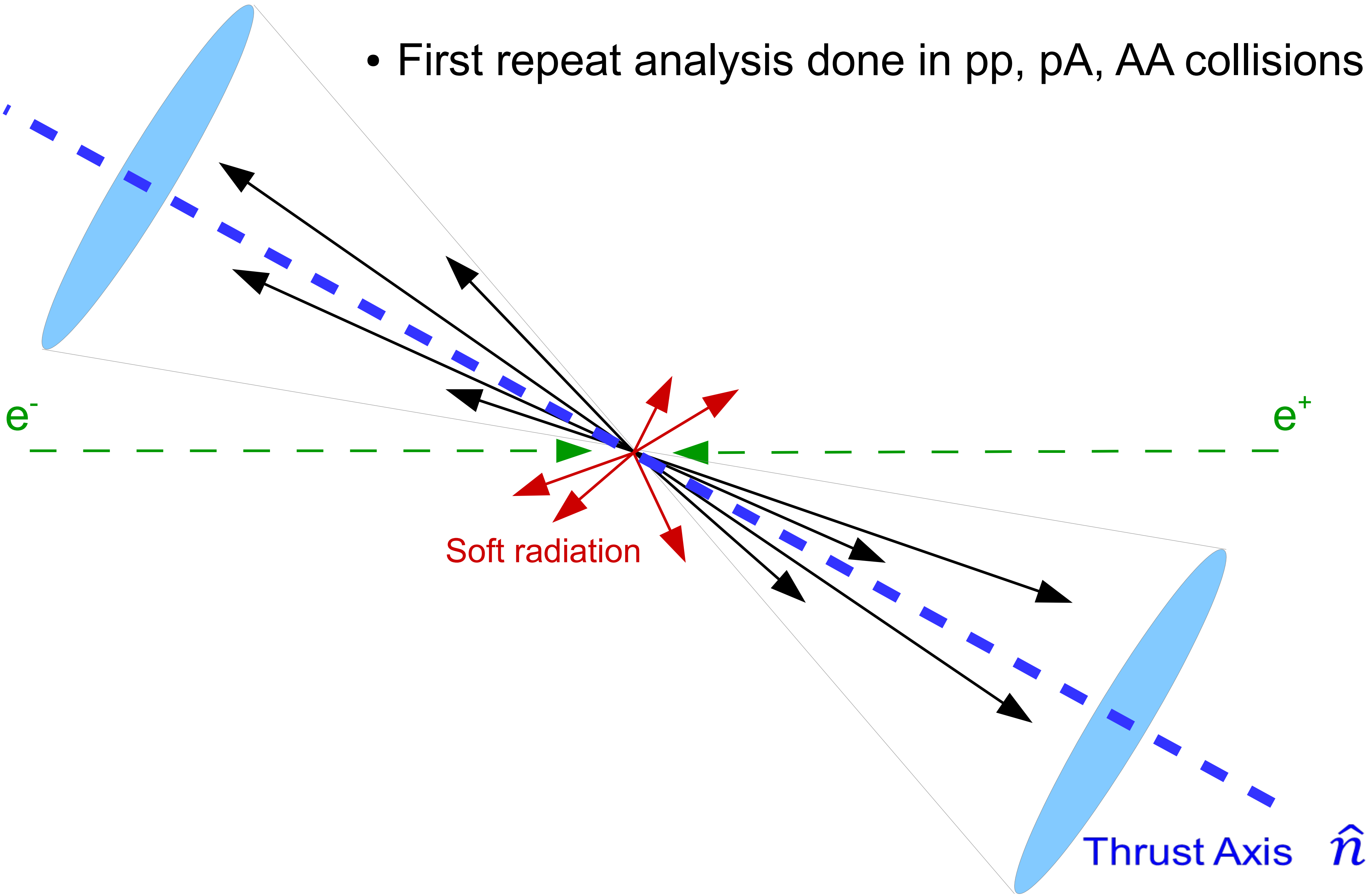


44 tracks

T = 0.57

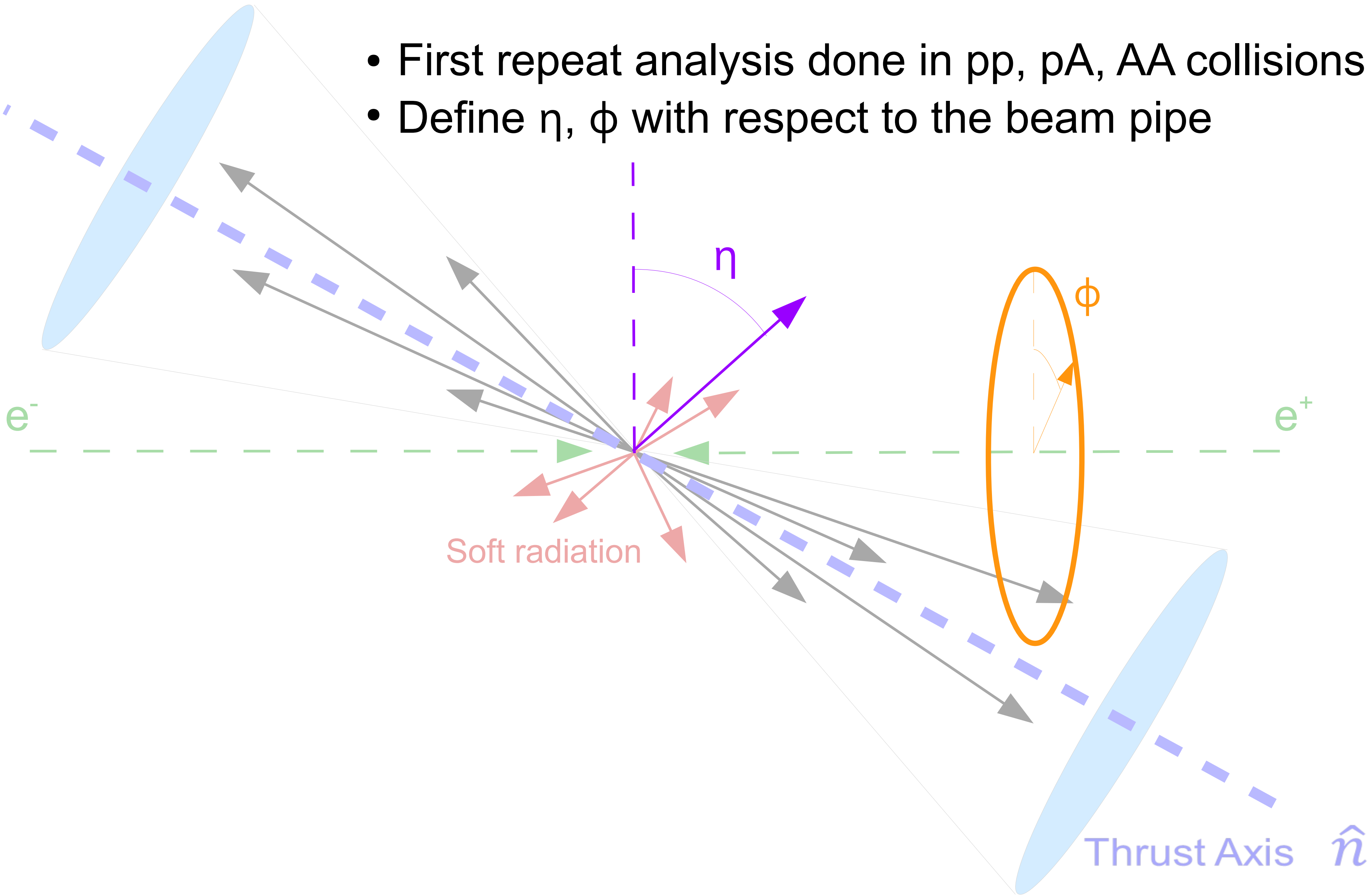
Beam-axis coordinates

- First repeat analysis done in pp, pA, AA collisions



Beam-axis coordinates

- First repeat analysis done in pp, pA, AA collisions
- Define η, ϕ with respect to the beam pipe



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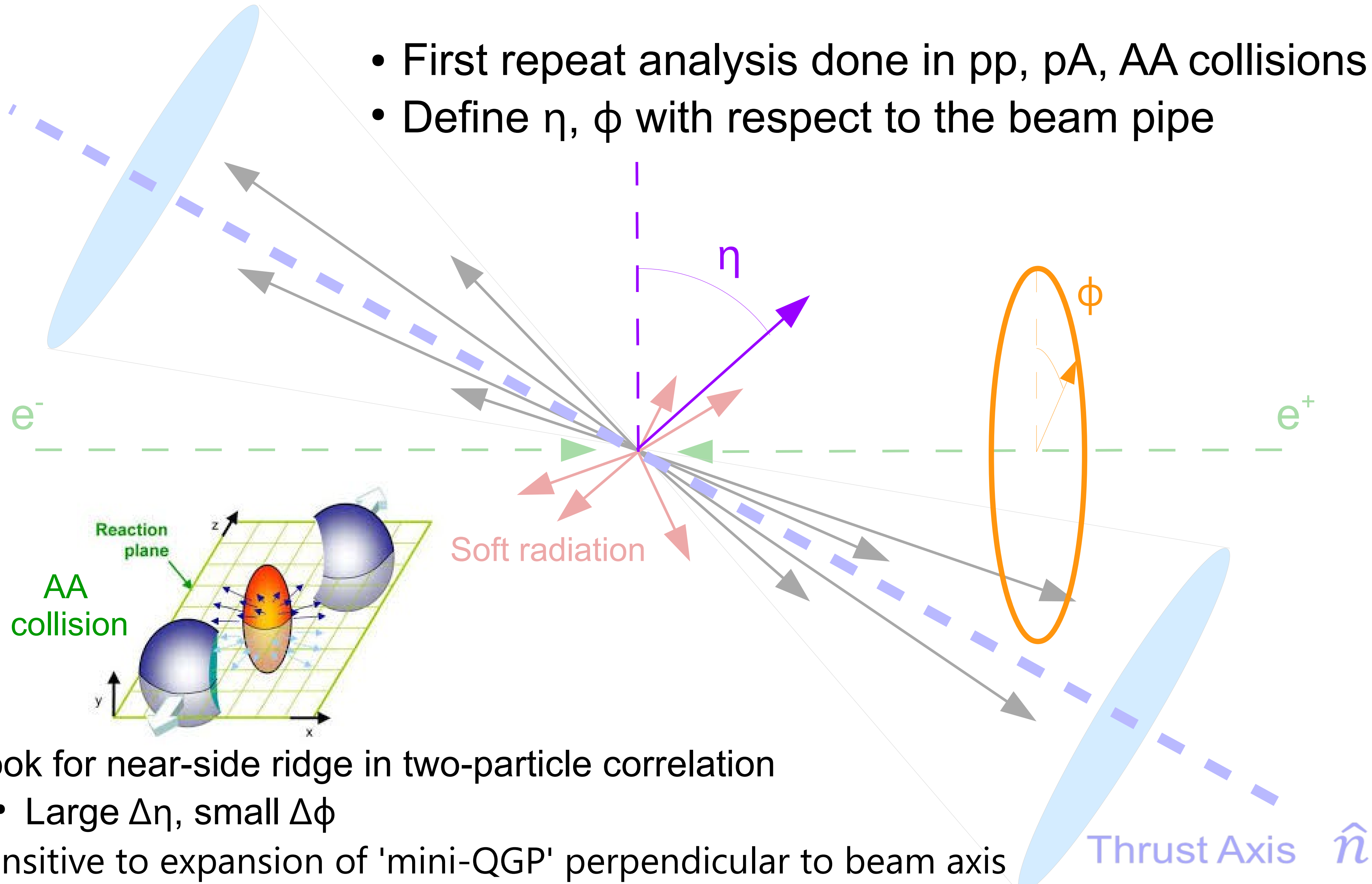
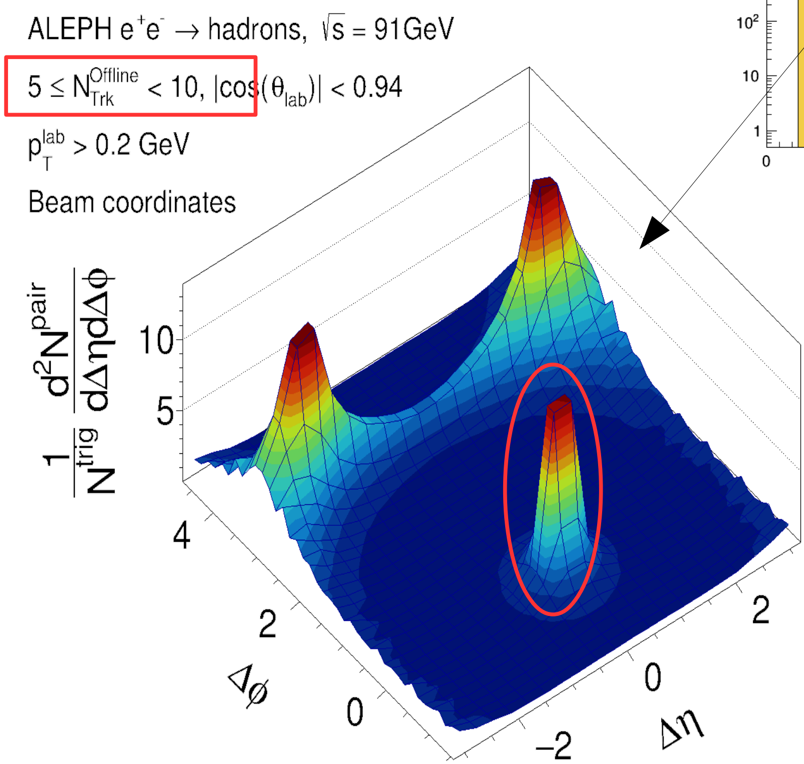
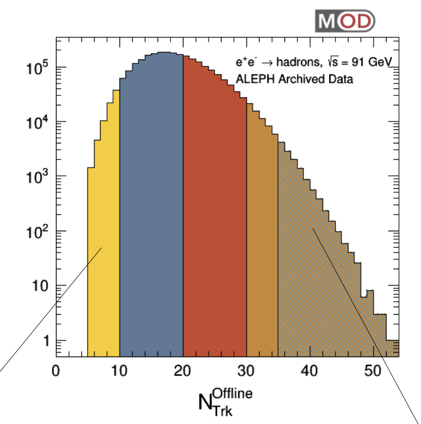


- Look for near-side ridge in two-particle correlation
    - Large Δη, small Δϕ
- Sensitive to expansion of 'mini-QGP' perpendicular to beam axis

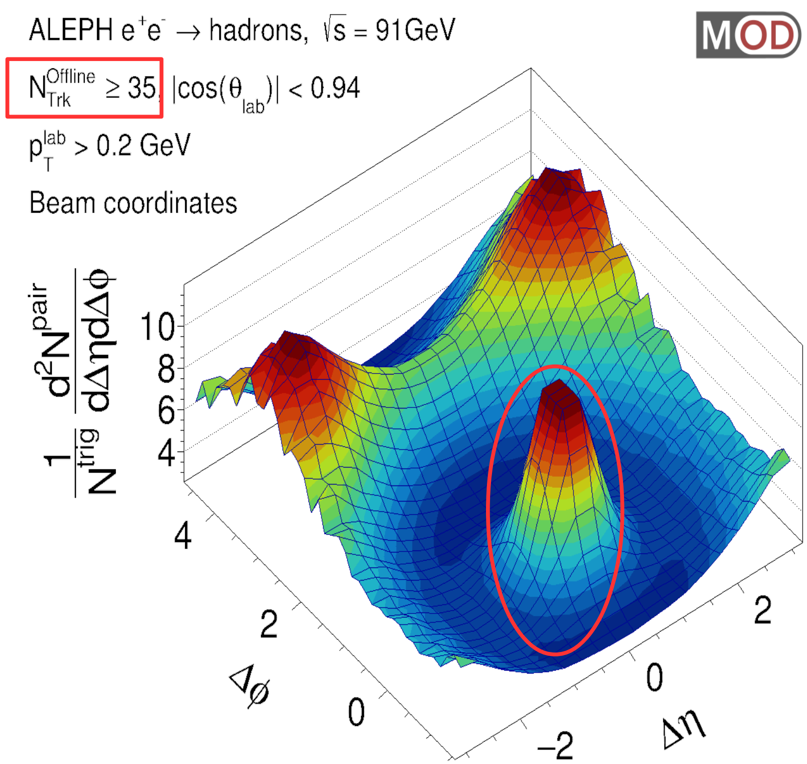
Beam-axis two-particle correlation

Low Multiplicity



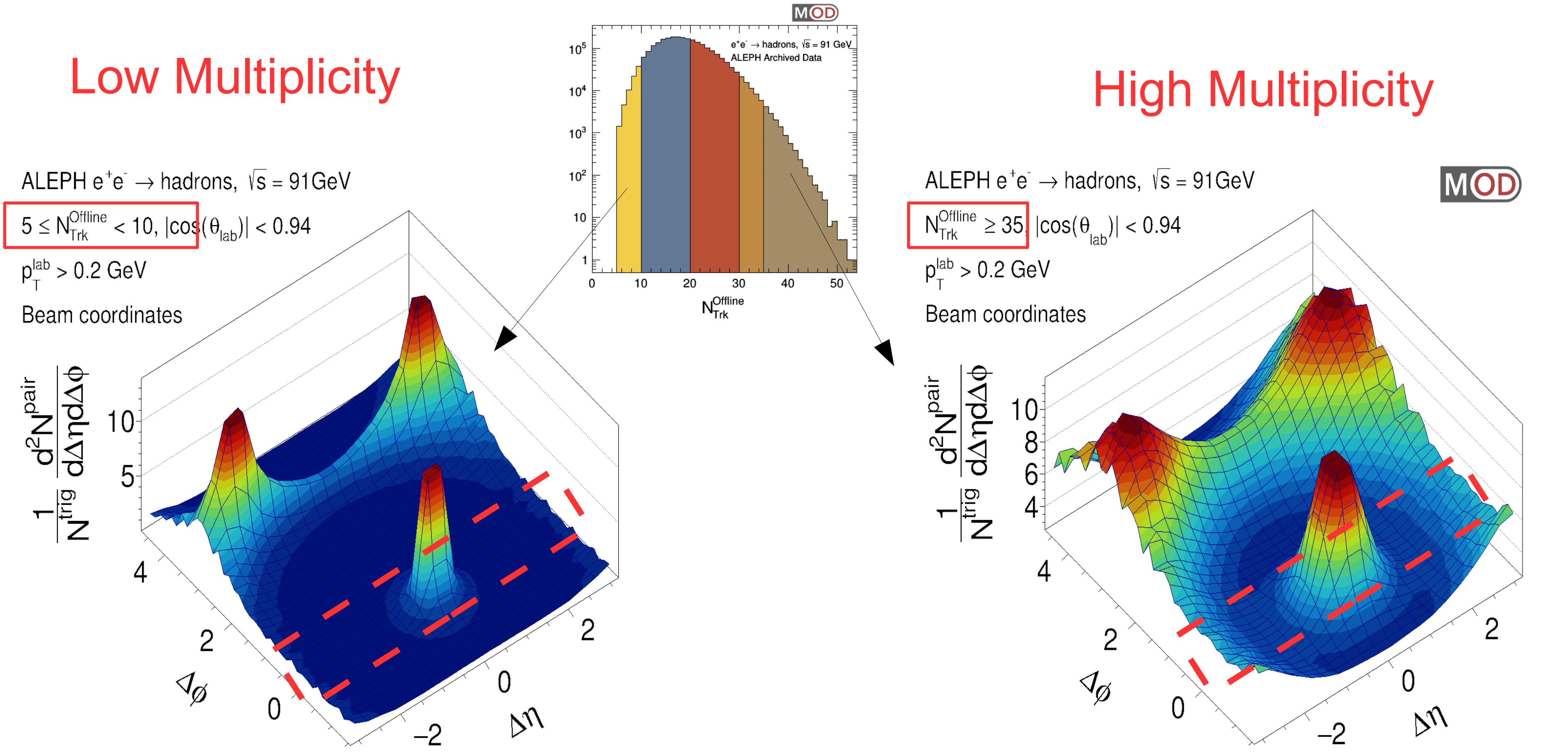


High Multiplicity



- Clear jet peak at $(\Delta\eta,\Delta\phi) = (0,0)$

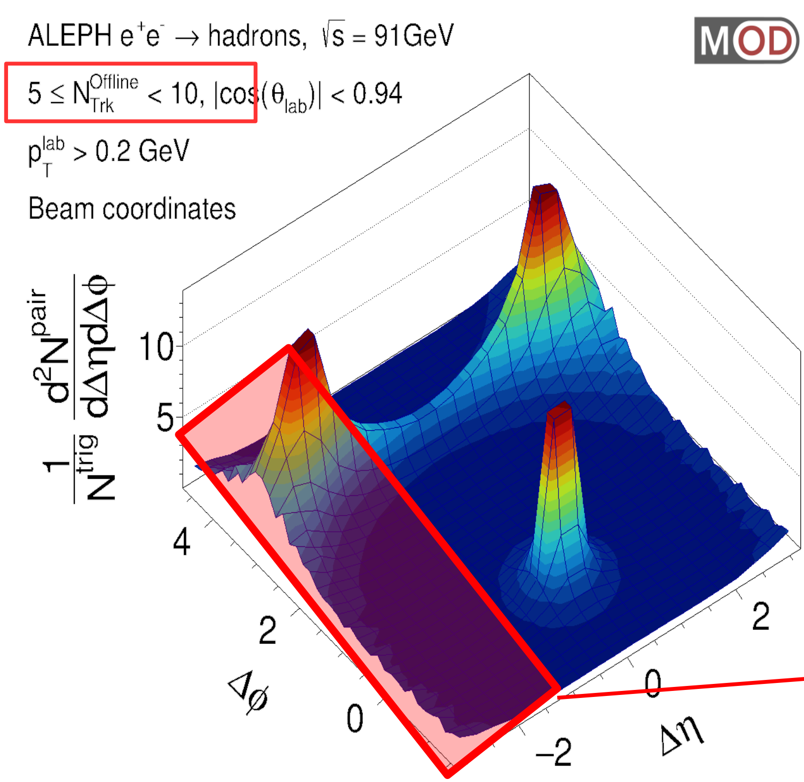
Beam-axis two-particle correlation

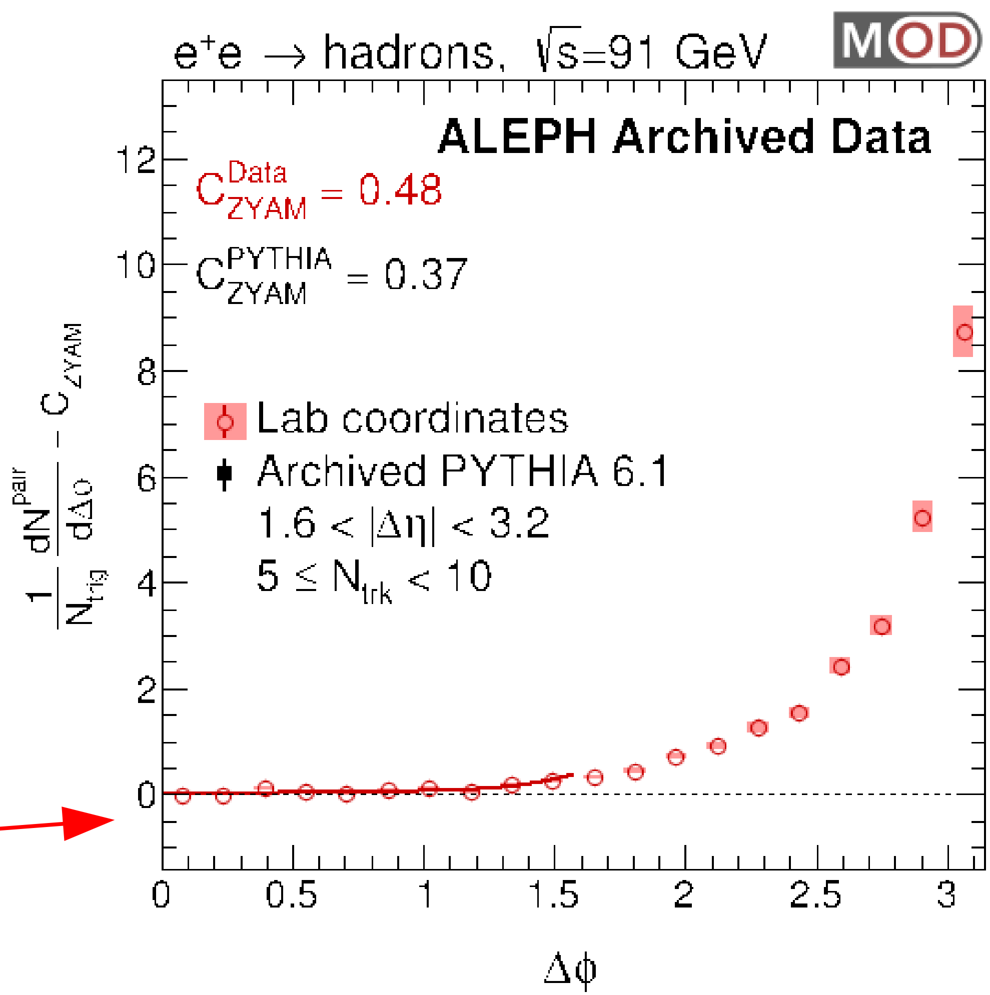


- Clear jet peak at $(\Delta\eta,\Delta\phi) = (0,0)$
- No clear near-side ridge

Projection

Low Multiplicity

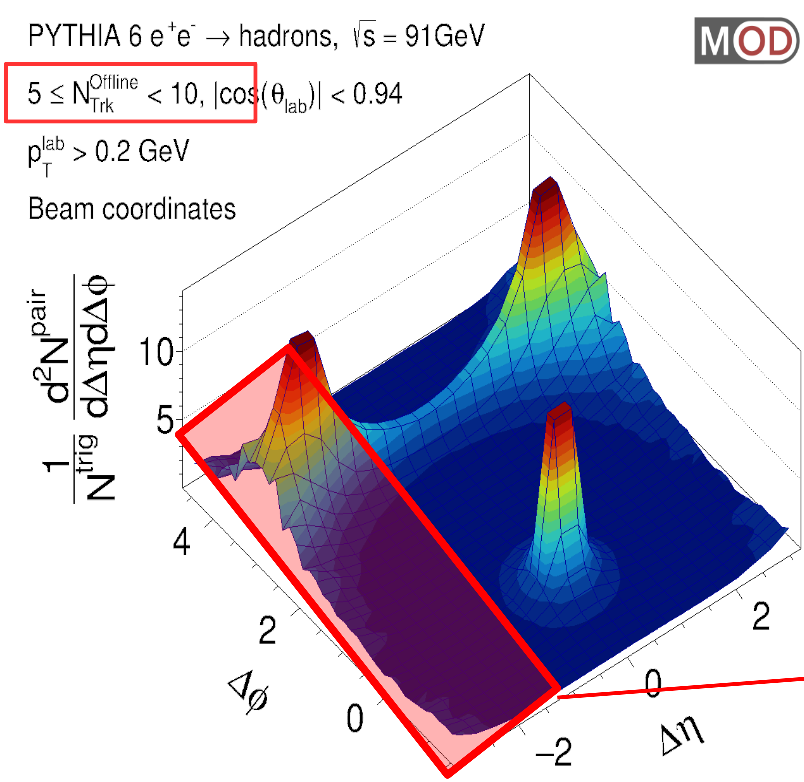


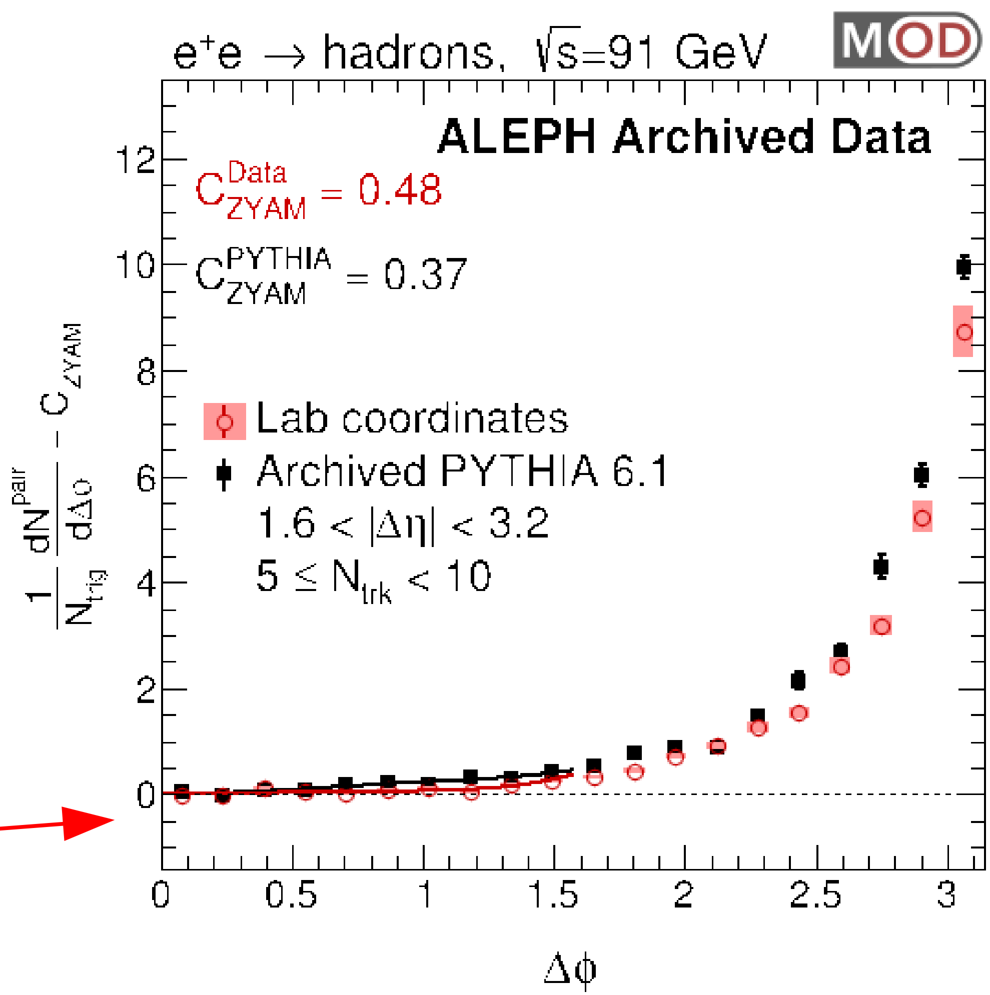


- Project 1.6<|Δη|<3.2 into a 1D plot
- Fit data from 0<|Δϕ|<π/2 with Fourier series
- Subtract off the 'zero yield at minimum' (ZYAM)

Projection

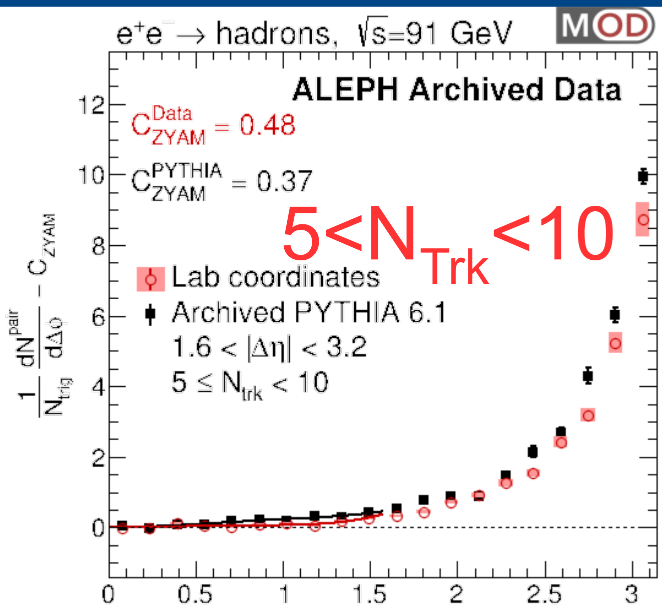
Low Multiplicity

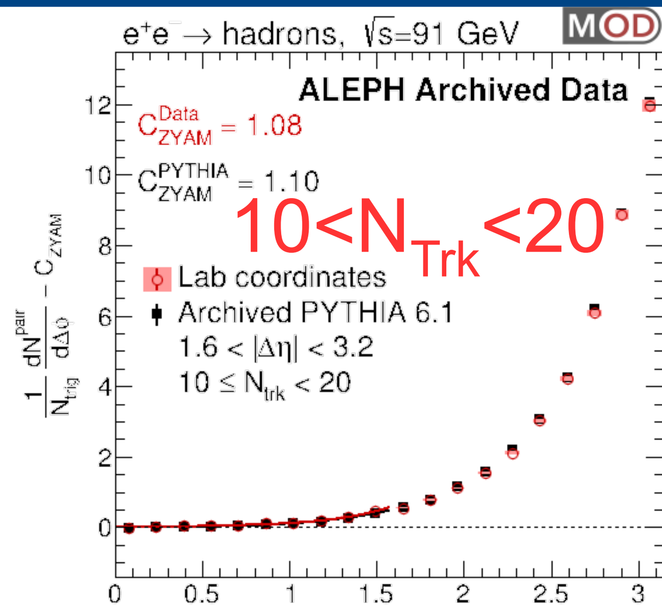


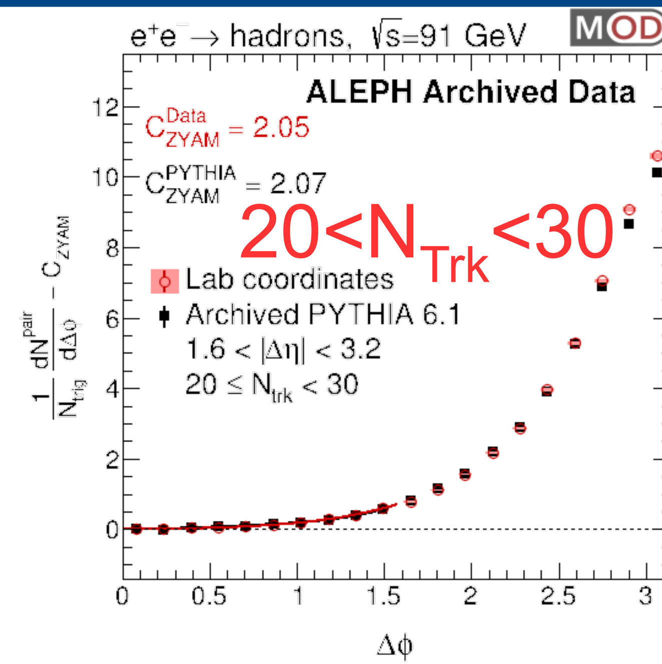


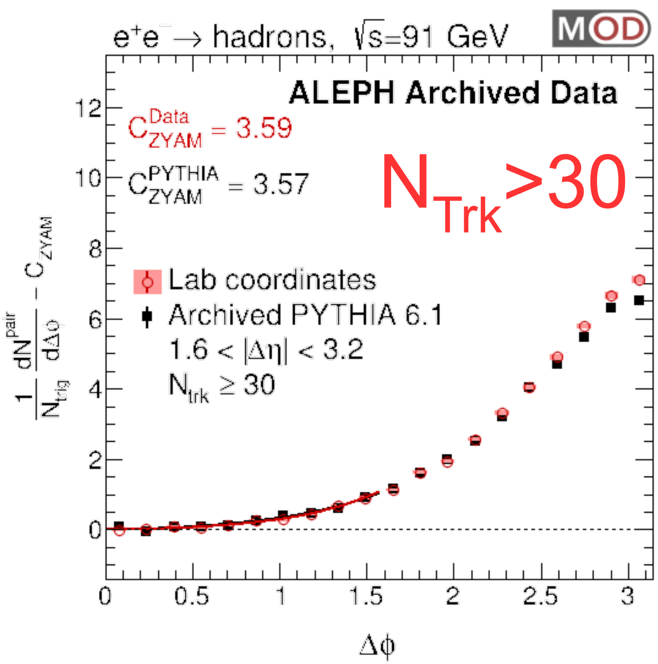
- Very similar to archived PYTHIA 6.1 predictions

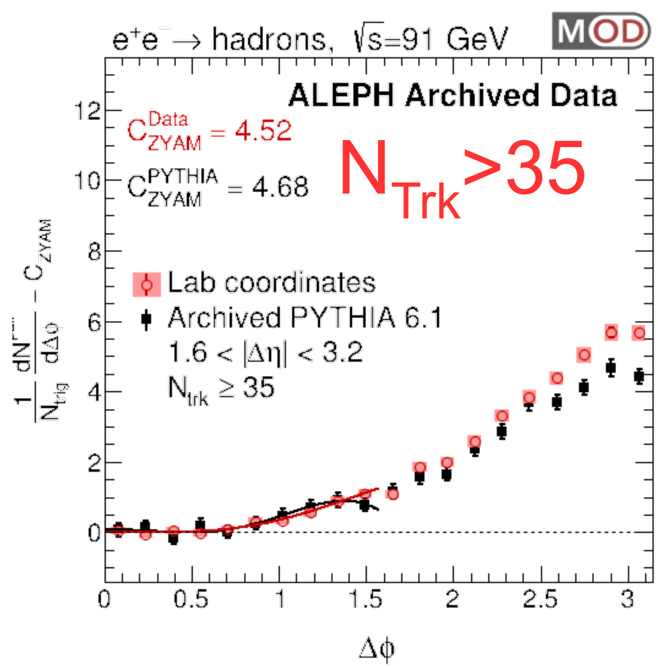
Going to higher multiplicities...







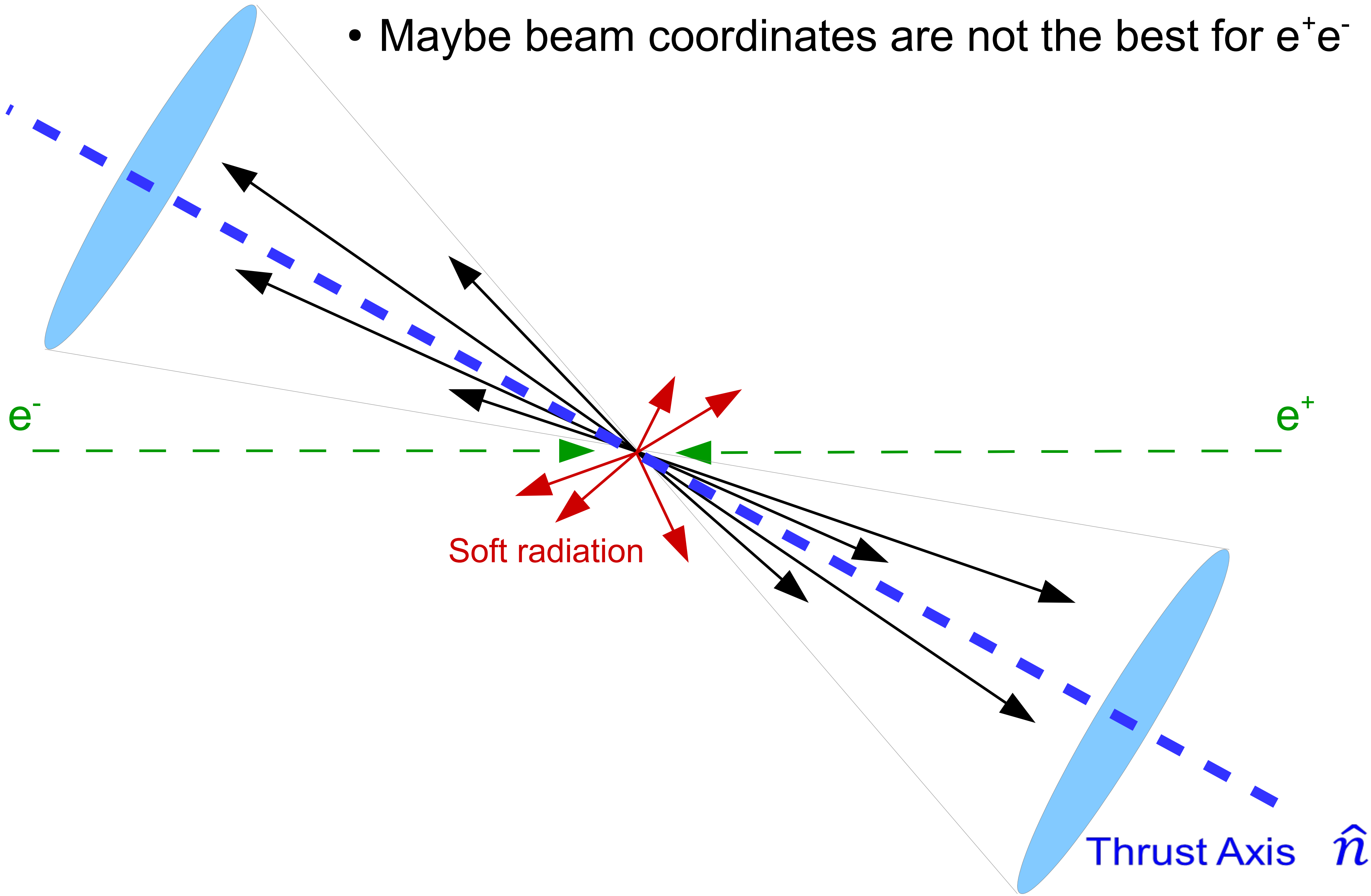




- No ridge observed!
- Agreement with PYTHIA6 is excellent for 10-20 multiplicity bin
- Some discrepancy at large Δϕ

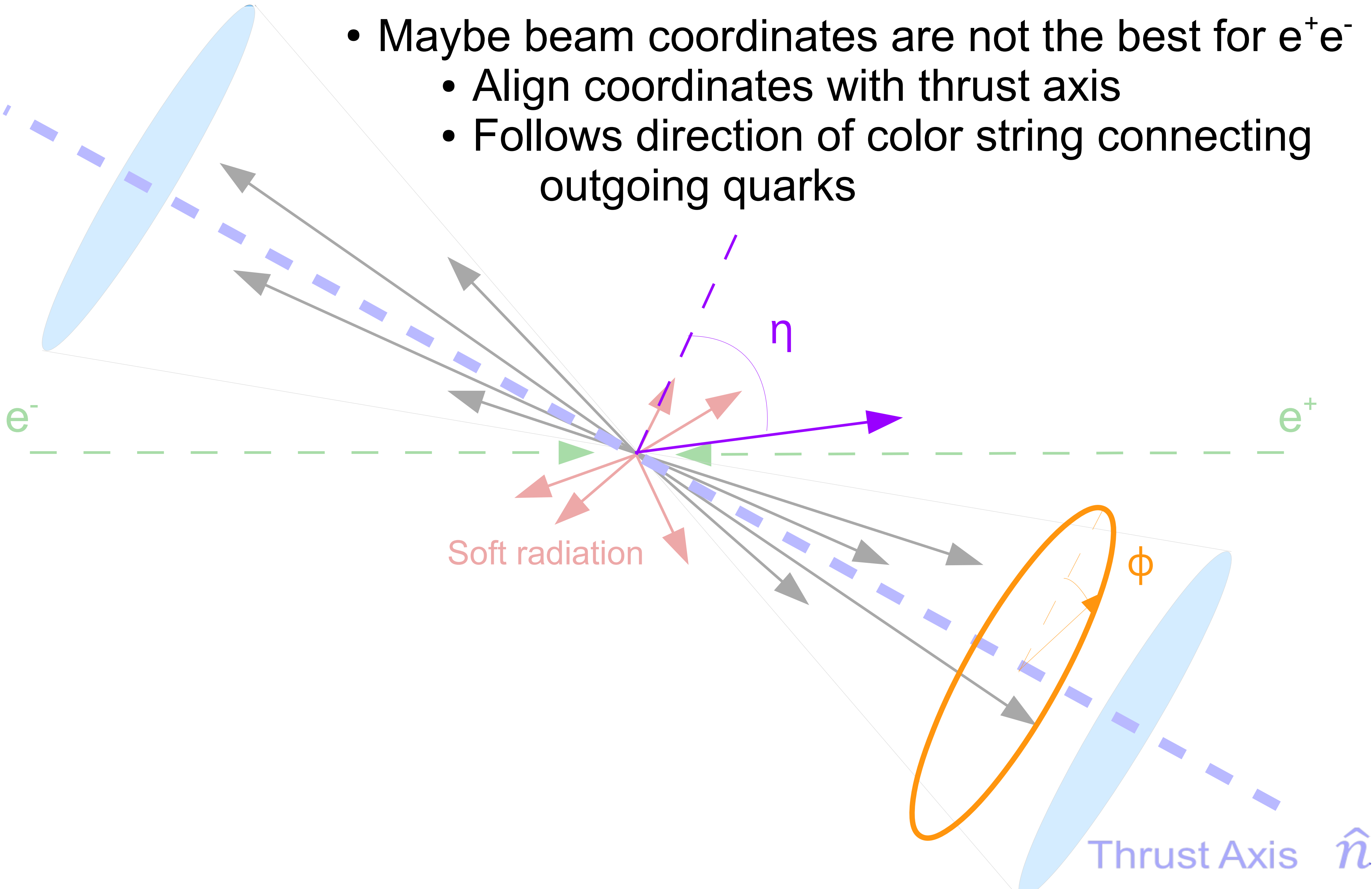
Thrust-axis coordinates

- Maybe beam coordinates are not the best for e^+e^-



Thrust-axis coordinates

- Maybe beam coordinates are not the best for e^+e^-
  - Align coordinates with thrust axis
  - Follows direction of color string connecting outgoing quarks



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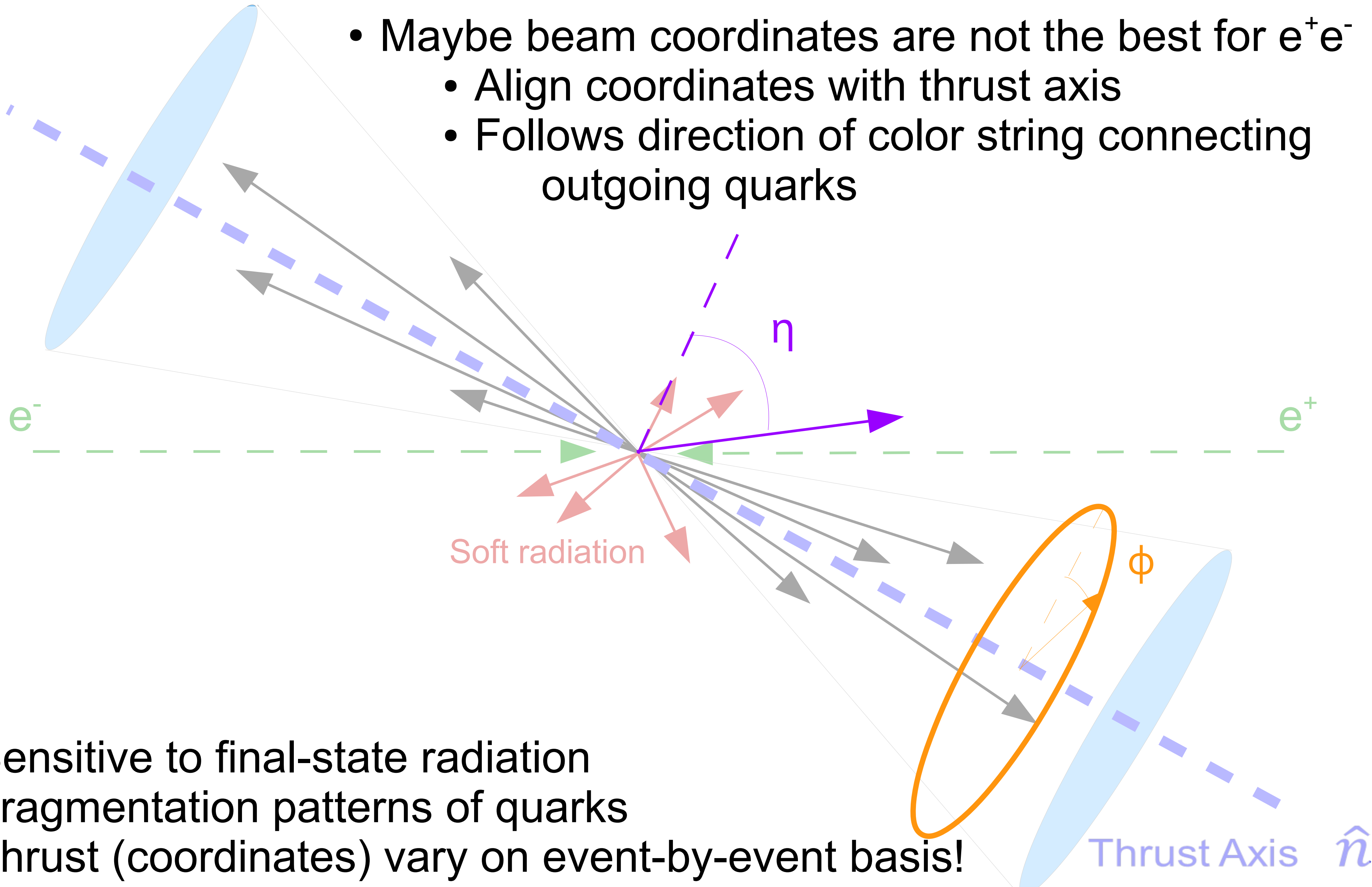
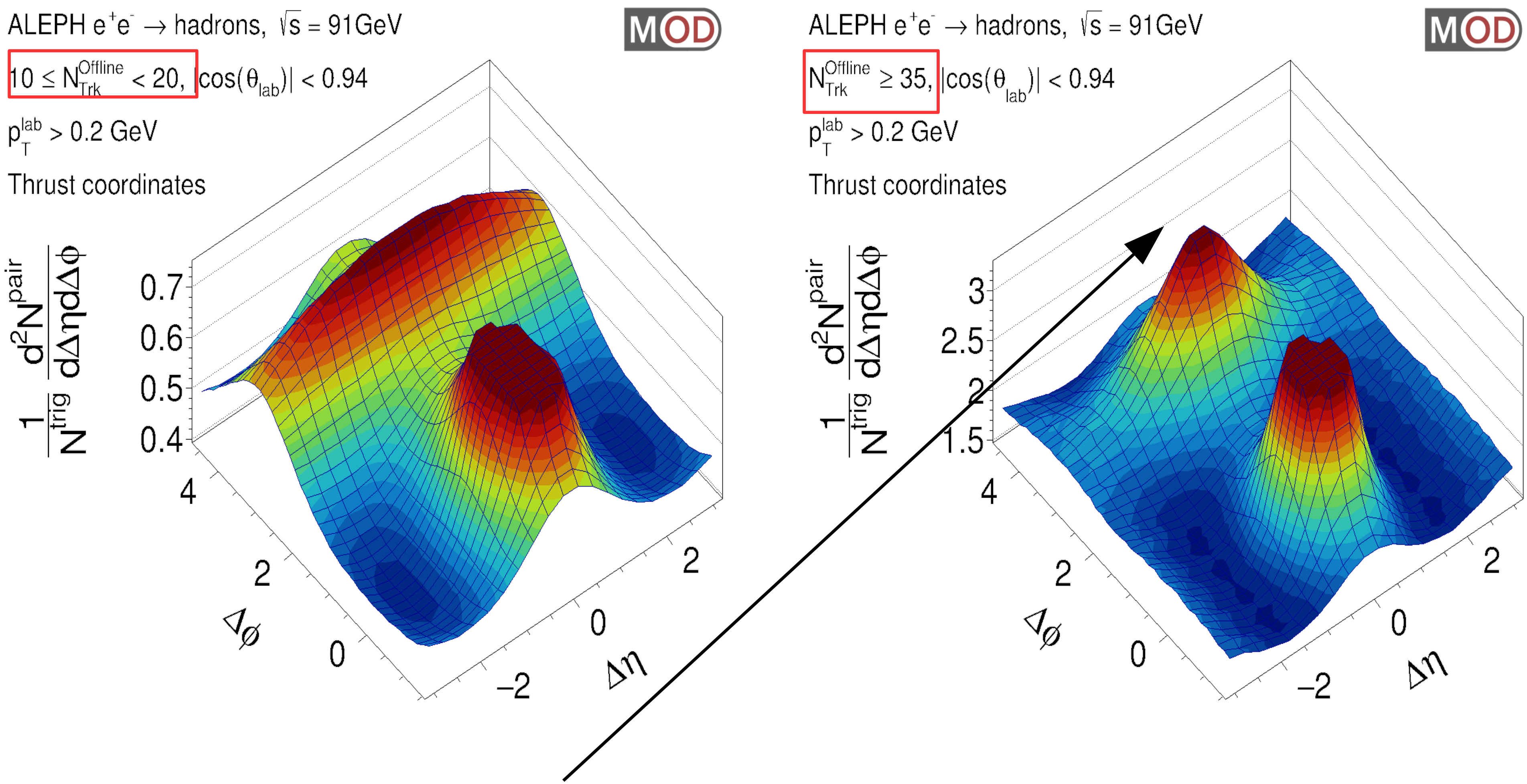


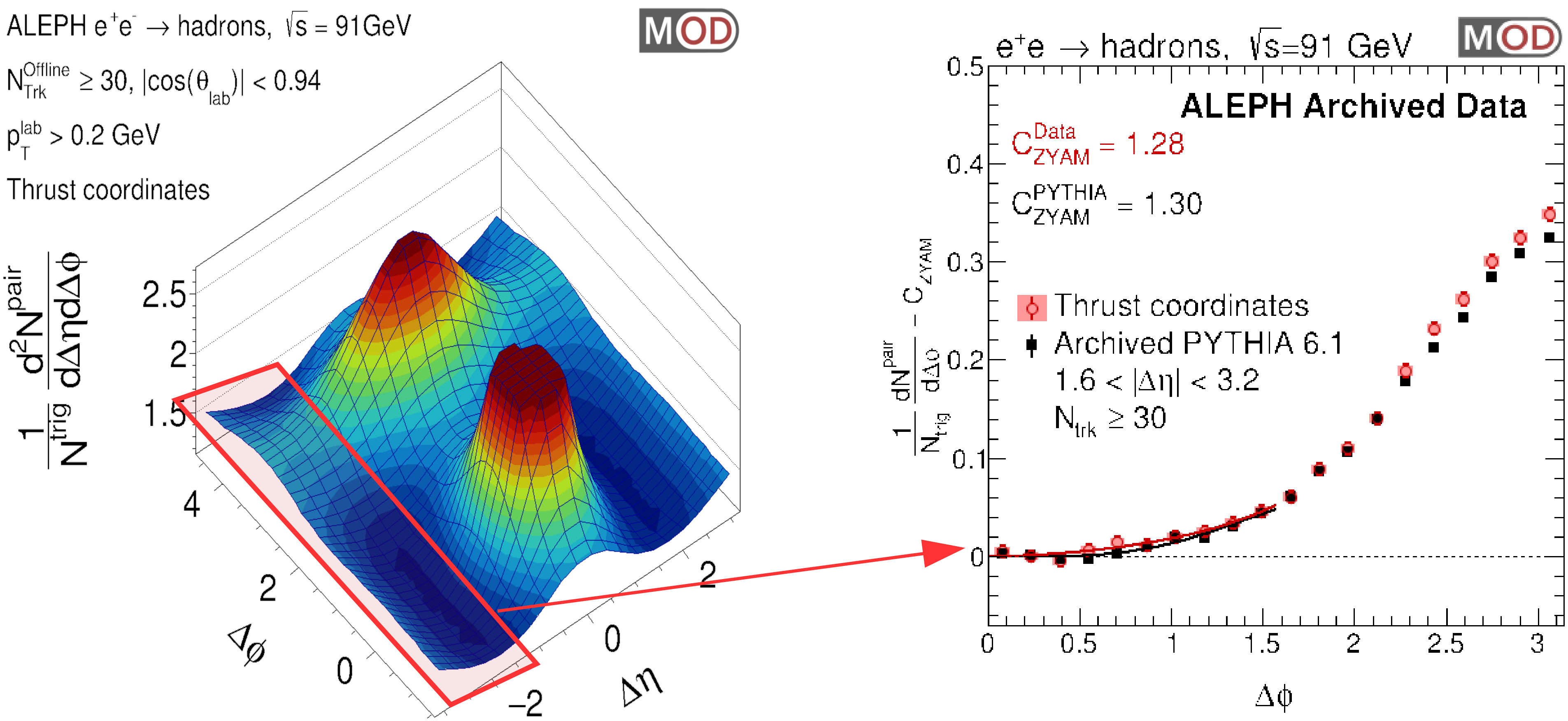
- Sensitive to final-state radiation
- Fragmentation patterns of quarks
- Thrust (coordinates) vary on event-by-event basis!

Correlation with thrust axis



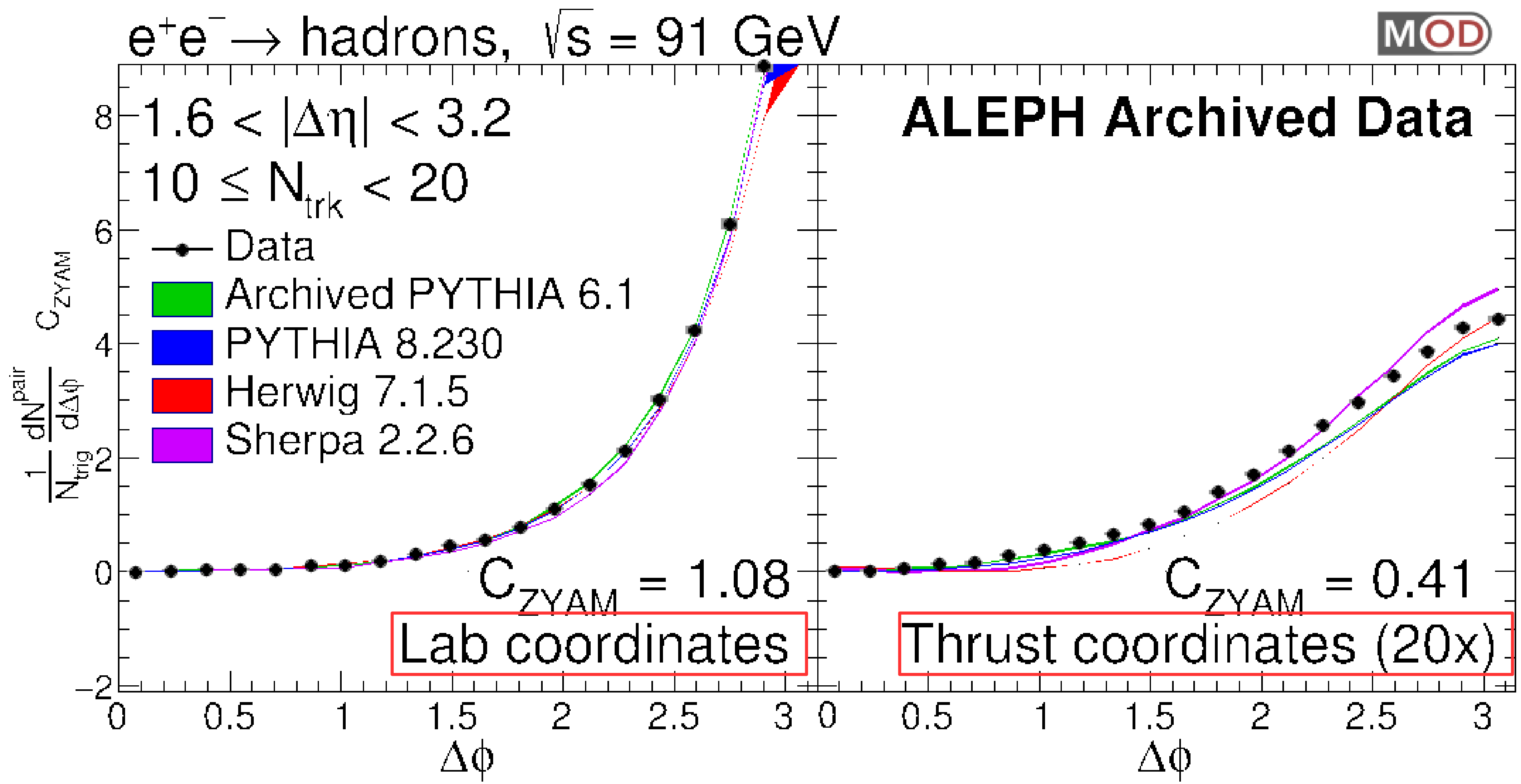
- Narrower away-side peak in high-multiplicity events
- Toy-event studies indicate this could be due to increased multi-jet events

Thrust axis projection N_{trk}>30



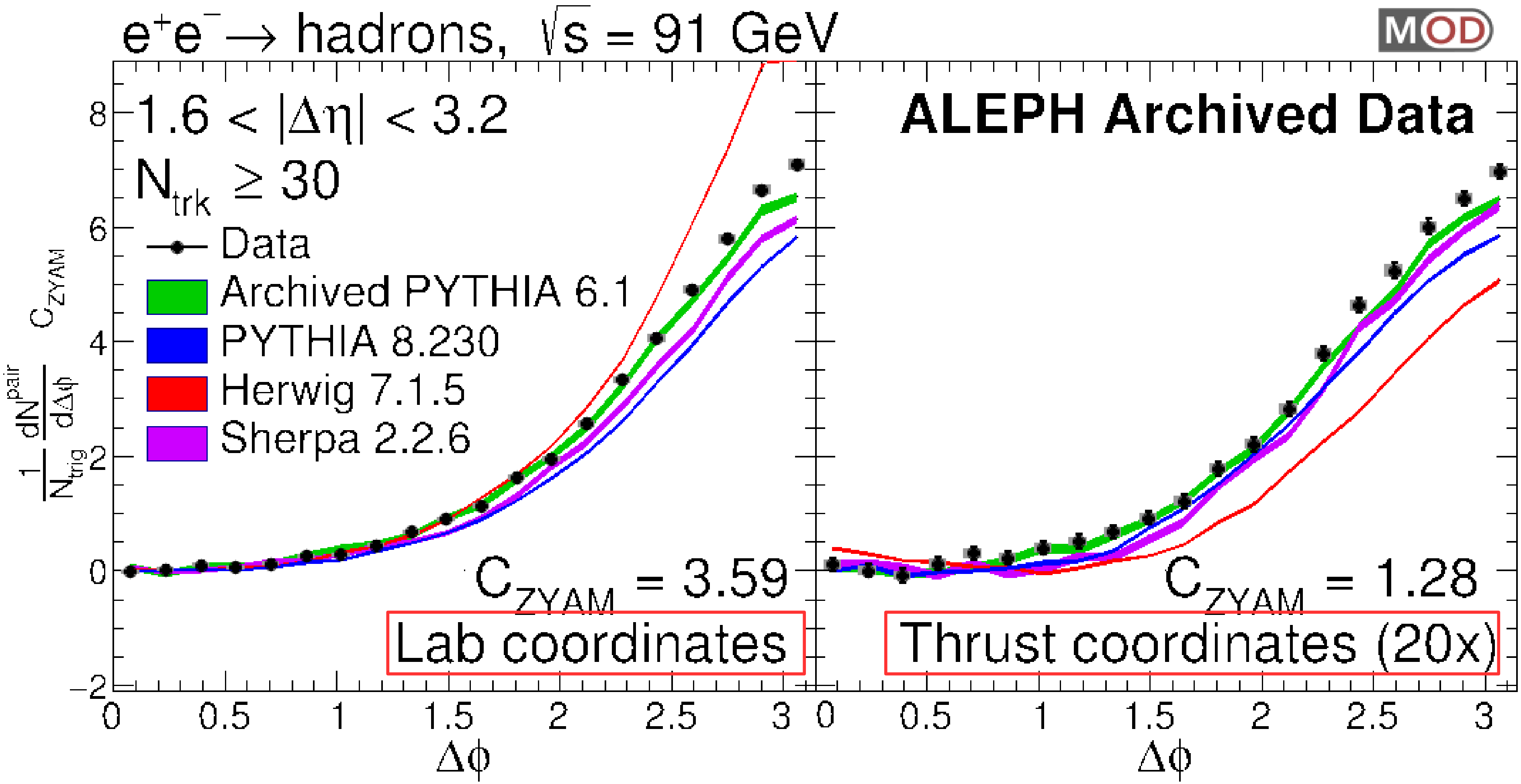
- Projection into $\Delta\phi$ + ZYAM shows data in agreement with PYTHIA 6
- No significant near-side ridge observed

Comparison to Modern MC (10-20)



- All generators are able to predict 10-20 multiplicity in lab coordinates
  - Slight shape differences in thrust analysis

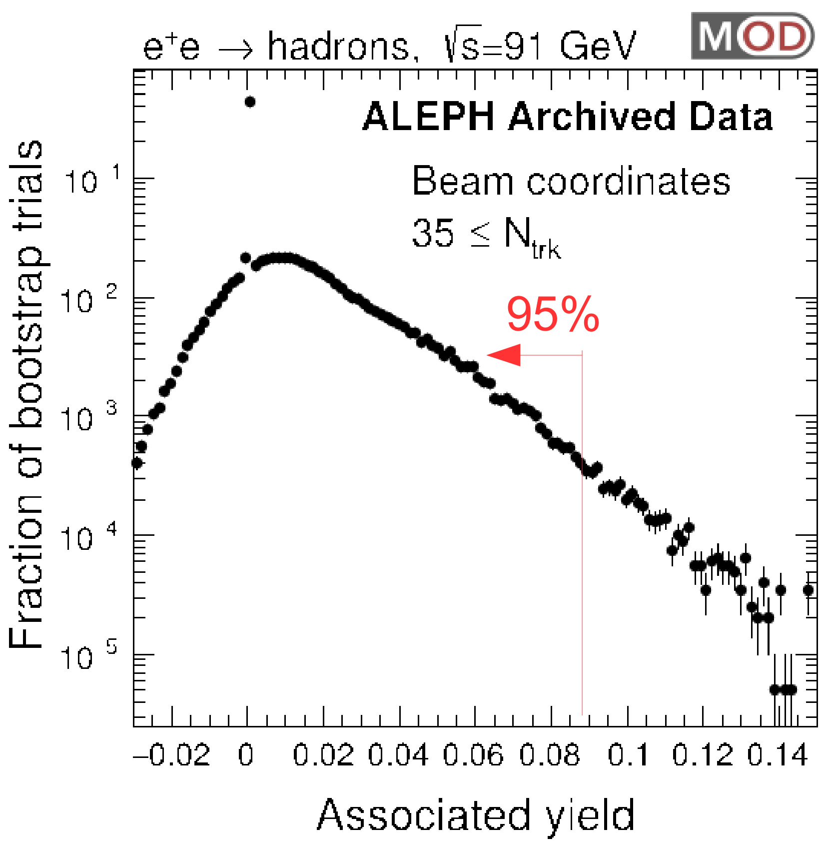
Comparison to Modern MC (>30)

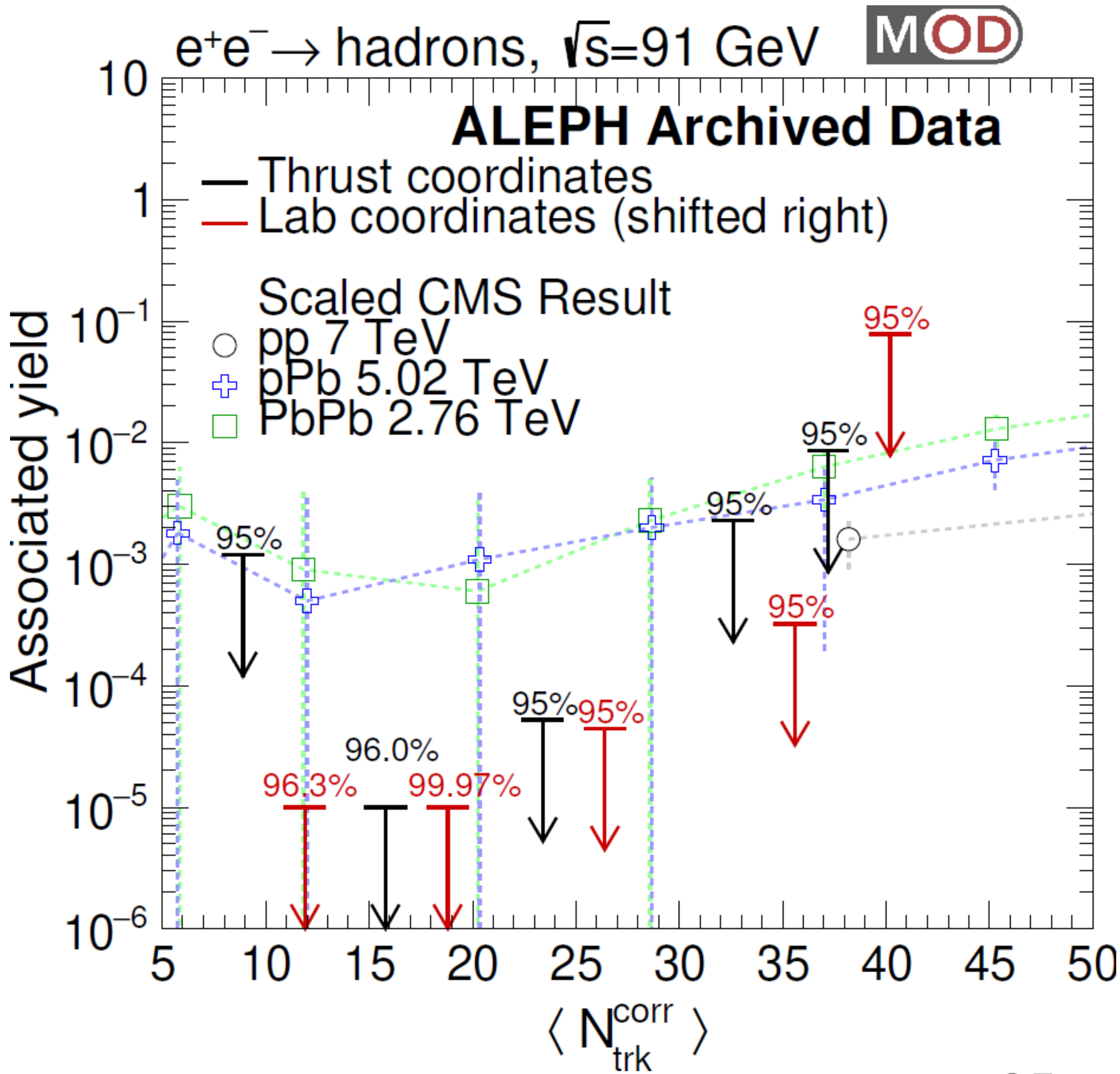


- More difficult to predict high multiplicity events
- Herwig 7 does not predict the thrust distribution well
- Archived Pythia 6 seems to be best (tuned to the ALEPH data)

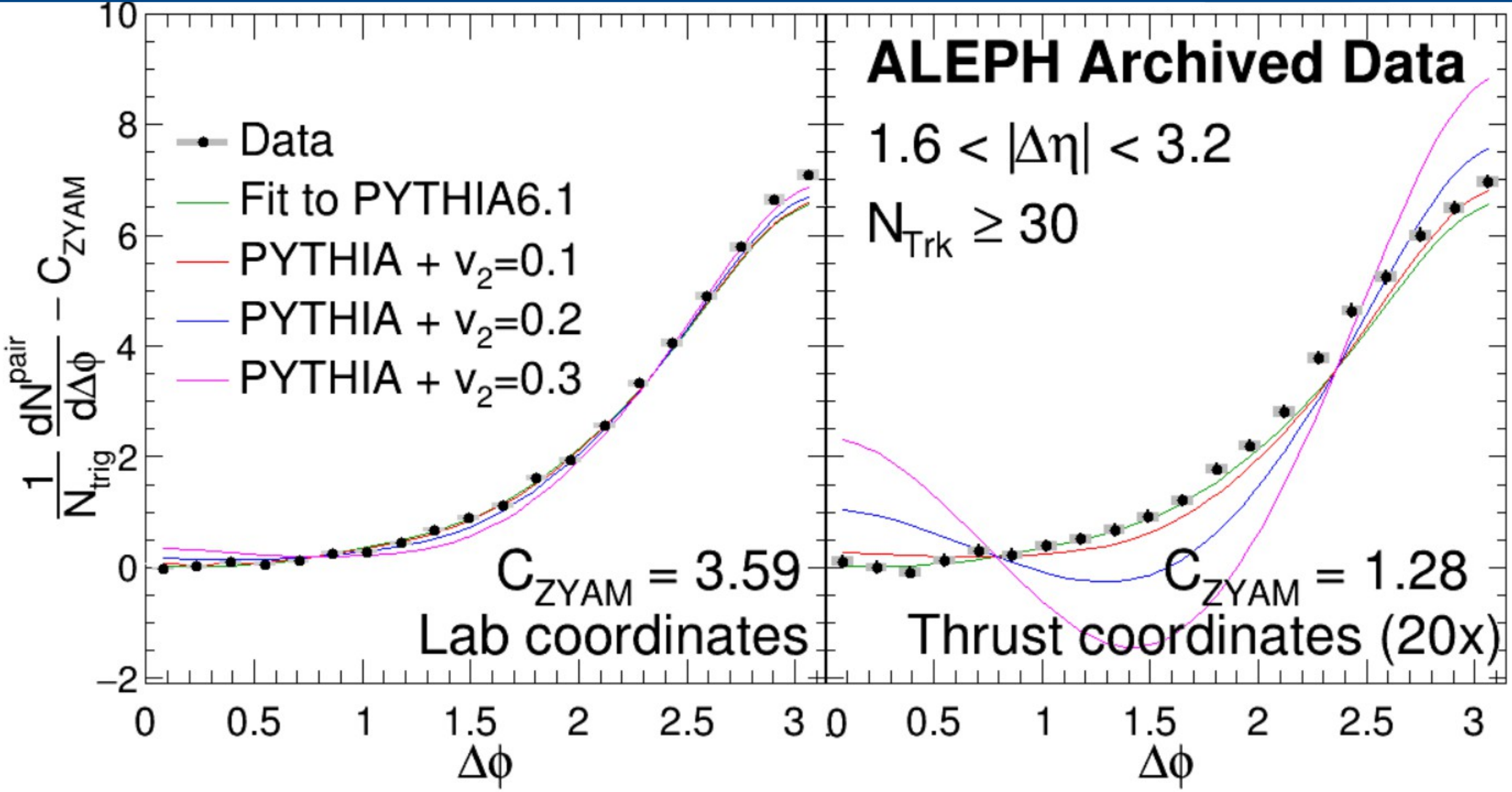
Setting a limit

- Vary data within uncertainties to create pseudodata
- Repeat fit + ZYAM, integrate any near-side yield
- Majority of trials have no yield
- Find value containing 95% of trials
- Limits lower than pPb/PbPb results





Connecting to v_2



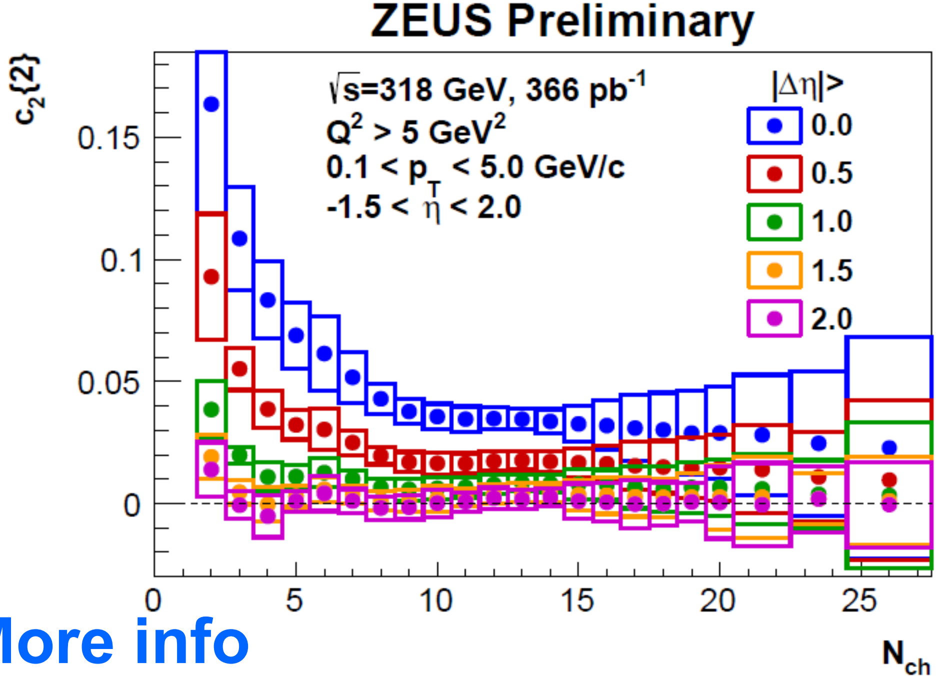
- Estimate sensitivity to v_2 by constructing a toy 1-D correlation
  - Assume ZYAM-subtracted pairs flow, everything else non-flow

- May not be sensitive to v_2<0.1 in lab coordinates (huge non-flow)
- Better sensitivity in thrust coordinates
- Exact conclusions depend on assumption of flow/non-flow fraction

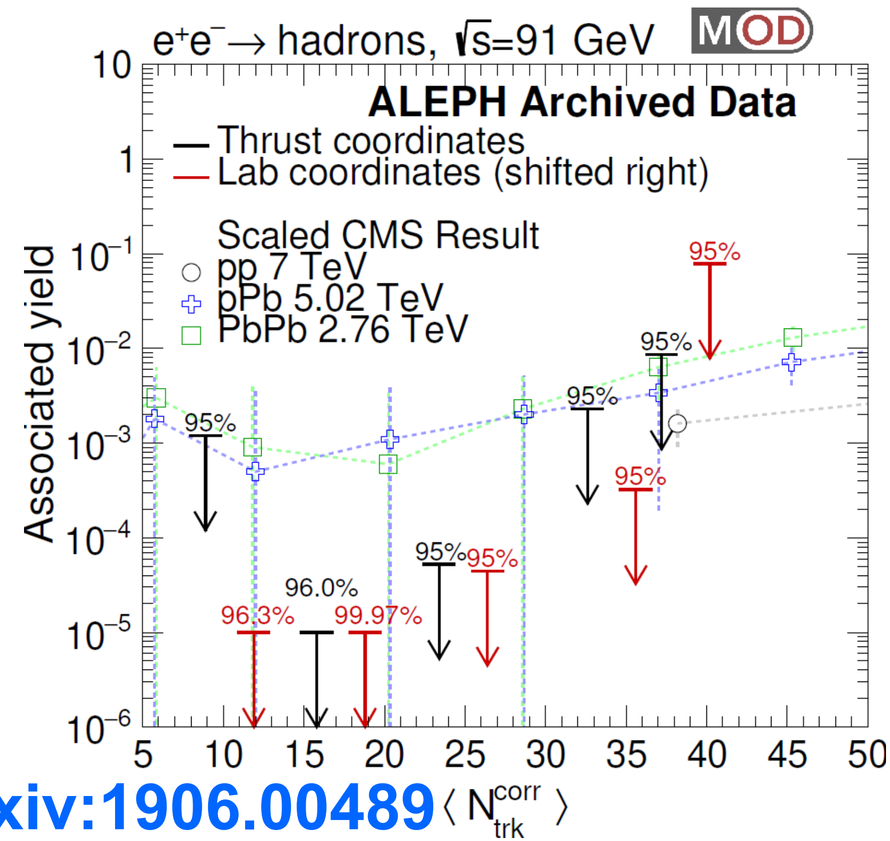
Summary

- No significant $c_2\{2\}$ observed in DIS data
- No associated yield seen in e^+e^- data
- High multiplicity measurements limited by statistics/acceptance
  - Interesting to revisit in future (EIC / LHeC / ILC)

- Data constrain MC in high multiplicity region where models differ
- References for studying collectivity in small systems



More info



Arxiv:1906.00489

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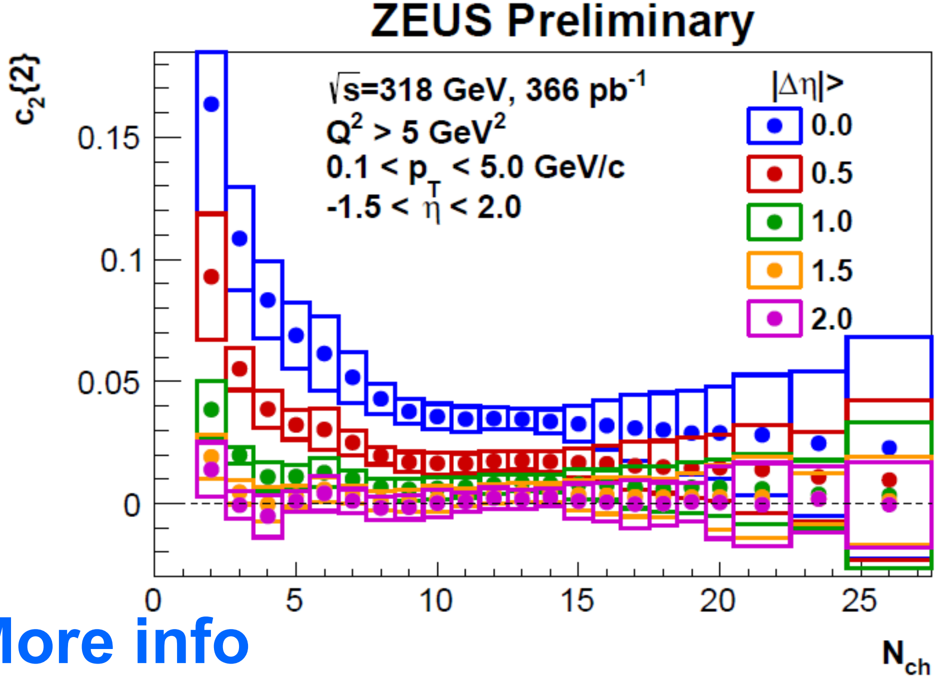
- ***Archive your data!***



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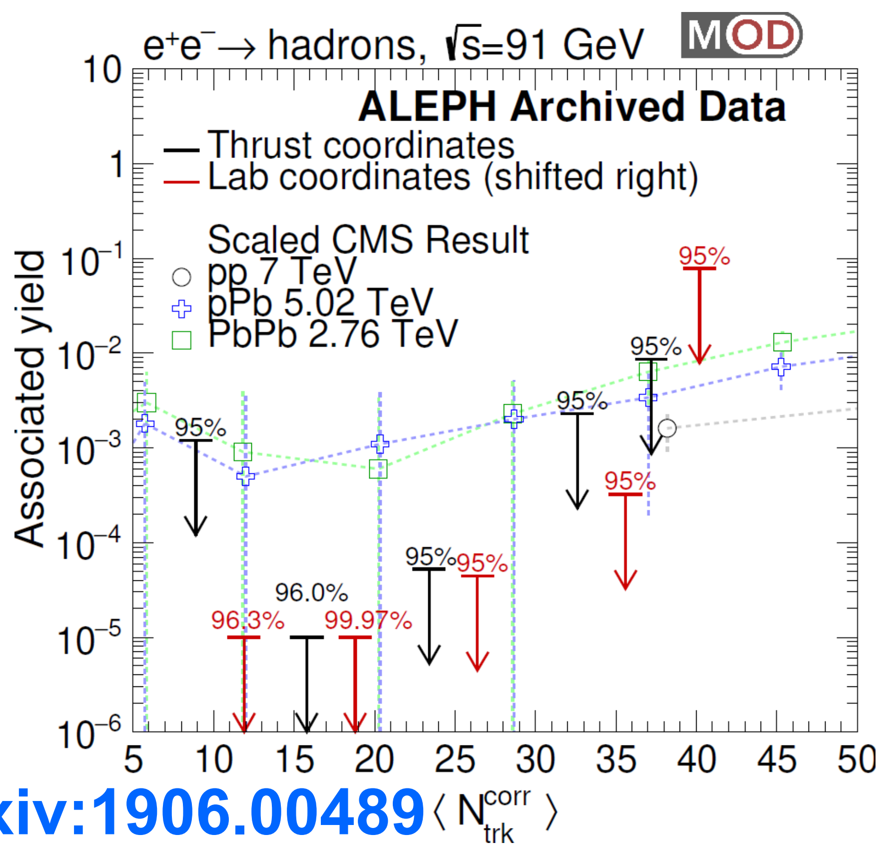

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ALEPH Acknowledgement

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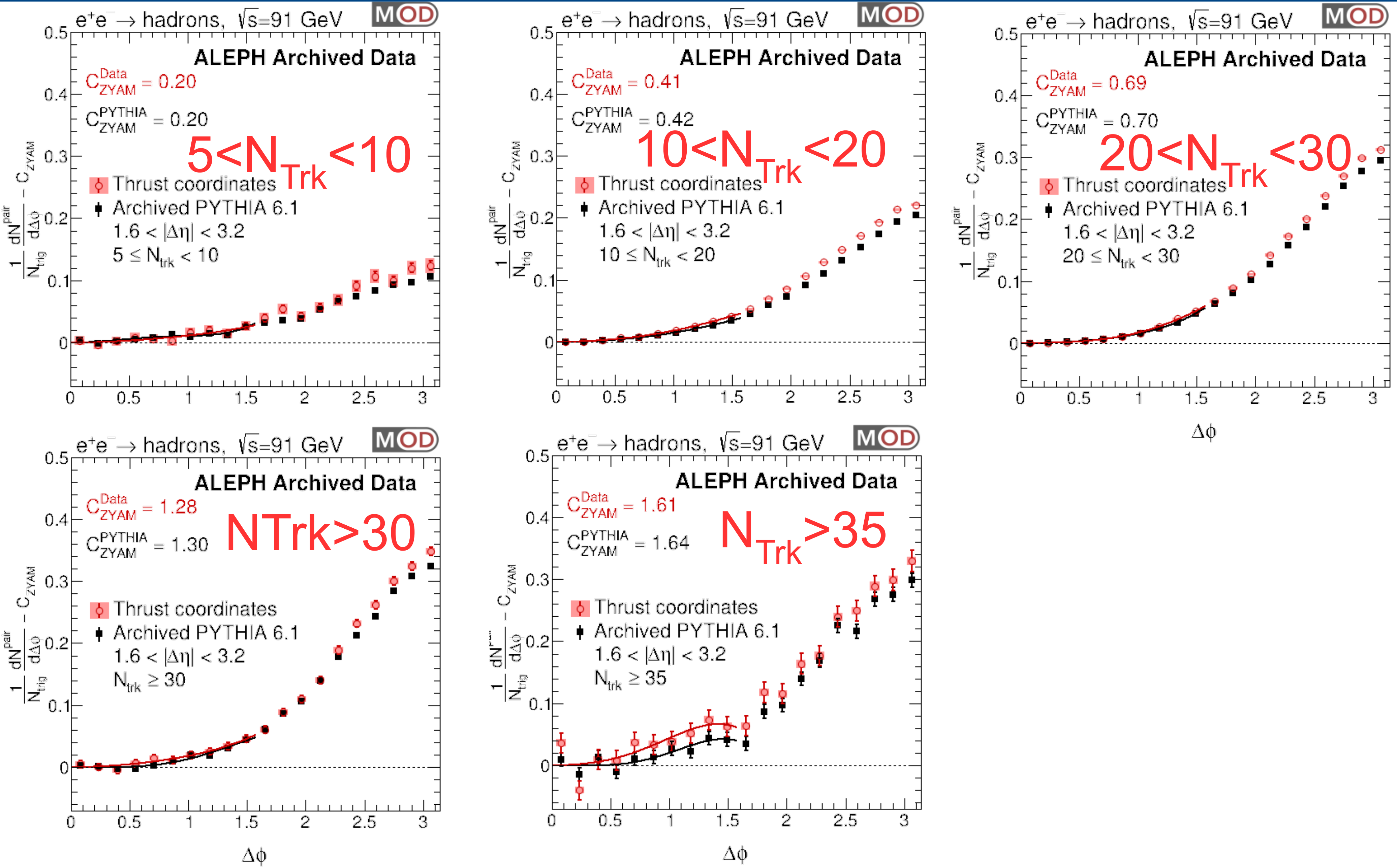
Wei Li, Maxime Guilbaud, Wit Busza, Yang-Ting Chien
and **Camelia Mironov** for the useful discussions on the analysis.

Backup

ALEPH Thrust 1D correlations



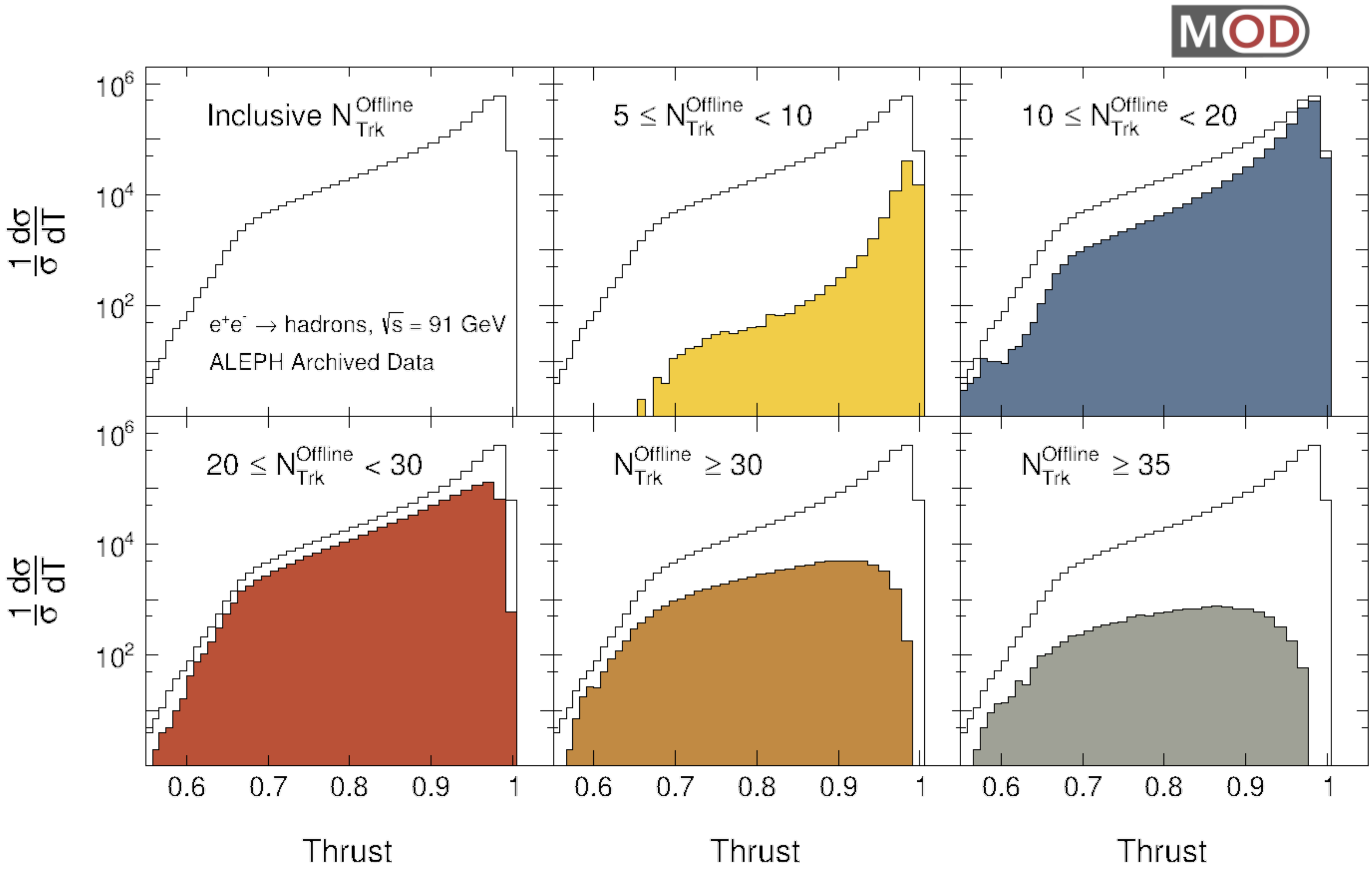
ALEPH e^+e^- N_{trk} bins

N_{trk} range	Fraction of data (%)	$\langle N_{trk} \rangle$	$\langle N_{trk}^{corr} \rangle$
$[5, 10)$	3.1	8.2	8.9
$[10, 20)$	59.2	15.2	15.8
$[20, 30)$	34.6	23.1	23.4
$[30, \infty)$	3.1	32.4	32.6
$[35, \infty)$	0.5	36.9	37.2

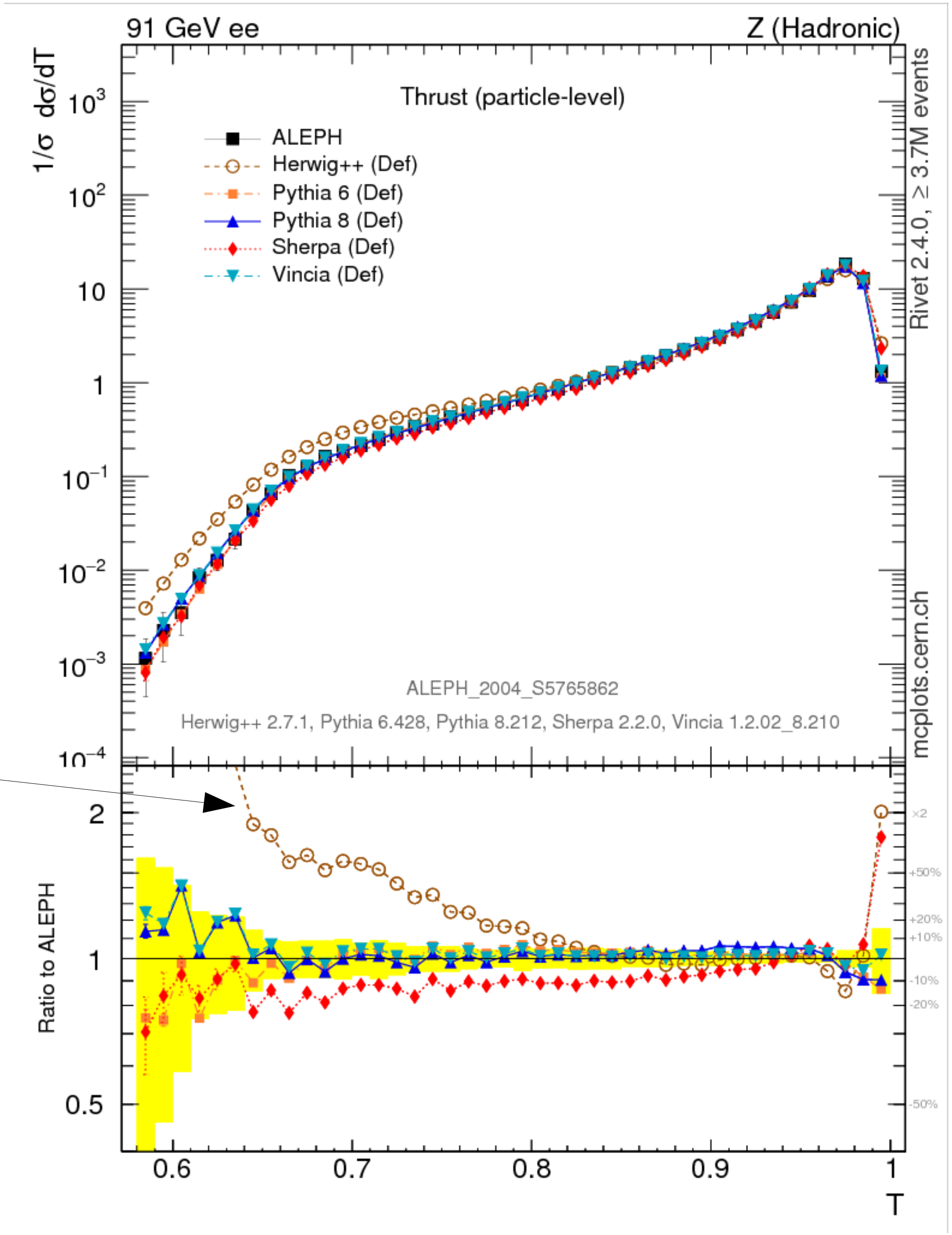
Measurements of two-particle correlations in e^+e^- collisions at 91 GeV with ALEPH archived data

Anthony Badea,[1] Austin Baty,[1] Paoti Chang,[2] Gian Michele Innocenti,[1] Marcello Maggi,[3]
Christopher McGinn,[1] Michael Peters,[1] Tzu-An Sheng,[2] Jesse Thaler,[1] and Yen-Jie Lee[1,*]

ALEPH Thrust vs Multiplicity



MC Thrust comparison



Herwig++