Two-Particle Correlation in e^+e^- Collisions at 91.2 GeV with ALEPH Archived Data

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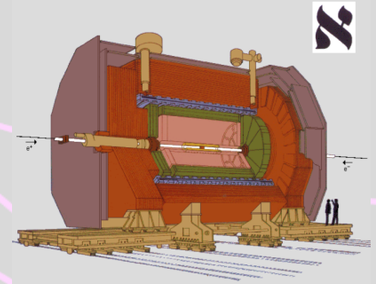
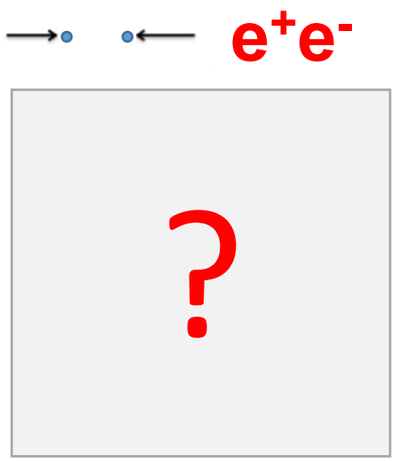
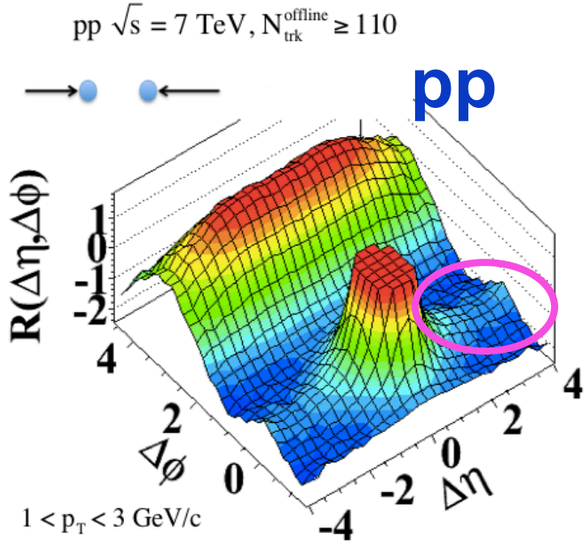


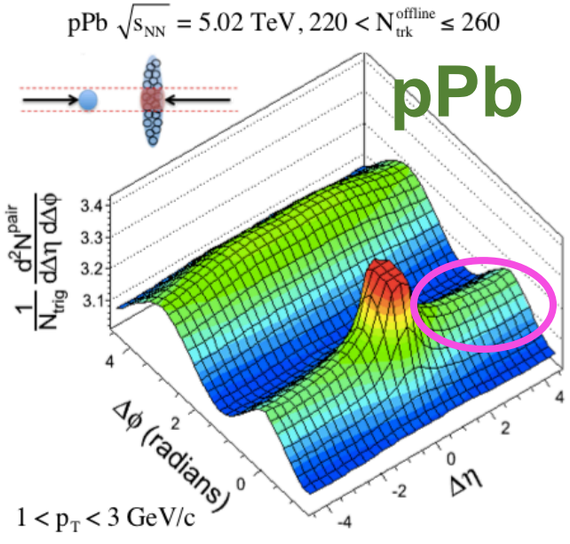
ICHEP 2018, Seoul, South Korea

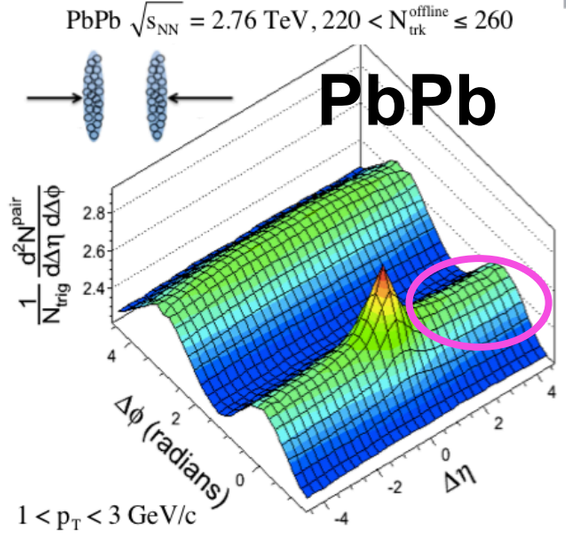
04-11 July, 2018

Motivation

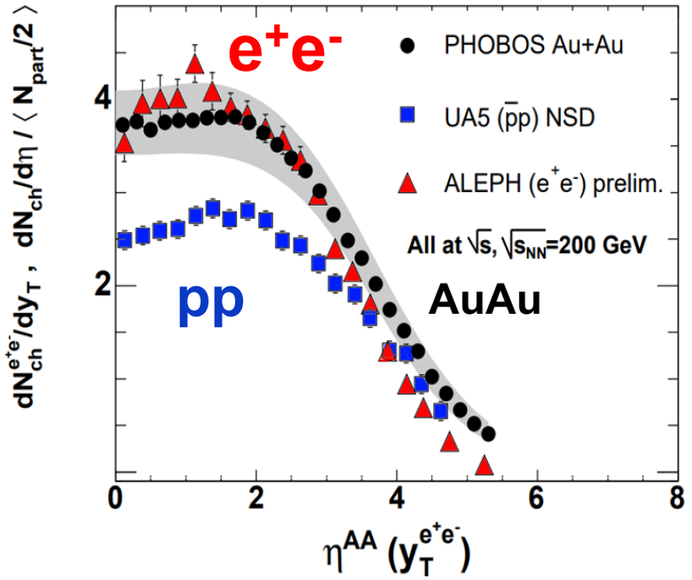






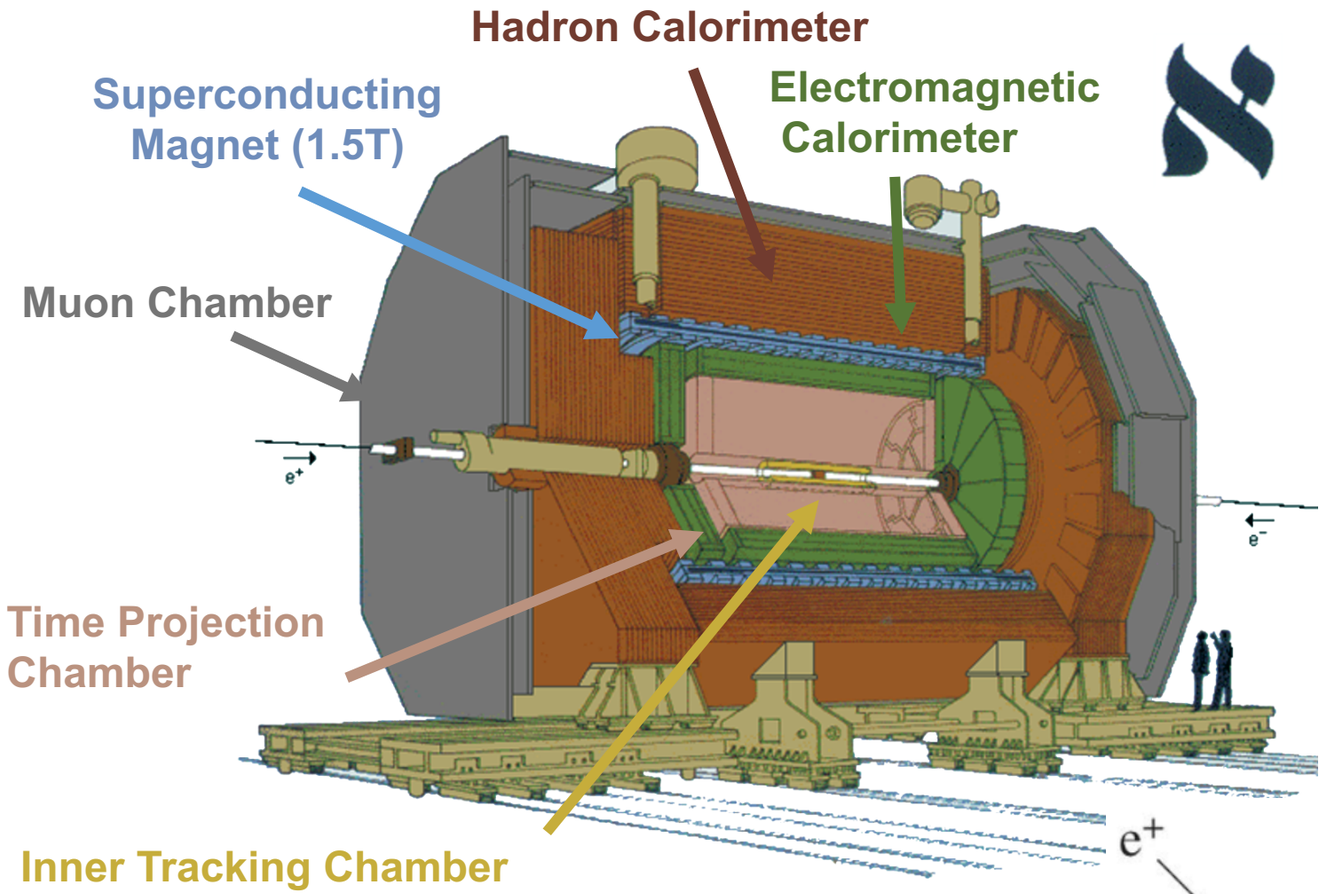


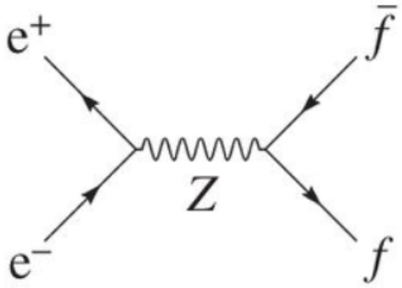
Charged Hadron dN/dη



- Ridge observed in small systems, possible explanations:
  - Initial state effect (CGC)
  - Final state effect due to mini-QGP
  - …
- Similarity between **e+e-**, **pp** and **AA**
  - Event multiplicity per participant
  - dN/dη(y)
- Study of high multiplicity event with well-defined initial condition:
  - No complication from hadron structure
  - No multi-parton interaction

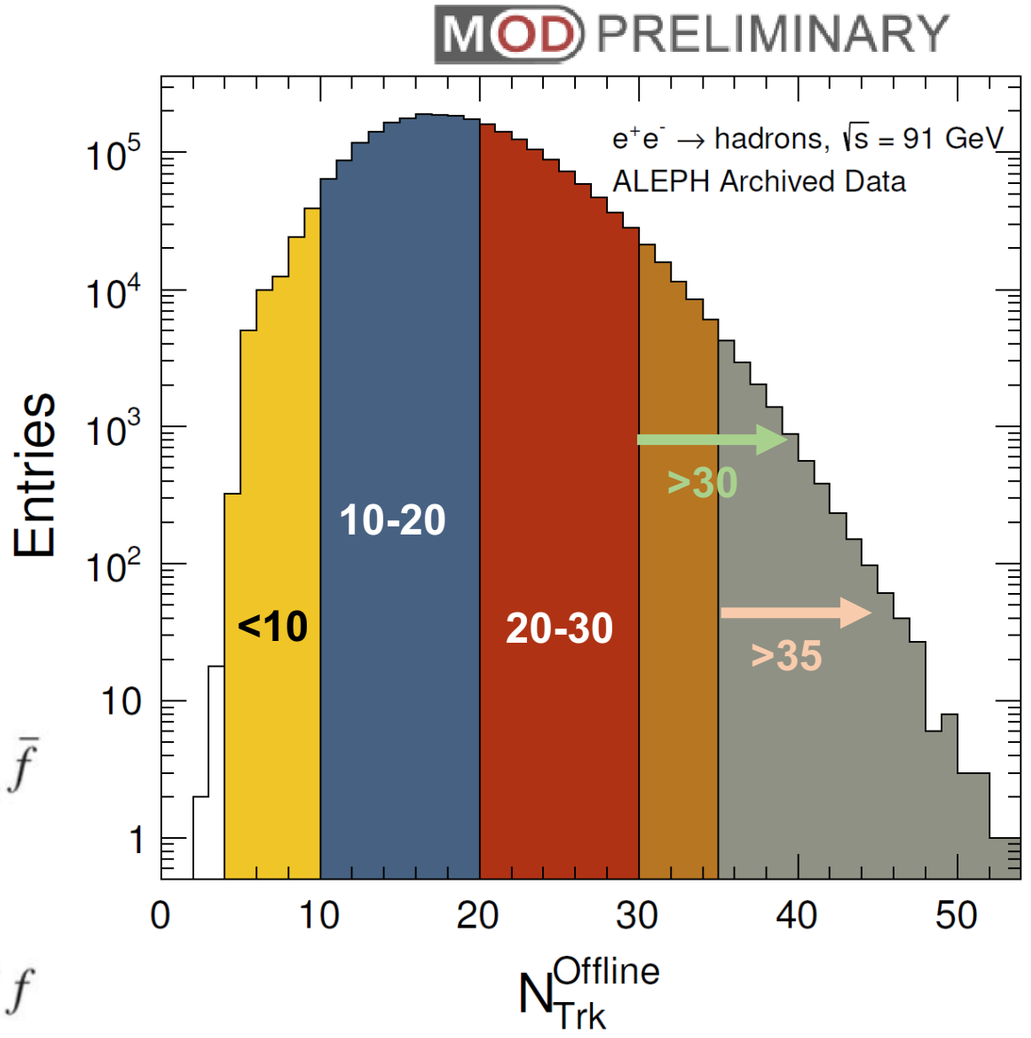
The ALEPH Detector



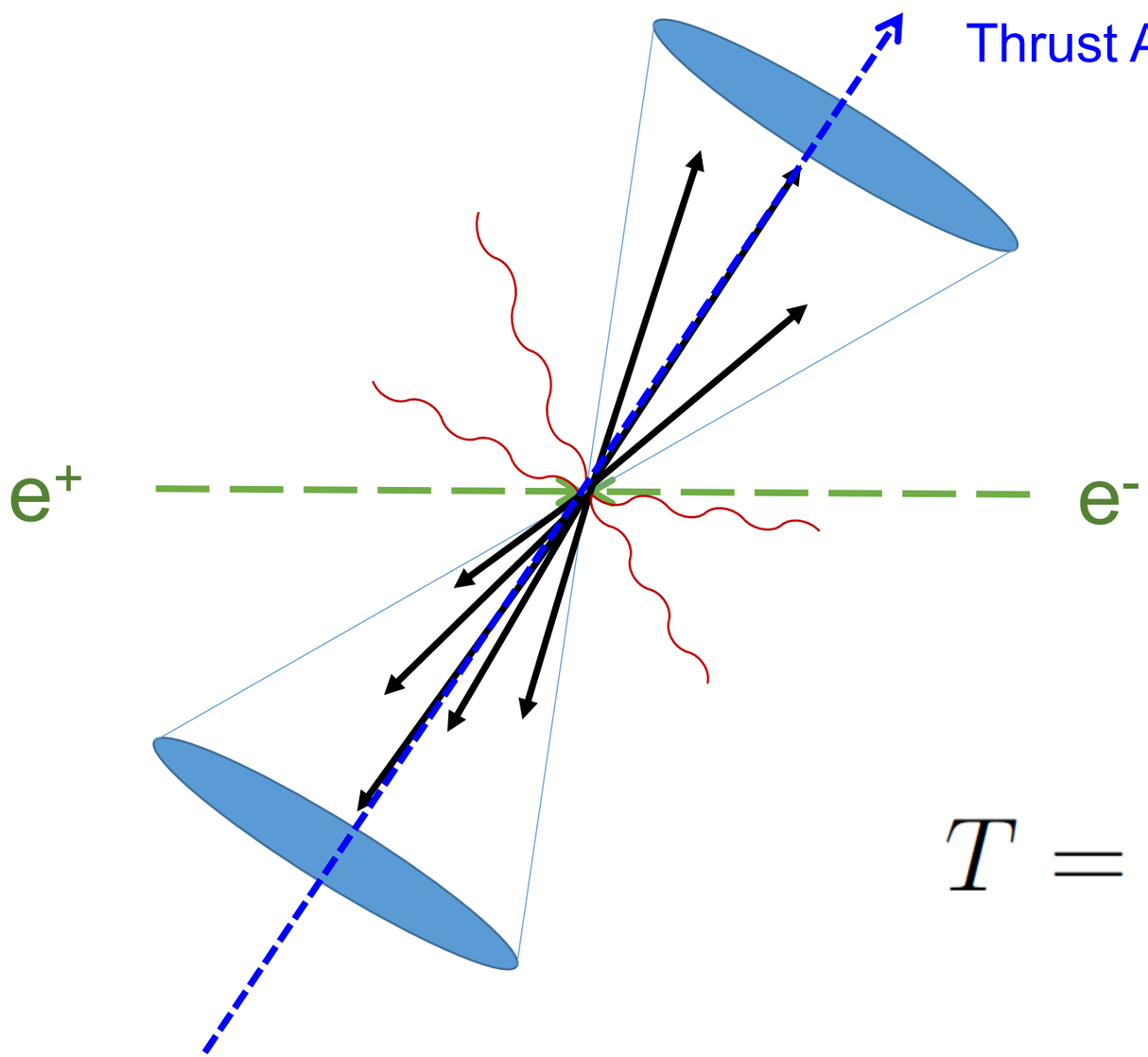


- LEP1 e^+e^- data at Z pole (91 GeV)
- Charged particles multiplicity:
  - $N_{Trk}^{Offline}$: p_T>0.2 GeV and |η|<1.74
- Jets are reconstructed by tracks + calorimeters

Charged Particle Multiplicity

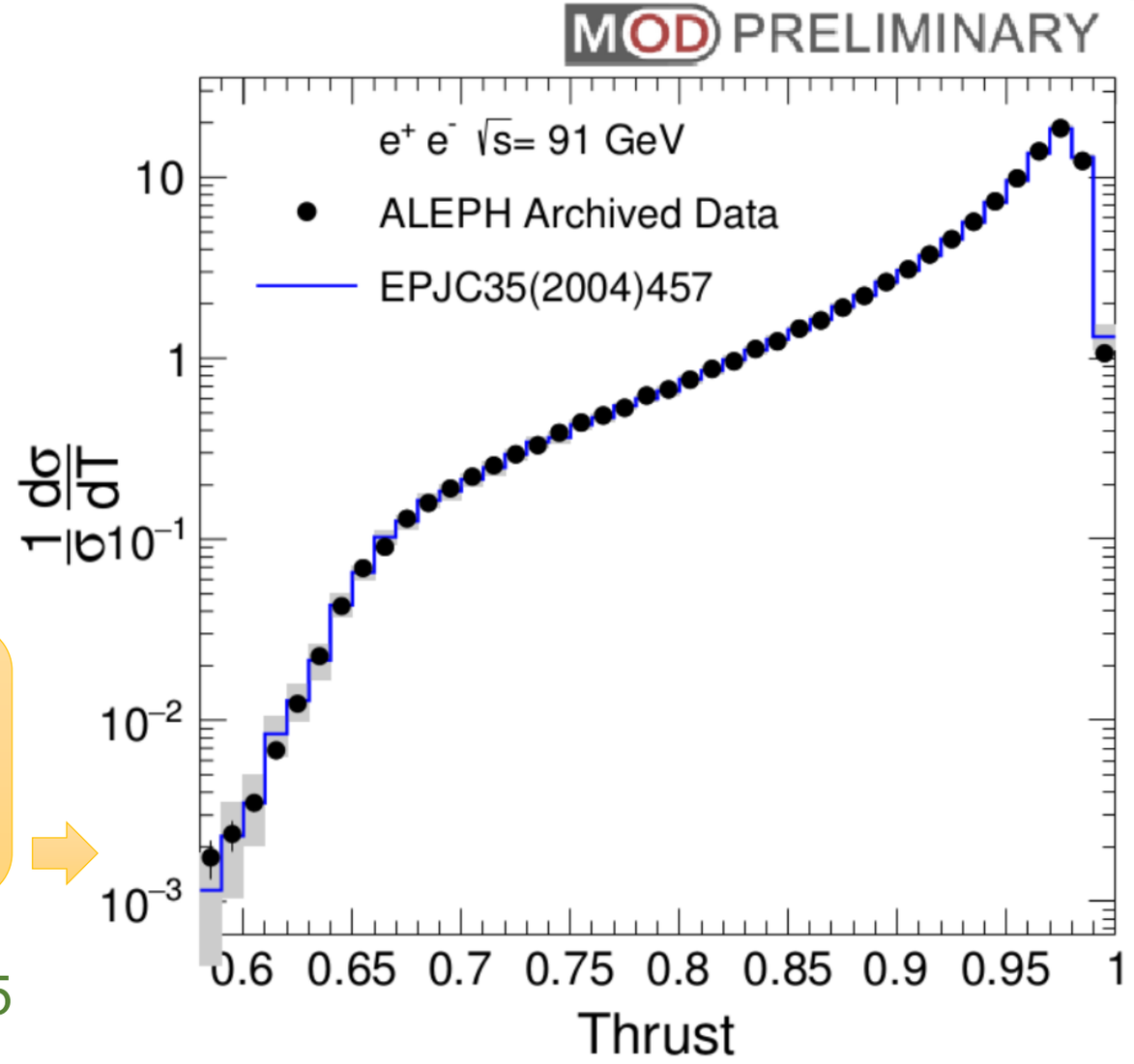


Event Shape: Thrust

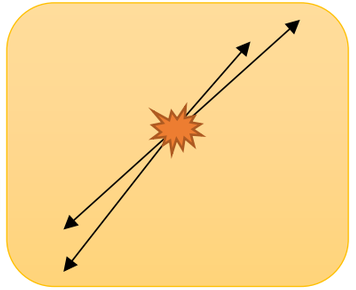


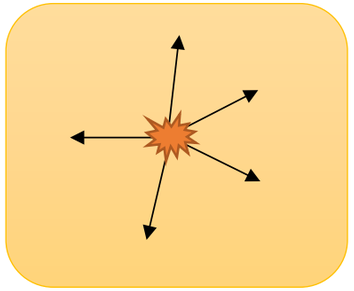
$$T = max_{\hat{n}} \frac{\sum_i |\hat{p}_i . \hat{n}|}{\sum_i |\hat{p}_i|}$$

Unfolded Thrust Distribution



Pencil-like: T~1





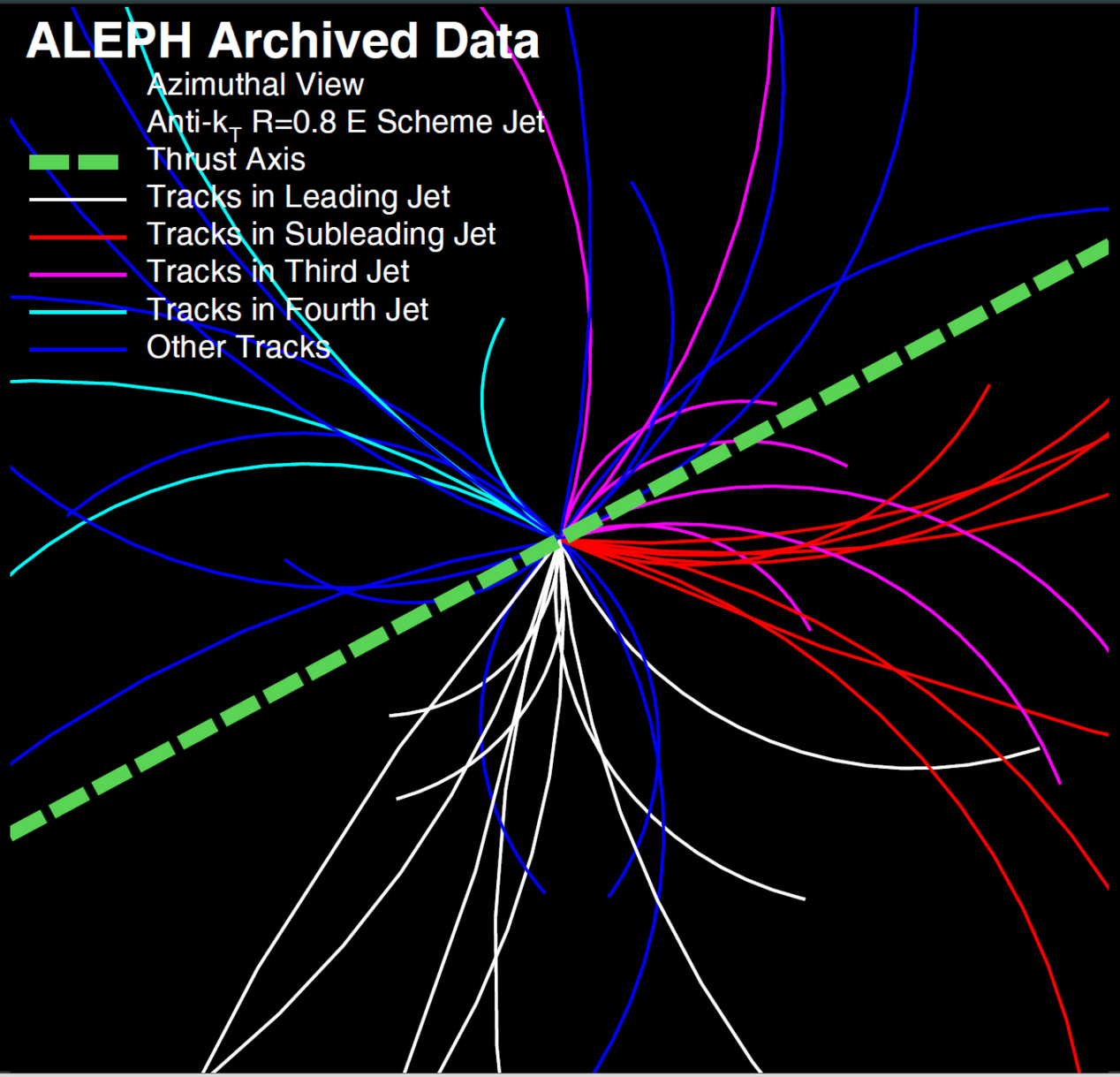
Spherical: T~0.5

Thrust (T)

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

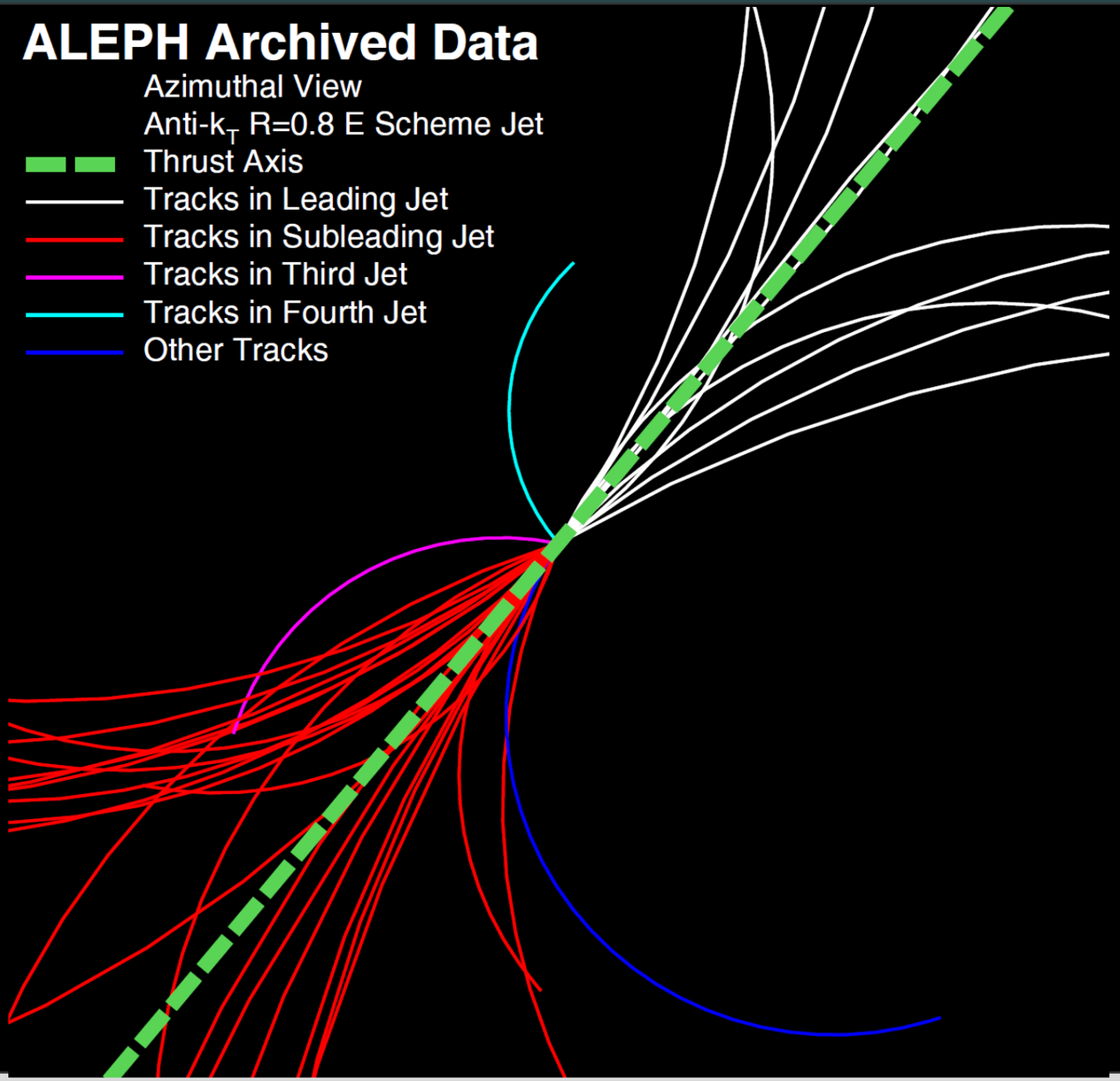
Typical e^+e^- annihilation events are more **pencil-like**

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



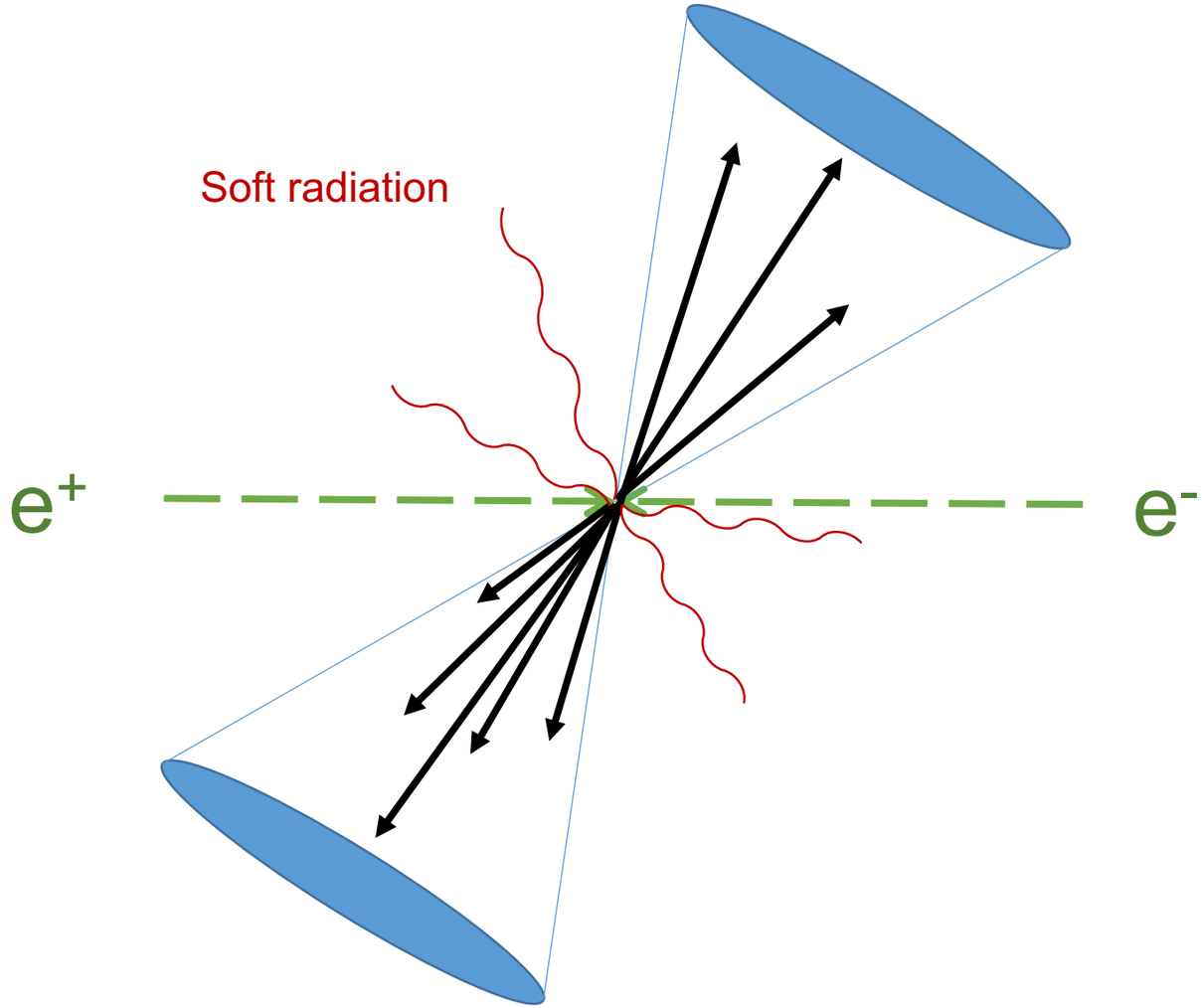
44 Tracks
T=0.57

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



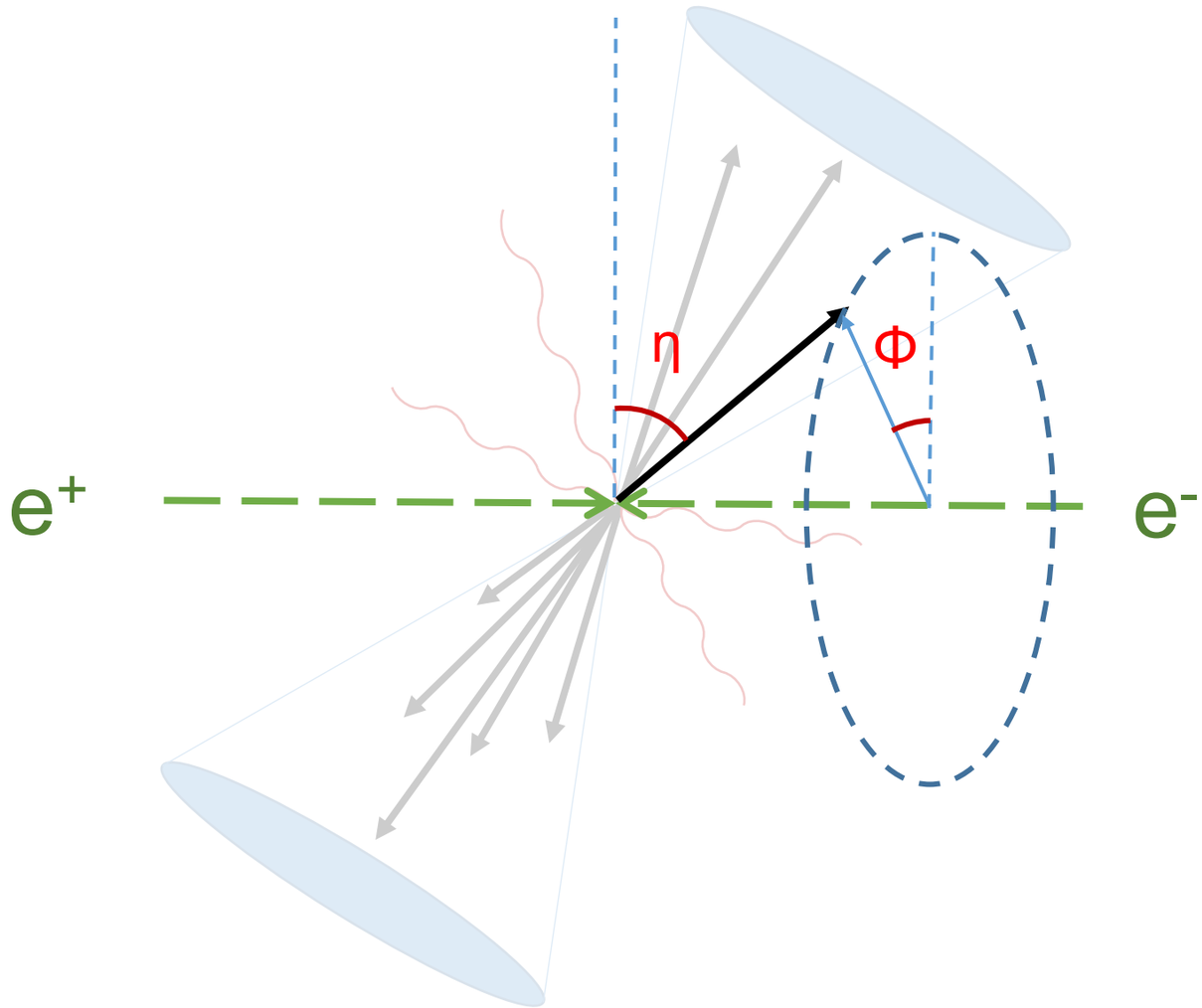
39 Tracks
T=0.98

Beam Axis Analysis



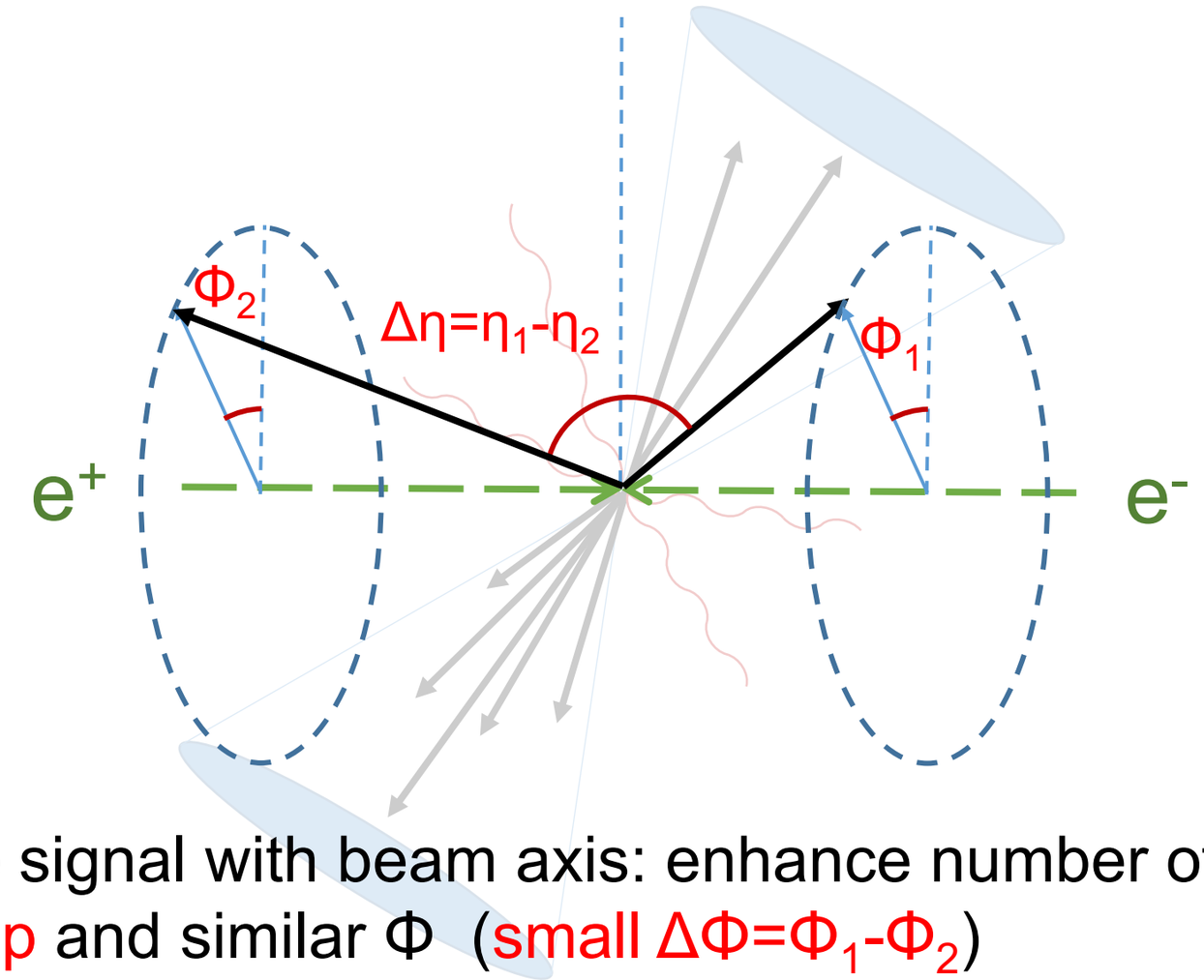
Identical measurement as performed in pp, pA and AA collisions in various experiments

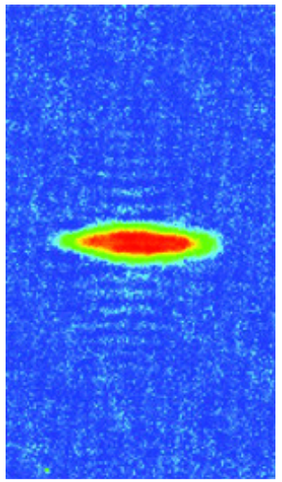
Beam Axis Analysis



Pseudorapidity (η) and azimuthal angle (Φ) are calculated with respect to the **beam pipe**

Beam Axis Analysis

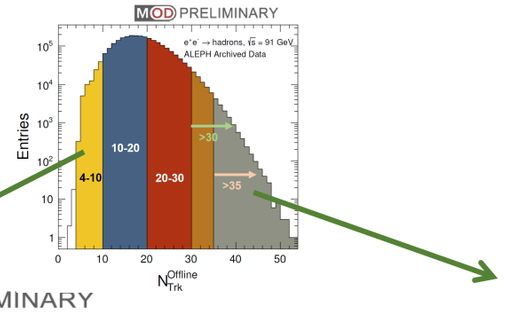




- Search for ridge signal with beam axis: enhance number of charged particle pairs with large Δη gap and similar Φ (small $\Delta\Phi=\Phi_1-\Phi_2$)
- Ex: Sensitive to **"pressure driven expansion"** of the medium in the direction perpendicular to the **beam axis**

Beam Axis Analysis Result

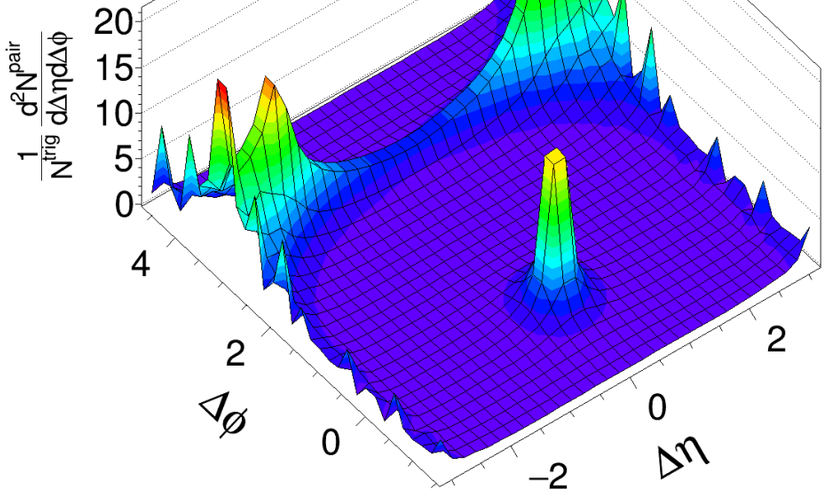
Low Multiplicity
$4 \le N_{Trk}^{Offline} < 10$



High Multiplicity
$N_{Trk}^{Offline} \ge 35$

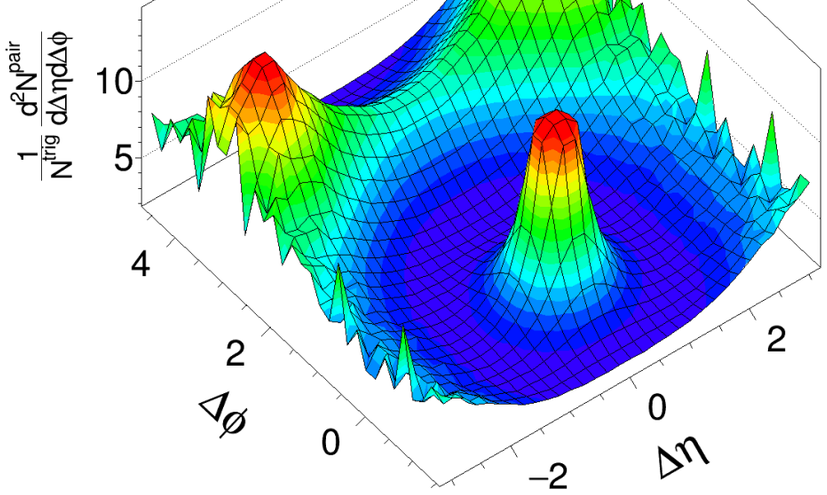
MOD PRELIMINARY

ALEPH e^+e^-, $\sqrt{s}$=91GeV
$4 \le N_{Trk}^{Offline} < 10$
$|\eta| < 1.6$
$0.4 < p_T < 100.0$ GeV
Beam Axis



MOD PRELIMINARY

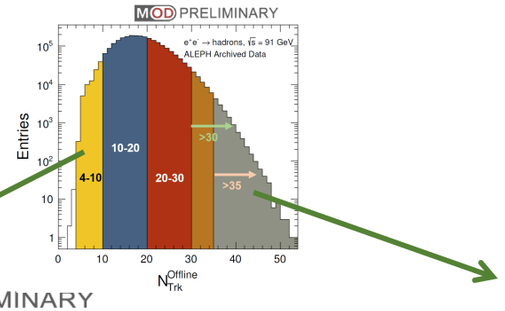
ALEPH e^+e^-, $\sqrt{s}$=91GeV
$35 \le N_{Trk}^{Offline} < 999$
$|\eta| < 1.6$
$0.4 < p_T < 100.0$ GeV
Beam Axis

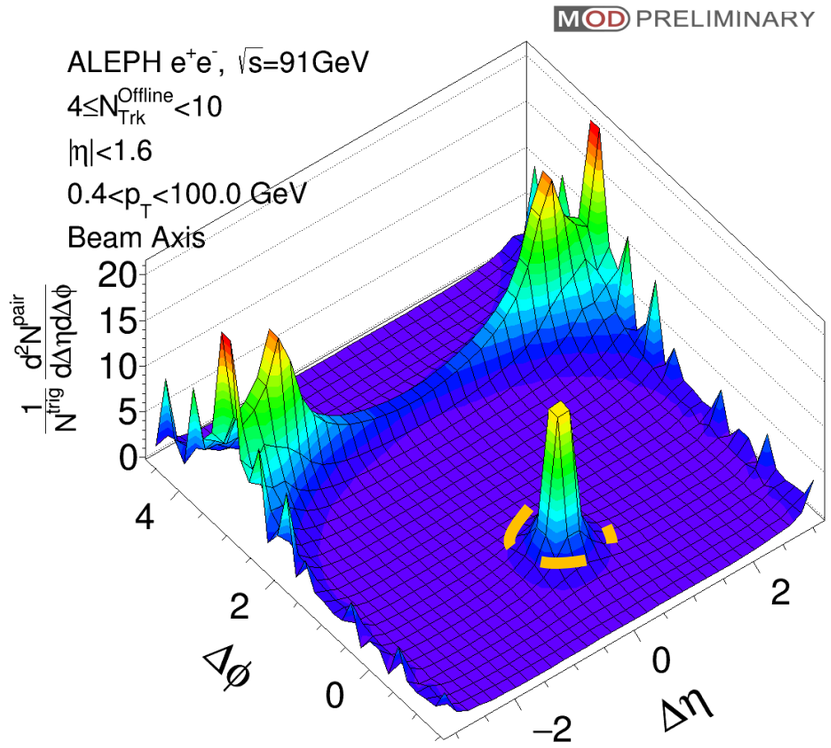


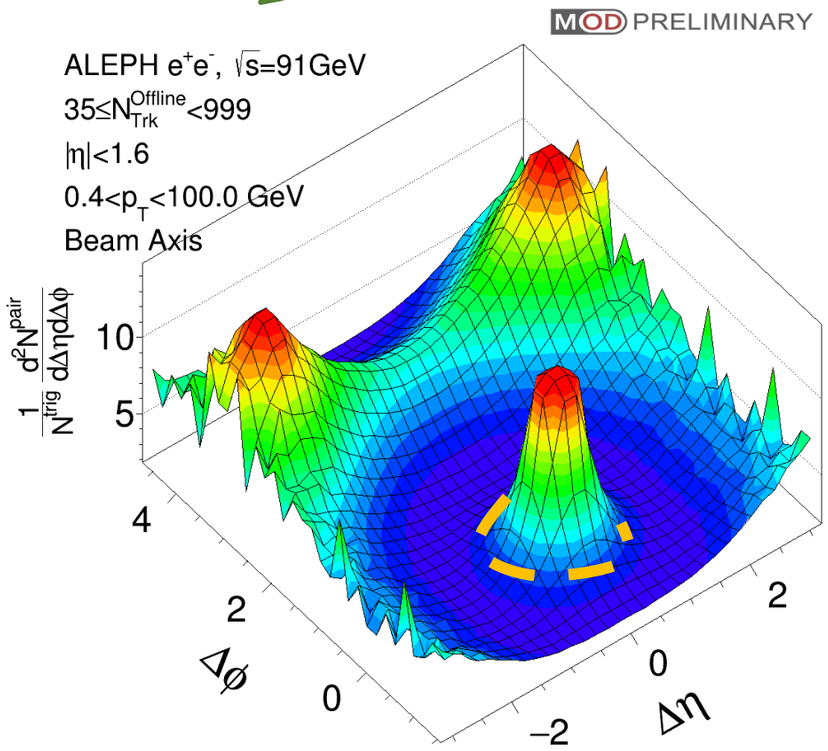
Beam Axis Analysis Result

Low Multiplicity
$4 \le N_{Trk}^{Offline} < 10$

High Multiplicity
$N_{Trk}^{Offline} \ge 35$





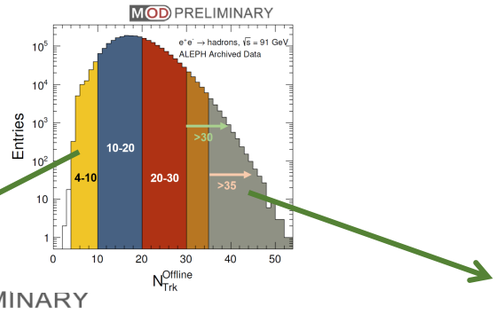


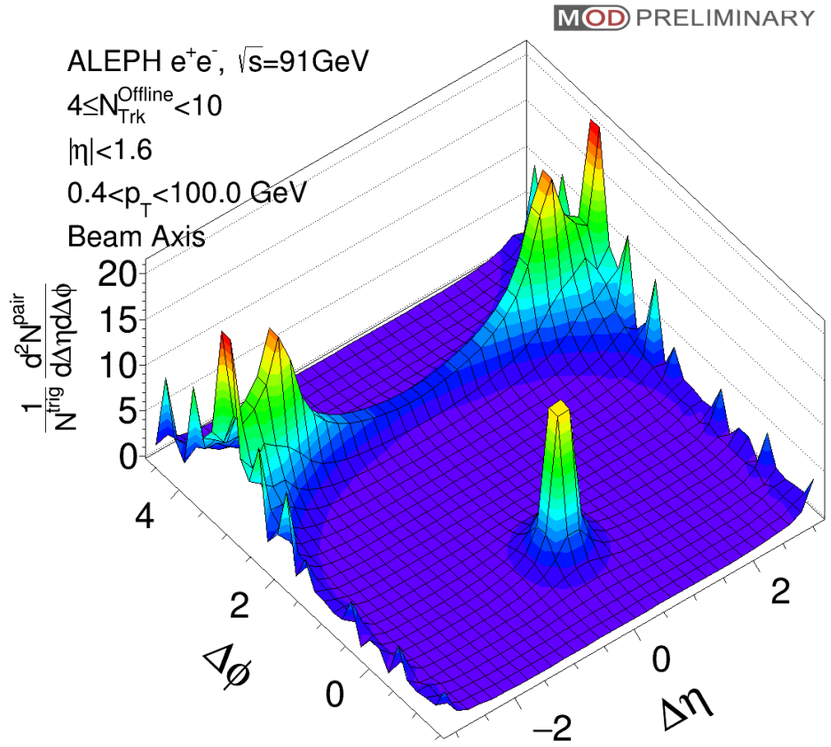
Beautiful jet-like structure at (Δη,ΔΦ) ~ (0,0)

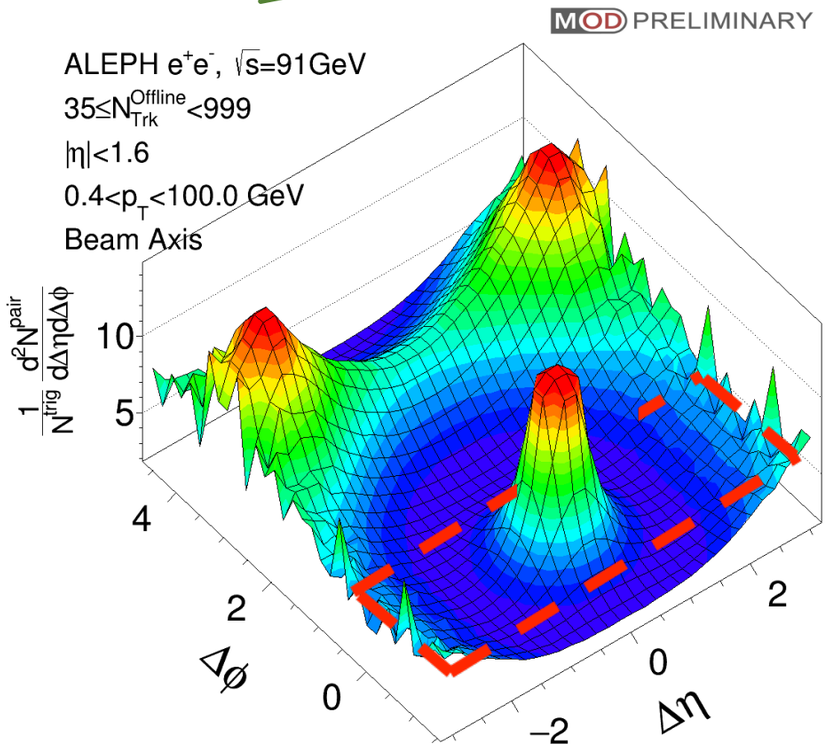
Beam Axis Analysis Result

Low Multiplicity
$4 \le N_{Trk}^{Offline} < 10$

High Multiplicity
$N_{Trk}^{Offline} \ge 35$





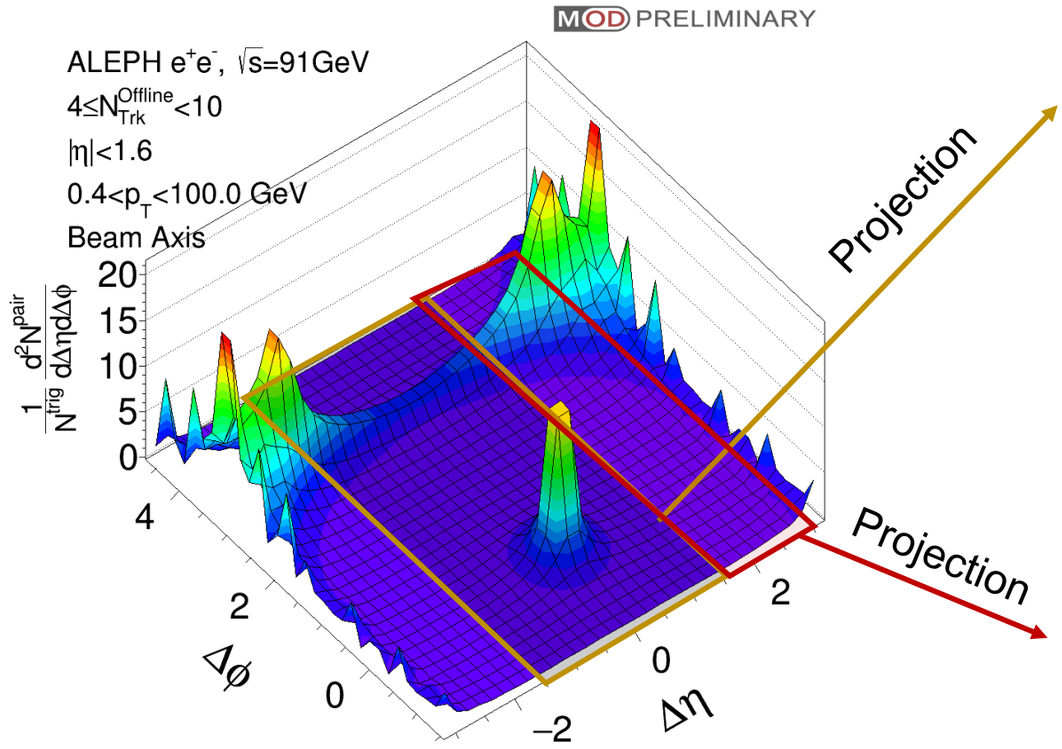


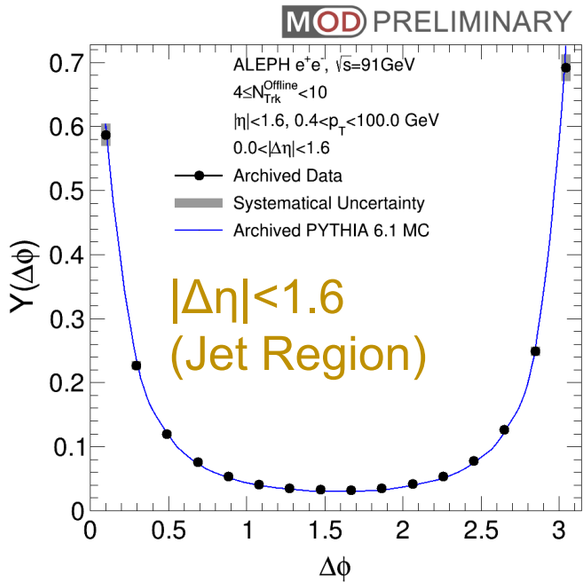
No ridge structure observed at small ΔΦ and large Δη

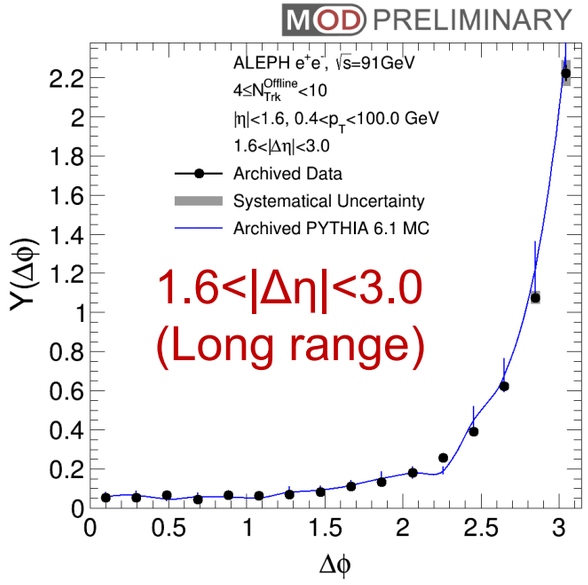
Beam Axis Analysis Result

Low Multiplicity
$4 \le N_{Trk}^{Offline} < 10$

PYTHIA6 (curve)
Data (dots)





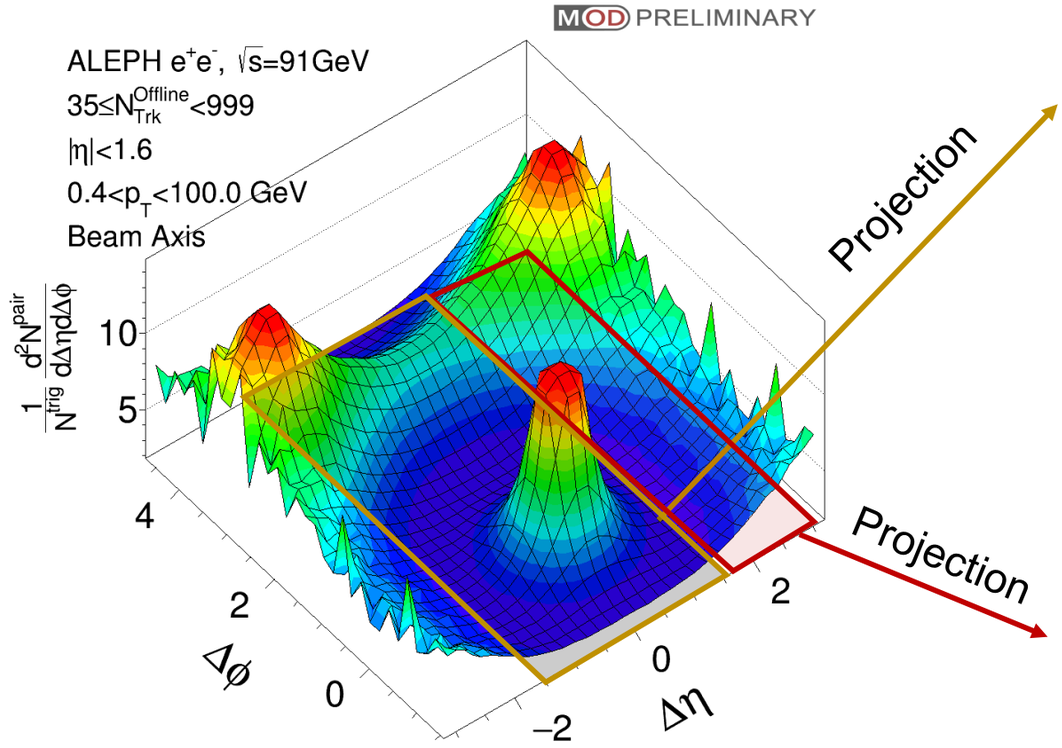


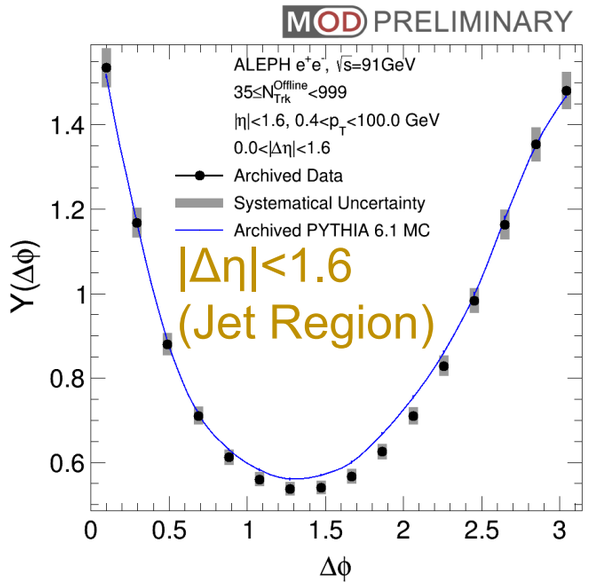
Excellent agreement between PYTHIA6 and Data

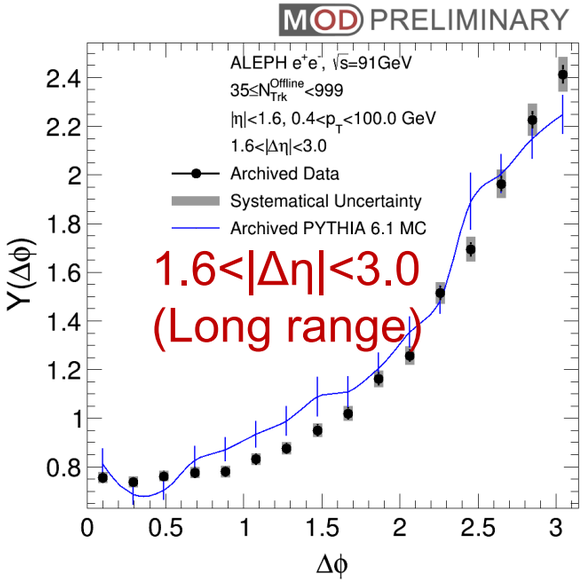
Beam Axis Analysis Result

High multiplicity
$N_{Trk}^{Offline}$>35

PYTHIA6 (curve)
Data (dots)





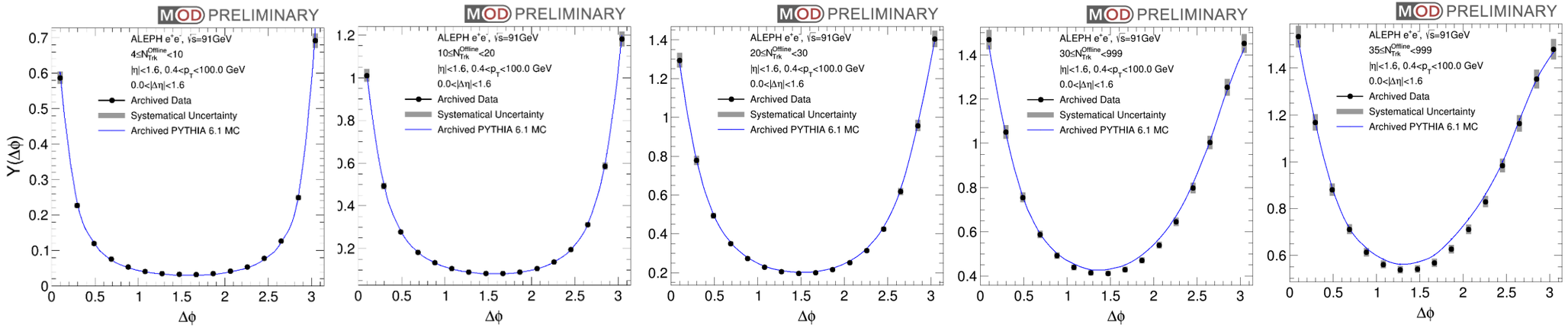


- Good agreement between PYTHIA6 and Data
- No near-side ridge observed

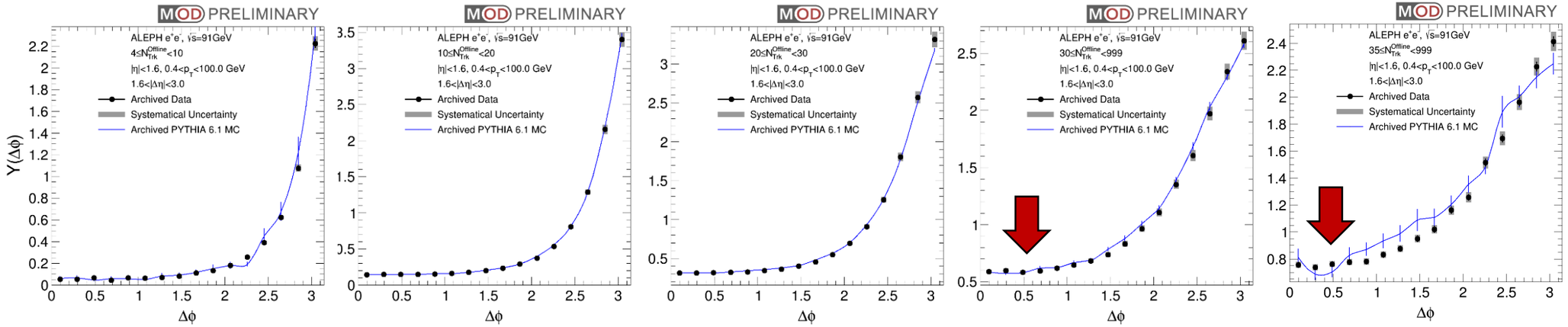
ΔΦ Projection vs. Event Multiplicity

4≤N<10 | 10≤N<20 | 20≤N<30 | N≥30 | N≥35

|Δη|<1.6
(Jet Region)



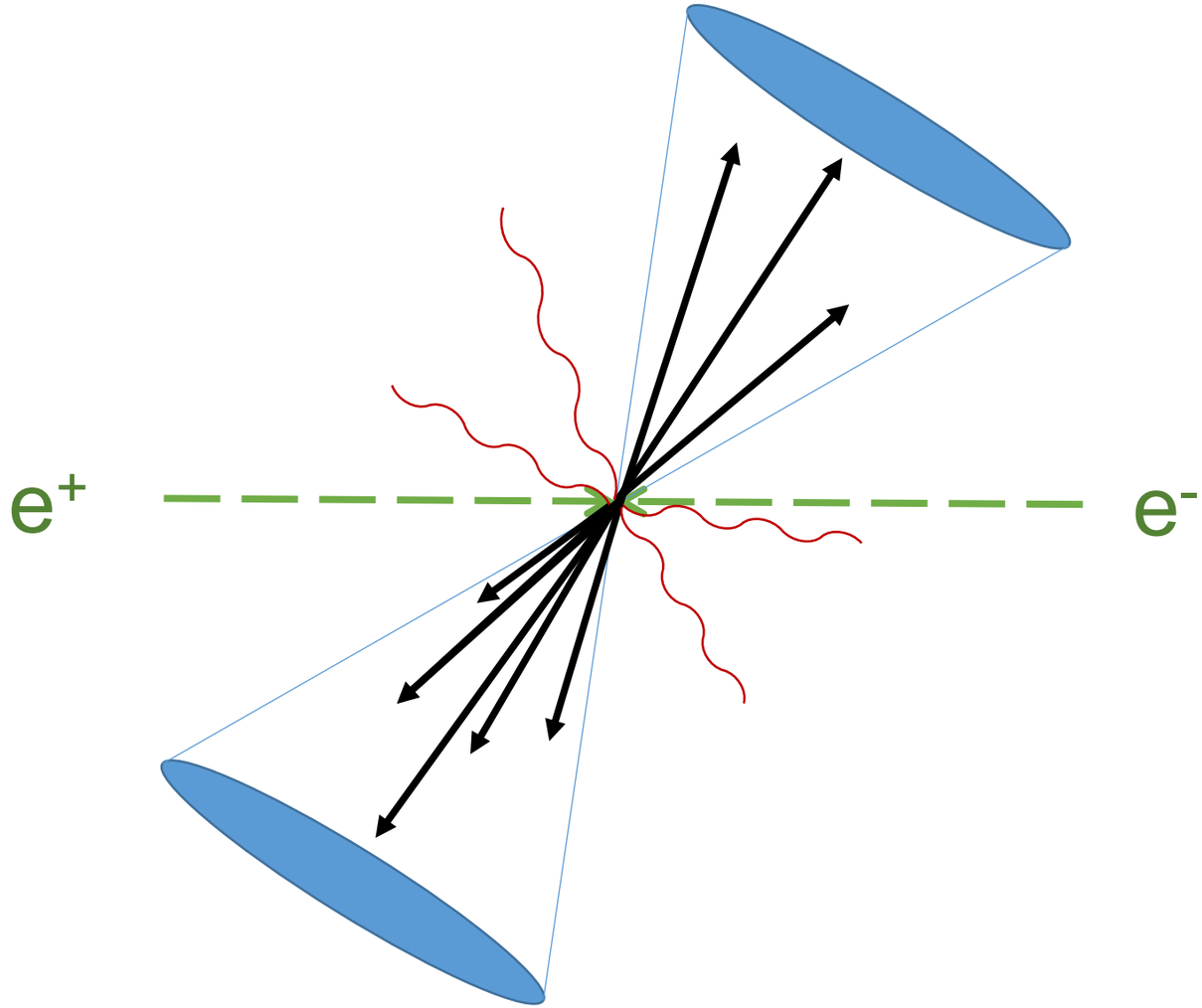
1.6<|Δη|<3.0
(Long range)



PYTHIA6 (curve) vs. **Data (dot) [Beam axis analysis]**

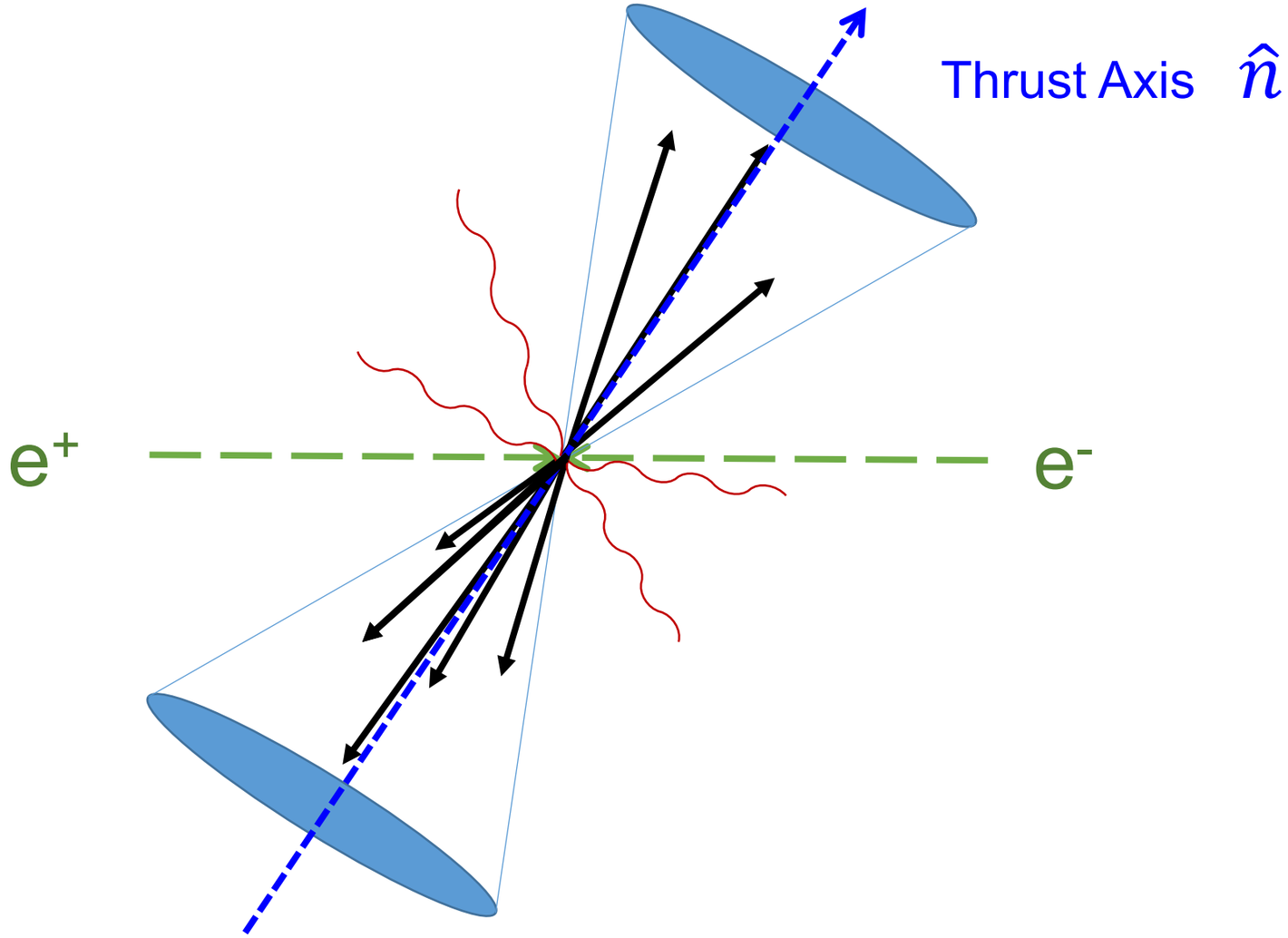
- Good agreement between PYTHIA6 and ALEPH Data for N<30
  - **No near-side peak (ridge) is found at small ΔΦ in long range correlation**
- Some difference observed at high multiplicity N ≥35

Beam Axis Analysis



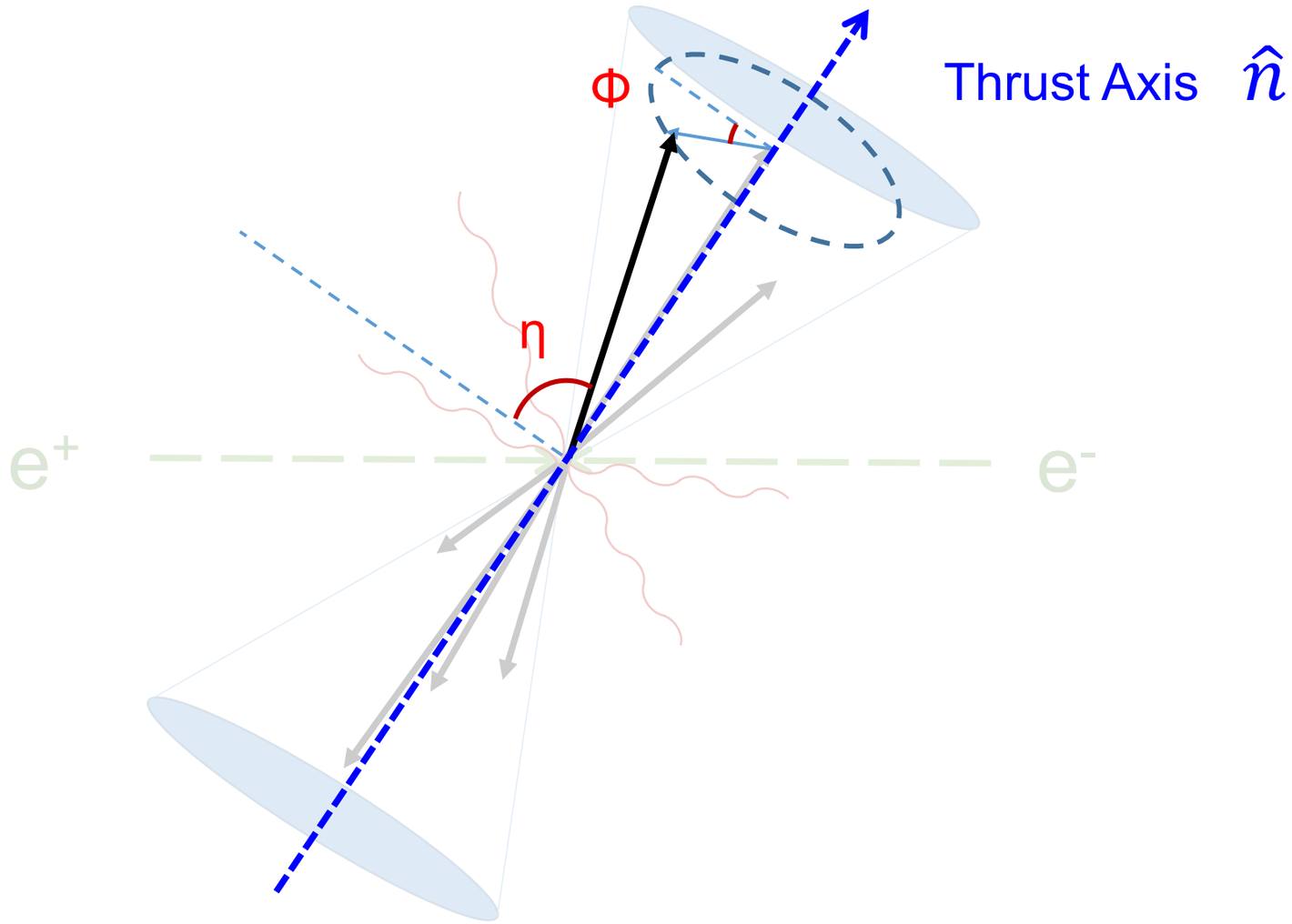
No ridge signal is found in beam axis analysis, which is sensitive to perturbative physics (+ parton shower)

Thrust Axis Analysis



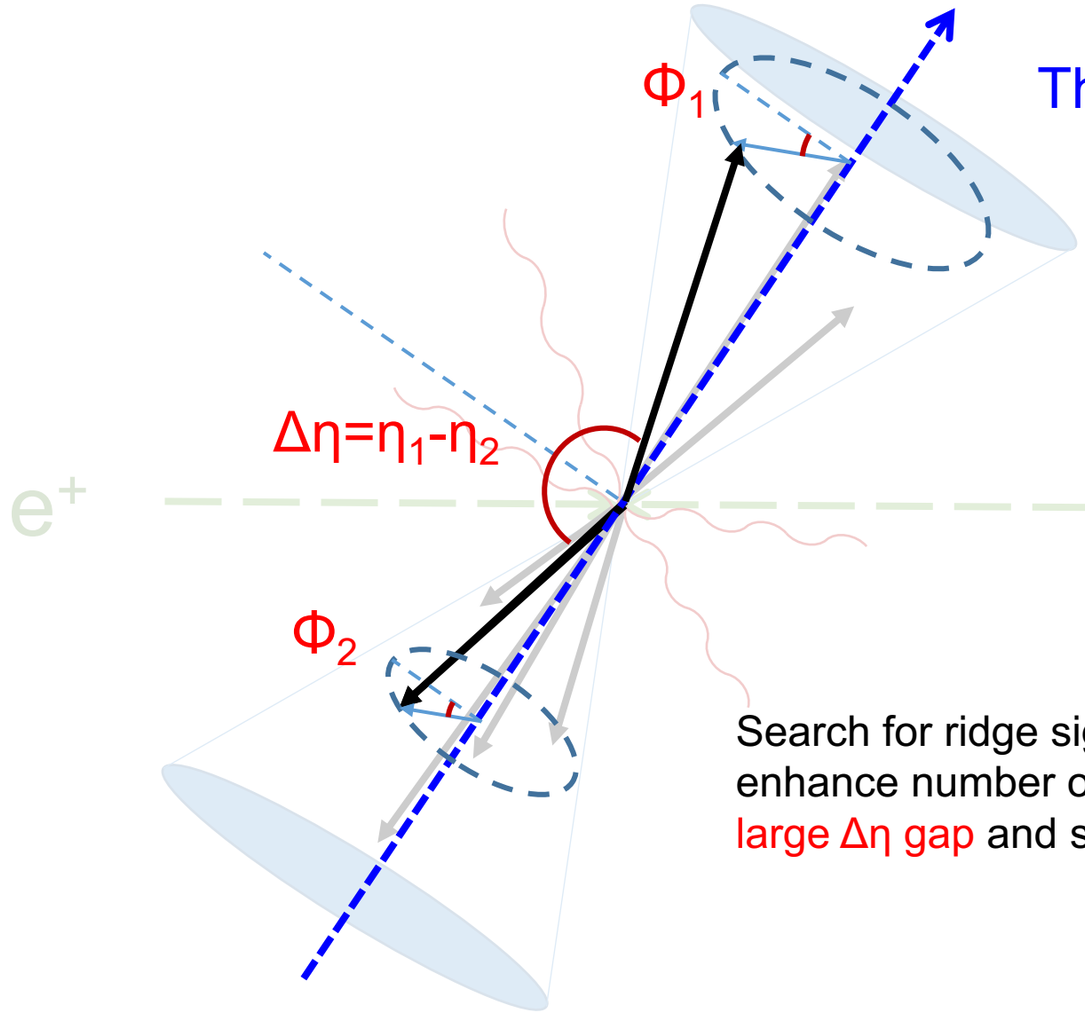
Thrust axis analysis to follow the “direction of color string”

Thrust Axis Analysis

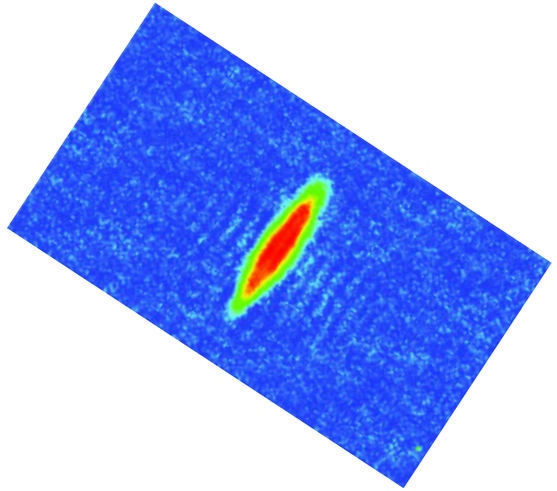


Pseudodorapidity (η) and azimuthal angle (Φ) are calculated with respect to the **Thrust Axis**

Thrust Axis Analysis



Thrust Axis $\hat{n}$



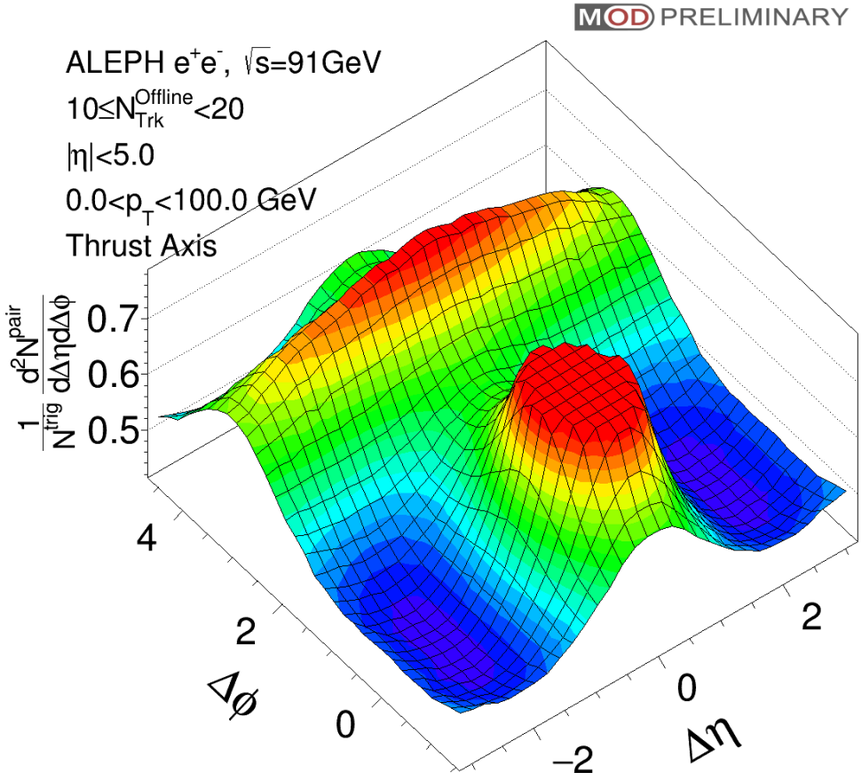
Search for ridge signal with thrust axis:
enhance number of charged particle pairs with large $\Delta\eta$ gap and similar Φ (small $\Delta\Phi=\Phi_1-\Phi_2$)

Pseudorapidity (η) and azimuthal angle (Φ) are calculated with respect to the **Thrust Axis**

Correlation Function with Thrust Axis

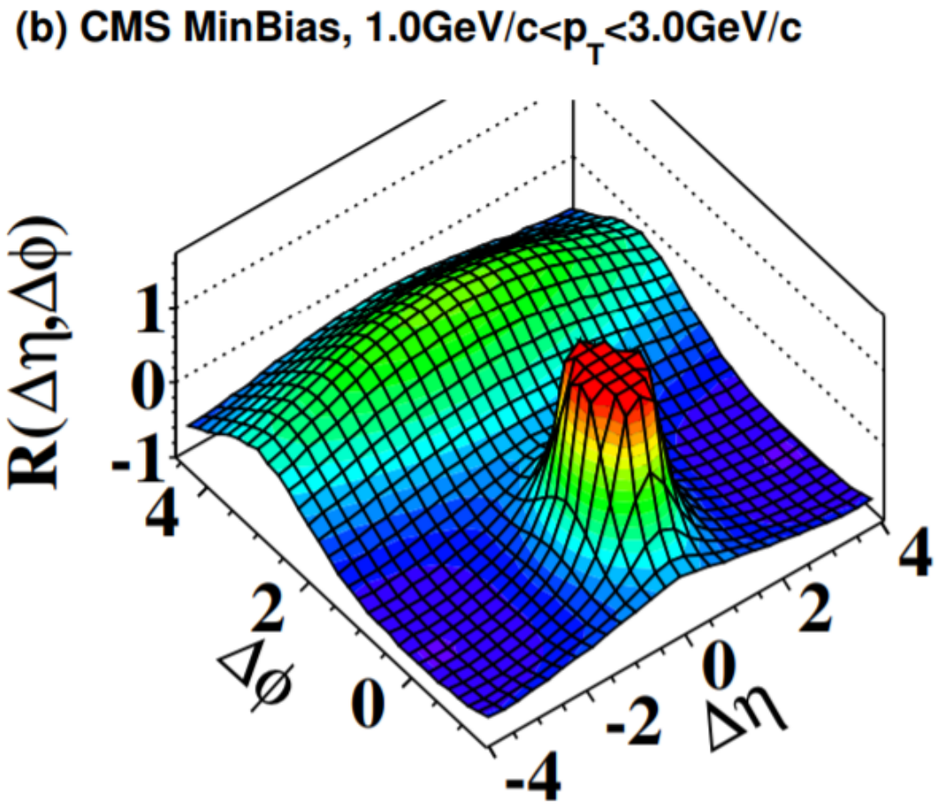
ALEPH e^+e^-

$10 \leq N_{Trk}^{Offline} < 20$ Thrust axis



CMS pp

Inclusive Beam axis

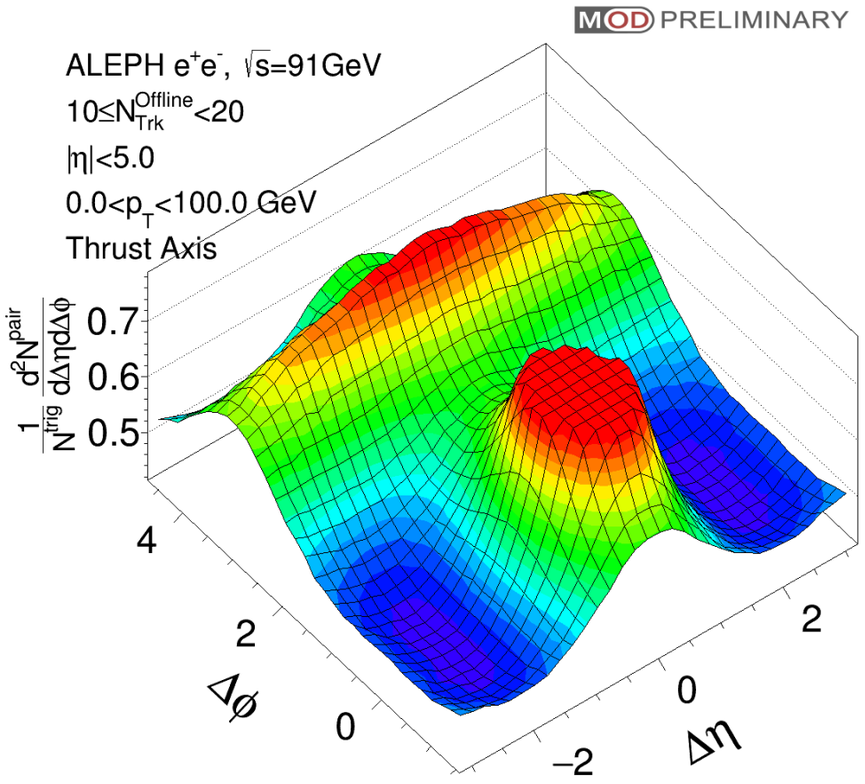


Correlation function with **Thrust Axis** as reference is much more similar to the beam axis result in pp collisions (with many caveats / differences)

Correlation Function with Thrust Axis

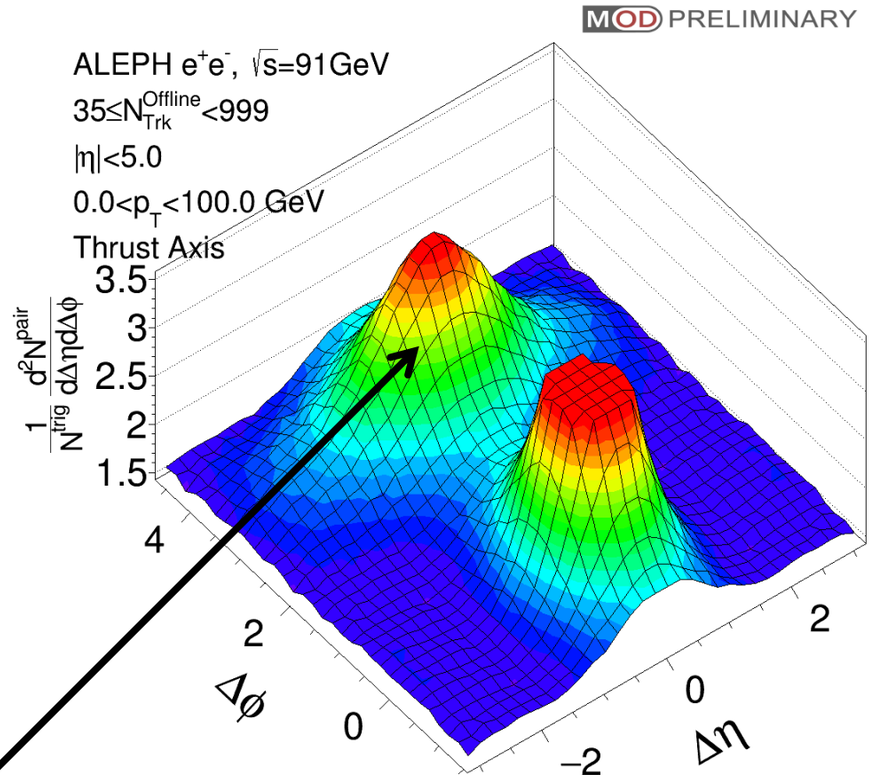
ALEPH e^+e^-

$10 \le N_{Trk}^{Offline} < 20$ Thrust axis



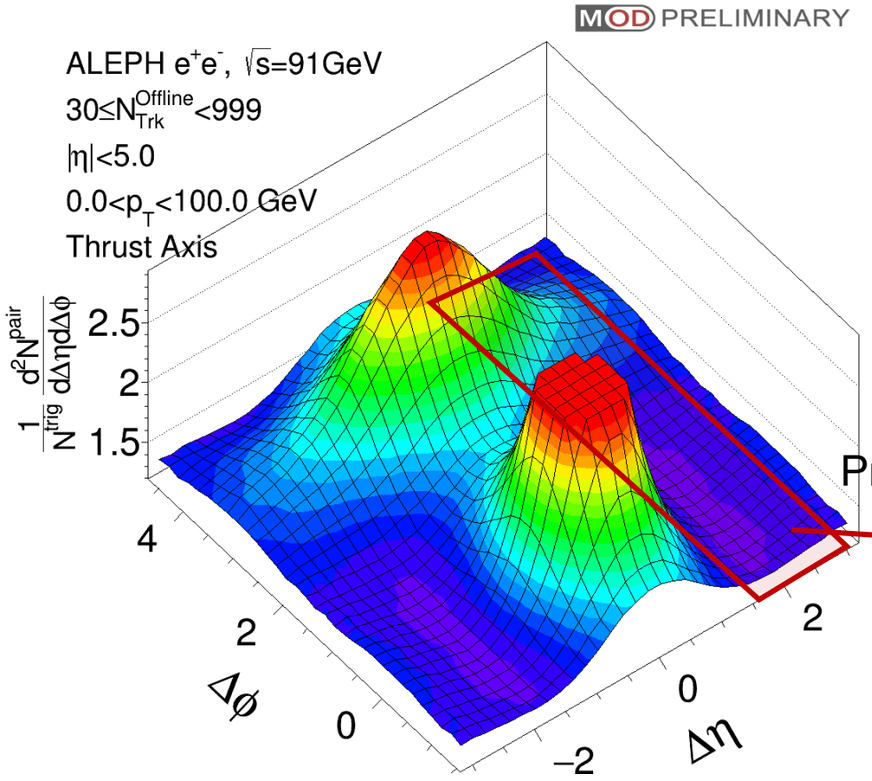
ALEPH e^+e^-

$N_{Trk}^{Offline} \ge 35$ Thrust axis

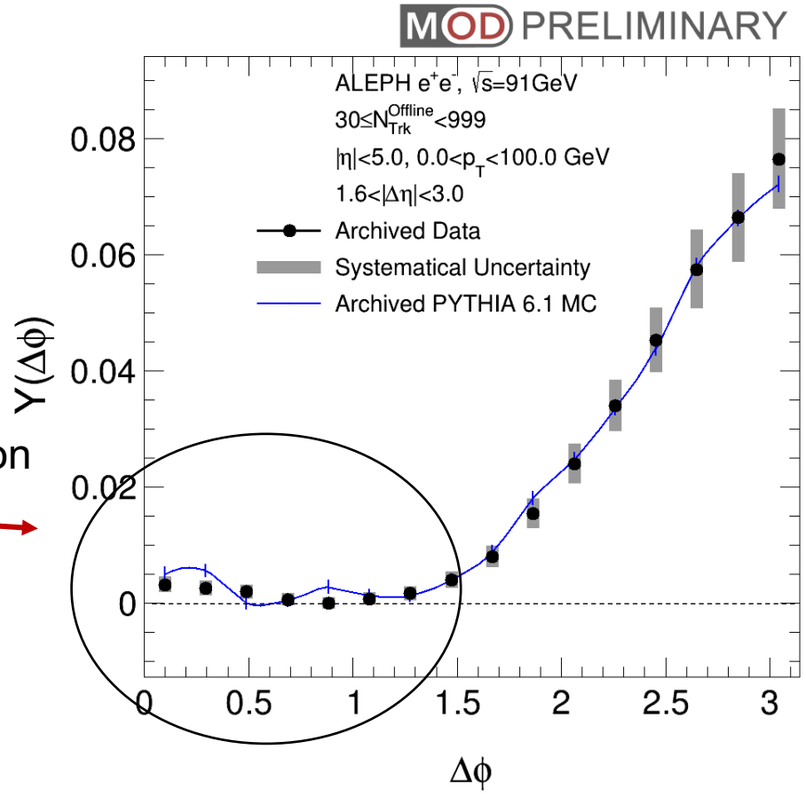


Narrower away side peak in high multiplicity events

LEP1 Data vs PYTHIA6 N≥30



Projection

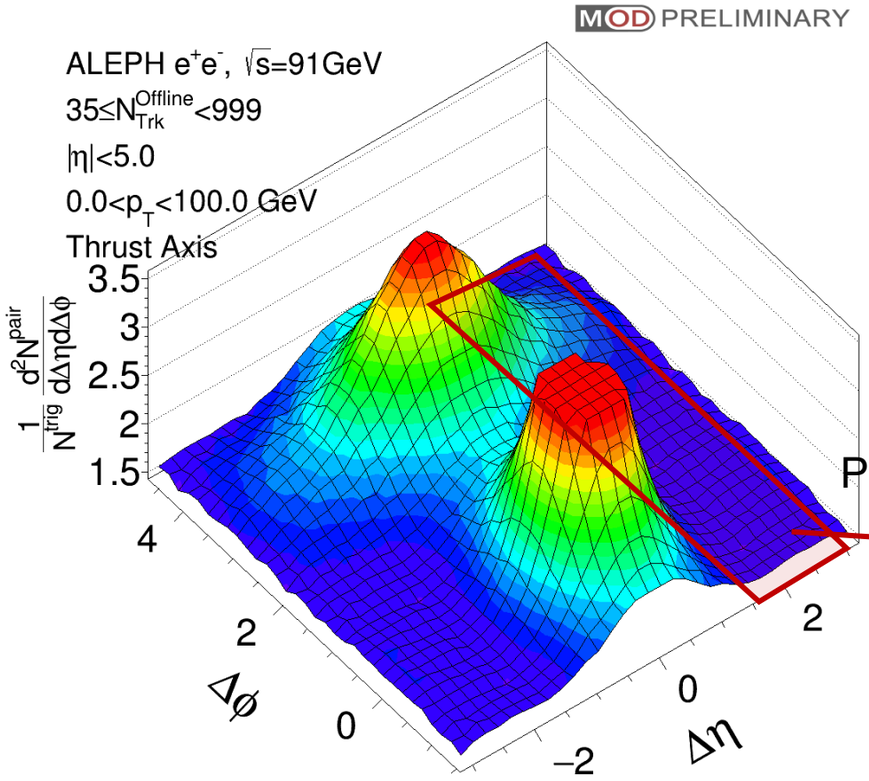


1.6<|Δη|<3.0
(Long range)

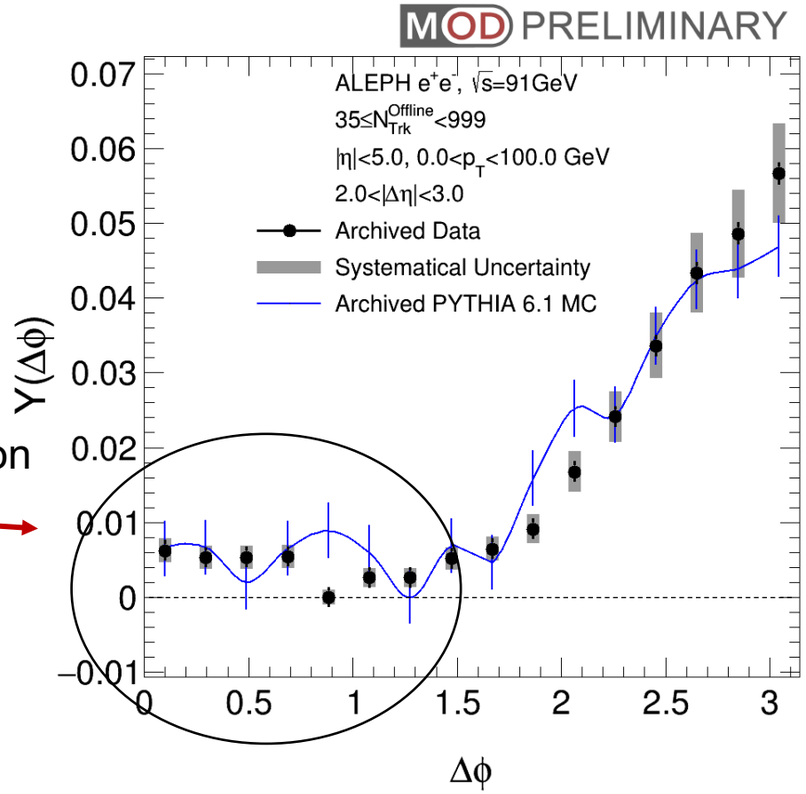
(ZYAM subtracted)

- Hint of near-side peak in data
  - Consistent with PYTHIA6 without final state effects
  - Contribution from multi-jet correlation
- PYTHIA6 reference limited by archive MC statistics

LEP1 Data vs PYTHIA6 N≥35



Projection



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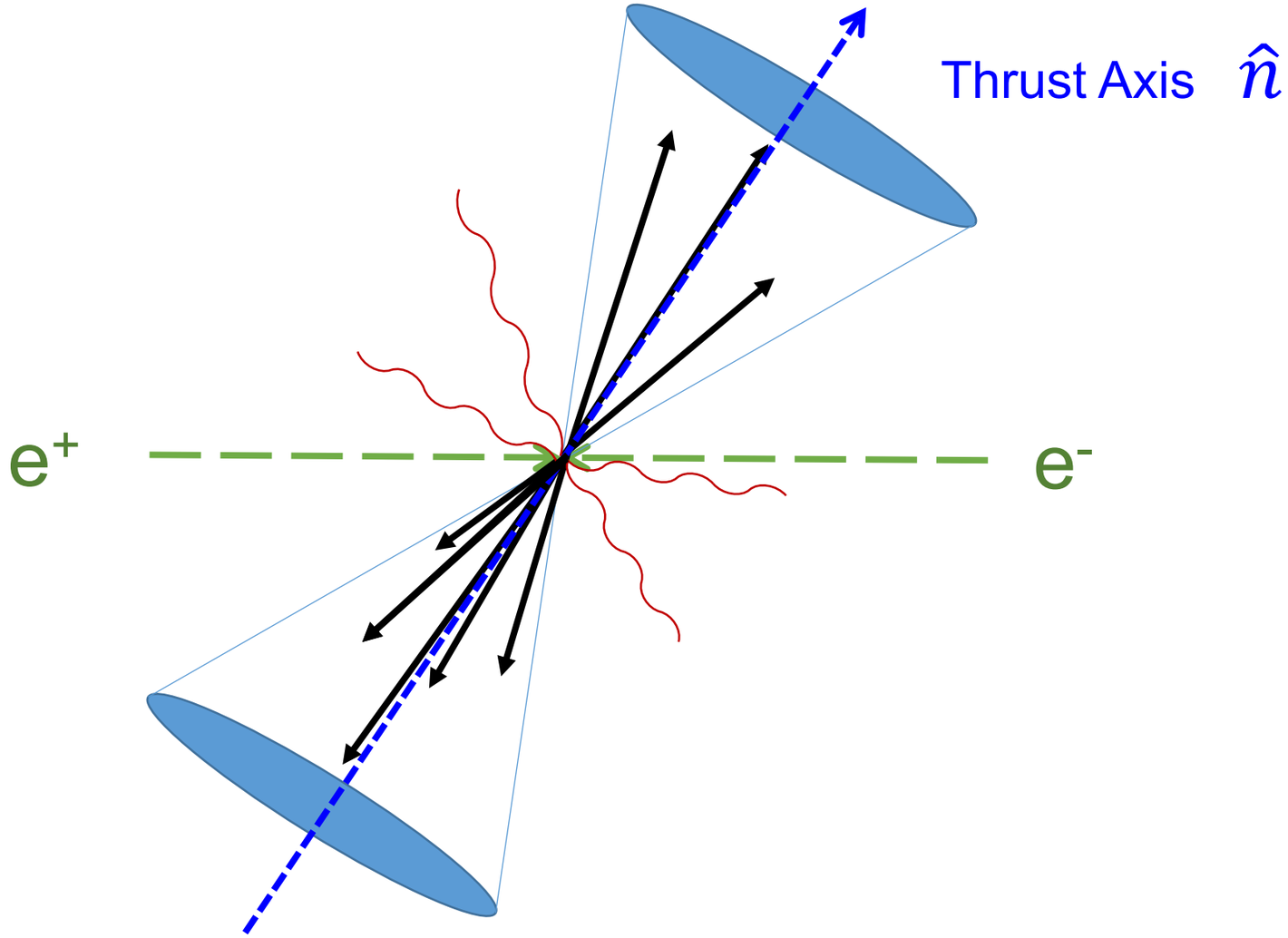
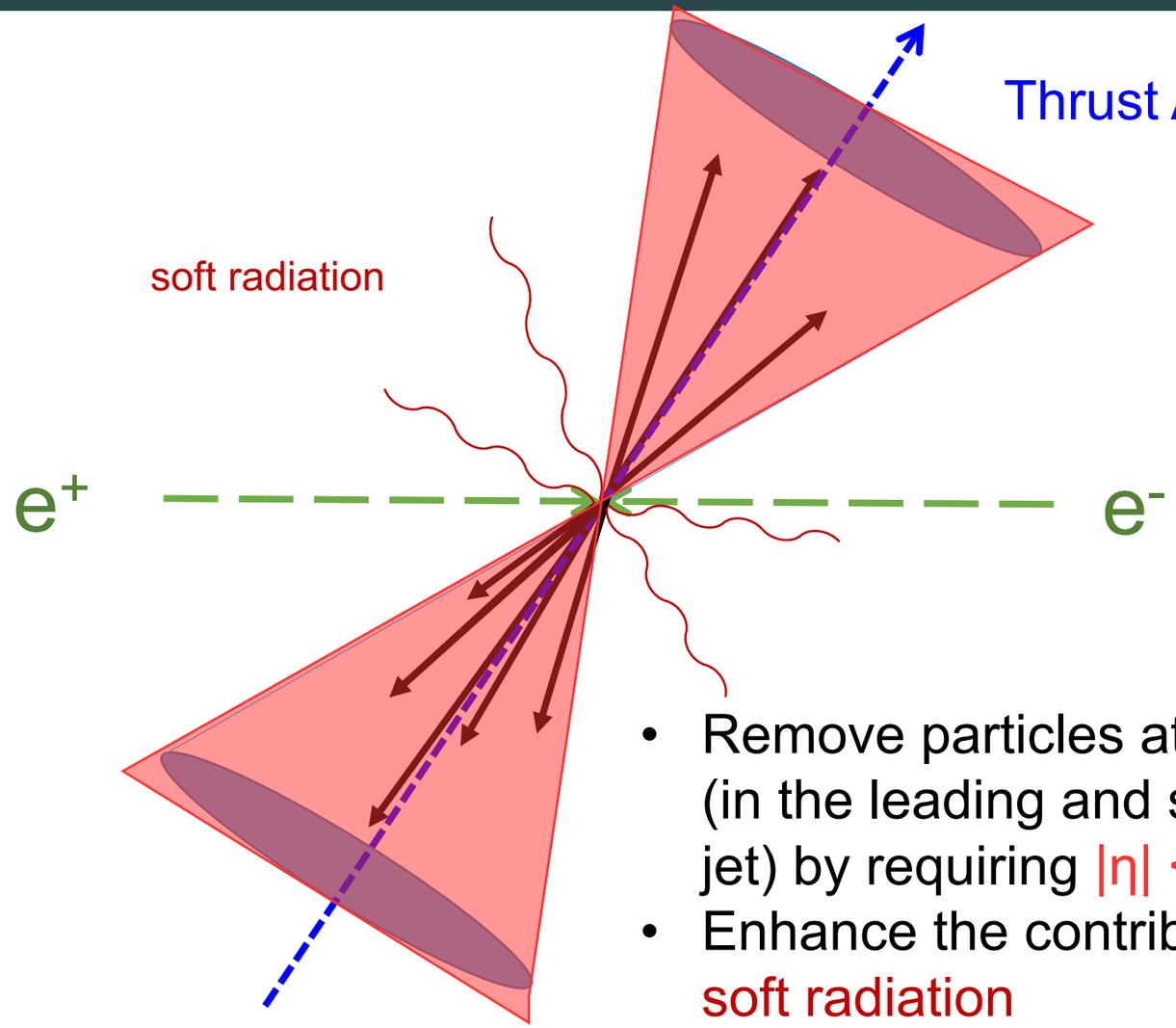
- PYTHIA6 reference limited by archive MC statistics

Thrust Axis Analysis



- "Perturbative QCD physics" still comes in the Thrust axis analysis (Jets)
- **One possibility to suppress jet component is to apply a |η| selection**

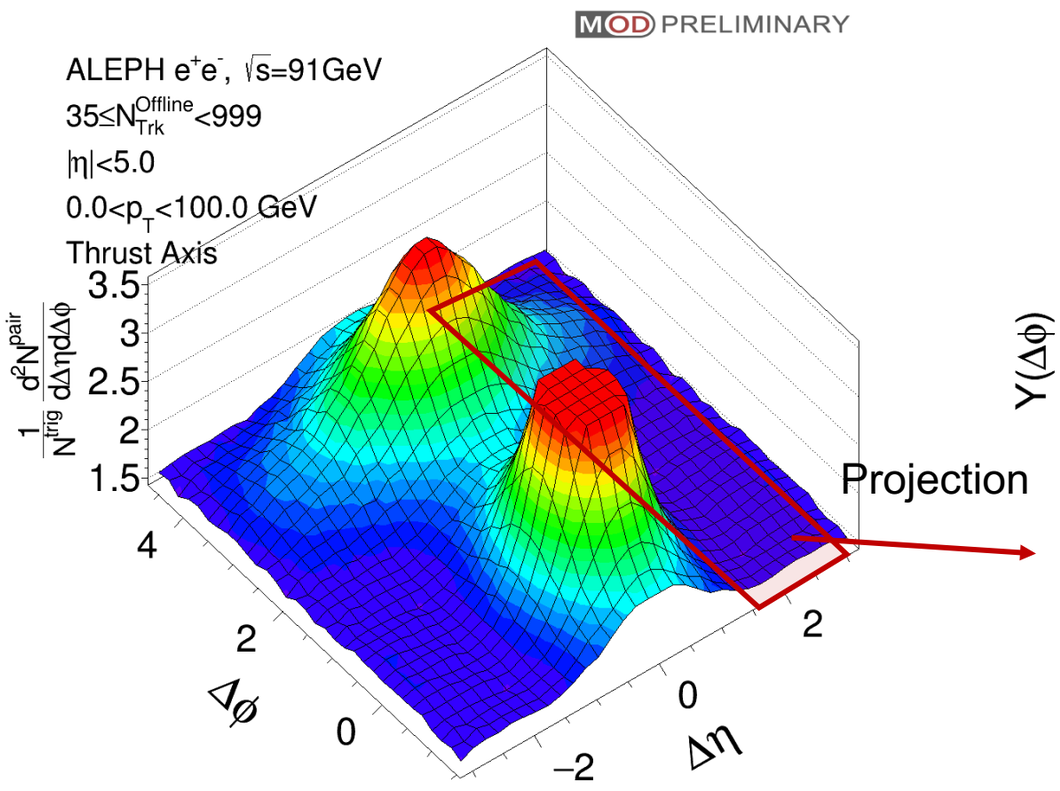
Thrust Axis Analysis with Jet Veto



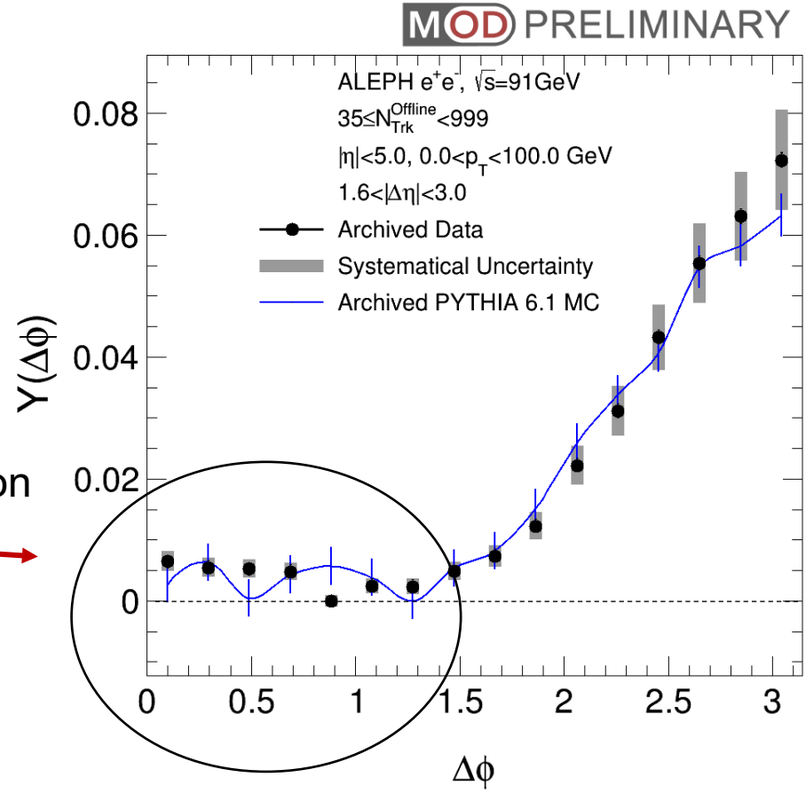
- Remove particles at large η (in the leading and subleading jet) by requiring $|\eta| < 1.6$
- Enhance the contribution of soft radiation

- "Perturbative QCD physics" still comes in the Thrust axis analysis (Jets)
- **One possibility to suppress jet component is to apply a |η| selection**

LEP1 Data vs LEP1 MC N≥35

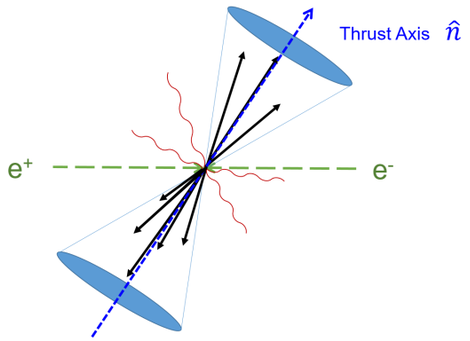


Projection

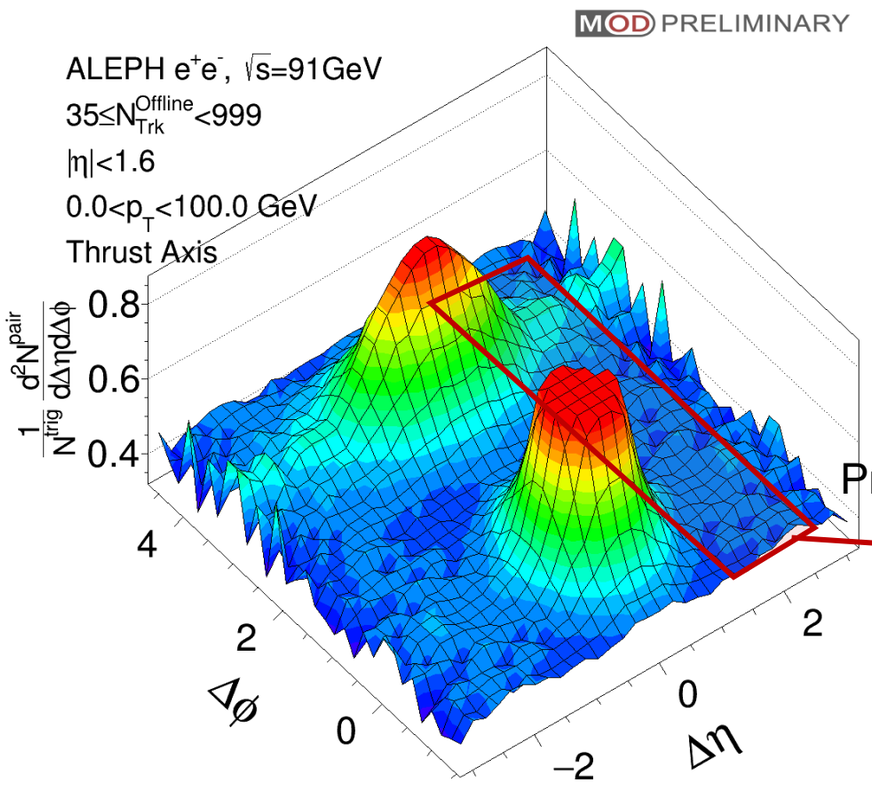


1.6<|Δη|<3.0
(Long range)

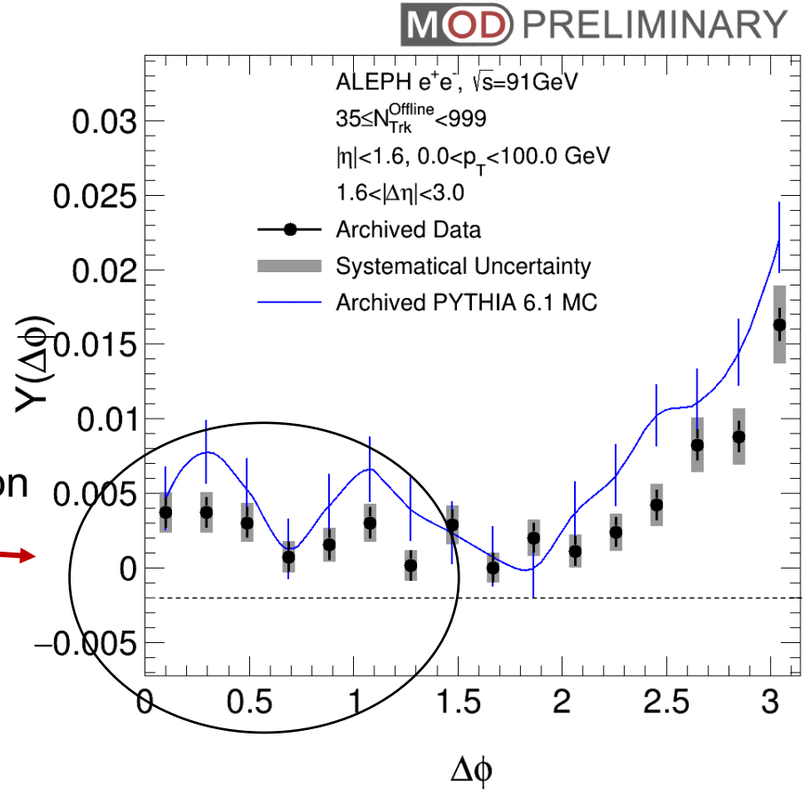
- Hint of near-side peak in data
  - Consistent with PYTHIA6 w/o final state effects
  - Contribution from multi-jet correlation
- PYTHIA6 reference limited by archive MC statistics



LEP1 Data vs LEP1 MC N≥35

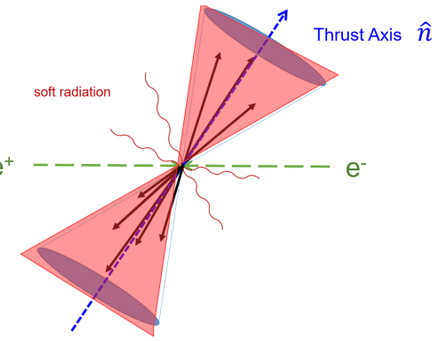


Projection



1.6<|Δη|<3.0
(Long range)

|η| < 1.6



- Hint of near-side peak in data
  - Consistent with PYTHIA6 w/o final state effects
  - Contribution from multi-jet correlation
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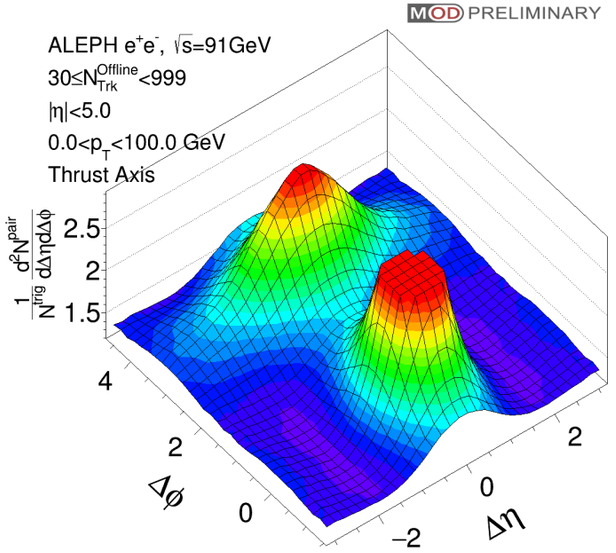
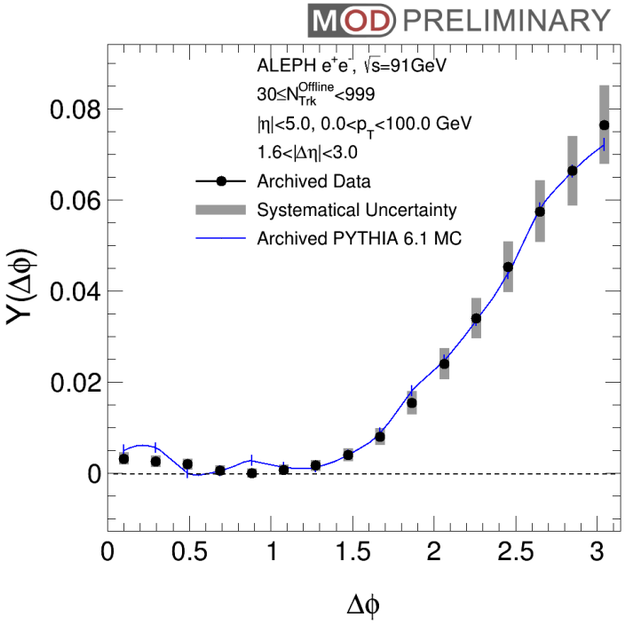
Summary





- The first two-particle correlation analysis in e^+e^- performed in bins of event multiplicity up to N = 35 - 55
  - No significant ridge signal is observed in beam axis analysis
- Thrust axis and jet region veto are employed to enhance the signal from soft radiations
  - No significant difference between ALEPH LEP1 data and PYTHIA6 observed
- No evidence of the final state effect in the probed event multiplicity ranges:
  - An important reference of the ridge signal observed in pp, pA, dA and AA collisions
- LEP2 Data analysis (up to $\sqrt{s}$~208 GeV) ongoing… stay tuned!

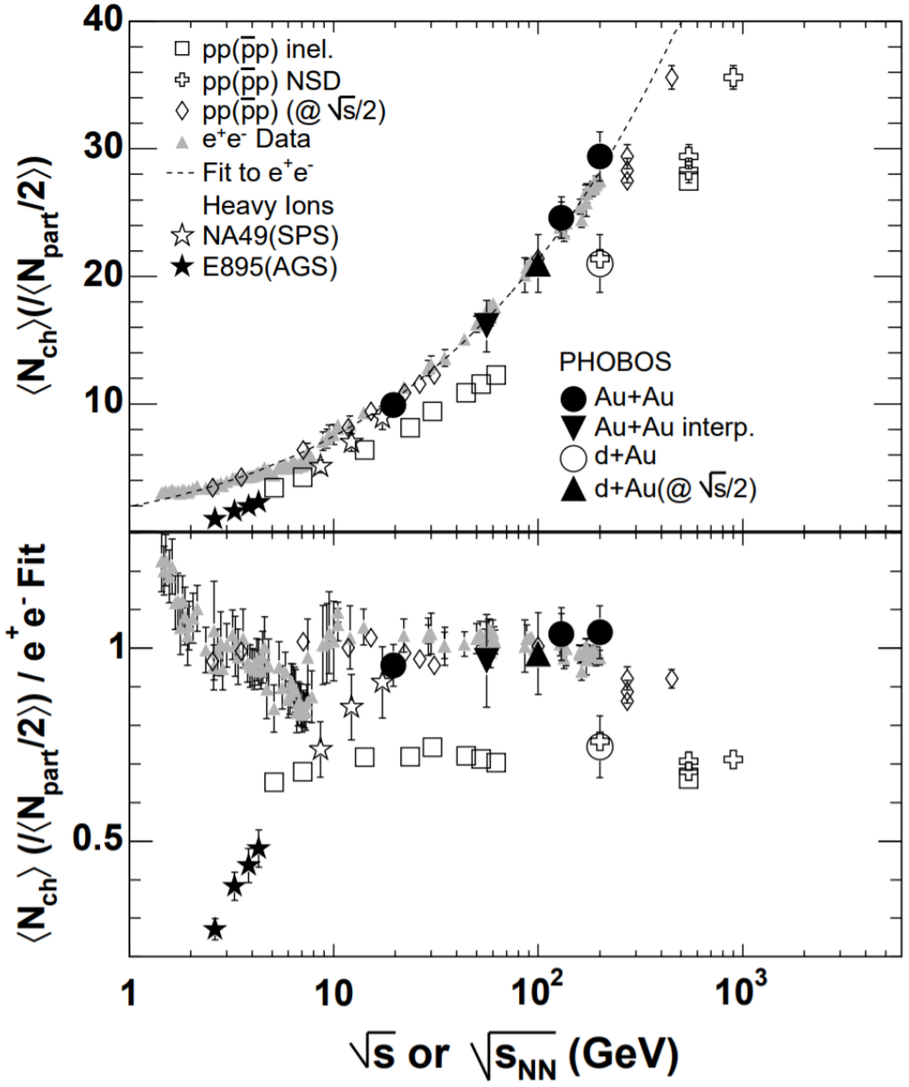
Acknowledgement

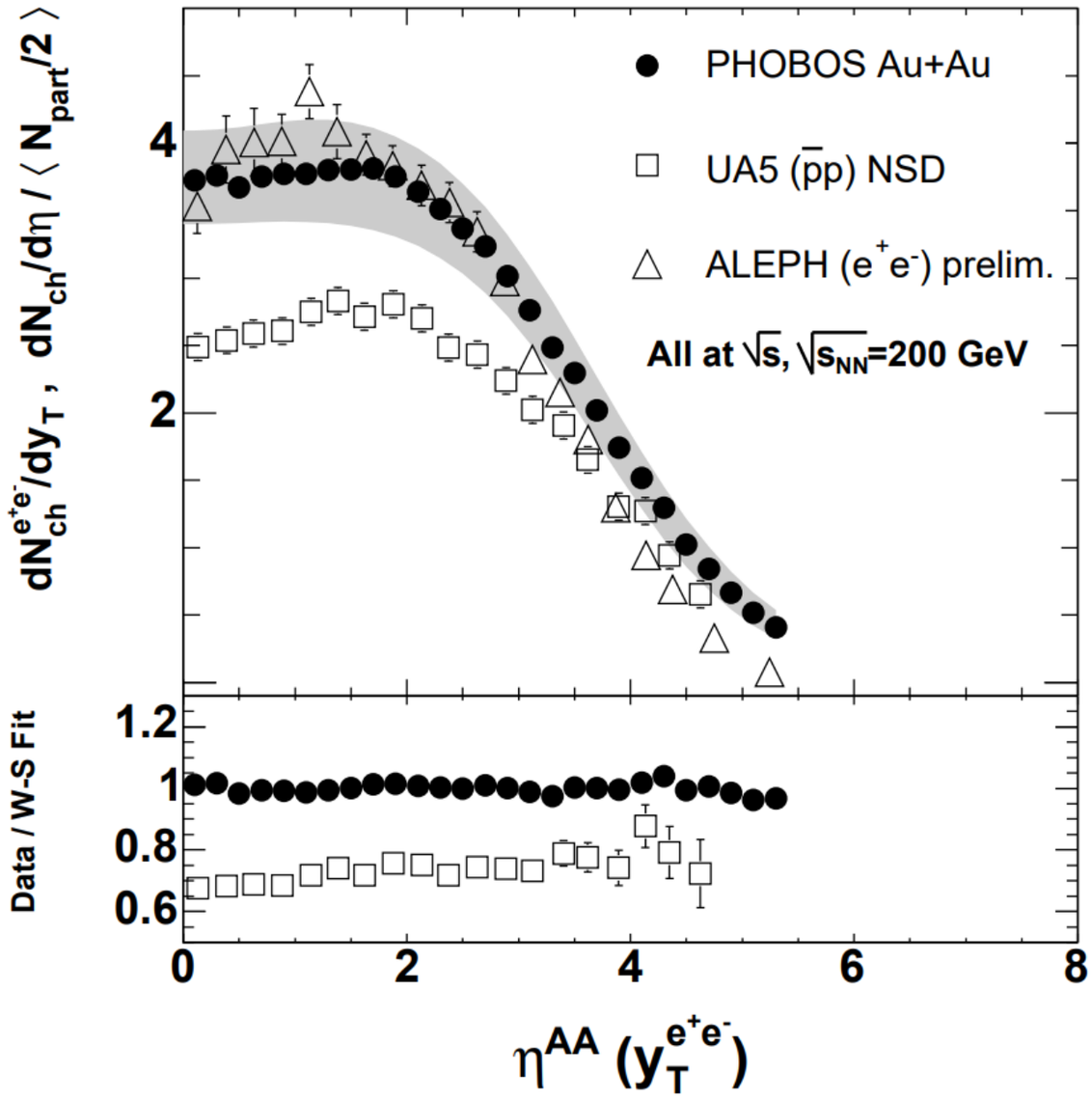
We would like to thank **Roberto Tenchini** and **Guenther Dissertori** from the ALEPH collaboration for the useful comments and suggestions on the use of ALEPH archived data.

We would like to thank **Wei Li**, **Maxime Guilbaud, Wit Busza** and **Yang-Ting Chen** for the useful discussions on the analysis.

The MIT group's work was supported by US DOE-NP

Particle Production





Event Selection

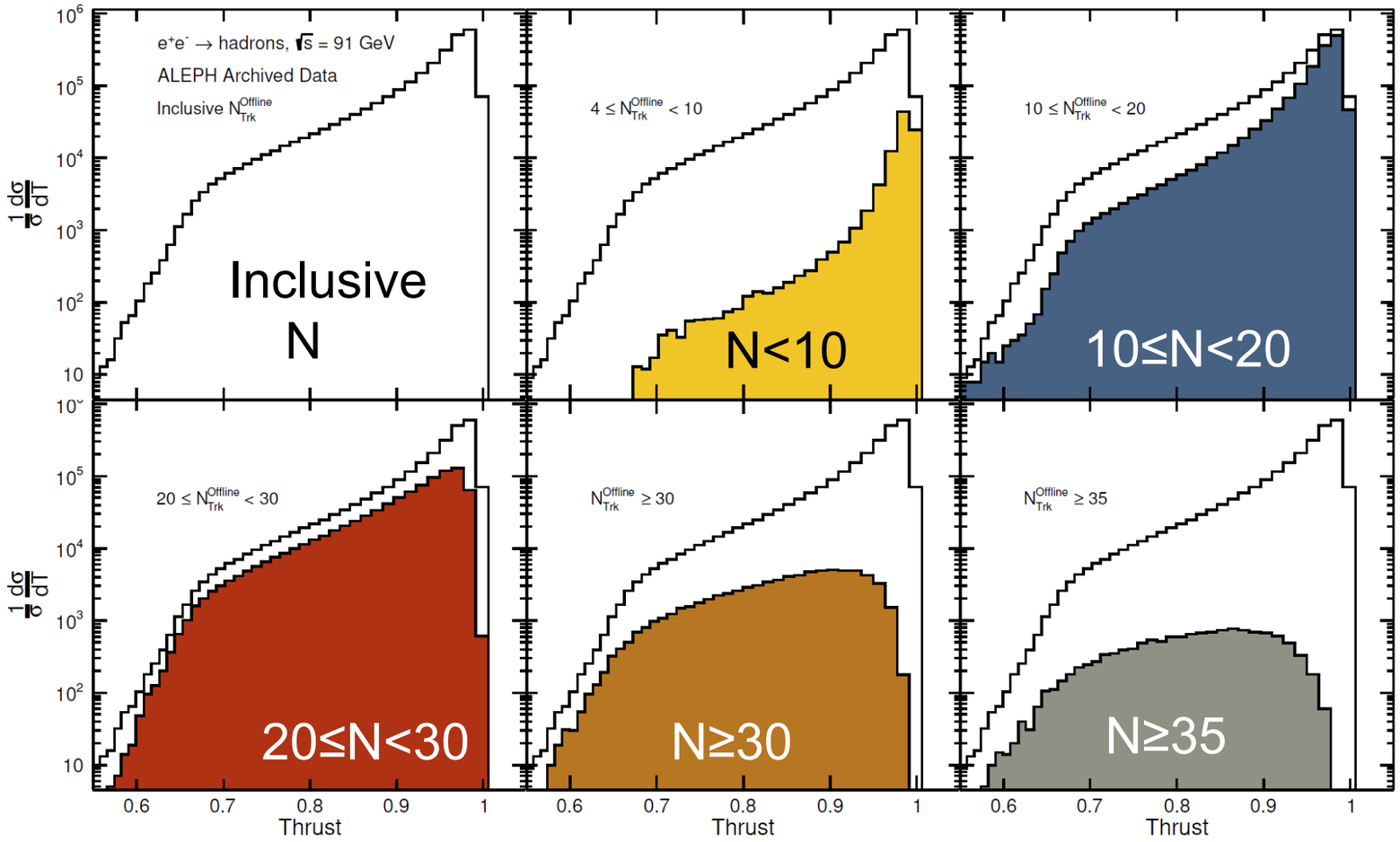
- **Track Selection:**
  - Particle Flow Candidate 0, 1, 2
  - Number of TPC hits for a charged tracks >= 4
  - |d0| < 2 cm
  - |z0|< 10 cm
  - |cosθ|<0.94
  - p_T> 0.2 GeV (transverse momentum with respect to beam axis)
  - N_{TPC} >=4
  - x^2/ndf < 1000.

- **Neutral Hadron Selection:**
  - Particle Flow Candidate 4, 5 (ECAL / HCAL object)
  - E> 0.4 GeV
  - |cosθ|<0.98

- **Event Selection:**
  - Number of good charged particles >= 5 (including charged hadrons and leptons)
  - Number of good ch+neu. Particles >= 13
  - $E_{charged}$ > 15 GeV
  - $|\cos(\theta_{sphericity})|$<0.82

Uncorrected Thrust Distributions

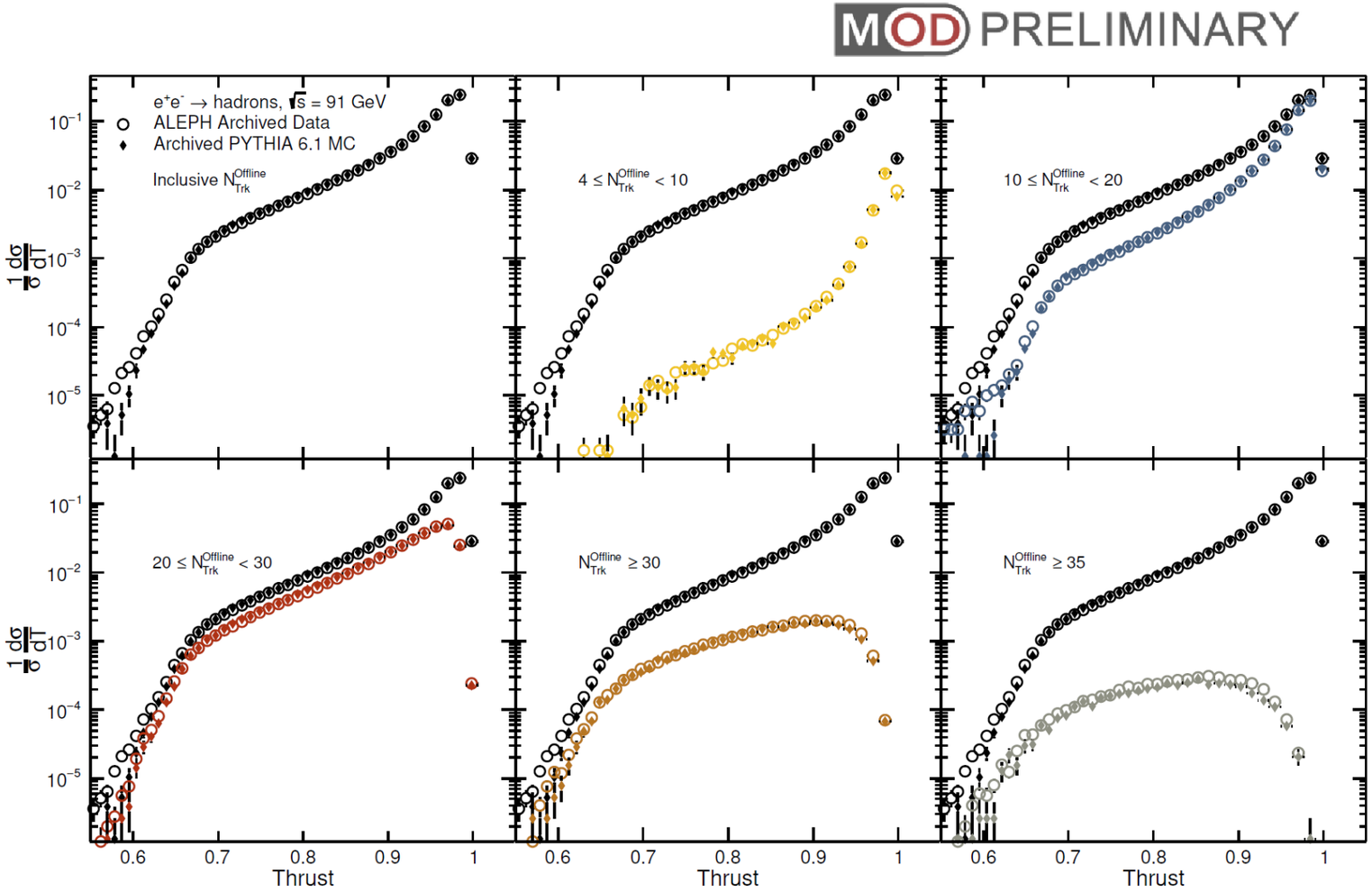
MOD PRELIMINARY



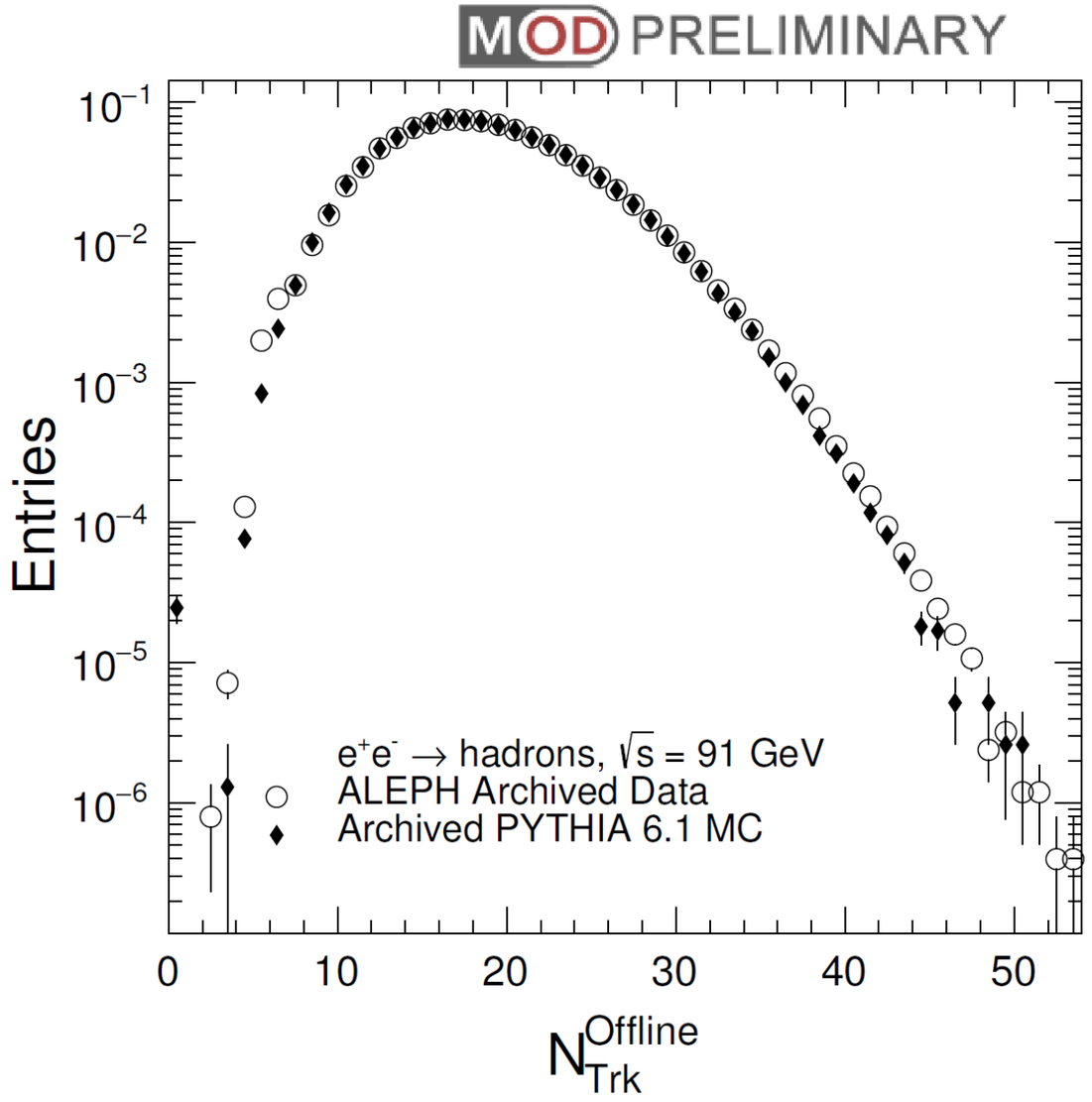
N: # of charged particles with p_T>0.2 GeV and |η|<1.74

High multiplicity events are more spherical

Uncorrected Thrust distributions in different N intervals



Charged Particle Multiplicity



Jet multiplicity