Long range correlations in high-multiplicity e^+e^- collisions using archived ALEPH data at 91-209 GeV

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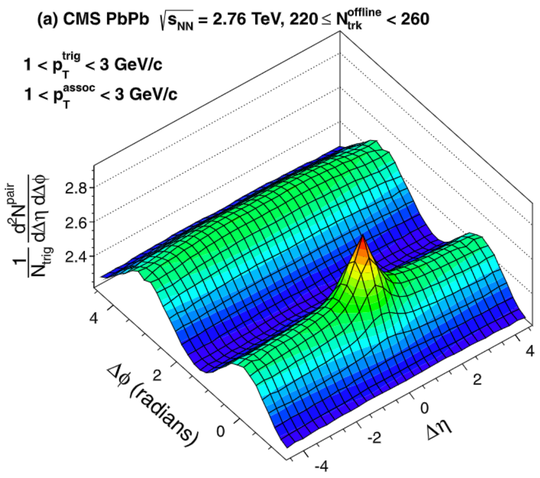
Collectivity in small systems

- **Collectivity observed across a wide range of system sizes**
- **Origin of collectivity is still not understood**
  - **‘Droplet of QGP’ and hydro?**
  - **Initial state effects (CGC)?**
  - **Escape mechanism and/or multiple rescatterings?**

PbPb



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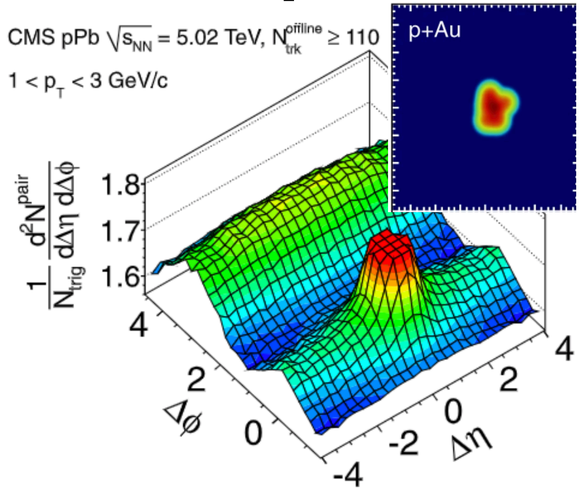
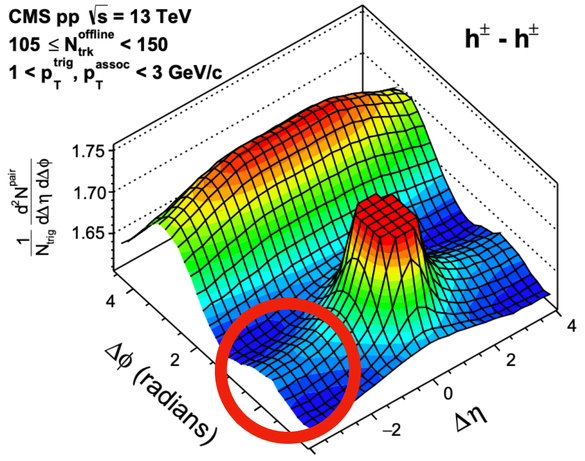
pPb



Phys. Lett. B 718 (2013) 795

High-multiplicity pp



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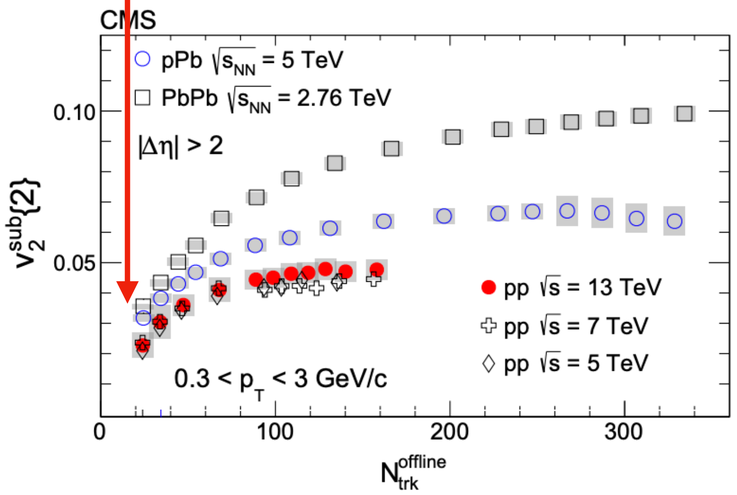
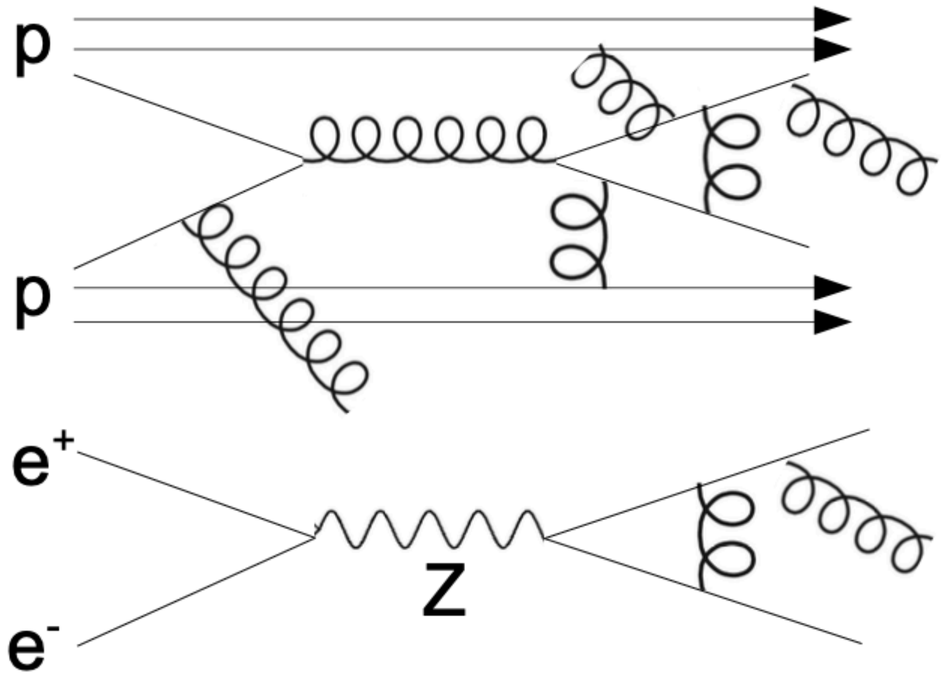
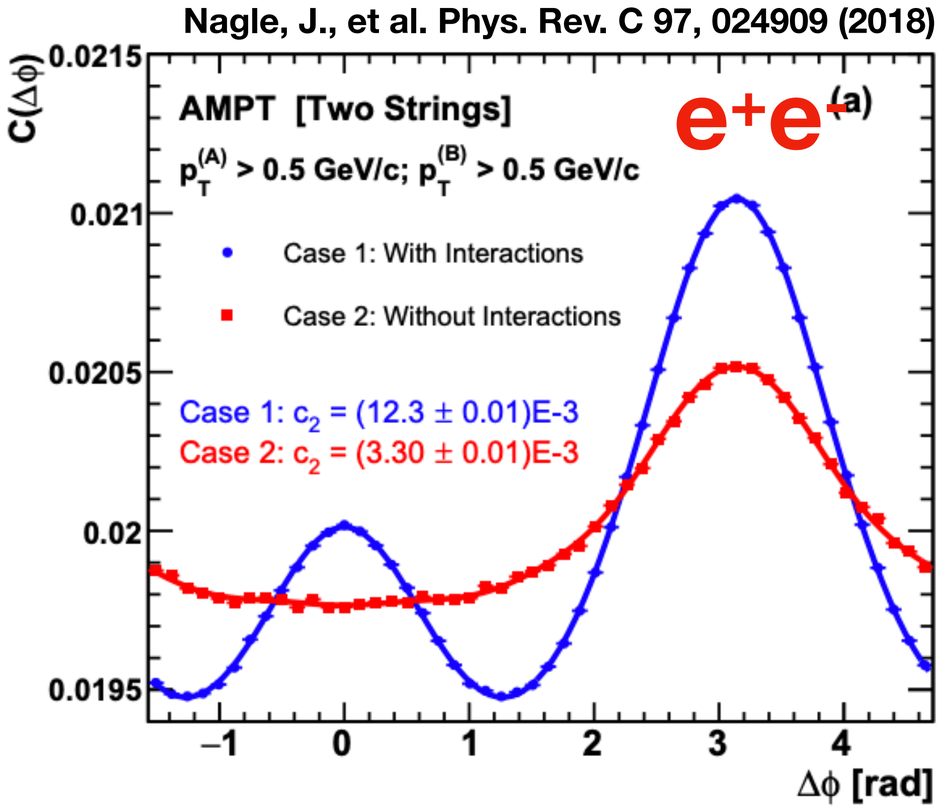
Nonzero v2 extending down to events with 30 particles!



The case for e^+e^-

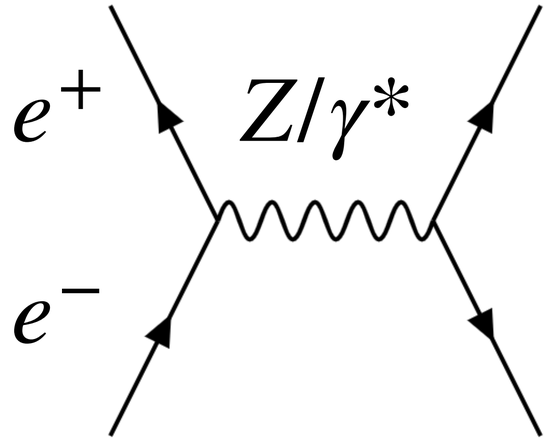
- **Try to simplify the system - remove hadron structure, MPIs, etc.**
- **Proposed that interactions between strings could cause some ridge in e^+e^-**
- **Need high-energy lepton collisions - need to look back in time**



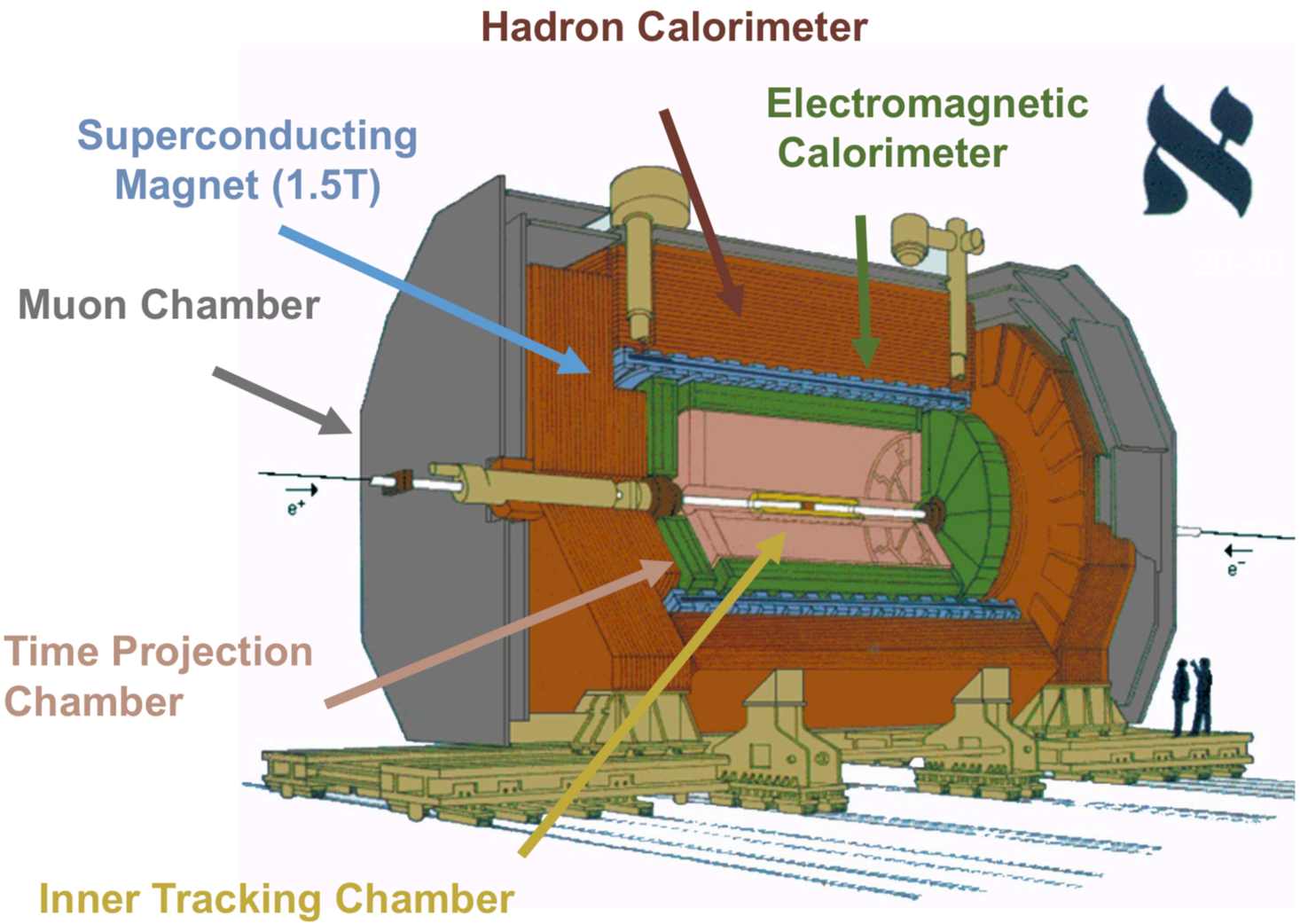


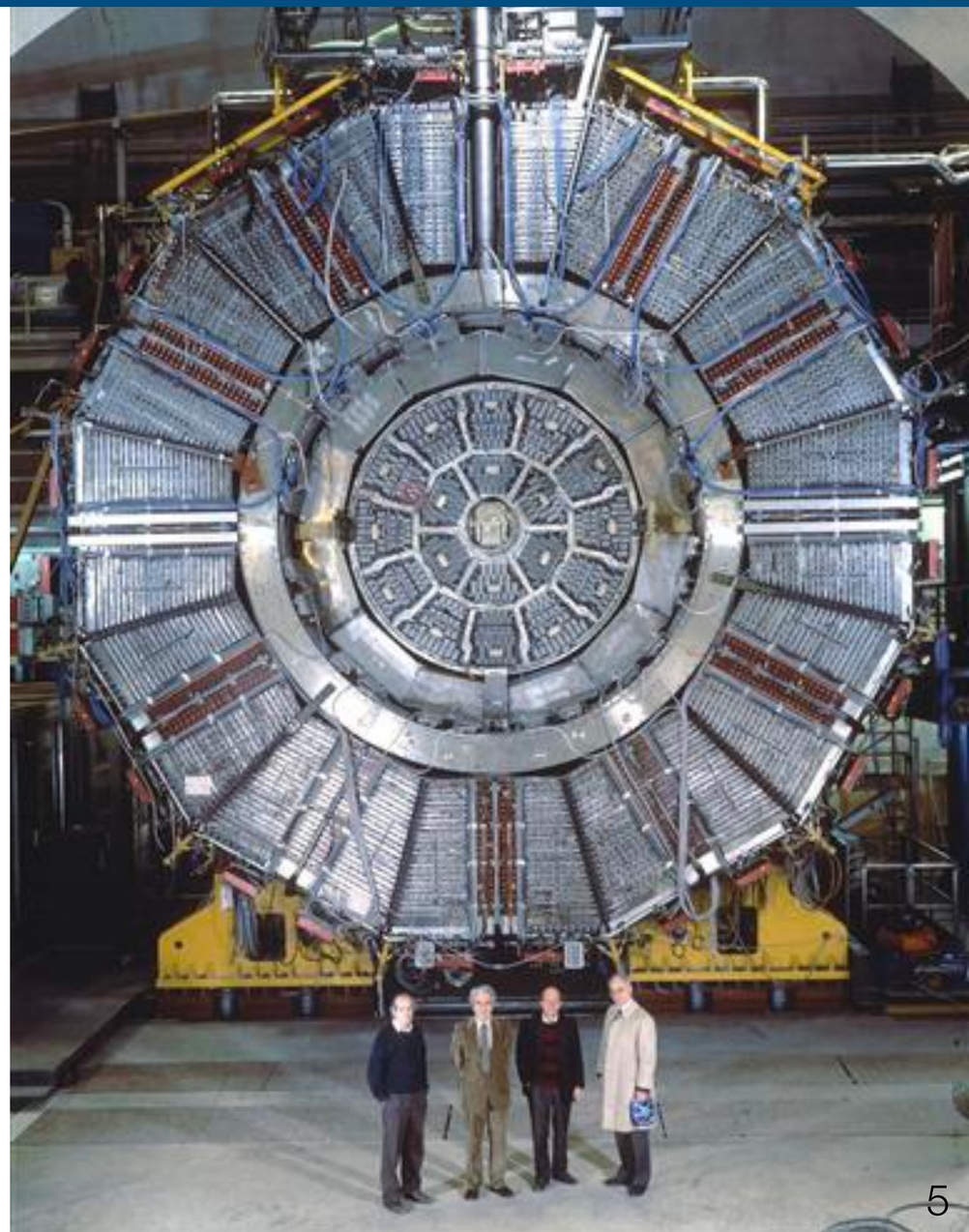
LEP accelerator

LEP 1 (1990-1994)

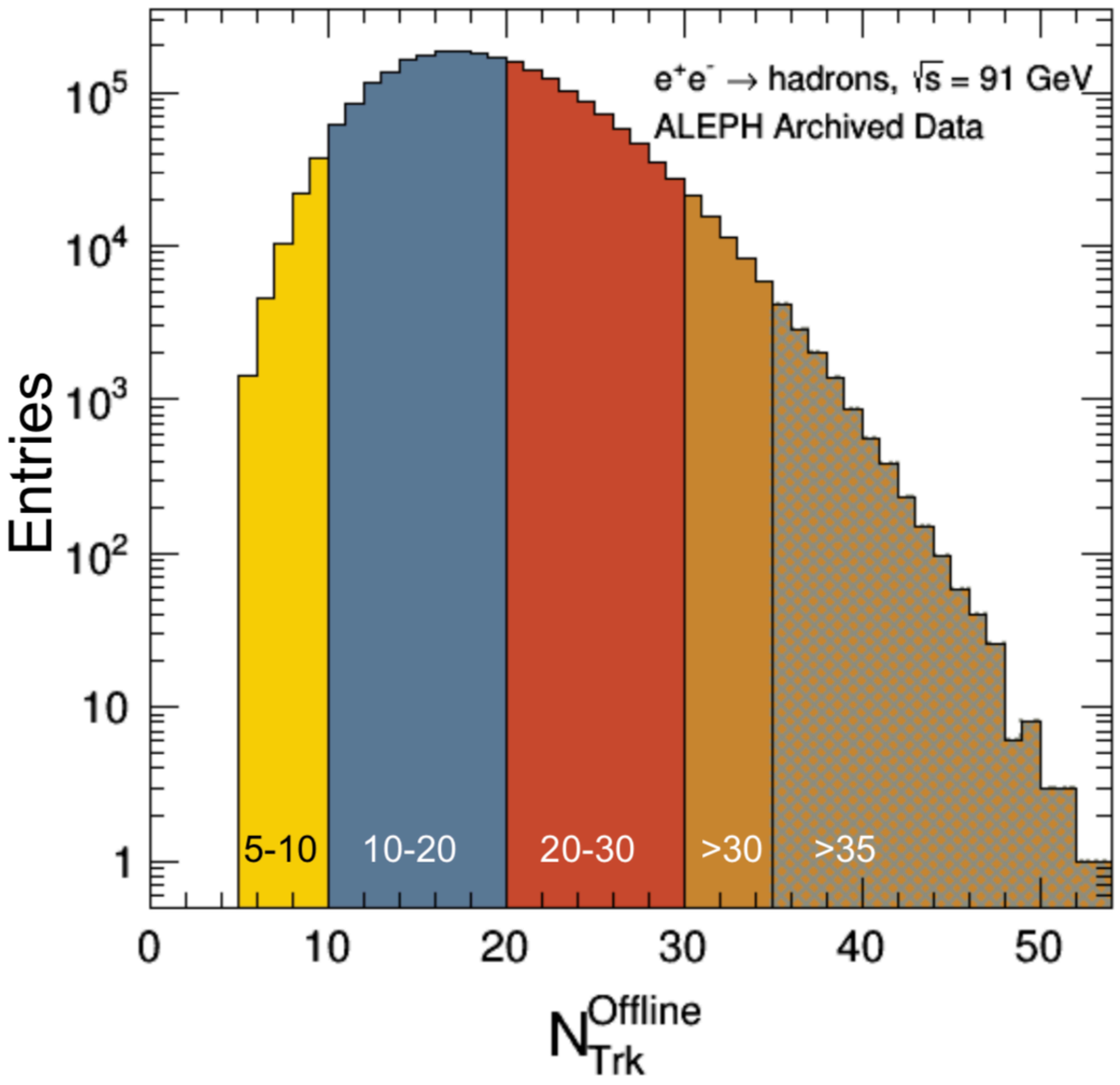


ALEPH experiment



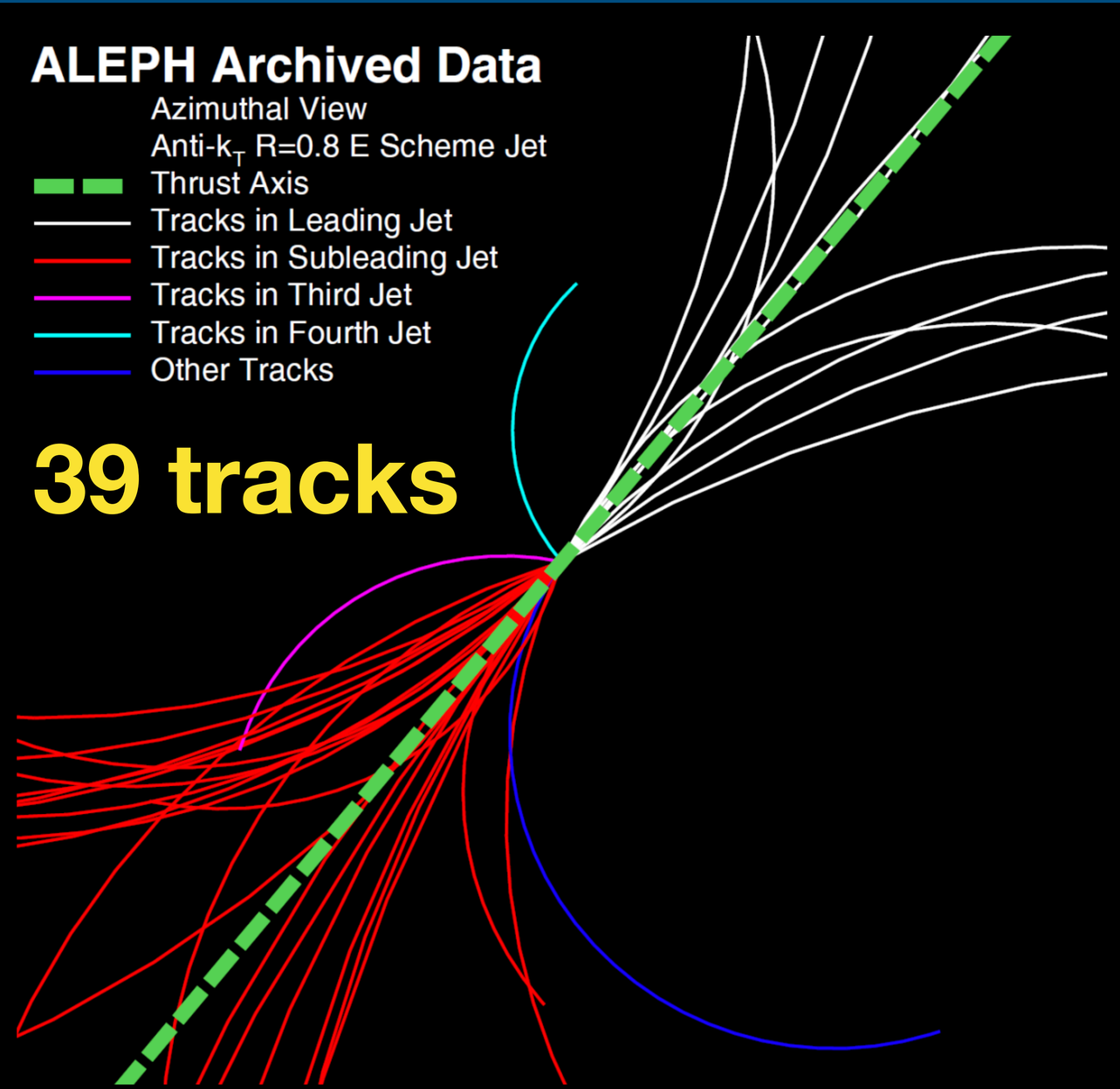


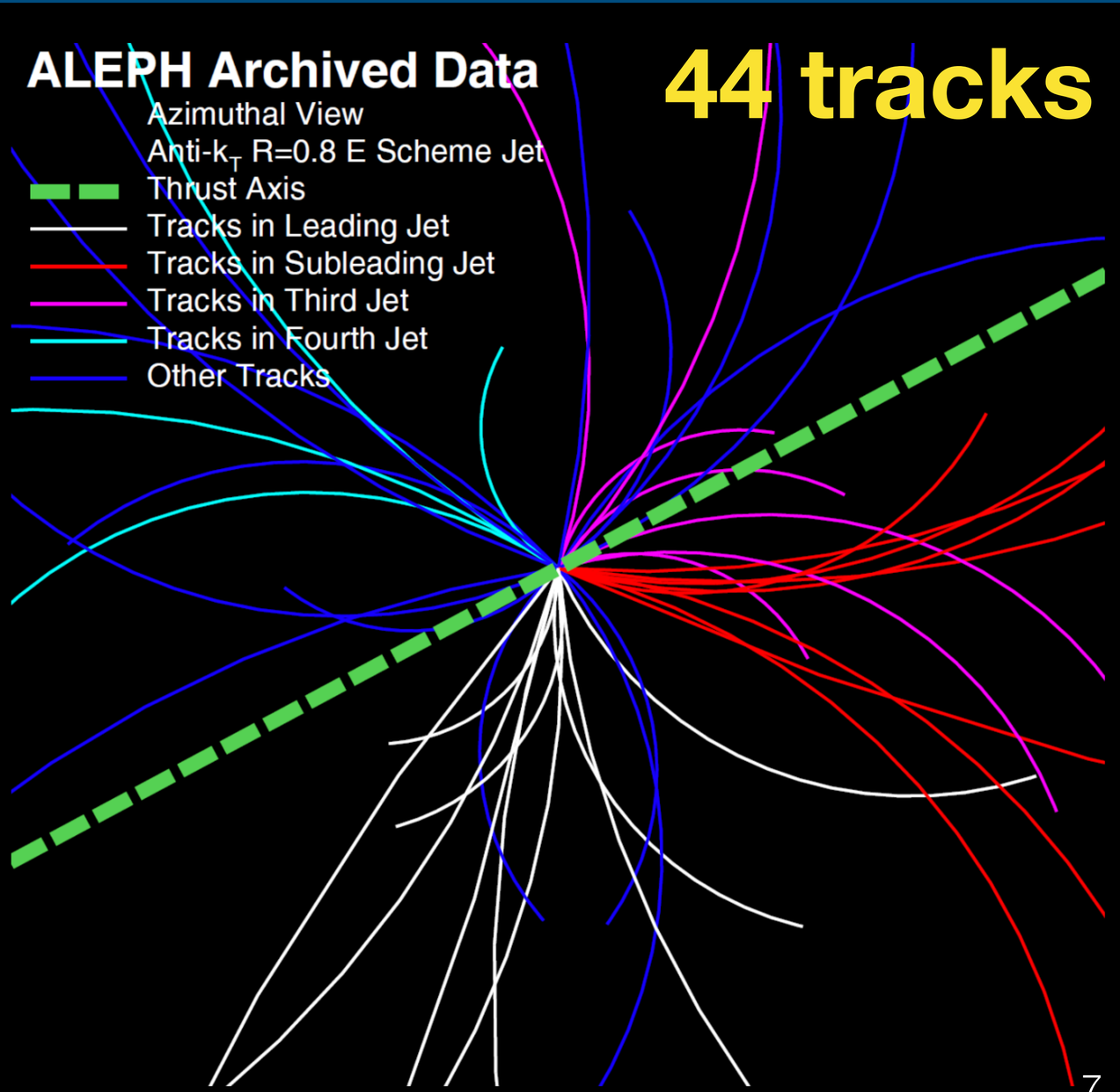
Archived ALEPH data



- **Clean dataset and efficient detector**
- **Information stored as ‘energy flow’ objects**
- **Some historical ‘detective’ work**
- **Particle multiplicities up to ~50**

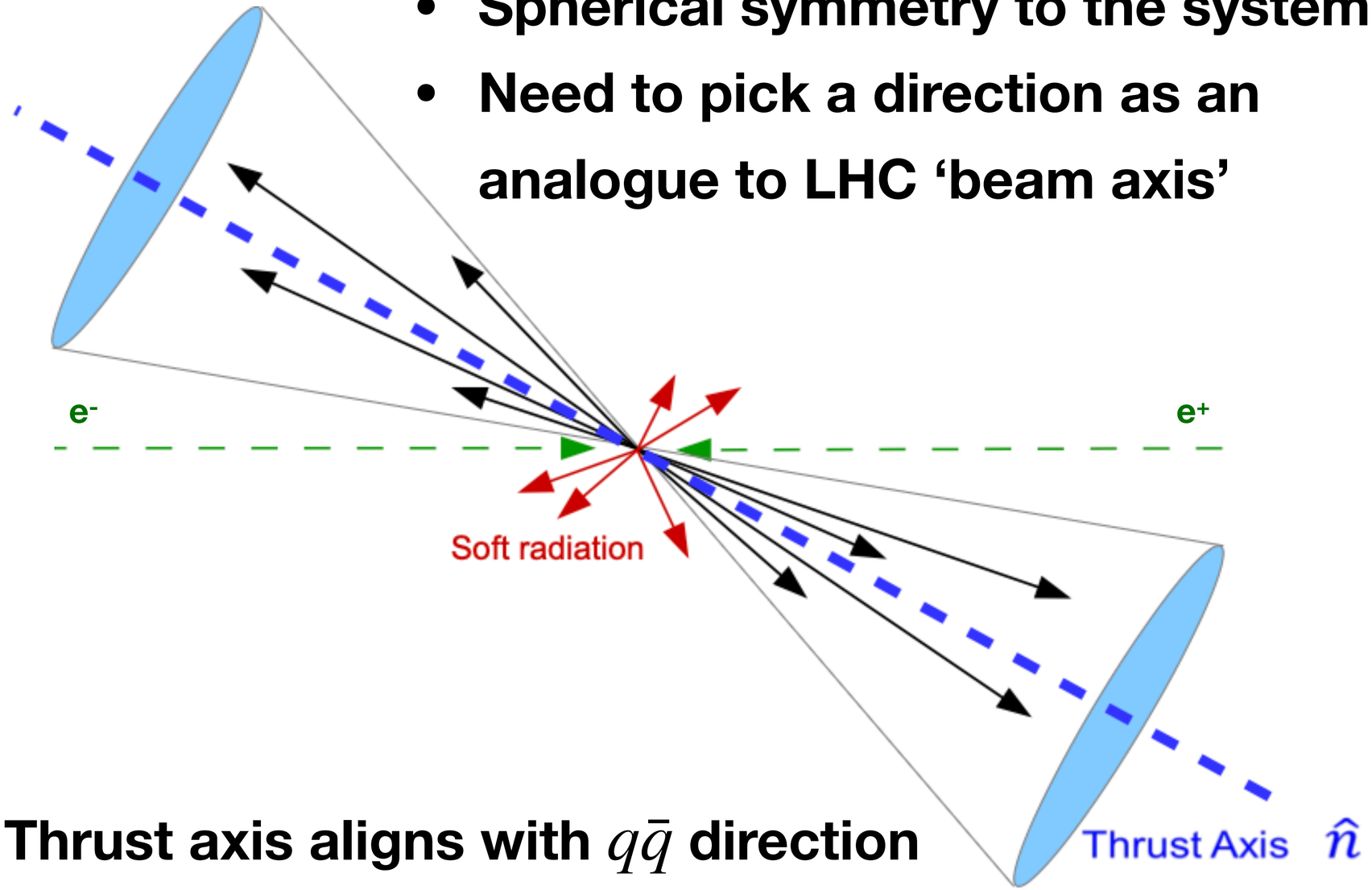
$e^+e^- \rightarrow Z \rightarrow q\bar{q}$ events





Thrust Axis

- **Spherical symmetry to the system**
- **Need to pick a direction as an analogue to LHC ‘beam axis’**



- **Thrust axis aligns with $q\bar{q}$ direction**

Thrust Axis

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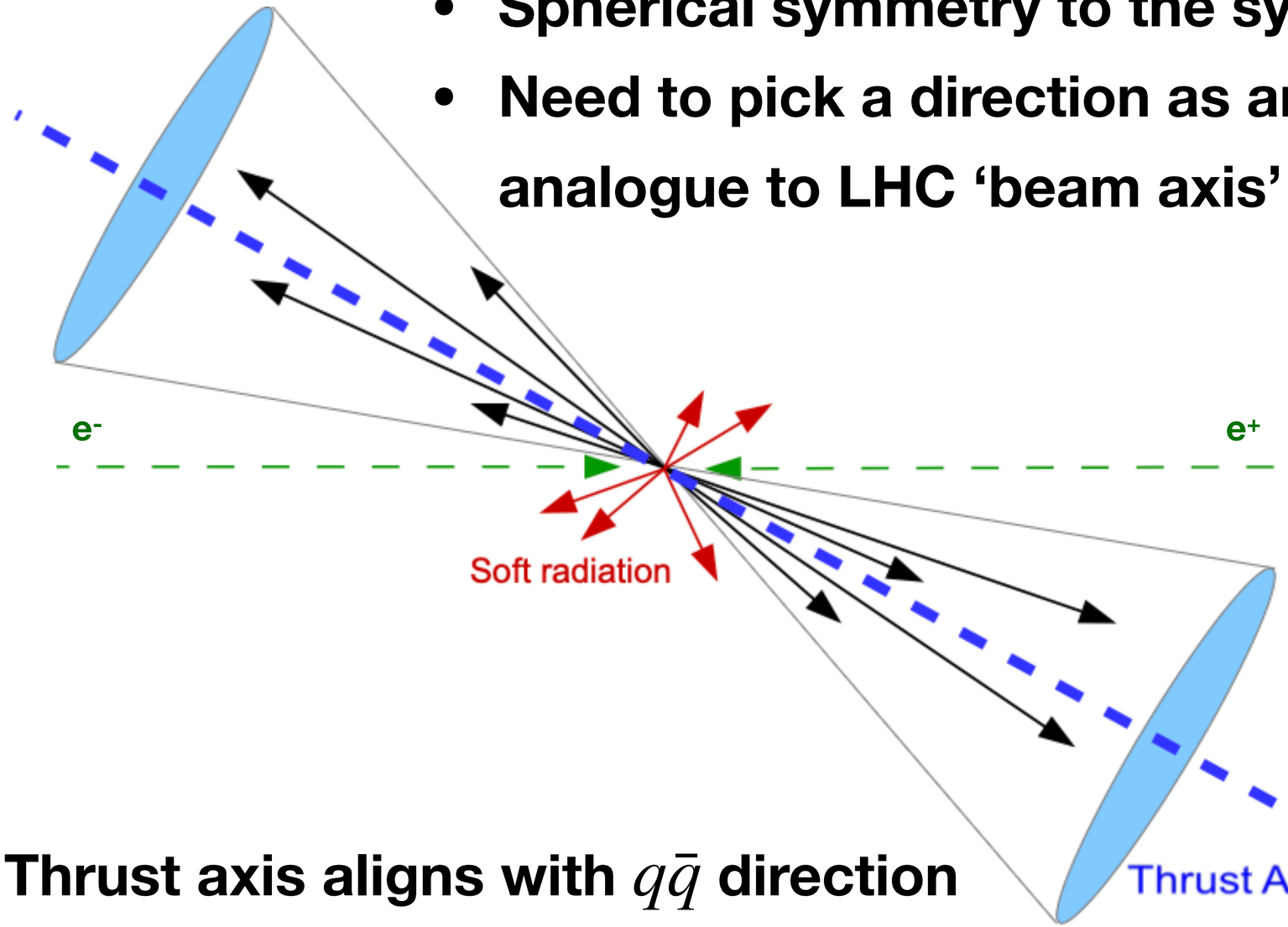
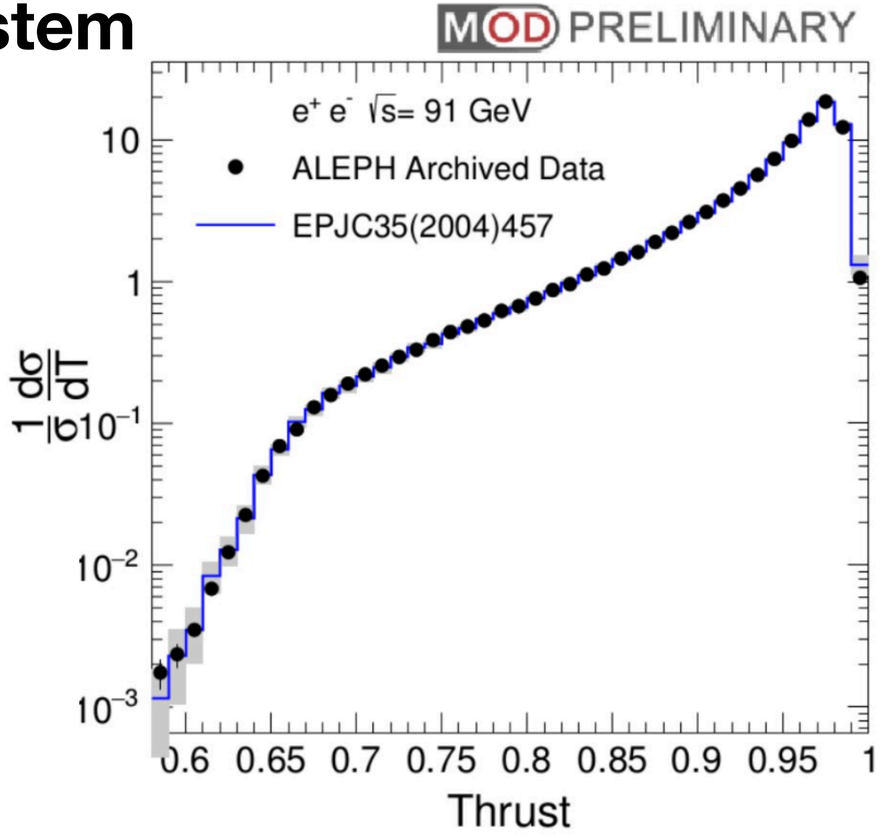




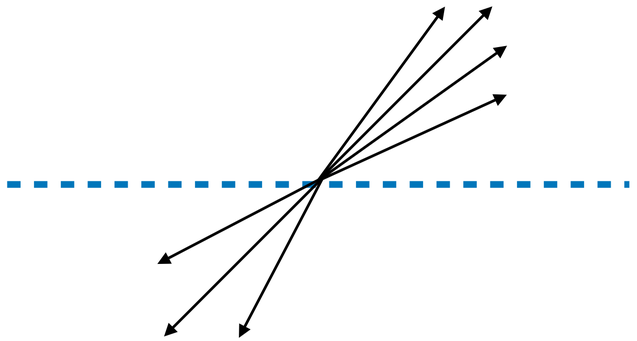
- **Can reproduce ALEPH measurements!**

- **Thrust axis aligns with $q\bar{q}$ direction**

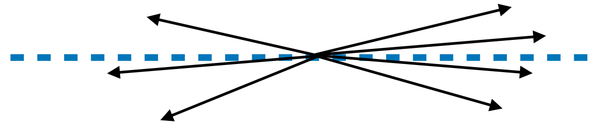
2-Particle correlation functions

- **Two reference frames analyzed**
- **No near-side ridge observed**

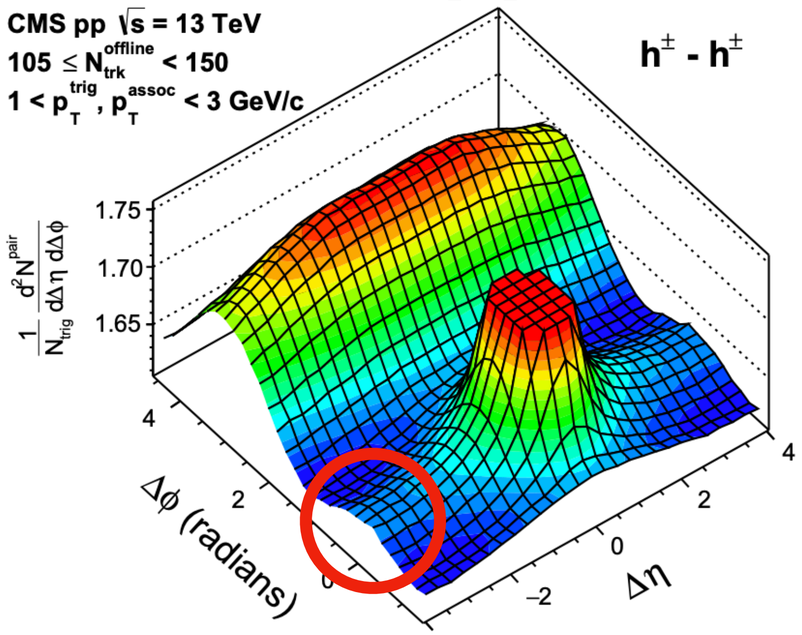
Align with incoming particles



Align with outgoing particles



pp



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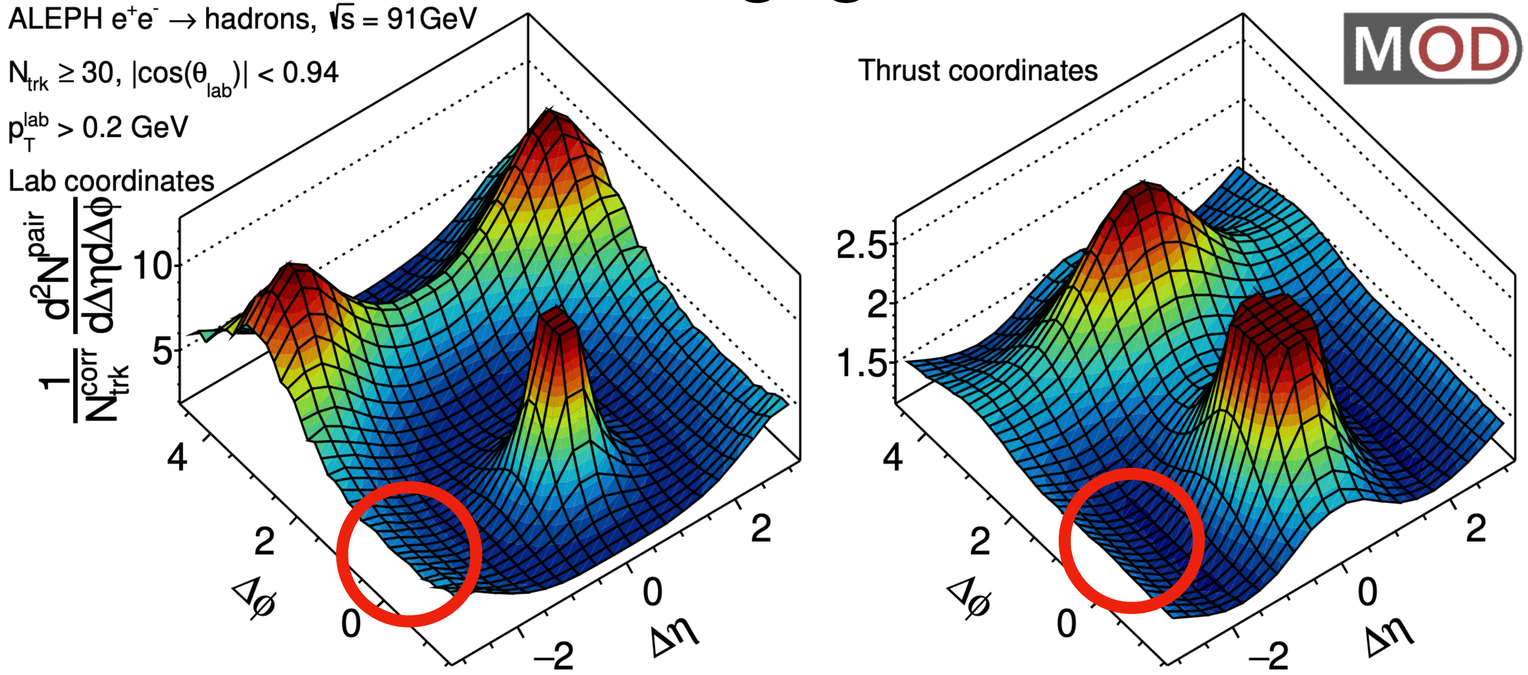
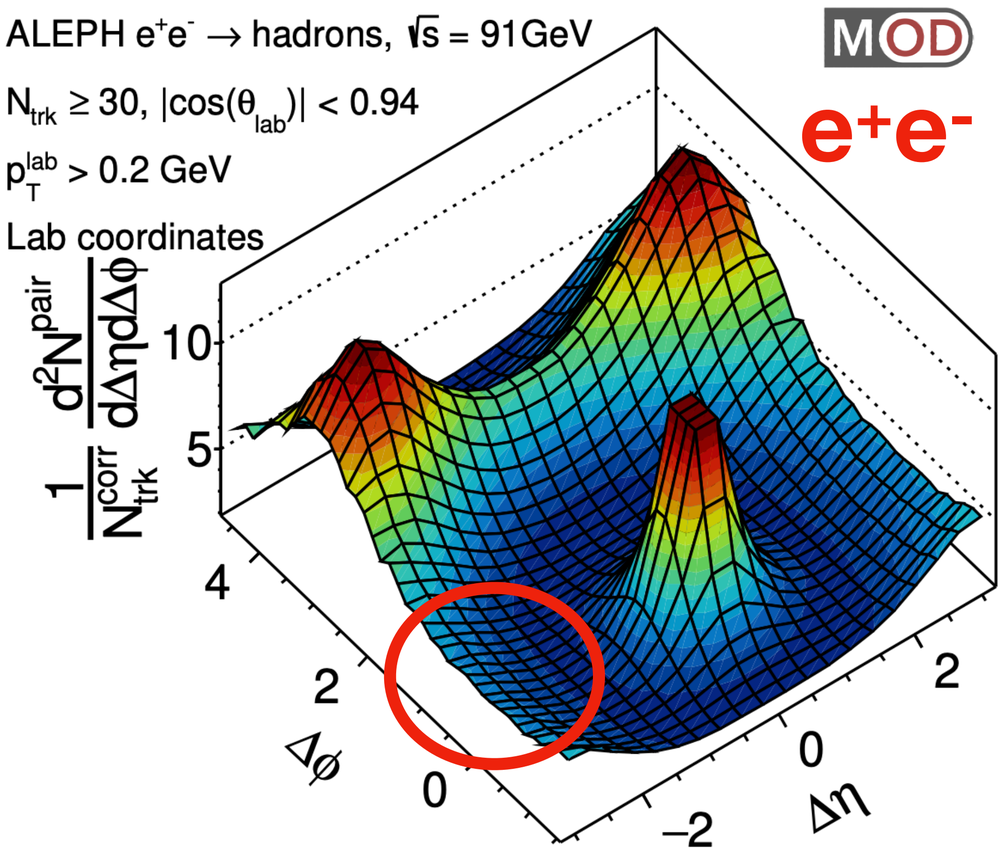
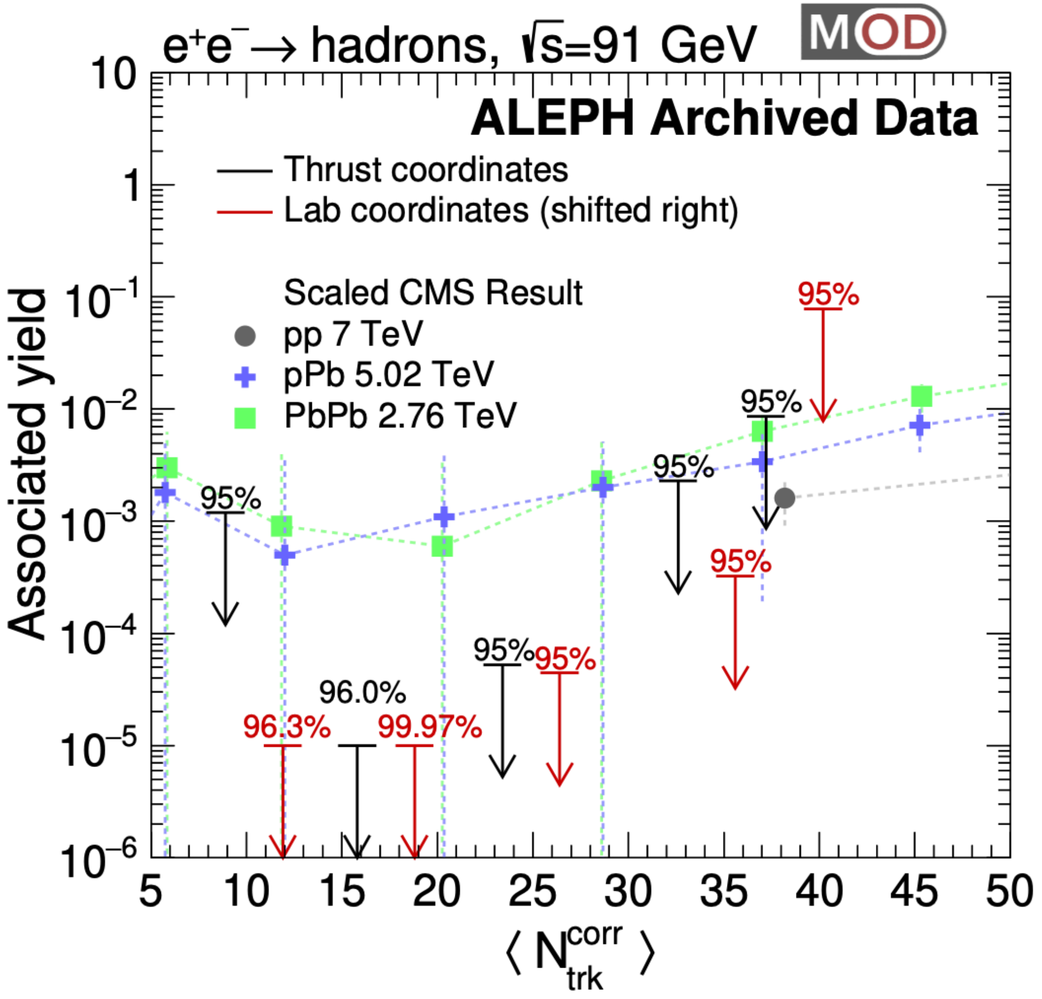
e^+e^-



Badea, A., Baty, A., et. al., Phys. Rev. Lett. 123, 212002 (2019)

Limits on near side ridge size

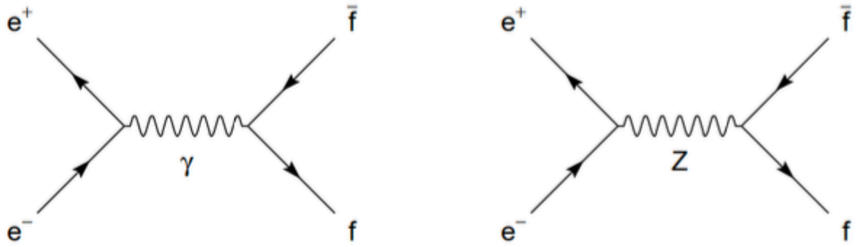




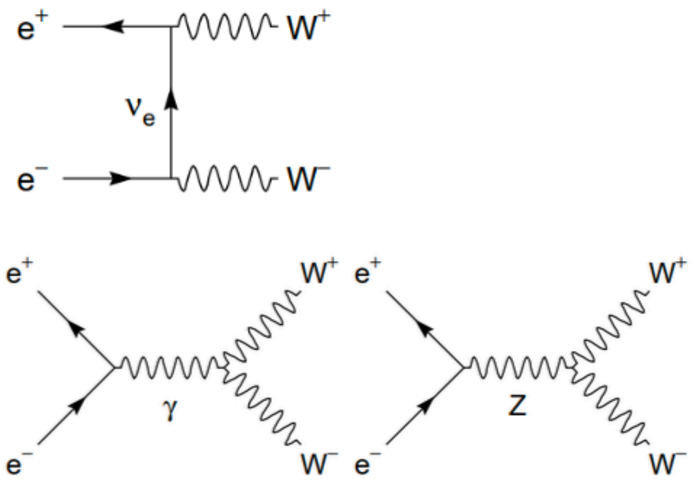
- **Set limits using 91 GeV data - limited by stats at high multiplicity**
- **LEP2 (~1997-2000) data is higher energy (183-209 GeV) ~ RHIC energy**

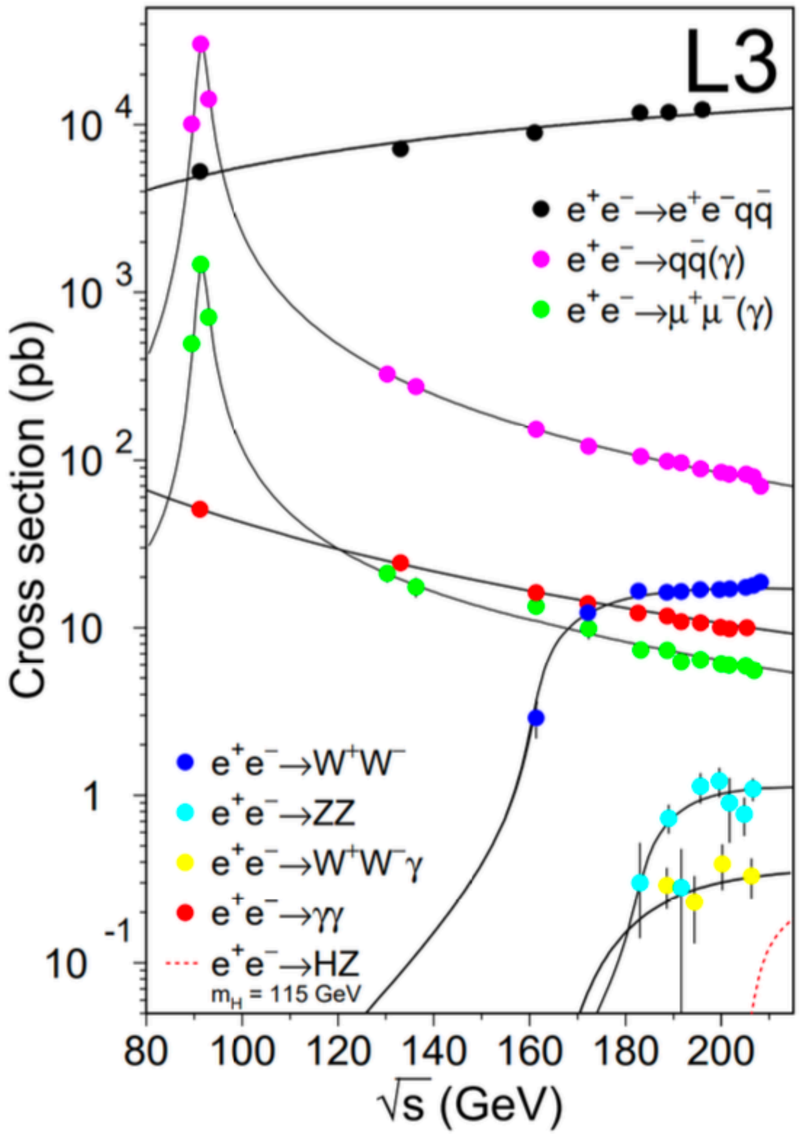
LEP 2 processes

- $e^+e^- \to q\bar{q}(\gamma)$



- $e^+e^- \to W^+W^-$





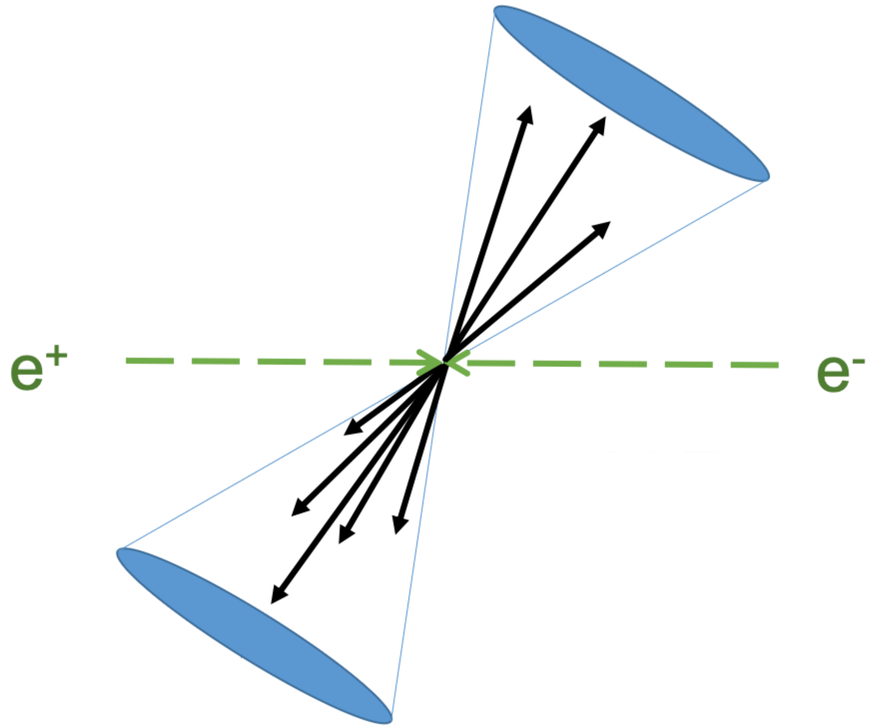
- **Leading process is still $q\bar{q}$ production**
  - **Remove 'return to Z' ISR component**
- **WW process also allowed now**

Phys. Rept. 532 (2013) 119-244

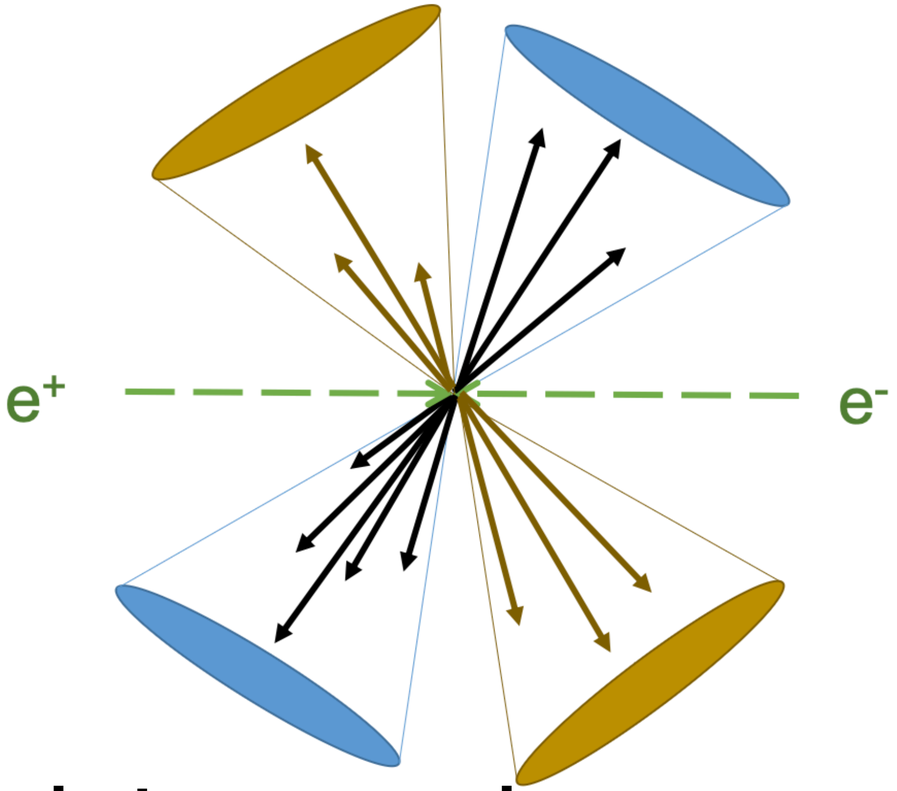
Potential for more interactions?

Diagrams from Y.J. Lee

$e^+e^- \to q\bar{q}$

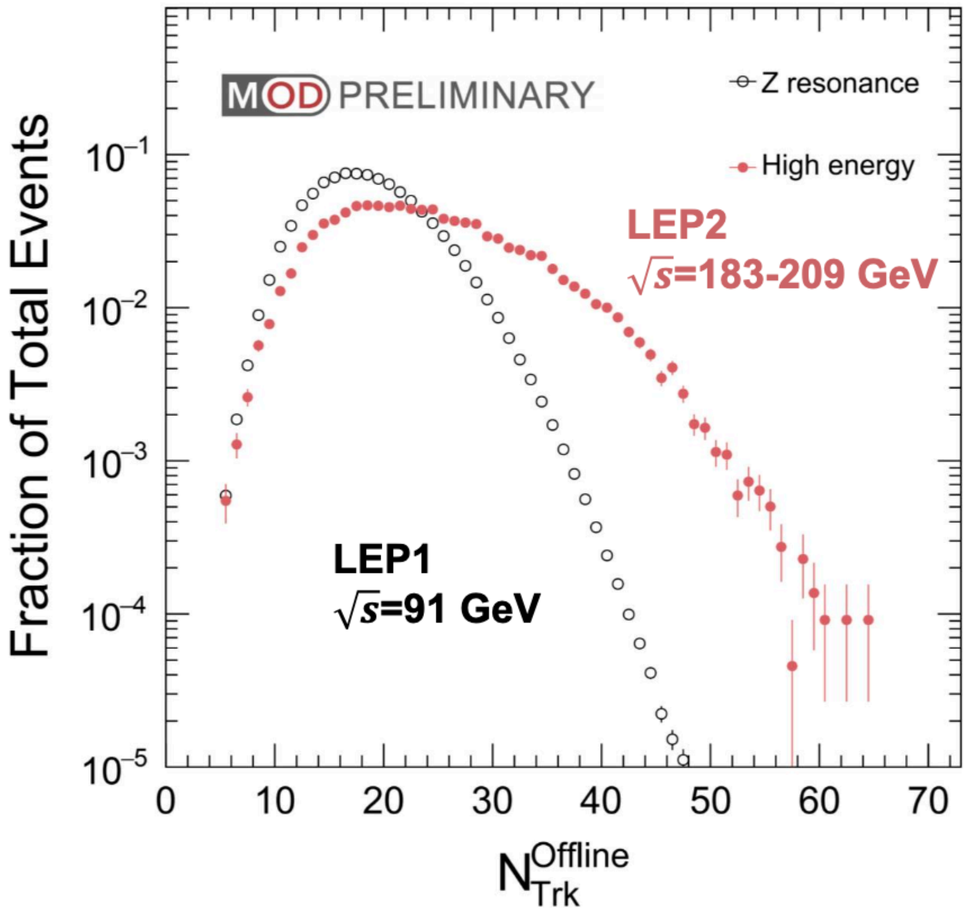


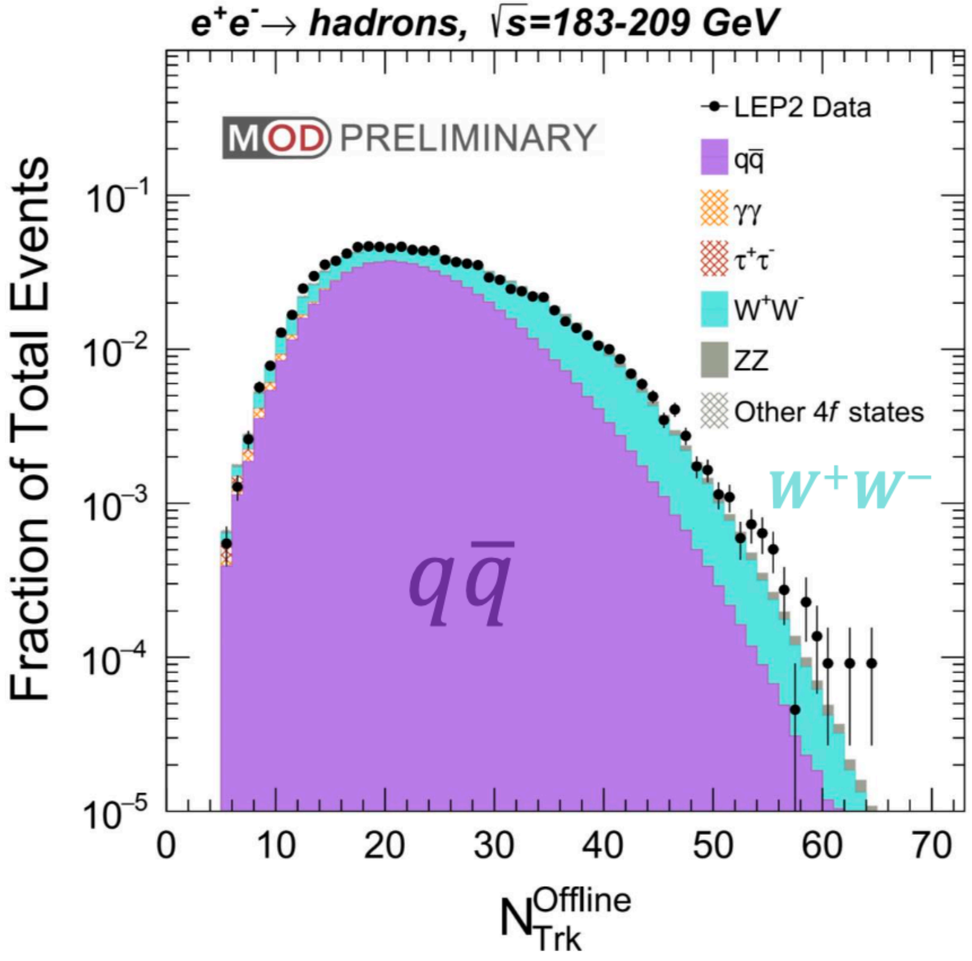
$e^+e^- \to W^+W^- \to q\bar{q}q\bar{q}$



- **WW process may produce more strings between quarks**
- **More chance for interactions - overlapping strings?**
  - **Closer to original motivation for looking in e^+e^-**

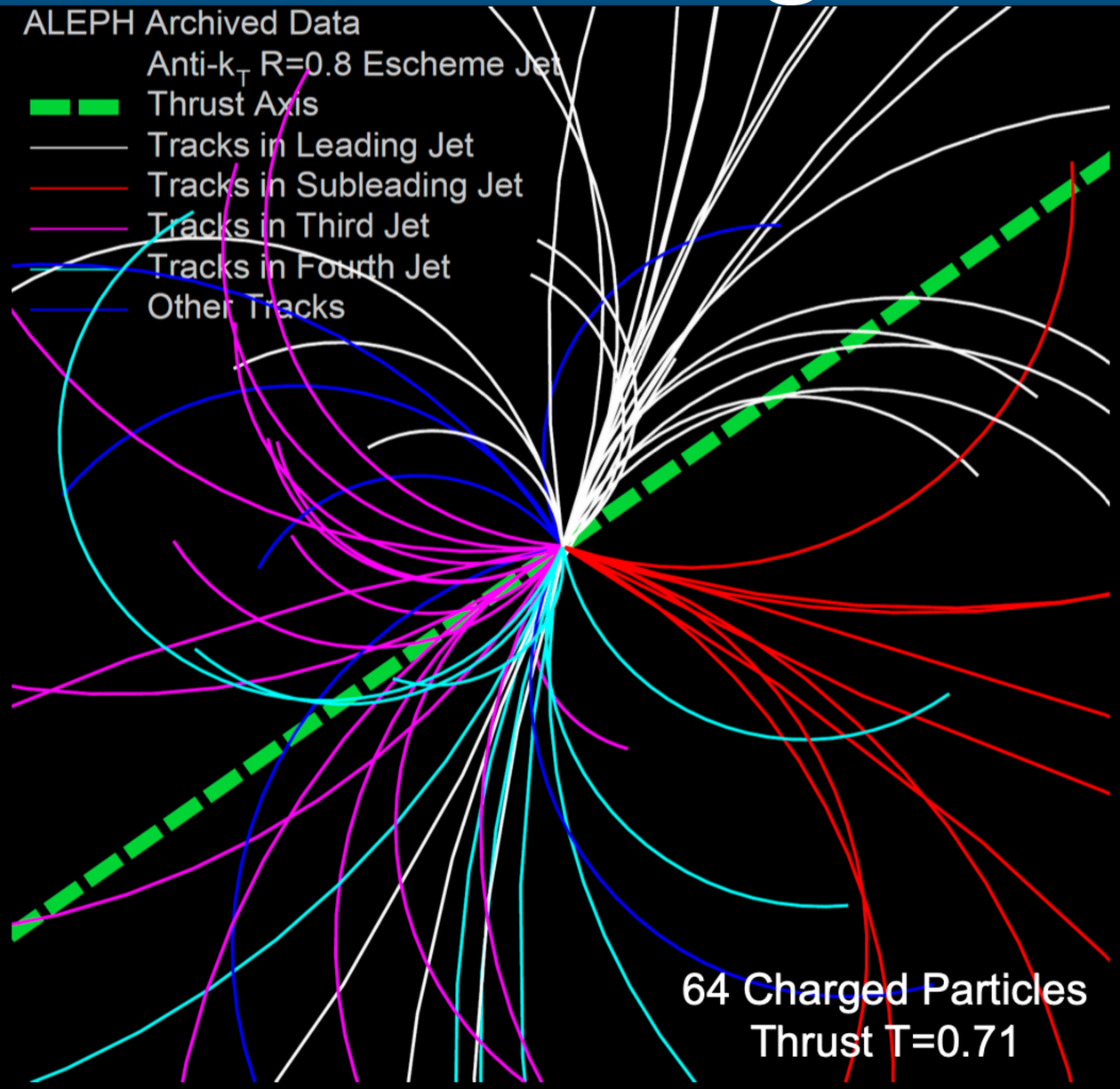
LEP 2 Multiplicity distributions

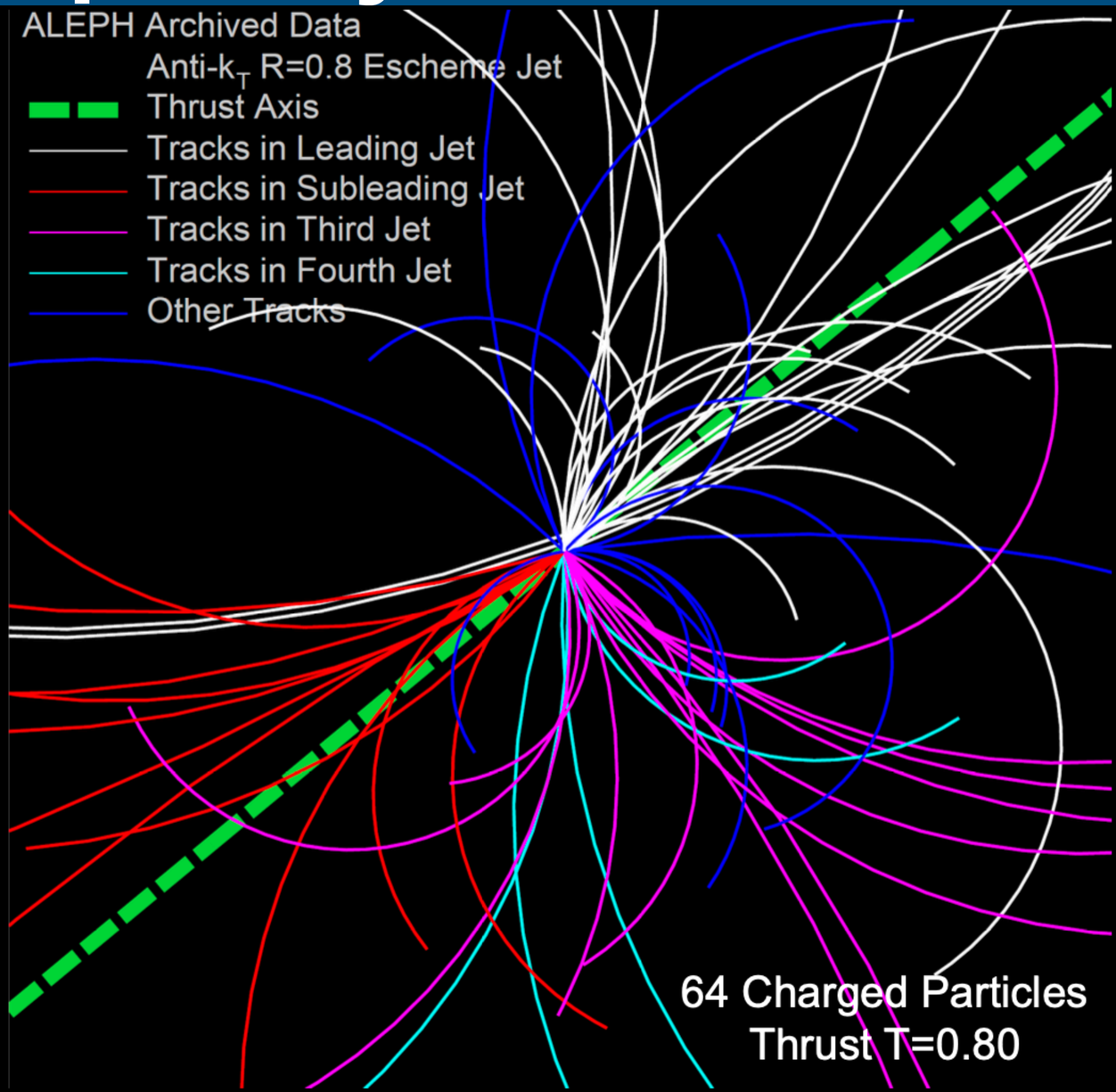




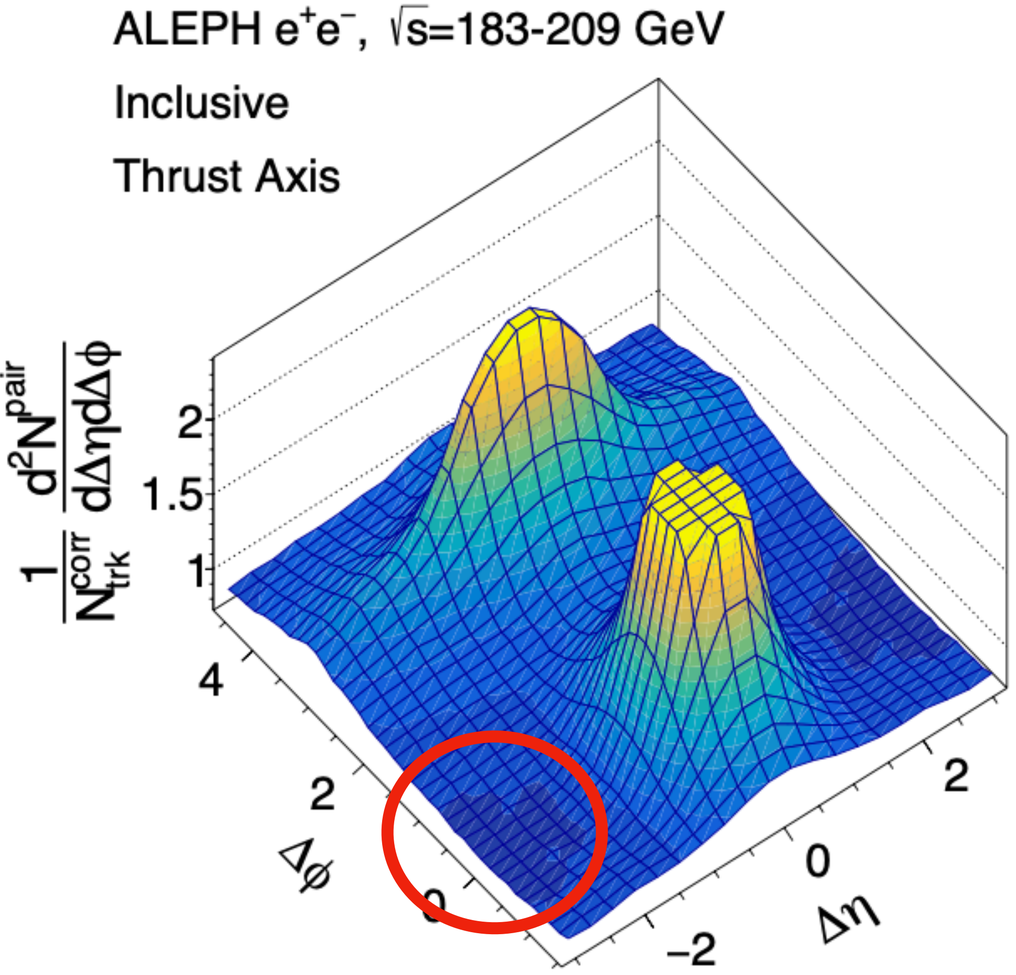
- **Significantly extended multiplicity reach with LEP 2**
- **High-multiplicity events have large WW process component**
  - **Good agreement with MC expectations!**

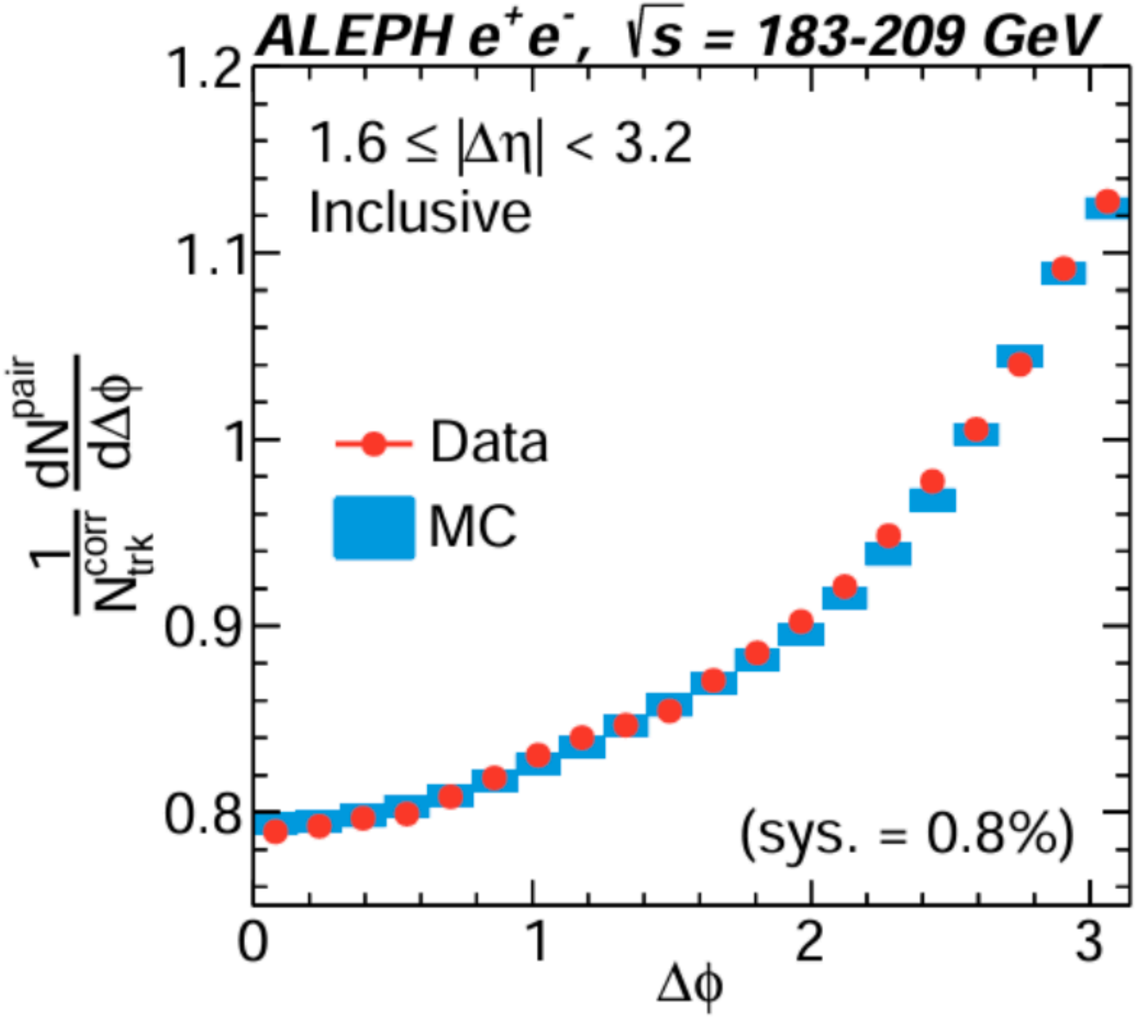
LEP 2 high-multiplicity events





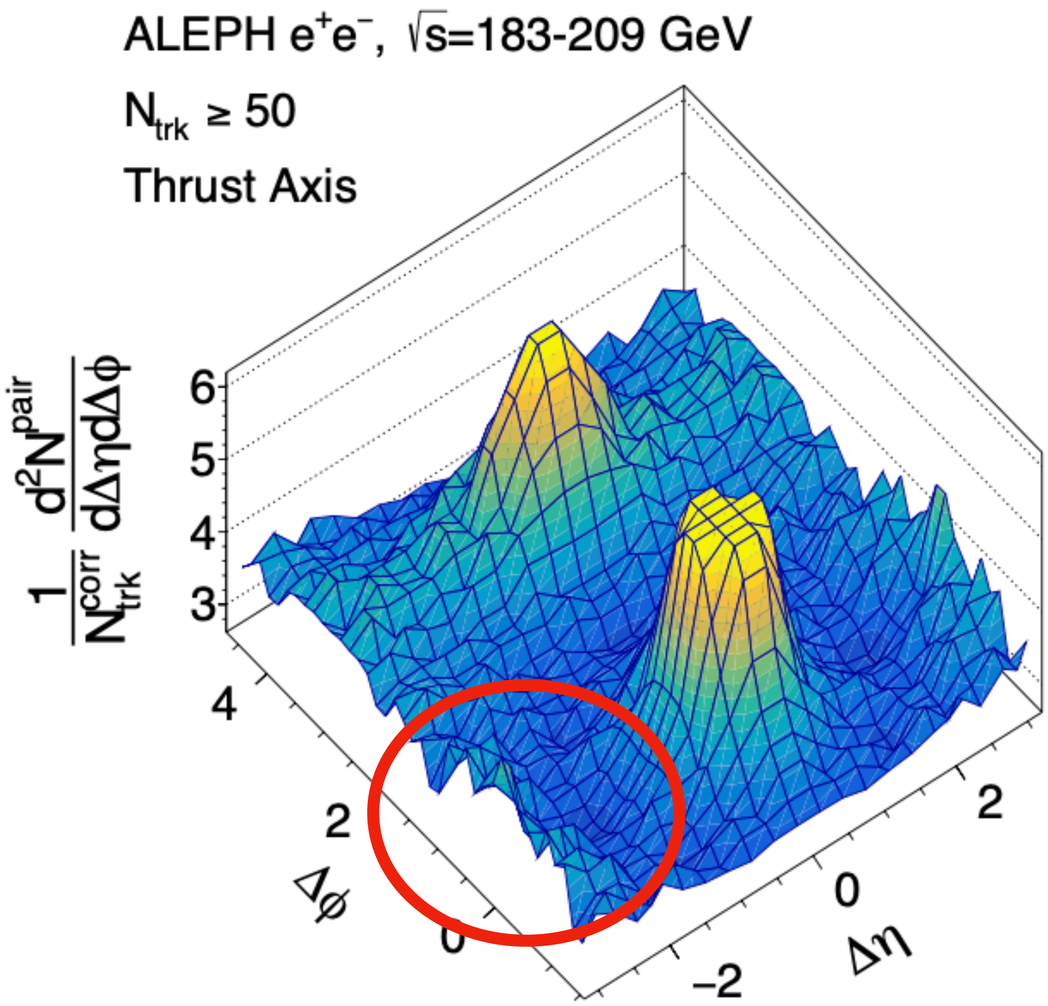
Inclusive LEP 2 data

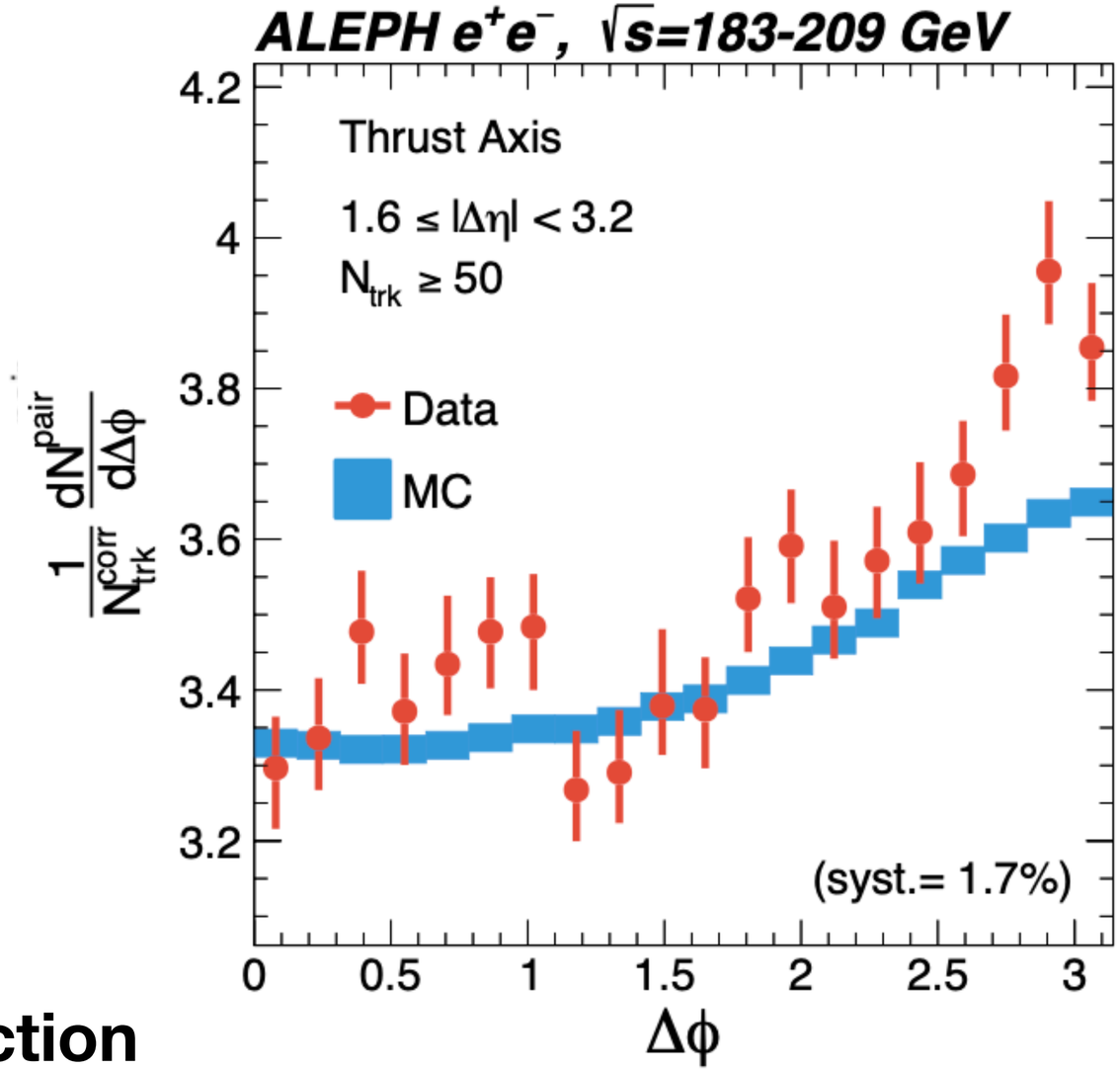




- **No ridge seen in inclusive events**
- **Excellent agreement with archived MC (PYTHIA 6)**

$N_{trk} > 50$ selection

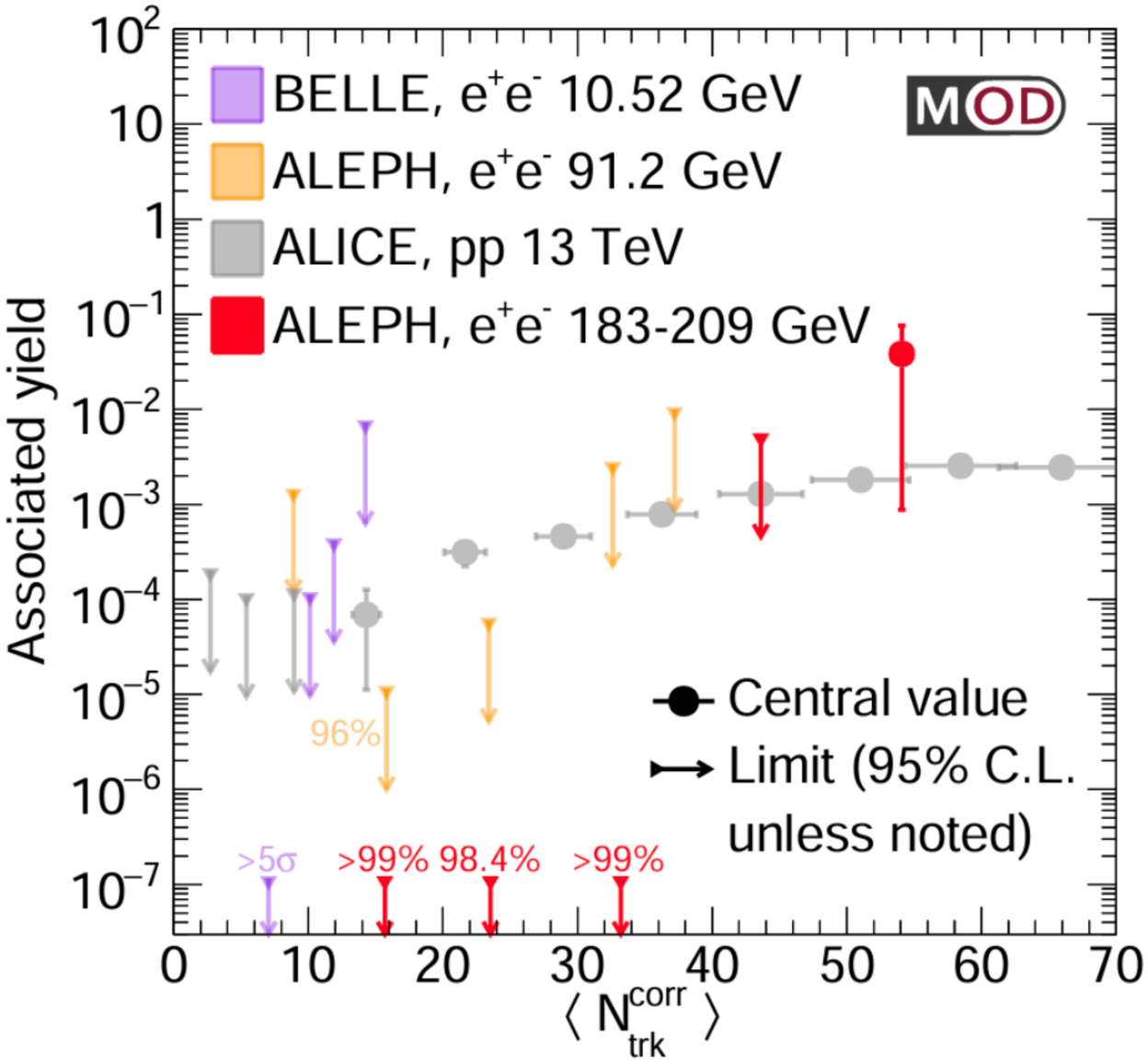




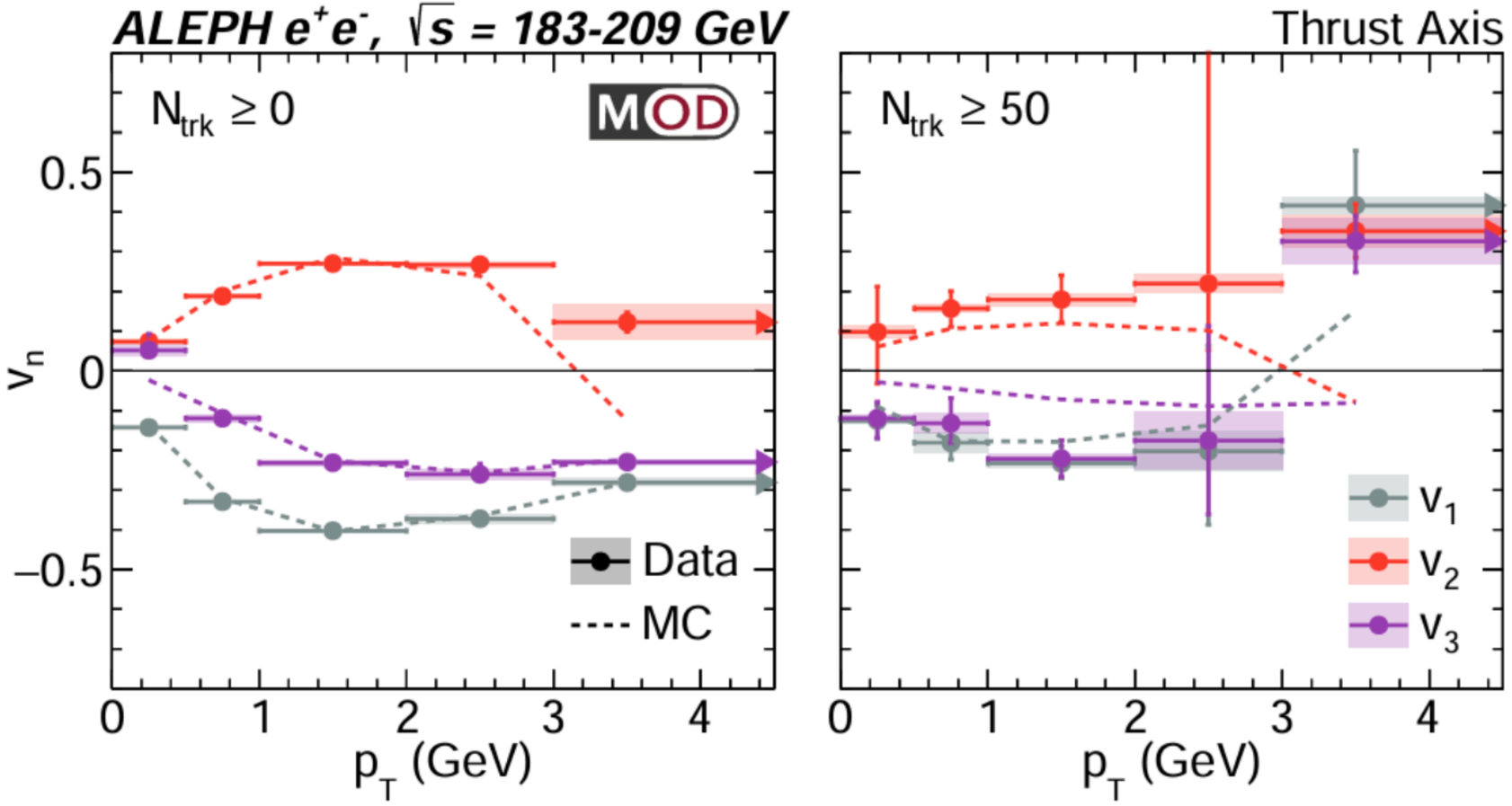
- **Less clear for high-multiplicity selection**
- **Deviations observed from MC, although sizable uncertainties**

Near side ridge size

- **Quantify size of any near-side ridge**
- **Fit data and do ZYAM subtraction**
- **Limits set for most multiplicity bins**
- **For N_{trk}>50, calculate yield nonzero with large uncertainty**
- **Consistent with recent ALICE data**



v_n coefficients

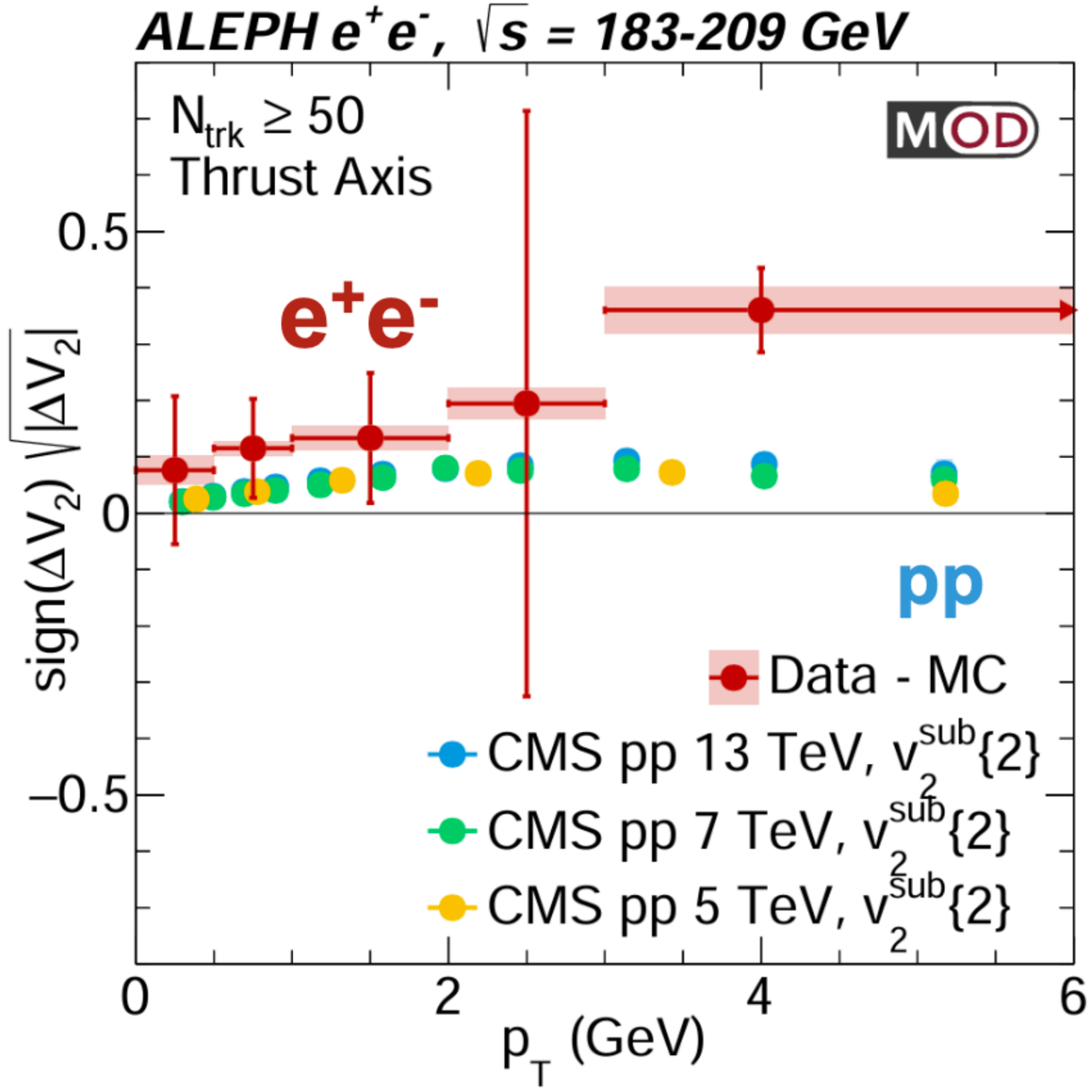


- **Calculate v_n using discrete Fourier Transform - dominated by non flow**
- **Plotted vs associated particle p_T**
  - **Slight deviations from MC for high multiplicity selection**

Correlations in e^+e^- data

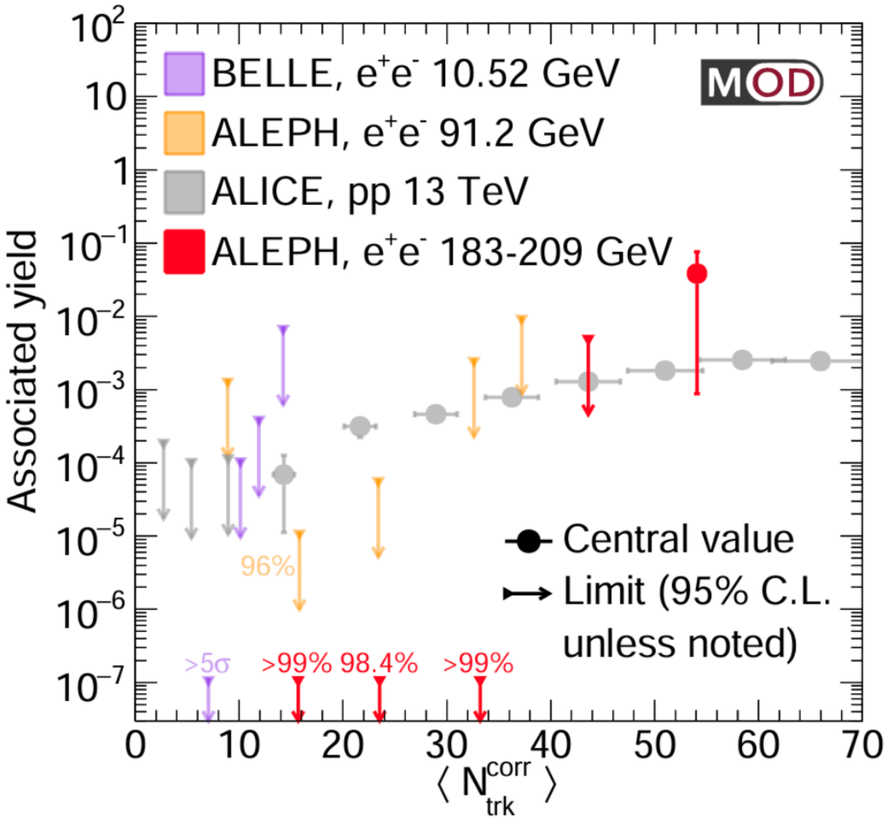
- **Subtract non flow using MC**
- **Compare to subtracted pp measurements**

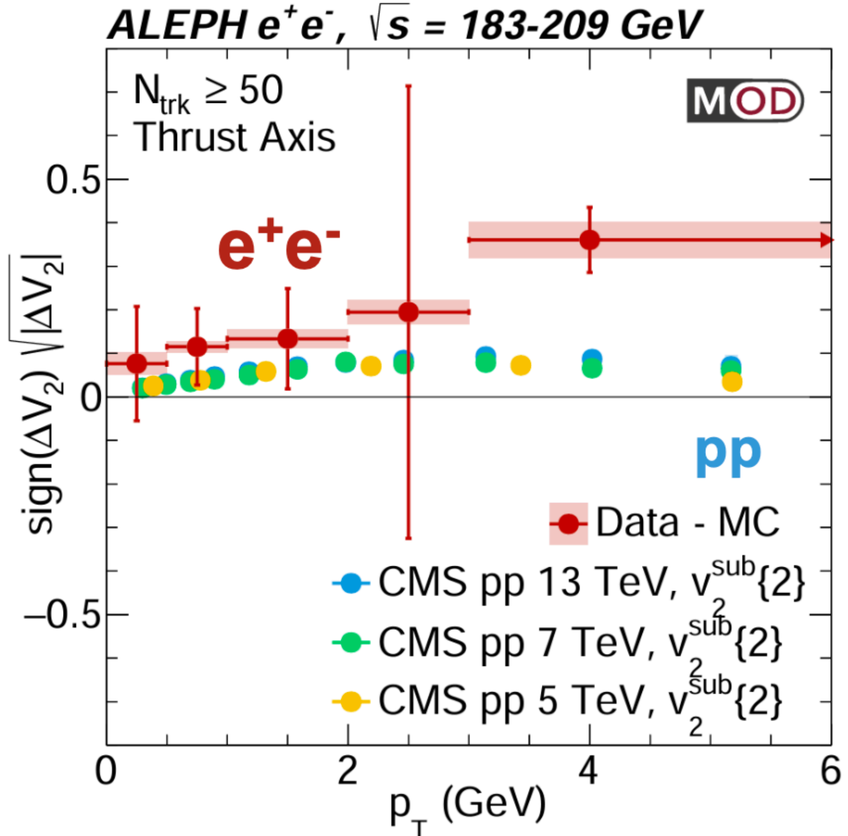
- **Data seem to show rising trend that is similar to pp data under 3 GeV**



Summary

- **Archived LEP data have been analyzed at 91 and 183-209 GeV**
- **Good agreement with MC at lower multiplicities**
- **Interesting structures emerge for N_{trk}>50 - final state origin of collectivity?**
- **Hadronic initial state may not be required for ridge formation**





More info at:

arXiv:2312.05084

arXiv:2309.09874

Backup