Tantalizing Structure in Long Range Correlations in High Multiplicity e^+e^- Collisions and Fourier Decomposition Using Archived ALEPH Data at 91-209 GeV

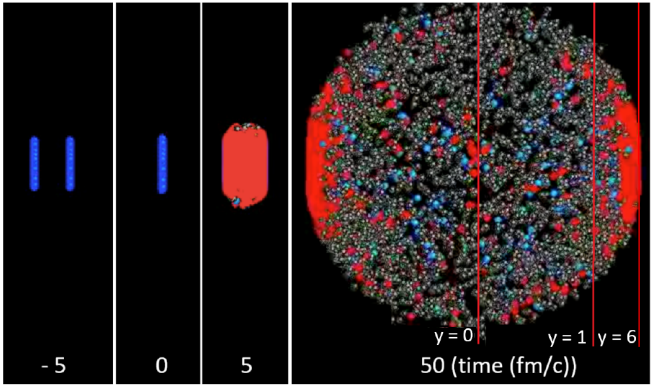
Chris McGinn on behalf of MOD

NN2024 at Whistler

19 August 2024

MITHIG group's work was supported by US DOE-NP

Motivation: From Large to Small (I)

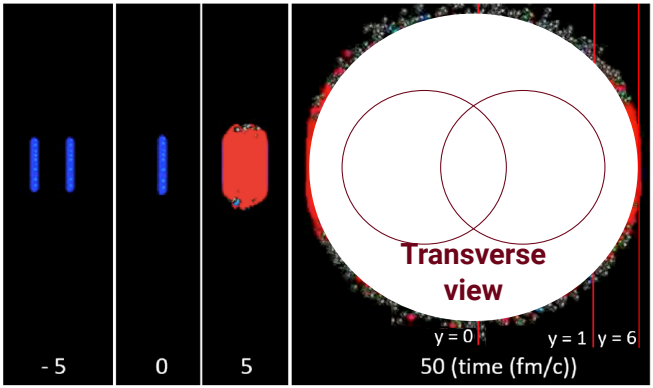


Still via Ann.Rev.Nucl.68 (2018)

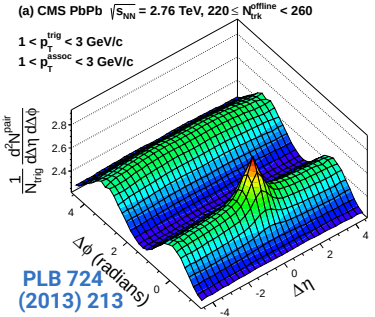
Full video via Yen-jie Lee, Wit Busza, and Andre Yoon

1. Lorentz-contracted nuclei inbound
2. Initial collision
3. After some formation time, Quark Gluon Plasma (QGP) - hydrodynamics takes over
4. After some longer time, freezeout and hadronization

Motivation: From Large to Small (II)



1 2 3 4



PLB 724 (2013) 213

Initial state geometry in AA → long range correlations via hydro.

1. Lorentz-contracted nuclei inbound
2. Initial collision
3. After some formation time, Quark Gluon Plasma (QGP) - hydrodynamics takes over
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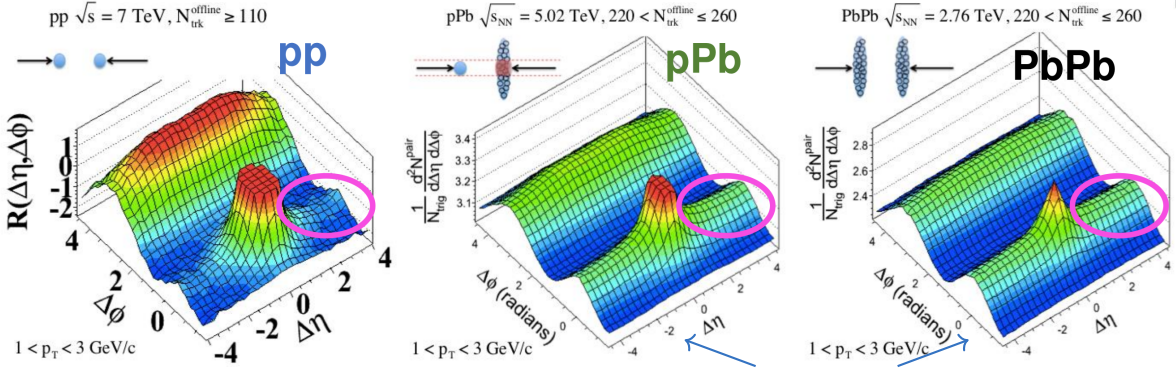
Motivation: From Large to Small (III)

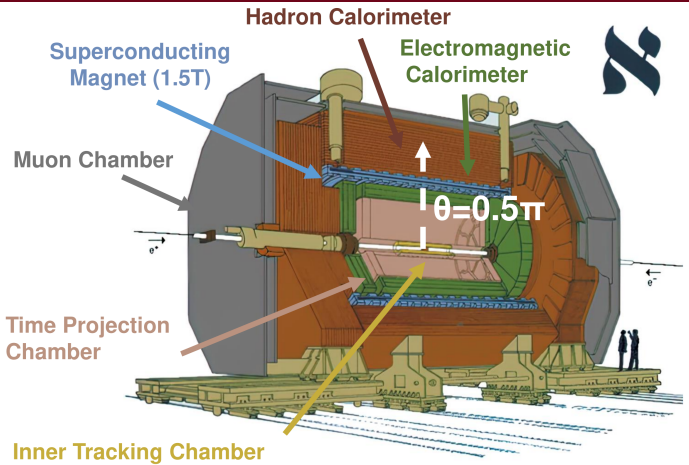


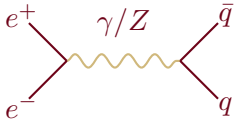
PLB 765 (2017) 193

PLB 724 (2013) 213

- Observable phenomena in collisions systems of all sizes!
- Possible signature of QGP droplet formation
- Alternatively, initial state correlations with no QGP
- How small can we go? Are there two-particle correlations in point-like systems?

The ALEPH Detector





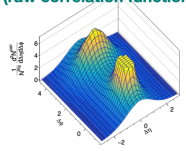
- At LEP from 1989-2000
- $\sqrt{s}$ at Z-pole until 1995
- Beyond 1995 at higher energy
  - Maxing at 209 GeV

- Collisions of e^+e^- are a clean environment for testing QCD
- Can we observe long range correlations in a point-like system?
  - Let's check archived data!

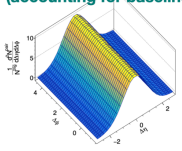
Defining Two-particle Correlations in e^+e^-

Two particle correlations:

Signal
(raw correlation function)



Background
(accounting for baseline of random pairing)



$$S(\Delta\eta, \Delta\phi) = \frac{1}{N_{trk}^{corr}} \frac{d^2N^{same}}{d\Delta\eta d\Delta\phi}.$$

$$B(\Delta\eta, \Delta\phi) = \frac{1}{N_{trk}^{corr}} \frac{d^2N^{mix}}{d\Delta\eta d\Delta\phi}.$$

in pp/AA, coordinates defined by beam-axis
but in e^+e^- the initial state annihilates...

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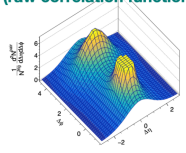

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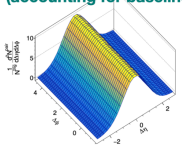

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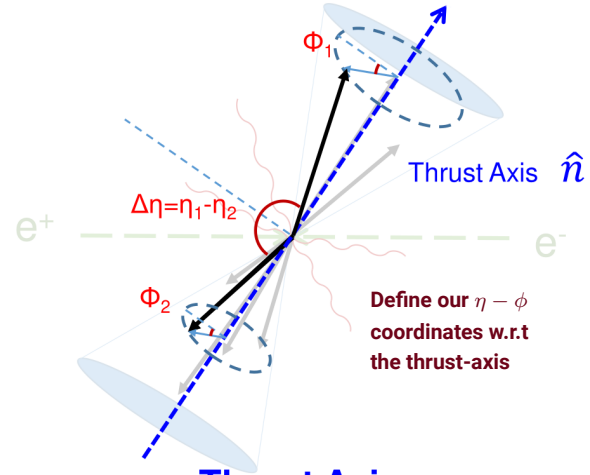
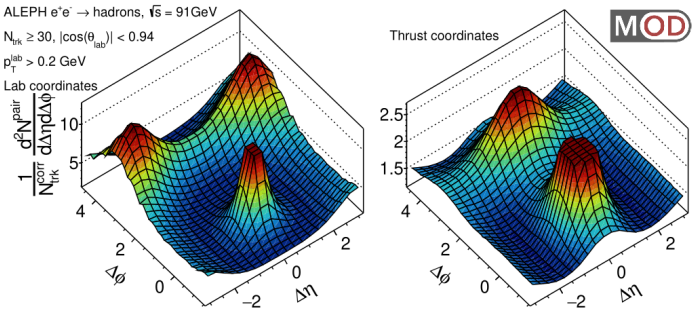


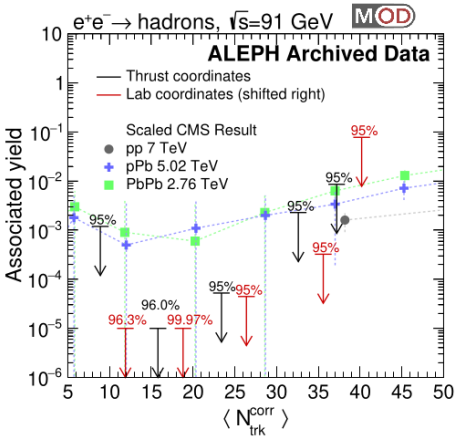
Thrust Axis

Maximizes particle momentum projections
In case of dijets, pencil-like events

Search with LEP-I Data



PRL 123 (2019) 21, 212002



- **Thrust-axis search shows no increase in associated particle yield**
- **Limit on associated yield magnitude set for $N_{\mathrm{trk}} \geq 35$**
  - **No associated particle yields at the Z-pole!**

Anthony Badea
(Chicago, ATLAS)

Motivating a Search with LEP-II Data

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

LEP-I Multiplicities

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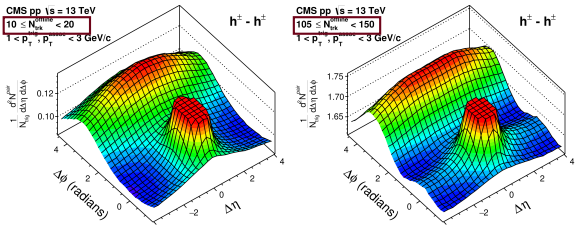
[30, 40)	3.7	32.6	35.9
[40, 50)	0.4	42.8	47.1
$[50, \infty)$	< 0.1	53.0	58.4

LEP-II Multiplicities



PLB 765 (2017) 193

In pp, correlations emerge at the high multiplicities

Motivating a Search with LEP-II Data

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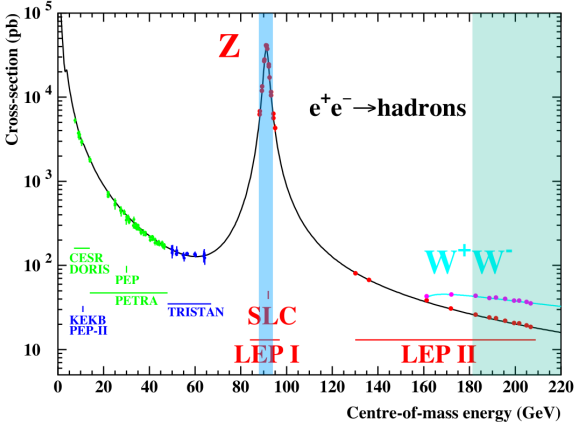
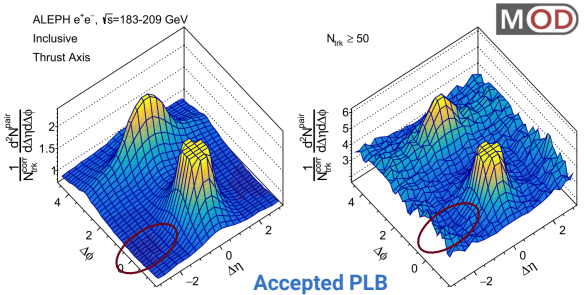


- More complex final state of W^+W^- might achieve conditions for correlations
- Studies in AMPT from Nagle et al. suggest two color strings are sufficient

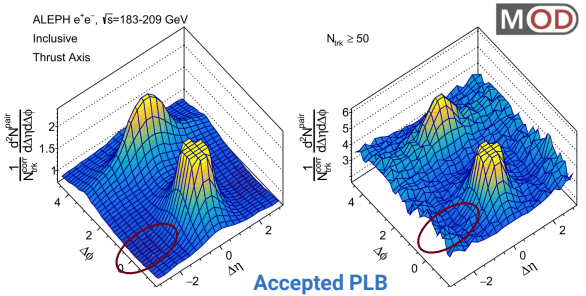
Two-particle Correlations in LEP-II



- Inclusive multiplicity has no correlation
- Hint of correlation at high multiplicity!
- Let's check the large $|\Delta\eta|$ projections...

Yu-Chen "Janice" Chen (MIT)

Two-particle Correlations in LEP-II



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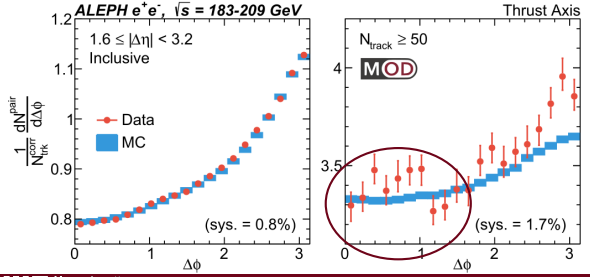

- Inclusive matches MC expectation
- Deviation from MC for $N_{trk} \geq 50$
- Correlations with no initial geometry!

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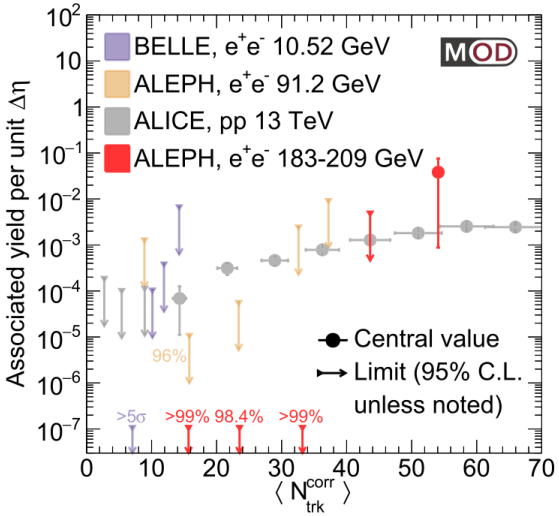
Extracting Associated Yields and Setting Limits



Accepted PLB

- **Low N_{trk}, can only set limits**
  - **Similar to LEP-I study shown**
- **At highest N_{trk}, extract significant associated yield**
  - **$W^+W^- \rightarrow \geq$ 2 color strings?**
  - **Other mechanisms?**
- **Compare with MC to check trivial effects**

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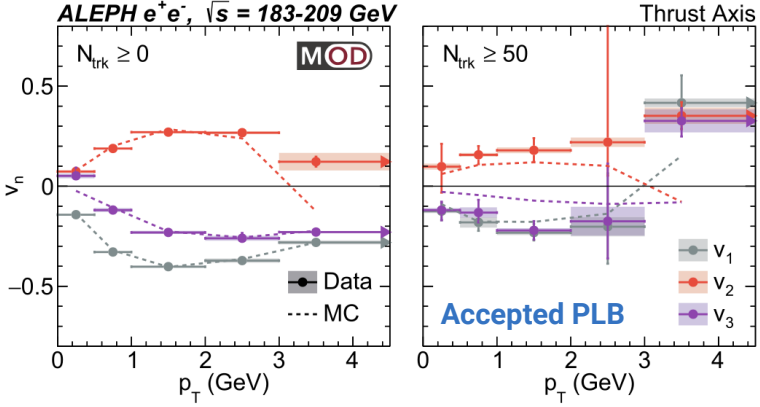
Comparing to theory and pp



- **Inclusive N_{trk} well modeled by MC; MC does not model $N_{\mathrm{trk}} \geq 50$ v_2**

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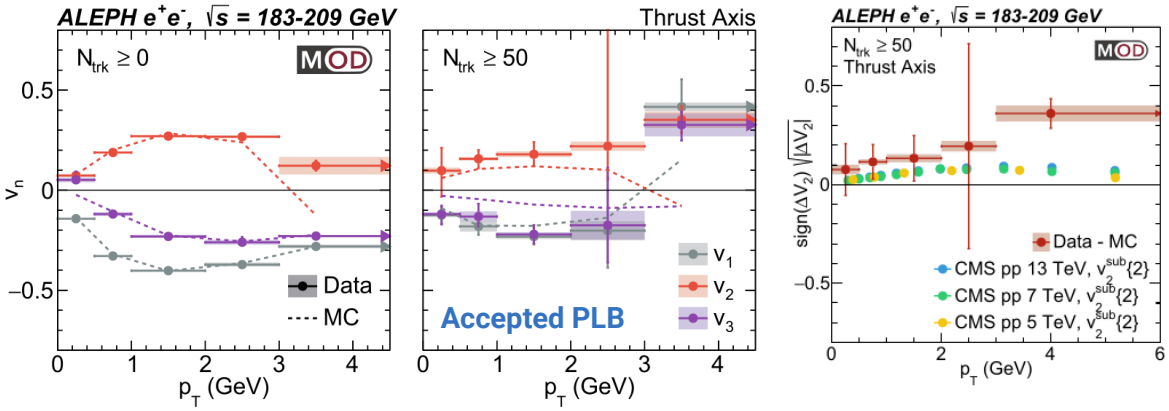
Comparing to theory and pp



- **Inclusive N_{trk} well modeled by MC; MC does not model $N_{trk} \geq 50$ v_2**
- **Rising with p_T behavior also seen in pp**
- **Highest p_T in e^+e^- exceeds pp trend**

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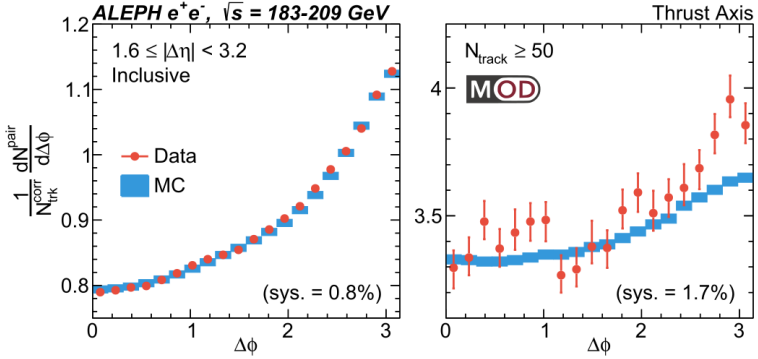
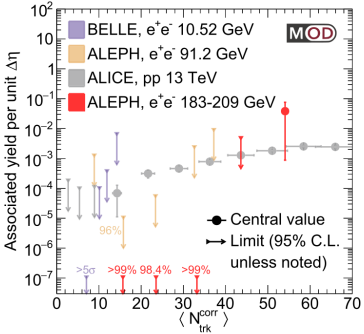
Conclusions





- **New paper on search for correlations in e^+e^- with archival ALEPH data**
  - **First search at higher energy and multiplicities of LEP-II**
  - **Observe a correlation-like signal!**
- **Another piece in a much larger puzzle of two-particle correlations**