

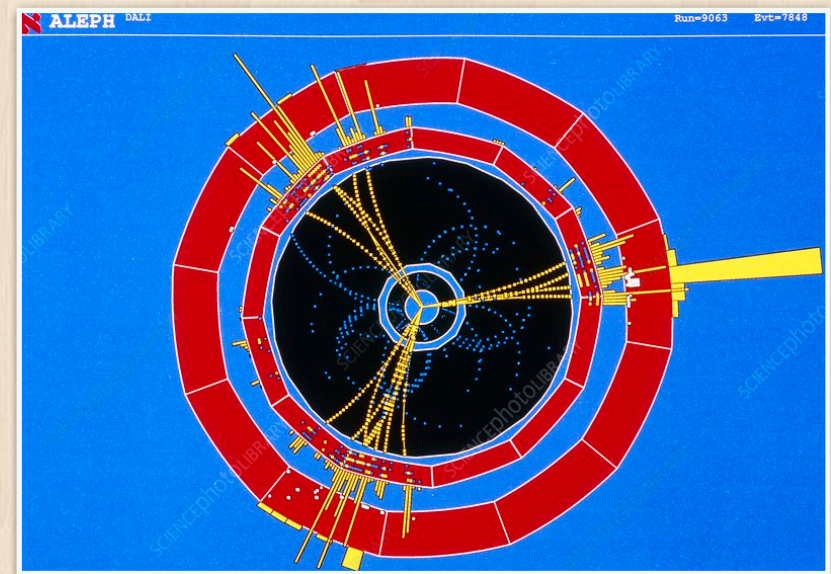


Recent highlights from the e^+e^- alliance

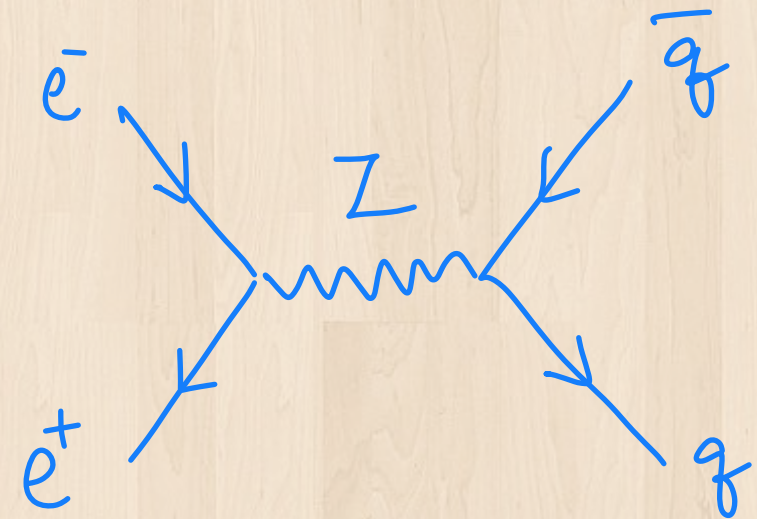
Yi (Luna) Chen for the e^+e^- alliance
Sep 29, 2026. QCD@LHC 2026

Why high-energy e^+e^- collisions?

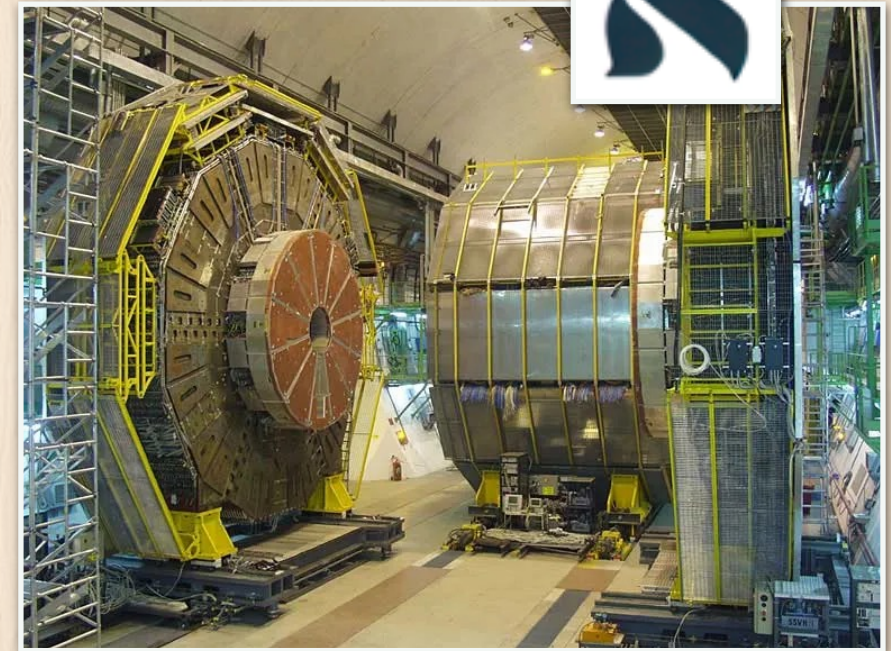
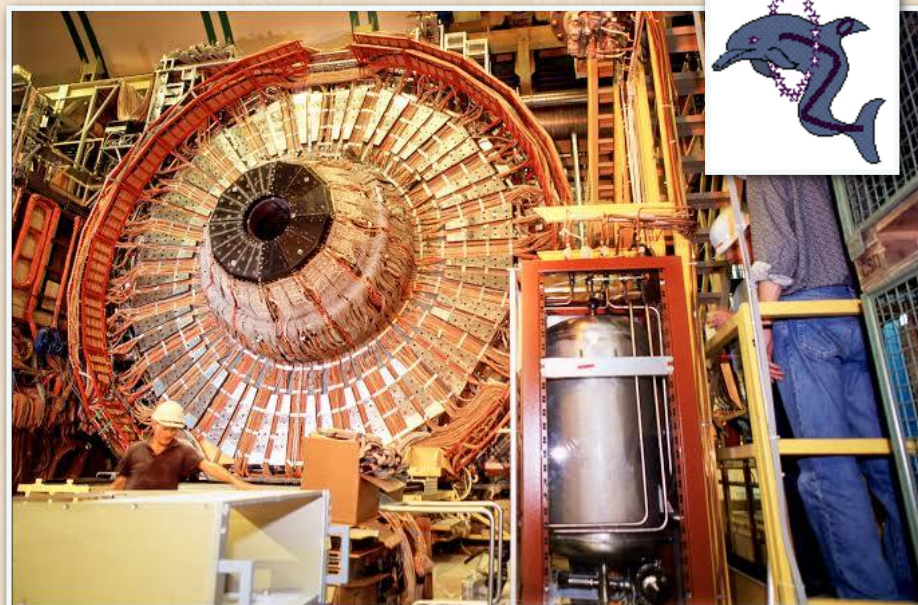
- Clean QCD environment:
 - Point-like initial state
 - controlled kinematics
 - quark-dominated jets
 - no PDF/MPI complications
- Unique dataset to study QCD



Cool 3 jet event

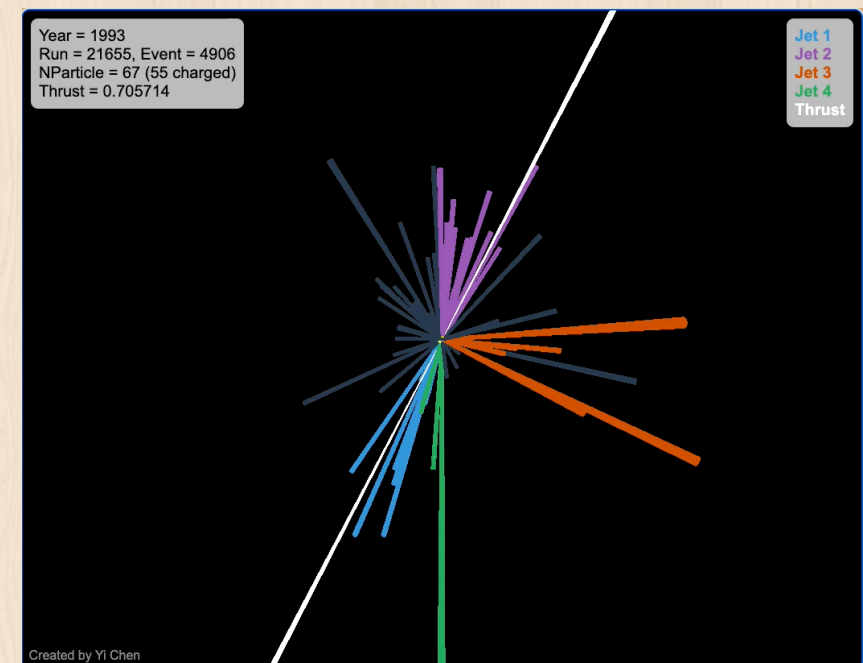
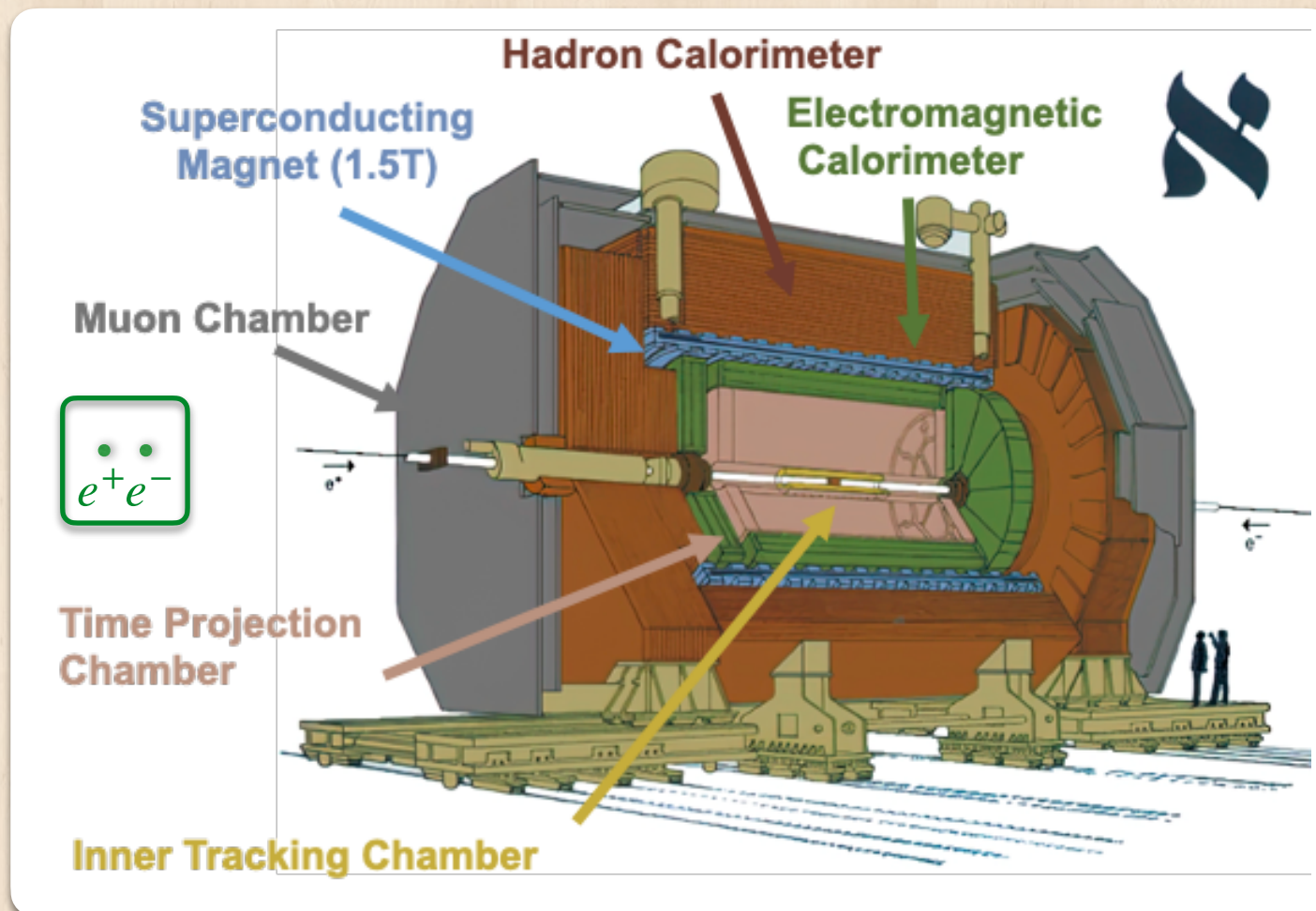


The LEP experiments



(Not shown: OPAL & L3)

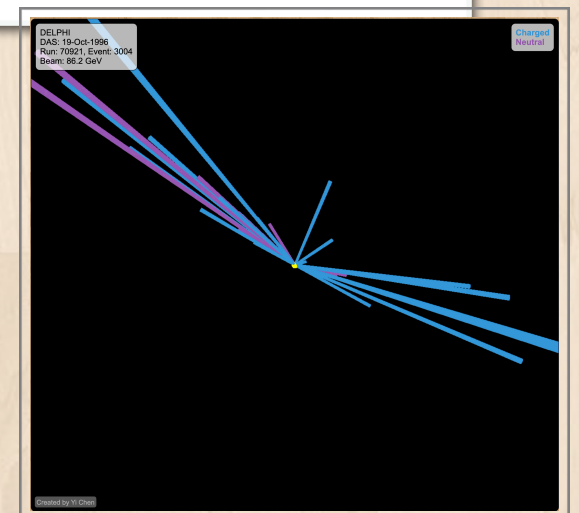
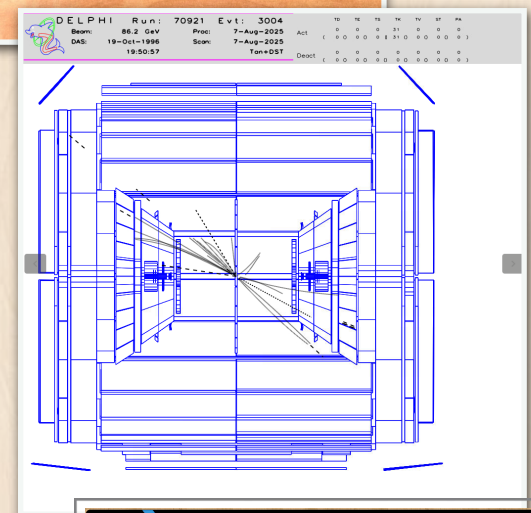
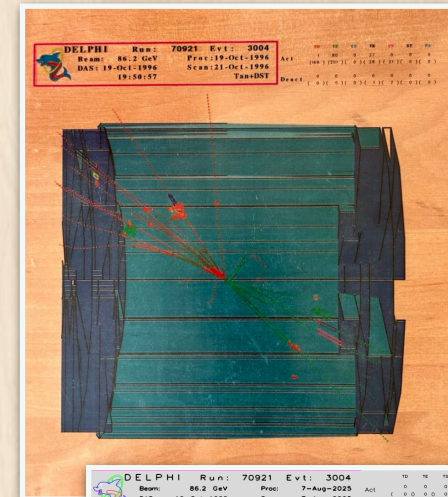
The archived ALEPH data



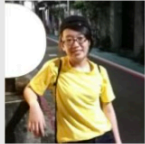
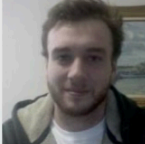
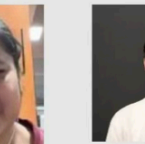
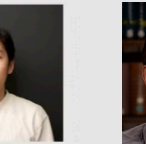
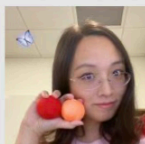
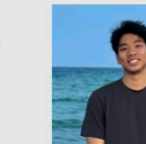
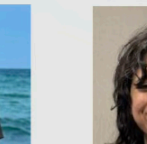
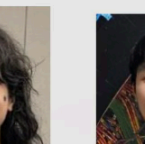
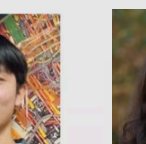
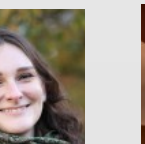
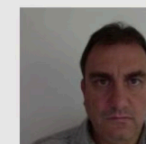
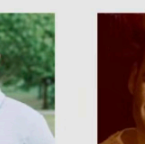
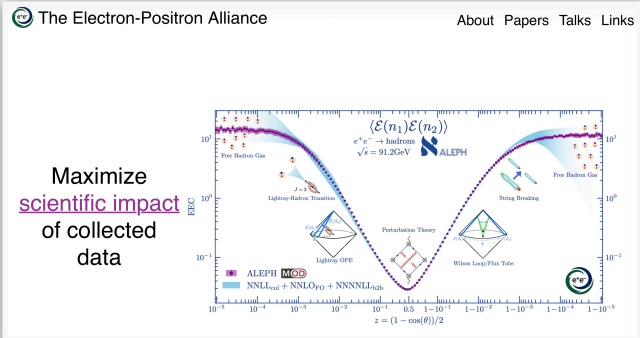
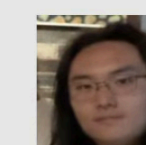
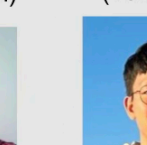
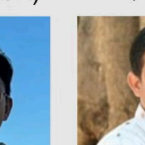
Incredible support from ALEPH members **Marcello Maggi, Roberto Tenchini, Gigi Rolandi, Guenther Dissertori** on the technical aspects and knowledge

The DELPHI open data

- DELPHI Open Data released in 2024
- Full access on data, simulation and simulation software (GEANT3-based)
- We can run modern generator
- Thanks to the DELPHI Collaboration, data preservation team, especially **Dietrich Liko** and **Ulrich Schwickerath** for guidance on how to use the data



e^+e^- reanalysis effort

 Janice Chen (MIT)	 Austin Baty (UIC)	 Chris McGinn (MIT)	 Michael Peters (MIT)	 Anthony Badea (UChicago)	 Paoti Chang (NTU)	 Cen Mo (SJTU)	 Yulei Zhang U. Washington	 Honey Khindri (IIT Madras)	 Xiaoyuan Zhang (MIT)	 Matt LeBlanc (Brown)
 Tzu-An Sheng (MIT)	 Ben Nachman (Stanford/SLAC)	 Yi Chen (Vanderbilt)	 Jingyu Zhang (Vanderbilt)	 Luke Lu (Vanderbilt)	 MJ Khan (Vanderbilt)	 Chen-Hua Hsu (NTU)	 Lauren Hay (Brown)	 Debojit Sarkar (IIT)	 Sunny Kumar Singh (IIT)	
 Hannah Bossi (MIT)	 Gian Innocenti (MIT)	 Jesse Thaler (MIT)	 Marcello Maggi (INFN Bari)	 Günther Dissertori (ETH Zürich)	 Nishant Gaurav (Vanderbilt)	 David d'Enterria (CERN)	 The Electron-Positron Alliance About Papers Talks Links Maximize scientific impact of collected data			
 Yen-Jie Lee (MIT)	 Jeetendra Gupta (UIC)	 Sascha Diefenbacher (LBNL)	 Bill Zhou (UIC)	 Cristian Baldenegro (MIT)	 Ting-Hsiang Hsu (NTU)	 Prabhat Pujahari (IIT Madras)				

<https://ee-alliance.org>

Main goal: preserve data and knowledge
and reanalyze with new observables



Growing physics program

- QCD/SM measurements
jet spectra radius scan, Lund plane & multiplicity, substructure correlation, HF jet tagging, axis decorrelation, energy-energy correlator, thrust, Q1 correlator, isotropy, ...
- Novel observables with connections to neighboring subfields (e.g. heavy-ions, electron-ion, ...)
2PC, cumulants, strangeness enhancement, $Z \rightarrow \tau\tau$ spin, in-jet azimuthal asymmetry, EIC clustering studies, identified particle 2PC, charge/baryon fluctuation, ...
- Testing ground for new techniques / methodologies
Machine learning, tagging, agentic AI, ...

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Today: highlight a few recent studies demonstrating what we can learn + the capabilities

Jet spectra in e^+e^-

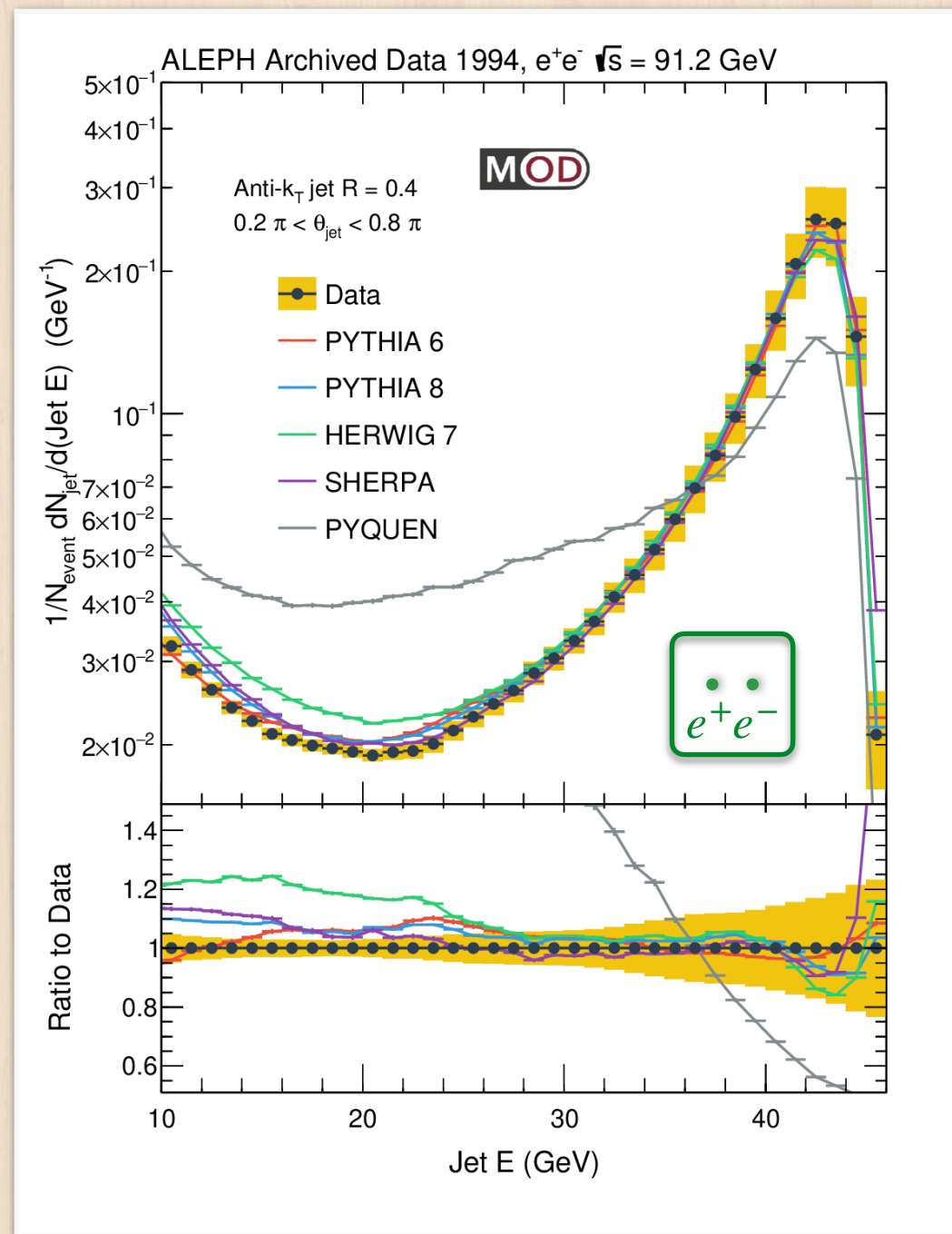
Early jet measurements



Many jet measurements are done with
previous generation of jet algorithms
=> Not ideal for LHC/RHIC/EIC comparisons

Opportunity for re-analysis with new algorithms

Few years back: anti- k_T , $R = 0.4$



Comparison to MC and theory calculations (not shown in this plot)

Most generators can describe the peak region

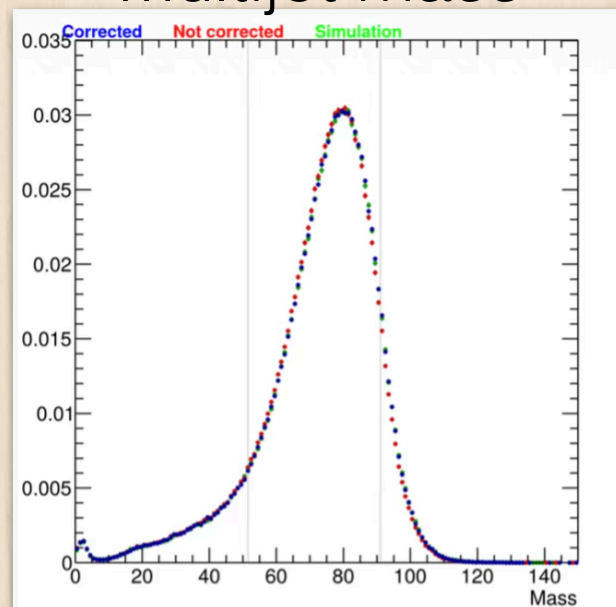
Up to 10-20% disagreement at low E
→ out-of-cone energy, wide angle emission, ...

New: jet radius scan

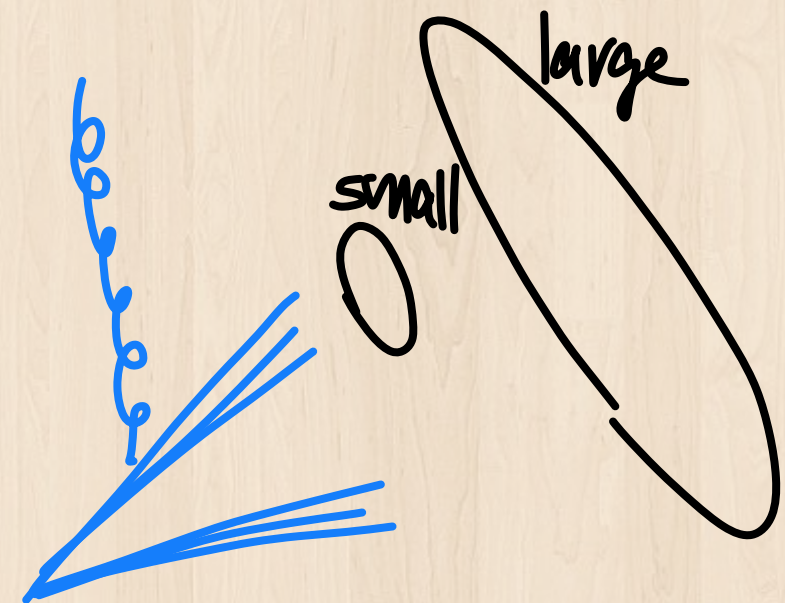
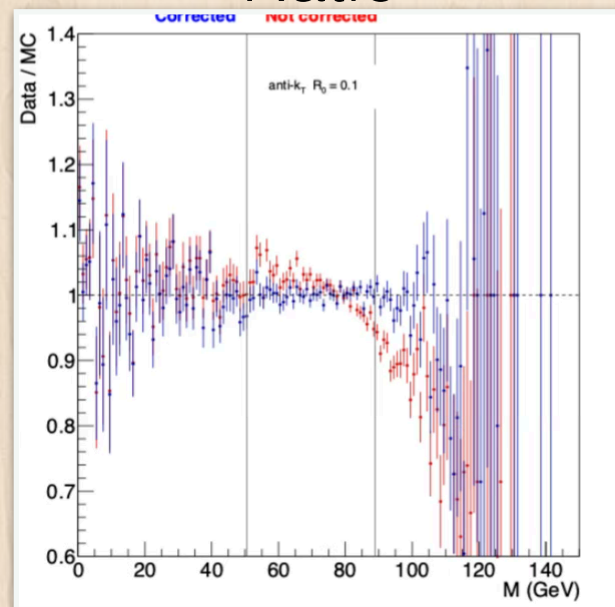
We recalibrated anti- k_T (e^+e^- variant) jets with
 $R = 0.1, 0.2, 0.3, (0.4), 0.5, 0.6, 0.8, 1.0, 1.2$
MC-based + data/MC correction

One example

Multijet mass



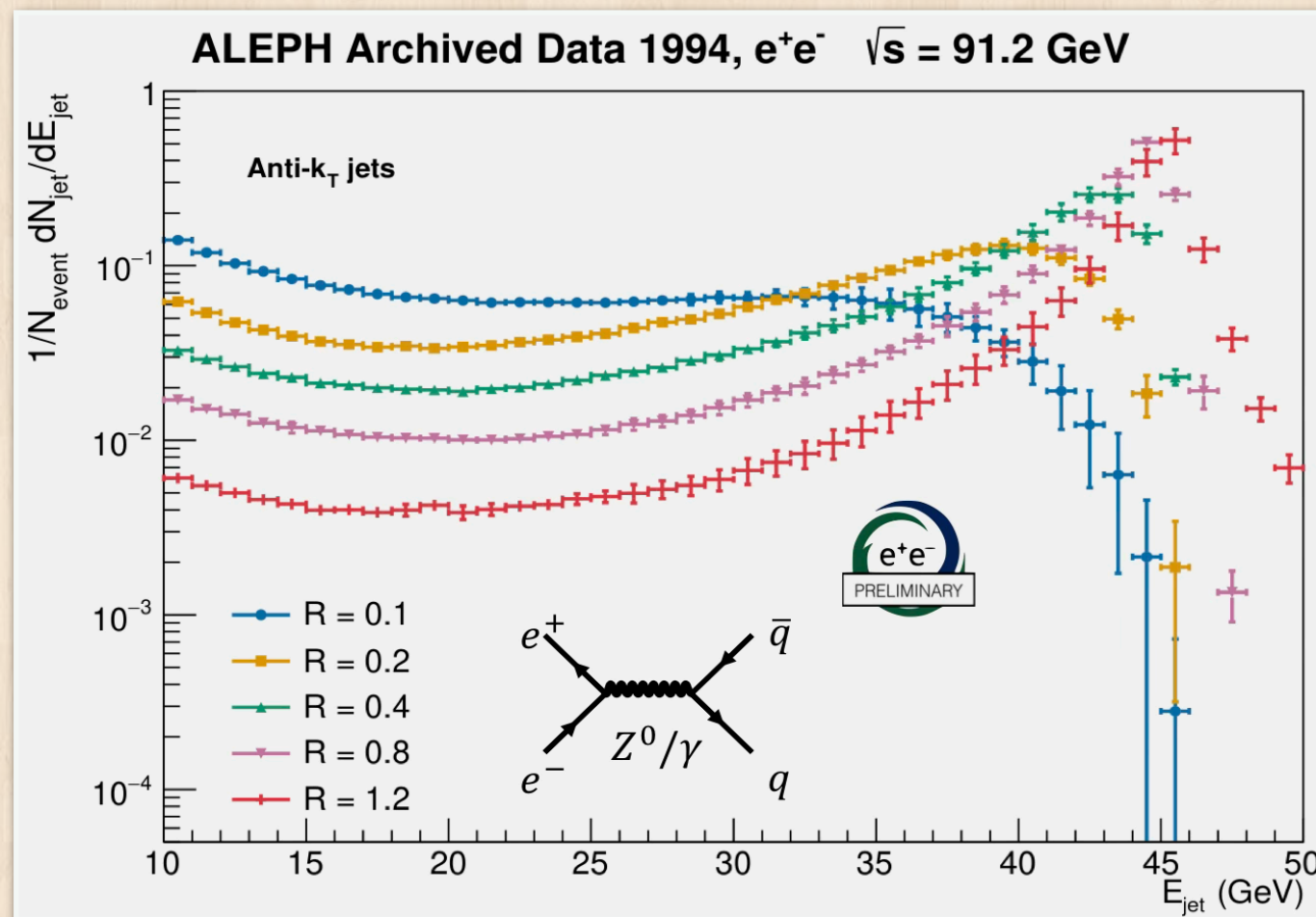
Ratio



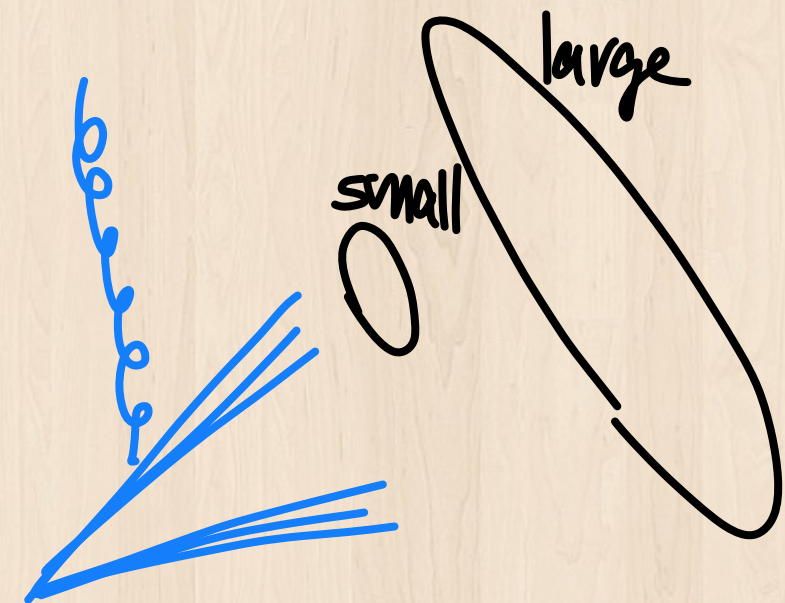
Small R — resolves shower structure

Large R — large angle out-of-cone energy

New: jet radius scan



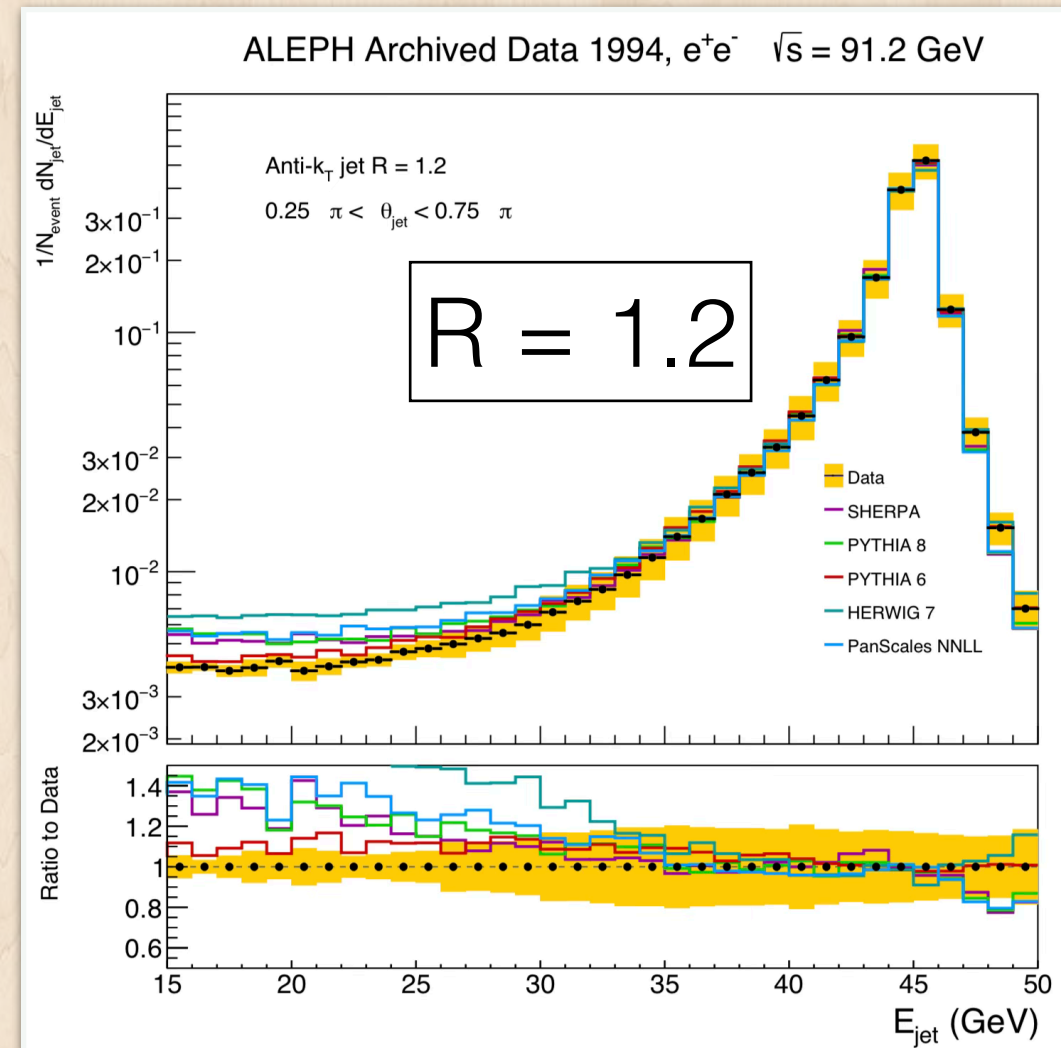
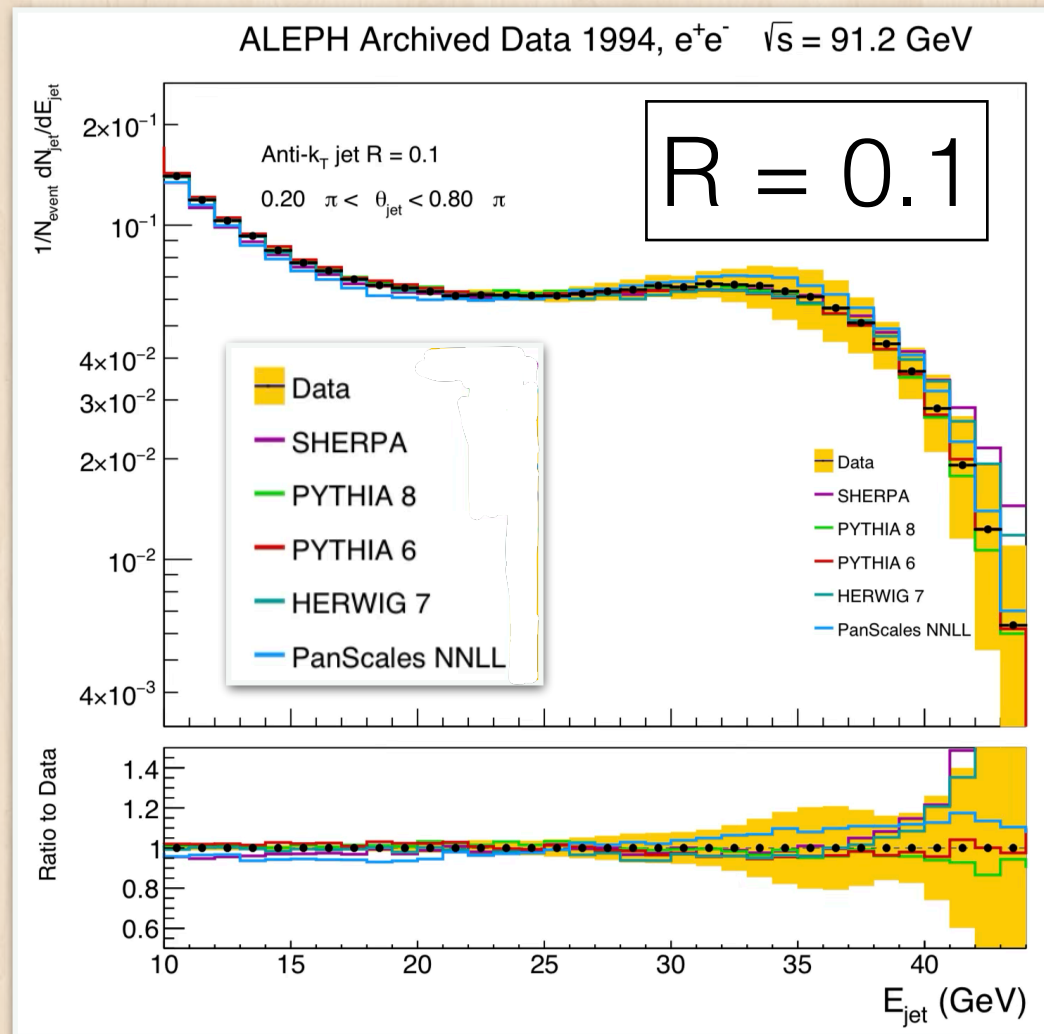
Fully unfolded jet spectra across R 's



Small R — resolves shower structure

Large R — large angle out-of-cone energy

New: jet radius scan

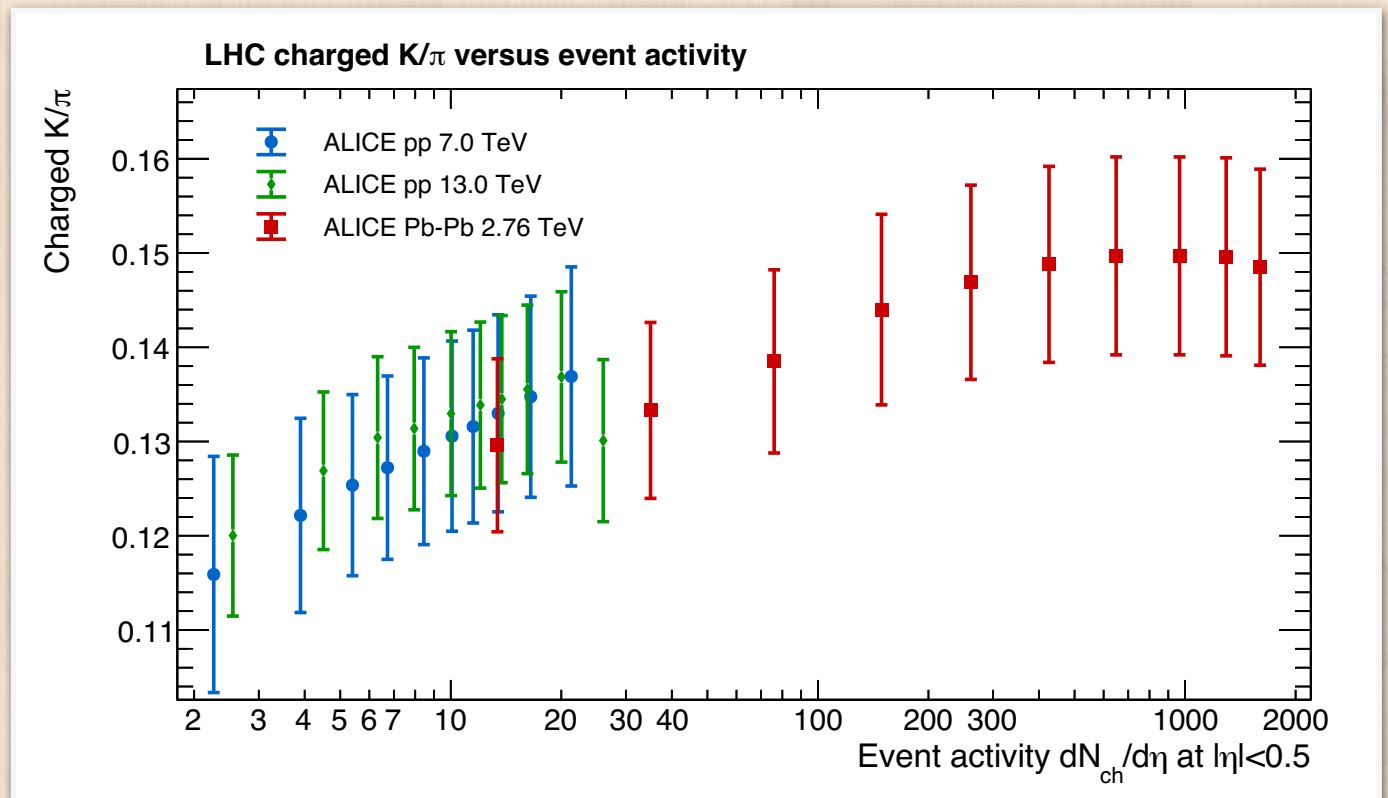
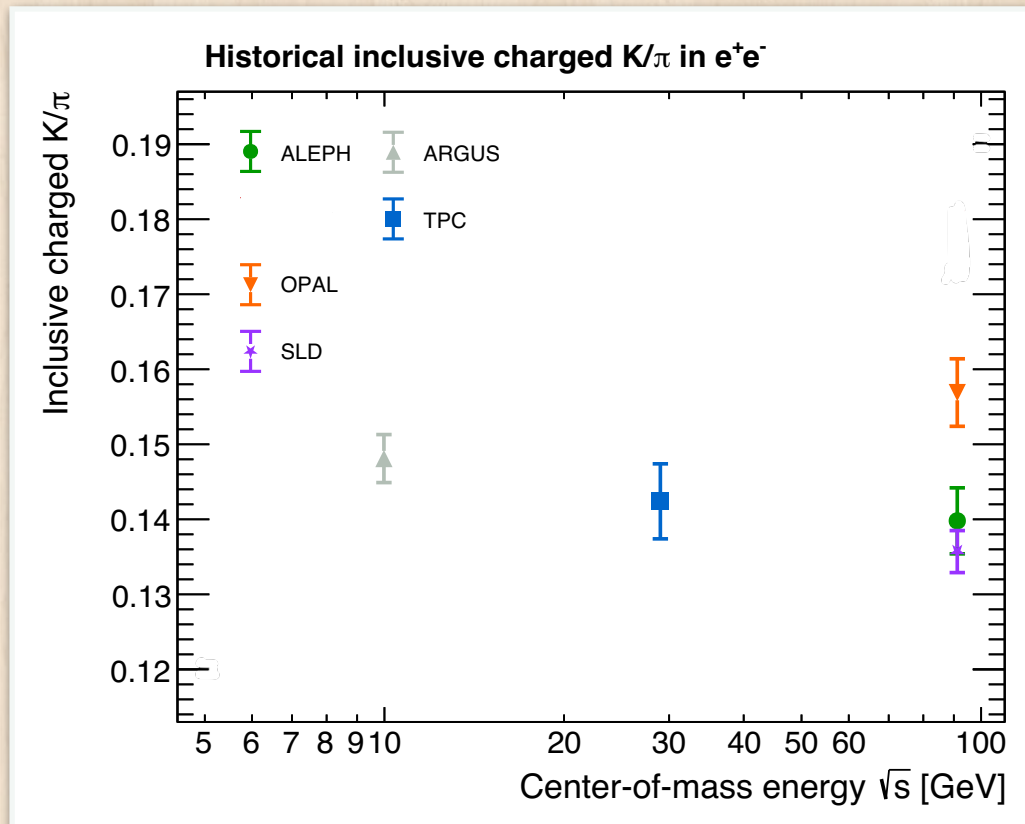


Data compared with modern generators

Most fail to fully describe data — especially low E region

K/π in e^+e^-

K/π ratio measurement



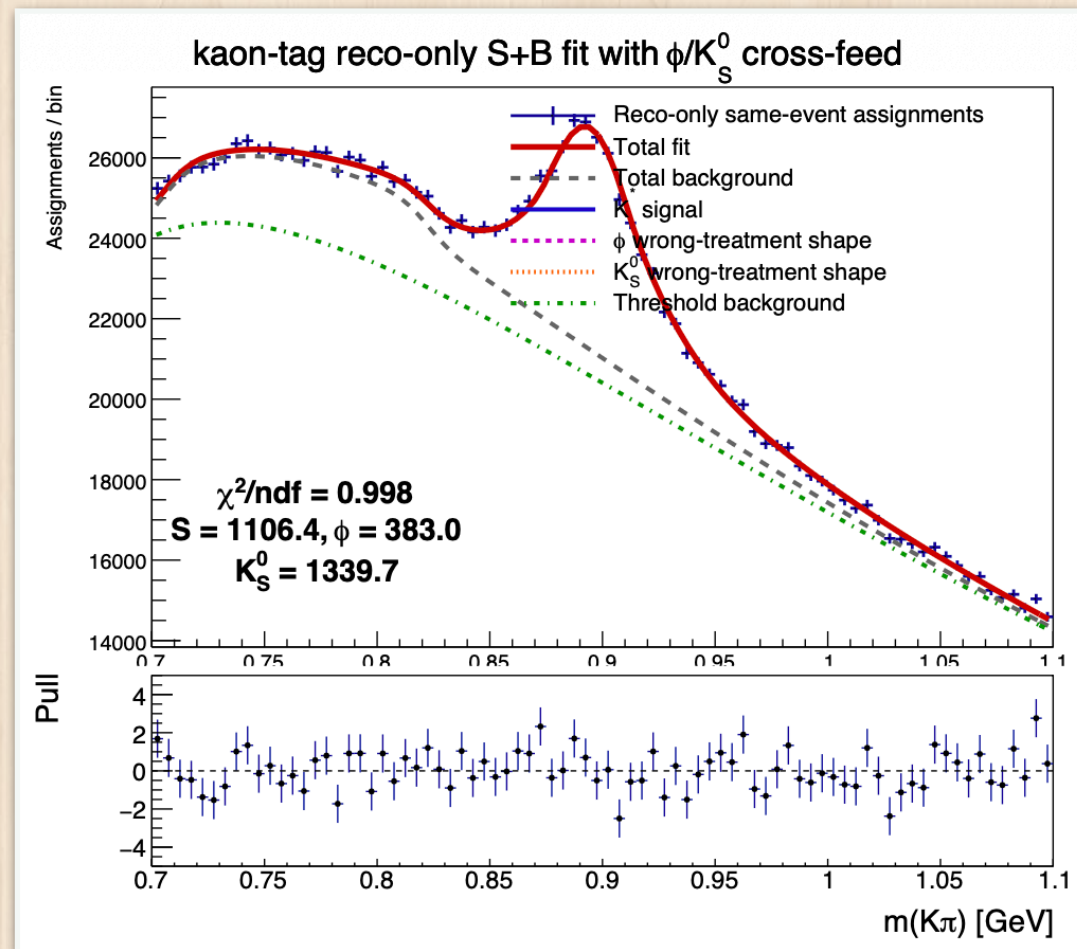
K/π ratio in the same ballpark as pp

However no directly analogous results from e^+e^-

Perform measurement with DELPHI Open Data
PID available + rederive data/MC efficiency scale factor

Particle ID capability

$p/K/\pi$ particle ID available in DELPHI open data
(People are also studying **HF jet tagging**)

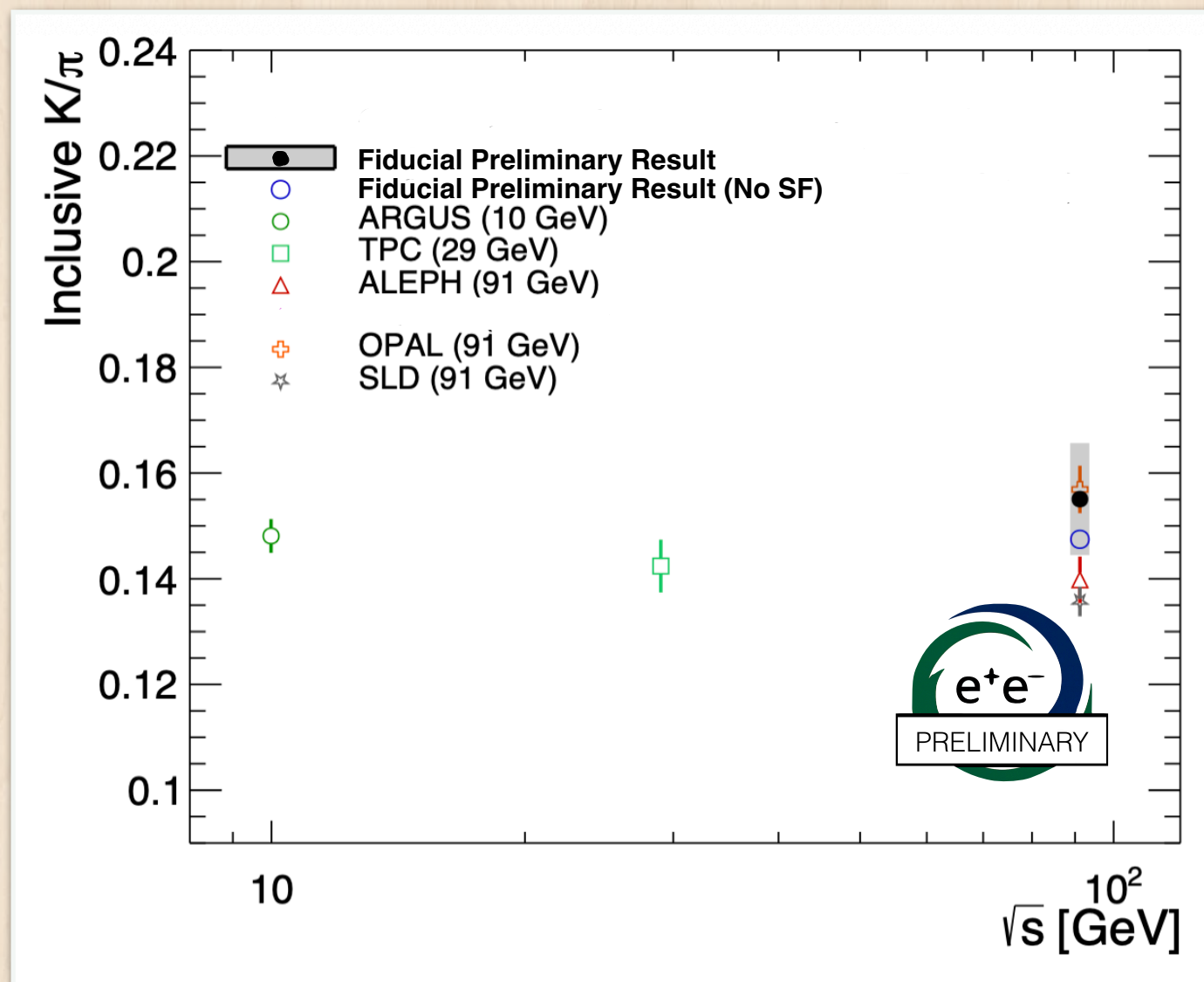


Example fit: K^*

In order to control tagging efficiency, we study the resonances

Efficiency of data & MC under good control

Integrated result



Broadly compatible
with other 91 GeV
results

Caveat: current result
is fiducial region

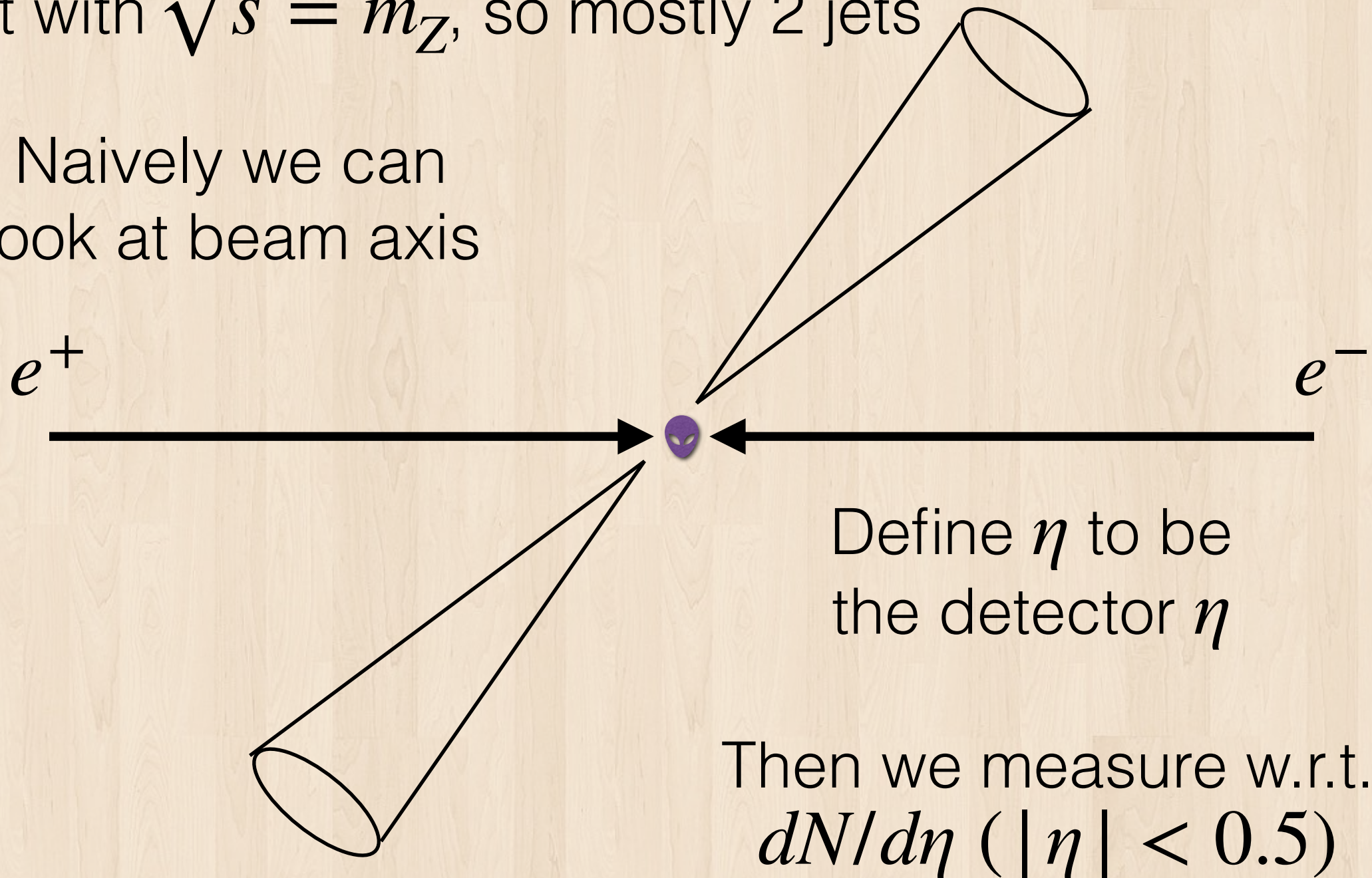
$|\cos \theta| \in 0.15 - 0.675,$
 $p_T \in 0.4 - 5.0$ GeV

Beware of the fiducial cuts

How to measure event activity?

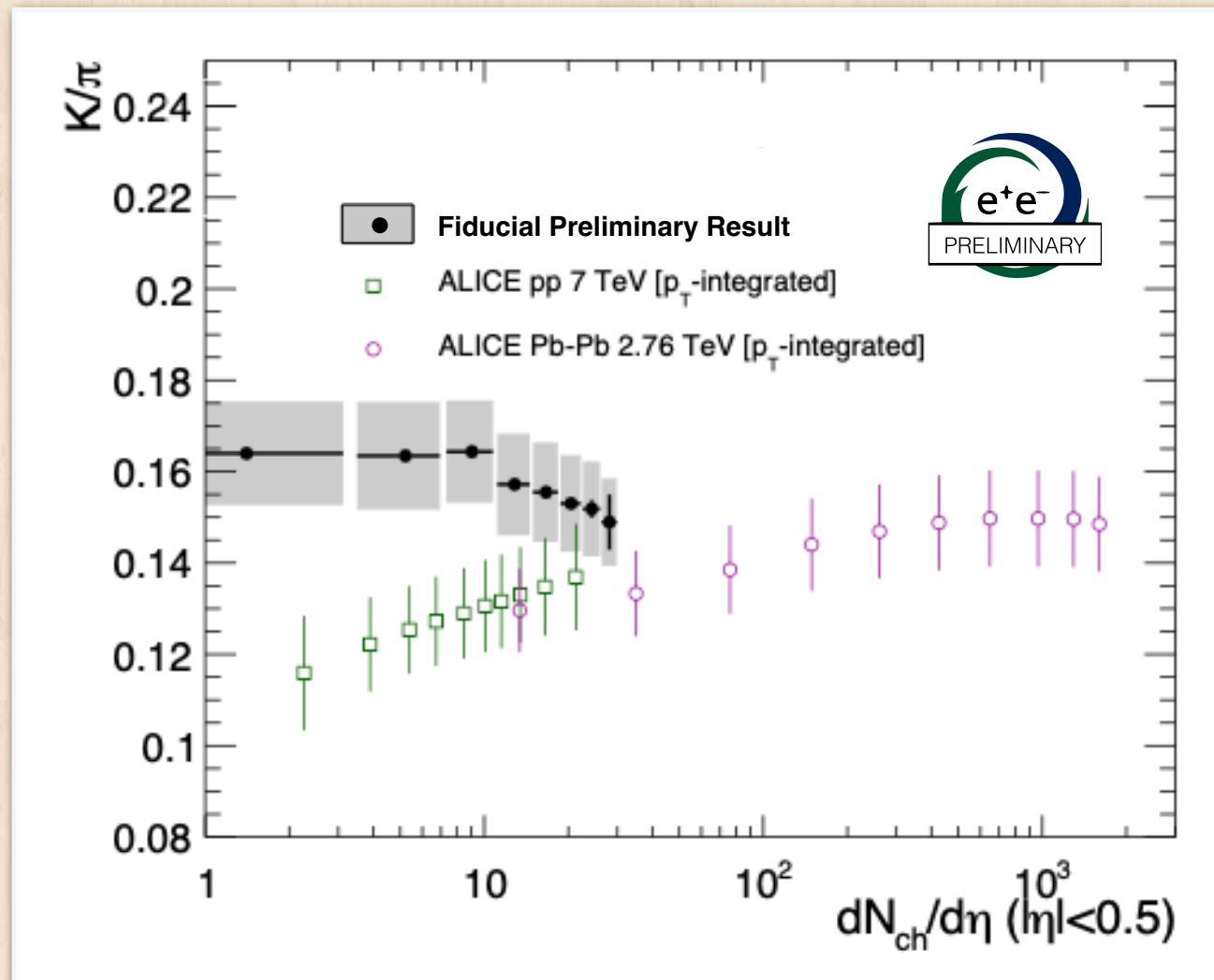
Start with $\sqrt{s} = m_Z$, so mostly 2 jets

Naively we can
look at beam axis



Beam $dN/d\eta$

Beware of the fiducial cuts



Dijet direction is random $\rightarrow dN/d\eta$ captures part of dijet

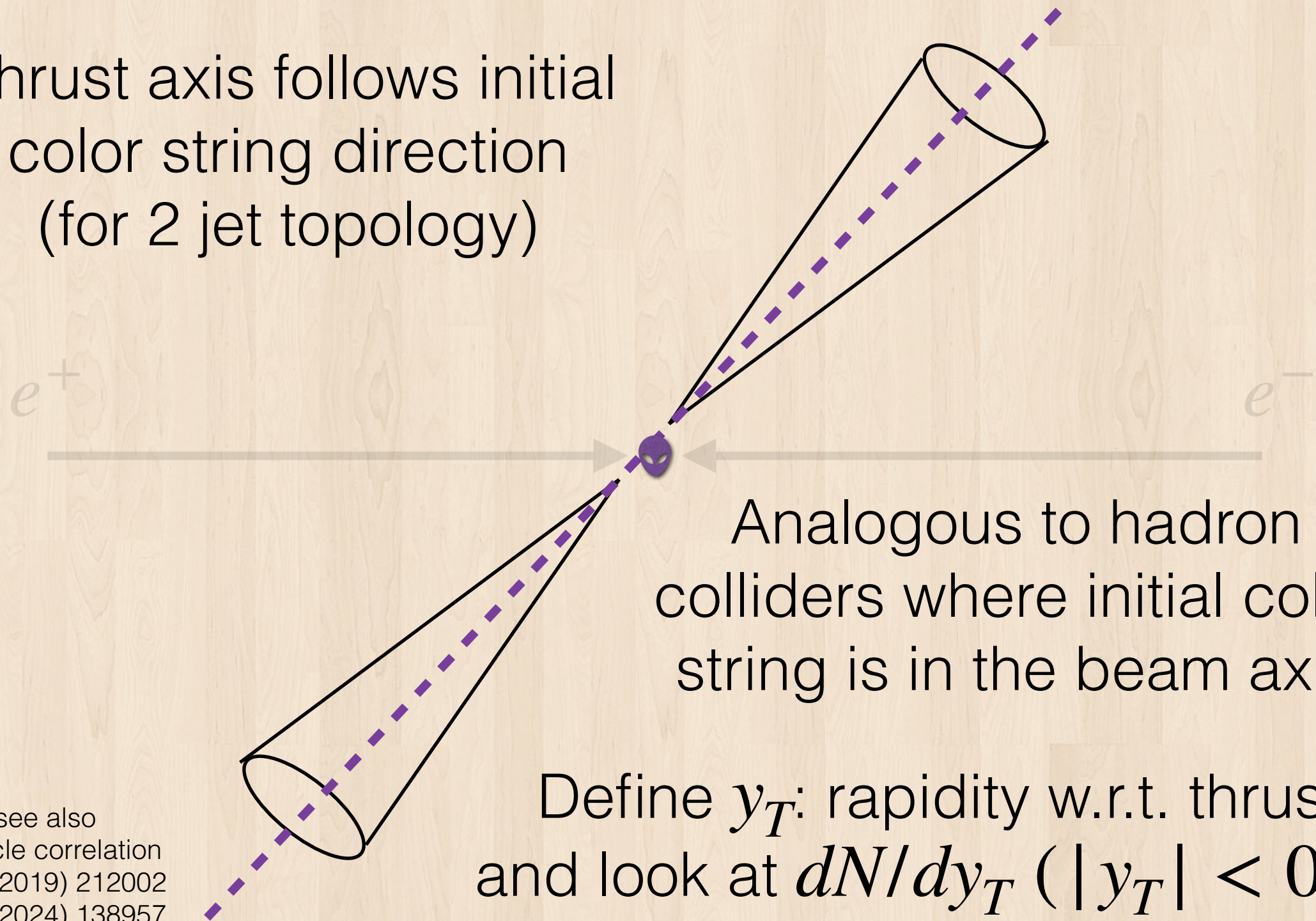
Doesn't seem to follow same trend as hadron colliders

Higher $dN/d\eta \rightarrow$ more shorter strings $\rightarrow$ harder to make $s/\bar{s}$?

Larger Q^2 might also lead to larger K/π

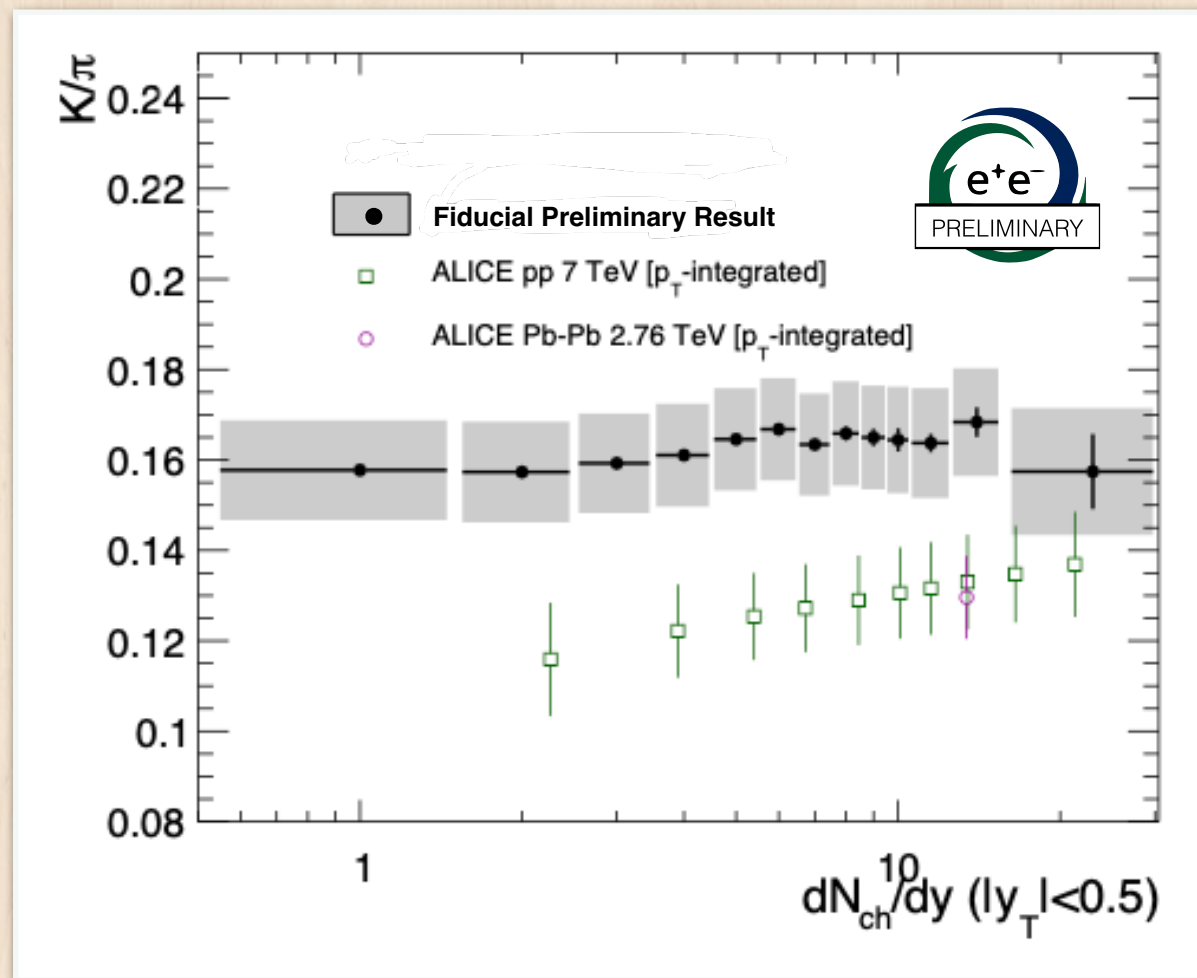
How to measure event activity?

Thrust axis follows initial
color string direction
(for 2 jet topology)



c.f. see also
two-particle correlation
PRL 123 (2019) 212002
PLB 856 (2024) 138957

Thrust dN/dy



Beware of the fiducial cuts

Thrust lines up with dijet

dN/dy largely
devoid of jet particles
if it's 2-jet topology

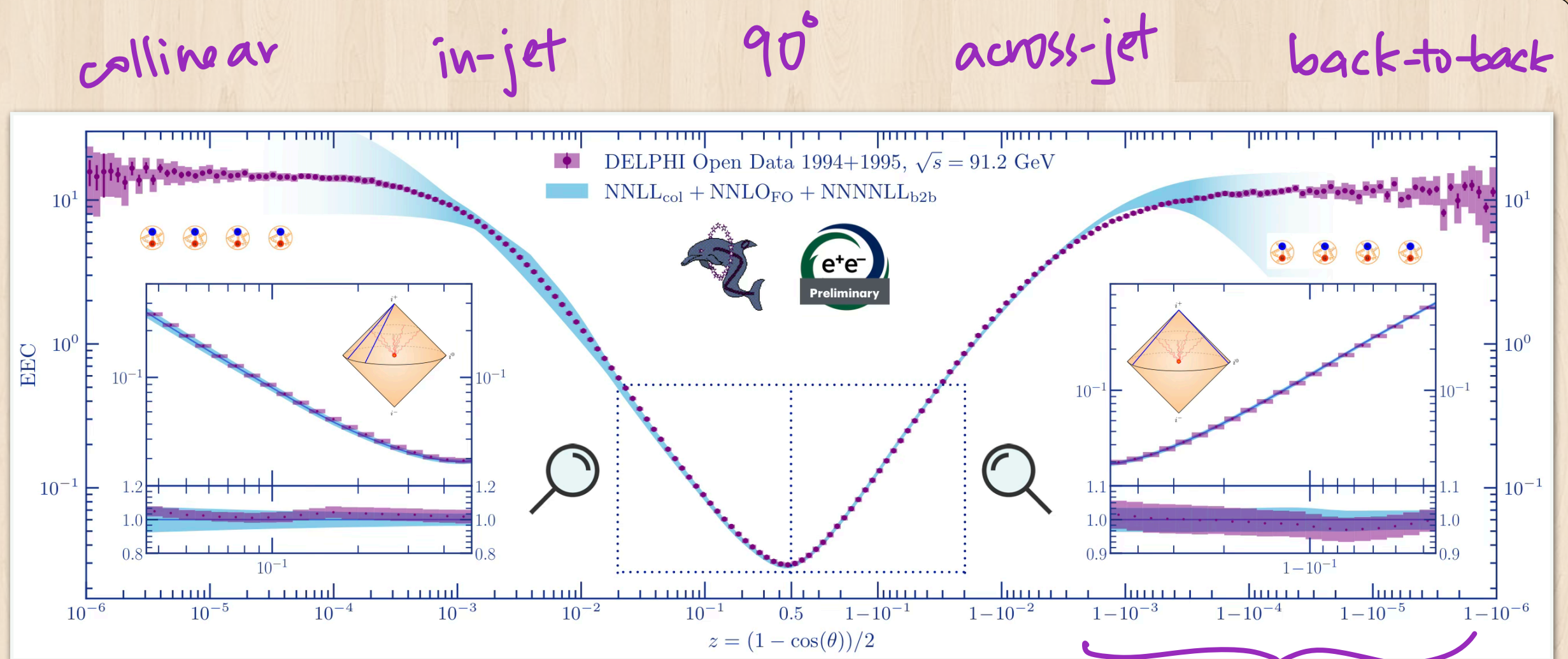
Multijet = higher dN/dy

No clear rising/
dropping trend

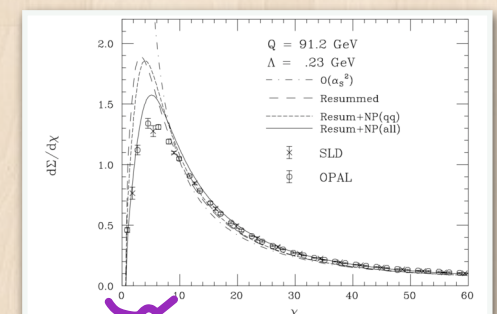
Caution: not apple-to-apple — “multiplicity” not the same

Other recent
highlights

EEC at 91.2 GeV



Compared with **state of the art theory calculation**
 npQCD-heavy region less well controlled
 Finer resolution in the npQCD-heavy regions



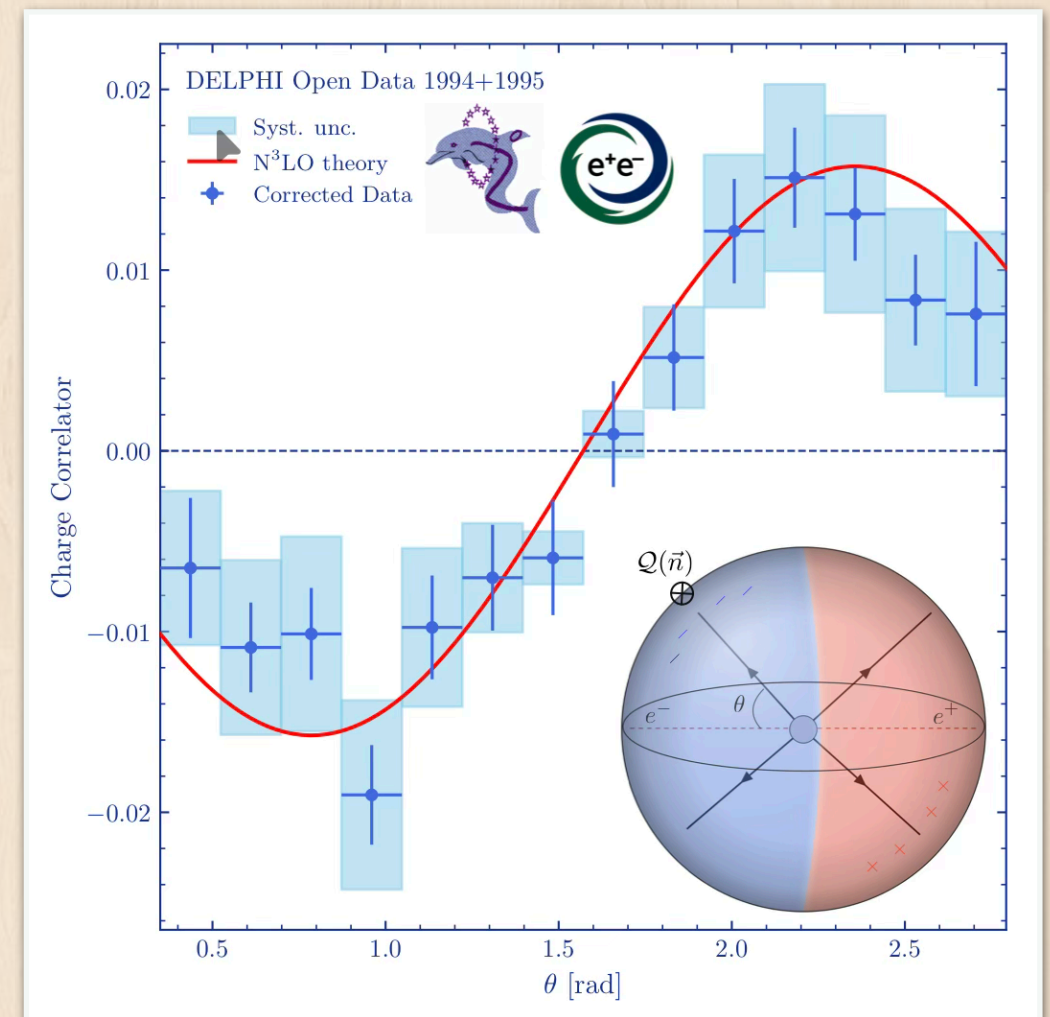
One-point charge correlator

$$Q_1(\theta) = \langle \sum_i q_i \cdot \delta(\theta_i - \theta) \rangle$$

~average charge as a function of angle

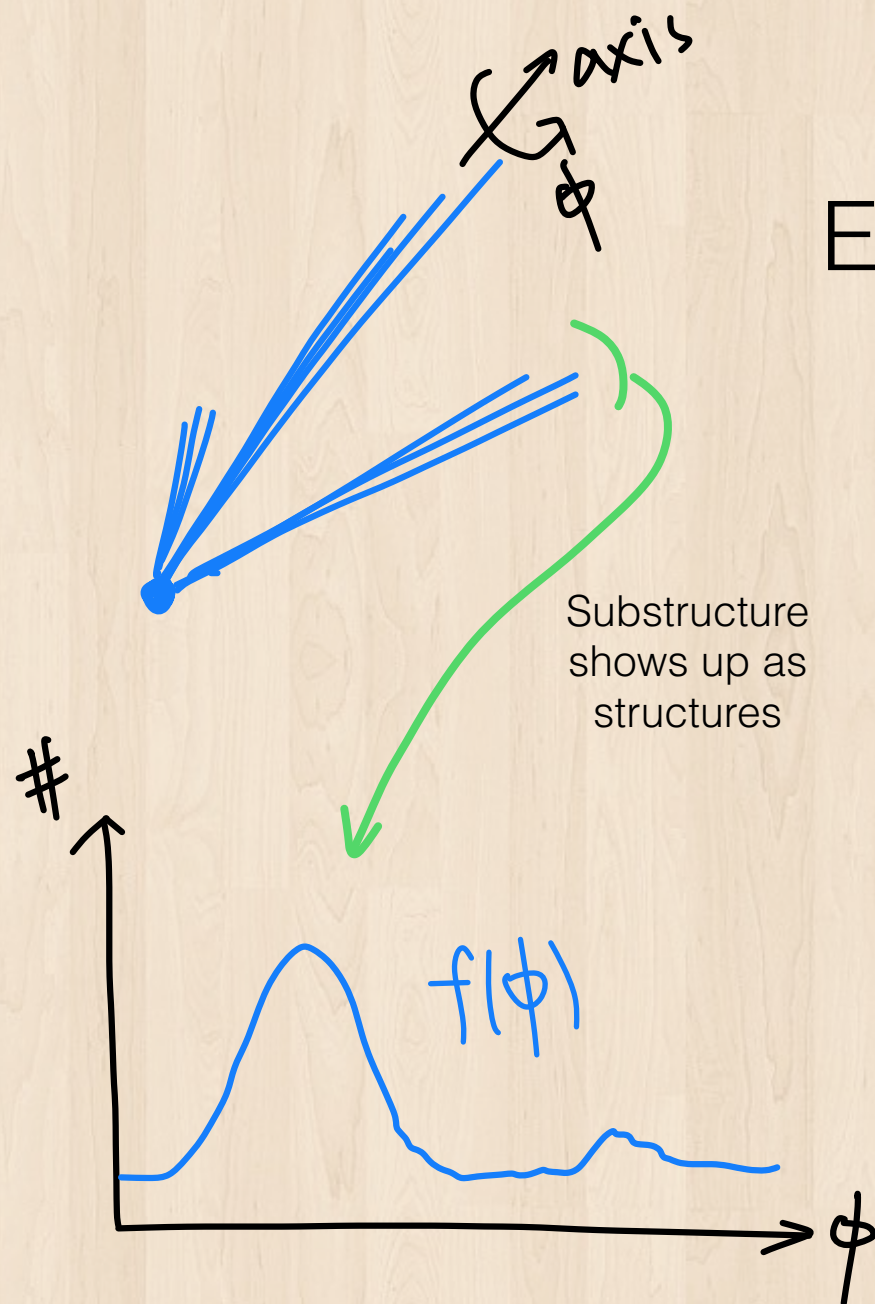
Controlling **charge mistag** is crucial: $Z \rightarrow \tau_h \tau_h$ based data-driven correction

Connection to A_{FB}
(but we defer extraction to future updates)

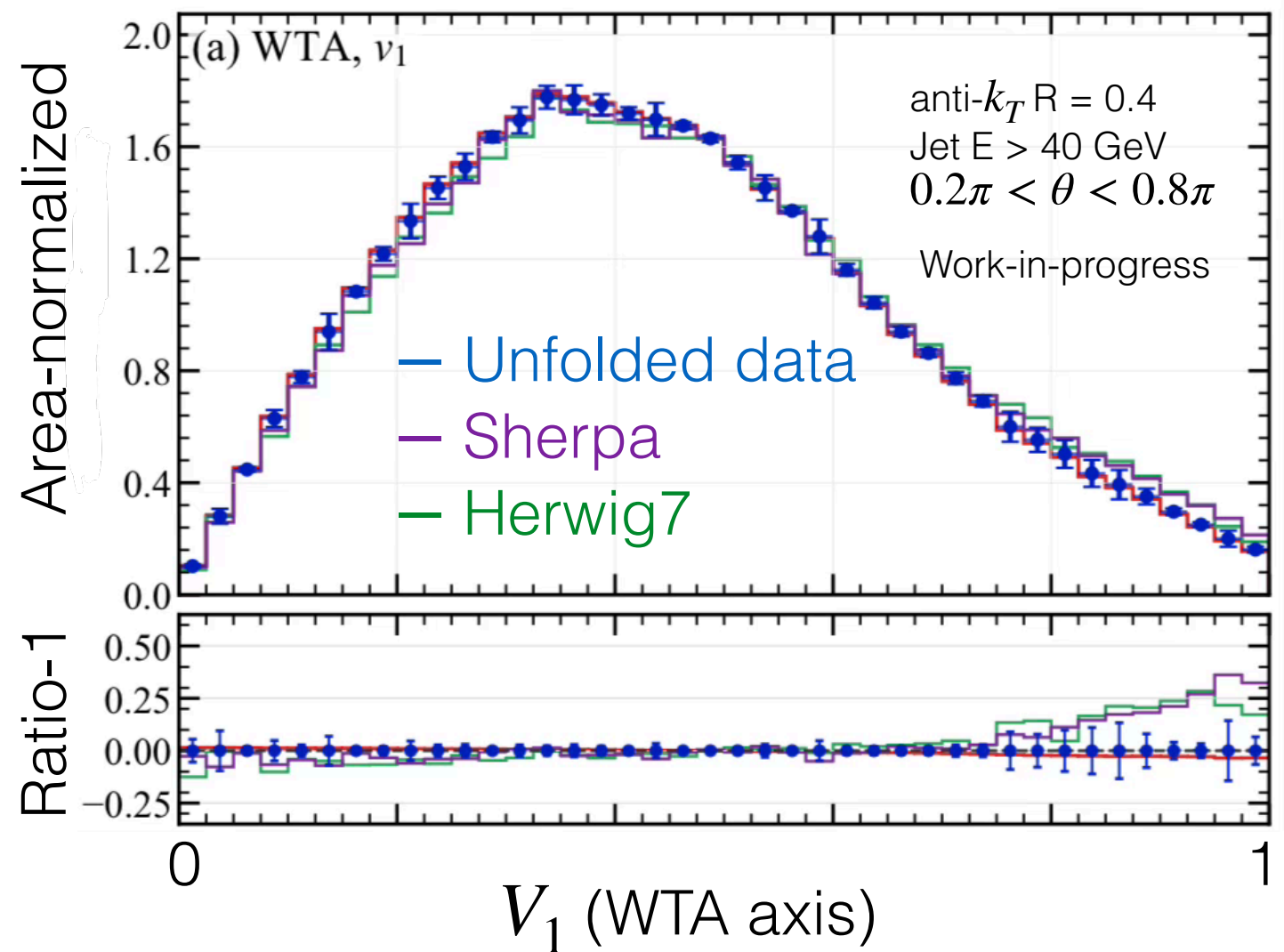


In-jet azimuthal asymmetry

Fourier components $f(\phi) \rightarrow \{V_n\}$
Encodes jet substructure information

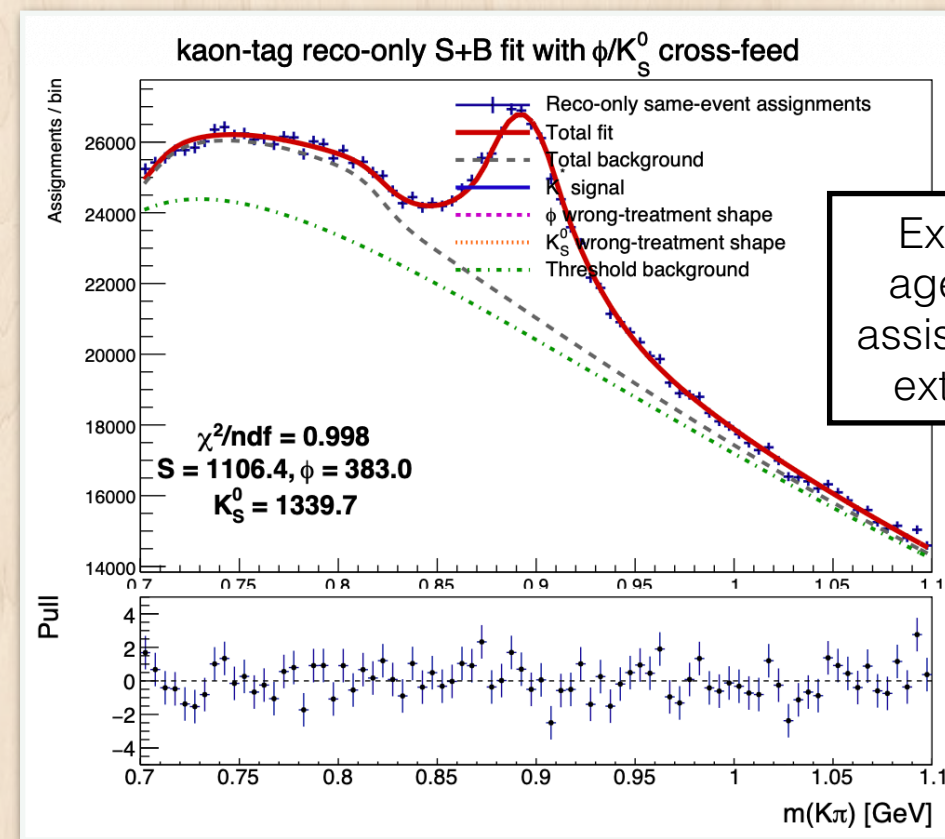
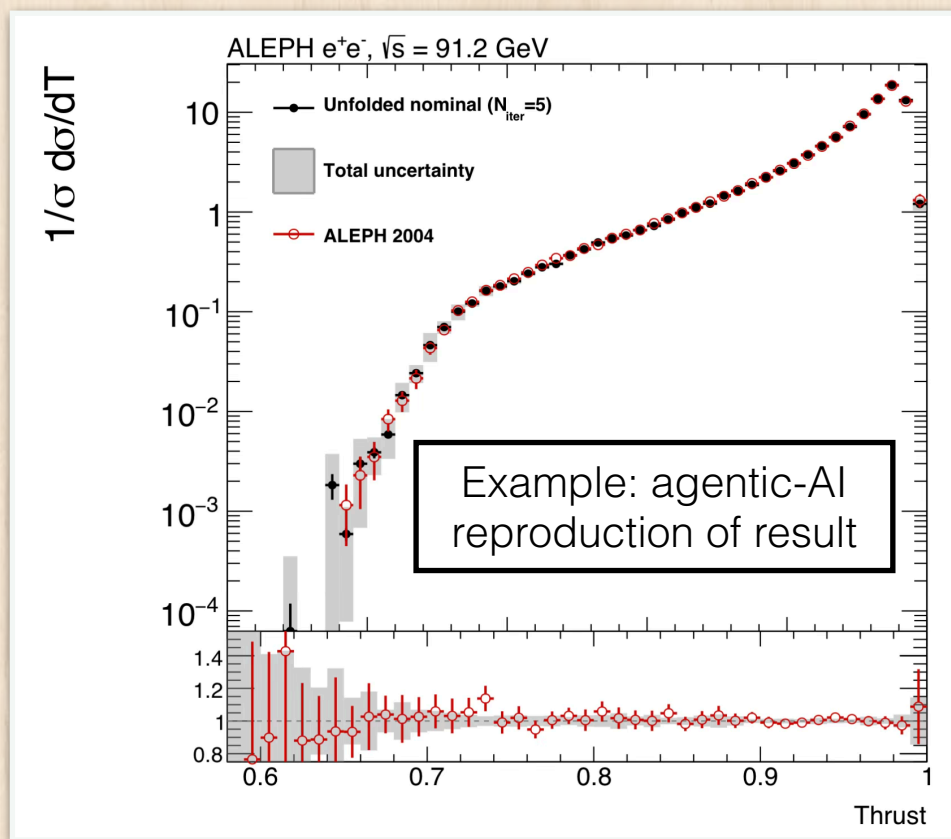


(also: motivation in Heavy-ion physics)



Agentic AI exploration

- The simpler e^+e^- provides excellent **testing ground** for new methods and agentic AI tools
- Cross check analysis, AI-assisted analysis, ...



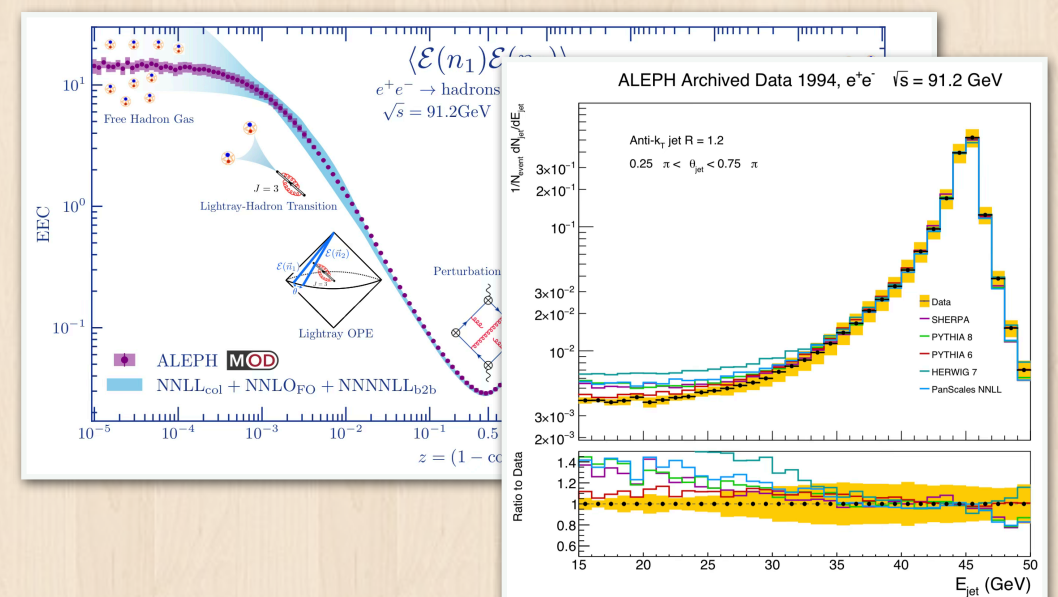
Concluding Remarks

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Summary

- e^+e^- provides a **unique dataset to study QCD** without the complication that comes with hadronic collision systems
 - **New information** can be gained from LEP data
 - Confronting state-of-the-art **QCD calculations with data**
 - The e^+e^- alliance is actively developing a program for precision QCD studies
- Capabilities on **jets, correlators, identified particle and novel observables**
- Many exciting possibility



Backup Slides Ahead

Questions?

