Multiplicity Dependence of the K/π Ratio in e^+e^- Collisions with DELPHI Open Data

Yi (Luna) Chen[1], Yen-Jie Lee[2], Nishant Gaurav[1], Honey Khindri[3]
for the Electron-Positron Alliance. SQM 2026, Mar 24, 2026

[1]Vanderbilt University [2]MIT [3]IITM

with



The Vanderbilt HENP group is supported by US DOE-NP

Preliminary

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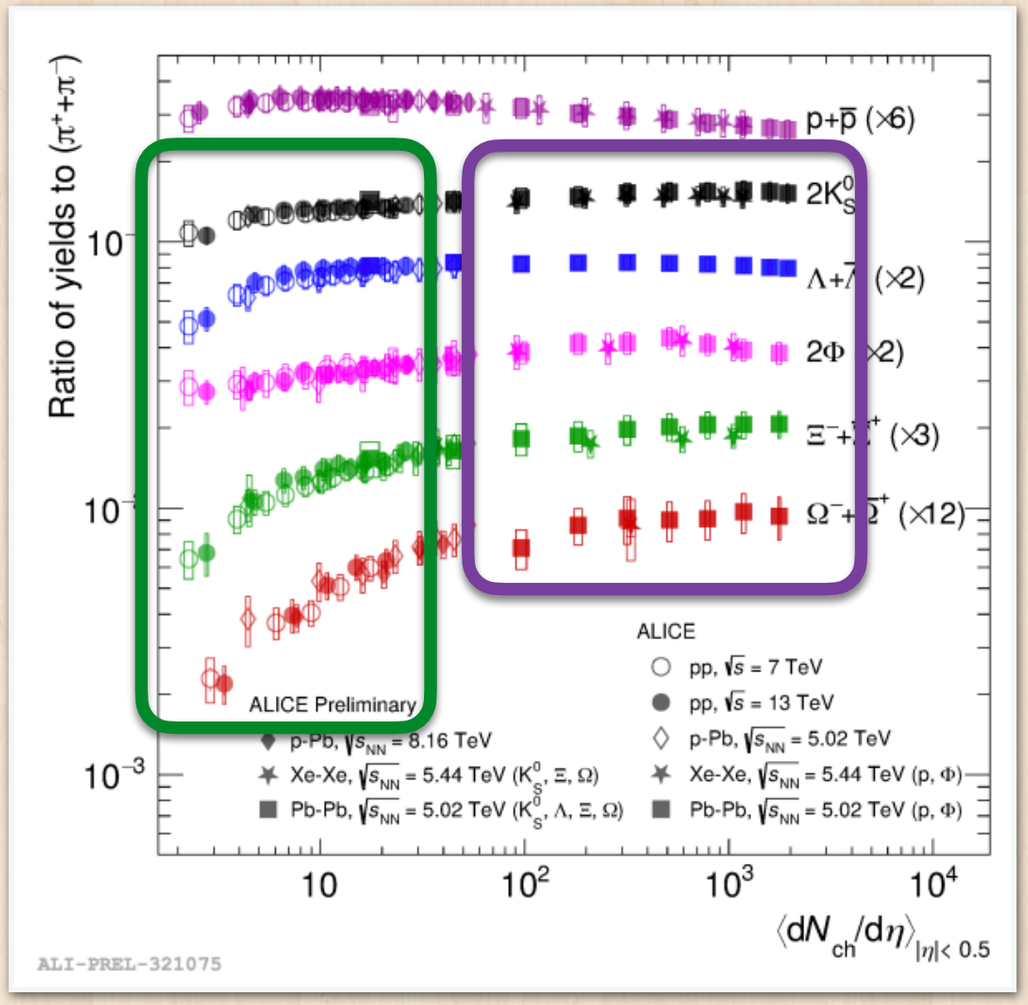
Motivation

Strangeness across *pp*/*pA*/*AA*

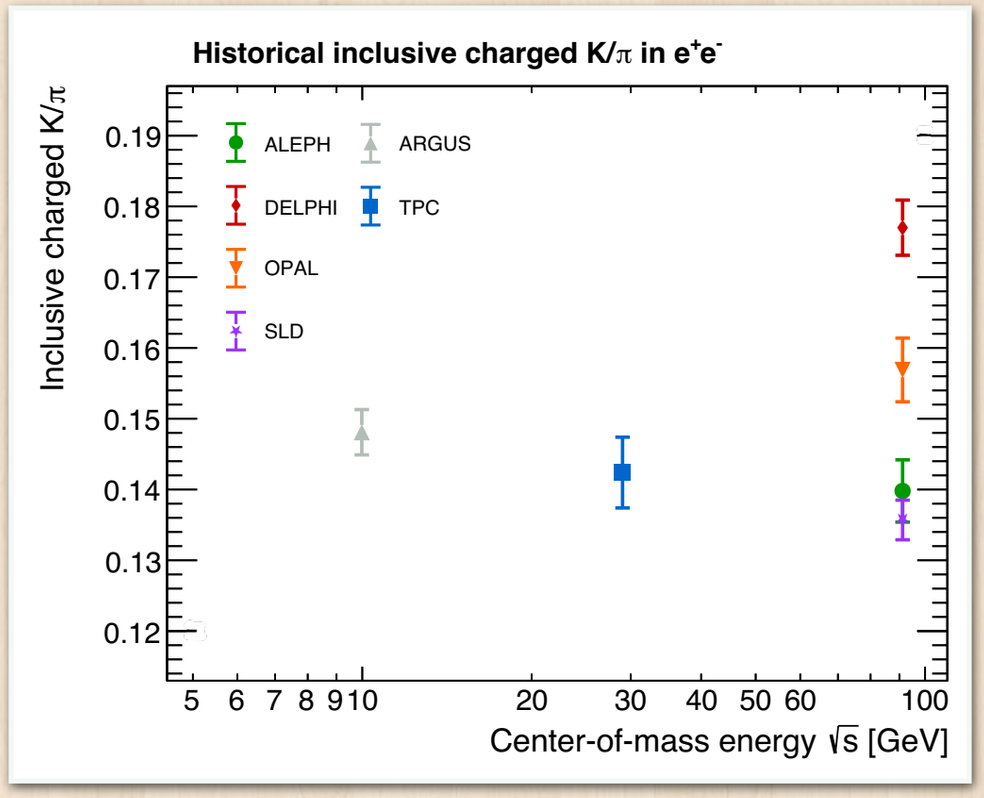


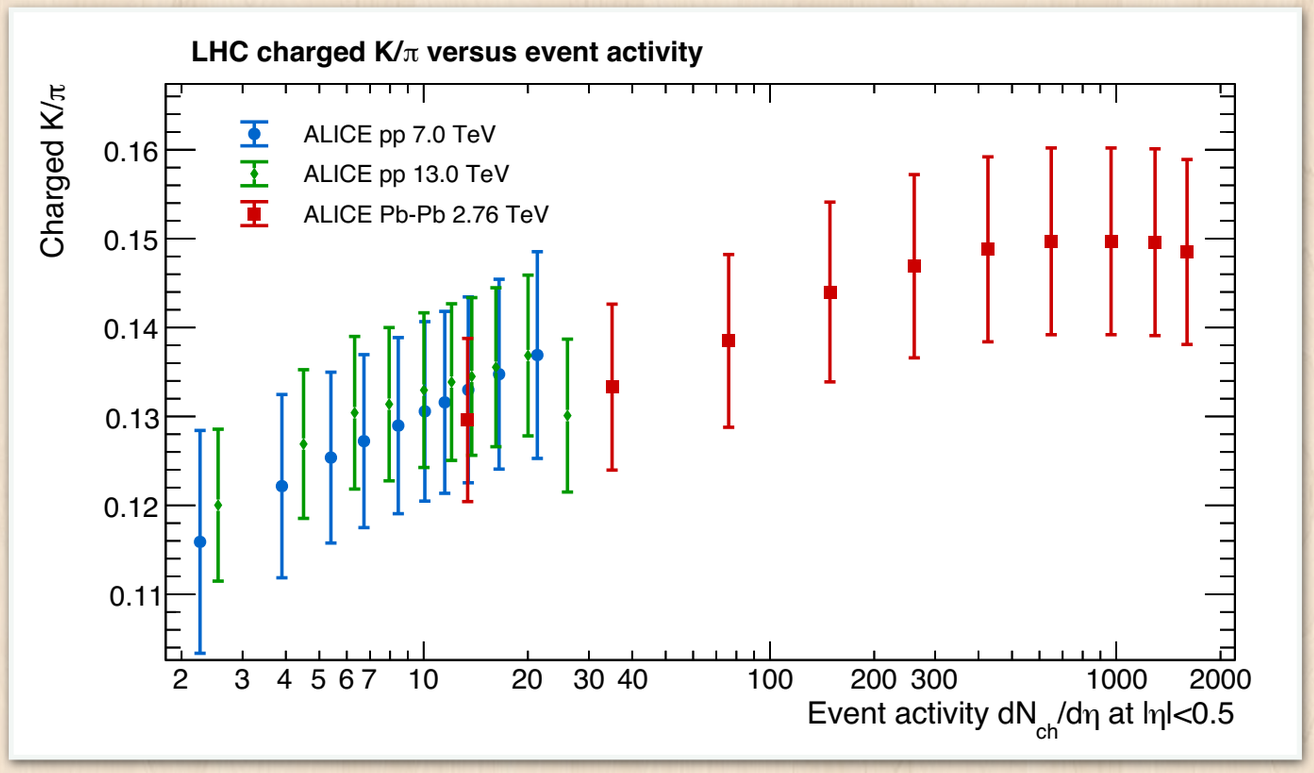
QGP temperature $> 2m_s$
we expect more $s\bar{s}$

Ratio is indeed lower in smaller system, however trend across systems

These are all hadronic collision systems

Now what about e^+e^-?





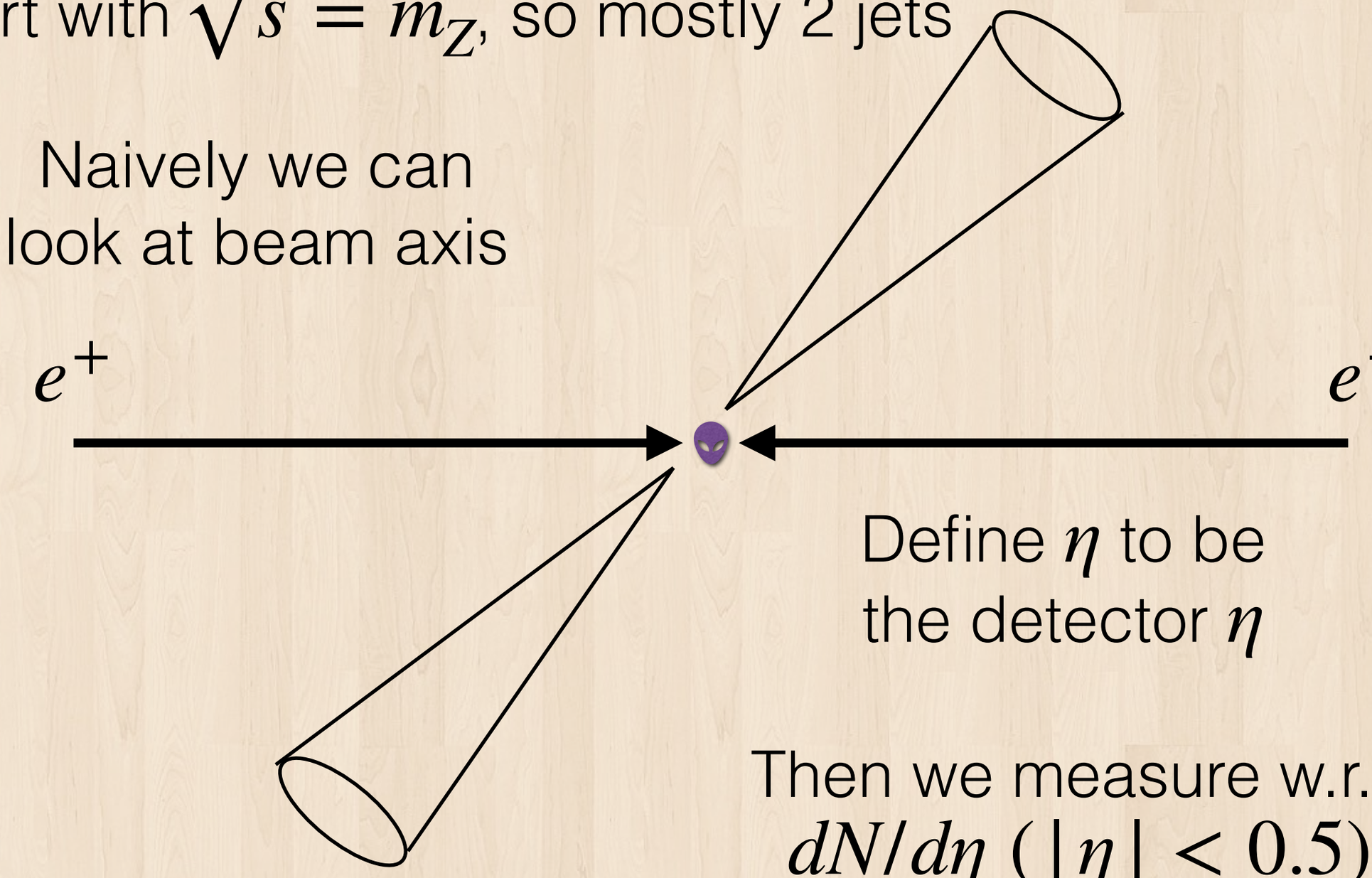
K/π ratio in the same ballpark as pp

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

How to measure event activity?

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

Naively we can look at beam axis

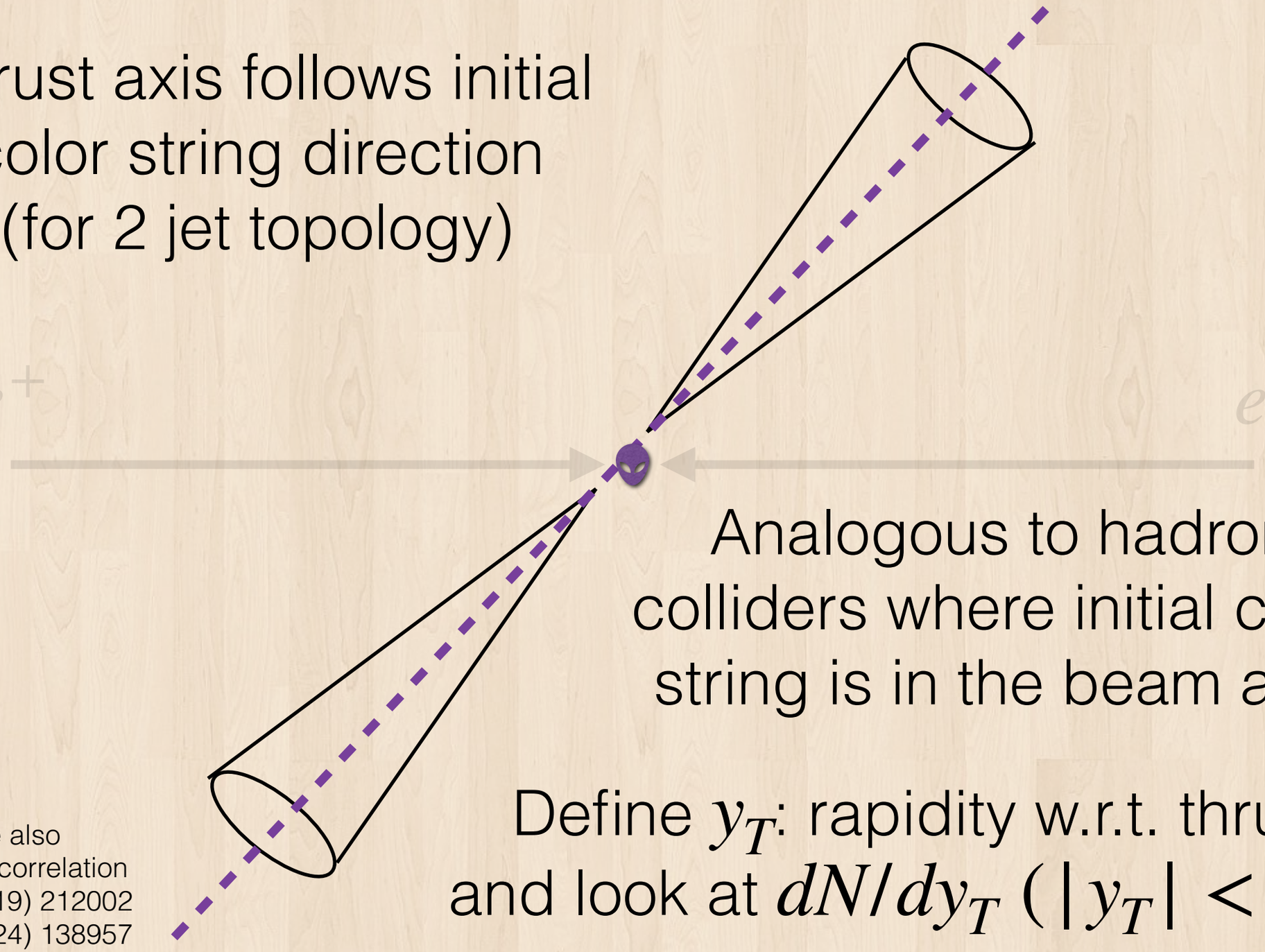


Define η to be the detector η

Then we measure w.r.t. $dN/d\eta\ (|\eta| < 0.5)$

How to measure event activity?

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

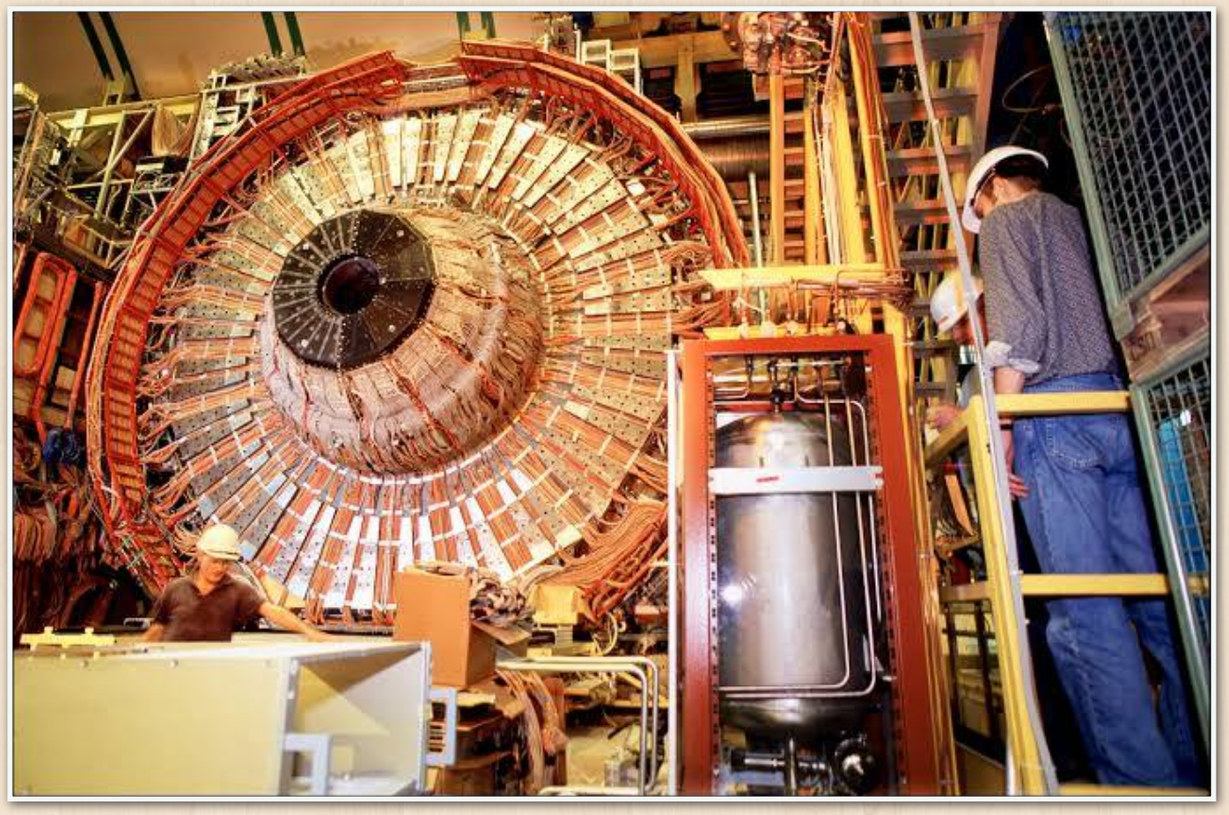


Analogous to hadron colliders where initial color string is in the beam axis

Define y_T: rapidity w.r.t. thrust and look at dN/dy_T ($|y_T| < 0.5$)

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

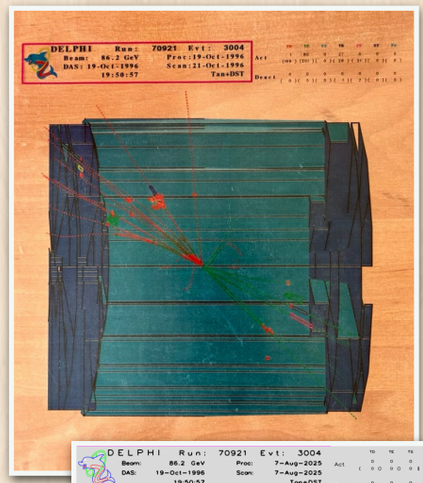
The LEP and DELPHI detector

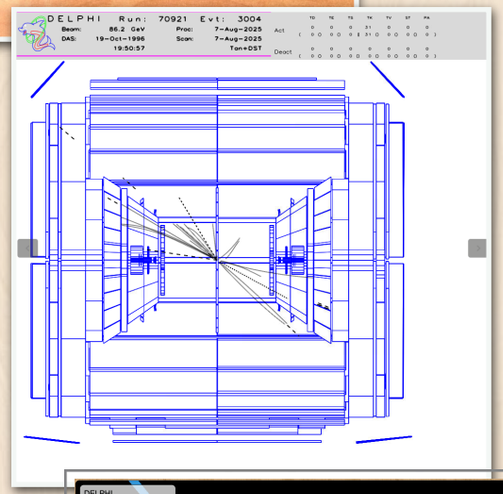


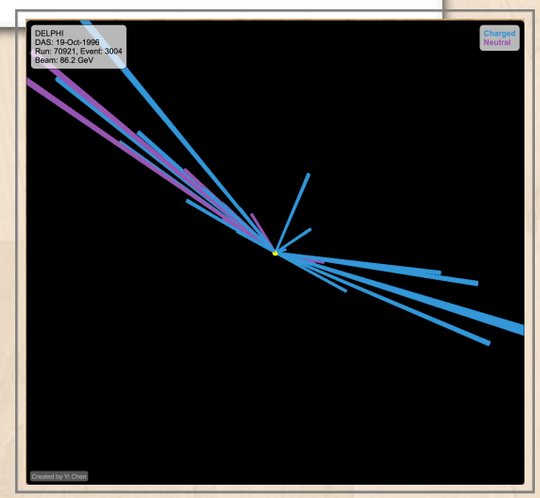
LEP1: collide at $\simeq m_Z$, few million hadronic events
LEP2: higher energy up to 209 GeV

The DELPHI open data

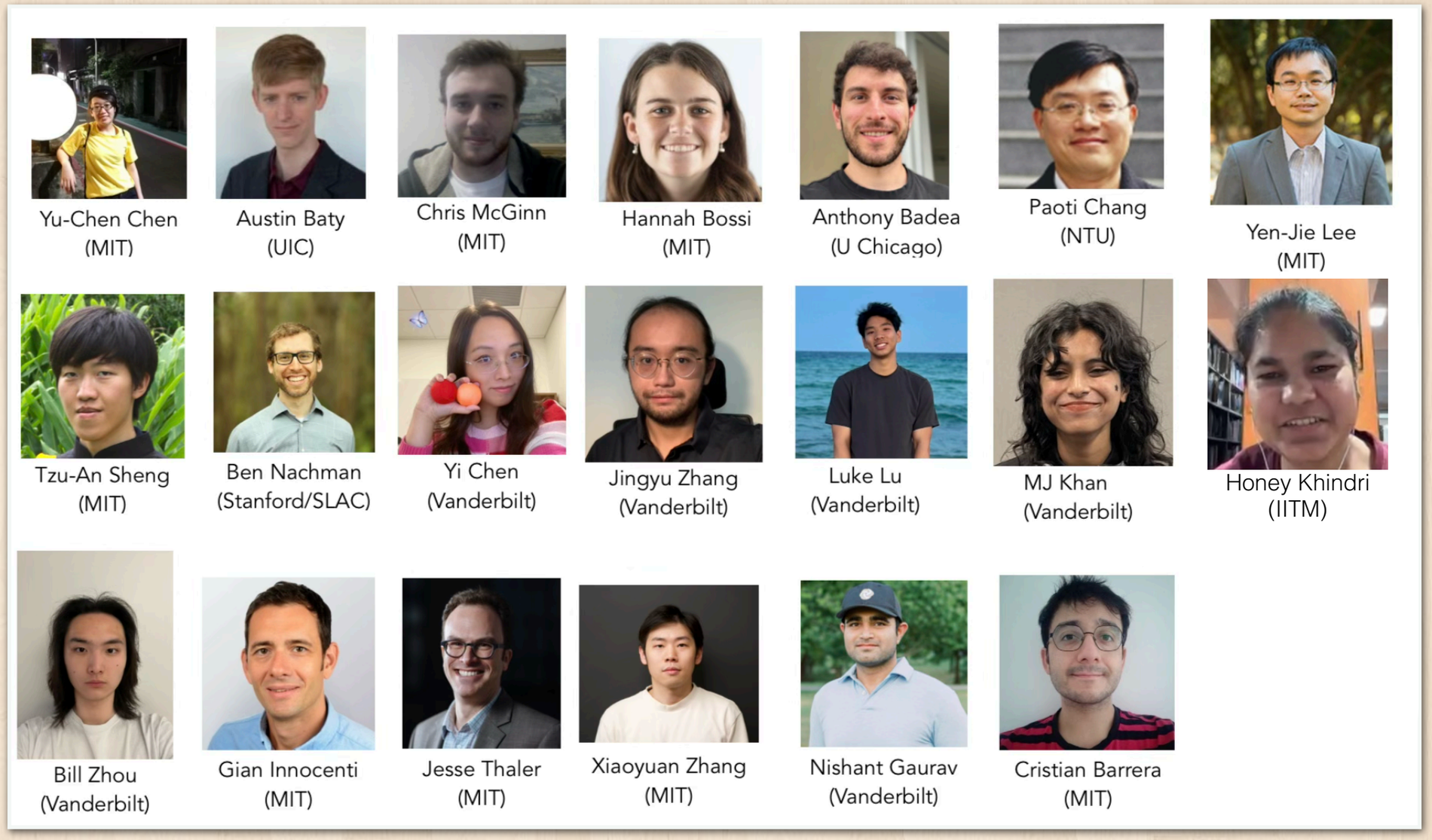
- DELPHI Open Data released in 2024
- Full access on data, simulation and *simulation software* (GEANT3-based)
  - We can run modern generator
- Thanks to the DELPHI Collaboration, data preservation team, especially **Dietrich Liko** and **Ulrich Schwickerath** for guidance on how to use the data







e^+e^- reanalysis effort



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

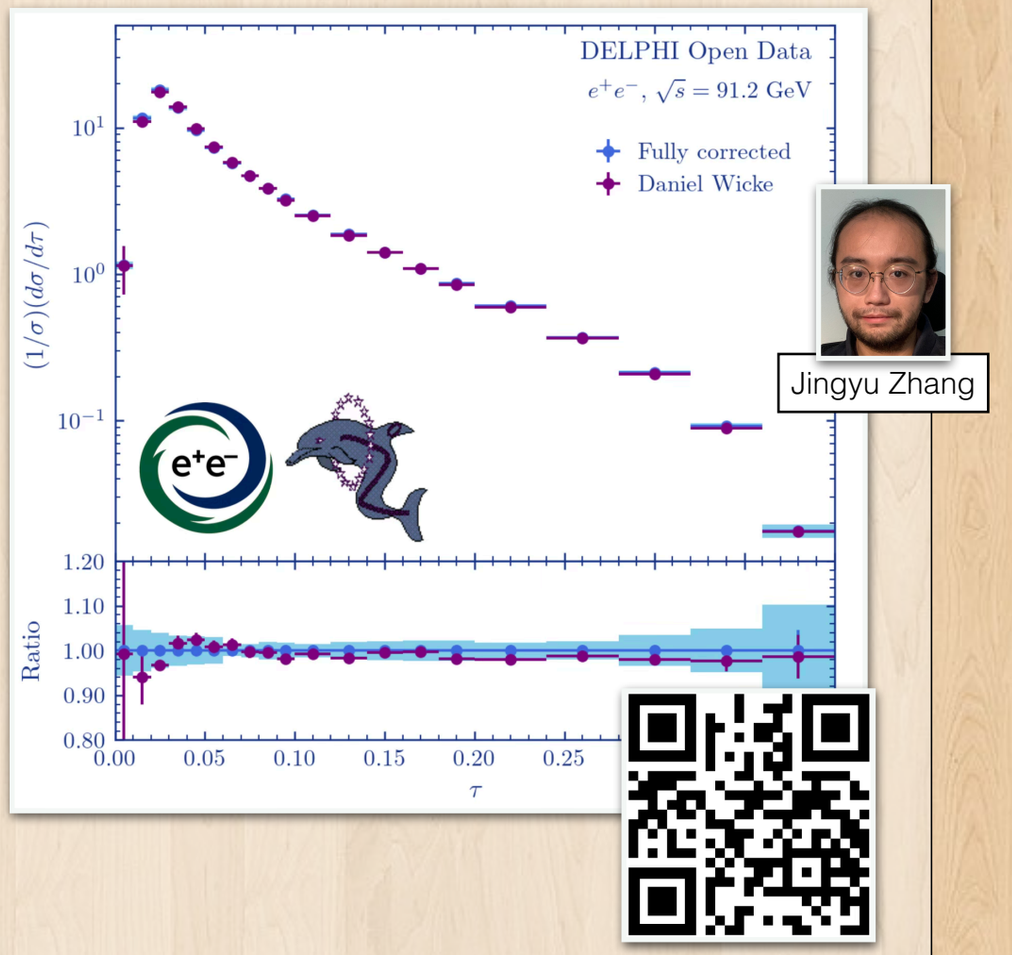
e^+e^- reanalysis effort

- Following the experience with ALEPH reanalysis, we started with understanding the basic detector performance and reproduce existing results

- First DELPHI reanalysis publication with thrust measurement coming soon

  - Technical note: 2510.18762

- See https://ee-alliance.org/ for more information



The analysis in a nutshell

What we measure

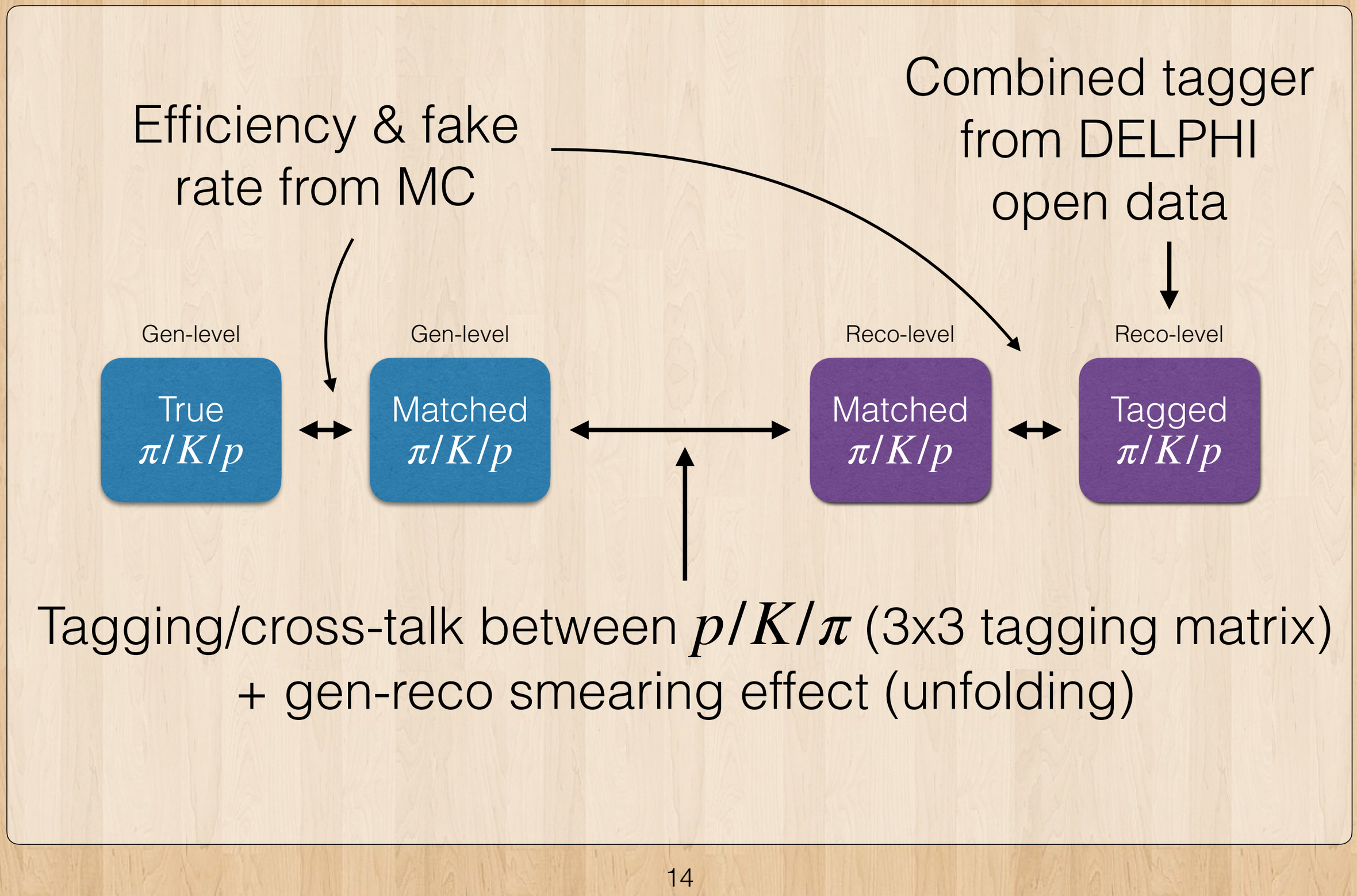
DELPHI Open Data 1994, $\sqrt{s} = m_Z$
Simulated PYTHIA8 (through DELSIM)

K/π ratio in
Fiducial region:
$|\cos\theta| \in 0.15 - 0.675$,
$p_T \in 0.4 - 5.0$

Two types of event activity measures
Beam $dN_{ch}/d\eta\,(|\eta| < 0.5)$
Thrust $dN_{ch}/dy_T\,(|y_T| < 0.5)$

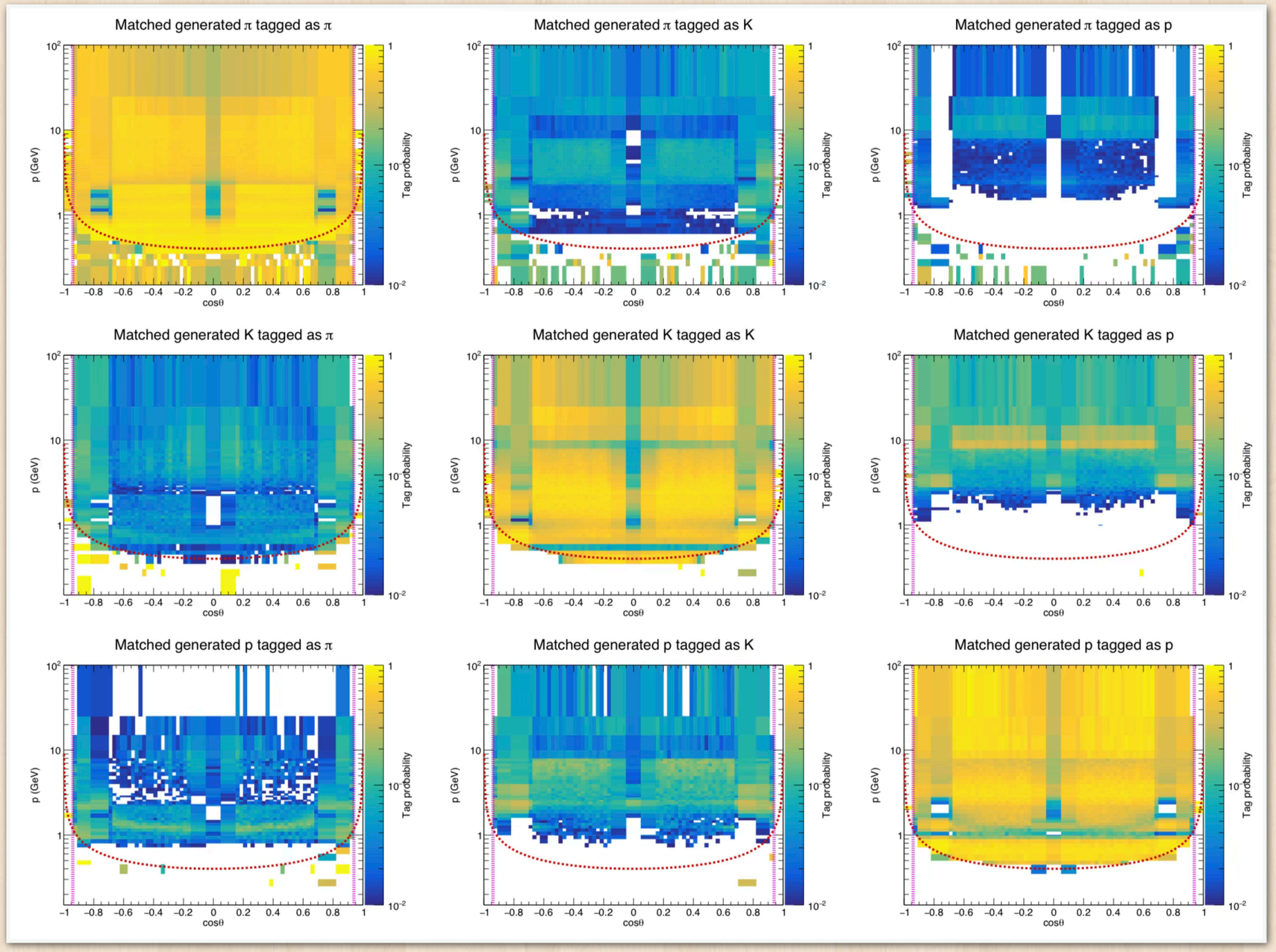
Baseline hadronic event selection
$N_{ch} \geq 7$
$E_{total} > \sqrt{s}/2$
Thrust θ: 30°-150°

Overall strategy



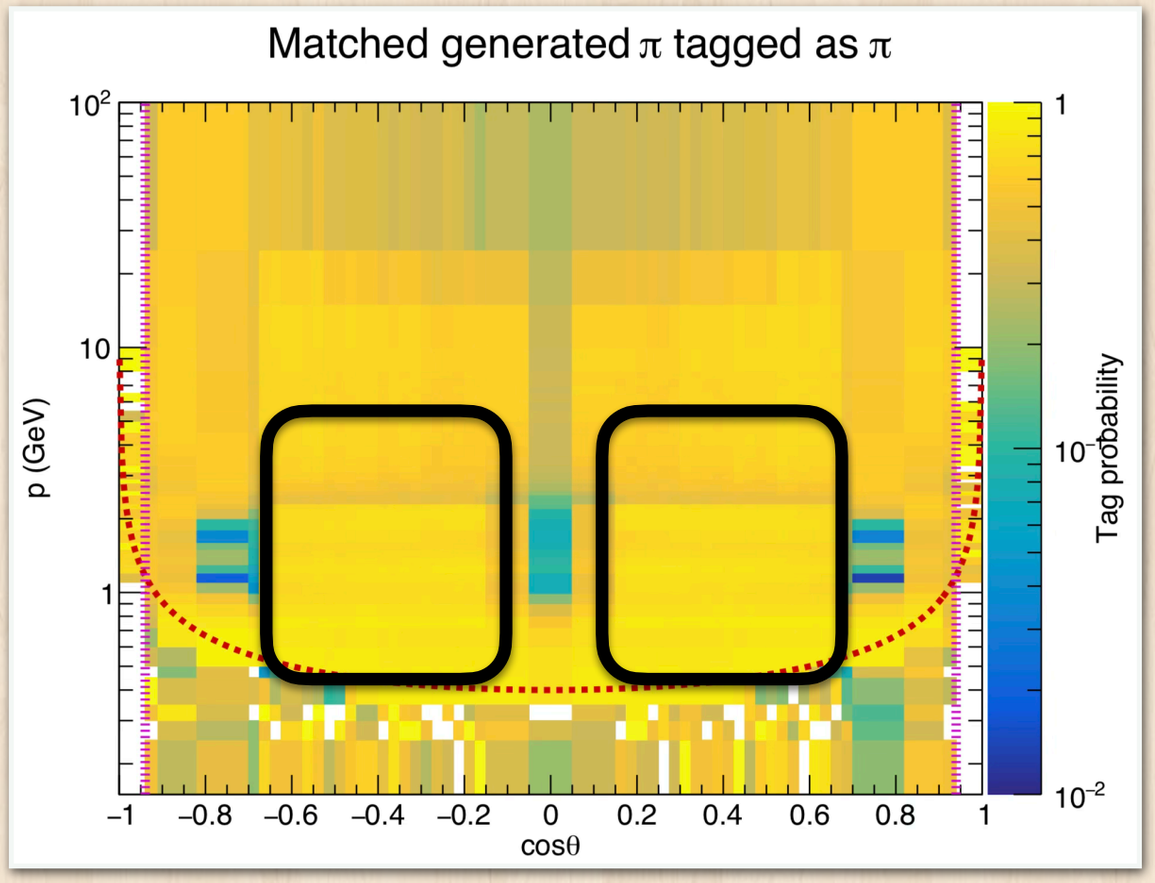
Tagging/cross-talk between $p/K/\pi$ (3x3 tagging matrix)
+ gen-reco smearing effect (unfolding)

MC Tagging Efficiency



MC Tagging Efficiency

Zoomed in for π tagging efficiency



This is the standard working point

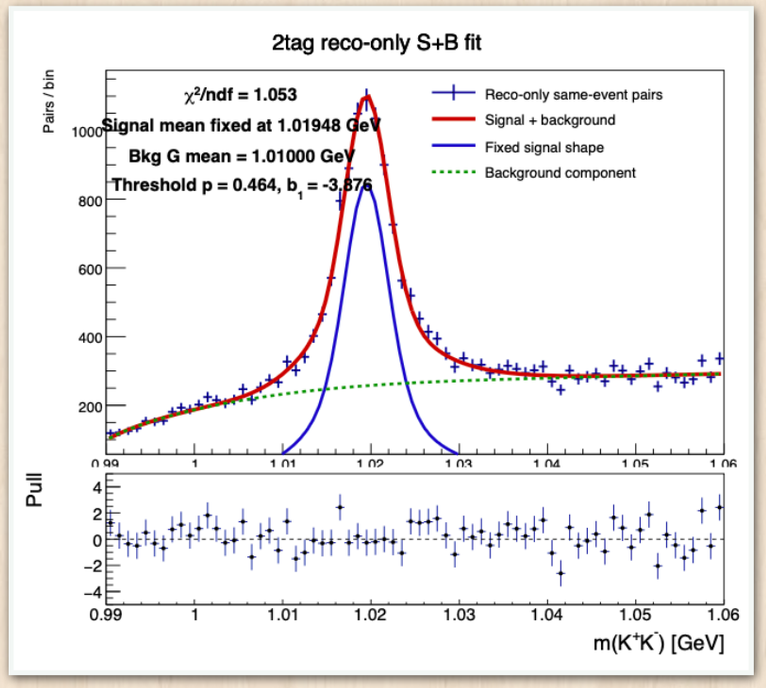
Generally good tagging efficiency

Some detector features → avoid these dips with fiducial region

Also non-negligible cross-talk (especially π tagged as K) → 3x3 tagging matrix inversion needed

Data/MC scale factor

Use $\phi \to KK$ to control K tagging efficiency



Example fit: ϕ

Fit for yield with 1 tag vs. 2 tag

Repeat for data & MC

Signal: Gauss+CB

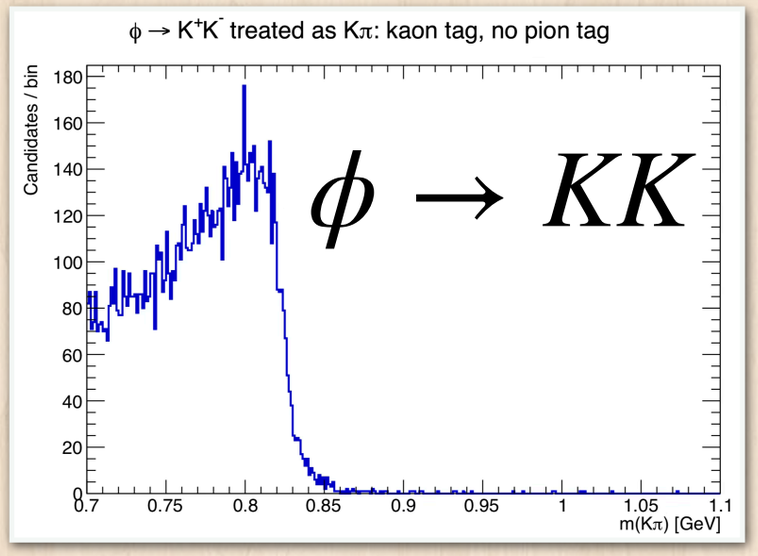
Background: $N(m - 2m_K)^p e^{bm}$

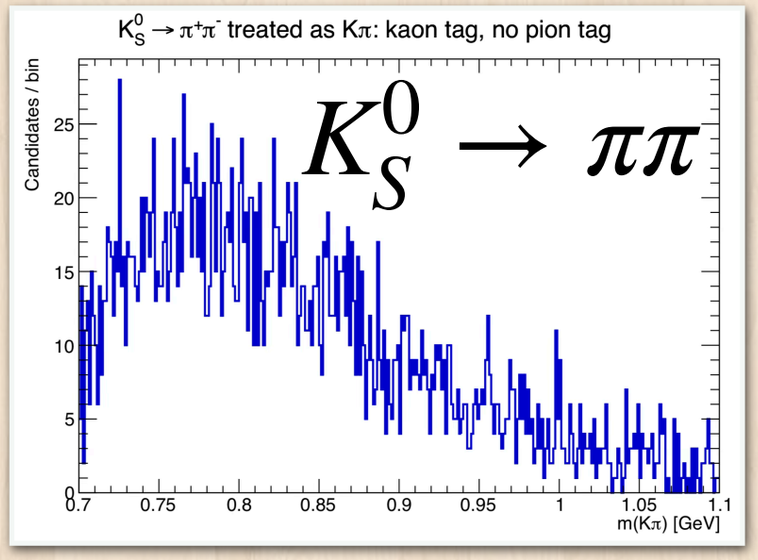
Source	ΔSF_ϕ
Signal function	0.0061
Background function	0.0496
Fit range	0.0077
Matching angle	0.0083
Total systematic	0.0513

Data/MC scale factor

Use $K^* \to K\pi$ for π tagging efficiency

(and $D^0 \to K\pi$ for cross check)





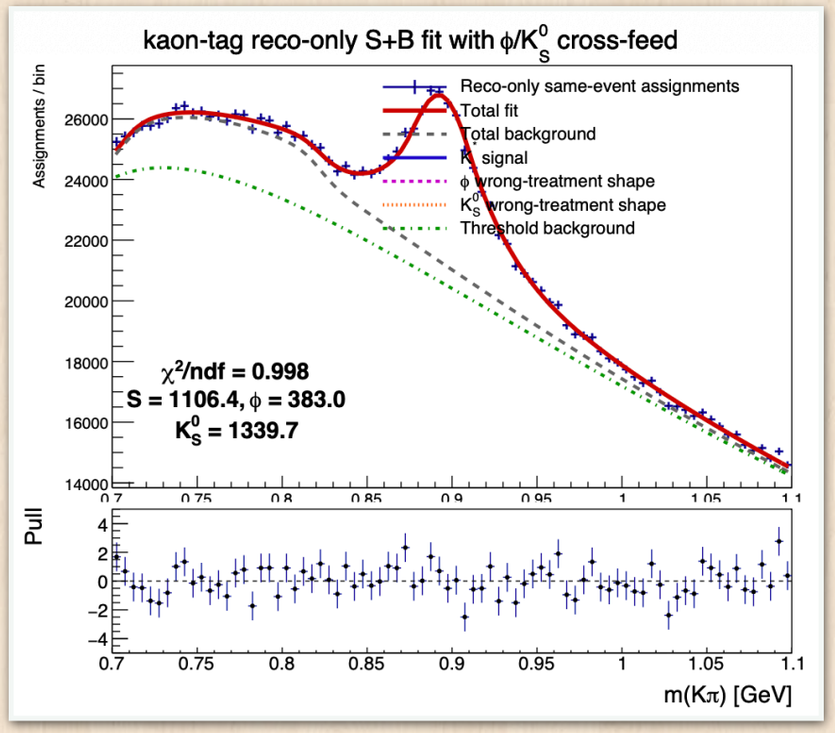
Wrong mass assignment for ϕ, K_S^0 fall in the same window as K^*

Fit shape from MC and transfer over as part of background

Data/MC scale factor

Use $K^* \to K\pi$ for π tagging efficiency

(and $D^0 \to K\pi$ for cross check)



Example fit: K^*

Signal: Gauss+CB

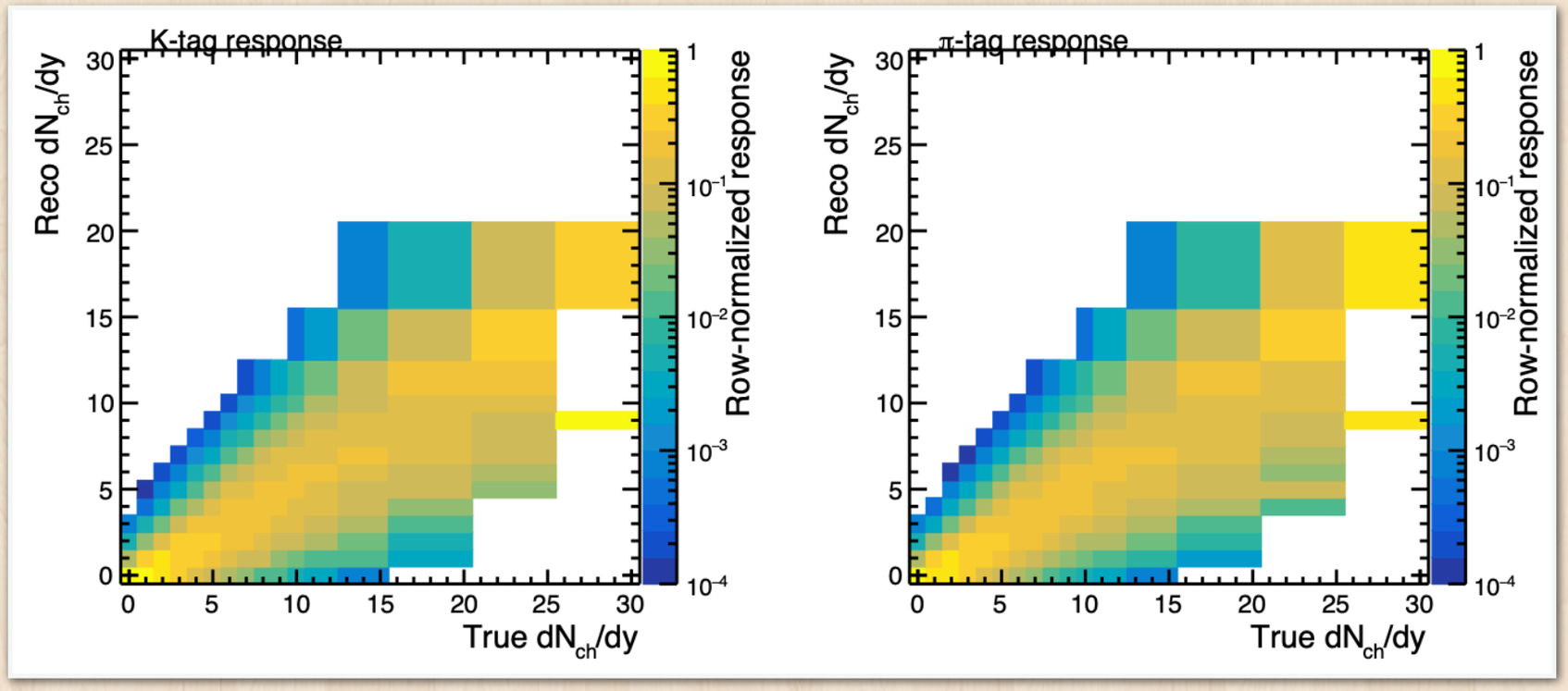
Background: threshold function

Variation	SF	Shift from nominal
Signal PDF	0.9482	-0.0089
Background PDF	0.9778	+0.0207
Fit range	0.9573	+0.0001
Matching angle	0.9580	+0.0009
Total systematic		0.0225

Background PDF variation again dominates

Reco-Gen unfolding

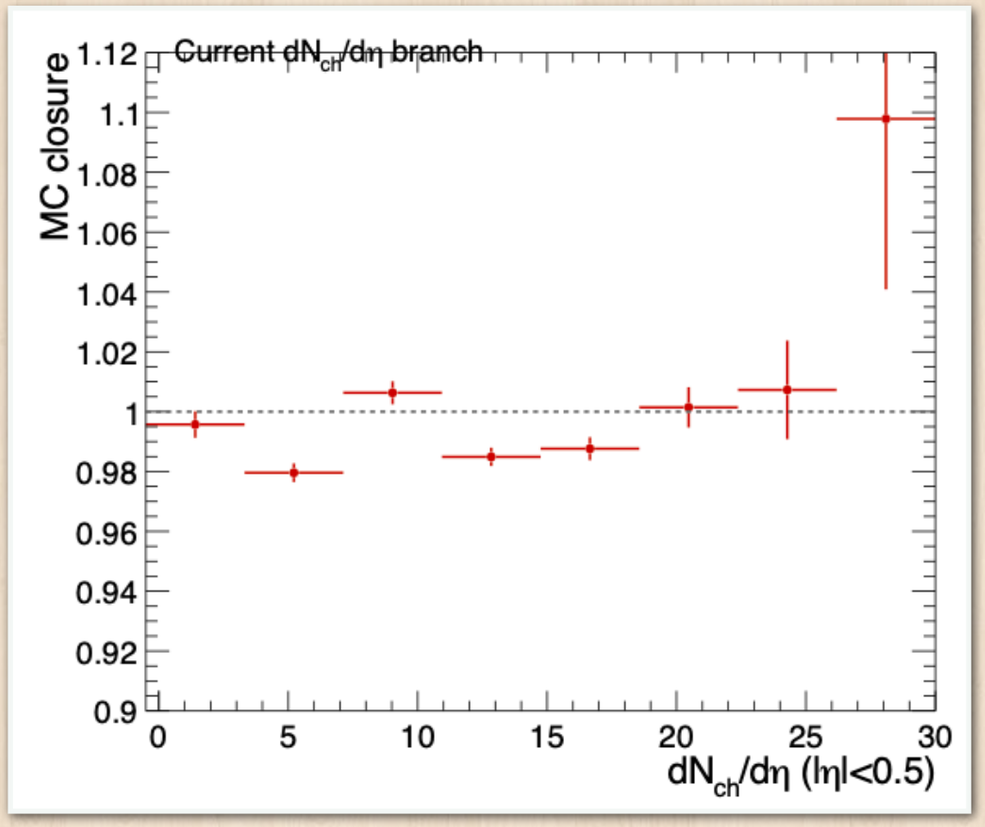
We apply explicit event-activity unfolding
to take into account bin migration



Example smearing matrix

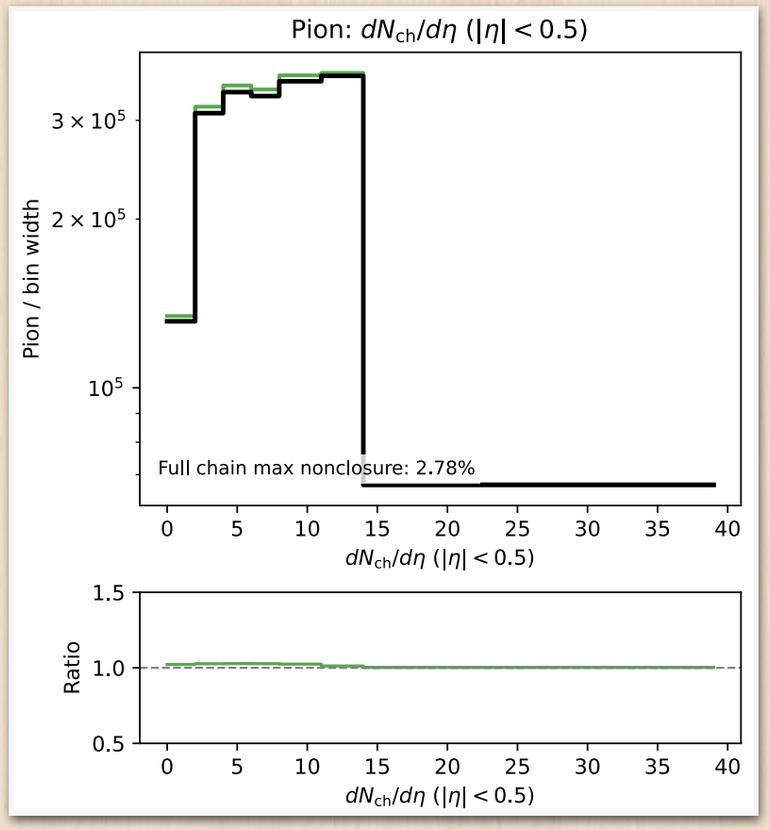
Unfold $N_{p/K/\pi}$ in bins of event activity

Analysis closure on MC



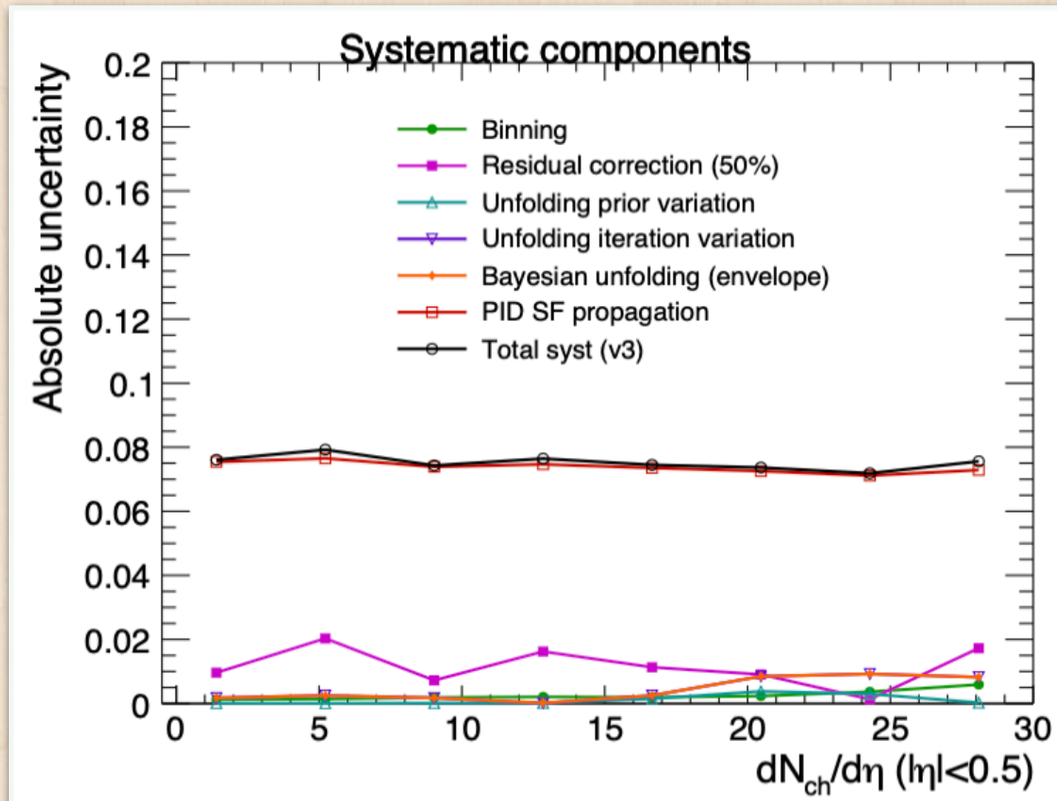
Closure of the main analysis: ~O(2%)

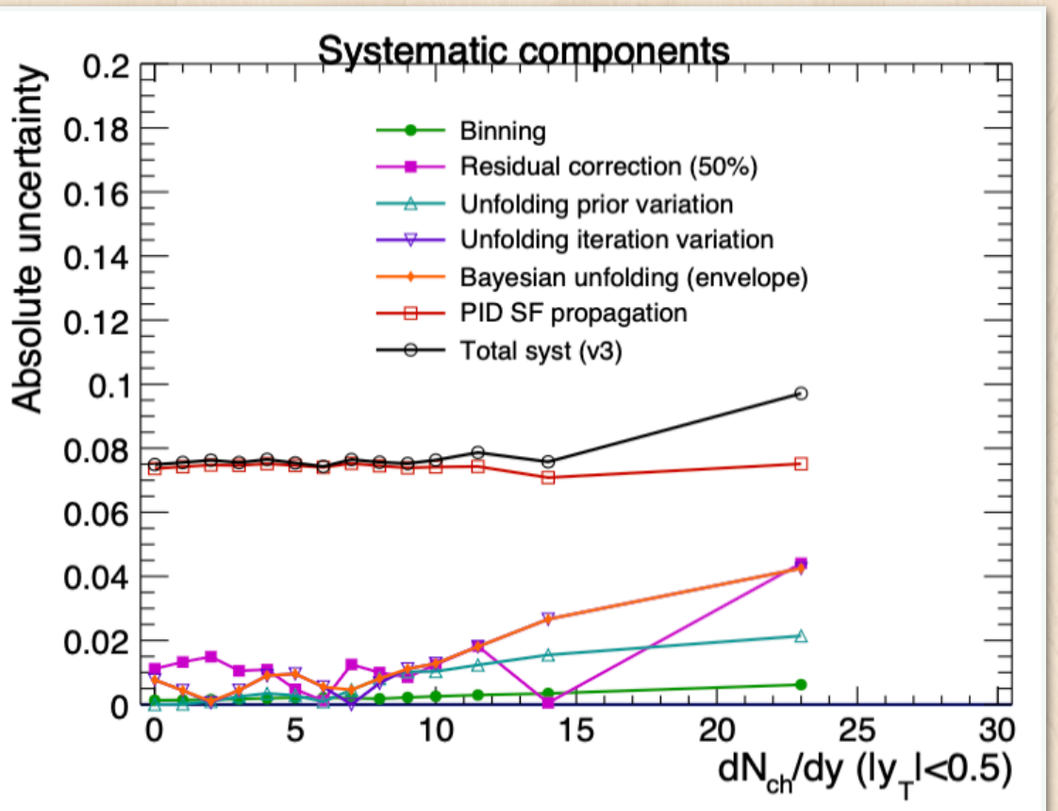
c.f. independent second cross check analysis



→ different approach but give compatible result

Systematic uncertainties





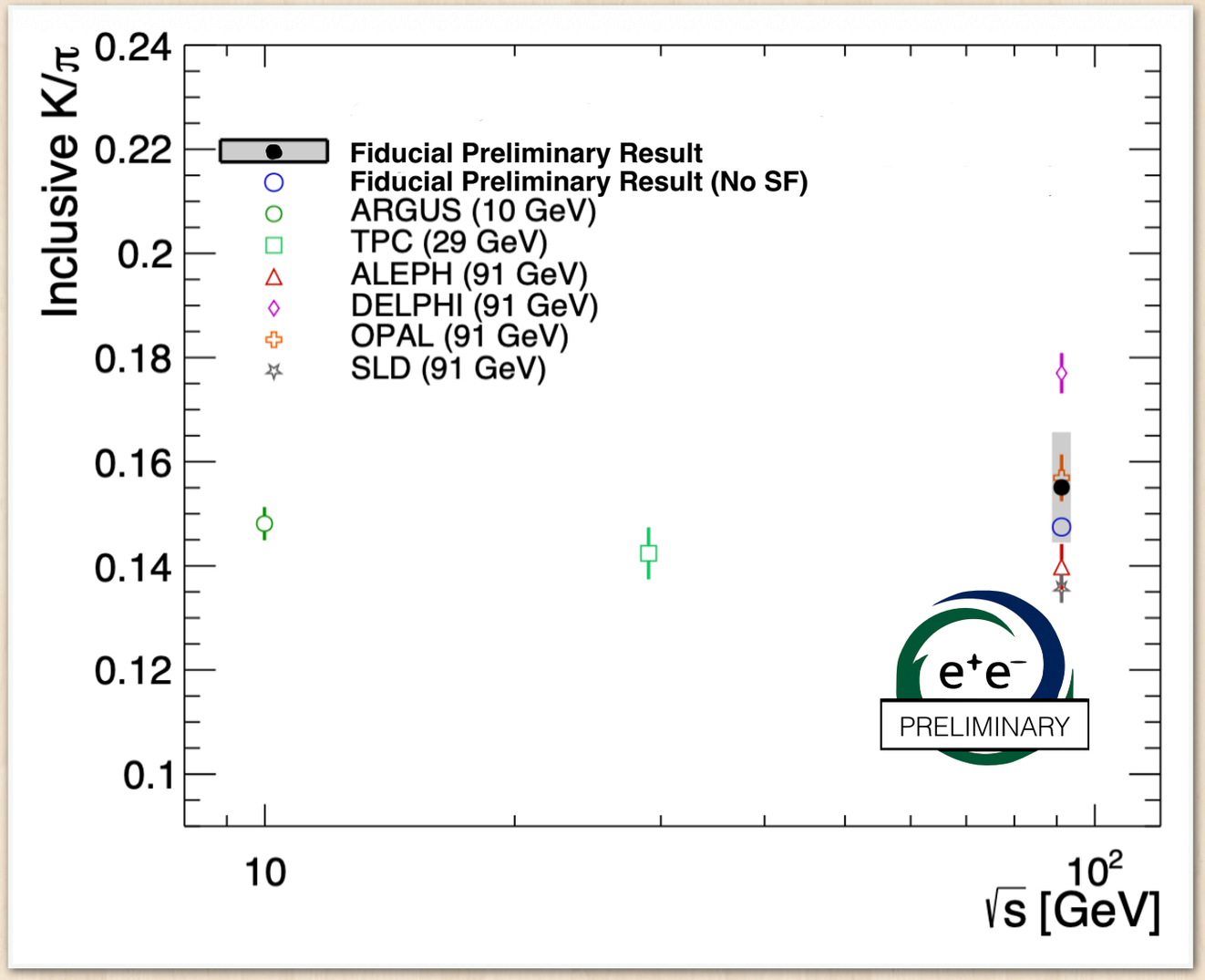
Dominant: data-driven PID efficiency scale factor

Fiducial region results

Warning: comparison with other experimental results depends on these fiducial cuts

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

Integrated result



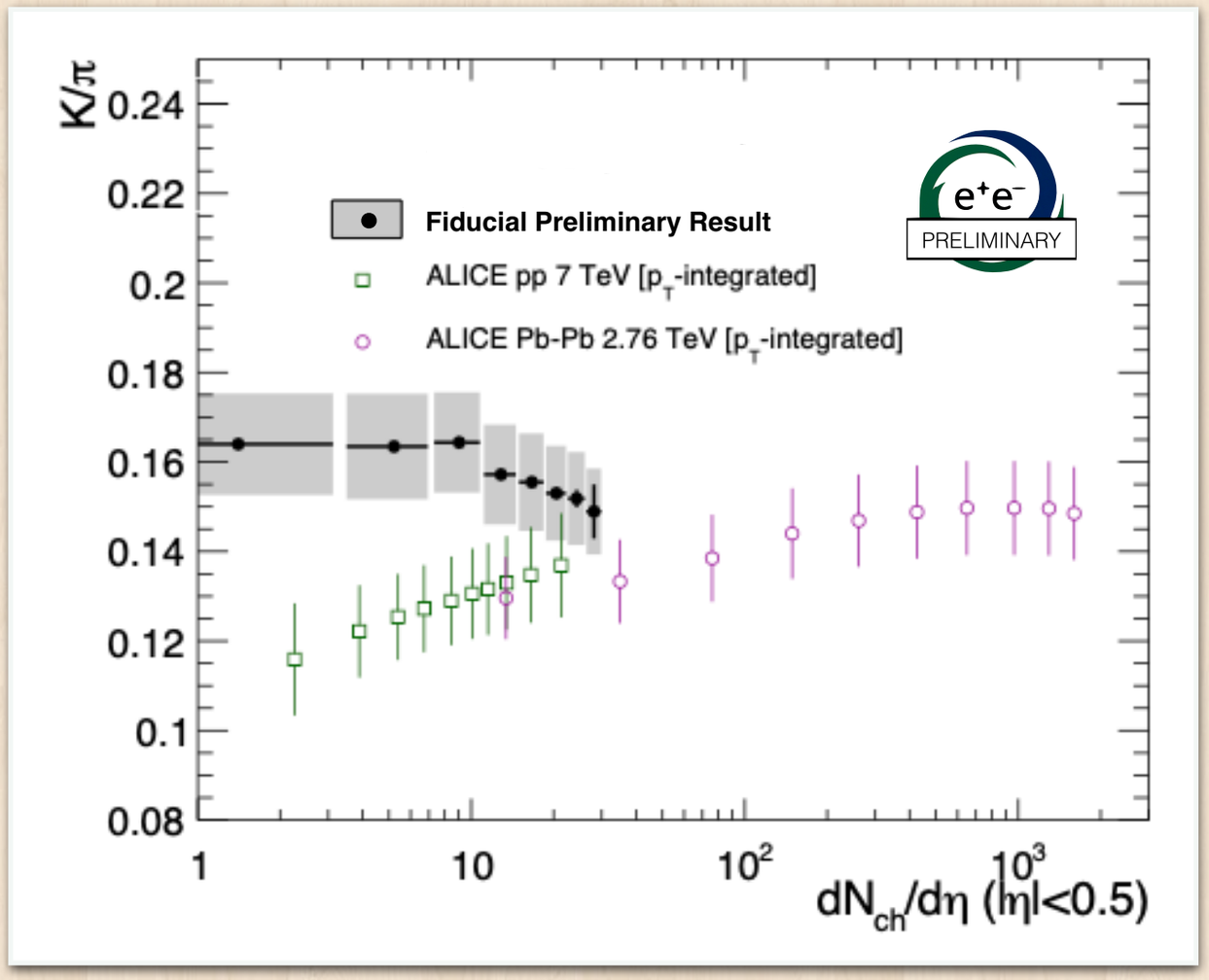
Beware of the fiducial cuts

Broadly compatible with other 91 GeV results

Caveat: current result is fiducial region

Beam $dN/d\eta$

Beware of the fiducial cuts



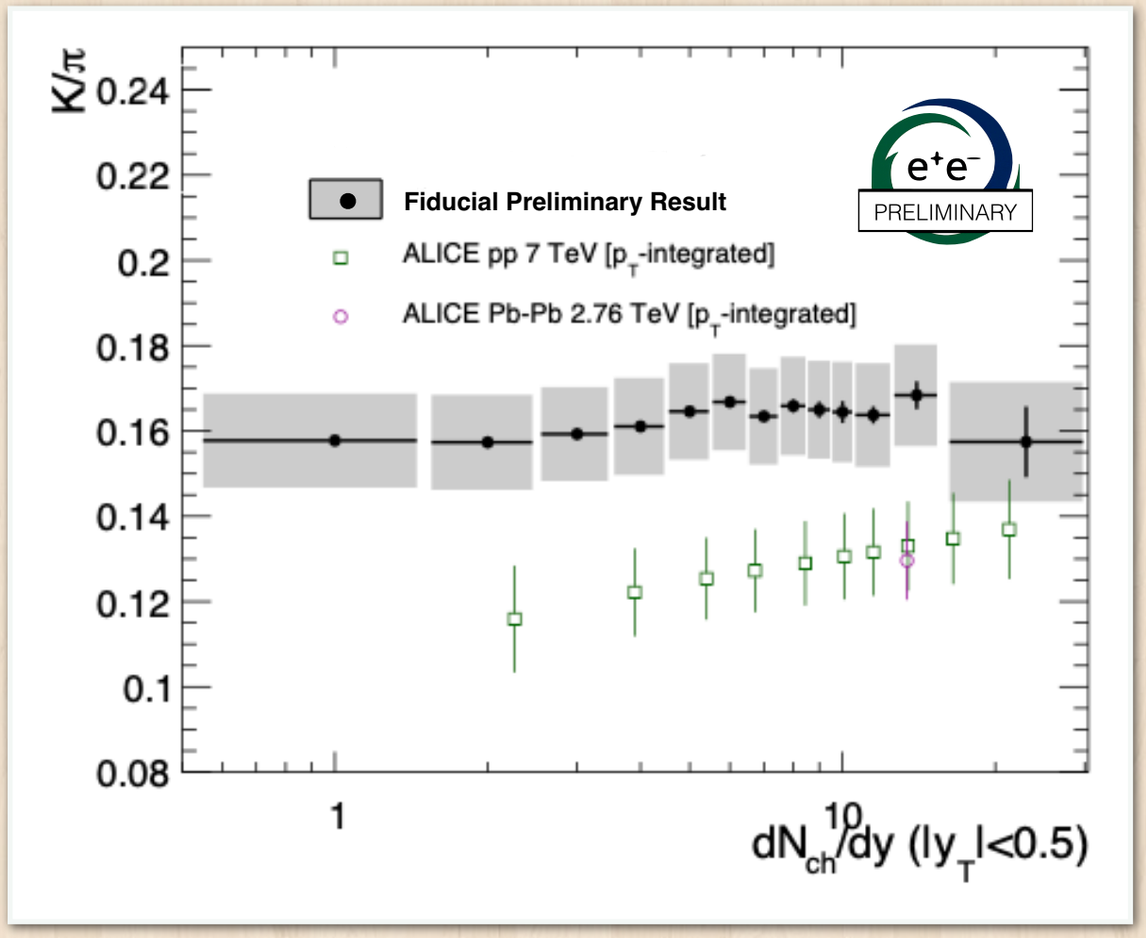
Dijet direction is random → $dN/d\eta$ captures part of dijet

Doesn't seem to follow same trend as hadron colliders

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

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

Thrust dN/dy



Beware of the fiducial cuts

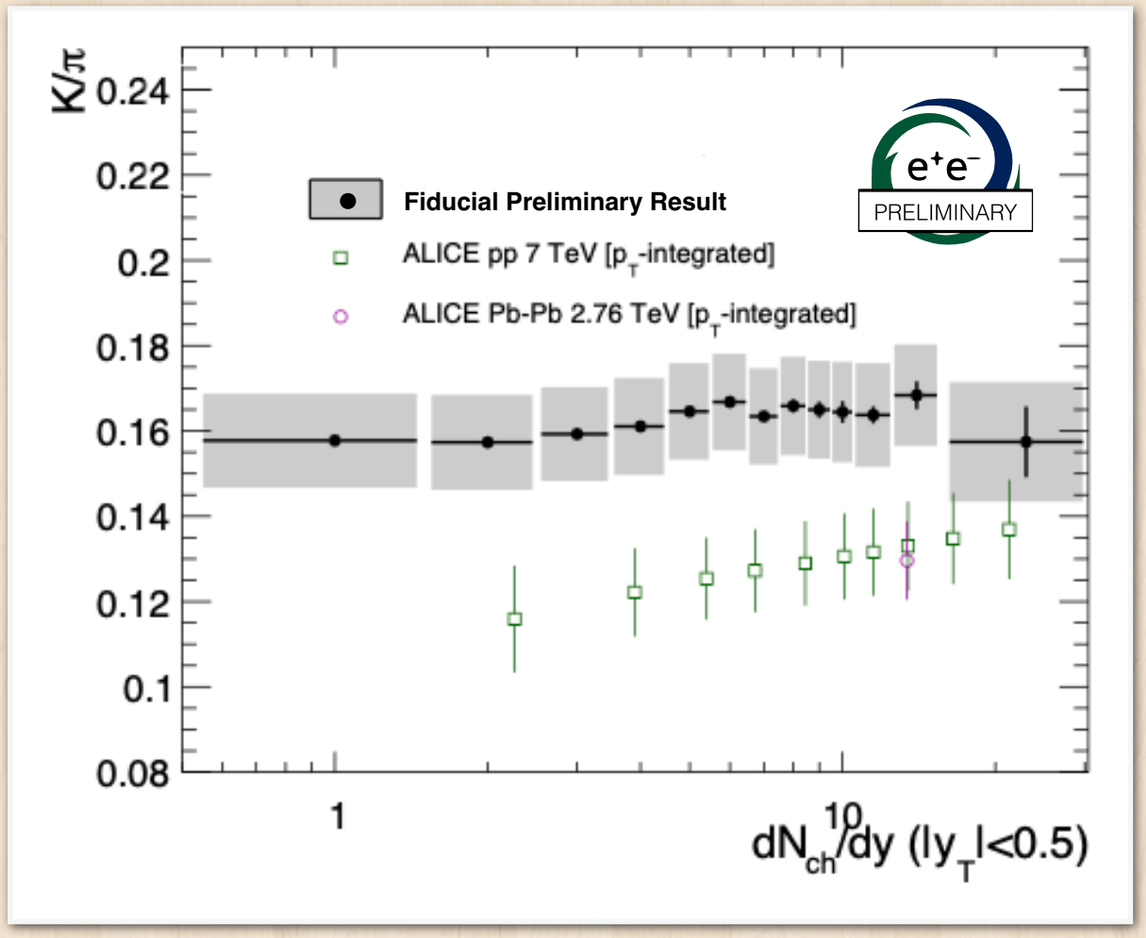
Thrust lines up with dijet

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

Multijet gives higher dN/dy

No clear rising/ dropping trend

Thrust dN/dy



Beware of the fiducial cuts

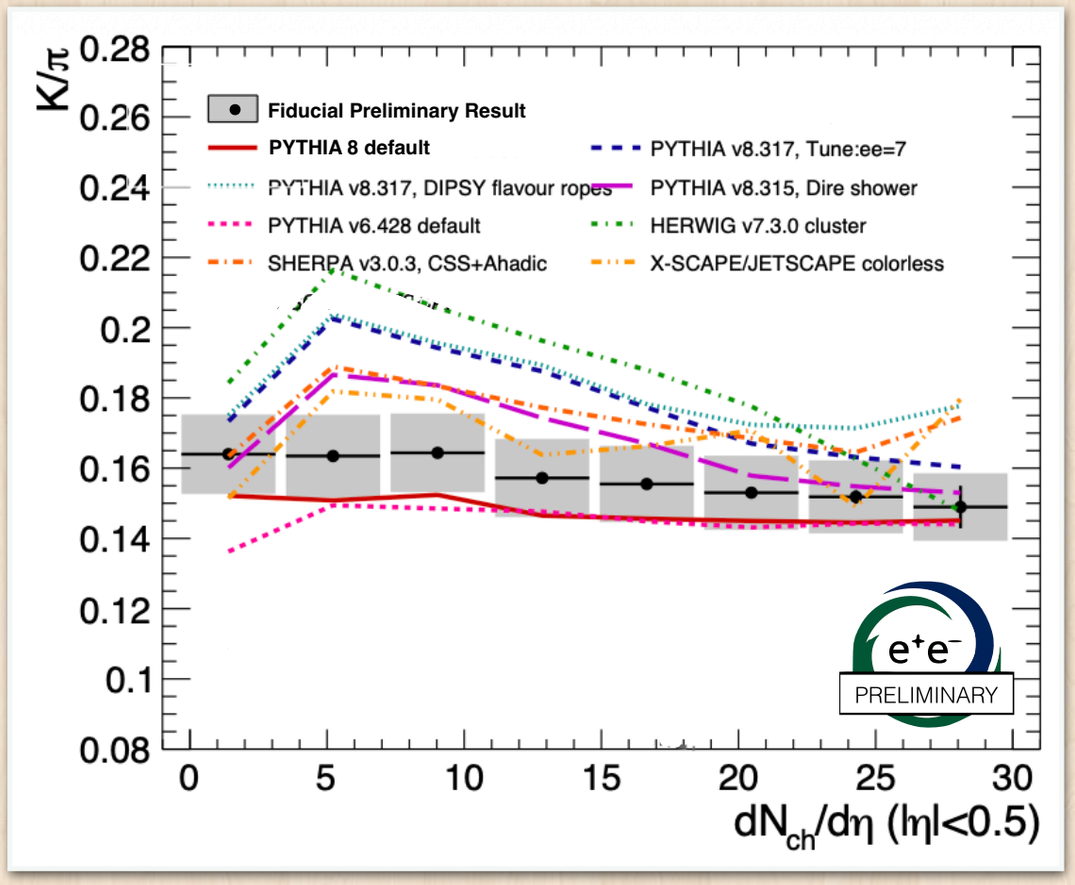
If trend stays the same with full phase space…

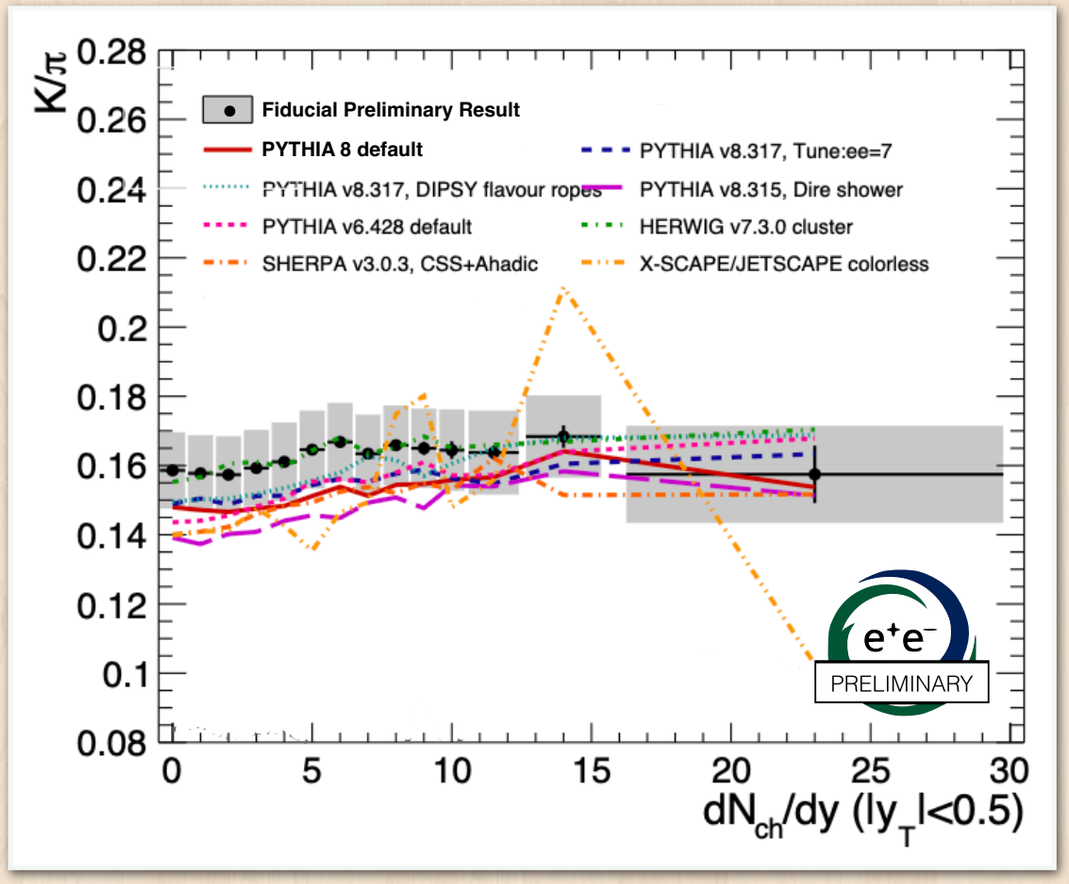
Smaller system → higher effective hadron density?

In-jet hadronization dominates?

Interesting to check other event activity measure

Comparison to MC





Overall trend mostly captured by simulations

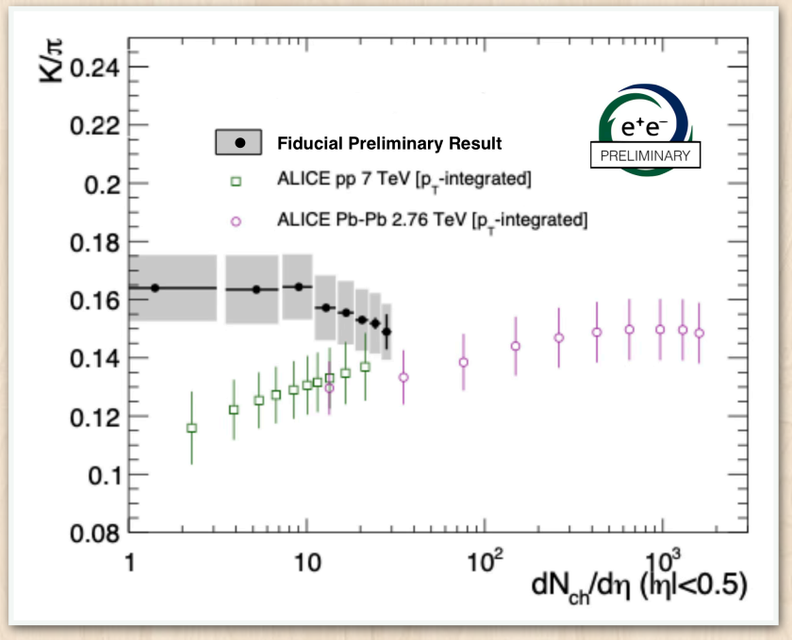
Different results from various generators — new input to generator tuning

We are actively finalizing the result so it's useful for tuning

Concluding remarks

Concluding remarks

- Preliminary <u>fiducial</u> K/π result
  - There does not seem have a clear sign of $pp/pA/AA$ trend as a function of event activity in 91.2 GeV e^+e^-



- Trend seems to be roughly captured by generators
- We are working to finalizing the result soon
  - All feedbacks welcome

Backup Slides Ahead