

Jet acoplanarity via hadron+jet measurements in Pb-Pb collisions at $\sqrt{s_{\text{NN}}} = 5.02$ TeV with ALICE

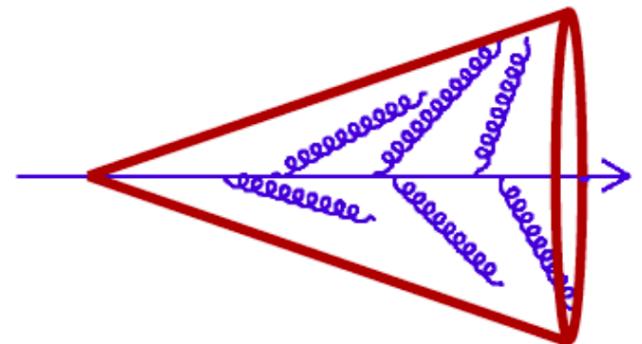
Jaime Norman on behalf of the ALICE collaboration
University of Liverpool
Hard Probes 2020



Introduction

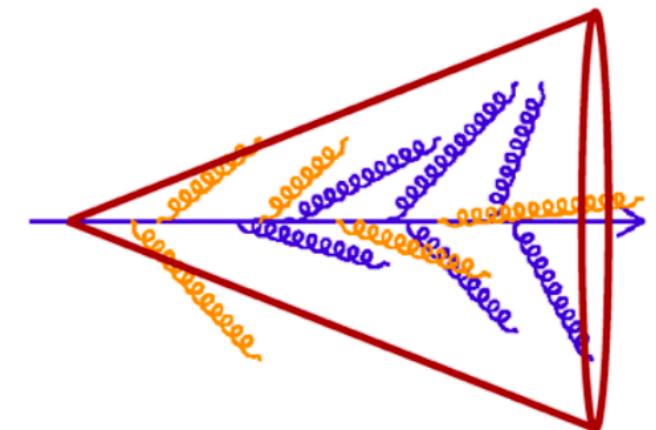
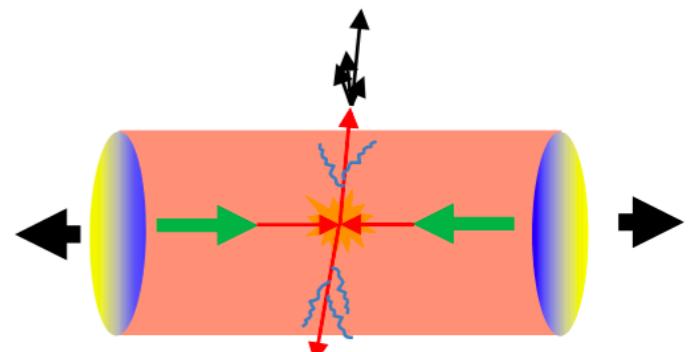
Jet production in vacuum

- Evolution of hard parton + gluon radiation
 - Precisely calculable in QCD
 - Reference for measurements in heavy-ion collisions



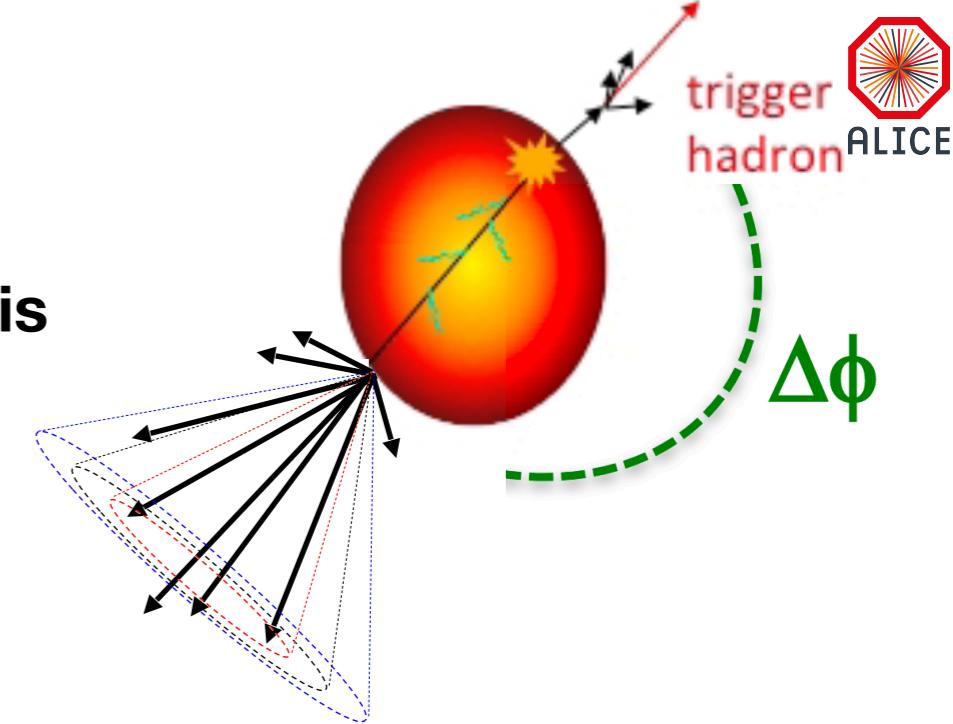
Jet modification in heavy-ion collisions

- Consequences of medium effects include:
 1. **Energy redistribution to larger angles (jet quenching)**
 2. **Modification to jet substructure**
 3. **Jet deflection (acoplanarity)**
 - Can be studied through semi-inclusive measurements of a jet recoiling from a trigger (e.g. γ -jet , Z-jet, or **hadron-jet**)

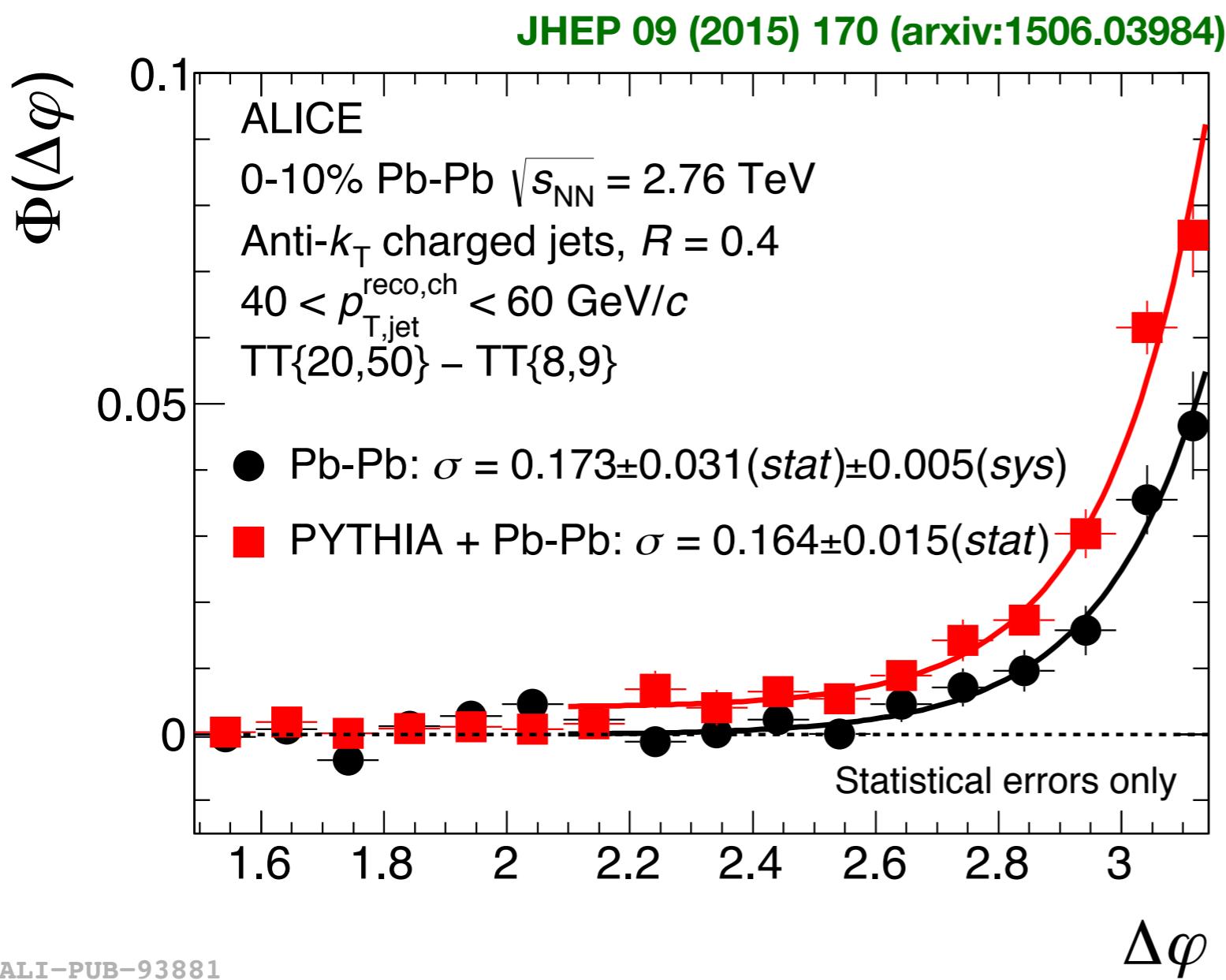


Jet acoplanarity

- Opening angle ($\Delta\phi$) of recoil jet relative to trigger axis



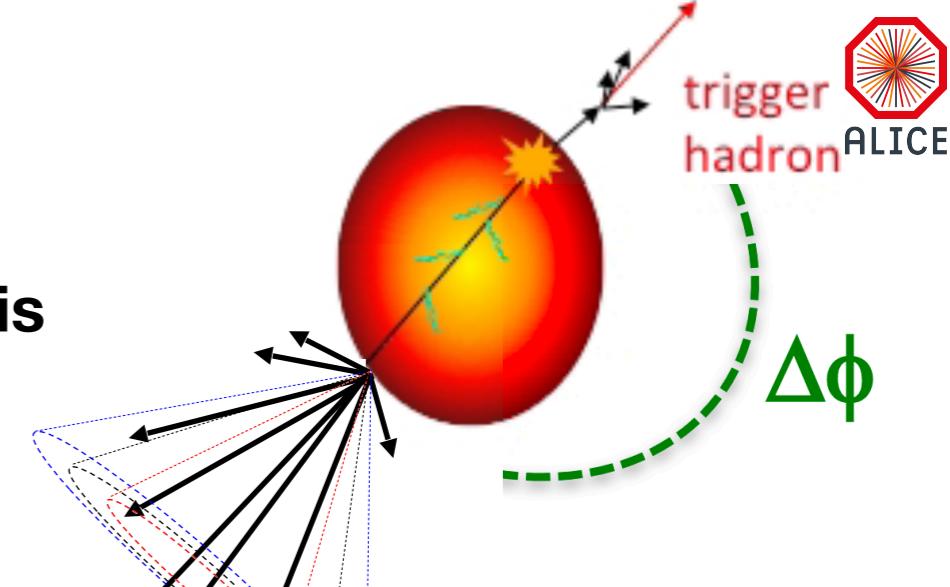
Run 1 measurement:



- Statistics-limited
- Mid- p_T jets ($40 < p_{T,jet} < 60$ GeV/c)
- Uncorrected for angular/ p_T smearing
- No medium-induced effects observed within uncertainties

Jet acoplanarity

- Opening angle ($\Delta\phi$) of recoil jet relative to trigger axis

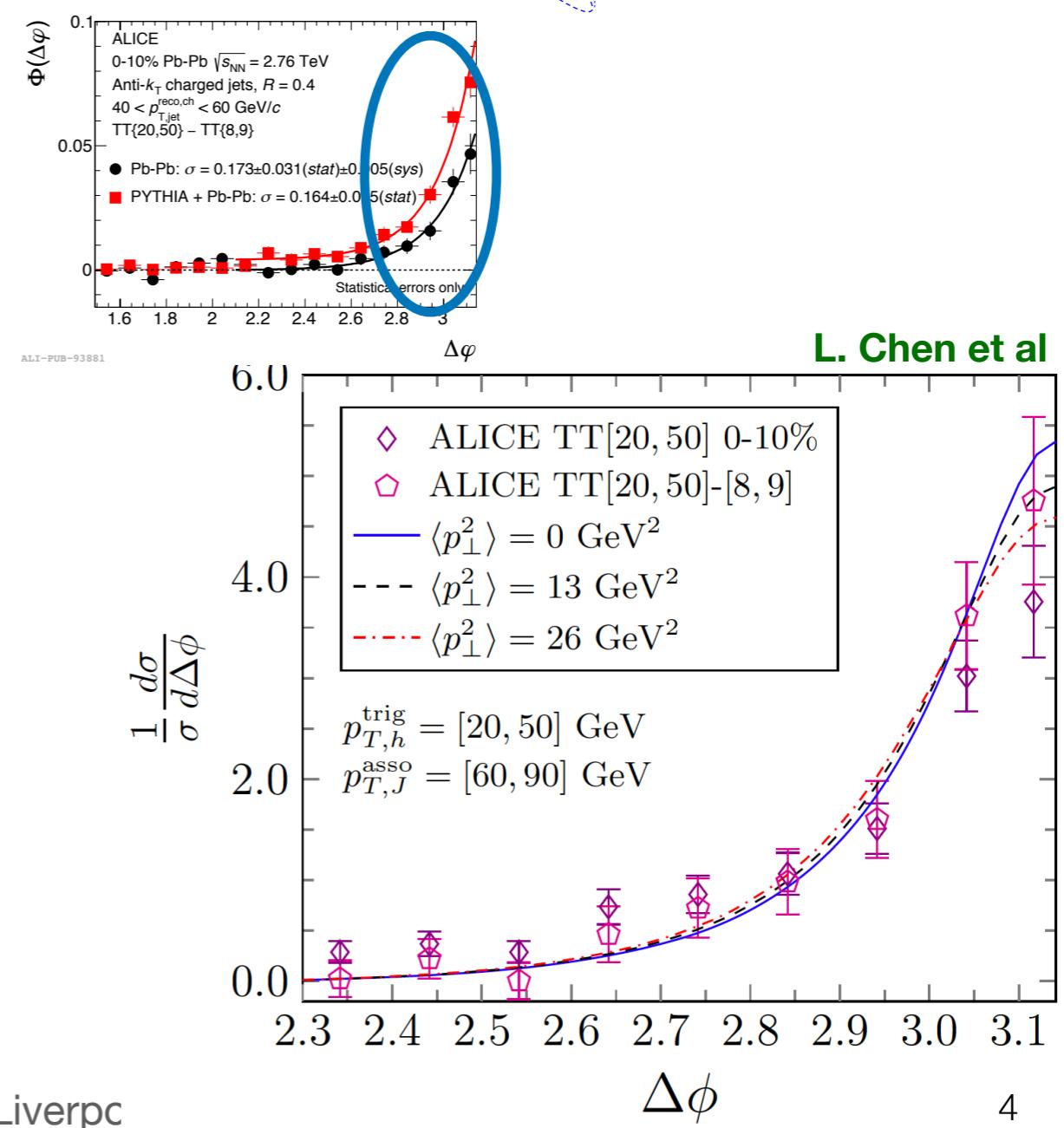


2 regions of interest:

1. $\Delta\phi \sim \pi$: **L. Chen et al, Phys. Lett. B773 (2017) 672**
M. Gyulassy et al., arxiv:1808.03238
B. G. Zakharov, arxiv:2003.10182

- Vacuum broadening (Sudakov radiation)
- Multiple soft scattering in the QGP may further broaden $\Delta\phi$ distribution
- Radiative corrections may be negative —> *reduction* of broadening

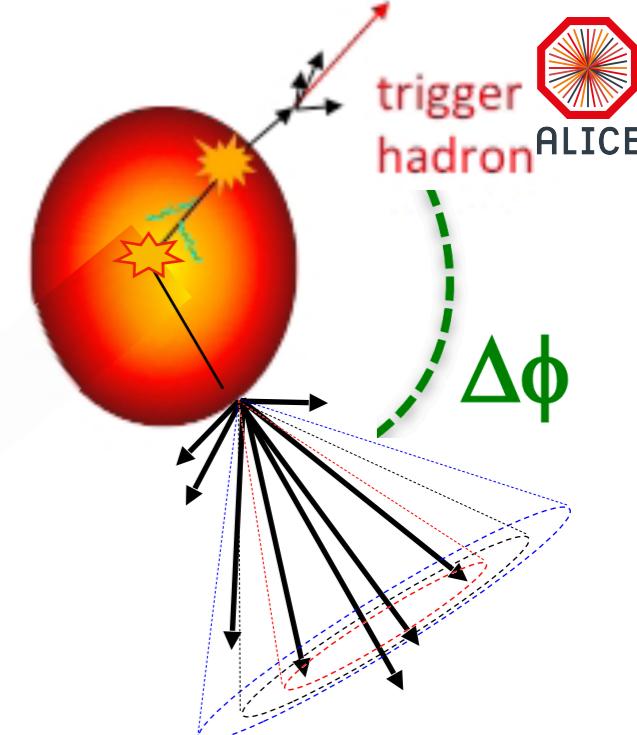
$$\langle p_\perp^2 \rangle = \hat{q}L$$



Low- p_T jets are most sensitive to $\Delta\phi$ broadening effects

Jet acoplanarity

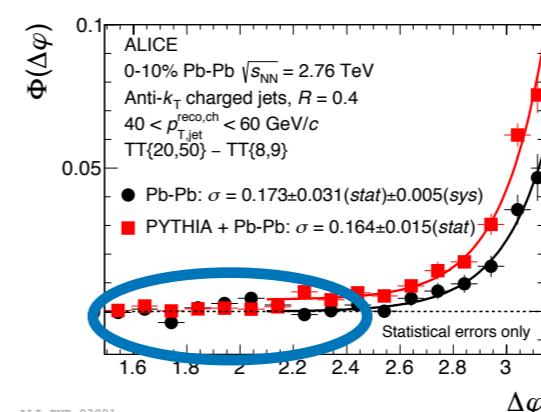
- Opening angle ($\Delta\varphi$) of recoil jet relative to trigger axis



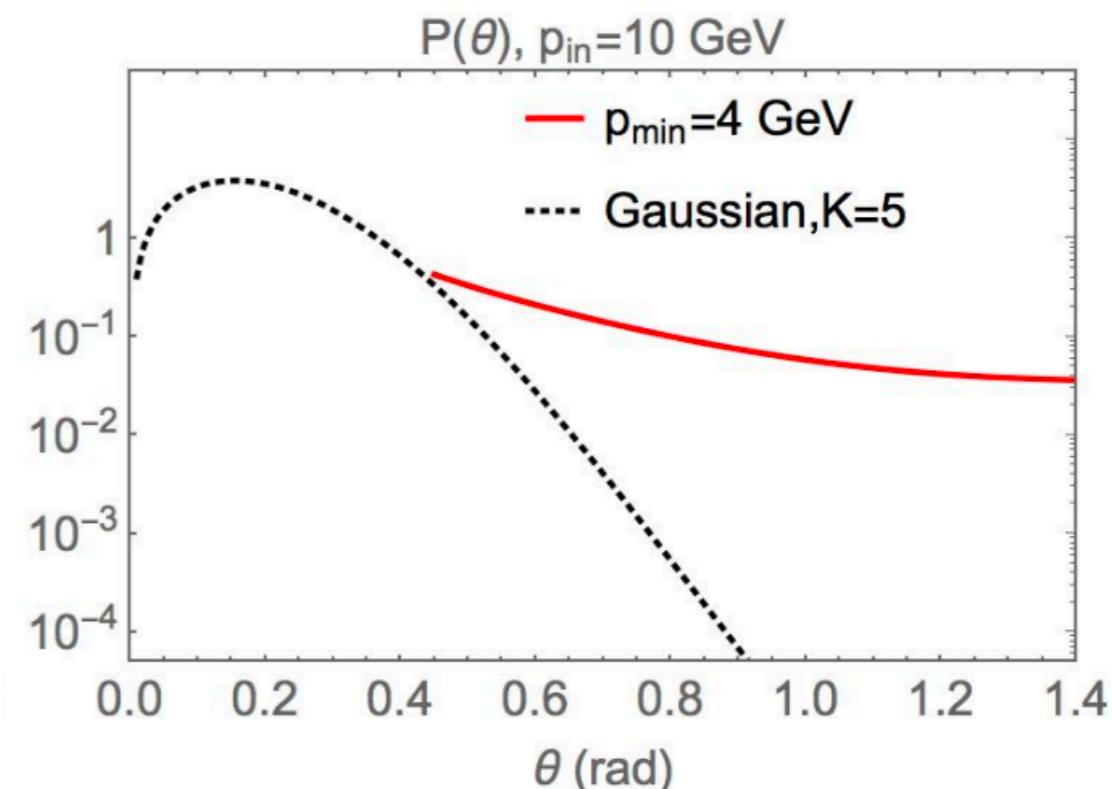
2 regions of interest:

2. $\Delta\varphi \ll \pi$: Large-angle deflection of hard partons off quasiparticles

- Probe short distance partonic structure of the QGP



F. D'Eramo, K. Rajagopal, Y. Yin, JHEP 01 (2019) 172



Low- p_T jets are most sensitive to $\Delta\varphi$ broadening effects

Detector and data sample

**Analysis uses 2018 Pb-Pb
data sample**

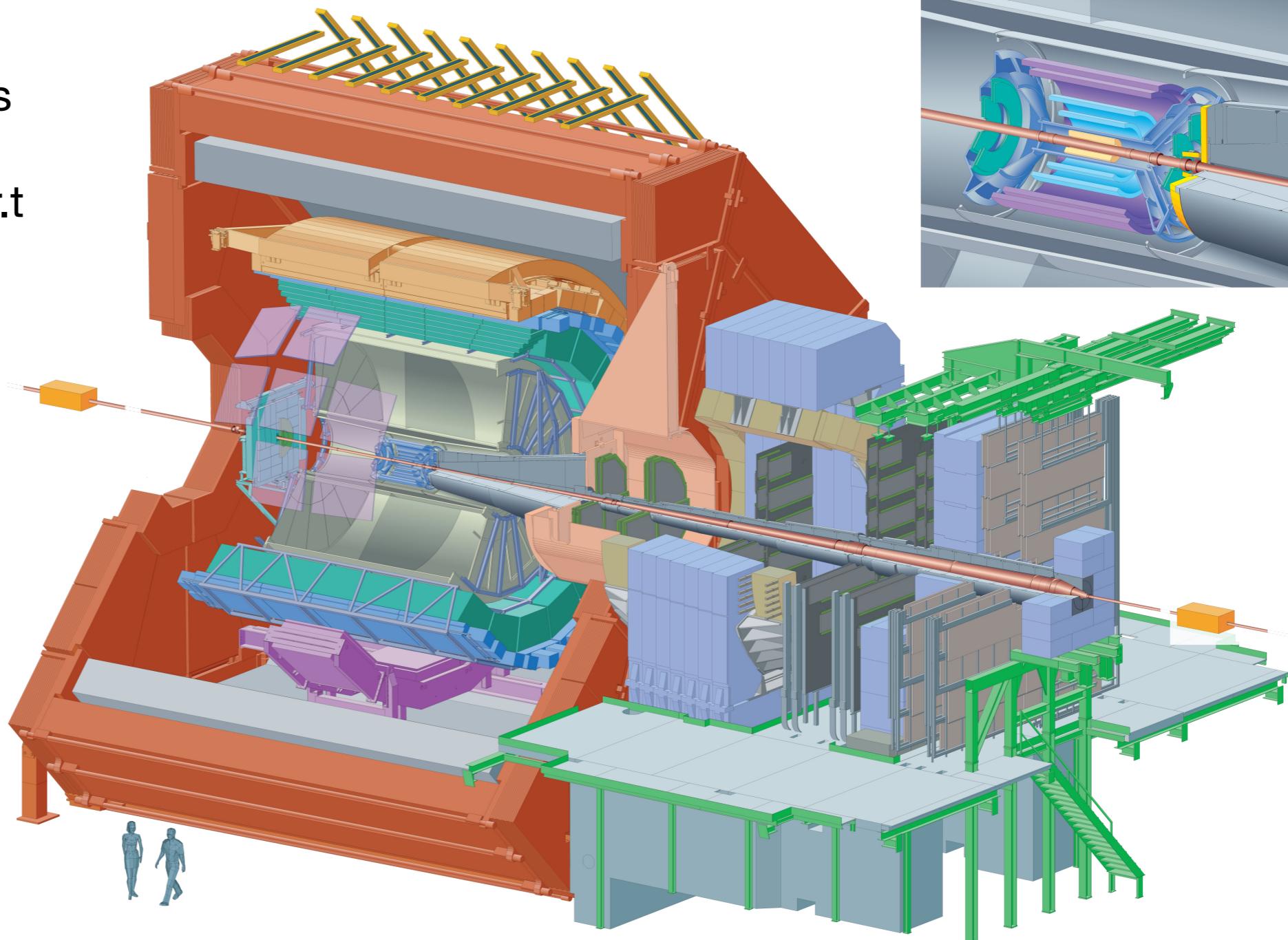
133M recorded 0-10%
central-triggered events

**Factor ~9x increase w.r.t
Run 1**

ITS $|\eta| < 0.9$
6-layer silicon tracker
Tracking, vertexing,

TPC $|\eta| < 0.9$
Tracking

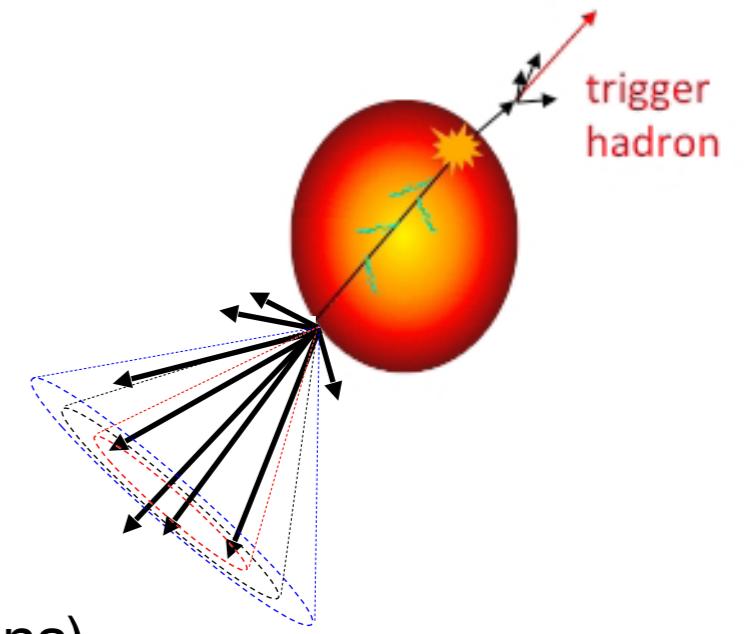
V0
Triggering
Centrality determination



Method

→ Measure trigger-normalised yield of jets recoiling from a trigger hadron

$$\frac{1}{N_{\text{trig}}^{\text{AA}}} \frac{d^3 N_{\text{jet}}^{\text{AA}}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta_{\text{jet}}} \Bigg|_{p_{T,h} \in \text{TT}} = \left(\frac{1}{\sigma^{\text{pp} \rightarrow h+X}} \cdot \frac{d^3 \sigma^{\text{pp} \rightarrow h+\text{jet}+X}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta} \right) \Bigg|_{p_{T,h} \in \text{TT}}$$



→ Well defined in pQCD (ratio of high p_T hadron/jet cross sections)

D. de Florian, Phys. Rev. D 79, 114014

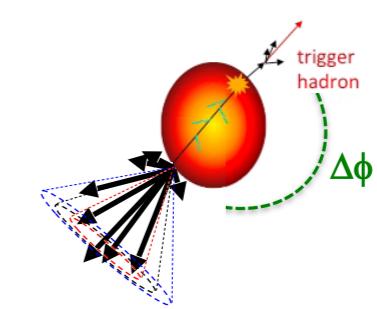
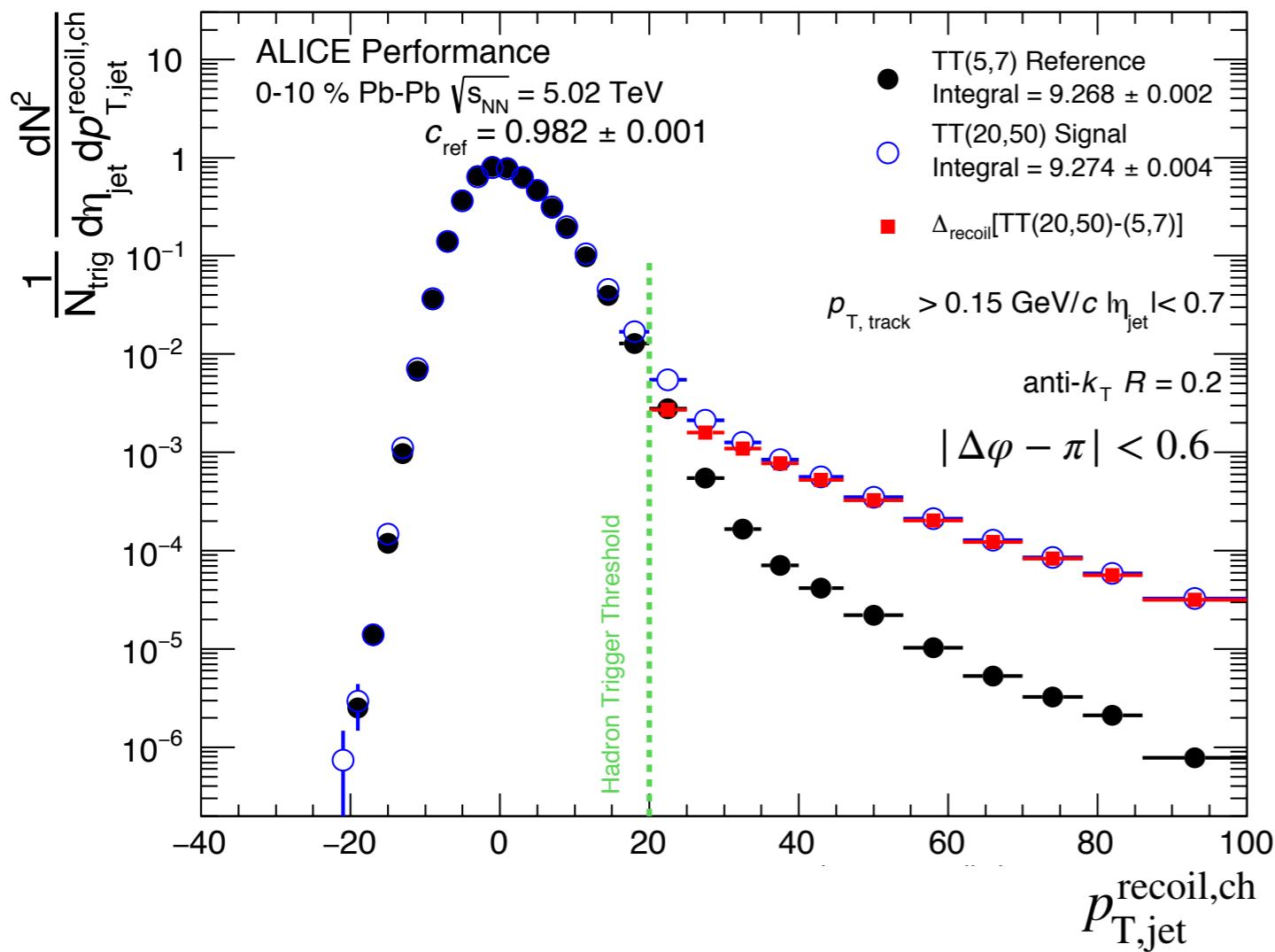
Recoil jets:

→ Statistical subtraction of combinatorial background:

- Unbiased fragmentation
- Access **Low p_T** jets: reduce vacuum broadening; most sensitive to jet deflection
- Access **Large R** jets: access to intra-jet broadening

→ Expected geometrical bias towards longer in-medium path lengths

Method - Δ_{recoil} observable



Jet p_{T} corrected for underlying event density ρ :

$$p_{T,\text{jet}}^{\text{recoil},\text{ch}} = p_{T,\text{jet}}^{\text{raw},\text{ch}} - \rho A_{\text{jet}}$$

TT_{sig}: $20 < p_{T,\text{trig}} < 50 \text{ GeV}/c$

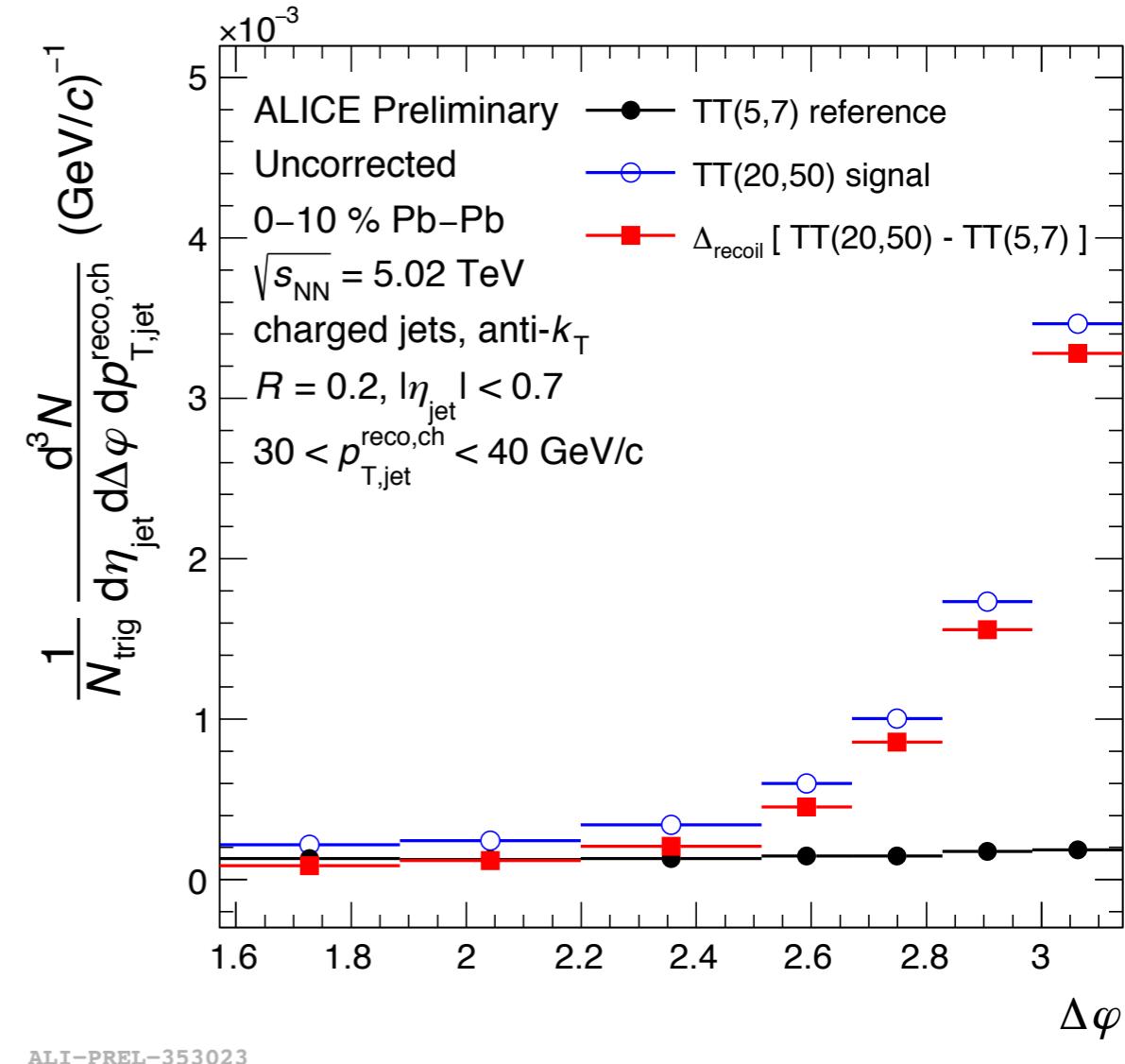
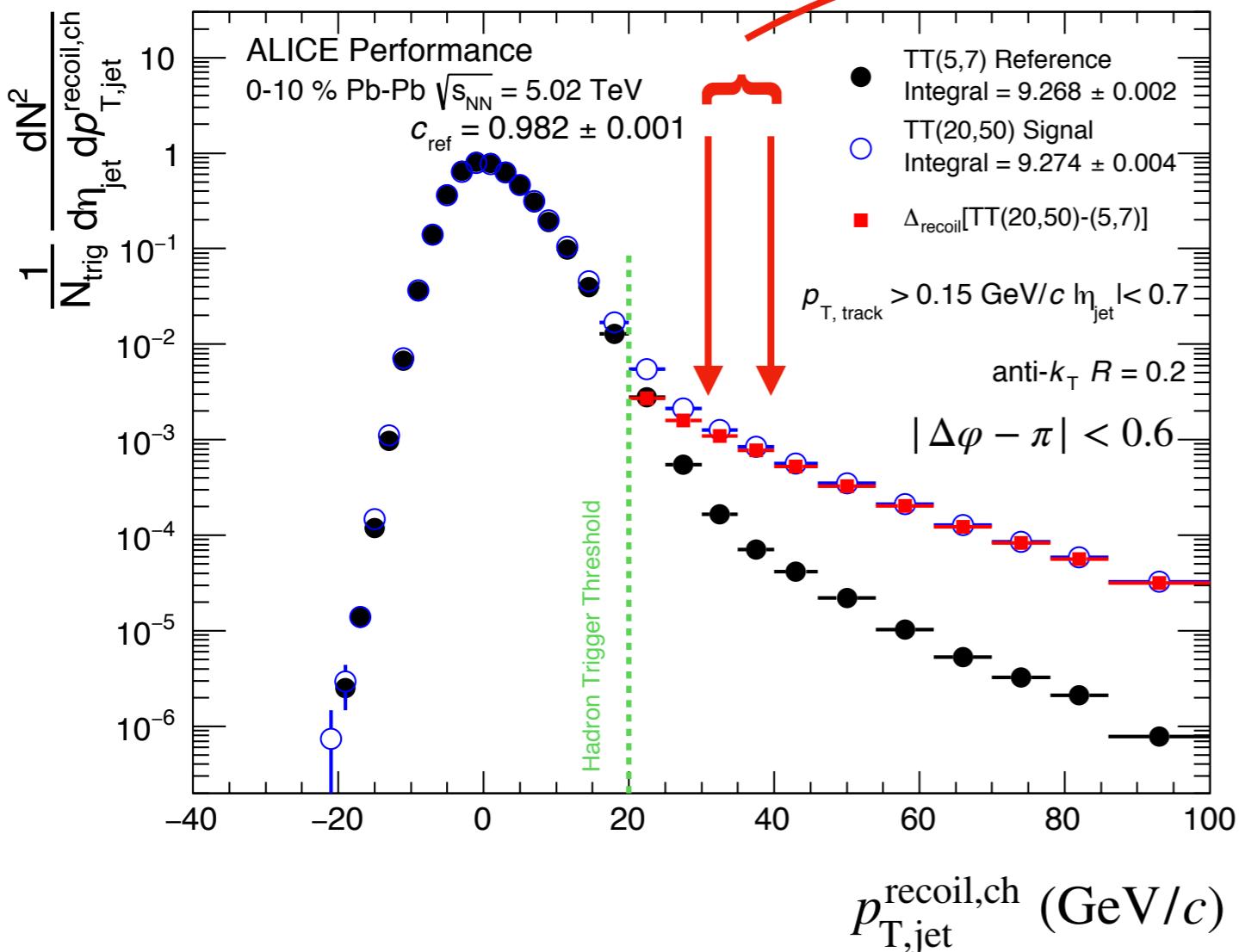
TT_{ref}: $5 < p_{T,\text{trig}} < 7 \text{ GeV}/c$

- anti- k_{T} $R=0.2$ **charged jets** recoiling from a high- p_{T} hadrons in two exclusive trigger track (TT) classes
- **Subtract combinatorial background:** difference between ‘signal’ and ‘reference’ distributions:

$$\Delta_{\text{recoil}} = \frac{1}{N_{\text{trig}}^{\text{AA}}} \frac{d^3 N_{\text{jet}}^{\text{AA}}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta_{\text{jet}}} \Bigg|_{p_{T,\text{trig}} \in \text{TT}_{\text{Sig}}} - c_{\text{ref}} \cdot \frac{1}{N_{\text{trig}}^{\text{AA}}} \frac{d^3 N_{\text{jet}}^{\text{AA}}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta_{\text{jet}}} \Bigg|_{p_{T,\text{trig}} \in \text{TT}_{\text{Ref}}}$$

Method - Δ_{recoil} observable

NEW



ALI-PREL-353023

- Δ_{recoil} is measured as a function of the jet p_{T} and $\Delta\varphi$

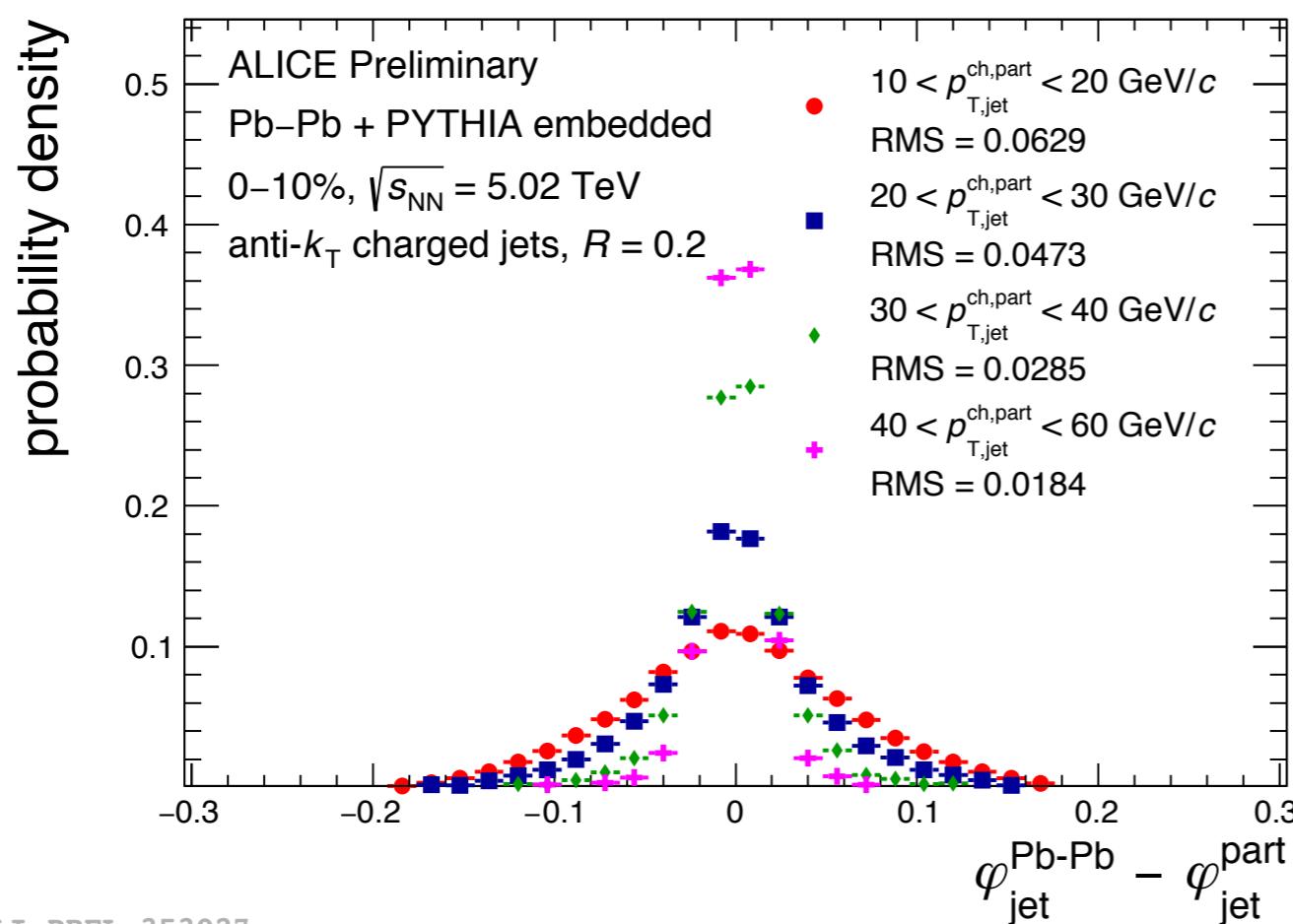
$$\Delta_{\text{recoil}} = \frac{1}{N_{\text{trig}}^{\text{AA}}} \frac{d^3 N_{\text{jet}}^{\text{AA}}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta_{\text{jet}}} \Bigg|_{p_{T,\text{trig}} \in \text{TT}_{\text{Sig}}} - c_{\text{ref}} \cdot \frac{1}{N_{\text{trig}}^{\text{AA}}} \frac{d^3 N_{\text{jet}}^{\text{AA}}}{dp_{T,\text{jet}}^{\text{ch}} d\Delta\varphi d\eta_{\text{jet}}} \Bigg|_{p_{T,\text{trig}} \in \text{TT}_{\text{Ref}}}$$

2D corrections: p_T and $\Delta\varphi$

- Distributions corrected for residual background fluctuations and detector inefficiencies via **2d Bayesian techniques**

T. Adye, CERN-2011-006 pp.313-318

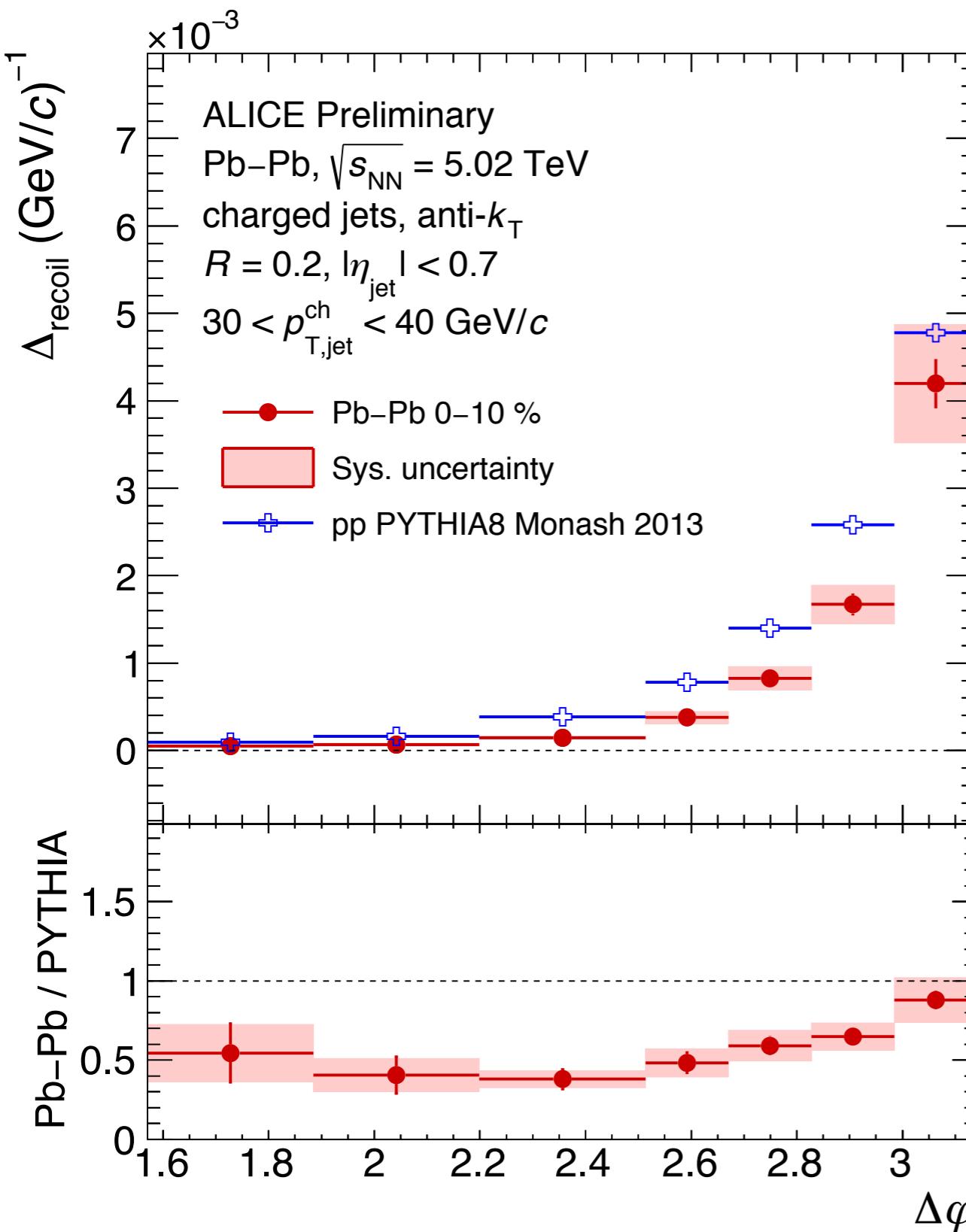
- Construct **4d response** mapping detector-level jet p_T and jet φ to particle level
- Correct p_T and $\Delta\varphi$ simultaneously
 - p_T smearing accounts for main correction



Good $\Delta\varphi$ resolution
 (~50 mrad for 25 GeV/c jets)

Results

NEW



- **First measurement of the fully-corrected hadron+jet $\Delta\varphi$ distribution**

- Recoil jet yield suppressed with respect to PYTHIA

- **Indication of a narrowing of $\Delta\varphi$ distribution in $30 < p_T < 40 \text{ GeV}/c$**

B. G. Zakharov, arxiv:2003.10182

Systematic uncertainties: tracking, unfolding (choice of prior, binning, regularisation parameter), c_{ref} scaling + jet matching

Summary and outlook

- First measurement of the fully-corrected hadron+jet $\Delta\varphi$ distribution for $R = 0.2$ jets in $30 < p_{T,\text{jet}}^{\text{ch}} < 40 \text{ GeV}/c$
- Suppression with respect to pp (PYTHIA)
- Indication of narrowing of $\Delta\varphi$ distribution with respect to pp (PYTHIA)
 - radiative corrections at play?
- Next steps:
 - pp reference: large-statistics 2017 pp sample at $\sqrt{s} = 5.02 \text{ TeV}$ (~ 1 billion events)
 - Push the measurement to low p_T and large R

Detailed characterisation of jet acoplanarity and yield modification over a broad kinematic region