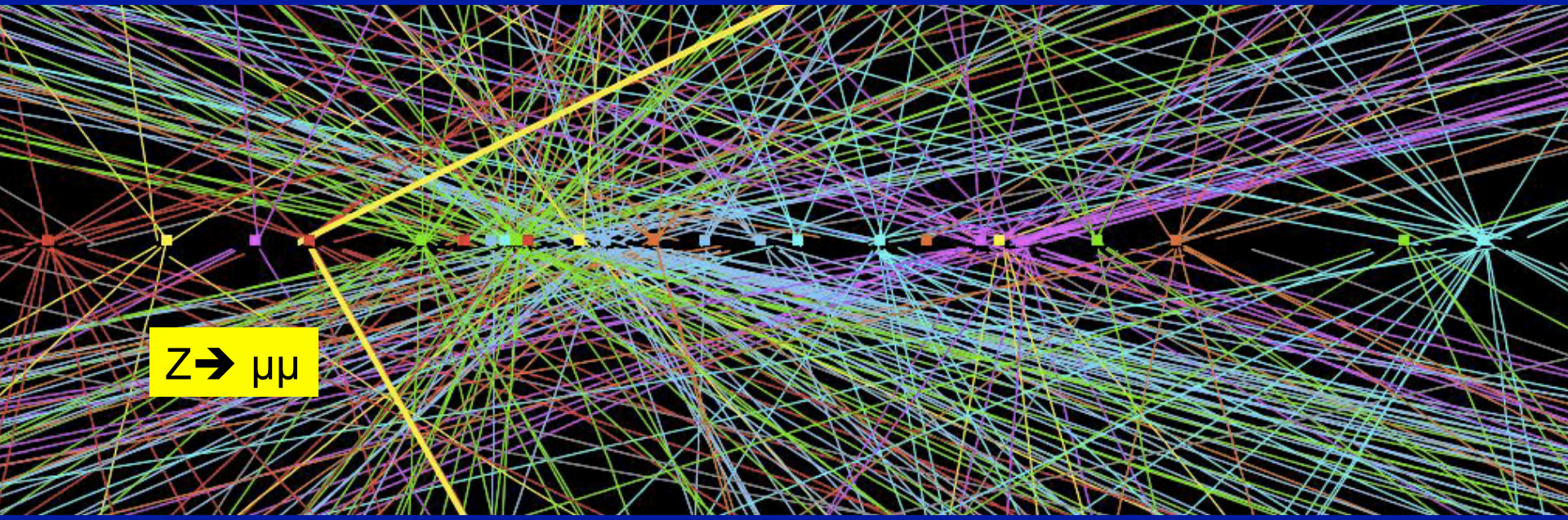
Measurement of long-range correlations in Z-tagged pp events with ATLAS



Adam Trzupek

on behalf of the ATLAS experiment

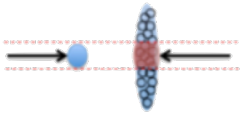
Institute of Nuclear Physics PAN, Kraków, Poland

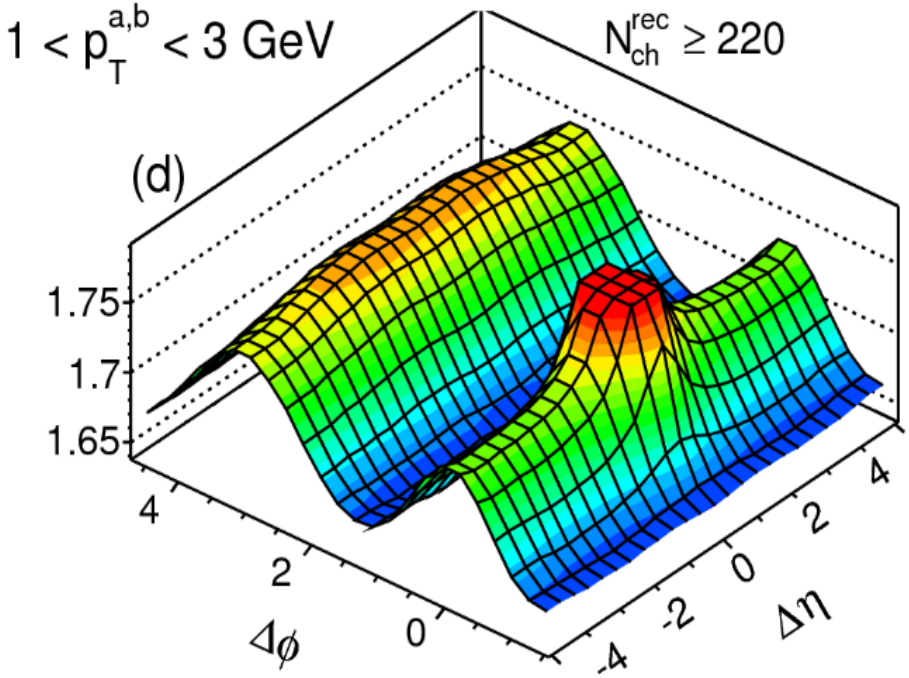
International Conference on Hard and Electromagnetic Probes of High-Energy Nuclear Collisions, Hard Probes 2018

Aix-Les-Bains, France, Oct 1 - 5, 2018

Ridge in High Multiplicity p+Pb and pp Collisions

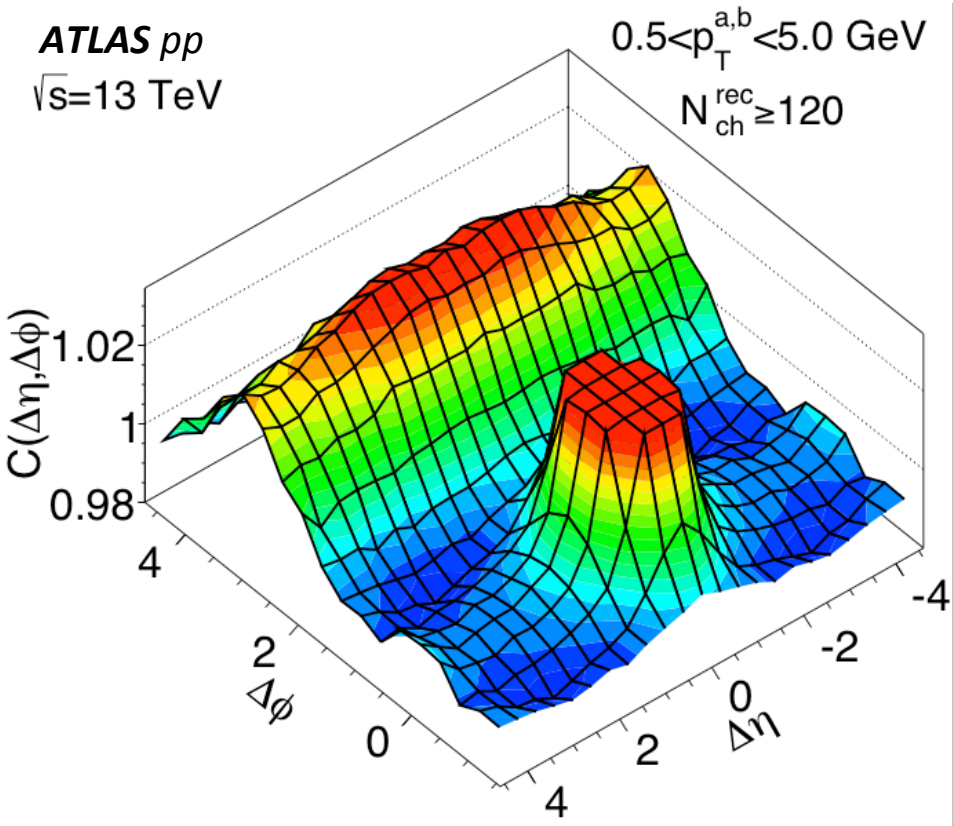
p+Pb ridge





PRC 90,044906 (2014)

pp ridge

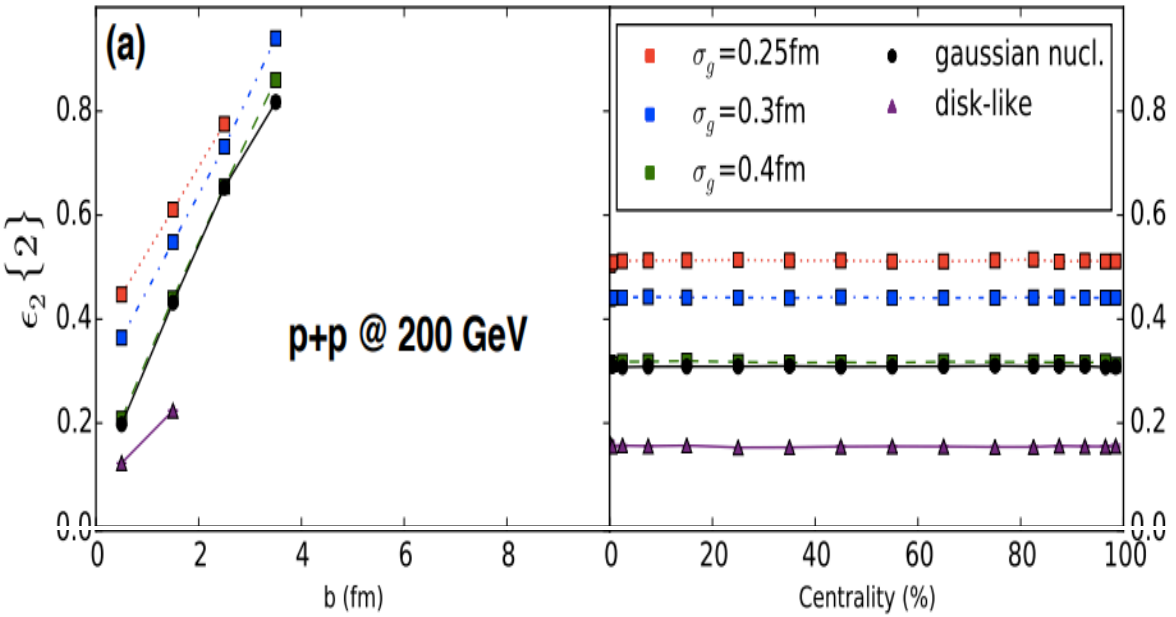


PRL 116, 172301 (2016)

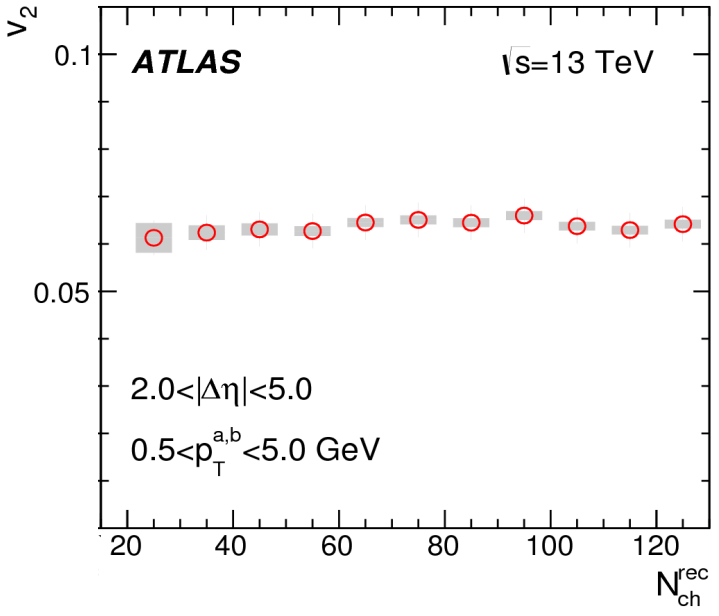
Strongly interacting QGP in small systems?

Constraining pp Geometry

PRC94 (2016) no.2, 024919



PRL 116, 172301 (2016)



- Fluctuations in the internal structure of the nucleon may lead to a strong correlation of ε_2 with b, being at the same time independent on multiplicity (PRC94 (2016) no.2, 024919)
- Presence of Z, a handle on the *pp* collision geometry
  - Measurement of 2PC in events with the Z boson

ATLAS-CONF-2017-007 – Measurement of long-range azimuthal correlations in Z-boson tagged pp collisions at 8 TeV

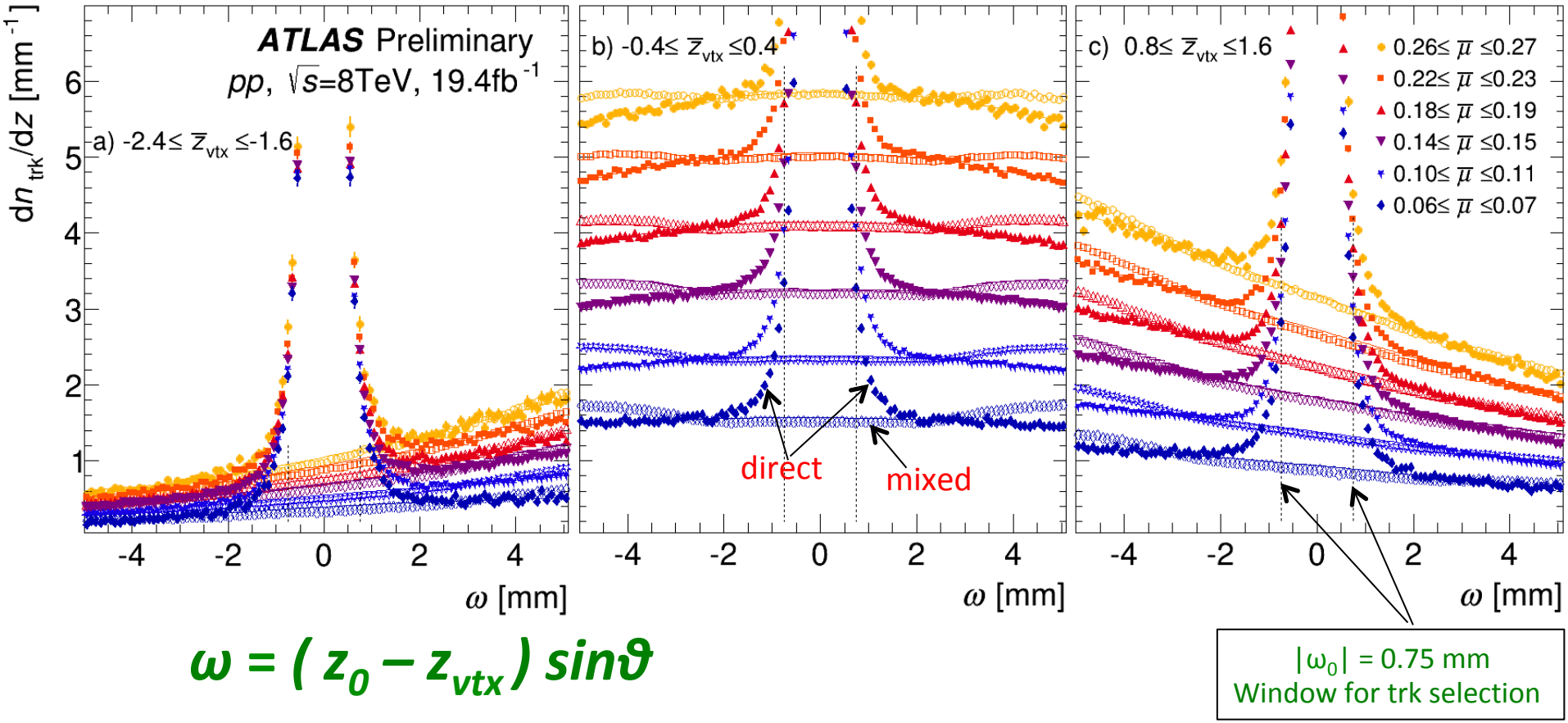
Datasets

8 TeV pp data collected in 2012 during Run 1

- L_{int} = 19.4 fb^{-1}, high-luminosity data, $\mu \sim 20$
- Collisions contain Z boson
- $Z \rightarrow \mu^+\mu^-$: $80 < M_{\mu\mu} < 100$ GeV, $p_T^{\mu} > 20$ GeV, $|\eta^{\mu}| < 2.4$
- 2PC are obtained with charged particles reconstructed in ID
  - $p_T > 0.4$ GeV, $|\eta| < 2.5$
  - $|\omega| < 0.75$ mm , $\omega = (z_0 - z_{vtx}) \sin\vartheta$
- All tracks belonging to Z-vertex (direct tracks) – n_{trk}^{direct}
  - $n_{trk}^{direct} = n_{trk}^{signal} + n_{trk}^{background}$
- Background (pileup) approximated by Mixed event sample
  - Random selection procedure (ATLAS, Eur. Phys. J. C74(2014)3195)
  - Mixed events contain tracks from different events at the same instantaneous luminosity μ and run as the Z-boson
  - Mixed event tracks fulfill: $|\omega| < 0.75$ mm (w.r.t. Z-vertex)

Pileup Background from Mixed Events

The mixed event and direct track densities for different $\bar{z}_{vtx}$ and $\bar{\mu}$



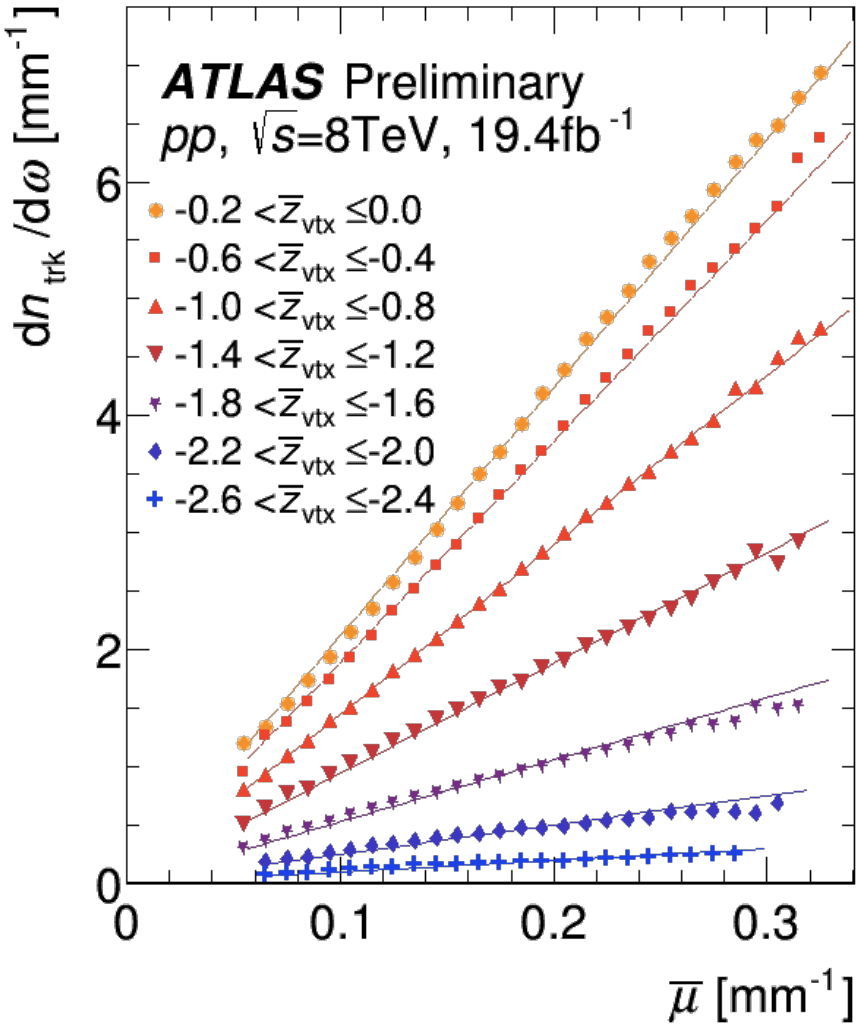
$$\omega = (z_0 - z_{vtx}) \sin\vartheta$$

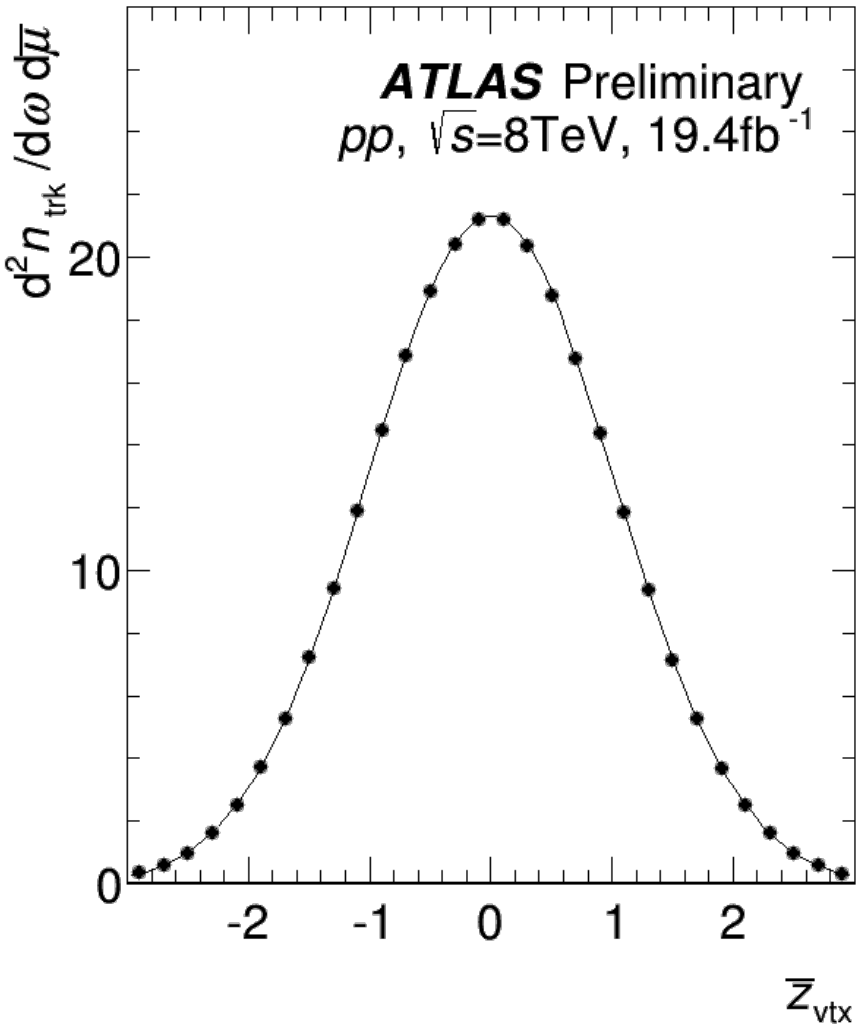
- Mixed events well approximate background: $n_{trk}^{mix} \approx n_{trk}^{background}$
- To assure run-by-run uniformity, reduced variables are used

$$(\bar{\mu}, \bar{z}_{\mathrm{vtx}}) = \left(\frac{\mu}{\sqrt{2\pi}\,\mathrm{RMS}(z_{\mathrm{vtx}})}, \frac{z_{\mathrm{vtx}} - \langle z_{\mathrm{vtx}} \rangle}{\mathrm{RMS}(z_{\mathrm{vtx}})} \right)$$

ATLAS-CONF-2017-007

Background Parametrization

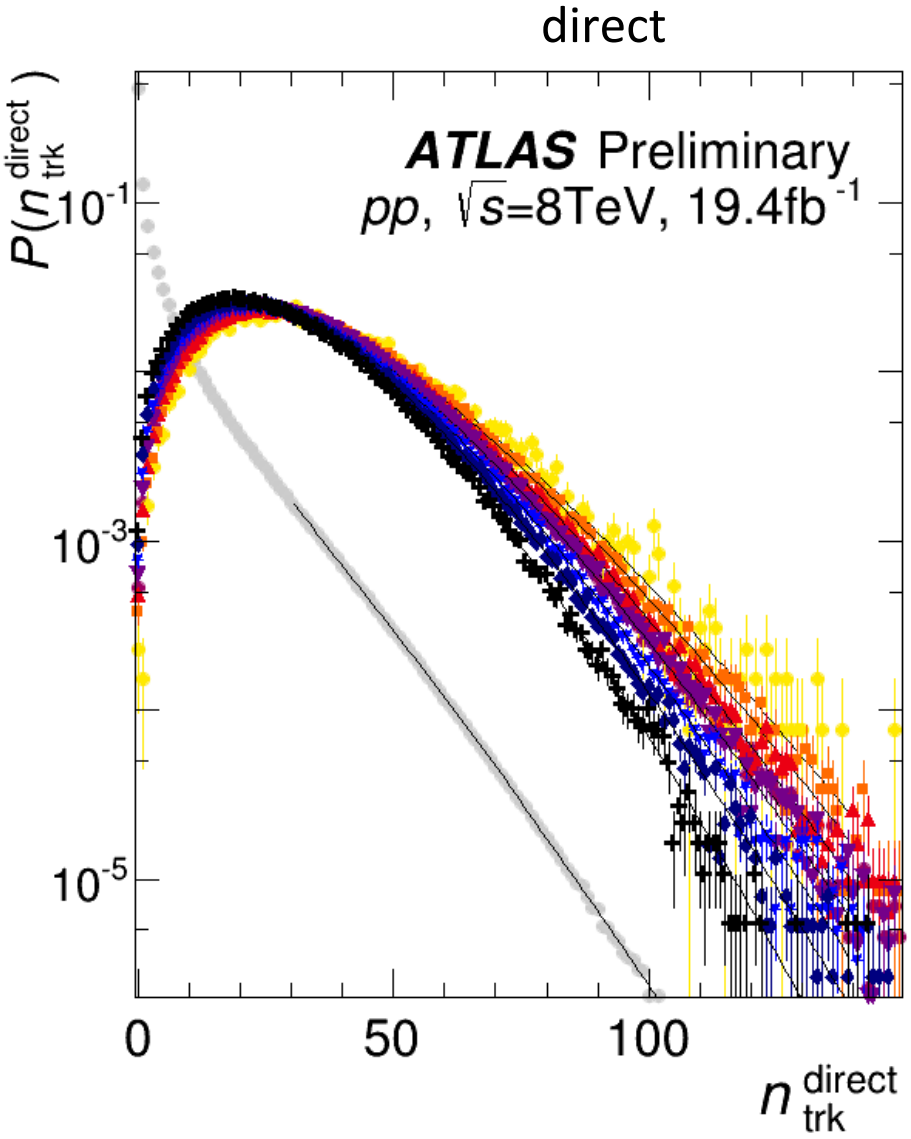


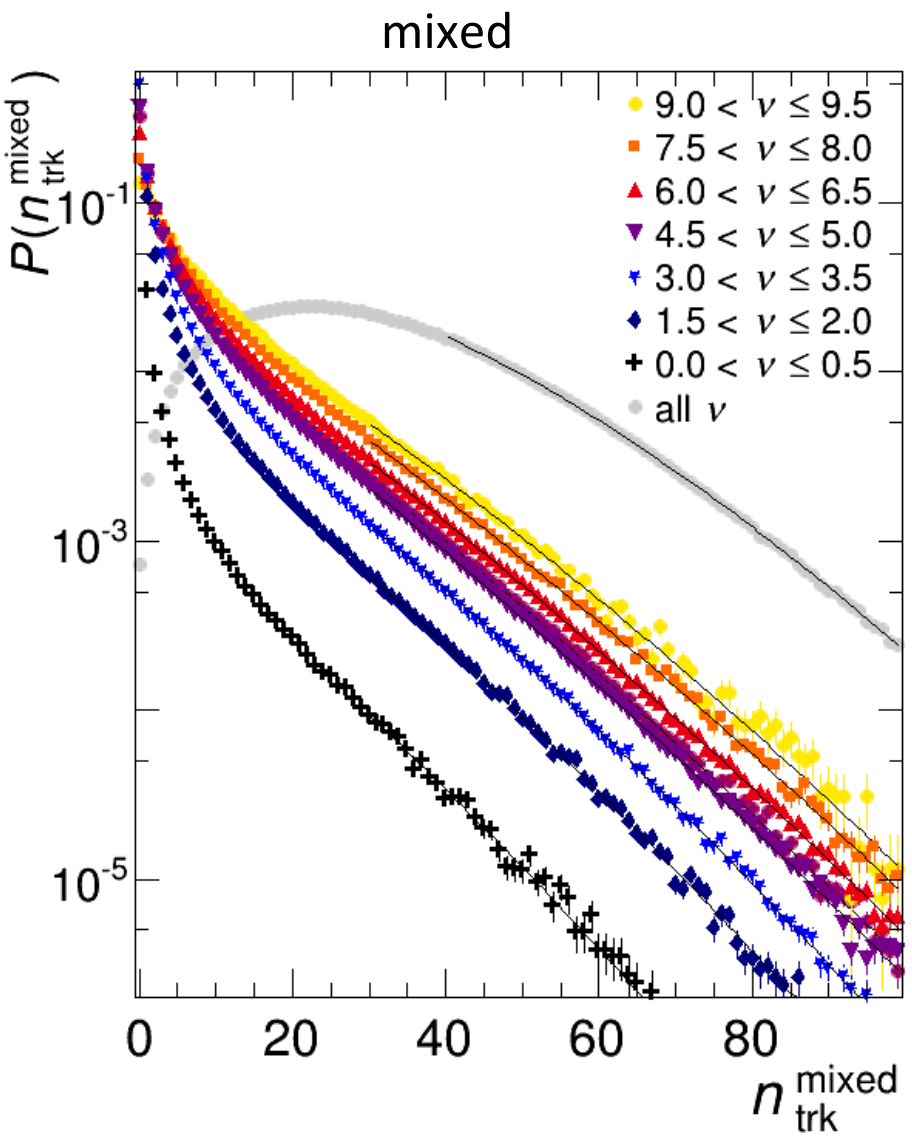


- Mean number of bkgd tracks, *ν*, depends on $\bar{\mu}$ and $\bar{z}_{vtx}$

ν is used to select (bin) events for 2PC pileup correction

Probability Distributions for n_{trk}^{direct} and n_{trk}^{mixed}





- n_{trk}^{direct} distribution for $\nu \leq 0.5$ is treated as n_{trk}^{signal} dist. (no pileup)
- For $9<\nu\leq 9.5$, n_{trk}^{direct} dist. for $n_{trk}^{direct}>100$ is dominated by pileup

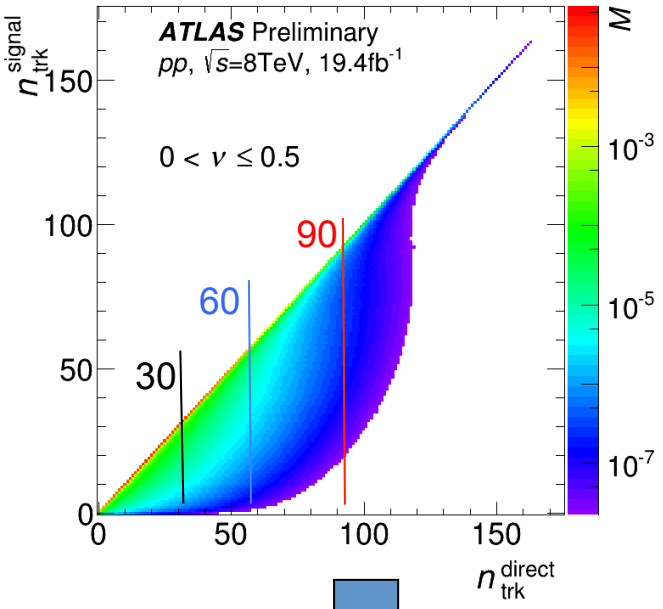
$$M\left(\nu, n_{\mathrm{trk}}^{\mathrm{signal}}, n_{\mathrm{trk}}^{\mathrm{direct}}\right) = P_{\mathrm{Direct}}\left(\nu < 0.5, n_{\mathrm{trk}}^{\mathrm{signal}}\right) P_{\mathrm{Mixed}}\left(\nu, n_{\mathrm{trk}}^{\mathrm{direct}} - n_{\mathrm{trk}}^{\mathrm{signal}}\right)$$

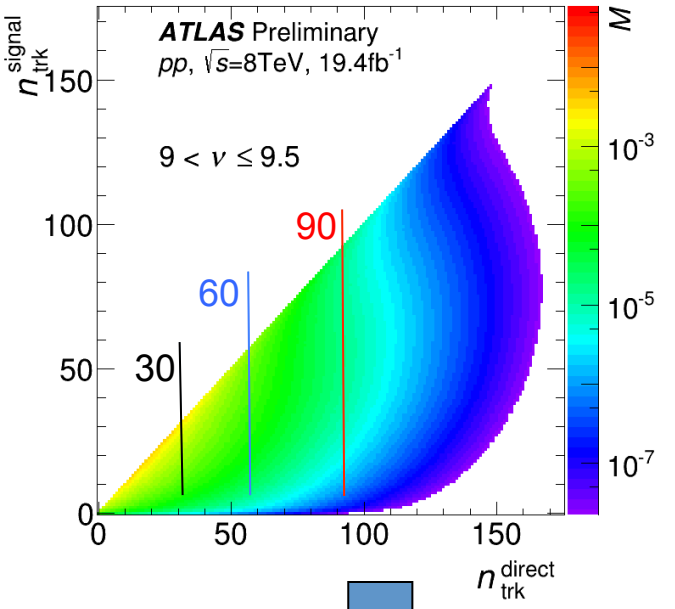
Matrices for Mapping

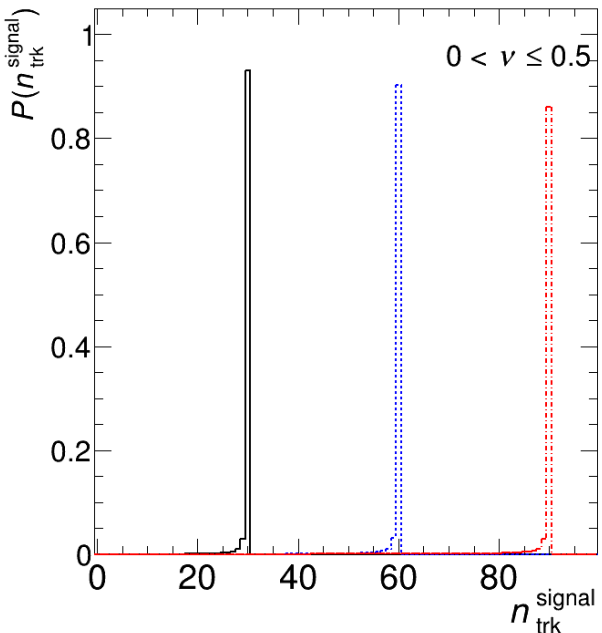
$n_{\mathrm{trk}}^{\mathrm{direct}} \rightarrow n_{\mathrm{trk}}^{\mathrm{signal}}$

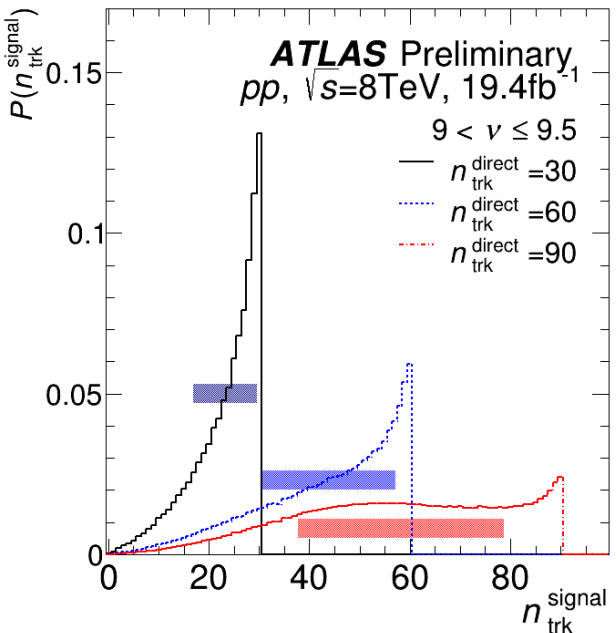
At large ν and $n_{\mathrm{trk}}^{\mathrm{direct}}$ significant contribution from $n_{\mathrm{trk}}^{\mathrm{signal}} < n_{\mathrm{trk}}^{\mathrm{direct}}$

Analysis restricted to $\nu < 7.5$









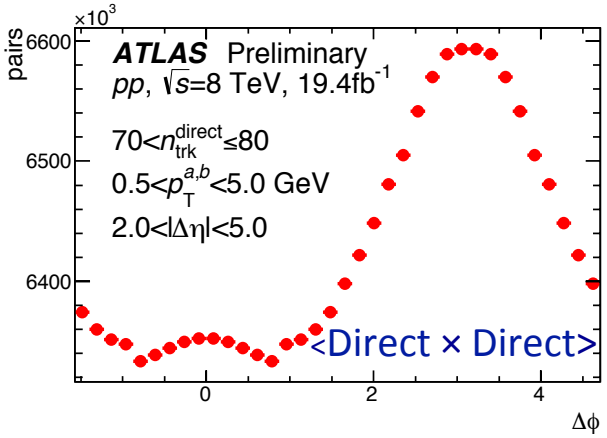
ATLAS-CONF-2017-007

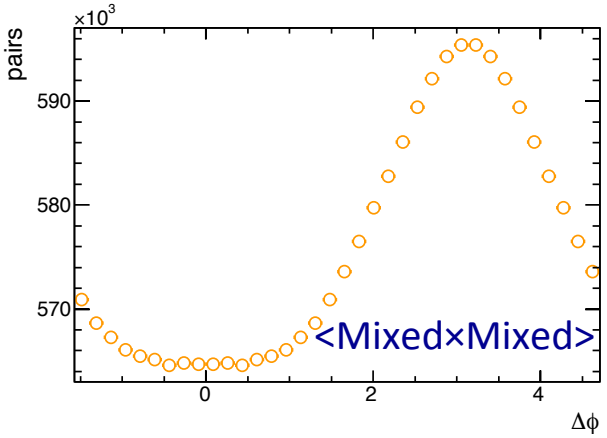
Two-particle correlations with pileup

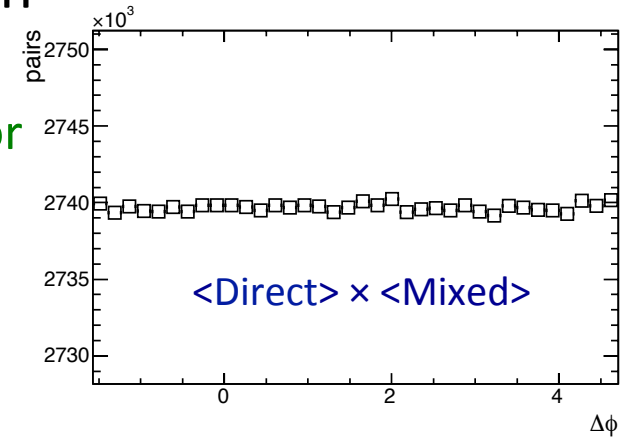
Direct tracks contain both Signal and Bkgd tracks

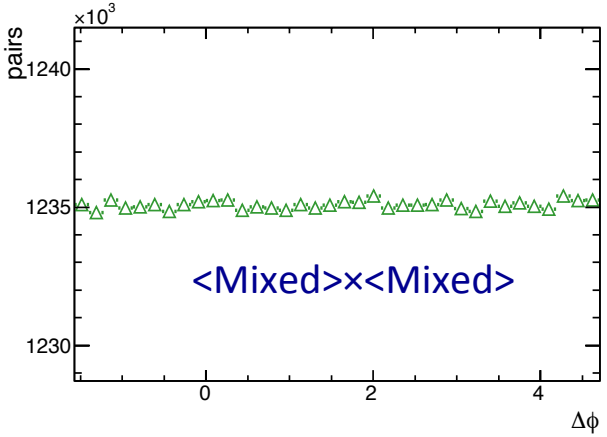
- 2PC has to be corrected for pileup

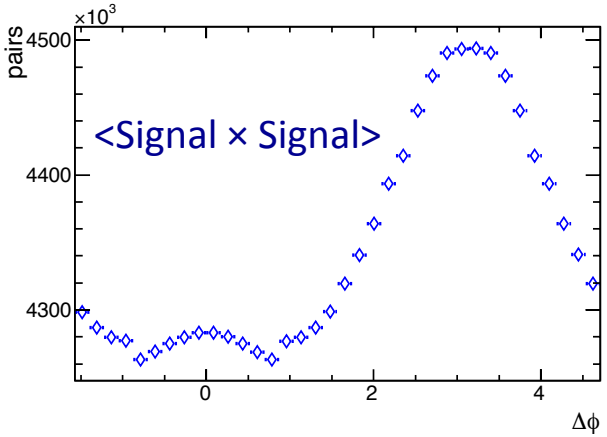
Averaged over ν ($\nu < 7.5$) in $70 < n_{trk}^{direct} \leq 80$
Muon inner detector tracks excluded from 2PC

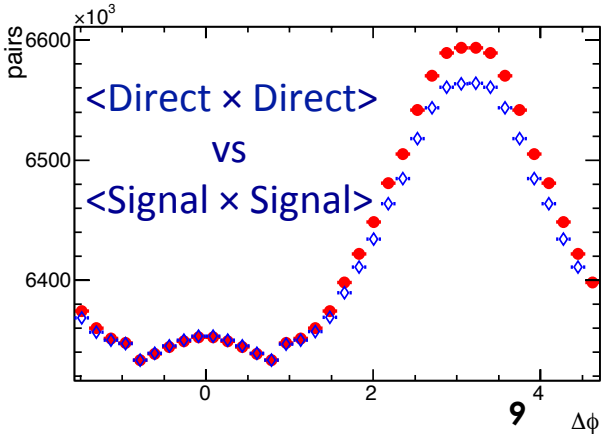












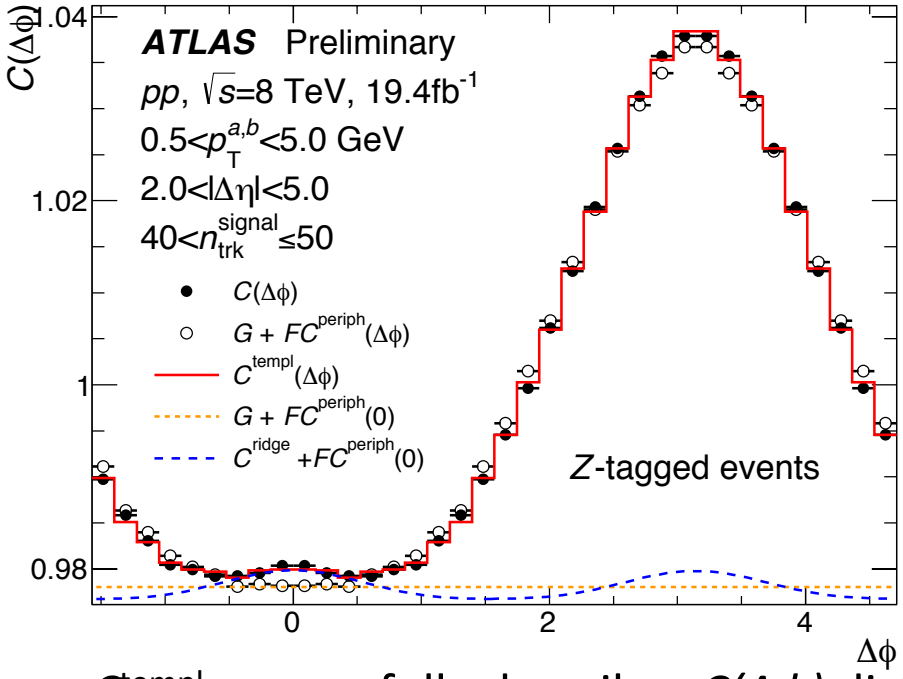
Template fitting method

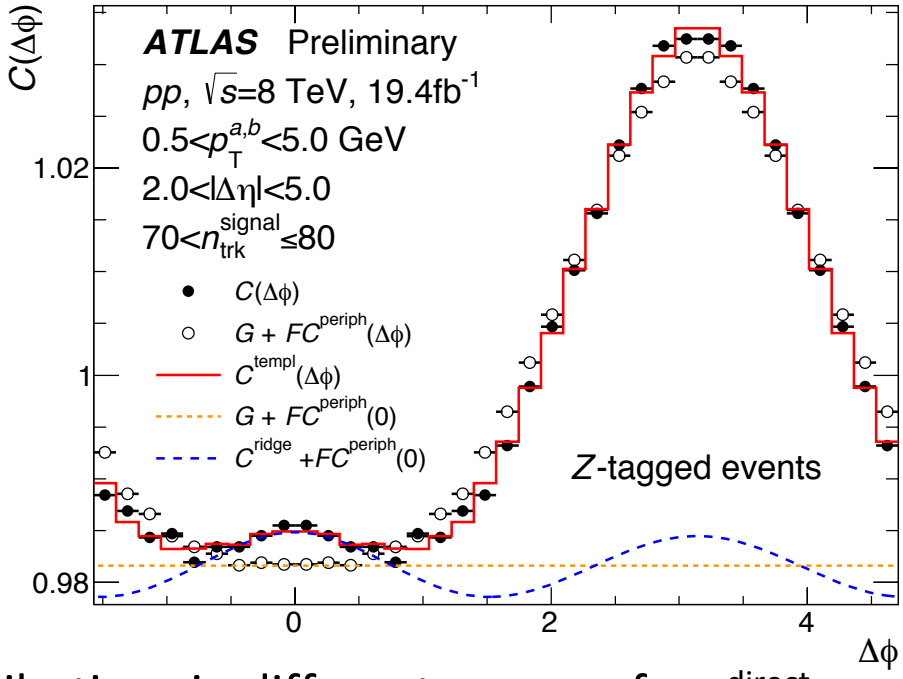
The pileup corrected two-particle correlation function is fitted with template function to separate non-flow (e.g. dijets) from the ridge correlations (PRL116 172301 (2016), PR C96 (2017) 024908)

$$C(\Delta\phi)^{\text{templ}} = F\,C^{\text{periph}}(\Delta\phi) + G\,(1 + 2\,\Sigma\, v_{2,2}\cos(n\Delta\phi))$$

(non-flow) (ridge)

$C^{\text{periph}}(\Delta\phi)$ - correlation function for peripheral events, $20 < n_{\text{trk}}^{\text{direct}} \le 30$



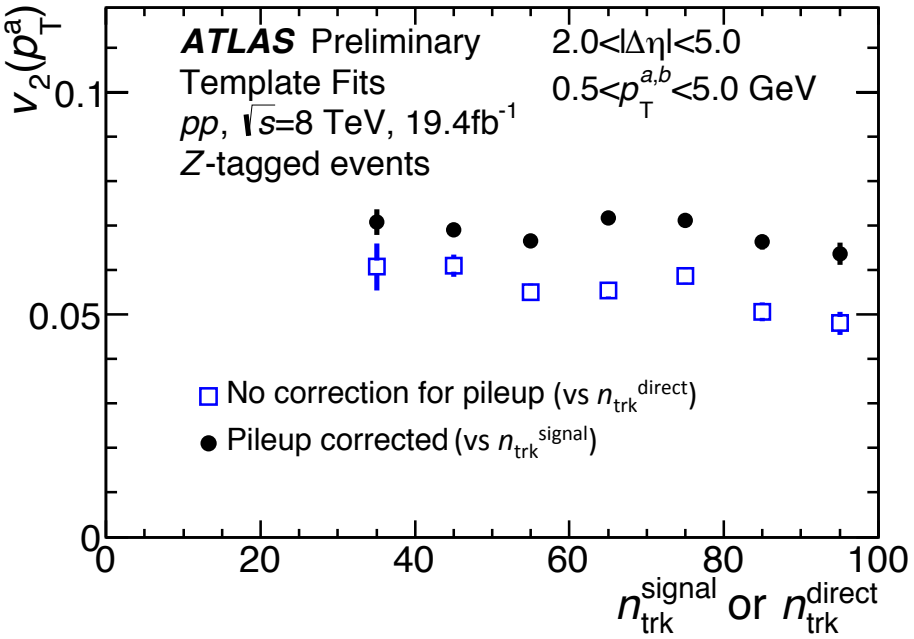


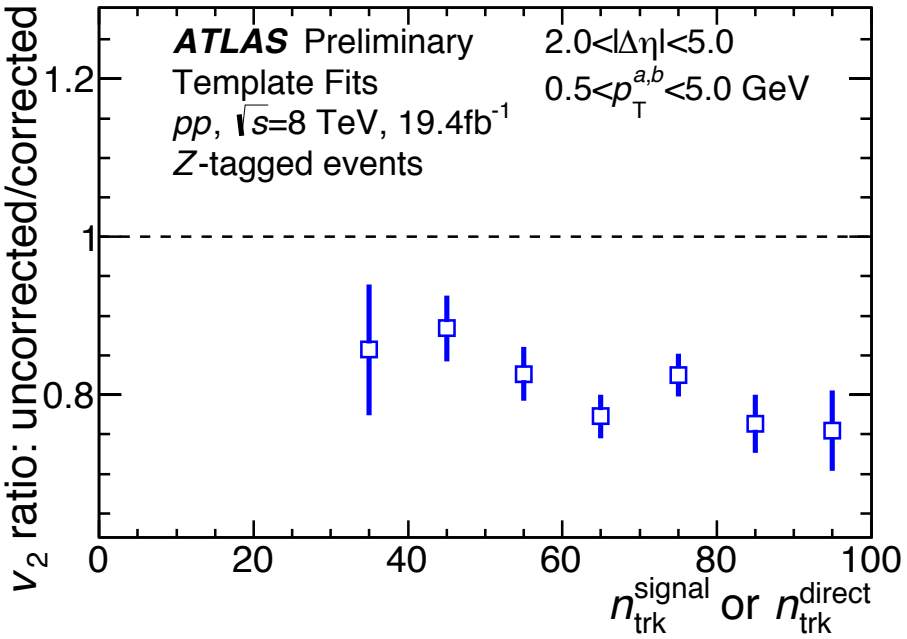
- C^{templ} successfully describes $C(\Delta\phi)$ distributions in different ranges of $n_{\text{trk}}^{\text{direct}}$
- The factorization is used to obtain v_2: $v_{2,2}(p_T^a, p_T^b) = v_2(p_T^a)v_2(p_T^b)$

Two-particle correlations with pileup

Comparison of v_2 obtained from template analysis with and without pileup correction

ATLAS-CONF-2017-007



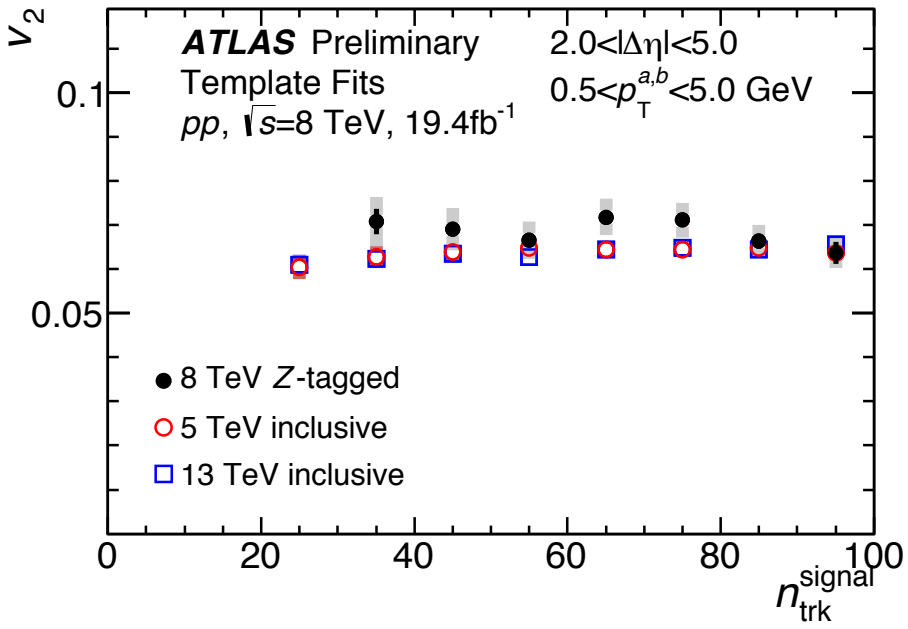


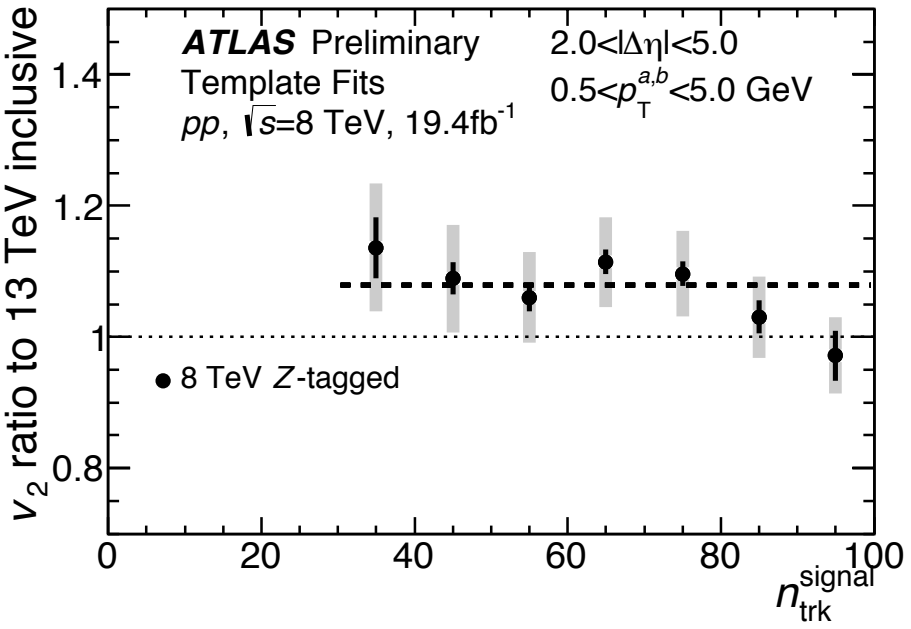
- Pileup correction increases v_2 by ~20%

Results

v_2 in Z-tagged events compared to inclusive 5 and 13 TeV pp results

ATLAS-CONF-2017-007





- No multiplicity dependence observed
- Integrated v_2 is 8 ± 6%* larger in Z-tagged events than inclusive v_2
  - Expected decrease, for constrained initial geometry not observed

** p_T-spectrum in collisions containing Z-boson is harder than in inclusive collisions*

Summary

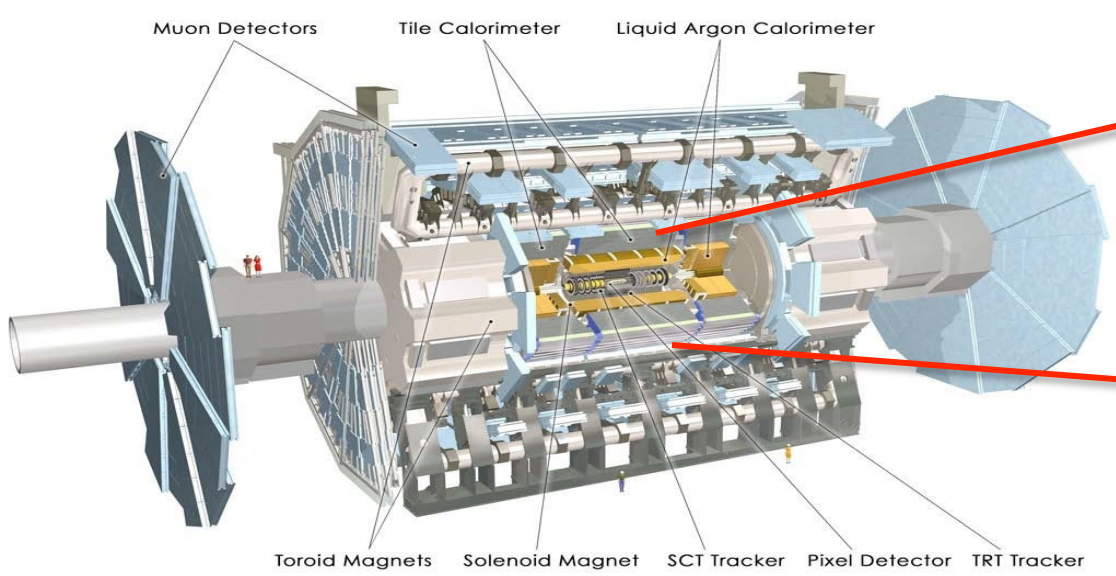
- ATLAS measured long-range two-particle azimuthal correlations in Z-tagged *pp* collisions at $\sqrt{s}$ = 8 TeV
  - Constraining initial pp collision geometry => origin of ridge
- First measurement of 2PC in high-pileup samples
  - luminosity μ ~ 20
  - Up ~20% pileup-correction to v_2
- v_2 in Z-tagged events shows no dependence on n_{trk}^{signal}
  - the v_2 is 8 ± 6%* larger than in inclusive 13 TeV *pp* coll.

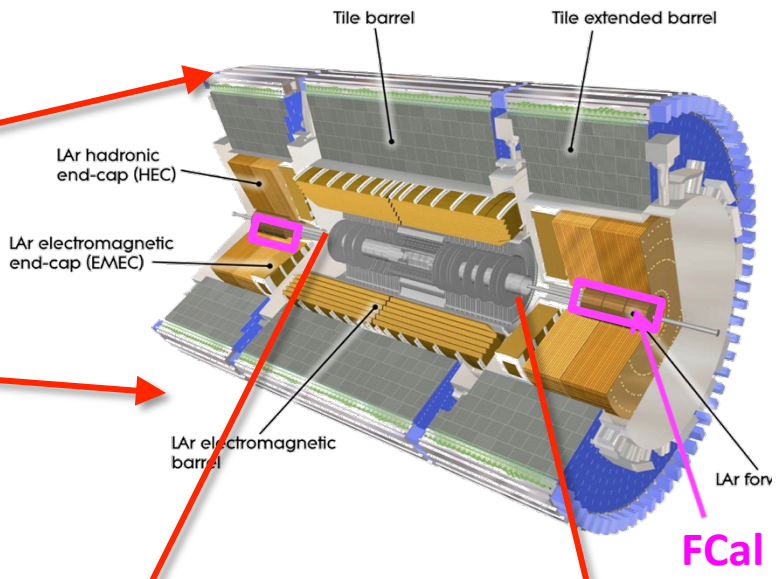
Method can be used in other high-pileup measurements in future HI analyses

* *p_T-spectrum in collisions containing Z-boson is harder than in inclusive collisions*

Backups

ATLAS Detector



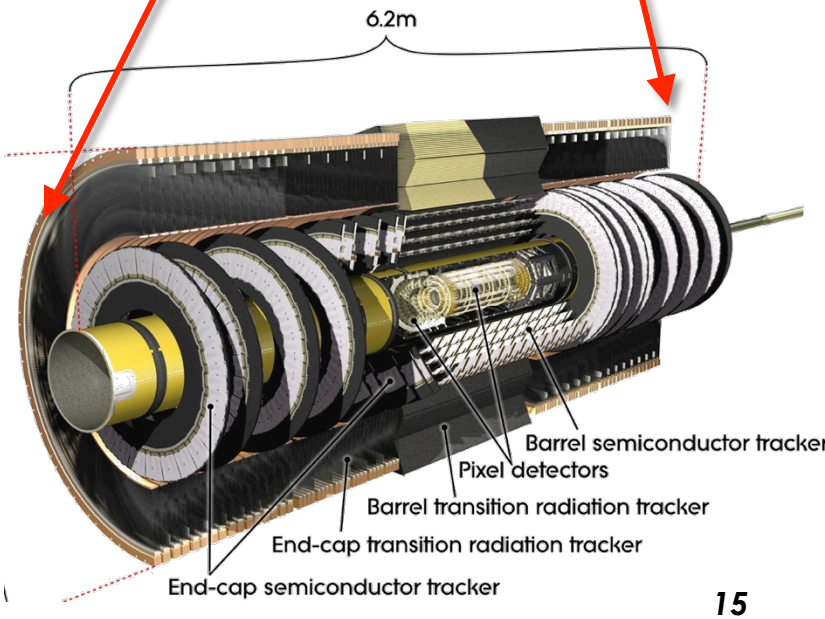


Three main subsystems:

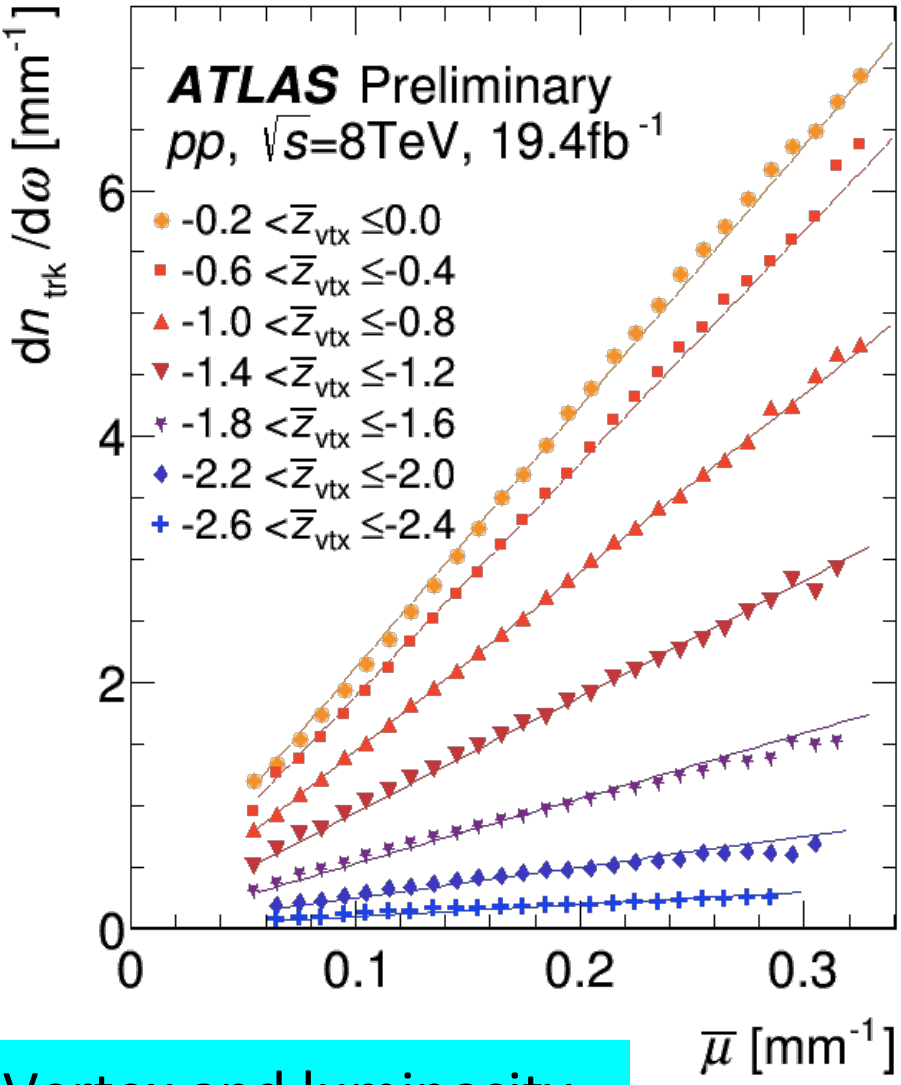
- Inner Detector – tracking
  - $|\eta|<2.5$, $p_T>0.4$ GeV
- Calorimetry – $|\eta|<4.9$
- Muon Spectrometer - $|\eta|<2.7$

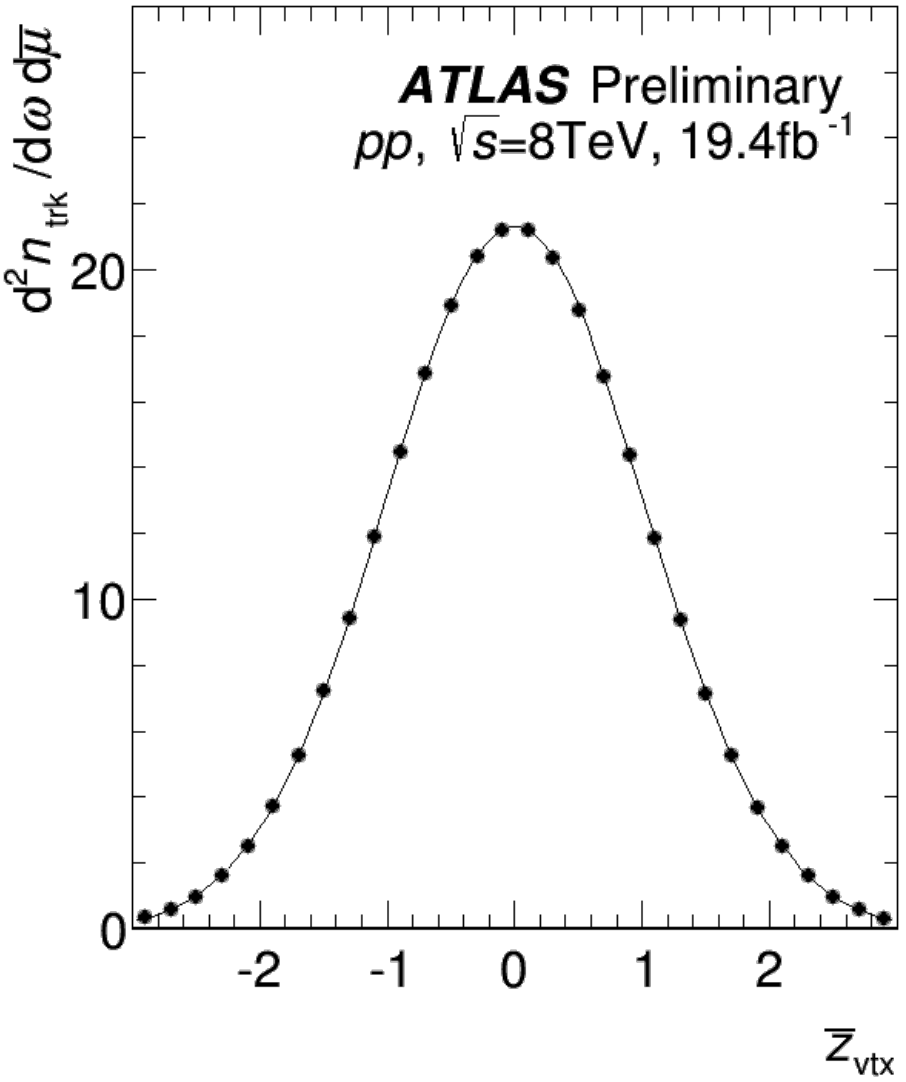
Fast trigger systems:

- Level 1 (L1,hardware), to 75 kHz
- L2 and L3 (software), to ~200Hz



Background Parametrization





Vertex and luminosity factorize in the mean number of bkgd tracks

$$\nu \equiv \langle n_{\mathrm{trk}}^{\mathrm{background}} \rangle = 2\omega_0 \frac{\mathrm{d}^2 n_{\mathrm{trk}}^{\mathrm{mix}}}{\mathrm{d}\omega\, \mathrm{d}\bar{\mu}} G(\bar{z}_{\mathrm{vtx}})\bar{\mu}$$

Two-particle correlations with pileup

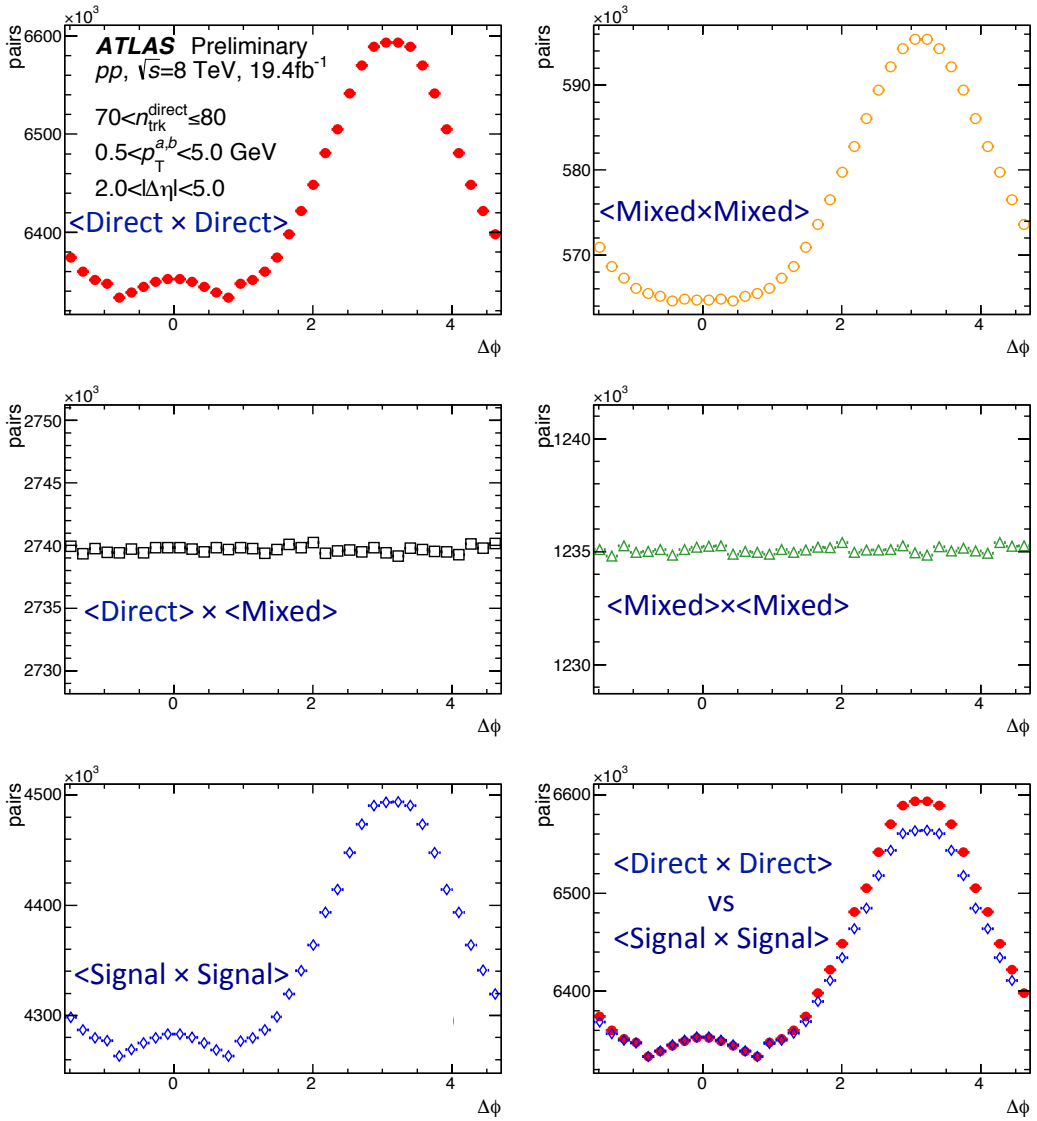
As Direct event has contributions from both Signal and Background tracks, 2PC has to be corrected for pileup:

$$\text{Signal}^a\times\text{Signal}^b = \text{Direct}^a\times\text{Direct}^b - \text{Signal}^a\times\text{Bkg}^b - \text{Bkg}^a\times\text{Signal}^b - \text{Bkg}^a\times\text{Bkg}^b$$

Assuming: <Background> ≡ <Mixed>

$$\langle\text{Signal}\rangle = \langle\text{Direct}\rangle - \langle\text{Mix}\rangle$$

$$\langle\text{Signal}^a\times\text{Signal}^b\rangle = \langle\text{Direct}^a\times\text{Direct}^b\rangle - \langle\text{Direct}^a\rangle\times\langle\text{Mix}^b\rangle - \langle\text{Mix}^a\rangle\times\langle\text{Direct}^b\rangle - \langle\text{Mix}^a\times\text{Mix}^b\rangle + 2\langle\text{Mix}^a\rangle\times\langle\text{Mix}^b\rangle$$



Averaged over all ν conditions ($\nu < 7.5$) and in $70 < n_{trk}^{direct} \leq 80$

Muon inner detector tracks excluded from 2PC

Systematic uncertainties for v_2

Source	$n_{\mathrm{trk}}^{\mathrm{signal}}$ range	Uncertainty [%]
Choice of peripheral bin	30–70	7–3
	70–100	3
Tracking efficiency	30–100	0.5
Pair acceptance	30–100	1
Mixed and Background equivalence	30–100	2
Accuracy of background estimation	30–100	1
Uncertainties in transition matrices	30–100	2
Pileup correction procedure	30–100	3.5
Total	30-100	6

Mixed tracks p_T and η distributions