Gluon TMDs from $J/\psi + \gamma$ final state simulation studies

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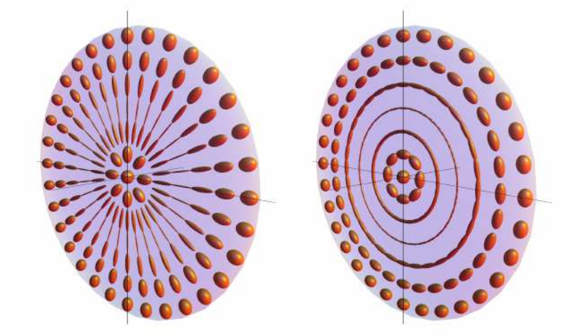
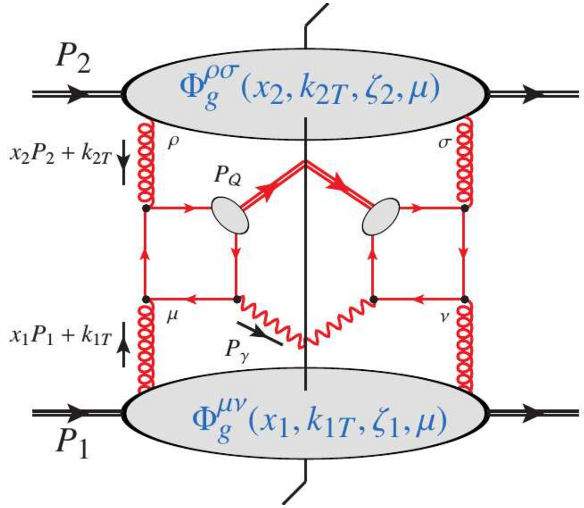
Gluon TMDs from $J/\psi + \gamma$ final state

- In general, parton distributions inside a proton can depend on the parton k_T
- Drell-Yan process provides a clean way of accessing quark and antiquark transverse-momentum-dependent (TMD) distributions from hadronic collisions
- Good knowledge of gluon TMDs is important for studies of any gluon-gluon collision subprocess, such as Higgs production
- Gluons inside a proton can be polarised, even if the proton itself is not
- The degree of linear polarisation may depend on the gluon's transverse momentum
- Many subprocesses considered to study these, but neither is perfect
- $J/\psi + \gamma$ considered as one of the most promising





den Dunnen PRL.112.212001, arXiv:1401.7611

Lansberg NP B920(2017)192, arXiv:1702.00305, arXiv:1710.01684

Formalism

The idea is to select events with a J/ψ and an isolated photon, such that the transverse momentum of the $J/\psi + \gamma$ system q_T is (much) smaller than its invariant mass Q, and

1. Measure the q_T^2-dependence of the cross section to assess the unpolarised TMD f_1^g
2. Measure the $\cos 2\phi$ and/or $\cos 4\phi$ modulation to assess the linearly polarised TMD $h_1^{\perp g}$

$$\begin{aligned} \frac{d\sigma}{dQ dY d^2 q_T d\Omega} &= \frac{A(Q^2 - M^2)}{s\, Q^3 D} \times \\ &\times \quad \left\{ F_1 \mathcal{C}[f_1^g f_1^g] + \cos 2\phi\ F_3 \mathcal{C}[w_3 f_1^g h_1^{\perp g}] + \cos 4\phi\ F_4 \mathcal{C}[w_4 h_1^{\perp g} h_1^{\perp g}] \right\}, \end{aligned}$$

The convolution terms $\mathcal{C}$ depend on q_T alone, and are the quantities we are interested in.

Coefficient functions F_1, F_3, F_4 depend on invariant mass Q and $\cos\theta$, but NOT on q_T or ϕ.

Collins-Soper azimuthal dependence is given by $1, \cos 2\phi, \cos 4\phi$ – a handle on the separation of the three terms.

One expects the last two terms to be of roughly equal size, much smaller than the first.

Point of this talk

- The nice factorisation and separation of variables looks very encouraging
- Could be true for a perfect experiment with full acceptance – but no such thing exists
- A general-purpose LHC experiment can identify and measure muons and photons above certain p_T thresholds
- Need to study how these acceptance cuts affect the nice picture above
- Question 1:
  How is the q_T distribution distorted by the acceptance cuts, and what can we do to have a 'clean' access to the term $\mathcal{C}[f_1^g f_1^g]$?
- Question 2:
  How is the ϕ distribution distorted by the acceptance cuts, and what can we do to have a 'clean' access to the terms $\mathcal{C}[w_3 f_1^g h_1^{\perp g}]$ and $\mathcal{C}[w_4 h_1^{\perp g} h_1^{\perp g}]$

Acceptance cuts

The above picture applies once the invariant mass Q of the $J/\psi + \gamma$ system is much larger than its transverse momentum q_T

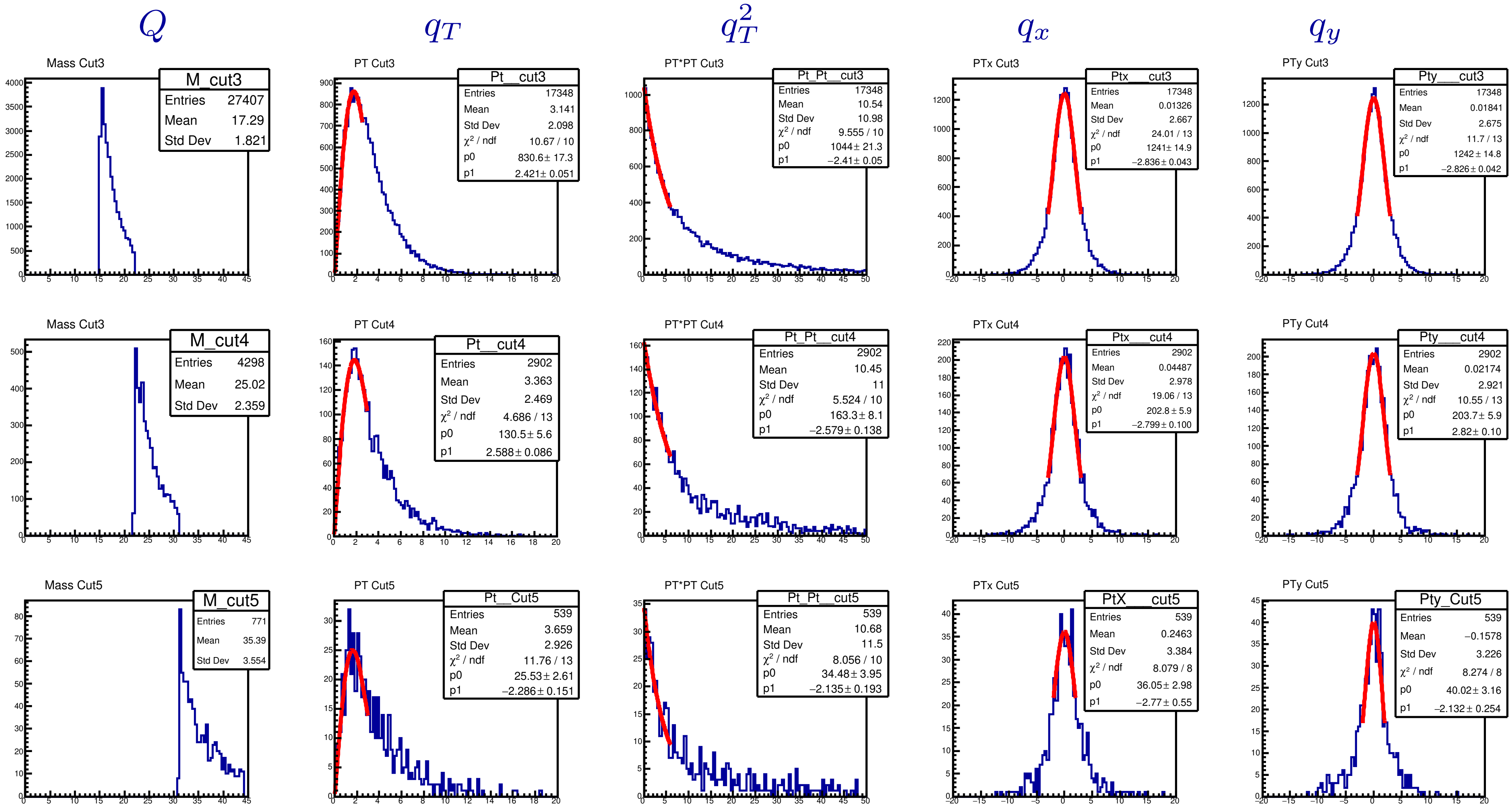
On the other hand, a general purpose LHC detector cannot reliably identify and measure muons and photons with low transverse momenta

Typical accpetance cuts for muons are $p_T(\mu) > 4$ GeV – which, by the way, effectively means $p_T(J/\psi > 8$ GeV

Quality of photons improves at higher $p_T(\gamma)$, typically $p_T(\gamma) > 5$ GeV or more

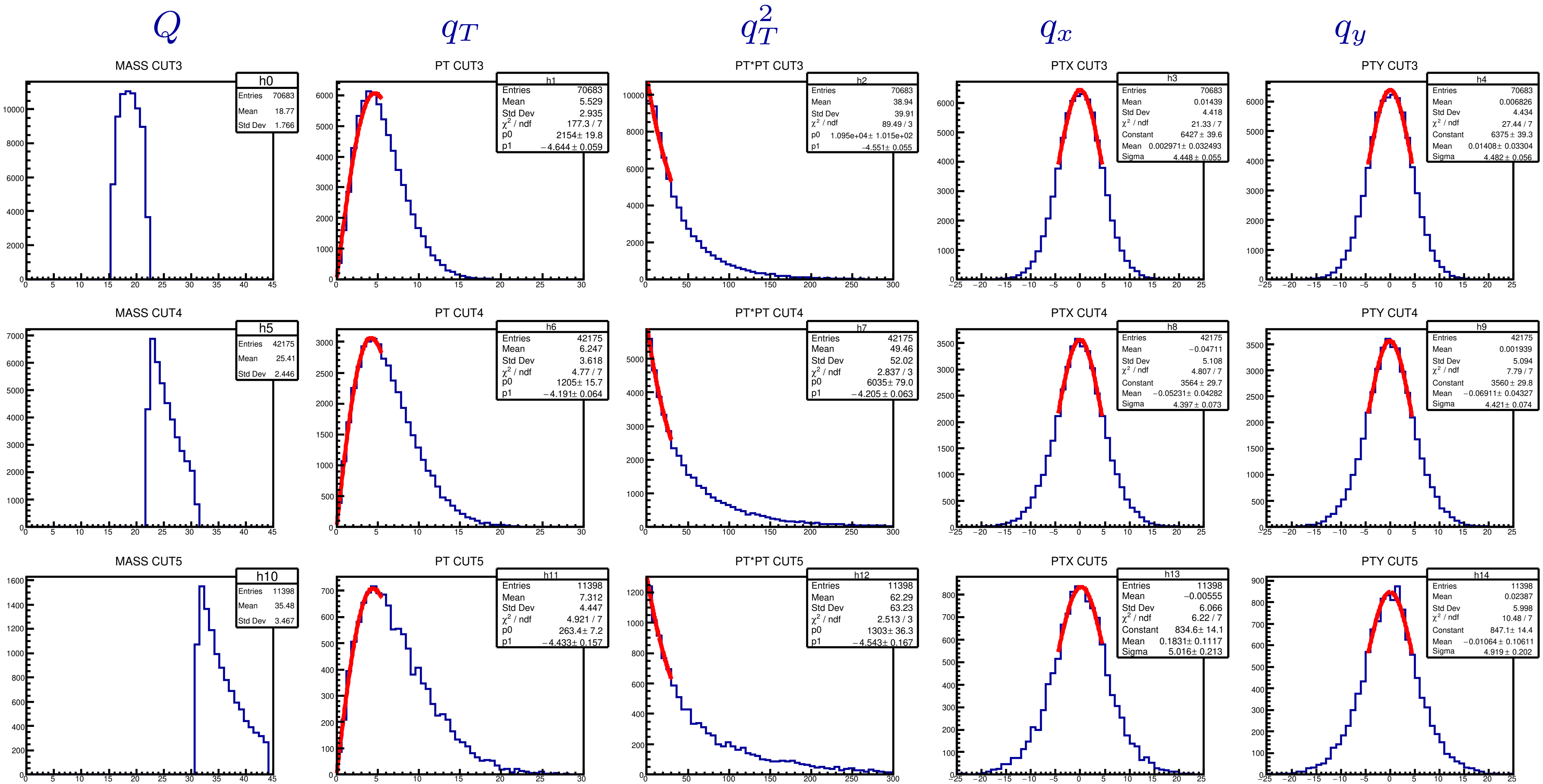
These cuts affect all kinds of distributions, some of them significantly

Simulation with no cuts



$\sqrt{\langle k_T^2 \rangle} \simeq 2.5$ GeV, independent of $J/\psi + \gamma$ invariant mass

$p_T(\mu) > 4$ **GeV,** $p_T(\gamma) > 6$ **GeV**



$\sqrt{\langle k_T^2 \rangle} \simeq 4.4$ GeV, slightl$p_T(\gamma)$y increasing with $J/\psi + \gamma$ invariant mass

$p_T(\mu) > 4$ GeV, $p_T(\gamma) > 9$ GeV

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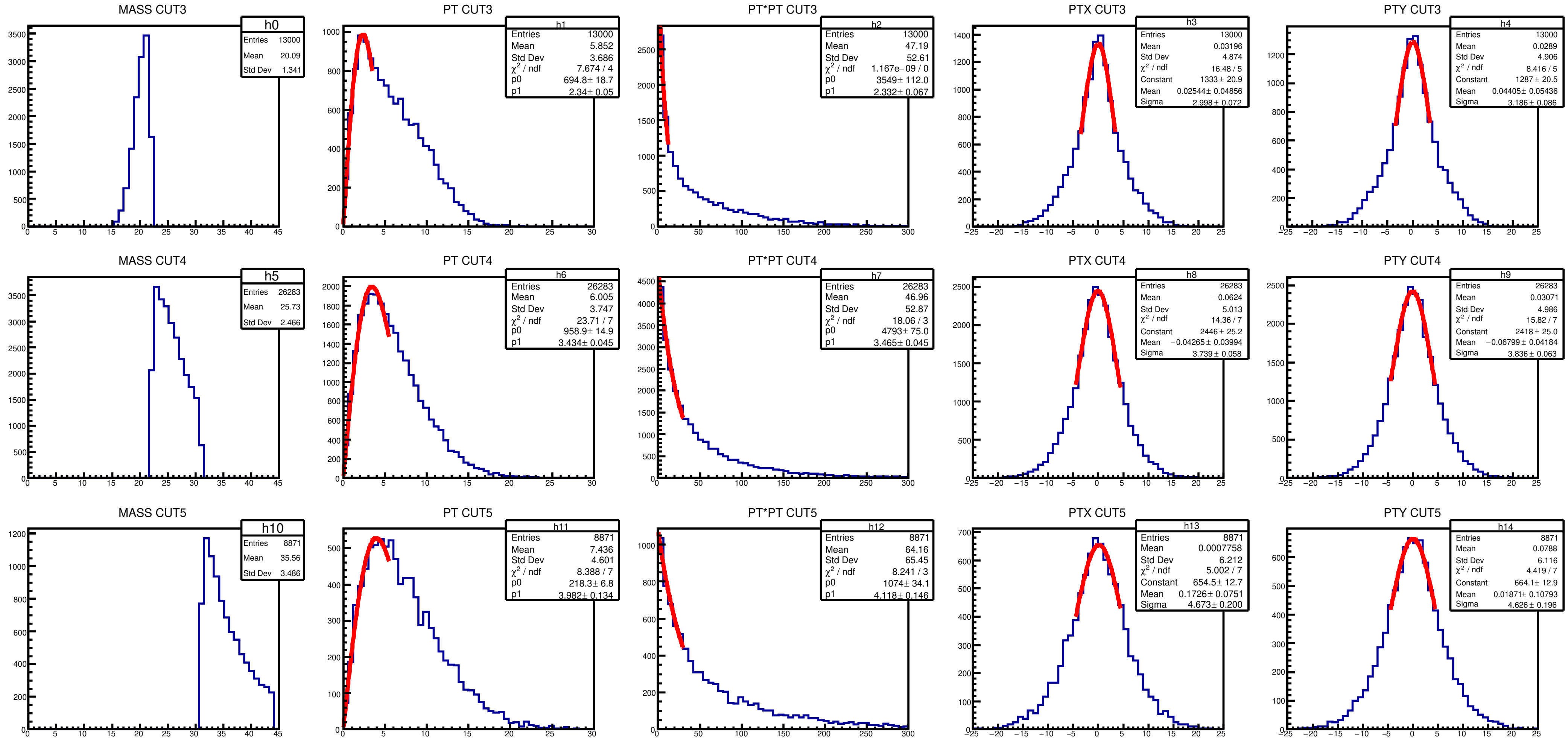
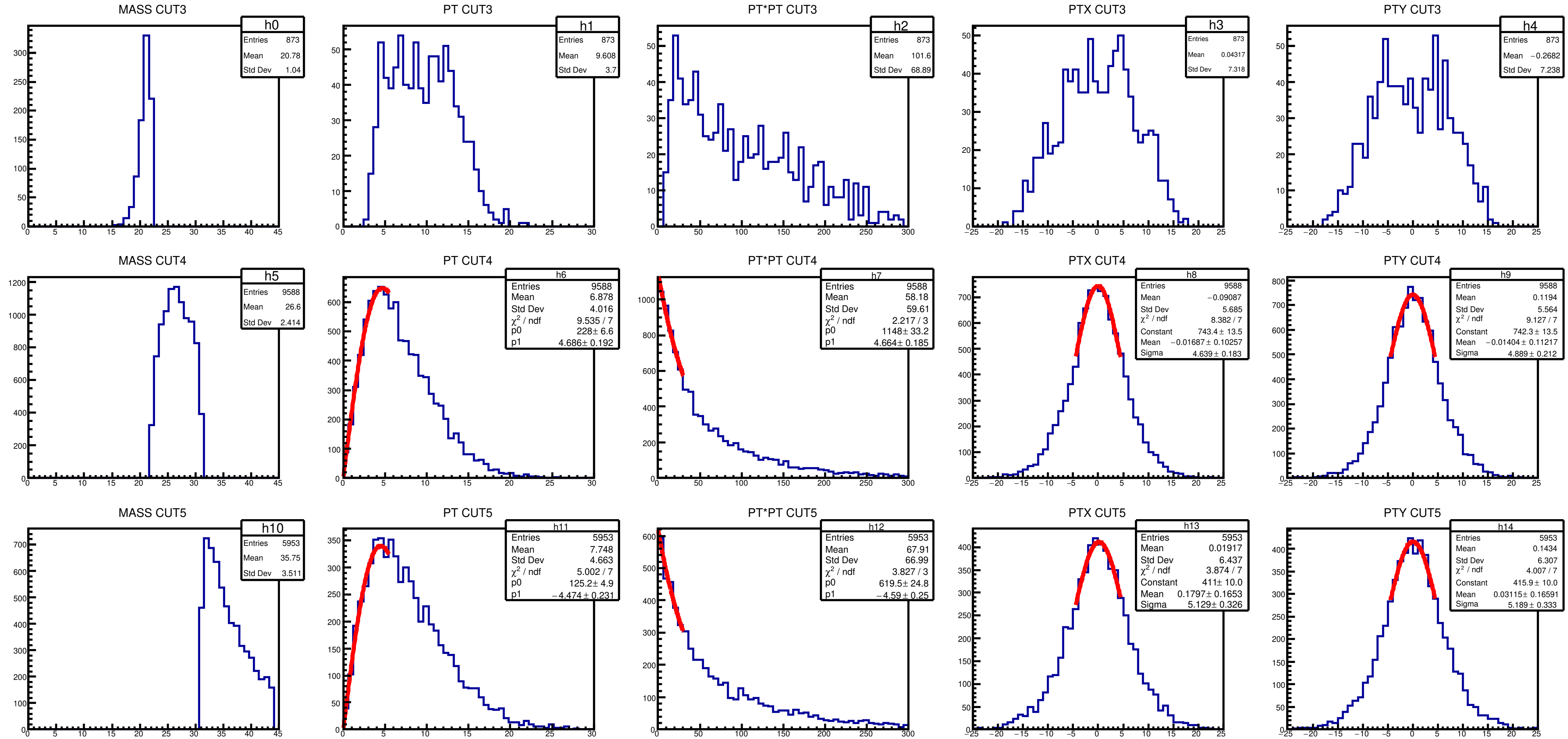
Q | q_T | q_T^2 | q_x | q_y



$\sqrt{\langle k_T^2 \rangle} \simeq 3$ GeV, grows with $J/\psi + \gamma$ invariant mass, bulge noticeable

$p_T(\mu) > 4$ GeV, $p_T(\gamma) > 12$ GeV

Q | q_T | q_T^2 | q_x | q_y



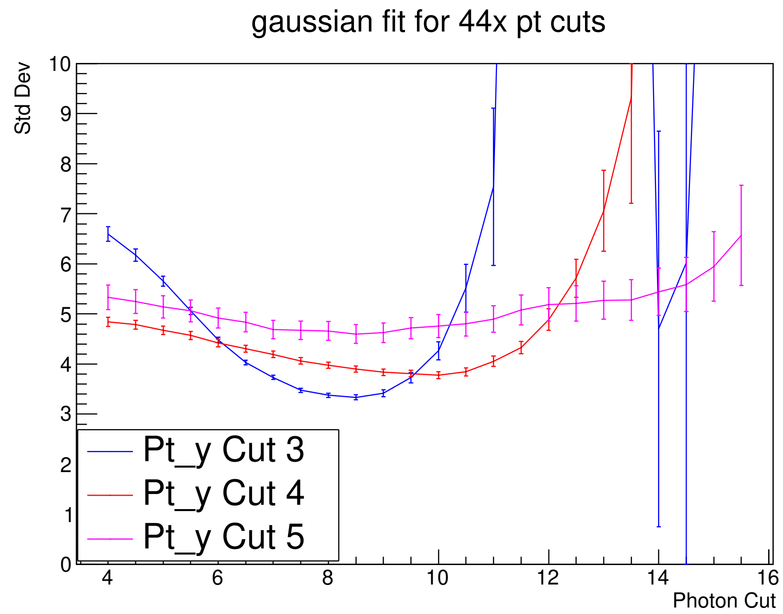
$\sqrt{\langle k_T^2 \rangle} \simeq 4.5$ GeV, low mass breaks down

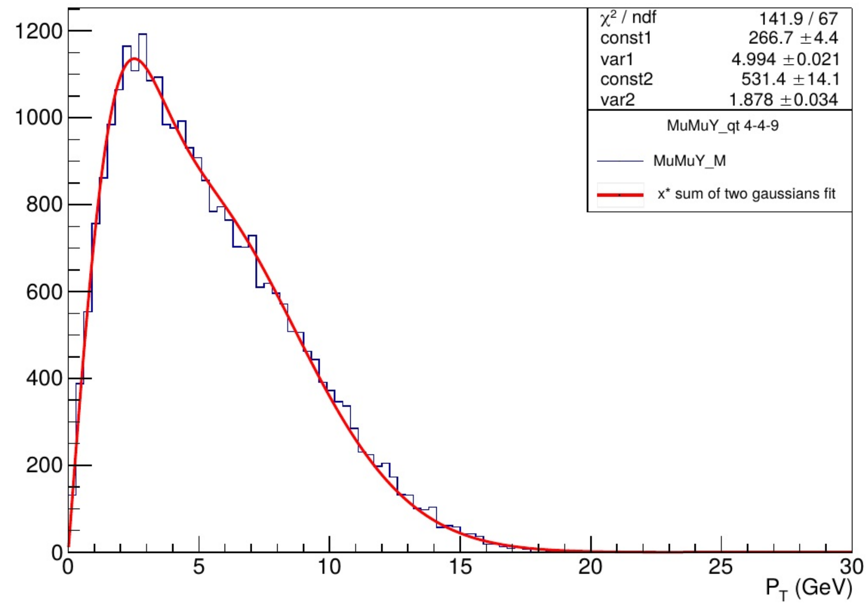
Imbalance dependence

With muon cut fixed (by necessity), photon cut regulates the imbalance of $J/\psi + \gamma$ system

With large imbalances, some distributions break down

'Best' results obtained with photon balancing out J/ψ transverse momentum at ~ 9 GeV



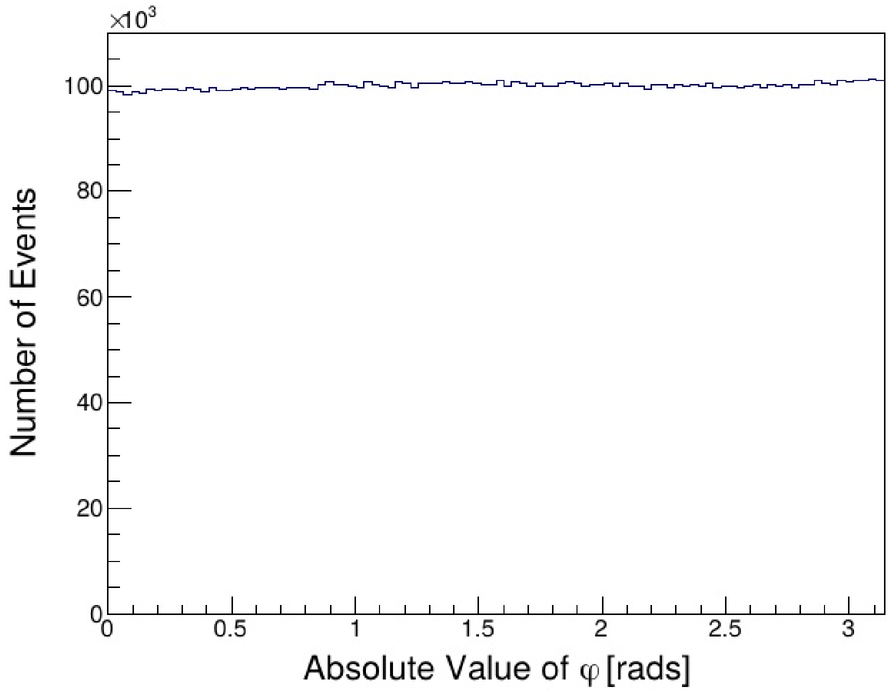


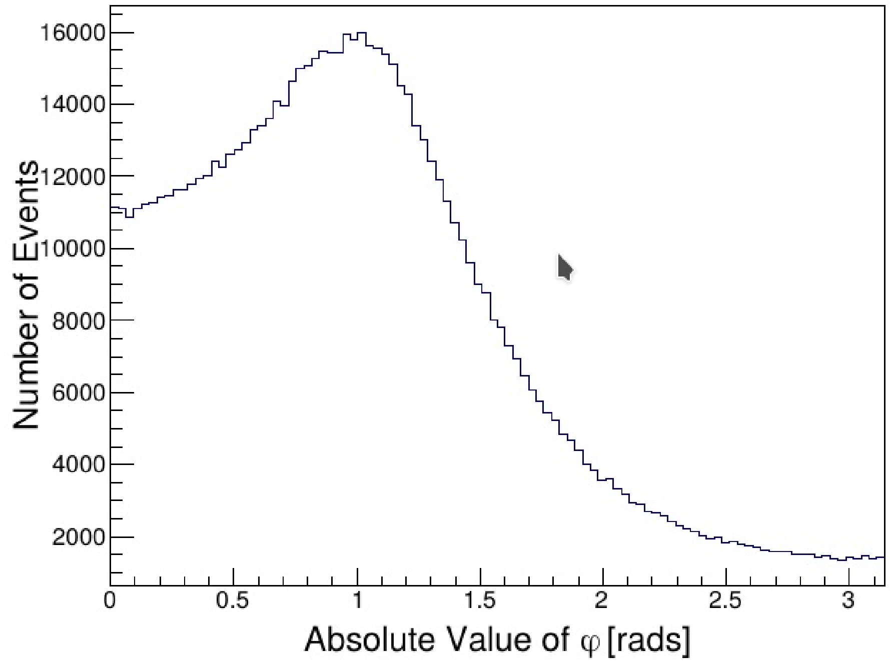
Significant dependence on system invariant mass is an unwanted feature

More sophisticated analyses needed to extract the 'narrowest' part of the distribution

Fit with a sum of two Gaussians can 'see' the narrow component – sometimes...

Collins-Soper ϕ before and after the cuts





A perfectly flat 'native' ϕ distribution (left) develops fairly strong ψ dependence after acceptance cuts of 4 GeV on muons and 5 GeV on photons (right)

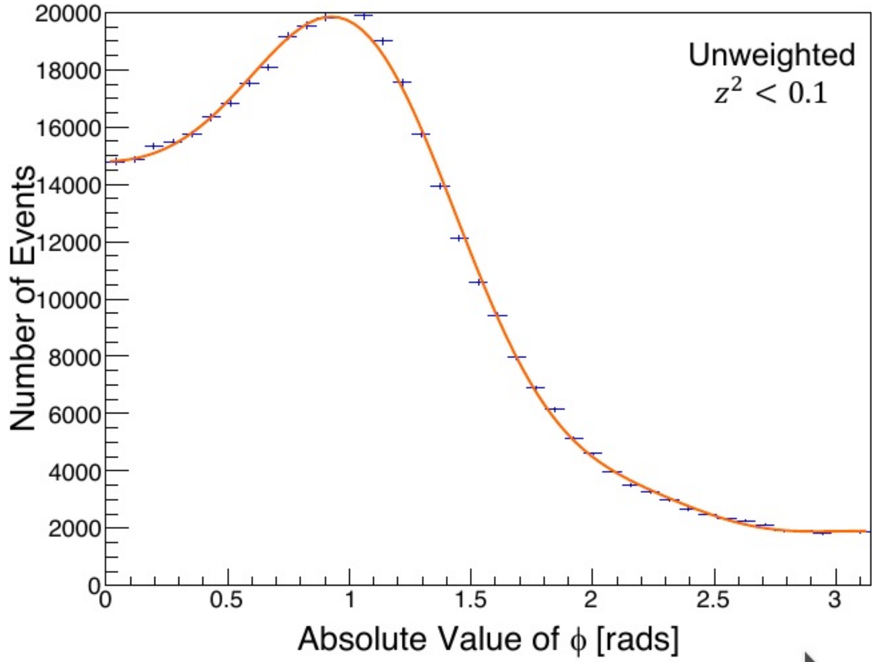
The after-cuts distribution has a very large 2ϕ harmonic and a significant 4ϕ one as well, even without any gluon polarisation in the simulation

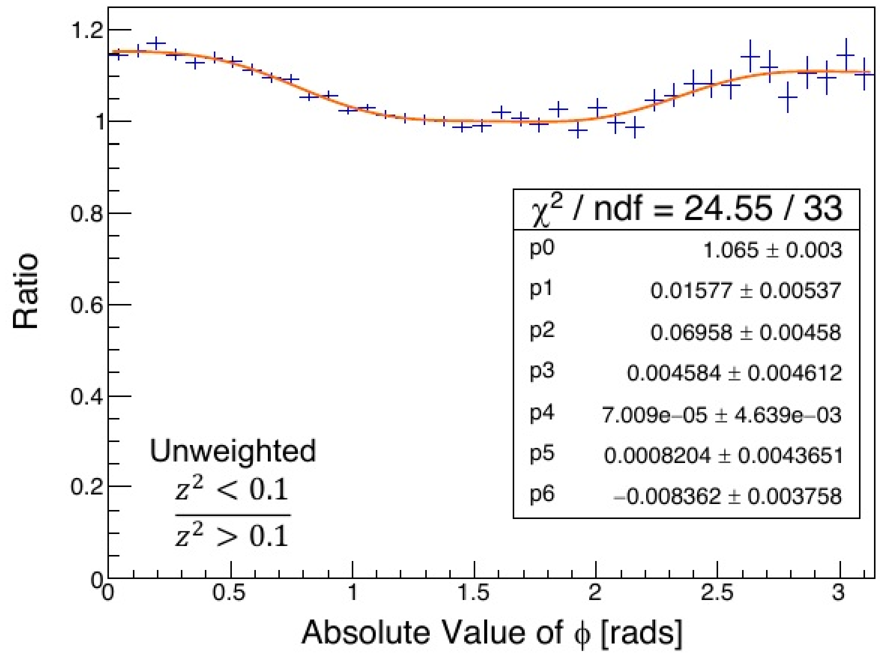
Separating in Collins-Soper $\cos\theta \equiv z$

Fortunately, the $\cos 4\phi$ modulation term has a relative coefficient of $\frac{(1-z^2)^2}{9+6z^2+z^4}$

Low $z^2 < 0.1$ is far more sensitive to gluon polarisation, than High $z^2 > 0.1$.

Kinematic distortion almost uniform in $z \quad \Rightarrow \quad$ take the Low/High ratio:





$$P_0(1 + P_1 \cos\phi + P_2 \cos 2\phi + P_3 \cos 3\phi + P_4 \cos 4\phi + P_5 \cos 5\phi + P_6 \cos 6\phi)$$

Truncated Fourier fit shows still some modest 2ϕ term of 7%, but no 4ϕ contribution.

Two models for $h_1^{\perp g}$

Emulate the effects of non-zero $h_1^{\perp g}$: weight events with $\left\{1 + \cos 4\phi \, \frac{F_4 \mathcal{C}[w_4 h_1^{\perp g} h_1^{\perp g}]}{F_1 \mathcal{C}[f_1^g f_1^g]}\right\}$

Assume Gaussian $f_1^g = \frac{1}{\pi \langle k_T^2 \rangle} \exp\left(-\frac{k_T^2}{\langle k_T^2 \rangle}\right)$

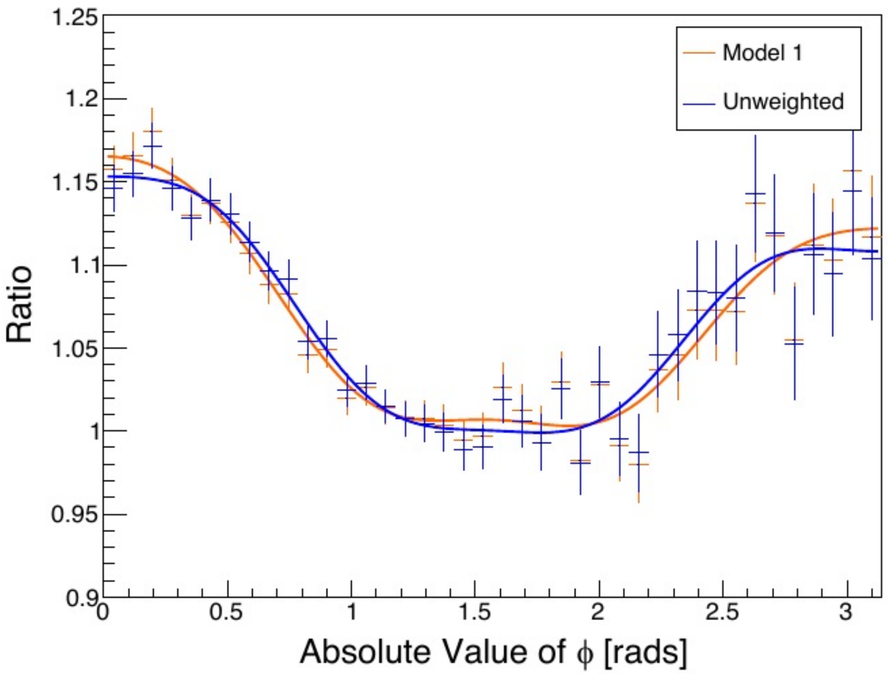
Boer PRL 108(2012)032002 arXiv:1109.1444

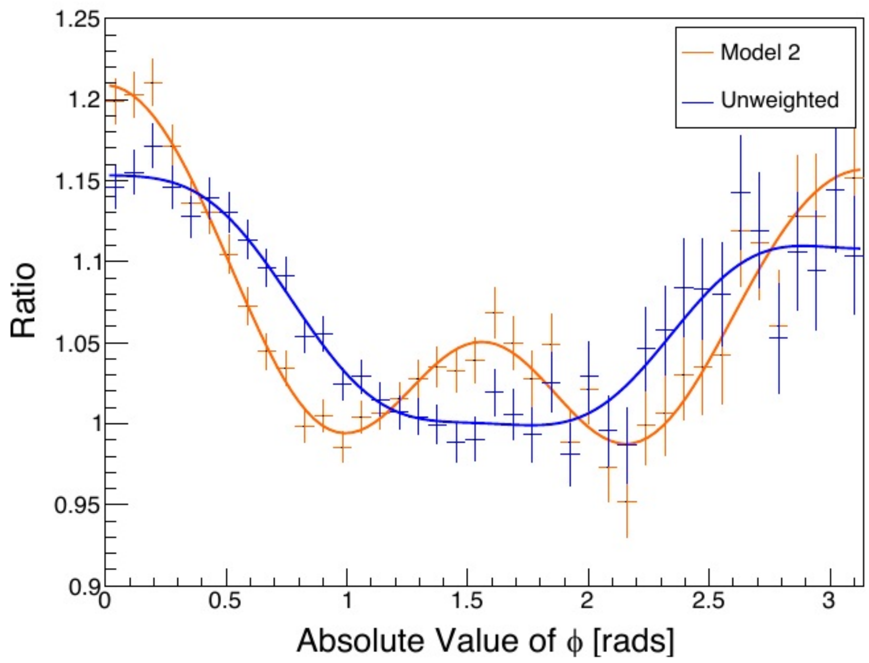
Lansberg PLB 784(2018)217 arXiv:1710.01684

Mulders PRD 63(2001)094021, arXiv:hep-ph/0009343

'Model 1': $h_1^{\perp g} = \frac{M^2}{\pi \langle k_T^2 \rangle^2} \exp\left(1 - \frac{k_T^2}{r \langle k_T^2 \rangle}\right), r = 2/3$

'Model 2' saturates the positivity bound $k_T^2 |h_1^{\perp g}| \leq 2M^2 f_1^g$.





Summary

Question 1: How is the q_T distribution distorted by the acceptance cuts, and what can we do to have a 'clean' access to f_1^g ?

- ✦ Acceptance cuts cause extra smearing of the q_T distribution
- ✦ Seems to depend also on invariant mass Q
- ✦ Reliable extraction of f_1^g requires further insight and more complex analysis methods

Question 2: How is the ϕ distribution distorted by the acceptance cuts, and what can we do to have a 'clean' access to $h_1^{\perp g}$

- ✦ Acceptance cuts cause strong dependence of the $J/\psi + \gamma$ cross section on Collins-Soper angles
- ✦ Fortunately, different areas in $\cos\theta$ are distorted similarly, while 4ϕ modulation due to $h_1^{\perp g}$ is specific to low $\cos^2\theta$
- ✦ Taking the ratio of ϕ distributions for low over high $\cos^2\theta$ may improve the chances to observe this modulation

Watch this space for the results of actual measurements!