Modelling the Underlying Event in Photon-Initiated Processes

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Observations and motivations

- The Underlying Event (UE) makes up most of the background data
- Qualitative models from Monte-Carlo generators are needed to describe these "softer" interactions
- A large part of UE comes from multiple interactions between partons (MPI)
- Current models have been tuned to describe data in specific kinematic regions
- No current tune describes photon-proton (ɣp) collisions at colliders like EIC

AIM: Test models of MPI for ɣɣ, ɣp, and pp collisions using current data

Outline

- Multiple interactions with hadrons
- Multiple interactions with photons
- PYTHIA MPI model
- Experimental data considered
- Some results
- Conclusions and outlook for EIC

RIVET 3.1.8

PYTHIA 8.310

Multiple interactions with hadrons

- Collisions with hadrons can have multiple partons interact simultaneously
- Probabilities derived from 2→2 scattering cross sections
- Calculations become divergent for low transverse momentum p_T, so a “screening” parameter $\boldsymbol{p_{T0}}$ is needed to regulate these interactions

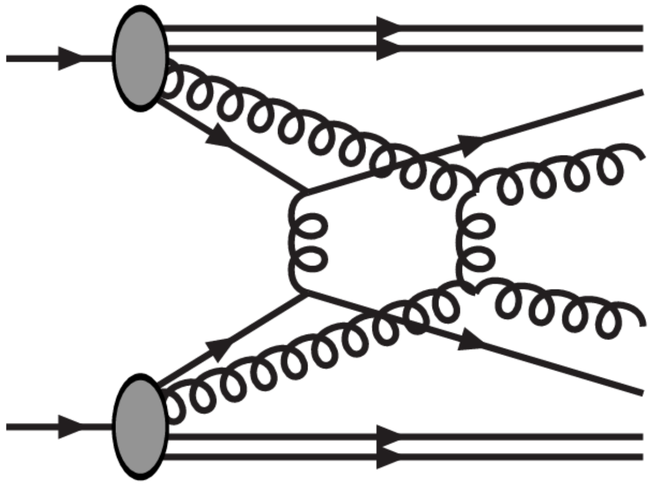


Fig 1: An example of an MPI[1]

Multiple interactions with photons

- Low-Q^2 virtual photons (~1 GeV) can fluctuate into $q\bar{q}$ and develop hadronic structure
- “Resolved” photons give conditions necessary for multiple interactions in ee and ep colliders (and EIC!)

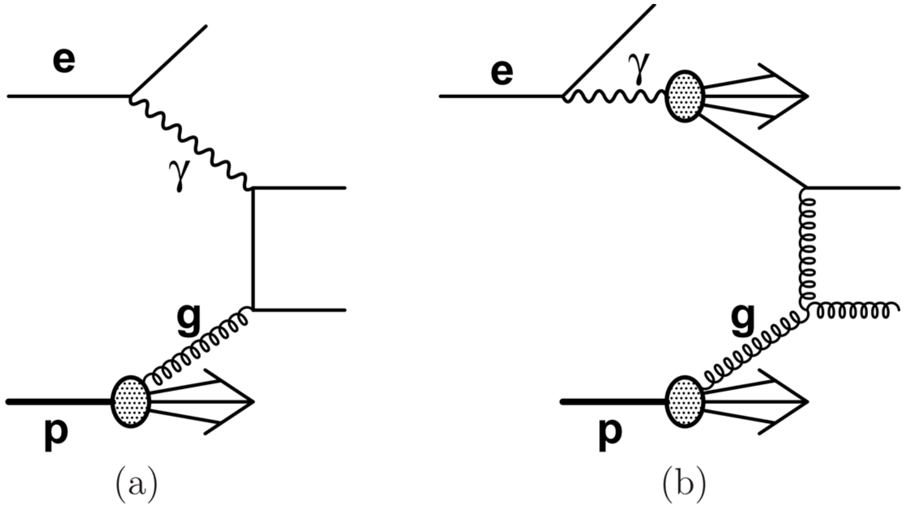


Fig 2: An example of direct and resolved photoproduction[2]

PYTHIA MPI model

- Screening parameter p_{T0} parameterises MPI activity
- Scales with centre-of-mass energy
- Two scaling laws: power and logarithmic

$$p_{T0}(\sqrt{s}) = p_{T0}^{ref}\left(\frac{\sqrt{s}}{\sqrt{s}^{ref}}\right)^{\alpha}$$

$$p_{T0}(\sqrt{s}) = p_{T0}^{ref} + \alpha \cdot log\left(\frac{\sqrt{s}}{\sqrt{s}^{ref}}\right)$$

	LEP (γγ)	LHC (pp)
p_{T0}^{ref}	1.54 GeV	2.28 GeV
$\sqrt{s}^{ref}$	100 GeV	7000 GeV
α	0.413	0.215
Default scale	**Log**	**Power**
Flipped scale	Power	Log

PYTHIA MPI model

- LHC/POWER (Monash)
- LHC/LOG
- LEP/POWER
- LEP/LOG
- Detroit (lower energy pp data)
- 2C (lower energy pp data)
- “No MPI”

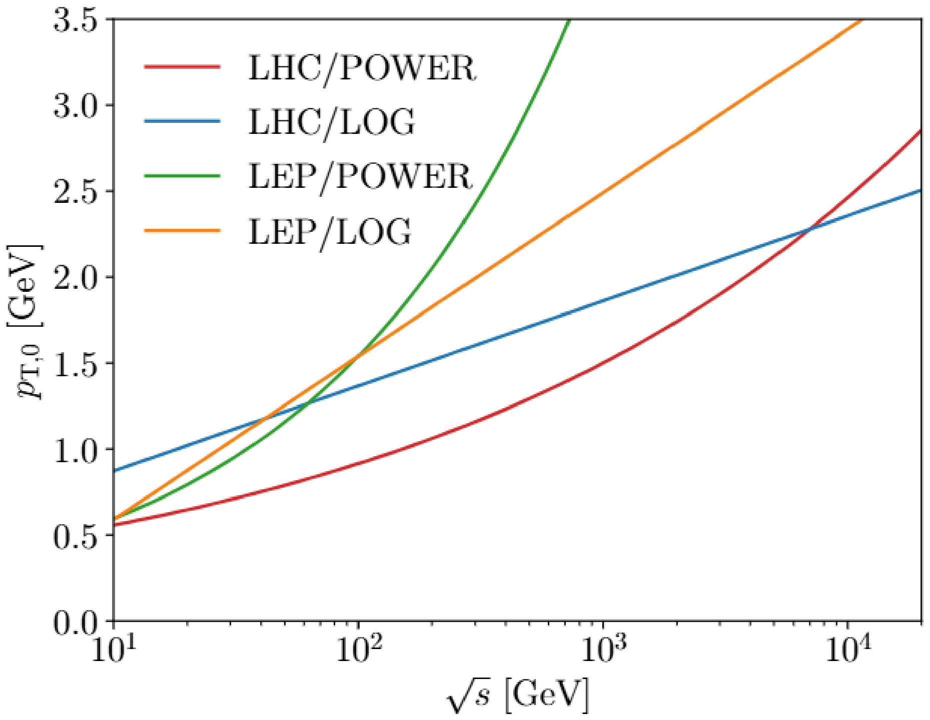
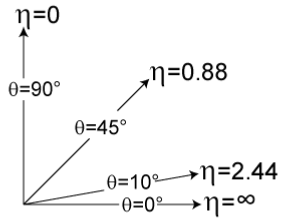


Fig 3: Energy scaling of p_{T0} parameter for different MPI tunes

Experimental data considered

- Dijet production from $\gamma\gamma$ collisions (LEP2)
- Dijet photoproduction at various transverse jet energies (HERA)
- Multi-jet photoproduction (HERA)
- Charged particle production in photoproduction (HERA)
- Charged hadron production from $\gamma\gamma$ collisions (LEP2)
- Charged particle production in pp collisions (LHC)

Low energy dijet data (γp and γγ)



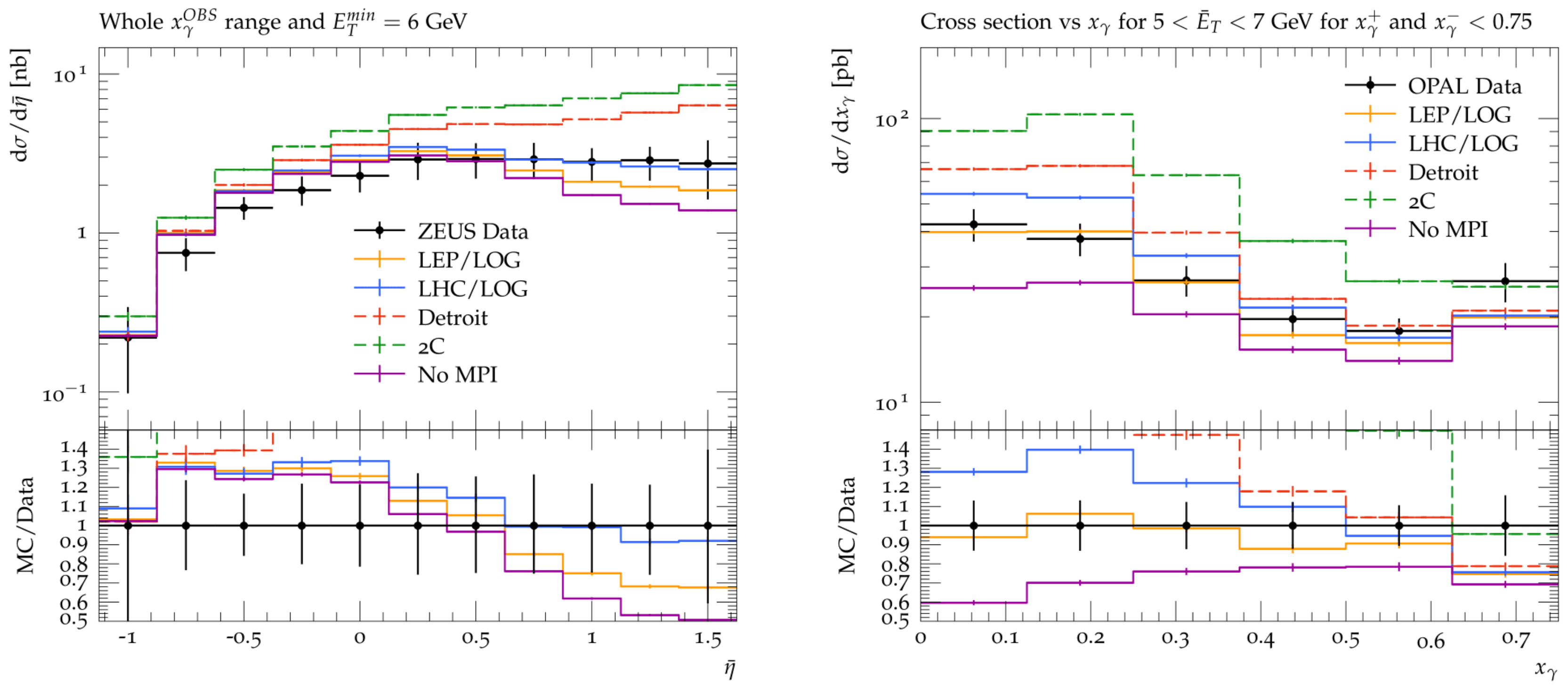


Fig 4: (Left) HERA low minimum energy dijet photoproduction data, and (right) LEP dijet data compared to models of the underlying event in Pythia.

<u>Observations</u>

- **MPI is required to describe data**
- pp tunes do a poor job describing data (Detroit and 2C)
- LEP/LOG and LHC/LOG provide reasonable descriptions of data

High energy dijet data (ɣp)

$$x_\gamma^{obs} = \frac{E_T^{jet1} e^{-\eta^{jet1}} + E_T^{jet2} e^{-\eta^{jet2}}}{2yE_e}$$

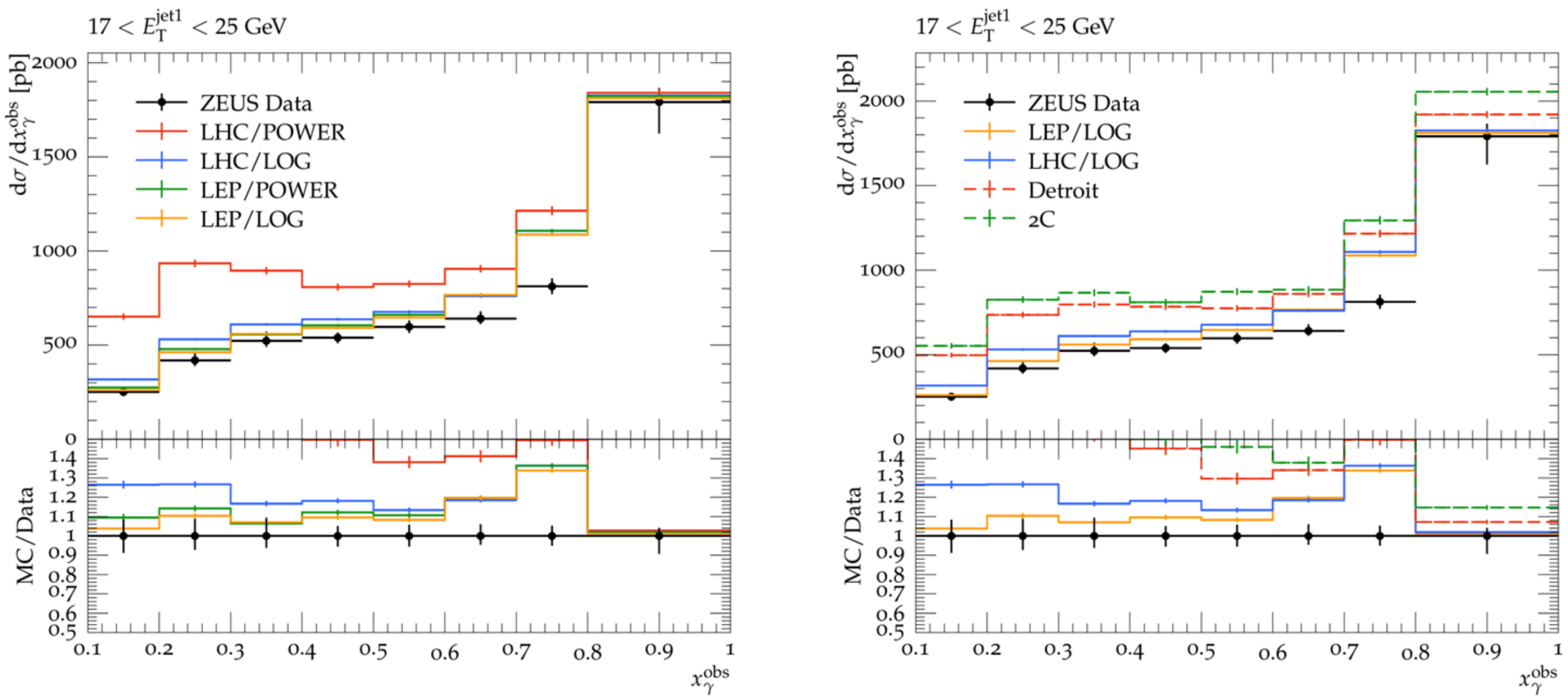
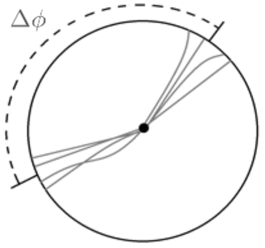


Fig 5: Higher energy dijet photoproduction data compared to models of the underlying event in Pythia.

<u>Observations</u>

- **All standard pp tunes do a poor job describing data**
- LEP tunes and LHC/LOG provide reasonable descriptions of data

More high energy dijet data (ɣp)



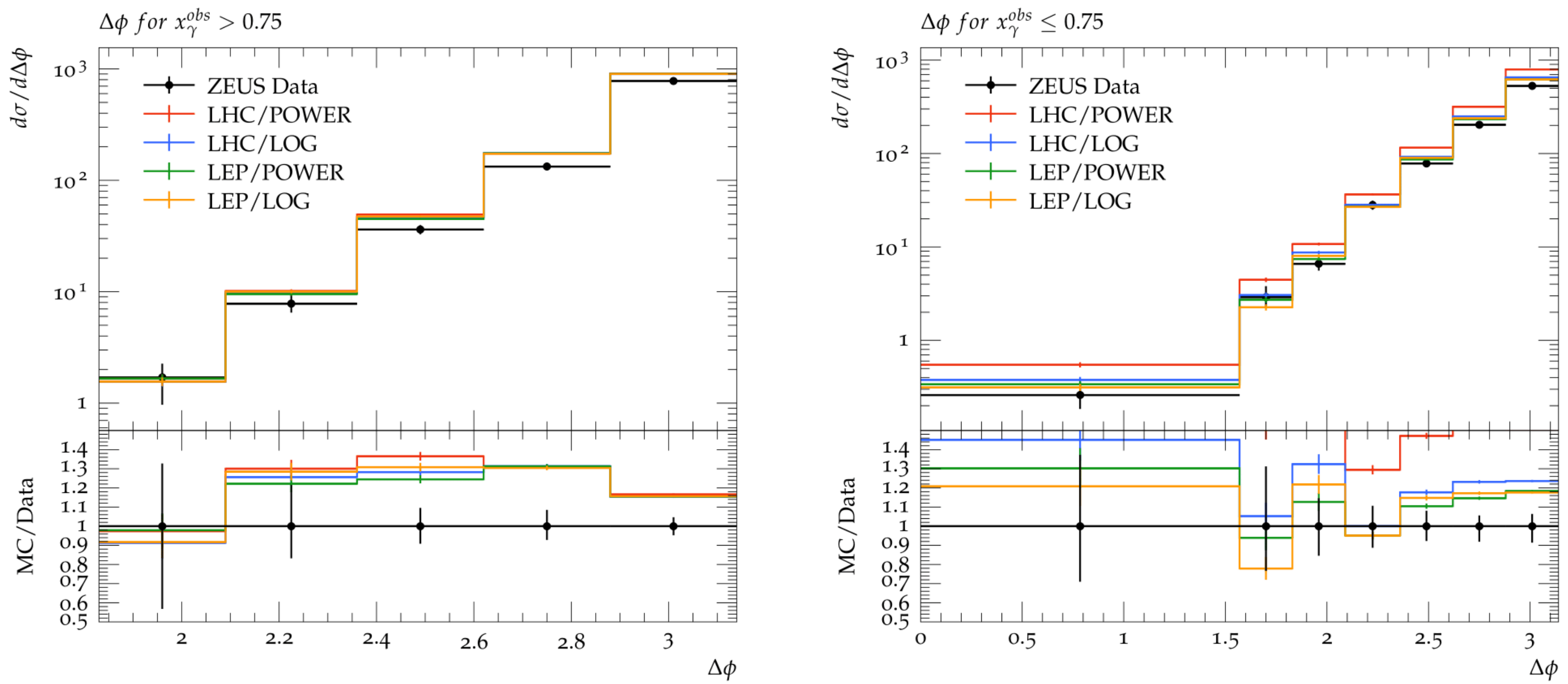


Fig 6: High energy dijet photoproduction data compared to models of the underlying event in Pythia.

<u>Observations</u>

- LHC/POWER rising above data around Δϕ~π
- **So far: LEP tunes are favored for ɣp data**

Lower energy multi-jet data (ɣp)

$$cos(\psi_3) = \frac{(\mathbf{p}_{beam} \times \mathbf{p}_3)\cdot(\mathbf{p}_4 \times \mathbf{p}_5)}{|\mathbf{p}_{beam} \times \mathbf{p}_3|\cdot|\mathbf{p}_4 \times \mathbf{p}_5|}$$

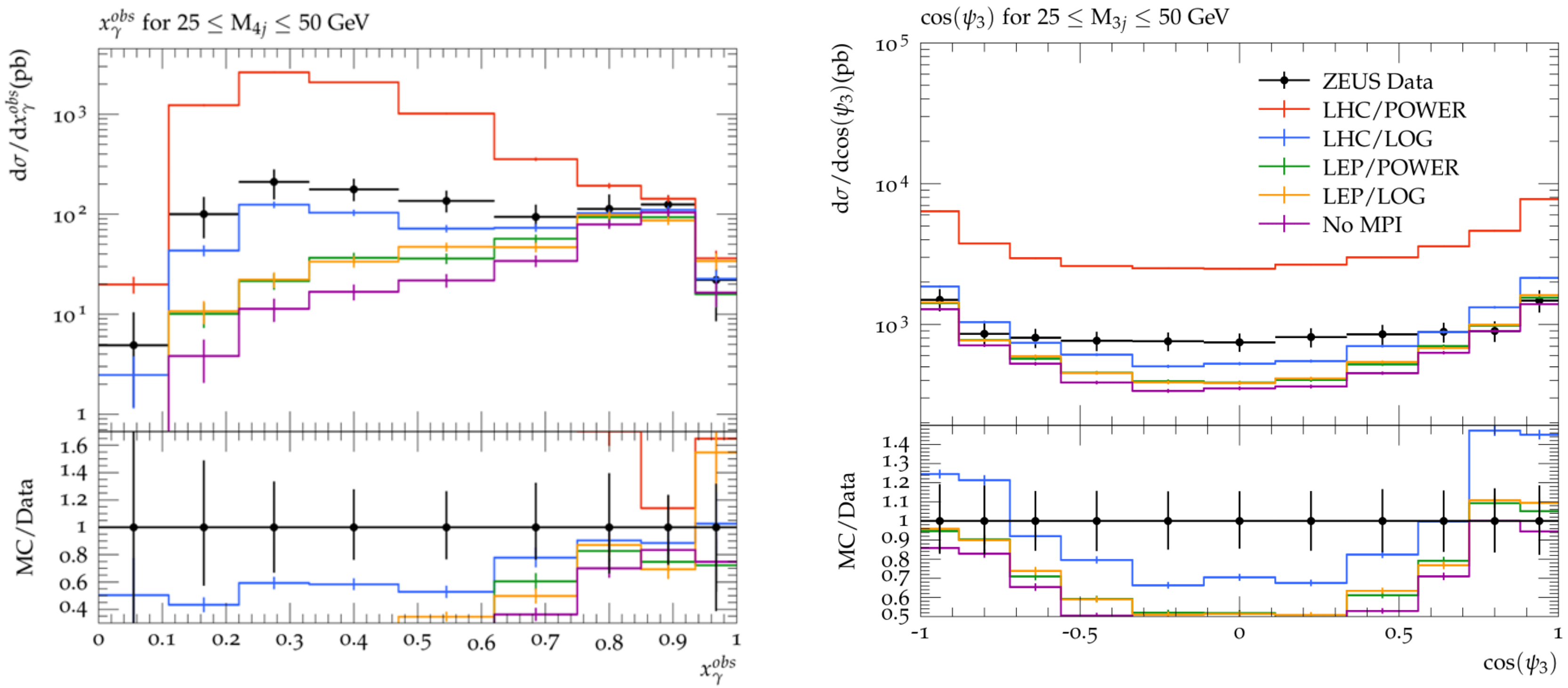


Fig 7: Low energy 3- and 4-jet photoproduction data compared to models of the underlying event in Pythia.

<u>Observations</u>

- **LEP tunes now sit well below the data**
- LHC/LOG provides best description
- All tunes rise too steeply around $\cos(\psi_3)$ ~ 1, -1

Charged particle distributions (γp)

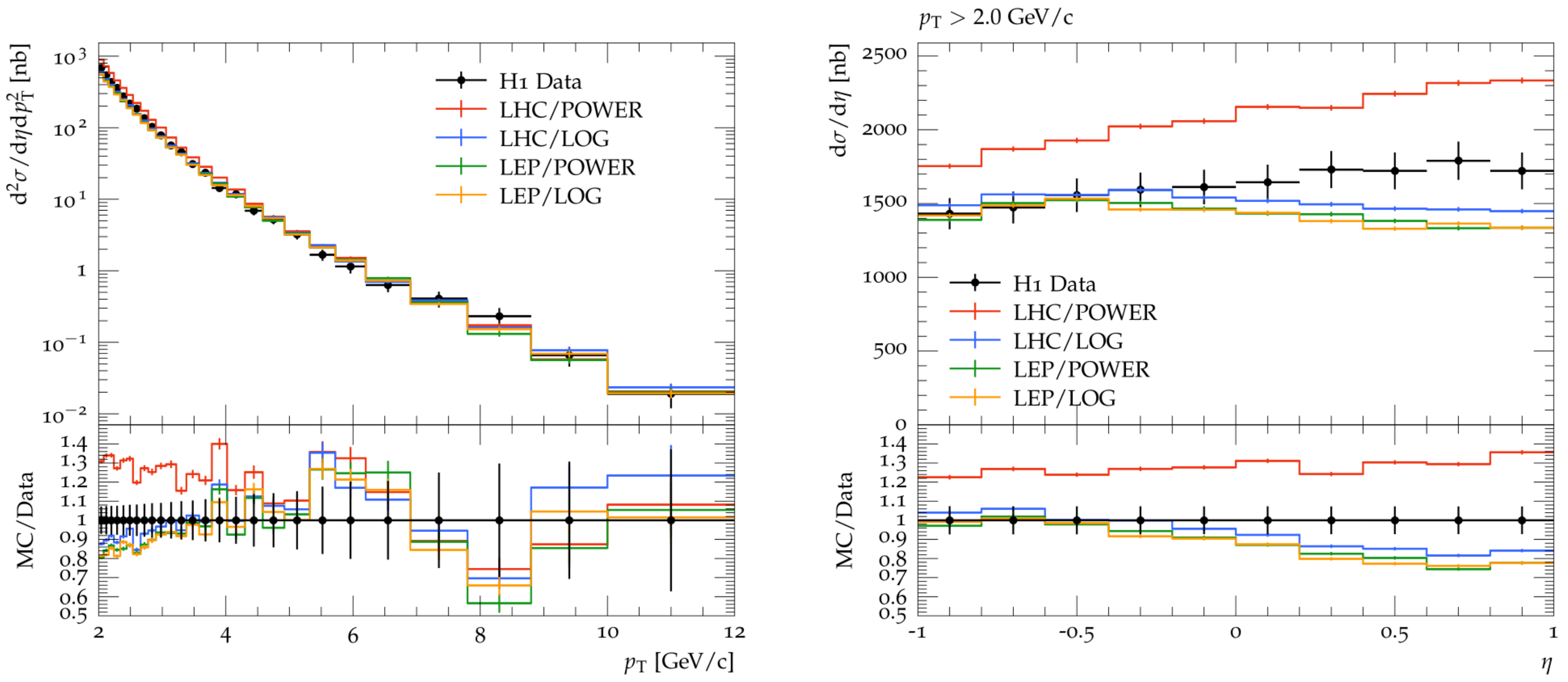


Fig 8: Charged particle distributions of photoproduction data compared to models of the underlying event in Pythia.

<u>Observations</u>

- LEP tunes and LHC/LOG provides best descriptions
- Tunes underestimate data in forward η region
- LHC/POWER still sits above data

Charged particle distributions (γγ)

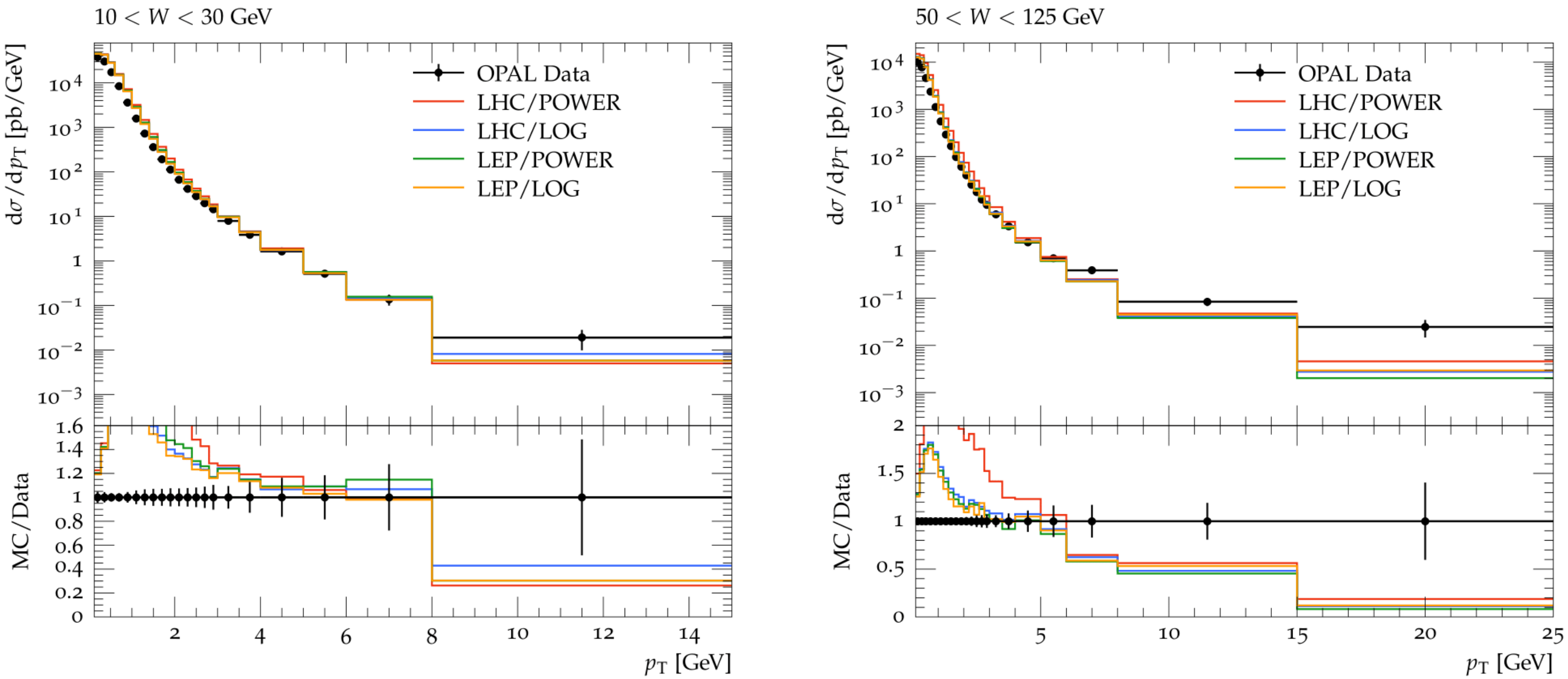


Fig 9: Charged particle distributions of γγ data compared to models of the underlying event in Pythia.

<u>Observations</u>

- All tunes rise above the data at lowest p_T values
- All tunes drop below the data at the highest p_T values

Charged particle distributions (pp)

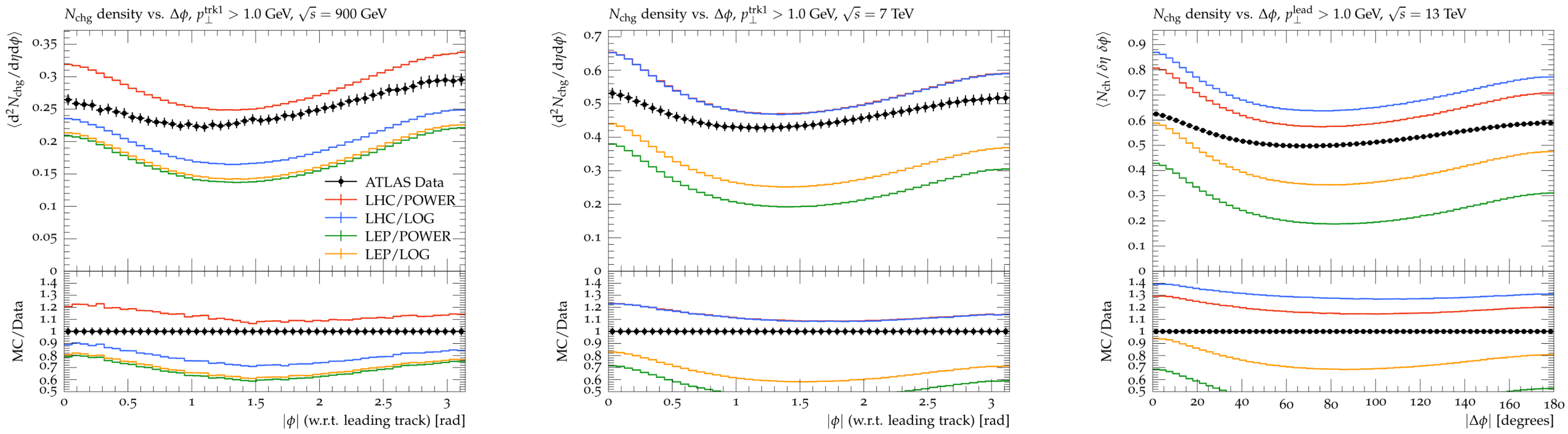


Fig 10: Charged particle distributions of underlying event data from the LHC compared to models of the underlying event in Pythia.

<u>Observations</u>

- LHC/POWER provides best description
- **LHC/LOG does not scale properly with C.O.M. energy**
- LEP tunes provide poor description

Summary & Outlook for EIC

- Considered data provide further constraints for dedicated $\gamma\gamma$ and γp tunes
- Standard pp models generate too many MPI for $\gamma\gamma$, γp collisions
- **LHC/LOG** provides best description of data across all collisions types and energies and should be used for future colliders like EIC
- May be useful to investigate matter distributions / impact parameter dependence of photons

Supplementary Slides

Kinematics of experimental data

- ɣp1 (fig 4) – "Dijet cross-sections in photoproduction at HERA" required $E_T^{jet1,2} > 6$ GeV
- ɣp2 (fig 5) – "Dijet photoproduction at HERA and the structure of the photon" required $E_T^{jet1,2} > 14, 11$ GeV
- ɣp3 (fig 11) – "Photoproduction of Dijets with High Transverse Momenta at HERA" required $E_T^{jet1,2} > 25, 15$ GeV
- ɣp4 (fig 6) – "High-E_T dijet photoproduction at HERA" required $E_T^{jet1,2} > 20, 15$ GeV
- ɣp5 (fig 7) – "Three- and four-jet final states in photoproduction at HERA" required $E_T^{jet} > 6$ GeV
- ɣp6 (fig 8) – "Charged particle cross sections in photoproduction and extraction of the gluon density in the photon" required $p_T > 2$ GeV
- ɣɣ1 (fig 4) – "Di-Jet Production in Photon-Photon Collisions at $\sqrt{s_{ee}}$ from 189 GeV to 209 GeV" required $E_T^{jet} > 5$ GeV
- ɣɣ2 (fig 9) – "Inclusive Production of Charged Hadrons in Photon-Photon Collisions" required $p_T > 1.5$ GeV
- pp1 (fig 10) – "Measurement of underlying event characteristics using charged particles in pp collisions at $\sqrt{s}$ = 900 GeV and 7 TeV with the ATLAS detector"
- pp2 (fig 10) – "Measurement of charged-particle distributions sensitive to the underlying event in $\sqrt{s}$ =13 TeV proton-proton collisions with the ATLAS detector at the LHC"

*More high energy dijet results (γp)

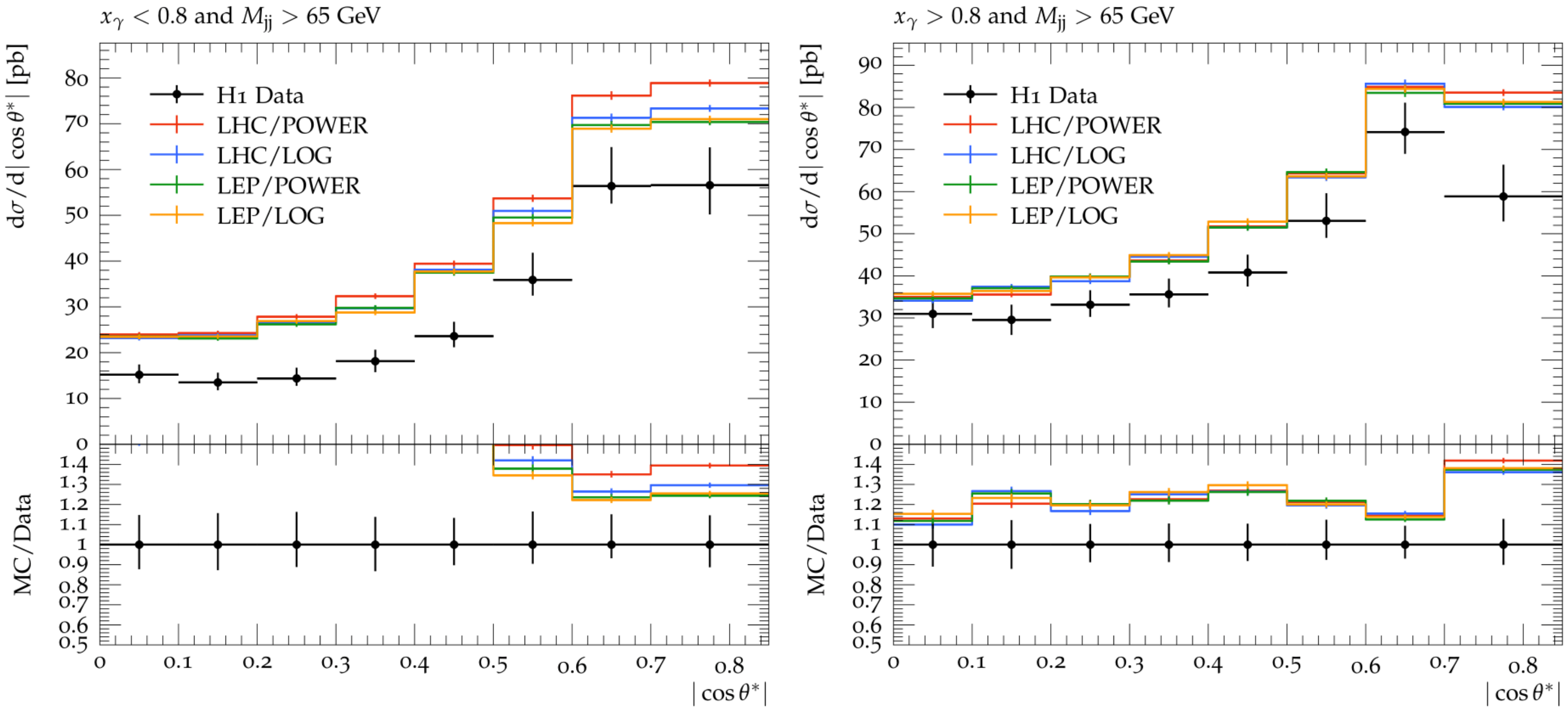
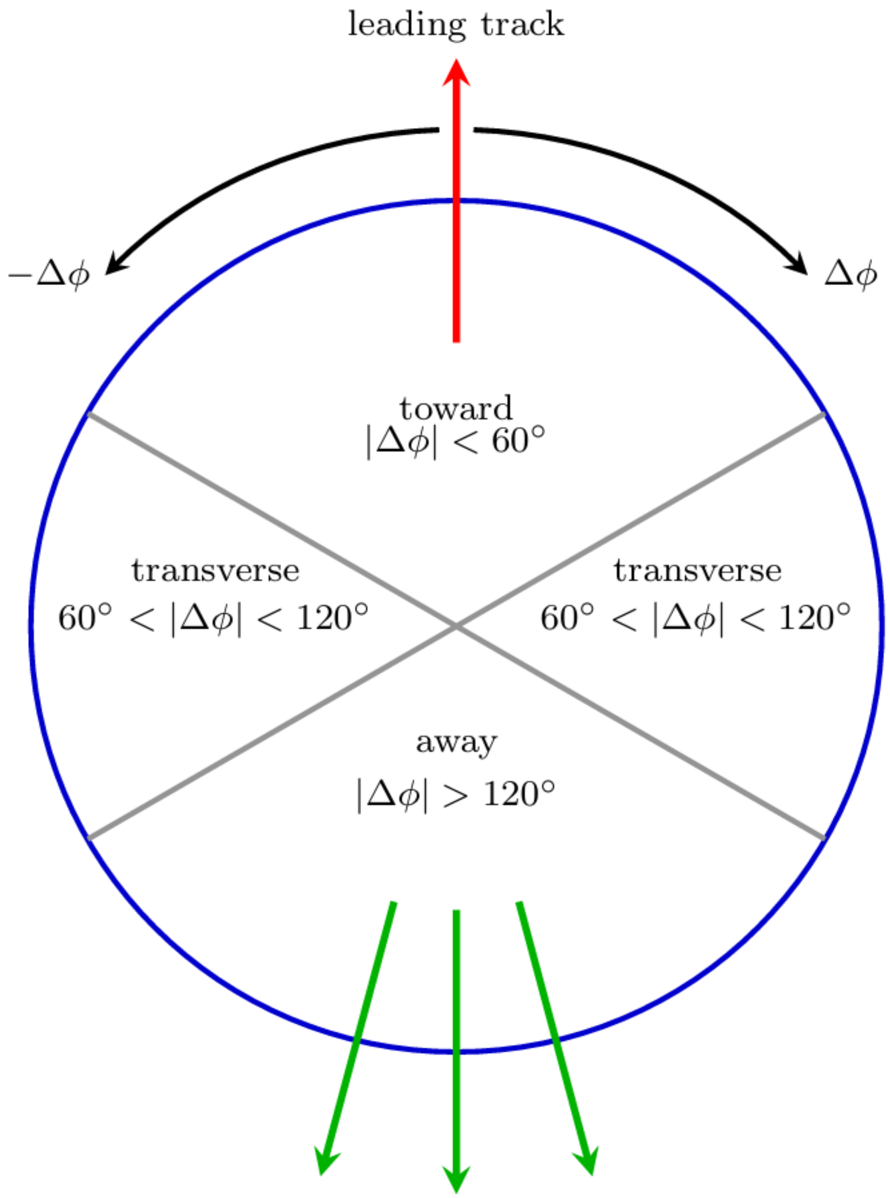


Fig 11: High energy dijet photoproduction data compared to models of the underlying event in Pythia.

Observations:

- Overestimation for entire range (likely from x_{γ}^{obs} ~ 0.6-0.8)
- Little differences in MPI tunes (low MPI sensitivity)



for charged particle measurements

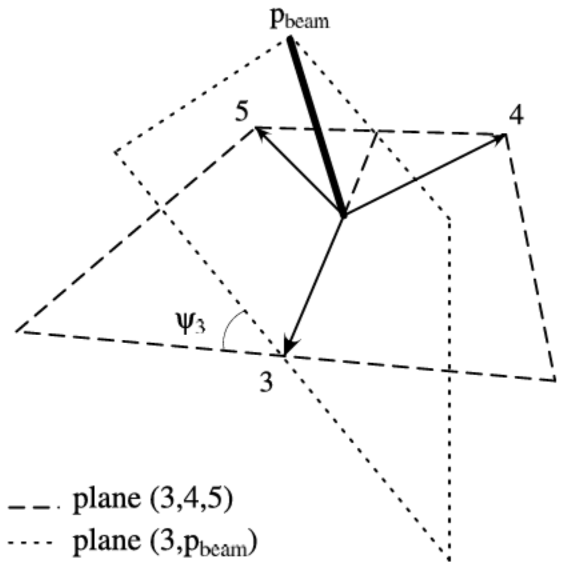
Extra Notes

- LEP/LOG validated from charged particle production from photon-photon collisions with 10 < W < 125 GeV but **not extensively tested**
- Detroit validated for RHIC p-p bar collisions at 200 GeV, and CDF data at 300, 900, 1960 GeV with newer proton PDF than Monash
- 2C predates Monash tune validated for lower energy CDF data
- Detroit and 2C have more adjusted parameters than just p_{T0} which are related to overlap profiles

Extra Notes

- Cross section is divergent like $1 / p_T^4$ so the screening parameter is implemented with the factor

$$\frac{\alpha_s^2(p_{T0}^2+p_T^2)}{\alpha_s^2(p_T^2)} \cdot \frac{p_T^4}{(p_{T0}^2+p_T^2)^2}$$



Extra Notes

```
!Make sure MPI is on
PartonLevel:MPI = on

! Photoproduction
PDF:beamB2gamma = on ! Allowing photon subbeam from beam 2 (positron)
Photon:ProcessType = 0 ! All photon processes (direct-direct, resolved-resolved, etc.)
PhotonParton:all = on ! All dijet MEs with photons
Photon:Q2max = 1 ! Maximal Q2
PDF:GammaSet = 1 ! PDFs for resolved photon beams
HardQCD:all = on ! All hard QCD processes enabled

! MPI
MultipartonInteractions:pT0parametrization = 0 ! Power law
MultipartonInteractions:ecmRef = 7000.0 ! LHC parameters
MultipartonInteractions:pT0Ref = 2.28
MultipartonInteractions:ecmPow = 0.215

!Phase space cuts
PhaseSpace:pThatMin = 7. ! pT min cut
```