Double parton scattering studies with Pythia 8 and Herwig++

Florian Bechtel (Hamburg / Lund)

HERA-LHC workshop, May 27th 2008

Universität Hamburg

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- **CDF analysis**
- **Compare with new models**
  - Herwig++
  - Pythia 8
- **LHC expectations**

Thanks to:

Torbjörn Sjostrand

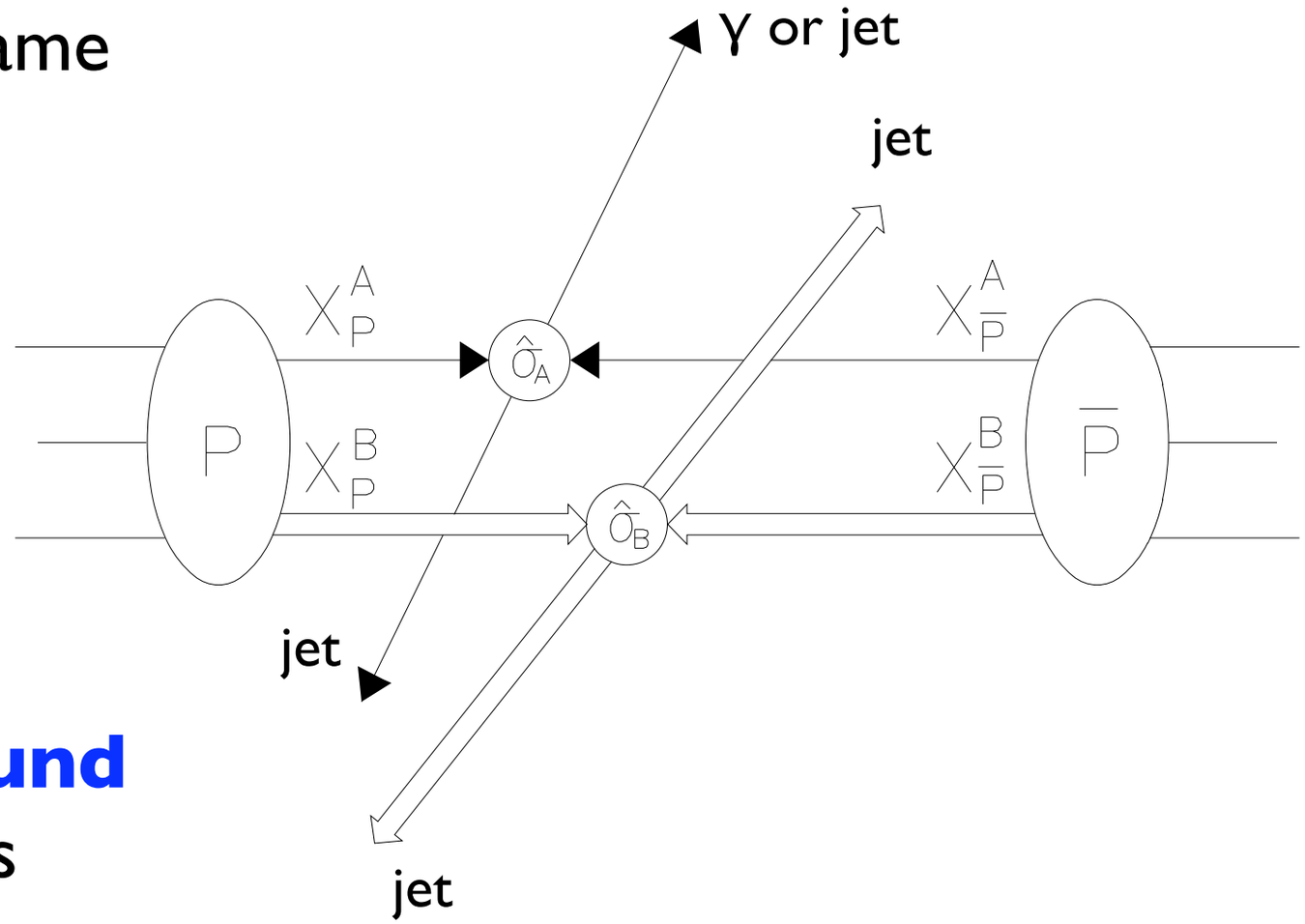
Manuel Bähr

Double-parton-scattering

- ***Double-Parton-Scattering* (DPS):**
  - Two hard interactions in the same proton-(anti-)proton-scattering

- **Direct information on...**
  - spatial distribution of partons in proton
  - parton-parton-correlations

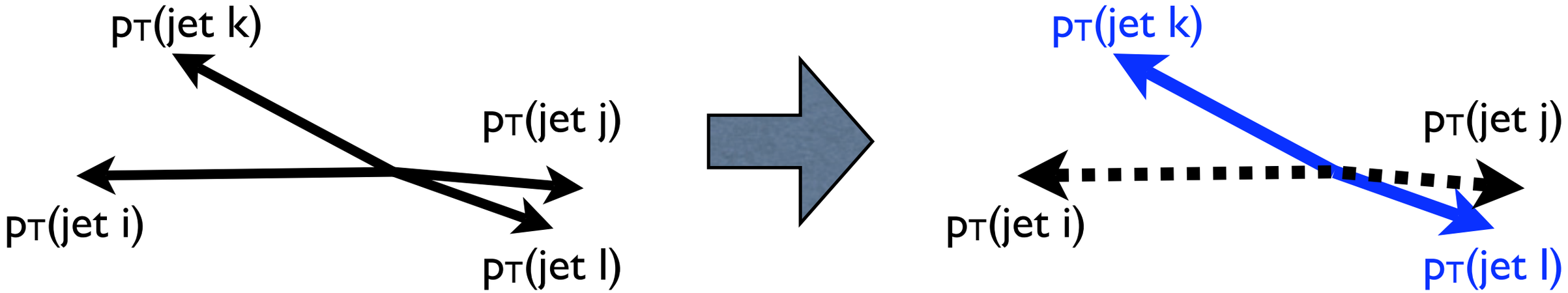
- **DPS: Irreducible background**
  - e.g. production of $W^{\pm}W^{\pm}$ pairs



- **Here: Identify *double-parton-scattering* in final states with one photon and three jets**
  - Process A creates photon-jet-pair, process B creates dijet-pair

DPS analysis: jet assignment I

- **Find pairwise balanced jets**



- **AFS solution:**

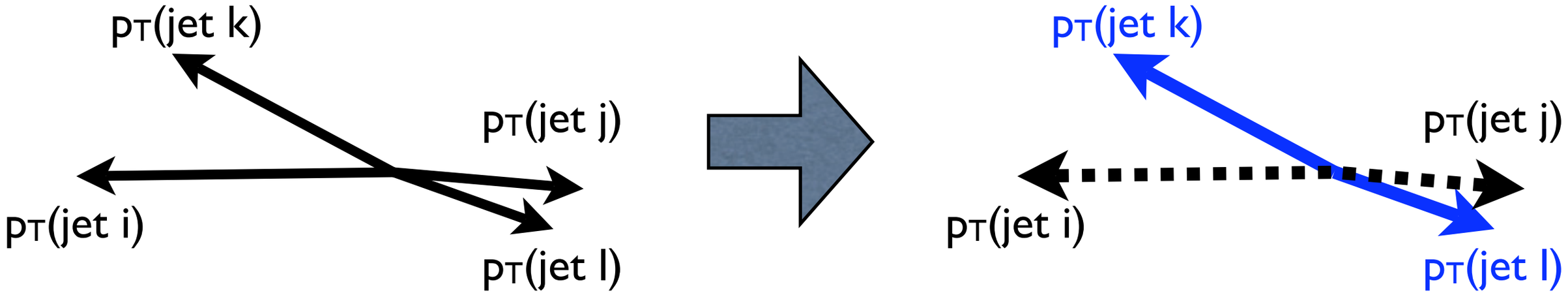
$$\min\left(\left|\vec{p}_{Ti} + \vec{p}_{Tj}\right|^2 + \left|\vec{p}_{Tk} + \vec{p}_{Tl}\right|^2 \right)$$

- **UA2 solution (→ CDF):**

$$\min\left(\frac{\left|\vec{p}_{Ti} + \vec{p}_{Tj}\right|^2}{\left|\vec{p}_{Ti}\right| + \left|\vec{p}_{Tj}\right|} + \frac{\left|\vec{p}_{Tk} + \vec{p}_{Tl}\right|^2}{\left|\vec{p}_{Tk}\right| + \left|\vec{p}_{Tl}\right|} \right)$$

DPS analysis: jet assignment 2

- **Find pairwise balanced jets**



- **Drees, Han (*Phys.Rev.Lett.77:4142-4145,1996*):**
  - for each pair i j, require

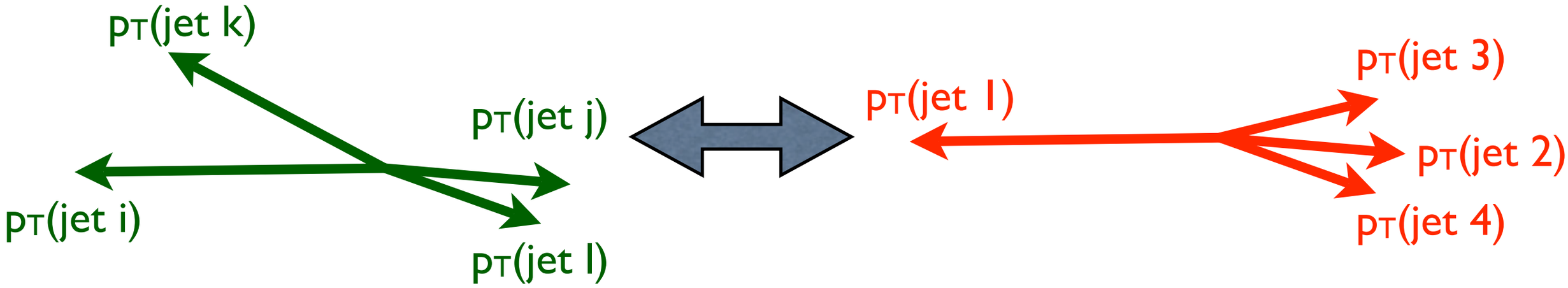
$$\cos\left(\phi_i - \phi_j\right) \leq -0.9$$

$$\left||\vec{p}_T(i)| - |\vec{p}_T(j)|\right| \leq c_{ij}\sqrt{\delta^2(|\vec{p}_T(i)|) + \delta^2(|\vec{p}_T(j)|)}$$

$$\delta(|\vec{p}_T|) = a \cdot \sqrt{|\vec{p}_T|} \oplus b \cdot |\vec{p}_T|$$

Angular correlations

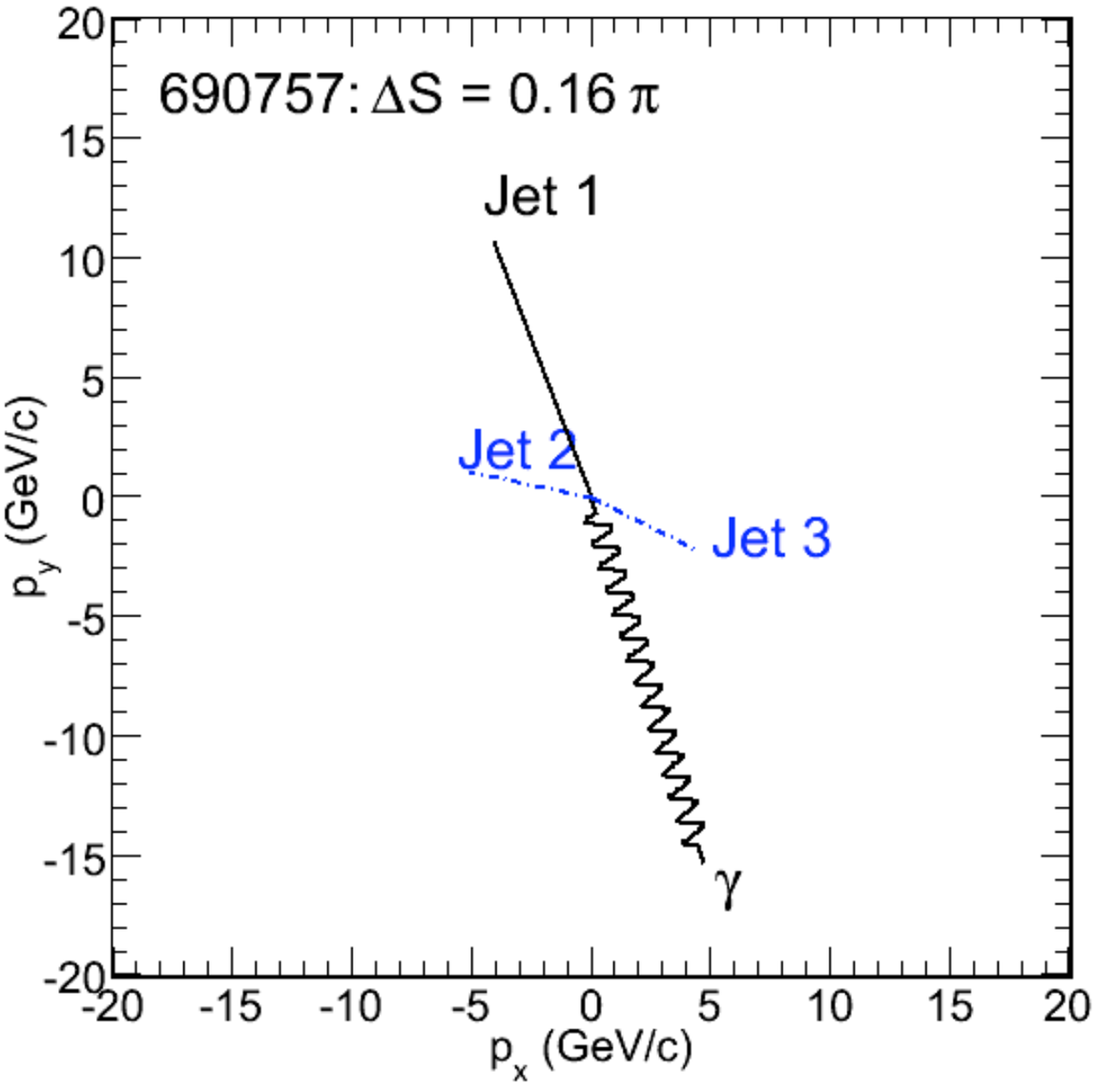
- **Disentangle double-parton-scattering from bremsstrahlung**



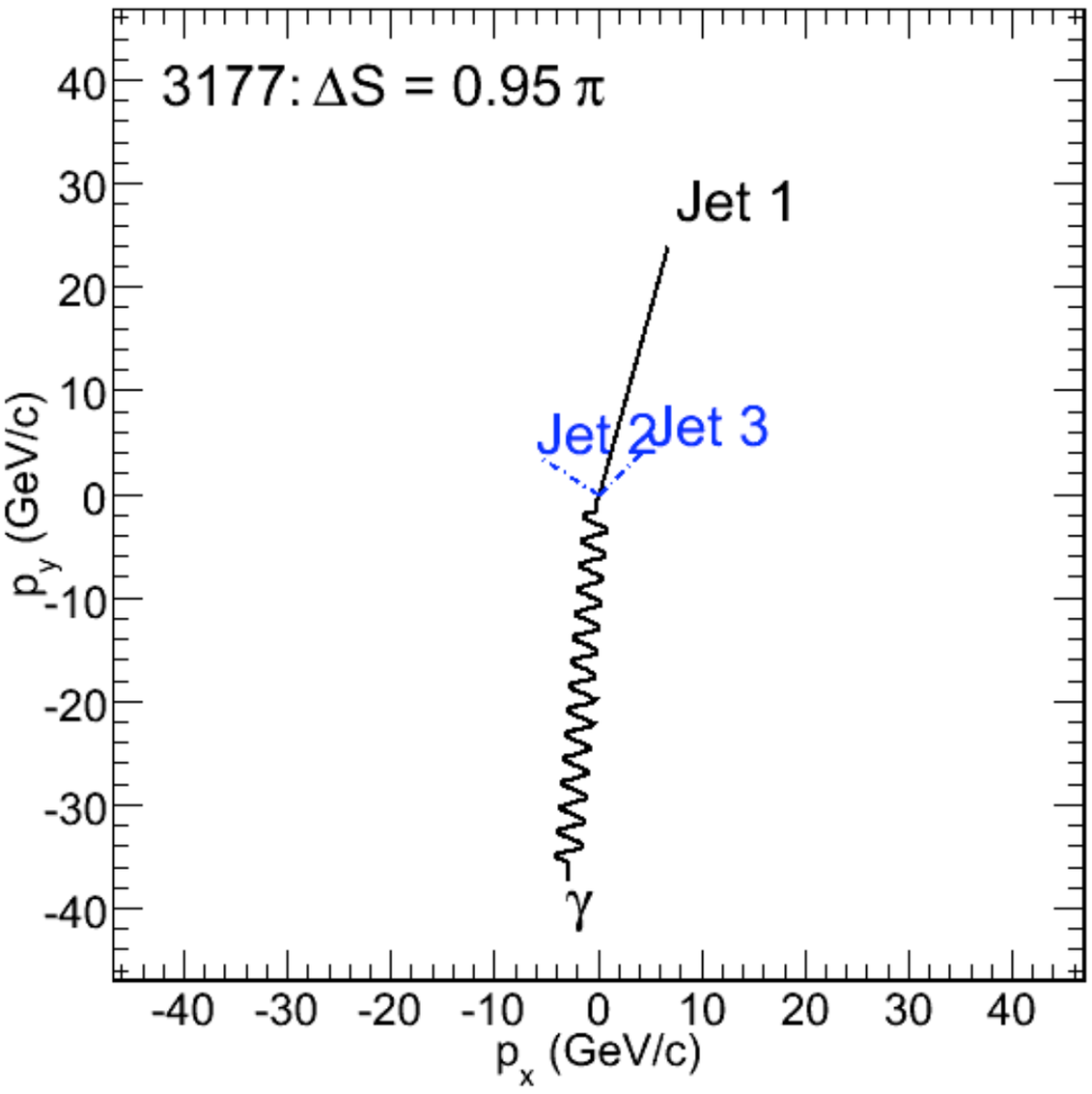
- **Make use of different correlations between jet pairs**
  - No correlation (DPS) versus strong correlation (BS)
- **AFS solution:**
  - Study Δφ between $\mathbf{p_{T1} - p_{T2}}$ and $\mathbf{p_{T3} - p_{T4}}$
- **CDF solution:**
  - Study Δφ between $\mathbf{p_{T1} + p_{T2}}$ and $\mathbf{p_{T3} + p_{T4}}$ (CDF nomenclature: ΔS)

Gen. event displays

Double-parton-scattering:



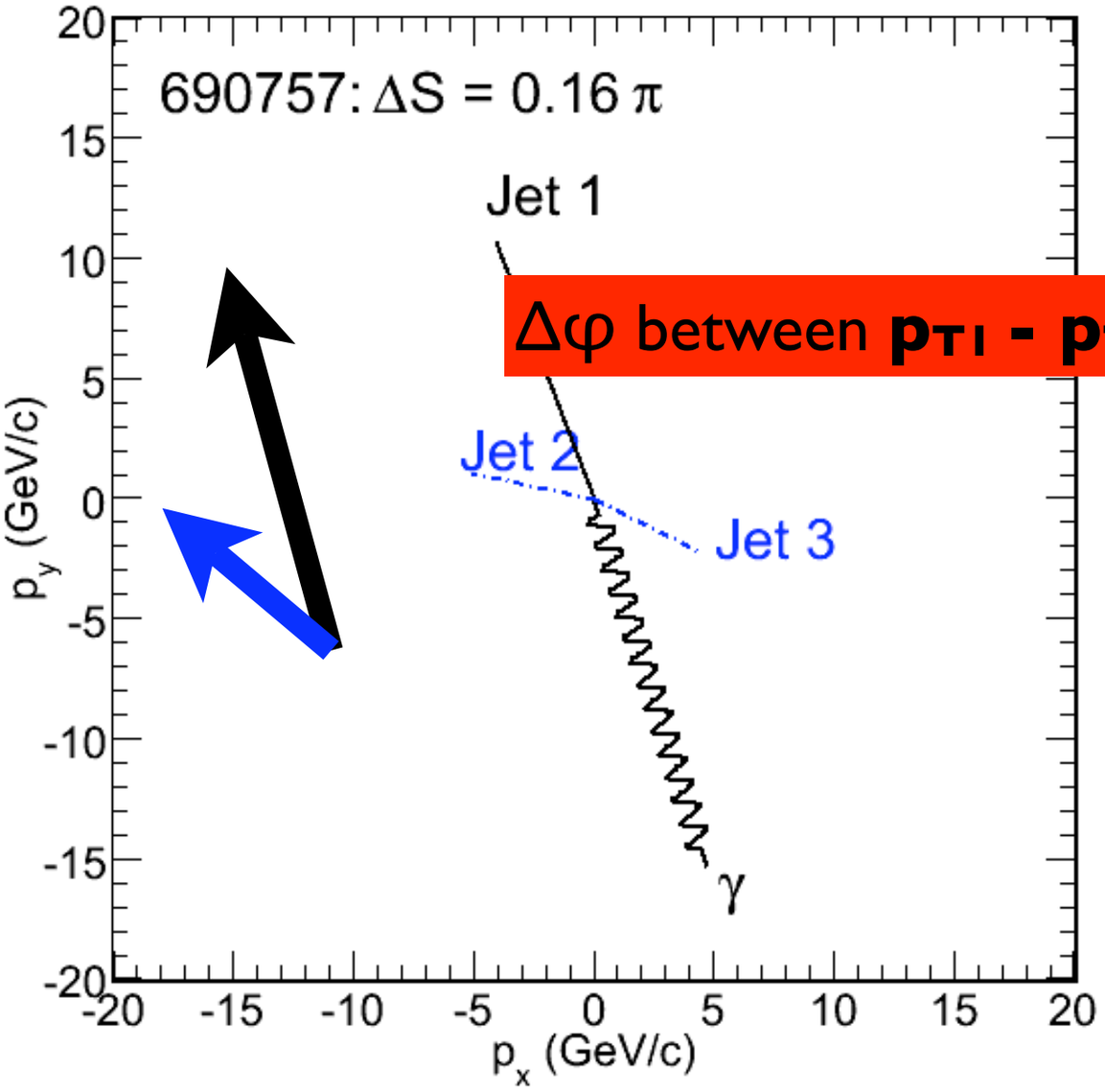
Double-bremsstrahlung:



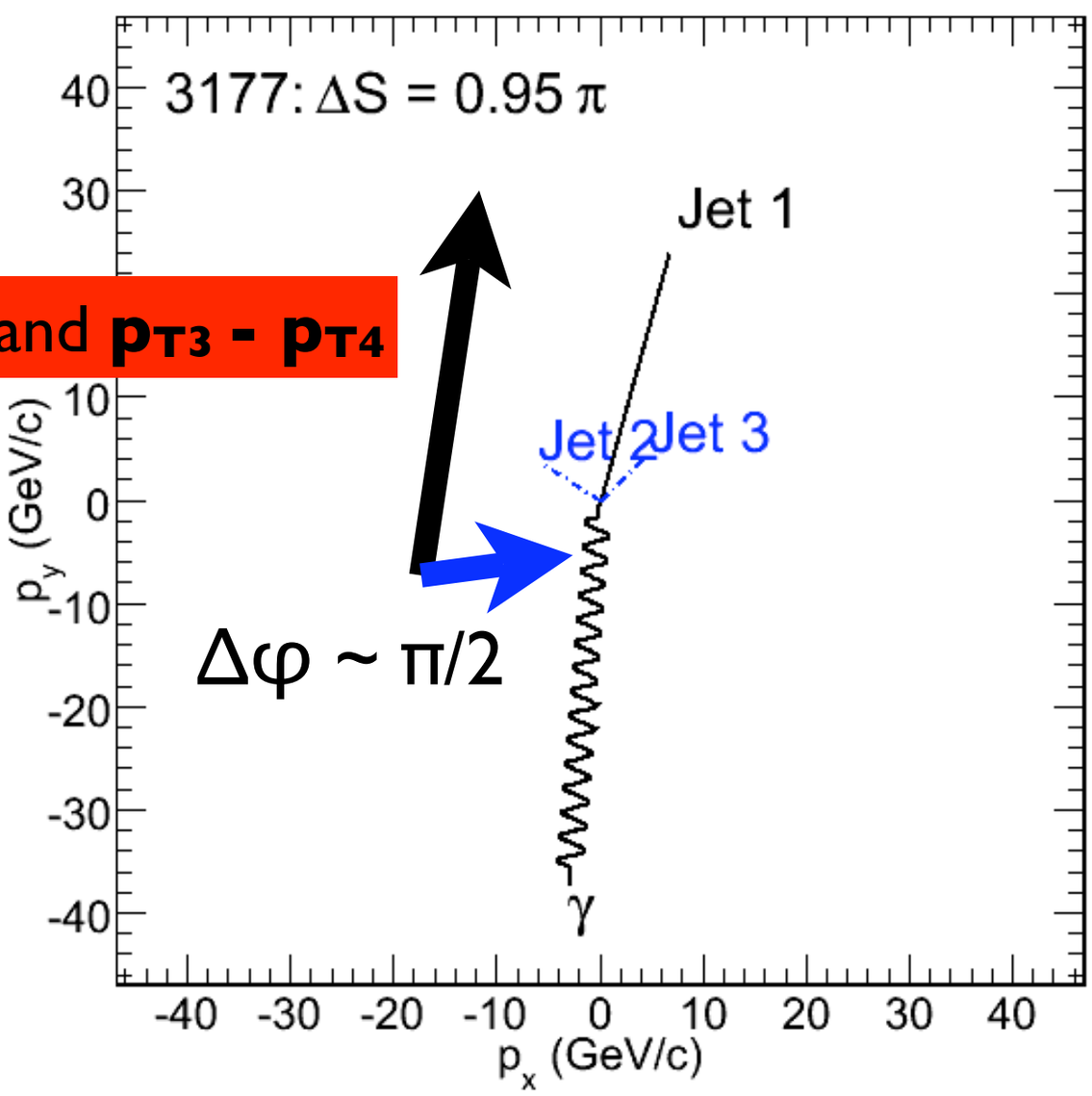
Gen. event displays

Double-parton-scattering:

Double-bremsstrahlung:



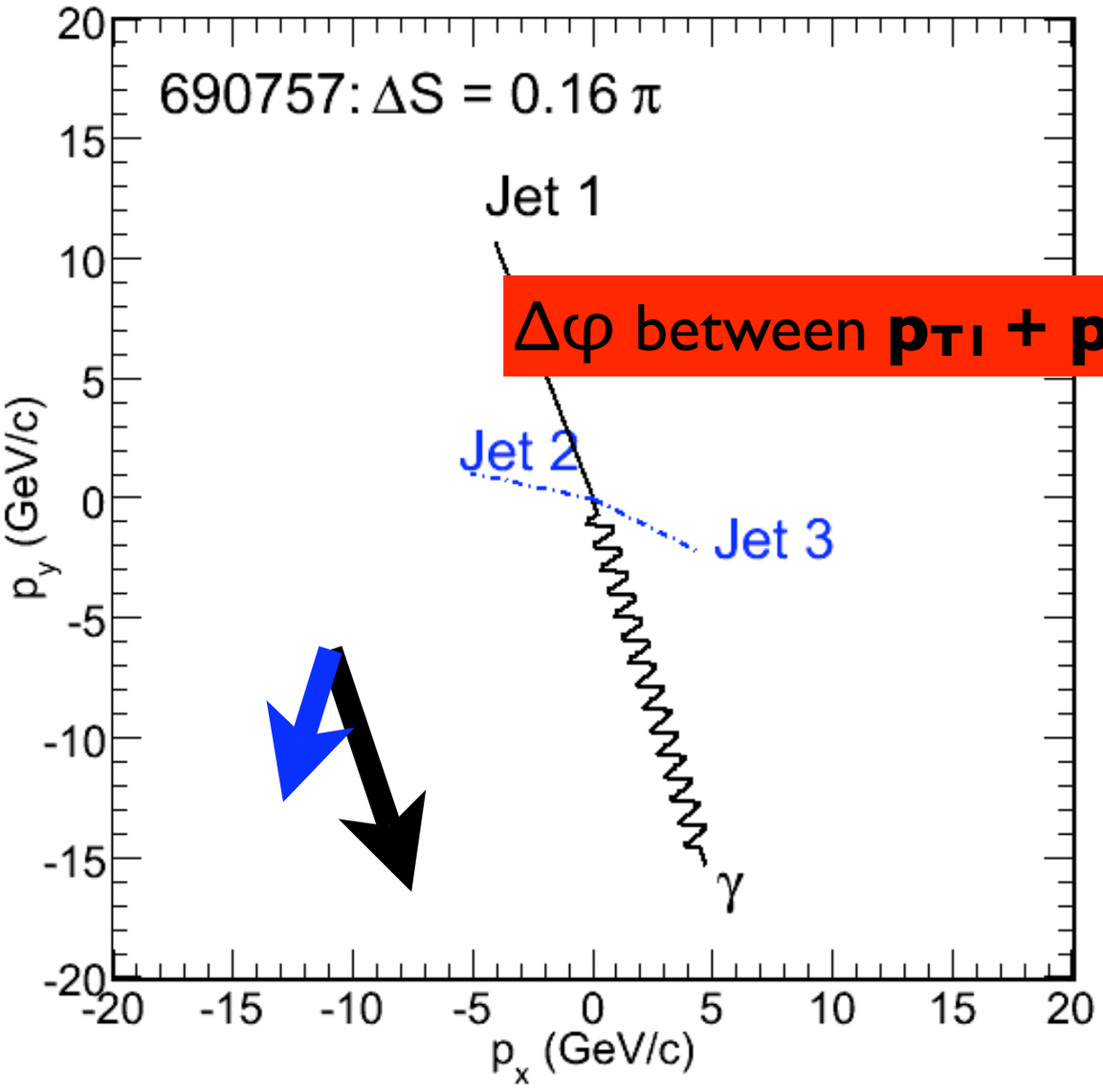
Δφ between p_{T1} - p_{T2} and p_{T3} - p_{T4}



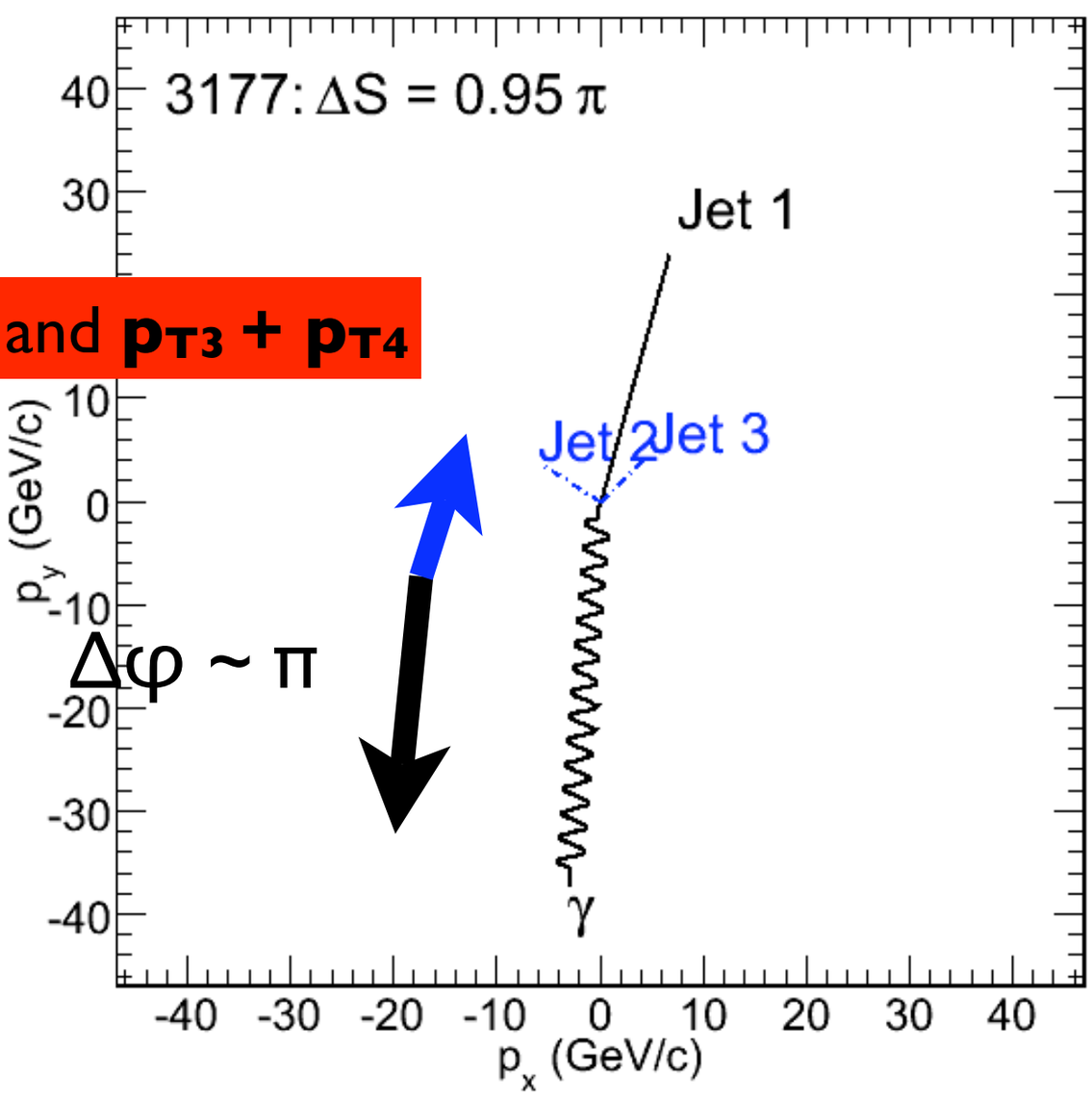
Gen. event displays

Double-parton-scattering:

Double-bremsstrahlung:

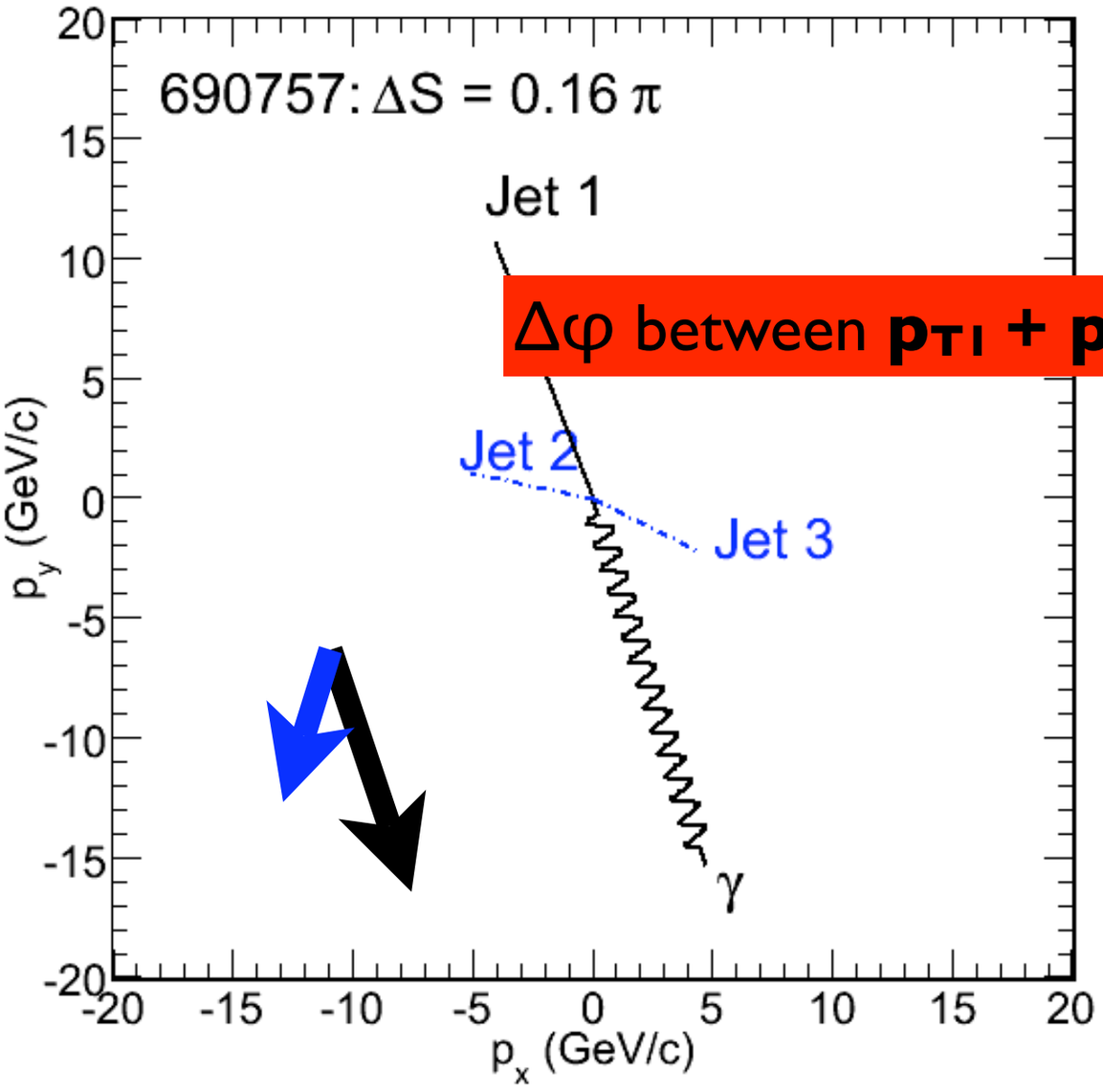


Δφ between $p_{T1} + p_{T2}$ and $p_{T3} + p_{T4}$

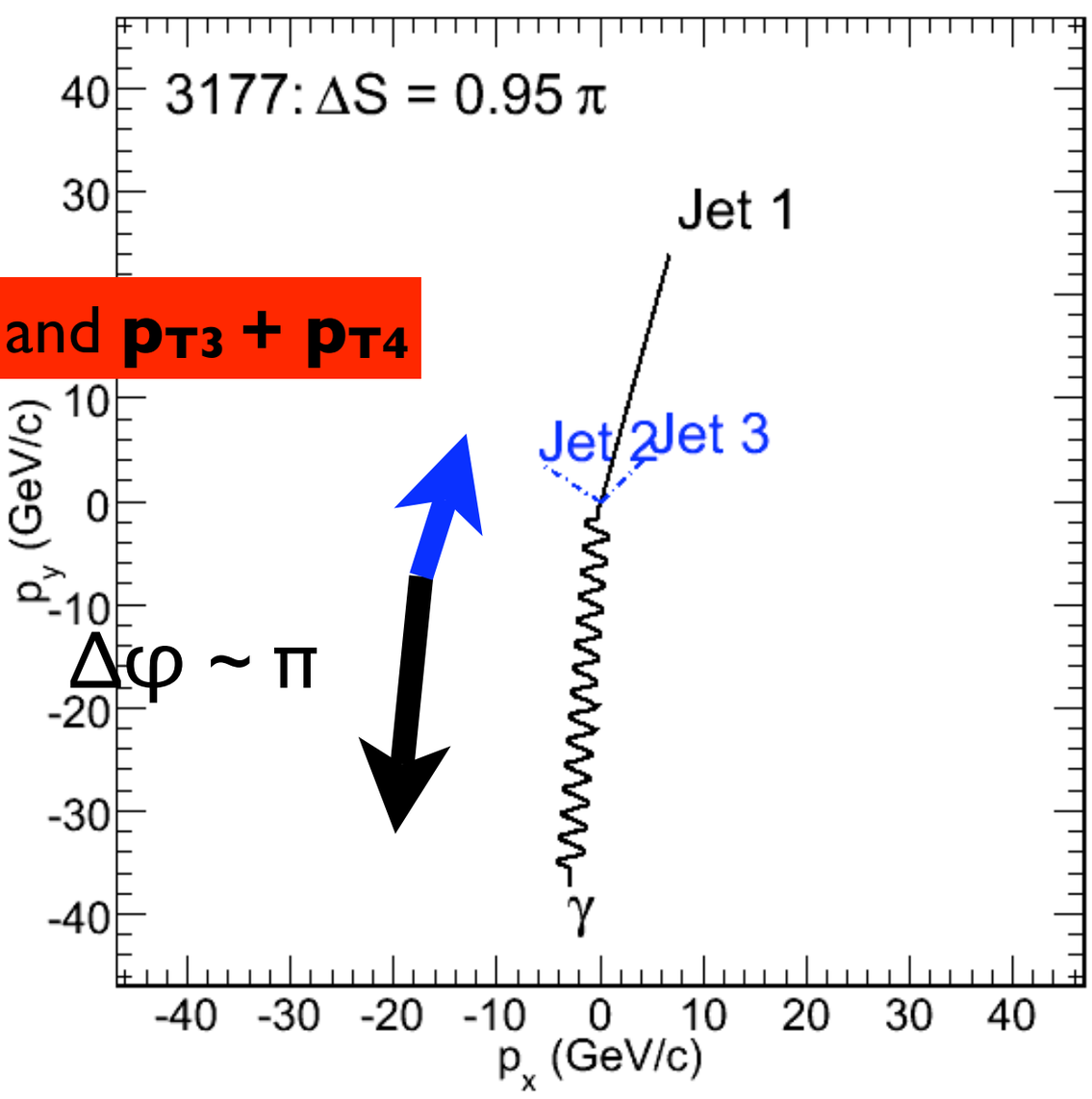


Gen. event displays

Double-parton-scattering:



Double-bremsstrahlung:

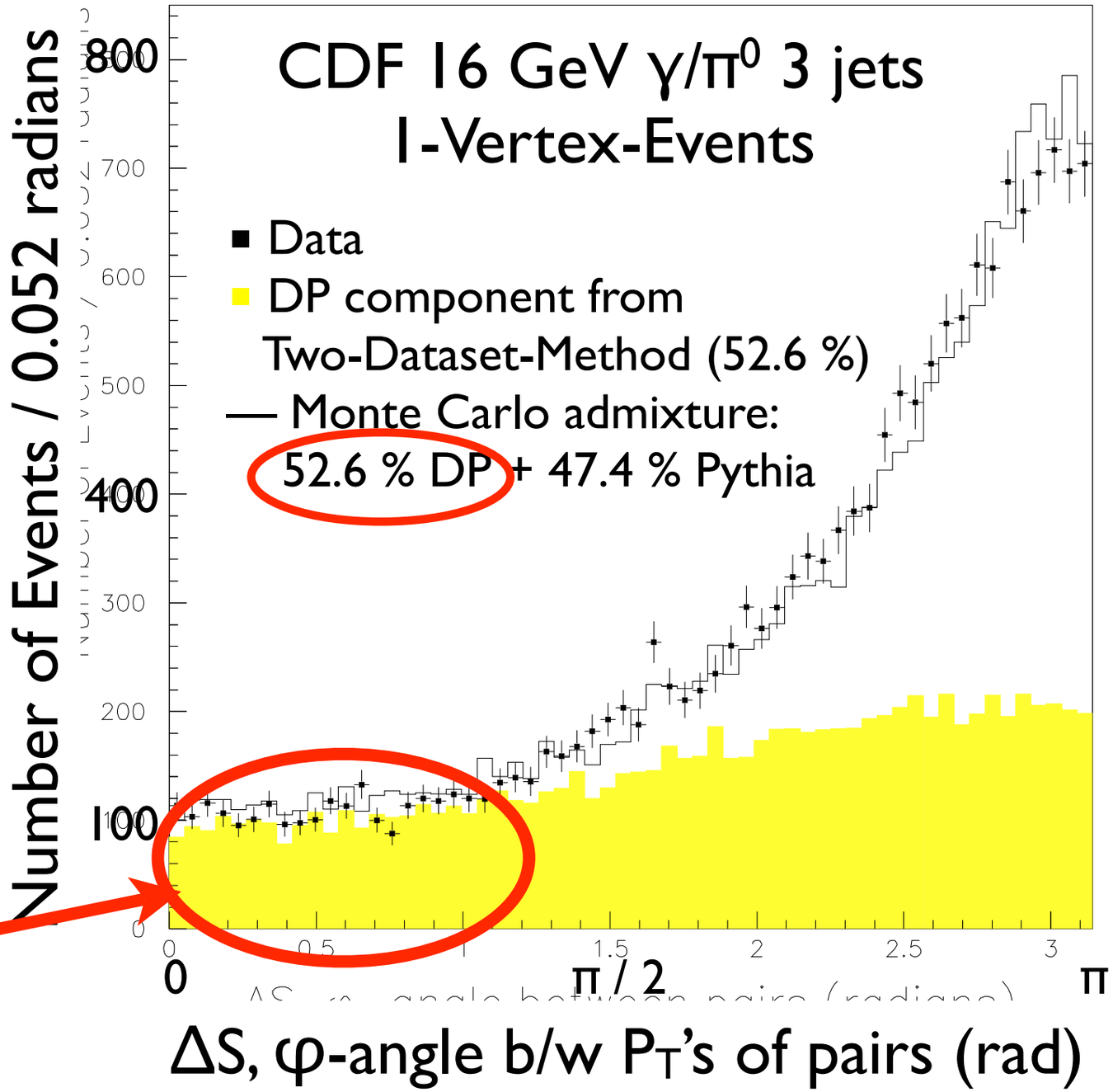


Δφ between $p_{T1} + p_{T2}$ and $p_{T3} + p_{T4}$

→ **Use ΔS to separate** double-parton-scattering from bremsstrahlung

CDF results on γ j j j

- **CDF analysis**
  - Choose pairs which minimize event imbalance
  - study Δφ (ΔS) between $p_{T\gamma}$ + p_{T1} and p_{T2} + p_{T3}
- **DPS model: admixture**
  - Pythia, MPI switched off
  - add sum of min-bias and γ +jet datasets
- **Need double-parton component to describe the data**



New MI models

- **Sjöstrand, Skands (Pythia 8)**
  - Flavour and colour correlations, junction topologies and the relationship to beam remnants (JHEP 0403:053, 2004)
  - Interleaving with initial-state radiation making use of transverse-momentum-ordered initial- and final-state showers (Eur. Phys. J. C39: 129-154, 2005)

- **Bähr, Gieseke, Seymour (Herwig++)**
  - → see Manuel Bähr's talk (hep-ph/0803.3633)

- **Study both models for $p\bar{p}/pp \rightarrow \gamma j + X$ ($\sqrt{s}$ = 1.8...14 TeV)**

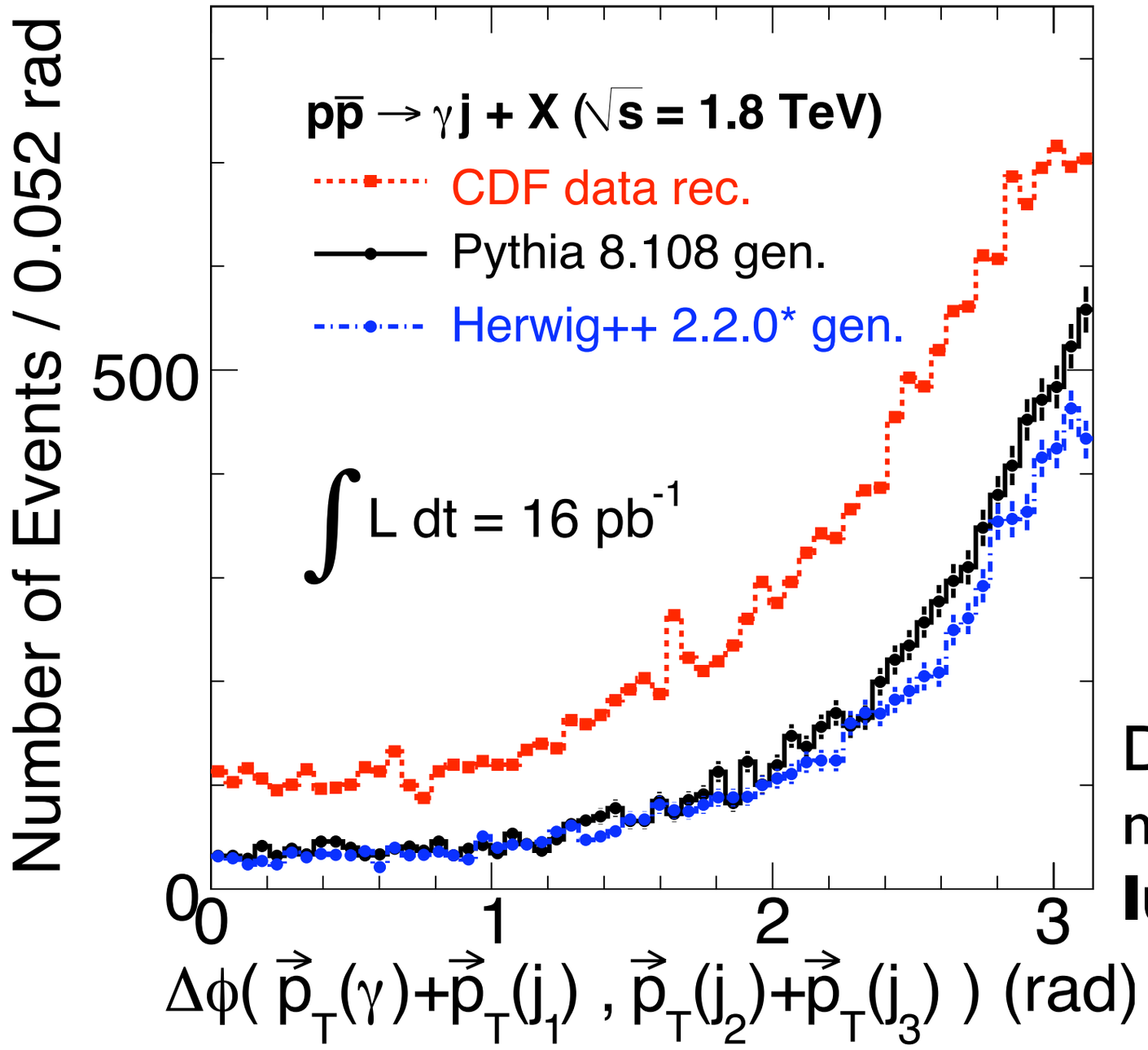
Event selection @ Tevatron

- **Follow CDF analysis ($p\bar{p} \rightarrow \gamma/\pi^0$ + 3 jets, 16 pb^{-1}) on generator level** (Phys. Rev. D56:3811-3832, 1997)

- **Photon:**
  - $|\eta| < 1.1$
  - $E_T > 16$ GeV ($\rightarrow$ CDF inclusive photon trigger)

- **Jets:**
  - Generator-level: from all final-state particles (except neutrinos) reconstructed with k_T-algorithm (R=0.4)
  - CDF: from calo-towers reconstructed with cone-algorithm (R=0.7)
  - $|\eta| < 4.2$
  - $E_T > 5$ GeV
  - exactly three jets
  - two lowest E_T-jets: $E_T < 7$ GeV

Model comparison @ TVT



Distributions normalized to **luminosity**

→ Pythia and Herwig predictions for **$p\bar{p} \rightarrow \gamma j + X$** agree

→ Next: Simulate **$p\bar{p} \rightarrow jj + X$** to compare with CDF rates

Event selection @ LHC

- **1st step: Follow CDF analysis, find "best" E_T thresholds:**
  - MI and ISR/FSR compete to produce additional jets

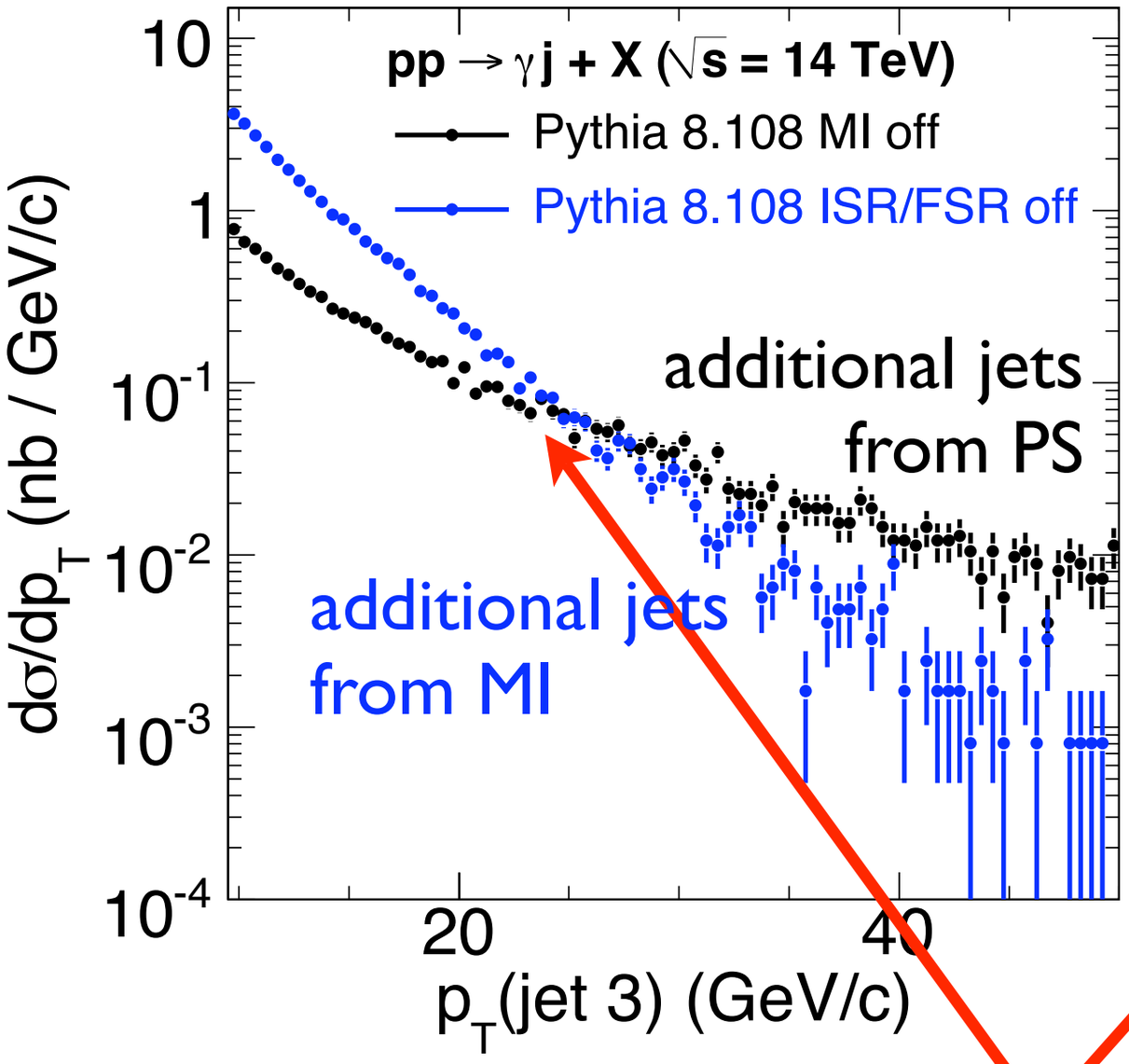
- **Photon:**
  - $|\eta| < 1.1$ (CMS: $|\eta| < 2.5$)
  - $E_T > 16$ GeV (CMS HLT thresholds: $E_T > 10, ..., 40$ GeV)

- **Jets:**
  - $|\eta| < 4.2$ (CMS: $|\eta| < 5$)
  - $E_T > 5$ GeV (CMS: $E_T > 30$ GeV)
  - ~~exactly~~ **at least** three jets
  - ~~two lowest E_T-jets: $E_T < 7$ GeV~~

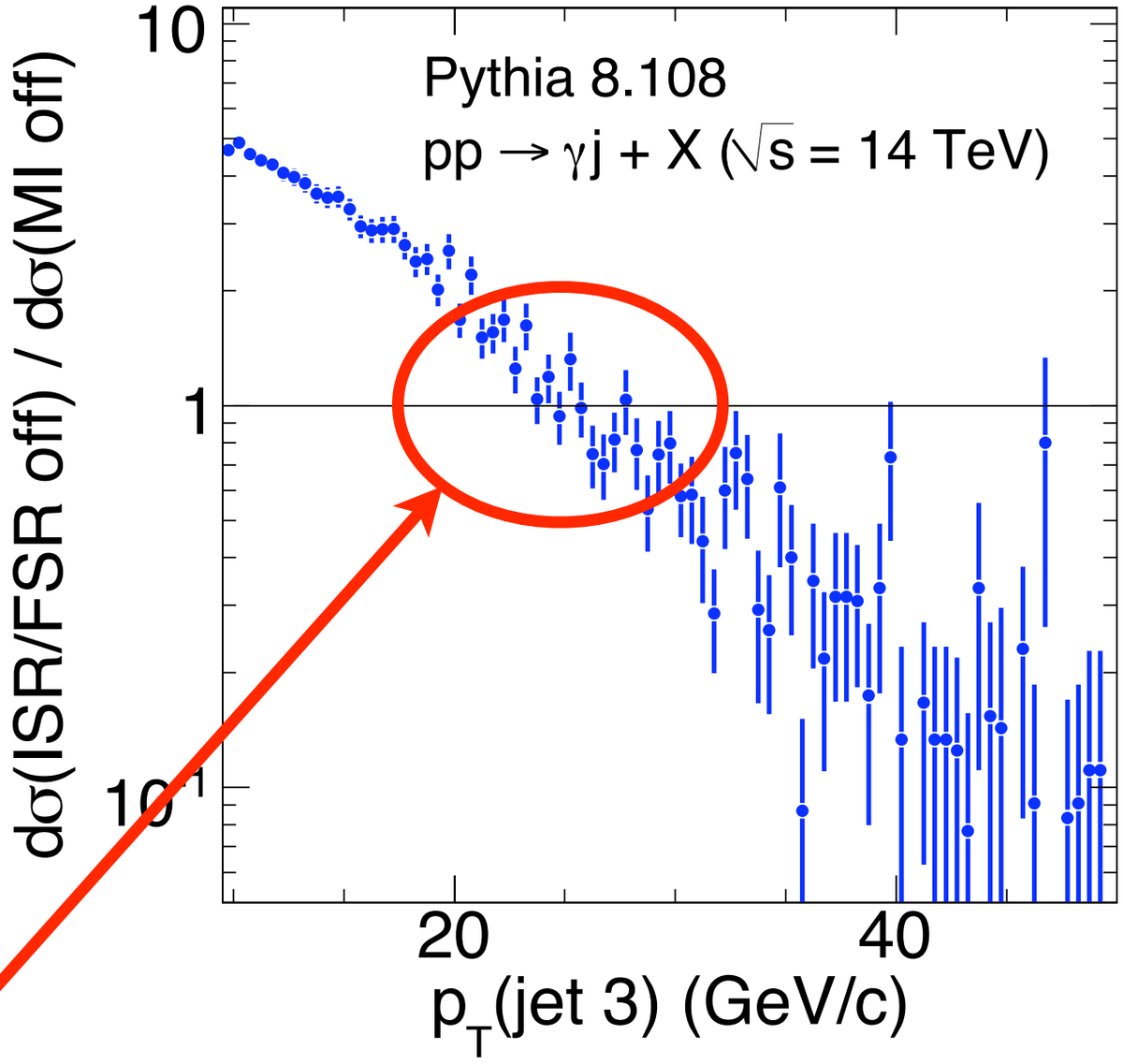
→ "Performance of Jet Reconstruction at CMS" (C. Sander)

Find best E_T threshold

Cross section:

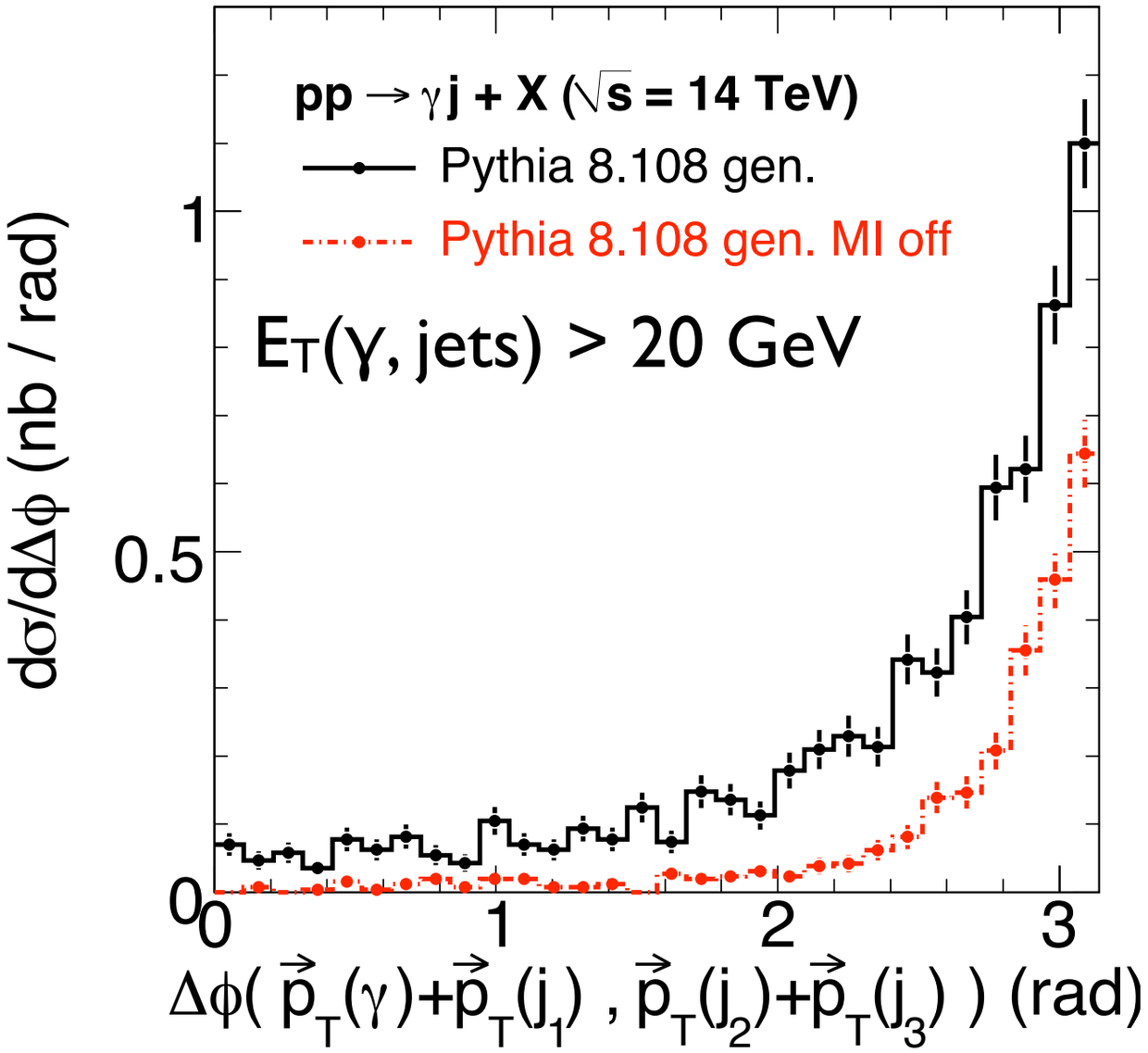


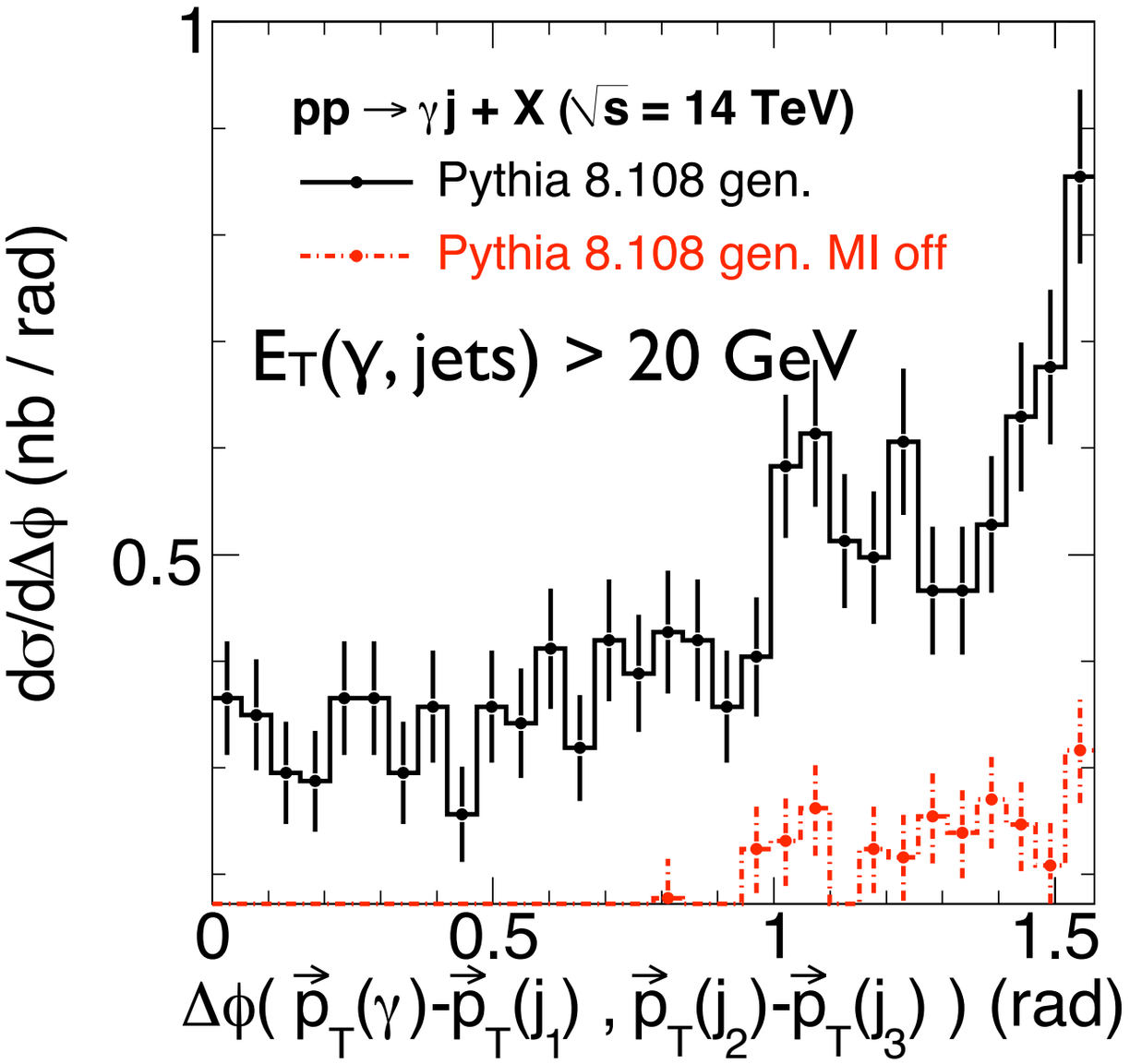
Ratio:



→ choose **p_T > 20 GeV/c** for contributions from double-parton-scattering and bremsstrahlung of the same order

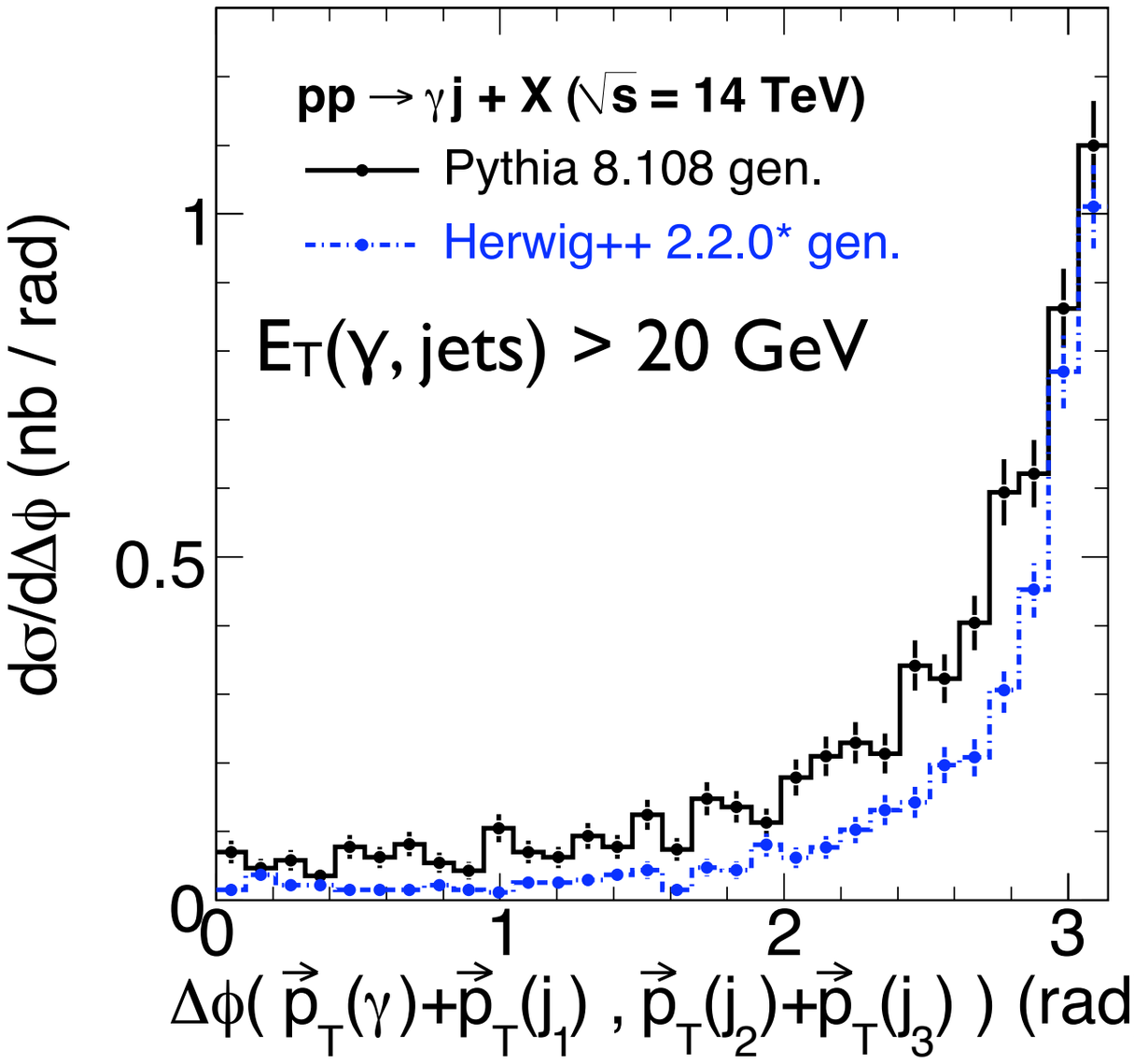
LHC: Impact of Mult. Int.

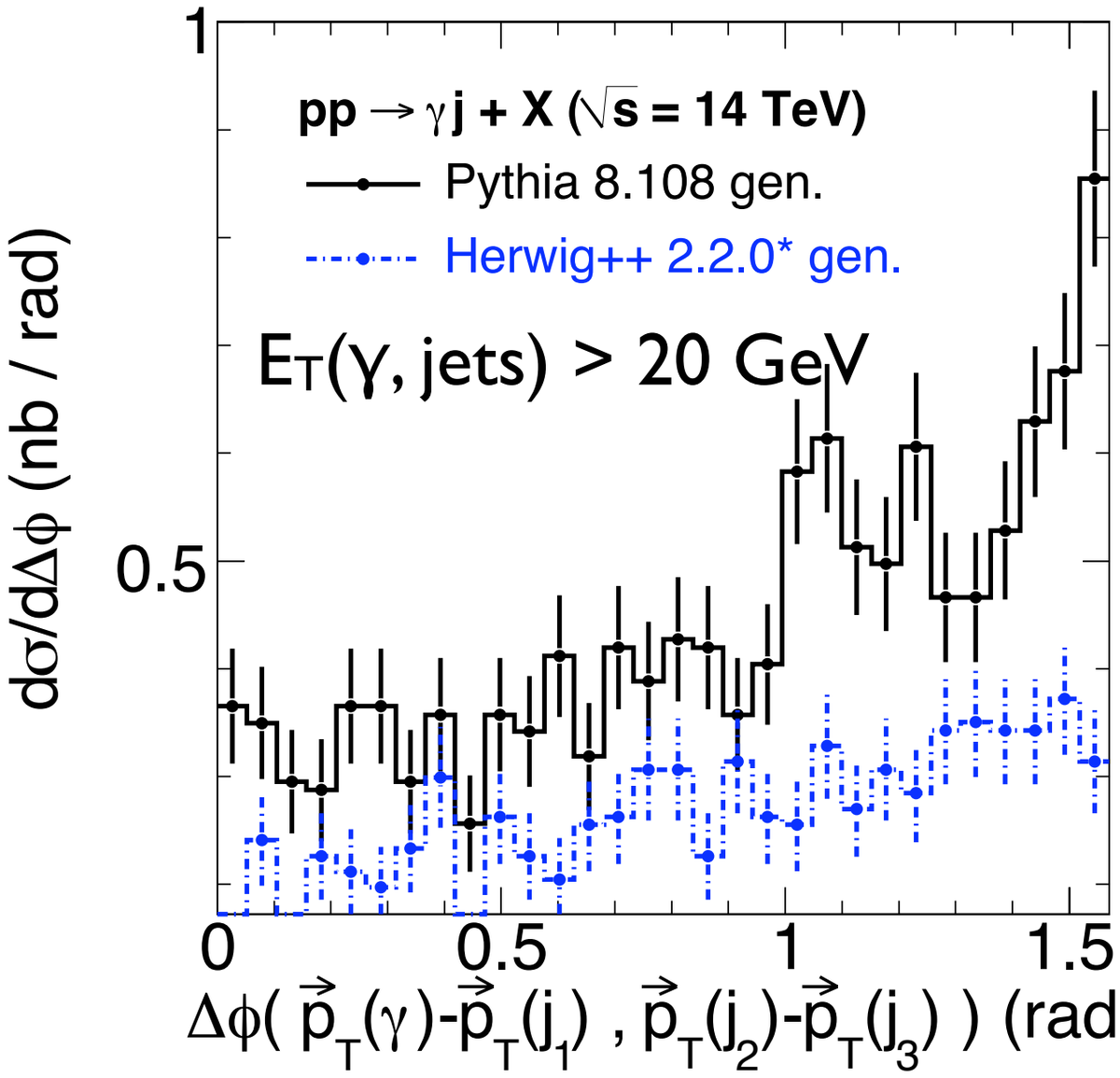




→ MI dominant for small azimuthal angle between pairs

Model comparison @ LHC





→ More statistics underway to clear potential disagreement

→ Default PDFs used: CTEQ5L (Pythia) and MRST98 (Herwig)

Summary

- **Double-parton-scattering: Direct evidence for multiple parton-parton interactions**
- **New multiple interactions models agree at Tevatron**
- **LHC threshold studies: MI contribute 50% for p_T^{min} = 25 GeV/c**
- **New multiple interaction models studied for LHC energies**
- **Next steps: More statistics & detector studies**

BACKUP

DPS: Exp. parametrization

- **DPS comprised of scatterings A and B (A ≠ B):**

$$\sigma_{\mathrm{DP}} = \frac{\sigma_{\mathrm{A}}\sigma_{\mathrm{B}}}{\sigma_{\mathrm{eff}}}$$

  - σ_{eff} - effective cross section (process-independent)
  - from matter overlap distribution

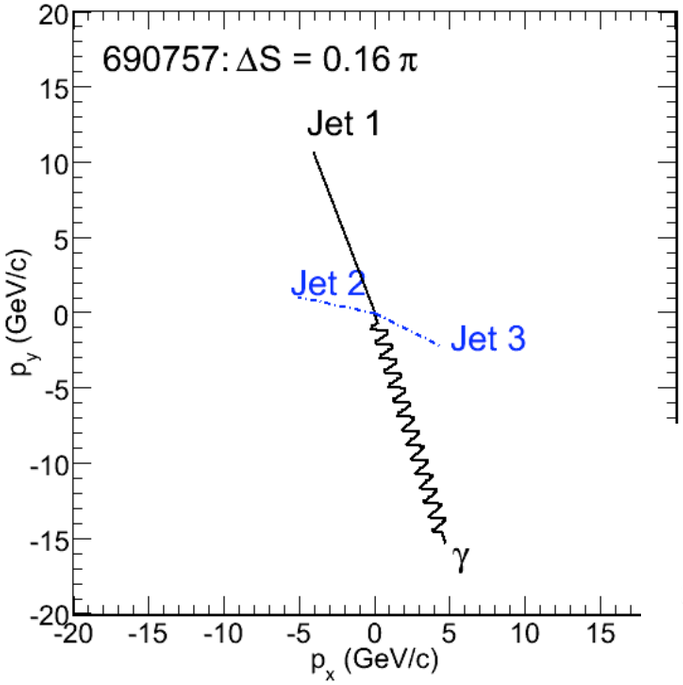
- **σ_{eff} related to number of collisions N:**

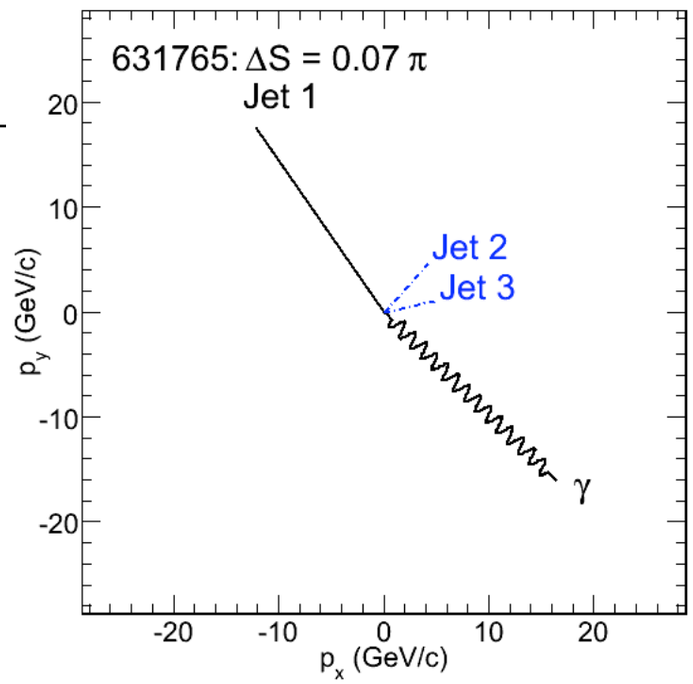
$$\langle \mathrm{N}(\mathrm{N}-1) \rangle = \langle \mathrm{N} \rangle^{2} \frac{\sigma_{\mathrm{hard}}}{\sigma_{\mathrm{eff}}}$$

- **Pythia: $\sigma_{AB} = \langle f_{impact} \rangle \sigma_A \sigma_B / \sigma_{Non\text{-}Diffractive}$**
  - f_{impact} - enhancement/depletion factor for MPI
  - → Pythia "predicts" $\sigma_{eff} = \sigma_{Non\text{-}Diffractive} / \langle f_{impact} \rangle$

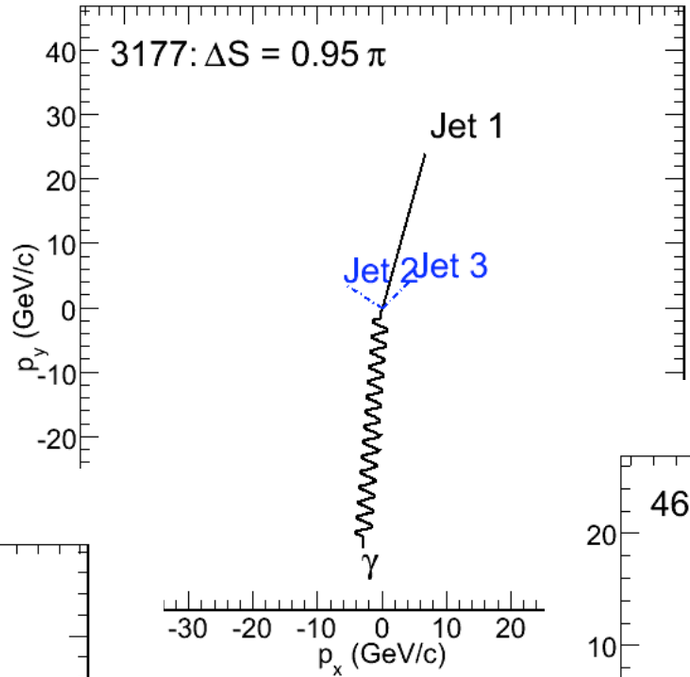
More event displays

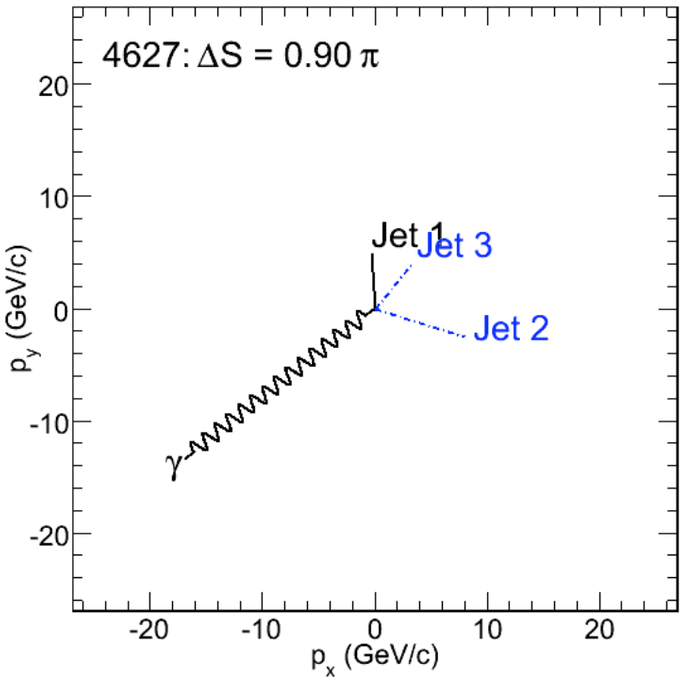
Double-parton-scattering





Double-bremsstrahlung





poor assignment

additional jets not related to hard interaction