# Validation of double high $P_T$ interactions in Pythia 8

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on behalf of the CMS QCD@low $P_T$ group

HERA and the LHC Working Group Week
DESY, October 31st 2007

- Pythia 8
- Double high $P_T$ interactions
- Validation plans

# Oct 20th: Pythia 8.1 released

- **First operational release** of complete C++ rewrite
  - Standalone generator with new user interface
  - Not yet a replacement of the old code in every respect

- Some **new Physics** aspects
  - transverse-momentum-ordered showers
  - interleaving with multiple interactions

- Brief introduction: arXiv:0710.3820
  - Presentation by Torbjorn Sjostrand in GENSER meeting 10/24
  - http://indico.cern.ch/getFile.py/access?contribId=4&resId=0&materialId=slides&confId=22105

- Download
  - http://www.thep.lu.se/~torbjorn/Pythia.html

# Physics summary (I)

- Hard processes
  - pp, $p\bar{p}$, $e^+e^-$, $\mu^+\mu^-$ (no ep, no incoming photons)
  - Most Pythia 6 processes available (no SUSY, no Technicolor)
  - Default PDF is CTEQ5L (can link LHAPDF sets)
  - Possible to use different PDF set A for the hard interaction and PDF set B for subsequent showers and multiple interactions

- Parton showers
  - Initial- and final-state algorithms based on $P_T$-ordered evolution
  - Branching $\gamma \rightarrow$ fermion pair in final-state evolution possible
  - Initial-state evolution, multiple interactions and final-state evolution interleaved into one common decreasing $P_T$ sequence

# Physics summary (2)

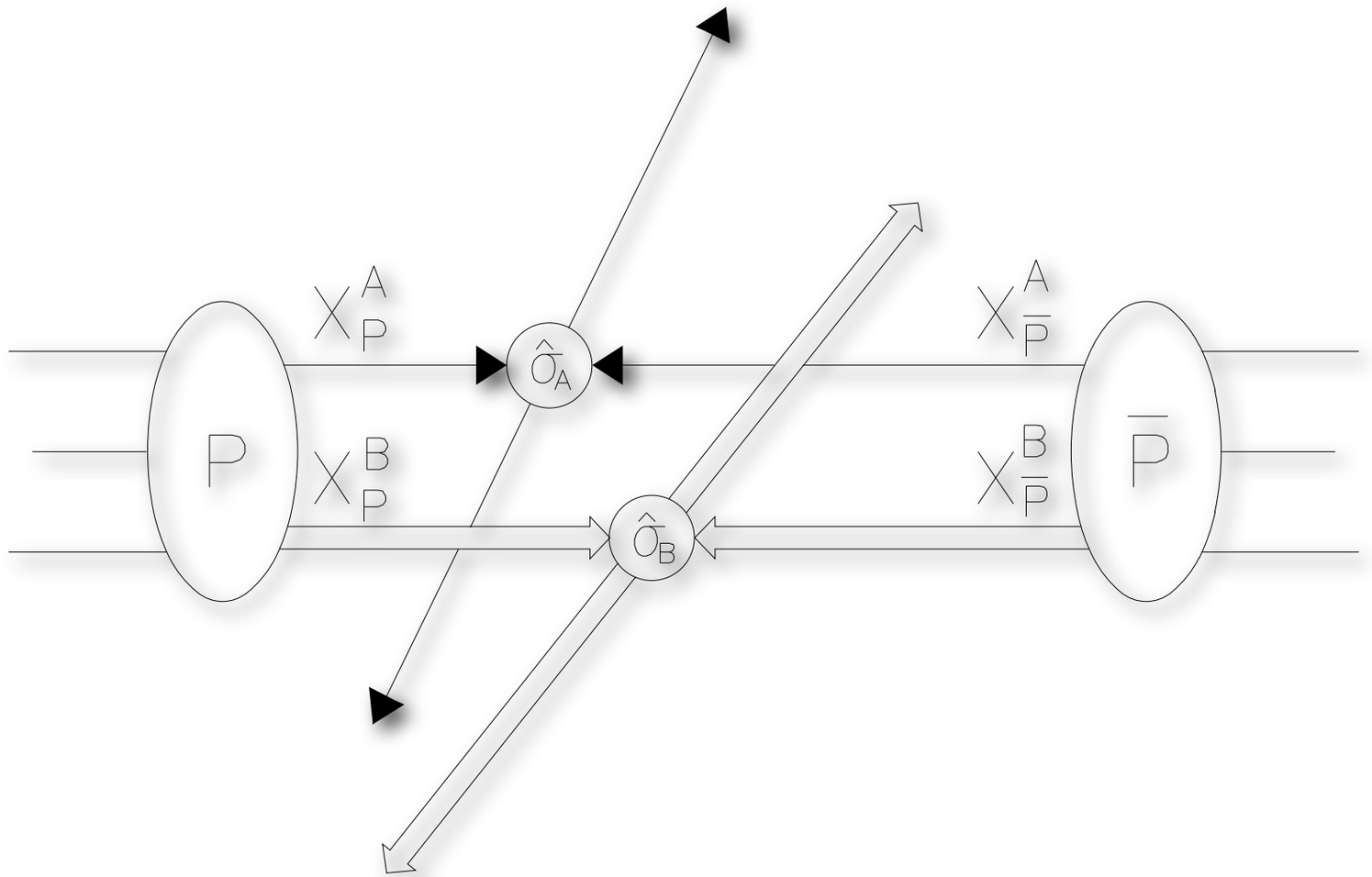
- Multiple interactions and beam remnants
  - Full functionality introduced in Pythia 6.3
  - Rescaled parton densities defined after 1st interaction taking into account the nature of previously extracted parton
  - Final-state colour reconnection: colours of partons from two subscatterings can be interarranged such that the total string length is reduced
  - Underlying-event processes: QCD 2→2, prompt γ, $c\bar{c}$, $b\bar{b}$, low-mass Drell-Yan pairs, t-channel $\gamma^*/Z^0/W^\pm$
  - Can set two hard interactions in the same event

- Hadronisation
  - Lund string fragmentation

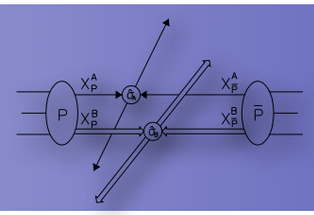
Many interesting new features to study multiple parton interactions

# Double Parton scattering

- Definition: **two parton-parton hard scatterings** take place within one pp collision
- Provides information on **distribution of partons** within the proton and on possible **parton-parton correlations**



# DP @ LHC



- Double parton scattering is dominant contribution to production of two b-quark pairs at LHC energies (Phys. Rev. D 66, 074012 (2002))

- Sizeable background to $pp \rightarrow WH+X$ with $W \rightarrow l\nu$ , $H \rightarrow b\bar{b}$ from double parton collisions (Phys. Rev. D 61, 077502 (2000))

- Expect non-negligible contributions in other channels as well:
  - $Z\, b\, \bar{b}$
  - W+jets, Wb+jets and $Wb\bar{b}$+jets
  - $t\,\bar{t} \rightarrow l\, l\, \nu\, \nu\, b\, \bar{b}$
  - $t\, \bar{b} \rightarrow b\, \bar{b}\, l\, \nu$
  - $b\, \bar{b} \rightarrow$ jets
  - production of many jets when $P_T^{min} \cong 25$ GeV

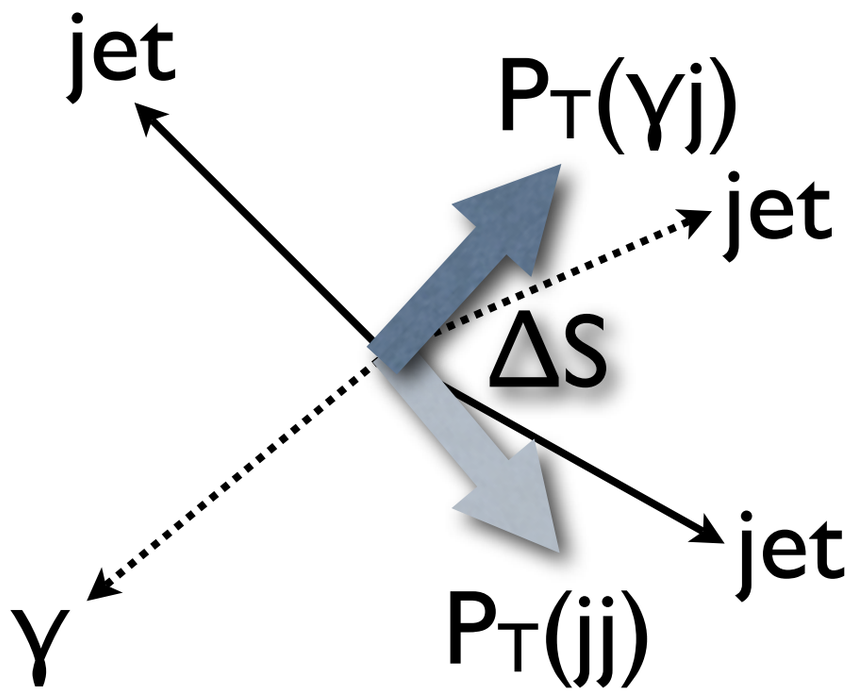
# Measure the 2nd hard process

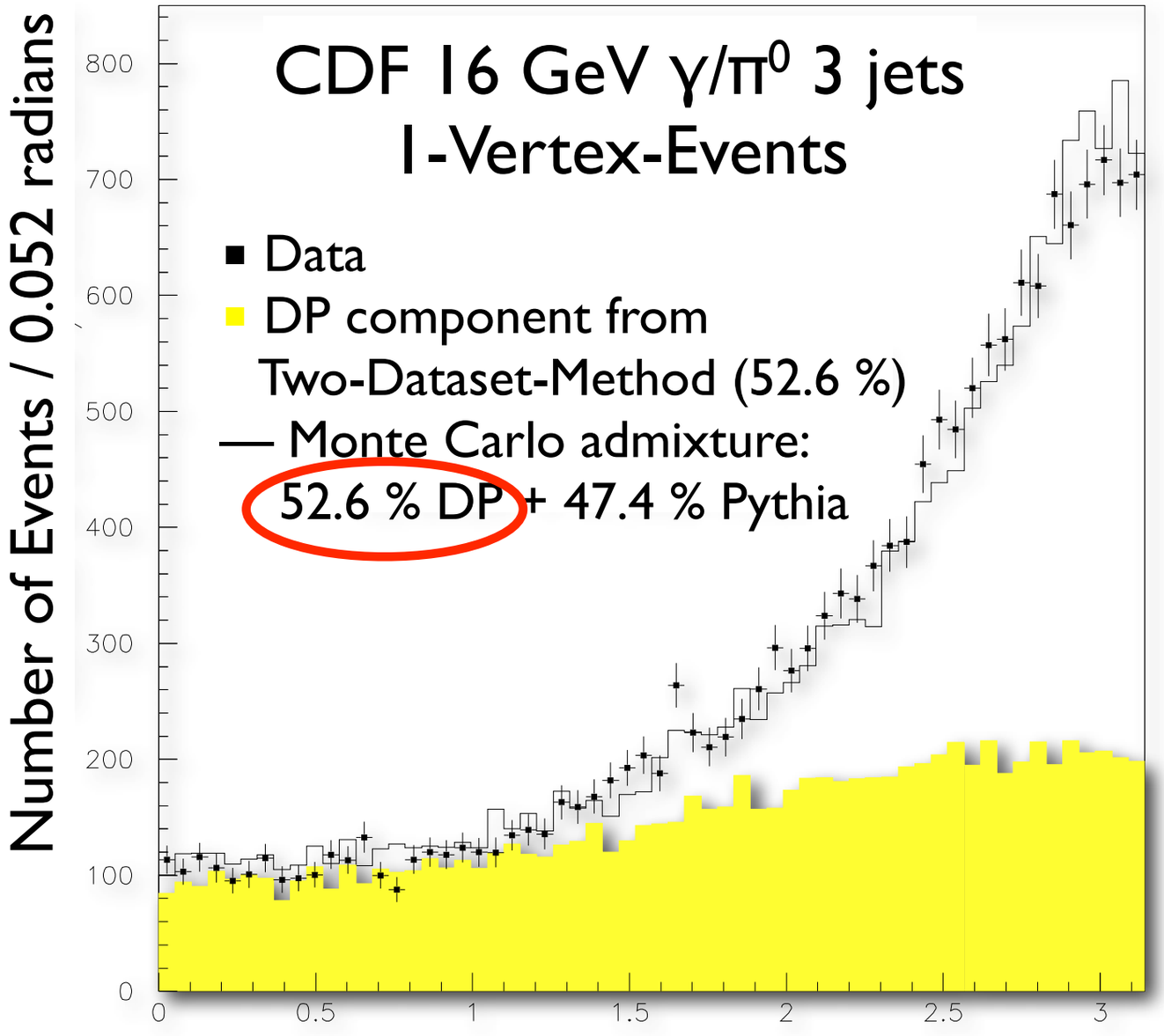
- Final states of interest
  1. (jet+jet)+(jet+jet) i.e. "mini-jets" (combinatorics)
  2. (jet+jet)+(b-jet+b-jet) (b-tagging)
  3. **(jet+jet)+(γ+jet) i.e. γ+3-jets**
     - enlarged jet acceptance wrt. (1.) (use single photon trigger)
     - profit from better resolution in photon angle and energy

- CDF measurement of γ+3-jet final states
  - *Phys. Rev. D 56, 3811 (1997)*
  - Double parton scattering model from mixing independent sets of CDF data
  - CDF data can only be described when adding **>50% contribution from double high $P_T$ scatterings**

# γjjj @ CDF

- CDF measured γjjj final states and studied the azimuthal angle between $P_T$ vectors of γj and jj



# Simulate the 2nd hard process

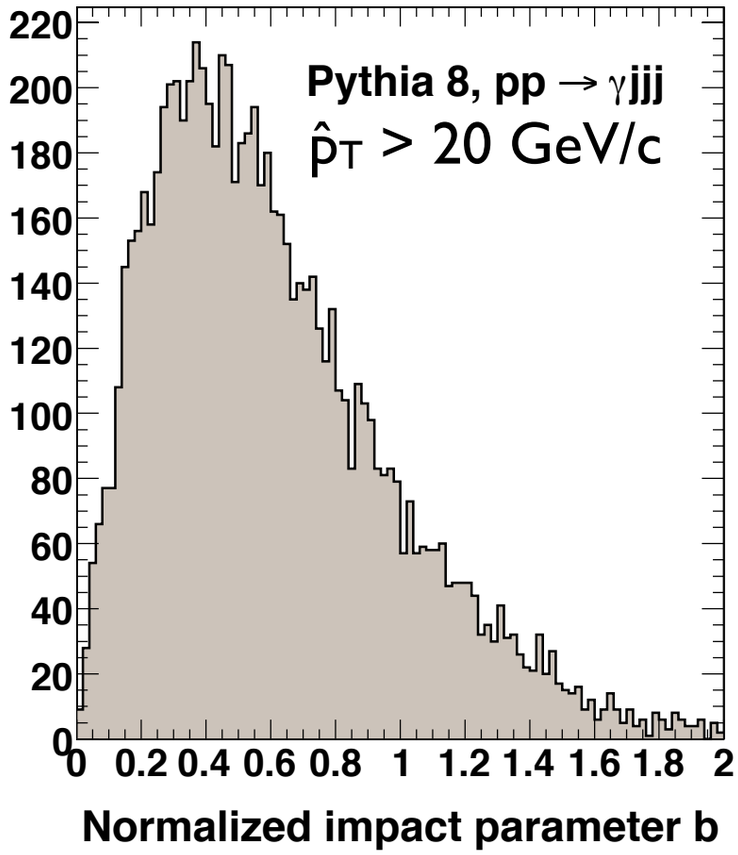
- Multiple interactions framework can add **further interactions** to build up realistic underlying event
  - further interactions occasionally quite hard

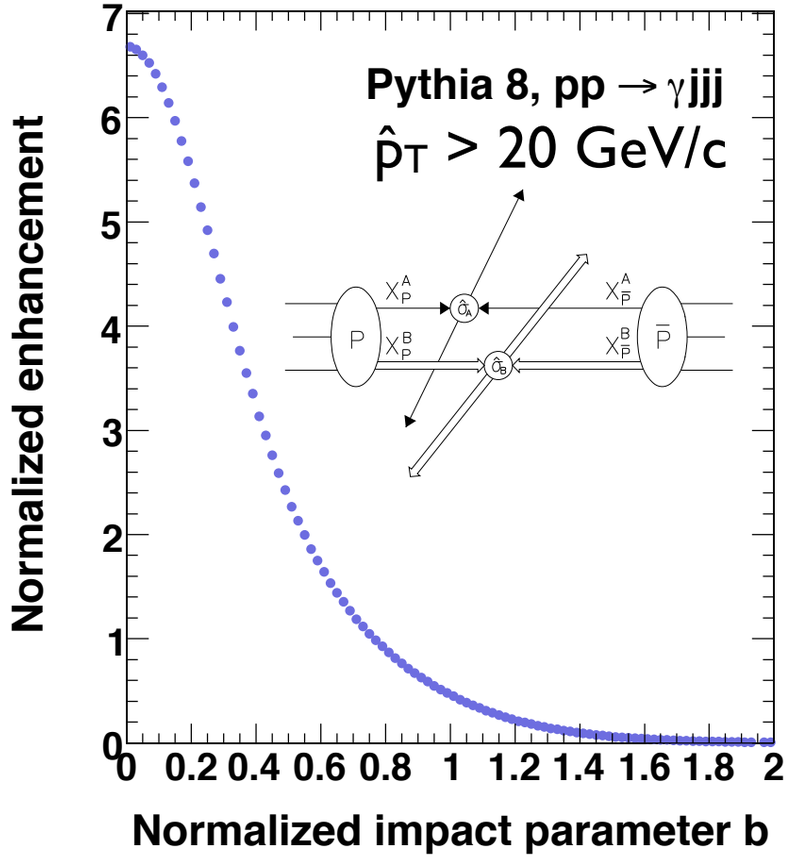
- Pythia 8 allows to **specify the second hard interaction** rather precisely
  - No Sudakov factors included for both hard interactions
  - Description is almost completely symmetric between 1st and 2nd process

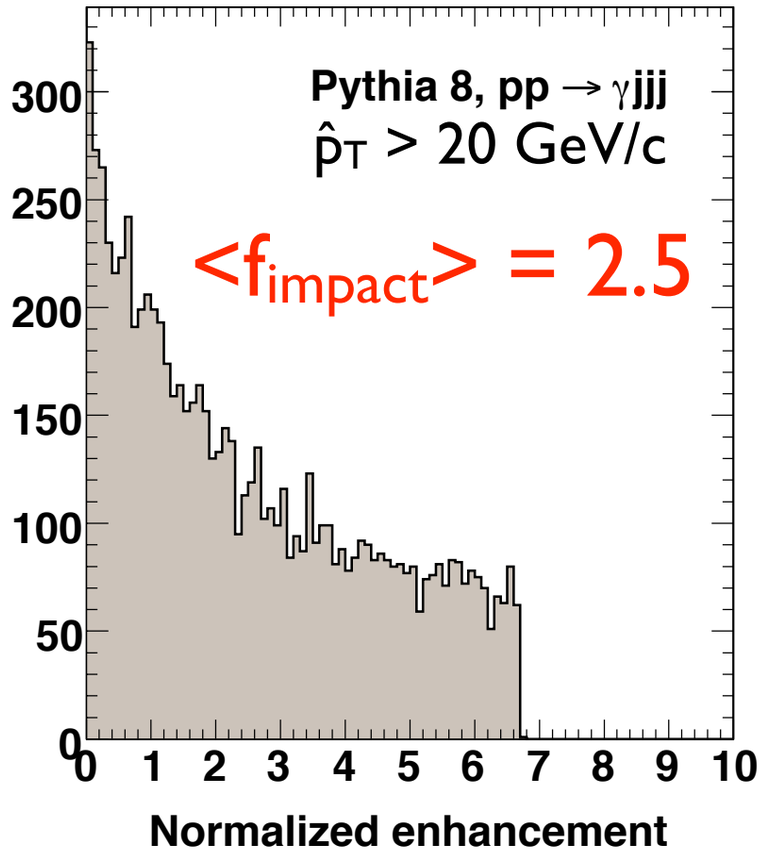
- 2nd hard process obeys **exactly the same selection rules** for process properties and phase space cuts as the first
  - In particular: $P_T^{min}$ cut for $2 \rightarrow 2$ applies to 1st and 2nd process alike

# Parametrization (Pythia 8)

- Central collisions likely to have more activity than the average, peripheral less
- "Trigger bias" effect: selecting events with a hard process means you favour events at small **impact parameter** (origin of "**pedestal effect**" in Pythia)
- Matter overlap profile → **enhancement/depletion factor** $f_{impact}$ is chosen event-by-event




**Double Gaussian matter distribution assumed**

# Parametrization (CDF)

- Cross section for DP comprised of scatterings A and B (A ≠ B):

$$\sigma_{DP} = \frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

where $\sigma_{eff}$ - **effective cross section**, i.e. process-independent scale factor (from the overlap of the matter distributions of the two interacting hadrons)

- $\sigma_{eff}$ related to dispersion of distribution in the **number of collisions:**

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

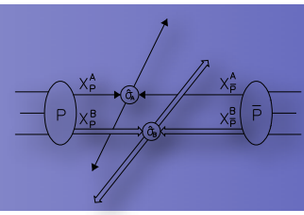
- Experimental indication: $\sigma_{eff}$ = 11 mb

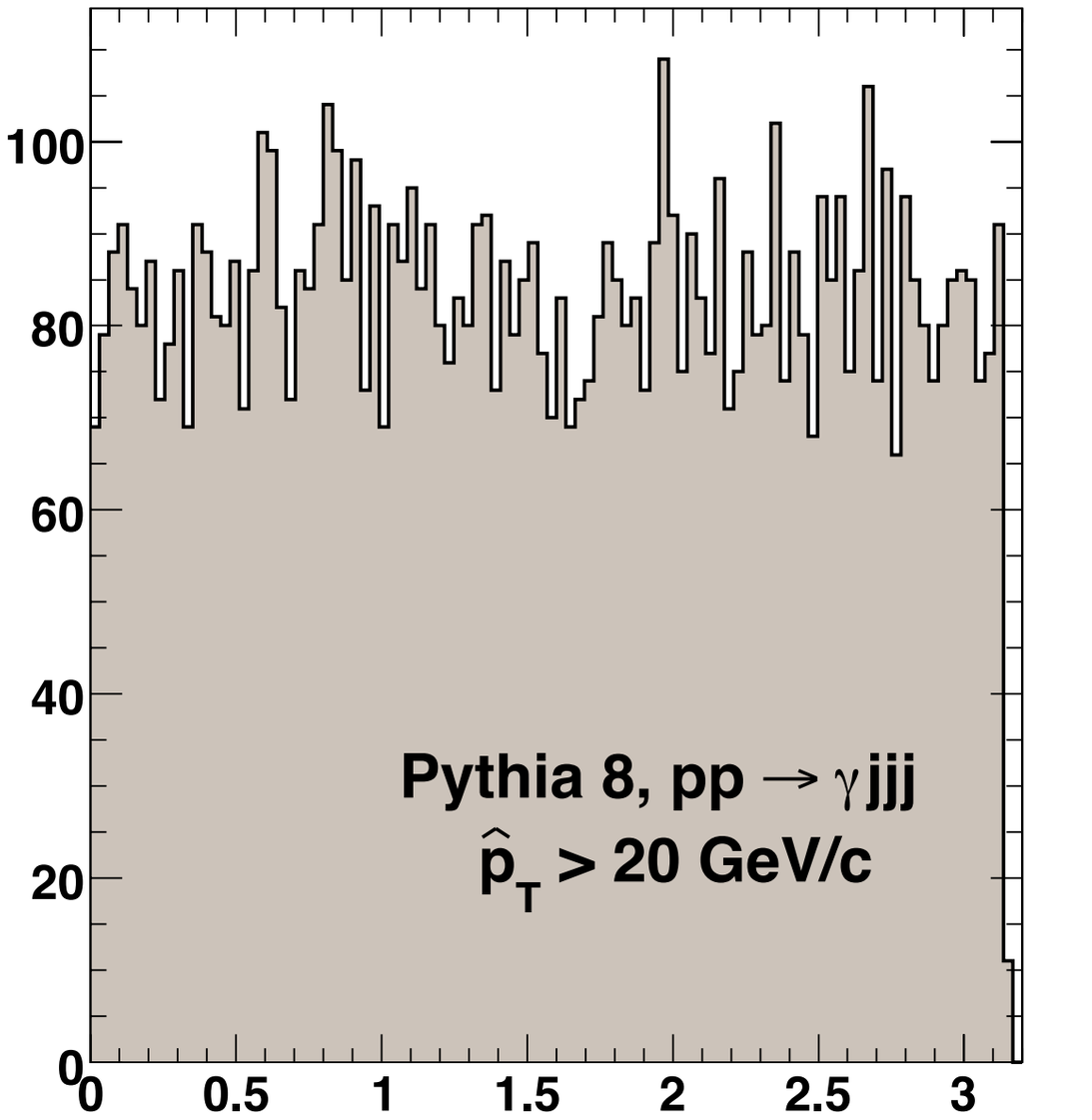
- NB: in Pythia, $\sigma_{AB} = \langle f_{impact} \rangle \sigma_A \sigma_B / \sigma_{Non\text{-}Diffractive}$

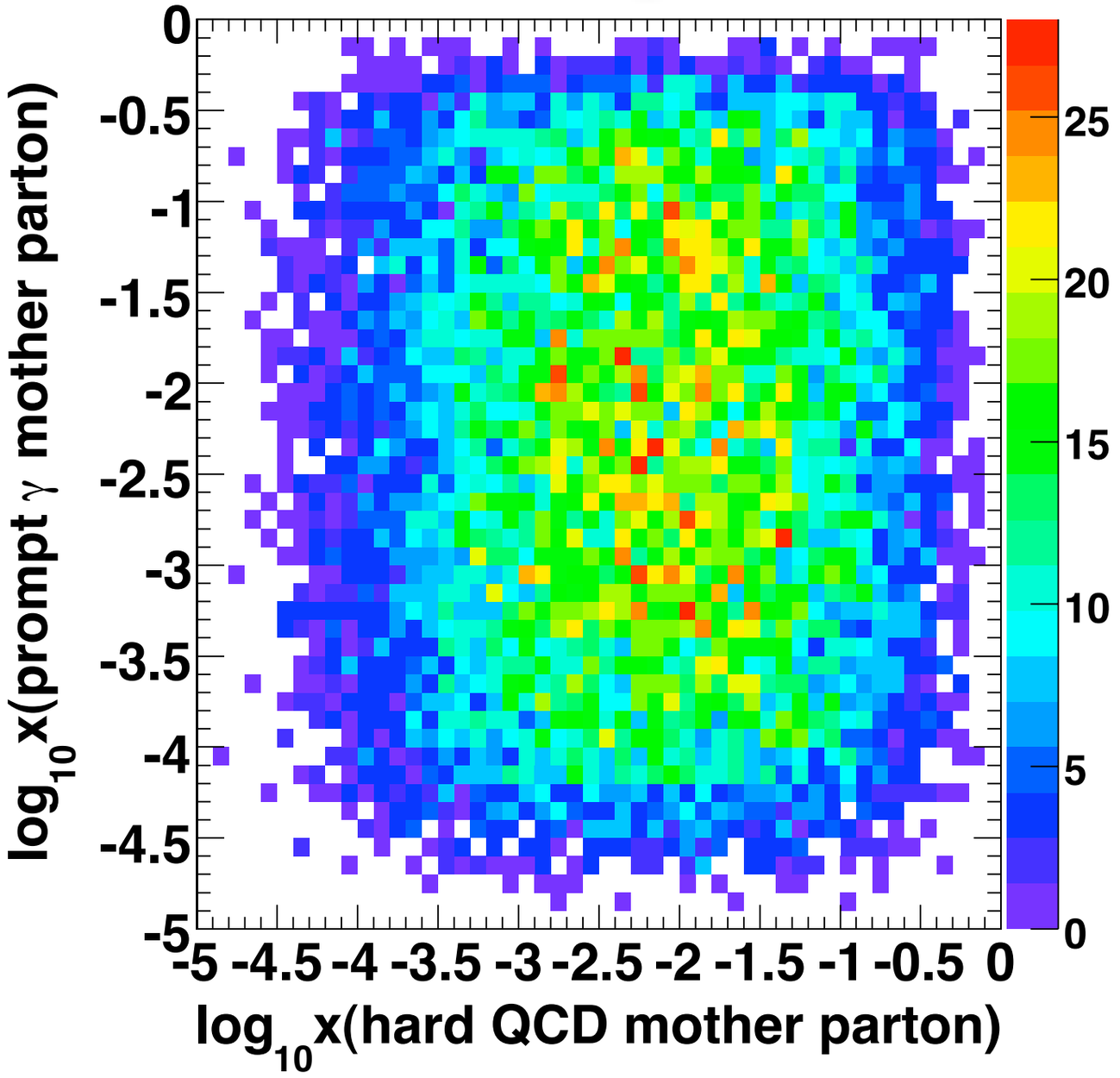
→ Pythia 8 "predicts" **$\sigma_{eff} = \sigma_{Non\text{-}Diffractive} / \langle f_{impact} \rangle$**

(here: $\sigma_{eff}$ = 54.71 mb / 2.5 ≈ 20 mb)

# MPI kinematics






- No angular correlations on parton level
- Partons from proton sea contribute dominantly

# Cross section estimation

- Use bare Pythia 8 and estimate $\sigma_{DP}( pp \rightarrow \gamma jjj )$
- $\hat{p}_T$ > 20 GeV, 1st hard process: prompt γ, 2nd hard process: hard QCD

$2 \rightarrow 2$, $|\eta(\gamma)| < 2.7$

| E(γ) [GeV] | σ [nb] |
|---|---|
| 20-60 | 2.04 |
| 60-120 | 1.03 |
| 120-180 | 0.57 |
| 180-240 | 0.22 |
| 240-300 | 0.08 |
| 300-7000 | 0.08 |

Expect sizeable cross section contribution from double parton scattering

# Summary and outlook

- **First production version** of Pythia 8 available: Pythia 8.100
  - Allows simulation of 2nd hard interaction

- Expect **non-negligible background** contribution from **multiple parton-parton interactions** to many final states of interest at the LHC

- **Study multiple parton-parton interactions** in large variety of final states