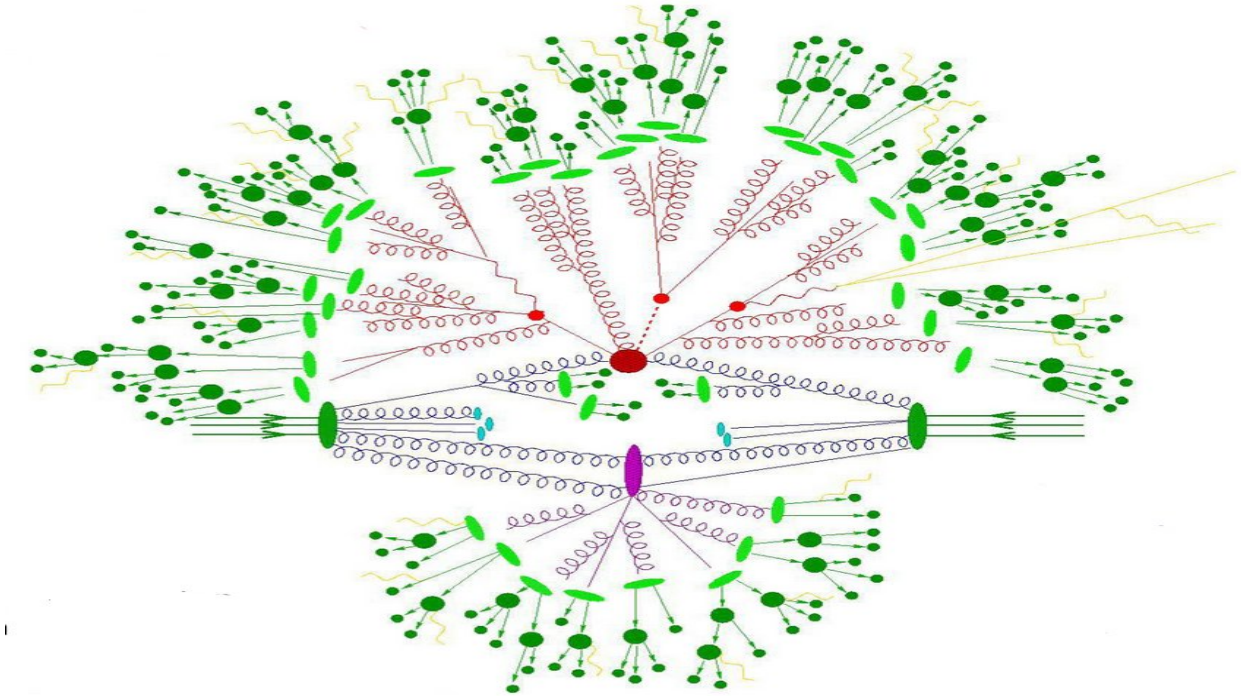
Deutsches Elektronen-Synchrotron
(DESY), Hamburg
(and University of Antwerp)

# Studies of double parton scattering and Monte Carlo tuning

*Paolo Gunnellini*
*Work done within the CMS Collaboration*

**DIS 2017**
**Birmingham (England)**
**Altarelli award**

# What is a proton-proton collision?



Hard scattering

Initial and Final State Radiation

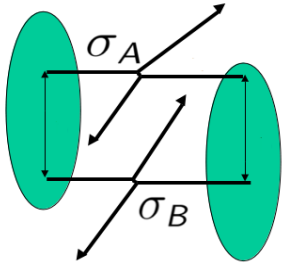
Multiple Parton Interaction (MPI)

Beam-beam remnants

**Underlying Event**

In general, it is a softer contribution but..some MPI can be hard!

Double Parton Scattering (DPS)



# Double parton scattering and experimental overview

$$\sigma_{AB}^{DPS} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

Internal structure of the proton
DPS background for any physics channel

$\rightarrow$ What are the different pieces of this formula?

m: symmetry factor (equal to 1 or 2)

$\sigma_A$, $\sigma_B$: (partonic) inclusive cross sections for processes A and B

$\sigma_{eff}$: we can extract experimentally

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BUT..experimental issue: very difficult to define inclusive cross sections at parton level!

$\sigma_{eff}$ value differs for different definitions of single cross sections!

PRD76 (2007) 076006, JHEP 03 (2013) 129

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**Example: $\gamma$+3 jets measured by CDF at 1.8 TeV**

Exclusive $\sigma_A$, $\sigma_B$

$\sigma_{eff} \sim$ **14.5±1.7$^{+1.7}_{-2.3}$ mb**

Inclusive $\sigma_A$, $\sigma_B$

$\sigma_{eff} \sim$ **10.3 mb**

Assuming unknown number of scatters

$\sigma_{eff} \sim$ **12.0±1.3$^{+1.3}_{-1.5}$ mb**

**THERE IS AMBIGUITY!**

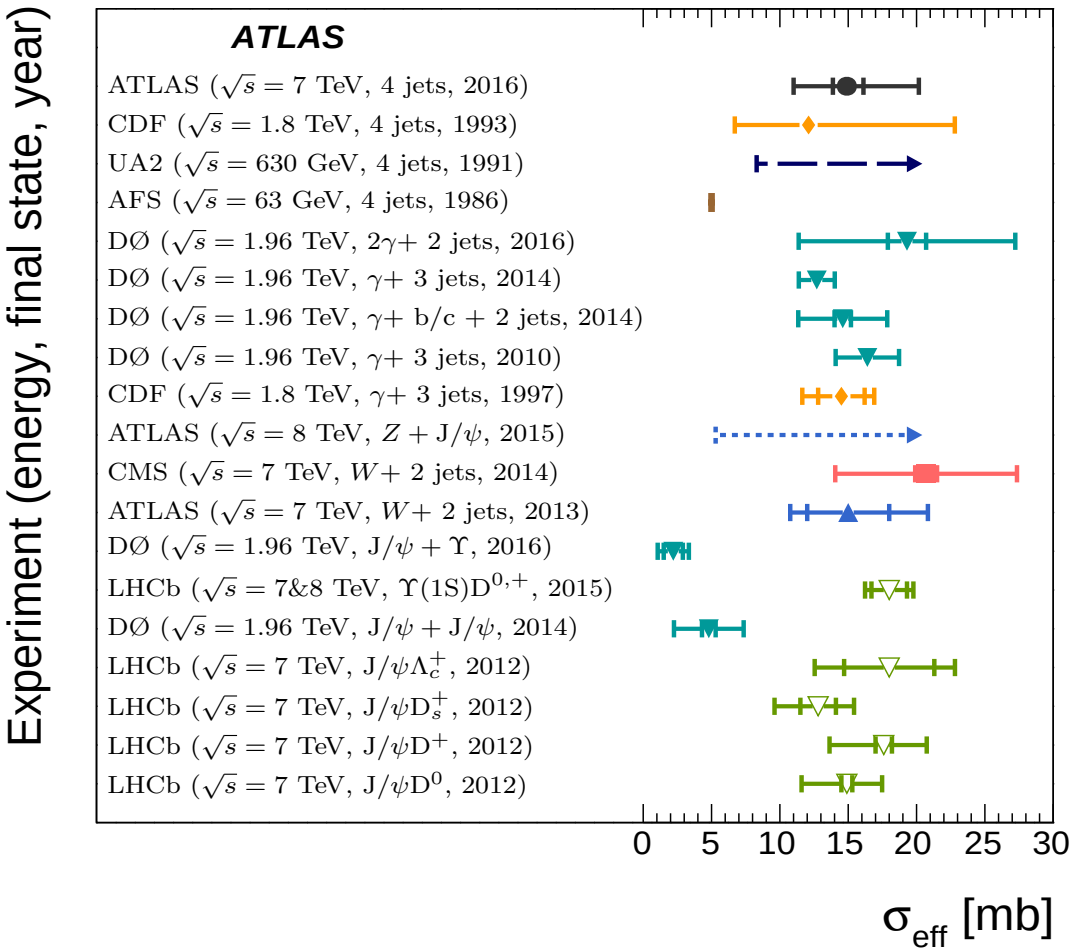
PRD76 (2007) 076006, JHEP 03 (2013) 129

# Double parton scattering and experimental overview

$$\sigma_{AB}^{DPS} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

Internal structure of the proton
DPS background for any physics channel

→ Which channels have been used to look for DPS signals?




→ Many sensitive channels at various energies

→ Scatter of values ranging between 10-25 mb

→ Large uncertainties, mainly due to $\sigma_{eff}$ extraction method

$$\sigma_{AB}^{DPS} = \frac{m}{2}\frac{\sigma_A \sigma_B}{\sigma_{eff}}$$

Internal structure of the proton
DPS background for any physics channel

→ Which channels have been used to look for DPS signals?

**In this presentation:**

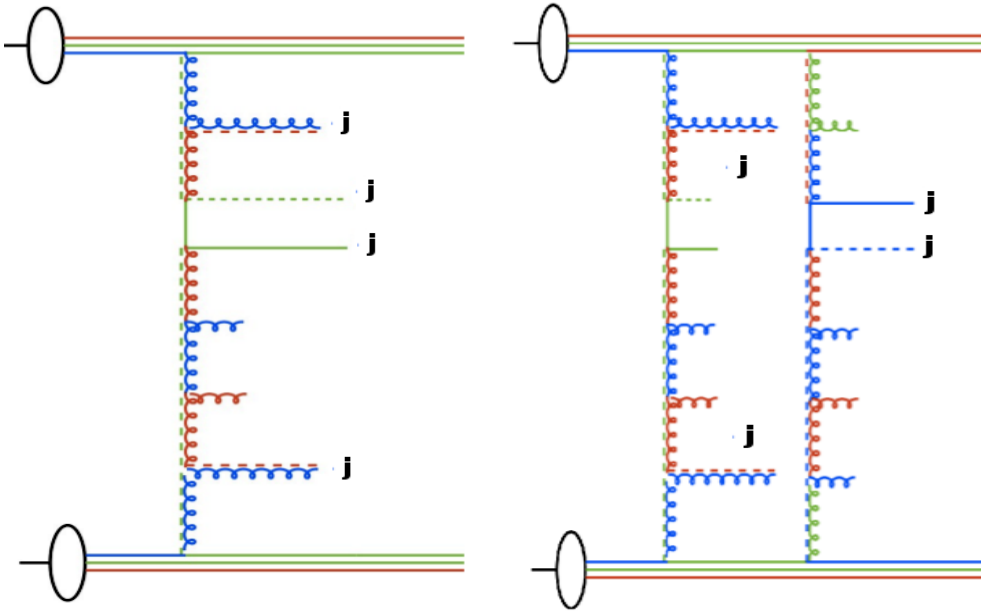
four-jets

two b-jets + two additional jets

# Physics of a four-jet scenario (I)

A four-jet final state may arise from one or two hard scatterings:

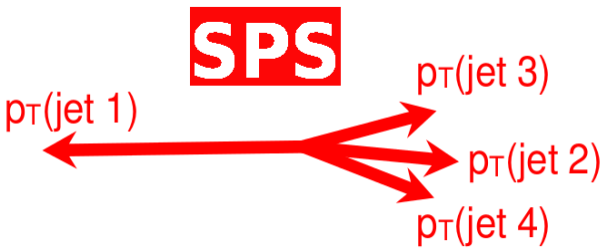
- the two additional jets may be produced via hard radiation or 2nd hard scattering

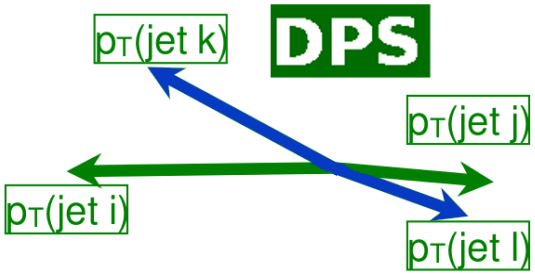



## Discriminating observables:

$$\Delta^{rel}_{soft} p_T = \frac{|p_T(j_l, j_k)|}{|p_T(j_l)| + |p_T(j_k)|}$$

$$\Delta S = \arccos\left(\frac{\vec{p}_T(j^l, j^k) \cdot \vec{p}_T(j^j, j^i)}{|\vec{p}_T(j^l, j^k)| \cdot |\vec{p}_T(j^j, j^i)|}\right)$$




! Selection of jet pairs at different scales helps the jet association !

# Physics of a four-jet scenario (II)

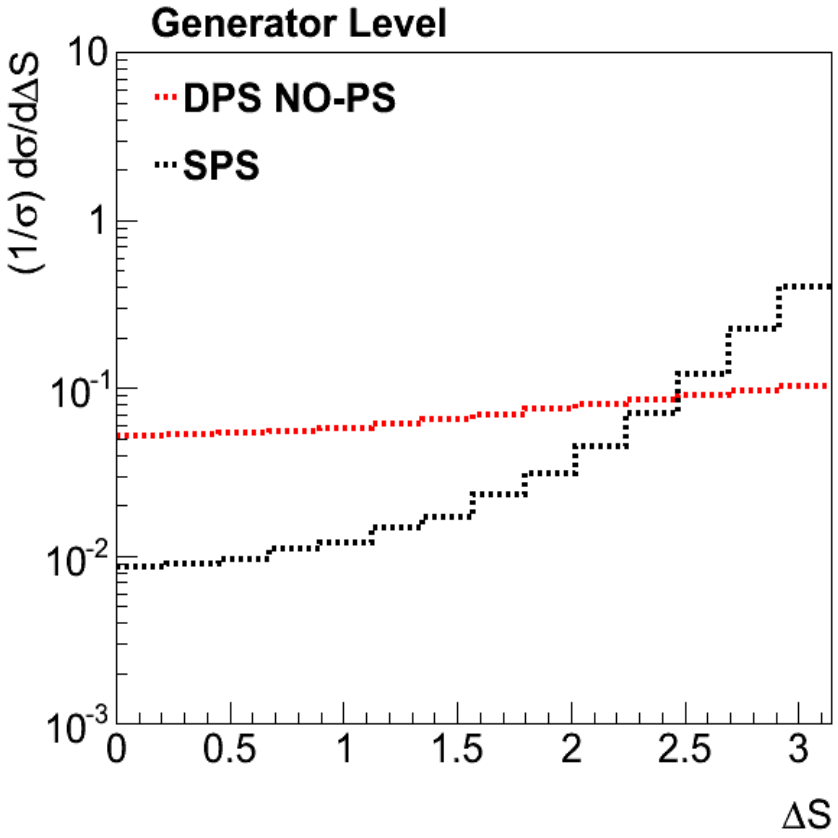
Which regions of the phase space are interesting for DPS detection?

Selection of a four-jet final state in generator level studies performed with PYTHIA8:

- two jets with $p_T > 50$ GeV
- two jets with $p_T > 20$ GeV

A SIMPLE scenario:

- SPS: MPI contribution switched off
- DPS-NO PS: Two hard scatterings at the parton level forced to happen w/o parton shower




$$\Delta S = \arccos\left(\frac{\vec{p}_T(j^l, j^k) \cdot \vec{p}_T(j^j, j^i)}{|\vec{p}_T(j^l, j^k)| \cdot |\vec{p}_T(j^j, j^i)|}\right)$$

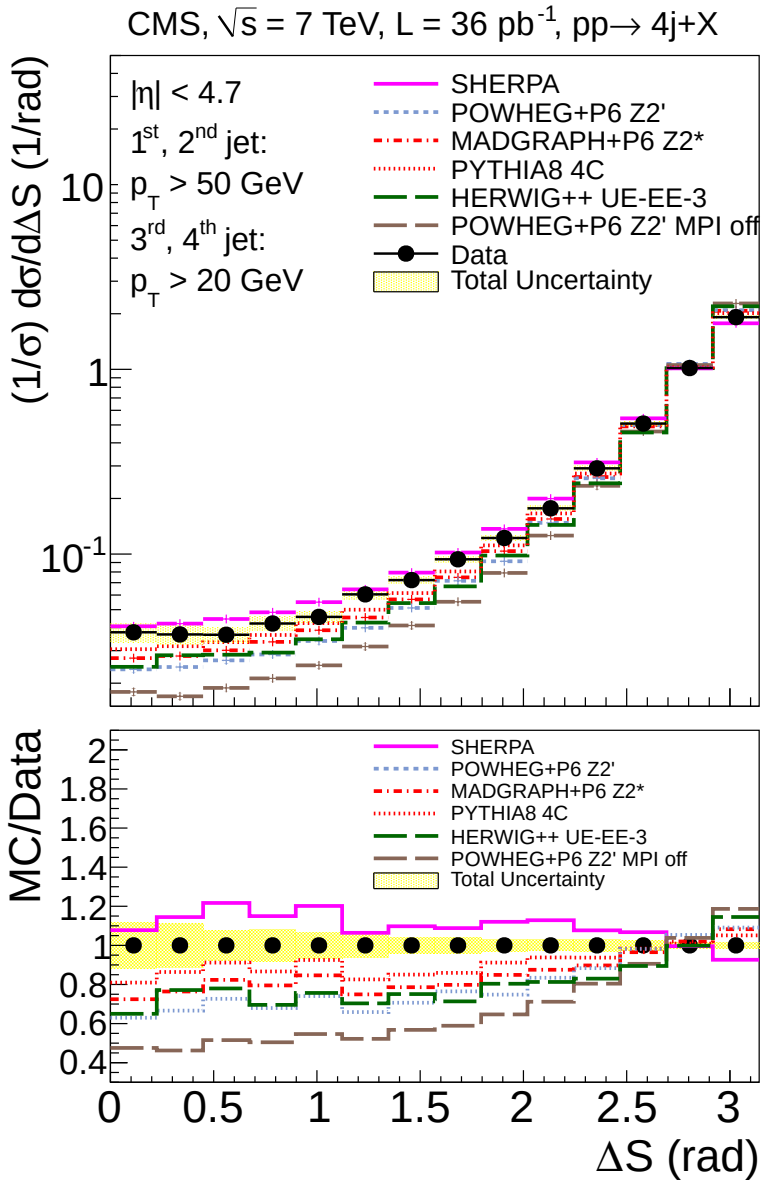
Discriminating power:

→ Different shapes of the two processes

→ Specific regions filled by the two

# Correlation observables: normalized cross sections

Kinematical topology of the jets of the final state in the transverse plane:

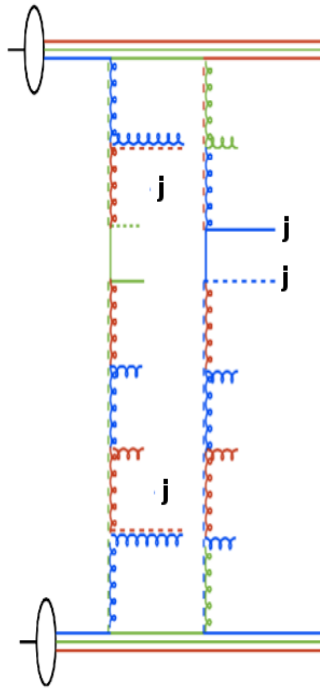



POWHEG w/o MPI is far below for ΔS

ΔS sensitive to MPI contribution:

**ROOM for DPS!**

ΔS (soft,hard)




Soft jets are expected to be produced also by a $2^{nd}$ scattering

Phys. Rev.D 89, 092010 (2014)

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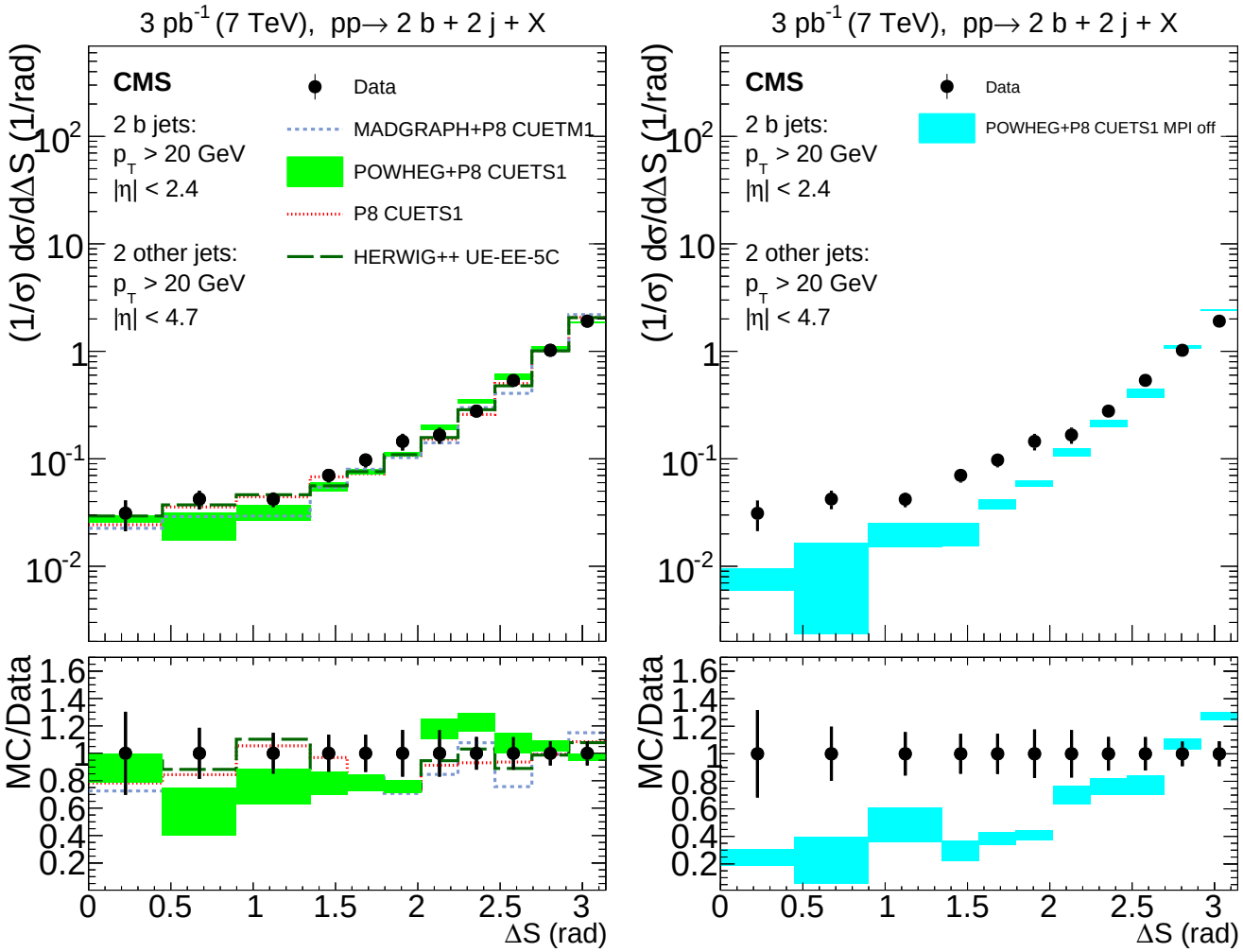
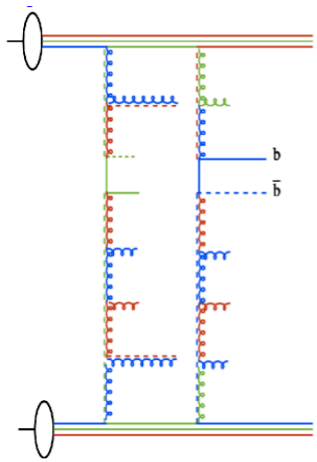



## ΔS (light,bottom)




Light jets are expected to be produced also by a $2^{nd}$ scattering

PRD 94, 112005

- Predictions including MPI follow the trend of the data
- POWHEG w/o MPI is far below for $\Delta S$: ROOM for DPS!

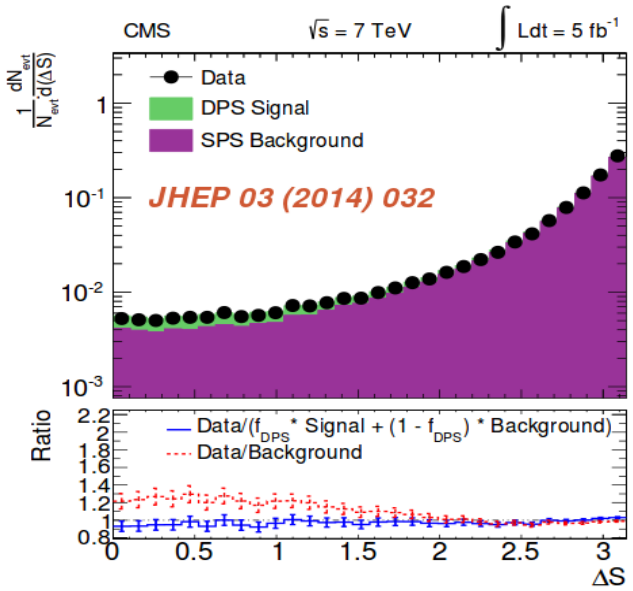
# How to determine the DPS contribution from exp. data?

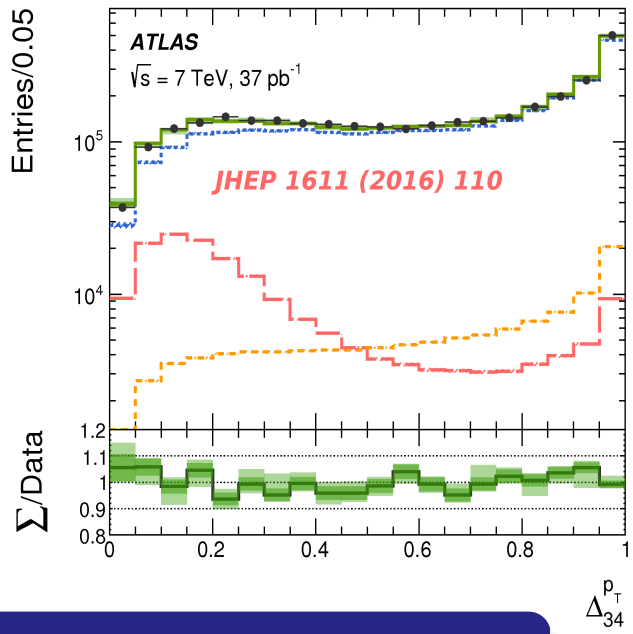
**Used so far...**

TEMPLATE METHOD

Construction of two templates:

SPS background
DPS signal




## Some open issues..

→ Definition of background and signal can be ambiguous
→ MC-dependent background template definition
→ Difficult to define experimentally $\sigma_A$ and $\sigma_B$ in pocket formula
→ Difficult to define partonic cross sections from particle-level ones

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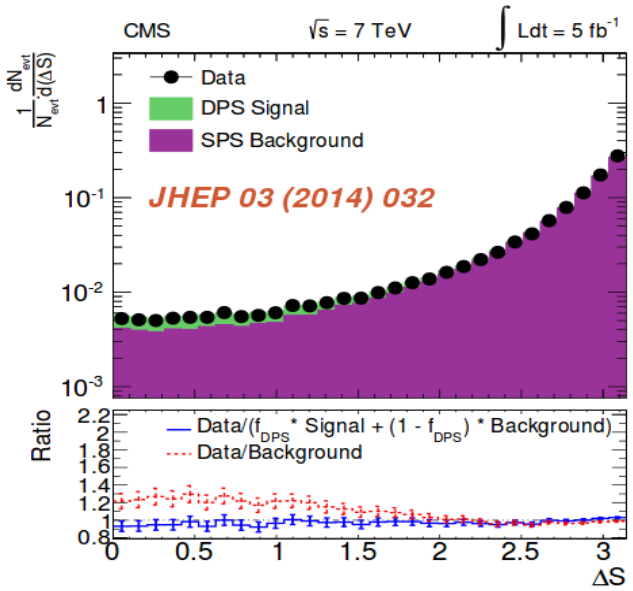


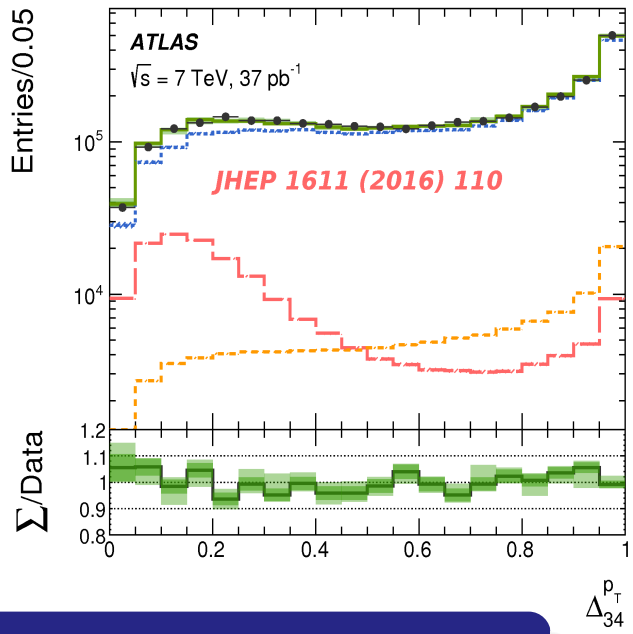


**Some open issues..**

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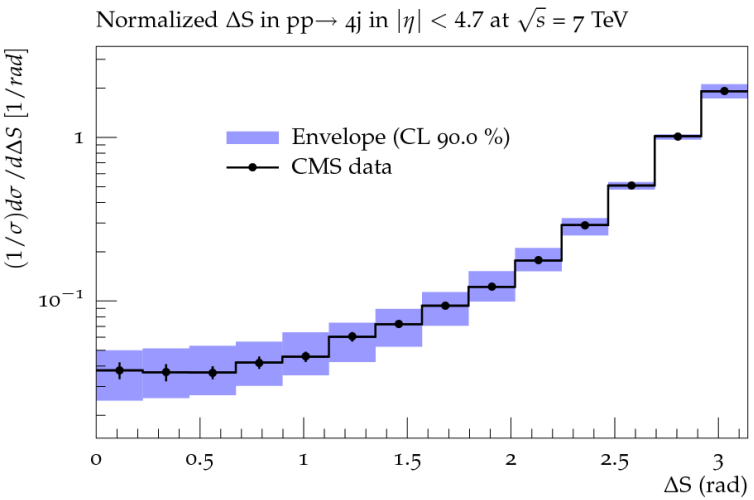
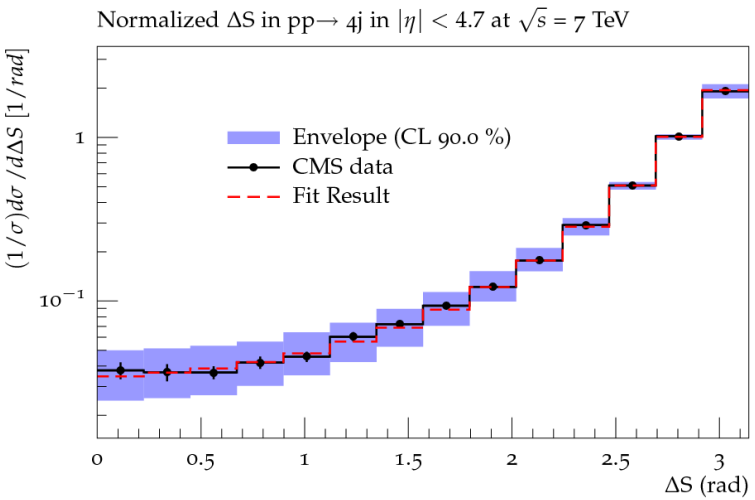
- INCLUSIVE (TUNING) METHOD

# The inclusive method

Automatized generation of predictions with different UE parameters
Inclusive fits of DPS-sensitive observables $O$
Minimization of the binned $\chi^2 = \sum_O \sum_{b \in O} \frac{(MC^b - DATA^b)^2}{\Delta_b^2}$




MINIMIZ.




→ The UE parameters obtained from the best fit define the value of $\sigma_{eff}$

ASSUMPTIONS:

- "Pocket formula"
- Uncorrelated uncertainties from data

PROs:

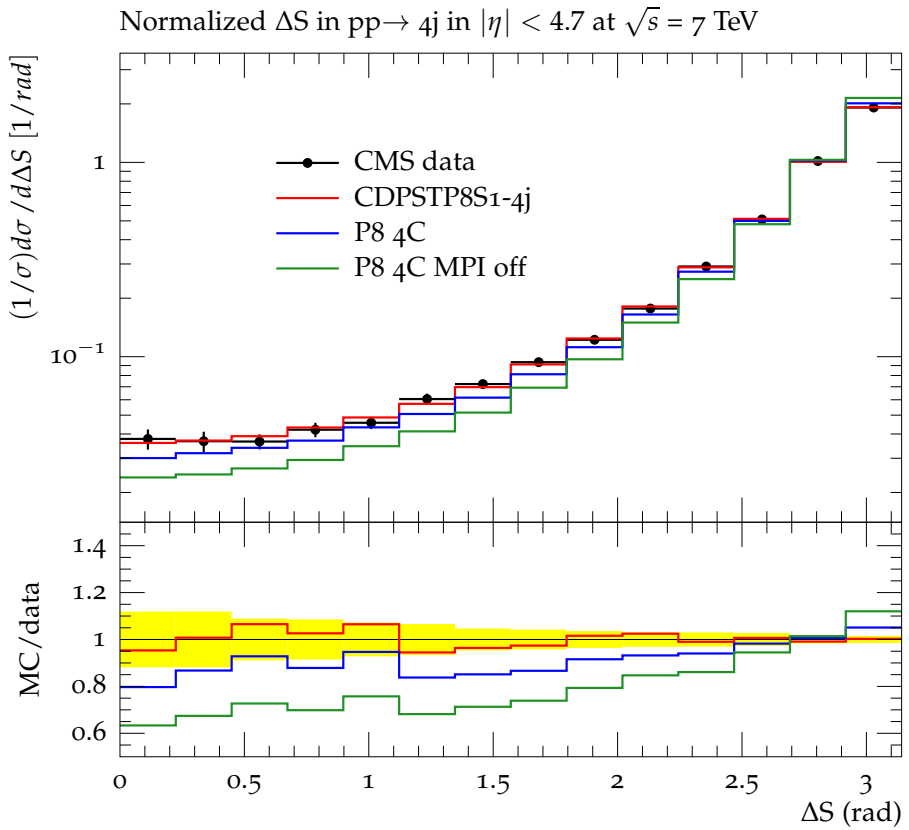
- **No separation between signal and background**
- **Possibility to extract $\sigma_{eff}$ from any model / Monte Carlo generator**

# Determination of $\sigma_{eff}$ in four-jet final states

Fit to the $\Delta S$ correlation observable

MC Generator: PYTHIA 8

| Tune | Goodness of fit | $\sigma_{eff}$ (mb) | |
|---|---|---|---|
| P8 4C | - | 30.3 | ← P8 UE tune |
| CDPSP8S-4j | 0.751 | $19.0^{+4.7}_{-3.0}$ | ← P8 DPS tune |




4C MPI off: bad data description

4C: improved but not optimal agreement

CDPSP8S-4j: very good data description

$\Delta S$ (soft,hard)

EPJC 76 (2016) 155

# Determination of $\sigma_{eff}$ in 2b2j final states

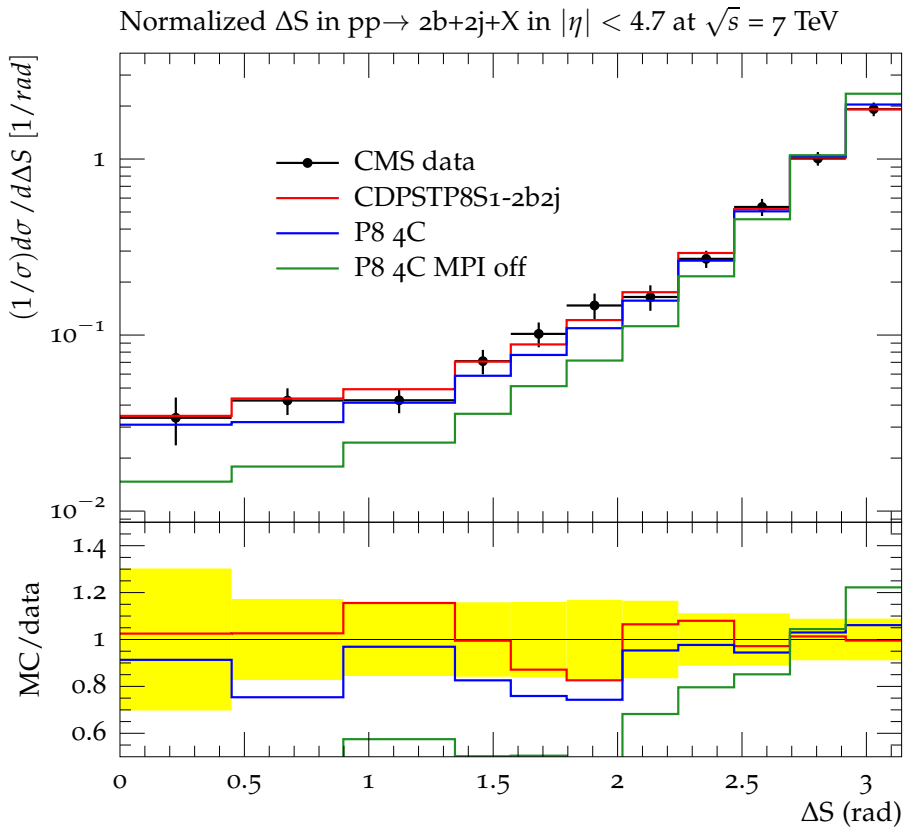
Fit to the $\Delta S$ correlation observable

MC Generator: PYTHIA 8

| Tune | Goodness of fit | $\sigma_{eff}$ (mb) |
|---|---|---|
| P8 4C | - | 30.3 |
| CDPSP8S-2b2j | 0.352 | $23.2^{+3.3}_{-2.5}$ |

← P8 UE tune

← P8 DPS tune




4C MPI off: bad data description

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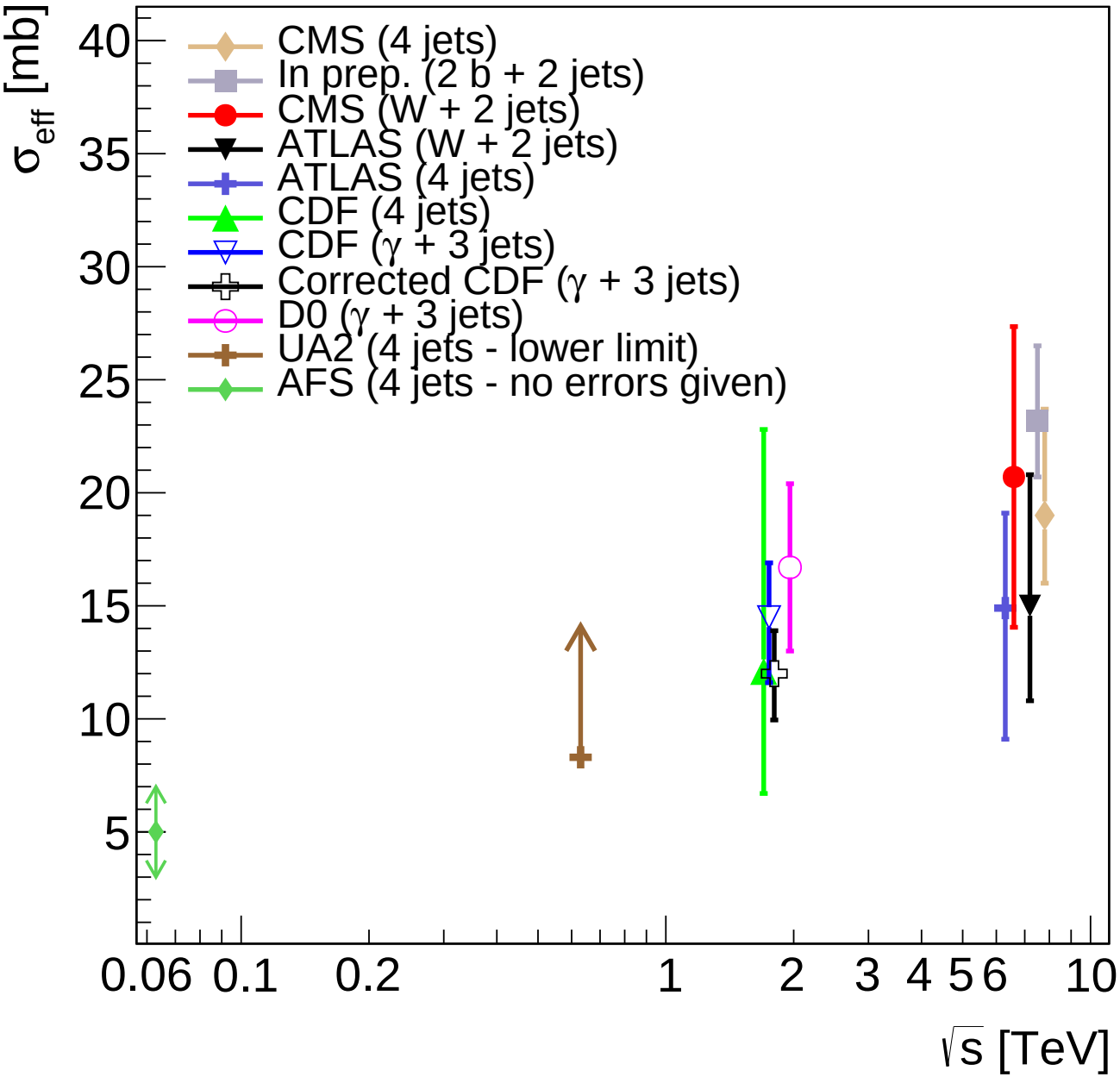
CDPSP8S-2b2j: very good data description

$\Delta S$ (light,bottom)

DESY-THESIS-15-010

# Summary of DPS measurements




**Waiting for values at 13 TeV!**

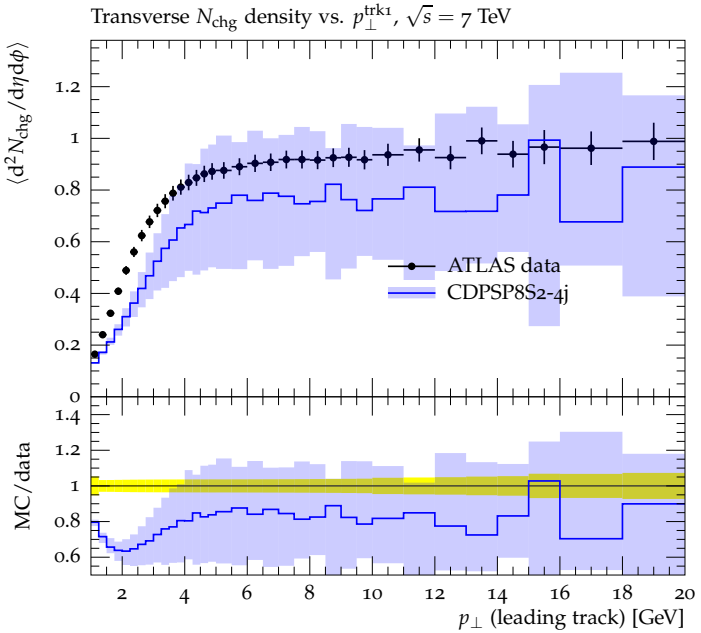
# Are soft and hard MPI described in the same framework?

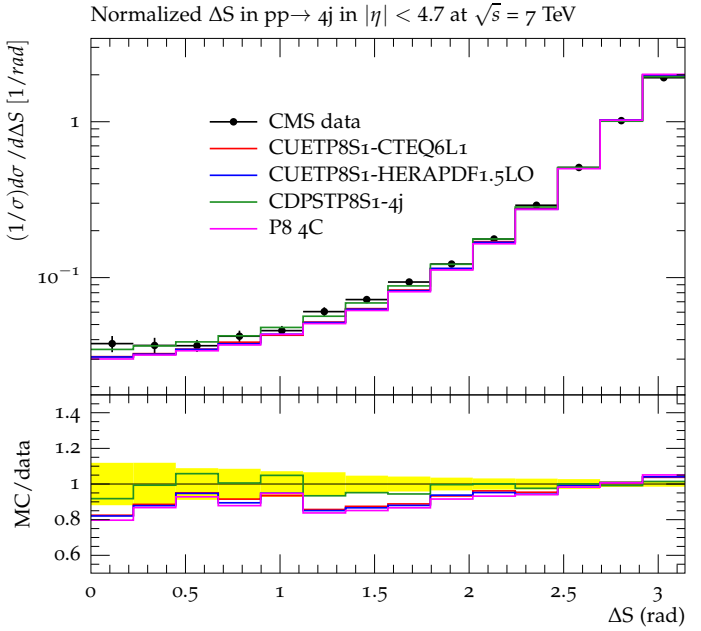
Is the same set of UE parameters able to describe

- UE data
- DPS-sensitive measurements ?

| Tune | $\sigma_{eff}$ (mb) |
|---|---|
| P8 4C | 30.3 |
| P6 Z2* | 33.0 |
| CUETP8S1-CTEQ6L1 | $27.8^{+1.2}_{-1.3}$ |
| CUETP8S1-HERAPDF1.5LO | $29.0^{+2.3}_{-2.0}$ |
| CDPSTP8S-4j | $19.0^{+4.7}_{-3.0}$ |
| CDPSTP8S-2b2j | $23.2^{+3.3}_{-2.5}$ |

Tension between UE-based and DPS-based tunes



# Outlook and prospects

→ **DPS "pocket" formula needs some improvement**

i.e. Parton correlations in initial state

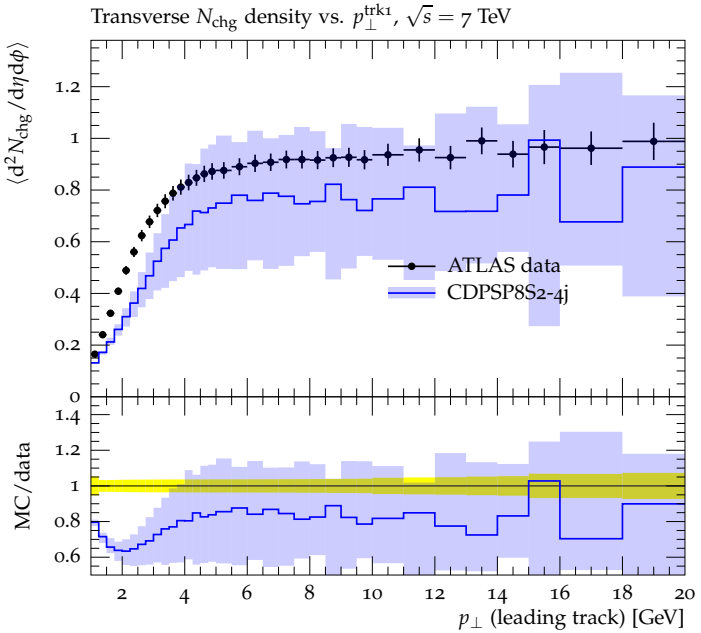
- double/generalized PDF
- "dynamic" value of $\sigma_{eff}$

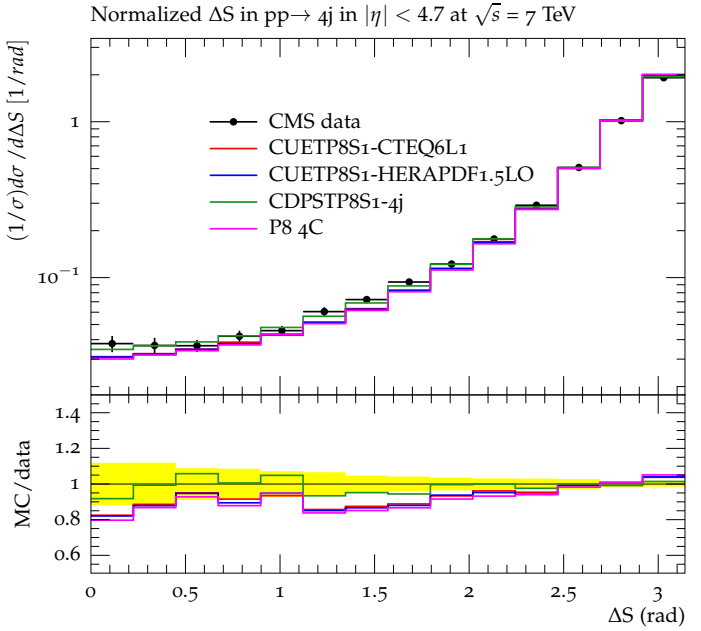
→ **Better understanding of the SPS background**

- $k_T$-factorization scheme

**Further experimental measurements will constrain and refine the various approaches**

**The inclusive method can be used for any experimental measurement**



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**THANKS FOR YOUR ATTENTION**