MPI in Vector Boson plus jet(s) production at the LHC

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Outline

* Introduction
* Recap of V+4j results
* Update on top-antitop
* Z+jets
* Conclusions

What we know, what we would like to know

- MPI well established experimentally eg: γ+3j AFS, UA2, CDF, D0
- Each interaction hard enough to be treated by perturbative QCD
- In first approximation

  $\sigma_{DPI} = \sigma_1 \sigma_2 / \sigma_{eff}$ /k $\sigma_{eff} \approx 14.5$ mb CDF,D0 k=1,2

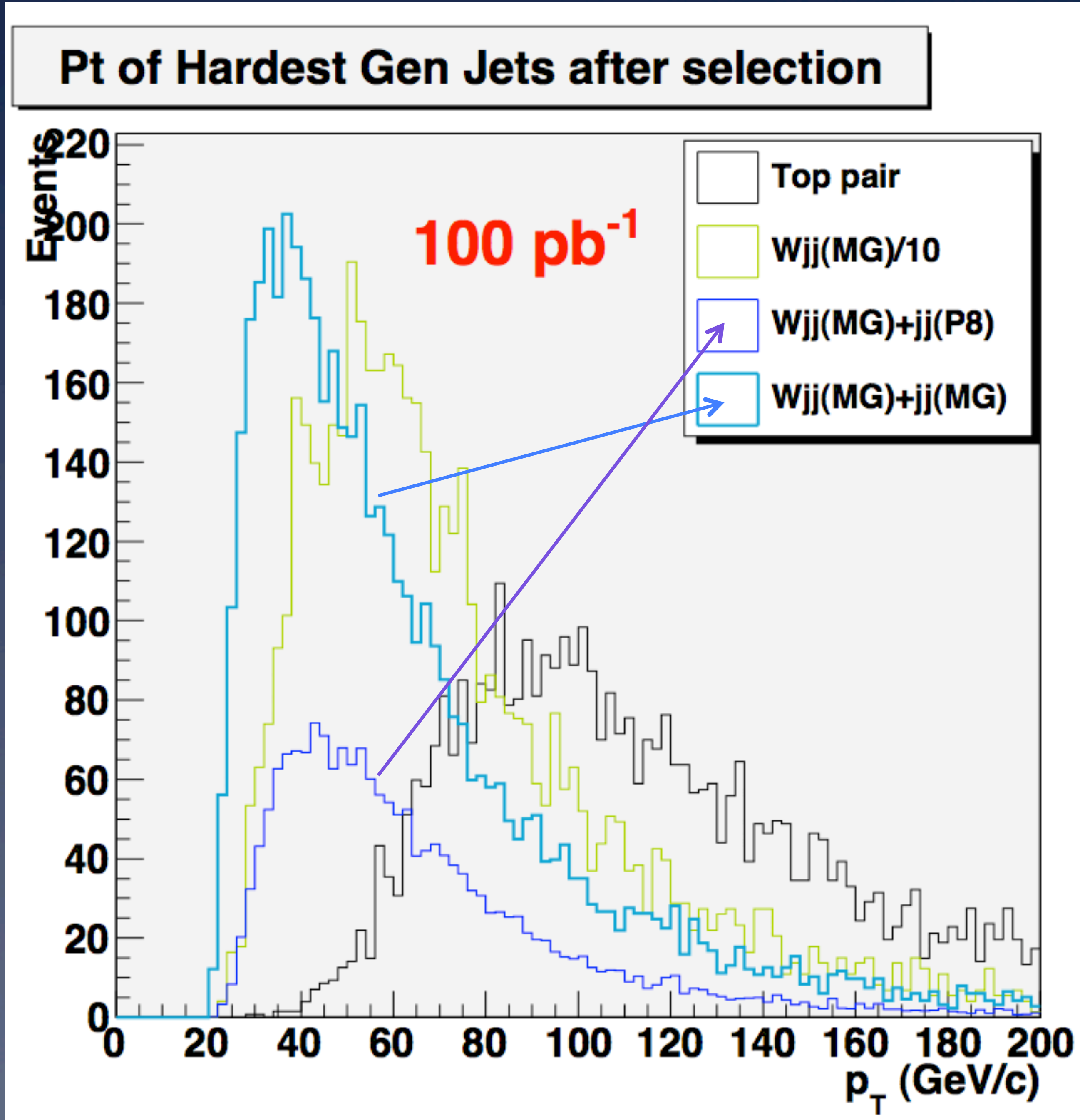
  Treleani argues for $\sigma_{eff} \approx 12$ mb at the LHC

- Pythia/Herwig/Sherpa describe UE in terms of MPI

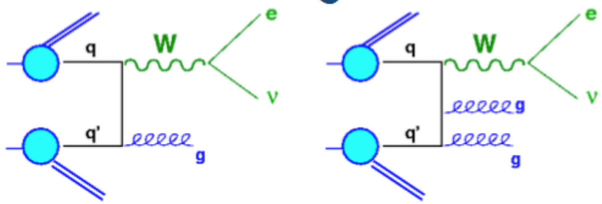
$\sigma_{DPI(Pythia)} = \langle f \rangle \sigma_1 \sigma_2 / \sigma_{ND}$ /k $\sigma_{ND} \approx 51.6$ mb $\langle f \rangle \approx 1.33$ @7TeV

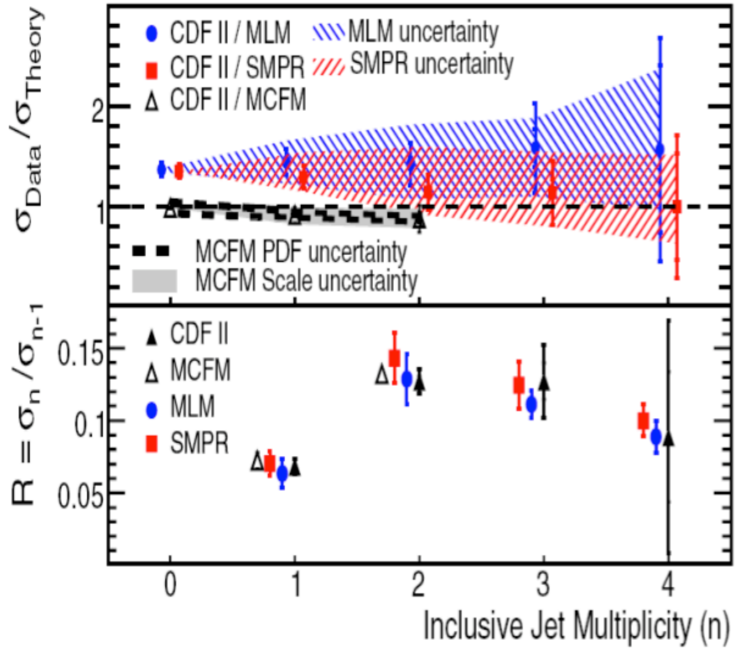
$\sigma_{eff(Pythia)} = \sigma_{ND} / \langle f \rangle \approx 39$ mb

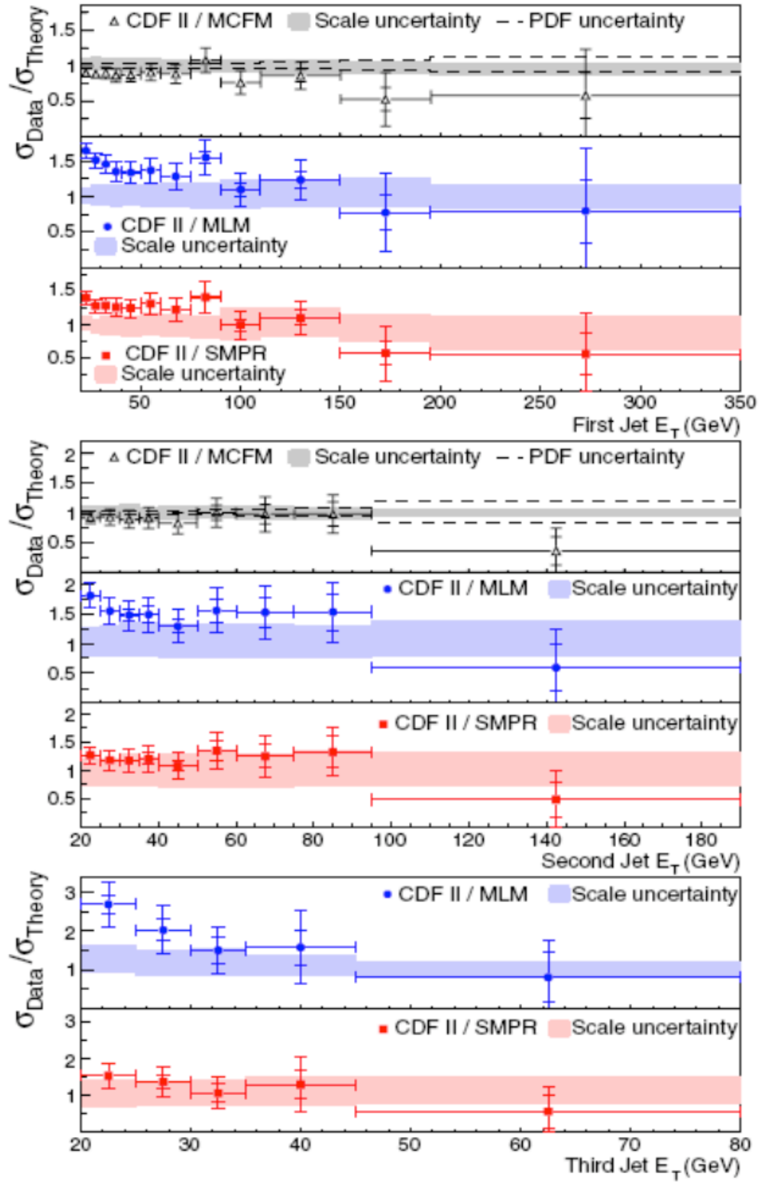
W(lv)+4j
MG=Madgraph LHAF file
P8 =PYTHIA8



W+jet(s)







Good agreement with pQCD NLO calculation

ME+ PS needs UE contributions at low P_T and suffers scale uncertainties at large N_{jet} but describes the σ_N/σ_{N-1} ratios

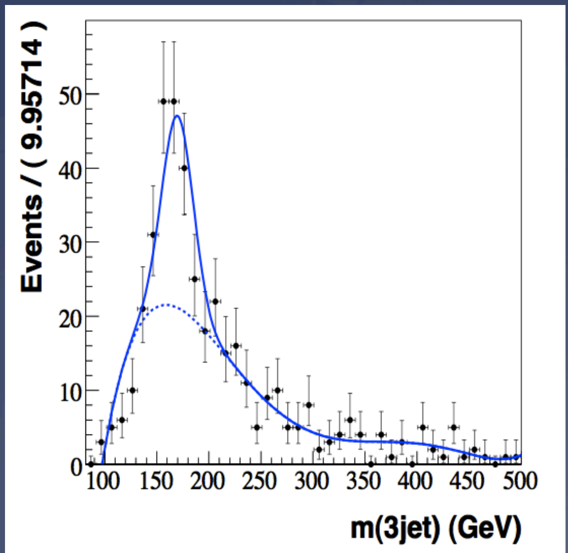
What we know, what we would like to know II

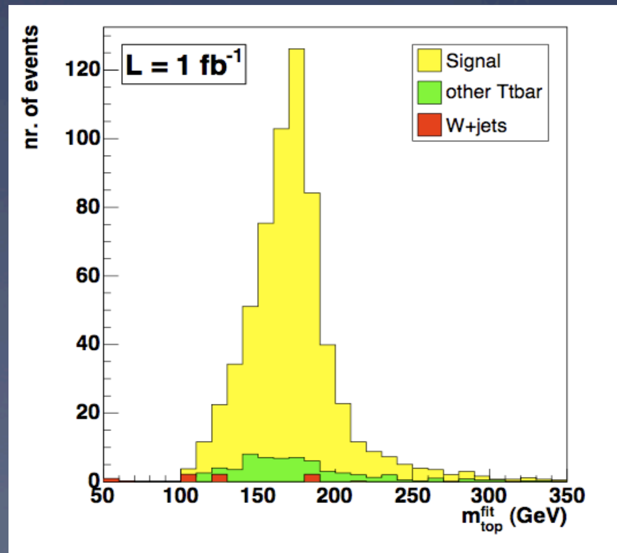
* How serious is the MPI background for interesting physics?
* Which high pT MPI reactions can be studied at the LHC?
* Can we measure Triple Particle Interactions and higher?
* What can be done at 7 TeV and 1 fb^{-1}?

MPI,SPI,DPI,TPI: Multiple,Single,Double,Triple Parton Interactions

t-tbar production: an ideal playground

- Early measurement at the LHC
- M_{top} is a fundamental parameter for the SM
- Best channel: semileptonic lν+4j
- Main background W+4j





$100\ pb^{-1}$ No b-tagging
Reconstruct from mass of jet triplet with largest pT
Main background: W+4j

$1\ fb^{-1}$ b-tagging
Full reconstruction of final state
Main background: misidentification and combinatorics

Method: $\sigma_1 \otimes \sigma_2 \otimes \ldots$

* Generate events for the two processes separately: eg jj, jjW with MadEvent
* Superimpose one event from each sample
* No check on energy conservation (No problem in practice)
* No flavour correlations (Treleani up to 40% reduction)
* No color correlations (irrelevant at generator level)
* Analyze: impose cuts on combined events

V+4j can be produced in MPI as:

$jj \otimes jjV$

$jjj \otimes jV$

$jjjj \otimes V$

$jj \otimes jj \otimes V$

$W \to \mu\nu$

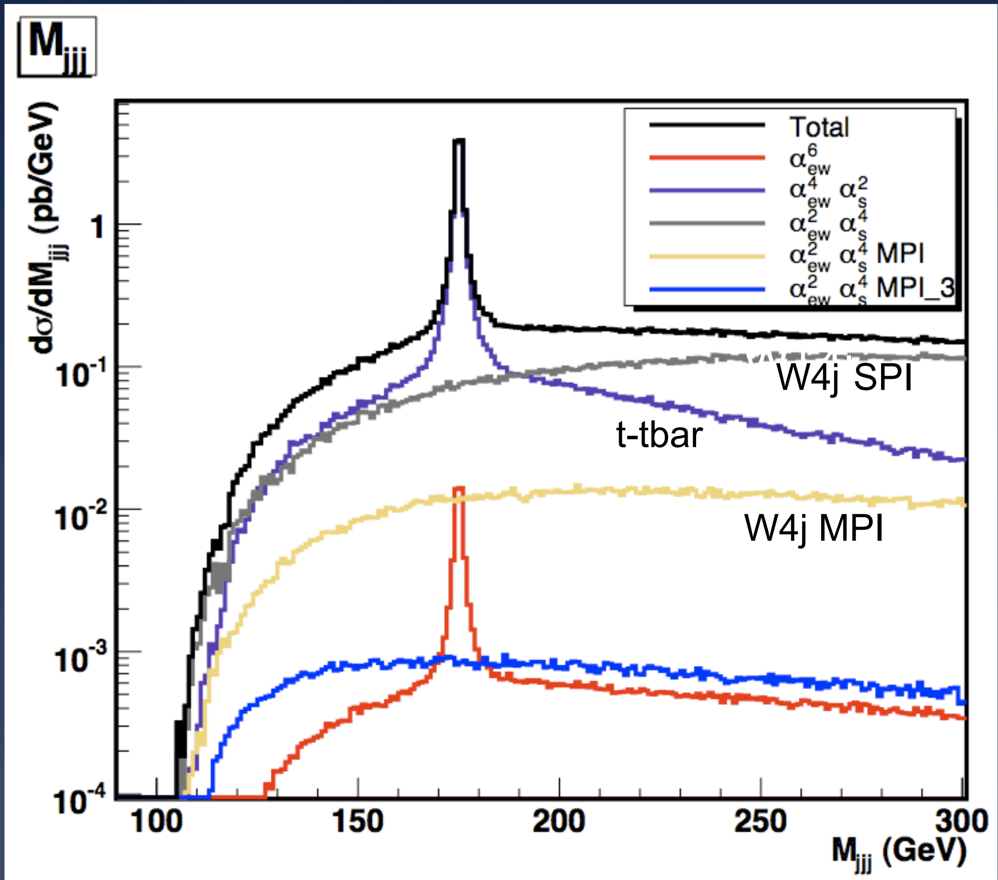
$Z \to \mu\mu$

JHEP04(2009) 098 W4j

JHEP09(2009) 081 Z4j

5 final state partons
allows Triple Parton Int.'s

Single Parton Interactions: PHANTOM & MadEvent



M_{top} = 175 GeV σ_{eff}=14.5 mb

M_{jjj} = mass of jet triplet with max pT

W → μν only

Process	Cross section
$\mathcal{O}(\alpha_{EM}^4\alpha_S^2)$	10.8 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$	0.76 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$DPI	0.12 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$TPI	0.01 pb
$\mathcal{O}(\alpha_{EM}^6)$	0.04 pb

170 GeV < M_{jjj} < 180 GeV

W+4j /tt ≈ 7% MPI/tt ≈ 1%

Not a problem for mass measurement. Cross section?
Negligible when b-tagging available

A bit more realistic…

R. Chierici, E.M. - LesHouches09
in arXiv:1003.1643

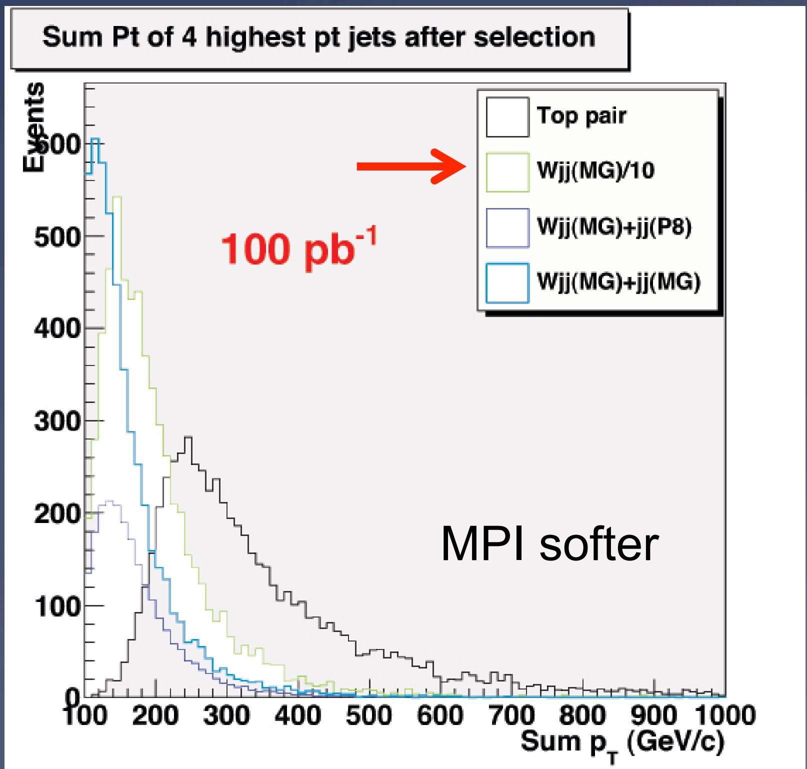
10 TeV

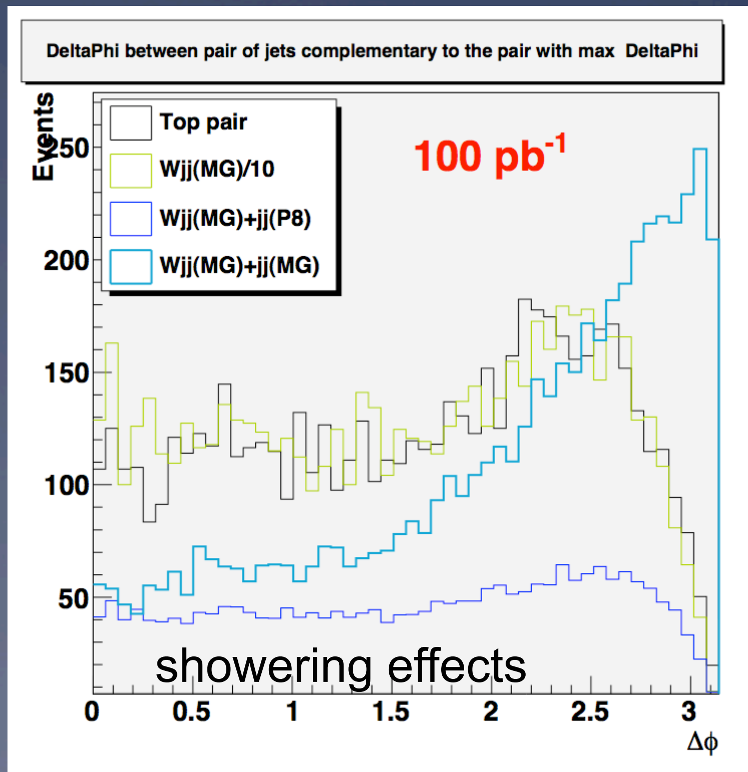
Used Pythia8 to generate t-tbar, Wj⊗jj, Wjj(MG)⊗jj, b-bbar⊗jj, b-bbar(MG)j⊗jj
with showering and and jet clustering

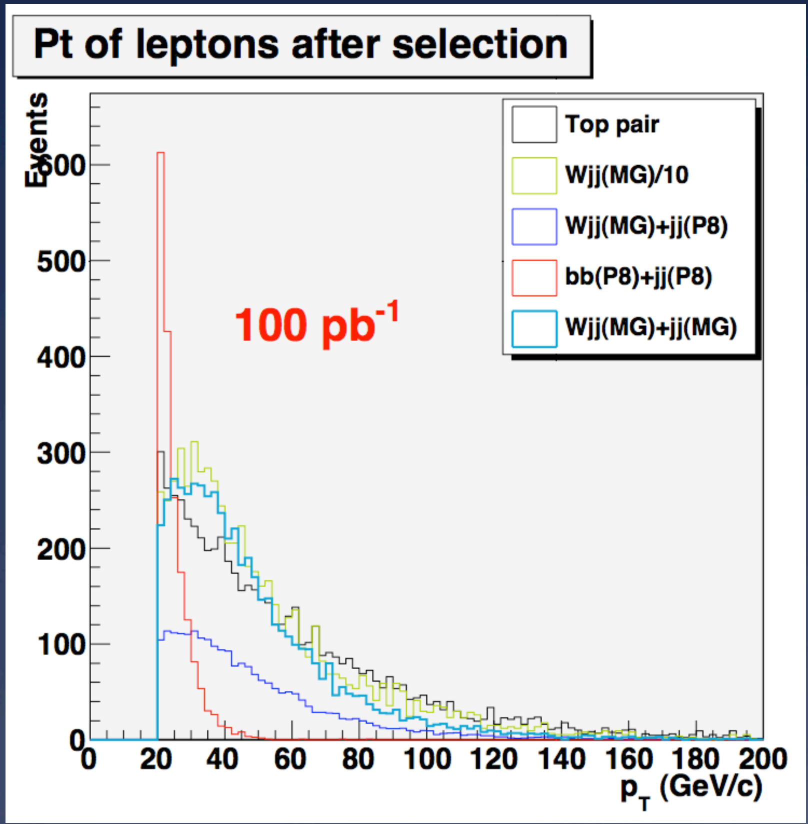
Require isolated, central and energetic lepton

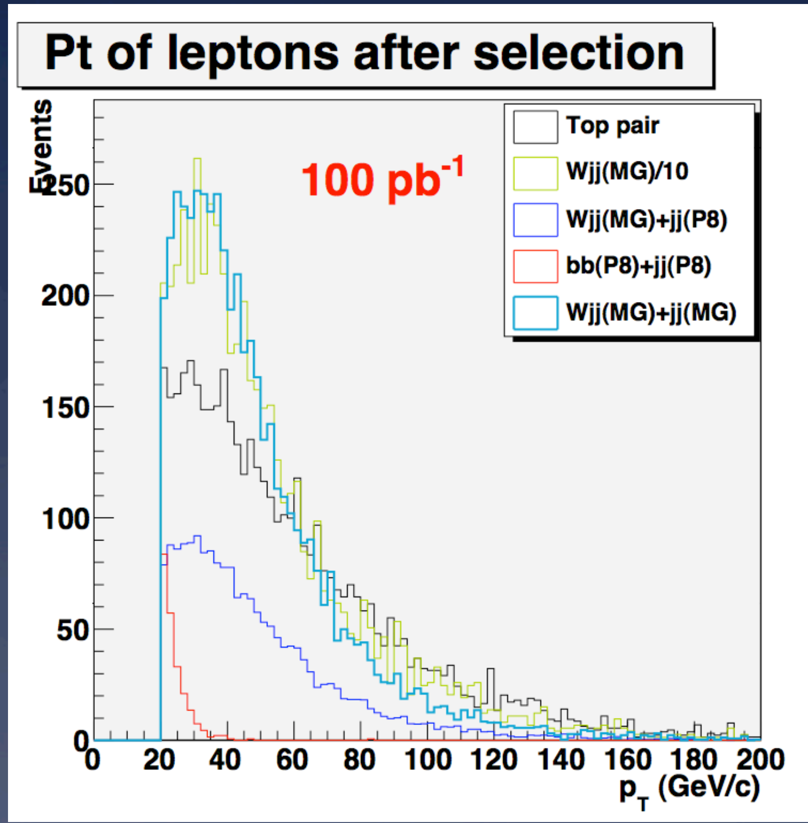
$$p_{T_l} \geq 20 \text{ GeV}, \quad |\eta_l| \leq 2.5, \quad E_{iso} \leq 20 \text{ GeV}$$

ΔR=0.1









$\Delta R=0.1$ $\Delta R=0.5$

Lepton isolation cut kills bb-bar background

Cuts which eliminate Wjj+shower can deal with MPI too!

Looking for MPI in lν+4j

Basic cuts $\Delta R(jj) > 0.5 \quad \Delta R(jl^{\pm}) > 0.5$

Process	Cross section	Cross section
$\mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$	25.0 pb	22.0 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)$	64.7 pb	58.9 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{DPI}}$	5.6 pb	5.3 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{TPI}}$	0.27 pb	0.26 pb
$\mathcal{O}(\alpha_{EM}^6)$	0.22 pb	0.20 pb

* Get rid of t-tbar

  $|M_{jjj}-M_t|>10$ GeV

* MPI gives larger separation

  of forward/backward jets

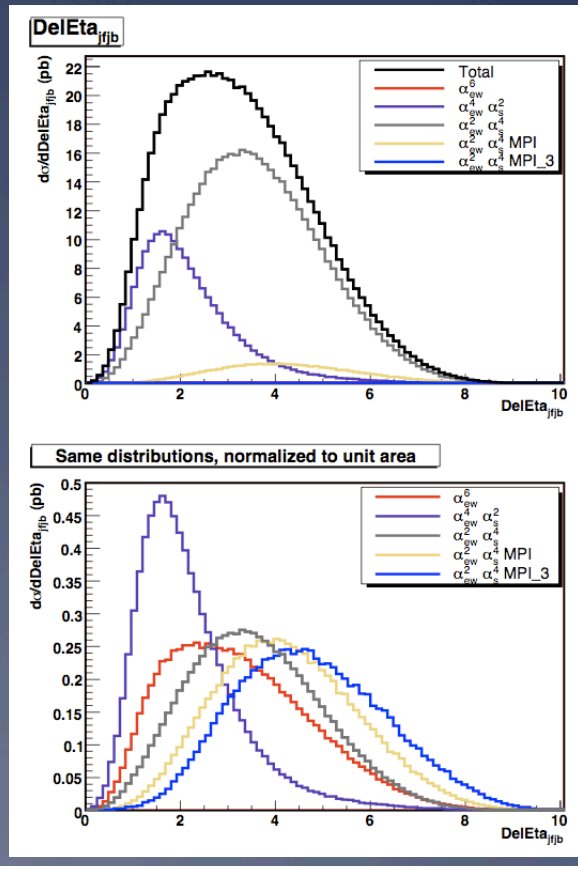
  $|\Delta\eta(j_f j_b)|>3.8$ $\sigma_{eff}=14.5$ mb

Process	Cross section
$\mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$	1.16 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)$	24.01 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{DPI}}$	2.91 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{TPI}}$	0.16 pb
$\mathcal{O}(\alpha_{EM}^6)$	0.05 pb

Dominated by jj⊗Wjj

$S/B^{1/2}$ = 5.8(6.1)
$L=100\ pb^{-1}$

MPI/4jW=1/8



Triple Parton Interactions: so far unobserved

Two jet pairs back to back in the transverse plane

DY W with “zero” pT (also in DPI: less effective)

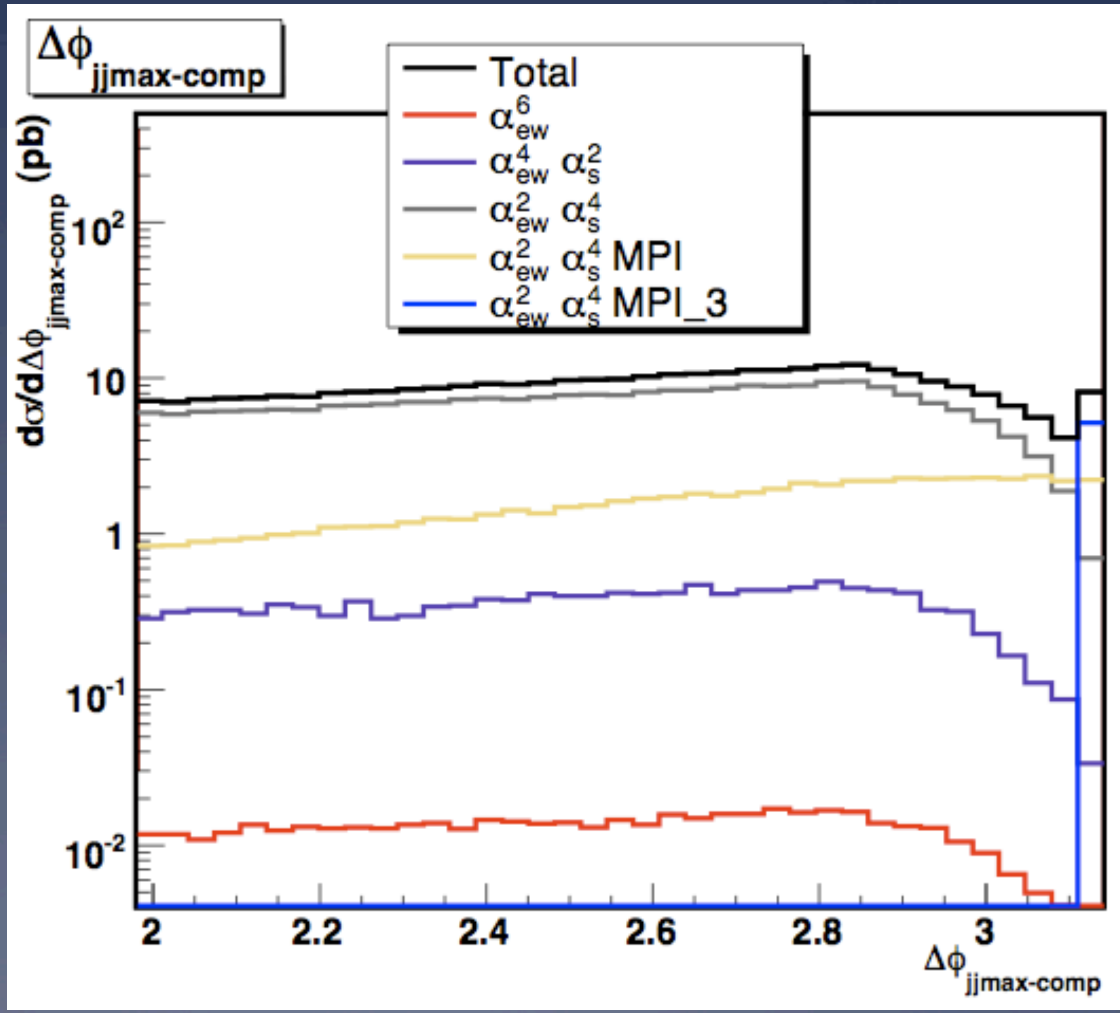
$\sigma_{TPI} = \sigma_1 \sigma_2 \sigma_3 / \sigma_{eff}^{\ 2} / k$

Process	Cross section
$\mathcal{O}(\alpha_{EM}^4 \alpha_S^2)$	0.75 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)$	15.61 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{DPI}}$	2.61 pb
$\mathcal{O}(\alpha_{EM}^2 \alpha_S^4)_{\mathrm{TPI}}$	0.16 pb
$\mathcal{O}(\alpha_{EM}^6)$	0.03 pb

$$|\Delta\phi(jj)_{\mathrm{max}}| > 0.9 \cdot \pi$$

TPI/DPI/Bkg
1 / 16 /100

16k events for L=10 fb^{-1}
TPI more than 50% of last bin: 2 deg.



Looking for MPI in $Z(l^+l^-)+4j$

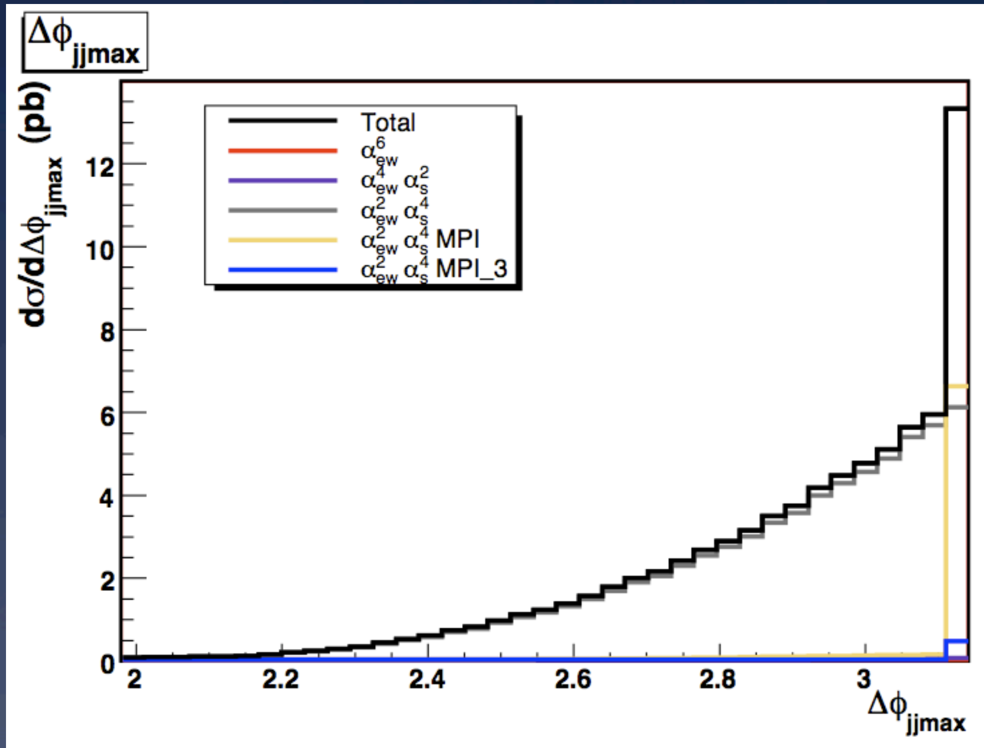
$$p_{T_j} \geq 30 \text{ GeV}\,, \quad |\eta_j| \leq 5.0\,,$$

$$p_{T_\ell} \geq 20 \text{ GeV}\,, \quad |\eta_\ell| \leq 3.0\,,$$

$$M_{jj} \geq 60 \text{ GeV}\,, \quad M_{ll} \geq 20 \text{ GeV}$$

$$\Delta R(jj) > 0.5 \qquad \Delta R(jl^\pm) > 0.5$$

$$|\Delta\eta(j_f j_b)| > 3.8$$



Process	Basic Cross section	iso Cross section	$\Delta\eta(j_f j_b)$ Cross section
$\mathcal{O}(\alpha_{EM}^4\alpha_S^2)$	106.6 fb	87.7 fb	26.3 fb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$	6404.67 fb	5626.6 fb	2209.7 fb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\text{DPI}}$	515.5 fb	469.1 fb	272.7 fb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\text{TPI}}$	23.2 fb	21.4 fb	15.1 fb
$\mathcal{O}(\alpha_{EM}^6)$	16.5 fb	13.9 fb	7.6 fb

σ_{eff}=14.5 mb

$S/B^{1/2}$ = 5.8(6.1)
L=1 fb^{-1}

MPI/4jZ=1/8

PDF's Correlations

- Factorization ansatz for dPDF's is violated by dGLAP evolution
- Gaunt&Stirling has provided a set of correlated DPDF's which satisfy flavour and number sum rules. Based on the MSTW2008 set. Allows two different scales for the two interactions.

What can be done with 1 fb^{-1} or less @ 7 TeV ?

Method: reweighting

- Two sets of unweighted events generated independently with Madgraph using CTEQ6 PDF's
- Reweight e.g. $(q_i\bar{q}_i \to gl^+l^-) \otimes (gg \to gg)$ with

$$R = \frac{F_i^{MRST}(t_1)F_{\bar{i}}^{MRST}(t_1)}{F_i^{CTEQ}(t_1)F_{\bar{i}}^{CTEQ}(t_1)} \times \frac{\alpha_s^{MRST}(t_1)}{\alpha_s^{CTEQ}(t_1)} \times \frac{F_g^{MRST}(t_2)F_g^{MRST}(t_2)}{F_g^{CTEQ}(t_2)F_g^{CTEQ}(t_2)} \times \frac{\alpha_s^{MRST}(t_2)^2}{\alpha_s^{CTEQ}(t_2)^2}$$

- Produce combined sample of weighted events. Error could be an issue
- As a byproduct estimate sensitivity to PDF choice

Z+n-jets n=2,3,4 $Z \to l^+ l^-$

- Large cross section ~ pb
- Simplest case has only two jets (γ+jets needs three)
- Easily identifyable final state. Stringent cuts on lept iso not needed

  Heavy quark decay not a problem
- Conclusions valid also for W+n-jets with × 10 σ → $S/B^{1/2}$ 3 times

  larger
- If Pythia is right $S/B^{1/2}$ 1.7 times smaller

$$p_{T_j} \geq 30 \text{ GeV}, \quad |\eta_j| \leq 5.0,$$
$$p_{T_\ell} \geq 20 \text{ GeV}, \quad |\eta_\ell| \leq 2.5,$$
$$\Delta R_{jj} \geq 0.1, \quad \Delta R_{jl} \geq 0.1$$

Z+2-jets

$\Delta R_{jj}=0.5$ $\sigma_{eff}=12$ mb

in pb	14 TeV			10 TeV			7 TeV		
Process	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09
SPI	52.65	60.70		30.63	35.15		16.56	18.88	
DPI	11.27	13.80	15.08	4.80	5.86	6.30	1.88	2.28	2.40

SPI : 15% increase CTEQ6L1 → MSTW2008LO
DPI : 20% increase CTEQ6L1 → MSTW2008LO
$\alpha_s(MZ)_{CTEQ}=0.130$ $\alpha_s(MZ)_{MSTW}=0.139$

$Q^2=\sum p_T^2$ larger in SPI
$Q^2=M_Z^2$ for DY

10% increase MSTW2008LO → GS09

initial state qg

DPI_{GS}/SPI_{MSTW} = 0.25, 0.18, 0.13 @ 14, 10, 7 TeV

$S/B^{1/2}$ = 19, 10, 5.5 for $L=100$ pb^{-1}

Z+3-jets

DPI_{GS}/SPI_{MSTW} = 0.19, 0.13, 0.09 @ 14, 10, 7 TeV

S/B ½ = 26, 13, 6 for L=1 fb^{-1}

ΔR_{jj}=0.5 σ_{eff}=12 mb

in pb	14 TeV			10 TeV			7 TeV		
Process	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09
SPI	15.71	19.10		8.46	10.23		4.11	4.93	
DPI	2.70	3.41	3.62	1.02	1.28	1.32	0.34	0.43	0.43

Z+4-jets

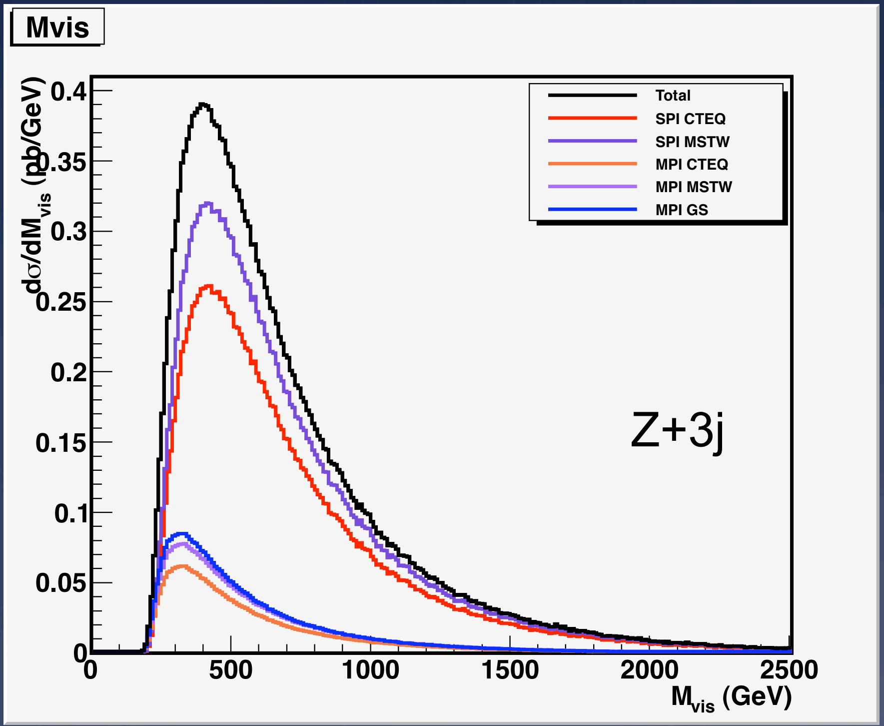
DPI_{GS}/SPI_{MSTW} = 0.24, 0.17, 0.12 @ 14, 10, 7 TeV

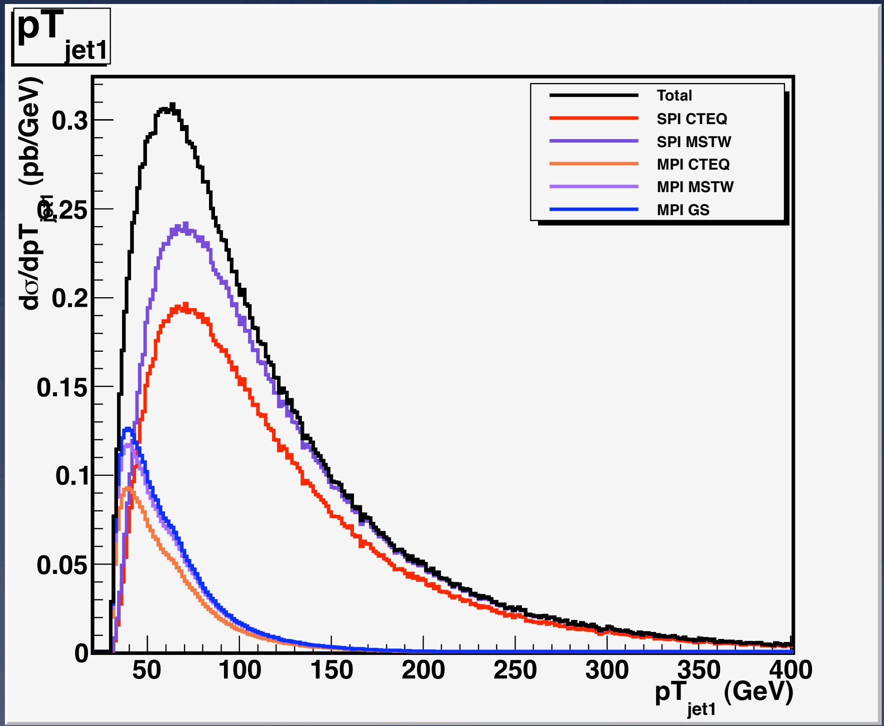
S/B ½ = 18, 8, 3.7 for L=1 fb^{-1}

ΔR_{jj}=0.5

in pb	14 TeV			10 TeV			7 TeV		
Process	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09	CTEQ	MSTW	GS09
SPI	4.26	5.41		2.00	2.53		0.83	1.04	
DPI	0.96	1.28	1.30	0.33	0.43	0.42	0.10	0.13	0.12

S/B ½ is fine but a counting experiment is not such a good idea





SPI contribution can be measured at large jet pT
V+3j available at NLO. V+4j first results YESTERDAY **arXiv:1009.2338**.

Other kinematical variables are available.

Conclusions

- MPI do represent a significant background to high pT processes at the LHC
- A large number of high PT reaction which are sensitive to MPI can be measured at the LHC
- Correlation effects are not large
- Discrepancy in normalization between PYTHIA and D0/CDF should be fixed asap by new measurements
- V+jets are good candidates already @ 7 TeV and 1 fb^{-1}