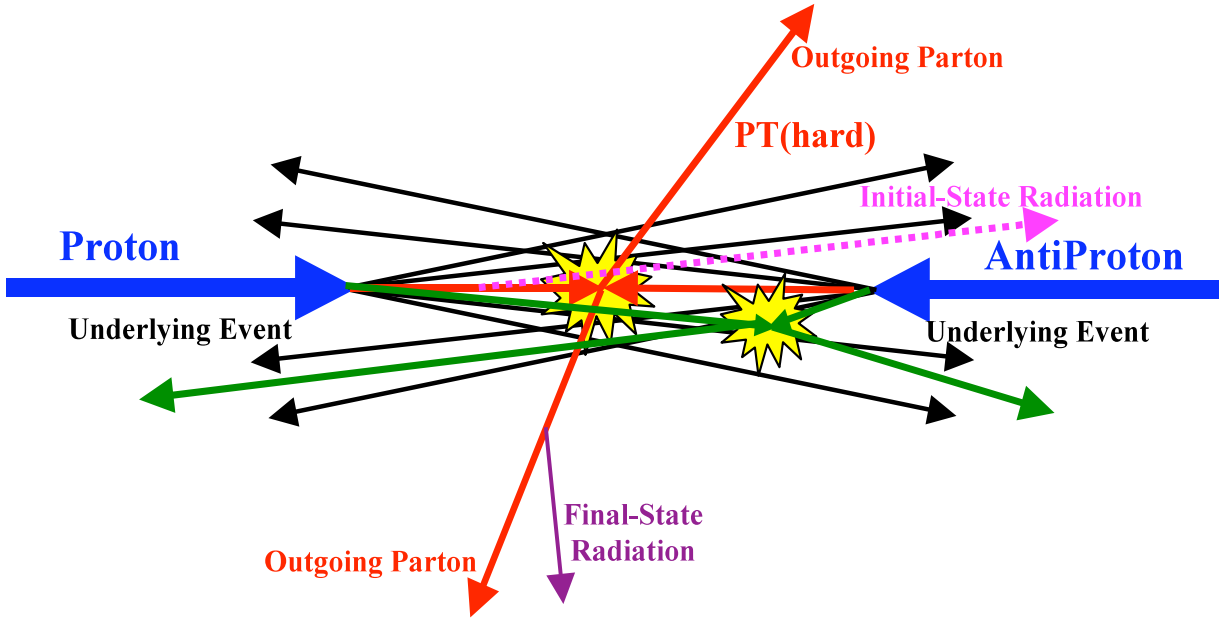
Multiple Parton Interactions, top-antitop, W+4j and Z+4j production at the LHC



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Facts and questions

- MPI established experimentally eg: γ+3j AFS, UA2, CDF, D0
- Each interaction hard enough to be treated by perturbative QCD
- $\sigma_{DPI} = \sigma_1 \sigma_2 / \sigma_{eff} / k$ $\sigma_{eff} \approx 14.5$ mb CDF $k=1,2$
- $\sigma_{TPI} = \sigma_1 \sigma_2 \sigma_3 / \sigma'^2_{eff} / k$ $\sigma'_{eff} = \sigma_{eff}$?

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

- Can MPI be a background to interesting physics ?
- Can MPI be studied in more complex environment than $2 \to 2 \otimes 2 \to 2$?

Flavour dependence, x-dependence

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

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 (trivial to add)
- No flavour correlations (Treleani up to 40% reduction)
- No color correlations (irrelevant at generator level)
- Analyze: impose cuts on combined events

lν+4j can be produced in MPI as:

jj⊗jjW
jjj⊗jW
jjjj⊗W
jj⊗jj⊗W

W→μν only

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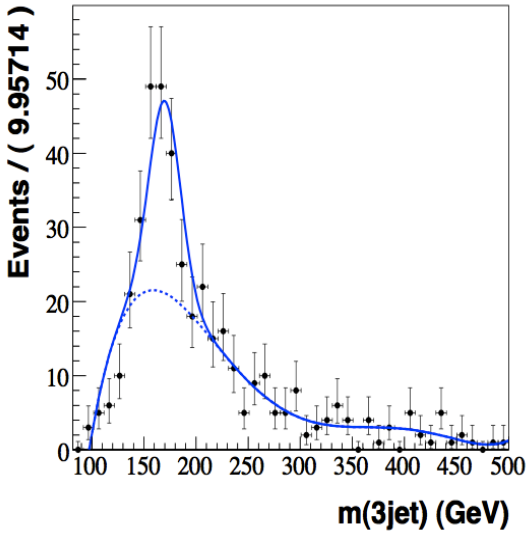
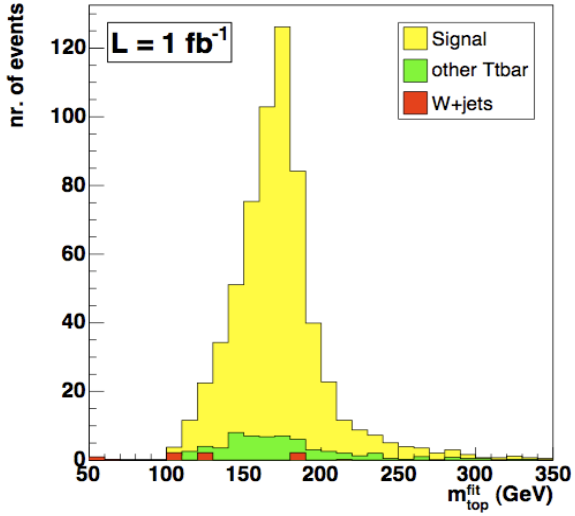
+ Z4j unpublished

Single Parton Interactions: PHANTOM & MadEvent

t-tbar production: an ideal playground

- Early measurement at the LHC
- M_{top} is a fundamental parameter for the SM
- Best channel: semileptonic lv+4j
- Main background W+4j: 5 body final state



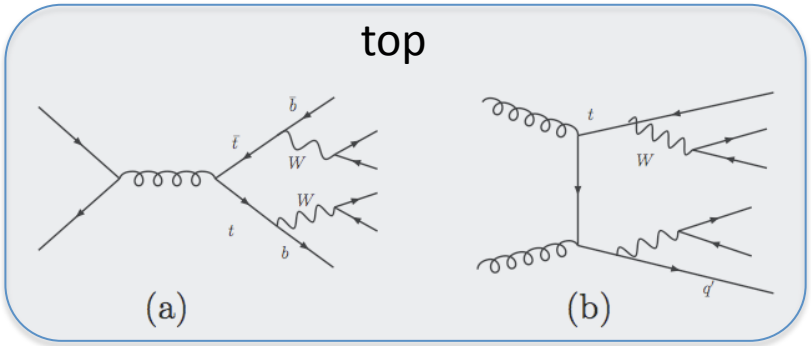


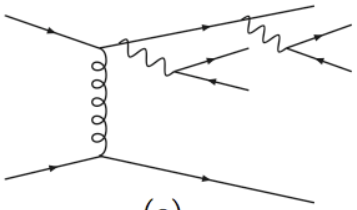
100 pb^{-1} No b-tagging
Reconstruct from mass of jet triplet with largest pT
Main background: W+4j

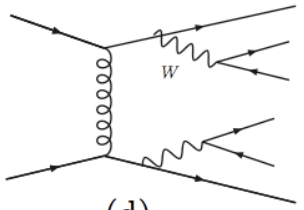
1 fb^{-1} b-tagging
Full reconstruction of final state
Main background: misidentification and combinatorics

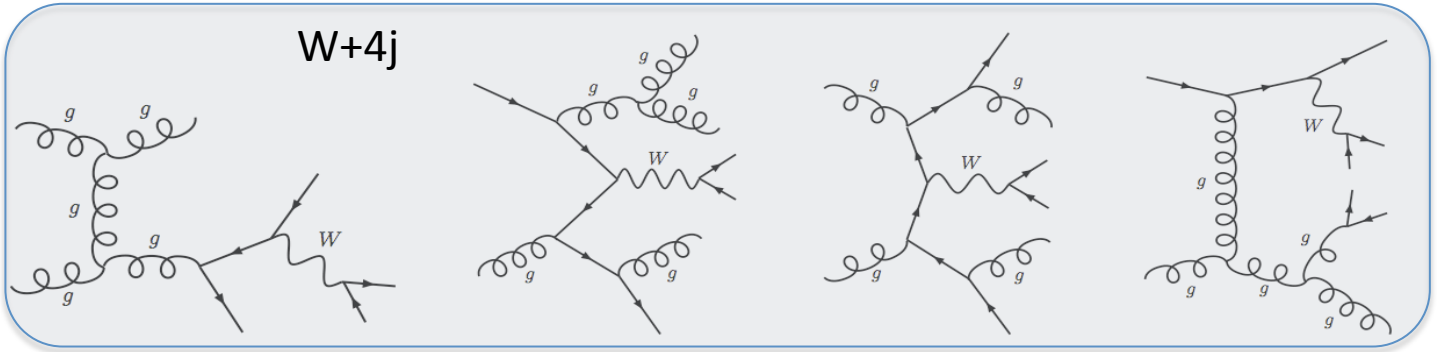
$\alpha^4 \alpha_s^2$

Three perturbative orders contribute to 4j+lv

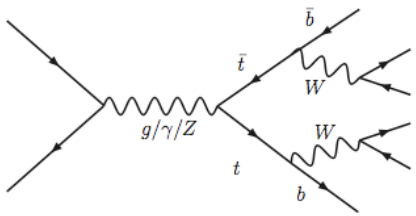


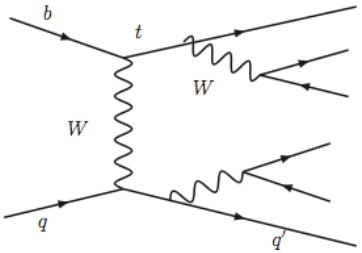






$\alpha^2 \alpha_s^4$





α^6

$$p_{T_j} \geq 30\ \text{GeV}\,, \quad |\eta_j| \leq 5.0\,,$$
$$p_{T_\ell} \geq 20\ \text{GeV}\,, \quad |\eta_\ell| \leq 3.0\,,$$
$$M_{jj} \geq 60\,\text{GeV}$$

generation cuts

LHC luminosity:
Low 30 fb^{-1}/year
High 100 fb^{-1}/year
Total 300 fb^{-1}/year

MPI

Process	Cross section	Combined
jj	1.44e8 pb	4.03 pb
$jj(\mu^-\bar{\nu}_\mu + \mu^+\nu_\mu)$	6.54e2 pb	
jjj	7.64e6 pb	0.68 pb
$j(\mu^-\bar{\nu}_\mu + \mu^+\nu_\mu)$	1.82e3 pb	
$jjjj$	1.16e6 pb	0.88 pb
$\mu^-\bar{\nu}_\mu + \mu^+\nu_\mu$	1.09e4 pb	

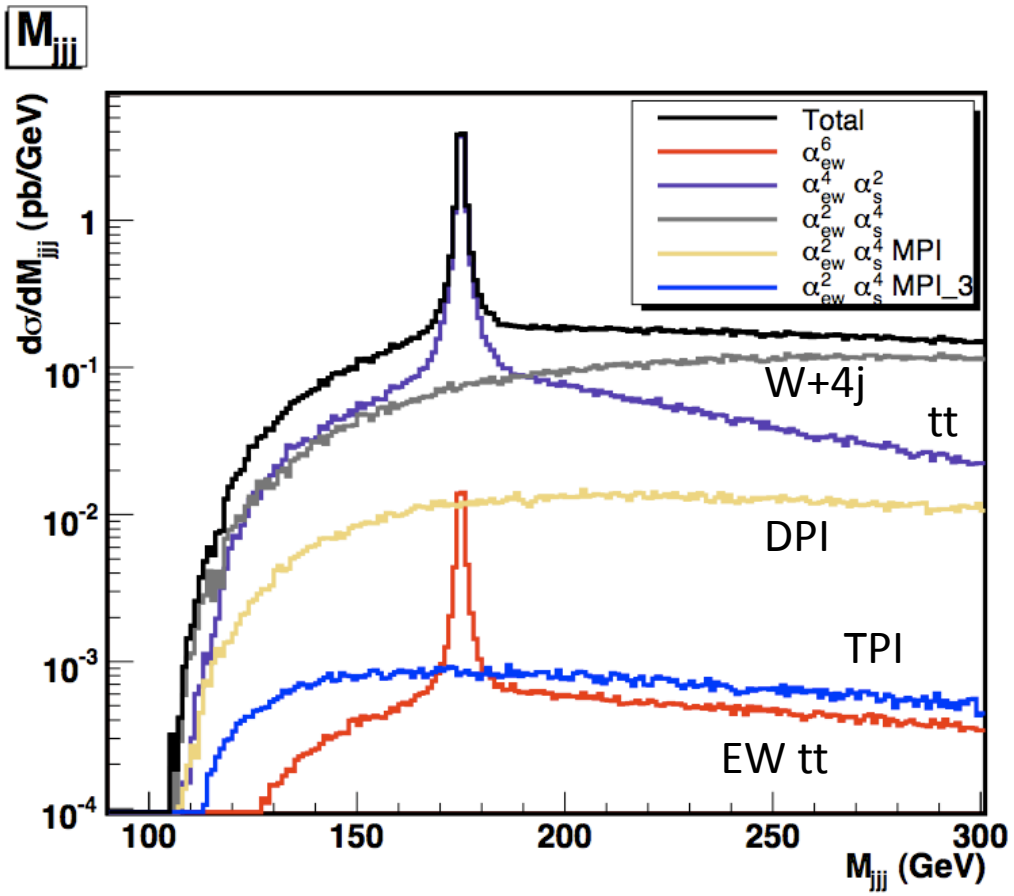
Process	Cross section	Combined
jj	1.44e8 pb	0.27 pb
jj	1.44e8 pb	
$\mu^-\bar{\nu}_\mu + \mu^+\nu_\mu$	1.09e4 pb	

$\sigma < \sigma_1\,\sigma_2\,/\,\sigma_{eff}$

Process	Cross section	Cross section	
$\mathcal{O}(\alpha_{EM}^4\alpha_S^2)$	25.0 pb	22.0 pb	t-tbar
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$	64.7 pb	58.9 pb	W+4j
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\text{DPI}}$	5.6 pb	5.3 pb	DPI
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\text{TPI}}$	0.27 pb	0.26 pb	TPI
$\mathcal{O}(\alpha_{EM}^6)$	0.22 pb	0.20 pb	EW negligible

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

Isolation cuts



M_{top} = 175 GeV

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
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{DPI}}$	0.12 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{TPI}}$	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

Looking for MPI in lv+4j

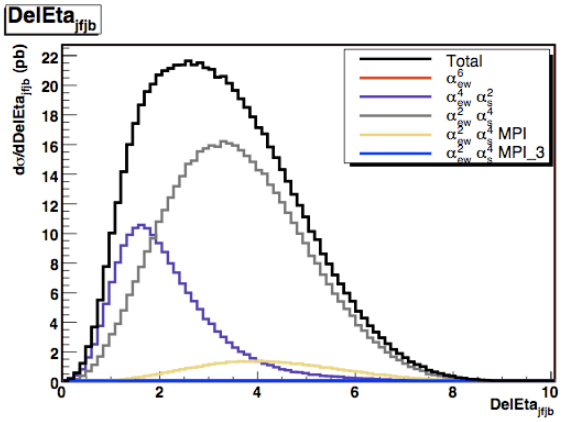
- Get rid of t-tbar
  $|M_{jjj}-M_t|>10$ GeV
- MPI gives larger separation of forward/backward jets
  $|\Delta\eta(j_f j_b)|>3.8$

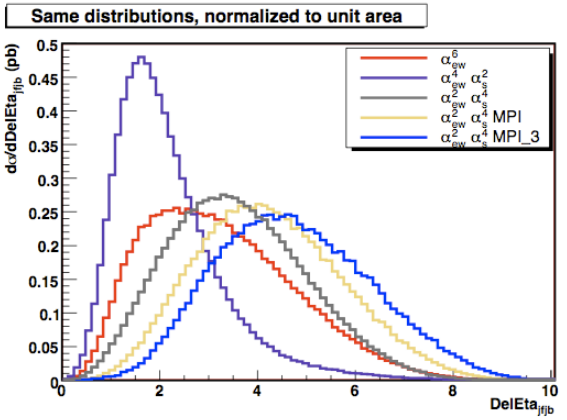
Process	Cross section
$\mathcal{O}(\alpha_{EM}^4\alpha_S^2)$	1.16 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$	24.01 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{DPI}}$	2.91 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{TPI}}$	0.16 pb
$\mathcal{O}(\alpha_{EM}^6)$	0.05 pb

S/B ½ = 5.8(6.1)
L=100 pb^{-1}

MPI/4jW=1/8

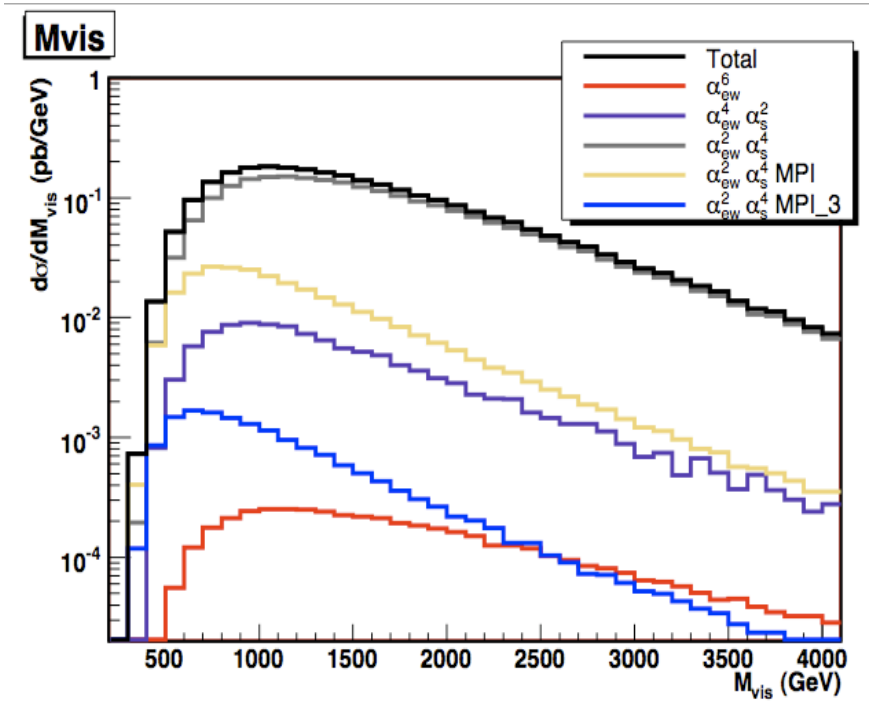
Process	Basic cuts Cross section	Iso cuts Cross section
$\mathcal{O}(\alpha_{EM}^4\alpha_S^2)$	25.0 pb	22.0 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)$	64.7 pb	58.9 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{DPI}}$	5.6 pb	5.3 pb
$\mathcal{O}(\alpha_{EM}^2\alpha_S^4)_{\mathrm{TPI}}$	0.27 pb	0.26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

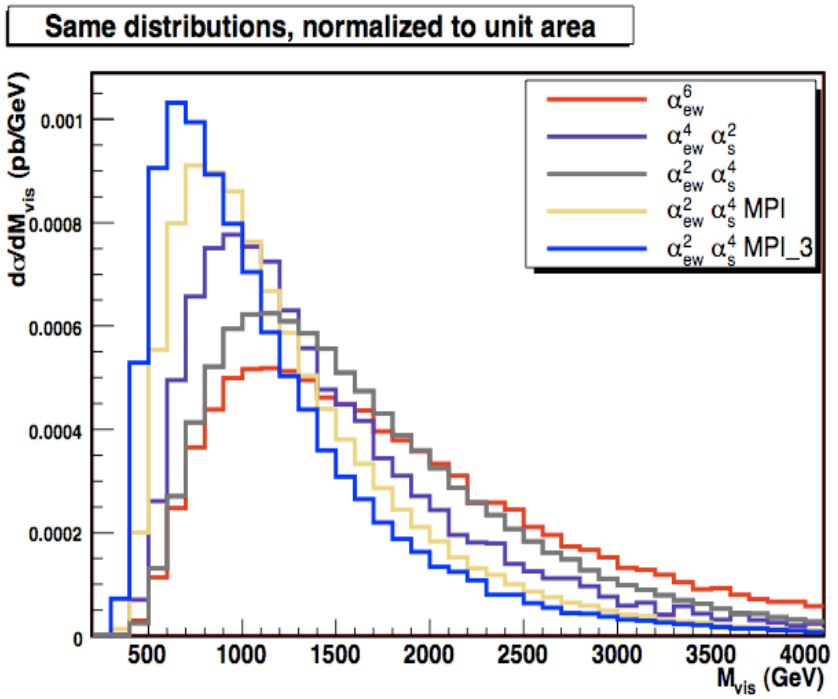




Visible mass:
3j+$l^{\pm}$

MPI softer





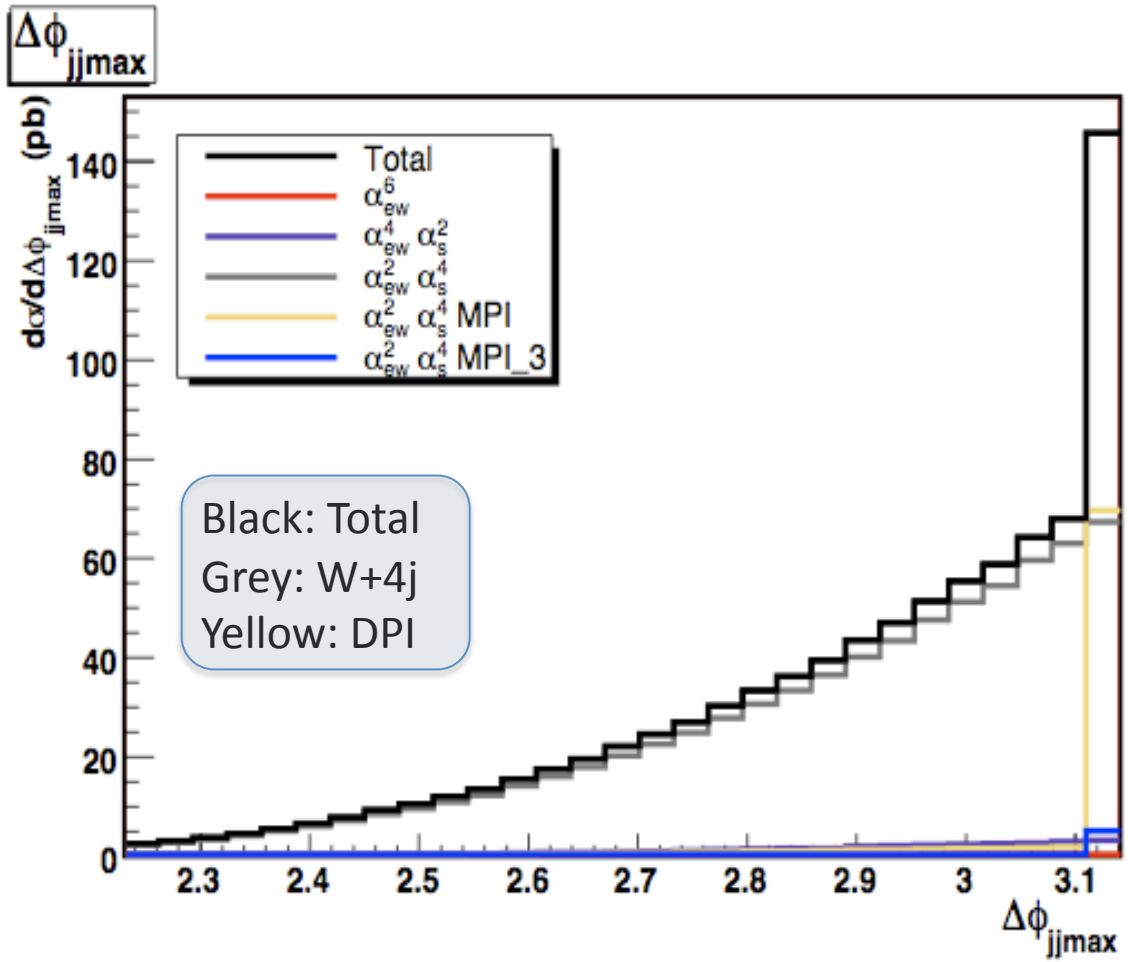
jj⊗jjW is dominant ➡ expect Δφ=π jet pair as in γ+3j or Z+3j

jjj⊗jW
jjjj⊗W
} no such feature

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

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

MPI/tot = 17%



Triple Parton Interactions: so far unobserved

Two jet pairs back to back in the transverse plane

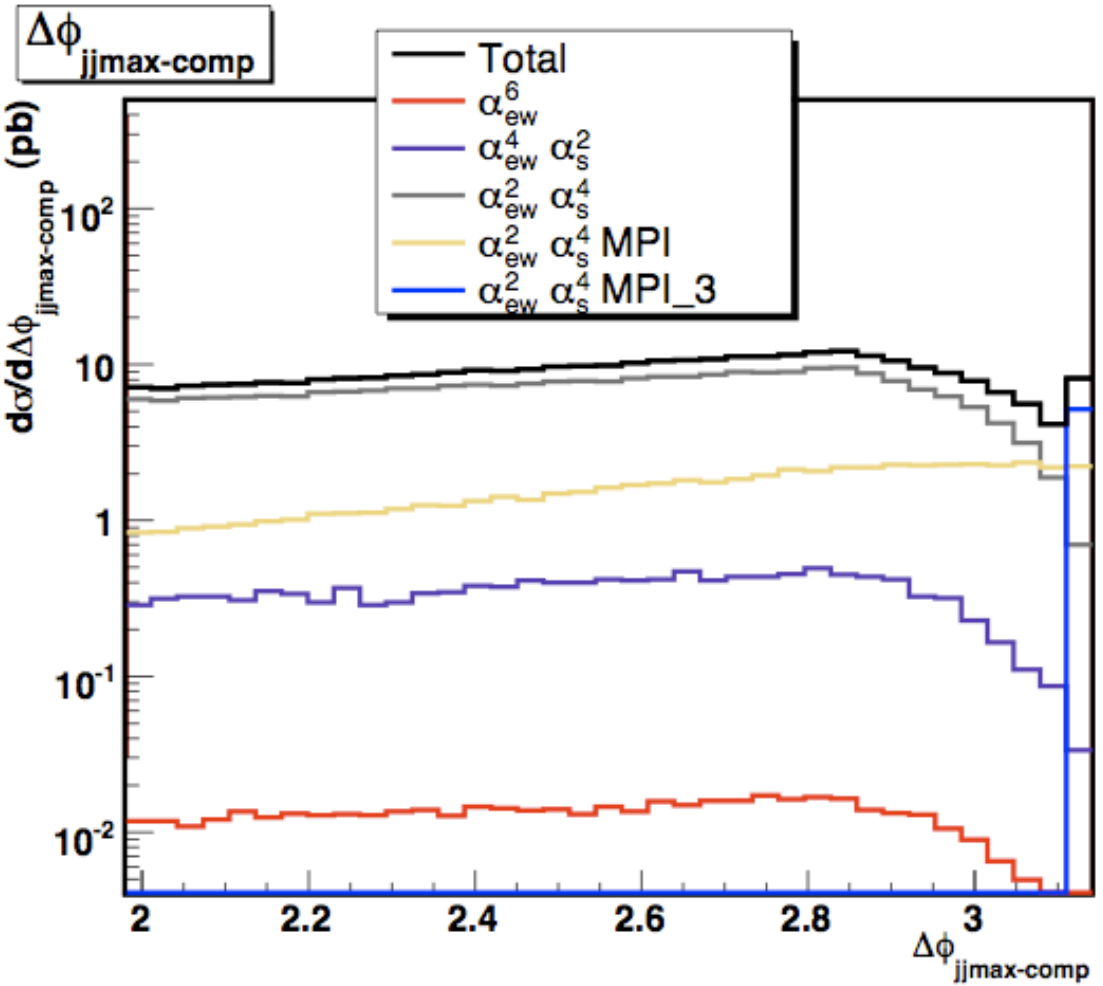
DY W with “zero” pT (also in DPI: less effective)

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

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

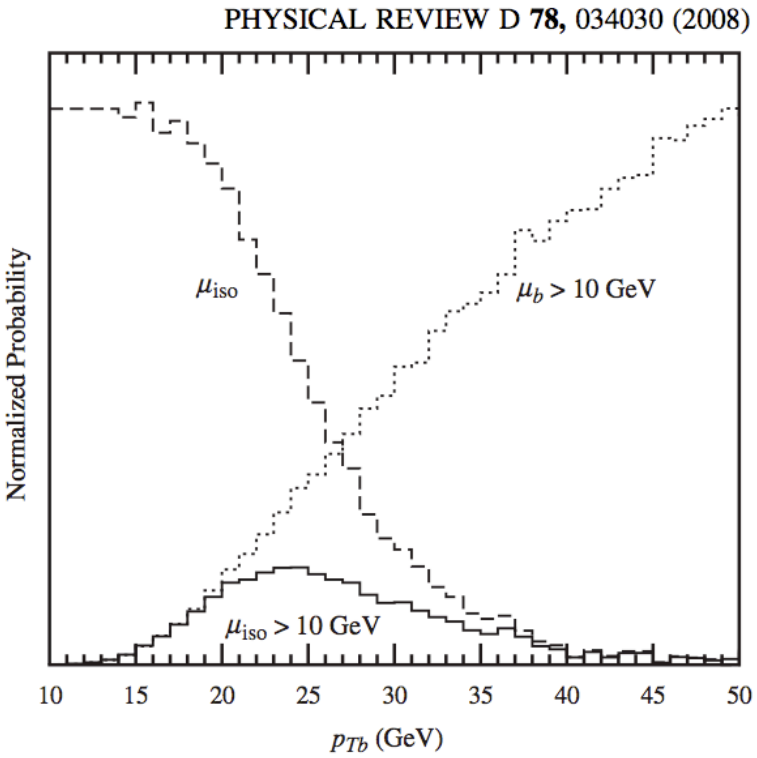
TPI/DPI/Bkg
1 / 16 /100

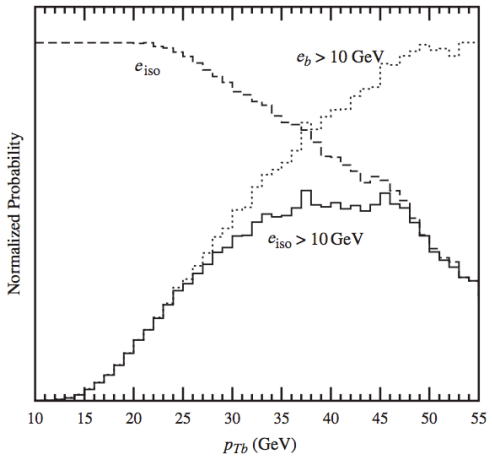
16k events for L=10 fb^{-1}
TPI more than 50% of last bin: 2 deg.



CAVEAT: isolated leptons from b-hadron decay

Sullivan,Berger
PRD78(2008)034030





BR(b-had → μ) = 9-14%

Isolation = geometrical iso (ΔR) OR
Energy iso

More isolated electrons because of
- Lower Energy Iso Thresholds (higher noise in ECAL)
- More fakes from charged pions

We use a 20 GeV pT_l threshold which is safer

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

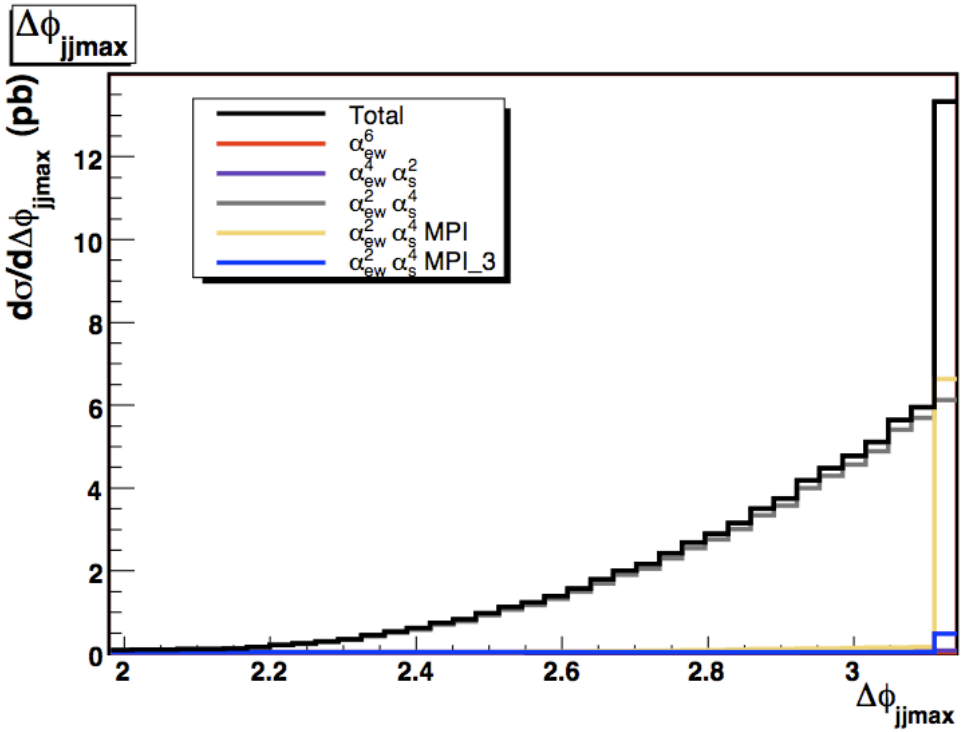
$$p_{T_j} \geq 30\ \text{GeV}\,, \quad |\eta_j| \leq 5.0\,,$$

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

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

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

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



Process	Basic Cross section	iso Cross section	Delta_jfjb 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

S/B ½ = 5.8(6.1)

L=1 fb^{-1}

MPI/4jW=1/8

Z's much easier to identify; No bkg from b-quark decays

Conclusions

MPI provide a small but non negligible background to t-tbar if no b-tag available

MPI provides a 10% background to W+4j and Z+4j with typical selection cuts

MPI can be studied in W+4j and Z+4j channels above QCD background exploiting $\Delta\varphi=\pi$ jet pairs

TPI can hopefully be measured in W+4j production

More careful analysis including correlations between interactions needed

QUESTIONS

Does Pythia confirm that MPI provides a sizable background to V+4j?
Pythia 6 and Pythia 8 treat MPI differently. Differences here?

Does showering radically change the picture at the LHC?

Correlations among PDF's

Are there other reactions which might show similar behavior?
MPI ⟶ large background; MPI tests

B⟶isolated-lepton+X is large. What if combined with N-jets in MPI?

What can be done @ 10 GeV and 200 pb^{-1}?