CMS DPS Studies

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(on the behalf of the CMS Collaboration)

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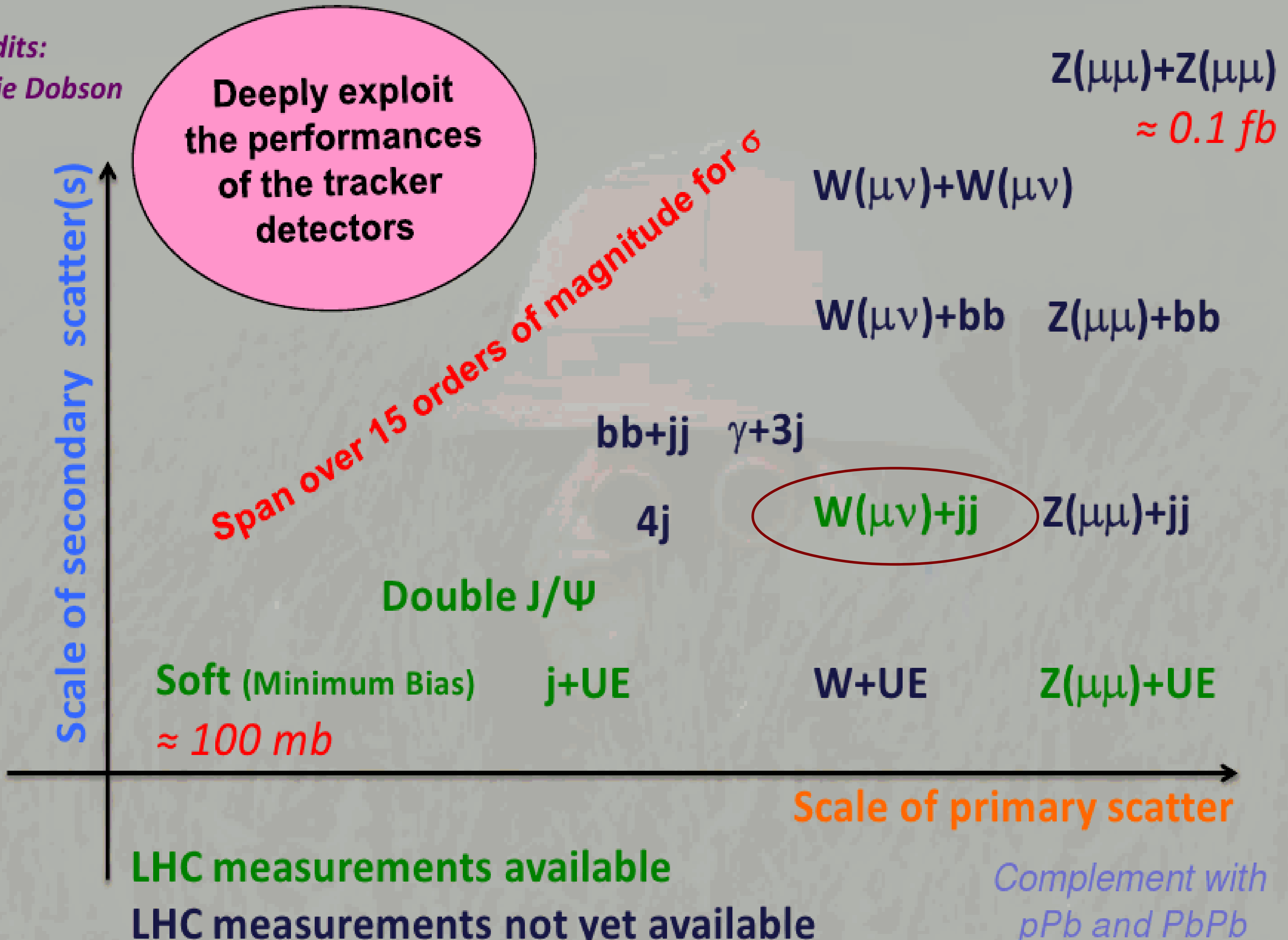
Where can we see Multiple Parton Interactions?

Credits:
- Ellie Dobson

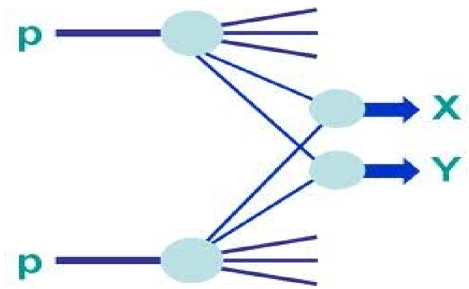


Bottom-line: Soft Multiple Parton Interactions Highlights

- Charged multiplicity measurements:
  - CMS confirms large multiplicity tails and KNO violation more pronounced at high energies.
  - à On the other hand MPI models have been invented to describe large multiplicity tails and KNO violation at SPS.
- MPI certainly play a major role in the “ridge” effect at the LHC.
- UE Measurements
  - MPI in GPDF(Generalized Parton Distribution Function) explain the single scale picture in the case of DY topologies, two scale picture in the case of jets and the relative size of UE(DY)/UE(jets).
- Evidence of MPI effects provided also in terms of Forward-Central correlations.

MPI from Soft to Hard : Double Parton scattering

➢"The large parton densities at small-x values, increase the probability of having two (or more) simultaneous parton-parton scatterings."



In DPS studies,

Effective x-section (σ_{eff}) should be regarded as the most natural link to theories.

σ(A+B) **= m * σ**(A) *** σ**(B) **/ σ**eff**,** (m = ½ for identical interactions, m = 1 otherwise)

In case of W+2jets,
“effective cross-section”
may be calculated as:

$$\sigma_{eff} = \frac{\sigma_{w}^{Incl} \times \sigma_{2j}^{Incl}}{\sigma_{DPS}}$$

$$\sigma_{eff} = \left[\left(\frac{\epsilon_s}{\epsilon_b}\right)\left(\frac{1}{f}\right)\right] \times \sigma_{2j}^{Incl}$$

Signal Efficiency

Signal Fraction

Background Efficiency

Di-jet cross-section

Differential Measurements of σeff needs to be performed...

σ_{eff} ≈ *(process,)* scale and √s independent according to D. Treleani et al.

3->4 processess may be relevant at high x-Bjorken

MPI from Soft to Hard : Double Parton scattering

But, √s, scale and process in-dependencies, should NOT be assumed...!!!

Of course, from an experimental point of view these properties should rather be tested. However the measurements may be affected by large uncertainties…

- σ_{eff}(Tevatron) ≈ **10-15 mb** from CDF & D0 3jet+γ

Pythia: $\sigma_{eff} = \sigma_{non\text{-}Diff} / \langle f_{impact} \rangle$
where $\langle f_{impact} \rangle$ is tune dependent σ_{eff} (Tevatron) ≈ **20-30 mb**

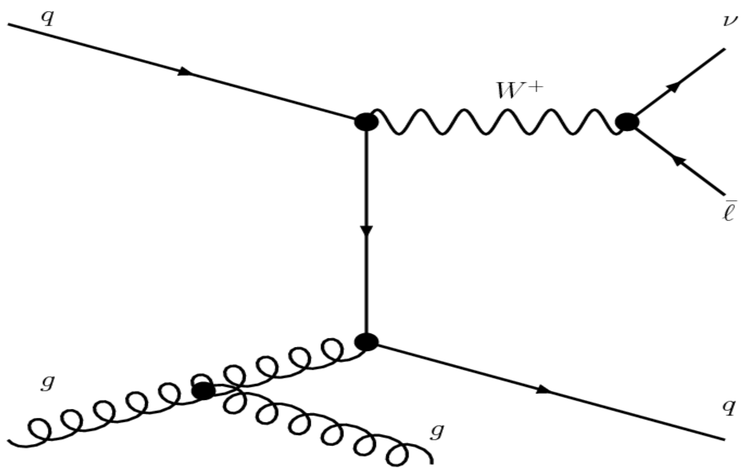
So, MC models along with up to date tunes predict σ_{eff} values, which are about a factor of 2 higher w.r.t Tevatron Measurements.

Let us measure Sigma-eff(in a differential way)
- access to the information regarding hadron structure.
- understanding of potential background to searches.
- understanding of relative amount of MPI and radiation.

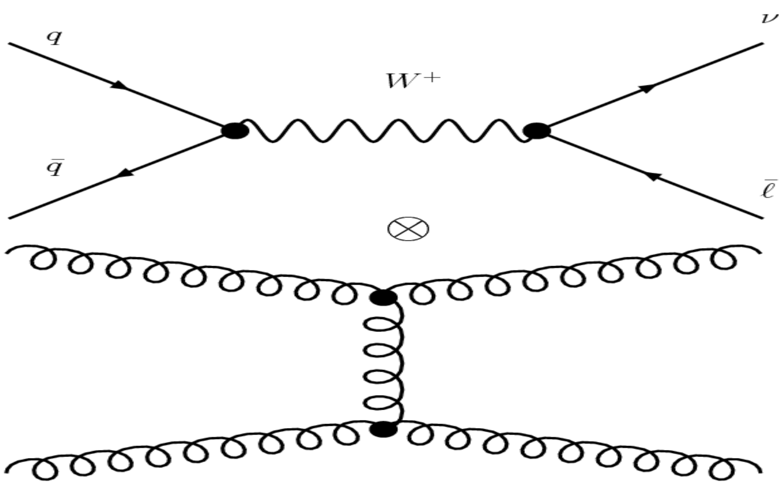
DPS via W+2jets

Signal: W from first hard parton-parton interaction, atleast two jets from second one.
Decay of W in muon channel is studied only.

Background: W + jets from single interaction (SPS)



SPS, Background



DPS, Signal

Important prescriptions applying also to other DPS analyses:

SIGNAL + BACKGROUND should cover the full phase space.

When looking for an extra di-jet interaction at a given pT from DPS whatever is below such scale should be considered BACKGROUND even in the case it comes from DPS.

Event Selection

One Mu pT>30 GeV and |η|<2.1
Missing Transverse Energy > 30 GeV
W Transverse Mass > 50 GeV
At-least Two jets with pT>20 GeV and |η|<2.0

INCLUSIVE

Signal:

- **W from First hard scattering**
- **Atleast two jets from the 2nd Hard scattering.**

A threshold of 20 GeV/c is put on the 2nd Hard Scattering i.e.
Any event from a process with scale <20 GeV/c would be considered as BACKGROUND, even if comes from DPS.

Apart from this **Background also constitute the events with W+n-jet(n>=2) from Single Parton scattering.**

Monte-Carlo Samples Used

- **Pythia8 MPI off**
- **Pythia8 MPI on (Inclusive)**
- **Pythia8 DPS Signal**
- **Pythia8 filtered**

→ Tune: pp5
Version: 8.1.45

- **MadGraph(+Py8) MPI off**
- **MadGraph(+Py8) MPI on**

→ Tune: PythiaUEZ2star
Qcut:30
Max no. of jets from ME=4

- **Sherpa W+0jet MPI on**
- **Sherpa W+1jet MPI on**
- **Sherpa W+2jet MPI on**
- **Sherpa W+3jet MPI on**

→ Version: 1.4.0
Max no. of jets from ME=n
n=0, 1, 2, 3

MPI ON samples means that these samples already contain a fraction of “signal”.

MadGraph MPI ON is used as Pseudo-data in our studies for the extraction of Signal fraction.

Basic Terminology

MPI off – MPI Switch is kept off, events from SPS only will contribute

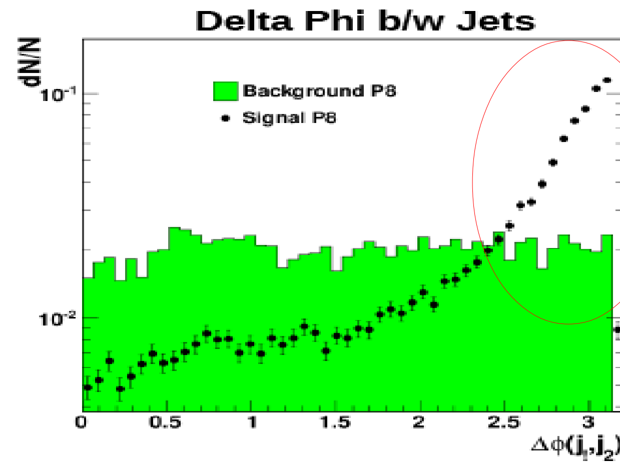
MPI on – MPI Switch kept ON, a fraction of Signal would be present
i.e. contribution from SPS and DPS as well

Signal DPS – W from 1st hard interaction
and atleast 2 jets from 2nd one

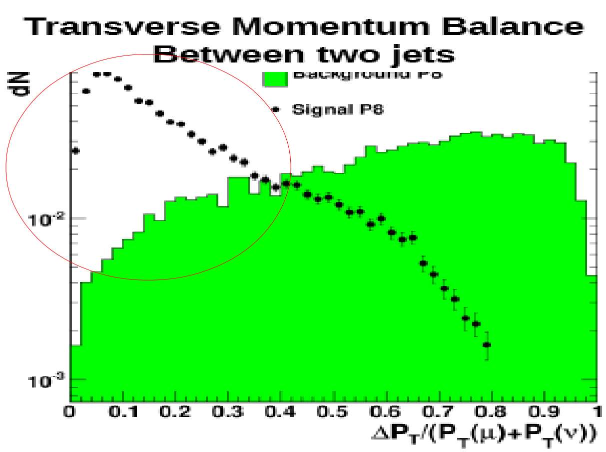
Background or filtered – W+jets from SPS
and events from 2nd interaction below 20 GeV

DPS Observables

Tune:pp5, Pythia8.1.45

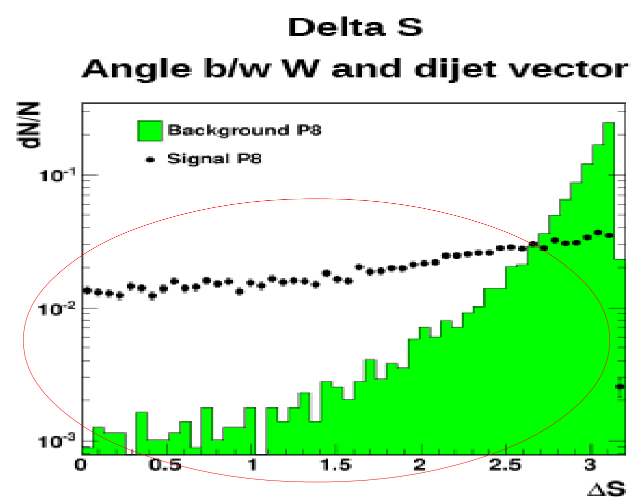


ΔΦ(j1, j2): *azimuthal separation between two jets*. As in case of DPS events two jets are independent of W produced from first interaction and two jets balance each other, which is not the case for W + 2 jet from SPS. Therefore, two jets are back-to-back in case of DPS events and randomly distributed for SPS.



$$S_{pT(j1,j2)} = \left(\frac{\vec{pT}(j1)+\vec{pT}(j2)}{|pT(j1)|+|pT(j2)|}\right)$$

ΔpT(j1, j2): *transverse momentum imbalance between two jets*. In case of DPS events two jets balance each other and hence ΔpT(j1, j2) have small value, close to 0, whereas in case of SPS events this observable has large value.



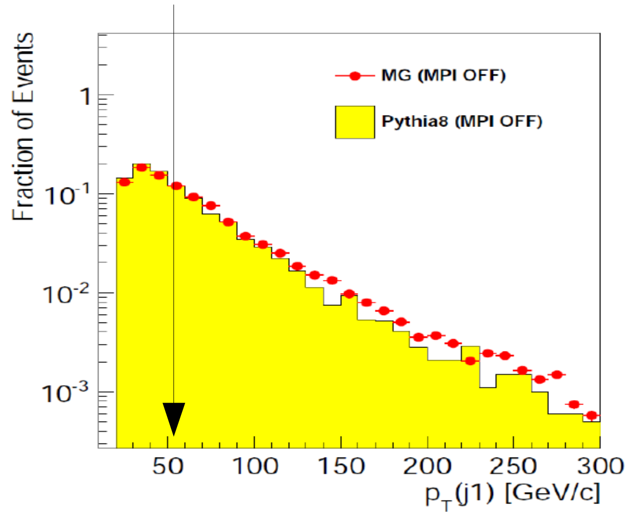
$$\Delta S = \arccos\left(\frac{\vec{pT}(1)\circ\vec{pT}(2)}{|pT(1)|.|pT(2)|}\right)$$

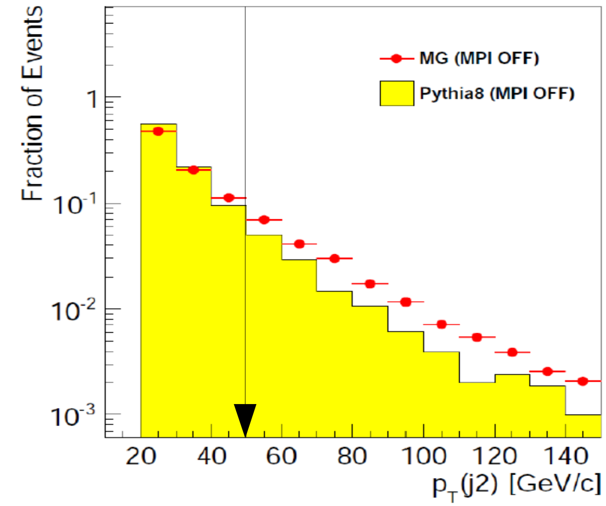
ΔS: *azimuthal separation between W and di-jet vector*. **I**n case of DPS event, W and dijet events are independent of each other, hence W and dijet vector are randomly oriented w.r.t. each other.

**where pT(1) is the resultant transverse momentum vector of muon and MET and pT(2) is the resultant transverse momentum vector of two jets.*

Concern : background template from Pythia8

We can control MPI quite well in Pythia8. But, It is not clear how MPI is taken care while matching in ME-PS i.e. MadGraph or Sherpa.



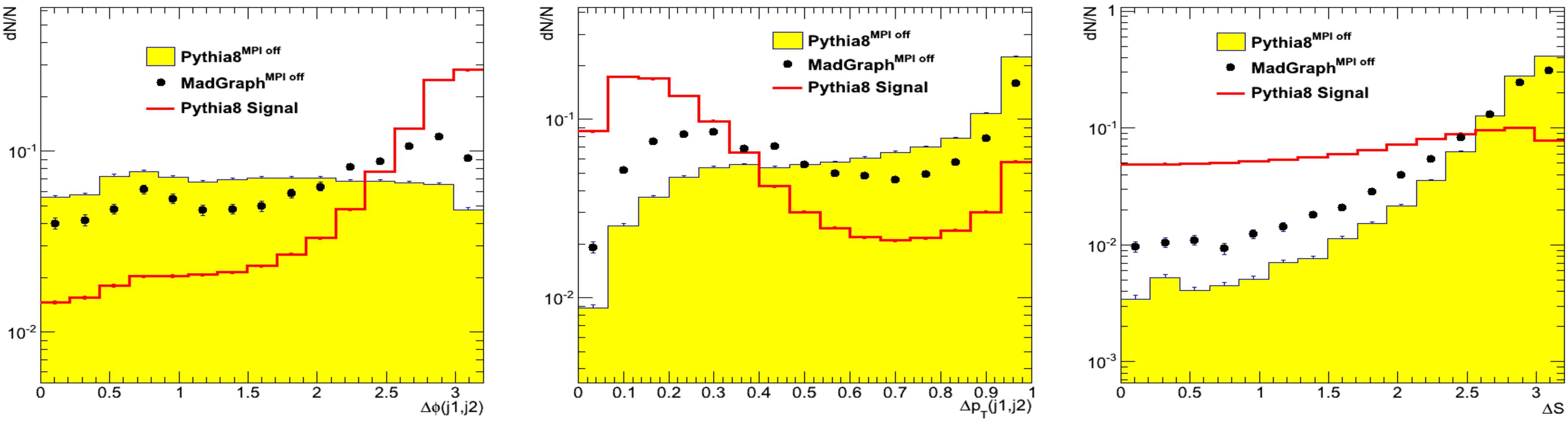


In Pythia8, jets are from Parton Shower only, which are dominating in low pT bins only leding to a dis-agreement with MadGraph (ME+PS) in the higher bins.

So, we choose the phase-space for which the parton-shower MC is giving a sufficient description.

We limit our phase space with jets in pT range 20-50 GeV/c, to study DPS observables.

Concern : background template from Pythia8



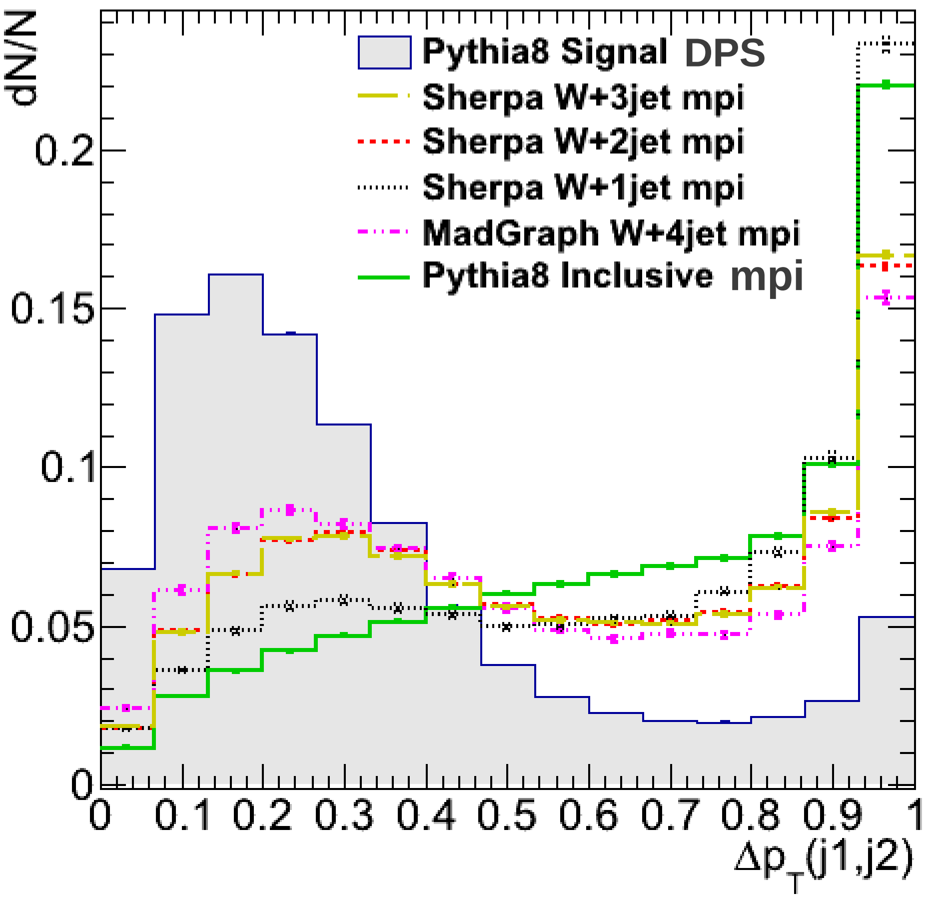
Even if we limit the jets in pT in (20,50) only, where an fine agreement b/w MadGraph and Pythia8 is there, even than DPS observables are not similar for MG (MPI off) and Py8 (MPI off) .

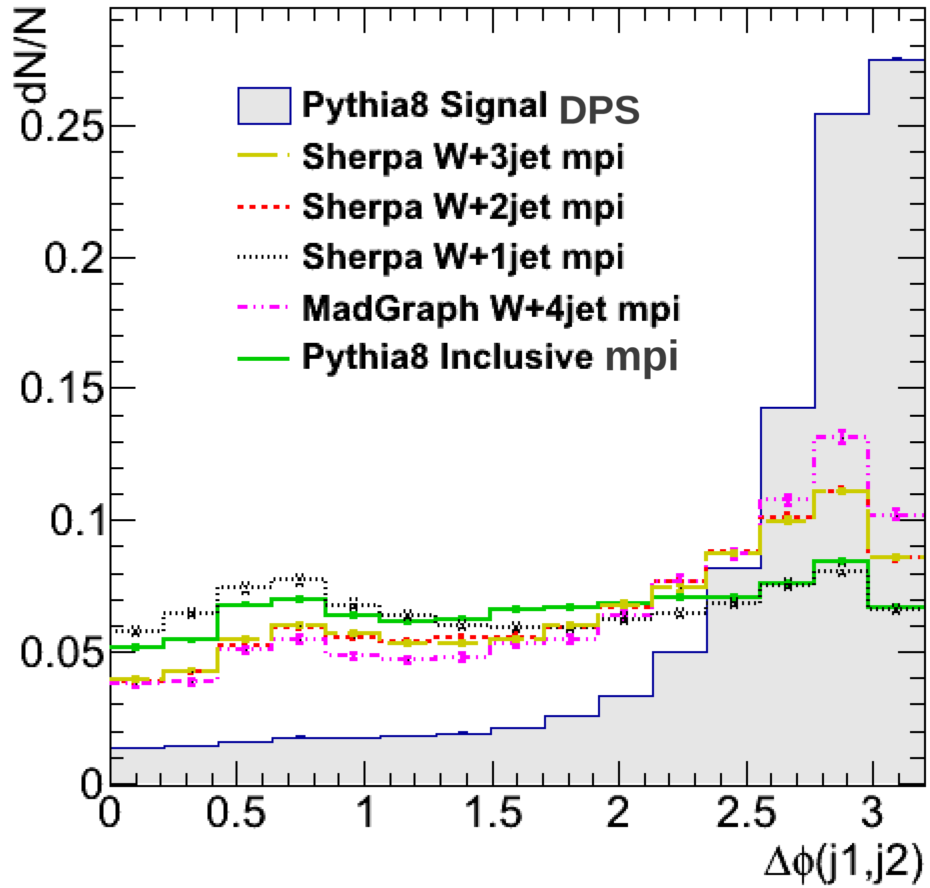
Some work has been also done to test the robustness against the variation in the definition of the signal. e.g
We choose the other signal and background definition with same kinematic cuts and condition along-with an additional condition of jet-DPS parton matching with in a cone-size of radius 0.5.

This new signal and background templates also covers full phase space.

Effect of additional branches on DPS Observables

A generator level test is performed with: Pythia8, MadGraph & Sherpa.





Further Signal fraction is extracted using these various samples.

Extraction of Extra DPS fraction

MadGraph MPI on as PseudoData

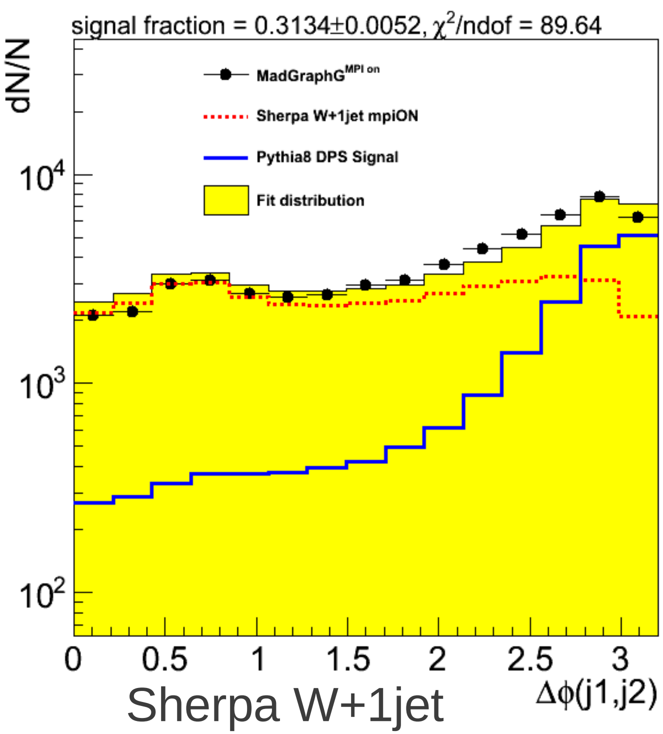
Pythia8 DPS Signal Events Constitute Signal Template

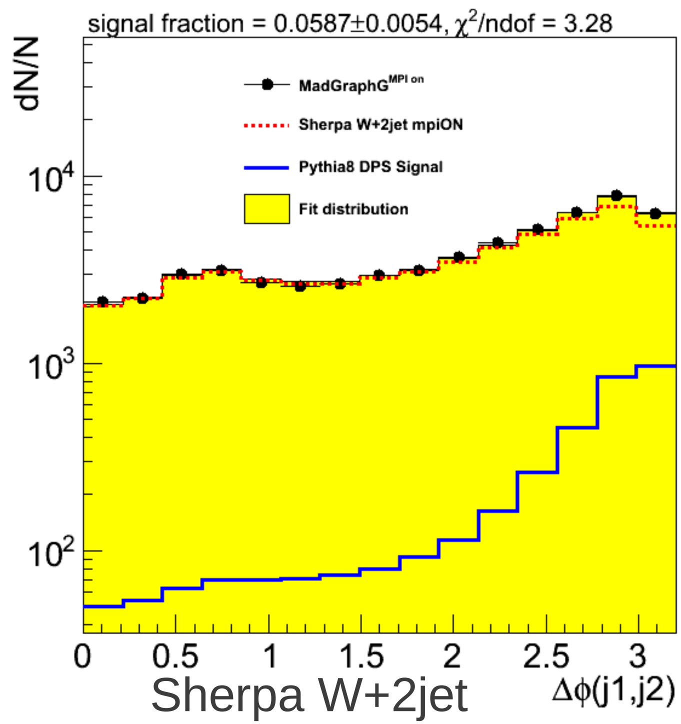
Tool TfractionFitter is used to extract this fraction

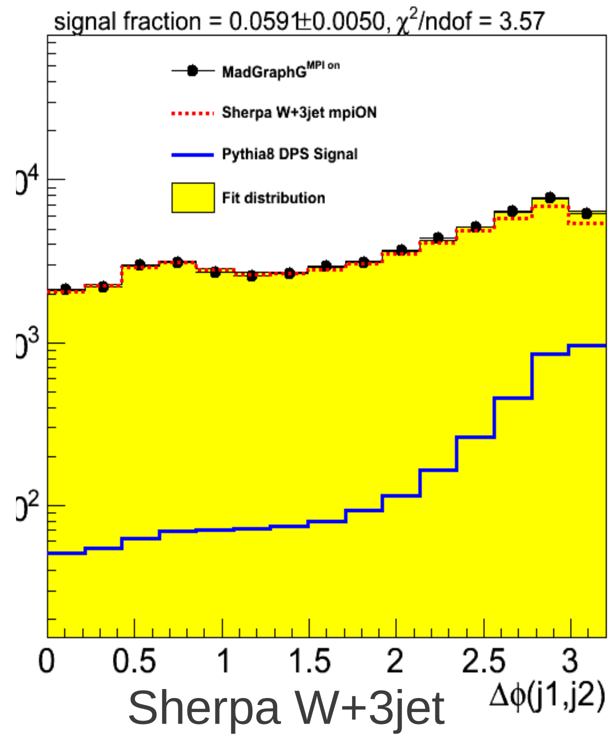
Extraction of Extra DPS fraction-using TFractionFitter

Background = First row in table & Signal = Pythia8 DPS Signal

Background:	dphi	dpt	dS
Sherpa W+0 jet mpi on	17.05+-0.75, 15.18	5.32+-0.48, 25.14	8.32+-0.41, 40.51
Sherpa W+1jet mpi on	31.34+-0.52, 89.64	23.16+-0.031, 286.29	9.84+-0.030, 32.24
Sherpa W+2jet mpi on	**5.87+-0.54, 3.28**	**6.68+-0.29, 5.81**	**5.55+-0.25, 2.64**
Sherpa W+3jet mpi on	**5.91+-0.50, 3.57**	**6.66+-0.29, 5.09**	**3.48+-0.25, 0.90**







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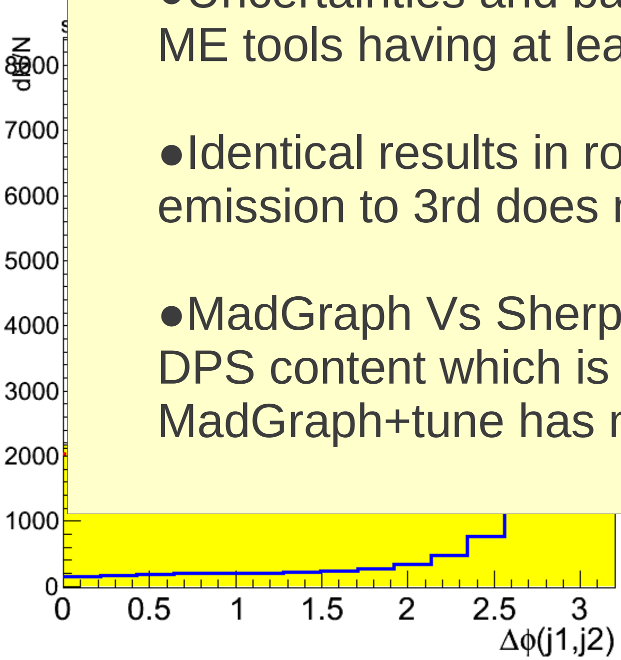
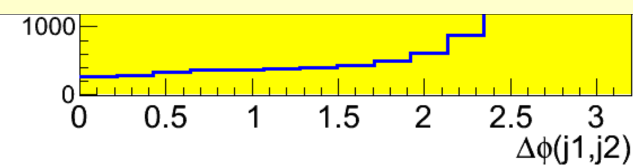
Conclusions:

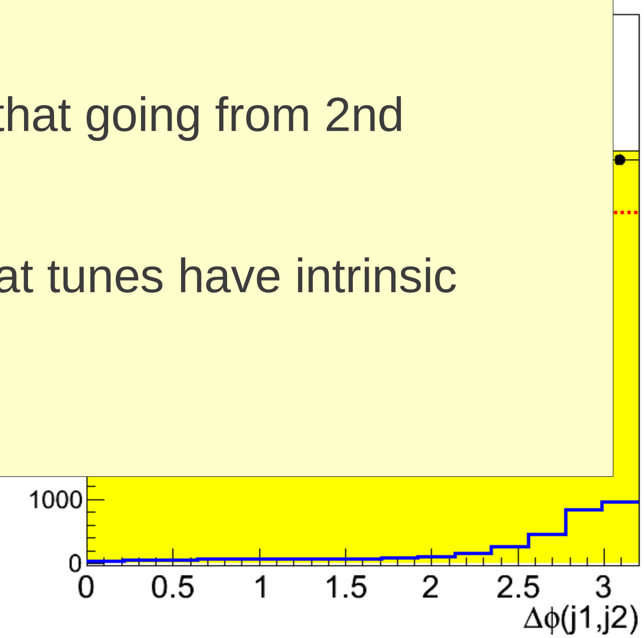
- Uncertainties and bad fit seen for W+0jet, W+1jet indicate that we can trust only ME tools having at least 2 extra emissions.

- Identical results in rows for W+2jet and W+3jet indicate that going from 2nd emission to 3rd does not effect the results much.

- MadGraph Vs Sherpa does not give exact 0% means that tunes have intrinsic DPS content which is different for both the cases.
MadGraph+tune has more DPS than Sherpa+DPS.







Extraction of Extra DPS fraction-using TFractionFitter

Background = First row in table & Signal = Pythia8 DPS Signal

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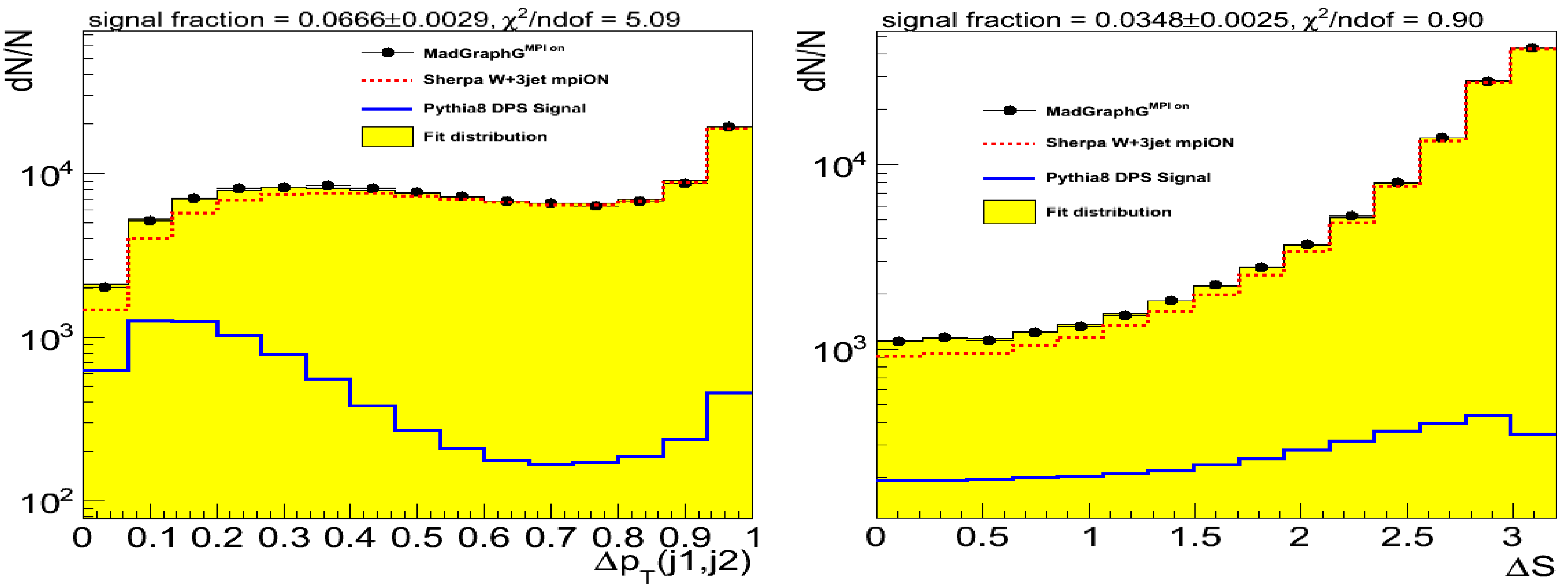
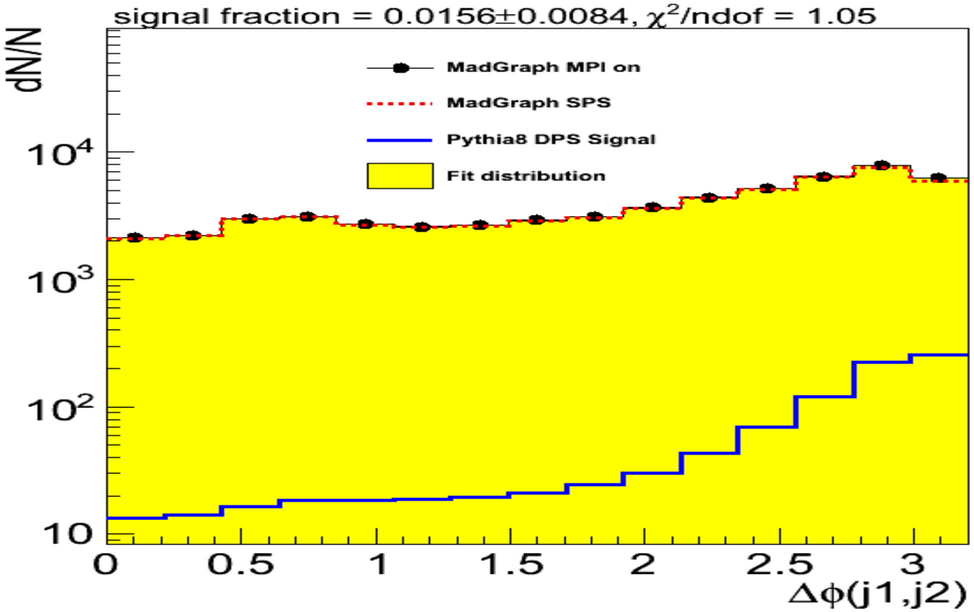
Sherpa W+3jet mpi on	**5.91+-0.50, 3.57**	**6.66+-0.29, 5.09**	**3.48+-0.25, 0.90**

- Even on W+3jets the three tested DPS sensitive observable don't give exactly the same results within, an intrinic uncertainty of around 3% on the DPS fraction applies (figure quoted comparing dpt and dS).



Matrix Element(ME)+Parton Shower MC Event Generator

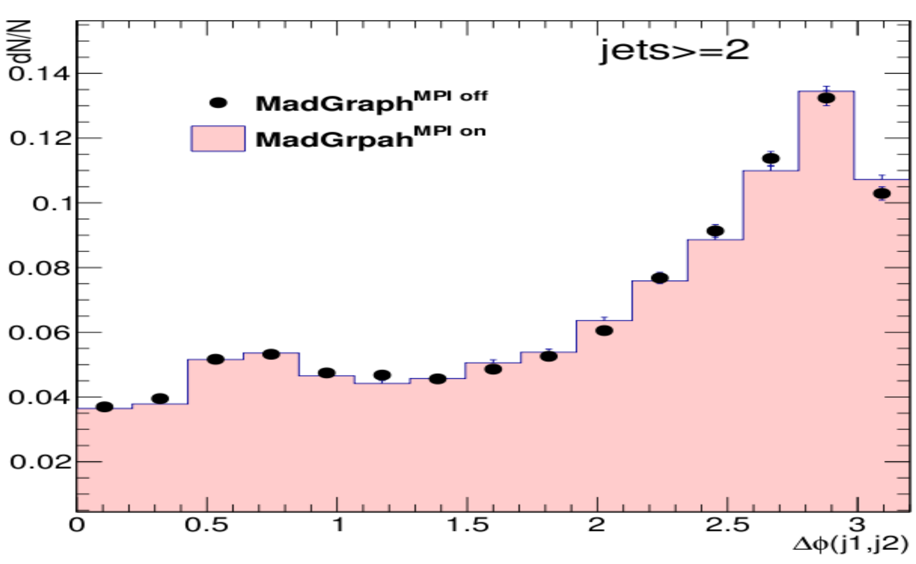


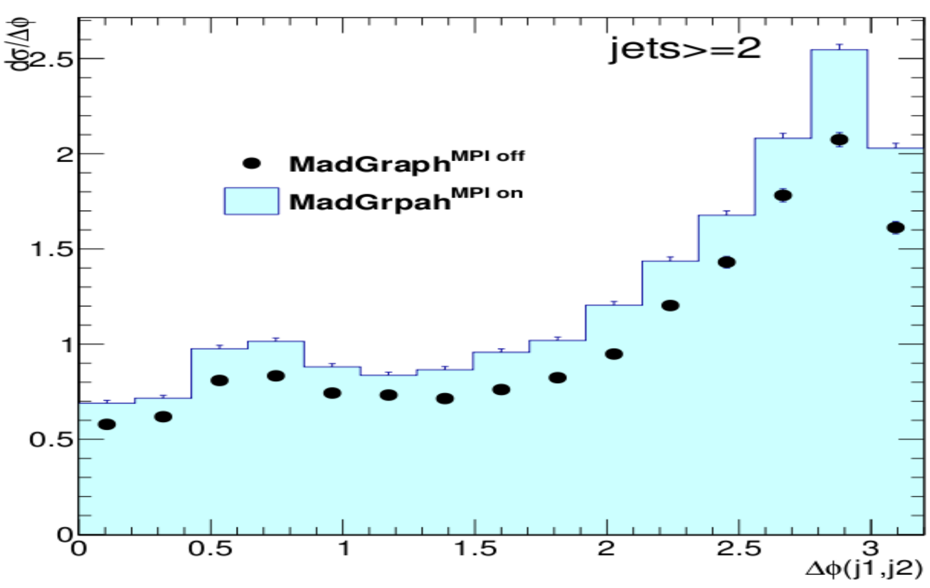
Δphi Distribution

Background:	dphi
MadGraph MPI off	1.56+-0.84, 1.05

- Effect of switching off MPI is visible in absolute normalization.

- but shape remain almost same.





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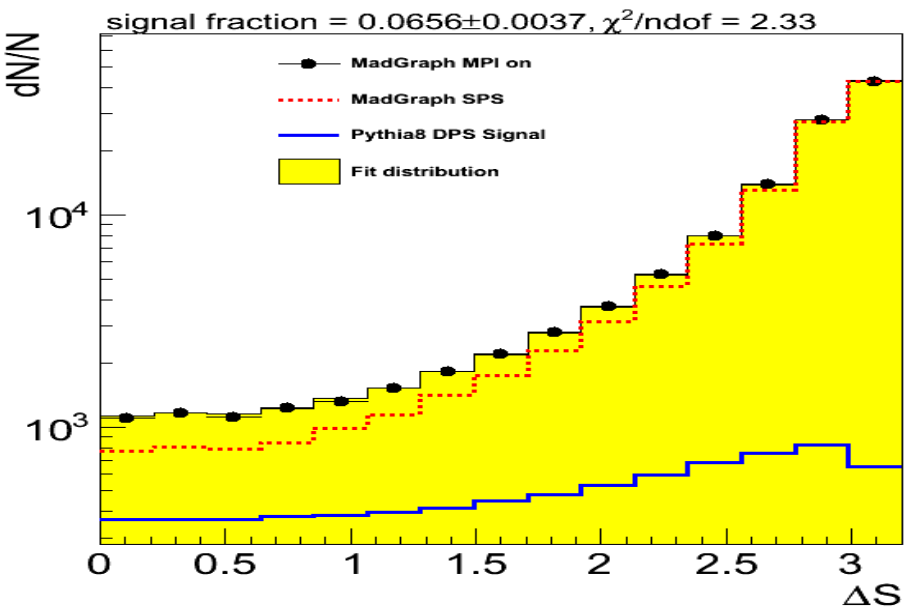
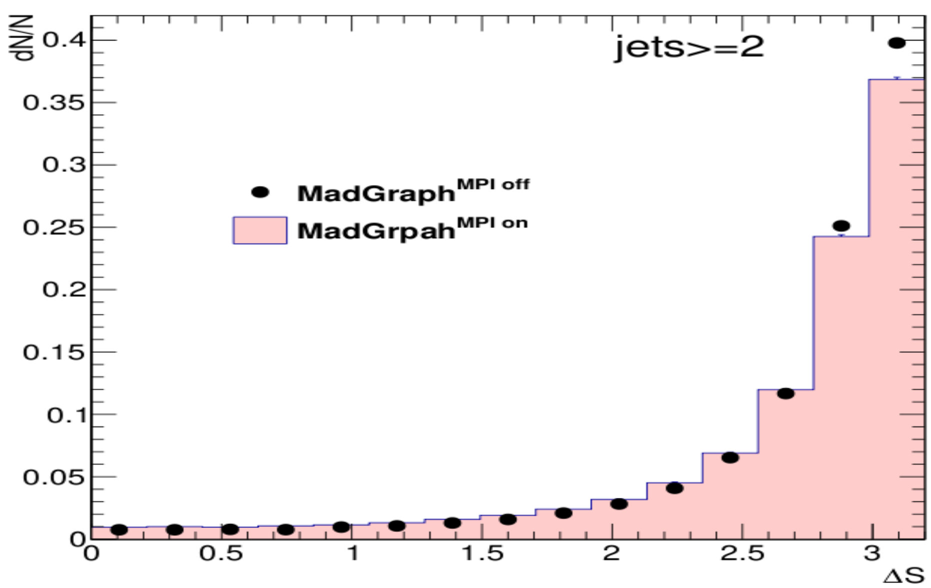
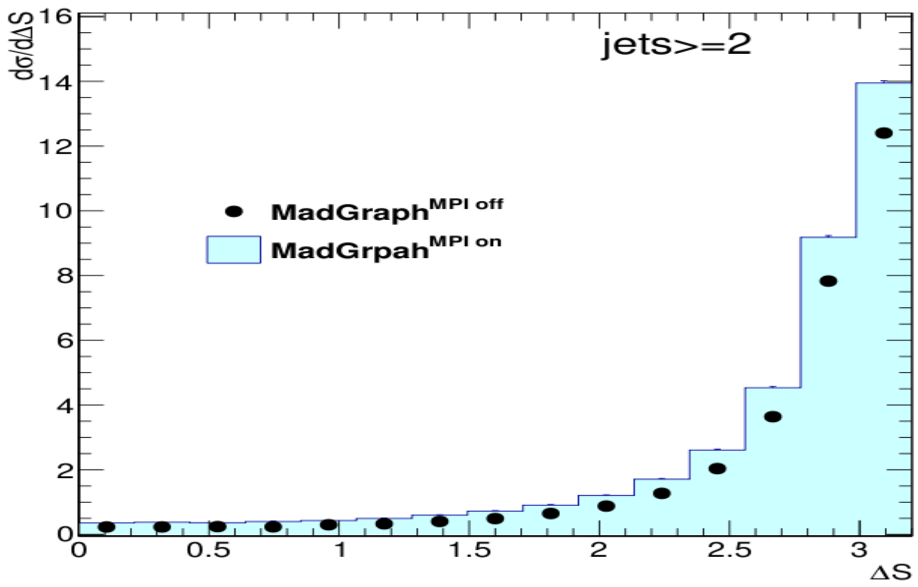


ΔS Distribution

Background:	dS
MadGraph MPI off	6.56+-0.37, 2.33

It confirms, switching ON and OFF MPI, effects the distribution.(although very little).
May be choice of variable kills the DPS region sensitivity.





Summary & Conclusion

- CMS has a rich MPI research program. The legacy of the early (MB/UE) measurements represents a resource for the forthcoming high pT DPS measurements. Here some MC studies are presented focusing on the W+2jets+X channel.

- Sigma Effective should be considered as the most efficient link to theories. Differential measurement of Sigma Effective are planned (pT and pseudorapidity of extra-jets etc.).

- Favour exclusive measurements (in the case of exclusive measurements the corresponding formalism by D.Treleani considering the contribution of triple interactions should be applied.

- The DPS measurement deeply rely on the MC modelling of signal and background.

- The phase space should be fully covered, in particular no holes should be permitted in the scale of the 2nd interaction.

- ME tools turn out to be essential in the background modeling, however there are still technical difficulties to access MPI-related parameters in ME+PS hybrids.

PTO

Summary & Conclusion

- The performed pseudo-data experiment on the W+2jets+X channel shows that results significantly depend on the choice of the DPS-sensitive variable: the choice of the observable represent one of the main sources of systematic uncertainty.

- The sensitiveness of the observables identified relying on preliminary investigations made with PS MCs is diluted when adding higher orders. In particular the shapes of these observables predicted by Madgraph (up to 6 extra jets) with and without MPI turn out to be basically the same. Only normalization effect can be clearlly seen when swithing ON/OFF MPIs.

- Further studies are currently promoted in CMS in order to identify corners of the phase space where differences between these observables show up. In the W(Z)+2jets+X channel it seems promising to focus on DPS enhancement provided by the requirement of low W(Z) pT.

Thank You... :)

Suggestions & Comments...

Back-up

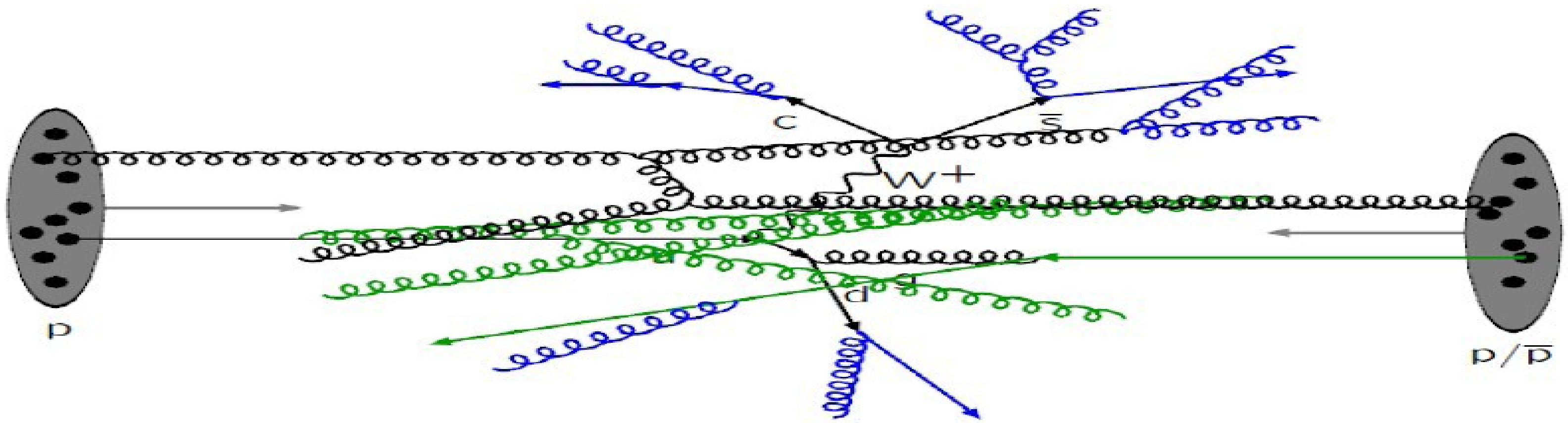
Motivation

Factorization Theorem : proton-proton collisions can be described in terms of single parton-parton scattering...

BUT, experimentally observed hadron-hadron collision is much more complicated

? Possibility of more than single parton-parton scattering in p-p collision ?

➢ Proton-proton (p-p) collisions at the high centre of mass energies of the Large Hadron Collider (LHC) probe very small values of the momentum fraction 'x' carried by the colliding partons



Multiple Parton Interactions(MPI)

- MPI usually constitutes soft part and considered as an important part of Underlying Events.
- Various measurements at different collision energies and using various processes
  e.g. leading jet/track, Drell-Yan.

- **Sometime MPI can be hard enough to produce high pT/mass particles i.e. dijet, J/psi, etc.**

1st part: the basic soft QCD measurements

Kinematics:

QCD-09-010: "Transverse momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ = 0.9 and 2.36 TeV ". J. High Energy Phys. 02 (2010) 041

QCD-10-006: "Transverse-momentum and pseudorapidity distributions of charged hadrons in pp collisions at $\sqrt{s}$ = 7 TeV ".
Phys. Rev. Lett. 105 (2010) 022002

QCD-10-004: "Charged particle multiplicities in pp interactions at $\sqrt{s}$ = 0.9, 2.36, and 7.0 TeV ". J. High Energy Phys. 01 (2011) 079

QCD-10-007: "Strange particle production in pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV".
J. High Energy Phys. 1105:064, 2011, 1102.4282

Using also high pT triggers to explore the tails:

QCD-10-008: "Charged particle transverse momentum spectra in pp collisions at $\sqrt{s}$ = 0.9 and 7 TeV ".

Correlations:

J. High Energy Phys. 08:086, 2011, 1104.3547

QCD-10-003: "First measurement of Bose–Einstein correlations in proton-proton collisions at $\sqrt{s}$ = 0.9 and 2.36 TeV at the LHC ". Phys. Rev. Lett. 105 (2010) 032001

QCD-10-023: "Measurement of Bose–Einstein Correlations in pp Collisions at $\sqrt{s}$ = 0.9 and 7 TeV at the LHC".J. High Energy Phys. 1105:029, 2011, 1101.3518

Using also large multiplicity triggers to avoid jet bias:

QCD-10-002: "Observation of Long-Range, Near-Side Angular Correlations in Proton-Proton Collisions at the LHC ". J. High Energy Phys. 09 (2010) 091

≈ measuring low pT tracks and identifying hadrons in pp interactions
Impact on detector occupancies, pT spectra, PU features etc.
Access to deep information of the hadron structure

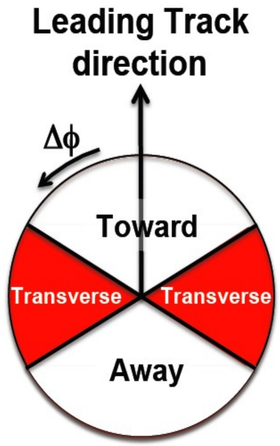
2nd part: the Underlying Event measurements

Central Region (Tracks)

QCD-10-001: "First Measurement of the Underlying Event Activity at the LHC with √s = 0.9 TeV". Eur. Phys. J. C 70 (2010) 555-572.
QCD-10-010: "Measurement of the Underlying Event Activity at the LHC with √s = 7 TeV and Comparison with √s = 0.9 TeV". JHEP 1109, 109 (2011).
QCD-10-021: "Measurement of the Underlying Event Activity with the Jet Area/Median Approach at 7 TeV and comparison to 0.9 TeV". CERN-PH-EP-2012-152, arXiv (2012), 1207.2392, submitted to JHEP.
QCD-11-012: "Measurement of the Underlying Event Activity in the Drell-Yan process in proton-proton collisions at √s = 7 TeV". CERN-PH-EP-2012-085, arXiv:1204.1411v1, submitted to Eur. Phys. J. C.

Forward Region (E-Flow)

FWD-10-008: "Forward Energy Flow, Central Charged-Particle Multiplicities, and Pseudorapidity Gaps in W and Z Boson Events from pp Collisions at 7 TeV. ". Eur.Phys.J . C72 (2012) 1839.
FWD-10-011: "Measurement of energy flow at large pseudorapidities in pp collisions at √s = 0.9 and 7 TeV". JHEP 1111 (2011) 148, Erratum-ibid. 1202 (2012) 055.
FWD-11-003: "Study of the Underlying Event at Forward Rapidity in Proton-Proton Collisions at the LHC". CDS Record: 1434458.



≈ Measuring low pT tracks in phase space regions not affected by the leading interaction
impact on isolations, jet pedestals, vertex reco etc.
"There would not be a vertex in H → $\gamma\gamma$ events without the Underlying Event." [QCD-10-010]

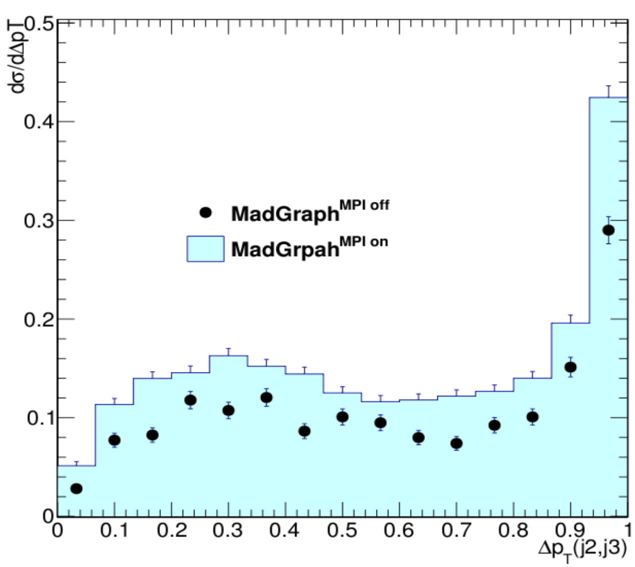
Handle on soft MPI and beam remnants.

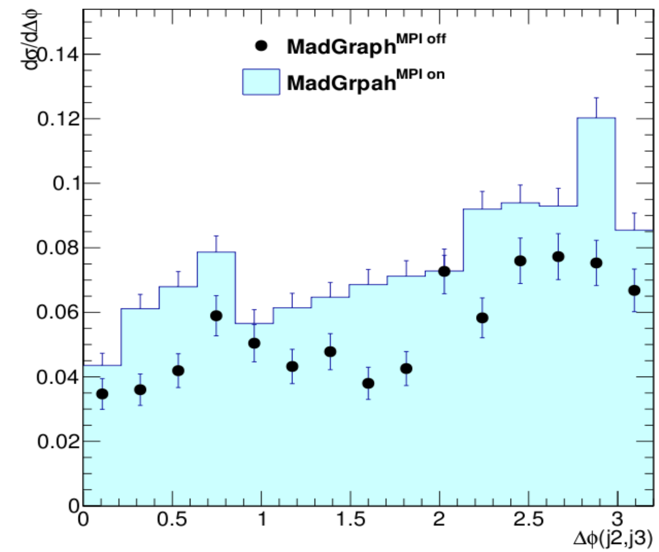
In W + j1 from 1st interaction & j2 and j3 from 2nd interaction

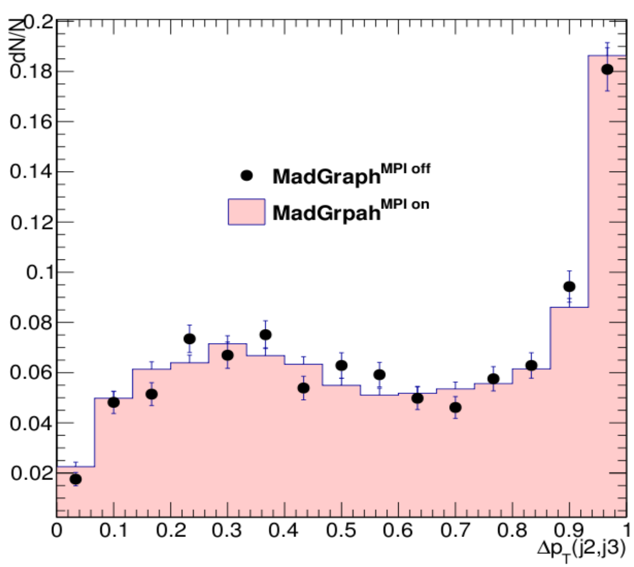
MadGraph

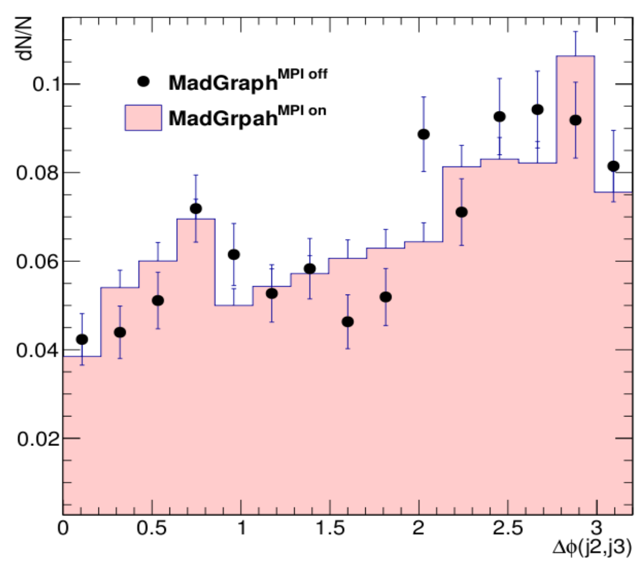
20<Jet pT<50

ΔpT(j2,j3) | **Δφ**(j2,j3)









PseudoData = 95% MadGraph MPI on + 5% Py8 DPS Signal
Background = First row in table & Signal = Pythia8 DPS Signall

Background	dphi	dpt	dS
Pythia8 filtered	33.69+-0.53, 38.30	17.12+-0.37	14.55+-0.31, 7.22
W+0 jets Sherpa	21.41+-0.74, 14.50	10.26+-0.48, 24.02	-5.46+-0.42, 24.29
W+1jet Sherpa	35.23+-0.52, 83.86	27.70+-0.32, 266.30	14.58+-0.30, 29.82
W+2jet Sherpa	10.63+-0.57, 3.02	11.42+-0.31, 5.28	10.32+-0.26, 2.21
W+3jet Sherpa	10.68+-0.56, 3.27	11.40+-0.30, 4.62	8.32+-0.26, 0.76
MadGraph	6.47+-0.92, 1.02	8.04+-0.47, 1.18	11.28+-0.35, 2.17

PseudoData = 95%MadGraph MPI off + 5% Py8 DPS Signal
Background = Pythia8 filtered & Signal = Pythia8 DPS Signal

	dphi	dpt	ds
Pythia8 filtered	33.64+-0.75, 25.71	14.95+-0.51, 62.29	8.55+-0.40, 7.43

PseudoData = 90% MadGraph MPI on + 10% Py8 DPS Signal
Background = First row in table & Signal = Pythia8 DPS Signal

Background	dphi	dpt	dS
Pythia8 filtered	37.50+-0.53, 35.57	21.80+-0.39, 83.63	19.06+-0.32, 6.77
W+0 jets Sherpa	25.75+-0.72, 13.77	15.19+-0.48, 22.84	-2.70+-0.43, 14.19
W+1jet Sherpa	39.08+-0.52, 78.03	32.14+-0.32, 246.64	19.30+-0.31, 27.44
W+2jet Sherpa	15.37+-0.58, 2.77	16.16+-0.32, 4.78	15.08, 0.27, 1.85
W+3jet Sherpa	15.43+-0.57, 2.99	16.13+-0.31, 4.18	13.16+-0.27, 0.65
MadGraph	11.38+-0.89, 0.98	12.86+-0.47, 1.14	15.99+-0.37, 2.02

PseudoData = 95%MadGraph MPI off + 5% Py8 DPS Signal
Background = Pythia8 filtered & Signal = Pythia8 DPS Signal

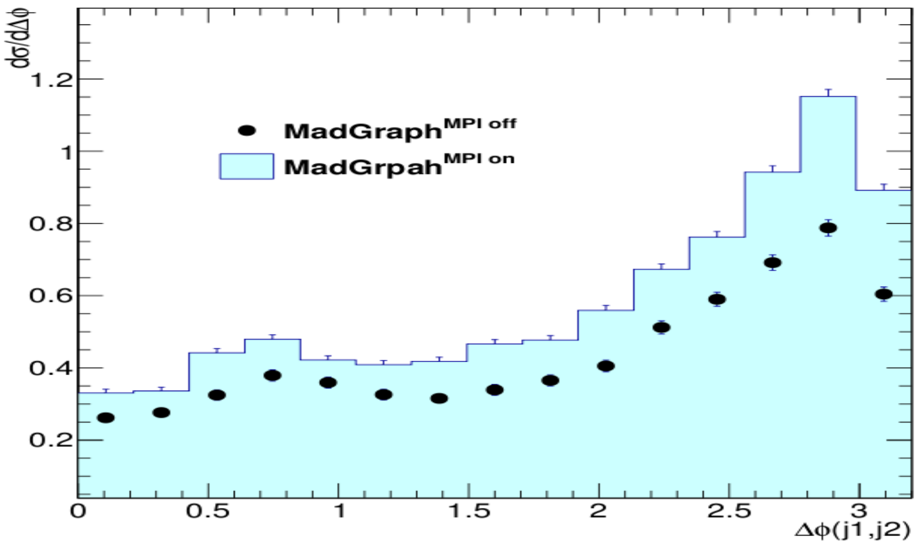
	dphi	dpt	ds
Pythia8 filtered	37.49+-0.76, 23.37	19.88+-0.51, 57.83	13.31+-0.41, 6.99

Background:	dphi	dpt	dS
Pythia8 filtered	29.87+-0.53, 40.99	12.43+-0.36,92.09	10.02+-0.29, 7.67
W+0 jets Sherpa	17.05+-0.75, 15.18	5.32+-0.48, 25.14	8.32+-0.41, 40.51
W+1jet Sherpa	31.34+-0.52, 89.64	23.16+-0.031, 286.29	9.84+-0.030, 32.24
W+2jet Sherpa	5.87+-0.54, 3.28	6.68+-0.29, 5.81	5.55+-0.25, 2.64
W+3jet Sherpa	5.91+-0.50, 3.57	6.66+-0.29, 5.09	3.48+-0.25, 0.90
MadGraph MPI off	1.56+-0.84, 1.05	Fit cant be performed	6.56+-0.37, 2.33

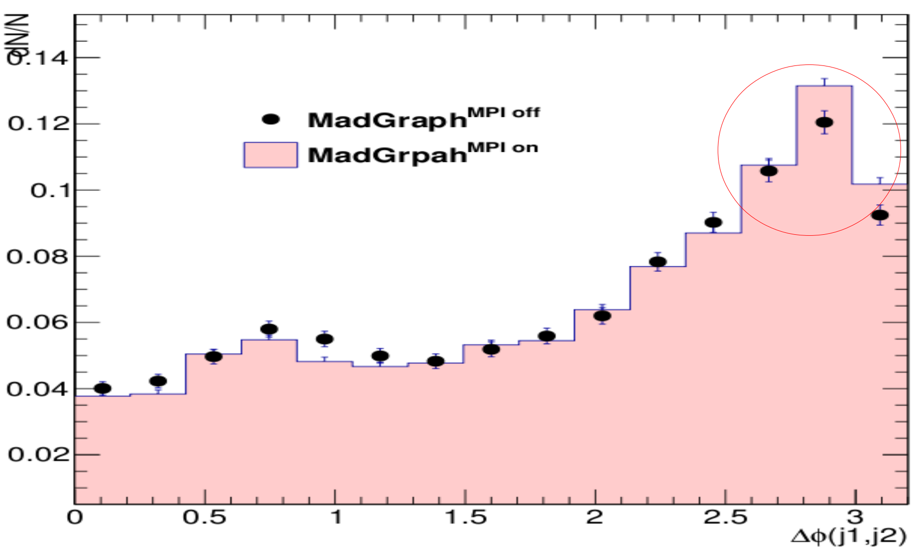
Matrix Element(ME)+Parton Shower MC Event Generator

20<Jet pT<50

Δφ Distribution



- Similar observation for dphi distribution.
- **Effect of switching off MPI is visible in absolute normalization.**
- **but shape remain almost same.**



This almost similar shapes for Signal and background makes it difficult to extract DPS fraction.

Similar studies are performed with **Sherpa** MC Event Generator.

- BUT, **no big difference** in shape with and without MPI in Sherpa is observed as well.

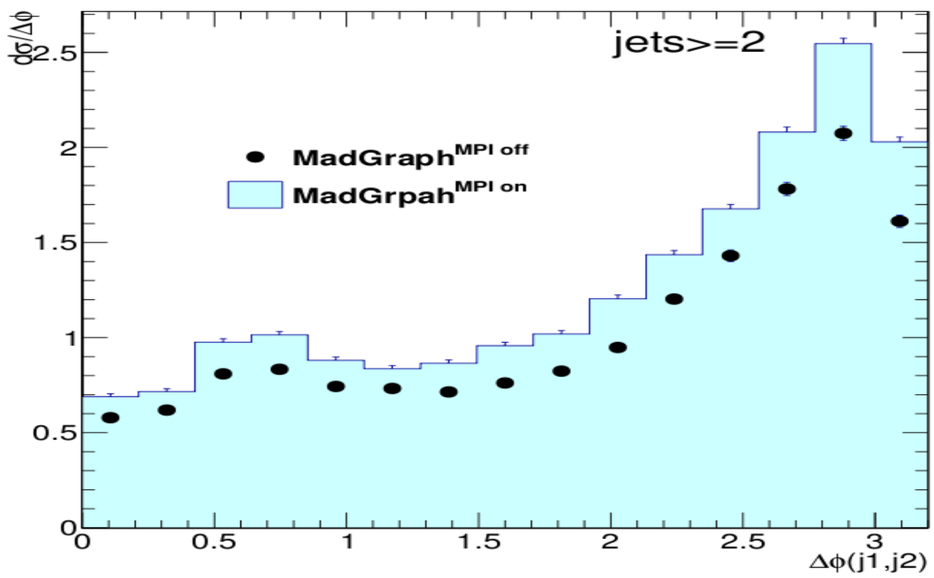
(σ_{eff}) - Most Natural Link to Theories

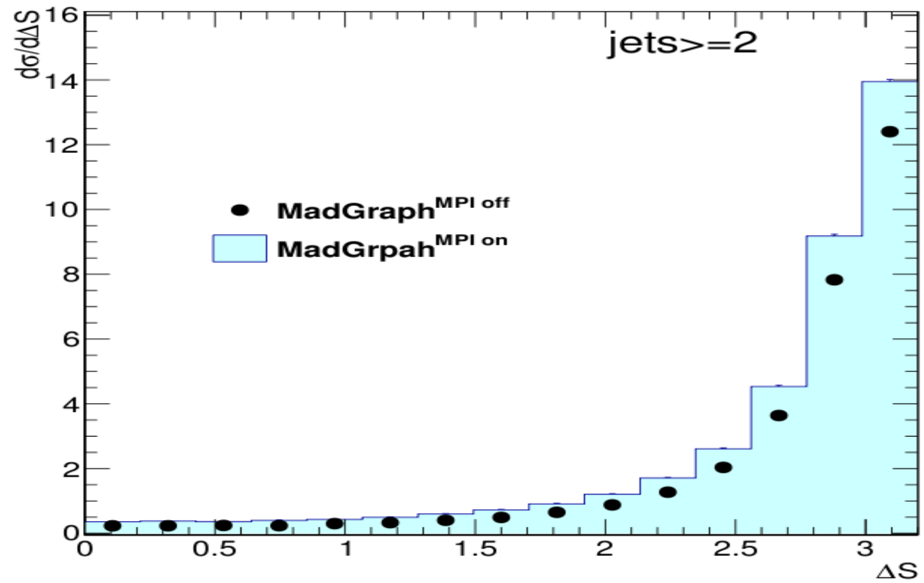
Signal fraction is dependent on the selection cuts.

So, it is always better to quote σ_{eff} rather than Signal fraction, as Sigma-eff is expected to be independent of selection cuts.

Sigma-2j= 0.325mb(POWHEG)
Epsilon-s=0.0784

Extraction of Signal fraction from Absolute Normalization





As can be seen, Effect of MPI Switch(off/on) is significantly visible in absolute normalization, so based on number of events passing the selection, we calculate DPS fraction from MadGraph and Sherpa.

MC used	MPI(off)/MPI(on)	f=S/(S+B)
MadGraph	79.744%	20.256%
Sherpa	83.587%	16.413%