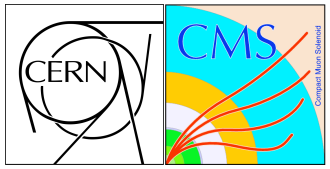


STRATEGIES FOR MPI MEASUREMENTS AT CMS

RADEK OFIERZYNSKI (NORTHWESTERN UNIVERSITY)

MPI@LHC 2010, GLASGOW, UK

Overview of CMS measurements

- Measurements ongoing in
  - 3 jets + γ
  - 4 jets
  - 2 jets + 2 b's
  - same sign W analysis
  - charged mini jets and charged mini jet pairs

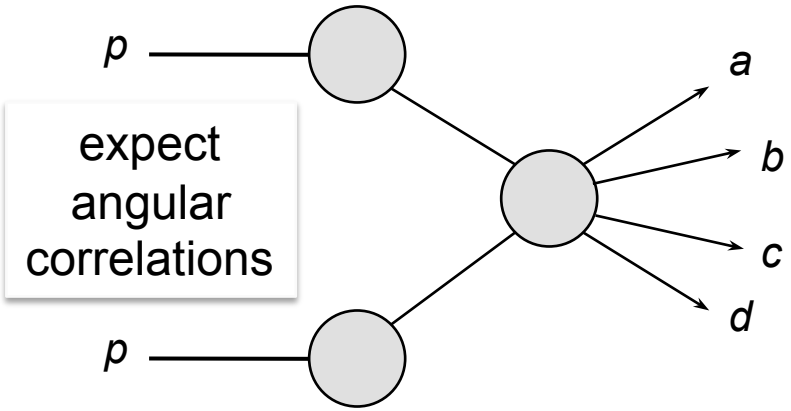
DPS past measurements

- past measurements by:
  - AFS 1987: σ_{eff} ~ 5 mb,
  - UA2 1991: no signal, σ_{eff} > 8.3 mb,
  - CDF 1993: using ~2000 four jet events: $\sigma_{eff} = 12.1^{+10.7}_{-5.4}$ mb;
    1997: using ~14000 events 3 jets + γ/π^0: $\sigma_{eff} = 14.5 \pm 1.7\ ^{+1.7}_{-2.3}$ mb,
    (Treleani: estimated inclusive $\sigma_{eff} \approx 11$ mb)
  - D0 2010: using ~16000 events 3 jets + γ/π^0:
    $\sigma_{eff} = 16.4 \pm 0.3 \pm 2.3$ mb (also in 3 bins of $p_T^{2.jet}$)
- Important measurement with first LHC data
  - understand parton correlations within hadrons, parton distributions
  - ireducible background to production of 4-jet events, important for searches
  - part of LHC MinBias & Underlying Event Working Group (MBUEWG) effort

Double Parton Scattering

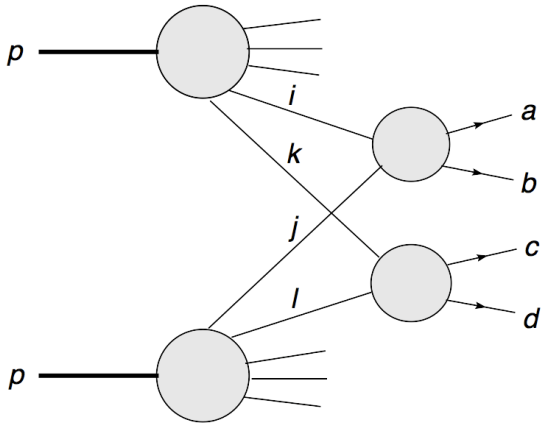
- Two hard interactions in the same proton-(anti-)proton scattering
- Main background: QCD bremsstrahlung

SPS:



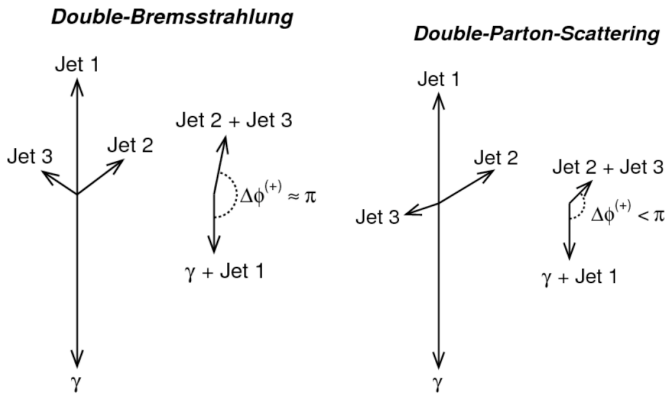
expect angular correlations

DPS:



no angular correlations

- How to identify the pairs of jets ?
  - use p_T balancing
  - don't do it → "democratic" distributions
  - study a final state where pairing is clear



3 Jets & 1 photon

- 1st DPS analysis at CMS that started – shown at MPI08 – along Tevatron experience
- study final state with jet+γ from one, dijet pair from other process
- pair assignment according to p_T balancing, i.e. pairing which minimizes

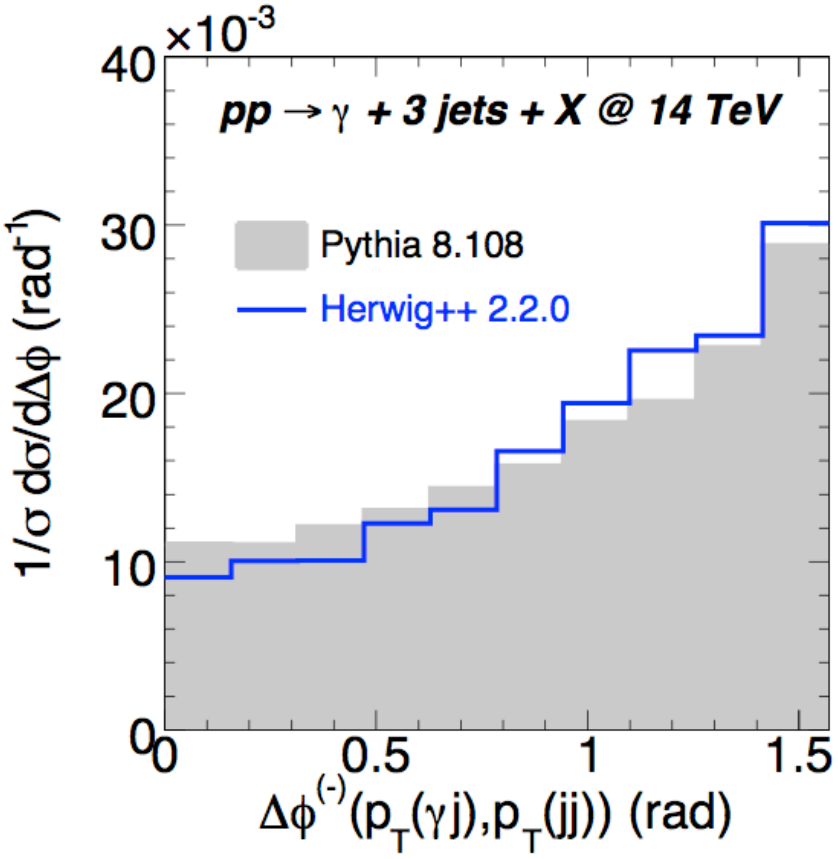
$$\frac{|\vec{p}_T^{\,\gamma} + \vec{p}_T^{\,i}|^2}{|\vec{p}_T^{\,\gamma}| + |\vec{p}_T^{\,i}|} + \frac{|\vec{p}_T^{\,j} + \vec{p}_T^{\,k}|^2}{|\vec{p}_T^{\,j}| + |\vec{p}_T^{\,k}|}$$

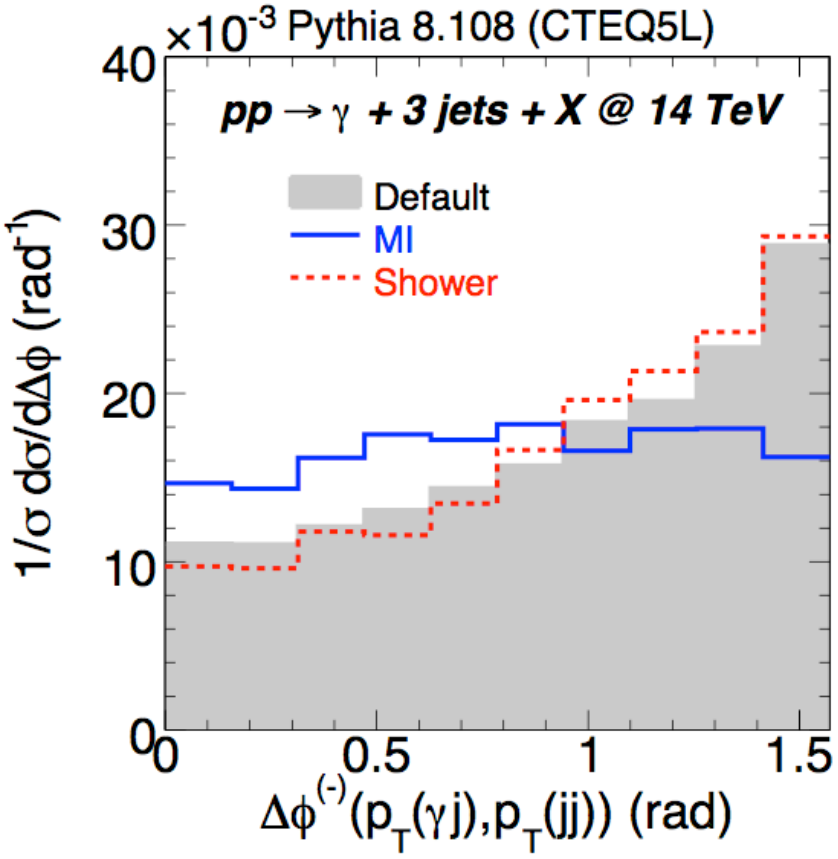
- Preliminary selection:

	CDF	LHC extrapolation
Photon	$\|\eta\| \leq 1.1$	$\|\eta\| \leq 2.5$
	$E_T \geq 16$ GeV	$E_T \geq 50$ GeV
	Cone $R = 0.7$	$k_\perp$ $D = 0.4$
Jets	$\|\eta\| \leq 4.2$	$\|\eta\| \leq 5$
	$E_T \geq 5$ GeV	$E_T \geq 20$ GeV
	$E_{T4} < 5$ GeV	$E_{T4} < 10$ GeV
	$E_{T2}, E_{T3} < 7$ GeV	$E_{T2}, E_{T3} < 30$ GeV

3 Jets & 1 photon

$$\Delta\phi^{(-)} = \angle\left(\vec{p}_T^{\,\gamma} - \vec{p}_T^{\,1}, \vec{p}_T^{\,2} - \vec{p}_T^{\,3}\right)$$

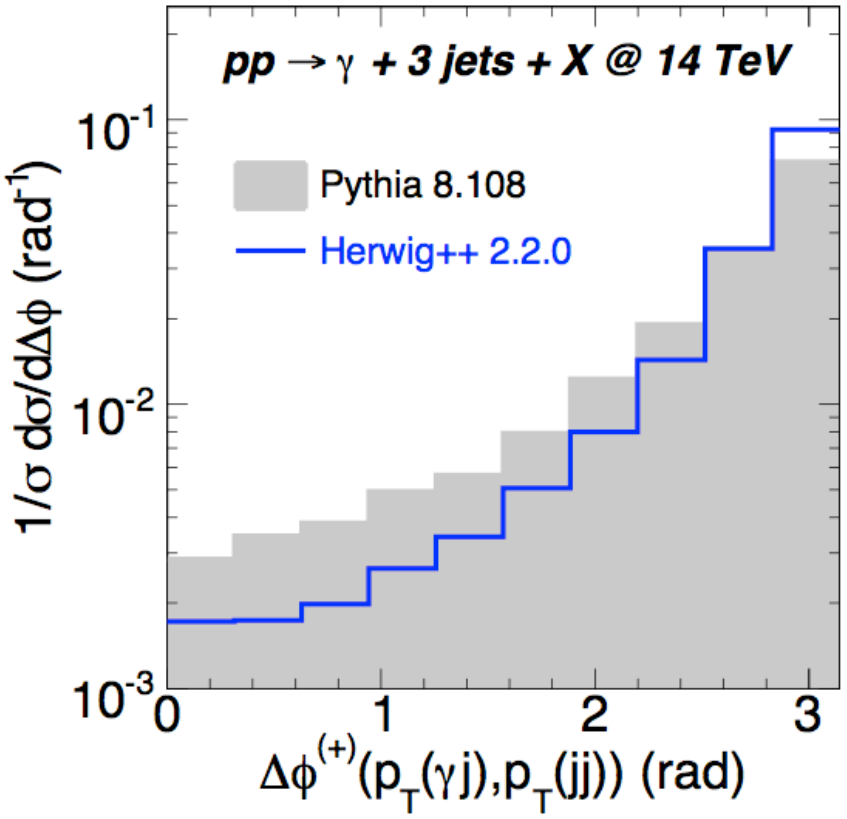


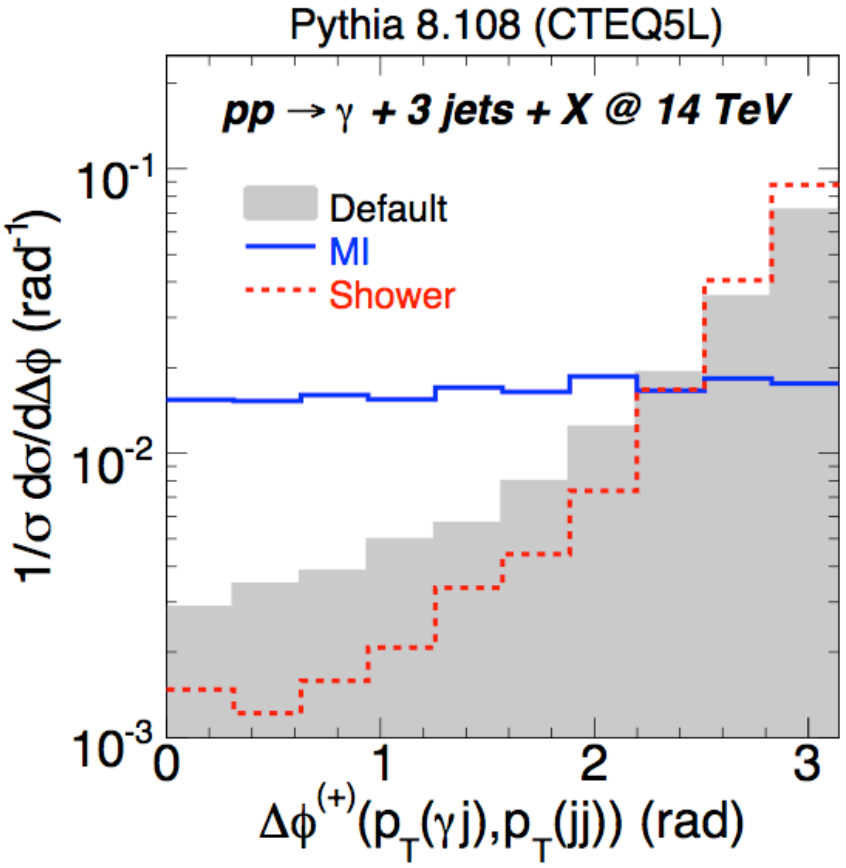


default = PYTHIA out of the box
MI = parton showers switched off
Shower = MI switched off

3 Jets & 1 photon

$$\Delta\phi^{(+)} = \angle\left(\vec{p}_T^{\,\gamma} + \vec{p}_T^{\,1}, \vec{p}_T^{\,2} + \vec{p}_T^{\,3}\right)$$





default = PYTHIA out of the box
MI = parton showers switched off
Shower = MI switched off

Four Jets

- Follow CDF measurement from 1993
- select jets with p_T > 20 GeV, sum of 2 leading jet p_T's > 70 GeV, $|\eta| < 2.4$, some quality cuts, use particle flow jets
- 1st set of observables: select pairing based on p_T balancing:

$$S(i+j,k+l) \equiv \left\{ \left[\left(\frac{|\mathbf{p}_{T_i} + \mathbf{p}_{T_j}|}{\sqrt{p_{T_i} + p_{T_j}}} \right)^2 + \left(\frac{|\mathbf{p}_{T_k} + \mathbf{p}_{T_l}|}{\sqrt{p_{T_k} + p_{T_l}}} \right)^2 \right] / 2 \right\}^{1/2}$$

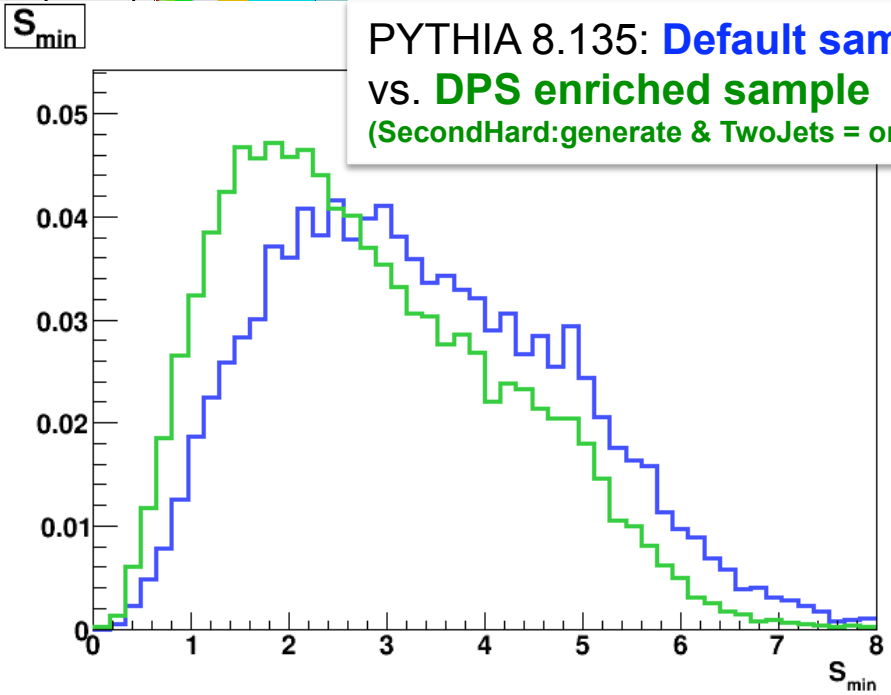
minimized over the 3 possible jet pairings

  - angular correlations: use azimuthal angle between sum of paired p_T's → Δ_S (same as $\Delta\phi^{(+)}$)

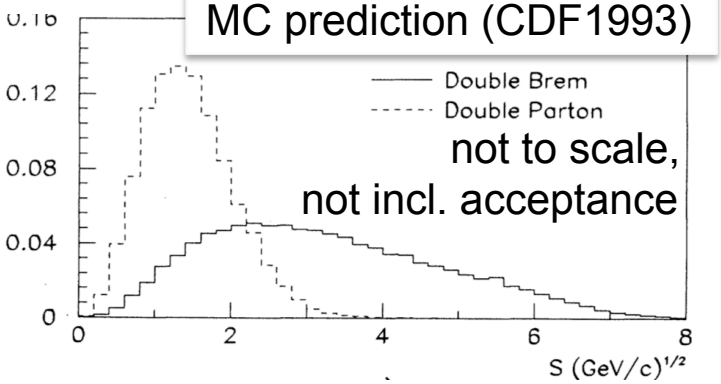
- 2nd set of observables:
  following Berger, Jackson, Shaughnessy, Phys. Rev. D 81, 014014 (2010)
  → plot all combinations of pairing

Four Jets - S_{min}

PYTHIA 8.135: **Default sample**
vs. **DPS enriched sample**
(SecondHard:generate & TwoJets = on)

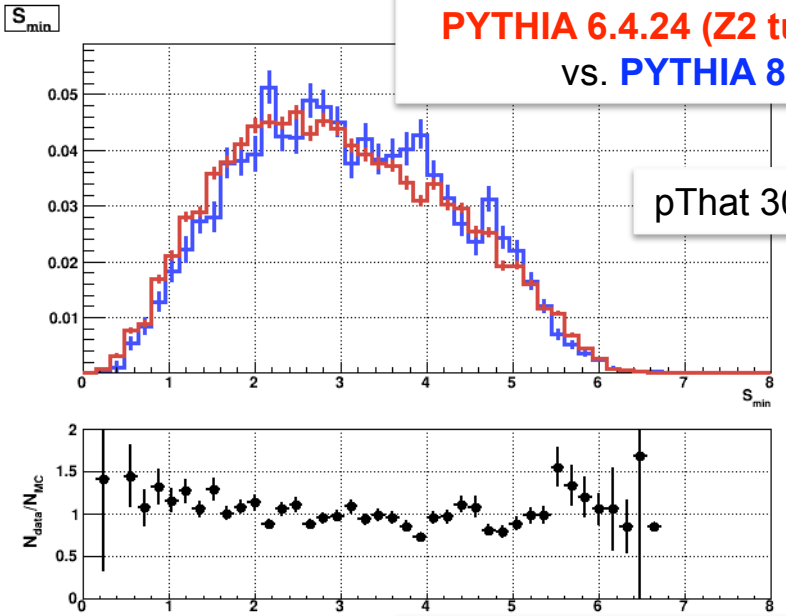


MC prediction (CDF1993)



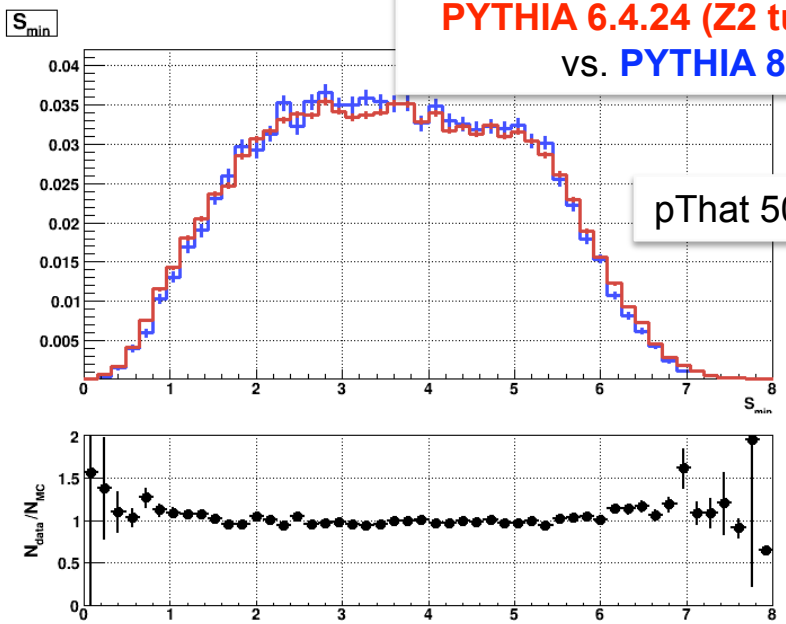
PYTHIA 6.4.24 (Z2 tune)
vs. **PYTHIA 8.140**

pThat 30-50

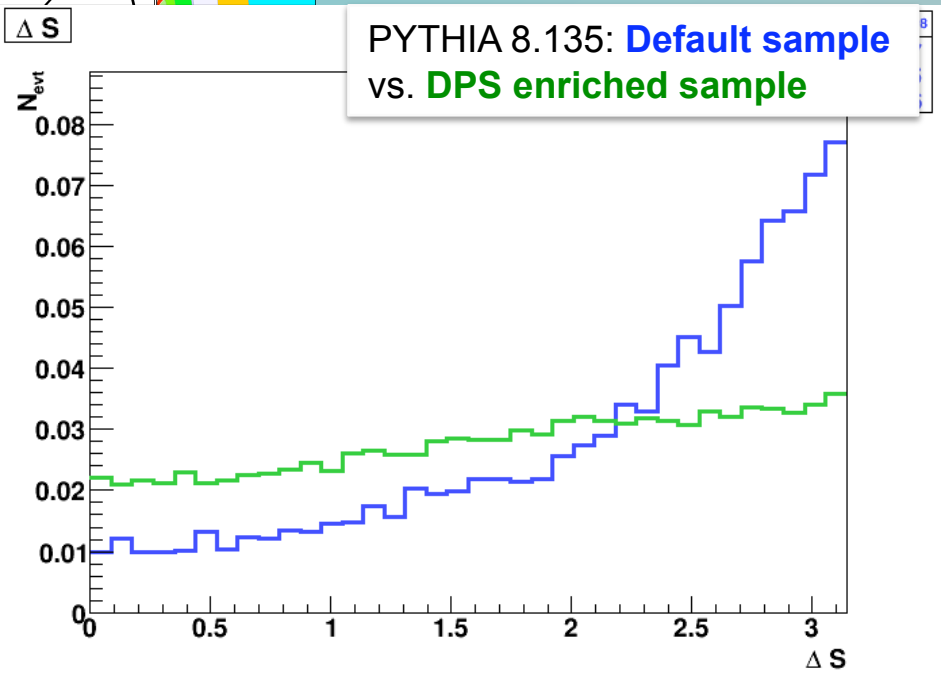


PYTHIA 6.4.24 (Z2 tune)
vs. **PYTHIA 8.140**

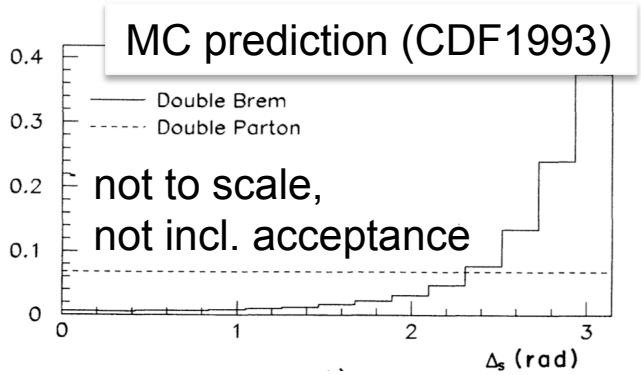
pThat 50-80



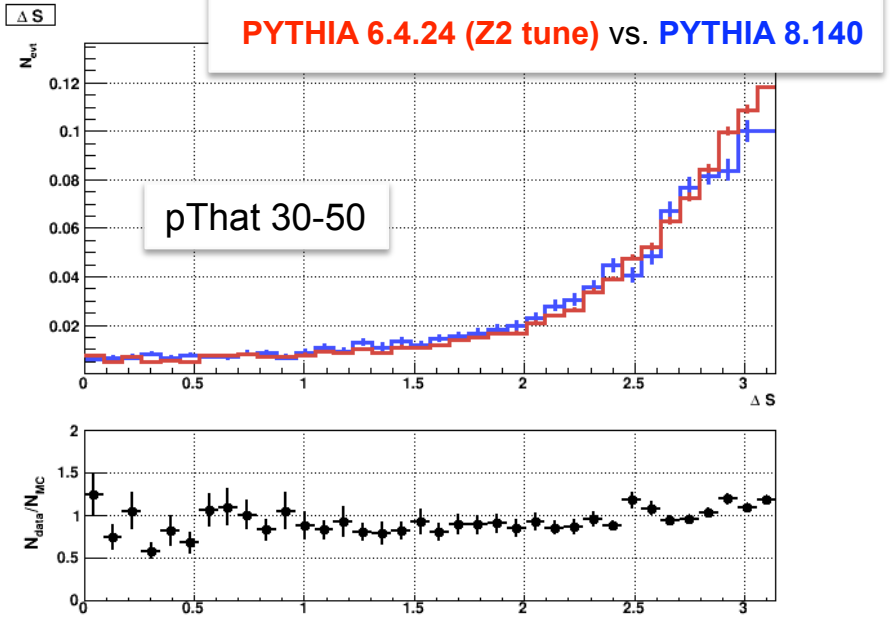
Four Jets - Δ_S



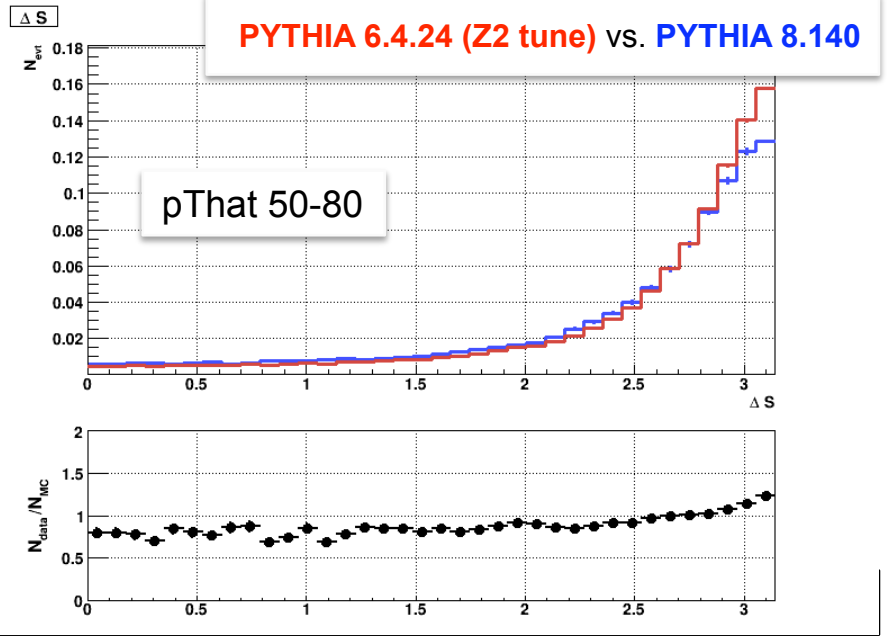
PYTHIA 8.135: **Default sample** vs. **DPS enriched sample**



MC prediction (CDF1993)

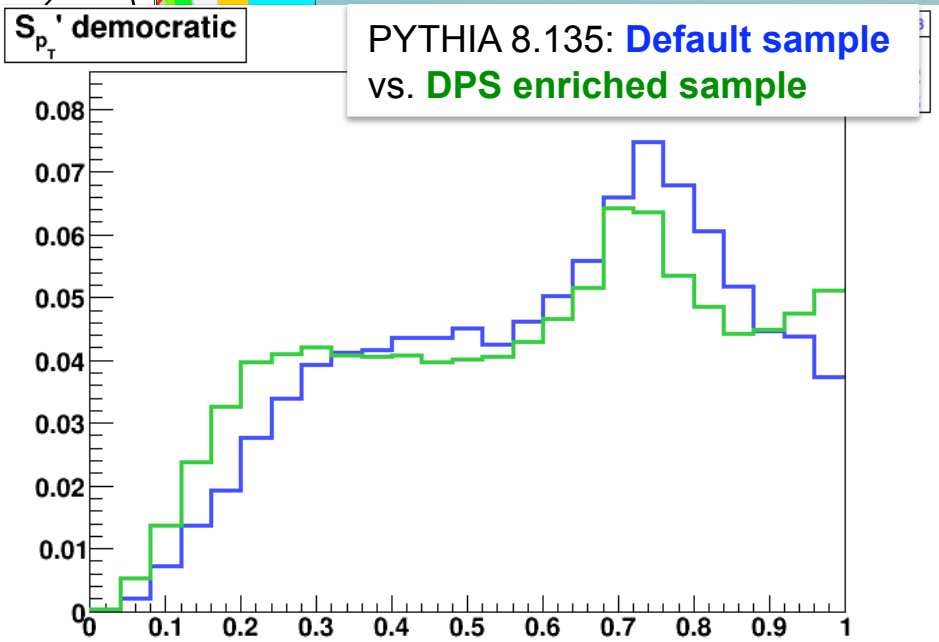


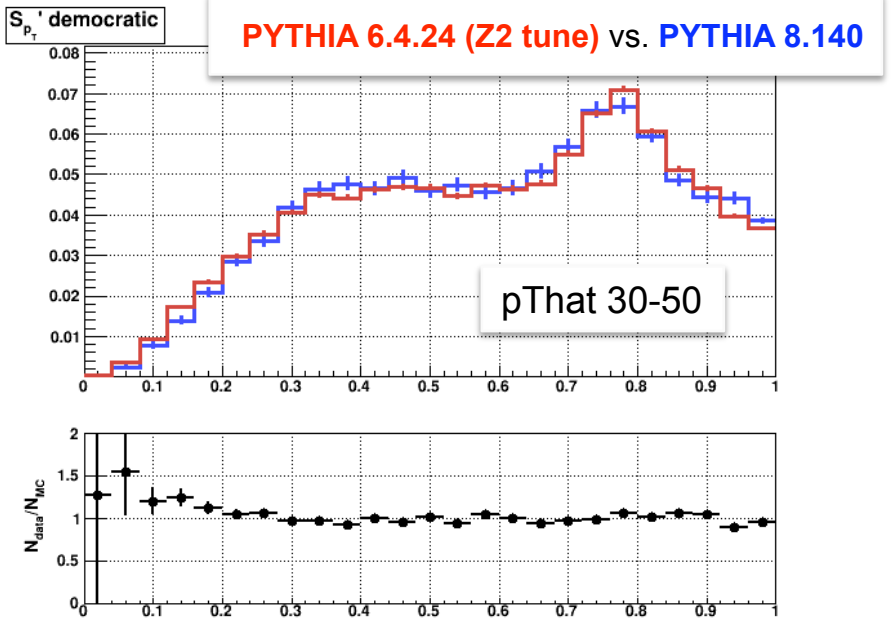
PYTHIA 6.4.24 (Z2 tune) vs. **PYTHIA 8.140**



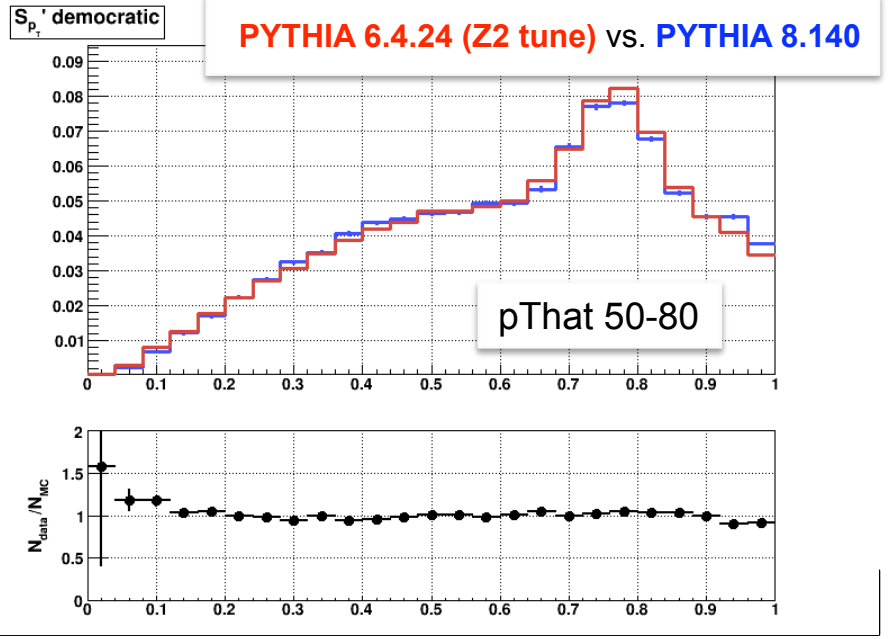
PYTHIA 6.4.24 (Z2 tune) vs. **PYTHIA 8.140**

Four Jets – $S_{pT,\ democratic}$

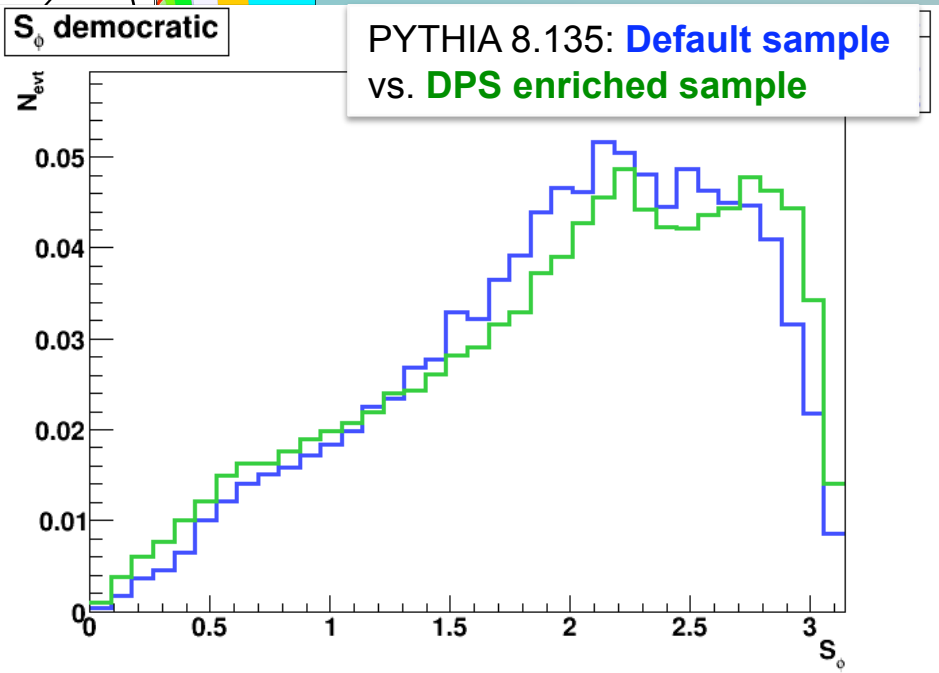


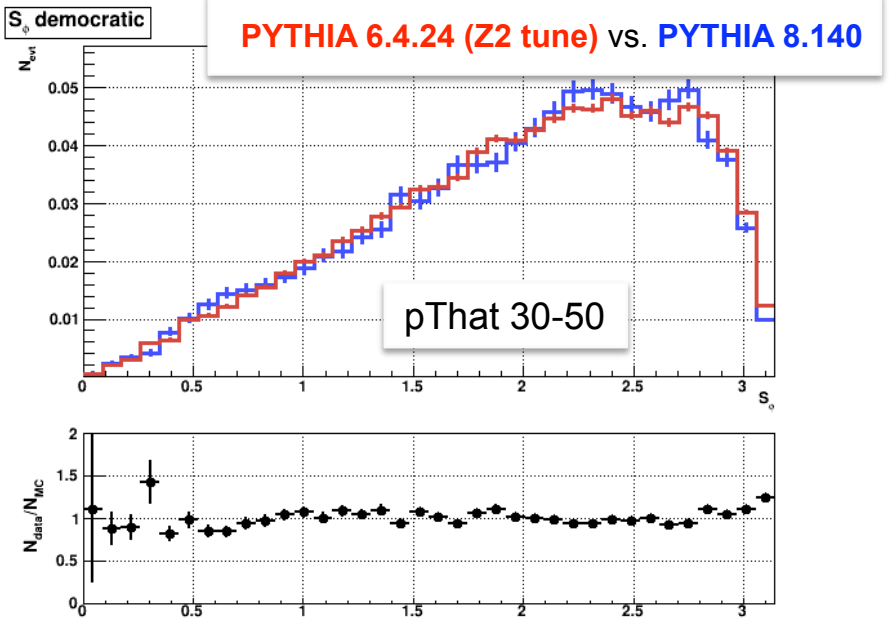


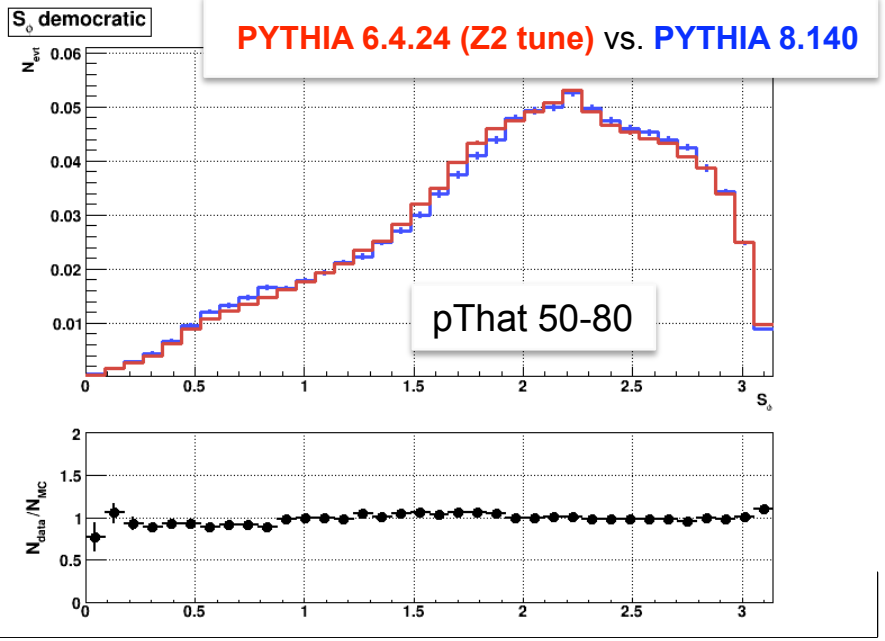
$$S'_{p_T} = \frac{1}{\sqrt{2}}\sqrt{\left(\frac{|p_T(j_a, j_b)|}{|p_T(j_a)| + |p_T(j_b)|}\right)^2 + \left(\frac{|p_T(j_c, j_d)|}{|p_T(j_c)| + |p_T(j_d)|}\right)^2}$$



Four Jets – S_ϕ, democratic



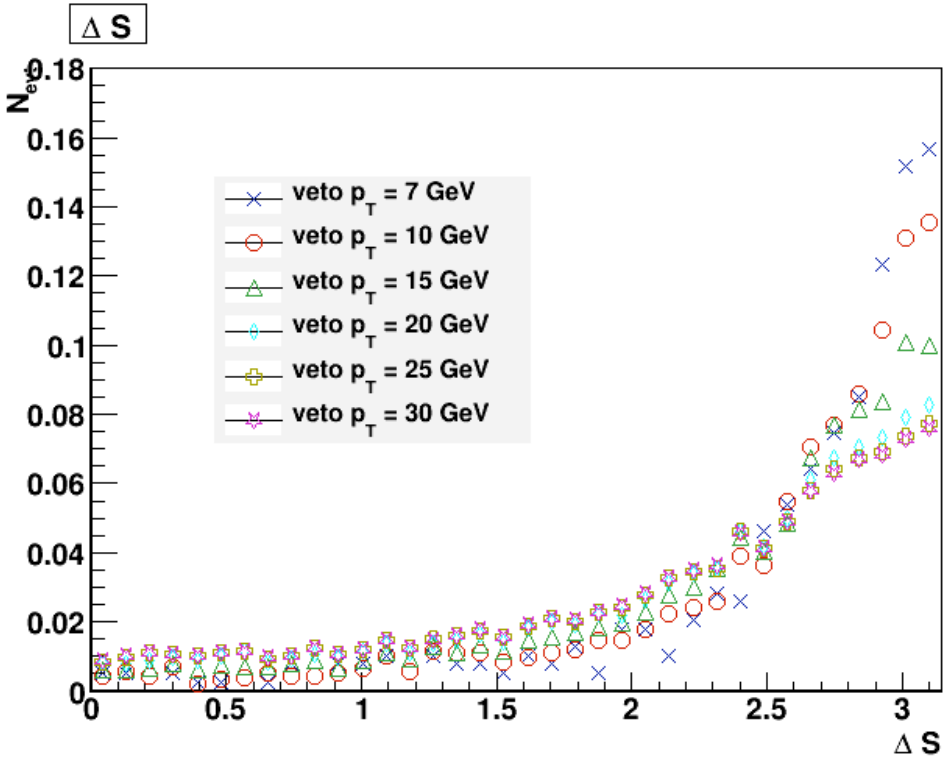


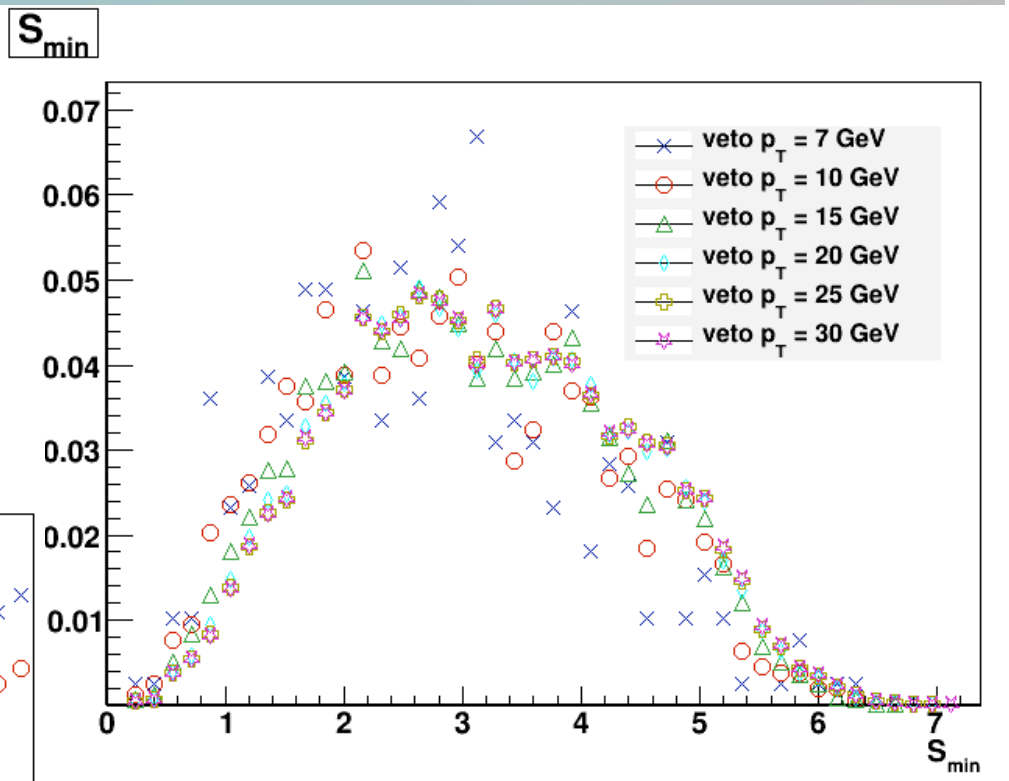


$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\Delta\phi(j_a, j_b)^2 + \Delta\phi(j_c, j_d)^2}$$

Four Jets – inclusive vs. exclusive

Plot observables with various vetoes on the 5th jet p_T (PYTHIA 8)



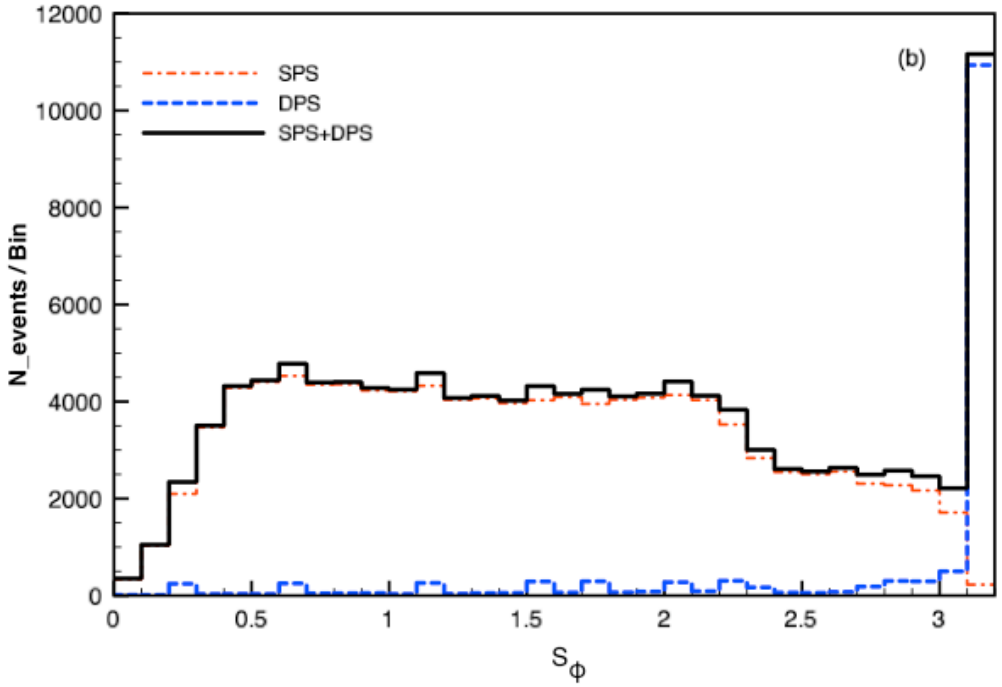


higher threshold ⇒
more MPI-signal-like

Two Jets & Two b's

- use two b-tagged and two anti-b-tagged jets to determine the pairing → no minimization, no "democracy"
- selection as for 4 jets, but raise minimum p_T to 25 GeV
- use b-tagging algo based on track counting, loose working point (but c's are also fine)

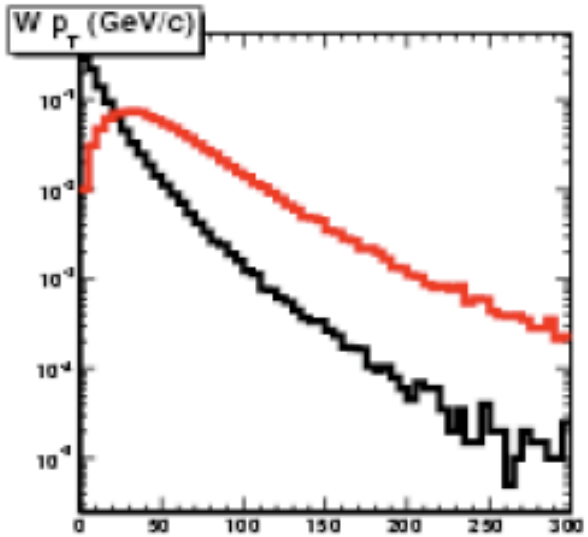
from Berger, Jackson, Shaughnessy 2010

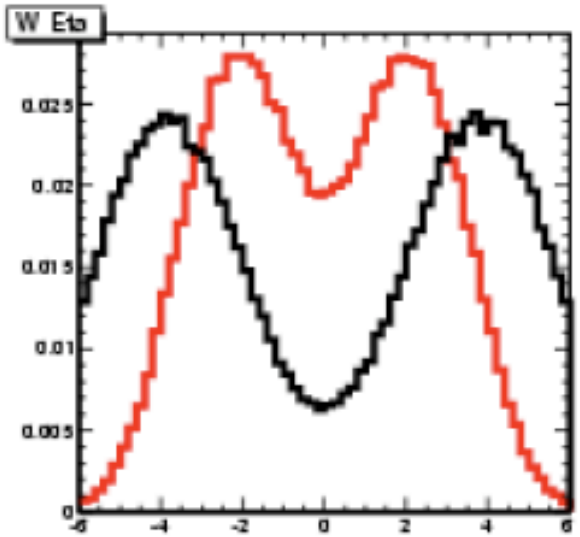


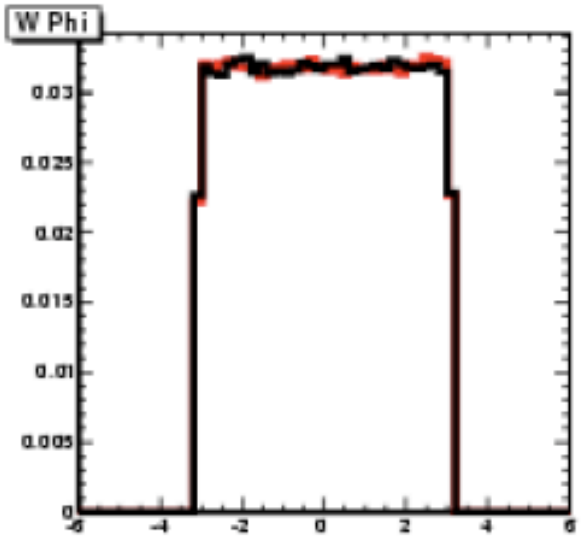
Same Sign W Analysis

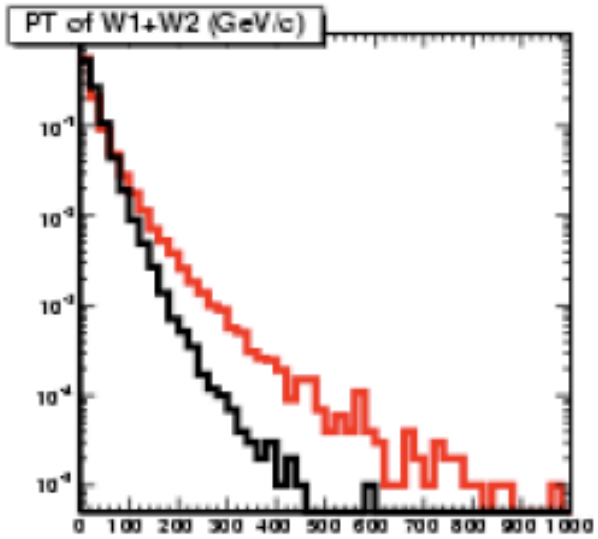
- Starting up analysis of same sign W boson production
- requires high luminosity O(1fb^{-1})
- benchmark process for study of DPS (Gaunt et al, arxiv:1003.3953)
- Same-sign WW has no irreducible background
- Same-sign WW is an irreducible background to same-sign leptons SUSY/Exotica searches
- Selection like opposite sign WW analysis so normalization to it is possible

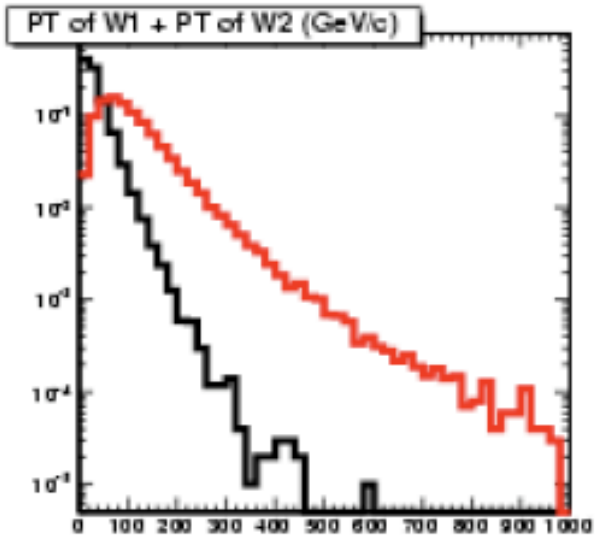
DPS WW vs SPS WW: W distributions

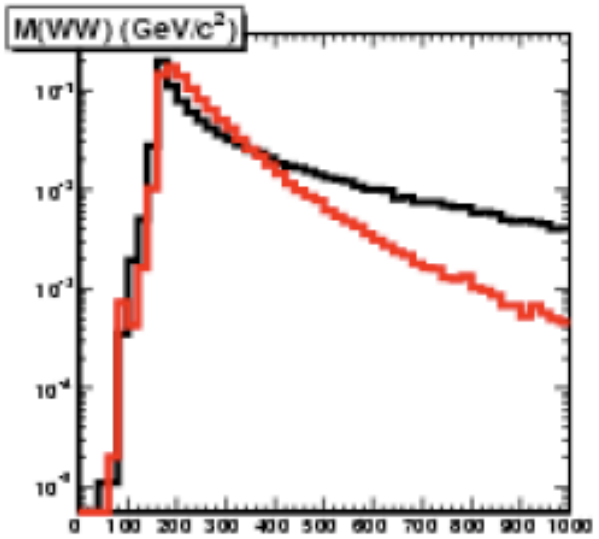












Charged Mini-Jets

- Treleani 2007: use jets down to very low p_T to reconstruct a signature of hard & semi-hard collisions, by pairing them according to basic kinematic criteria → count detectable collisions as a function of their minimum allowed p_T

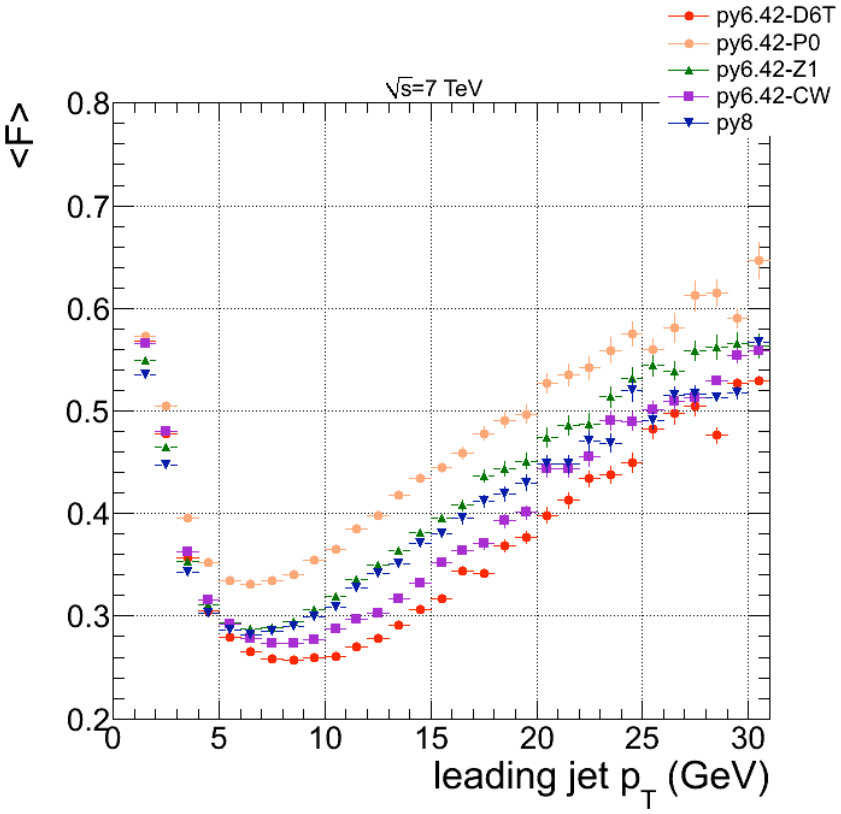
- Use excellent CMS tracking to reconstruct charged tracks jets down to the scale of a GeV
- Loss of neutral component, but no noise problems and granularity issues from calorimetry
- Analyze jets with $p_T > 2$ GeV in minimum bias pp collisions

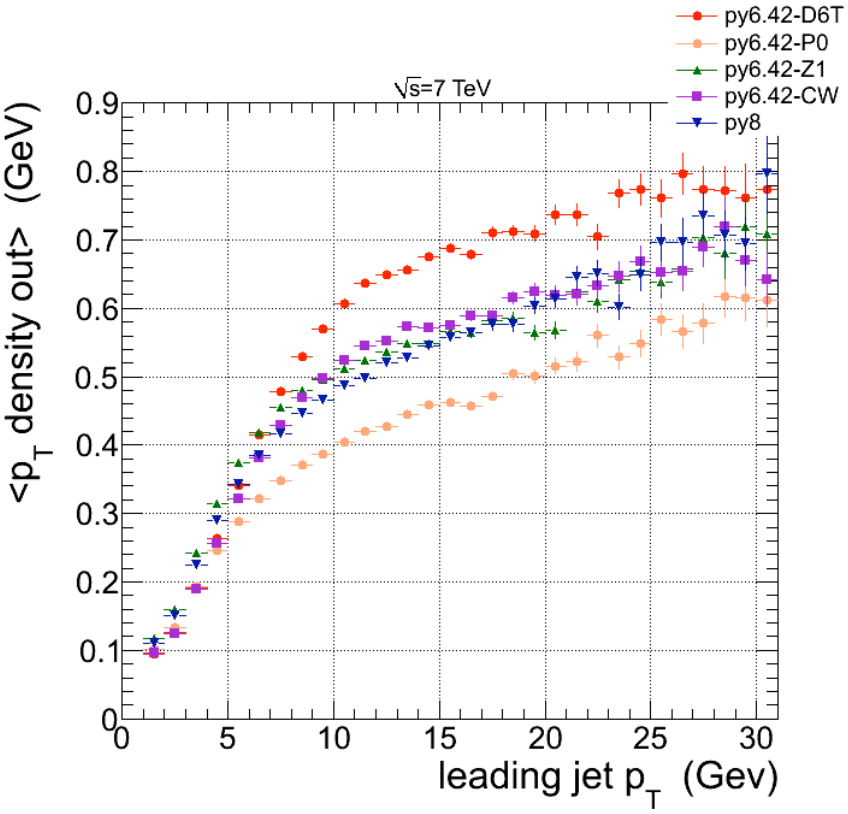
Charged Mini-Jets: Lead. Jet Shape

leading jet transverse momentum fraction inside core of the jet

$\langle F \rangle = \langle \sum pT(R=0.1) / \sum pT(R=0.5) \rangle$ vs. pT1

Transverse momentum densitiy around axis of leading jet, integrated over pseudorapidity range $1.5 < \eta < 2.5$

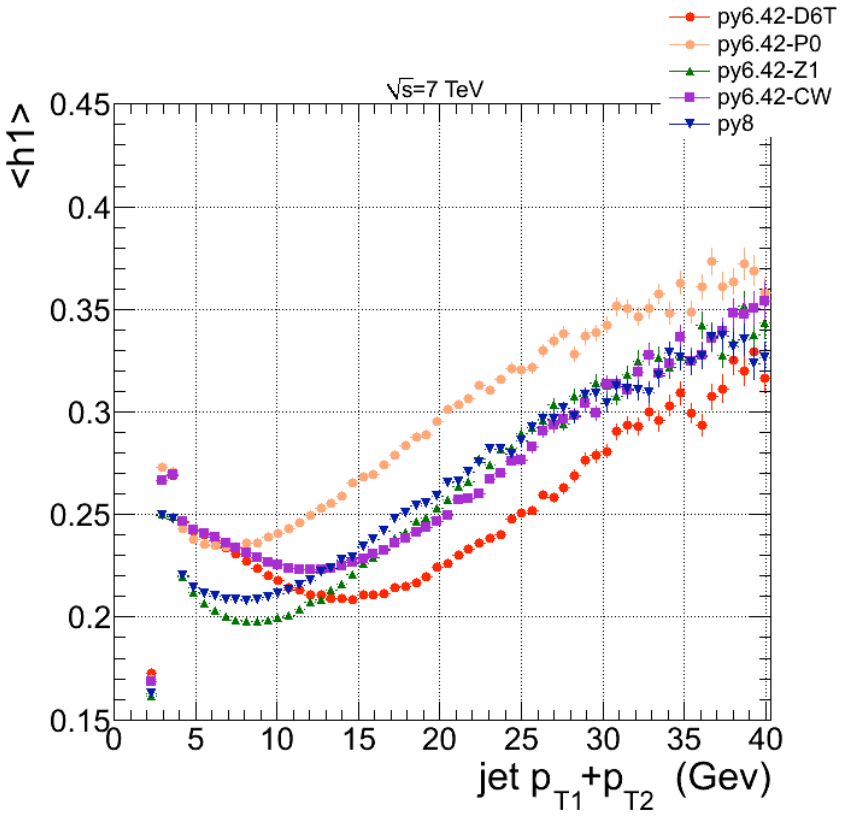




Charged Mini-Jets: Event Shape

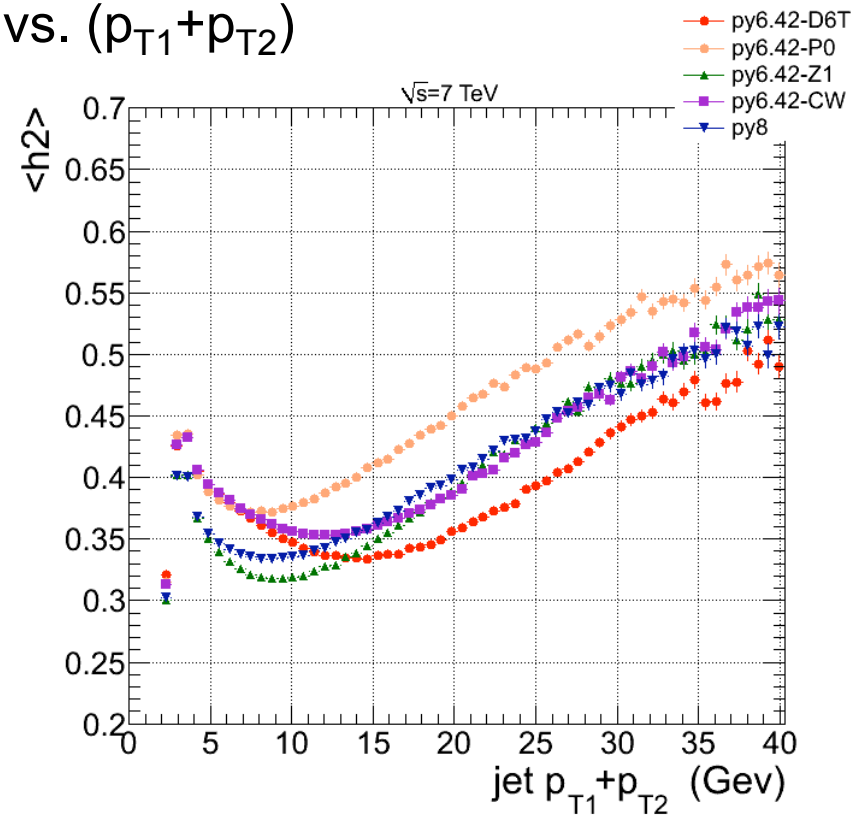
p_T fraction of leading jet to the total p_T of the event:

$\langle h_1 \rangle = \langle p_{T1}/\Sigma p_T \rangle$ vs. $(p_{T1}+p_{T2})$



p_T fraction of leading and next-to -leading jet to the total p_T of the event:

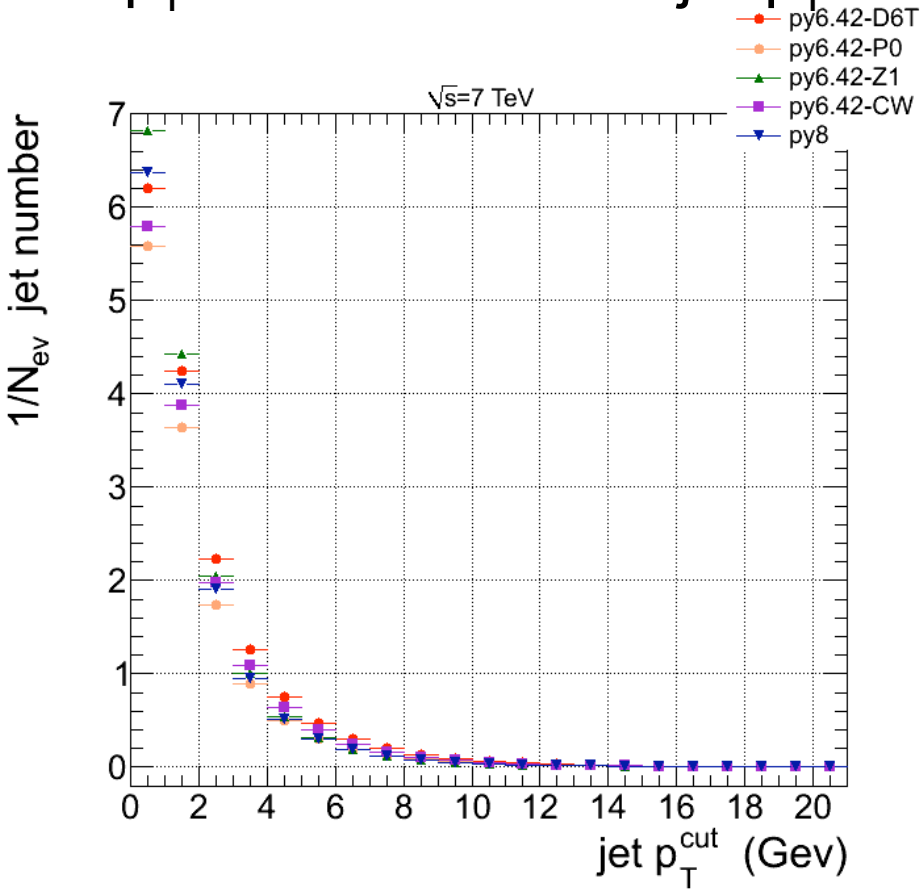
$\langle h_2 \rangle = \langle (p_{T1}+p_{T2})/\Sigma p_T \rangle$ vs. $(p_{T1}+p_{T2})$

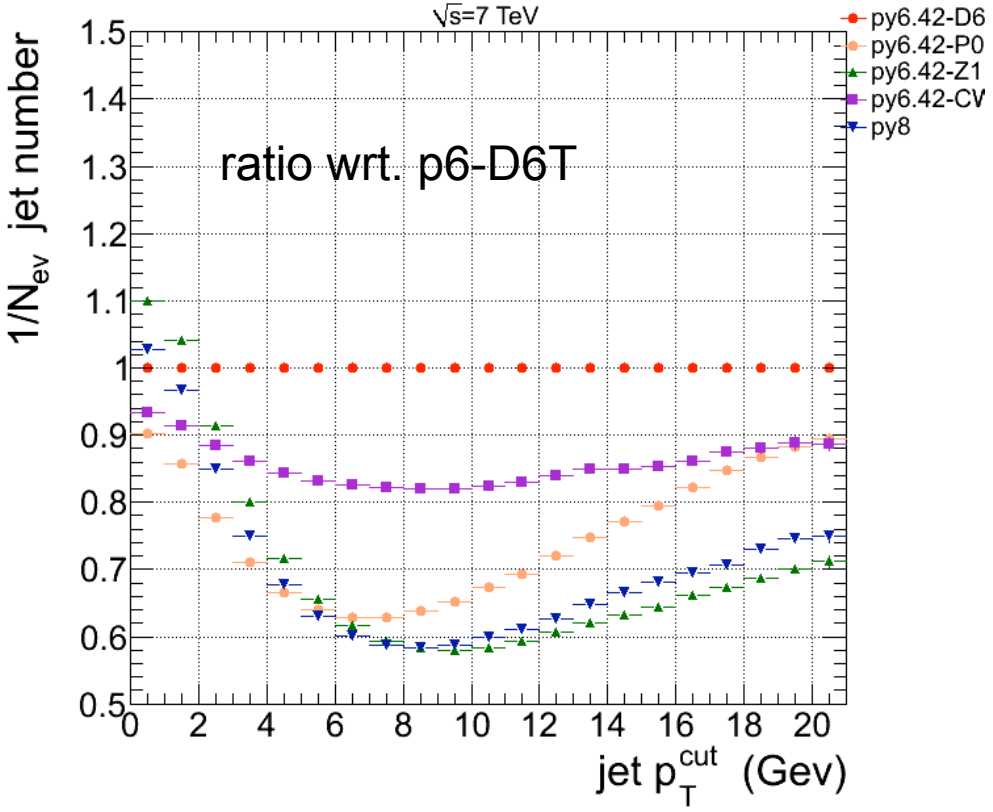


Linked to the scale of transverse momentum of the hard interaction

Charged Mini-Jets

Observables connected to number of parton interactions in the event:
average number of jets per event with $p_T > p_T^{cut}$
p_T^{cut} – threshold on jet p_T



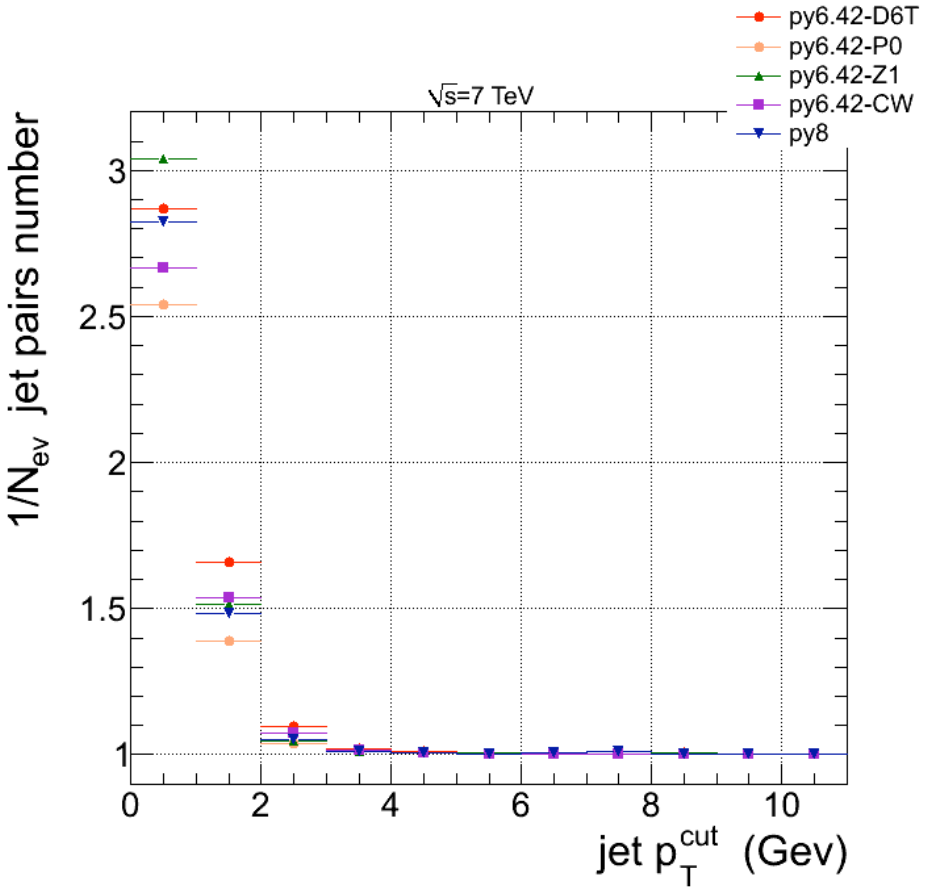


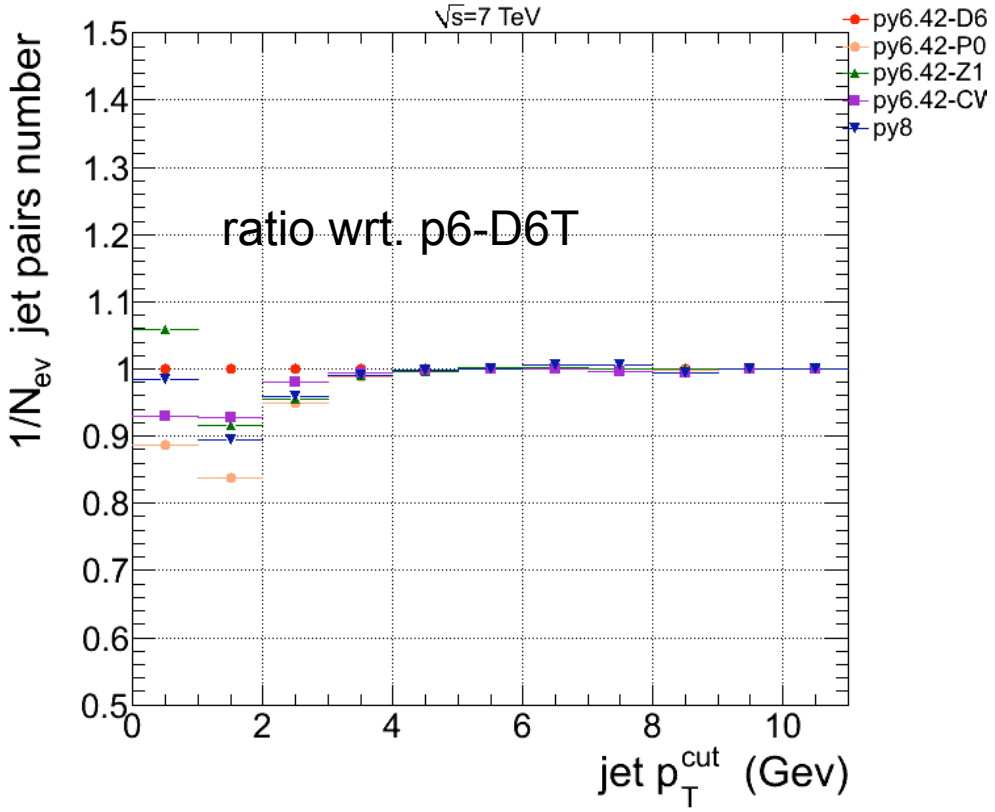
Charged Mini-Jet Pairs

average number of jet pairs per event with $p_T > p_T^{cut}$

p_T^{cut} – threshold on jet p_T

pairs assigned according to p_T with constraint on $\Delta\phi$ and p_T ratio





→ study evolution of parton interaction activity with energy scale

Summary

- Moving forward from average measurements (UE) to the investigation of the topology of Multiple Parton Interactions, re-starting from Double Parton Scattering

- Which is the impact of the initial state? (qq vs gg MPIs)
- Which is the impact of the Energy scale of the leading interaction?
- Are MPI x-sections really mostly driven just by geometrical features?
- To what extent MPIs are independent from each other? (correlations)
- Is the color flowing between different interactions?
- Are the popular MC MPI models adequate to describe double, triple, quadruple... interactions?

- CMS has several analyses already running to improve our understanding of MPIs
- Expect first results for winter conferences