Double Parton Scattering with Herwig++

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8^{th} MCnet meeting, 24 September 2010

FNSPE CTU, Prague

Multiple Parton Scattering

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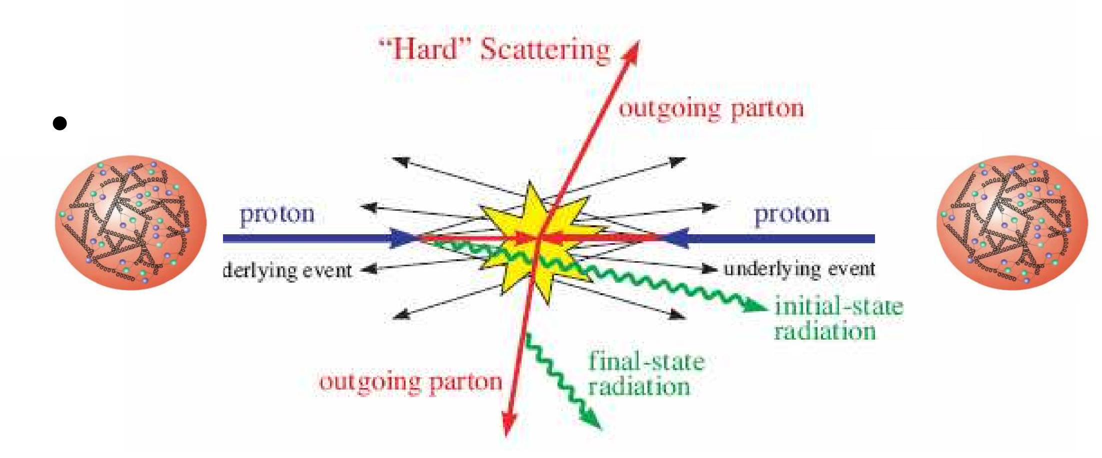
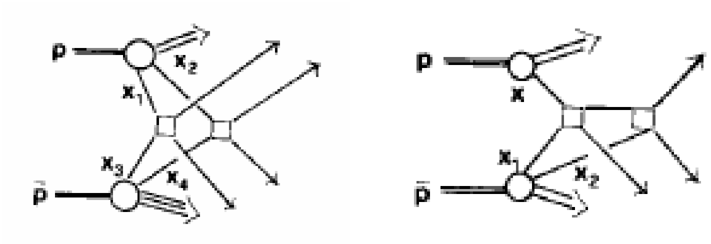


Double (multiple) parton scattering *(DPS / MPS)* = process, where two (more) parton-parton interactions occur in one hadron-hadron interaction

Disconnected scattering vs. Rescattering



DPS cross section :

$$\sigma_D = \frac{m}{2} \int_{p_T^c} \Gamma_A(x_1, x_2; b)\hat{\sigma}(x_1, x_1')\hat{\sigma}(x_2, x_2')\Gamma_B(x_1', x_2'; b)dx_1 dx_1' dx_2 dx_2'$$

Multiple Parton Scattering

- Poissonian model: $$\sigma_N = \int \frac{1}{N!}\Big(\sigma_S F(b)\Big)^N d^2b$$
  - assumes no correlations for partons inside the hadron
  - allows the simple factorization of complex distribution function:
  $$\Gamma(x_1, x_2; b) = f(x_1) f(x_2) F(b)$$
  - limited for low x region (mostly true)
  - all the information about spatial distribution in transverse space is integrated into

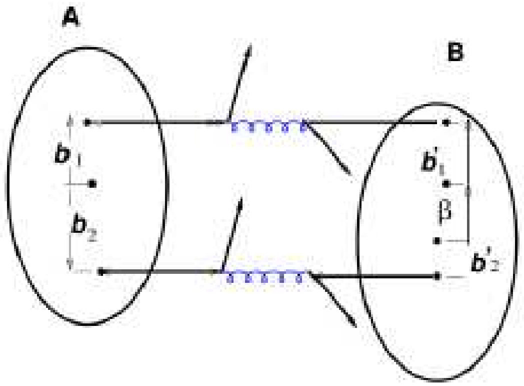
DPS cross section is then simple: $$\sigma_D = \frac{1}{2}\frac{\sigma_S^2}{\sigma_{eff}}$$

Effective cross section: $$\sigma_{eff}^{-1} = \int \Big[F(b)\Big]^2 d^2b$$

- dPDF's: (e.g. GS08)
  - considering long. mom. correlations and conservation
  - obeying double DGLAP equation
  - the dPDFs and sPDFS are related by sum rules, e.g.

$$\sum_a \int_0^{1-x_2} dx_1 x_1 f_{ab}(x_1, x_2; Q^2) = (1-x_2) f_b(x_2, Q^2)$$

Herwig++: Eikonal Model



- At fixed impact parameter **b** partons interact independently
  – Poissonian distribution
- Mean number of scatters is (for general sub-processes):

$$\langle n(b=|\mathbf{b}|,s)\rangle = \int \mathrm{d}^2\mathbf{b}' \int_{p_T^{\min 2}} \mathrm{d}p_T^2 \sum_{ij} \frac{1}{1+\delta_{ij}} \frac{\mathrm{d}\hat{\sigma}_{ij}(x_1\sqrt{s}, x_2\sqrt{s}, p_T^2)}{\mathrm{d}p_T^2}$$

$$\otimes G_{i/h_1}(x_1, \mathbf{b}-\mathbf{b}', \mu^2) \otimes G_{j/h_2}(x_2, \mathbf{b}', \mu^2) \quad = A(b)\cdot\sigma^{\mathrm{inc}}(s; p_T^{\min})$$

- p_T^{min} and μ^2 are important steering parameters for UE tune
  - There is a strong and constant correlation between p_T^{min} and μ^2: the smaller hadron radius always balance against a larger p_T cutoff (for UE activity)
  - Old tune (H++ 2.3.0): p_T^{min} = 3.4 GeV, μ^2 =1.5 GeV^2
  - New tune (H++ 2.4.2): p_T^{min} = 4.1 GeV, μ^2 =1.33 GeV^2
- Inclusive cross section (k int. of type 1, m int. of type 2):

$$\sigma_{k,m}(\sigma_a,\sigma_b) = \int \mathrm{d}^2b \;\; \mathcal{P}_k(A(b)\sigma_a)\; \mathcal{P}_m(A(b)\sigma_b) \;=\; \int \mathrm{d}^2b \; \frac{(A(b)\sigma_a)^k}{k!}\, e^{-A(b)\sigma_a} \; \frac{(A(b)\sigma_b)^m}{m!}\, e^{-A(b)\sigma_b}$$

Herwig++: Eikonal Model

- Generation algorithm:
  - factorization:

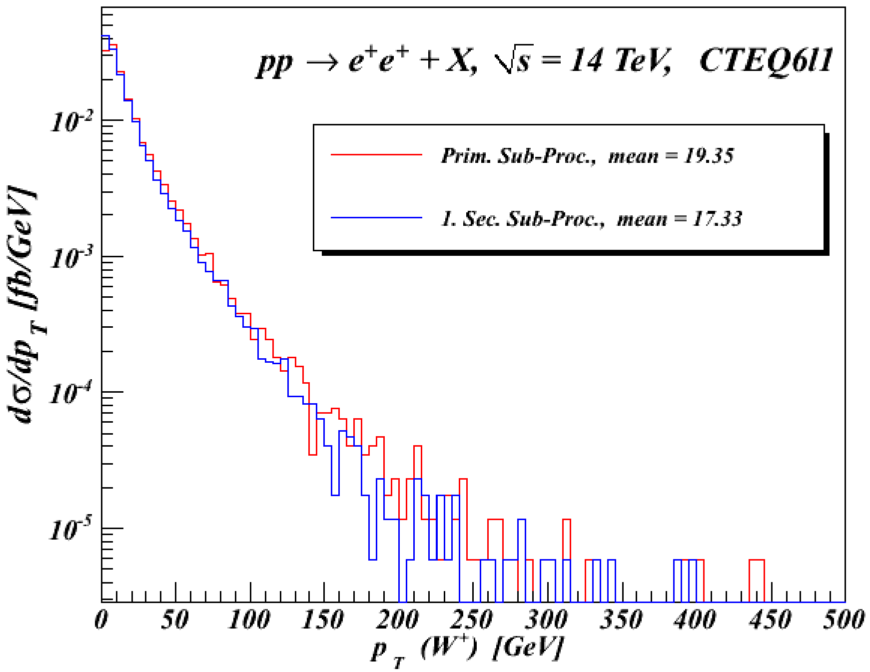
$$G(x, \mathbf{b}, \mu^2) = f(x, \mu^2) \cdot S(\mathbf{b})$$

  - elmag. form factor-like form:

$$S_{\bar{p}}(\mathbf{b}) = S_p(\mathbf{b}) = \int \frac{d^2\mathbf{k}}{2\pi} \frac{e^{i\mathbf{k}\cdot\mathbf{b}}}{(1+\mathbf{k}^2/\mu^2)^2}$$

  - Overlap function evaluation:

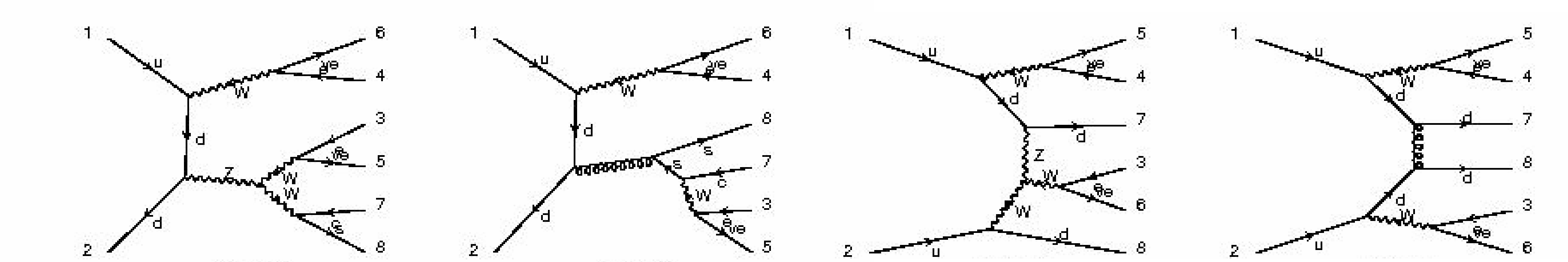
$$A(b) = \frac{\mu^2}{96\pi}(\mu b)^3 K_3(\mu b)$$



- Primary Sub-Process untouched
- 1st Secondary Sub-Process forced to be same ME
- Other Sub-Processes (till <n>) QCD 2→2
- Event veto for momentum conservation violation
- no p_T ordering (unlike e.g. Pythia)

Process: $p+p \rightarrow W^{+}+W^{+}+X$

- Signal process: (DPS): 2 (hard) independent $qq \rightarrow W^{+} \rightarrow e^{+}\nu_{e}$ sub-processes
- Background:
  - (SPS) SM $e^{+}e^{+}$ + jj production:



  - SM $W^{+}Z$ and ZZ production

    - while electron is outside the detector acceptance $|\eta|< 2.5$ (Atlas ID)

    - no detector effects are considered (for now)
  - heavy flavor quark production
  - DPS and pile-up effects are assumed to be negligible

Process: Generation

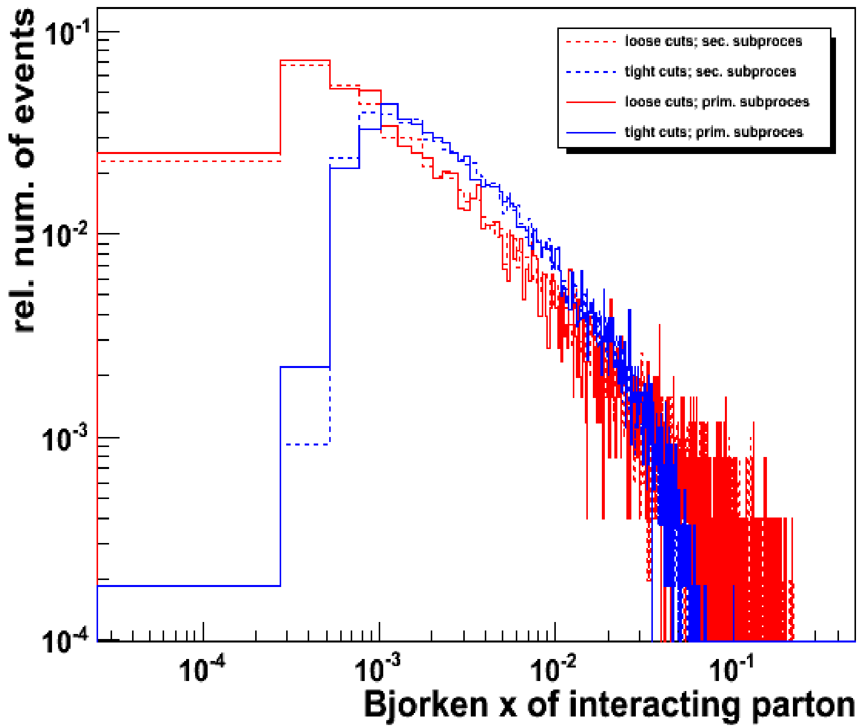
- DPS: Herwig++ 2.4.2
- SPS: Madgraph v.4 + Herwig++
- $\sqrt{s}$ = 7 & 14 TeV; PDF: cteq6l1, mrst2007lomod.lhgrid
- set MPIHandler:softInt Yes
- set MPIHandler:twoComp Yes

(soft inv. radius squared: 7TeV(cteq): 0.51 GeV^2, (mrst): 0.49 GeV^2,
14TeV(cteq): 0.47 GeV^2, (mrst): 0.43 GeV^2)

- Herwig++ (DPS generation):
  - insert SimpleQCD:MatrixElements[0] MEqq2W2ff
  - set MEqq2W2ff:Wcharge 1 #only W+
  - set MEqq2W2ff:Process 3 #only positrons
  - set LeptonKtCut:MinKT 0.001*GeV
  - set LeptonKtCut:MaxEta 5
  - set LeptonKtCut:MinEta -5
  - set MassCut:MinM 0.002*GeV

Tight vs. loose generation cuts

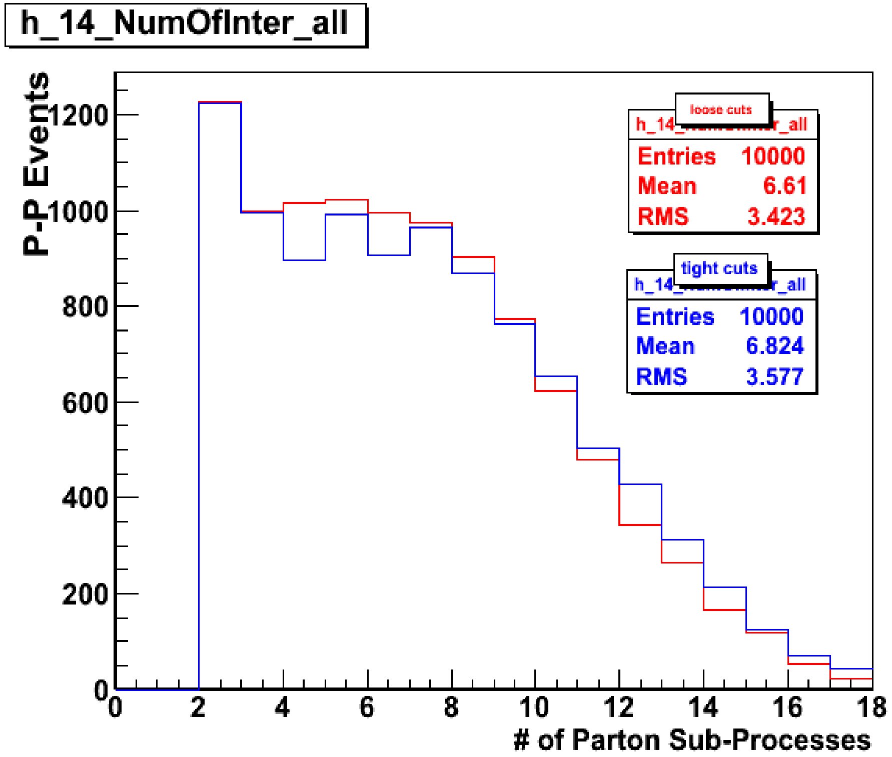
- cross section depends significantly on the cuts used for direct event filtering during the generation

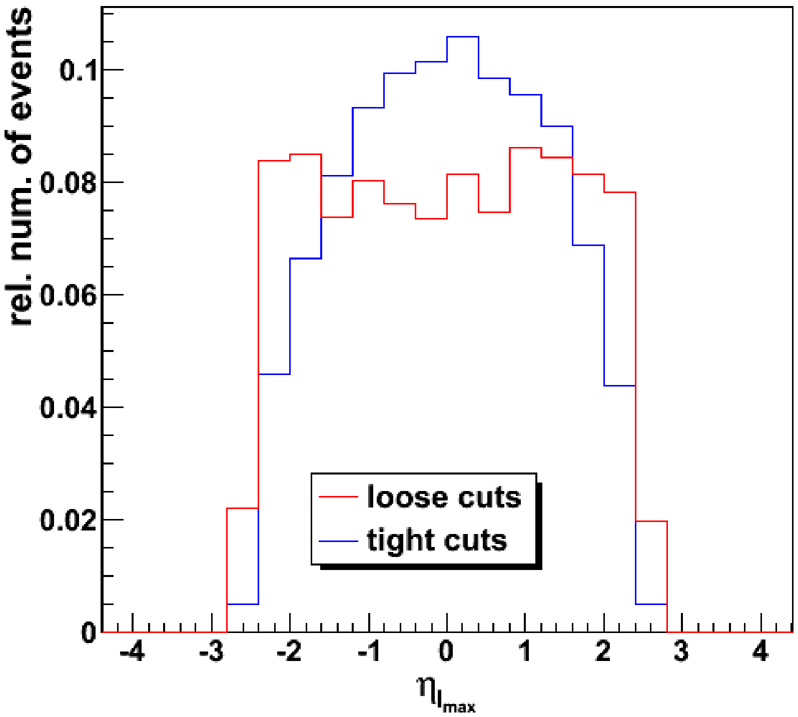


- tight cuts: $p_T(e^+)$>5GeV, $|\eta| < 2.5$
- loose cuts: $p_T(e^+)$>1MeV, $|\eta| < 5$

- e.g.: 14 TeV & cteq6l1
  - x – frac. of long. momentum dependence on cuts
  - no strong dependence on PDF's used

Tight vs. loose generation cuts

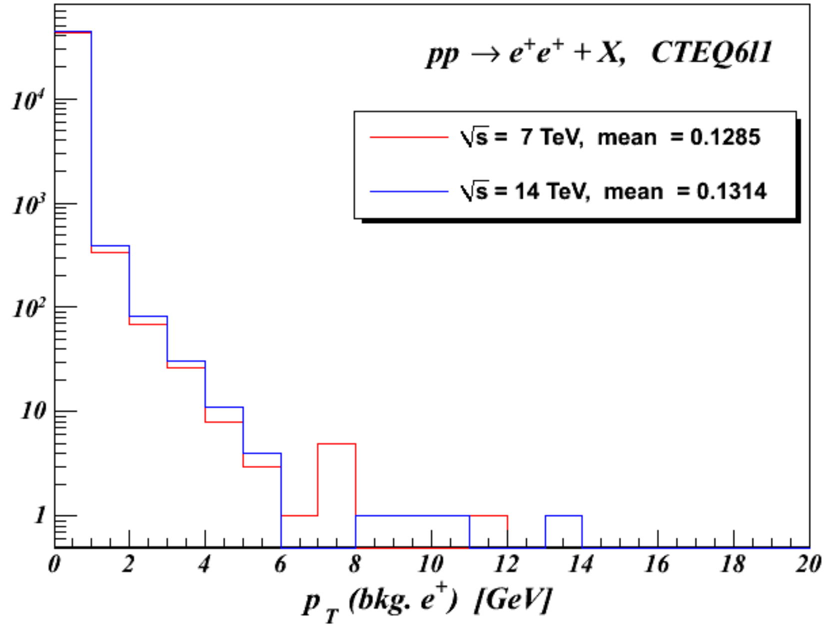




- plots for $\sqrt{s}$ = 14 TeV, PDF: cteq6l1
- filtering affects distribution of number of parton sub-processes as well as other kin. variables (e.g. pseudorapidity of hardest positron)

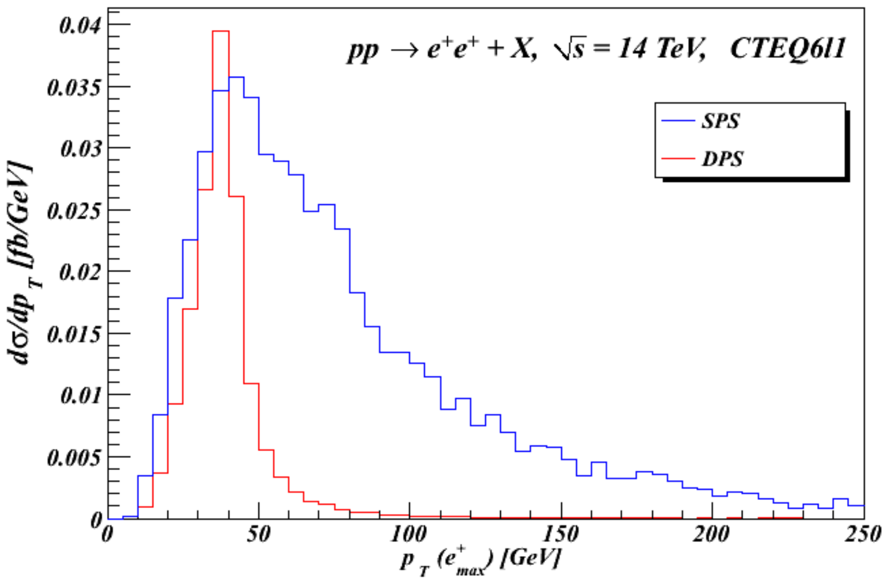
Data Analysis

- final state requirements:
  - always at least two positrons with $p_T > 5$ GeV, $|\eta| < 2.5$
    - 2 analyzed objects: e^+_{max}, e^+_{min}
  - if jet: then $p_T > 5$ GeV, $|\eta| < 2.5$
    - anti-k_T algorithm, R = 0.4
    - analysed object: jet_{max}
  - isolation requirements:
    $\Delta R(e^+e^+) > 0.2$, $\Delta R(e^+j) > 0.2$
    (57% survive isolation cuts)
  - veto on hard electrons $p_T > 5$ GeV

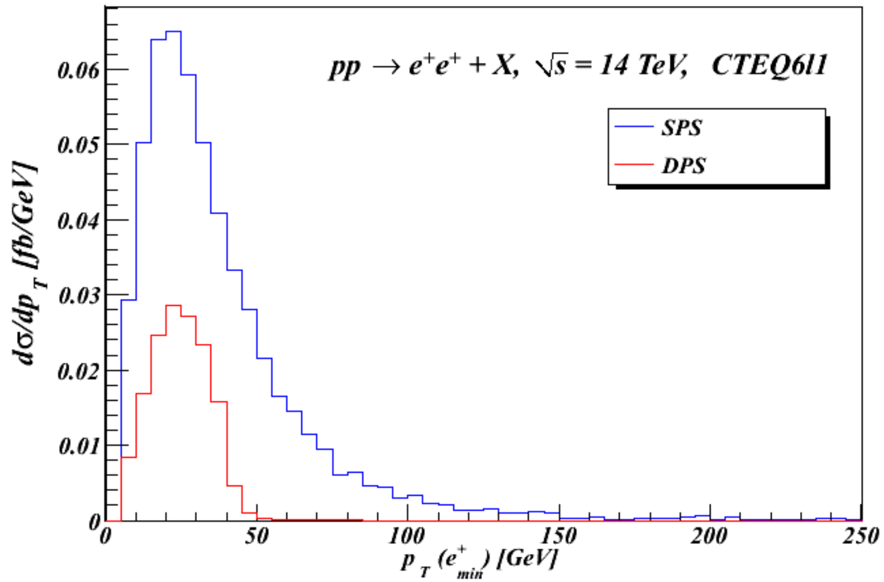


Results:
Transverse Momentum Distribution

Left: the hardest positron



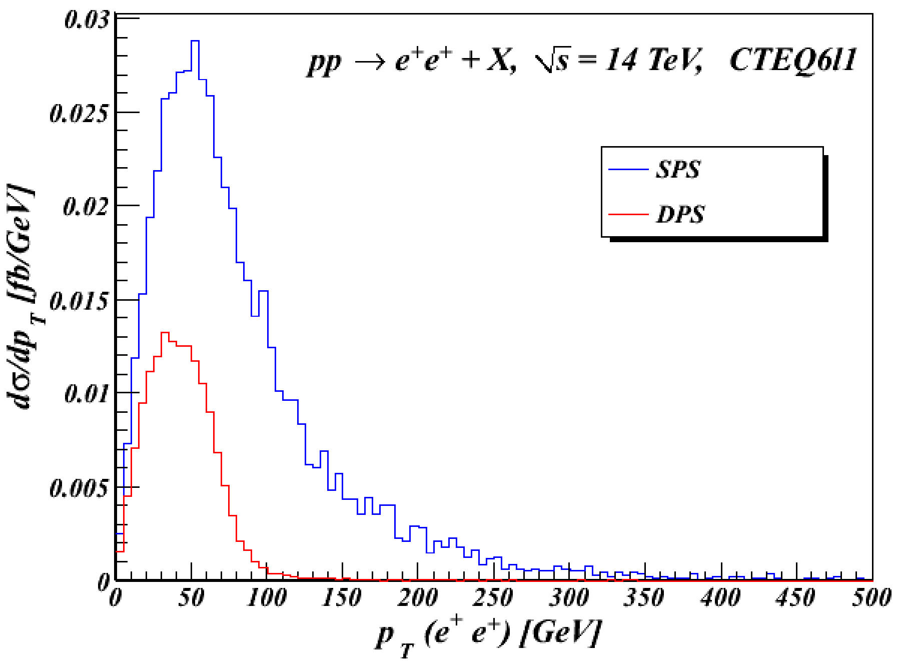
Right: the 2nd hardest positron

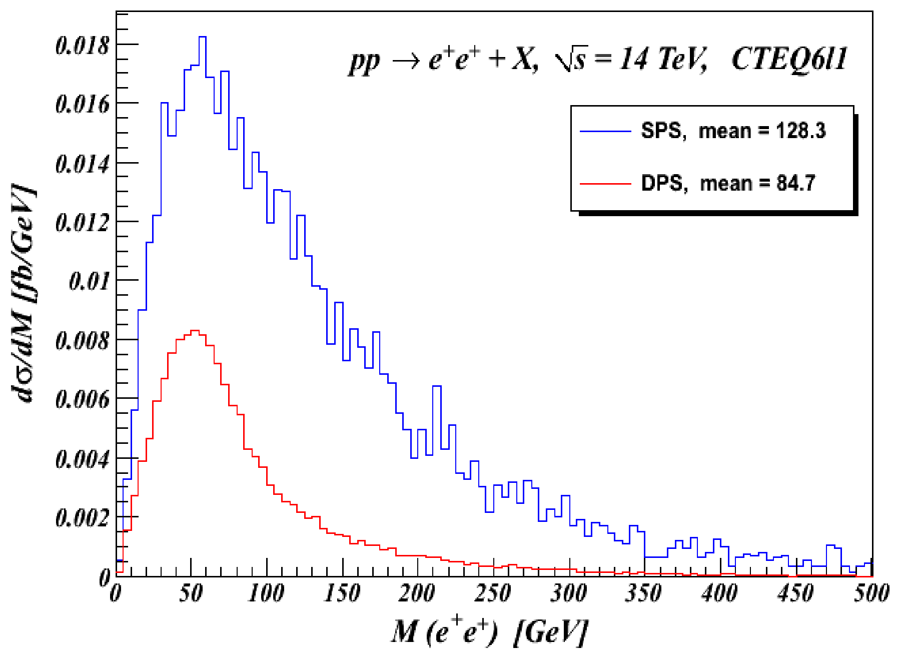


Results:
Positron-Positron Pair Characteristics

Left: transverse momentum

Right: invariant mass

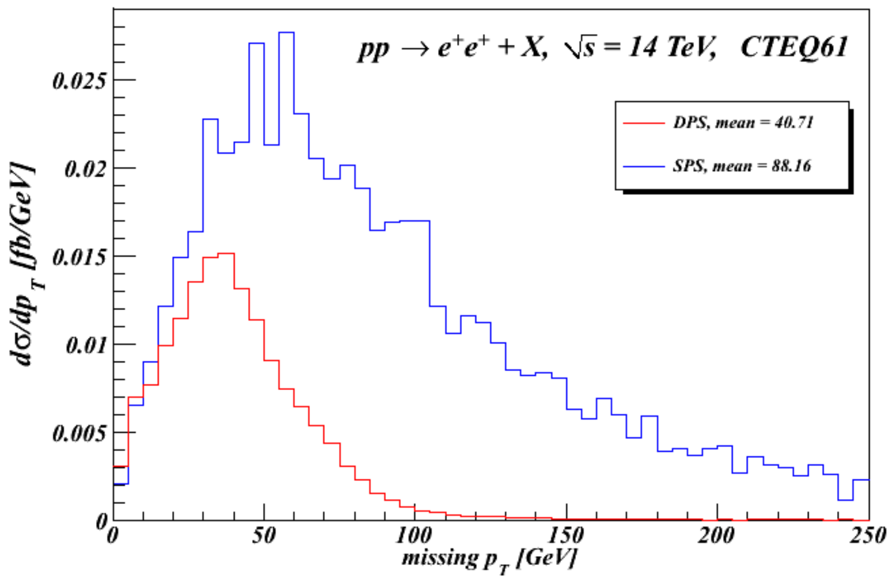


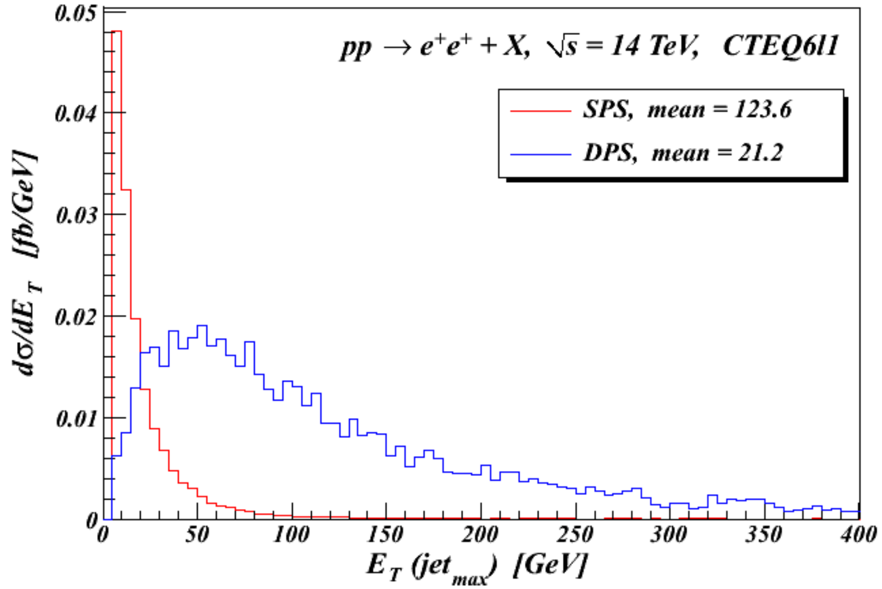


Results:
Background Characteristics

Left: missing transverse momentum

Right: transverse energy of the hardest jet



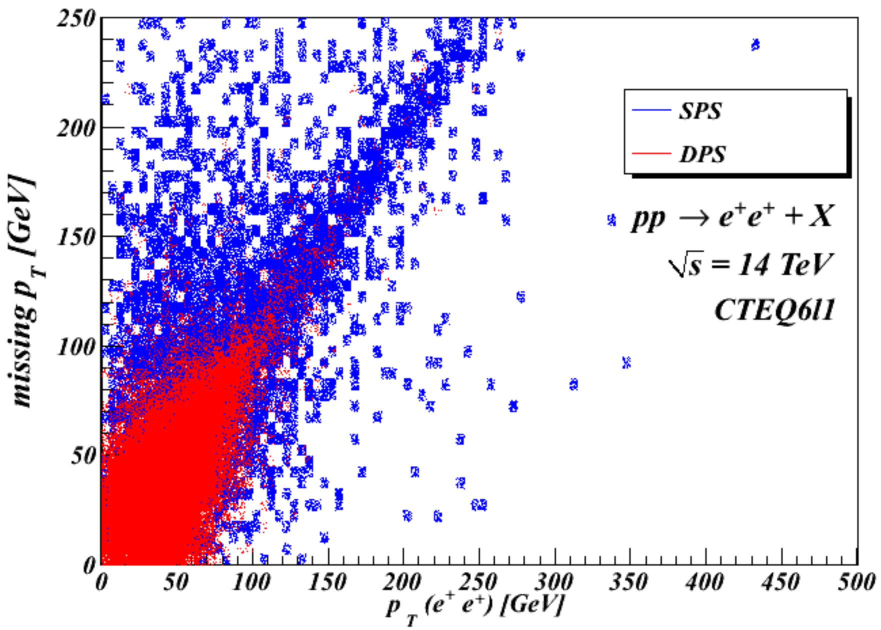


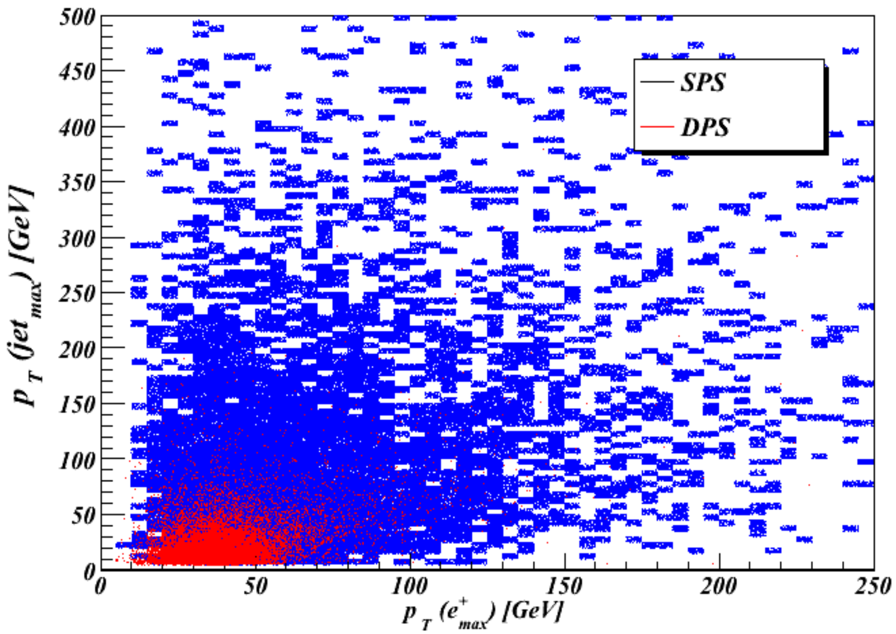
Results:

2D histograms: demonstration of complementarity of selective vetoes

Left: transverse momentum: positron pair vs. missing part

Right: transverse momentum: hardest positron vs. hardest jet





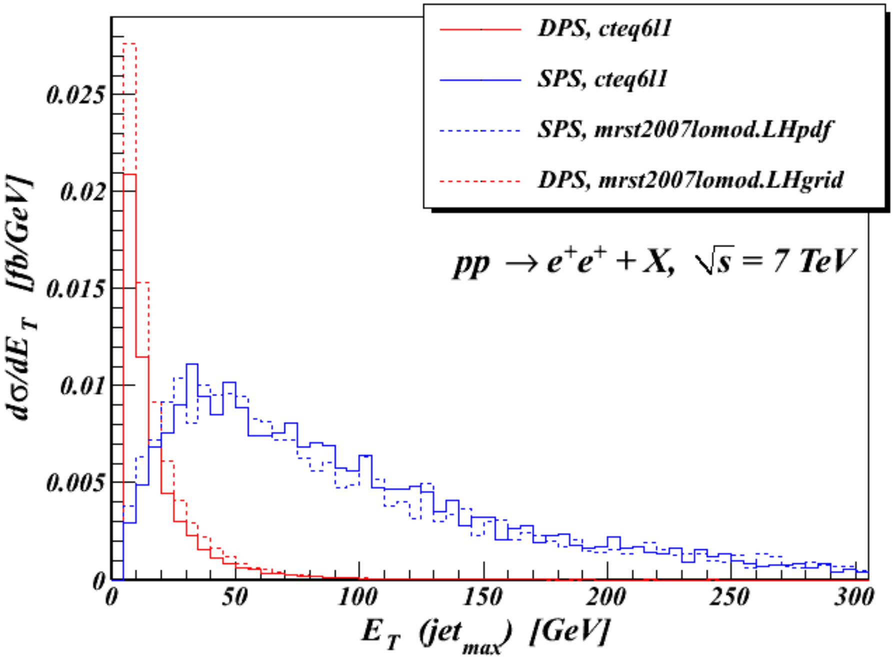
Results: Cross sections; $\sigma_{eff} = 11.5$ mb

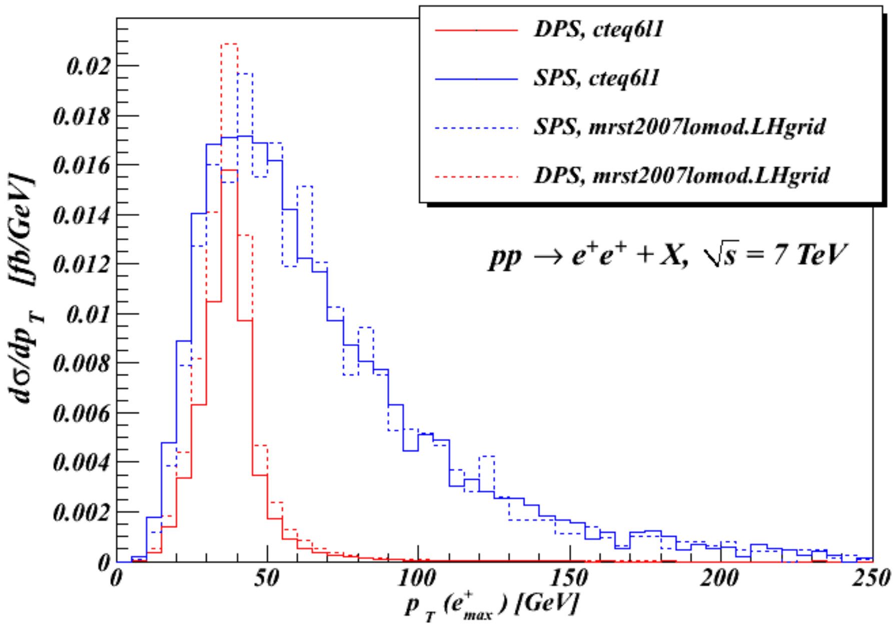
σ [fb]	**DPS**				**SPS: SM e^+e^+ jj**			**SPS: W^+Z**
	14 TeV		7 TeV		14 TeV	7 TeV		14 TeV
	cteq	mrst	cteq	mrst	cteq	cteq	mrst	cteq
total	**0.75**	1.03	0.28	0.37	**2.69**	1.20	1.17	**6.45**
jet veto 20 GeV	**0.54** 72%	0.74 72%	0.22 79%	0.29 78%	**0.16** 6%	0.08 7%	0.09 8%	**4.45** 69%
jet veto 30 GeV	0.63 84%	0.85 83%	0.25 89%	0.33 88%	0.32 12%	0.17 14%	0.19 16%	5.16 80%

Results: Comparison of PDF's -uncertainty in the cross section

Left: transverse momentum of the hardest jet

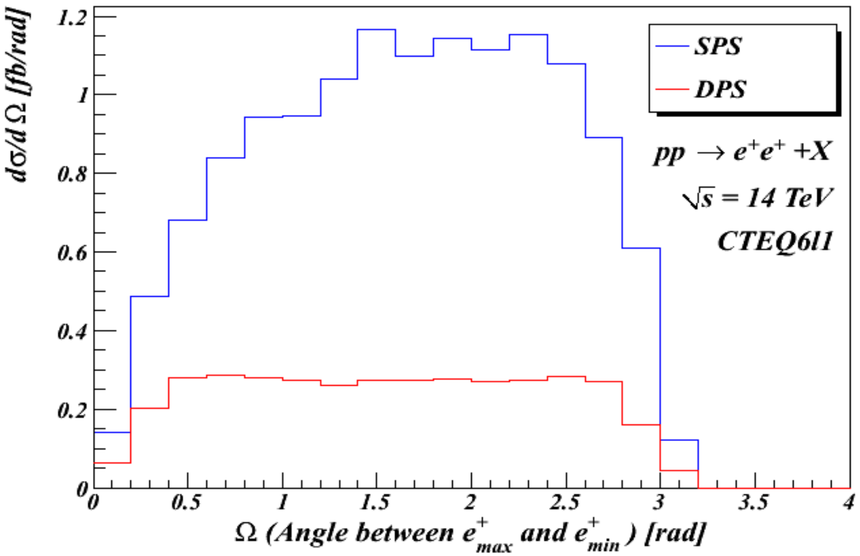
Right: transverse momentum of the hardest positron





Another handlers to separate signal different from p_T/E_T distributions

- distributions of Φ and η, their difference and other functions could provide another helpful tool



- e.g. Pseudorapidity asymmetry.

$$a_{\eta_l} = \frac{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) - \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}{\sigma(\eta_{l_1} \times \eta_{l_2} < 0) + \sigma(\eta_{l_1} \times \eta_{l_2} > 0)}$$

Summary and next steps

- Double parton production of same-sign W pair was performed for $e^+\nu_e$ decay channel

- SM background process $pp \rightarrow e^+e^+ jj$ was prepared and found to be strongly reduced by p_T vetoes

- SM background process $pp \rightarrow W^+Z$ under construction – preliminary results show it's dominance

- To do:
  - other sources of background need to be investigated as well as other final states (muon or multi-jets)
  - invisible component does not allow for usage of pair-to-pair variables characteristic for DPS events