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Double Parton Scattering at the SppC

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In collaboration with
Yandong Liu, Ke-Pan Xie, Bin Yan, arXiv:1609.xxxxx

Outline

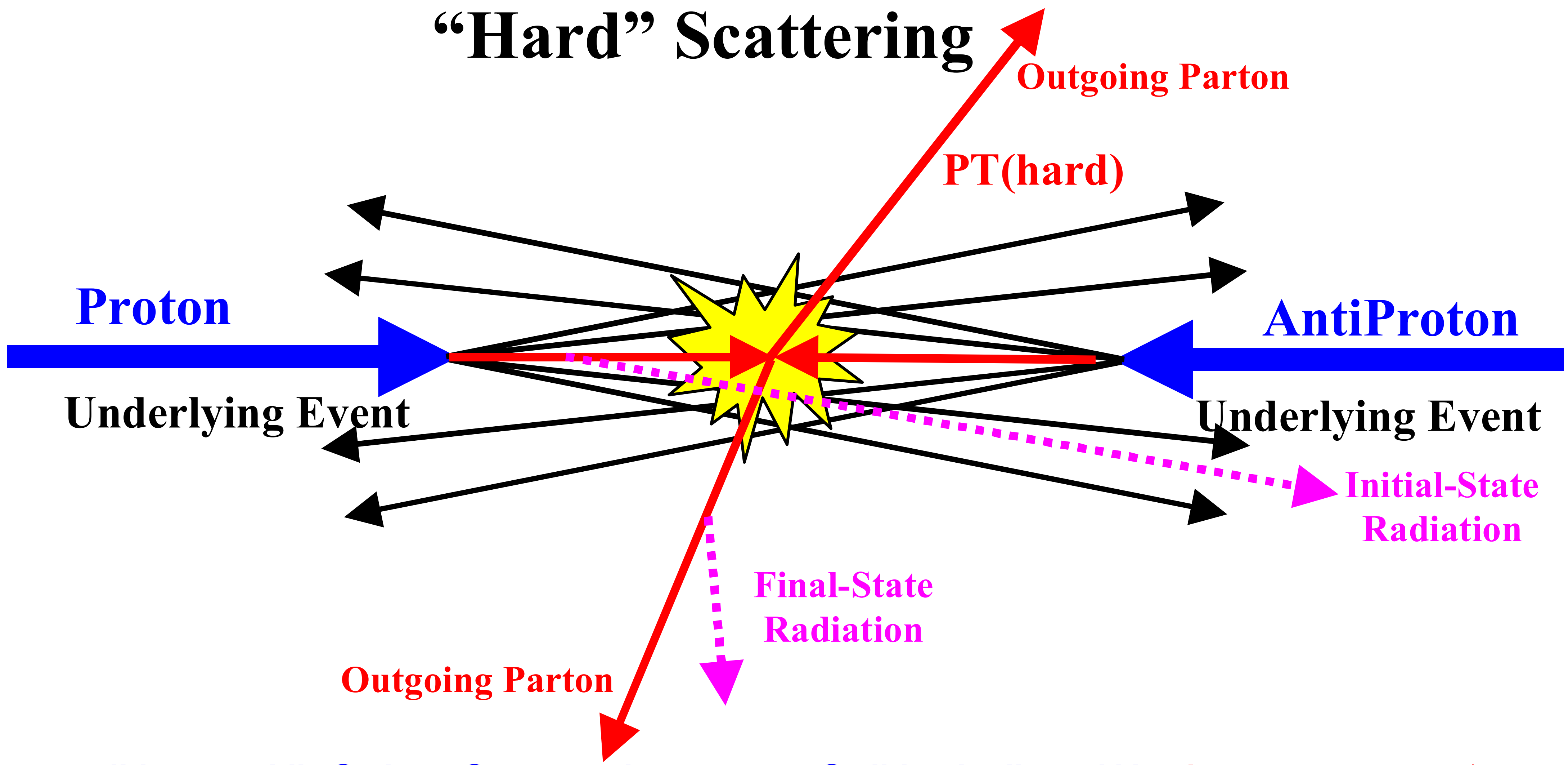
- ✦ What is Double Parton Scattering (DPS)?
- ✦ Electroweak DPS processes at the SppC

1. Wjj production
2. Same-sign WW pair production

- ✦ Summary

High energy hard collision

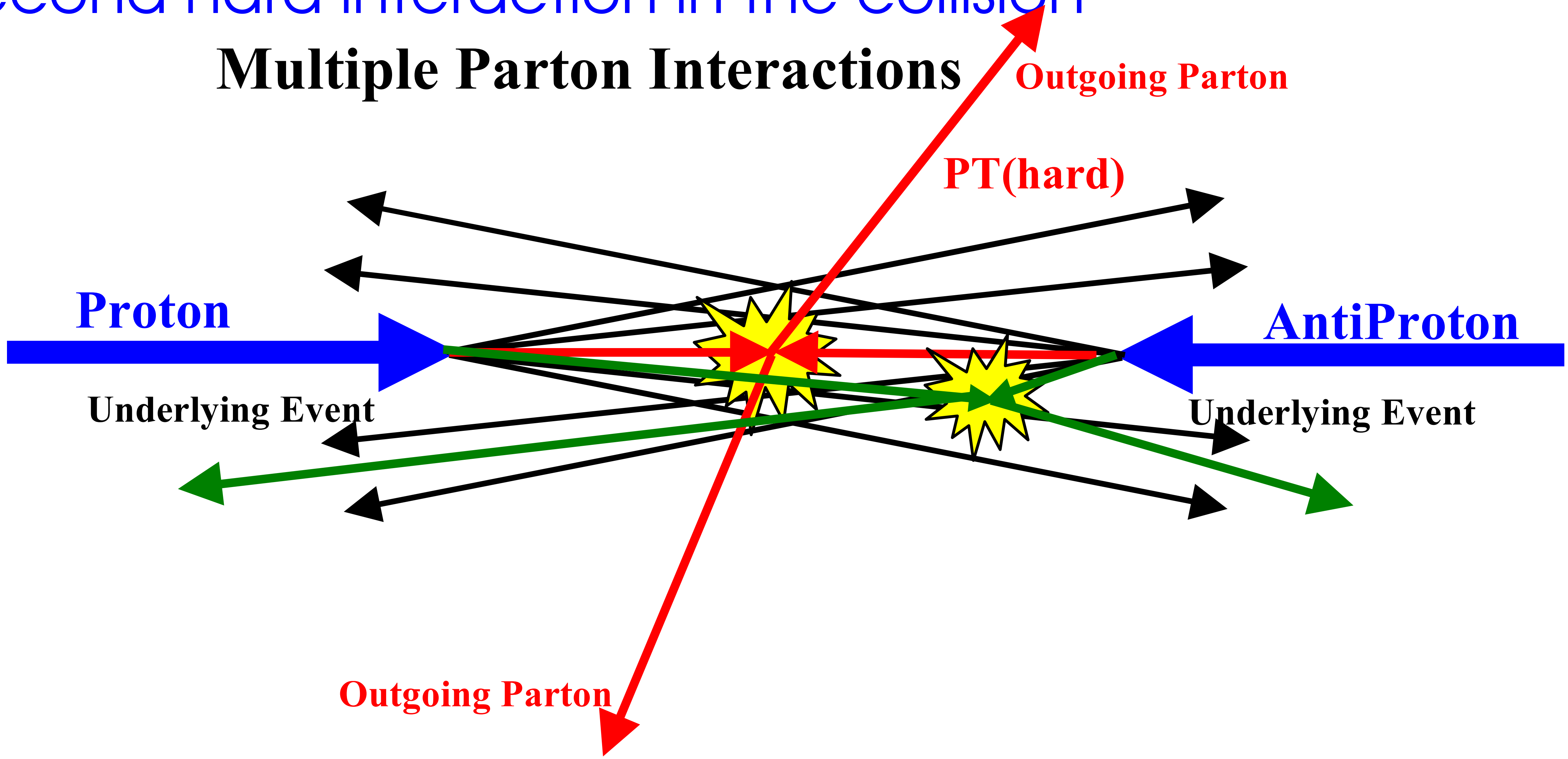
Generally a complex interaction, here a $p\bar{p}$ collision



- One "hard" 2 to 2-parton $\to$ 2 "jets" with large $P_{T1}(\mathrm{hard})$
- breakup of the p and $\bar{p}$ ("beam remnants")
- "underlying event" $=$ remnants $+$ initial-state radiation
- can replace the 2 jets by $\gamma + \mathrm{jet}$, W, Higgs, etc

Two hard interactions in one collision

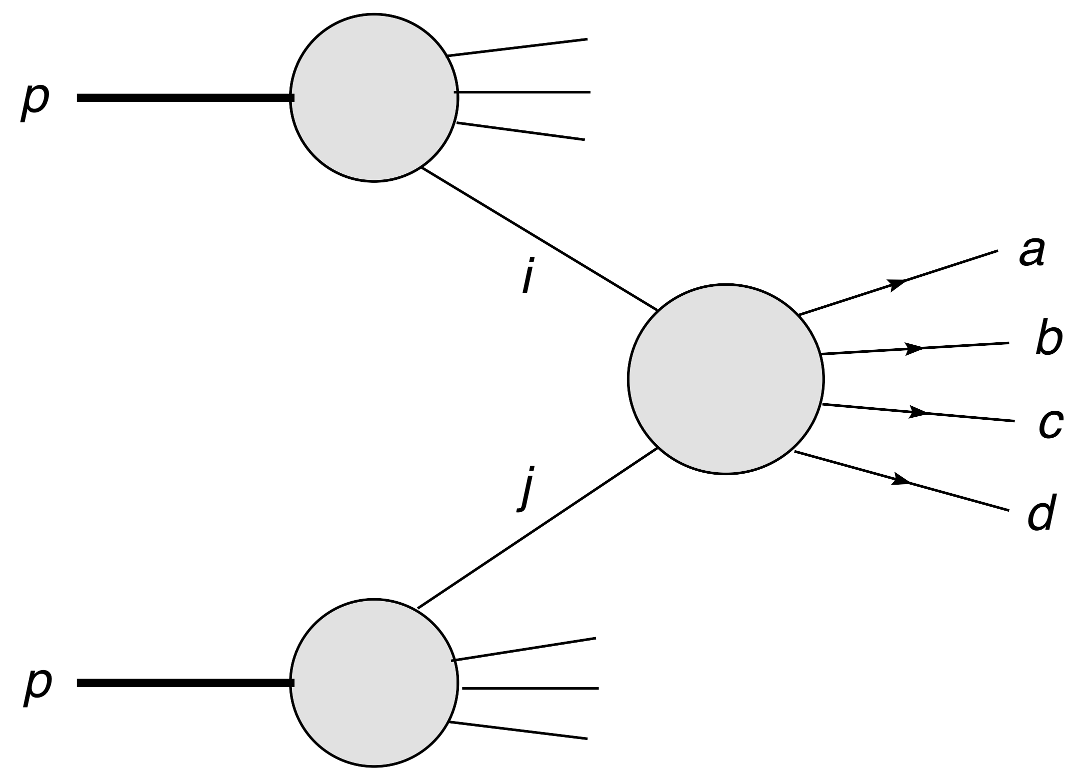
A second hard interaction in the collision



- "hard" 4 to 4-parton scattering $\rightarrow$ 4 "jets" with large $P_{T1}(\mathrm{hard})$, $P_{T2}(\mathrm{hard})$, plus the underlying event
- also processes in which 2 initial partons produce 4 jets

Single parton scattering

- One hard collision per pp interaction: $ij \rightarrow abcd$

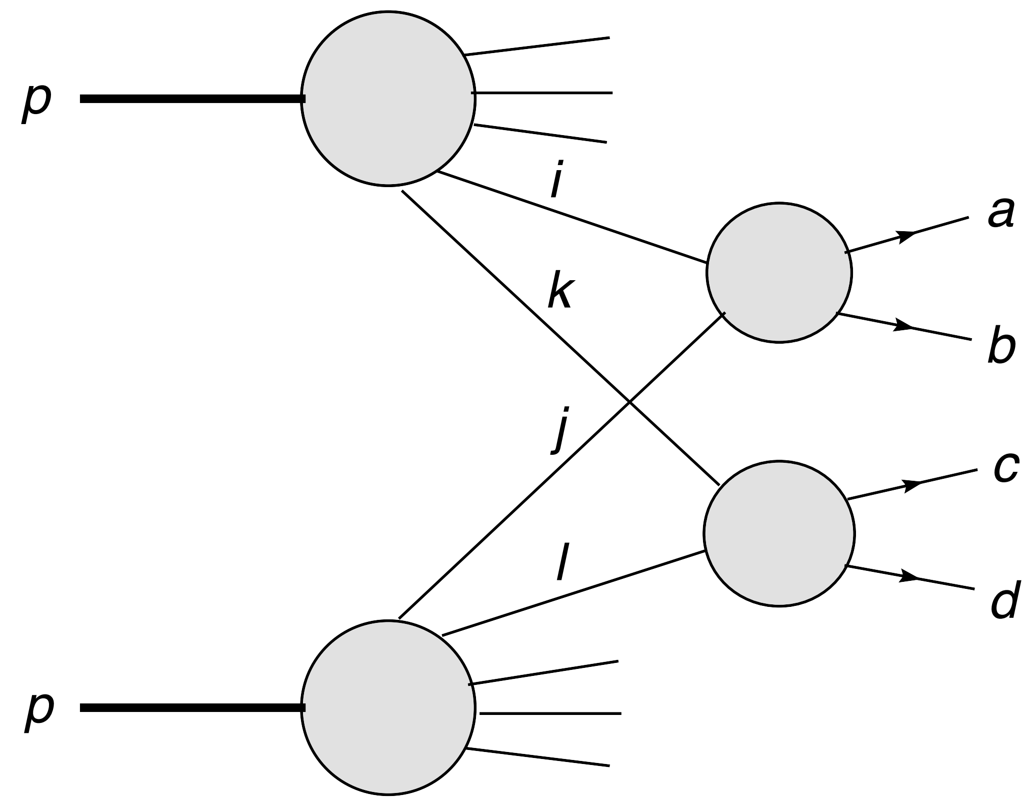


- Well established methodology for calculations

$$d\sigma^{SPS} = \sum_{i,j} \int f_p^i(x_1, \mu) f_p^j(x_1', \mu) d\hat{\sigma}_{(ij \rightarrow abcd)}(x_1, x_1', \mu) dx_1 dx_1'$$

What is double parton scattering?

- Two hard collisions per pp interaction



- Does it exist as a discernable contribution?
- What are its characteristics, allowing its measurement?
- Heuristic cross section for $pp \to b\bar{b}j_1j_2X$,

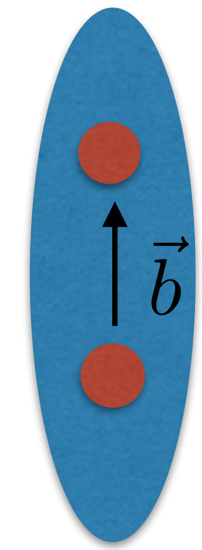
$$d\sigma^{DPS}(pp \to b\bar{b}j_1j_2X) = \frac{d\sigma^{SPS}(pp \to b\bar{b}X)d\sigma^{SPS}(pp \to j_1j_2X)}{\sigma_{\text{eff}}}$$

Parton distribution of two partons

Several Assumptions

$$F(x_1, x_2, \vec{b}) = f(x_1) f(x_2) G(\vec{b})$$

Longitudinal component **Transverse component**



transverse distance

$x_{1,2}$: longitudinal momentum fraction

1) Longitudinal component:

Products of two independent single PDF *(reasonable for small x)*

2) Transverse component:

$$G(\vec{b}) = \int F_{\perp}(\vec{b}_1) F_{\perp}(\vec{b}_1 - \vec{b}) d^2 \vec{b}_1$$

Effective transverse overlap area of partonic interaction

$$\Rightarrow \quad \frac{1}{\sigma_{eff}} = \int d^2 b G^2(\vec{b})$$

$$d\sigma^{DPS}(pp \to b\bar{b}j_1j_2X) = \frac{d\sigma^{SPS}(pp \to b\bar{b}X)\, d\sigma^{SPS}(pp \to j_1j_2X)}{\sigma_{\text{eff}}}$$

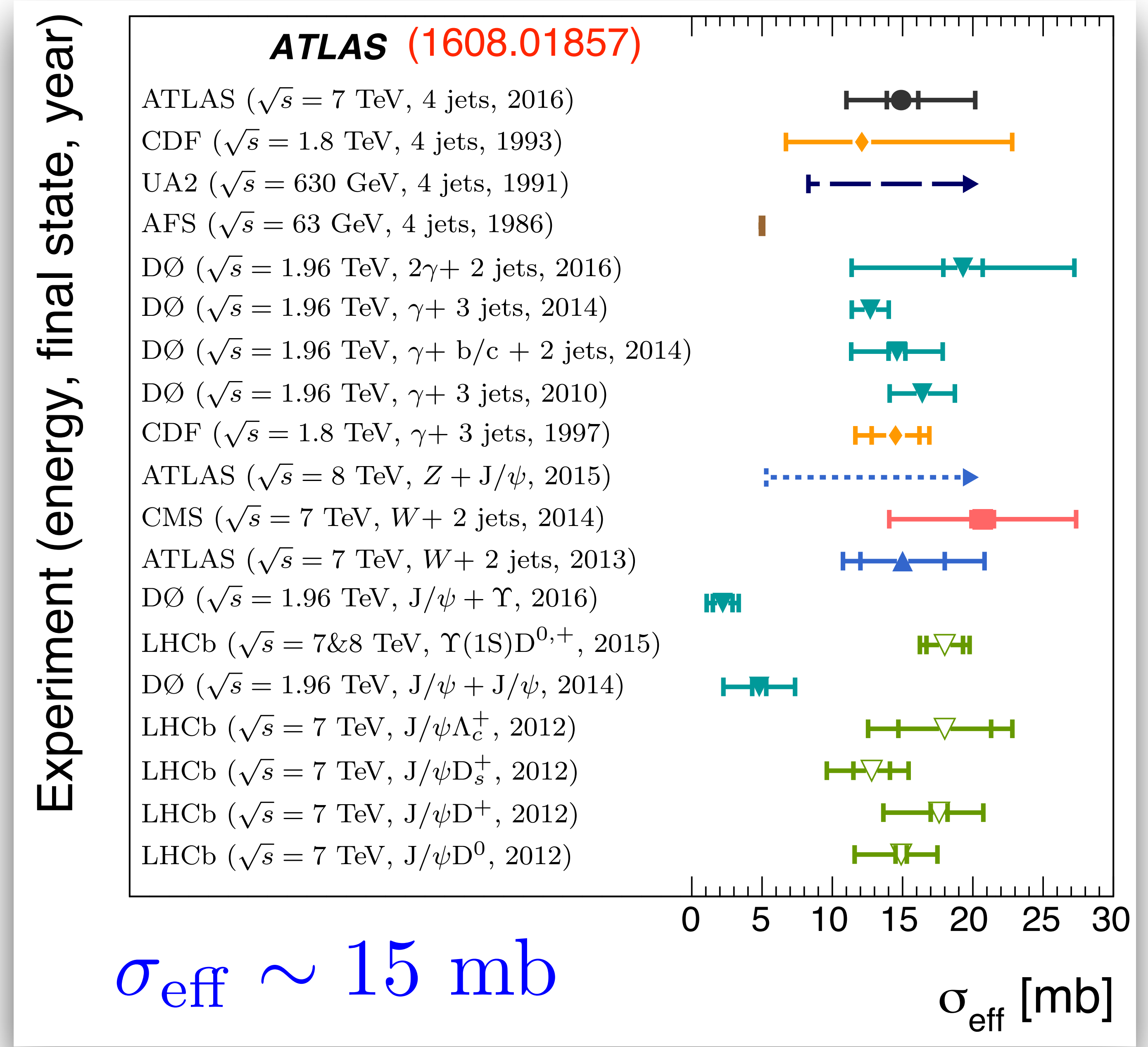
Factorization/independent hard scatters cannot be strictly true, certainly not if any parton $x > 0.5$

σ_{eff}

Measures the effective size of the core in which accompanying partons are confined

Bounded by the transverse size of a proton

Different for gg and qq subprocesses? Energy dependent?



Large dynamic range of SppC offers opportunity to explore this phenomenology; measure σ_{eff}

Electroweak DPS at the LHC and SppC

$$\sigma^{DPS}(AB) = \frac{m}{2\sigma_{\rm eff}}\sigma^{SPS}(A)\sigma^{SPS}(B) \qquad \sigma_{\rm eff} \sim 15 \text{ mb}$$

SPS x-sec (LHC)

jj: $\sim 10^8$ pb

W/Z: $\sim 10^4$ pb

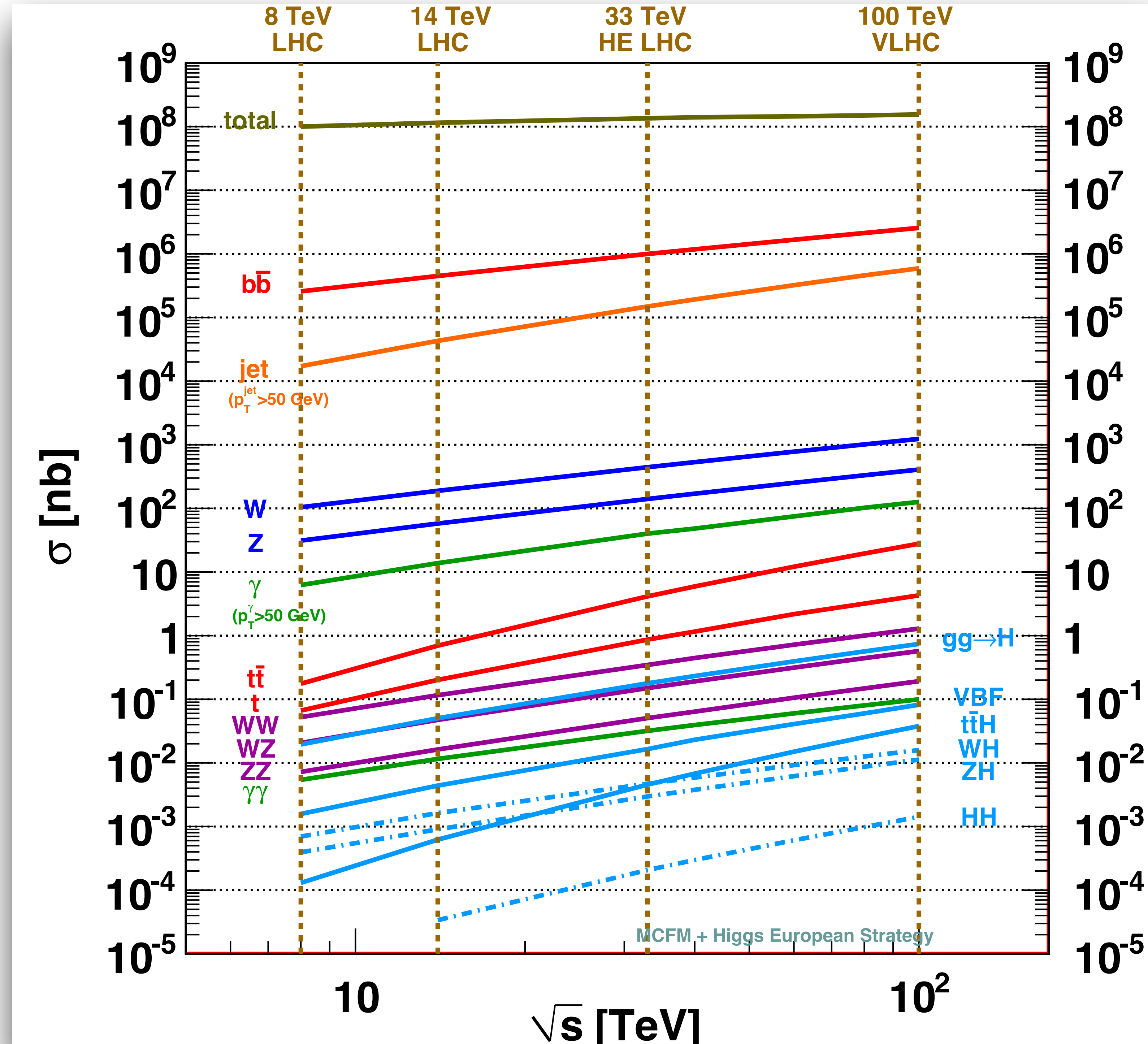
$j{+}\gamma$: $\sim 10^5$ pb

DPS combo:

$jj \otimes jj$

$jj \otimes W/Z$

$W/Z \otimes W/Z$



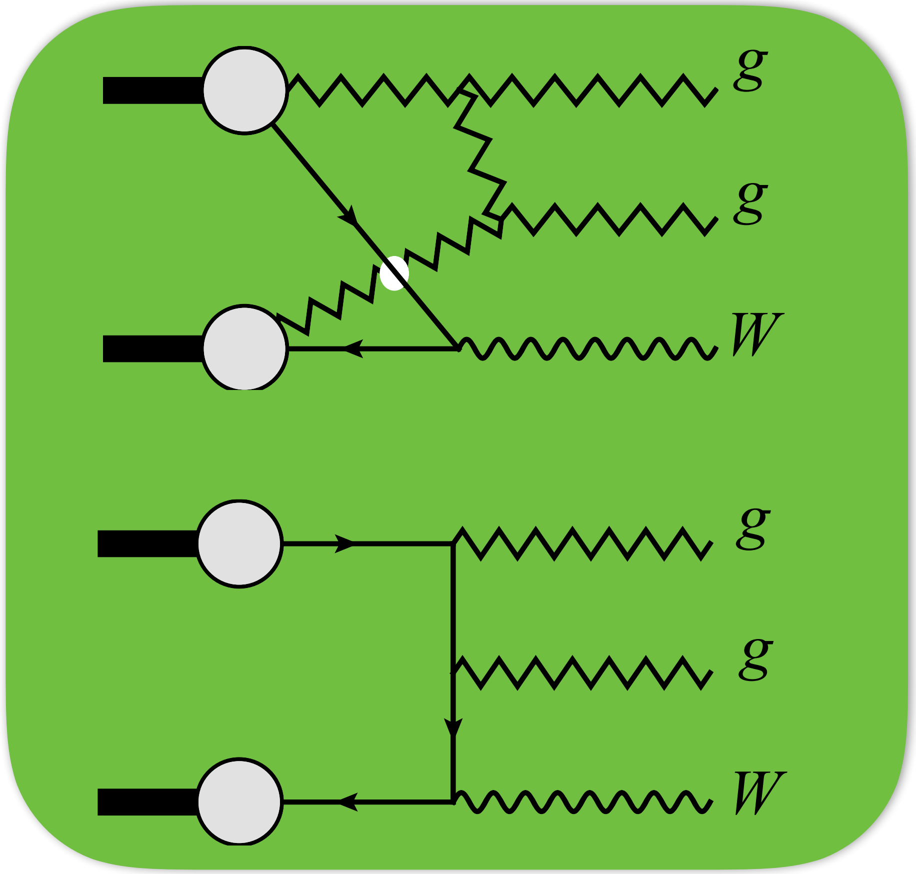
Electroweak DPS at the LHC and SppC

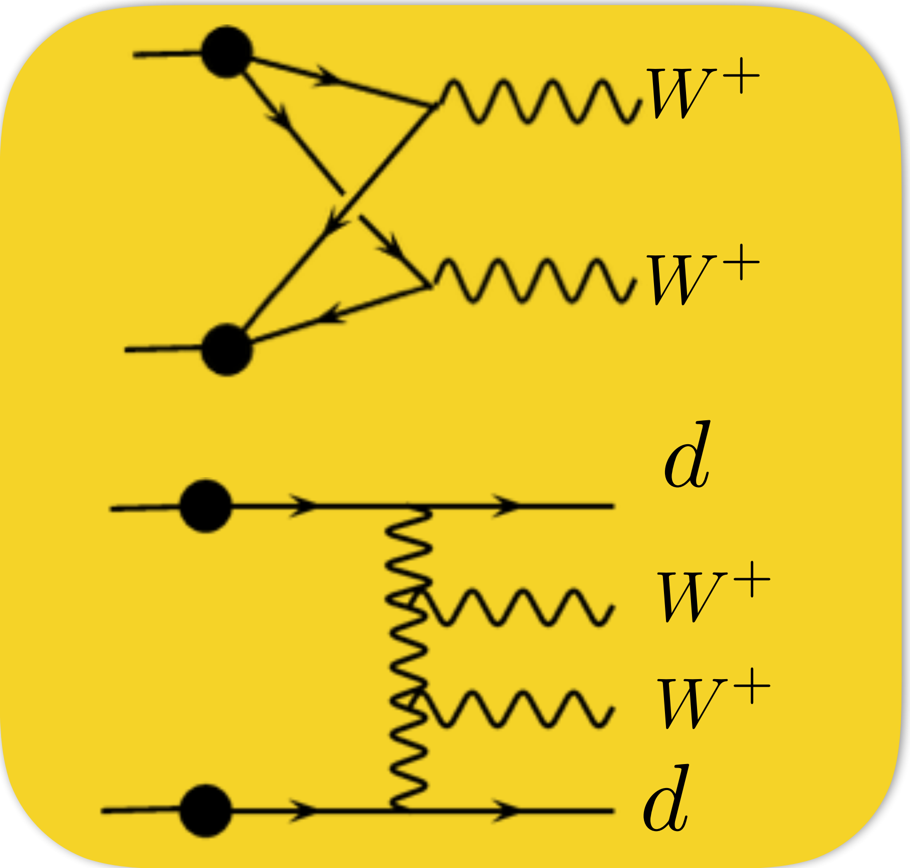
$$\sigma^{DPS}(AB) = \frac{m}{2\sigma_{\rm eff}}\sigma^{SPS}(A)\sigma^{SPS}(B)$$

$\sigma_{\rm eff} \sim 15$ mb

SPS x-sec: jj: ~ 10^8 pb; W/Z: ~ 10^4 pb; j+γ: ~ 10^5 pb

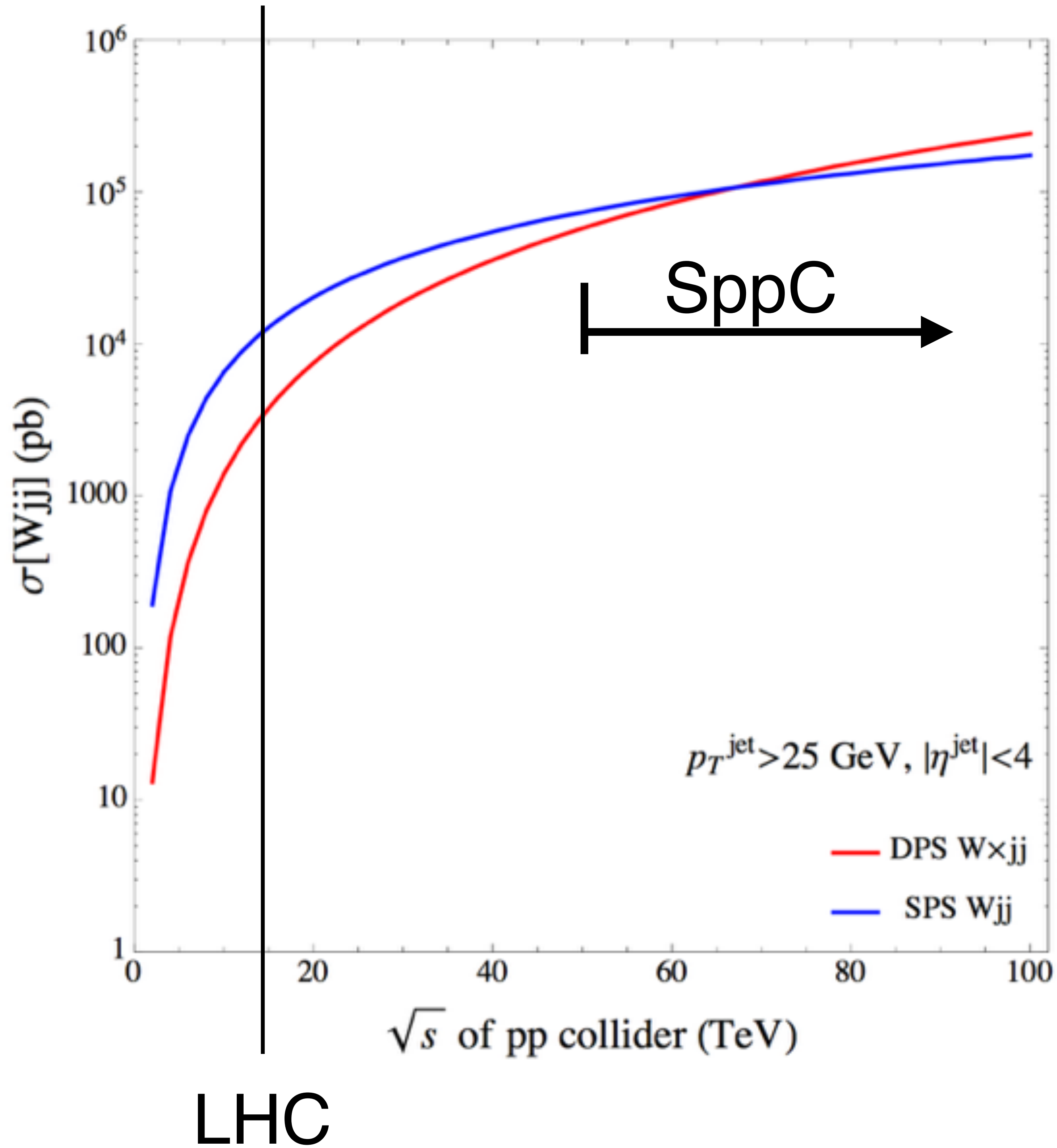
DPS process: $jj \otimes jj$ $\quad jj \otimes W/Z$ $\quad W/Z \otimes W/Z$





R. M. Godbole et al. Z. Phys. C47, 69 (1990);
E. L. Berger et al. Phys. Rev. D81, 014014 (2010), 0911.5348;
S. Chatrchyan et al. (CMS), JHEP 03, 032 (2014), 1312.5729.

1) $W \otimes jj$ production: DPS versus SPS



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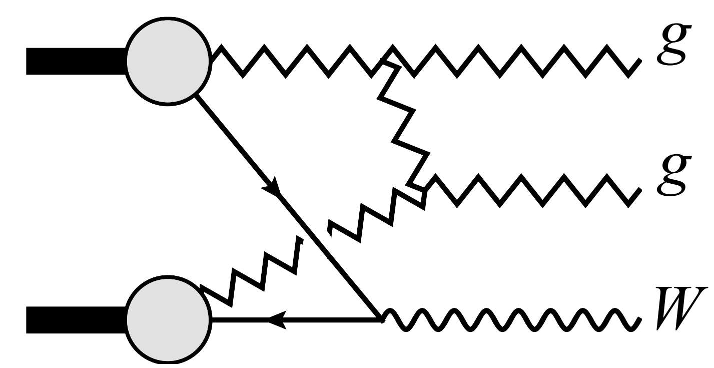

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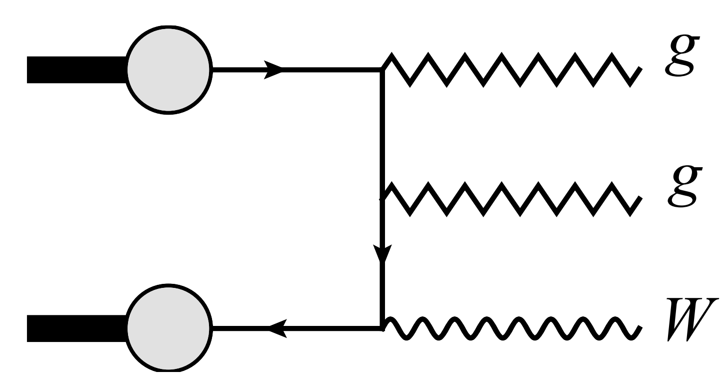
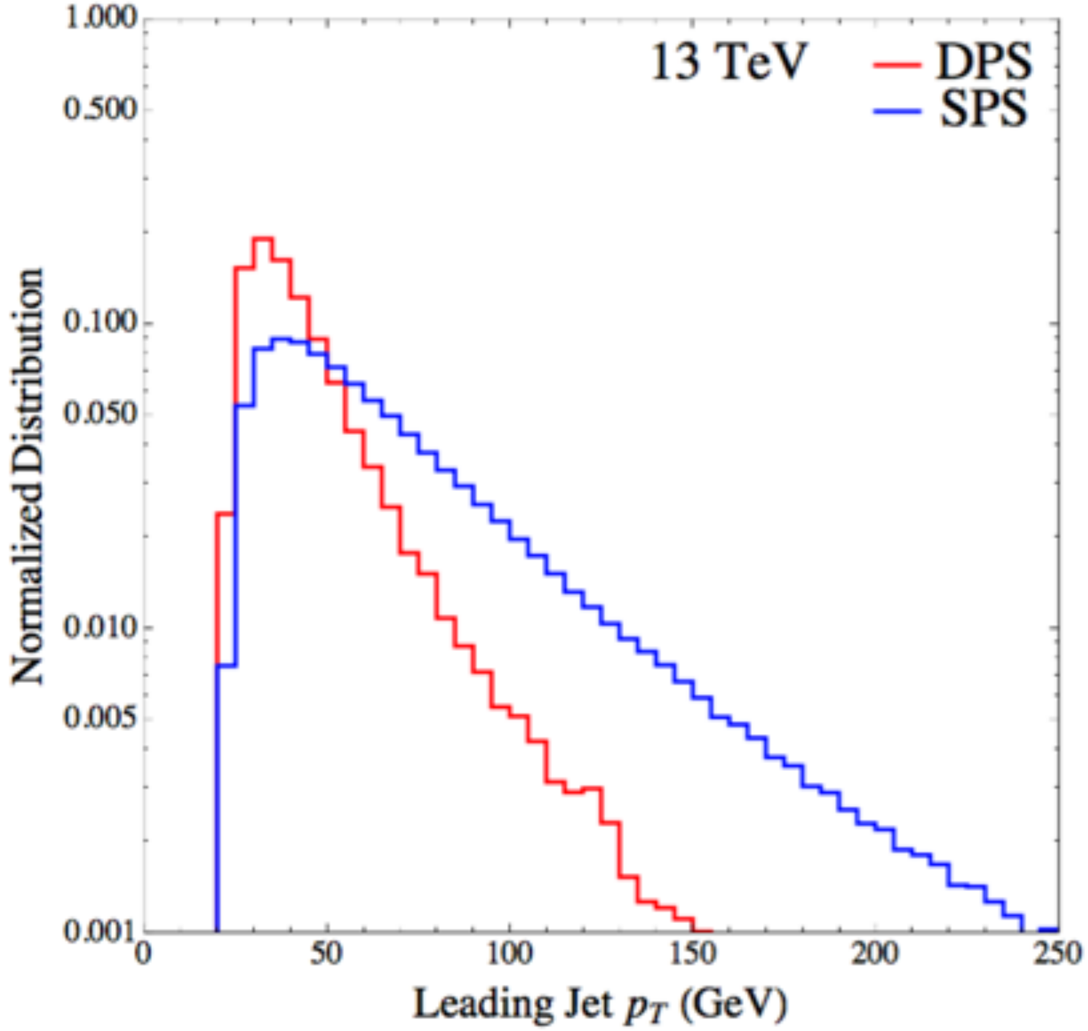
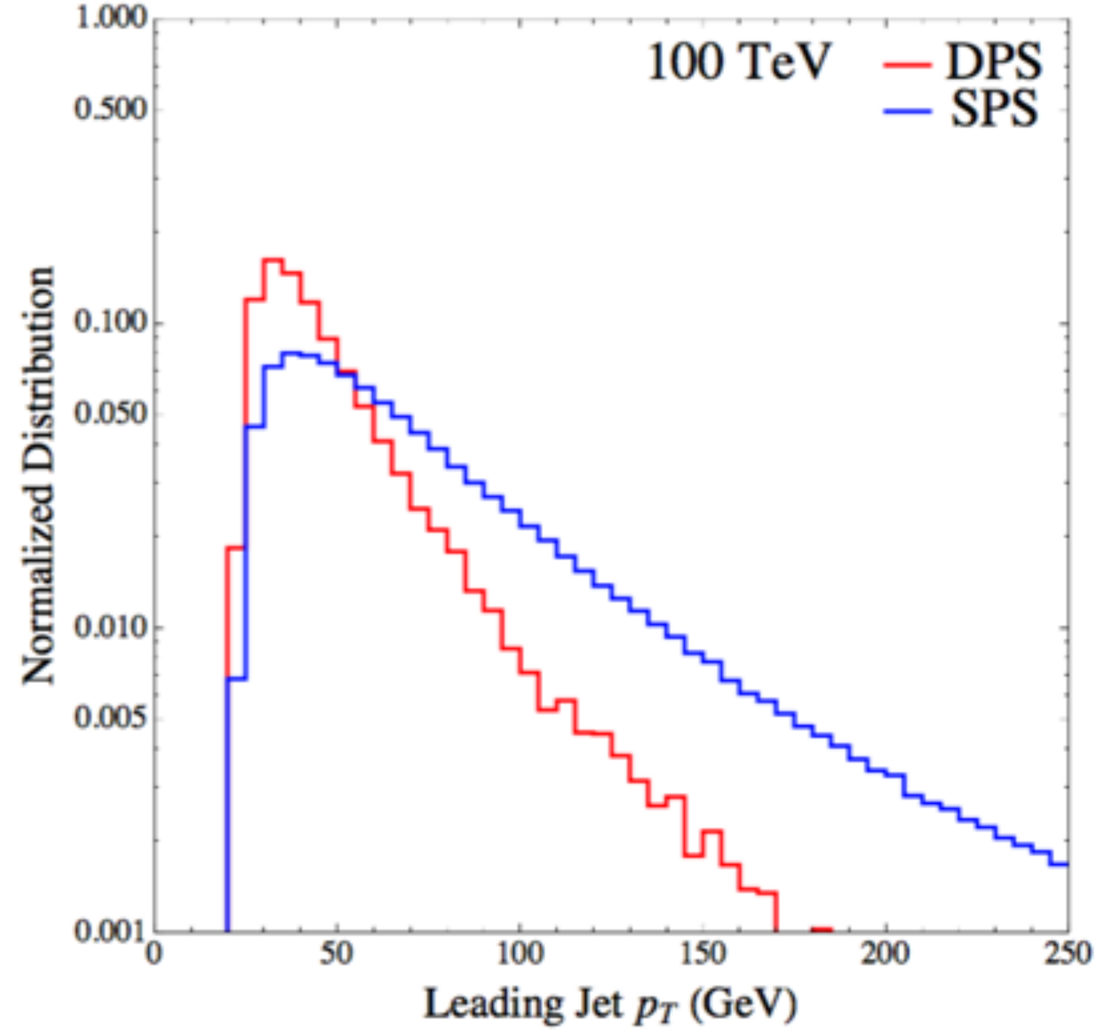


Kinematic distributions

Transverse momentum of the leading jet





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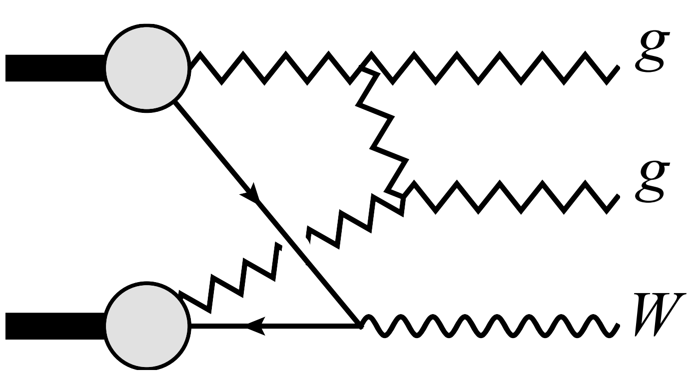

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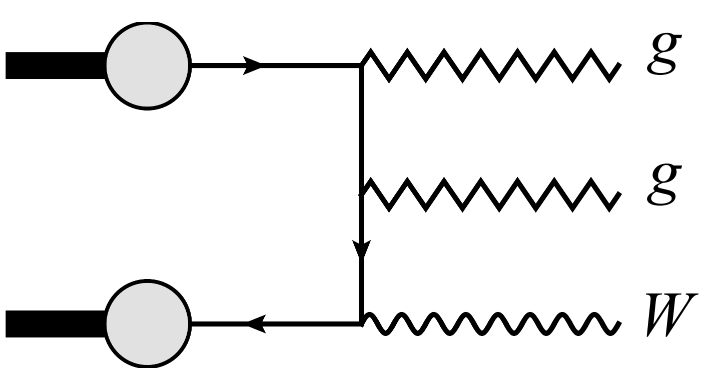
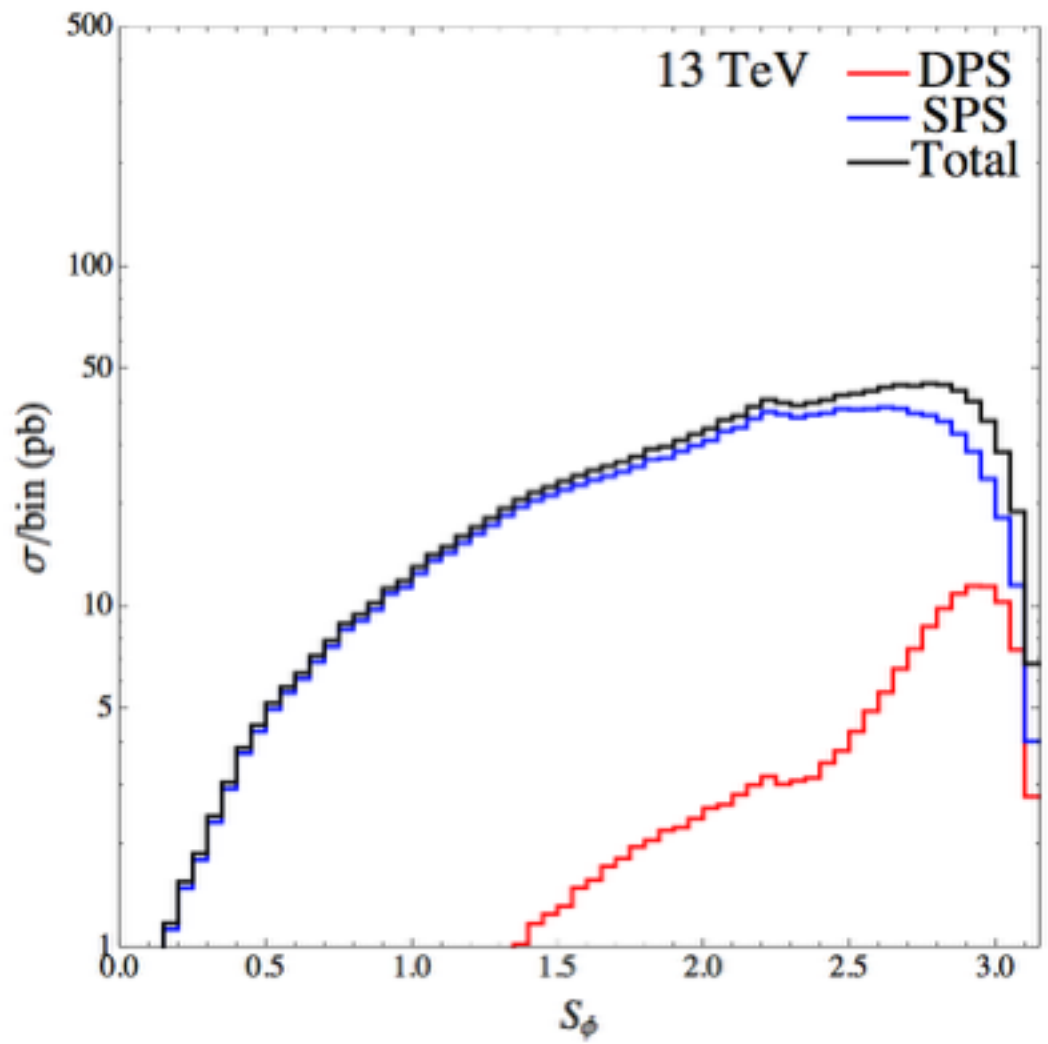
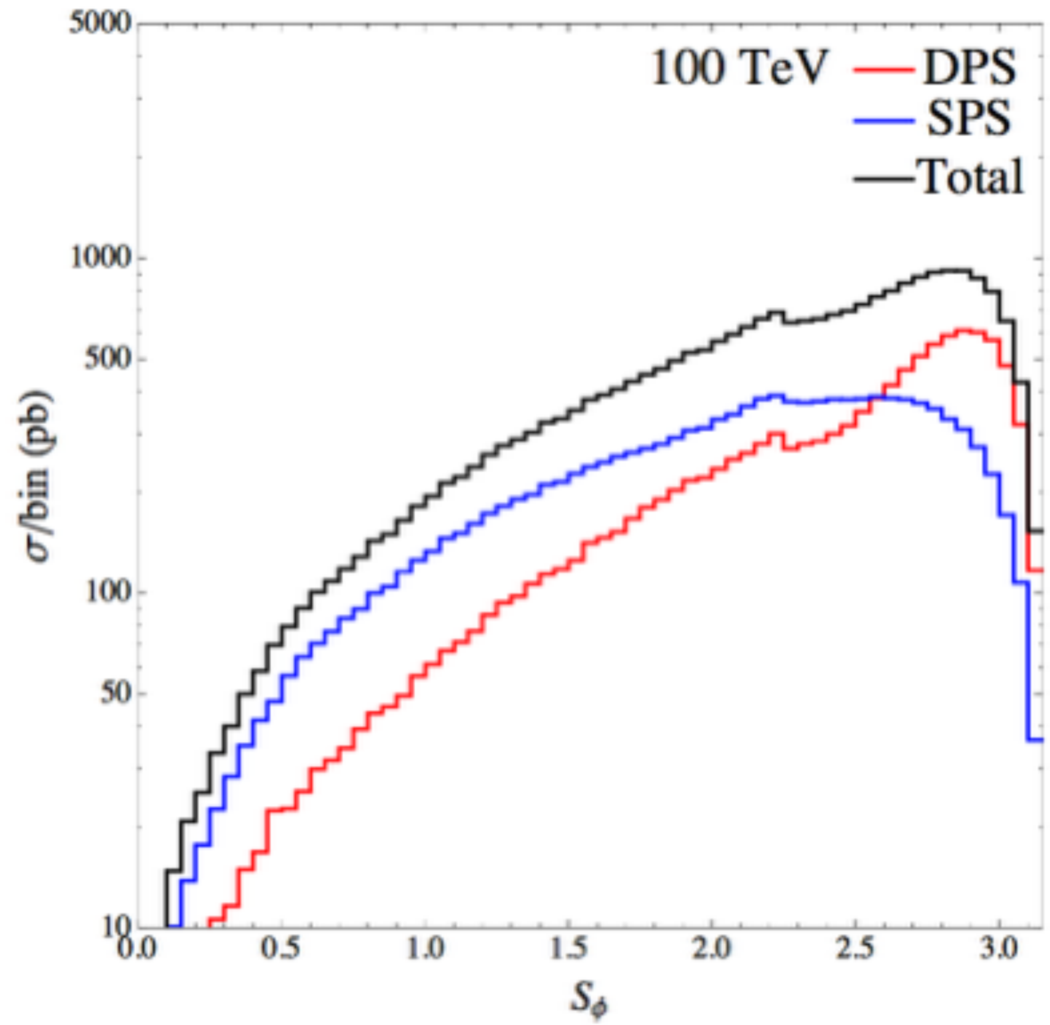


Kinematic distributions

$$S_\phi = \frac{1}{\sqrt{2}}\sqrt{\Delta\phi(l, \not{E}_T)^2 + \Delta\phi(j_1, j_2)^2}$$





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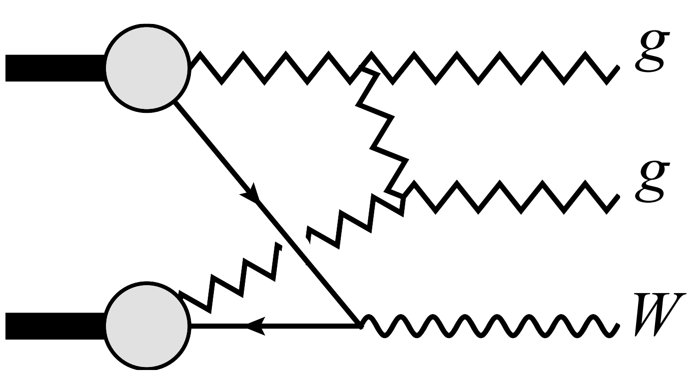

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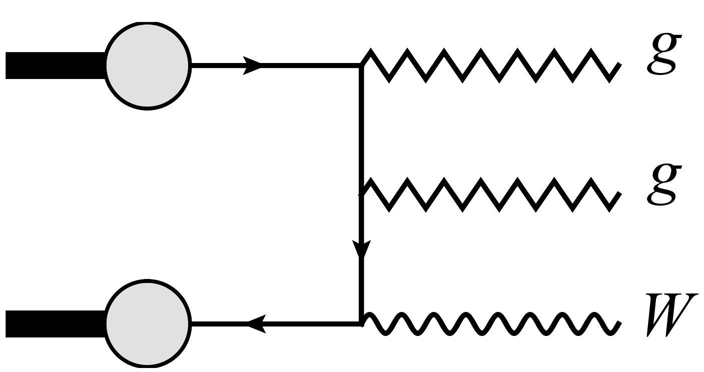
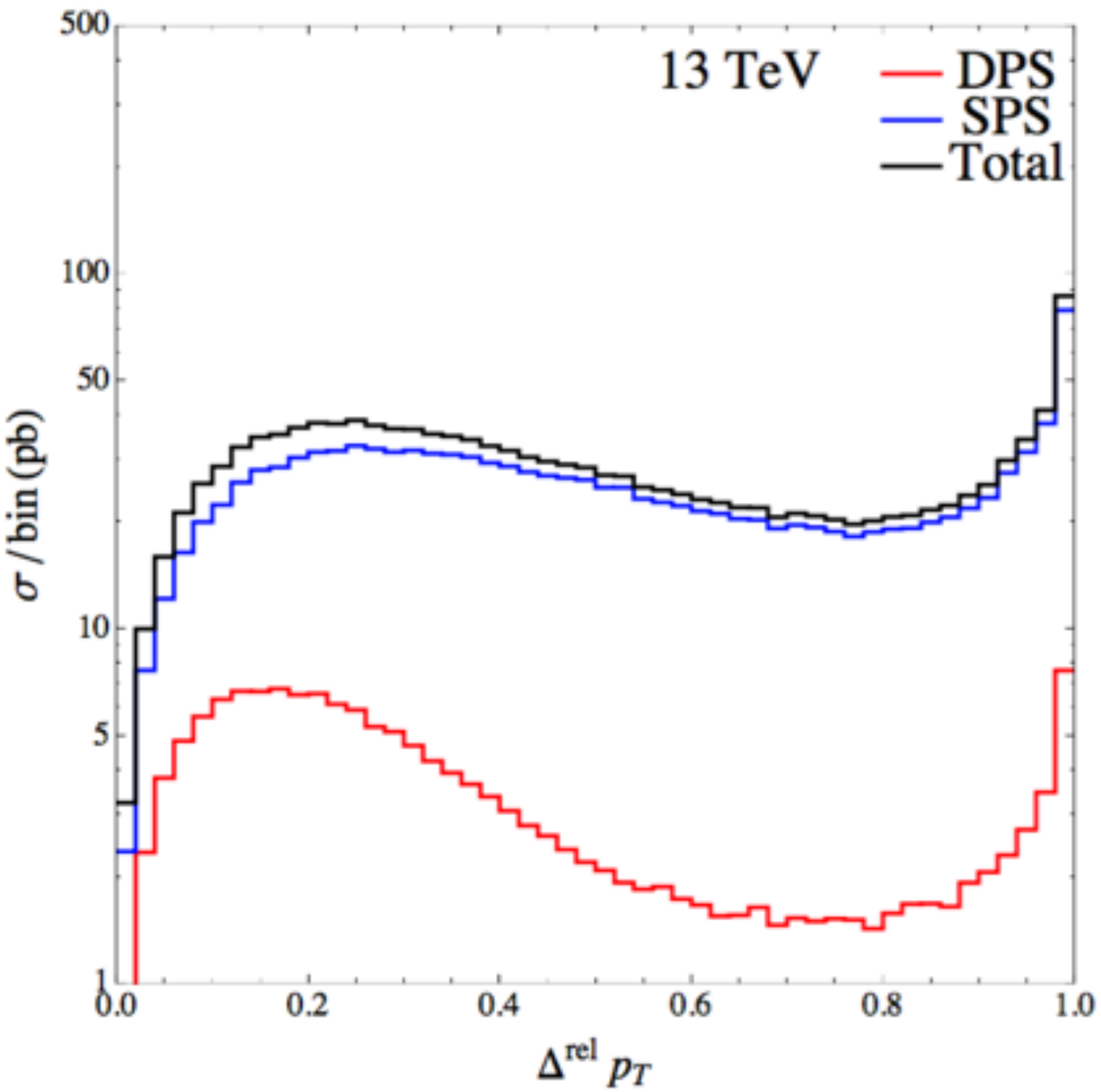
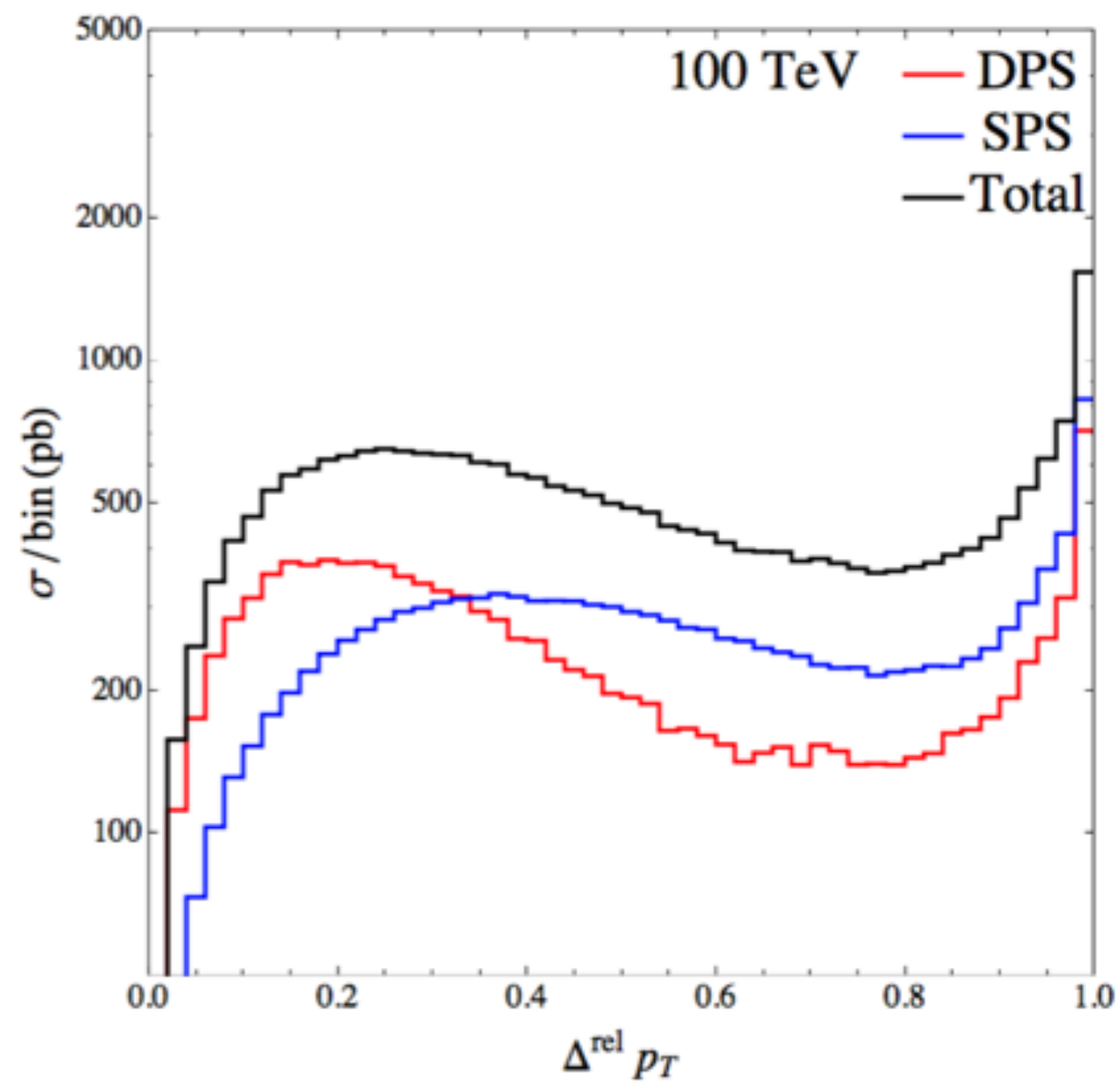


Kinematic distributions

$$\Delta^{\rm rel} p_T = \frac{|p_T(j_1, j_2)|}{|p_T(j_1)| + |p_T(j_2)|}$$





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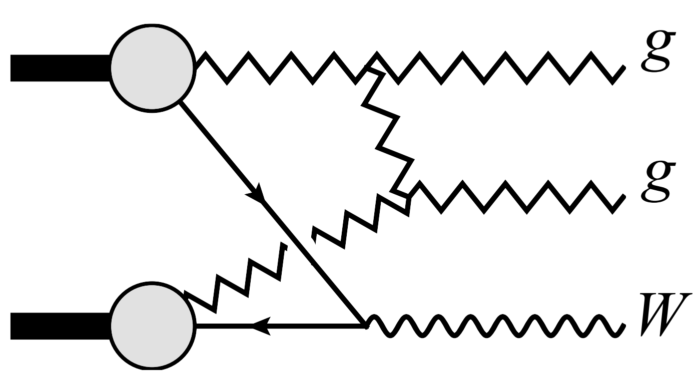

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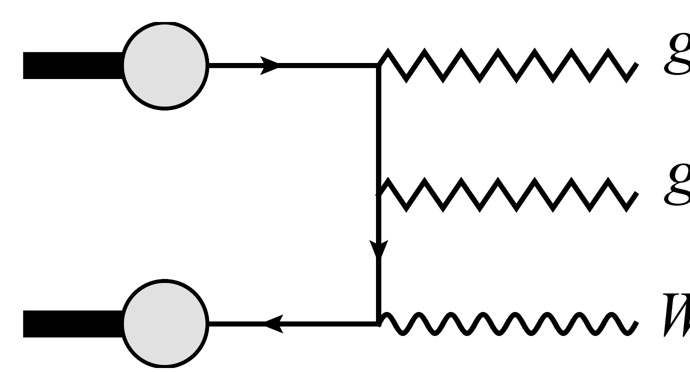
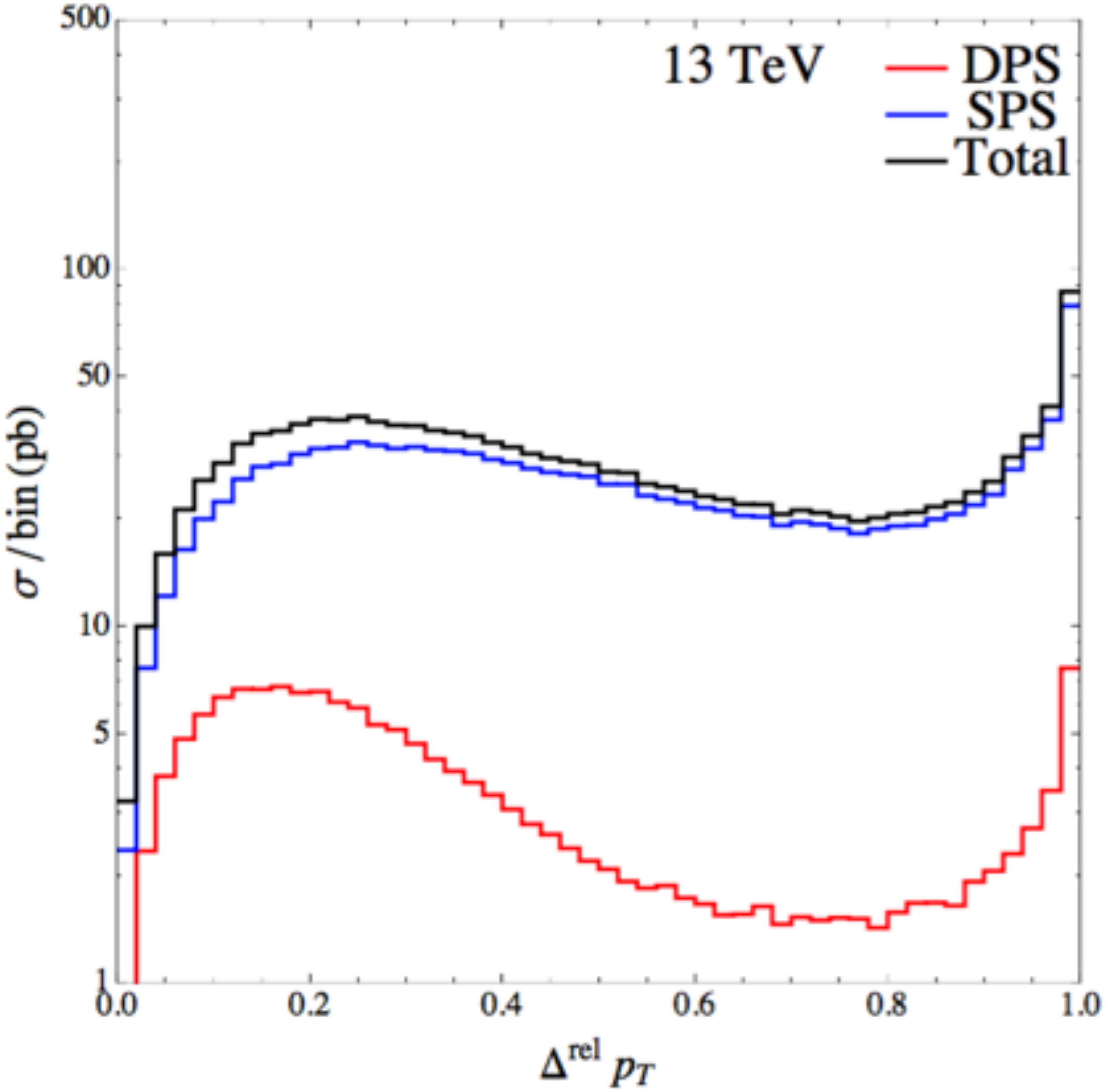
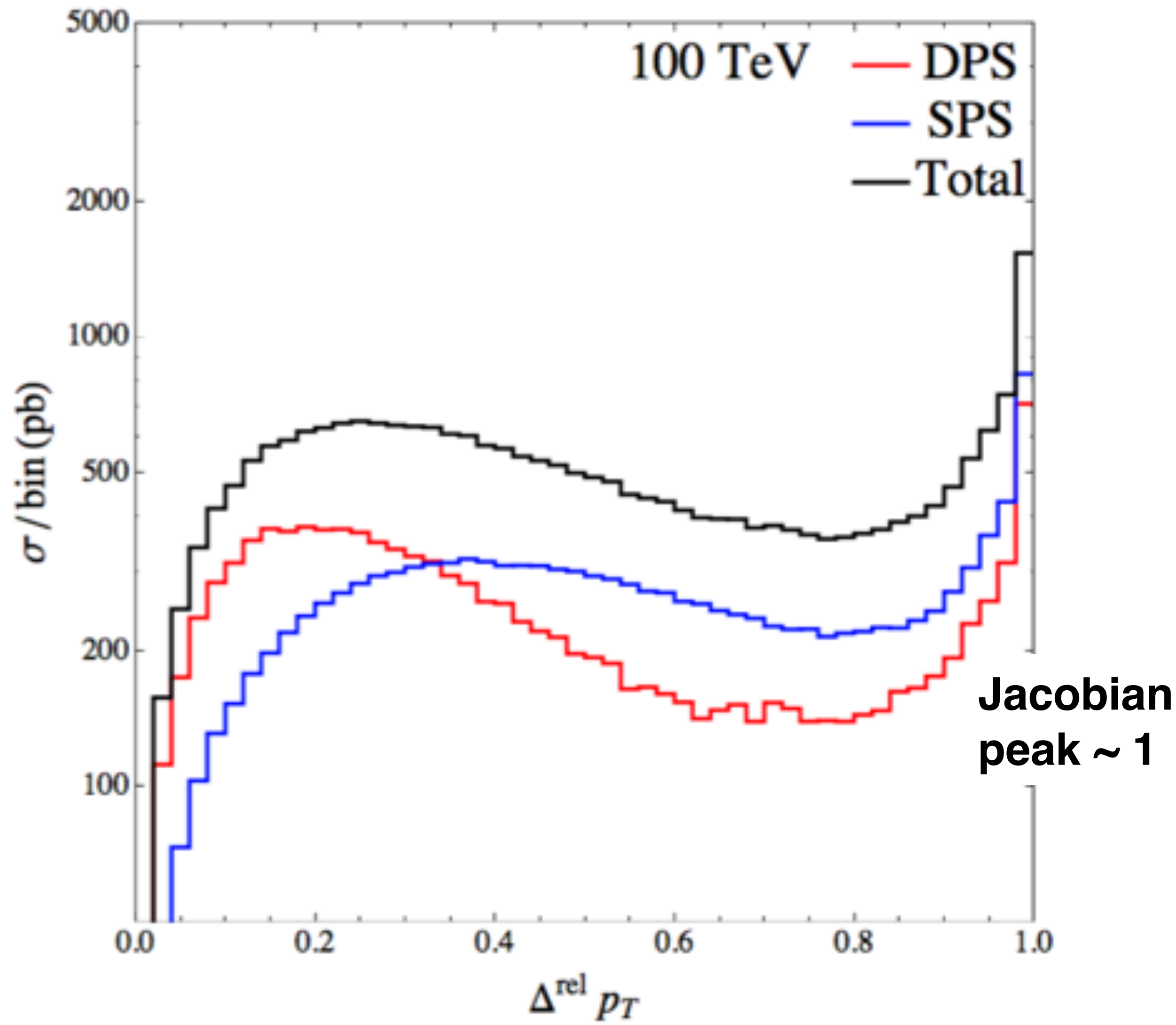


Kinematic distributions

$$\Delta^{\rm rel} p_T = \frac{|p_T(j_1, j_2)|}{|p_T(j_1)| + |p_T(j_2)|}$$

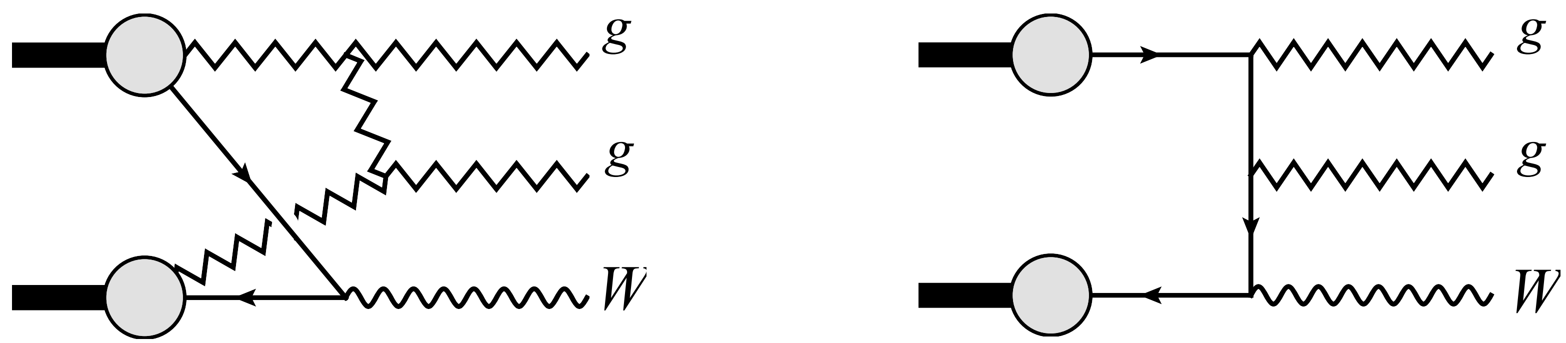




$$p_T(j_1) \approx p_T(j_2) \approx p_T$$

$$\Delta^{\rm rel} p_T = \frac{|p_T(j_1, j_2)|}{|p_T(j_1)| + |p_T(j_2)|} \approx \frac{\sqrt{2p_T + 2p_T \cos(\Delta\phi_{j_1 j_2})}}{2p_T} = \frac{\sqrt{1 + \cos(\Delta\phi_{j_1 j_2})}}{\sqrt{2}}$$

Collider simulation



W-boson decaying into a pair of leptons

1. exactly one charged lepton with $p_T^l \geq 35$ GeV, $|\eta^l| \leq 2.5$;
2. exactly two hard jets with $p_T^j \geq 25$ GeV, $|\eta^j| \leq 2.5$;
3. $\not{E}_T \geq 30$ GeV;
4. $M_T = \sqrt{2 \cdot p_T^l \cdot \not{E}_T \cdot \Big(1 - \cos(\Delta\phi[l, \not{E}_T])\Big)} > 50$ GeV.

MadEvent / Pythia /Delphes
(Parton level results checked with homemade code)

Collider simulation

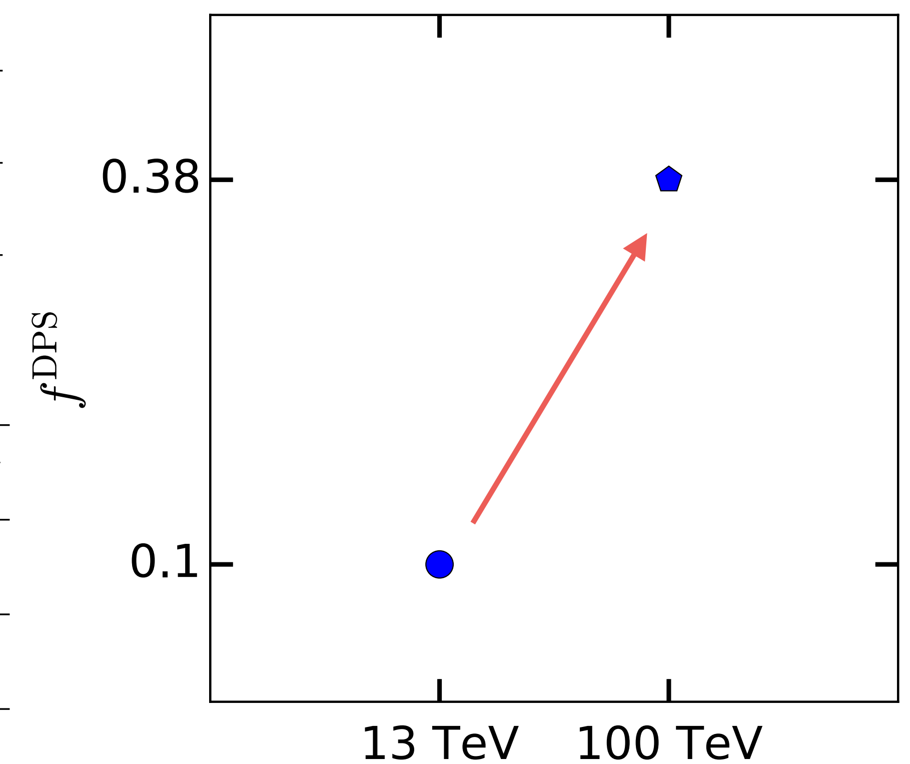
13TeV LHC (L=1 fb^{-1})

Process	Generator level	After cut I	After cut II	After cut III	After cut IV
DPS $W(\to l\nu_l)jj$	639056	141639	35170	24308	23546
$W(\to l\nu_l)jj$	7529710	2262220	395275	228330	193813
$t\bar{t}$ (all possible decays)	461001	76162	10255	8457	6455
$t(\to bl\nu_l)j$	36577	13456	5751	4069	3344
tW (all possible decays)	39450	7214	2012	1506	1154
$Z(\to ll)jj$	284037	129799	53003	5594	4200
f^{DPS}	–	0.05	0.07	0.09	0.10

100TeV SppC (L=0.1 fb^{-1})

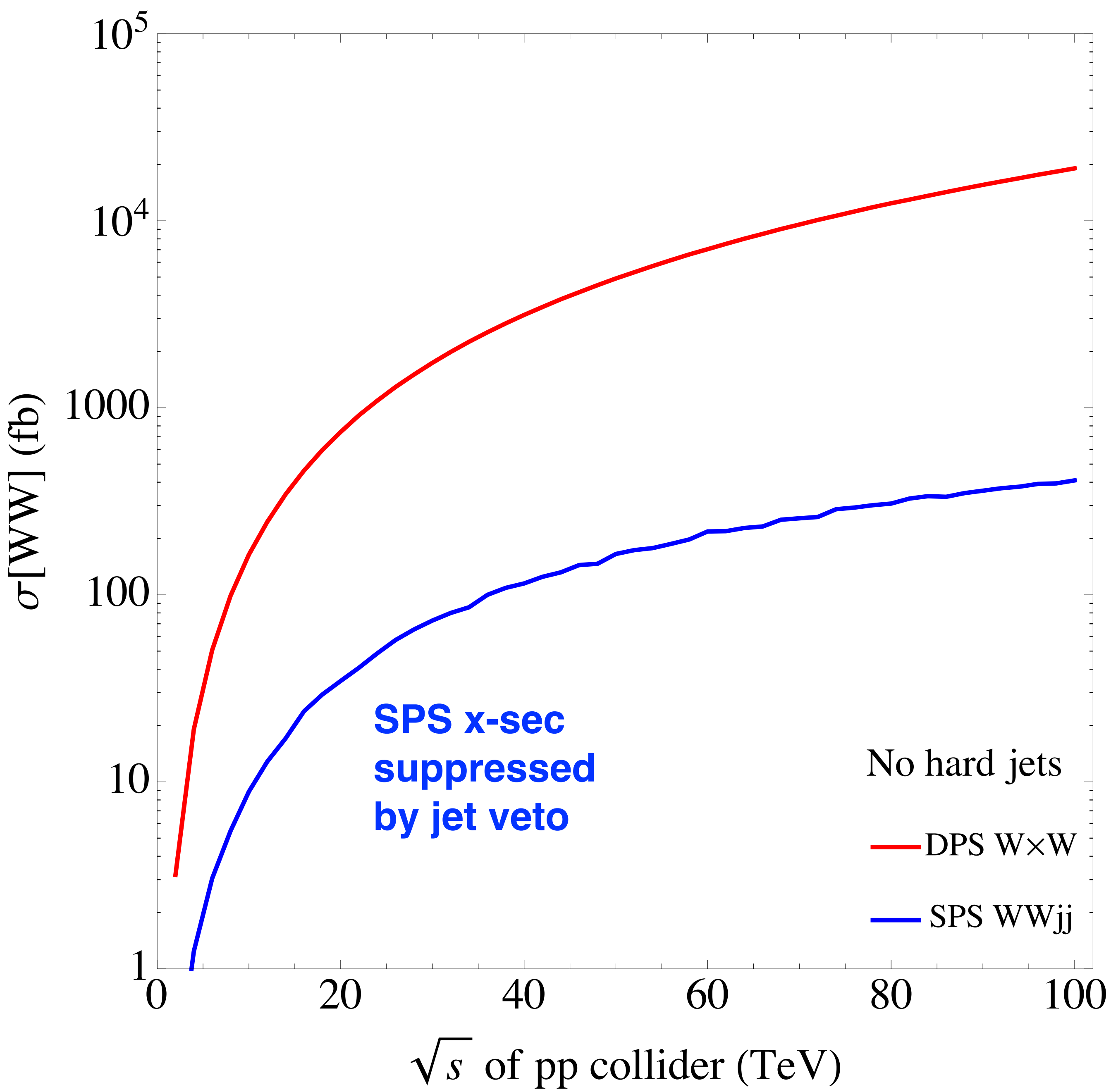
Process	Generator level	After cut I	After cut II	After cut III	After cut IV
DPS $W(\to l\nu_l)jj$	5375310	945360	246794	163131	154847
$W(\to l\nu_l)jj$	7768790	2124970	422557	253758	211377
$t\bar{t}$ (all possible decays)	2401890	333570	41949	34872	26642
$t(\to bl\nu_l)j$	51296	17127	6856	4956	3964
tW (all possible decays)	174203	27599	6607	5252	3829
$Z(\to ll)jj$	449478	167953	61483	9038	6906
f^{DPS}	–	0.26	0.31	0.35	0.38

$$f \equiv \frac{\#(\mathrm{DPS})}{\#(\mathrm{DPS}+\mathrm{SPS}+\mathrm{BG})}$$



2) Same-sign WW pair production

(golden channel of DPS)



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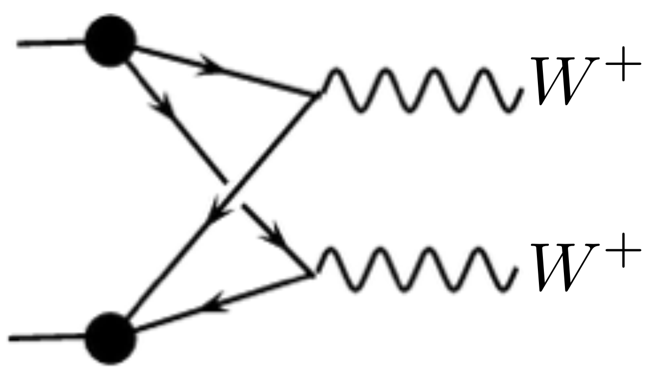

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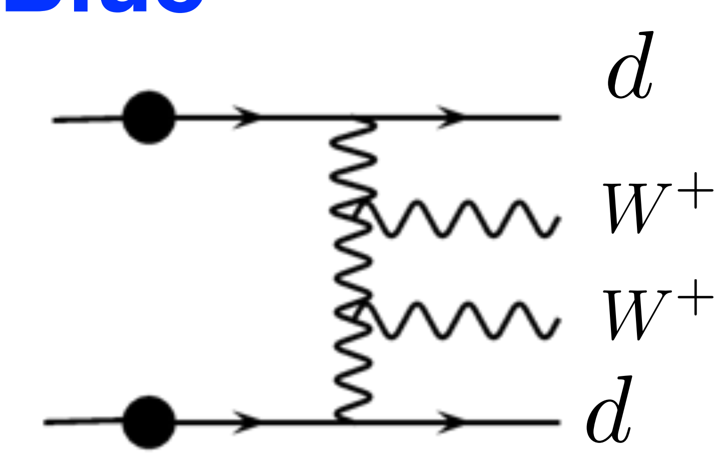
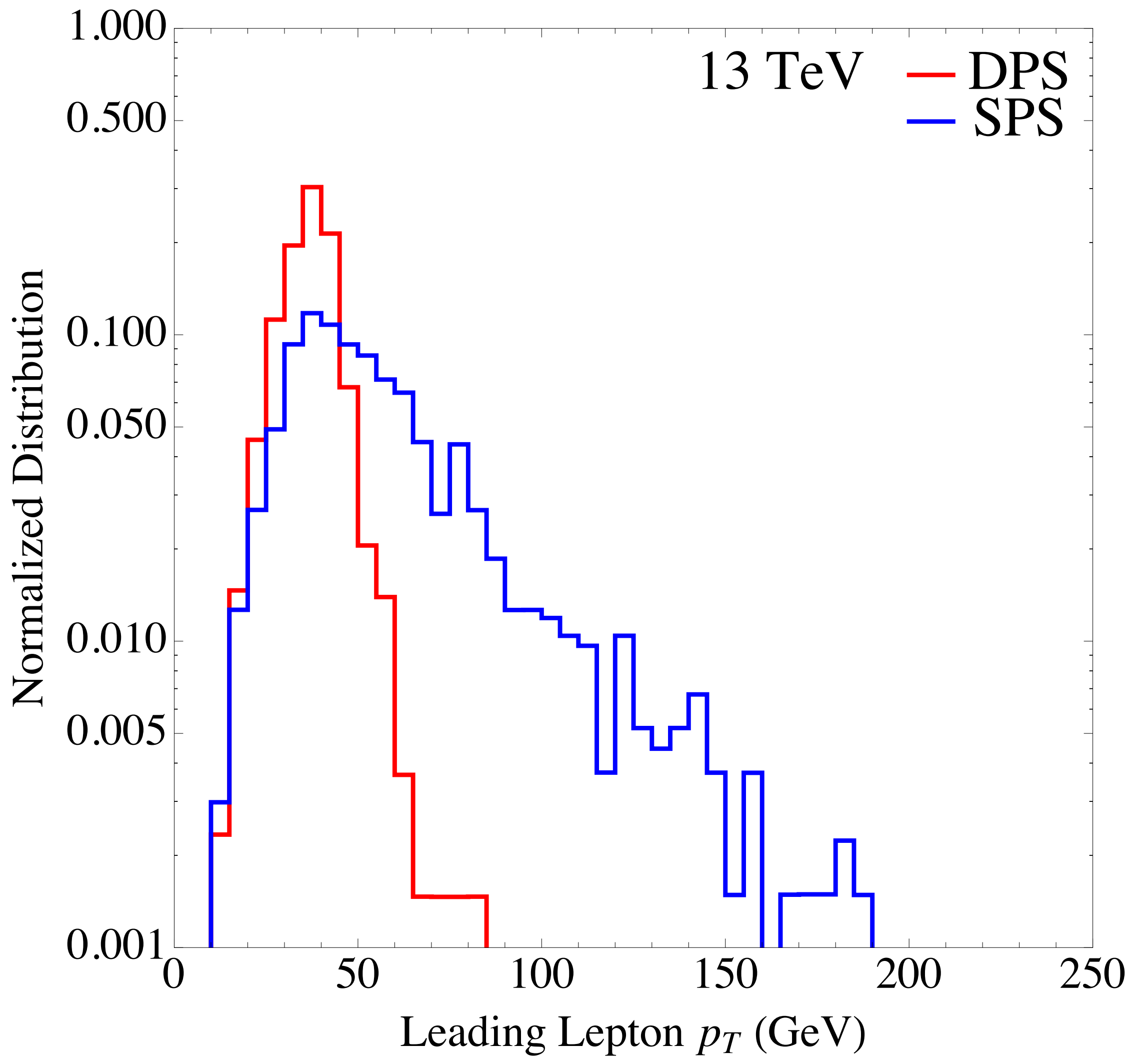
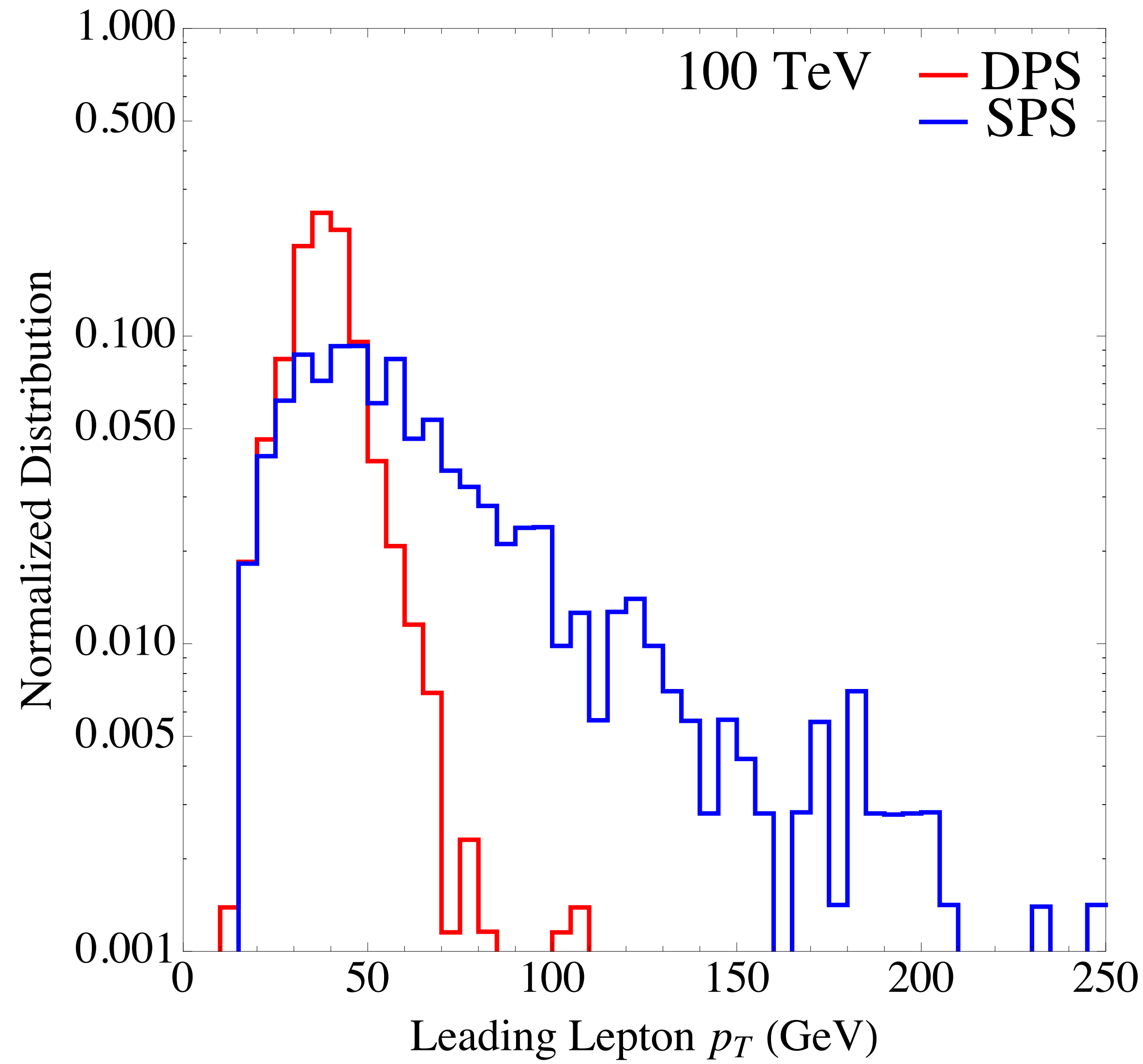


Kinematic distributions

Transverse momentum of the leading lepton





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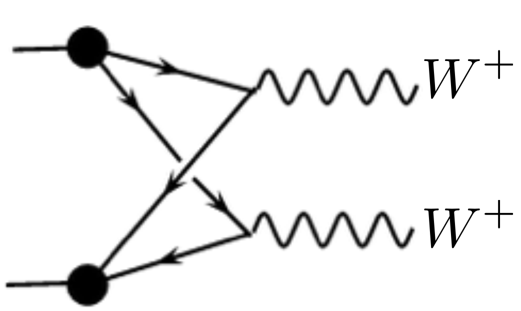

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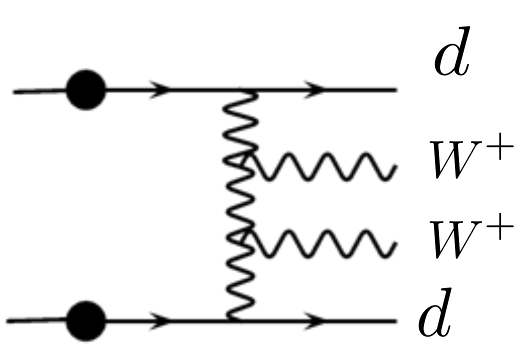
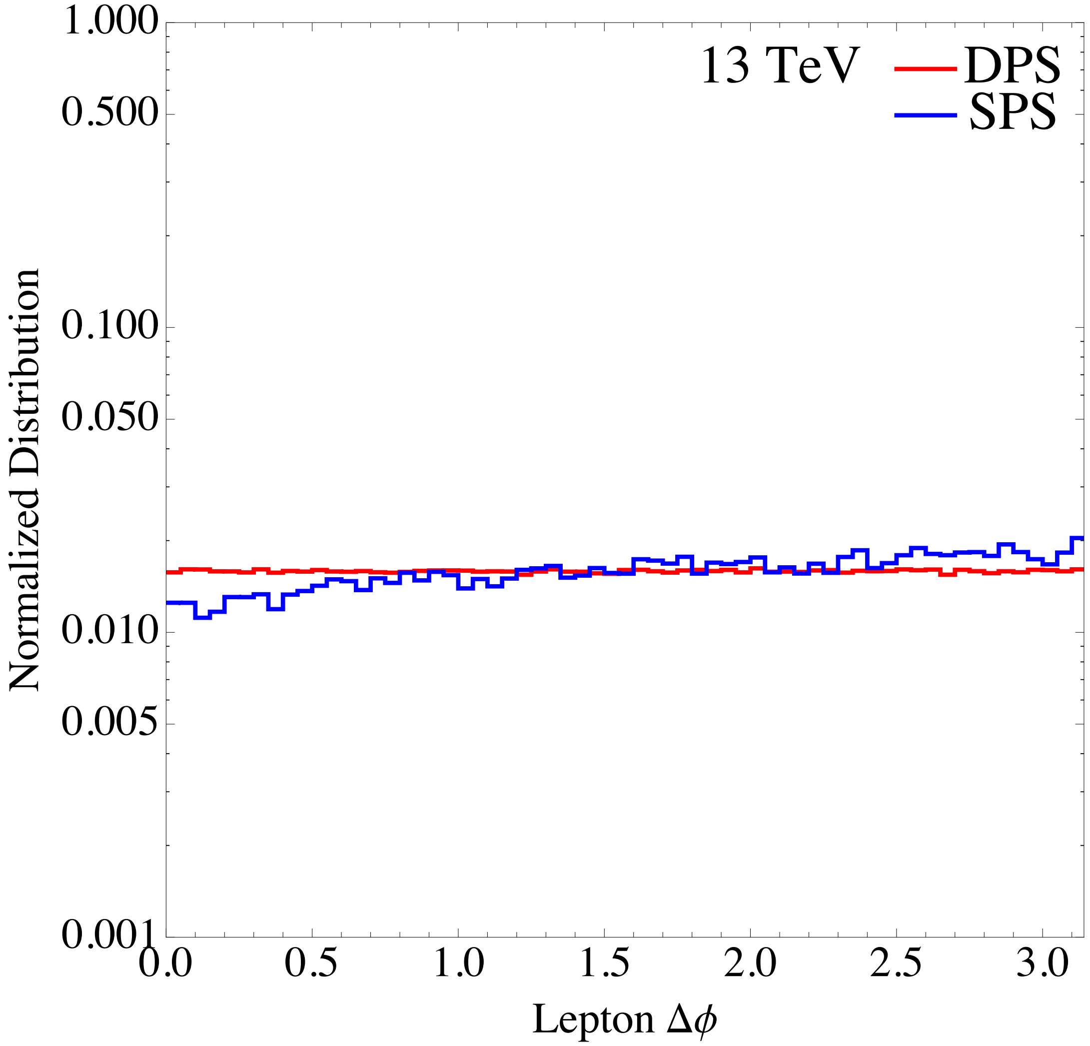
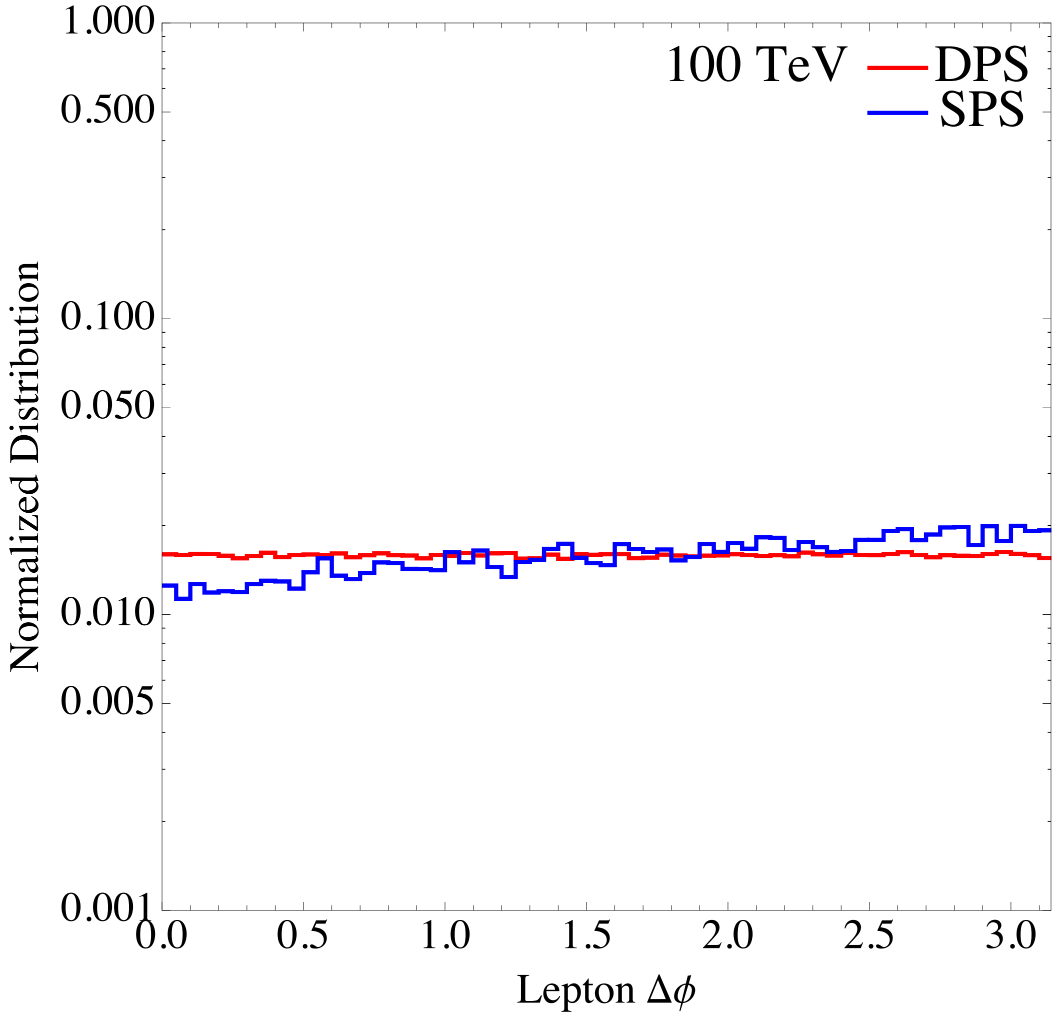


Kinematic distributions

Azimuthal angle info: not very useful





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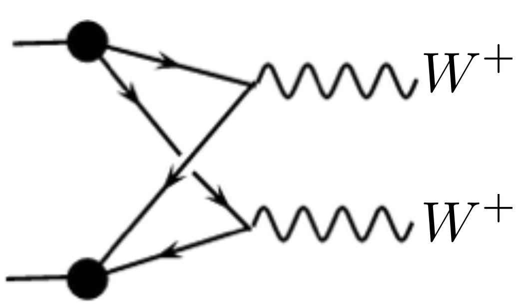

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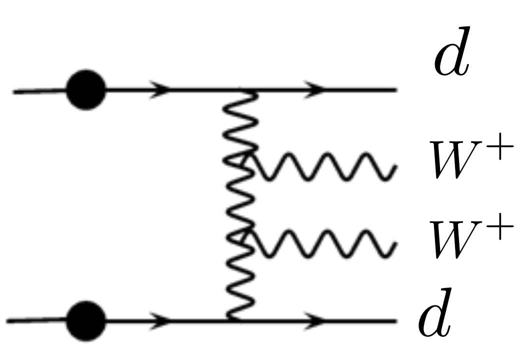
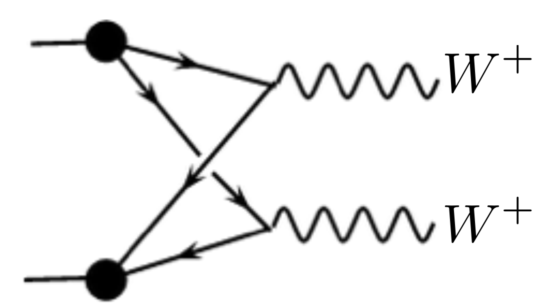


Collider simulation

1. exactly two same sign charged leptons, with the leading lepton $p_T^{l_1} \geq 20$ GeV, $|\eta^{l_1}| \leq 2.5$, and the trailing lepton $p_T^{l_2} \geq 10$ GeV, $|\eta^{l_2}| \leq 2.5$;
2. exactly 0 jet with $p_T^j \geq 25$ GeV, $|\eta^j| \leq 2.5$;
3. $\not{E}_T \geq 20$ GeV;
4. $|p_T^{l_1}| + |p_T^{l_2}| > 45$ GeV;
5. $M_{l_1 l_2} \in [20, 75] \cup [105, +\infty]$ GeV;
6. $|p_T^{l_1}| < 60$ GeV, and $|p_T^{l_2}| < 60$ GeV.

Red



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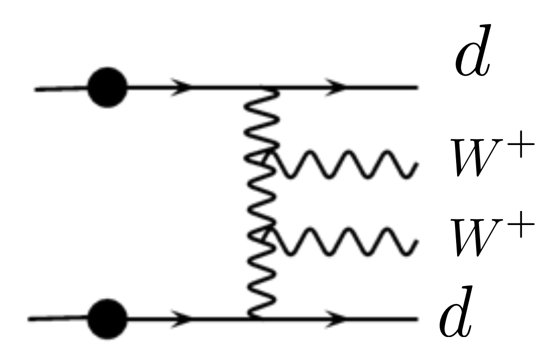


Collider simulation

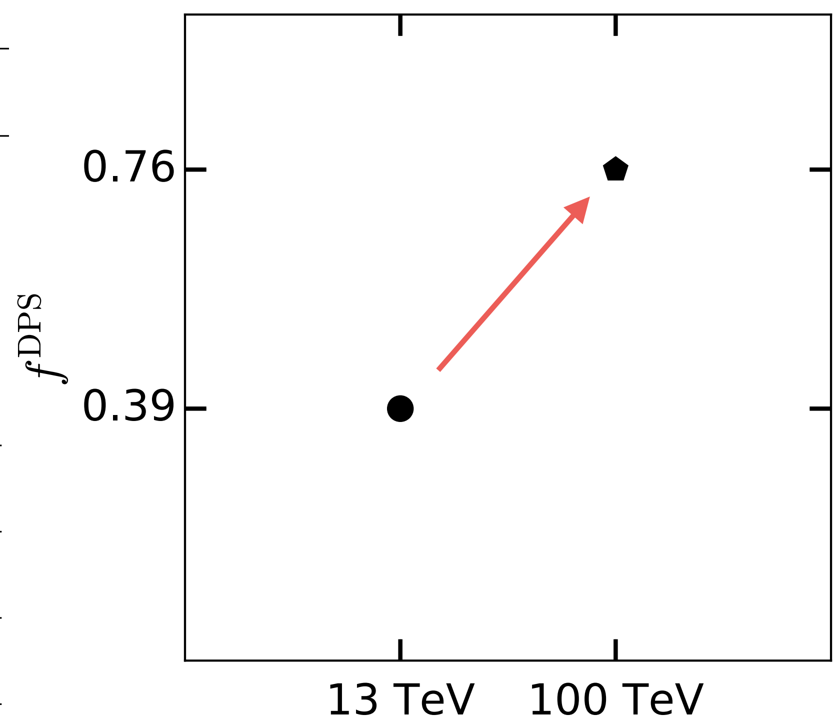
13TeV LHC (L=50 fb^{-1})

Process	Generator level	After cut I	After cut II	After cut III	After cut IV	After cut V	After cut VI
DPS $W^\pm W^\pm$	807	199.5	129.7	108	99.3	82.8	82
$W^\pm W^\pm jj$	718	204.07	4.71	4.20	3.97	3.24	2.06
$t\bar{t}$	23050050	177.53	2.82	2.82	1.88	1.88	0.94
Wl^+l^-	19600	1807.88	333.26	284.05	262.87	244.61	123.9
$l^+l^-l^+l^-$	1615	94.62	8.69	1.41	1.28	1.03	0.59
f^{DPS}	–	0.08	0.27	0.27	0.27	0.25	0.39

$$f \equiv \frac{\#(\mathrm{DPS})}{\#(\mathrm{DPS}+\mathrm{SPS}+\mathrm{BG})}$$

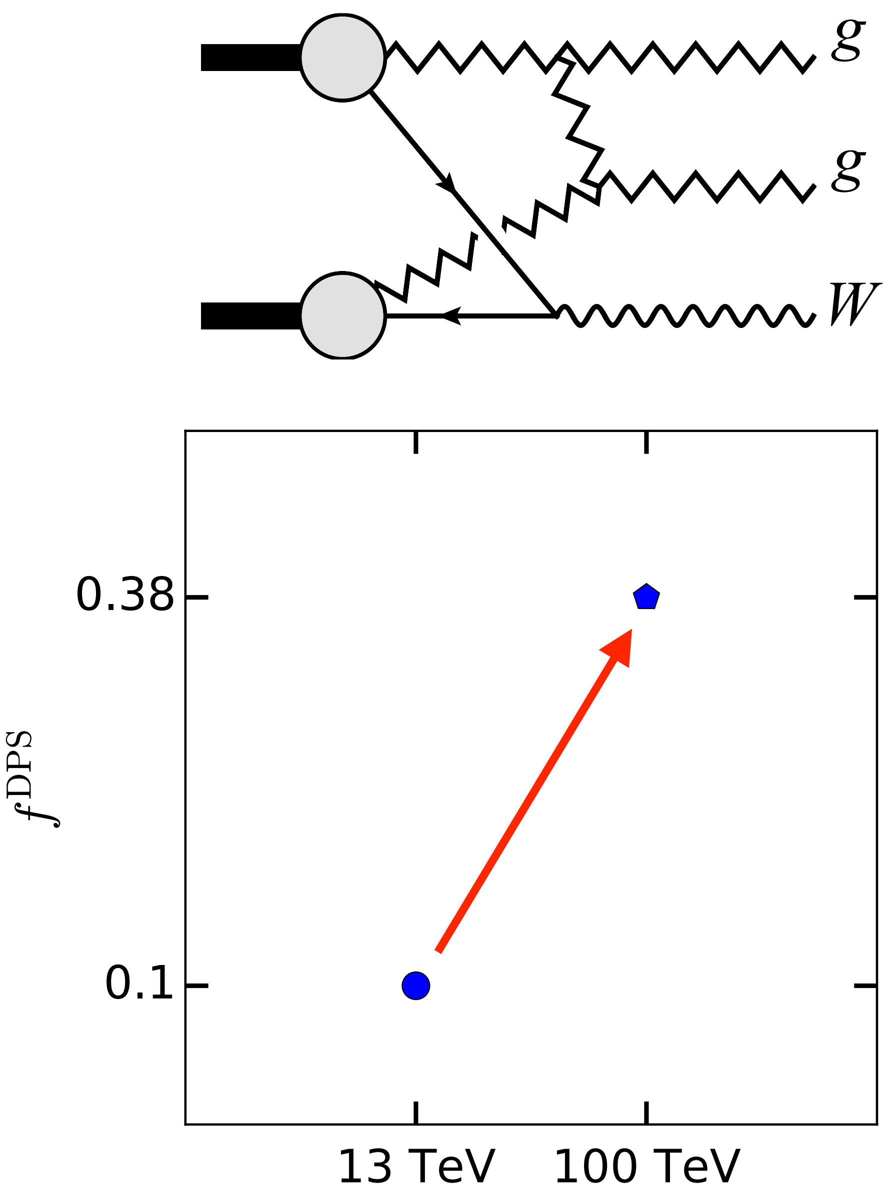
100TeV SppC (L=1 fb^{-1})

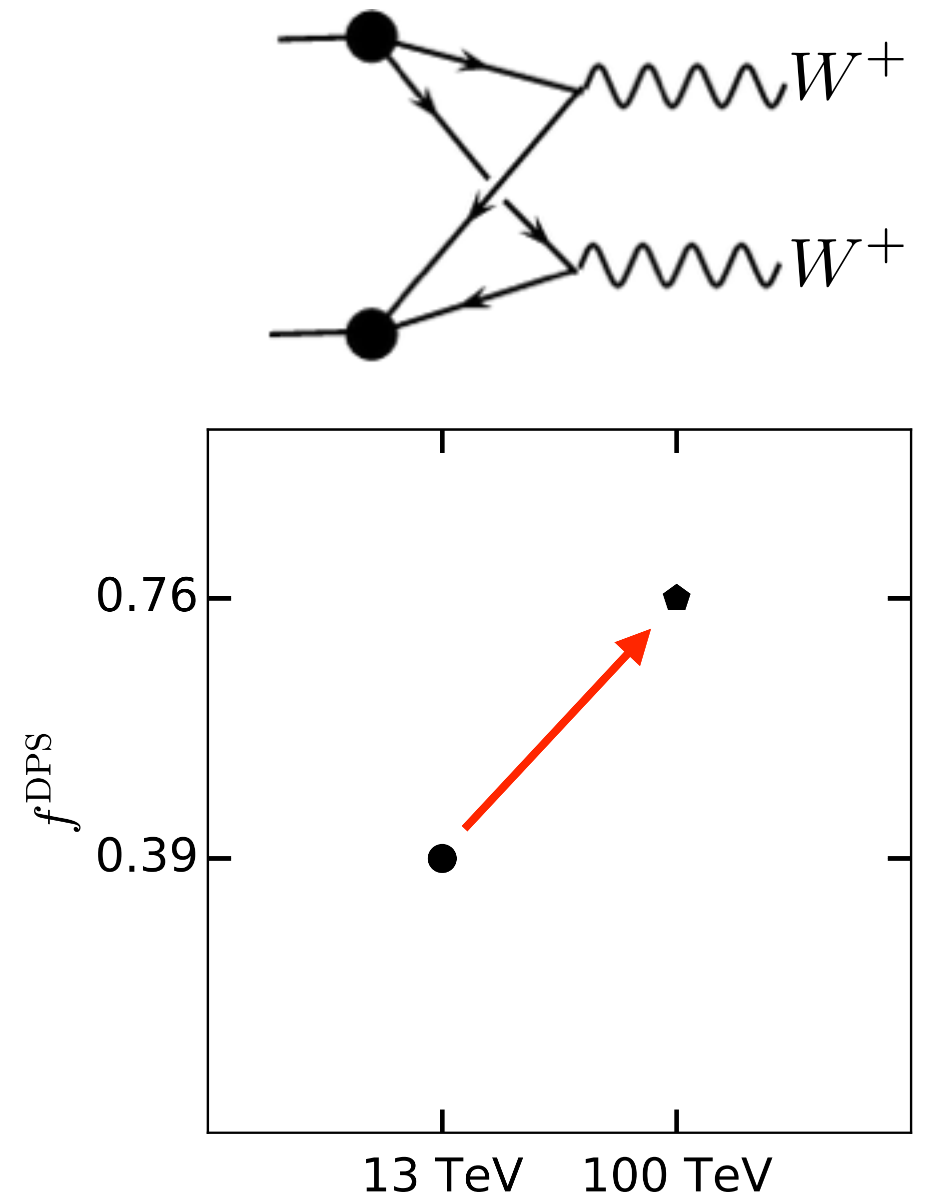
Process	Generator level	After cut I	After cut II	After cut III	After cut IV	After cut V	After cut VI
DPS $W^\pm W^\pm$	1100	151.1	78.1	64.1	58	47.6	46.9
$W^\pm W^\pm jj$	223.53	39.25	0.79	0.7	0.65	0.54	0.29
$t\bar{t}$	24018900	149.69	5.87	5.87	2.43	0	0
Wl^+l^-	4044	360.73	42.1	36.08	33.76	26.77	14.76
$l^+l^-l^+l^-$	275	17.09	1.25	0.24	0.22	0.17	0.08
f^{DPS}	–	0.21	0.61	0.60	0.61	0.63	0.76



Summary

Large dynamic range of SppC offers opportunity to explore the DPS phenomenology and measure $\sigma_{\rm eff}$





$$f \equiv \frac{\#(\mathrm{DPS})}{\#(\mathrm{DPS}+\mathrm{SPS}+\mathrm{BG})}$$