Multibosons from the Parton Shower

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PITT PACC, University of Pittsburgh

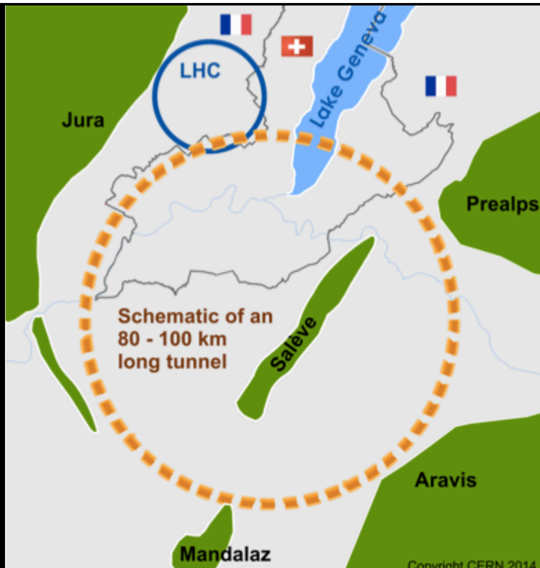
@ BNL Multiboson Interactions Workshop

30 October 2014

* Work in progress with J Chen & T Han

A Future pp Collider, E ~ 100 TeV

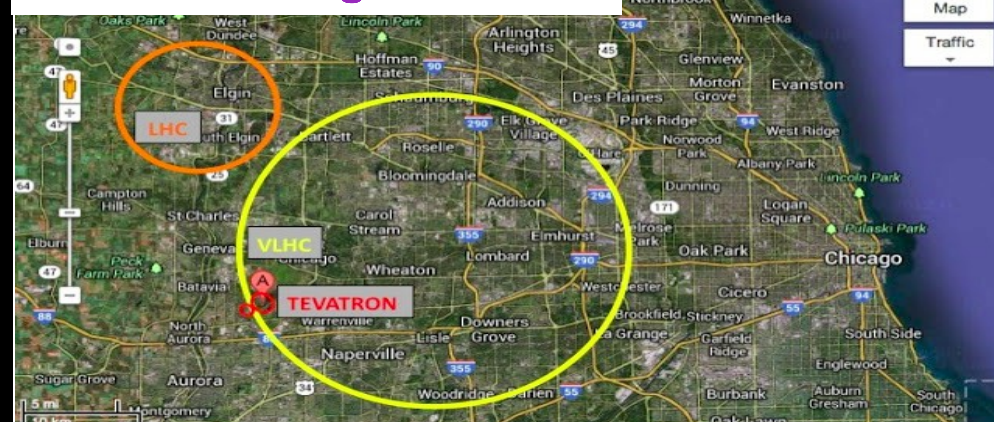
Future CERN Collider



* also HE-HLC (33 TeV)

Future China Collider

Future Chicago Collider



A Multiboson Factory

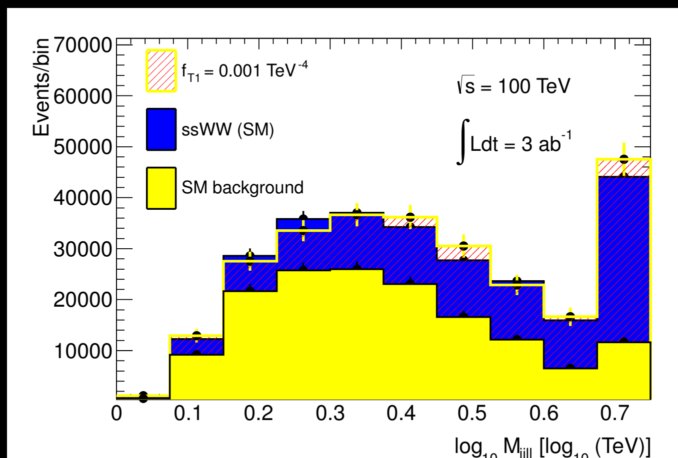
At 100 TeV:

WW	σ=770 pb
WWW	σ=2 pb
WWZ	σ=1.6 pb
WWWW	σ=15 fb
WWWZ	σ=20 fb
....	

Mangano

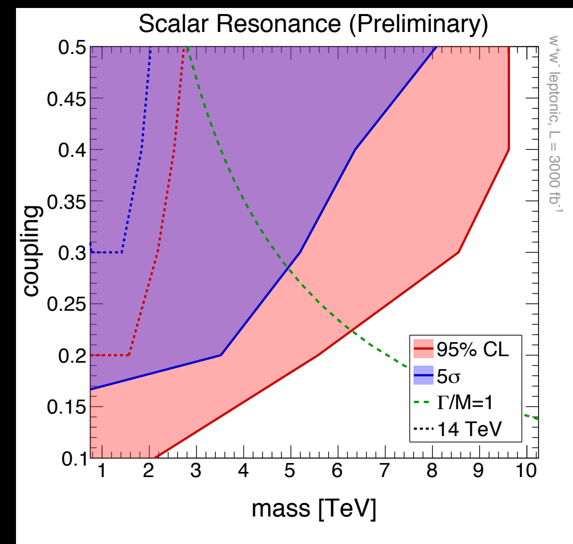
WW Scattering

Degrande, et al (1309.7452)



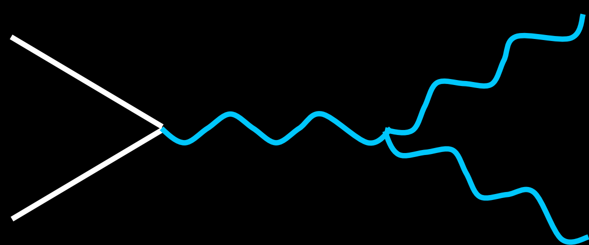
Parameter	$\sqrt{s}$ [TeV]	Luminosity [fb^{-1}]	pileup	5σ [TeV^{-4}]	95% CL [TeV^{-4}]
f_{T1}/Λ^4	14	300	50	0.2 (0.4)	0.1 (0.2)
f_{T1}/Λ^4	14	3000	140	0.1 (0.2)	0.06 (0.1)
f_{T1}/Λ^4	14	3000	0	0.1 (0.2)	0.06 (0.1)
f_{T1}/Λ^4	100	1000	40	0.001 (0.001)	0.0004 (0.0004)
f_{T1}/Λ^4	100	3000	263	0.001 (0.001)	0.0008 (0.0008)
f_{T1}/Λ^4	100	3000	0	0.001 (0.001)	0.0008 (0.0008)

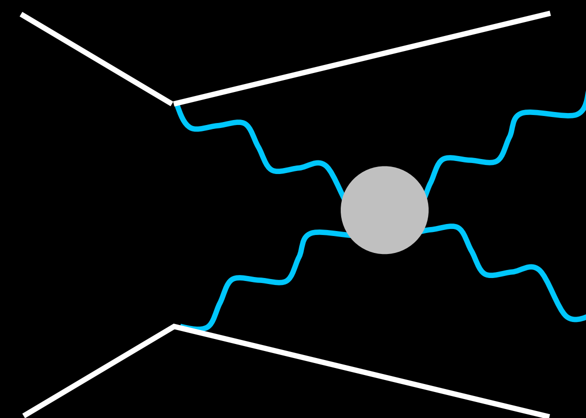
Low (10 Oct talk @ VLHC meeting)



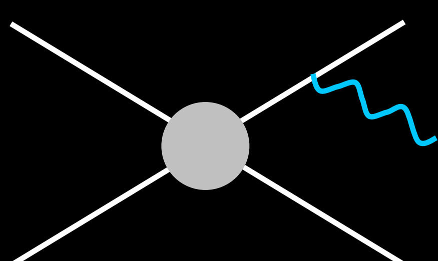
How Weak Bosons are Made

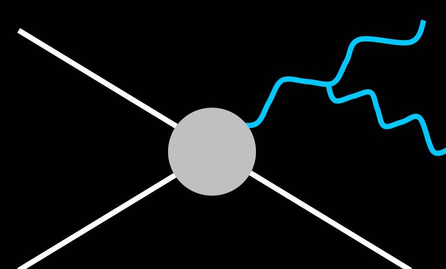
At the hard process scale





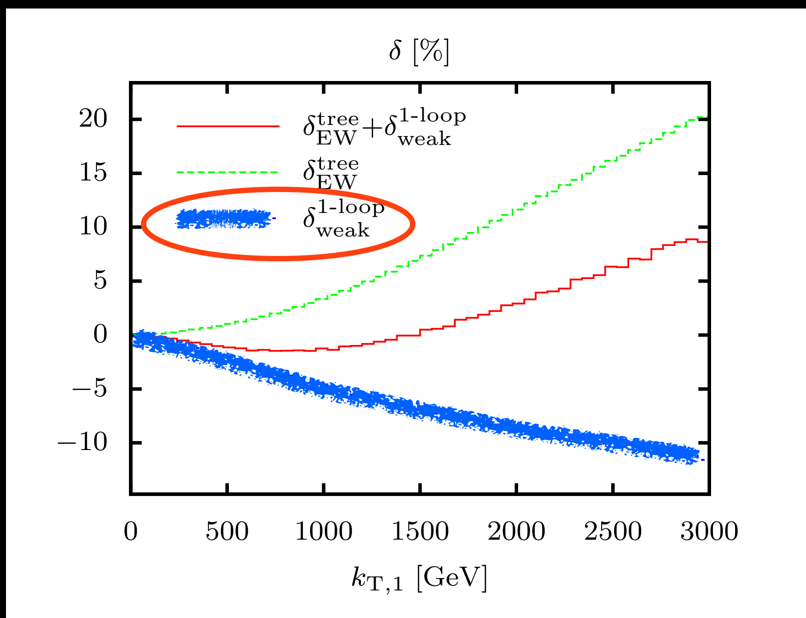
Hierarchically below the hard process scale...EW parton shower





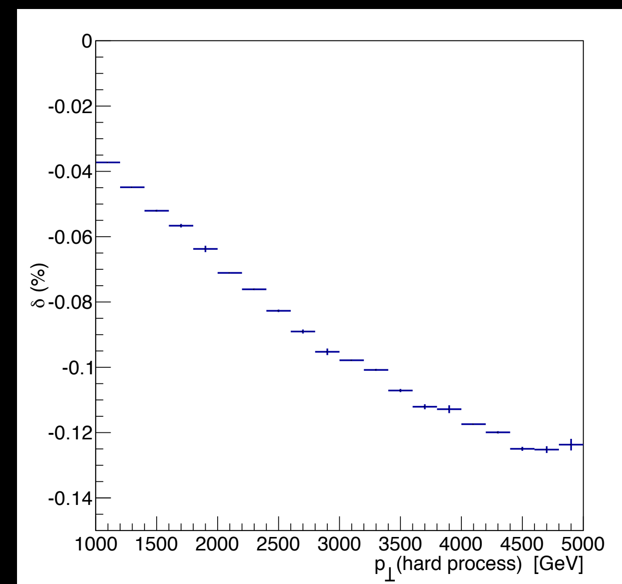
Electroweak Sudakovs

Dittmaier, Huss, Speckner (1210.0438)



Virtual weak corrections to exclusive dijets at LHC14

Christiansen & Sjöstrand (1401.5238)

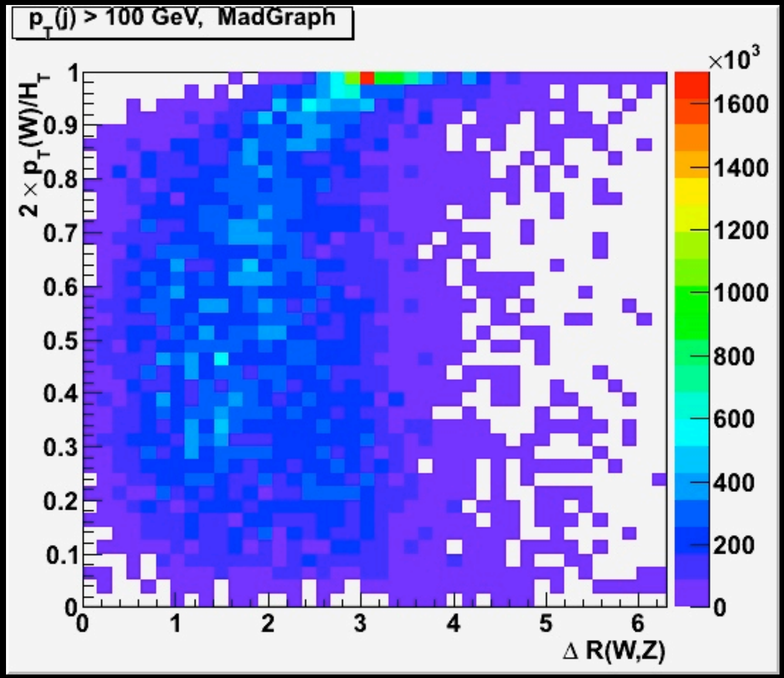


LO rate minus real W/Z emission events

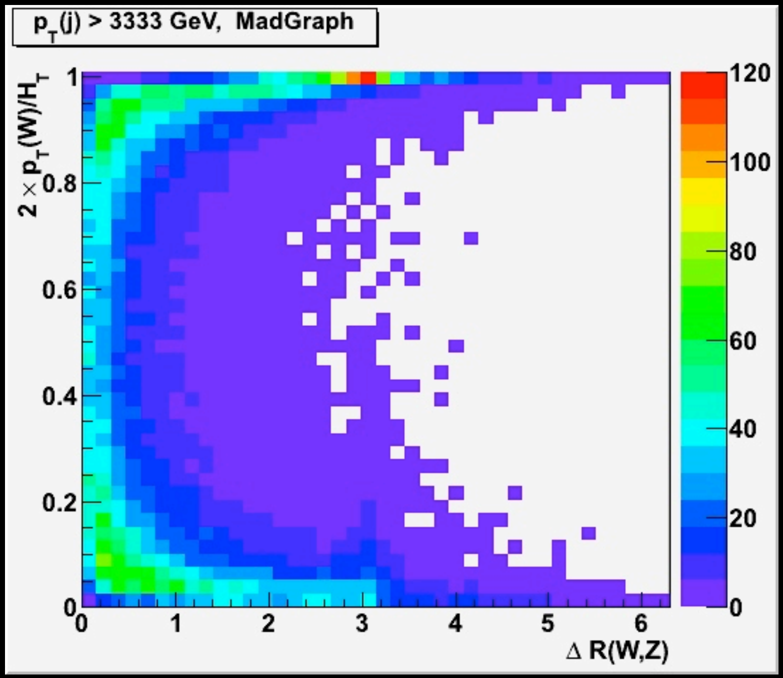
also **Moretti, Nolten, Ross (hep-ph/0606201),**
many other related works

Example: WZ+Jet @ 100 TeV

$p_T(j) > 100$ GeV

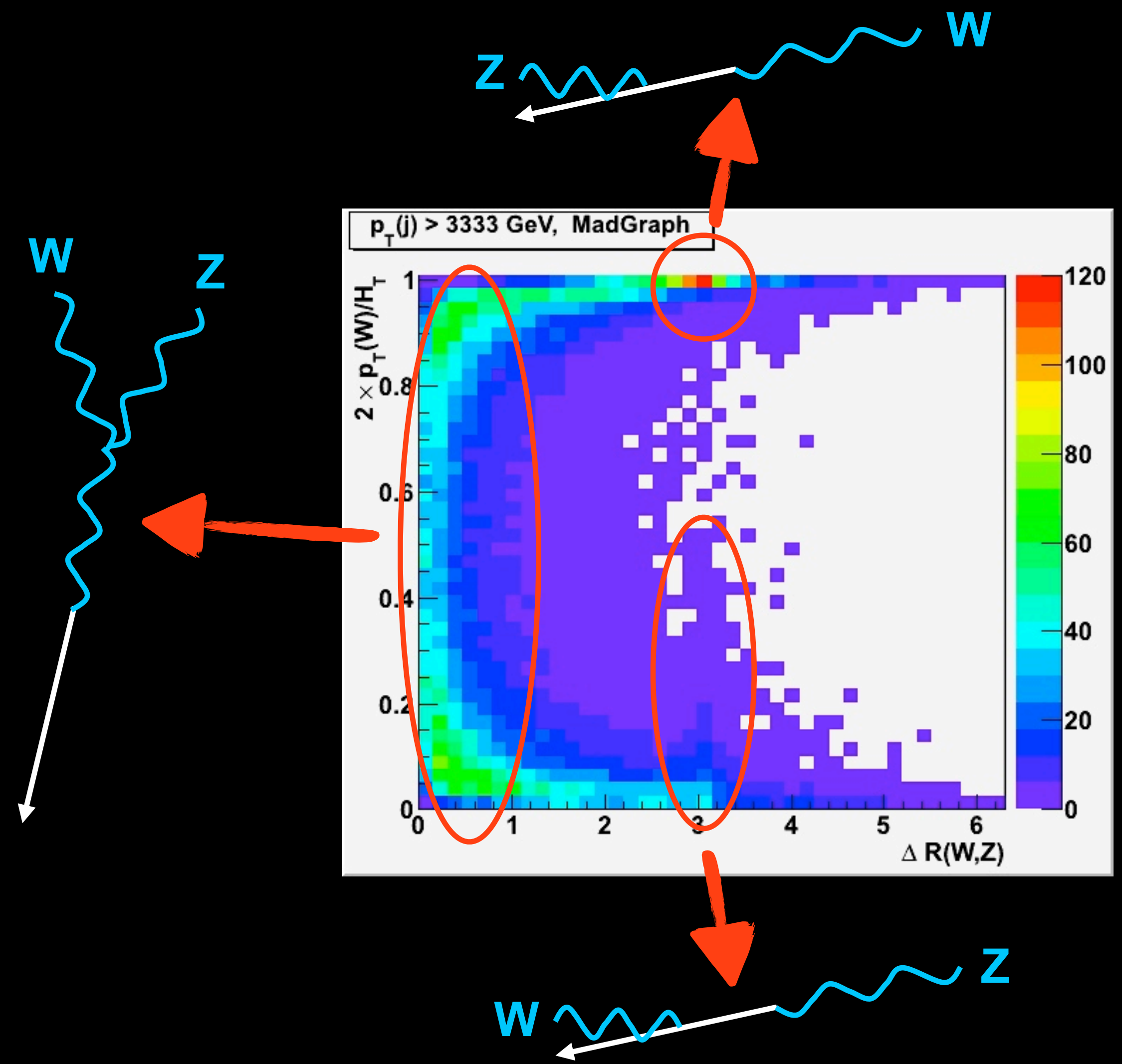


$p_T(j) > 3.3$ TeV



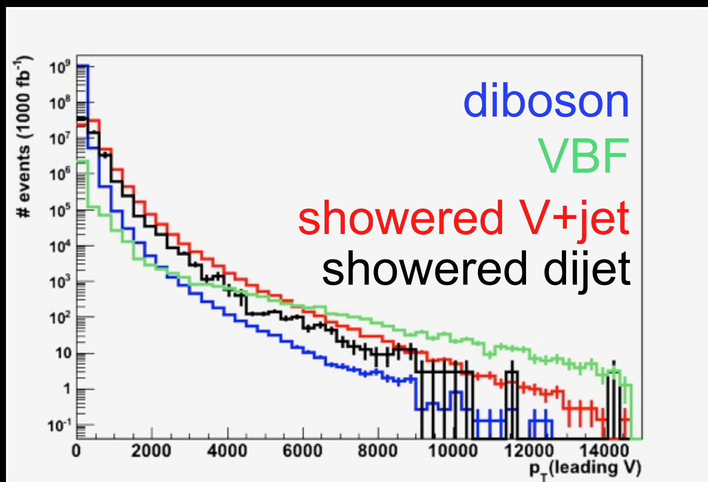
*** assumed lumi = 1 ab^{-1}**

Example: WZ+Jet @ 100 TeV

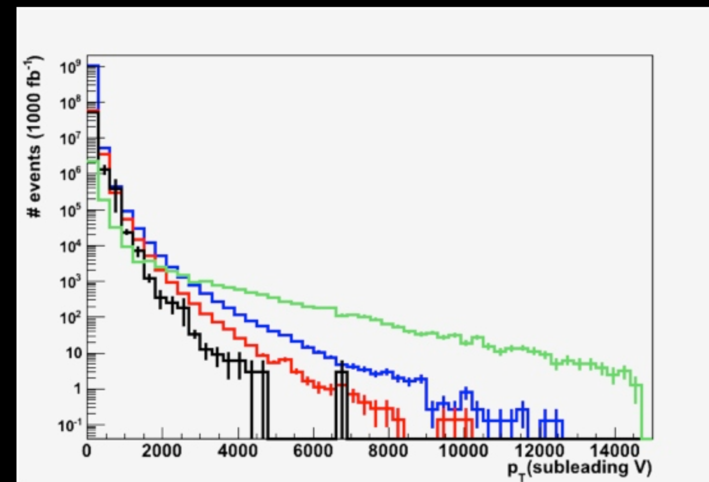


"Shower" Vs "Prompt"

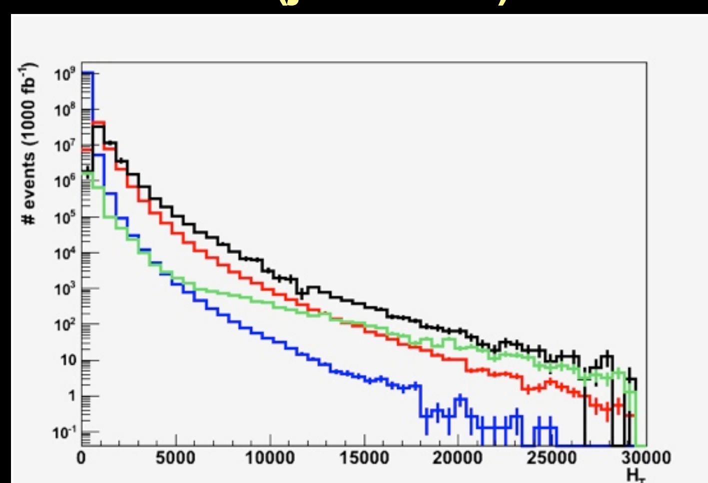
p_T(leading V)



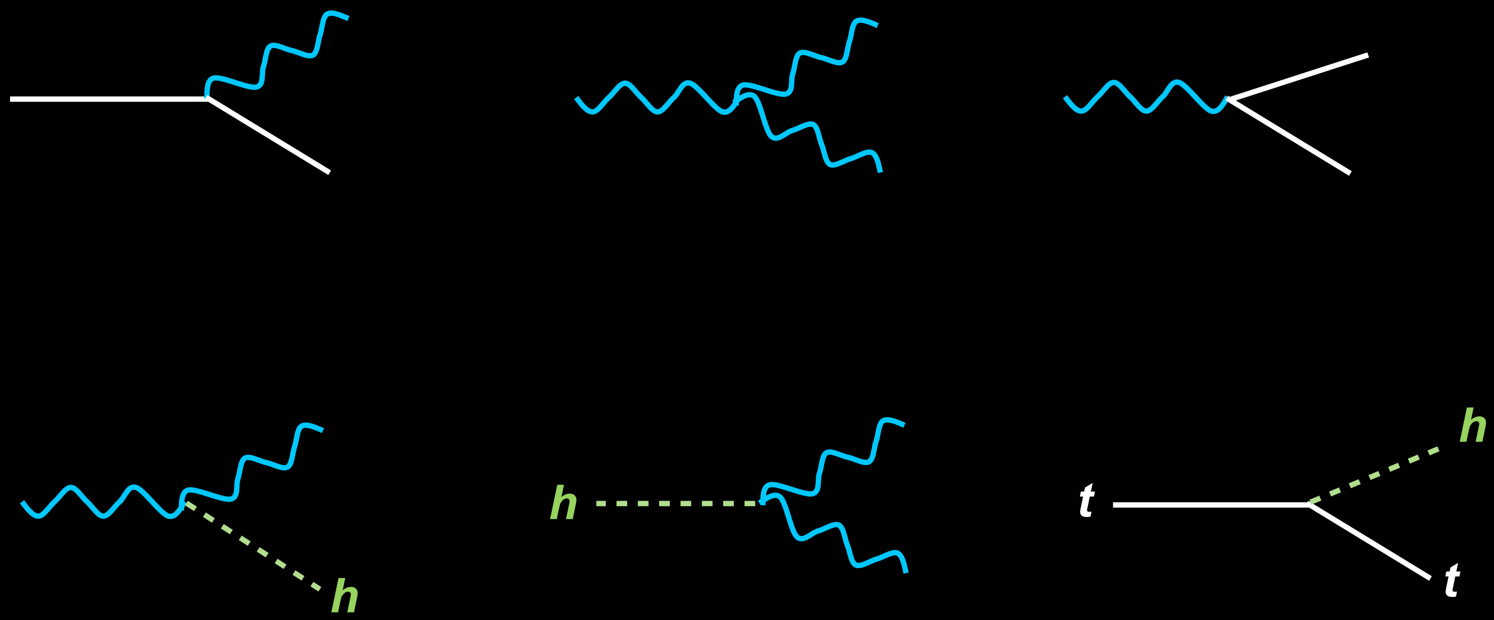
p_T(subleading V)



H_T(jets + V's)



Electroweak Splittings

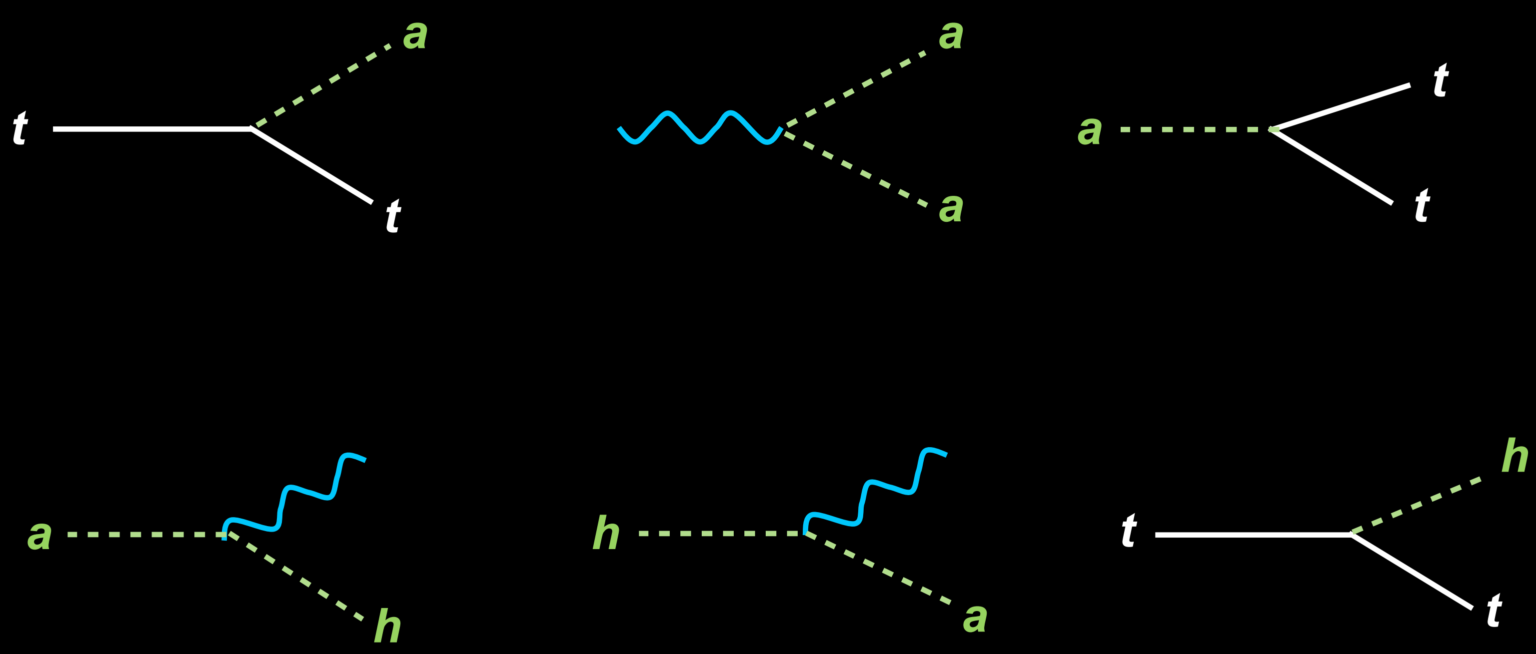


Etc...

* Including splittings with photons

Electroweak Splittings

... With many hidden Goldstone equivalencies with longitudinal bosons



Etc...

* Including splittings with photons

Integrated Quark Splitting Rates

Averaged over flavors & helicities, summed over W & Z

$$\mathcal{P}(q \to V_T q) \simeq (3 \times 10^{-3}) \left[\log \frac{E}{m_{\rm EW}}\right]^2 \quad \Rightarrow \quad \mathcal{P}(1\ \text{TeV}) \simeq 1.7\%, \quad \mathcal{P}(10\ \text{TeV}) \simeq 7\%$$

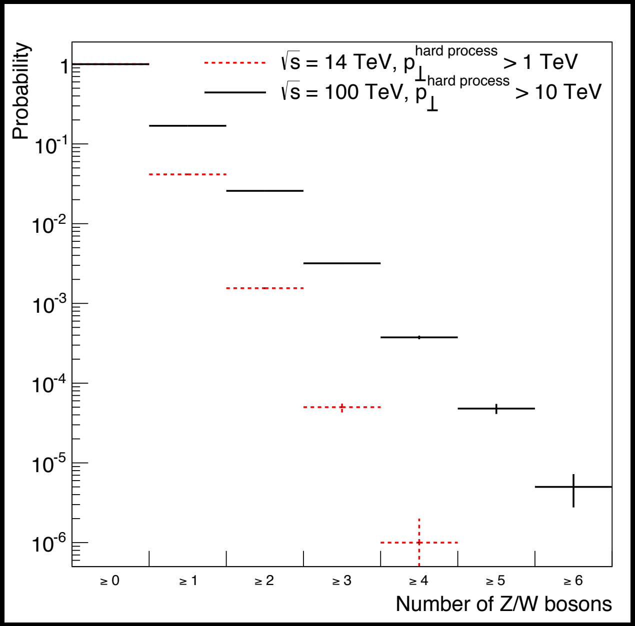
$$\mathcal{P}(q \to V_L q)^{*} \simeq (2 \times 10^{-3}) \log \frac{E}{m_{\rm EW}} \quad \Rightarrow \quad \mathcal{P}(1\ \text{TeV}) \simeq 0.5\%, \quad \mathcal{P}(10\ \text{TeV}) \simeq 1\%$$

* Massless fermions here...massive (top/bottom) will also have "equivalent Goldstone" contributions

Work So Far with q→Vq

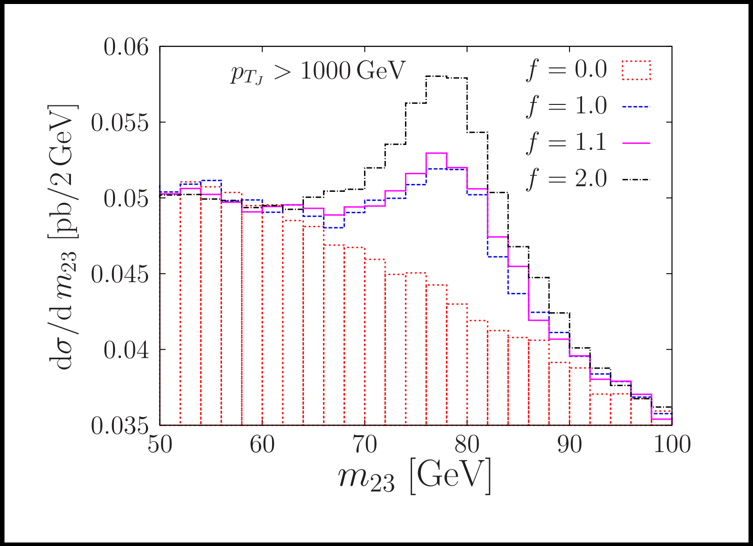
PYTHIA8

Christiansen & Sjöstrand (1401.5238)



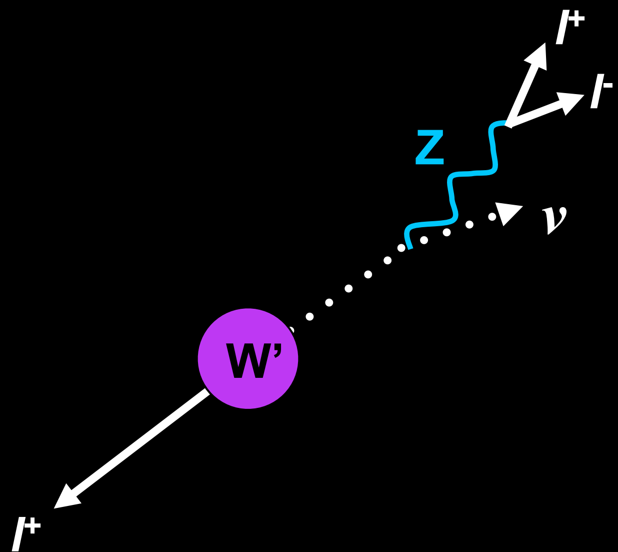
SHERPA

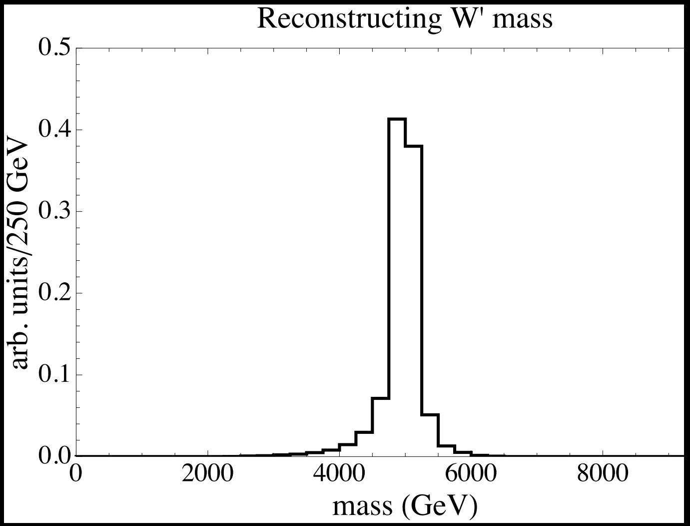
Krauss, Petrov, Schönherr, Spannowsky (1403.4788)



*** Both use dipole-like qq→qqV splittings**

… And with Leptons/Neutrinos





Use radiated Z-boson to determine full neutrino 3-vector direction (and test for W' chirality)

Hook & Katz (1407.2607)
also Rizzo (1403.5465)

Integrated Transverse Vector Splitting Rates

$$\mathcal{P}(V_T \to V_T V_T) \simeq (0.01) \left[\log \frac{E}{m_{\rm EW}}\right]^2 \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 6\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 22\%$$

$$\mathcal{P}(V_T \to V_T V_L) \simeq (0.01) \log \frac{E}{m_{\rm EW}} \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 2\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 5\%$$

$$\mathcal{P}(V_T \to V_L V_L) \simeq (4 \times 10^{-4}) \log \frac{E}{m_{\rm EW}} \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 0.1\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 0.2\%$$

$$\mathcal{P}(V_T \to f\bar{f}) \simeq (0.04) \log \frac{E}{m_{\rm EW}} \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 10\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 20\%$$

$$\mathcal{P}(V_T \to V_L h) \simeq (4 \times 10^{-4}) \log \frac{E}{m_{\rm EW}} \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 0.1\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 0.2\%$$

$$\mathcal{P}(V_T \to V_T h) \simeq (3 \times 10^{-4}) \quad \Rightarrow \quad \mathcal{P}(1~\text{TeV}) \simeq 0.03\%, \quad \mathcal{P}(10~\text{TeV}) \simeq 0.03\%$$

Integrated Longitudinal Vector Splitting Rates

$$\mathcal{P}(V_L \to V_T V_L) \sim (2 \times 10^{-3}) \quad \Rightarrow \quad \mathcal{P}(1 \text{ TeV}) \sim 1\%, \quad \mathcal{P}(10 \text{ TeV}) \sim 4\%$$

$$\mathcal{P}(V_L \to V_T h) \sim (2 \times 10^{-3}) \quad \Rightarrow \quad \mathcal{P}(1 \text{ TeV}) \sim 1\%, \quad \mathcal{P}(10 \text{ TeV}) \sim 4\%$$

Plus others.....

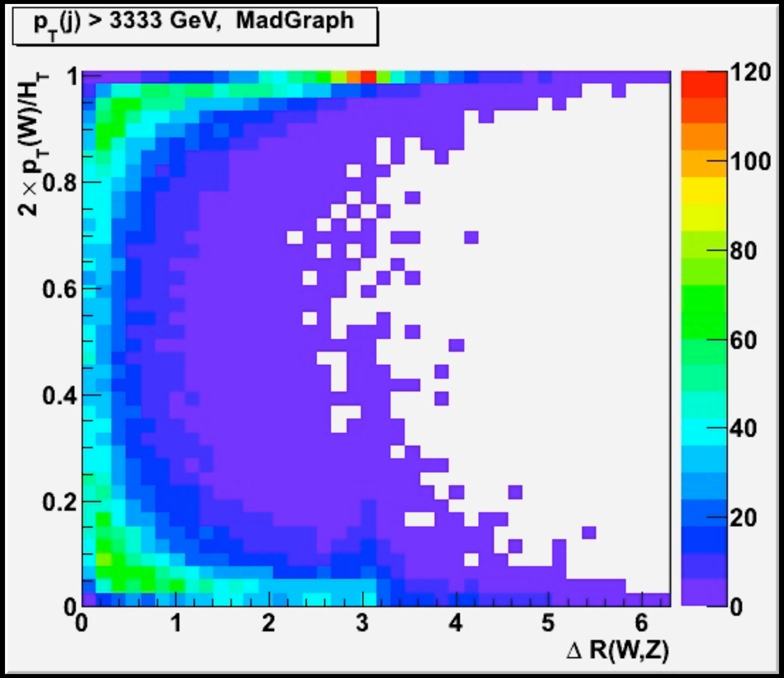
Our Shower Program

- PYTHIA6-like virtuality-ordered
  - collinear approximation, no coherence between dipoles
- Polarized splittings
- Massive splitting functions
  - amplitudes and phase space
- Secondary splittings reweighted to account for virtual mother's production rate
  - e.g., q → W(on-shell) q ≠ q → W(off-shell) q
- Only FSR (so far)

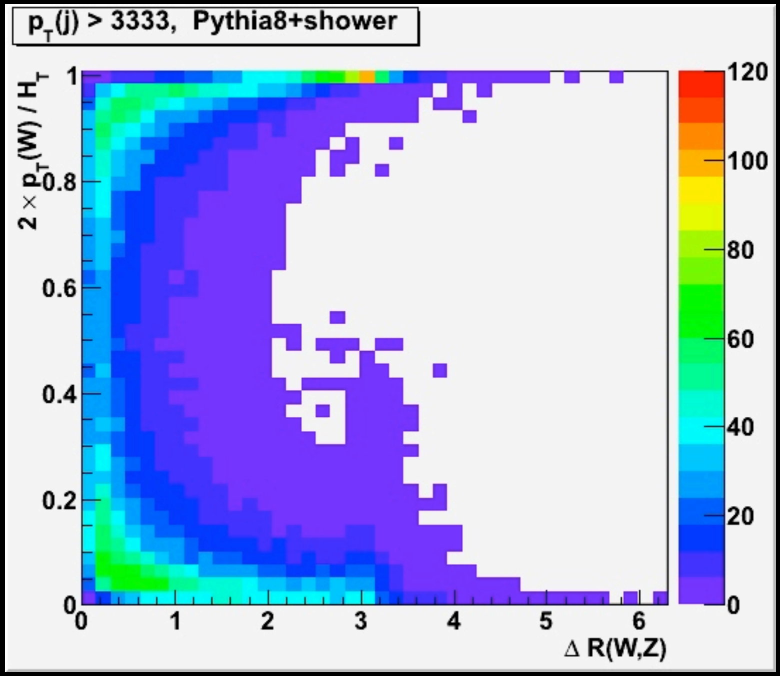
$$\frac{d\mathcal{P}(a \to bc)}{dz_b\, d\log Q_a^2} = \frac{1}{16\pi^2} \frac{z_b z_c E_a(|\vec{p}_a| + |\vec{p}_b|)}{E_b E_c} \frac{Q_a^2}{(Q_a^2 - m_a^2)^2} |\mathcal{A}(a \to bc)|^2 \qquad z_{a,b} \equiv \frac{|\vec{p}_{a,b}|}{|\vec{p}_a| + |\vec{p}_b|}$$

WZ+Jet Revisited

MadGraph

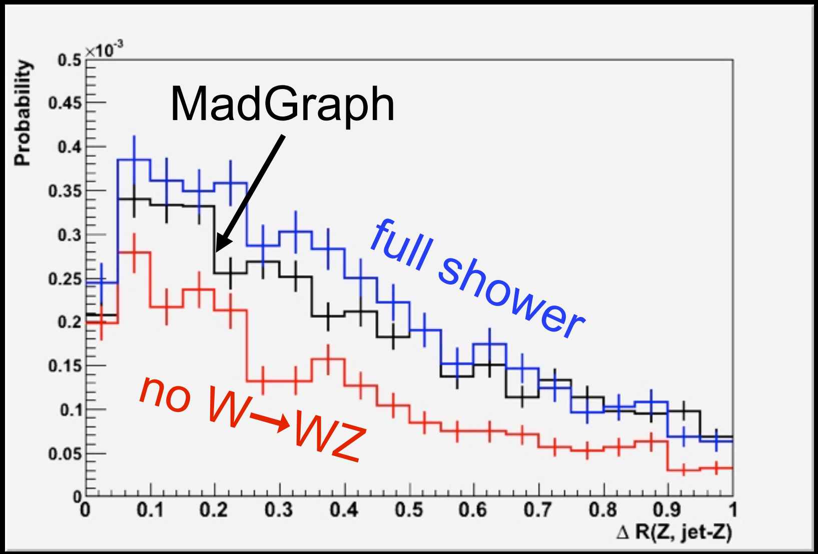


Pythia8 W/Z+jet + EW-Shower

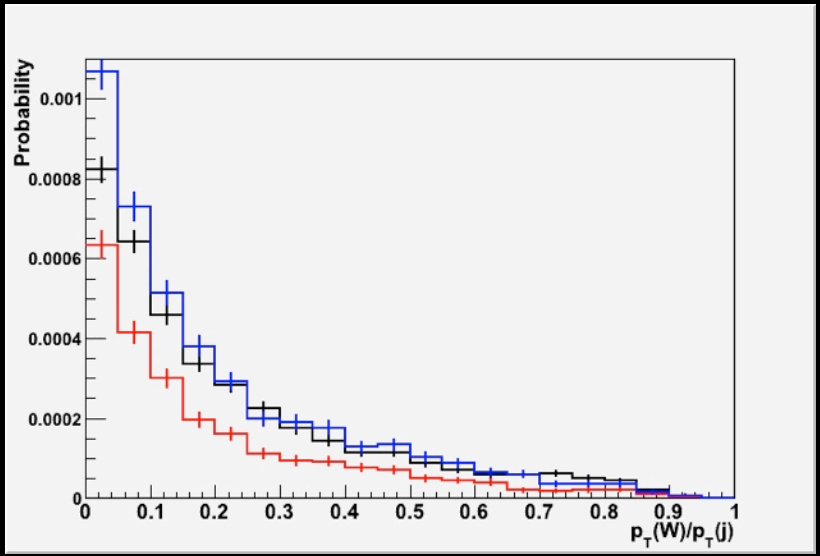


Diboson Inside One Jet

$u_L(10\text{ TeV}) \rightarrow d_L W^+ Z$



ΔR(Z, rest of jet)



$p_T(W)$ / $p_T(j)$

* R=1.0 anti-kT jet, W/Z as partons

Back-of-the Envelope Applications

- $W_T W_T$ production at O(10 TeV)
  - $W_T W_T \to W_T W_T$ scattering: potentially O(1) showering probability
  - KK graviton: corrections up to "many 10's of %"
- $W_L W_L$ production at O(10 TeV)
  - $W_L W_L \to W_L W_L$/hh, $Z' \to Z_L h$, $W' \to W_L h / W_L Z_L$: O(10%) showering probability
- SM V+jets and diboson
  - there are still events up at $p_T \sim 10$ TeV, with O(10's of %) splitting rates
  - a laboratory for studying weak splittings (analog of QCD c1980)
  - splittings to Higgs would be particularly fun (though rare)
- Insert your favorite multi-TeV model...

What's Next?

- ISR
- Top/bottom
- W/Z splittings to fermions
- Complete longitudinal splittings
- γ/Z interference
- Vector decays
- Interleave with QCD (already available)
- As a plug-in to an existing program such as PYTHIA...matching??

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- At a 100 TeV pp collider, EW bosons are "the new gluons"
  - high-p_T multiboson production from showering processes becomes appreciable
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- We are in the process of constructing a *complete* EW parton shower
  - the standard “quick and dirty” way to capture leading-log effects
  - $V \rightarrow VV$ splittings for the first time, plus various Higgs and “Goldstone equivalent” processes
  - very new, and full implications still being worked out
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- A new regime to study multiboson physics!