Electro-Weak and Top Physics @ 100 TeV

Michele Selvaggi

CERN

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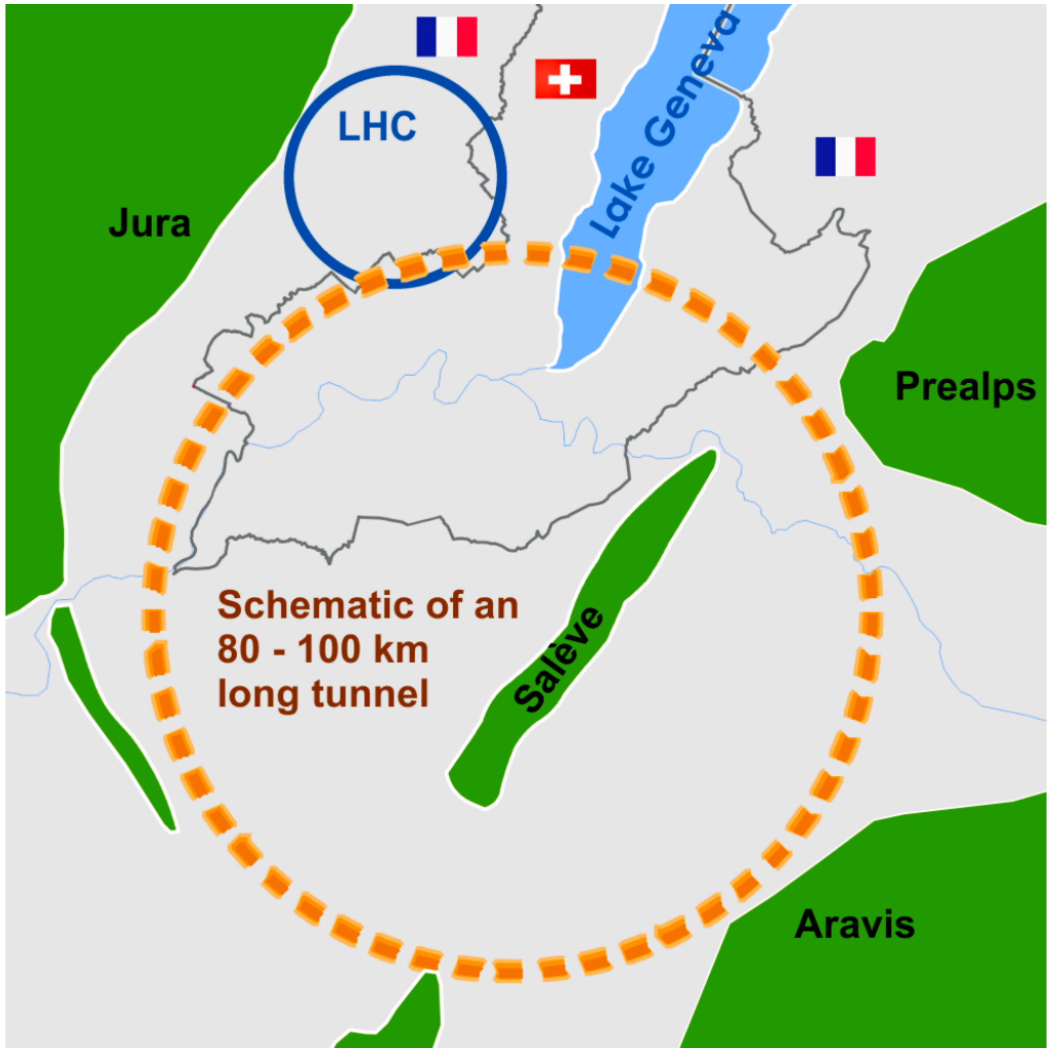
The FCC-hh

- E_{CM} =100 TeV
- 100 km long
- needs 16T magnets

Access to:

- direct production of heavy states up to m ≈ 40 TeV
- precision SM physics:
  - Higgs potential, self-coupling
  - Higgs, Top, EWK physics in new extreme dynamical regimes (complementary to e^+e^-)



Top and EWK rates @ 100TeV

- Top pair production increases by x40 @100TeV, σ(tt) = 30 nb, at 30 ab^{-1}:

  → 10^{13} tops

  → 10^{13} W's

  → 10^{13} b's , (charge tagged, CPV)

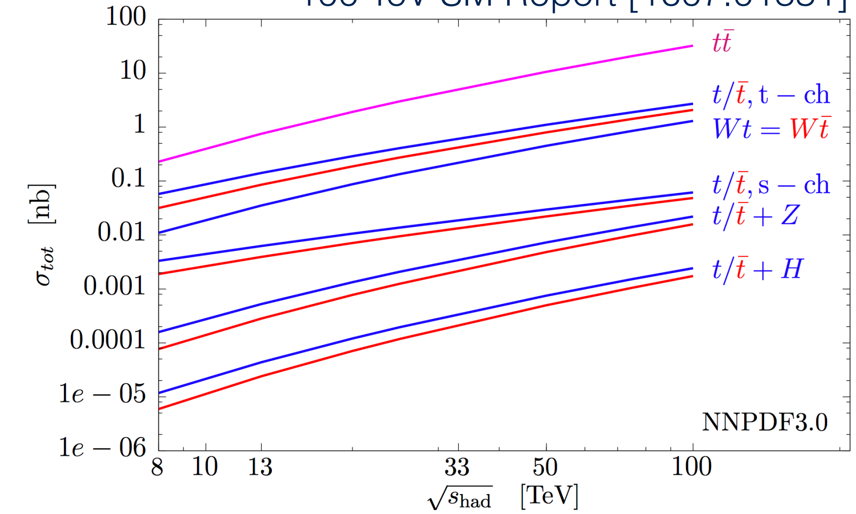
  → 10^{12} τ's (rare decays τ → 3μ, CPV)

- W/Z single production increase by x(5-7) @100 TeV, σ(W/Z) = 1.7 μb

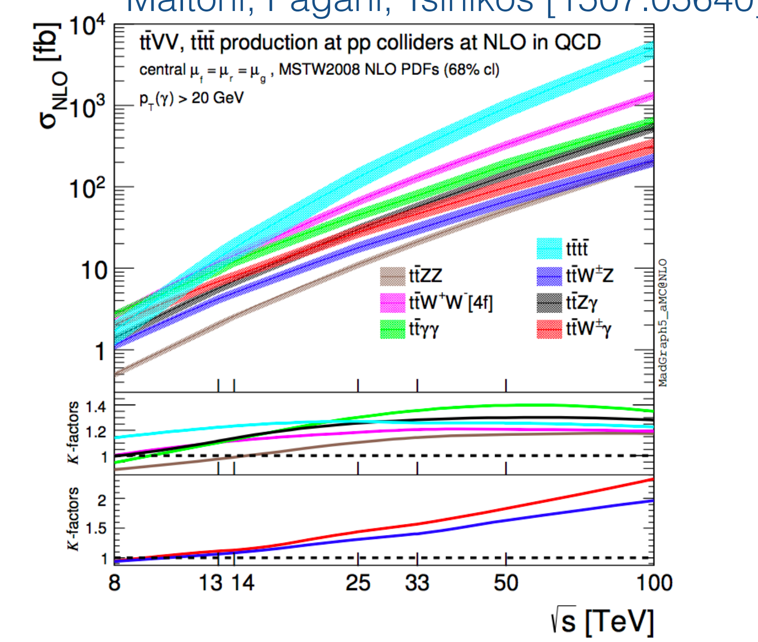
- Multi-top/boson production x(100-1000)

- High statistics can be used to study pure/ boosted samples

100 TeV SM Report [1607.01831]



Maltoni, Pagani, Tsinikos [1507.05640]



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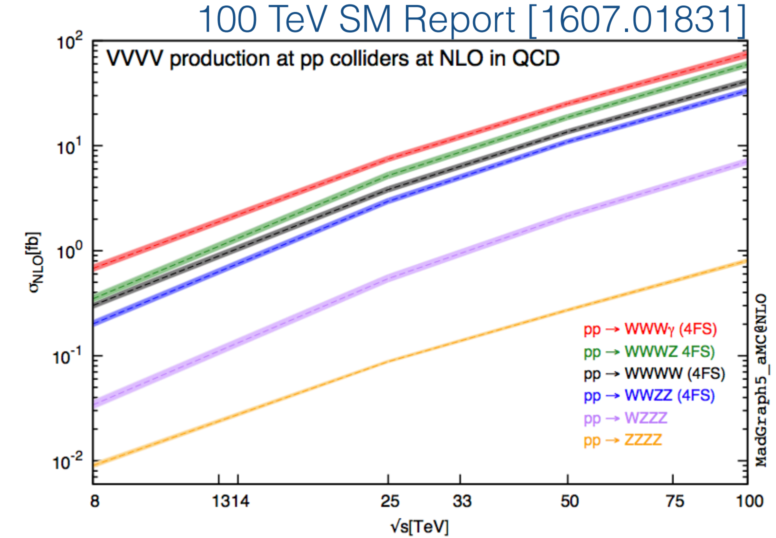
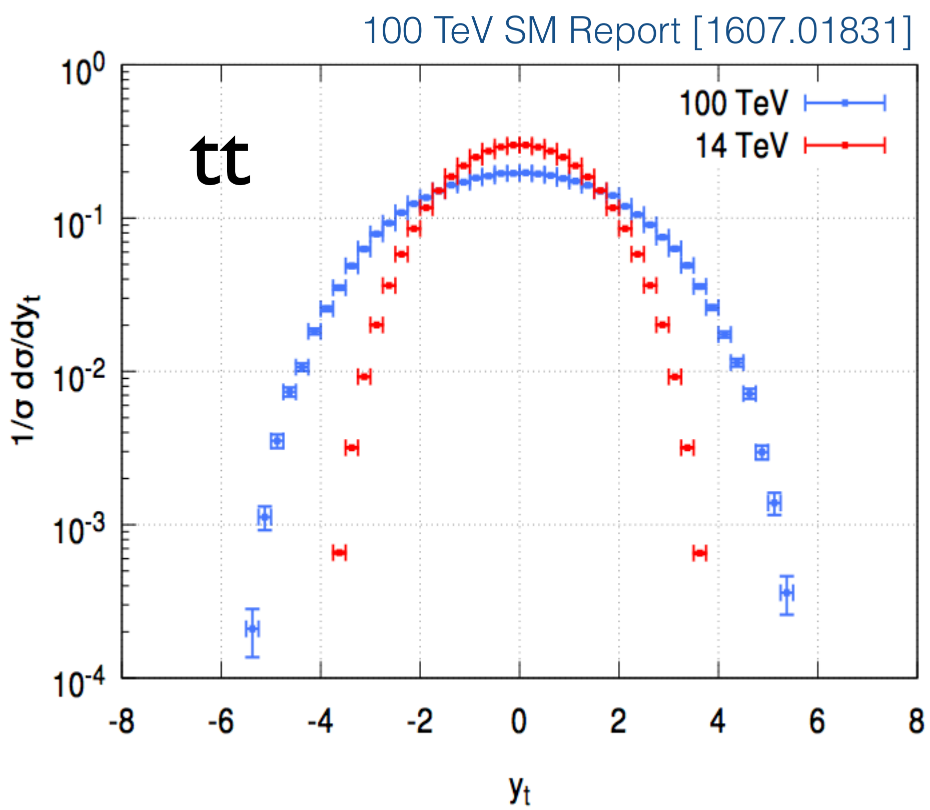
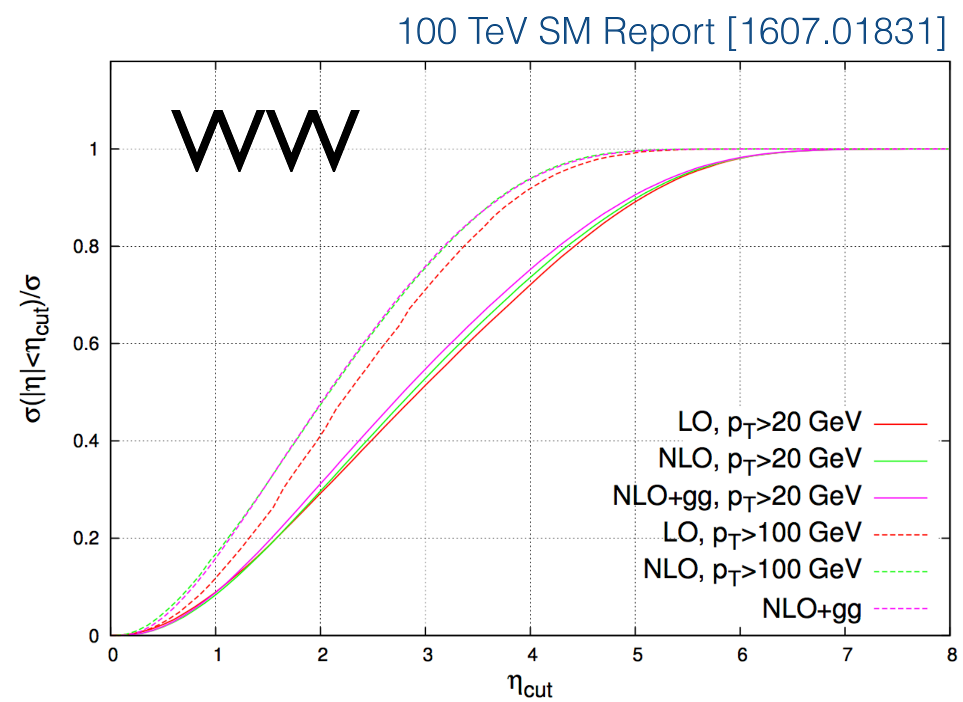


Kinematics





- Low p_T physics lies at higher rapidity at 100 TeV
- Make sure detectors cover well these regions
  → may have to consider dedicated detectors!

Outline

- Boosted Top and EWK bosons (as tools)
- Measurements @100 TeV

Boosted tops, W, Z's @100 TeV

- Boosted 2 body decay from massive object has typical angular size:

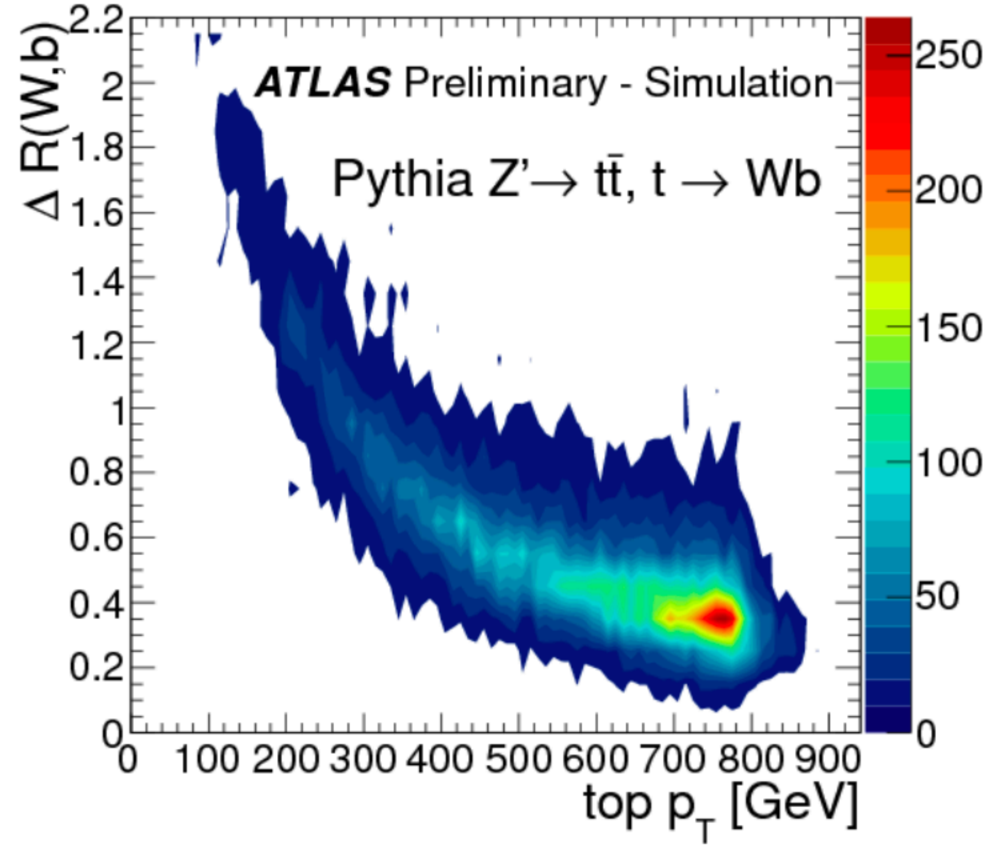
$$\Delta R \approx 2\, m / p_T$$

- Top quark:

  p_T = 1 TeV → ΔR = 0.5
  p_T = 10 TeV → ΔR = 0.05

- W/Z bosons:

  p_T = 1 TeV → ΔR = 0.25
  p_T = 10 TeV → ΔR = 0.025



- Detector resolution (CMS/FCC):

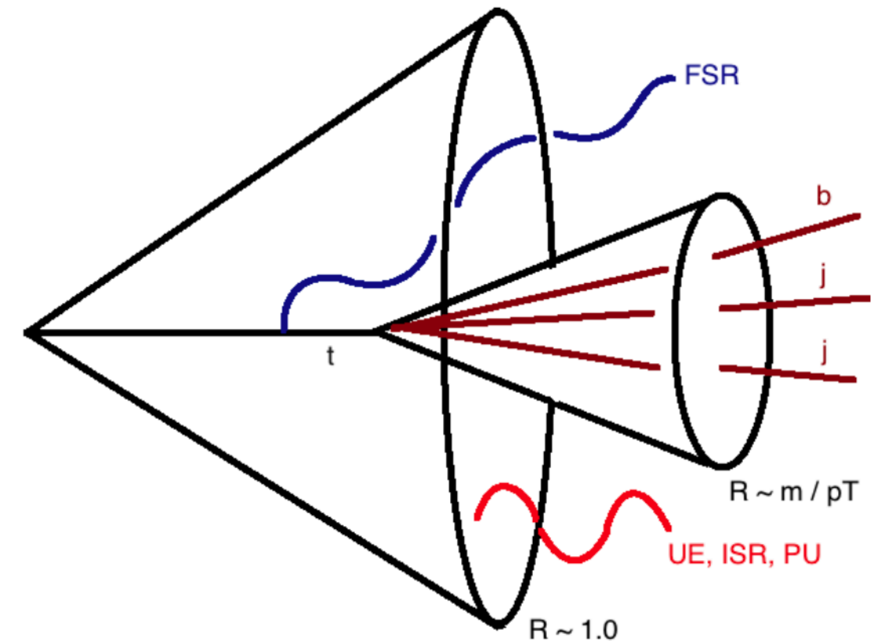
  Tracking → ΔR = 0.002/0.001
  ECAL → ΔR = 0.02/0.01
  HCAL → ΔR = 0.1/0.05

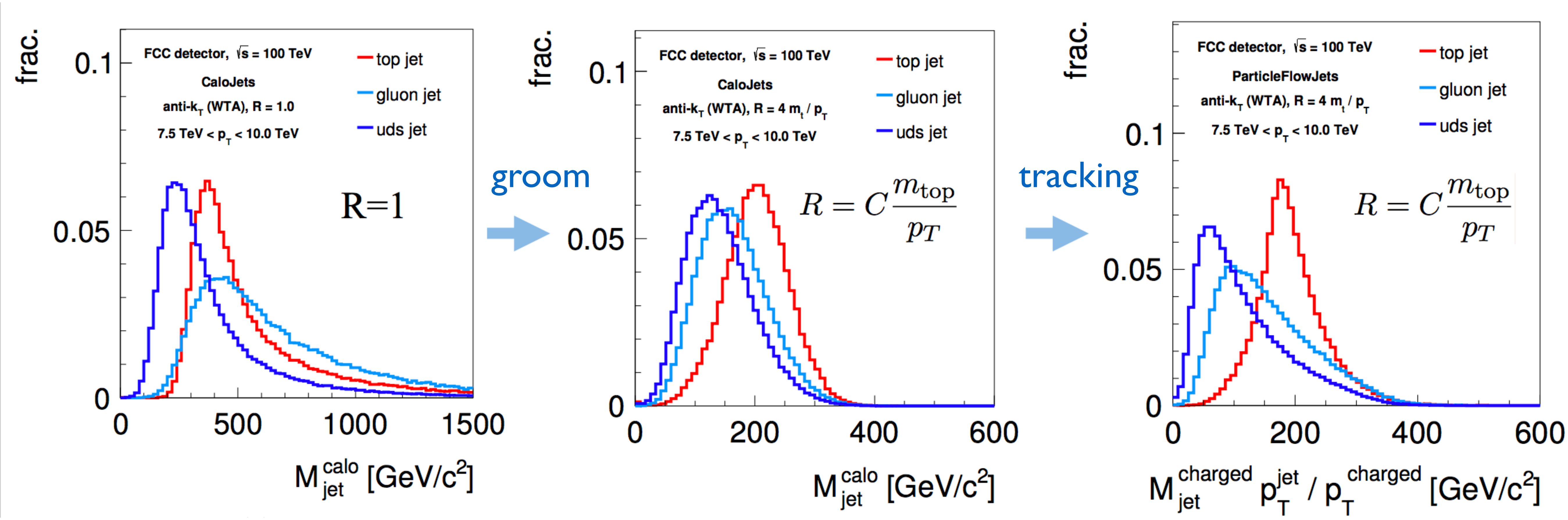
Hit fundamental "conventional" calorimeter limit at extreme boosts

Hyper boosted Top jets

- Top quark carries colour charge, and undergoes final state radiation
- Soft contamination (UE, ISR, PU) can produce large corrections to the top mass:
  - Scale $R \approx m_t / p_T$
  - Apply grooming (pruning, soft drop, trimming)
  - Use tracking

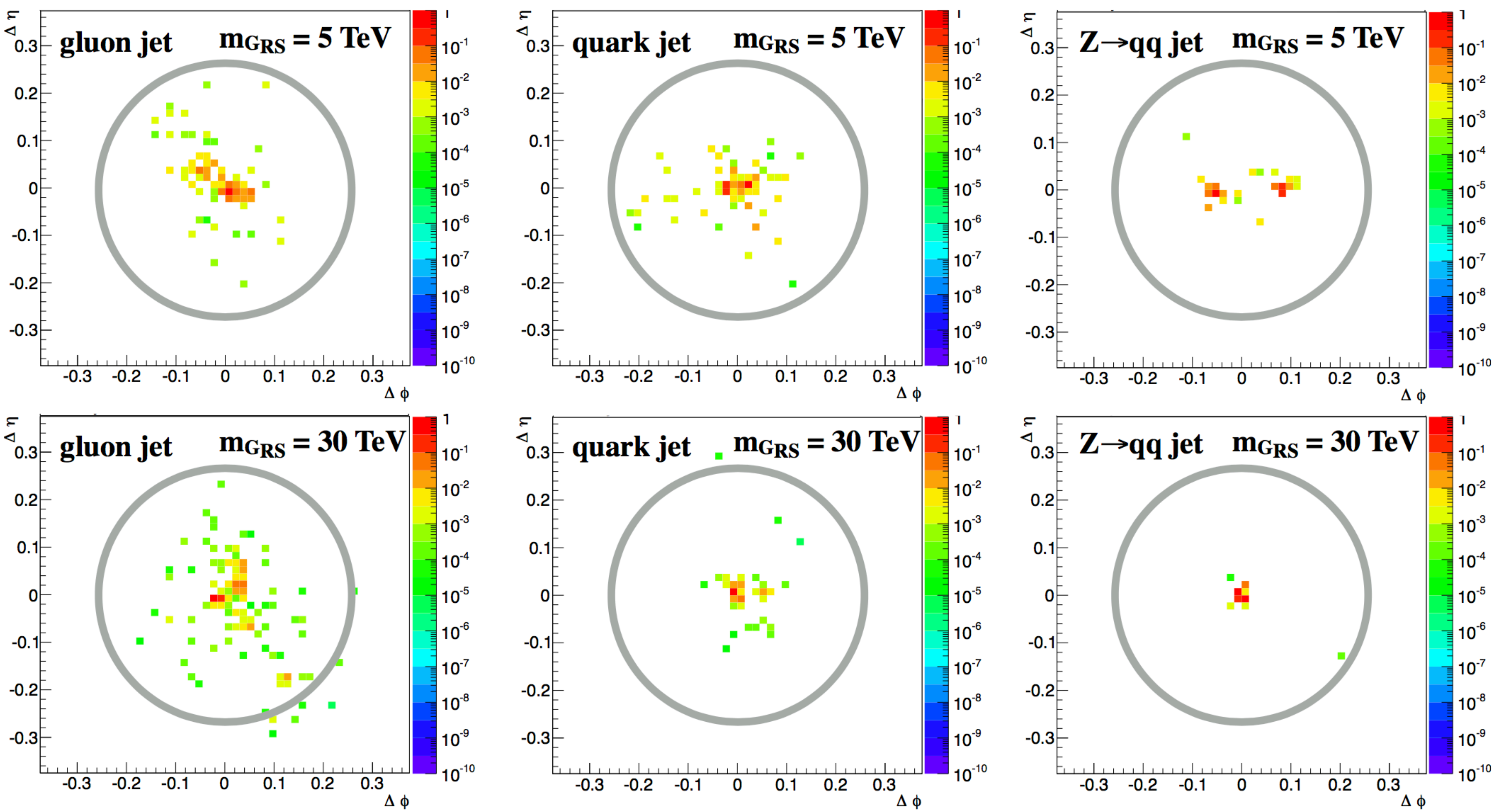
Larkoski, Maltoni, MS [1503.03347]





Hyper boosted W/Z jets

Pierini, 100 TeV SM Report [1607.01831]

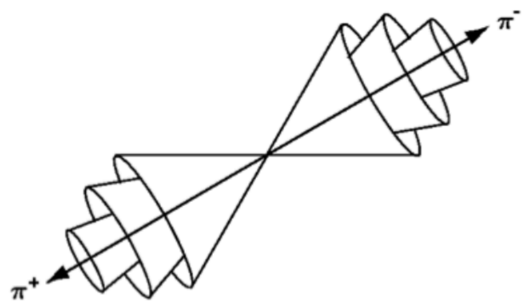


- Color singlets feature little activity around the jet core (unlike QCD)
- Identify W/Z (and H) as "narrow jets"

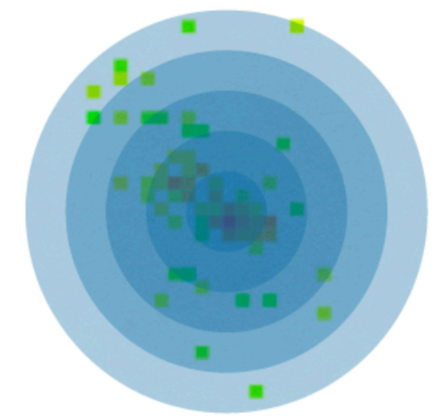
Hyper boosted W/Z jets

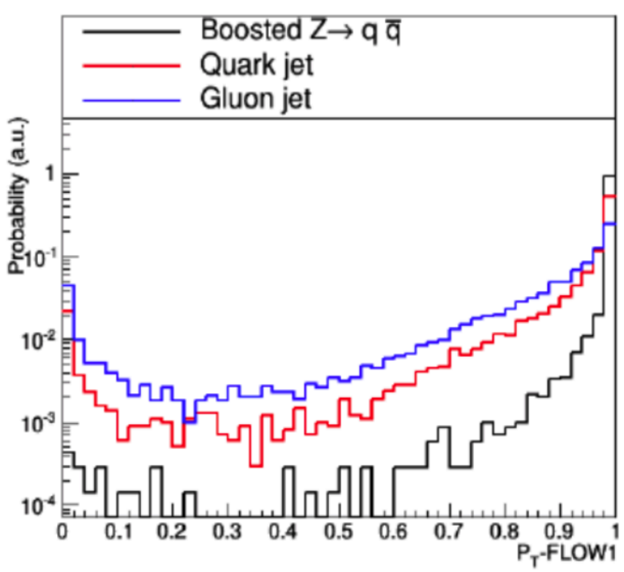
Pierini, 100 TeV SM Report [1607.01831]

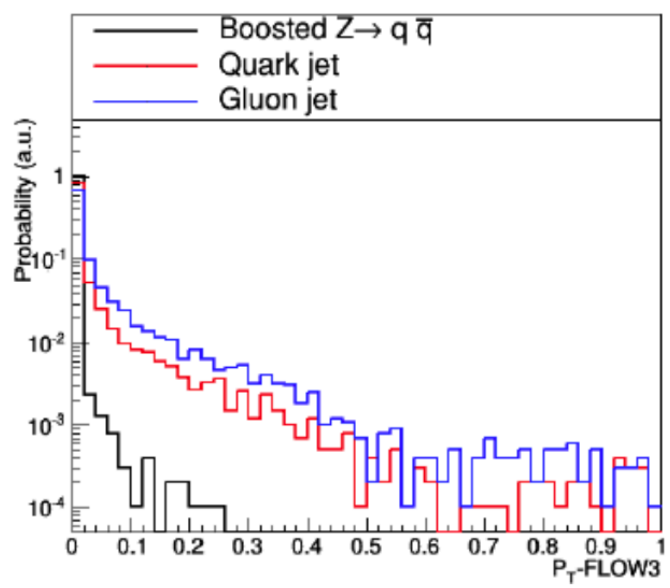
Build "isolation" in concentric annuli

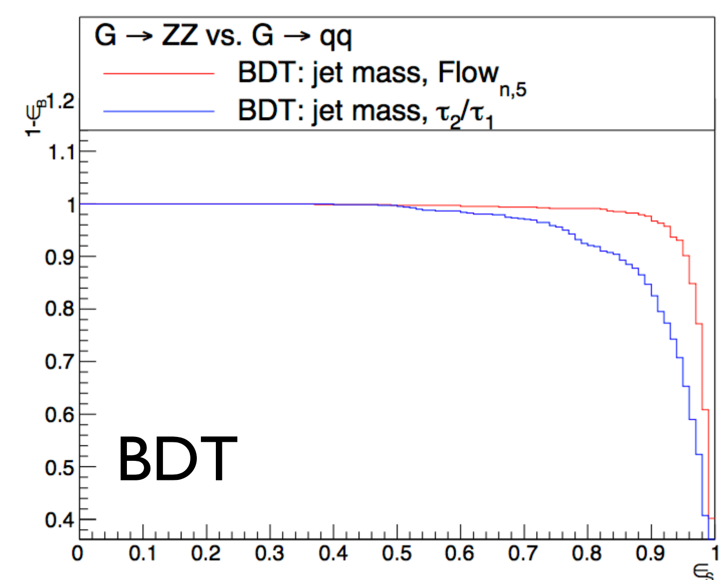


$$p_T^i(flow) = \frac{\sum_{p\epsilon C_i} p_T^p}{p_T^{jet}}$$



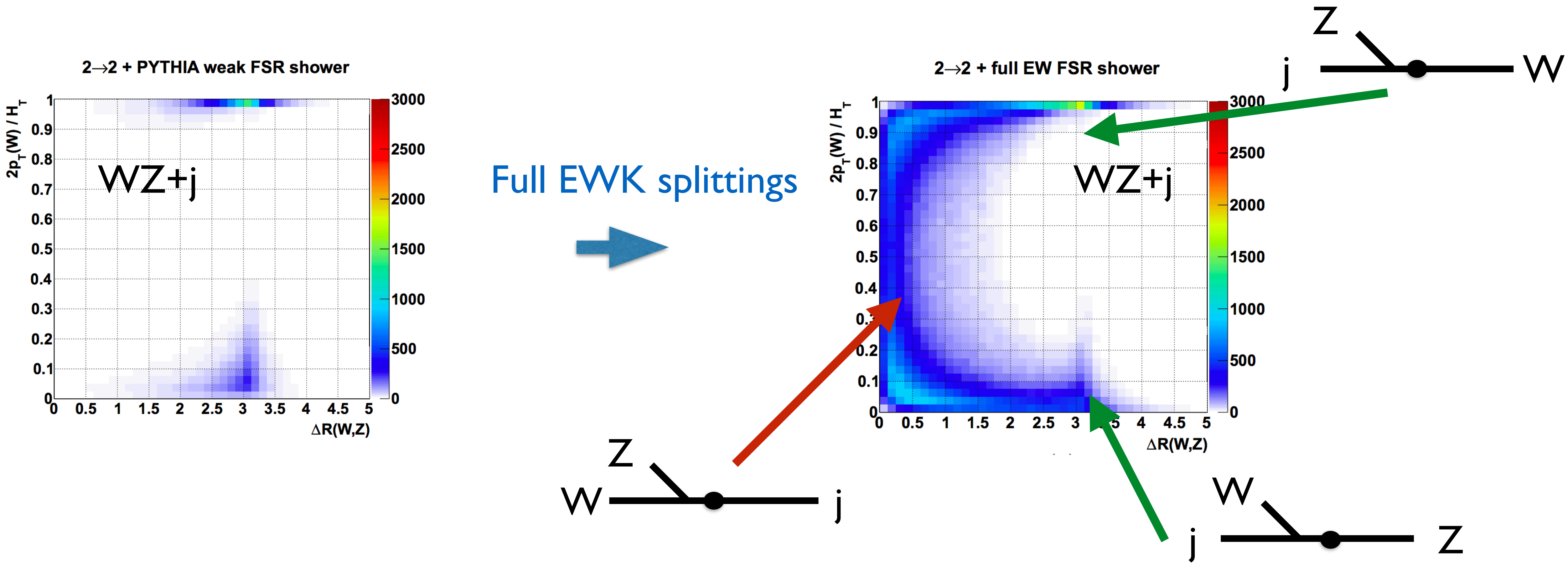






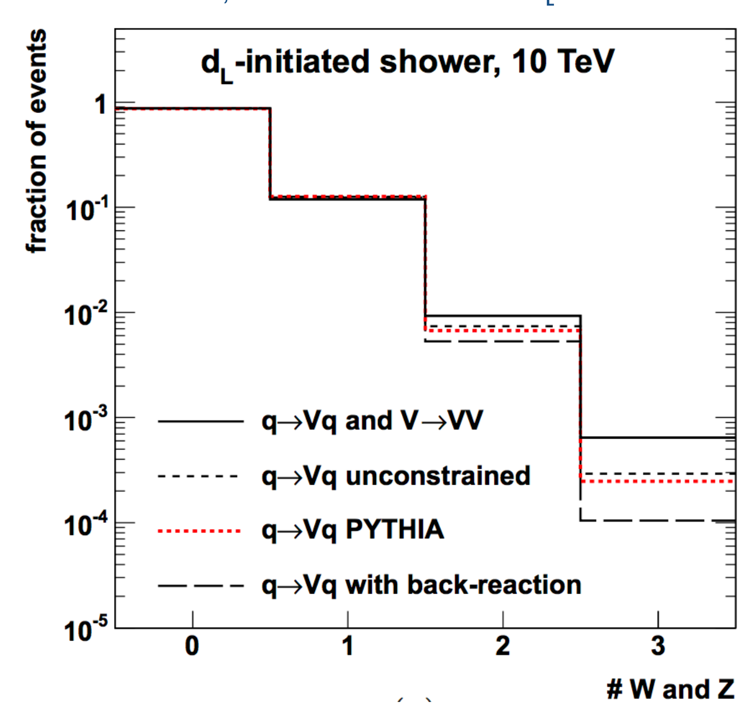
Lesson: exploiting radiation pattern can be more effective than the jet "pronginess"

EWK high energy showers



- EWK showers are important at high energy:
  - j → jW can easily fake a top jet (~up to 10%)
- Gauge bosons and scalar can also radiate (not included in Pythia8):
  - can affect boosted top, bottom (yukawa) and vector identification performance
- Unlike QCD showers, EWK showers are directly observable
- Full set of EWK splitting has been worked out and is being implemented as plugin for Pythia8.

Chen, Han and Tweedie [1611.00788]



Measurements @100 TeV

Top dipole moments (gtt coupling)

$$\mathcal{L}_{tg} = -g_s \bar{t}\gamma^\mu \frac{\lambda_a}{2} t\, G^a_\mu + \frac{g_s}{m_t}\bar{t}\sigma^{\mu\nu}(d_V + i d_A \gamma_5)\frac{\lambda_a}{2} t\, G^a_{\mu\nu}$$

SM (~ α_s)

BSM
SM via loop

Enhance chromo-electric/magnetic contribution by going at p > m_t

Strategy:

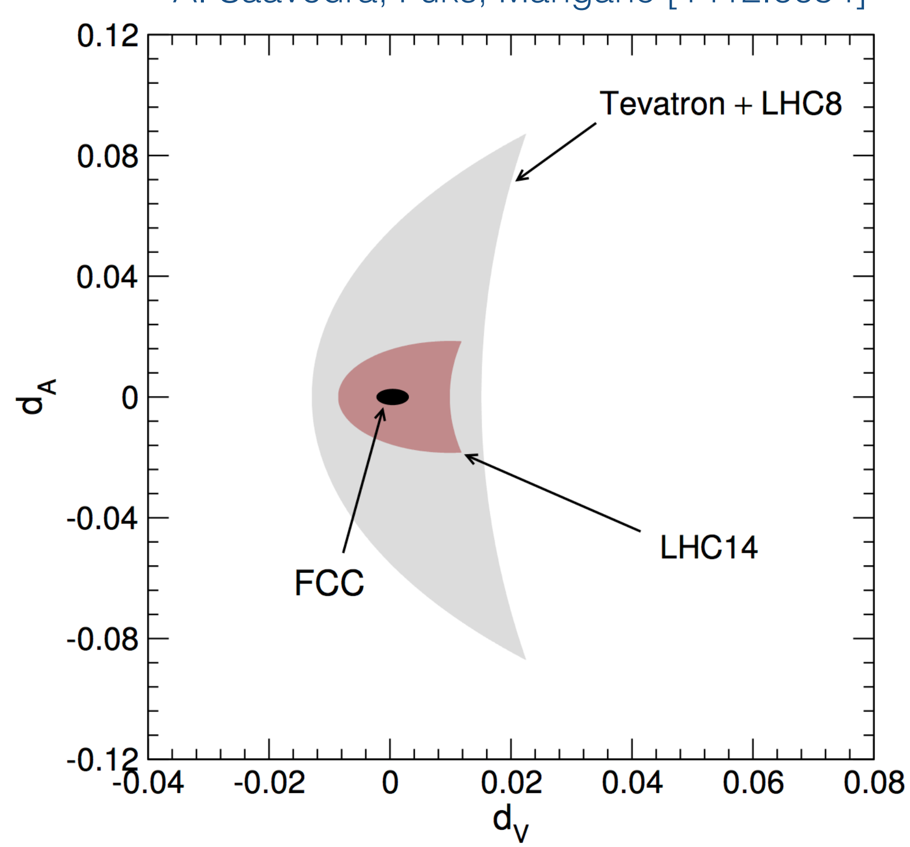
- Measure σ (m(tt) > X) at high mass
- Tag tops with high pT muons:

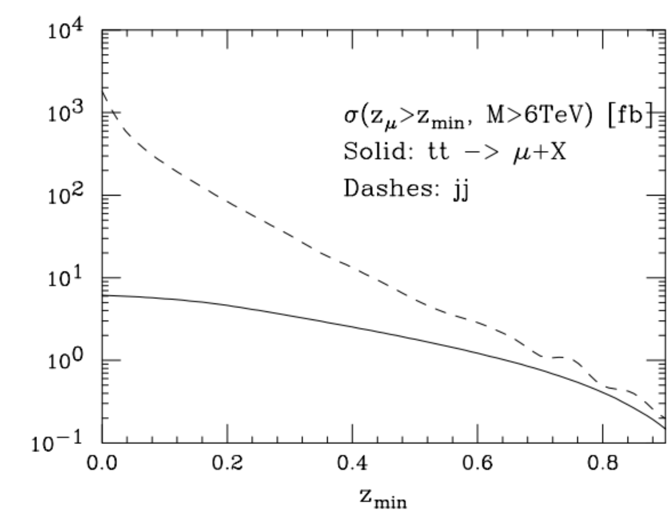
$$z_\mu = \max_{i=1,\dots,n} \frac{p_T(\mu_i)}{p_T(j_i)} \longrightarrow z_\mu \gtrsim 0.5$$

At 100 TeV constraints from σ (m(tt) > 10 TeV)

$|d_{A,V}| \lesssim 0.0025$

A. Saavedra, Fuks, Mangano [1412.6654]



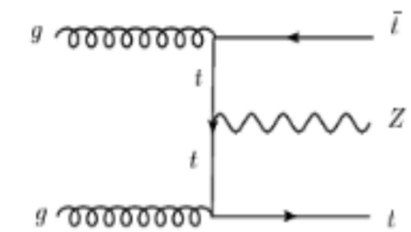


Top - Z coupling

enhance at $q >> M_z$

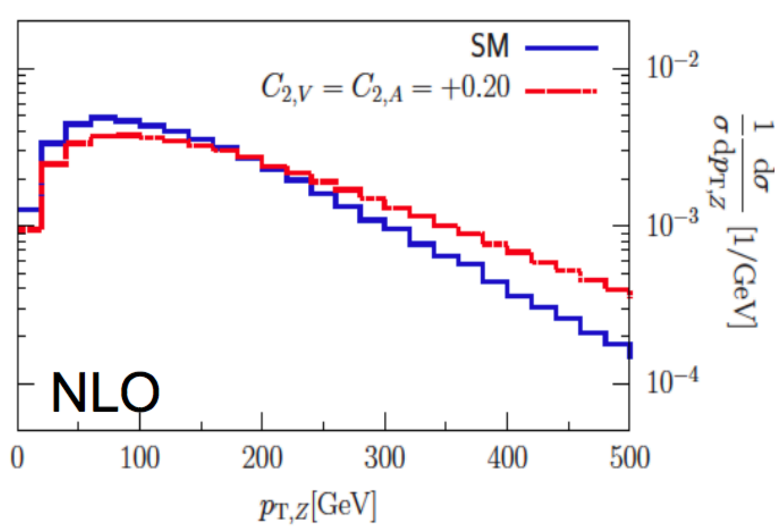
$$\mathcal{L}_{t\bar{t}Z} = e\bar{u}(p_t)\left[\gamma^\mu (C^Z_{1,V} + \gamma_5 C^Z_{1,A}) + \boxed{\frac{i\sigma^{\mu\nu}q_\nu}{M_Z}(C^Z_{2,V} + i\gamma_5 C^Z_{2,A})}\right] v(p_{\bar{t}}) Z_\mu$$

SM

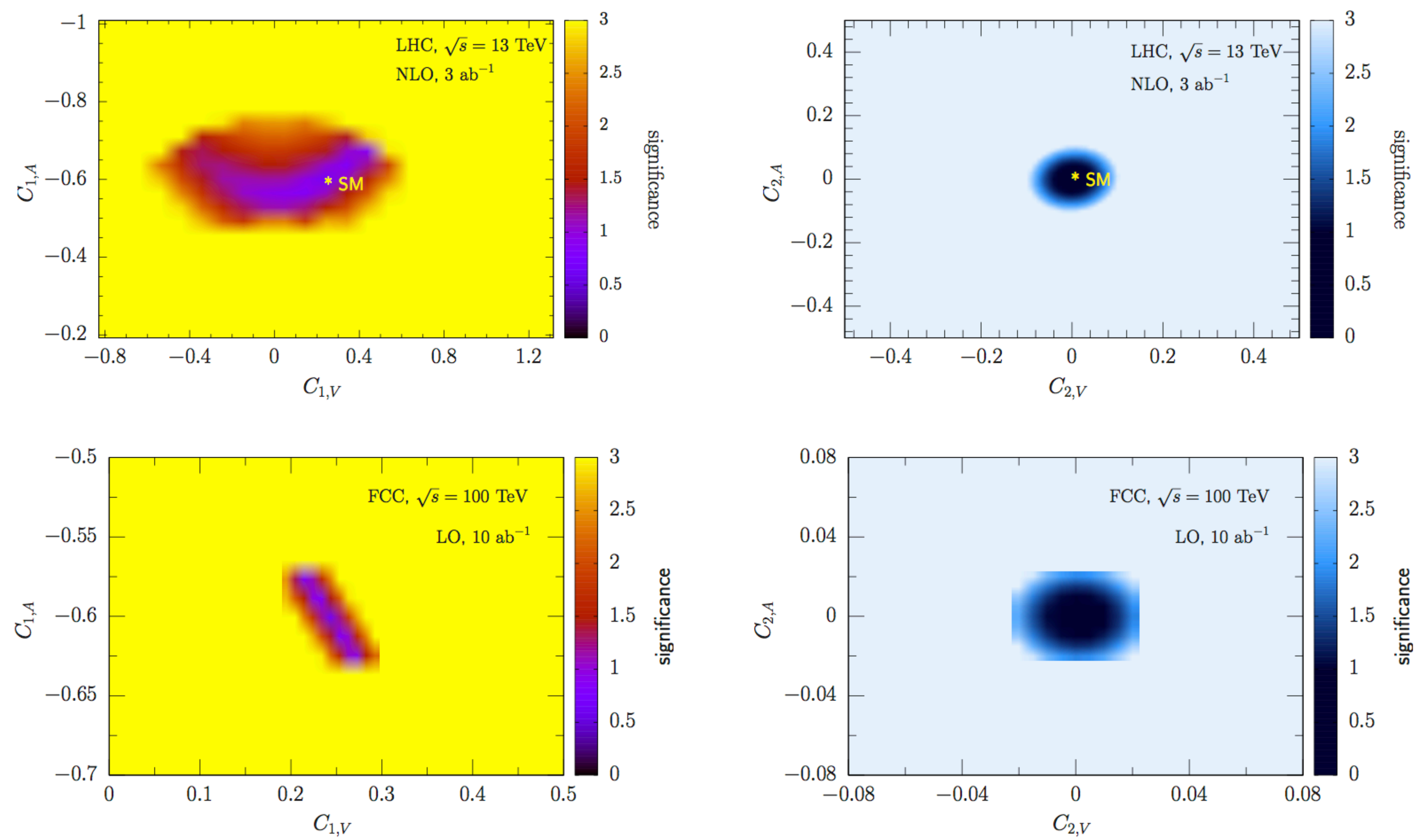


ttZ production rate increases by x50 @100 TeV

Rontsch, Schulze [1501.05939]



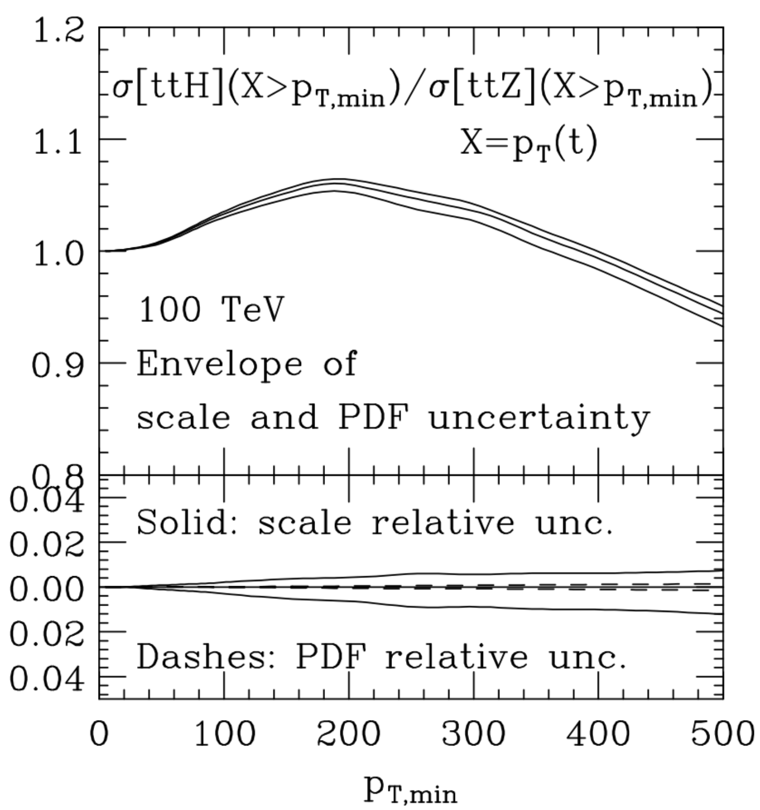
100 TeV SM Report [1607.01831]



ttZ/ttH as probe for y_t

- σ_{ttX}(100 TeV) / σ_{ttX}(14 TeV) ≈ 50-60
- Theory uncertainties between ttZ and ttH are highly correlated:
  - production dynamics and radiative corrections (reduced scale dependence)
  - kinematics ($m_H \approx m_Z$) are similar (reduced PDF uncertainties)
- Can measure $\sigma_{ttZ} / \sigma_{ttH}$ to very high accuracy (production, luminosity unc. cancel out)

	$\sigma(t\bar{t}H)$[pb]	$\sigma(t\bar{t}Z)$[pb]	$\frac{\sigma(t\bar{t}H)}{\sigma(t\bar{t}Z)}$
13 TeV	$0.475^{+5.79\%+3.33\%}_{-9.04\%-3.08\%}$	$0.785^{+9.81\%+3.27\%}_{-11.2\%-3.12\%}$	$0.606^{+2.45\%+0.525\%}_{-3.66\%-0.319\%}$
100 TeV	$33.9^{+7.06\%+2.17\%}_{-8.29\%-2.18\%}$	$57.9^{+8.93\%+2.24\%}_{-9.46\%-2.43\%}$	$0.585^{+1.29\%+0.314\%}_{-2.02\%-0.147\%}$

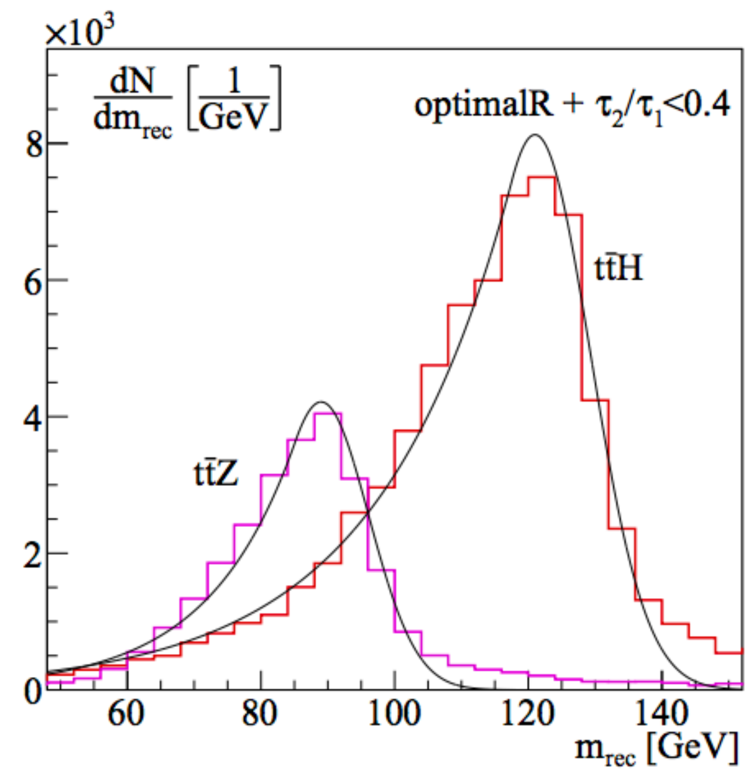


Mangano, Plehn, Reimitz, Schell, Shao [1507.08169]

$\Delta y_t/y_t \approx 1\%$ within reach @100 TeV !

(assuming BR(H→bb) is known)

Top fat C/A jet(s) with R = 1.2, |y| < 2.5, and pT,j > 200 GeV

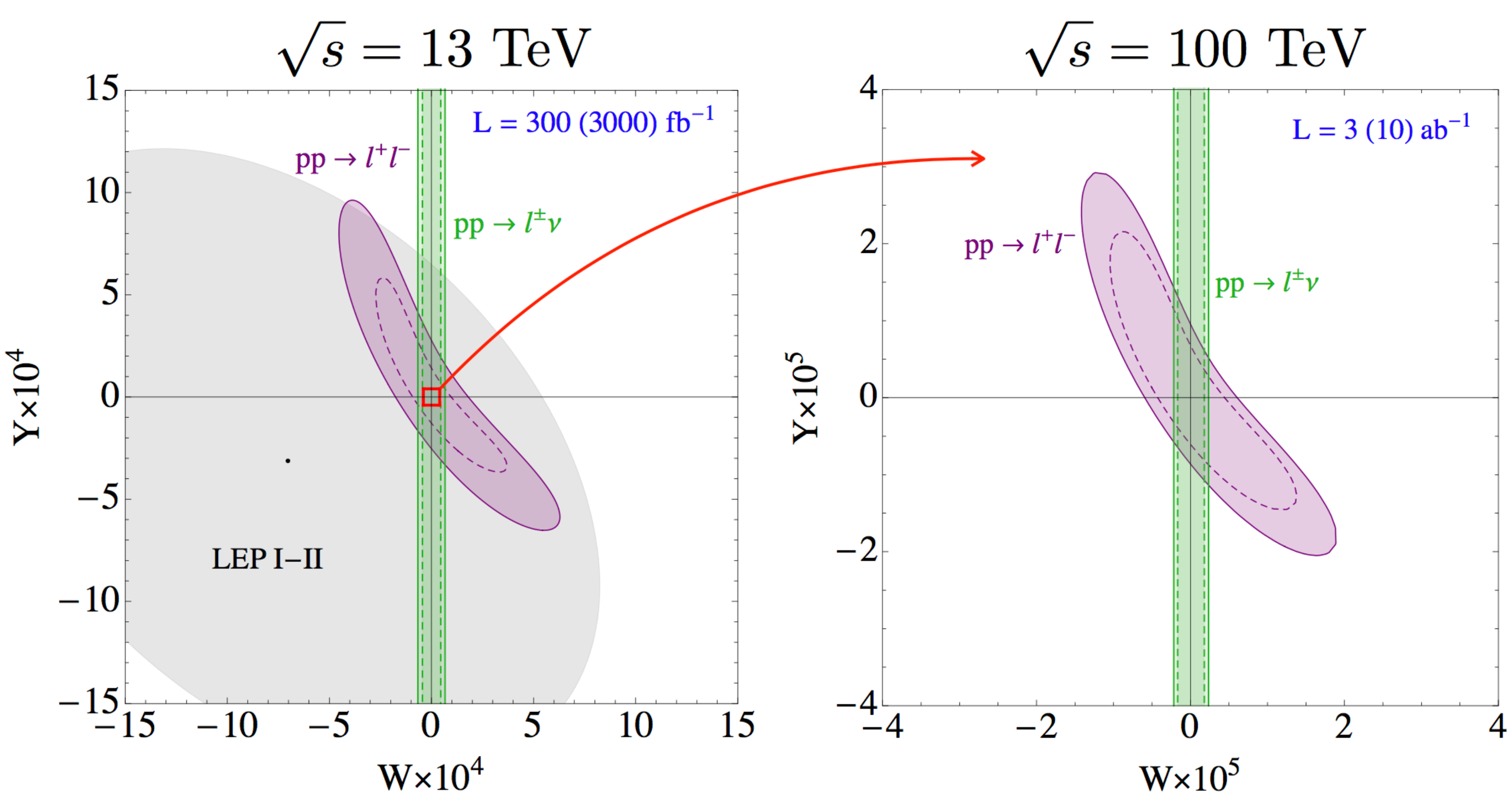


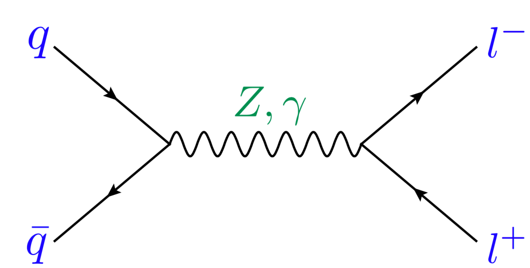
High-Q^2 Drell Yan

$$\mathcal{L} \supset \frac{1}{\Lambda_S^2} H^\dagger W_{\mu\nu} H B_{\mu\nu} + \frac{1}{\Lambda_T^2} |H^\dagger D_\mu H|^2 + \frac{1}{\Lambda_W^2} (D_\rho W^a_{\mu\nu})^2 + \frac{1}{\Lambda_Y^2} (\partial_\rho B_{\mu\nu})^2$$

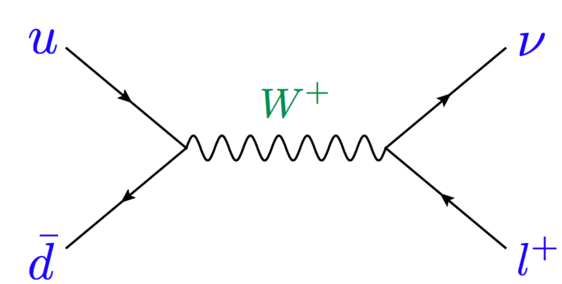
Dim. 6 operators in SMEFT modify high energy behaviour of EWK gauge boson propagators

Farina, Panico, Pappadopulo, Ruderman, Torre, Wulzer [1609.08157]





$$\frac{\delta\sigma}{\sigma} \propto \frac{q^2}{\Lambda^2_{W,Y}}$$



$\Lambda_W \gtrsim 24$ TeV

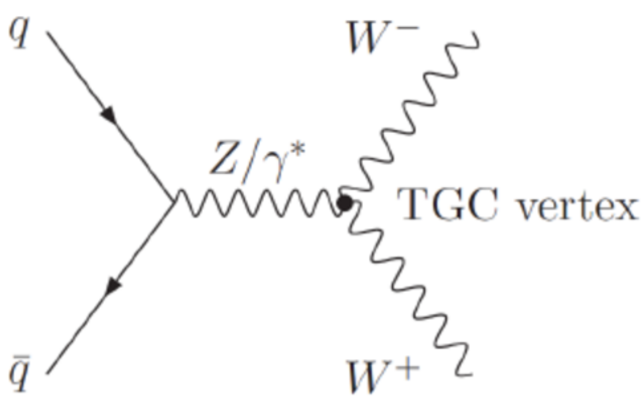
$\Lambda_Y \gtrsim 15$ TeV

- neutral: $\delta_{\rm cor} = \delta_{\rm unc} = 2\%$
- charged: $\delta_{\rm cor} = \delta_{\rm unc} = 5\%$

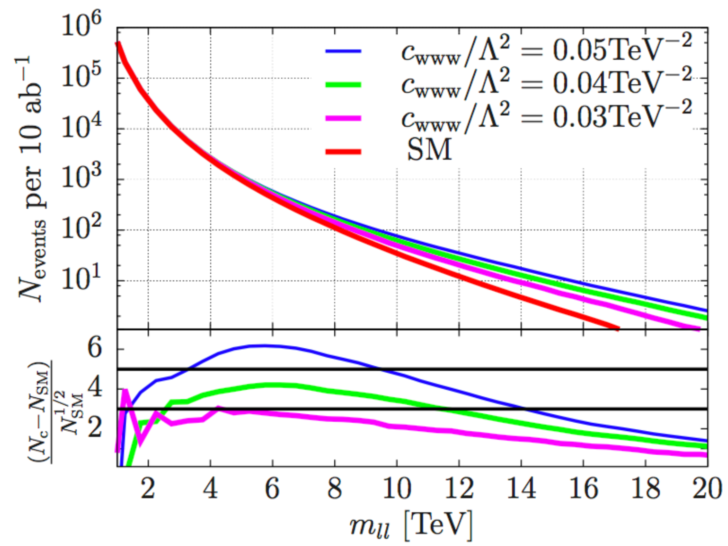
$\Lambda_W \gtrsim 110$ TeV

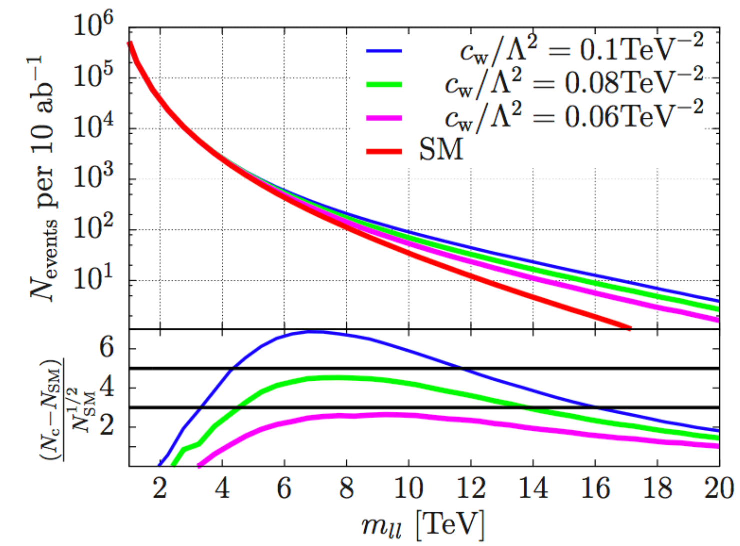
$\Lambda_Y \gtrsim 70$ TeV

TGC's in di-boson production



100 TeV SM Report [1607.01831]





- High sensitivity for O_{WWW}

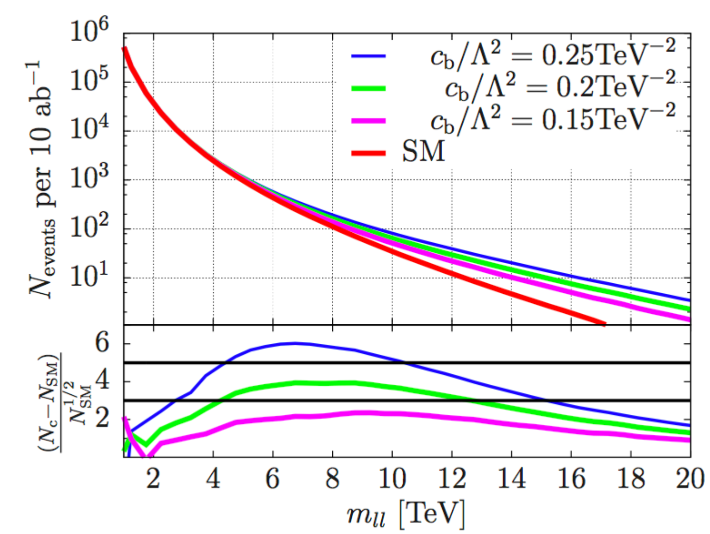
→ x100 compared to ATLAS 8 TeV

$$\mathcal{O}_{WWW} = \mathrm{Tr}[W_{\mu\nu}W^{\nu\rho}W_{\rho}^{\mu}]\,,$$
$$\mathcal{O}_{W} = (D_\mu\Phi)^\dagger W^{\mu\nu}(D_\nu\Phi)\,,$$
$$\mathcal{O}_{B} = (D_\mu\Phi)^\dagger B^{\mu\nu}(D_\nu\Phi)\,,$$

- For O_W and O_B questionable use of EFT, since valid only for

$$\Lambda \gtrsim 10\,\mathrm{TeV}$$

→ need ~ strong coupling



Conclusions

- High energy proton machine will produce tens of trillions of tops, W/Z bosons.
- Such high statistics can be used to target unexplored corners of the phase-space (boosted regime)
- Contrary to common belief, high energy proton colliders are suitable for high precision measurement
- Can challenge precision obtained in e+e- machine on observables that receive enhancement at high momentum transfer (.ie W,Y parameters in DY, top dipole moments, VBS, tWb, etc ..)
- Systematic comparison in the SMEFT framework of synergies and complementarity between FCC ee/hh still has to be performed

Thank you