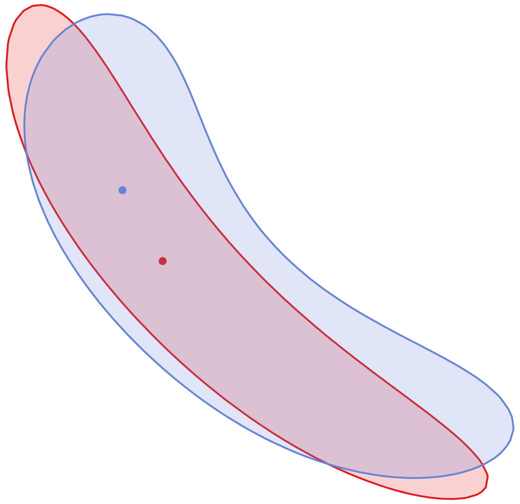
Electroweak Precision Tests from Drell-Yan @100 TeV

Josh Ruderman (NYU)
@CERN, 1/17/2017

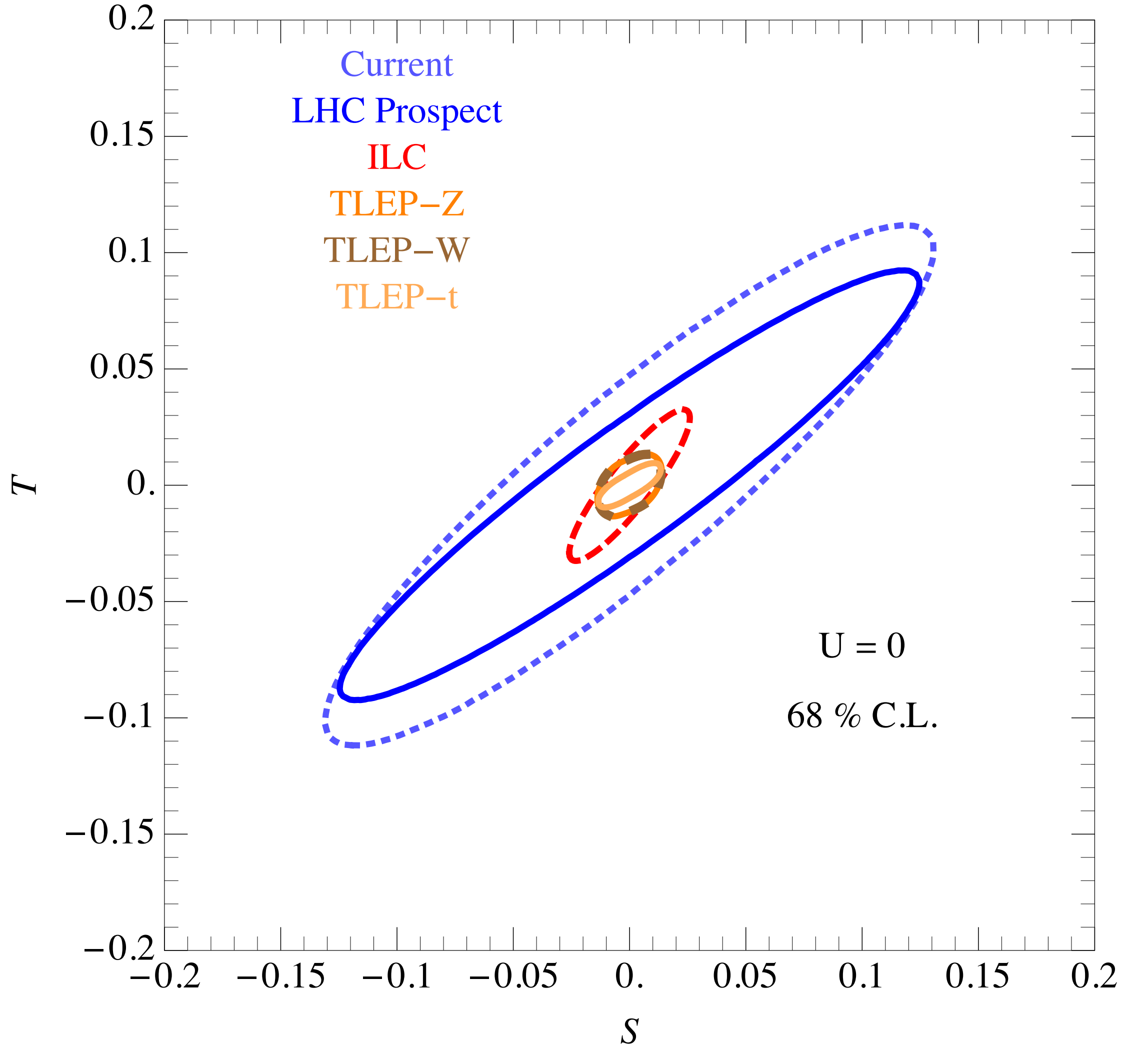


- Farina, Panico, Pappadopulo, JTR, Torre, Wulzer **1609.08157**
- Alioli, Farina, Pappadopulo, JTR, *to appear*

Conventional FCC Wisdom

step 1

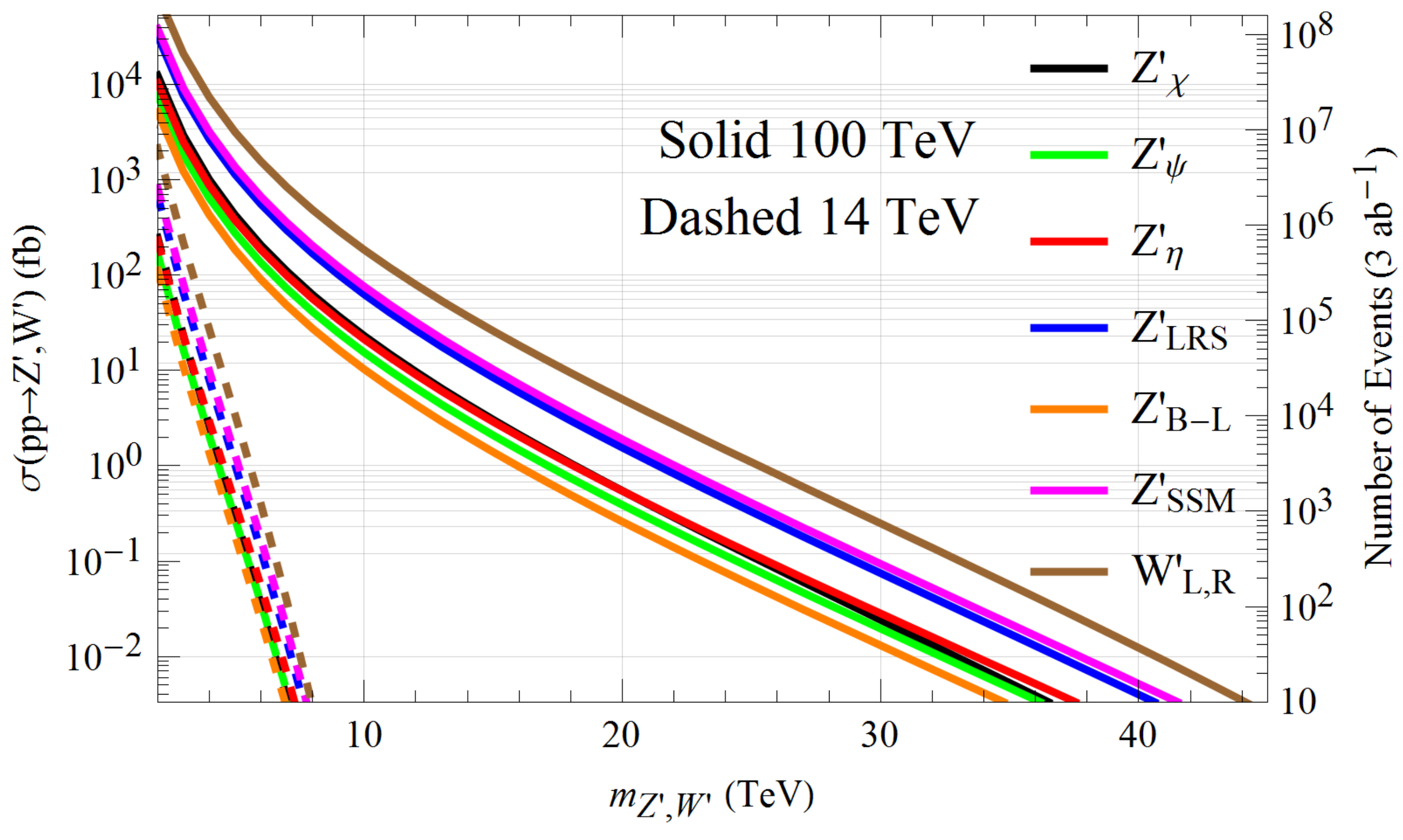
FCC-ee: precision



- Fan, Reece, Wang **1411.1054**

step 2

FCC-pp: direct production

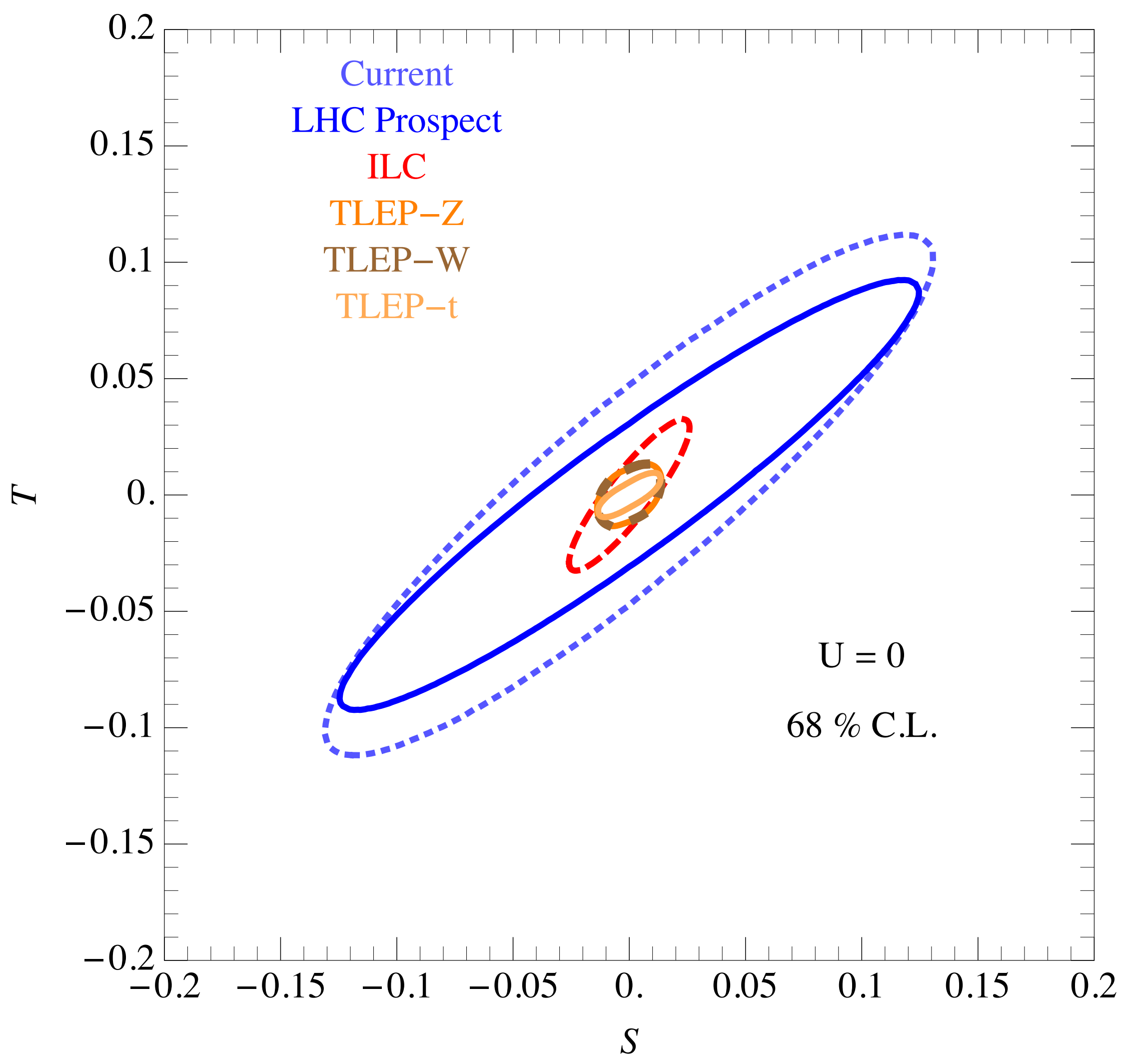


- Arkani-Hamed, Han, Mangano, Wang **1511.06495**

Conventional FCC Wisdom

step 1

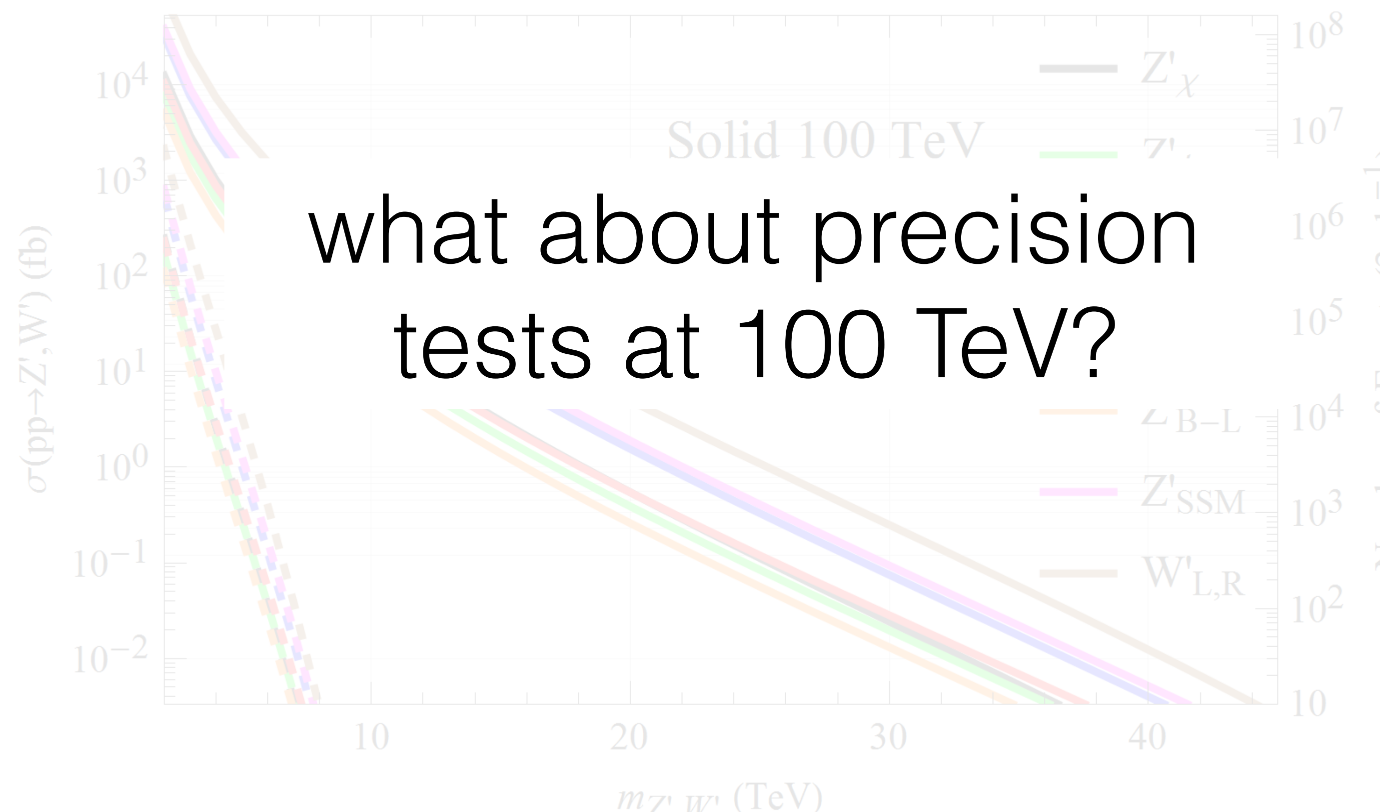
FCC-ee: precision



- Fan, Reece, Wang **1411.1054**

step 2

FCC-pp: direct production



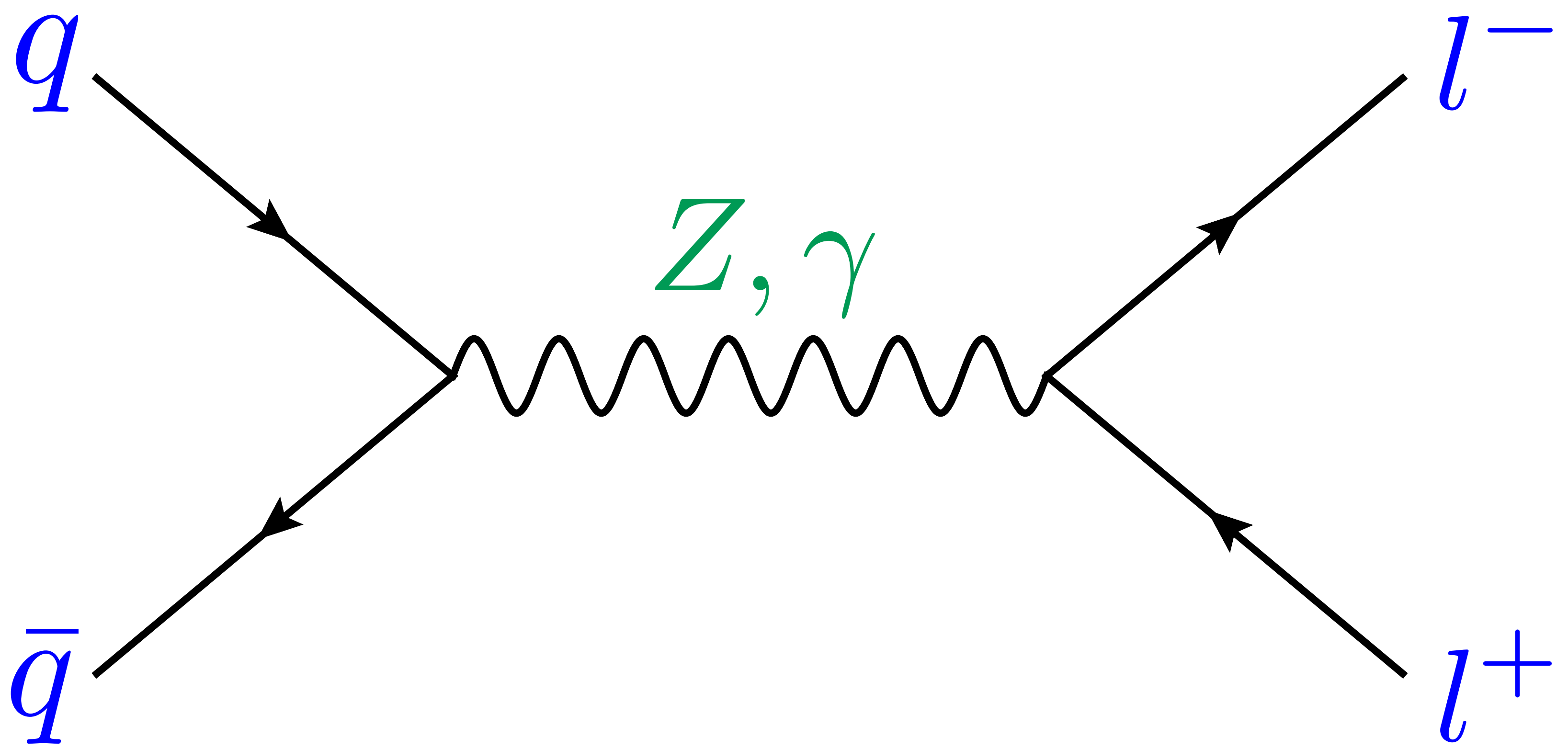
what about precision tests at 100 TeV?

- Arkani-Hamed, Han, Mangano, Wang **1511.06495**

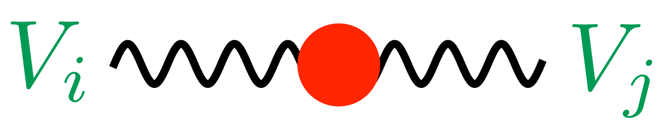
plan

1. Electroweak Precision from Drell-Yan
2. Drell-Yan at 100 TeV
3. SM EFT from jets at 100 TeV

1. Electroweak Precision from Drell-Yan



Oblique Parameters



$$V = \gamma, Z, W^{\pm}$$

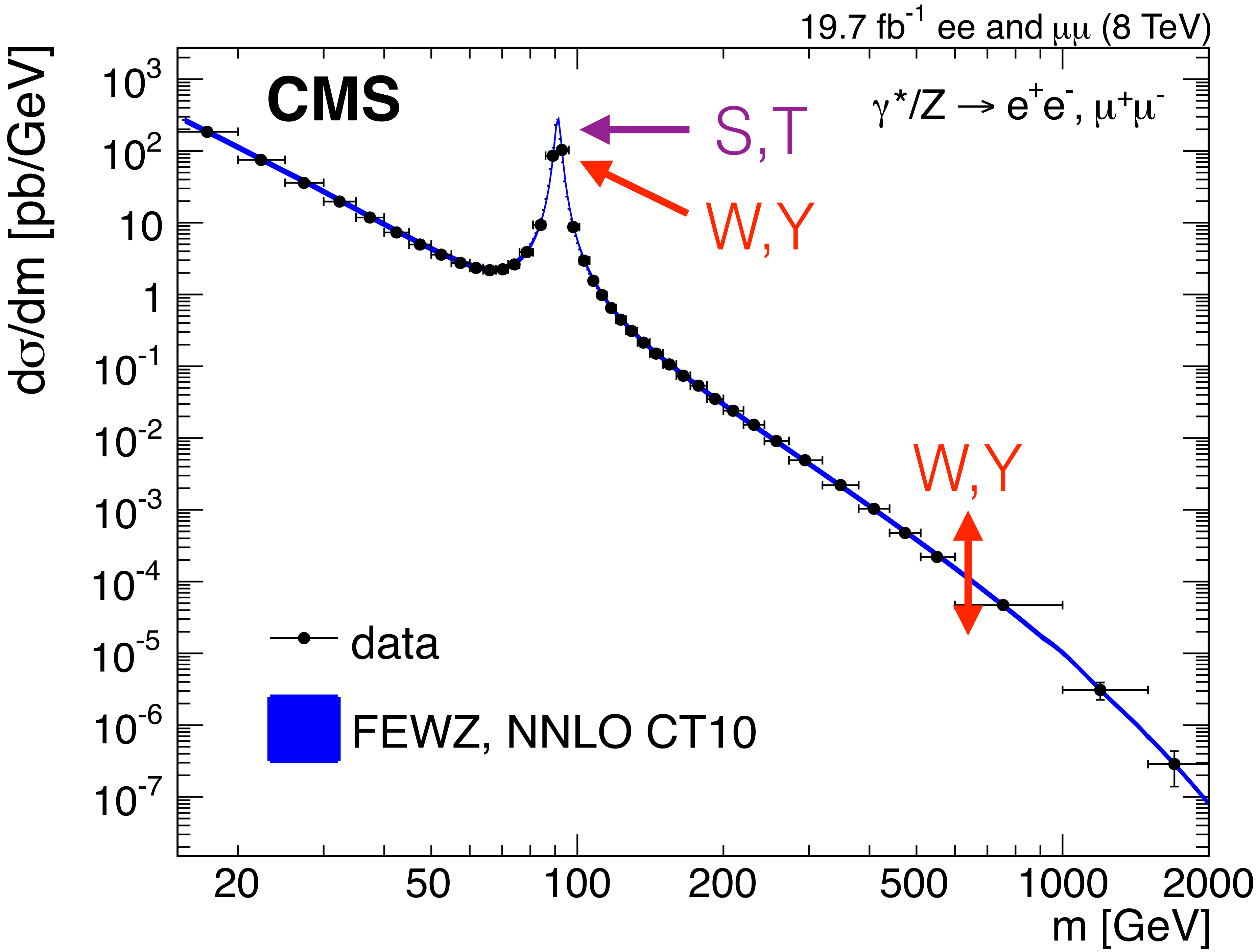
$$\Pi_{V_i V_j}(q^2) = \Pi_{V_i V_j}(0) + q^2 \Pi'_{V_i V_j}(0) + \frac{1}{2} q^4 \Pi''_{V_i V_j}(0) + \ldots$$

form factor	operator	parameter
$\Pi'_{W_3 B}(0)$	$\frac{1}{\Lambda_S^2} H^\dagger W_{\mu\nu} H B_{\mu\nu}$	$S = -\frac{16\sin(2\theta_W)}{g^2\alpha}\frac{m_W^2}{\Lambda_S^2}$
$\Pi_{W_3 W_3}(0) - \Pi_{W^+ W^-}(0)$	$\frac{1}{\Lambda_T^2}\lvert H^\dagger D_\mu H\rvert^2$	$T = -\frac{2}{g^2\alpha}\frac{m_W^2}{\Lambda_T^2}$
$\Pi''_{W_3 W_3}(0)$	$\frac{1}{\Lambda_W^2}(D_\rho W^a_{\mu\nu})^2$	$W = -4\frac{m_W^2}{\Lambda_W^2}$
$\Pi''_{BB}(0)$	$\frac{1}{\Lambda_Y^2}(\partial_\rho B_{\mu\nu})^2$	$Y = -4\frac{m_W^2}{\Lambda_Y^2}$

- Peskin, Takeuchi **1990**
- Barbieri, Pomarol, Rattazzi, Strumia **hep-ph/0405040**

Drell-Yan with Oblique Parameters

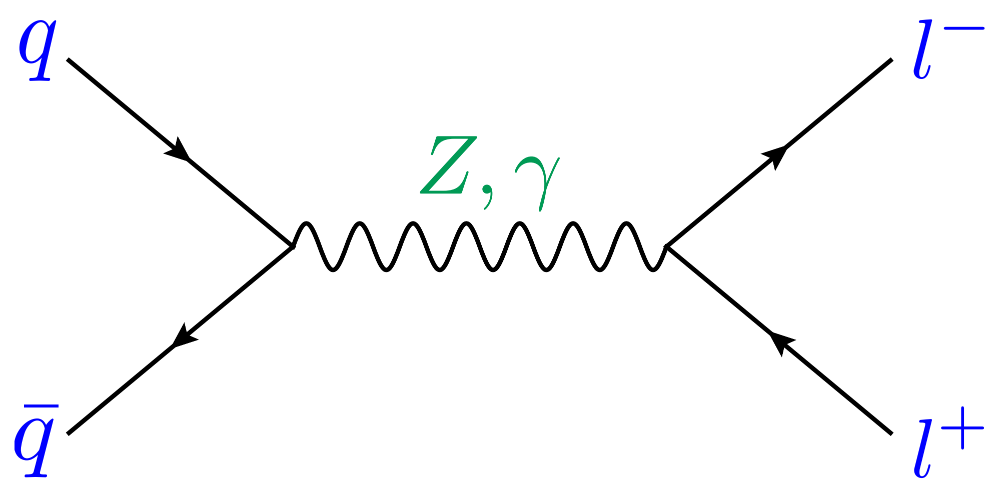
$$\mathcal{L} \supset \frac{1}{\Lambda_S^2} H^\dagger W_{\mu\nu} H B_{\mu\nu} + \frac{1}{\Lambda_T^2} |H^\dagger D_\mu H|^2 + \frac{1}{\Lambda_W^2} (D_\rho W^a_{\mu\nu})^2 + \frac{1}{\Lambda_Y^2} (\partial_\rho B_{\mu\nu})^2$$



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

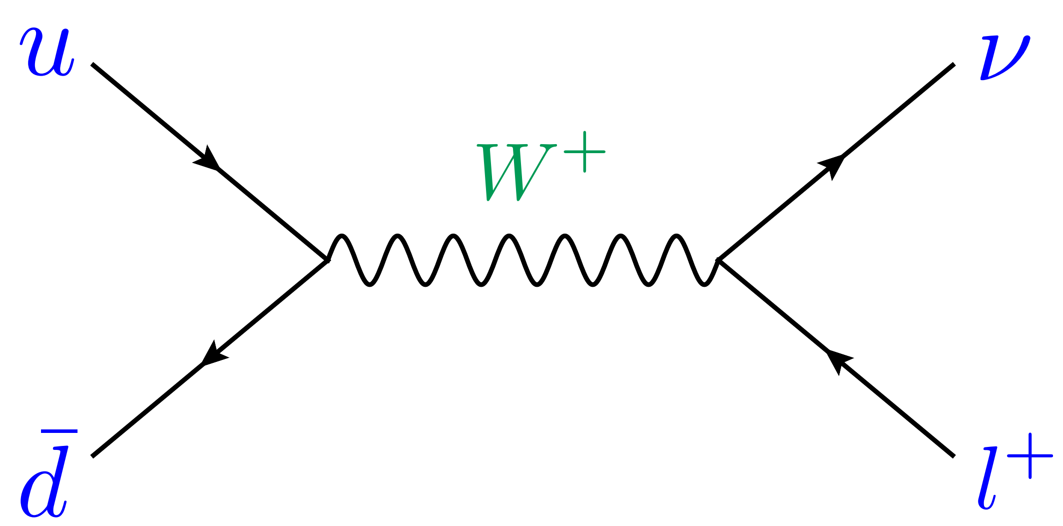
High Mass Drell-Yan Probes W/Y

- neutral current:



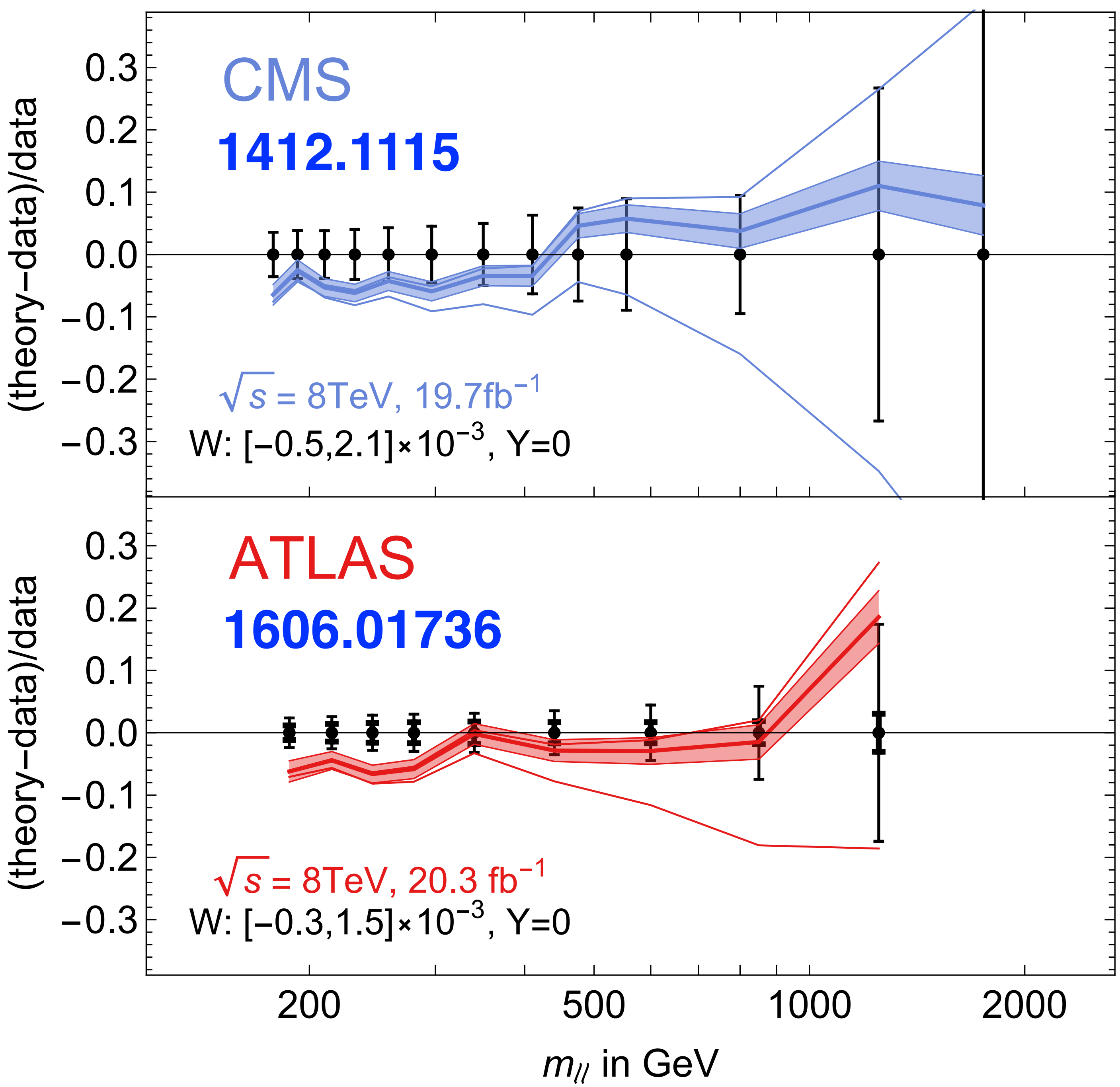
$M_{l^+l^-}(W, Y)$

- charged current:



$M_T(W)$

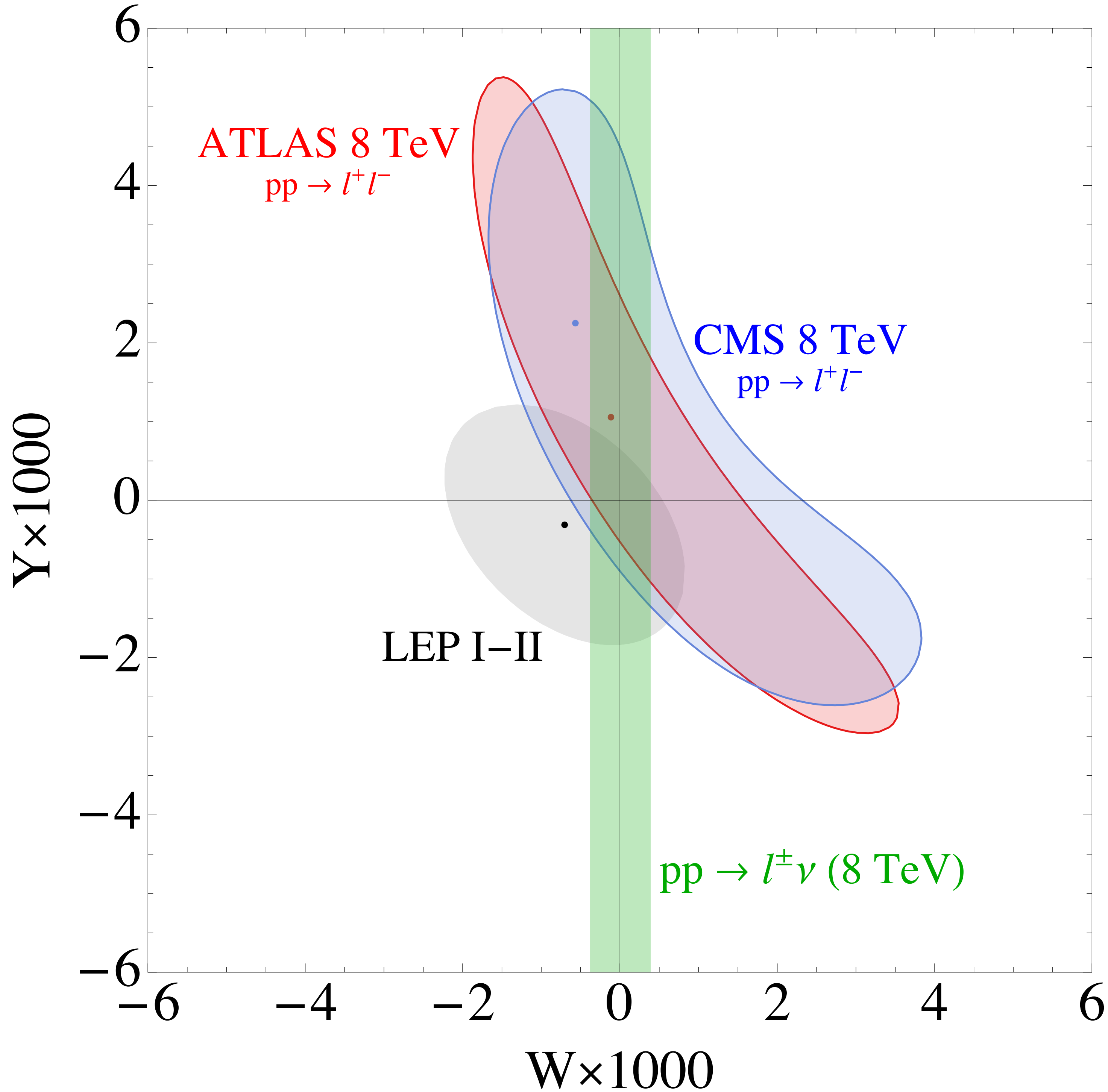
Theory vs. Drell-Yan Data



we include:

- experimental uncertainties (with correlations)
- NNLO scale uncertainty (from **FEWZ**)
- PDF uncertainty (**NNPDF**, with correlations)

LHC8 Limits



$\Lambda_Y \gtrsim 4$ TeV

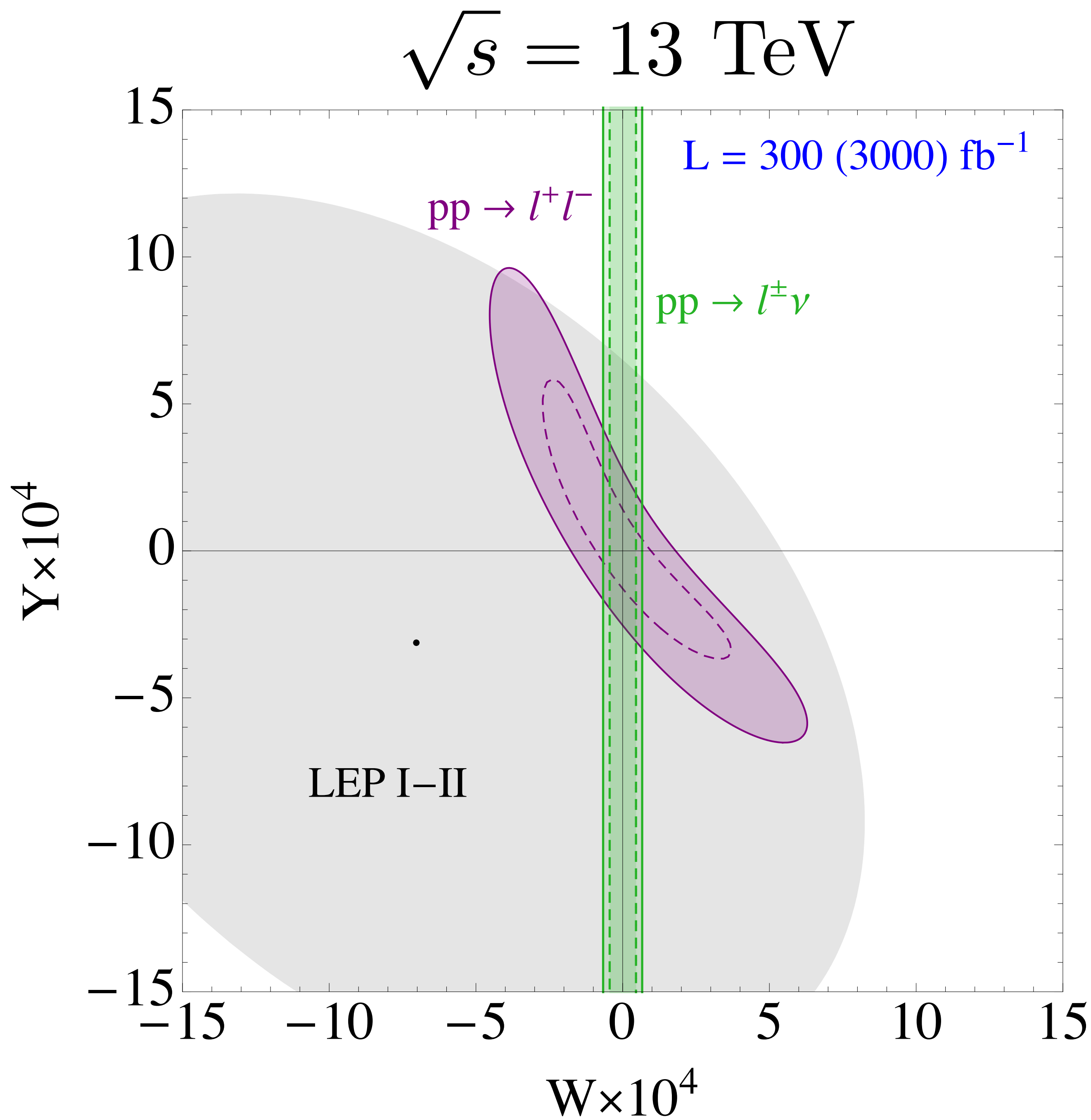
$\Lambda_W \gtrsim 8$ TeV

experimental uncertainty:

$\delta_{\rm cor} = 5\%$

$\delta_{\rm unc} = 5\%$

Future W/Y Reach

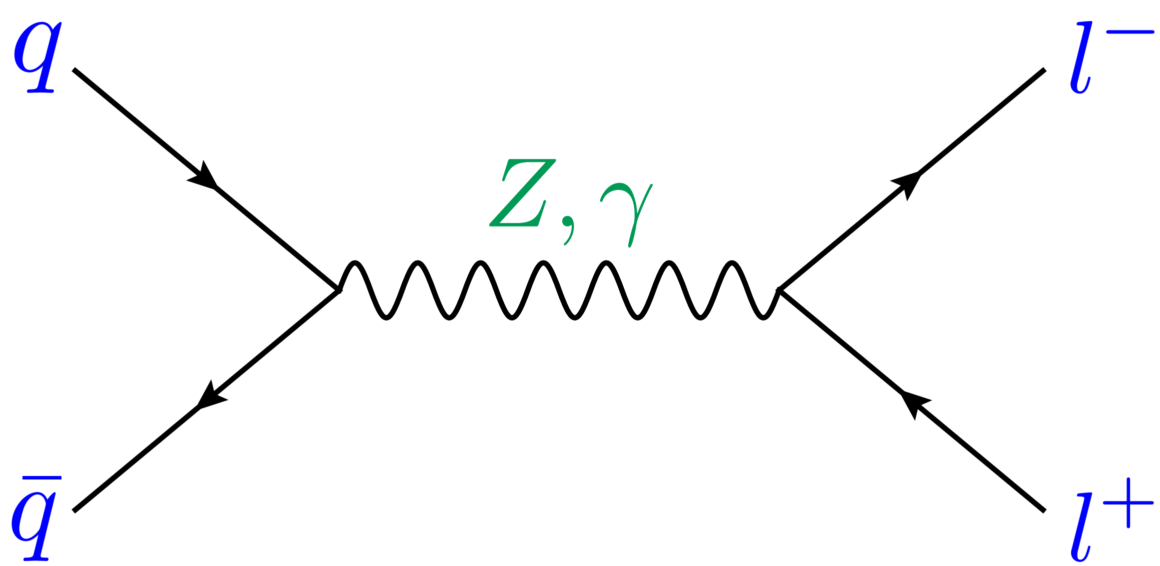


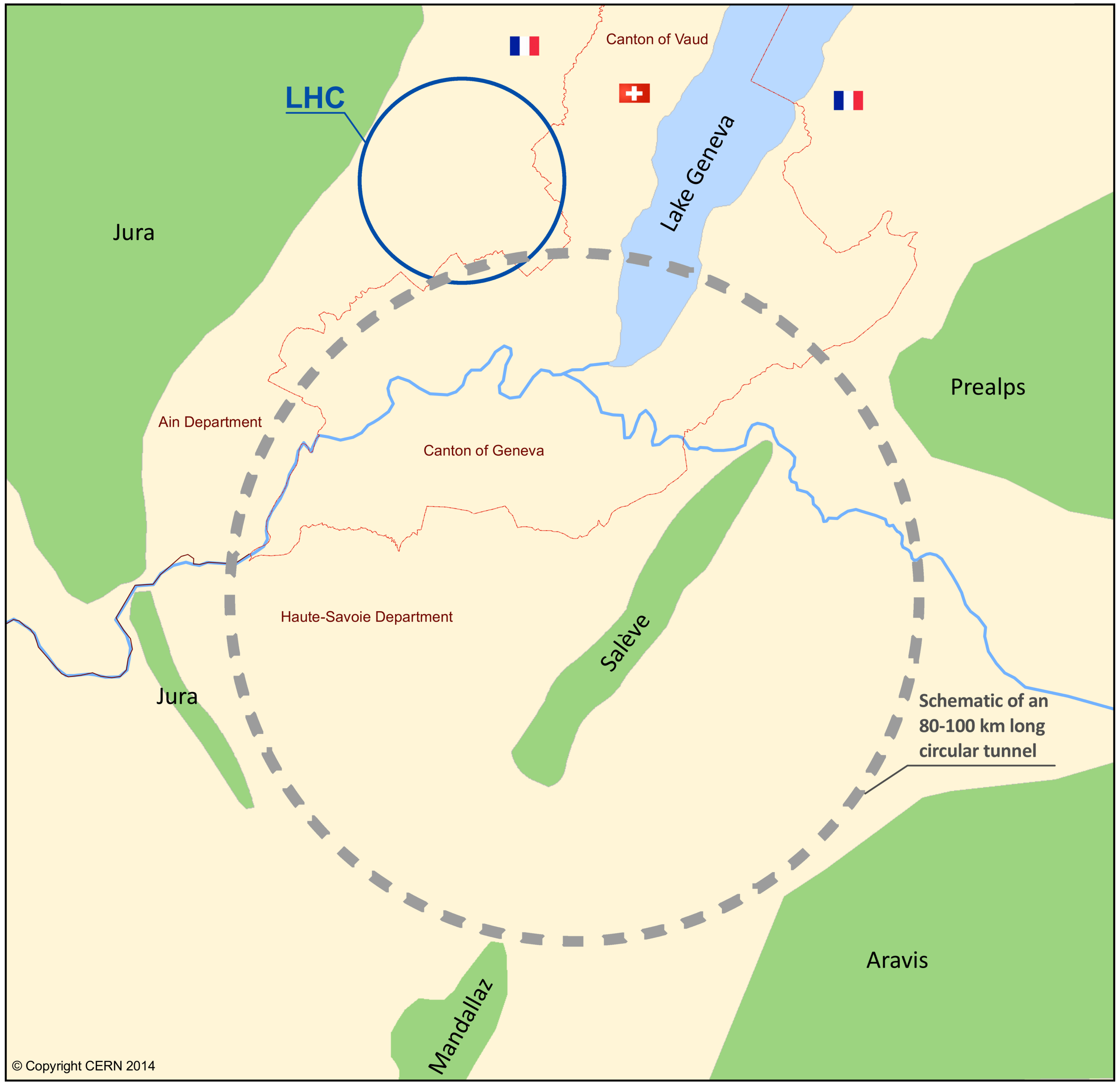
$\Lambda_W \gtrsim 24$ TeV

$\Lambda_Y \gtrsim 15$ TeV

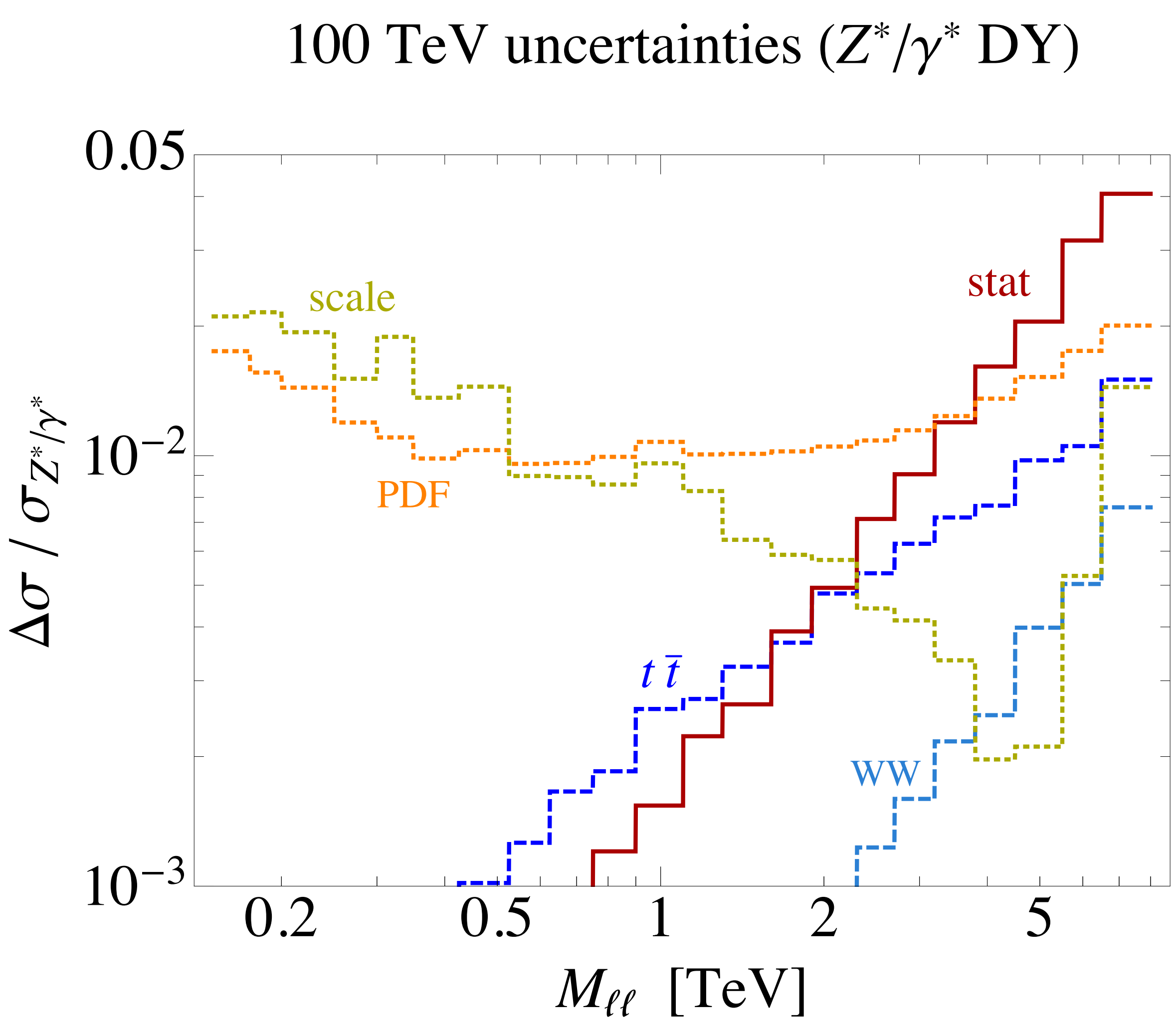
- neutral: $\delta_{\rm cor} = \delta_{\rm unc} = 2\%$
- charged: $\delta_{\rm cor} = \delta_{\rm unc} = 5\%$

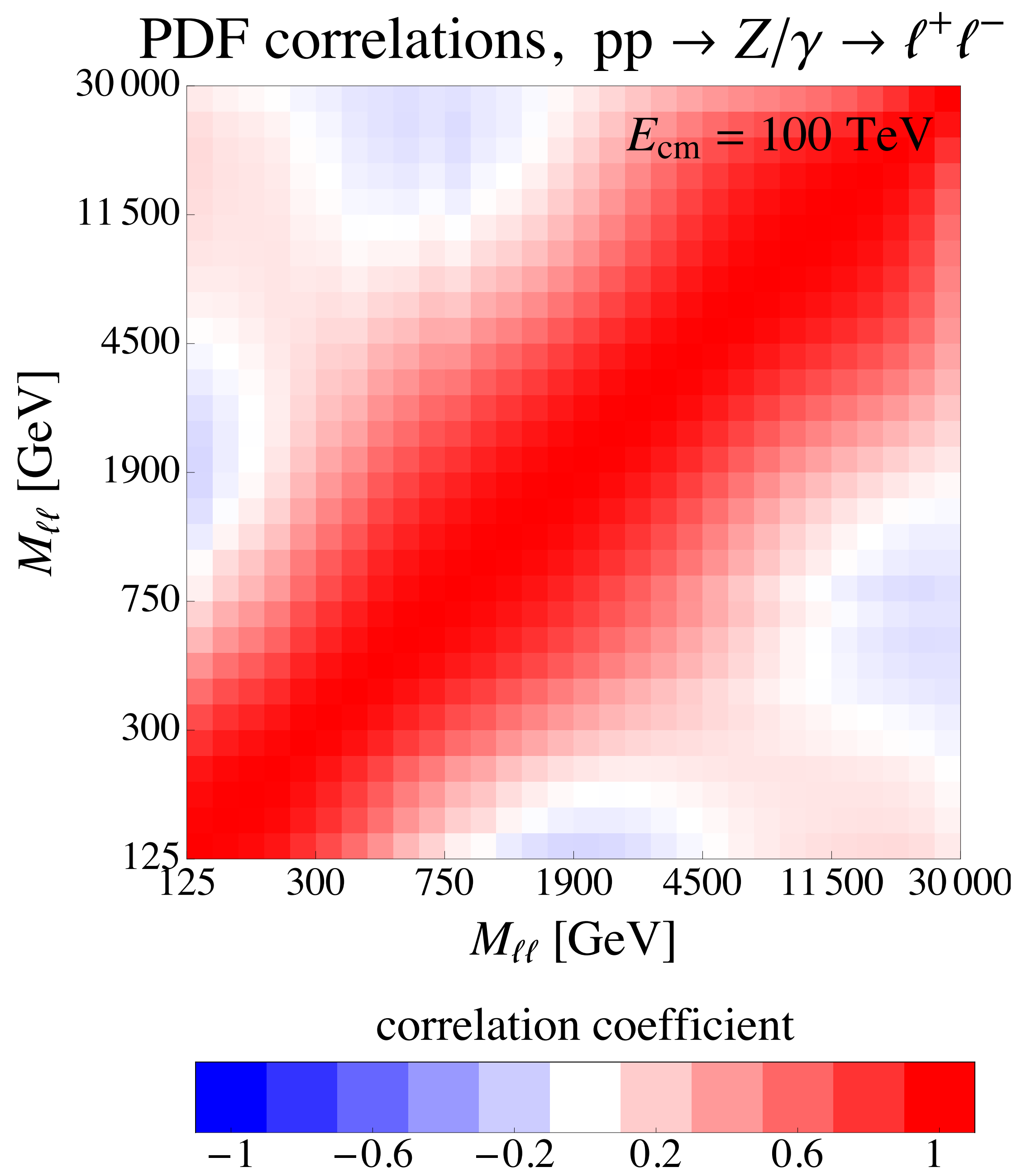
2. Drell-Yan at 100 TeV





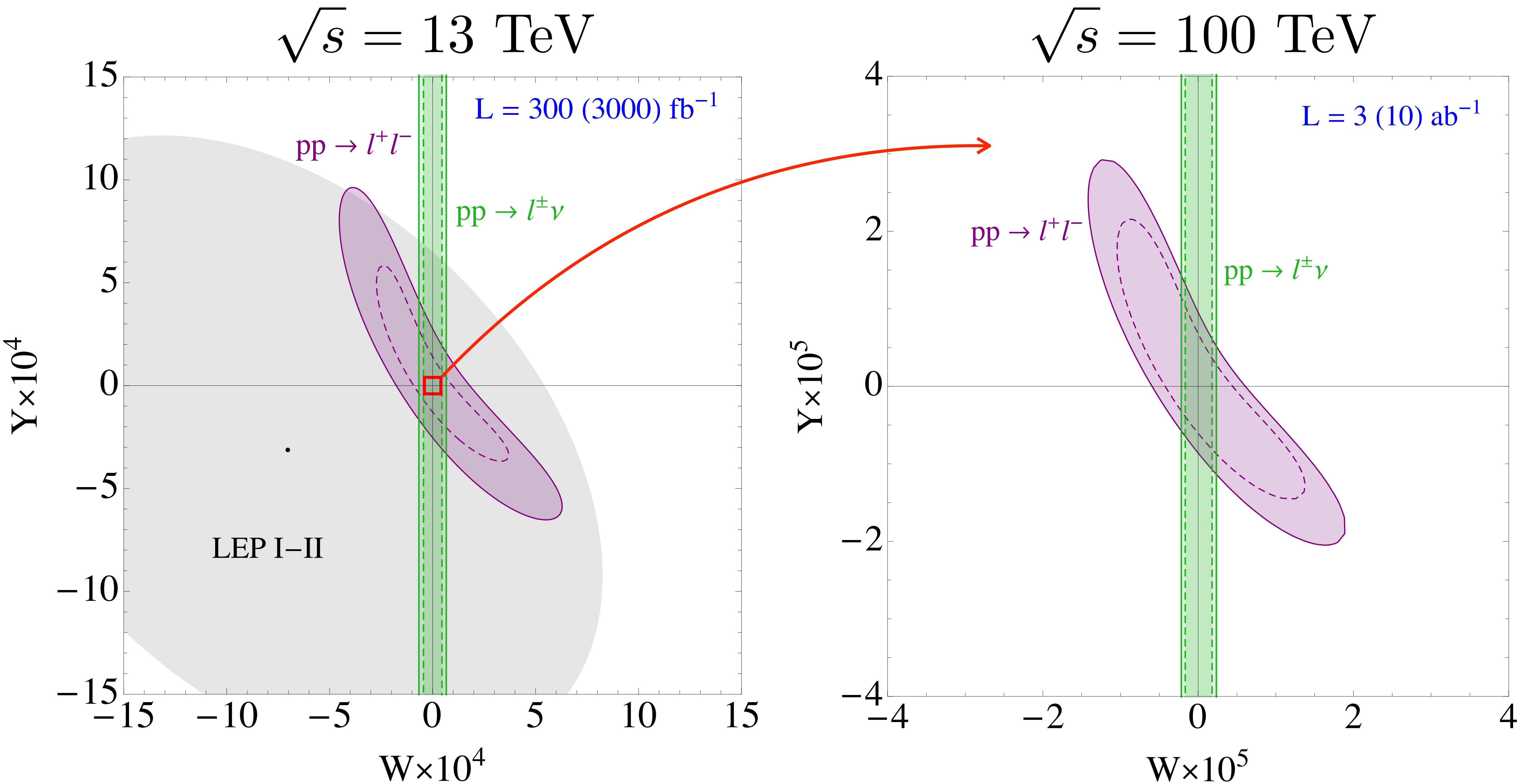
Drell-Yan Uncertainties @100TeV





- Alves, Galloway, JTR, Walsh **1410.6810**

Future W/Y Reach



$\Lambda_W \gtrsim 24$ TeV

$\Lambda_Y \gtrsim 15$ TeV

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

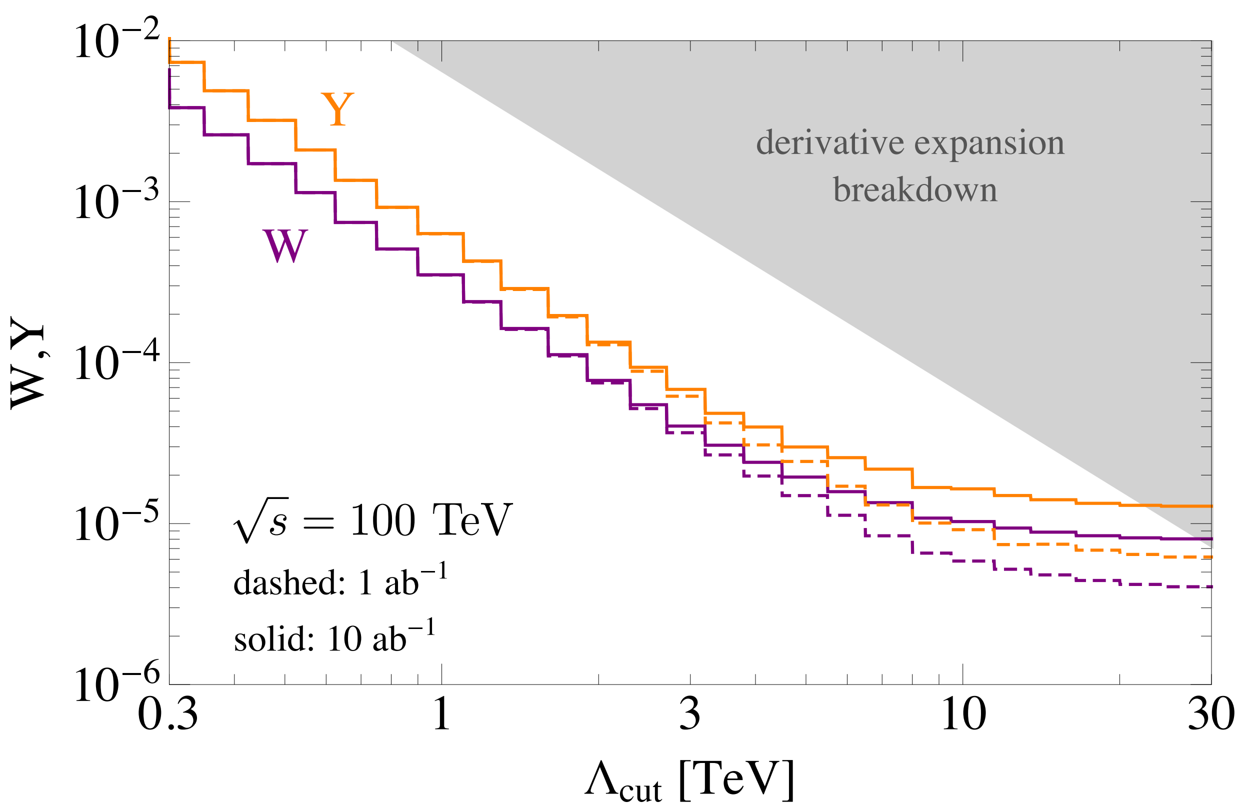
$\Lambda_W \gtrsim 110$ TeV

$\Lambda_Y \gtrsim 70$ TeV

EFT Validity

neutral current

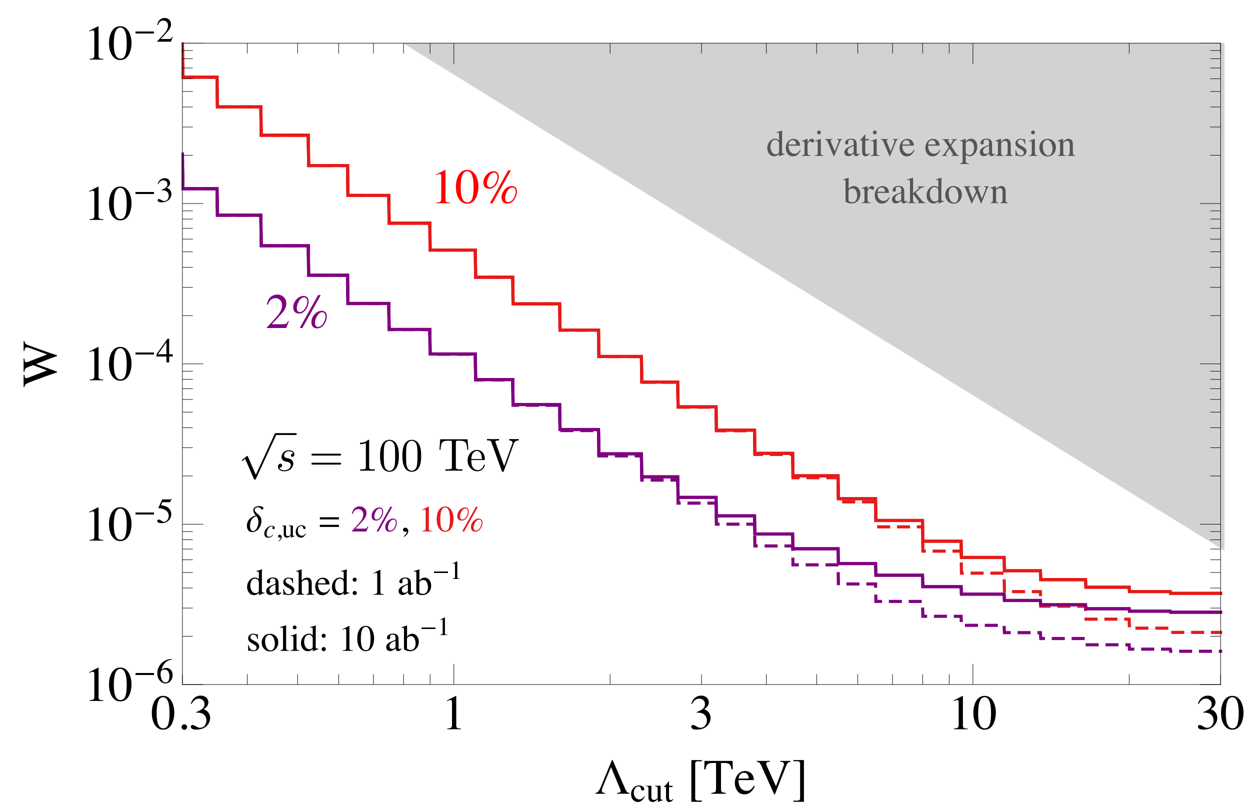
$pp \to \ell^+\ell^-$



$$m_{l^+l^-} < \Lambda_{\rm cut}$$

charged current

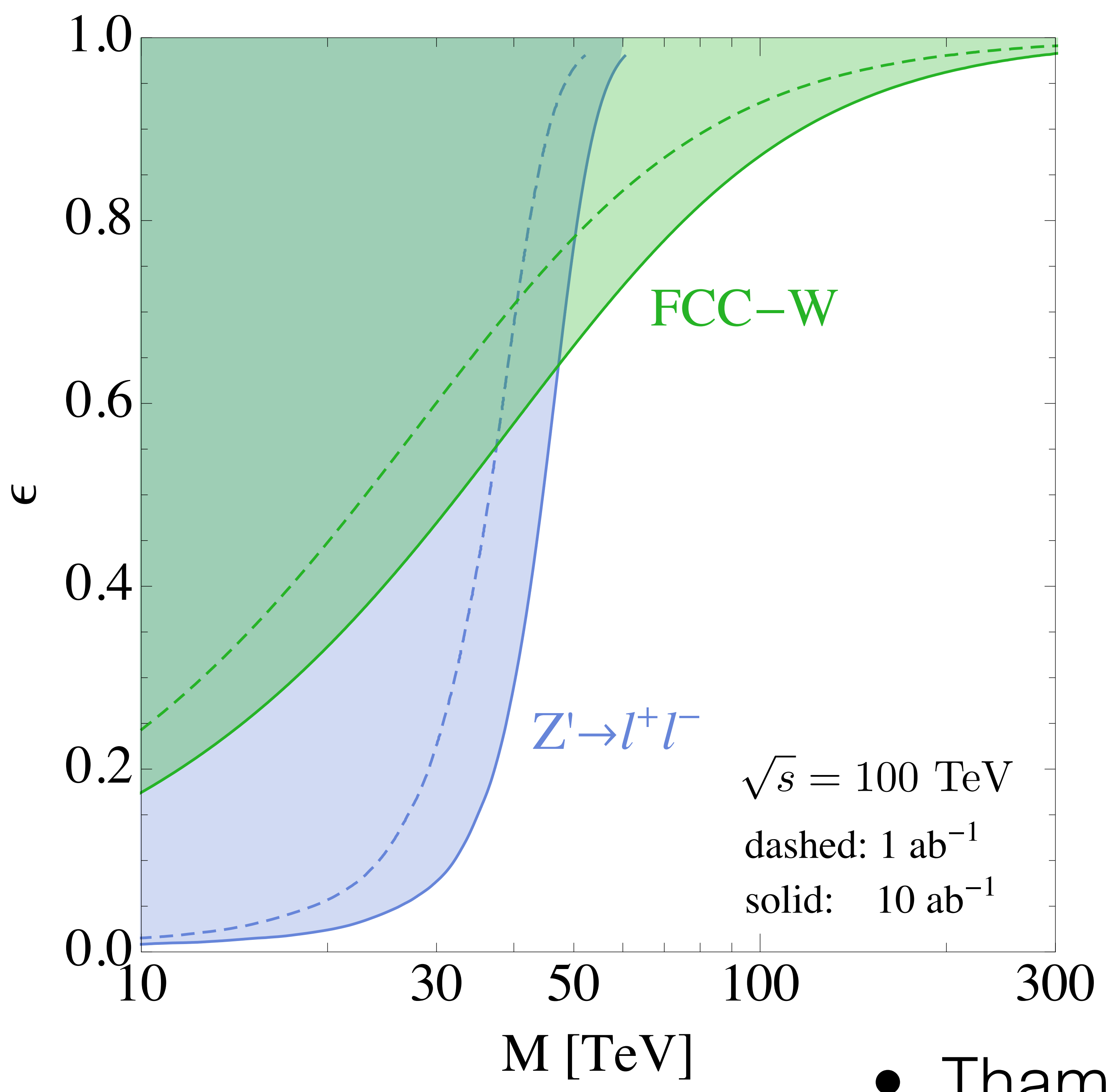
$pp \to \ell^\pm\nu$

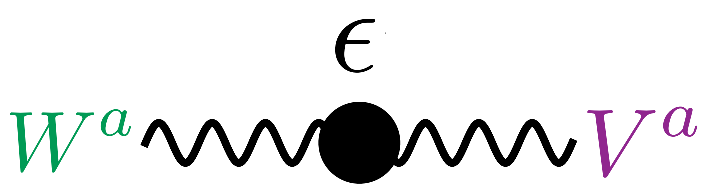


$$M_T < \Lambda_{\rm cut}$$

ex) heavy vector triplet

$$\mathcal{L} \supset -\frac{1}{4} W^a_{\mu\nu} W_a^{\mu\nu} - \frac{1}{4} V^a_{\mu\nu} V_a^{\mu\nu} - \frac{\epsilon}{2} W^a_{\mu\nu} V_a^{\mu\nu} + \frac{M^2}{2} V^2$$





direct Z' reach from:

- Thamm, Torre, Wulzer **1502.01701**

comparing colliders

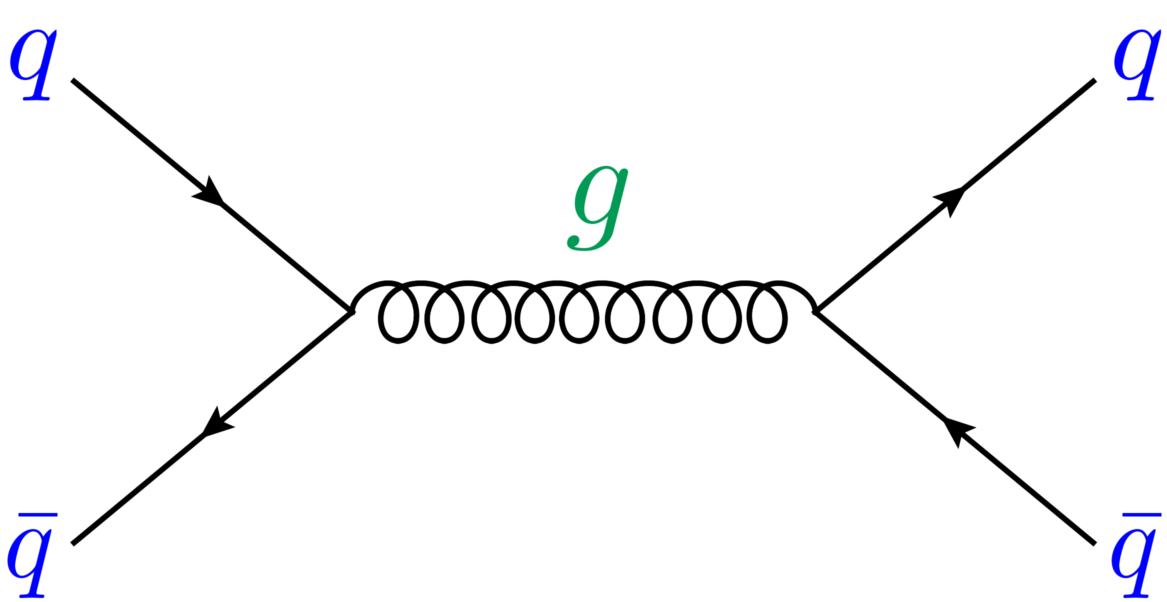
FCC-pp

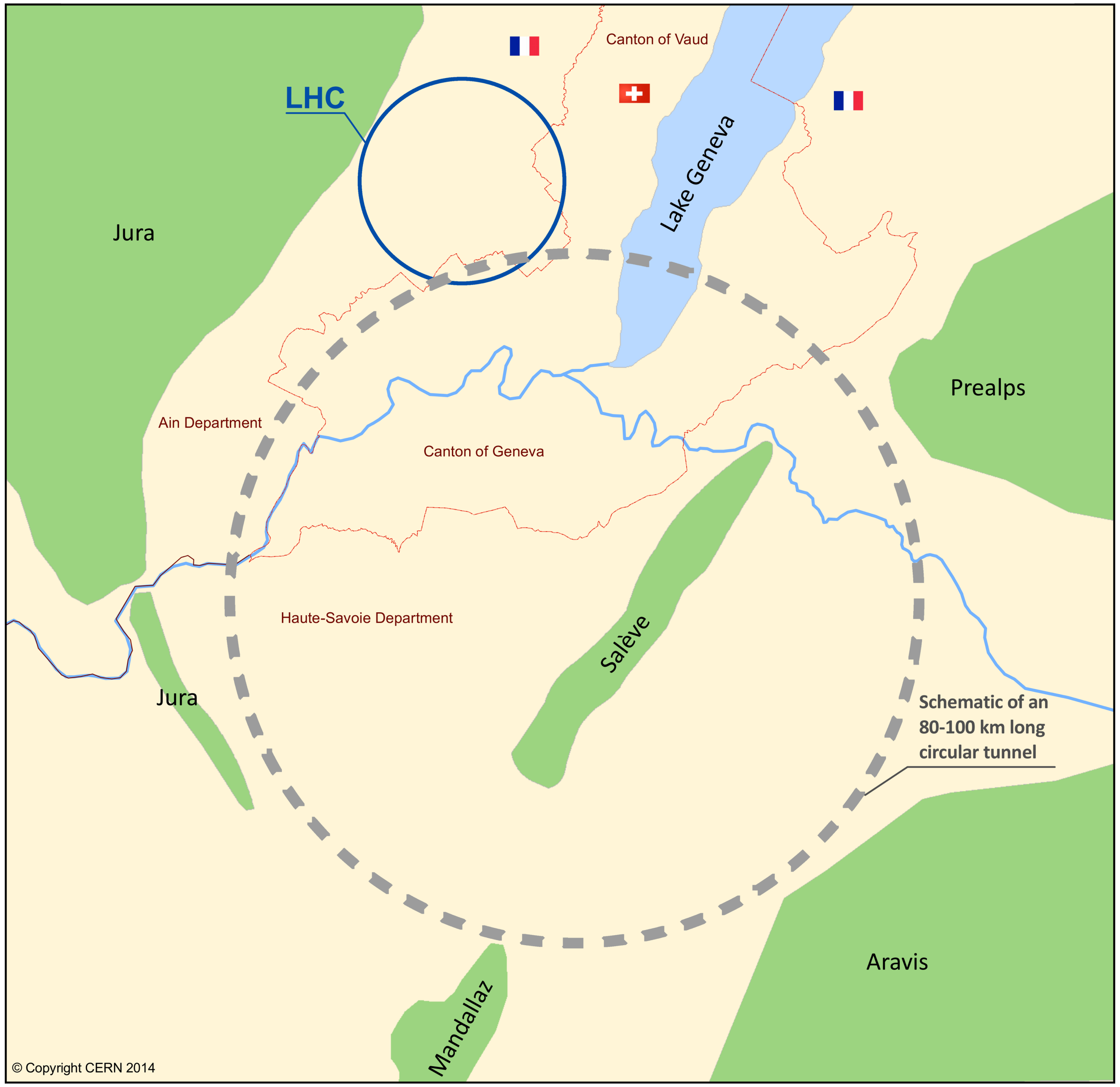
		LEP	ATLAS 8	CMS 8	LHC 13		100 TeV	ILC	TLEP	ILC 500 GeV
	luminosity	$2 \times 10^7\ Z$	$19.7\,\text{fb}^{-1}$	$20.3\,\text{fb}^{-1}$	$0.3\,\text{ab}^{-1}$	$3\,\text{ab}^{-1}$	$10\,\text{ab}^{-1}$	$10^9\ Z$	$10^{12}\ Z$	$3\,\text{ab}^{-1}$
NC	$\text{W}\times 10^4$	$[-19, 3]$	$[-3, 15]$	$[-5, 22]$	± 1.5	± 0.8	± 0.04	± 3	± 0.7	± 0.3
	$\text{Y}\times 10^4$	$[-17, 4]$	$[-4, 24]$	$[-7, 41]$	± 2.3	± 1.2	± 0.06	± 4	± 1	± 0.2
CC	$\text{W}\times 10^4$	—	± 3.9		± 0.7	± 0.45	± 0.02	—	—	—

FCC-ee

(what about FCC-ep?)

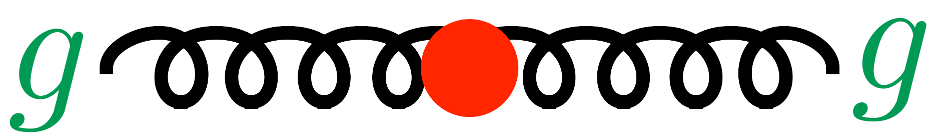
3. SM EFT from jets at 100 TeV

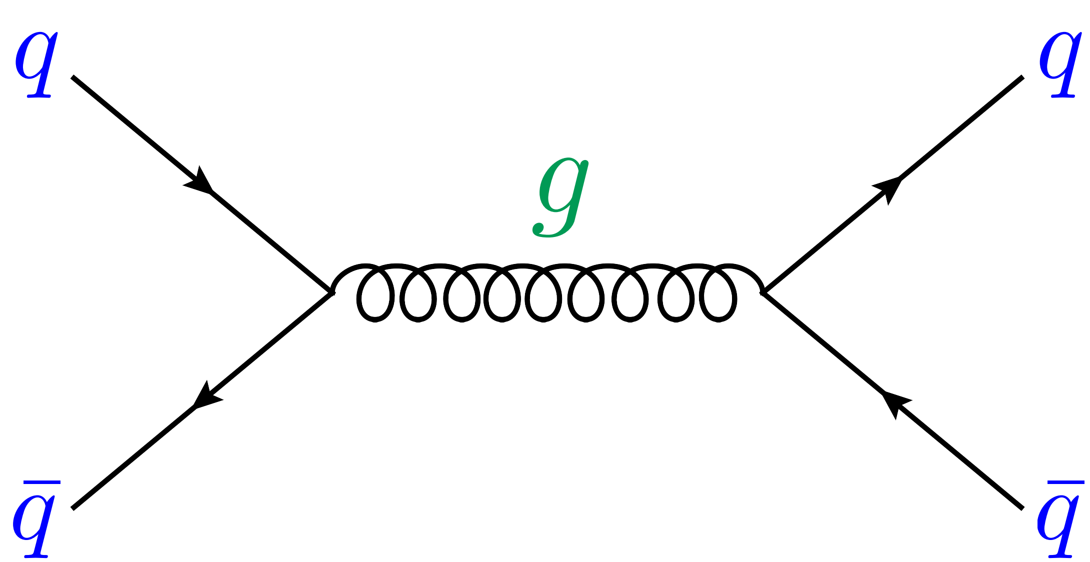




Z

$$\mathcal{L}_{\text{eff}} \supset \frac{1}{\Lambda_Z^2}(D_\rho G^a_{\mu\nu})^2 \qquad\qquad Z = -\frac{4m_W^2}{\Lambda_Z^2}$$





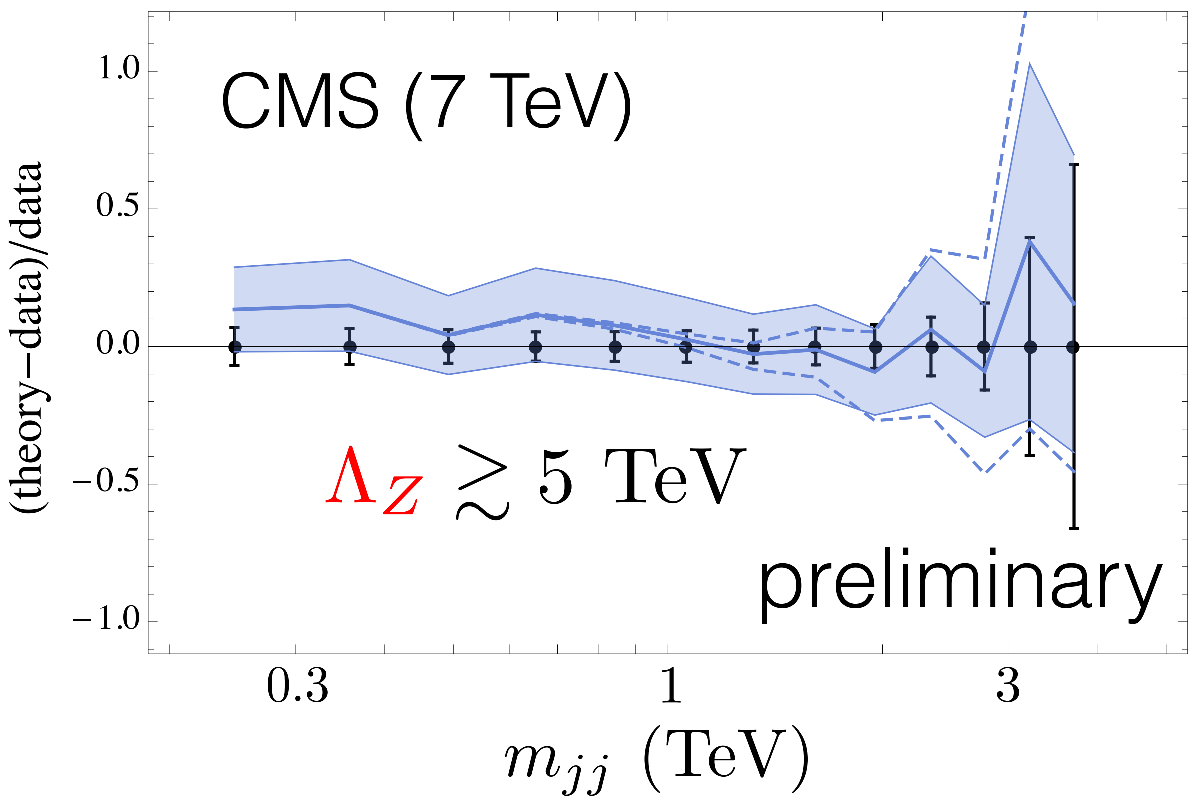
$$M_{jj}(Z)$$

earlier bounds:

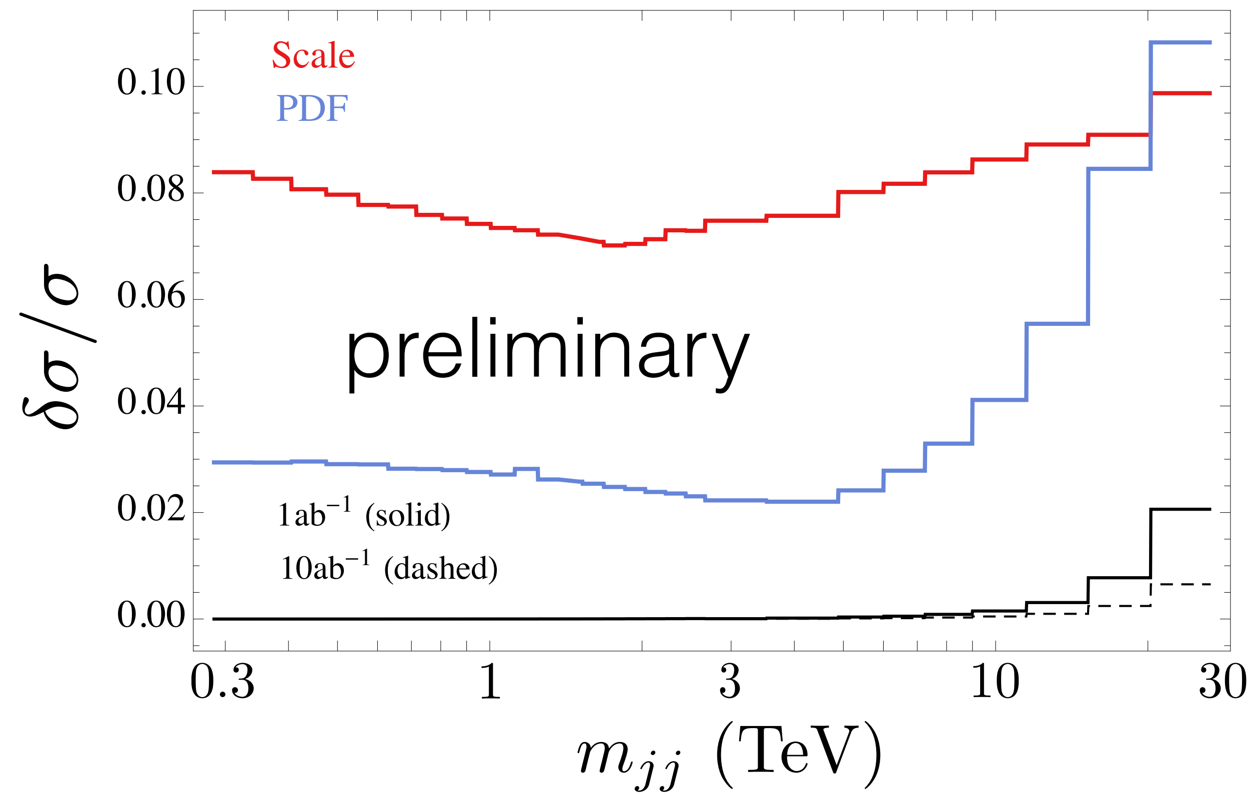
- Cho, Simmons **hep-ph/9307345**
- Domenech, Pomarol, Serra **1201.6510**

Z from Dijets

LHC (7 TeV)



FCC (100 TeV)



- CMS **1212.6660**

$-1.1 \times 10^{-3} < Z < 0.7 \times 10^{-3}$

- ATLAS **1312.3524**

$-0.7 \times 10^{-3} < Z < 0.7 \times 10^{-3}$

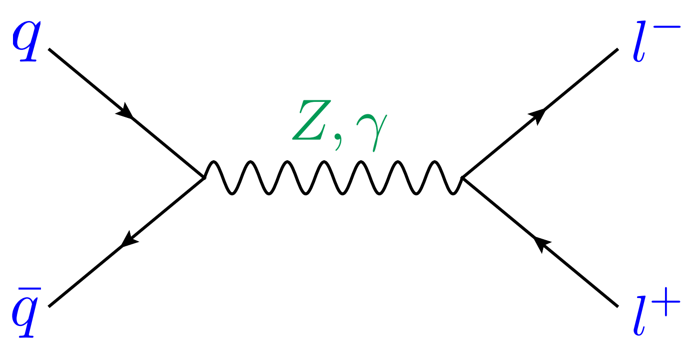
$|Z| < 0.3 \times 10^{-5}$

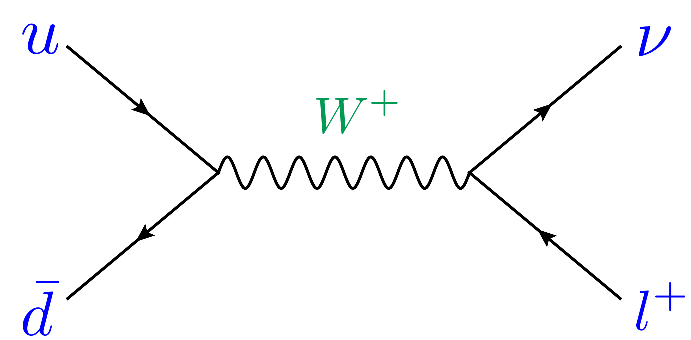
$\Lambda_Z \gtrsim 90$ TeV

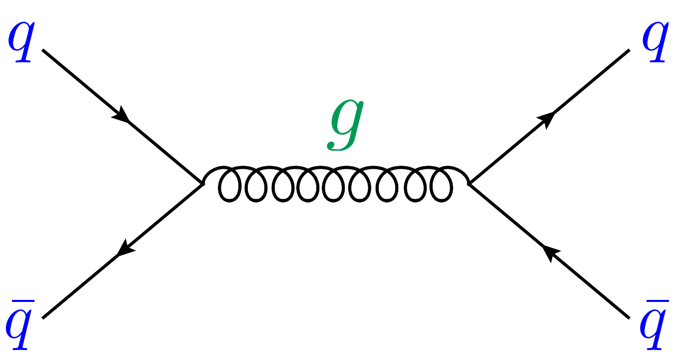
take away

$$\mathcal{L}_{\text{eff}} \supset \frac{1}{\Lambda_Y^2}(\partial_\rho B_{\mu\nu})^2 + \frac{1}{\Lambda_W^2}(D_\rho W^a_{\mu\nu})^2 + \frac{1}{\Lambda_Z^2}(D_\rho G^a_{\mu\nu})^2$$

- FCC-pp reach:







$\Lambda_Y \gtrsim 70$ TeV $\quad \Lambda_W \gtrsim 110$ TeV $\quad \Lambda_Z \gtrsim 90$ TeV

(preliminary)

- wishlist:
  - more operators with energy growth
  - more processes
  - SMEFT at FCC-ep
  - interplay of SMEFT and PDF extraction