EWPO measurements and impact on SM constraints

G.Cacciapaglia (IP2I Lyon)

LPNHE, 14/05/2020

Why do we need New Physics?

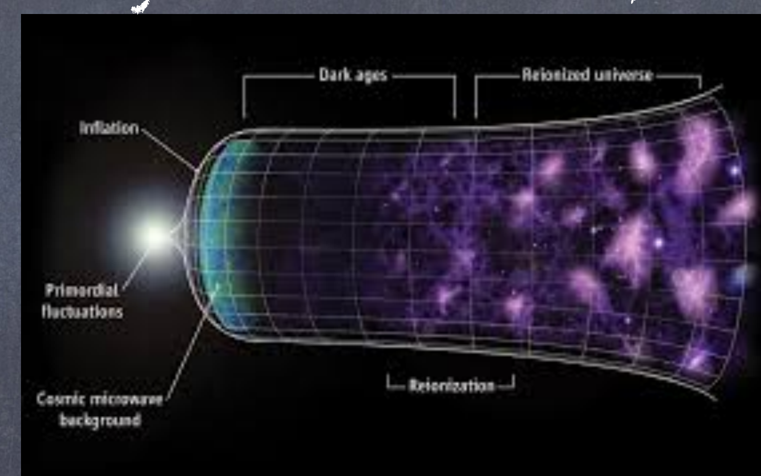
- Several observations in Nature:

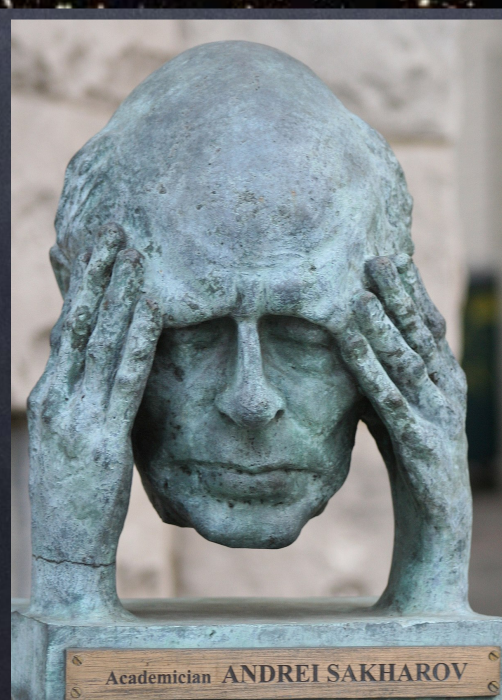
Dark Matter, or...

why is the Universe so heavy?

Inflation, or...

why is the Universe so flat?





Baryogenesis, or...

why is the Universe so interesting?

+ more (to your taste)!

Why do we need New Physics?

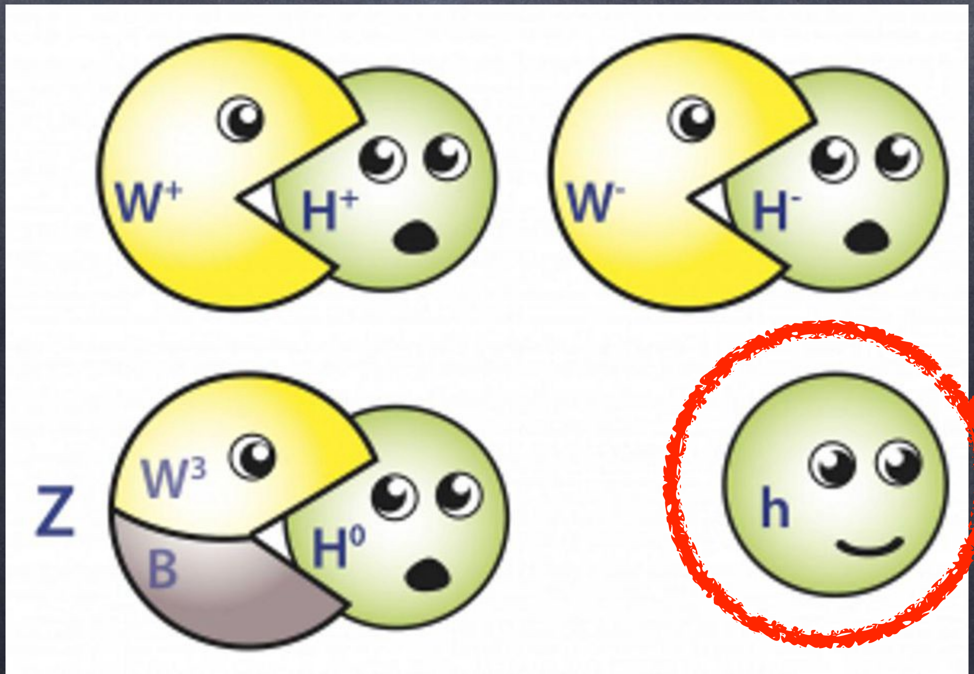
- But we have "The Standard Model"!

→ No Dark Matter (primordial Black Holes?),
No Inflation (Higgs Inflation -> non-standard gravity)

→ Two Sakharov condition NOT satisfied!

- How well do we know the EW sector?

EW precision tests told us a lot on W+, W- and Z physics at per-mille level!



How well do we know this guy?

LHC 2020: an appraisal

- No "expected New Physics" has been found!
- The SM is valid up to E = TeV-ish

Do we need to give-up naturalness?
No BSM guiding principle?

$$\delta m_h^2 = -\frac{3y_t^2}{8\pi} M_{\rm BSM}^2$$

$$M_{\rm BMS} \approx \mathcal{O}(1\ {\rm TeV})$$

i.e.

$$0.1 \div 10\ {\rm TeV}$$

Just starting to pull the carrots!

LHC 2020: an appraisal

- No "expected New Physics" has been found!
- The SM is valid up to E = TeV-ish

Do we need to give-up naturalness?

NO!

Future colliders can push validation scale of the SM to 10 TeV, thus "rule out" naturalness! *

*Personal view.

New Physics may also manifest via light and feebly coupled states, or heavy states with small mixings.

Why do we need precision?

It's the way to validate the SM!
Synergy between FCC-ee and FCC-hh!

- FCC-ee: precision measurements of EW properties, @ teraZ, WW and tt thresholds!

  -> EW precision tests pushed to $10^{-4} \div 10^{-5}$ probing scales up to 10 times higher (~ 70 TeV)

  -> this also allows to probe small couplings (for instance, via mixing of SM states)

- FCC-hh: energy helps precision in processes growing with energy

FCC-ee: precision machine

- Measurements at the Z-pole

Observable	present value ± error	FCC-ee Stat.	FCC-ee Syst.	Comment and dominant exp. error
m_Z (keV)	91186700 ± 2200	5	100	From Z line shape scan Beam energy calibration
Γ_Z (keV)	2495200 ± 2300	8	100	From Z line shape scan Beam energy calibration
R_ℓ^Z ($\times 10^3$)	20767 ± 25	0.06	0.2-1.0	ratio of hadrons to leptons acceptance for leptons
$\alpha_s(m_Z)$ ($\times 10^4$)	1196 ± 30	0.1	0.4-1.6	from R_ℓ^Z above [41]
R_b ($\times 10^6$)	216290 ± 660	0.3	<60	ratio of $b\bar{b}$ to hadrons stat. extrapol. from SLD [42]
σ_{had}^0 ($\times 10^3$) (nb)	41541 ± 37	0.1	4	peak hadronic cross-section luminosity measurement
N_ν($\times 10^3$)	2991 ± 7	0.005	1	Z peak cross sections Luminosity measurement
$\sin^2\theta_W^{eff}$($\times 10^6$)	231480 ± 160	3	2 - 5	from $A_{FB}^{\mu\mu}$ at Z peak Beam energy calibration
$1/\alpha_{QED}(m_Z)$($\times 10^3$)	128952 ± 14	4	small	from $A_{FB}^{\mu\mu}$ off peak [32]
$A_{FB}^b, 0$ ($\times 10^4$)	992 ± 16	0.02	1-3	b-quark asymmetry at Z pole from jet charge
$A_{FB}^{pol,\tau}$ ($\times 10^4$)	1498 ± 49	0.15	<2	τ polarisation and charge asymmetry τ decay physics

See upcoming talks on systematic errors

CERN-ACC-2018-0056

FCC-ee: precision machine

- Measurements at thresholds

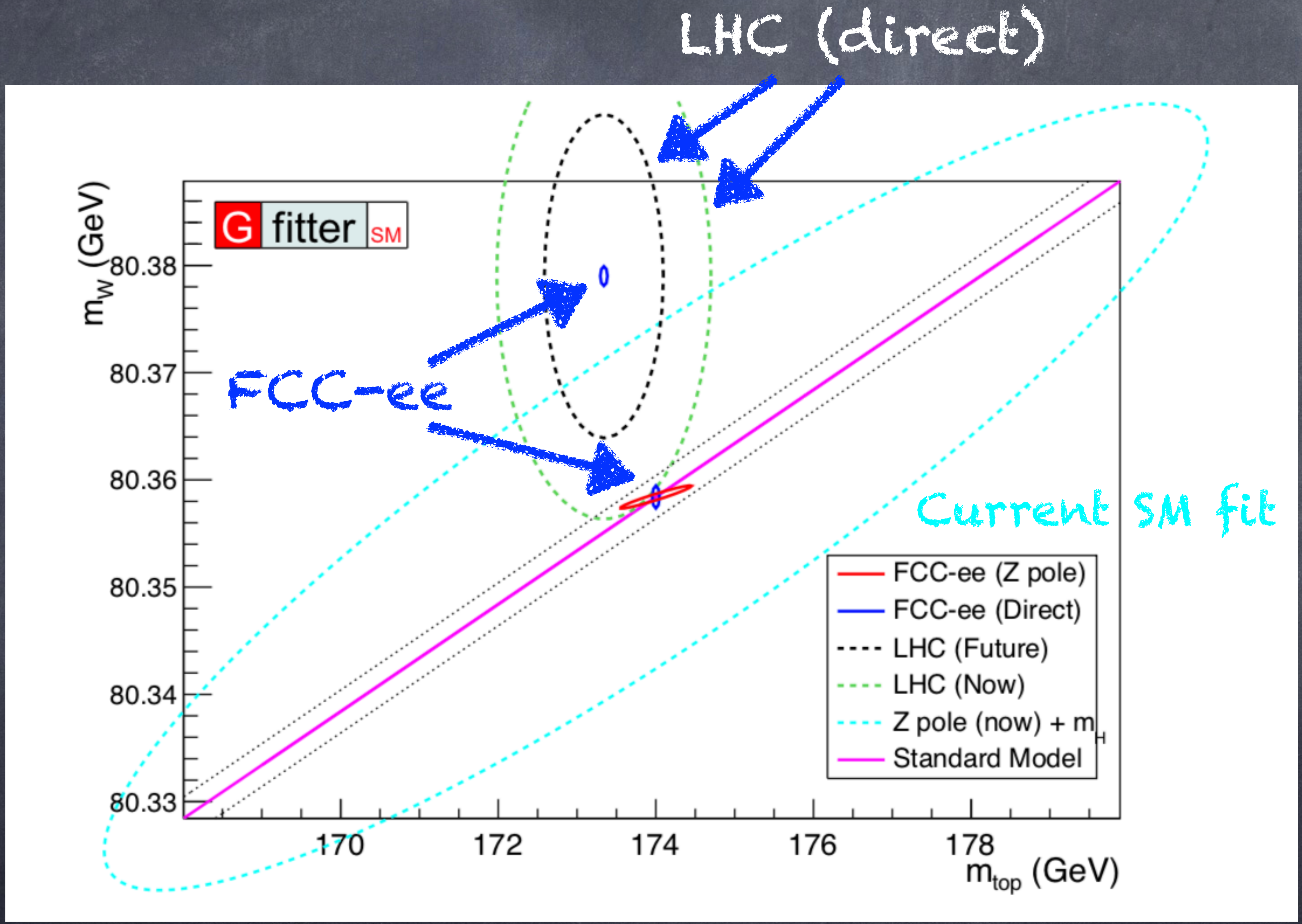
See upcoming talks on systematic errors

m_W (MeV)	80350 ± 15	0.6	0.3	From WW threshold scan Beam energy calibration
Γ_W (MeV)	2085 ± 42	1.5	0.3	From WW threshold scan Beam energy calibration
$\alpha_s(m_W)(\times 10^4)$	1170 ± 420	3	small	from R_ℓ^W [43]
$N_\nu(\times 10^3)$	2920 ± 50	0.8	small	ratio of invis. to leptonic in radiative Z returns
m_{top} (MeV)	172740 ± 500	20	small	From $t\bar{t}$ threshold scan QCD errors dominate
Γ_{top} (MeV)	1410 ± 190	40	small	From $t\bar{t}$ threshold scan QCD errors dominate
$\lambda_{top}/\lambda_{top}^{SM}$	1.2 ± 0.3	0.08	small	From $t\bar{t}$ threshold scan QCD errors dominate
ttZ couplings	$\pm$ 30%	0.5 – 1.5%	small	From E_{CM} = 365GeV run

CERN-ACC-2018-0056

$$m_W(SM) = 80358 \pm 8 \text{ MeV}$$

FCC-ee: precision machine



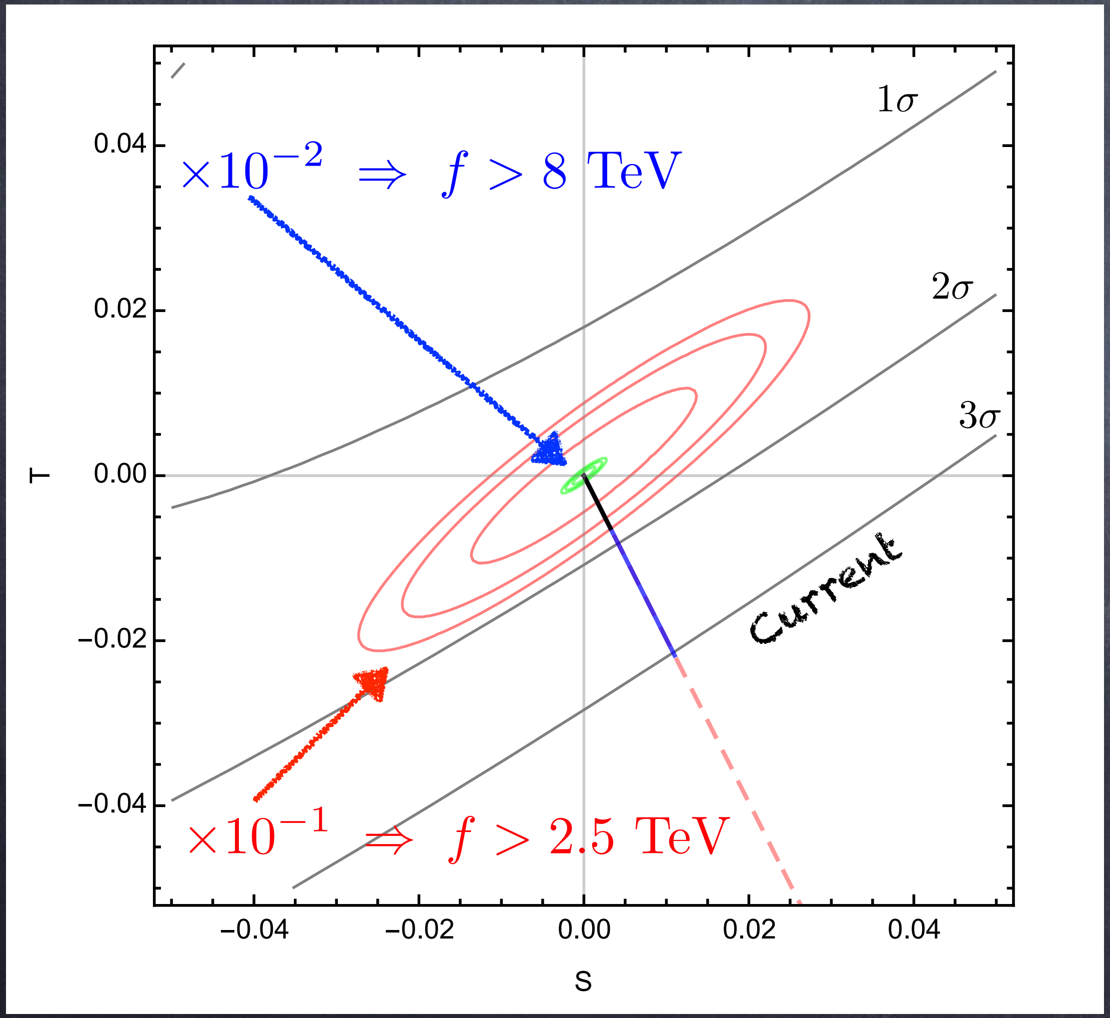
CERN-ACC-2018-0057

Any deviation will be a sign of New Physics!

Implications: my favourite example

Composite Higgs models

f = Higgs decay constant (analog to the pion decay constant)



Current bounds (EWPO):

$$\frac{v^2}{f^2} < 0.04 \quad \Rightarrow \quad f > 1.2 \text{ TeV}$$

With FCC-ee improvement:

$$\frac{v^2}{f^2} < 0.0004 \quad \Rightarrow \quad f > 12 \text{ TeV}$$

Above (my) threshold!

FCC-hh: energy machine

- efficient probe of energy-dependent processes!

Prime example: contact interactions in Drell-Yann processes.

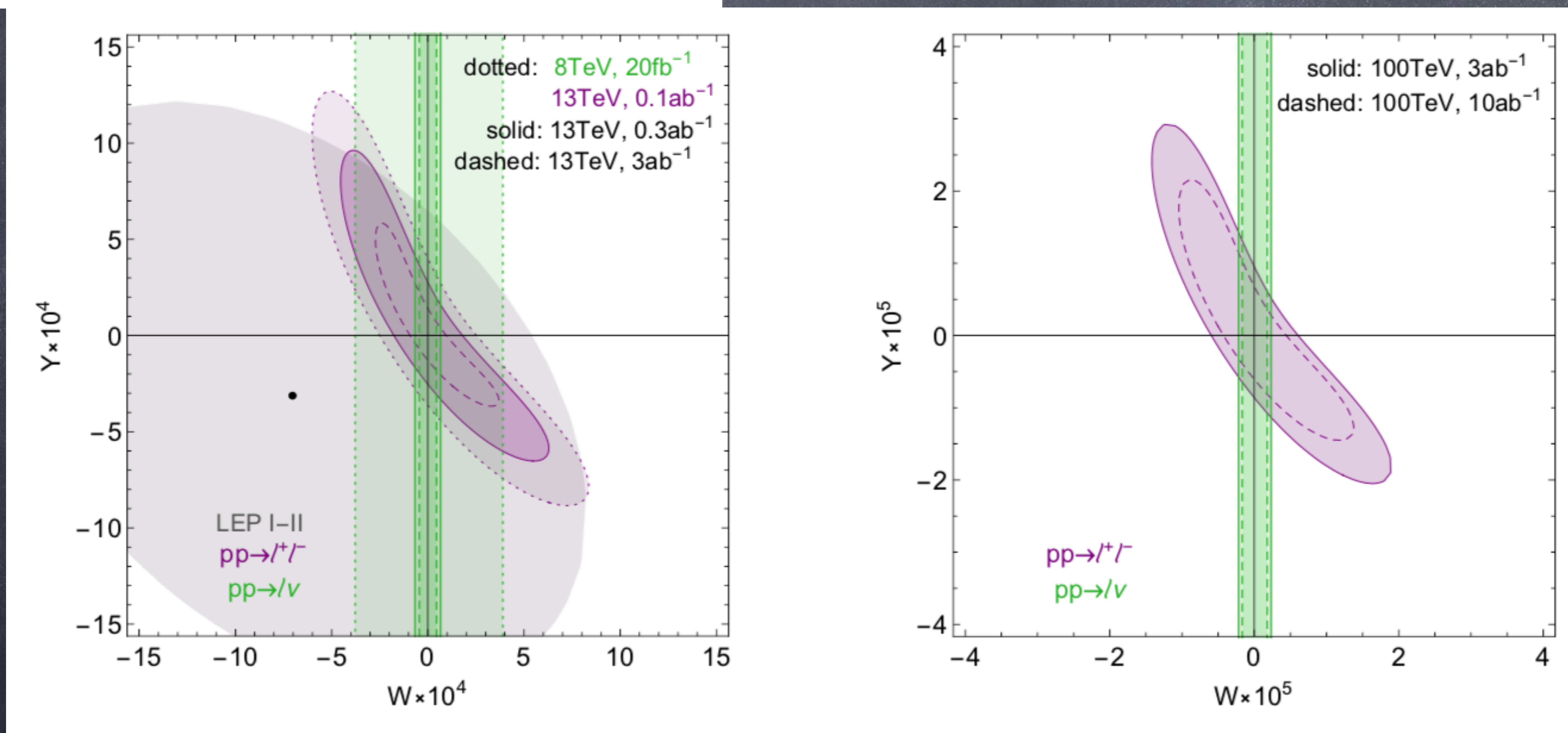
	universal form factor ($\mathcal{L}$)	contact operator ($\mathcal{L}'$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$	$-\frac{g_2^2\mathrm{W}}{2m_W^2} J_L{}^a_\mu J_L{}^\mu_a$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$	$-\frac{g_1^2\mathrm{Y}}{2m_W^2} J_Y{}_\mu J_Y{}^\mu$

see 1609.08157, 1712.01310, etc

FCC-hh: energy machine

	universal form factor ($\mathcal{L}$)	contact operator ($\mathcal{L}'$)
W	$-\frac{\mathrm{W}}{4m_W^2}(D_\rho W^a_{\mu\nu})^2$	$-\frac{g_2^2\mathrm{W}}{2m_W^2} J_{L\,\mu}^{\;a} J_{L\,a}^{\;\mu}$
Y	$-\frac{\mathrm{Y}}{4m_W^2}(\partial_\rho B_{\mu\nu})^2$	$-\frac{g_1^2\mathrm{Y}}{2m_W^2} J_{Y\,\mu} J_Y^{\;\mu}$

see 1609.08157, 1712.01310, etc



$$\frac{W/Y}{4m_W^2} \to \frac{g_*^2}{\Lambda^2} \quad \Rightarrow \quad \Lambda > g_* \times 50\ \mathrm{TeV}$$

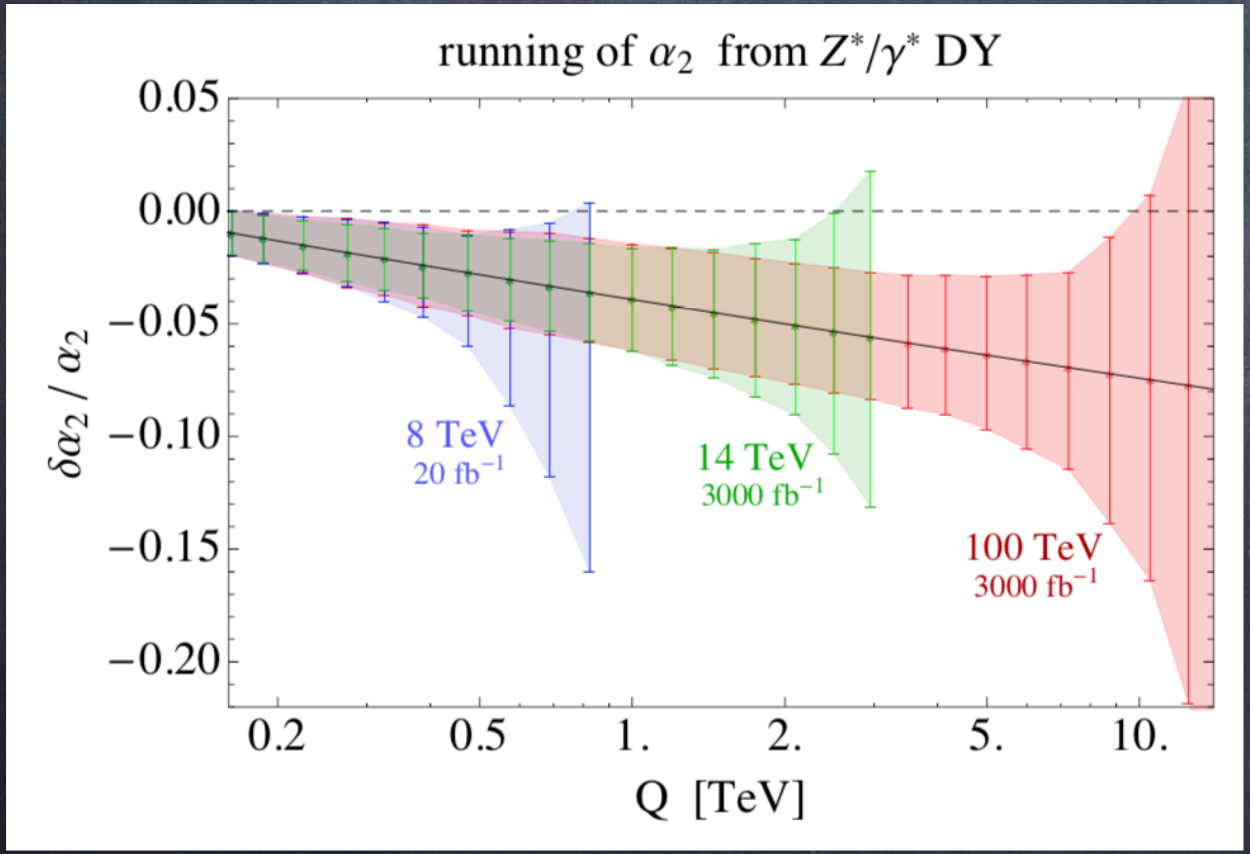
Above (my) threshold!

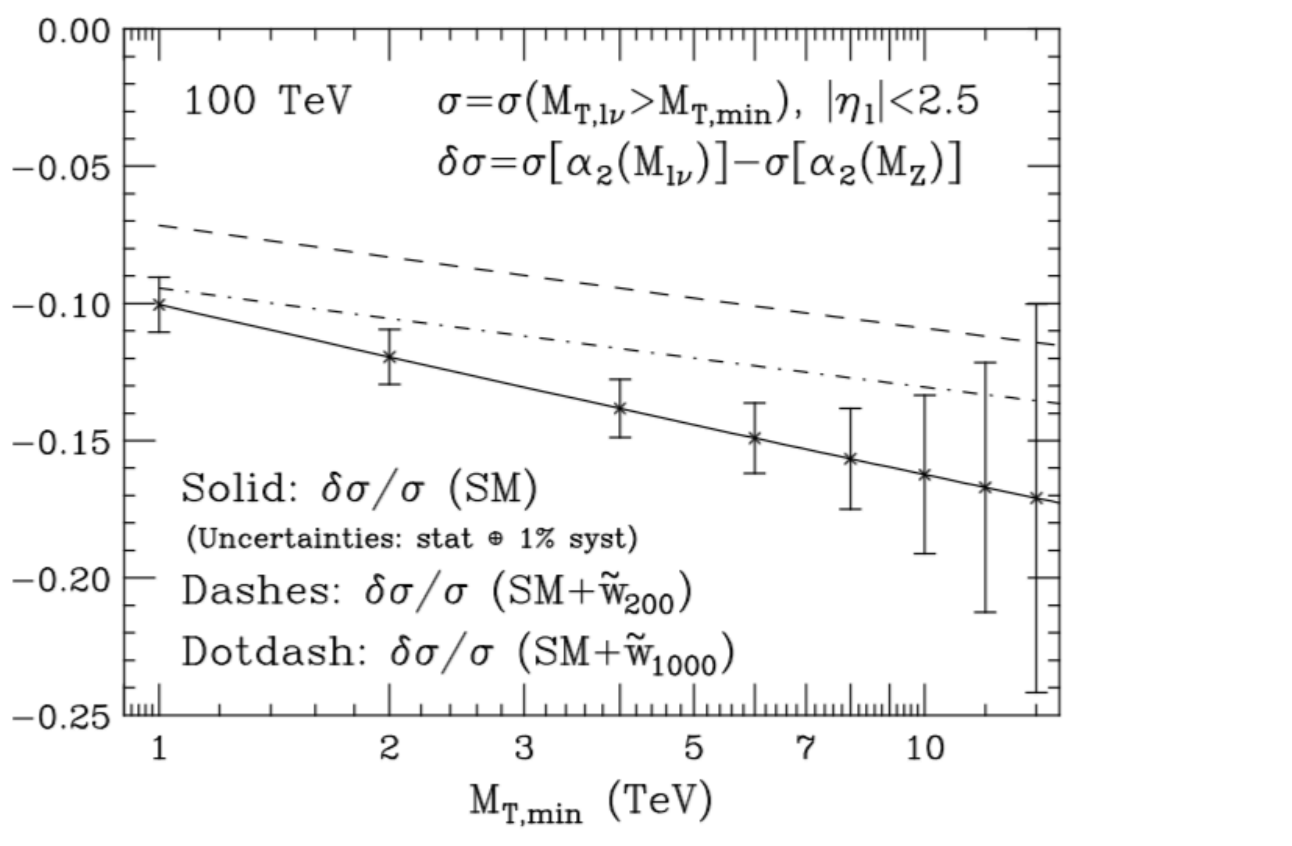
FCC-hh: energy machine

- More on Drell-Yann: loop effects

Testing the running of the EW gauge couplings

1410.6810





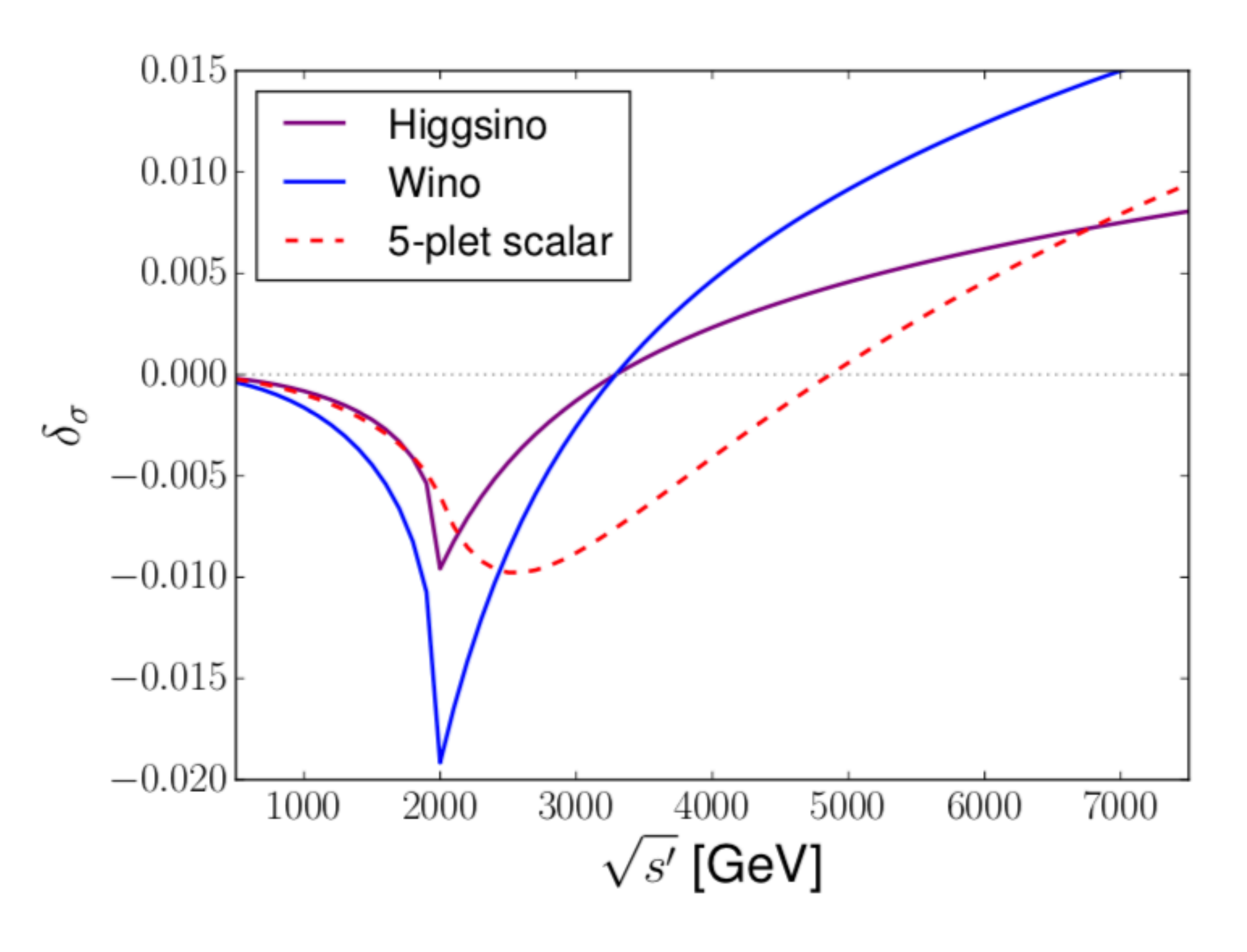
Indirect probe of EW interacting new particles

FCC-hh: energy machine

- More on Drell-Yann: loop effects

  Complete 1-loop contribution modifies the invariant mass distribution

1904.11162



Negative interference produces a "dip" in the distribution

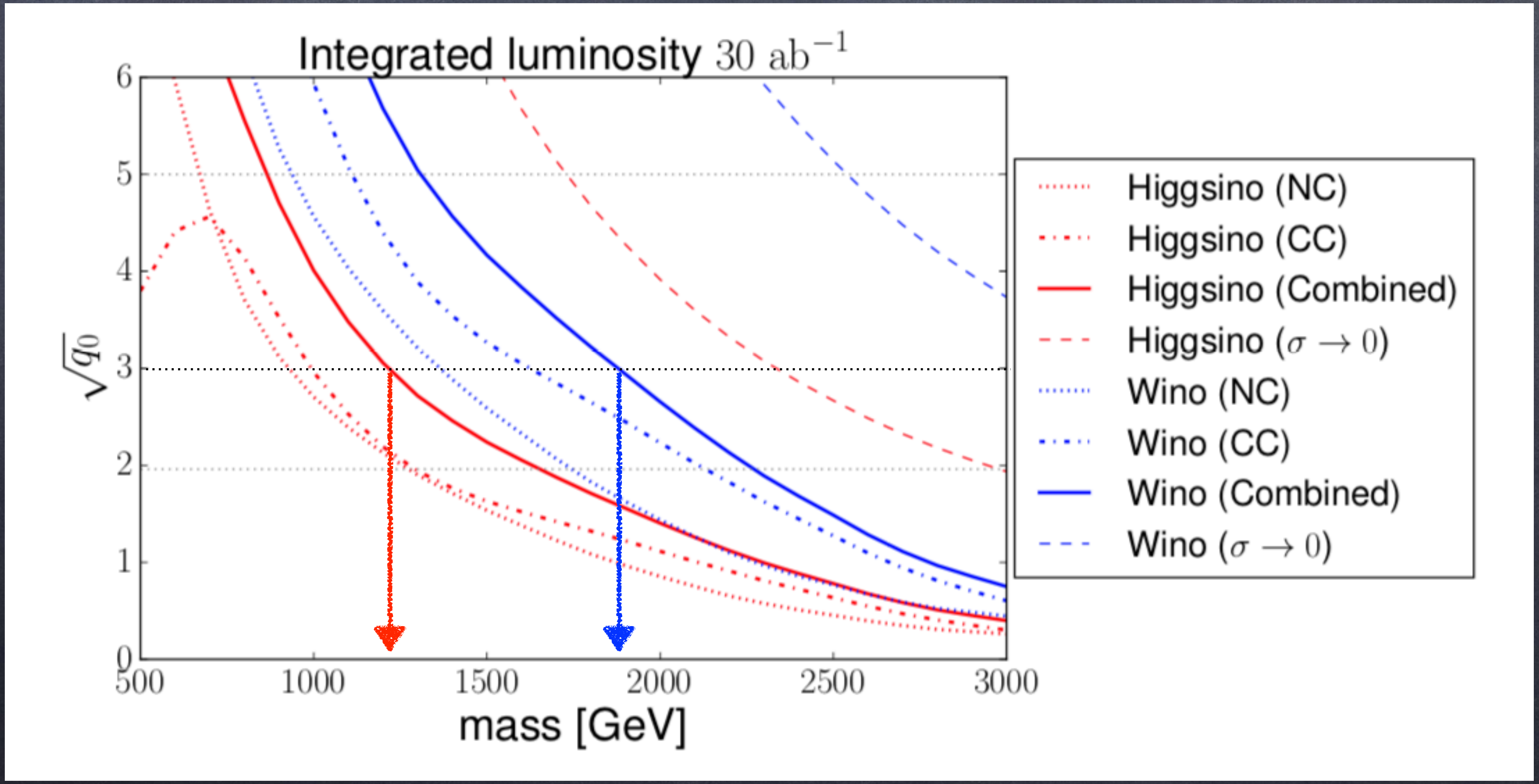
FCC-hh: energy machine

- More on Drell-Yann: loop effects

  Complete 1-loop contribution modifies the invariant mass distribution

1904.11162

Significance

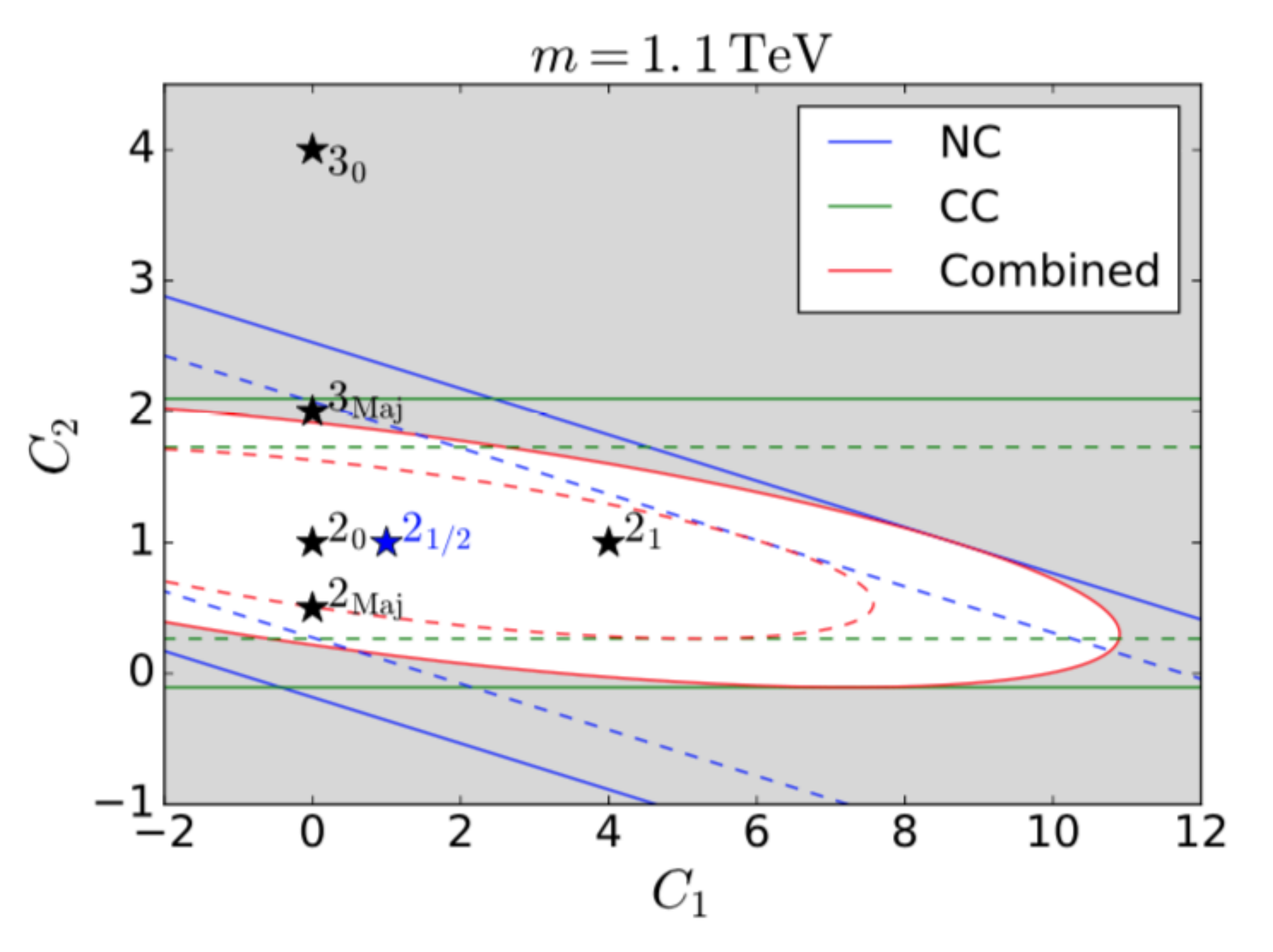


FCC-hh: energy machine

- More on Drell-Yann: loop effects

Complete 1-loop contribution modifies the invariant mass distribution

1904.11162



Combining l+l- and l nu, one can discriminate models!

Signal injected: Higgsino 1.1 TeV

Outlook:

- "Naturalness" is still on the plate! New physics is a must! (light/heavy, strongly/weakly/feebly coupled)
- Higgs precision is a must - talks tomorrow.
- EWPO can constraint the SM beyond naturalness
- How precise are theory predictions?