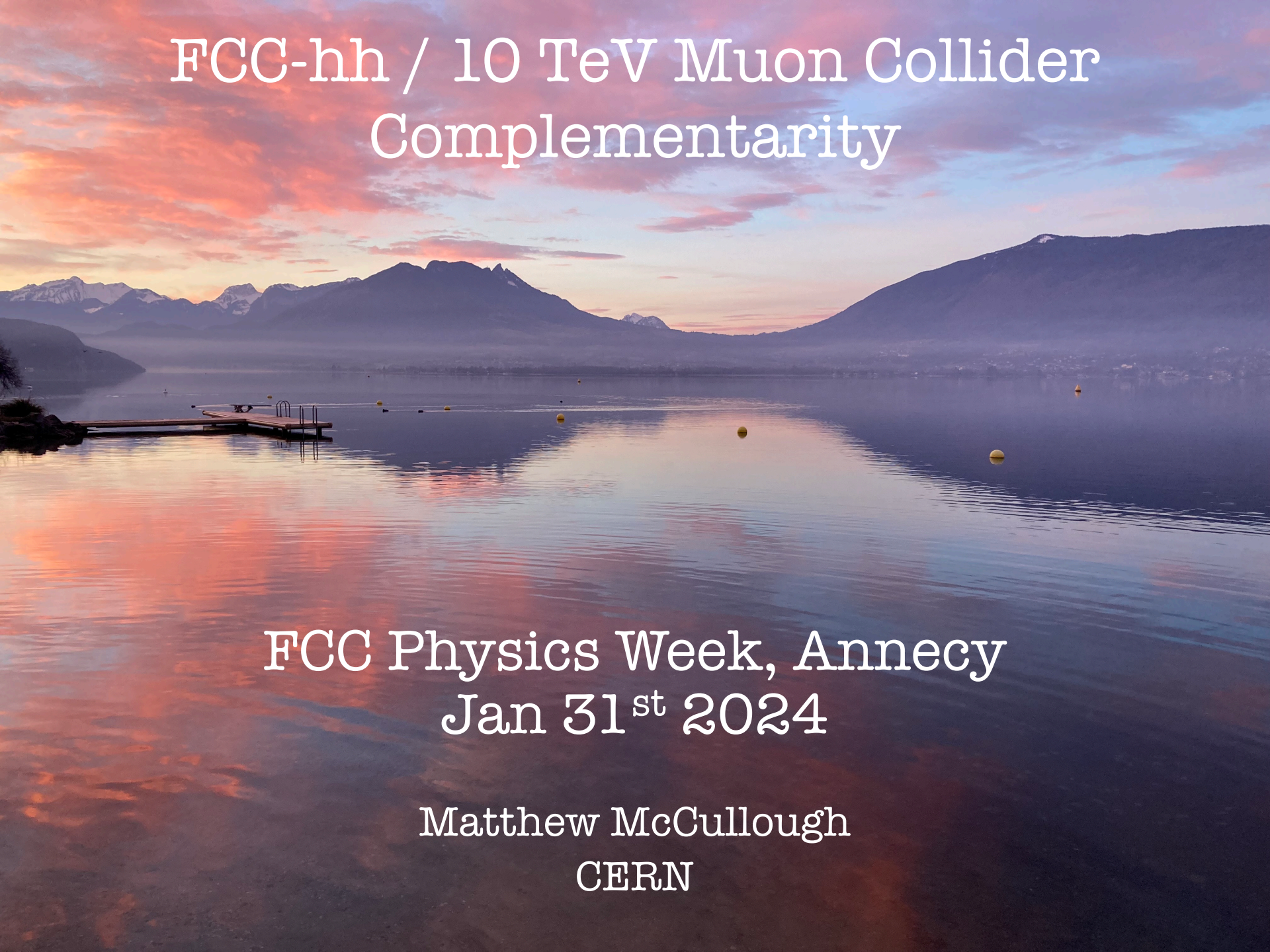
FCC-hh / 10 TeV Muon Collider Complementarity



FCC Physics Week, Annecy
Jan 31st 2024

Matthew McCullough
CERN

FCC-hh

FCC-ee is the precision machine: Deep indirect exploration of new physics at short distances.

Ultimately we want to directly explore to reveal the new physics responsible for microdeviations. Enter FCC-hh...

μ-collider

10 TeV μ-collider reaches very high parton-level energies in a clean experimental environment.

A blend of energy and precision.

FCC-hh Exploration

Across photon, gluon, (W&Z) and five-flavour scheme for quarks, FCC-hh collides

$$N = 144\,,196$$

different initial states. Broad exploration. Writing cross section as

$$\sigma = r\frac{C_{yy}}{s}$$

where

$$C_{gg} = \frac{\pi^2}{8}\int_\tau^1 \frac{dx}{x} f_g(x) f_g(\tau x)\,, \quad C_{q\bar{q}} = \frac{4\pi^2}{9}\int_\tau^1 \frac{dx}{x}\left[f_q(x) f_{\bar{q}}(\tau x) + f_{\bar{q}}(x) f_q(\tau x)\right]$$

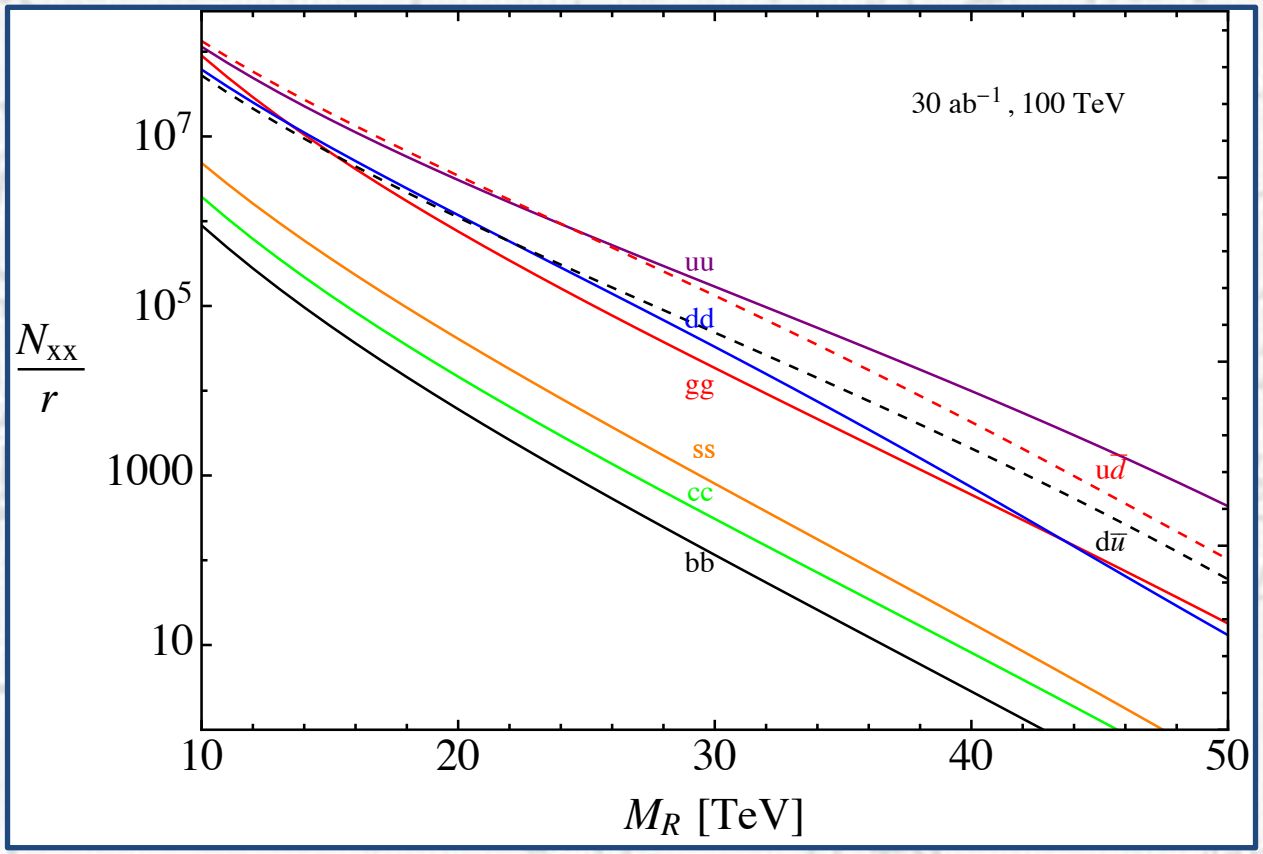
and

$$r = (2S+1) B_{yy} B_{xx} \frac{\Gamma_R}{M_R}$$

FCC-hh Initial States

Then, recalling, $r = (2S+1)B_{yy}B_{xx}\dfrac{\Gamma_R}{M_R}$

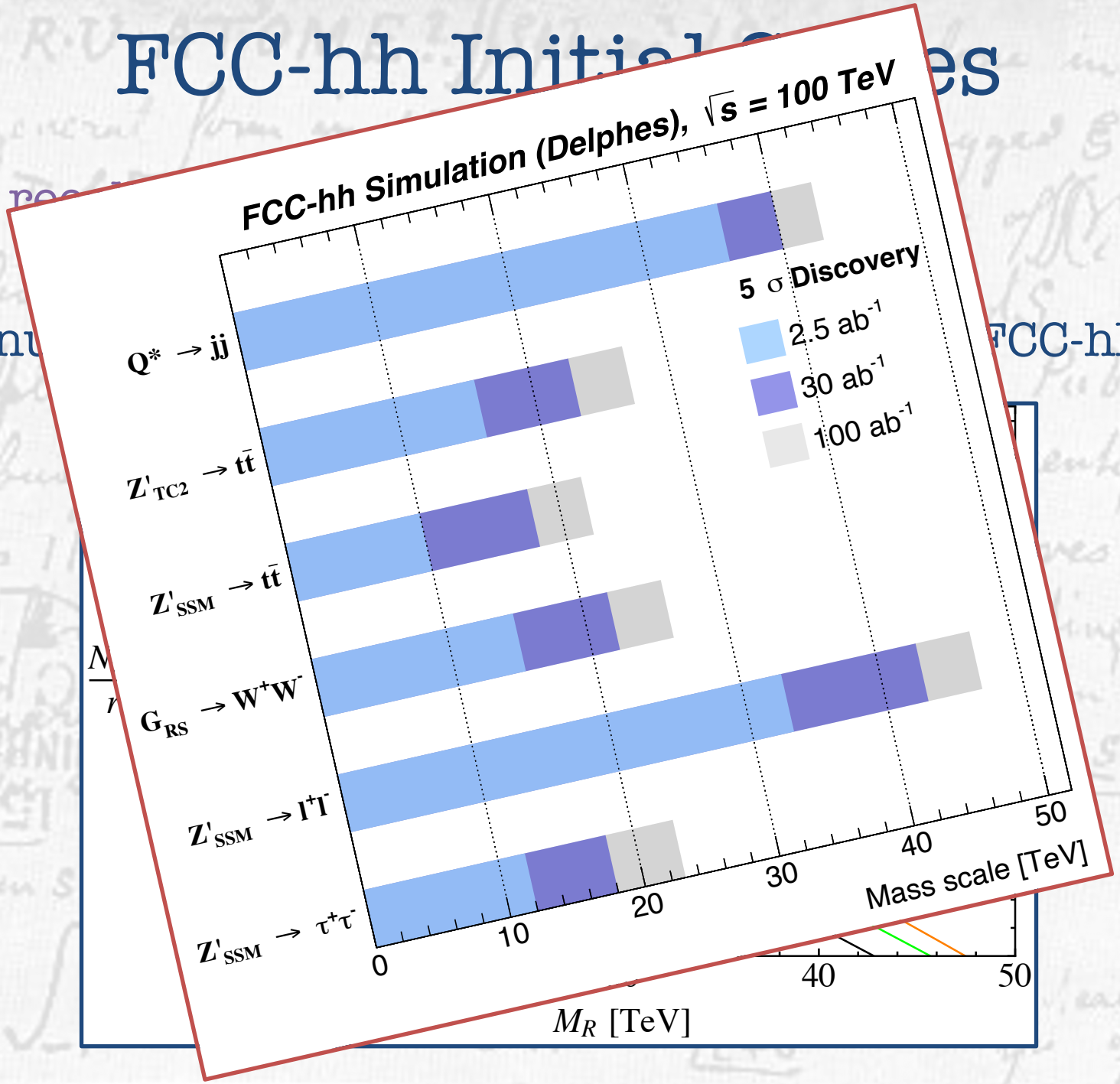
...the number of events you get above 10 TeV at FCC-hh is:



FCC-hh Initial S… …es

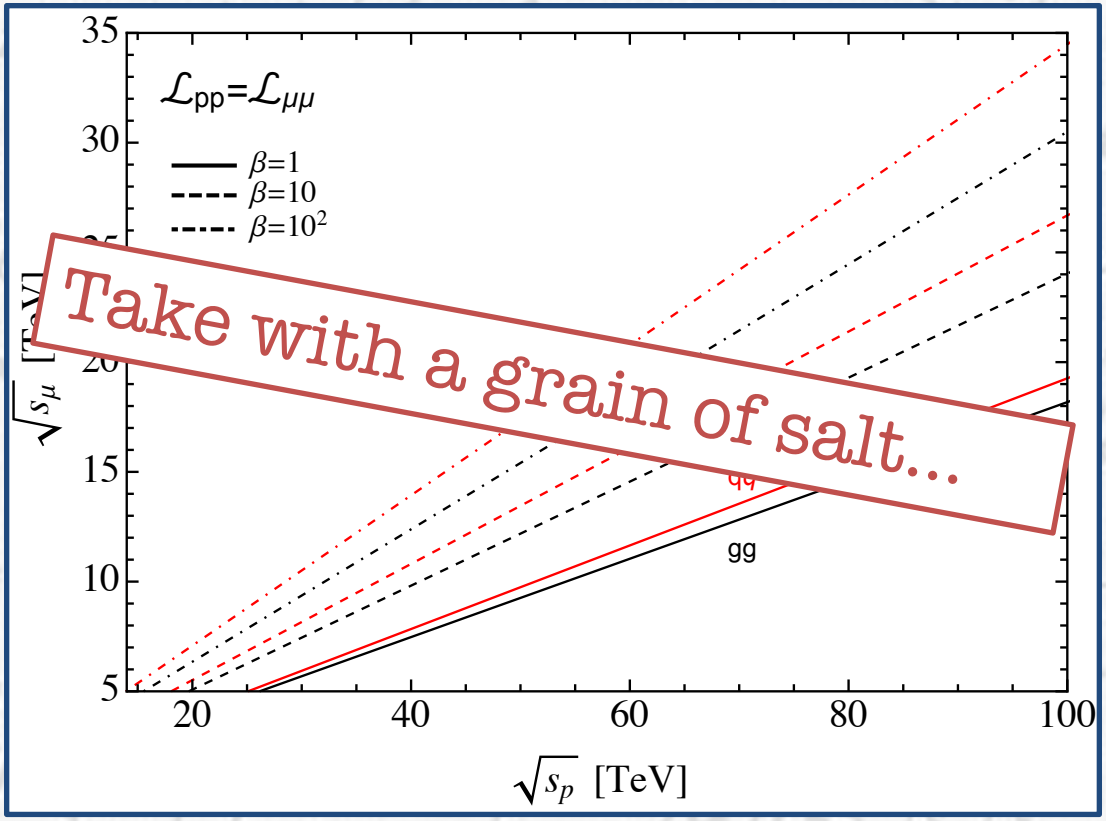
Then, re…

…the nu… …FCC-hh is:



Resonances - Comparison

Here "β" is the parton level enhancement compared to $\mu\mu$. Unity for the same coupling (like EW) or greater for QCD-charged (e.g. 100 for squarks). Following 2203.07256.



Red for quarks, black for gluons.

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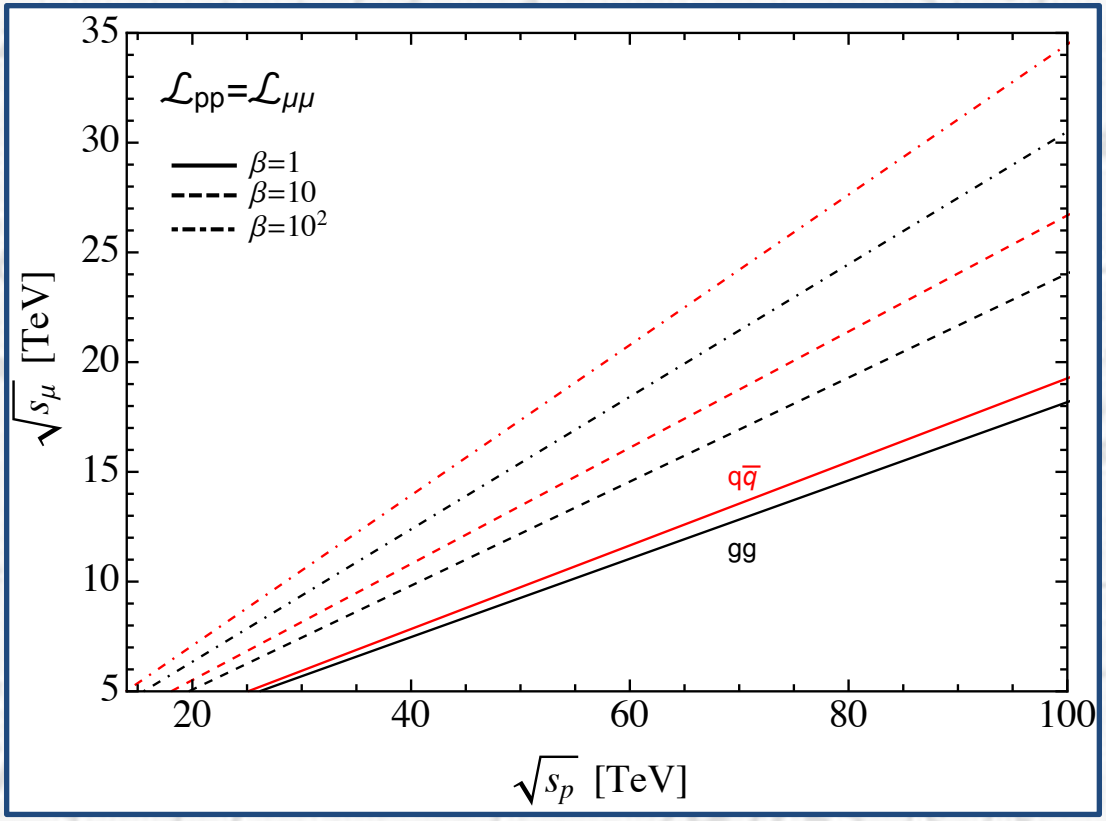

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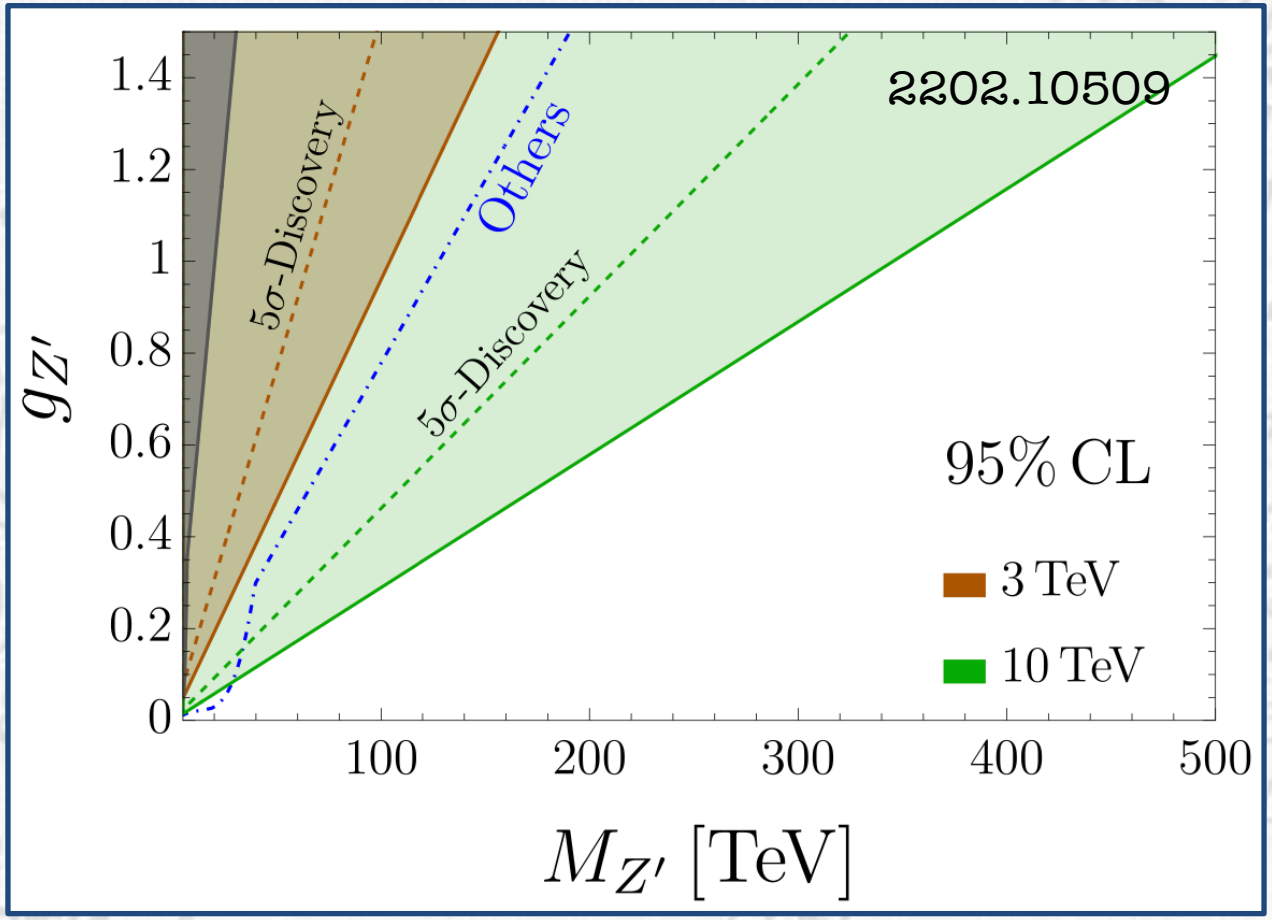
Indirect

Consider universal Hypercharge Z'.



Indirect reach of μ-coll exceeds "Others", including FCC-hh. Why?

Indirect

In EFT corresponds to O_{2B}...

2202.10509	SILH basis
W&Y	$O_{2W} = (D_\mu W^{\mu\nu,a})^2$ $O_{2B} = (\partial_\mu B^{\mu\nu})^2$
Di-boson	$O_W = \frac{ig}{2}(H^\dagger \sigma^a \overleftrightarrow{D}_\mu H) D^\nu W^a_{\mu\nu}$ $O_B = \frac{ig'}{2}(H^\dagger \overleftrightarrow{D}_\mu H)\partial^\nu B_{\mu\nu}$

Which gives SM-like amplitude with correction scaling as

$$\mathcal{M} \approx \mathcal{M}_{\rm SM}\left(1 + \frac{E^2}{M^2}\right)$$

so here energy + accuracy powerful.

Indirect

Lesson carries through to questions of Higgs compositeness.

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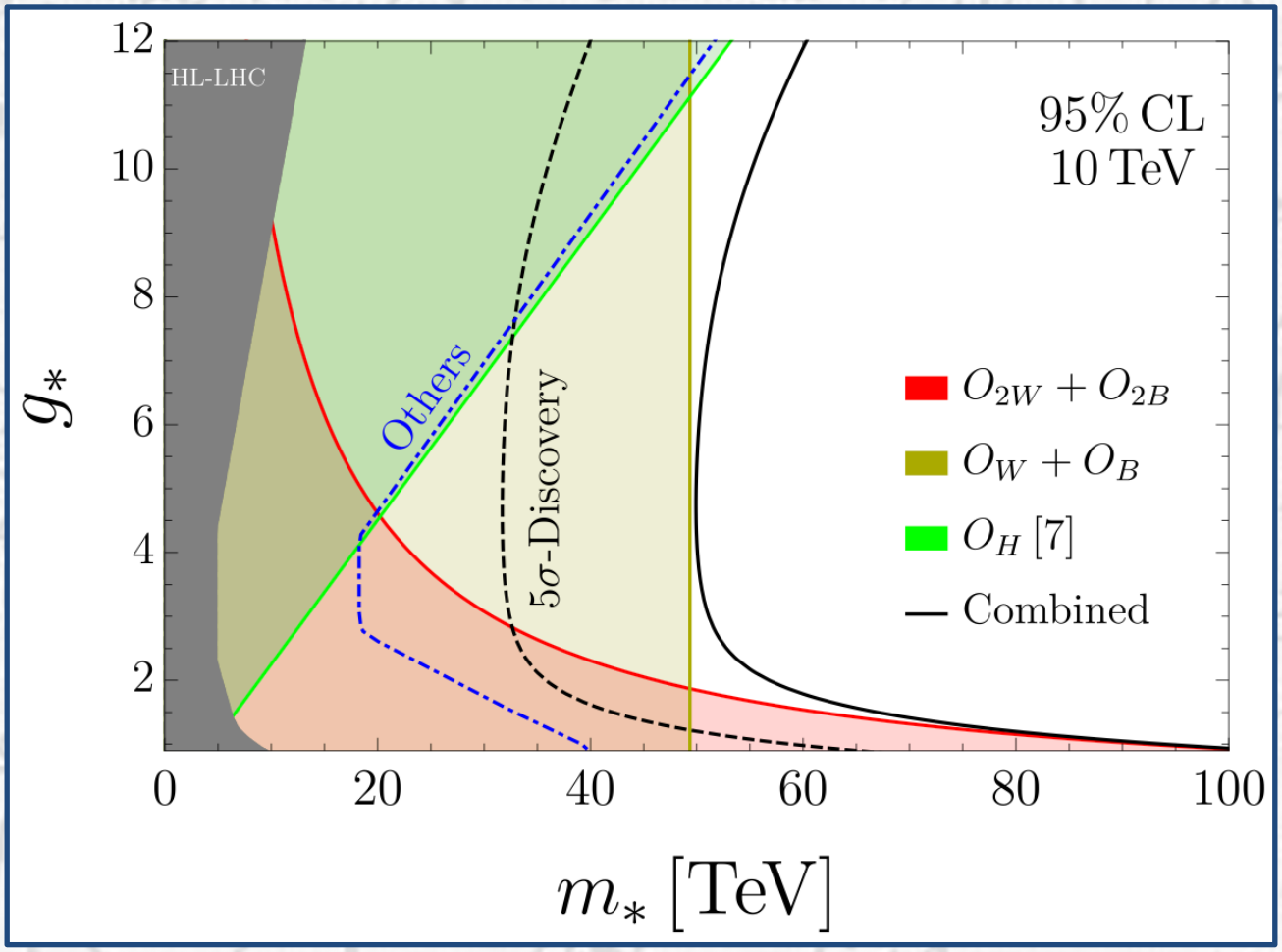


Resonance Roundup

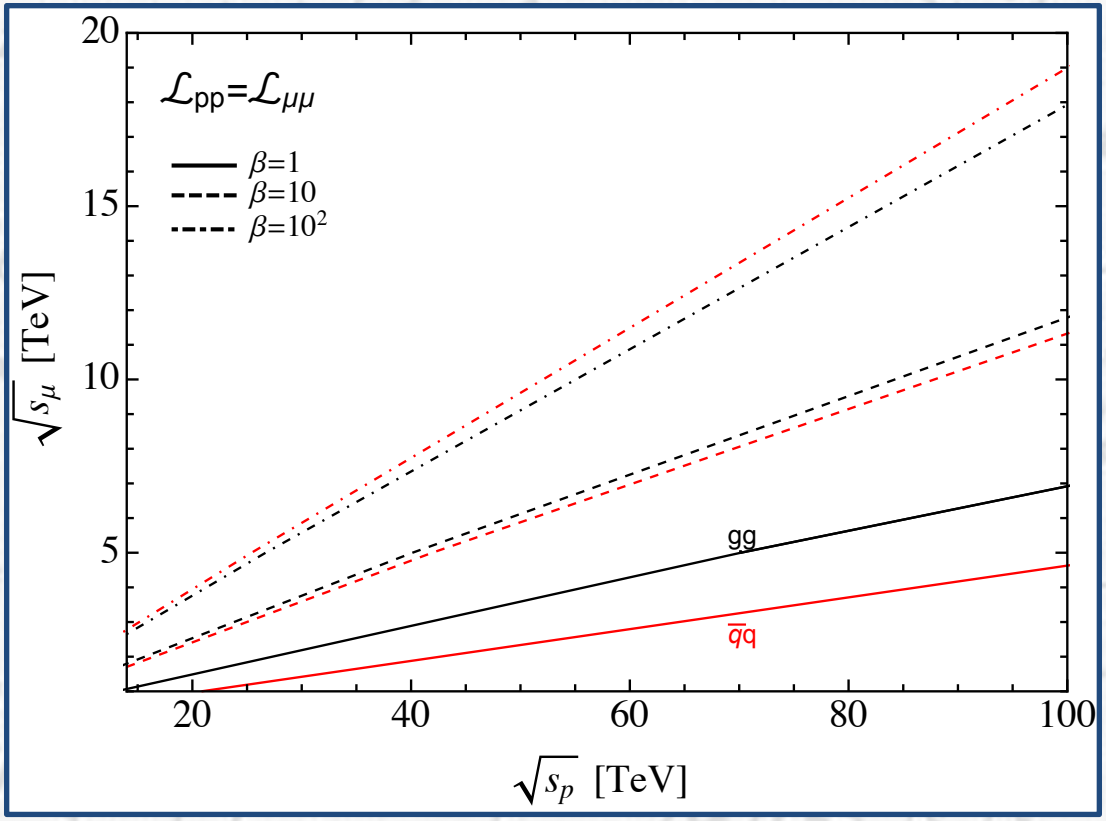
- FCC-hh explores direct resonance production well beyond kinematic limit of 10 TeV μ-coll.

- FCC-hh collides EW and QCD-charged initial states: If new physics is colour or EW/quark produced: FCC-hh can cover it well.

- Indirect sensitivity of 10 TeV μ-coll would reach very far for EW/muon production, due to clean environment / low-BG, energy-growth of effects.

Pairs

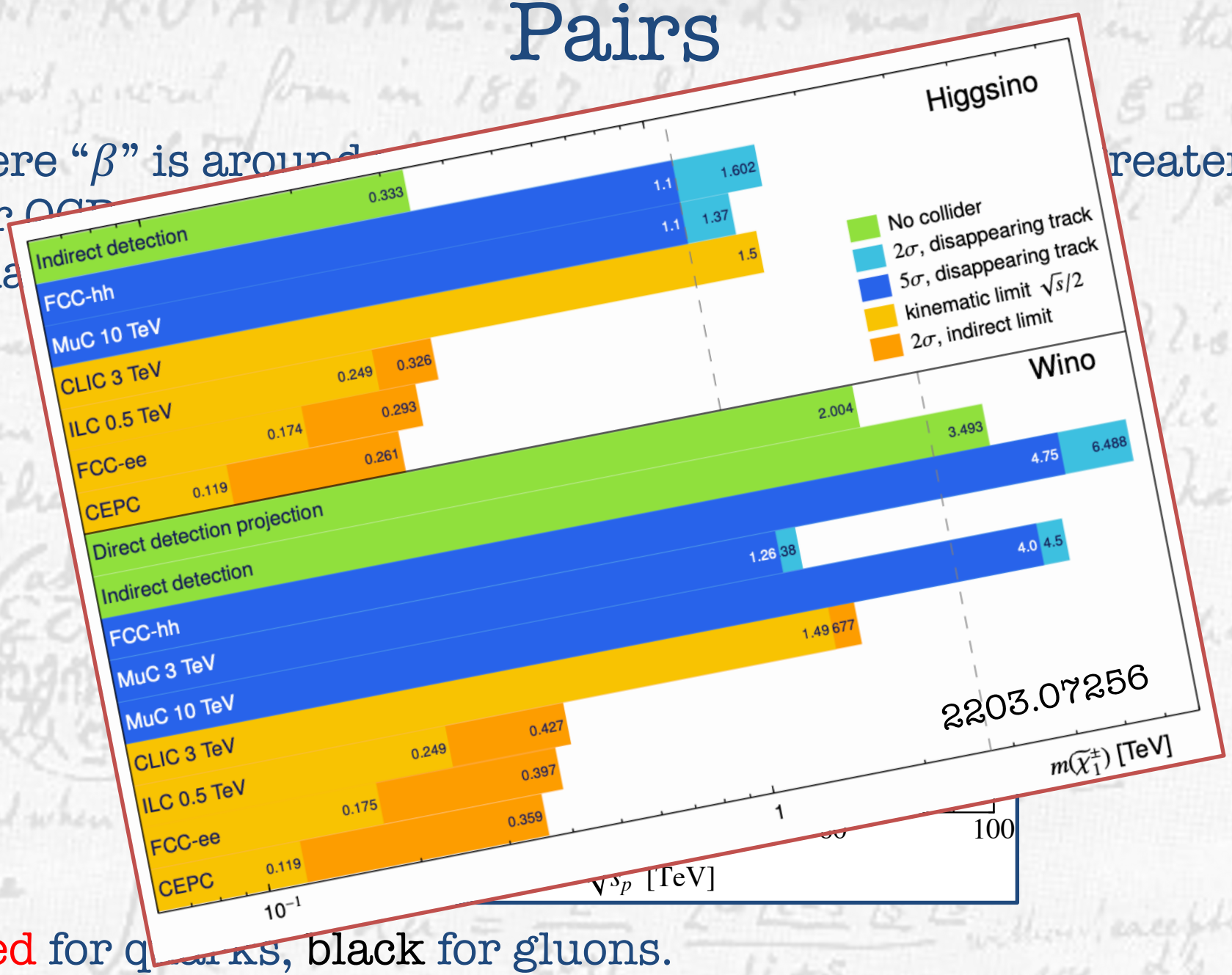
Here "β" is around unity for the same (like EW) or greater for QCD-charged. For pairs of new pairs of states with same coupling to quarks then μ-coll does well.



Red for quarks, black for gluons.

Pairs

Here "β" is around [illegible] greater for QCD [illegible] cha[illegible]



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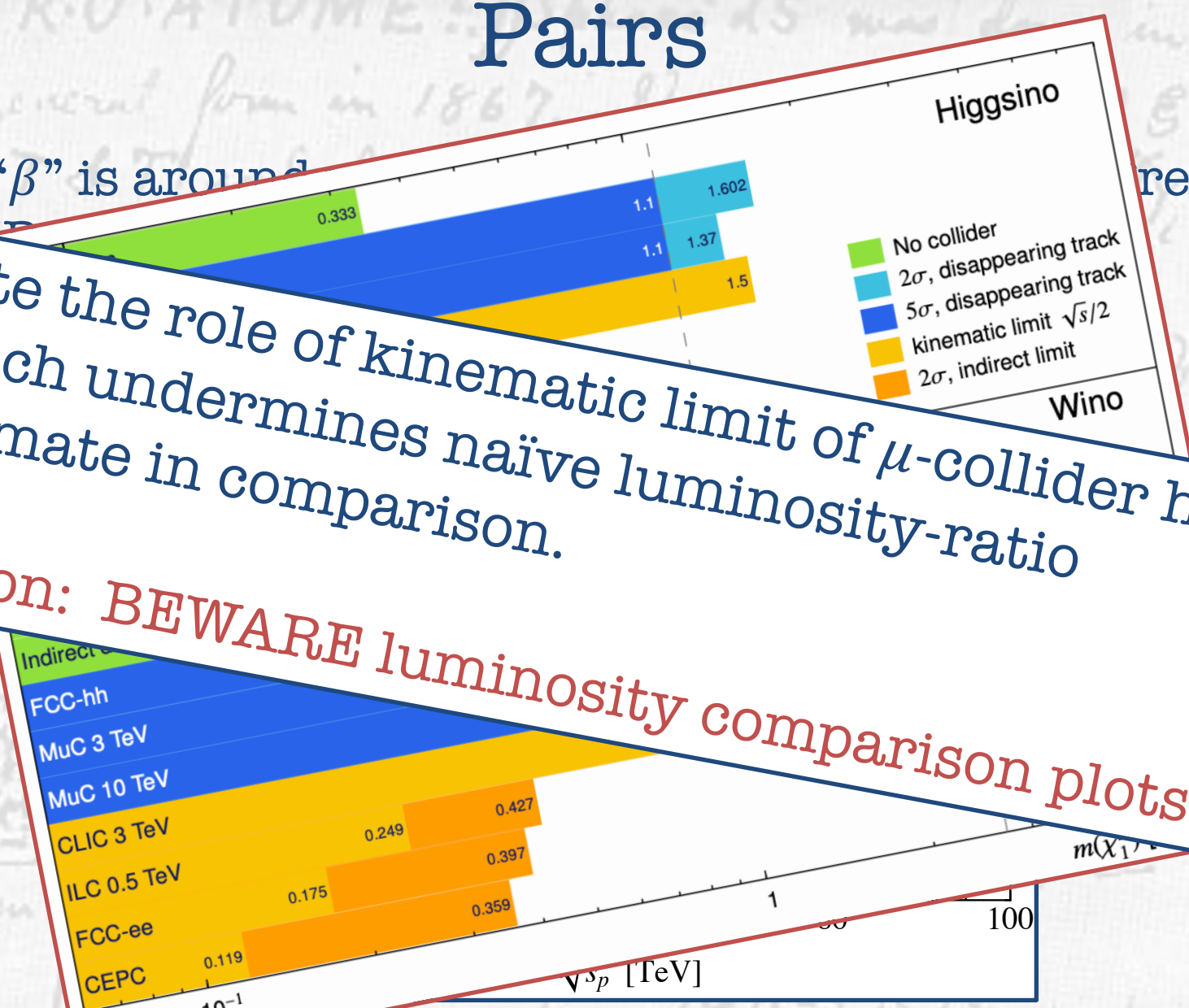
Pairs

Here "β" is around … greater
fo…
c…



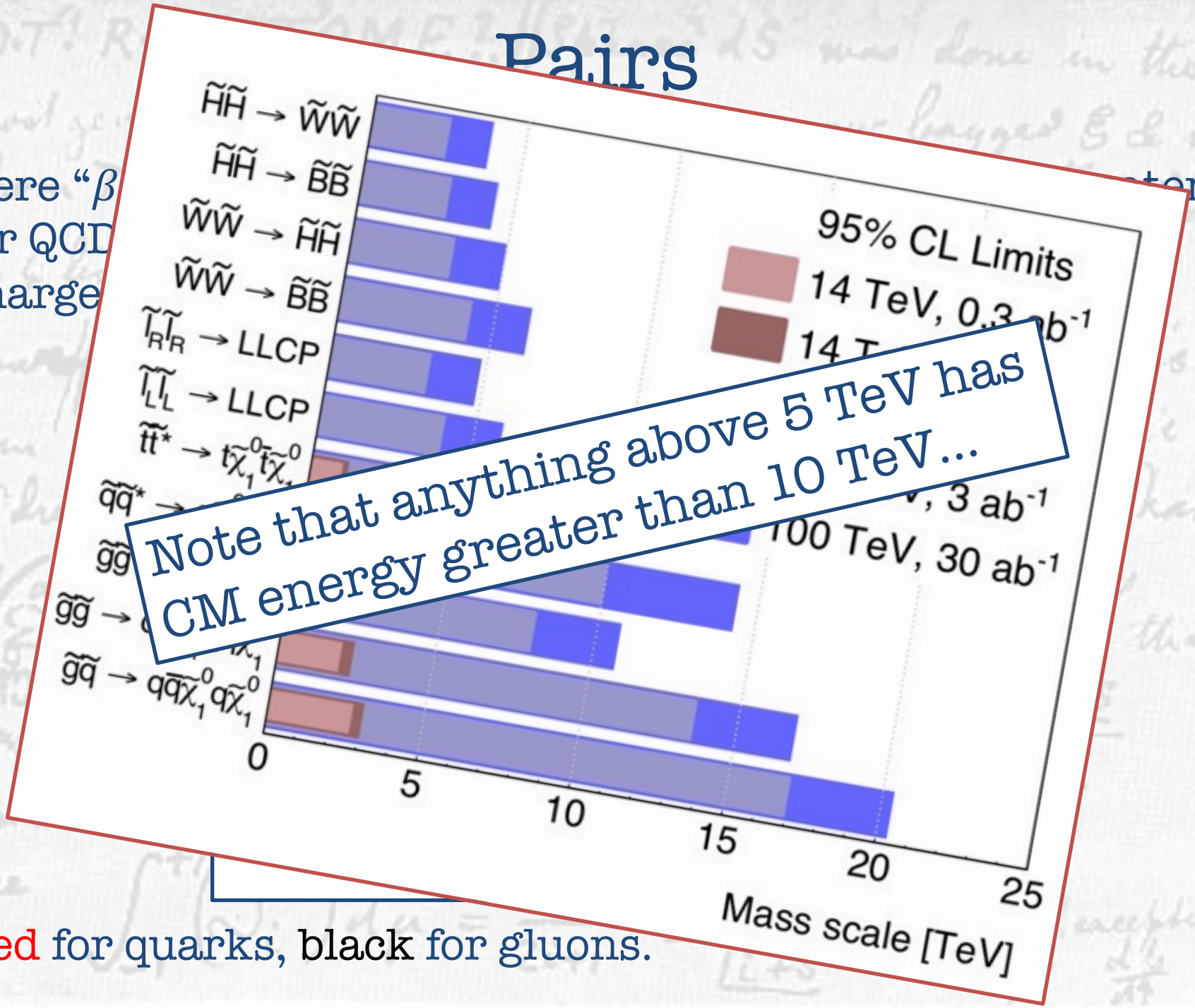
Note the role of kinematic limit of μ-collider here, which undermines naïve luminosity-ratio estimate in comparison.

Lesson: BEWARE luminosity comparison plots!

Red for q…rks, black for gluons.

Pairs

Here "β
for QCD
charge



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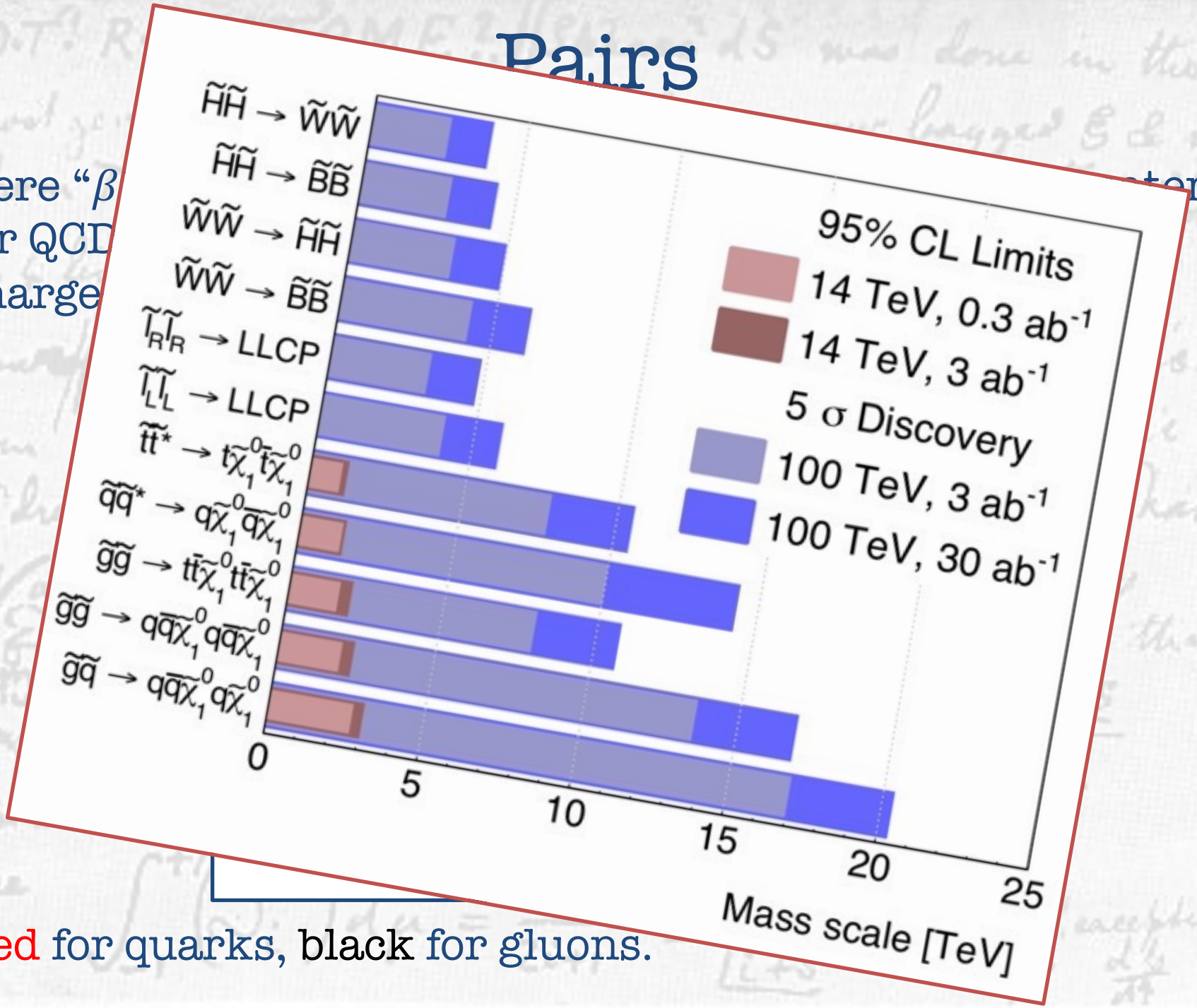

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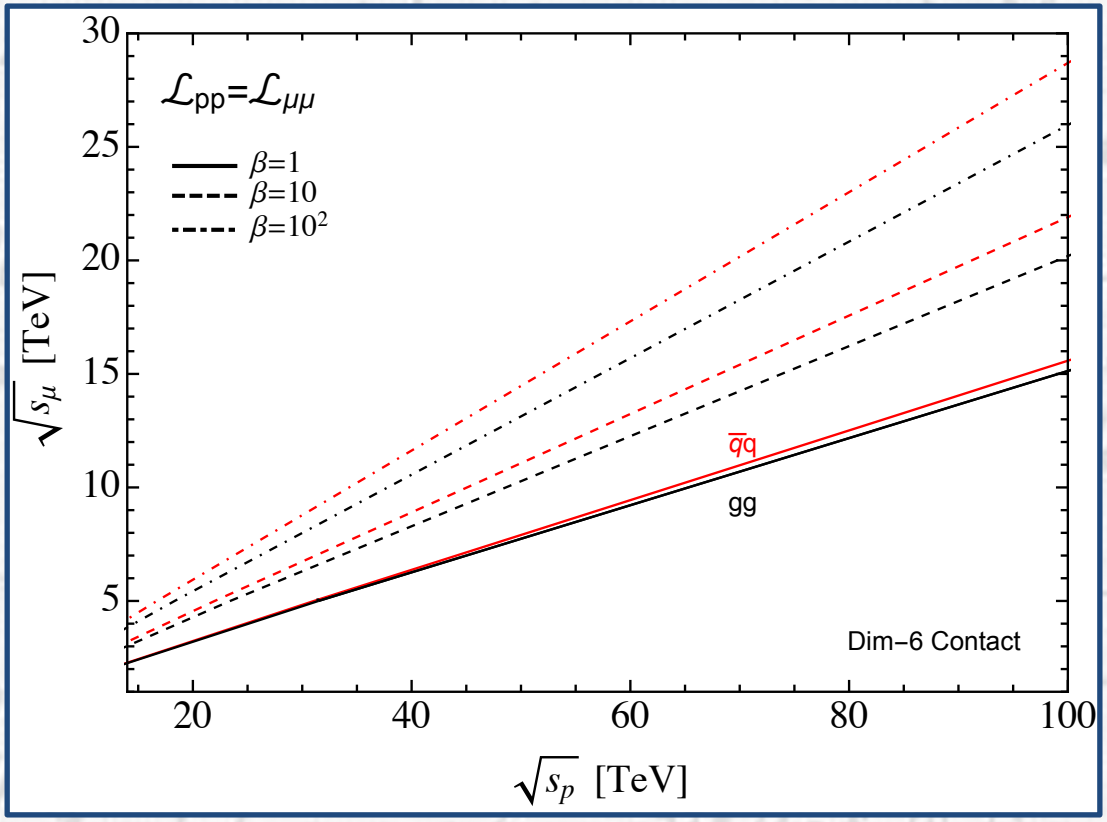
Pairs – Dim 6

Another caveat to comparisons concerns production. Suppose states produced through dim-6 operator, like new heavy resonance above threshold. Then picture changes again…



Red for quarks, black for gluons.

Pairs Roundup

- Depending on production channel, if not QCD-charged then FCC-hh naïvely explores direct pair production comparably to 10 TeV μ-coll, but keep kinematic limit in mind.

- 10 TeV μ-coll and FCC-hh good probes of EW-charged states, including Higgsino and Wino DM candidates.

Conclusions

Conclusions

- FCC-hh covers EW, QCD, and wide variety of exotic initial state production modes.
- FCC-hh direct discovery reach exceeds 10 TeV total mass in many cases.
- 10 TeV μ-collider provides a novel blend of energy and precision, with indirect reach (well) beyond 10 TeV in some cases.