Physics : benchmarks and planning

RD_MUCOL - Incontro con i referee - 16 Sett 2020

μ^+ → ← μ^-

$\sqrt{S_{\mu\mu}}$ ~ 3, 10, 14, 30 TeV

3 sectors :

- direct pair production of new heavy states...
- $W^+W^- \to X\,\nu\nu$ (vs $\mu^+\mu^- \to X$)
- Precision measurements (including Higgs) → probe indirect / off-shell / radiative effects of even heavier states (e.g. $\mu^+\mu^- \to Z'^*$ ($M_{Z'} > \sqrt{S}$))

INFN Roma Barbara Mele

Tentative Target Parameters

Parameter	Unit	3 TeV	10 TeV	14 TeV
L	10^{34} cm^{-2}s^{-1}	1.8	20	40
N	10^{12}	2.2	1.8	1.8
f_r	Hz	5	5	5
P_{beam}	MW	5.3	14.4	20
C	km	4.5	10	14
<B>	T	7	10.5	10.5
ε_L	MeV m	7.5	7.5	7.5
σ_E / E	%	0.1	0.1	0.1
σ_z	mm	5	1.5	1.07
β	mm	5	1.5	1.07
ε	μm	25	25	25
$\sigma_{x,y}$	μm	3.0	0.9	0.63

Based on extrapolation of MAP parameters

Note: The study will have to verify that these parameters can be met

Develop emittance budgets

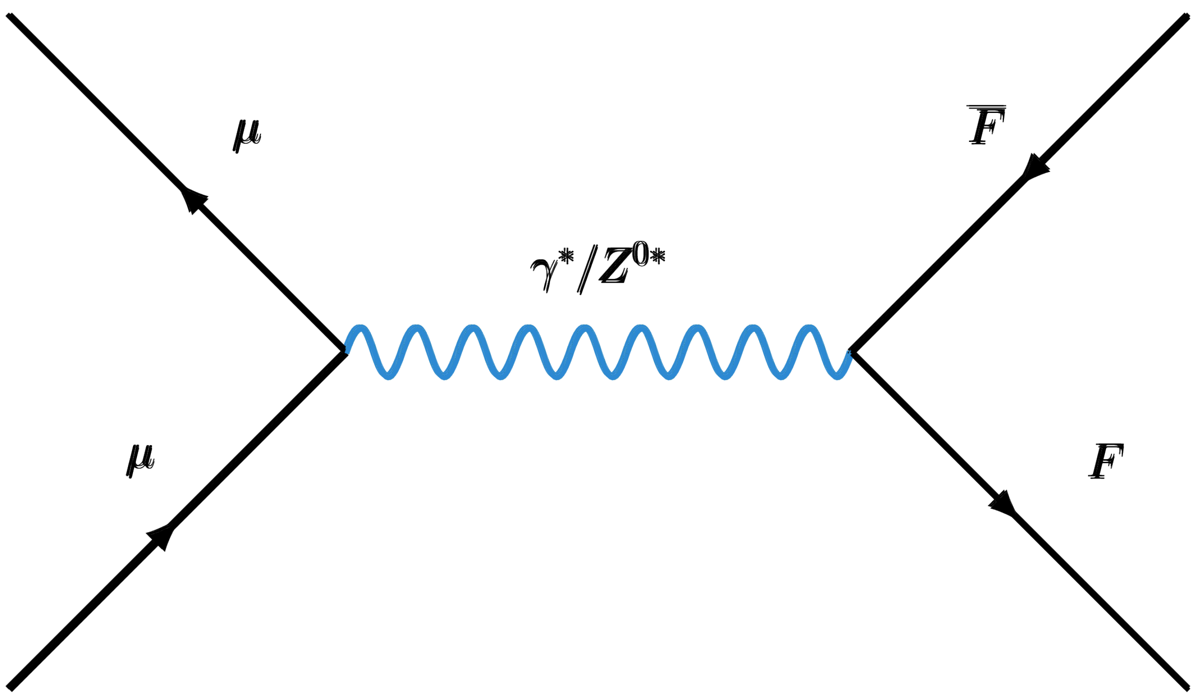
Schulte, July 2020

$$\mathcal{L} = (E_{\mathrm{CM}}/10\ \mathrm{TeV})^2 \times 10\,\mathrm{ab}^{-1}$$ *in 5 years (10^7 s)*

✱ what can one do with muon collisions

@ $\sqrt{S_{\mu\mu}}$ up to tens of TeV ???

FIRST AND FOREMOST



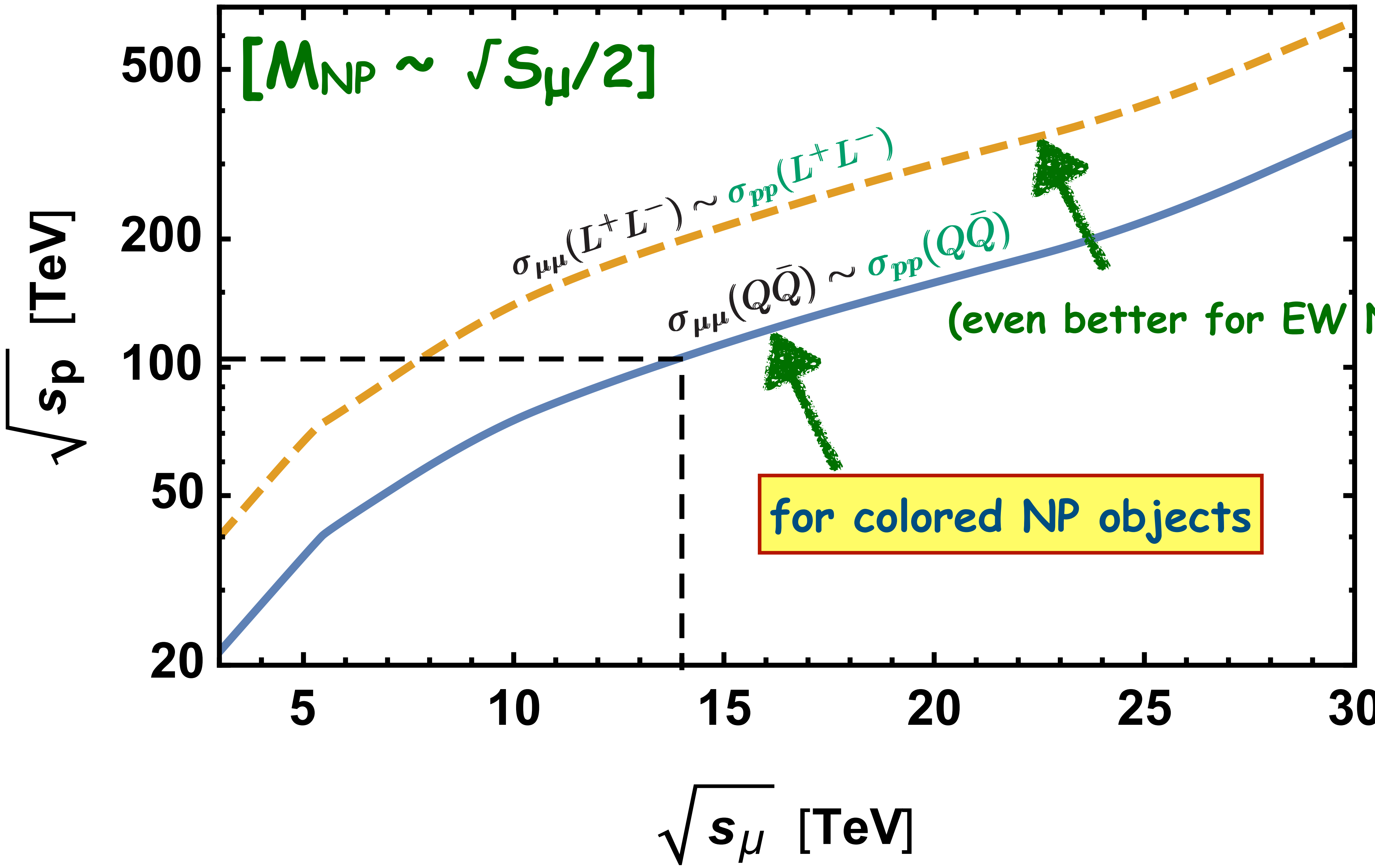
$$\mu^+\mu^- \to F\bar{F}$$

✱ plain pair production of new heavy states...

$m_F \lesssim \sqrt{S_{\mu\mu}}/2$

~ 3, 5, 7,15 TeV !!!

"equivalent" reach in pp after rescaling for pdf's



arXiv:1901.06150

- μμ @ 14 TeV → pp @ 100 $(200)_{EW}$ TeV !
- μμ @ 30 TeV → pp @ 350 $(600)_{EW}$ TeV !!

yet unexplored pheno !!!

WARNING !!

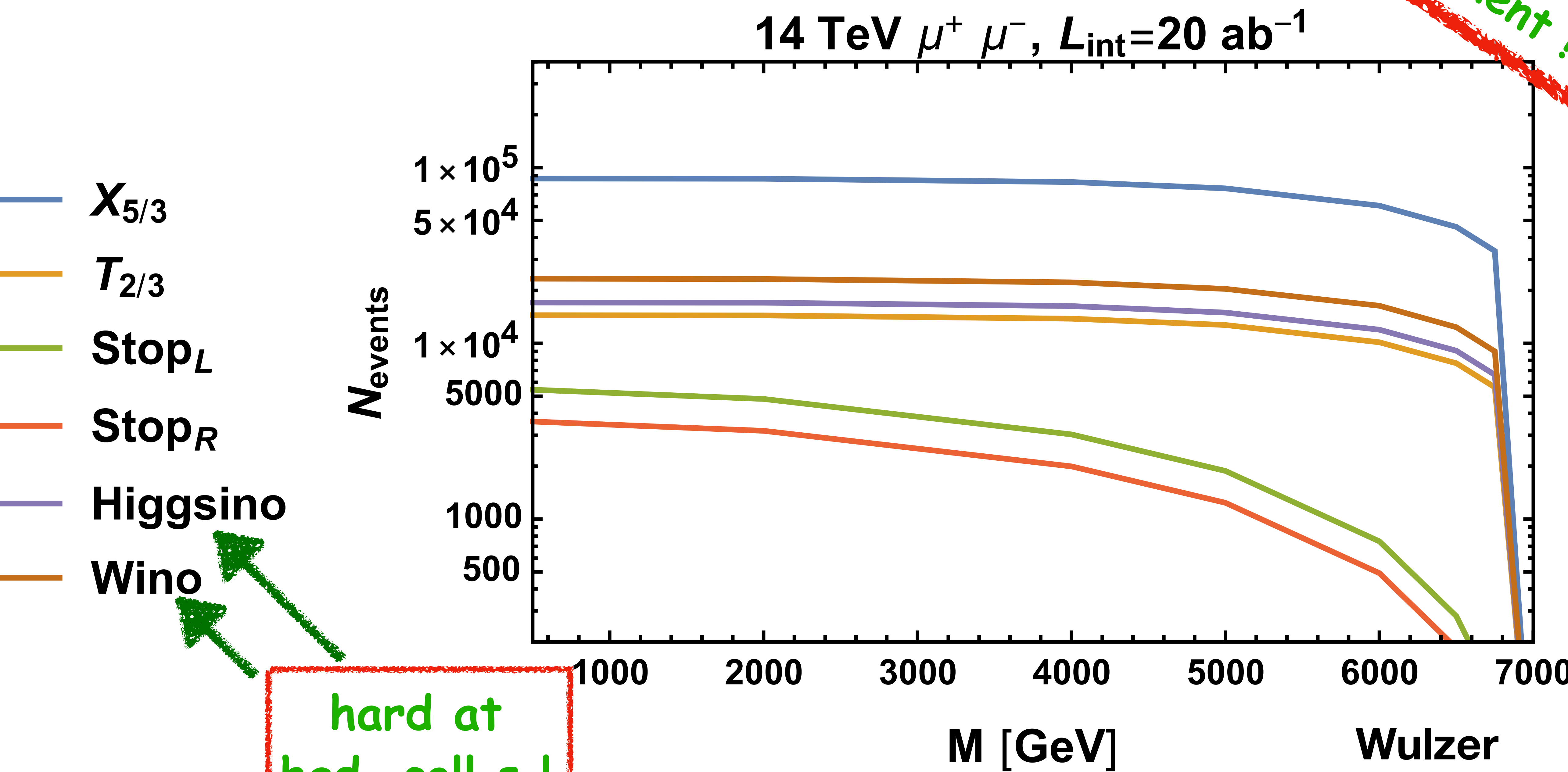
* actually physical BACKGROUND to $\mu^+\mu^-$ (e^+e^-) collisions hugely better than in hadron collisions

* this moves equivalent $\sqrt{S_{\mu\mu}}$ (at fixed $\sqrt{S_{pp}}$) at even lower values in general…

* Beam-induced Background !!! (requires work and assumptions...)

Direct production $\mu\mu \to XX$

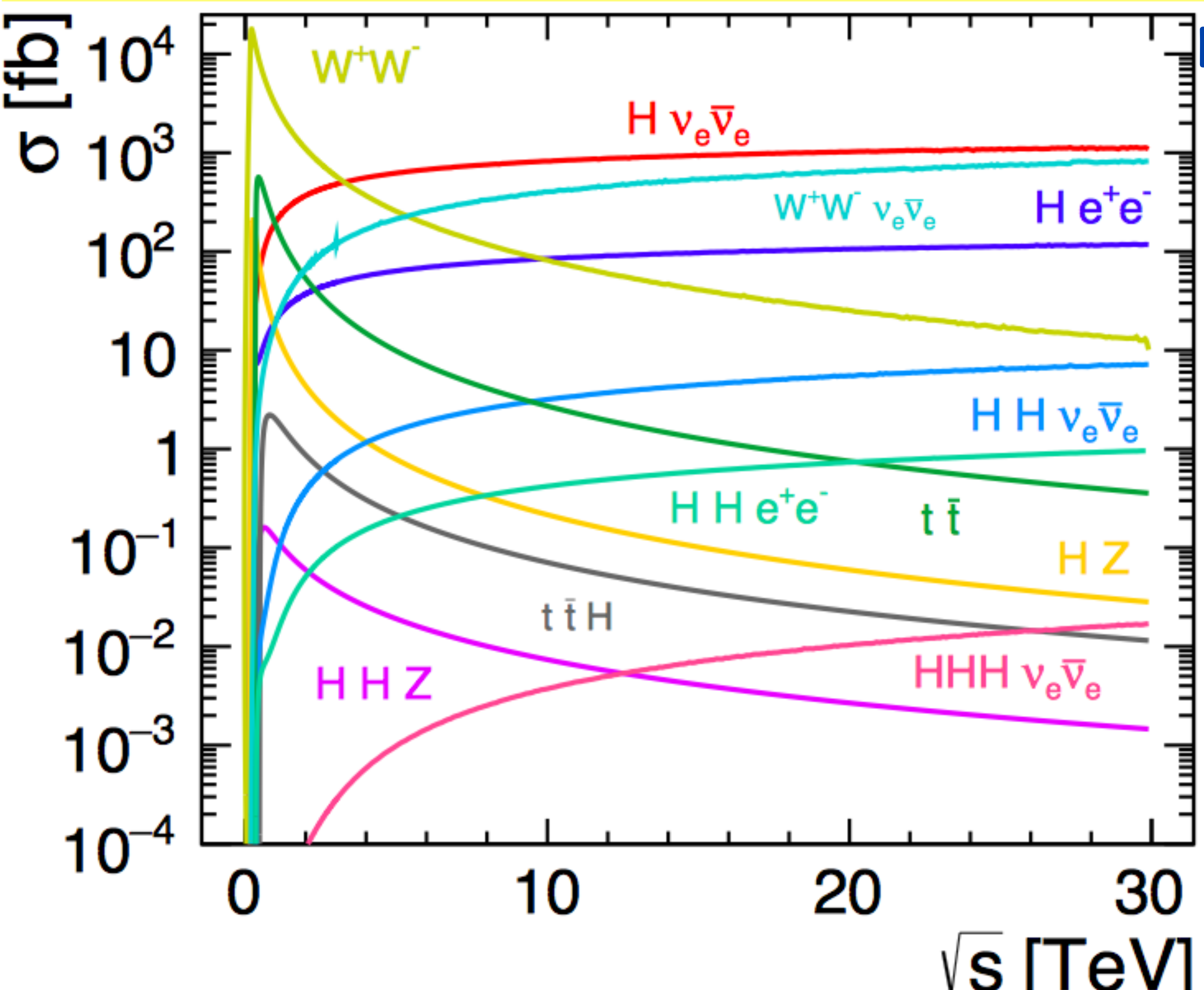
in a clean environment !!!



hard at had. coll.s !

$\sigma_{\mu\mu \to XX}$ ~ uniform up to threshold $m_F \sim \sqrt{S_{\mu\mu}}/2$!

at $\sqrt{S_{\mu\mu}}$ > a few TeV's
point $\sigma_{\mu\mu\to X}$ superseded by $\sigma_{WW\to X}$!



[10^2 ab^{-1}]

10^8ev

10^6ev

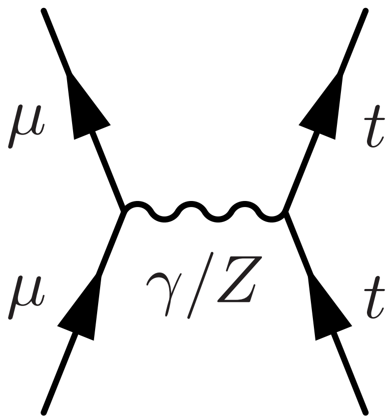
10^4ev

plenty of Higgs's !

Effectively a EW boson collider!

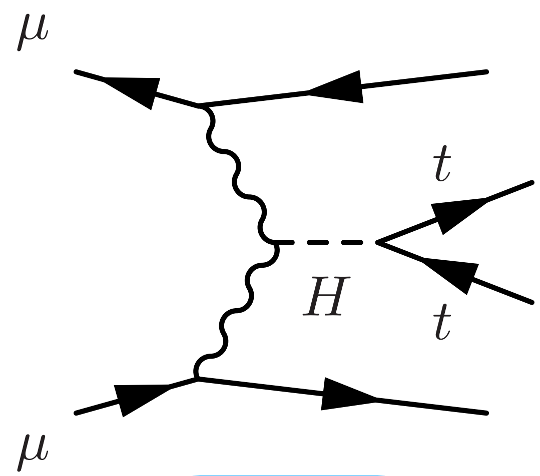
Different mode of production at different energies

$\sqrt{s} \lesssim$ 1-5 TeV



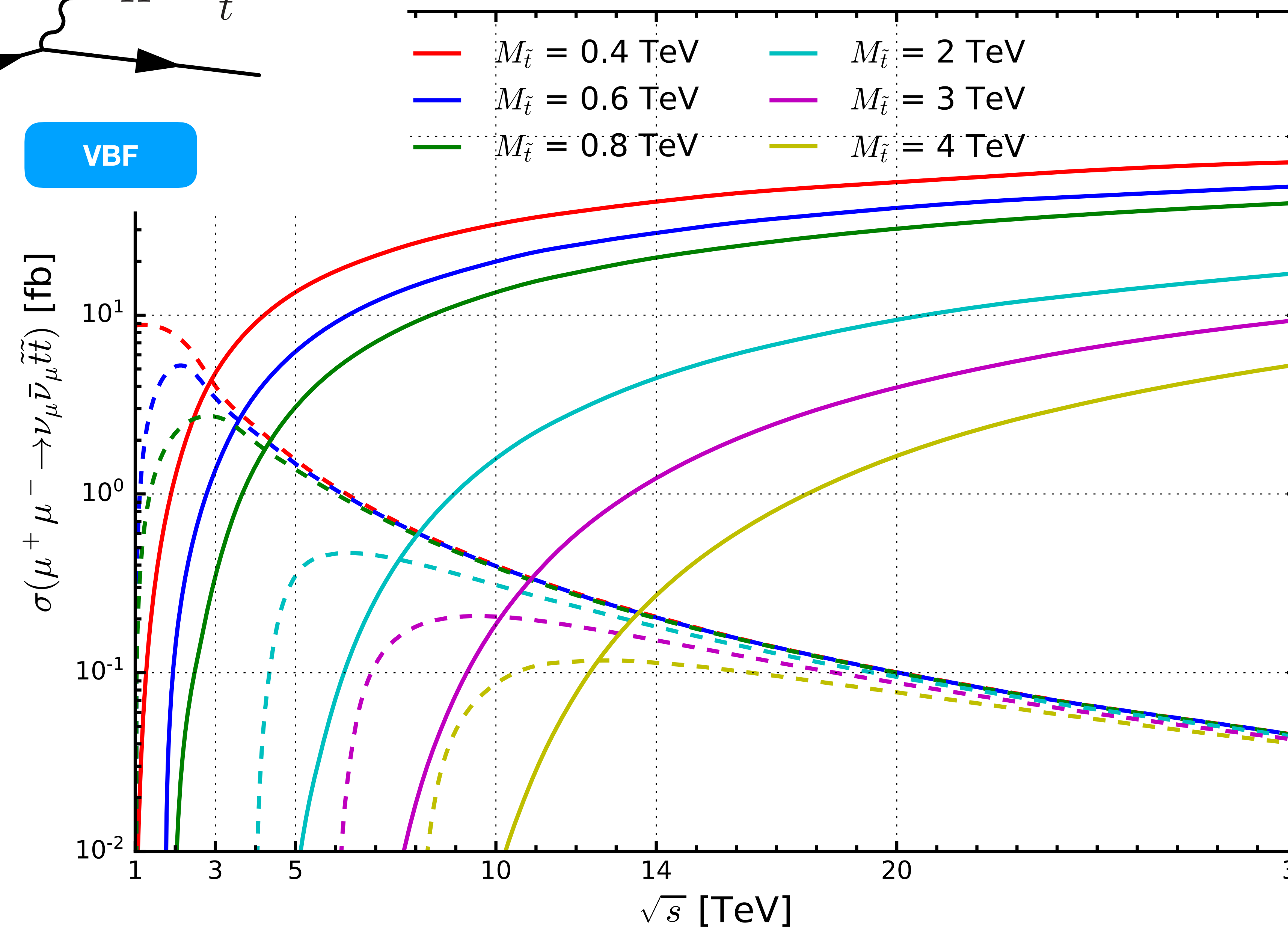
s-channel

$\sqrt{s} \gtrsim$ 1-5 TeV



VBF

Stop pair



brand new study on VBF vs s-channel

Vector boson fusion at multi-TeV muon colliders

Costantini, De Lillo, Maltoni, Mantani, Mattelaer, Ruiz, Zhao
arXiv:2005.10289v1 [hep-ph] 20 May 2020

Contents

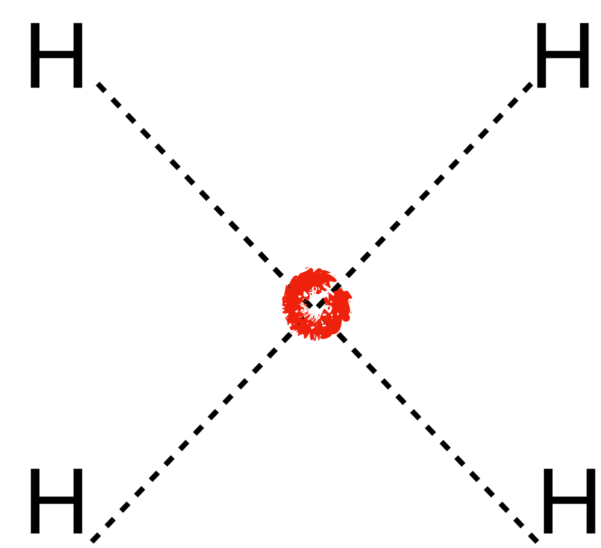
Higgs self-interaction couplings

- * the "tough topic" even at "most-future" colliders
- * most interesting to measure from theory side....

$$\mathcal{L} = -\frac{1}{2} m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4$$

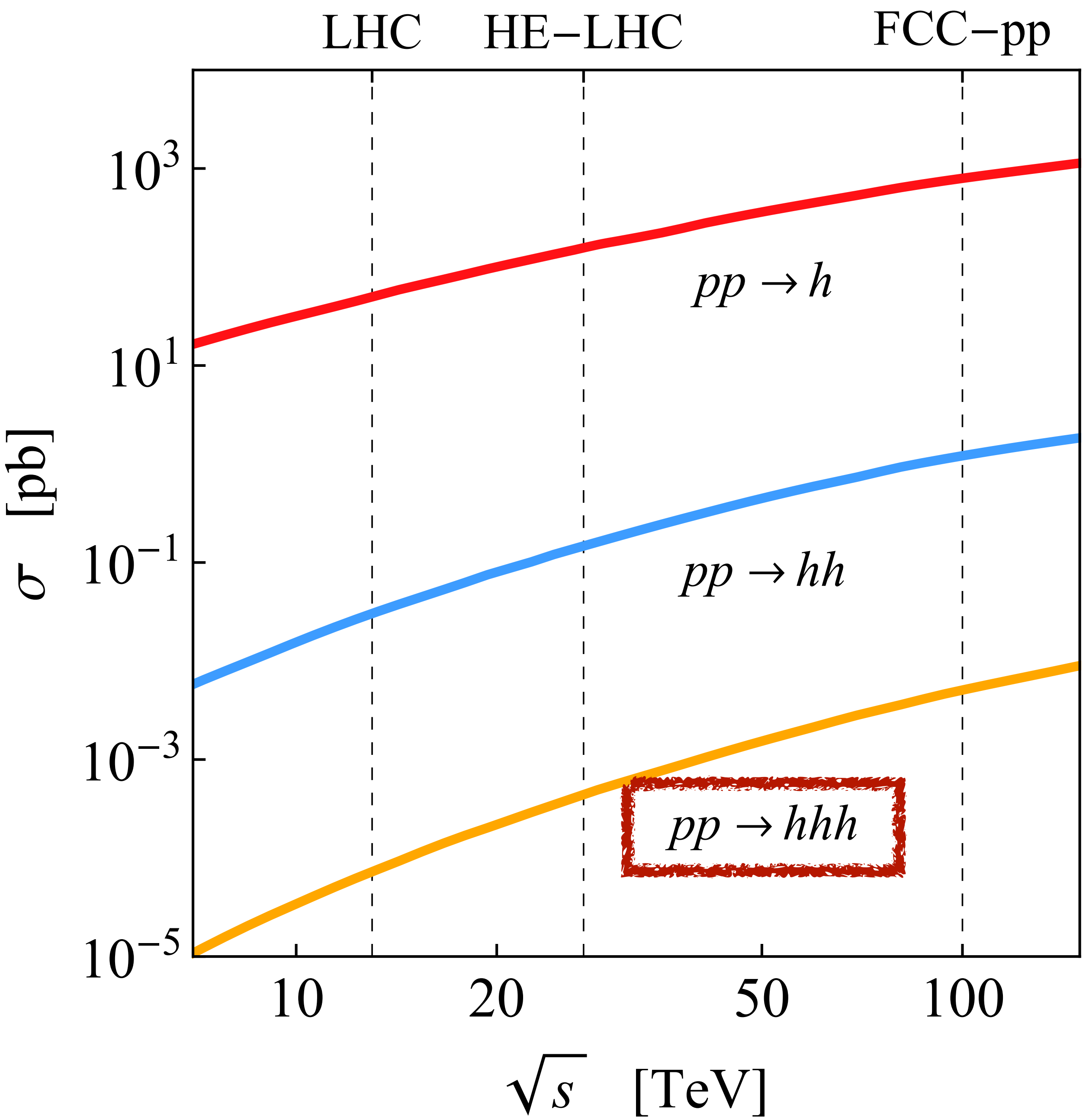
$$\lambda_3^{SM} = \lambda_4^{SM} = 1$$

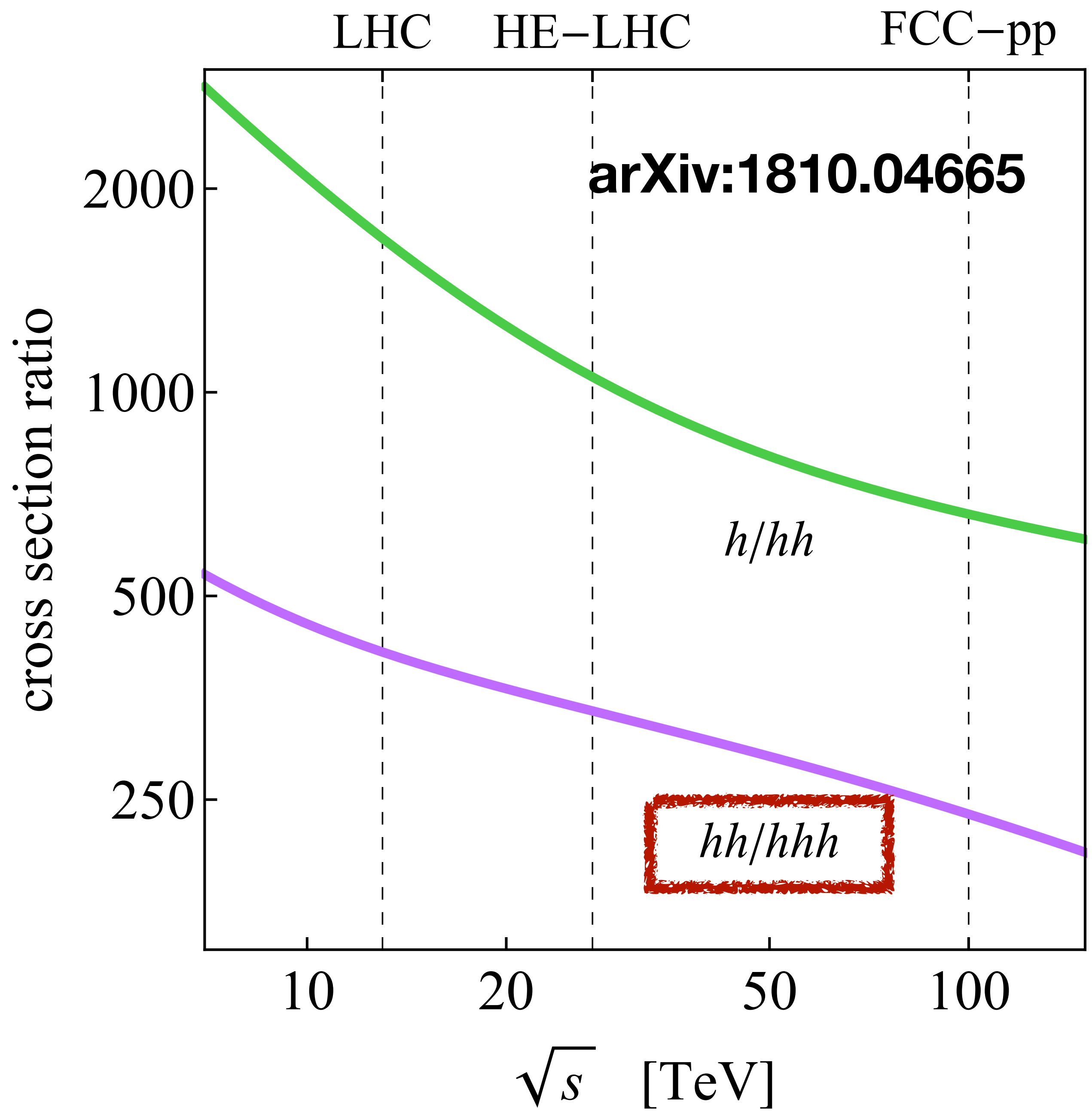
what about quartic H self-coupling ?



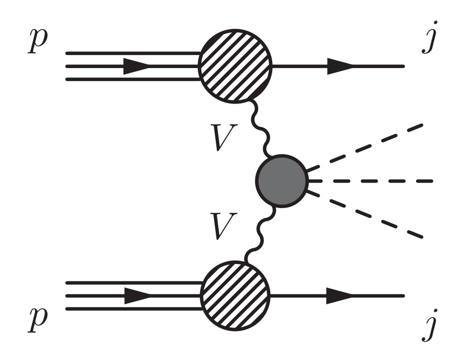
FCC-pp : λ_4

$$\mathcal{L} = -\frac{1}{2} m_h^2 h^2 - \lambda_3 \frac{m_h^2}{2v} h^3 - \lambda_4 \frac{m_h^2}{8v^2} h^4$$





hhh → (b¯b)(b¯b)(γγ) [optimistic scenario !!!] :



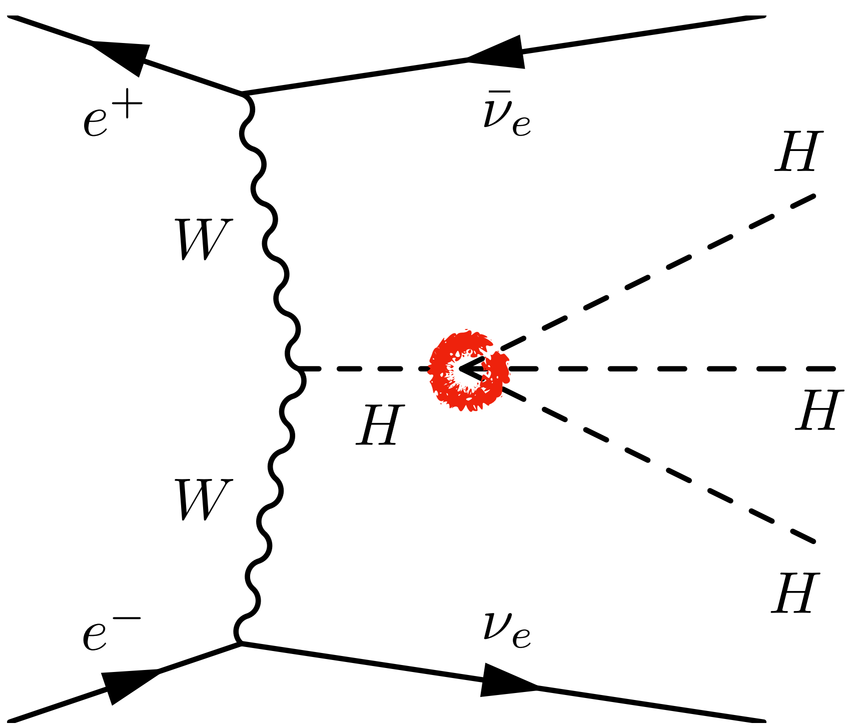
$\lambda_4 \in [\sim -4, \sim +16]$ at 100 TeV, 30 ab^{-1}

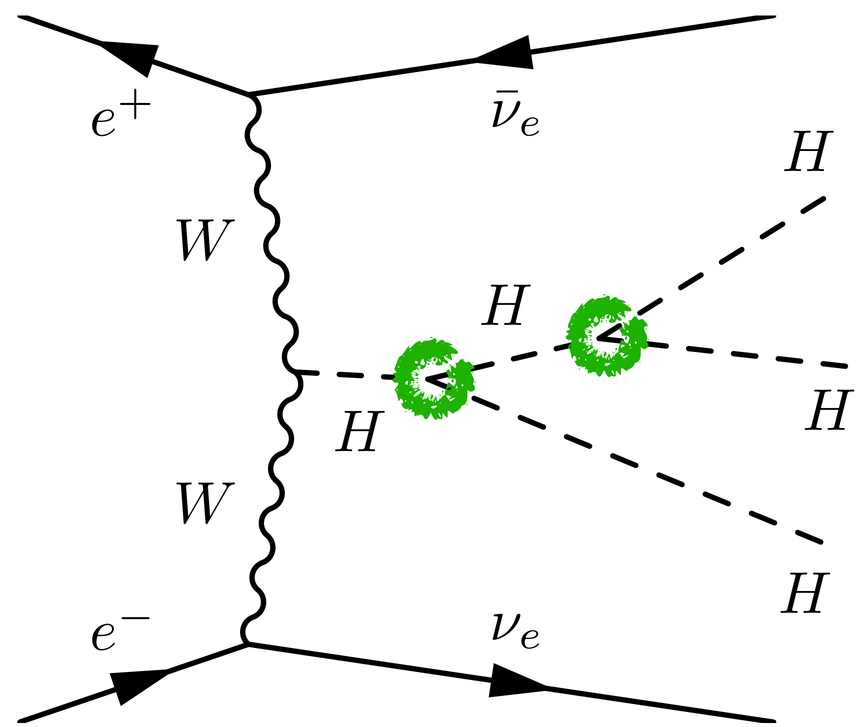
(95%C.L.)

arXiv:1606.09408

$\mu^+\mu^- \to HHH\nu\bar{\nu}, \ (\nu = \nu_e, \nu_\mu, \nu_\tau)$

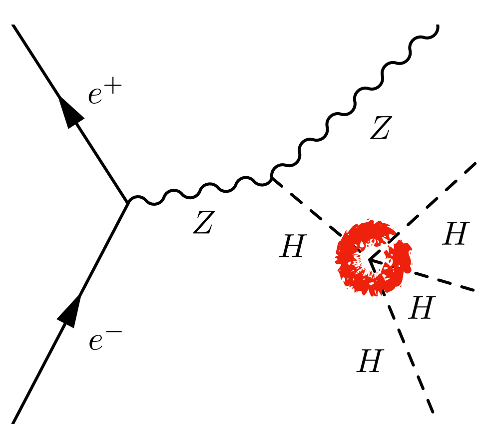
$$V_{\rm h} = \frac{m_h^2}{2} h^2 + (1 + \kappa_3)\lambda_{hhh}^{\rm SM} v h^3 + \frac{1}{4}(1 + \kappa_4)\lambda_{hhhh}^{\rm SM} h^4$$

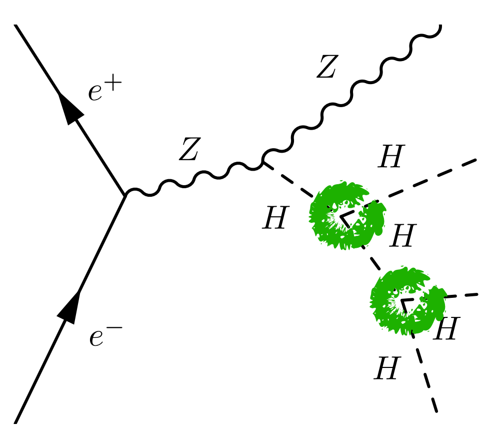




($\kappa_i \to \delta_i$)

$$\Delta = \frac{N - N_{SM}}{\sqrt{N_{SM}}} = \left(c_1\kappa_3 + c_2\kappa_4 + c_3\kappa_3\kappa_4 + c_4\kappa_3^2 + c_5\kappa_4^2 + c_6\kappa_3^3 + c_7\kappa_3^2\kappa_4 + c_8\kappa_3^4\right)$$





HHHZ negligible !

σ_{HHHZ} ~ 1/2 σ_{HHH} @ 3TeV

~ 1/50 σ_{HHH} @ 30TeV

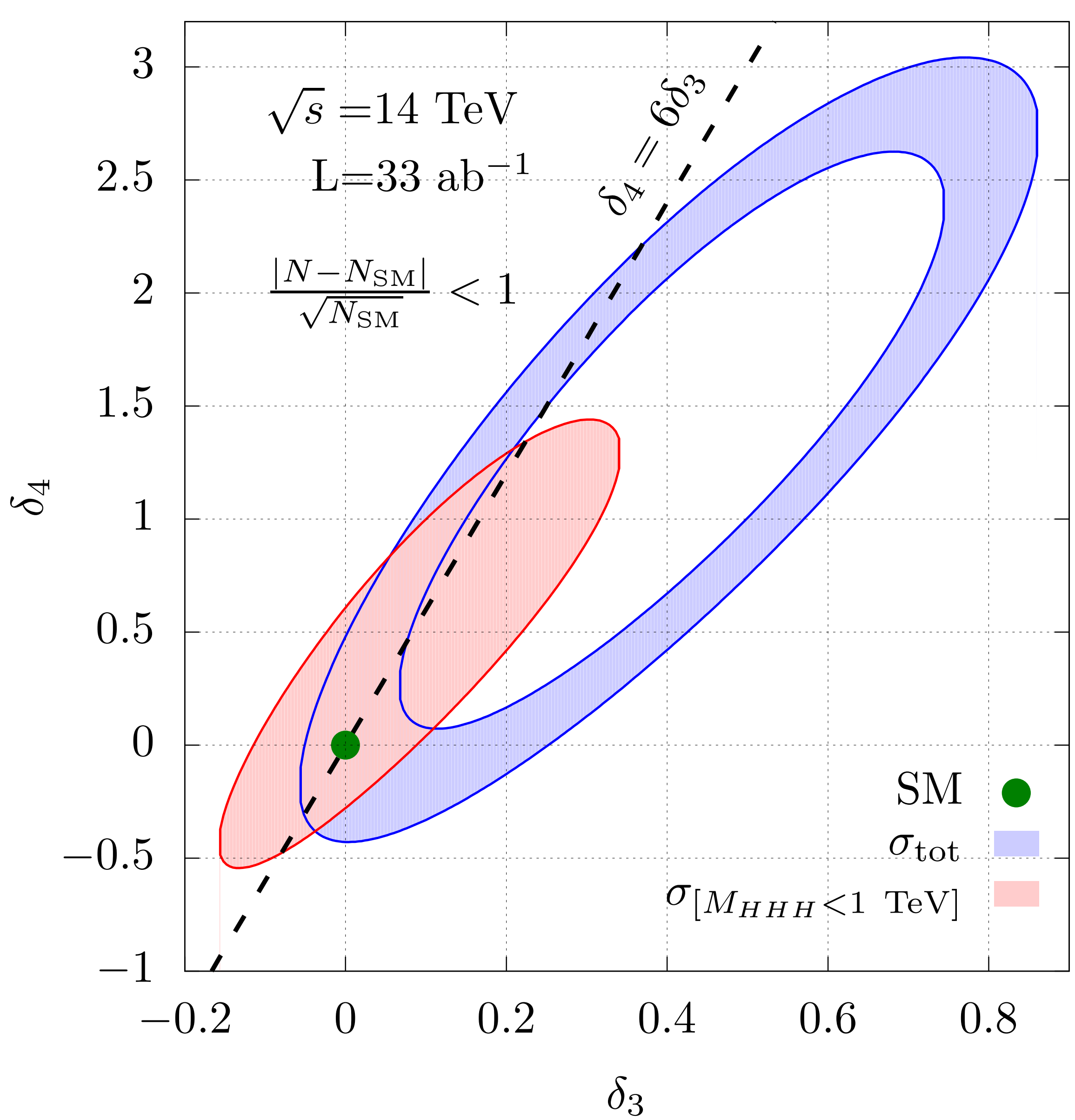
$(N-N_{SM})/\sqrt{N_{SM}}$ versus (δ_3,δ_4)

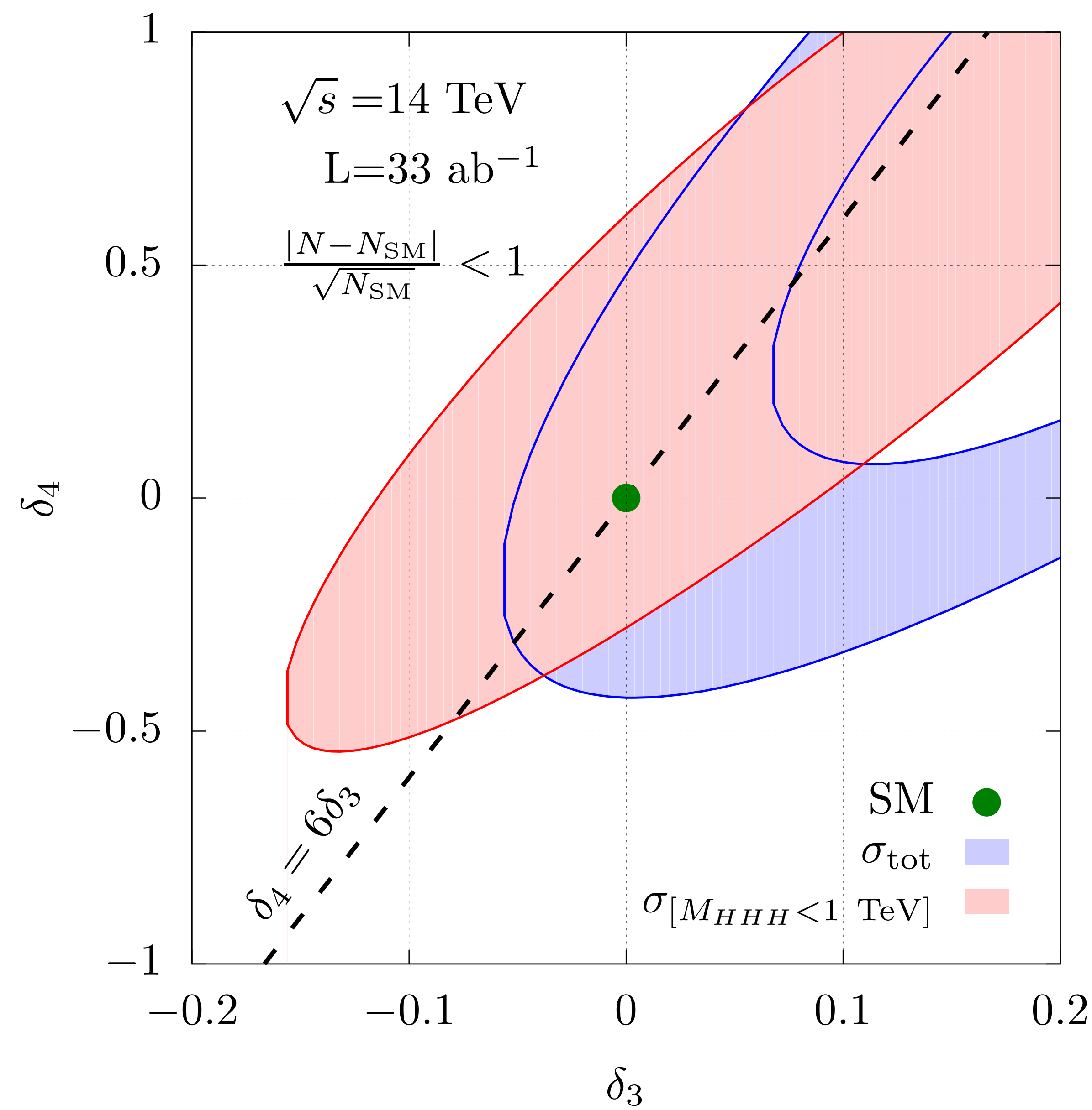
VBF→HHH

Chiesa, Maltoni, Mantani, BM, Piccinini, Zhao, 2003.13628
to appear in JHEP

$$\lambda_3 = \lambda_{SM}(1+\delta_3) = \kappa_3\lambda_{SM}$$

$$\lambda_4 = \lambda_{SM}(1+\delta_4) = \kappa_4\lambda_{SM}$$





[δ_3=0] $-0.4 < \delta_4 < 0.4$ (68%CL) !!!

$(N - N_{SM})/\sqrt{N_{SM}}$ versus δ_4

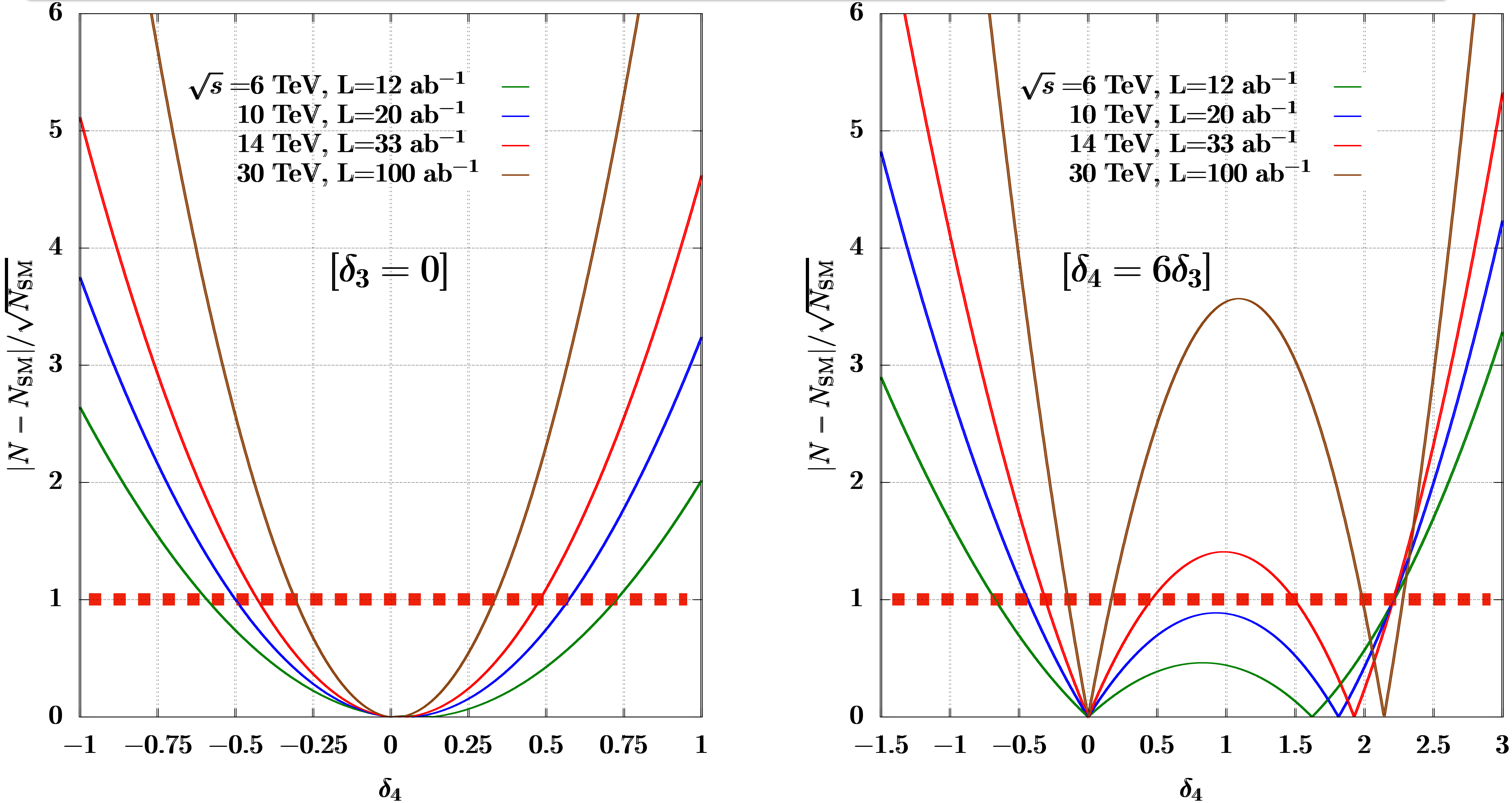
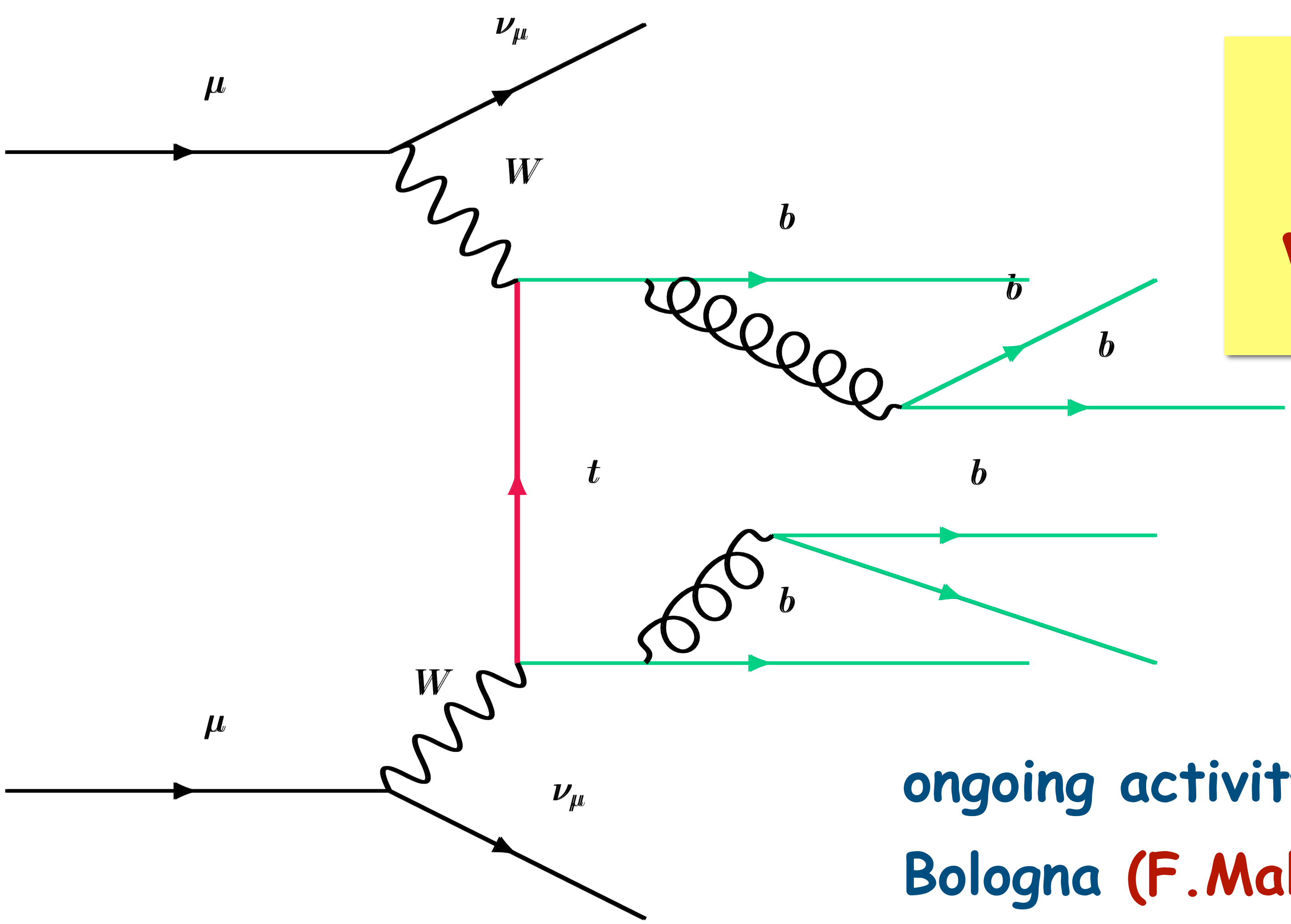


Figure 13: Sensitivity to the quartic Higgs self-coupling in terms of standard deviations $|N - N_{\rm SM}|/\sqrt{N_{\rm SM}}$ with respect to the SM configuration, where the event numbers N refer to $\sigma(\mu^+\mu^- \to HHH\nu\bar{\nu})$, for $M_{\bar{\nu}\nu} \gtrsim 150$GeV, for $\delta_3 = 0$ (left), and $\delta_4 = 6\delta_3$ (right). Results are obtained considering deviations from the inclusive cross sections only.

backgrounds to VBF → HHH

- 8-body final states (at least !)
  → very hard to evaluate via MC's
- all H decay modes are relevant ! [BR(HHH → 6 b) ~ 20 %]
- 6b-jet bckgr moderate at FCC-pp [arXiv:1801.10157]
- might be S/B >> 1 at multi-TeV muon colliders...



MC development for WW approx. needed !

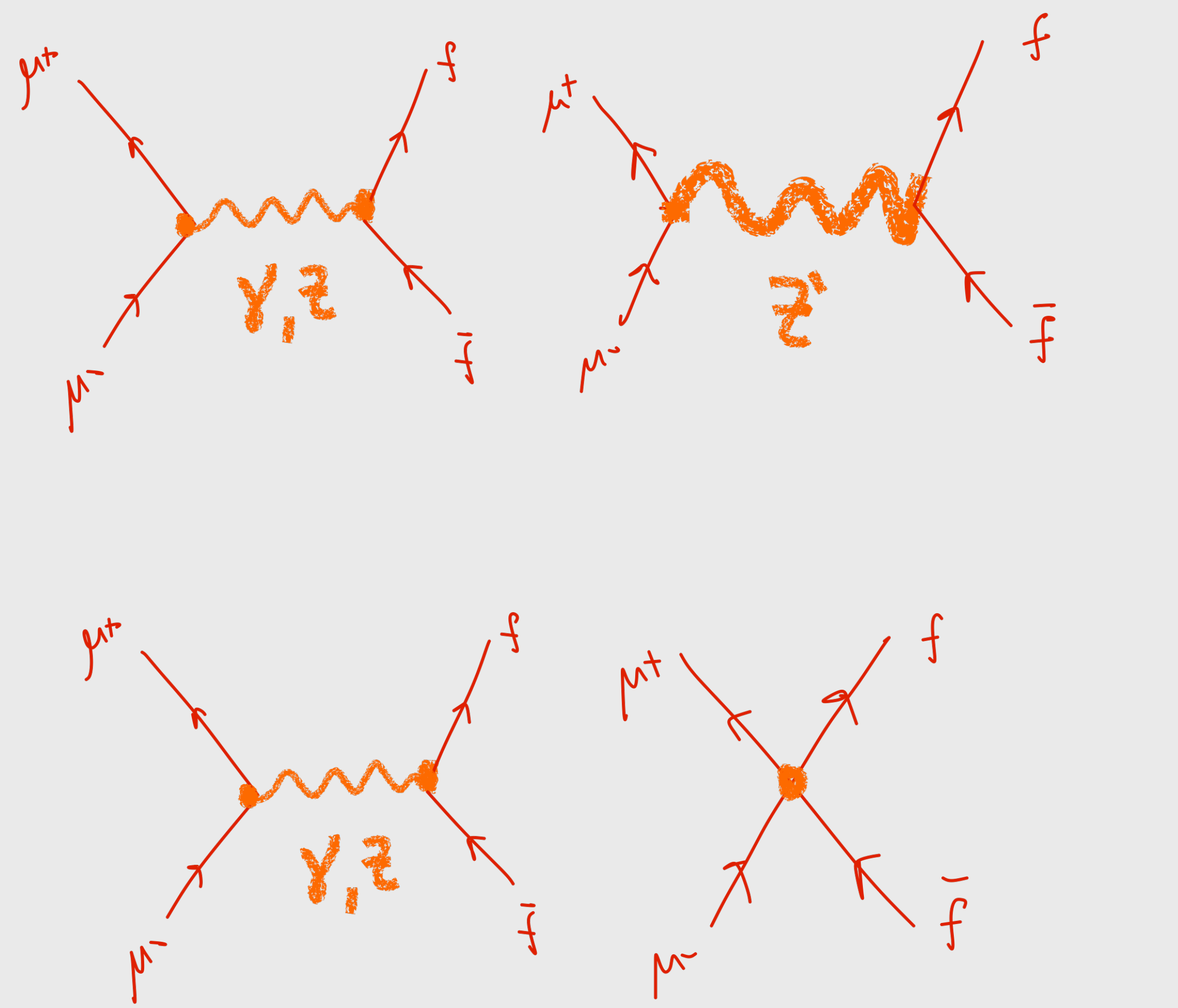
ongoing activity Pavia (M.Chiesa and F.Piccinini)
Bologna (F.Maltoni, L.Mantani, X.Zhao) Roma1 (BM)

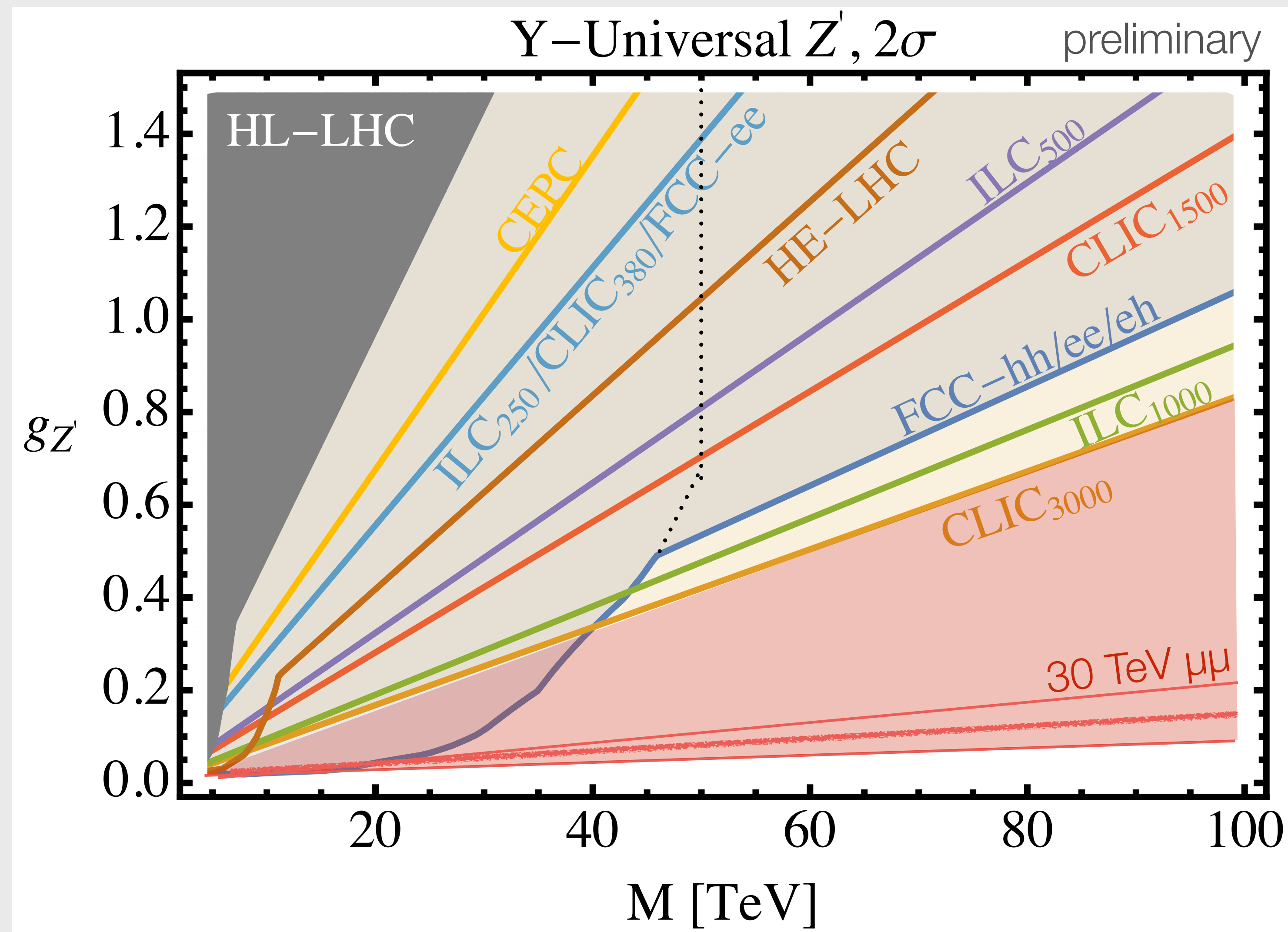
off-shell effects

A heavy Z'

Franceschini

DRELL-YAN | RATES AND ANGULAR DISTRIBUTIONS

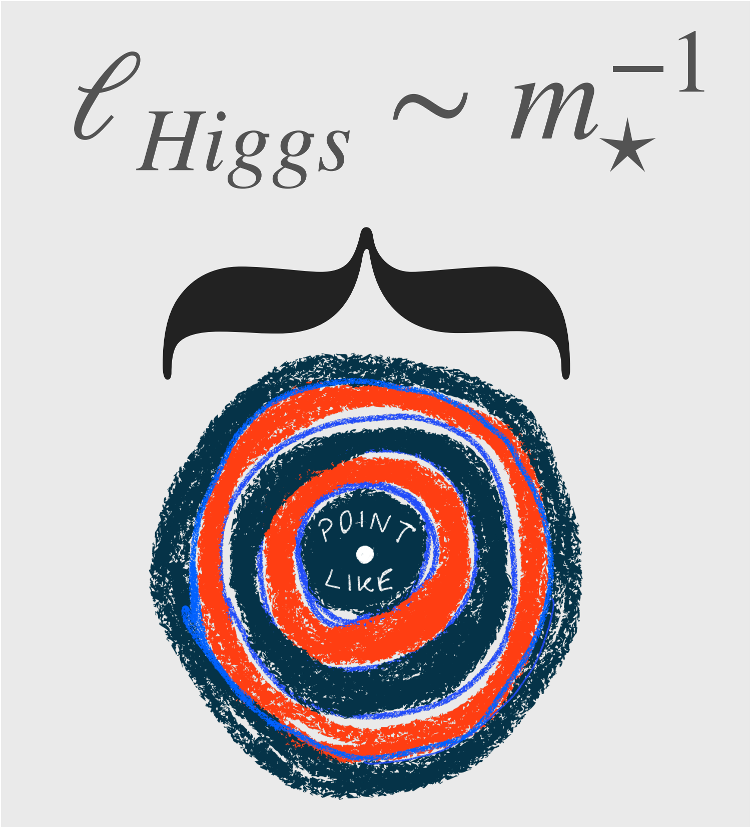




o Franceschini Muon Collider Workshop https://indico.cern.ch/event/845054/contributions/3573348/

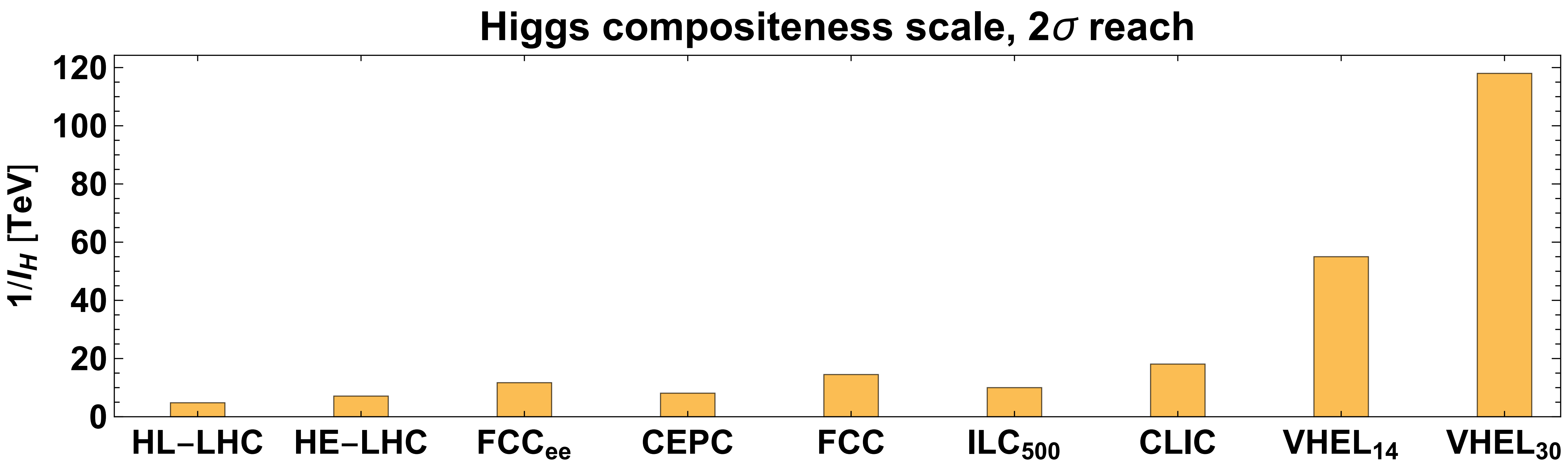
the "size" of the Higgs boson

Buttazzo, Franceschini, Wulzer



(EFT approach)

Compositeness Reach:



a few final comments

* such a high energy at pointlike level opens up hugely new perspectives !
* capability of direct production of new heavy states paramount!
* μ colliders @10'sTeV can be considered WW colliders !
* qualitatively new Higgs physics (test quartic self-coupl.)
* physics bckgds expected mild also for hadronic final states BUT simulations are quite hard (many particles in phase-space)
  → implement Equivalent Vector-Boson Approx. in MC's !
* many many possible new directions for exploring BSM in off-shell/indirect effects via precision measurements
  [also VBF-production role to be extensively considered…]

topics submitted as LoI to Snowmass2021 on Physics at Muon Colliders

(a lot of Italian contributions...)

Letter of Interest: Muon Collider Physics Potential

D. Buttazzo, R. Capedevilla, M. Chiesa, A. Costantini, D. Curtin, R. Franceschini
T. Han, B. Heinemann, C. Helsens, Y. Kahn, G. Krnjaic, I. Low, Z. Liu,
F. Maltoni, B. Mele, F. Meloni, M. Moretti, G. Ortona, F. Piccinini, M. Pierini,
R. Rattazzi, M. Selvaggi, M. Vos, L.T. Wang, A. Wulzer *, M. Zanetti, J. Zurita

Muon Collider: Study of Higgs couplings and self-couplings precision

C. Aimè[a], F. Balli[b], N. Bartosik[c], L. Buonincontri[d], M. Casarsa[e], M. Chiesa[f], F. Collamati[g],
C. Curatolo[d], D.Lucchesi[d], B. Mele[g], F. Maltoni[h], B. Mansoulié[b], A. Nisati[g],
N. Pastrone[c], F. Piccinini[i], C. Riccardi[a], P. Sala[l], P. Salvini[i], L. Sestini[m], I. Vai[a], D. Zuliani[d]

Muon Collider: Study of methods for the luminosity measurement

C. Aimè[a], N. Bartosik[b], L. Buonincontri[c], M. Casarsa[d], M. Chiesa[e], C.M. Carloni Calame[a],
F. Collamati[f], C. Curatolo[c], U. Dosselli[g], A. Ferrari[h], S. Giovannella[i], C. Giraldin[c],
F. Happacher[i], G. Krintiras[l], D.Lucchesi[c], A. Mereghetti[m], S. Miscetti[i], G. Montagna[a],
O. Nicrosini[n], N. Pastrone[b], F. Piccinini[n], C. Riccardi[a], P. Sala[o], P. Salvini[n], I. Sarra[i], L. Sestini[g],
I. Vai[a], D. Zuliani[c]

Letter of Interest: EW effects in very high-energy phenomena

C. Arina, G. Cuomo, T. Han, Y.Ma, F. Maltoni, A. Manohar, S. Prestel, R. Ruiz, L. Vecchi, R. Verheyen, B. Webber, W. Waalewijn, A. Wulzer, K. Xie

to be submitted to the Theory Frontier (TF07) and Energy Frontier (EF04)

Letter of Interest: Tau-neutrino Production at a multi-TeV Lepton Collider

GaetanoMarco Dallavalle, Fabio Maltoni, Silvia Pascoli, Antonio Sidoti

to be submitted to

the Accelerator Frontier (AF04), Energy Frontier (EF03), and Neutrino Frontier (NF06)