

PHYSICS OPPORTUNITIES AT THE FCC

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Padova - 27 Feb 2015

Theory overview

(mostly FCC-hh but not only)

FCC-HH TWIKI



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Twiki for 100 TeV pp collider studies (Future Circular Collider FCC-hh)

This twiki is intended to provide a common area to collect and share information related to FCC-hh studies.

Detector studies (Under construction):

- [DetectorGeneral](#)
- [InnerDetector](#) (to be done)
- [CalorimetrySystem](#) (to be done)
- [MuonsSystem](#) (to be done)
- [MagneticSystem](#) (to be done)

Physics studies:

- [Tools](#) (to come soon)
- [Standard Model](#) (to come soon)
- [HiggsEWSymmetry](#)
- [BSM](#)
- [HeavyIons](#)

Some useful related links:

- Agenda for the FCC-hh meetings: [indico agenda](#)

– [BenHooberman](#) - 10 Jan 2014

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Topic revision: r15 - 2015-02-05 - [AndreaDainese](#)

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FCC-HH PHYSICS INDICO

The screenshot shows the Indico website interface. At the top, there is a blue header with the Indico logo on the left and navigation options for 'Europe/Zurich', 'English', and 'Login' on the right. Below the header is a dark navigation bar with links for 'Home', 'Create event', 'Room booking', and 'Help'. A breadcrumb trail below that reads: 'Home > Projects > FCC > Physics and Experiments > Hadron Collider Physics and Experiments > FCC-hh collider physics WGs'. The main content area is titled 'FCC-hh collider physics WGs' and features a calendar view. The calendar is organized by month, with the following events listed:

- February 2015**
 - 26 Feb: FCC-hh BSM group informal meeting (link)
 - 25 Feb: FCC Higgs/EWSB WG meeting
- November 2014**
 - 24 Nov: Higgs/EWSB group, workplan discussion
- October 2014**
 - 30 Oct: FCC-hh BSM group, workplan discussion
 - 10 Oct: Higgs and EWSB group, conveners' planning discussion
- April 2014**
 - 17 Apr: FHC experiments informal meeting
- March 2014**
 - 20 Mar: FHC experiments informal meeting
- February 2014**
 - 06 Feb: FHC experiments informal meeting
- January 2014**
 - 27 Jan: FHC experiments informal meeting
 - 10 Jan: FHC experiments informal meeting
- November 2013**
 - 26 Nov: FHC experiments informal meeting
 - 18 Nov: FHC experiments informal meeting

At the bottom of the calendar view, there is a button that says 'Hide the events in the past (10)'. On the right side of the page, there is a 'Managers' section with a magnifying glass icon and a list of names: Bell, A.; Contino, R.; Gianotti, F.; Gray, H.; and Moortgat, F.

SM, HIGGS AND EWSB

- Precision Studies of the SM (FCC-ee)
- Precision Studies of Higgs Properties (e.g.)
 - * Higgs CS at 100 TeV
 - * Extrapolation of single Higgs analyses to 100 TeV
 - * Higgs studies with extreme kinematical configurations
 - * Off-shell Higgs measurements
- Exotic/Rare Higgs decays
- Double Higgs Production
- WW scattering at high energy
- Additional BSM Higgs bosons: discovery reach and precision physics program
- New handles on the study of the EWSB dynamics

BSM

- Dark Matter (e.g.)
 - * Mono-SM like searches for DM (SUSY, non SUSY)
 - * Minimal Dark Matter (directly and indirectly)
- SUSY (e.g.)
 - * Rare susy processes
 - * Test of very compressed spectra
 - * Split SUSY
- Non-SUSY (e.g.)
 - * Resonances (jets vs leptons)
 - * New physics in VBF
 - * Running EW couplings
 - * Top dipole moments
 - * Composite Higgs resonances (vectors, top partners)
 - * Twin Higgs (twin partners, heavy vectors etc.)

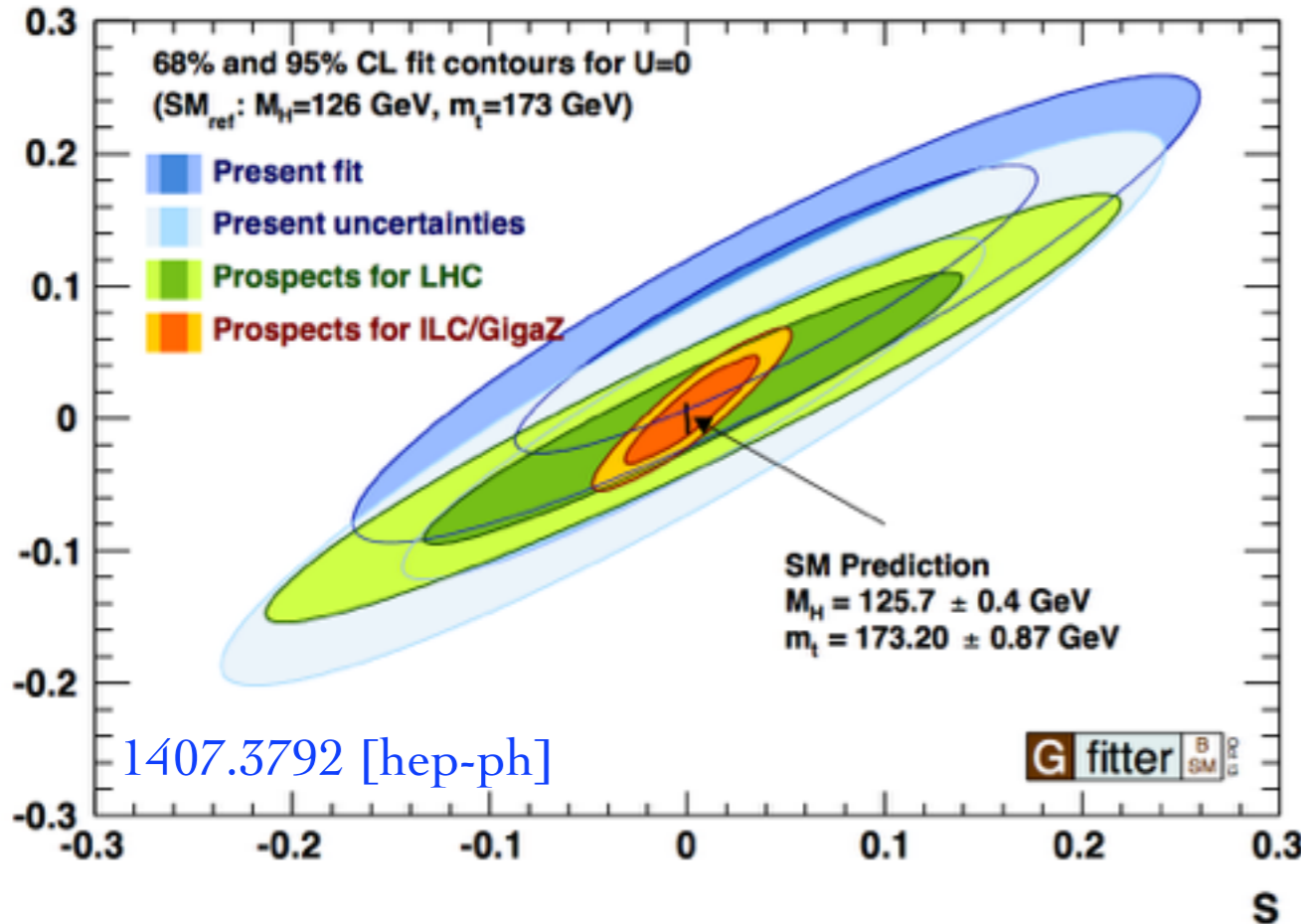
Some examples

(from performed or ongoing studies)

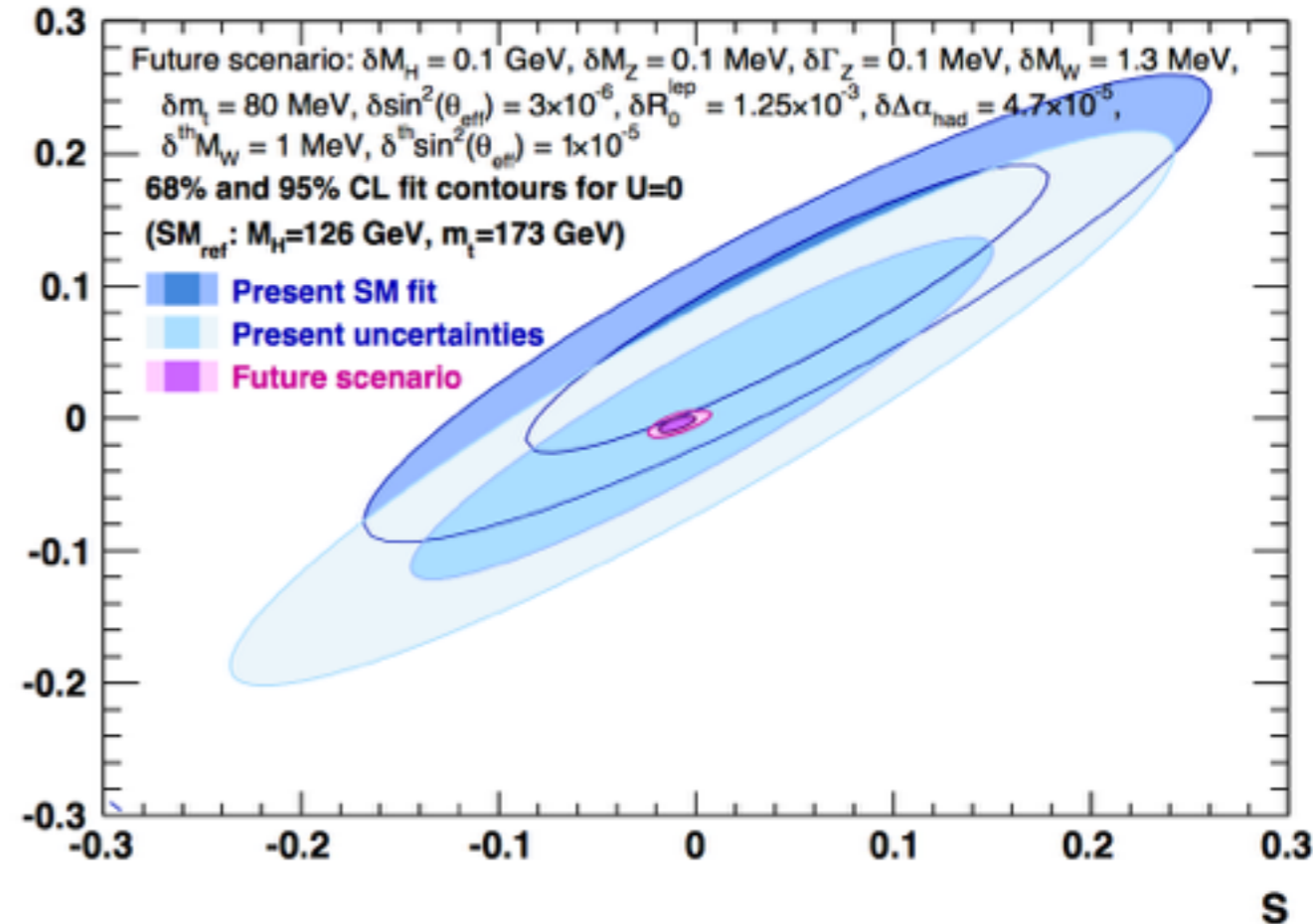
OBLIQUE OBSERVABLES AT TLEP

For the oblique precision observables S and T (and possibly U) a factor of 10 improvements at TLEP

Present / LHC / ILC



Future scenario



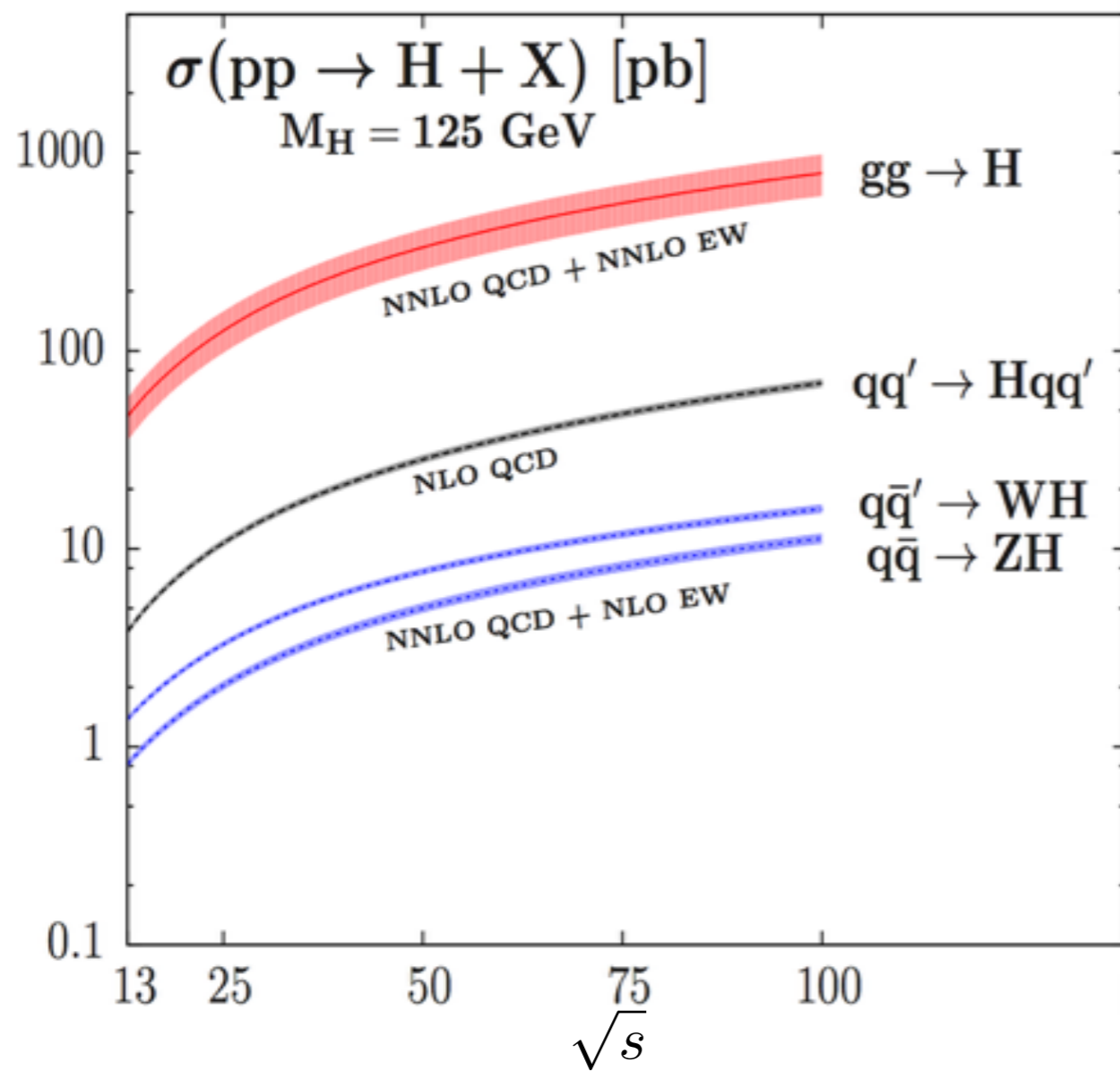
Baak, Cuth

Important to assess the precision possibilities of the FCC-hh

Less clean environment, but enhancement of the higher order observables (W, Y, V, X) with the energy (see EW couplings running in 3 slides)

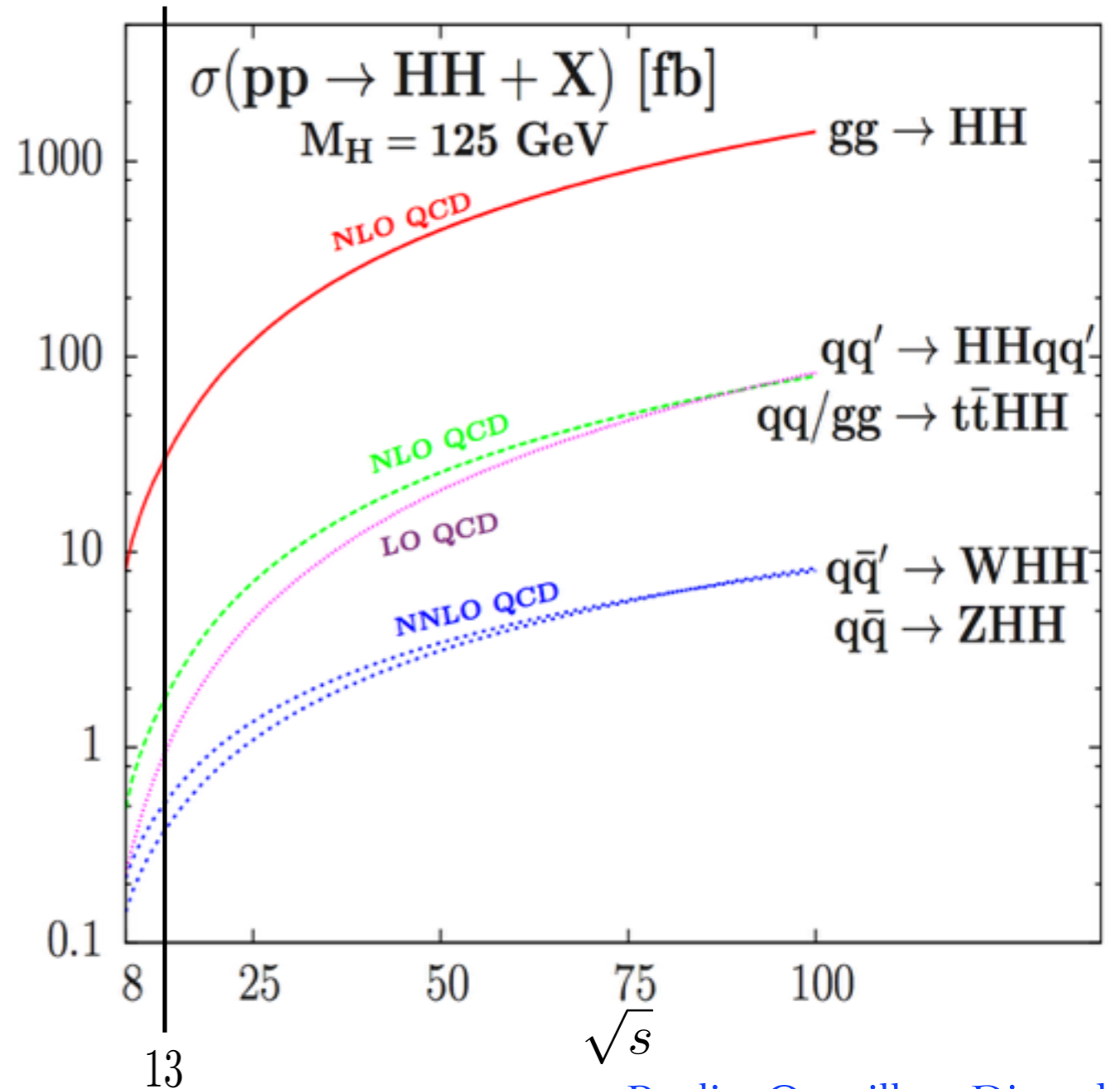
This could lead to important constraints complementary to the S,T,U ones

HIGGS @ 100 TEV



Double Higgs production CS

Single Higgs production CS



Baglio, Quevillon, Djouady

BOOSTED HIGGS @ 100 TEV

$$\mathcal{L}_{\text{eff}} = -k_t \frac{m_t}{v} h t \bar{t} + k_g \frac{\alpha_S}{12\pi v} h G_{\mu\nu}^A G^{A\mu\nu}$$

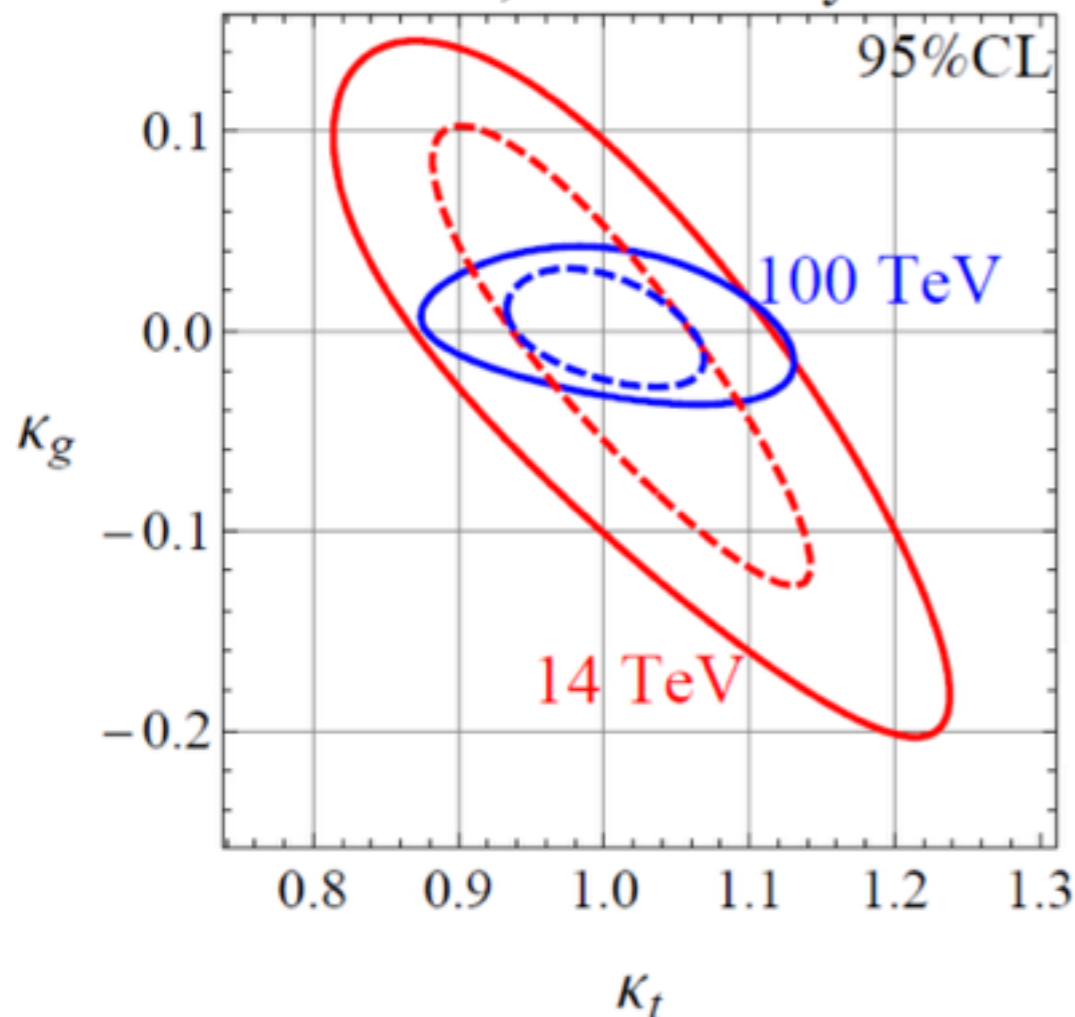
Inclusive production

$$\frac{\sigma(pp \rightarrow h)}{\sigma(pp \rightarrow h)_{\text{SM}}} \simeq (k_t + k_g)^2$$

Recoil against hard jet

$$\frac{\sigma(pp \rightarrow h)^{p_T^{\text{min}}}}{\sigma(pp \rightarrow h)_{\text{SM}}^{p_T^{\text{min}}}} \simeq (k_t + k_g)^2 + \delta k_t k_g + \epsilon k_g^2$$

3000 fb⁻¹, 10 or 5% syst. unc.



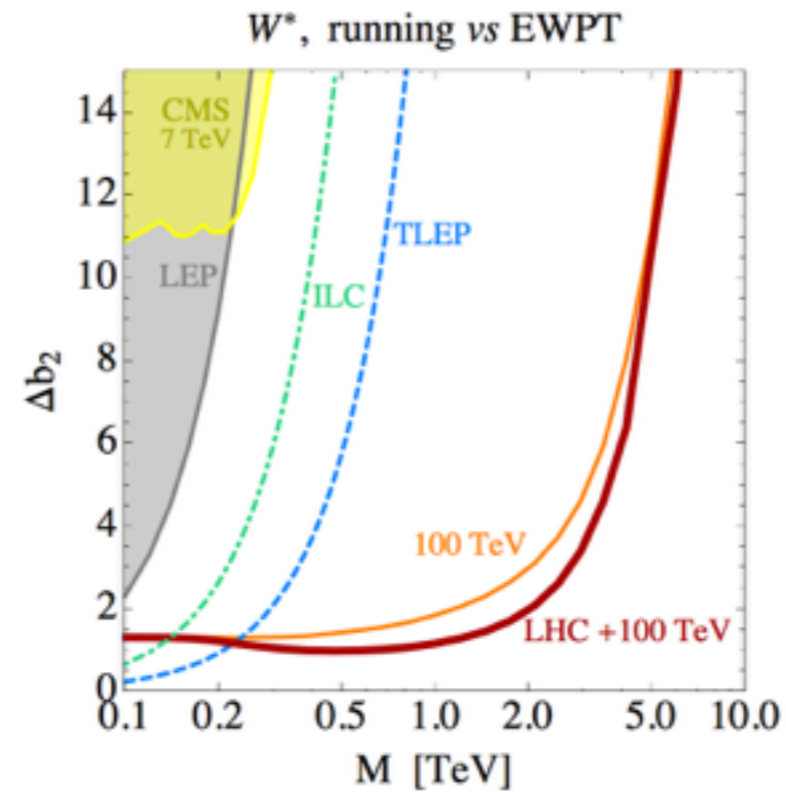
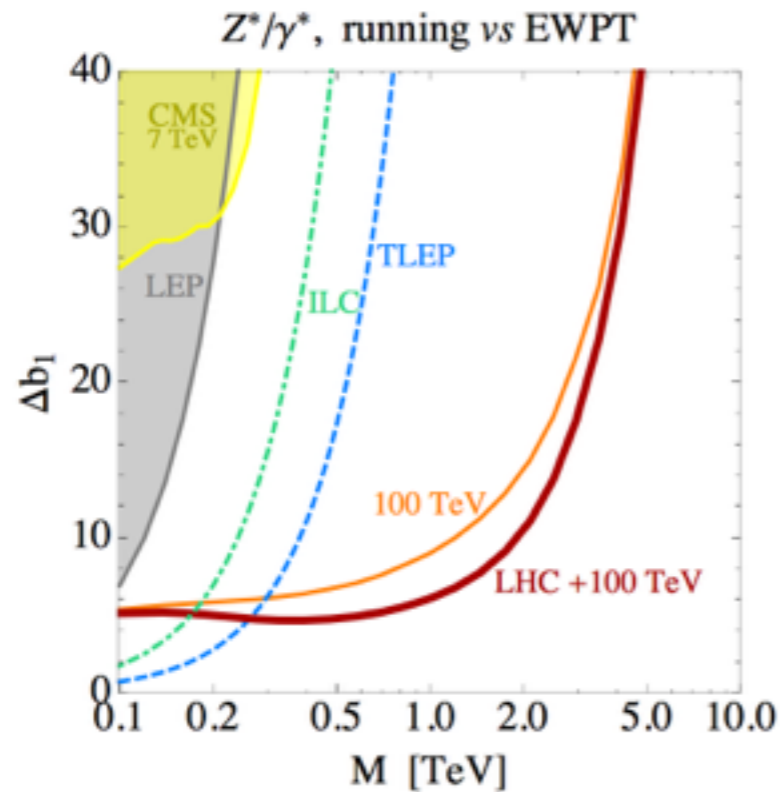
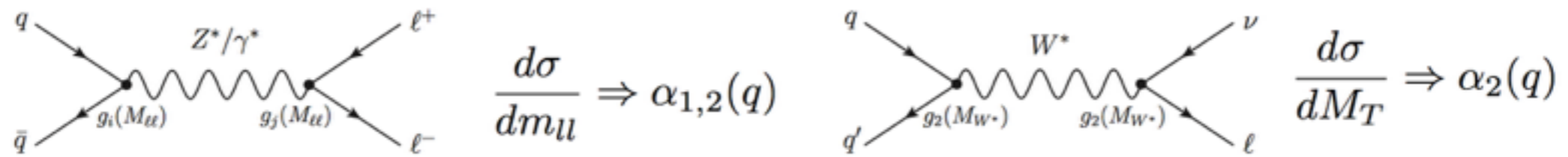
$$\mathcal{R}_{14} = \frac{\sigma(p_T > 650 \text{ GeV})}{\sigma(p_T > 150 \text{ GeV})}$$

$$\mathcal{R}_{100} = \frac{\sigma(p_T > 2000 \text{ GeV})}{\sigma(p_T > 500 \text{ GeV})}$$

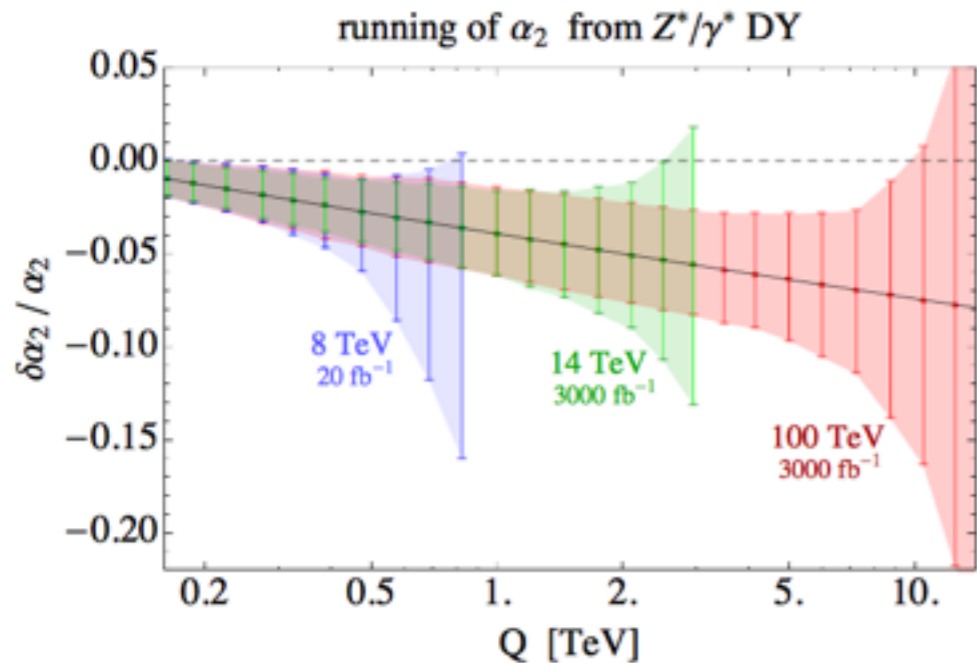
Discrimination power increases strongly at 100 TeV

$$\sigma(p_T > 650 \text{ GeV}, 14 \text{ TeV}) \approx \sigma(p_T > 2000 \text{ GeV}, 100 \text{ TeV})$$

RUNNING EW COUPLINGS @ 100 TEV



100 TeV:
 reach (2σ):
 $m_{\tilde{W}} \lesssim 1.3 \text{ TeV}$
 $m_5 \lesssim 5 \text{ TeV}$



$$W, Y = \frac{\alpha_{2,1}}{20\pi} \frac{M_W^2}{M_x^2} \times \Delta b_{2,1}$$

	ΔM_W (GeV)	$\Delta \Gamma_Z$ (GeV)	ΔA_{LR}	ΔW	ΔY
EWPT+LEP2 [61-63]	$3.4 \cdot 10^{-2}$	$2.3 \cdot 10^{-3}$	$2.1 \cdot 10^{-3}$	$8 \cdot 10^{-4}$	$1.2 \cdot 10^{-3}$
ILC (GigaZ) [64]	$6 \cdot 10^{-3}$	$8 \cdot 10^{-4}$	10^{-4}	$3 \cdot 10^{-4}$	$3 \cdot 10^{-4}$
TLEP (TeraZ) [65]	$5 \cdot 10^{-4}$ (sys)	10^{-4} (sys)	$1.5 \cdot 10^{-5}$	$7 \cdot 10^{-5}$	$1 \cdot 10^{-4}$

Alves, Galloway, Ruderman, Walsh, 1410.6810 [hep-ph]

TOP CHARGE ASYMMETRY

$$A_c^t = \frac{N(\Delta_\eta^t > 0) - N(\Delta_\eta^t < 0)}{N(\Delta_\eta^t > 0) + N(\Delta_\eta^t < 0)} \quad \Delta_\eta^t = |\eta_t| - |\eta_{\bar{t}}|$$

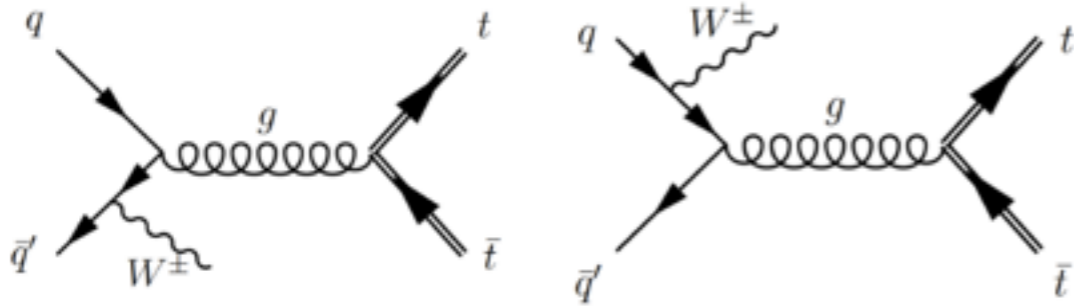
Instead of looking at $t\bar{t}$ events we consider also the emission of a W boson

PROS

- $q\bar{q}$ vs gg so that the asymmetry generated at NLO in QCD is larger
- the tops inherit the polarization of the quarks as induced by the W emission so that the decay products of the top show a large asymmetry already at LO in QCD

CONS

- the rate is dramatically reduced, i.e. the FCC does much better than the LHC

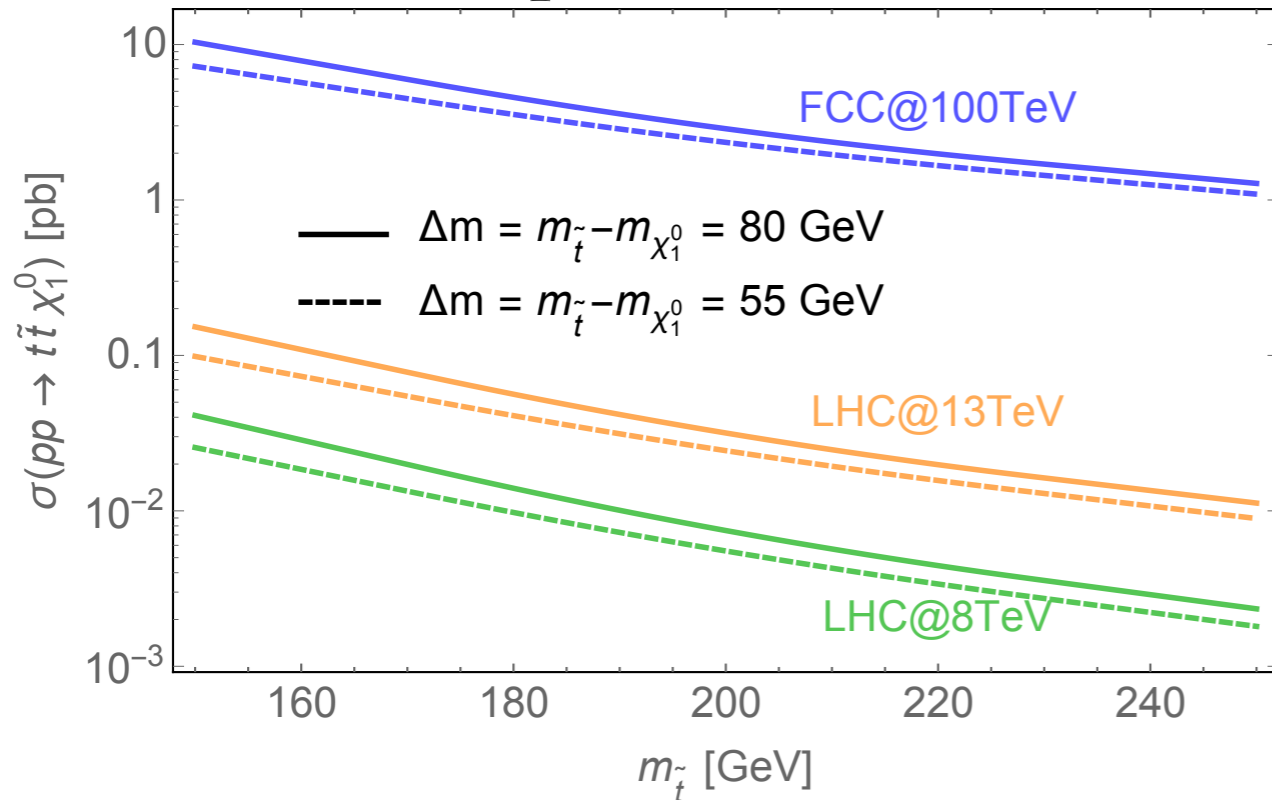


		8 TeV	13 TeV	14 TeV	33 TeV	100 TeV
$t\bar{t}$	$\sigma(\text{pb})$	$198^{+15\%}_{-14\%}$	$661^{+15\%}_{-13\%}$	$786^{+14\%}_{-13\%}$	$4630^{+12\%}_{-11\%}$	$30700^{+13\%}_{-13\%}$
	$A_c^t(\%)$	$0.72^{+0.14}_{-0.09}$	$0.45^{+0.09}_{-0.06}$	$0.43^{+0.08}_{-0.05}$	$0.26^{+0.04}_{-0.03}$	$0.12^{+0.03}_{-0.02}$
$t\bar{t}W^\pm$	$\sigma(\text{fb})$	$210^{+11\%}_{-11\%}$	$587^{+13\%}_{-12\%}$	$678^{+14\%}_{-12\%}$	$3220^{+17\%}_{-13\%}$	$19000^{+20\%}_{-17\%}$
	$A_c^t(\%)$	$2.37^{+0.56}_{-0.38}$	$2.24^{+0.43}_{-0.32}$	$2.23^{+0.43}_{-0.33}$	$1.95^{+0.28}_{-0.23}$	$1.85^{+0.21}_{-0.17}$
	$A_c^b(\%)$	$8.50^{+0.15}_{-0.10}$	$7.54^{+0.19}_{-0.17}$	$7.50^{+0.24}_{-0.22}$	$5.37^{+0.22}_{-0.30}$	$3.36^{+0.15}_{-0.19}$
	$A_c^e(\%)$	$-14.83^{+0.95}_{-0.65}$	$-13.16^{+1.12}_{-0.81}$	$-12.84^{+1.11}_{-0.81}$	$-9.21^{+1.05}_{-0.87}$	$-4.94^{+0.72}_{-0.63}$

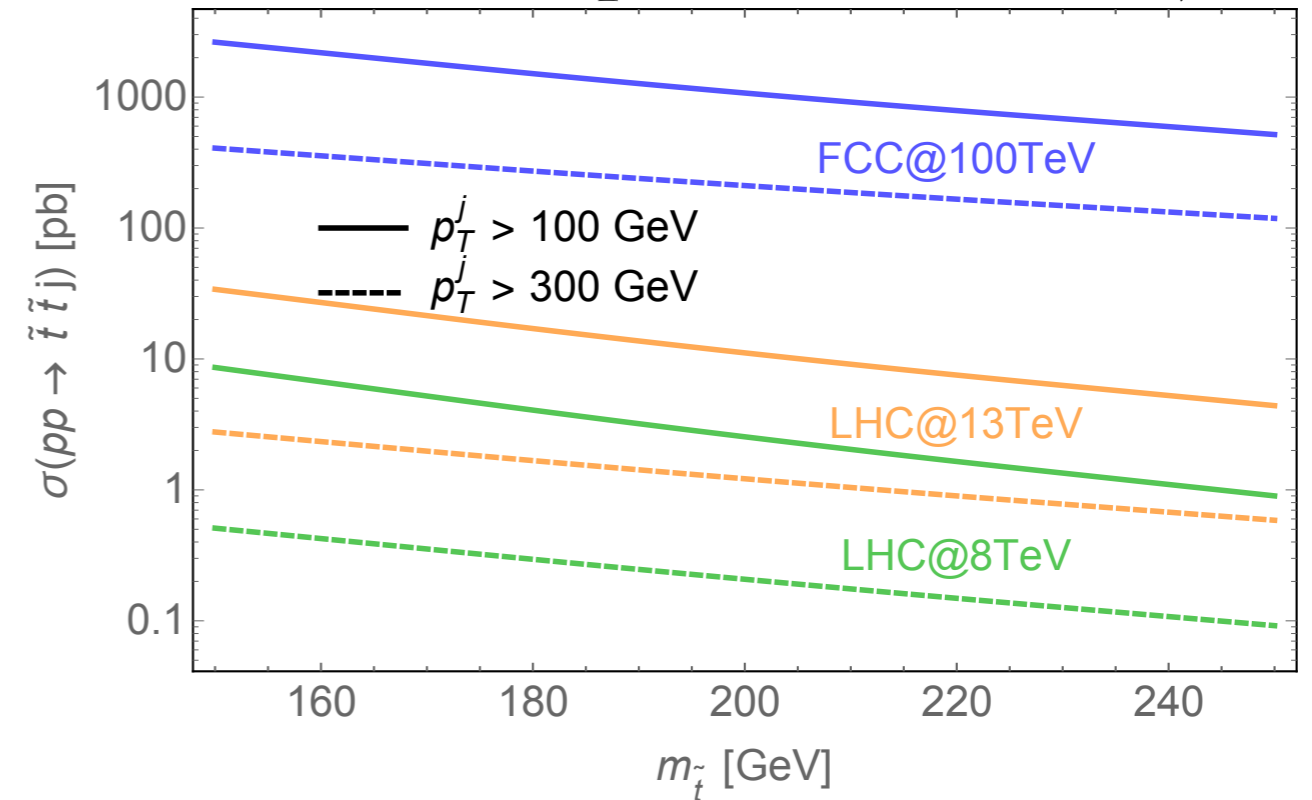
Maltoni, Mangano, Tsinikos, Zaro, 1406.3262 [hep-ph]

SOMETHING SIMILAR WITH SUSY

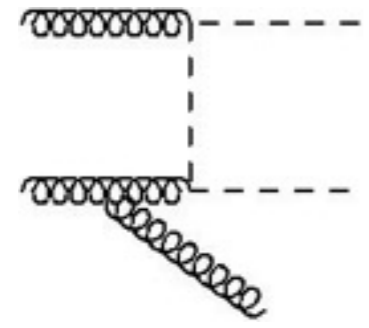
2 → 3 Stop Pair Production + LSP



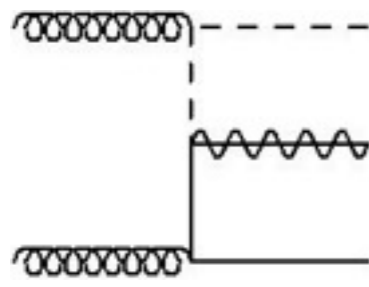
2 → 3 Stop Pair Production + j



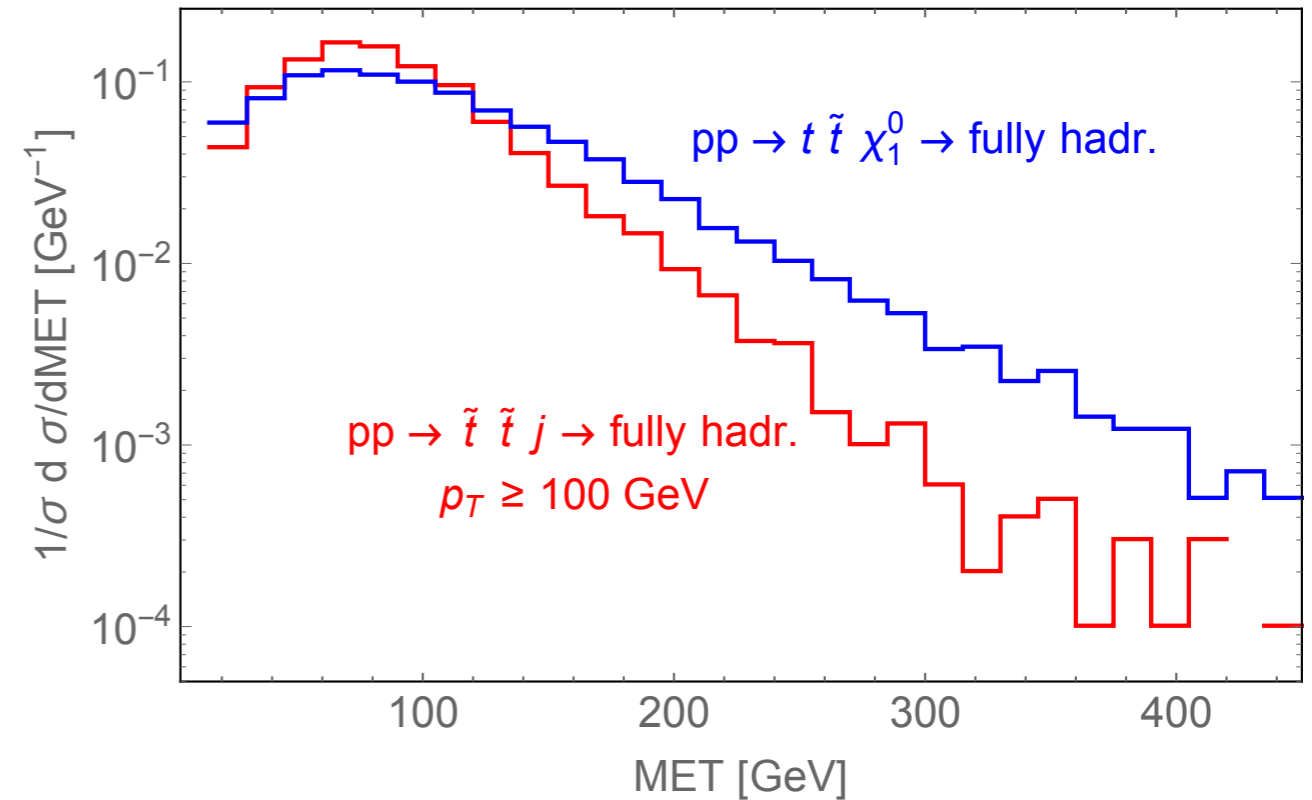
2 → 3 Stop Pair Production + j



2 → 3 Stop Pair Production + LSP



Analogous to the $t\bar{t}h$ measurement of γt



Ferretti, Franceschini, Petersson, Torre

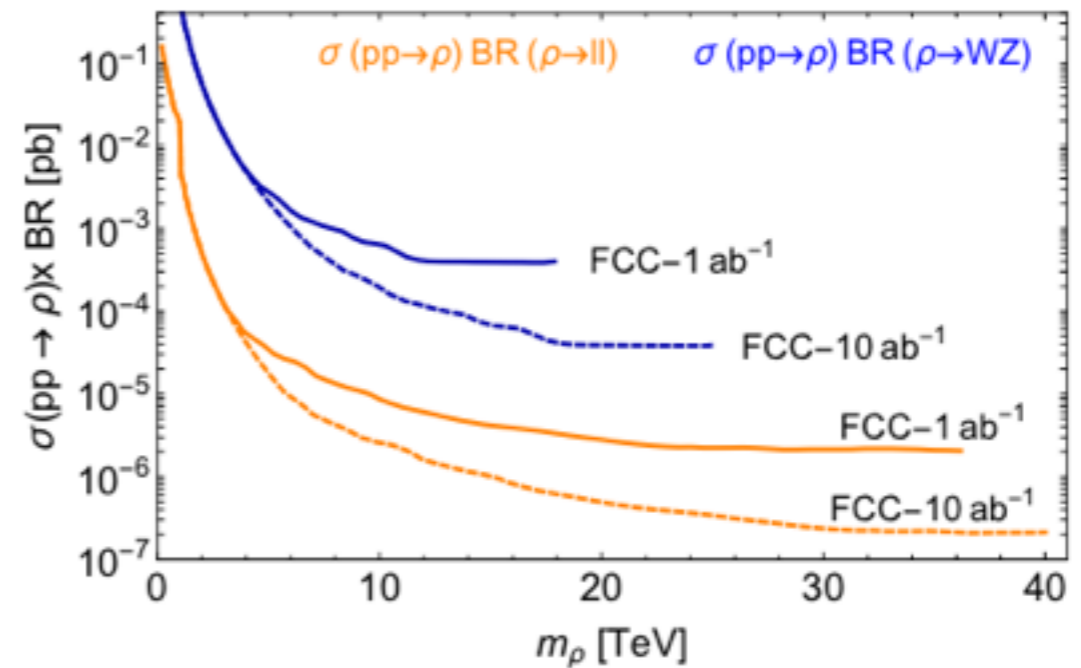
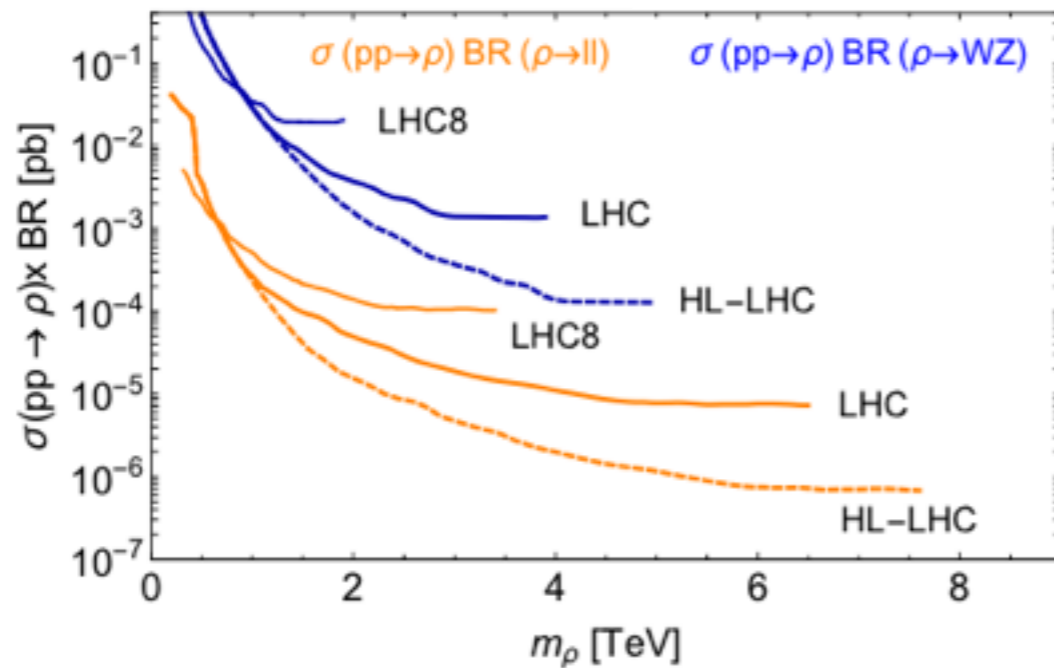
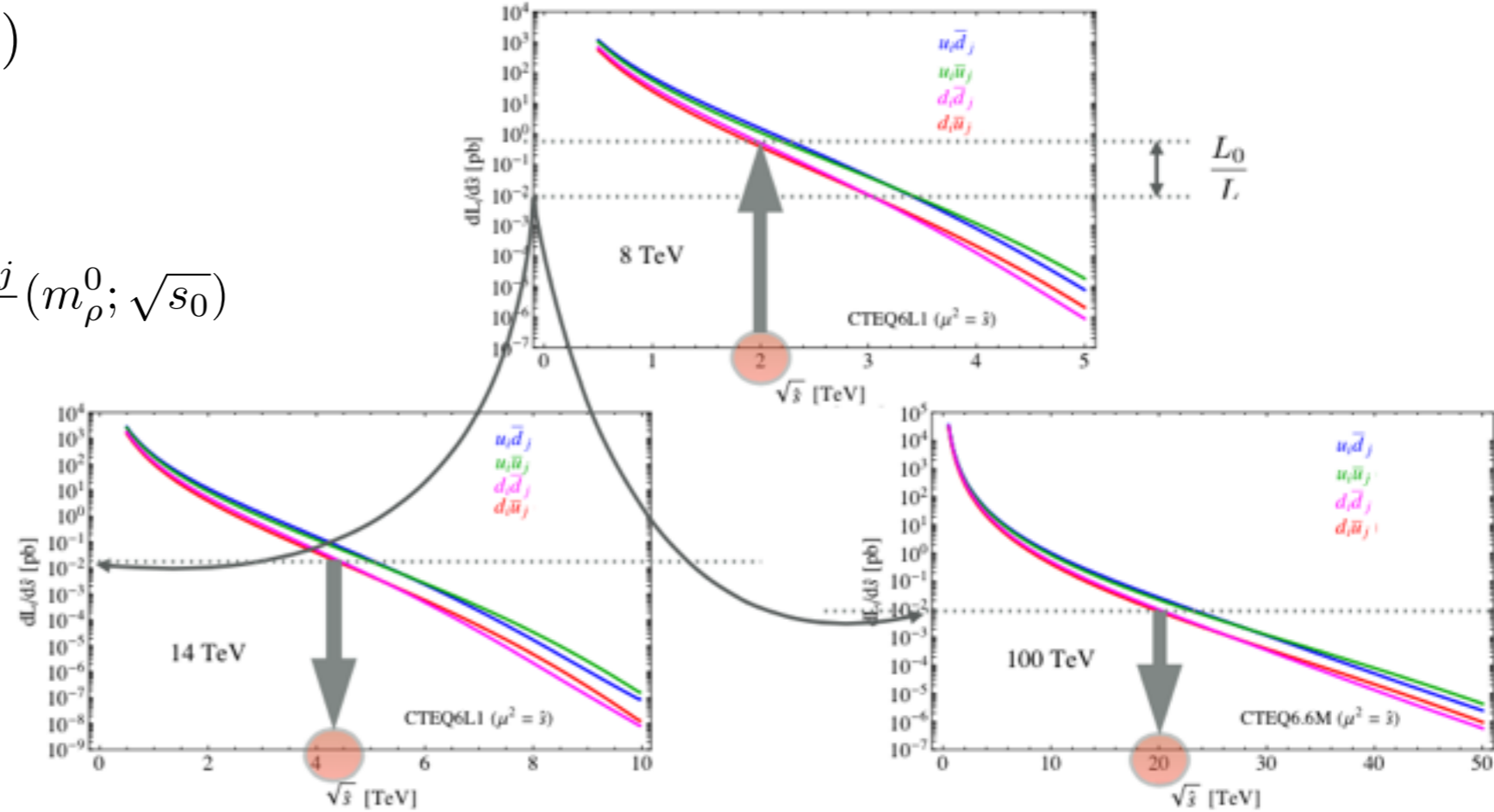
COMPOSITENESS @ 100 TEV

$$B(s, L, m_\rho) = B(s_0, L_0, m_\rho^0)$$



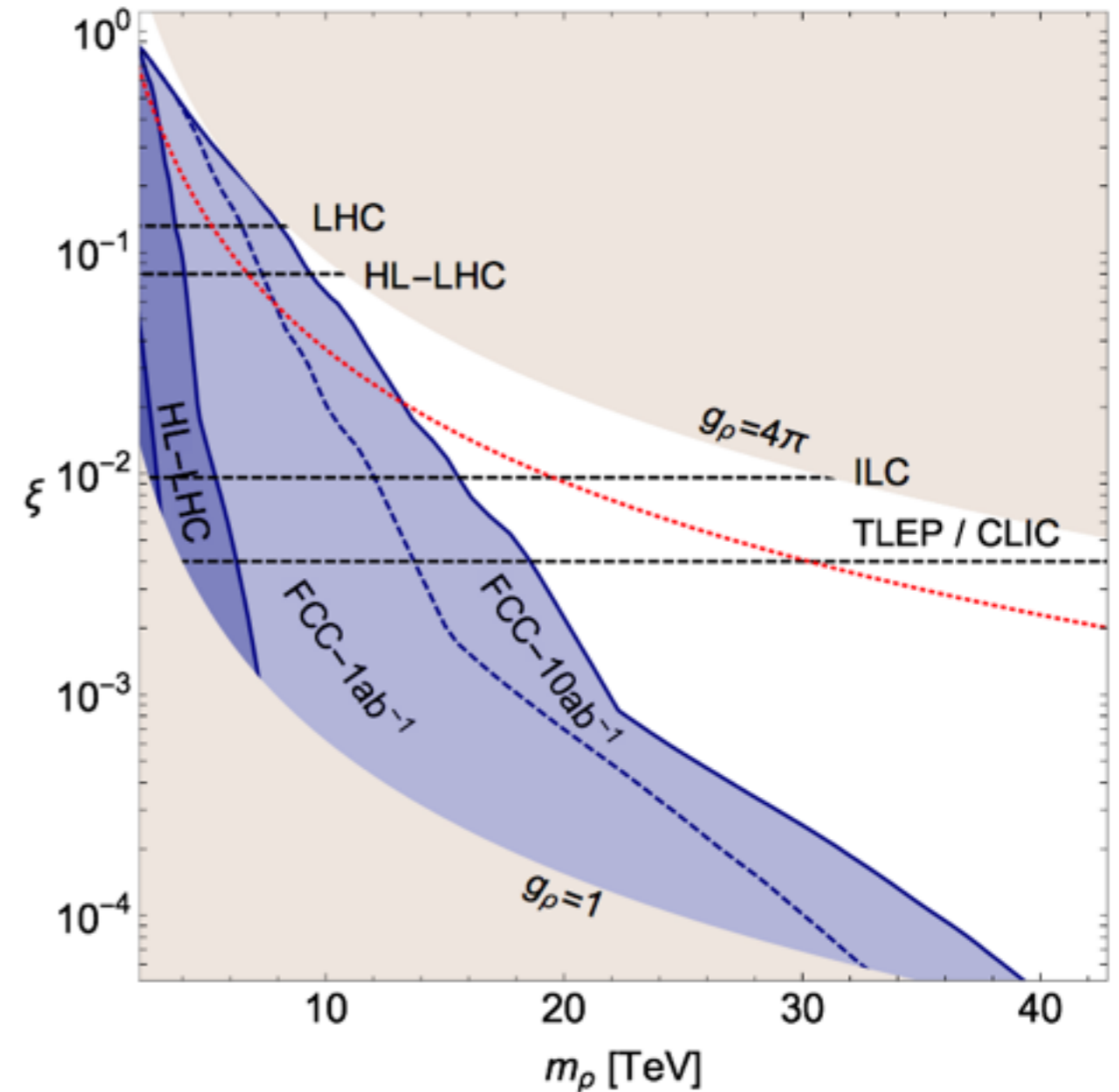
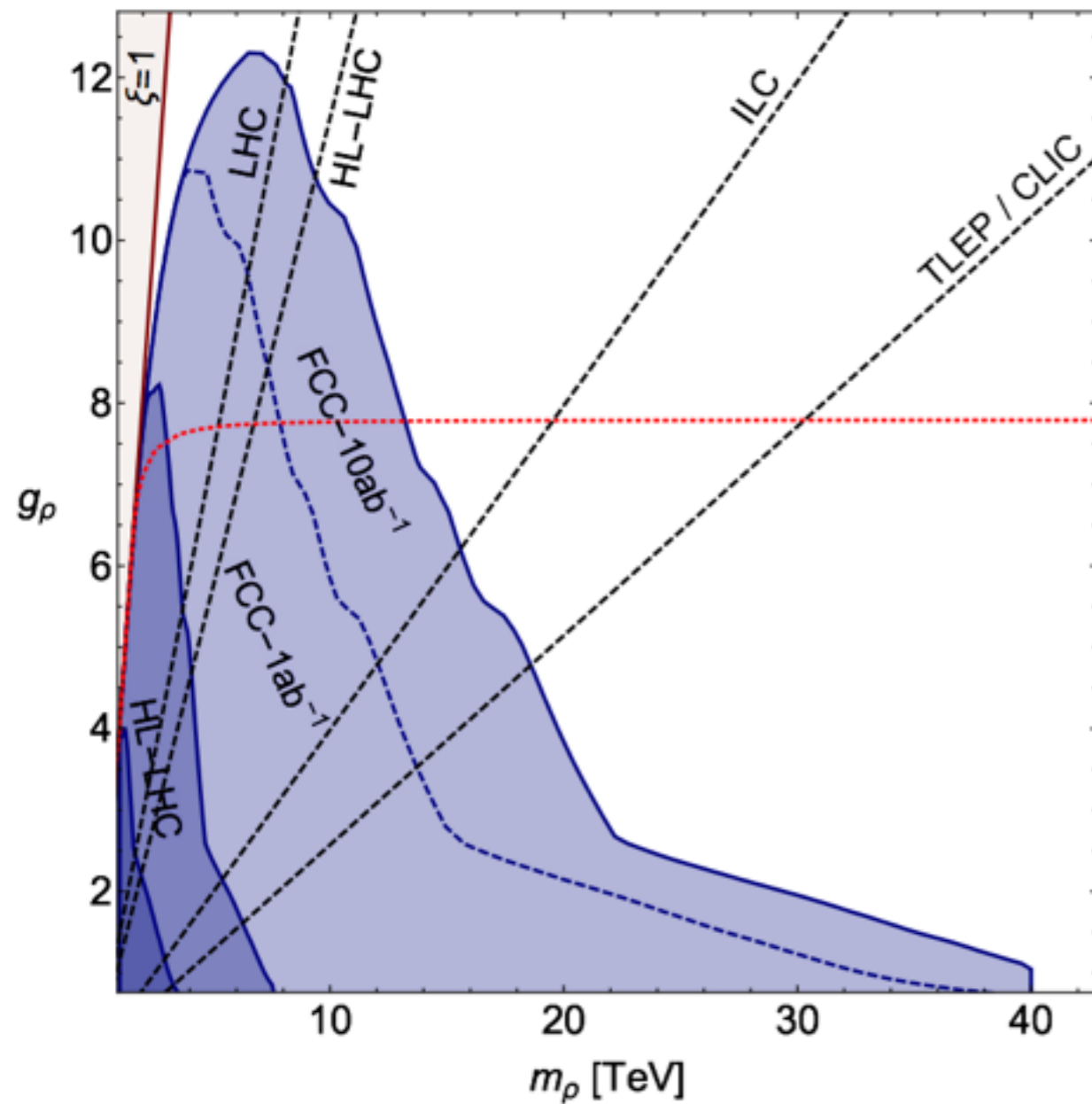
$$\sum_{\{i,j\}} c_{ij} \frac{d\mathcal{L}_{ij}}{d\hat{s}}(m_\rho; \sqrt{s}) = \frac{L_0}{L} \sum_{\{i,j\}} c_{ij} \frac{d\mathcal{L}_{ij}}{d\hat{s}}(m_\rho^0; \sqrt{s_0})$$

Extrapolation of current bounds to 100 TeV based on Background Parton Luminosities



Thamm, Torre, Wulzer, 1502.0170 [hep-ph]

COMPOSITENESS: DIRECT VS INDIRECT



High complementarity between FCC-hh and FCC-ee

Needed studies of precision at FCC-hh for a conclusive comparison between the two

Thamm, Torre, Wulzer, 1502.0170 [hep-ph]

THANK YOU