TOP & BSM STUDIES @ FCC-EE

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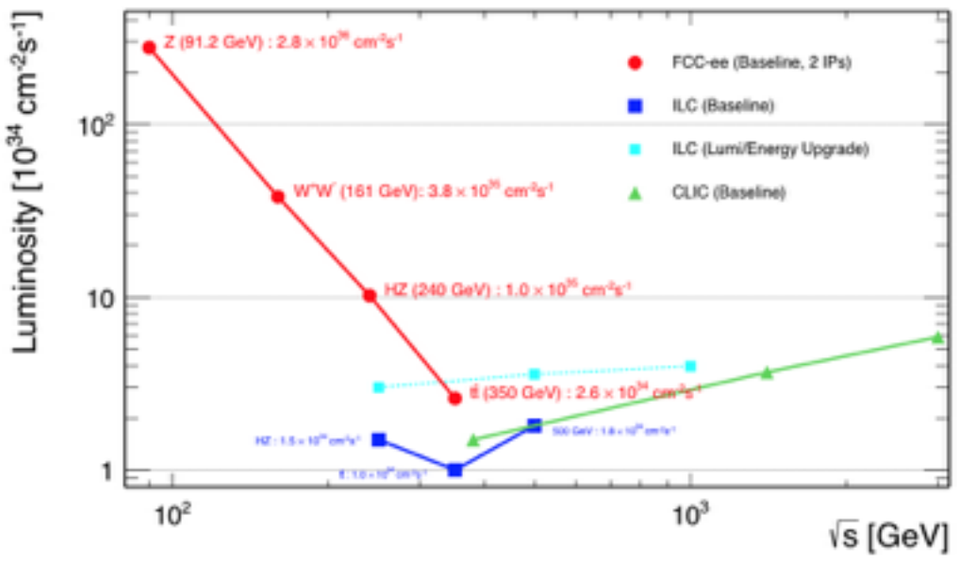
Maybe this possible at CEPC as well now? not in CDR

TOP PHYSICS AT FCC-EE

- Dedicated run of ~1.5 ab-1 at and around tt threshold @350GeV « Mega-Top »
  - 0.2 ab-1 for mass measurement from threshold scan
  - higher energy runs for top coupling measurement (ttZ,ttγ,ttH)
- Profit of the run at 240GeV (5ab-1) dedicated to HZ production for studies with single top
  - periodic returns at the Z-peak in « FCC-ee top » conditions for calibration



Strength of the FCC-ee program is the ability to span several centre of mass energies at high luminosities

Top physics comes in the program in several places

BUT WHY?

➤The SM fits need a precise knowledge of the top quark mass to enhance the sensitivity to new physics effects

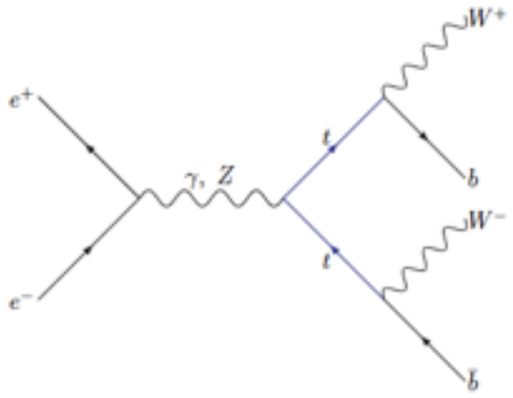
➤Top precision measurements are a **portal to new physics effects at high scales**, the clean environement and large statistics at FCC-ee will allow to probe:

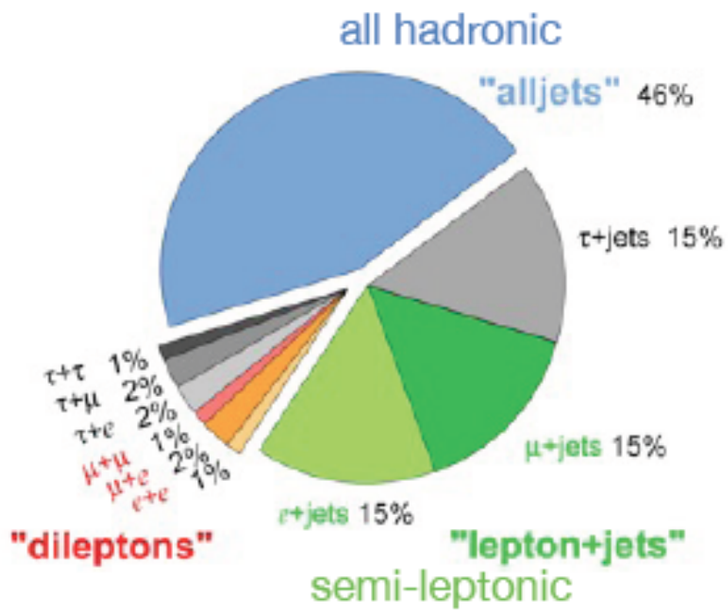
- **(anomalous) couplings**
- **indirect effects** from loop contributions
- **suppressed and rare decays**
- at FCC-ee, by construction, and at other planned lepton collider, because of the current experimental limits, the window for direct production of heavier new physics objects is tiny
- standing on the shoulders of LHC-Run2 results for possible direct discovery of new particles in the TeV range
  - next machine allowing direct searches for multi-TeV objects will be the FCC-hh

TOP PRODUCTION & DECAY

➤Top physics analysis is driven by production and decays modes

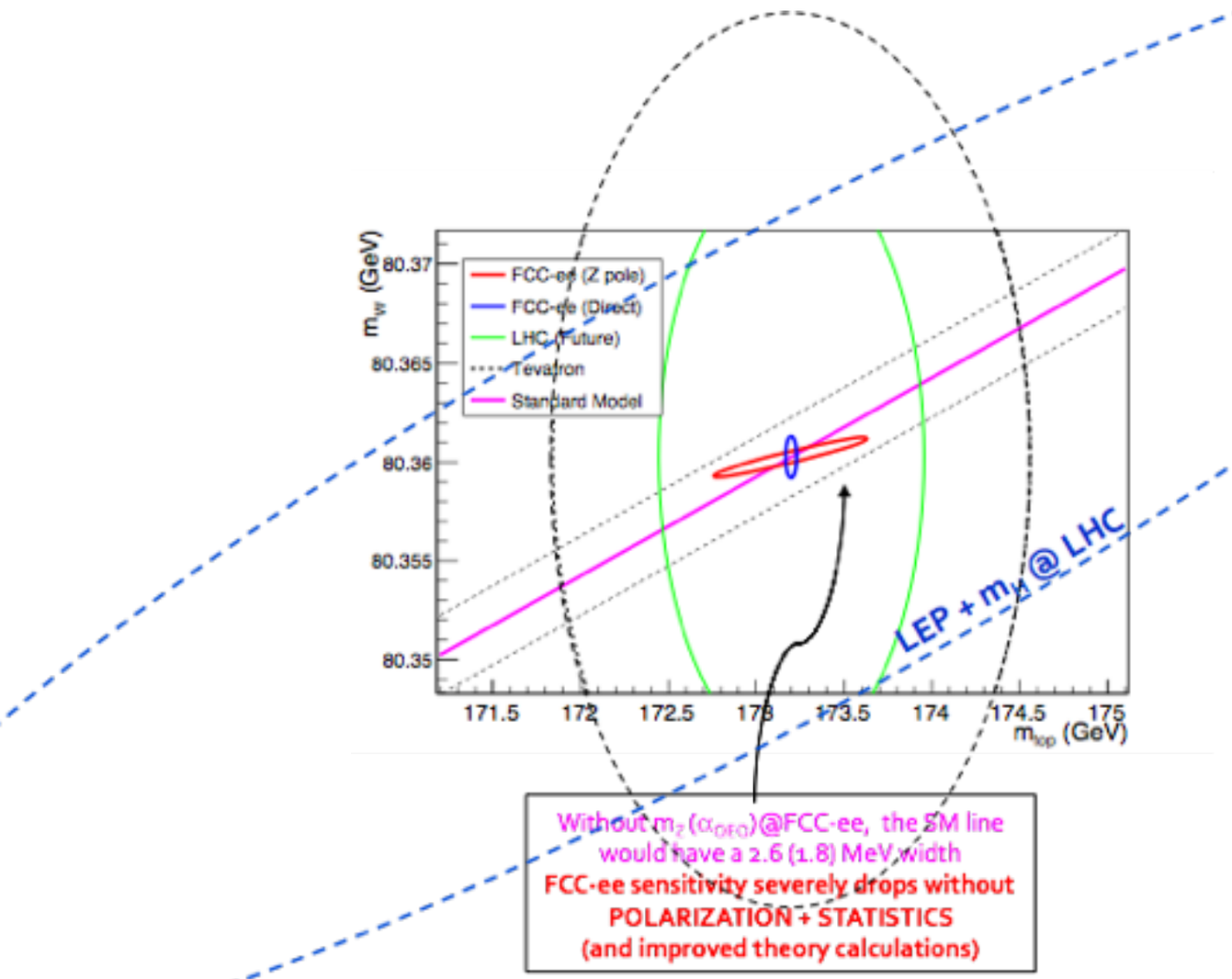
- at lepton collider running close to threshold (or above), pair production dominates



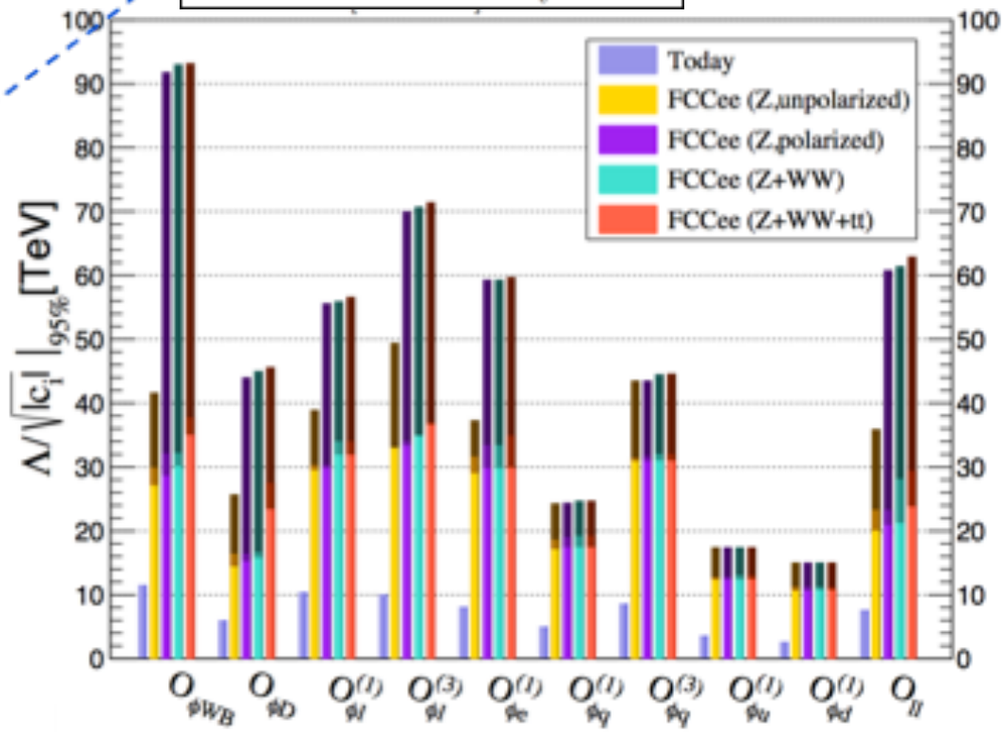


- The decay ~100% BR in Wb
  - final states classified on the basis of the Ws decay
- at lower center of mass energies can profit of (anomalous) production of single top
  - SM cross section is tiny and basically impossible to disentangle from pair production at ee colliders

PROSPECTIVES EWK T-W FITS AFTER FCC-EE



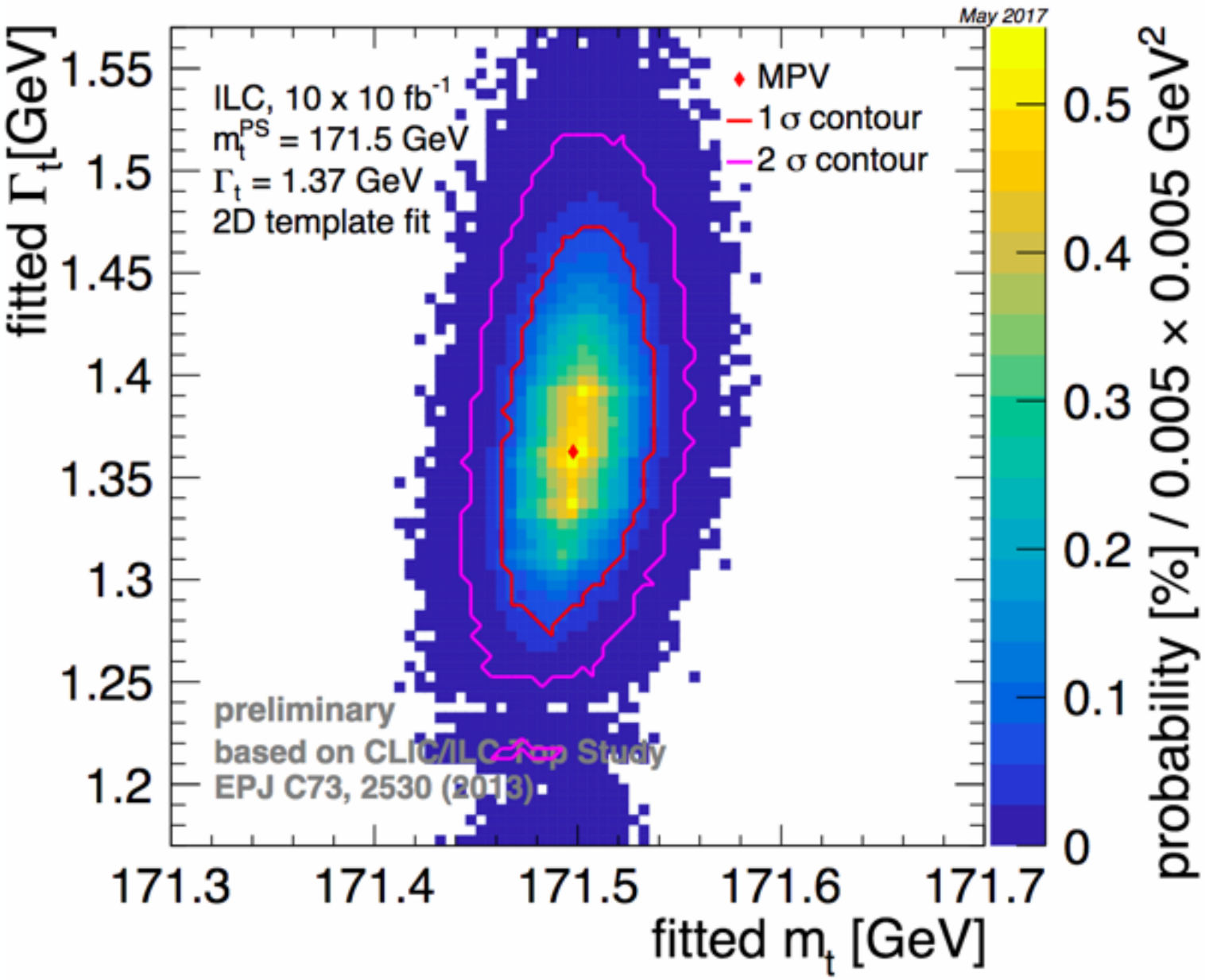
$$\mathcal{L}_{\rm SMEFT} = \mathcal{L}_{\rm SM} + \sum_i \frac{c_i}{\Lambda^2}\mathcal{O}_i$$



- Improvements in m_{top}, α_S, M_W at FCC-ee will improve understanding consistency SM in top-W-H radiative corrections
- Sensitivity for NP scale extended up to 100 TeV

FROM FRANK SIMON

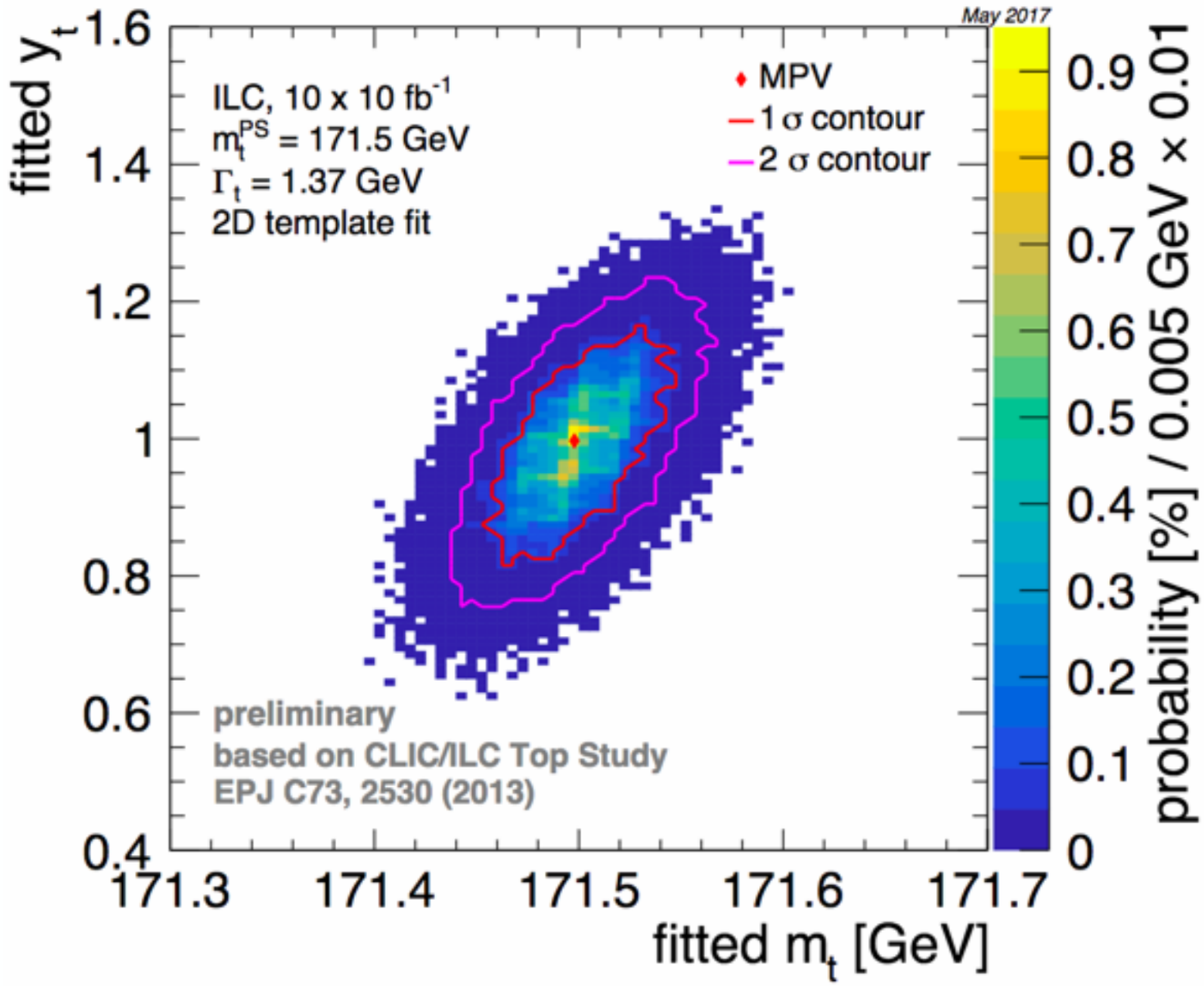
Mass & Width: 2D Template Fit ILC, CLIC, FCCee



- 1D mass resolution (assuming def. Γ_t)
  18 MeV (ILC)
  21 MeV (CLIC)
  16 MeV (FCCee)
- 1D width resolution (assuming def. m_t)
  43 MeV (ILC)
  51 MeV (CLIC)
  37 MeV (FCCee)
- Extension of 1 σ contour:
  m_t +39 -35 MeV
  Γ_t +90 -45 MeV **(ILC)**
  m_t +40 -45 MeV
  Γ_t +130 -95 MeV **(CLIC)**
  m_t +35 -30 MeV
  Γ_t +95 -65 MeV **(FCCee)**

FROM FRANK SIMON

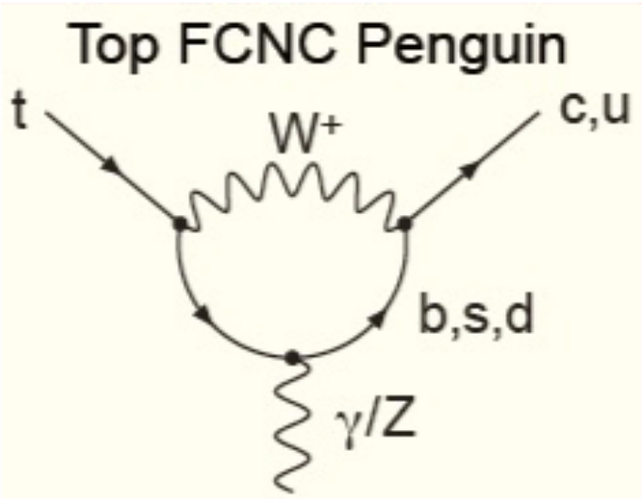
Mass & Yukawa: 2D Template Fit ILC, CLIC, FCCee

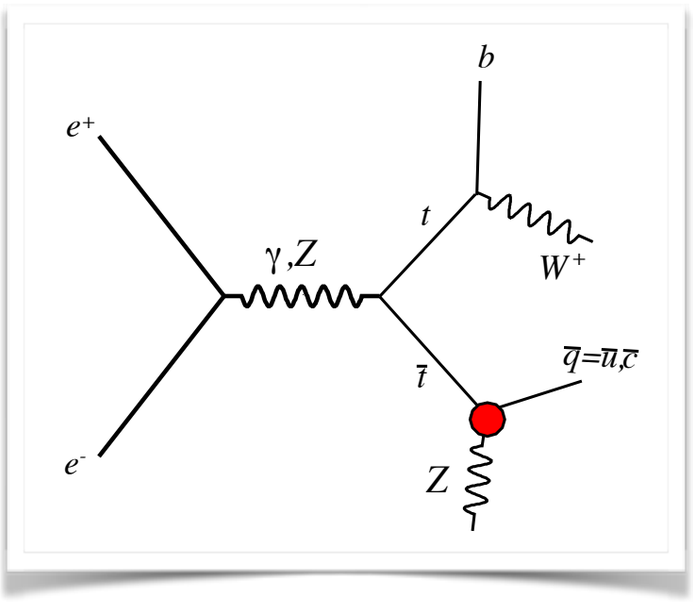


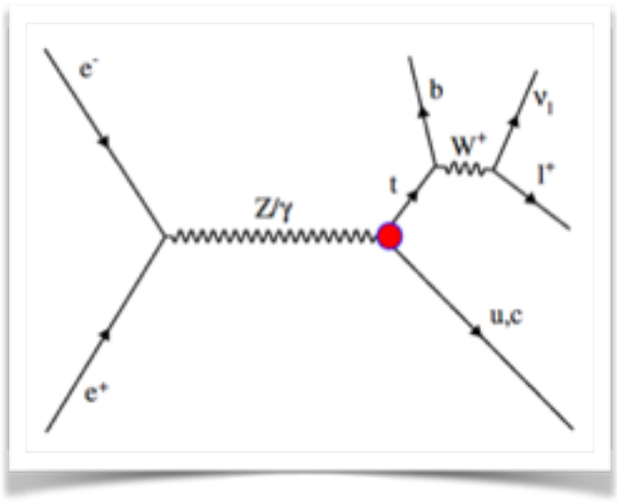
- 1D mass resolution (assuming def. y_t)
  18 MeV (ILC)
  21 MeV (CLIC)
  16 MeV (FCCee)
- 1D Yukawa resolution (assuming def. m_t)
  0.067 (ILC)
  0.067 (CLIC)
  0.057 (FCCee)
- Extension of 1 σ contour:
  m_t +49 -45 MeV
  y_t +0.168 -0.182 **(ILC)**
  m_t +55 -50 MeV
  y_t +0.168 -0.182 **(CLIC)**
  m_t +40 -36 MeV
  y_t +0.130 -0.140 **(FCCee)**

FCNC IN TOP PRODUCTION AND DECAY

- FCNC in the SM are forbidden at tree level and only allowed via higher order corrections: strongly suppressed.
  - Can be strongly enhanced in BSM models
- At the FCC-ee they can be studied:
  - at decay vertex in pair production at √s=350 GeV
  - at production vertex in single top events at √s=240 GeV and √s=350 GeV







Process	SM
$t \to Zu$	7×10^{-17}
$t \to Zc$	1×10^{-14}
$t \to gu$	4×10^{-14}
$t \to gc$	5×10^{-12}
$t \to \gamma u$	4×10^{-16}
$t \to \gamma c$	5×10^{-14}
$t \to hu$	2×10^{-17}
$t \to hc$	3×10^{-15}

FCNC IN TOP PRODUCTION AND DECAY

- Studies performed for tqZ-tqγ in single top production at √s=240+350 GeV in single lepton and all hadronic final state

$\sqrt{s} = 240$ GeV	l+jets, 5 ab-1	all-had, 5ab-1
$Br(t \to q\gamma)$	2.84×10^{-5}	1.5×10^{-4}
$Br(t \to qZ)$ $(\sigma_{\mu\nu})$	3.45×10^{-5}	3.9×10^{-4}
$Br(t \to qZ)$ (γ_{μ})	7.09×10^{-5}	1.9×10^{-4}

$\sqrt{s} = 350$ GeV	l+jets, 1.5 ab-1
$Br(t \to q\gamma)$	1.39×10^{-5}
$Br(t \to qZ)$ $(\sigma_{\mu\nu})$	1.99×10^{-5}
$Br(t \to qZ)$ (γ_{μ})	7.45×10^{-5}

H. Khanpour, S. Khatibi, M. Khatiri,
M. M. Najafabadi arXiv: 1408:2090
B. Mele, S. Biswas

Very preliminary studies, large potential to achieve competitive limits. Big challenge coming from HL-LHC. Profits of synergy of 240 GeV and 350 GeV running

SUMMARY TABLE OF PLANNED STUDIES FOR CDR

- very strong competition from HL-LHC on this topic (now it's a tie). We believe LC can still be competitive, but needs to be proven as a physic case.
  - Need to evaluate better the statistical but also the systematic power.
- Assumption: to have a single anomalous vertex in the event (either production or decay). Combine all possibilties properly.
- Collaborating groups: IPN Teheran, CLIC (Naomi Van Der Kolk)
- All analyses are being redone for FCCee CDR. Some with FullSim from CLIC, some with Delphes if we don't manage in time.

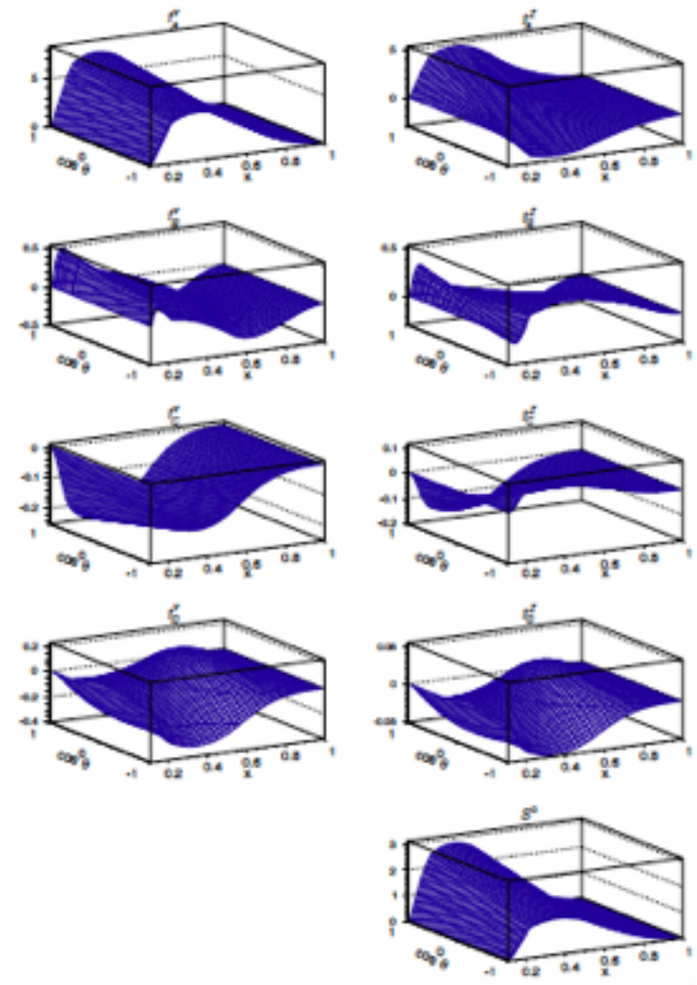
	@240 GeV Single top production	@350 GeV Single top production	@350 GeV pair top production
tqγ/tqZ l+jets final state	DONE	DONE	exists from CLIC/ILC
tqγ/tqZ all-jets final state	DONE	in progress	exist from CLIC
tcH/tqH	—	—	exists @500 In progress with ILC
tqg	—	—	exists @500

ELECTROWEAK COUPLINGS OF THE TOP QUARK (1)

- ttZ, ttγ couplings can be enhanced in extra dimensions and (particularly) composite Higgs models
  - Directly probed in the tt production process at FCC-ee
- Profit of the fact that top polarization information is maximally transferred to its final state particles via the weak decay
- Use lepton energy and angular distributions in top decay to disentangle ttZ from ttγ in l+jets
  - Sensitivity investigated in optimal observable analysis (confirmed by full simulation analysis)

Foppiani, Janot, Pajero

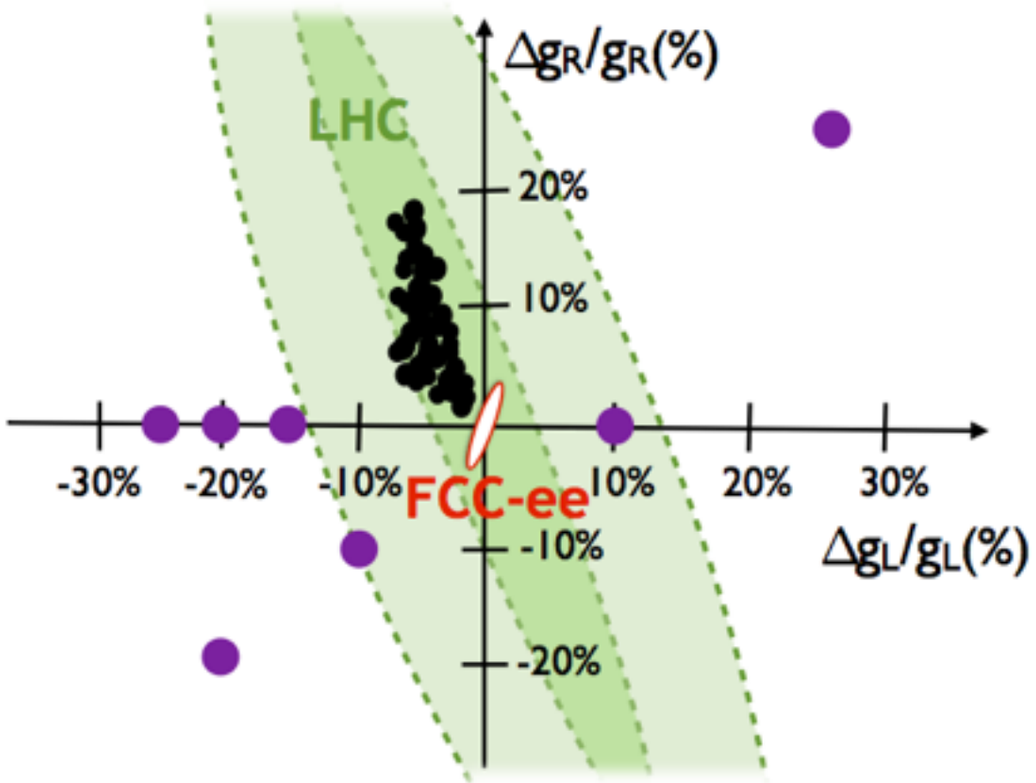
P. Janot arXiv: 1503.01325

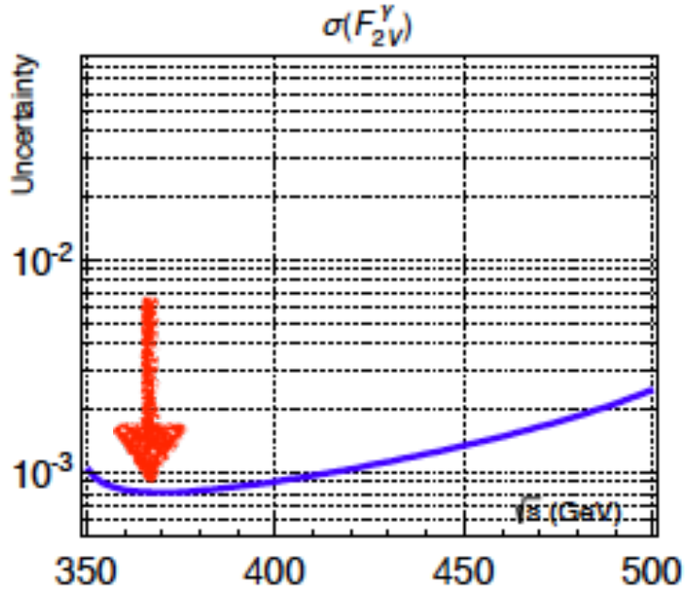


Standard Model

ELECTROWEAK COUPLINGS OF THE TOP QUARK(2)

- Large statistics and final state polarization allow a full separation of the ttZ/γ couplings with **NO need for polarization in the initial state.**
- **Optimal √s= 365-370 GeV**





- Fit includes conservative assumptions detector performance
- Theory uncertainty on production mechanism dominates

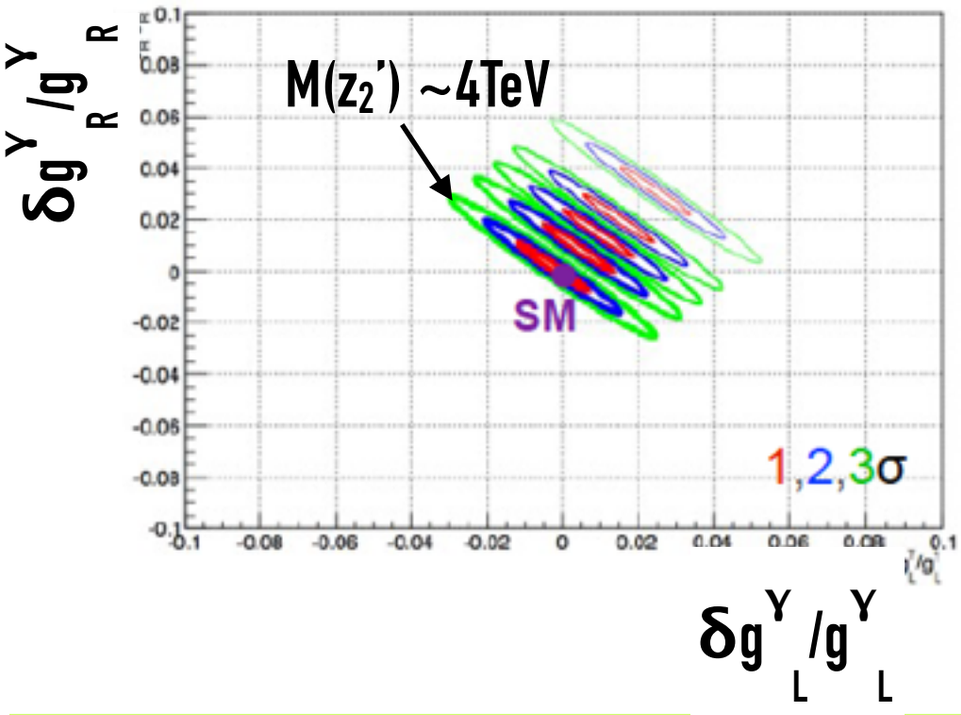
FCC-ee expects precision of order 10^{-2} to 10^{-3}

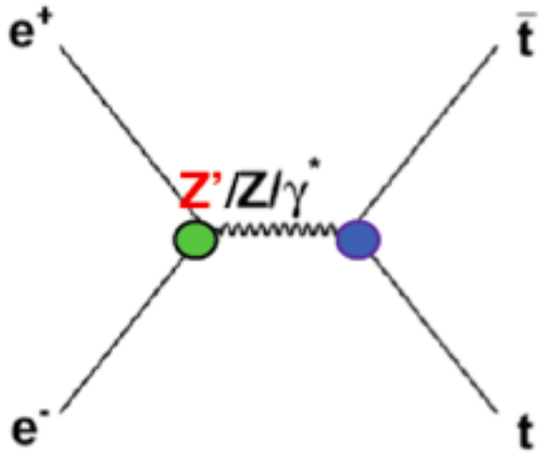
BSM POTENTIAL: COMPOSITE HIGGS MODEL

➤The CHM modification of the process arise via 3 effects:

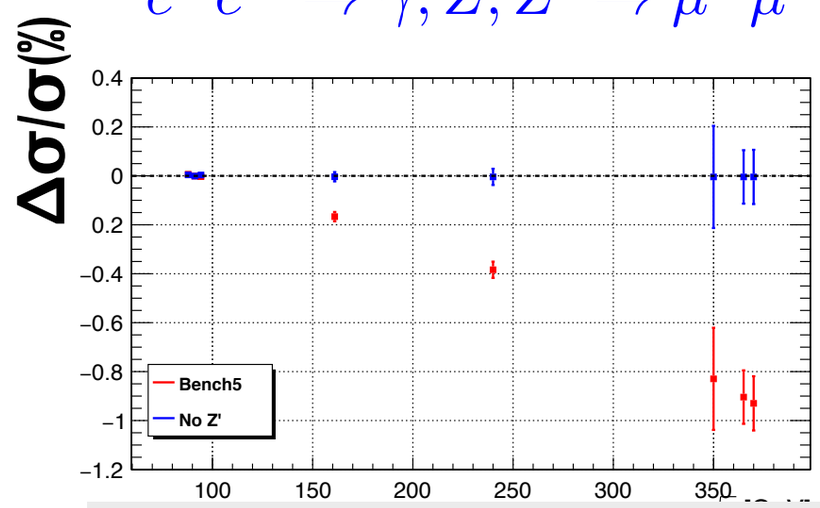
- ➤ modification of the Zee coupling (negligible)
- ➤ modification of the Ztt coupling from mixing between top and extra fermions, mixing between Z and Z's
- ➤ s-channel exchange of the Z's (interference)

Barducci, De Curtis,Moretti, Pruna 1311.3305





$e^+e^- \to \gamma, Z, Z' \to \mu^+\mu^-$



One more step!
By combining muon cross-sections and A_{FB} with the top optimal observables **the model can be fully characterized @FCCee**

With FCC-ee precision sensitivity up to 4TeV Z' mass

CONCLUSIONS

- the top physics program at FCCee is extremely rich due to:
  - the very high luminosity that can be collected
  - the possibility of runs at different(optimal) √s
- the measurement of the main parameters of the SM with unprecedented precision is a priority:

top mass precision at 10MeV | ttZ/ttγ couplings at ~% | indirect ttH coupling

- the opportunities offered for indirect effect of new physics in rare/forbidden/ FCNC processes are extremely interesting

sensitivity to CHM m(Z')~4 TeV | FCNC limits on tq(c)Z ~10^{-4}/10^{-5}

- These preliminary studies show that FCC-ee is able to achieve excellent precision on fundamental Top related measurements while:
  - **very large √s energy running is not needed**
  - **beam polarization is not needed**

ADDITIONAL PLANS & STUDIES FOR CDR

- Ongoing studies (not presented here) that will be included in the CDR:
  - **Top mass @threshold**: extract a new measurement with the native FCC software
    - *Optimization of scan points: N. Foppiani still helping but will be leaving Italy*
  - New estimate for precisions on **width** and indirect extraction of the **Yukawa coupling** from threshold scan
    - *F. Simon from CLIC confirmed help for CDR*
  - Update and optimize the **FCNC** analysis for l+jets and all-hadronic for the **tqZ/γ vertex** with some estimate of systematics as well.
    - Add the FCNC analysis for **tcH** vertex
      - *New help from CLIC analyzers (N. Van Der Kolk)*
  - Continue the potential for **characterization of BSM models** via precision top measurement
    - *Work from S. De Curtis/Moretti/Janot … anything else?*
- *Can add detector studies using top final states.*