Top physics at FCC

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On behalf of the FCC study group

ICHEP 2018, Seoul

Outline

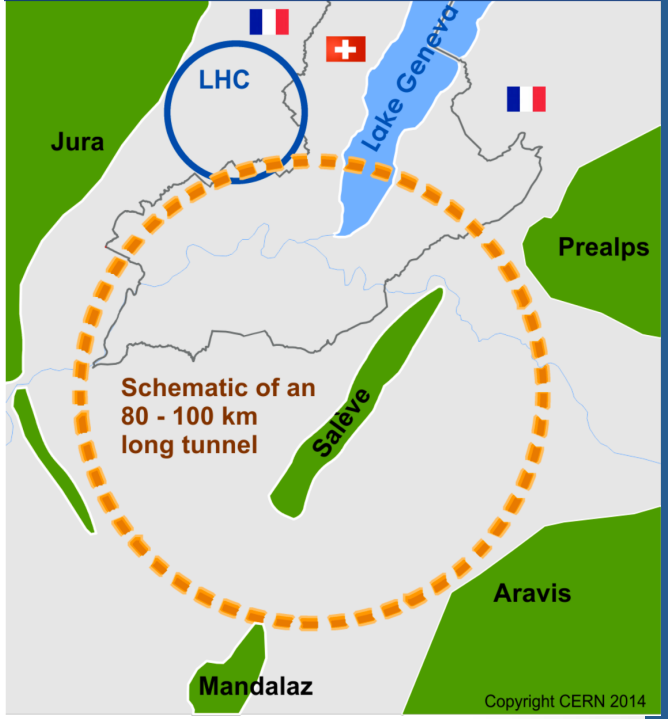
- FCC in a nutshell
- Top physics at FCC-ee
  - Generalities
  - Threshold scans
  - Electroweak couplings, Electroweak fits
  - FCNC
- Top physics at FCC-hh
  - Generalities
  - Boosted topologies
  - FCNC
- Summary

FCC scope

- FCC: 100km tunnel in the Geneva area

- FCC-hh:
  - √s =100TeV -> Needs 16T magnets
  - Heavy resonances up to m ≈ 40 TeV
  - Stops up to m ≈ 10TeV
  - Higgs self-coupling, rare decays
  - EWK, Top physics in extreme regimes

- FCC-ee
  - √s = 90 to 365GeV
  - 20 to 50 fold improvements in many SM parameters
  - Higgs width, DM as invisible decay of H
  - BSM through loops
  - Explore energy scales to ~10TeV scale



Schedule and physics program of both machine in perfect synergy

Top @ FCC-ee

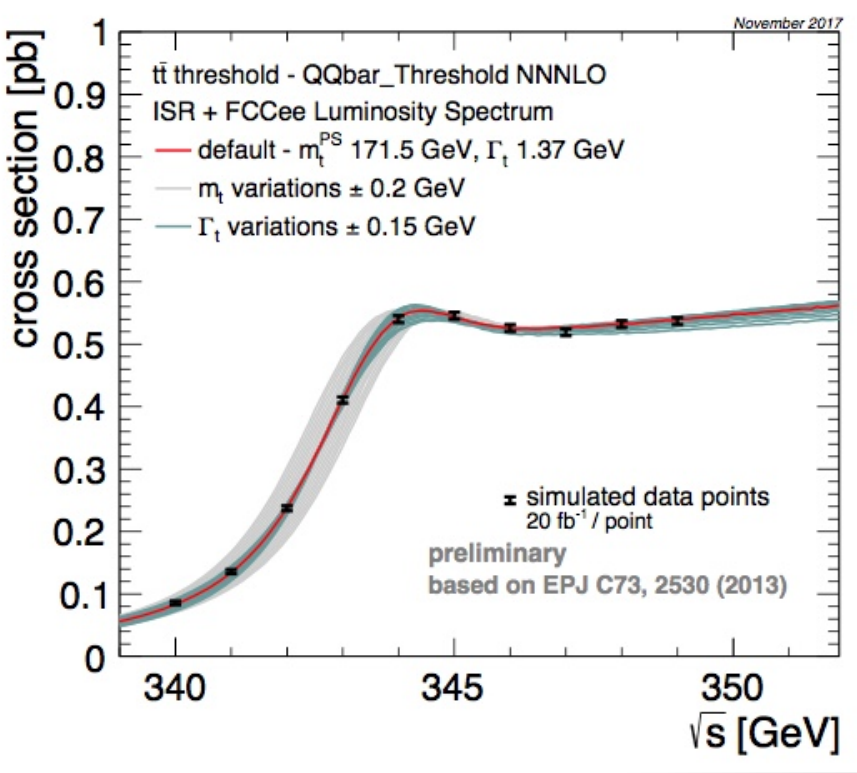
Top physics at FCC-ee

first time top quark will be seen at lepton collider giving sensitivity to production modes that are currently unavailable

- Running conditions
  - Dedicated run of ~1.5 ab^{-1} at and around tt threshold @350GeV
    - 0.2 ab^{-1} for measurement threshold scan
    - 365GeV runs for top coupling measurement (ttZ,ttγ,ttH)
- Statistics
  - Cross-section at threshold ~0.55pb
  - With 0.2+1.5ab^{-1} (6 years) ~ 10^6 high purity top-pair events
- Top measurements
  - Precise measurements, coupled with precise Theo. Calc. -> excellent discovery potential
  - Portal to new physics effects at high scales
  - Clean environment and large statistics at FCC-ee will allow to probe:
    - Anomalous couplings
    - Indirect effects from loop contributions
    - Suppressed and rare decays (from very clean final states)

Top at threshold scan

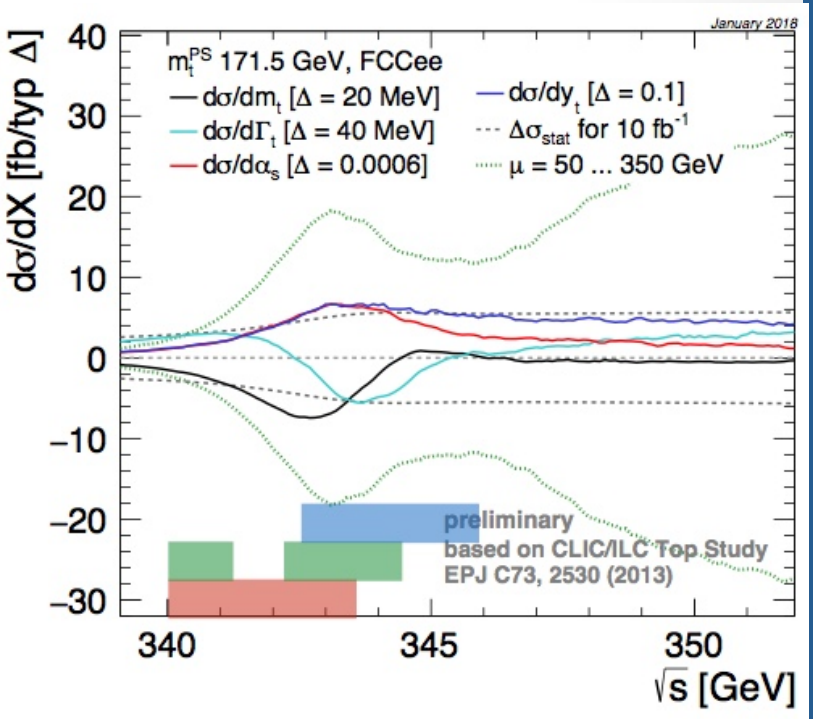
- Cross section at threshold
  - Highly sensitive to quark mass, width, α_s and Y_t
  - Can be calculated with high precision
- Measurement of the top pair prod. cross section
  - Different energy points in the threshold region
  - Other observables, top momentum, A_{FB} may increase sensitivity
- Default assumption
  - Each energy point with equal int. luminosity
  - Optimal way to distribute the integrated luminosity depends on the variables



Top at threshold scan

- Derivative of the cross section
  - For various parameters
  - Normalised to typical changes of these parameters

- Uncertainties
  - Theory uncertainty from scale variations lead to ~ 45MeV systematic on the top quark mass
  - Scale uncer. are roughly equivalent to a 3% luminosity uncertainty ->
    Needs to be known on the few per mille
  - Beam energy leads to an effective shift of the curve which directly translates to mass value.
    Goal < ~10 MeV



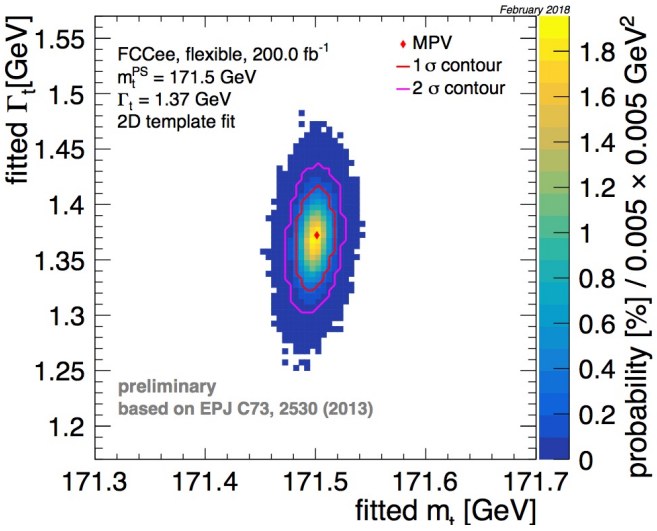
Sensitivity to

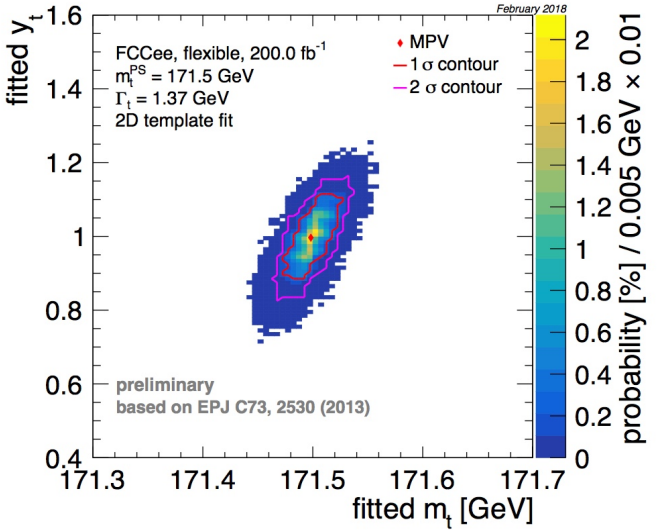
Top width and mass

- 2D Mass & Width fit
  - mass: +16.6, -18.8 MeV
  - width: +45, -50 MeV
  - Theory uncertainty (symmetrized): mass: 45 MeV; width: 36 MeV

- 2D Mass & Yukawa fit
  - mass: +29 MeV, - 26 MeV
  - y_t: +0.12, -0.11
  - Theory uncertainty (symm.): mass: 36 MeV; y_t: 0.11
  - α_s parametric uncertainty (2.10^{-4}): mass: 3MeV; y_t: 0.02

Summary With 0.2 ab^{-1}
Achieve Uncertainty
Top mass 45MeV
Top width 17MeV





- Precise exploration of top properties with small theo. uncertainties
- With FCC-ee α_s precision the corresponding uncertainty is negligible

F.Simon talk FCC week2018

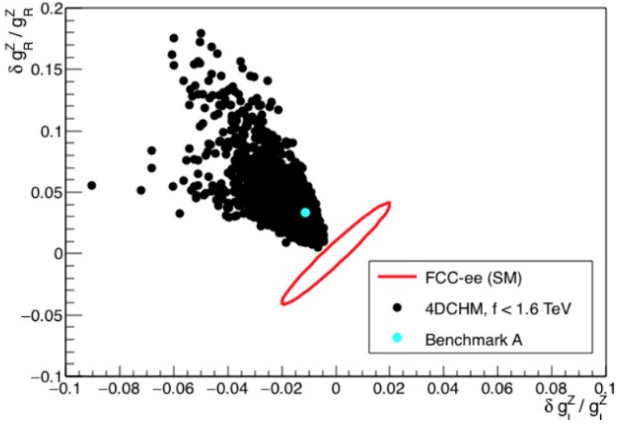
Top electroweak couplings

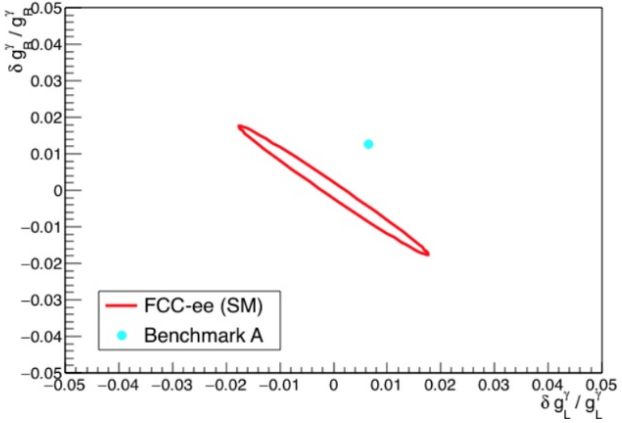
arXiv:1503.01325
And soon FCC CDR

- ttZ, ttγ couplings
  - Enhanced in extra dimensions, composite Higgs models
  - Directly probed in the tt production at FCC-ee

- 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 ~ 365GeV

- Fit includes conservative assumptions detector performance
- Theory uncertainty on production mechanism dominates
- FCC-ee expected precision of order 10^{-2} to 10^{-3}

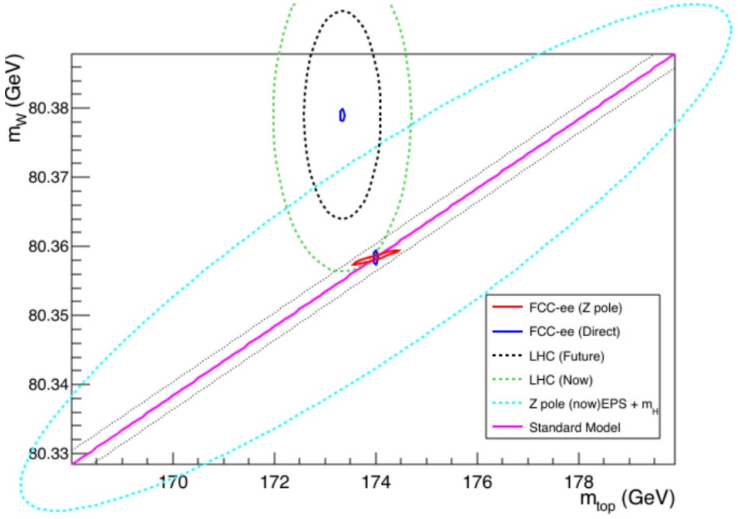


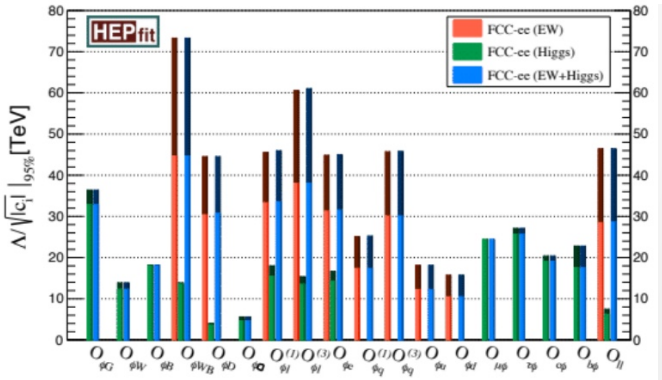


Prospective EWK t-W fits after FCC-ee

- Fit at the Z pole considering theo. uncertainties match experimental
- Improvements in m_t, α_S, m_W
  - FCC-ee will improve understanding and consistency of the SM in top-W-H radiative corrections
- Sensitivity for NP scale extended up to 70 TeV

Soon In the FCC CDR



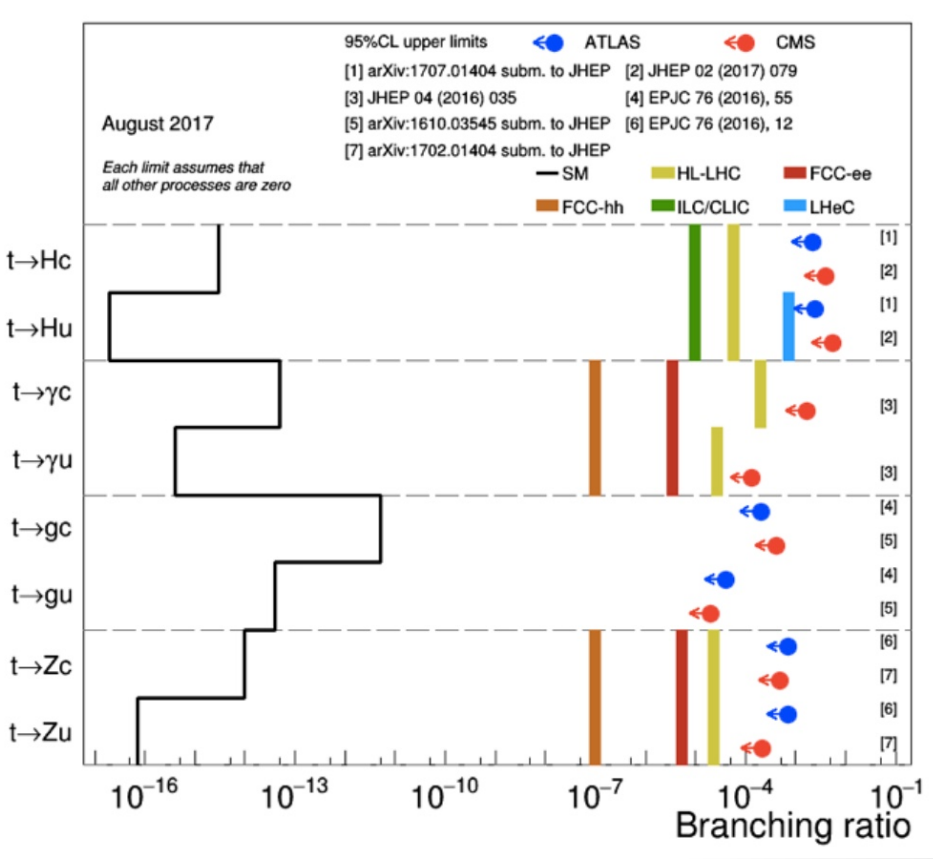


Top FCNC

Soon In the FCC CDR

- FCNC in the SM
  - Are forbidden at tree level
  - Only allowed via higher order corrections
  - Strongly suppressed is SM below 10^{-12}
  - Can be strongly enhanced in BSM models

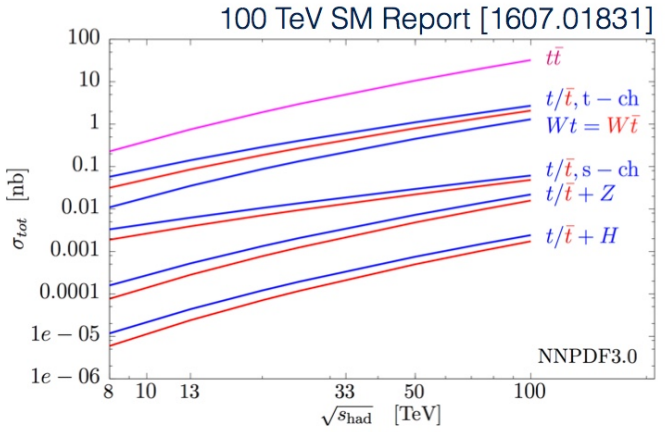
- At the FCC-ee they can be studied:
  - At decay vertex in pair production at $\sqrt{s}$=350 GeV
  - At production vertex in single top events at $\sqrt{s}$=240 GeV and $\sqrt{s}$=370 GeV
  - FCNC limits on tqϒ/tqZ $10^{-4}/10^{-5}$

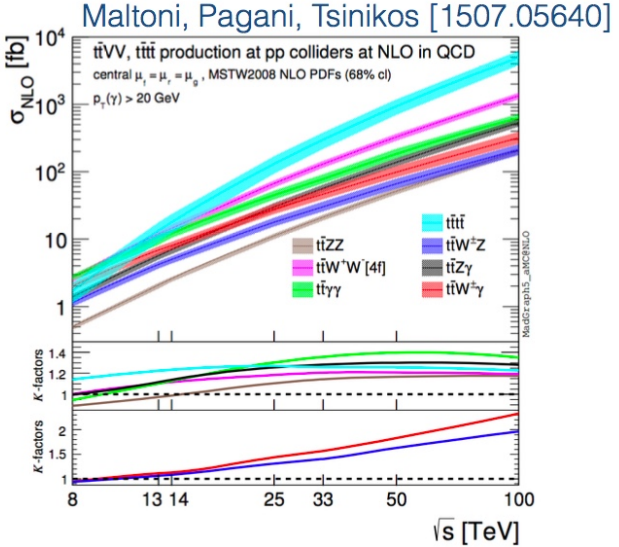


Top @ FCC-hh

Top production hh

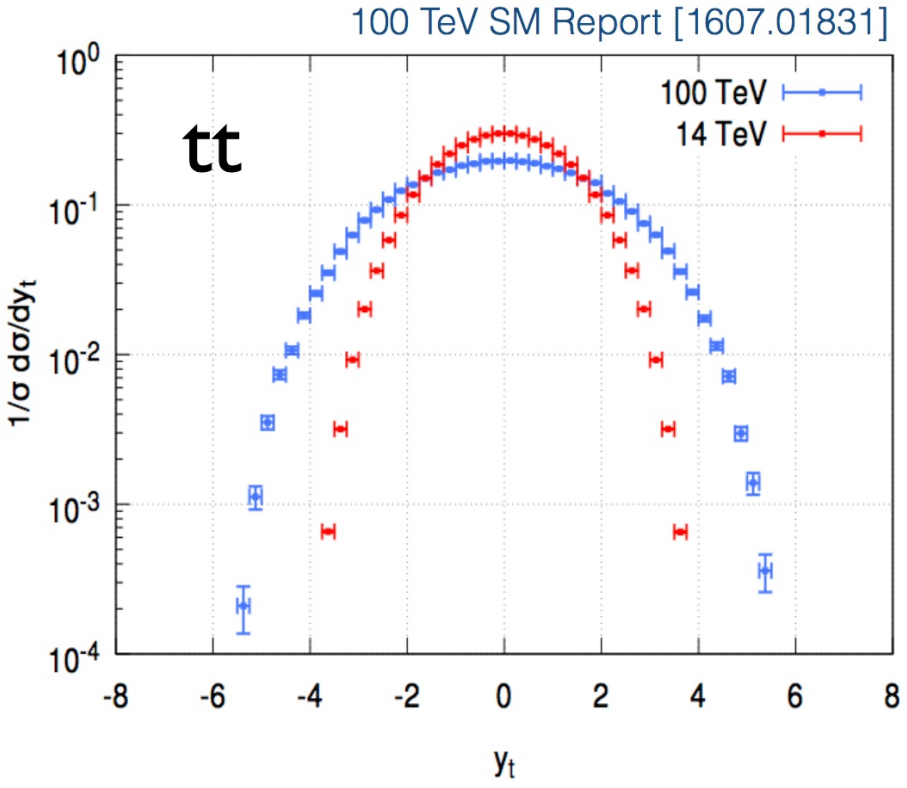
- At 100TeV dominated by gluon-gluon fusion
- Top pair cross section
  - 45 times larger than @13TeV
- With 20ab^{-1}
  - ~10^{13} top pairs -> ~10^{13} W's / b's
  - ~10^{12} tau (rare decays, CPV)
- For m_{tt}>15TeV
  - qq production dominates
  - ~20k events with 20 ab^{-1}
  - Interesting for new physics at high m_{tt}
- 4-top cross-section increase by ~1000





Top kinematics

- At high Q^2
  - can study the rapidity dependence
- @100TeV Top quarks
  - Tend to be produced at larger rapidity than at 14 TeV
  - Suggests that the top quarks at 100 TeV will be a copious source of large-rapidity lepton
- Make sure detectors cover well these regions



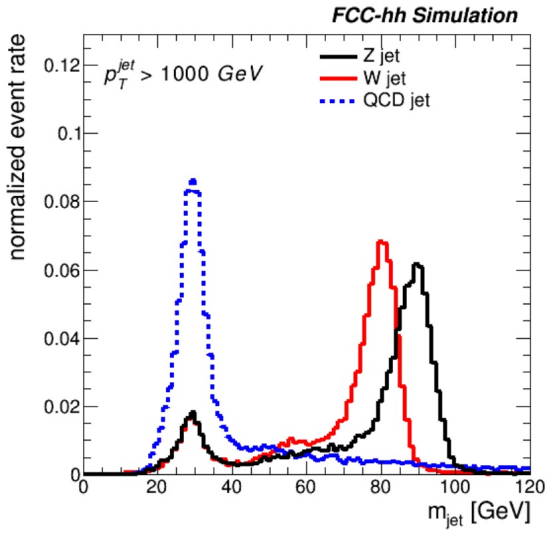
Boosted Top

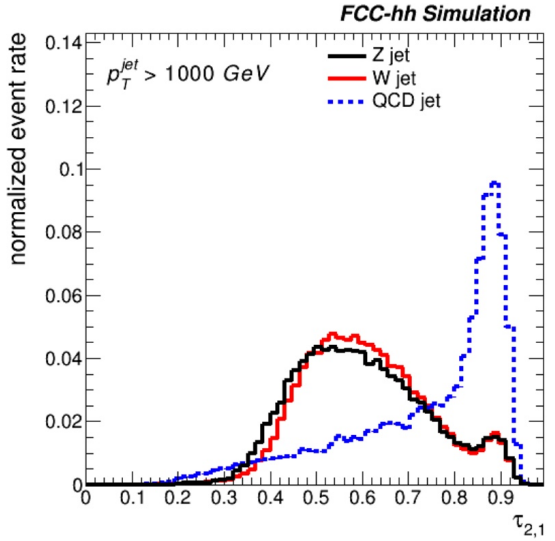
- Boosted two body decay from massive object has
  - typical angular size $\Delta R \sim 2m/p_T$
- Top-quark
  - LHC: $p_T \sim 1$TeV $\rightarrow \Delta R = 0.5$
  - FCC: $p_T \sim 10$ TeV $\rightarrow \Delta R = 0.05$
- W/Z bosons:
  - LHC: $p_T \sim 1$TeV $\rightarrow \Delta R = 0.25$
  - FCC: $p_T \sim 10$ TeV $\rightarrow \Delta R = 0.025$
- Factor of 10 in granularity!

- Detector resolution FCC
  - Tracking $\rightarrow \Delta R = 0.001$
  - ECAL $\rightarrow \Delta R = 0.01$
  - HCAL $\rightarrow \Delta R = 0.05$
  - Hit fundamental “conventional” calorimeter limit at extreme boosts

Boosted Top jets

- Top quark carries colour charge and undergoes final state radiation
- Soft contamination (UE, ISR, PU) can produce large corrections to the top mass
- Apply grooming (pruning, soft drop, trimming)
- Results from full simulation of an FCC-hh calorimeter system
  - To be done with top
  - Use tracking to improve discrimination

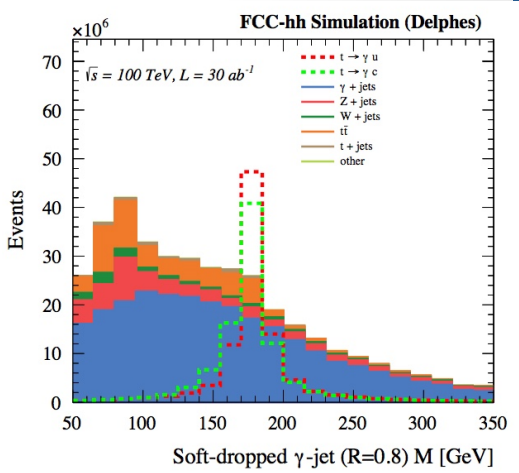


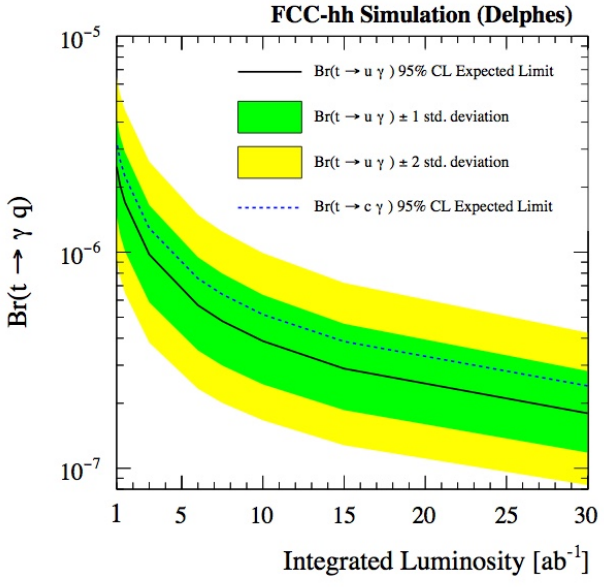


Top FCNC: tqγ

- In top decays
  - Use boosted top
  - One of them decaying to qγ
  - Good signal over background separation
  - Good mass reconstruction
- Improve existing experimental limits by 3-4 orders of magnitude

Process	Branching fraction for 30 ab^{-1} (3 ab^{-1})	Coupling strengths λ for 30 ab^{-1} (3 ab^{-1})
$t \to u\gamma$	$1.8 \cdot 10^{-7}$ $(9.8 \cdot 10^{-7})$	$6.5 \cdot 10^{-4}$ $(15.1 \cdot 10^{-4})$
$t \to c\gamma$	$2.4 \cdot 10^{-7}$ $(12.9 \cdot 10^{-7})$	$7.5 \cdot 10^{-4}$ $(17.3 \cdot 10^{-4})$





Summary

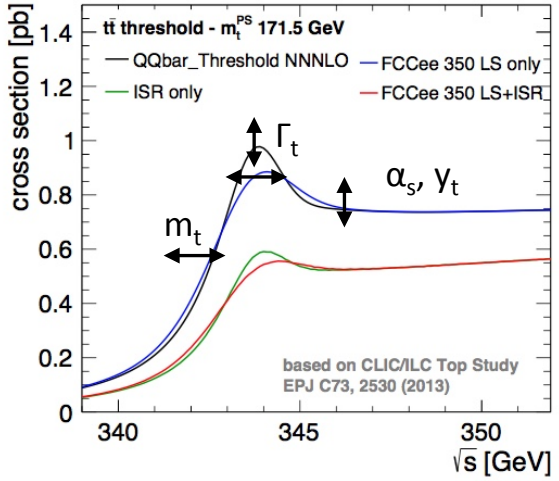
- At FCC-ee
  - Top threshold scan one of the core measurements
  - Enables the precise exploration of top quark properties, with small theoretical uncertainties
  - top mass precision at 10MeV ttZ/ ttγ couplings at few %
  - FCNC limits on tqϒ/tqZ $10^{-4}/10^{-5}$
- At FCC-hh
  - Produce tens of trillions of tops
  - Such high statistics can be used to target unexplored corners of the phase space
  - Contrary to common belief, high energy proton colliders are suitable for precision physics

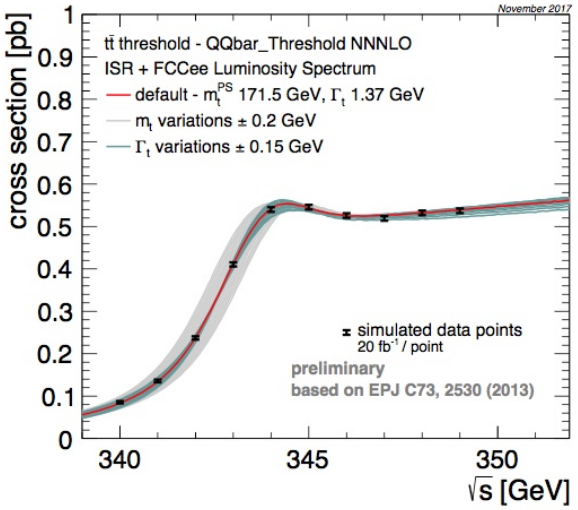
Complementarity between FCCs

Bonus

Top at threshold scan

- Cross section at threshold
  - Highly sensitive to quark mass, width, α_s and Y_t
  - Can be calculated with high precision
- Threshold shape affected by
  - Initial state radiation
  - Machine beam energy spread
- Assuming purely Gaussian energy distribution
  - With no beamstrahlungs-tail
  - Only smearing, no reduction in effective cross section
- Measurement of the top pair production cross section
  - Different energy points in the threshold region
  - Other observables, top momentum, A_{FB} may increase sensitivity

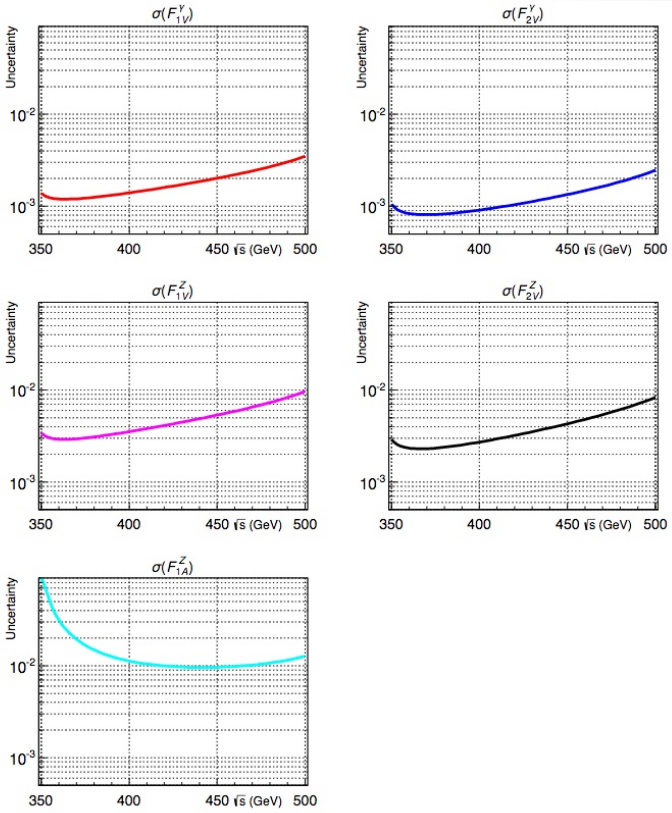




Top electroweak couplings

arXiv:1503.01325

- 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=365-370GeV
- Fit includes conservative assumptions detector performance
- Theory uncertainty on production mechanism dominates
- FCC-ee expected precision of order 10^{-2} to 10^{-3}



Top versus QCD jet tagger

Variables:
Soft dropped mass
τ32, τ21, τ1/2/3

N-subjetiness
Arxiv:1011.2268