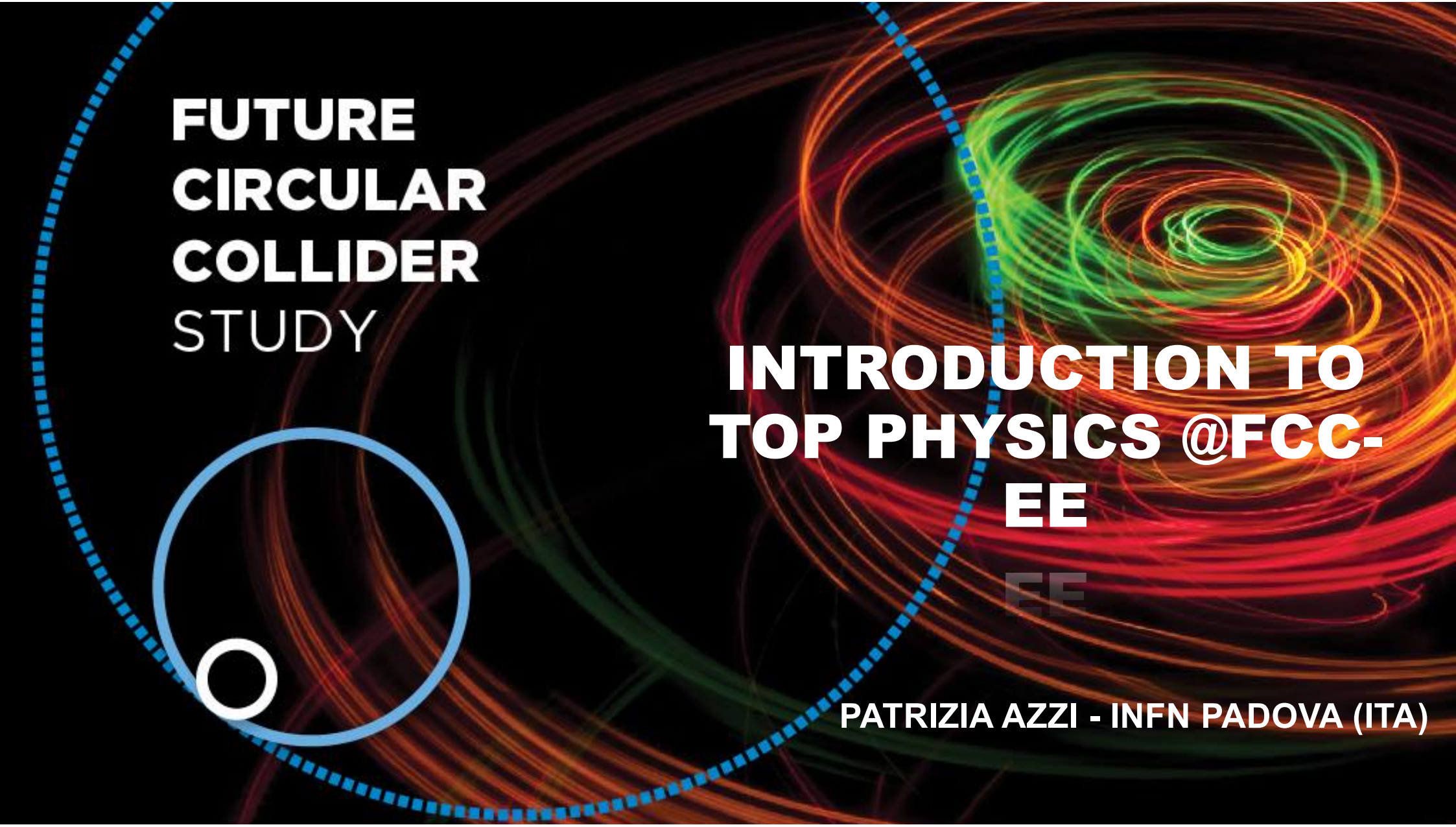
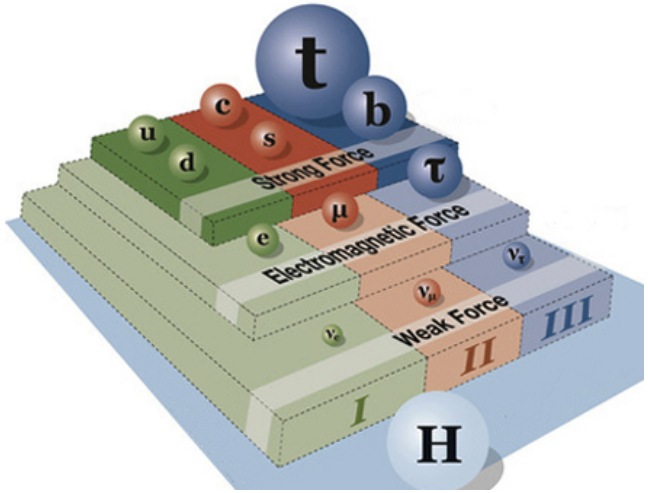
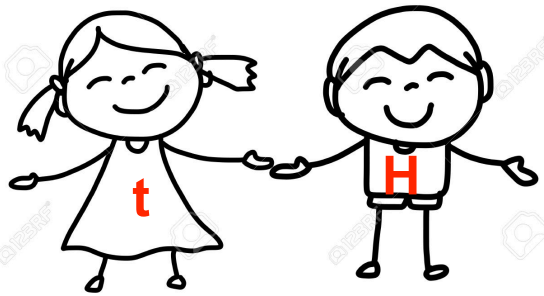

FUTURE
CIRCULAR
COLLIDER
STUDY
INTRODUCTION TO TOP PHYSICS @FCC-EE
EE
PATRIZIA AZZI - INFN PADOVA (ITA)

NEED MORE TOP PHYSICS!

- Top being the heaviest quark (and particle) in the SM is the one that most strongly influences the Higgs and its potential
- Its mass leads to a yukawa coupling of about 1. Coincidence?
- Top mass also close to the critical value between the region where the Higgs potential is stable up to the Plack scale (or not)





FCC will complete redefine the landscape of top studies and measurements: each machine providing the ultimate precision for various flagship measurements, greatly improving over HL-LHC precision studies.

THE SHOPPING LIST

- Mass and Width
- (anomalous) Couplings: y_t, g_{tWb}, g_{Ztt}, $g_{\gamma tt}$
- FCNC and rare decays

FCC-ee

- Asymmetries & other properties
- multi-top+multi-boson production
- single top measurements
- tops in the initial state (top_{PDF})
- physics with/of (hyper)-boosted tops

FCC-hh

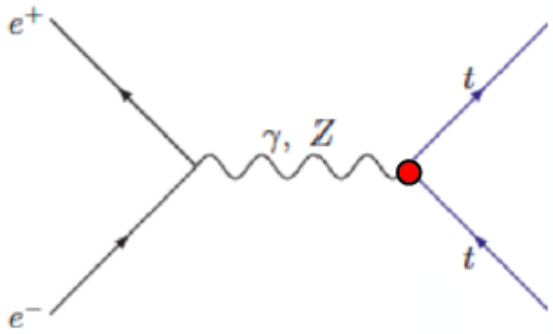
The FCC project can achieve in a coherent way the ultimate precision on measurement of top properties

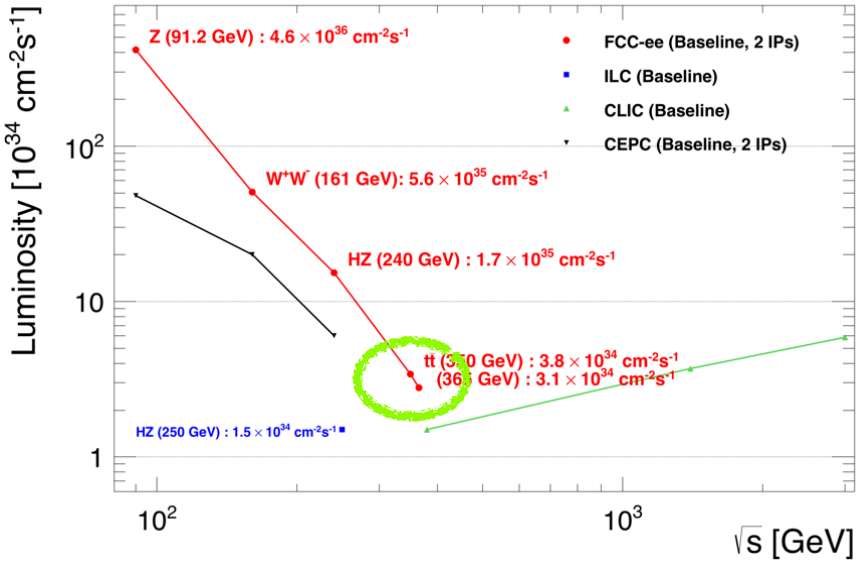
Complementary info & details in Frank Simon's talk

Not discussing here top production from decay of NP particles

HL-LHC will extend significantly the current top precision results (see YR WG1 report https://arxiv.org/abs/1902.04070) however the FCC projects goes order(s) of magnitudes beyond in precision and can reach completely unexplored parameter space.

TOP PROGRAM @FCC-EE



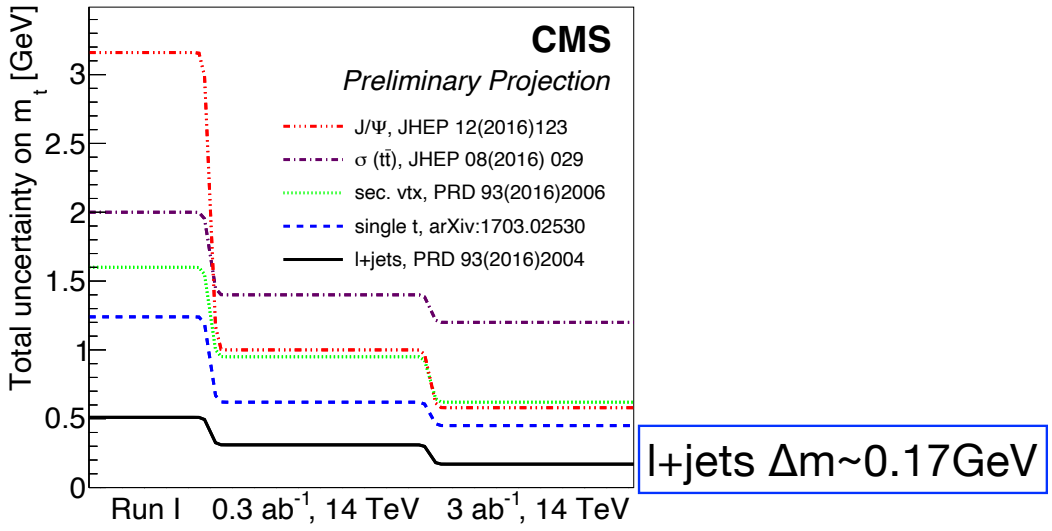


- Run of ~1.5 ab^{-1} above tt threshold @365GeV (Mega-Top) for top properties measurement
- Dedicated energy scan of 0.2 ab^{-1} at tt threshold for mass measurement
- Profit of the run at 240GeV (5ab^{-1}) dedicated to HZ production for top FCNC
  - periodic returns at the Z-peak in « FCC-ee top » conditions for calibration

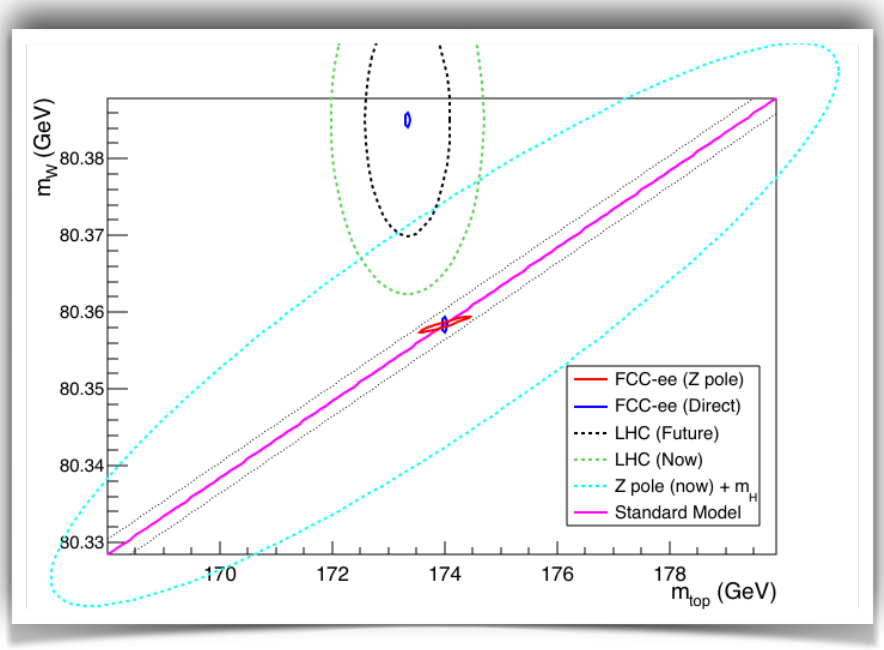
FCC-ee

PRECISION TOP MASS MEASUREMENT

- Precision measurements are a **portal to new physics effects at high scales**, the clean environment and large statistics at FCC-ee will allow to probe effects at much higher energies.
- In particular the SM fits need a precise knowledge of the **top quark mass** (in a well defined scheme) possibly below the 100MeV which is extremely difficult to achieve at a pp collider even with the statistics of the HL-LHC.

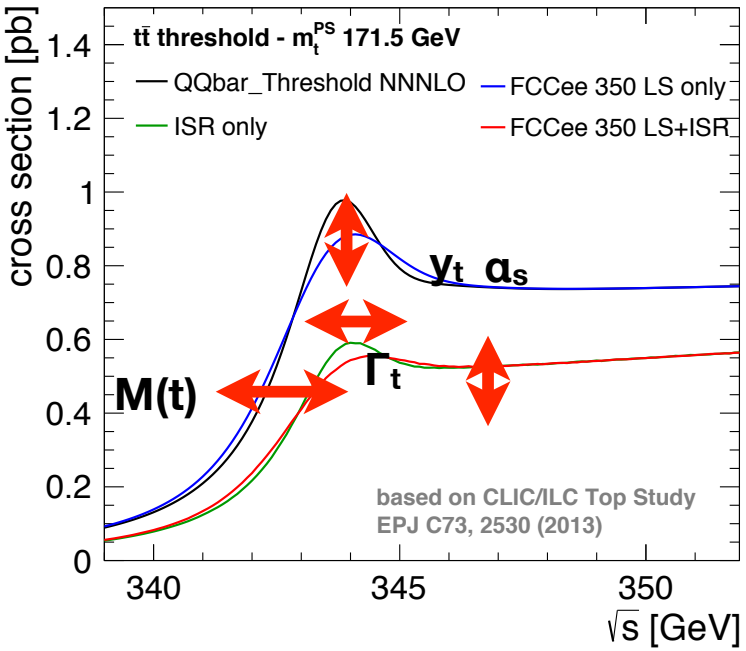


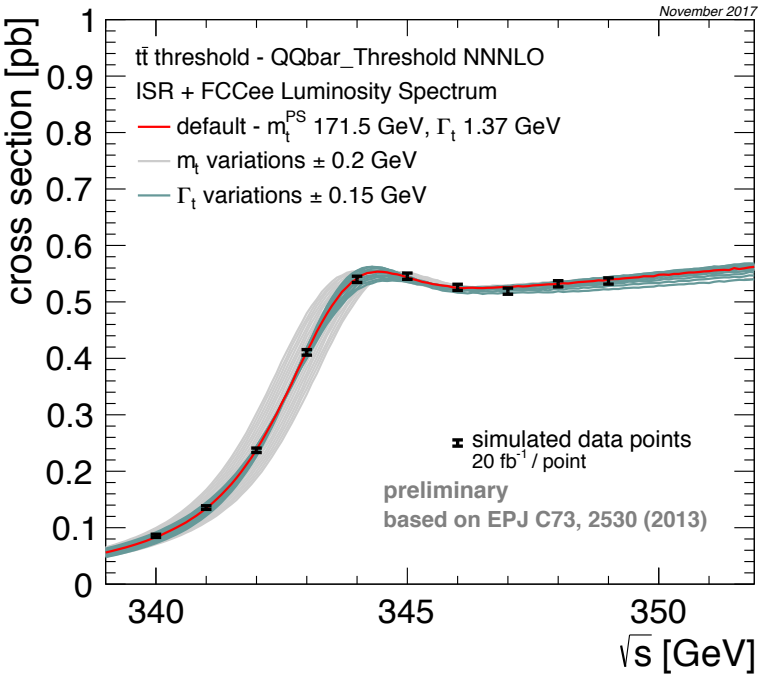
l+jets Δm~0.17GeV



FCC-ee

TOP MEASUREMENTS FROM THRESHOLD SCAN @FCC-ee

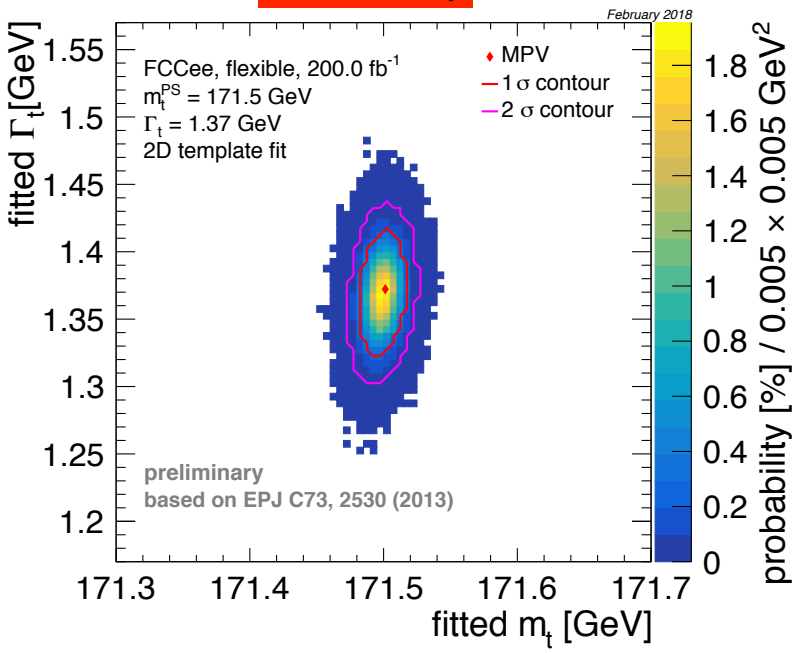




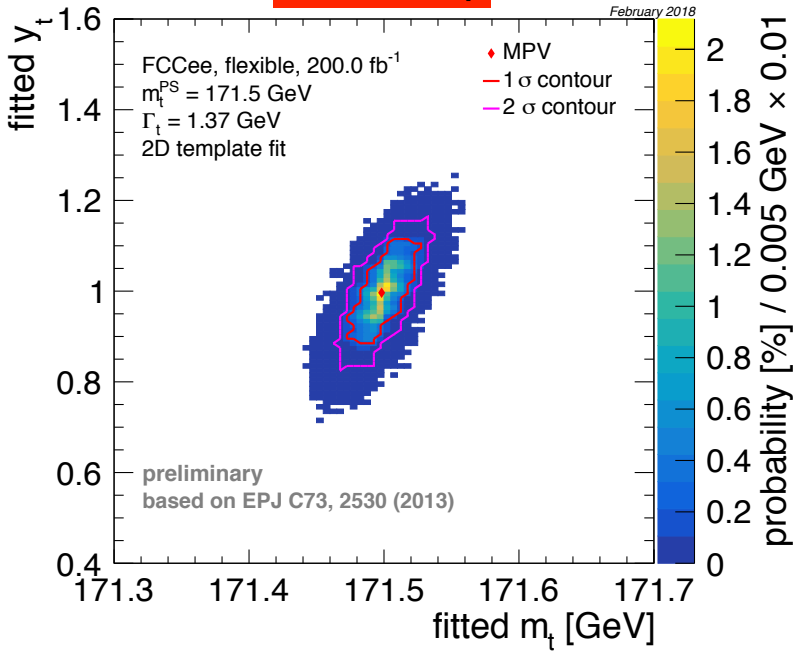
- Cross section shape depends strongly on top quark mass & width (and Yt): threshold scan to measure
  - choice of fit points optimized based on theory uncertainties (F. Simon arXiv:1611:03399v1(2016))
  - threshold shape affected by ISR and machine beam energy spread
  - Best measurement of Yt will be eventually obtained with FCC-hh

TOP MEASUREMENTS FROM THRESHOLD SCAN @FCC-ee

Γ_t vs m_{top}



Y_t vs m_{top}



Y_{top} can be extracted with a10% uncertainty

With 200 fb^{-1} FCC-ee can measure $m_{top}(\Gamma_{top})$ with ~17(45) MeV statistical accuracy.

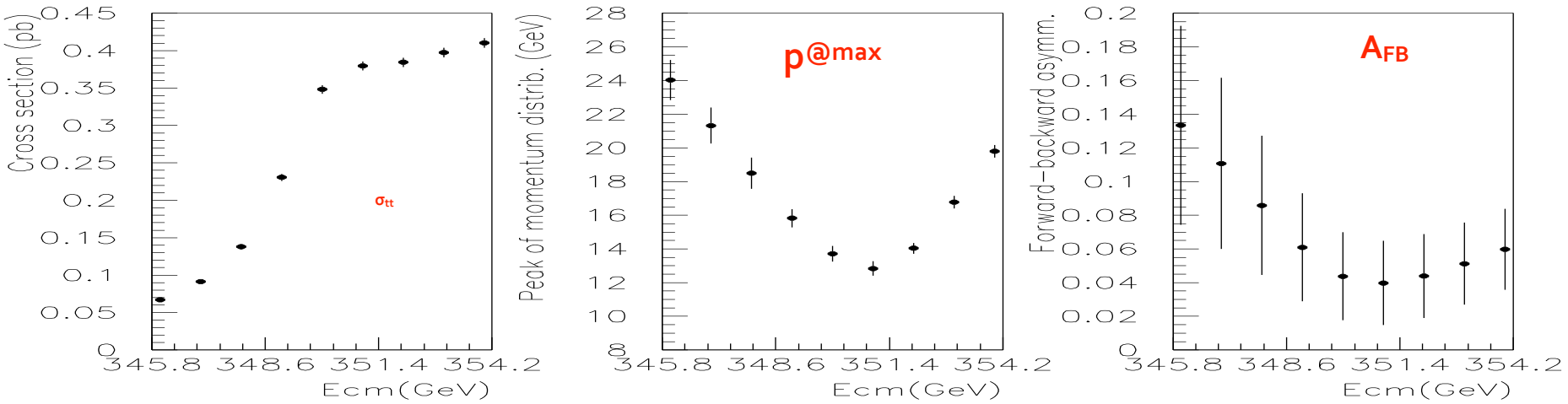
Systematics: 3MeV from center of mass energy, 5MeV from α_s (2×10^{-4} as measured at lower energy) and ~40MeV from theory uncertainties (NNNLO)

A CASE STUDY - MASS FROM THRESHOLD SCAN

- The threshold measurement is primarily a counting experiment: need to identify the production of top pair events above the background.
  - profit of all the final state channels to maximize statistics
  - l+jets and all-hadronic final state characterized by:
    - large number of jets (4 to 6)
    - top basically at rest
    - two b-jets
- Priority is to devise an efficient selection to optimize for measurement precision:
  - study of different strategies for jet reconstructions and algorithms
  - b-tagging algorithm WP
  - even selection requirements
  - in principle no need for top kinematic fitting
- Also: very important MC studies for correct description of threshold behavior (see Jeremy's talk)

Jet reconstruction & b(c)-tagging WP

A CASE STUDY - DIFFERENTIAL VARIABLES AT THRESHOLD

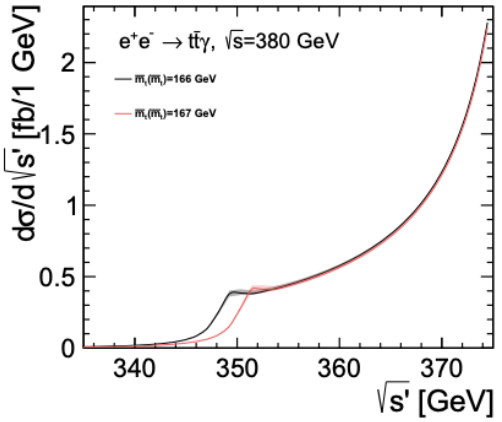


- Threshold run to study the differential behaviour of other top variables
- For instance, the asymmetry A_{fb}, would need:
  - a precise reconstruction of top and anti-top (correct assignment)
  - large statistics coming from including also all-hadronic case
  - Perfect case study for hadronic jet reconstruction and kinematic fit

Kinematic fit: correct association & b(c)-tagging WP

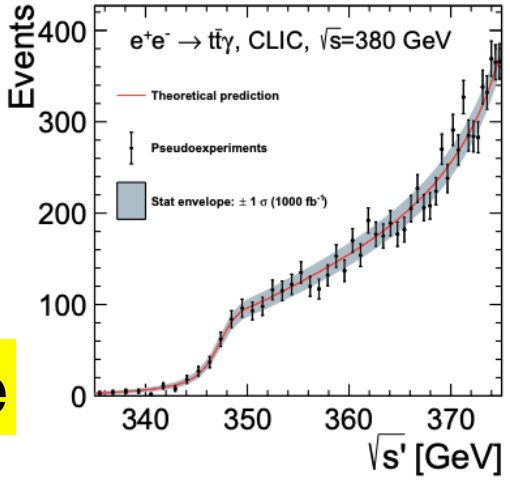
TOP MASS FROM RADIATIVE RETURNS - NEW CASE STUDY?

- Top mass can be measured also from template fits of radiative ttγ events above threshold.
  - Study performed for CLIC 380GeV (1ab-1) with 90MeV uncertainty on top mass
  - https://arxiv.org/pdf/1912.01275.pdf
    - most sensitive region is where the √s' is close to the production threshold
  - in this case the photon acceptance and energy are crucial variables
  - effects from beam lumi spectrum and spread
  - no kinematic fit is necessary
- not competitive with threshold mass measurement but orthogonal systematics



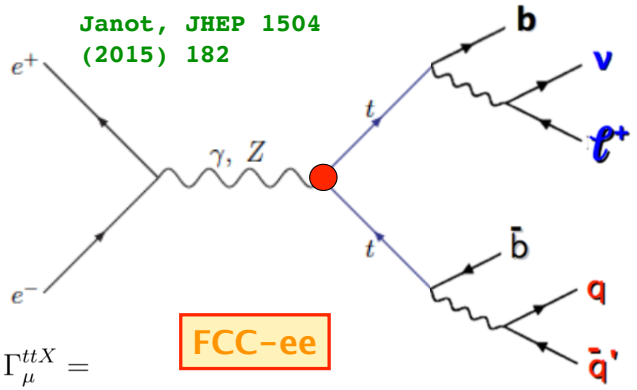
photon Energy>5GeV and

angle between 8° and 172°



Photon energy & acceptance

ELECTROWEAK COUPLINGS OF THE TOP QUARK @FCC-ee



$$\Gamma_\mu^{ttX} = -ie\left\{\gamma_\mu\left(F_{1V}^X + \gamma_5 F_{1A}^X\right) + \frac{\sigma_{\mu\nu}}{2m_t}(p_t + p_{\bar{t}})^\nu\left(iF_{2V}^X + \gamma_5 F_{2A}^X\right)\right\}$$

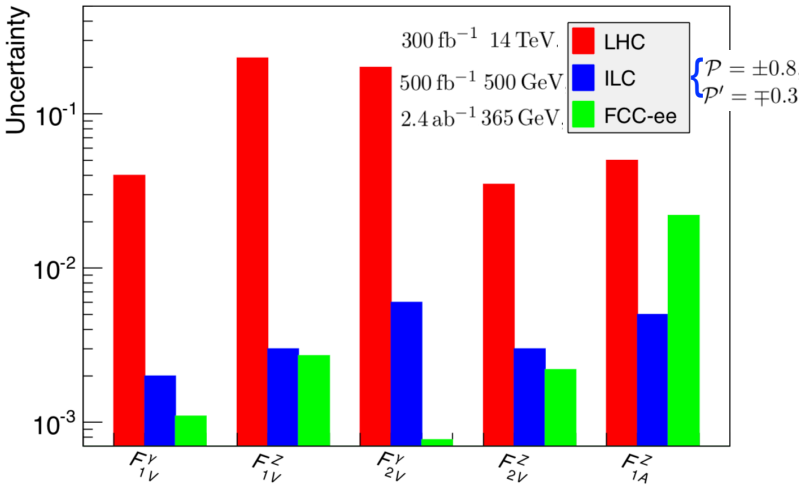
➤**ttZ, ttγ couplings can be directly probed in the tt production process at FCC-ee**

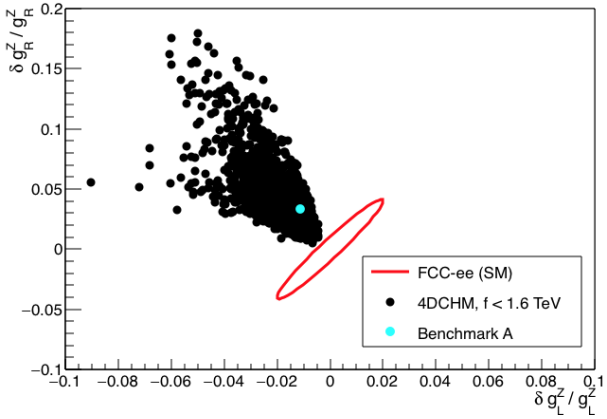
➤Large statistics and final state polarization allow a full separation of the ttZ/γ couplings with **NO need for (long.) polarization in the initial state.**

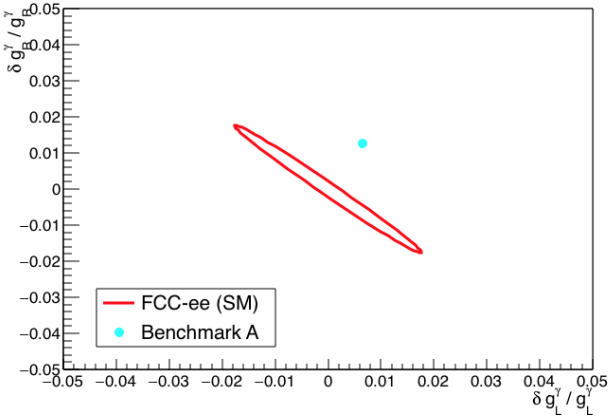
➤Optimal √s= 365 GeV

➤precise ttZ coupling important input to Yt measurement at FCC-hh

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







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

A CASE STUDY - ELECTROWEAK COUPLINGS

- The measurement of the EWK top coupling happens ABOVE the top threshold
  - Need to select top events (as for the mass). Focus on l+jets final state in current analysis.
  - Need to fit the two tops and assign correctly the b-jet to correct top quarks (tops are basically at rest cannot profit of kinematical boost)
    - Study of the jet reconstruction
    - Study of b (and c)-tagging: to exploit using the b-jet as observable as well (in addition to the lepton)
    - study of kinematical fit optimizing the correct association

Kinematic fit: correct association & b(c)-tagging WP

TOP FLAVOR CHANGING NEUTRAL CURRENTS

- **FCNC is a process where the top decays via a neutral exchange (Z,γ,g) instead of a W**
- It is forbidden at tree level in the SM and so highly suppressed
- Enhancements from new physics!

	SM	2HDM	MSSM
BR(t→cg)	5×10^{-12}	10^{-8} - 10^{-4}	10^{-7} - 10^{-6}
BR(t→cZ)	1×10^{-14}	10^{-10} - 10^{-6}	10^{-7} - 10^{-6}
BR(t→cγ)	5×10^{-14}	10^{-9} - 10^{-7}	10^{-9} - 10^{-8}
BR(t→cH)	3×10^{-15}	10^{-5} - 10^{-3}	10^{-9} - 10^{-5}

IN DECAY

FCC-ee

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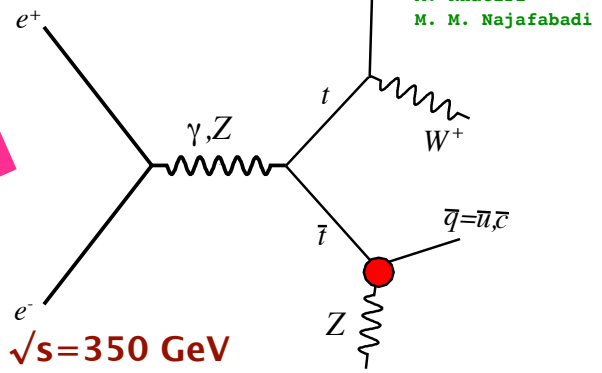
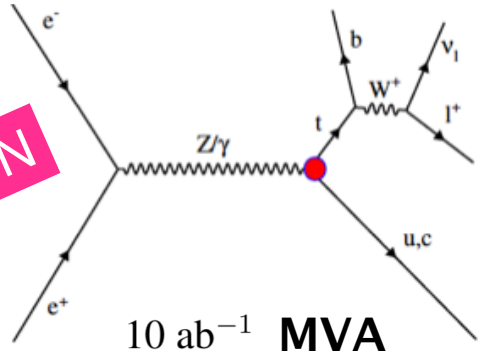
M. Khatiri
M. M. Najafabadi



√s=350 GeV

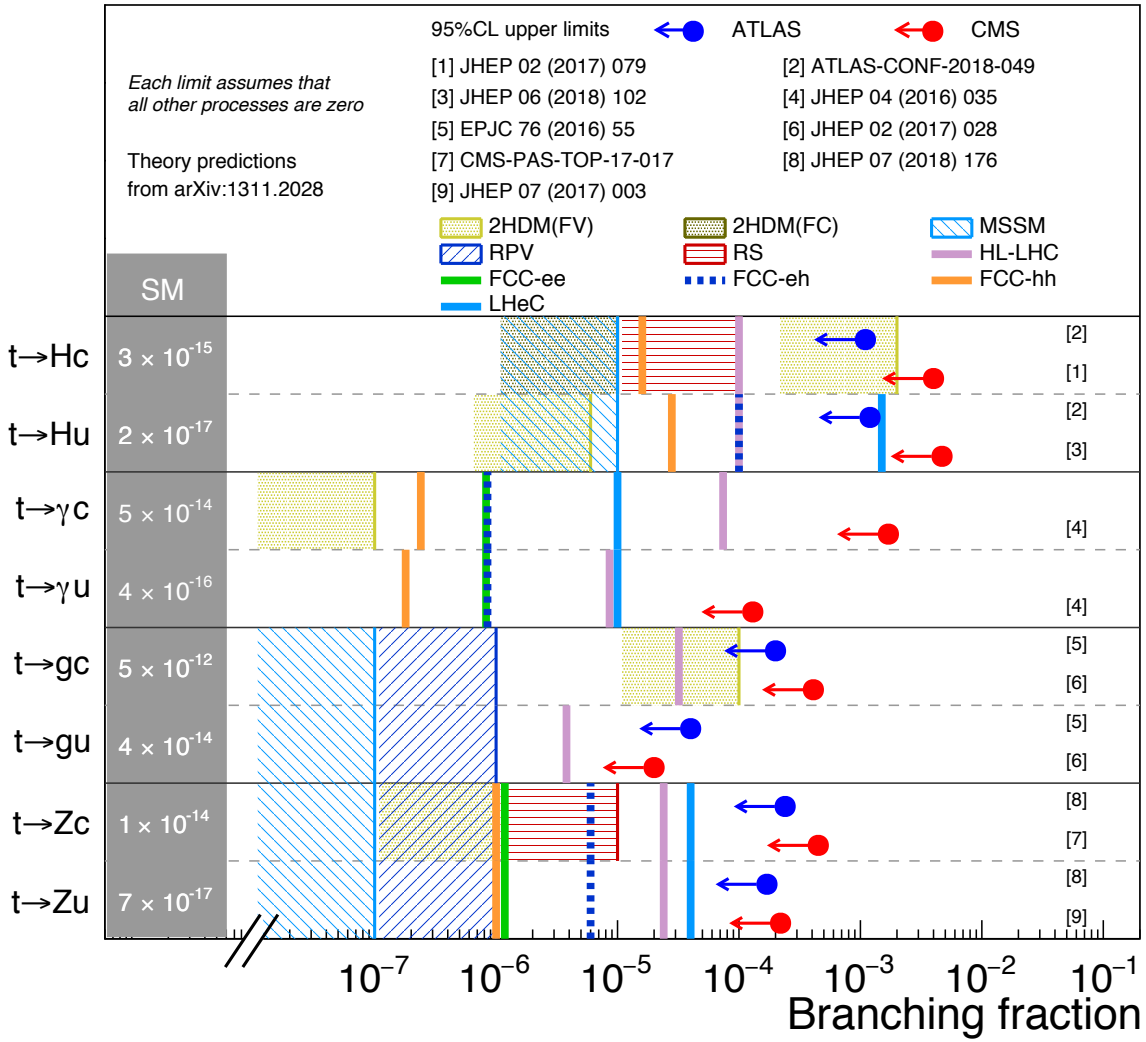
IN PRODUCTION



$10\ ab^{-1}$ **MVA**

√s=240 GeV and √s=350 GeV

FCNC GRAND SUMMARY



- FCC-ee similar reach to HL-LHC: can provide studies in case of observation
- FCC-hh: best reach due to the very large statistics available. Exploiting boosted topologies to compensate large pileup

FCC program can start probing anomalous BR from BSM models

A CASE STUDY - FCNC

- At 365 GeV the measurement looks for anomalies in the DECAY of one of the top quarks:
  - jet & photon reconstruction
  - kinematic fit of the top (with different objects, also leptons and photons)
  - S/B improvement
- At 240 GeV the measurement looks for a SM decaying top quark (t->Wb) accompanied by a non-b quark
  - requirements on b and charm tagging
  - kinematic fits for the SM top and correct association of the jets
  - need of a performant background reduction
- Some preliminary studies (fromp INP) showed a significant effect on sensitivities due to b and c- tagging. Good starting point

b(c)-tagging WP & kinematic fit for S/B & association

THE NEXT STEPS

- The top physics program at FCC-ee collider allows to achieve ultimate precision on fundamental SM parametes and extend sensitivites to more top properties.
  - This is a completely new regime, never been looked at before
- Top physics measurements, for their rich final state with many particles and lots of hadronic jets, are the perfect playground for our « case studies » geared toward the optimization and the detector requirements concerning:
  - hadronic jet reconstruction
  - kinematical fits
  - b and c-tagging
    - some photons too (form ttgamma and FCNC)
  - *Connection with theory and accurate MC description of top & background process at threshold and above*

Concrete work is starting: looking forward having results soon!

Contact PPC coordinators for more info on how to get started