CepC/SppC Workshop, Bejing, 2-3 September 2016

Physics interests & activities for Future Colliders @INFN

P. Azzi - INFN Padova

Italy interests and efforts in future projects

- Large italian experimental community (hardware and software)
  - significant fraction involved in LHC activities for Run2 data taking and upgrades
- fraction of the community is interested by several future projects (ILC, CLIC, FCC(ee, hh, eh), Muon Collider …) in connection with our theory colleagues.
  - From the software, theory and physics standpoint there are very strong similarities and synergies among all these projects and also with the CepC/SppC one.
  - Indeed there are alredy cross-collaborations in progress
- The physics studies presented here (done in the context of FCC study group for historical reason) can be translated and/or extended to CepC/SppC case without much effort.

« FC » Italy

New INFN Budget Line for « Future Collider » grouping together people interested in future machines to profit of the synergies: ILC,CLIC,FCC,CepC,SppC,MuColl

Bari
M. Abbrescia, N. De Filippis,

Bologna
L. Bellagamba, D. Boscherini, S. Braibant, P. Giacomelli, P. Alessandro

Ferrara
R. Camattari, G. Cibinetto, V. Guidi, A. Mazzolari

Lecce
C. Esposito, F. Grancagnolo, A. Maffezzoli, M. Panareo, G.F. Tassielli, G. Zavarise

Laboratori Nazionali di Frascati
M. Antonelli, M.E. Biagini, G. O. Blanco, M. Boscolo, F. Collamati, S. Dabagoy, S. Guiducci, M. Rotondo, M. Testa

Milano
A. Andreazza, M. Caccia, C. Curatolo, S. Romualdo, L. Serafini

Padova
P. Azzi, N. Bacchetta, A. Bertolin, P. Checchia, D. Lucchesi, A. Lupato, M. Morandin, R. Rossin, L. Sestini, M. Zanetti

Perugia
G. Mario Bilei, C. Cecchi, L. Fano', F. Moscatelli, D. Passeri, A. Rossi

Pisa
F. Bedeschi, V. Cavasinni, C. Roda, R. Tenchini, G.E. Tonelli

Pavia
G. Introzzi, G. Polesello, P. Salvini

Roma1
F. Anulli, G. Campogiani, M. Marongiu, L. Palumbo

Roma3
M. Biglietti, B. Di Micco,A. Farilla

Trieste
A. Bressan, M. Cobal, S. Dalla Torre, S. Dasgupta, S. Levorato, A. Martin, F. Tessarotto

In this list are not included the theory colleagues, nor the students/postdocs without a permanent contract.

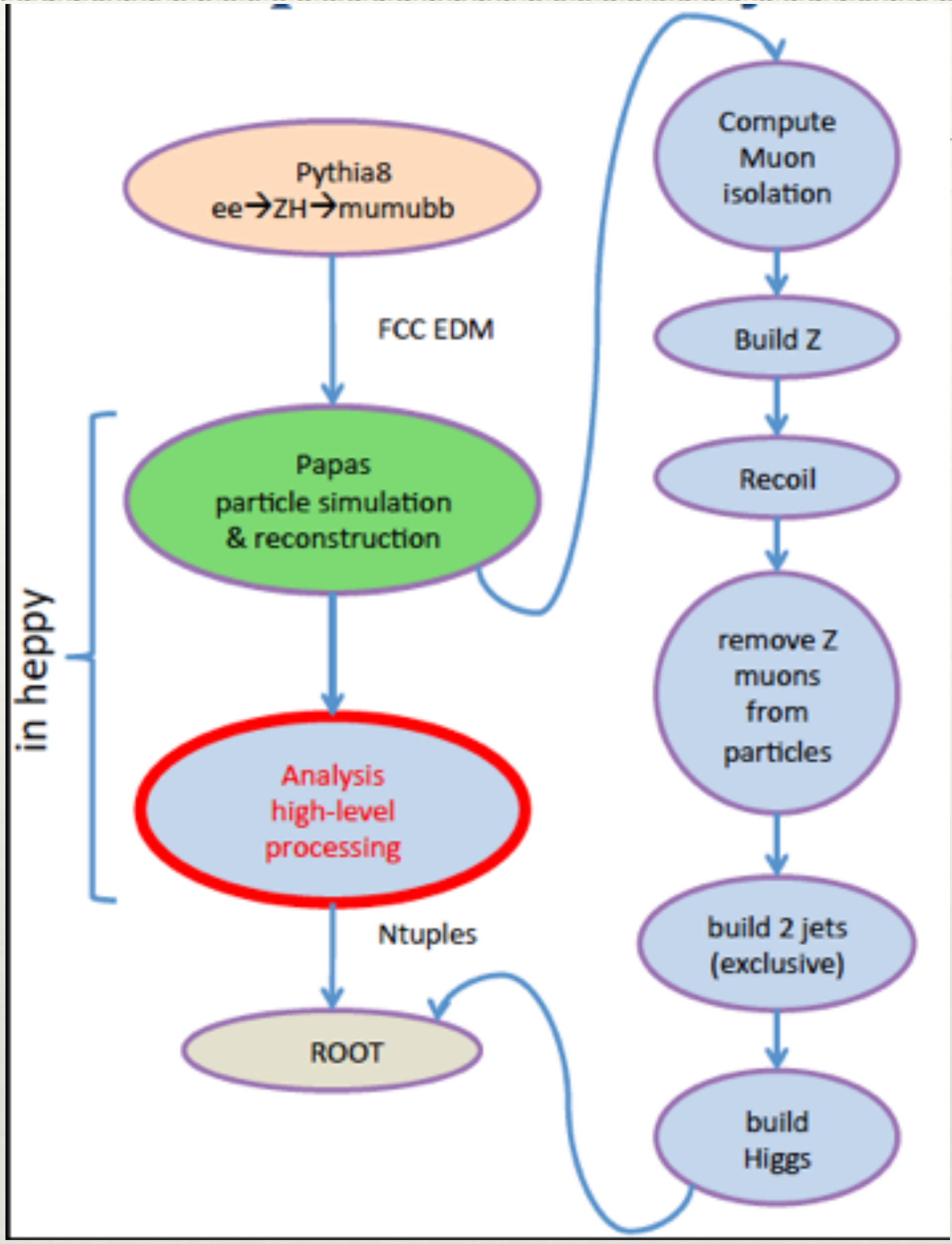
FCC Software Framework is open source!

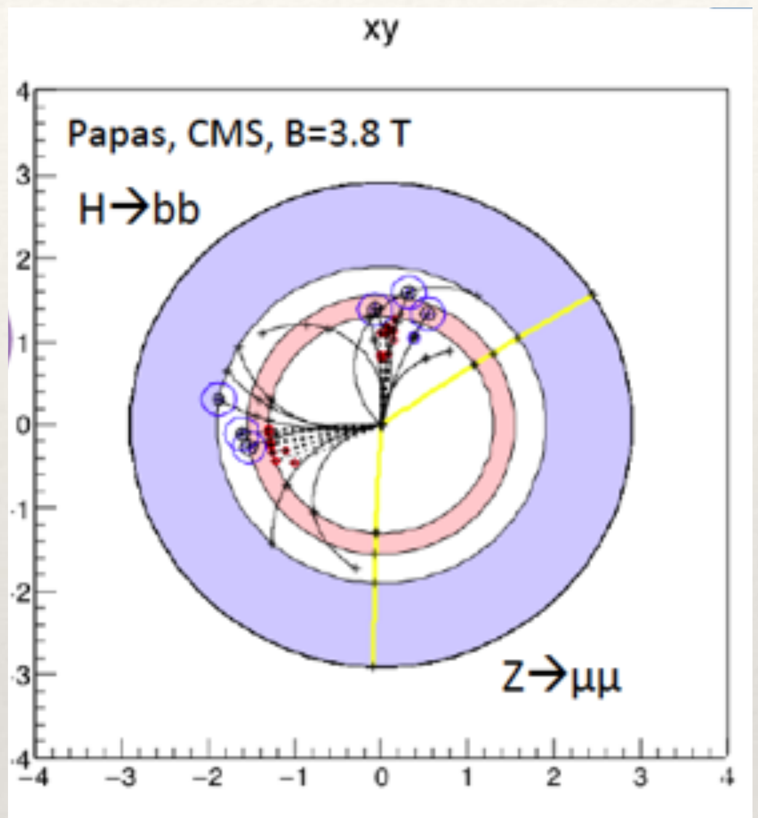
- Common software project for FCC-hh,ee,eh.
    - Supporting multiple detectors in simulation and reconstruction with different level of details and choices.
        - Delphes integrated and ready to use (also used in HL-LHC) with different detector descriptions. Most widely used (also in HL-LHC)
            - VERY EASY TO ADD/MODIFY NEW DETECTOR CARDS
        - PAPAS is a new FastSimulation with integrated PFlow reconstruction approach. Currently being validated with FCC-ee analyses
            - VERY EASY TO ADD/MODIFY NEW DETECTOR RESOLUTION FUNCTIONS
        - Geant4 will be used for Full Simulation
        - DD4hep for detector description
- **Strong collaboration across sevearl experiments ATLAS/CMS/LHCb/CLIC!**

http://fccsw.web.cern.ch/fccsw/

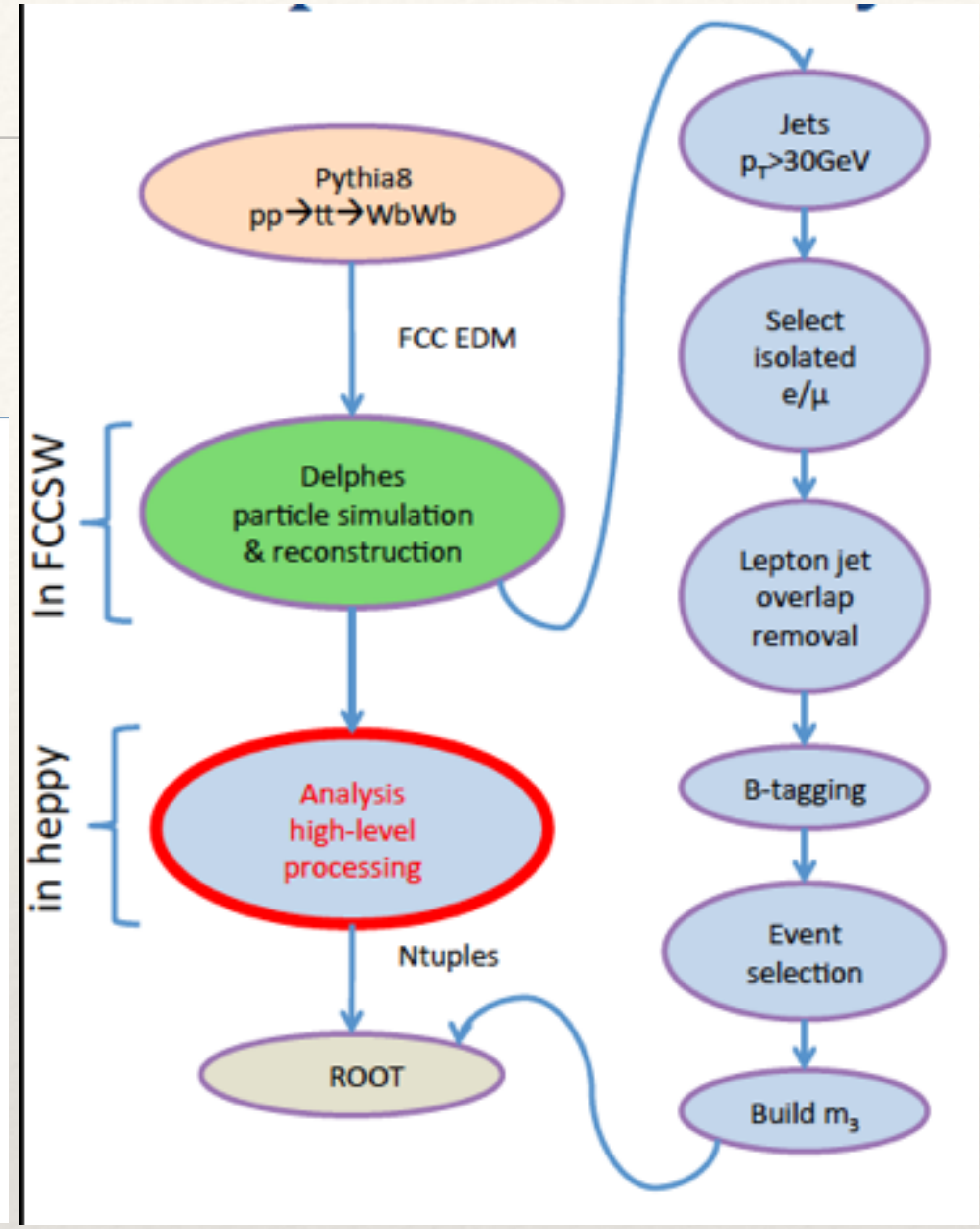
http://github.com/HEP-FCC: open source code on GitHub

Example in PAPAS of ZH analysis





Example of DELPHES tt analysis

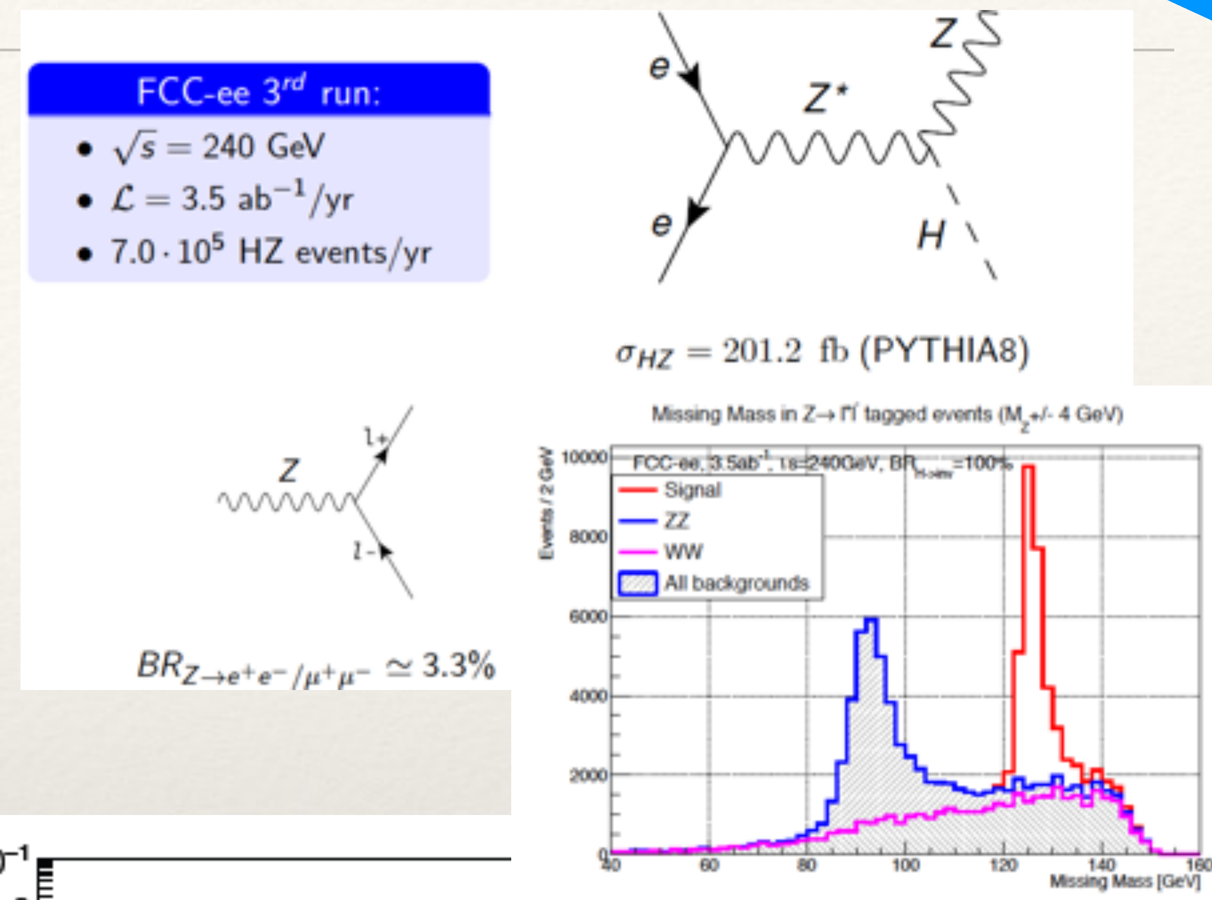


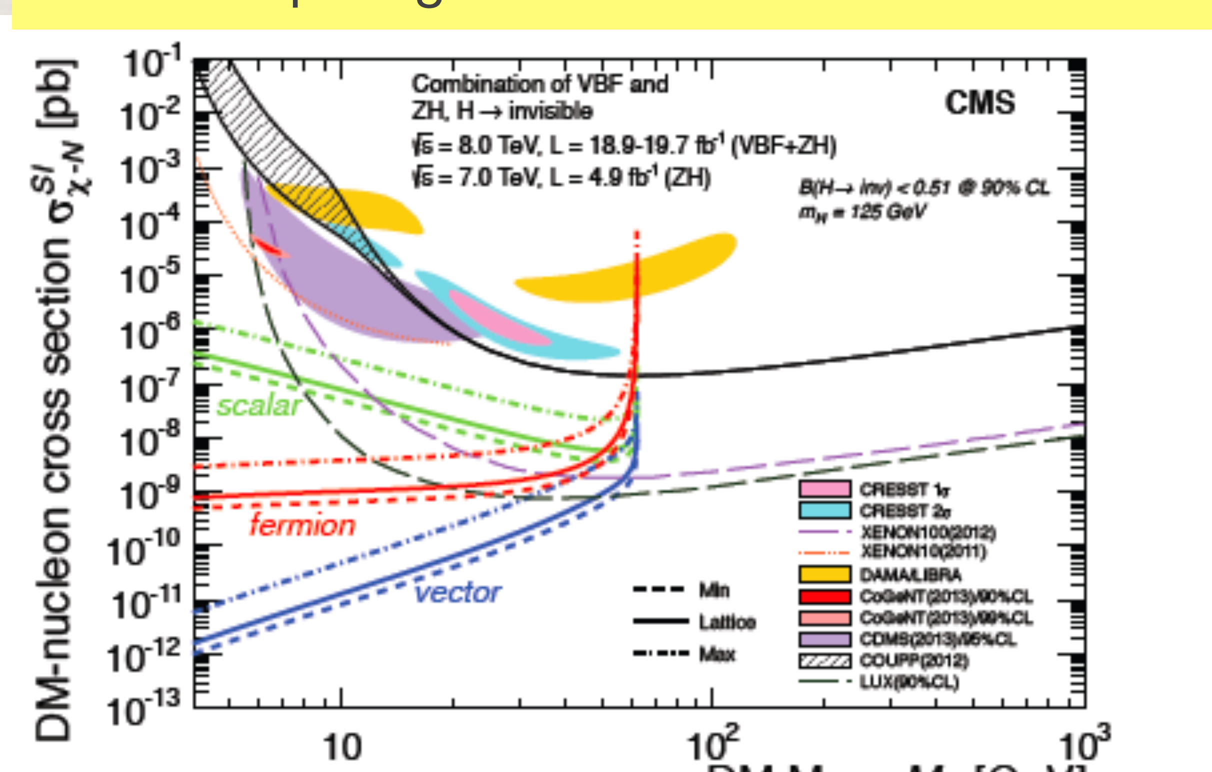
- Analysis done mostly in python nowadays (but also C++ is supported).
- Heppy as an analysis framework is becoming popular because it is used already also in the LHC experiments.

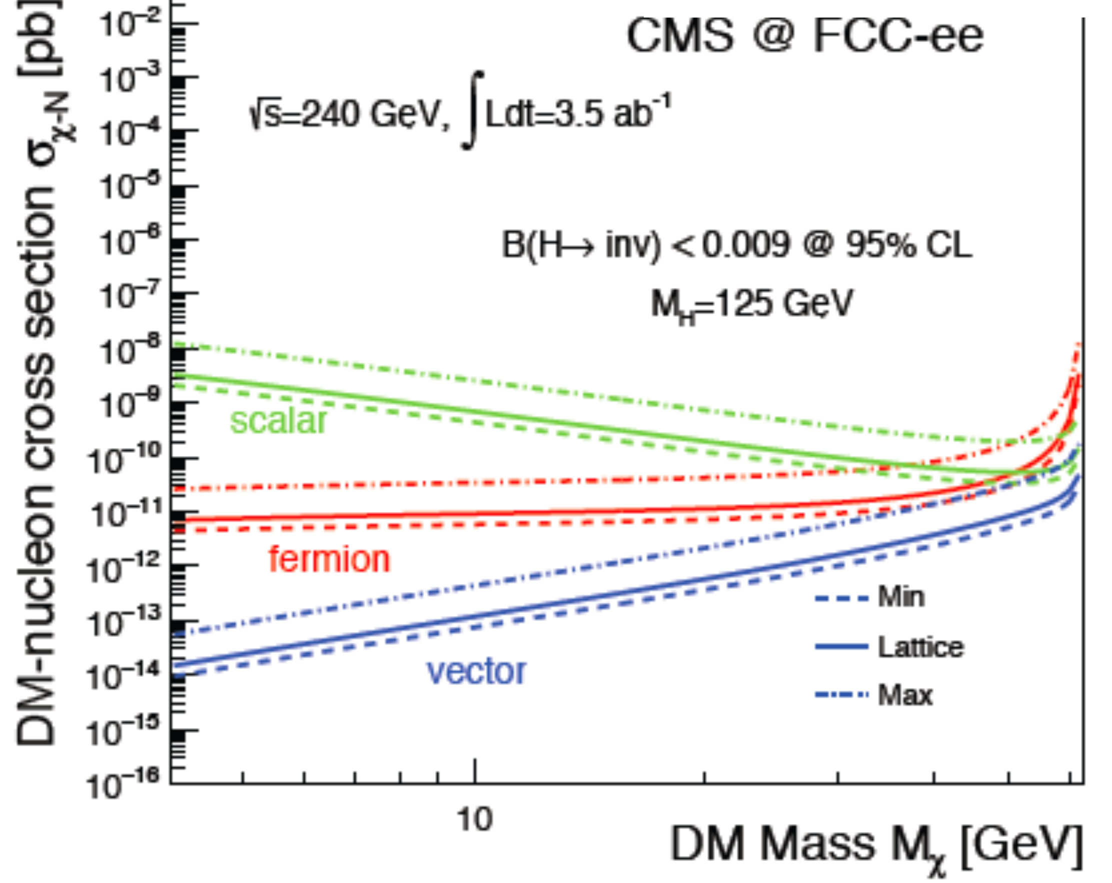
Higgs studies & invisible width

FCC-ee

- **The first studies on the Higgs concerning a circular e+e- machine were documented in the « First look at the physics case of TLEP » (arXiv: 1308.6176).** This type of document ages quickly.
    - the CMS full Geant based detector simulation was used
- in 2015 a new study of the Higgs invisible width was performed using Delphes for the detector simulation.
    - comparing also the CMS and ILD detector



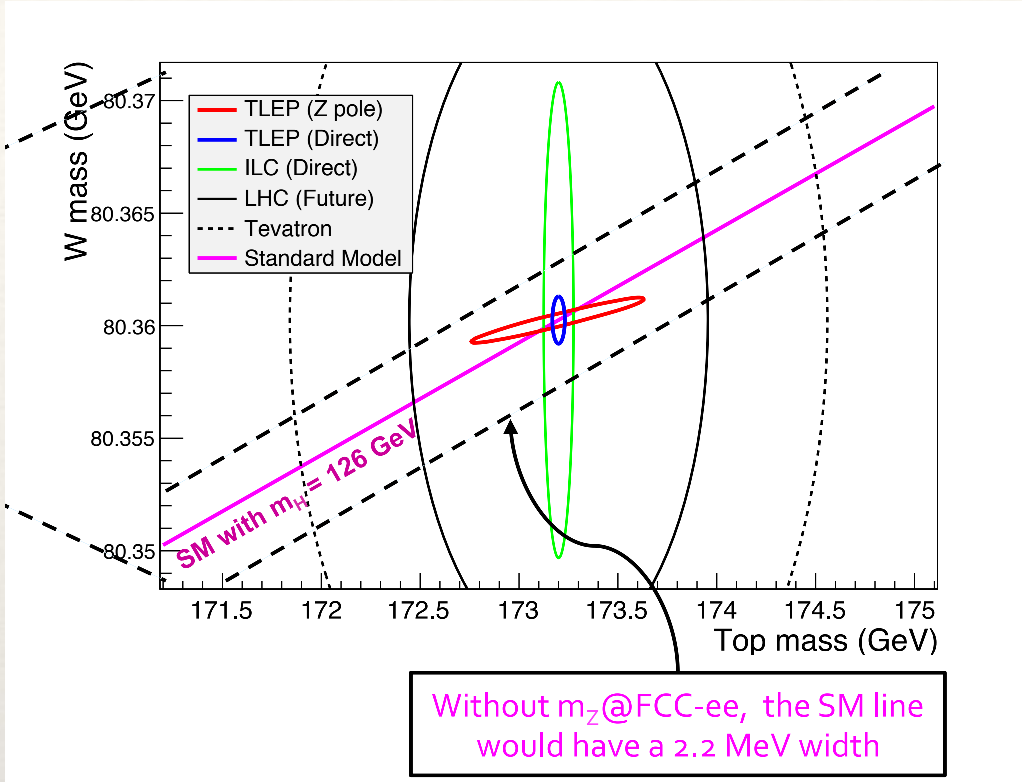




O. Cerri, A. Podo, L. Rolandi (SNS), M. De Gruttola, M. Pierini (CERN)

ElectroWeak Precision Physics

FCC-ee



R. Tenchini (Pisa), F. Piccinini (Pavia) are conveners of the « EWK Working Group(WG1+WG2) » for FCC-ee Experimental Studies

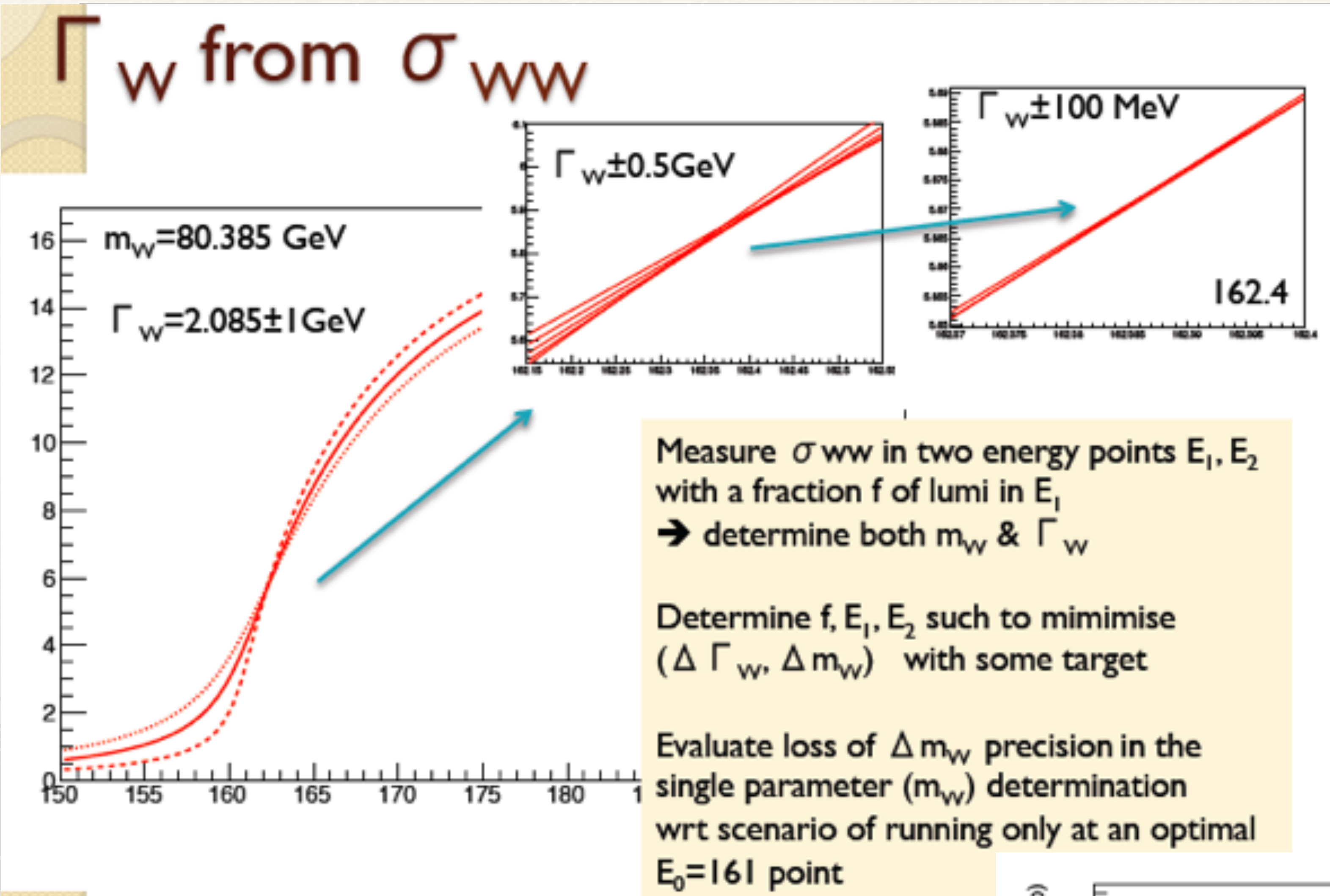
- More expertise available for studies focused on EWK precision variables

Quantity	Physics	Present precision	Measured from	Statistical uncertainty	Systematic uncertainty	Key	Challenge
m_Z (keV)	Input	91187500 ± 2100	Z Line shape scan	5 (6) keV	< 100 keV	E_{beam} calibration	QED corrections
Γ_Z (keV)	$\Delta\rho$ (not $\Delta\alpha_{had}$)	2495200 ± 2300	Z Line shape scan	8 (10) keV	< 100 keV	E_{beam} calibration	QED corrections
R_ℓ	α_s, δ_b	20.767 ± 0.025	Z Peak	0.00010 (12)	< 0.001	Statistics	QED corrections
N_ν	PMNS Unitarity, ...	2.984 ± 0.008	Z Peak	0.00008 (10)	< 0.004		Bhabha scat.
N_ν	... and sterile ν's	2.92 ± 0.05	$Z\gamma$, 161 GeV	0.0010 (12)	< 0.001	Statistics	
R_b	δ_b	0.21629 ± 0.00066	Z Peak	0.000003 (4)	< 0.000060	Statistics, small IP	Hemisphere correlations
A_{LR}	$\Delta\rho, \epsilon_3, \Delta\alpha_{had}$	0.1514 ± 0.0022	Z peak, polarized	0.000015 (18)	< 0.000015	4 bunch scheme, 2exp	Design experiment
m_W (MeV)	$\Delta\rho$, $\epsilon_3, \epsilon_2, \Delta\alpha_{had}$	80385 ± 15	WW threshold scan	0.3 (0.4)MeV	< 0.5 MeV	E_{beam}, Statistics	QED corrections
m_{top} (MeV)	Input	173200 ± 900	$t\bar{t}$ threshold scan	10 (12) MeV	< 10 MeV	Statistics	Theory interpretation

Proceedings of Workshop « Physics Behind Precision »
Appearing soon (https://indico.cern.ch/event/469561/)

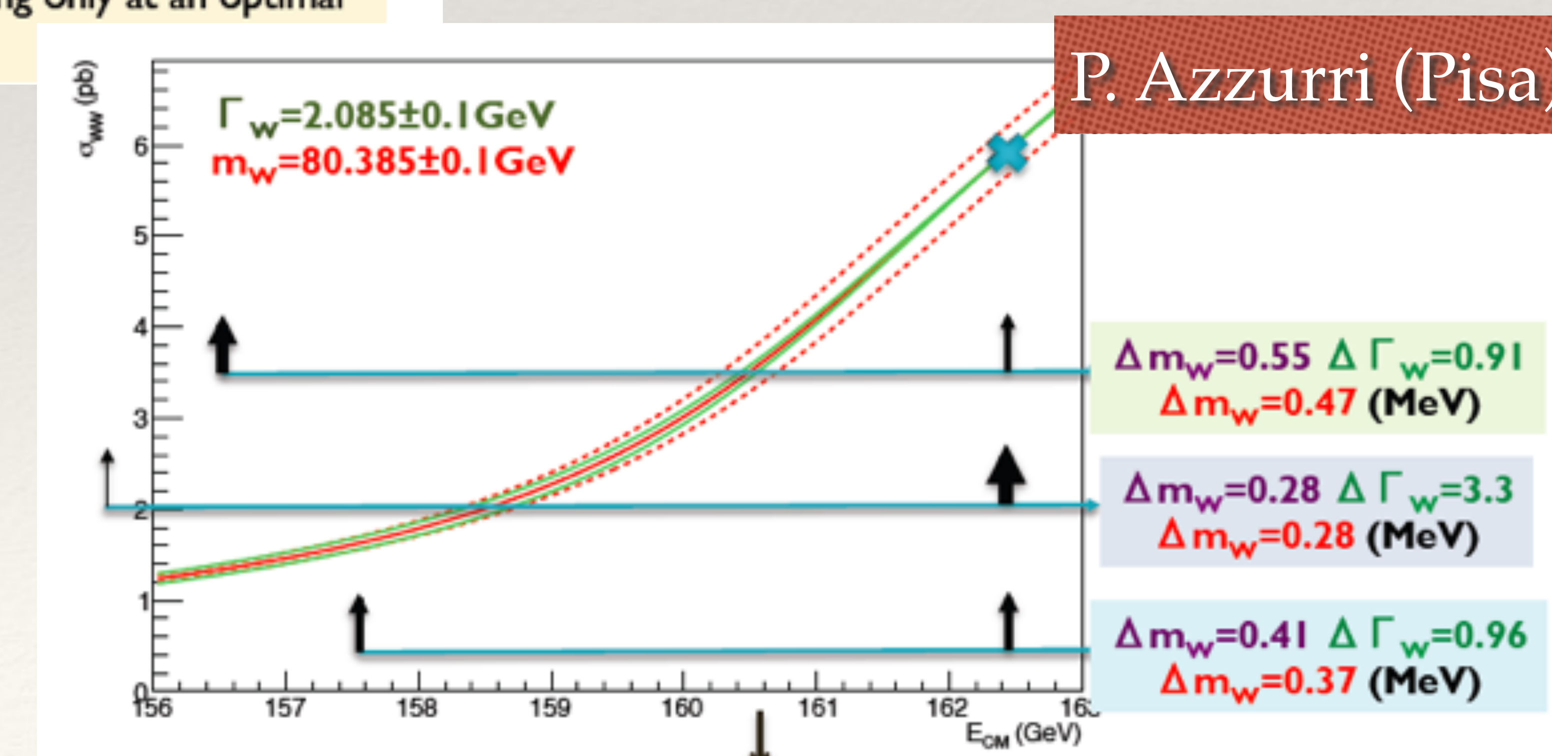
m_W and Γ_W from threshold scan

FCC-ee



- Two parameter (m_W, Γ_W) fits of (σ_1, σ_2)
  - 15/ab only statistics uncertainties
  - pure lineshape study
- Challenge for knowledge of energy (<1 MeV), acceptance (10^{-4}), backgrounds (<1fb).
  - Measurement strategy can vary if syst uncertainties are limiting

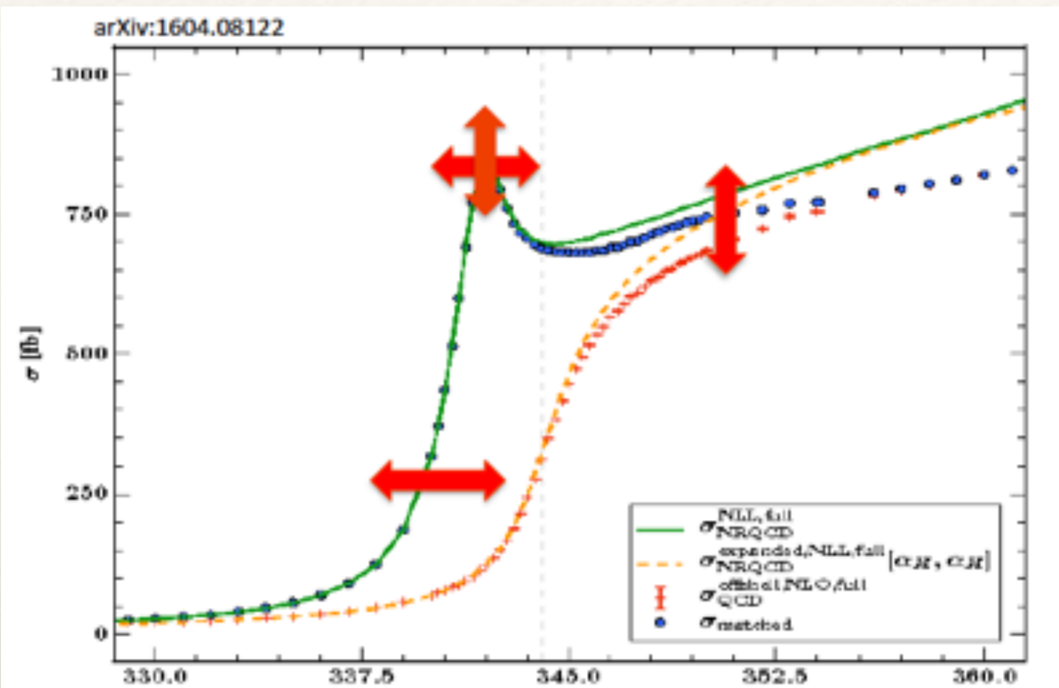
The interest in the σ_{WW} (E) lineshape could go beyond m_W and Γ_W

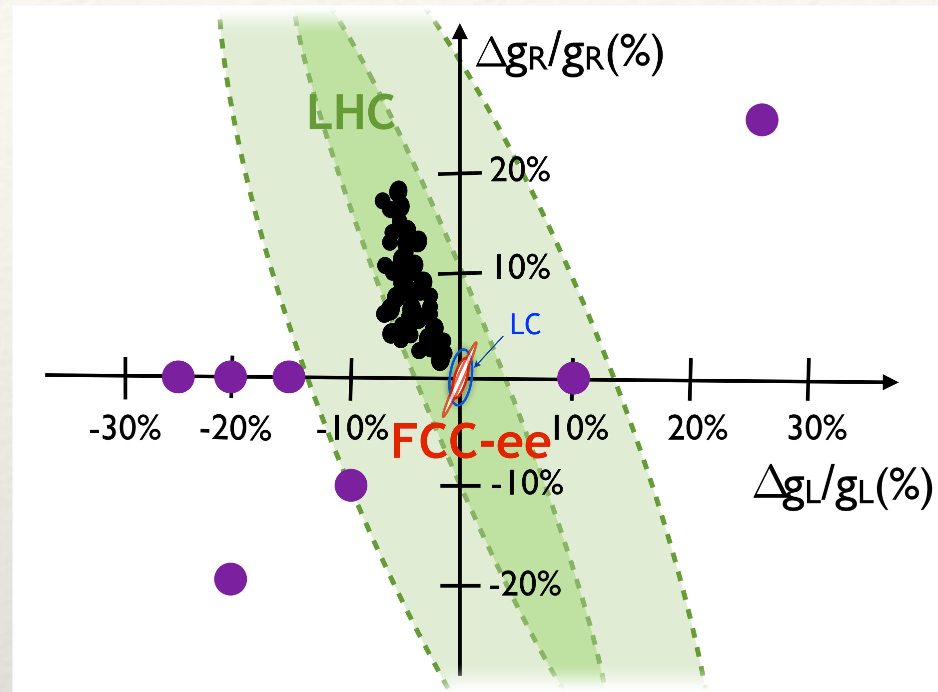


Expertise on top physics at lepton collider

FCC-ee

- At the √s=of 350-365 GeV could measure top mass, top width, EWK couplings and estimate of top Yukawa





Probing Composite Higgs models at higher scales

S. De Curtis (Roma1), S Moretti (UK)

	Lumi / 5 years	# top pairs	Δm_{top}	$\Delta\Gamma_{top}$	$\Delta\lambda_{top}/\lambda_{top}$
FCC-ee TLEP	4×650 fb^{-1}	1,000,000	10 MeV	12 MeV *	13%

* using α_s from Tera-Z

λtop ~13% with indirect extraction from threshold scan.
To improve need higher energy or FCC-hh.

- New analysis with FCC-ee framework and fast simulation (PAPAS) in progress.

P. Azzi (INFN Padova) , N. Foppiani, G. Rolandi (INFN Pisa & SNS)

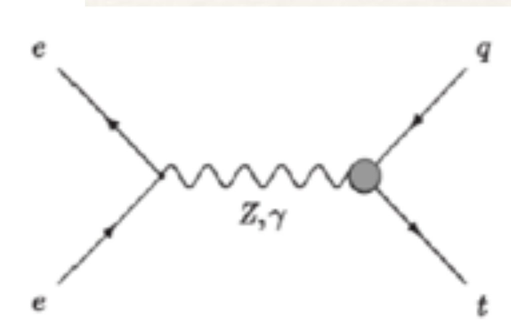
N. Foppiani, T. Pajero, G. Rolandi (INFN Pisa & SNS)

Sensitivity for Top FCNC

- Can study single top production via FCNC @240GeV

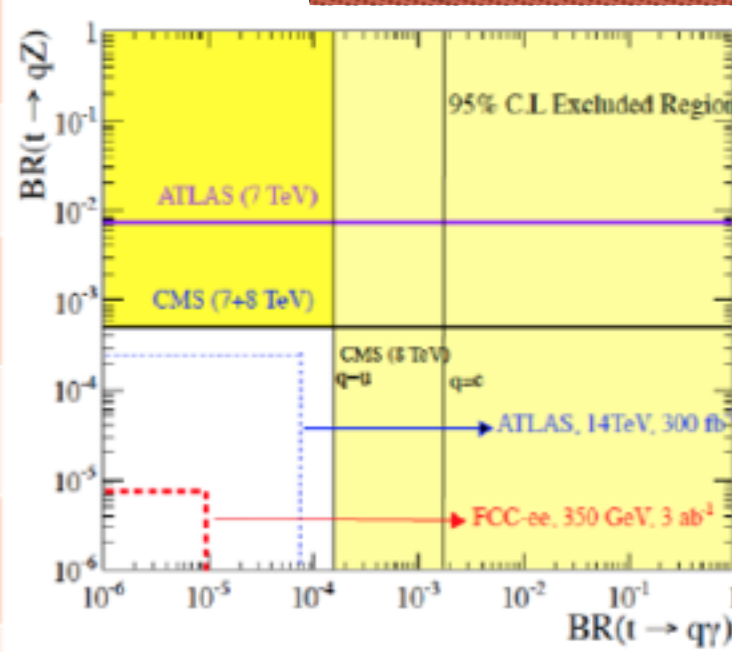
Sensitivity FCNC: 95% CL exclusion limits

- Limits in all-hadronic and lepton+jets channel compatible



All Hadronic: S. Biswas, F. Magaroli, B. Mele (INFN Roma 1)

Sqrt(s) and lumi	240 GeV 100 fb-1	240 GeV 10 ab-1	350 GeV 3 ab-1
BR(t->qγ) all hadronic	1.43 x 10-4	3.17 x 10-5	
BR(t->qγ) semileptonic	-	2.01 x 10-5	9.86 x 10-6
BR(t->qZ) ($\sigma_{\mu\nu}$) All hadronic	1.86 x 10-4	4.12 x 10-5	
BR(t->qZ) ($\sigma_{\mu\nu}$) semileptonic	-	2.44 x 10-5	1.41 x 10-6
BR(t->qZ) ($\gamma_{\mu\nu}$) All hadronic	3.78 x 10-4	8.22 x 10-5	
BR(t->qZ) ($\gamma_{\mu\nu}$) semileptonic	-	5.02 x 10-5	5.27 x 10-5

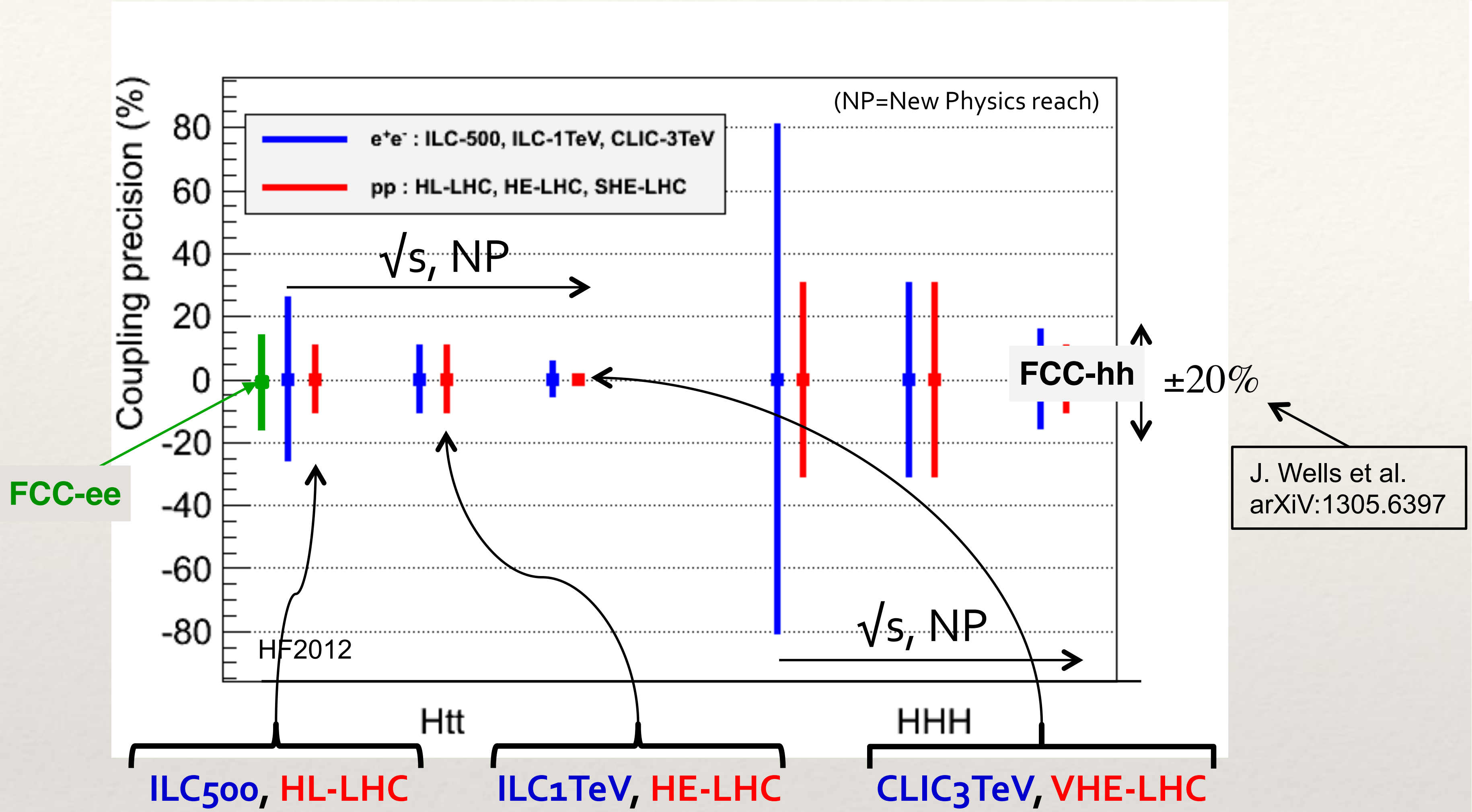


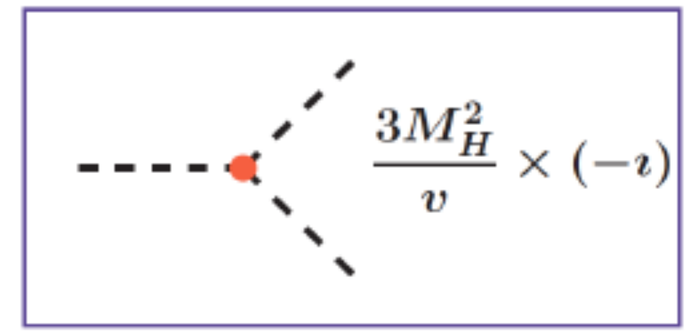
FCC-ee expected to substantially improve beyond HL-LHC

Delphes ILD-like detector card used for this study

Higgs Self-Coupling @100TeV

FCC-hh





~ × 40 at 100 TeV wrt to 14 TeV

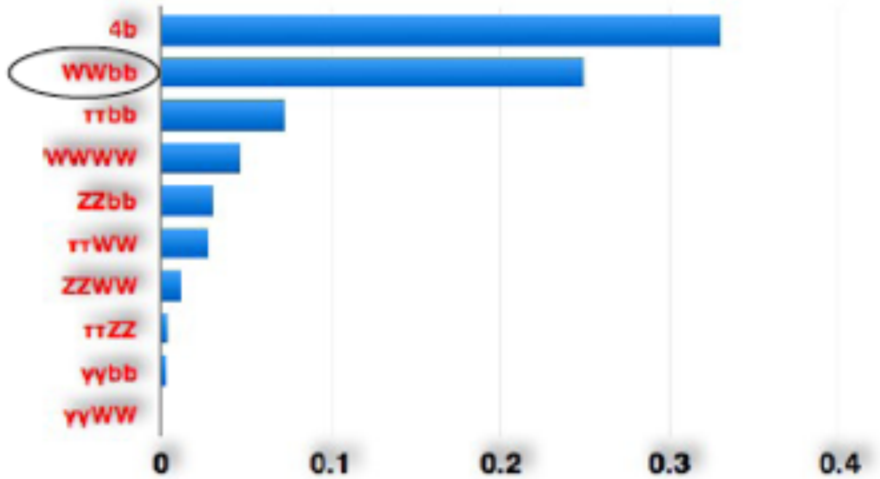
$\sqrt{s}$ [TeV]	σ^{NLO} [fb]
8	8.2
14	33.9
33	207.3
100	1417.8

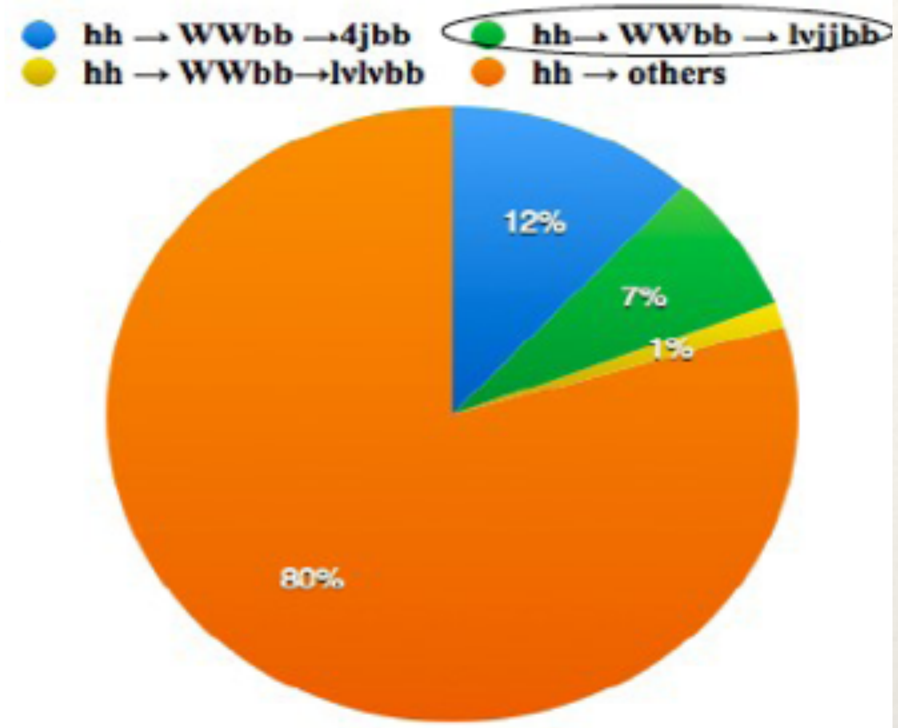
	HL-LHC	ILC500	ILC500-up	ILC1000	ILC1000-up	CLIC1400	CLIC3000	HE-LHC	VLHC
$\sqrt{s}$ (GeV)	14000	500	500	500/1000	500/1000	1400	3000	33,000	100,000
$\int \mathcal{L}dt$ (fb^{-1})	3000	500	1600‡	500/1000	1600/2500‡	1500	+2000	3000	3000
λ	50%	83%	46%	21%	13%	21%	10%	20%	8%
λ_t	4%	14%		4%	2%	4%	<4%	3%	1%

HH->WWbb->lvjjbb

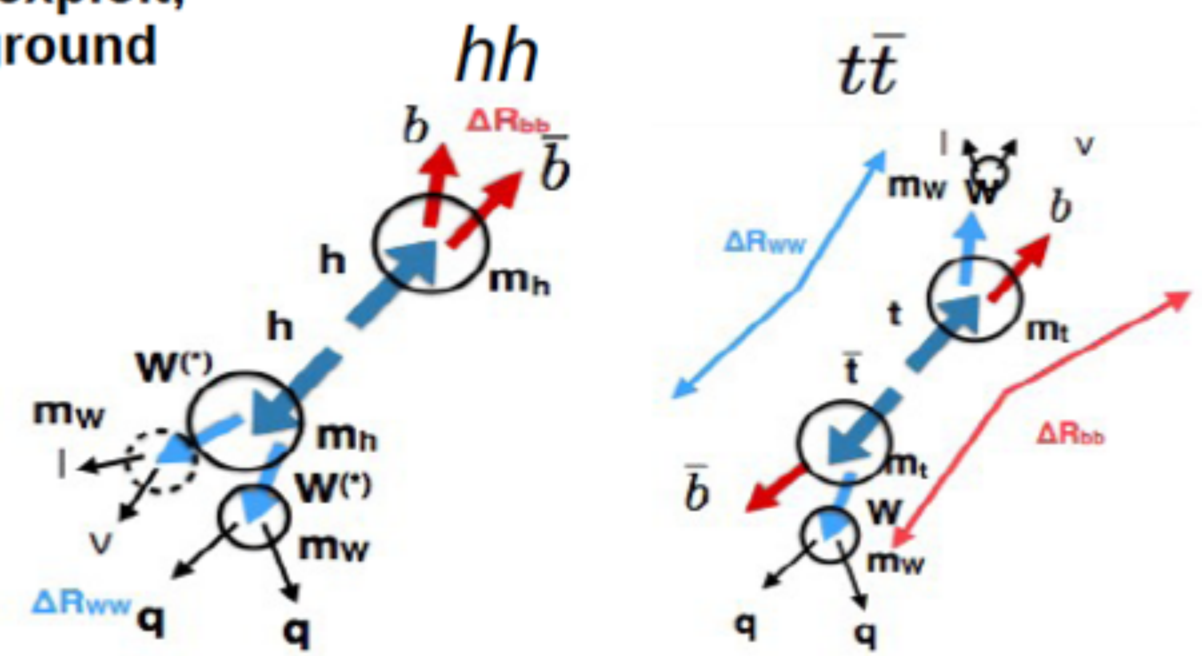
FCC-hh

B. Di Micco (Roma3), M. Testa (LNF)





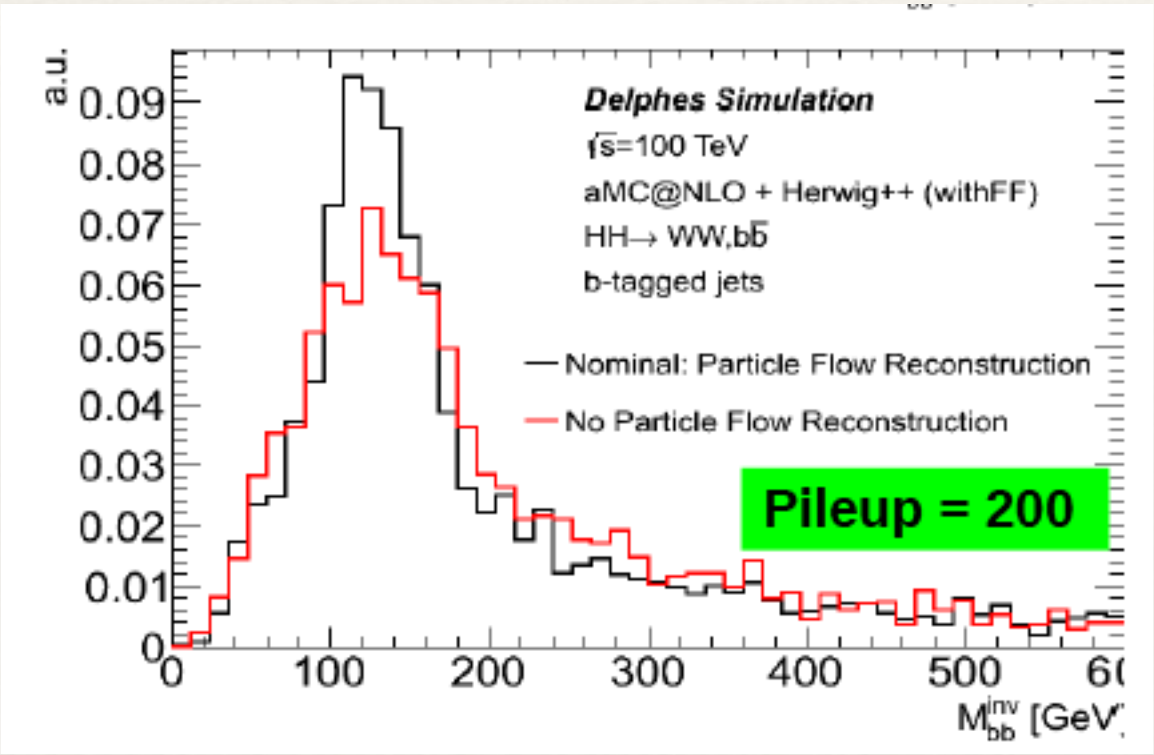
- BR lvjj bb ~ 7% of the total
- 4j channel also interesting to exploit, but overwhelming QCD background
  - Main background: $t\bar{t}$ with same final state
  - Main discriminant variables: M_{bb}, ΔR_{bb}, ΔR_{WW}
  - Kinematics can be closed
  - Crucial to have good, E_T^{miss} and jet, p_T and angular resolution
  - Challenging in high pile-up environments.



σ(100 TeV) / σ(14 TeV)~ × 40(32) for HH (tt)

HH->WWbb->lvjjbb

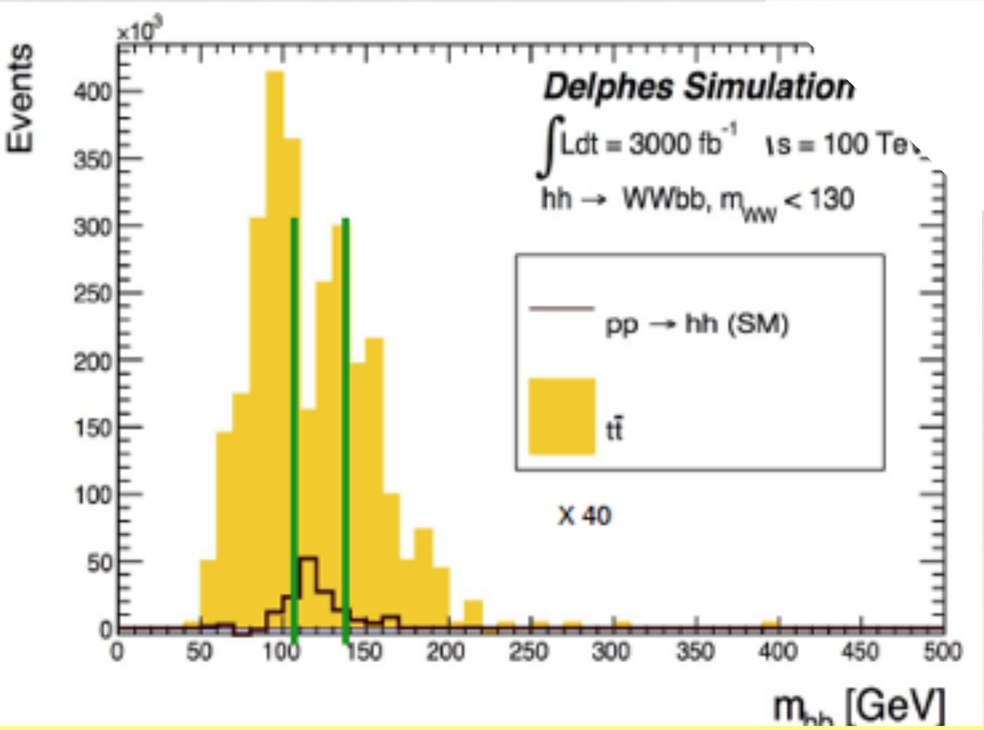
- Simulation of FCC-hh detector in Delphes card (FCChh_DelphesCard_WithDipole_v00.tcl)
- Studied and validated the performance of the detector at different PU(50,200,900!)



- 200PU configuration still not optimised, however:
  - 20% improvement in S/B
  - factor ~3 reduction in the signal yield

Preliminary selection

Variable	Cut
$p_T(bb)$	> 230 GeV
ΔRbb	< 1.2
$p_T(WW)$	> 140 GeV
ΔR_{WW}	< 1.2
m_{WW}	< 130 GeV
m_{bb}	105 – 135 GeV

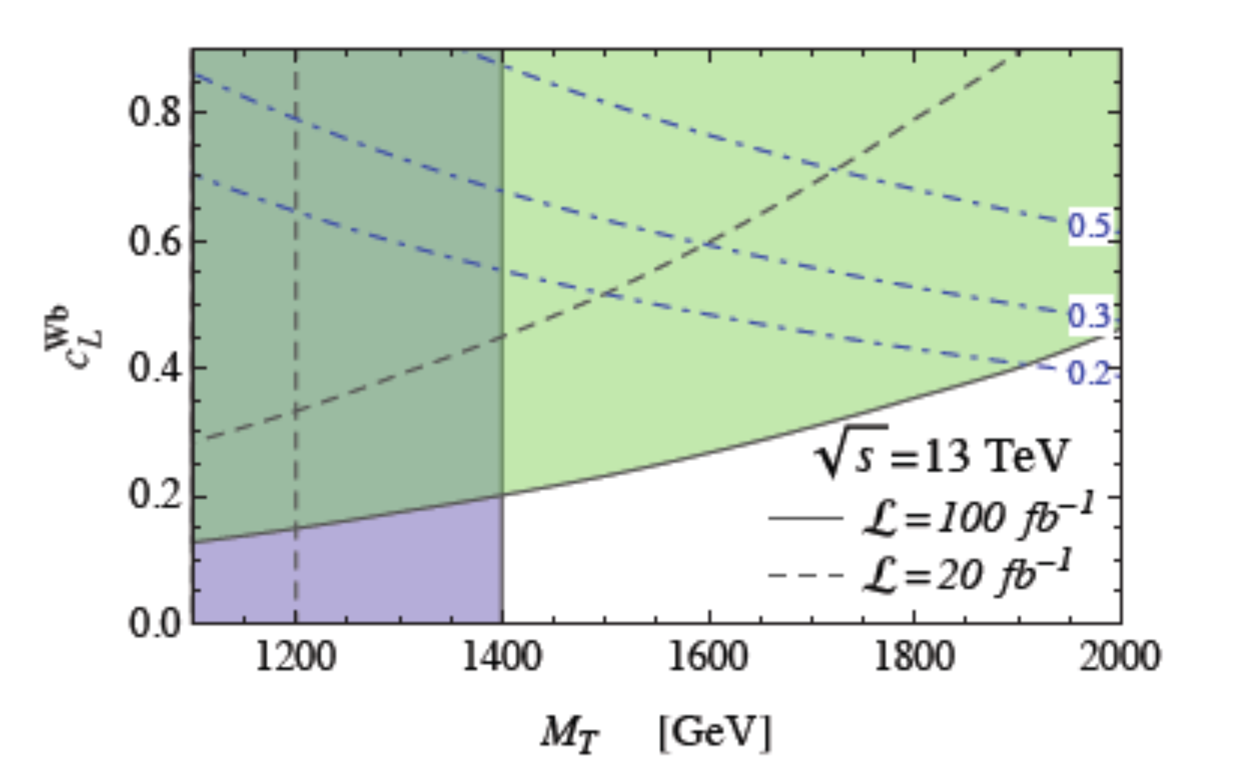


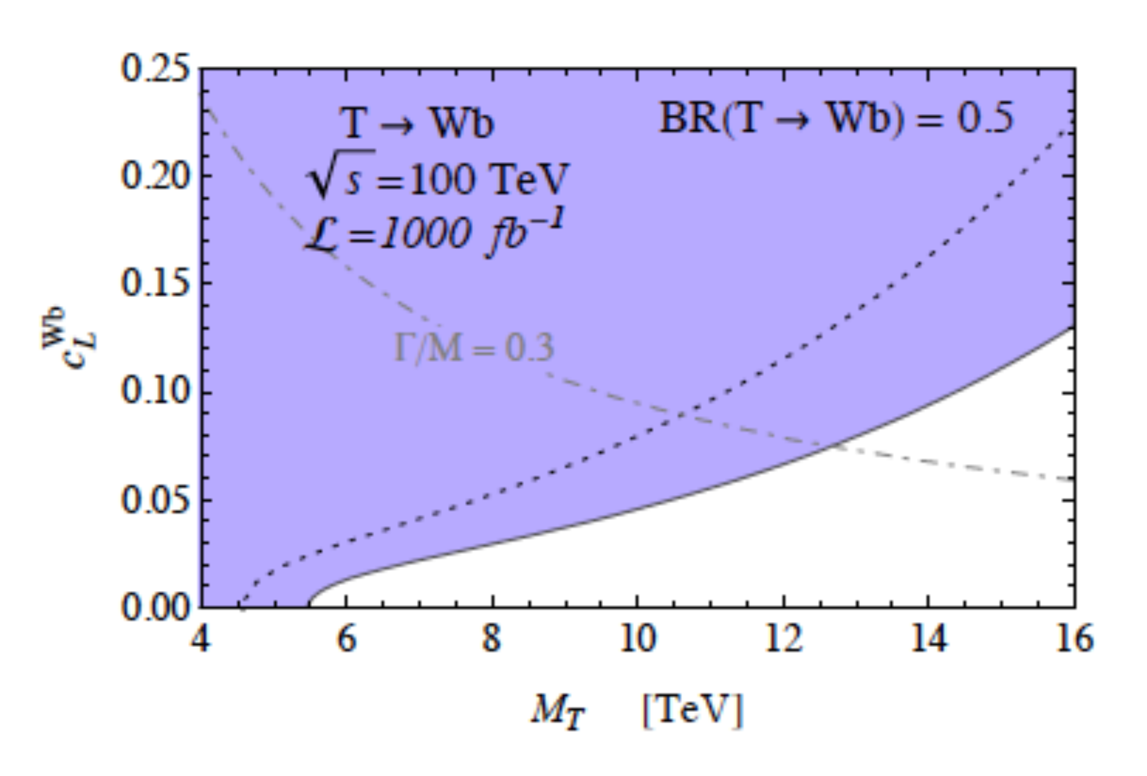
N. De Filippis (Bari), P. Giacomelli (Bologna)

NEW interest: HH->4lbb and lljjbb

Search for Top Partners

- Phenomenology projections for discovery of Composite Higgs models
  - see INFN White paper Frascati Phys.Ser. 60 (2015) 1-302
  - theory expertise available and interested
  - extrapolation of sensitivities to direct discoveries at different machines (LHC, Hi-LUMI, FCC-hh) as a function of mass and coupling

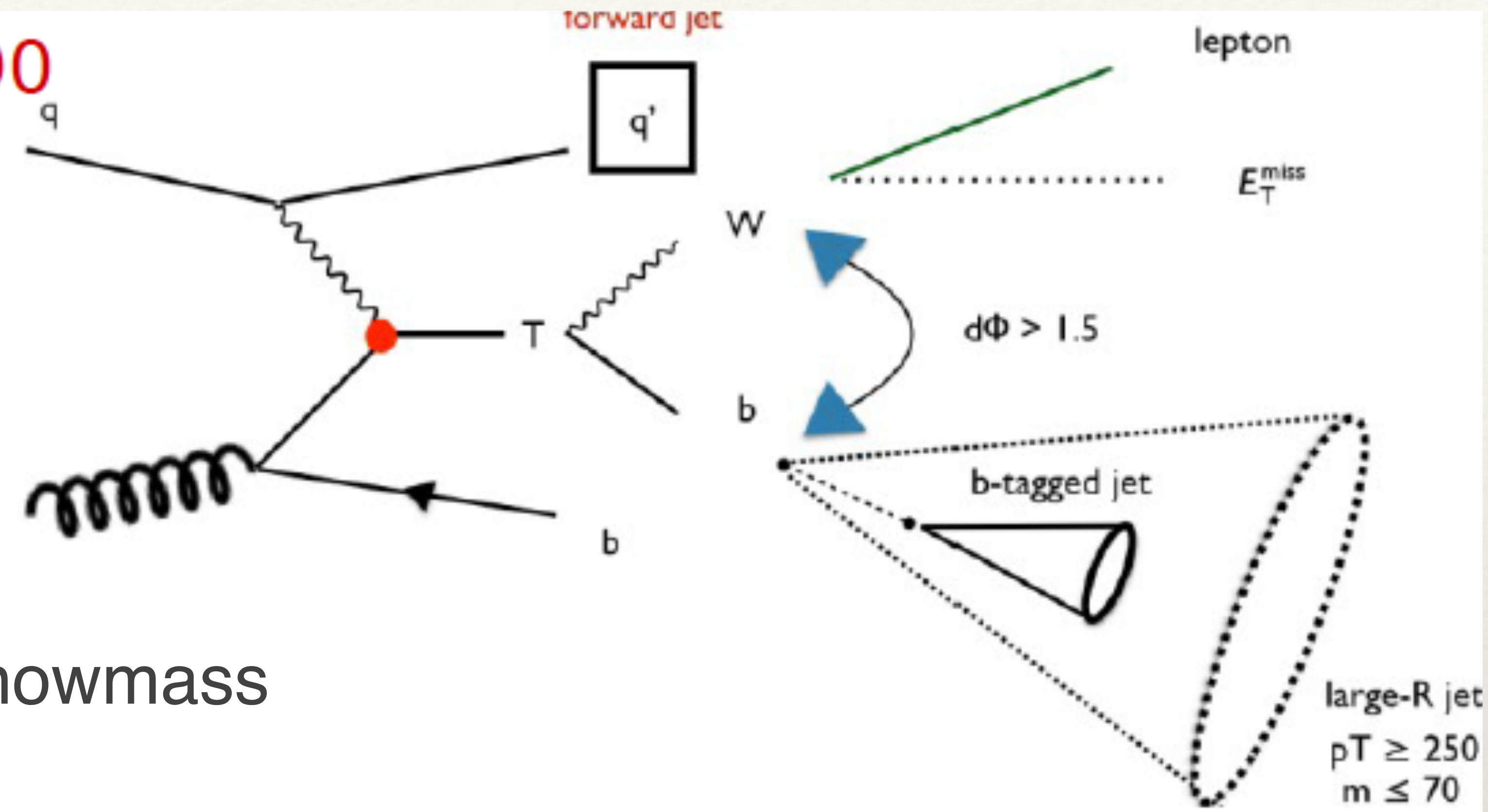




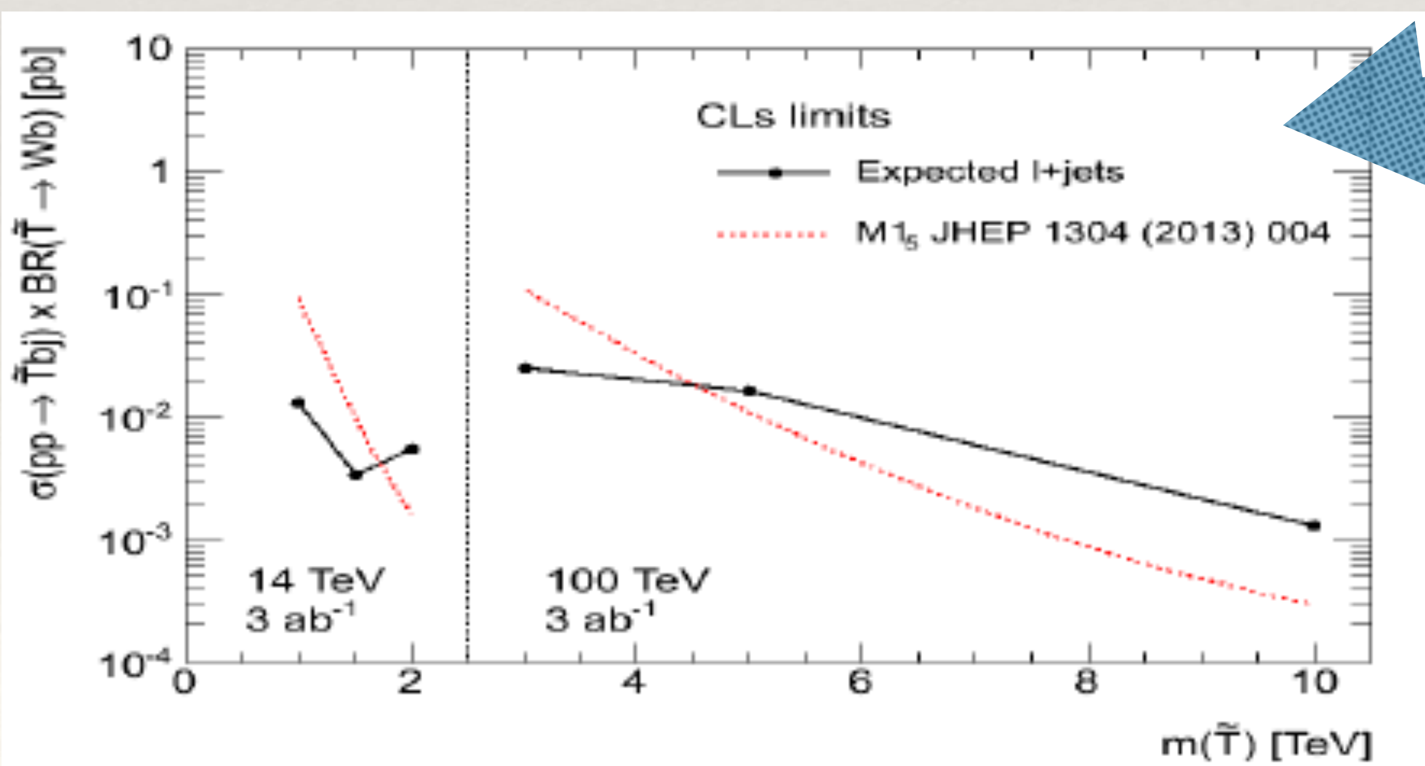
A. Wulzer, R. Torre

Direct search for VLQ

- Based on arXiv:1403.7490
- Prospects for LHC @14 and 100 TeV
- Single production of $T_{2/3}$



➡ Signal generation with Madgraph, detector simulation with Delphes (Snowmass cards)



L+jets channel: A. Gennaro, M. Cobal, G. Panizzo, M. Pinamonti (University of Udine and INFN trieste)

All-had channel: P. Azzi (INFN Padova), P. Ferrarese (U. Gottingen)

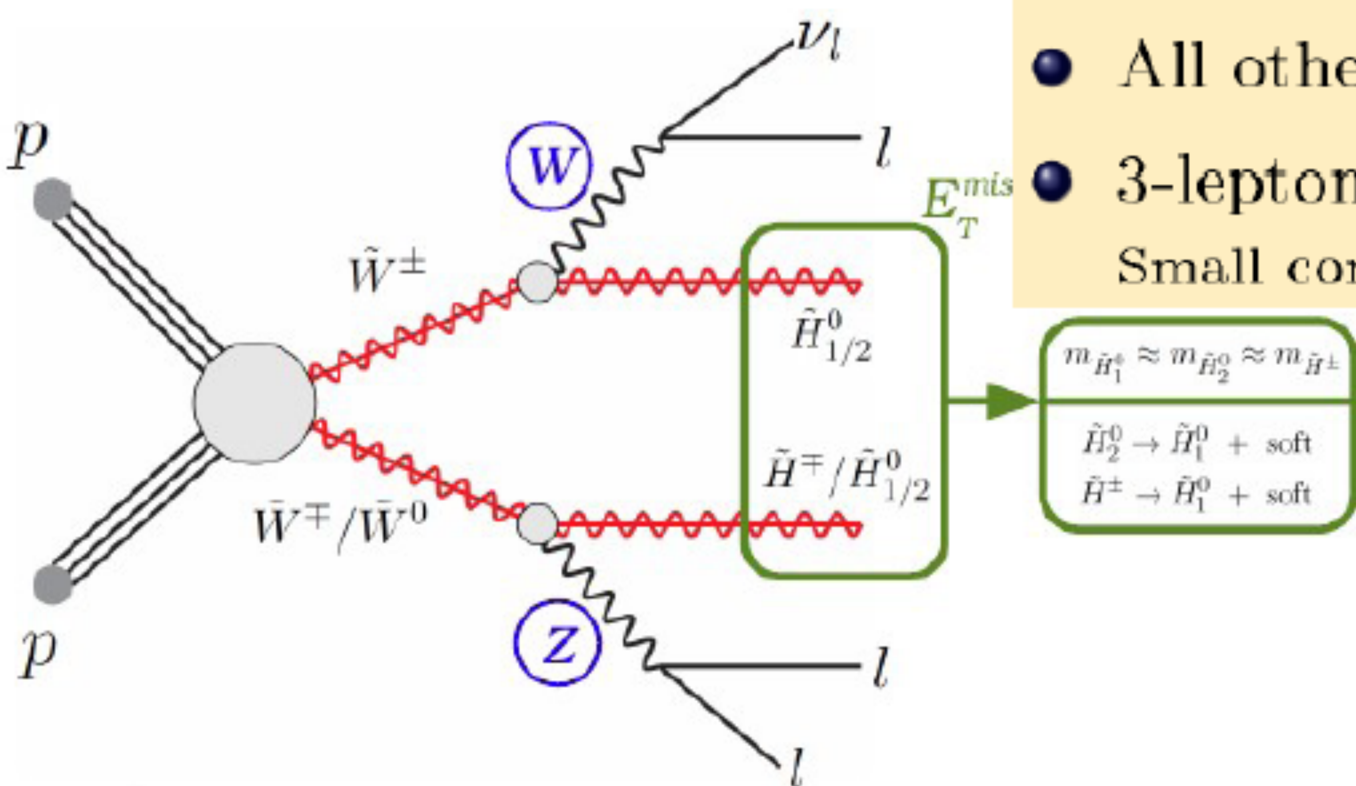
Direct SUSY search

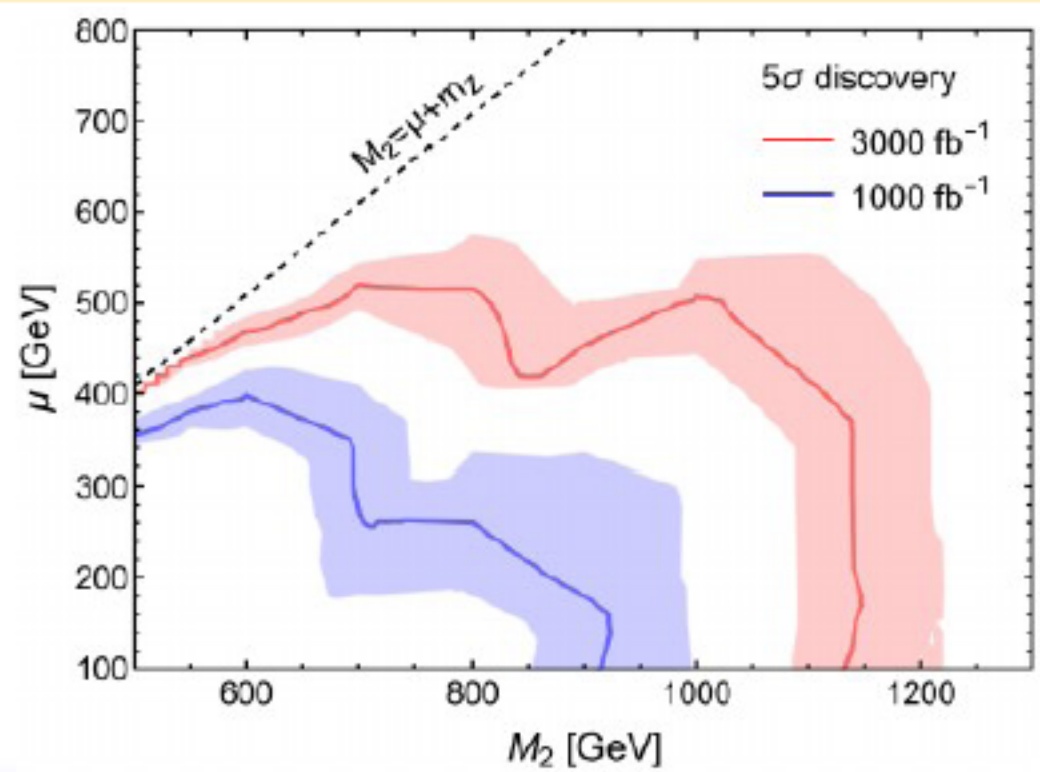
FCC-hh

Bobby Acharya (ICTP)+K. Bozek, K. Sakurai, C. Pongitivanichkul

- Prospects for observing charginos and neutralinos @ 100TeV pp collider
  - arXiv:1410.1532

- Higgsino LSP, W-ino NLSP ($\mu < M_2 < M_1$),
  This is the most promising scenario considering production x-secs,
- All other SUSY particles decouple,
- 3-lepton WZ final state ($3l + E_T^{miss}$ signature),
  Small contribution of Zh($\approx$ 10%) and ZZ(5%) modes





- Analysis limited by lepton isolation:
  - Need higher detector granularity

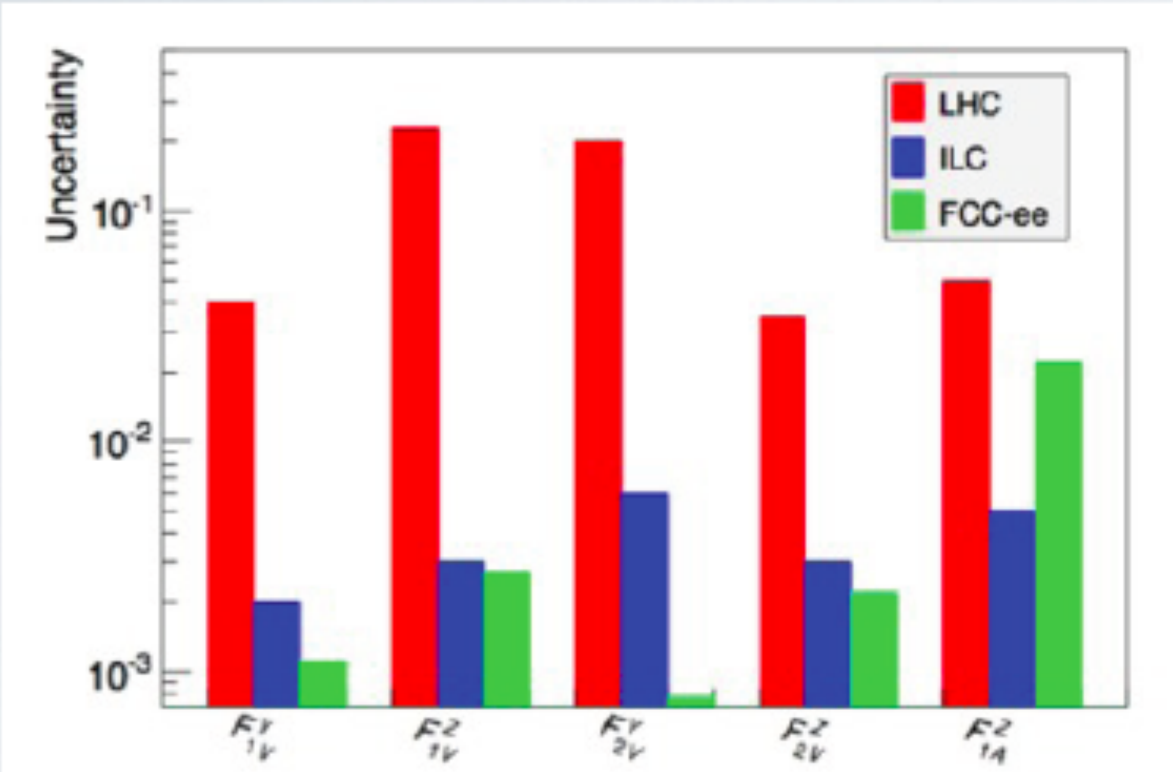
Conclusion and perspectives

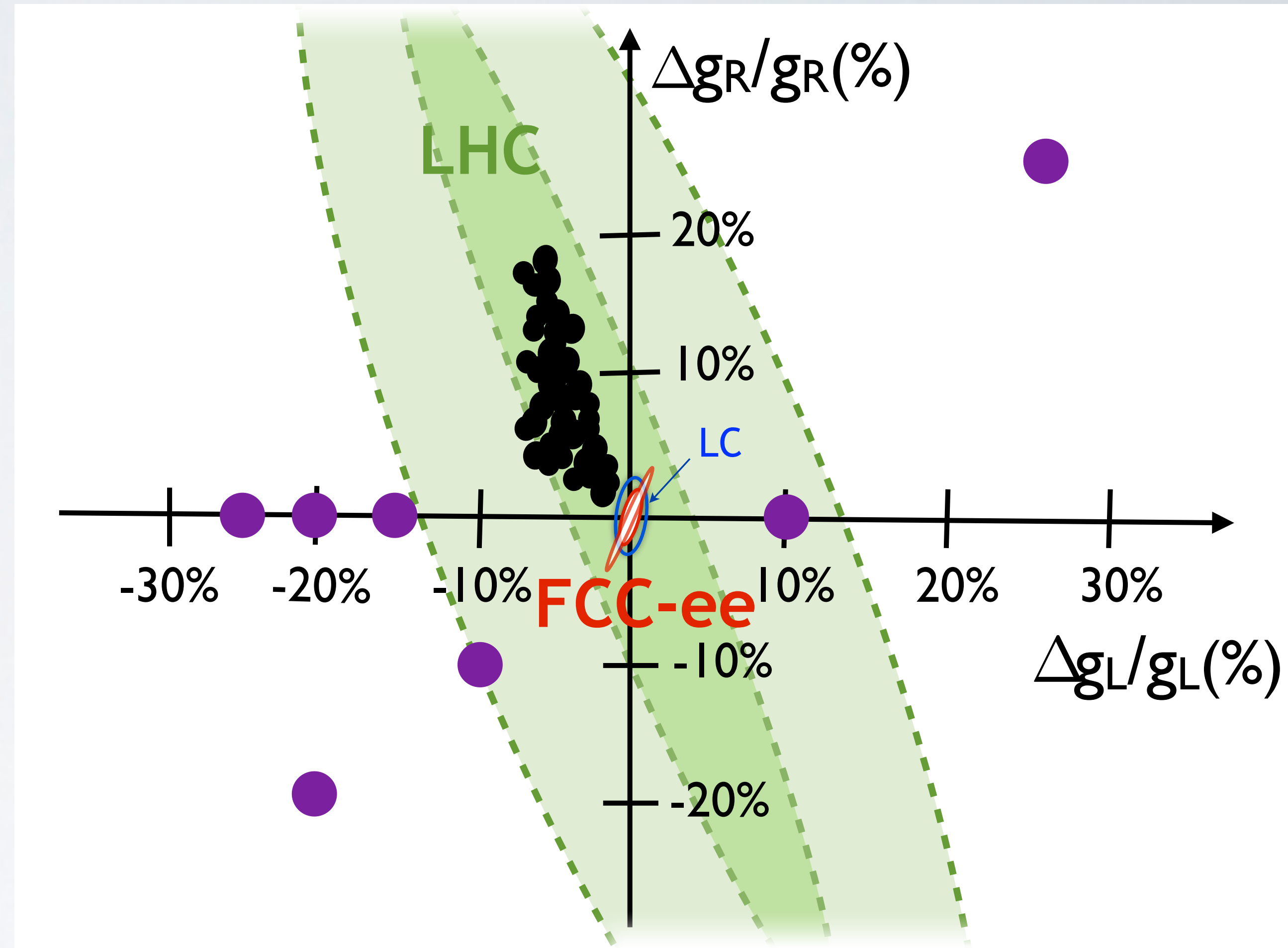
- Italy has shown interest in the development of studies for future colliders that spans several topics that overlap with the interest of the CepC/SppC projects
  - Expertise in basically all areas for physics and detector studies. Very interested in the possibilities offered by the potential of this project
- An optimization of the time, choice of topics and synergies with other projects would be the key for a profitable collaboration
  - The recent choice of INFN to support development and studies for Future Colliders is indeed helping to attract new collaborators.

Backup

FCC-ee

EWK couplings to the Top





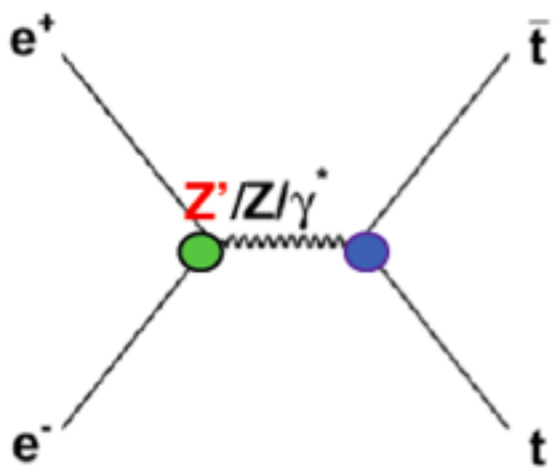
LHC (14 TeV, 300 fb^{-1})
ILC(500GeV, 500 fb^{-1}) with polarized beams
(ILC-TDR 1306.6352; Amjad et al. 1505.06020)
FCC-ee (360GeV, 2.6 ab^{-1}) from lepton angular and energy distributions
(Janot 1503.01325)

continuous(dashed): from angular and energy distributions of leptons (b-quarks)
(Janot, EPS HEP 2015, WhatNext White paper of CSN1)

N. Foppiani, T. Pajero, G. Rolandi
(INFN Pisa & SNS)

* Analytical results verified with full simulation analysis in 2015
* Signal generation with Whizard and ILC/CLIC simulation and reconstruction

Probing Composite Higgs models



The CHM modifications 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 (partial compositeness), mixing between Z and Z's
- ☑ the s-channel exchange of the new Z's (interference) - commonly neglected BUT can be very important also for large $M_{Z'}$

$e^+e^- \rightarrow t\bar{t}$ production is one of the most prominent 6f process, strong sensitivity also to new particles. Asymmetries O(1)

This model has effects also on Higgs couplings, see JHEP 02(2014)005

S. De Curtis (Roma1), S Moretti (UK)