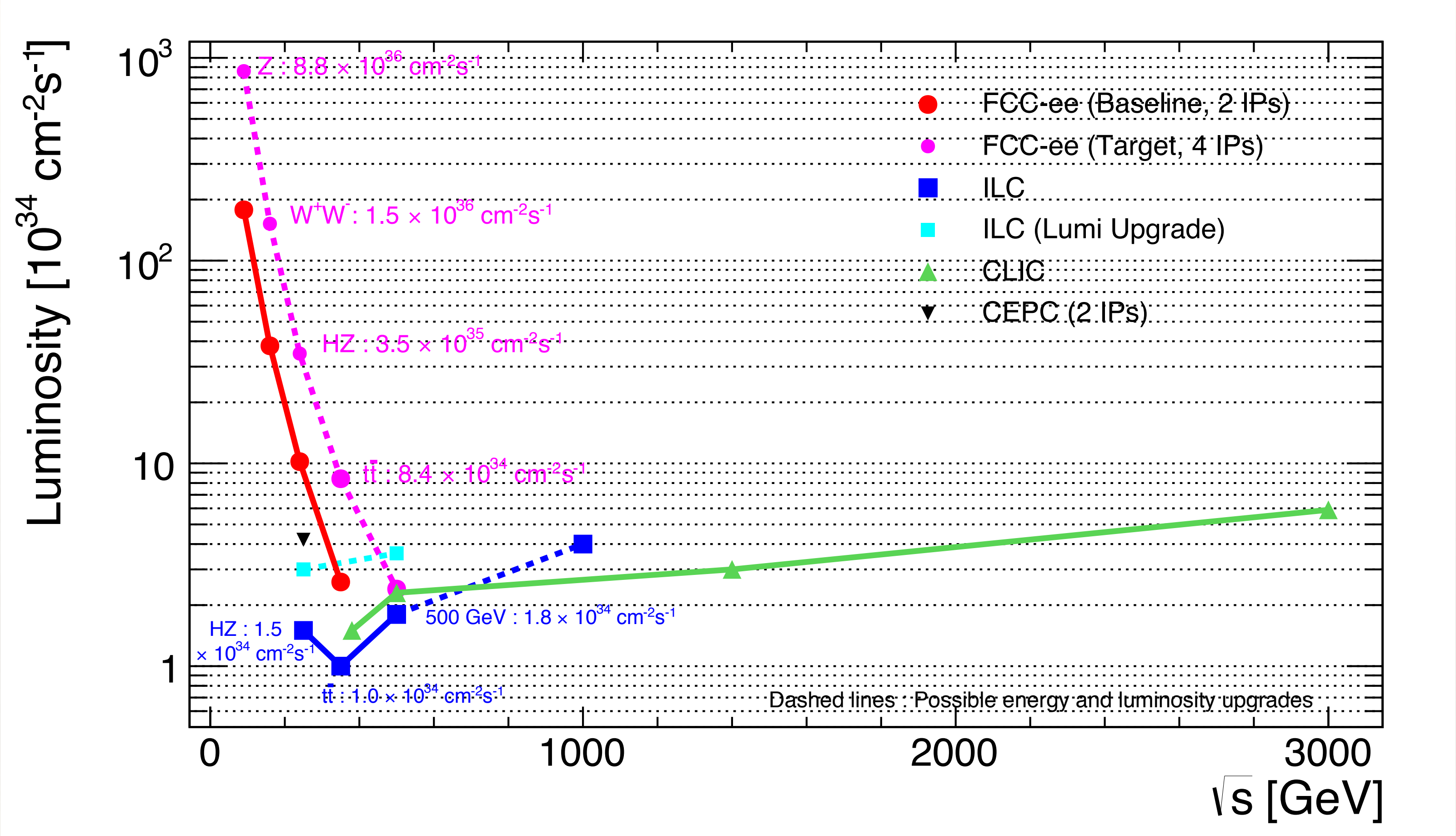
FCC Week Rome 2016

Progress in FCC-ee experimental studies

Patrizia Azzi - INFN Padova

High luminosity from $\sqrt{s}$=90-350GeV



Unprecedented precision: a challenge also to theory expectations

👍 Robust baseline ...all working hard toward target lumi

Run plan

Appellation	*Tera-Z*	*Oku-W*	*Mega-Higgs*	*Mega-top*	
√s (GeV)	90 (Z)	160 (WW)	240 (HZ)	350 ($t\bar{t}$)	350+ (WW→H)
Lumi [10^{34} $cm^{-2}s^{-1}$]	880	152	24	10	10
Lumi [ab^{-1}/yr]	88.0	15.2	3.5	1.0	1.0
Events/year	3.7×10^{12}	6.1×10^{7}	7.0×10^{5}	4.2×10^{5}	2.5×10^{4}
Target # events	**(10^{12}) 10^{13}**	**10^{8}**	**2×10^{6}**	**10^{6} $t\bar{t}$**	
# years	(0.3) 2.5	1	3	0.5	3

- **FCC-ee is the ultimate Z, W, H and top factory!**
- **Physics program can be completed in 10 years with target luminosities**
- Logically the program can be divided in two parts:
  - Precision Higgs Physics @ √s=240 GeV
  - Precision ElectroWeak Physics at √s=90, 160, and 350 GeV

Reminder: FCC-ee « core » physics

- A very rich menu, covering the bread & butter physics measurements, arXiv:1308.6176, « First Look at the Physics Case of TLEP », now with 198 citations!
- The « core » program condensed here:

- The Z pole scan, $\sqrt{s}$=88-95 GeV
  - m_Z, Γ_Z to < 100 keV, $\sin^2\theta_W$ to 5×10^{-6}, $\alpha_{QED}(m_Z)$ to 2×10^{-5}, $\alpha_s(m_Z)$ to 2×10^{-4}, ...
  - Rare decays/process searches and flavour physics with up to 10^{13} Z decays
- The WW threshold scan, $\sqrt{s}$=160-165 GeV
  - m_W to 300 keV, $\alpha_s(m_Z)$ to 2×10^{-4}, ...
- The Higgs factory, $\sqrt{s}$=240 GeV and above
  - Improve HL-LHC precision on Higgs couplings by an order of magnitude
  - Measure the Higgs width to better to 1%, and BR_{invis} to 0.1%
- The top threshold scan, $\sqrt{s}$=340-350 GeV
  - m_{top} to 10-20 MeV
- Set constraints on new physics scale to 100 (10) TeV if weakly (Higgs) coupled
  - Possibly discover very-weakly-coupled new physics through rare processes

Well matched to FCC-hh discovery range

What's new (and unique)

- Several new studies emphasizing the uniques opportunities offered by this machine and testing out some prejudices from the past:
  - **precision measurement of $\alpha_{QED}(m_Z)$**
  - **neutrino counting and search for RH neutrinos**

  with Tera-Z

  - **W mass and W width with the threshold scan**
  - precision measurement of $\alpha_S(m_Z)$

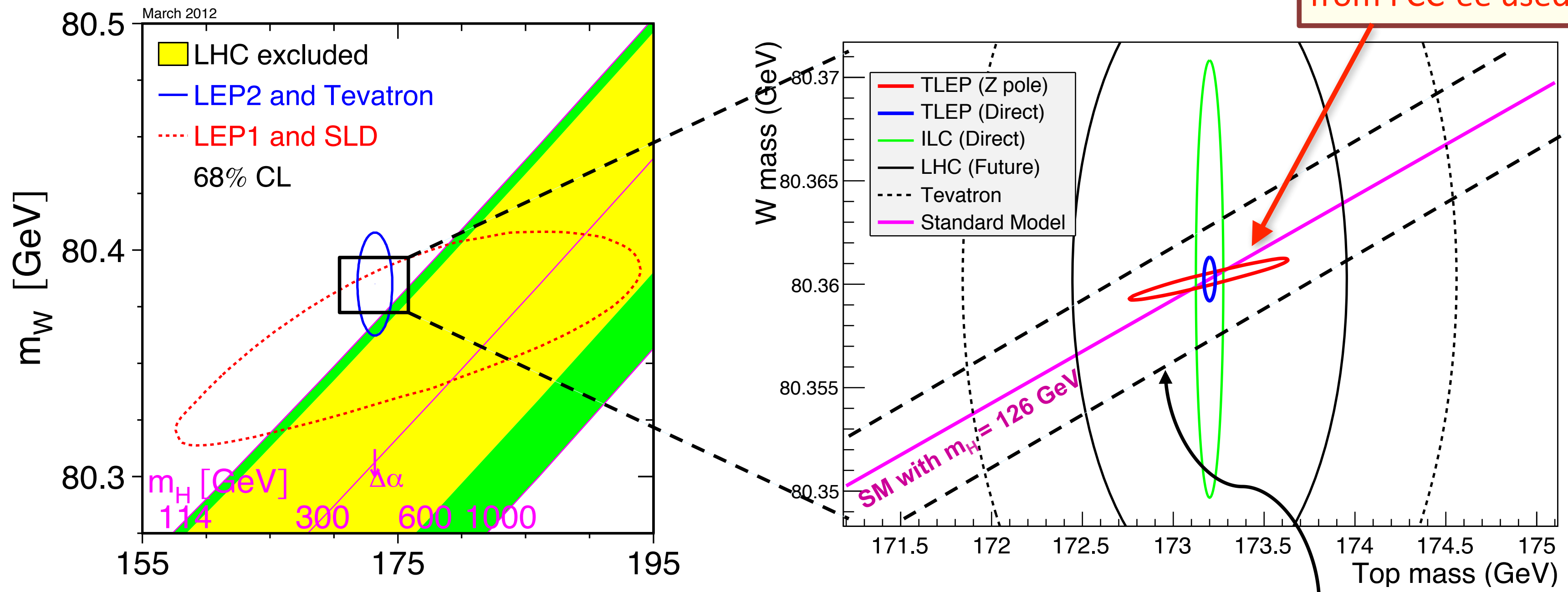
  with Oku-W

  - **Higgs as a Dark Matter portal** **@√s=240**
  - **top quarks EWK couplings to Z and γ** **@√s~350**
- Investigating run at $\sqrt{s}=m_H$ to determine Hee coupling measurement
- **Constraints from the EWK precision measurement to several BSM scenarios. Taking the ultimate precision from the whole program.**

Standard Model after FCC-ee

- **In absence of New Physics the m_{top} vs m_W plot would look like this:**

Note: αQED(mZ) from FCC-ee used here

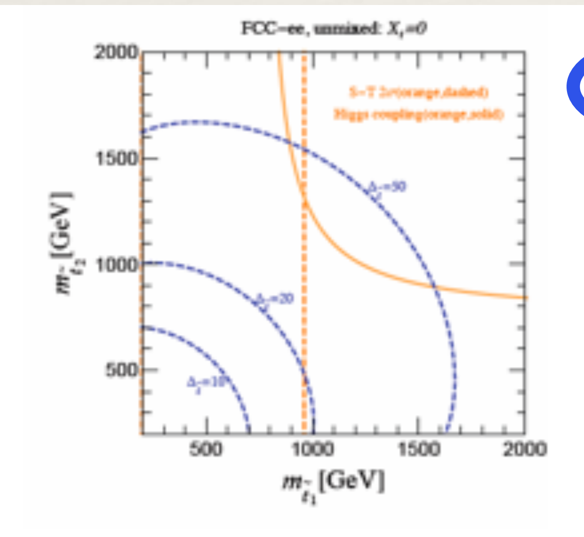


Without m_Z@FCC-ee, the SM line would have a 2.2 MeV width

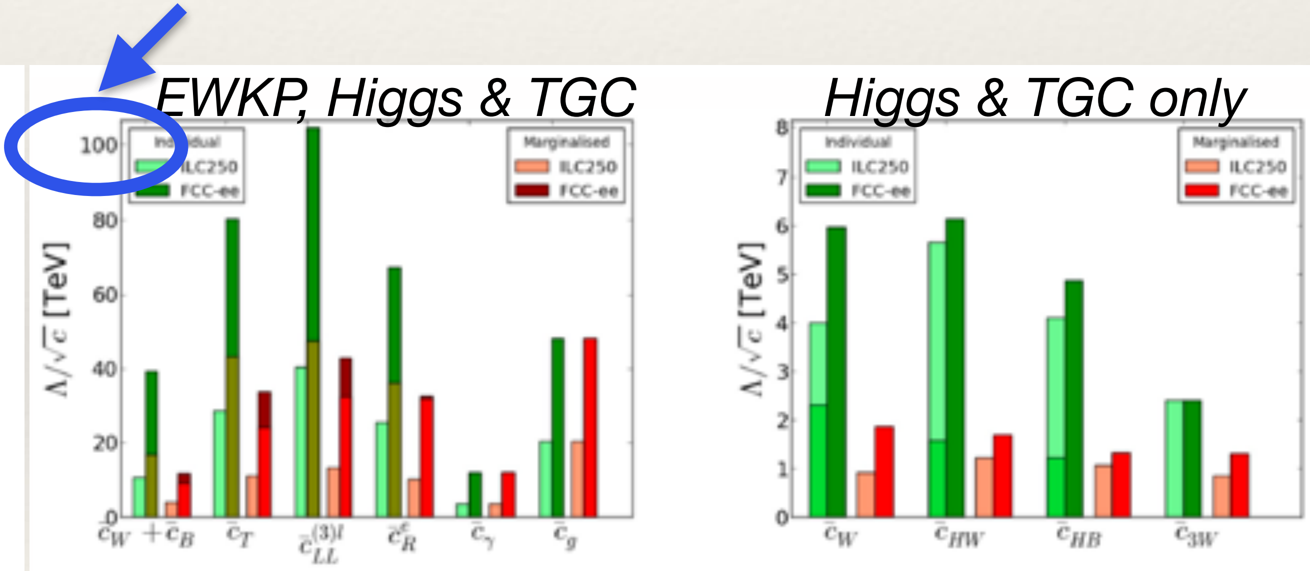
- **Constraints on new physics ?**

Indirect BSM constraints

- Results below come from the phenomenological side of the studies
  - give a simple representation of the full potential that could be achieved putting together all the precision information in a global manner.
- The New Physics scales that can be probed reach values that nicely match the FCC-hh collider region of interest.



EW precision and Higgs data probe TeV-stops



Ellis & You '15

Fan,Reece,Wang '14

Discovery potential

Of course discovery depends on the goodwill of nature.
This is what we could discover if is there just waiting for us

- **EXPLORE 10 to 100 TeV energy scale with Precision Measurements**
  - ~20-50 fold improved preicision on many EW quantities (which is equivalent to a factor 5-7 in mass scale) m_Z, m_W, m_{top}, $\sin^2\theta_W^{eff}$, R_b, $\alpha_{QED}(m_Z)$, $\alpha_S(m_Z)$, Higgs and top couplings
- **DISCOVER a violation of flavour conservation**
  - FCNC ($Z \rightarrow \mu\tau$, $e\tau$) in $5 \cdot 10^{12}$ Z decays + flavour physics (10^{12} bb events)
- **DISCOVER Dark Matter as « invisible decay » of Z or Higgs**
- **DISCOVER very weakly couples particles in 5-100 GeV energy range**
  - Right-Handed Neutrinos, Dark Photons, etc…

Physics Studies Organization

Physics Studies Coordination
A. Blondel, P. Janot (EXP), J. Ellis, C. Grojean (TH)

EW Physics (Z pole)
R. Tenchini, F. Piccinini
S. Heynmeier, A. Freitas

Diboson Physics (MW)
R. Tenchini, F. Piccinini
S. Heynemeier, A. Freitas

Higgs Properties
M. Klute, K. Peters
S. Heynemeier, A. Freitas

Top Quark Physics
P. Azzi, F. Blekman
S. Heynemeier, A. Freitas

Synergy with FCC-hh physics, LC physics, LEP physics

QCD and γγ Physics
D. D'Enterria
P. Skands

Flavor Physics
S. Monteil
J. Kamenik

New Physics
M. Pierini, C. Rogan
M. McCullough

Global Analysis,Combination, Complementarity
J. Ellis

Develop the necessary tools

Offline Sofwtare
C. Bernet, B. Hegner,
C. Helsens

Synergy with FCC-hh, LC, LHC

Online & Trigger
C. Leonidopoulos,
E. Perez

Understand experimental conditions

MDI
N. Bacchetta,
M. Boscolo

Joined with FCCee-acc

Detector Design
A. Cattai, M. Dams,
G. Rolandi

Set constraints on possible detector designs to match statistical precision

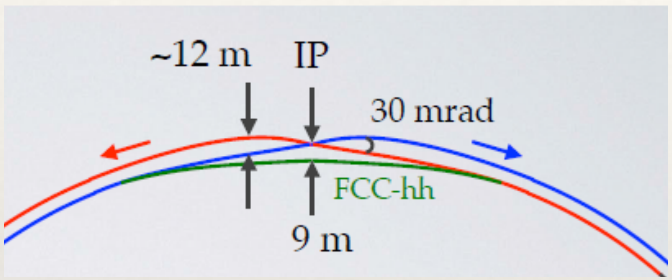
Synergy with Linear Colliders and others

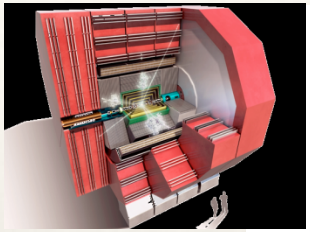
FCC-ee Activities

- All working groups have conveners appointed & ongoing activities
- Regular VIDYO meetings for physics, accelerator and joined (MDI) as well as Working Group meetings.
- **Mini-Workshops**
  - **Detector** (Leonidopoulos, Perez, Dam) 17-18 June 2015
  - **Precision Calculations** (Heynemeier, Ellis, Grojean) 13-14 July 2015
  - **Higgs** (Klute, Peters) 24-25 September 2015
  - **Alpha$_S$** (D'Enterria, Skands) 12-13 October 2015: summary published in **arXiv: 1512.05194**
  - **Physics Behind Precision** (Azzi, Blekman, Locci, Piccinini, Tenchini) 2-3 February 2016: summary publication in preparation
  - *…more coming this year!*
- **FCC-ee 10th General Workshop 4-5 February @CERN**
- **For more information subscribe to the FCC-ee website: http://cern.ch/fcc-ee**

Machine Detector Interface

- **Mandate**: come up with a plausible design and necessary technical R&D or measurements. **Started February 2016**: chairs M. Boscolo(LNF) and N. Bacchetta(INFN-PD/CERN)

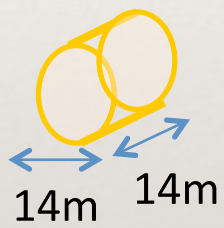


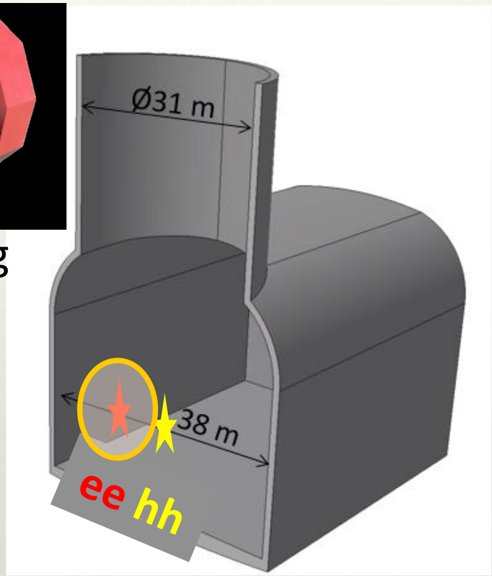


Typical e+e- detector (ILD, CLIC-SID) is 14m across&long

W.Klempt

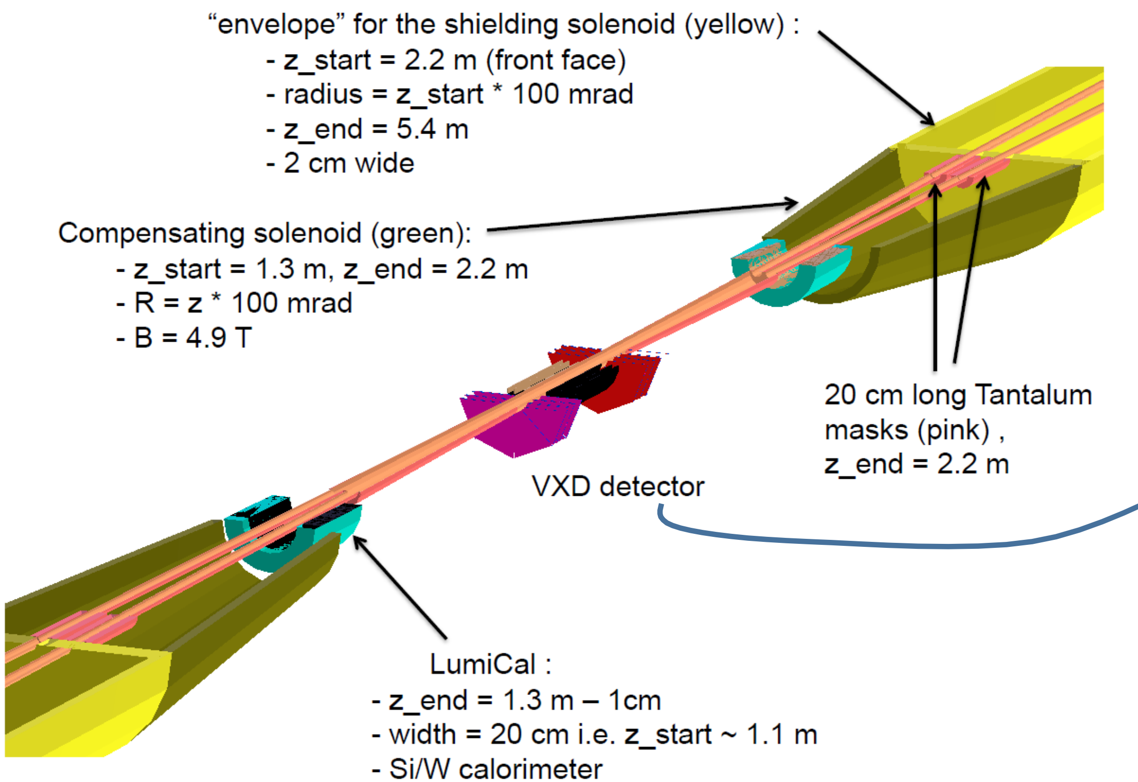
Asymmetric IR helps (a lot)
with Synchrotron Radiation
Displaced w.r.t. hh collision point (and cavern?)
leaves 10m between IR and (preliminary) cavern →

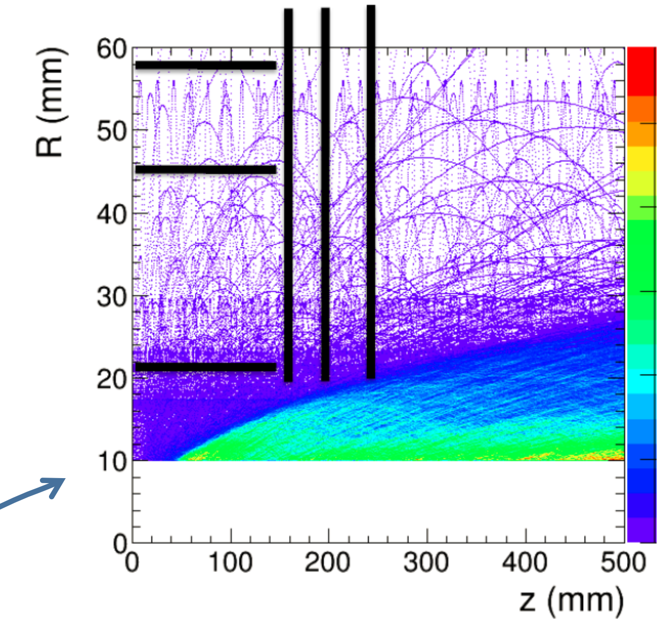




- **Constraints on detector:**
  - small L*~O(2m)
  - 30 mrad crossing leads to transverse field on beam ☞need solenoid compensation
  - two beam pipes entering the detector+small L* ☞ delicate design of lumi monitor
  - wrt LC detectors: prbably need to reduce magnetic field (2T?), increase tracking length ☞ overall size might be wider
  - first studies of beam induced backgrounds taking place

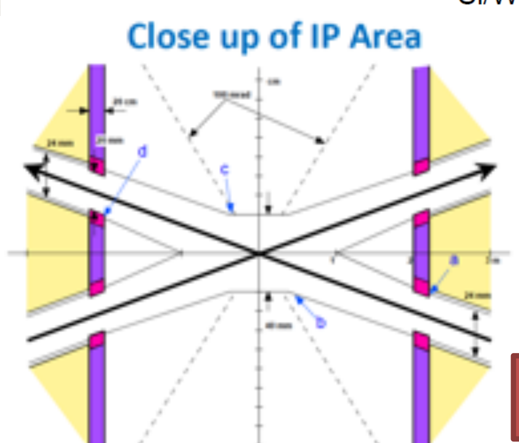
Toward layout of the IP





Simulations of e+e- pairs produced by beamstrahlung
R_pipe = 2cm → out of trouble

Kolano,Perez



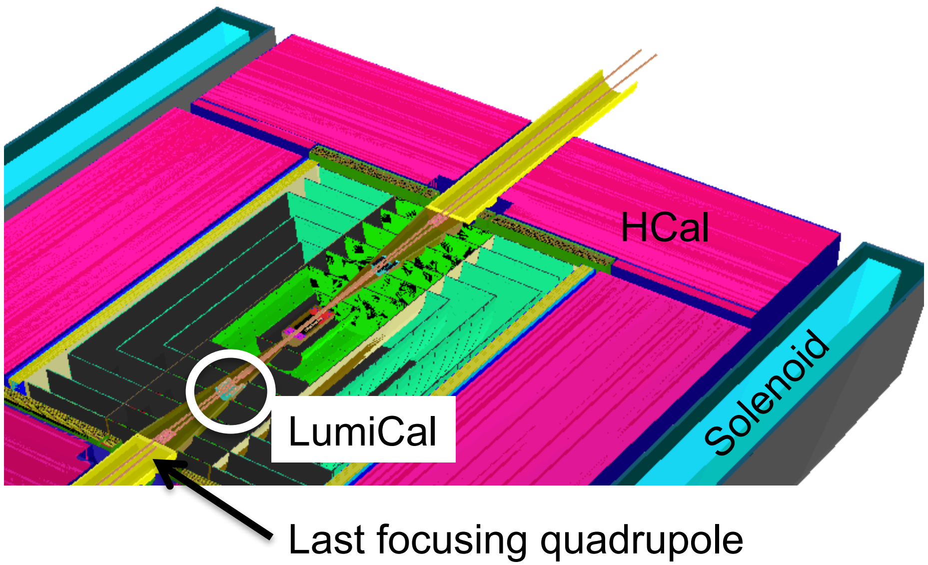
Final Focus Quads
AND solenoid compensation
AND lumi monitors
AND masks, etc…
to fit within 100mrad cone!

Sullivan,Oide,Dams,Koratzinos

Lots to do…
but it has STARTED!

Interaction Region & Detector Model in G4

- First implementation of a possible interaction region and detector for FCC-ee for GEANT4 full simulation



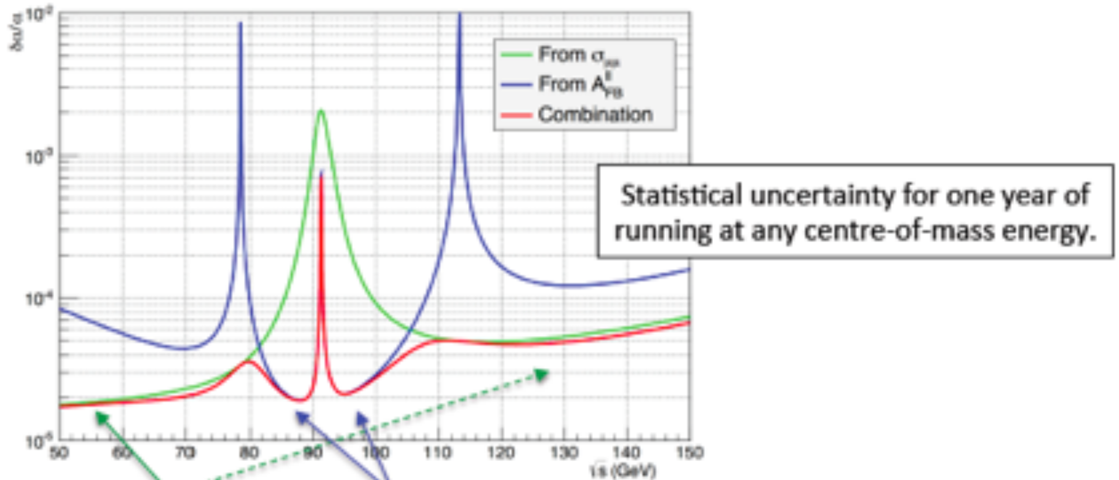
- Using the CLIC software tools
  - description of the geometry based on DD4HEP
- interaction region for FCC-ee
  - esp. QD0 and LumiCal quite close to the IP
- add on top the CLIC detector
  - minimal changes to the inner det. to comply with FCC-ee IR
  - and lower B = 2 T

First studies make use of this implementation :
- for the simulation of backgrounds (SR, pair-production bckgd, etc)
- using CLIC software suite to run the full simulation and basic analysis

- FCC-CLIC Collaboration: use CLIC experience and tools for the time being. Soon to be ported to FCC Software

Direct α(QED) measurement

- Standard method involves extrapolation from $\alpha_{QED}(0)$ to $\alpha_{QED}(M_Z)$.
  - Error dominated by dispersion integral over hadronic cross section (low energy res)
- Profit of large statistics: measuring α_{QED} directly close to the Z



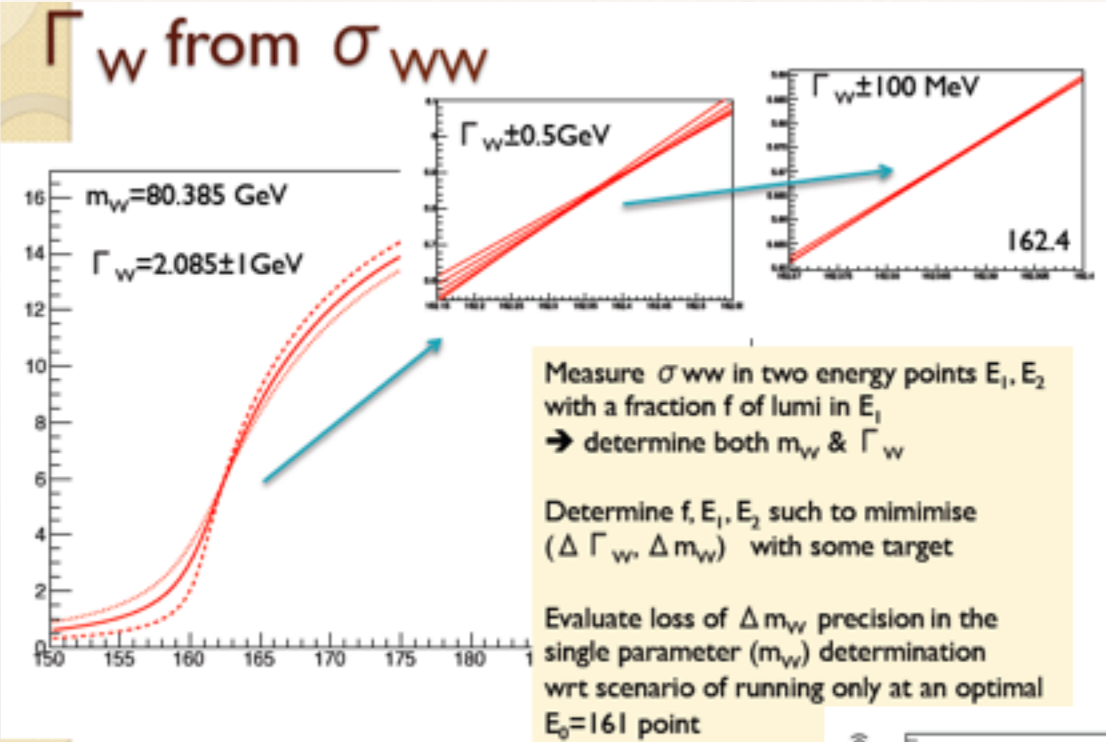
From $\sigma_{\mu\mu}$ measurement
- Sensitivity best "far" away from Z peak, particularly at the low side
- Systematics (normalisation) probably a killer

From $A_{FB}^{\mu\mu}$ measurement
- Sensitivity best at points $\sqrt{s}$ = 87.9 and 94.3 GeV
- Theoretical systs. largely cancel by "averaging" over 87.9 and 94.3 GeV points.
  - Higher order EW to be calculated (few x 10^{-4})
- Experimental systs. controlable; dominant contribution from knowledge of E_{BEAM}: **1 x 10^{-5}**

By running six months at each of 87.9 and 94.3 GeV points:
➢ Potential to reach a precision of : **$\delta\alpha/\alpha = 3 \times 10^{-5}$**

P. Janot arXiv:1512.05544

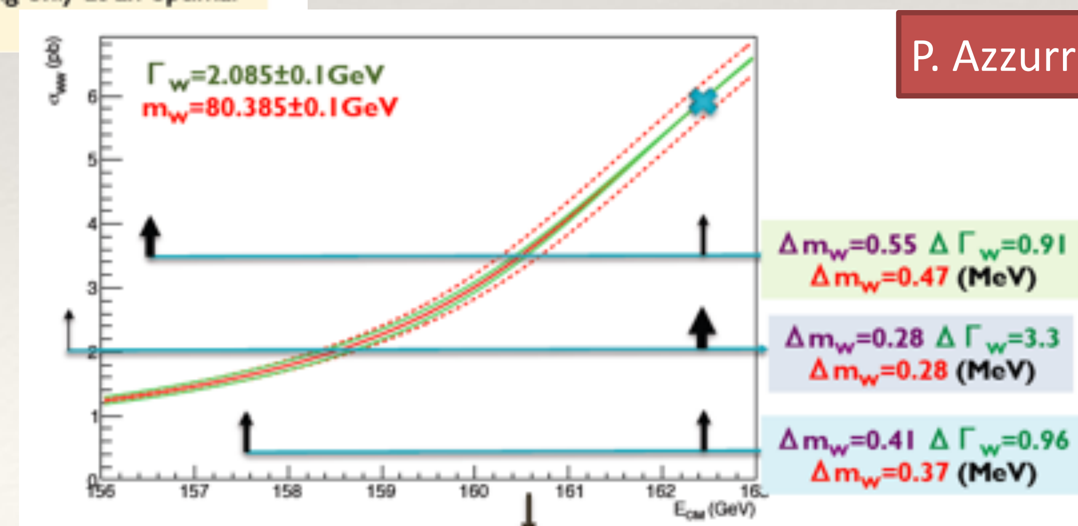
m_W and Γ_W from threshold scan



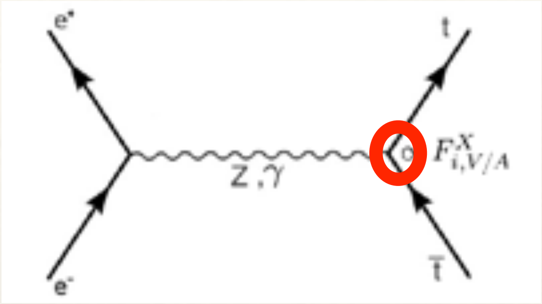
- Two parameter (m_W, ΓW) fits of (σ_1, σ_2)
    - 15/ab only statistics uncertainties
- Challenge for knowledge of energy (<1 MeV), acceptance (10^{-4}), backgrounds (<1fb).
    - Measurement strategy can vary if systuncertainties are limiting

P. Azzurri

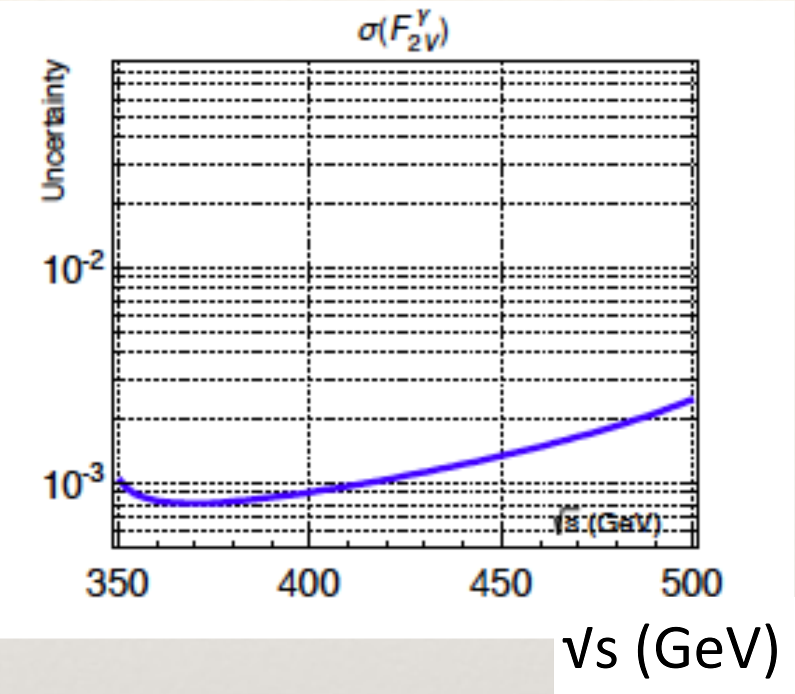
The interest in the σ_{WW} (E) lineshape could go beyond m_W and Γ_W



Top Electroweak Couplings



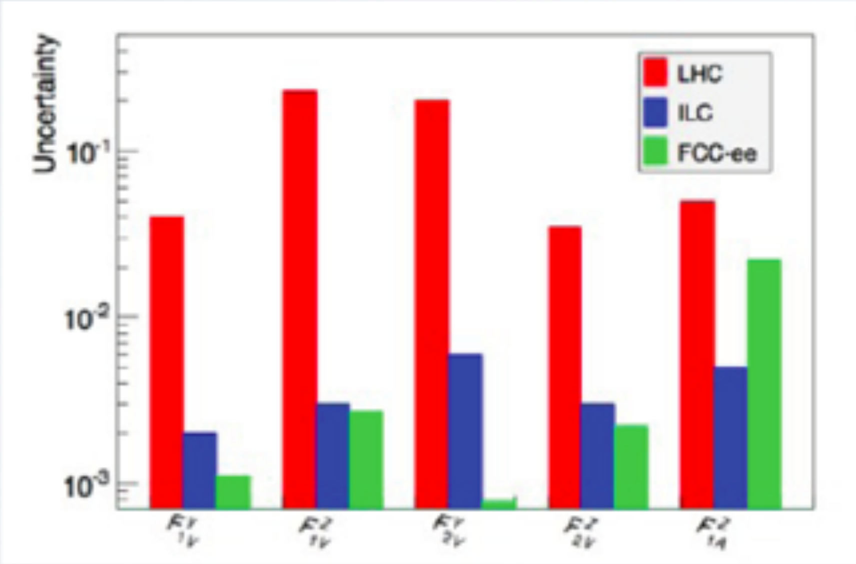
- Access the separate components from the ttZ and ttγ couplings and possible anomalous contributions from the top decay properties.
- Top polarization information is maximally transferred to its final state via the weak decay
  - **the lack of beam polarization is compensated by the final state polarization and by the larger statistics (1.6M top in 3 years)**
- Some optimal observable can be defined. In the case of tt->l+jets: the lepton direction and energy.
- main systematics comes from predicted event rate

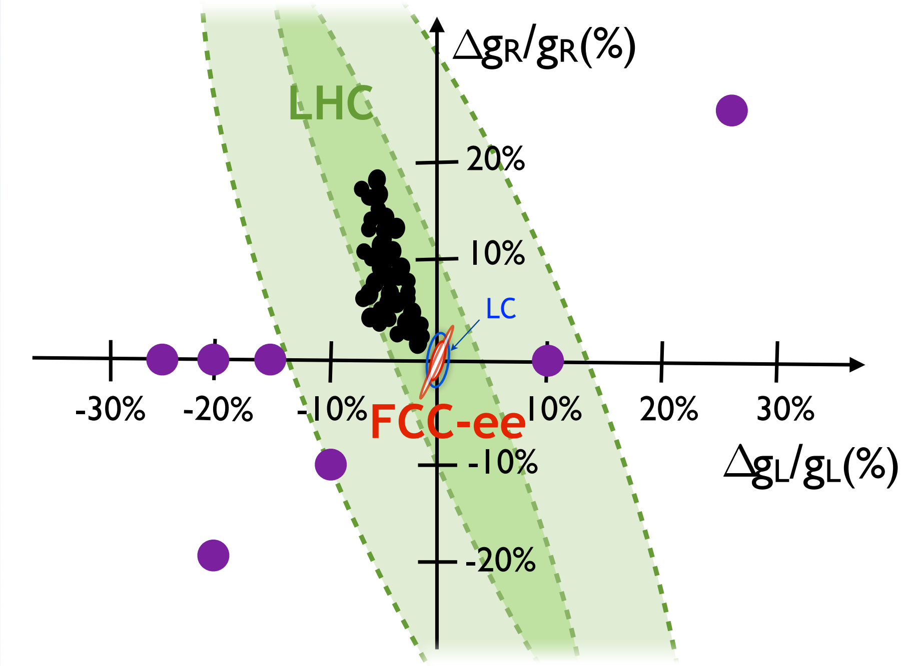


- target precision at the per-mil level
- no need for high energy runs, far above the threshold: √s=365 GeV is optimal

P. Janot arXiv:1503.01325

Accuracy on Top Couplings





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

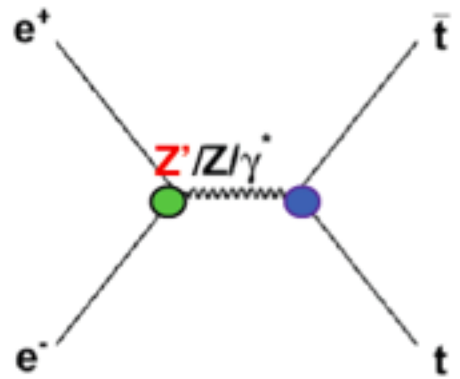
(Janot 1503.01325)

continuous(dashed): from angular and energy distributions of leptons (b-quarks)

Analytical results also verified with full simulation analysis in 2015

Foppiani,Pajero

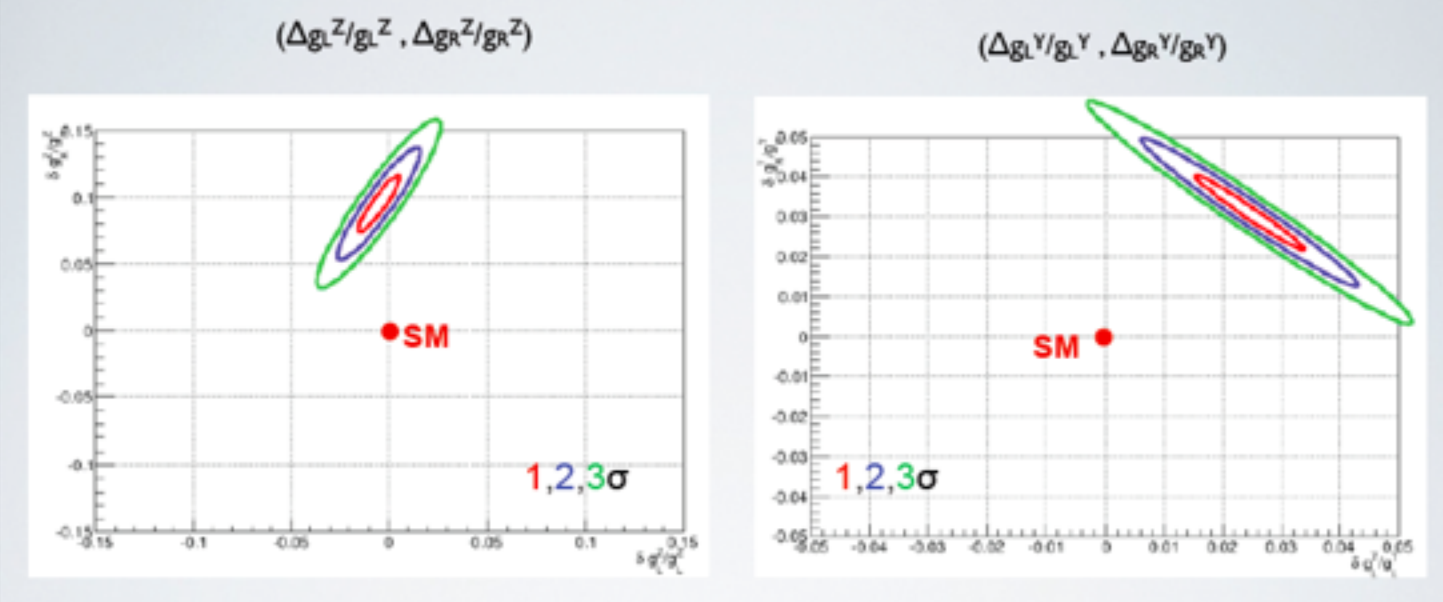
Probing Composite Higgs models



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 $M_{Z'}$

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



S. De Curtis, S. Moretti

RH Neutrino search

- **Search for sterile neutrinos in Z decays:**

$$\nu_L = \nu\cos\theta + N\sin\theta$$

Light "normal" neutrino

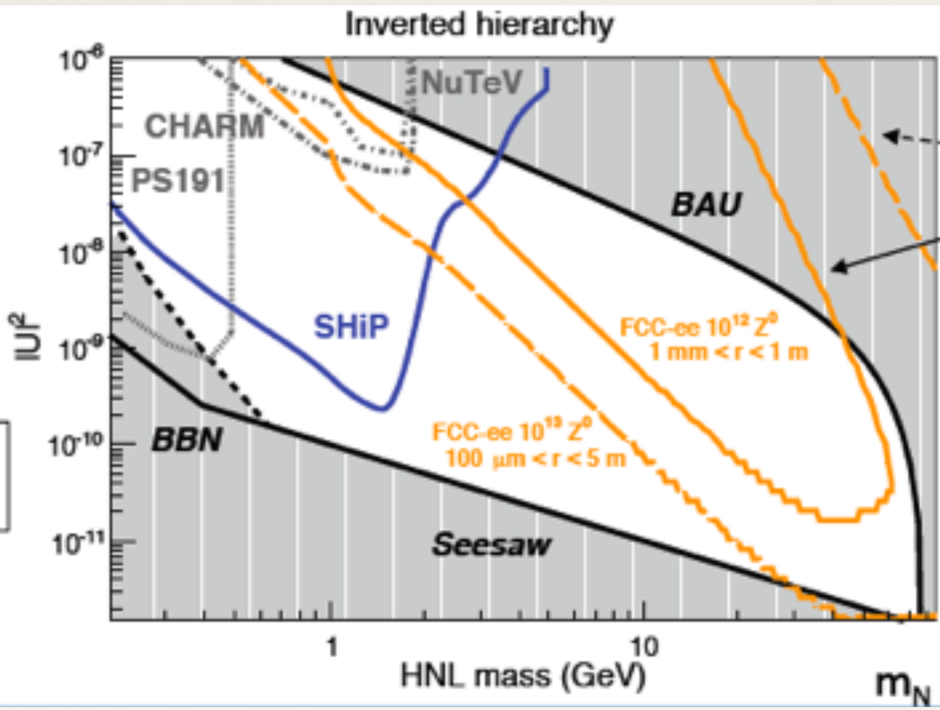
Heavy "sterile" neutrino

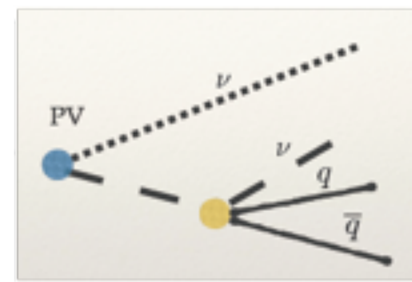
$Z \rightarrow N\nu_i$, with $N \rightarrow W^{*}l$ or $Z^{*}\nu_j$

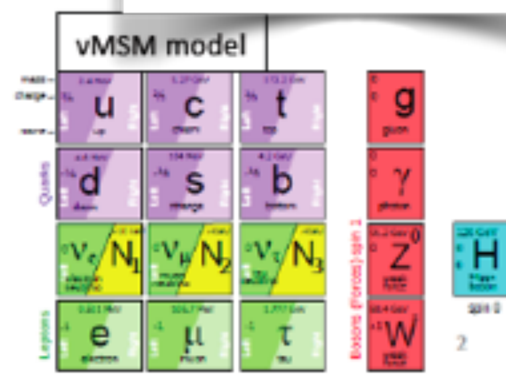
Number of events depends on mixing between N and ν, and m_N

(Very) Displaced SV, detector challenge!

Mixing between N and ν



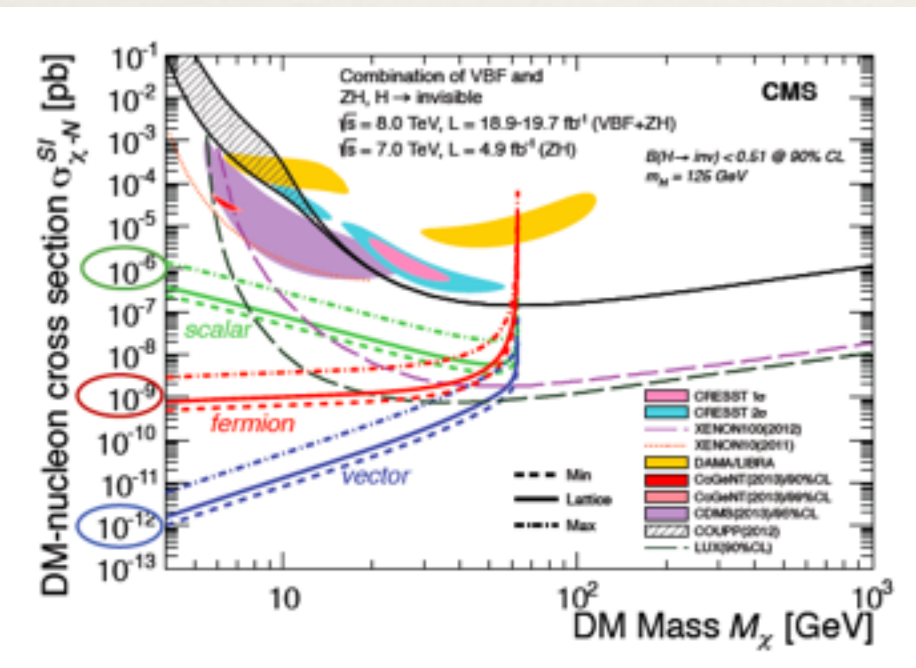


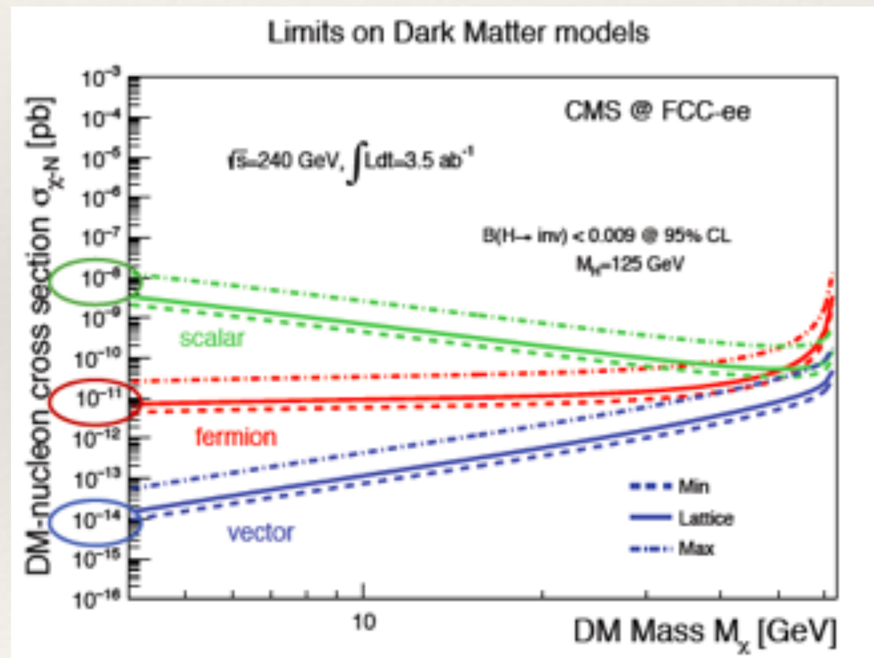


Blondel, Graverini, Serra, Shaposhnikov arXiv:1411.5230

Dark Matter potential

- FCC-ee can be particularly relevant in models such as « SM neutral DM + light mediators »
  - the mediator could be the Higgs itself —> « Higgs Portal »
  - Γ_Z and Γ_H are the most efficient wat to explore SM-mediated DM at colliders





Study using CMS detector simulation

Cerri,DeGruttola

Conclusions

- All these measurements and potential discoveries stem from the unique properties of the FCC-ee project amongst lepton colliders
  - Makes the FCC-ee very complementary and synergetic with the FCC-hh

All results presented are based on the target luminosity plan.
We'll never complain for too much luminosity.

- More details on the studies mentioned (and more) to be followed here:
  - FCC-ee phenomenology on Tuesday afternoon
  - FCC-ee MDI Wednesday morning
  - FCC-ee Software (joint) Thursday morning
  - FCC-ee Experiments Thursday afternoon
  - Poster Session —> Poster with Run Plan