FCC-ee: Detector constrains on Invisible width of the Higgs and and dark matter in Higgs portal models

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FCC week, Rome, 14/04/2016

Outline

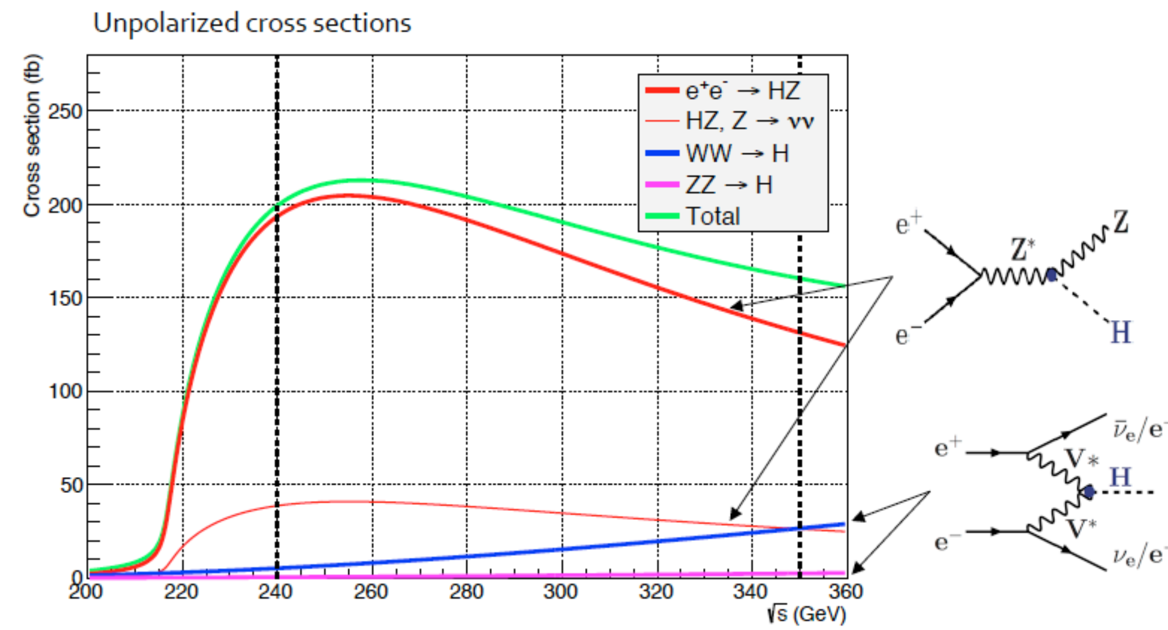
- prospects for *H->inv* discovery/constraint at FCC-ee
- repeat first the analysis done for TLEP
- recompute for FCC-ee luminosity proposal
- comparison of two detector Simulations
    - CMS and ILD using Delphes fast-simulation
- interpretation in the Higgs Portal model and compare with HL-LHC and future DM experiment

Motivations

- Constraining *H->inv* down 1% is very important
  - indirect constrains from fitting the others BR
    - Total Higgs width: needed to understand possible BSM decays in a model-independent way.
  - direct constraints
    - if Higgs of shell, limits on light DM ($m_{DM}<m_{h/2}$)
- New Physics (NP) is likely to be near the electroweak scale
  - co-responsible for generating it is a candidate to stabilize it
  - NP is likely to interact with the newly discovered h boson
    - higgs as Dark Matter (DM) Portal , where DM is supposed to carry no charges in the Standard Model gauge interactions

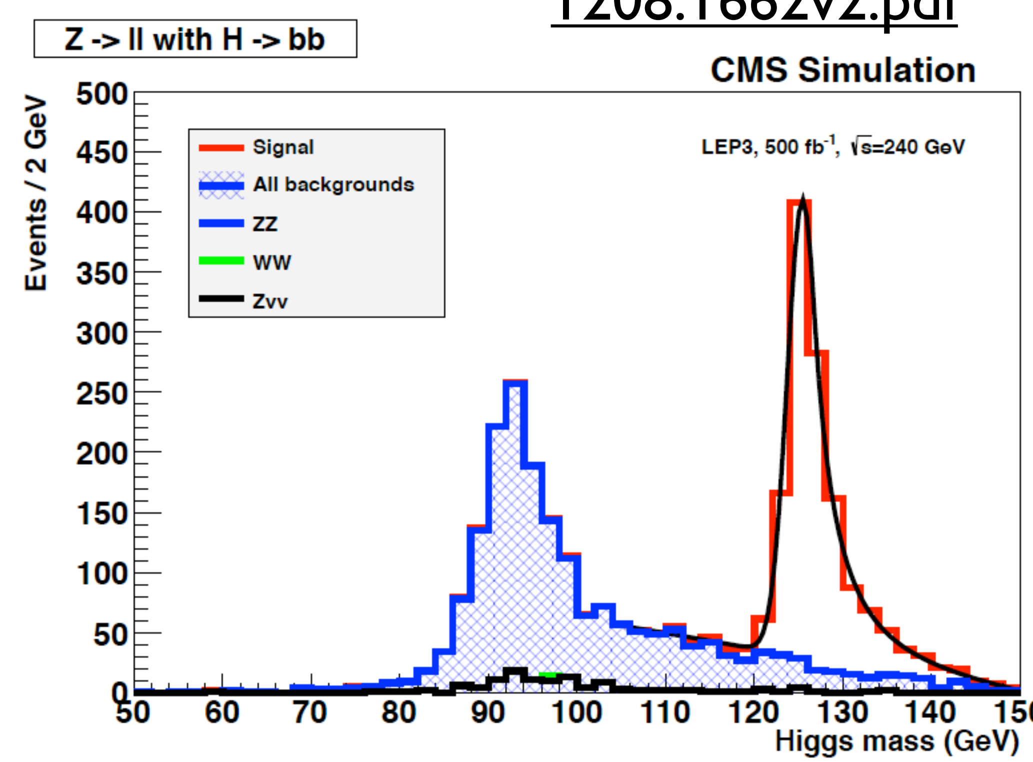
FCC-ee: Higgs factory

- FCC-ee at 240 GeV is very suitable for that!
  - FCC-ee 3rd run
    - $\sqrt{s}$ = 240GeV
    - L = 3.5ab^{-1}/yr
    - $7.0\cdot10^5$ ZH events/yr
  - Reconstructed peak at m_{miss} = mH independent of H decay mode!
  - inclusive measurement of Zh production
    - tagging events under the peak allows determination of individual BRs
  - Missing mass distribution may also be used to search for invisible decays
    - $B(H \to inv) = \Gamma_{inv}/(\Gamma_{SM} + \Gamma_{inv})$



$$M_{\rm miss} = \sqrt{(\sqrt{s} - E_Z)^2 - |\vec{p}_Z|^2}$$

LEP3 http://arxiv.org/pdf/1208.1662v2.pdf



H->inv

- *H->inv*
  - generation with Pythia8 of signal and backgrounds (WW, ZZ, ...)
  - CMS-like and ILD-like detectors in Delphes 3.2.0 standalone simulation
  - Vetoes and event selection:
    - No jets with PT > 20GeV detected
    - 2μ OR 2e with opposite charge and PT > 10 GeV
    - 1 max reconstructed2with PT > 10 GeV. If present, it is assumed to be FSR
    - to reduce ZZ
      - Angle between leptons in the laboratory frame Δθll > 100 deg
      - Longitudinal momentum of the lepton pair < 50 GeV
    - to avoid Radiative return
      - angle between the plane containing the lepton momenta and the beam axis θaco > 10 deg
      - Transverse momentum of the lepton pair Pll_T > 10 GeV
    - to kill WW:
      - m^{ll} in M^Z ± 4 GeV

Final efficiency

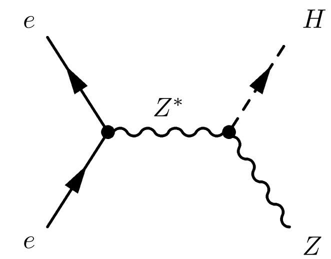
HZ events: 74%

WW events: 3.5%

ZZ events: 36%

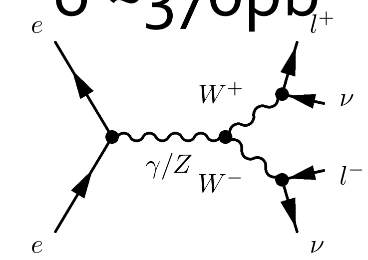
ZH, Z->ll H->inv(100%)

σ ~13pb^{-1}



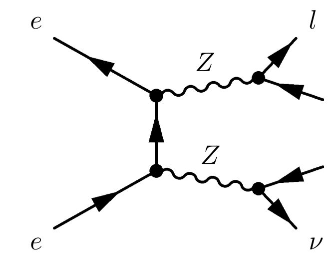
WW->llνν

σ ~370pb^{-1}



ZZ->llνν

σ ~30pb^{-1}



Pythia8

↓

Delphes
CM-like vs ILD-like

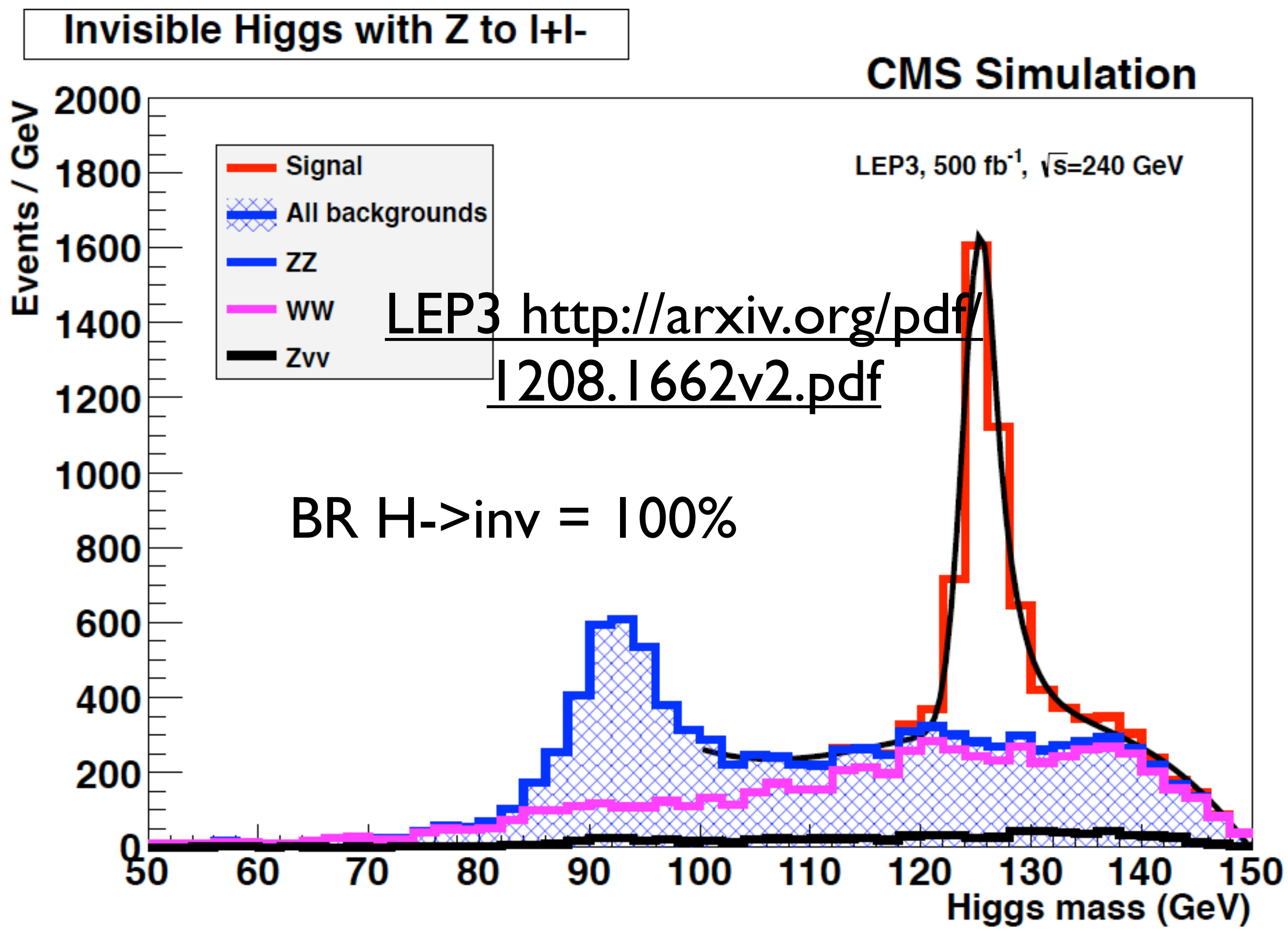
↓

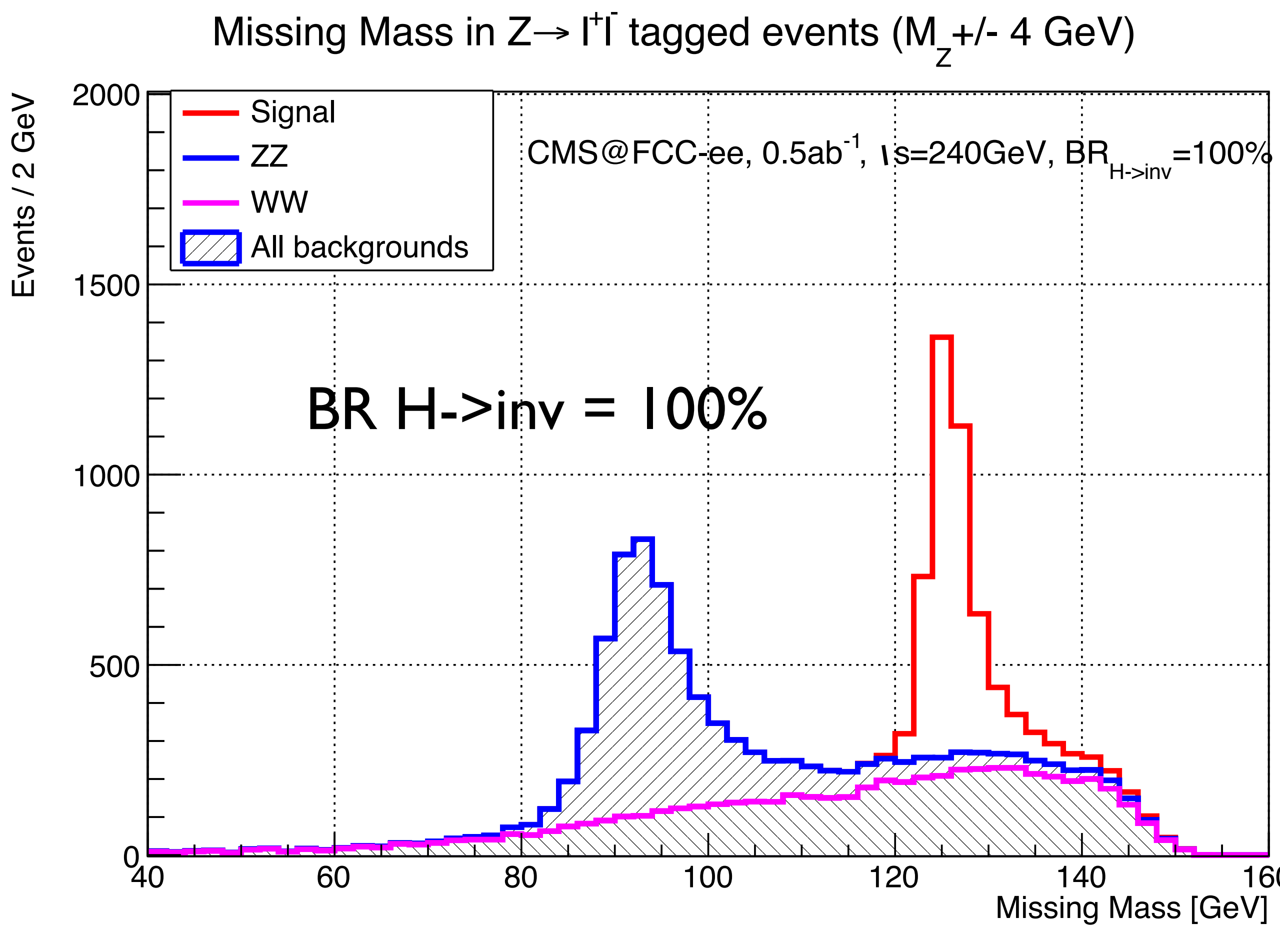
Root/RooStat

CLs, p-values

Comparison with LEP3, CMS

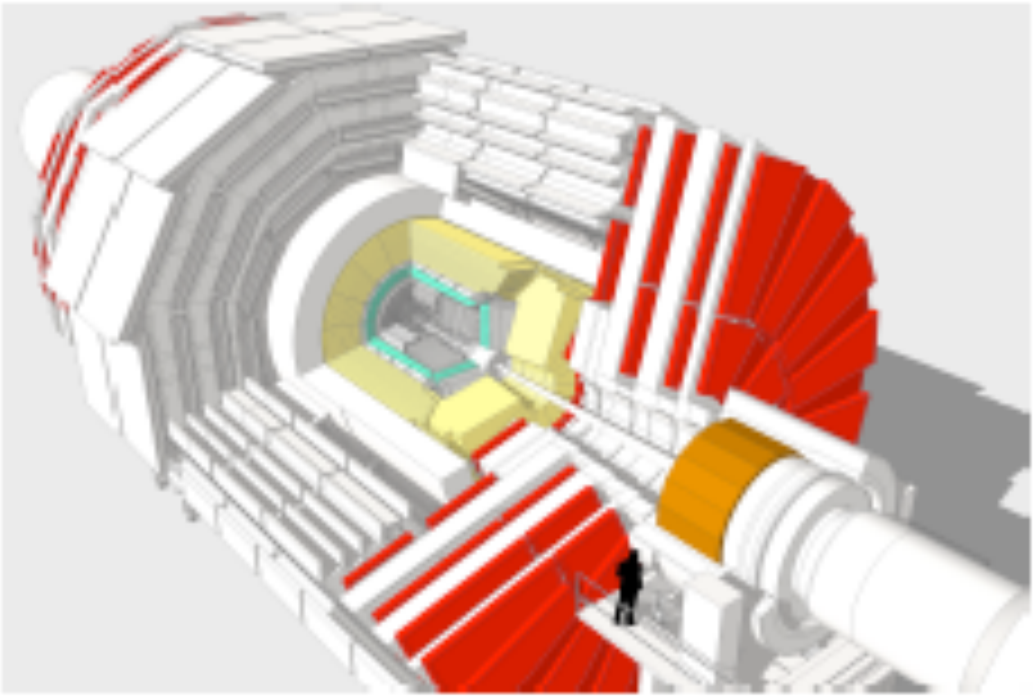
- LEP3 studies used CMS full simulation for 500 fb^{-1}

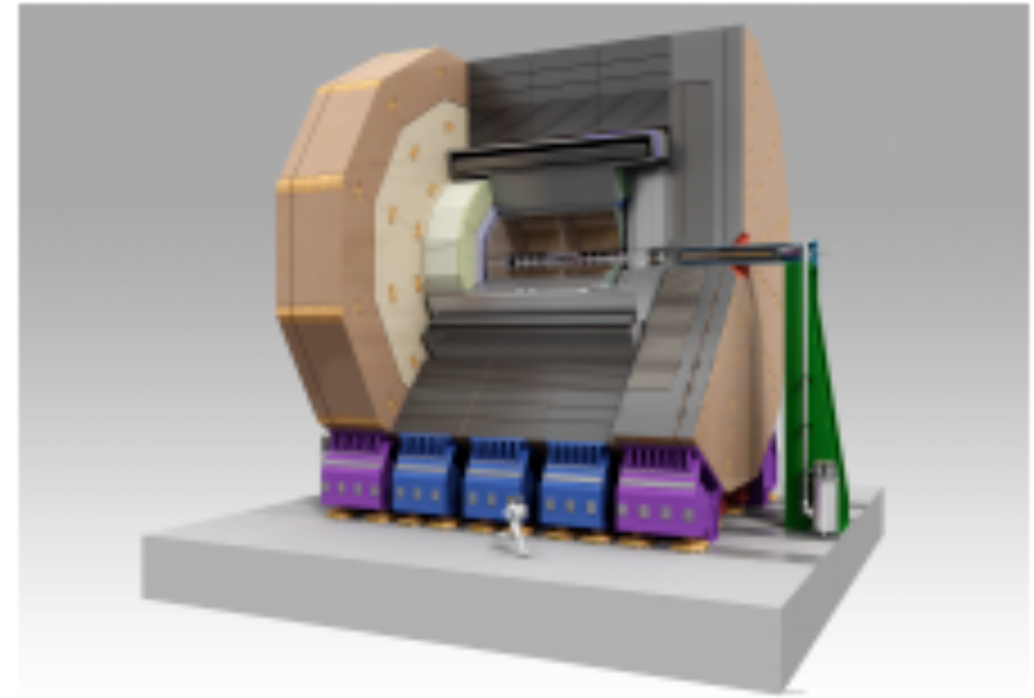




- very similar number of expected events and performance
  - differences attributed to fast vs full simulation

CMS vs ILD





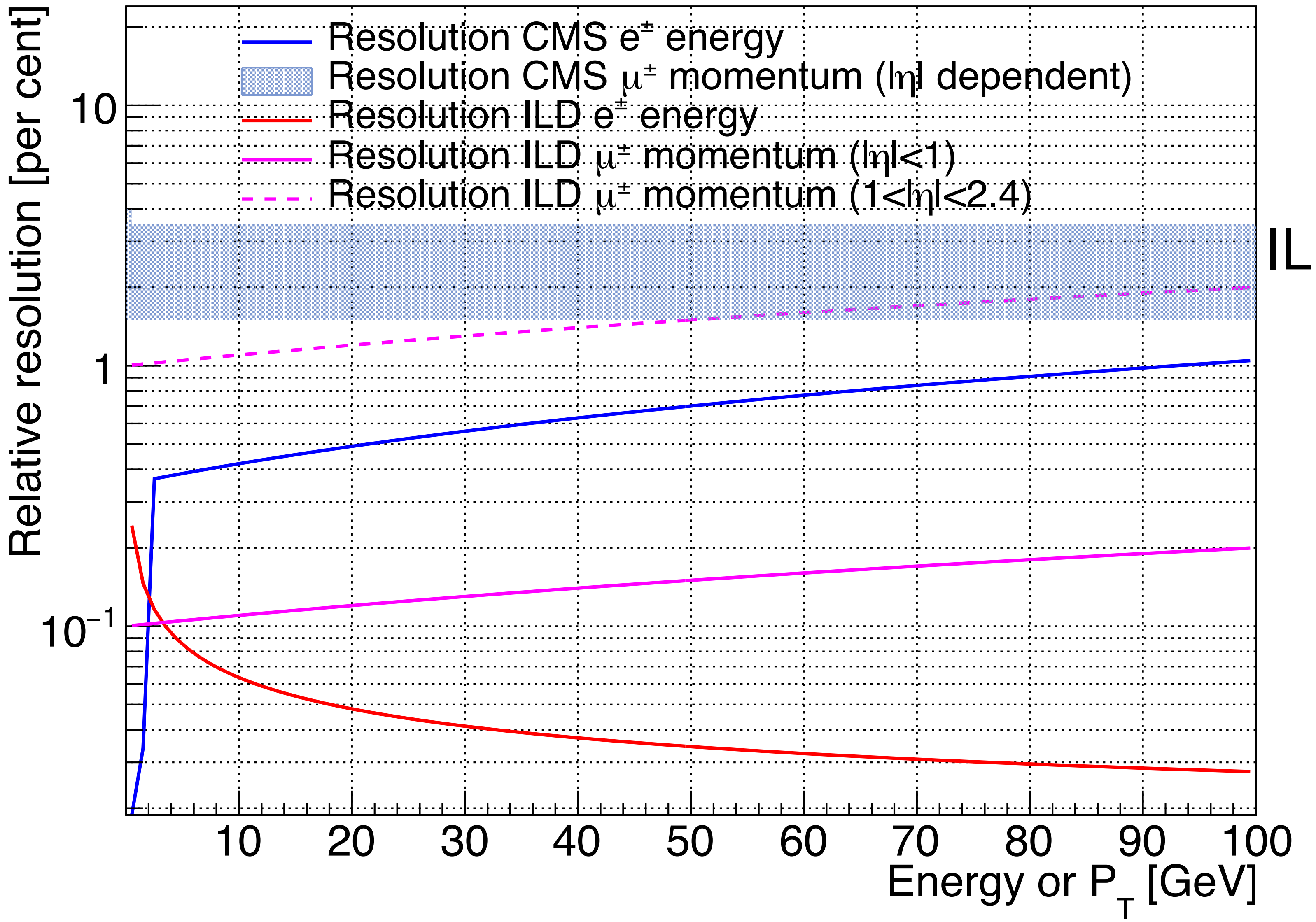
CMS

- B_Z=3.8T
- $R_{B=}$1.29m, L_B= 3.0m
- acceptance up to θ = 85.3 deg
- Tracker: silicon pixels and strips
- calorimetry LHC optimized

ILD

- B_Z=3.5T
- $R_{B=}$1.8m, L_B= 2.4m
- acceptance up to θ = 84.8 deg
- Tracker: TPC and silicon
- calorimetry optimized for e+e- collision

CMS vs ILD (2)



ILD o(10) better for both muons and electron resolution

CMS

- Tracking eff. : 95% for PT >100 MeVand |η|<2.5
- Reconstruction eff. : 85 – 95% (e,μ and γ) for PT > 10GeV

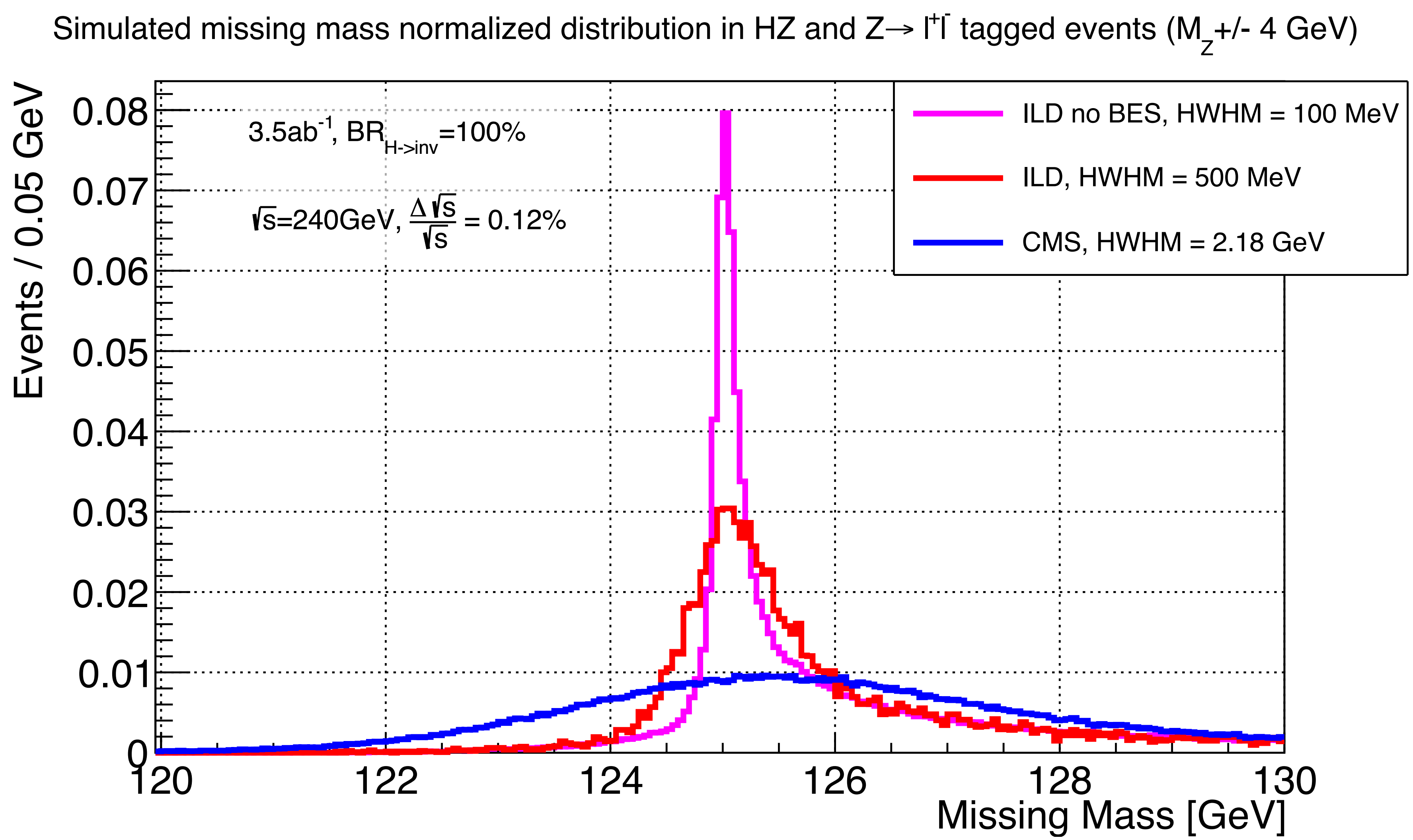
ILD

- Tracking eff. : 99% for PT >100 MeVand |η|<2.4
- Reconstruction eff. : 99% (e,μ and γ) for PT > 10GeV

CMS vs ILD

- effect on M_{miss} after inclusion of beam energy spread (0.12% on total C.M. Energy)

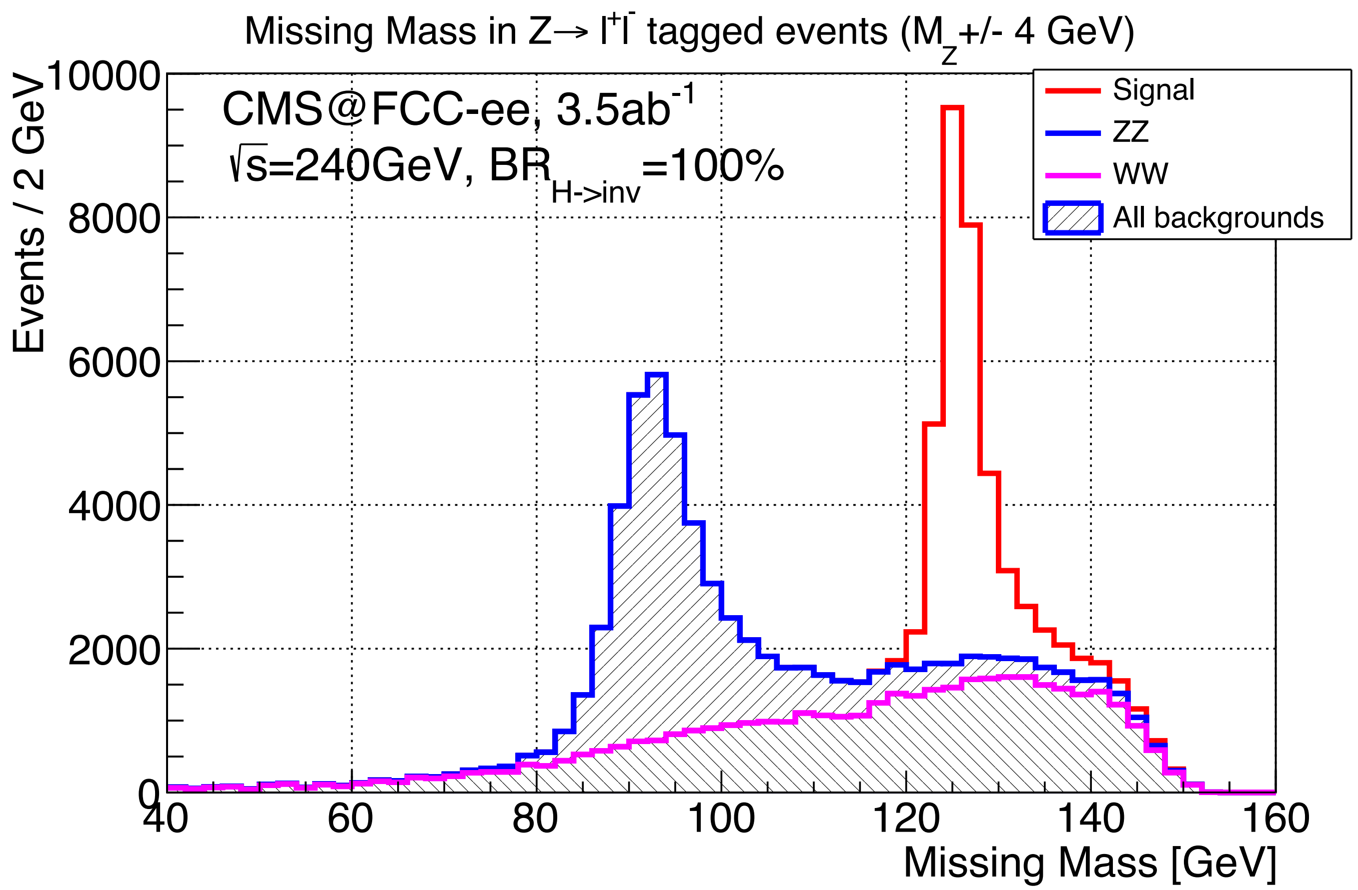
$$\frac{\Delta M}{M} \sim \frac{\Delta\sqrt{s}}{\sqrt{s}} \oplus \frac{\Delta P}{P}$$



- ILD better tracking allows to have smaller width
  - but despite 10 better p^T resolution for ILD like detector we have ~4 better resolution in M_{miss}
  - beam energy precision is a limiting factor for ILC, at least for better Higgs physics

Constraint H->inv, CMS-like detector

- analytical fit with background templates
  - in "reality" we will use data for ZZ(ZZ->4l) and WW (->eμνν)
- Using s+b dataset and b only dataset, details in backup
- Tagging Z->ll, from the missing mass we get for 1 y of FCC

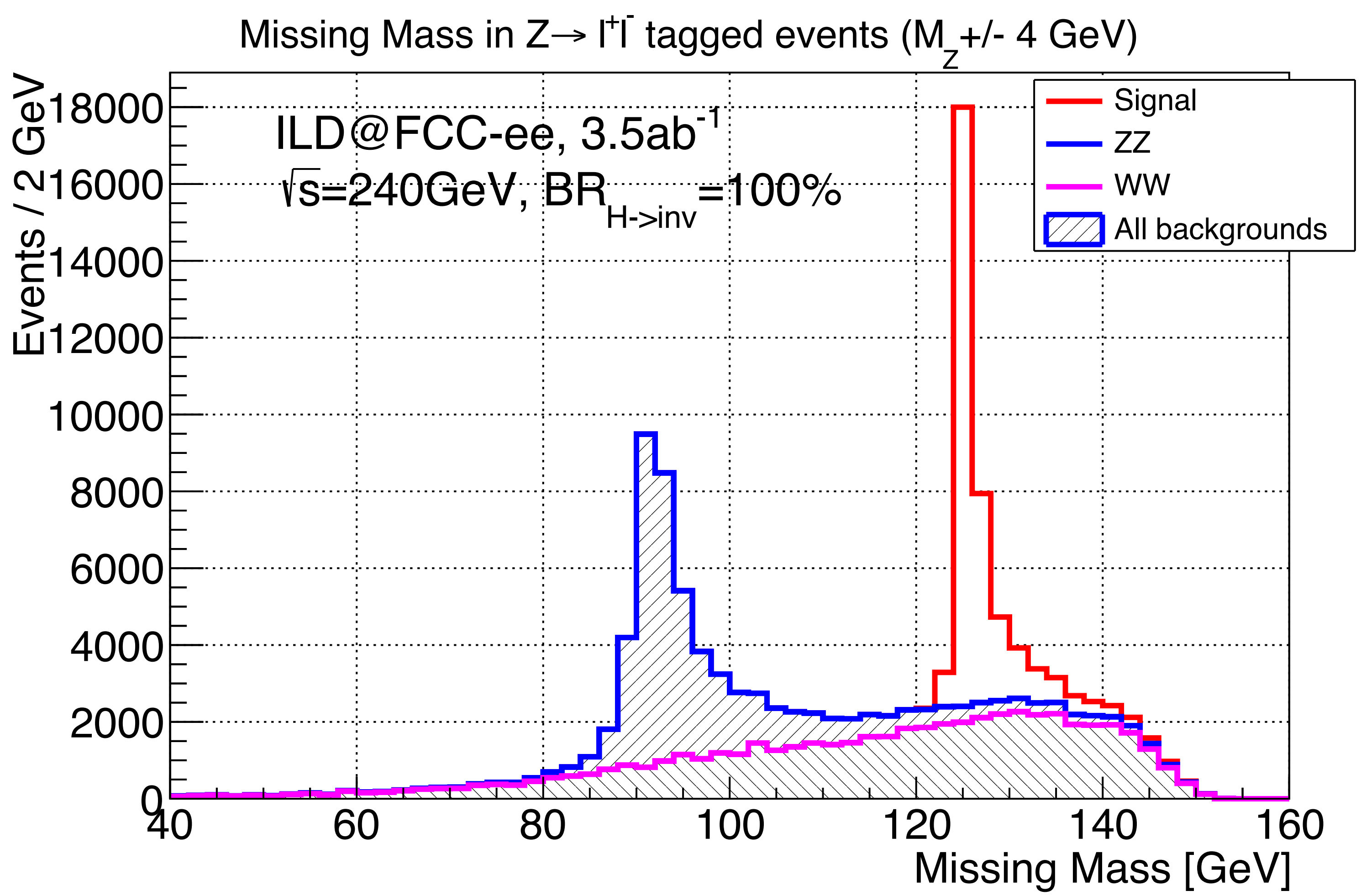


$BR_{lim95\%} = 0.92 \pm (0.30)_{stat} \pm (0.02)_{sys}\%$, 68% CL

$BR_{5\sigma} = 2.5 \pm (0.2)_{stat} \pm (0.1)_{sys}\%$, 68% CL

Constraint H->inv, ILD-like detector

- Repeating the same for ILD detector
- Tagging Z->ll, from the missing mass we get for 1 y of FCC



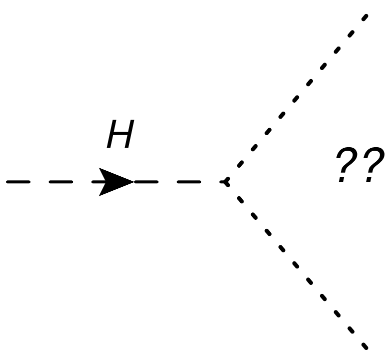
$$BR_{lim95\%} = 0.63 \pm (0.20)_{stat} \pm (0.02)_{sys}\%,\ 68\%\ CL$$

$$BR_{5\sigma} = 1.7 \pm (0.1)_{stat} \pm (0.01)_{sys}\%,\ 68\%\ CL$$

Comparison with LHC/HL-LHC

- CMS now and future

CMS-PAS-HIG-15-012



$BR_{H \to invisible} < 34\%$ (LHC)

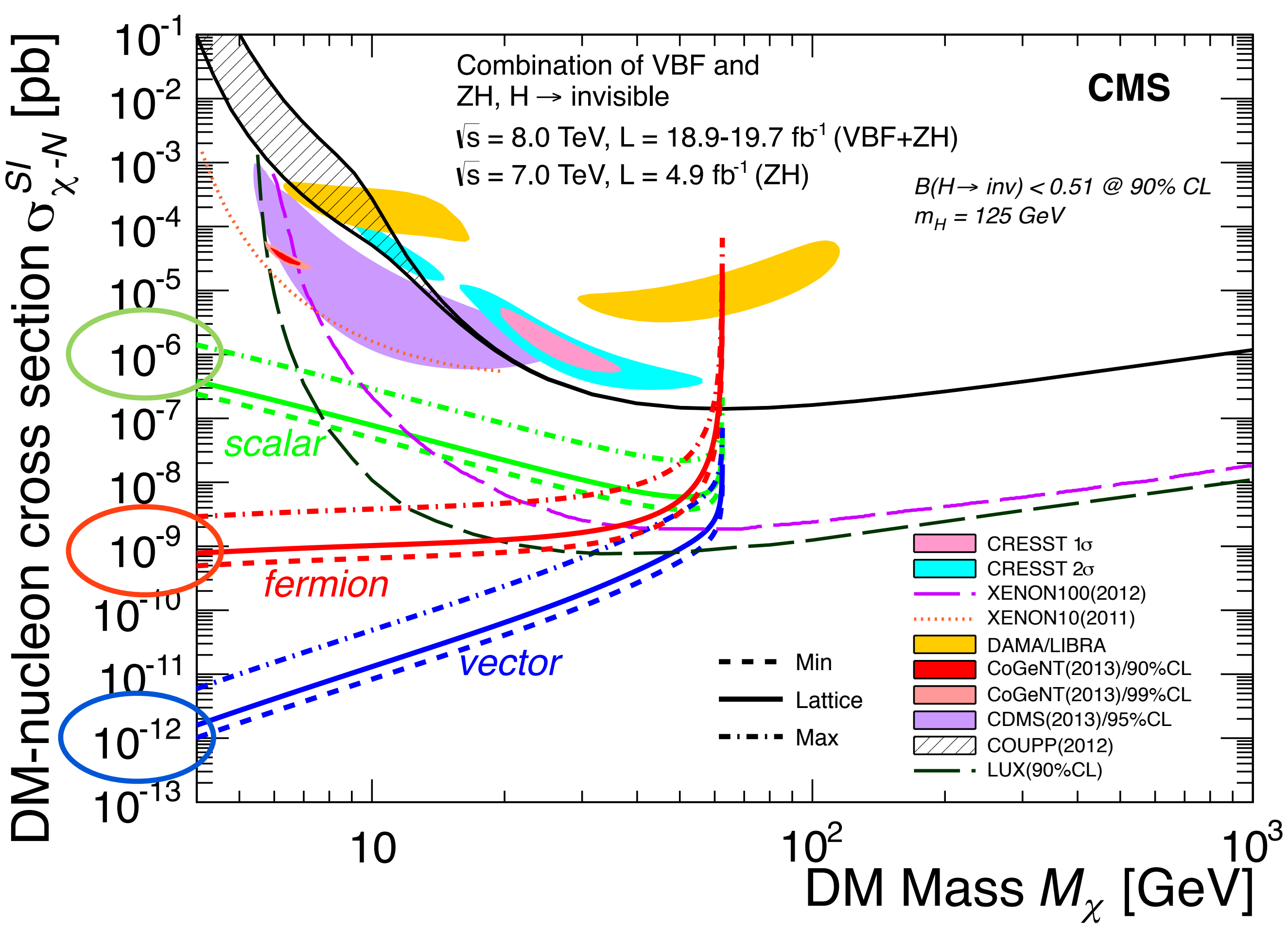
SNOWMASS http://arxiv.org/pdf/1307.7135.pdf
HL-LHC

L (fb^{-1})	$\gamma\gamma$	WW	ZZ	bb	$\tau\tau$	$Z\gamma$	$\mu\mu$	inv.
300	[6, 12]	[6, 11]	[7, 11]	[11, 14]	[8, 14]	[62, 62]	[40,42]	[17, 28]
3000	[4, 8]	[4, 7]	[4, 7]	[5, 7]	[5, 8]	[20, 24]	[20,24]	[6, 17]

- ATLAS has (of course!) comparable performance, so HL-LHC would give H->inv $BR_{limit95\%}$ ~5%

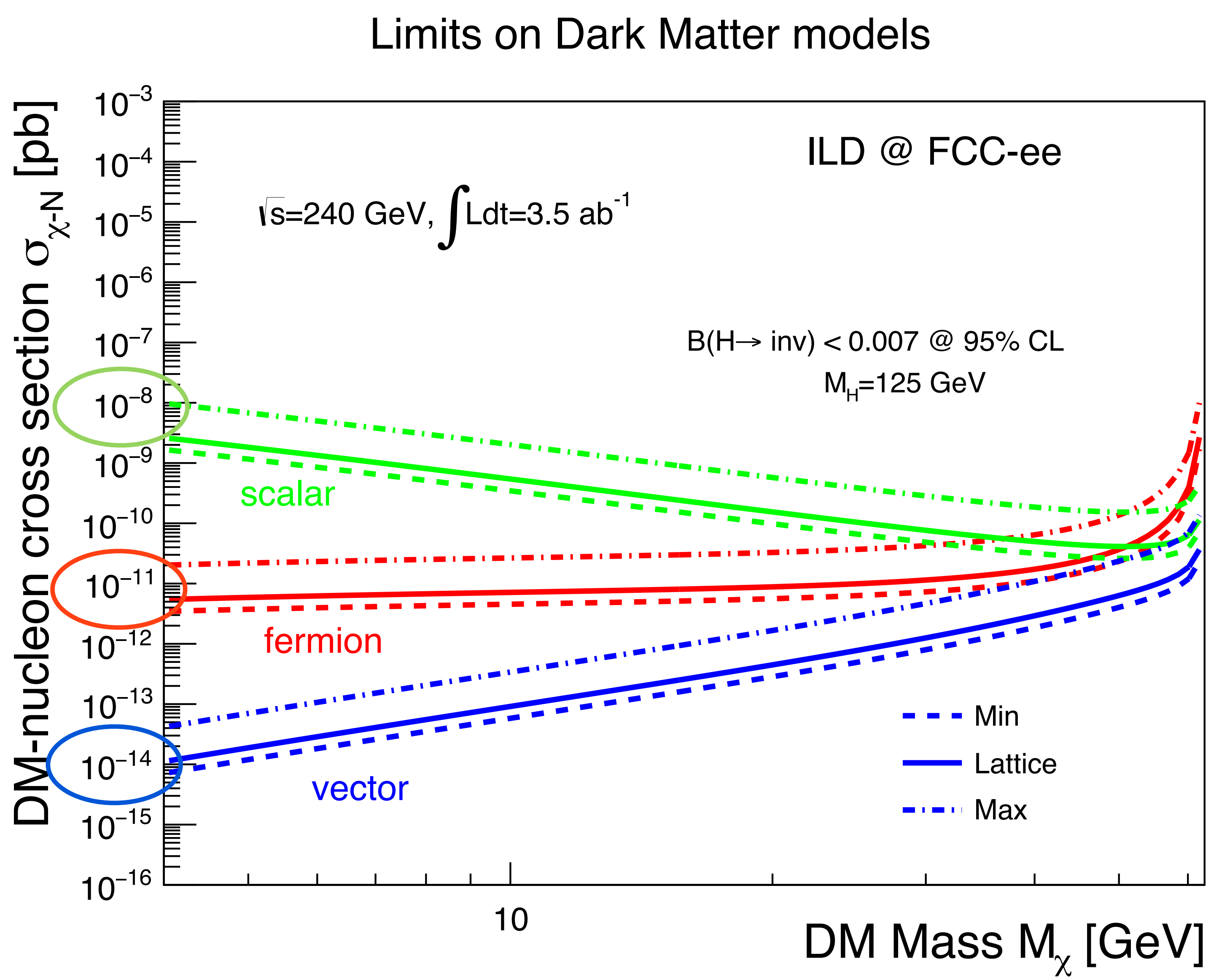
Interpretation in Hidden Sector

- at colliders:
  - If the DM candidate has a mass below $m_{H/2}$, the invisible Higgs boson decay width, Γ_{inv}, can be directly translated to the spin-independent DM-nucleon elastic cross section
    - for scalar (S), vector (V), and fermionic (f) DM
      - scalar interpretation is the only one does not assume other mechanisms at higher mass
    - equivalent to say m_{med} = 125 GeV in DM searches
- In direct detection experiments:
  - the elastic interaction between DM and nuclei exchanged through the Higgs boson results in nuclear recoil which can be reinterpreted in terms of DM mass, Mχ, and DM-nucleon cross section.



Eur. Phys. J. C 74 (2014) 2980

FCC-ee ILD@3.5ab^{-1}

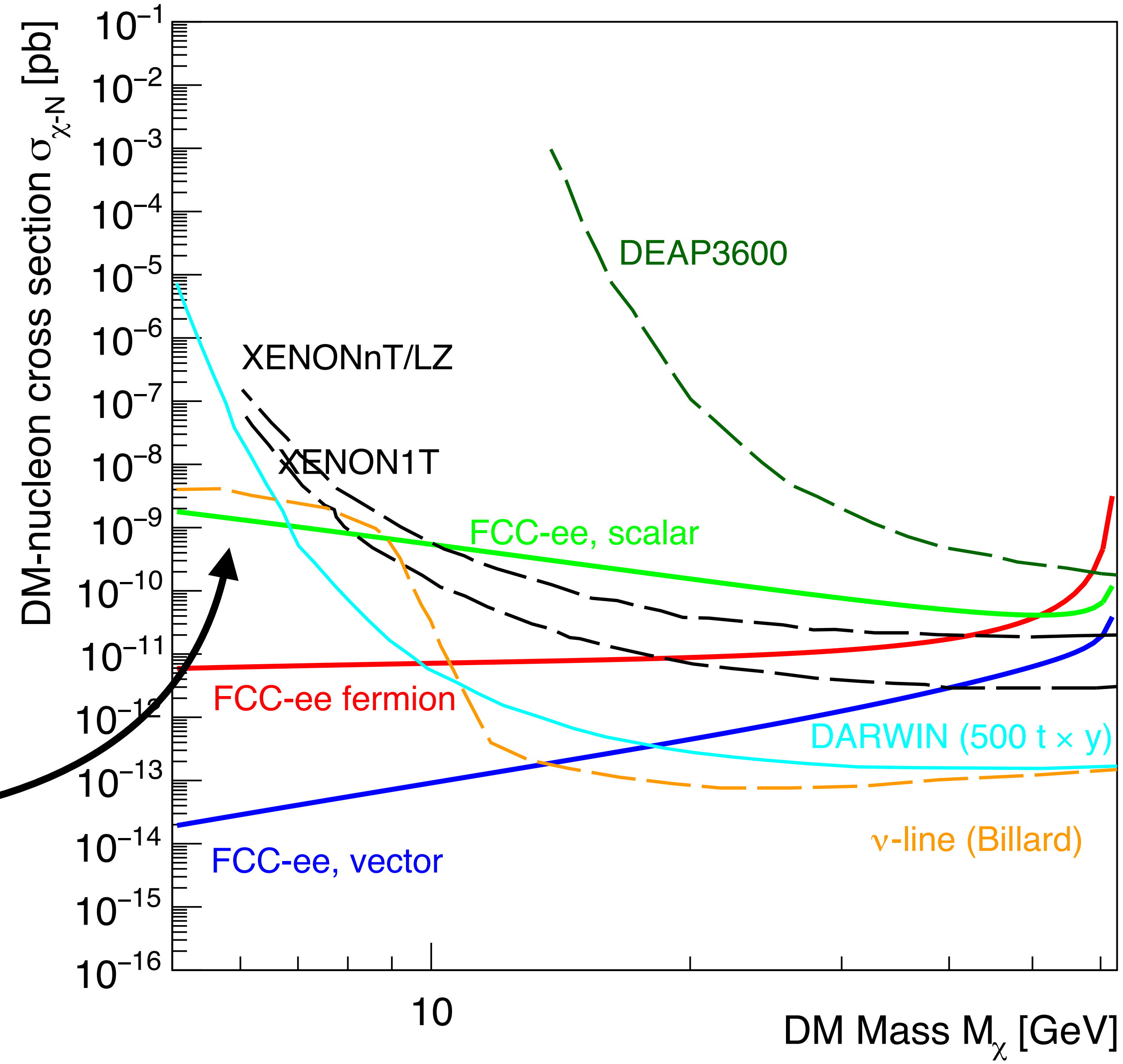


- with 1y of FCC-ee we get an improvement of 2 order of magnitude wrt current LHC

FCC-ee vs future direct DM detector experiments

- Comparing FCC-ee (1y) with projections on underground direct DM detection experiment

FCC-ee (1y) will be very competitive at lower DM masses



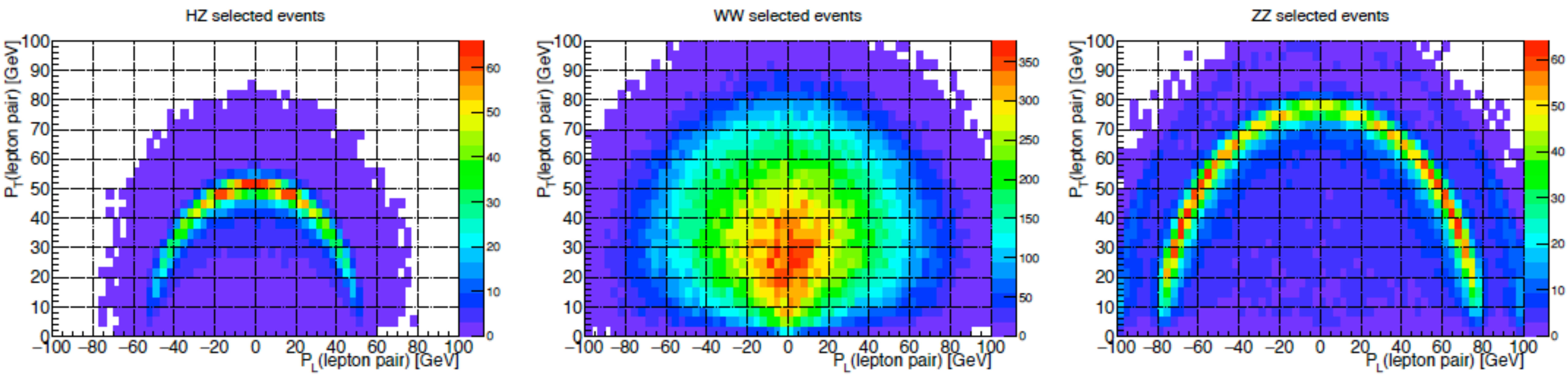
- projections for direct experiment adapted from http://arxiv.org/abs/1509.00869

Conclusions

- FCC-ee very well suited for constraining the H->inv width
- With FCC-ee, 1 y of data taking we can easily reach precision around .6%
  - BR limit 95% CL of 0.6% with ILD-like detector!
  - This would improve 2! order of magnitude current constraint on the DM--nucleon cross section in the Higgs portal model and allow FCC-ee to remain competive with projections of future direct detectors
- We compared CMS and ILD-like performances
  - ILD-like detector allow to achieve better resolution
    - but beam energy resolution starts to be a limiting factor, at least for this measurement

- BACKUP

Angular/kinematical cuts



Statistical analysis

Discovery significance:

- s+b dataset, s from fixed BR
- $\sigma = \sqrt{-2 \log \frac{\mathcal{L}_b}{\mathcal{L}_{s+b}}}$

Limit on BR(95% cl):

- b only dataset
- $0.95 \equiv \int_0^{N_S^*} \mathcal{L}(s+b|N_S)dN_S$