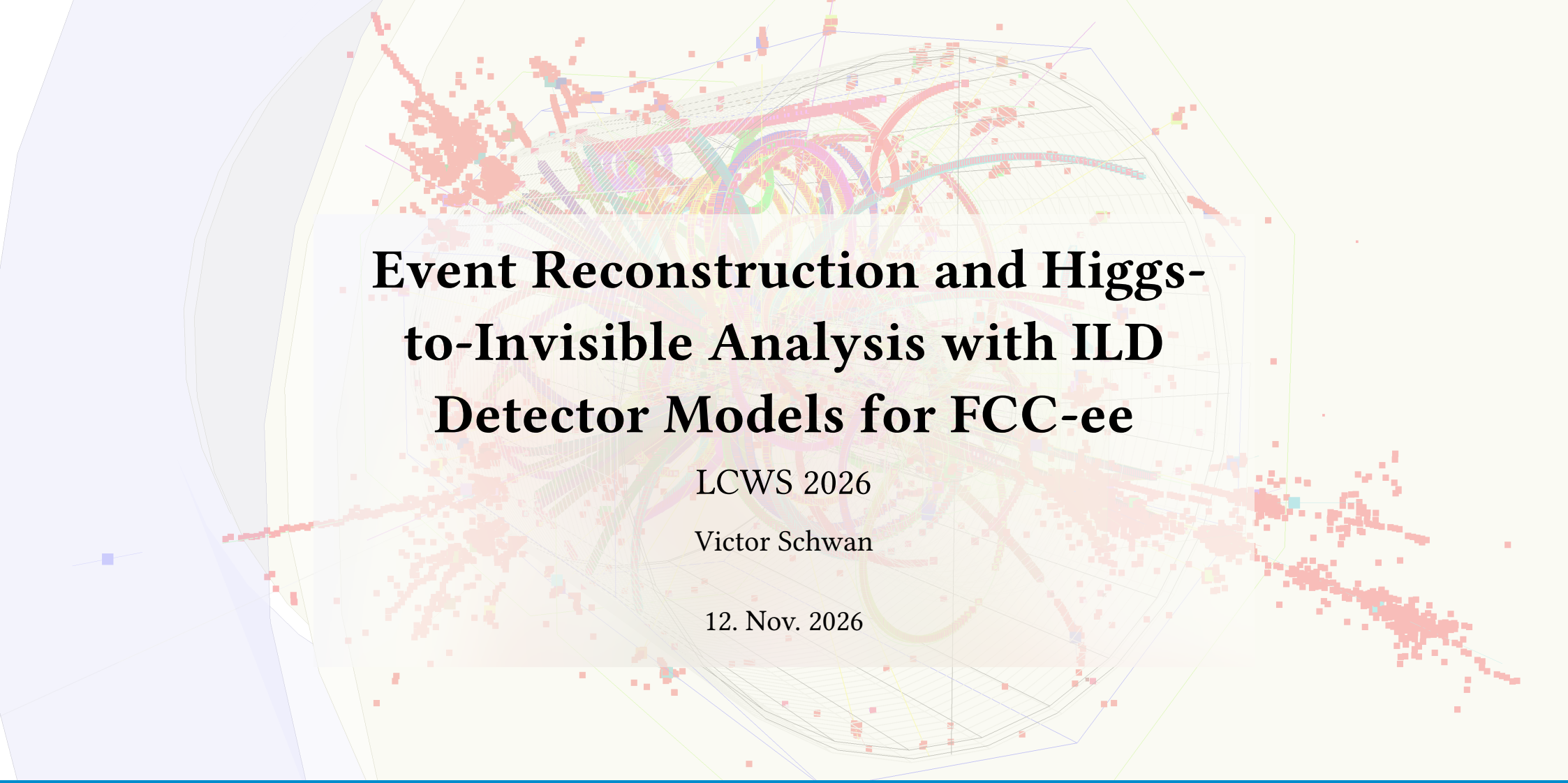


Event Reconstruction and Higgs-to-Invisible Analysis with ILD Detector Models for FCC-ee

LCWS 2026

Victor Schwan

12. Nov. 2026

FCC ILD DESY. UHH Universität Hamburg DER FORSCHUNG | DER LEHRE | DER BILDUNG HELMHOLTZ CLUSTER OF EXCELLENCE QUANTUM UNIVERSE PIER Partnership of University of Hamburg and DESY EAJADE Europe-America-Japan Accelerator Development Exchange Programme

Outline

Adapting ILD to FCC

Analysis

Results

Summary & outlook

Collider Comparison

	ILC250	**FCC-ee240**
B field	3.5 T	2 T
Half crossing angle	7 mrad	15 mrad
L*	4.1 m	2.4 m
$\sqrt{s}$ @ ZH	250 GeV	240 GeV
Beam polarisation	$P(e^-, e^+) = (\mp 0.8, \pm 0.3)$	none
Integrated luminosity	2 ab^{-1}, of which 0.9 ab^{-1} each for $(-0.8, +0.3)$ and $(+0.8, -0.3)$	10.8 ab^{-1}

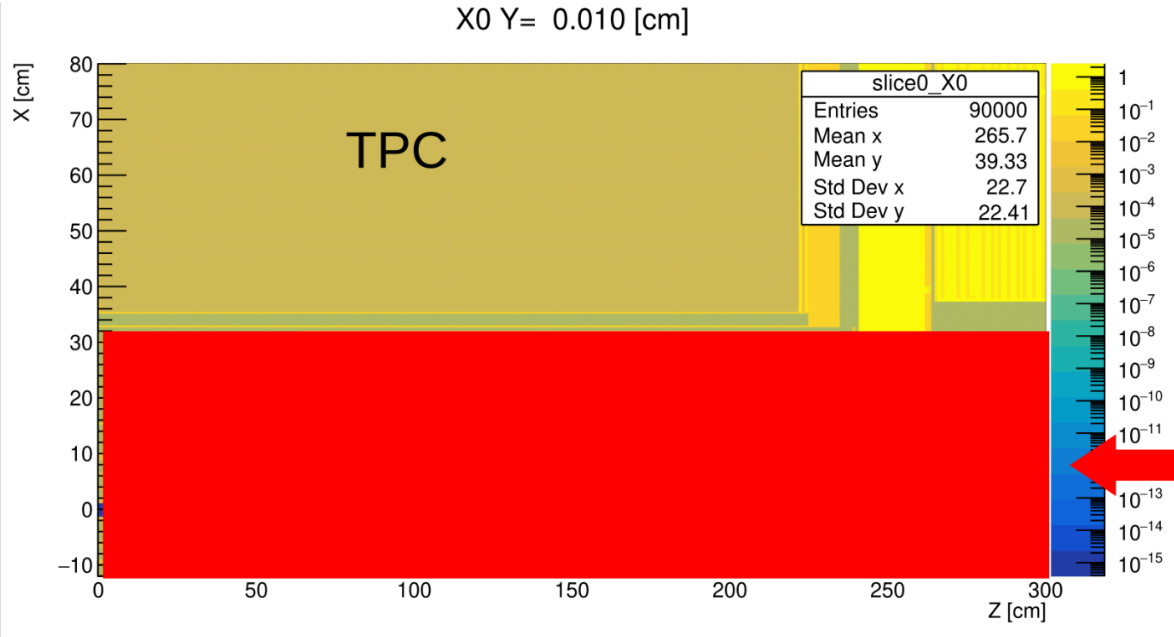
Birth of ILD@FCC

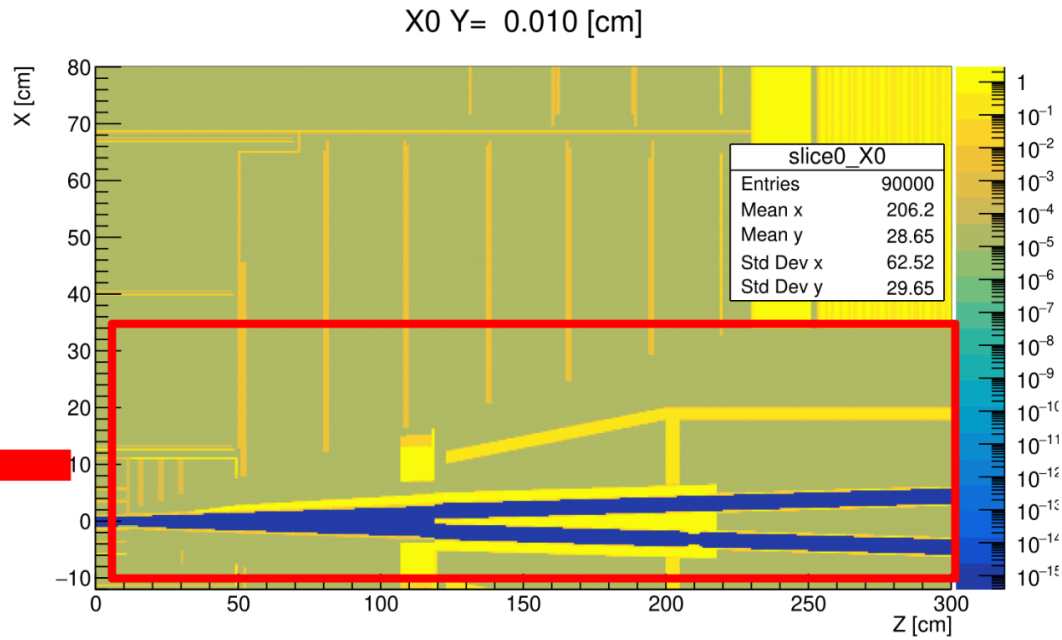
ILD@ILC

- ILC MDI
- Hybrid tracking layout

CLD@FCC

- FCC-ee MDI
- All-silicon tracking

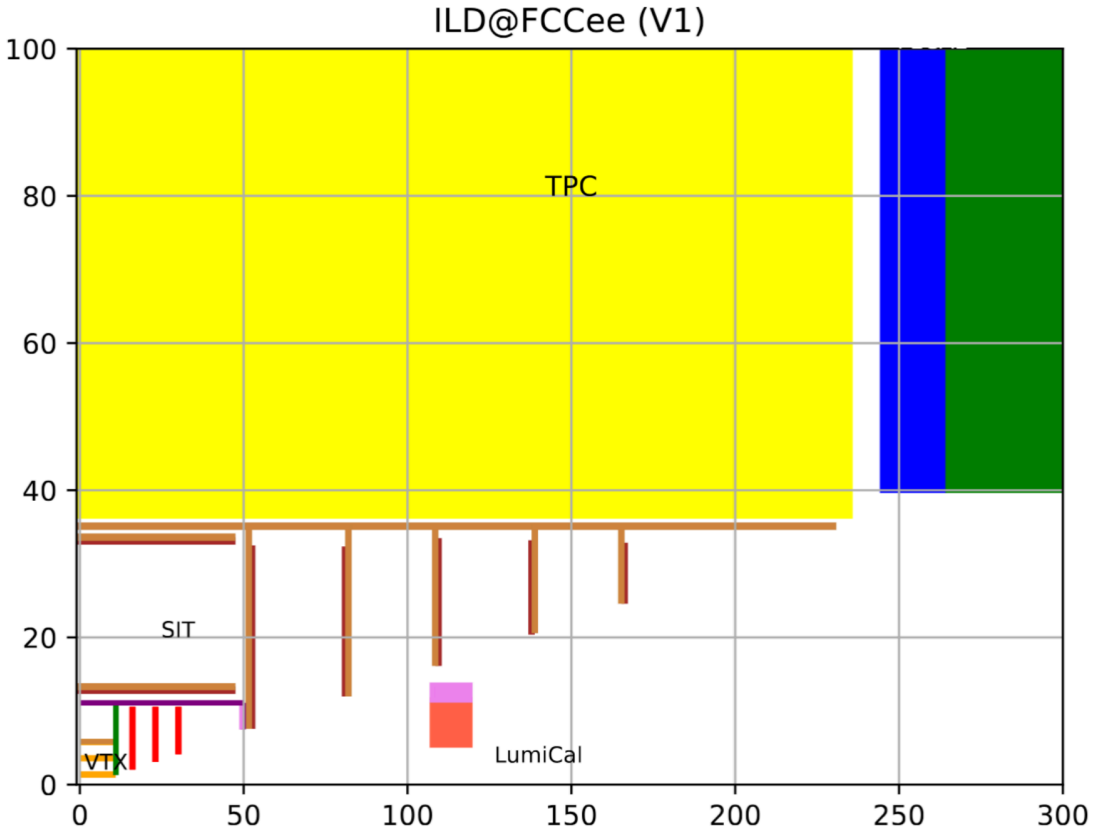


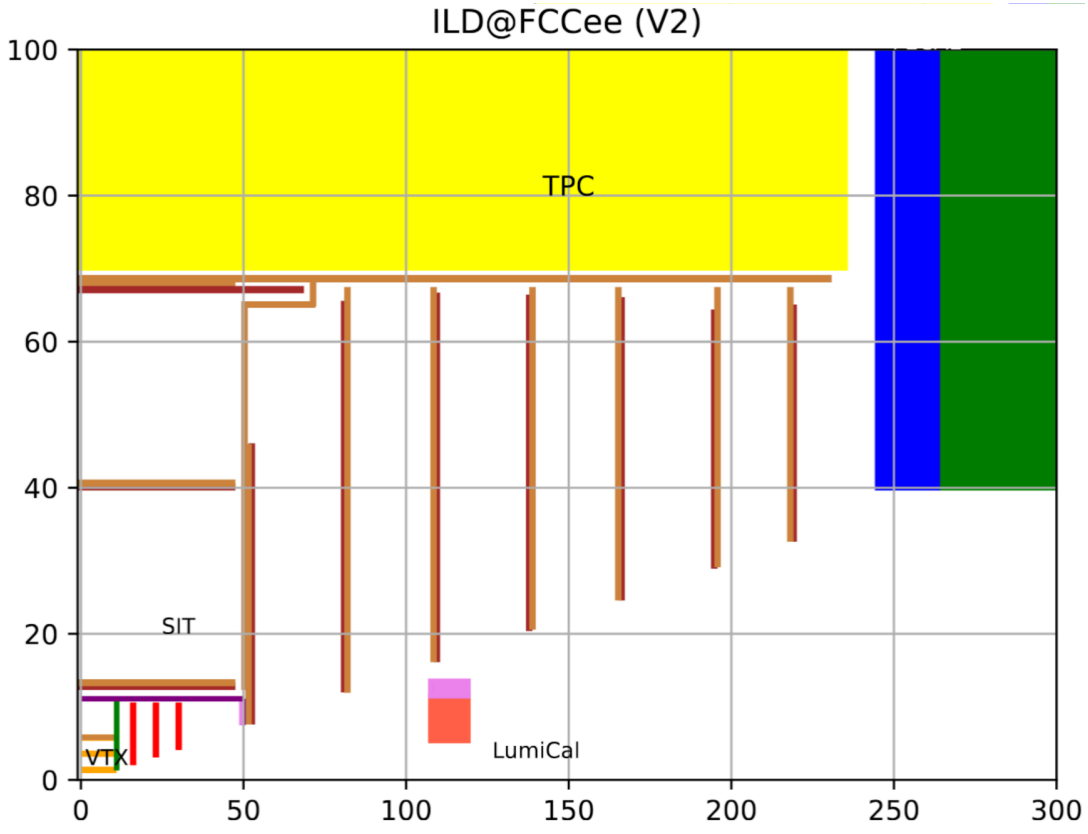


Ansatz:

1) Remove everything inside of the TPC from ILD
2) Replace with CLD subdetectors

ILD@FCC Detector Models

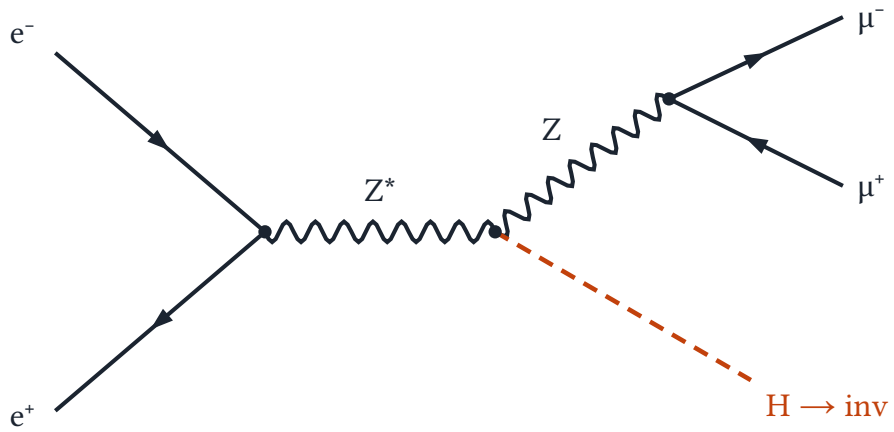




Credit: Teresa Nunez Pardo de Vera

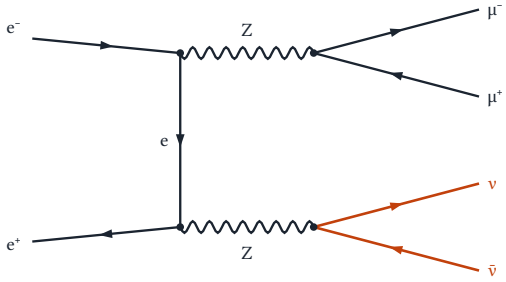
Motivation: H ⟶ Invisible

- SM: BR($H \to \text{inv}$) ≈ 0.1 %
  ($H \to ZZ^* \to 4\nu$)
- Enhancement ⟹ new physics
  (Higgs portal, dark matter)
- LHC, 95 % CL upper limits:
  ATLAS 10.7 %, CMS 15 % **TODO:** full refs
- e^+e^- Higgs factory: **recoil method** tags ZH independently of the Higgs decay

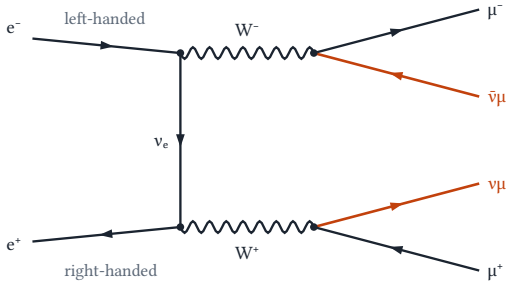


Dominant Backgrounds

$\mu\mu\nu\nu$

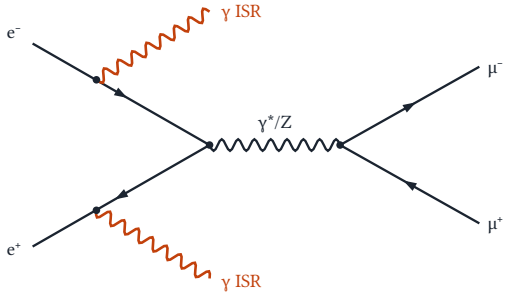


ZZ: irreducible



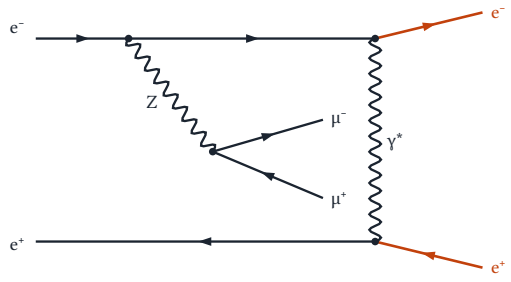
WW: only for $e^-_L e^+_R$

$\mu\mu(\gamma)$



radiative return,
$p_T \approx 0$

$ee\mu\mu$



forward electrons lost,
usually 3–4 isolated
leptons

Simulation Chain and Samples

WHIZARD 3.1.5 generation → **SGV** ILD_l5_o1_v02 / ILD_FCCee_v01 → **k4run** IsolatedLeptonTagging (μ, then e) + LeptonPairingCombined (ZHH) → **Python** analysis

Signal: $e^+e^- \to \mu\mu H$, $H \to ZZ \to 4\nu$ (PYTHIA6) as invisible proxy

Process	Events	σ eL.pR [fb]	σ eR.pL [fb]	σ FCC [fb]	Generator cut
$\mu\mu H(\text{inv})$	10k	16.960	10.861	6.760	–
$\mu\mu\nu\nu$	10k	854.5	36.95	226.7	$m_{\mu\mu} > 10$ GeV
$\mu\mu$	200k	9087	6657	4180	$m_{\mu\mu} > 40$ GeV
$ee\mu\mu$	100k	9132	9069	8219	$m_{\mu\mu} > 40$ GeV

Weight $w = \sigma \cdot L \cdot f_{\text{hel}}/N_{\text{gen}}$, $f_{\text{LR}} = (1 - P^-)(1 + P^+)/4$

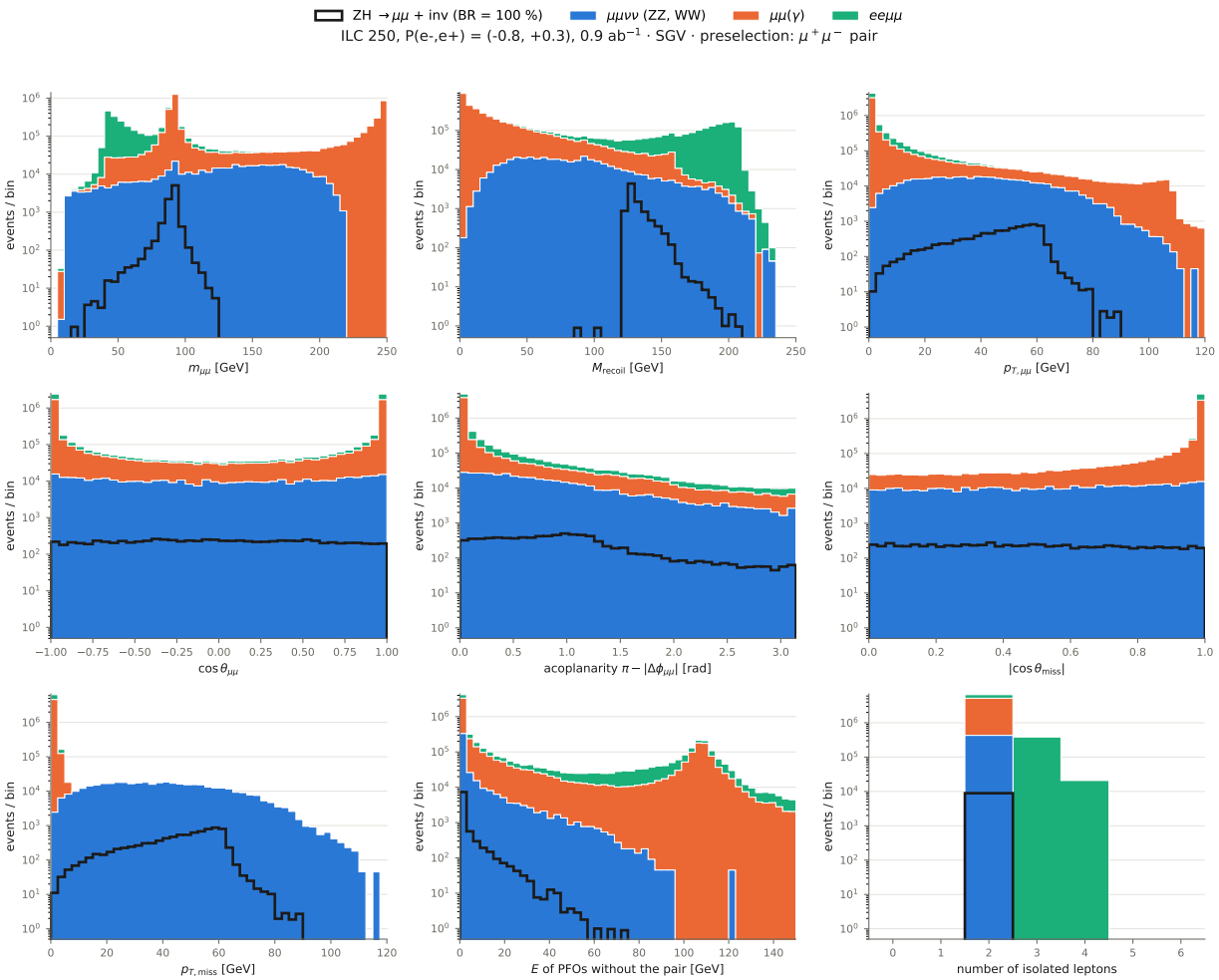
After the $\mu^+\mu^-$-Pair Preselection

Run	Signal	$\mu\mu\nu\nu$	$\mu\mu(\gamma)$	$ee\mu\mu$
ILC $(-0.8, +0.3)$, 0.9 ab^{-1}	8895	$4.3 \cdot 10^5$	$4.7 \cdot 10^6$	$1.8 \cdot 10^6$
ILC $(+0.8, -0.3)$, 0.9 ab^{-1}	5996	$4.3 \cdot 10^4$	$3.6 \cdot 10^6$	$1.8 \cdot 10^6$
FCC-ee 240, 10.8 ab^{-1}	$6.85 \cdot 10^4$	$2.3 \cdot 10^6$	$4.1 \cdot 10^7$	$2.4 \cdot 10^7$

signal with BR($H \to$ inv) = 100 %

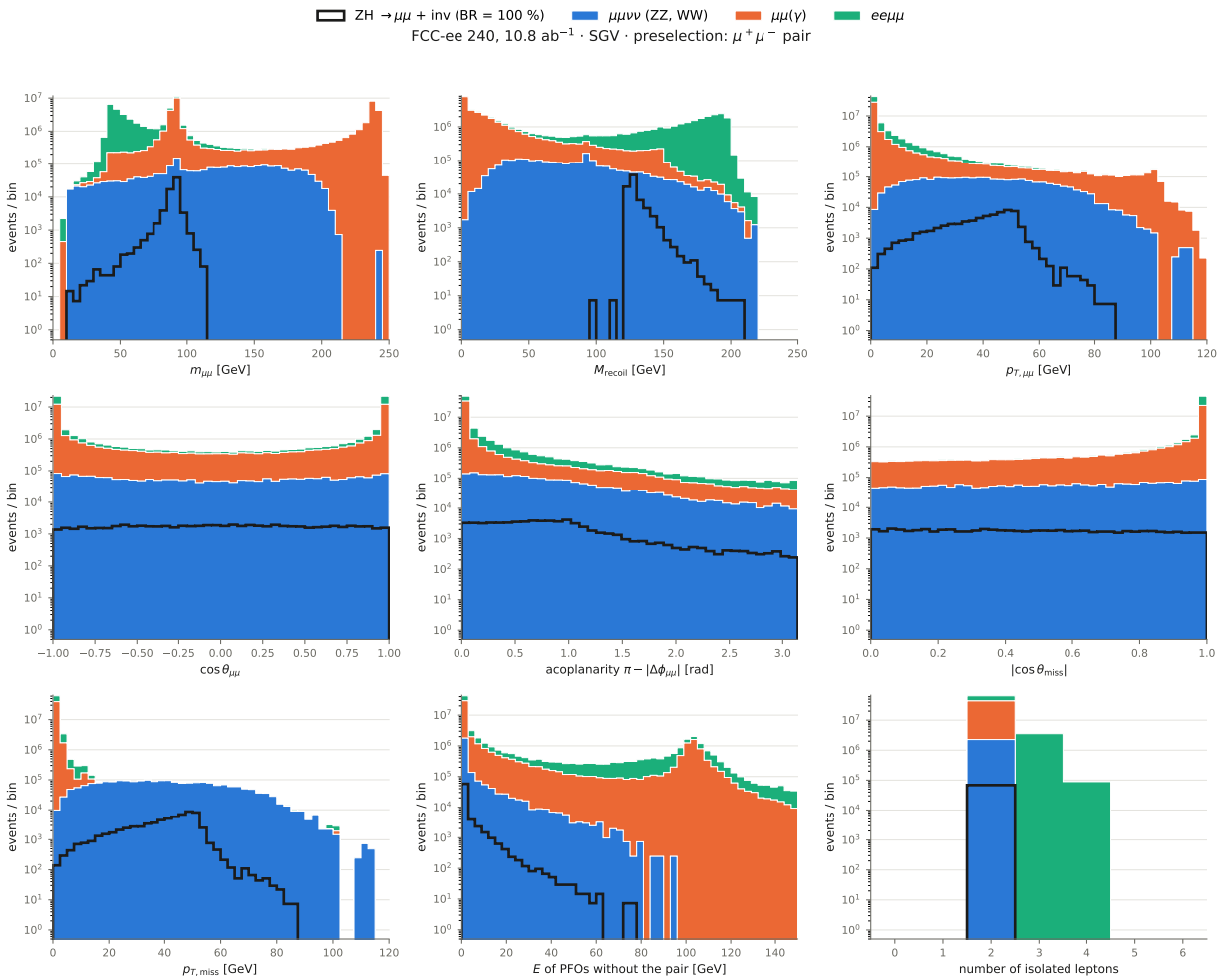
Right-handed e^- polarisation suppresses $\mu\mu\nu\nu$ (WW) by $\approx \times 10$,
at the cost of $\approx 1/3$ of the signal

Control Plots: ILC250, $P(e^-, e^+) = (-0.8, +0.3)$



- $\mu\mu(\gamma)$:
  $p_T \approx 0, |\cos\theta_{\text{miss}}| \approx 1$
- $ee\mu\mu$:
  $n_{\text{isolep}} \geq 3$,
  M_{recoil} at 150–210 GeV
- $\mu\mu\nu\nu$: overlaps the signal
  $\rightarrow$ dominant background after cuts

Control Plots: FCC-ee240



- $\mu\mu(\gamma)$:
  $p_T \approx 0, |\cos\theta_{\text{miss}}| \approx 1$
- $ee\mu\mu$:
  $n_{\text{isolep}} \geq 3$,
  M_{recoil} at 150–210 GeV
- $\mu\mu\nu\nu$: overlaps the signal
  → dominant background after cuts

Selection and Cut Flow

	ILC $(-0.8, +0.3)$				ILC $(+0.8, -0.3)$				FCC-ee 240			
Cut	□	■	■	■	□	■	■	■	□	■	■	■
lepton pair	–	–	–	–	–	–	–	–	–	–	–	–
exactly 2 isolated leptons	–	–	–	–	–	–	–	–	–	–	–	–
$m_{\mu\mu}$ window	–	–	–	–	–	–	–	–	–	–	–	–
$p_{T,\mu\mu}$	–	–	–	–	–	–	–	–	–	–	–	–
$\lvert\cos\theta_{\text{miss}}\rvert$	–	–	–	–	–	–	–	–	–	–	–	–
E_{rest}	–	–	–	–	–	–	–	–	–	–	–	–
M_{recoil} window	–	–	–	–	–	–	–	–	–	–	–	–

TODO: Figure: M_{recoil} after the full selection, ILC and FCC-ee

,

Expected Limit on BR(H ⟶ inv)

Collider	Luminosity	Exp. 95 % CL limit on BR($H \to$ inv)
ILC250 (LR + RL combined)	2×0.9 ab^{-1}	**TODO:** value
FCC-ee240	10.8 ab^{-1}	**TODO:** value

$\mu\mu$ channel, statistical uncertainties only

Summary & outlook

Summary

- ILD_FCCee_v01/v02 in SGV & k4geo
- $\mu\mu H \rightarrow$ Inv with SGV:
  ILC250 and FCC-ee240
- RH polarisation: $\mu\mu\nu\nu \approx \times$ 10 lower,
  signal −1/3
- **TODO:** expected limits

Outlook

- ee and qq channels
- Full detector simulation with ILD_FCCee for signal + most relevant backgrounds
- Full SM background simulation (SGV)
- Improved MC statistics: per-event weights up to ≈ 900 at FCC-ee

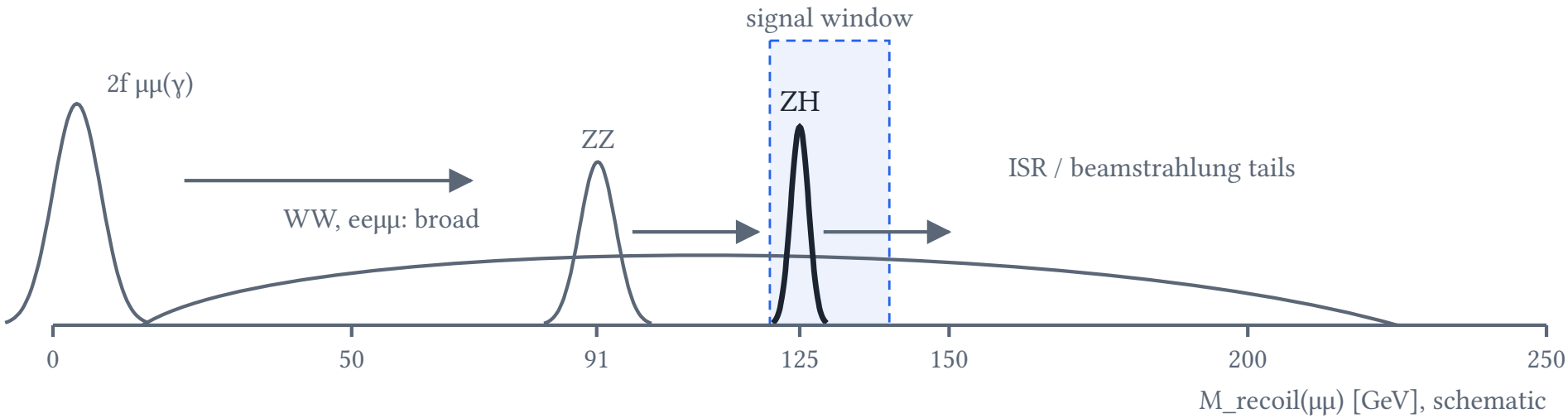
Backup

Recoil Method

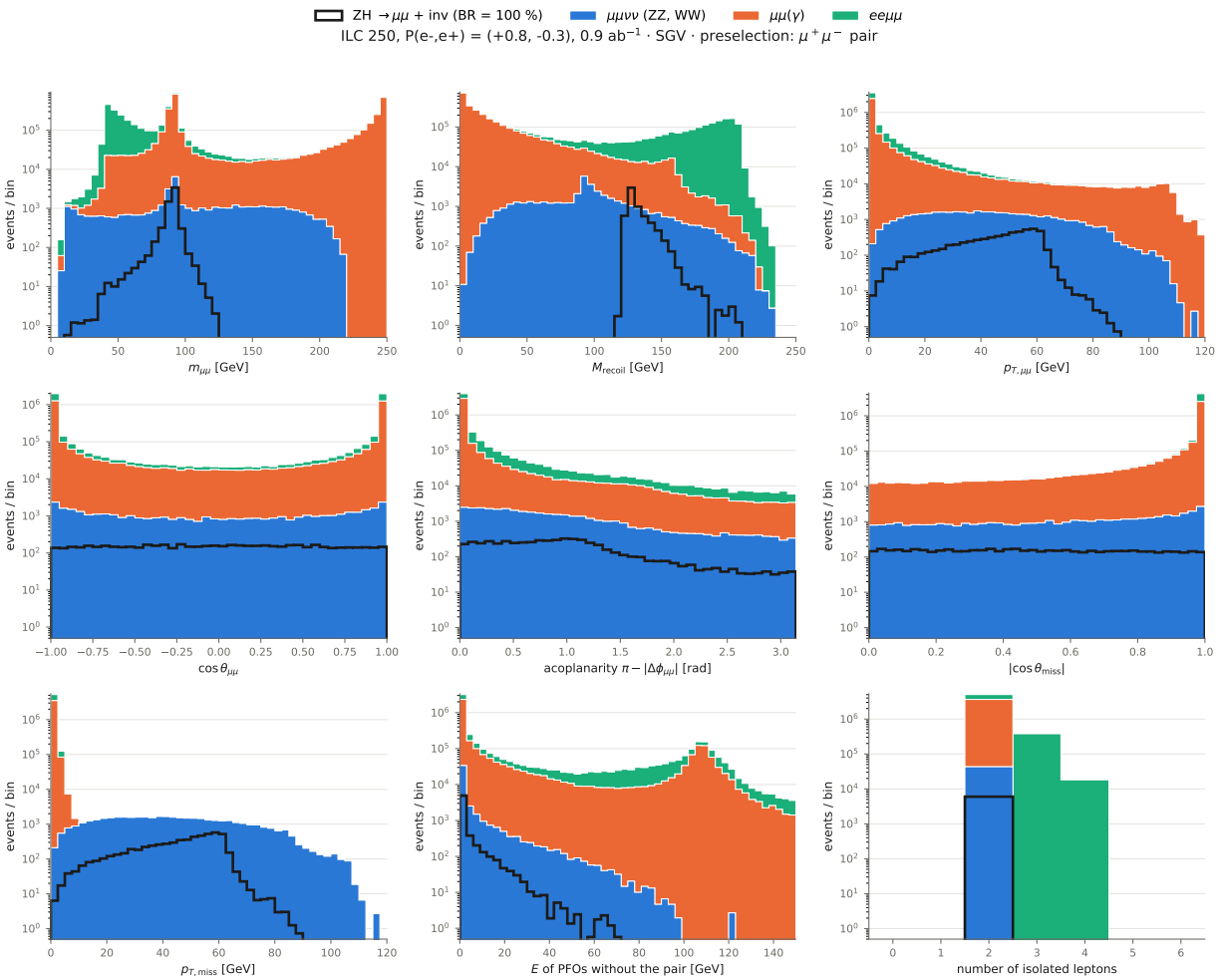
$$M^2_{\text{recoil}} = \left(\sqrt{s} - E_{\mu\mu}\right)^2 - |\vec{p}_{\mu\mu}|^2$$

evaluated with the true initial state, incl. the crossing-angle boost

- Topology: two isolated muons, $m_{\mu\mu} \approx m_Z$, nothing else
- ISR and beamstrahlung shift M_{recoil} upwards



Backup: control plots ILC250, $P(e^-, e^+) = (+0.8, -0.3)$



- $\mu\mu(\gamma)$:
  $p_T \approx 0, |\cos\theta_{\text{miss}}| \approx 1$
- $ee\mu\mu$:
  $n_{\text{isolep}} \geq 3$,
  M_{recoil} at 150–210 GeV
- $\mu\mu\nu\nu$: overlaps the signal
  $\rightarrow$ dominant background after cuts

Backup: polarisation weights

Event weight

$$w = \frac{\sigma \cdot L \cdot f_{\text{hel}}}{N_{\text{gen}}}$$

Helicity fractions for beam polarisations P^-, P^+:

$$f_{\text{LR}} = \frac{(1 - P^-)(1 + P^+)}{4}$$

$$f_{\text{RL}} = \frac{(1 + P^-)(1 - P^+)}{4}$$

Run (P^-, P^+)	f_{LR}	f_{RL}
$(-0.8, +0.3)$	0.585	0.035
$(+0.8, -0.3)$	0.035	0.585

Backup: lepton object definition

IsolatedLeptonTagging (k4run)

- $p > 5$ GeV
- Muons: $E_{\text{cal}}/p < 0.3$
- Isolation MVA with the ILD full-simulation weights
- Applied to SGV **without re-tuning**
- Two passes: muons first, then electrons

Backup: SGV notes

- Half crossing angle applied by SGV as a **boost**
- Geometries: ILD_l5_o1_v02 (3.5 T) / ILD_FCCee_v01 (2 T)

TODO: Further SGV notes (steering adaptation for ILD@FCC, …)