Search for Invisibly Decays
of the Higgs Boson at the ILC Using key4HEP

Carsten Hensel, Second ECFA Workshop on e+e- Higgs/Electroweak/Top Factories
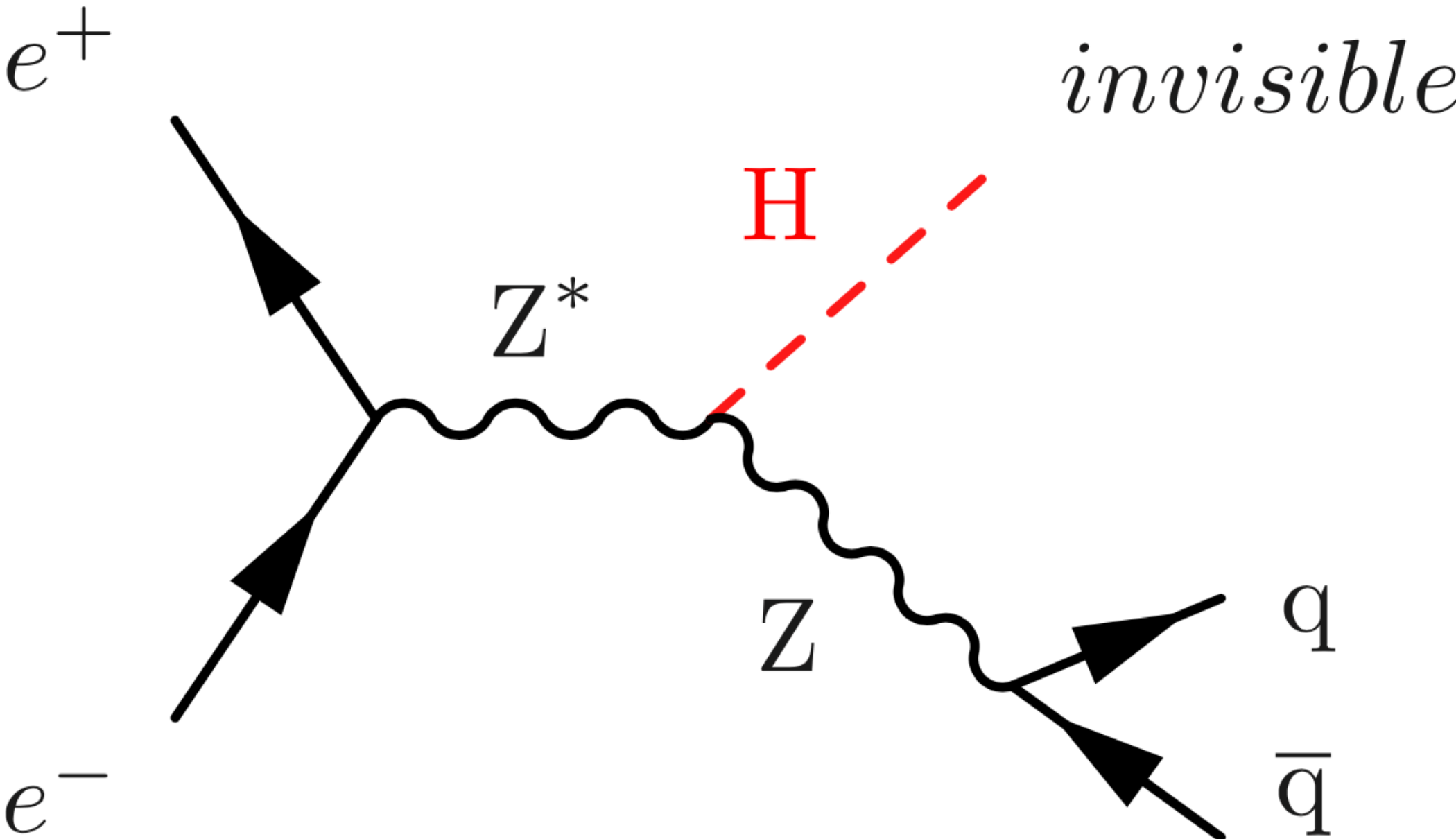
CBPF
Centro Brasileiro
de Pesquisas Físicas

UNIDADE DE PESQUISA DO MCTI

Outline

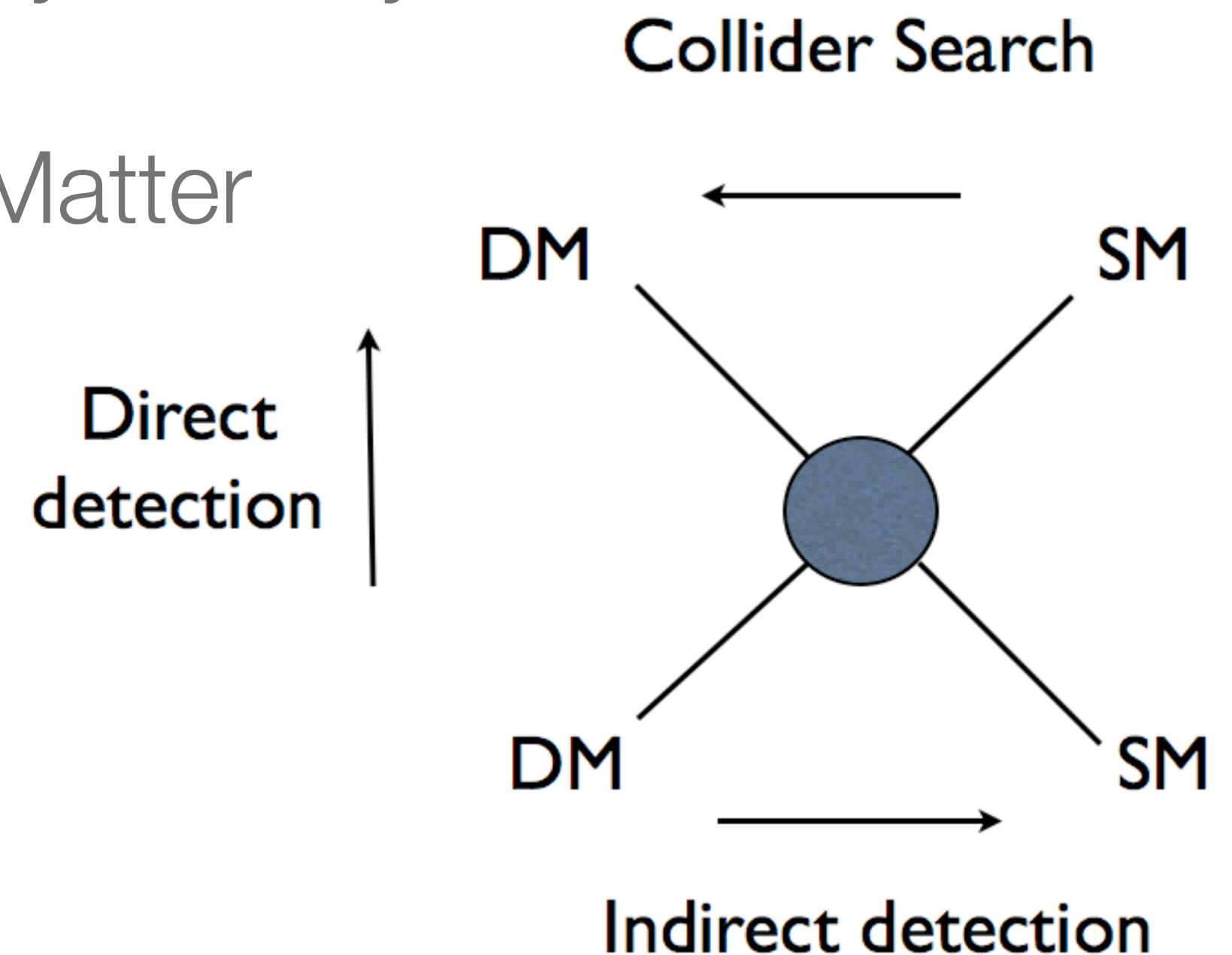# Higgs Boson: A Tool to Discover New Physics

- only invisible Higgs decay in the SM: $H \to ZZ^\star \to 4\nu$

- BR is small: $\sim 0.1\,\%$

- if size-able invisible Higgs decays found: sign for physics beyond SM

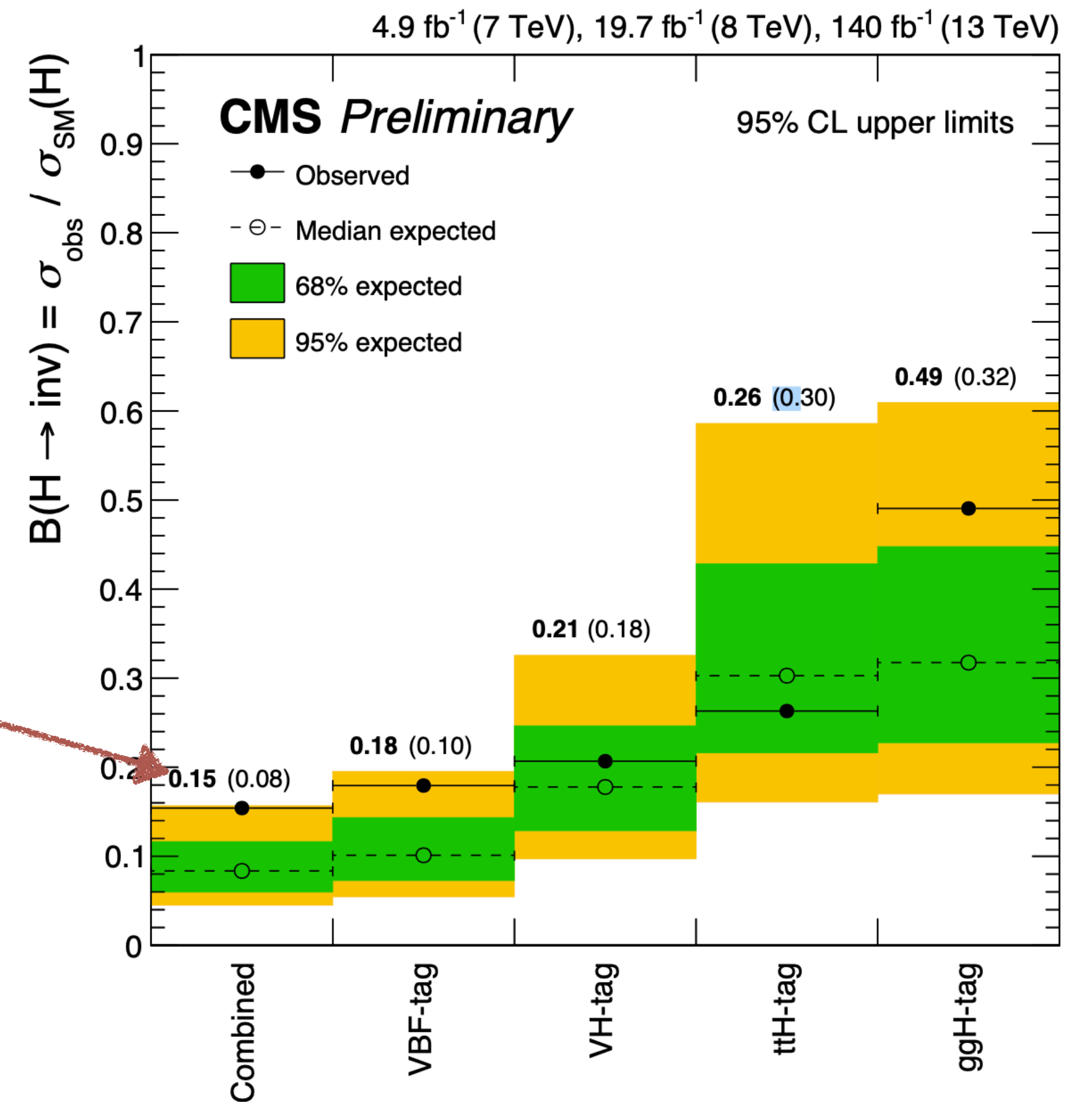 - e.g. Higgs Portal Model connects SM and Dark Matter

$$SM \to H \to \chi\chi$$

  - (DM candidate χ scalar, fermionic or vectorial)

Collider Search

DM   SM

Direct detection

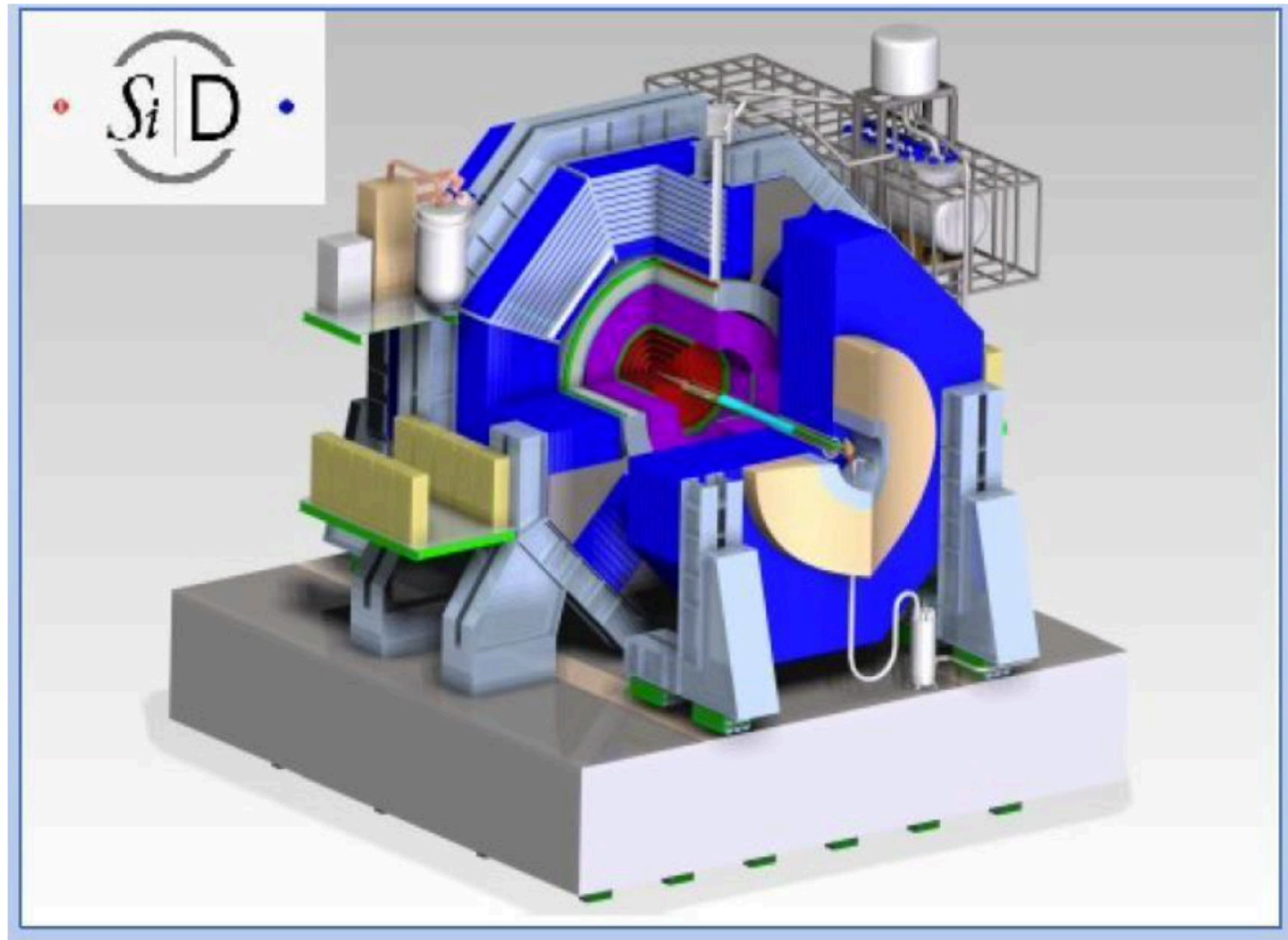DM   SM

Indirect detection

LHC Results

- invisible Higgs decays were searched with $qq \rightarrow ZH$ and $qq \rightarrow qqH$ (VBF)

- using missing E_T (and M_{qq})

- very hard to achieve better than 10% at LHC

Analysis	95% C.L. upper limit observed (expected)
Combination	$\mathcal{B}(H \rightarrow inv.) < 15\%$ (8%)

CMS Preliminary

4.9 fb^{-1} (7 TeV), 19.7 fb^{-1} (8 TeV), 140 fb^{-1} (13 TeV)

95% CL upper limits

- Observed
- Median expected
- 68% expected
- 95% expected

$B(H \rightarrow inv) = \sigma_{obs} / \sigma_{SM}(H)$

Combined: **0.15** (0.08)
VBF-tag: **0.18** (0.10)
VH-tag: **0.21** (0.18)
ttH-tag: **0.26** (0.30)
ggH-tag: **0.49** (0.32)

Upper Limits ILC

250 GeV, 900 fb^{-1}, LR+RL

ee 0.33%
$\mu\mu$ 0.27%   combined 0.16
qq 0.25%

(2203.08330)

250 GeV, 900 fb^{-1}, LR+RL

$\ell\ell$ 0.57%*
combined 0.23
qq 0.25%
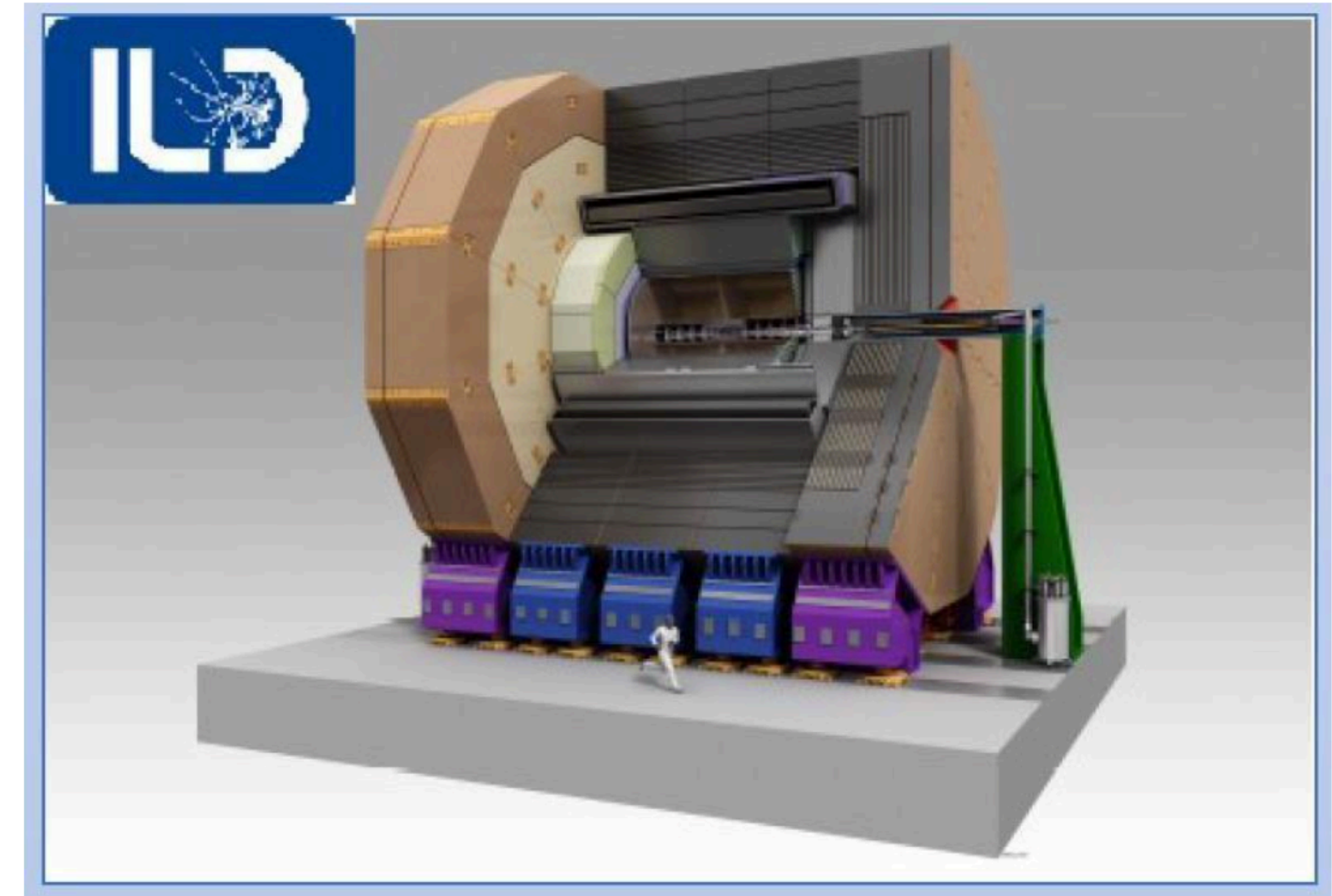
(2002.12048)

Upper Limits ILC
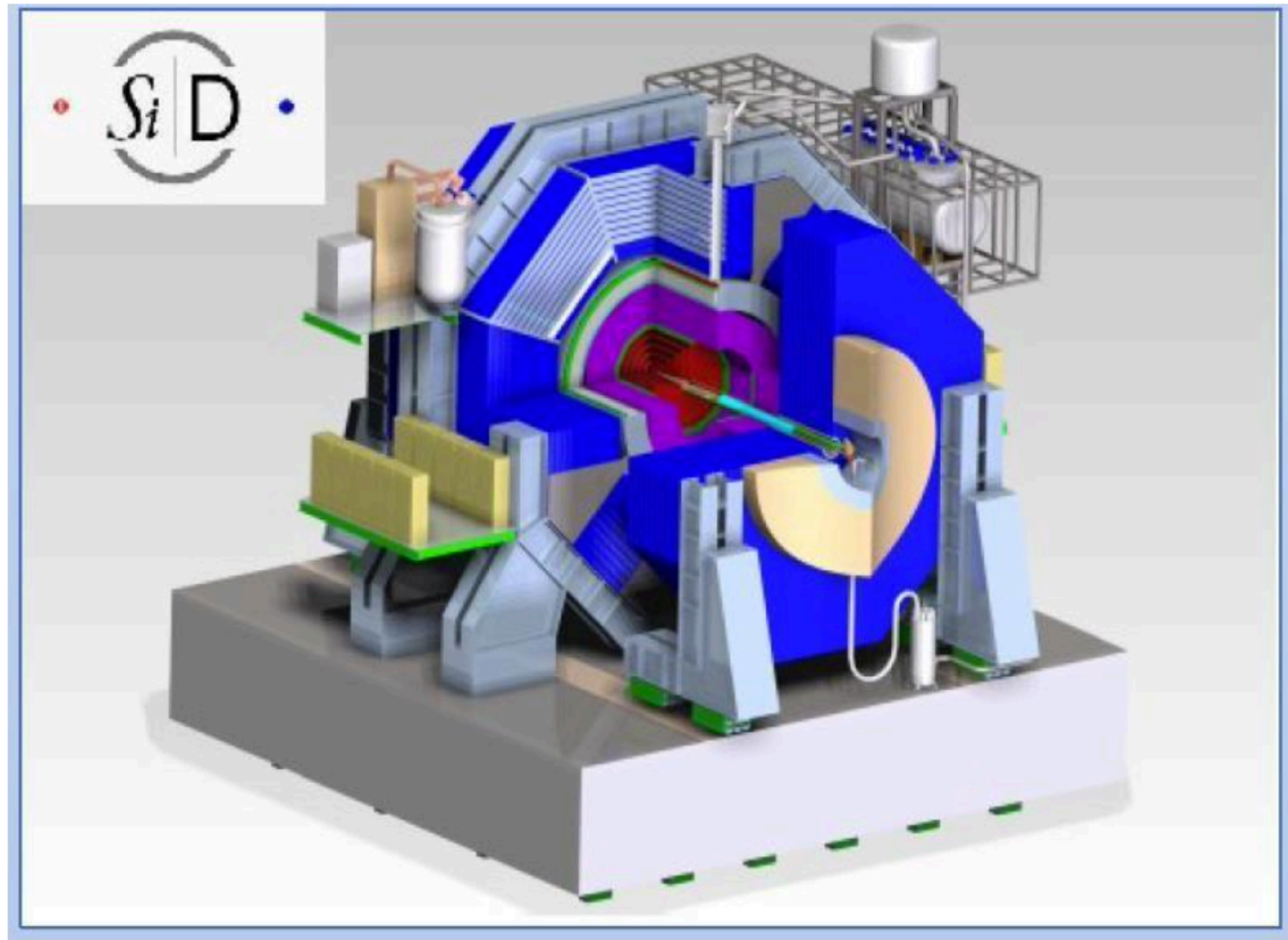
250 GeV, 900 fb⁻¹, LR+RL

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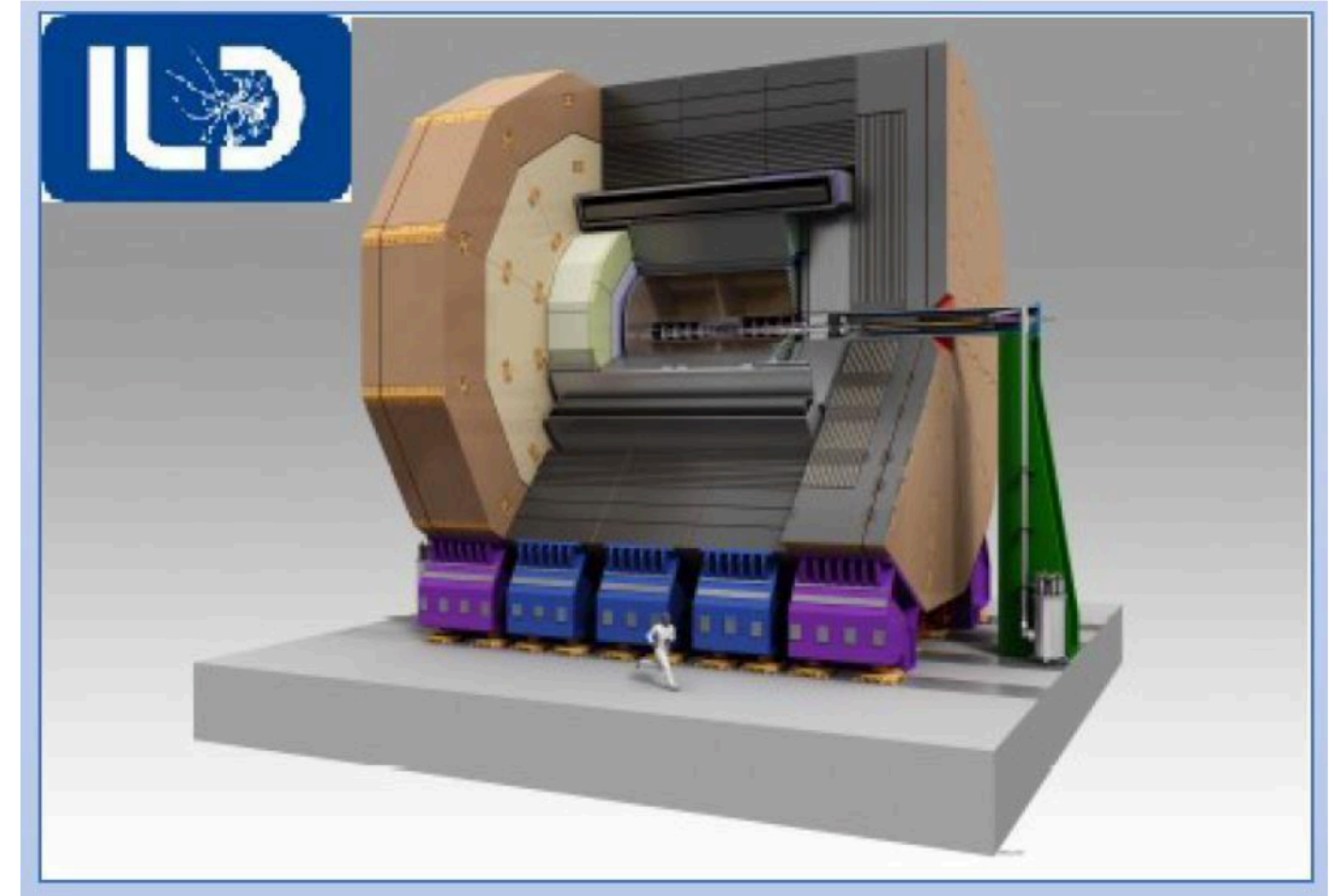
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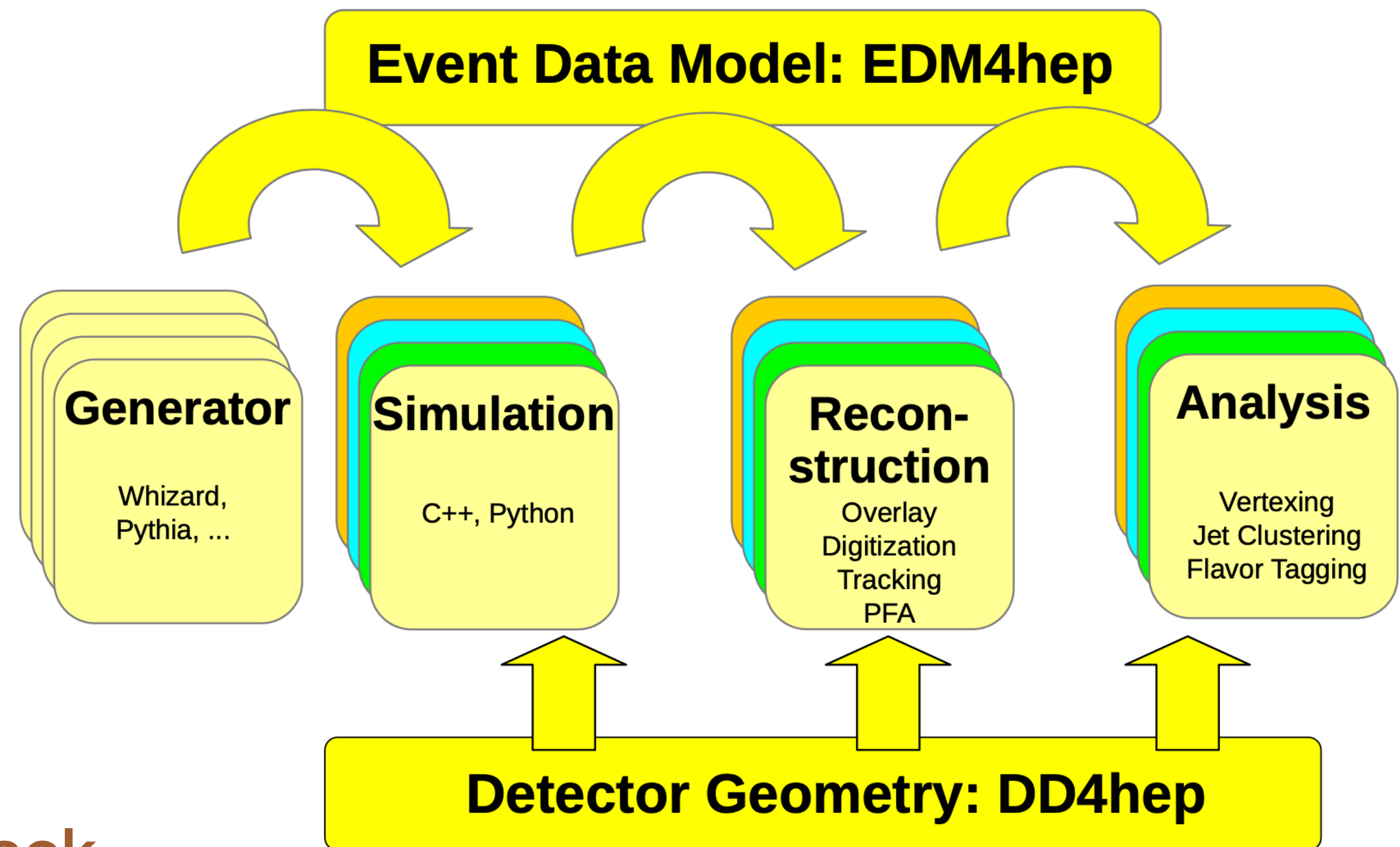
approaching SM limit

key4HEP

- software stack that connects and extends individual packages towards a complete data processing framework for detector studies

  - fast/full simulation

  - reconstruction

  - analysis

- Ingredients

  - Event data model: **EDM4hep**

  - Geometry information: **DD4hep**

  - Framework: **Gaudi**

  - Packaging and deployment: **Spack**

Analysis Structure

- forced two-jet reconstruction/two leptons required

- isolated lepton veto/jet veto

- Z mass reconstruction from di-jet/di-lepton

- ISR corrected recoil mass selection

- toy MC to set upper limit

More Analysis Details

- MC files: lcio files converted to EDM4hep

- **fastjet** (Marlin wrapper)

- **IsolatedLeptonTagging** (Marlin wrapper)

    - identify all isolated leptons

- **LeptonPairing** (Marlin wrapper)

    - select Z pair candidate

    - brems/FSR recovery

k4MarlinWrapper runs **Marlin** processors as **Gaudi** algorithms.

	Marlin	Gaudi
language	C++	C++
working unit	Processor	Algorithm
configuration language	XML	Python
set up function	init	initialize
working function	processEvent	execute
wrap up function	end	finalize
transient data format	LCIO	anything

Analysis Details: Major Backgrounds

- $e^+e^- \to ZZ \to Z\nu\nu$

- $e^+e^- \to WW \to W\ell\nu$

- $e^+e^- \to Z\nu_e\nu_e$

- $e^+e^- \to We\nu_e$
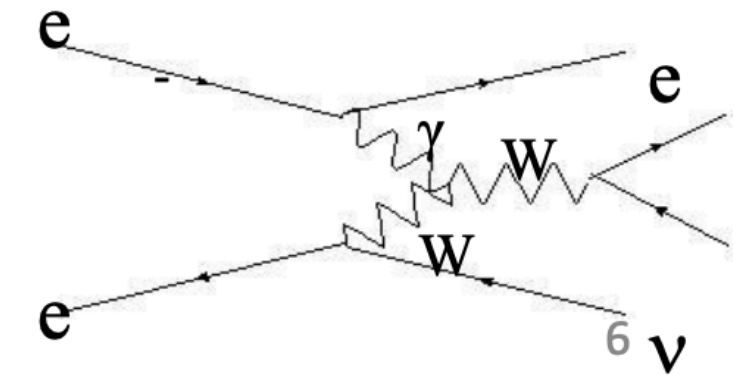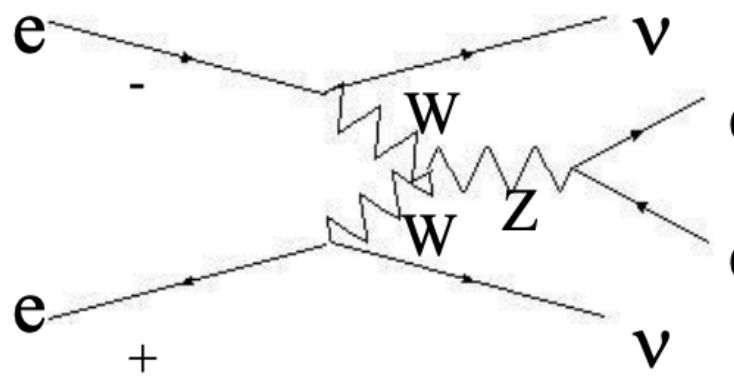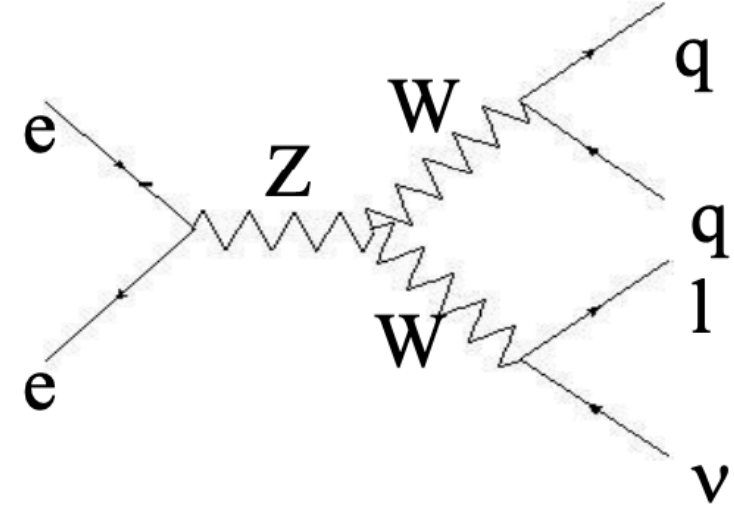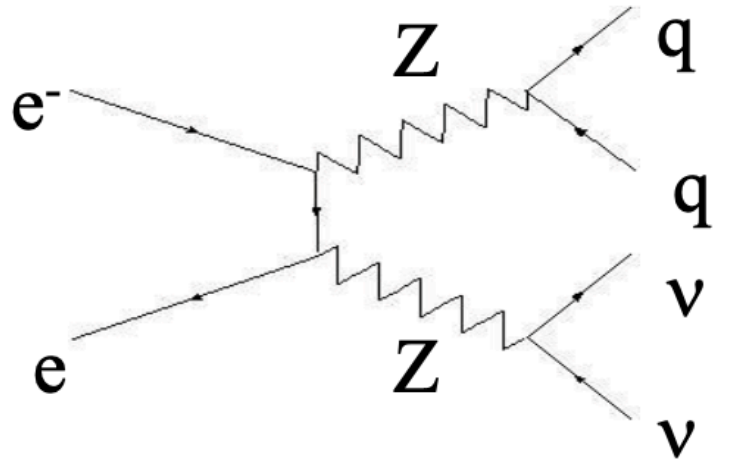
Status

- key4HEP analysis environment is set up

- working now on complete analysis chain

- full signal (background) MC available

- project student joined efforts

- started writing some documentation (log)

Plans

- measurement of the expected sensitivity to invisible Higgs boson decays

  - cut-based analysis (project student)

  - (multivariate analysis)

- comparison of ILD and SiD results

- key4HEP 'audit'

  - key4HEP example analysis

  - (tutorial)