Snowmass 2021 :EF-01Highlights

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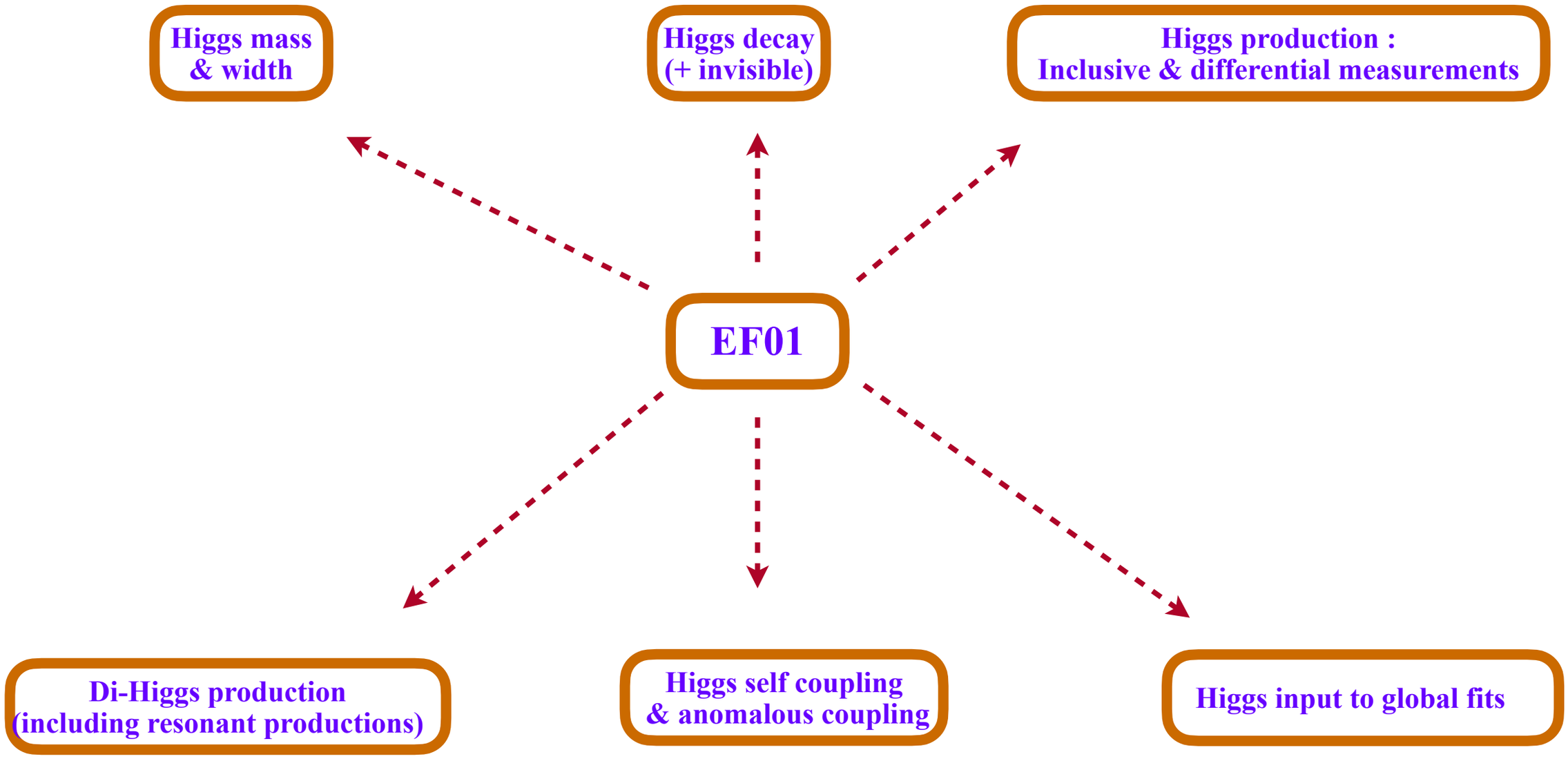
(on behalf of EF01 group)

24/09/2021

EF-01 Group : Activities & Contacts

https://snowmass21.org/energy/higgs

Sally Dawson, Andrey Korytov, Caterina Vernieri



EF-01 Group : Highlighting the LOI's

1	AF/SNOWMASS21-AF3_AF0-EF1_EF0_Tim_Barklow-209.pdf	31/08/2020
2	AF/SNOWMASS21-AF3_AF4-EF1_EF2_C3_Collaboration-243.pdf	01/09/2020
3	AF/SNOWMASS21-AF3_AF6-EF1_EF4_Litvinenko-062.pdf	26/08/2020
4	EF/SNOWMASS21-EF1-033.pdf	06/08/2020
5	EF/SNOWMASS21-EF1-AF1-015.pdf	26/06/2020
6	EF/SNOWMASS21-EF1_EF0-050.pdf	26/08/2020
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8	EF/SNOWMASS21-EF1_EF0-135.pdf	31/08/2020
9	EF/SNOWMASS21-EF1_EF0_Chertok-199.pdf	31/08/2020
10	EF/SNOWMASS21-EF1_EF0_Cristina_Mantilla_Suarez-067.pdf	28/08/2020
11	EF/SNOWMASS21-EF1_EF0_Patrick_Janot-169.pdf	31/08/2020
12	EF/SNOWMASS21-EF1_EF0_Sze_Ching_Leung-059.pdf	27/08/2020
13	EF/SNOWMASS21-EF1_EF0_Xin_Shi-098.pdf	30/08/2020
14	EF/SNOWMASS21-EF1_EF1_Ter_gerd-275.pdf	14/08/2021 late
15	EF/SNOWMASS21-EF1_EF1_Ter_gerd-276.pdf	14/08/2021 late
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17	EF/SNOWMASS21-EF1_EF2-105.pdf	30/08/2020
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20	EF/SNOWMASS21-EF1_EF2-137.pdf	31/08/2020
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22	EF/SNOWMASS21-EF1_EF2-196.pdf	31/08/2020
23	EF/SNOWMASS21-EF1_EF2-IF3_IF0_Valentina_Maria_Martina_Cairo-047.pdf	25/08/2020
24	EF/SNOWMASS21-EF1_EF2-TF7_TF0_Ian_Lewis-222.pdf	31/08/2020
25	EF/SNOWMASS21-EF1_EF2-TF7_TF0_Lucien_Heurtier-156.pdf	31/08/2020
26	EF/SNOWMASS21-EF1_EF2_DanielJeans-113.pdf	30/08/2020
27	EF/SNOWMASS21-EF1_EF2_Dorival-122.pdf	30/08/2020
28	EF/SNOWMASS21-EF1_EF2_Mark_Neubauer-256.pdf	01/09/2020
29	EF/SNOWMASS21-EF1_EF2_Patrick_Janot-171.pdf	31/08/2020
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53	EF/SNOWMASS21-EF2_EF1_Han_Qin-089.pdf	29/08/2020
54	EF/SNOWMASS21-EF3_EF1-TF7_TF0-043.pdf	24/08/2020
55	EF/SNOWMASS21-EF4_EF1-129.pdf	31/08/2020
56	EF/SNOWMASS21-EF4_EF1-241.pdf	31/08/2020
57	EF/SNOWMASS21-EF4_EF1-TF7_TF0_Sally_Dawson-044.pdf	25/08/2020
58	EF/SNOWMASS21-EF4_EF1_Zhao_Li-039.pdf	21/08/2020
59	EF/SNOWMASS21-EF6_EF1-074.pdf	29/08/2020
60	IF/SNOWMASS21-IF3_IF5-EF1_EF4-183.pdf	01/09/2020

Lot's of interesting ideas have been proposed !!

61	IF/SNOWMASS21-IF3_IF6-EF1_EF4_Andy_White,_Marcel_Stanitzki-027.pdf	28/08/2020
62	IF/SNOWMASS21-IF6_IF0-EF1_EF0-RF5_RF0-069.pdf	30/08/2020
63	IF/SNOWMASS21-IF6_IF0-EF1_EF0_Hwidong_Yoo-063.pdf	30/08/2020
64	IF/SNOWMASS21-IF6_IF0-EF1_EF2_EF3_EF4_Philip_Chang-024.pdf	28/08/2020
65	IF/SNOWMASS21-IF6_IF0-EF1_EF2_Hwidong_Yoo-062.pdf	30/08/2020
66	IF/SNOWMASS21-IF6_IF2-EF1_EF4-071.pdf	30/08/2020
67	IF/SNOWMASS21-IF6_IF4-EF1_EF4-102.pdf	31/08/2020
68	TF/SNOWMASS21-TF6_TF4-EF5_EF1-035.pdf	30/08/2020
69	TF/SNOWMASS21-TF7_TF0-EF1_EF2-033.pdf	30/08/2020
70	TF/SNOWMASS21-TF7_TF0-EF1_EF4-CompF3_CompF0-048.pdf	31/08/2020
71	TF/SNOWMASS21-TF7_TF0-EF1_EF4-CompF3_CompF0-049.pdf	31/08/2020

What are the major physics goals?

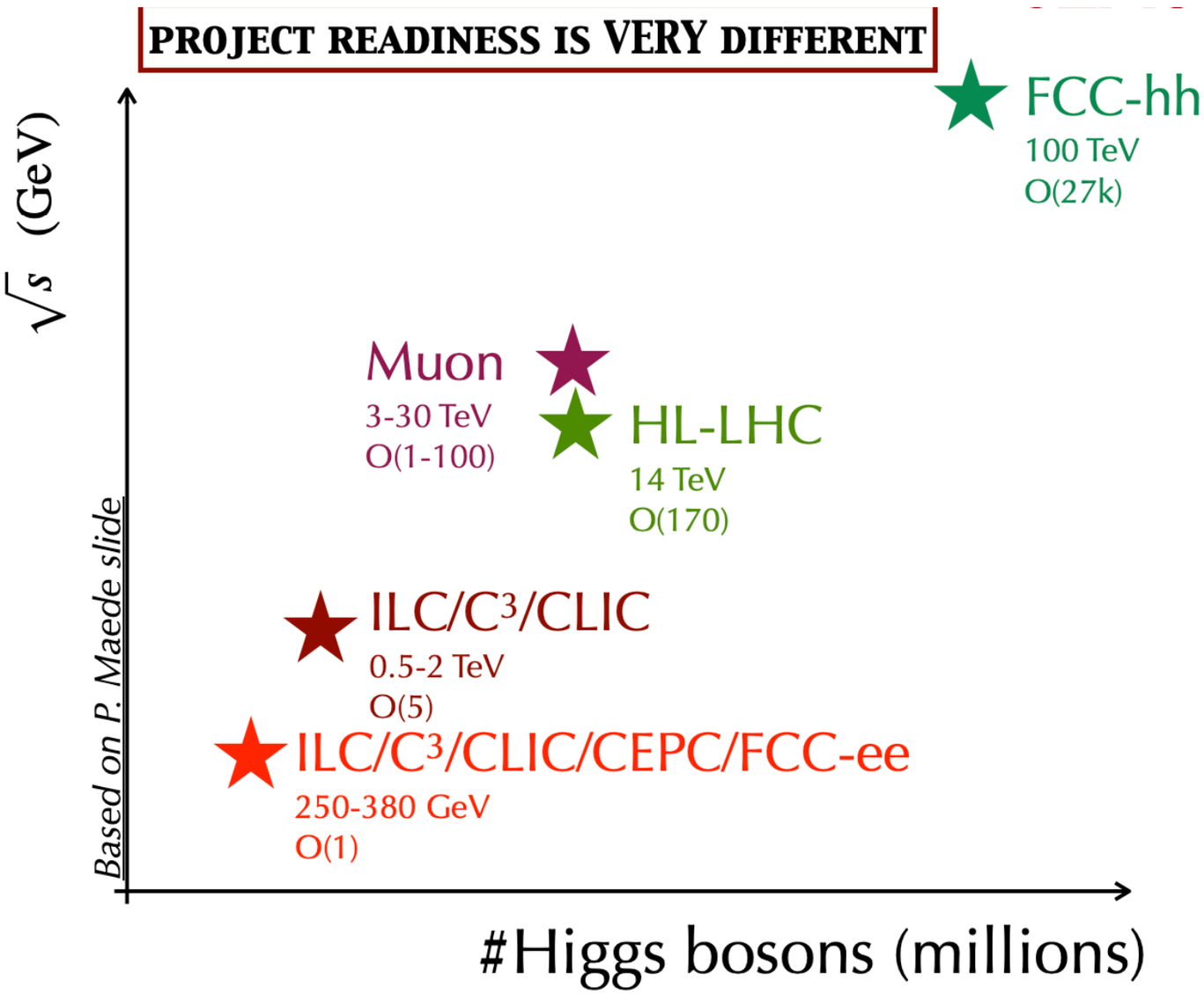
Which collider to look into?

LEPTON COLLIDERS

- **Circular e+e-** (CEPC, FCC-ee)
  - **90-350 GeV**
  - *strongly limited by synchrotron radiation above 350– 400 GeV*
- **Linear e+e-** (ILC, CLIC, C³)
  - **250 GeV — 3TeV**
  - *Reach higher energies, and can use polarized beams*
  - *Relatively low radiation / beam induced backgrounds*
  - ***C³** plans is to run at 250/550 GeV*
    C3 proposal - talk on Wed
- μ+μ-
  - **3-30 TeV**

HADRON COLLIDERS

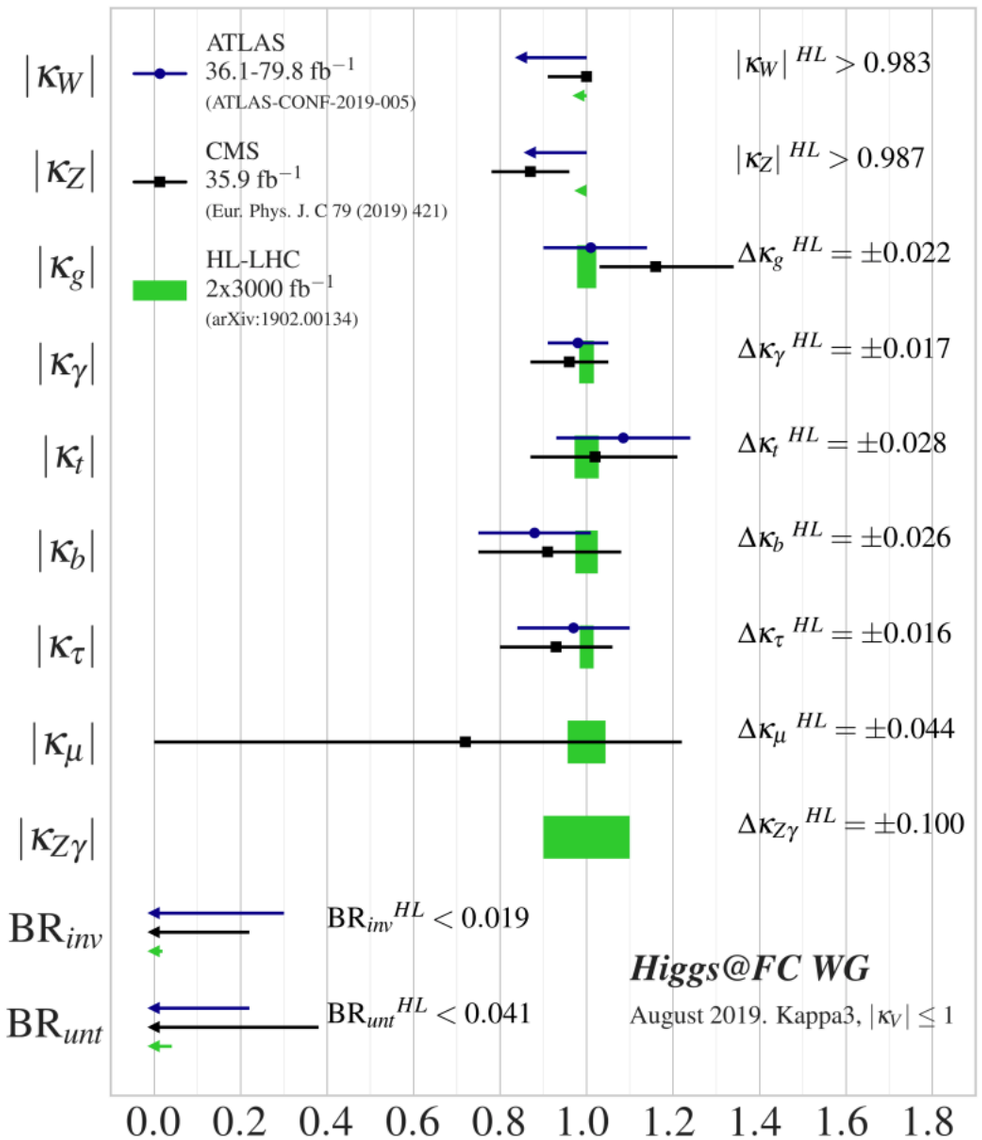
- **75-200 TeV** (FCC-hh)

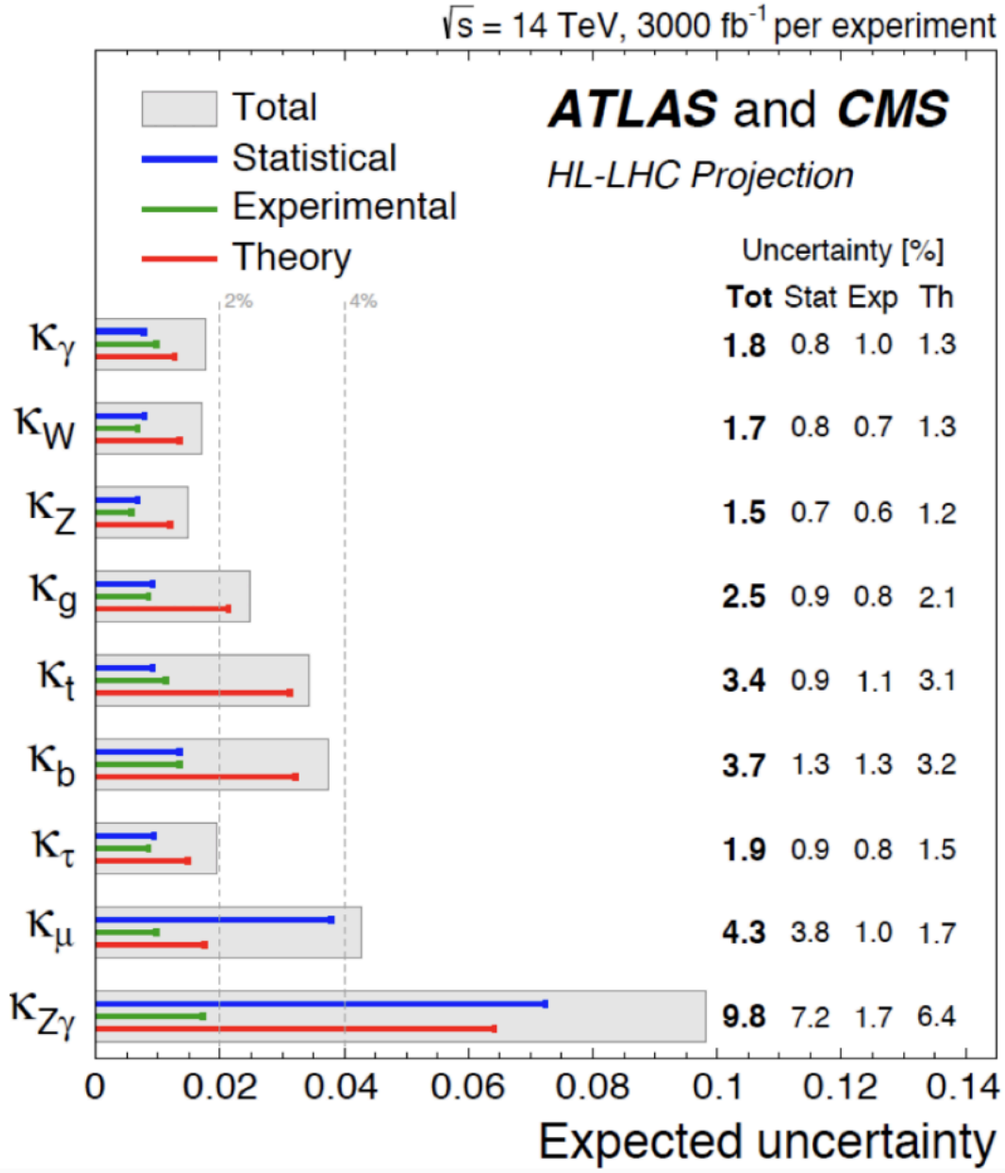


Stolen from C. Vernieri's slide

Higgs couplings at future colliders

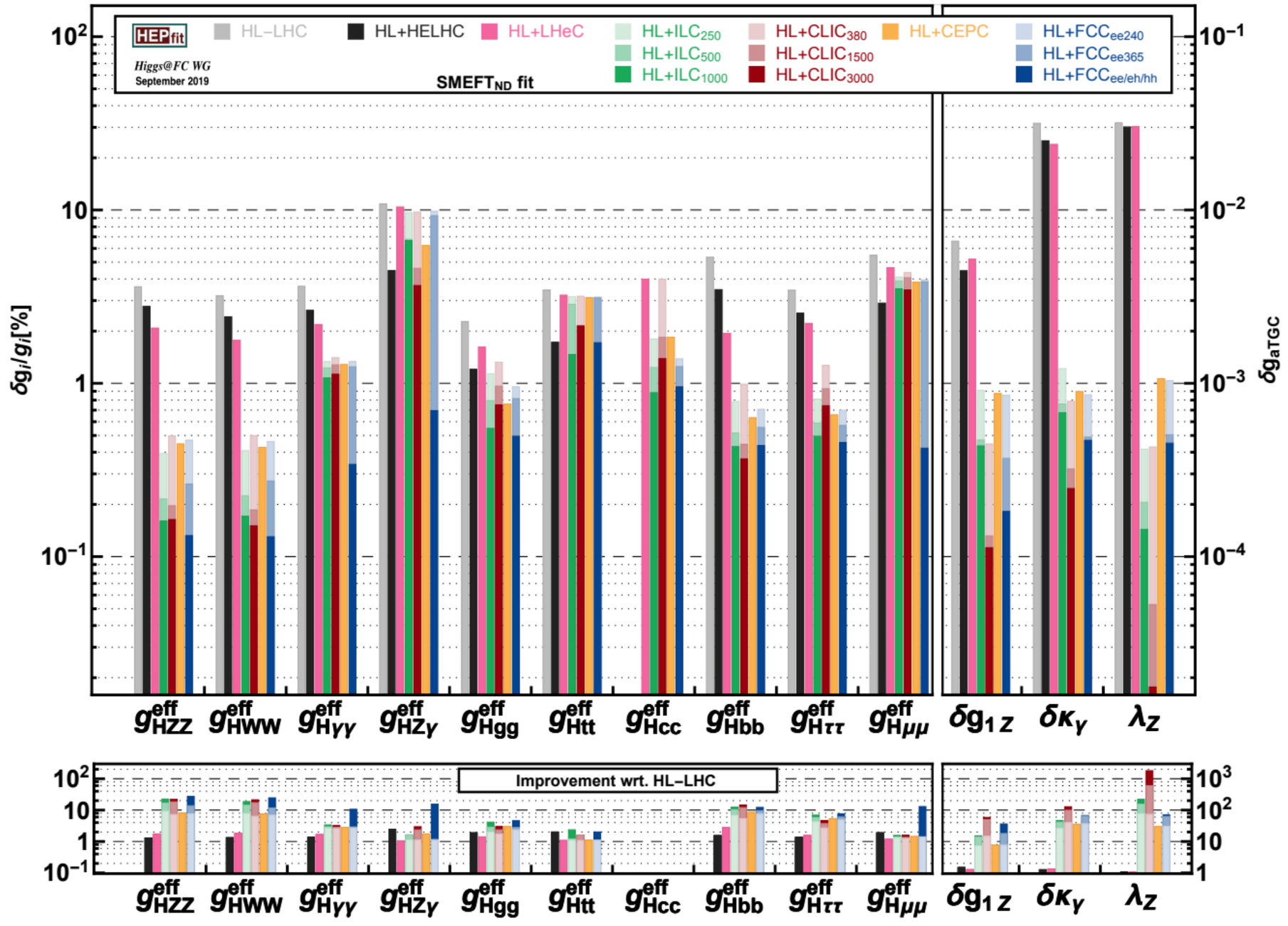
LHC projection arXiv : 1910.11775





Higgs couplings at future colliders

LHC projection arXiv : 1905.03764

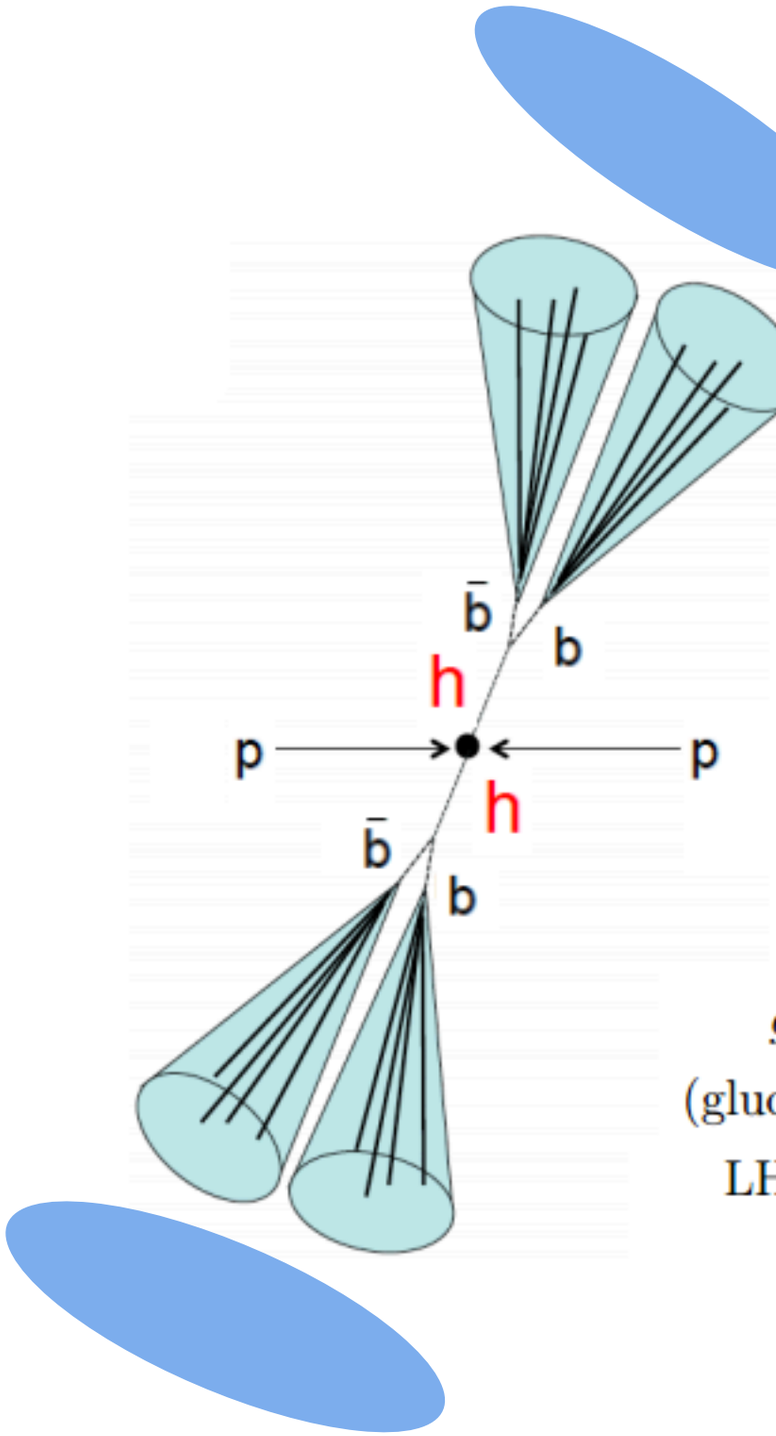


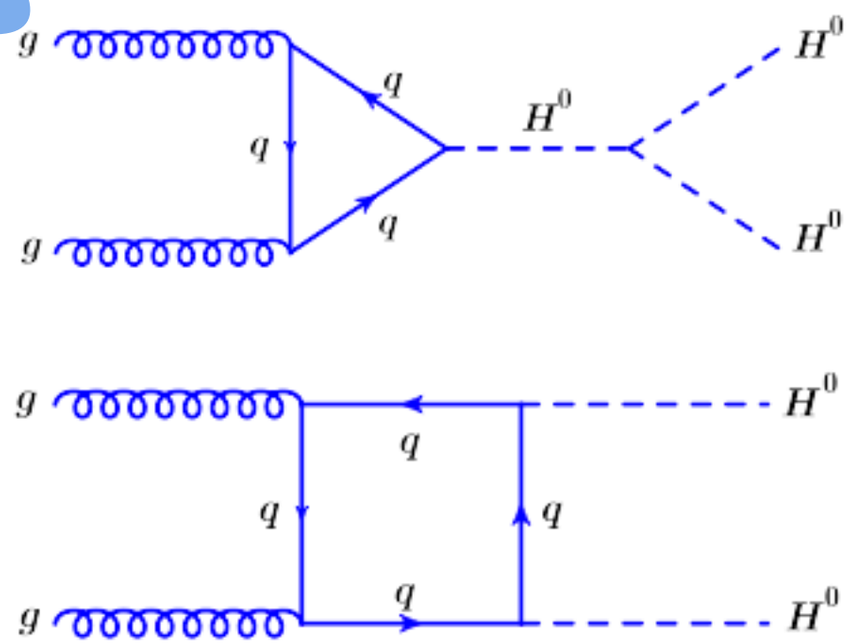
Measurements from HL-LHC and other colliders will complement each other.

Some recent studies :HH using GNN

For boosted di-Higgs production we look for two Ak-08 jets with track subjets

Daniel Diaz, Javier Duarte,
Sanmay Ganguly, Samadrita Mukherjee, Brian Sheldon





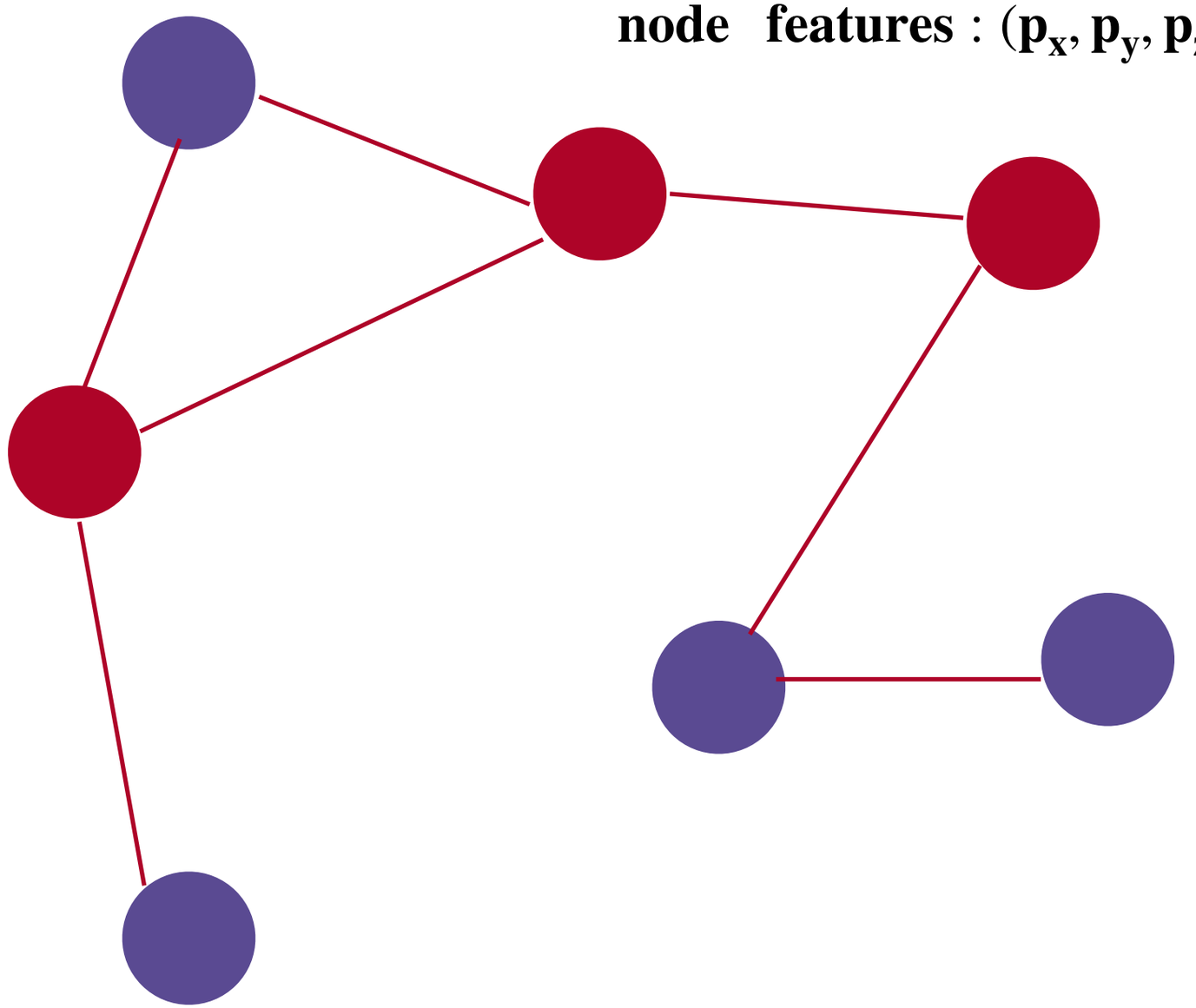
$gg \to H^0H^0$
(gluon-gluon fusion)
LHC at $\sqrt{s} = 14$

$\sigma(pp \to H^0H^0)$ [fb]	
NNLO	$40.2^{+3.2}_{-3.5}$

pic credit : https://francis.naukas.com/2014/08/22/el-campo-de-higgs/

Event as a graph

node features : (p_x, p_y, p_z, E, two_sub, one_sub)



Locate all the R=0.8 PF jets and 0.4 track jets in the η , ϕ plane.
Connect the k-NN neighbour through edges.
For each nodes : assign 4-vector + two and one subjettiness observables.
Use this graph representation for the events to be fed in GNN.

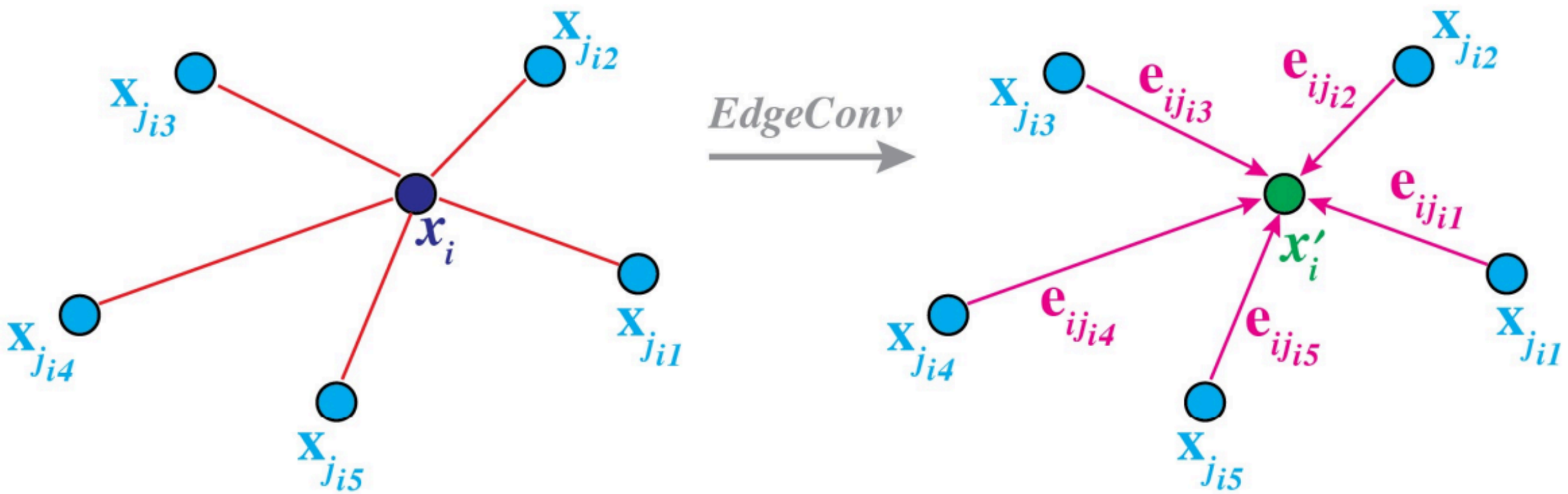
The graph network

https://arxiv.org/pdf/1801.07829.pdf

In a graph, each node can "learn" about the state of neighboring node through message passing operation

$$(x')_i^{l+1} = max_{j \in \mathcal{N}(i)}\ \Theta_x(x_j^l - x_i^l) + \Phi_x(x_i^l)$$

$$(e')_i^{l+1} = mean_{j \in \mathcal{N}(i)}\ \Theta_e(e_j^l - e_i^l) + \Phi_e(e_i^l)$$



The graph network

https://arxiv.org/pdf/1801.07829.pdf

$(\overrightarrow{x_1}, E_1)$

$(\overrightarrow{x_2}, E_2)$

$(\overrightarrow{x_3}, E_3)$

$\cdot$

$\cdot$

$\cdot$

$(\overrightarrow{x_N}, E_N)$

→ **$EC_{L1}(d_{in} = 3,\ d_{out} = M)$** →

(z_1^M, E_1^{L1})

(z_2^M, E_2^{L1})

(z_3^M, E_3^{L1})

$\cdot$

$\cdot$

$\cdot$

(z_N^M, E_N^{L1})

Forms a K-NN graph and performs the message passing

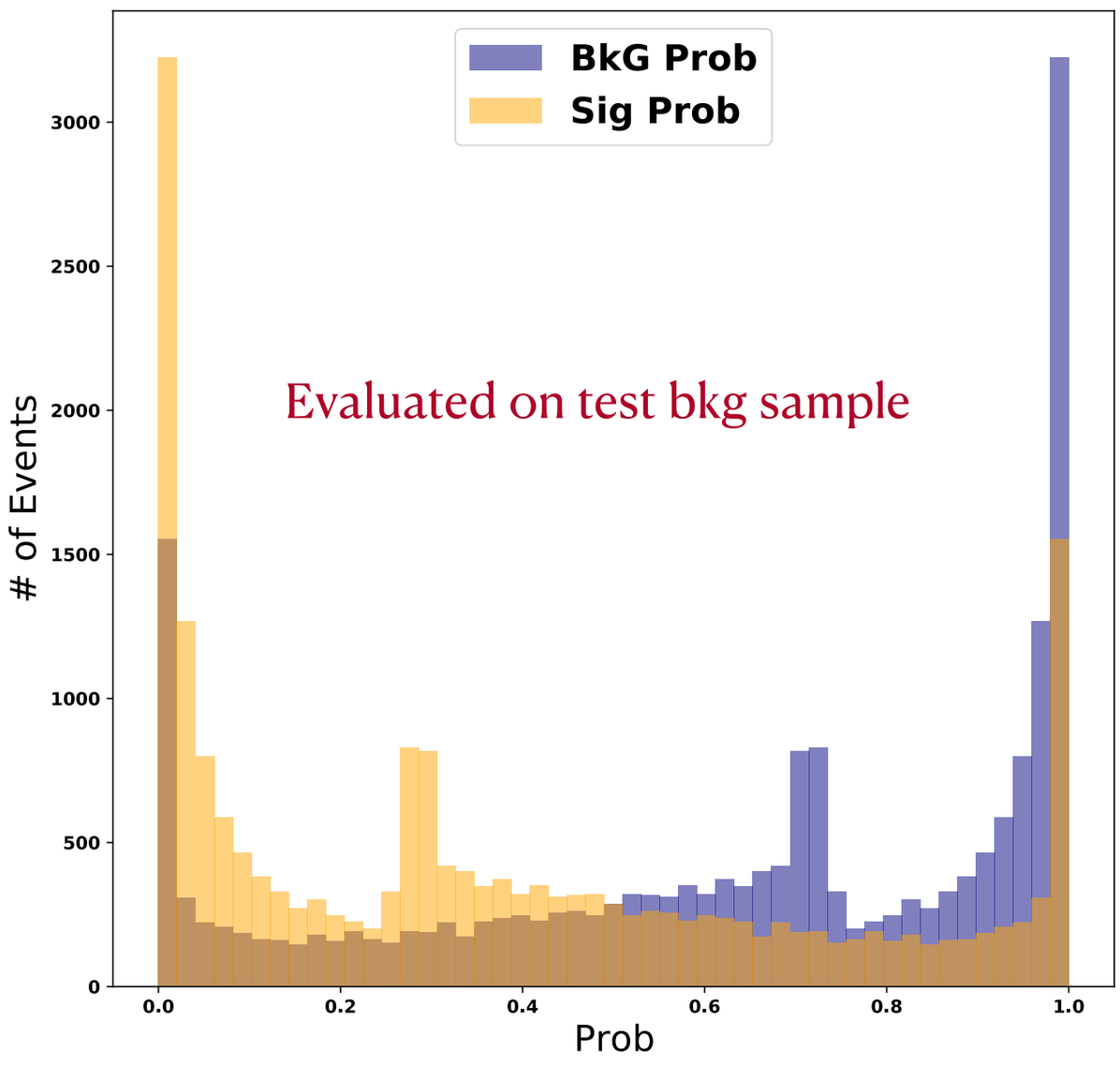
$$(x')_i^{l+1} = max_{j \in \mathcal{N}(i)}\ \Theta_x(x_j^l - x_i^l) + \Phi_x(x_i^l)$$

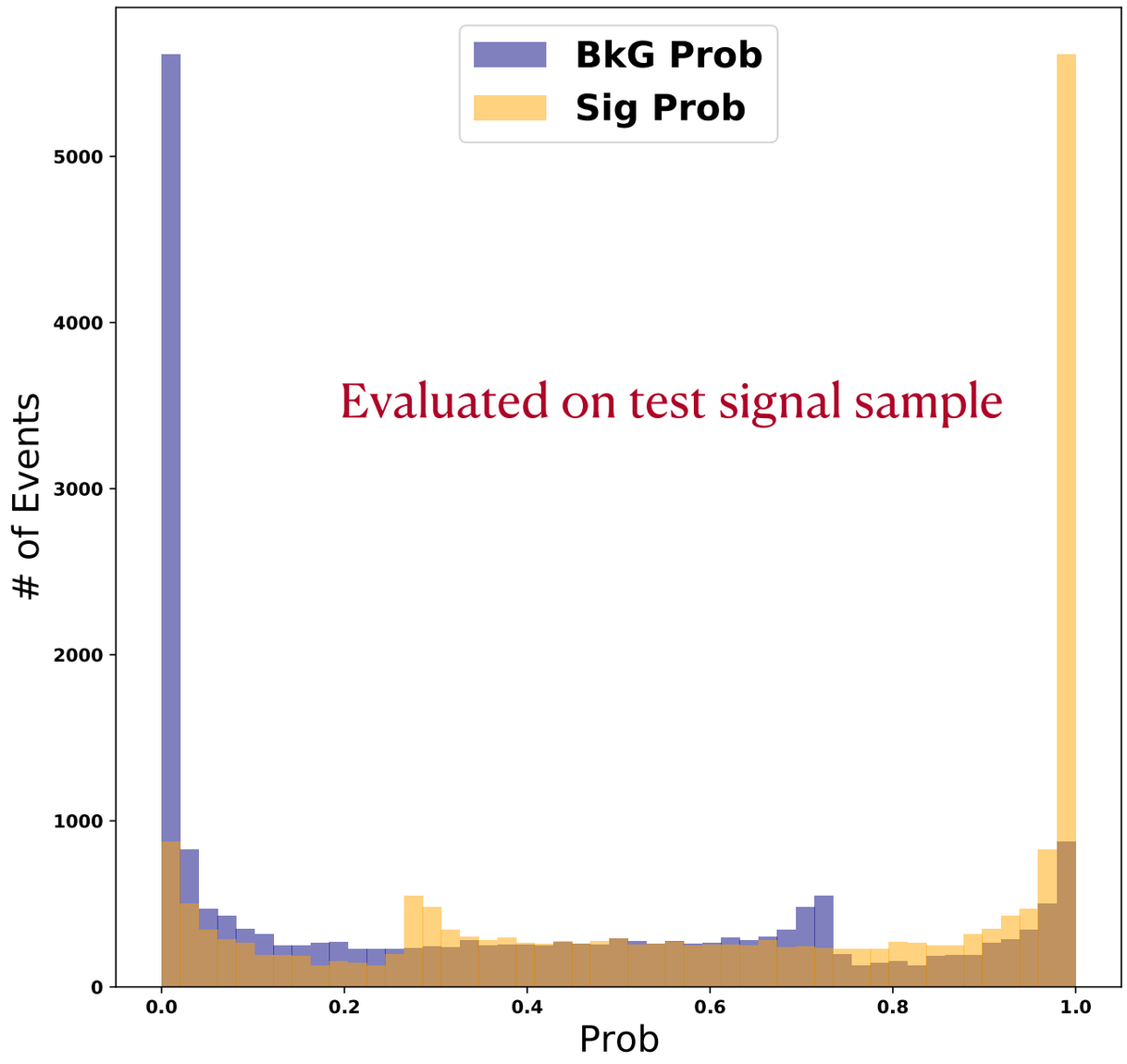
$$(e')_i^{l+1} = mean_{j \in \mathcal{N}(i)}\ \Theta_e(e_j^l - e_i^l) + \Phi_e(e_i^l)$$

After p message passing layers , the q-th node has following energy representation :

$$\left(\mathbf{E_q}, \mathbf{E_q^{L1}}, \mathbf{E_q^{L2}}, \ldots, \mathbf{E_q^{Lp}} \right) \longrightarrow \boxed{\textbf{MLP}} \longrightarrow [p_{sig}, p_{bkg}]$$

Signal vs QCD bkg separation using GNN



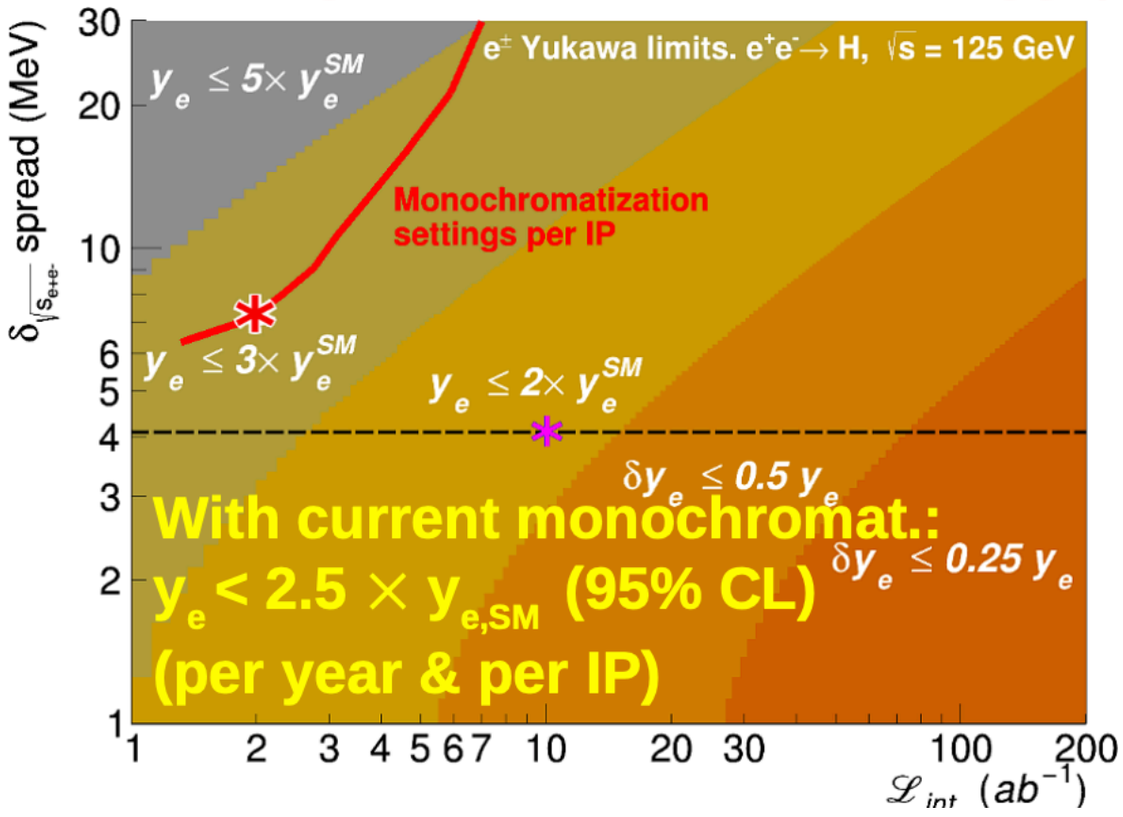


Trying to improve the study with heterograph representation

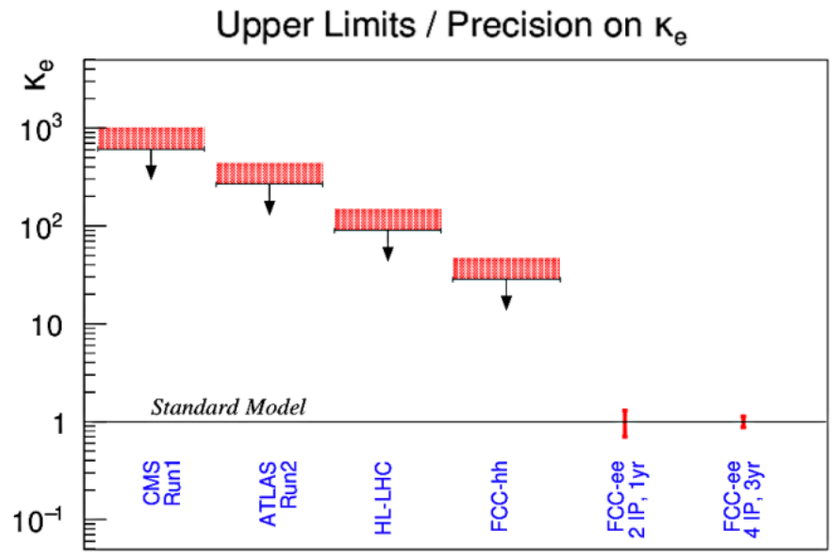
Slides

Some recent studies : el Yukawa FCC-ee

Most significant channels: H→gg (for light-q mistag ~1%), H→WW*→l+jets



For 10 ab^{-1} & $\sqrt{s}_{spread} = \Gamma_H$: Signif ≈ 1.3σ



arXiv.org > hep-ex > arXiv:2107.02686

High Energy Physics – Experiment

[Submitted on 6 Jul 2021]

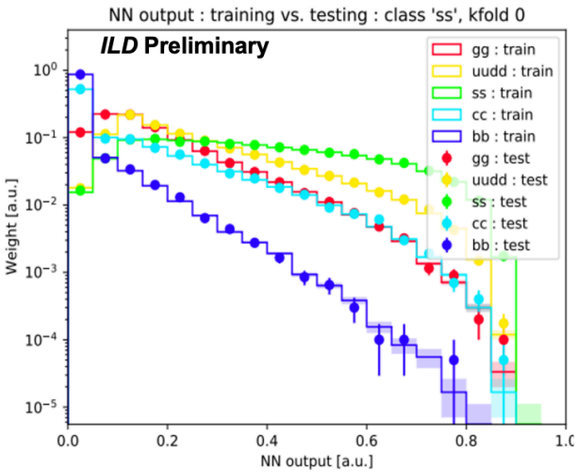
Measuring the electron Yukawa coupling via resonant s-channel Higgs production at FCC-ee

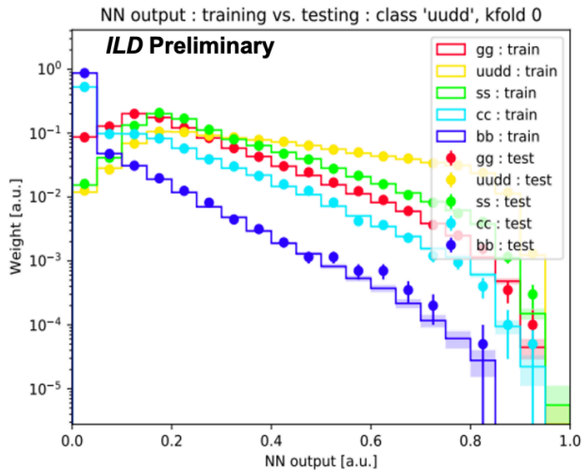
David d'Enterria, Andres Poldaru, George Wojcik

- Fundamental unique physics accessible:
  - → Electron Yukawa coupling: Limits X100 (X30) better than HL-LHC (FCC-hh)
  - → BSM scale affecting e± Yukawa pushed up to Λ_{BSM} > 110 TeV

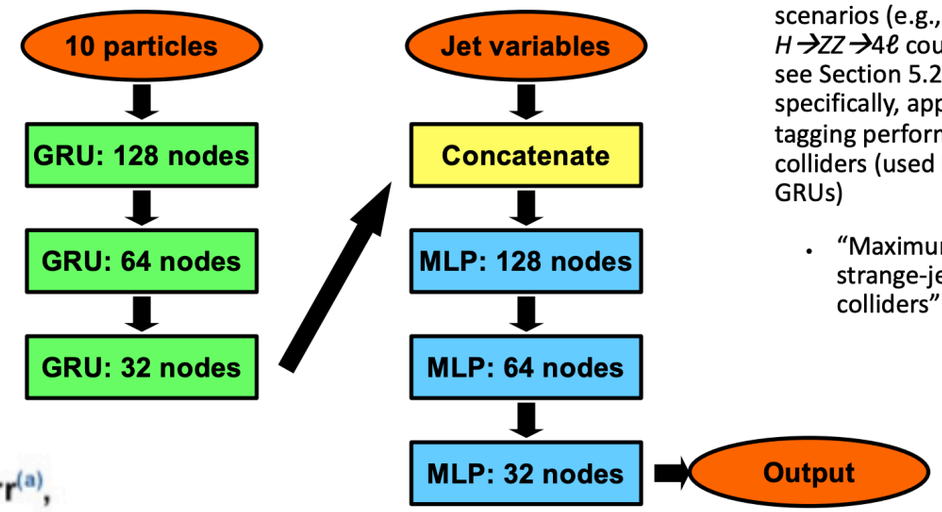
Slides

Some recent studies : Strange tagging at ILC





- Use a ***multiclassifier* tagger**, which assigns probabilities to the possible flavours of a jet simultaneously
- Train on **ILD-reconstructed *H->qq/gg* samples** (*qq* = *uu*, *dd*, *ss*, *cc*, *bb*) with $\sqrt{s}$ = 250 GeV and $P_L[e^-]$ = -100% and $P_R[e^+]$ = +100%
  - *Unskimmed*, except for $N_{jets} \geq 2$, $N_{leptons} = 0$, and truth $H \rightarrow qq/gg$ cuts
- Use **per-jet level inputs** as well as variables on the **10 leading particles** in each jet (with kinematics re-defined relative to the jet axis and re-normalized relative to jet momentum)
  - Jets:
    - momentum *p*, pseudorapidity *η*, polar angle *ϕ*, mass *m*, *b*/*c*-tagger scores, $N_{particles}$
  - Particles:
    - *p*, *η*, *ϕ*, *m*, charge, **truth** electron/muon/pion/kaon/proton likelihoods (0 or 1, using PDG ID – ***dE/dx* and TOF likelihoods in ILD samples have a bug – not used in current analysis, opted for truth info instead**)



- Architecture shows up in many different HEP measurement scenarios (e.g., recent ATLAS $H \rightarrow ZZ \rightarrow 4\ell$ couplings measurement, see Section 5.2 of 2004.03447); specifically, applied even to strange tagging performance at **hadron** colliders (used LSTMs instead of GRUs)
  - "Maximum performance of strange-jet tagging at hadron colliders" (2011.10736)

M.J. Basso[a], V.M.M. Cairo[b], U. Heintz[c], J. Luo[c], M. Narain[c], R. S. Orr[a], A. Schwarzman[b], D. Su[b], E. Usai[c], C. Vernieri[b], C. Young[b]
J. Hofgard, V. Cavaliere
(a) University of Toronto, Toronto ON - Canada
(b) SLAC National Accelerator Laboratory, Stanford CA - USA
(c) Brown University, Providence RI - USA

Slides

Some recent studies : Xcc

σ(e⁻γ→e⁻H) Measurement

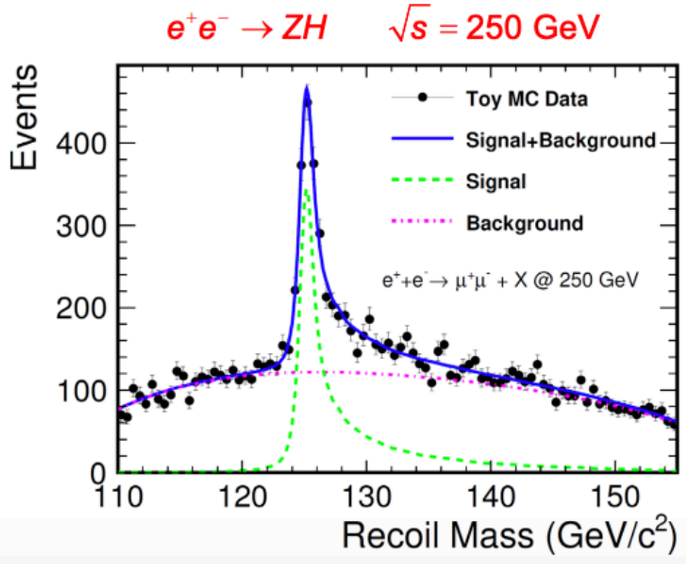
A WHIZARD-based analysis has been peformed including $e^-\gamma \to e^-\gamma$ and all $e^-\gamma \to e^- f \bar{f}$ processes. Nominal EM calorimeter resolution is assumed.

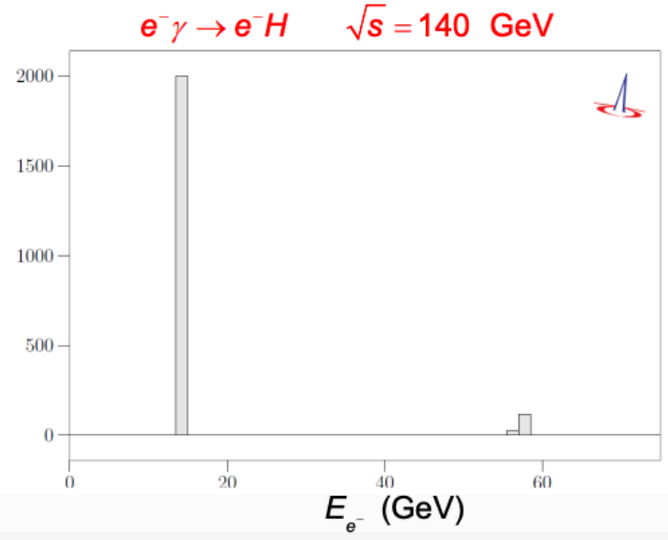
The largest background is $e^-\gamma \to e^- e^+ e^-$

Timothy Barklow

We require 1 electron with E=14.1 GeV and $0.75 < \cos\theta < 0.99$ and no other EM calorimeter cluster with E > 54 GeV and $-0.8 < \cos\theta < 0.999$.

$\sigma(e^+e^- \to ZH) \approx 250$ fb @ $\sqrt{s} = 250$ GeV vs. $\sigma(e^-\gamma \to e^-H) \approx 4$ fb @ $\sqrt{s} = 140$ GeV. But factoring in BR($Z \to e^+e^-, \mu^+\mu^-$) = 0.067 and larger background for $e^+e^- \to ZH$, the $\sigma(e^-\gamma \to e^-H)$ measurement is competitive





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Discussion

☑EF01 activities are targeted towards better understanding of Higgs couplings and properties.

☑A whole lot of activities are ongoing or will start in this group towards better understanding of Higgs physics in current and future colliders.

☑An unique crossroad for better experimental measurement, theoretical understanding and in some cases exploration of the novel ML algorithms.

☑Measuring light quark Yukawa couplings are major challenge for upcoming & future collider study. A major effort of EF01 will be dedicated towards this program. (EF restart link)

☑Let's stay tuned to all these efforts.

THANK YOU !!