WHY BSM?

MIHOKO NOJIRI
(KEK, THEORY)

- As typical Japanese, start from apologizing something
- "Particle Physics has been answering big questions and has been allowed to exist because it can answer remaining big questions (my talk in PASCOS 2016)

- it is good idea to outspoke your best BSM time to time

(such as origin of symmetry breaking, charge, gauge interaction, dark matter)"

@CERN

If you have completely forgotten
here is a partial list

from talk of Catarinna Vernieri

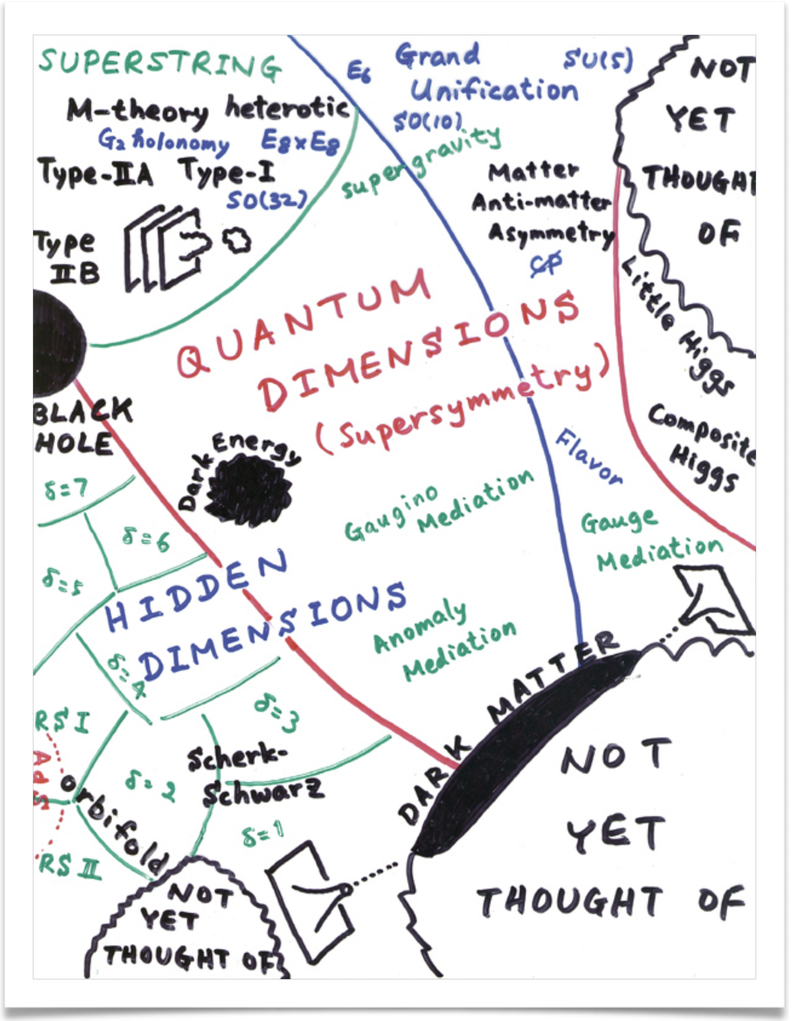
Where is new physics?

We don't know

Exploring the unknown

- signature-based generic searches
- model-driven targeted searches

New technique to explore new ground



Hitoshi?

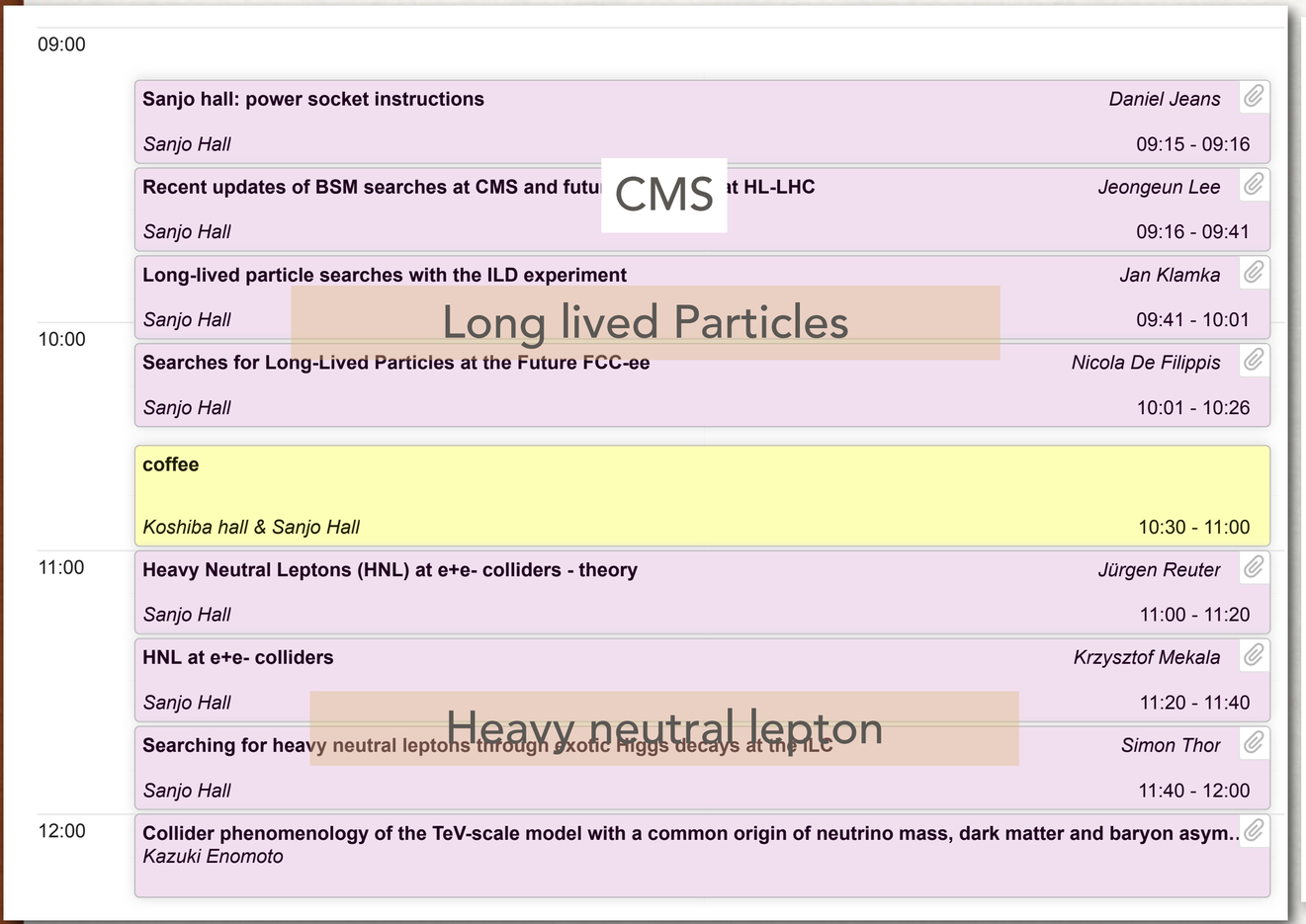
BSM AND GLOBAL INTERPRETATION

PROGRAM

Second day

09:00	**Status of BSM searches at ATLAS including some future prospects at HL-LHC** ATLAS	*Caterina Vernieri*	
	Fukutake Hall		09:00 - 09:25
	"Here be SUSY" - Prospects for SUSY searches at future colliders	*Mikael Berggren*	
	Fukutake Hall		09:25 - 09:45
	Consistent excesses in SUSY searches at the LHC: Physics case for a Linear Collider SUSY	*Sven Heinemeyer*	
10:00	*Fukutake Hall*		09:45 - 10:05
	Stau searches at future e+e- colliders	*Mikael Berggren*	
	Fukutake Hall		10:05 - 10:25
14:00	**Investigating hidden sectors at future e+e- colliders through two-particle angular correlations**	*Emanuela Musumeci*	
	Fukutake Hall		14:00 - 14:20
	Searches for BSM physics at a gamma-gamma collider with Energy < 12 GeV based on European XFEL	*Marten Berger*	
	Fukutake Hall		14:20 - 14:40
	Probing BSM neutral gauge boson in high and low energy experiments	*Arindam Das*	
	Fukutake Hall		14:40 - 15:00
15:00	**Unconventional Searches of Exotic particles at Future Lin** *Dr Nilanjana Kumar*		
	coffee		

Third day

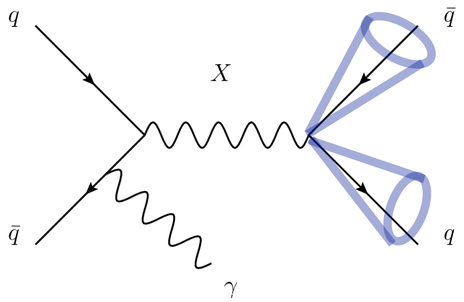

09:00
Sanjo hall: power socket instructions
Daniel Jeans
Sanjo Hall
09:15 - 09:16
Recent updates of BSM searches at CMS and futu
t HL-LHC
Jeongeun Lee
Sanjo Hall
09:16 - 09:41
CMS
Long-lived particle searches with the ILD experiment
Jan Klamka
Sanjo Hall
09:41 - 10:01
Long lived Particles
10:00
Searches for Long-Lived Particles at the Future FCC-ee
Nicola De Filippis
Sanjo Hall
10:01 - 10:26
coffee
Koshiba hall & Sanjo Hall
10:30 - 11:00
11:00
Heavy Neutral Leptons (HNL) at e+e- colliders - theory
Jürgen Reuter
Sanjo Hall
11:00 - 11:20
HNL at e+e- colliders
Krzysztof Mekala
Sanjo Hall
11:20 - 11:40
Heavy neutral lepton
Searching for heavy neutral leptons through exotic Higgs decays at the ILC
Simon Thor
Sanjo Hall
11:40 - 12:00
12:00
Collider phenomenology of the TeV-scale model with a common origin of neutrino mass, dark matter and baryon asym..
Kazuki Enomoto


14:00
Overview on low mass scalars at e+e- facilities - theory
Tania Natalie Robens
Sanjo Hall
14:00 - 14:
The 95 GeV Higgs at e^+e^- colliders
Georg Ralf Weiglein et al.
Sanjo Hall
14:20 - 14:
A BSM world with doubly charged scalars. Consequences for e+e- projects.
Dr Francois Richard
Sanjo Hall
14:40 - 15:
Light Scalers
15:00
Prospects for light exotic scalar measurements at the e+e- Higgs factory.
Aleksander Filip Zarnecki
Sanjo Hall
15:00 - 15:
Feasibility study on the search for an…
CHENG-HSU NEE
coffee
Koshiba Hall & Sanjo Hall 15:30 - 16:00
EAJADE: by invitation
Steinar Stapnes, Thomas Schoerner-Sadenius
1017, Science building n.1 15:30 - 16:
16:00
Probing GHU models at the ILC with
Adrian Irles
Global EFT fits for future colliders
Eleni Vryonidou
Sanjo Hall
16:30 - 16:
EFT
17:00
CP-violating top-Higgs coupling in SMEFT
Ya-Juan Zheng
Sanjo Hall
16:55 - 17:
Probing SMEFT operators using polarizations and spin correlations at current and future colliders
Amir Sub

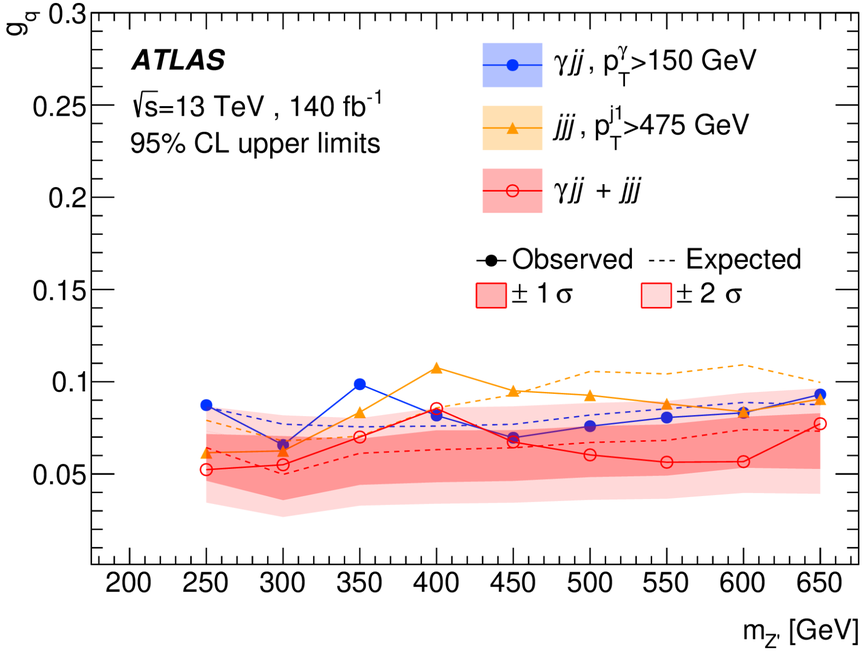
ATLAS TALK: TRIGGER IDEAS AND REDUCED THRESHOLD

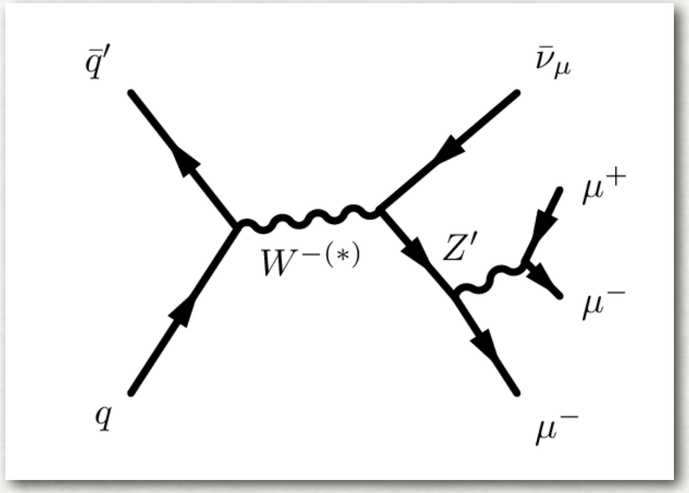
Light dijet resonances: Z'+ISR

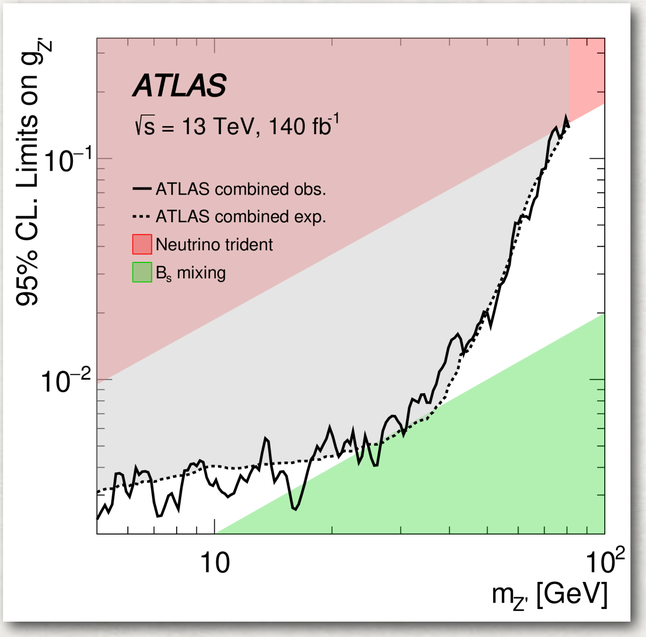
arXiv:2403.08547



- ISR γ allows to lower jet p_T threshold
- The search is performed in the 250–650 GeV dijet mass range

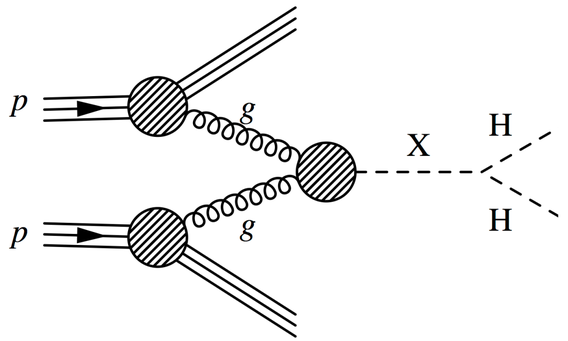




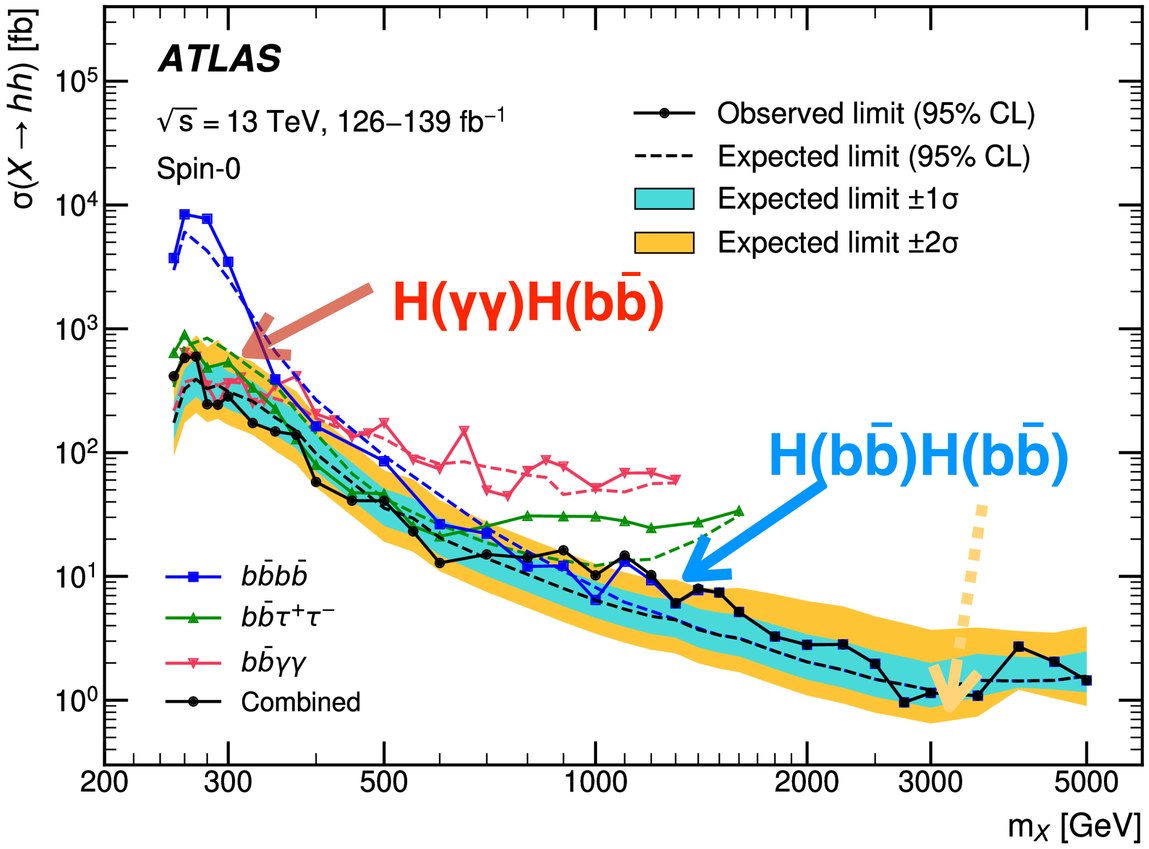


ATLAS TALK

X→HH



Phys. Rev. Lett. 132 (2024) 231801



H(bb̄)H(bb̄) most sensitive channel for m_X > 400/500 GeV

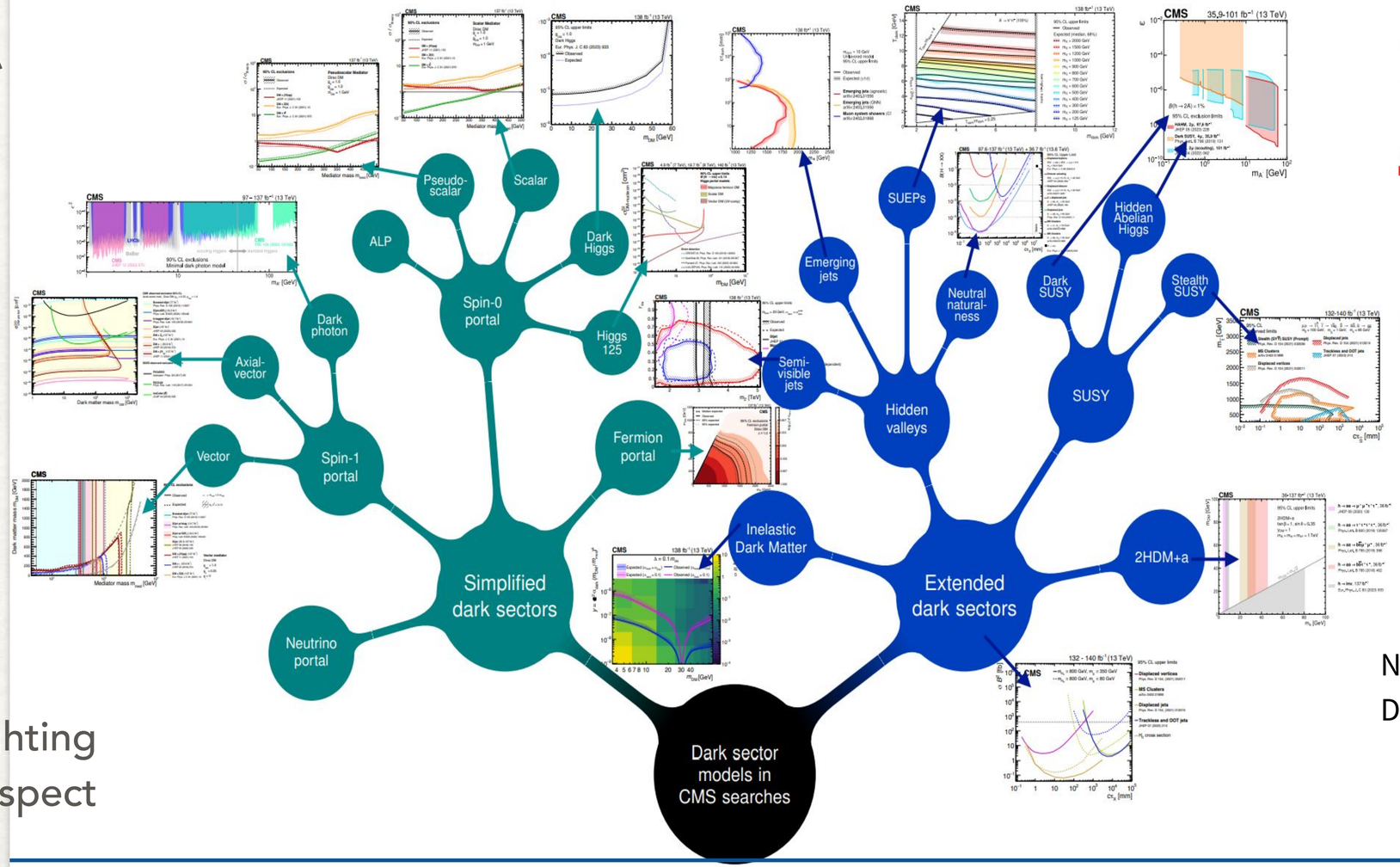
H(γγ)H(bb̄) complement in the low mass

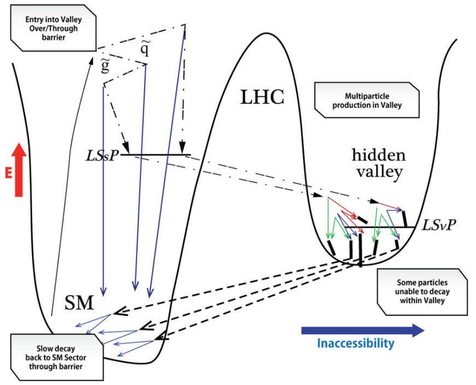
ML helps to reduce background

DARK SECTOR SEARCH AT LHC AND HL-LHC

- \

Dark Sector Report map





Hidden Valley model

Nice CMS Review article of Dark sector (2405.13778)

Highlighting HL-prospect

New Resonance Search in Merged γγ pair

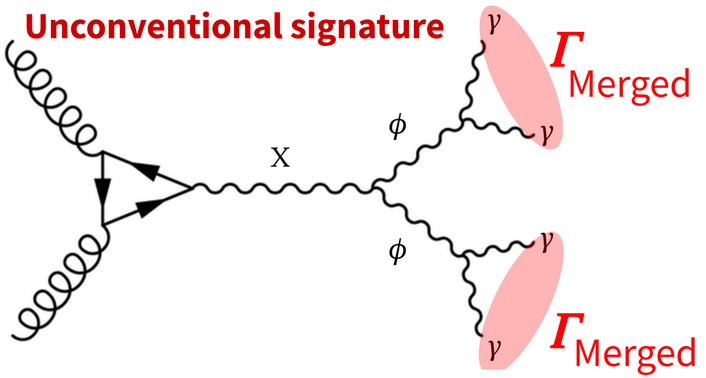
- Search for X, ϕ scalars in the extended Higgs Sector
  - X →$\phi\phi$ kinematically allowed for m(ϕ) < 2m(bb/cc)
  - Highly boosted ϕ for m(X) >> m(ϕ) ⇒ merged diphoton Γ(= γγ)
- Analysis strategy:
  - Exploiting CNN to classify events with two Γ clusters
  - Data binned in slices of α_{reco} = m(Γ)/M($\Gamma\Gamma$) = [0.5% ~ 2.5%].
  - Search for excess in data M($\Gamma\Gamma$)
- Background estimation
  - parametrized fit of falling M($\Gamma\Gamma$) in data
- Result

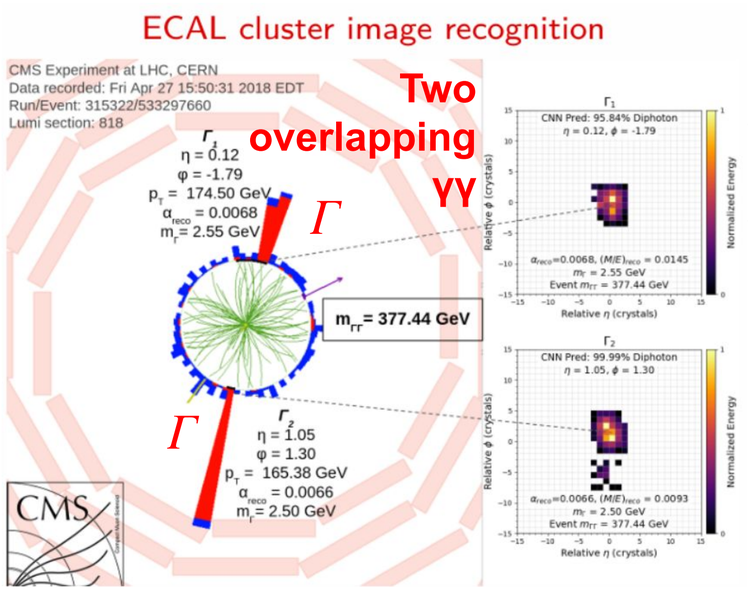
  Largest excess at m(X) = 720 GeV, α = 0.7% (m(ϕ) ~ 5 GeV)

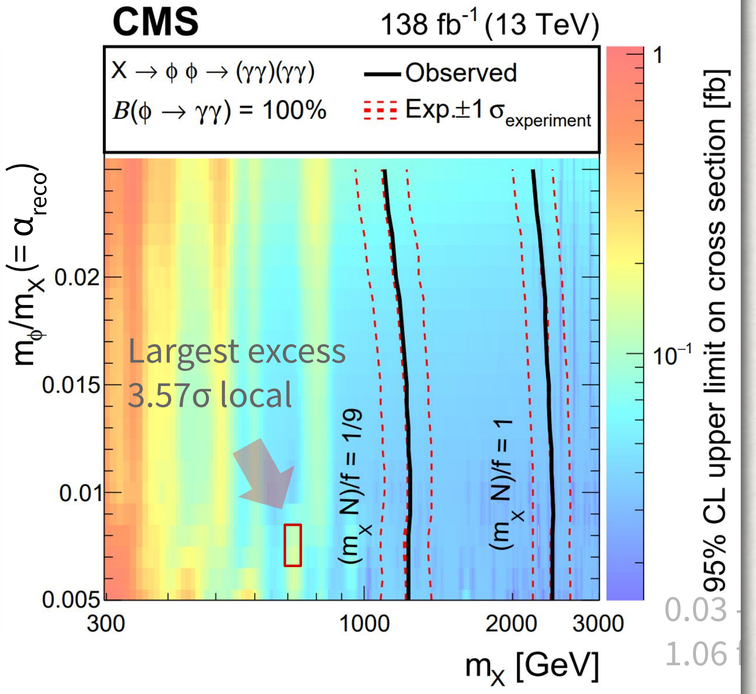
  ⇒ local (global) significance of 3.57σ (1.07σ)

First time!
Unconventional signature

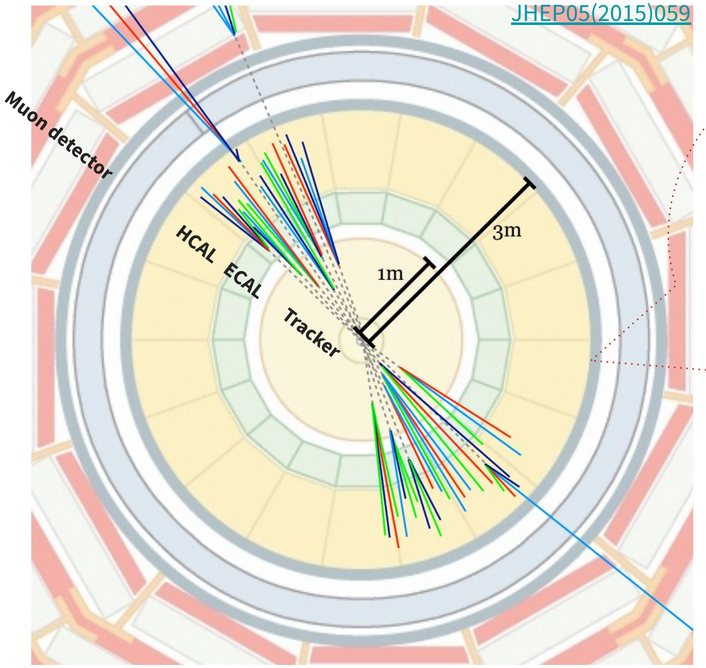
arxiv:2405.00834

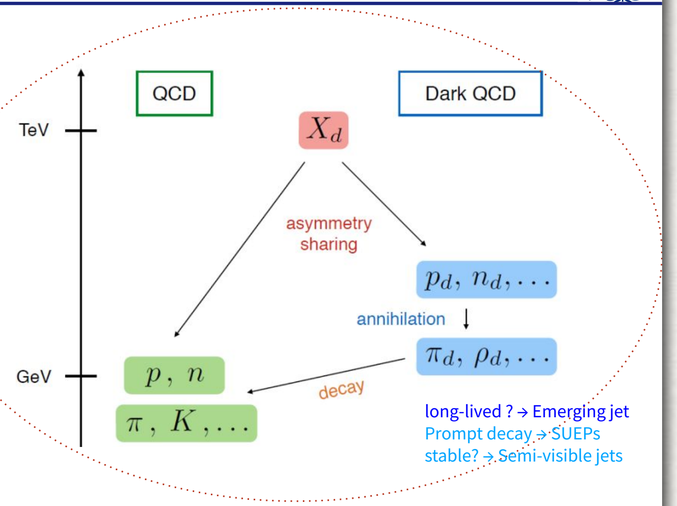






Dark Shower : Emerging Jets

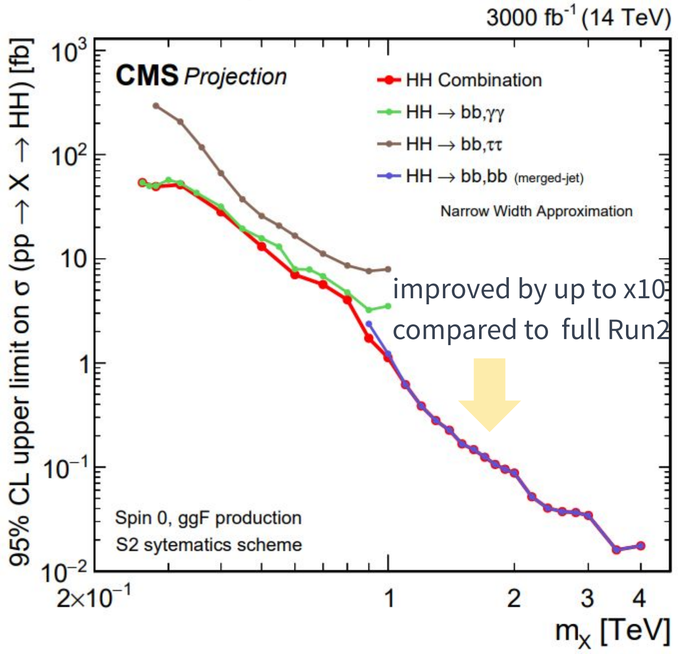


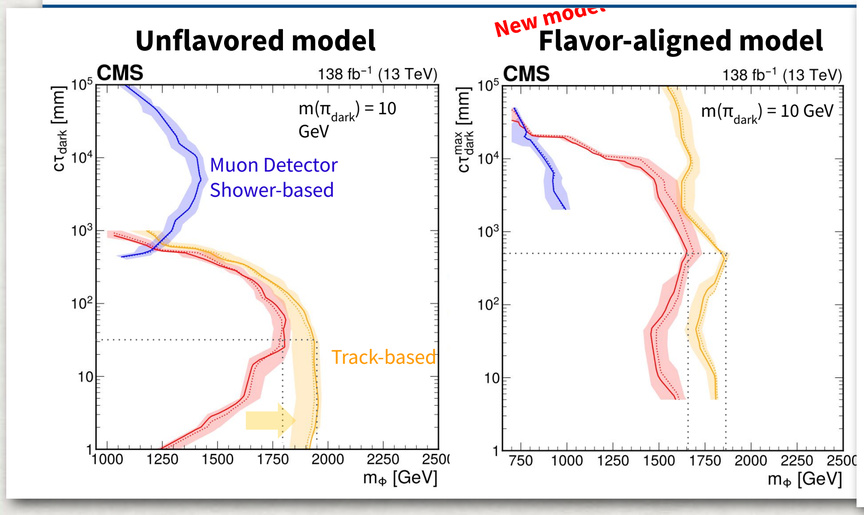


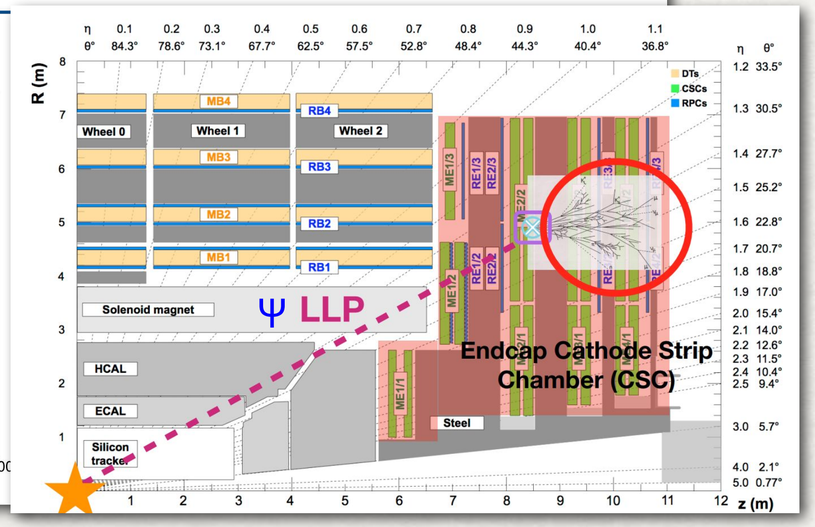
- Unique DM-targeted signatures → Probing **dark QCD within HV model → Dark showers**
- Tracks start near the edge of the tracker, in the ECAL and HCAL, and even in the muon stations.

HL-LHC projection

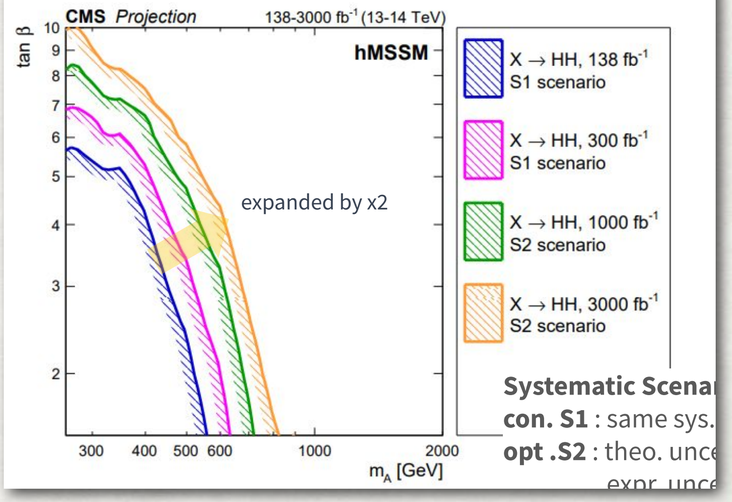
Discovery potential for X →HH







Projection in Benchmark: hMSSM

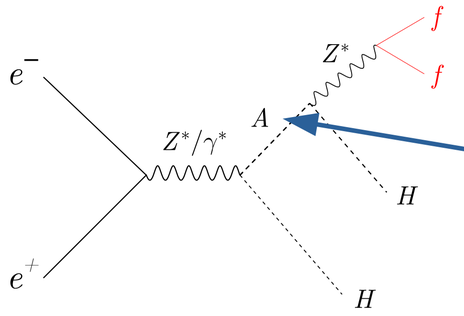


Systematic Scenar
con. S1 : same sys.
opt .S2 : theo. unce
expr. unce

LLP AT ILC

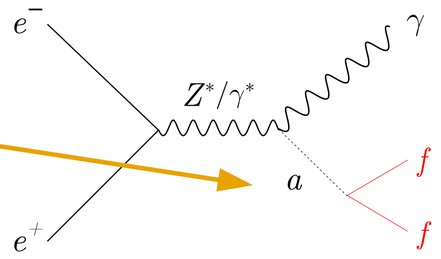
As a challenging case (small boost, low-pT final state) we considered: $\sqrt{s} = 250\,\mathrm{GeV}$

→ heavy scalar LLP (A) and DM (H) pair-production with small mass splitting, $Z^* \to \mu\mu$



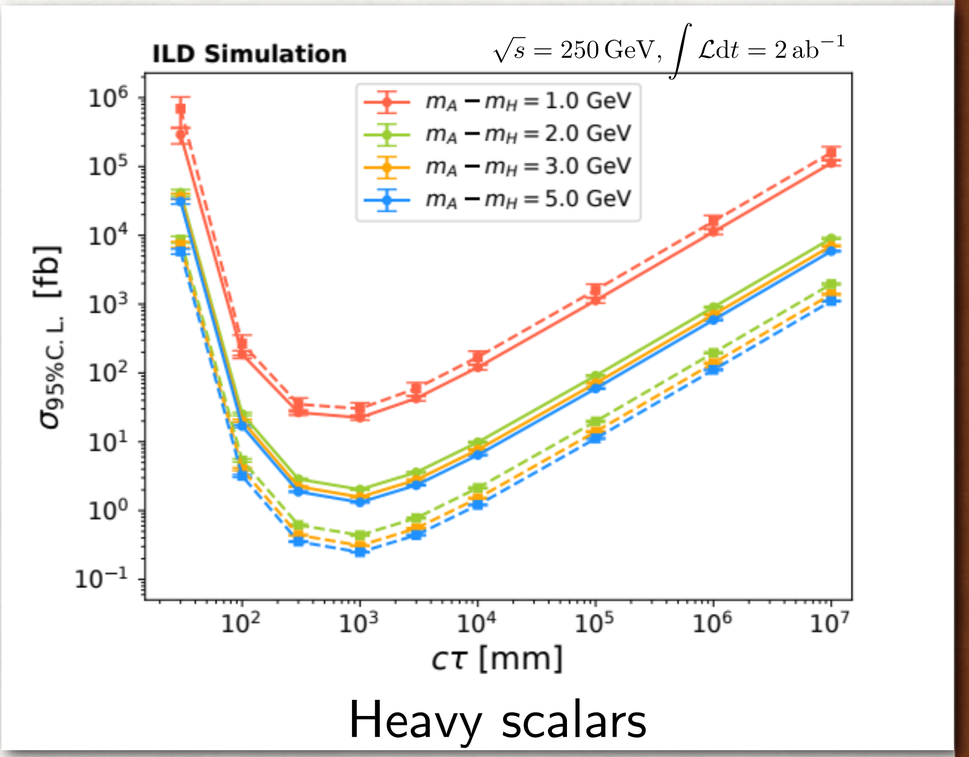
Long-lived, with $c\tau = 1\,\mathrm{m}$
$m_A = 75\,\mathrm{GeV}$
$m_A - m_H = 1, 2, 3, 5\,\mathrm{GeV}$

Long-lived, $c\tau = 10 \cdot m_a\,[\mathrm{mm}]$
$m_a = 0.3,\ 1,\ 3,\ 10\,\mathrm{GeV}$



The opposite extreme case, (large boost, high-pT final state)

→ light pseudoscalar LLP $a \to \mu\mu$

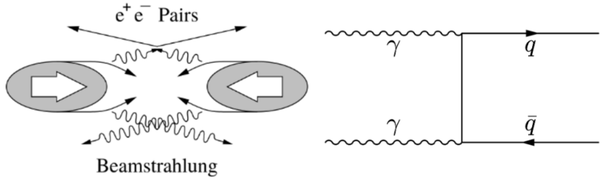


Heavy scalars

Comparison of ILD TPC and all Silicon ILD

At linear e^+e^- colliders beams are strongly focused and radiate photons, so $\gamma\gamma$ interactions also occur in detector. On average, in each bunch-crossing (BXs) at ILC, produced are:

- **1.55 $\gamma\gamma$ → low-p_T hadrons** events
- **O(10^5) incoherent e^+e^- pairs**, only a small fraction enters detector



These events are soft, usually important because they **overlay** on "hard" events

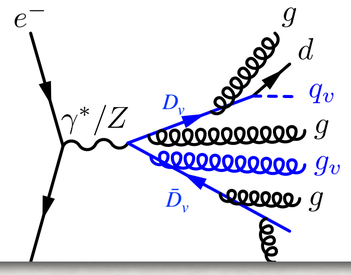
talk by Klamka

DARK QCD

Emanuela Musumeci

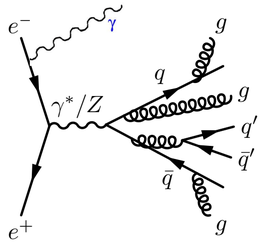
SIGNAL

$e^+e^- \to \gamma^*/Z^0 \to D_V\bar{D}_V \to$ hadrons



BACKGROUND

i) $q\bar{q}$ production with ISR

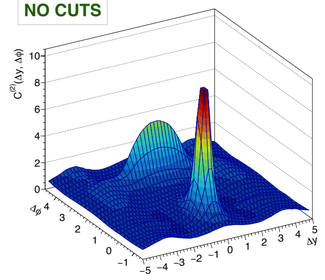


ANALYSIS AT DETECTOR LEVEL

$\sqrt{s} = 250$ GeV, $\mathscr{L} = 2$ ab^{-1}

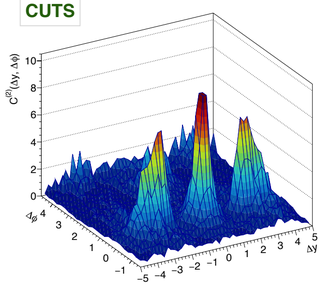
BACKGROUND

Thrust axis — NO CUTS



SM

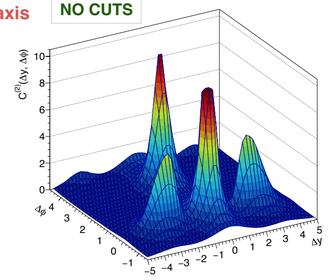
CUTS



SM

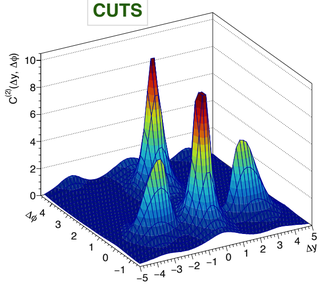
SIGNAL

Thrust axis — NO CUTS



HV (m_{q_v}=100 GeV)

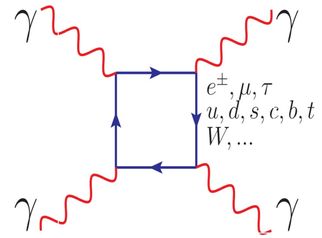
CUTS



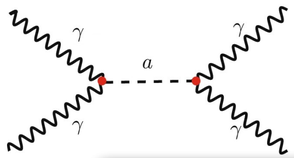
HV (m_{q_v}=100 GeV)

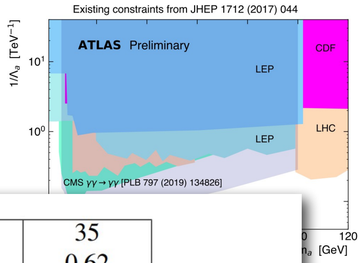
Idea on low energy gamma gamma collider

Light-by-light scattering



- Has been done for a long time [Lifshitz, De Tollis, Karplus, Neuman]
- So far observed by ATLAS
  - most recent results from 2020
- Possibility to observe BSM contributions





$2E_0$	GeV	35
N per bunch	10^{10}	0.62
Collision rate	kHz	13.5
σ_z	μm	70
$\varepsilon_{x,n}/\varepsilon_{y,n}$	mm · mrad	1.4/1.4
β_x/β_y at IP	μm	70/70
σ_x/σ_y at IP	nm	53/53
Laser wavelength λ	μm	0.5
Parameters x and ξ^2		0.65, 0.05
Laser flash energy	J	3
Laser pulse duration	ps	2
f# $\equiv F/D$ of laser system		27
Crossing angle	mrad	~ 30
b (CP–IP distance)	mm	1.8
$\mathcal{L}_{ee,\text{geom}}$	10^{33} cm^{-2}s^{-1}	1.45
$\mathcal{L}_{\gamma\gamma}$ ($z > 0.5z_m$)	10^{33} cm^{-2}s^{-1}	0.19
$W_{\gamma\gamma}$ (peak)	GeV	12

[V. Telnov `20]

SUSY

Tue 09/07

09:00	**Status of BSM searches at ATLAS including some future prospects at HL-LHC**	*Caterina Vernieri*	
	Fukutake Hall		09:00 - 09:25
	"Here be SUSY" - Prospects for SUSY searches at future colliders	*Mikael Berggren*	
	Fukutake Hall		09:25 - 09:45
	Consistent excesses in SUSY searches at the LHC: Physics case for a Linear Collider	*Sven Heinemeyer*	
10:00	*Fukutake Hall*		09:45 - 10:05
	Stau searches at future e+e- colliders	*Mikael Berggren*	
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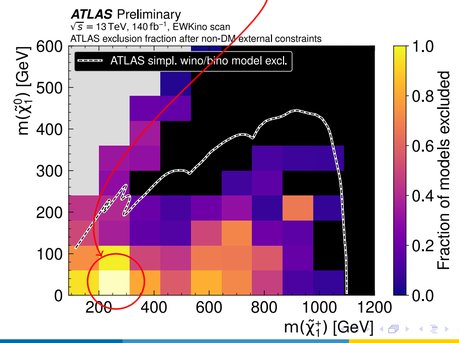
14:00	**Investigating hidden sectors at future e+e- colliders through two-particle angular correlations**	*Emanuela Musumeci*	
	Fukutake Hall		14:00 - 14:20
	Searches for BSM physics at a gamma-gamma collider with Energy < 12 GeV based on European XFEL	*Marten Berger*	
	Fukutake Hall		14:20 - 14:40
	Probing BSM neutral gauge boson in high and low energy experiments	*Arindam Das*	
	Fukutake Hall		14:40 - 15:00
15:00	**Unconventional Searches of Exotic particles at Future Lin**		
	Dr Nilanjana Kumar		
	coffee		

ATLAS

SUSY

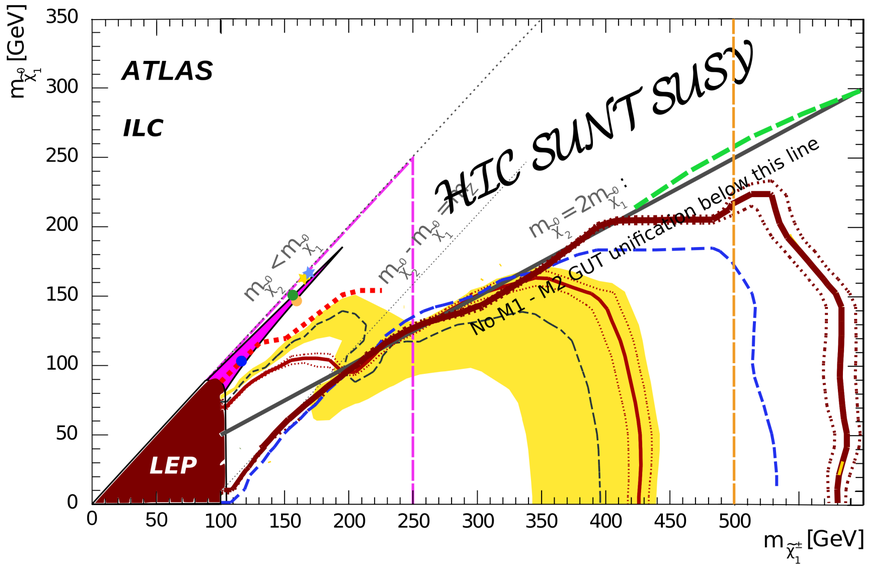
Hot off the press: ATLAS-CONF-2023-055: pMSSM-19 (-7) scan in M_{LSP} vs. $M_{\tilde{\chi}_1^\pm}$

Only this one is actually excluded !



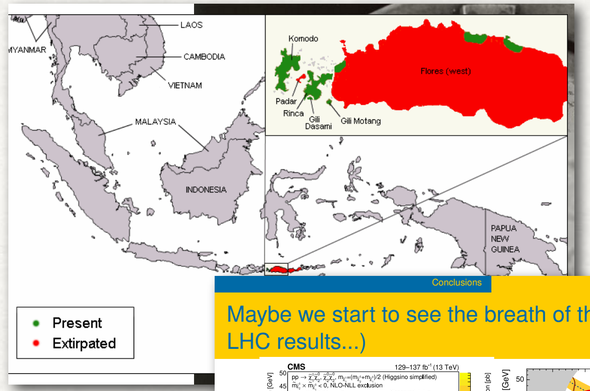
Here be SUSY !

Talk By Berggren

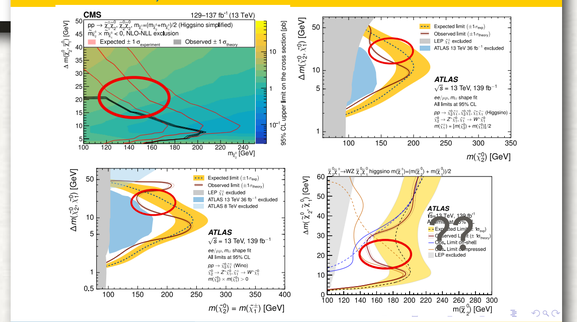


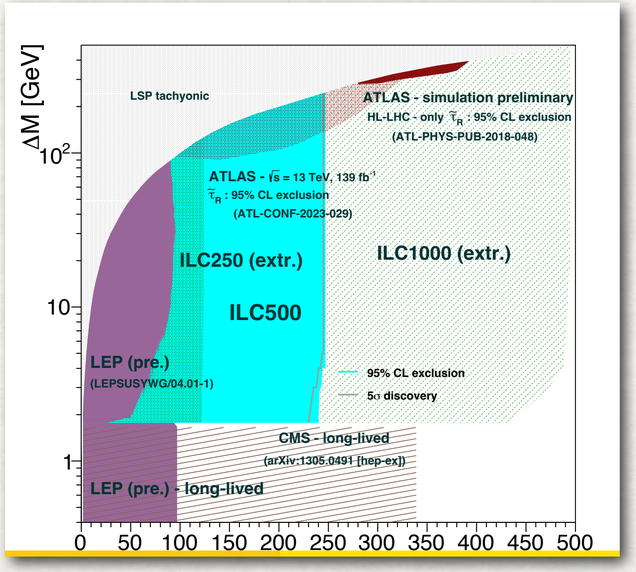
ATLAS Eur Phys J C 78,995 (2018),Phys Rev D 101,052002 (2020),arXix:2106.01676;

ATLAS HL-LHC ATL-PHYS-PUB-2018-048; ILC arXiv:2002.01239; LEP LEP LEPSUSYWG/02-04.1



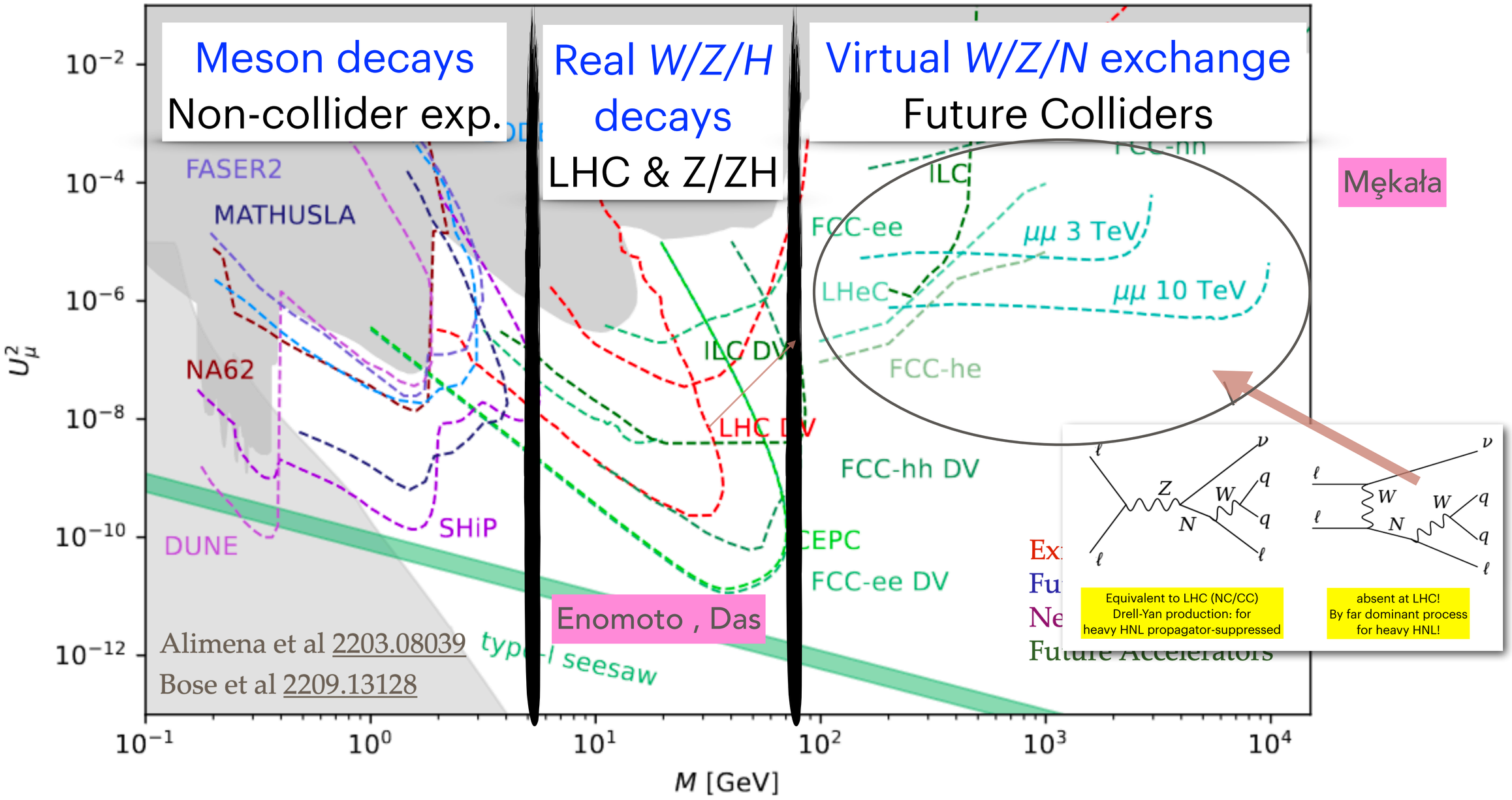
Maybe we start to see the breath of the dragon (latest LHC results...)





Also new ILD study on

Searches for Heavy Neutral Leptons

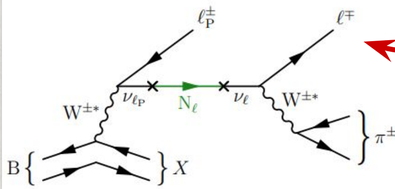


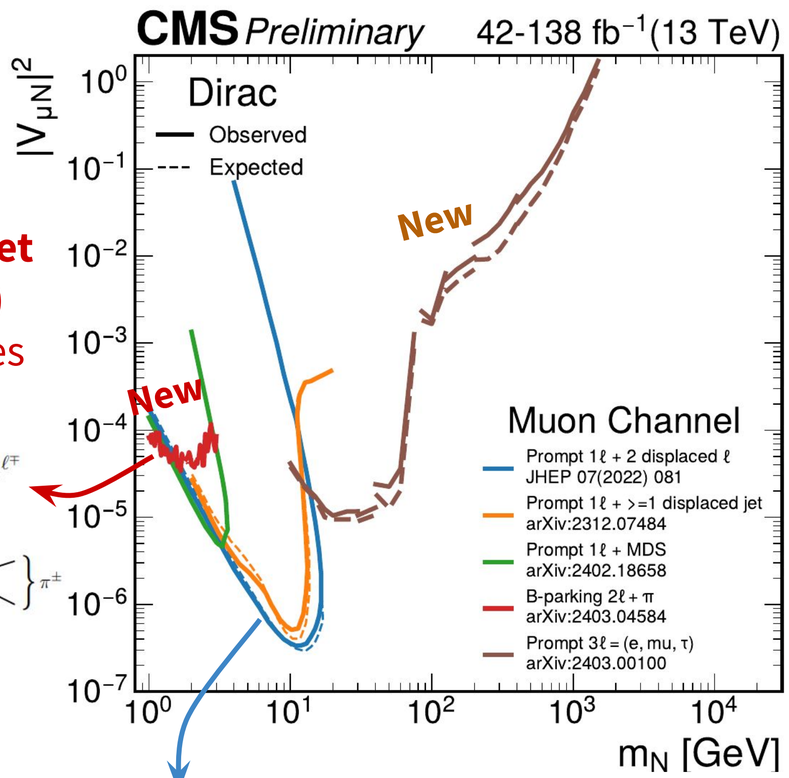
Heavy Neutral Lepton Search in Run-2

2405.17605 : Review of searches for vector-like quarks, vector-like leptons, and heavy neutral leptons at the CMS experiment

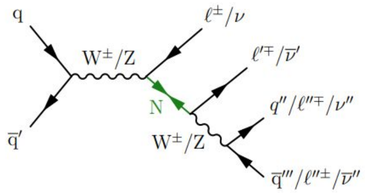
HNL in the Type-I seesaw model

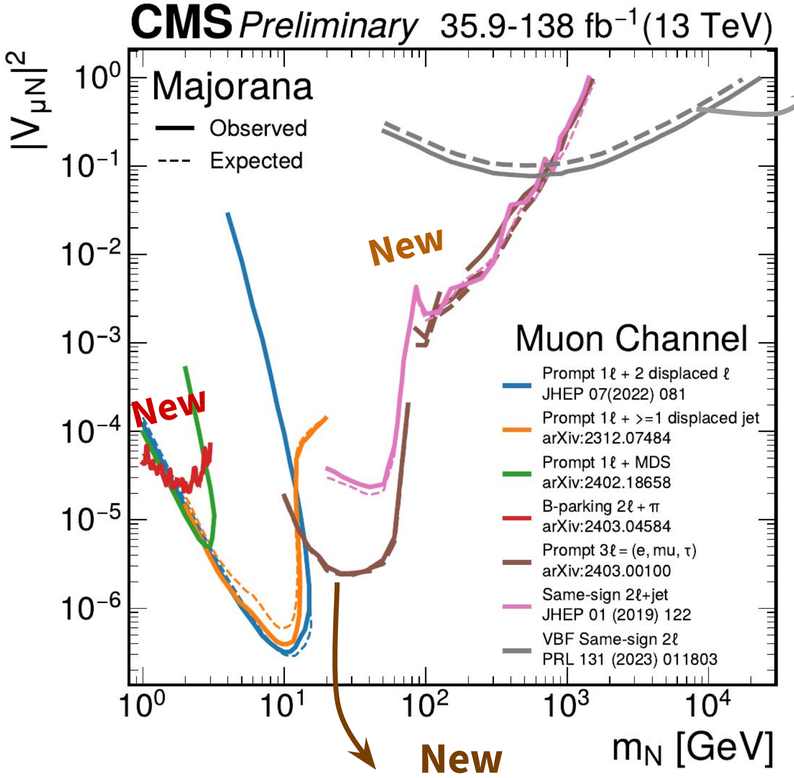
New
B-parking dataset
(10^{10} $b\bar{b}$ events)
displaced vertices
+ π meson





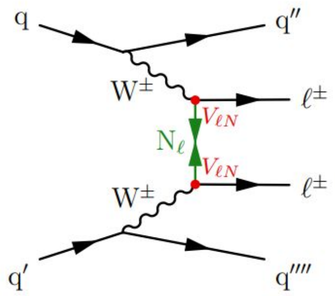
Prompt lepton + displaced dilepton
displaced vertices/jets

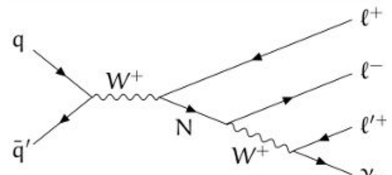




New
Prompt 3 leptons
Same-sign lepton/jet pair

ββ0ν process with VBF
same-sign lepton pair

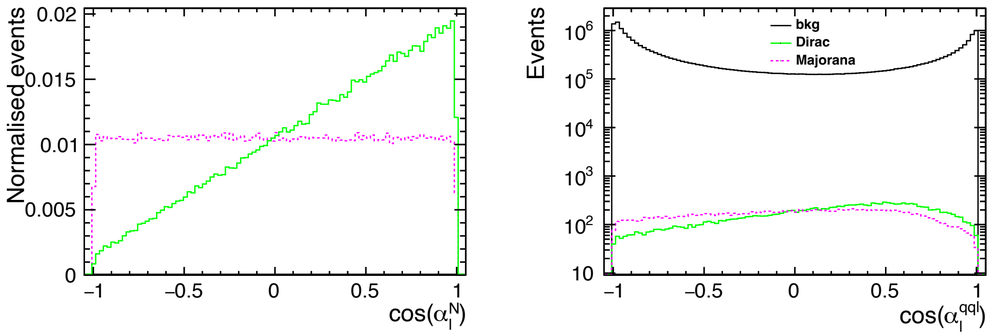




HNL Summary Plot

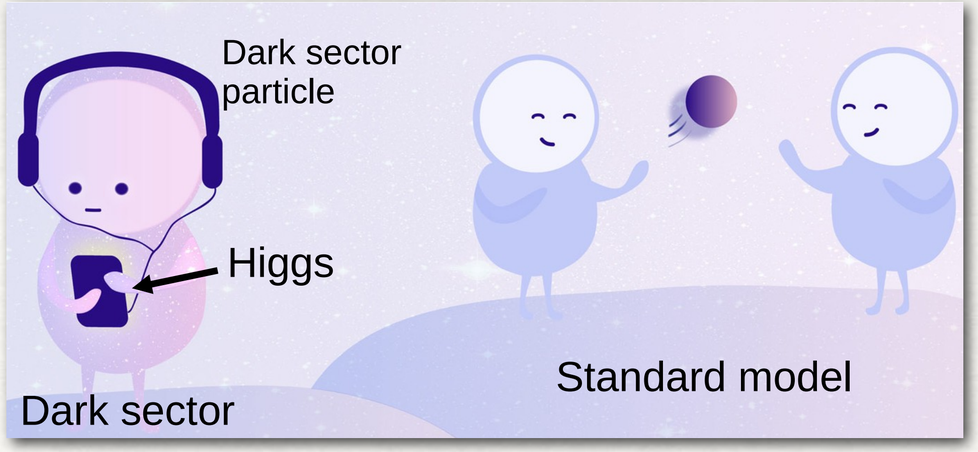
MODEL DISCREMINATION

Lepton emission angle in the N rest frame:



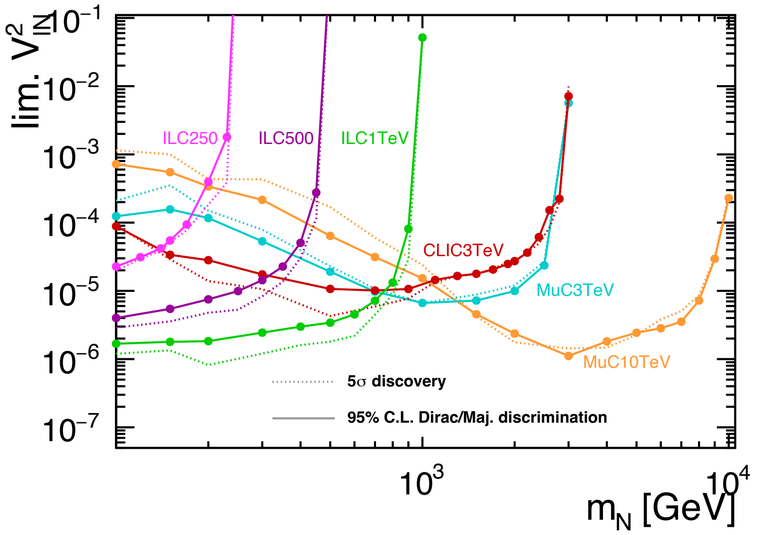
generator vs. detector

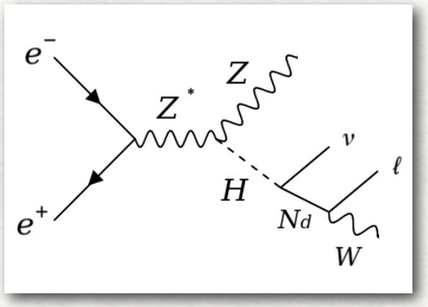
CLIC 3 TeV

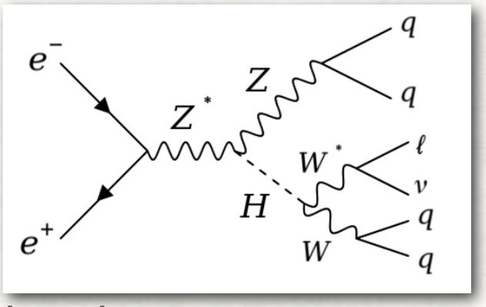


https://www.hep.ucl.ac.uk/~pbolton/#

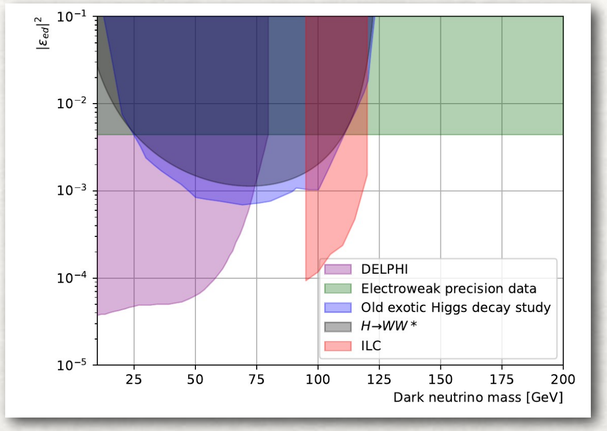
Dirac vs. Majorana – results





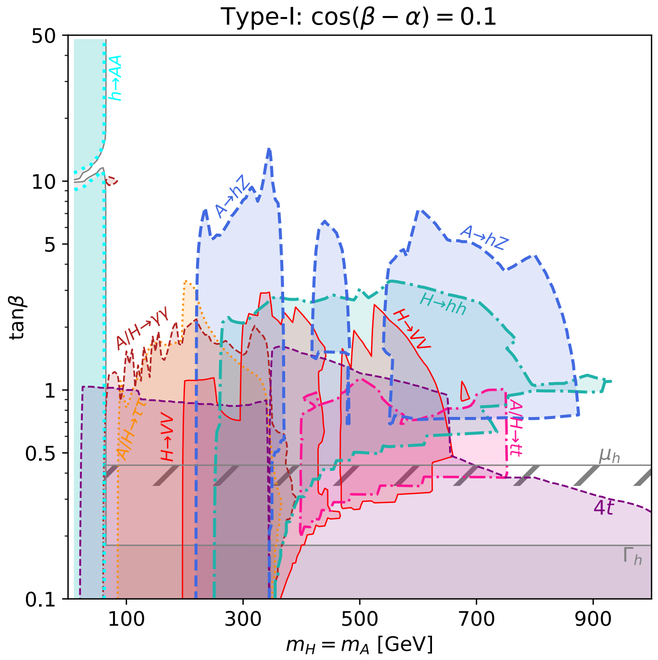


by Thor

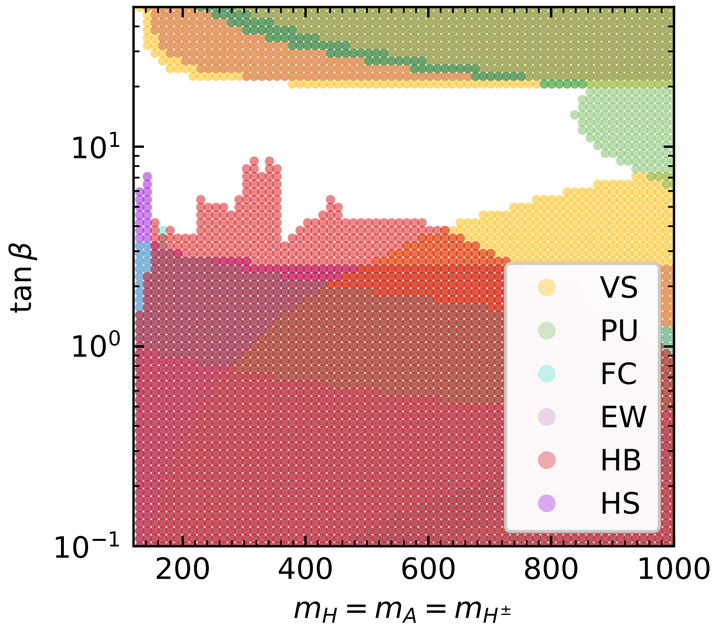


Enomoto: connection to scalar production in radiative see-saw model

2HDM parameter space for fixed $\cos(\beta - \alpha)$



[F. Kling, S. Su, W. Su, JHEP 06 (2020) 163]

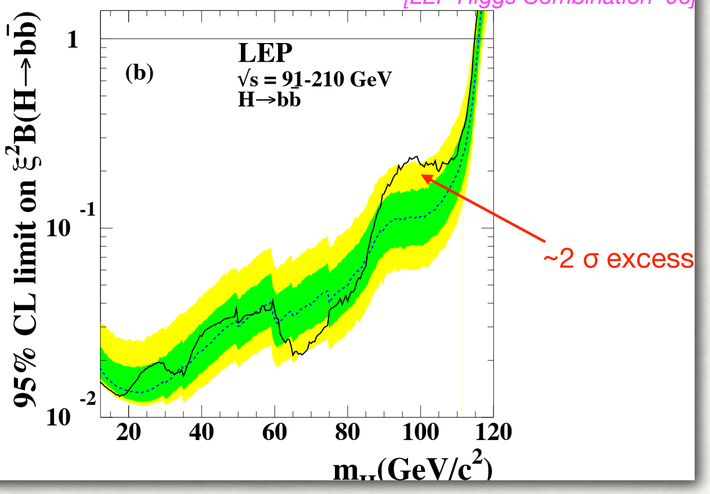


[from thdmtools, thanks to K. Radchenko]

Introduction

Low-mass Higgs searches at LEP, $e^+e^- \to Zh$, $h \to bb$

[LEP Higgs Combination '06]



honestly I do not remember this one…

but I remember this one

The 115 GeV Higgs Odyssey

https://arxiv.org/abs/hep-ex/0011086

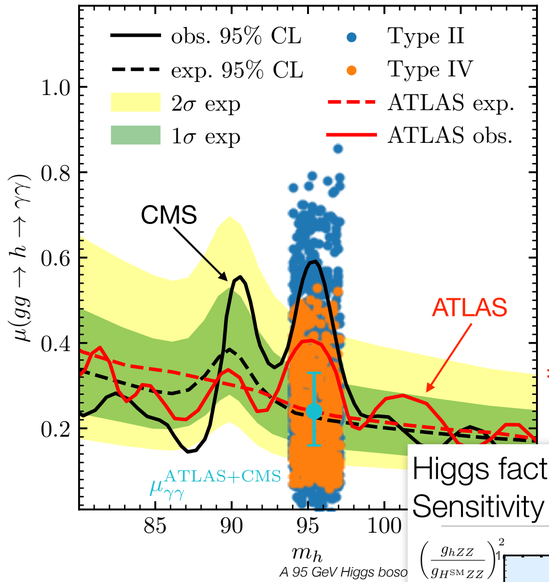
at that time we were planning to start LHC at 2005, but took more than 10 years and John is responsible(^^)

CERN financial crisis , termination of small experiments and R&D, It takes longer than planned always

Renewed interests on light scalers.

LHC: CMS + ATLAS excess in $\gamma\gamma$ channel at 95 GeV, interpretation in 2HDM + singlet (S2HDM)

CMS + ATLAS excess in $\gamma\gamma$ channel at 95 GeV:



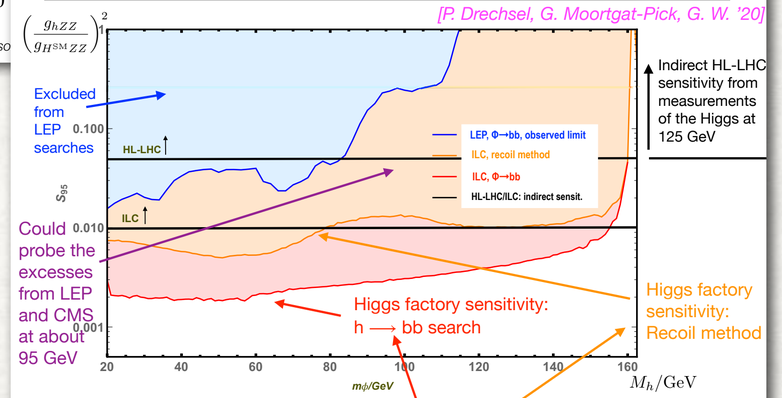
[T. Biekötter, S. Heinemeyer, G. W. '23]

Example interpretation: S2HDM, type II and IV

⇒Good description in extended Higgs sectors with an

Higgs factory: discovery potential for a low-mass Higgs; Sensitivity at 250 GeV with 500 fb^{-1}

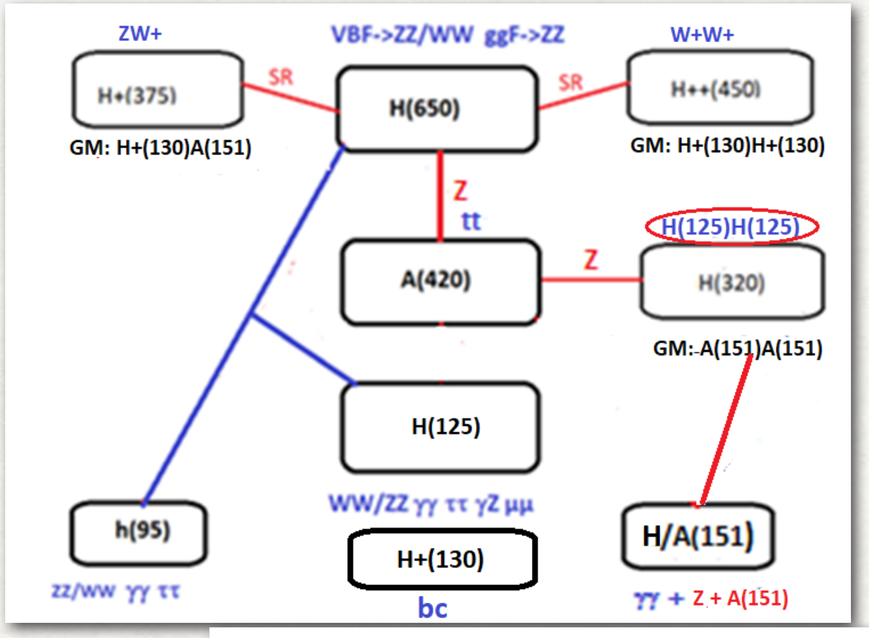
[P. Drechsel, G. Moortgat-Pick, G. W. '20]



⇒ Higgs factory at 250 GeV will explore a large untested region!

KEEP GOING ON

Richard



H(650) for example

Steps	Mode	Origin	Local sd	Remark	Globa
0	ZZ->4ℓ	ATLAS+CMS from [7]	3.8	ATLAS+CMS 113.5 fb-1 Defines mass & width	2.8
1	ZZ->4ℓ	From ATLAS	3.5	From histogram	3.5
2	WW->ℓνℓν	From CMS	3.8	Official statement	5
3	h(95)h(125)->bbγγ	From CMS	3.8	Official statement	6.1

GM	Isosinglet	h95	h125
	Isotriplet	A151->γγ	H+130->bc
	Isofiveplet	H320->hh	H+375->ZW+ H++450->W+W+
GM +1 isodoublet		A420->ZH320	H650 H+->ttW ?

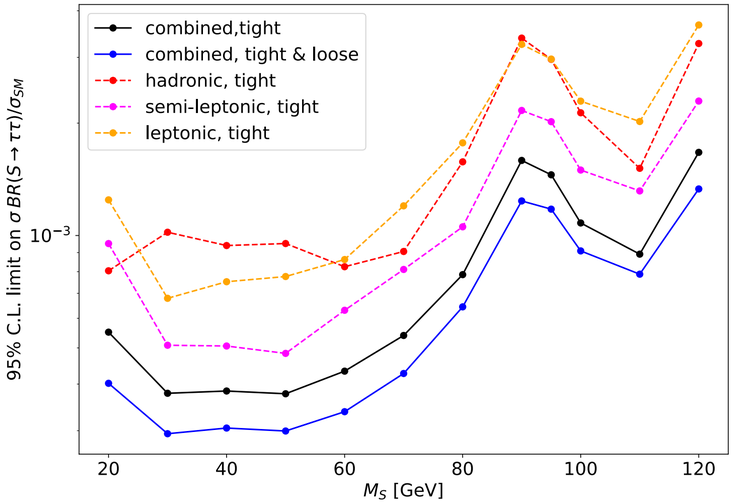
prediction of H++ and H+ in context of Georgi Machachek model

Report from ECFA ILC study Zarnecki

$S \to \tau^+\tau^-$

Results

Cross section limits for $\sigma(e^+e^- \to Z\,S) \cdot BR(S \to \tau\tau)$
for different event categories and combined analysis



Semi-leptonic sample most sensiti
new scalar production

Significant improvement when
including loose-selection categorie

Global EFT fits for future Lepton collider (Elini Vryonidou)

gauge Higgs unification from e+e- forward backward asymmetry (Adrian Irles)

double tagged sample

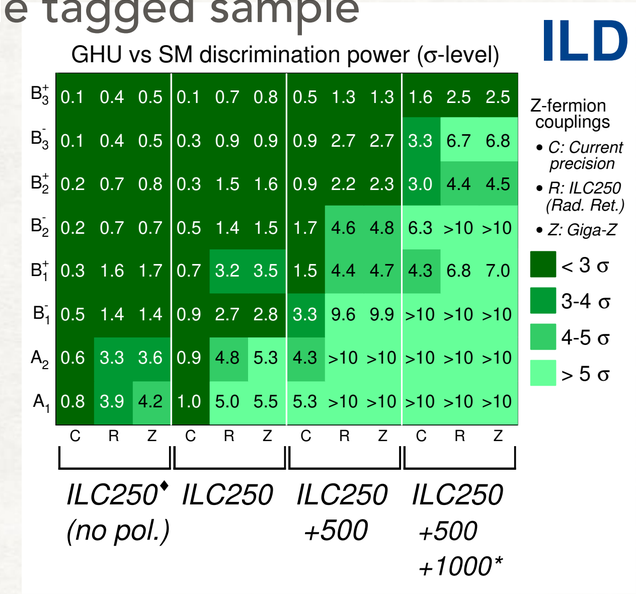
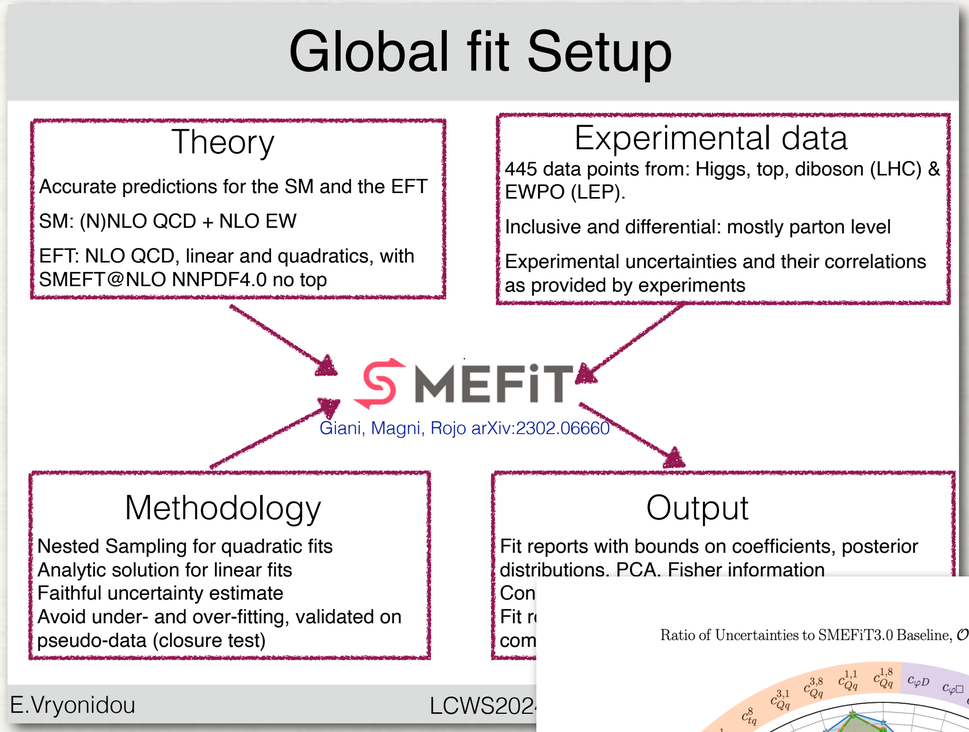
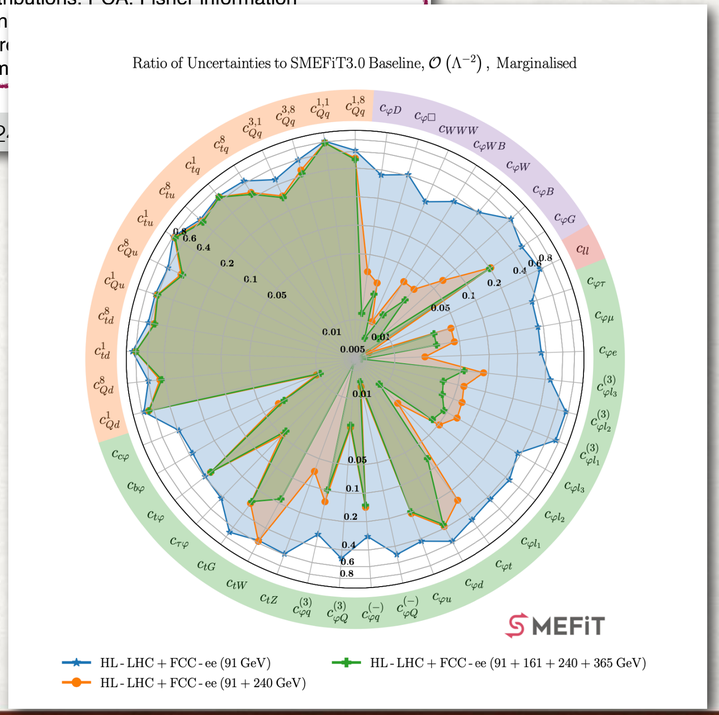


Fig. 4. Statistical discrimination power between the GHU mod-





- We are required to **measure the jet charge**
  - Using K-ID and/or full Vtx charge measurement
  - K-ID is better suited for the C-quark (Vtx is better suited for b-quark)

- K-ID: via TPC (dEdx or dNdx)

SMEFT AND DEVELOPMENT IN MC

Feynman-Diagram (FD) gauge

- Weak bosons are 5-components $W^{\pm}_M=(W^{\pm}_\mu,\pi^{\pm})$, unlike in R_ξ gauge, EOM mixes $W^{\pm}_\mu$ and $\pi^{\pm}$
- FD gauge propagator $n(q)^\mu_{\rm FD} = (\mathrm{sgn}(q^0), -\vec{q}/|\vec{q}|)$

$$G_{MN}(q) = \frac{i}{q^2 - m^2 + i\epsilon}\begin{pmatrix} -g_{\mu\nu} + \dfrac{q_\mu n_\nu + n_\mu q_\nu}{n\cdot q} & i\dfrac{m n_\mu}{n\cdot q} \\ -i\dfrac{m n_\nu}{n\cdot q} & 1 \end{pmatrix} \qquad M, N = 0 \text{ to } 4,$$

- Helicity ±1 states don't mix with the Goldstone boson. Helicity 0 state is a mixture of

$$-\frac{Q\, n^\mu}{n\cdot q} = \epsilon^\mu(q, h=0) - \frac{q^\mu}{Q}, \quad Q = \sqrt{|q^2|}$$

and the Goldstone boson.

- Because the Goldstone bosons are parts of the physical weak boson, all Goldstone boson vertices contribute to the scattering amplitudes in the FD gauge

[1] Kaoru Hagiwara, Junichi Kanzaki and Kentarou Mawatari, 'QED and QCD helicity amplitudes in Parton-shower gauge.' Eur.Phys.J.C 80(2020) 6, 584
[2] Junmou Chen, Kaoru Hagiwara, Junichi Kanzaki and Kentarou Mawatari, 'Helicity amplitudes without gauge cancellation for electroweak processes'Eur.Phys.J.C 83 (202
[3] Junmou Chen, Kaoru Hagiwara, Junichi Kanzaki, Kentarou Mawatari and Ya-Juan Zheng, 'Helicity amplitudes in light-cone and Feynman-diagram gauges'Eur.Phys.J.Plu

Ya-Juan Znhen's talk

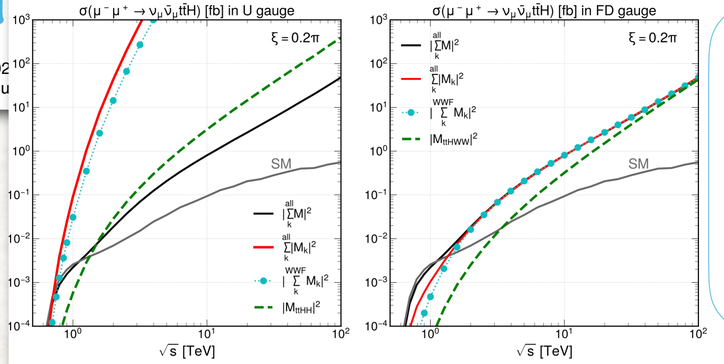
New FD gauge helps to reduce computational time and improve neumerical stability

SMEFT → bad behavior of amplitude

$$\mathcal{L}_{ttH} = -gH\bar{t}(\cos\xi + i\gamma_5 \sin\xi)t$$

$$\mathcal{L}^{\rm SMEFT}_{ttHH} = \frac{3(g_{\rm SM} - ge^{i\xi})}{v}\frac{H^2}{2}t^\dagger_L t_R + \text{h.c.}$$

FD gauge

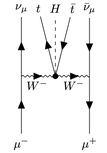


(a) (b)

- In this process, e.g.

$$\frac{g_{\rm SM} - ge^{i\xi}}{v^2}\pi^+\pi^- H t^\dagger_L t_R + \text{h.c.}$$

contributes as



and dominates the total cross section because of its dim-6 property.

Automatic generation of FD gauge is available in Madgraph by command 'set gauge FD'.

Thank you very much for everybody who had a single nice summary slide with a plot and all important things