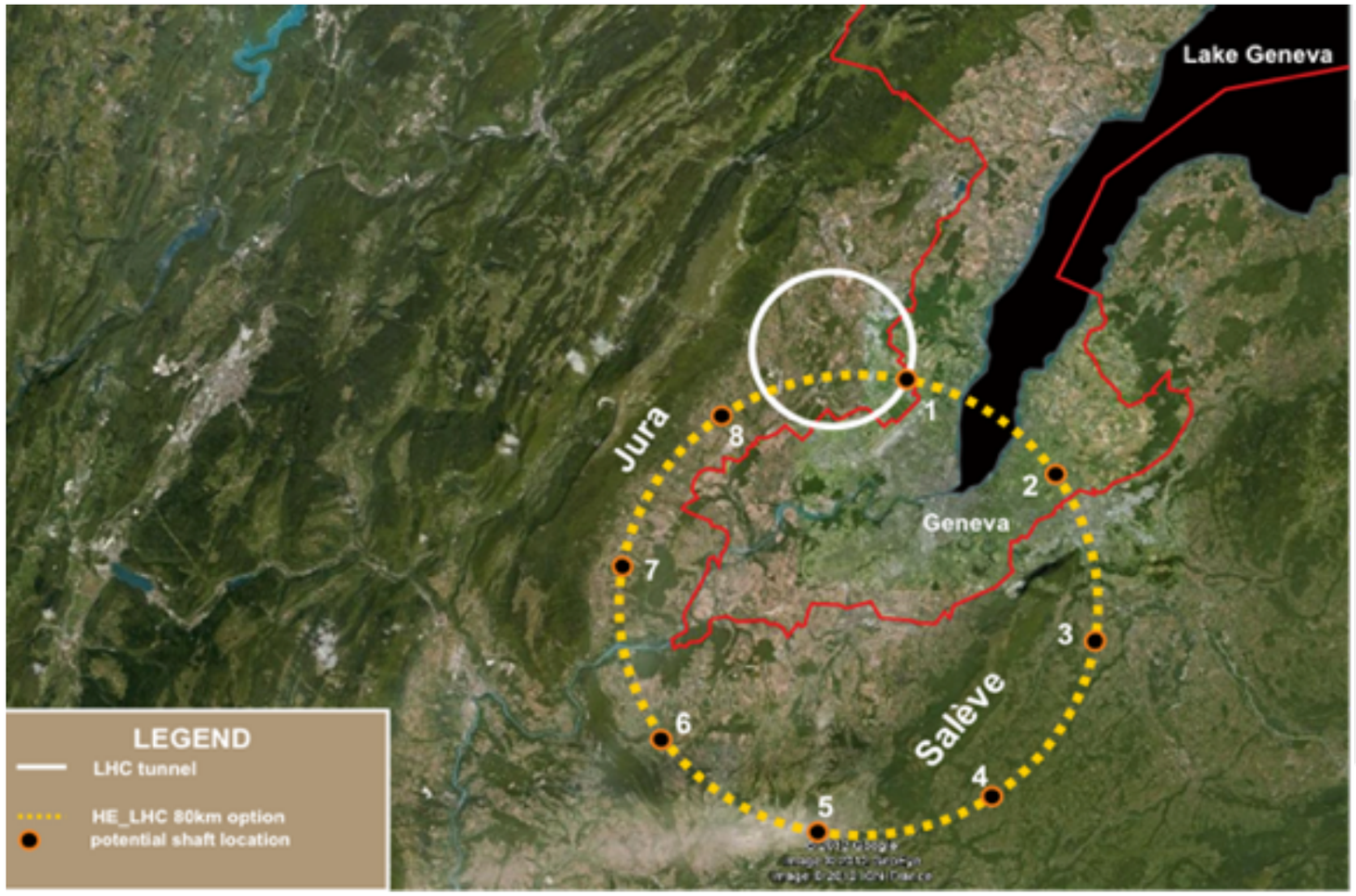
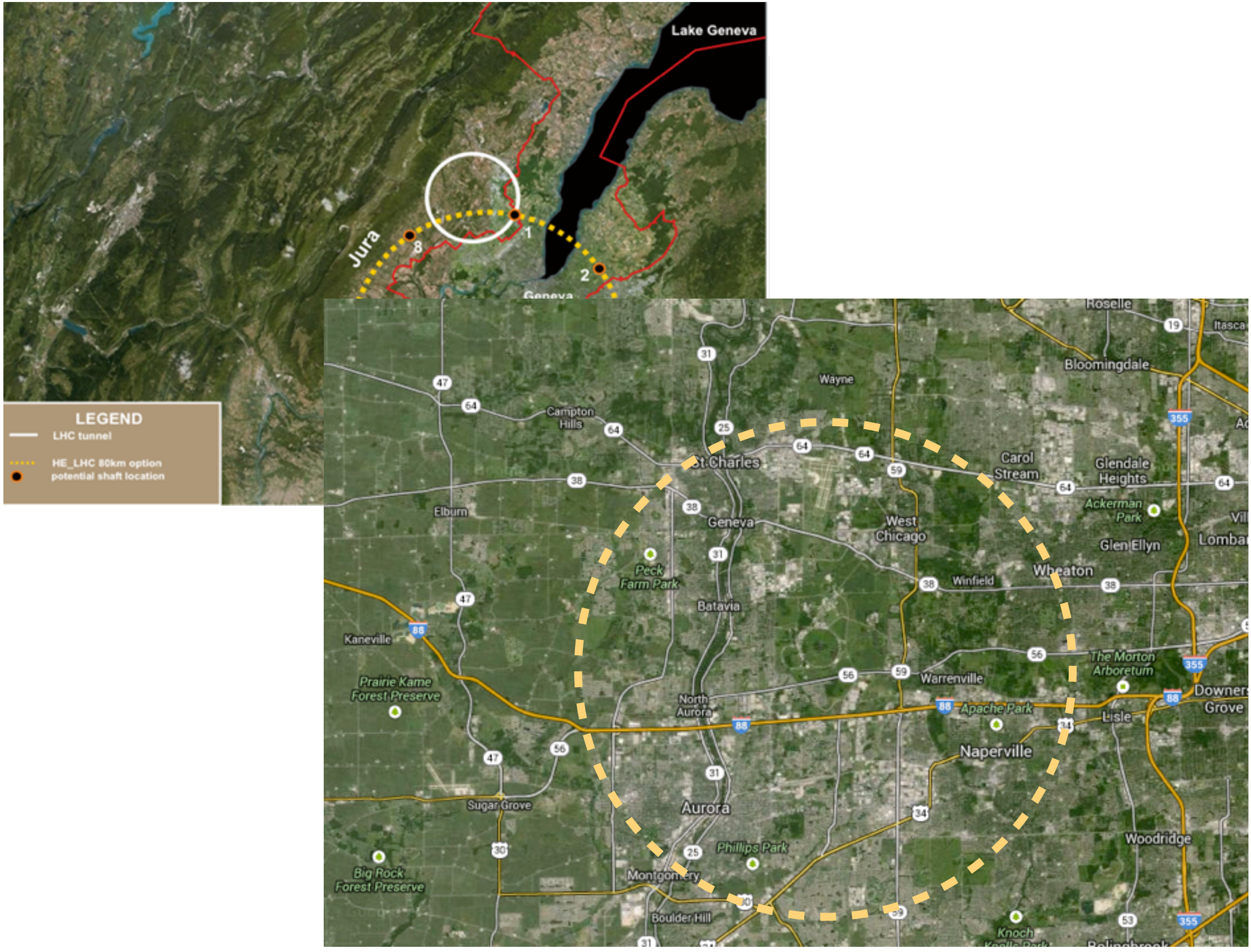
New Physics Models at TLEP

Patrick Fox

Fermilab


Lake Geneva
Jura
Geneva
Salève
1
2
3
4
5
6
7
8
LEGEND
LHC tunnel
HE_LHC 80km option
potential shaft location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Roselle
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Glendale Heights
Ackerman Park
Glen Ellyn
Wheaton
Winfield
West Chicago
Elburn
Geneva
Peck Farm Park
Batavia
Kaneville
Prairie Kane Forest Preserve
North Aurora
Warrenville
The Morton Arboretum
Apache Park
Lisle
Naperville
Sugar Grove
Aurora
Phillips Park
Montgomery
Boulder Hill
Big Rock Forest Preserve
Woodridge
Knoch Knolls Park
Bolingbrook
Downers Grove

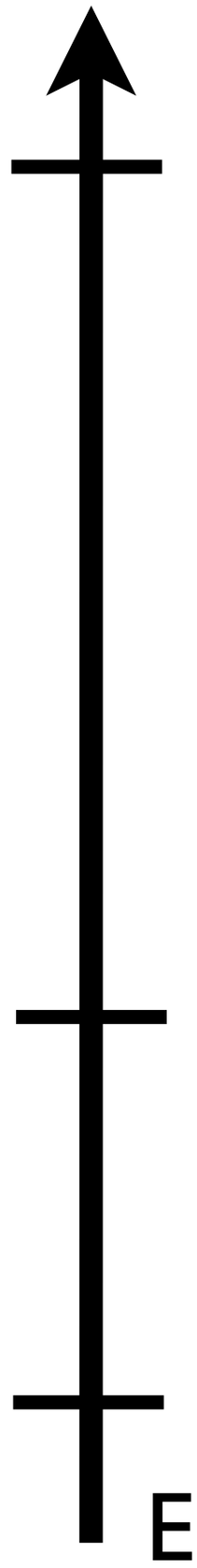
Prediction is difficult, especially about the future

-Neils Bohr

LHC: a pp machine going to 14 TeV,
L~300-3000/fb

TLEP: a e^+e^- machine going to ~350 GeV,
L~100-1000/fb

LEP: a e^+e^- machine going to ~200 GeV,
L~10-100/pb



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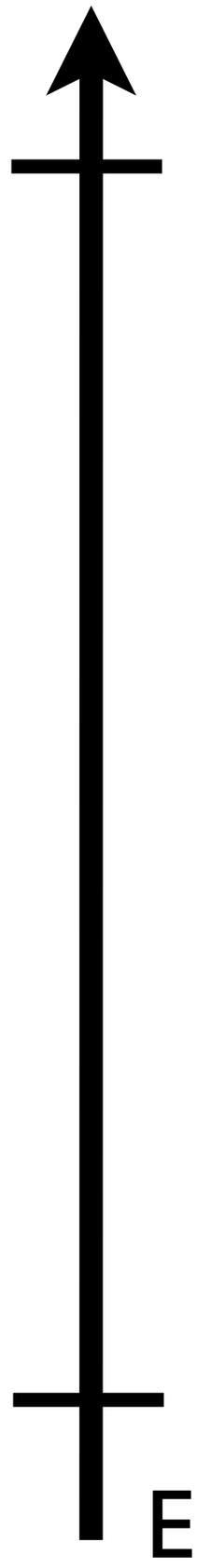

TLEP: a e^+e^- machine going to ~350 GeV,
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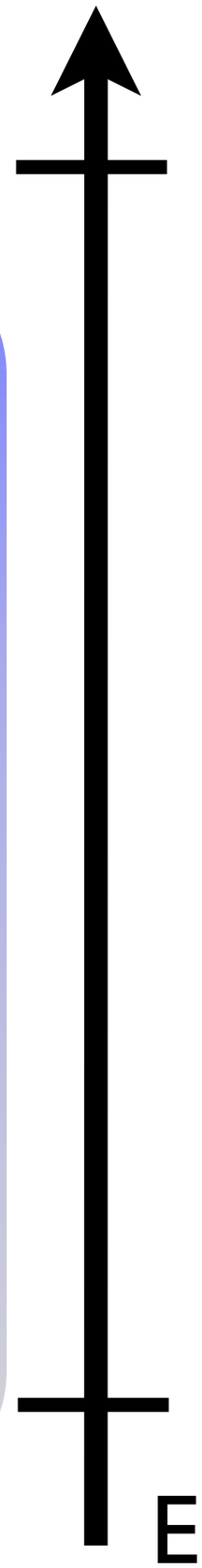
New Physics opportunities

- Physics hard to see at the LHC
- Physics that couples to electrons
- 200 GeV < M < 350 GeV
- M< 250 GeV, but weakly coupled
- Channels LEP was unable or unwilling to look in *

LEP: a e^+e^- machine going to ~200 GeV,
L~10-100/pb



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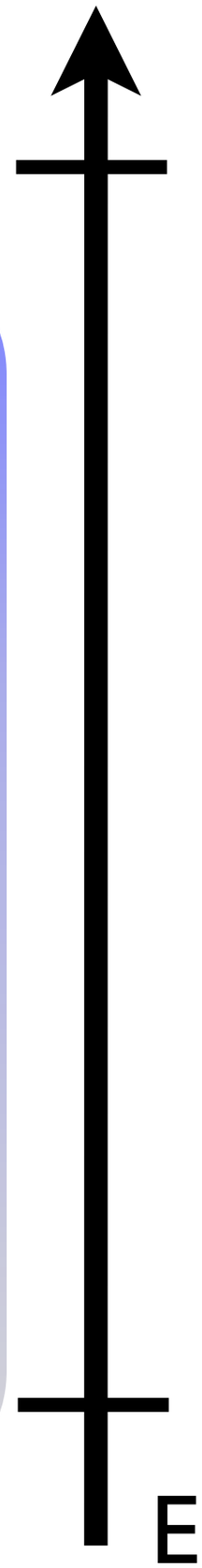


*this would be embarrassing

Couplings

New states coupled only to leptons

Direct constraints from LEP
Indirect constraints from precision leptonic observables

$$\Delta(g-2)_l \sim \frac{g_l^2}{4\pi^2}\frac{m_l^2}{M_U^2} \qquad \Delta(g-2)_\ell \lesssim \begin{cases} 10^{-11} & e \\ 10^{-9} & \mu \\ 10^{-2} & \tau \end{cases}$$

Plenty of room for something new

Z', extra Higgses, dark sector, neutrino sector

Z'

Easy to add a new $U(1)'$

Introduce a new vector and a Higgs: Z', ϕ

Couplings to SM fields?

Flavour universal couplings: anomalies, new heavy chiral fermions, non-standard representations

Flavour non-universal couplings: complicates Yukawa textures, makes some couplings non-renormalizable, forbids CKM entries

Effective Z' approach

Leave the SM as intact as possible

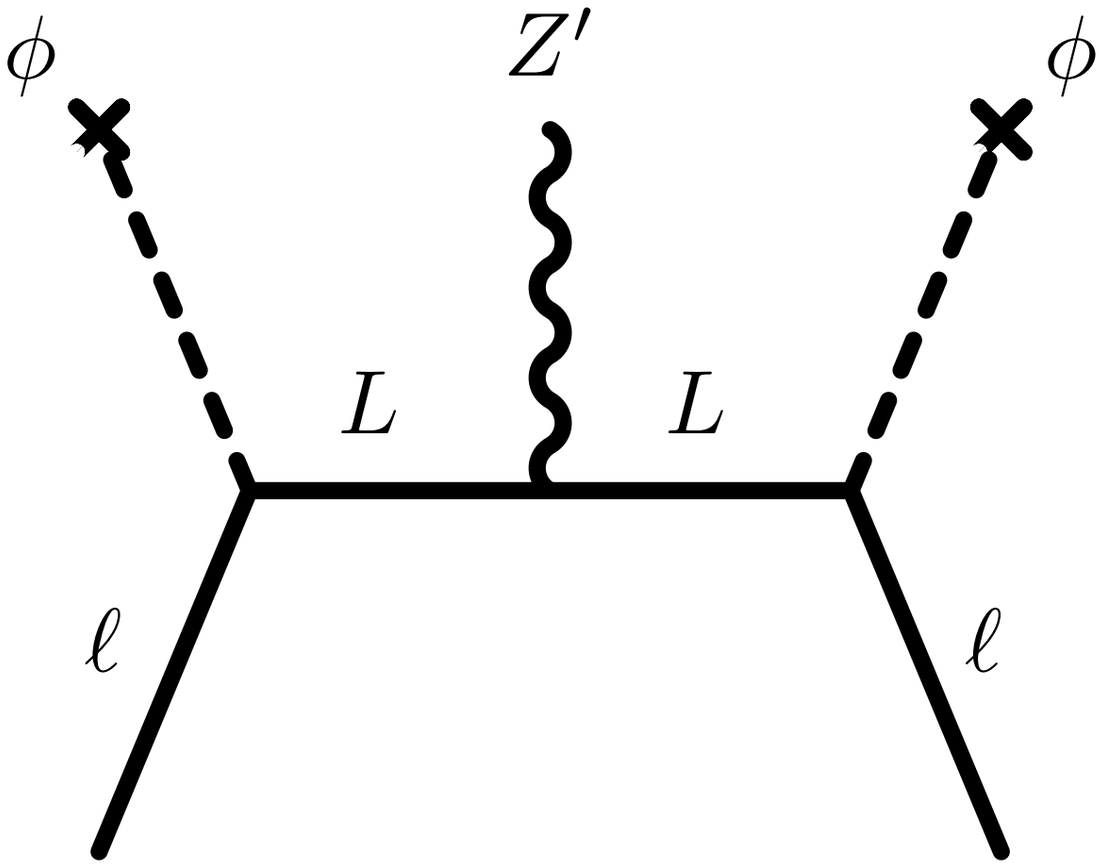
$$\mathcal{L} = \mathcal{L}_{SM} + \mathcal{L}_{Z',\phi} + \mathcal{L}_{\text{higher dim.}} - \lambda|H|^2|\phi|^2$$

$$\frac{c^i_j}{M^2}(\bar{q}_i\gamma^\mu q^j)(\phi^* D_\mu \phi) \supset g' \frac{c^i_j}{M^2}(\bar{q}_i\gamma^\mu q^j)(\phi^* Z'_\mu \phi)$$

SM "effectively" charged under $U(1)'$

Effective Z' approach

Only add vector-like matter in SM reps.
Which reps. determine which ϕ-kawa allowed



- Effective coupling $g_{eff} \leq g'$
- Only one linear combination SM leptons mix with ℓ. Rank of c^i_j determined by # of L
- Heavy leptons predicted at scale $\lesssim 4\pi M_{Z'}/g_{eff}$

$$M_L = \frac{\lambda/\sqrt{2}}{g' \sin\theta} M_{Z'} = \frac{\lambda/\sqrt{2}}{\sqrt{g' g_{eff}}} M_{Z'}$$

(Toy) UV Model

$$\mathcal{L} \supset -\mu Q Q^c - y\phi q Q^c$$

New "ϕ-kawa" coupling mixes states

$$\sin\theta = \frac{y\langle\phi\rangle}{\sqrt{\mu^2 + y^2\langle\phi\rangle^2}}$$

$$\tilde{Q} = \cos\theta Q + \sin\theta q \qquad \tilde{q} = -\sin\theta Q + \cos\theta q$$

Generates effective Z' coupling for SM quark

$$\bar{Q}\not{D}Q \supset \underbrace{g' \sin^2\theta}_{g_{eff}} Z'_\mu \bar{\tilde{q}}\gamma^\mu \tilde{q}$$

(Toy) UV Model

heavy quark, -1

SM quark, 0

$$\mathcal{L} \supset -\mu Q Q^c - y\phi q Q^c$$

heavy quark, +1

breaks U(1)', +1

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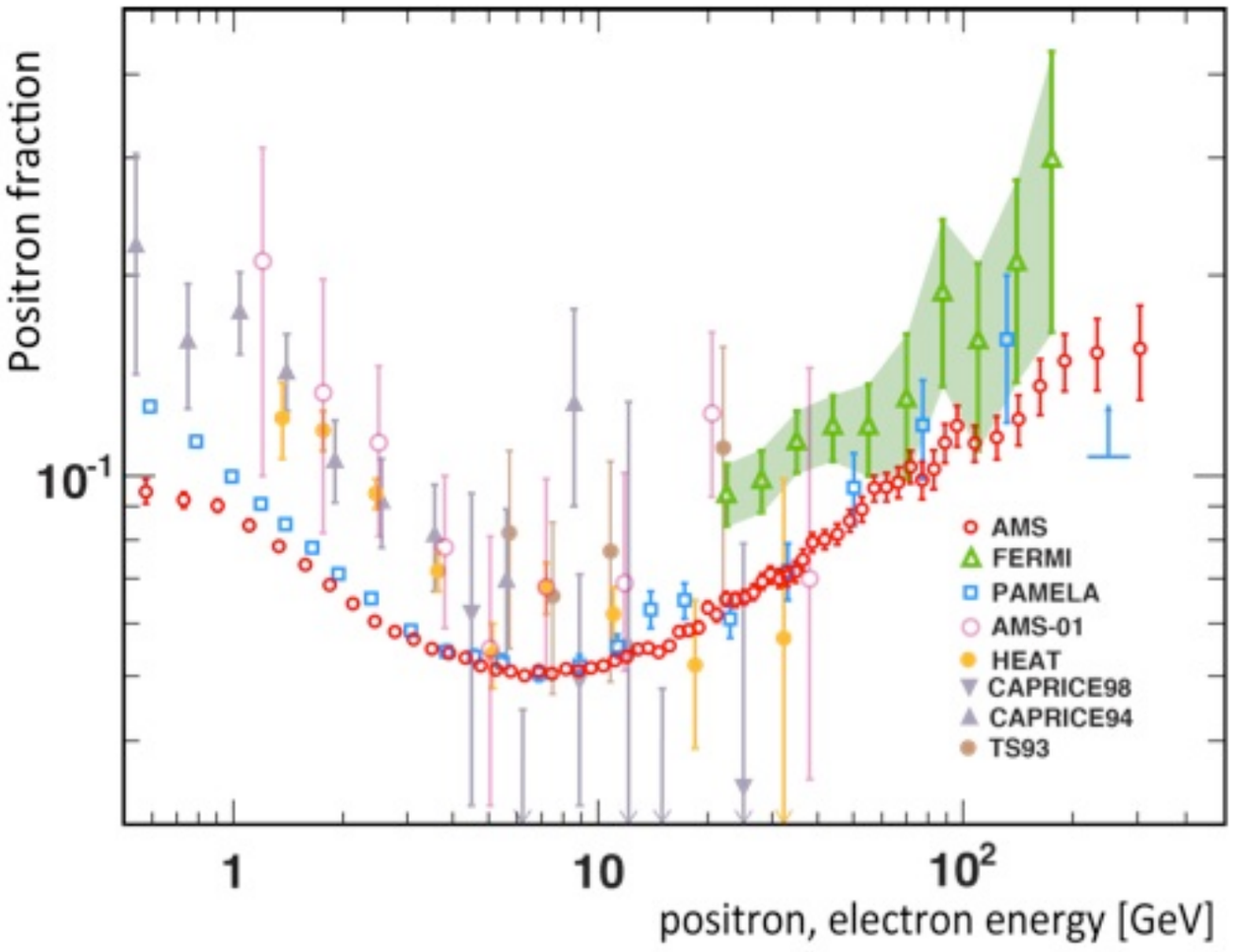
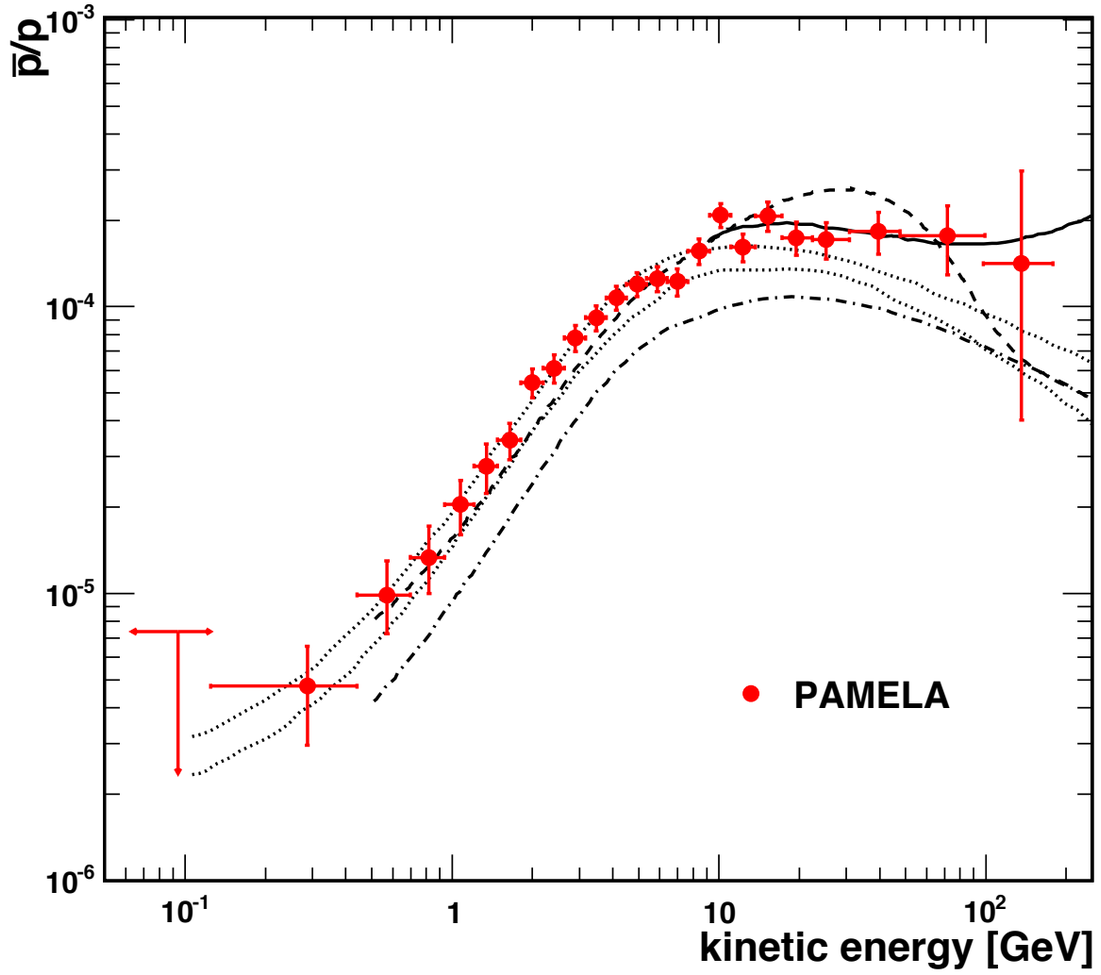
Astrophysics anomalies





Positron excess but no antiproton excess

Kinematics--light mediators?
or dynamics-- leptophilic DM?

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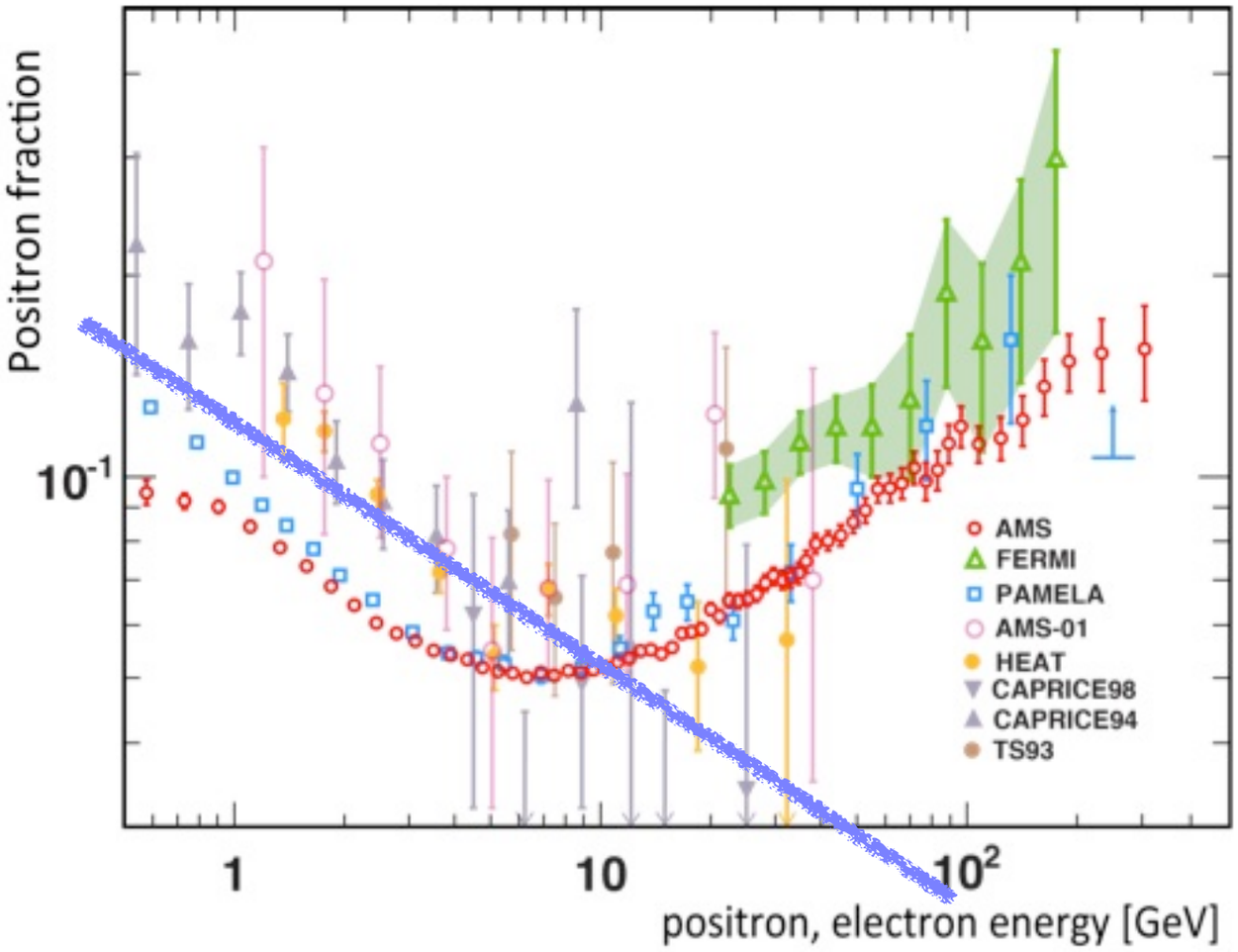

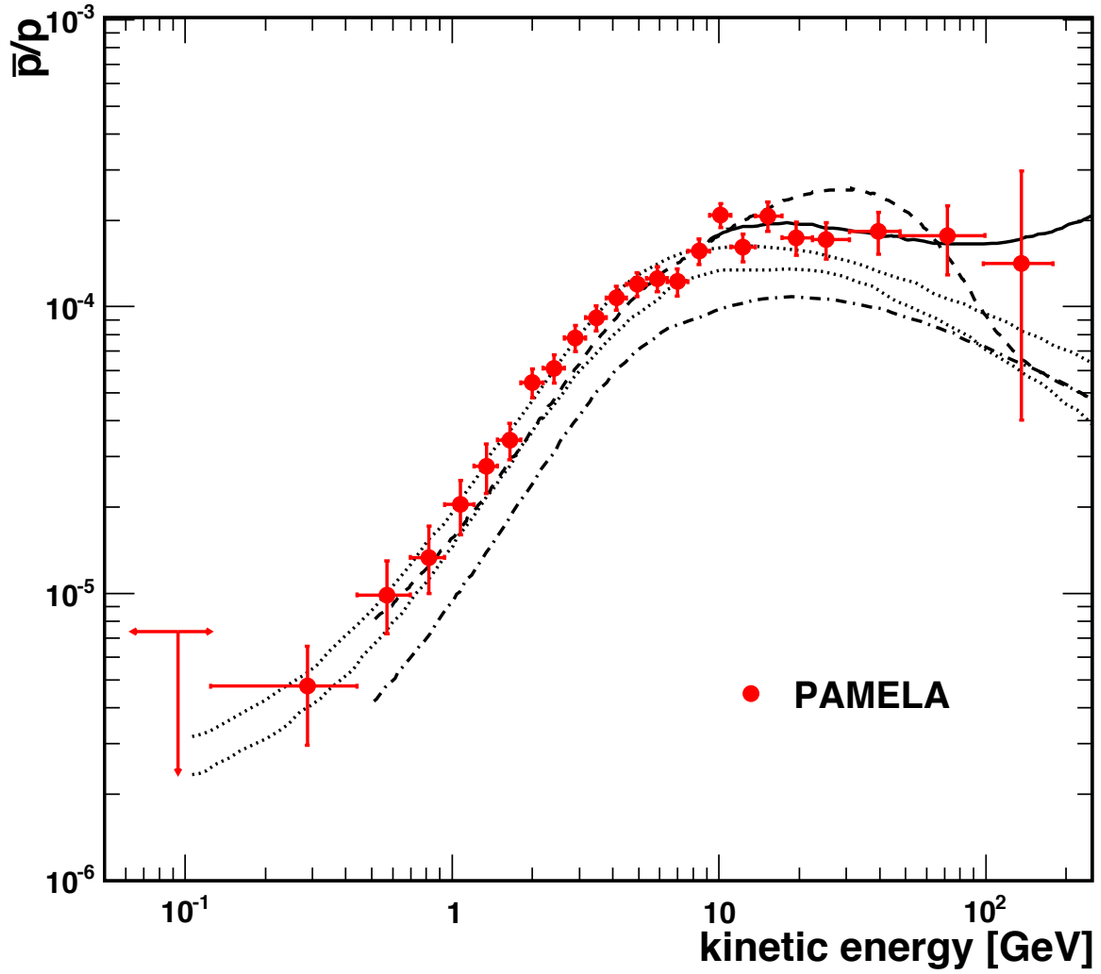

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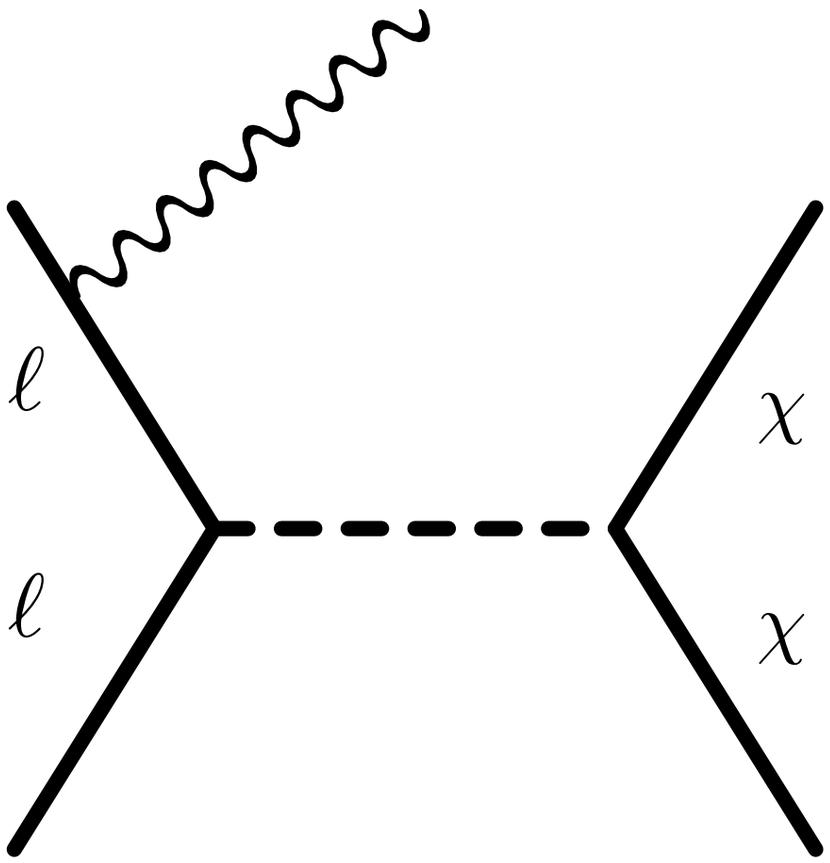
Collider bounds on leptophilic DM

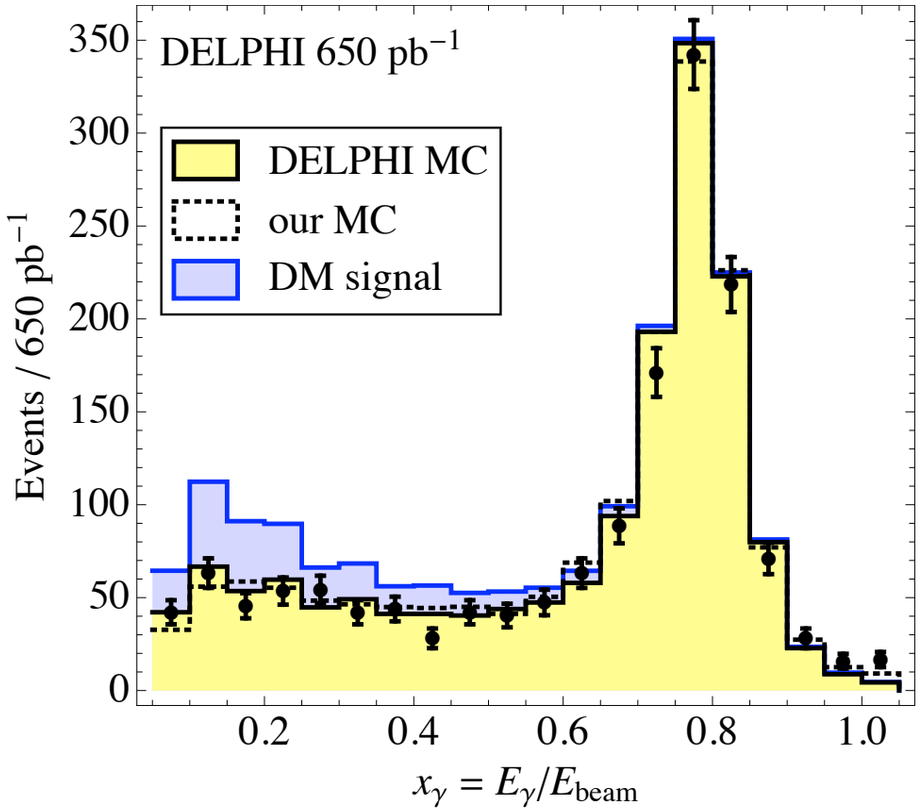


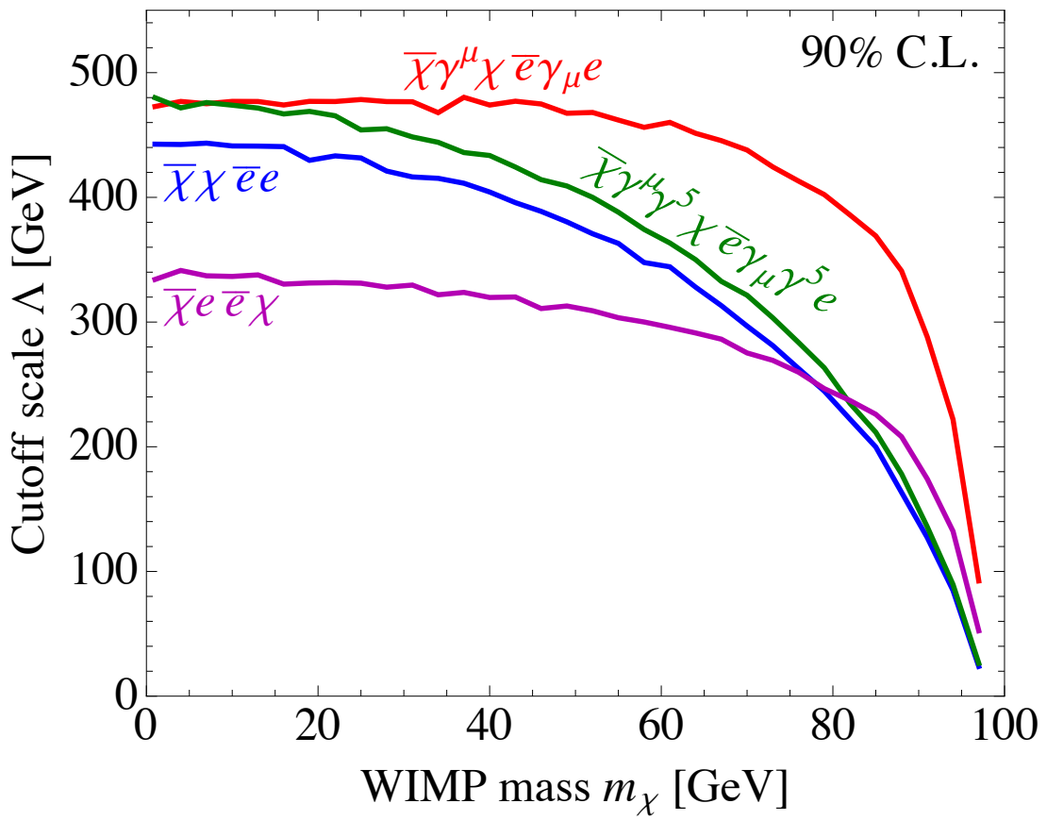
$$\mathcal{O}_V = \frac{(\bar{\chi}\gamma_\mu\chi)(\bar{\ell}\gamma^\mu\ell)}{\Lambda^2}\,,$$

$$\mathcal{O}_S = \frac{(\bar{\chi}\chi)(\bar{\ell}\ell)}{\Lambda^2}\,,$$

$$\mathcal{O}_A = \frac{(\bar{\chi}\gamma_\mu\gamma_5\chi)(\bar{\ell}\gamma^\mu\gamma_5\ell)}{\Lambda^2}\,,$$

$$\mathcal{O}_t = \frac{(\bar{\chi}\ell)(\bar{\ell}\chi)}{\Lambda^2}\,,$$





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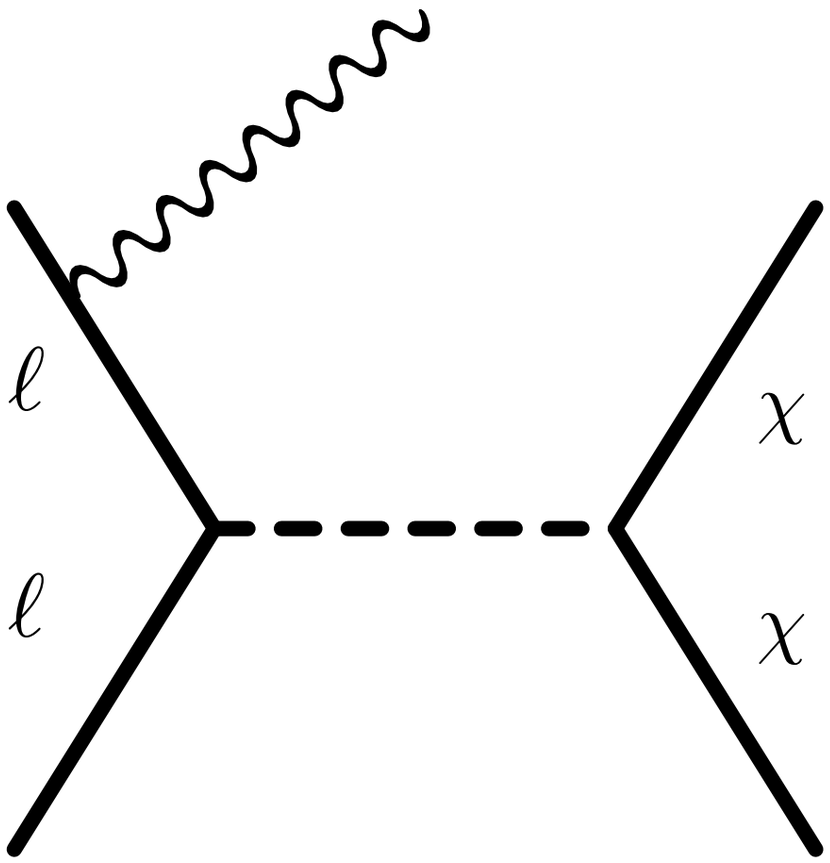

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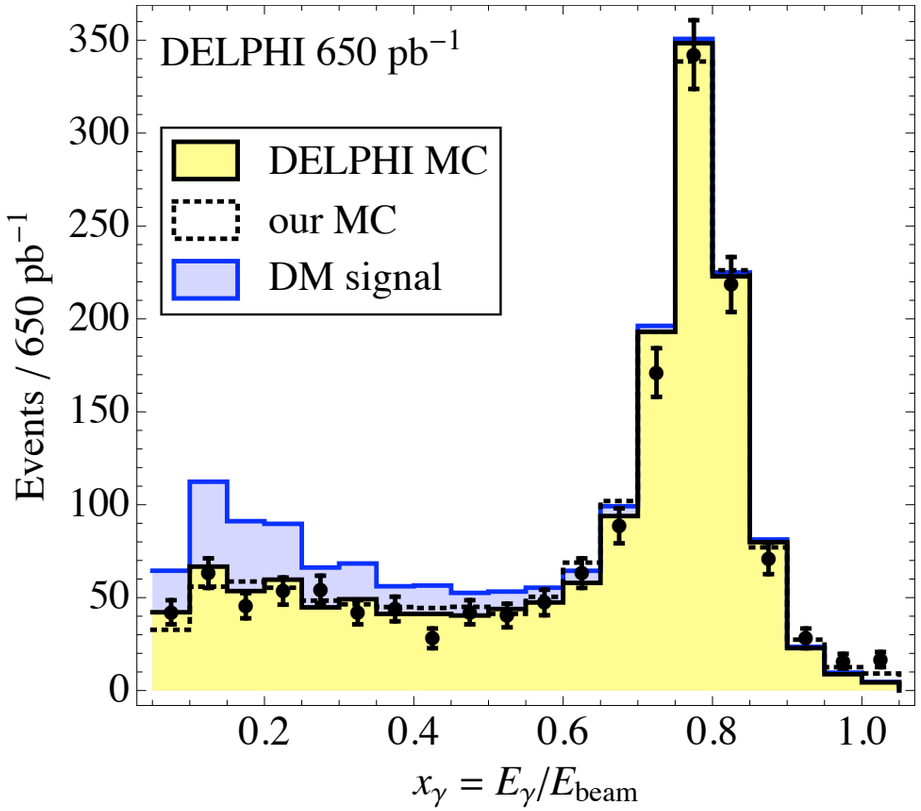
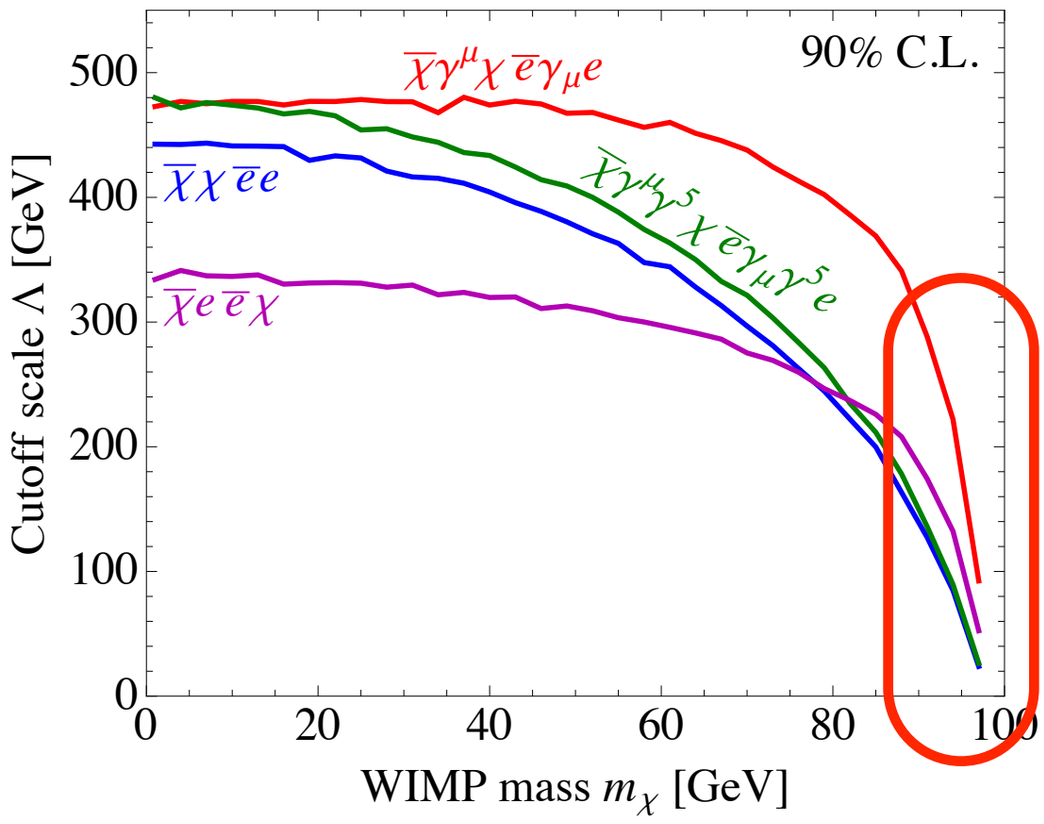


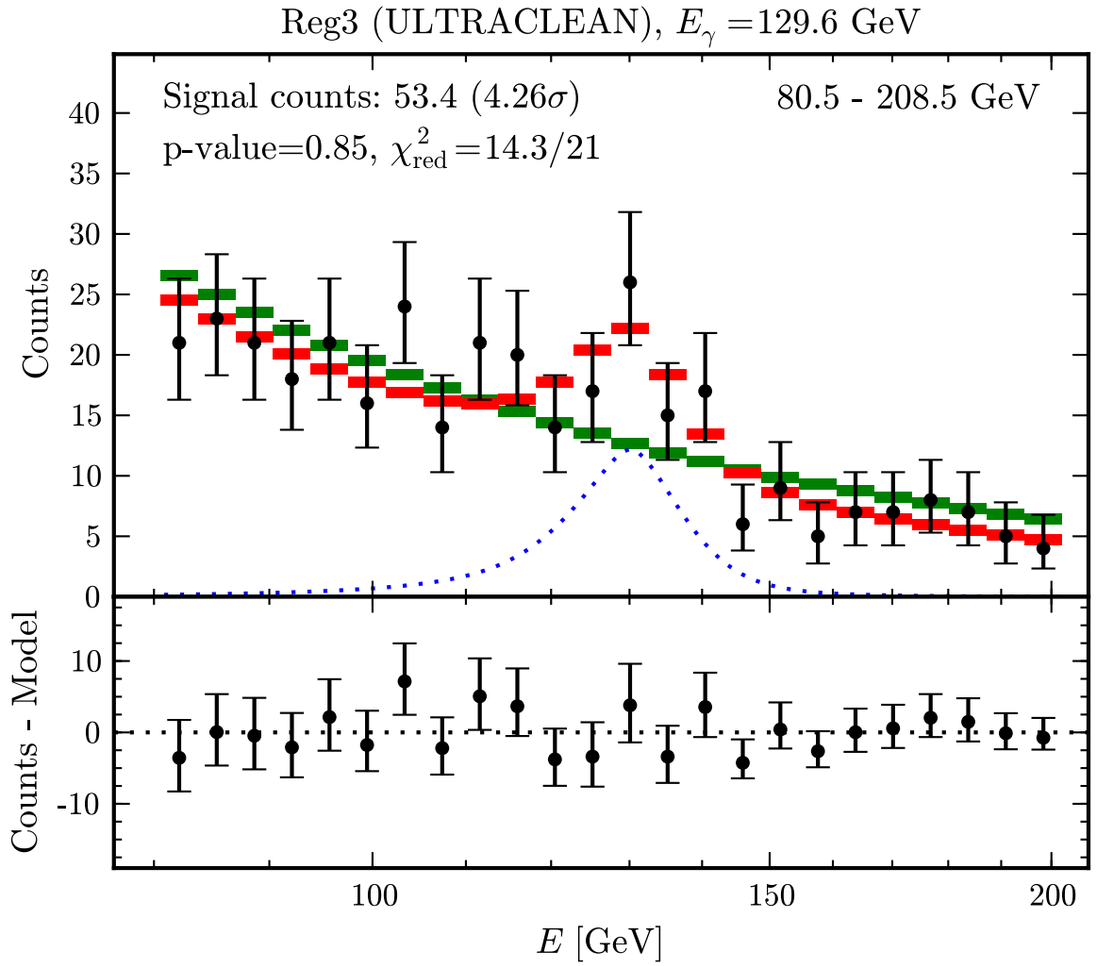


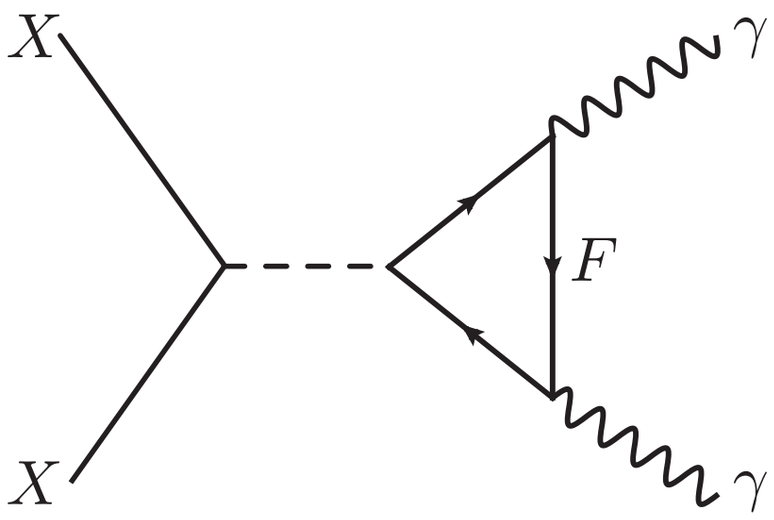
Fermi line

[Weniger]

Gamma-ray line from the (approximate) centre of the galaxy, E~130 GeV

Rate is high ~10^{-27}cm^{3}s^{-1}





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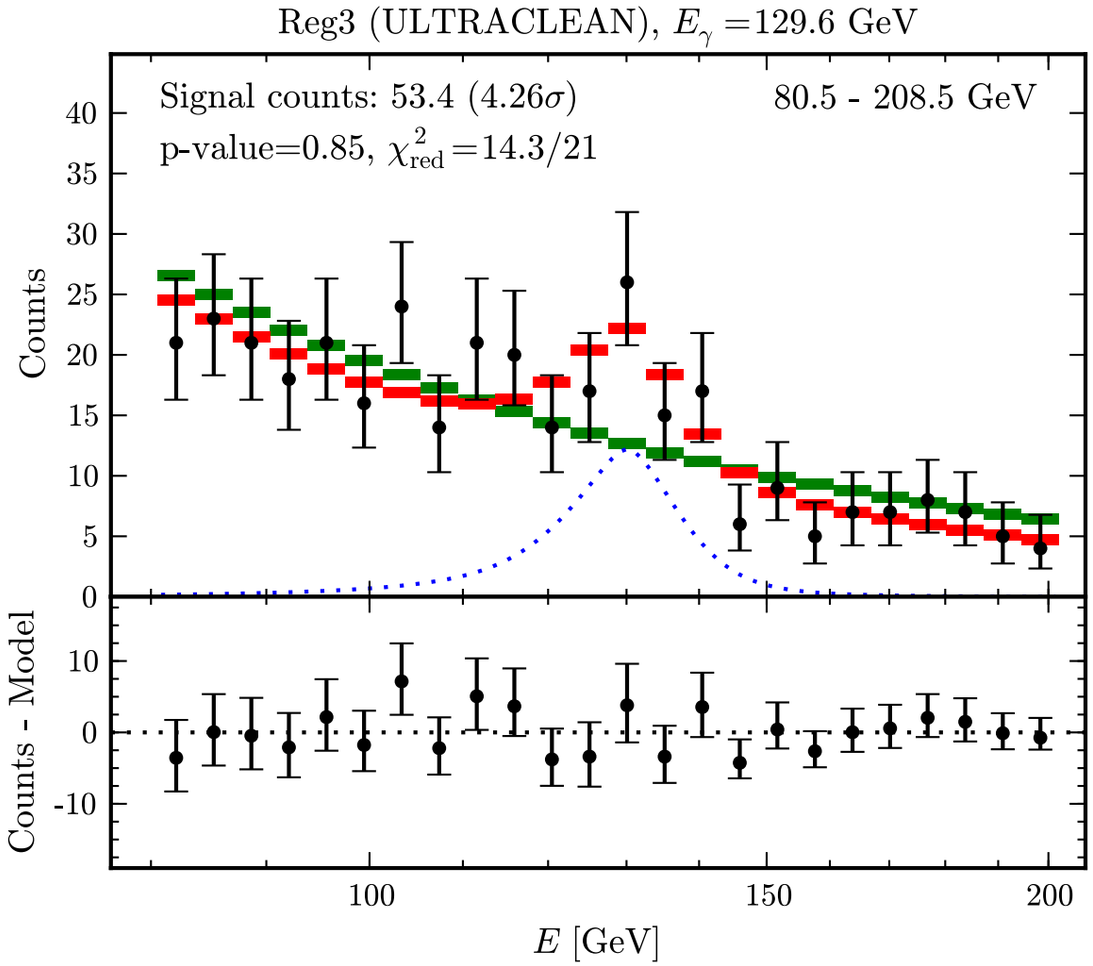
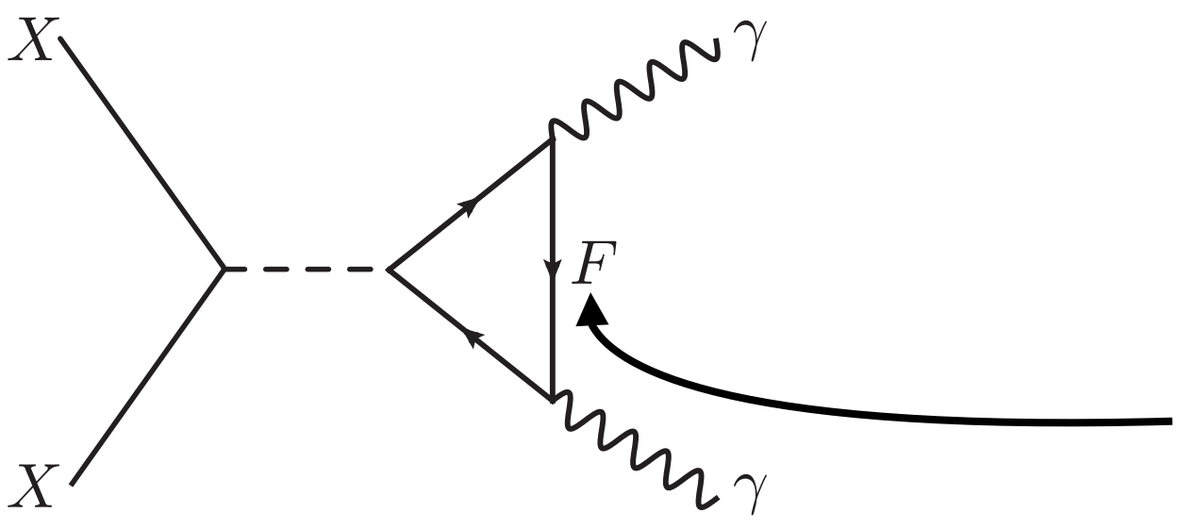
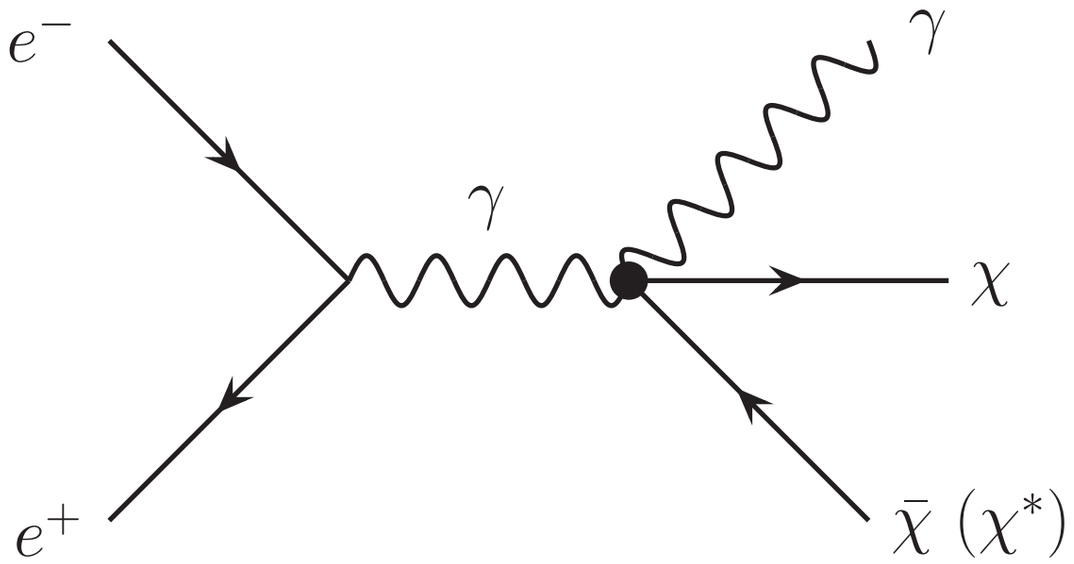
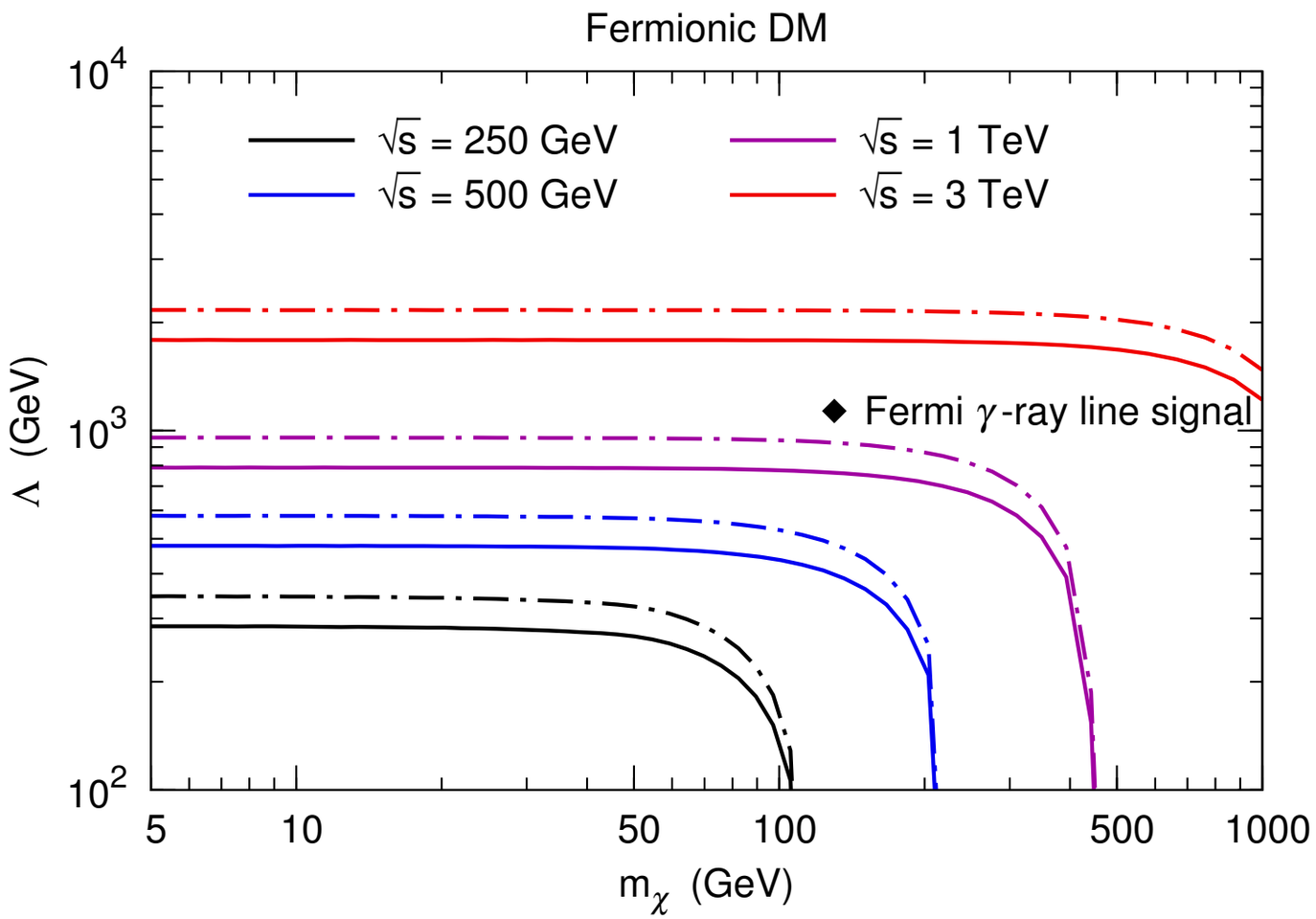




New light charged states

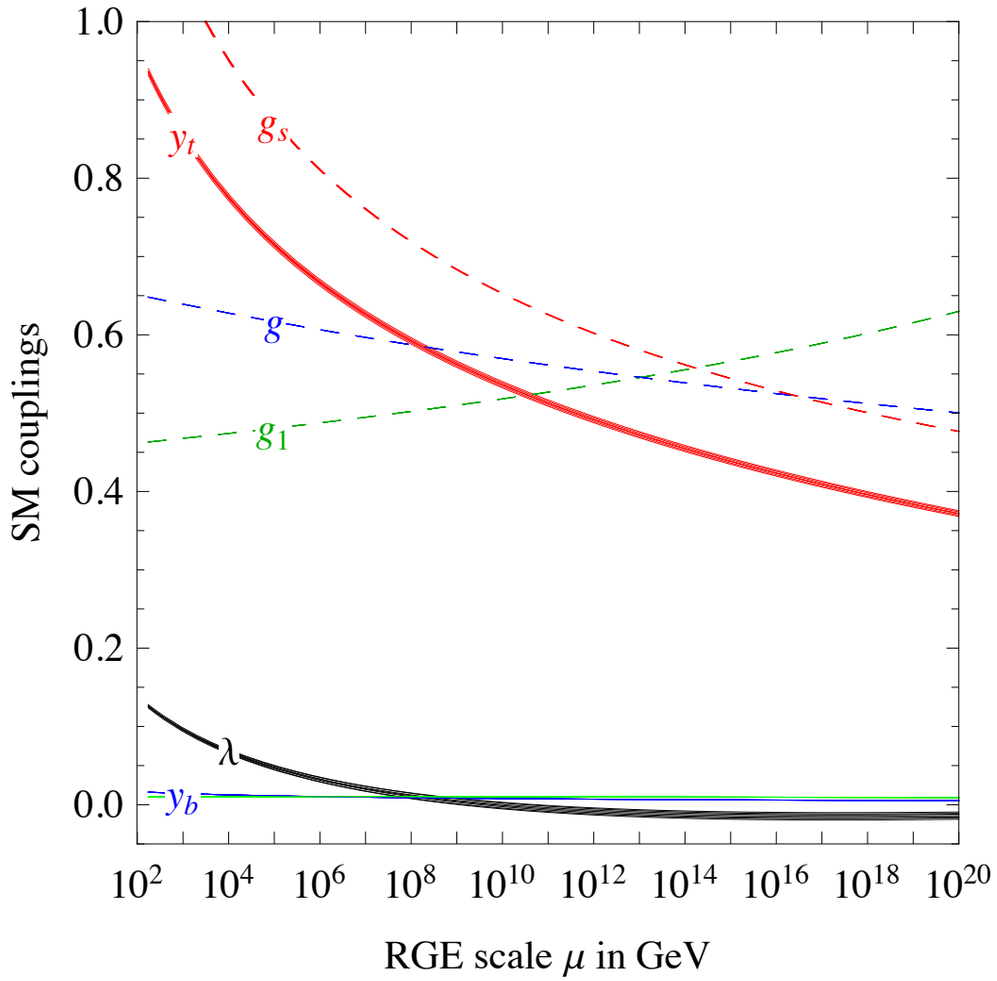
Fermi line

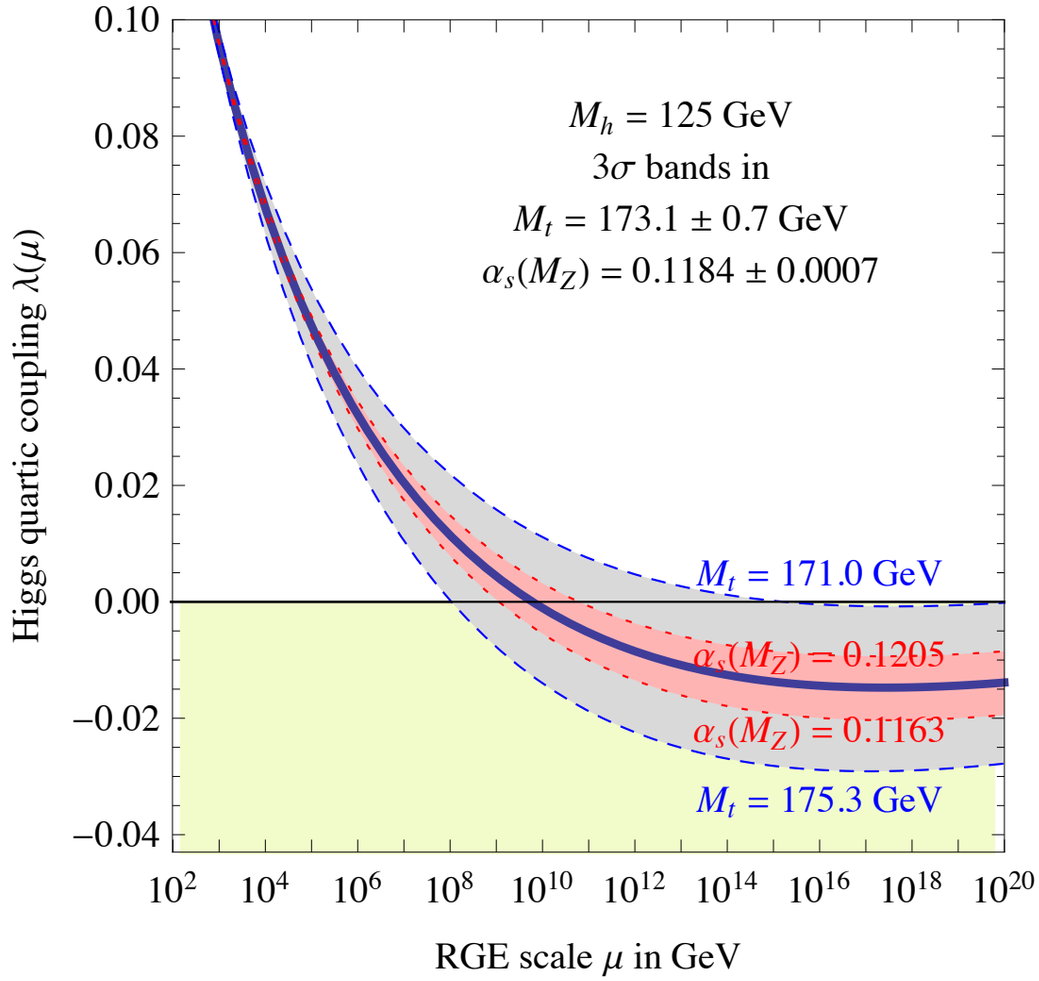




[Yu, Yan, Yin: 1307.5740]

A probe to very high scales?





[Degrassi et al: 1205.6497]

In SM Higgs quartic becomes negative, universe unstable?

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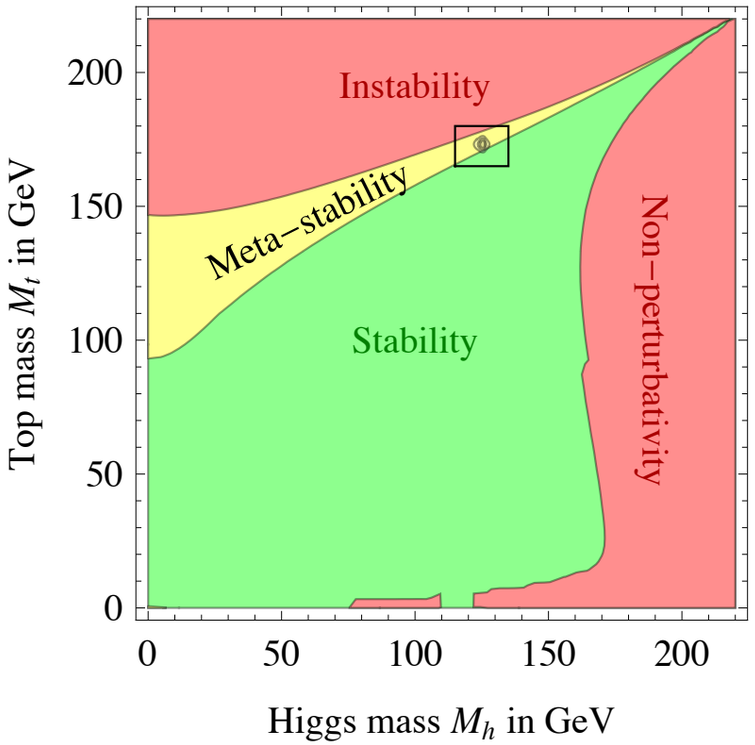

Type of error	Estimate of the error	Impact on M_h
M_t	experimental uncertainty in M_t	± 1.4 GeV
α_s	experimental uncertainty in α_s	± 0.5 GeV
Experiment	**Total combined in quadrature**	± 1.5 GeV
λ	scale variation in λ	± 0.7 GeV
y_t	$\mathcal{O}(\Lambda_{\rm QCD})$ correction to M_t	± 0.6 GeV
y_t	QCD threshold at 4 loops	± 0.3 GeV
RGE	EW at 3 loops + QCD at 4 loops	± 0.2 GeV
Theory	**Total combined in quadrature**	± 1.0 GeV

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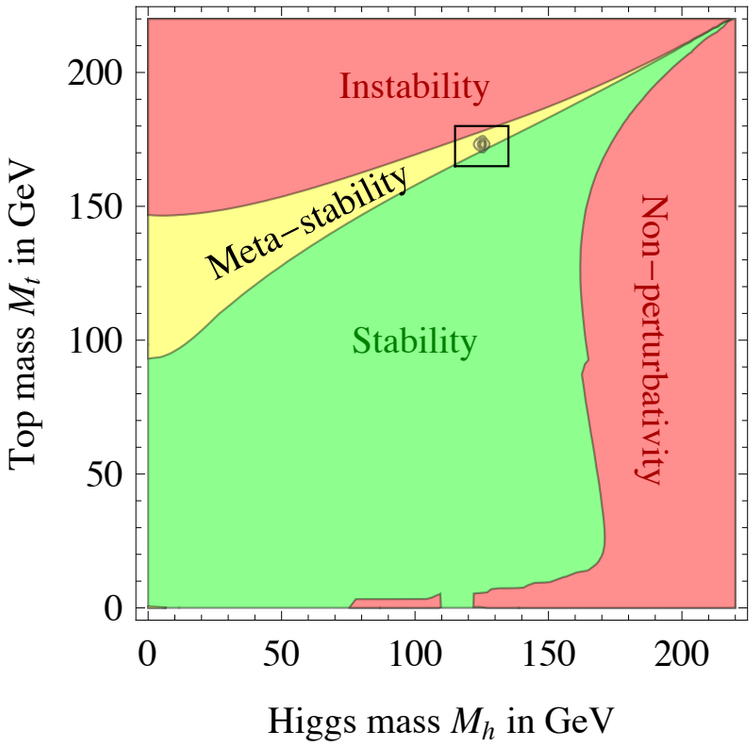

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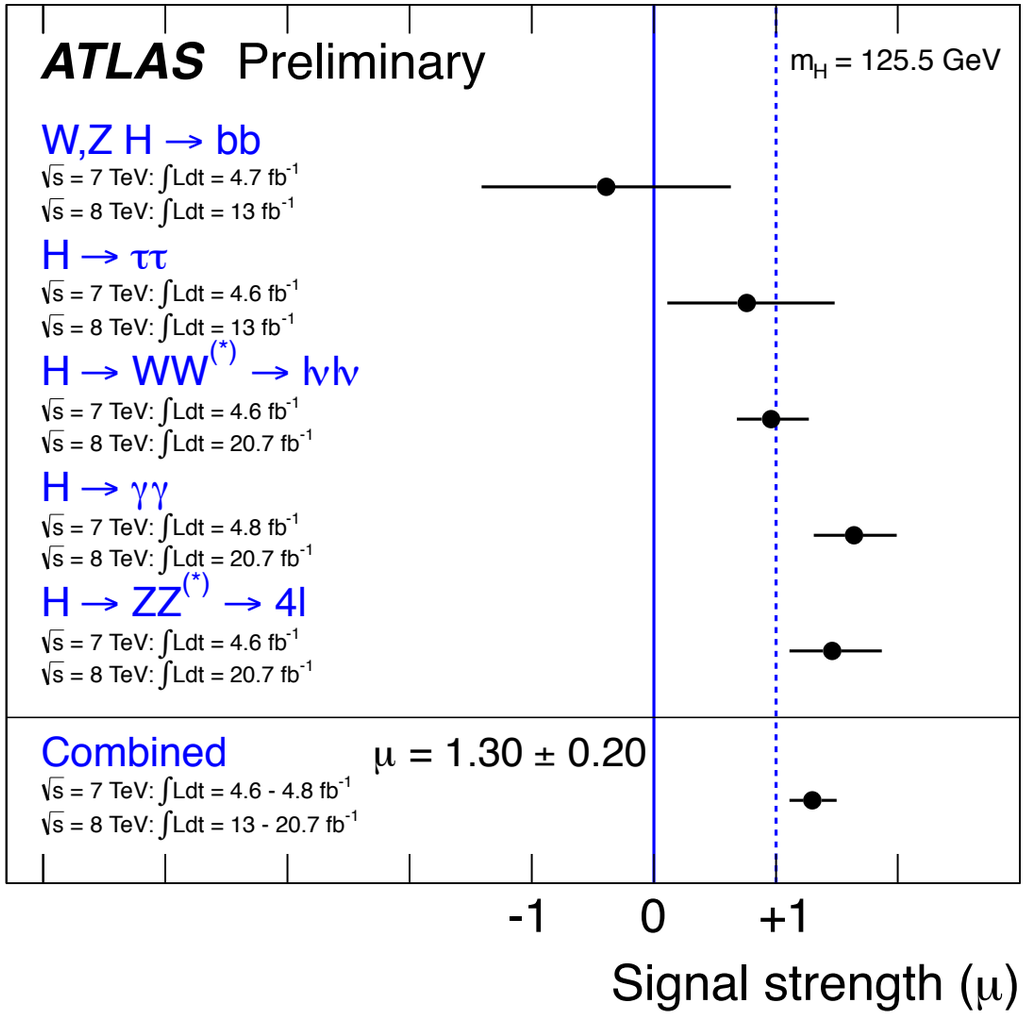
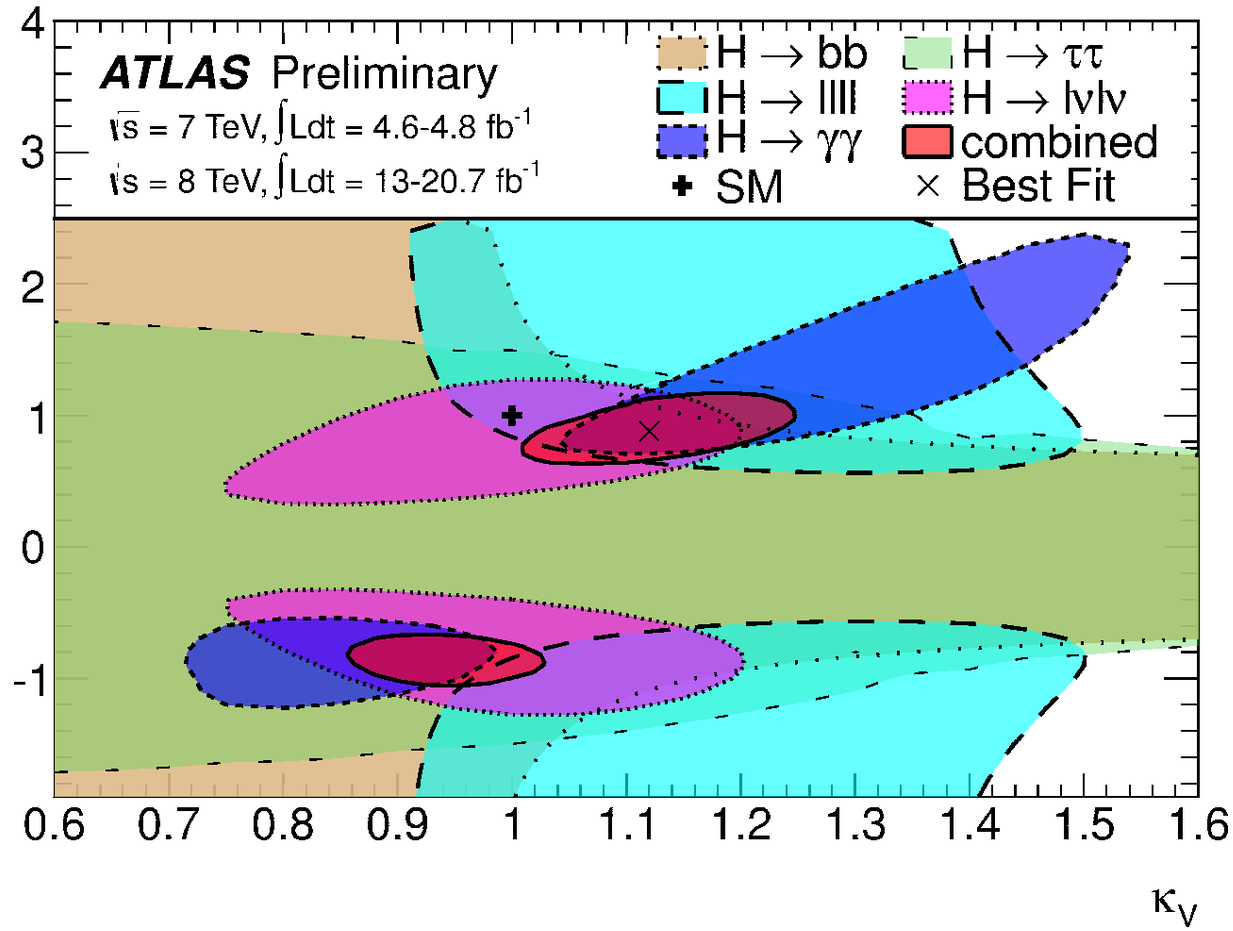
TLEP will determine this to ± 100MeV

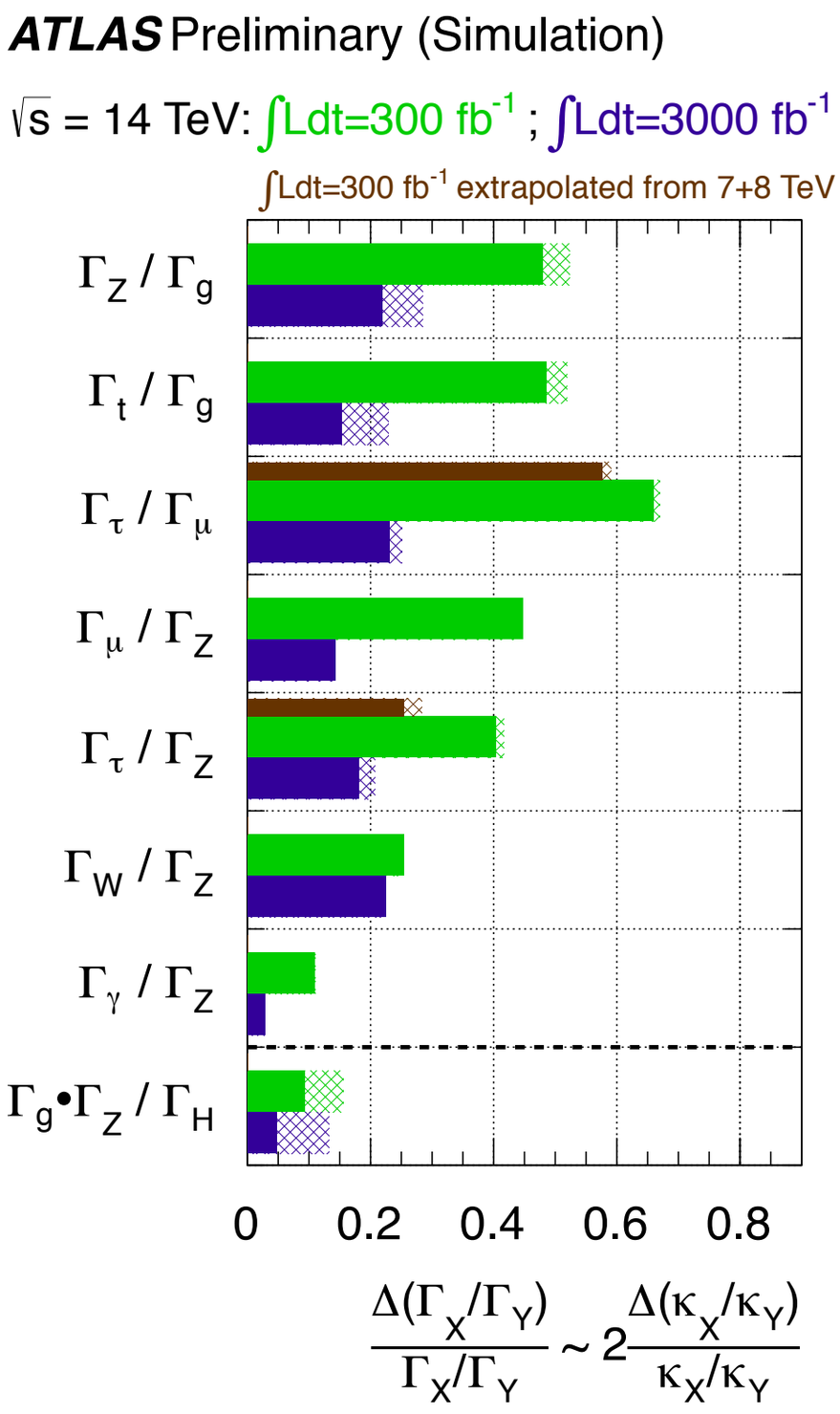
Higgs physics





How SM-like is the Higgs?
Are there exotic decays?
Total width?

Higgs physics



TLEP design study

m_H (MeV)	7
$\Delta\Gamma_H / \Gamma_H$	1.3%
$\Delta\Gamma_{inv} / \Gamma_H$	0.15%
$\Delta g_{H\gamma\gamma} / g_{H\gamma\gamma}$	1.4%
$\Delta g_{Hgg} / g_{Hgg}$	0.7%
$\Delta g_{Hww} / g_{Hww}$	0.25%
$\Delta g_{HZZ} / g_{HZZ}$	0.2%
$\Delta g_{H\mu\mu} / g_{H\mu\mu}$	7%
$\Delta g_{H\tau\tau} / g_{H\tau\tau}$	0.4%
$\Delta g_{Hcc} / g_{Hcc}$	0.65%
$\Delta g_{Hbb} / g_{Hbb}$	0.22%

Higgs portal

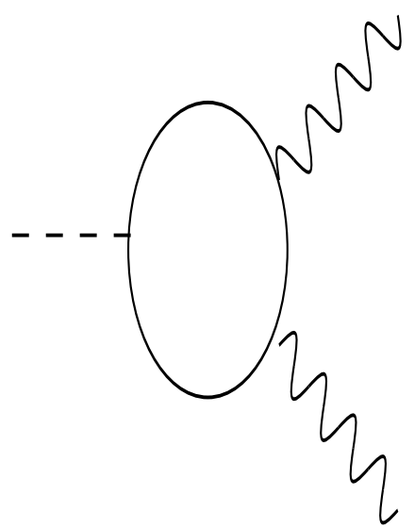
The Higgs is narrow, so small couplings to NP can be important

$$\mathcal{L} = \frac{c}{2} a^2 |H|^2$$

For c~0.02 $h \to aa$ is comparable to b-quark BR.

Depending on decays this BR may be very hard to see at LHC

$$h \to aa \to 4g$$

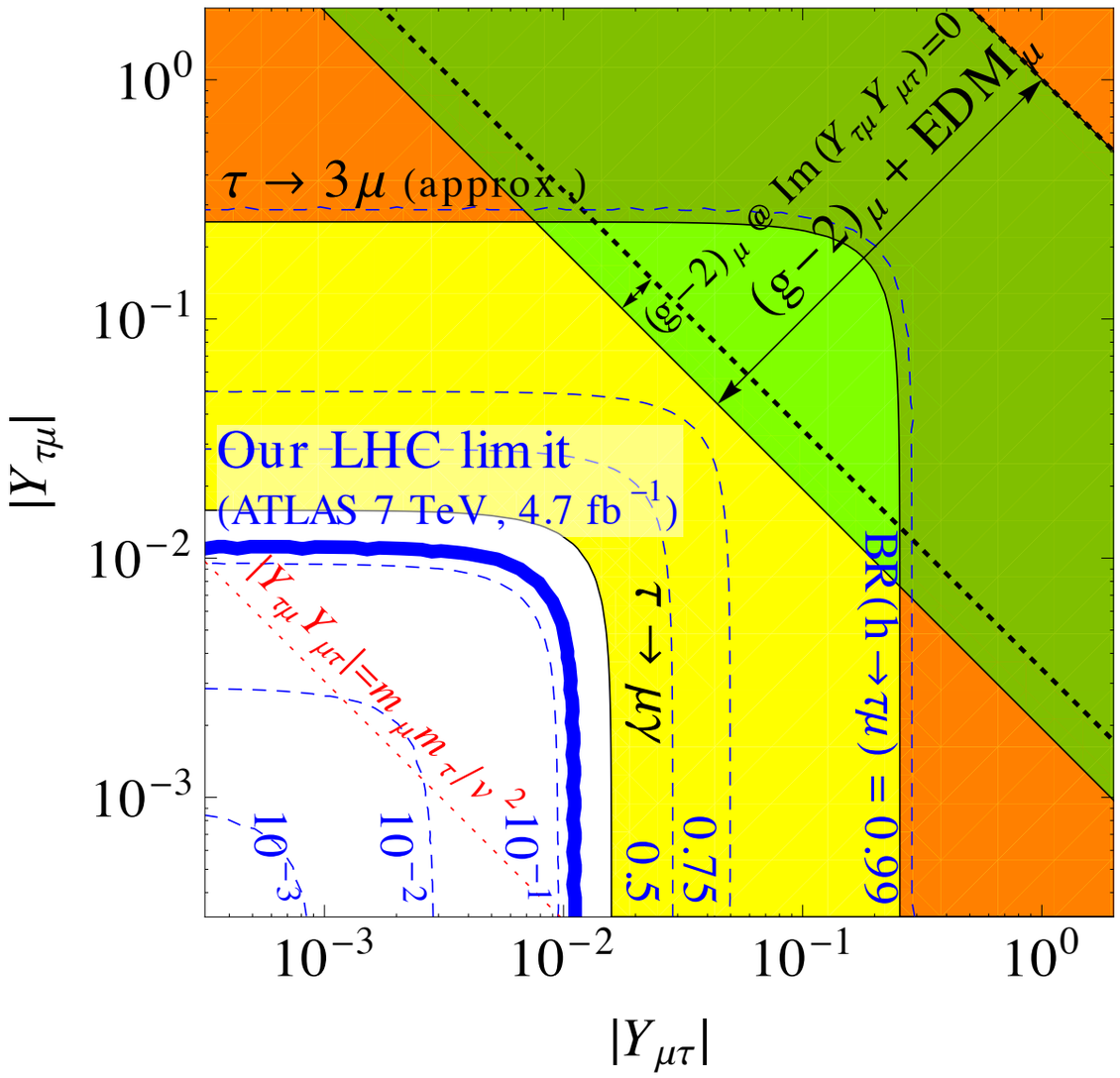


Rare Higgs Decays

[Harnik, Kopp, Zupan:1209.1397]

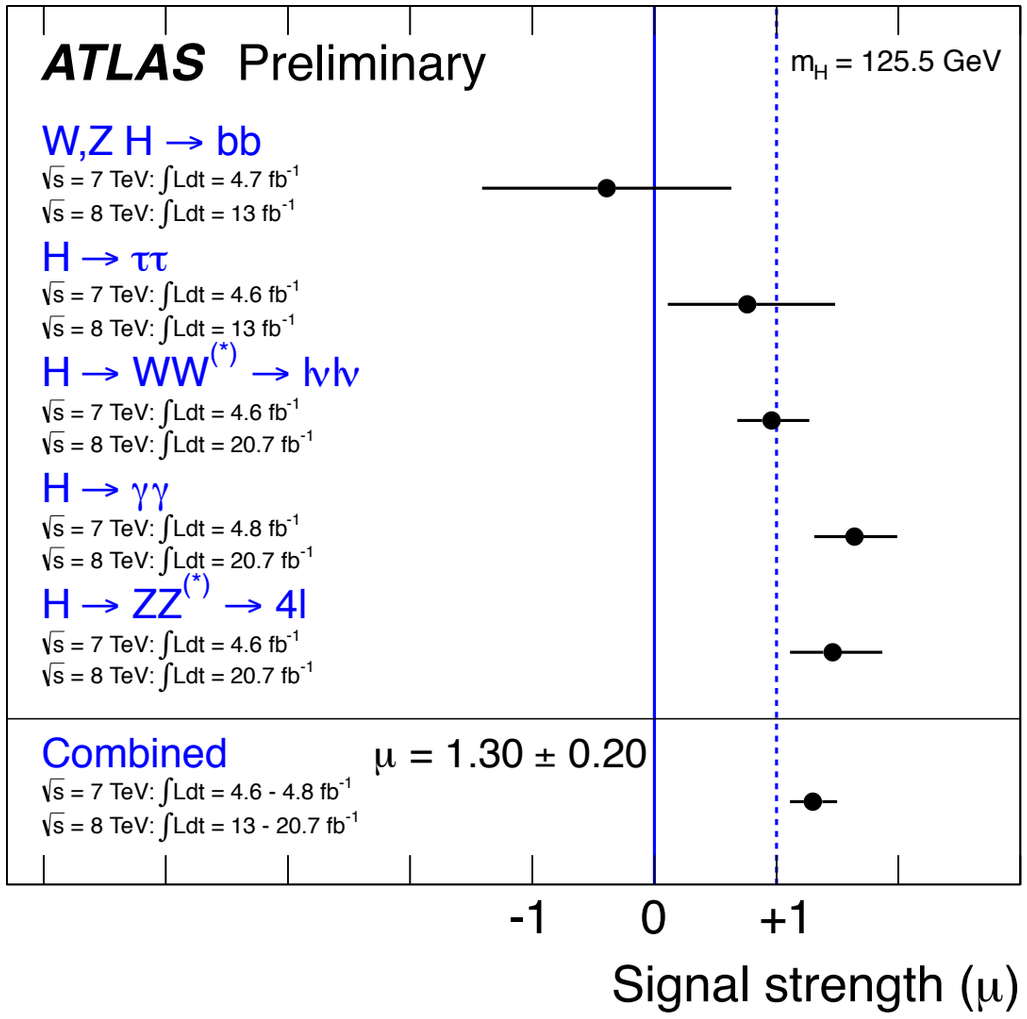
Higher dimension operators can lead to flavour violating Higgs decays

$$\Delta\mathcal{L}_Y = -\frac{\lambda'_{ij}}{\Lambda^2}(\bar{f}^i_L f^j_R)H(H^\dagger H) + h.c. + \cdots$$



e.g. $h \to \mu e,\ \mu\tau,\ e\tau$

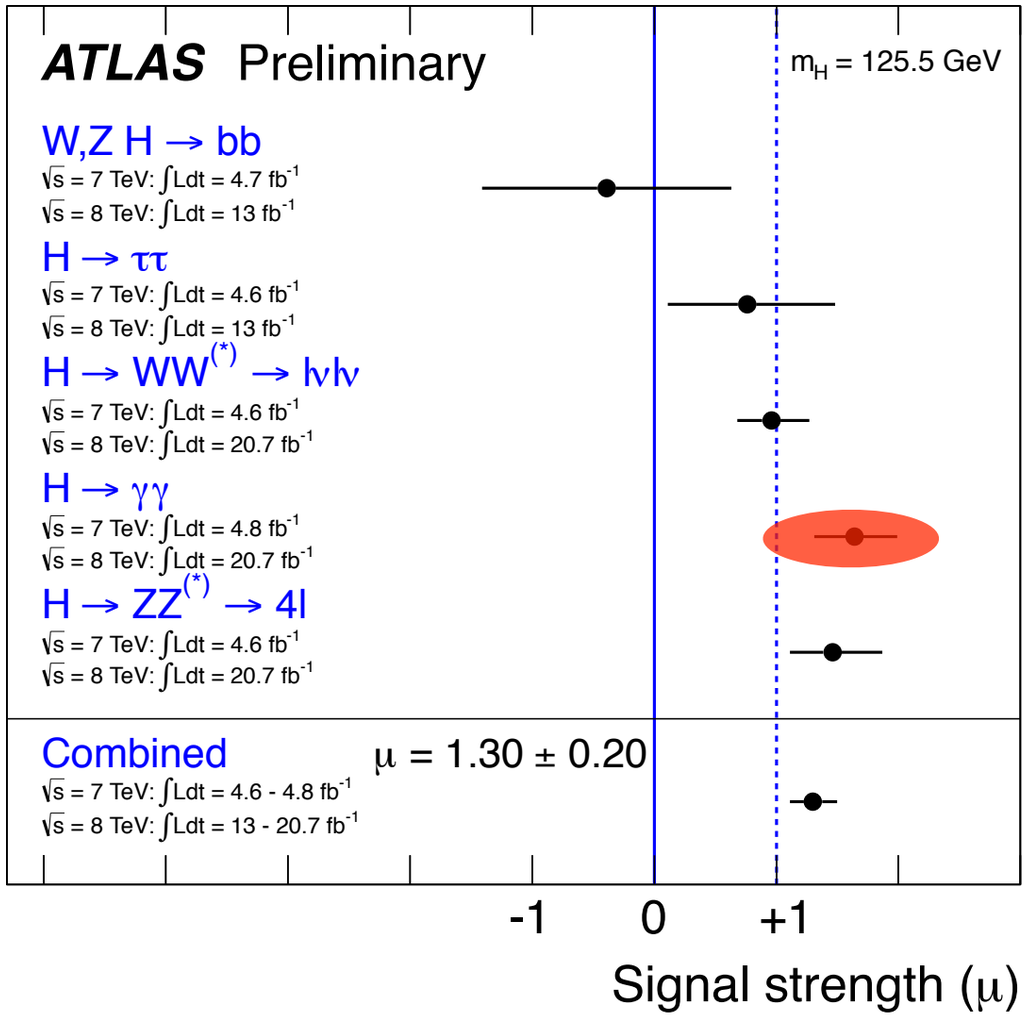
Higgs physics



New physics in loops, coupled to Higgs and photons

e.g. light staus, 2HDM (Type I, works best)

Higgs physics



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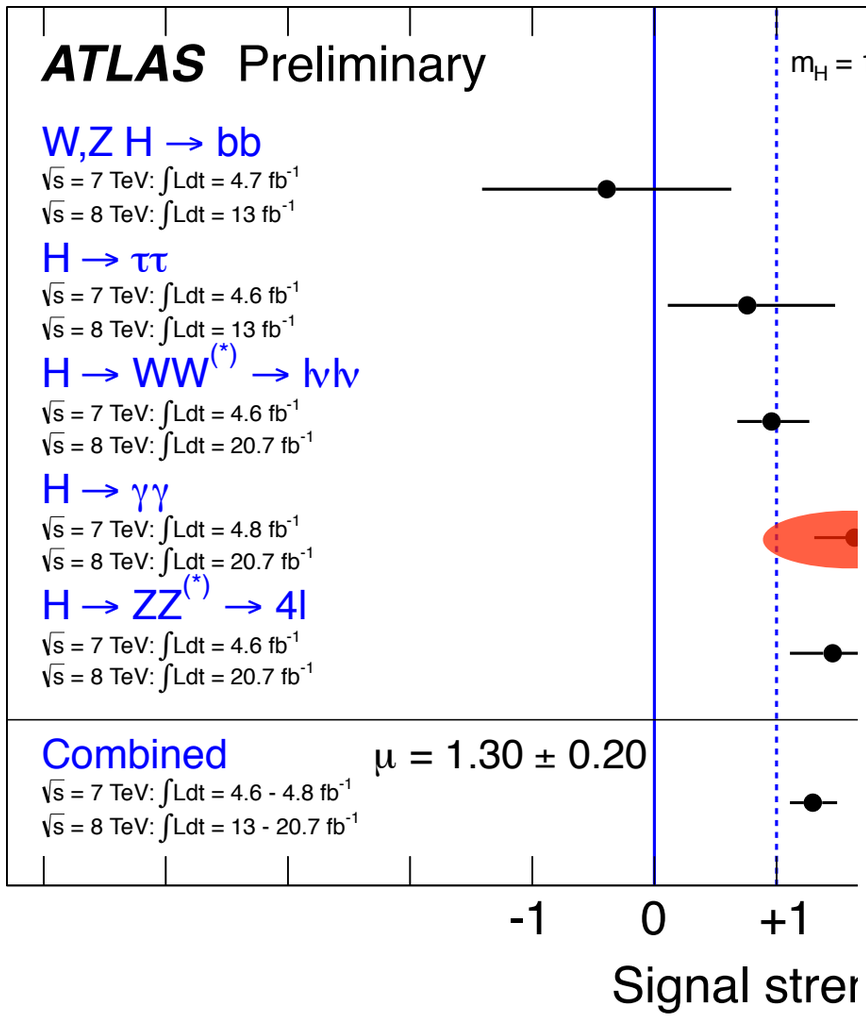

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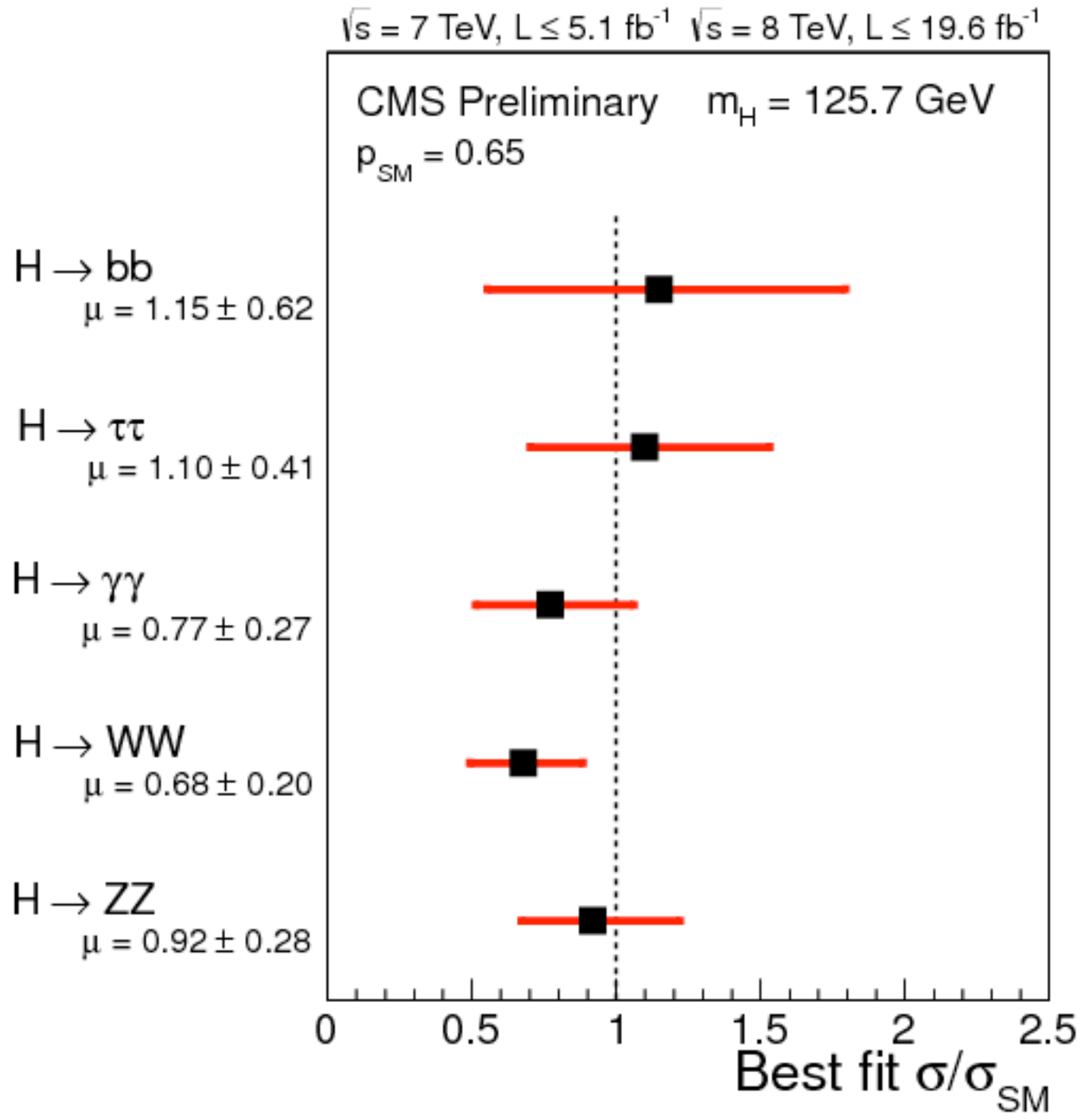

Supersymmetry

Reasonable SUSY models can be hard to see (invisible?) at the LHC

- Light sleptons, electroweakinos, but coloured states heavy?--Only LEP bounds for sleptons
- Compressed spectra--makes jets soft
- RPV--removes MET signal
- Light stops, with nearly degenerate neutralino

<u>Can they be made visible at TLEP?</u>

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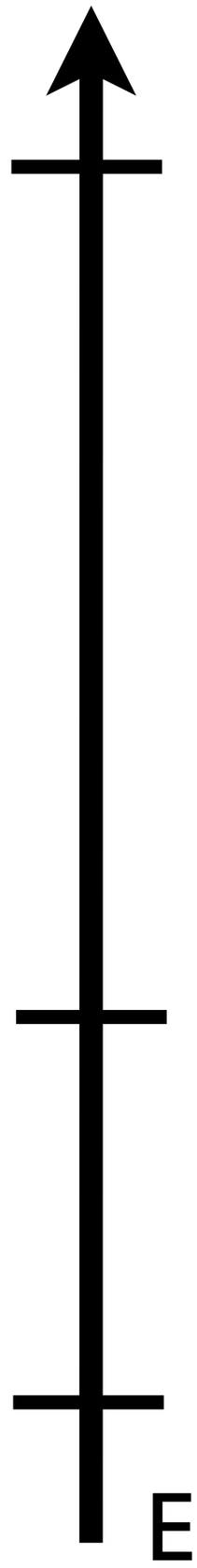

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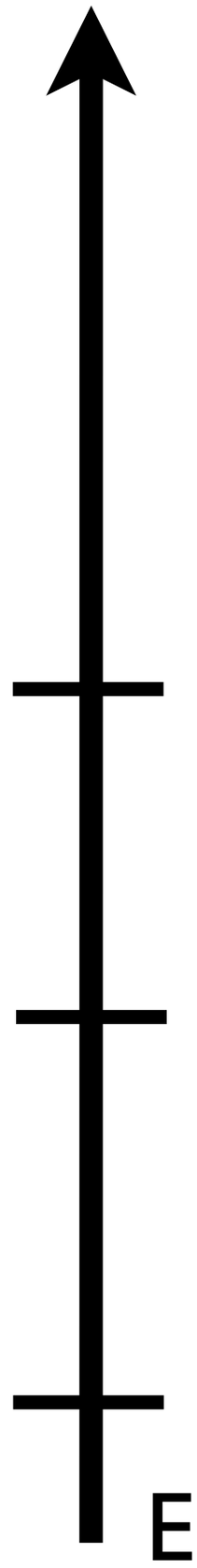
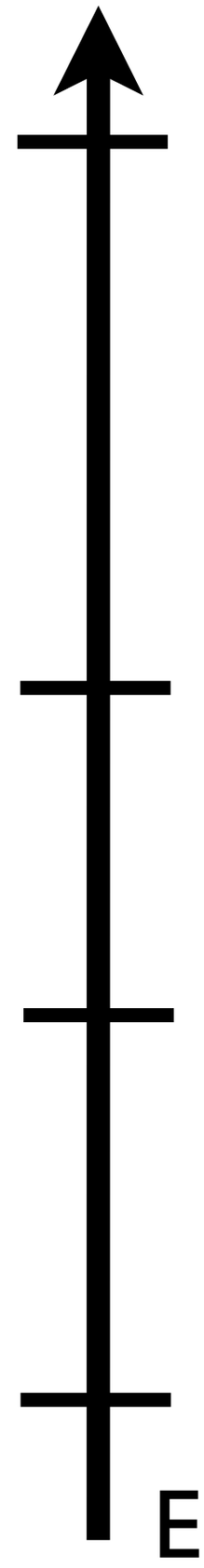


VHE-LHC: a pp machine going to 100 TeV, L~300-3000/fb

LHC: a pp machine going to 14 TeV, L~300-3000/fb

TLEP: a e^+e^- machine going to ~350 GeV, L~100-1000/fb

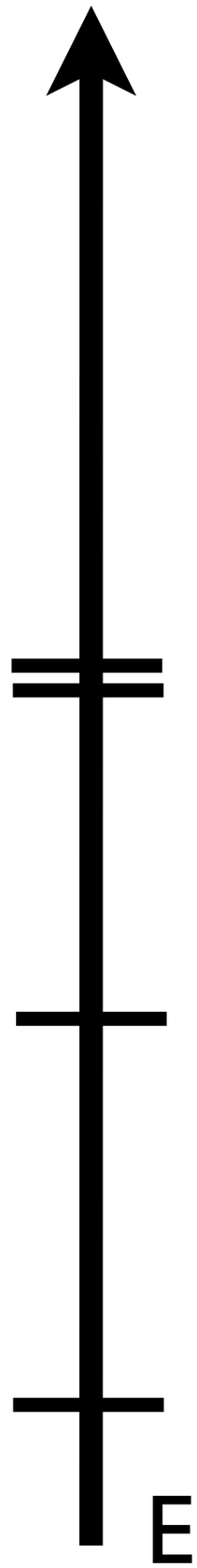
LEP: a e^+e^- machine going to ~200 GeV, L~10-100/pb



VHE-LHC: a pp machine going to ~100 TeV, L~300-3000/fb

TLEP: a e^+e^- machine going to ~350 GeV, L~100-1000/fb

LEP: a e^+e^- machine going to ~200 GeV, L~10-100/pb



Dijet resonance

[Dobrescu and Yu:1306.2629]