Summary/Prospects: Theory

Giacomo Cacciapaglia
IP2I Lyon, France

Many thanks to F. Piccinini, and all speakers.

Motivations for FCC

- Most new physics models driven by the Hierarchy problem...

- with new scale in the multi-TeV!

multi-TeV mountain

- What are we looking for?

-> Precision EW + Higgs observables
-> Higs potential recostruction
-> Ligght and weakly coupled states
-> multi-TeV new physics states

Motivations for FCC

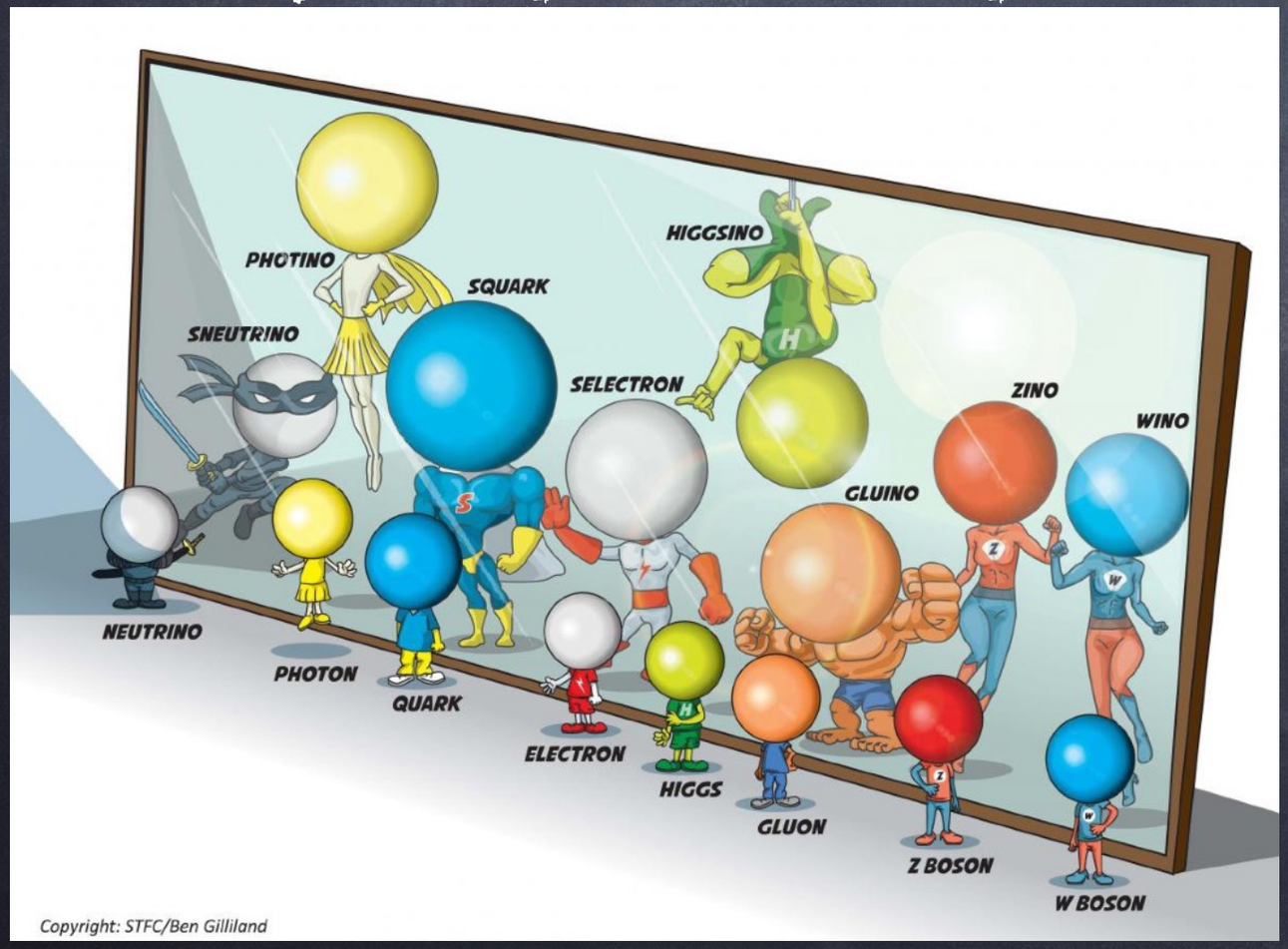
- Even if we got the naturalness argument all wrong...

- FCC would be pushing the frontiers of unexplored physics!

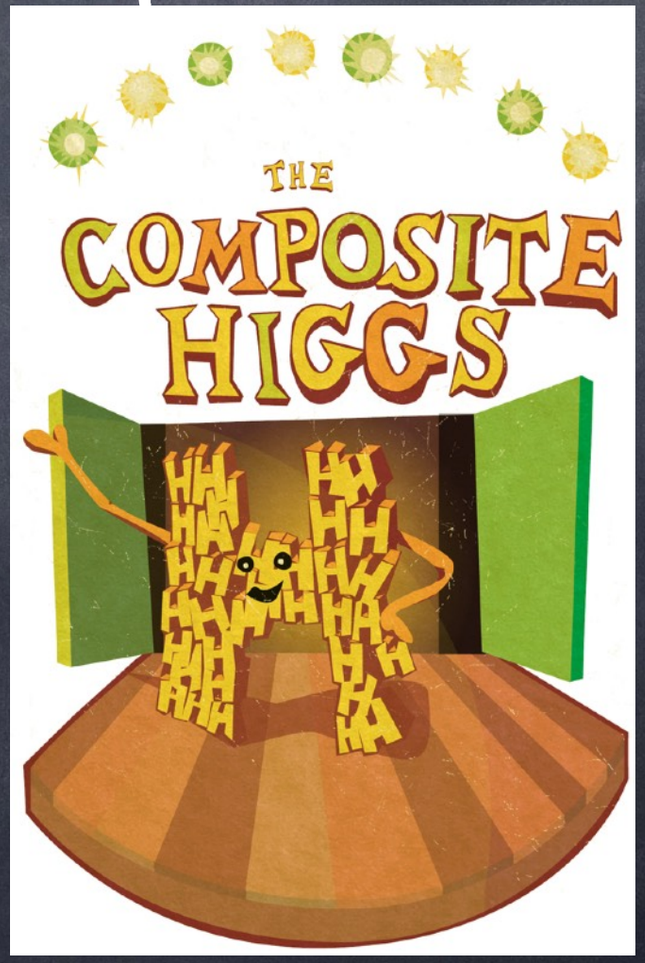
  -> Dark Matter
  -> Hints from flavour and lepton anomalies

The naturalness path

Supersymmetry



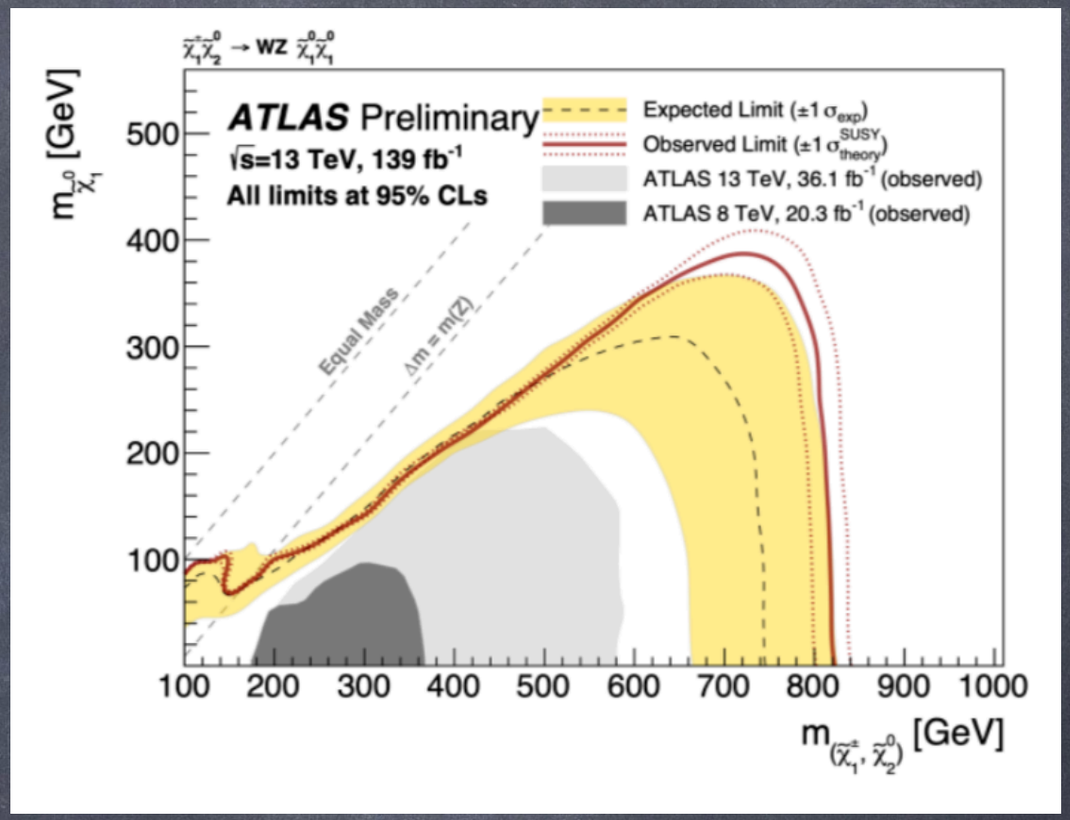
Compositeness



Supersymmetry

M.Goodsell

- Supersymmetry is not dead!
- TeV scale reached in some 'simplified' channels...
- Low energy holes left in many realistic models.
- Motivations for multi-TeV scale SUSY still hot!



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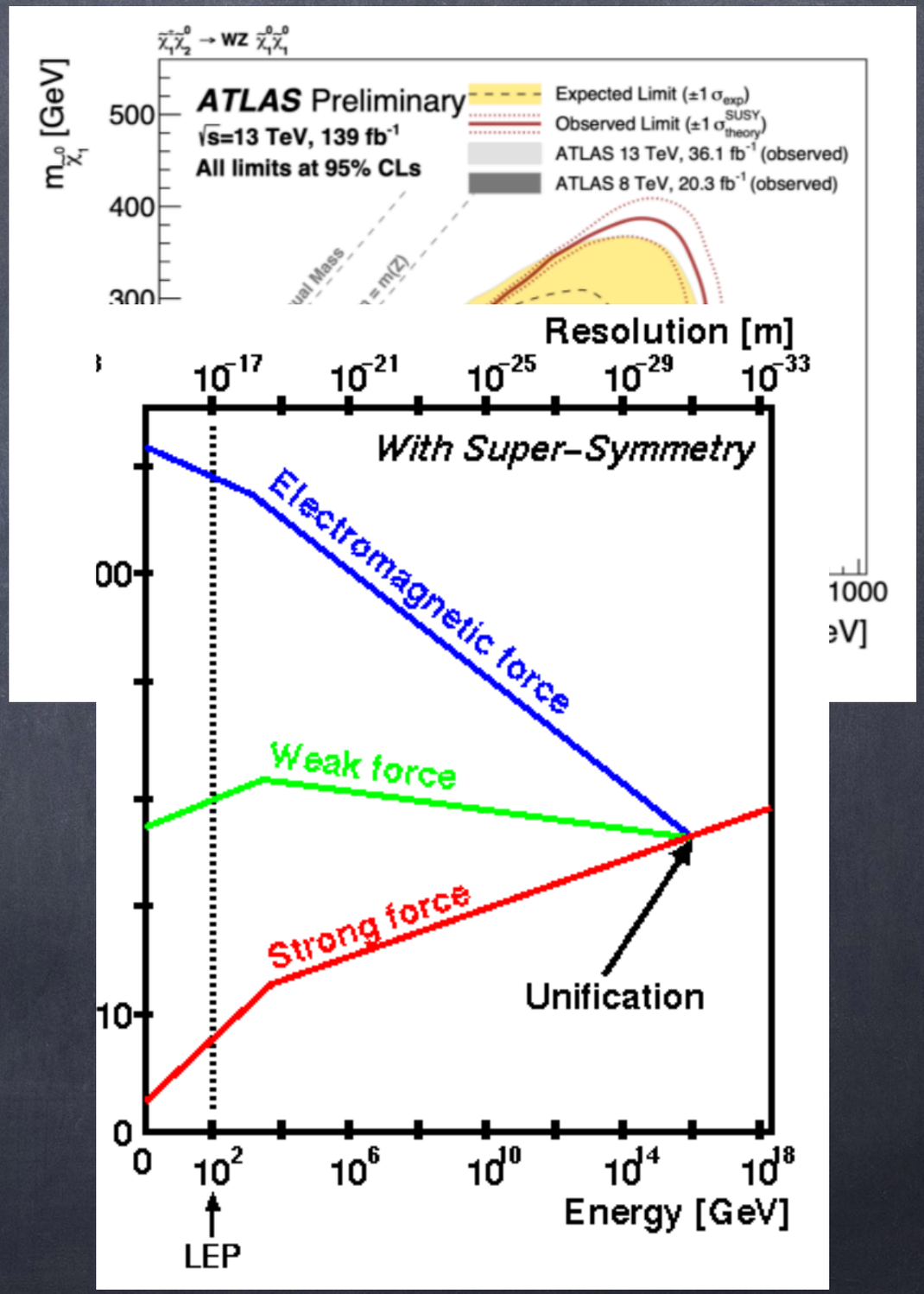
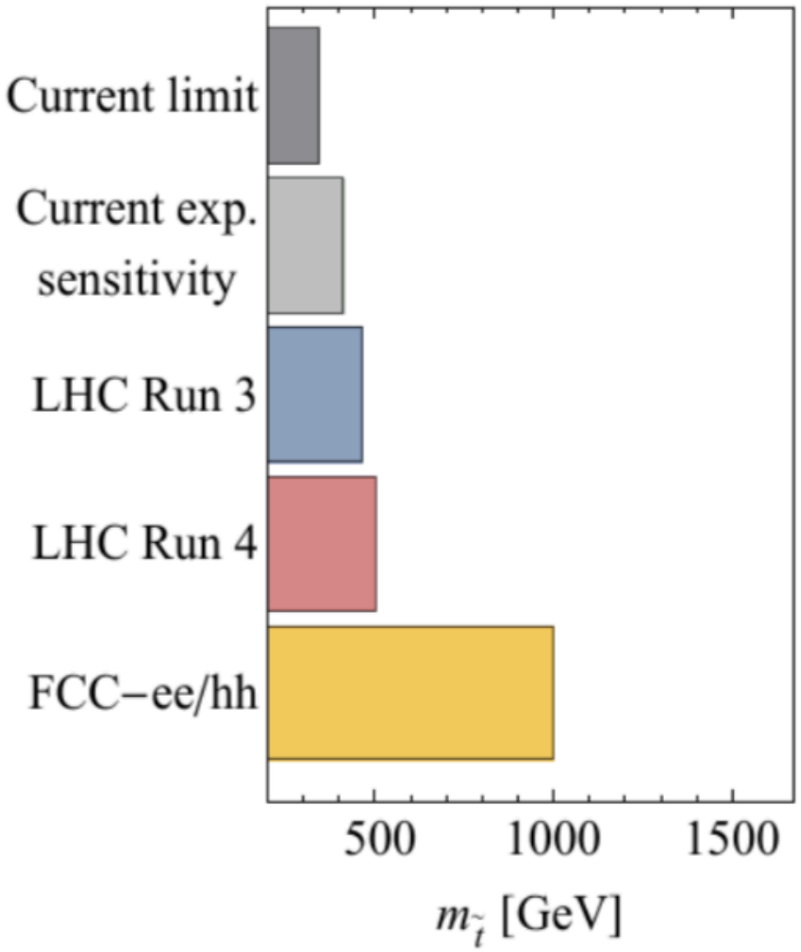
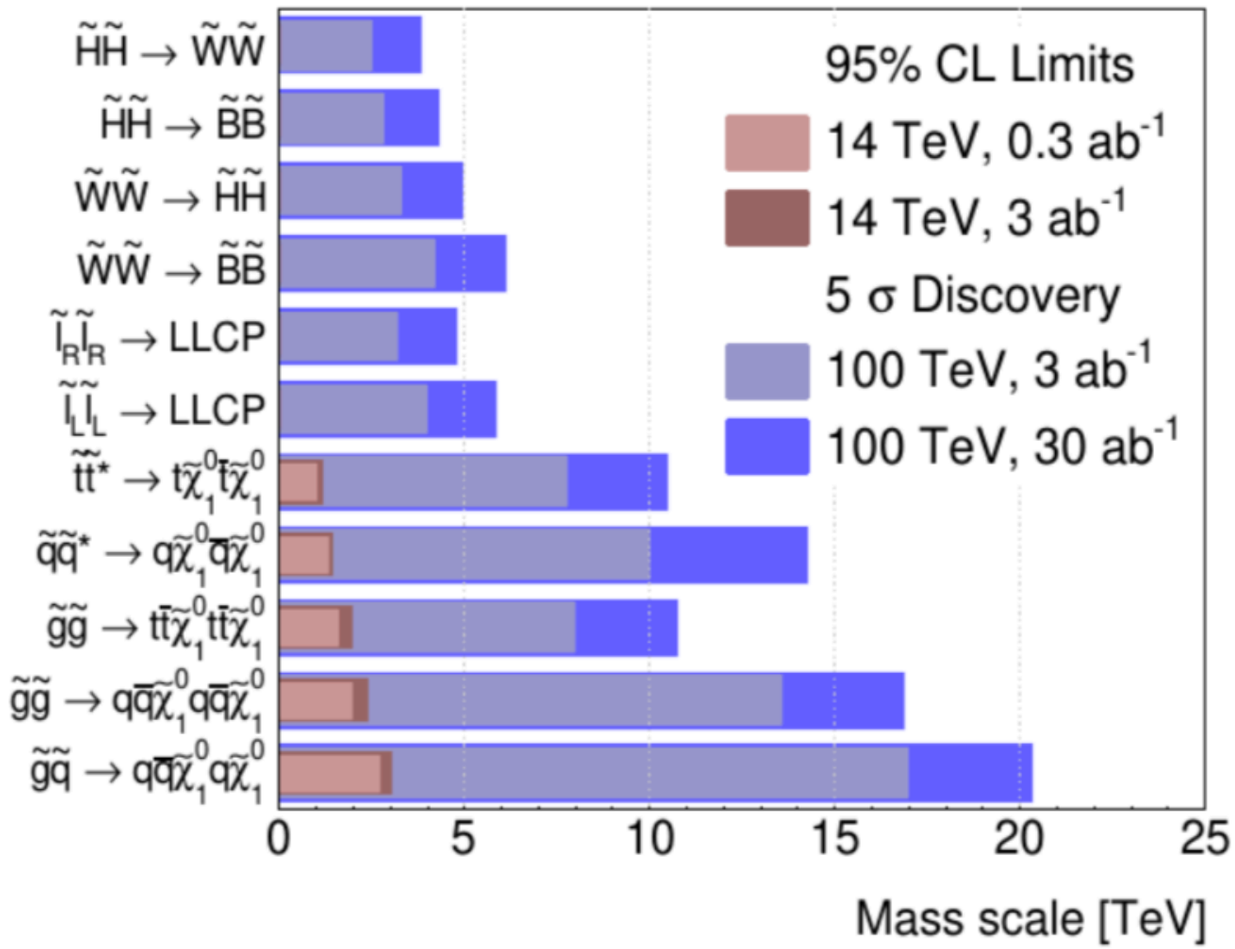
SUSY as an unification driver!

SUSY provides WIMPs!



FCC Projections for SUSY searches





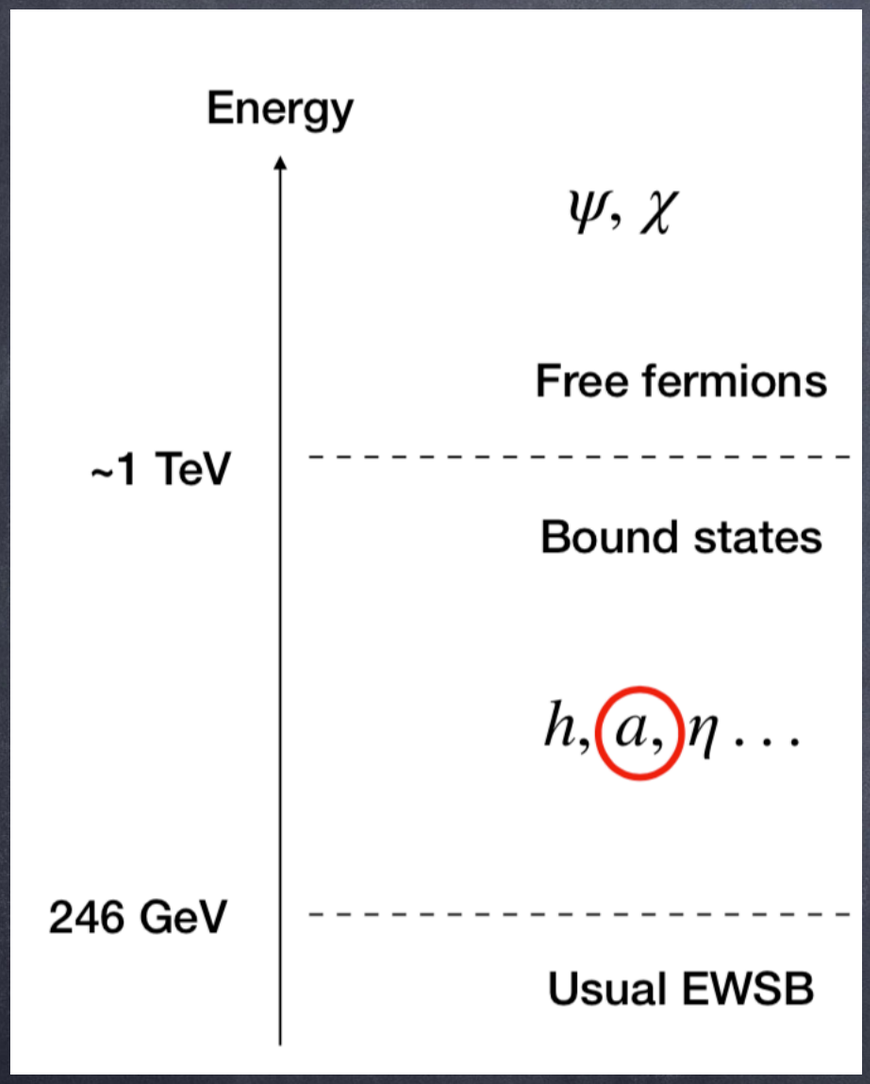
See Physics at a 100 TeV pp collider: beyond the Standard Model phenomena and FCC Physics Opportunities : Future Circular Collider Conceptual Design Report Volume 1

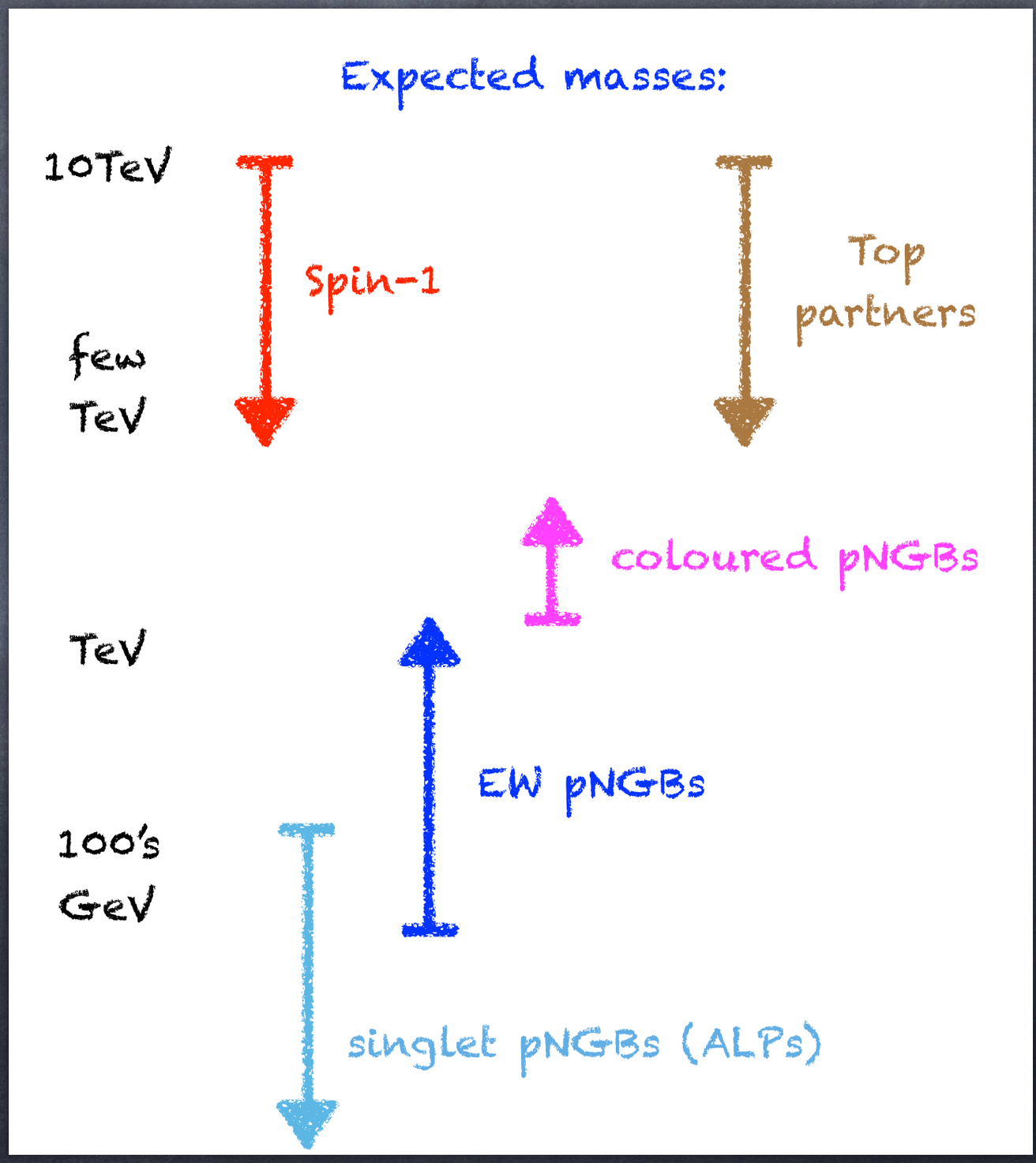
FCC Projections for SUSY searches

- Search strategies for the FCC seem to mimic LHC ones: monojet, pair production, disappearing tracks
- New searches are being developed for run 3 (displaced vertices, machine learning) which might also help FCC strategies …
- … I didn’t find much activity on this recently
- Also tools for projections for the FCC are needed! (notably cross-section calculators exist, key4HEP is a very encouraging development – need more automation for theorists too!)

Compositeness

A.Cornell
L.Schwarze

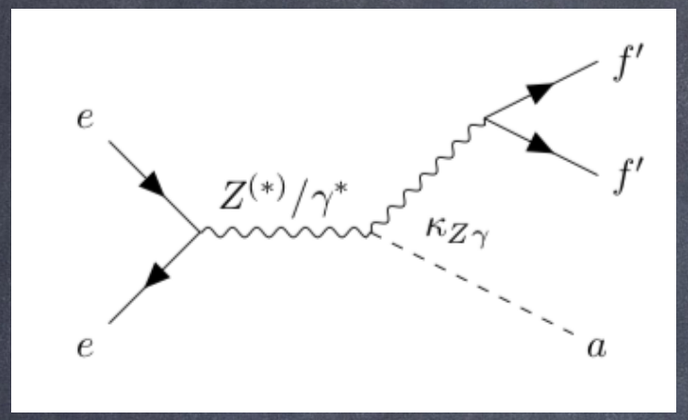




Light composite scalars

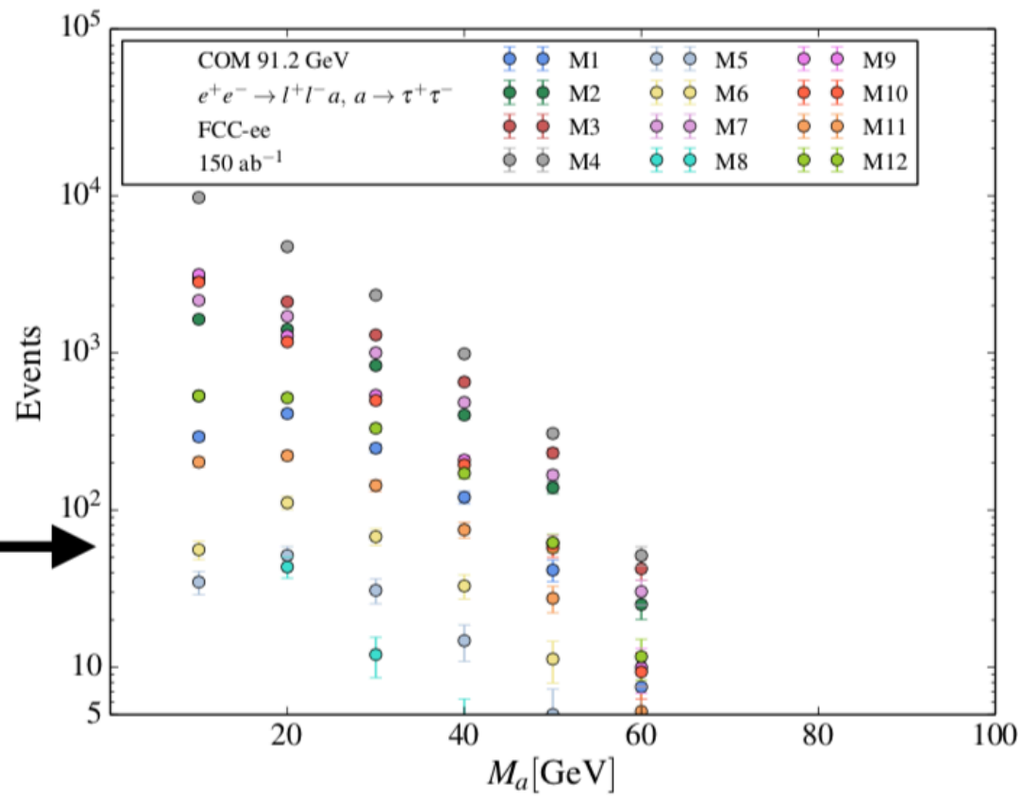
A.Cornell

Rare production, i.e.



BDT could help!

- Consider a produced with a pair of OS leptons (avoid multi jet bg)
- Signal events expected for subsequent decay to hadronic $\tau\tau$
- Sensitivity depends on model

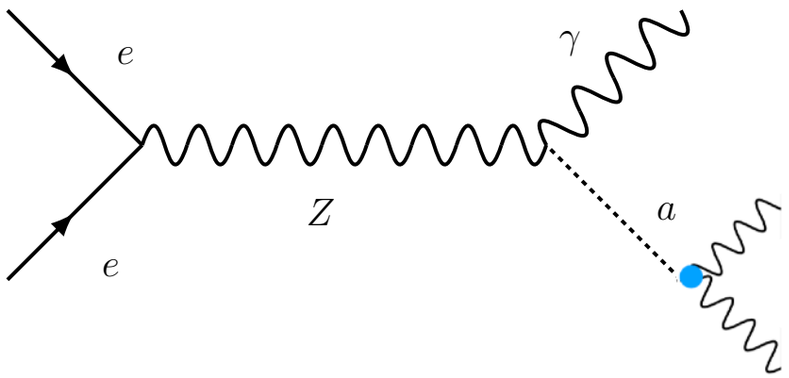


Light composite scalars

Photo-philic

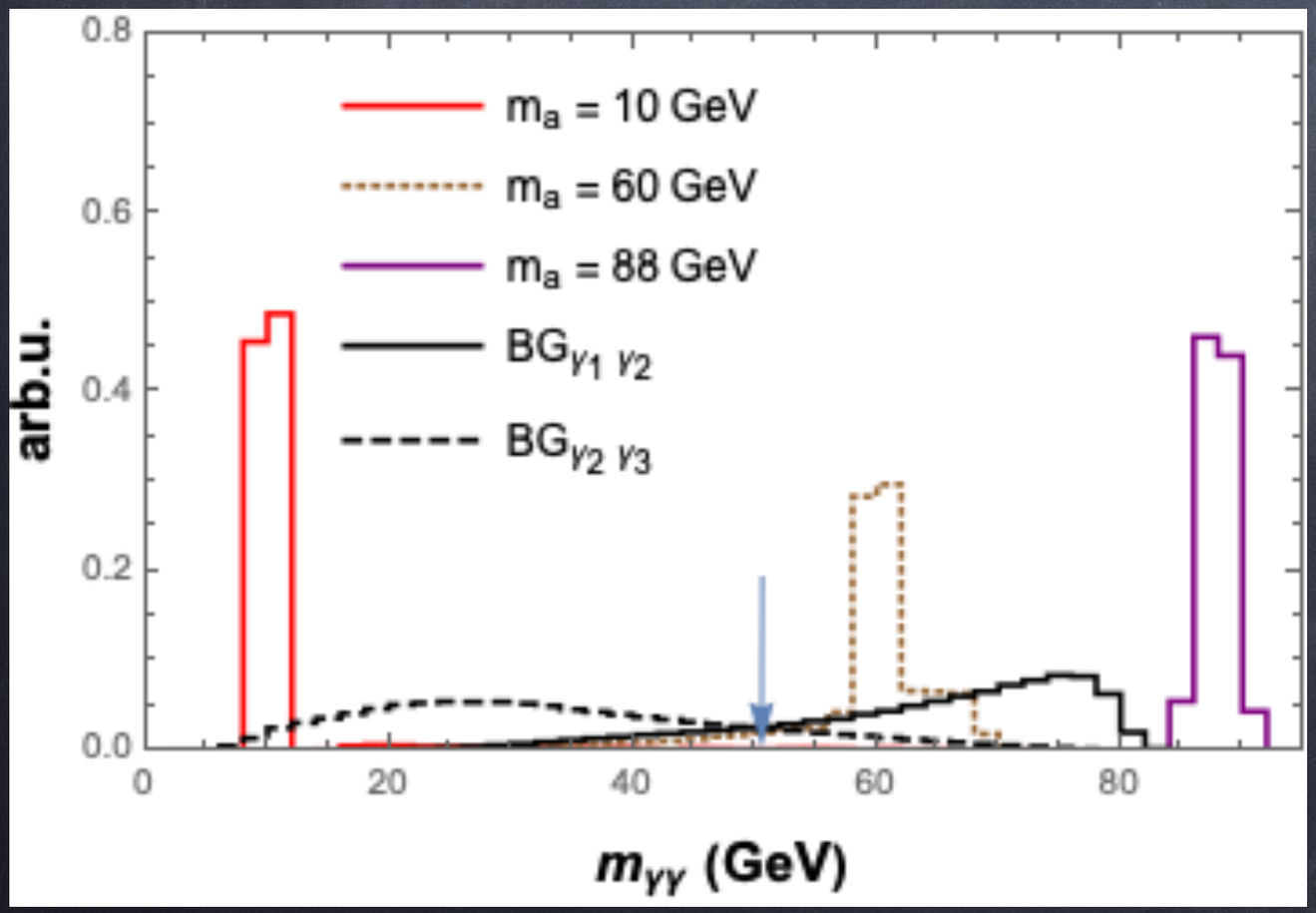
G.Cacciapaglia

Tera-Z!!



- Three isolated photons

$$BR(Z \to 3\gamma)_{\rm LEP} < 2.2 \cdot 10^{-6}$$



Discriminating variable:
invariant mass

Photon ordering changes
at inv. mass 50 GeV

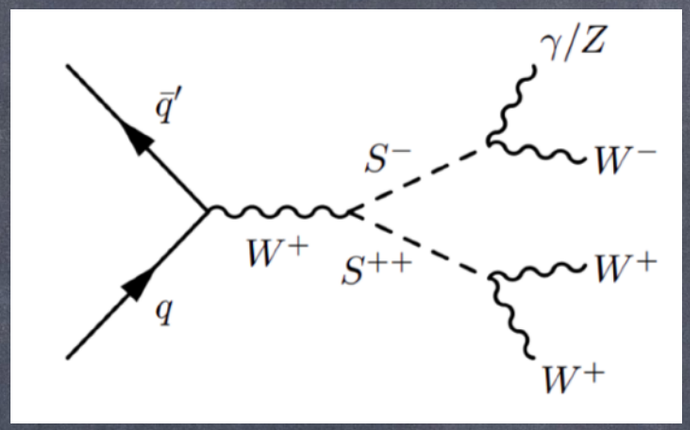
Bins above 80 GeV
populated by fakes:
hard to estimate!

Light composite scalars

L.Schwarze

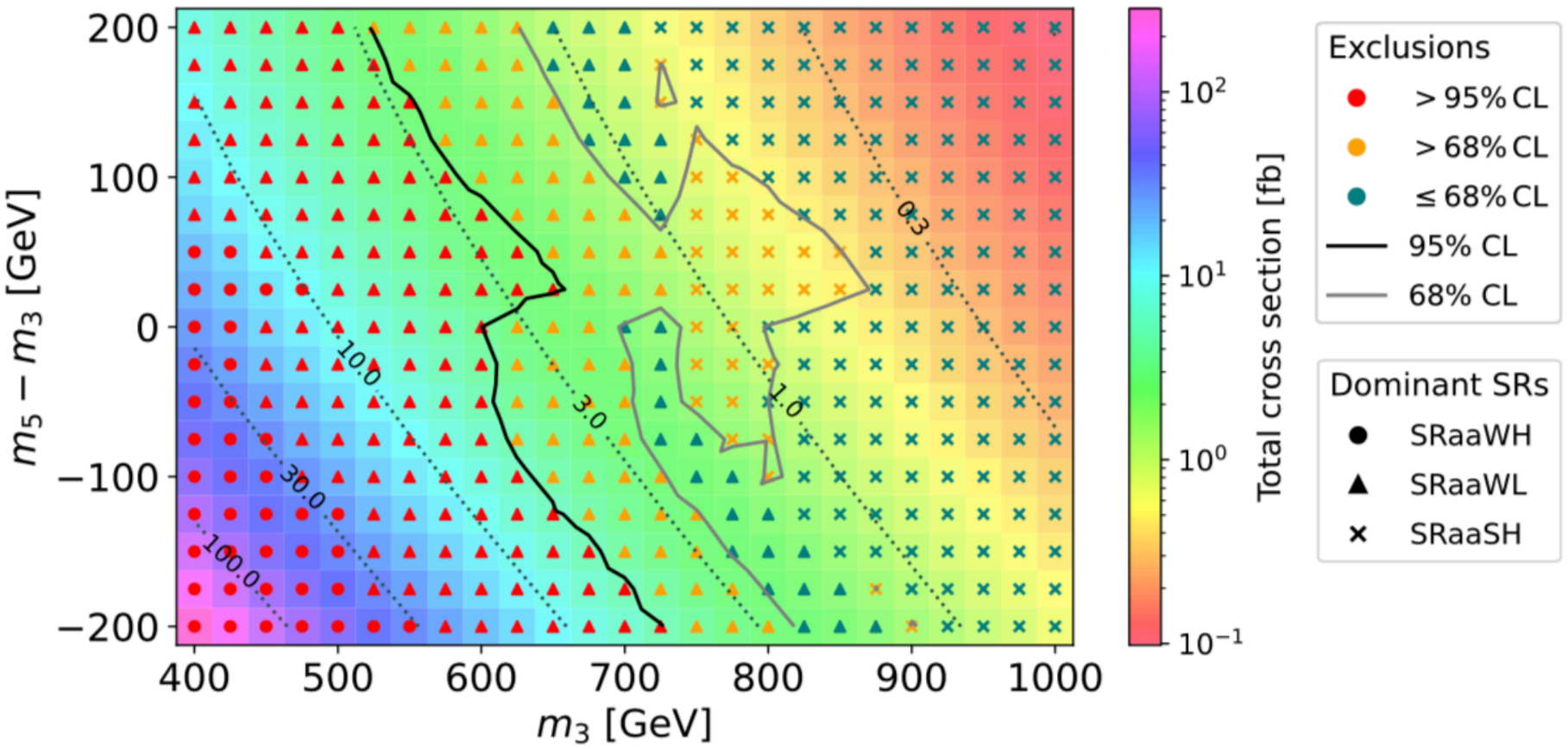
EW-charged scalars pair produced.

Case not studied in detail!



Decays to GBs or fermions (3rd)

Current LHC bounds:



Physics case for FCC-hh

Axion-like particles

J.Quevillon

- Generic EFT easy to write, but could be misleading.
- Crucial to define 'motivated' benchmark EFTs for collider studies – ongoing work!

Ultra-Violet model

Ex: PQWW axion
KSVZ invisible axion
DFSZ invisible axion
} QCD axion
ALP models
etc.

On going theoretical effort

ALP Effective Field Theory

$$\mathcal{L}_{SM-ALP-EFT} = \mathcal{L}_{SM} + \mathcal{L}_{a} + \mathcal{L}_{a-SM}$$

Ex:

$$\mathcal{L}^{D=5}_{a-SM} \supset \sum_f C_{ff}\frac{\partial^\mu a}{\Lambda}\bar{f}\gamma_\mu\gamma_5 f + C_{GG}\frac{a}{\Lambda}G_{\mu\nu}\tilde{G}^{\mu\nu} + C_{\gamma\gamma}\frac{a}{\Lambda}F_{\mu\nu}\tilde{F}^{\mu\nu} + C_{\gamma Z}\frac{a}{\Lambda}F_{\mu\nu}\tilde{Z}^{\mu\nu} + C_{ZZ}\frac{a}{\Lambda}Z_{\mu\nu}\tilde{Z}^{\mu\nu} + C_{WW}\frac{a}{\Lambda}W_{\mu\nu}\tilde{W}^{\mu\nu}$$

$$\mathcal{L}^{D\geq 6}_{a-SM} \supset \frac{C_{ah}}{\Lambda^2}(\partial_\mu a)(\partial^\mu a)H^\dagger H + \ldots$$

Which basis for ALP-SM couplings?

On going theoretical effort

Useful for model independent searches

Several independent Wilson coefficients : Is this always reasonable from a UV point of view?

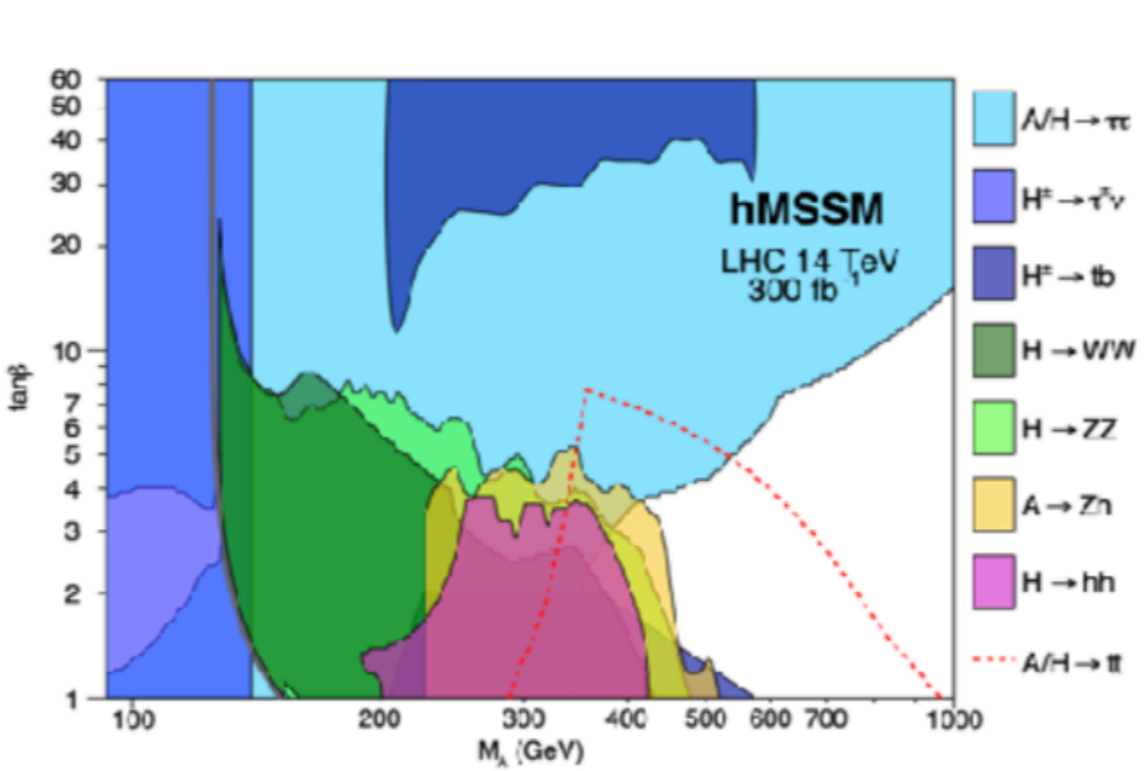
Axion-like particles

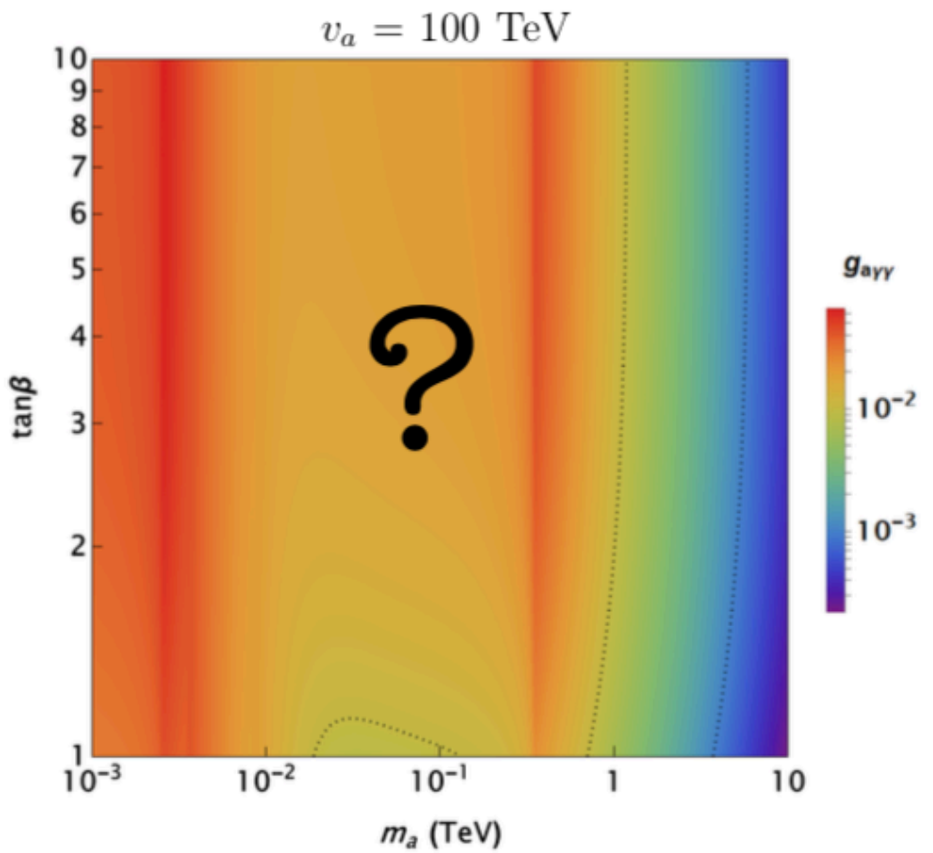
J.Quevillon

- Generic EFT easy to write, but could be misleading.
- Crucial to define 'motivated' benchmark EFTs for collider studies – ongoing work!

Current searches not effective in constraining specific models!

Allows to recast pseudoscalar searches for 2HDM on the DFSZ-like ALP parameter space

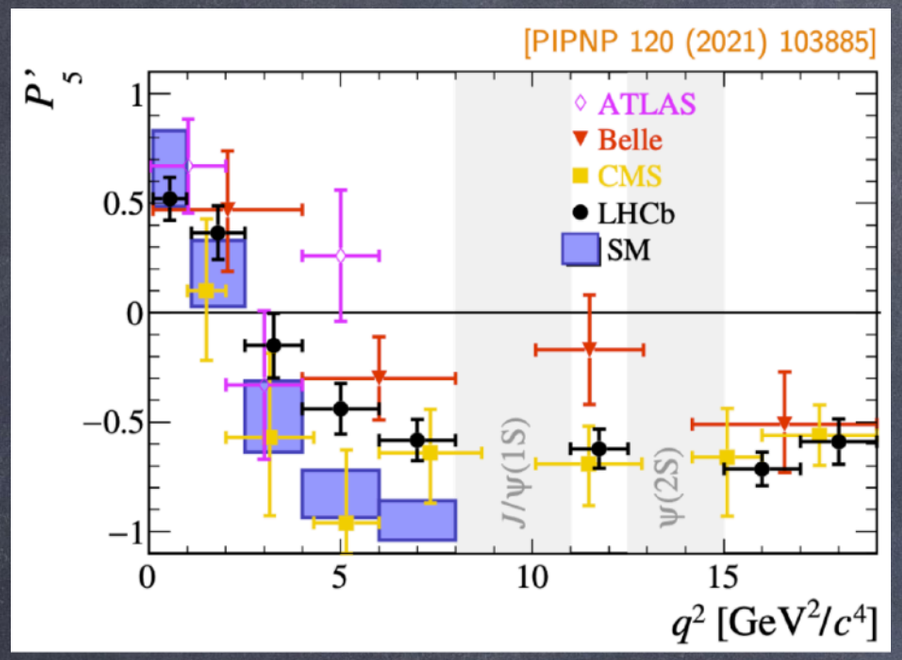




Flavour anomalies

A.Bharucha

b->s and b->c transitions:



Attribute	$\Upsilon(4S)$	pp	Z^0
	Belle II	LHC	FCC-ee
All hadron species		✓	✓
High boost		✓	✓
Enormous production cross-section		✓	
Negligible trigger losses	✓		✓
Low backgrounds	✓		✓
Initial energy constraint	✓		(✓)

Channel	Belle II	LHCb	Giga-Z	Tera-Z	10×Tera-Z (FCC-ee)
B^0, $\bar{B}^0$	5.3×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}	1.2×10^{12}
$B^\pm$	5.6×10^{10}	$\sim 6 \times 10^{13}$	1.2×10^8	1.2×10^{11}	1.2×10^{12}
B_s, $\bar{B}_s$	5.7×10^8	$\sim 2 \times 10^{13}$	3.2×10^7	3.2×10^{10}	3.2×10^{11}
$B_c^\pm$	-	$\sim 4 \times 10^{11}$	2.2×10^5	2.2×10^8	2.2×10^9
Λ_b, $\bar{\Lambda}_b$	-	$\sim 2 \times 10^{13}$	1.0×10^7	1.0×10^{10}	1.0×10^{11}

Taus only possible @ FCC!!!

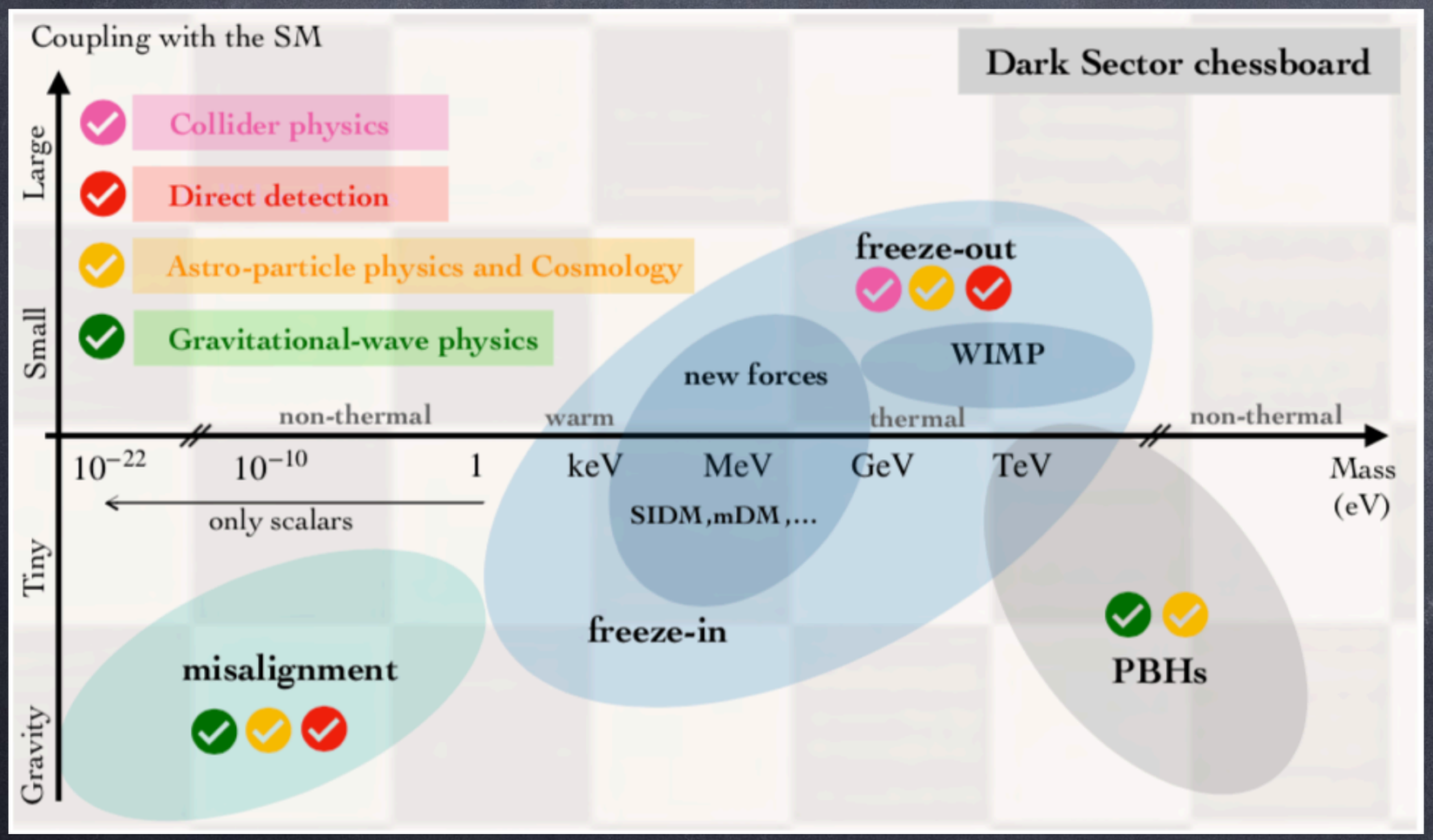
FCC prospects:

- High production rates, highly boosted, high reconstruction efficiency, all hadron species: very promising
- Sensitivity to decays with τ final states, e.g. $b \to s\tau\tau$, $B_c \to \tau\nu$, precise measurement ofLFV decays of b hadrons and more
- High sensitivity to τ decays, vibrant τ physics program

Dark Matter?

D.Buttazzo

We know it exists, we know its relic abundance...
we have no indication on its mass and couplings (besides gravity)!



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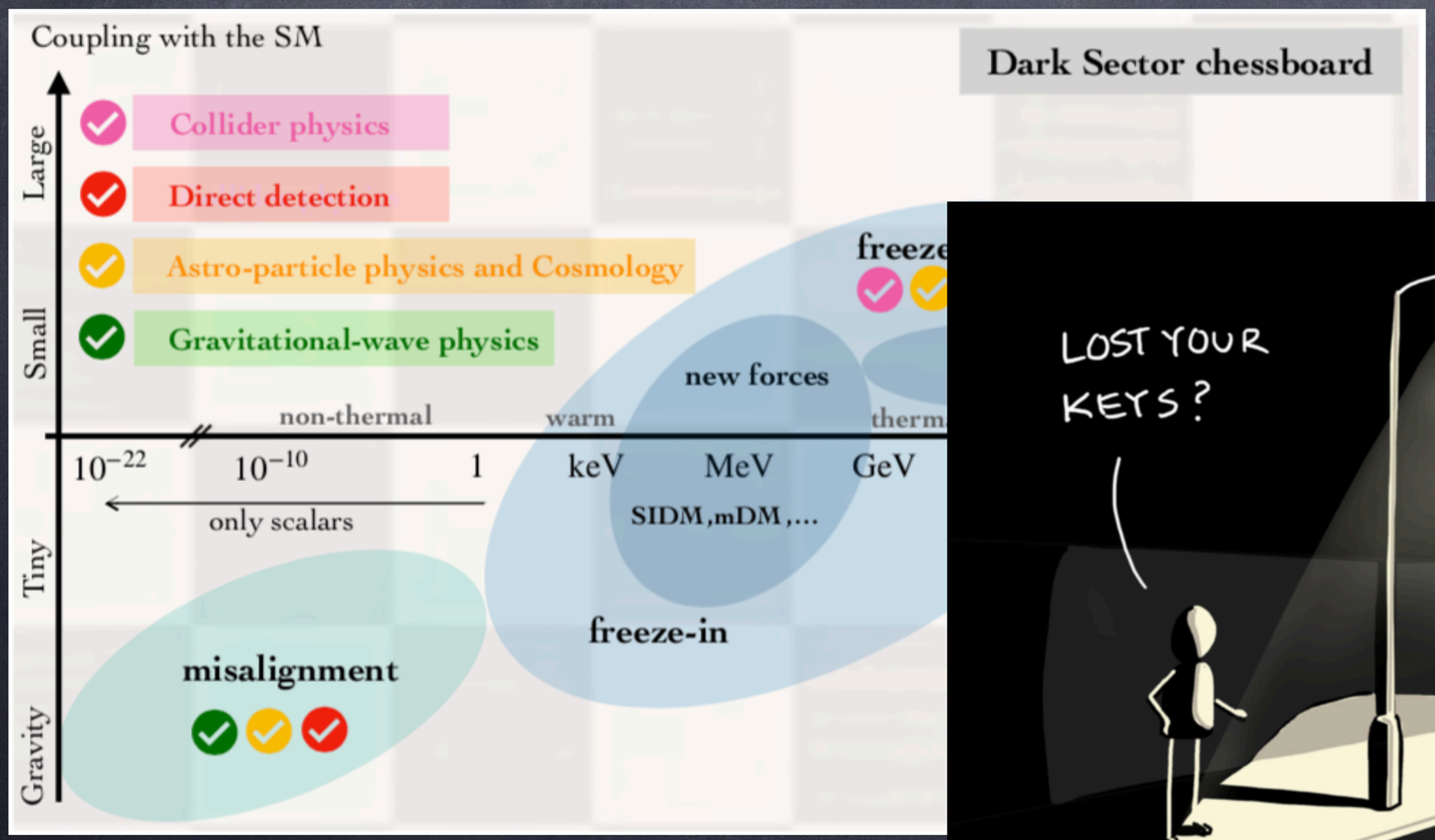
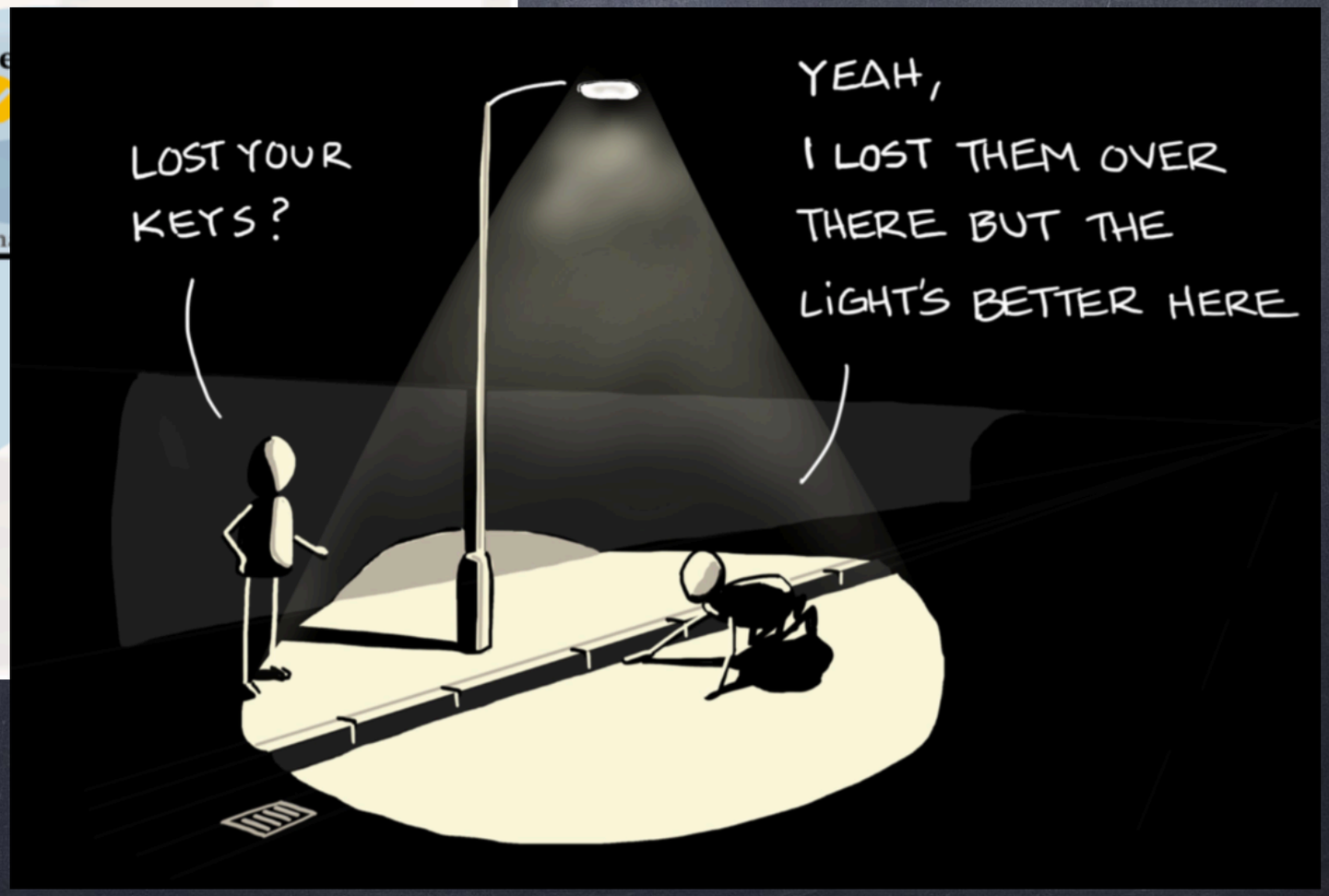
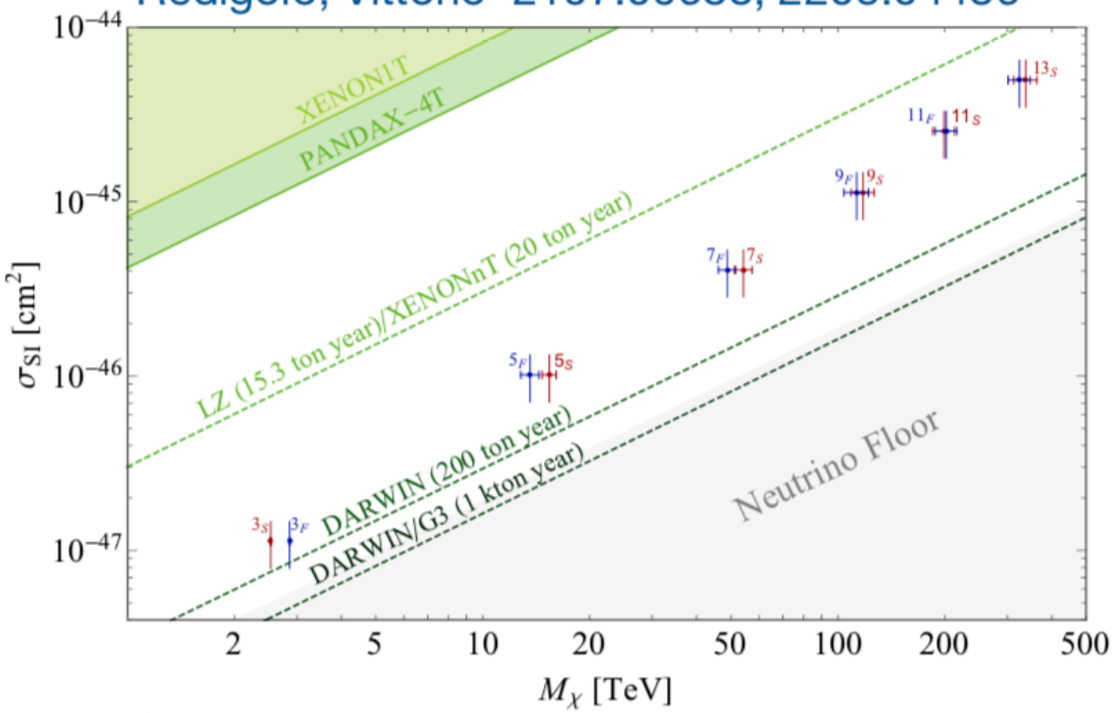




Dark Matter?

D.Buttazzo

Bottaro, DB, Costa, Franceschini, Panci, Redigolo, Vittorio 2107.09688, 2205.04486



Direct Detection challenging...

Potentially in reach of a high-energy collider!

	EW n-plet	Mass [TeV]
Majorana fermion	3_0	2.86
	5_0	13.6
	7_0	48.8
	9_0	113
	11_0	202
	13_0	324.6
Dirac fermion	$2_{1/2}$	1.08
	3_1	2.85
	$4_{1/2}$	4.8
	5_1	9.9
	$6_{1/2}$	31.8
	$8_{1/2}$	82
	$10_{1/2}$	158
	$12_{1/2}$	253

Dark Matter?

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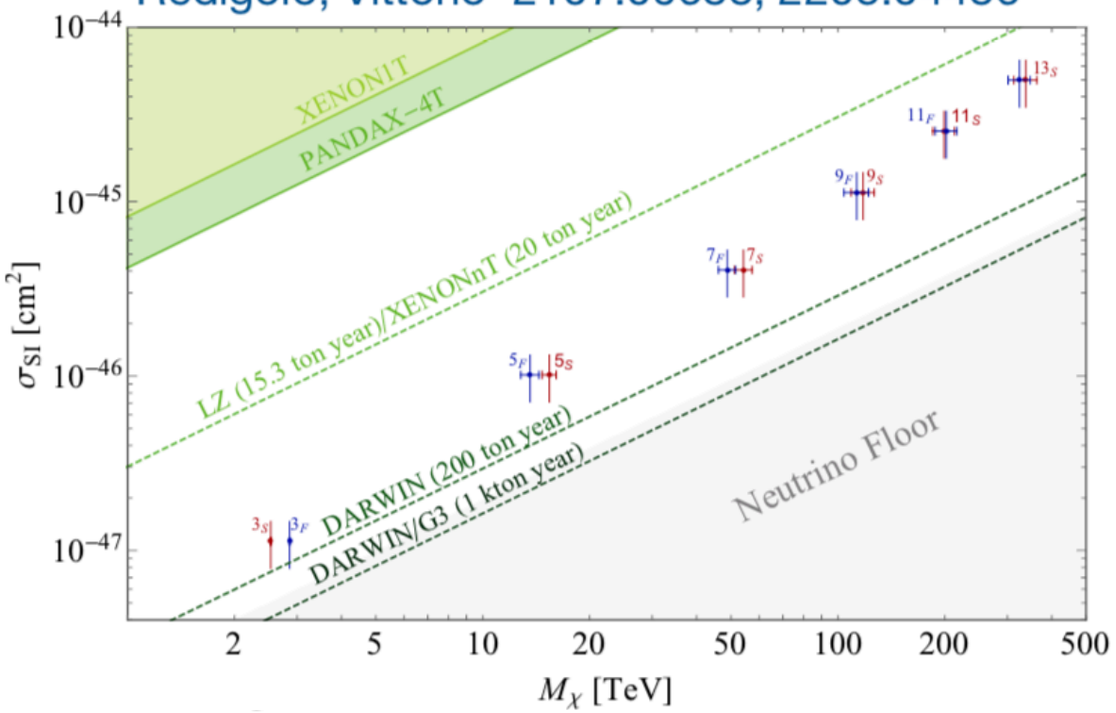

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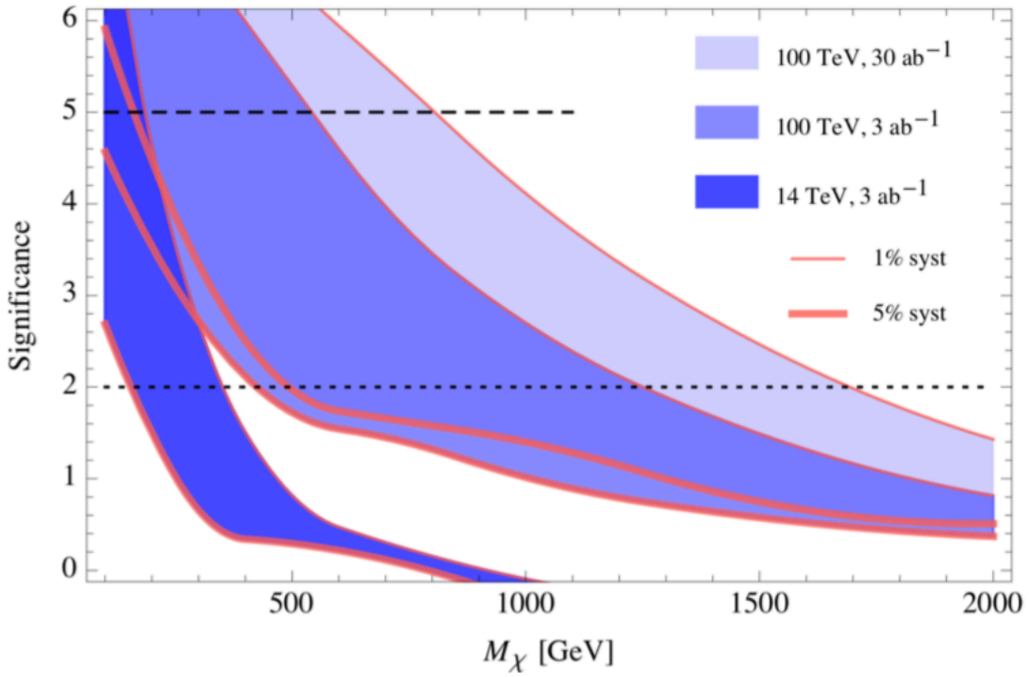
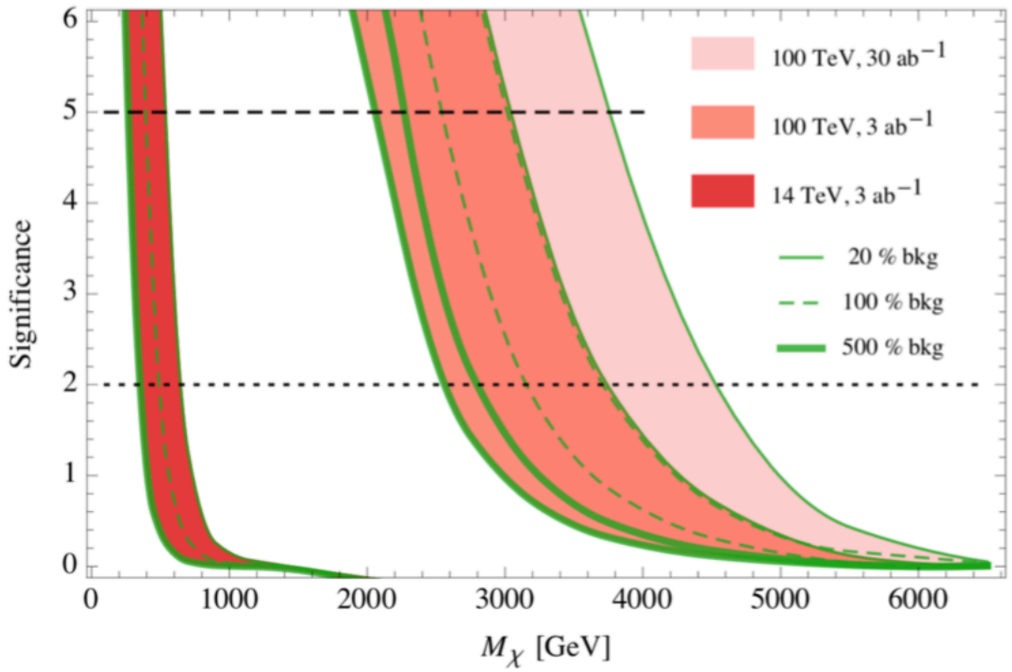
Monojet



Disappearing Tracks



ach of
collid

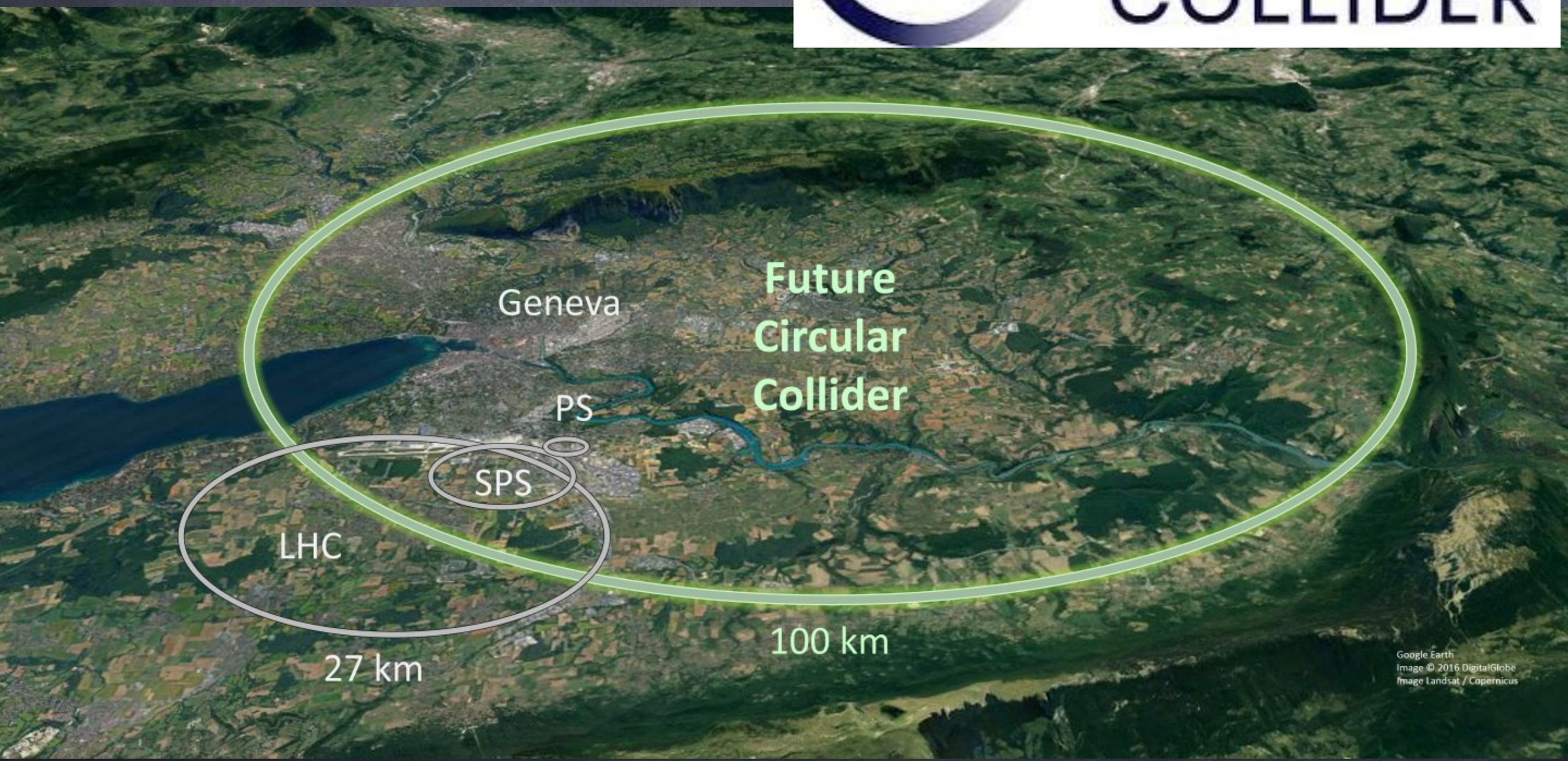
Perspectives

- A lot of work needs to be done to identify benchmarks for FCC studies.
- Automatic tools could help theorists to be more engaged.
- Complementarity and synergy among signatures must be exploited (direct production, precision, distribution tails...)
- Taus are a unique opportunity for BSM @ FCC
- Displaced vertices
- More involvement of theorists is needed!
- Precision calculation (see Fulvio's talk on Monday)

Perspectives

The FCC is already
in the present:
the project has started!

FUTURE
CIRCULAR
COLLIDER



Perspectives

The FCC is already
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the project has started!

FRONTIERS
CIRCULAR
COLLIDER

Future
Circular
Collider

Geneva

PS

SPS

LHC

27 km

100 km