

BSM Group Introduction

Theory Retreat
St Genis
Friday 4th Nov, 2016

Matthew McCullough



This talk.

- The BSM research program at CERN is shaped by the questions we must answer...

Hierarchy problem

Dark matter

Neutrinos

The unexpected

Flavour

Higgs Physics

Grav Waves

This talk.

- The BSM research program at CERN is shaped by the questions we must answer...

and the unique proximity to experimental frontier!

A light purple oval with a red border containing the text "LHC" in red serif font.

LHC

A light green oval with a purple border containing the text "FCC" in purple serif font.

FCC

This talk.

- The SM research program at CERN is shaped by the questions we are trying to answer...

I will try to give a taste of the things CERN folks are interested in currently in these areas...

Dark matter

Unexpected


Flavour

Grav Waves

and unique proximity to experimental results!

LHC

FCC



Hierarchy problem/
Weak scale naturalness

Older ideas in Naturalness

Composite Higgs

- No fundamental scalars = no problem.



- TeV scale correction to Higgs Effective Field Theory
- New resonances, weak and coloured, at TeV scale.

Older ideas in Naturalness

Supersymmetry

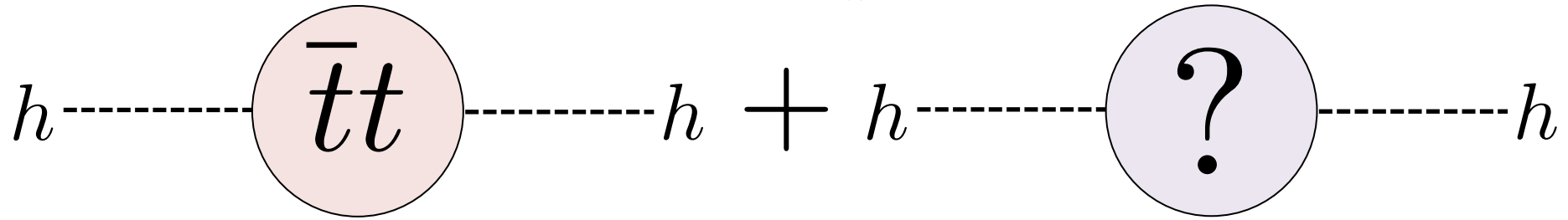
- Fermions have no hierarchy problem (chiral symm').
- SUSY ties scalar mass to fermion mass, hence no problem.

$$H \leftrightarrow \tilde{H} \longleftrightarrow M_H = M_{\tilde{H}}$$

- Still well motivated, and an active area of investigation.

Newer Ideas in Naturalness

Could there be a hidden “Top Partner”?



Newer Ideas in Naturalness

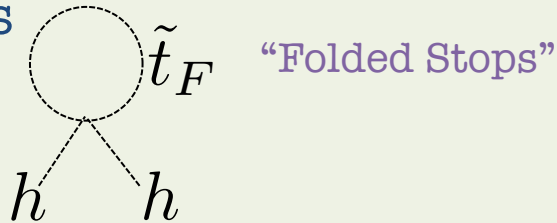
Could there be a hidden “Top Partner”?

Much attention now to alternative ideas:

Folded SUSY

hep-ph/
0609152

Theory where EW-charged
uncoloured scalars are top
partners

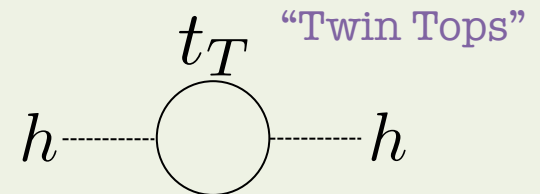


...but they must be charged
under new hidden QCD’.

Twin Higgs

hep-ph/
0506256

Theory where top partners
are SM **gauge neutral** fermions

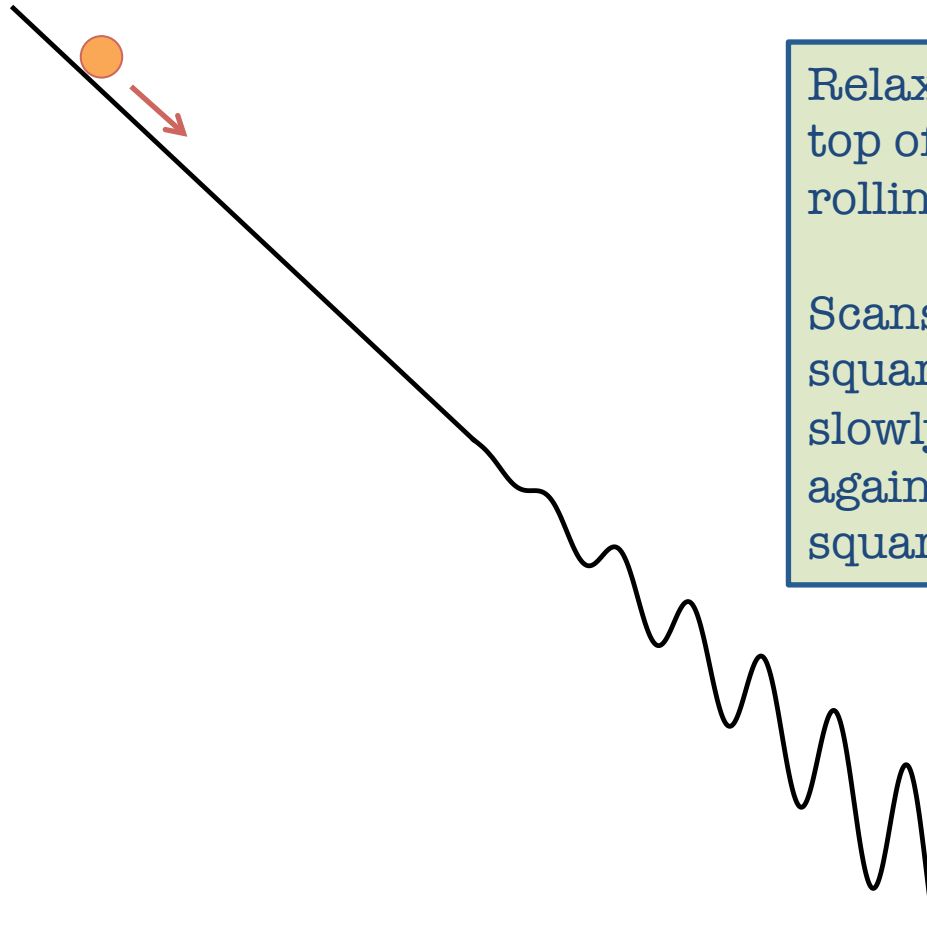


...but they must be charged
under new hidden QCD’.

The Relaxion

• Graham, Kaplan, Rajendran, 2015

- Is problem solved dynamically, through cosmological evolution?



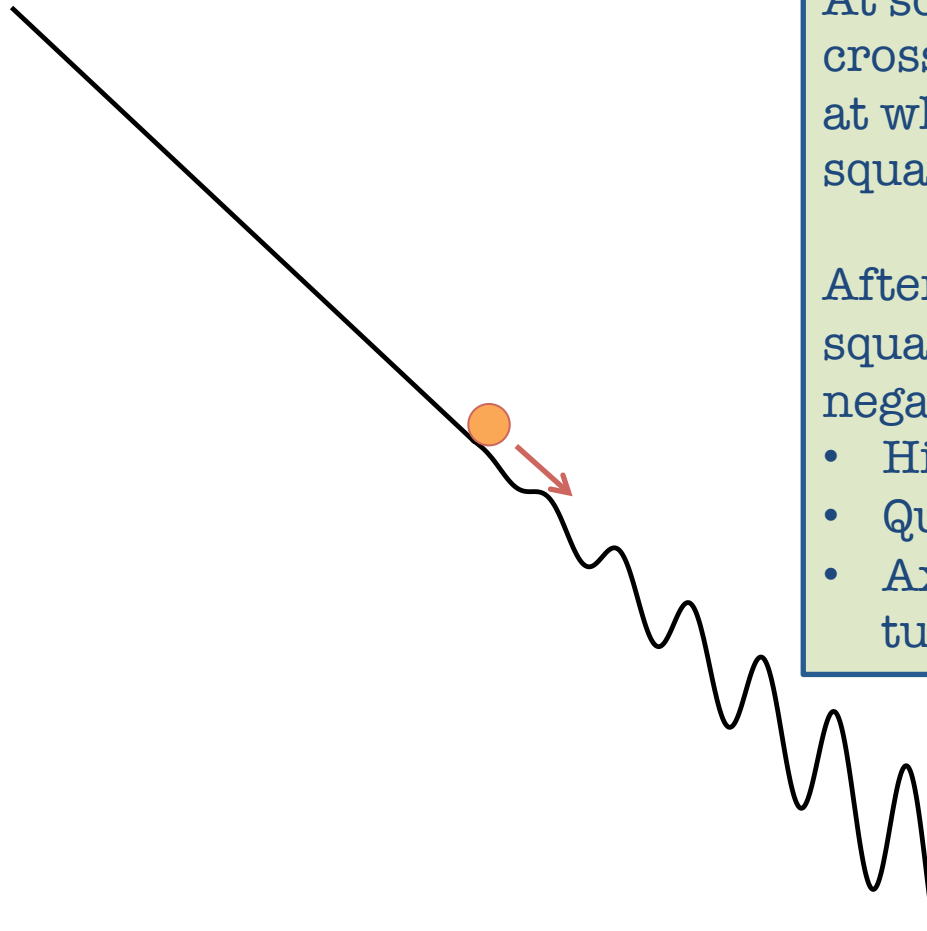
Relaxion starts at the top of potential. Starts rolling down.

Scans Higgs mass-squared while it rolls, slowly cancelling against large mass-squared.

The Relaxion

• Graham, Kaplan,
Rajendran, 2015

- Is problem solved dynamically, through cosmological evolution?



At some point relaxion crosses critical value at which Higgs mass-squared becomes zero.

After this mass-squared becomes negative:

- Higgs gets a vev
- Quarks get mass
- Axion potential turns on

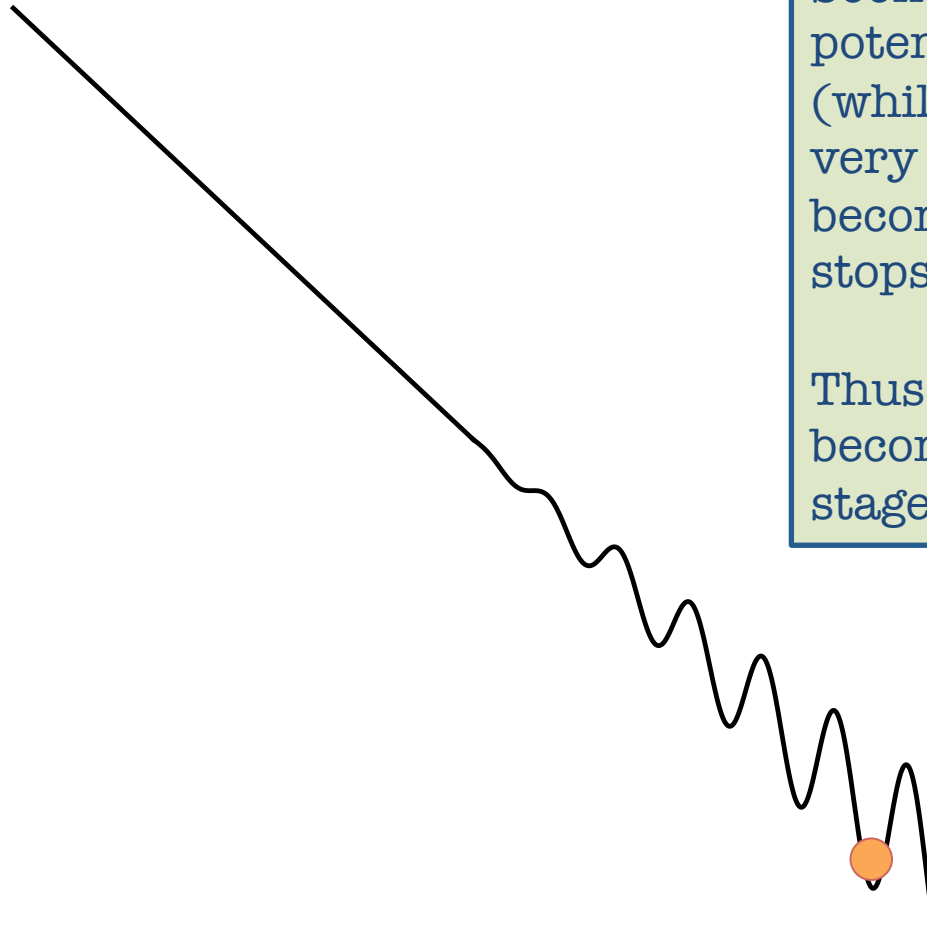
The Relaxion

• Graham, Kaplan,
Rajendran, 2015

- Is problem solved dynamically, through cosmological evolution?

Soon after axion potential turns on (while Higgs vev is still very small), relaxion becomes trapped and stops rolling.

Thus Higgs vev becomes stuck at this stage too.



The Relaxion

• Graham, Kaplan, Rajendran, 2015

- Is problem solved dynamically, through cosmological evolution?

Can choose “g” parameter such that field stops when $\langle h \rangle$ is still very small. This is a parameter choice, not a tuning, since radiatively stable.

Soon after axion potential turns on (while Higgs vev is still very small), relaxion becomes trapped and stops rolling.

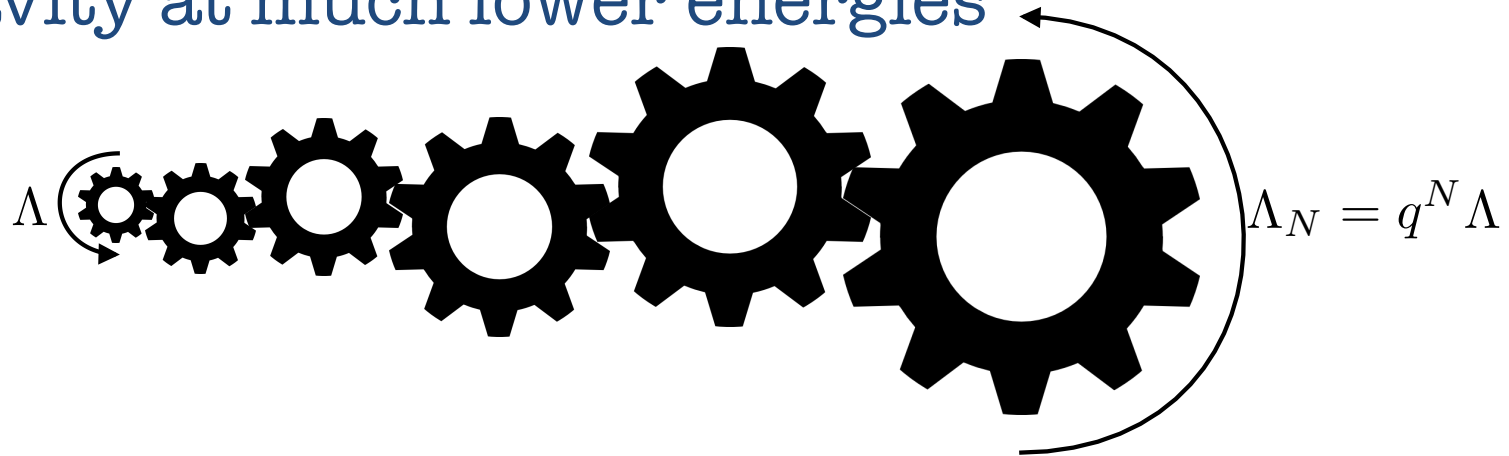
Thus Higgs vev becomes stuck at this stage too.

$$\frac{\partial V}{\partial \phi} \sim gM^2 - \frac{f_\phi^2 m_\pi^2}{f} \sin\left(\frac{\phi}{f}\right) = 0$$



Clockworking

- Maybe M_P is a fake, UV-completion of quantum gravity at much lower energies



- Many other unrelated applications. **Axions**, flavour, dark matter, **neutrinos**, colliders.

Dark Matters

Evidence for dark matter is now overwhelming

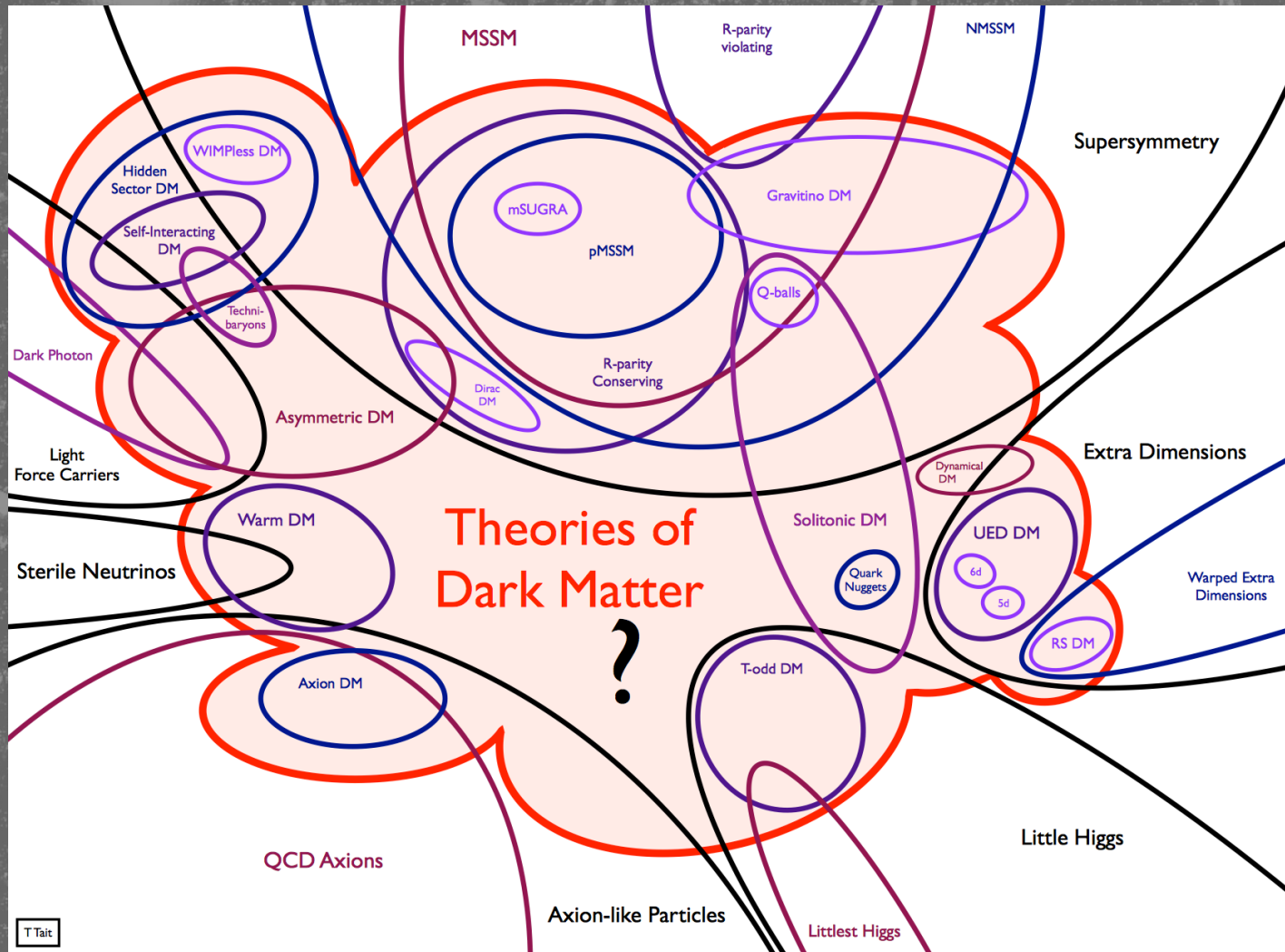
- Rotation curves
- CMB
- Large scale structure
- Velocity dispersions
- Gravitational lensing (Bullet Cluster)
-

Yet we have no clue what it is at the particle level!



Dark Matters

But there are some ideas...



Stolen from slides of Tim Tait

Dark Matter

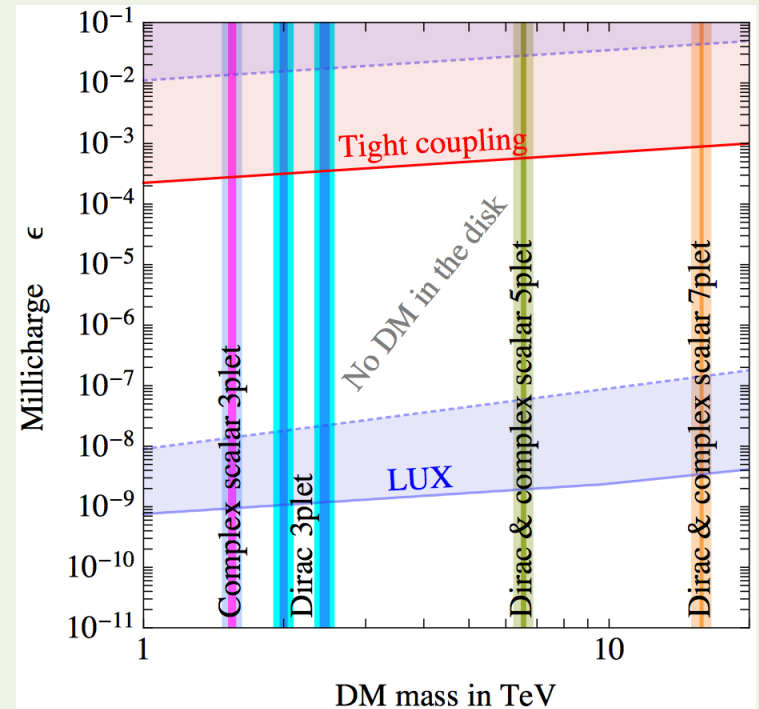
Del-Nobile,
Nardecchia,
Panci

CERN-TH at forefront of dark matter models...

Millicharged WIMPs

Millicharged MDM: $(1, n, \epsilon)$

$SU(3)_c$ $SU(2)_W$ $U(1)_Y$

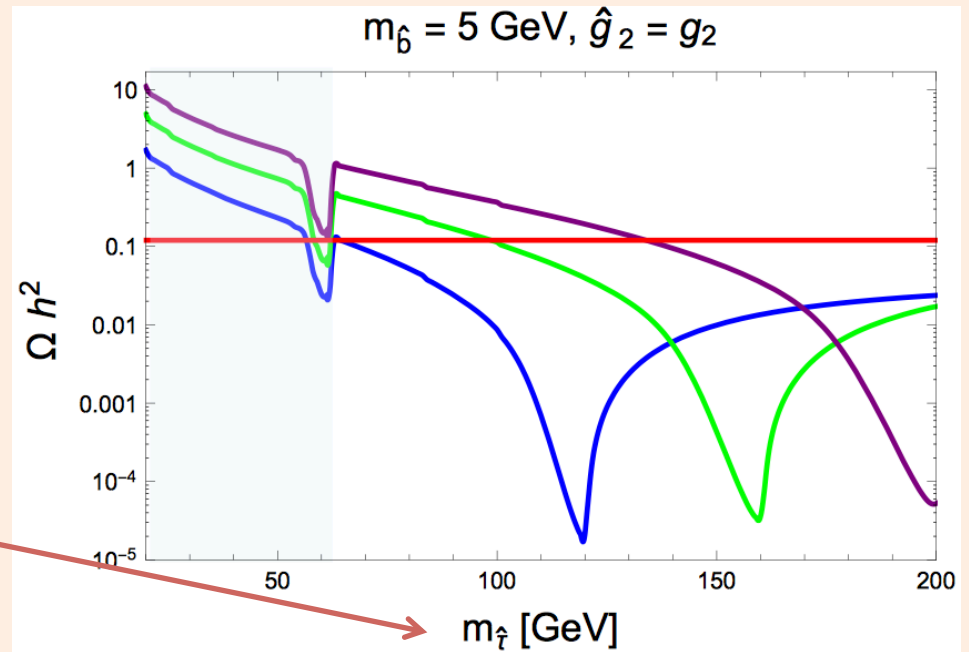
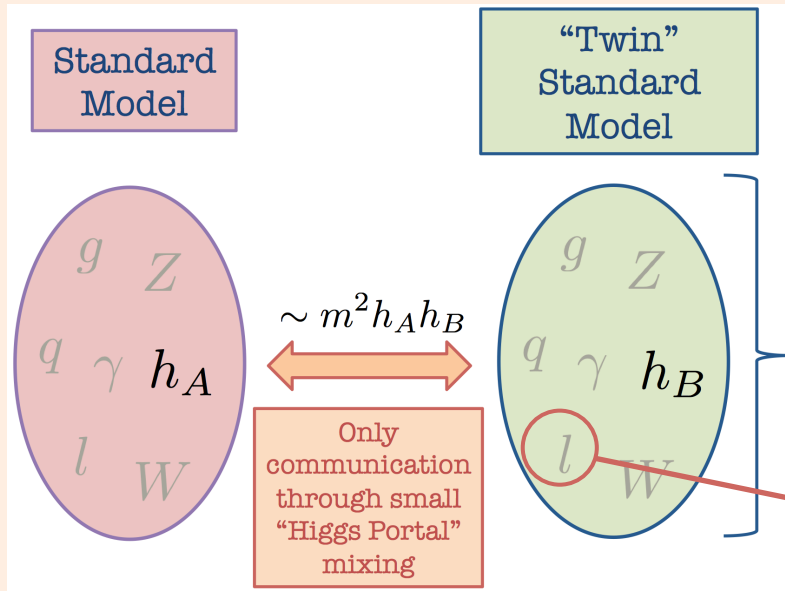


Dark Matter

Craig,
Katz

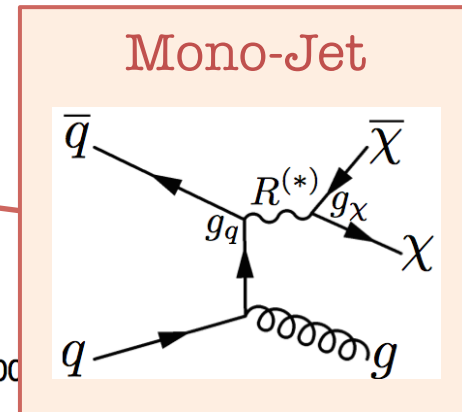
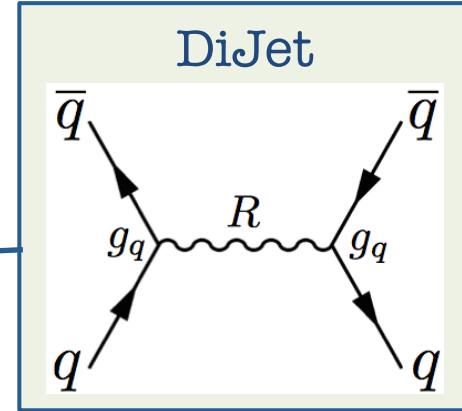
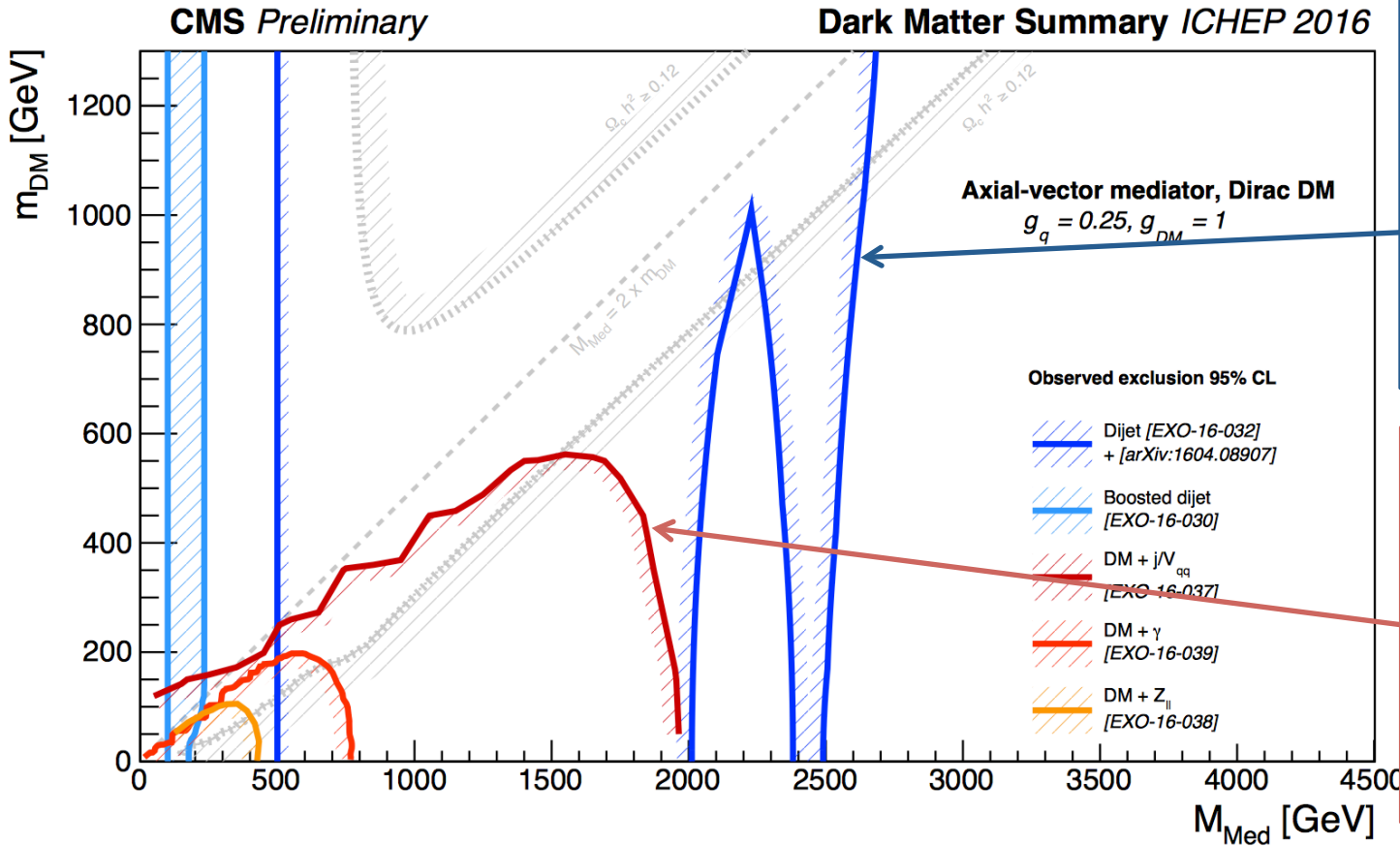
CERN-TH at forefront of dark matter models...

Twin Dark Matter



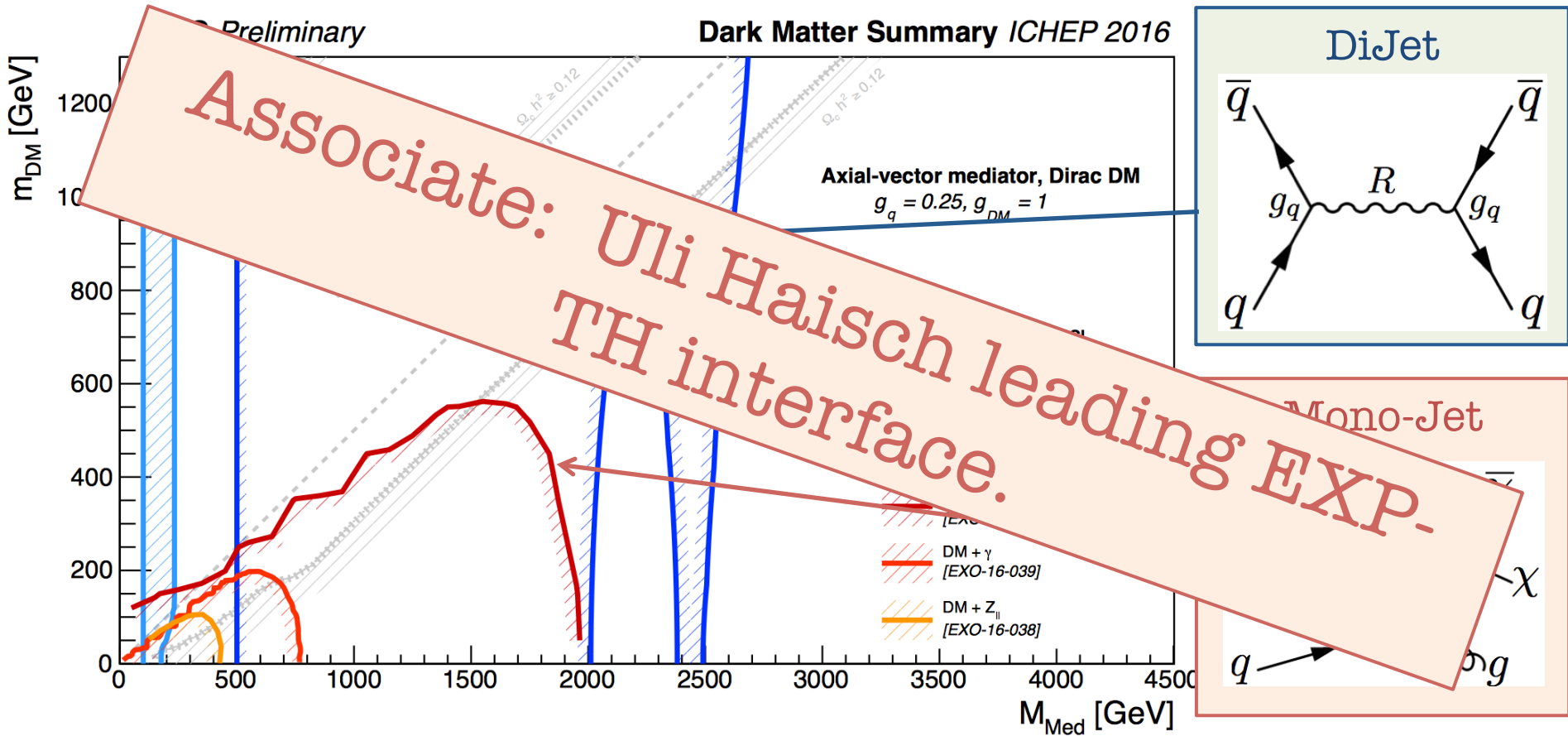
Dark Matter at the HL-LHC

CERN-TH at forefront of collider DM searches...



Dark Matter at the HL-LHC

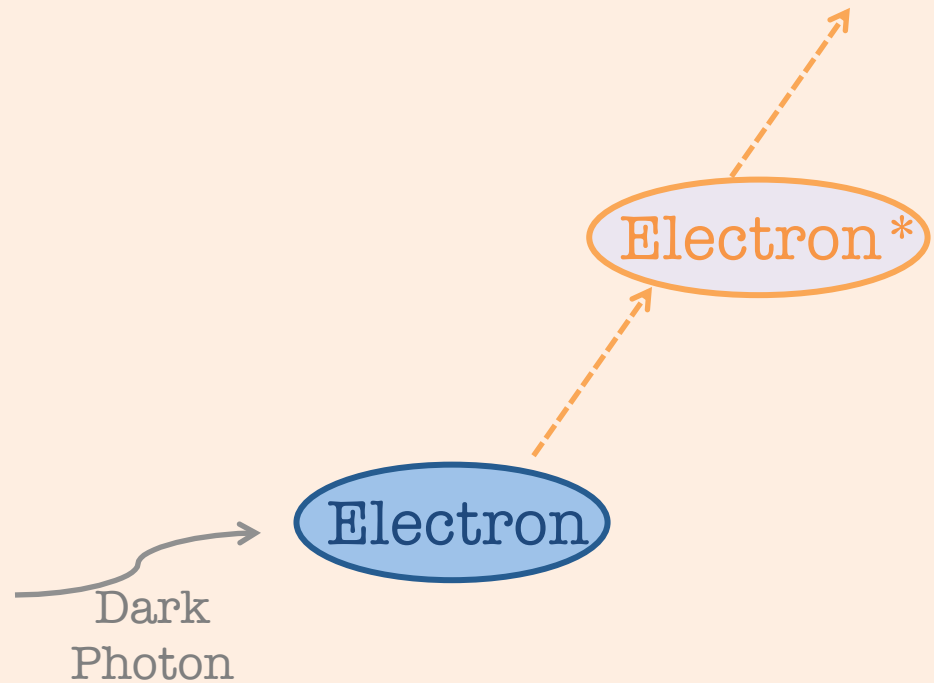
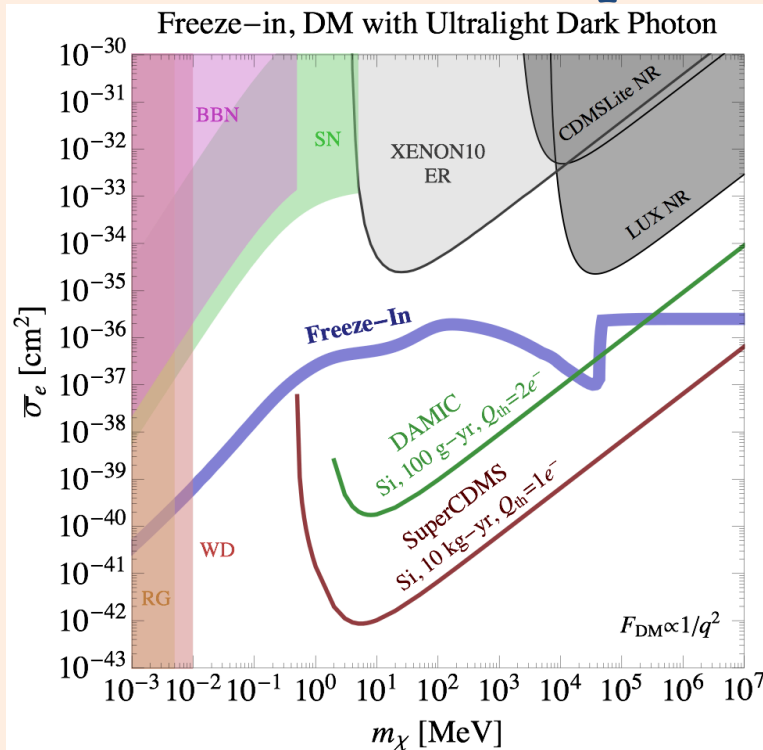
CERN-TH at forefront of collider DM searches...



Dark Matter

CERN-TH at the forefront of direct detection...

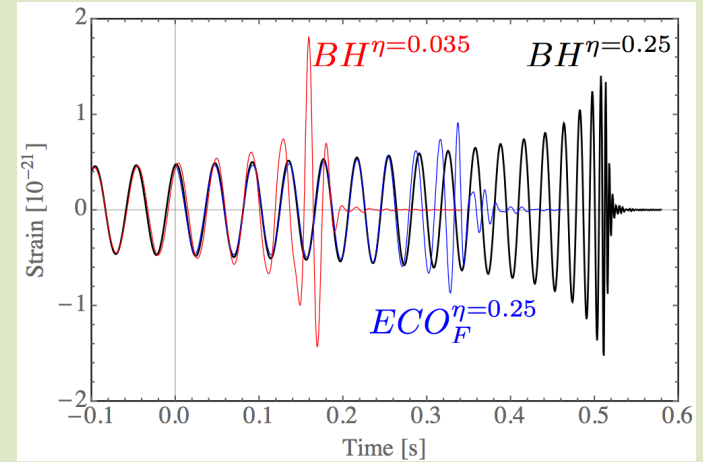
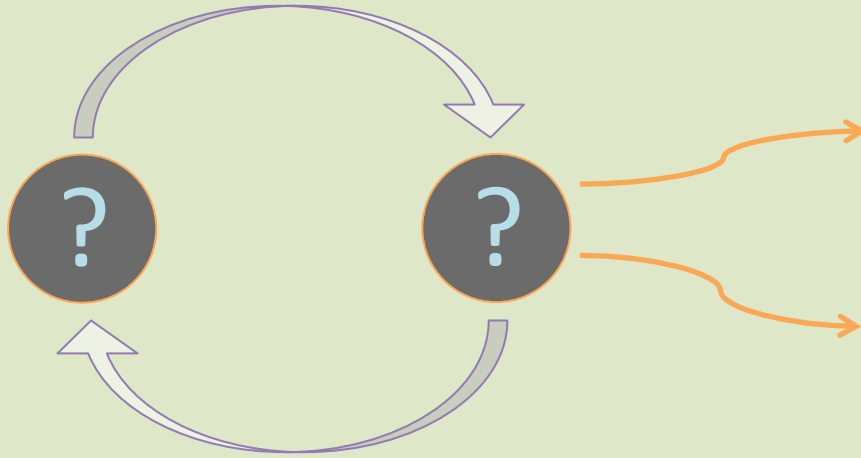
Absorption of light dark matter



Gravitational Waves

Giudice,
MM, Urbano

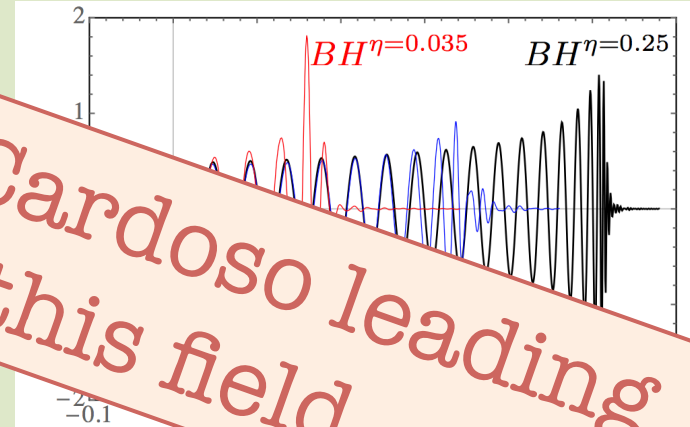
LIGO and new Dark Compact Objects



Gravitational Waves

LI Dark Compact Objects

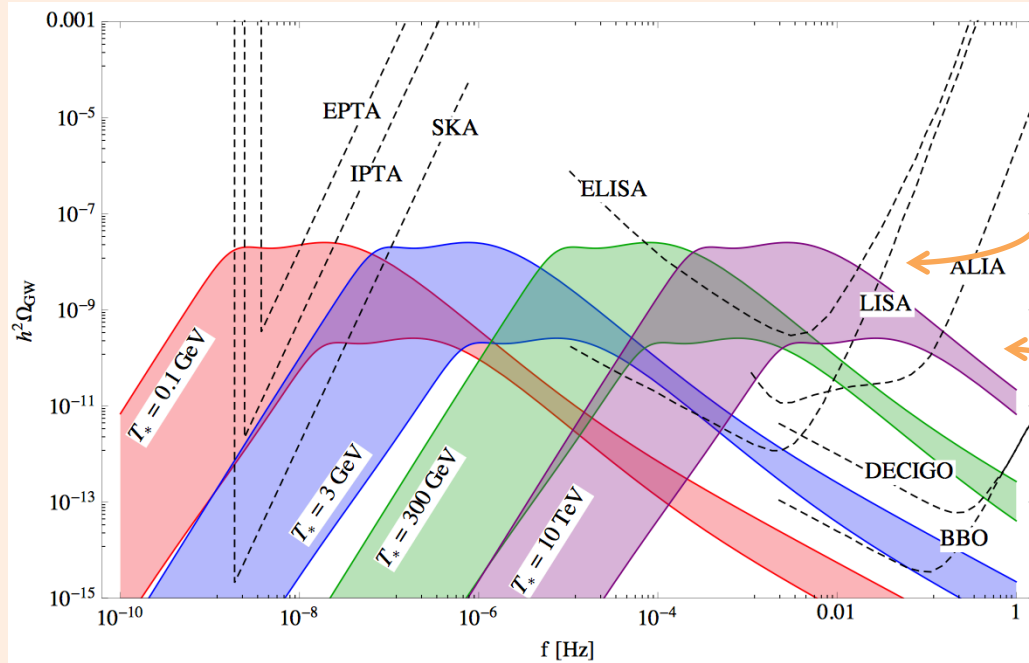
Associate: Vitor Cardoso leading authority in this field.



Gravitational Waves

Schwaller, **Katz**

eLISA and (Dark Sector) Phase Transitions

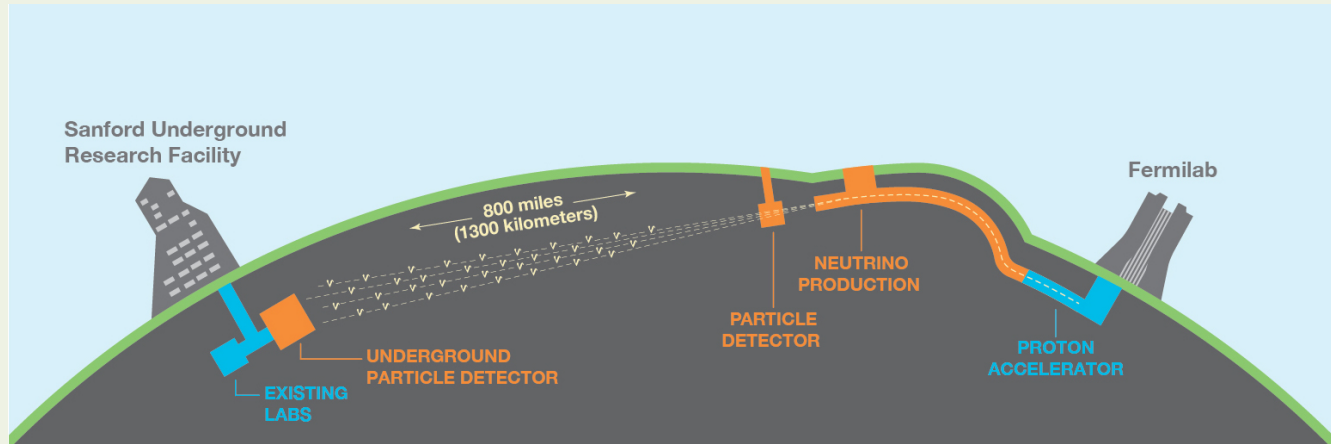


SM

New Decoupled Sectors

Neutrino Physics

Wider CERN role in neutrino exp, such as DUNE:



CERN-TH role: “Neutrino Platform”

Coordinators: Barenboim, Coloma, Hernandez,
Huber, Pascoli, Schwetz.

Kick-Off: 27th – 31st March 2017!

Flavour

Model building and data analysis. Numerous interesting anomalies...

Composite Higgs Exp for:

$$R_K = \frac{\mathcal{B}(B \rightarrow K\mu^+\mu^-)}{\mathcal{B}(B \rightarrow Ke^+e^-)} \Bigg|_{q^2 \in [1,6] \text{ GeV}}^{\text{exp}} = 0.745_{-0.074}^{+0.090} \pm 0.036.$$

From new resonances

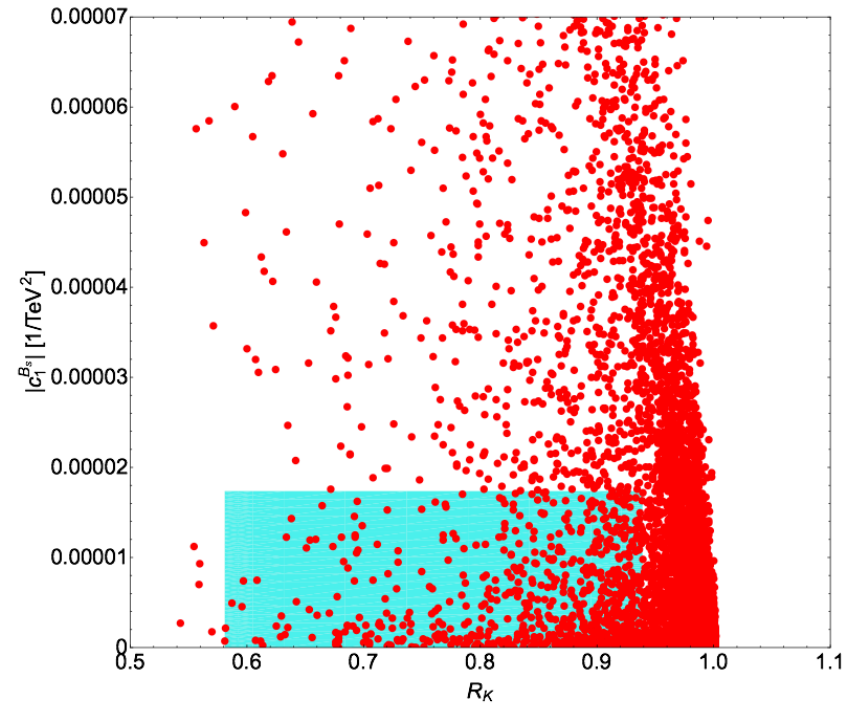
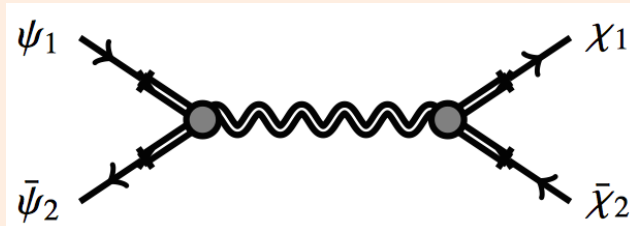
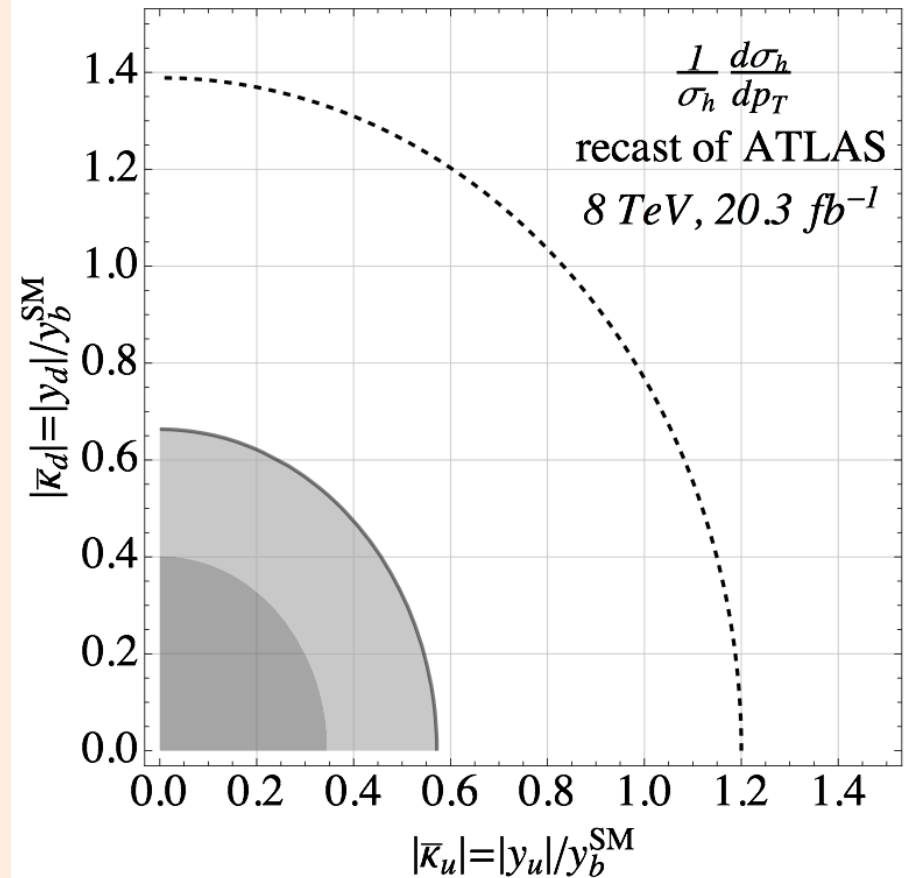
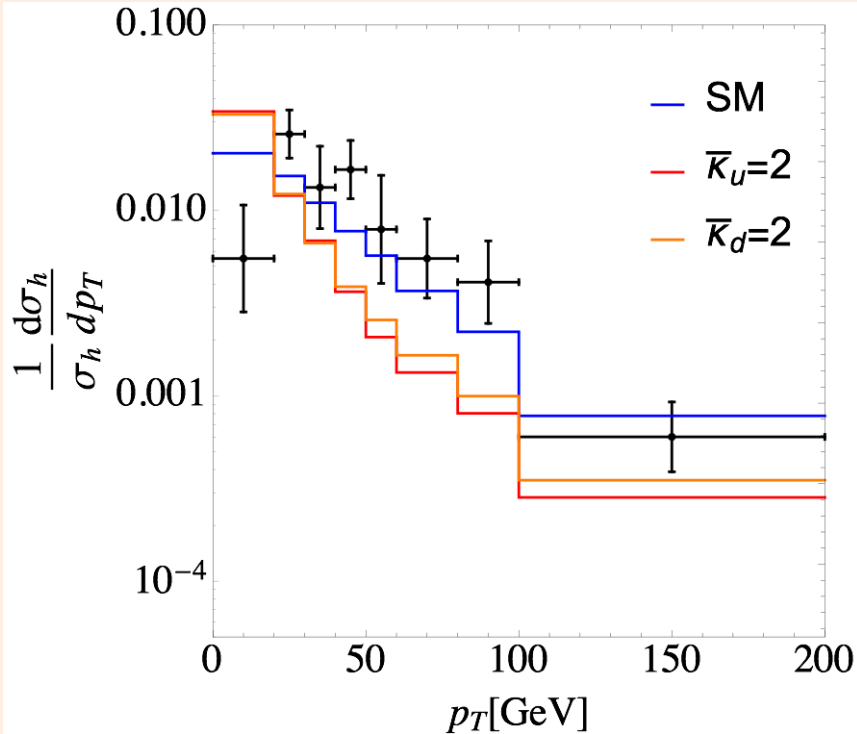


Figure 4: Value of $|c_1^{B_s}(m_\rho)|$ versus R_K for points reproducing the Higgs mass and within 2σ from $B_s \rightarrow \mu^+\mu^-$, for $f_\pi = 1.2$ TeV. The blue box marks the allowed values of R_K and $|c_1^{B_s}|$ at 95% C.L..

Higgs Physics

Soreq, Zhu,
Zupan

New ideas for probing Higgs couplings to light quarks at LHC:

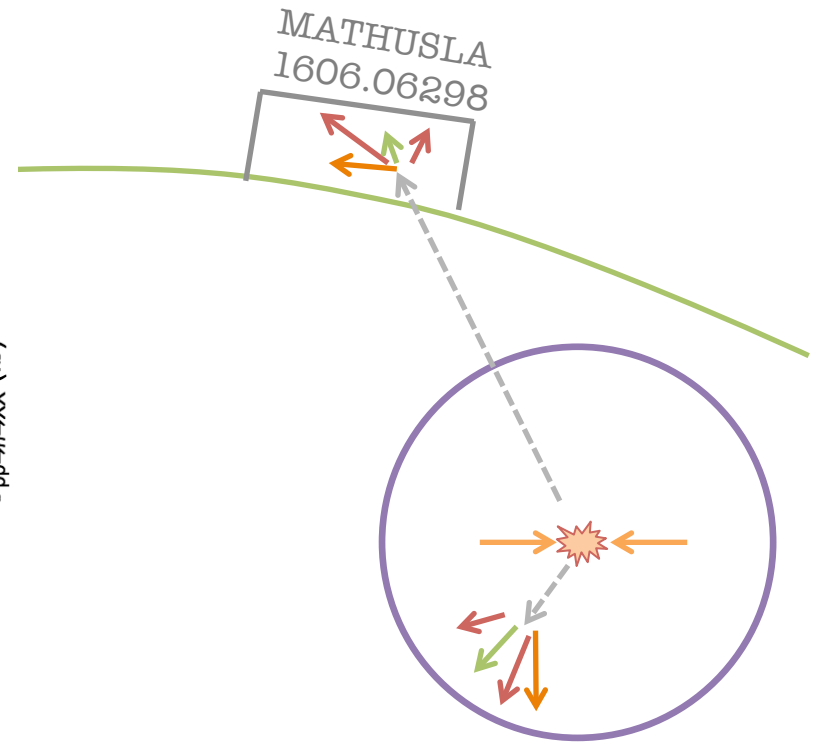
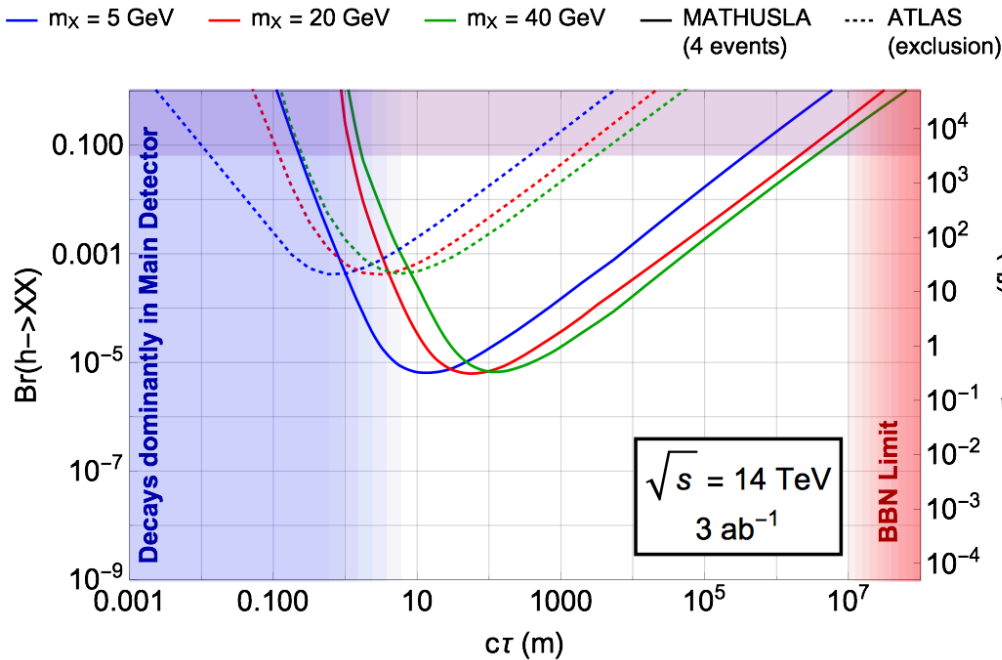


The Unexpected

Long-lived particles come up in many models.

Many exciting and creative ideas on the theoretical front...

and the detection front...



Projection based on 1606.06298.

to extend reach by several orders of magnitude!

BSM in the TH-Ecosystem.

Community very fortunate to have associates/
visitors:

Hernandez

Strumia

Mahbubani

Boyarsky

Kehagias

Arbey

De Blas

Ghilenca

Mahmoudi

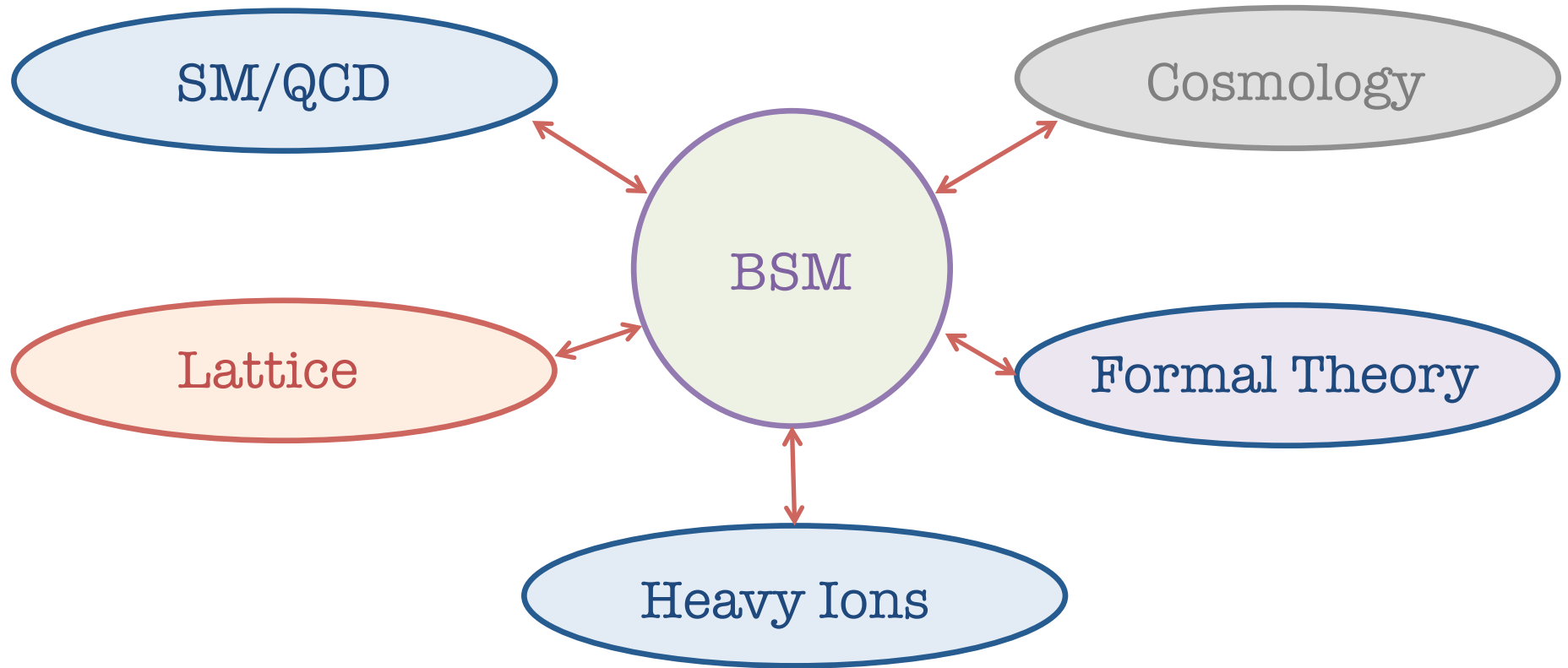
Zupan

Torre

Haisch

BSM in the TH-Ecosystem.

and the other groups...



BSM in the TH-Ecosystem.

and food...

BSM Lunch

Thursdays: Lunch + Seminar

$$S_{\text{On-Shell}} = \int_{\text{Belfast}}^{\text{Oxford}} \mathcal{L}_{\text{MM}} dt + \int_{\text{Oxford}}^{\text{MIT}} \mathcal{L}_{\text{MM}} dt + \int_{\text{MIT}}^{\text{CERN}} \mathcal{L}_{\text{MM}} dt$$

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Hierarchy problem

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Flavour.

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