CATERINA DOGLIONI - *SEMINAR AT VUB, 2017-10-26*
LUND UNIVERSITY

Search for (non-SUSY) Dark Matter at the Large Hadron Collider

(a very personal view)

ATLAS EXPERIMENT erc European Commission Horizon 2020 European Union funding for Research & Innovation

What this talk is not

1. Full of new excesses (unfortunately)
2. A comprehensive list of results

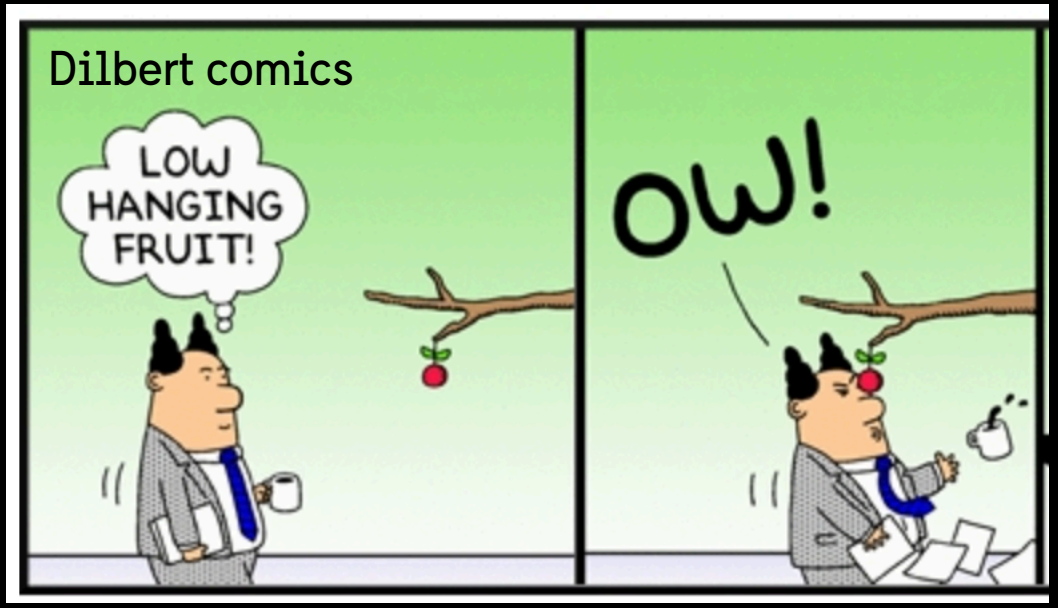
What this talk is

A rather personal view of LHC non-SUSY DM searches

(hoping not to upset anyone in the process)

First things first: what you want to know
(or: take-home messages)

1. *"Low-hanging fruit for DM @ LHC has been picked"*
   where do we go from here?
   Overview of Mono-X searches
   Next on the menu: long-lived particles (?)



First things first: what you want to know
(or: take-home messages)

2. *Mediator searches are a strength of the LHC*

   Highlighting complementarity among visible/invisible LHC searches

First things first: what you want to know
(or: take-home messages)

3. *We (already) have too much LHC data*

   What to do with it?

   Let's not discard and regret

Idea from LHCb talks, picture from the internet

Foreword

The main question for the LHC Run-1

Among the outstanding questions of the Standard Model:

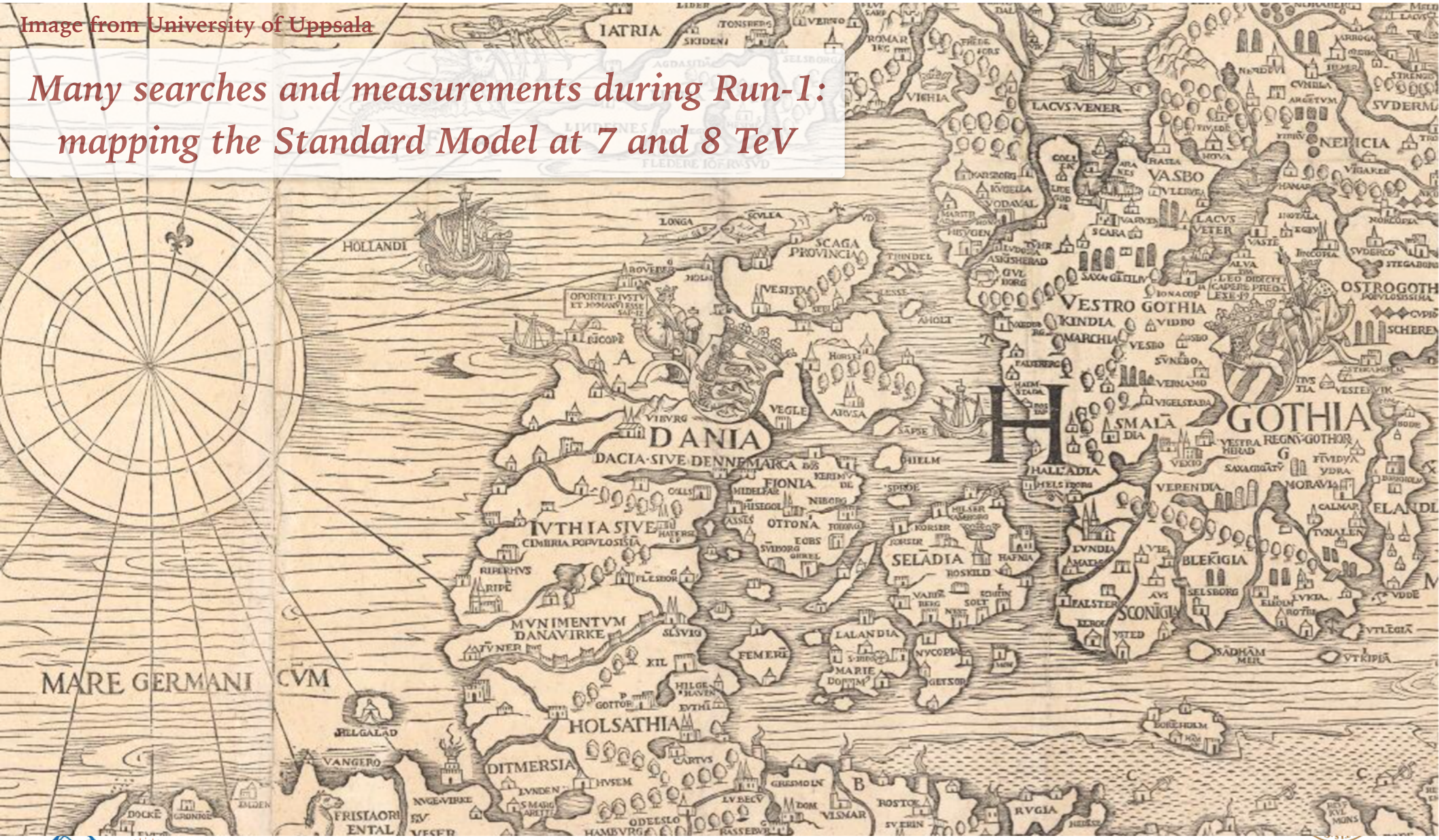
- How do particles get mass?
  - Higgs mechanism?

https://cds.cern.ch/record/874049

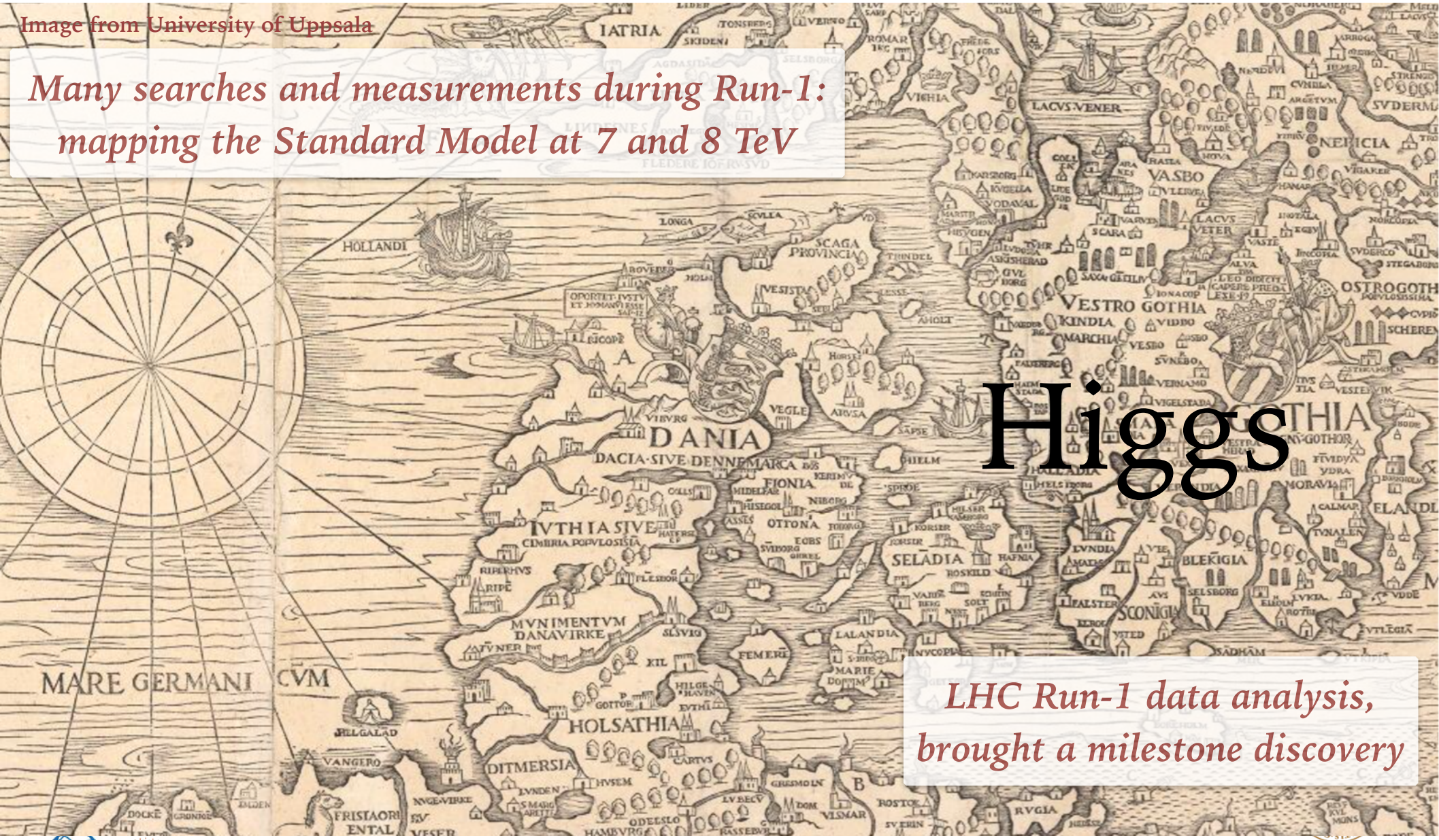
We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the Higgs boson, unlike the case with charm [3),4)] and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for the Higgs boson, but we do feel that people performing experiments vulnerable to the Higgs boson should know how it may turn up.

John Ellis

A chart of searches (and discoveries)



A chart of searches (and discoveries)

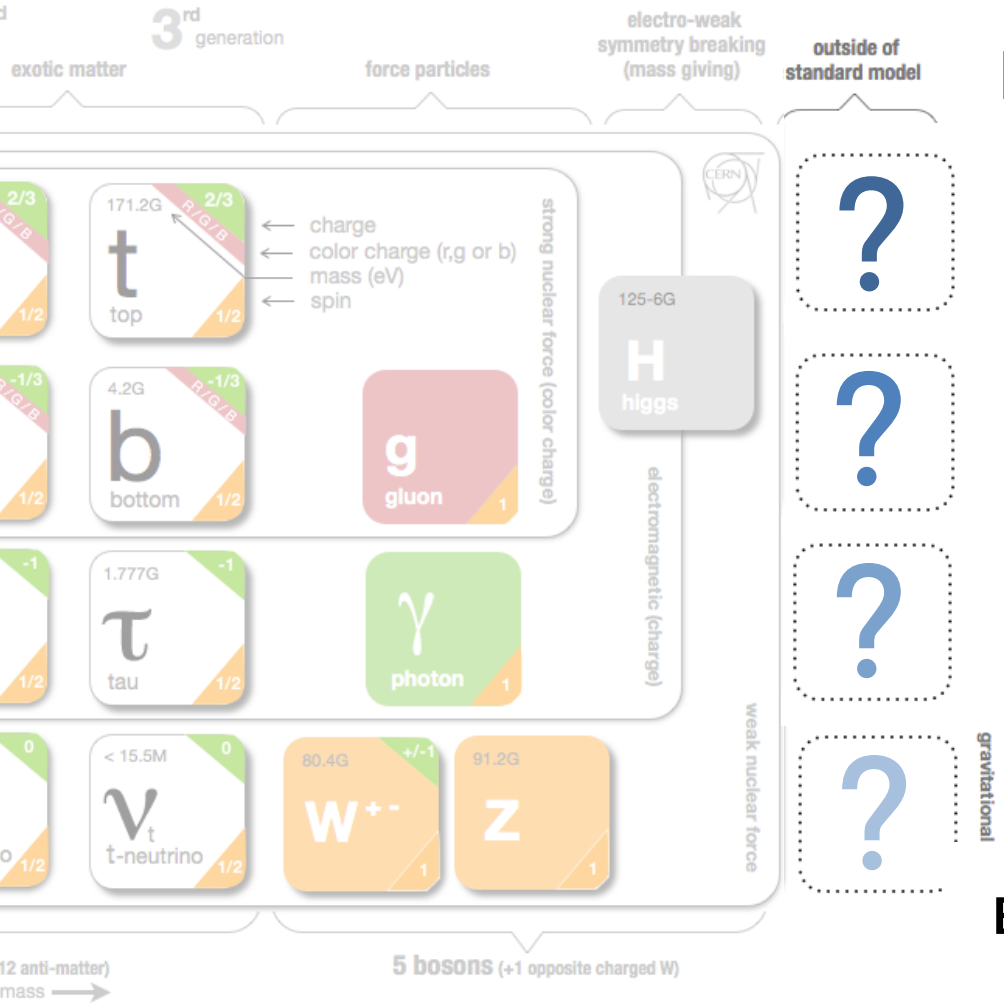


A chart of searches (and discoveries)

Discovery of the Higgs boson:

guided by **clues** from the **Standard Model** of particle physics

Uncharted discoveries in Run 2

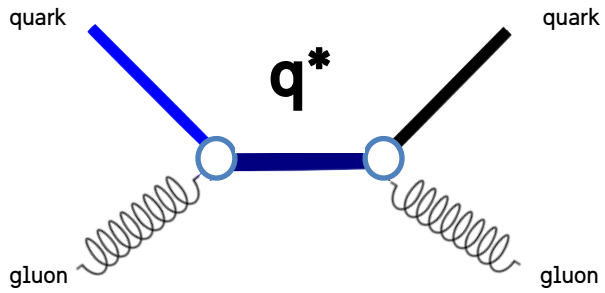


Where to look for new physics?

Everywhere, starting with high masses

Increase of LHC energy

Increase of reach for new phenomena



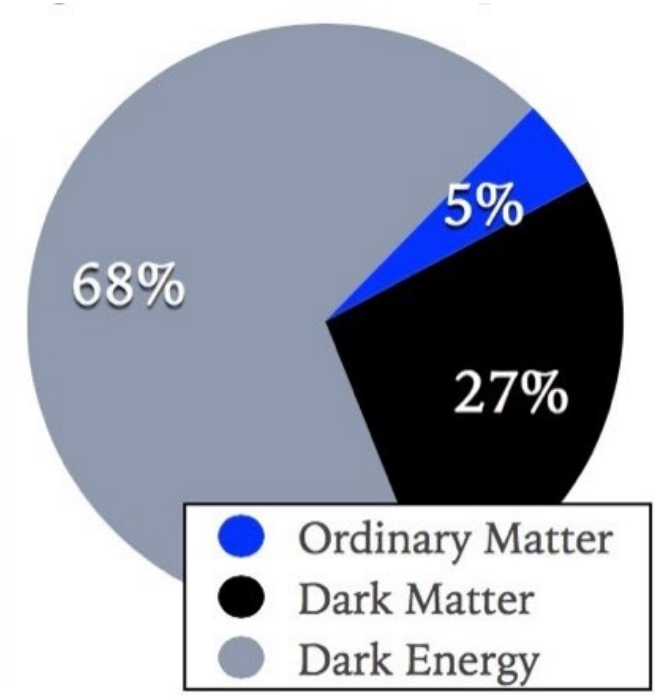
Example: production rate of excited quarks (q*) with mass of 4 TeV would **increase** by **56 times** from Run 1 to **Run 2**

Where ~~do~~ did we go from ~~here~~ the LHC Run-1?

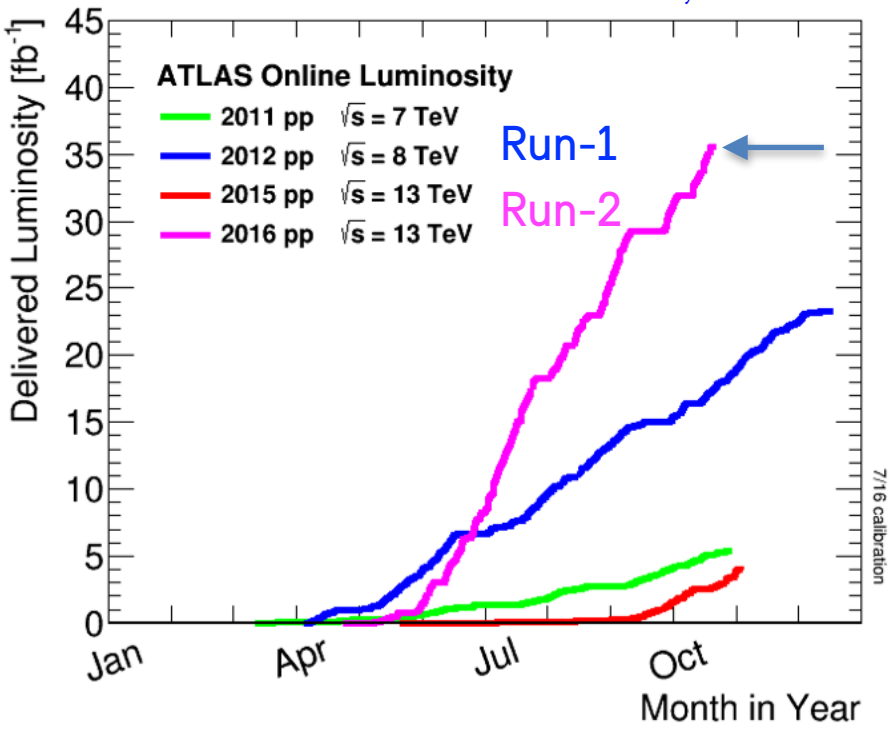
(Some) outstanding questions of the Standard Model:

- How do particles get mass?
  - Higgs mechanism ✓

- What is the nature of dark matter?



LuminosityPublicResults

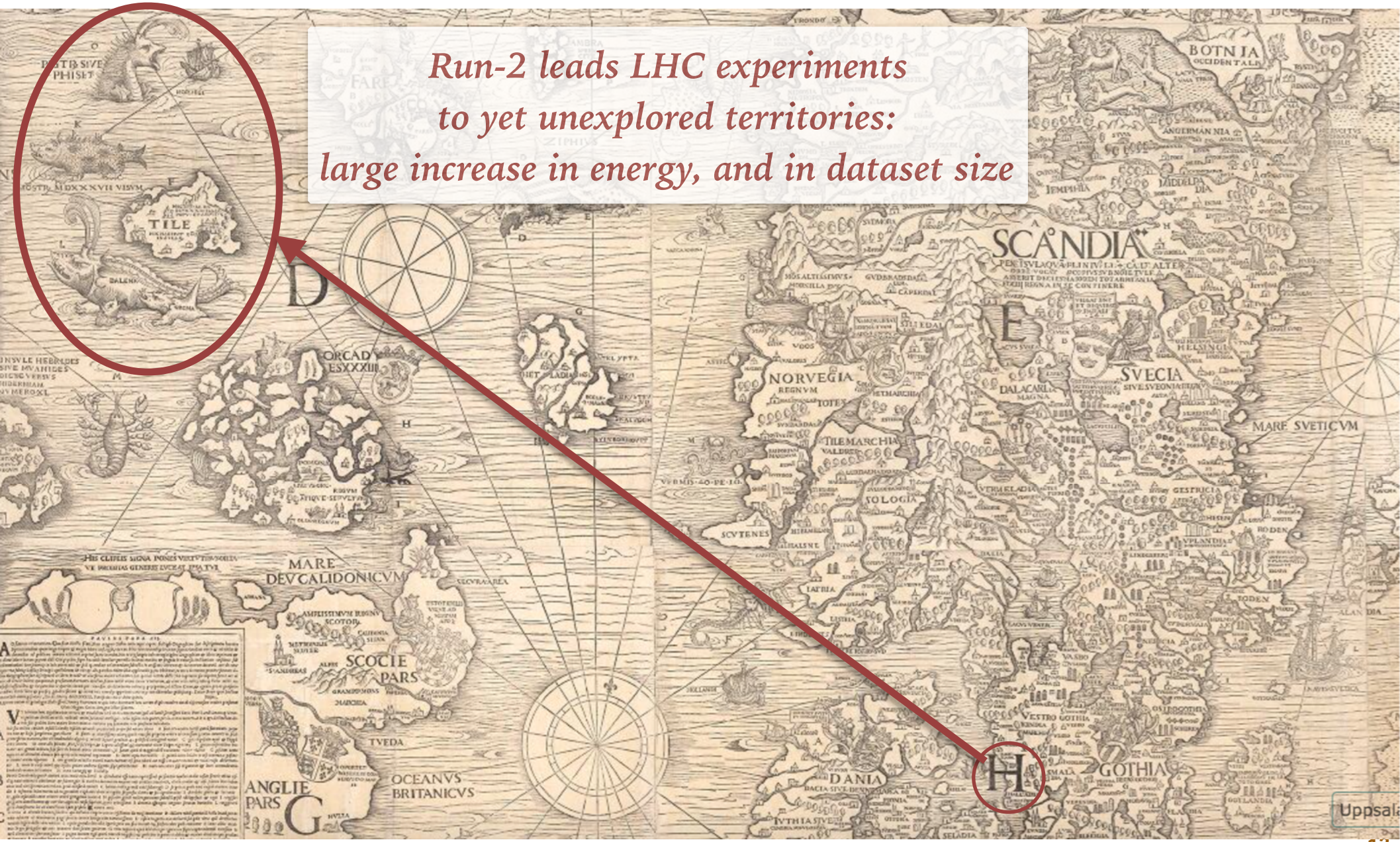


LHC operating beyond its design luminosity!

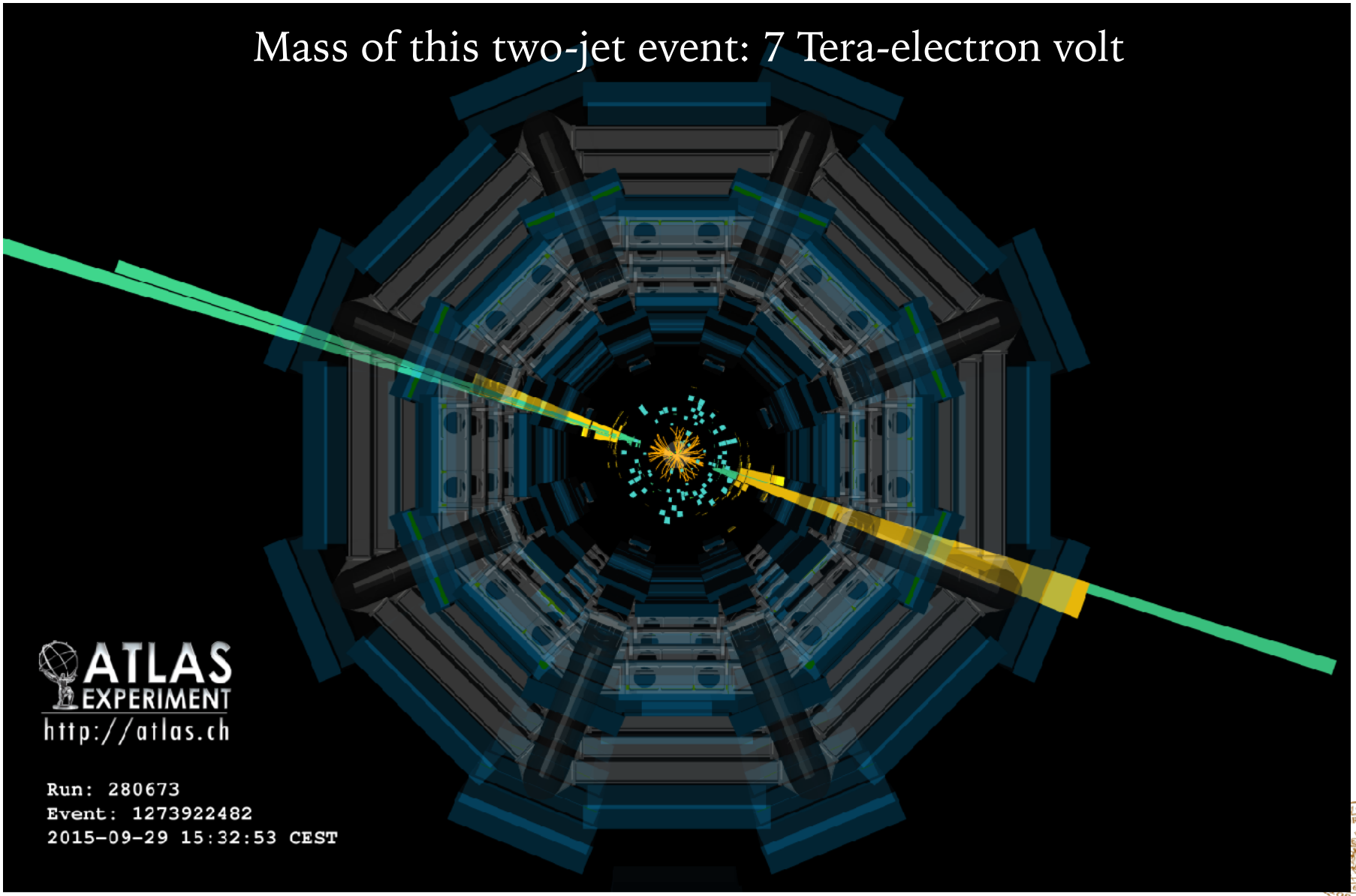
We have the chance to answer these questions with LHC Run-2 data

Uncharted energies at the LHC Run 2

Image from University of Uppsala



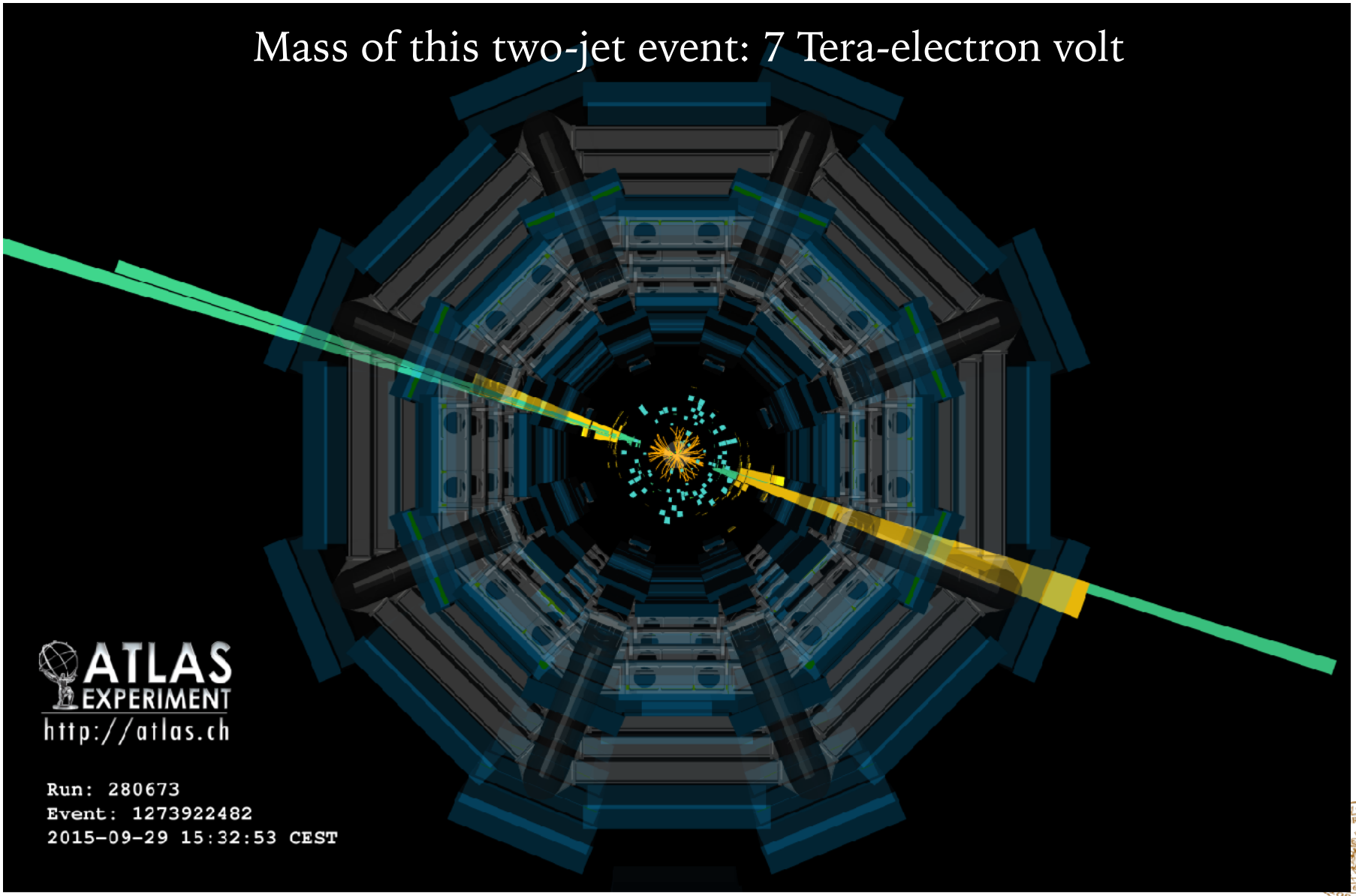
Uncharted energies in (ATLAS) Tile (calorimeter)



ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation
LUND UNIVERSITY

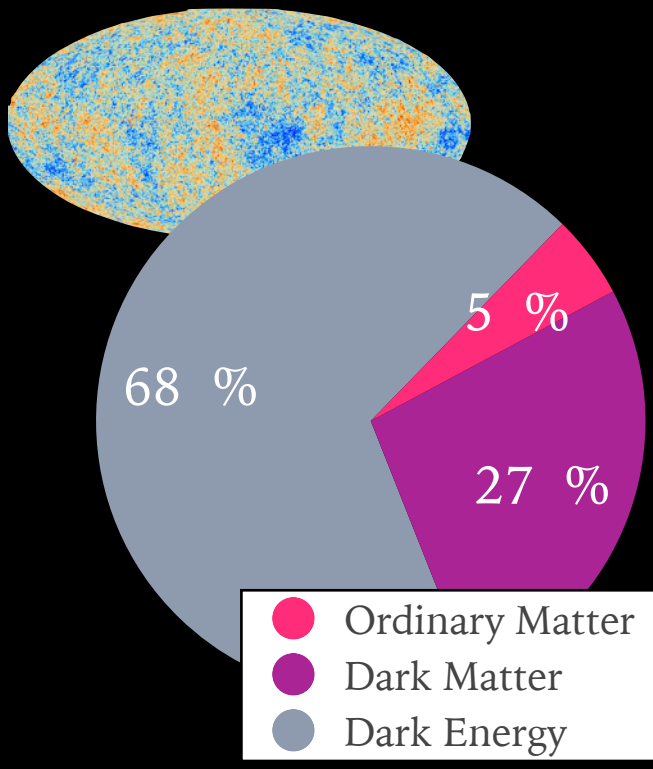
Is this how Dark Matter looks like?

Yes, but wait until the last part of this talk

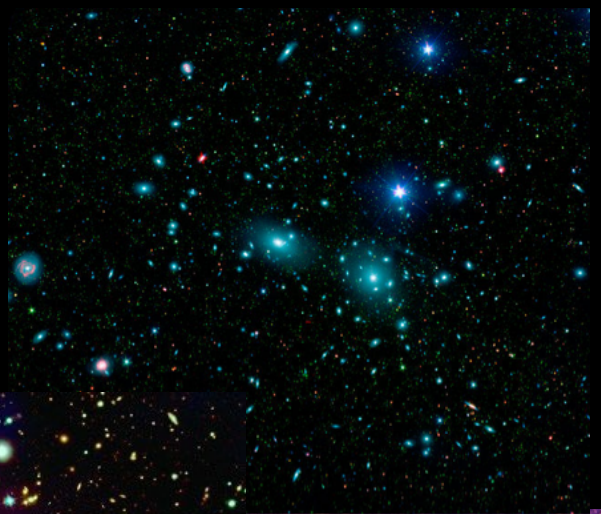


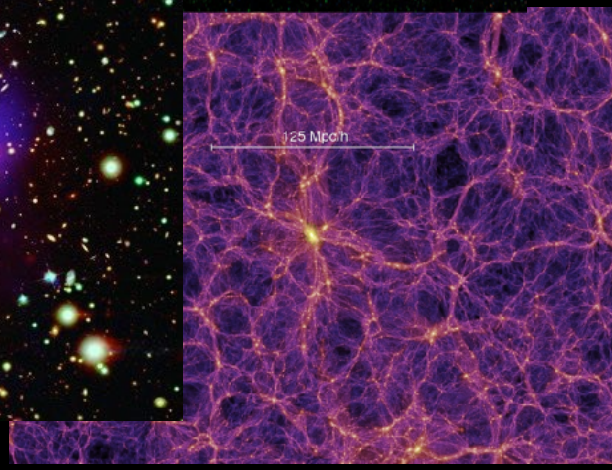
ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation
LUND UNIVERSITY

it is dark



it has mass

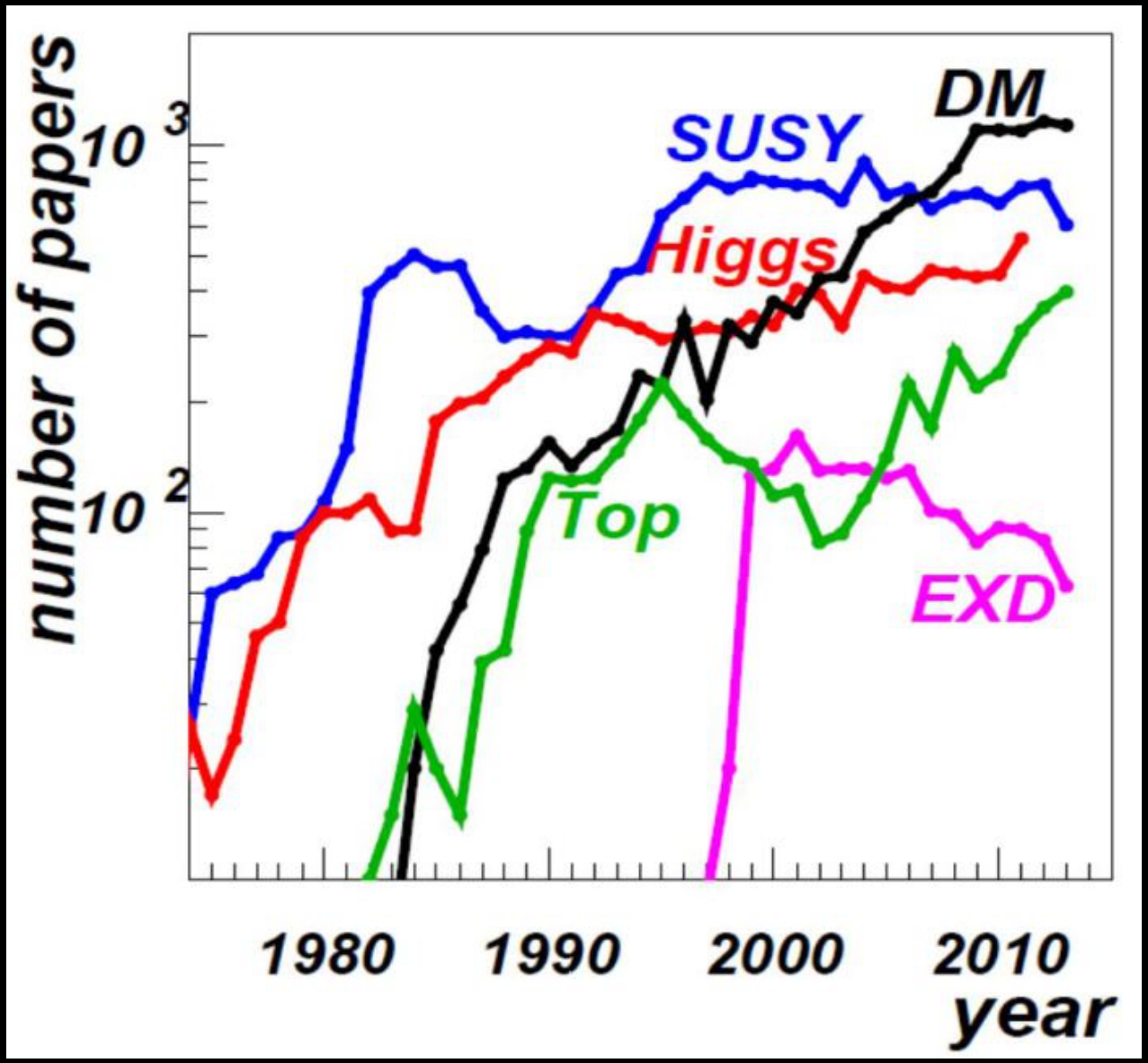




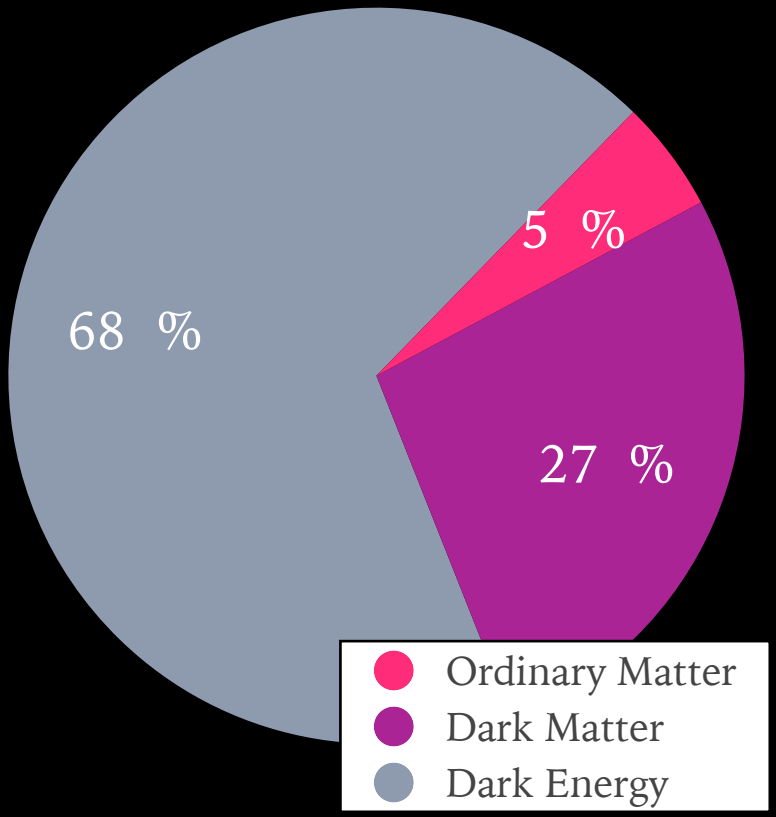
it constitutes
most of the matter
in the universe

(either that, or we need to rethink gravity)

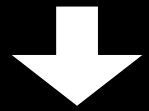
many physicists are talking about it



A. Belyaev



it constitutes
most of the matter
in the universe



relic density

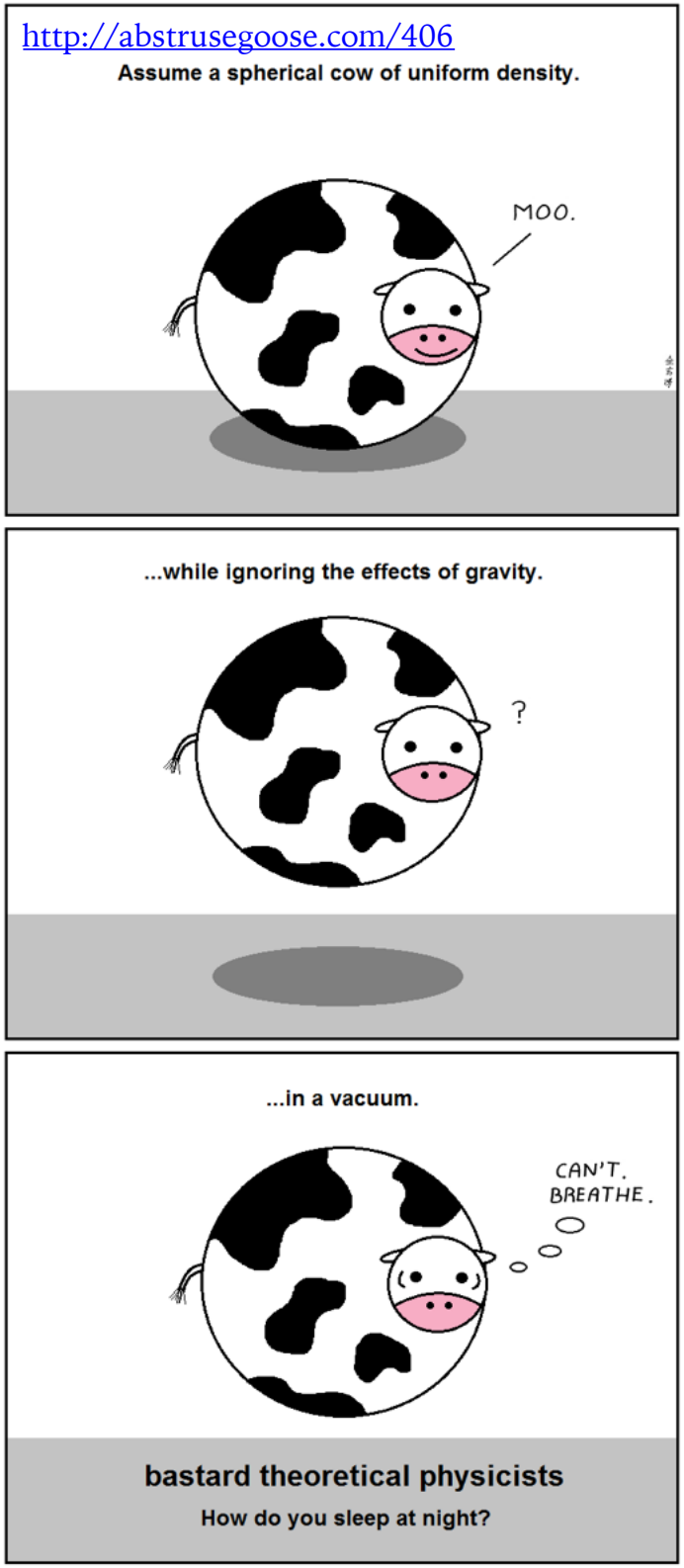
This relic density can be explained with

a new particle

- that interacts only weakly with known matter
- with mass in the range of current experiments

(Weakly Interacting Massive Particle)

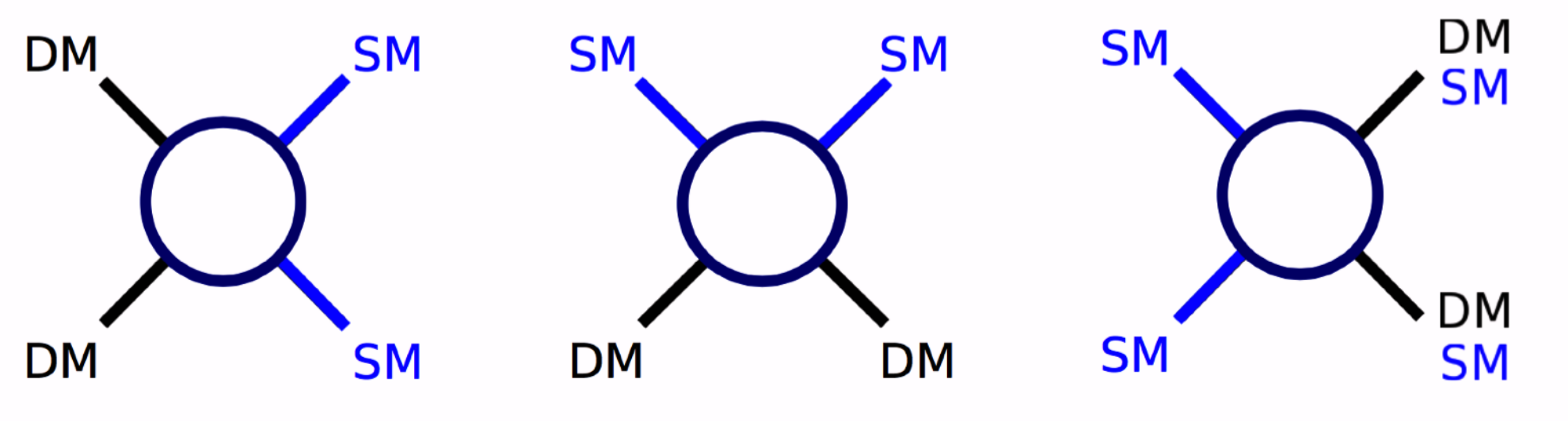
Under these assumptions…



...we could discover Dark Matter!

Dark Matter in different experiments

Dark Matter — **Ordinary particles**



Indirect Detection | Direct Detection | Particle Colliders

Complementary experimental strategies
All looking for **small signals**
over **large, complex backgrounds**

1. *"Low-hanging fruit has been picked"*

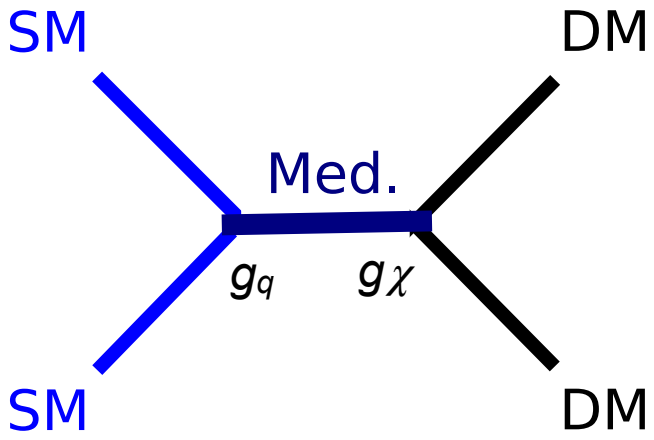
where have we been/where do we go from here?

Mono-X searches

Next on the menu: long-lived particles (?)

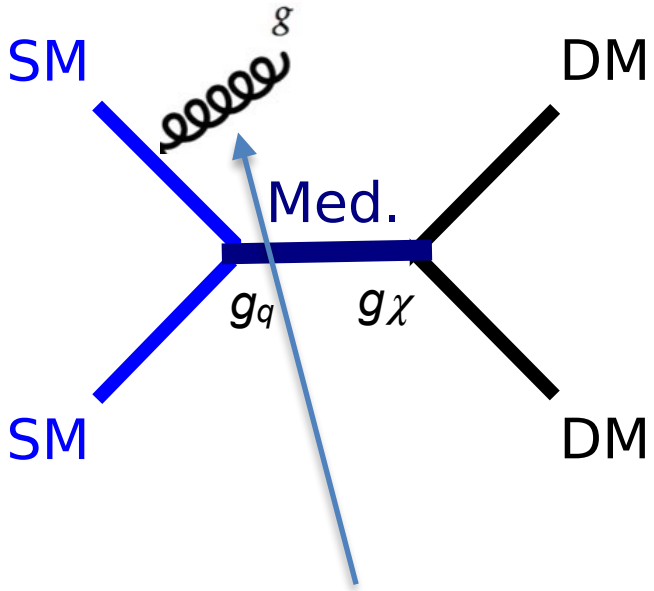
Looking for Dark Matter at the LHC

WIMPs are invisible to detectors

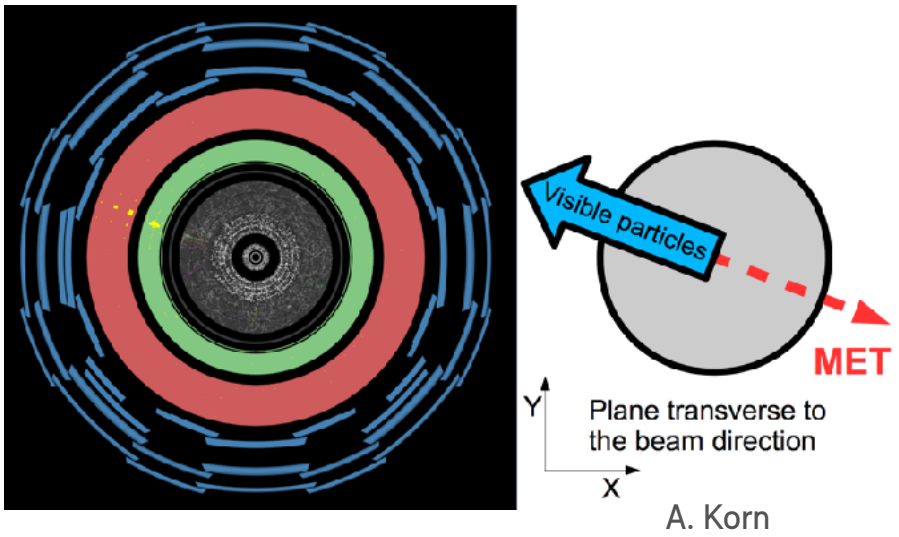


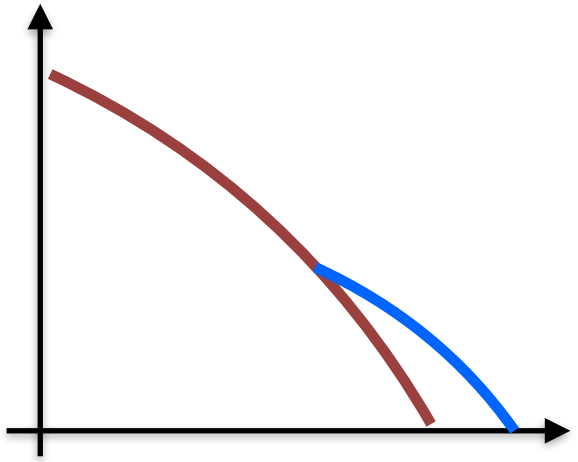
Looking for invisible Dark Matter at the LHC

Signature of Dark Matter:
missing transverse momentum



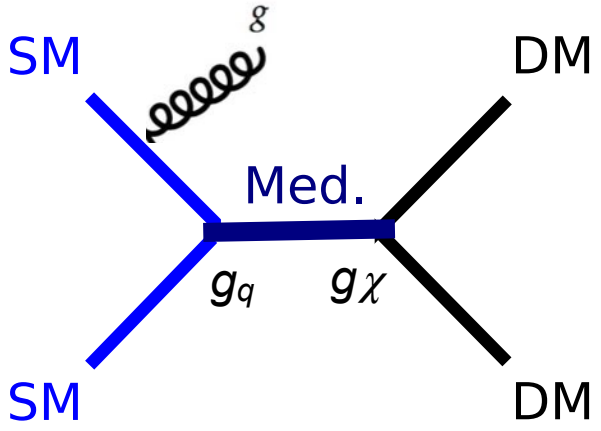
Invisible WIMPs:
Initial state radiation
makes them visible



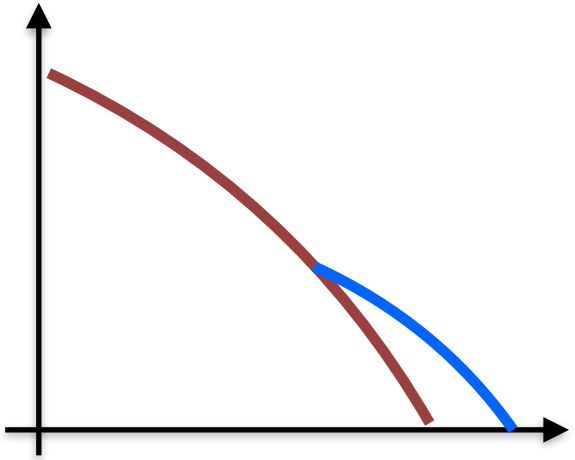


Excess of missing transverse momentum

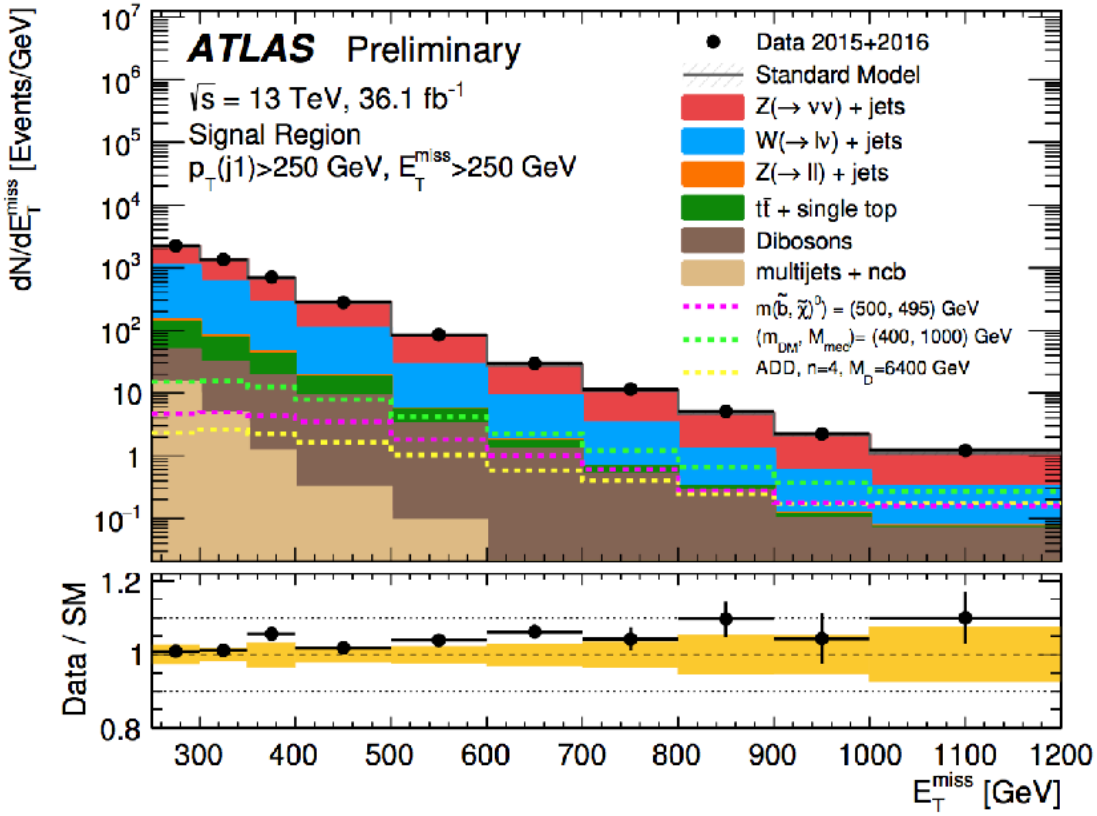
A sample "monojet" result



Signature of Dark Matter: **missing transverse momentum**



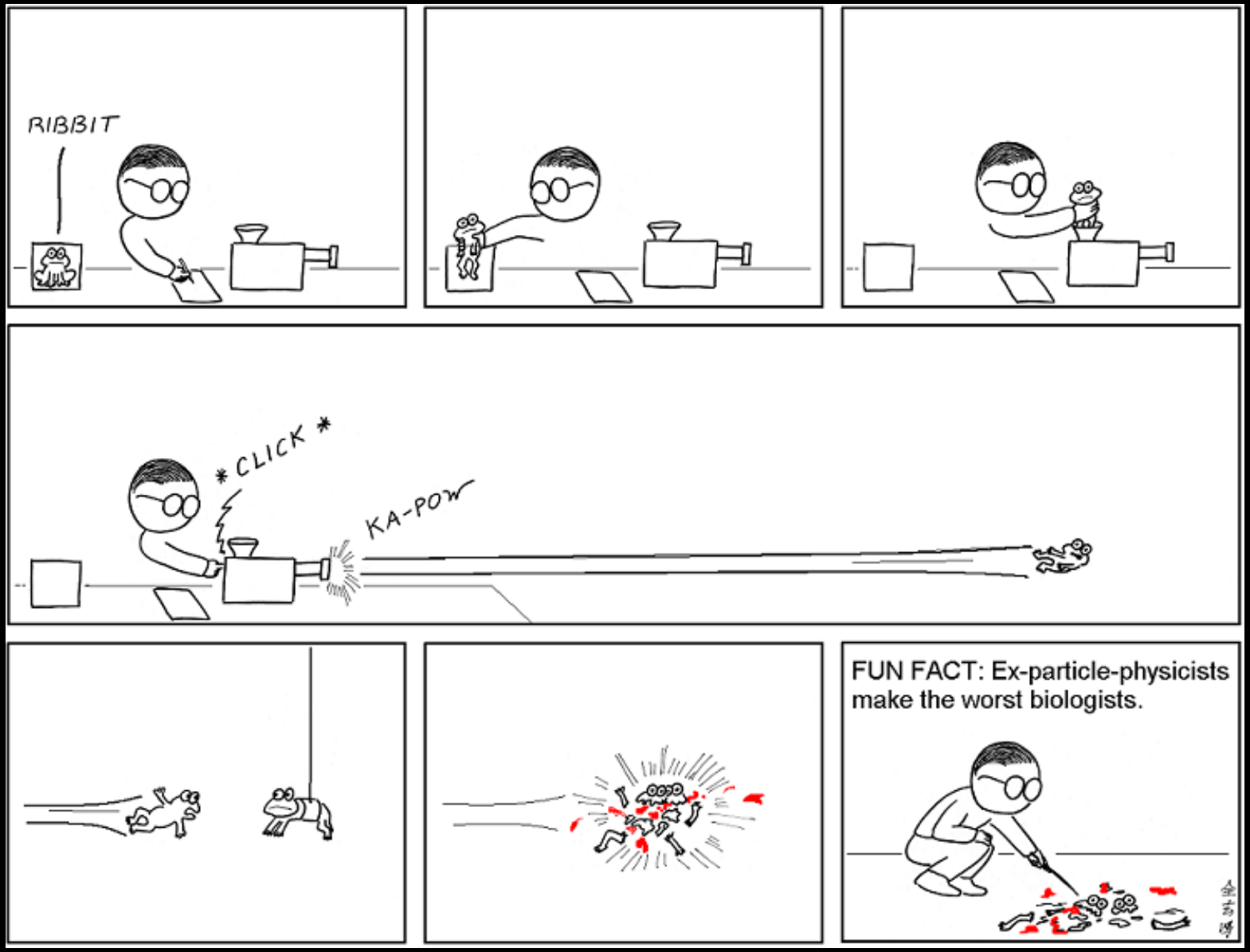
ATLAS-CONF-2017-060



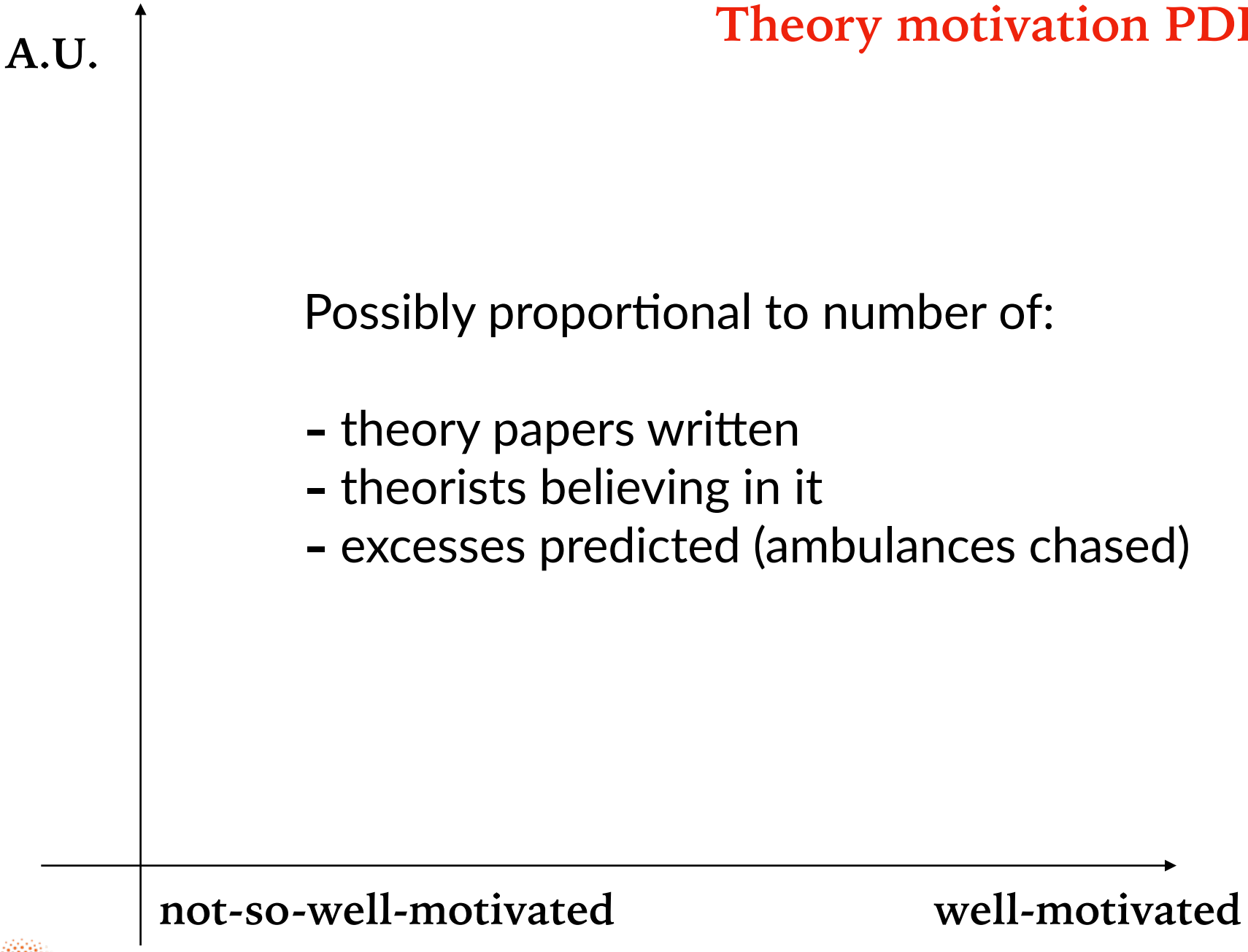
Can also use other radiated objects: photon, W, Z, Higgs

Horizon 2020
European Union funding
for Research & Innovation

Interlude: worst sociology



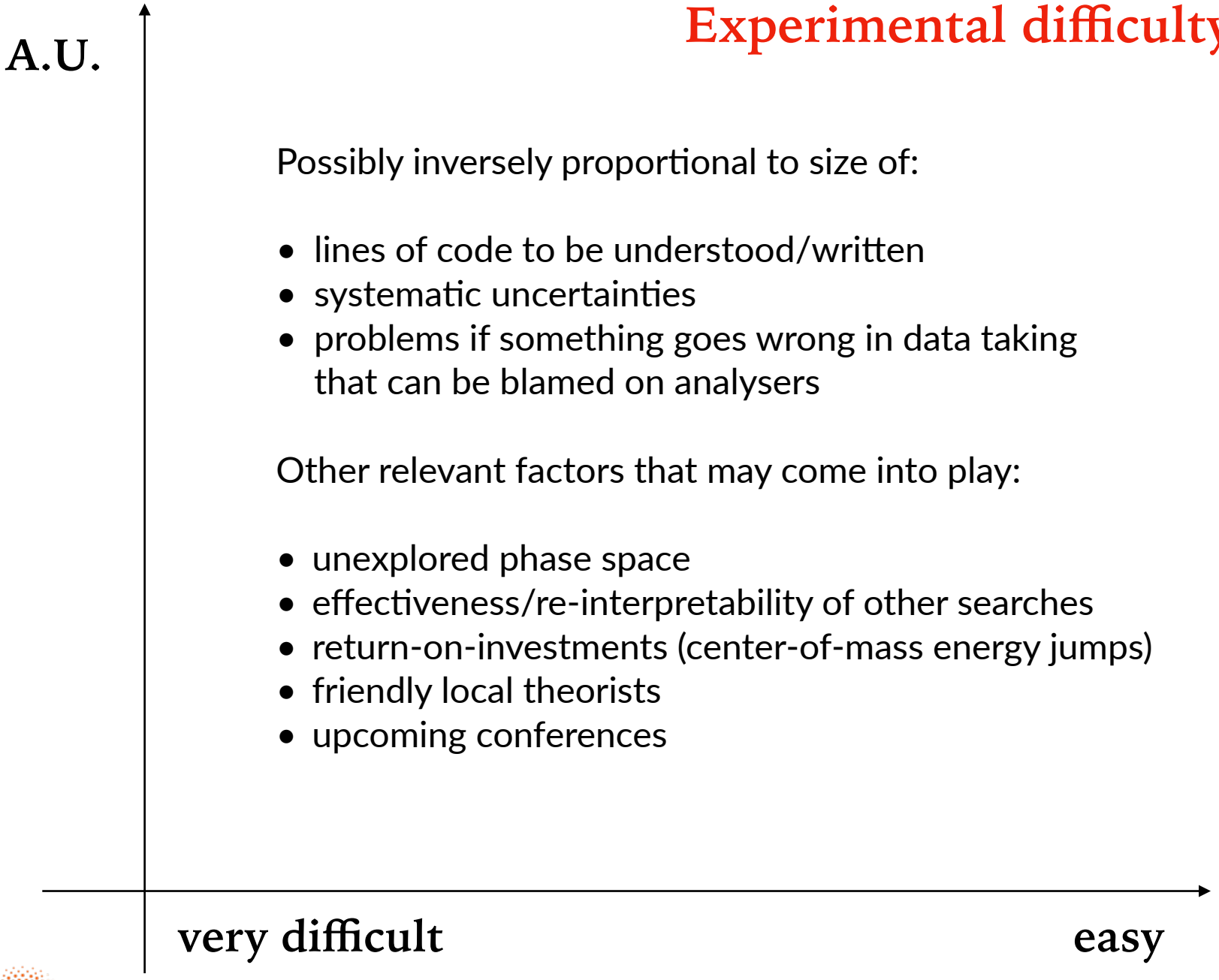
Theory motivation PDF



Possibly proportional to number of:

- theory papers written
- theorists believing in it
- excesses predicted (ambulances chased)

Experimental difficulty PDF

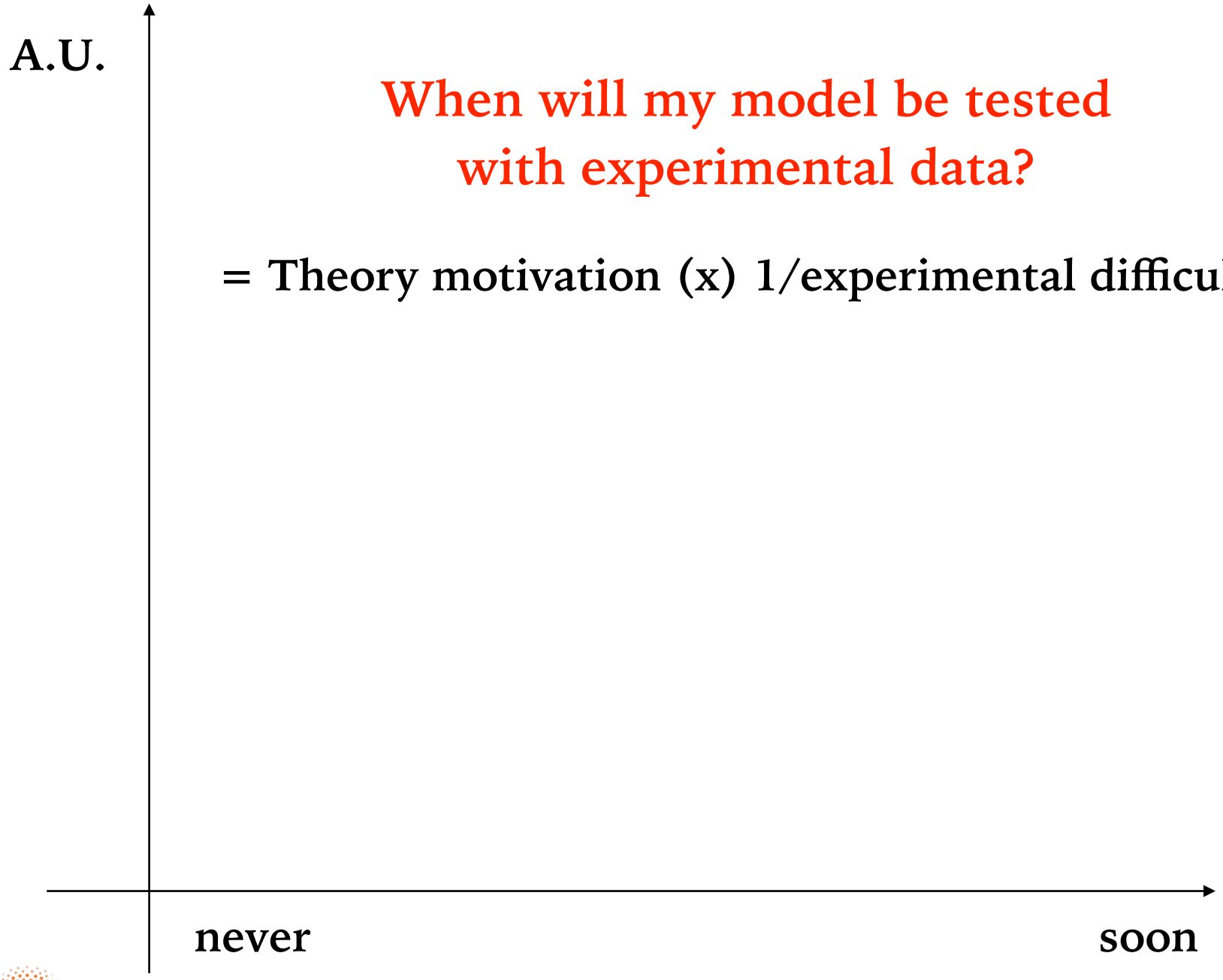


Possibly inversely proportional to size of:

- lines of code to be understood/written
- systematic uncertainties
- problems if something goes wrong in data taking that can be blamed on analysers

Other relevant factors that may come into play:

- unexplored phase space
- effectiveness/re-interpretability of other searches
- return-on-investments (center-of-mass energy jumps)
- friendly local theorists
- upcoming conferences

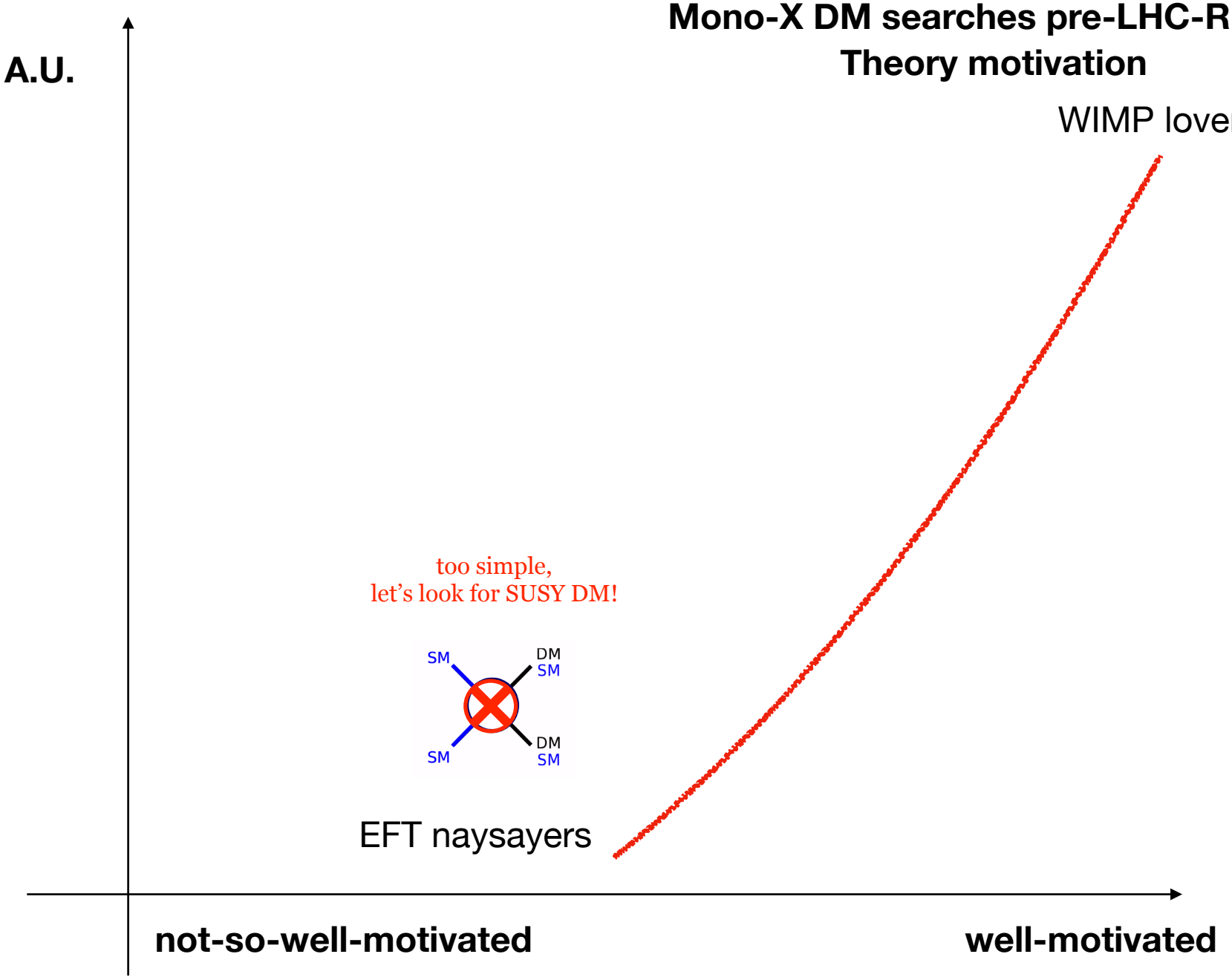


When will my model be tested with experimental data?

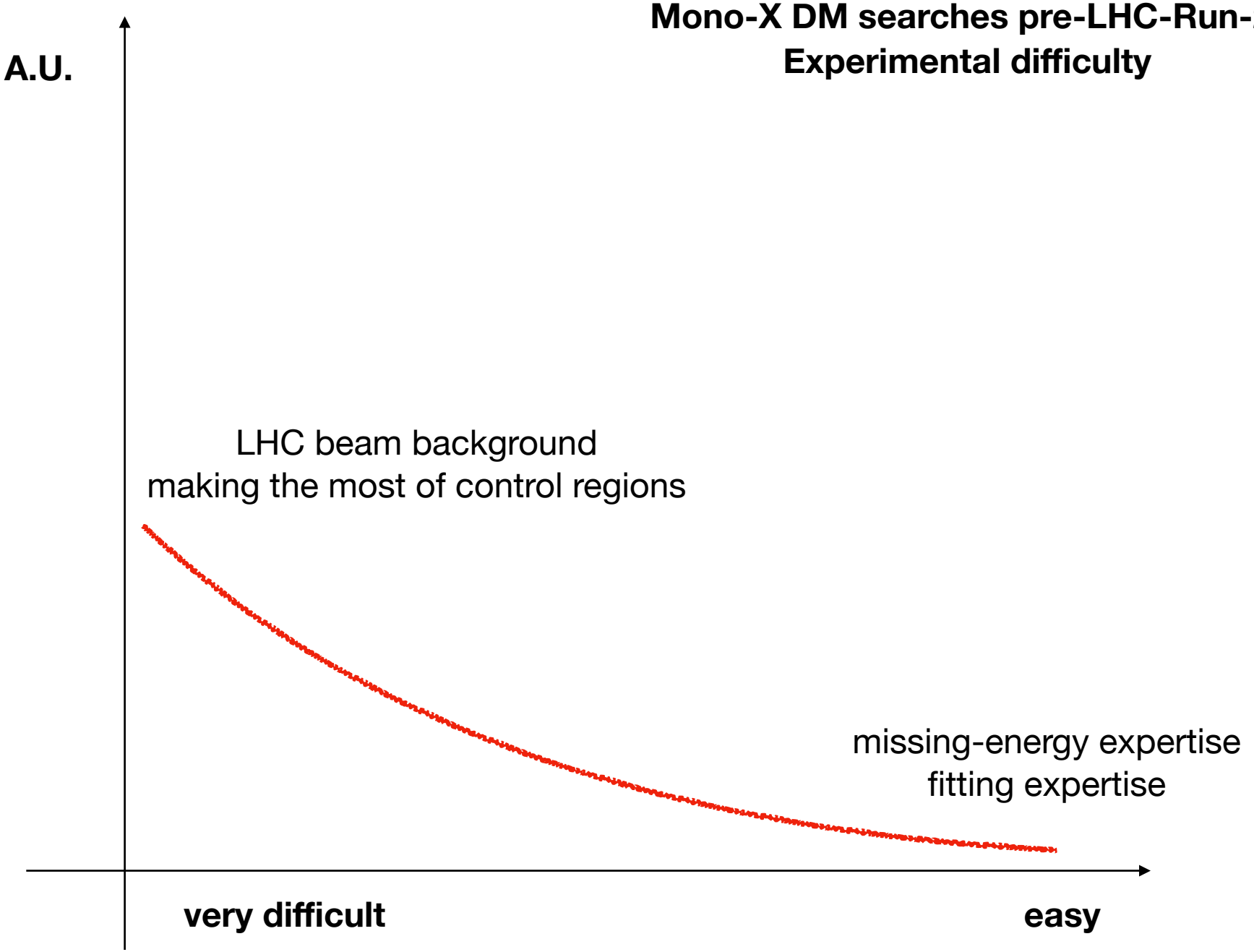
= Theory motivation (x) 1/experimental difficulty

1. Back to WIMP searches at the LHC

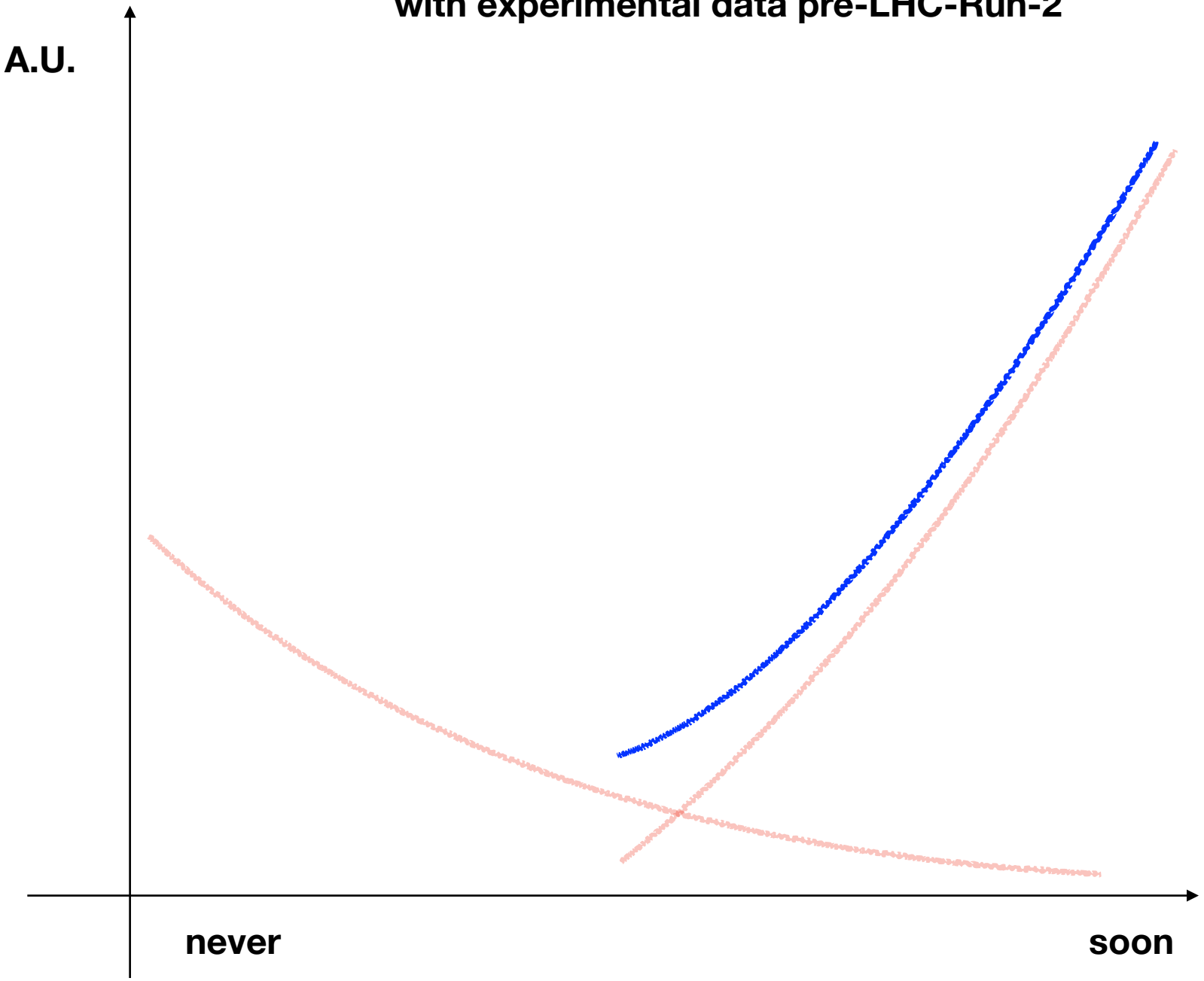
Mono-X DM searches pre-LHC-Run-2: Theory motivation



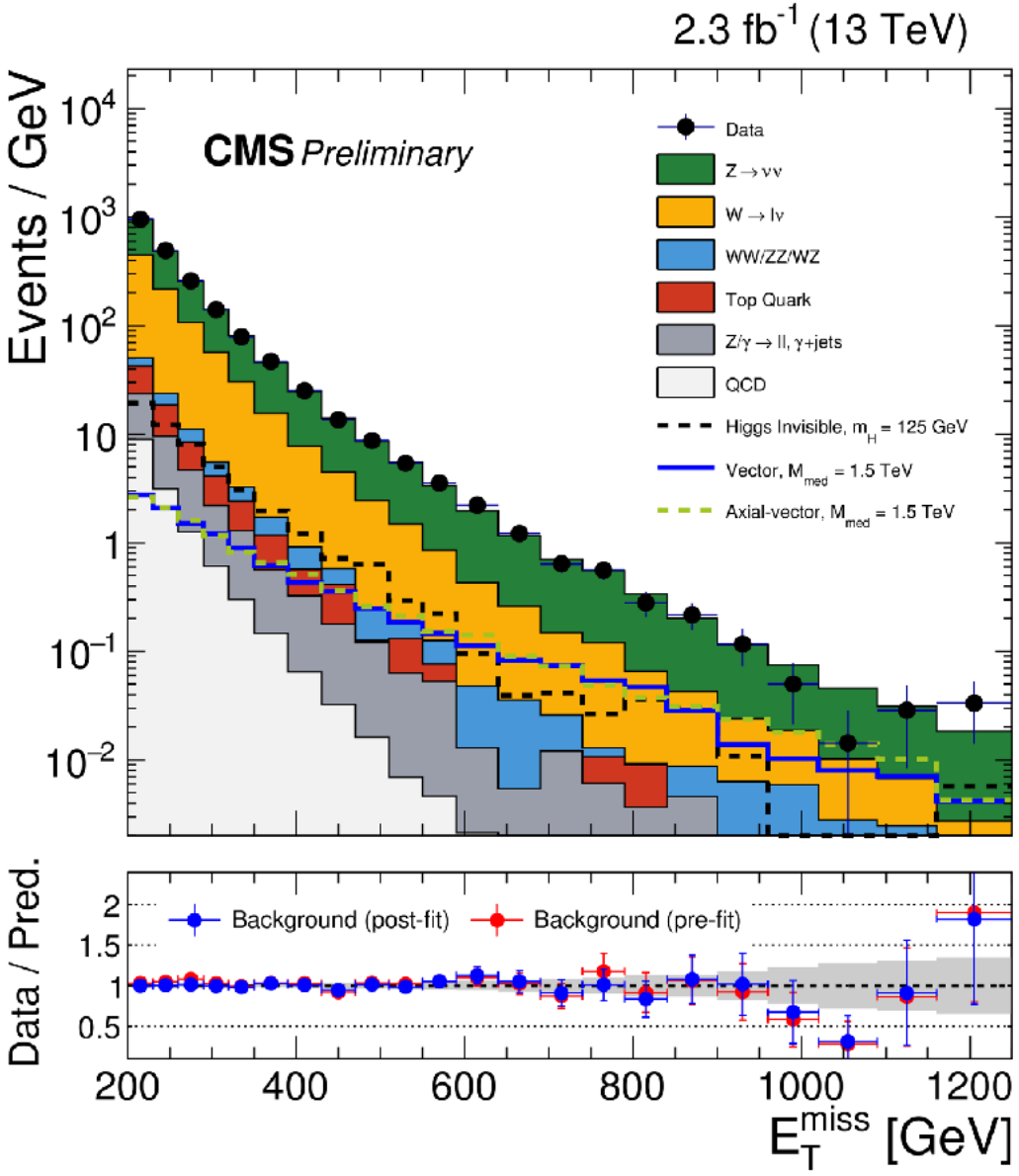
Mono-X DM searches pre-LHC-Run-2: Experimental difficulty



When (Mono-X) WIMPs are tested with experimental data pre-LHC-Run-2



Results from 2015 data CMS-PAS-EXO-16-013



Interpretation?

Horizon 2020
European Union funding
for Research & Innovation

Cornell University Library

knowledge support from the Simons Foundation and member institutions

Dark Matter Forum

arXiv.org > hep-ex > arXiv:1507.00966

Search (Help | Advanced search) All papers Go!

High Energy Physics – Experiment

nload:

r formats

(license)

Dark Matter Benchmark Models for Early LHC Run-2 Searches: Report of the ATLAS/CMS Dark Mat

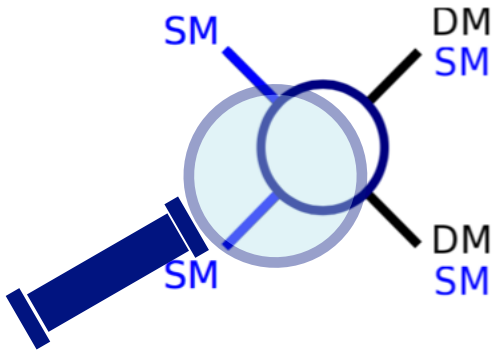
Danie
Allen
Azuel
Beach
Buchr
Cacci
Gome
Cowd
Roeck
Cater
Fisch

Simplified models as building blocks for **experimentalists** (designing and performing searches) and **theorists** (building new theories, reinterpreting searches) and as common framework for reinterpretation together with **complementary experiments**

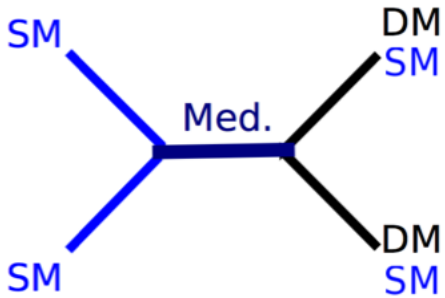
Caveat: very (too?) simple!

(Submitted on 3 Jul 2015)

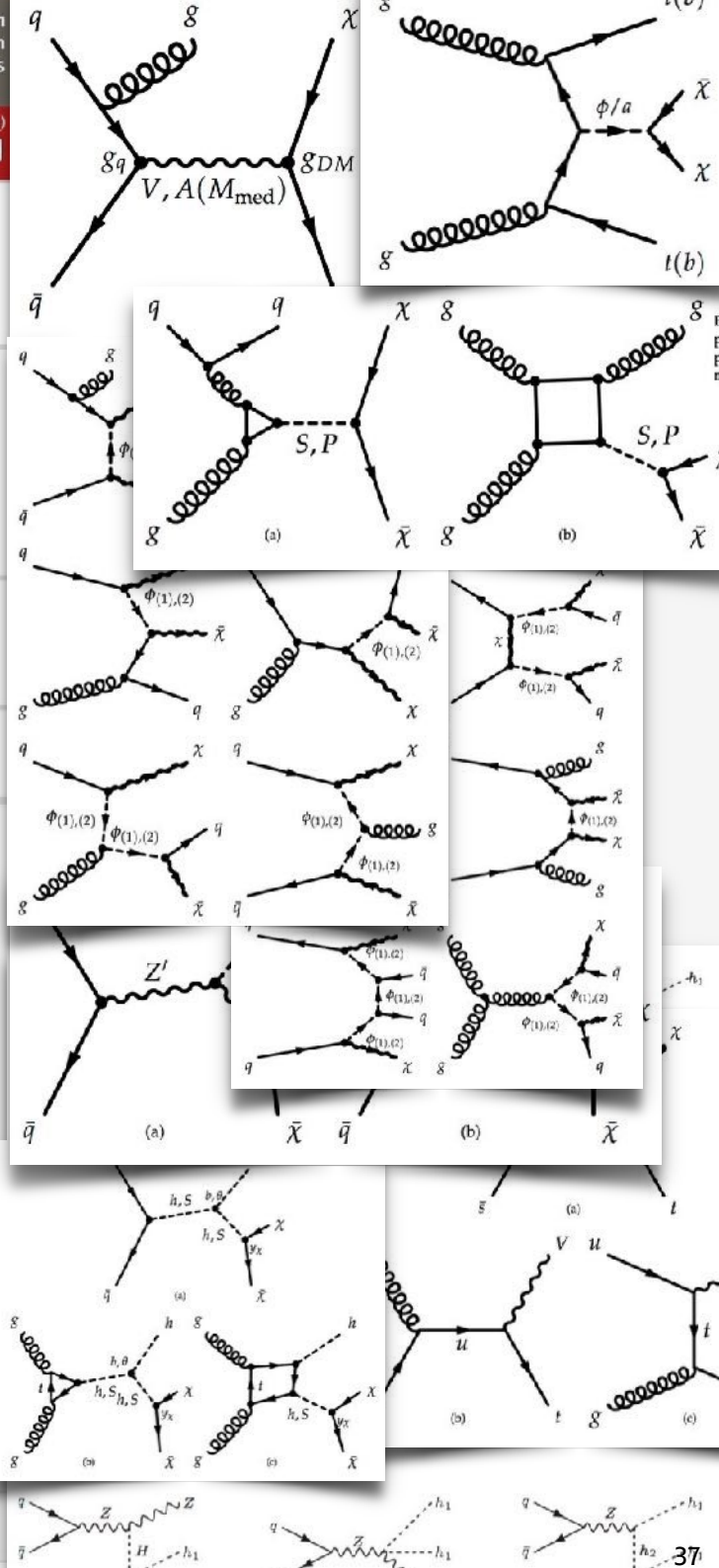
This document is the final report of the ATLAS–CMS Dark Matter Forum, a forum



Colliders (Effective Field Theory)



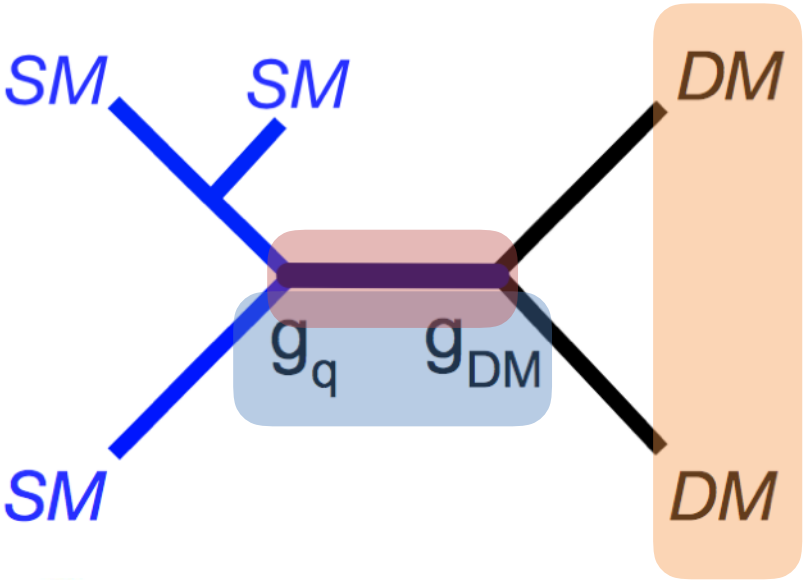
Colliders (Simplified Models)

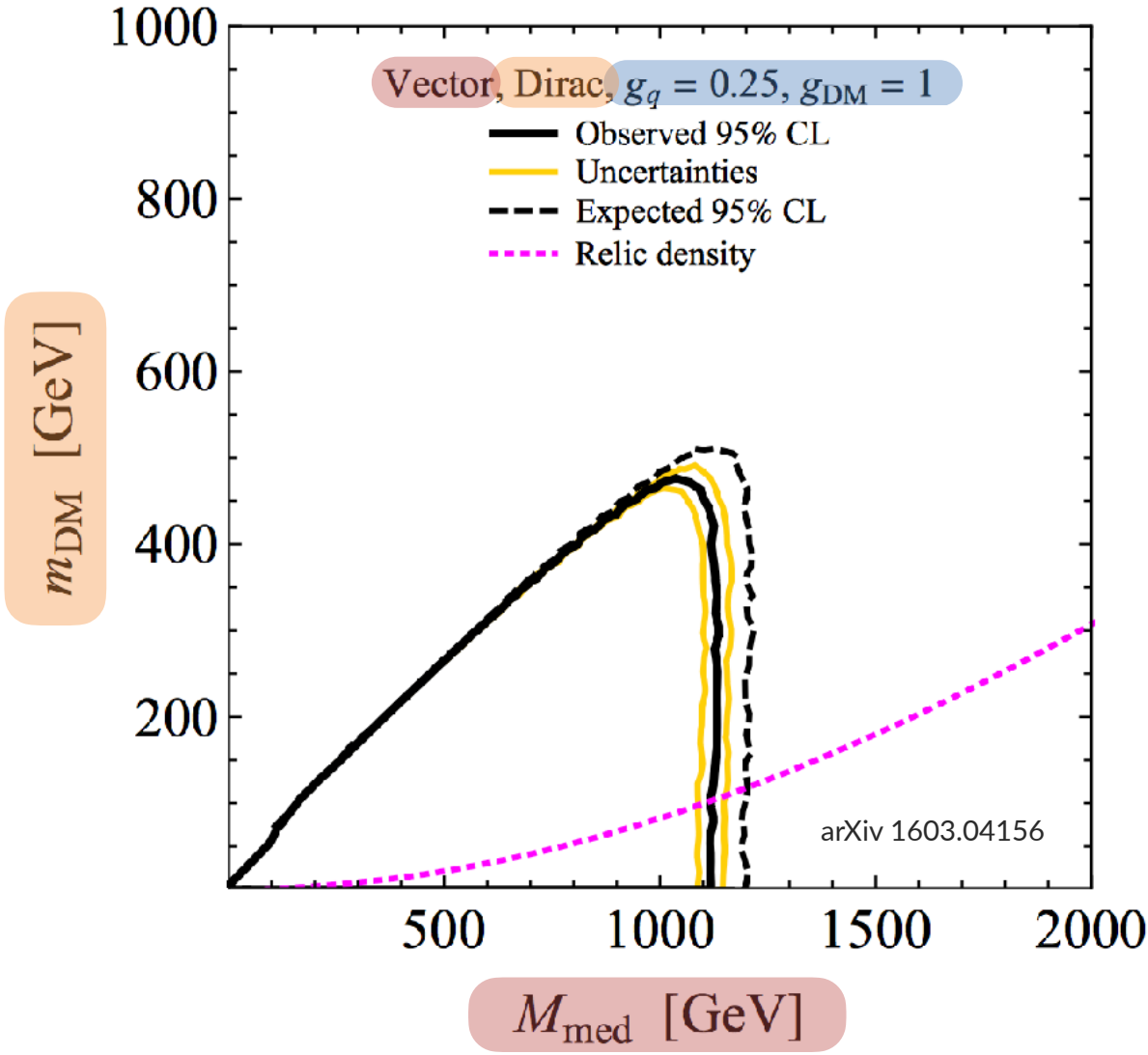


Collider results: mass-mass plots

How to display interpretation of collider search using simplified models

1. Characterise all elements of the simplified model
2. Vary mass of mediator and DM, fix couplings (for a 2D plot)
3. Display perturbative validity area, if present
4. Show relic density to guide the eye

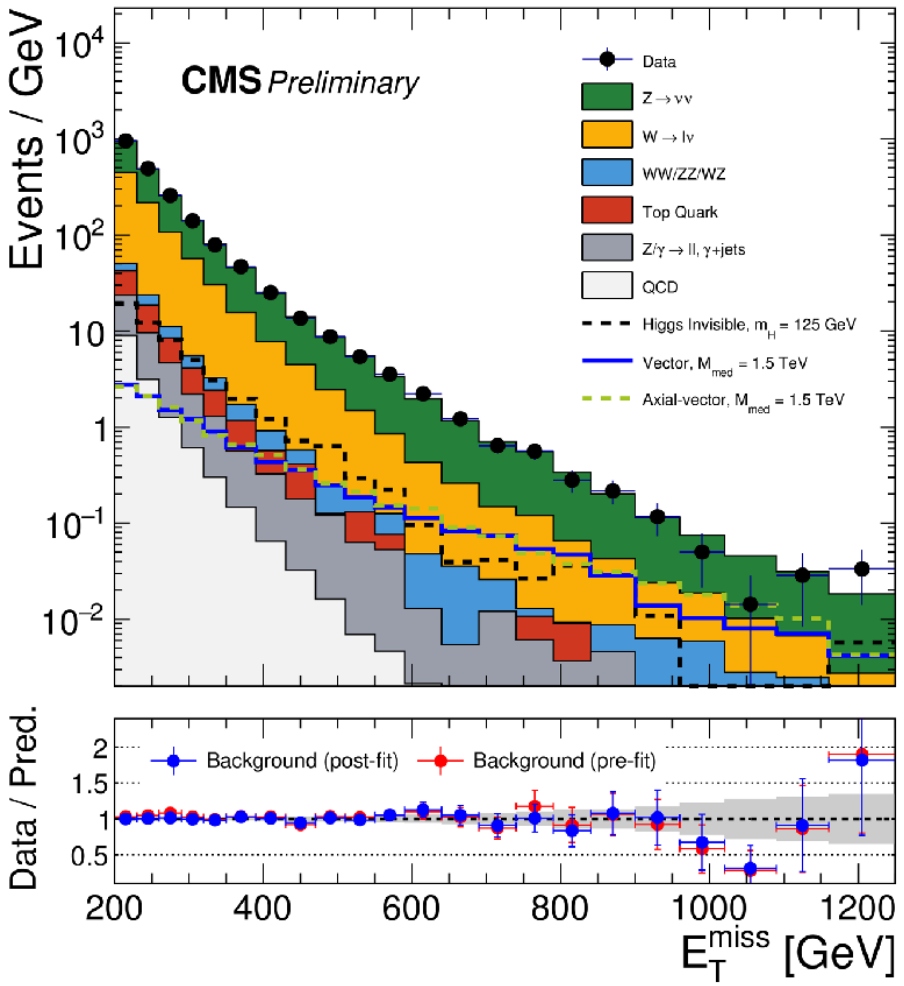


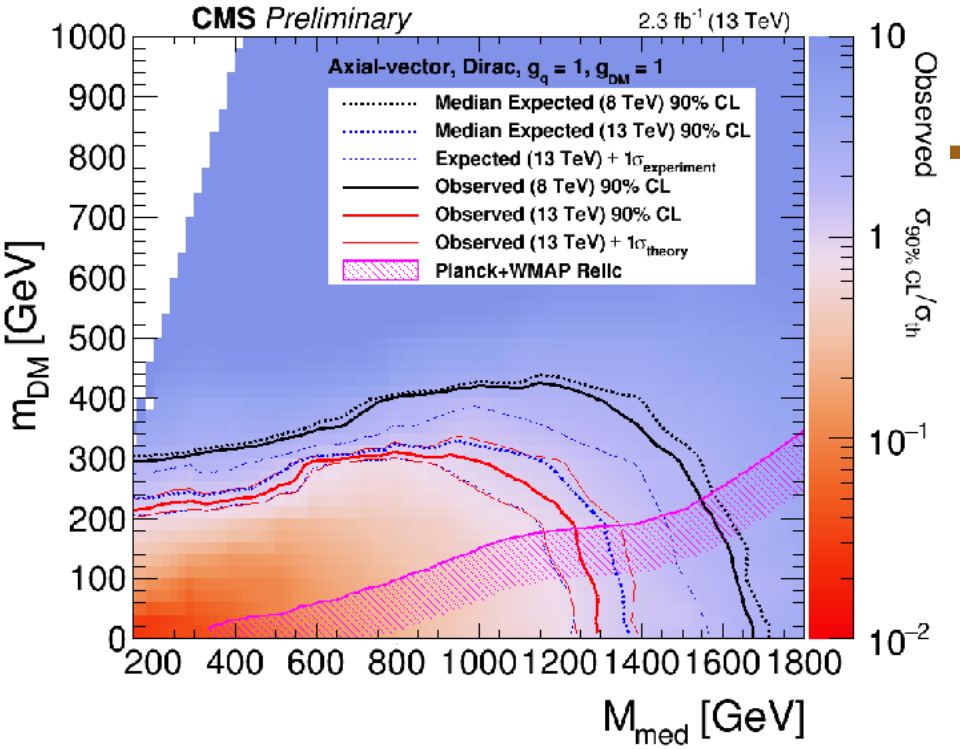


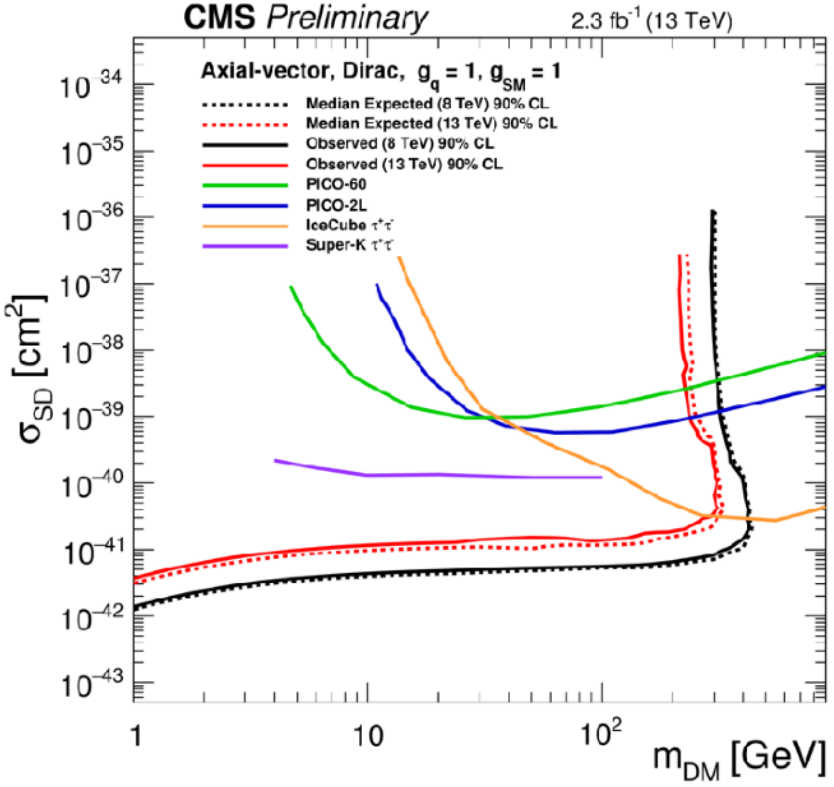
Dark Matter Working Group

Results from 2015 data

CMS-PAS-EXO-16-013 2.3 fb^{-1} (13 TeV)





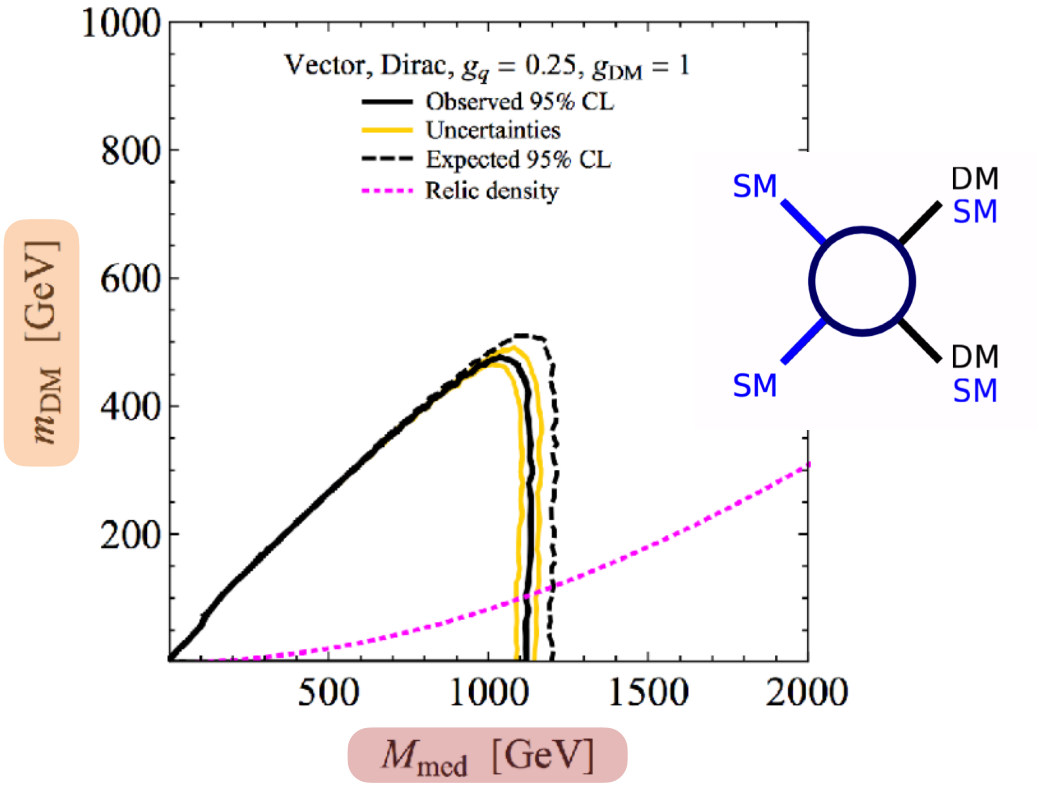


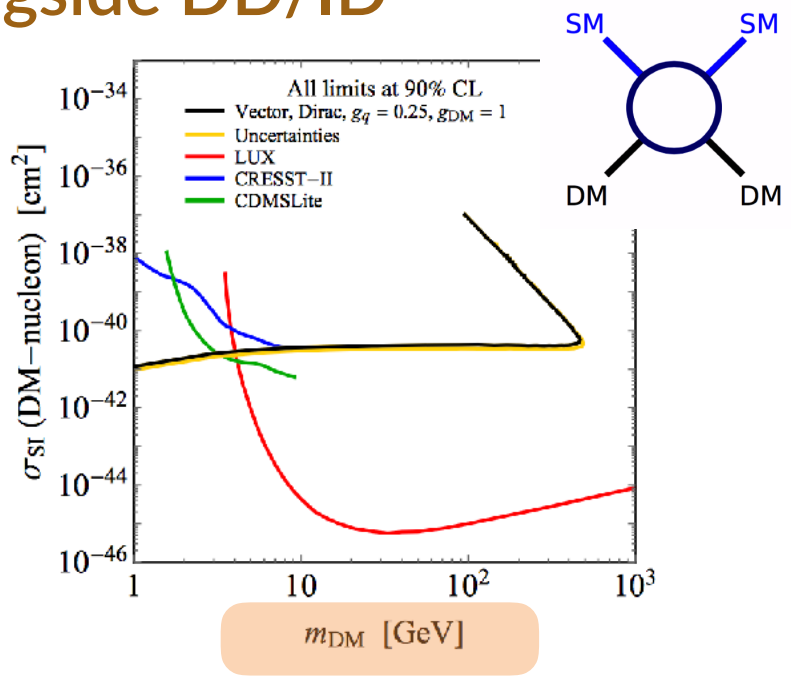
Horizon 2020
European Union funding
for Research & Innovation

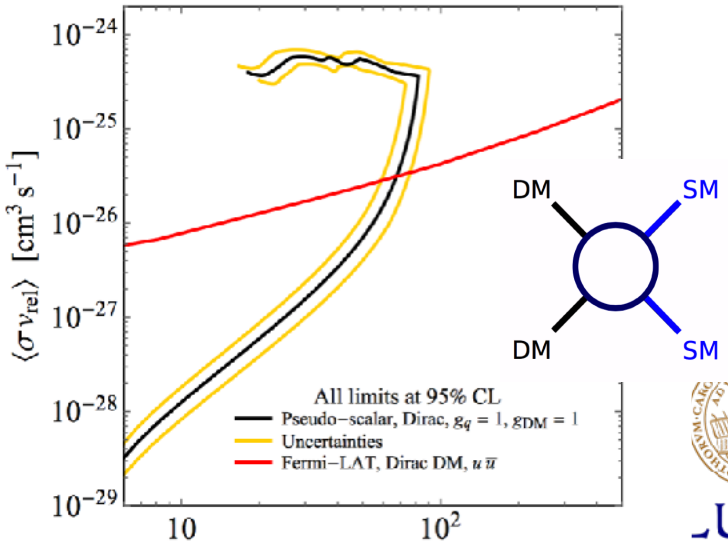
A (simplified) global picture of DM

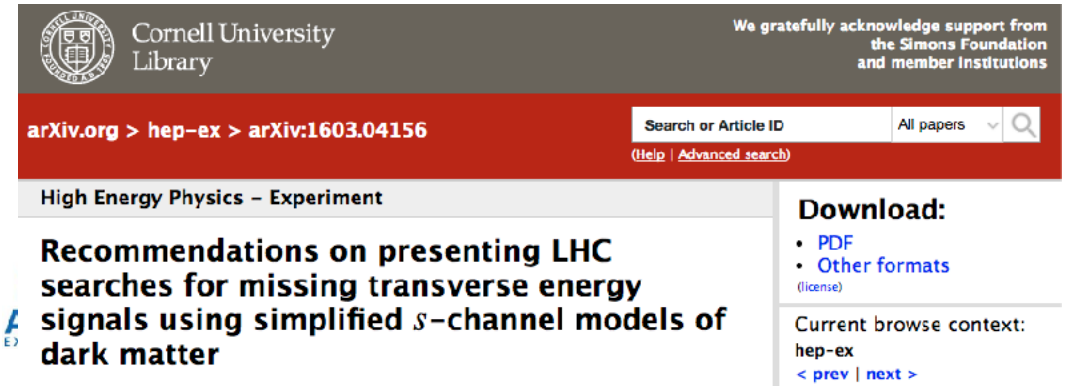
Dark Matter Working Group

How to display collider searches alongside DD/ID

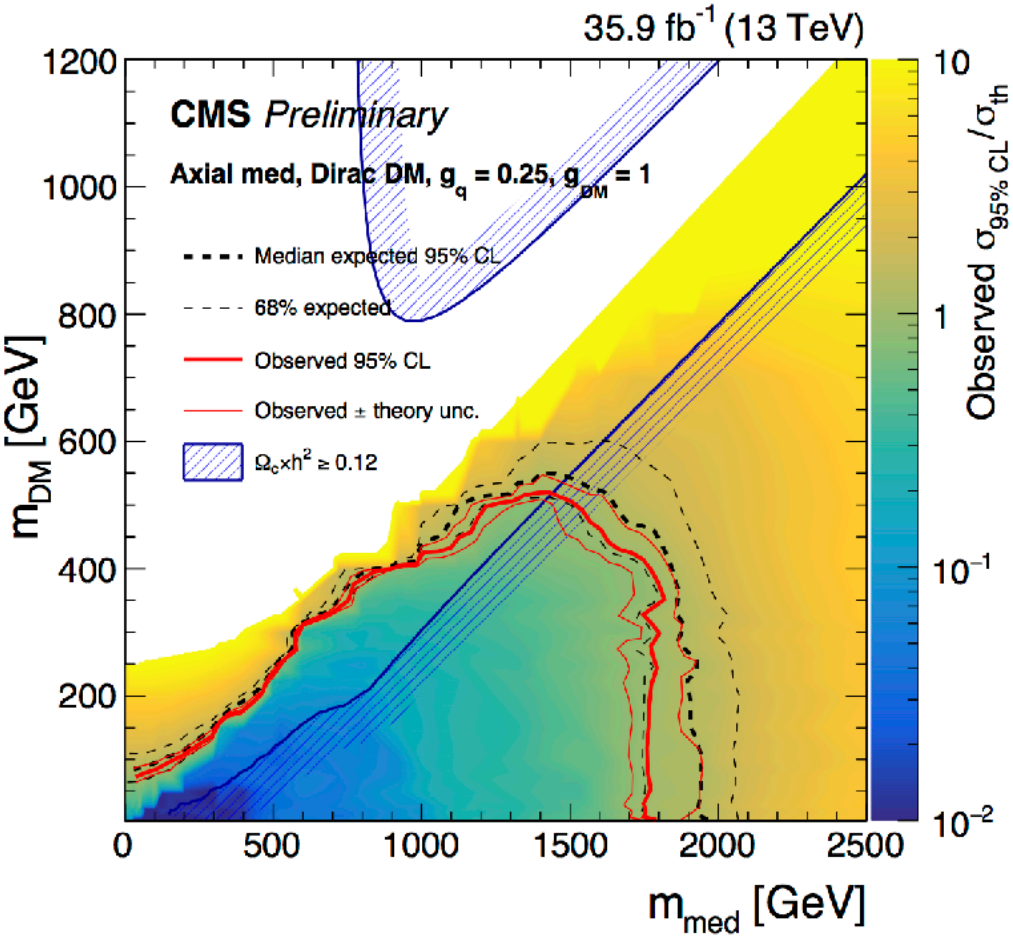


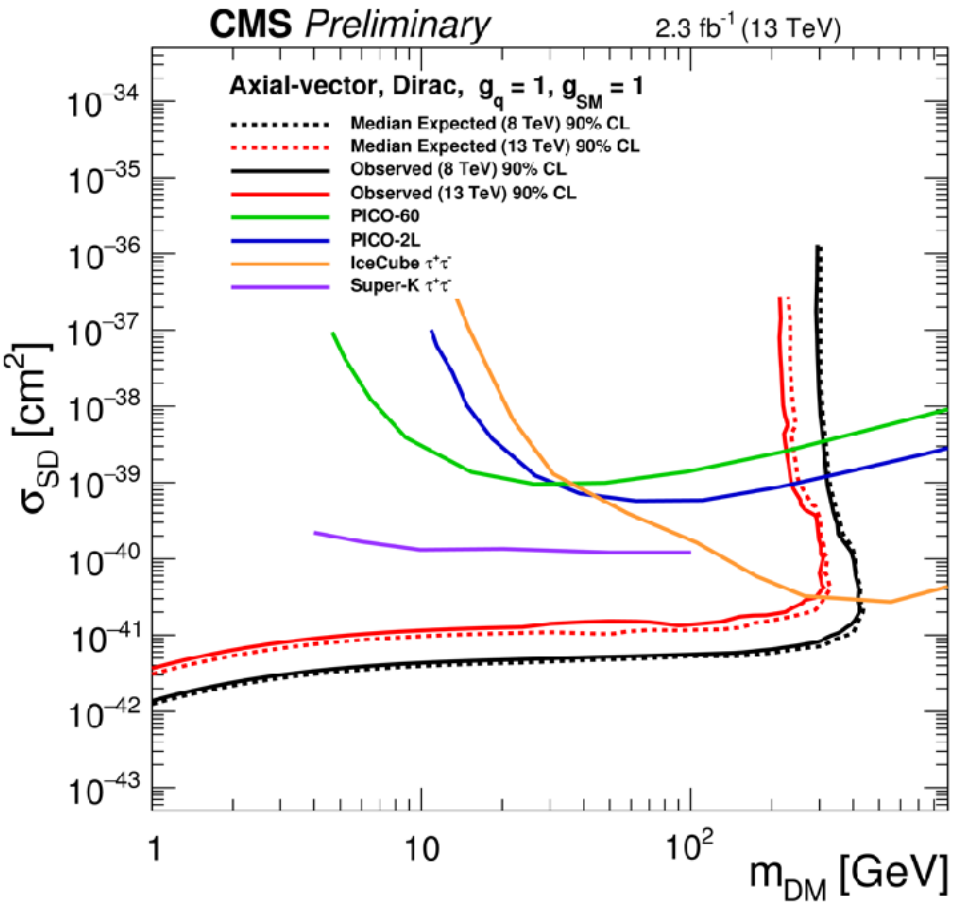






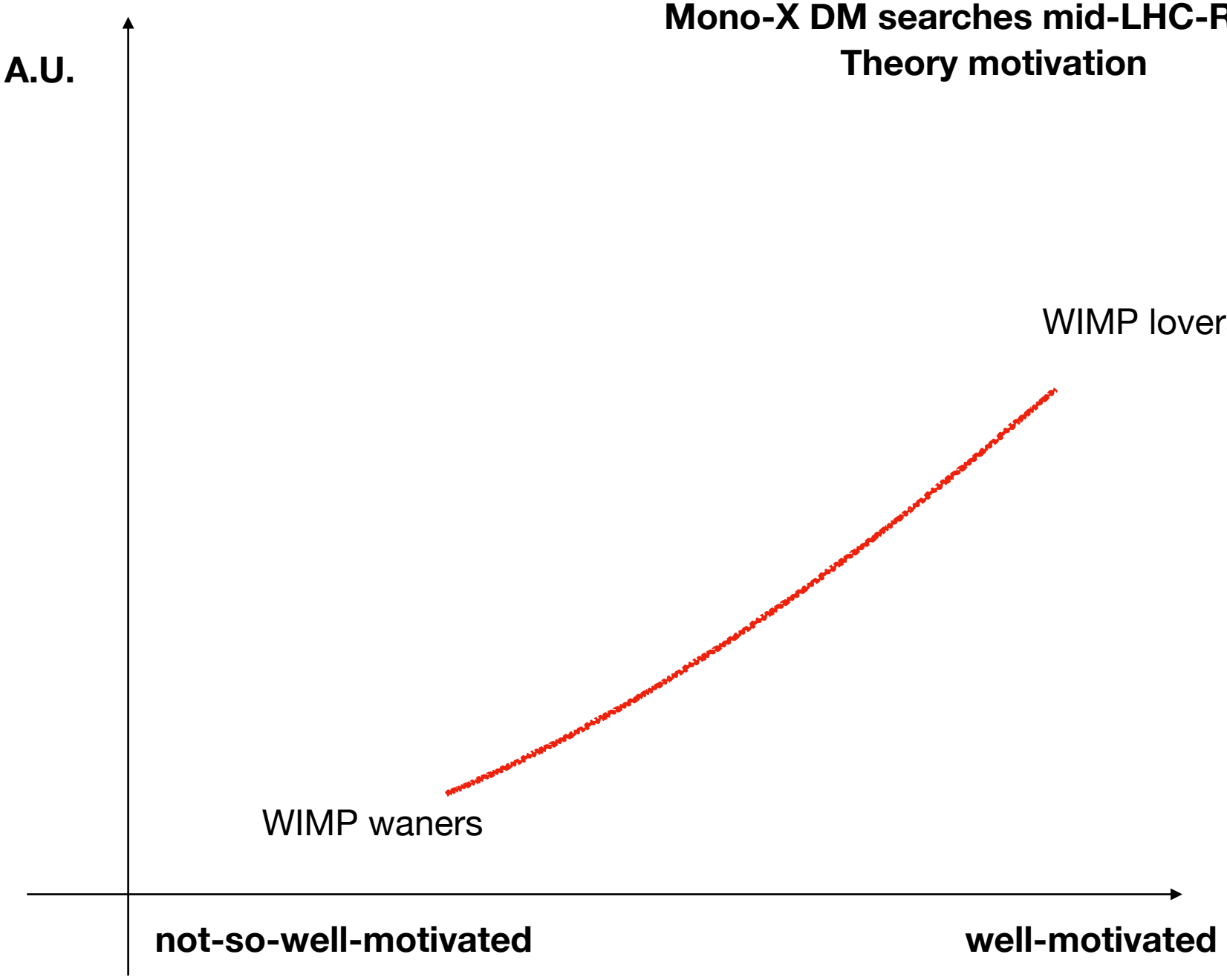
Results from 2015 data [CMS-PAS-EXO-16-013]



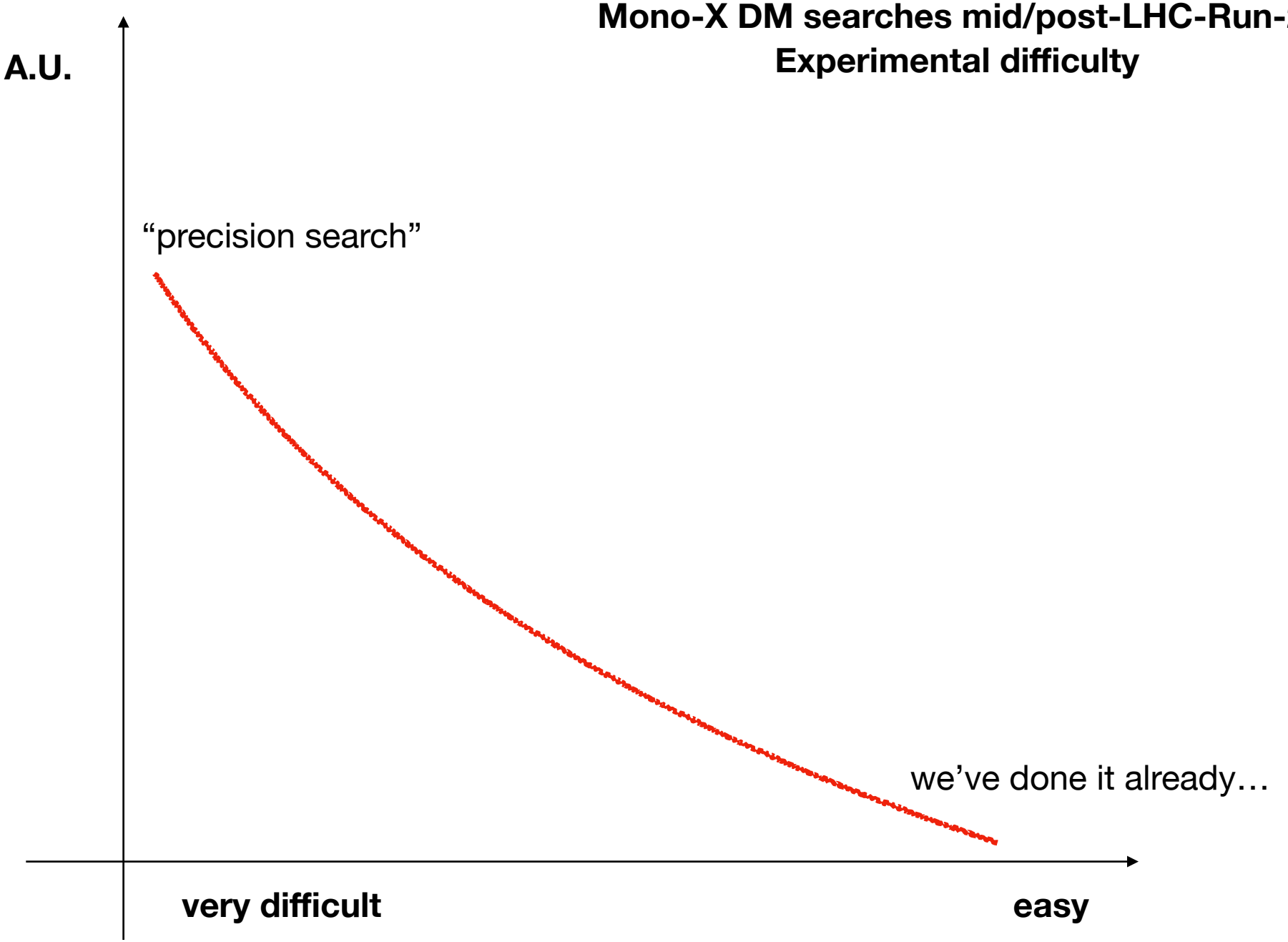


Horizon 2020
European Union funding
for Research & Innovation

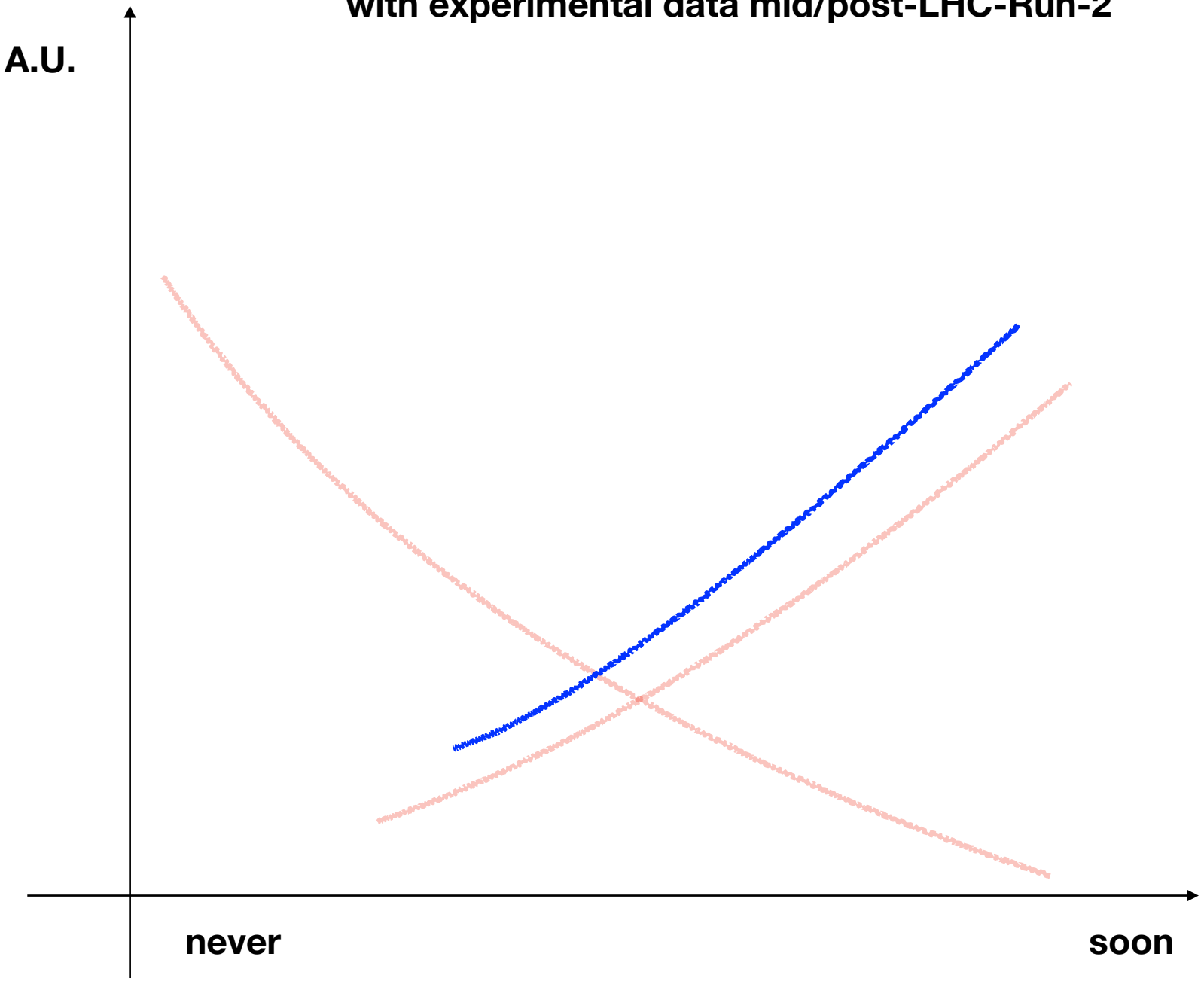
Mono-X DM searches mid-LHC-Run-2: Theory motivation



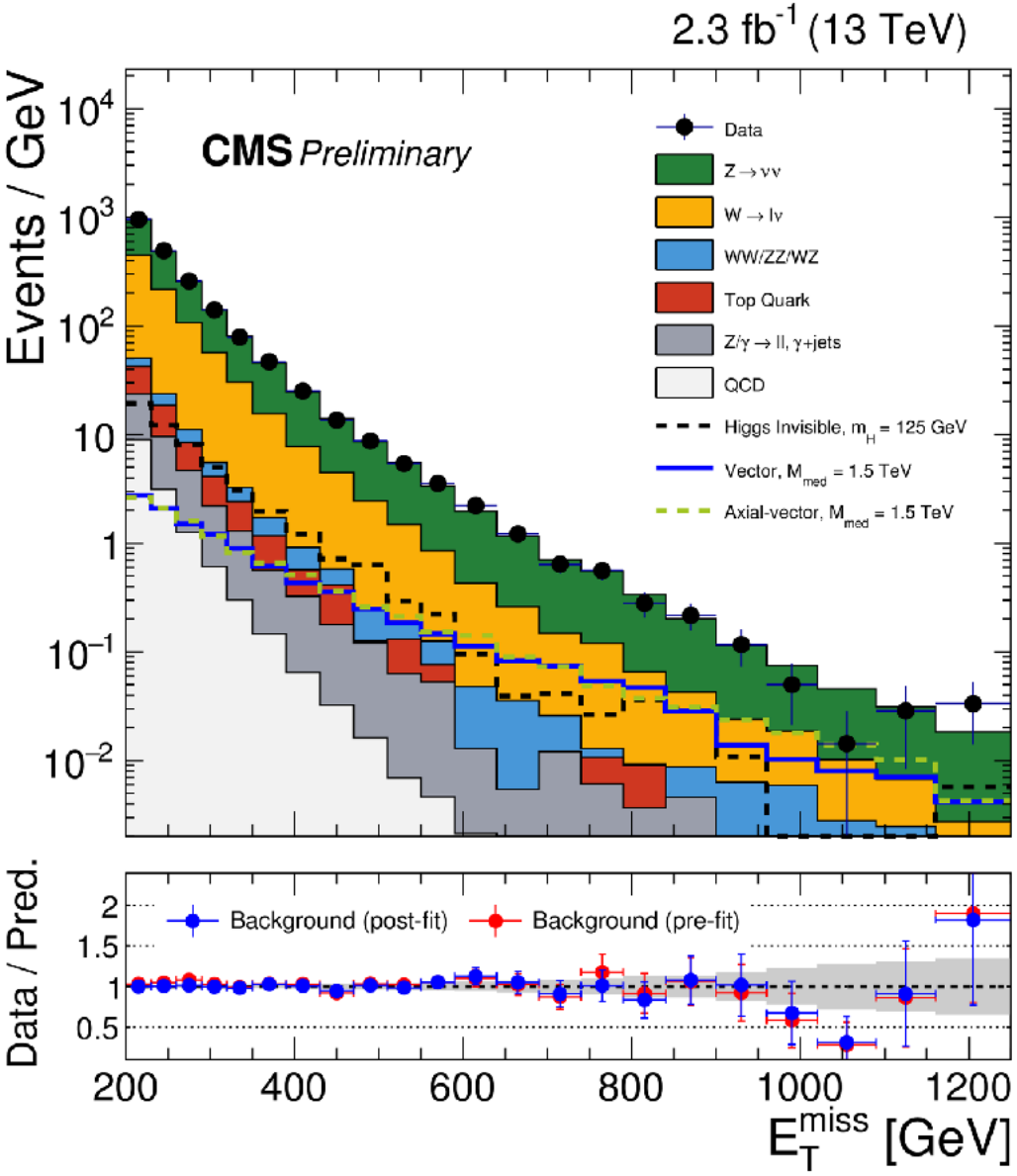
Mono-X DM searches mid/post-LHC-Run-2: Experimental difficulty

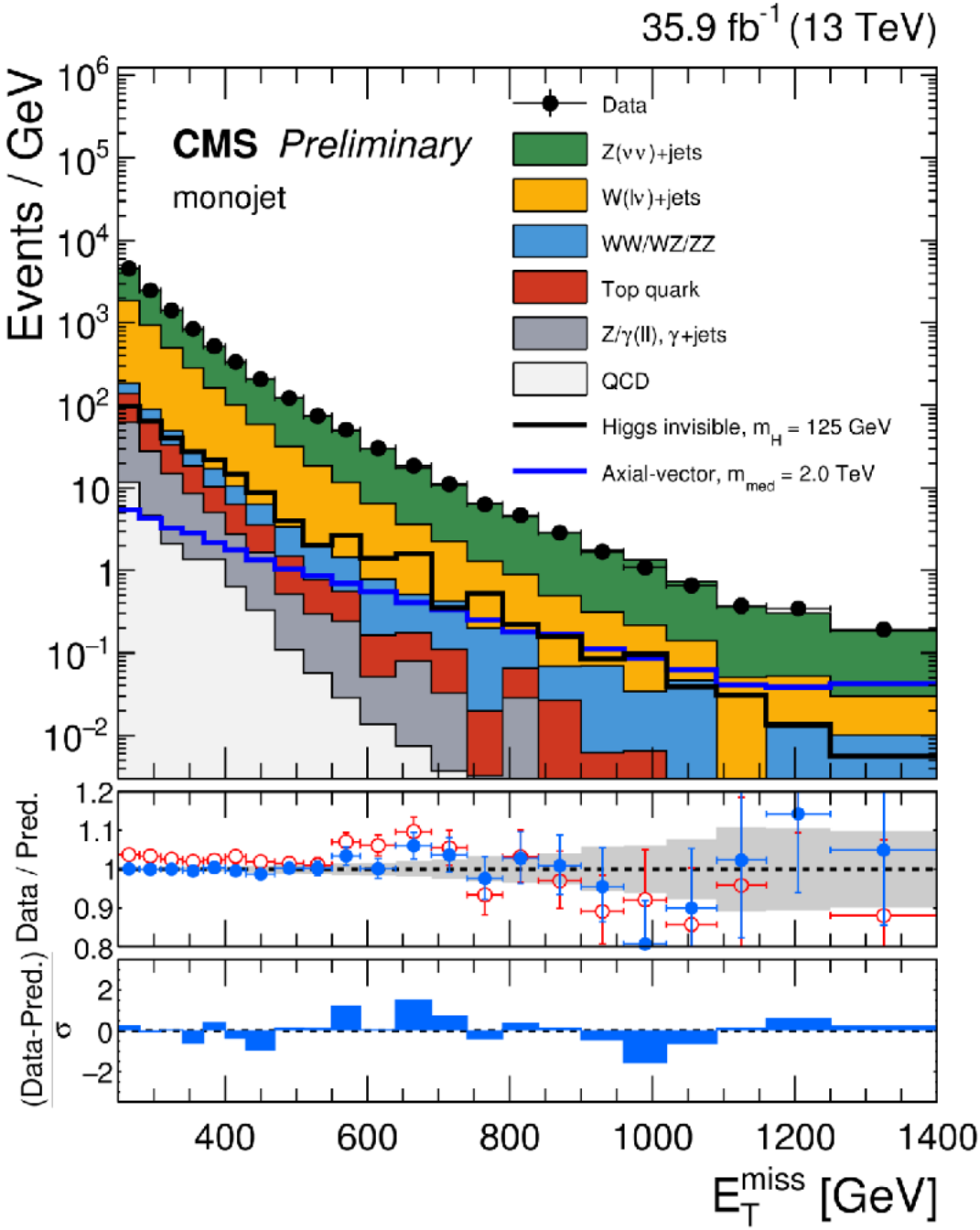


When (Mono-X) WIMPs will be tested with experimental data mid/post-LHC-Run-2



Results from 2015 and 2016 data

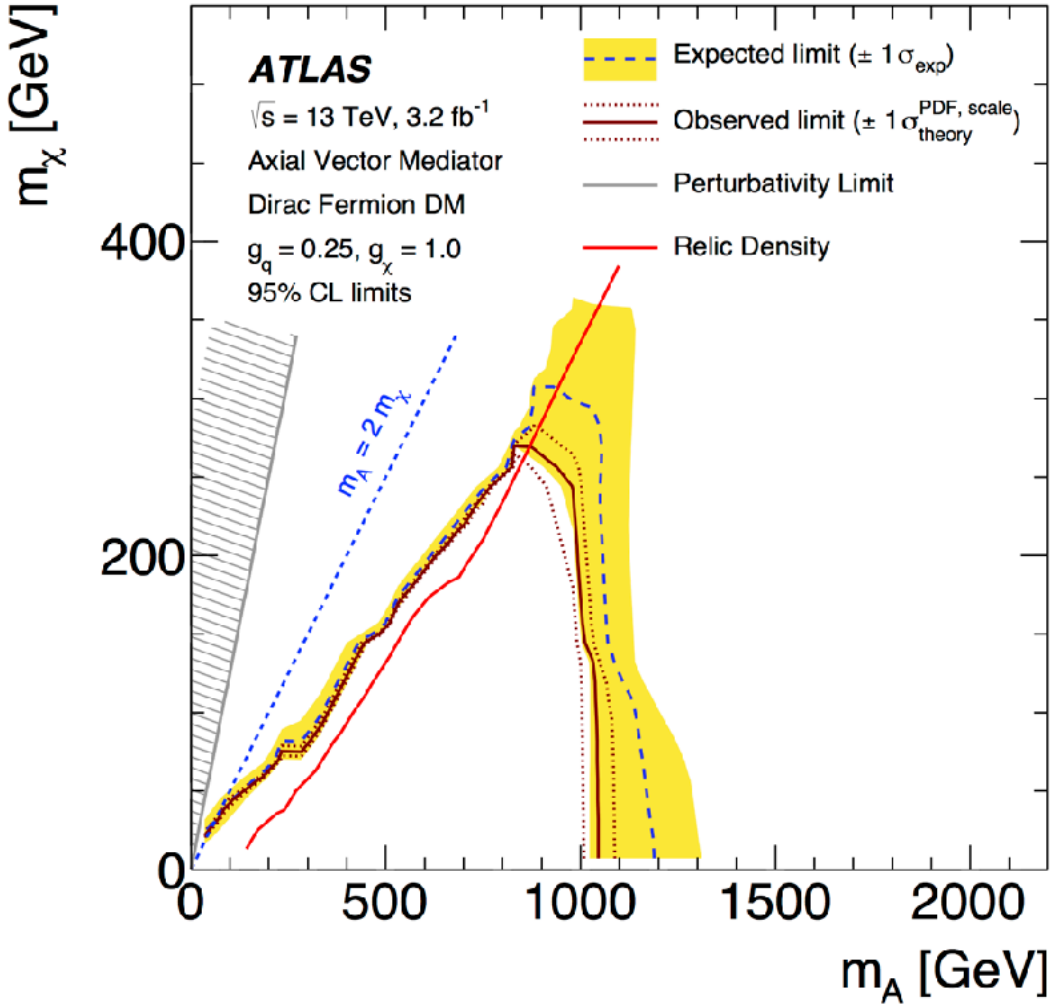


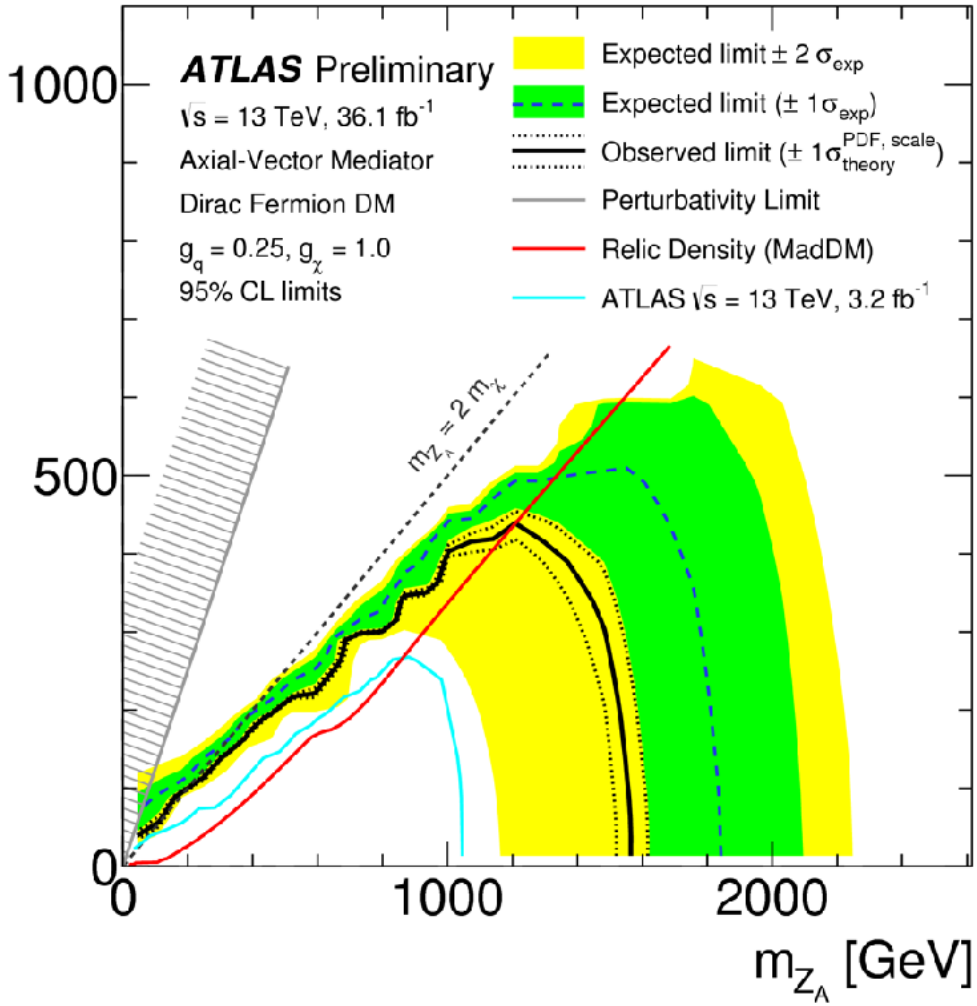


Horizon 2020
European Union funding
for Research & Innovation

Results from 2015 and 2016 data

ATLAS EXOT-2015-03
ATLAS-CONF-2017-060

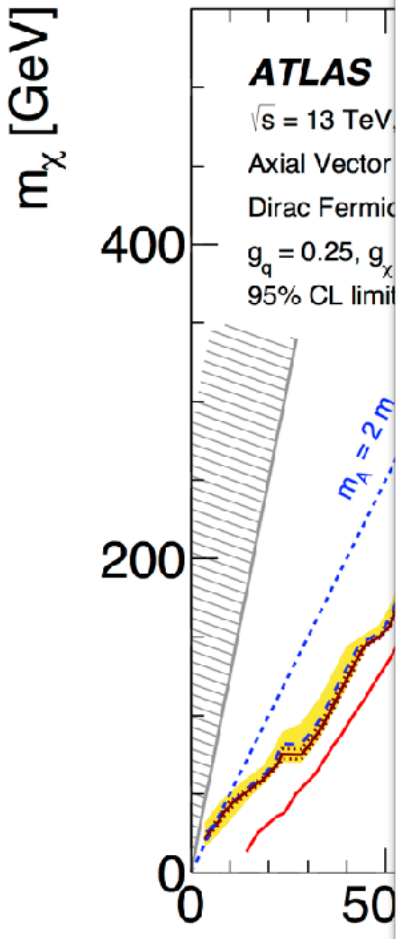




Horizon 2020
European Union funding
for Research & Innovation

Results from 2015 and 2016 data

ATLAS EXOT-2015-03
ATLAS-CONF-2017-060



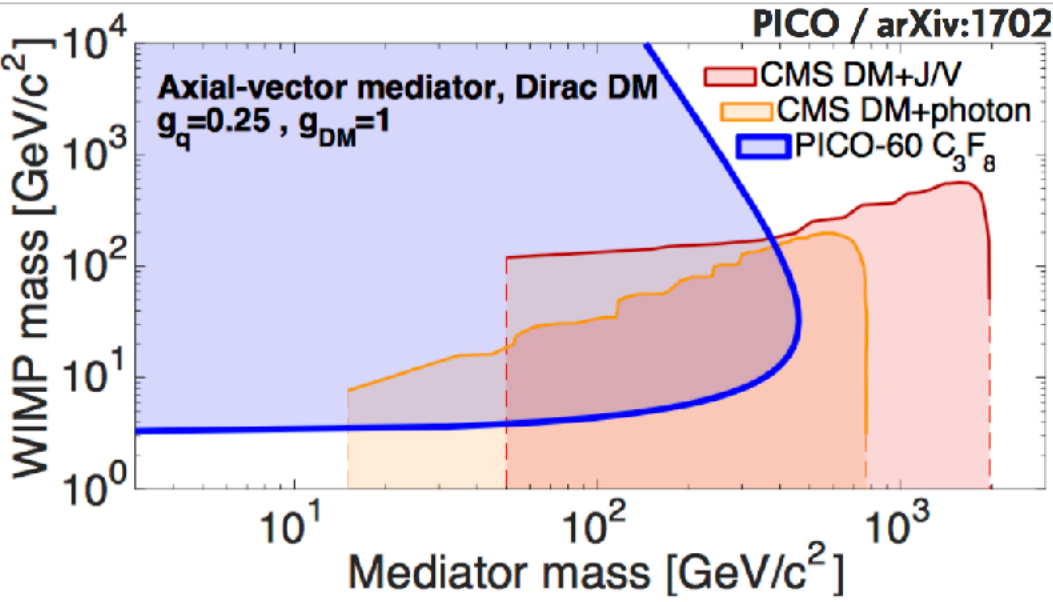
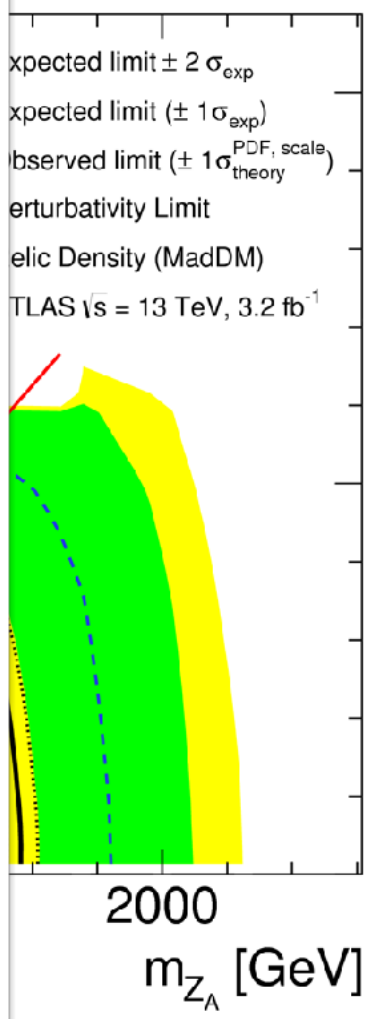


FIG. 6. Exclusion limits at 95% C.L. in the $m_{\mathrm{DM}} - m_{\mathrm{med}}$ plane. PICO-60 constraints (thick blue) are compared against collider constraints from CMS for an axial-vector mediator using the monojet/mono-V (red) [33] and mono-photon (orange) [34] channels. The shaded regions signify excluded parameter space for the chosen model. A similar analysis by ATLAS can be found in [52].

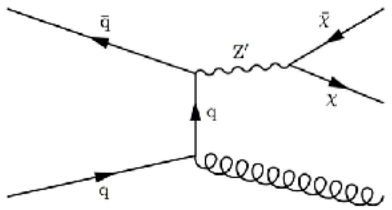


Horizon 2020
European Union funding
for Research & Innovation

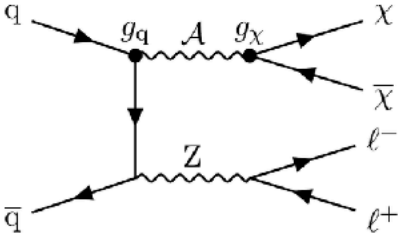
Many other MET+X searches not covered here

Mono-X Diagrams of Direct DM Production

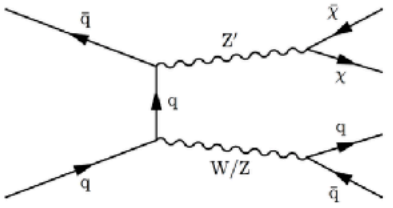
Eiko Yu's EPS talk



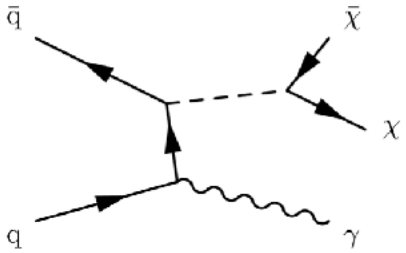
Mono-jet



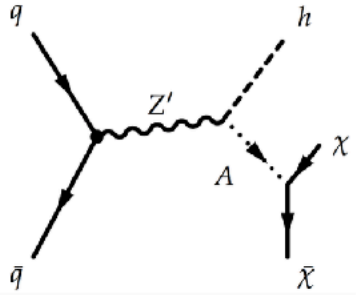
Mono-Z(leptonic)



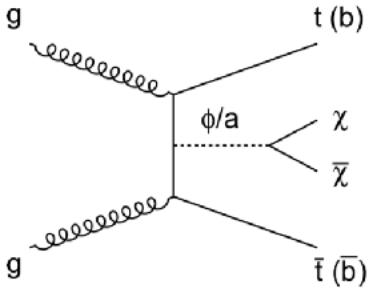
Mono-W/Z(hadronic)



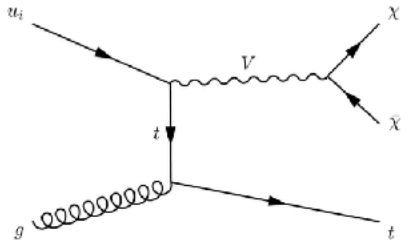
Mono-photon



Mono-h (bb, $\gamma\gamma$)



Mono-tt/bb



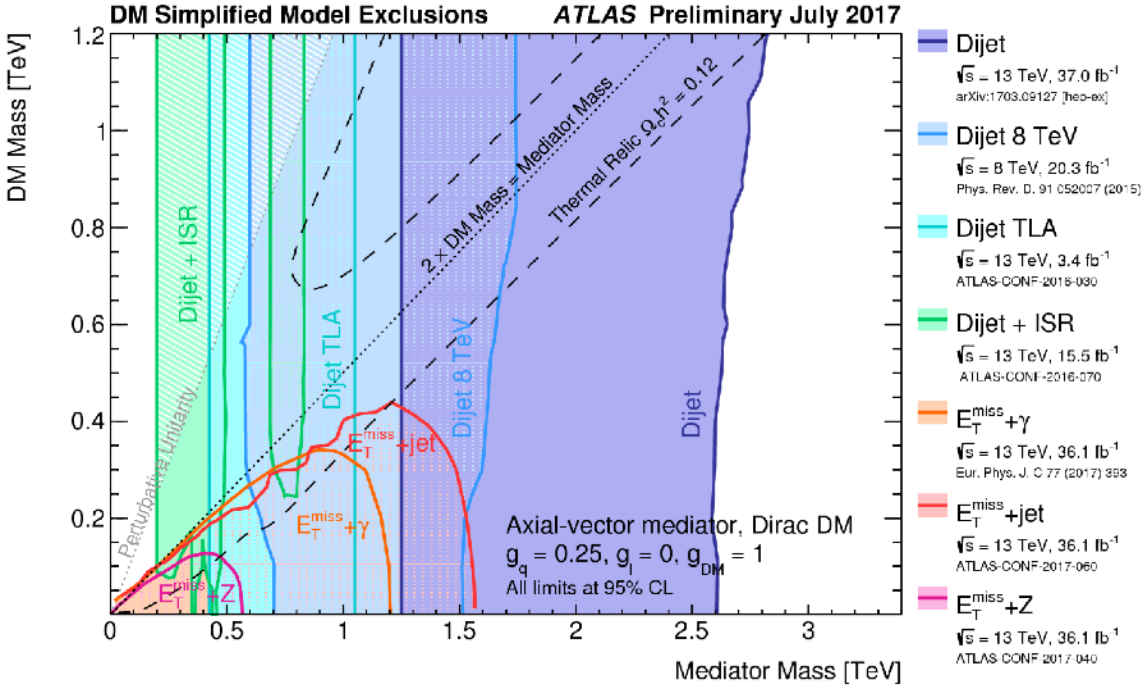
Mono-top

Shin-Shan Eiko Yu

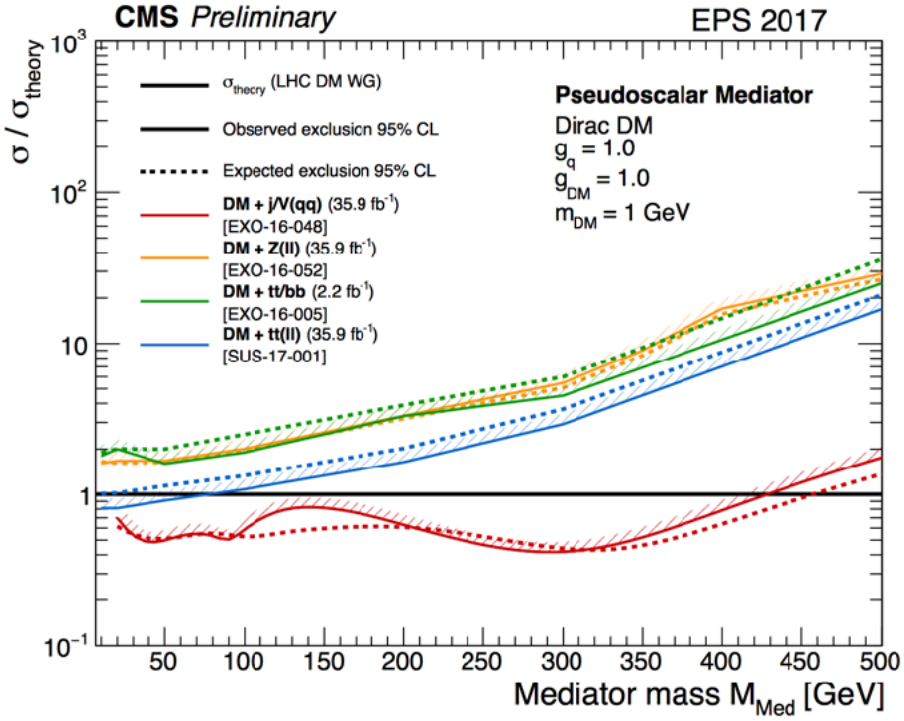
10

Many other "generic" MET+X searches

[ATLAS summary plots](#)



[CMS summary plots](#)



ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding for Research & Innovation

LUND UNIVERSITY

Where to go with simplified models: less simplified models

1. **Simplest scalar models:** Higgs portals, inert 2HDM

2. Add **singlet mixing with SM Higgs**, and DM

Dark Matter Working Group

3. Introduce an **additional Higgs doublet and a separate (pseudo-)scalar**

- generalisation of scalar singlet mixing model

- 125 GeV spin-0 state SM-like (alignment/decoupling limit)

- mix extra spin-0 states with a singlet to mediate DM interaction

=> see 1404.3716, 1612.03475, 1509.01110, 1611.04593, 1701.07427

2HDM + DM collider phenomenology:

Substantial mono-h, mono-Z signatures

- **different phenomenology**, depending on hierarchy of scalar masses, e.g. **resonantly-enhanced mono-h, mono-Z**

Dark Matter Working Group

Summer 2015
https://arxiv.org/abs/1507.00966

[Dark Matter Forum] Reach consensus on a common set of benchmark models for ATLAS and CMS early Run-2 searches

Winter 2015
https://arxiv.org/abs/1603.04156

Within the framework of the DMF simplified models, present results and compare Direct Detection (DD) / Indirect Detection (ID) / collider searches

Winter 2016
http://arxiv.org/abs/1703.05703

Agree on how to present searches for mediators of DM interactions in visible decays together with searches to DM particles, add lepton couplings to DMF benchmark models

Spring 2017
https://arxiv.org/abs/1705.04664

Arrive at a joint estimation of theory uncertainties for *precision DM searches* at colliders (e.g. mono-jet)

Fall 2017

Develop scalar sector and t-channel benchmark models

?

You're welcome to join and help define DM searches at the LHC!
http://lpcc.web.cern.ch/lpcc/index.php?page=dm_wg
subscribe to lhc-dmwg@cern.ch at https://e-groups.cern.ch

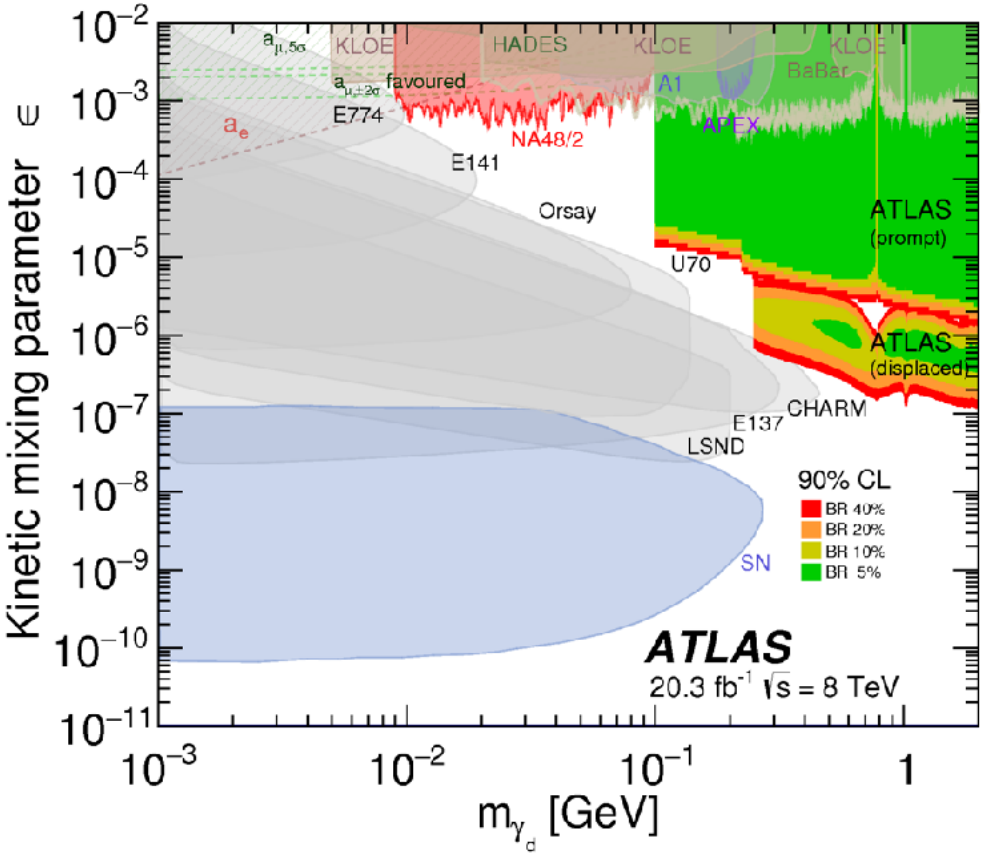
ATLAS EXPERIMENT erc European Commission Horizon 2020 European Union funding for Research & Innovation

LUND UNIVERSITY

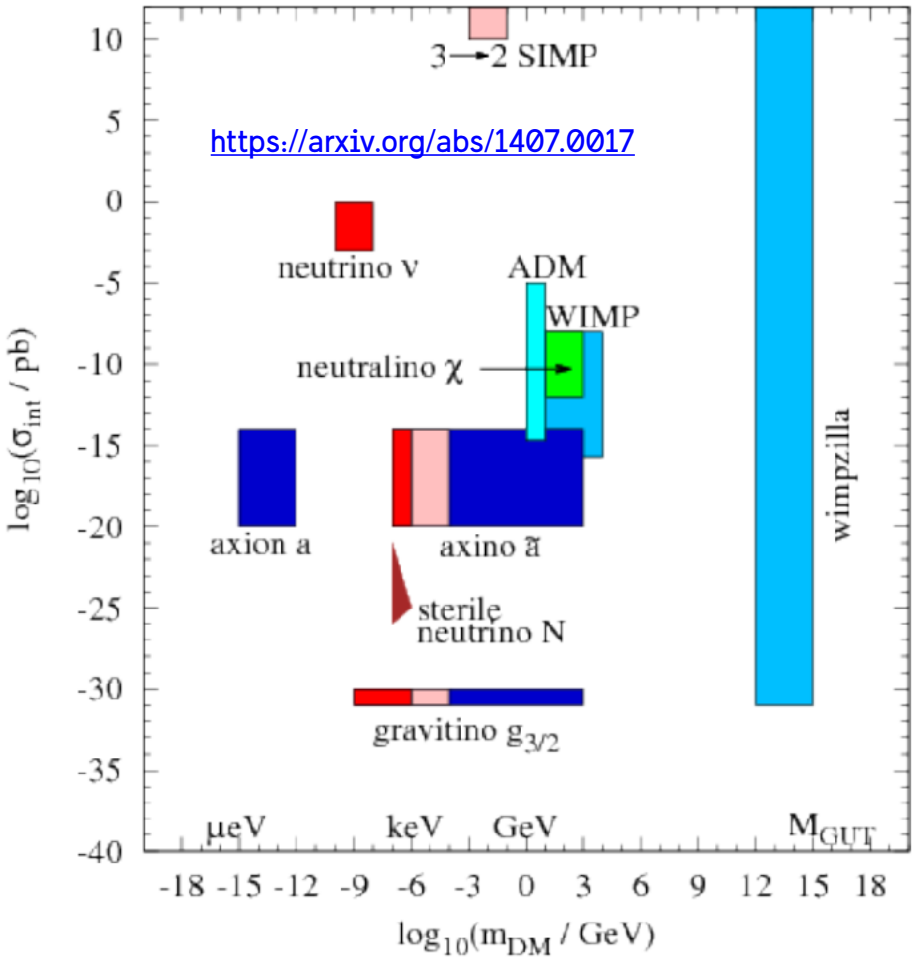
Everything we don't want to miss

by thinking of WIMPs only

Searches for Dark Sector particles
(no direct DM/SM interactions)

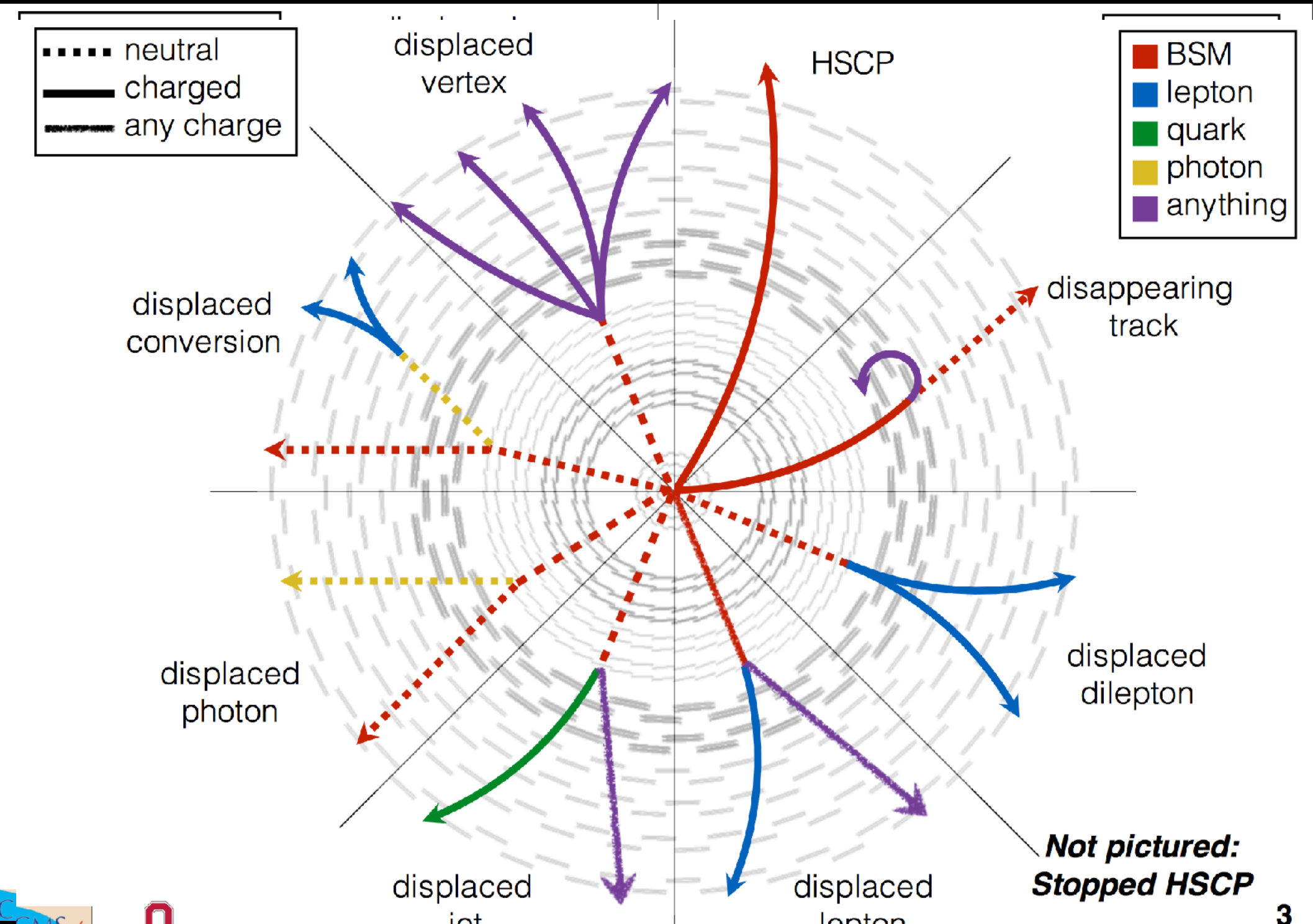


http://en.wikipedia.org/wiki/Streetlight_effect

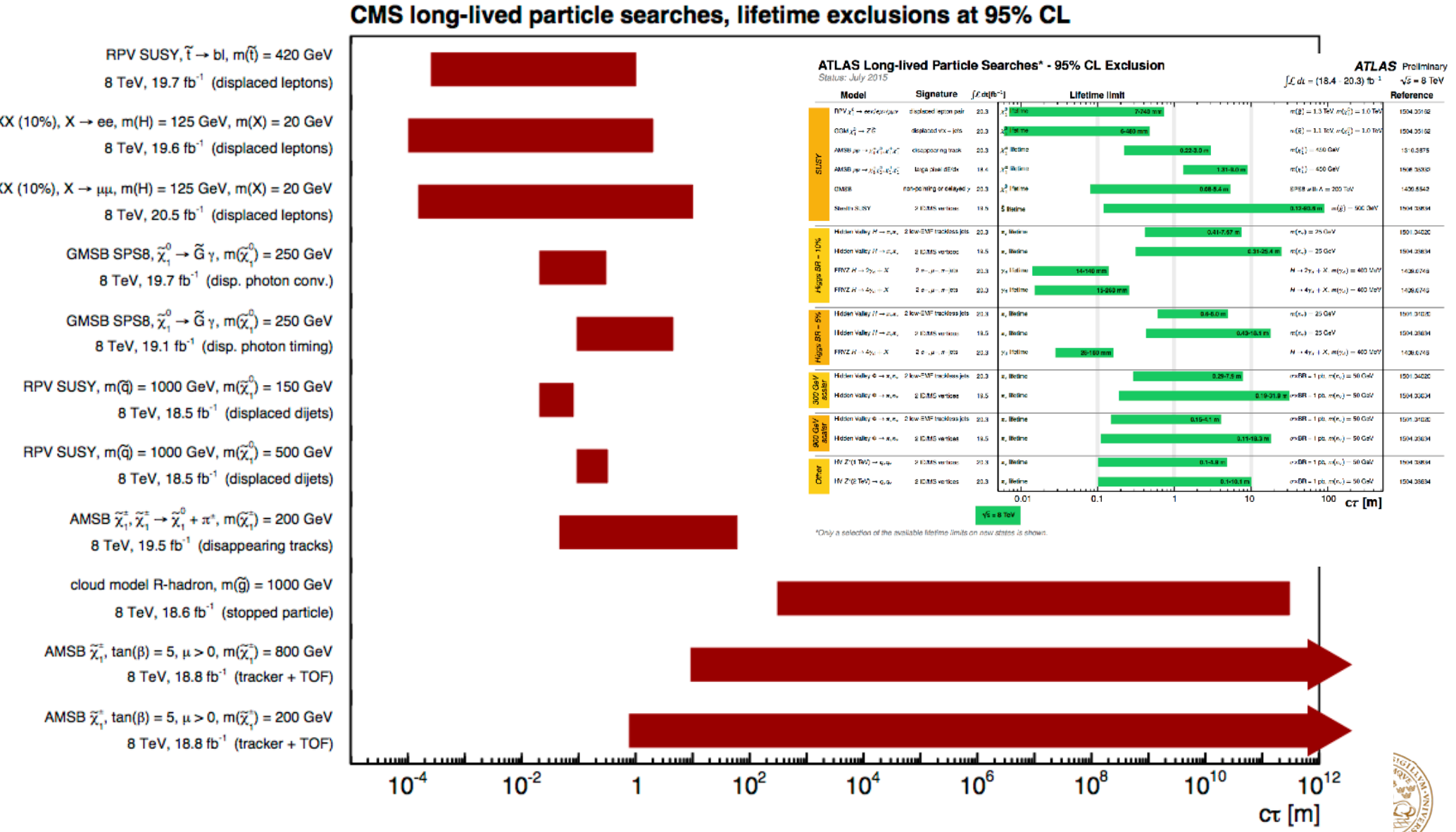


Many other interesting
and compelling DM candidates at colliders and beyond

B. Francis' TeVPA talk, Original drawing by Jamie Antonelli

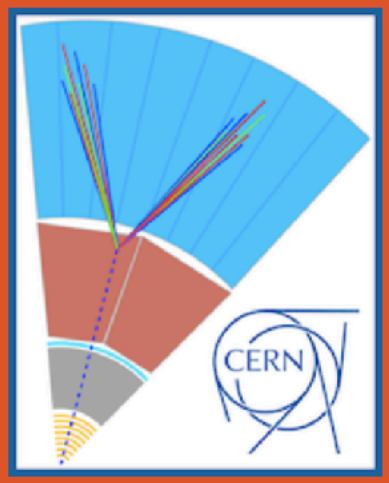


N examples: ATLAS/CMS searches



Horizon 2020
European Union funding
for Research & Innovation

Organization attempt: LLP WG



Searches for long-lived particles at the LHC:
Second workshop of the LHC LLP Community

https://indico.cern.ch/event/649760/

Mailing list for joining: lhc-llp@cern.ch

17-20 October 2017
ICTP, Trieste, Italy
Europe/Zurich timezone

Search...

Following the groundwork laid by the LHC Long-Lived Particle (LLP) Workshop in April of 2017, the LHC LLP Community -- composed of members of the CMS, LHCb, and ATLAS collaborations as well as theorists, phenomenologists and those interested in LLP searches with dedicated LHC detectors such as milliQan, MoEDAL, and MATHUSLA -- convenes again to finalize the community white paper and assess the state of LLP searches at the LHC.

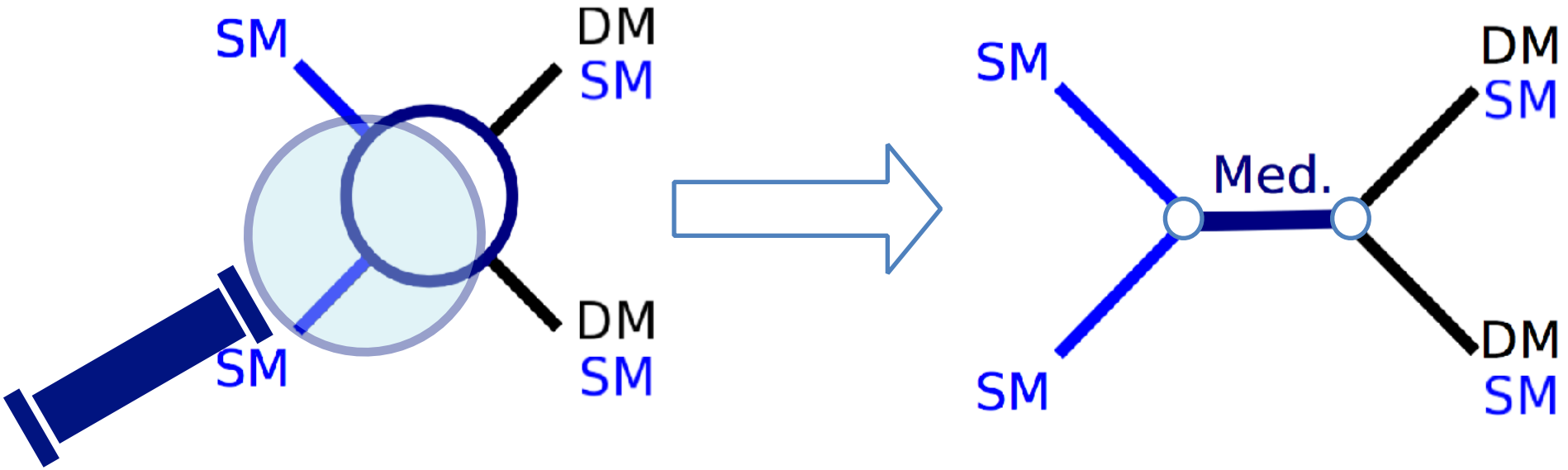
This workshop is the second of two workshops devoted to producing an LHC LLP white paper that proposes a set of simplified models for LLP searches; contains an enumeration of gaps in the coverage of classes of BSM models that can produce LLPs; proposes recommendations for new triggering strategies for LLPs in ATLAS, CMS, and LHCb; lists ideas for new searches for LLPs; and proposes a set of recommendations for the presentation of search results to ensure future reinterpretation and recasting.

2. *Mediator searches are a strength of the LHC*

Highlighting complementarity between visible/invisible LHC searches

Dark Matter mediators at the LHC

If there's a force there's a mediator:



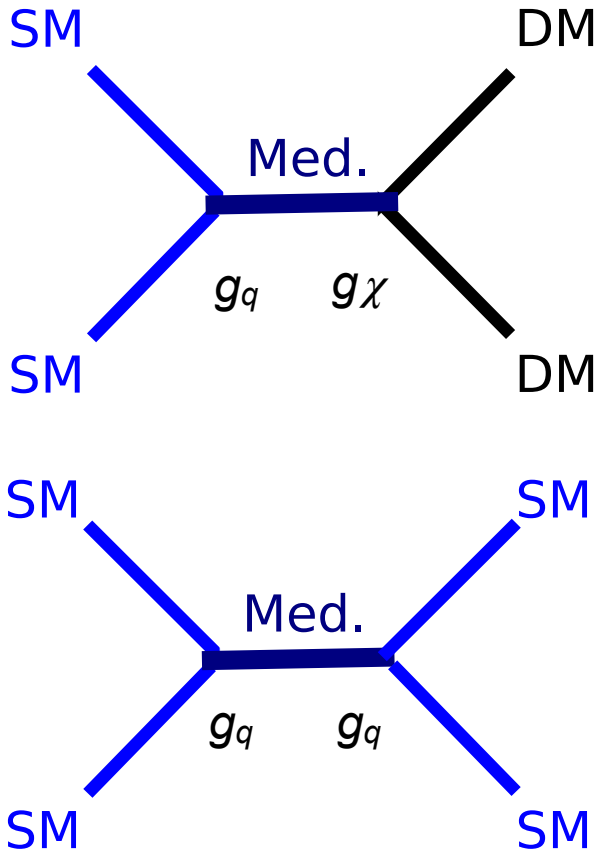
Particle Colliders

Can look for both invisible and visible decays of the mediator

(this talk: case in which the mediator is a new particle, but it can also be a known particle)

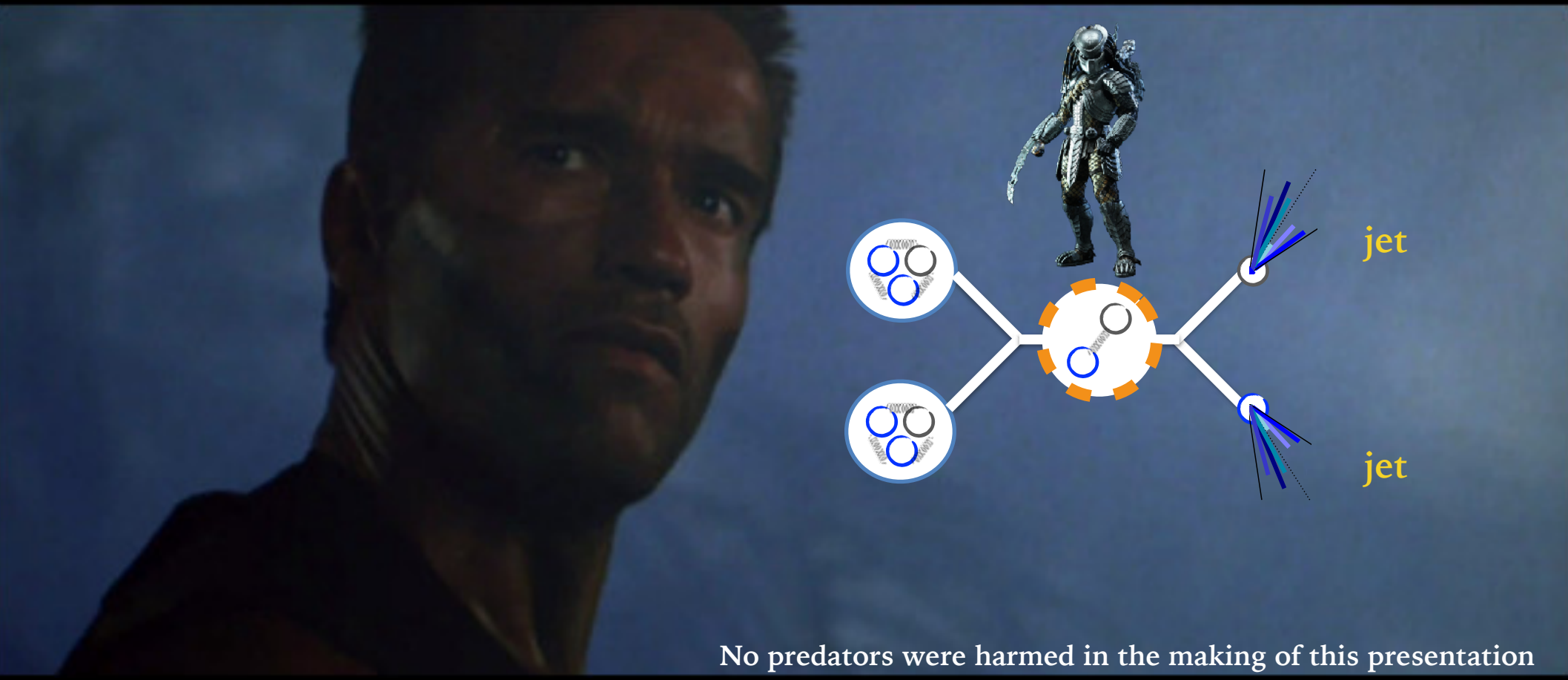
ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation
LUND UNIVERSITY

Searches for DM mediators



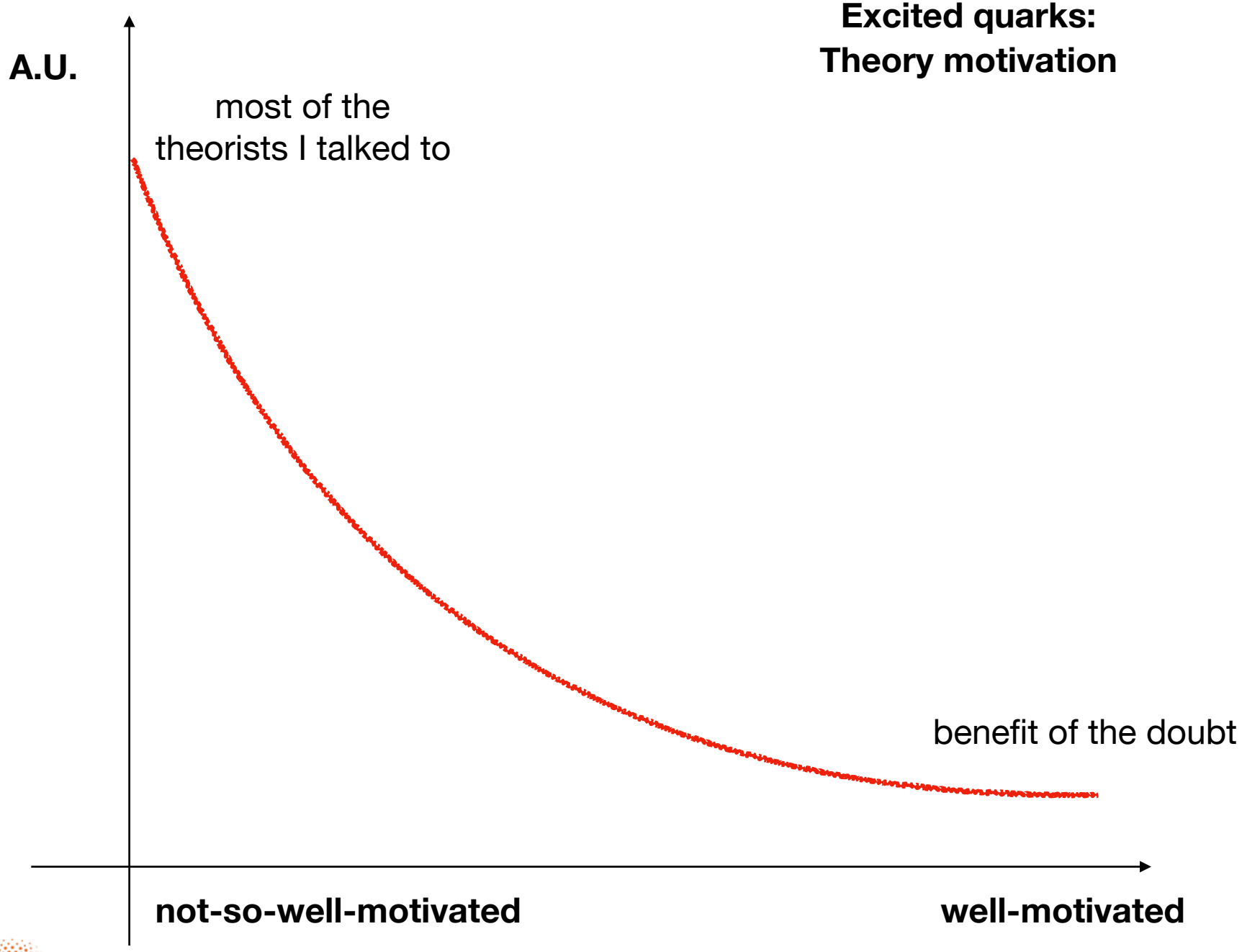
Look for an inevitable LHC physics process: **di-jet resonances**

IF IT ~~BLEEDS~~ IS PRODUCED FROM QUARK INTERACTIONS

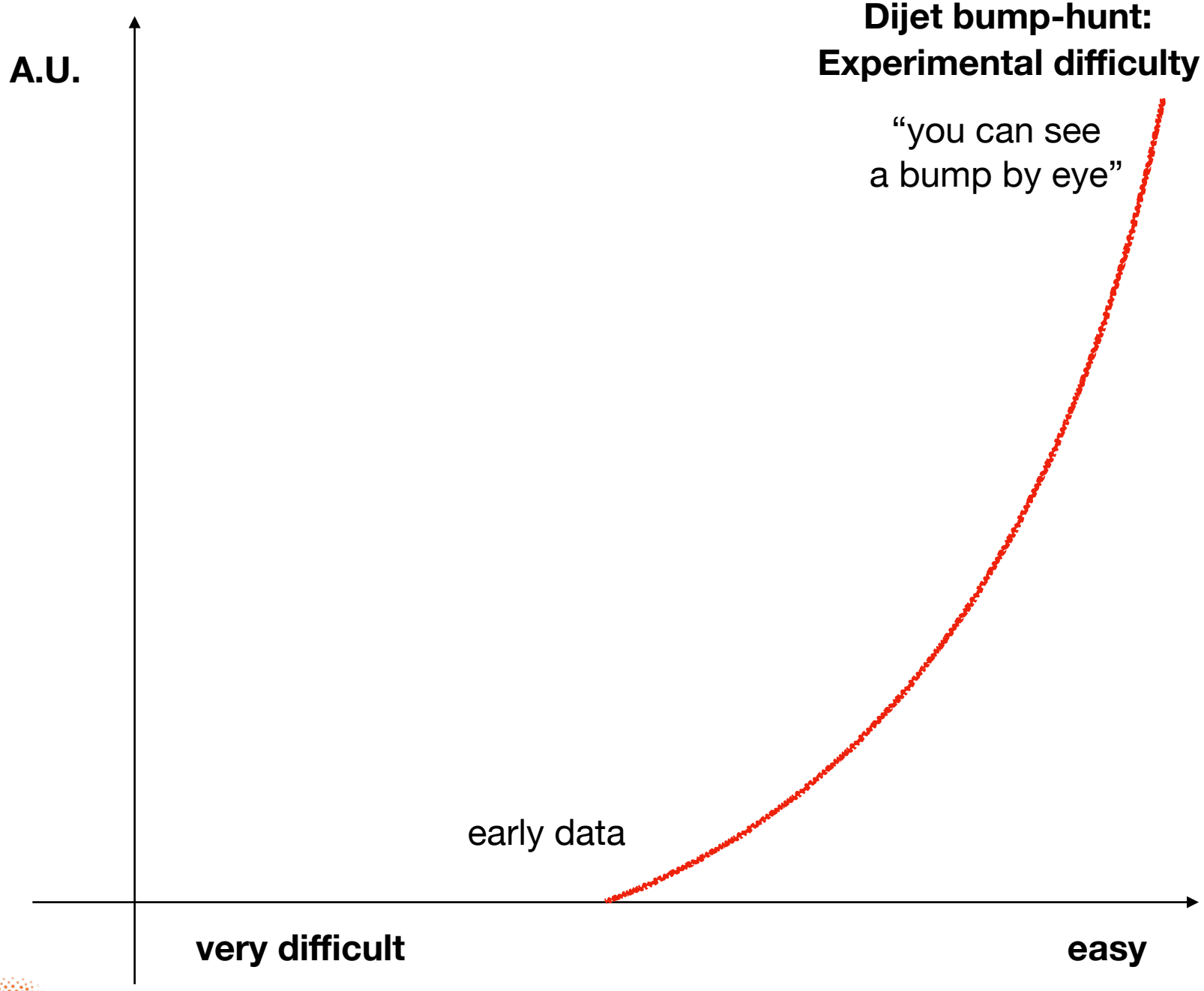


WE CAN ~~KILL IT~~ DISCOVER IT IN FINAL STATES WITH JETS

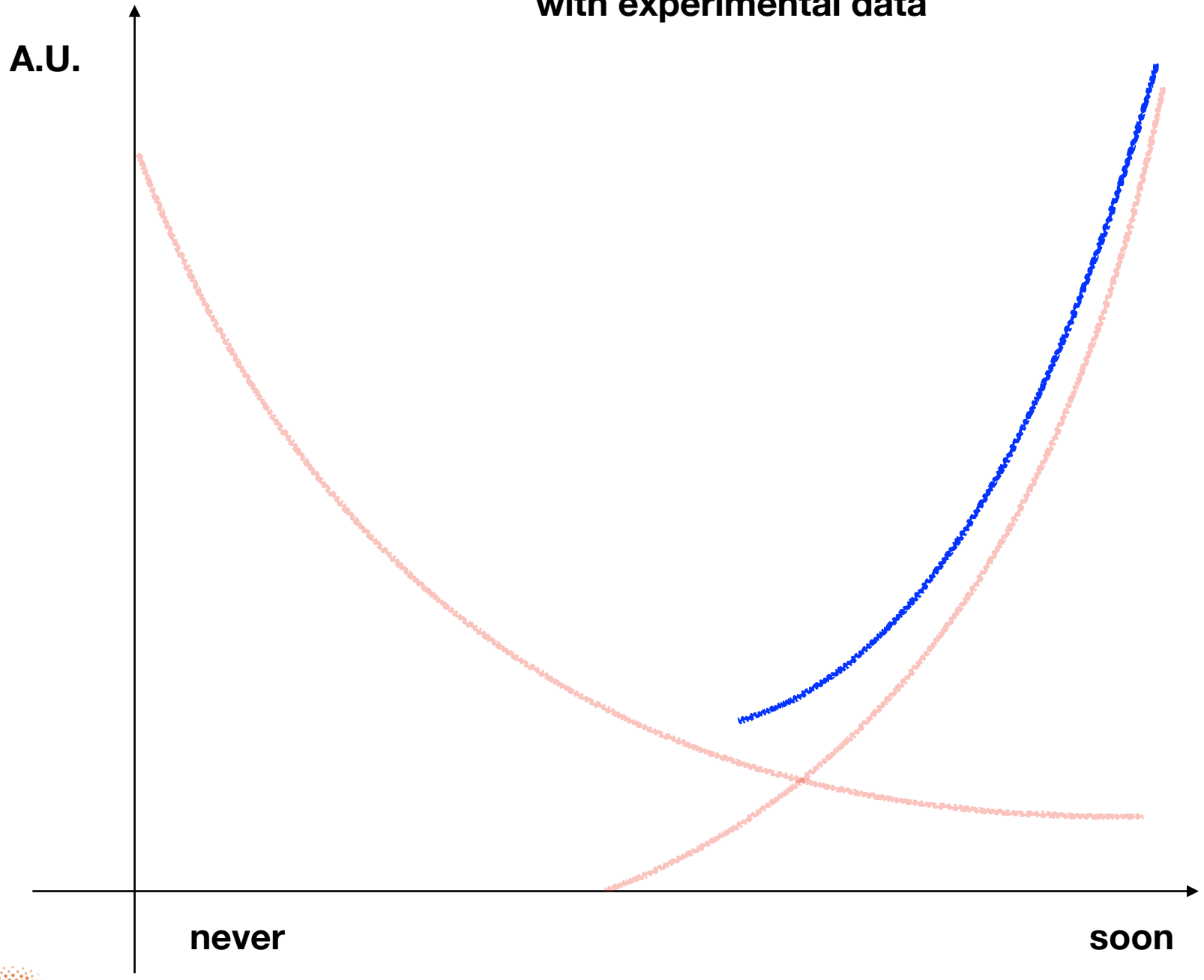
Excited quarks:
Theory motivation



Dijet bump-hunt:
Experimental difficulty

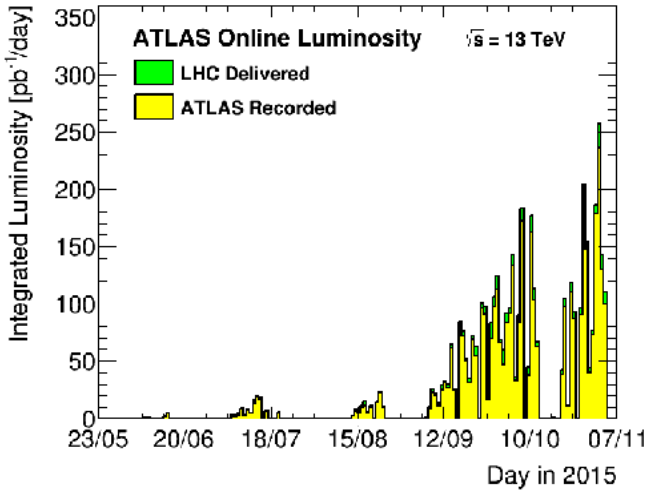


When high-mass dijet resonances are tested with experimental data



When high-mass dijet resonances are tested with experimental data

A.U.



Submission history

From: Atlas Publications [view email]
[v1] Fri, 4 Dec 2015 20:15:47 GMT (778kb,D)

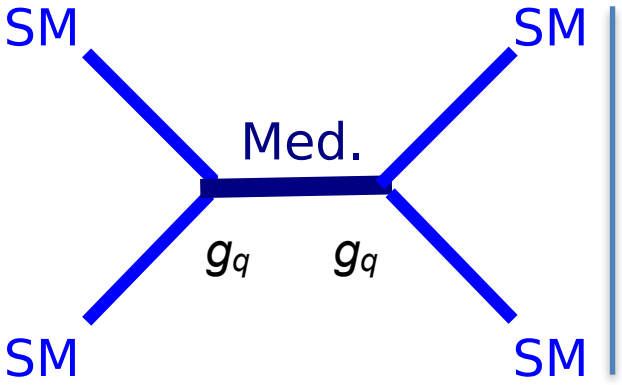
Submission history

From: The CMS Collaboration [view email]
[v1] Thu, 3 Dec 2015 20:49:43 GMT (1357kb,D)

never

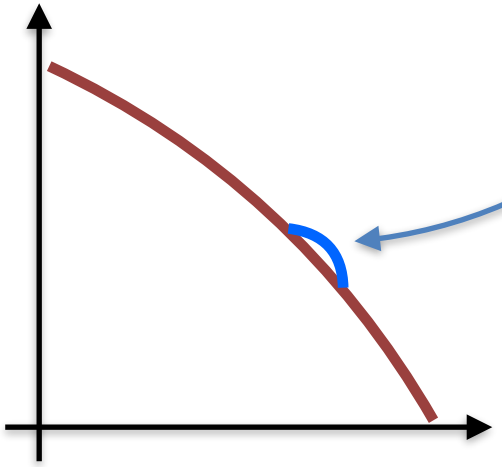
soon

Anatomy of a *bump-hunt*



invariant mass

number of events

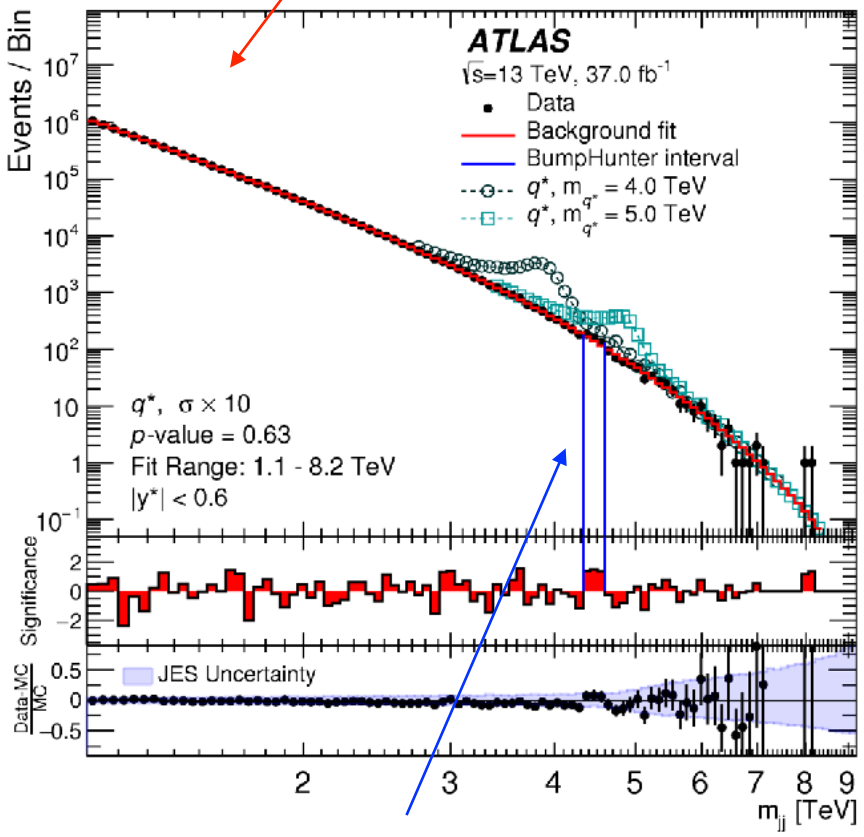


invariant mass

Data-driven background fit

$$f(z) = p_1(1-z)^{p_2} z^{p_3+p_4 \log z}$$

arXiv: highmassdijets



Most discrepant region

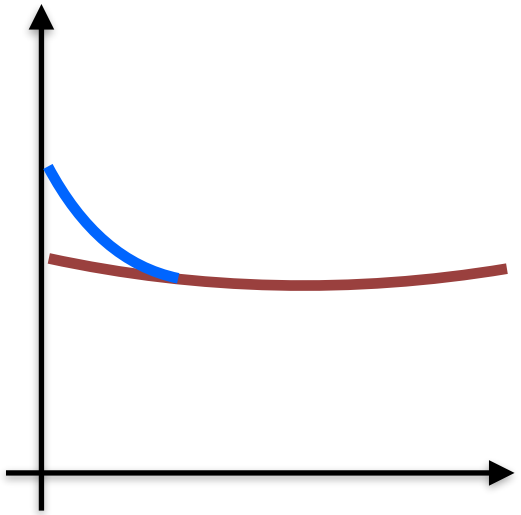
No signals of Dark Matter mediators
(or other resonances)

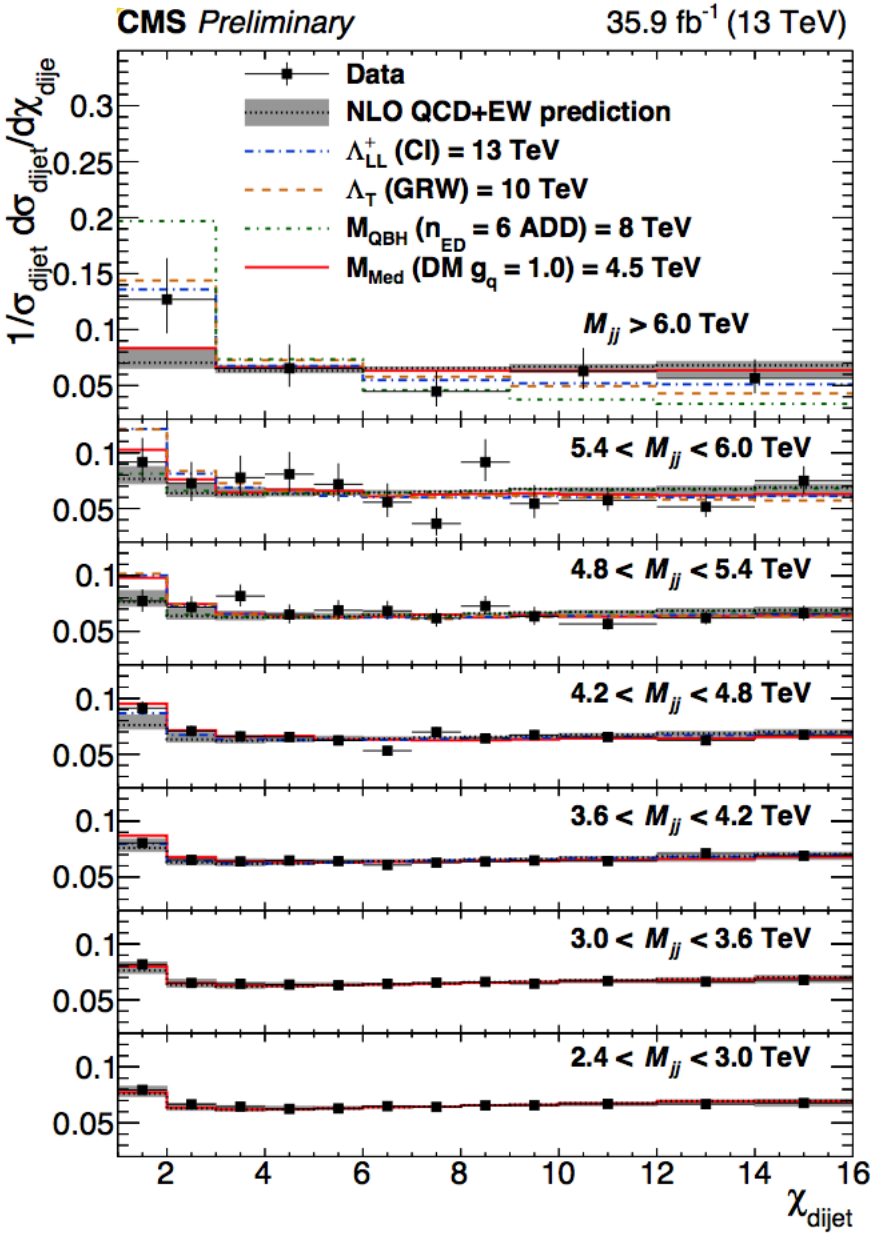
ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation

LUND UNIVERSITY

Wide mediators: angular distributions

If the **mediator is wide**,
a fit is not effective
→ use dijet scattering angle
to discriminate signal/background

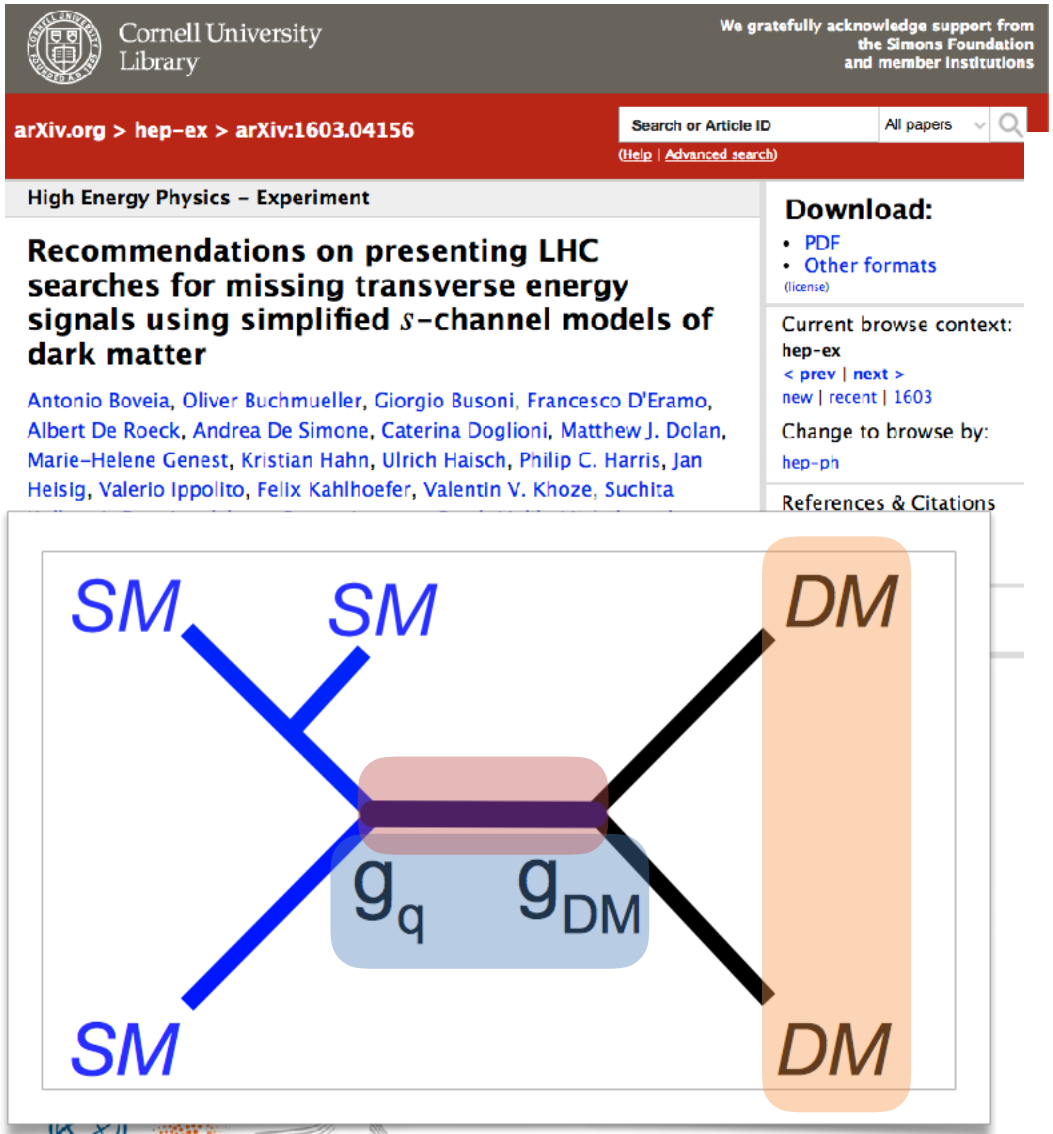




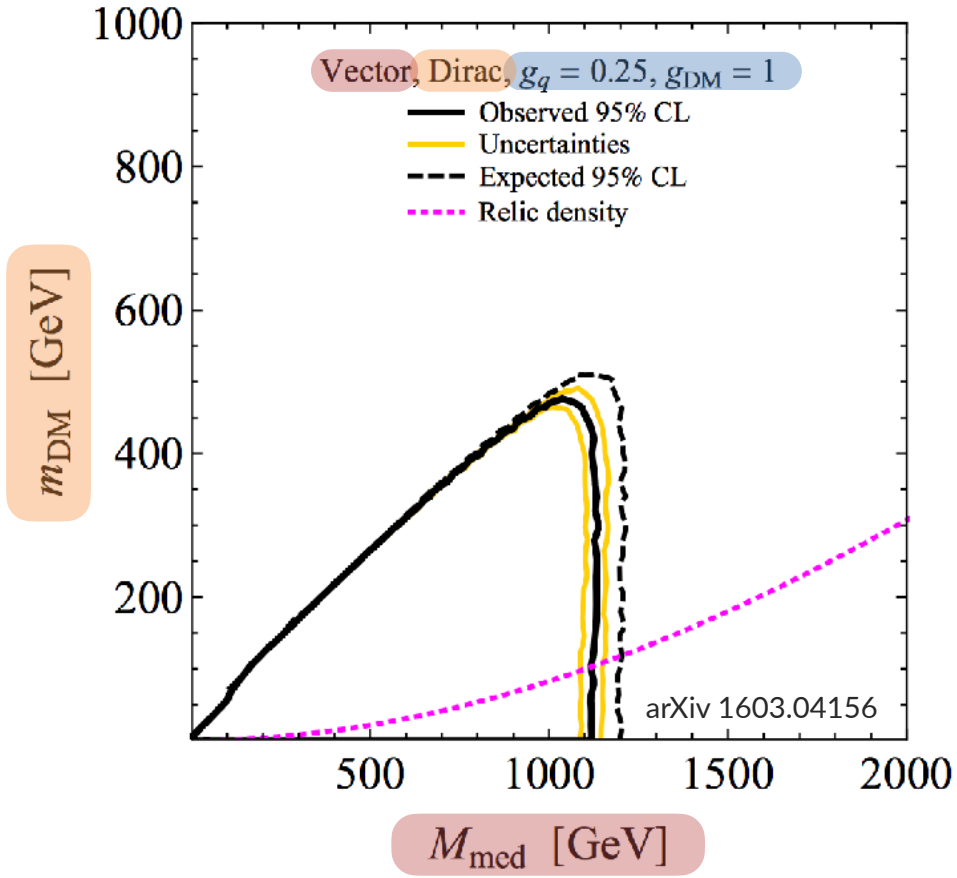
No signals of Dark Matter mediators

Visible/invisible DM LHC searches

How to display interpretation of collider search using simplified models



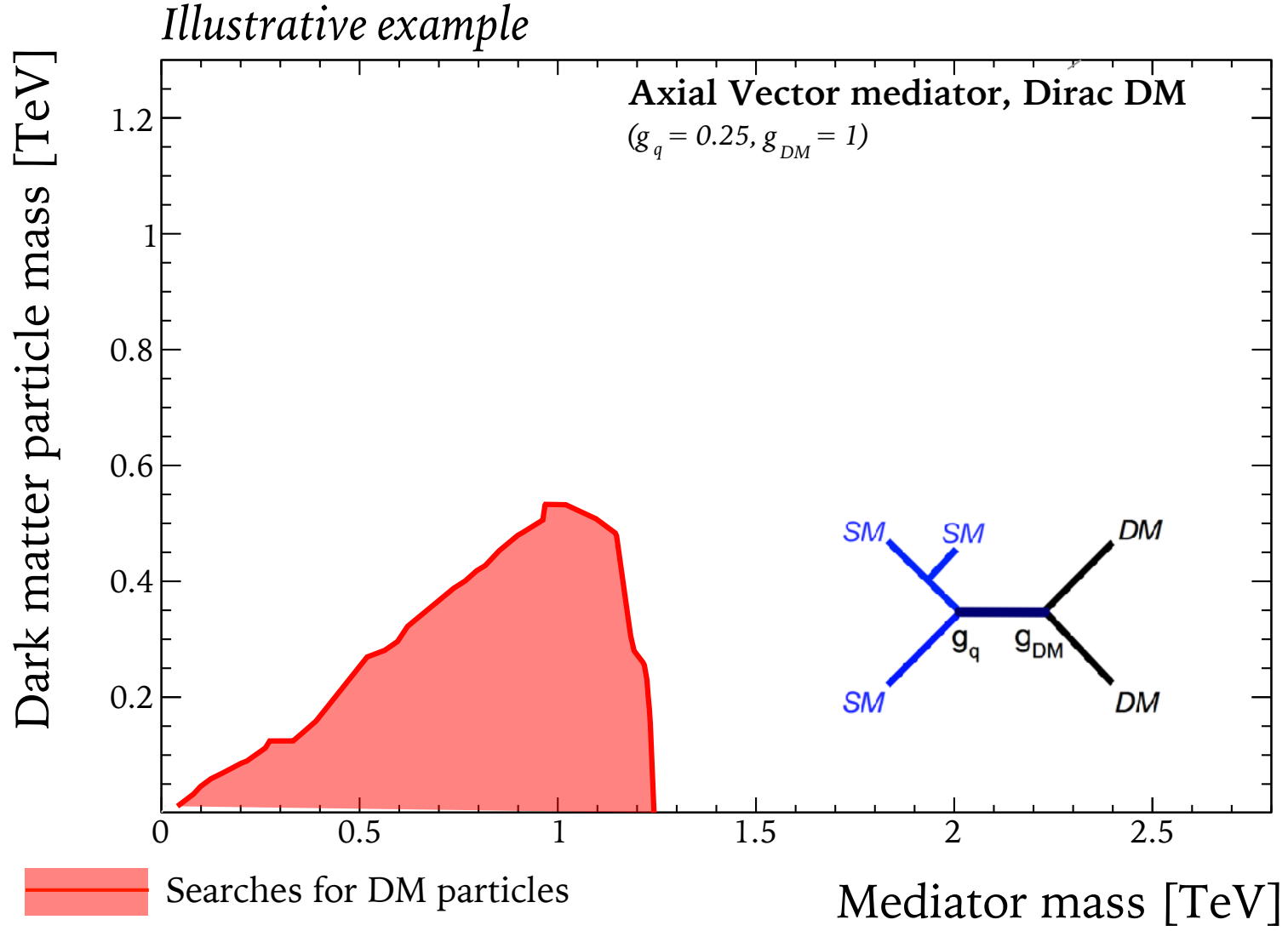
Dark Matter Working Group



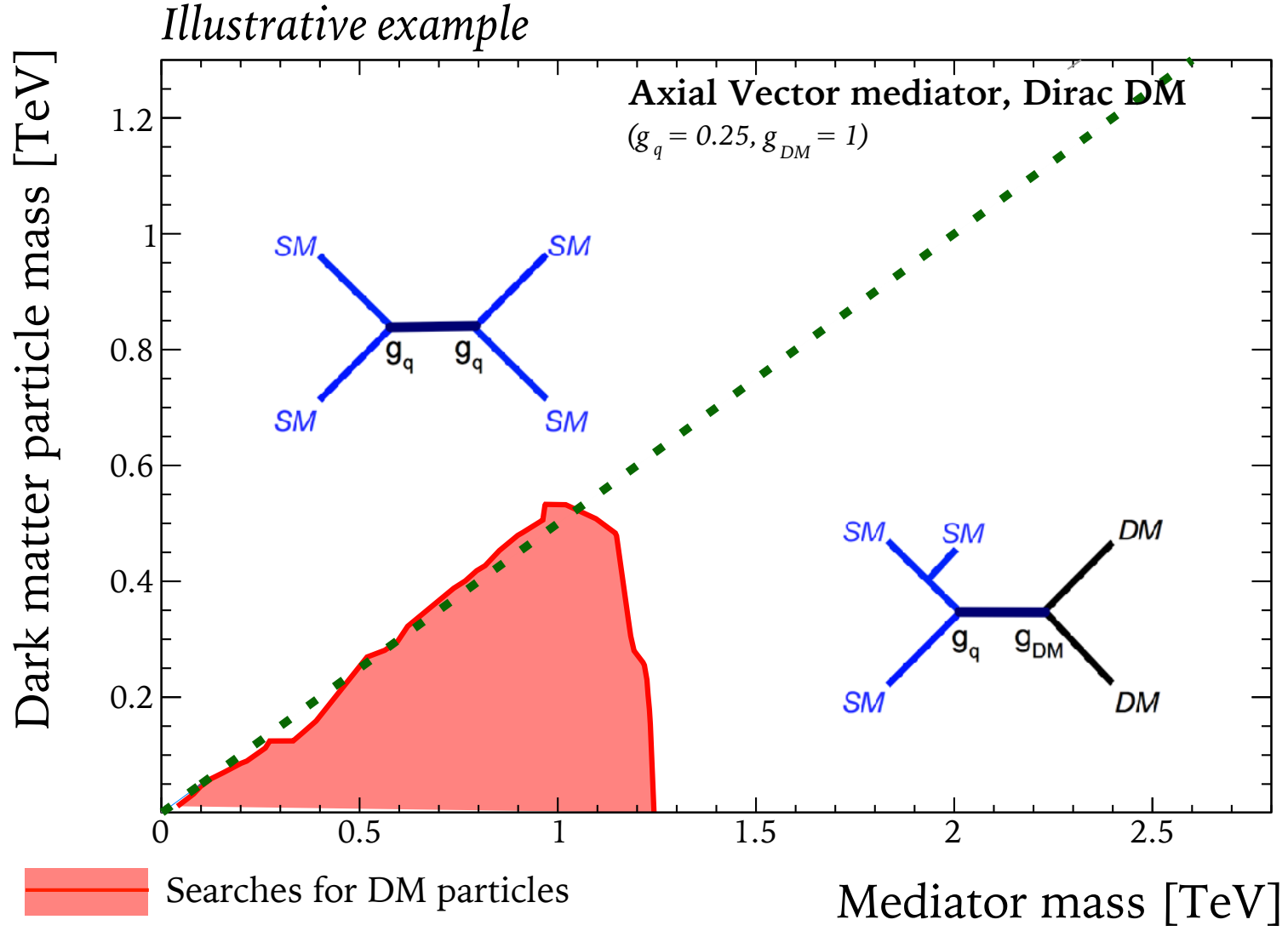
ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding for Research & Innovation

LUND UNIVERSITY

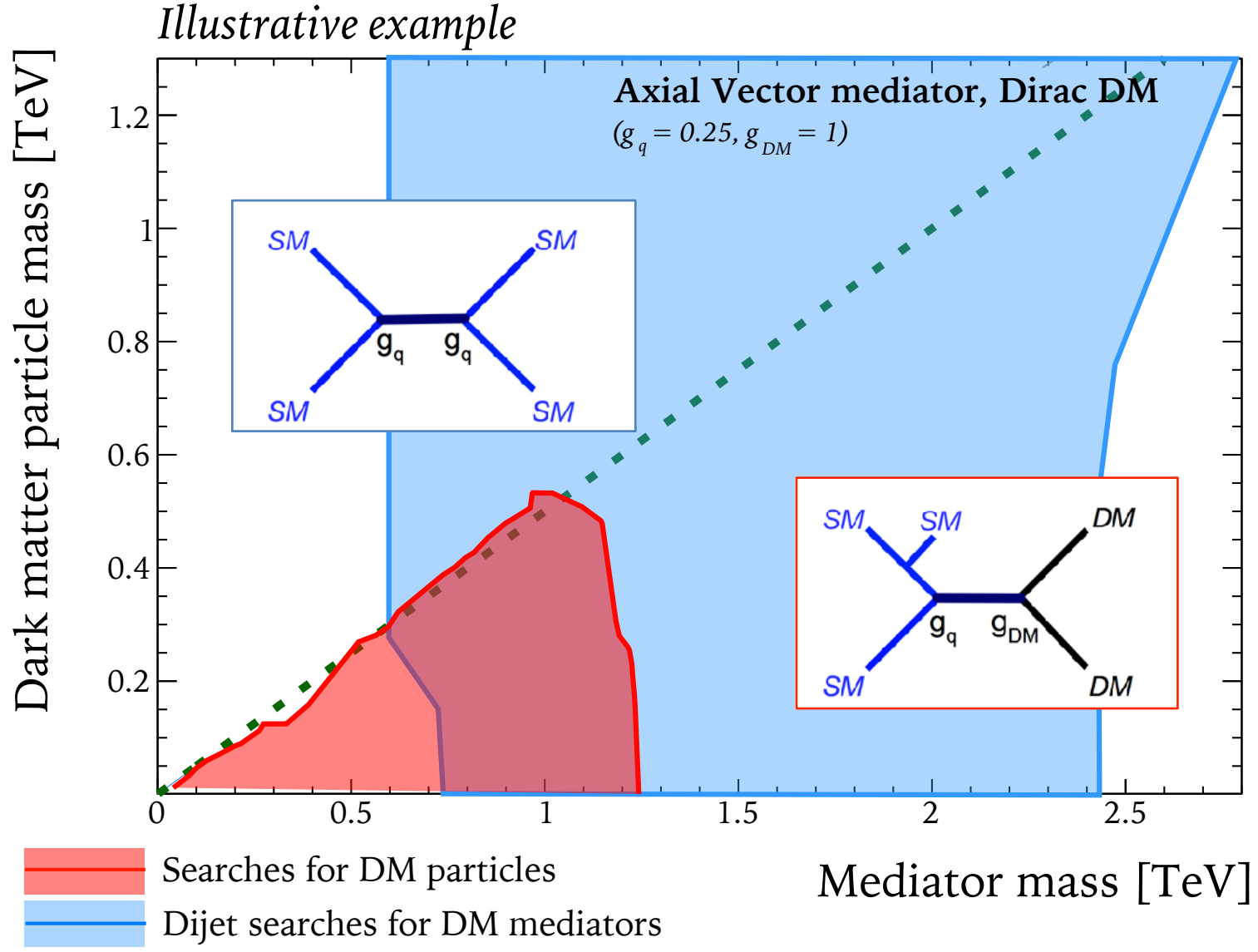
Visible/invisible DM LHC searches



Visible/invisible DM LHC searches

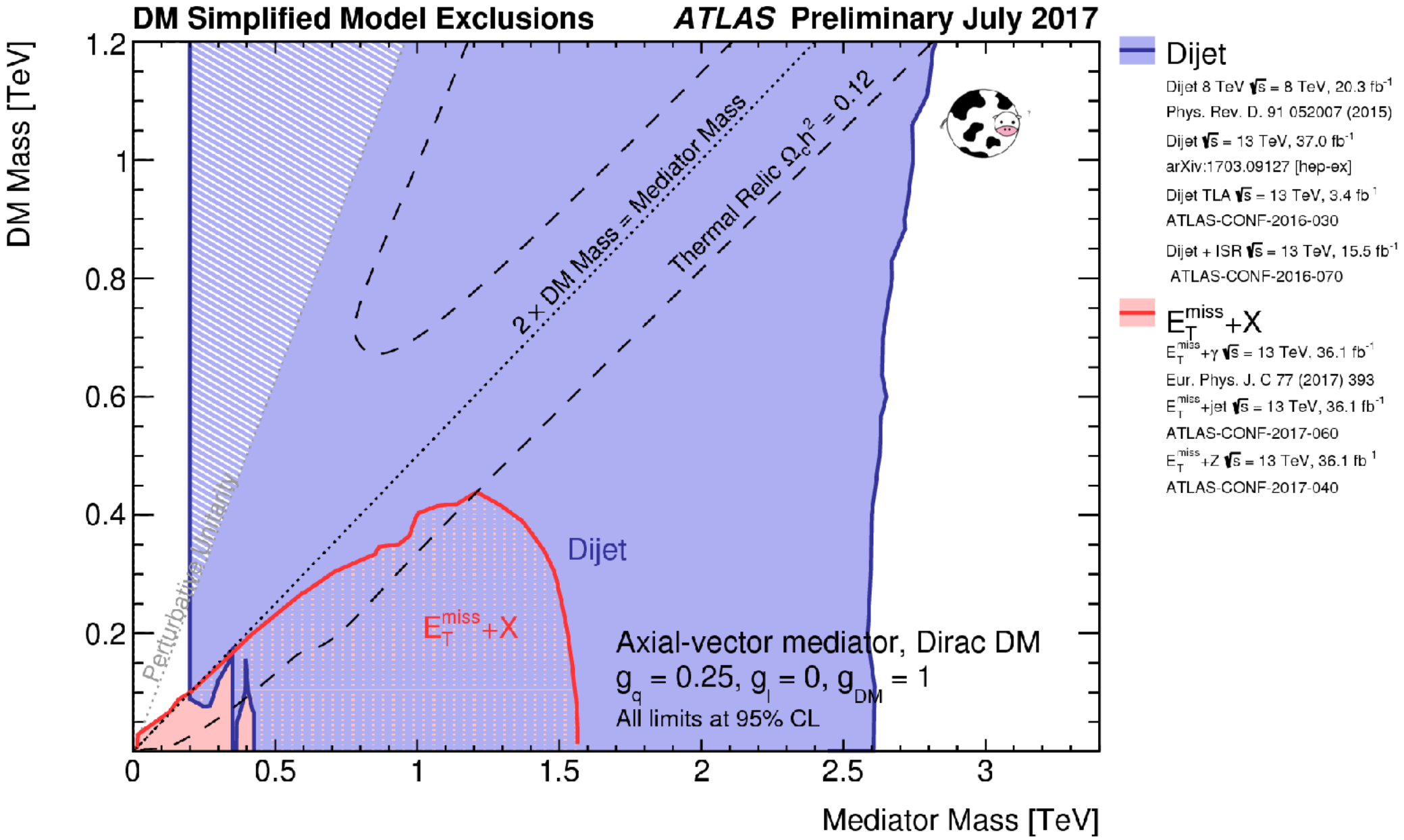


Visible/invisible DM LHC searches

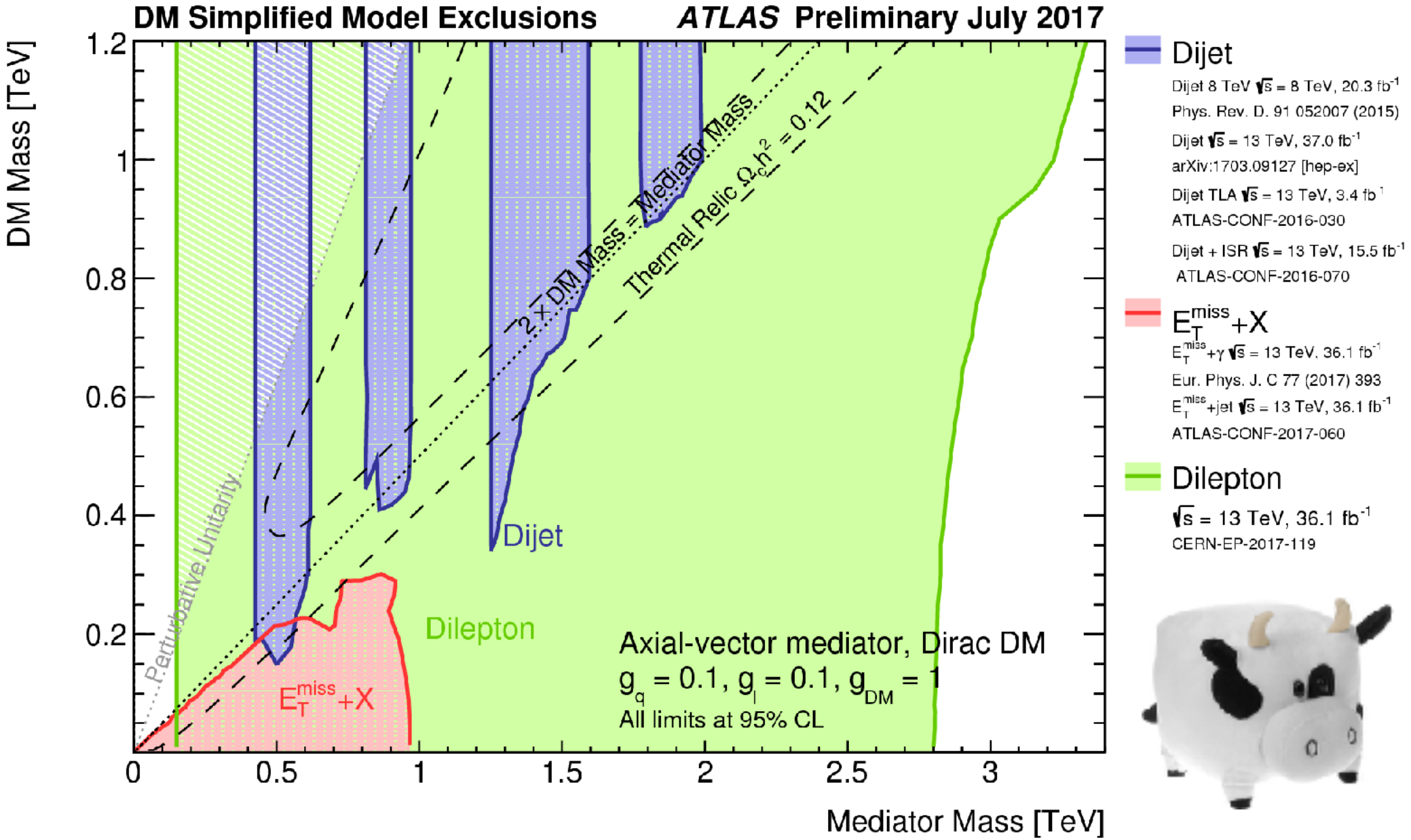


Collider strength: searches for visible mediator decays

Results on visible/invisible DM searches

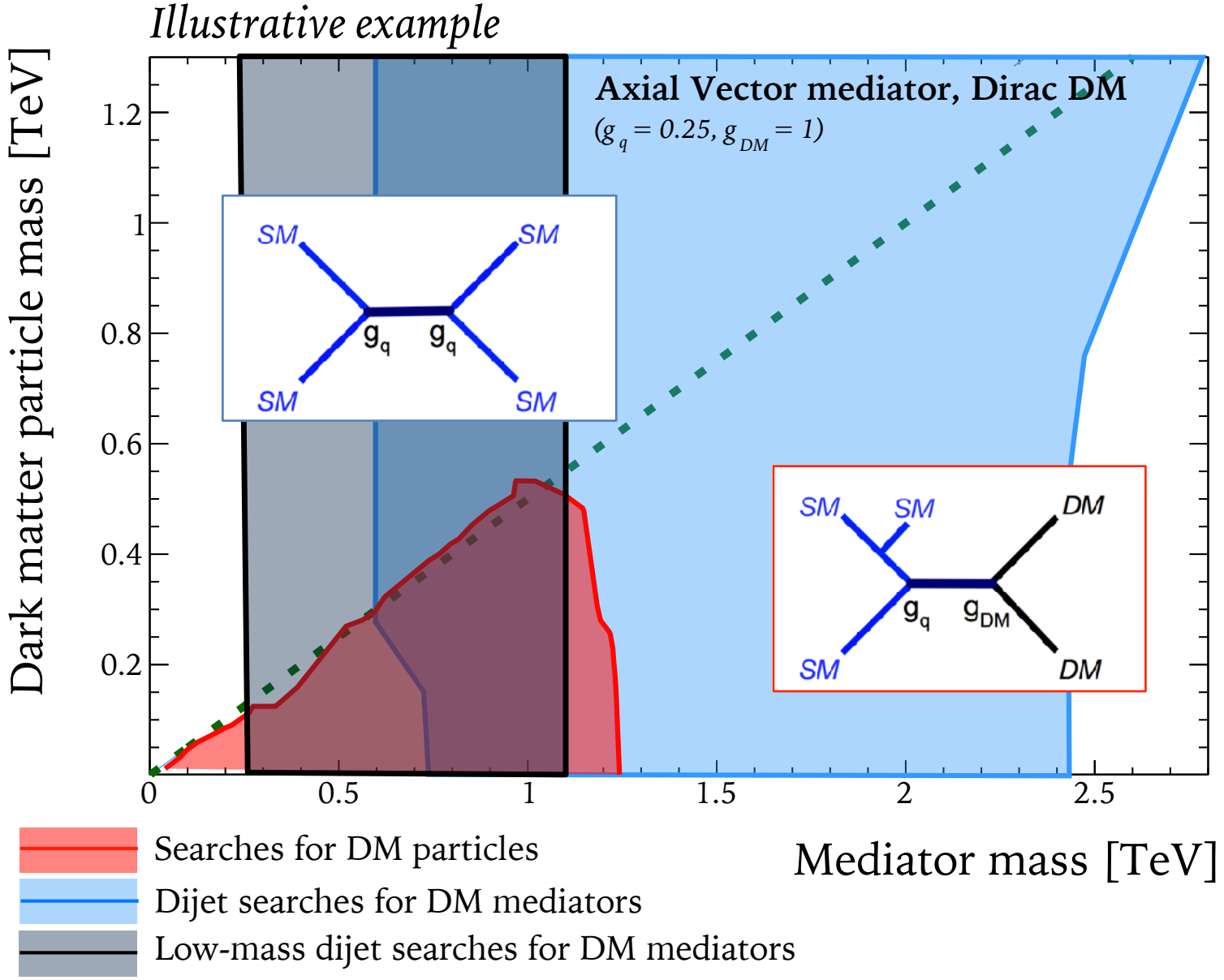


Results of visible/invisible DM searches



However, sensitivity is a coupling-dependent statement

Visible/invisible DM LHC searches



Motivating new searches for visible mediator decays

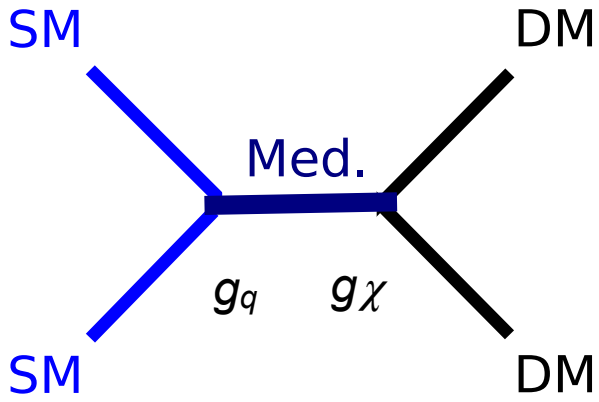
3. *We (already) have too much LHC data*

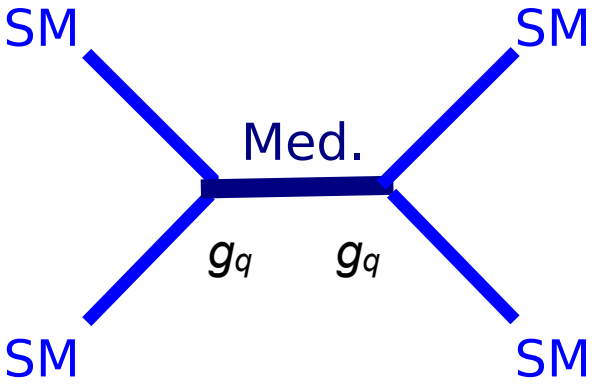
What to do with it?

Let's not discard and regret

Idea from LHCb talks, picture from the internet

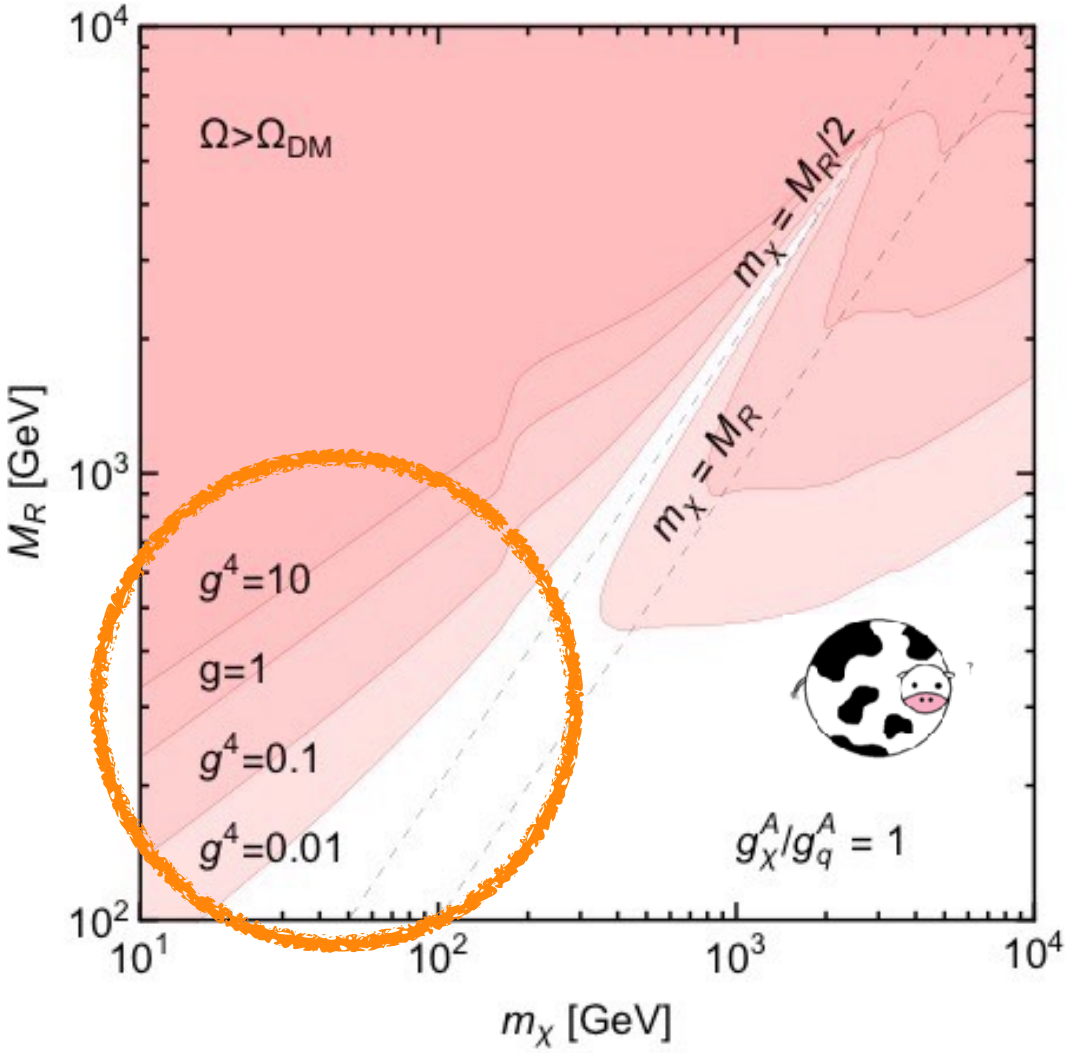
Visible low mass DM mediators: interesting!





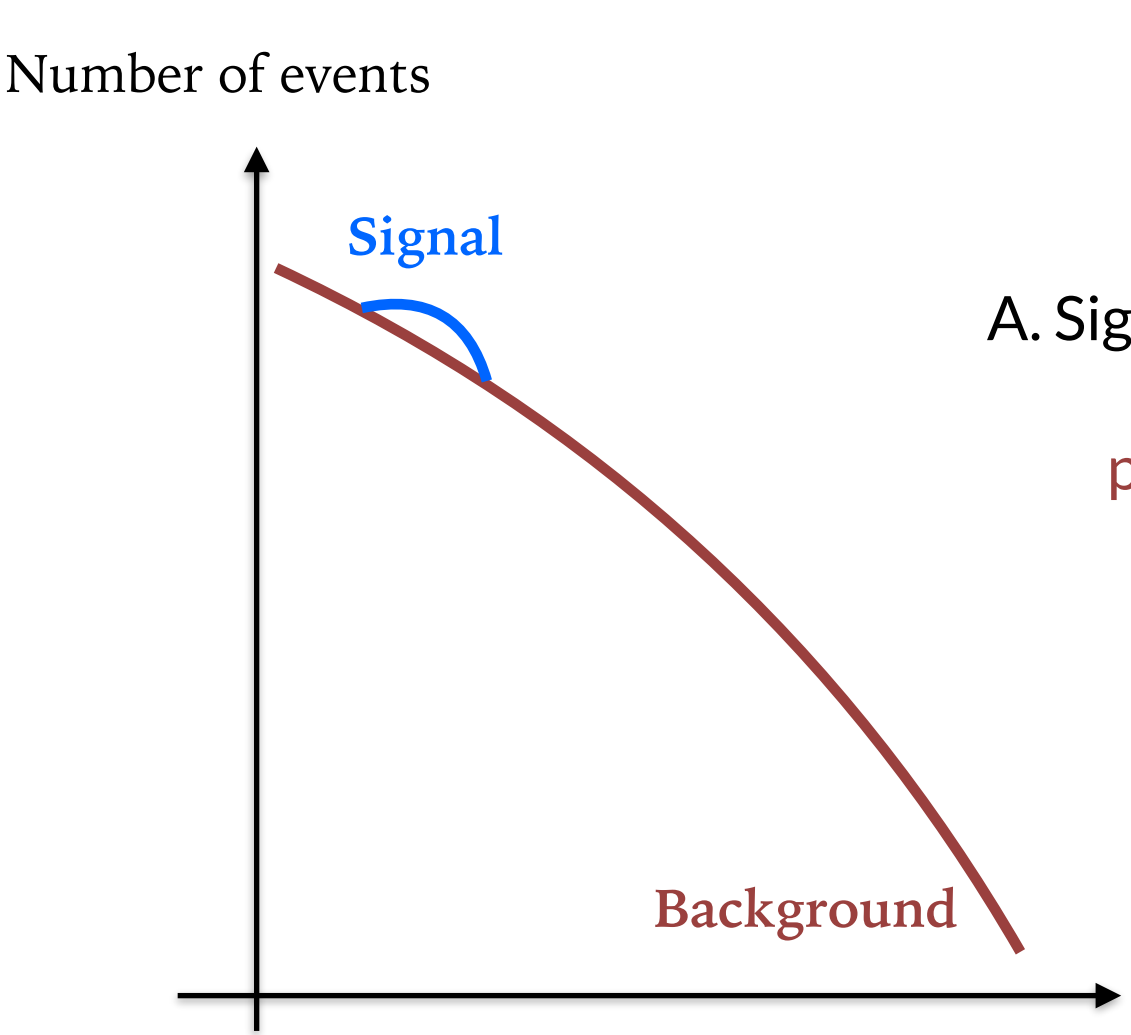
$$g \equiv (g_q^A \, g_\chi^A)^{1/2}$$

https://arxiv.org/abs/1503.05916



Signals and backgrounds with jets

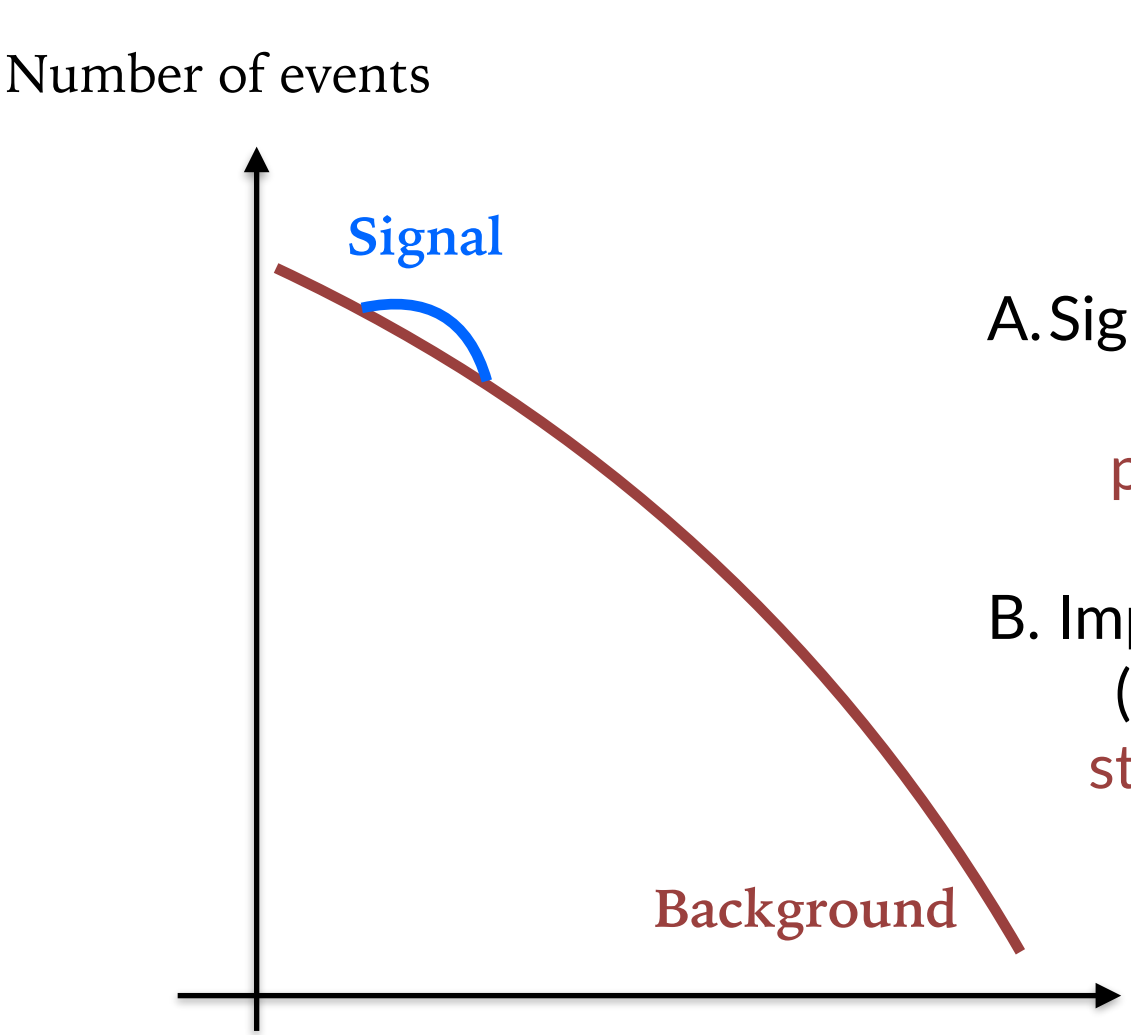
Main challenge for jet searches: large backgrounds, impossible to store all data



A. Signal overwhelmed by background if no discriminating power
poor sensitivity to new physics!

Signals and backgrounds with jets

Main challenge for jet searches: large backgrounds, impossible to store all data

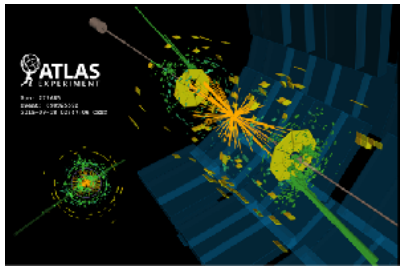


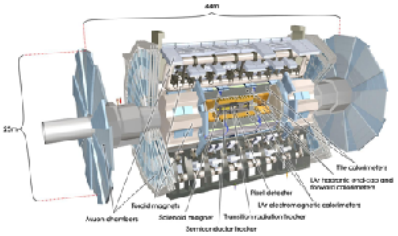
A. Signal overwhelmed by background: if no discriminating power poor sensitivity to new physics!

B. Impossible to record all events fully: (ATLAS **trigger system** needed) statistical error harms sensitivity!

ATLAS EXPERIMENT erc European Commission Horizon 2020 European Union funding for Research & Innovation

Data taking in ATLAS





Event selection (trigger) → Object reconstruction and calibration → Data analysis

Computing resources are essential for the full data taking chain

Trigger and data acquisition: select interesting events

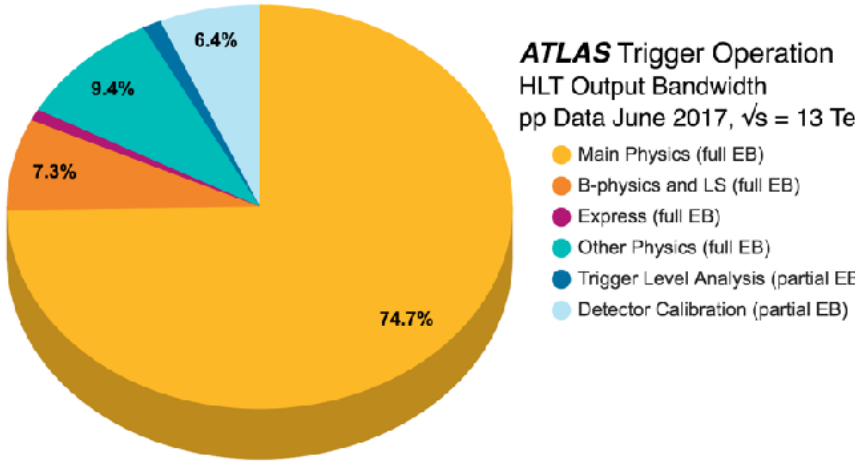
LHC delivers data at 40 MHz (events/second)
First step: **fast hardware selection (Level 1)**
data taking rate: 100 kHz
Second step: **computer farm (High-Level Trigger)**
data taking rate: 1000 Hz

Trigger Level Analysis technique (TLA)

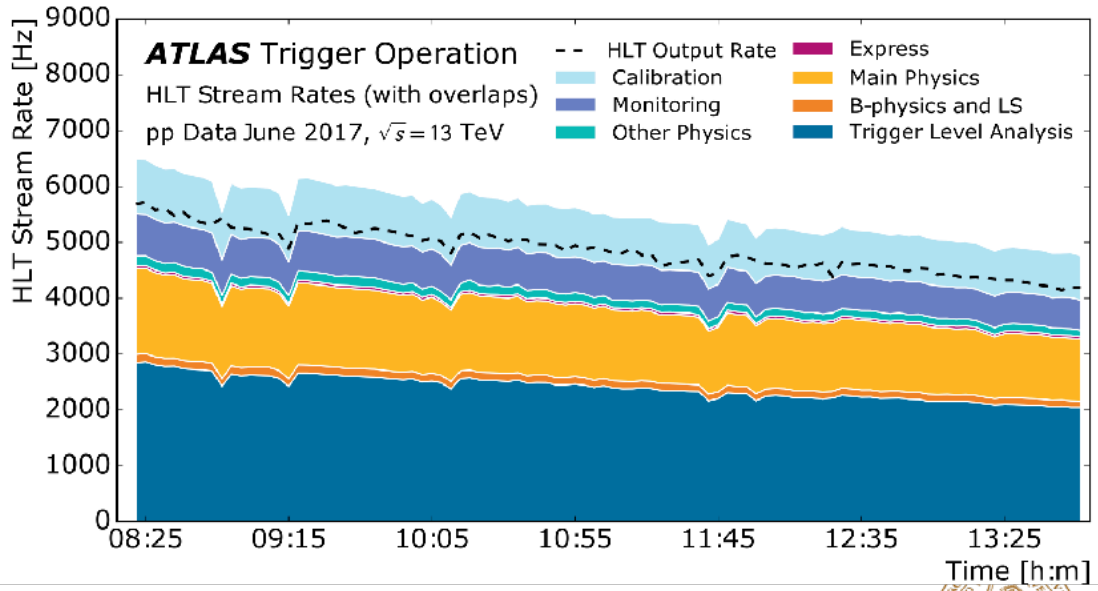
(CMS: Data Scouting, LHCb: Turbo Stream)

Record only necessary information for jet search: **jets**
Use information already available to make the decision: **trigger jets**

Event size reduced to <<5%
of fully recorded event

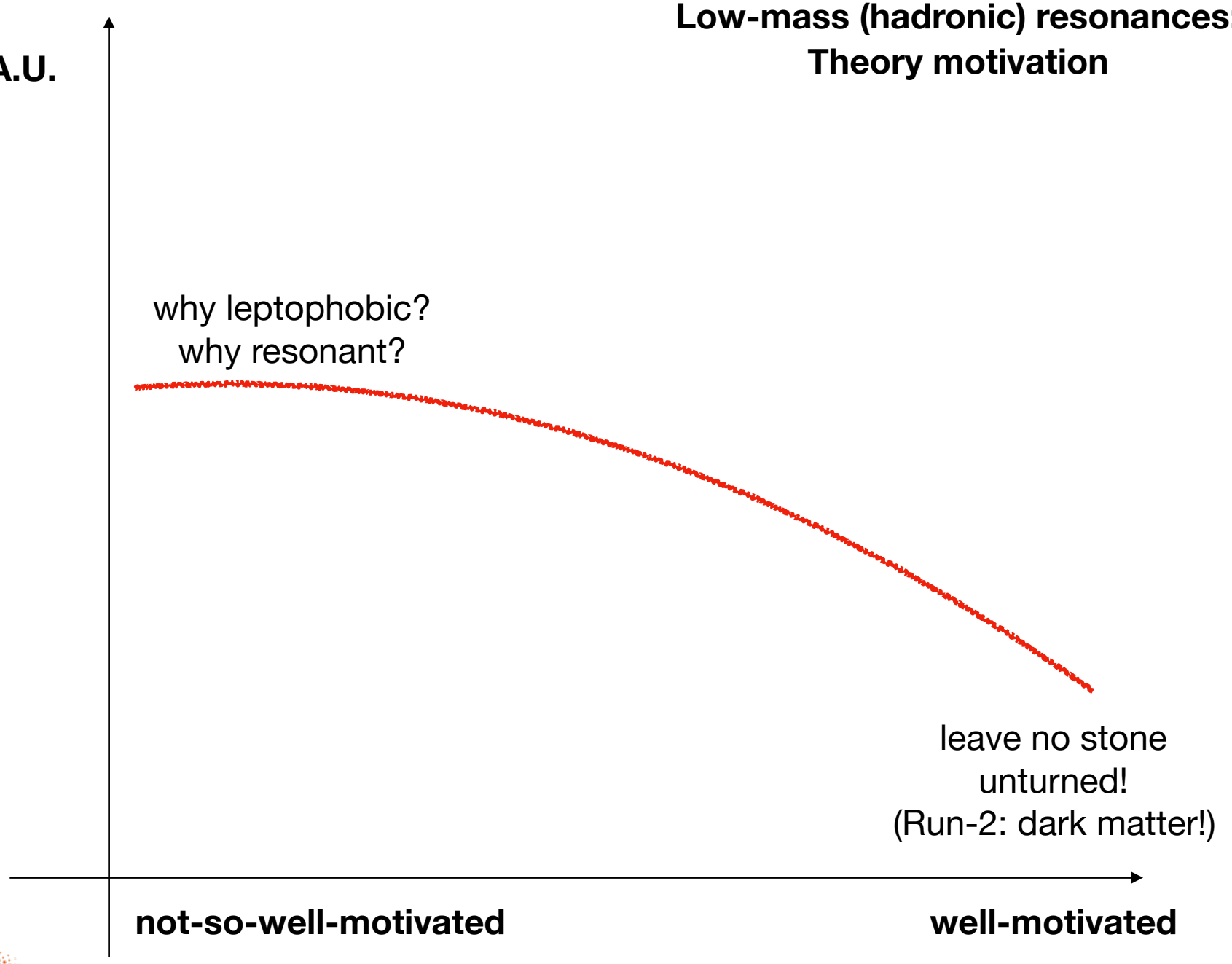


Reduced size -> increase number
of events that can be recorded

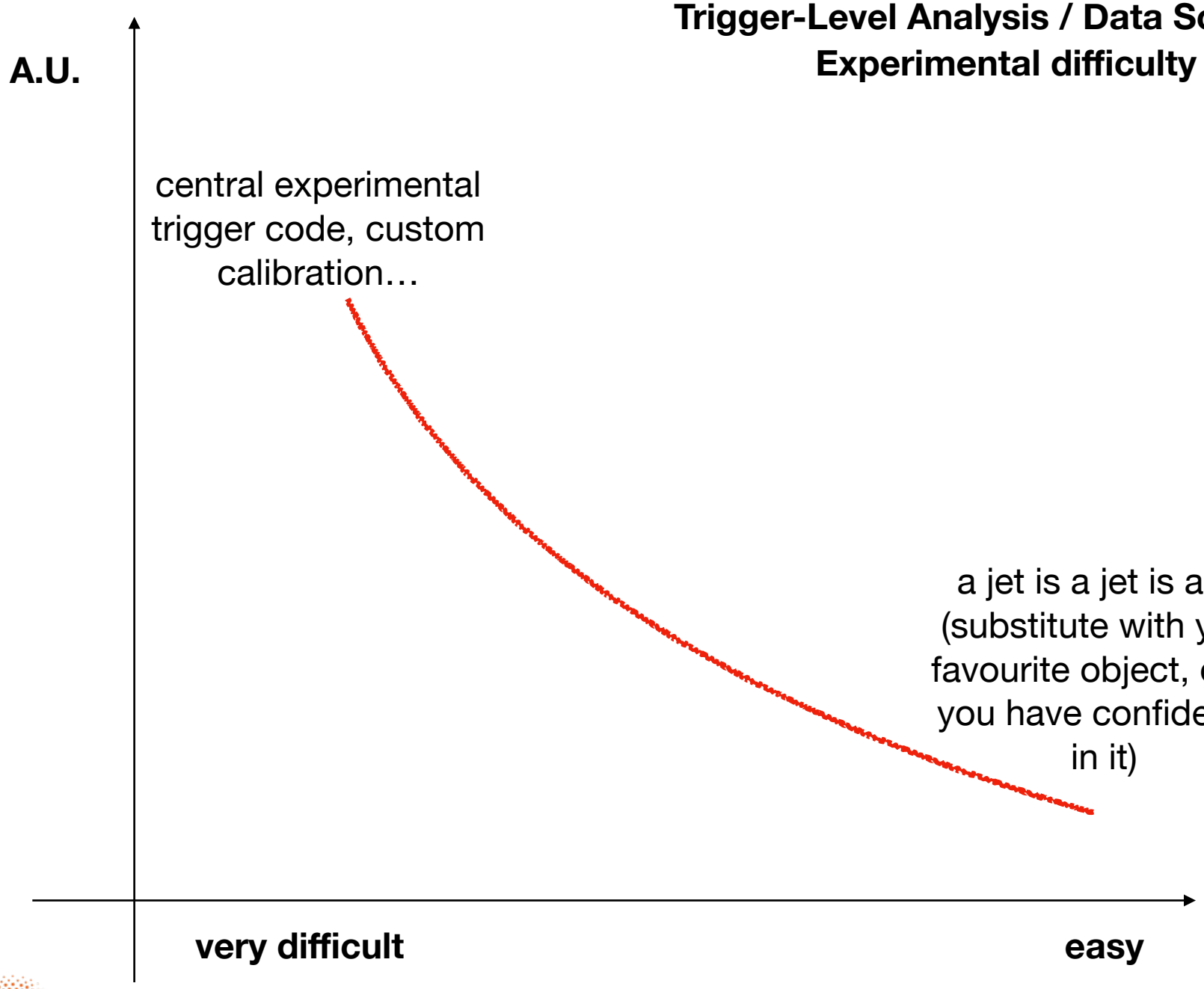


Other ways to get to low masses (beyond +ISR, +VBF):
prescaled triggers/data parking/delayed stream

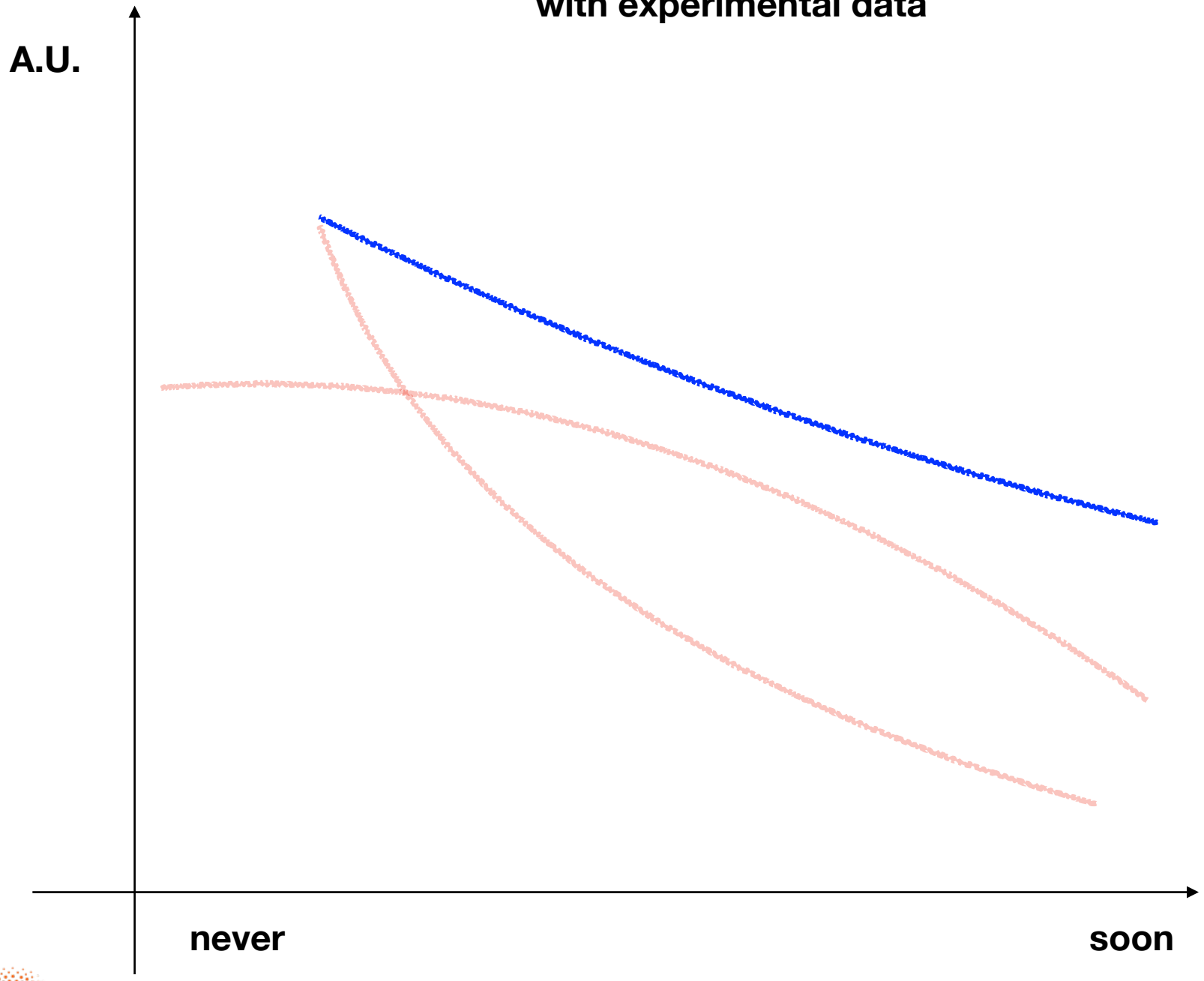
Low-mass (hadronic) resonances: Theory motivation



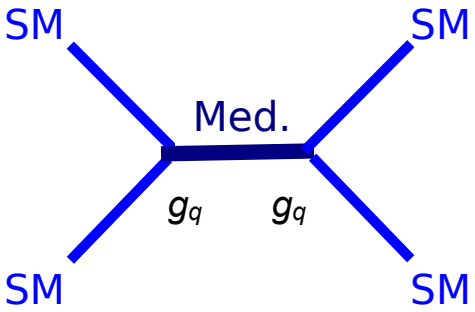
Trigger-Level Analysis / Data Scouting: Experimental difficulty



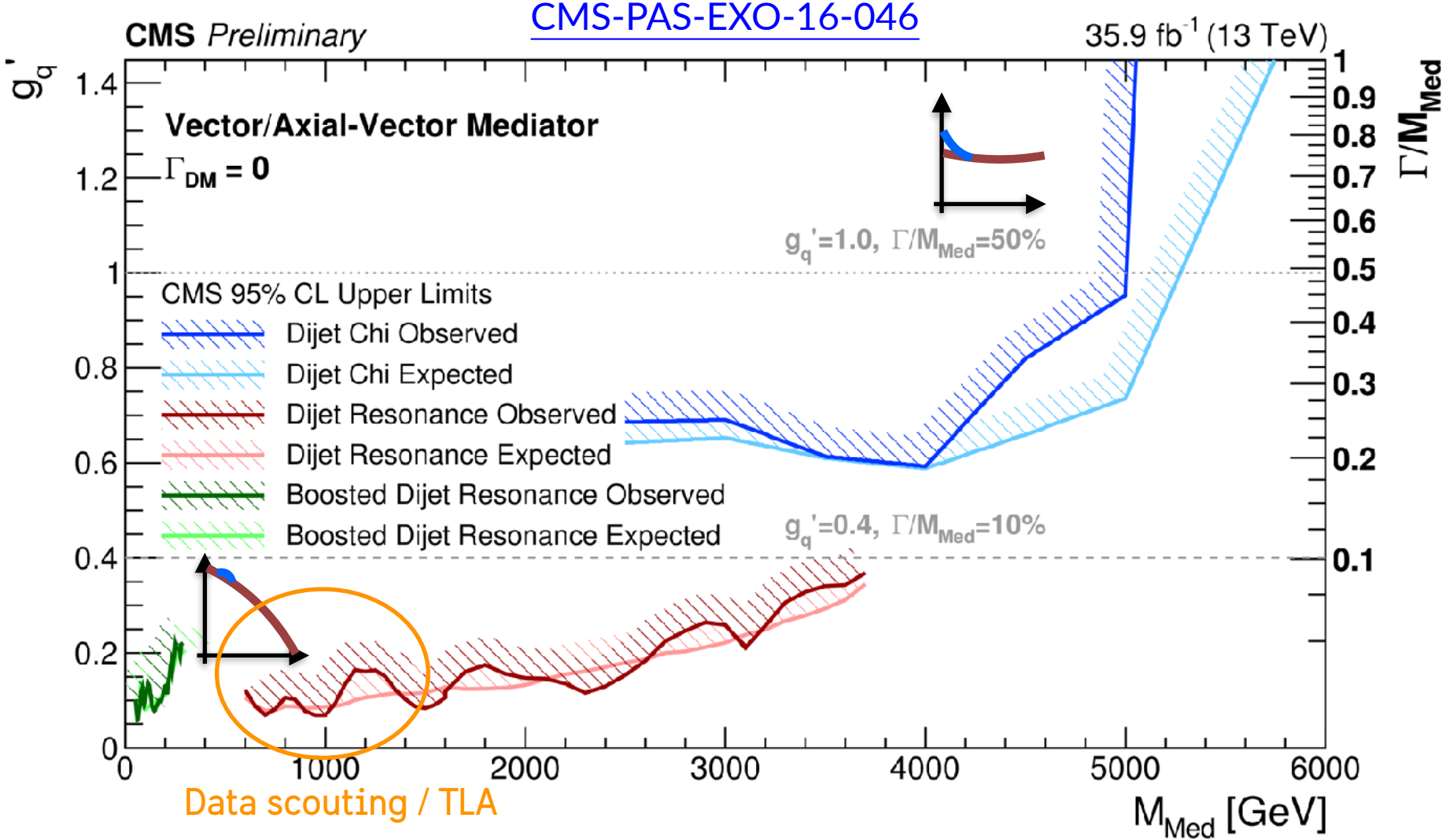
When more low-mass resonances are tested with experimental data



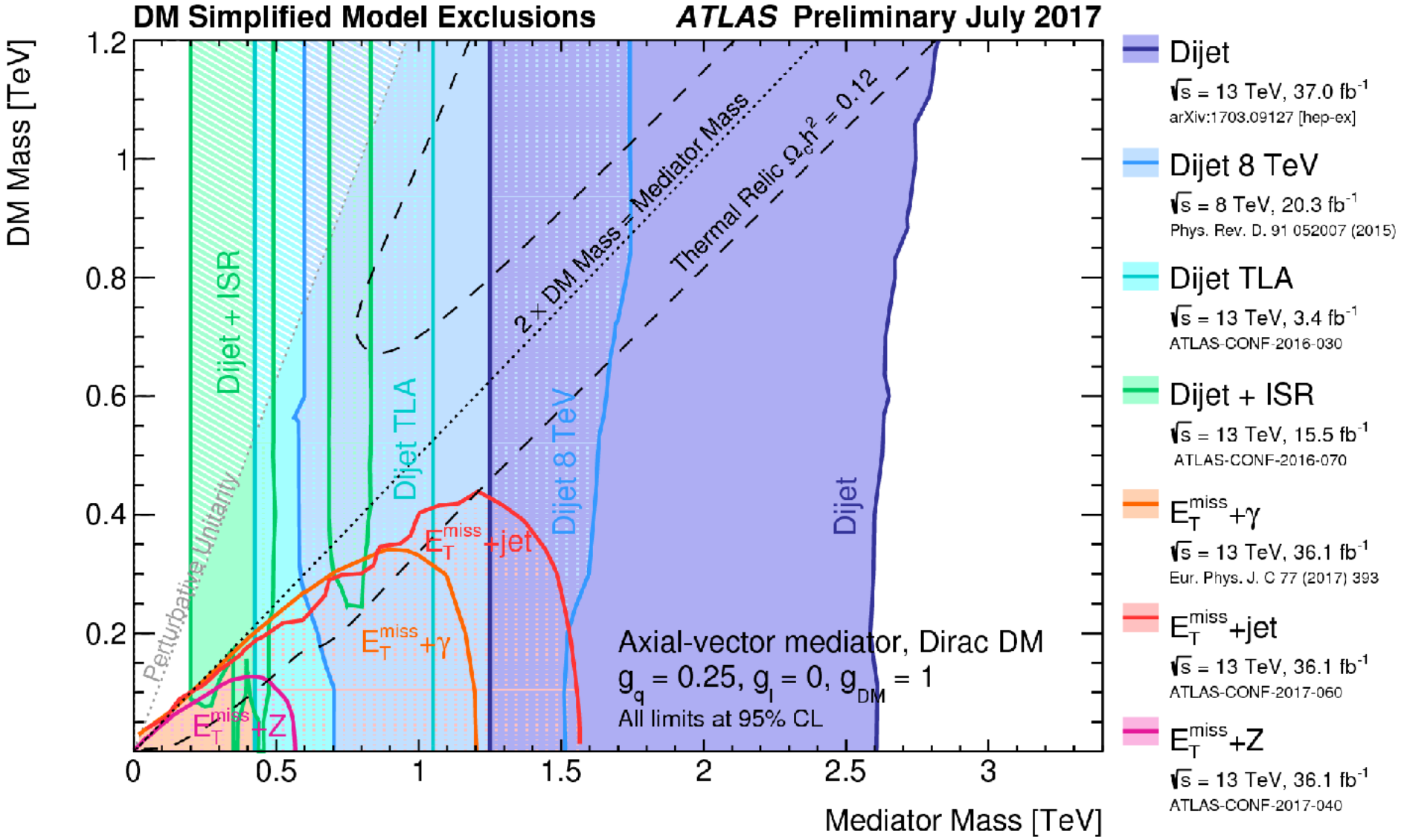
The full (CMS) picture of mediator searches



CMS-PAS-EXO-16-046



The full (ATLAS) picture of visible/invisible searches

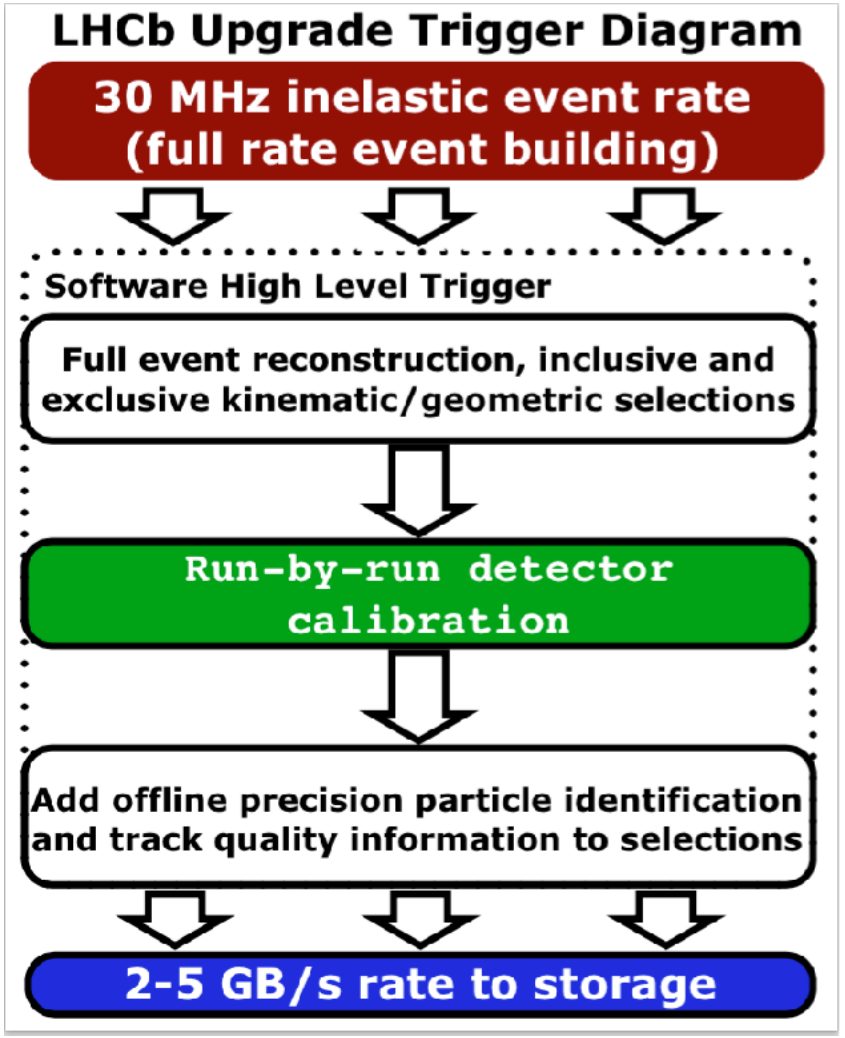


ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding for Research & Innovation

LUND UNIVERSITY

LHCb in the future (Run-3)

"Triggerless" readout

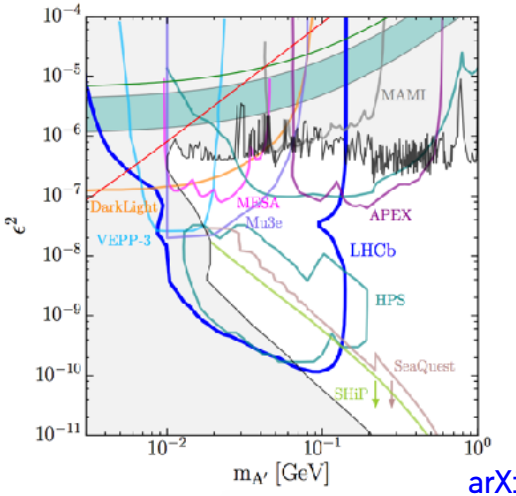


New physics at low mass

Same principle as dijets:
very large background
but good mass resolution online
→can discover new particles

Run-3 proposal: Dark Photon

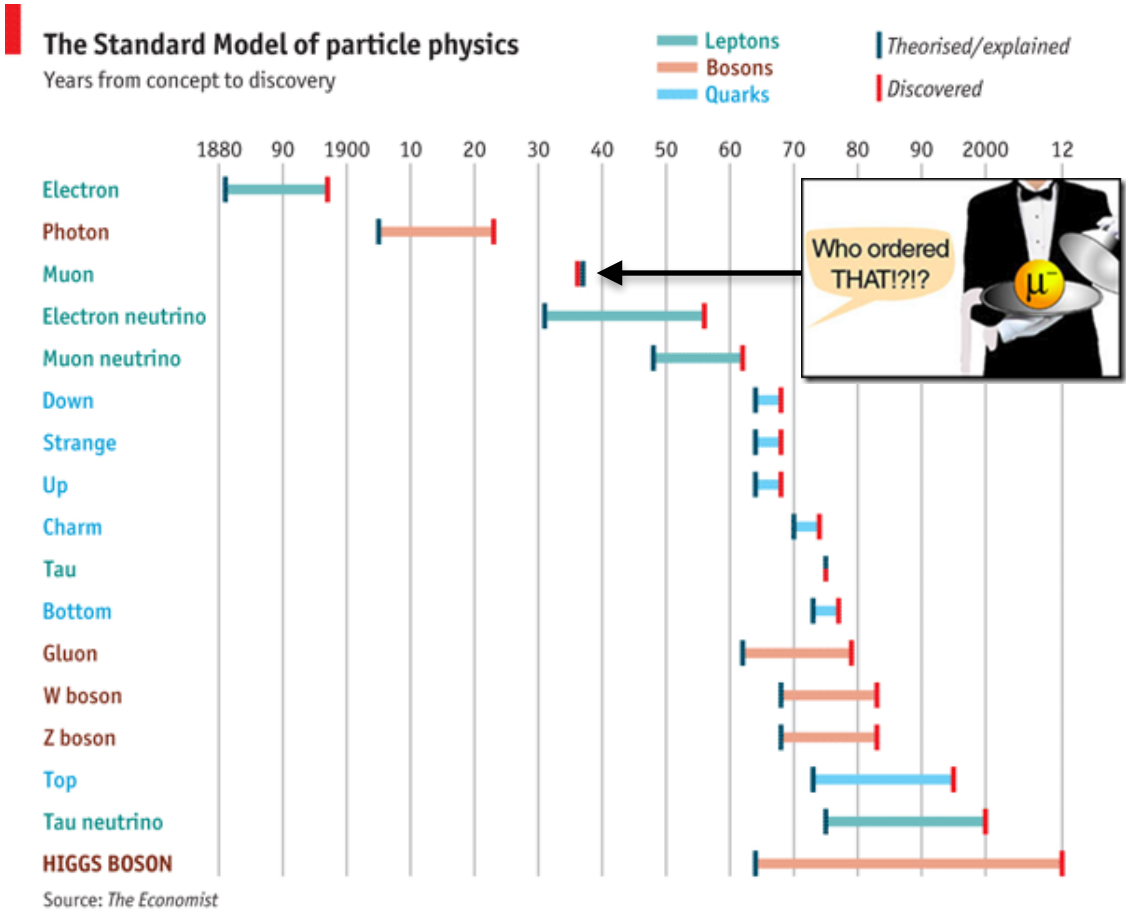
$$D^{*0} \to D^0 A', \quad A' \to e^+ e^-$$



arXiv:1509.06765

Conclusions

Where to look for DM and new particles?



Everywhere!

design **model-independent searches** for new phenomena

ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation
LUND UNIVERSITY

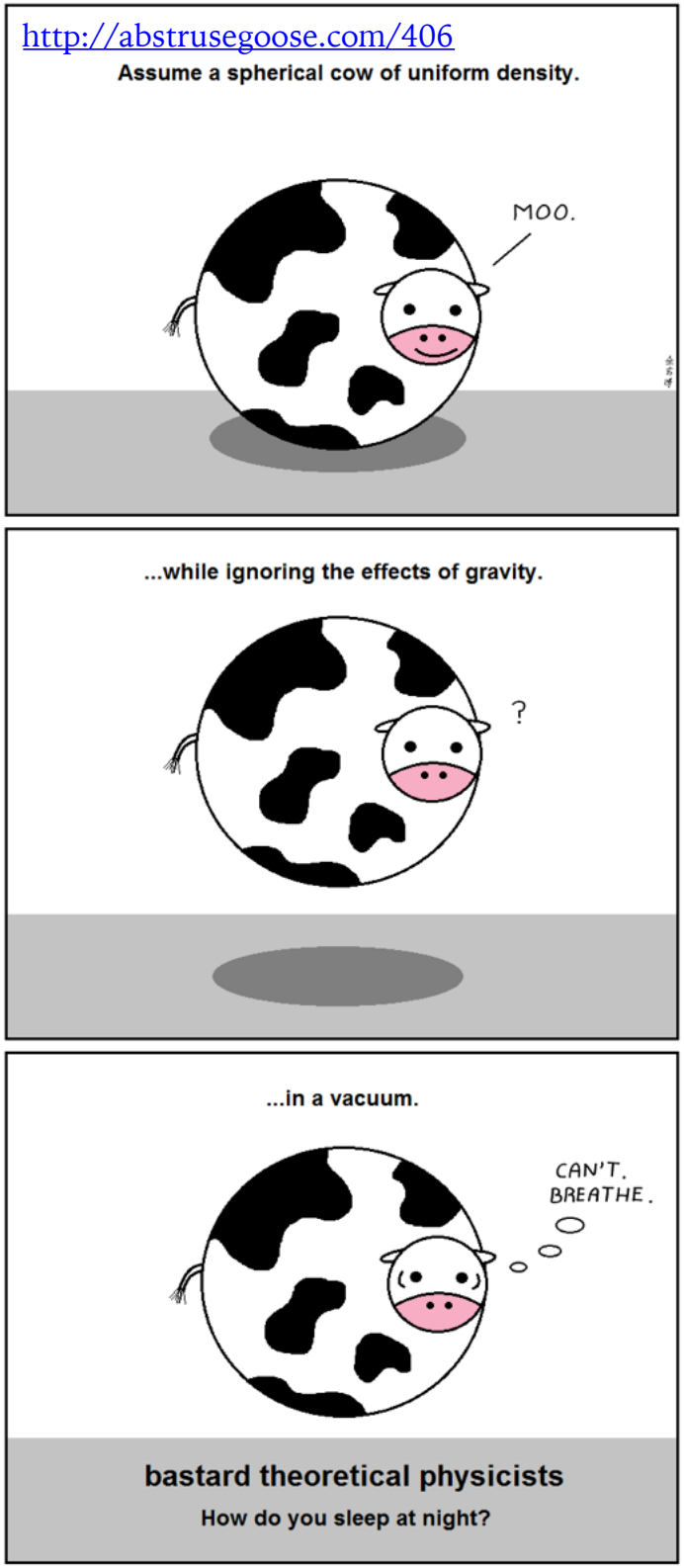
Looking forward to more searches

https://cds.cern.ch/record/874049

We should perhaps finish with an apology and a caution. We apologize to experimentalists for having no idea what is the mass of the **DM particle**, unlike the case with **the Higgs** and for not being sure of its couplings to other particles, except that they are probably all very small. For these reasons we do not want to encourage big experimental searches for **Dark Matter**, but we do feel that people performing experiments vulnerable to **Dark Matter** should know how it may turn up.

Experimentalists worldwide

Thanks for the invitation and for your attention!



For discussion

For further discussion

1. **Where do we go from here?**
   - Are we missing something?
   - *Pro domo mea*: LHC Dark Matter Working Group
   - Long-Lived Particle Working Group
2. **What makes the interpretation of a search "DM"?**
   - How seriously should we take relic density (many ramifications)?
3. **Connections with astrophysics**
   - See next slide

Further complementarity: astro/cosmo?

Relic density

Is the relic density a "guide for the eye" in the WIMP paradigm, or more? How should its (precise) measurement influence DM searches?

Galaxy formation

Is it possible to introduce different models and assumptions in simulations, or are those too fine-grained to make a difference?

Nature of DM

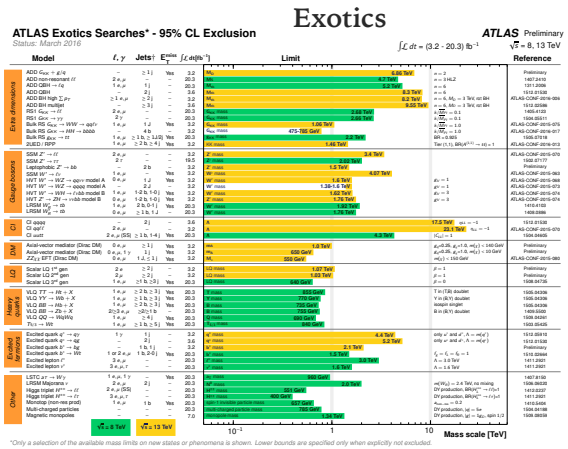
Could astrophysics help shedding light on the nature of DM? Growing interest (also in the direction of black holes) -> anything colliders can do?

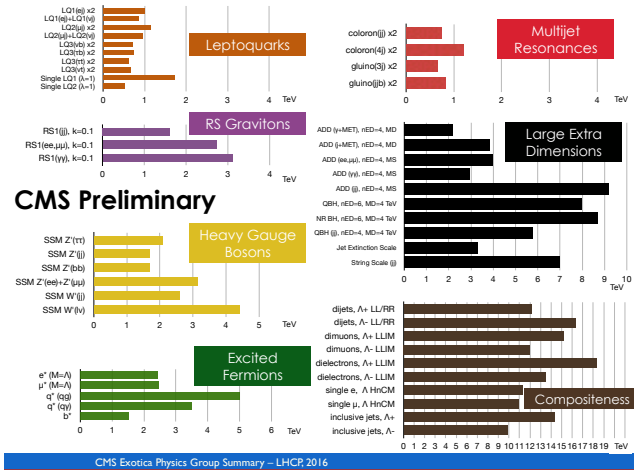
Role of the Higgs

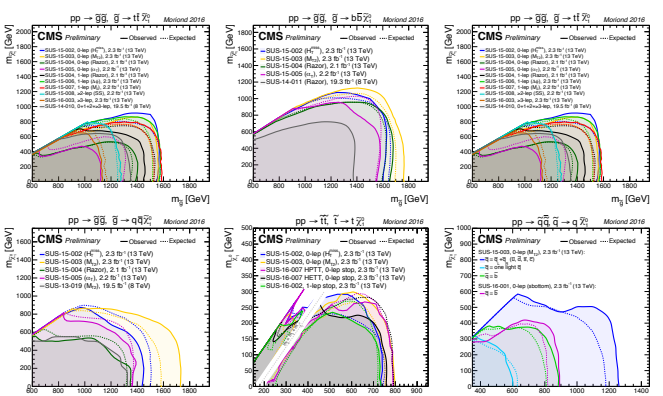
We discovered a new particle: what is the role it played in the early universe?

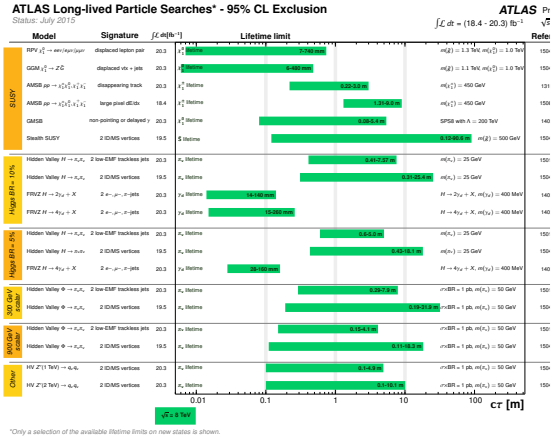
Backup slides

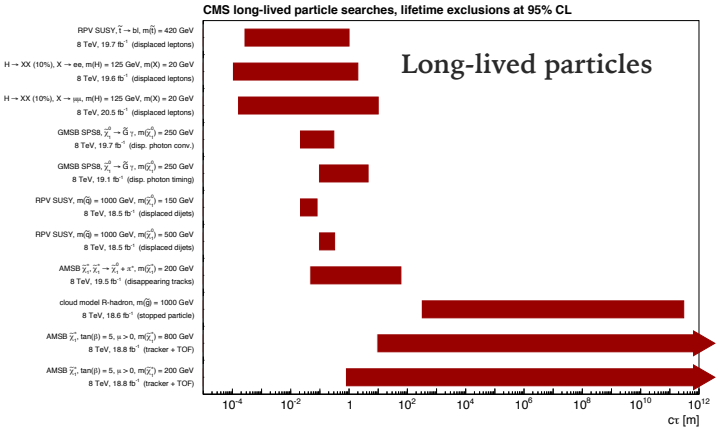
A not-too-motivational slide

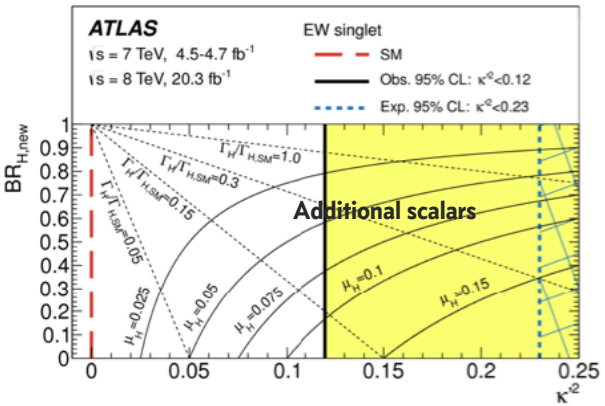












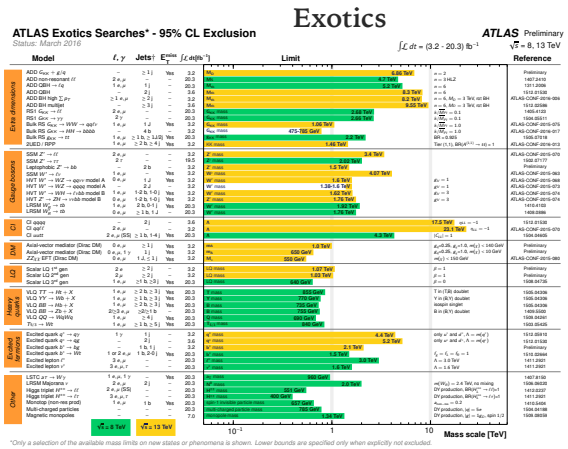
ATLAS Summary Plots

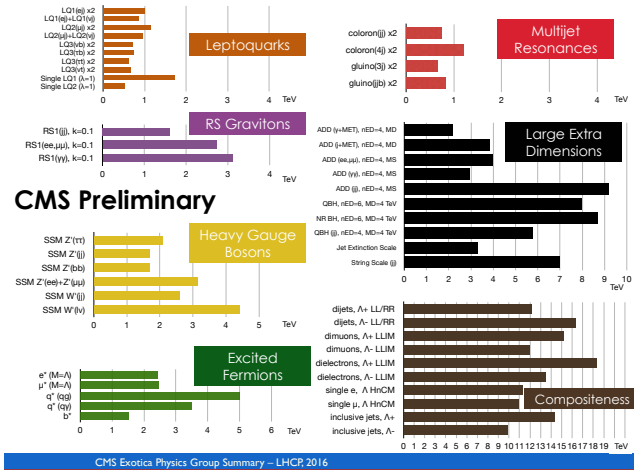
CMS Summary Plots

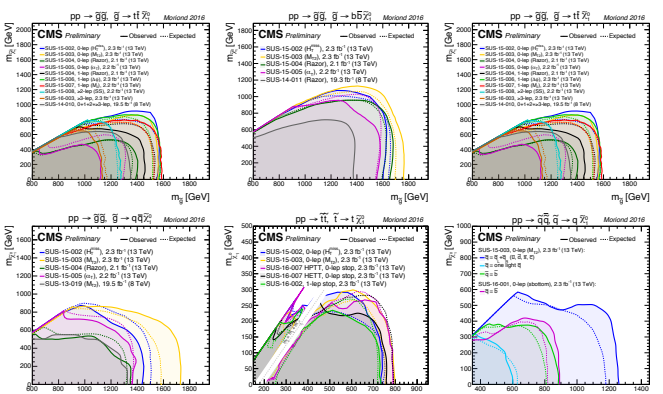
Can you point to the dark matter searches?

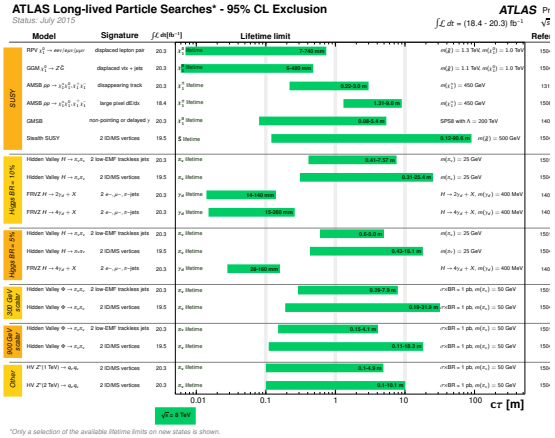
or: what makes a search a Dark Matter search?

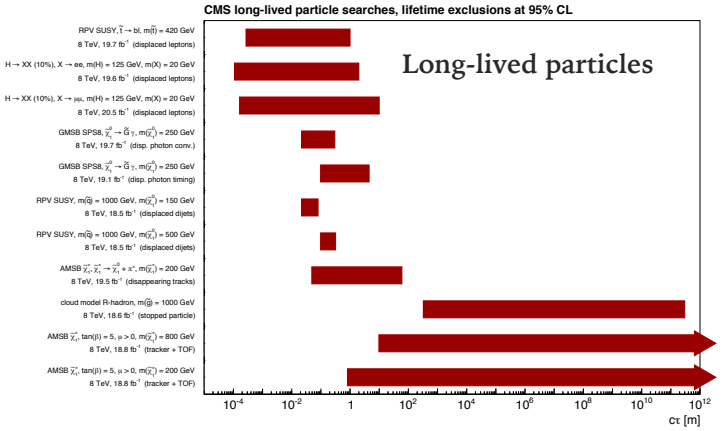
A motivational slide

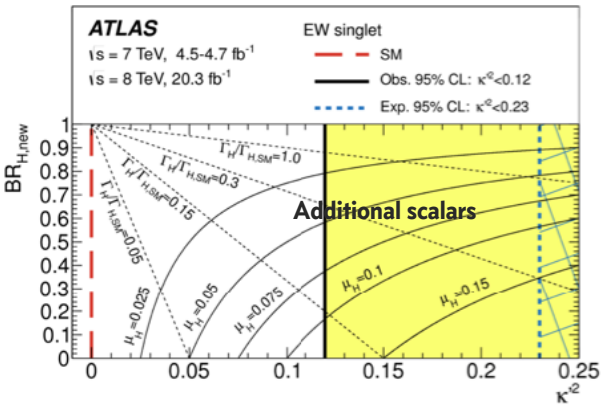












[ATLAS Summary Plots]

[CMS Summary Plots]

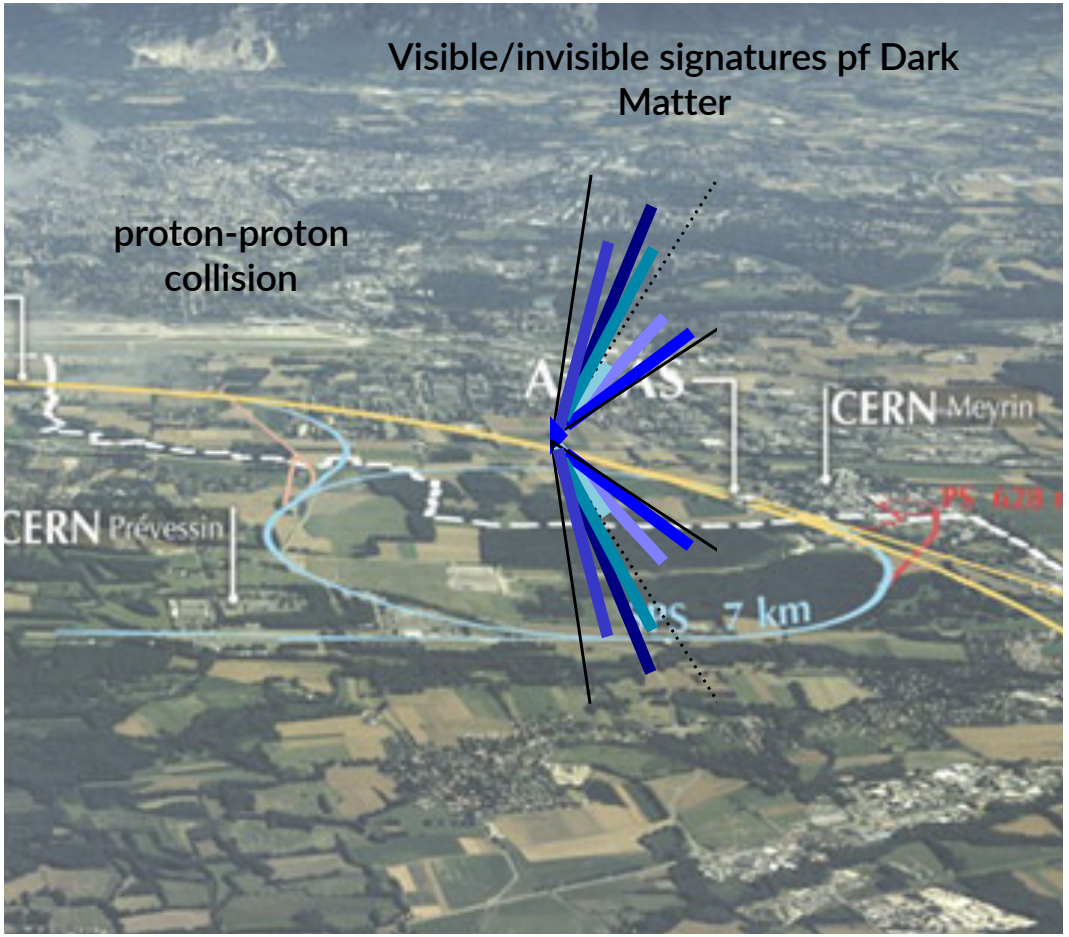
Experiments analysed **only 1%** of the planned LHC dataset so far

...rich program of measurements and searches up to 2035!

Dark Matter Working Group

ATLAS, CMS and theory, within LHC Physics Centre (LPCC)

- Mandate:
  - Define guidelines and recommendations for the benchmark models, interpretation and characterisation for broad and systematic DM searches at the LHC
    - Example: agree on **classes of benchmark models** used for experimental searches
    - Example: **improve tools** available to the experiments, such as higher-precision calculations of signals/backgrounds
  - Connect with broader DM community towards comprehensive understanding of viable dark matter models



ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding for Research & Innovation

LUND UNIVERSITY

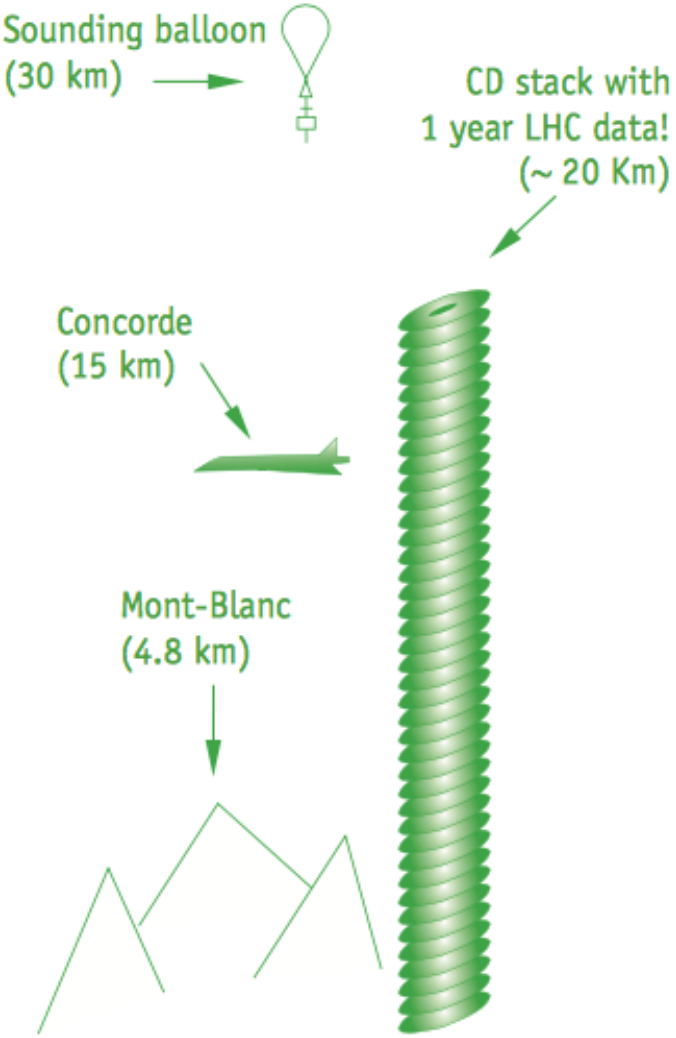
Data volumes at the LHC

- LHC: if everything was recorded…
  - up to 40 million collisions/second (MHz)
  - 1-1.5 MB/data per collision
  - 40 MHz * 1 MB = 40 TB/s
  - 40 TB/s * 10e+6 s/year = 0.05 ZB/year

- Facebook:
  - 600 TB/day ~ 200 PB/year [Facebook]

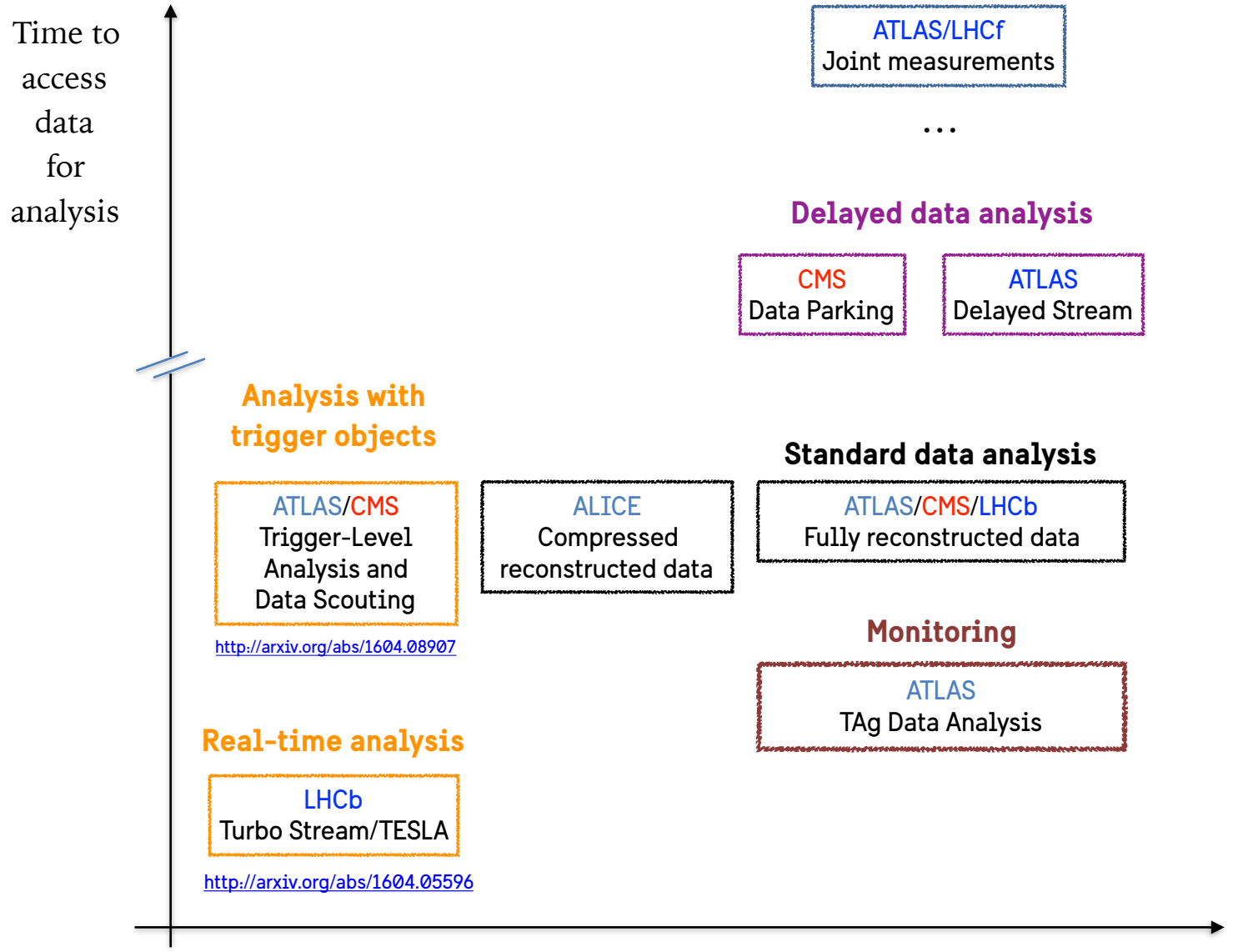
LHC experiments need to:

1. **process** all data, fast
2. **select** only interesting events



(**after** selecting interesting events)

Timing of LHC analyses



Limitations to recording all data

Limited by:

fast **read-out** of o(100M) detector channels

computing resources (reconstruction)

disk **storage** (saving for further processing)

everyone else's favourite **physics** channel

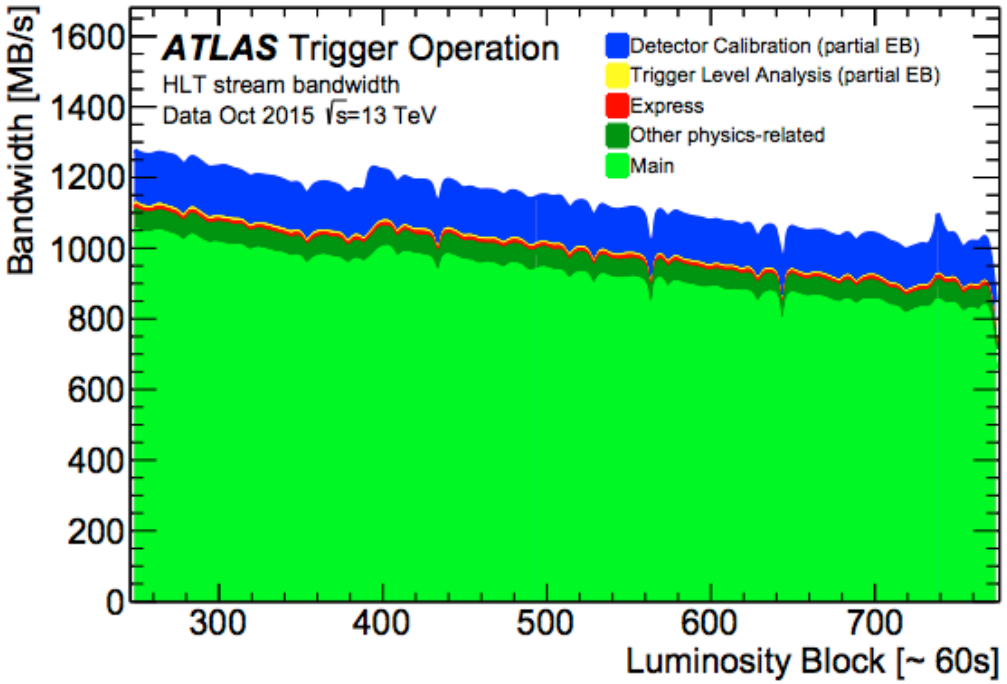
Bandwidth limit = Event rate **x** Event size

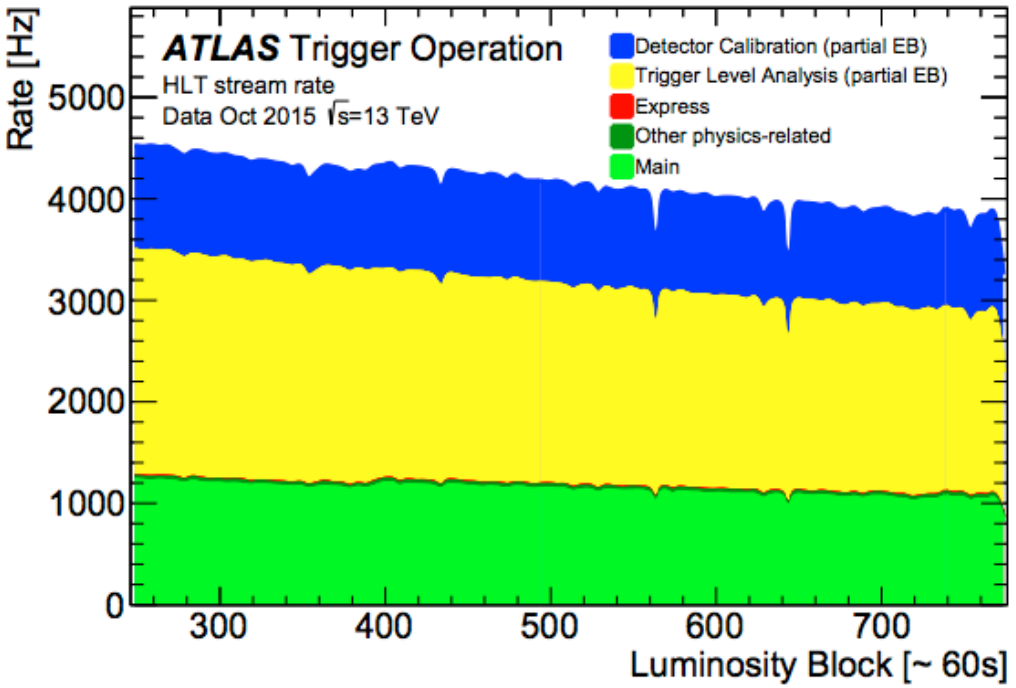
LHC: 40 MHz	(Reconstructed)
ATLAS: 1 kHz	ATLAS: o(MB)
LHCb: 12.5 kHz	LHCb: ~100 kB
CMS: 1 kHz	CMS: o(MB)

Also to keep in mind: it's not all about bandwidth,
it's also about implementation (—> outside the box)

Data Scouting / TLA

Bandwidth = **Event rate** x Event size





ATLAS EXPERIMENT
erc
European Commission
Horizon 2020
European Union funding
for Research & Innovation
LUND UNIVERSITY

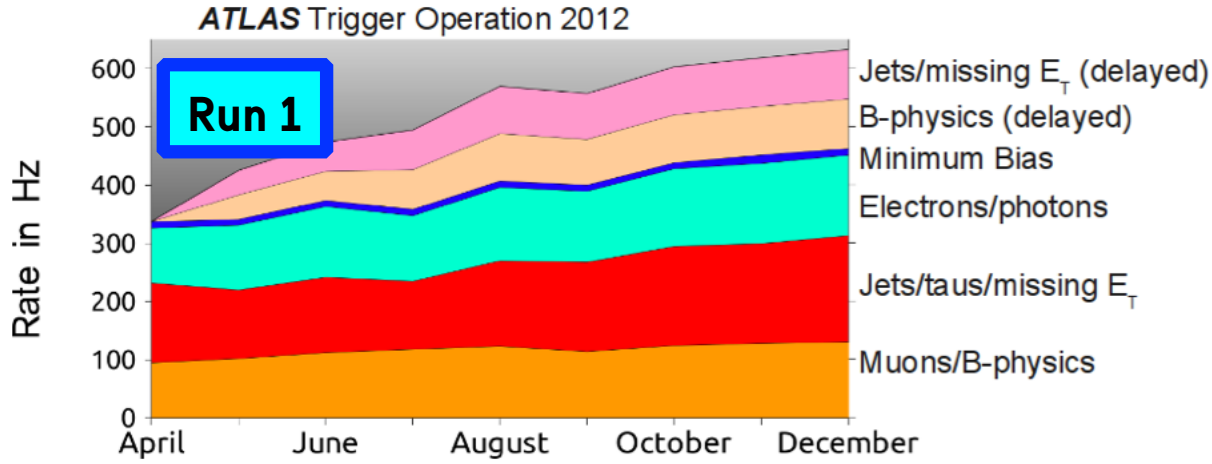
Data parking / delayed stream

Bandwidth limit = Event rate **x** Event size

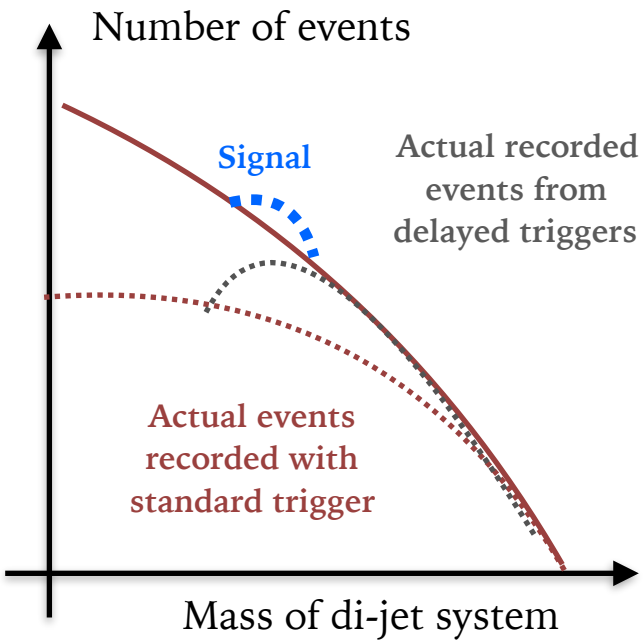
Extra bandwidth = Event rate **x** Event size

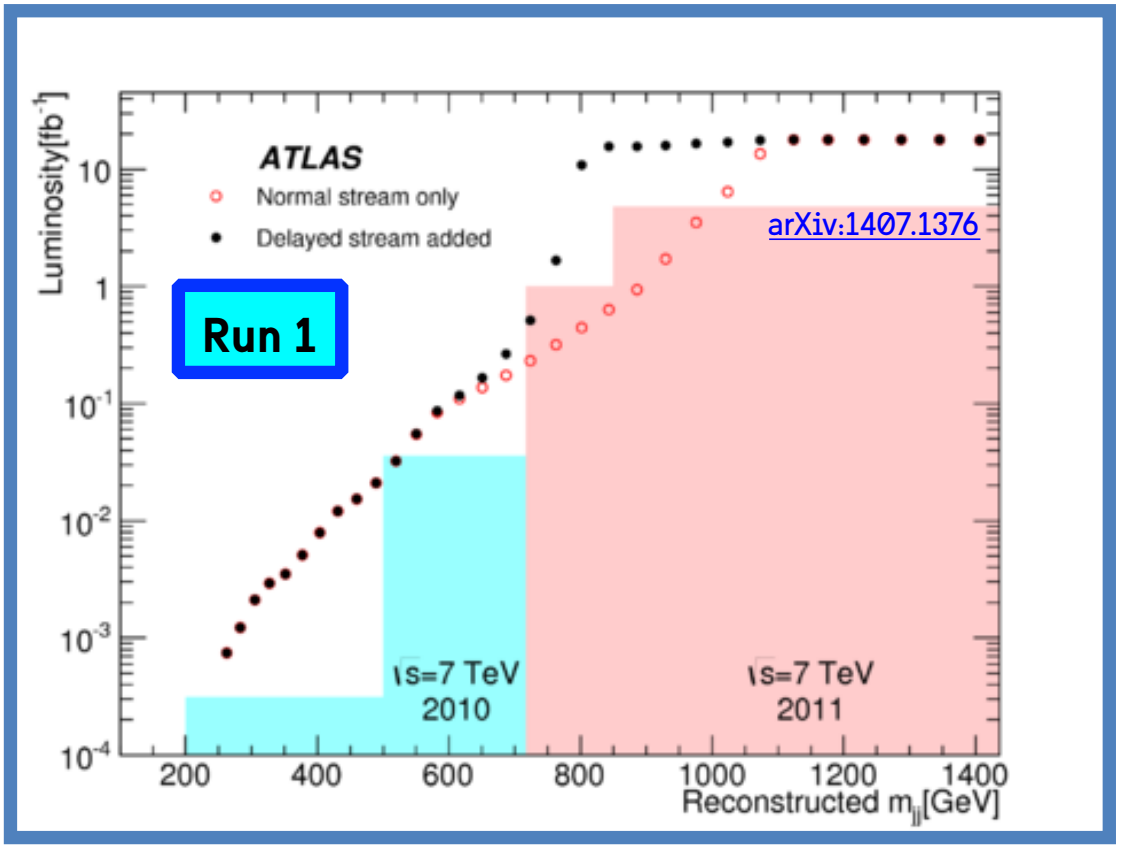
processed later

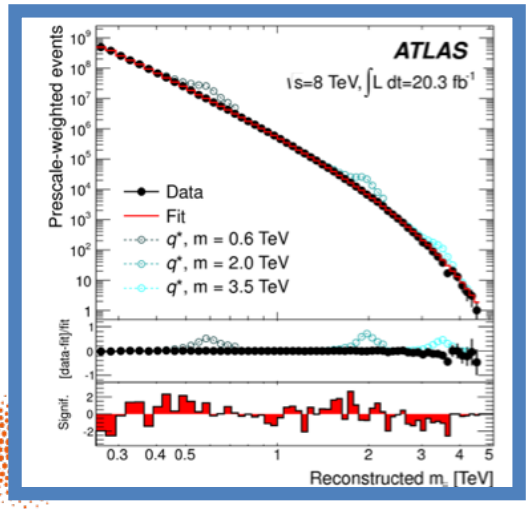
If computing resources for reconstruction limited:
park the raw data and wait (delay) until everything else is processed



ATLAS delayed stream results







Other analyses using delayed stream in ATLAS/CMS:

SUSY search for RPV stops

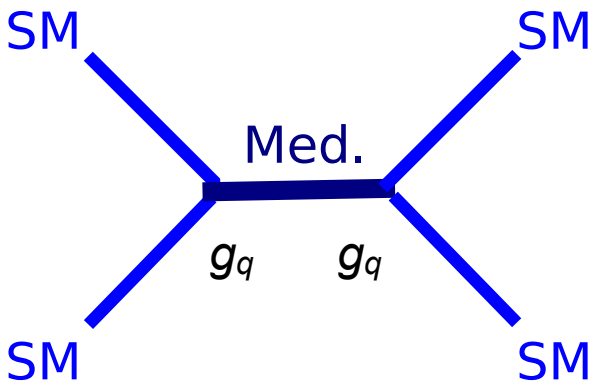
Dijet angular analysis…

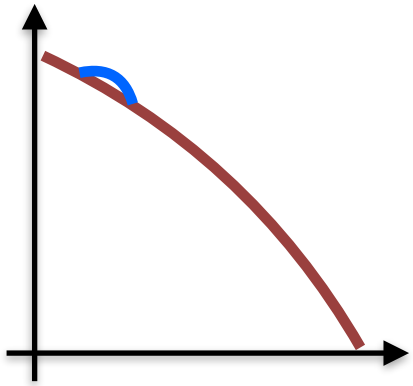
Higgs → bbar

Fully hadronic top

DM searches…

ATLAS Trigger Level Analysis results



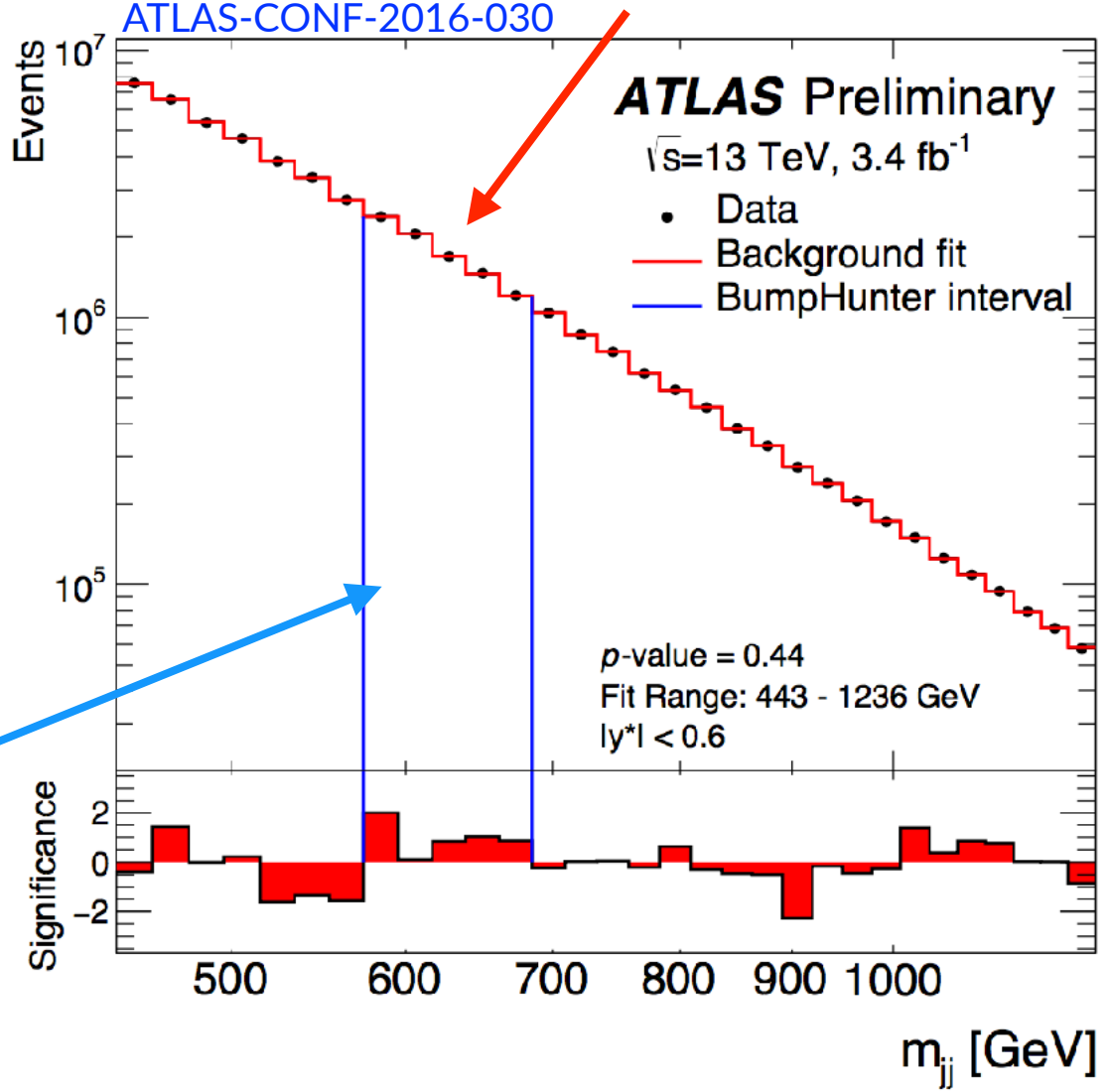


Most discrepant region (p-value 0.44)

Data-driven background fit

$$f(z) = p_1(1-z)^{p_2} z^{p_3+p_4 \log z}$$

ATLAS-CONF-2016-030



No signals of Dark Matter mediators