Synergies between astroparticle, particle and nuclear physics

CATERINA DOGLIONI - LUND UNIVERSITY

Inputs and discussion:
EPPSU PPG BSM, PPG DM, PPG Higgs, ATLAS Collaboration, Antonio Boveia, Oleg Brandt, Conor Fitzpatrick, Ulrich Haisch, Phil C. Harris, Isabelle John, Joerg Jaeckel, Matt McCullough, Jocelyn Monroe, Marco Rimoldi, Emma Tolley, Francesca Ungaro, Torsten Åkesson

@CatDogLund
http://www.hep.lu.se/staff/doglioni/

Outline

General **motivations** and **visions** of particle-astroparticle-nuclear physics

Concrete examples:

New physics discoveries (dark matter)

- How to **discover** new particles
- **Complementarity** of particle and astroparticle physics experiments
  - Weakly Interacting Massive Particles
  - The case of axion(-like) particles

Handling large, heterogeneous amounts of data

- LHC: direct and indirect searches for new physics
- Multimessenger astronomy (nuclear astrophysics)

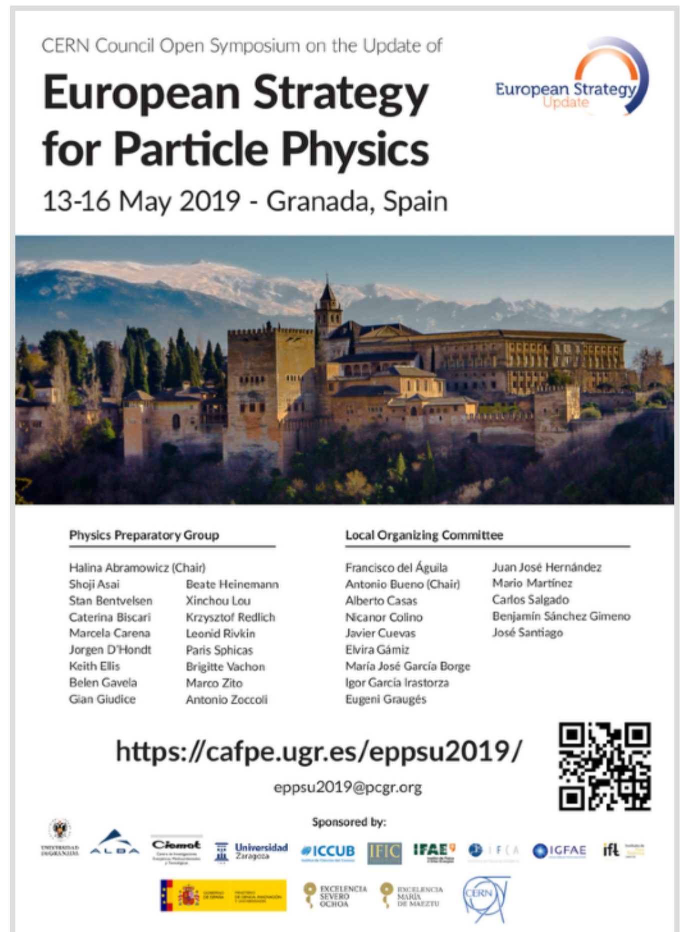
Examples of ongoing **synergistics initiatives**

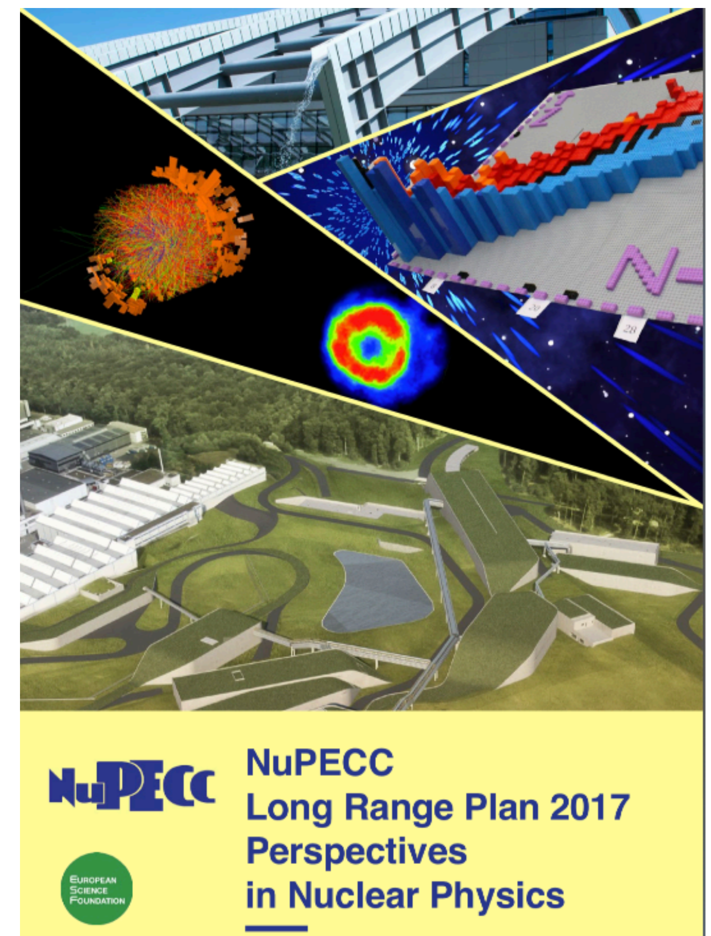
Conclusions and path forward

Much inspiration from EPPSU Granada talks, but also some (necessary) **personal selection of topics**

Visions: APPEC, ECFA, NuPECC

Astroparticle (APPEC) | **Particle (ECFA)** | **Nuclear physics (NuPECC)**





Astroparticle, particle and nuclear physics in Europe have **strategies and plans** that **recognize the importance of synergies** between the different fields

Visions: APPEC, ECFA, NuPECC

Some of the **common scientific goals** in the strategy documents:

Nature of dark matter and dark energy

Fundamental forces & symmetries

Properties of neutrinos at all energy scales

Origin of elements

Extreme states of matter

More synergies: ”foundations” for common challenges

Astroparticle Particle Nuclear

See C. De Los Heros's talk @ EPSHEP'19

See I. Irastorza's talk @ EPSHEP '19

See J. Fiete's talk @ EPSHEP'19

Common theory ground

instrumentation
(accelerators, beams, detectors, vacuum & cryogenics, control & automation…)

data acquisition, computing, data sharing & open science

See **C. Biscari**'s talk in this session

See **A. Cattai**'s talk in this session

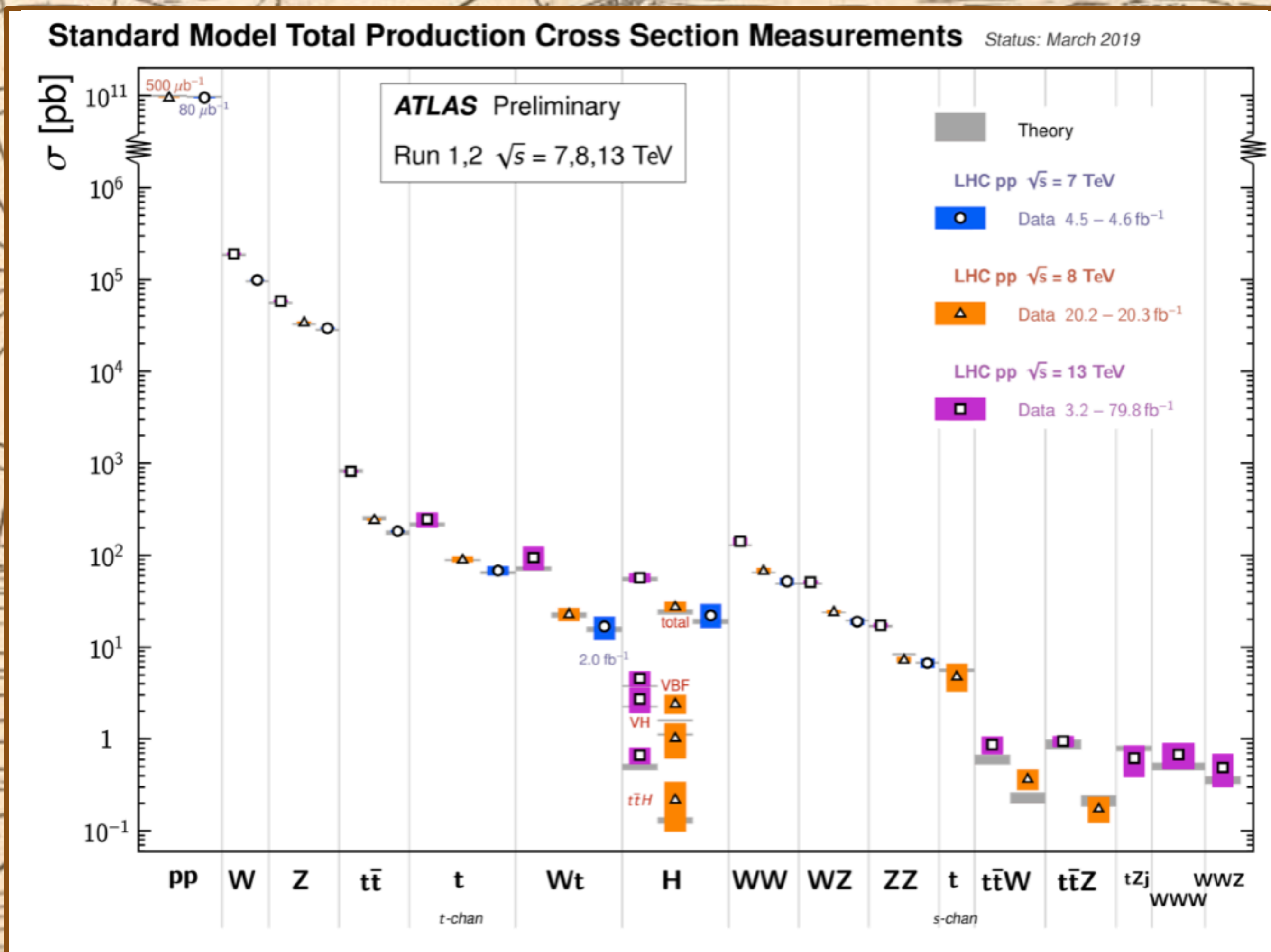
See **G. Stewart**'s talk in this session

Example of a physics synergy:
new physics (of Dark Matter)

A chart of measurements (and discoveries)

Image from University of Uppsala

Many searches and measurements during first years of the LHC: mapping the Standard Model…



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arXiv:1503.07589

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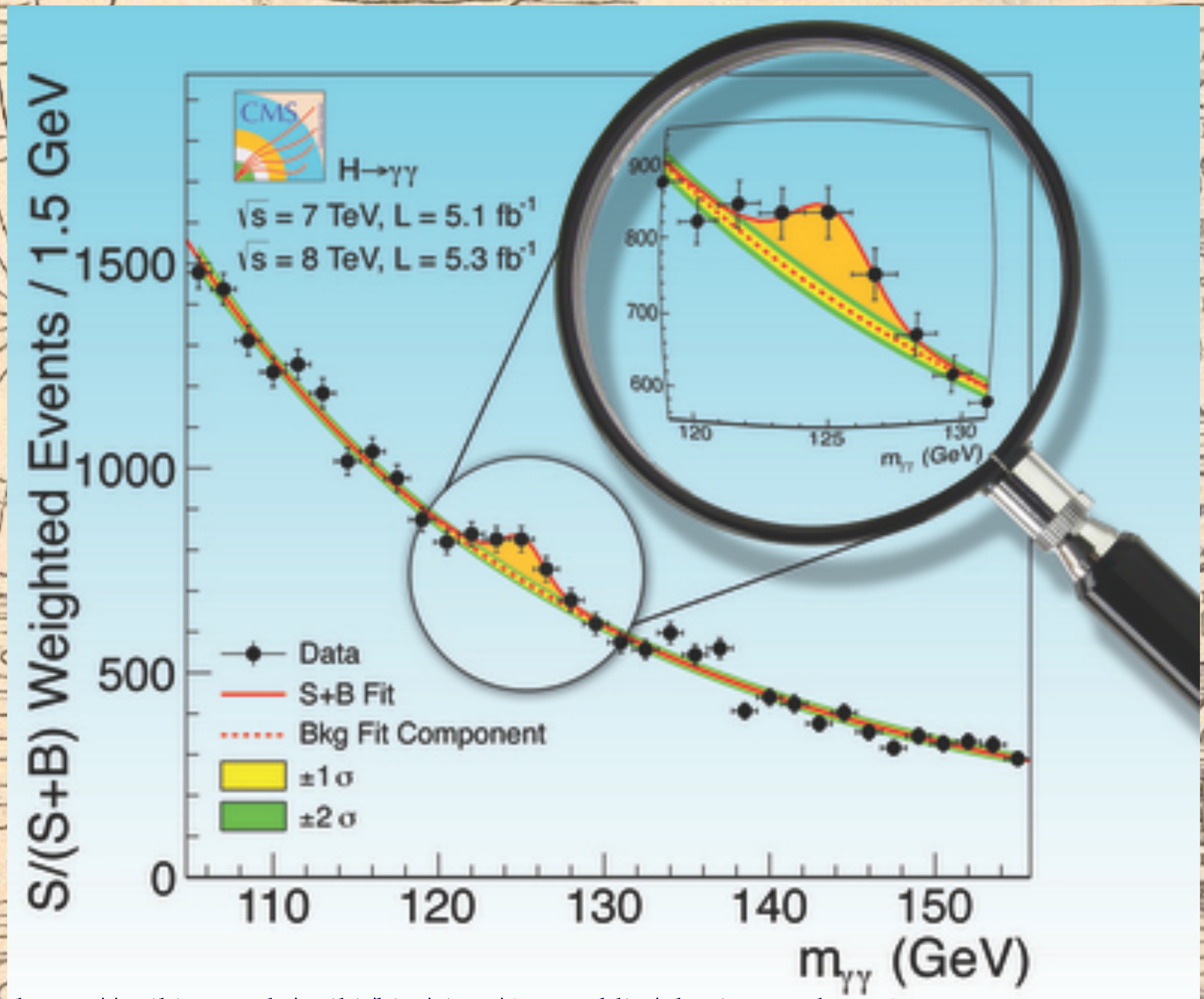


https://twiki.cern.ch/twiki/bin/view/CMSPublic/PhysicsResultsHIG

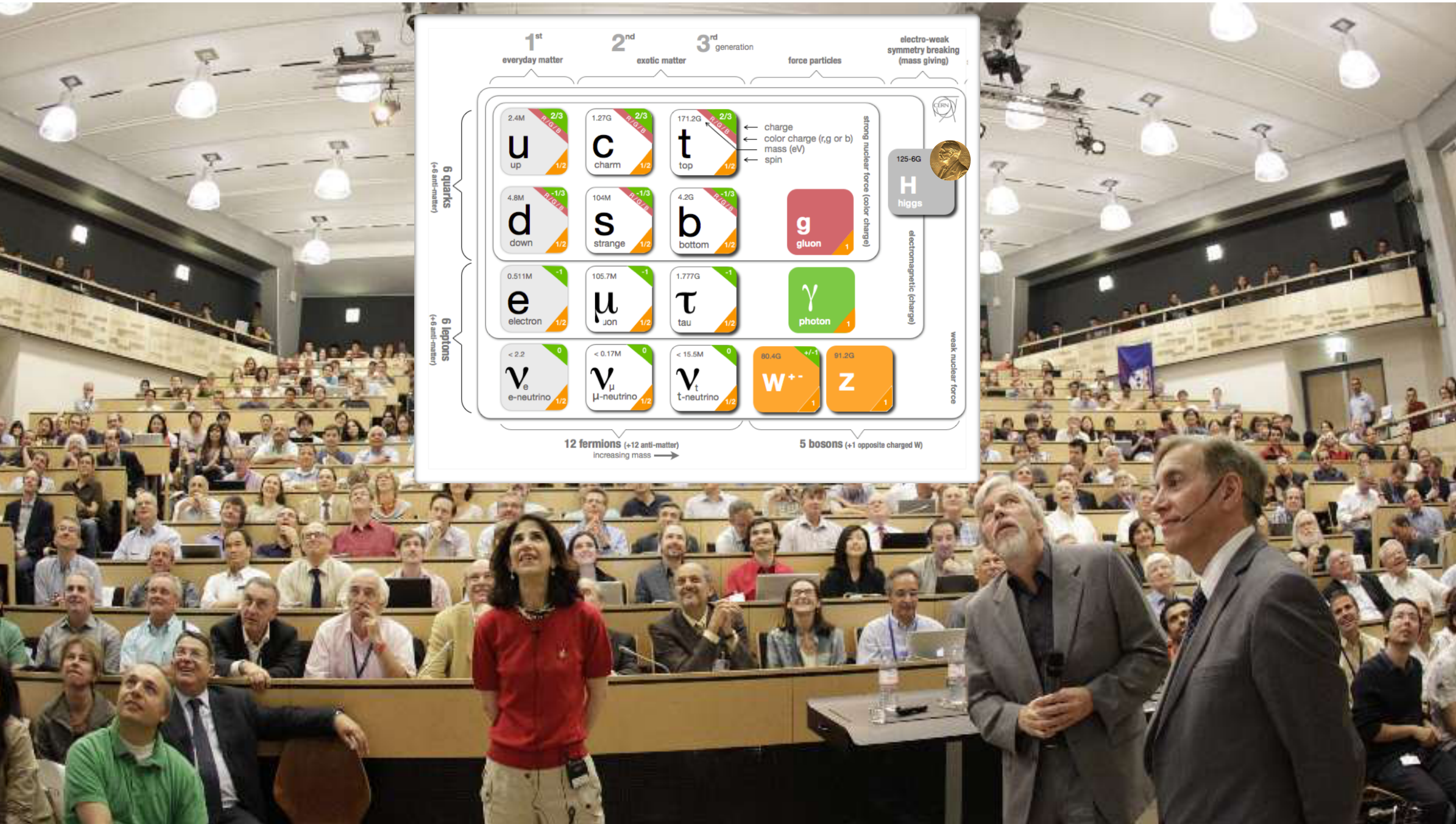
Higgs

…and a milestone discovery

A chart of searches (and discoveries)

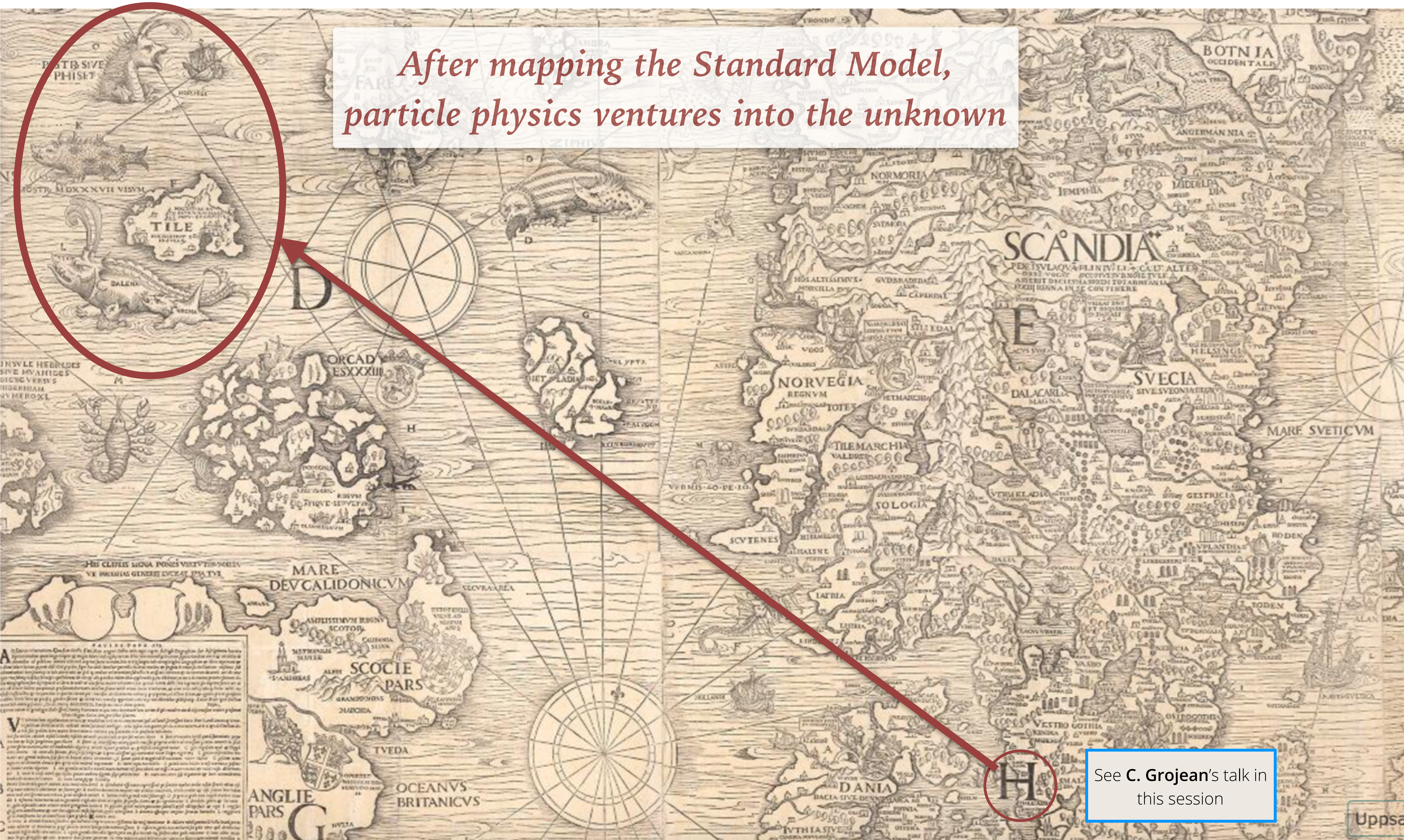
Discovery of the Higgs boson:

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



Where to go next? Uncharted territories

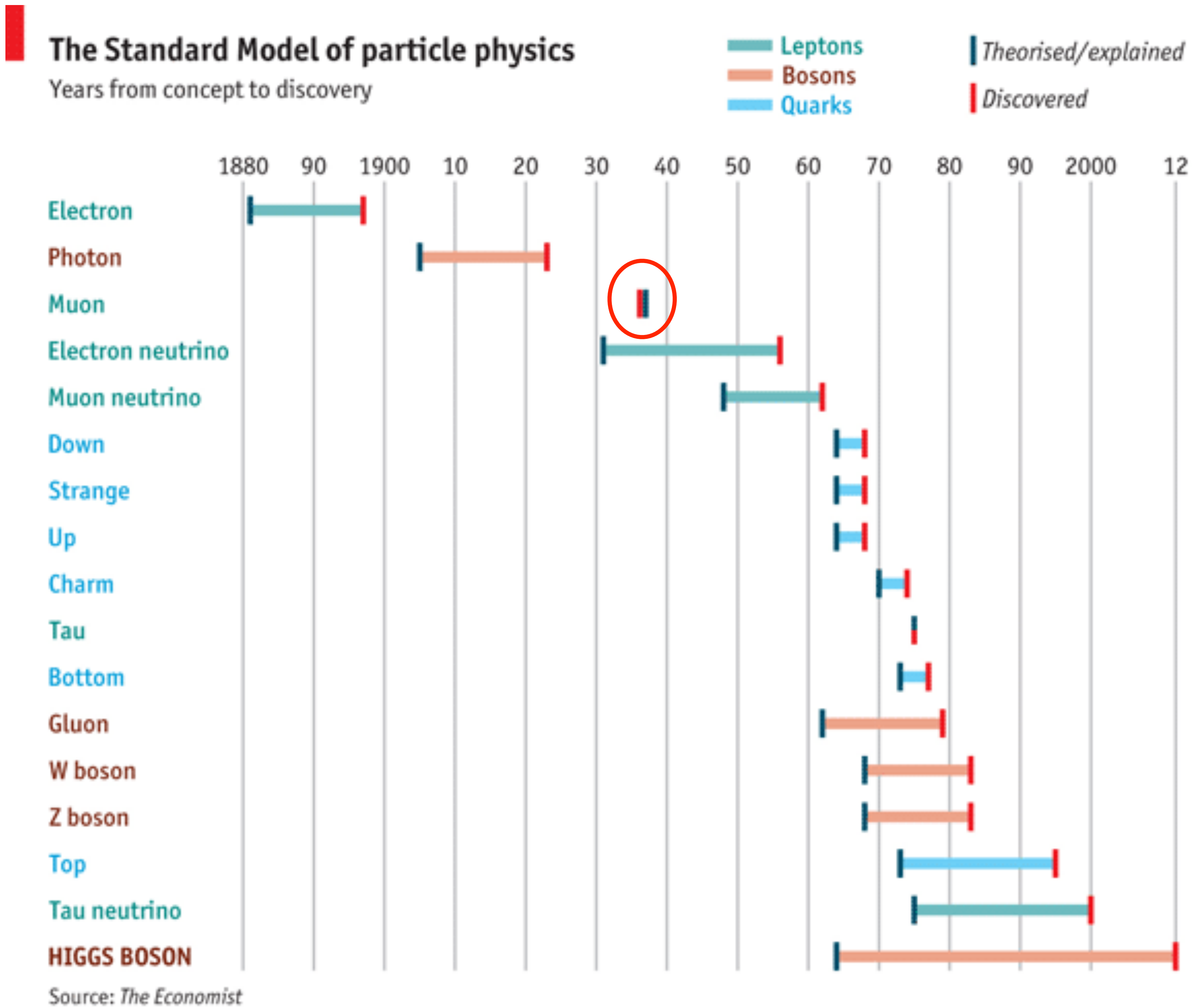
Image from University of Uppsala



After mapping the Standard Model, particle physics ventures into the unknown

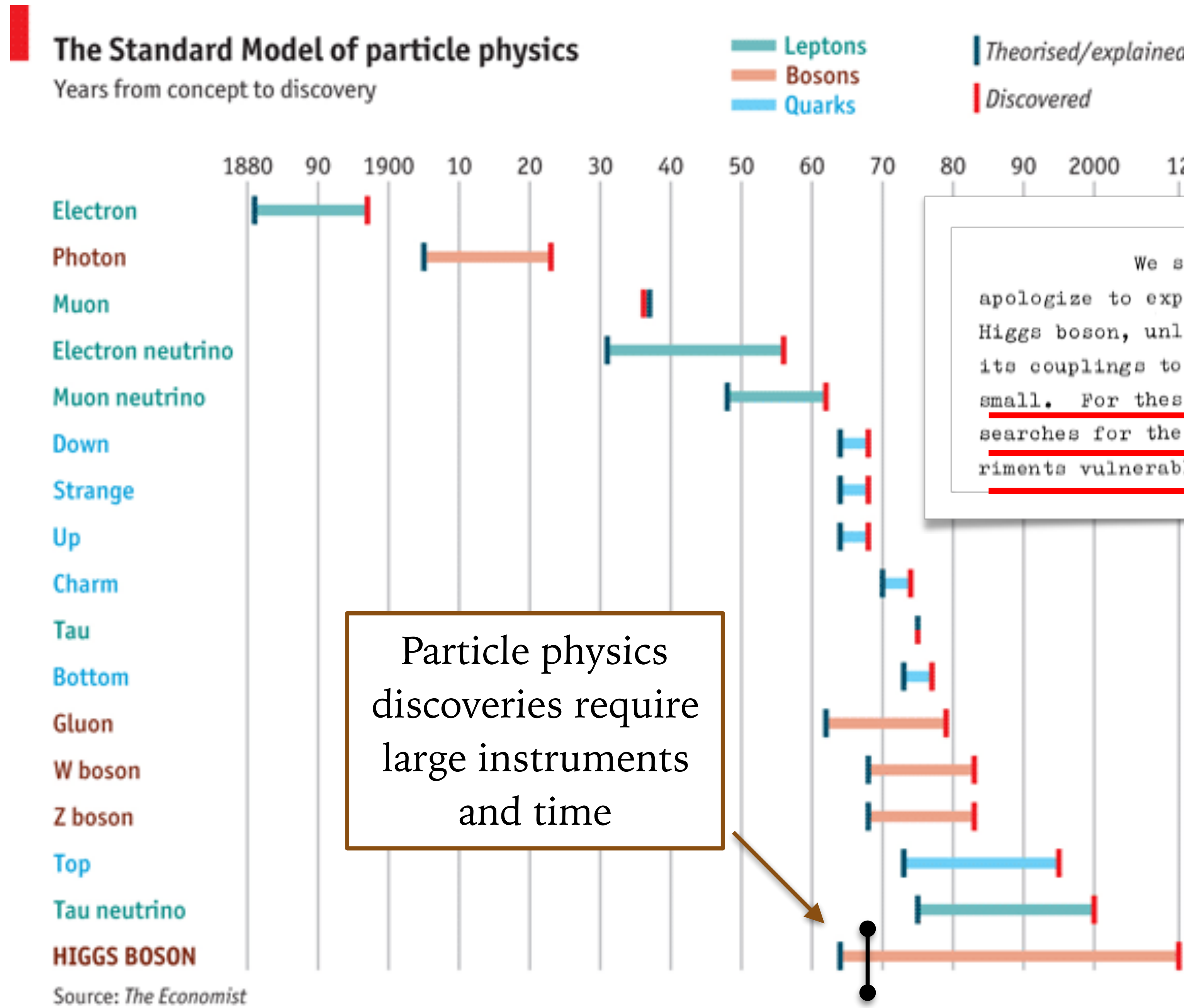
See **C. Grojean**'s talk in this session

Expected and unexpected particle discoveries



The Economist

Expected and unexpected particle discoveries



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

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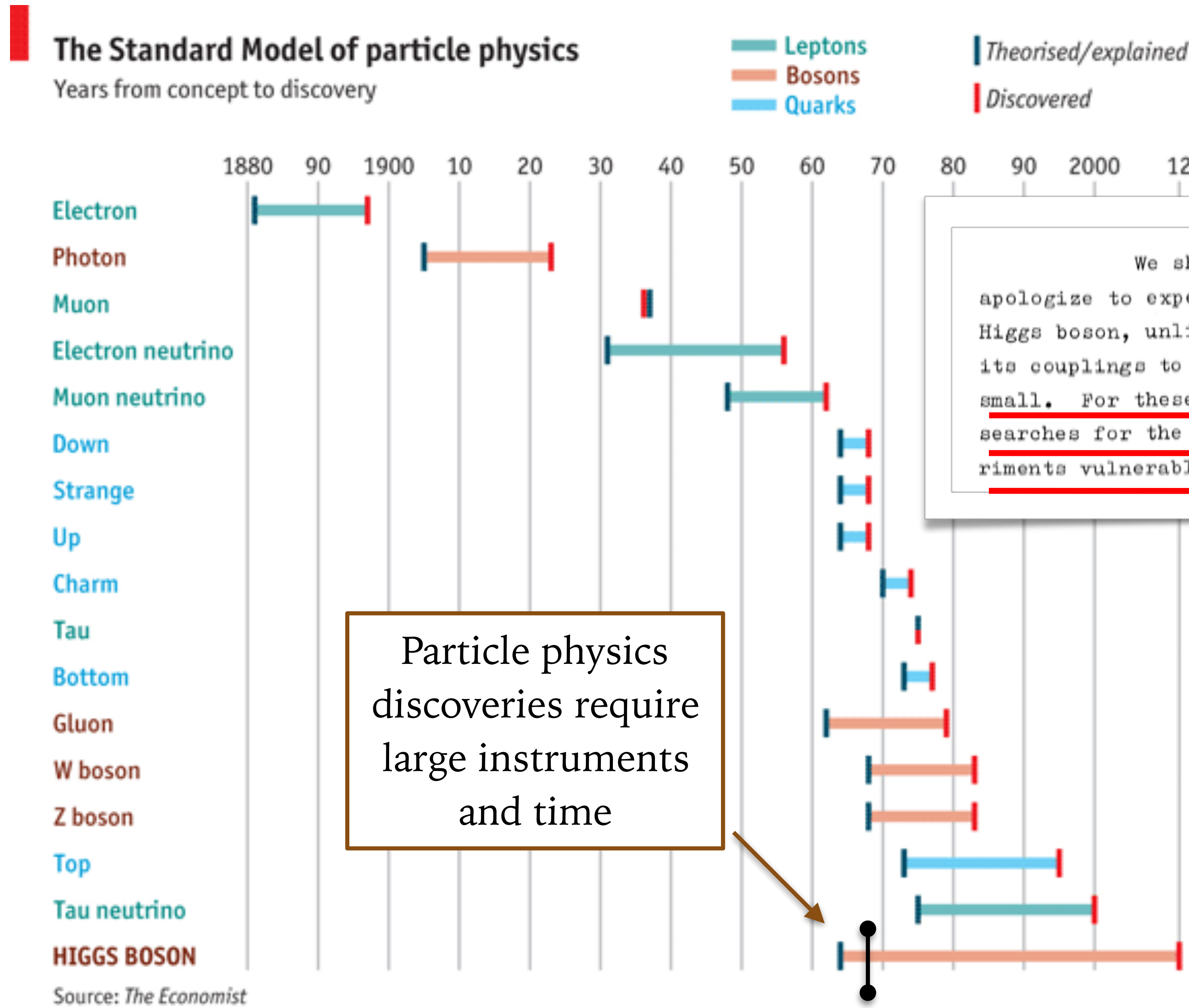
Particle physics discoveries require large instruments and time

The Economist

Expected and unexpected particle discoveries



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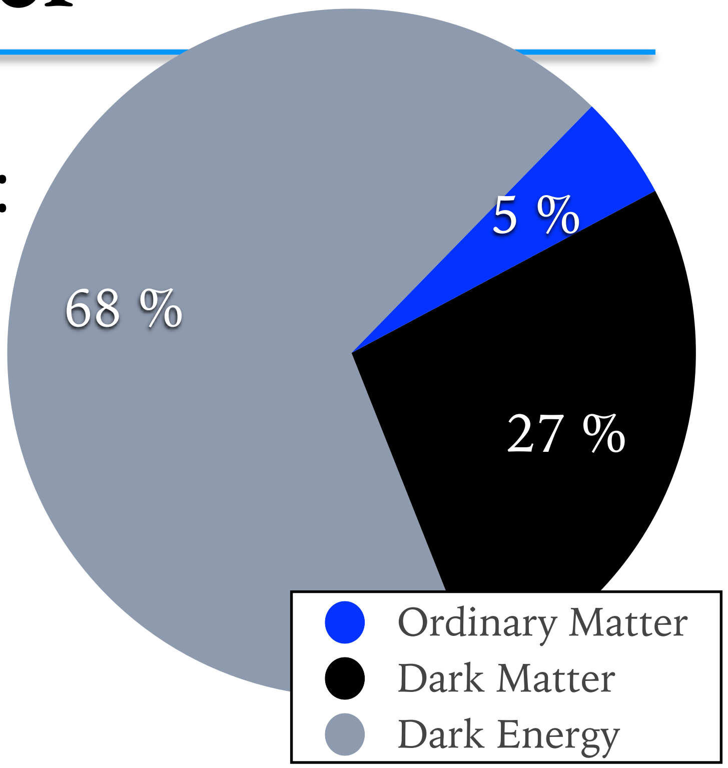
Particle physics discoveries require large instruments and time

[The Economist]

Where to look next?

Many **open problems in astrophysics** that need systematic approach to different discovery scenarios

Guidance from astrophysics: dark matter



Empirical **problem** in the Standard Model of Particle Physics:

arXiv:0704.2276v1

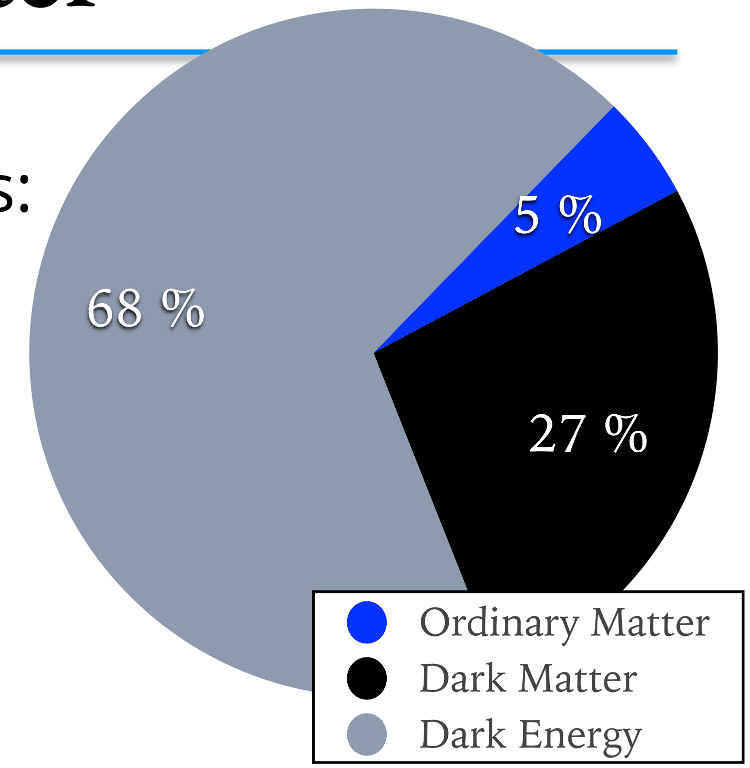
no explanation for **Dark Matter**

One of the possible **solutions,** guided by **relic density**:

invisible **Dark Matter particles** at the **TeV scale**

(*Weakly Interacting Massive Particles*)

Guidance from astrophysics: dark matter



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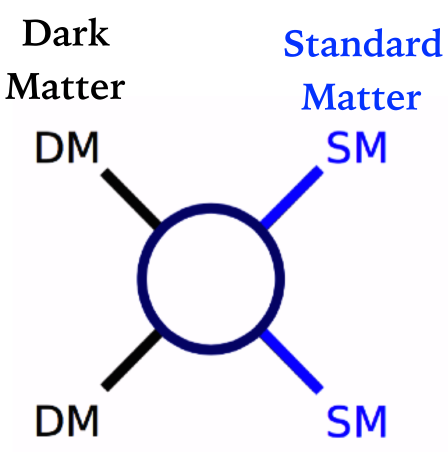
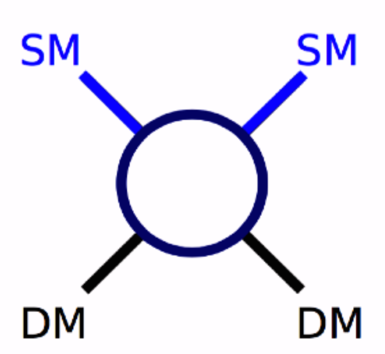
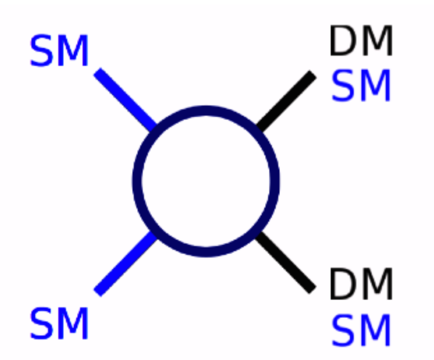


Indirect Detection

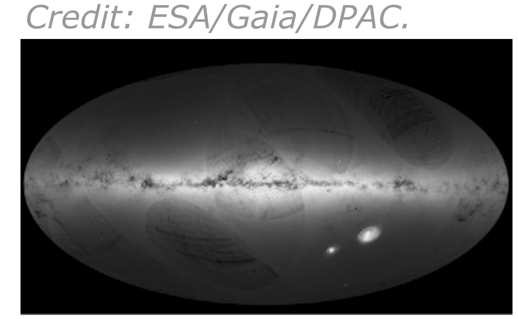


Direct Detection

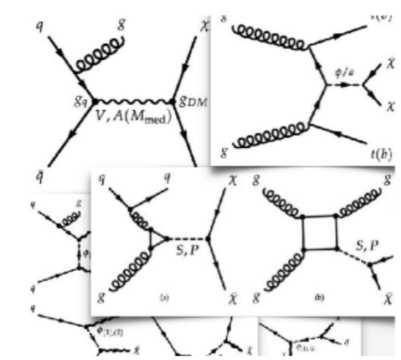


Colliders

Credit: ESA/Gaia/DPAC.



Astrophysics



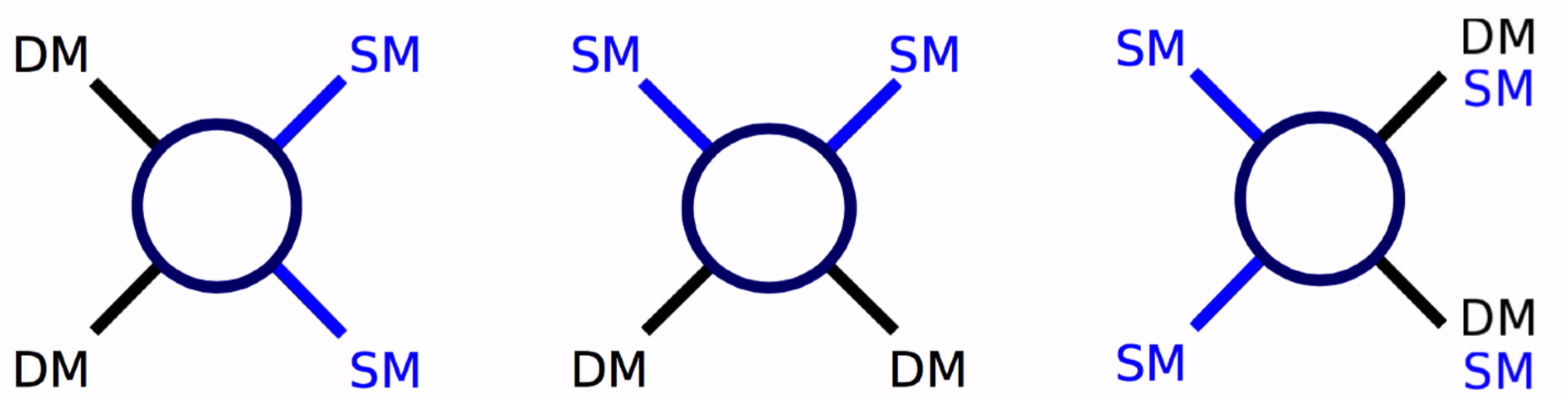
Theory

Complementary experimental strategies & inputs

Collider, direct and indirect detection

Big Question at Granada symposium:
How will Direct and Indirect DM Detection experiments inform/guide accelerator searches and vice-versa?

- Why we need complementarity:
  - DD/ID can discover DM with cosmological origin

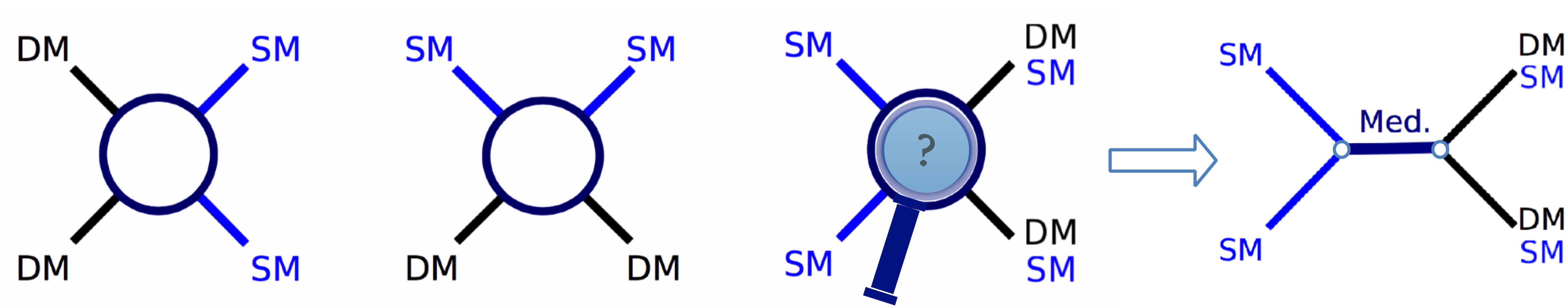


Indirect Detection Direct Detection Particle Colliders

Collider, direct and indirect detection

Big Question at Granada symposium:
How will Direct and Indirect DM Detection experiments inform/guide accelerator searches and vice-versa?

- Why we need complementarity:
  - DD/ID can discover DM with cosmological origin
  - Colliders can produce DM and probe the dark interaction



Indirect Detection Direct Detection Particle Colliders

See C. De Los Heros's talk @ EPSHEP'19

See I. Pellmann's talk @ EPSHEP'19

See M. Genest's talk @ EPSHEP'19

A simple example: scalar mediator between SM and DM

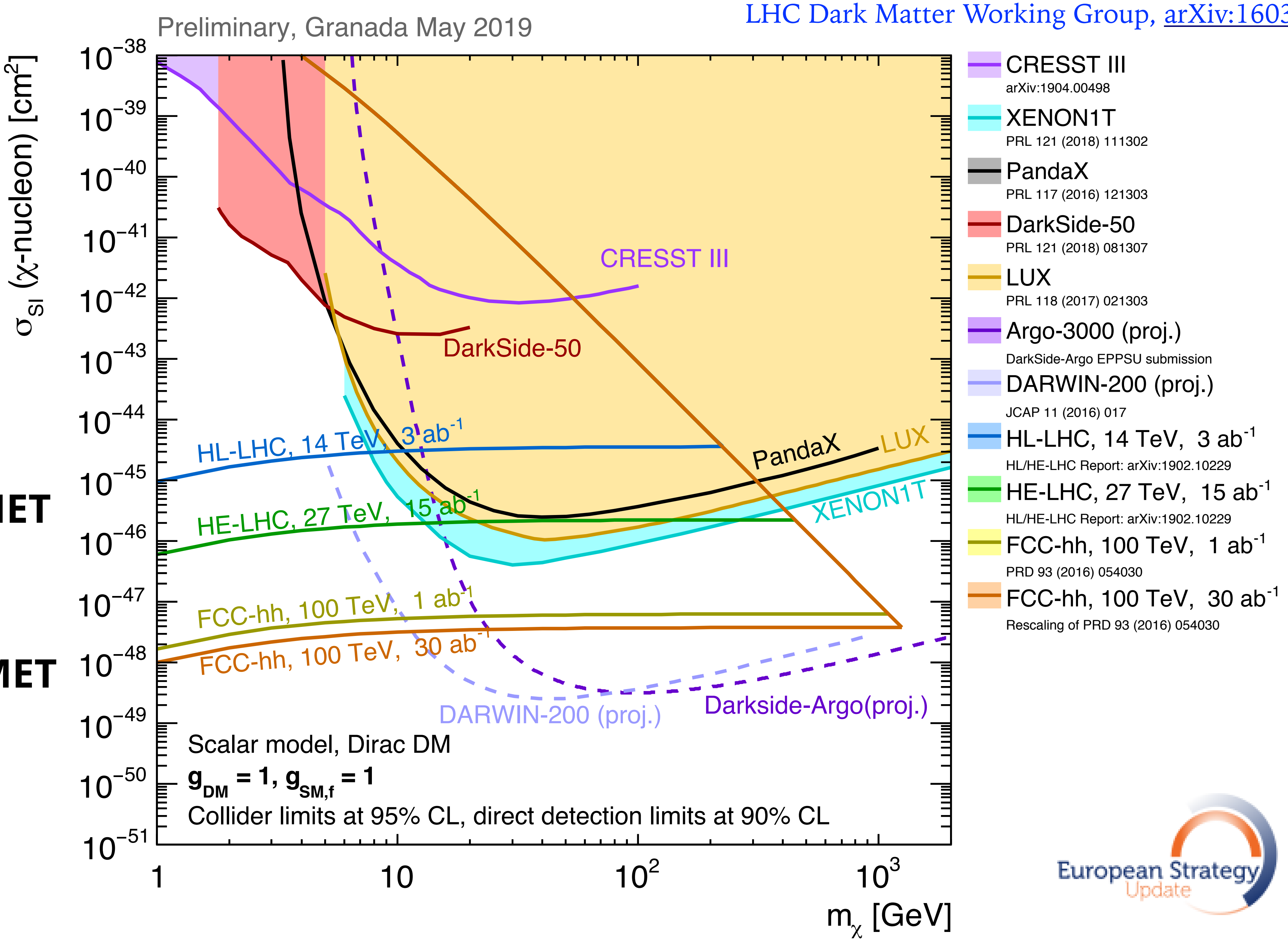
- Collider constraints on simple models of DM can be shown in terms of DM-nucleon interactions

$$\sigma_{\rm SI} \simeq 6.9 \times 10^{-43}\ {\rm cm}^2 \cdot \left(\frac{g_q g_{\rm DM}}{1}\right)^2 \left(\frac{125\ {\rm GeV}}{M_{\rm med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ {\rm GeV}}\right)^2$$

LHC Dark Matter Working Group, arXiv:1603.04156

ttbar+MET

V/jet+MET



European Research Council
Established by the European Commission

European Strategy Update

A simple example: scalar mediator between SM and DM

- Collider constraints on simple models of DM can be shown in terms of DM-nucleon interactions

$$\sigma_{SI} \simeq 6.9 \times 10^{-43}\ \mathrm{cm}^2 \cdot \left(\frac{g_q g_{DM}}{1}\right)^2 \left(\frac{125\ \mathrm{GeV}}{M_{med}}\right)^4 \left(\frac{\mu_{n\chi}}{1\ \mathrm{GeV}}\right)^2$$

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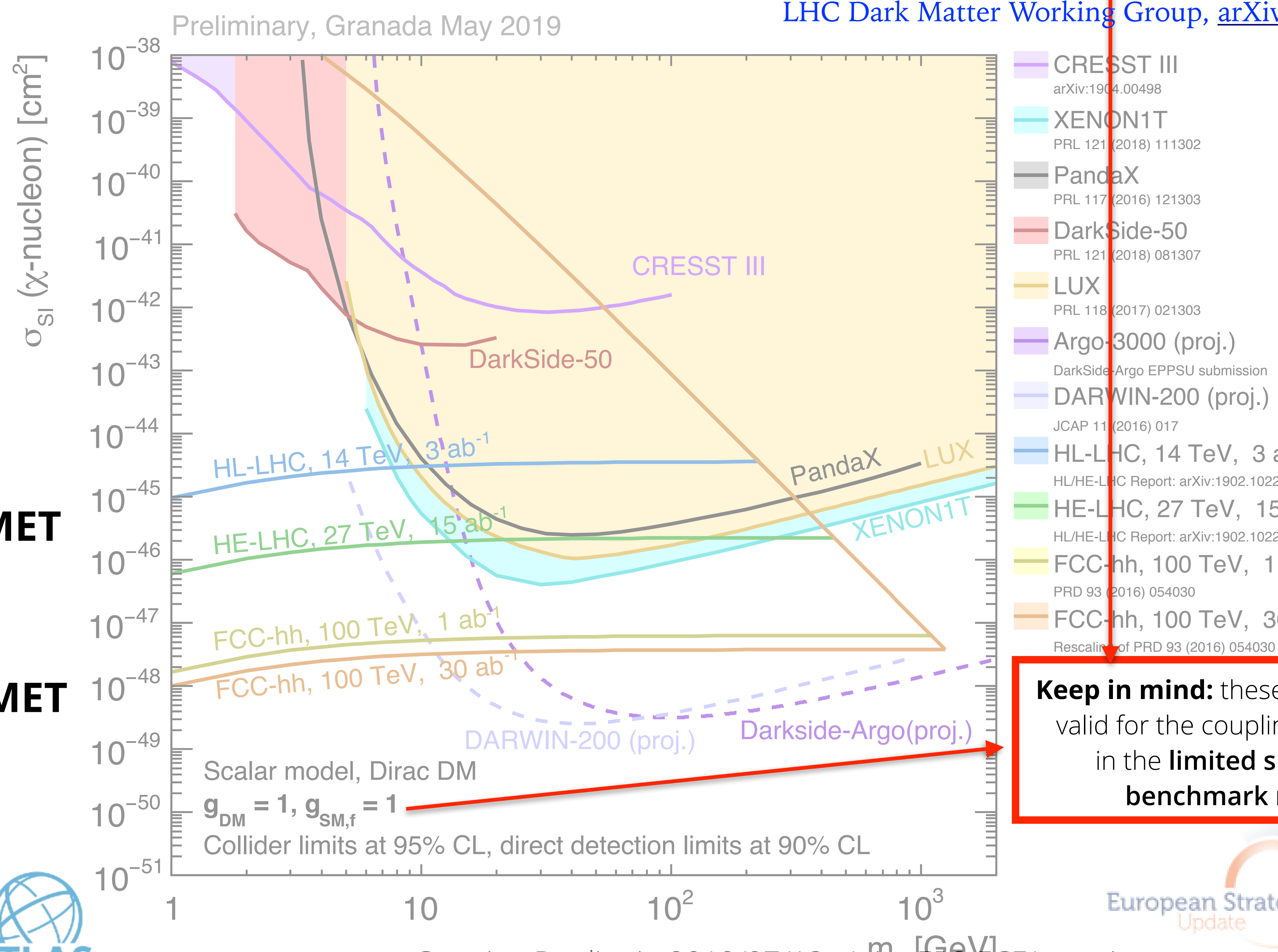
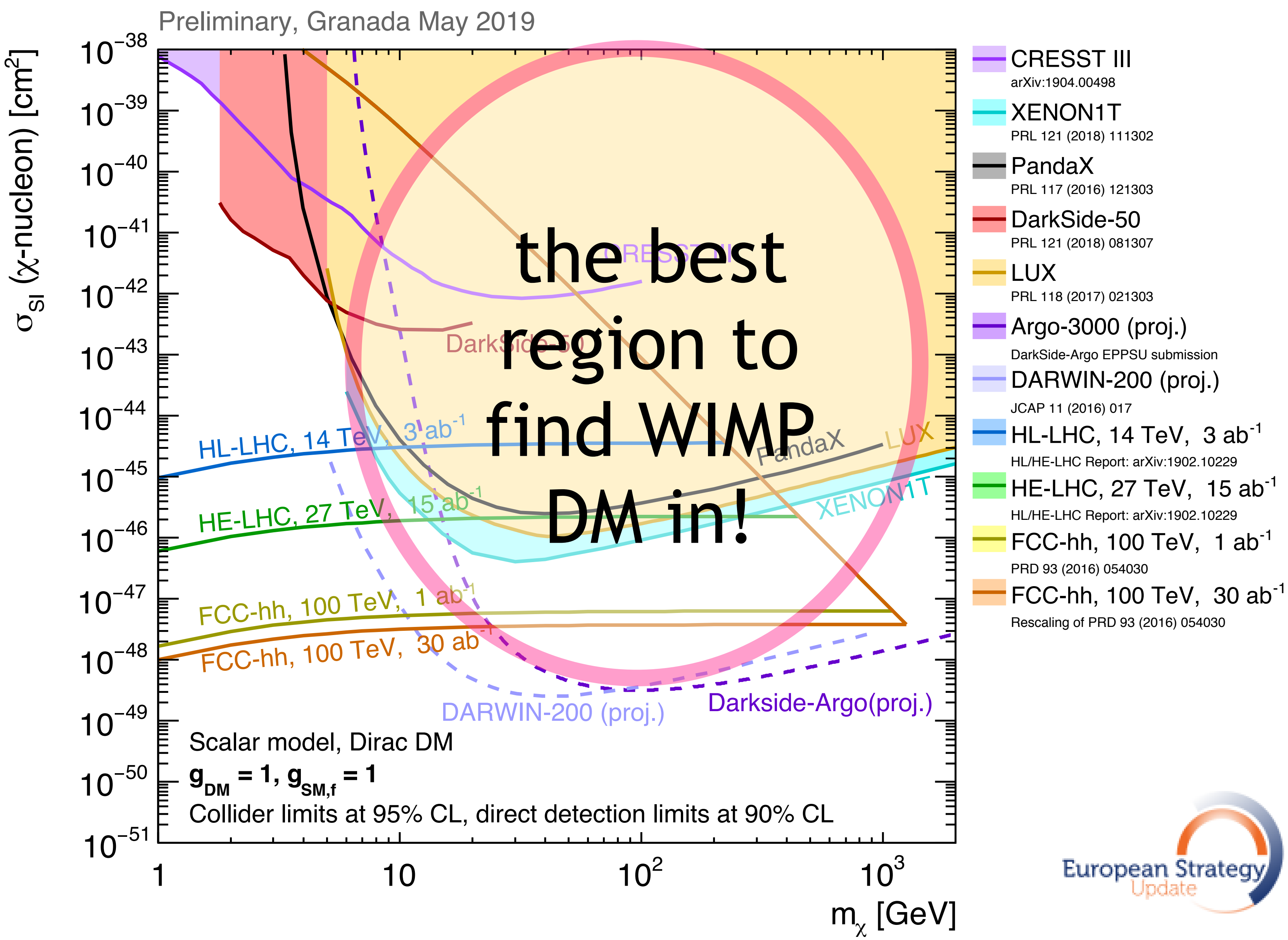


Keep in mind: these plots are only valid for the couplings specified, in the **limited space of a benchmark model**!

A simple example: scalar mediator between SM and DM

Synergy: complementary reach for future colliders and direct detection



- **Collider discovery** of invisible particle needs **confirmation of cosmological origin** from DD/ID
- **DD/ID discovery** needs collider **understanding of nature of interaction**
- A **future collider program** that increases sensitivity to invisible particles **coherently with DD/ID** serves these purposes

See **V. Dutta**'s talk @ EPSHEP'19

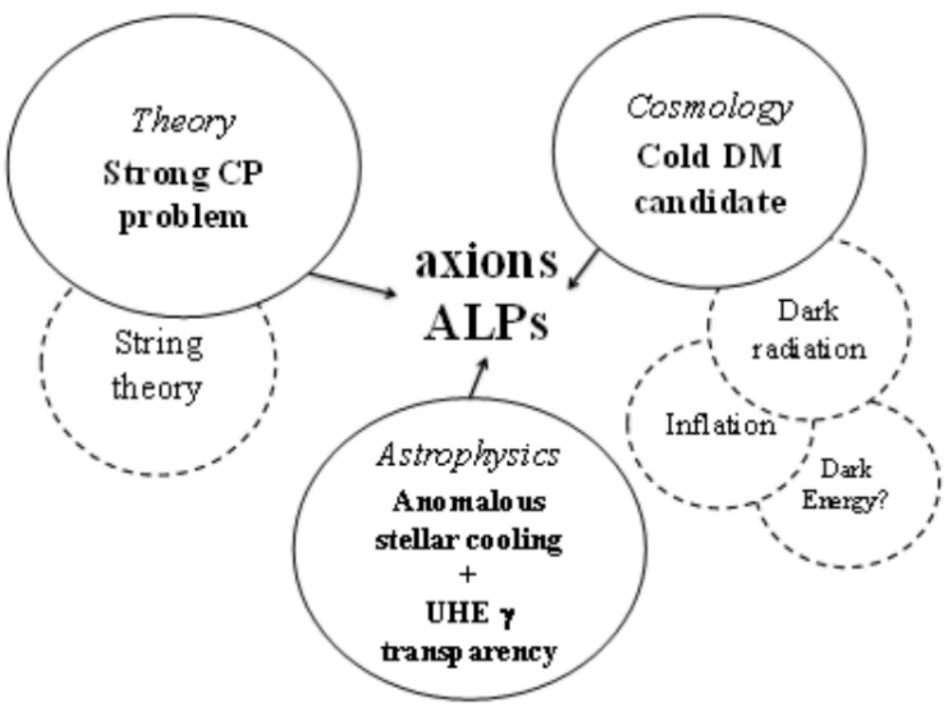
- Synergies with also in non-WIMP DM, for DD and beam dump experiments

See **S. Stapnes**'s talk @ EPSHEP'19

What if DM isn't a WIMP?

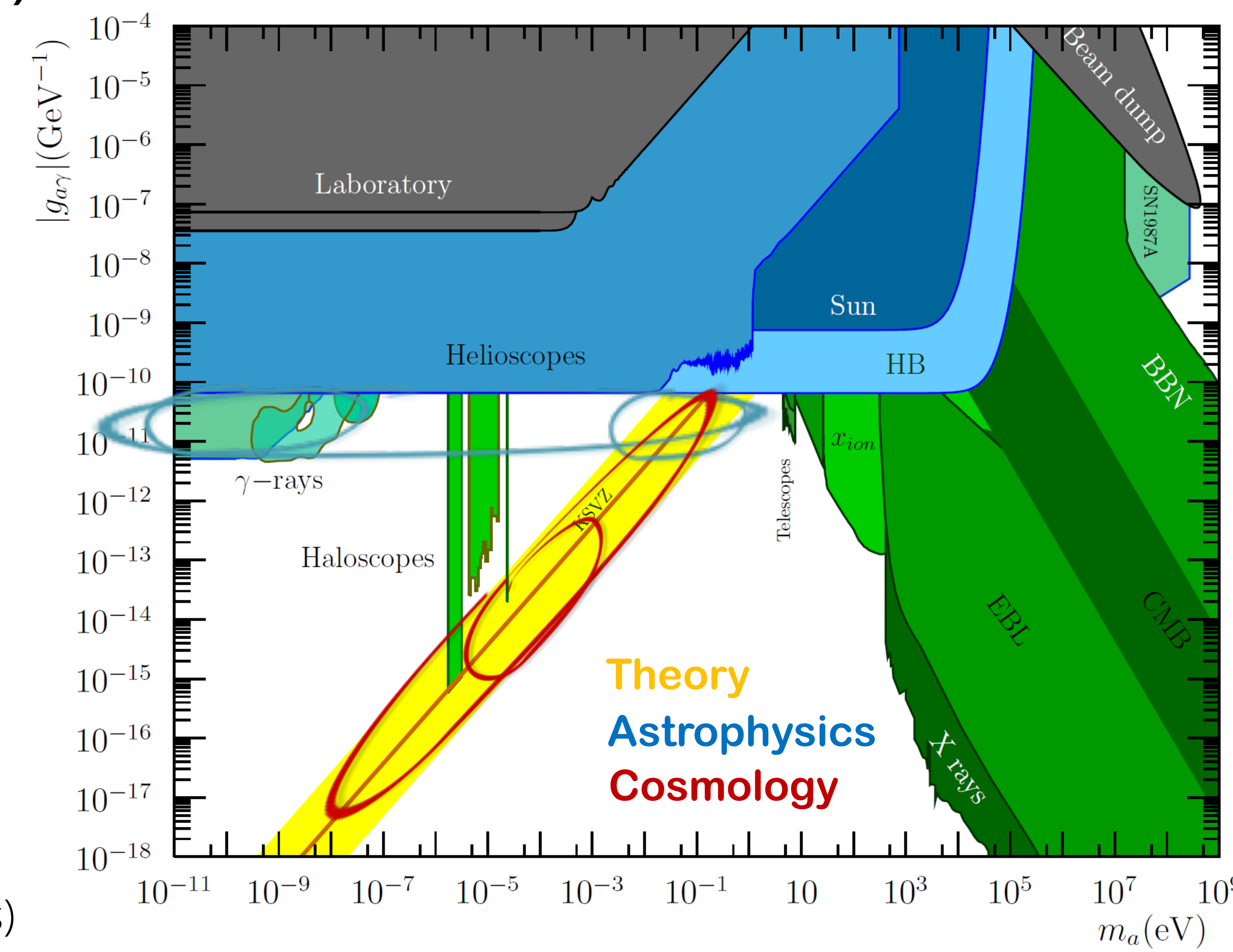
See **C. Vallee**'s talk in this session

Axions/Axion-Like Particles (ALPs):
example of new particle
with inter-field connections



also using nuclear physics experiments (EDM rings)

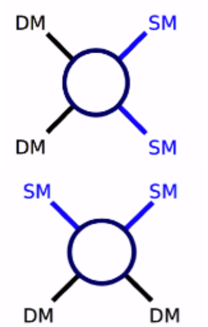
Figures taken From **I. Irastorza**'s talk @ EPSHEP '19



Synergies beneficial for many **smaller experiments:**
from **joint expertise** and **common discussion platforms**

Synergies in dark matter searches

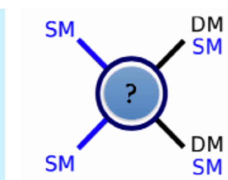
Huge progress planned for **direct and indirect detection** for **WIMP DM**
Future colliders and experiments can follow:
essential **complementarity** between



cosmological origin
astrophysics

and

nature of the DM-SM interaction
particle physics



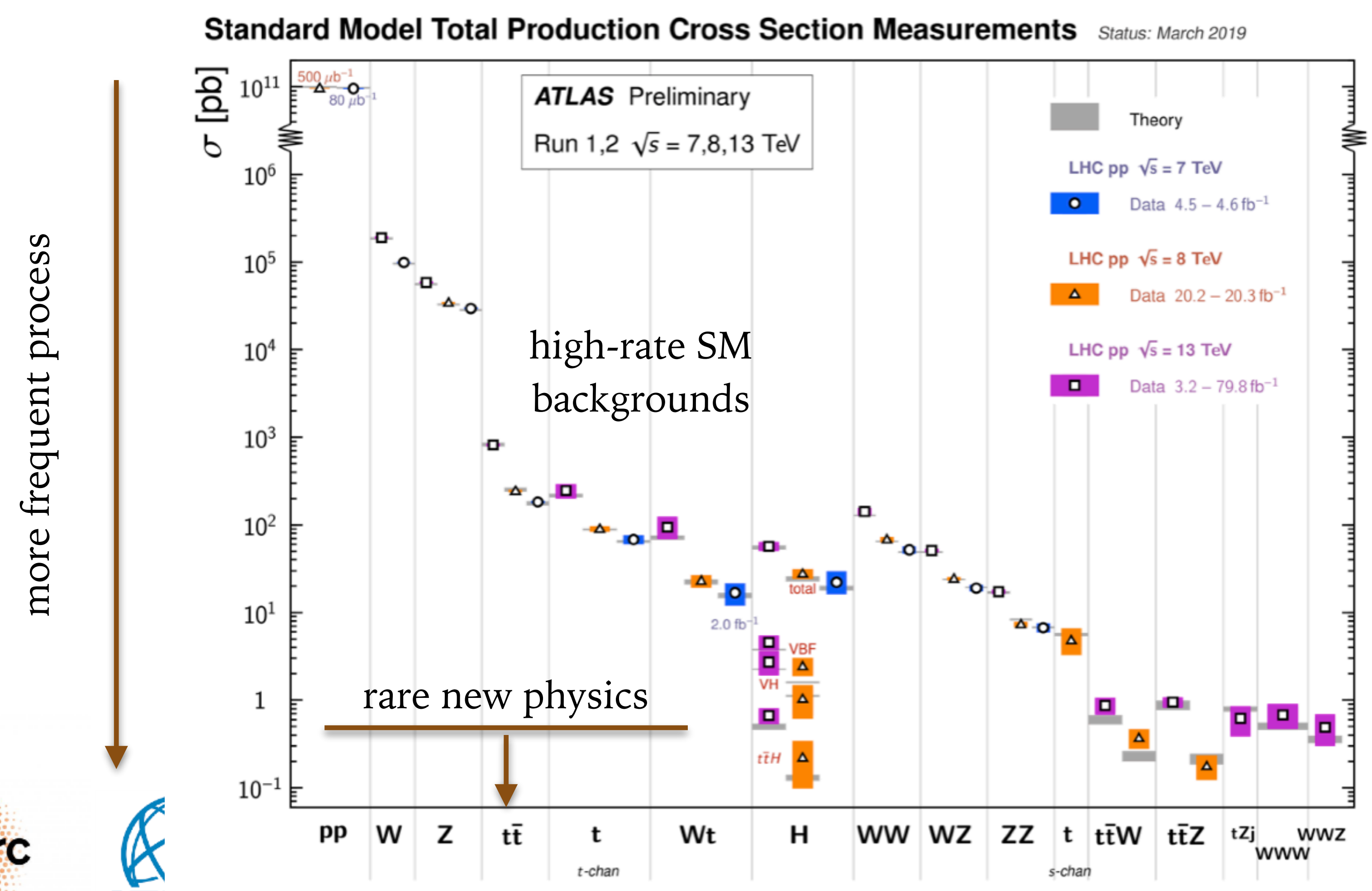
Similarly, **combination of complementary experiments + theory** needed to identify nature of DM in case of **non-WIMP DM**

How to **strengthen common foundations?**
Many **common challenges**, e.g.
particle **detectors and instrumentation,**
strategies to handle **large amounts of data**

Example of a common challenge: analysis of large, complex datasets

Enabling discoveries in particle physics

- **Many different theories** can explain **particle physics** shortcomings
  - None of these theories is yet favored by data
  - Very different signatures in the detector
    - Some signals buried in **high-rate backgrounds**



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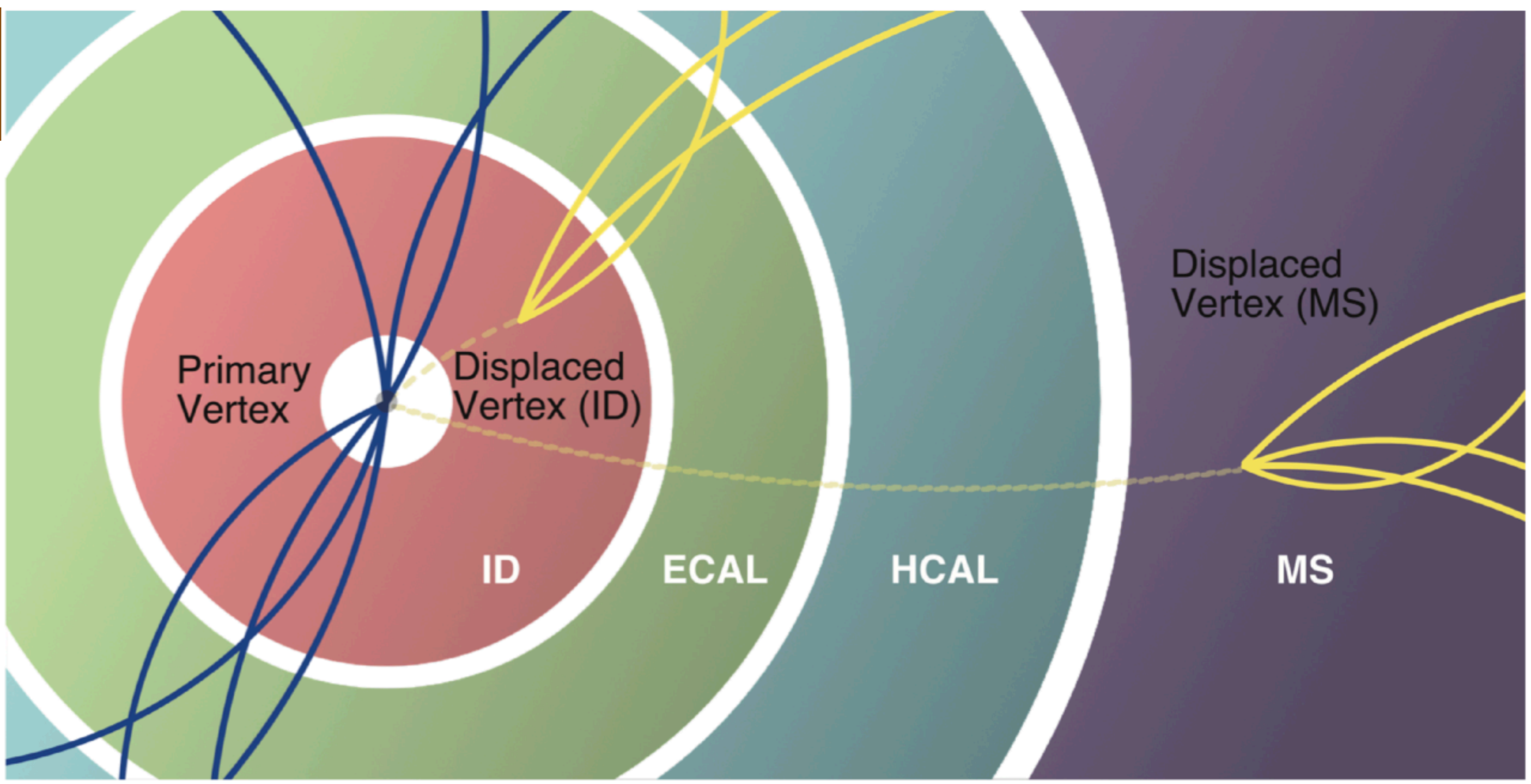
Enabling discoveries in particle physics

- **Many different theories** can explain **particle physics** shortcomings
  - None of these theories is yet favored by data
  - Very different signatures in the detector
    - Some signals buried in **high-rate backgrounds**
    - Some signals **very unusual but rare**

https://arxiv.org/abs/1810.12602

See e.g. **C. Ohm**'s talk @ EPSHEP'19

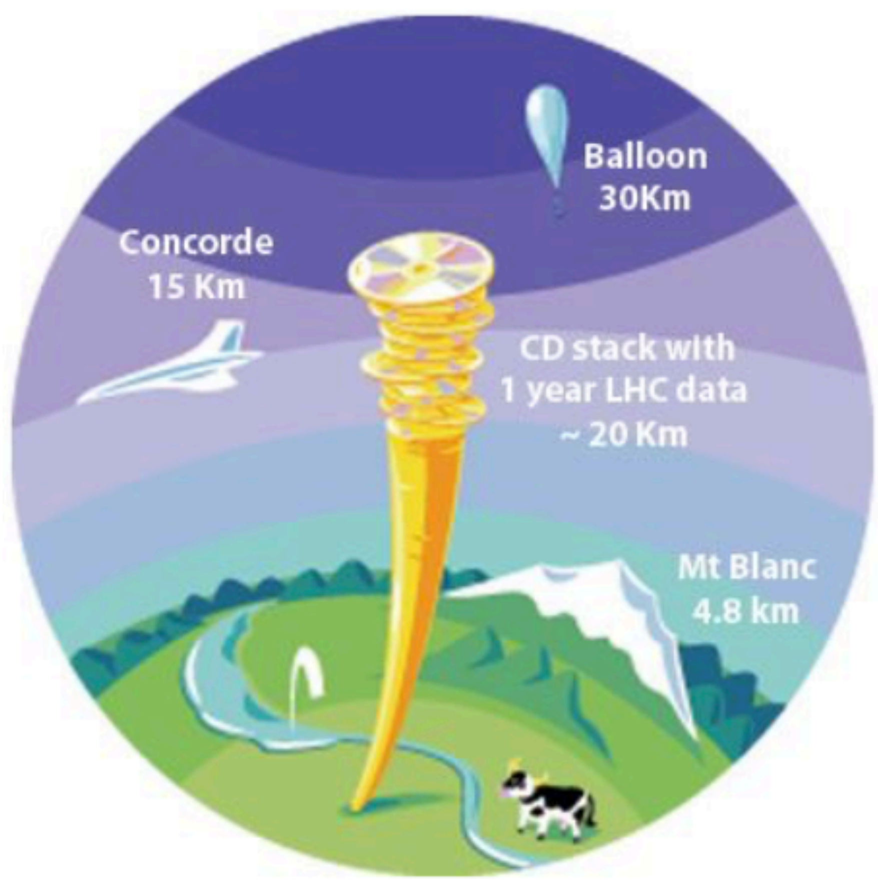


Enabling discoveries in particle physics

- **Many different theories** can explain **particle physics** shortcomings
  - None of these theories is yet favored by data
  - Very different signatures in the detector

A key challenge: within millions p-p collisions/second, select/analyze the interesting ones **in real time**

See **G. Stewart**'s talk in this session

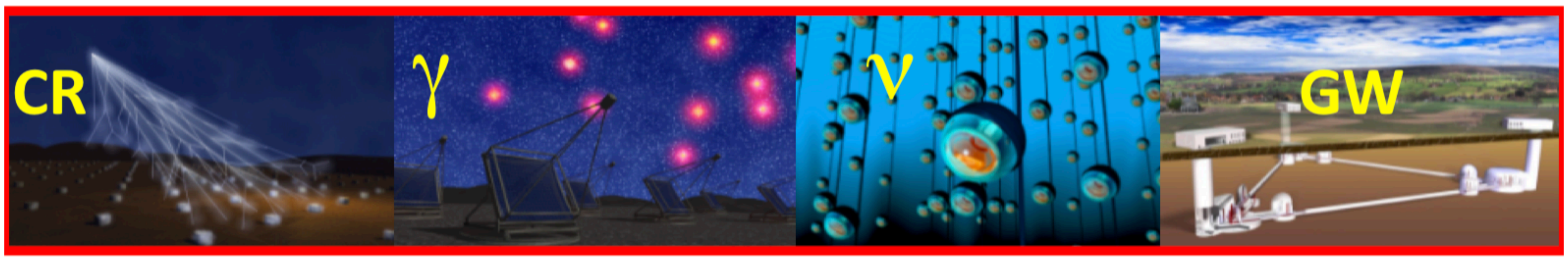


LHC data volumes after selection of "interesting" data

The advent of Multimessenger astronomy

- Revolutionary combination of information on the cosmos
- Simultaneous detection of astrophysics events
  - ”highly heterogeneous, high-volume, high-velocity datasets” arXiv:1807.04780.pdf

T. Montaruli, International Workshop on Neutrino Telescopes

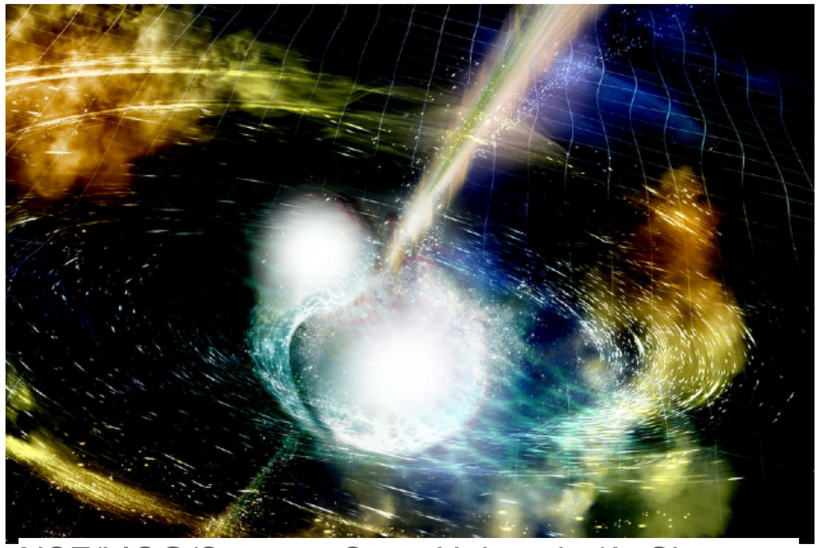


See **E. Bernardini**'s talk @ EPSHEP'19

The advent of Multimessenger astronomy

- Revolutionary combination of information on the cosmos
- Smultaneous detection of astrophysics events
  - ”highly heterogeneous, high-volume, high-velocity datasets” arXiv:1807.04780.pdf

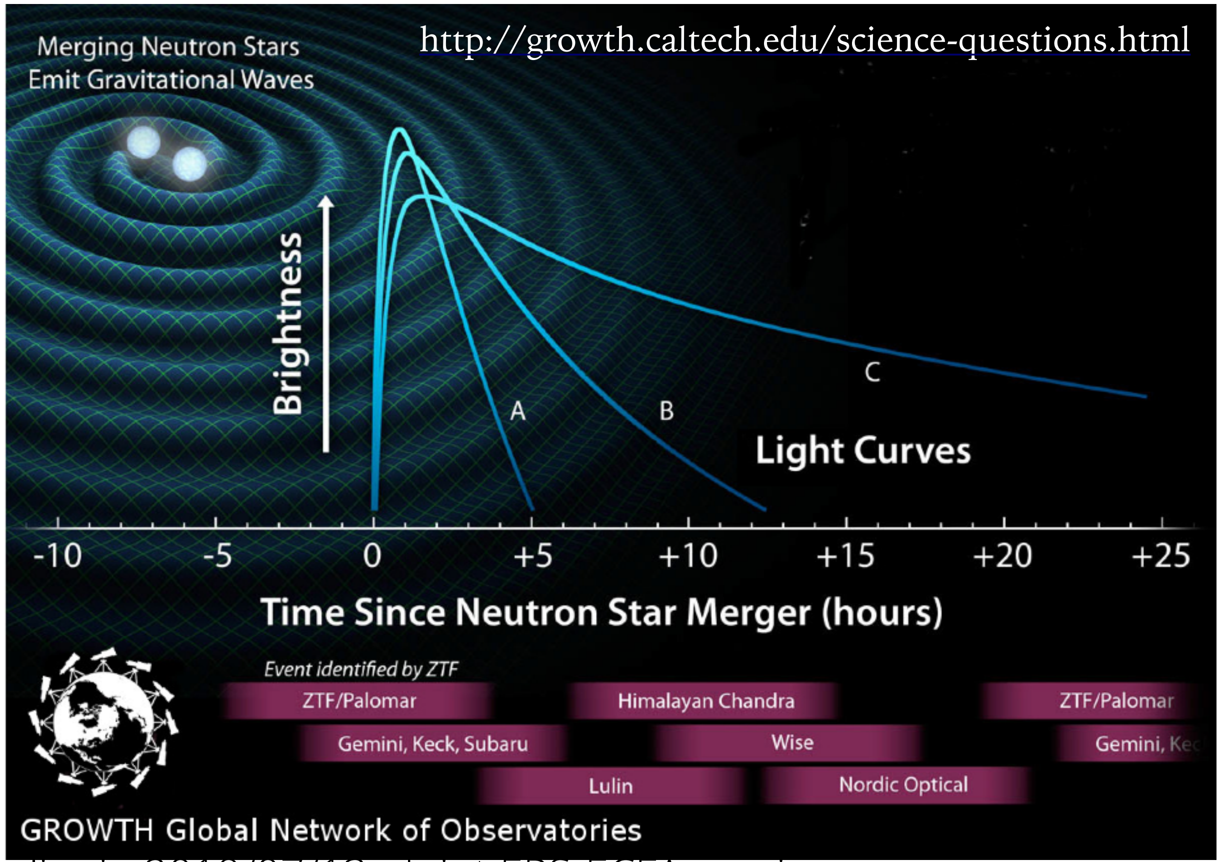
A key challenge: fast follow-up of interesting events with higher resolution instruments



NSF/LIGO/Sonoma State University/A. Simonnet

Light from neutron star mergers can shed light on cosmic origin of heavy elements

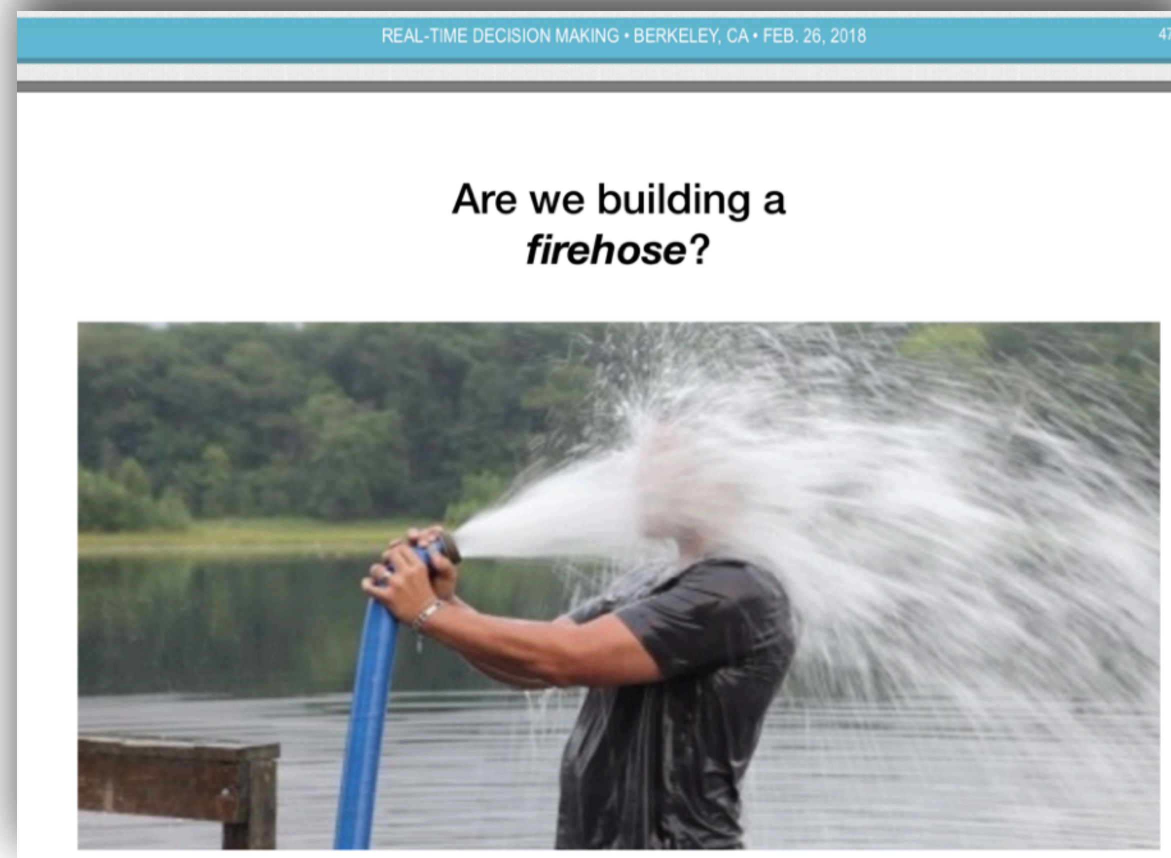
M. Kasliwal's talk at Simons Real-time workshop



Extremely large datasets, in different contexts

C. Fitzpatrick, **LHCb**

E. Bellm, **Large Synoptic Survey Telescope**



The LHC and modern astrophysics surveys are **data firehoses**

Can benefit from **common techniques and tools for data taking & data reduction**
(e.g. on-detector / real-time data analysis, machine learning)
with applications beyond physics research

Synergy initiatives and outlook

A constellation of activities and initiatives

APPEC news,
after Granada '19:
wish to enhance collaboration and discussion between LHC DMWG and DD/ID

Direct Detection collaborations input to EPPSU: strenghten common efforts

Astroparticle Particle Nuclear

European Center for Astroparticle Theory (EuCAPT)

Common theory ground

APPEC input to EPPSU:
taking off in 2019 with CERN as first 5-year host

instrumentation
(accelerators, beams, detectors, vacuum & cryogenics, control & automation...)

data acquisition, computing, data sharing & open science

HSF HEP Software Foundation

Conclusions and outlook

- Answering fundamental physics questions requires **concerted work** from **particle, astroparticle and nuclear physics**
  - Examples: dark matter (in this talk), neutrino physics…
  - Common challenges in terms of foundations (detector, computing…)
- A number of **synergistic initiatives** exist, many **hosted by CERN**
  - What is the best way forward? Discussion started at Granada meeting
- More discussion at the **APPEC-ECFA-NuPECC meeting** in Orsay this October

Thank you for your attention!