A Novel Beam Dump Experiment at CMS

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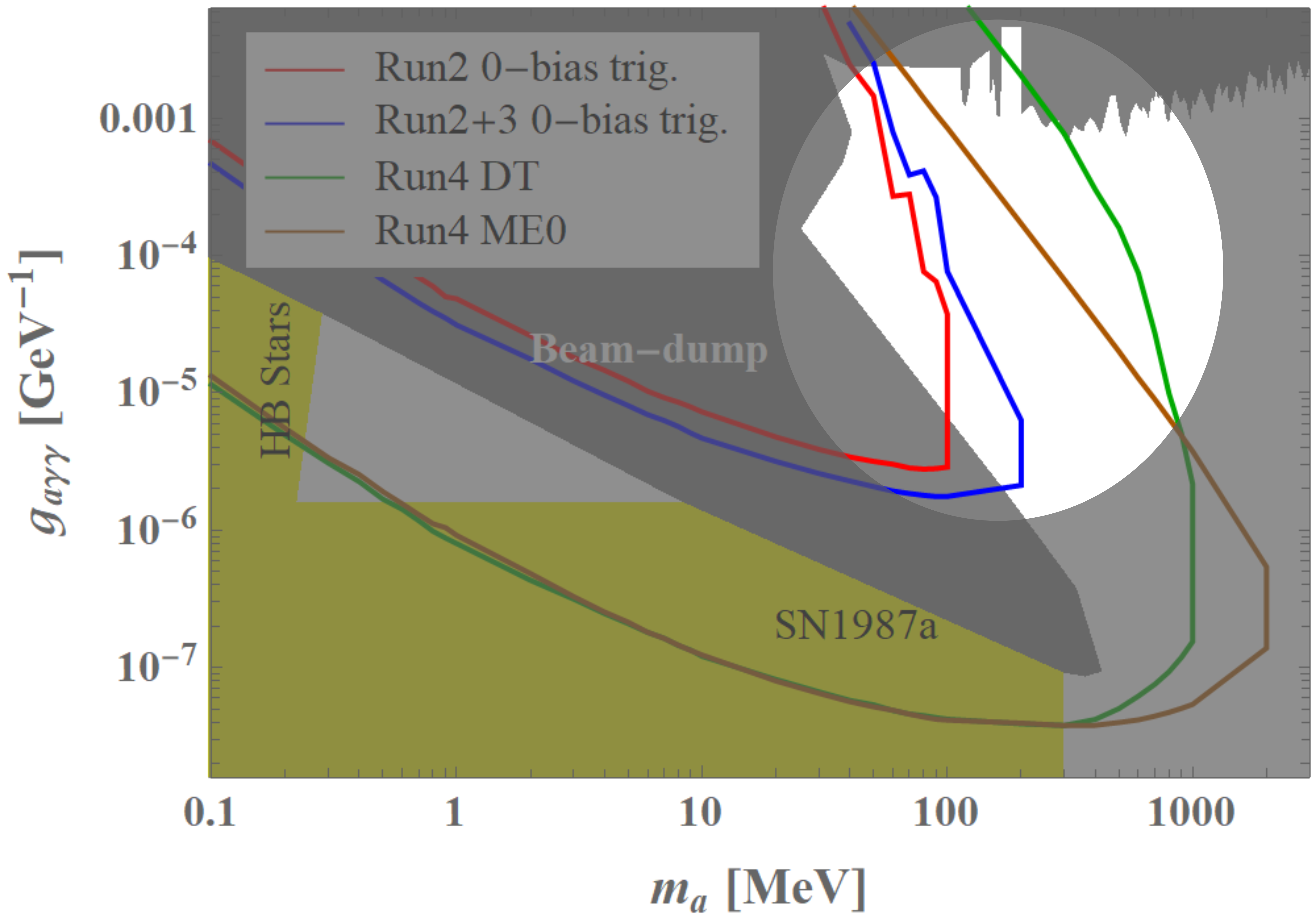
Introduction



- General dark sector search at the LHC
- Light dark sector mediator
- How to go sub-Gev?
- Collider search has limits on the mass and parameter space
- **A Novel Beam Dump Experiment at CMS can explore a unique parameter space**
    - Energetic particles
    - Short detector distance
    - 4 π coverage detector
    - Enormous particle flux

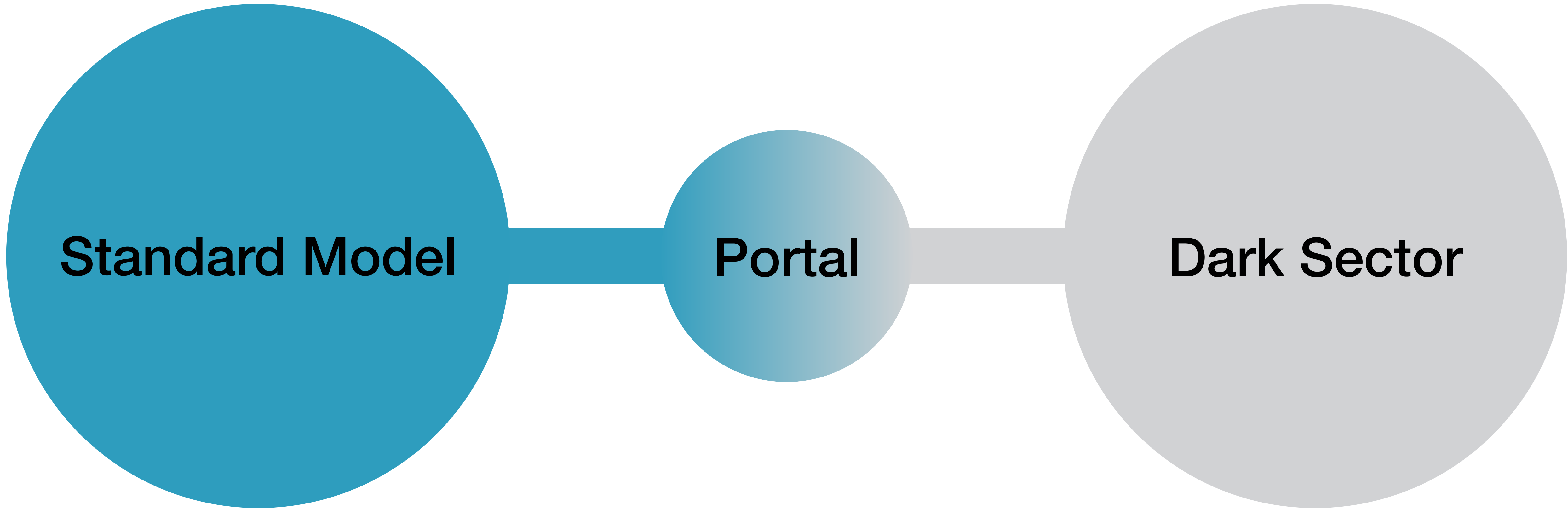
Dark Sector

- The search for dark matter has expanded to include the exploration of the dark sector
- The dark sector provides a framework for new particles and interactions
- The dark sector can solve Standard Model puzzles

Dark Sector Portal

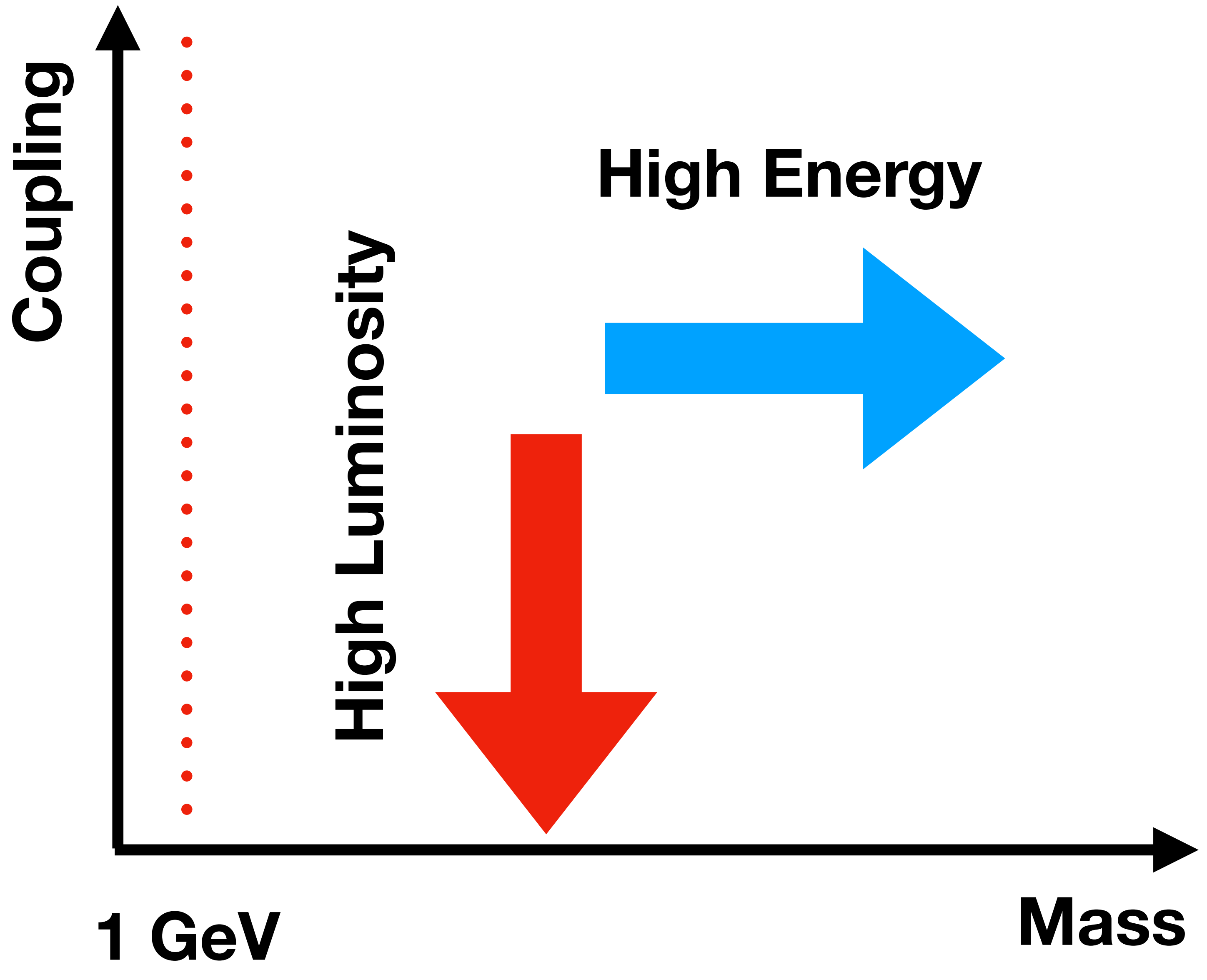
- The dark sector is **very weakly** coupled with new states **via a portal interaction**

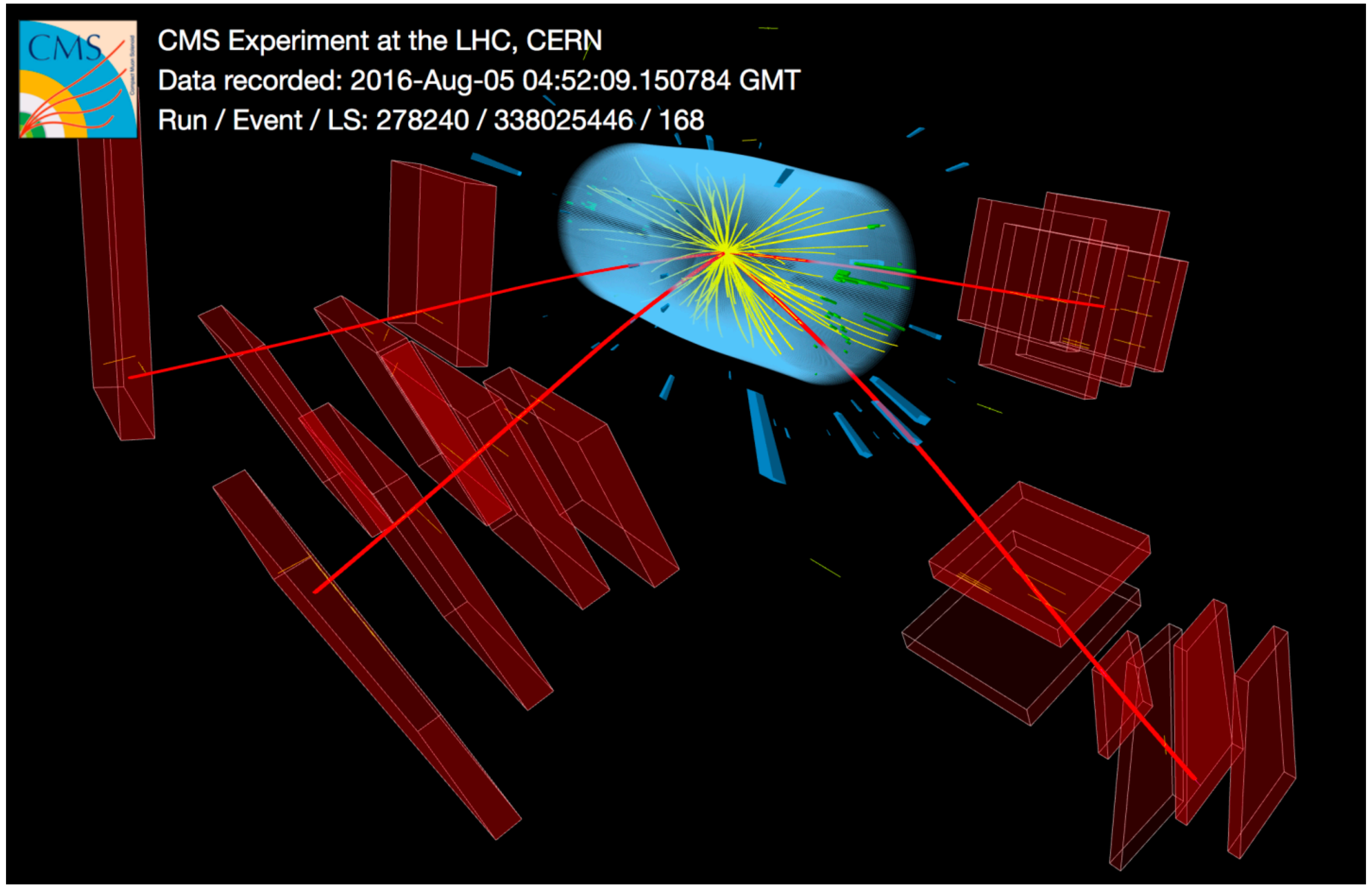
- Higgs portal, vector portal, ALP portal, neutrino portal …



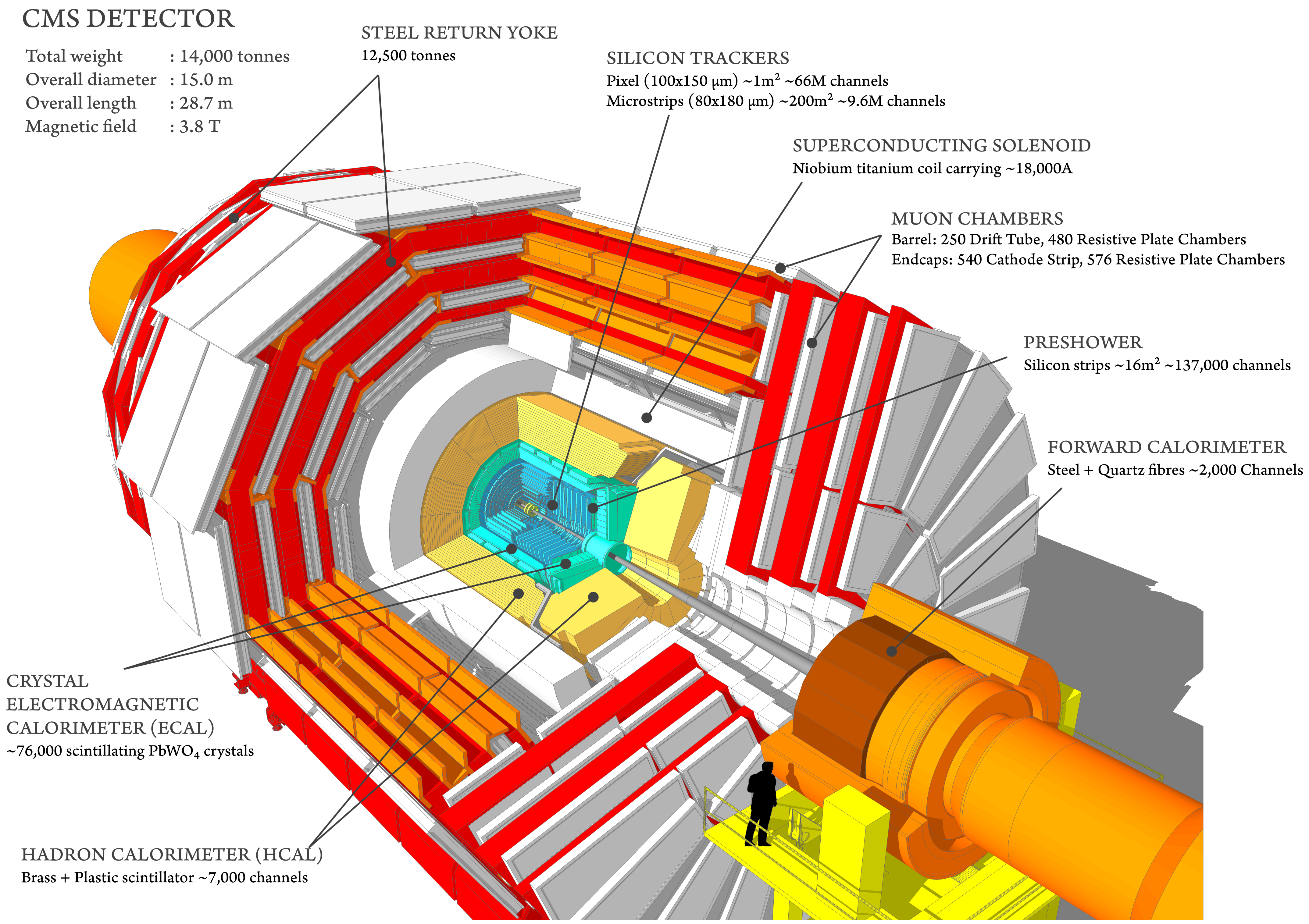
Dark Sector Research at the LHC

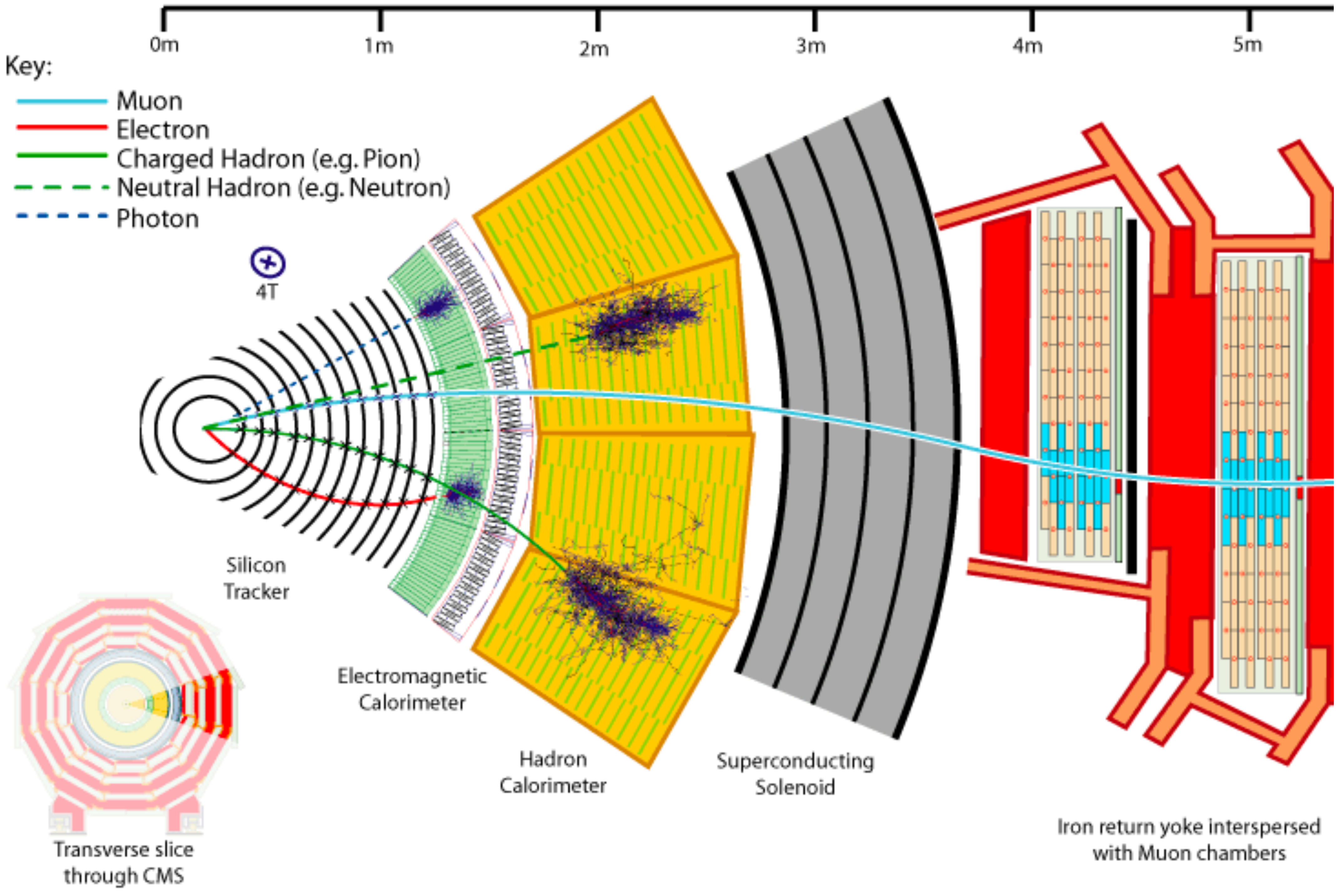
- **The LHC is a Higgs factory**
- Higgs portal
  - A simple extension of the Standard Model
- Energy frontier experiment
- HL LHC





Compact Muon Solenoid (CMS) Detector

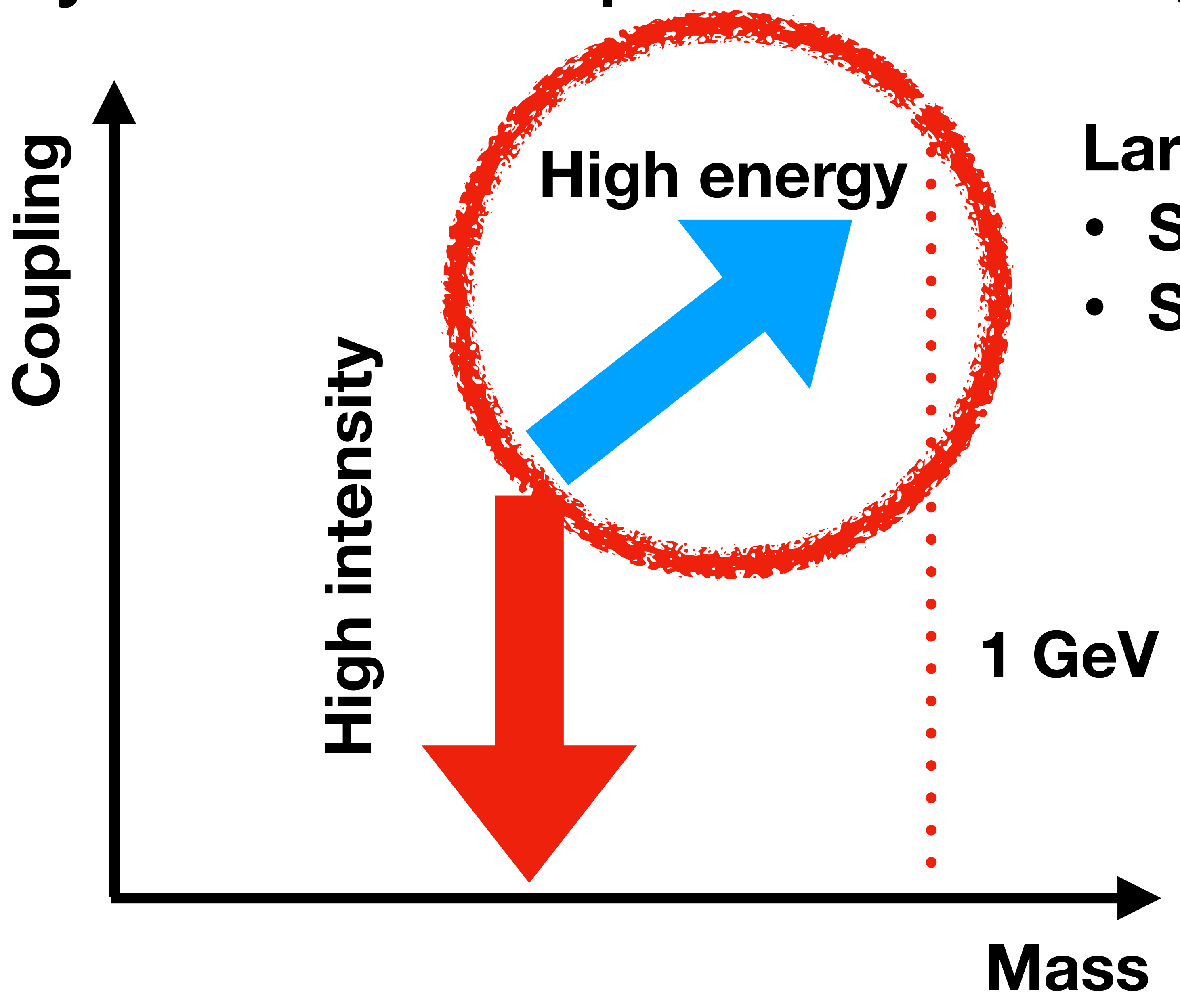




Beam Dump Experiments

- Background
  - MeV scale
  - The dark sector portal has very weak interactions

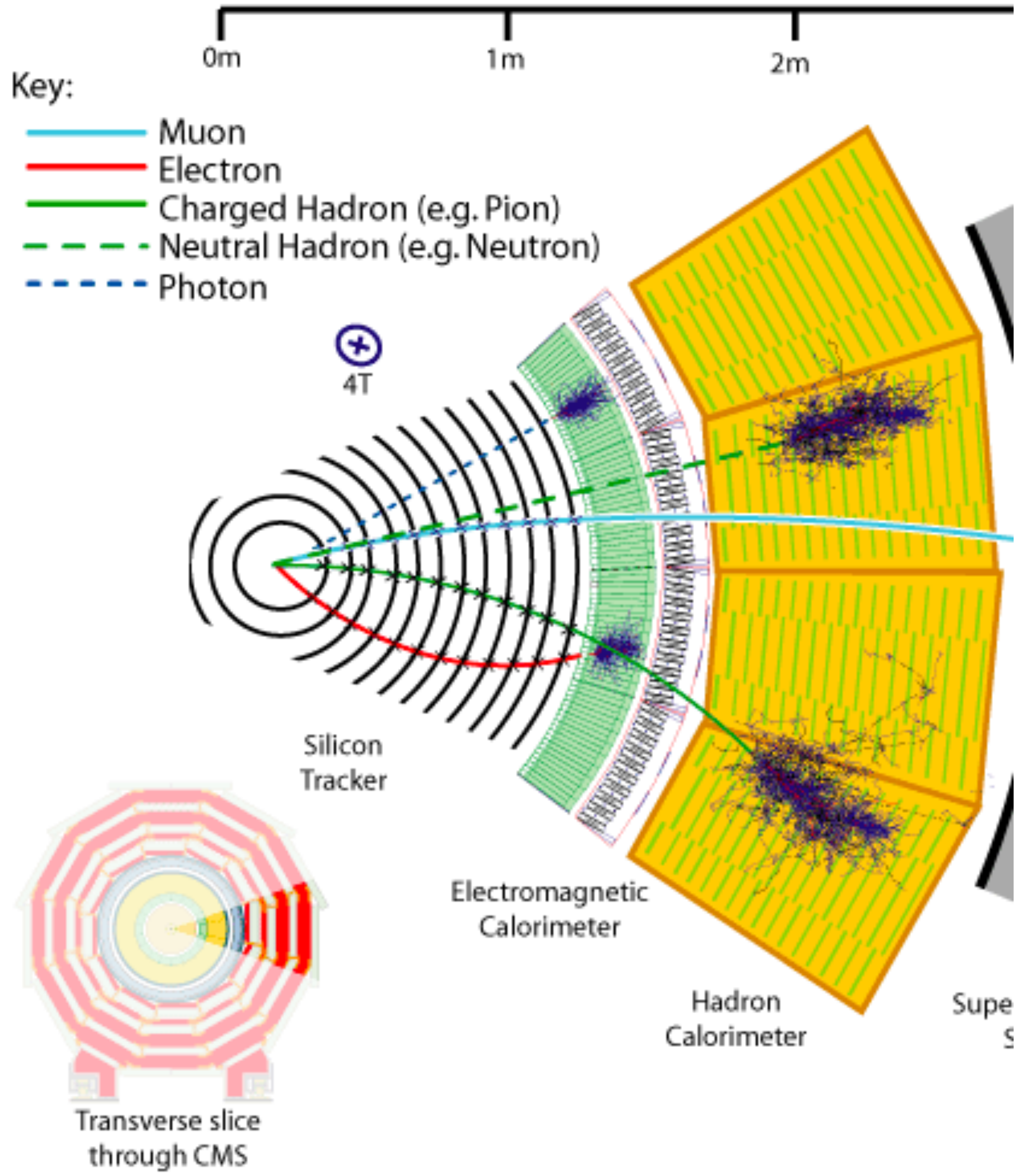
⇒ Intensity frontier experiments e.g. beam dump experiment



Larger coupling (short lifetime)
- **Significantly boosted**
- **Short detector distance**

A Novel Beam Dump Experiment at CMS

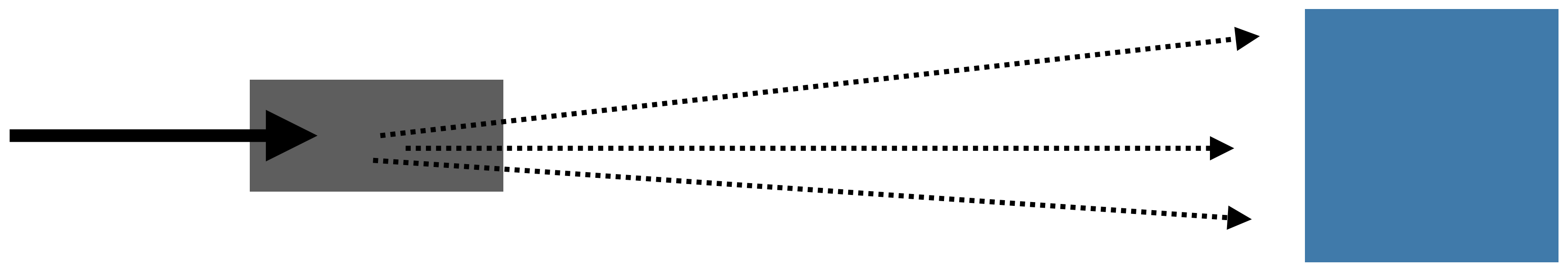
- In the CMS calorimeters, a huge number of **photons**, electrons, and charged mesons are created
- It means there are many collisions → still these collisions are the source of the new physics
- **Yes, we can do a beam dump experiment!**
- **A general search for the dark sector**



Beam Dump Experiments

Beam Dump

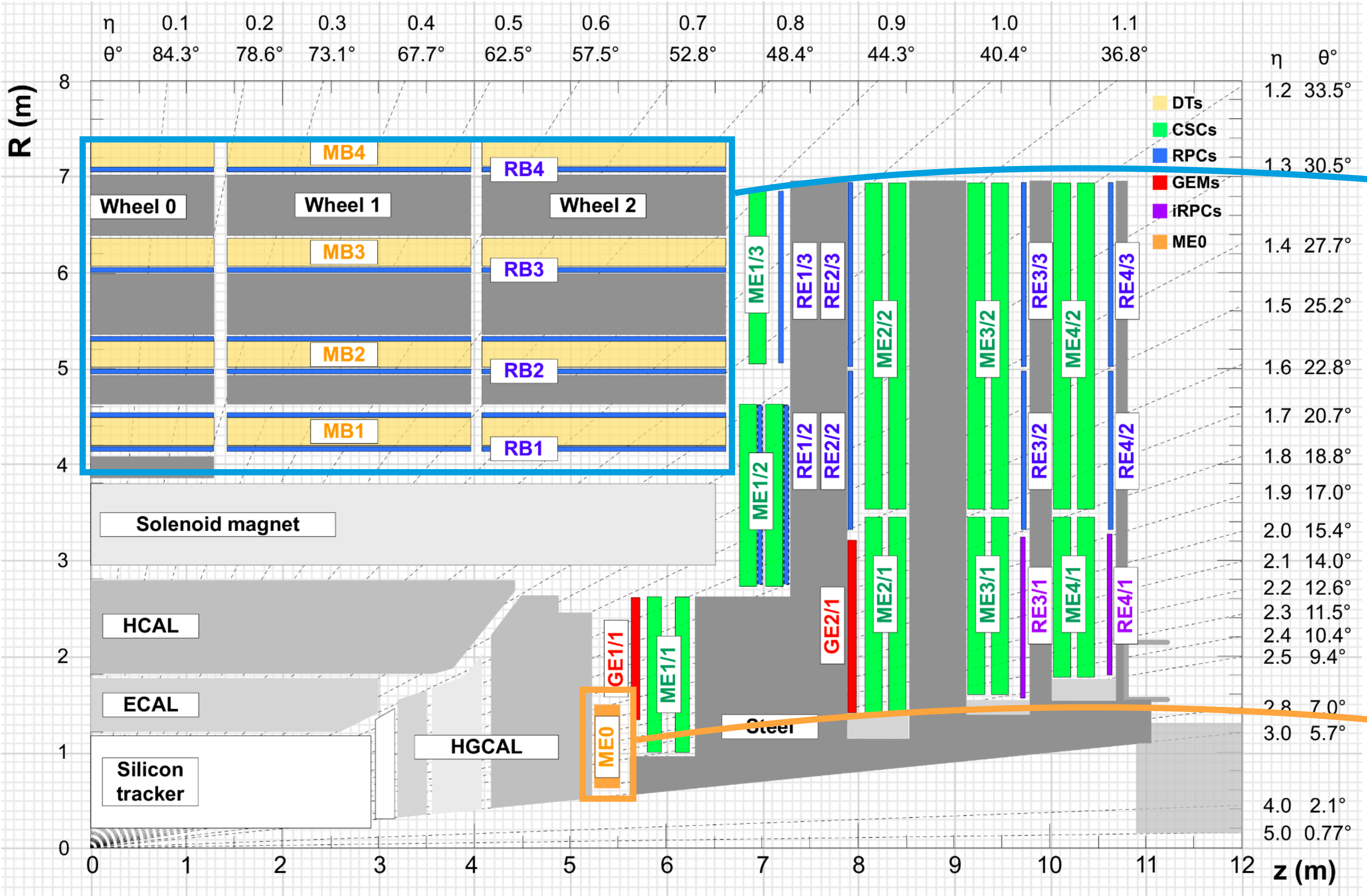
- Low energy beam ~ 1–100 GeV
- High intensity beam ~ 10^{20}–10^{23}/year
- Long distance detector ~ 0.5—1 Km
- Narrow solid angle



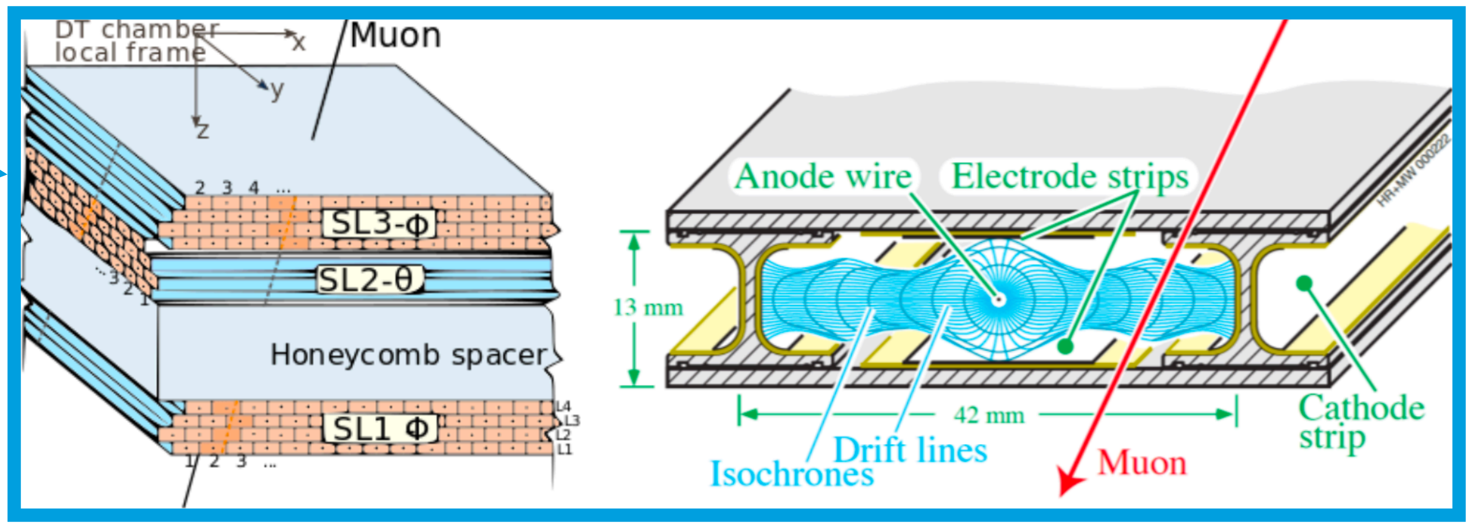
CMS Beam Dump

- 14 TeV collision
  - Energetic photons
  - The total production of photons is enormous
- 4 π coverage detector
- Short distance detector ~ 0.1 m
- **Cover other parameter space**

CMS Muon System

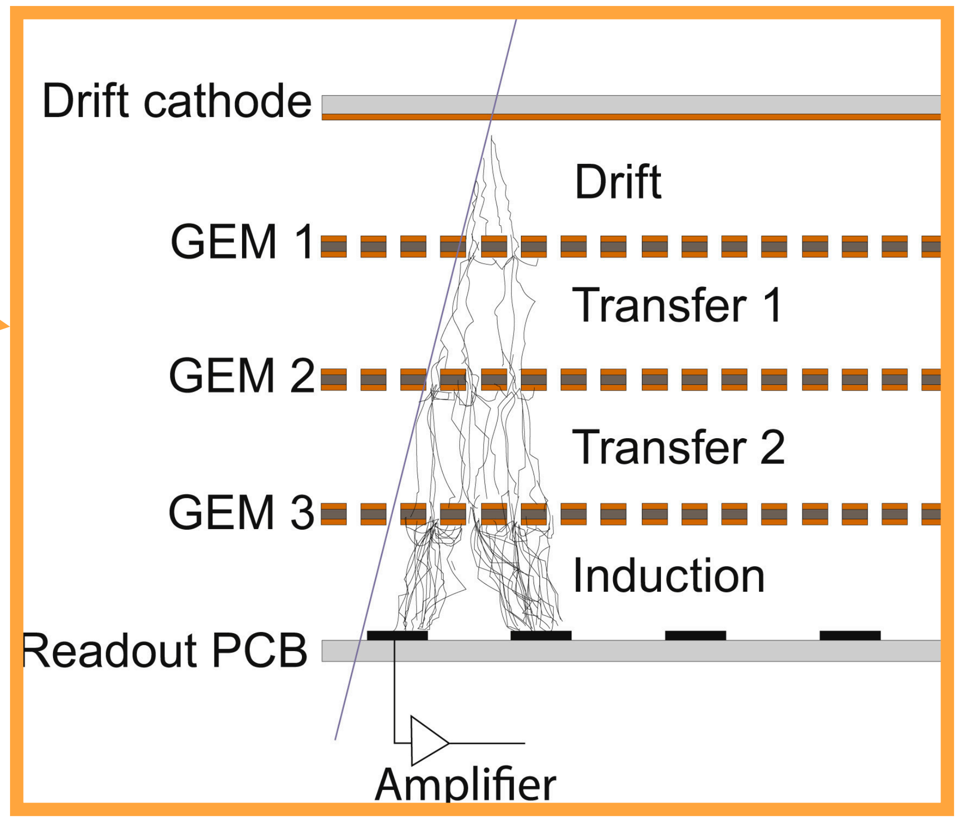


DT



$c\tau$: **2—8 m**

ME0



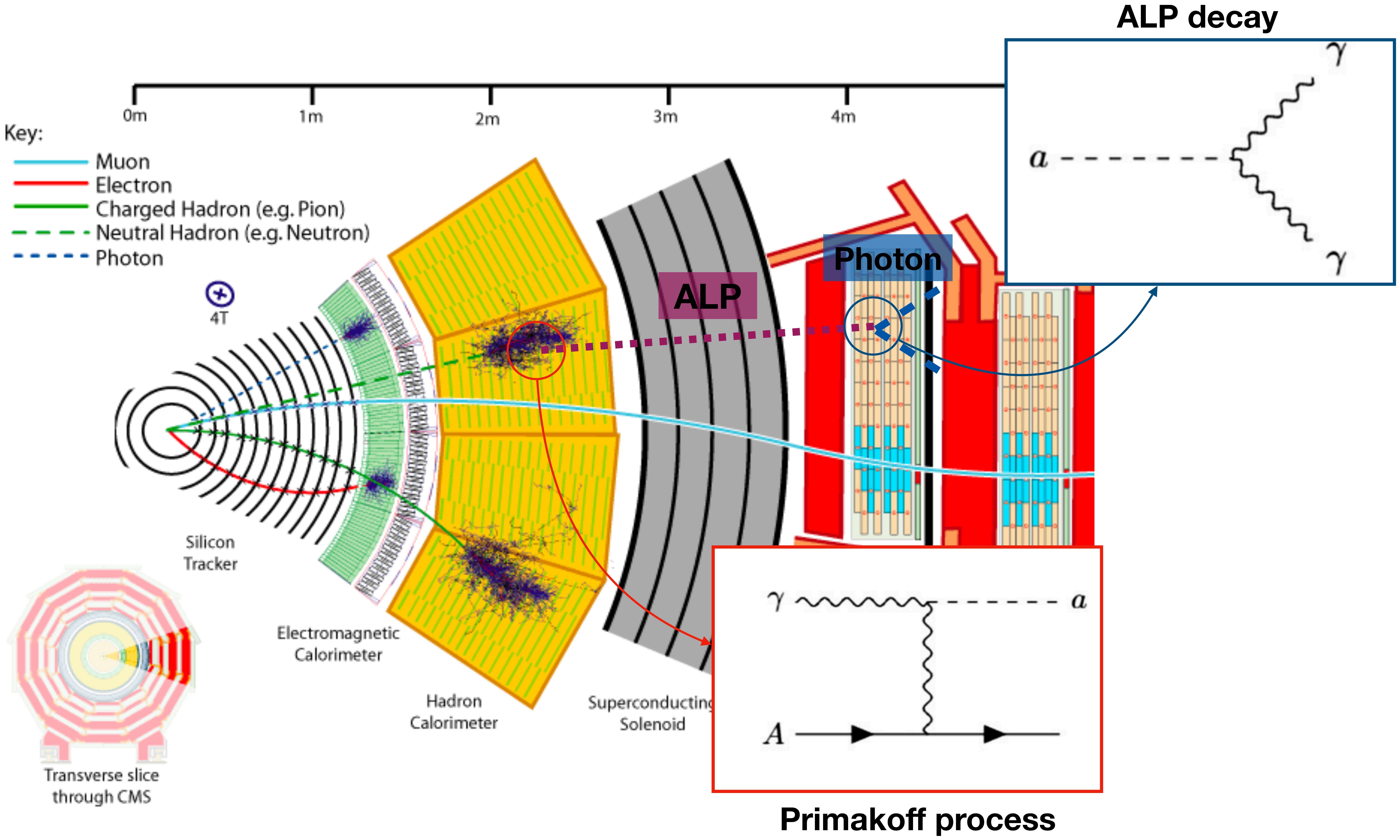
$c\tau$: **0.1—2 m**

ALP

- Axion: clean up the strong CP problem
- ALP (Axionlike particle): similar properties of Axion but pseudoscalar particle
- In particular, we focus on the search for ALP mediators related to photons

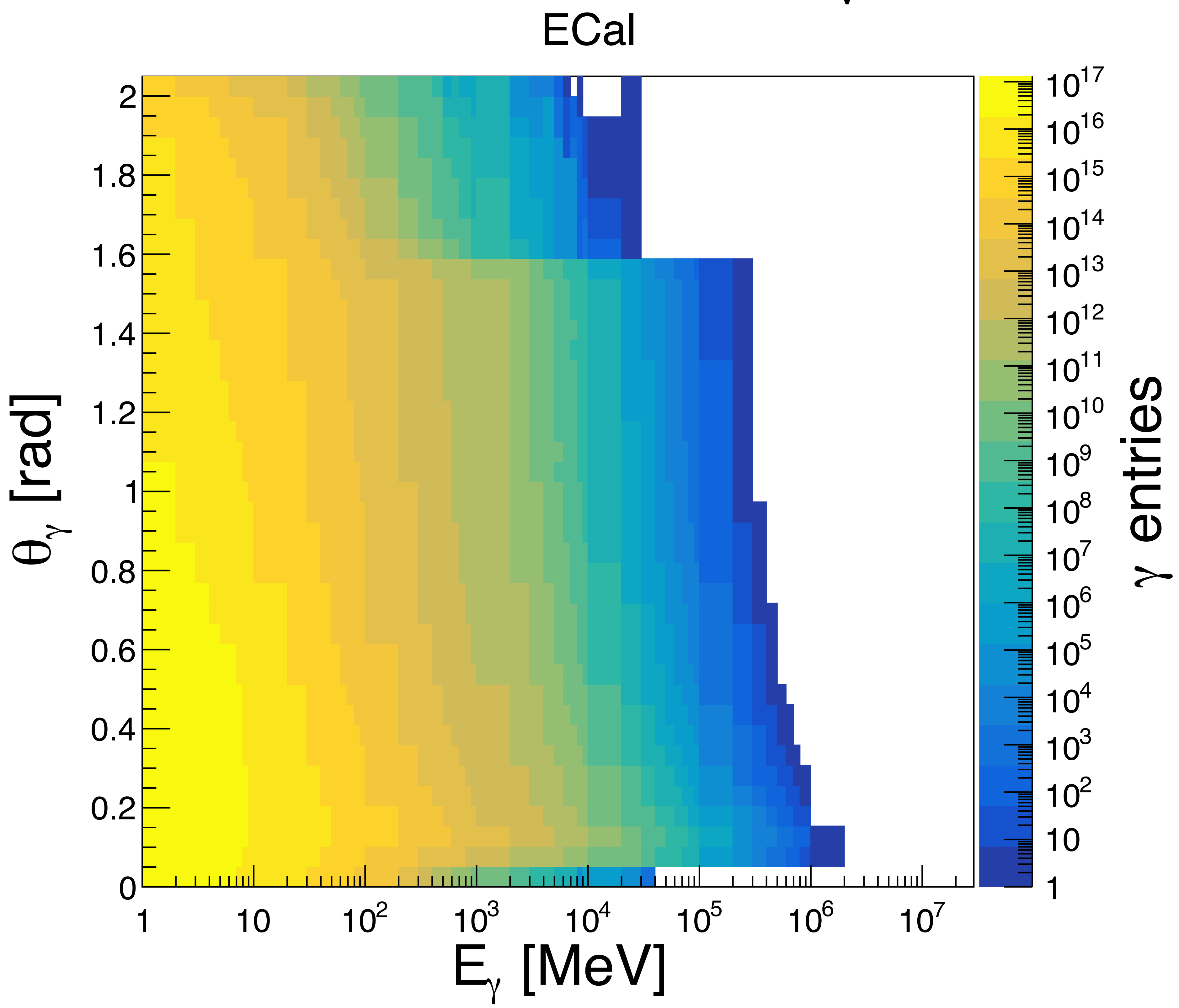
$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

Primakoff Process

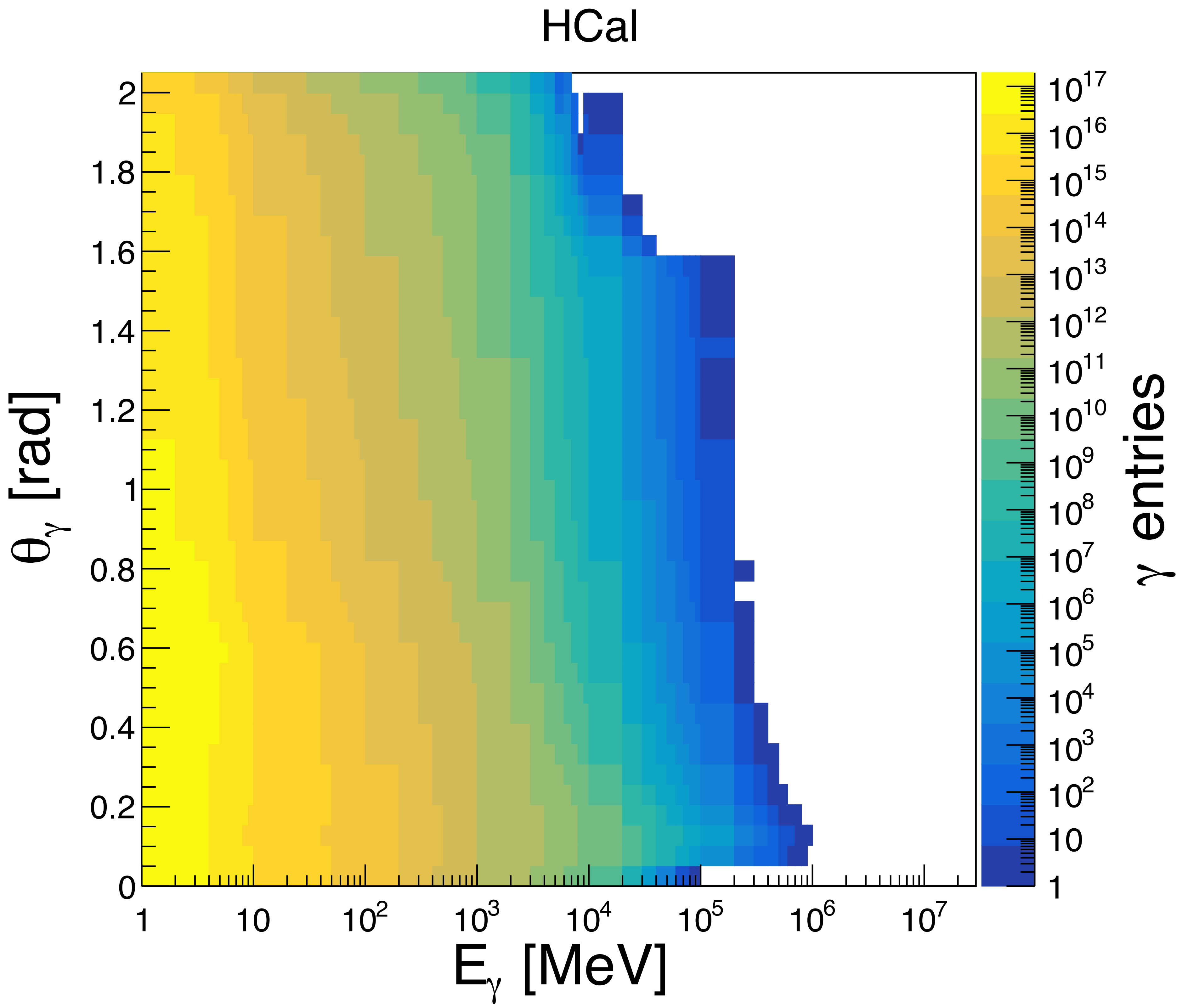


Photon Distributions

$$\sqrt{s} = 13.6 \text{ TeV}, 500 \text{ fb}^{-1}$$



Total 1.1×10^{19} **photons**

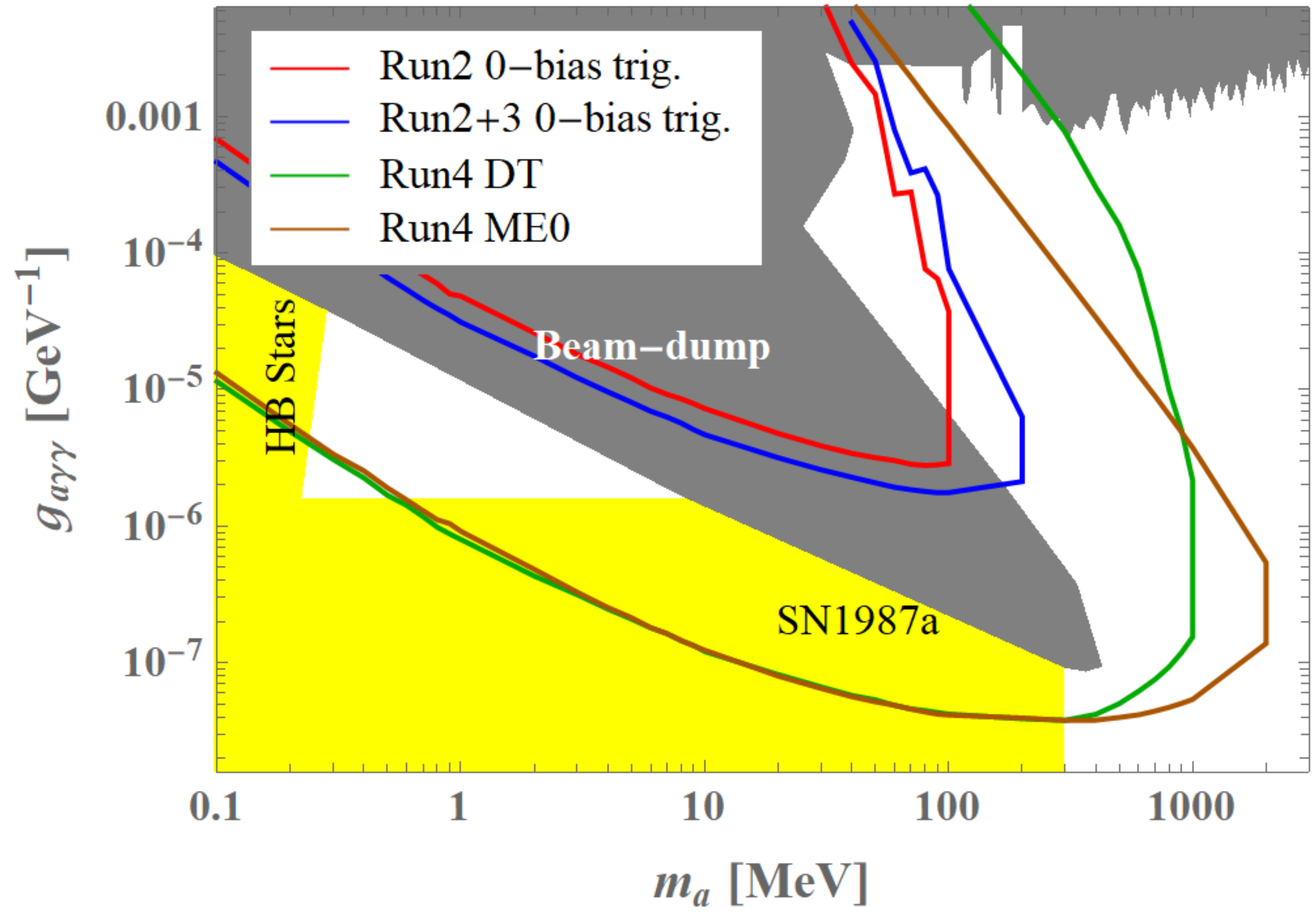


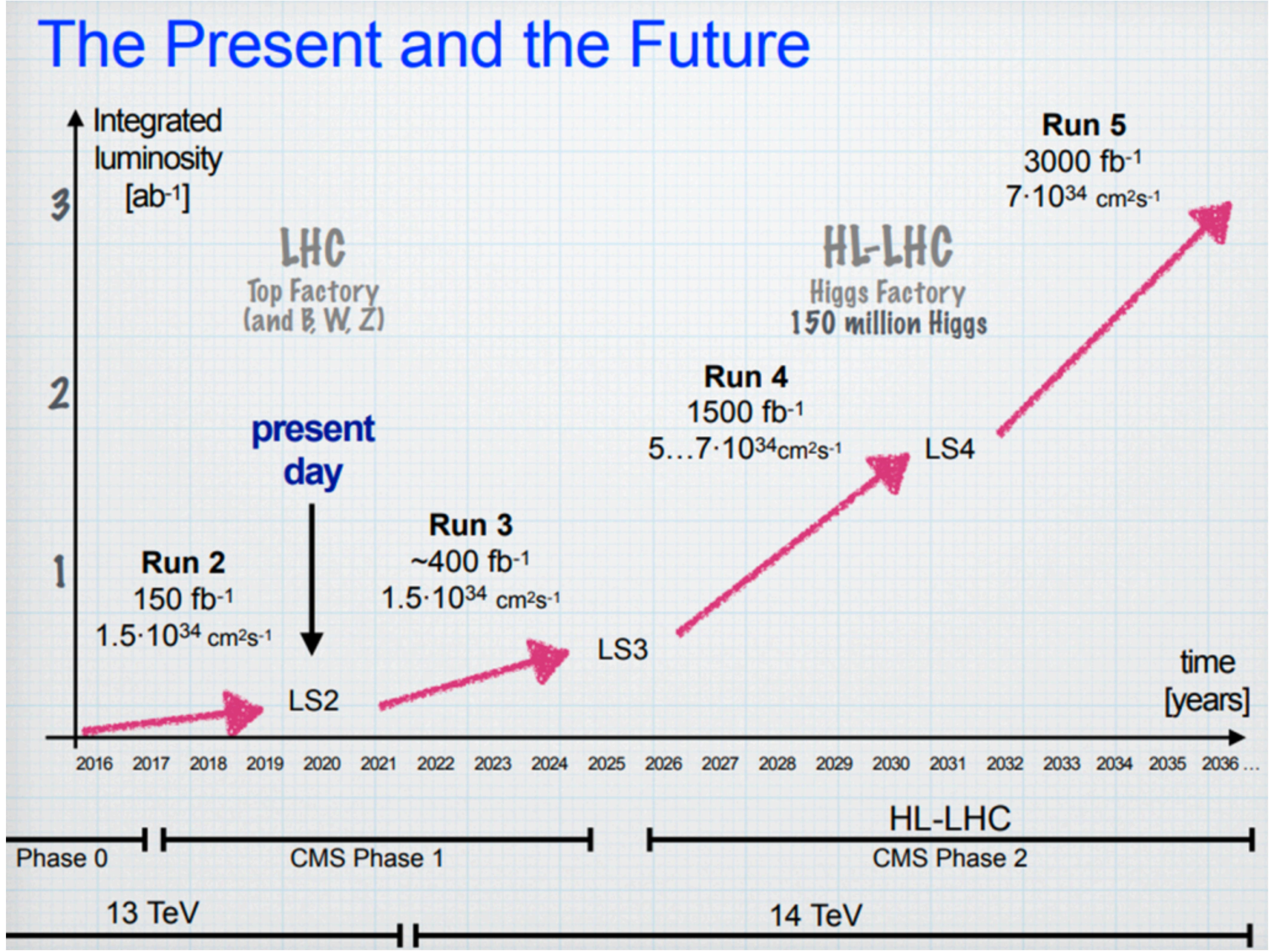
Total 9.3×10^{18} **photons**

Photons are inside jets $(\theta_\gamma < 0.5)$

Theoretical Expect

Expected 90% CL limits

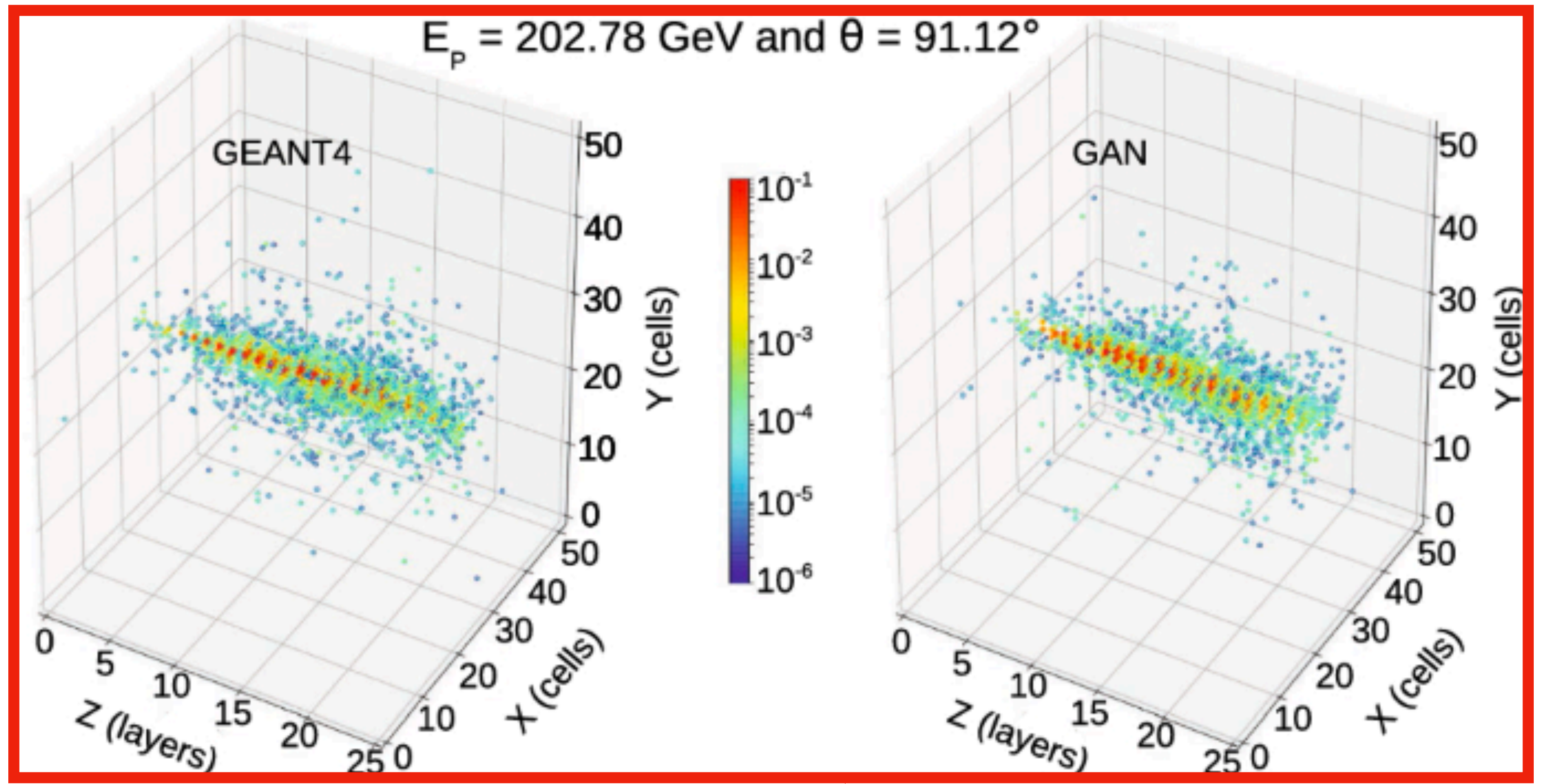




Challenges

- **Signal simulation**
  - How to implement the new concept of physics process in the calorimeter and muon system simulation
- **Trigger**
  - How to make dedicated triggers

Signal Simulation



- Signal simulation is important
  - To understand the signal feature
  - Reconstruction efficiency
- Regular simulation chain
  - Collision event generator → detector simulation → reconstruction

Input any new physics models **Common configuration part**

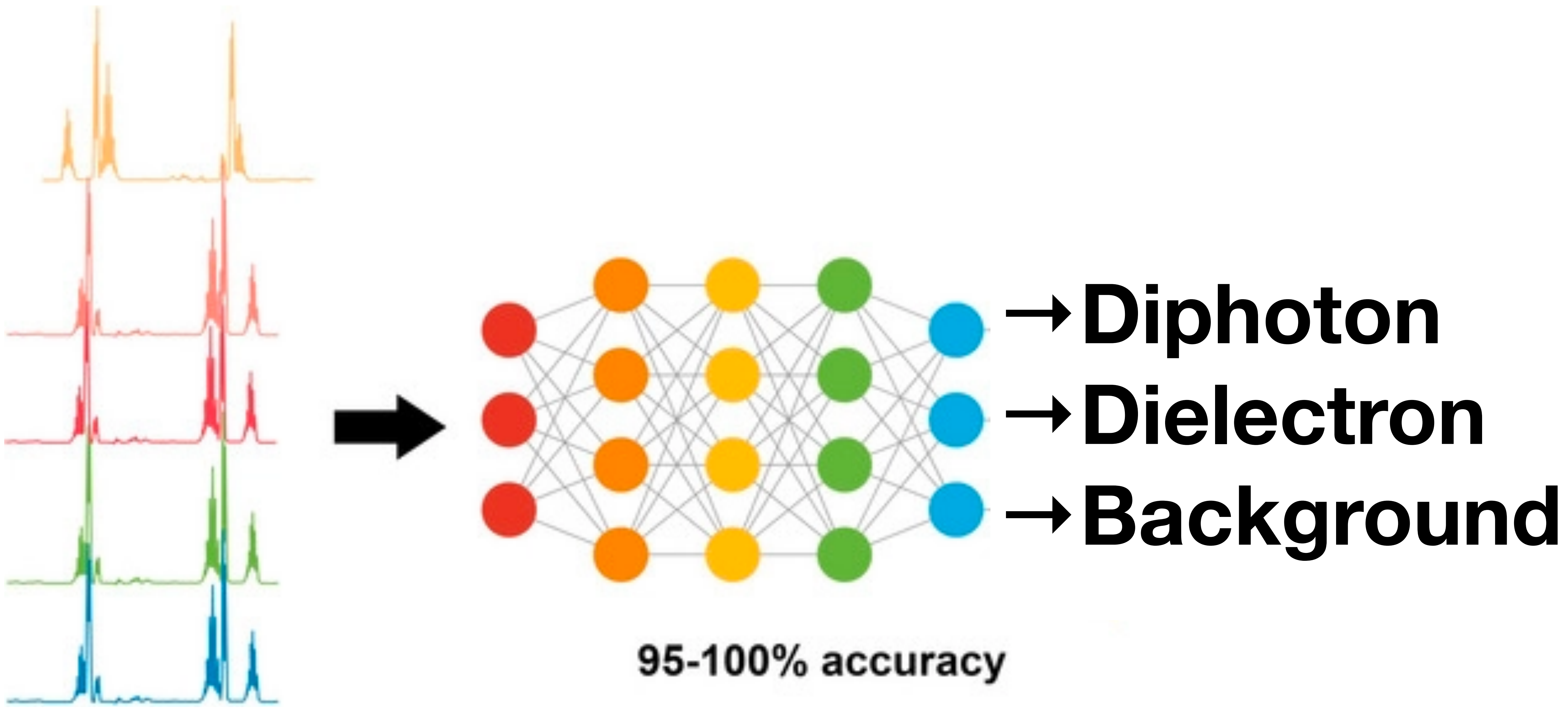
- **New beam dump experiment simulation chain**
  - Collision event generator → detector simulation → reconstruction

Generative Adversarial Network (GAN) ?

ALP Primakoff process and decay **Photon reconstruction in muon chambers**

Signal and Background

- Define signal features
  - Photon and electron efficiency in muon chambers
  - Geant4 and Garfield simulation
  - Extremely displaced dimuon reconstruction efficiency
- Estimate backgrounds
  - Hadron
  - Neutron gas
  - Muon shower

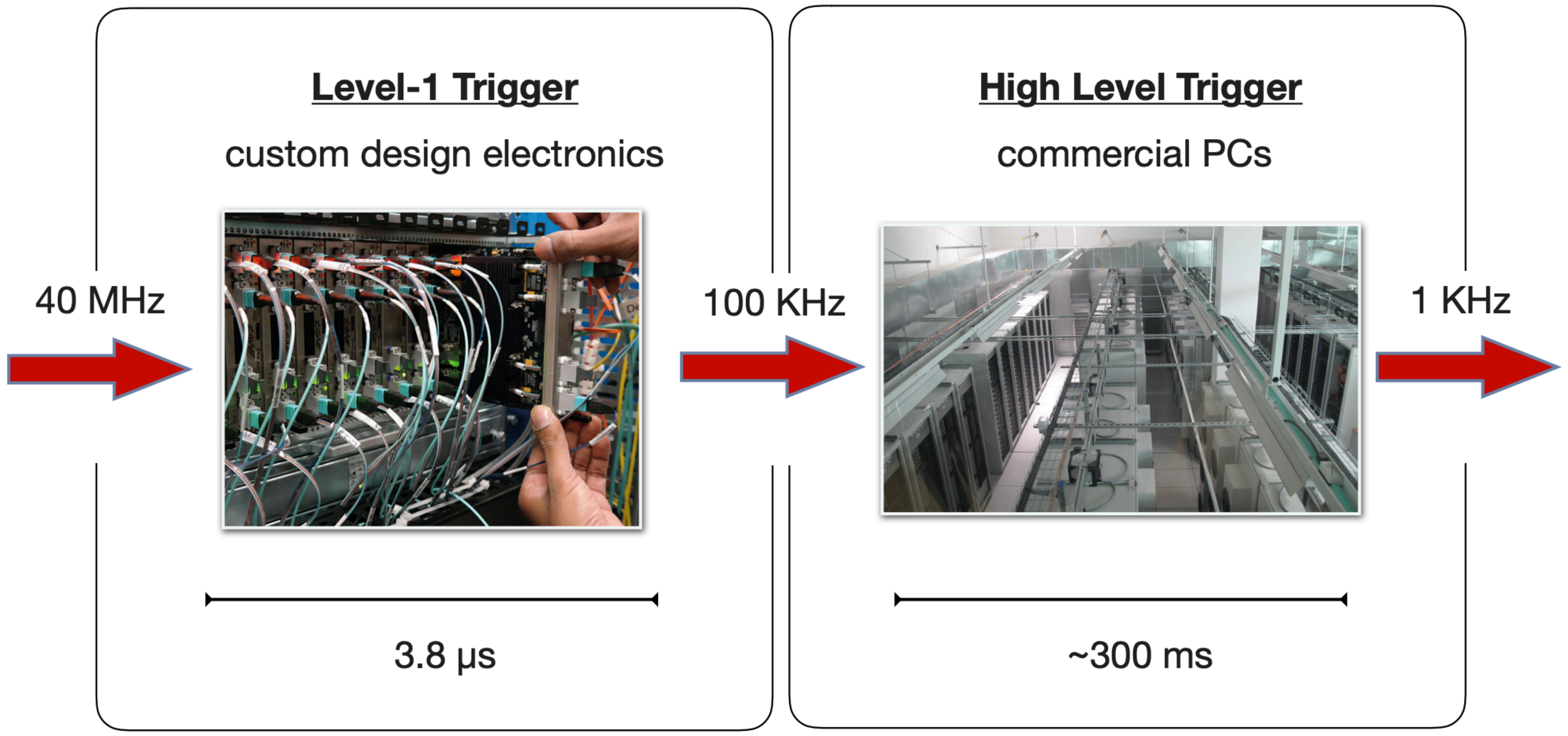


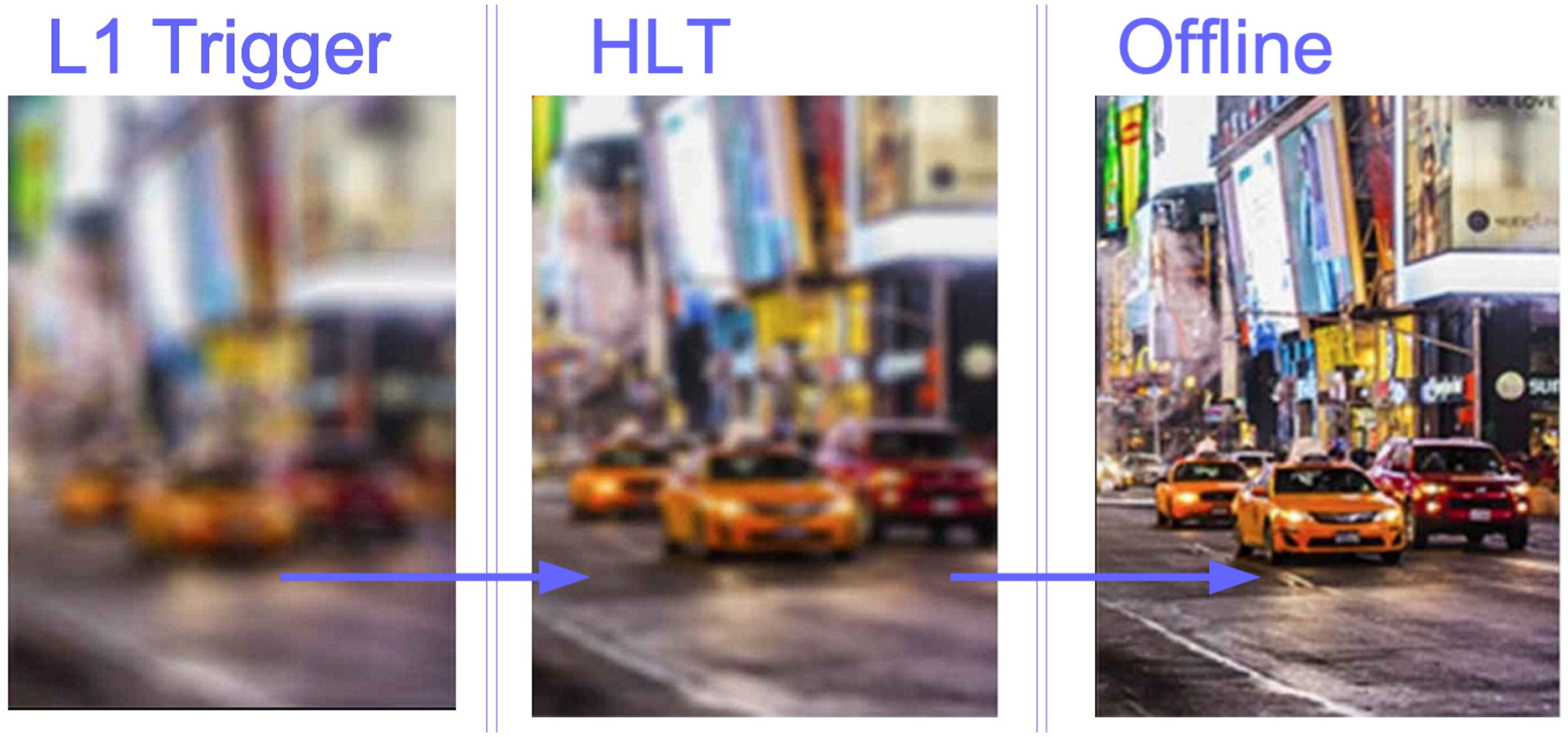
Muon chamber signals

Trigger

- Why is the trigger important?
  - LHC bunch crossing happens every 25 ns (40 MHz)
  - The recording capability is 1KHz
- CMS Trigger
  - Level1 Trigger (100 KHz): latency ~4 μs
  - High Level Trigger (1 KHz): latency ~300 ms
- How to improve
  - ML FPGAs, hardware accelerator reconstruction, and data scouting (a new trigger paradigm)

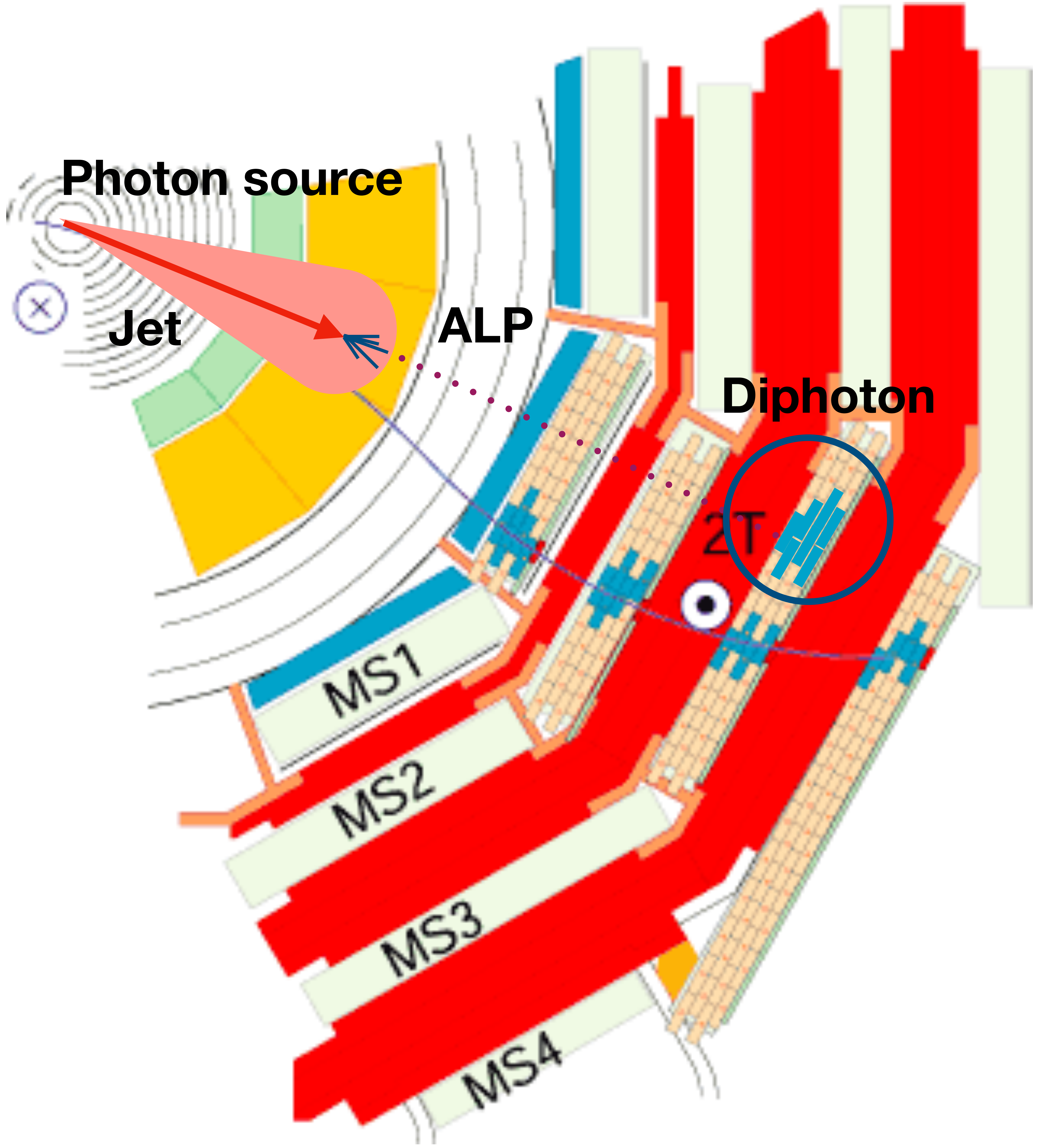
CMS has a 2 tier trigger system





New Trigger Research

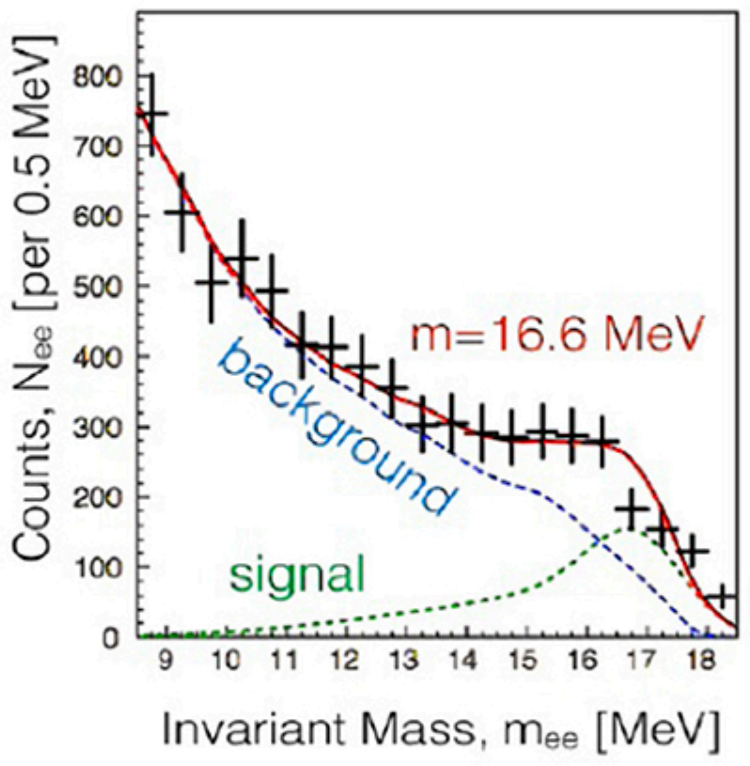
- ~~Muon L1 trigger~~
  - ~~Track finder~~
  - ~~Transverse momentum assignment~~
- Trigger requirement
  - Signal event signature: electron, photon, and **jet** + muon system hits
  - **Machine Learning FPGAs**
- Trigger efficiency
  - Detector efficiency
  - Segment efficiency

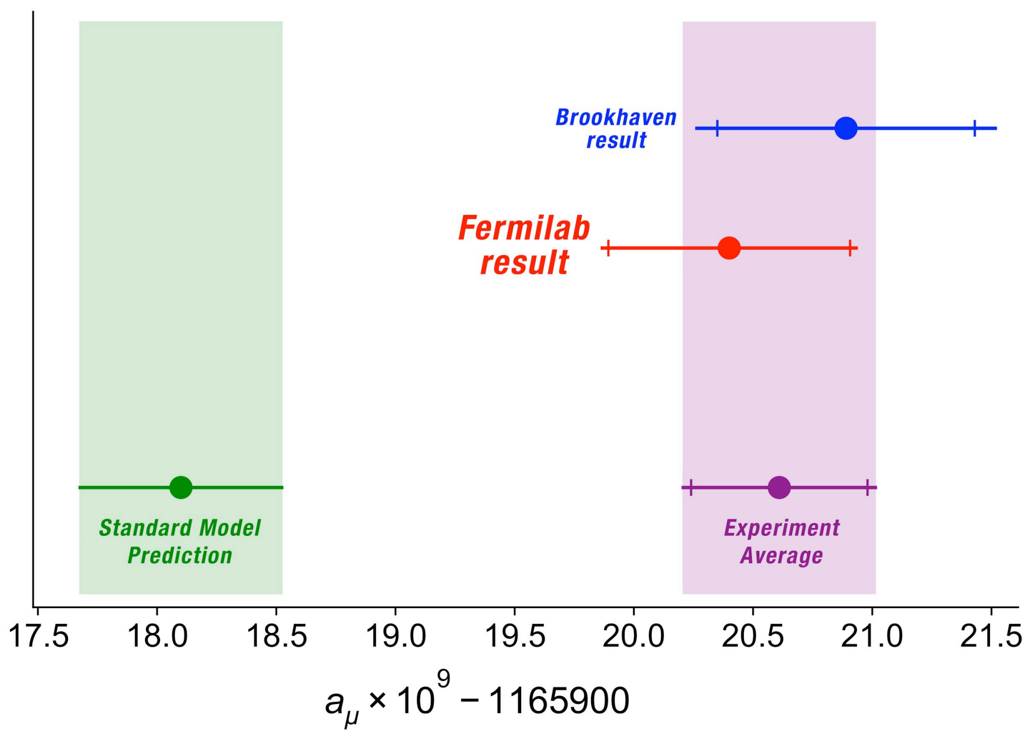


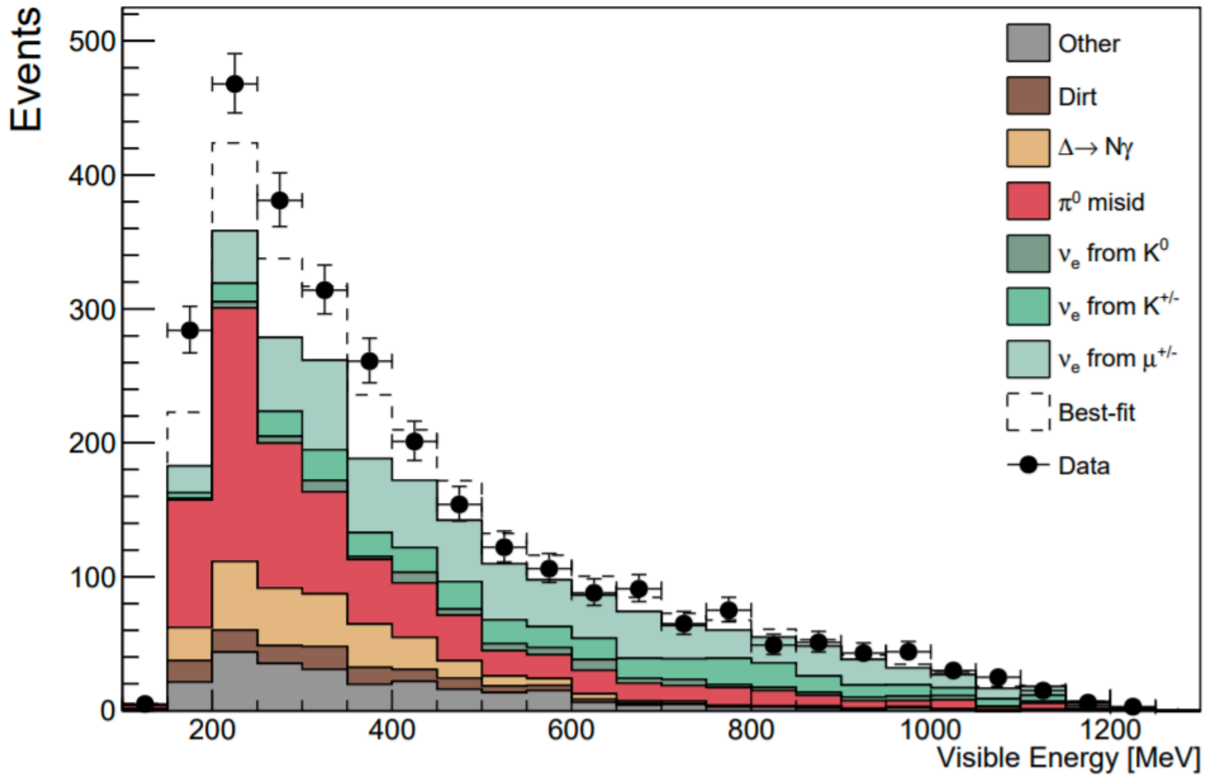
Other Models

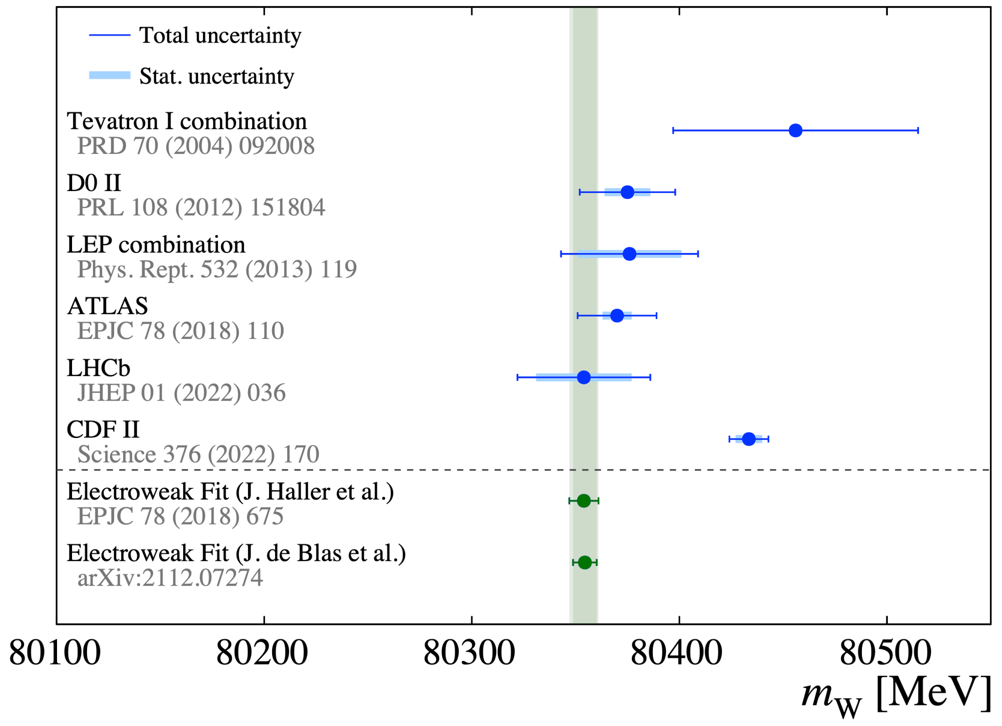
Background:

- **Dark sector**
- **Anomalies: ATOMKI, muon g-2, MiniBooNE excess, and CDF W mass**









ALP (Pseudoscalar) Portal

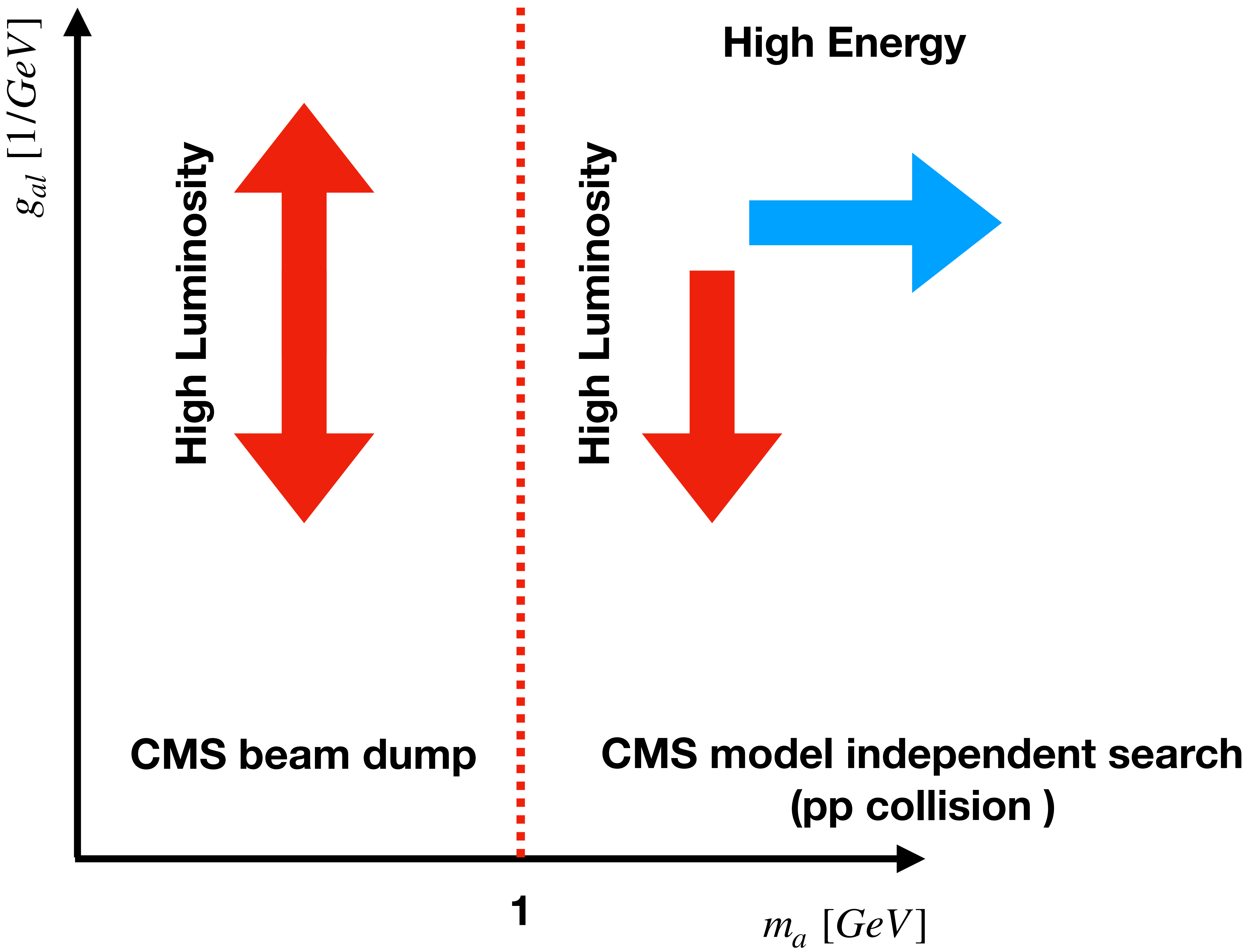
Primakoff process
Compton-like process
Nuclear reactions

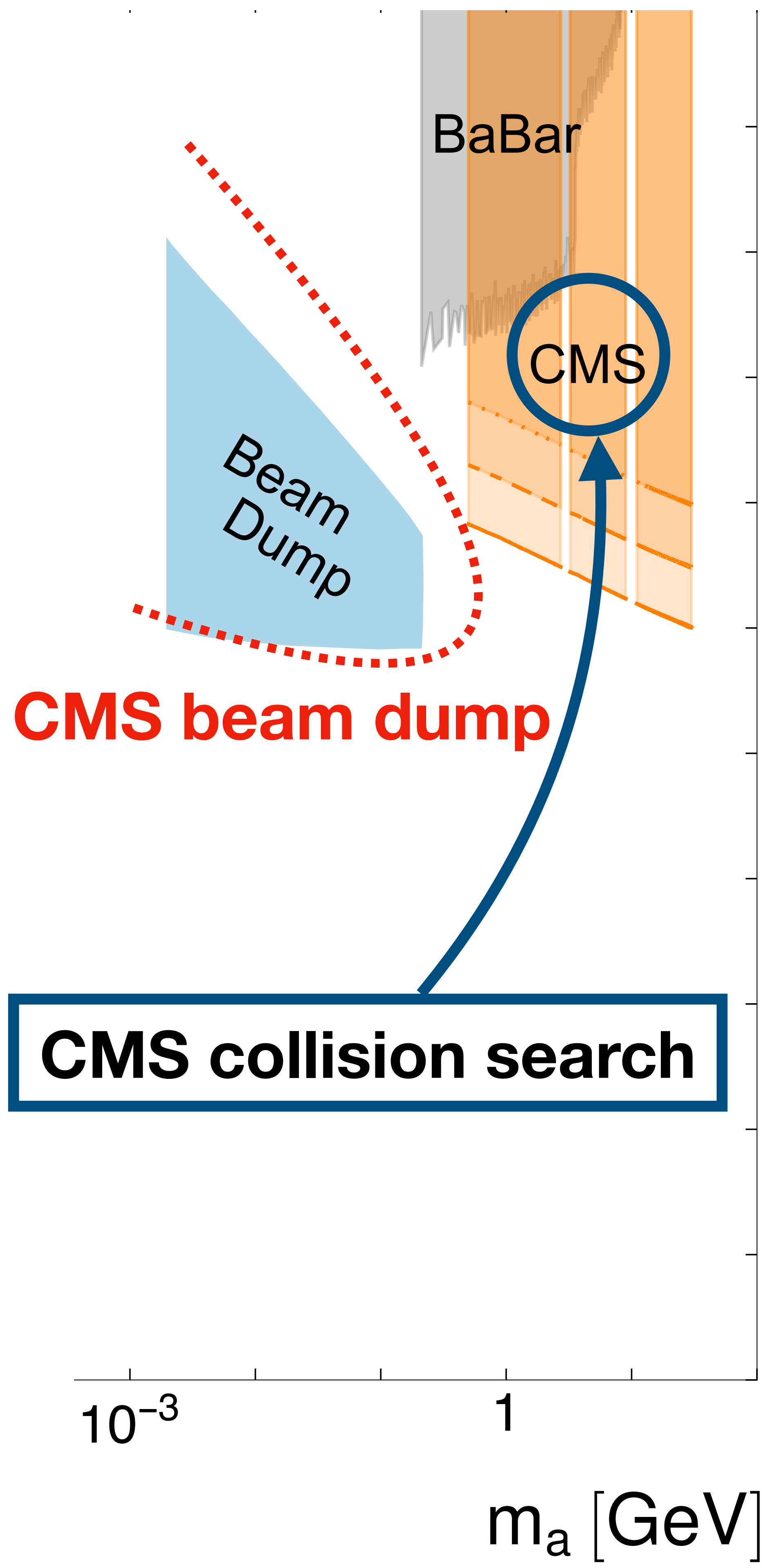
Higgs Portal
Vector Portal
Scalar Portal
Dark photon Portal
Neutrino Portal

Meson decay
Bremsstrahlung
Drell-Yan
SM Neutrino

Detection: Photon, electron, and muon in the muon system

ALP Lepton Channel





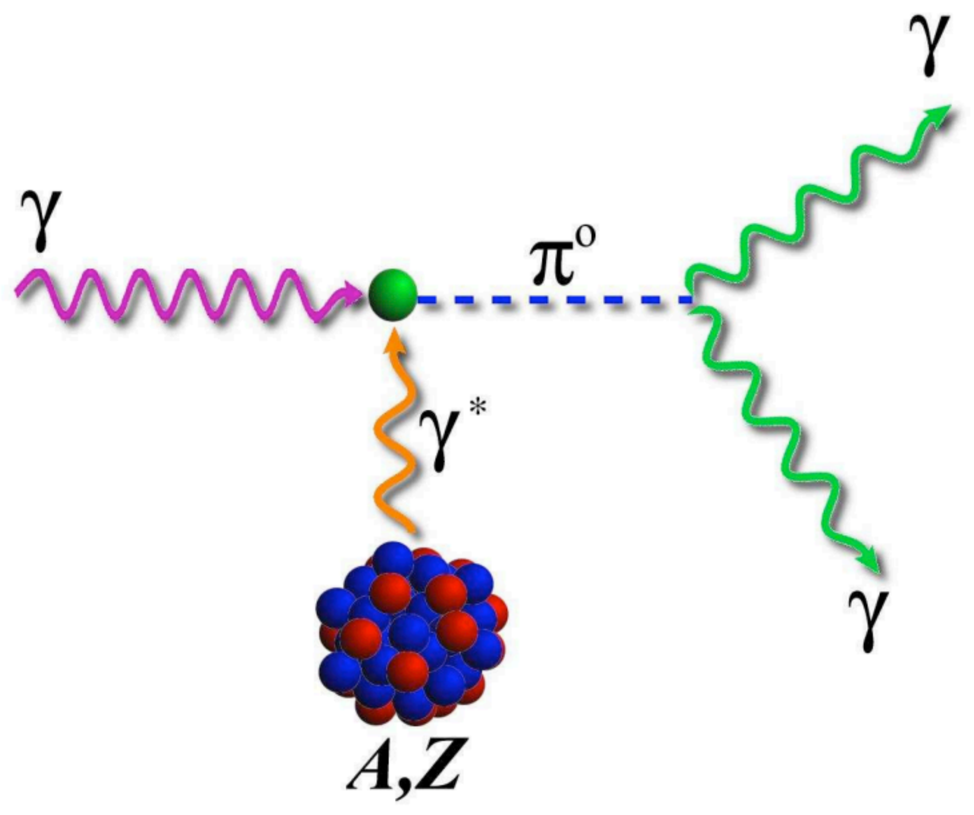
CMS beam dump experiment + collision search (Higgs portal) covers a large mass range of 1 MeV to 60 GeV

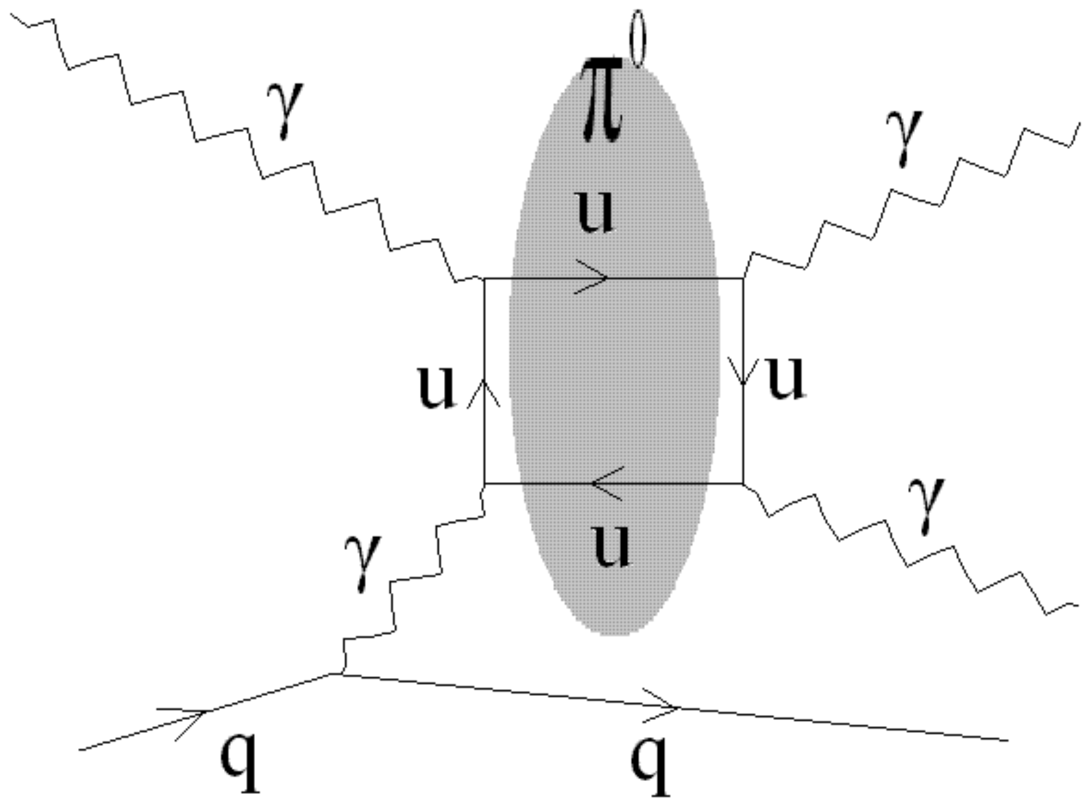
Summary

- The dark sector is very weakly coupled with new states via a portal interaction
- LHC search has limits on the mass and parameter space
- General search for the dark sector is feasible within the context of LHC experiments using a beam dump-like experiment
- A novel concept of beam dump experiments at CMS
- **Theoretical expectations suggest that the CMS beam dump experiment can explore a unique parameter space**

Backup

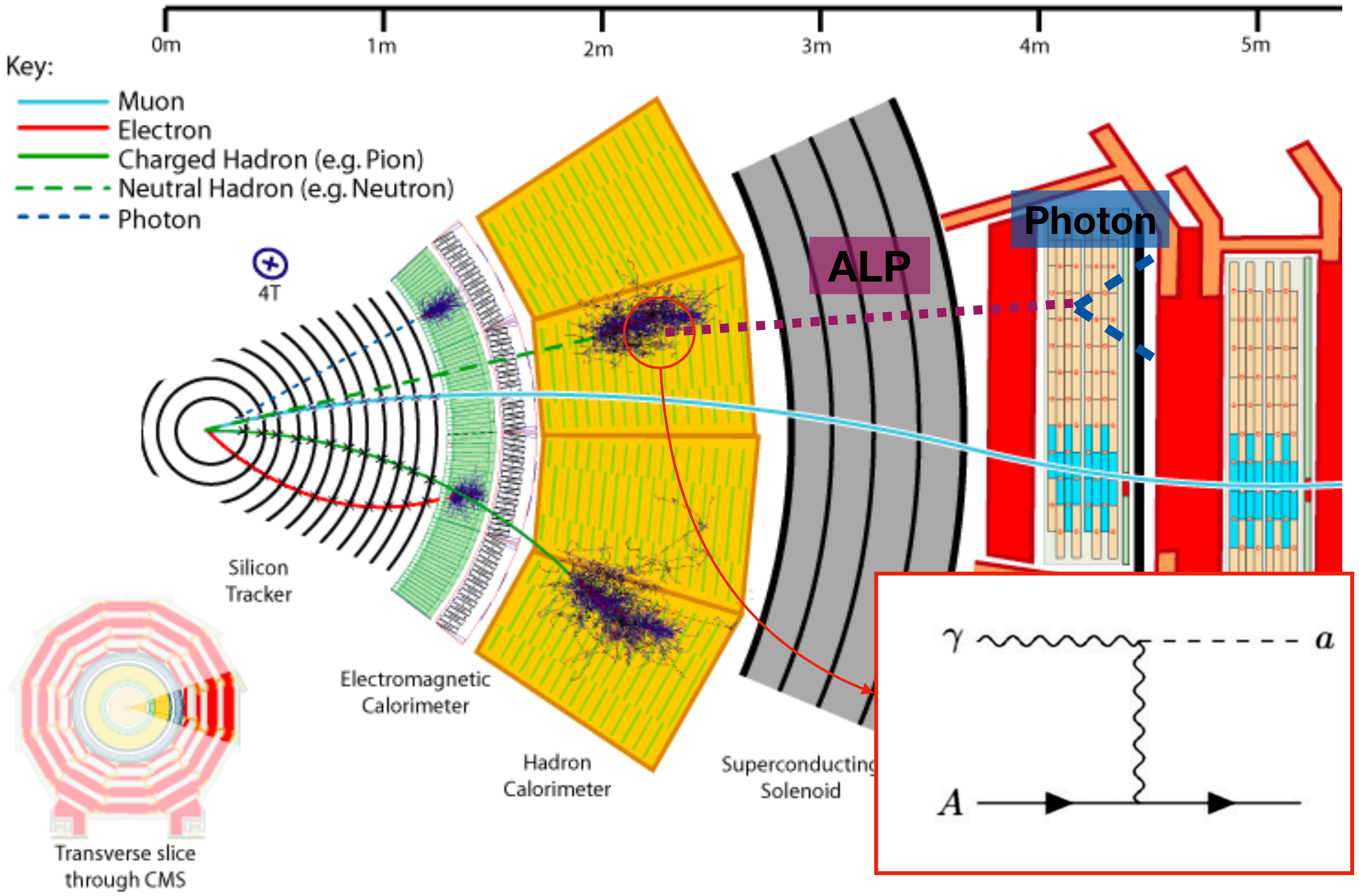
Primakoff Process





In particle physics, the Primakoff effect, named after Henry Primakoff, is the resonant production of neutral pseudoscalar mesons by high-energy photons interacting with an atomic nucleus. It can be viewed as the reverse process of the decay of the meson into two photons and has been used for the measurement of the decay width of neutral mesons.

Primakoff Process



A generic model where the ALP field can couple to a photon as described by interaction terms in the Lagrangian of the form

$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu}$$

$$\frac{\partial^2 \sigma_P}{\partial \theta'_a \partial \phi'_a} = \frac{g_{a\gamma}^2 \alpha}{8\pi} \frac{p_a^4}{q^4} \sin^3 \theta'_a F^2(q)$$