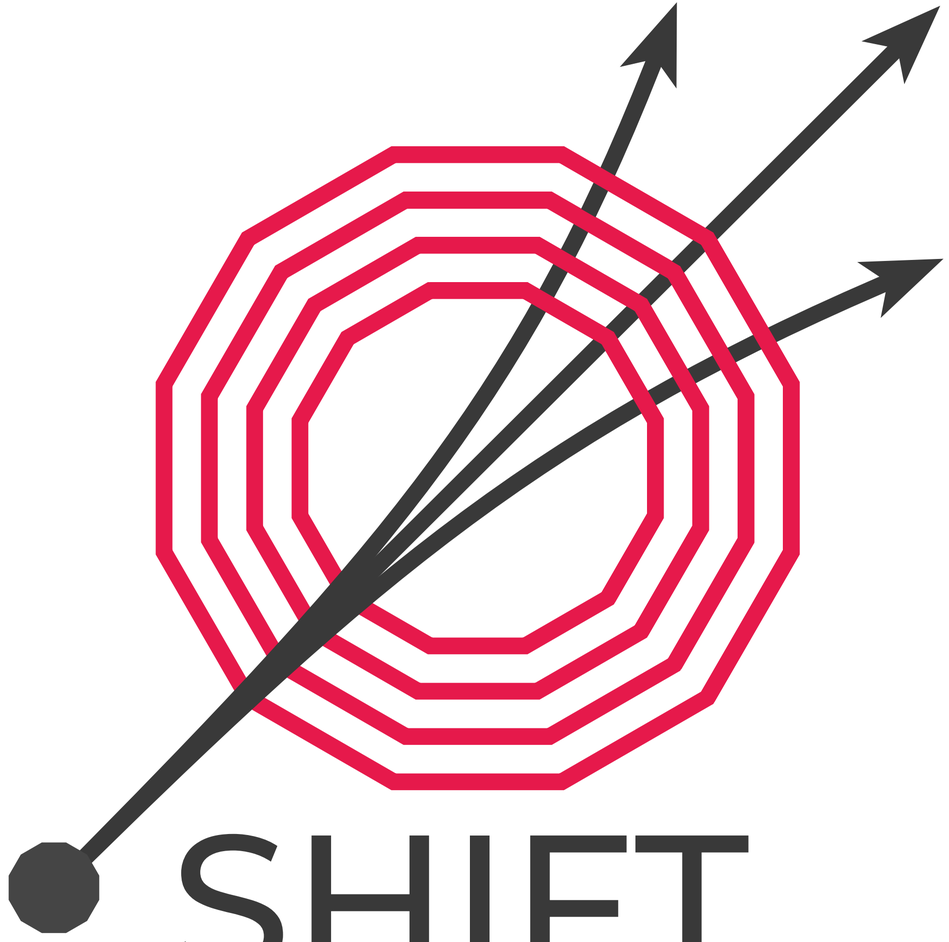
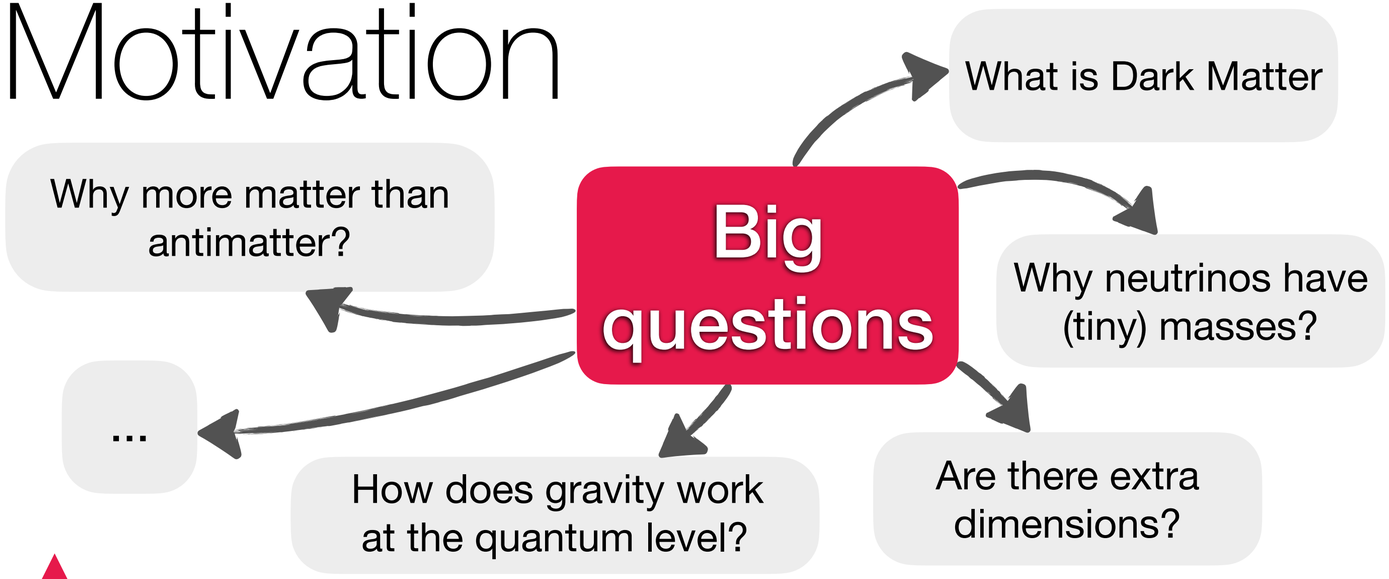


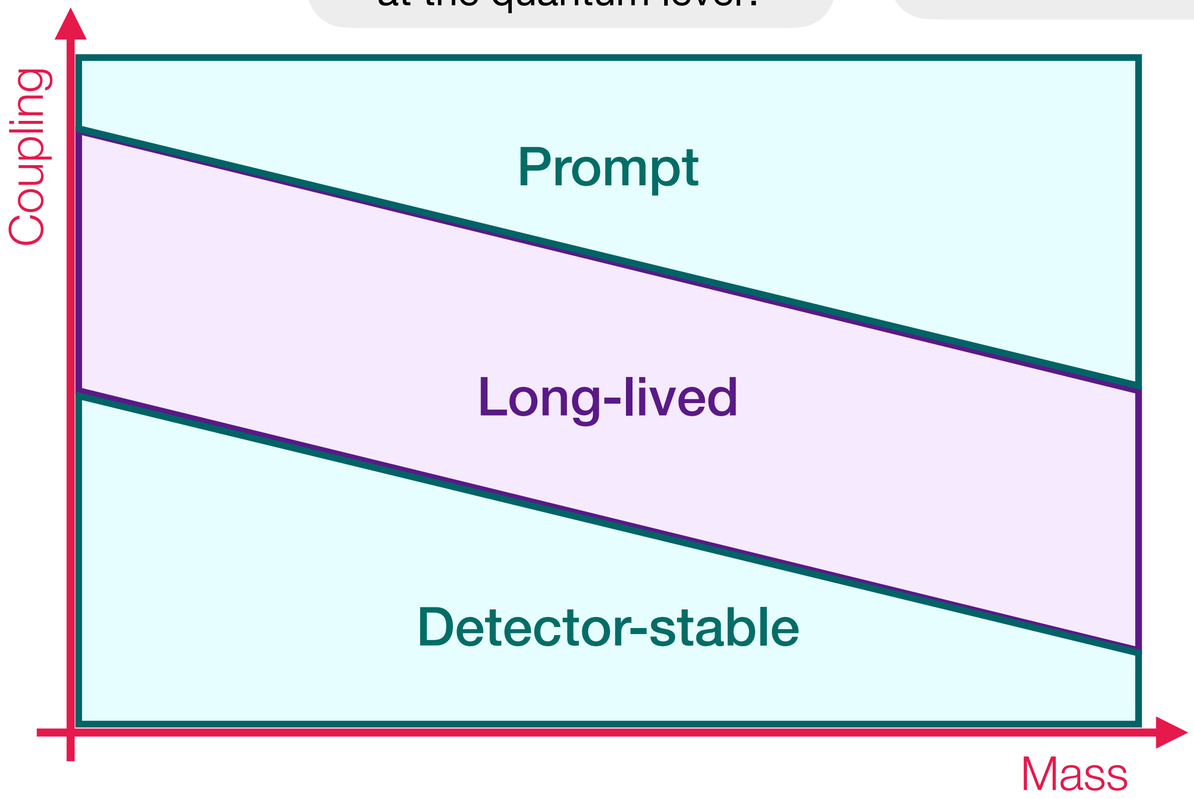
Shifted Interaction on a Fixed Target at the Large Hadron Collider

IIHE Seminar
18/06/2026

Jeremi Niedziela

Motivation



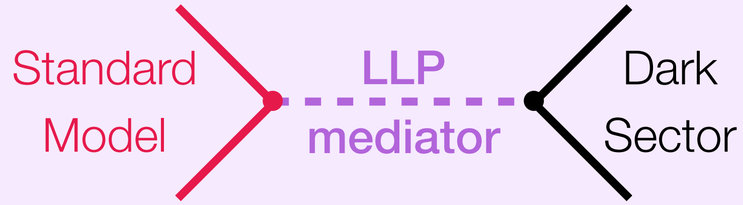


New particles can answer these questions!

Traditional searches: **stable** or **prompt**.

Long-lived particles (LLP)

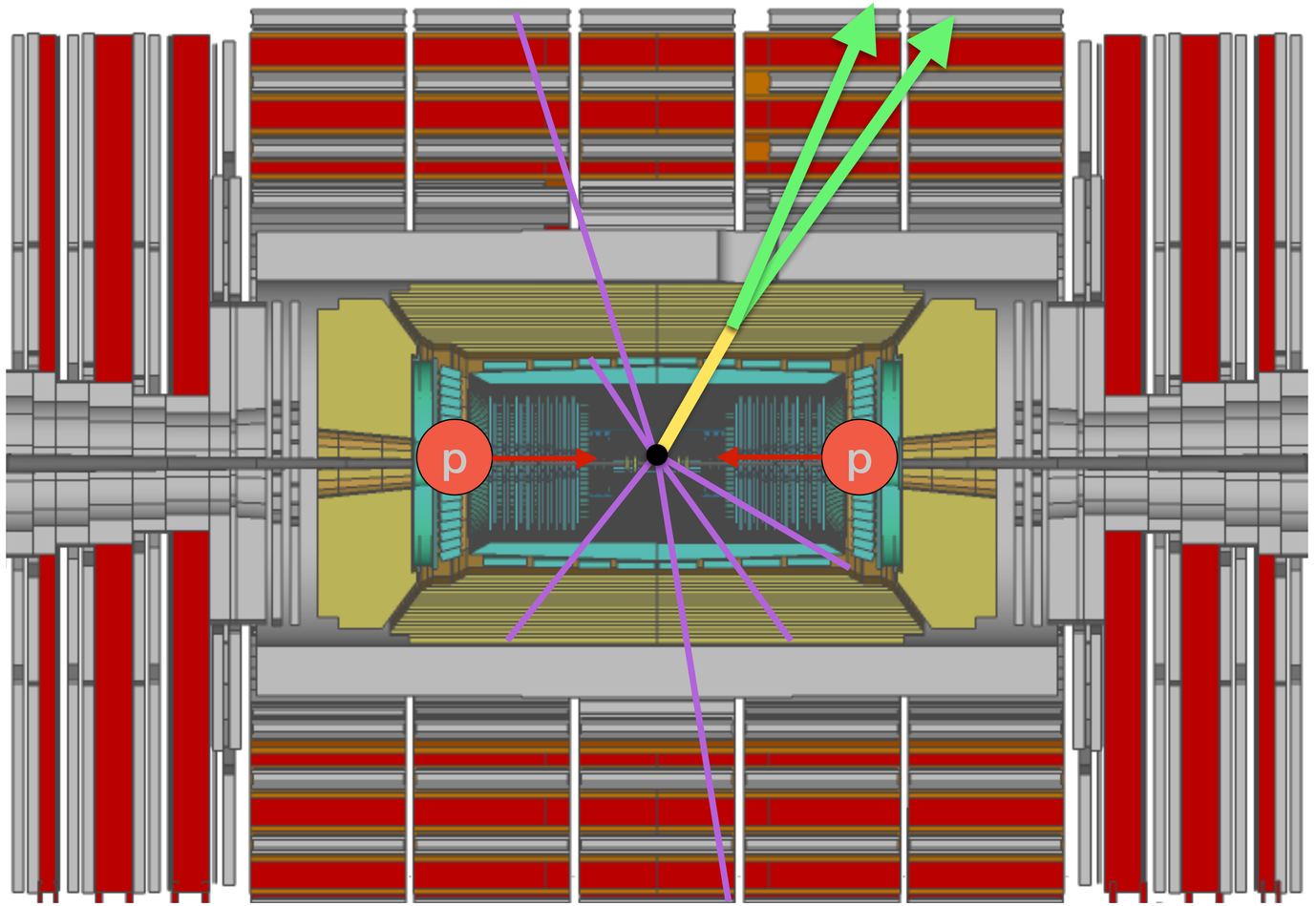
- **Large, interesting region** to cover.
- **Unconventional signatures**.
- Many examples in the Standard Model (SM).
  → new particles likely to be long-lived, too!
- Could mediate **SM ↔ DM interactions**:



- Generic new particle candidates:
  → A **model-agnostic search** is essential.

The Idea

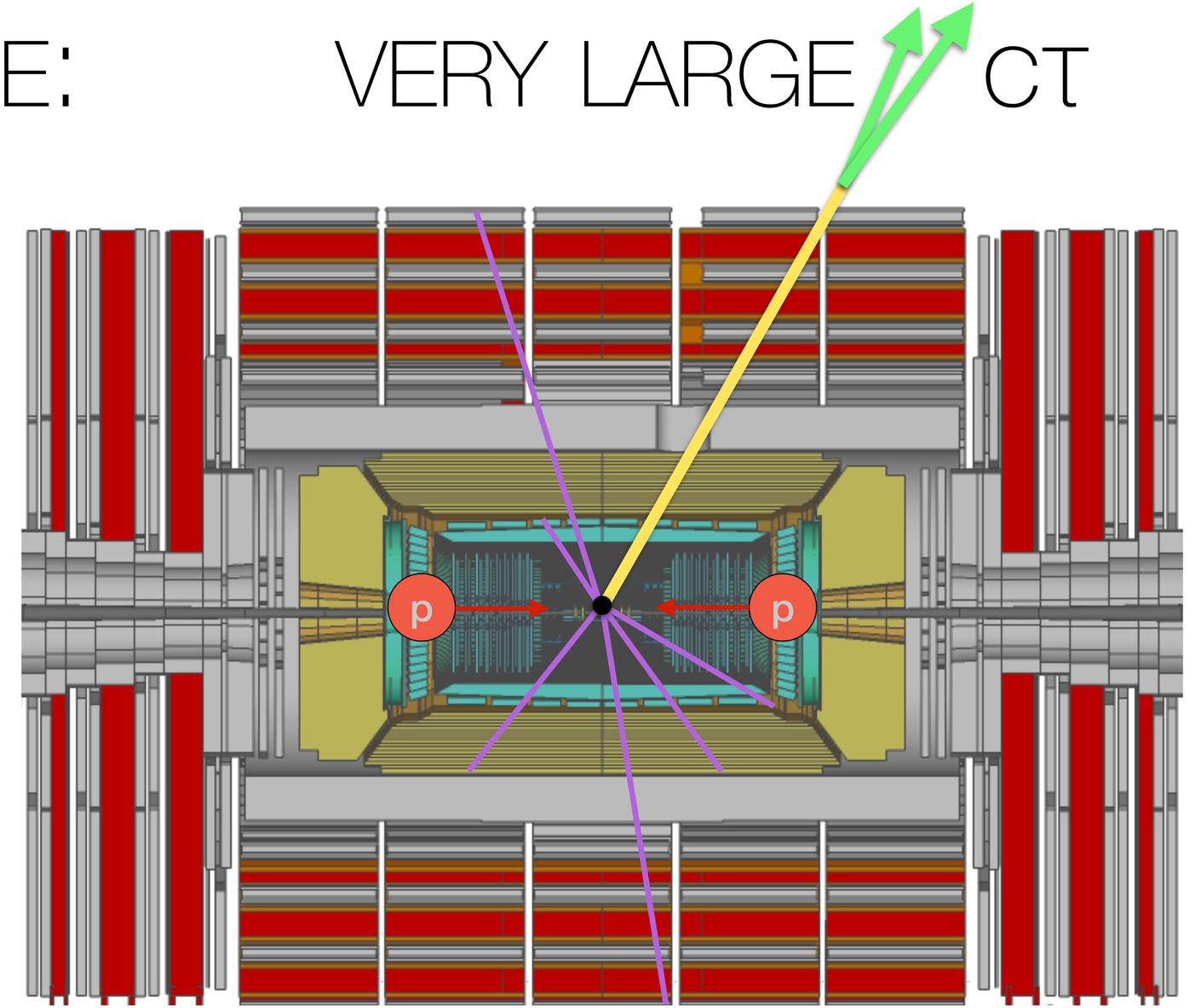
Rich LLPs program @CMS



Example

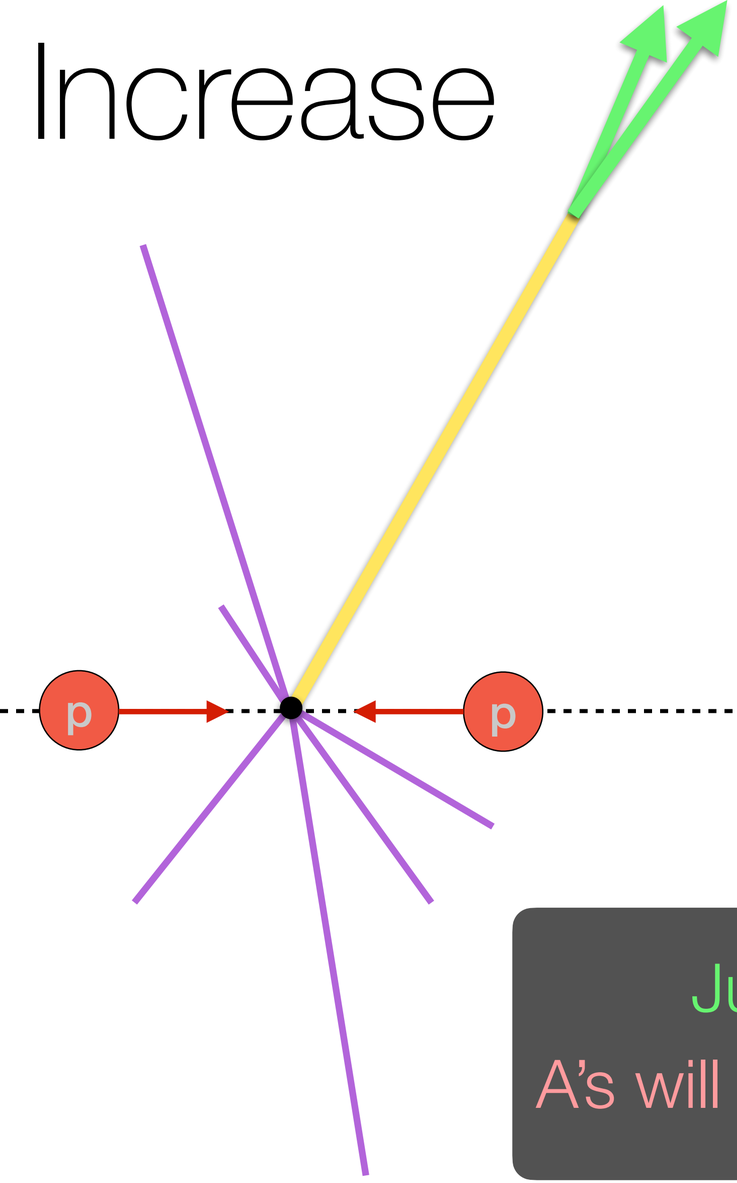
A’ → μμ

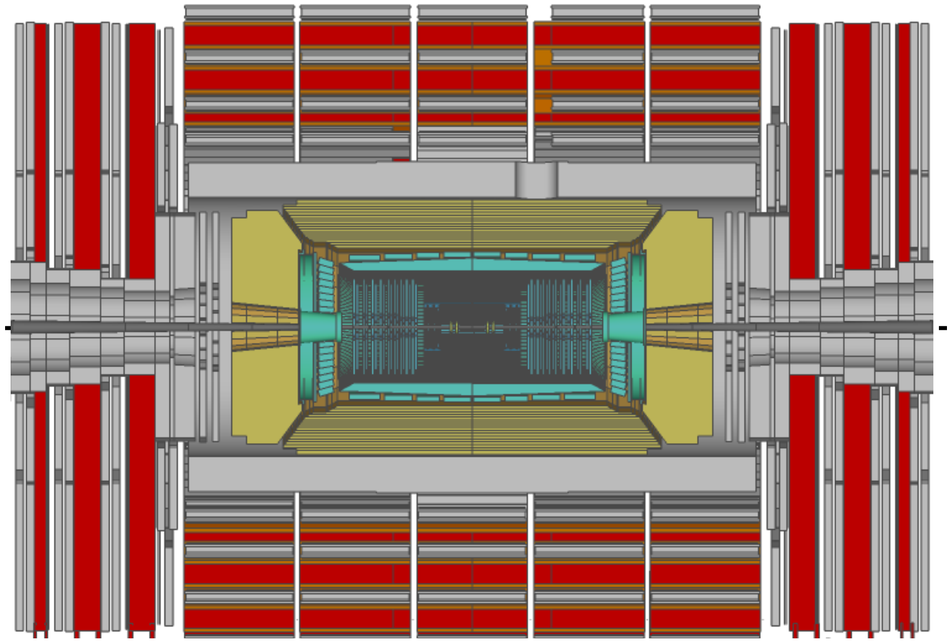
CHALLENGE: VERY LARGE cτ



Most A's decay outside of CMS

Increase decay volume

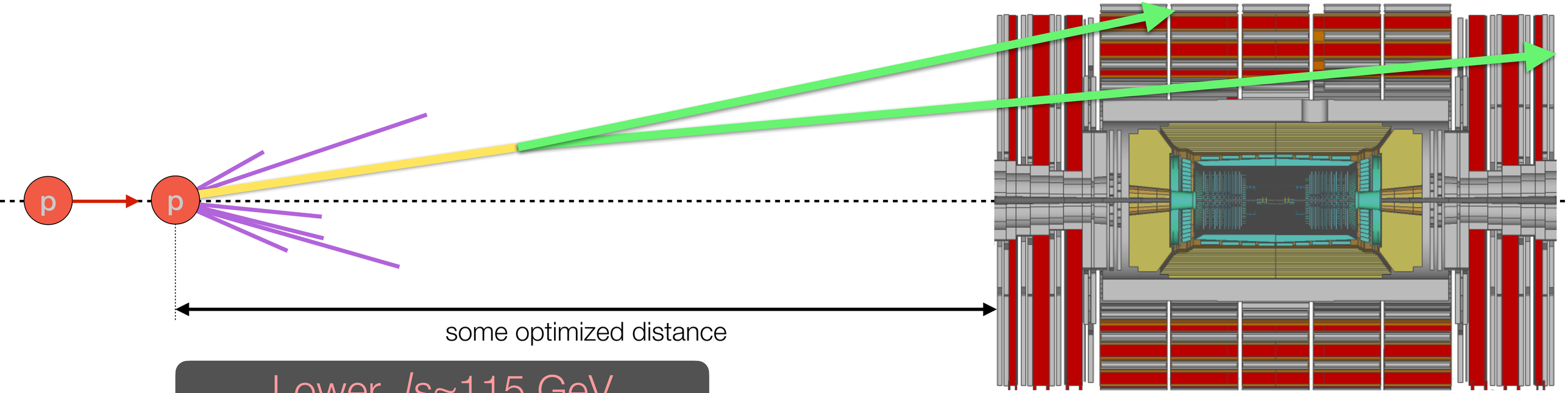




Just move the collision!

A's will mostly miss the detector…

Fixed target collision!

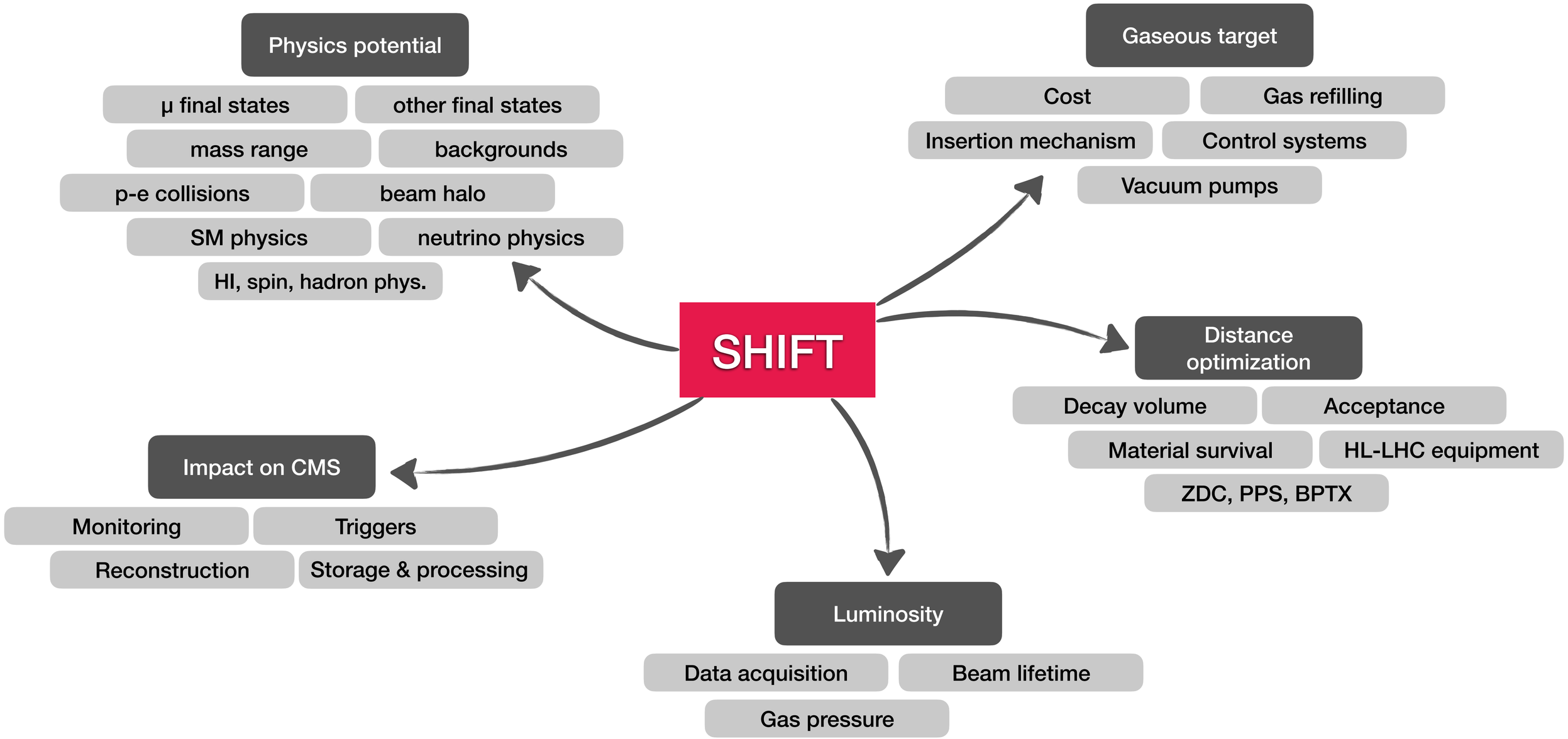


Lower $\sqrt{s} \approx 115$ GeV

Large decay volume

High acceptance

Backgrounds shielding

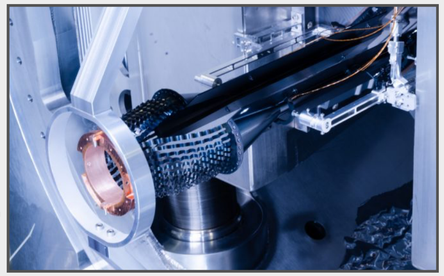

Physics potential
μ final states
other final states
mass range
backgrounds
p-e collisions
beam halo
SM physics
neutrino physics
HI, spin, hadron phys.
Gaseous target
Cost
Gas refilling
Insertion mechanism
Control systems
Vacuum pumps
SHIFT
Distance optimization
Decay volume
Acceptance
Material survival
HL-LHC equipment
ZDC, PPS, BPTX
Impact on CMS
Monitoring
Triggers
Reconstruction
Storage & processing
Luminosity
Data acquisition
Beam lifetime
Gas pressure

Can we actually do it?

Technical feasibility

Gaseous fixed target

- Similar to SMOG2.
- Just **1 gas** type (e.g., neon).
- Dedicated **insertion system**.
- Cost: **≈300 kCHF**.

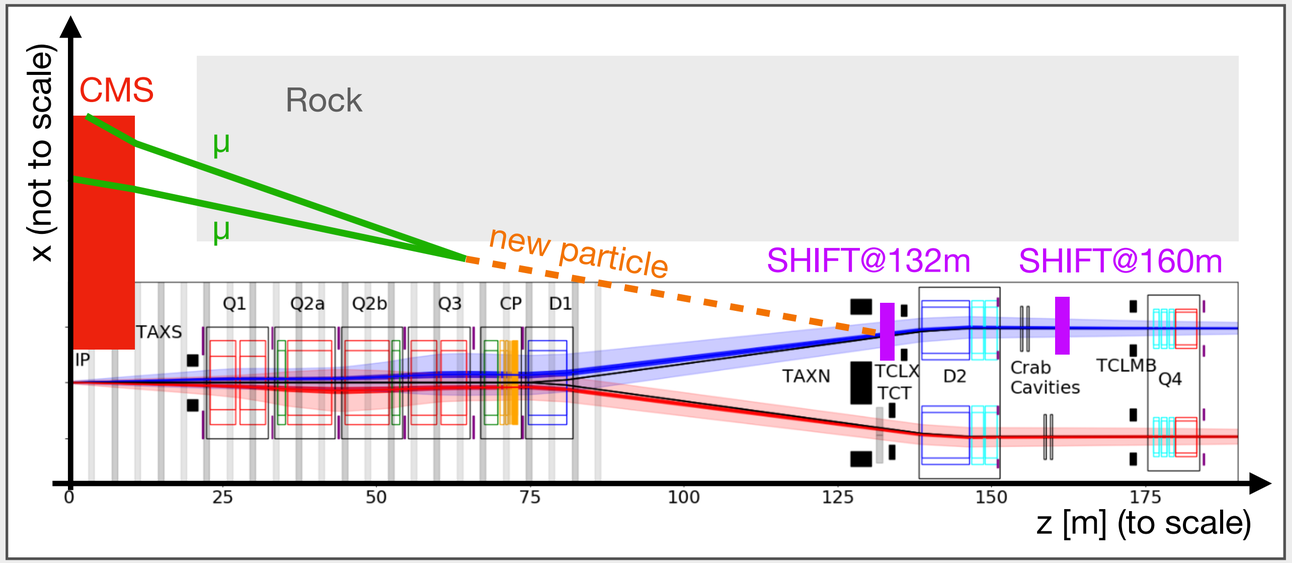


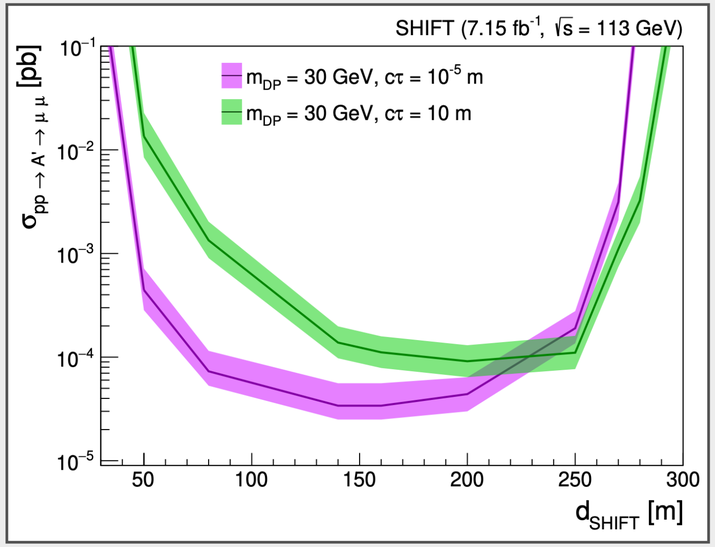
Luminosity & beam lifetime

- Aiming at **1% of the CMS lumi** for SHIFT.
- Requires **higher pressure** than in SMOG2.
  → **Doable** (pump more gas + 2 TMPs).
- **Beam loss** ≈1% over a 10-hour run.

HL-LHC integration

- Luckily, there are **empty sections** in the interesting region.
- The bulk of particles **avoids interaction with instrumentation**.





Distance optimization

- Interplay between **acceptance**, **decay volume**, and **material survival**.
- 150-250 meters is good.
- **160 meters is best** for a wide range of models.

On the CMS side

Triggers

- Beam-halo triggers (Run 1) and flags (Run 2/3) already exist.
- CMS standalone
  → based on the **pattern of hits** in the muon detectors.
- **Triggering detector** (optional) → supports the CMS trigger.

Monitoring

- Monitor & store the gas **pressure and temperature**.
- Necessary to ensure proper **operations**.
- Needed to determine **luminosity** offline.
  → A **small detector** would also help with that.

Reconstruction

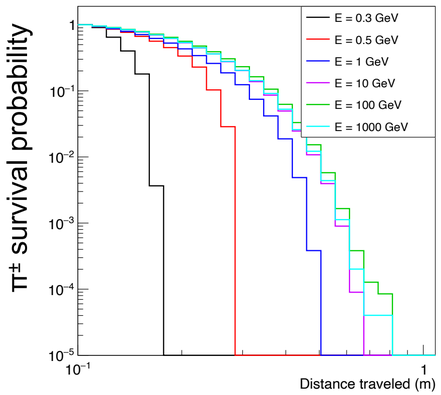
- 20+ GeV muons → **predictable paths**, no scattering.
- Sometimes partial tracks, sometimes longer than default.
- Algorithms need to be tuned/modified.

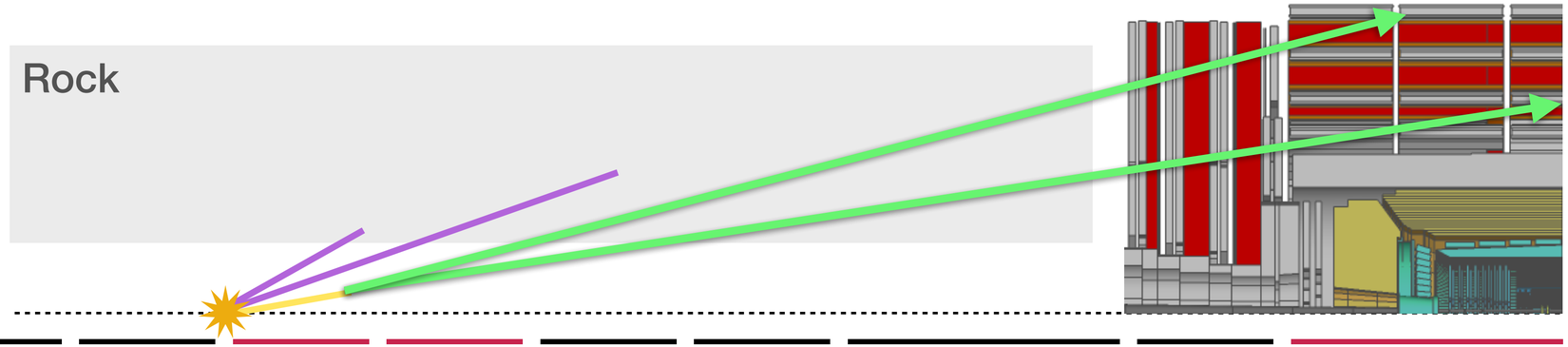
Do we gain something?

Backgrounds

SM processes at the target

- Mainly **QCD and DY**.
- $\pi^{\pm} \rightarrow \mu^{\pm}\nu$ **combinatorics**:
  - Suppressed by the material.
  - Still, it's the main background.
- $\gamma \rightarrow \mu\mu$ **continuum**:
  - Hard to suppress.
  - Second largest background.





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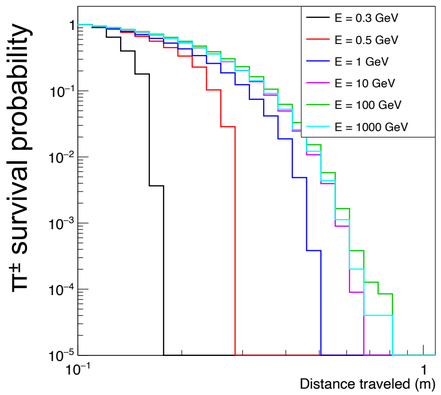
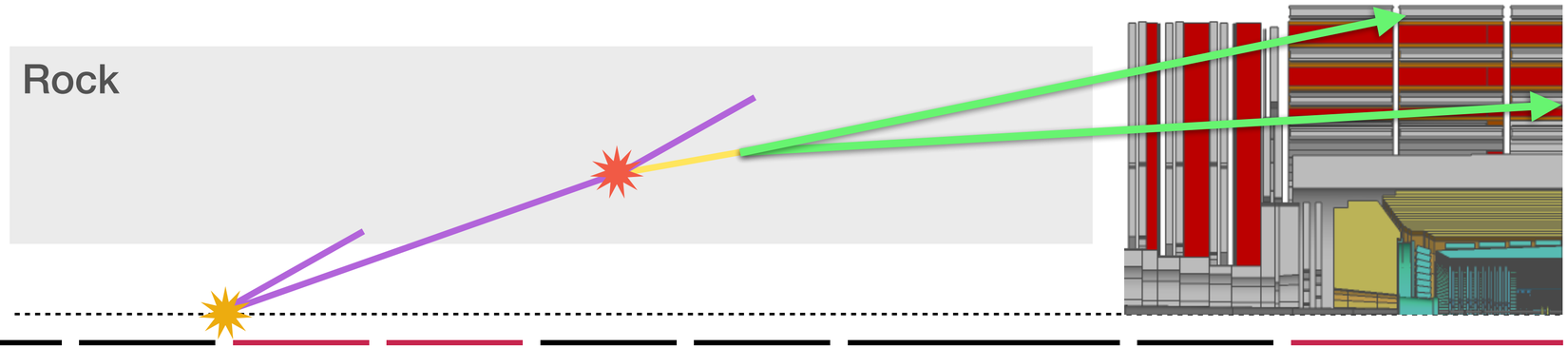


Secondary production in the material

- Mesons produced in secondary **collisions in the rock**
- Could **increase background** (and some signals) by a factor ≈2.
- **Suppressed with vertex cuts.**
  → Needs to be studied in detail.



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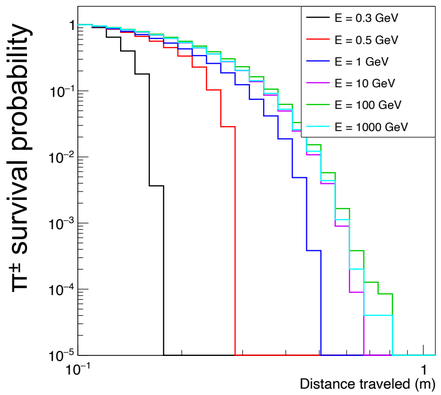

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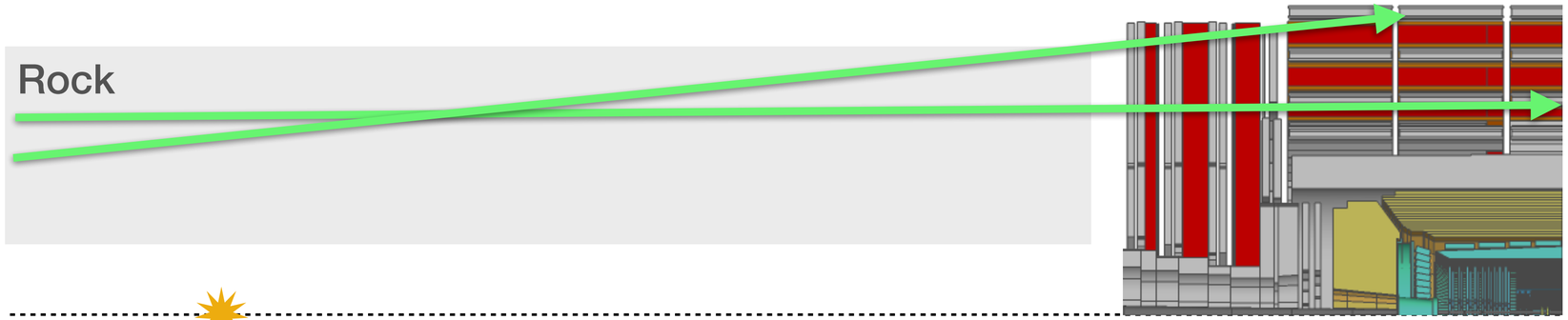
Cosmic muons

Would need:

- **Two muons** roughly in the **LHC plane.**
- **O(10 TeV)** to go through the rock.
- Roughly forming a **common vertex.**
- And arriving at the **same time.**

→ **Negligible.**



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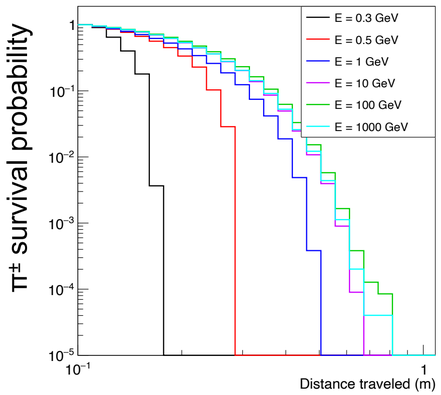

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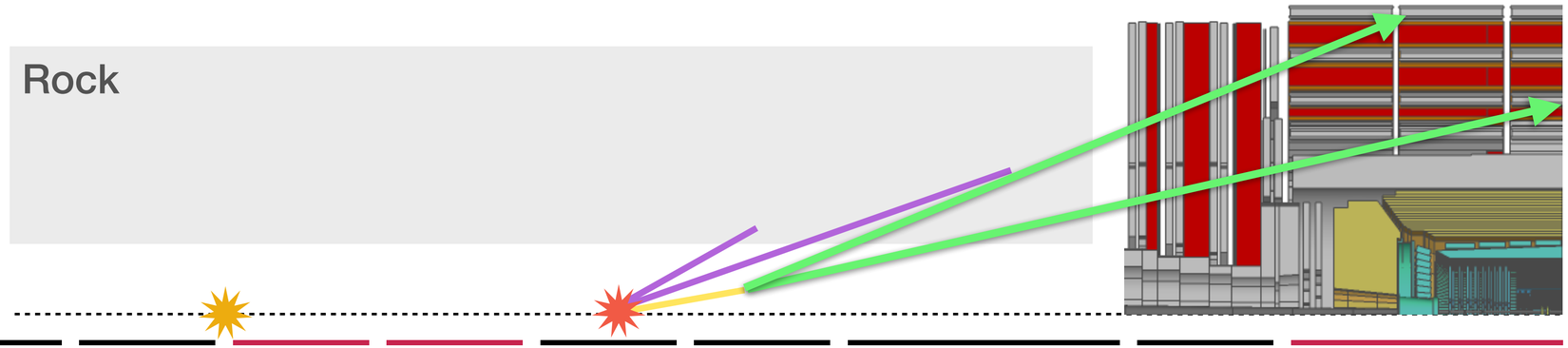
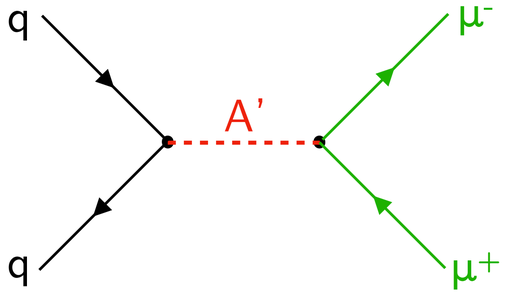
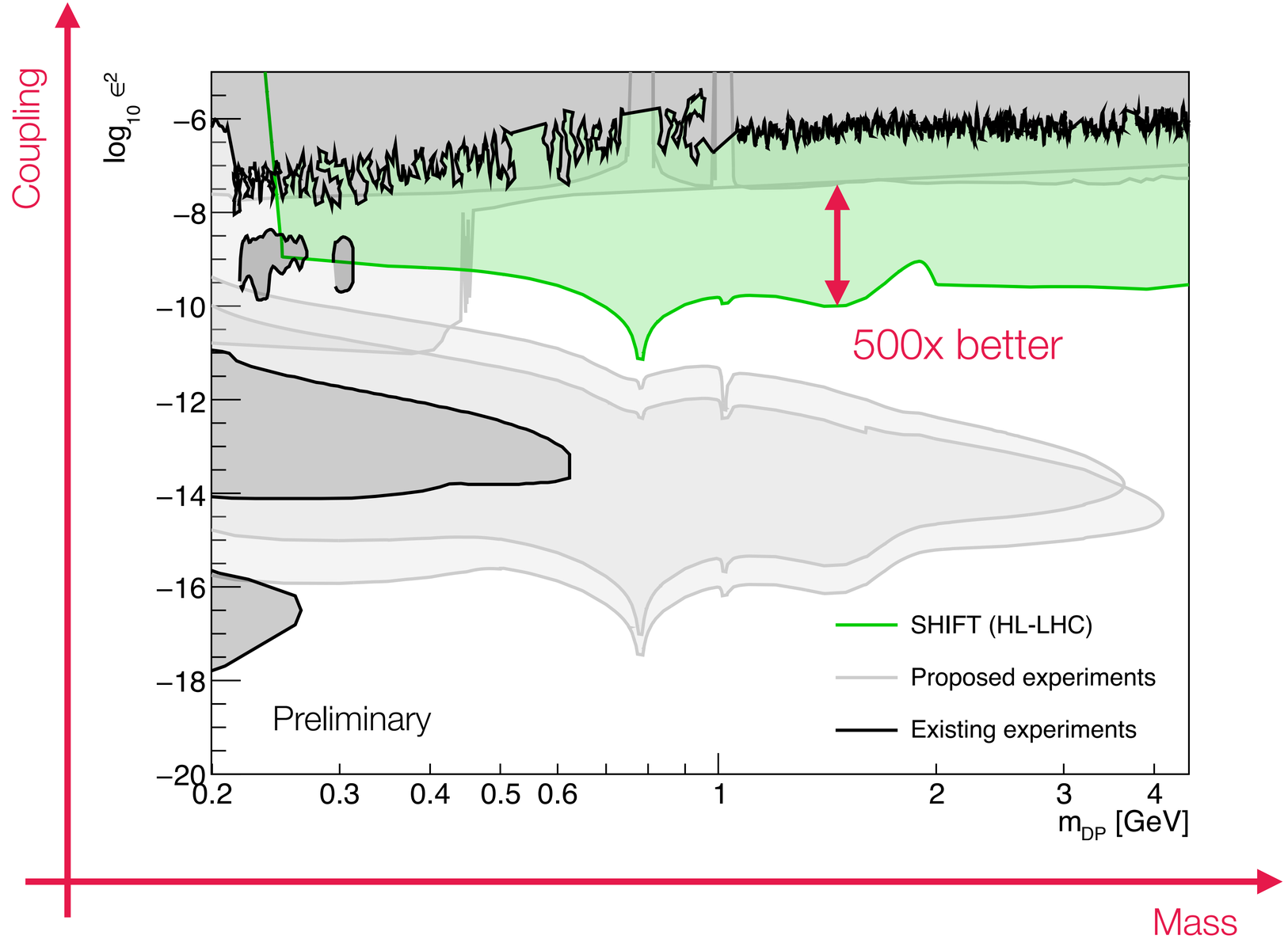
Beam-halo & beam-gas

- Actually, **very useful!**
- The **same signature.**
  → Can be used for **validation.**
- **Lower lumi, location not optimized.**
  → Plan B: use for **physics** if the target not installed.



Sensitivity: What do we gain?

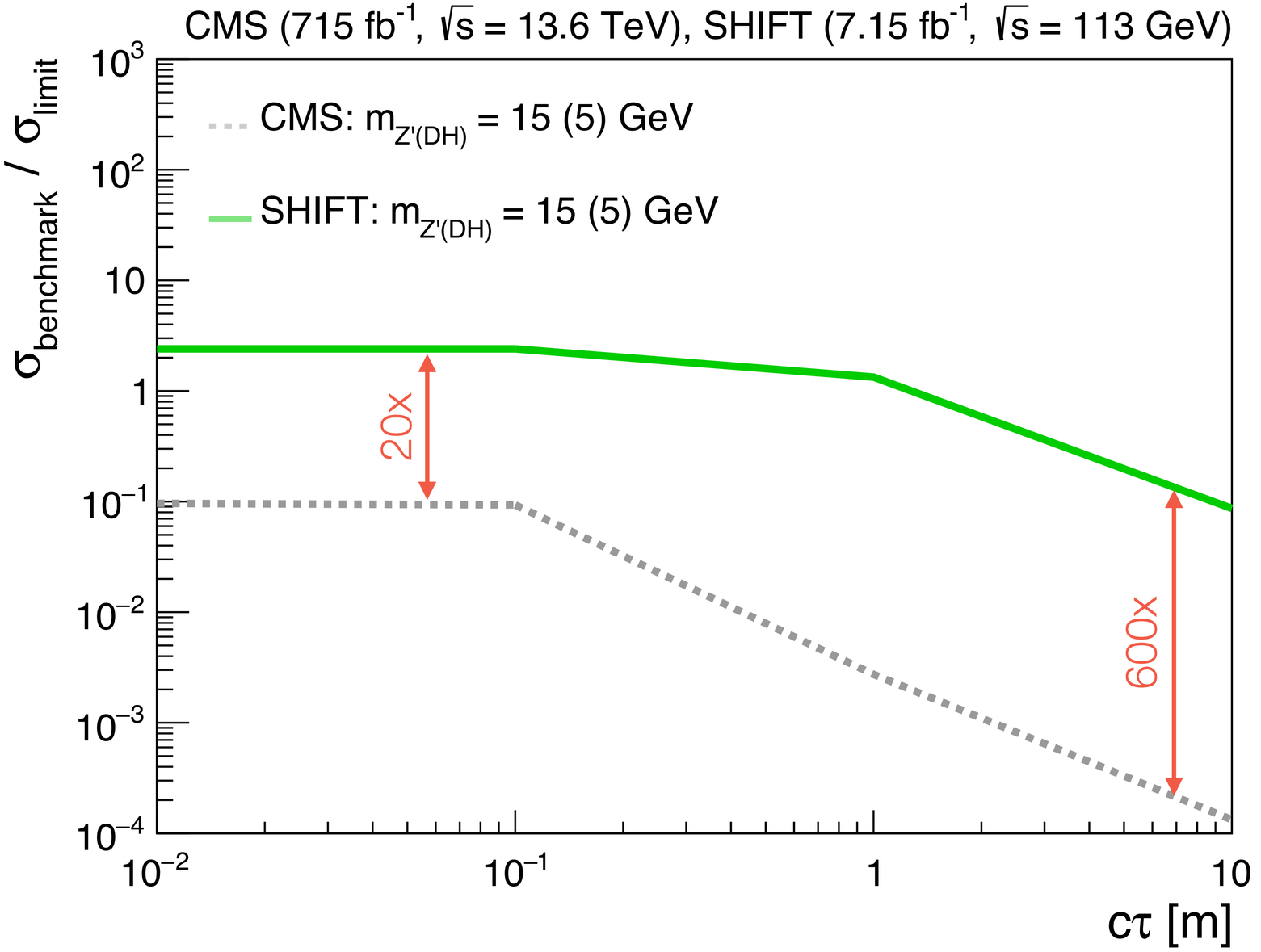


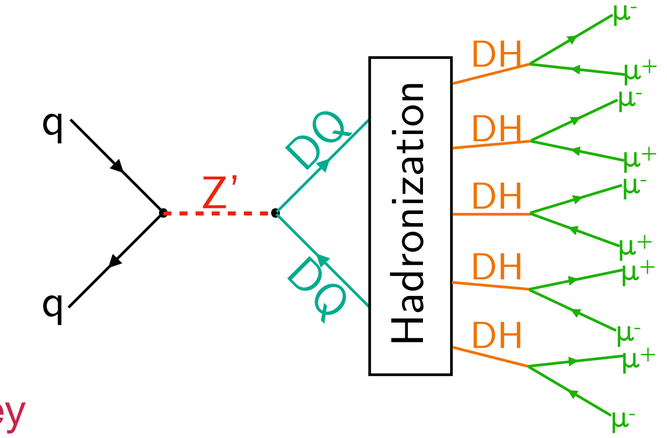


Dark Photons

- Simple dark photon scenario (PBC model).
- **1% of CMS luminosity** dedicated to SHIFT.
- SHIFT covers a **unique phase space.**
- **2-3 orders of magnitude improvement** over existing limits.

Sensitivity: What do we gain?

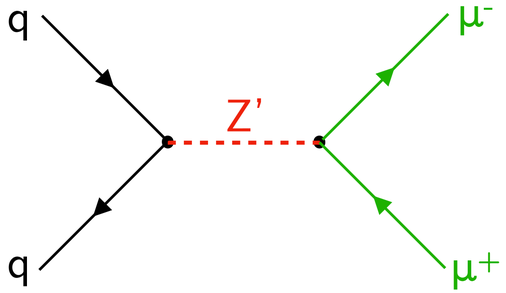


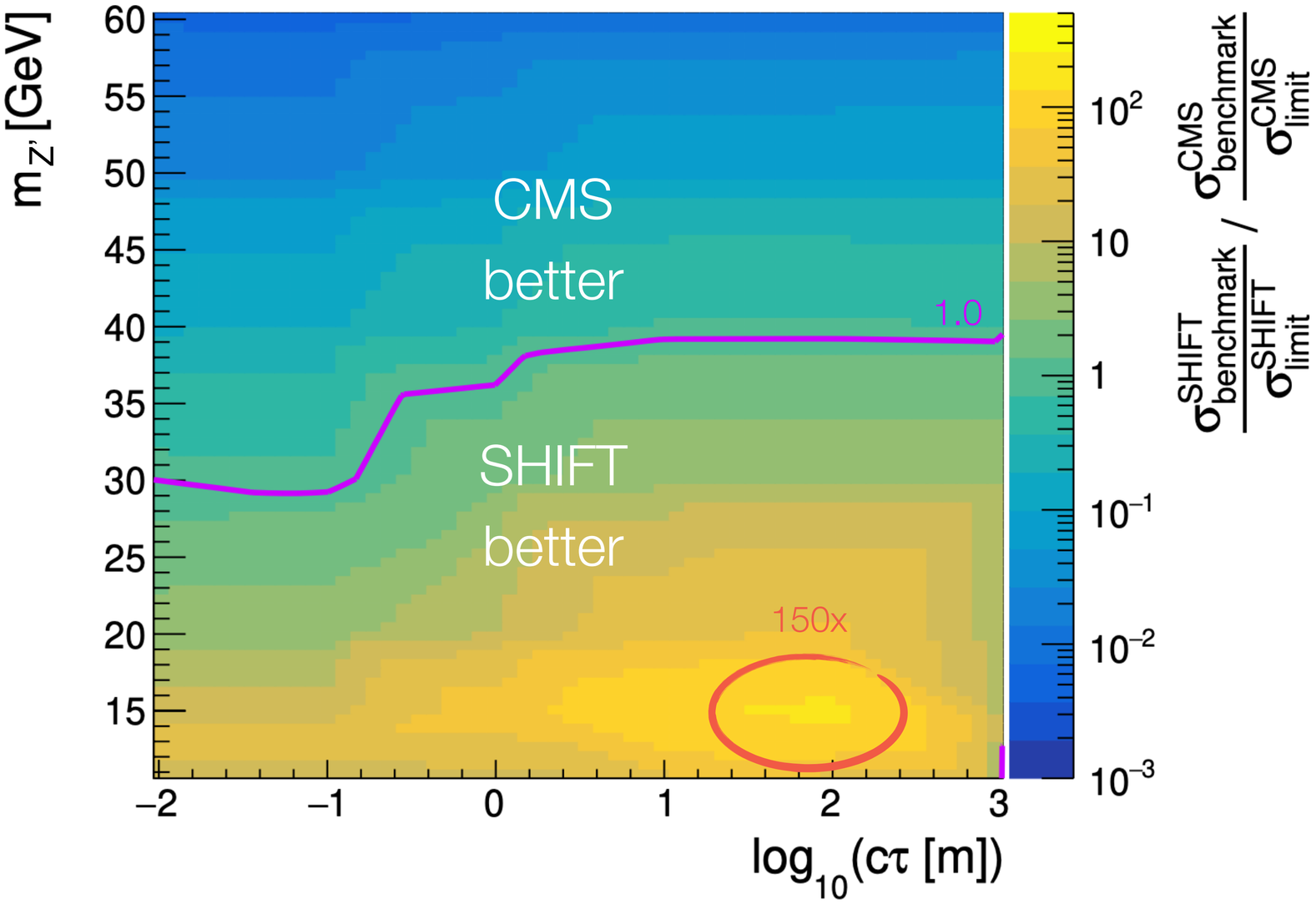


Hidden Valley

- Complex BSM scenario in Pythia.
- Z' portal between SM and the dark sector.
- Compared to CMS, LHCb, and SMOG2.
- **1% of CMS luminosity** dedicated to SHIFT, Run 4 lumi prediction.
- **Up to 600x** sensitivity improvement, → better at high cτ.

Sensitivity: What do we gain?





New Gauge Bosons

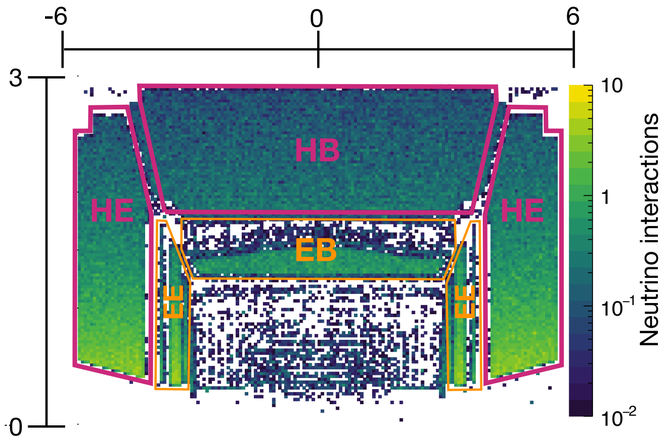
- Simple BSM scenario with a new boson, tuned to resemble SM Z mass spectrum.
- Compared to CMS, LHCb, and SMOG2.
- **1% of CMS luminosity** dedicated to SHIFT, Run 4 lumi prediction.
- **Up to 150x** sensitivity improvement, → optimum at $c\tau \approx 100$ m, $m_{Z'} \approx 15$ GeV.
- **Improvement for everything ≲35 GeV.**

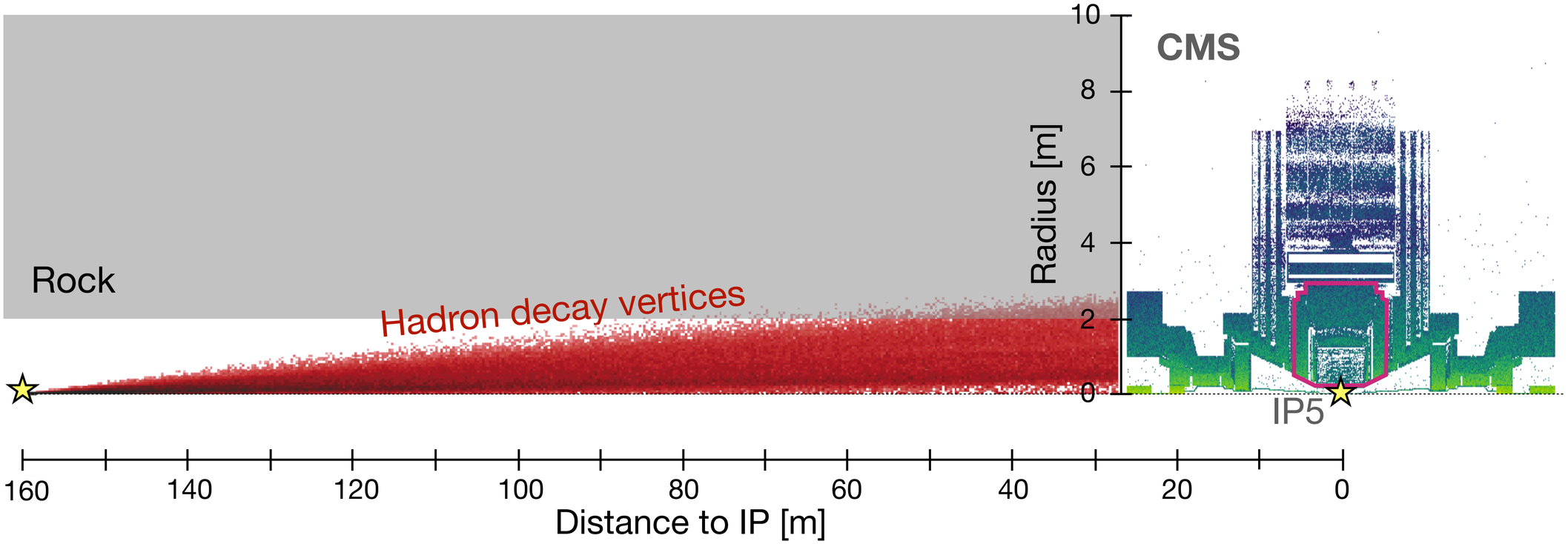
ONE MORE THING

A SHIFT of Perspective: Neutrinos in CMS

Neutrinos production and interactions

- **A lot of neutrinos** would be produced at the target and travel towards CMS!
- Calos and tracker in **line of sight**
- Reco **displaced jet+lepton** vertices:
  - Very challenging, but not impossible
  - Can use near-side muon/calo end-caps as a veto



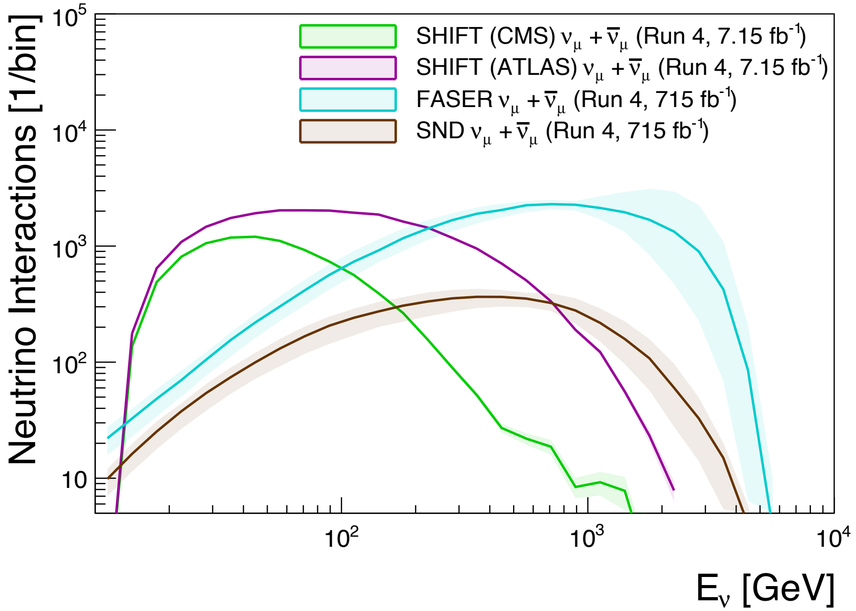


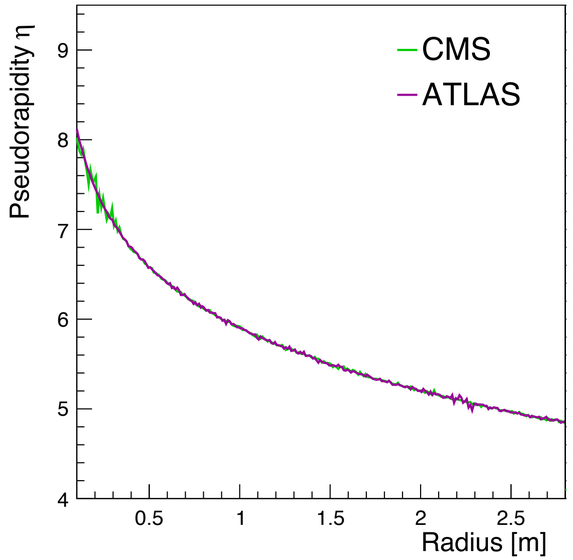
A SHIFT of Perspective: Neutrinos in CMS

What do we get?

- Measure 10^4 ν_μ and 10^3 ν_e in Run 4
  - First-ever measurement in a large LHC detector
  - Covers pseudorapidity range: $5 < \eta < 8$

    → complementary to FASER and SND
- Information about the **parent hadron η**
- Production in **p-[any gas] collisions**
- Neutrino interactions with **different materials**





What can we do with it?

- **Atmospheric neutrino flux** at O(10-100) GeV as ≈10% uncertianty
  - Even if ε_{reco} ≈10%, uncertainty ≈3%
- Measurements of **cross-sections ratios** for interactions on different materials
  - Similar precision to dedicated experiments (MINERvA, CHORUS)
  - First time for **tungsten and copper**
  - First time for **antineutrinos**

SUMMARY

What's next?

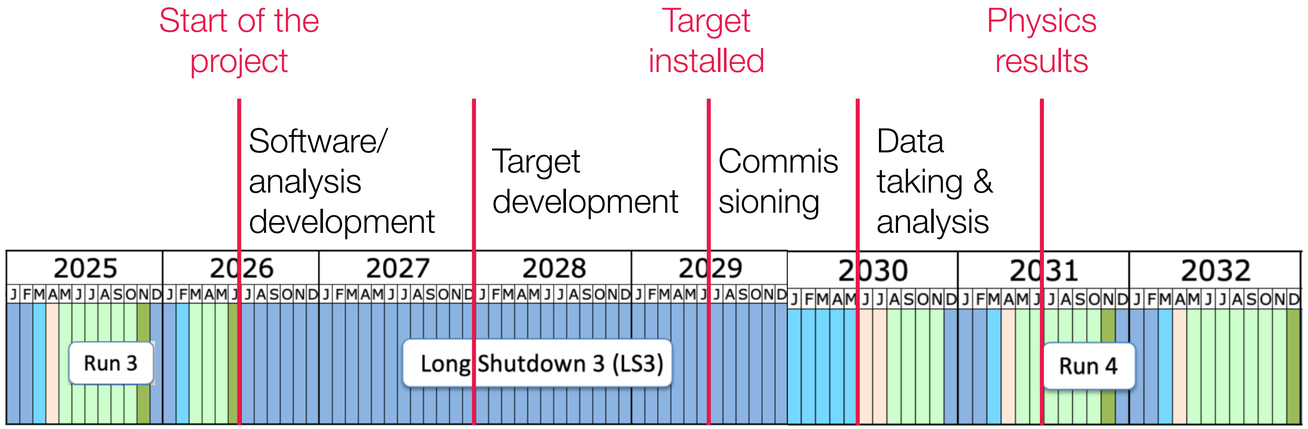
- CERN
  - EP Department Head ✓
- CMS
  - Team & Group Leaders ✓
  - Spokesperson Team ✓
  - Technical Coordination ✓
  - PPS Detector Expert ✓
- Physics Beyond Colliders
  - Feebly Interacting Particles ✓
  - Fixed Targets ✓
  - Forward Detectors ✓
- LHC
  - Vacuum experts ✓
  - Beam Operations ✓

Interesting physics

No showstoppers

Done

- The **sensitivity improvement demonstrated**
- Many **physics and technical questions answered.**
- **ERC CoG** proposal:
  - 2025: passed to interview, not funded
  - 2026: didn't pass to interview this time



Future

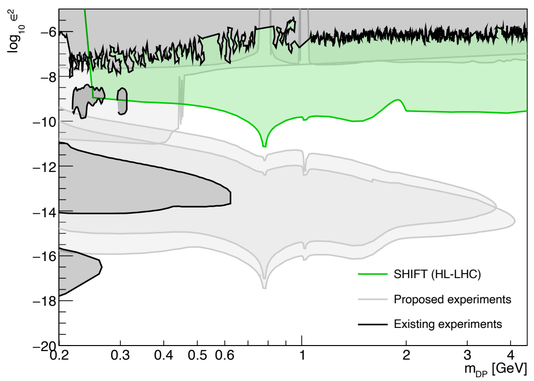
- Target **hardware development** becomes more difficult.
- Looking into **other funding options.**
- Realistically, we're probably already in the "Plan B" situation:
  - Development of **triggers**, **simulation**, and **reconstruction.**
  - Using **beam-halo** for simplified studies.
  - Think about the **target later**…

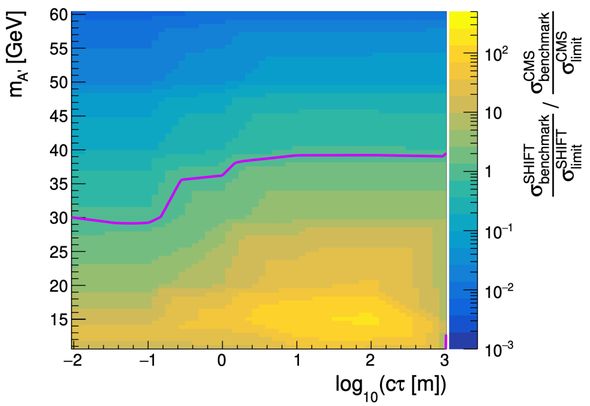
Summary

SHIFT

Gaseous fixed target in front of CMS:

- Comes with many **challenges**, but overall **feasible.**
- Can cover **new phase space in LLP searches!**





Not a dedicated one-time experiment!

- **New facility** for all CMS users.
- Will **enhance CMS LLP searches** program.
- Invites more ideas, also in **SM and HI physics.**

SHIFT

Heavy Ion physics in a new kinematic regime (?)

TMD PDFs @ very low p_T (?)

LLP BSM ✓

Neutrinos ✓

Spin physics with polarized target (?)

- *SHIFT@LHC* JHEP 2024, 204
- *A SHIFT of Perspective* 2510.11816 (accepted by PRD)