New Proposal for Detecting LLPs Trapped in Detector Material

Jan Kieseler, Juliette Alimena, Jasmine Simms, Thea Aarrestad, Maurizio Pierini, Alexander Kish

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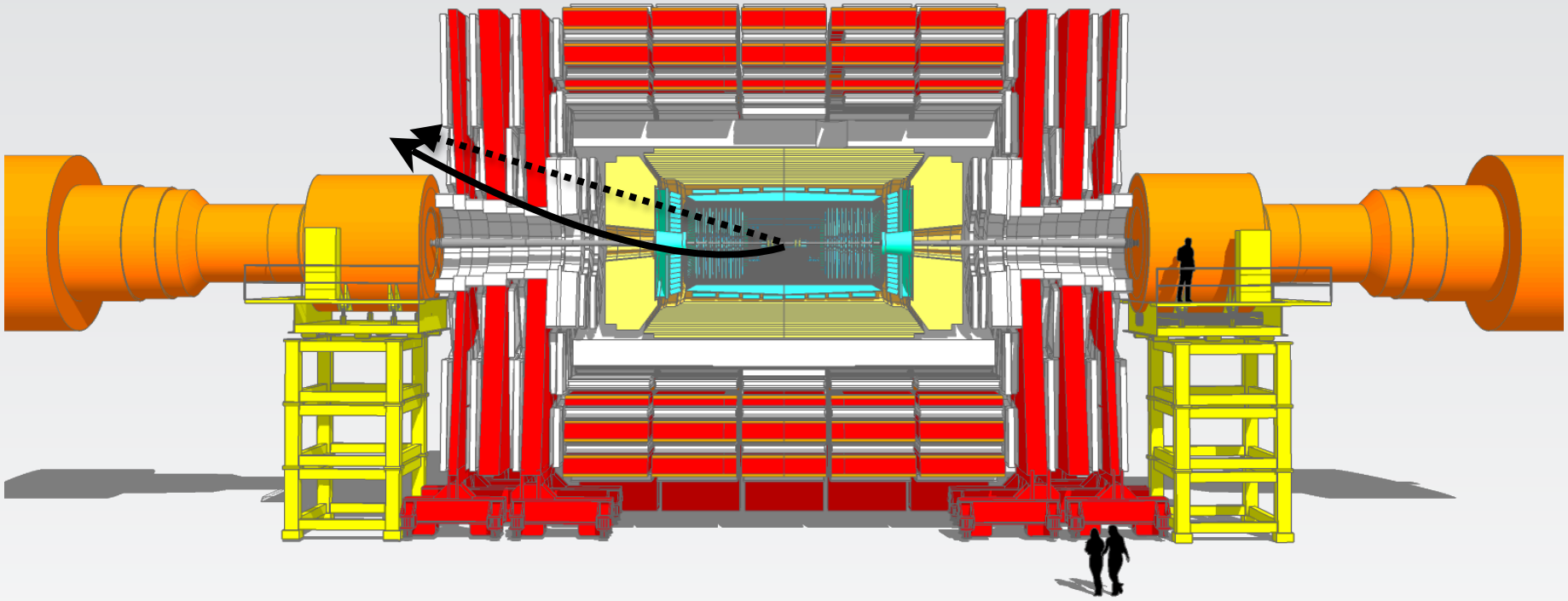
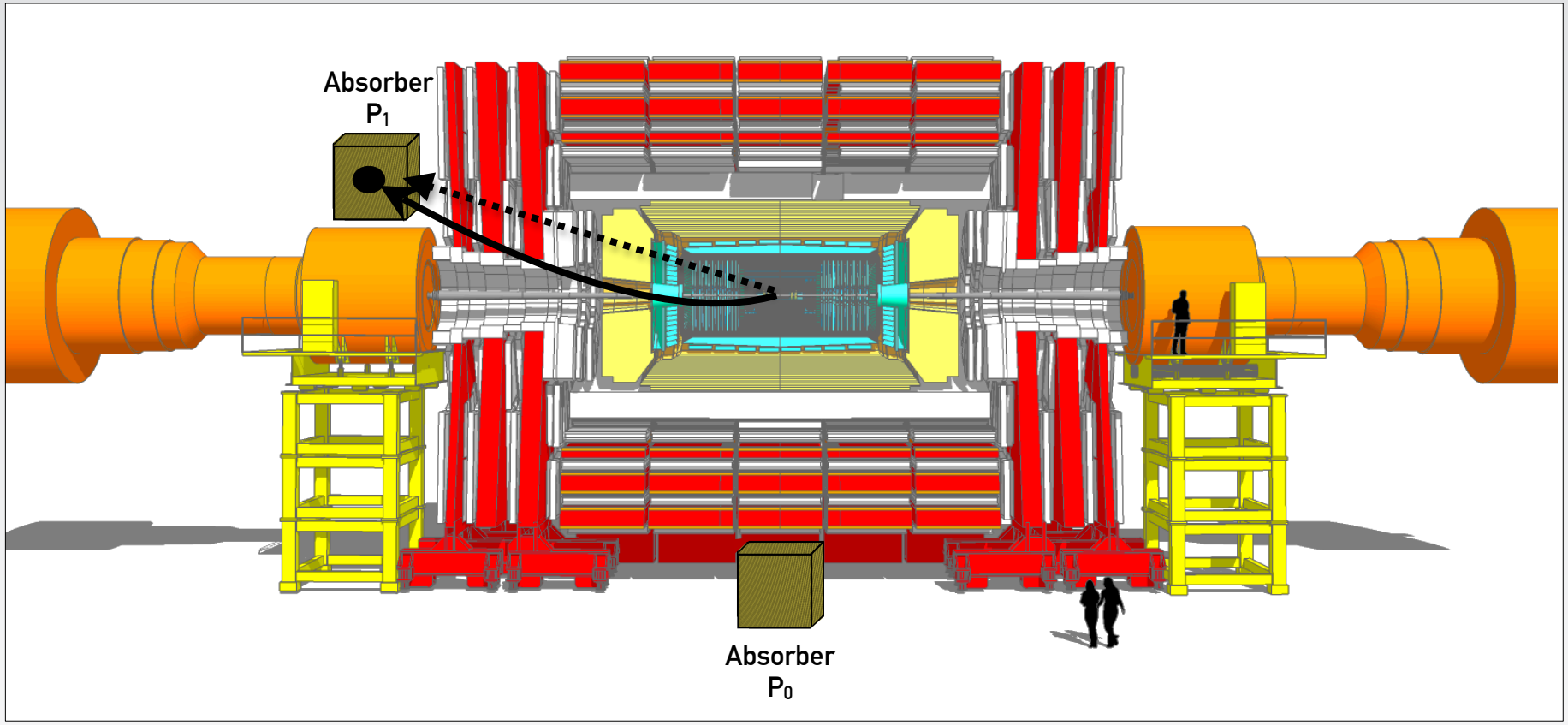
Consider an LLP…



- LLP is produced from an LHC collision, and then travels through, say, the CMS detector
- If it's reasonable heavy (10, 100+ GeV), can have a unique signature:
  - Large energy loss (through ionization or nuclear interactions)
  - Slow-moving (large time-of-flight)
  - Could also be neutral and forward

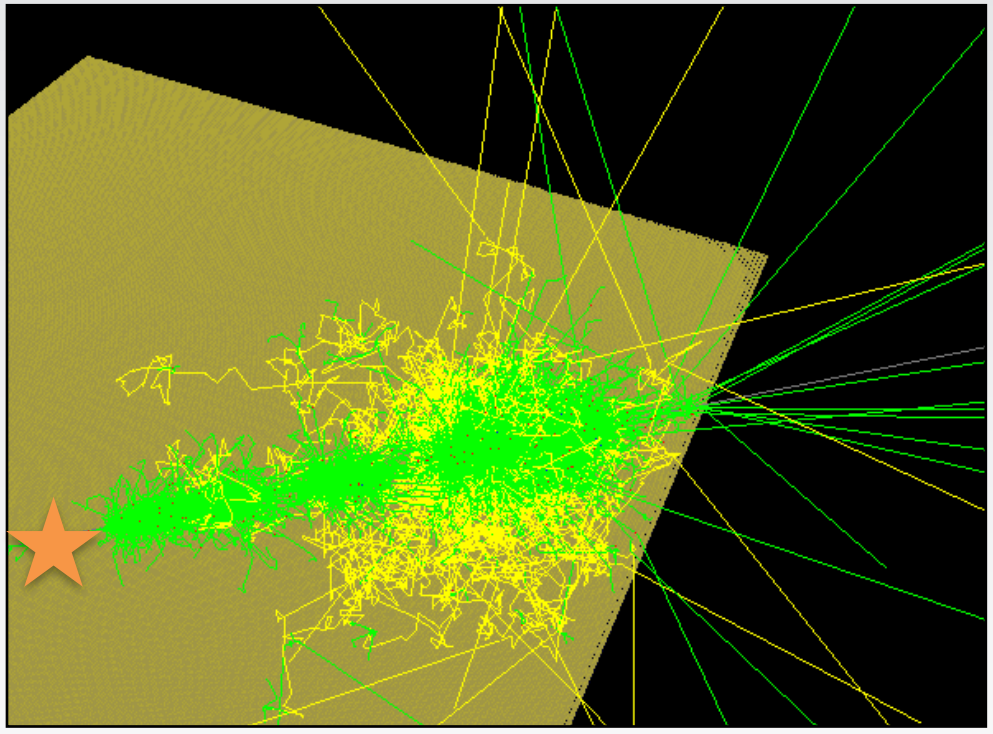
1: Stop the particle



- Place dense absorber material close to interaction point aiming to stop particle: can even be moved
- Density determines the absorption efficiencies

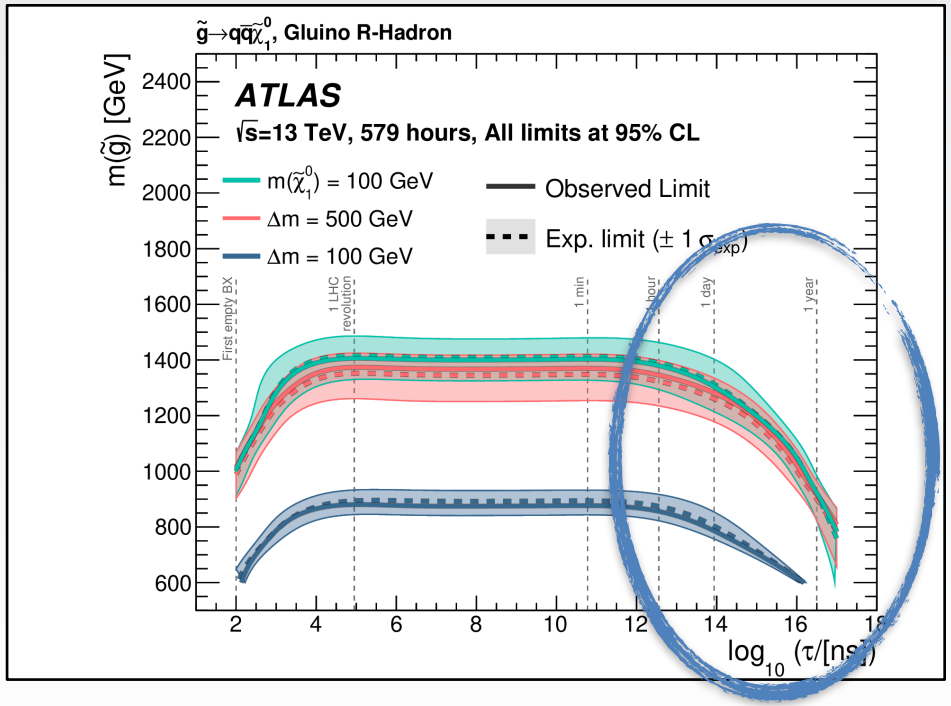
2: Wait for it to decay and detect

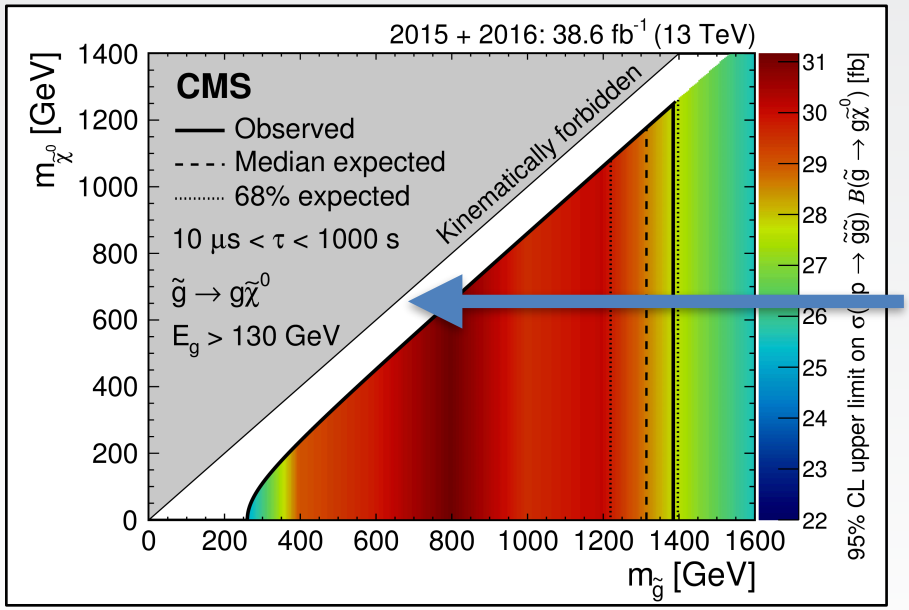
- Stopped particle might decay to SM+BSM eventually
- Leaves detectable EM/hadronic energy:
  calorimeter signature
- For long lifetimes decay happens significantly after absorption
- Open up new avenues: make absorption material removable
  - Change position w.r.t. beam spot: **target different LLP mass ranges**
  - Remove from cavern for detection:
    reduce background and avoid trigger thresholds
- **Target: long lifetimes, low energy SM decay products**



Previous Searches at ATLAS and CMS

- Both CMS and ATLAS have performed several searches for particles that stop in the detectors and then decay later
- Most recent CMS: 10.1007/JHEP05(2018)127
- Most recent ATLAS: 10.1007/JHEP07(2021)173
- Both experiments set cross section and mass limits for lifetimes between **100 ns and 10 days,** $\Delta m \gtrsim 100$ GeV
- **Benchmark model: split SUSY gluino R-hadrons**

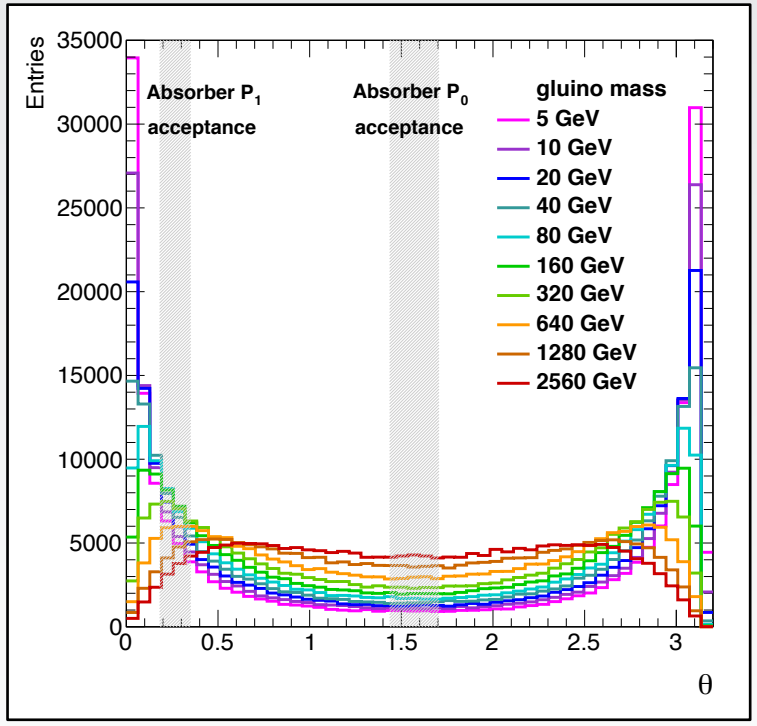


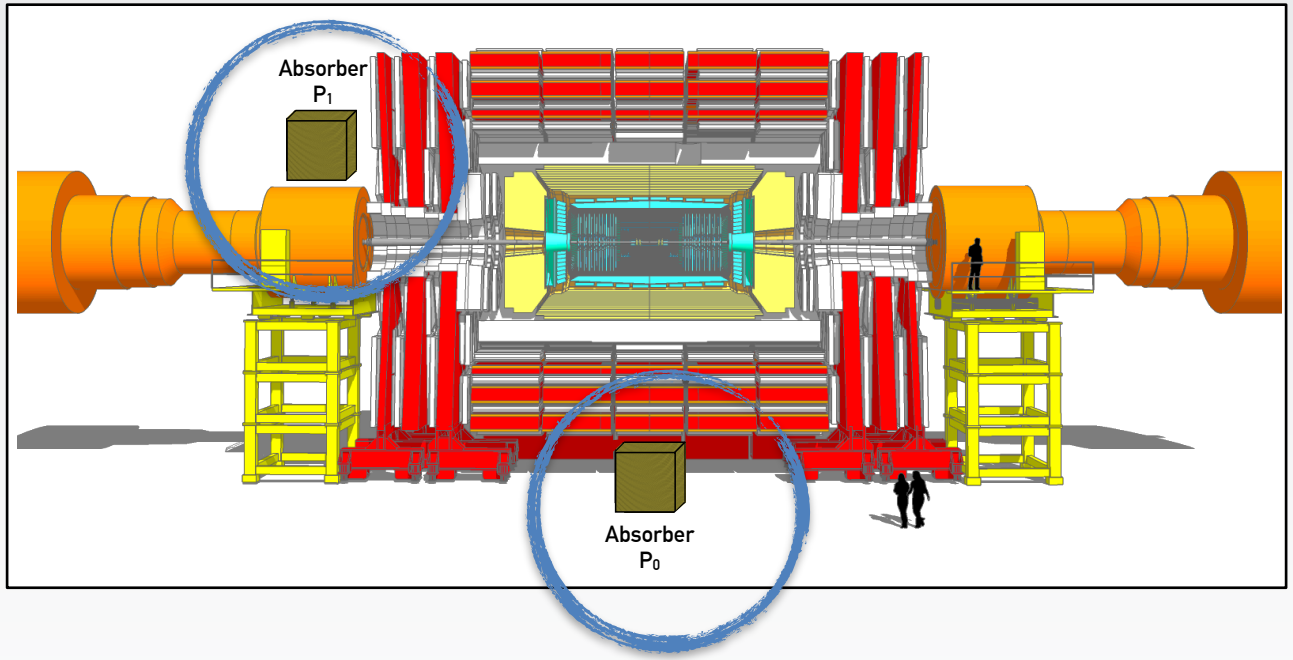


- **No trigger needed**
- **no collider detector thresholds**

Acceptance for Gluino Benchmark Model

- Benchmark case where the stopped particle is gluino ($\widetilde{g}$) in split SUSY
  - SUSY must be broken at a scale much higher than the weak scale
  - Very massive squarks
  - Gluino becomes long-lived due to large mass difference between them and squarks, which mediate their decay
- Generate gluinos and their R-hadrons in Pythia8 to obtain the kinematic acceptance



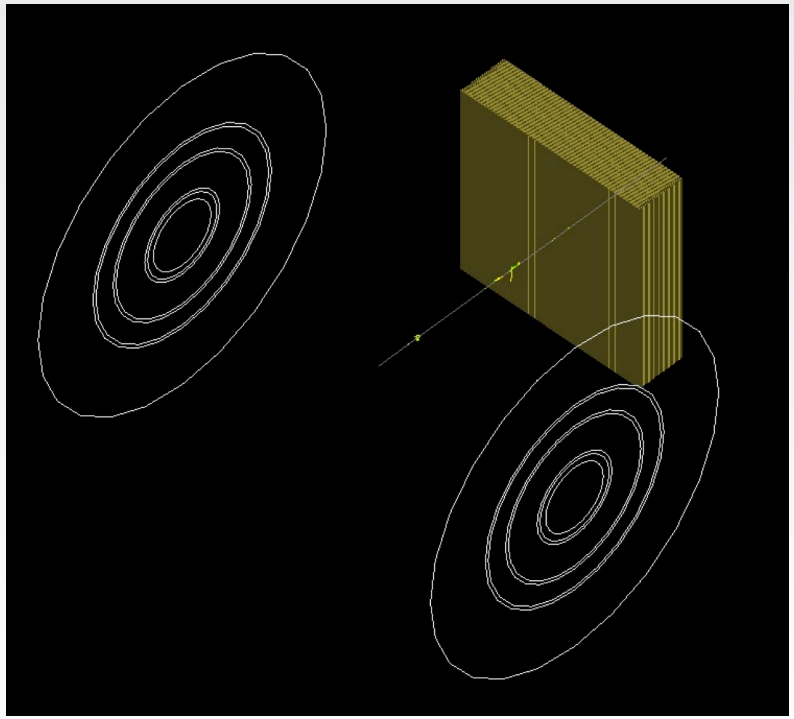


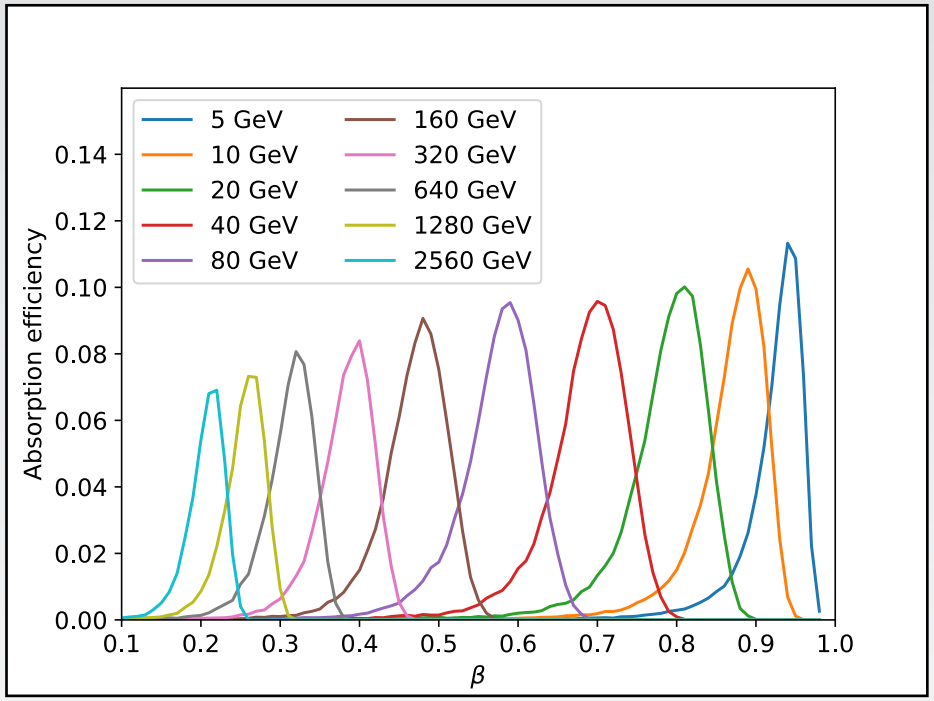
- Detector position can be changed and adapted to targeted mass range

Absorption

- As absorber: brass rods
  - High density
  - Relatively cheap
  - Re-usable in/from (hadronic) calorimeters

- Simulate neutral R-hadrons passing through an approximation of CMS material with Geant4

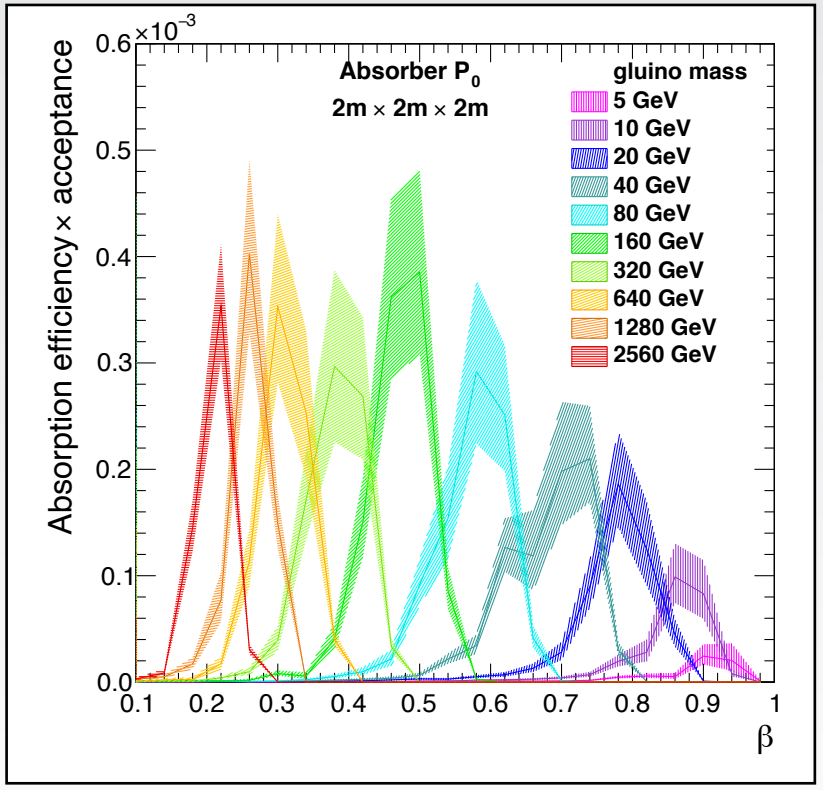


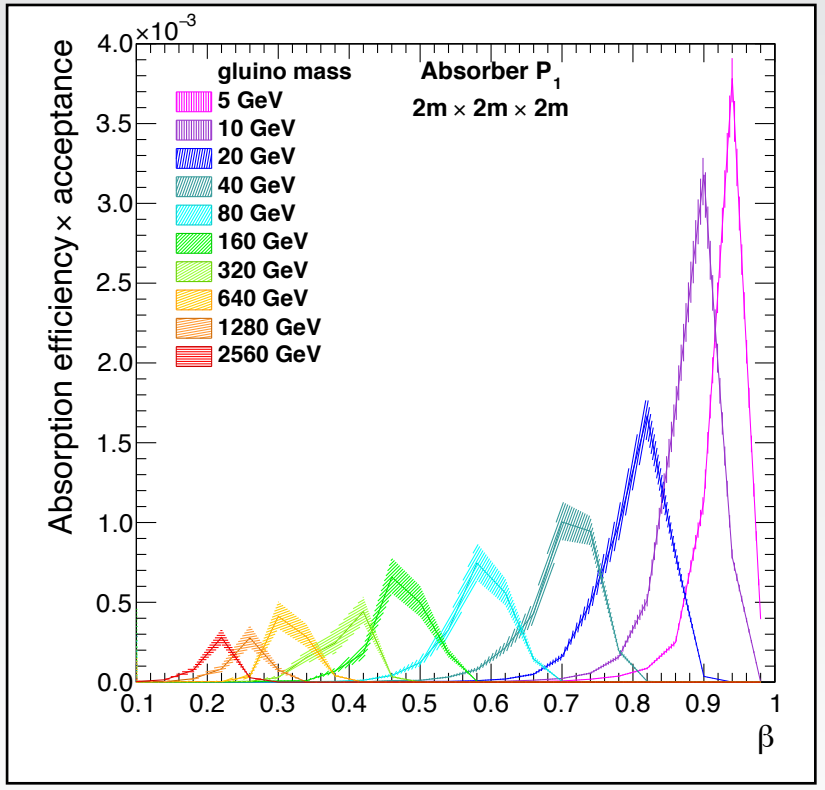


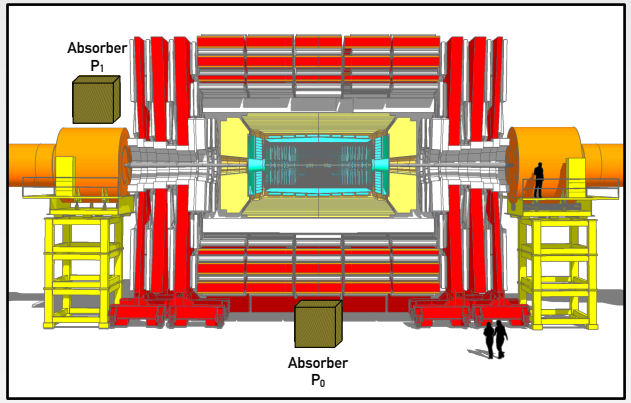
- R-hadrons hit brass rods and are absorbed
- Absorption depends on velocity, mass, and depth
- For practical reasons, chose 2x2x2 m absorber

Total trapping efficiency

- Convolve R-hadron angular acceptance and absorption efficiency to get the total efficiency times acceptance:



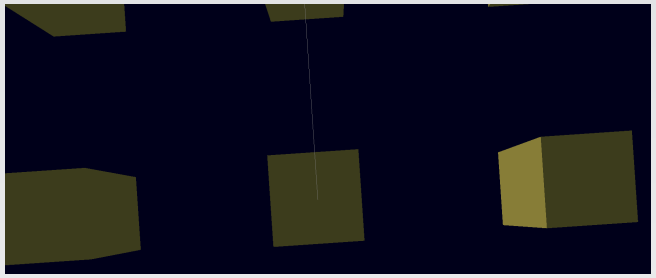




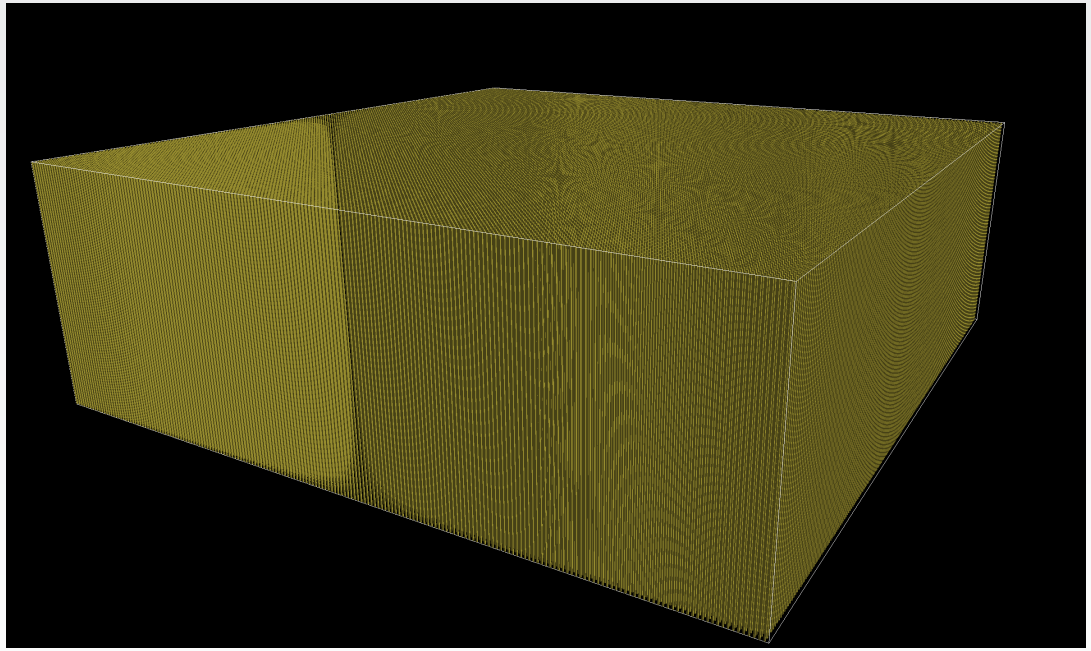
- Total trapping efficiency between 0.1 and 1%, depending on the considered mass and position

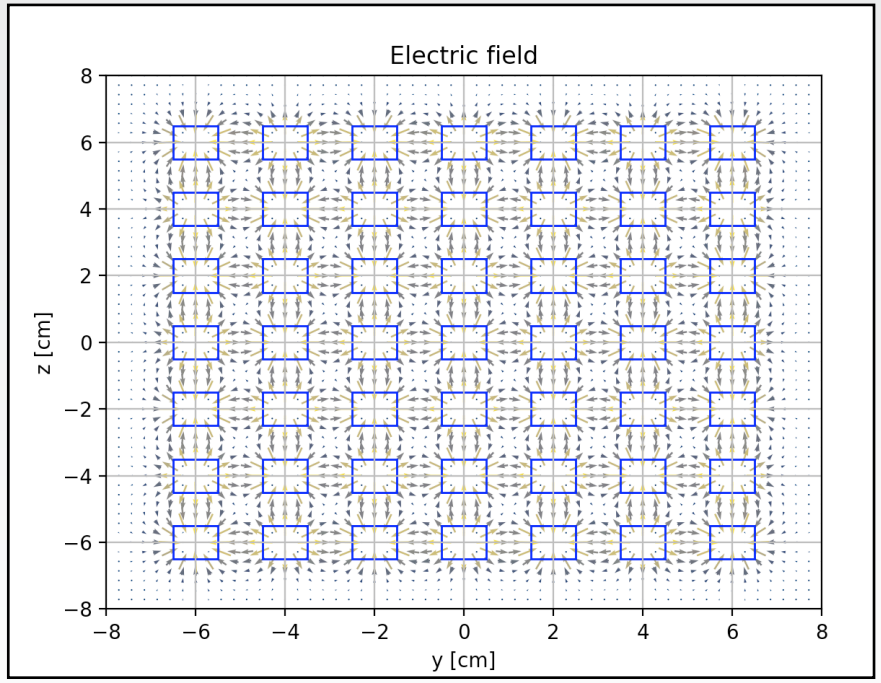
Detection setup

- Take the absorber apart (brass rods, 1cm x 1cm)
- Submerge into LAr, leave 1cm space between rods
- Apply voltage to each rod and attach readout electronics
  - LAr calorimeter!



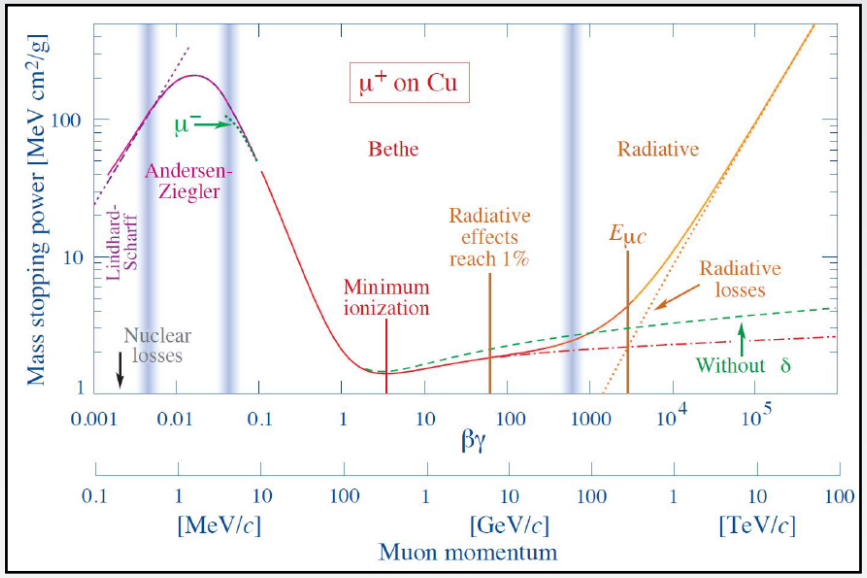
- Particles above ~100MeV escape the rods
- Primary SM particles above 3 GeV can easily be detected by setup

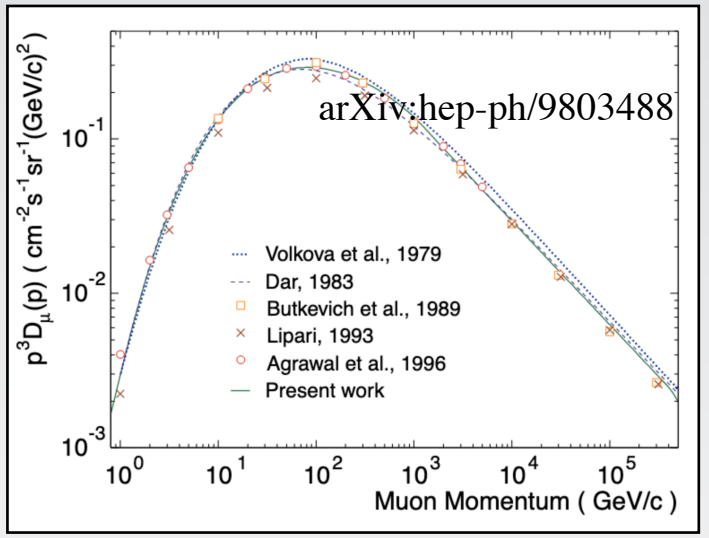


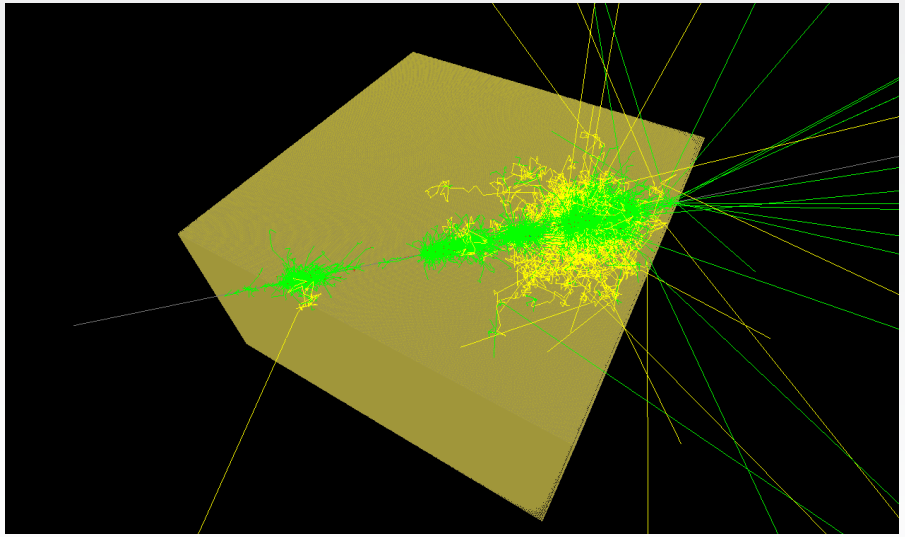


Backgrounds

- Detection happens far away from interaction point: **only background from cosmics**
- Shielding can reject everything but muons





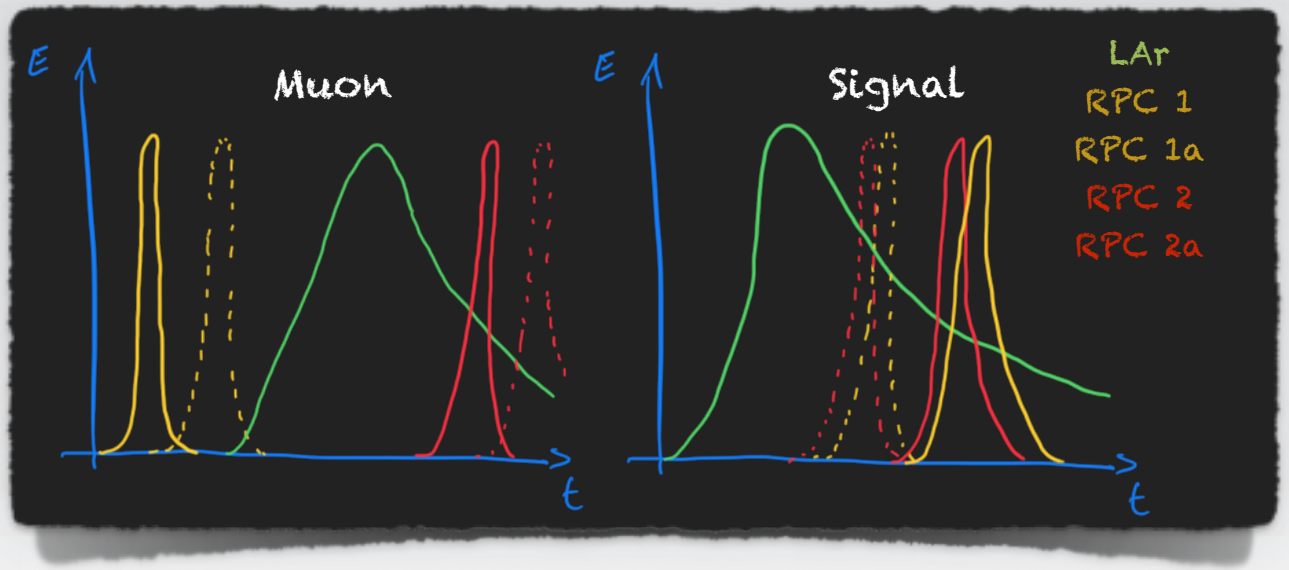


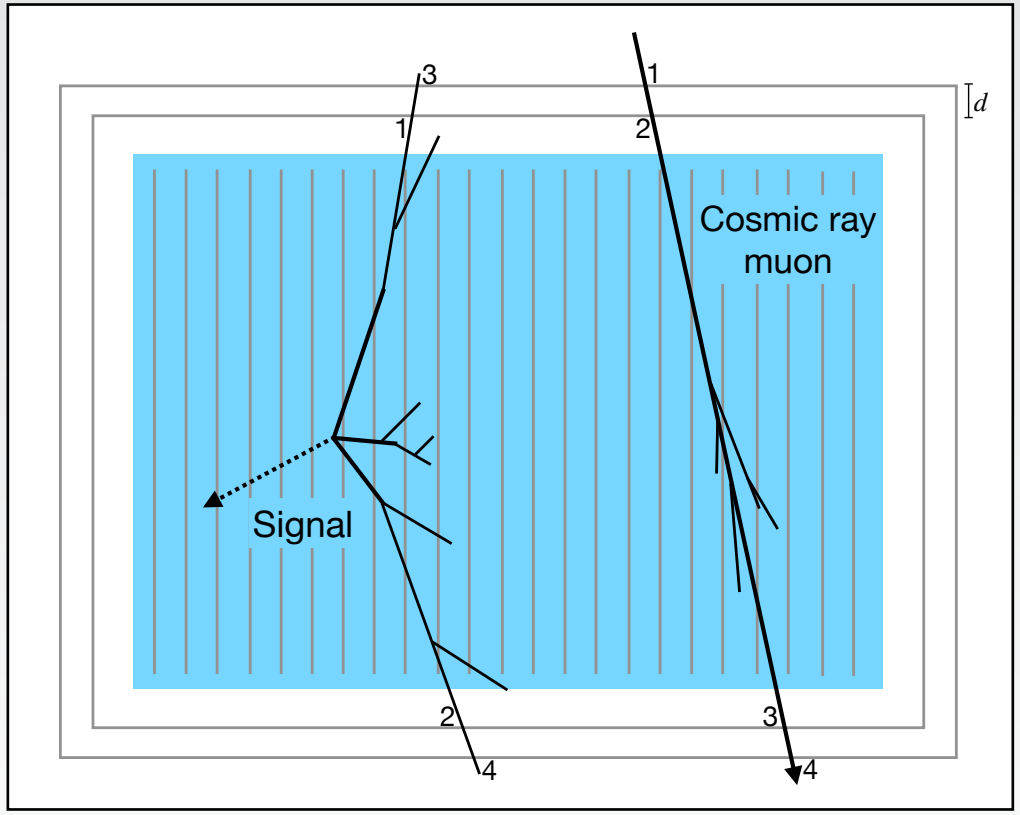
- Cosmic muons can fake signal: a few GeV for ~TeV muon

- Relative energy deposit studied in simulation
  (shooting from worst possible angle)

Cosmic Muon Rejection

- RPCs + timing can reduce the muon background



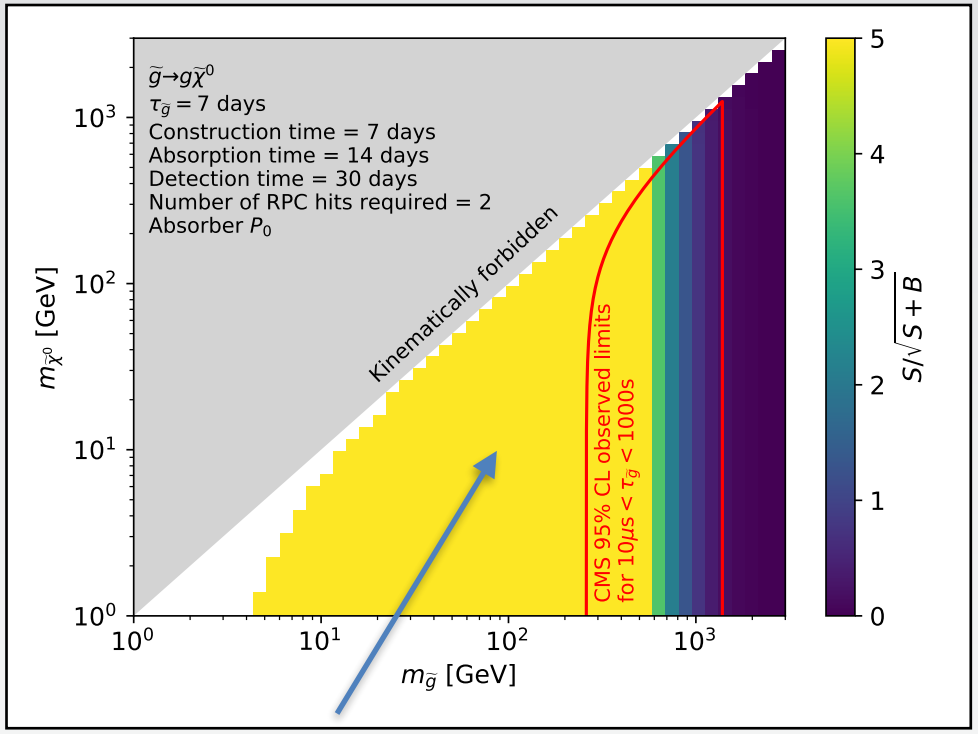


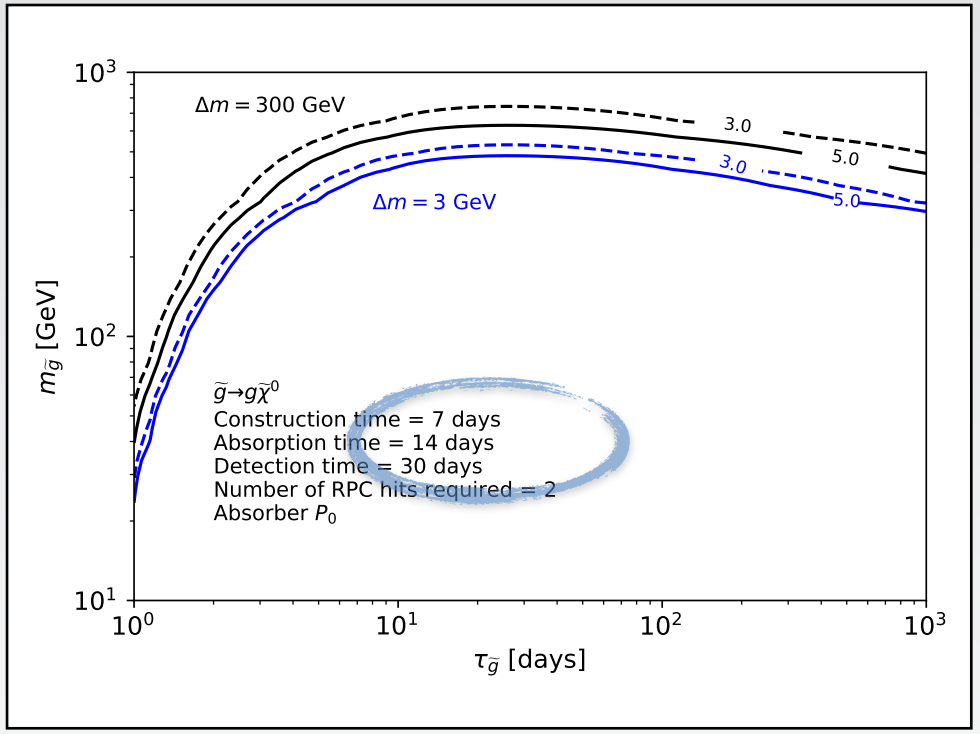
- Timing precision defined by distance (d):
  large enough, timing does not need to be very precise

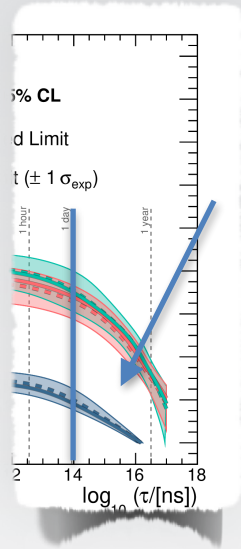
- Assume RPC efficiency + convolve cosmic muon spectrum with energy deposits from muons = background estimate
  - Can also be derived from data with unexposed rods!

- Take all muons that leave an energy above $\Delta m/2$

Sensitivity







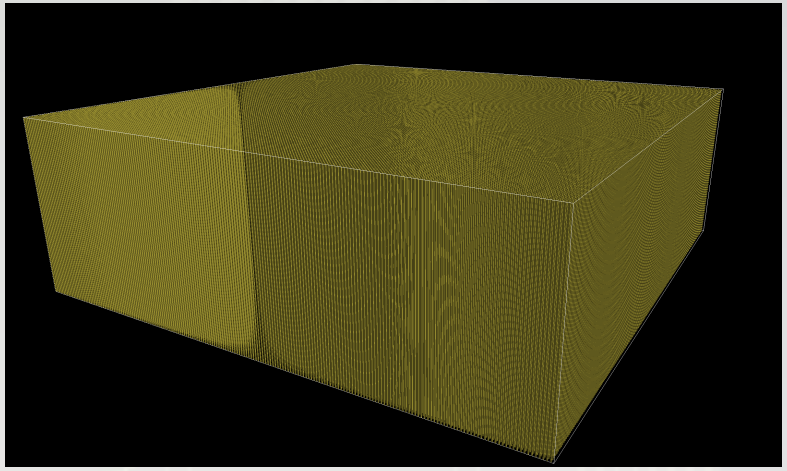
- Complimentary to ATLAS and CMS, in both mass and lifetime coverage
- Covering dark corners of the phase space

- Can target different lifetimes by adjusting exposure and detection times

Summary

- We propose a two-stage experiment to discover LLPs produced at the LHC, stop in detector material, and decay later

- Would bring unique sensitivity to the small mass splitting regime (~3-100 GeV)
- Uniquely sensitive to lifetimes on the order of days to years
- Possibility of discovery reach within a few months of operation



- Relatively low cost (~1M CHF)
- Construction could be carried out without interfering with existing scientific operations at CERN

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Backup

Fraction of Energy Deposited in LAr