The MATHUSLA Detector

Exploring the Lifetime Frontier and Cosmic Ray Physics

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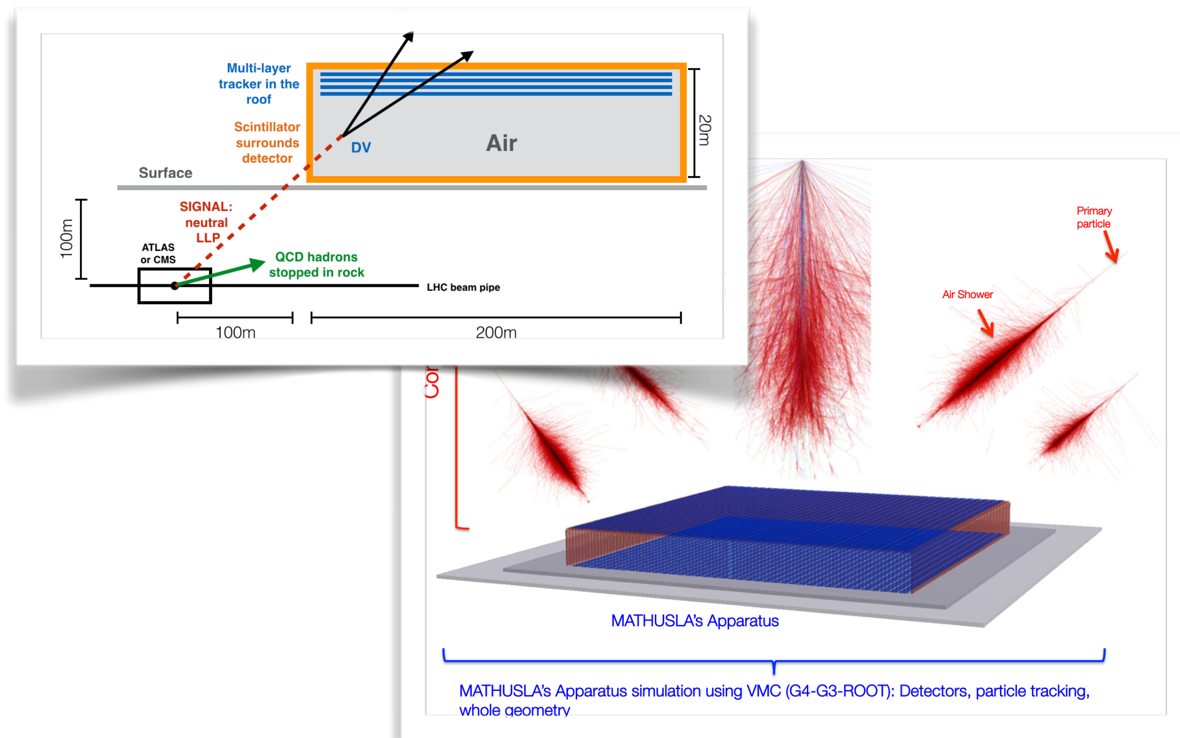
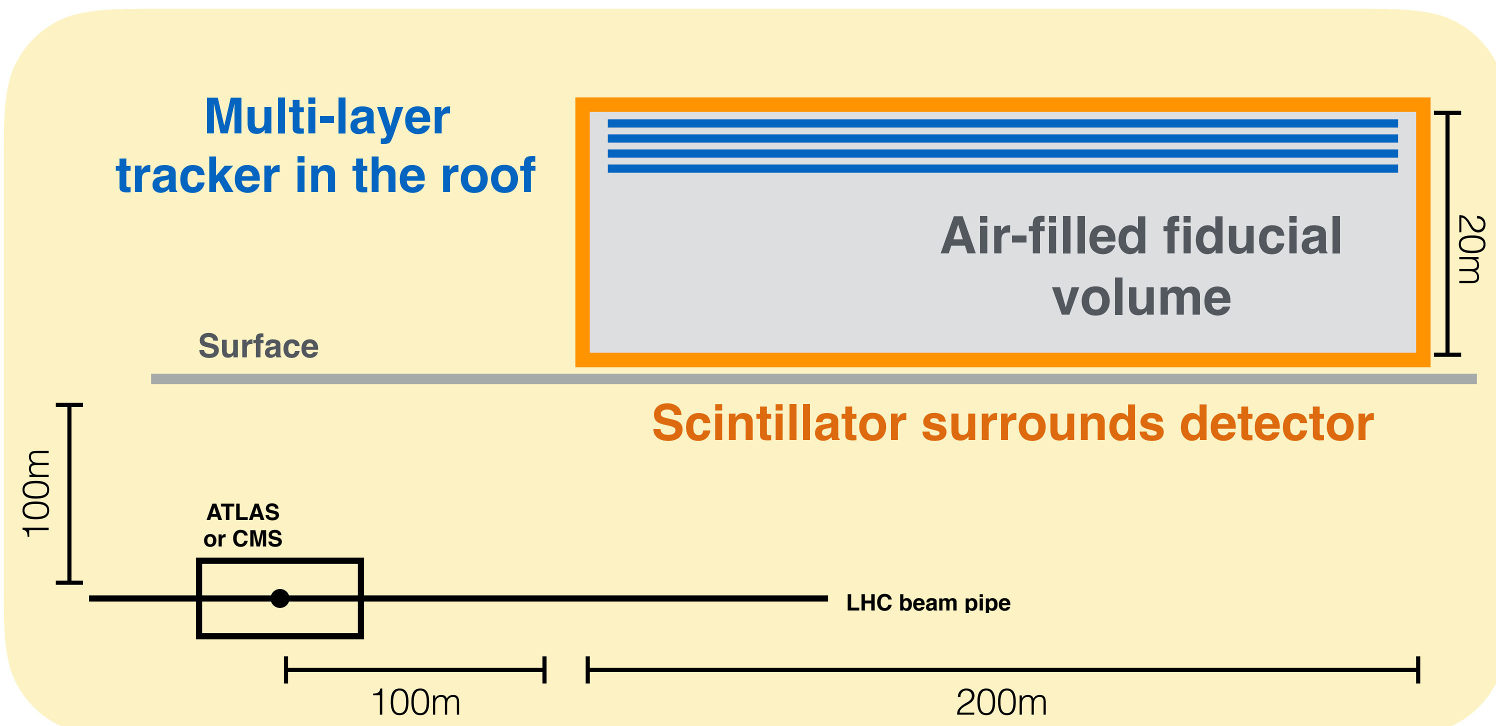
University of Toronto



The MATHUSLA Detector

MAssive Timing Hodoscope for Ultra Stable neutraL pArticles

A proposal for big tracker with a with a gigantic (~ 200x200x20m) fiducial volume on the surface above ATLAS or CMS at the HL-LHC



Chou, DC, Lubatti 1606.06298

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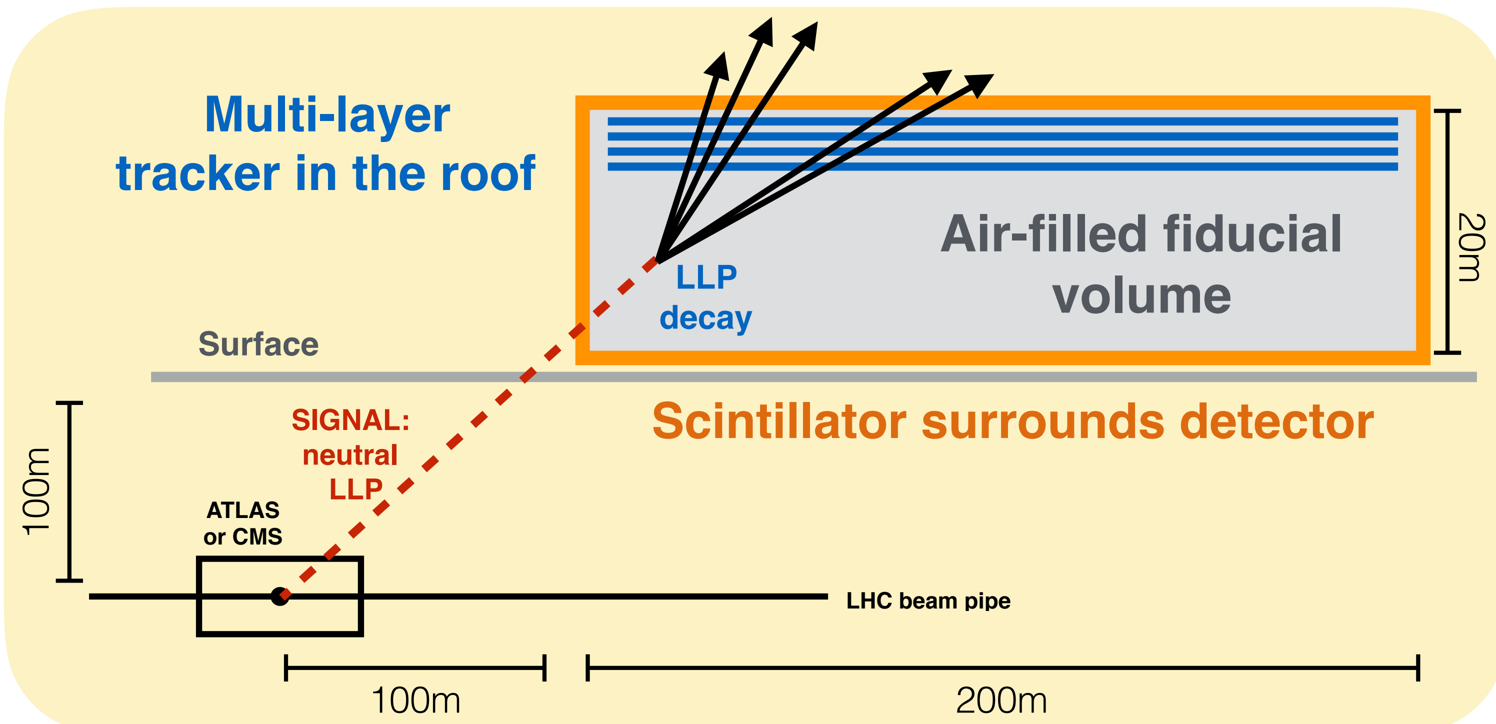
Aim: observe **BSM Long-Lived Particles (LLPs)** produced in LHC collisions



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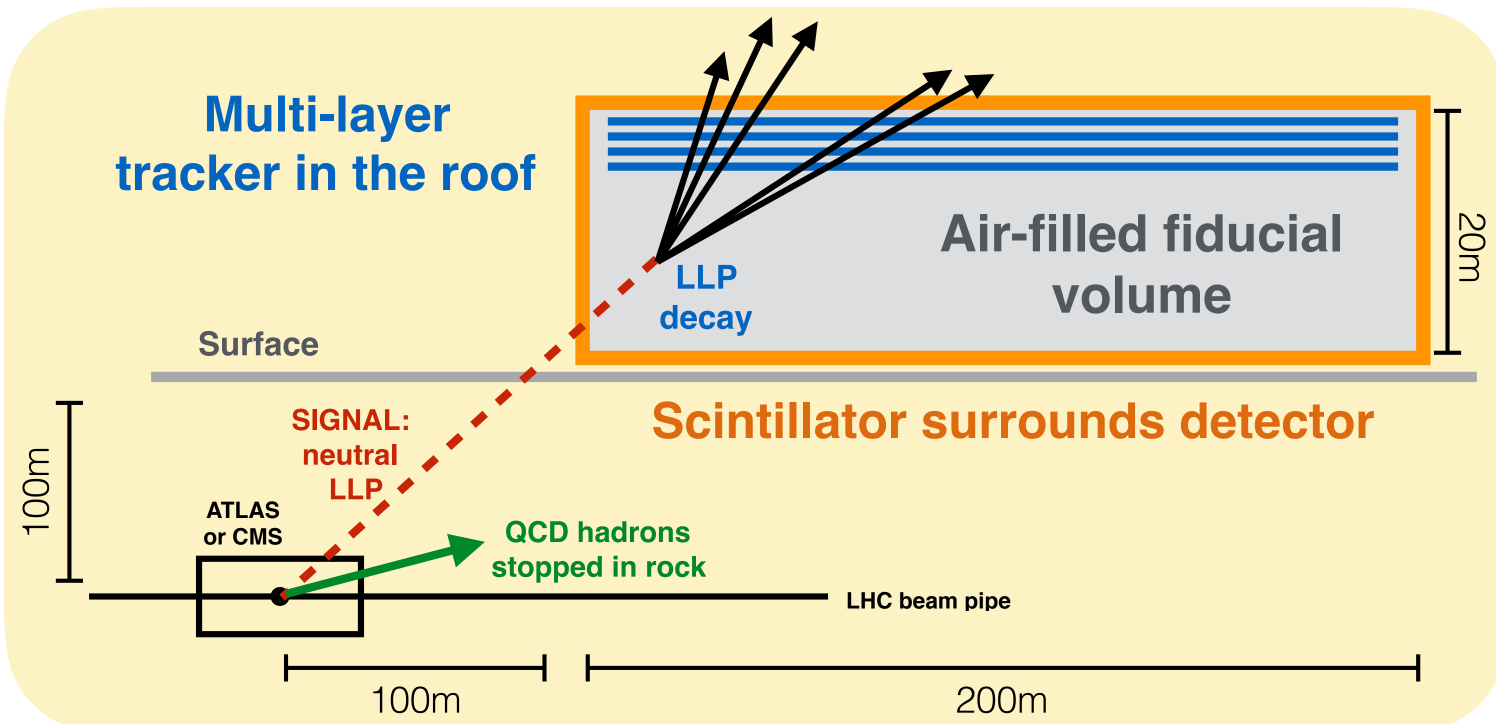
LLPs are difficult to see in LHC main detectors.
MATHUSLA does not suffer from collision-related backgrounds.



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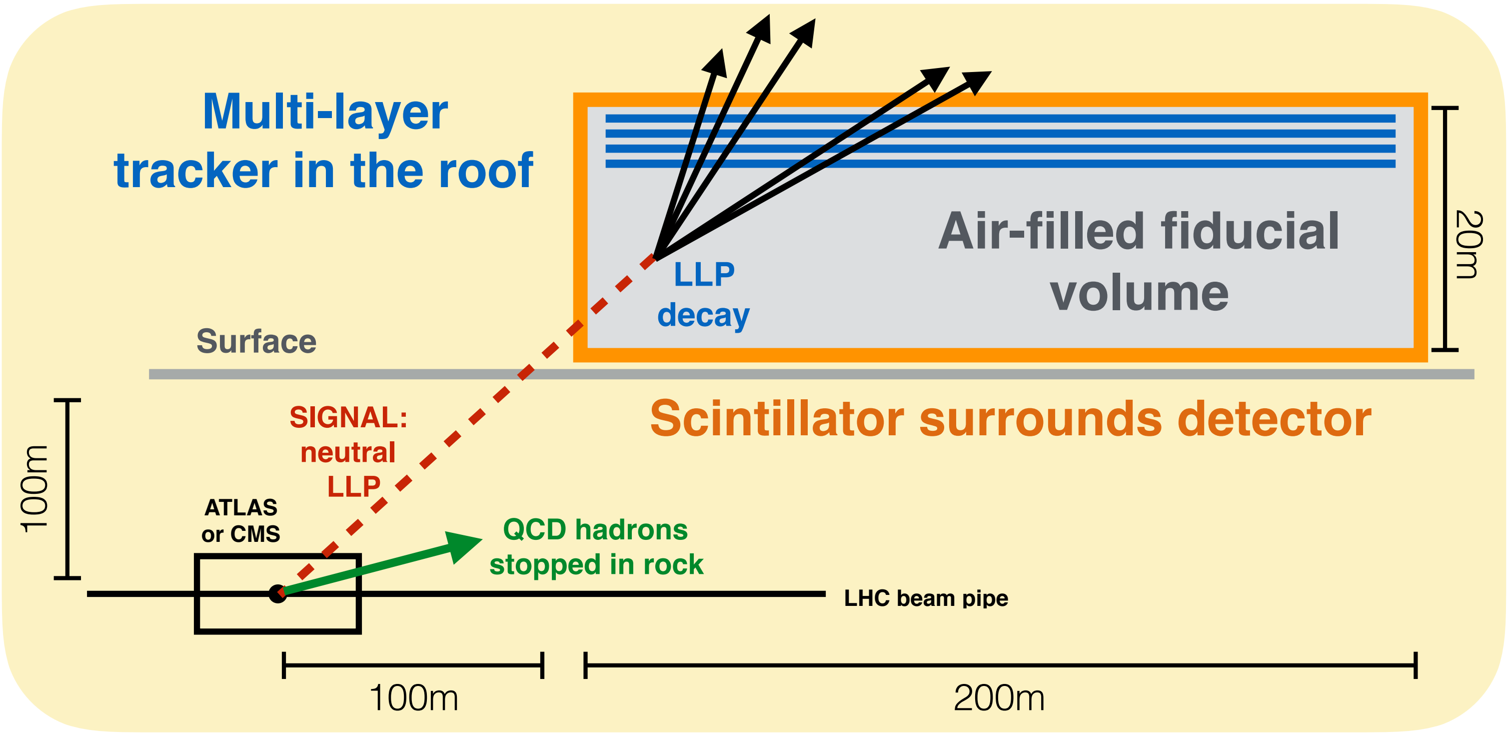
MATHUSLA does not suffer from collision-related backgrounds.

→ MATHUSLA is up to 10^3 x more **sensitive** to BSM LLP production ATLAS/CMS alone!



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BSM Motivation for the Lifetime Frontier

The theory motivation for building MATHUSLA is very strong

LLPs show up in ~ every BSM theory framework, and are the smoking gun of hidden valleys and non-minimal dark sectors.

These theories can solve many fundamental mysteries like the Hierarchy Problem, Dark Matter, Baryogenesis, …
but they would have escaped detection at the LHC so far!

Detecting Ultra-Long-Lived Particles: The MATHUSLA Physics Case

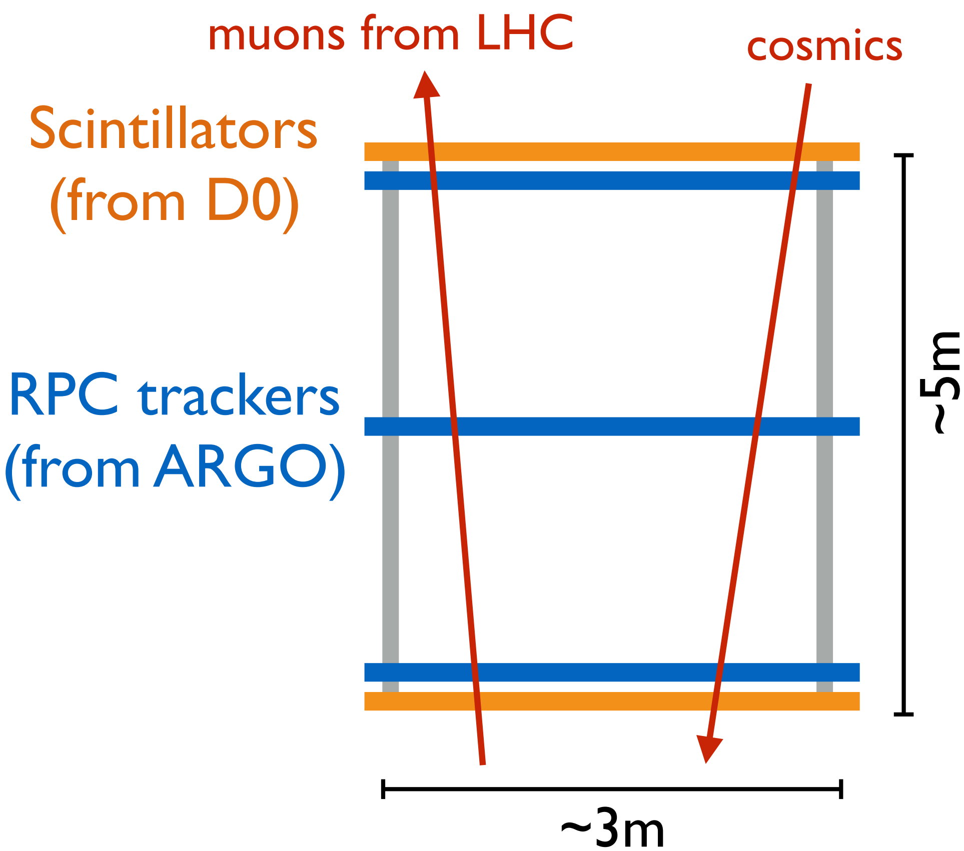
Editors:
David Curtin[1], *Marco Drewes*[2], *Matthew McCullough*[3], *Patrick Meade*[4], *Rabindra Mohapatra*[1], *Michele Papucci*[5], *Jessie Shelton*[6], *Brian Shuve*[7]

To be published later this year.

+ ~ 70 contributors

Status of MATHUSLA experiment

~ 40 experimentalists from ~ 10 institutions joined effort, including CR groups from ALICE and ARGO-YBJ



A small-scale **Test Stand** to demonstrate operation of a MATHUSLA-like detector is **currently under construction at CERN!**

Start taking data in a few months with beam on & off!

Cosmic Rays @ MATHUSLA

1. Cosmic Rays as Background to LLP decays

2. A dedicated Cosmic Ray Physics program at MATHUSLA?

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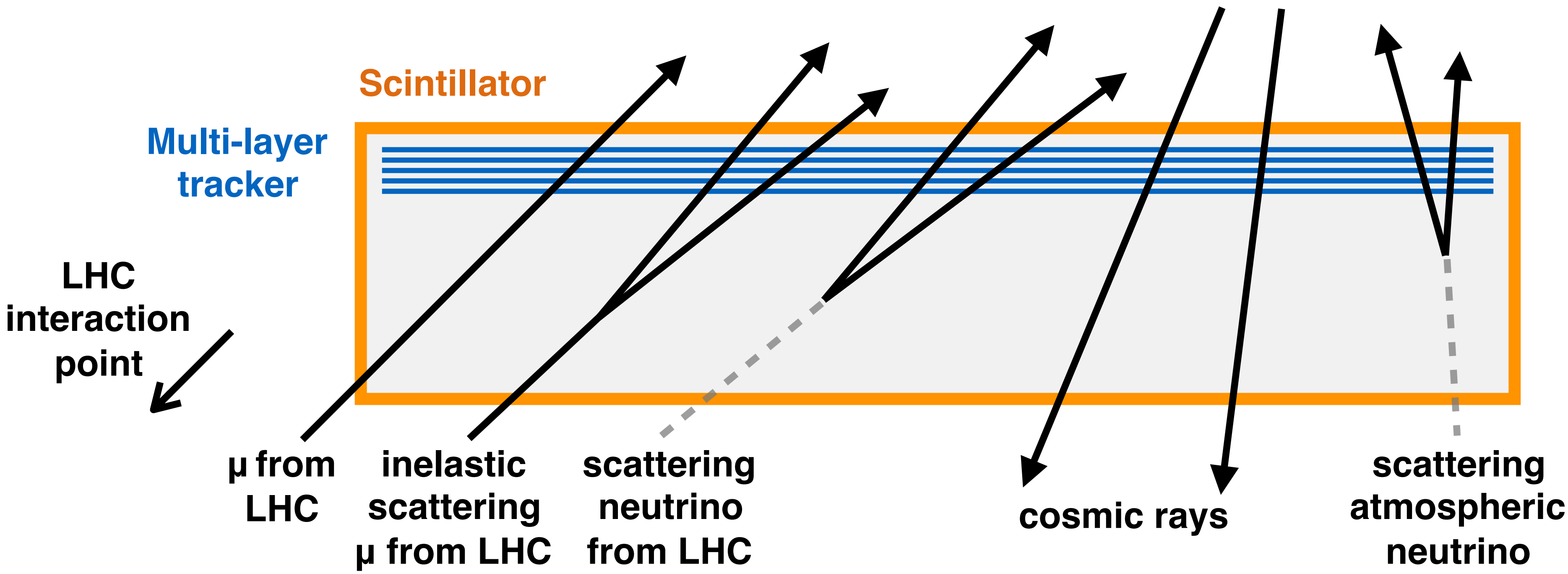
Background to LLP Detection



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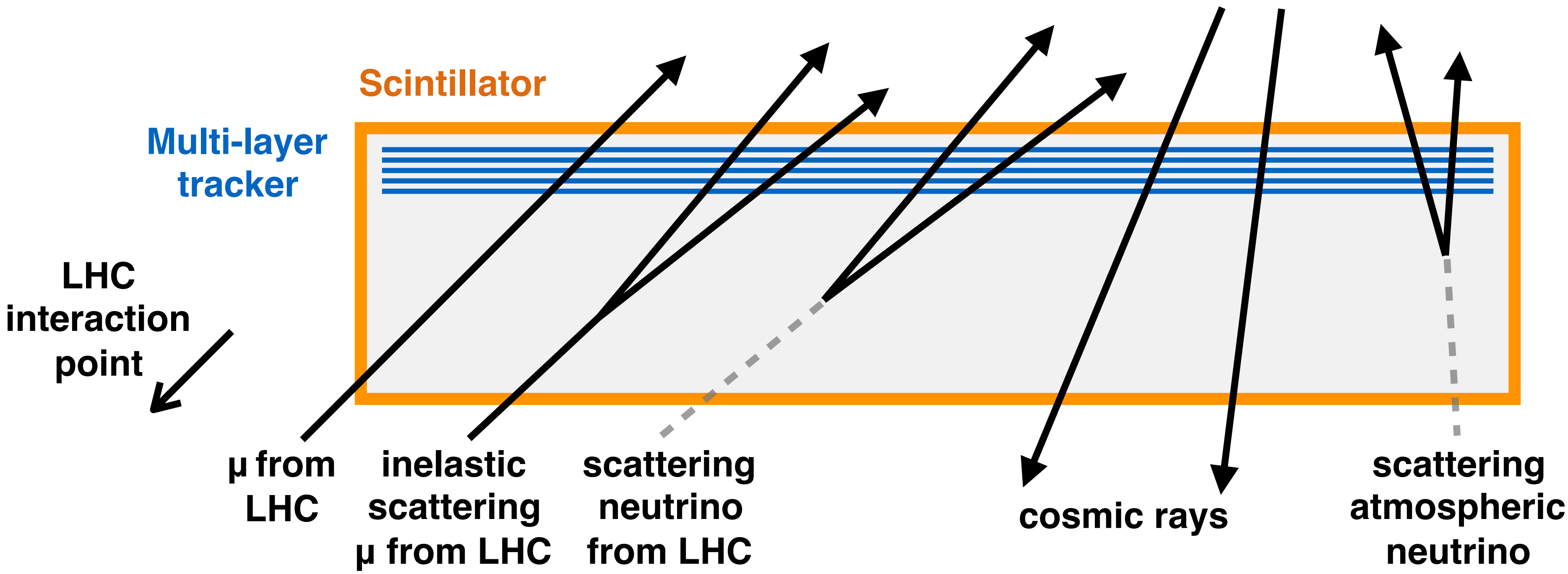
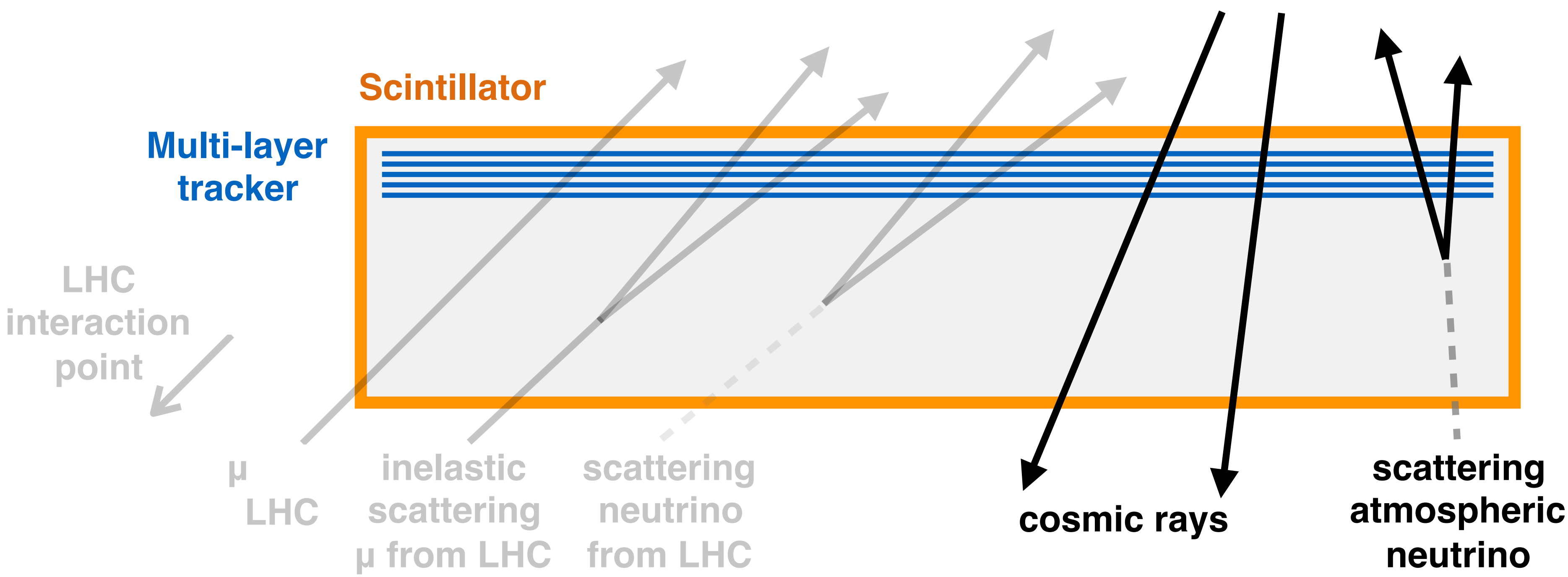


Claim: all of those can be rejected using geometry and timing of charged particle trajectory measurements

LLP decay signal is *highly distinctive*: many charged particles emerging from single point in space & time

Background to LLP Detection



Consider cosmic ray related backgrounds

Rejecting Cosmic Rays

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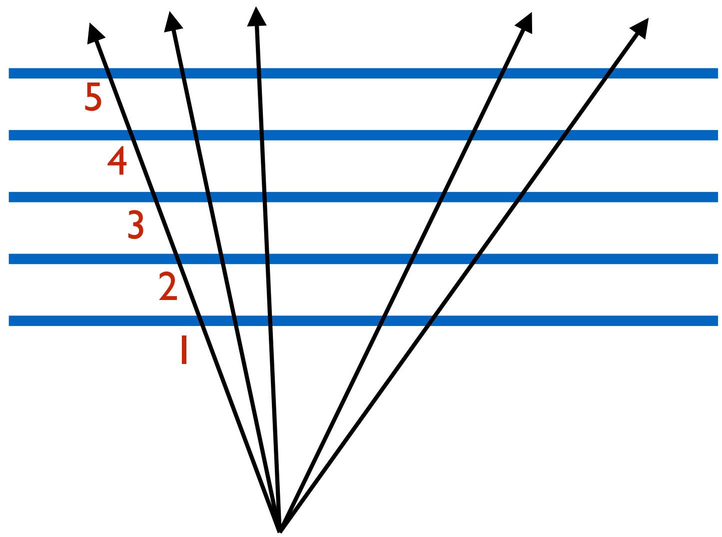
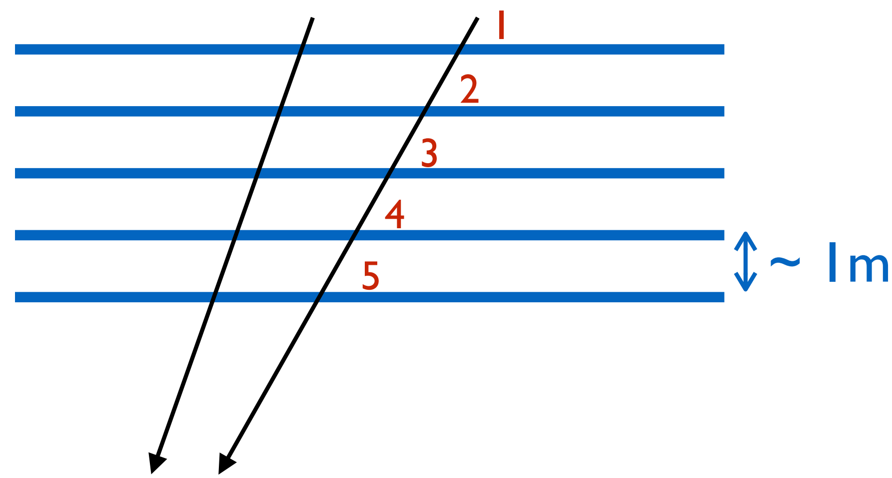
LLP Signal



(say) 5 tracking layers with ~ ns, cm resolution

Cosmic Ray: ~ 10^{14}/year



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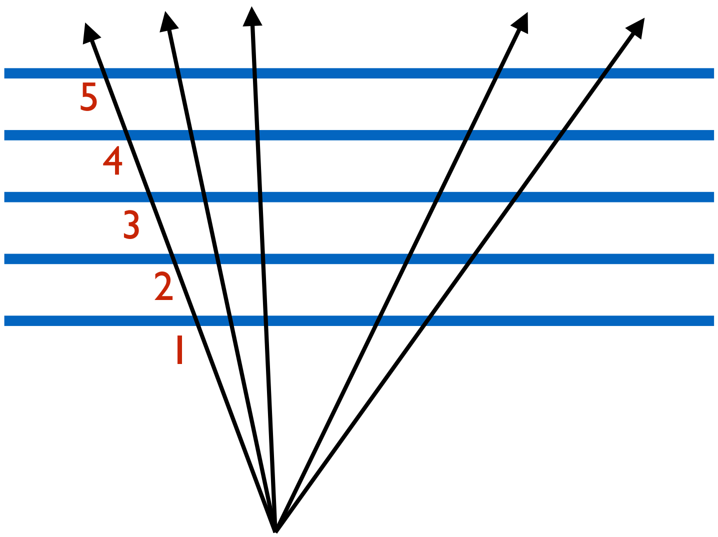

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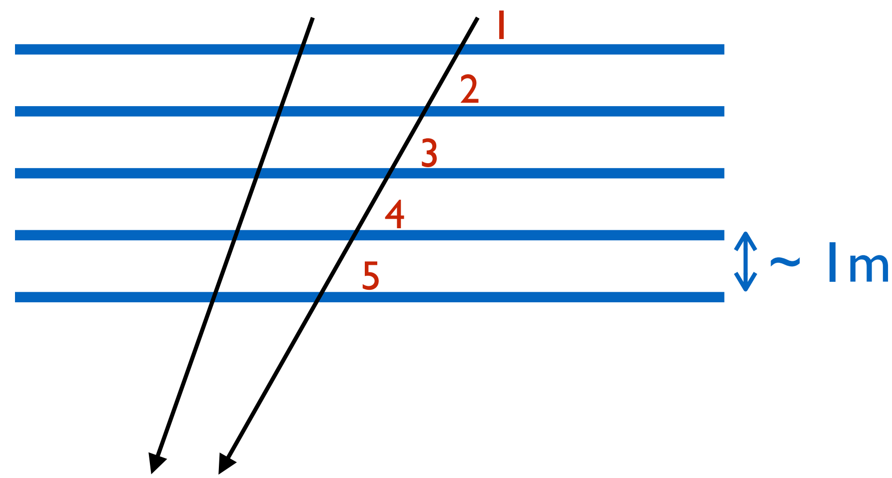

Stringent signal requirements:

→ hits in all (!) tracking layers

→ all tracks in region-of-interest must converge on displaced vertex (DV)

→ timing of track hits used to verify charged particles emerged from DV at same *instant in time!*

→ require otherwise relatively "empty" detector

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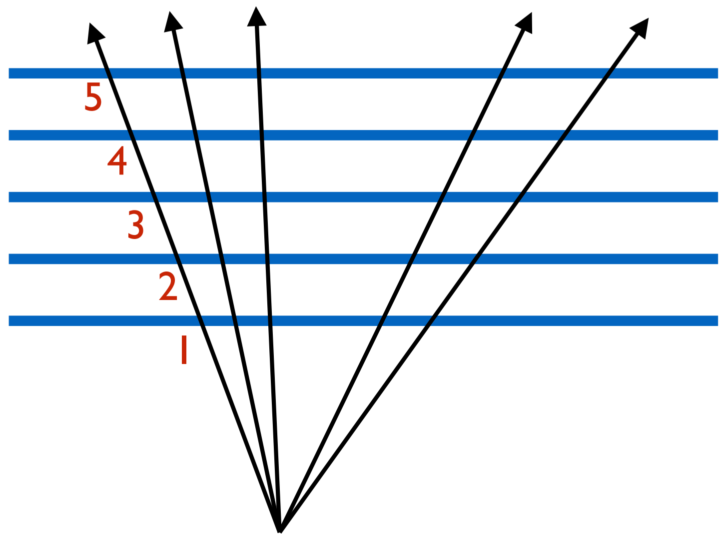
Rejecting Cosmic Rays

LLP Signal



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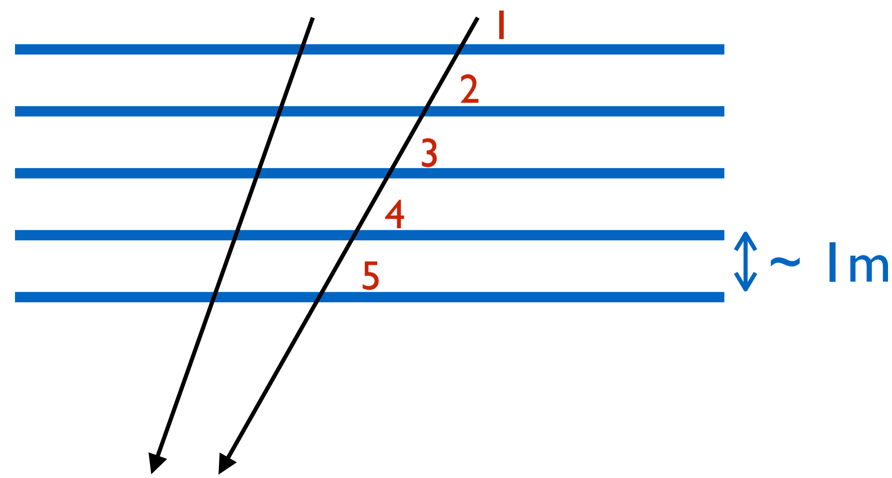

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Even if only 3 layers fire, rate of confusing single down-wards going CR for upwards-going charged particle is < 10^{-15}.

Only need 10^{-8} to reject fake DVs.

Could imagine (??) fake DVs from high-multiplicity CR events, but those are easy to reject.

Rejecting Neutrinos

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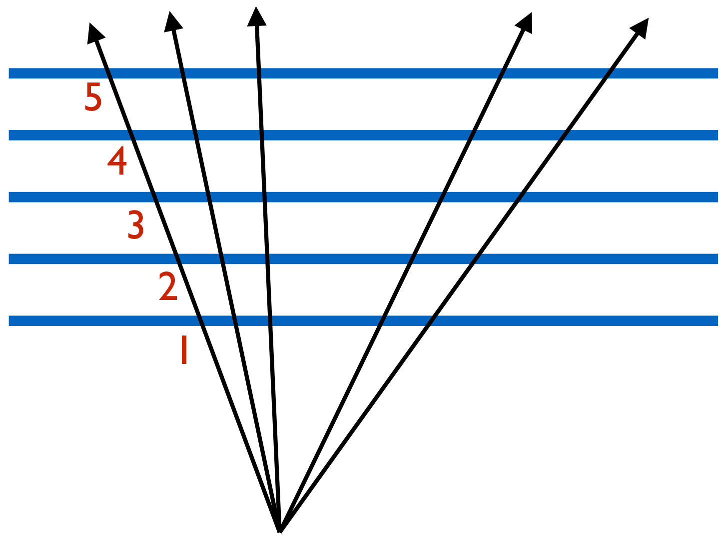
LLP Signal



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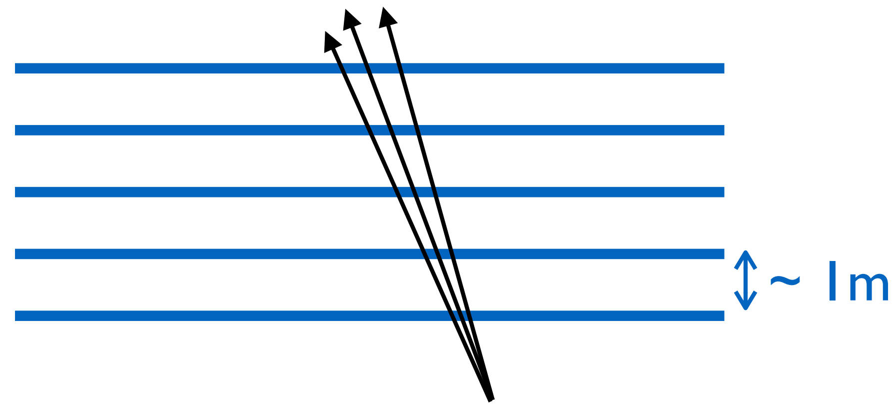
Neutrino Scattering: ~70/year



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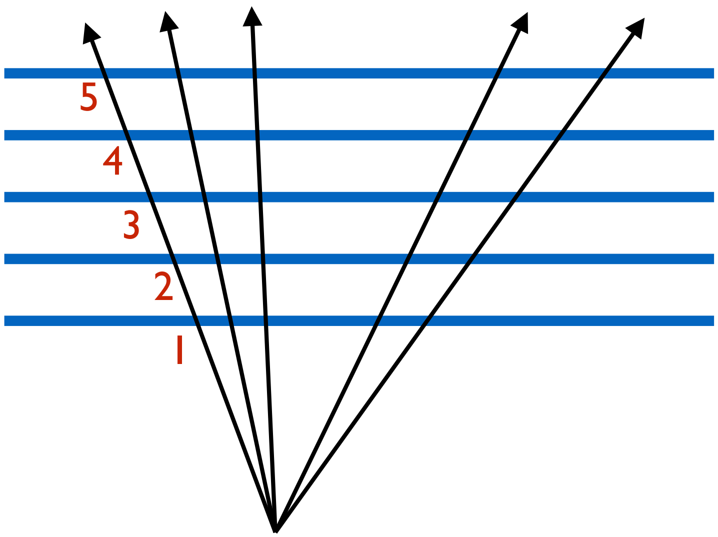

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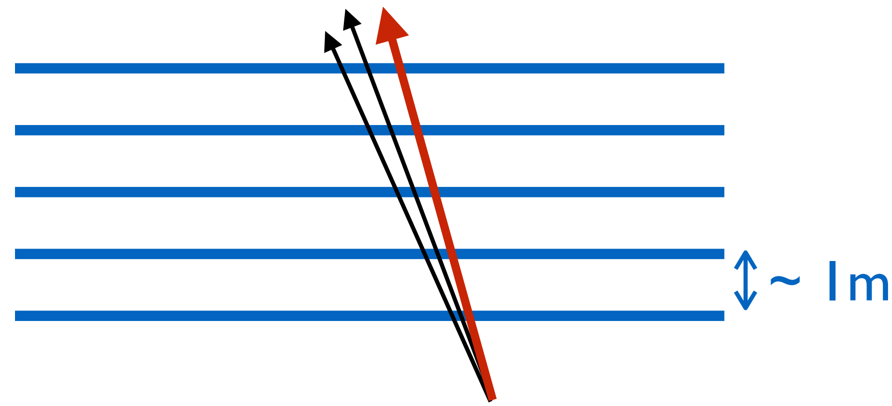

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Narrow opening angle, does not point back to LHC collision point.

Can be rejected with simple timing cuts, e.g. **90% have NR proton in final state, different from LLP signal**

Rejection of cosmic ray background looks *plausible* to allow background-free LLP detection.

Obviously, much more study is needed!
How many tracking layers are needed? 3? 7?

Requires full simulations & **data from the test stand!**

Hope to sort this out in time for letter-of-intent in 2018!

Join us if you're interested!

1. Cosmic Rays as Background to LLP decays

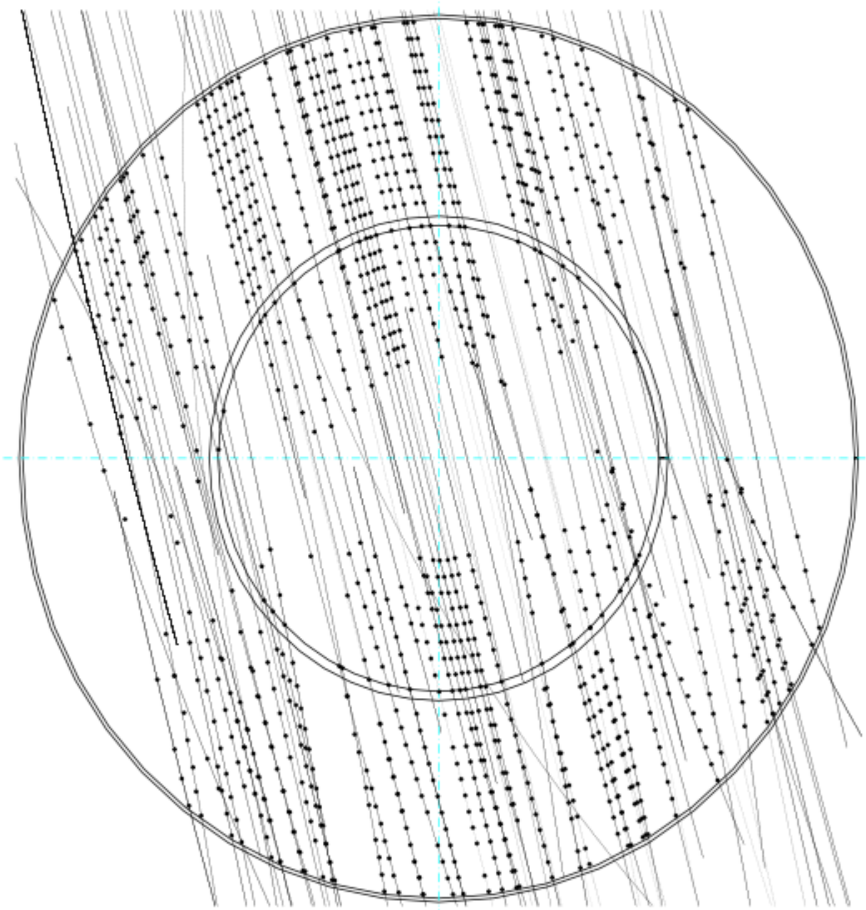
2. A dedicated Cosmic Ray Physics program at MATHUSLA?

High-Multiplicity Muon Bundles

The LEP detectors ALEPH and DELPHI did ~ 2 week measurements of CR muon multiplicity

CERN EP/2000-152
0706.2561

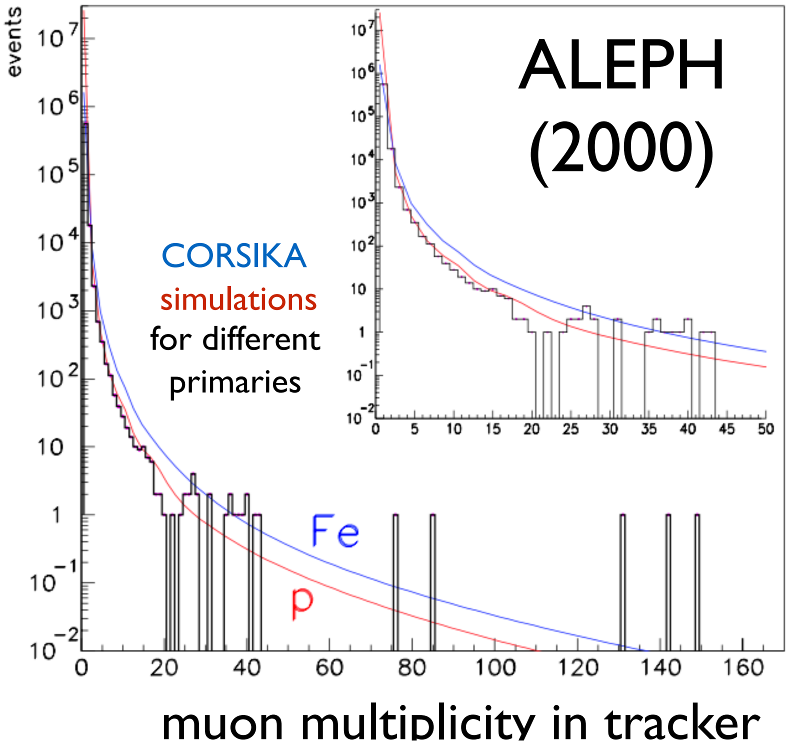
ALEPH: 140m underground $\longleftrightarrow$ E_μ > 70 GeV



Underground Collider Detectors probe different part of extended air showers (EAS) compared to surface arrays like KASCADE-GRANDE (E_μ > GeV) or deep underground detectors like MACRO (E_μ > TeV).

Measured muon multiplicity, spectra, etc are sensitive to **CR primary composition**

High-Multiplicity Muon Bundles

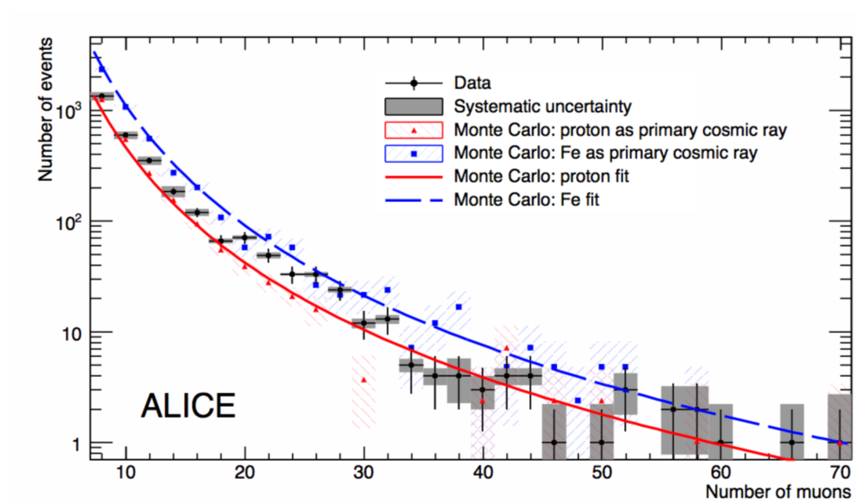


Measurement shows excess compared to CORSIKA - QGSJET of the time, even for pure Fe primaries

Connected to CR primary composition above the "knee", E > 10^{16} eV

Hints of high-E high-multiplicity muon excess at other experiments (NEVOD-DECOR, AUGER, IceCube)

ALICE did a similar measurement (1507.07577) with **E_μ > 16 GeV** which can be made to agree with **UPDATED CORSIKA - QGSJET** with large Fe primary fraction* above the knee, but uncertainties are large. **Need more data!**



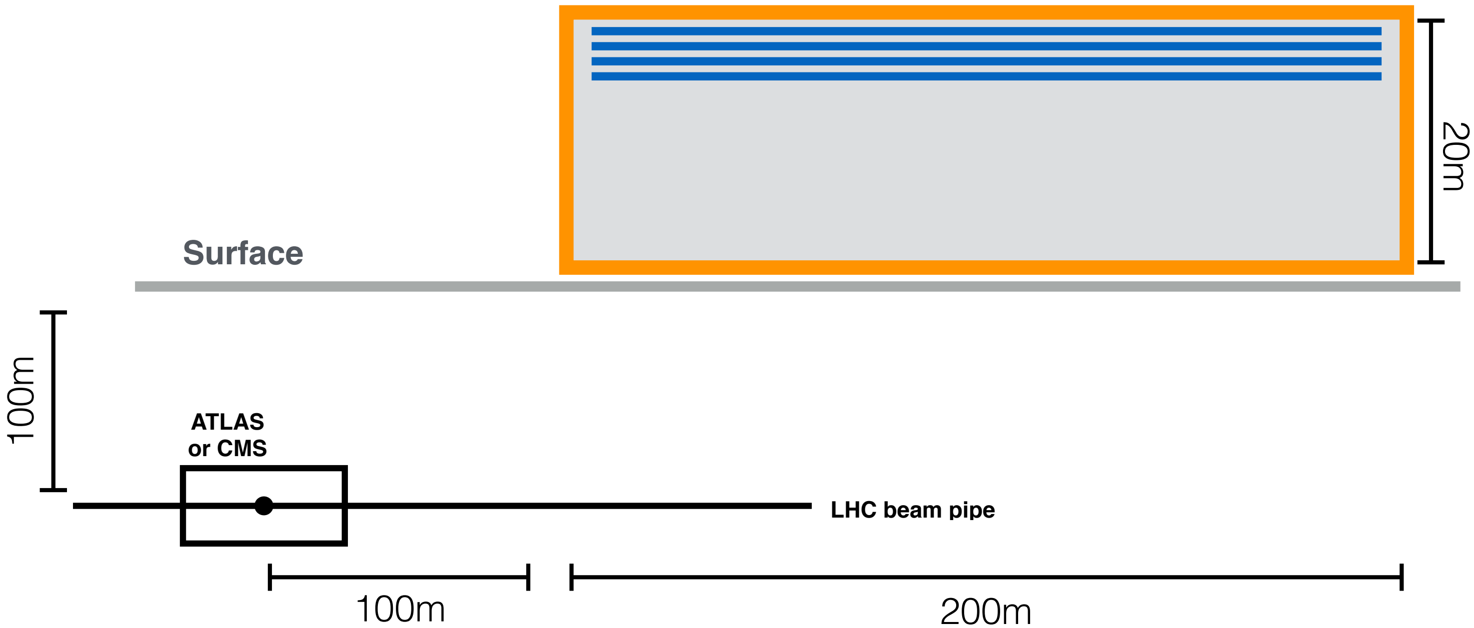
*e.g. KASCADE-GRANDE PhysRevLett.107.171104

Explanations?

Significant uncertainties in models of CR primary composition & hadronic interaction!

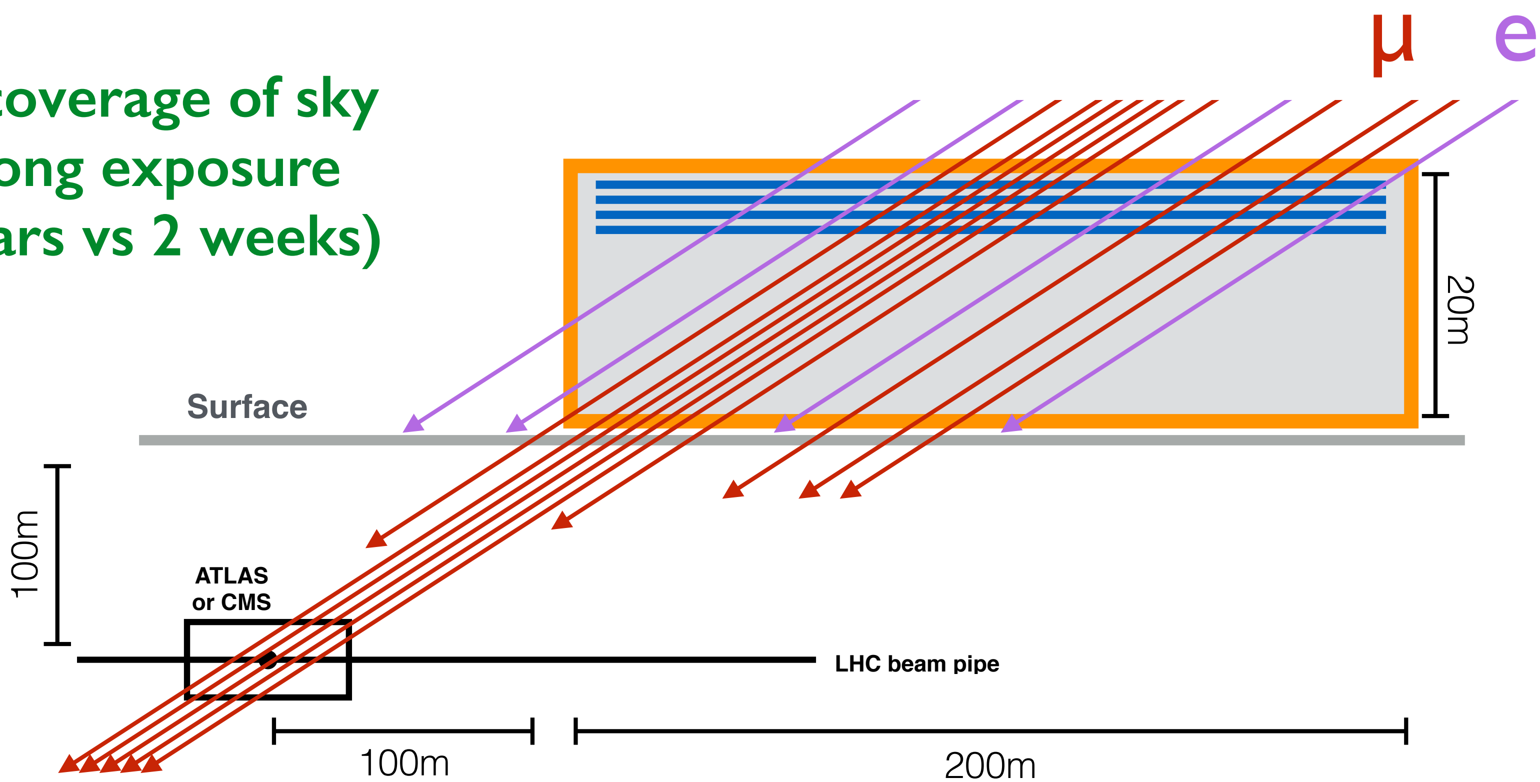
Nuclear Effects?	Klein nucl-ex/0611040
Quark-Gluon Plasma?	Ridky hep-ph/0012068
Strangelets?	Rybczynski, Wlodarczyk, Wilk hep-ph/0410064
Quark-Gluon Matter?	Petrukhin, Nucl.Instrum.Meth. A742 (2014) 228-231

Can MATHUSLA Help?



Can MATHUSLA Help?

~ 5% coverage of sky
but long exposure
(10 years vs 2 weeks)



Main detector can measure core of muon bundle (multiplicity, direction, spatial distribution, momentum)

MATHUSLA measures correlated e/μ (distinguish?) direction, spatial distribution at surface

Would require dedicated CR trigger at main detector
(new hardware? not sure yet…)

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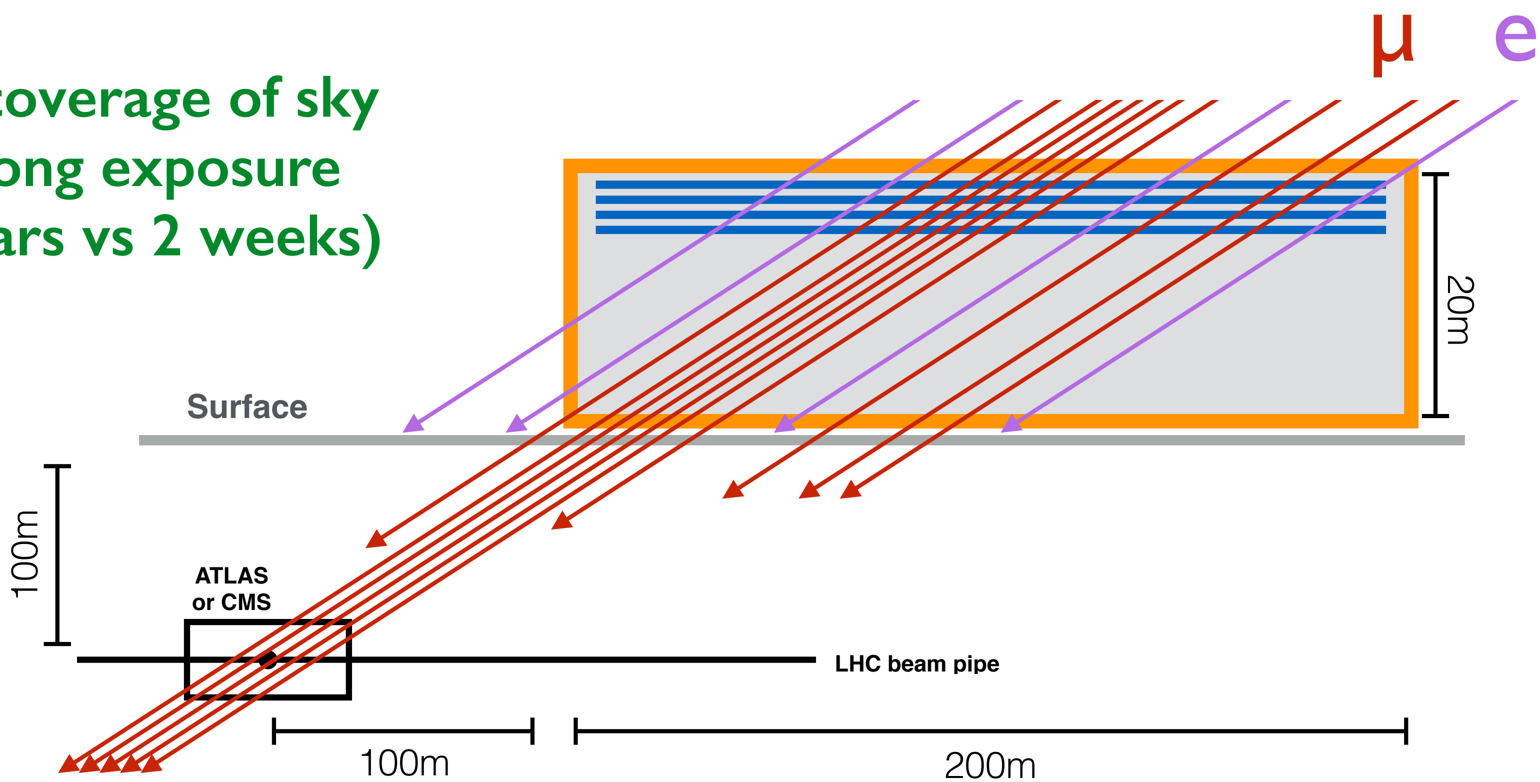
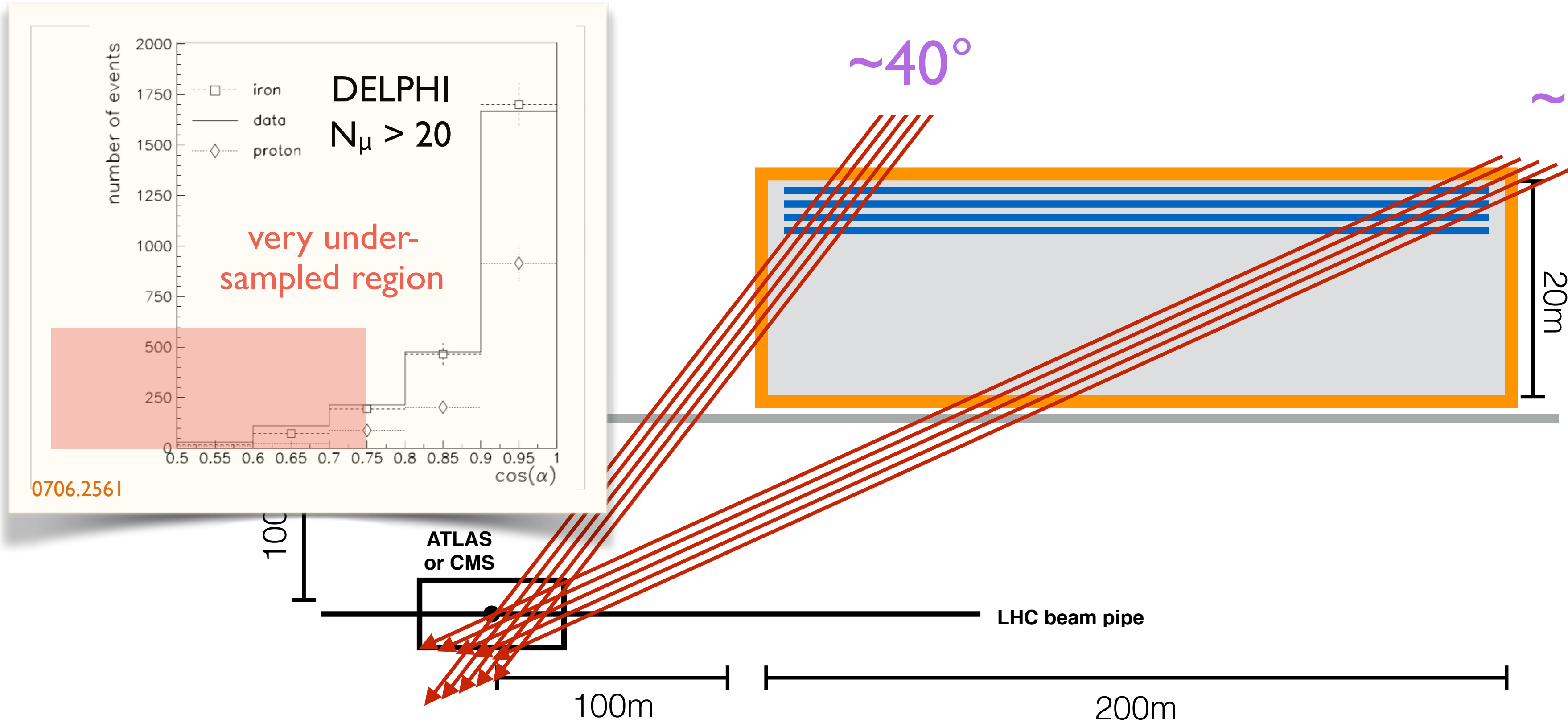


In this energy range, correlating underground data on muon bundle core (e.g. multiplicity, decoherence function) with shower data from surface could provide new sensitivity to hadronic interaction model or exotic bundle explanations?!

Can MATHUSLA Help?



MATHUSLA's **large size**, **vertical offset** from main detector, and **high exposure** also means you can probe detailed **muon bundle properties** at large range of inclination up to > 60°, which has never been probed with high statistics before.

Astropart.Phys. 14 (2000) 109-120

Will supply important information on primary CR composition above knee!

May even be able to see **ultra-high-energy neutrino primaries!**

Conclusion

MATHUSLA is a proposed BSM Long-Lived Particle surface detector for the HL-LHC.

LLP searches are highly motivated, and MATHUSLA improves main detector sensitivity by x 1000

Rejection of Cosmic Ray Backgrounds for LLP search is plausible but needs much more study.

MATHUSLA + ATLAS/CMS together may provide new data to probe CR primary composition above the knee and understand cause of high-multiplicity/high-energy CR muon excesses!

Thoughts? Suggestions?

Join us!

Backup

MATHUSLA + ATLAS/CMS vs other cosmic ray detectors

MATHUSLA + ATLAS/CMS:

- probe 100 GeV muons underground + full shower (for E ~ 10^{16} eV) at surface
- **granularity of detector:** resolve individual charged tracks (cm) and full coverage in detector area. No difficulty studying showers at high elevation.

Air Shower Arrays

- larger area to capture higher energy showers
- reconstruct primary energy/composition from sampling small shower fraction in ground detectors & fluorescent shower light detection
- no individual tracks, not full coverage on ground

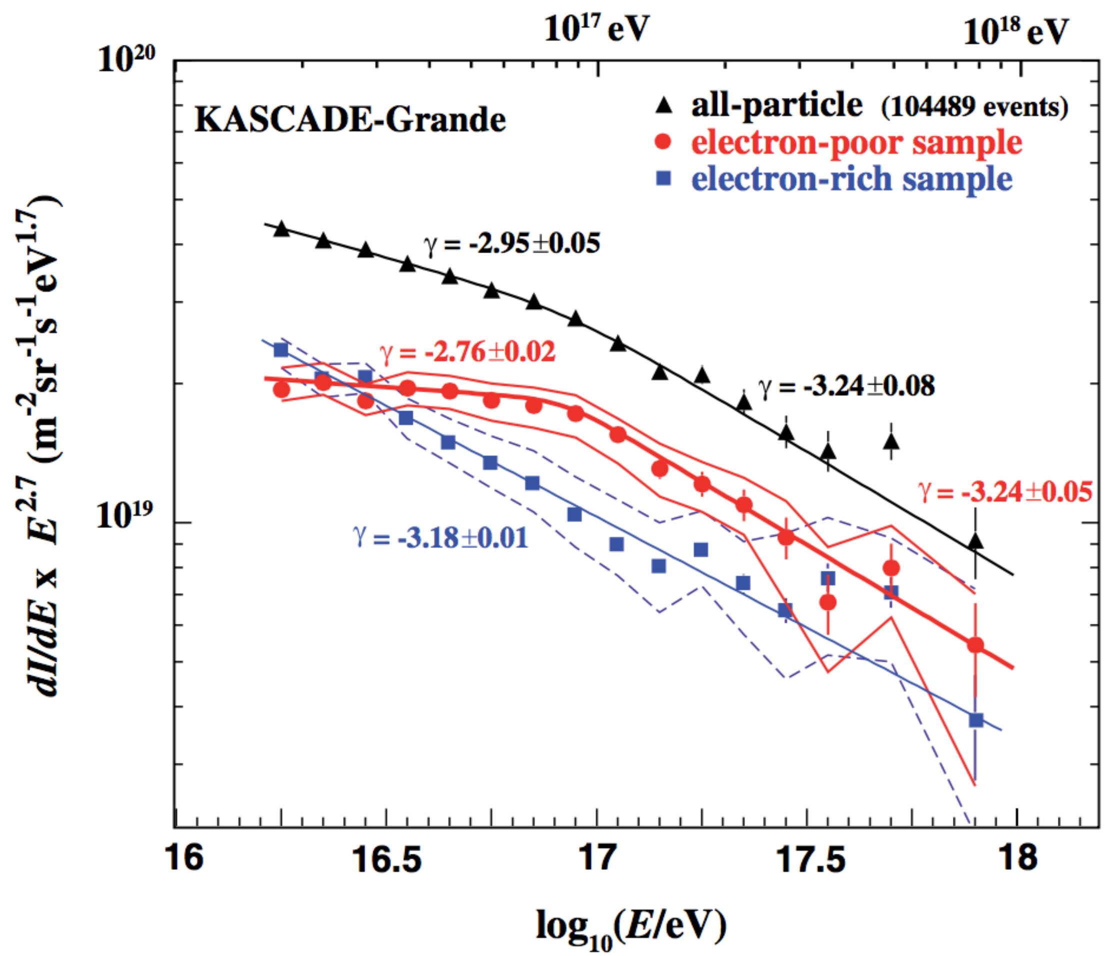
Ice Cube

- can distinguish single muons from muon bundles (dE/dx) but not individual muon tracks (scintillator pods are ~ meters apart)
- ..

Data on Primary CR composition

Still highly uncertain

KASCADE-GRANDE PhysRevLett.107.171104



iron + silicon

lighter nuclei