MATHUSLA: From the subatomic world to the stars

J.C. Arteaga-Velázquez[1] for the MATHUSLA Collaboration

[1]*Instituto de Física y Matemáticas, Universidad Michoacana*

XXXII Annual Meeting
Division of Particles and Fields
Mexican Physical Society

MATHUSLA: From the subatomic world to the stars

Content

1. Motivation
2. MATHUSLA detector
3. Cosmic rays in MATHUSLA
4. Cosmic ray physics case
5. MATHUSLA test
6. Finall remarks

Motivation

1. Standard Model of particles and interactions (**SM**):
   a. In very good agreement with most experimental data.
   b. But need to be extended as it does not explain

   - Dark Matter,
   - asymmetry of matter-antimatter in universe,
   - smallness of neutrino mass,
   - inflation,
   - how to solve the hierarchy problem, etc.

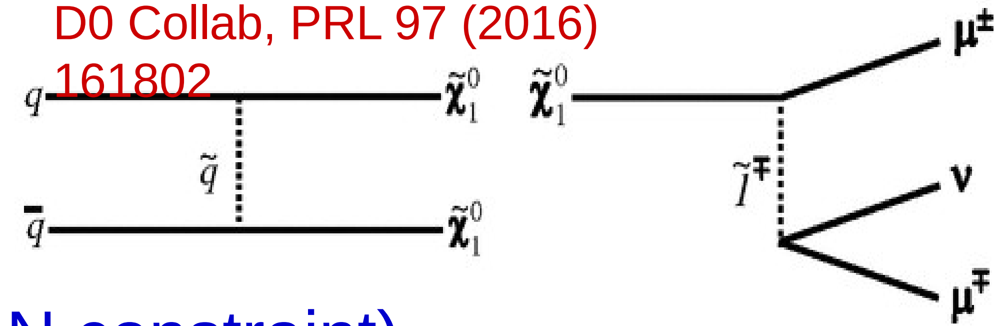
2. Physics beyond the SM is needed to solve these problems.
   They usually requiere the existance of new particles, e.g.
   neutral long-lived (**LL**) particles:
   Gluinos, neutralinos, hidden hadrons, etc.

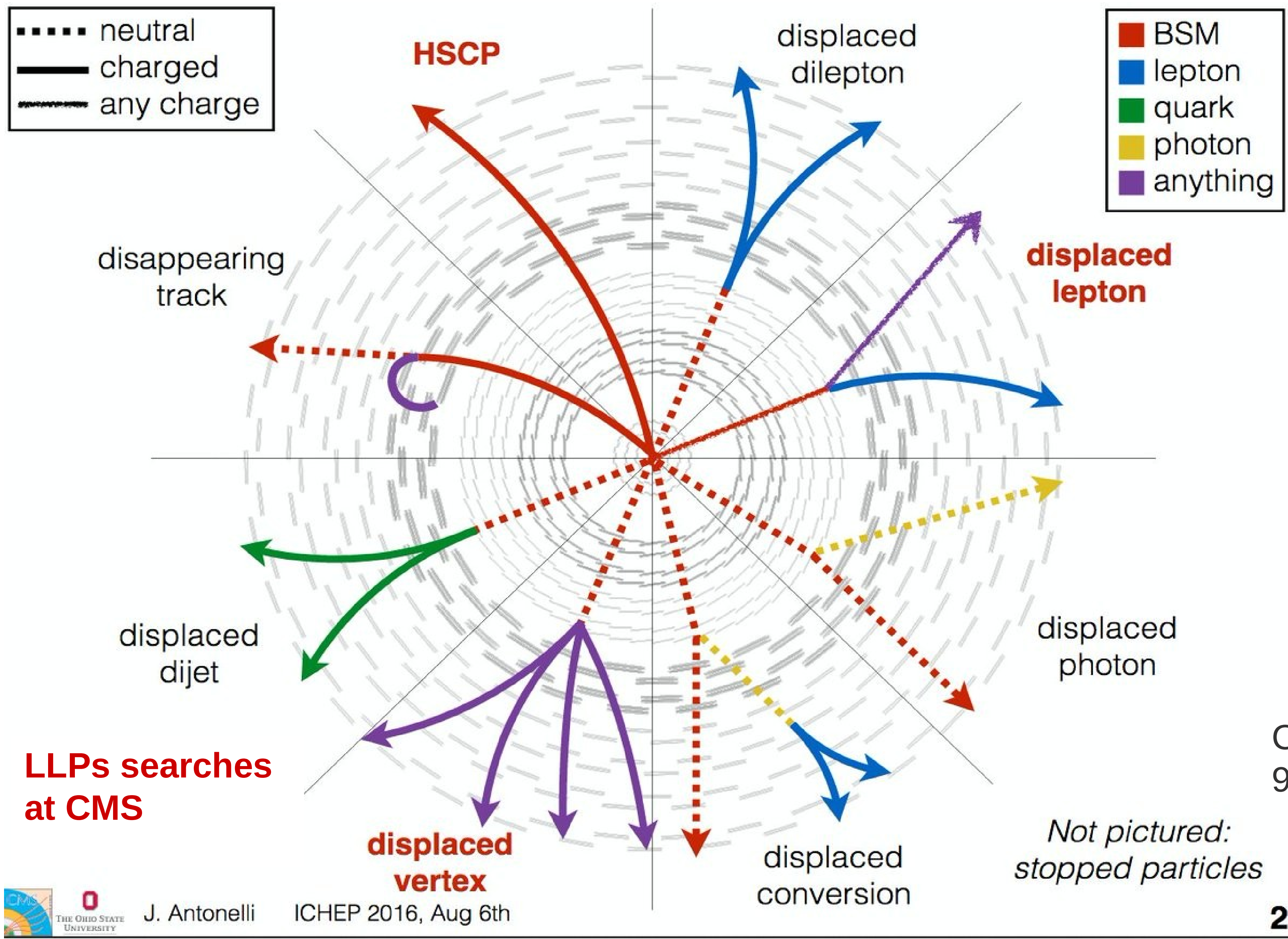
   D. Curtin aand Raman Sundrum, Phys. Today 70, 6, 46 (2017)

Motivation

3. Neutral LLPs:
   a. Non interacting with SM matter.
   b. Only visible once it decays.
   c. μm < Decay length ($c\tau$) < 10^7 -10^8 m (BBN constraint).

D0 Collab, PRL 97 (2016) 161802





LLPs searches at CMS

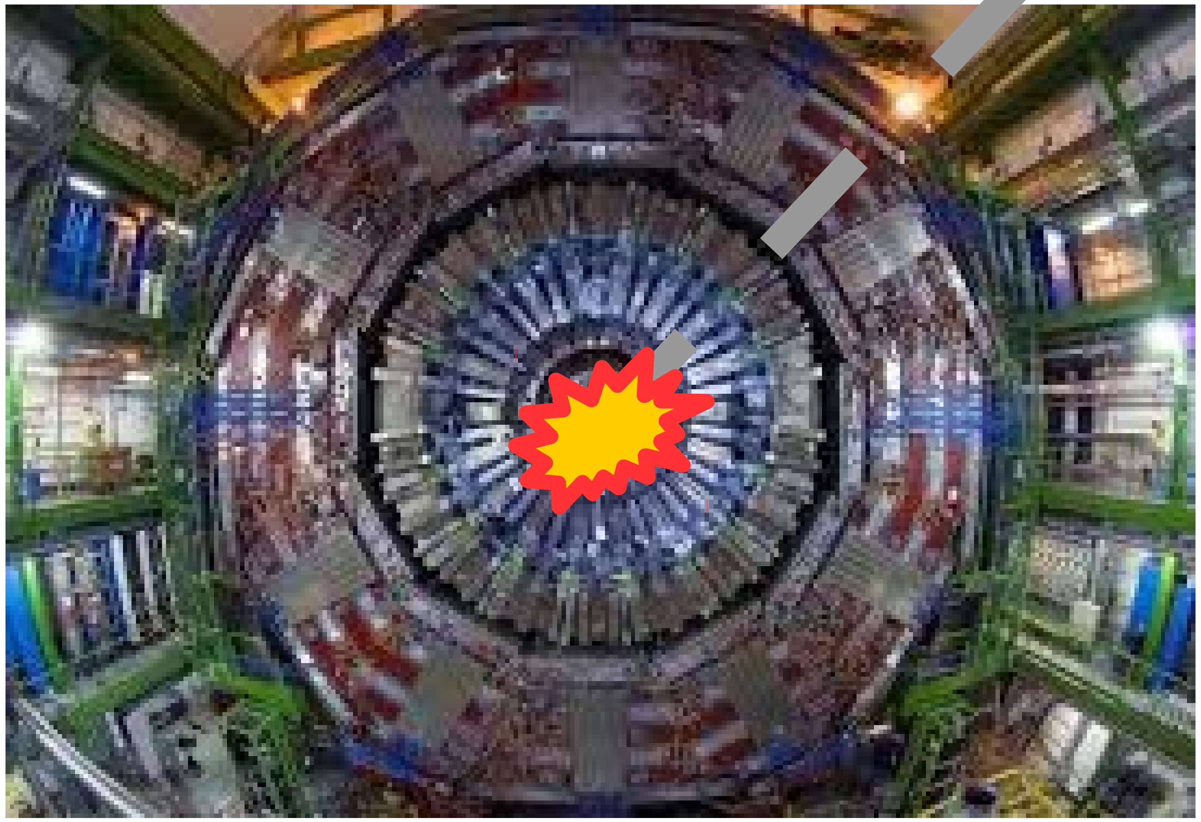
CMS Collab., PRD 94 (2016) 112004

Motivation

4. Detector size and QCD background constrain LHC searches of neutral LLPs:

   a. Ultra long lived particles (**ULLPs**, $c\tau \sim 10^7 - 10^8$ m) could escape without detection, even if they are detected

   b. it would be difficult to determine whether they are stable/unstable.



How to detect ULLPs?

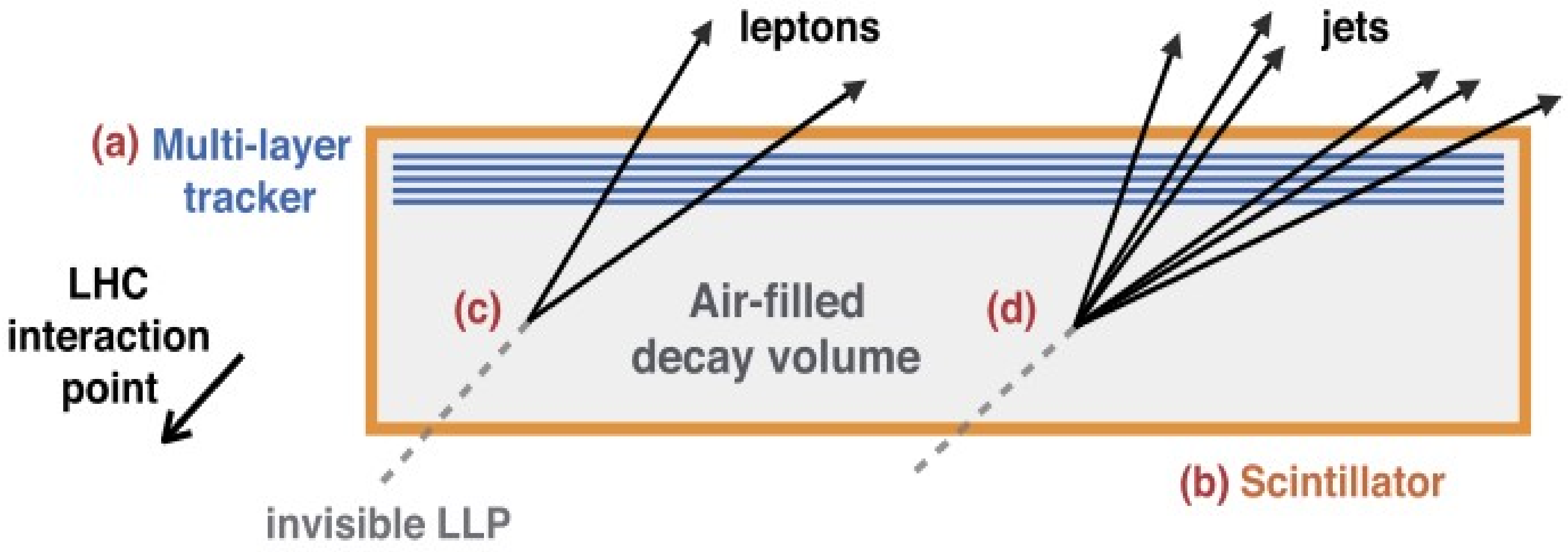
MATHUSLA detector

(**MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutral p**A**rticles)

1. Purpose:
- Search for LLPs with 10^2 m < $c\tau < 10^8$ m.
- To complement searches of LLPs at CERN.

2. Description:
- Large volume tracking detector on surface above LHC experiment.

3. Instrumentation:
- RPC tracking layers in a building covered by scintillator layers.



RPCs:

σx, σy ~ 1 cm

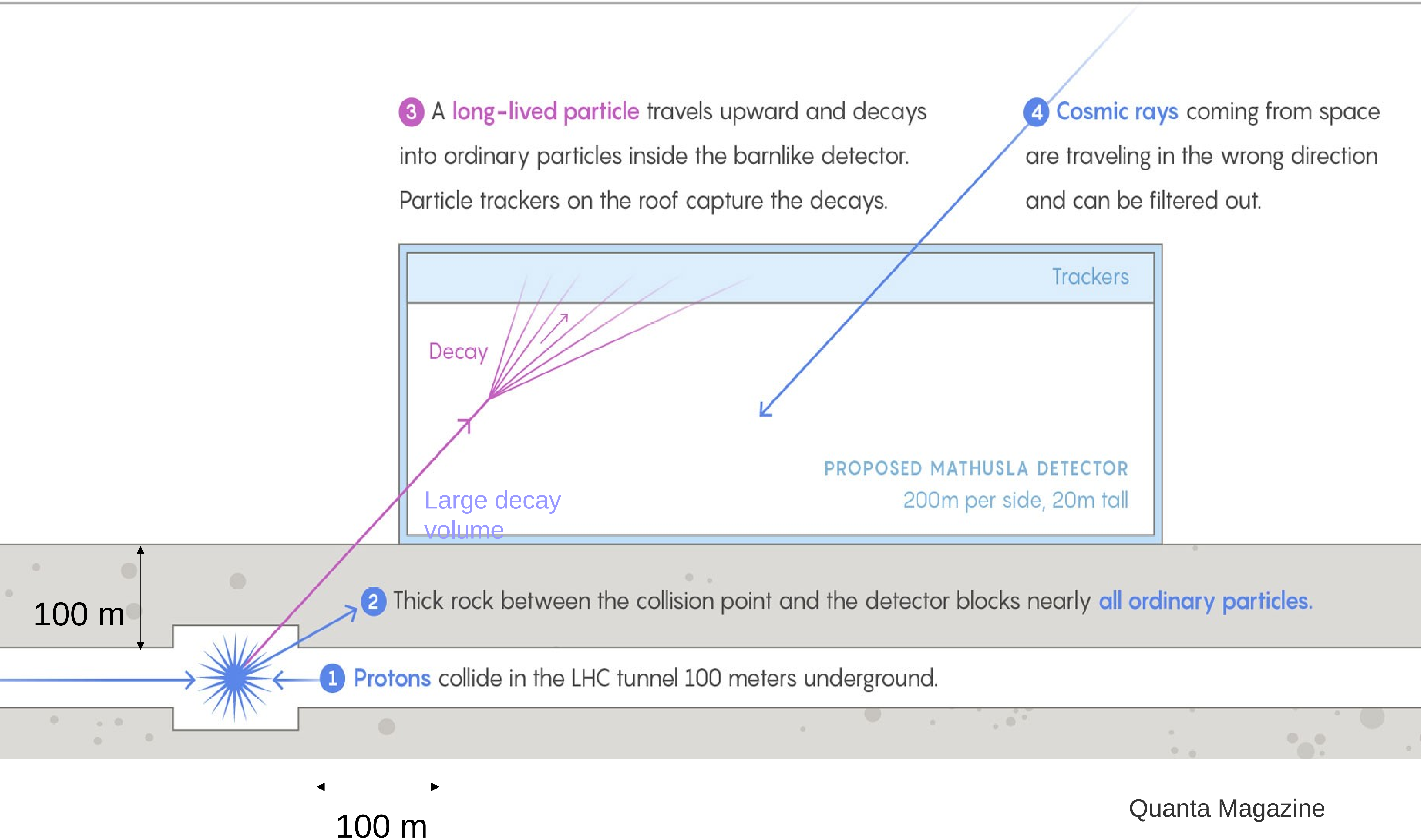
σt ~ 1 ns

J.P Chou, D. Curtin, H.J.Lubatti, Phys. Lett. B 767 (2017) 29

D. Curtin and M. E. Peskin, Phys. Rev. D 97, 015006 (2018)

MATHUSLA detector

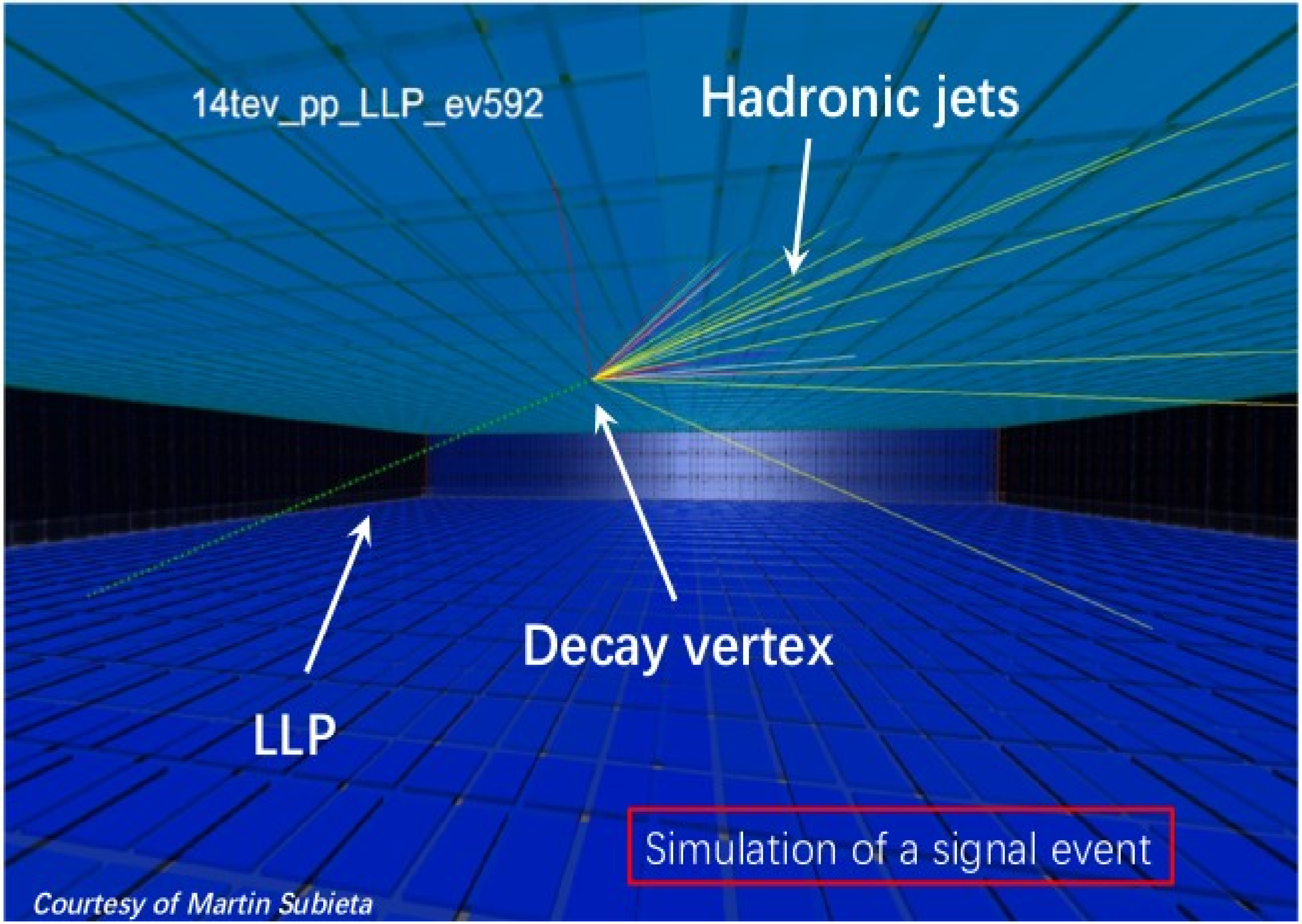
(MAssive Timing Hodoscope for Ultra Stable neutral pArticles)



Quanta Magazine

MATHUSLA detector

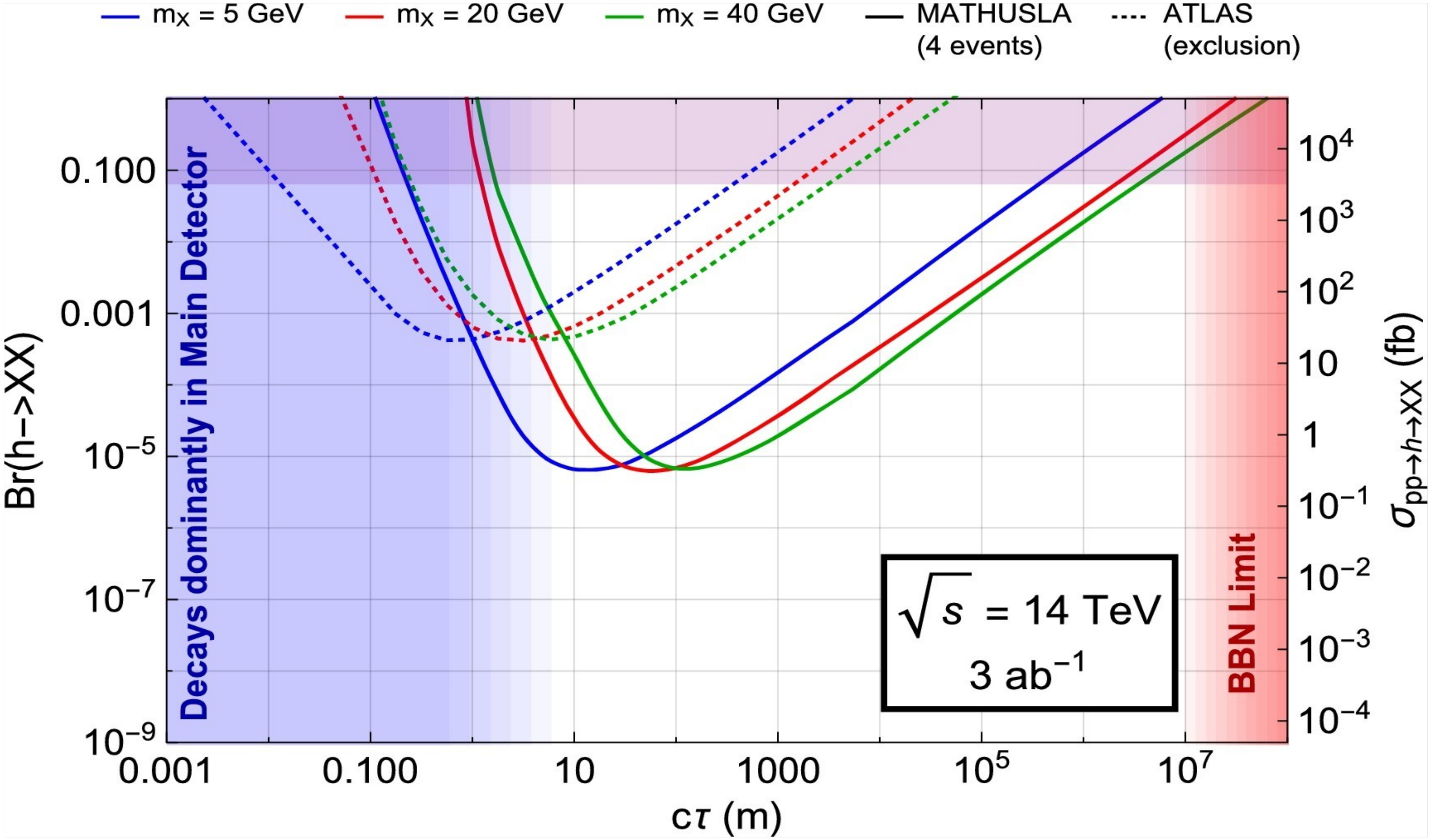
(**MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutral p**A**rticles)



C. Zhang, Pekin University, 2017

MATHUSLA detector

(**MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutral p**A**rticles)



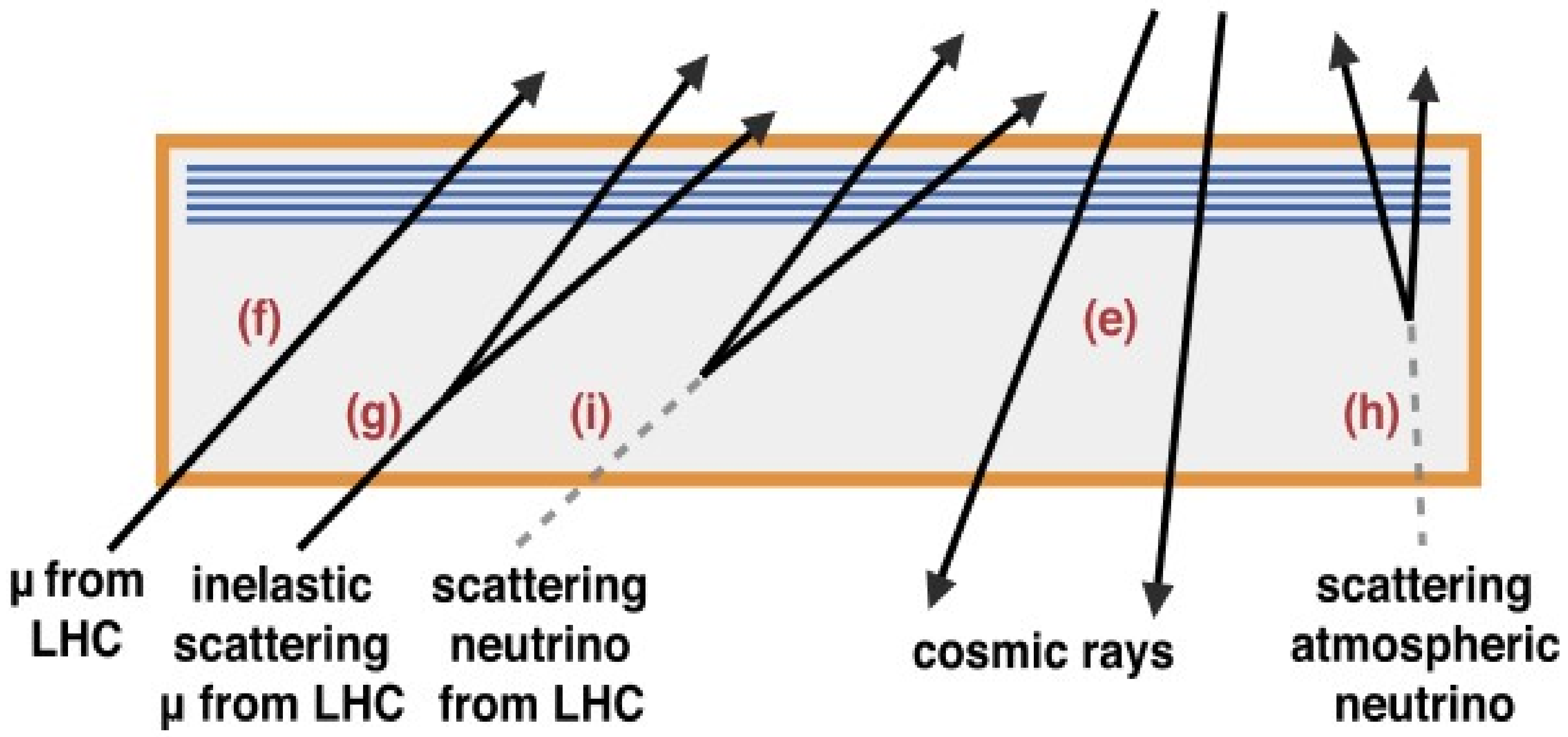
J.P Chou, D. Curtin, H.J.Lubatti, Phys. Lett. B 767 (2017) 29
D. Curtin and M. E. Peskin, Phys. Rev. D 97, 015006 (2018)

MATHUSLA detector

(**MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutral p**A**rticles)

4. Background:

- Neutrinos and muons from LHC, atmospheric neutrinos, cosmic rays
- Rejected from information of tracking system and timing information.



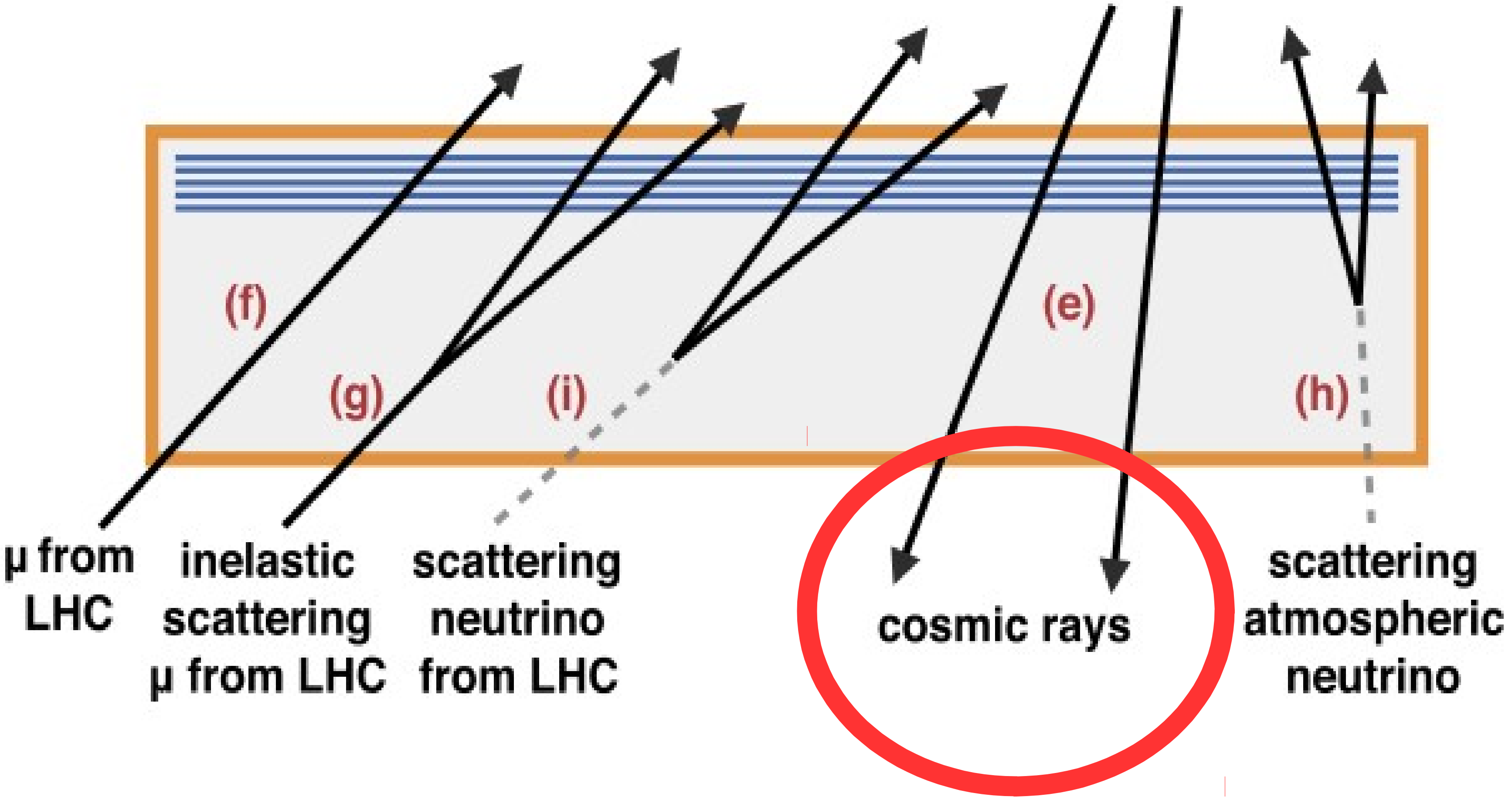
J.P Chou, D. Curtin, H.J.Lubatti, Phys. Lett. B 767 (2017) 29

MATHUSLA detector

(**MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutral p**A**rticles)

4. Background:

- Neutrinos and muons from LHC, atmospheric neutrinos, cosmic rays
- Rejected from information of tracking system and timing information.

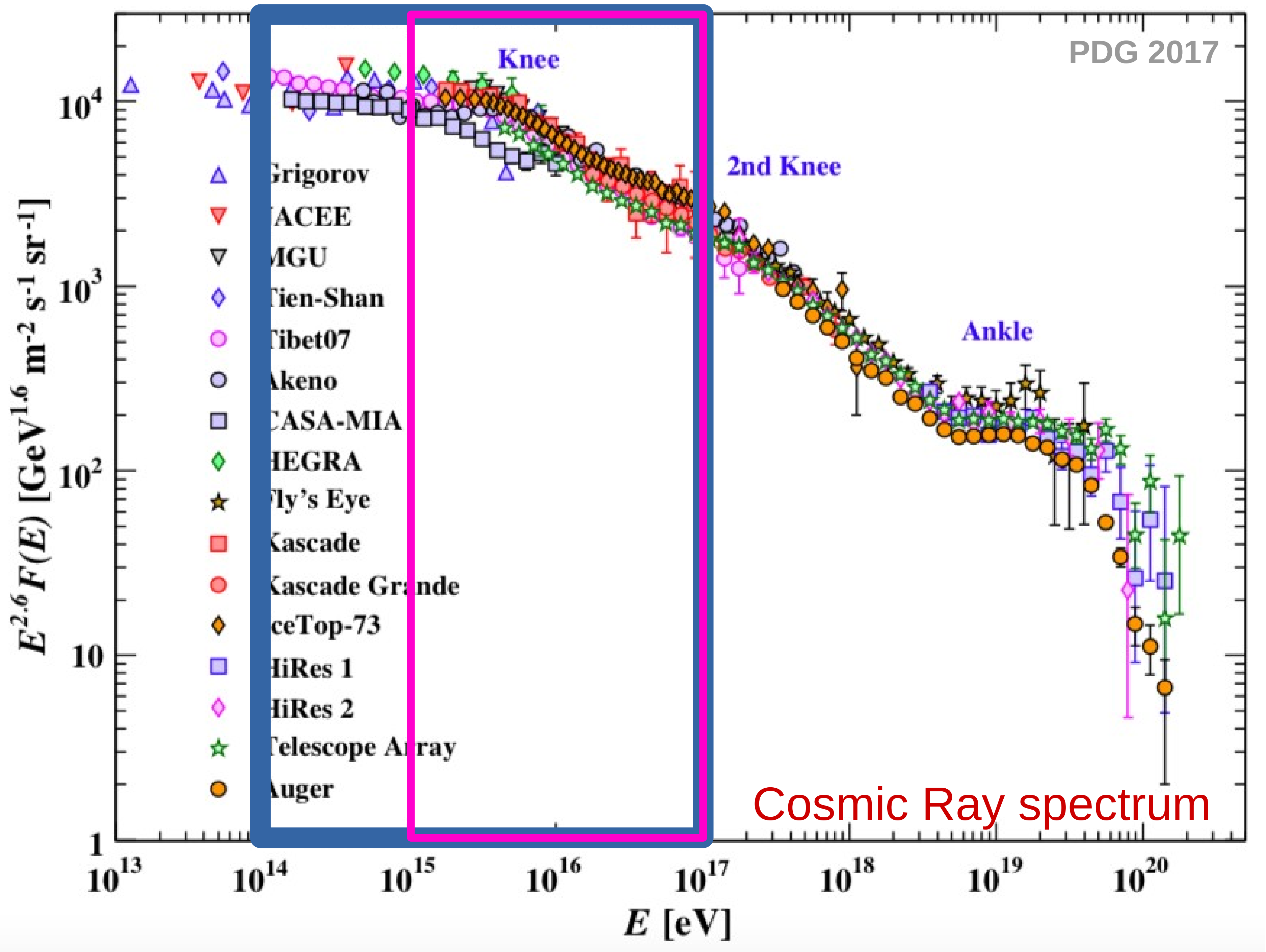


J.P Chou, D. Curtin, H.J.Lubatti, Phys. Lett. B 767 (2017) 29

Cosmic rays in MATHUSLA

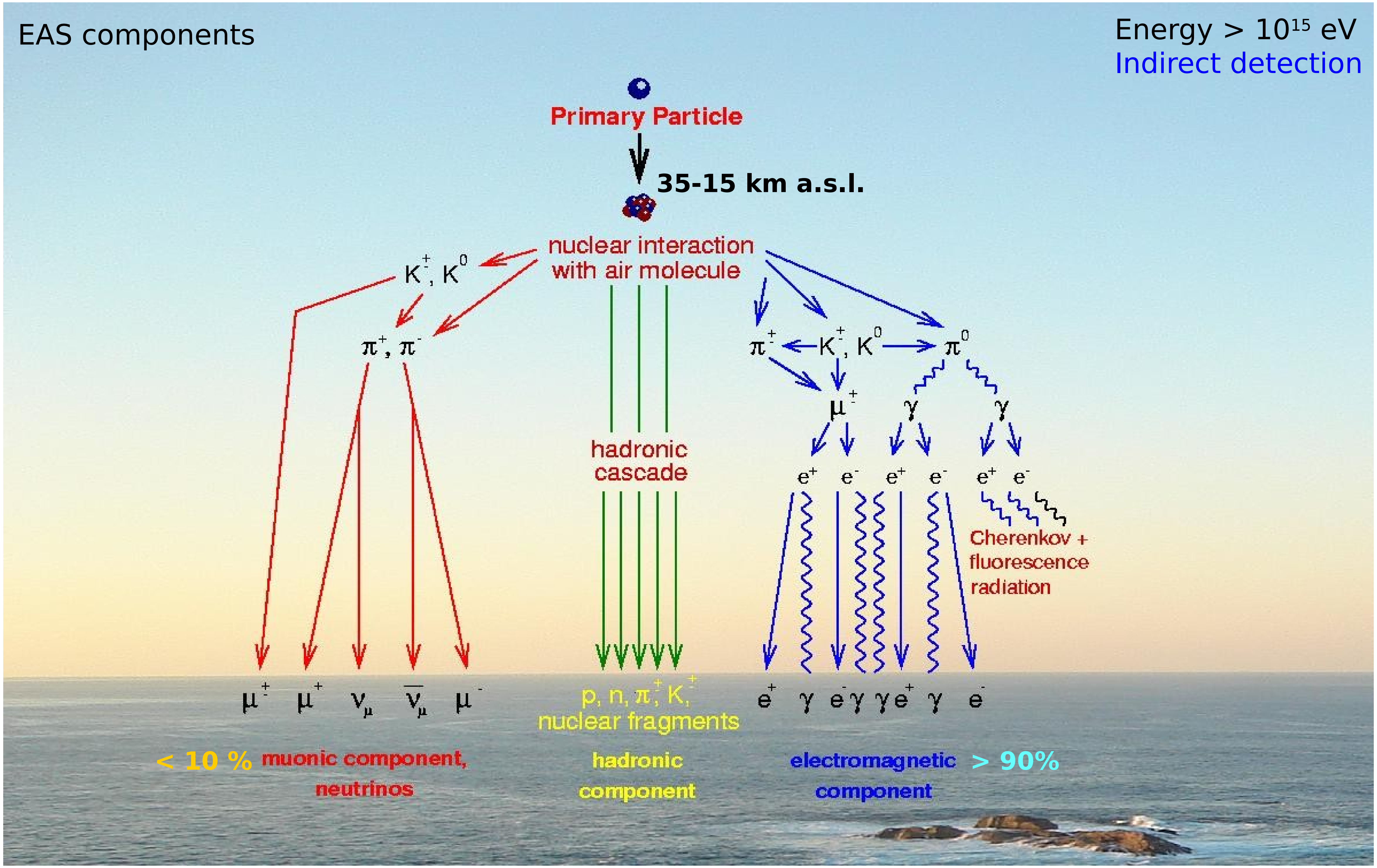
From the size of the instrument and altitude:

Expected energy range: 10^{14} - 10^{17} eV **Full efficiency > 10^{15} eV**



Cosmic rays in MATHUSLA

Indirect detection of cosmic rays through extensive air showers (EAS)



Cosmic rays in MATHUSLA

Reconstruction of number of particles

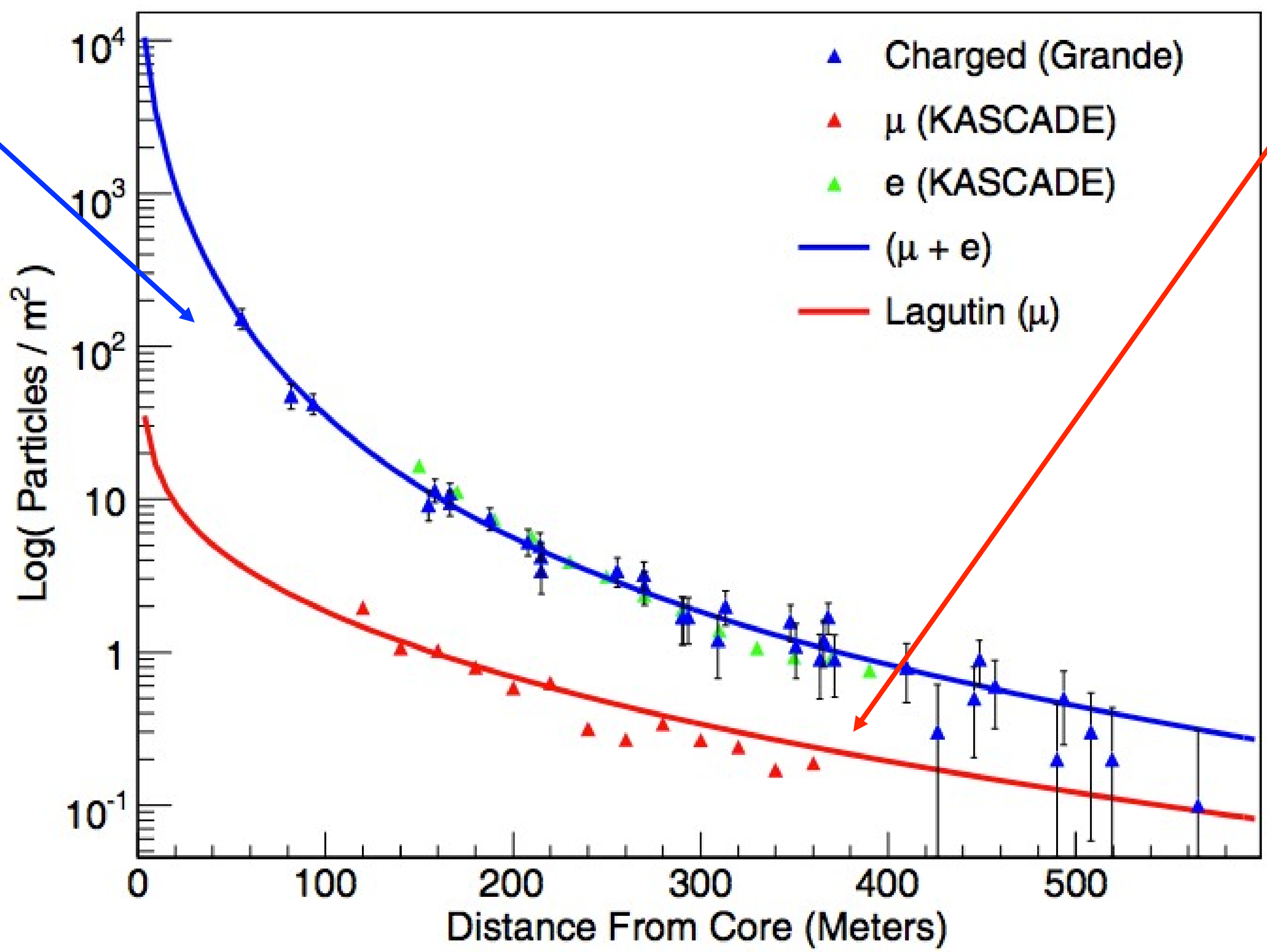
N_{ch}: Number of charged particles

N_{μ} : Number of muons

Fit to data:

$\rho_{ch}(r) = N_{ch} \times f_{ch}^{NKG}(s, r)$

$\rho_{\mu}(r) = N_{\mu} \times f_{\mu}^{Lagutin}(r)$

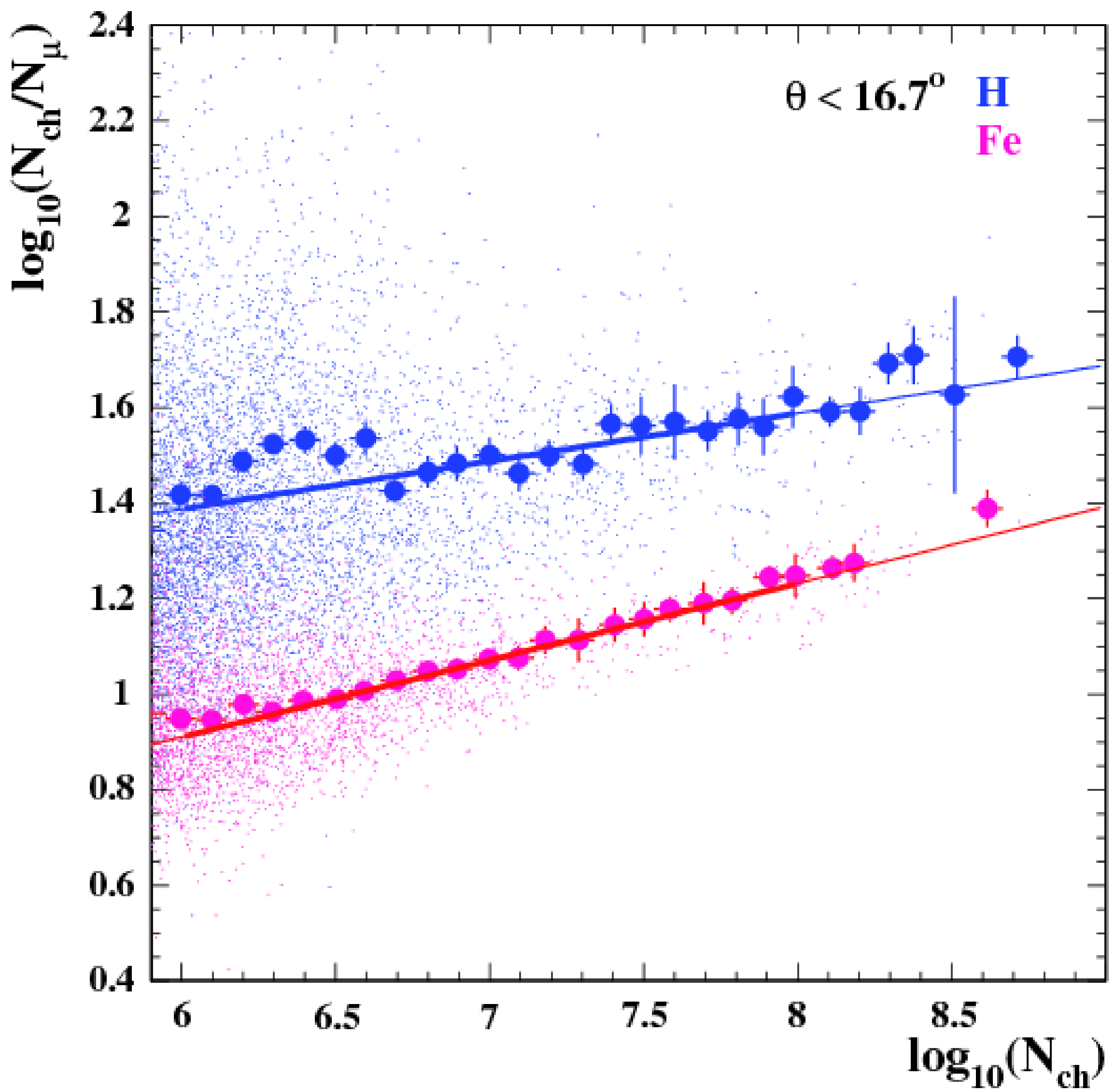


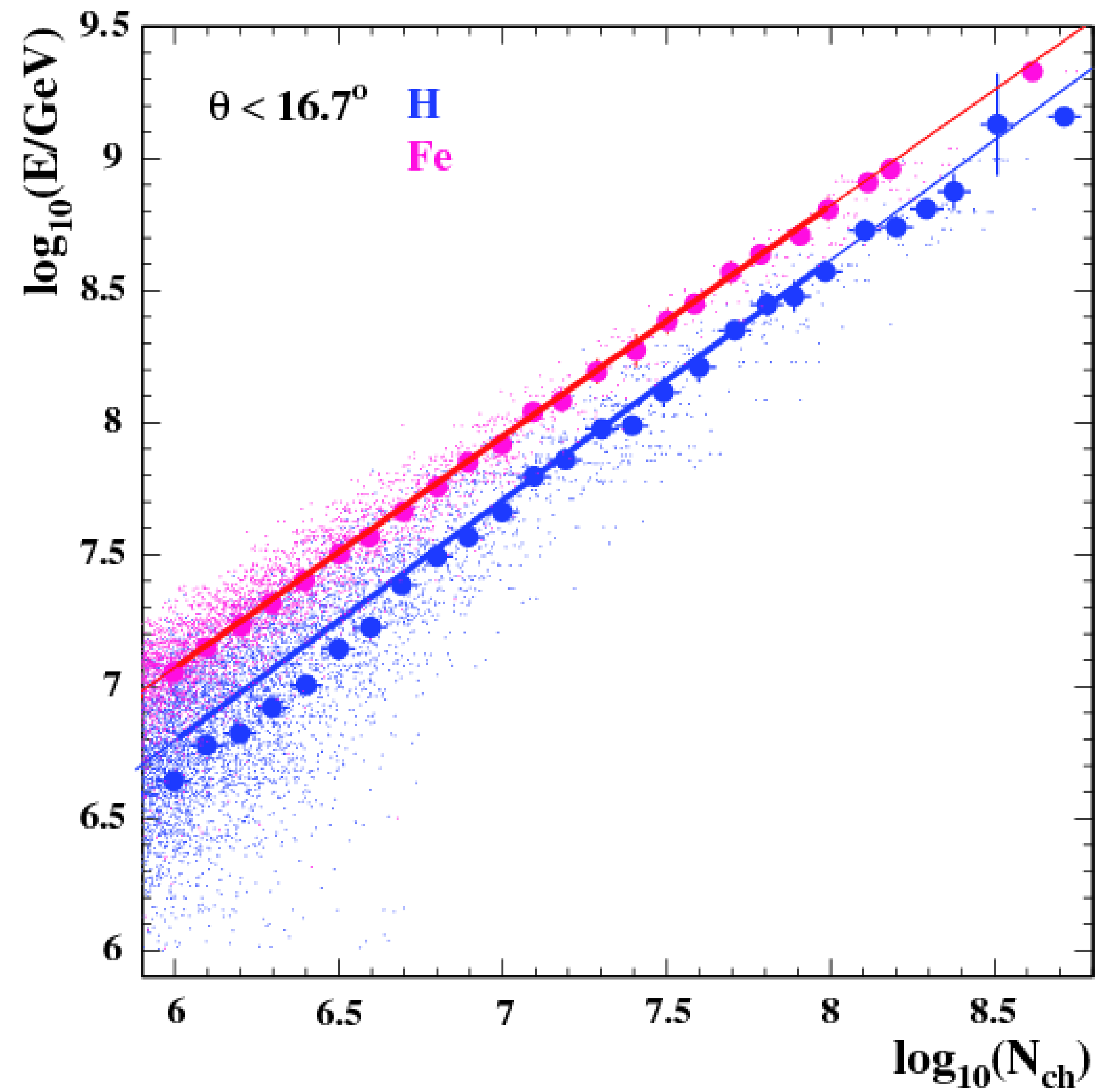
A. Haungs et al., ,Nucl. Phys. B (Proc. Suppl.) 196 (2009)

Cosmic rays in MATHUSLA

Correlation between observables like Nch and Nm can be used for composition studies

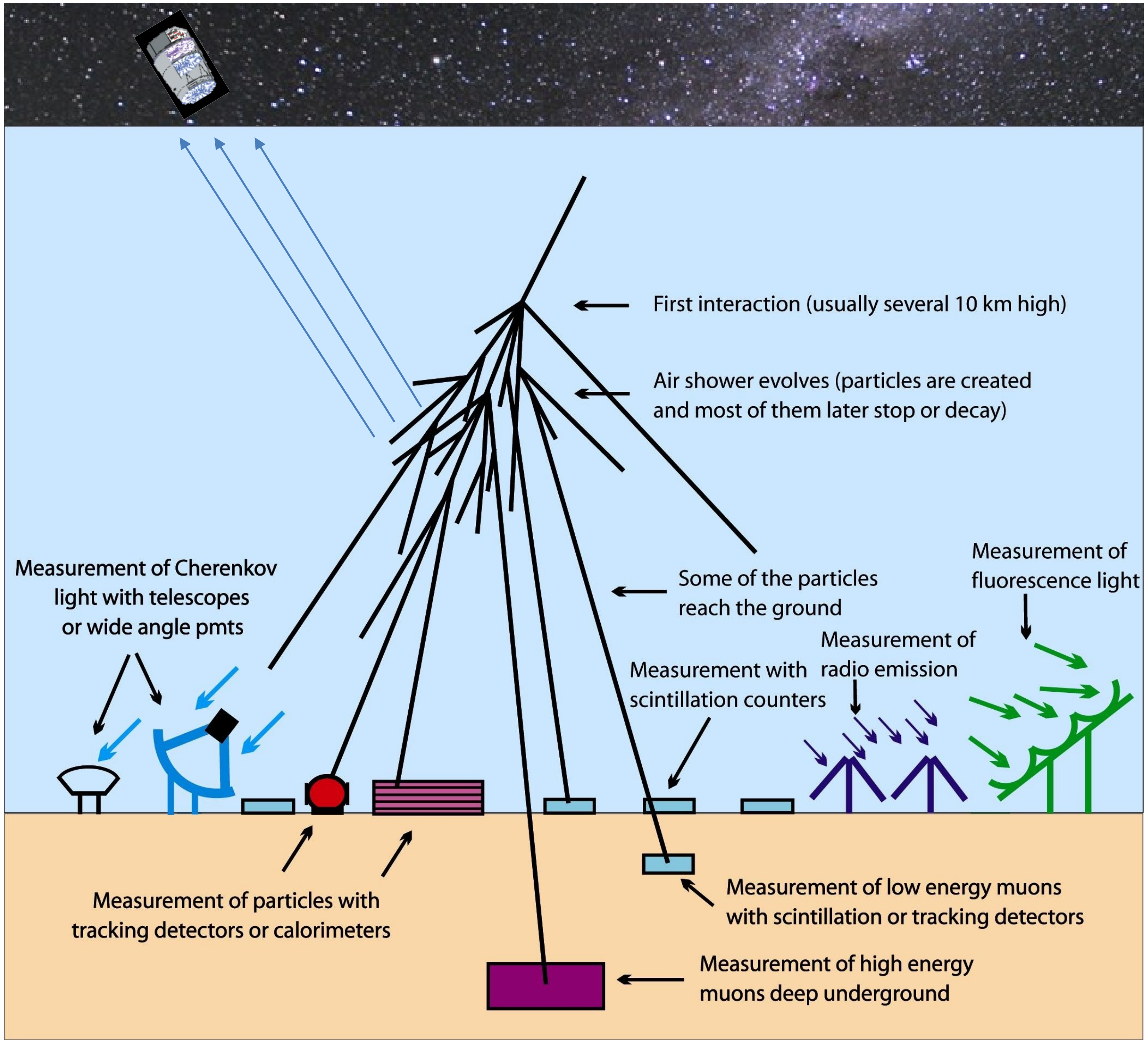
KASCADE-Grande Collab., App 36 (2012) 183





Cosmic rays in MATHUSLA

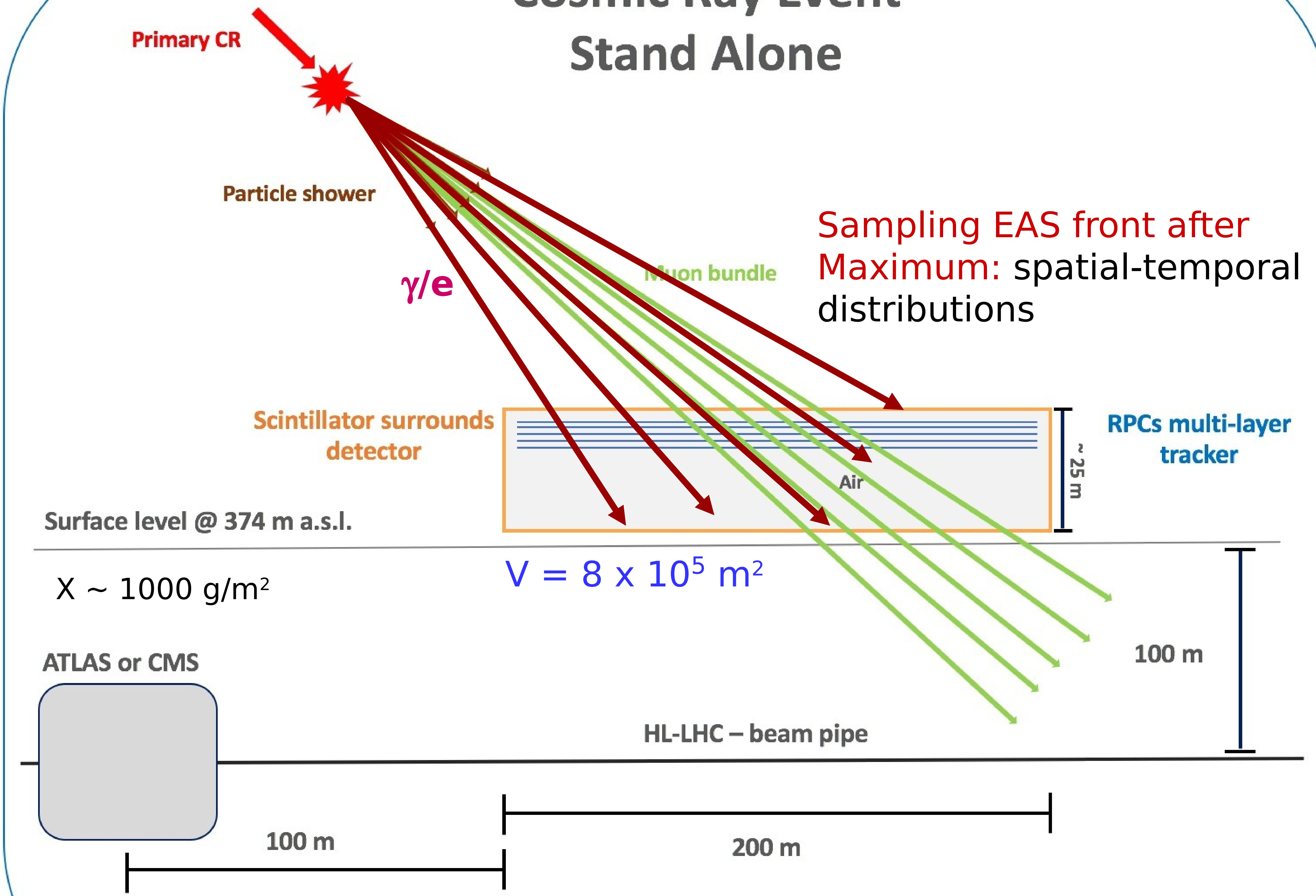
EAS detection



A. Haungs

MATHUSLA: Resistive plate chambers as tracking detectors

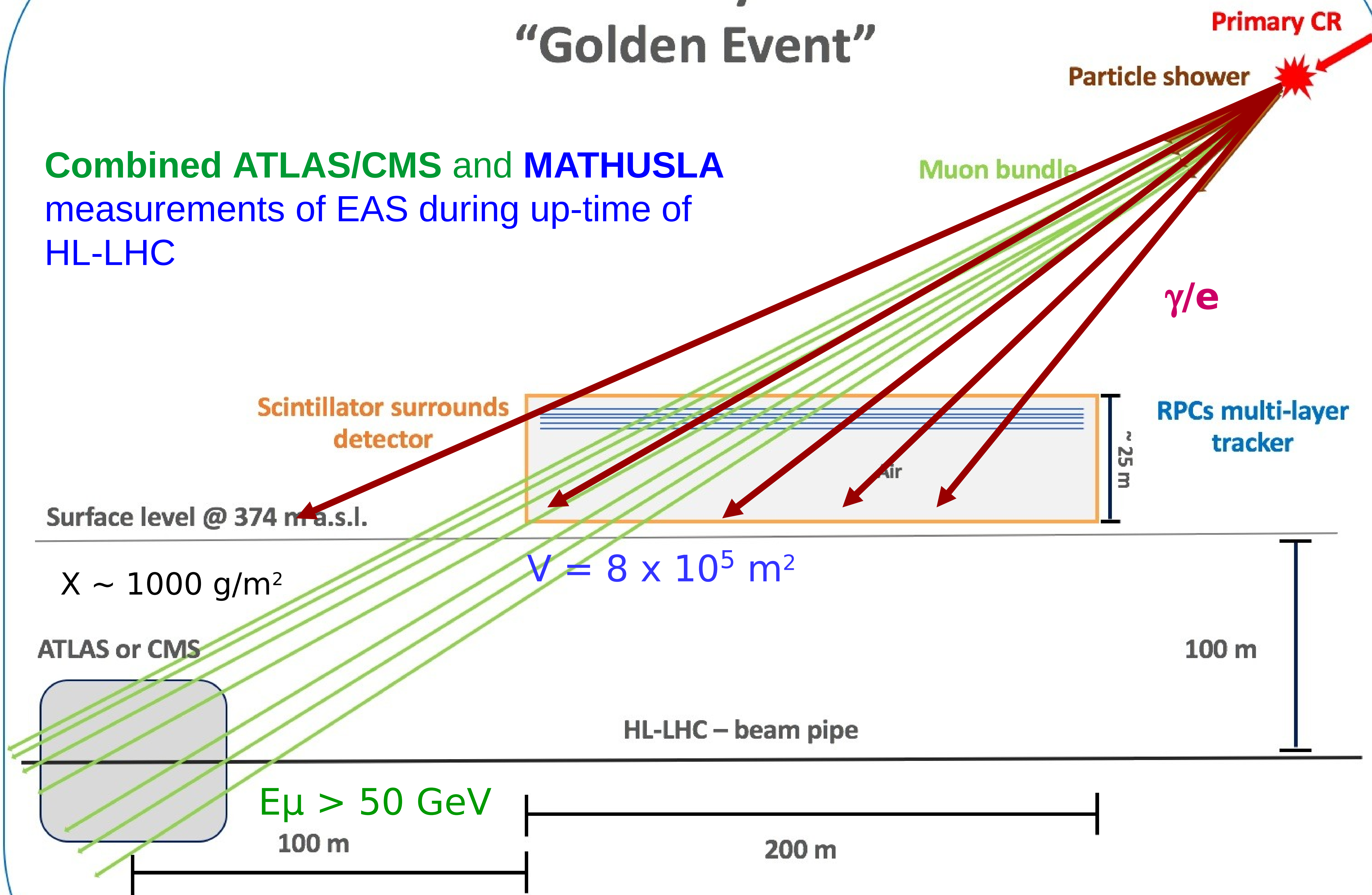
Cosmic Ray Event Stand Alone



Martin Subieta

Cosmic Ray Event
“Golden Event”

Combined ATLAS/CMS and **MATHUSLA** measurements of EAS during up-time of HL-LHC



Martin Subieta

Cosmic rays in MATHUSLA

Expected EAS events (Stand alone mode)

Assuming:

Aeff ∼ 4 x 10^4 m^2

DAQ period = 3 yr (HL-LHC Run 4: 2026-2029)

Field of view = π sr

—> Acceptance ~1.2× 10^{13} $m^2 \cdot s \cdot sr$.

If the integral intensity of primary cosmic ray nuclei is parameterized as

$$I(>E) \approx 10^{-7} \left(\frac{E}{10^{15}\,\mathrm{eV}} \right)^{-2.1} \mathrm{m}^{-2} \cdot \mathrm{s}^{-1} \cdot \mathrm{sr}^{-1},$$

Expected number of events

—> n(> 1 PeV) ~1.2× 10^6

—> n(> 10 PeV) ~9.4× 10^3

Golden events: **(70 % of DAQ period and θ < 50^0)**

—> 0.4 x events in Stand Alone mode

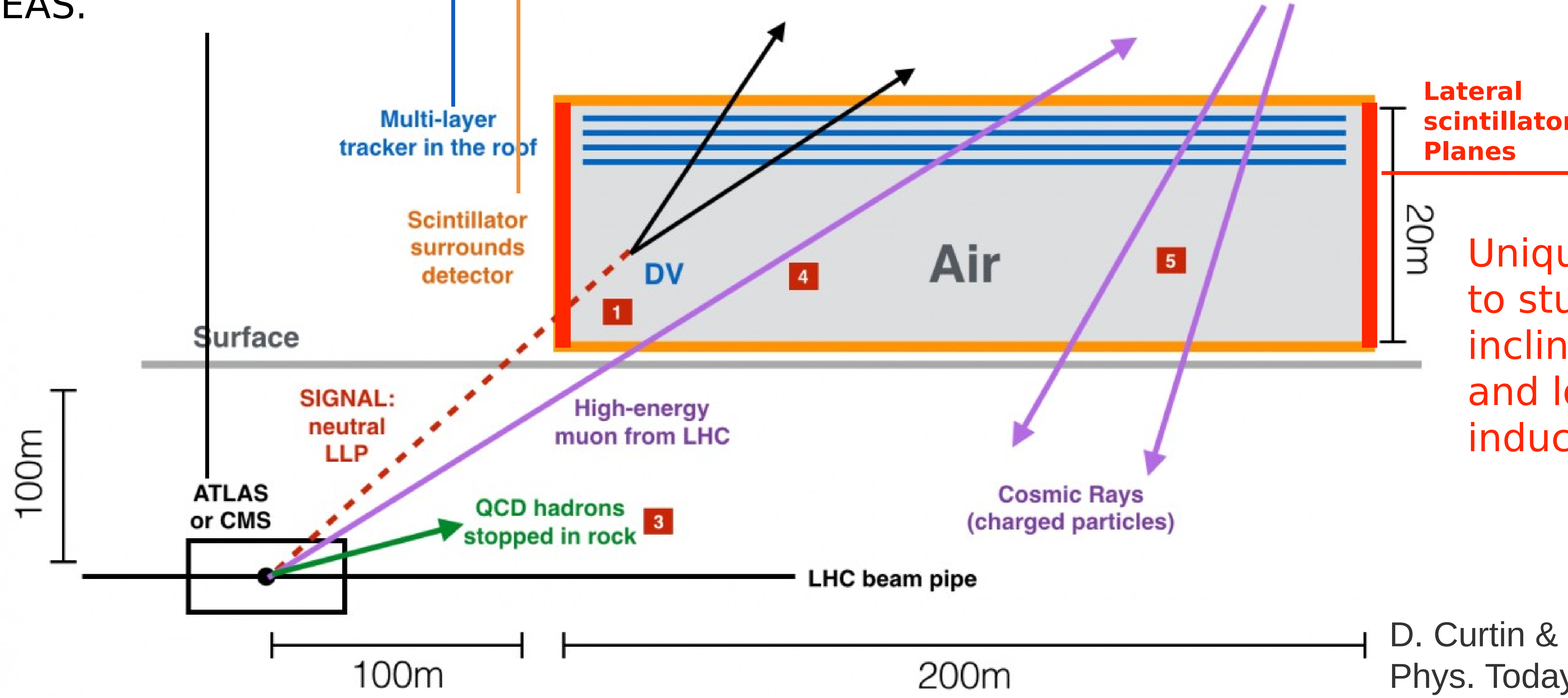
EAS measurements in MATHUSLA

Monitor northern hemisphere, day and night, independent of weather conditions (increased statistics in comparison with Cherenkov arrays)

1. Enhanced angular resolution and better precision in EAS core location than other particles detector arrays.
2. Spatial-temporal measurements of EAS front at the finest level (**might help for shower particle ID**).

1. Help in the study of μ-bundles.
2. In CB mode will complement MATHUSLA measurements of EAS.

1. Help in reconstruction of arrival direction and core location of air showers.
2. Help to check systematics on EAS observables.



Unique feature to study inclined EAS and look for ν induced events

D. Curtin & R. Sundrum, Phys. Today 70, 6, (2017) 46.

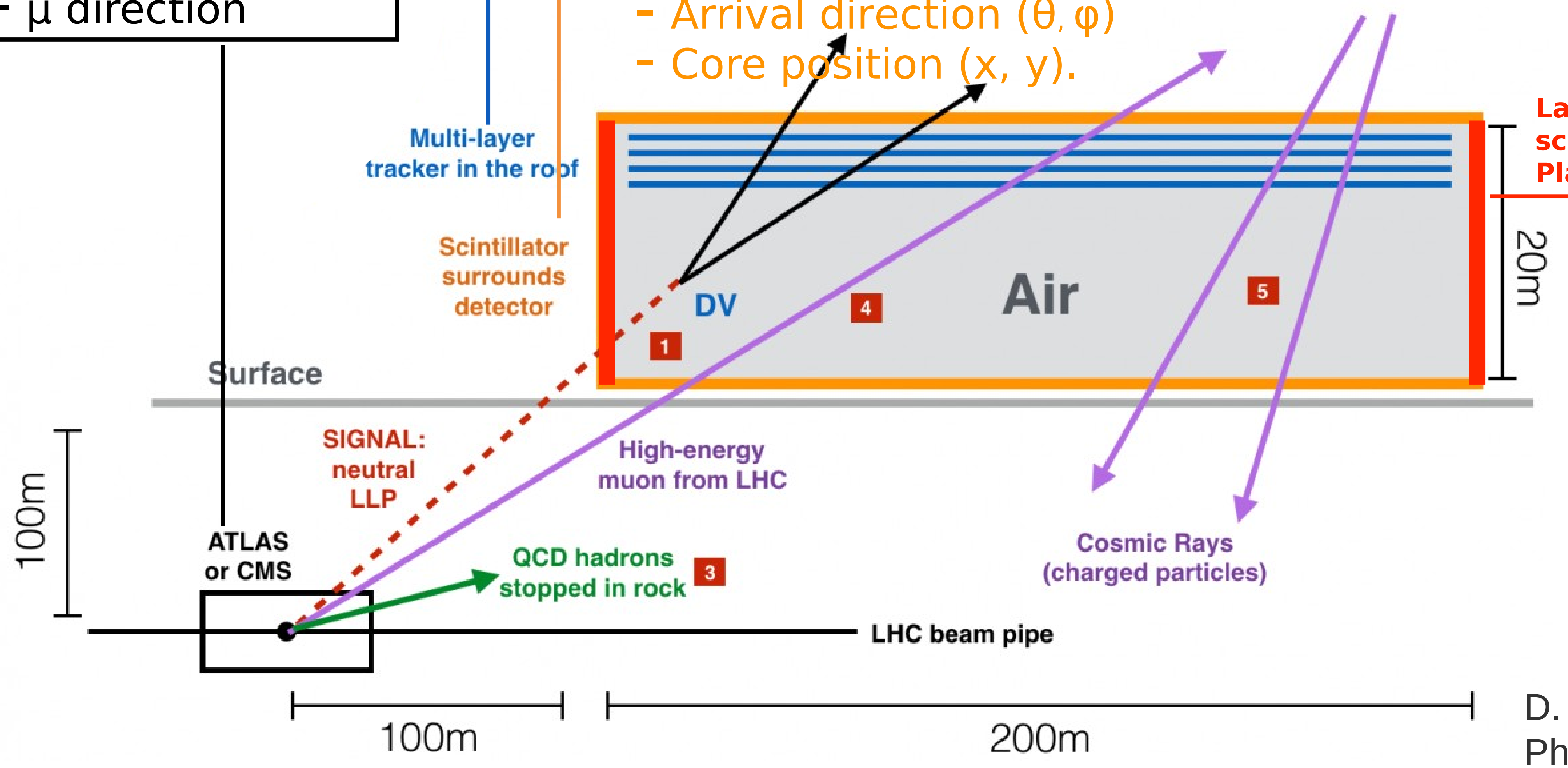
EAS measurements in MATHUSLA

With no e/μ separation

- Lateral density distribution: $\rho_{ch}(r)$.
- Total number of charged particles: N_{ch}.
- Arrival times: $t(r)$.
- Lateral shower age: s.
- Arrival direction (θ, φ)
- Core position (x, y).

- Lateral density distribution: $\rho_{ch}(r)$.
- Total number of charged particles: N_{ch}.
- Arrival times.
- Lateral shower age: s.
- Arrival direction (θ, φ)
- Core position (x, y).

- μ densities
- μ^+/μ^- ratio
- μ energy spectrum
- μ direction



Lateral
scintillator
Planes

Inclined EAS
- μ production height: h_μ
- Maximum of μ production depth: X_μ^{max}
- Muon content: N_μ

D. Curtin & R. Sundrum, Phys. Today 70, 6, (2017) 46.

Cosmic ray physics case

1. Cosmic rays

+ Energy spectrum of cosmic rays

    Obtain fine details of spectrum

+ Composition

    Spectra of individual chemical species

    New light knee ~ 700 TeV as observed by ARGO-YBJ?

    Fine spectrum of heavy component of CRs

+ Anisotropies

    Look for point sources

    Anisotropy maps vs composition?

2. High energy neutrinos

+ Look for Earth-skimming/atmospheric/cosmic events.

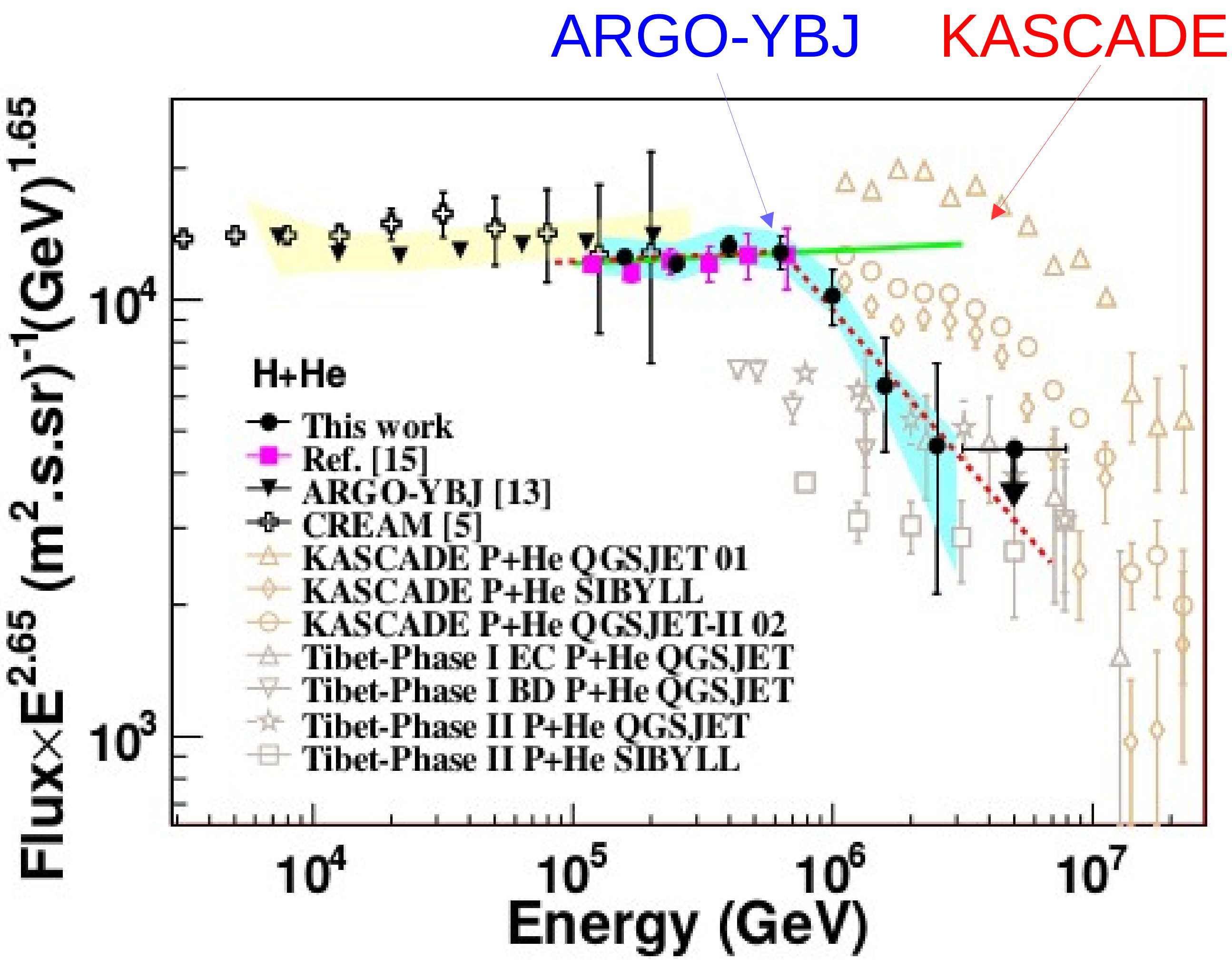
    Neutrino oscillations, atmospheric flux, neutrino interactions, etc

Cosmic ray physics case

Light spectrum of CRs

+ Two knees in the PeV light (H+He) spectrum?

+ Hidden systematic error?

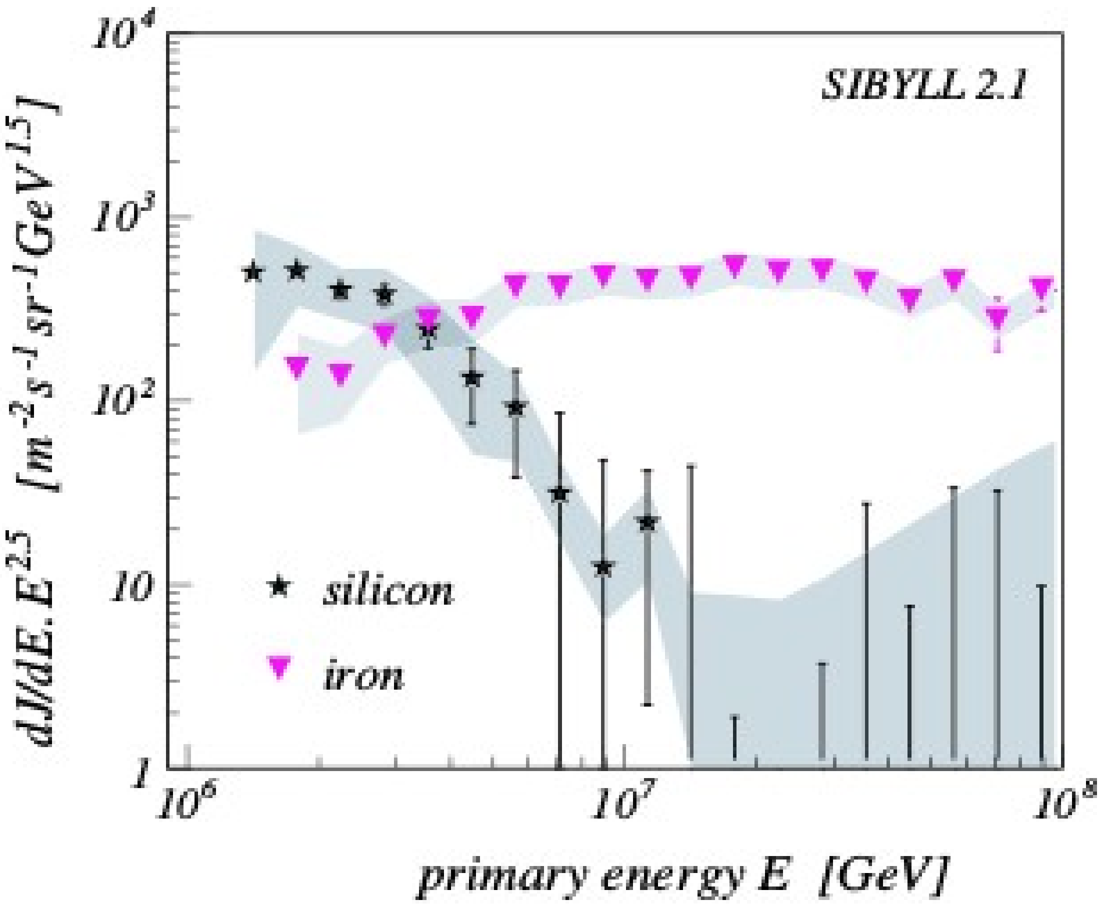


ARGO-YBJ Collab., astro-ph 1502.03164

Heavy spectrum of CRs

+ Fine structure in spectrum?

+ Systematic errors?



KASCADE Collab., Astrop. Phys 24 (2015) 1

Cosmic ray physics case

3. Tests of hadronic interaction models

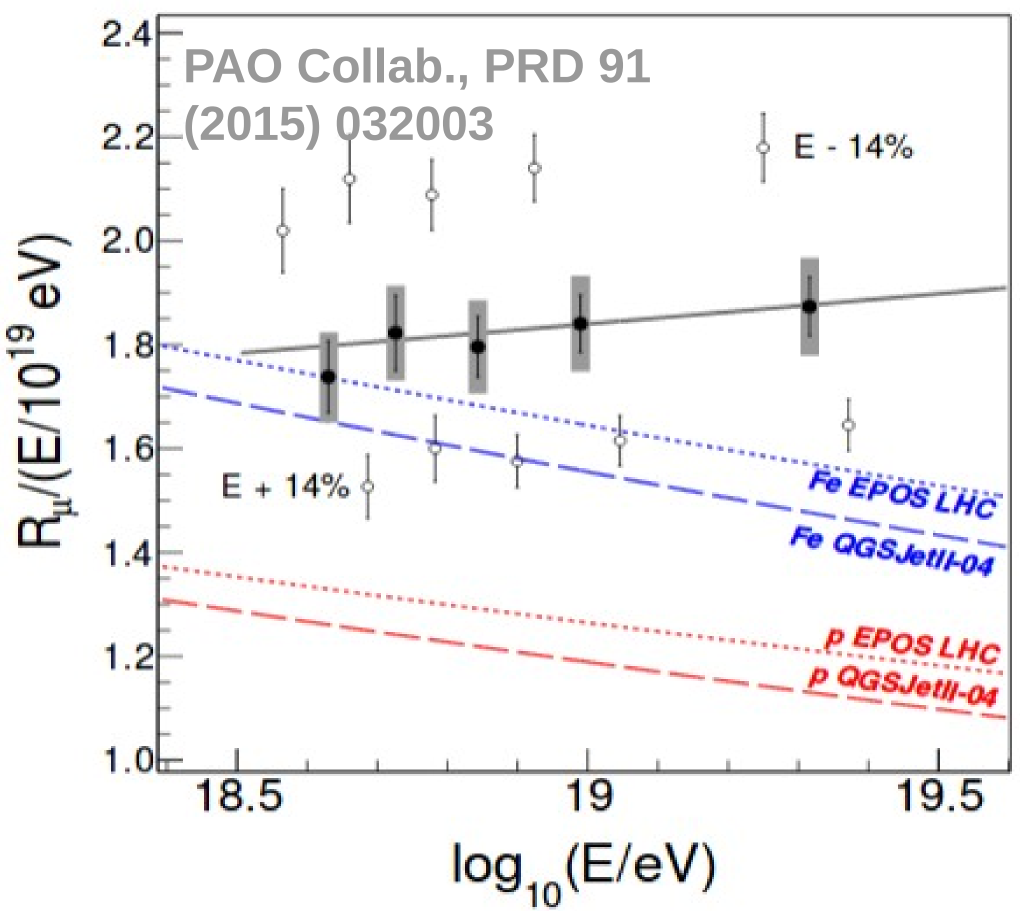
+ Confirm and/or constrain validity of model

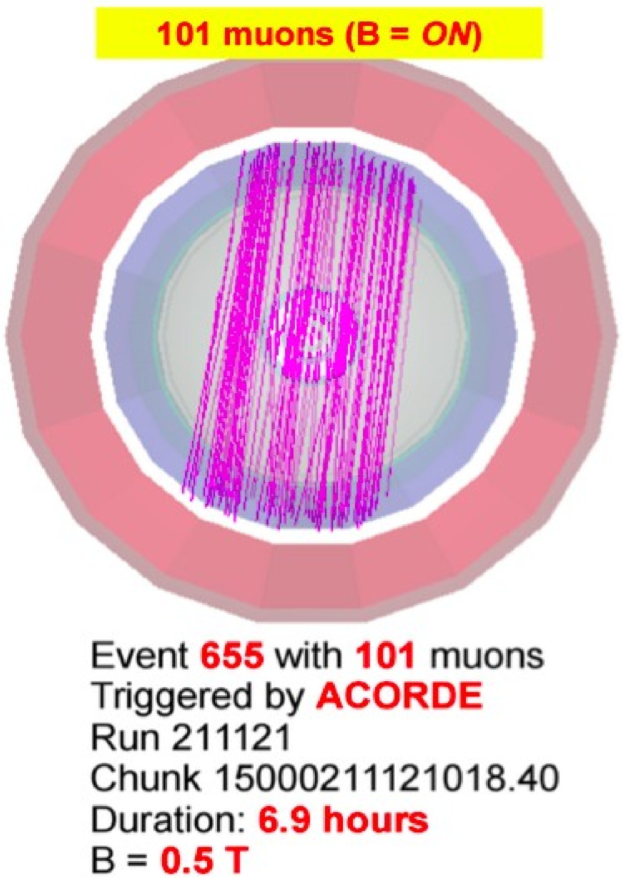
Shape of temporal and radial density distributions

Muon content and evolution in EAS

Check possible presence of muon excess in EAS for inclined EAS

Study of muon bundles





Alice Collab., JCAP01 (2016) 032.

A.Fernández Téllez, M. Cahuatzin, Alice warms with cosmics, Alice Matters,March 2015

MATHUSLA test

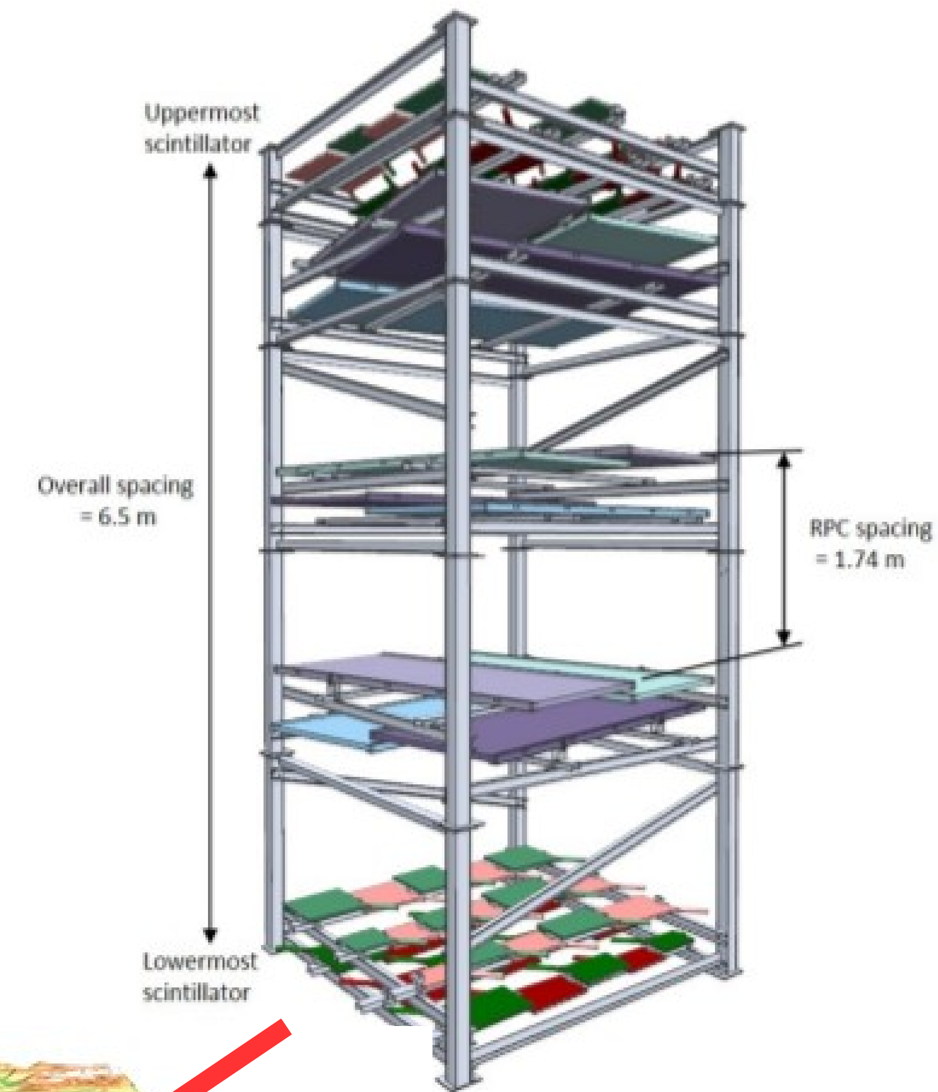
+ Installed at ground level in the ATLAS SX1 building at CERN in November 2017.

+ Tests up to end of LHC Run 2.

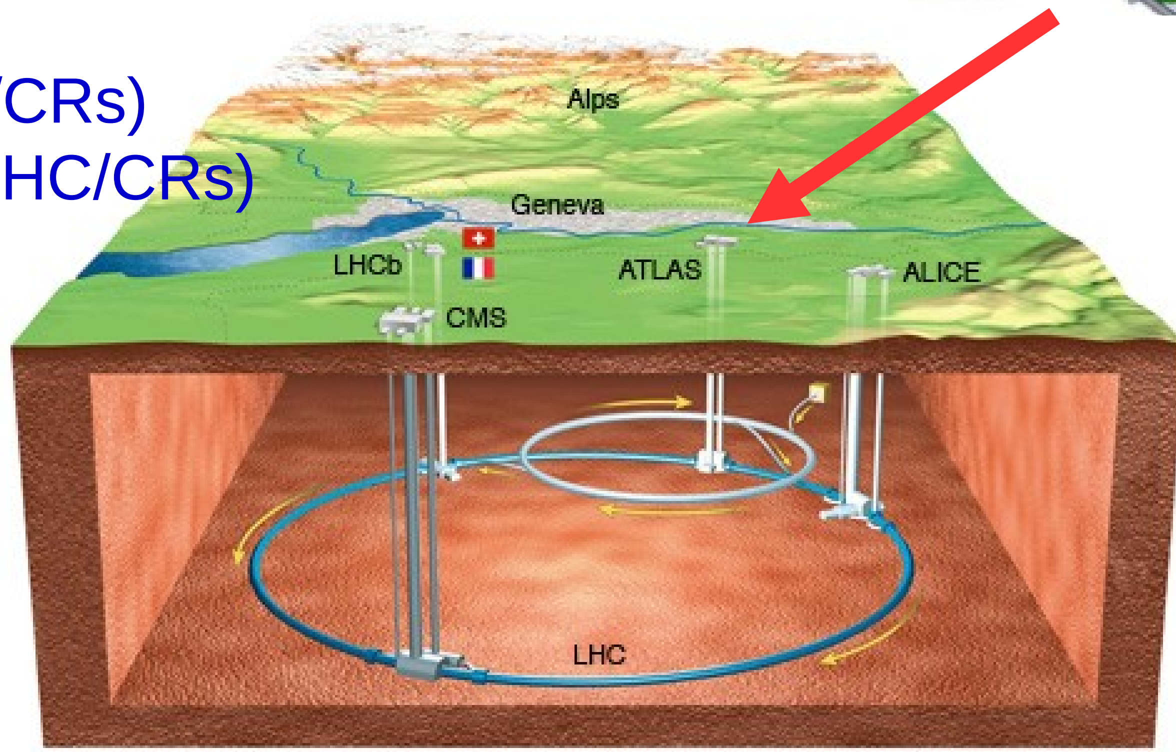
+ 2 layers of scintillators and three of RPCs.
  6.5 m high
  2.5 m x 2.5 m area

+ Triggers for upward/downward going particles.

+ Provide information for:
  - Measure background (LHC/CRs)
  - Test rejection capabilities (LHC/CRs)
  - Improve final design



MATHUSLA Collab., MATHUSLA physics white paper (2018)



Final remarks

+ A detector like MATHUSLA would complement the **Long Lived Particle searches** at the LHC.

+ As pay-back MATHUSLA would also allow to **study several open issues** in astroparticle physics (Cosmic rays, dark matter, gamma-rays, neutrinos, …).

+ It would provide quality data on **extensive air showers** with **unprecedented precision at PeV energies**.

+ It would permit to **validate/test predictions of hadronic interaction models** at very high energies with cosmic rays.

+ **White paper** for the MATHUSLA physics case (and intro to the Cosmic Ray potential) has been finished, **CR MATHUSLA white paper** is preparation.

+ Final design is under study.

MATHUSLA Collaboration

University of Washington, Seattle

Rutgers State University of New Jersey

SLAC

Toronto University

Universita di Tor Vergata

Sapienza Universita di Roma

Benemérita Universidad Autónoma de Puebla, Mexico

Universidad Michoacana de San Nicolás de Hidalgo, Mexico

Universidad Autónoma de Chiapas, Mexico

Universidad Mayor de San Andrés, Bolivia

Tel Aviv University

Mexican members

Universidad de Puebla (BUAP): Arturo Fernández Téllez, Mario Cahuatzin

Universidad Michoacana (UMSNH): Juan Carlos Arteaga Velázquez

Universidad de Chiapas (UNACH): Karen Salomé Caballero Mora

Thank you!