Explore the Lifetime Frontier with MATHUSLA

Cristiano Alpigiani

on behalf of the MATHUSLA Collaboration

21th June 2018

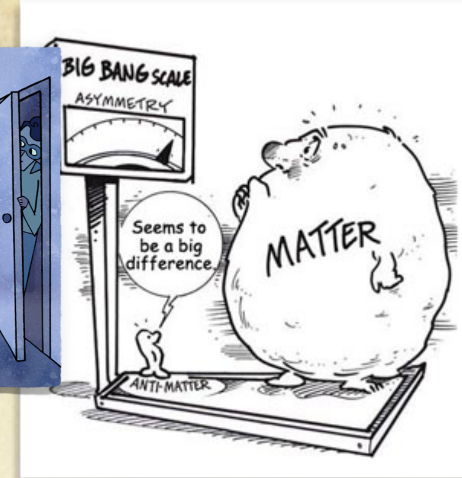
New Physics with Displaced Vertices

NCTS Hsinchu, Taiwan

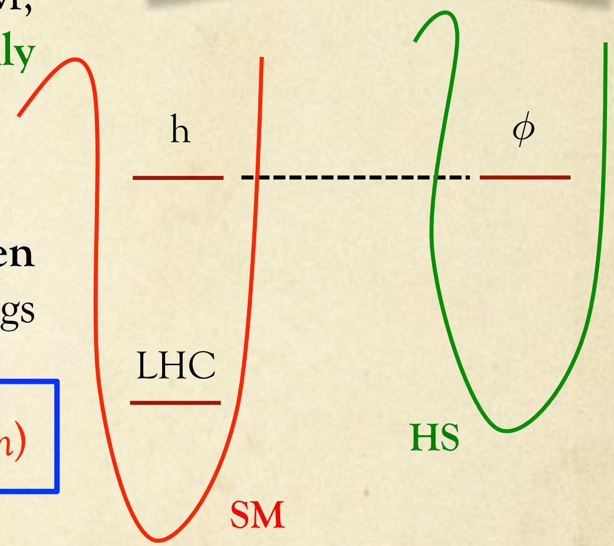
UNIVERSITY *of* WASHINGTON

MATHUSLA

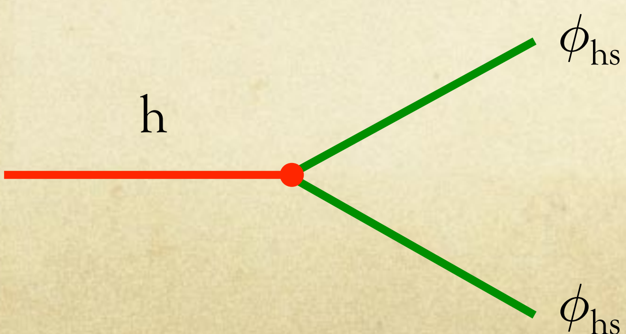
The Hidden Sector



- The Standard Model (SM) is in amazing agreement with the experimental data, but **still some problems remain unsolved**: dark matter, neutrinos masses, hierarchy, matter-antimatter asymmetry…
- Many extensions of the SM (Hidden Valley, Stealth SUSY, 2HDM, baryogenesis models, etc) include particles that are **neutral**, **weakly coupled**, and **long-lived** that can decay to final states containing several hadronic jets
- Long-lived particles (LLPs) occur naturally in **coupling to a hidden sector (HS)** via small scalar (Higgs) or vector (γ, Z) portal couplings



❖ Wide range of possible lifetimes from $\mathcal{O}$(mm) up to $\mathcal{O}$(m/km)



The mixing of Higgs with HS results in a Higgs like particle decaying into LLPs:

small coupling → long lifetimes [Phys. Lett. B6512 374-379, 2007]

~ 10^8 Higgs boson @ HL-LHC

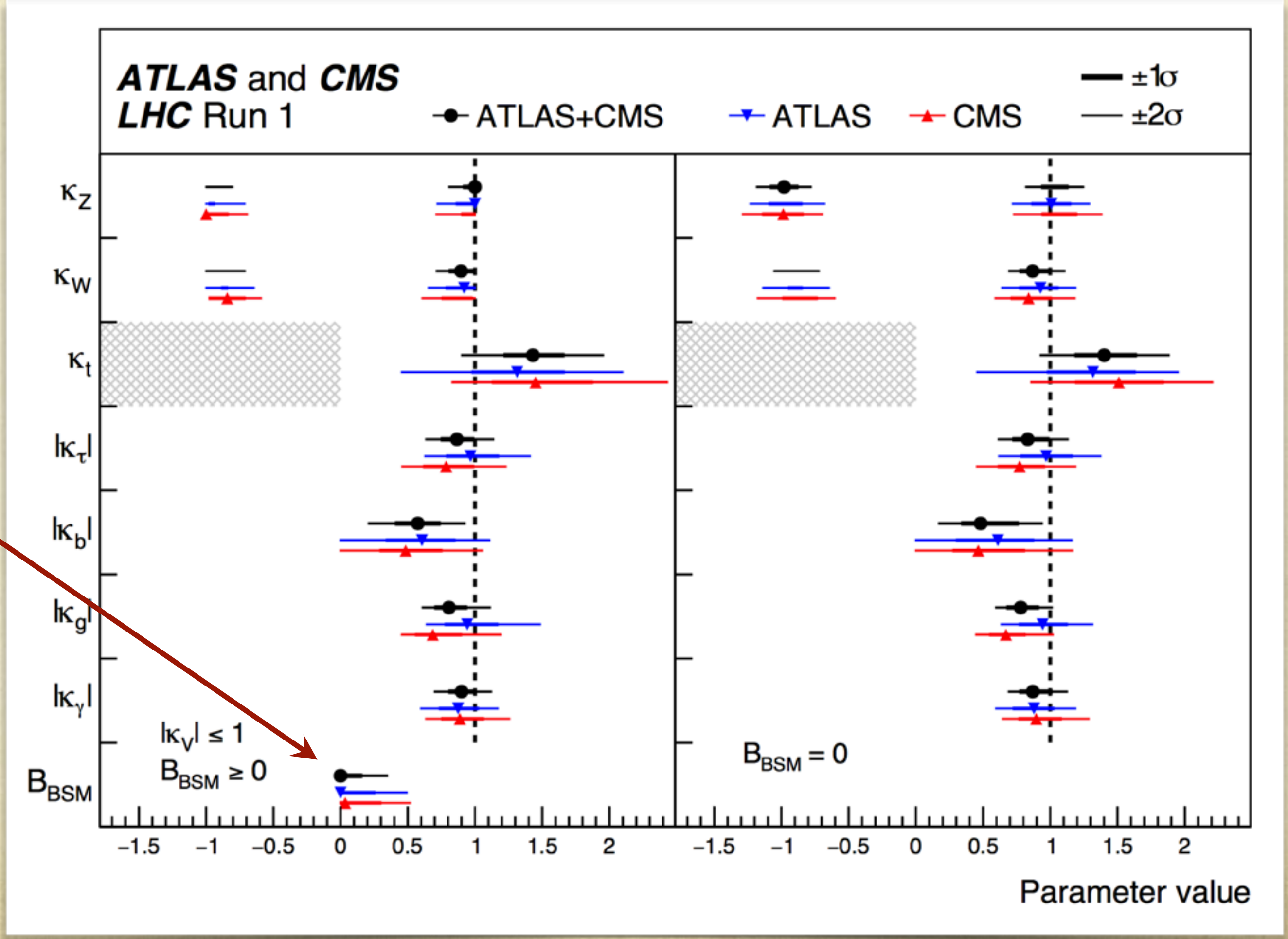
Oh...btw... HL-LHC works just started!

Geneva, 15 June 2018. A ground-breaking ceremony at CERN celebrates the start of the civil-engineering work for the High-Luminosity LHC (HL-LHC)

Higgs Boson Decay Modes

- Combined ATLAS-CMS Run 1 results w.r.t. standard model expectations
- Good agreement with SM…BUT…

BUT > 30% BSM allowed



LLP Searches in the LHC Detectors

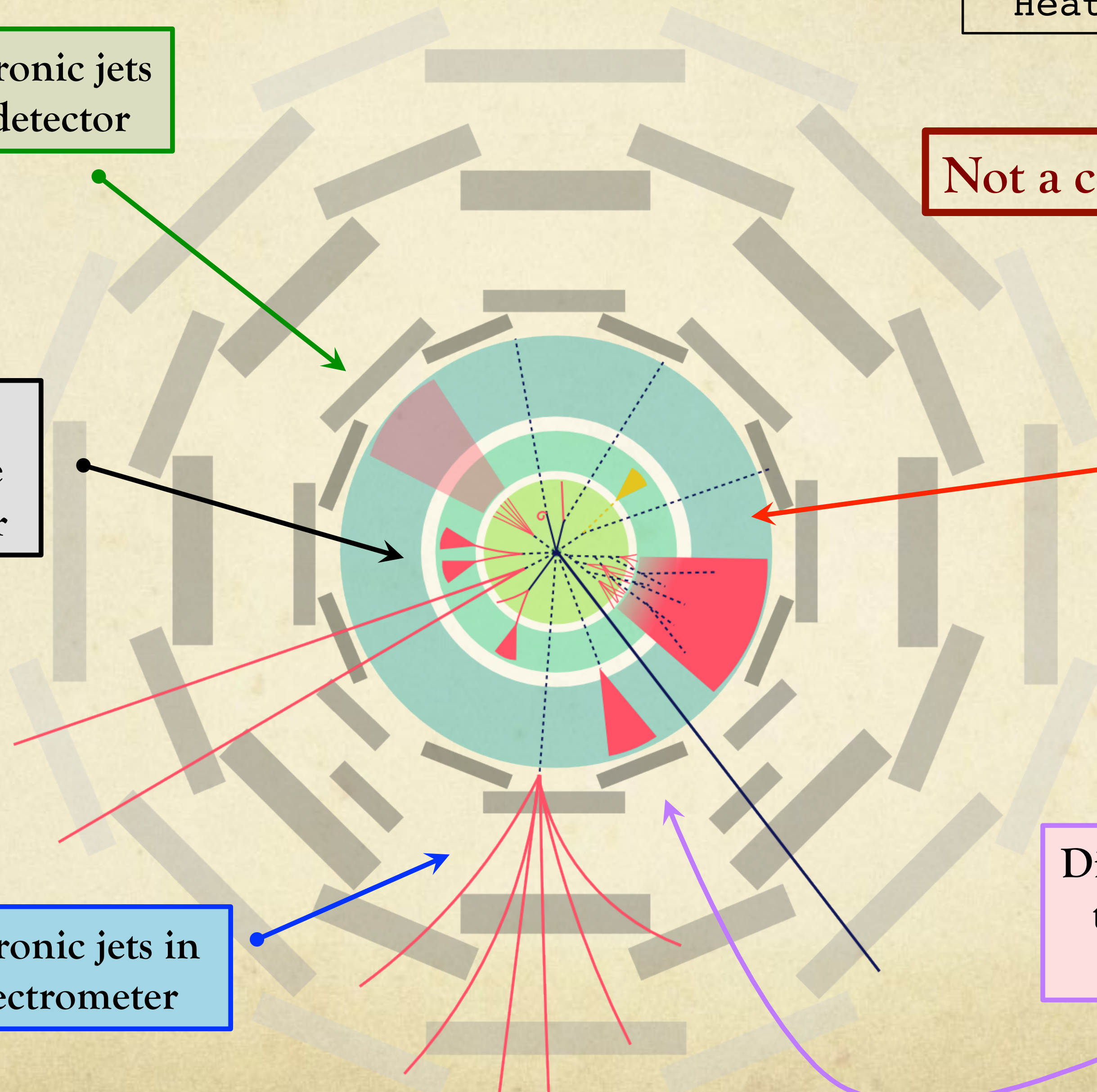
Image courtesy of Heather Russell

Displaced hadronic jets in the inner detector

Not a complete list!

Displaced leptons in the inner detector

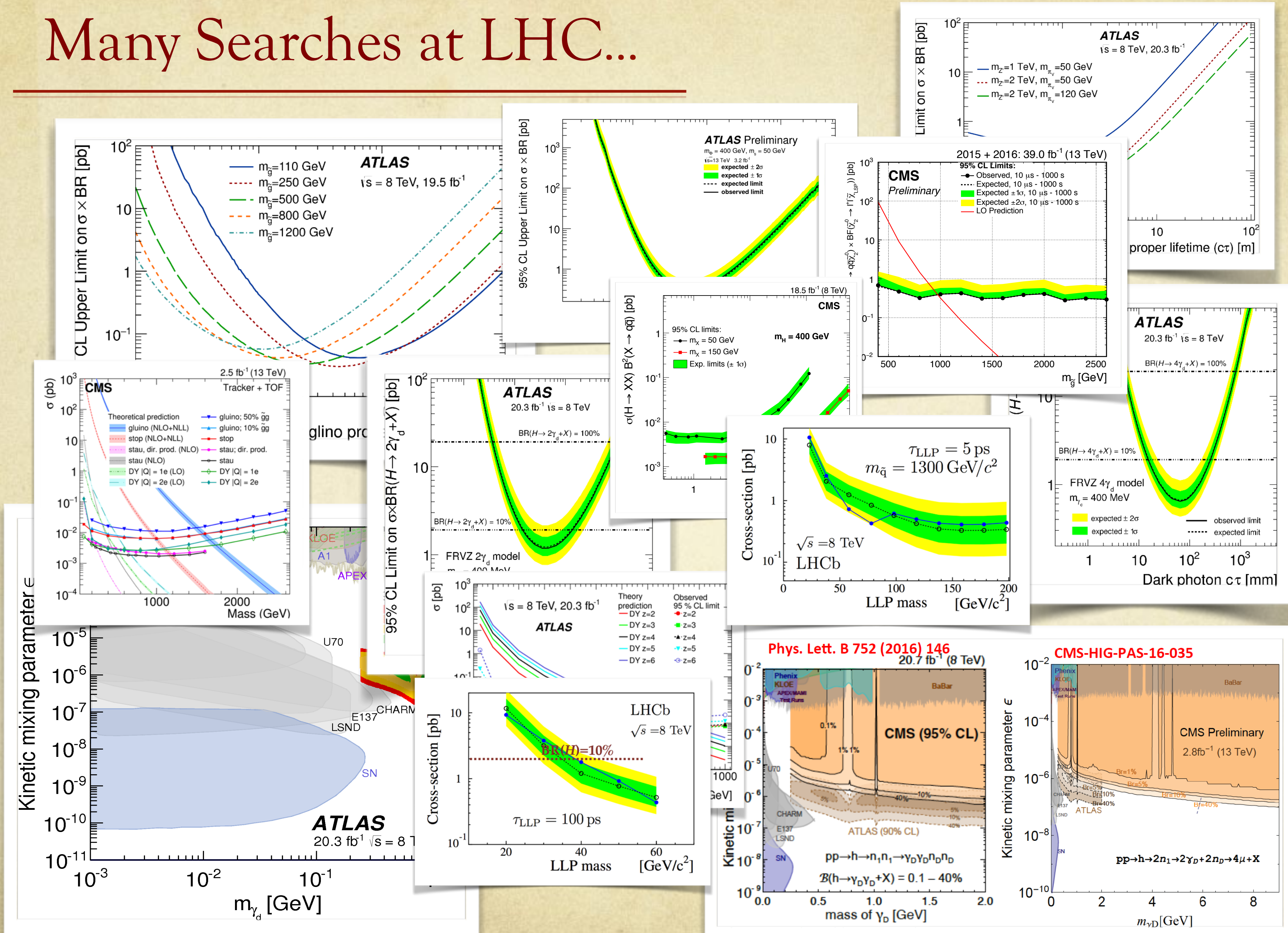
Emerging jets



Displaced hadronic jets in the muon spectrometer

Displaced jets in the hadronic calorimeter

Many Searches at LHC…



Many Searches at LHC…

- Strong dependence on the sub-detectors of ATLAS, CMS and LHCb
- Detector signature depends of production and decay operators of a given model

- LHC detector searches limited by large backgrounds
  - ✓ Large QCD jet production
  - ✓ Pile-up problems
  - ✓ Beam halo issues
  - ✓ …

→ **Need a background-free detector!**

…and who ya gonna call?


MATHUSLA!

MATHUSLA

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

MATHUSLA detector → **MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutra**L** p**A**rticles

- Dedicated detector **sensitive to neutral long-lived particles that have lifetime up to the Big Bang Nucleosynthesis** (BBN) limit (10^7 – 10^8 m) for the HL-LHC
- **Large-volume, air filled detector located on the surface** above and somewhat displaced from ATLAS or CMS interaction points
- HL-LHC → **order of N_h = 1.5 x 10^8** Higgs boson produced
- Observed decays:

$$N_{\text{obs}} \sim N_h \cdot \text{Br}(h \to \text{ULLP} \to \text{SM}) \cdot \epsilon_{\text{geometric}} \cdot \frac{L}{bc\tau}$$

ϵ = geometrical acceptance along ULLP

L = size of the detector along ULLP direction

$b \sim m_h / (n \cdot m_X) \leq 3$ for Higgs boson decaying to n = 2, $m_X \geq 20$ GeV

❖ To collect a few ULLP decays with $c\tau \sim 10^7$ m require a 20 m detector along direction of travel of ULLP and about 10 % geometrical acceptance

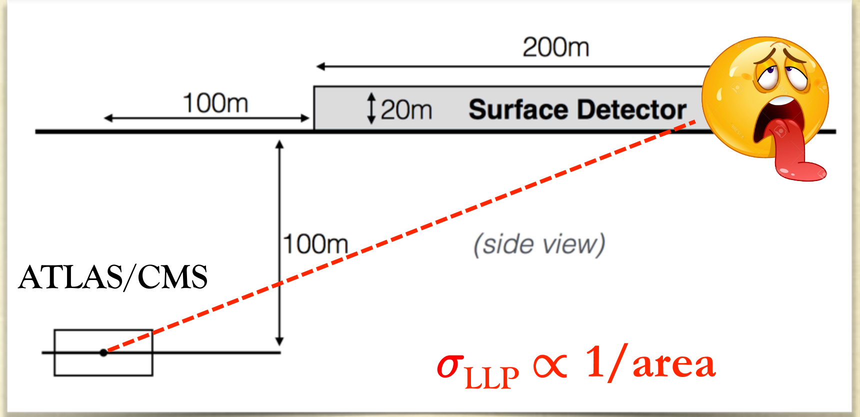
$$L \sim (20\text{ m}) \left(\frac{b}{3}\right) \left(\frac{0.1}{\epsilon_{\text{geometric}}}\right) \frac{0.3}{\text{Br}(h \to \text{ULLP})}$$

MATHUSLA

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

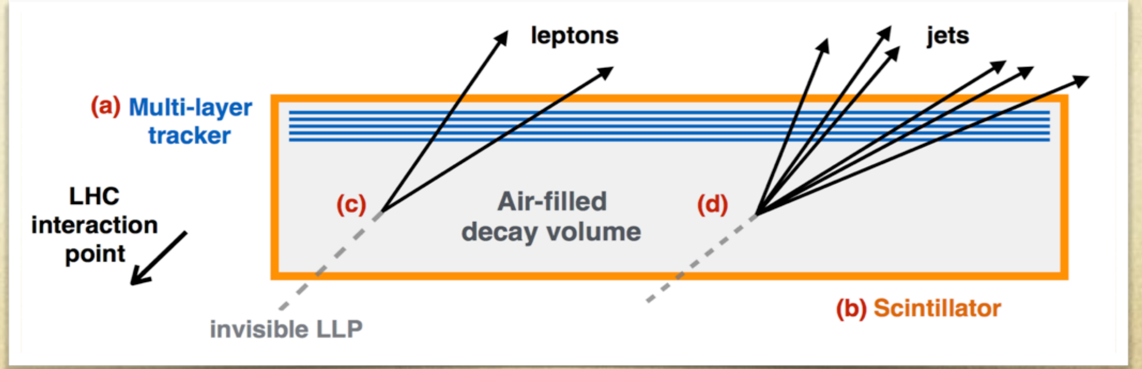
MATHUSLA detector → **MA**ssive **T**iming **H**odoscope for **U**ltra **S**table neutra**L** p**A**rticles

- Large area **surface detector (200 x 200 m^2)** above an LHC p-p IP dedicated to detection of ultra long-lived particles
- Air decay volume with **tracking chambers surrounded by scintillators**



- **Need robust tracking**
- **Excellent background rejection**
  - → **RPCs** planes are an attractive choice (**good space and time resolution** for vertex reconstruction and cosmic ray rejection)
  - → **Scintillator** planes for redundant background rejection – timing

But other technologies can be investigated for the main detector



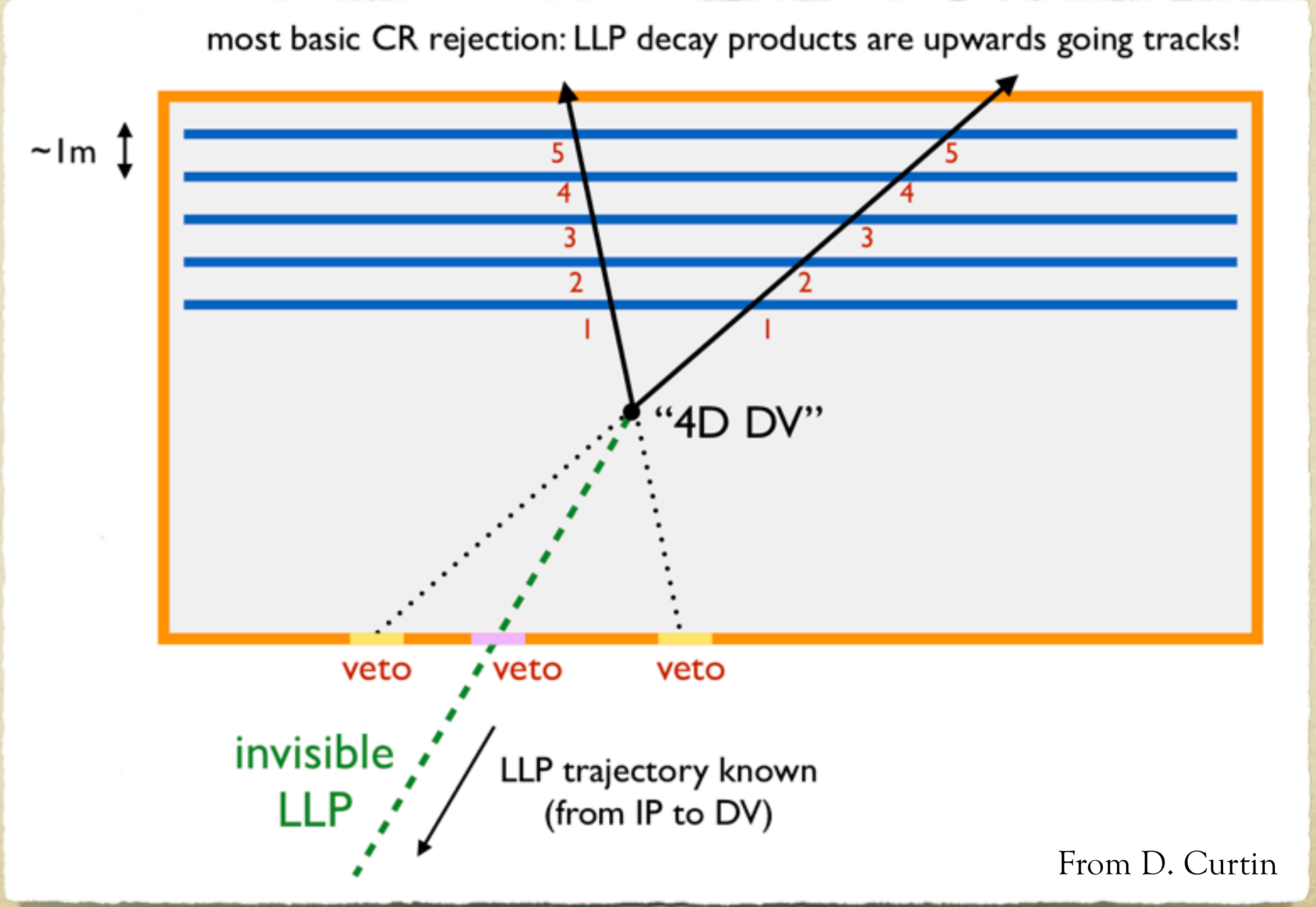
MATHUSLA – signal reconstruction example (1)

Leptonic 2-body decay of a LLP

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

- Δt between tracking layers >~ 3.5 ns

Tracks are reconstructed in **3D** and with detailed **timing** information at each layer, the DV is really a **4D DV**



From D. Curtin

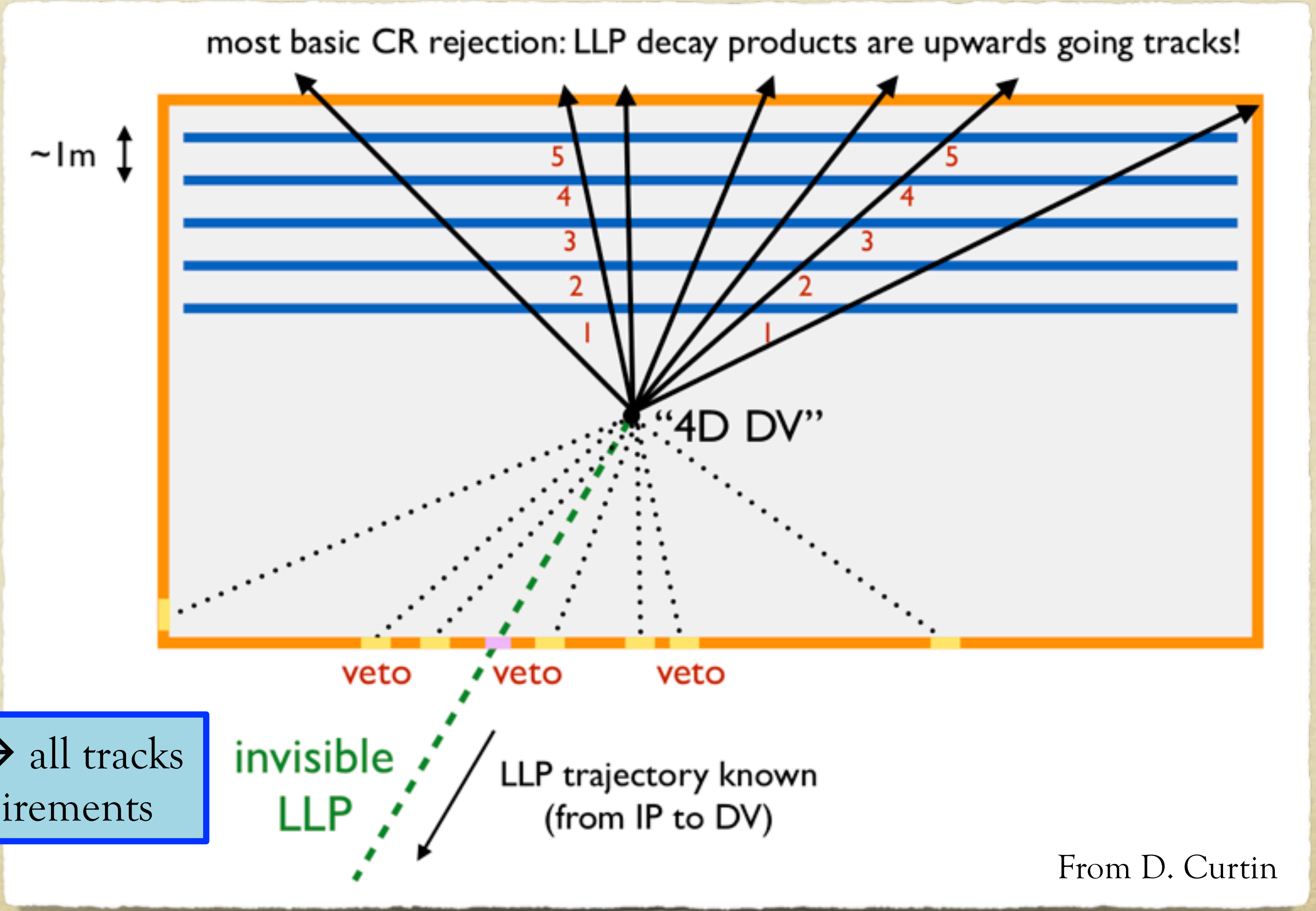
MATHUSLA – signal reconstruction example (2)

Hadronic decay of a LLP

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

- Δt between tracking layers >~ 3.5 ns

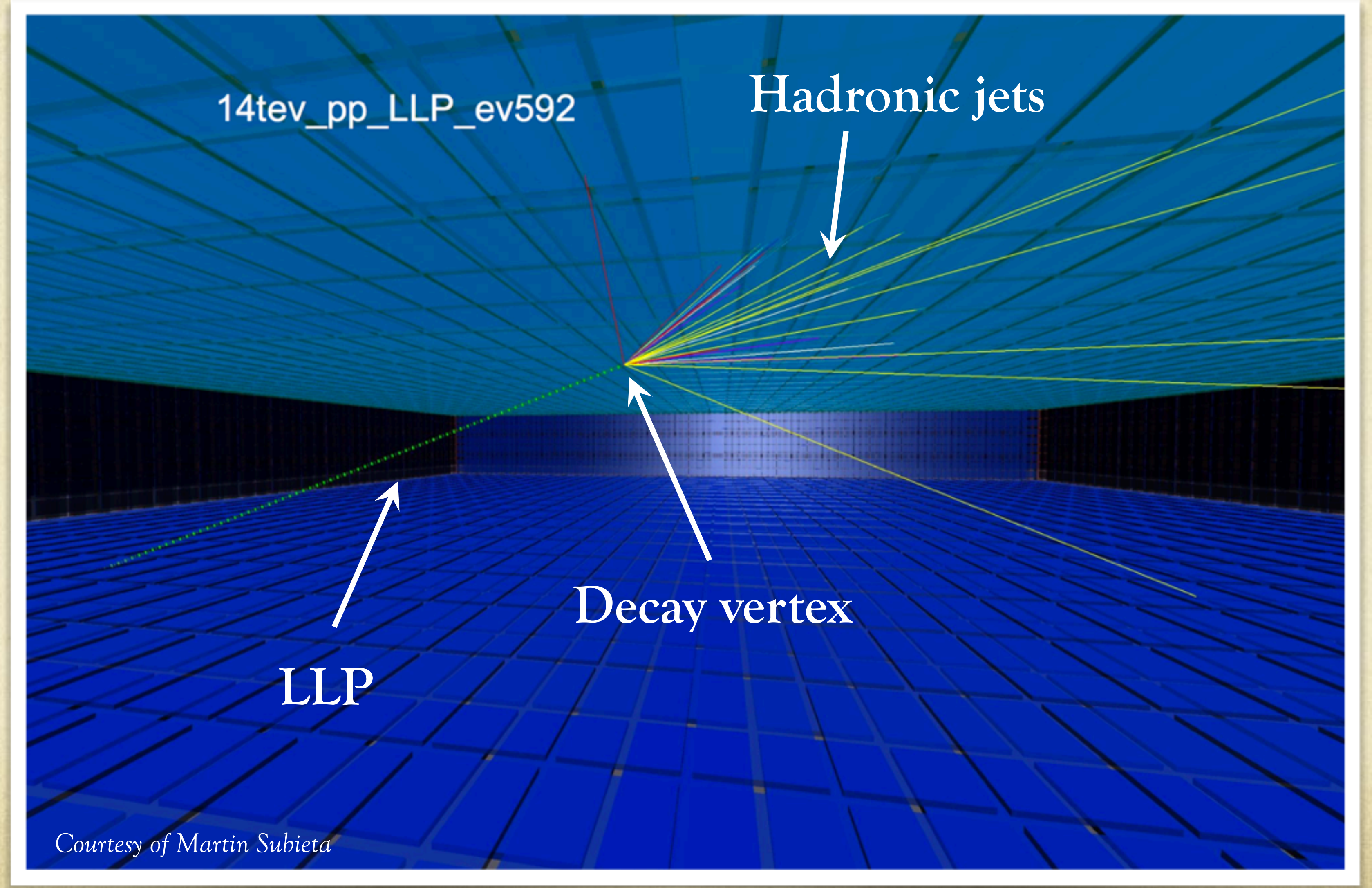
Tracks are reconstructed in **3D** and with detailed **timing** information at each layer, the DV is really a **4D DV**



More difficult to fake → all tracks have to pass veto requirements

MATHUSLA – Signal Simulation

Hadronic decay of a LLP



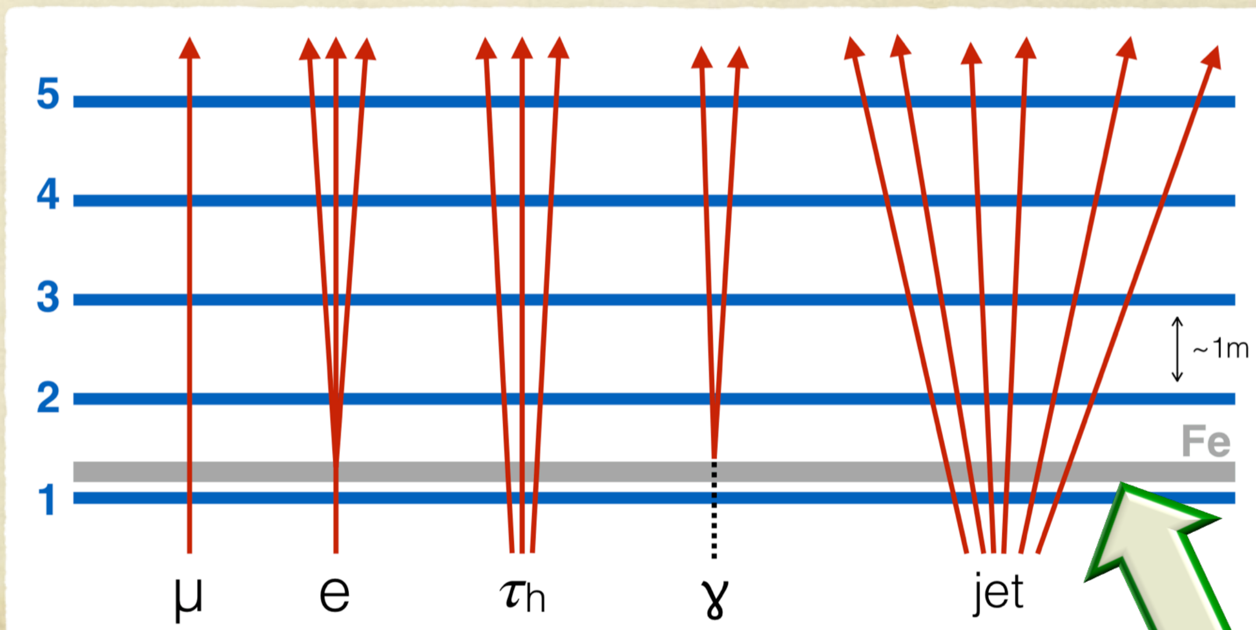
MATHUSLA – particle identification

D. Curtin, M. Peskin, arXiv:1705.06327

With the current detector design muons and electrons are undistinguishable, while photons are invisible

- **New idea:** insert a layer of iron few cm thick between the first and the second tracking layer
  - Provide 1-2 X_0 to convert electron and photons generating visible electromagnetic showers

No energy or momentum measurements, but allows to qualitatively distinguish the various particle types

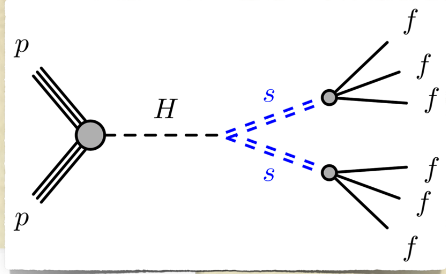


Angle of the charged tracks w.r.t. trcking plane can be know with a precision of **~ 2 mrad**

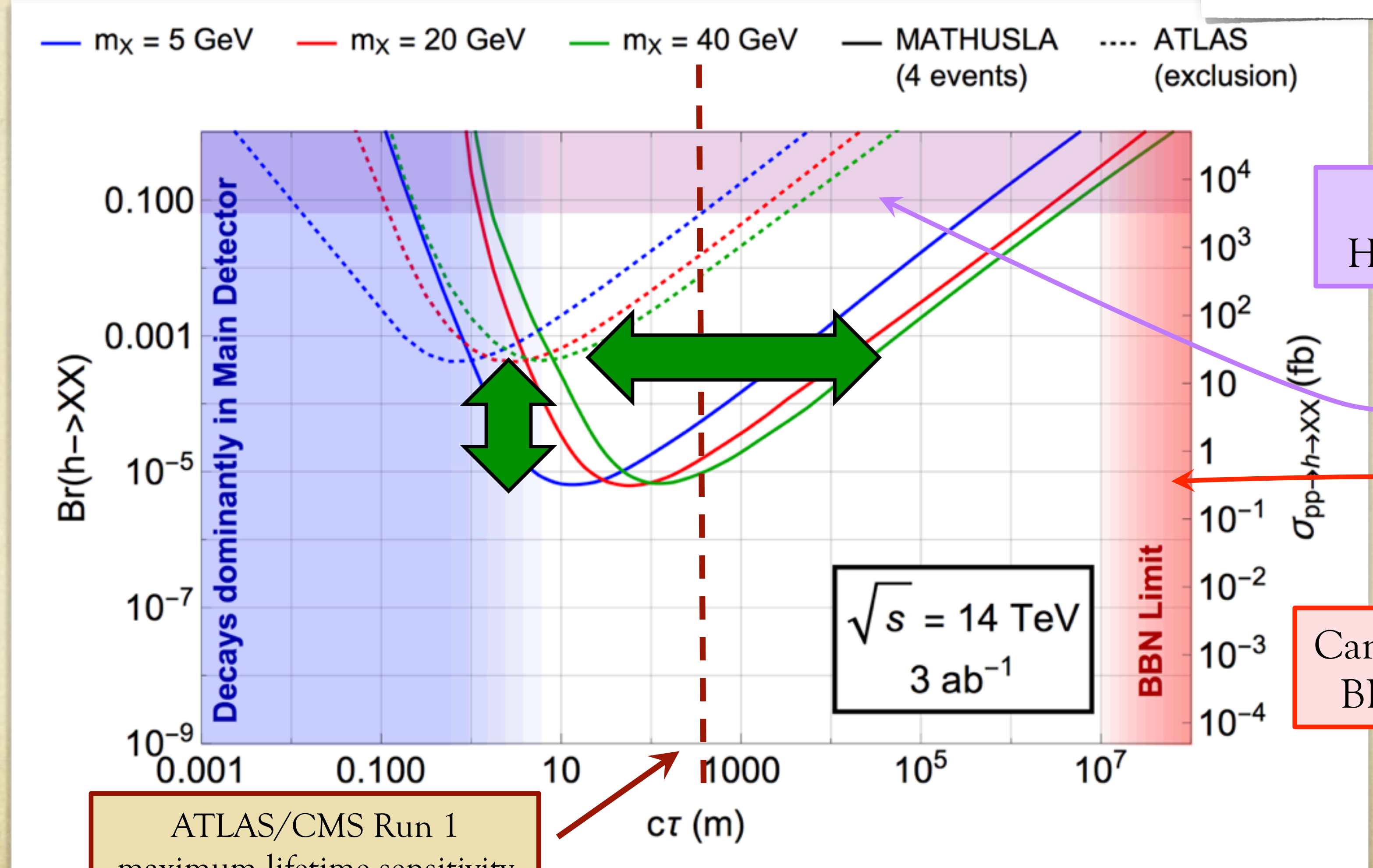
Details about location, material, thickness, etc. still under investigation

HL-LHC Sensitivity Estimate

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298



- Decay of Higgs boson to pair of scalars for different masses m_X
- No QCD background → big sensitivity gain



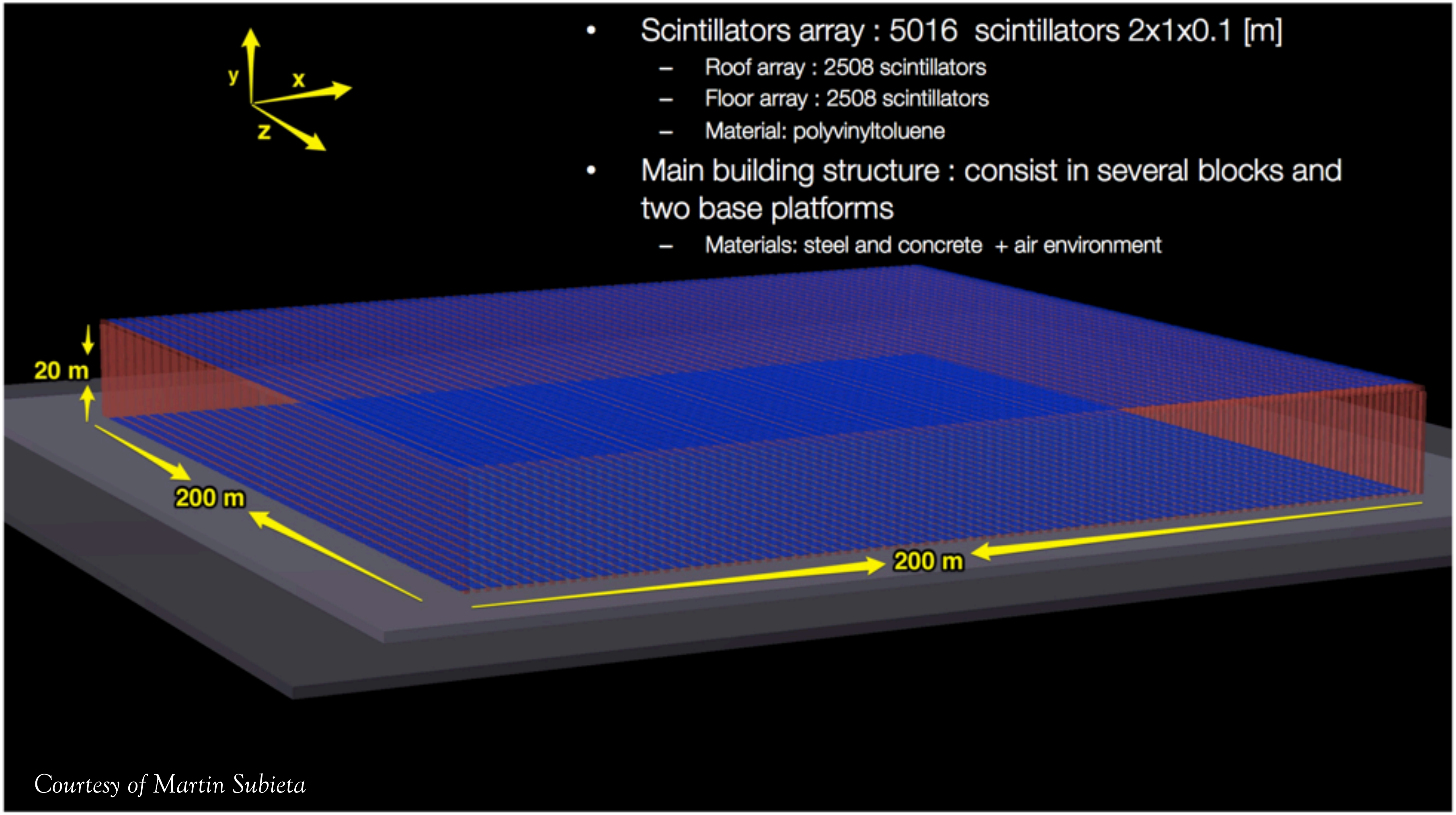
h → inv
HL-LH limit

Can approach
BBN limit!

ATLAS/CMS Run 1
maximum lifetime sensitivity

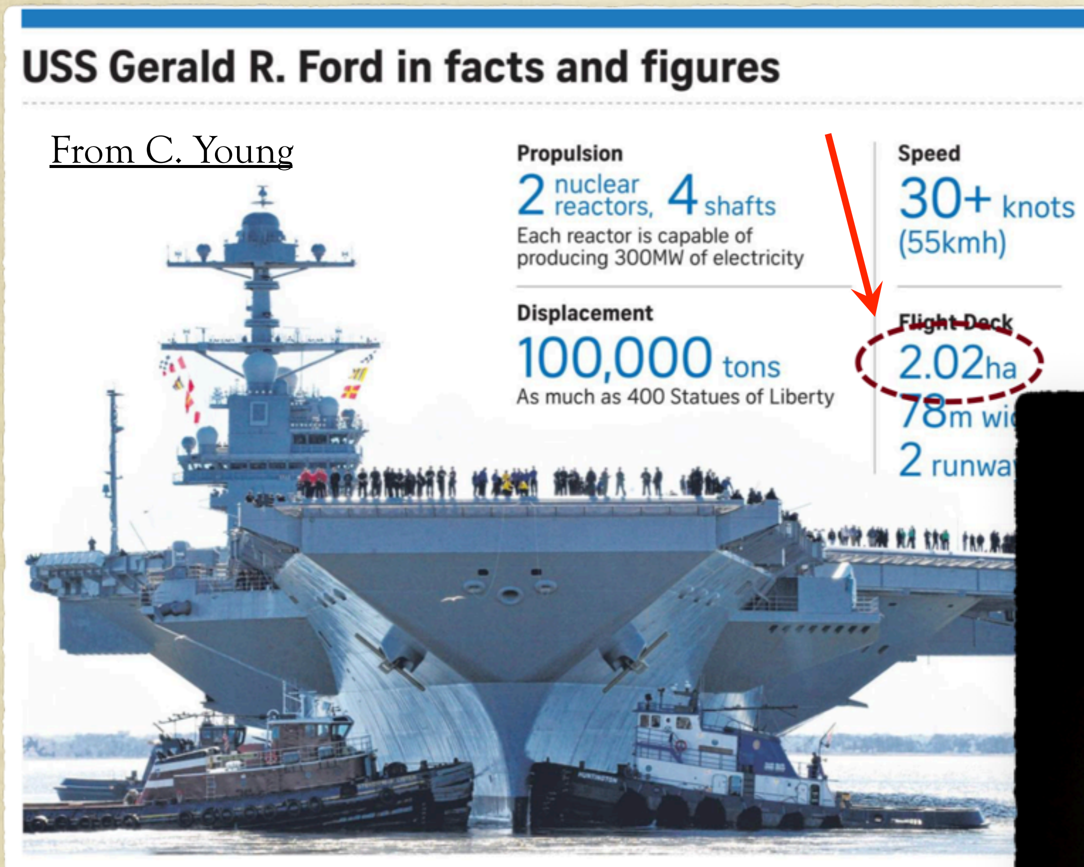
MATHUSLA – Main Detector

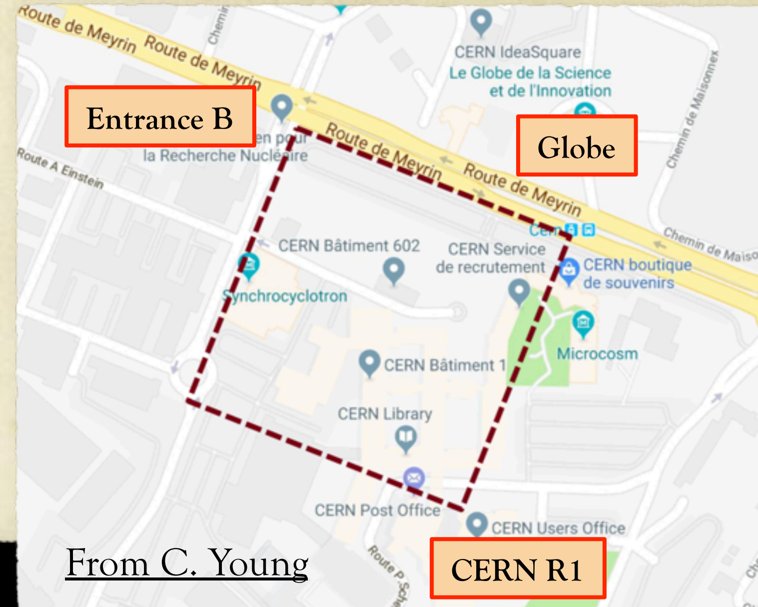
Main detector simulation

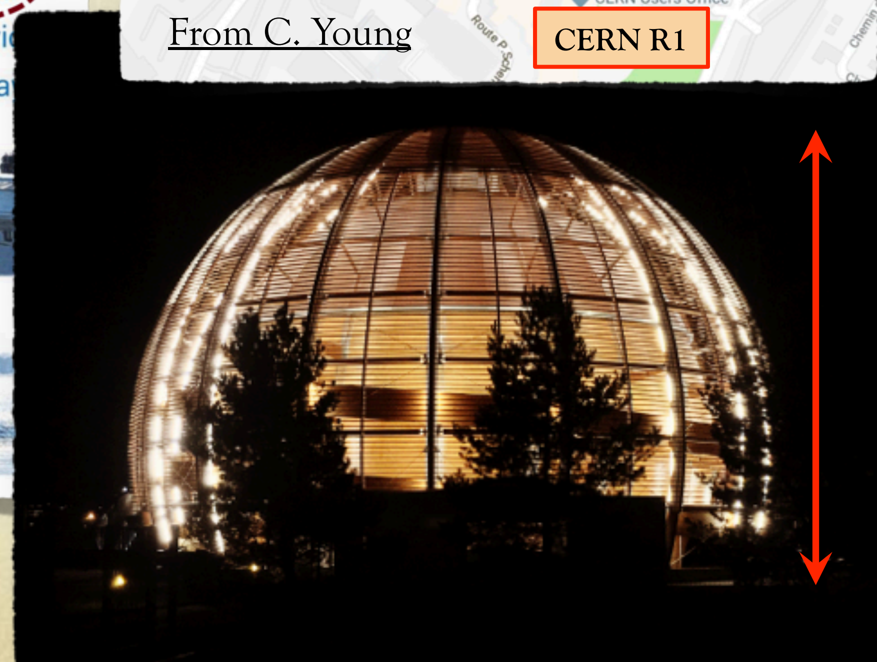


Courtesy of Martin Subieta

200 x 200 x 20 m^3 ...just to have an idea...

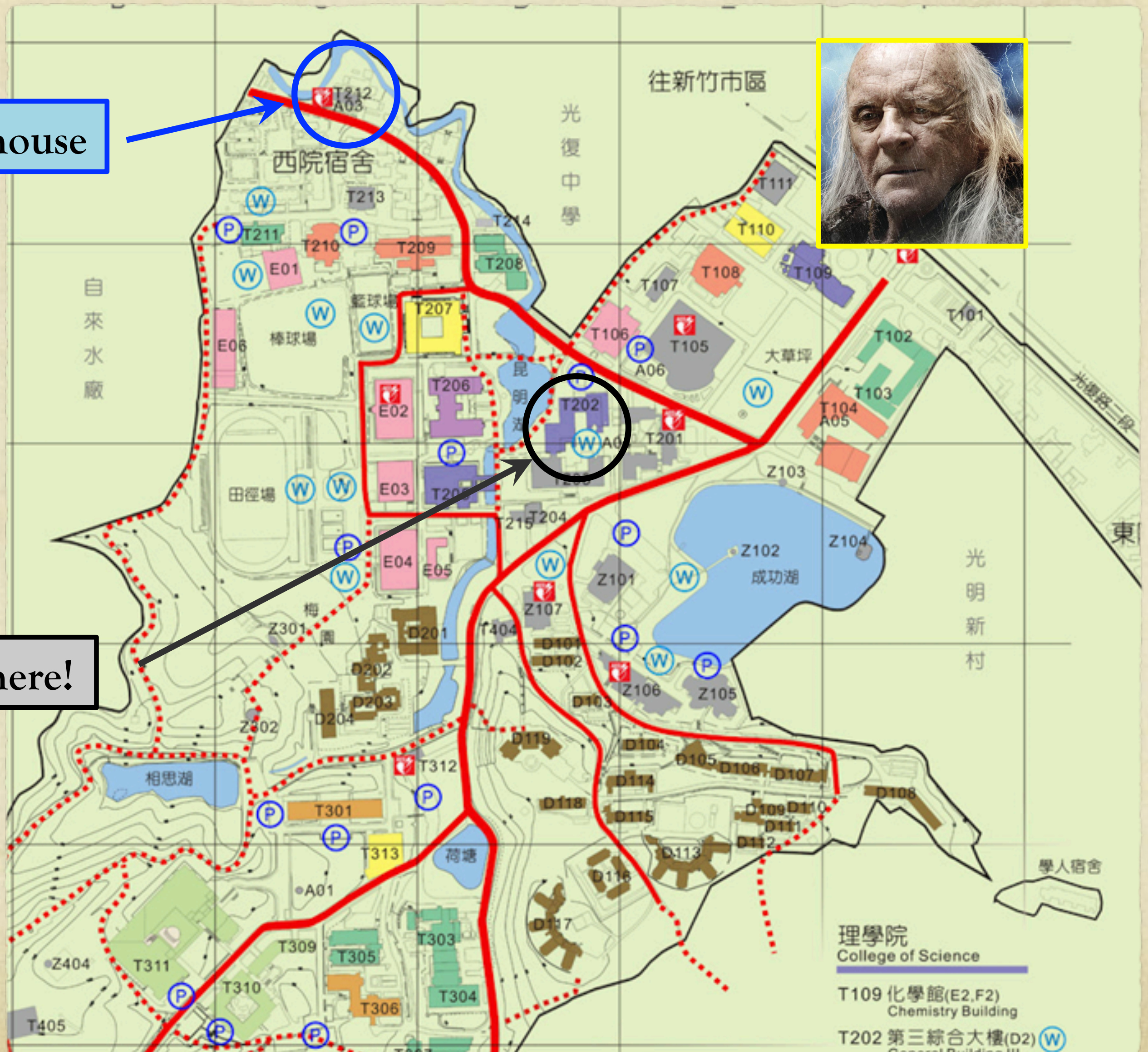






200 x 200 x 20 m^3 ...just to have an idea (local)...

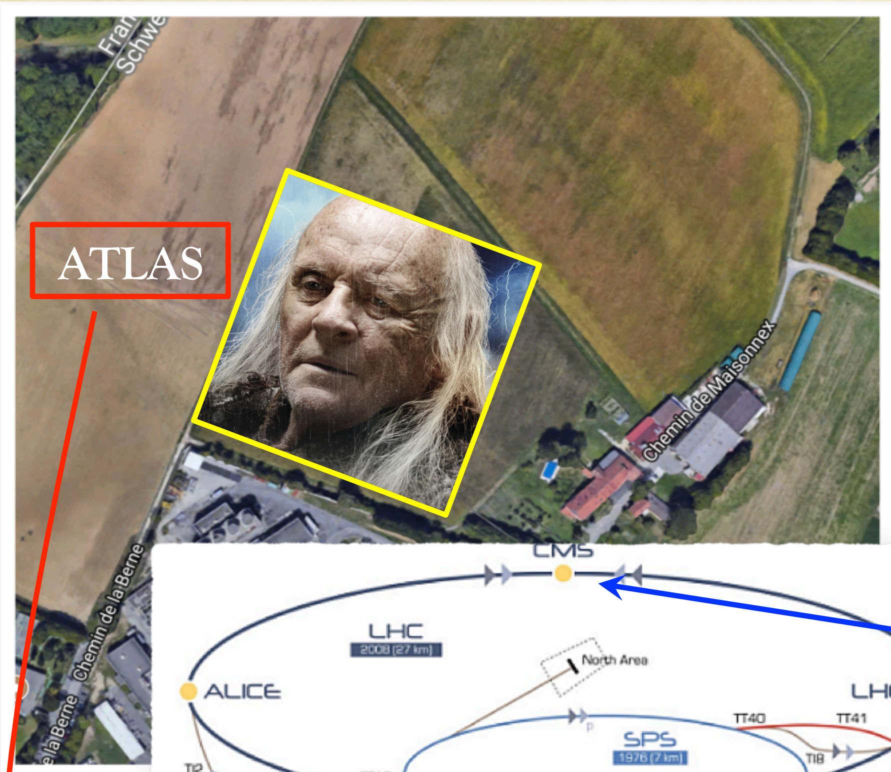
Guest house

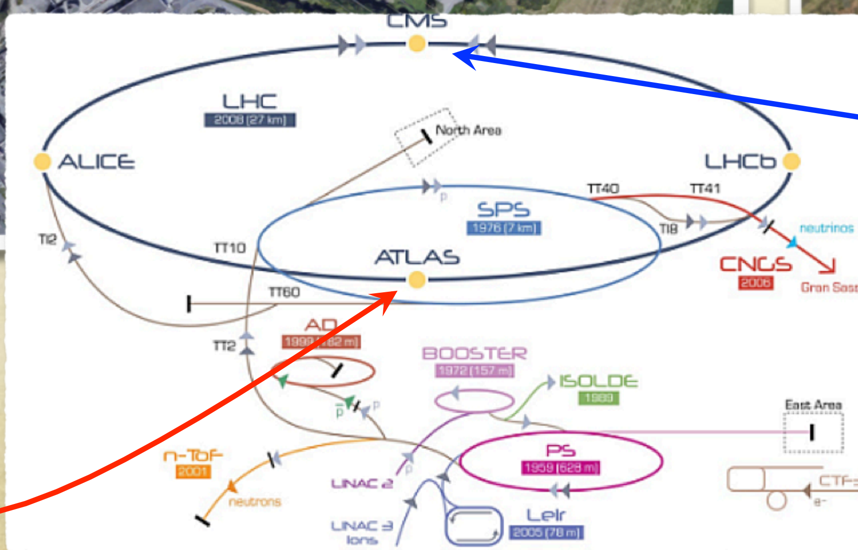


We are here!

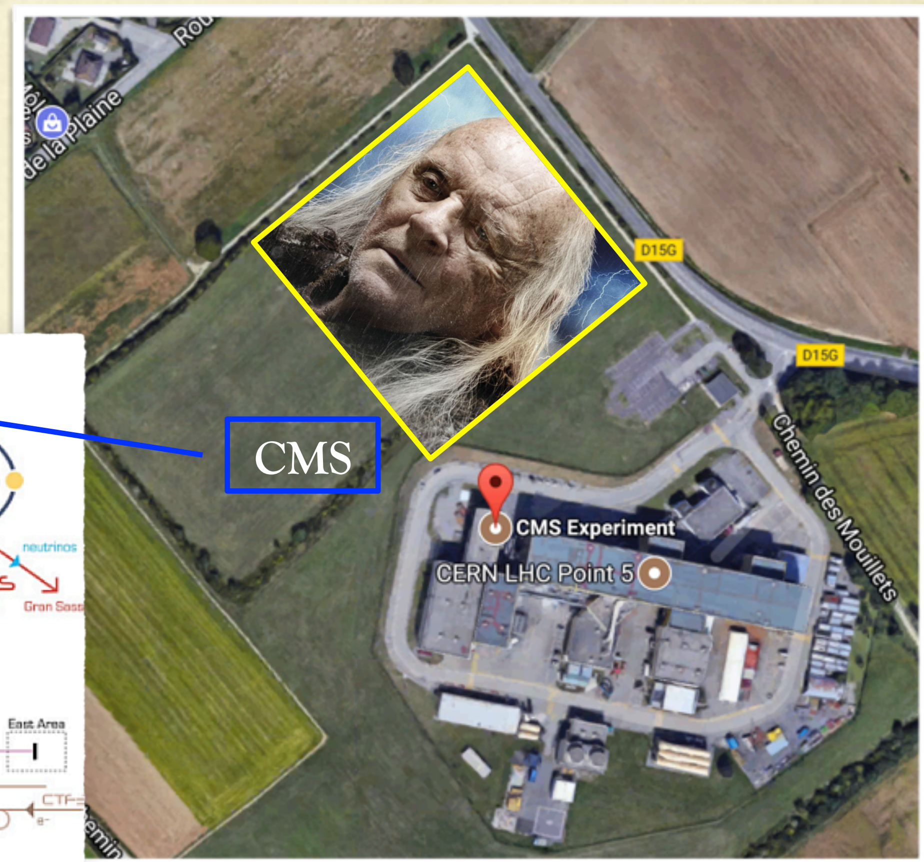
Where MATHUSLA could be located?

- We need a large surface close to a p-p interaction point (IP)



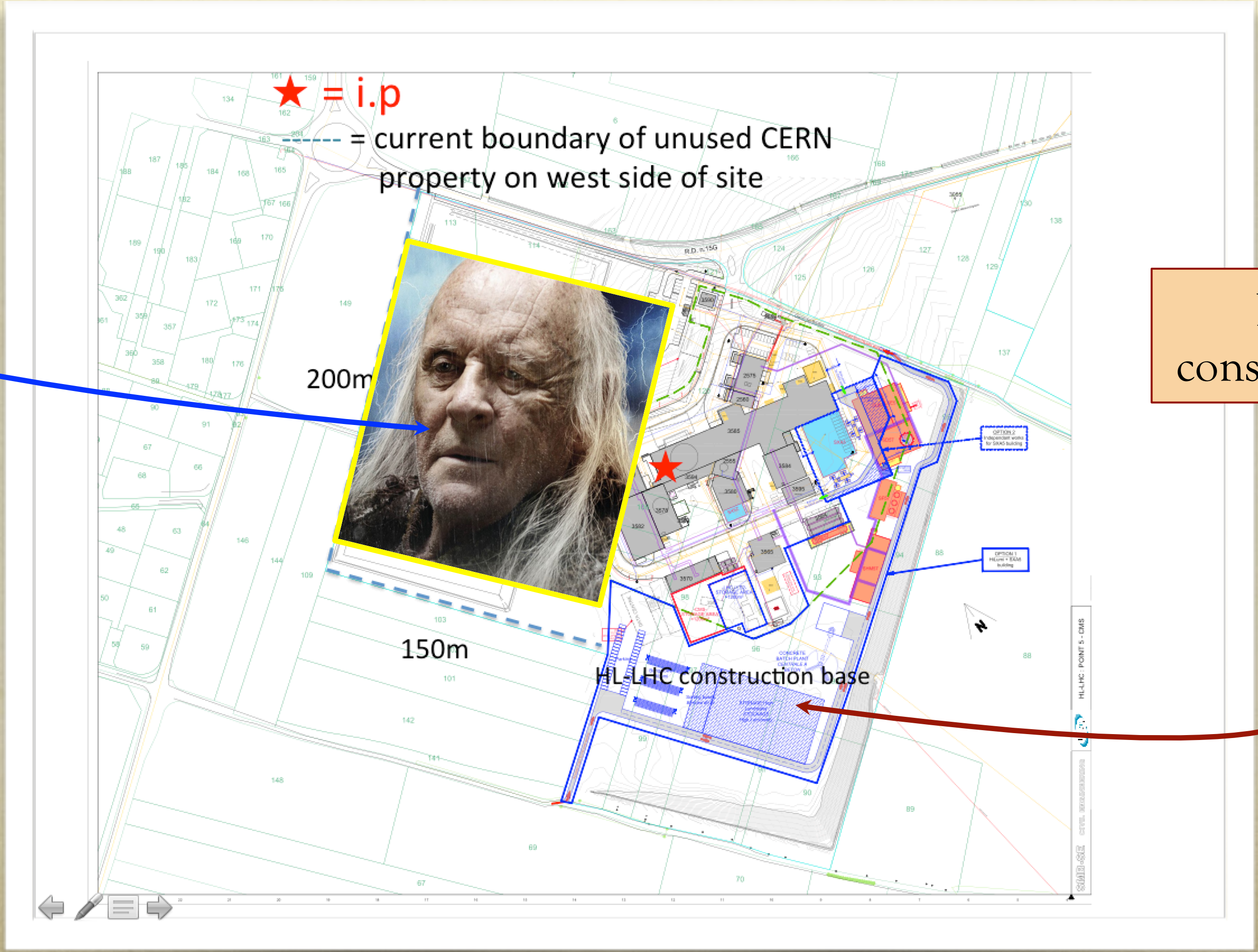


MATHUSLA could be located above either ATLAS (P1) or CMS (P2)



Where MATHUSLA could be located?

- ...not sure there is enough space around ATLAS...
- But **CMS site has a large area that is owned by CERN and there are no plans to occupy it in the future!**



HL-LHC construction base

What is the expected background for MATHUSLA?

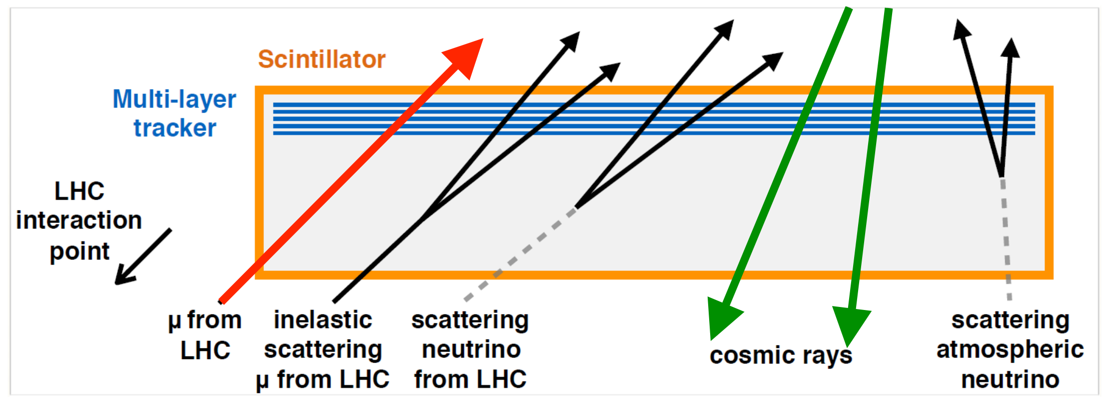
MATHUSLA - Backgrounds

J-P Chou, D. Curtin, H. Lubatti
arXiv 1606.06298

Non-collision backgrounds can be measured when no LHC collisions

No LHC QCD background, BUT…

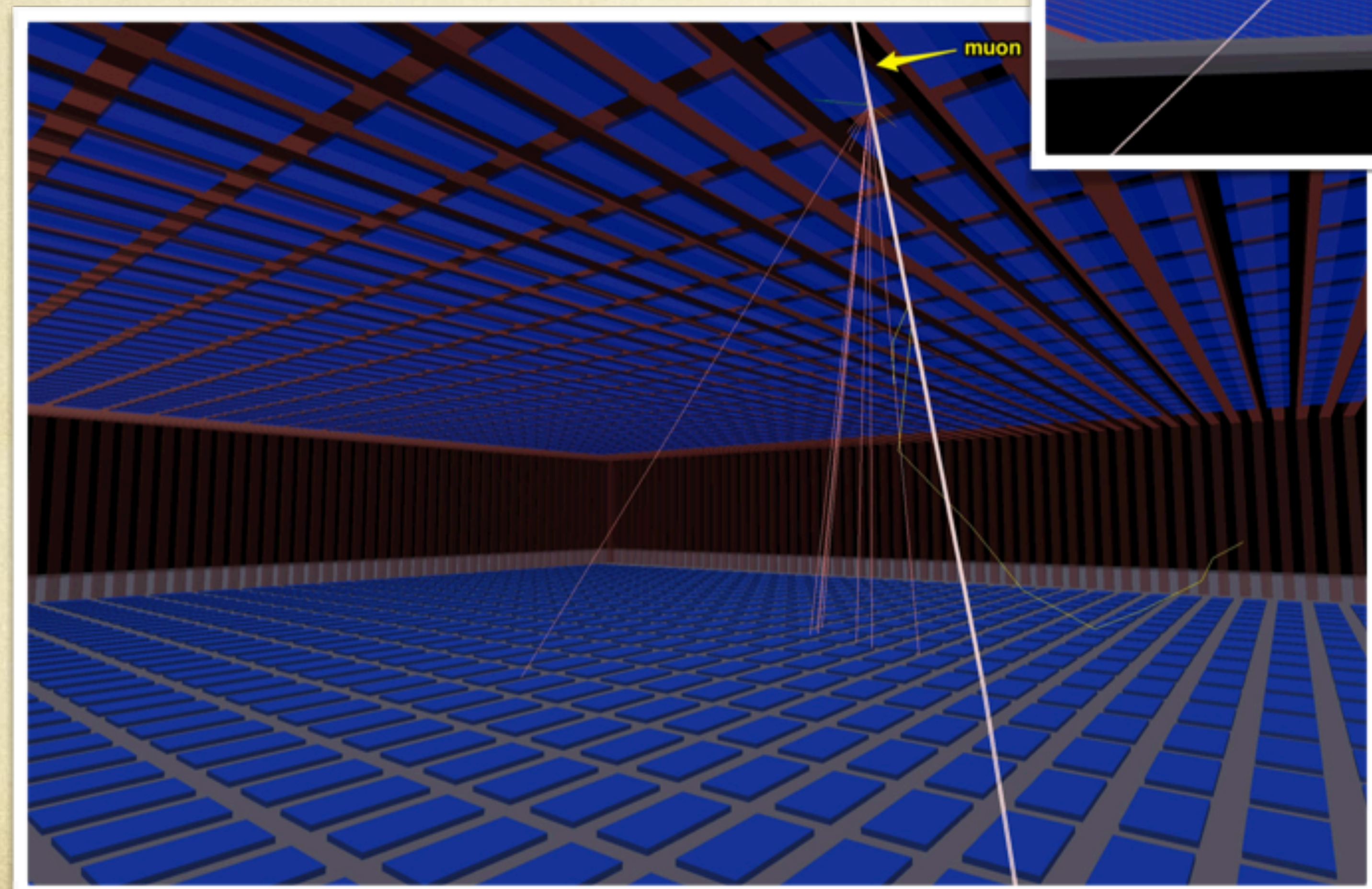
- **Cosmic muon** rate of about **10 MHz** (200 m^2)
  → rejected with scintillator timing (1.5 ns timing resolution)
- LHC collision backgrounds
  - ✓ LHC muons about **10 Hz**
    → **Reject with scintillator timing and entrance hit position**

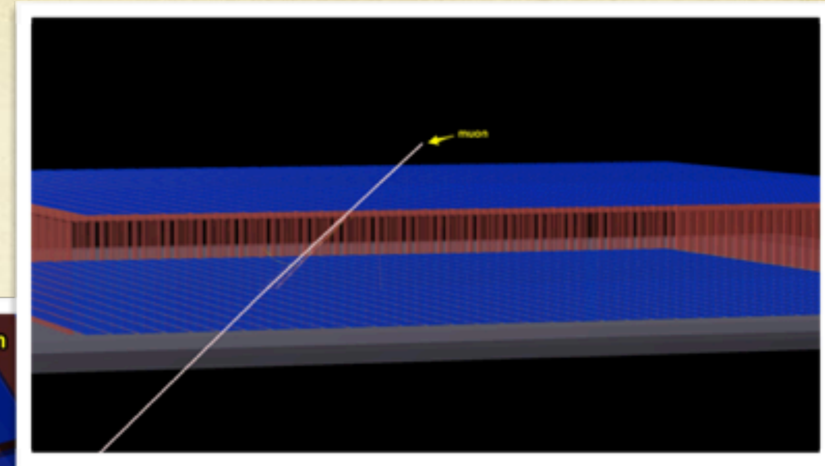


  - ✓ **LHC neutrinos** (subdominant background) → MATHUSLA should observe a **few events during HL-LHC data taking period**
- **Upward atmospheric neutrinos** that interact in air decay volume
  - ✓ Estimate Low rate ~ **70 events per year above 300 MeV**
  - ✓ Mostly "decay" to low momentum proton → reject with time of flight

Goal is a background-free MATHUSLA!

MATHUSLA – Cosmic Muon Background Event





MATHUSLA – Any other “crazy” background

Are we really taking into account all backgrounds?

- We are looking at very rare events, so we are very sensitive to less obvious backgrounds!

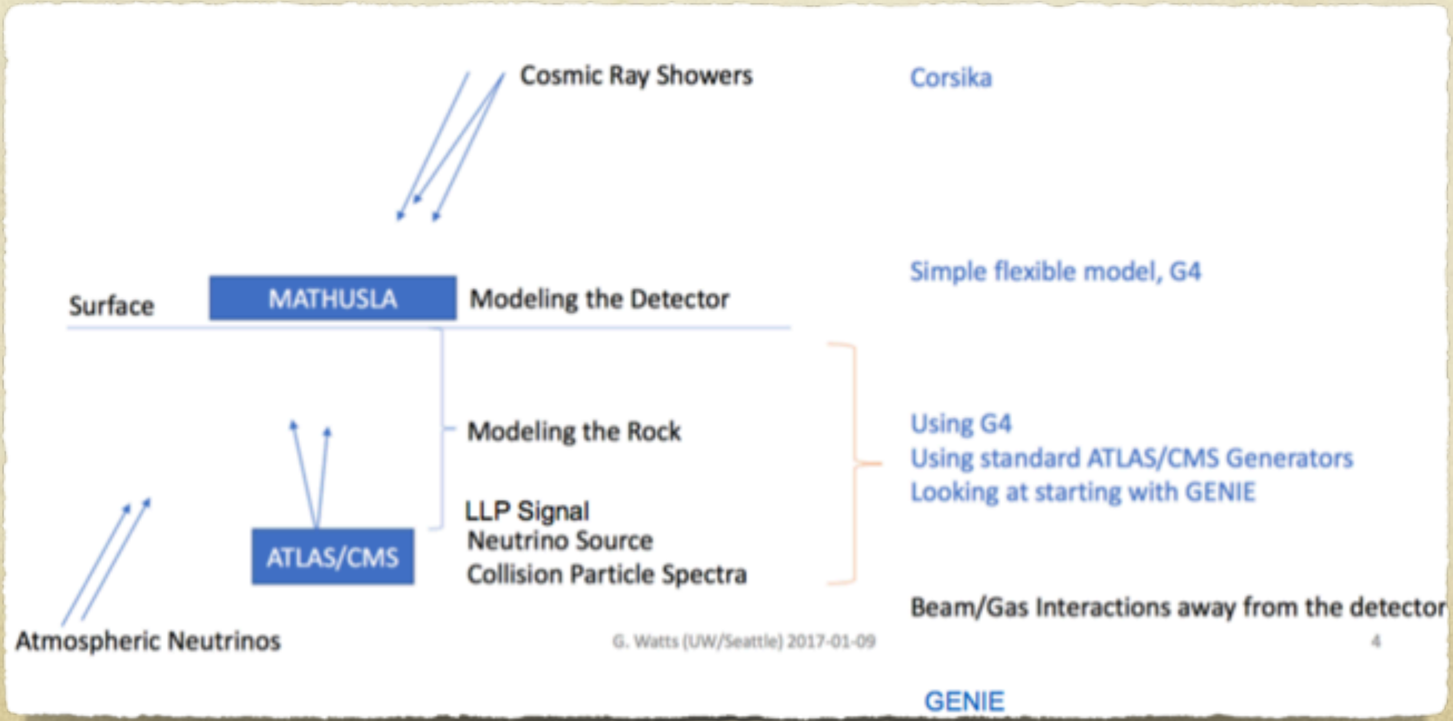
  - **Horizontal cosmic rays hitting atoms below MATHUSLA in floor**
  - **Single K_L or neutron traveling upwards, decaying in MATHUSLA (exactly a LLP signal!)**
    - ✓ Rate estimated to be very small, but…
  - **Cosmic rays hitting material in detector, either floor or walls or support structures? and creating K_L or neutron?**
  - **???**

We are working on precisely estimating (and simulating, if possible) all these rare backgrounds!

MATHUSLA - Background Simulations

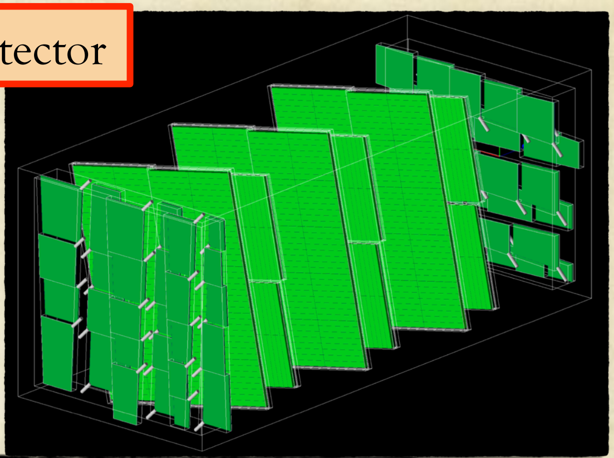
Effort underway to develop simulations of all the sources of backgrounds

- Current plan to deal with **muons** and **neutrinos traveling upwards** is to create a "gun" that shoots particles into MATHUSLA
- Cosmic ray showers simulated using **CORSIKA** (work is well advance!)
- Atmospheric neutrinos simulated using **GENIE**



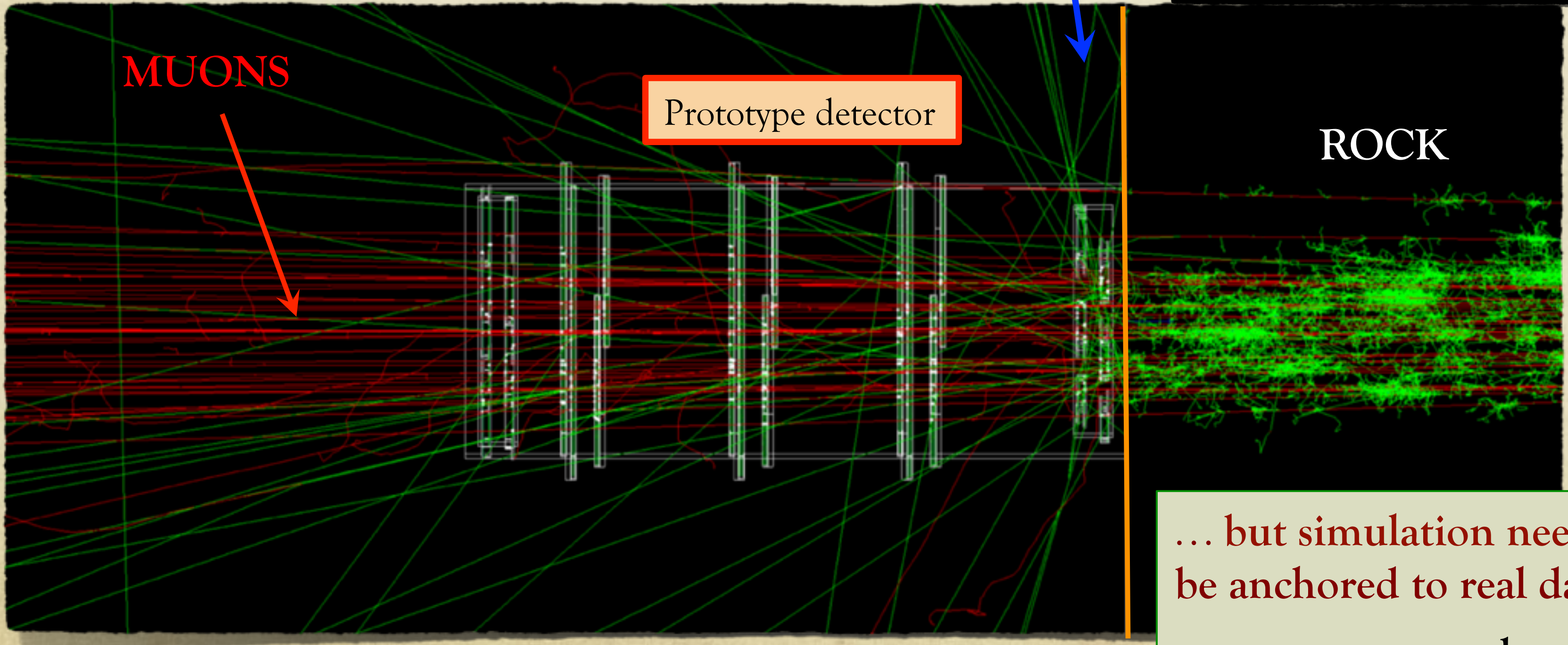
MATHUSLA - Background Simulations

Effort underway to develop simulations of all the sources of backgrounds



Simulation of a muons through the prototype detector

- Muon gun generated with Pythia8

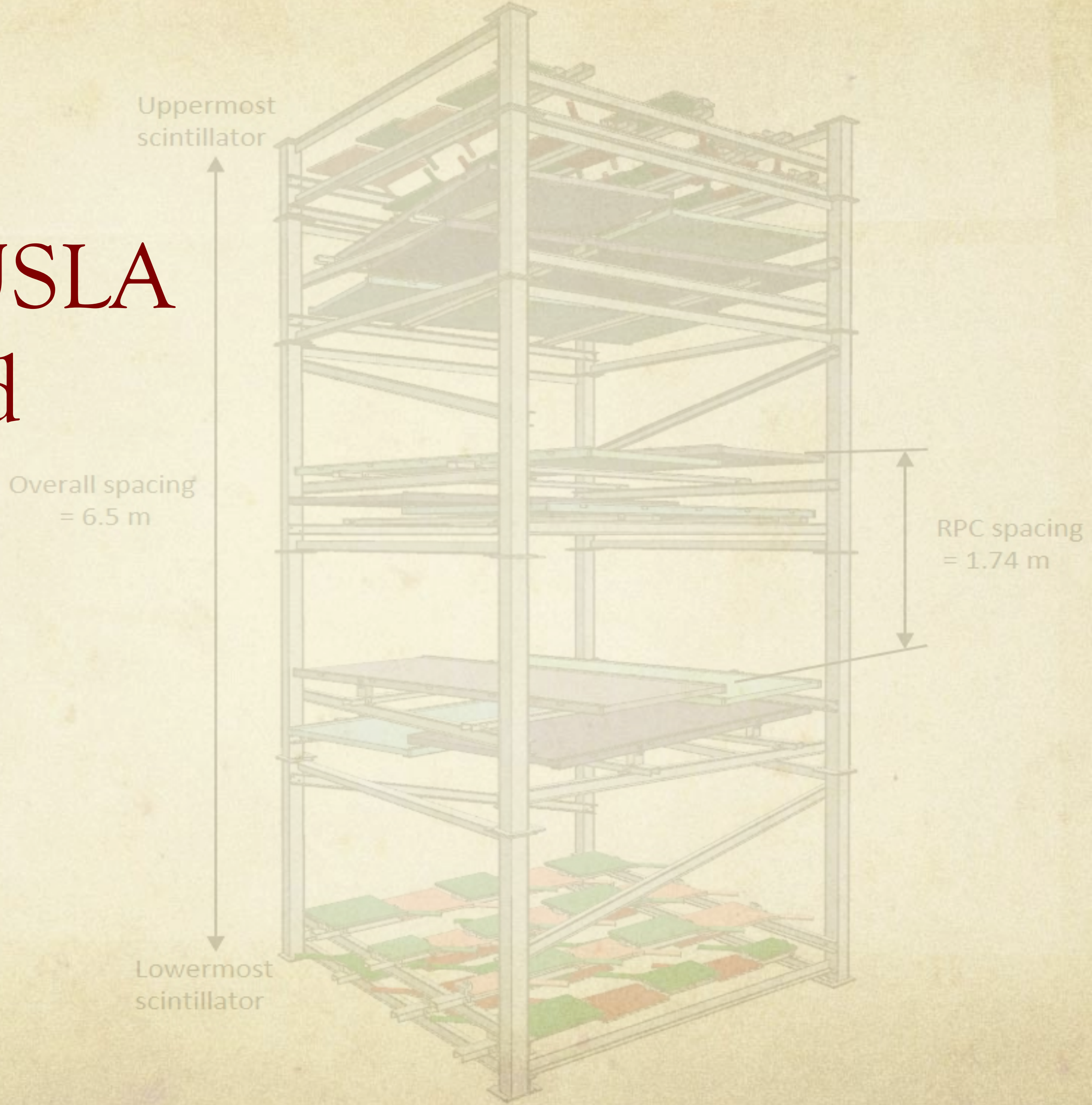


ATLAS/CMS IP

... but simulation need to be anchored to real data!

...so we need a...

MATHUSLA test stand



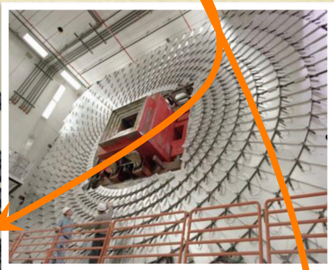
MATHUSLA Test Stand

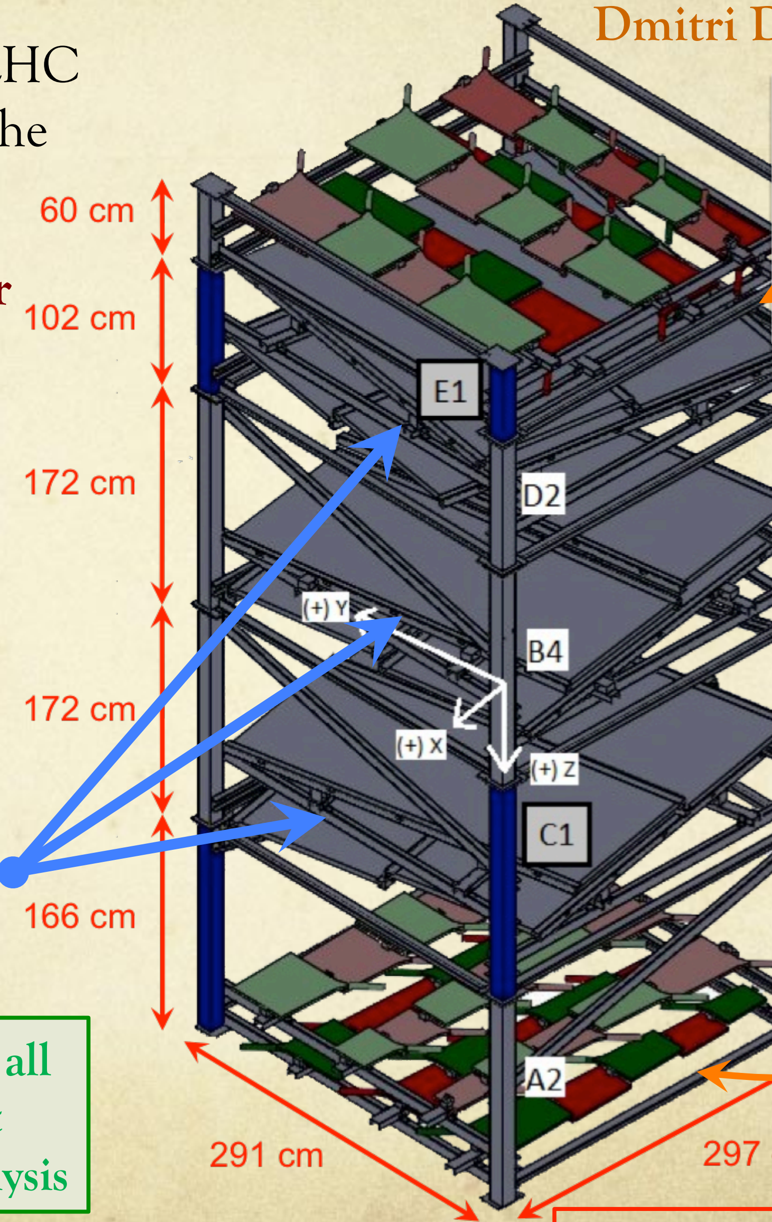
- MC simulations need data with LHC colliding protons and also when the beam is off
- **Test stand assembled last October thanks to the big help of CMS and ATLAS!**
- The goal is to measure charged tracks from LHC, not to search for LLP

3 layers of RPCs provided by University of Tor Vergata (Rome) by Rinaldo Santonico (from Argo Experiment)

Excellent for students participation at all stages of an experiment: design, test components, install, take data and analysis

Top and bottom scintillator layers from Tevatron DØ provided by Dmitri Denisov

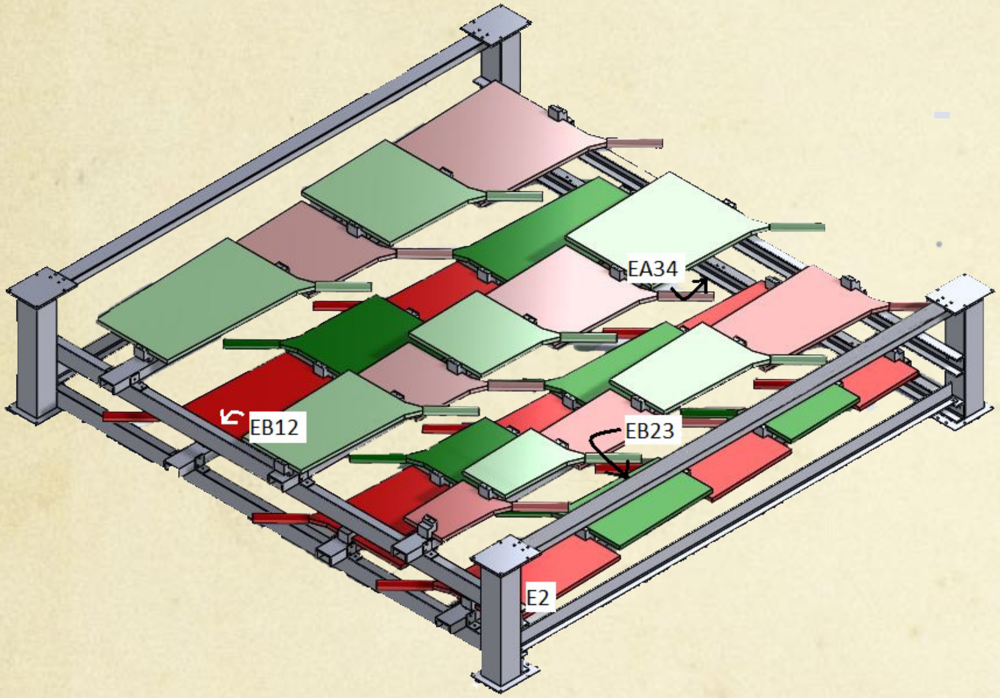




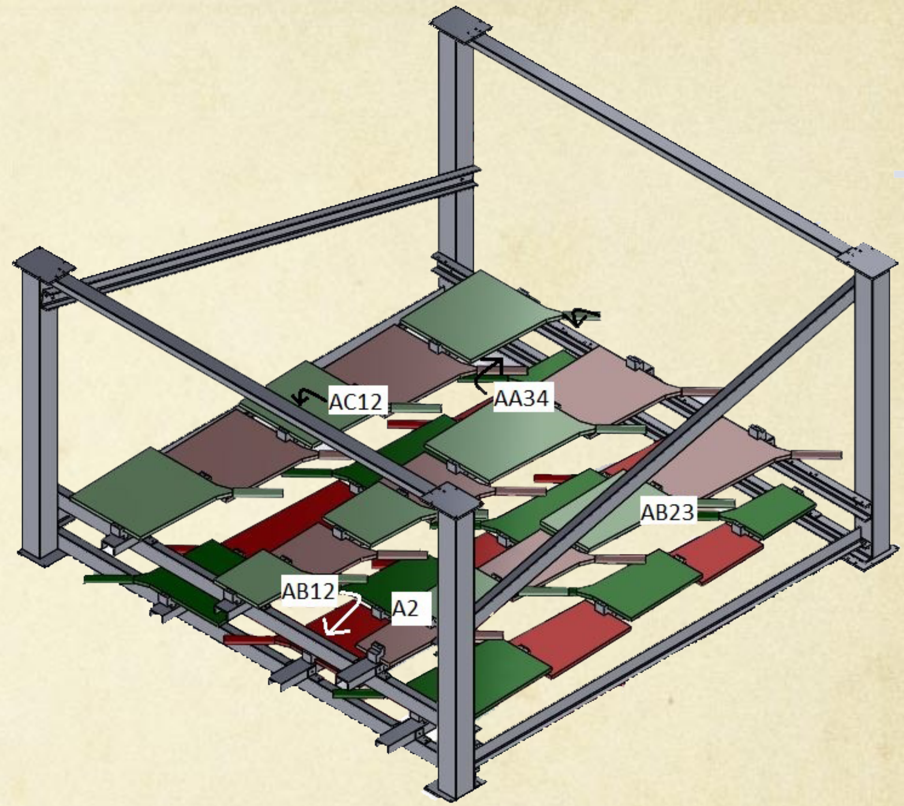
Active area ~ 2.5 x 2.5 x 6.0 m^3

MATHUSLA Test Stand – Scintillator details

Top – 31 scintillators



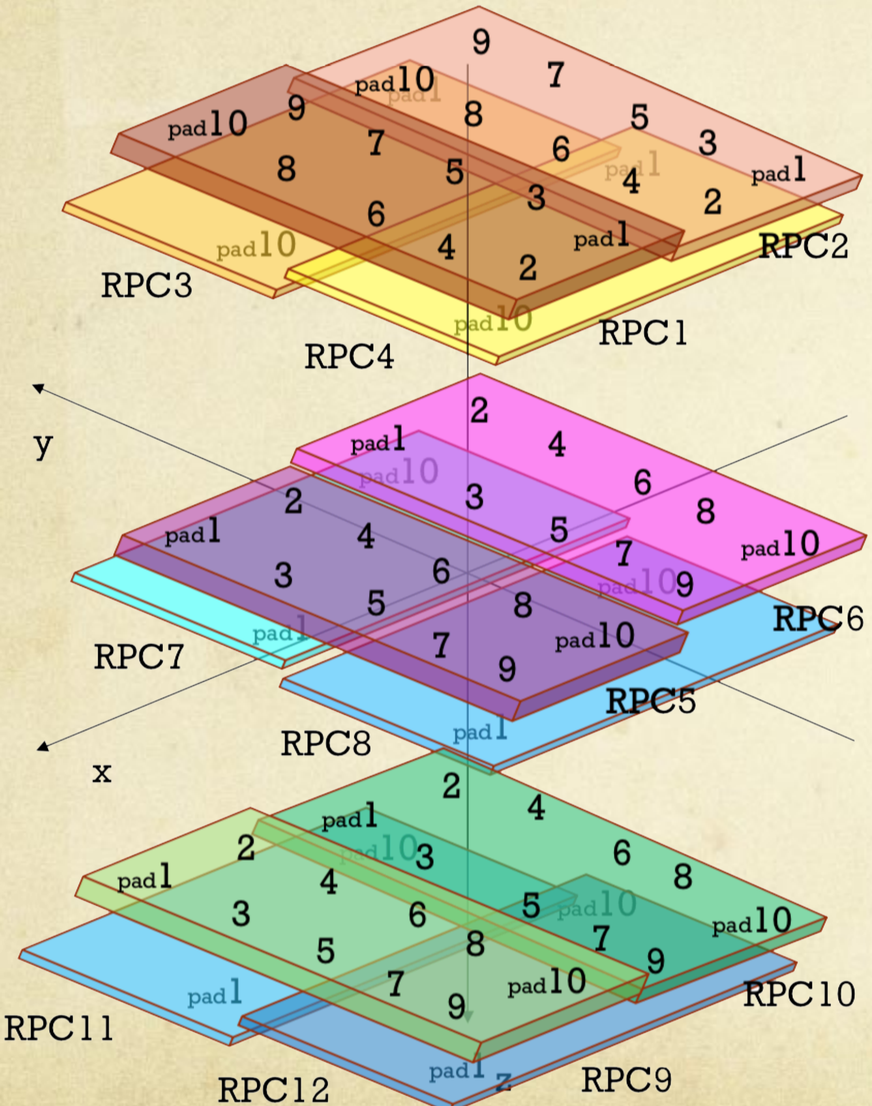
Bottom – 28 scintillators

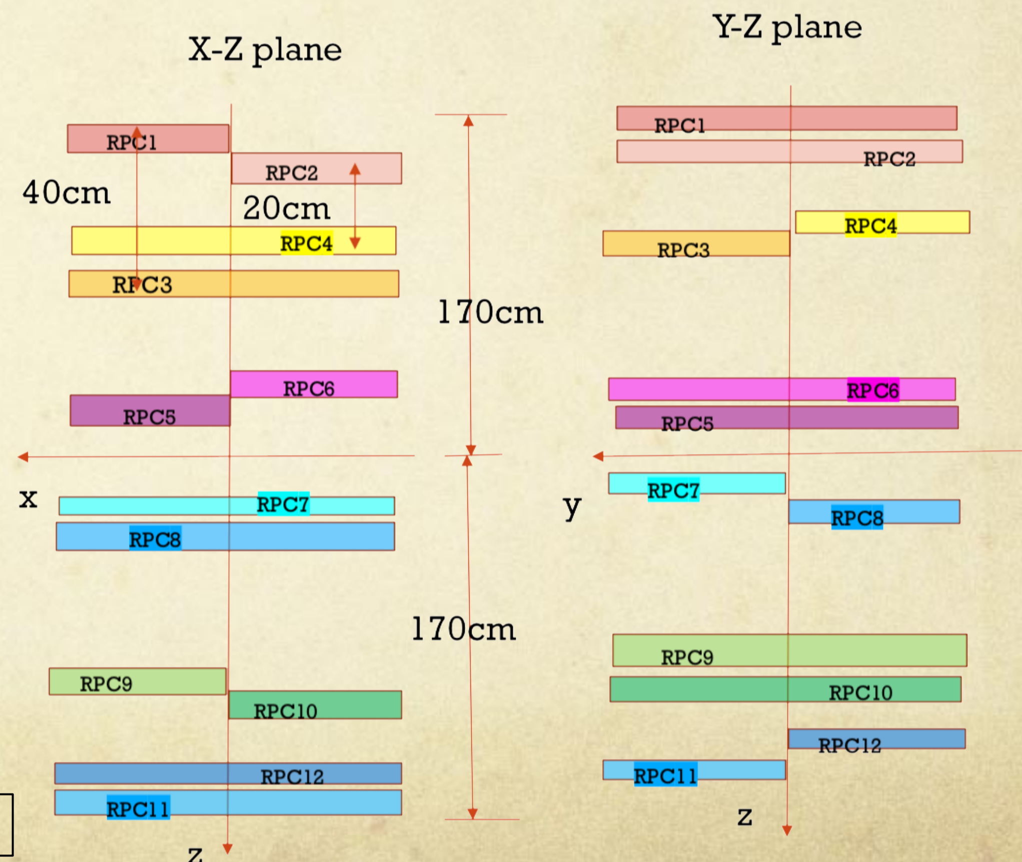


12.8-mm-thick BICRON 404A of trapezoidal shape
+ WLS bars for light collection

MATHUSLA Test Stand – RPC details

- ✓ Operating in streamer mode
- ✓ Chamber size: 1.25 x 2.80 m^2
- ✓ 10 Pads (55.6 x 61.8 cm^2) for each RPC
- ✓ 8 Strips (6.75 x 61.8 cm^2) for each Pad
- ✓ Ar + ATLAS RPC gas **($C_2H_2F_4$/Iso-C_4H_{10}/SF_6 (94.7/5/0.3)**

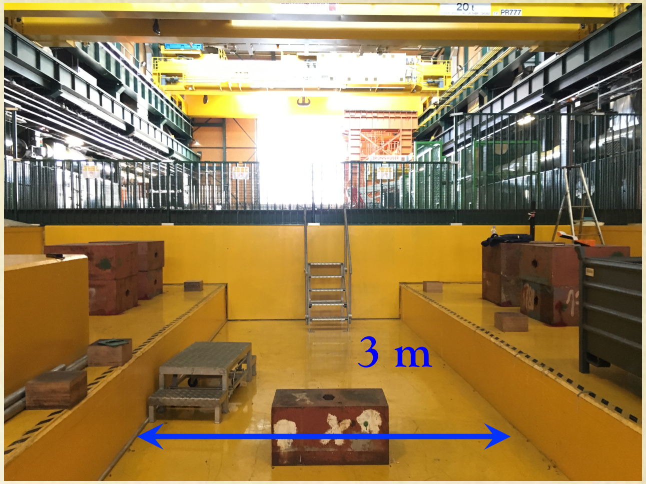


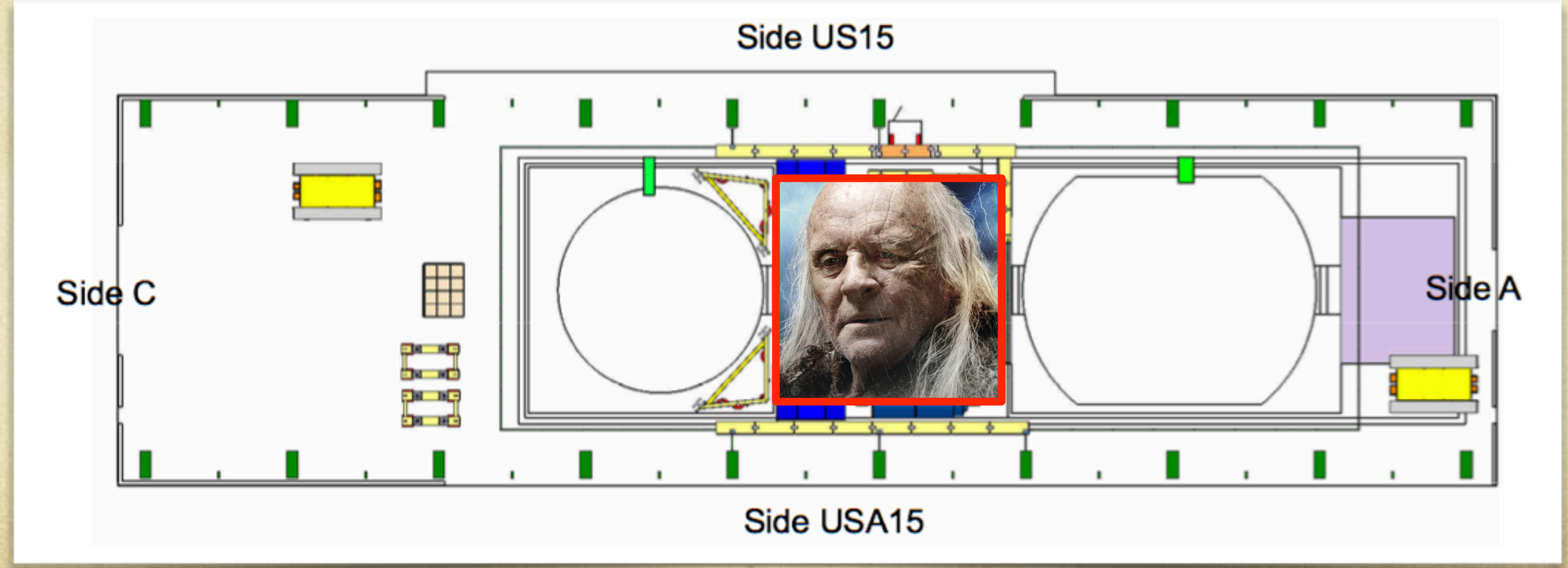


Tingting Cao

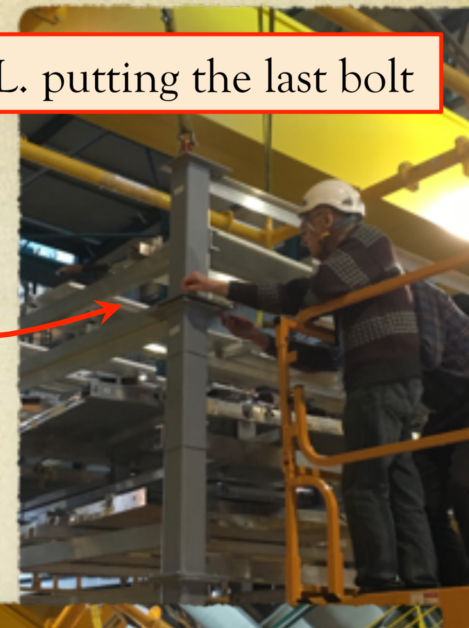
Installation in ATLAS P1 (1)

- Cosmic background well understood
- Need to quantify the **background from ATLAS**
- Test stand installed in the (Buffer Zone) on the surface area above ATLAS (exactly above IP) in November (during ATLAS operations this space is empty)
    - ✓ **Perform measurements with beam on and off**



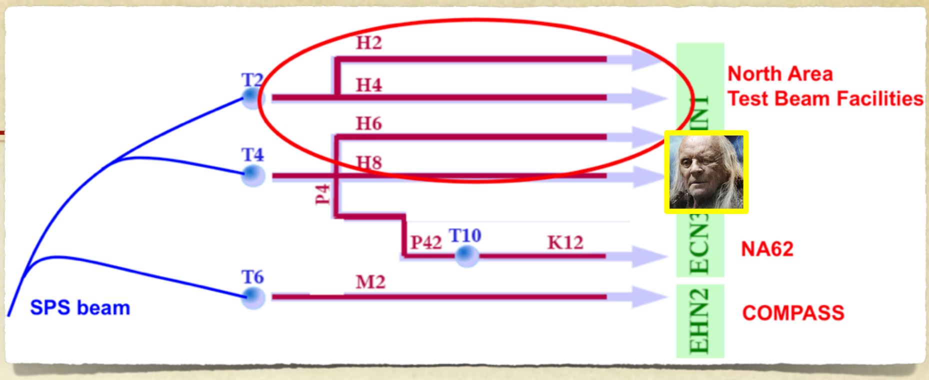


Installation in ATLAS P1 (2)



P1 data-taking lasted < 2 weeks

MATHUSLA @ H8



- With the opening of the ATLAS cavern, the buffer zone was filled with ATLAS radioactive material (beam pipe shielding, etc...)
- At the **end of November MATHUSLA test stand moved to a temporary space in CERN Prevessin** (H8 SPS extraction line)
  - Performed test with cosmic rays
  - Improved data-taking
  - Improved performance of the RPCs

Delay boxes for trigger

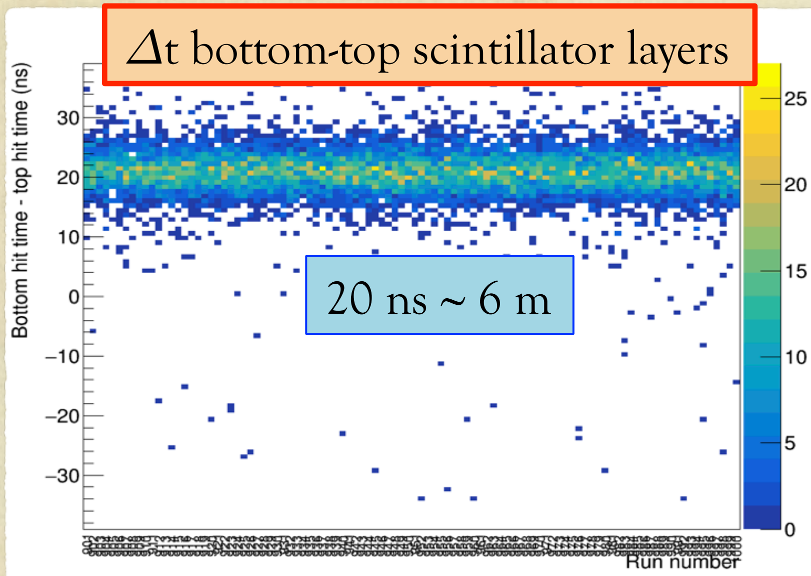
MATHUSLA back to P1 (end May 2018)

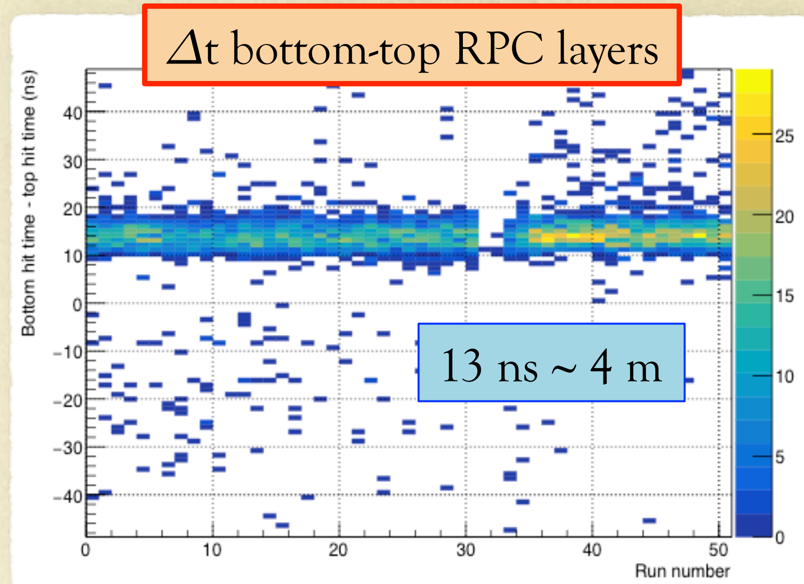
- MATHUSLA test stand move back to ATLAS P1

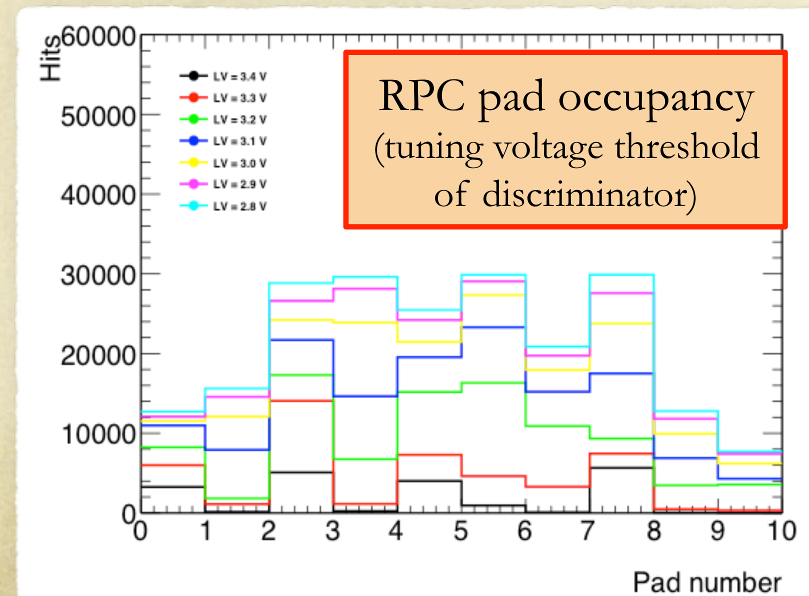
- Finalising the detector commissioning
- **Data taking will start next week and it will continue until the end of LHC p-p collisions (November)**

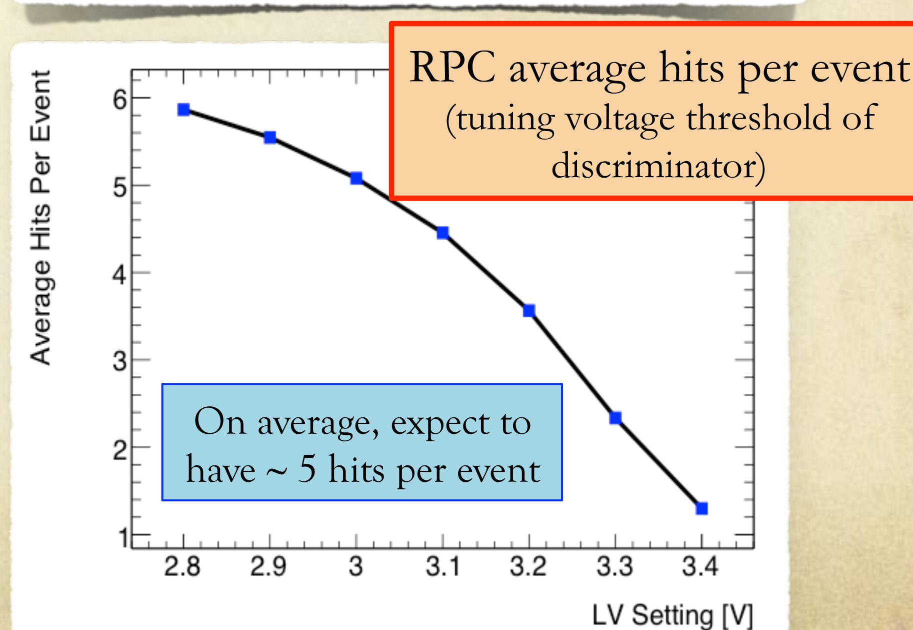
MATHUSLA
performance

MATHUSLA Performance (Scintillators & RPC)









MATHUSLA tracking

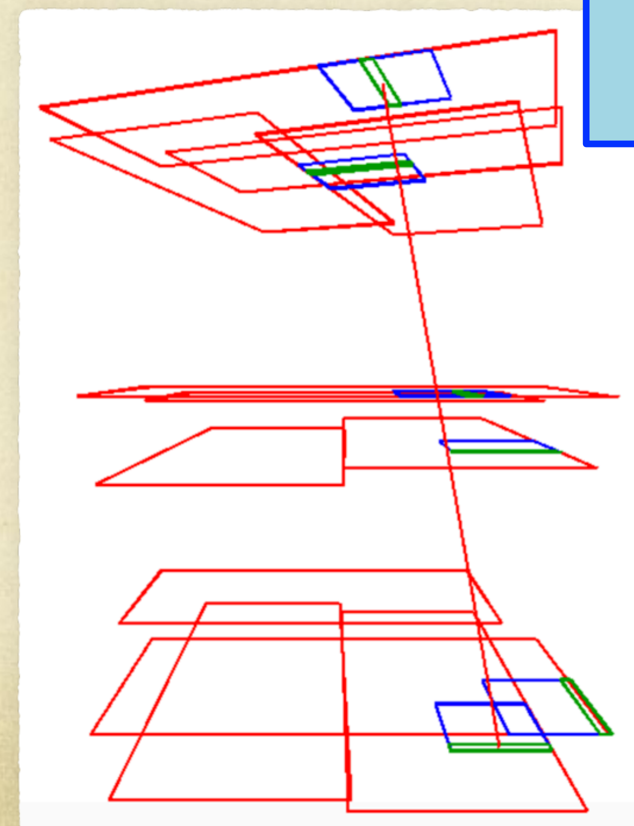
Remember:

- 8 Strips (6.75 x 61.8 cm^2) for each Pad

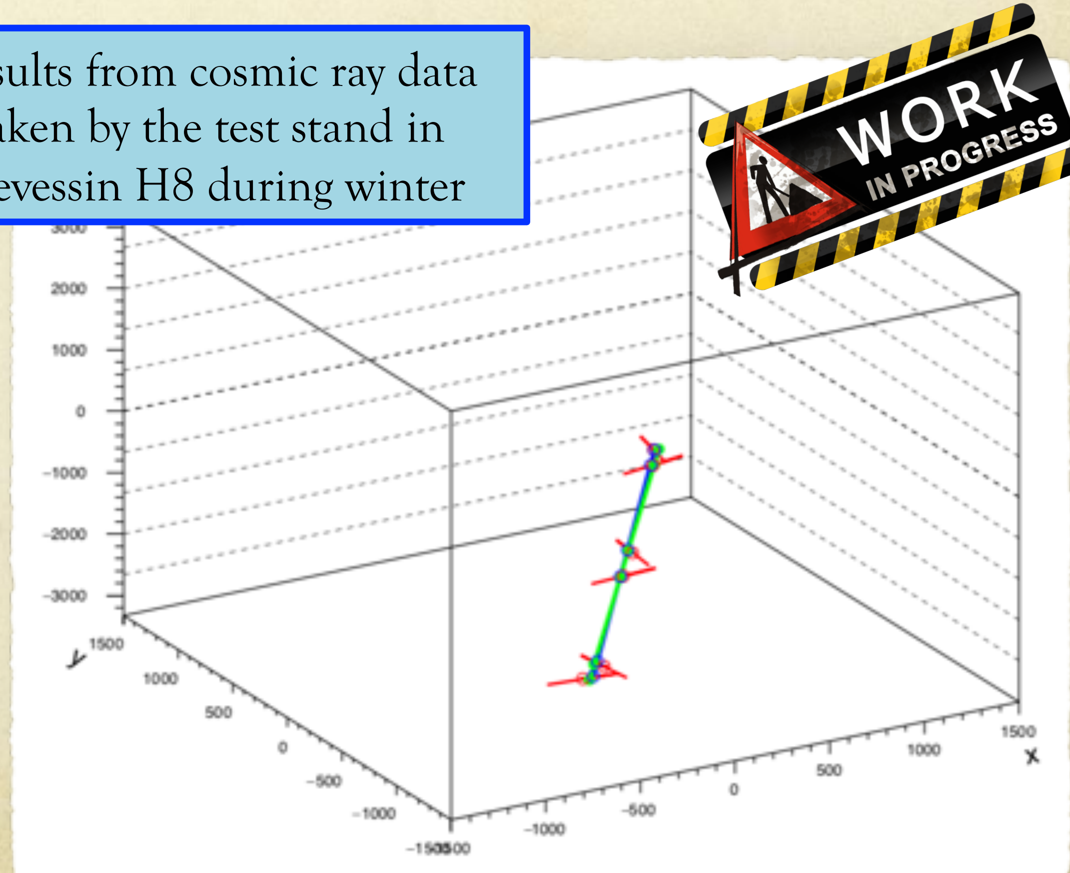
- On-going effort
- Very simple track reconstruction, χ^2 fit

$$\Delta\chi^2 = \left[(\vec{x}_{hit} - \vec{x}_{track}) \cdot \hat{L}/\sigma_L\right]^2 + \left[(\vec{x}_{hit} - \vec{x}_{track}) \cdot \widehat{W}/\sigma_W\right]^2$$

- **Preliminary results**

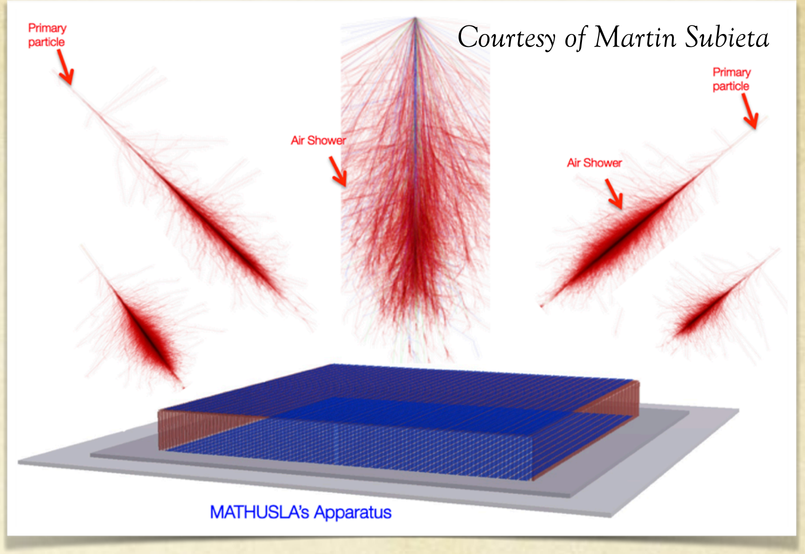


Results from cosmic ray data taken by the test stand in Prevessin H8 during winter



Is MATHUSLA only LLP?

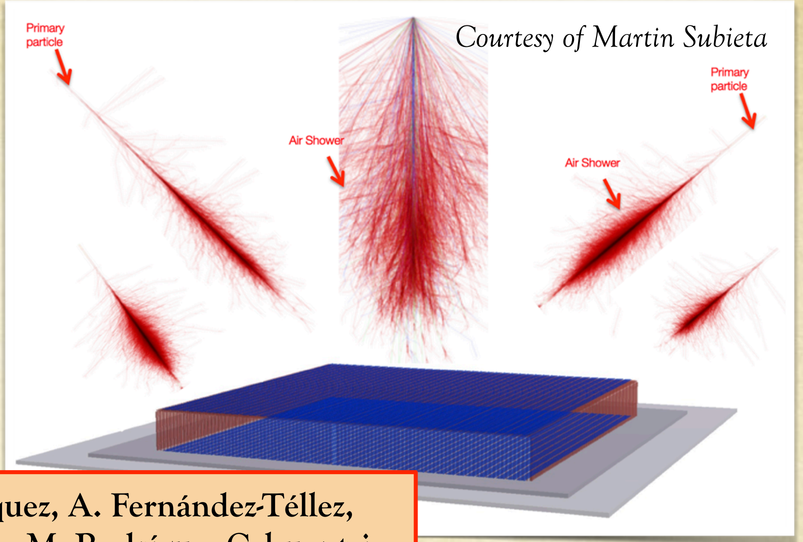
MATHUSLA - Cosmic Rays



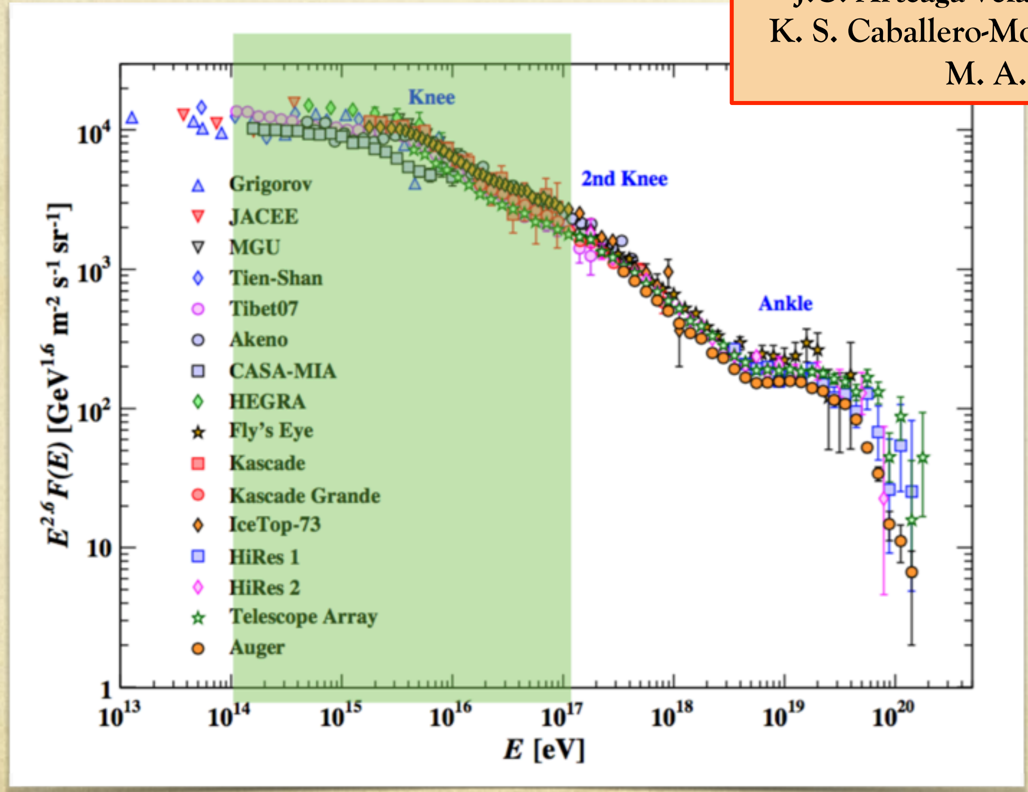
- MATHUSLA could perform **cosmic rays studies at PeV energies**
- MATHUSLA will provide **quality data on EAS with better resolution than past and present experiments**
- **In stand alone mode**
  - MATHUSLA will provide measurements of **EAS direction, core position, density and time distributions** (assuming no e/μ separation)
  - MATHUSLA could be used to measure the all-particle energy spectrum, study the cosmic ray anisotropies, study muon content of very inclined events, test hadronic models, and possibly perform composition studies
- **In combined mode with CMS/ATLAS**
  - MATHUSLA will provide data on the **muon content of EAS** with $E_\mu > 50\text{-}70$ GeV for vertical incidence
  - MATHUSLA will extend the test of hadronic models and permit to study other EAS phenomena such as muon bundles and may be, the composition of cosmic rays
- Muons from nucleus-nucleus interaction events at the collider points might be also studied with MATHUSLA, allowing to discriminate between hadronic models.

MATHUSLA - Cosmic Rays

- MATHUSLA could perform **cosmic rays studies at PeV energies**
- MATHUSLA will provide **quality data on EAS with better resolution than past and present experiments**



J.C. Arteaga-Velázquez, A. Fernández-Téllez, K. S. Caballero-Mora, M. Rodríguez-Cahuantzi, M. A. Subieta-Vásquez



Cosmic Ray White Paper released ~ mid-2018

Guarantee physics return!

Plans…

MATHUSLA White Paper

- Collaboration of 70+ theorists (+ some experimentalists ☺)

Long-Lived Particles at the Energy Frontier:
The MATHUSLA Physics Case

Editors:
David Curtin[1], *Marco Drewes*[2], *Matthew McCullough*[3], *Patrick Meade*[4], *Rabindra Mohapatra*[5], *Jessie Shelton*[6], *Brian Shuve*[7,8].

Contributors:
Elena Accomando[9], *Cristiano Alpigiani*[10], *Stefan Antusch*[11], *Juan Carlos Arteaga-Velázquez*[12], *Brian Batell*[13], *Martin Bauer*[14], *Nikita Blinov*[8], *Karen Salomé Caballero-Mora*[15,16], *Jae Hyeok Chang*[4], *Eung Jin Chun*[17], *Raymond T. Co*[18], *Timothy Cohen*[19], *Peter Cox*[20], *Nathaniel Craig*[21], *Csaba Csaki*[22], *Yanou Cui*[23], *Francesco D'Eramo*[24], *Luigi Delle Rose*[25], *P. S. Bhupal Dev*[26], *Keith R. Dienes*[27,5], *Jeff A. Dror*[28,29], *Rouven Essig*[4], *Jared A. Evans*[30,6], *Jason L. Evans*[17], *Arturo Fernández Tellez*[31], *Oliver Fischer*[32], *Thomas Flacke*[33], *Anthony Fradette*[34], *Claudia Frugiuele*[35], *Elina Fuchs*[35], *Tony Gherghetta*[36], *Gian F. Giudice*[3], *Dmitry Gorbunov*[37,38], *Rick S. Gupta*[39], *Claudia Hagedorn*[40], *Lawrence J. Hall*[28,29], *Philip Harris*[41], *Juan Carlos Helo*[42,43], *Martin Hirsch*[44], *Yonit Hochberg*[45], *Anson Hook*[5], *Alejandro Ibarra*[46,17], *Seyda Ipek*[47], *Sunghoon Jung*[48], *Simon Knapen*[29,28], *Eric Kuflik*[45], *Zhen Liu*[49], *Salvator Lombardo*[22], *Henry Lubatti*[10], *David McKeen*[50], *Emiliano Molinaro*[51], *Stefano Moretti*[9,52], *Natsumi Nagata*[53], *Matthias Neubert*[54,22], *Jose Miguel No*[55,56], *Emmanuel Olaiya*[52], *Gilad Perez*[35], *Michael E. Peskin*[8], *David Pinner*[57,58], *Maxim Pospelov*[59,34], *Matthew Reece*[57], *Dean J. Robinson*[30], *Mario Rodríguez Cahuantzi*[31], *Rinaldo Santonico*[60,61], *Matthias Schlaffer*[35], *Claire H. Shepherd-Themistocleous*[52], *Andrew Spray*[33], *Daniel Stolarski*[62], *Martin A. Subieta Vasquez*[63,64], *Raman Sundrum*[5], *Andrea Thamm*[3], *Brooks Thomas*[65], *Yuhsin Tsai*[5], *Brock Tweedie*[13], *Stephen M. West*[66], *Charles Young*[8], *Felix Yu*[54], *Bryan Zaldivar*[55,67], *Yongchao Zhang*[26,68], *Kathryn Zurek*[29,28,3], *José Zurita*[32,69].

1. arXiv:1806.07396 [pdf, other] hep-ph

Long-Lived Particles at the Energy Frontier: The MATHUSLA Physics Case

Authors: David Curtin, Marco Drewes, Matthew McCullough, Patrick Meade, Rabindra Mohapatra, Jessie Shelton, Brian Shuve, Elena Accomando, Cristiano Alpigiani, Stefan Antusch, Juan Carlos Arteaga-Velázquez, Brian Batell, Martin Bauer, Nikita Blinov, Karen Salomé Caballero-Mora, Jae Hyeok Chang, Eung Jin Chun, Raymond T. Co, Timothy Cohen, Peter Cox, Nathaniel Craig, Csaba Csáki, Yanou Cui, Francesco D'Eramo, Luigi Delle Rose , et al. (63 additional authors not shown)

Abstract: ...100m are particularly difficult to probe, as the sensitivity of the LHC main detectors is limited by challenging backgrounds, triggers, and small acceptances. MATHUSLA is a proposal for a minimally instrumented, large-volume surface detector near ATLAS or CMS. It would search for neutral LLPs produced in HL-LHC collisions by reconstructing displaced vertice... ▽ More

Submitted 19 June, 2018; **originally announced** June 2018.

Comments: 208 pages, 72 figures

Public on arXiv few hours ago!!!!

MATHUSLA - Next Steps

- Plan to make a report at the **Physics Beyond Colliders** CERN working group (http://pbc.web.cern.ch/) comparing MATHUSLA/CODEX-b/FASER to ShiP at the end of 2018

- Working on a **MATHULA paper** focusing on test stand results and **MATHUSLA Letter Of Intent** - by the end of 2018

A Letter of Intent for MATHUSLA: a dedicated displaced vertex detector above ATLAS or CMS

Cristiano Alpigiani,[a] Roberto Cardarelli,[f] Mario Cahuatzin,[g] John Paul Chou,[d] David Curtin,[b] Miriam Diamond,[e] Marco Drewes,[w] Erez Etzion,[c] Rouven Essig,[p] Jared Evans,[u] Oliver Fischer,[v] Andy Haas,[k] Ken Johns,[l] Audrey Kvam,[a] Dragoslav Lazic,[n] Zhen Liu,[x] Henry Lubatti,[a] Giovanni Marsella,[m] Matthew McCullough,[n] David McKeen,[o] Patrick Meade,[p] David Morrissey,[o] Mason Profitt,[a] Caballero Mora,[i] Antonio Policicchio,[j] Karen Salom,[i] Rinaldo Santonico,[f] Jessie Shelton,[s] Brian Shuve,[r] Daniel Stolarski,[q] Arturo Fernndez Tllez,[g] Emma Torro,[a] Yuhsin Tsai,[t] Juan Carlos Arteaga Velzquez,[h] Gordon Watts,[a] Charlie Young,[e] Jose Zurita.[v]

- Letter of Intent will be finalised at dedicated collaboration meeting in August 2018

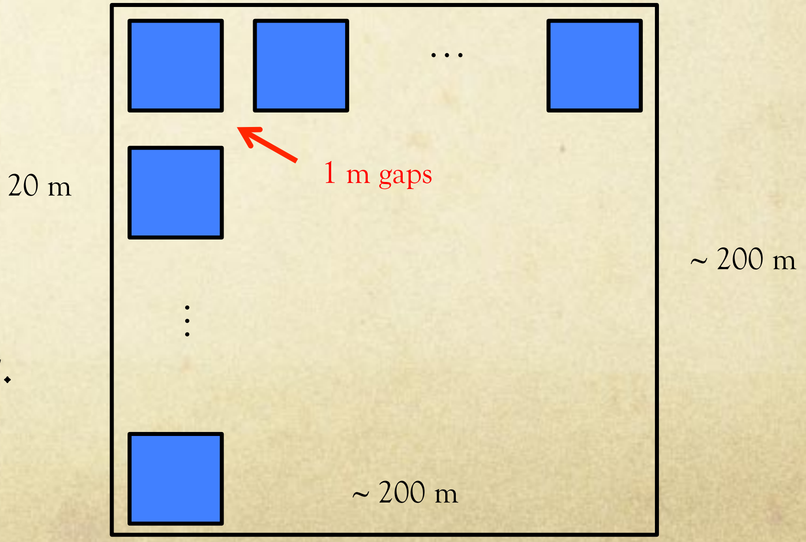
MATHUSLA - Modularity

- We can of course construct a building of 200 x 200 m^2

  ...somebody already did that ☺ so...
  but do we really need it?

- We always talked about an "ideal" detector
- The reality is that we need:
  - Detector services
  - Easy access
  - Emergency exits
  - Keep a temperature under ~ control (for RPC gas)
  - Etc...
- Some early thoughts on modularity to simplify construction and for incremental deployment e.g.

100 x (20 m x 20 m x 20 m) boxes



A preliminary cost estimate

Scintillators (C. Young)

- Top and bottom are = 2 x 200 m^2 = 80 000 m^2 + sides = 4 x 200 x 20 m^2 = 16 000 m^2

  → Total area = 96 000 m^2
- Assume thickness = 1 cm, density = 1 gm/m^3
- Assume 3 USD / kg (low end of NOνA estimates) excluding electronics

  → **Total cost ~ 3M USD**

RPCs (R. Santonico)

- Resistive electrode of high pressure laminate based on phenolic resin → 80 E/m^2
- Gas gap construction and procurement of all materials excluded the electrode laminate → 160 E/m^2
- Signal read out panels → 60 E/m^2
- Mechanical support panels (could be optmised, should be cheaper) → 200 E/m^2
- Front end electronics → 150 E/m^2
- Total/m^2 → 650 E/m^2

  → **Total for 10^5 m^2 → 65M E**

Not included: mounting of the FE electronics over the strip panels; power system (LV and HV); gas system; trigger and DAQ; cabling and piping.

Conclusions

- We are studying the feasibility of a large scale detector to measure LLPs with very long lifetimes
- Several studies have already been performed
- A test module has been installed on the ATLAS surface area in November 2017 and it will continue taking data until the end of the year (end of LHC Run 2 operations)
  - Background tests will continue to prove MATHUSLA potential in rejecting background from LHC (and cosmics)
- Aiming to prepare a **letter of intent** by the end of the year
- **A lot of work still need to be done, so…**

Conclusions

- We are studying the feasibility of a large scale detector to measure LLPs with very long lifetimes

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- Aiming to prepare a **letter of intent** by the end c

- **A lot of work still need to be done, so…**
  if we want to help, we have rum! ☺

❖ **Contacts:**

- Cristiano.Alpigiani@cern.ch
- mathusla.experiment@cern.ch

BACKUP

LHC Detector Signatures

- Strong dependence on the sub-detectors of ATLAS, CMS and LHCb.
  - Inner detectors, calorimeters an muon systems not the same in the three detectors
  - All LHC detectors need to overcome obstacles
- Boost of LLP determines opening angle(s) and that affects trigger efficiencies.
  - Efficiencies can also depend on trigger algorithm and subsystem readout at trigger level
  - Presents a challenge for generic, model independent searches

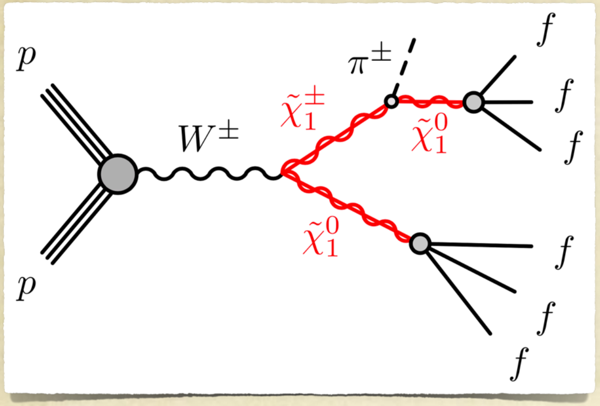
Signature Space of Displaced Vertex Searches

- Detector signature depends of production and decay operators of a given model
  - Production determines cross section and number and characteristics of associated objects
  - Decay operator coupling determines life time, which is effectively a free parameter
- Common Production modes
  - Production of single object - with No associated objects (AOs)
    - Higgs-like scalar Φ that decays to a pair of long-lived scalars, ss, that each in turn decay to quark pairs – Hidden Valley, Neutral Naturalness, …
    - Vector (γ_{dark},Z′) mixing with SM gauge bosons – kinetic mixing
  - Production of a single object P with an AO – Many SUSY models
    - AO jets if results from decay of a colored object
    - AO leptons if LLP produced via EW interactions with SM
- Common detector signatures ⇒ generic searches

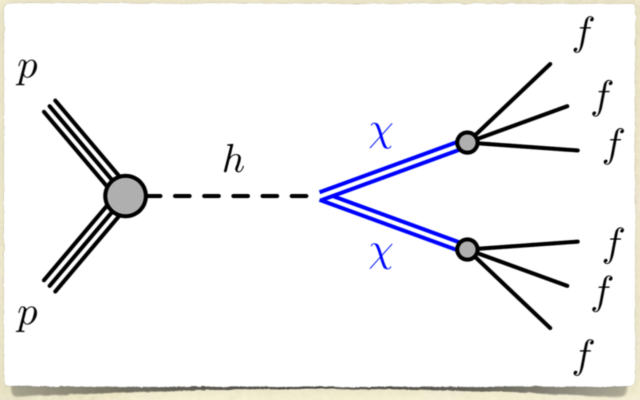
Neutral Long-lived Particles

- Neutral LLPs lead to displaced decays with no track connecting to the IP, a distinguishing signature
  - SM particles predominantly yield prompt decays (good news)
  - SM cross sections very large (eg. QCD jets) (bad news)
- To reduce SM backgrounds many Run 1 ATLAS searches required two identified displaced vertices or one displaced vertex with an associated object
  - Resulted in good rejection of rare SM backgrounds
  - BUT limited the kinematic region and/or lifetime reach
- None the less, these Run 1 searches were able to probe a broad range of the LLP parameter space (LLP-mass, LLP-cτ)
- ATLAS search strategy for displaced decays - based on signature driven triggers that are detector dependent

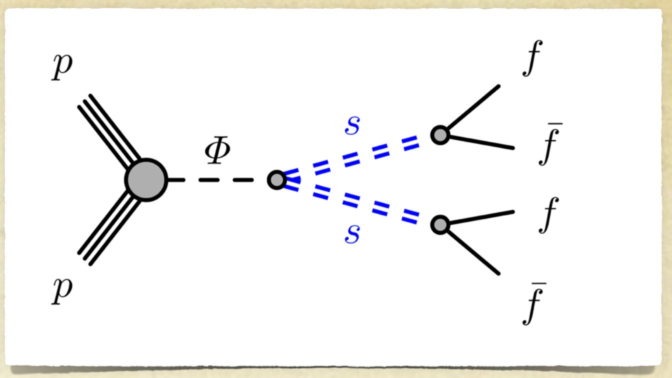
Some of the LLP Models



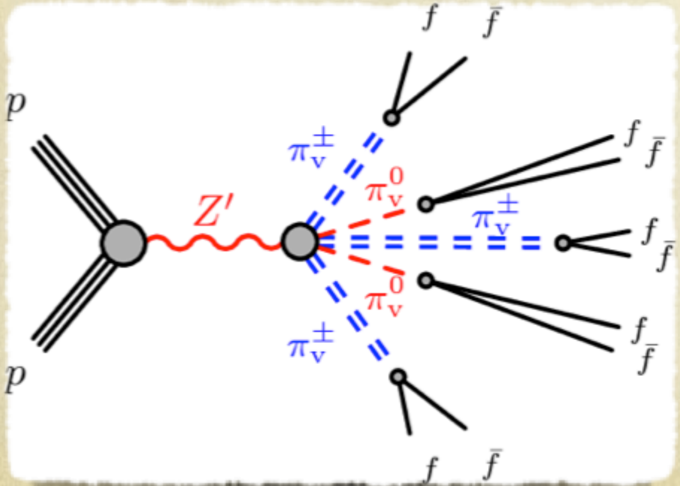
Baryogenesis
wino-like model



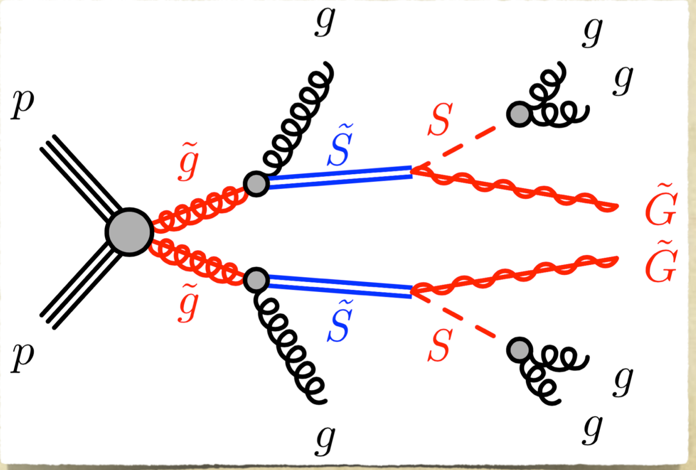
Baryogenesis
Higgs portal



Low/high
mass bosons
to scalars



Z' models



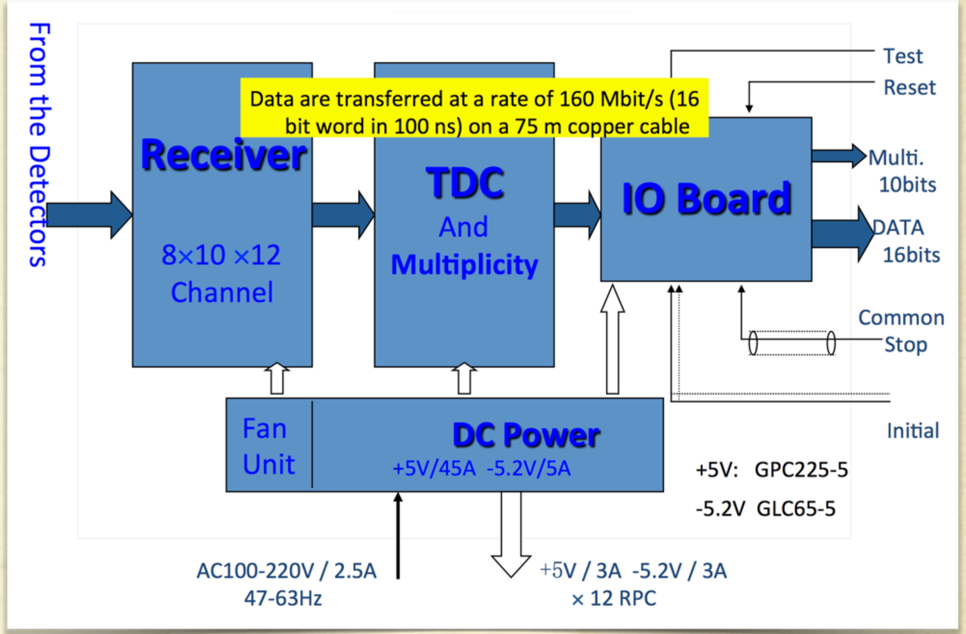
Stealth SUSY

MATHUSLA – DAQ and Trigger

Test module DAQ

- **Scintillators:** PMTs interfaced with a VME crate connected to a PC

- **RPCs: Argo Experiment Local Station** (from Lecce). Data from each RPC acquired from a Receiver Card which reads out and digitises the space and time information from 10 pick-up pads and gives out the pad multiplicity for trigger purposes. On trigger occurrence the Local Station sends the collected data to the PC

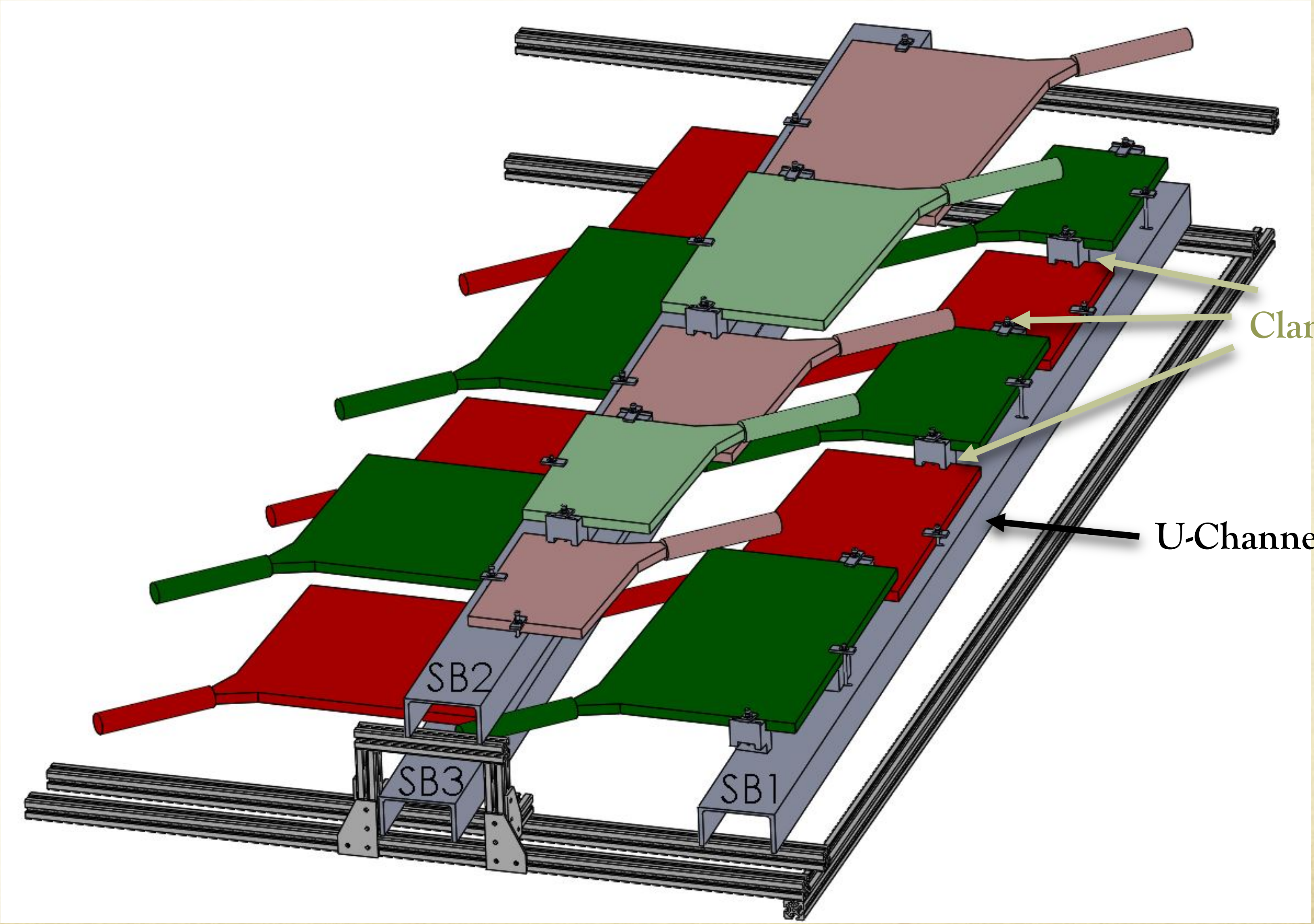


Test module trigger

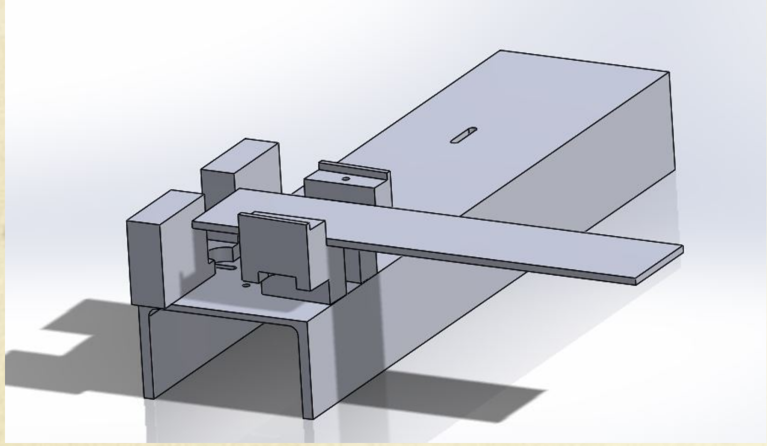
Two possible triggers: top and bottom scintillators in coincidence, with:

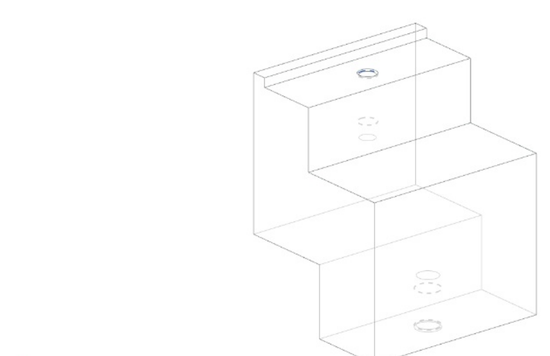
1. **Timing appropriate for <u>downward</u> going particle** (cosmic ray events can be used for space and time alignment)
2. **Timing appropriate for <u>upward</u> going particle**

MATHUSLA – Scintillators Support Details (1)



MATHUSLA – Scintillators Support Details (2)



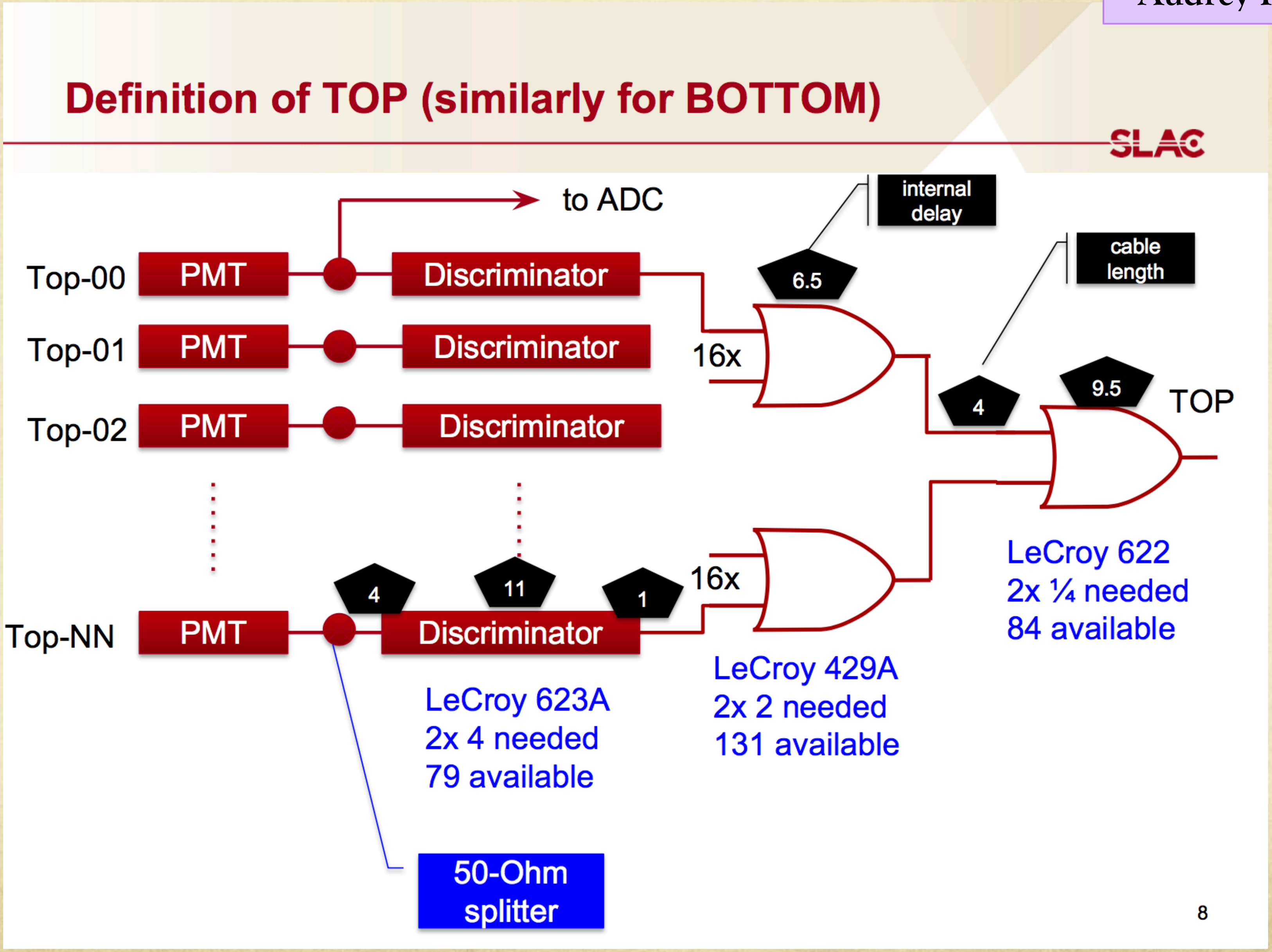


Shim simple design

- Tapped holes not through holes.
- Soft rubber spacers between the shim and detector to evenly distribute the clamping force.
- Working on eliminating the side clamps entirely - requires a different alignment.
- Assembly test with two small scintillators this week.
- Will tweak some of the shim dimensions based on our assembly test.

MATHUSLA – Trigger Development (1)

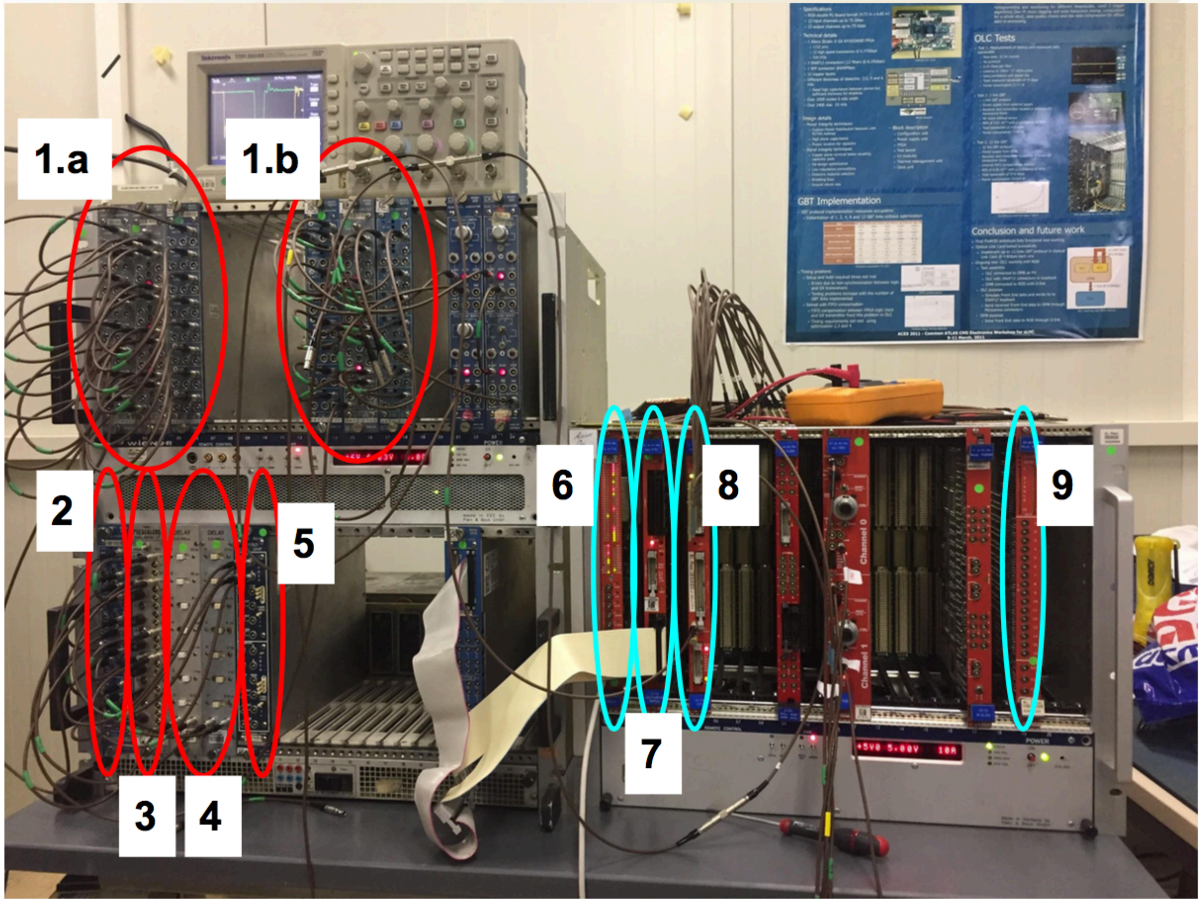
Courtesy of Audrey Kvam



MATHUSLA – Trigger Development (1)

Courtesy of Audrey Kvam

Putting together (some of) trigger in 175

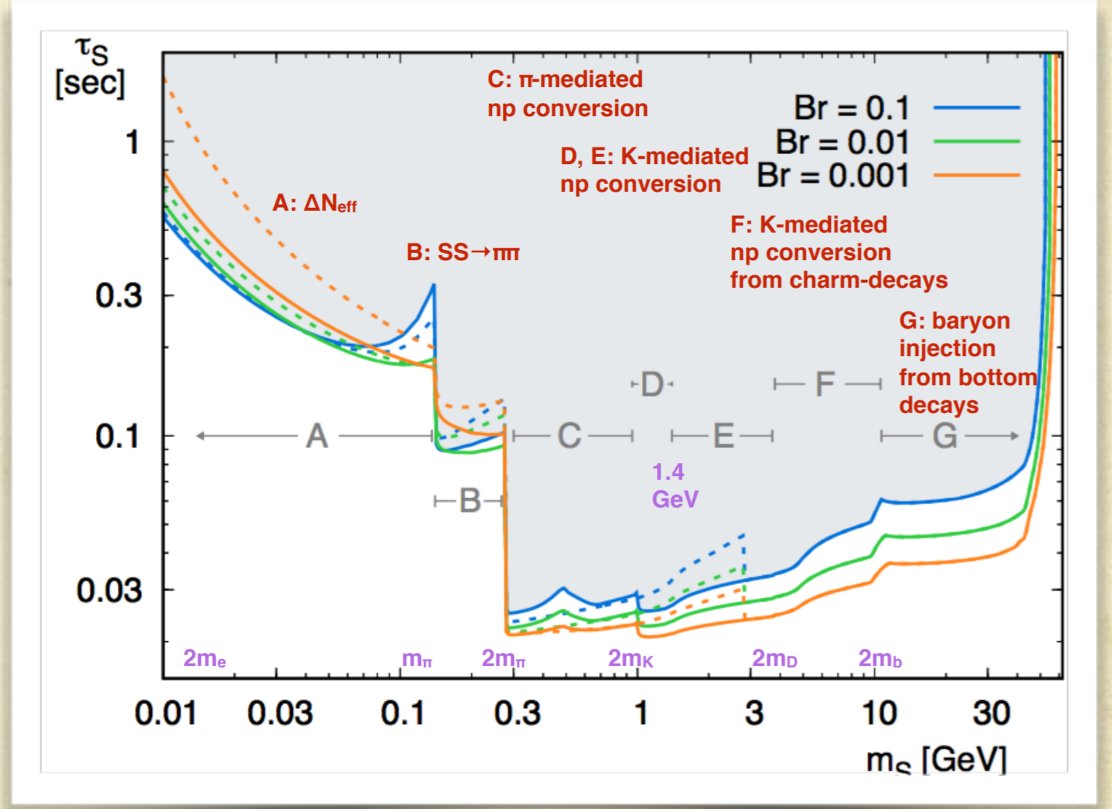


1. Disc + first level OR logic
   a. TOP
   b. BOTTOM
2. Second level OR + AND between TOP & BOTTOM
3. Prescaler
4. Delay boxes
5. OR for 4 triggers
6. Controller
7. TDC
8. ADC
9. Input Register

6

MATHUSLA – Scalar LLP Lifetime Constraints

- A recent paper [A. Fradette and M. Pospelov, arXiv:1706.01920v1] examines the BBN lifetime bound on lifetimes of long-lived particles in the context of constraints on a scalar model coupled through the Higgs portal, where the production occurs via $h \rightarrow ss$, where the decay is induced by the small mixing angle of the Higgs field h and scalar s.



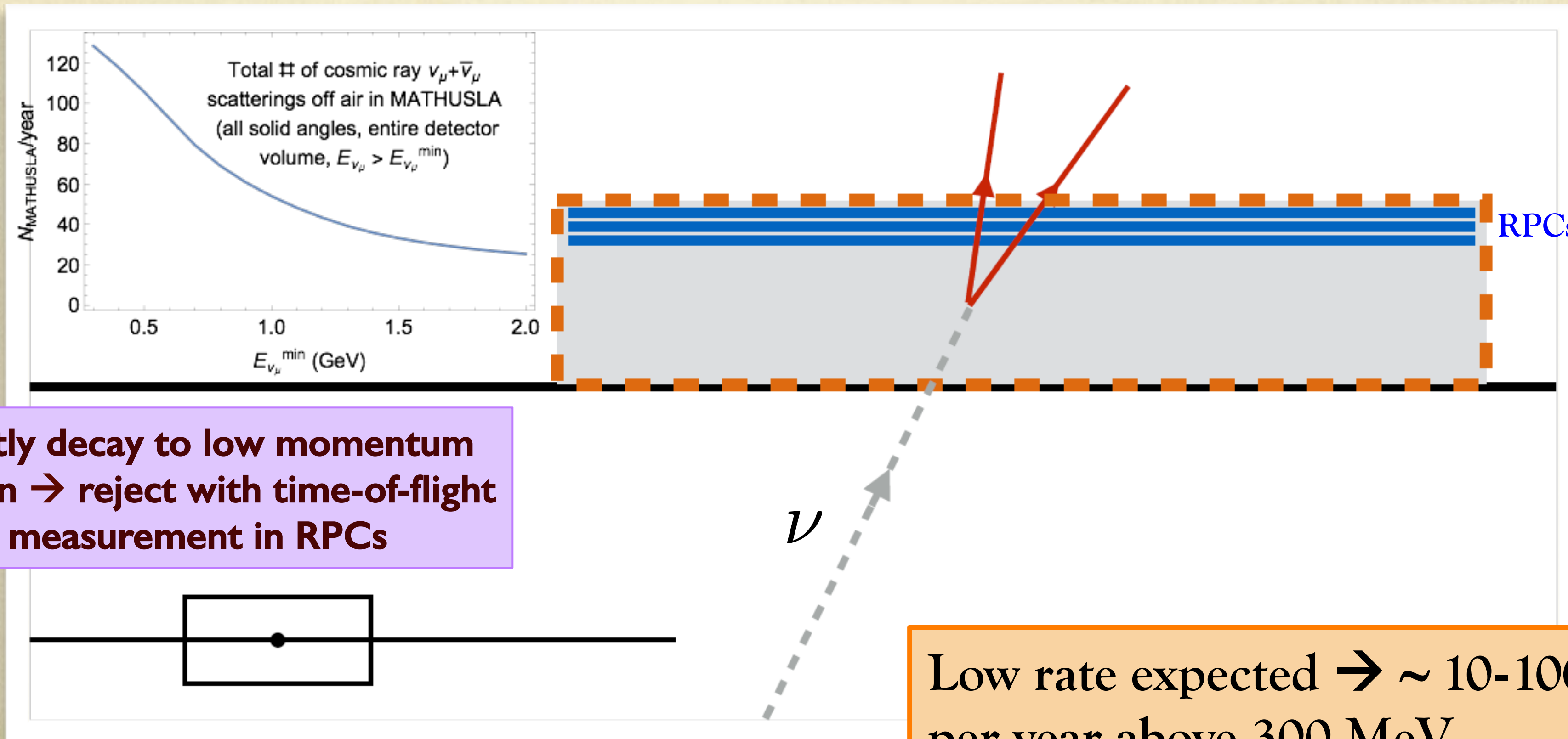
- For $m_s > m_\pi$ the lifetime $\tau < 0.1$ s.

- Conclusion does not depend strongly on BR($h \rightarrow ss$)

MATHUSLA – Cosmic Neutrinos Background

No LHC QCD background, BUT…

- Cosmic neutrinos traveling upwards that have inelastic interactions in the decay volume

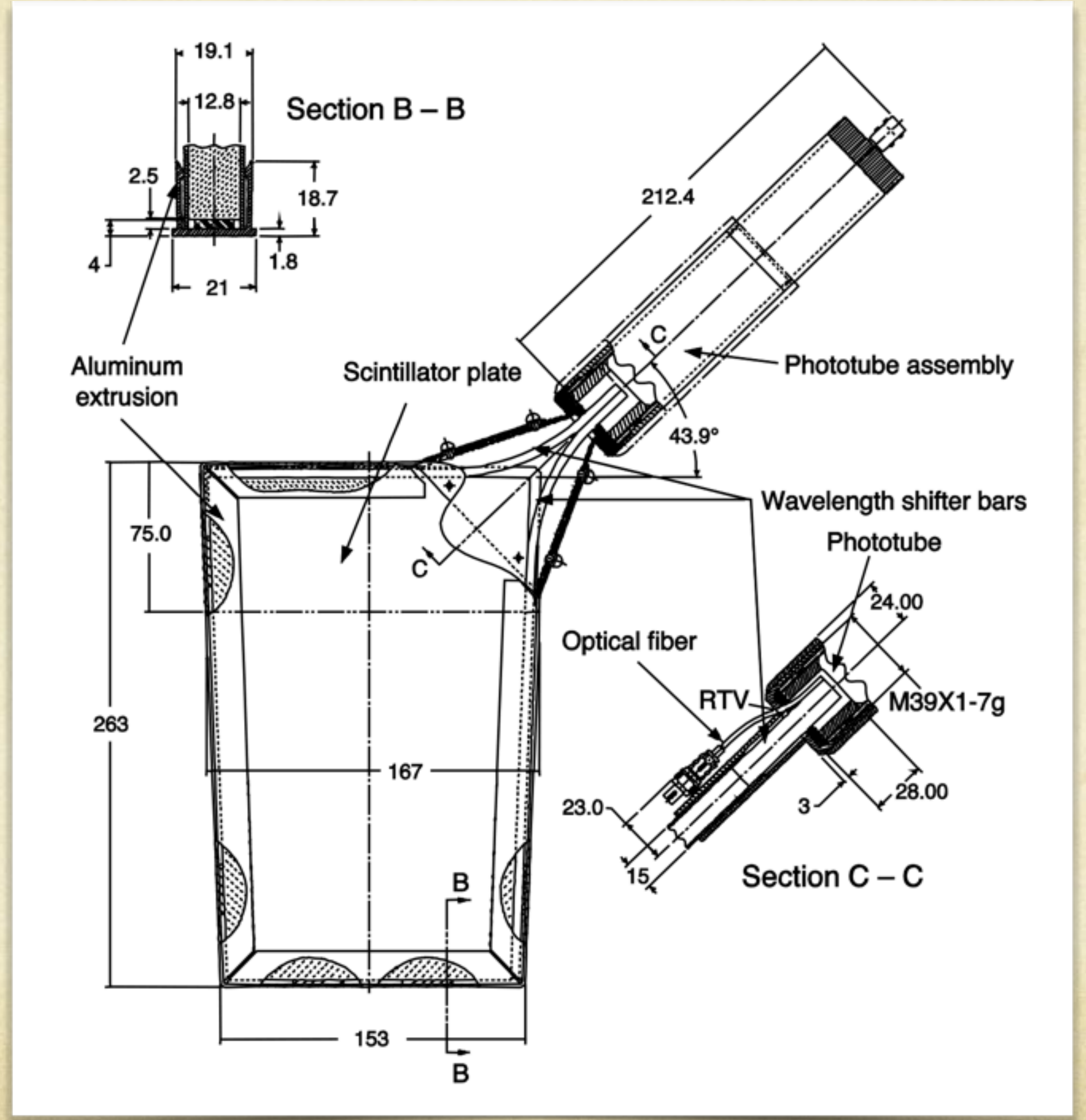


Mostly decay to low momentum proton → reject with time-of-flight measurement in RPCs

Low rate expected → ~ 10-100 per year above 300 MeV

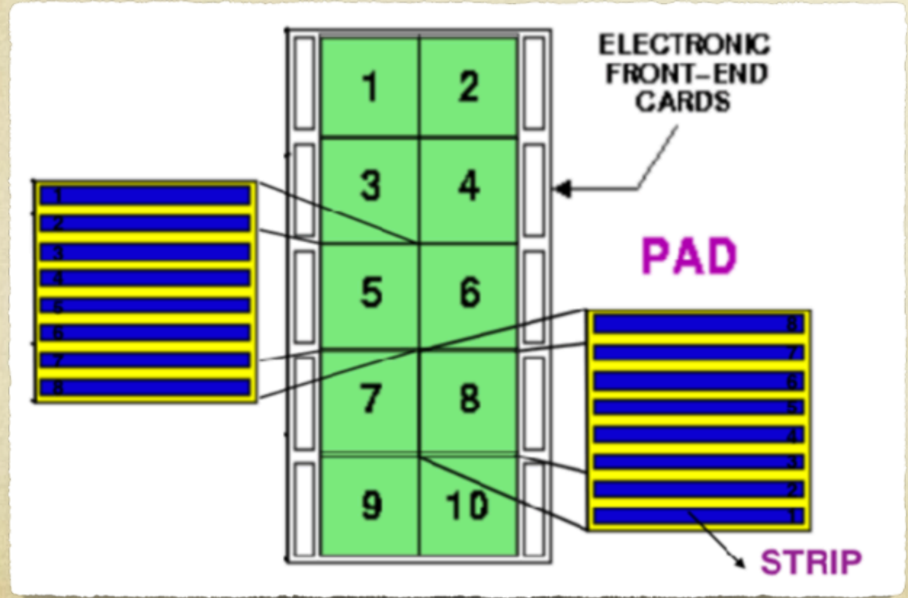
❖ This background can be measured when there is <u>no beam in the LHC</u>!

MATHUSLA – Scintillators Details

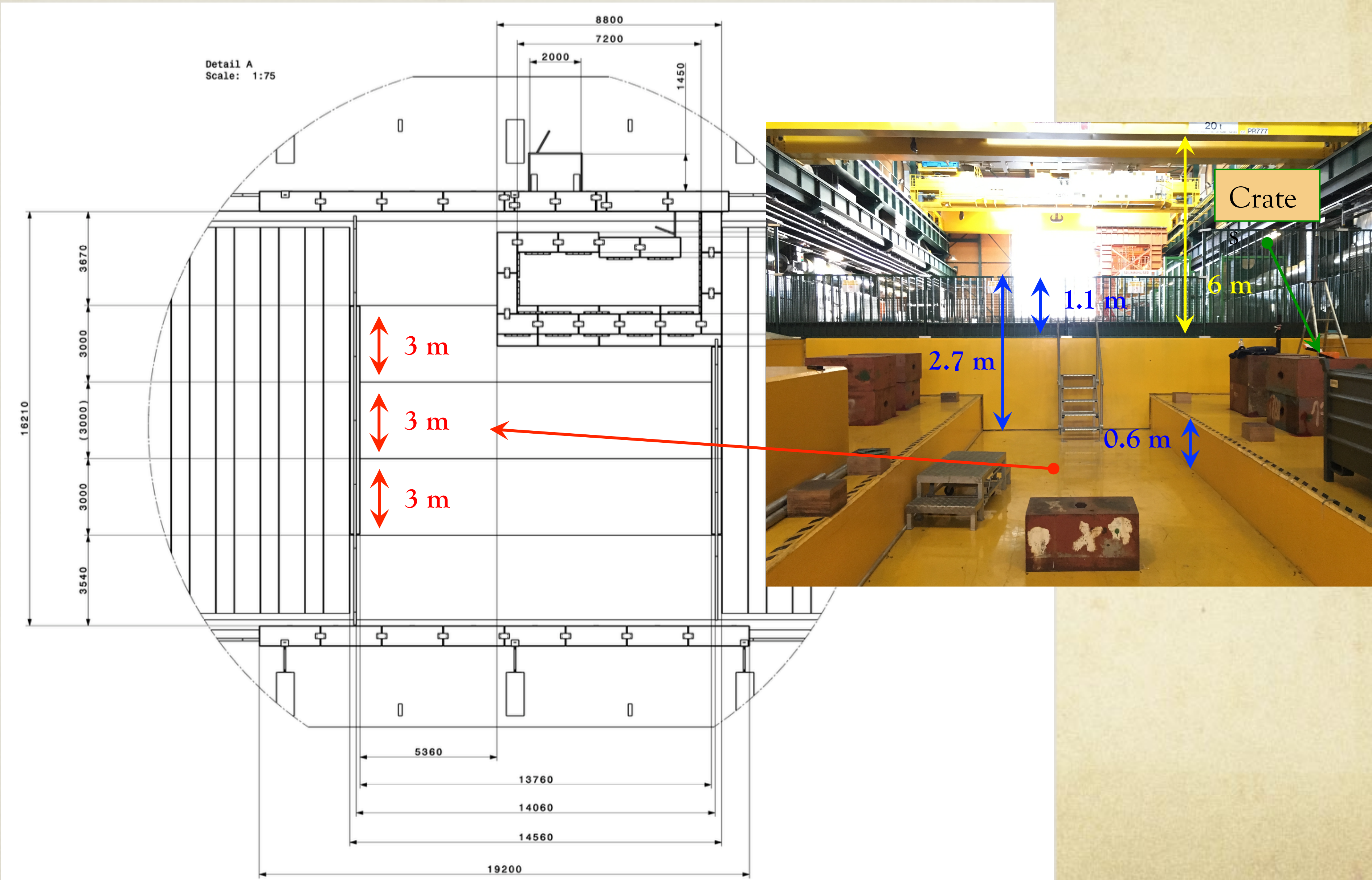


MATHUSLA – RPC Details

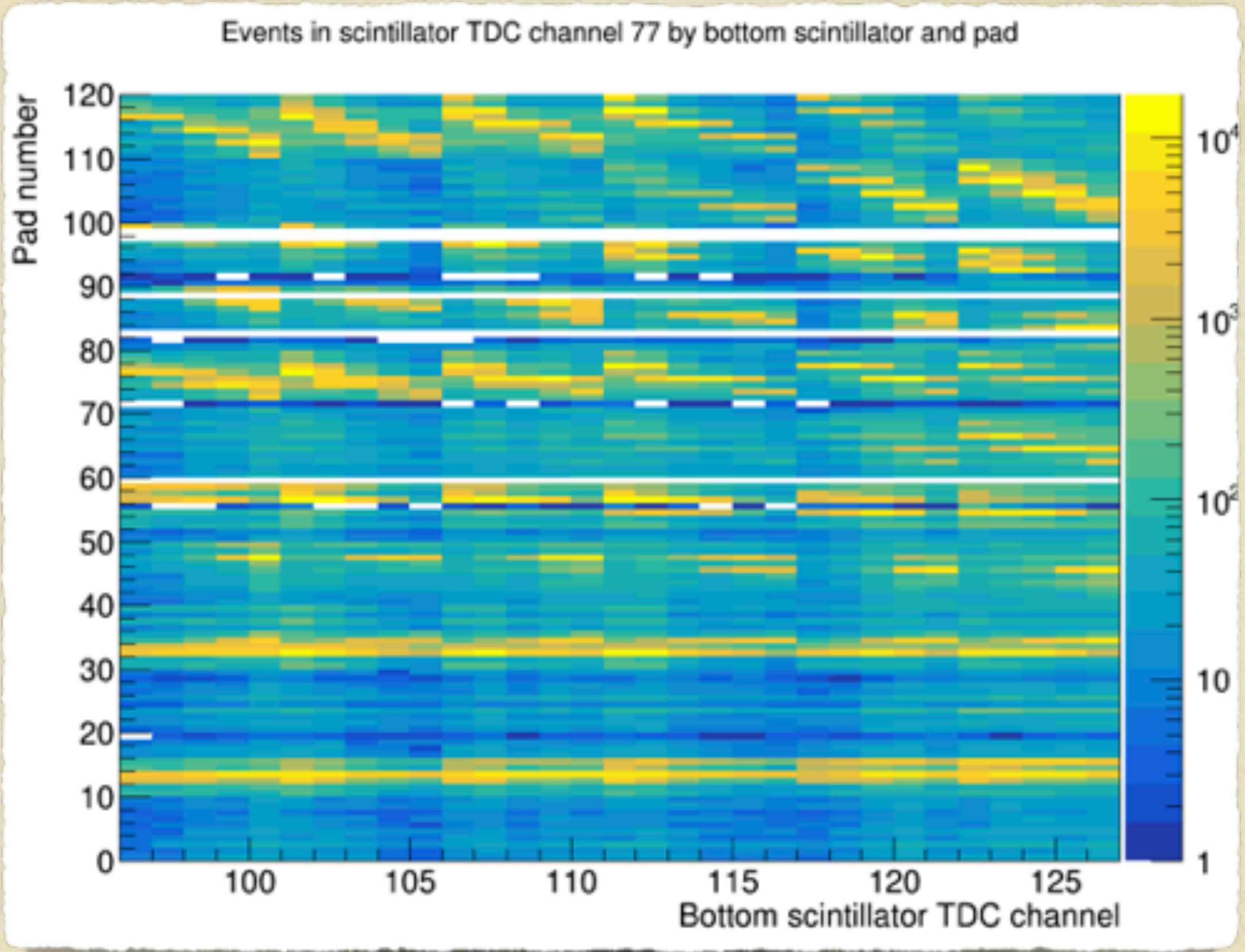
- 12 RPCs and DAQ from the prototype of ARGO cosmic ray shower experiment in Tibet
- Operating in streamer mode
- Chamber size: 1.25 x 2.80 m^2
- 10 Pads (55.6 x 61.8 cm^2) for each RPC
- 8 Strips (6.75 x 61.8 cm^2) for each Pad
- Gas Ar mixed with the ATLAS RPC gas ($C_2H_2F_4$/Iso-C_4H_{10}/SF_6 (94.7/5/0.3)



Installation in ATLAS P1 (2)



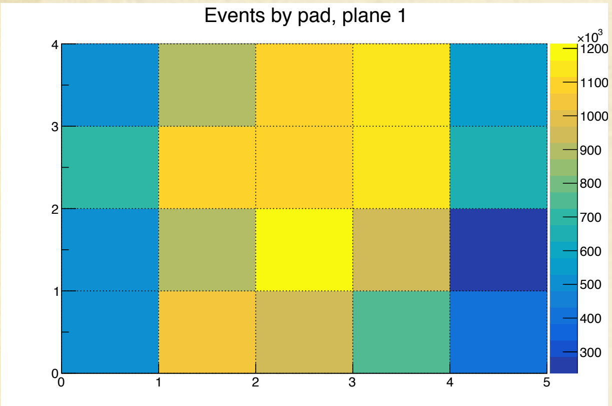
MATHUSLA Performance (Scintillators & RPC)

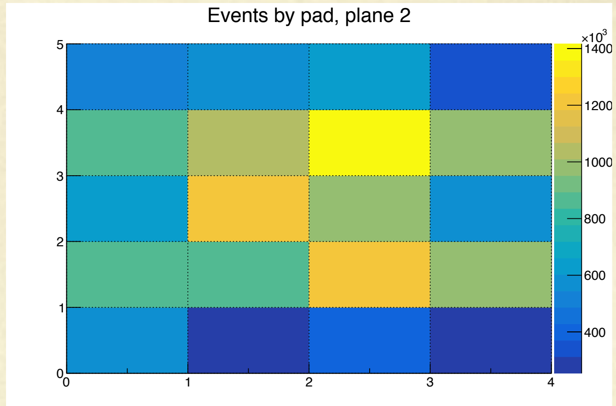


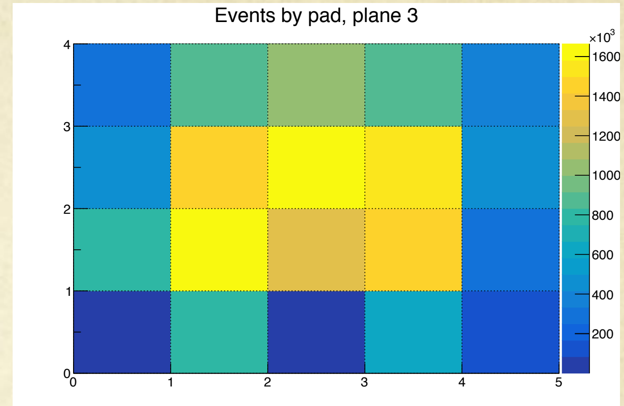
A very rough tracking!

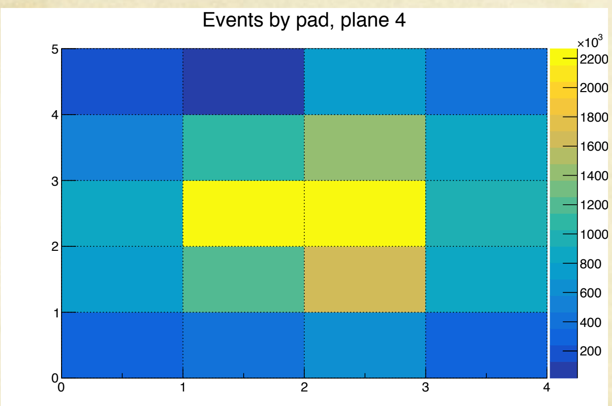
MATHUSLA Performance - RPC

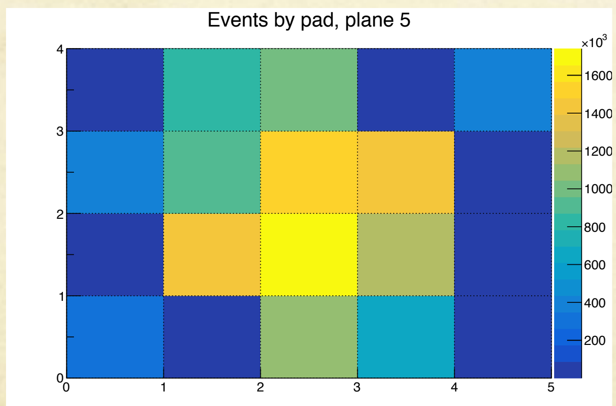
- Number of event per pad

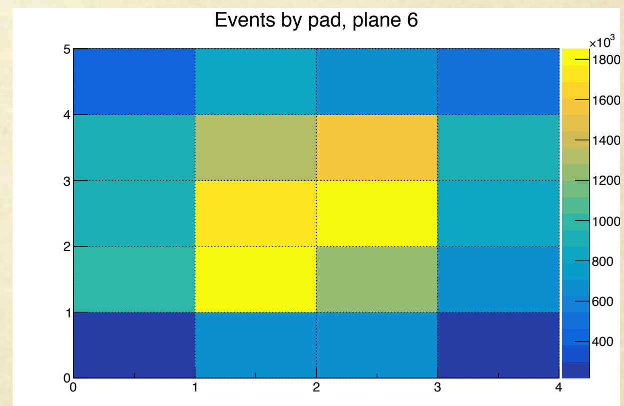






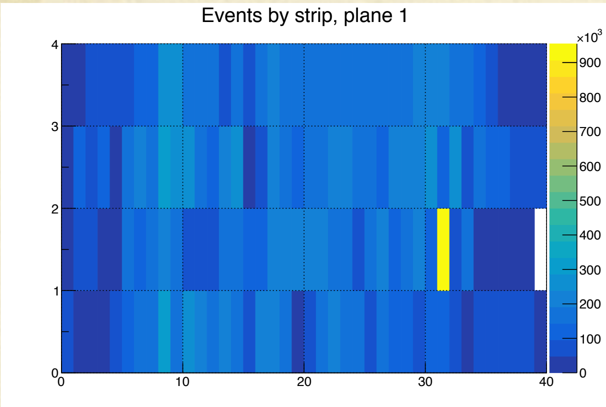


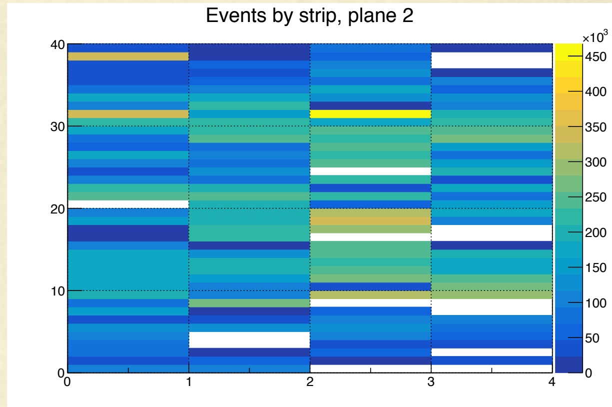


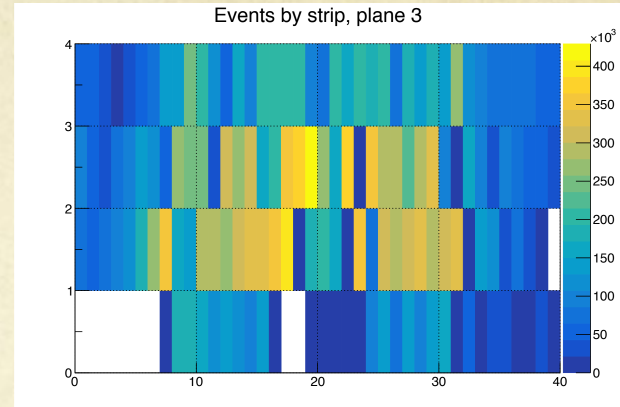


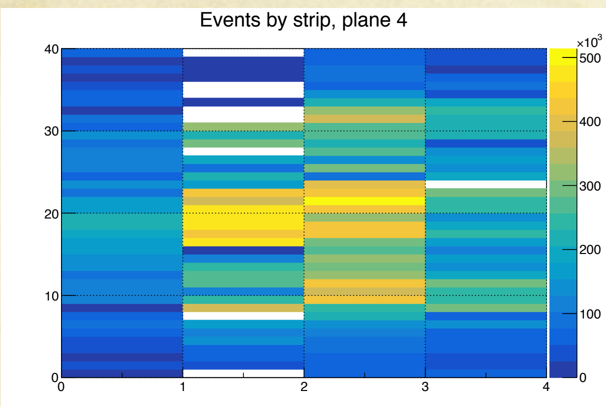
MATHUSLA Performance - RPC

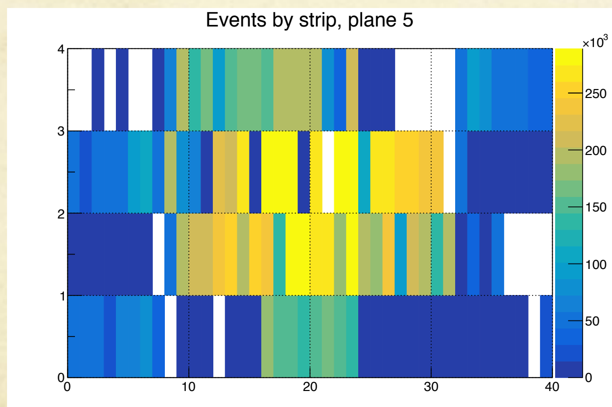
- Number of event per strip

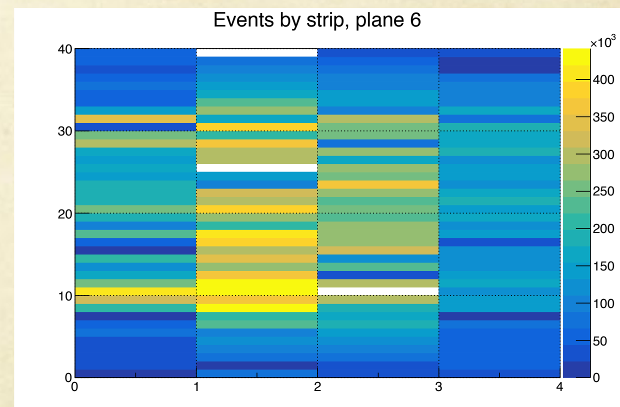






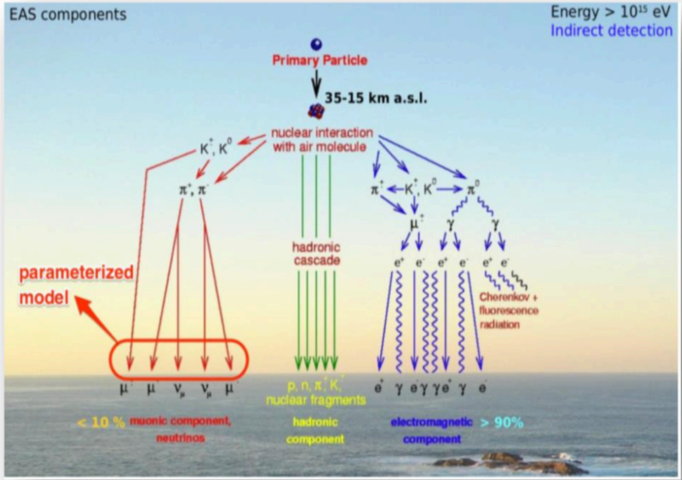


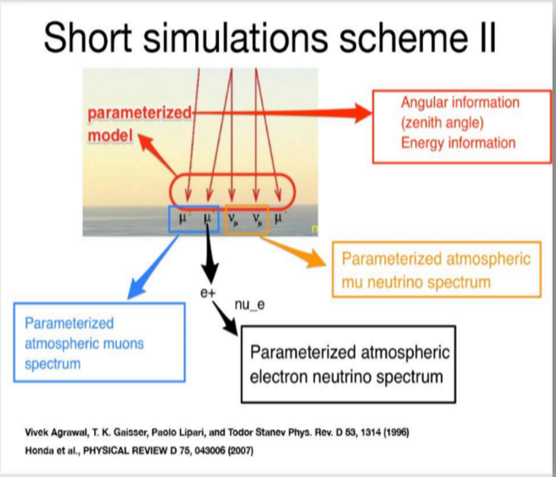




Cosmic Ray Simulation Details

- Cosmic Ray Simulation Strategy
  - Muon component
  - E&M component
- Muon Component
  - Easy to do parameterized
  - Will generate files that we can use as input
  - “short”
- E&M and other components
  - Will require full CORSIKA simulation
  - “long”
- Shared sample config files for CORSIKA and ROOT output files.





G. Watts (UW/Seattle)

MATHUSLA Collaboration

University of Washington Seattle, Tel Aviv University, University of Toronto, Autonomous University of Puebla, Rutgers State University of New Jersey, SLAC, Università di Tor Vergata, Università della Calabria, Sapienza Università di Roma and CERN

Cristiano Alpigiani	Cristiano.Alpigiani@cern.ch	University of Washington - Seattle
Audrey Katherine Kvam	audrey.katherine.kvam@cern.ch	University of Washington - Seattle
Henry Lubatti	lubatti@u.washington.edu	University of Washington - Seattle
Mason Louis Proffitt	mason.louis.proffitt@cern.ch	University of Washington - Seattle
Joseph Rothberg	Joseph.Rothberg@cern.ch	University of Washington - Seattle
Gordon Watts	gwatts@uw.edu	University of Washington - Seattle
Emma Torró Pastor	emma.torro.pastor@cern.ch	University of Washington - Seattle
Yan Benhammou	Yan.Benhammou@cern.ch	Tel Aviv University
Meny Ben Moshe	Menyb@post.tau.ac.il	Tel Aviv University
Tingting Cao	Tingting.cao@cern.ch	Tel Aviv University
Erez Etzion	Erez.Etzion@cern.ch	Tel Aviv University
Tamar Garbuz	tgarbuz137@gmail.com	Tel Aviv University
Gilad Mizrahi	giladmiz01@gmail.com	Tel Aviv University
Yiftah Silver	yiftahsi@gmail.com	Tel Aviv University
Abi Soffer	Abner.Soffer@cern.ch	Tel Aviv University
David Curtin	david.r.curtin@gmail.com	University of Toronto
Roberto Guida	Roberto.Guida@cern.ch	CERN

Mario Rodriguez Cahuantzi	mario.rodriguez.cahuantzi@cern.ch	Autonomous University of Puebla
Martin Hentschinski	martin.hentschinski@gmail.com	Autonomous University of Puebla
Mario Ivan Martinez Hernandez	Mario.Martinez.Hernandez@cern.ch	Autonomous University of Puebla
Guillermo Tejeda Munoz	Guillermo.Tejeda.Munoz@cern.ch	Autonomous University of Puebla
Arturo Fernandez Tellez	Arturo.Fernandez.Tellez@cern.ch	Autonomous University of Puebla
Martin Alfonso Subieta Vasquez	martin.alfonso.subieta.vasquez@cern.ch	Autonomous University of Puebla
John Paul Chou	john.paul.chou@cern.ch	Rutgers, State University of New Jersey
Steffie Ann Thayil	steffie.ann.thayil@cern.ch	Rutgers, State University of New Jersey
Charlie Young	young@slac.stanford.edu	SLAC
Paolo Camarri	paolo.camarri@cern.ch	Università di Tor Vergata
Roberto Cardarelli	roberto.cardarelli@roma2.infn.it	Università di Tor Vergata
Rinaldo Santonico	santonic@roma2.infn.it	Università di Tor Vergata
Antonio Policicchio	Antonio.Policicchio@cern.ch	Sapienza Università di Roma
Marco Schioppa	Marco.Schioppa@cern.ch	Università della Calabria
Giovanni Marsella	giovanni.marsella@cern.ch	INFN Lecce e Università del Salento