Searches for Long Lived Particles at the LHC – Present and Future

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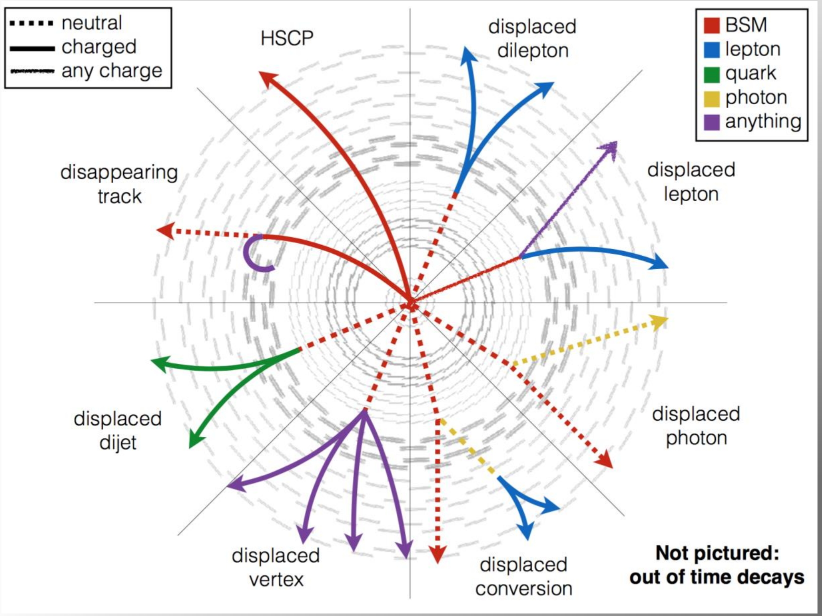
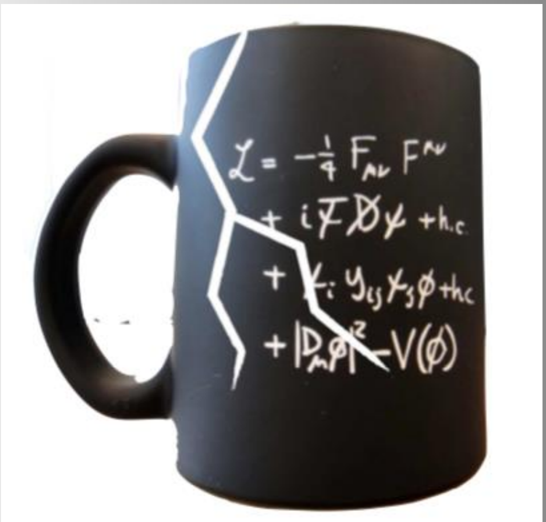
11th January 2020

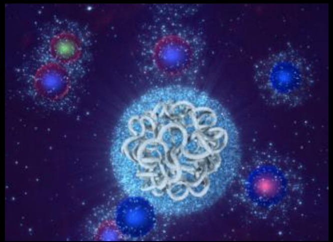
CERN



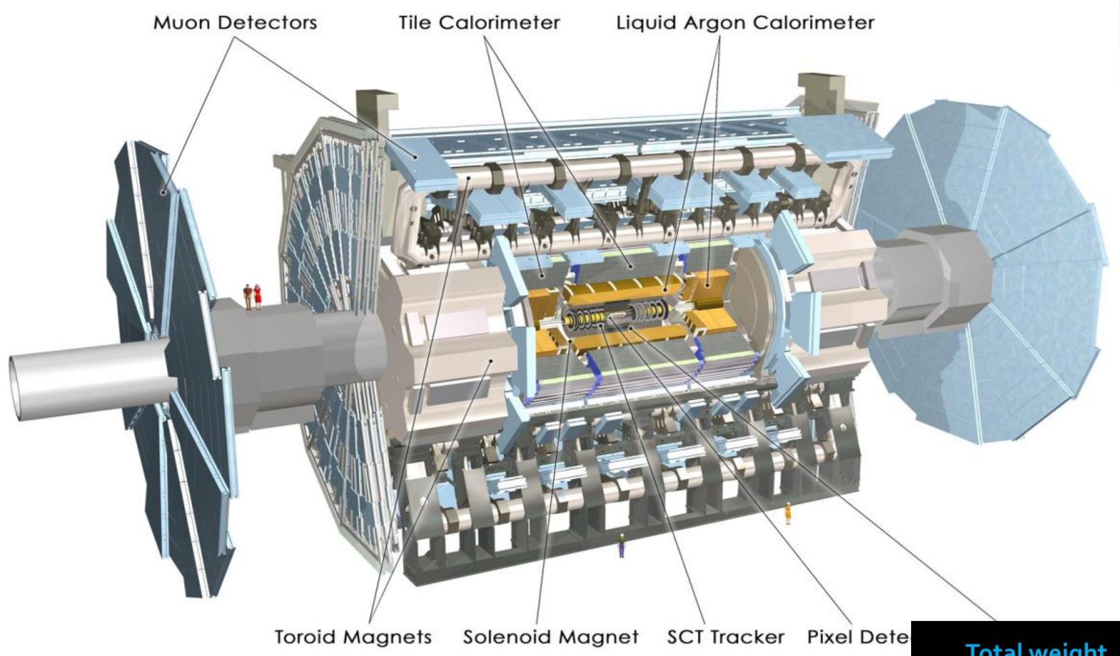


Outline

- Introduction
- Dedicated experiments @ LHC
- Several new proposals/ideas
  - MilliQan, MAPP, MATHUSLA, FASER, CODEX-b, AL3X, ANUBIS
  - XSEN Experiment for neutrino physics at the LHC
- Summary & Outlook



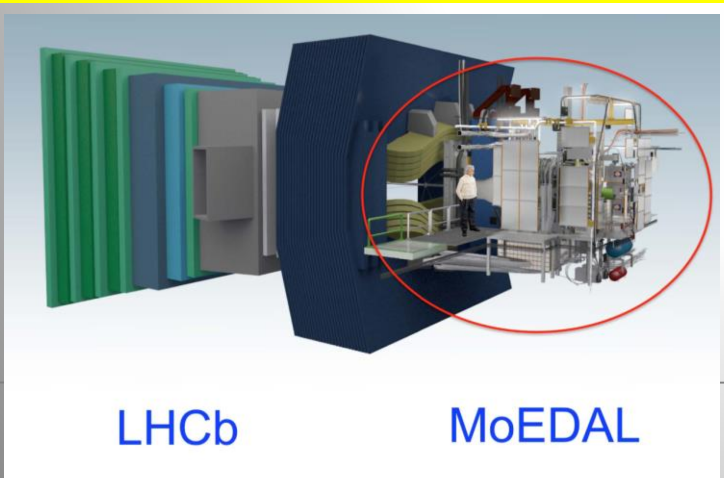
New Physics Hunters @ the LHC

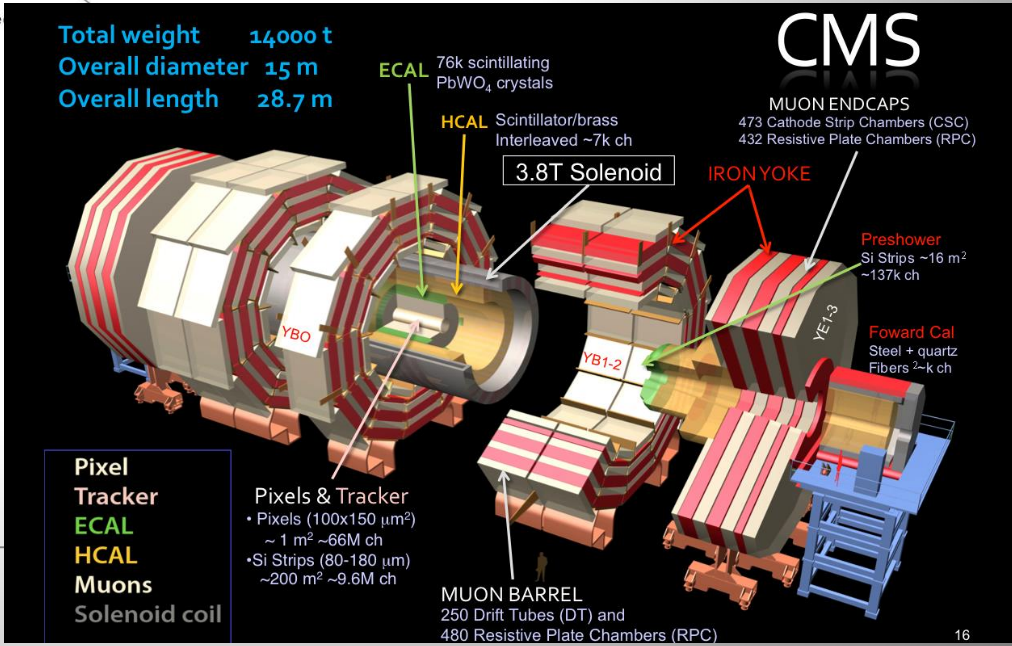


The ATLAS experiment

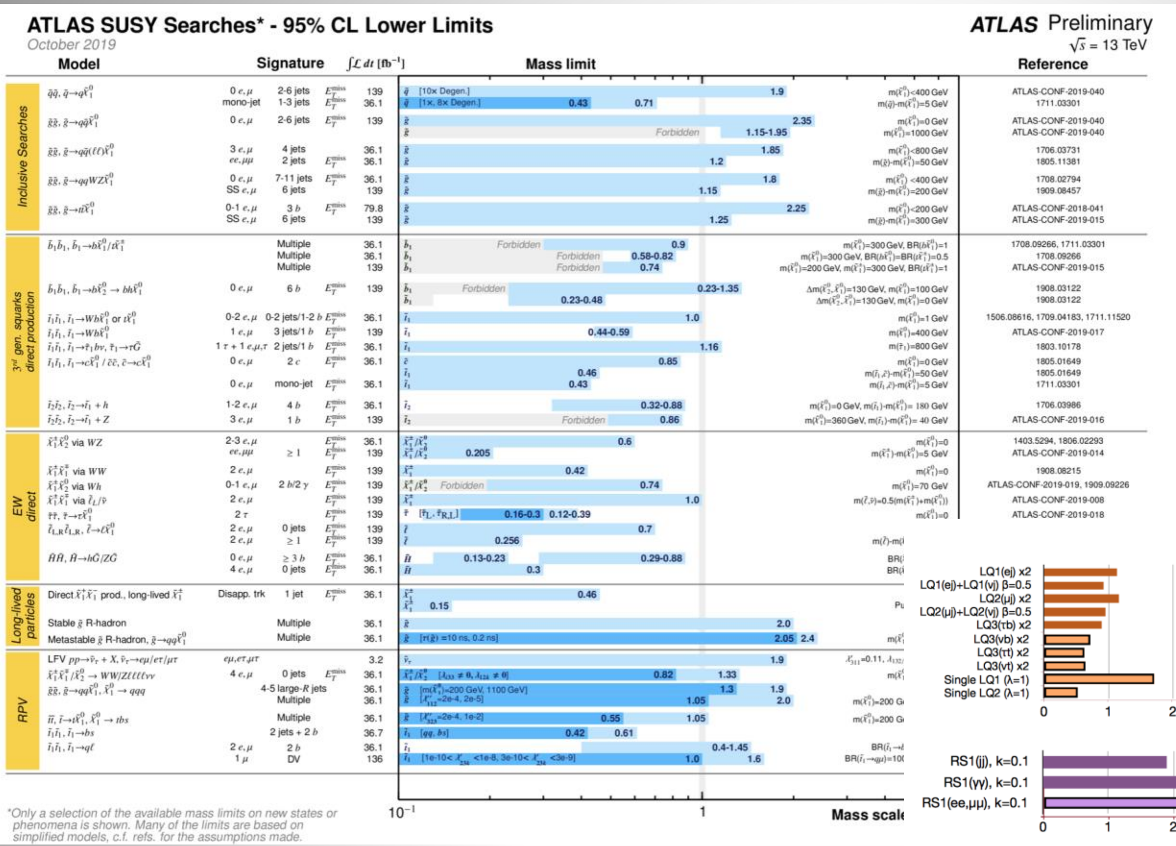
The CMS experiment

…And also LHCb and MoEDAL

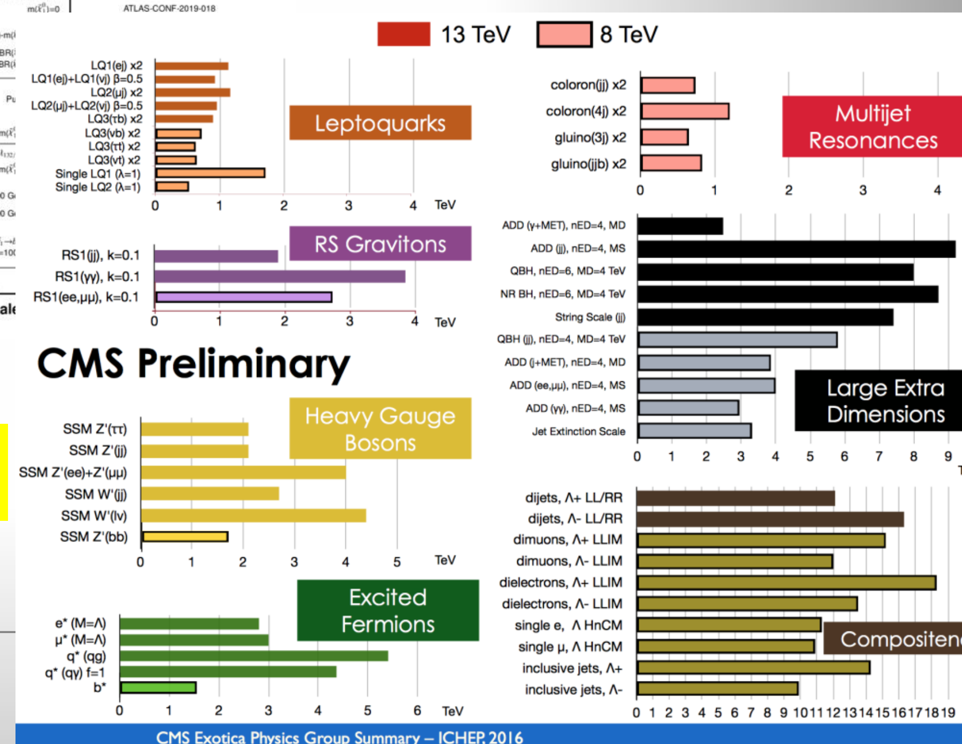




LHC: So far no new physics



Classical Searches
-Superymmetry
-Exotica
-Flavor Universality
-...



No signal of new physics so far!!

Are we leaving no stones unturned?

- No New Physics found yet at the LHC. The LHC BSM searches are indispensable and should be continued in the new energy regime and with increasing statistics (higher mass, lower couplings)
- But are we looking at the right place and do we leave not stones unturned? -> Recent focus on long lived particles
- Time for more effort in thinking of complementary searches: -> What could the LHC miss with the present detectors?

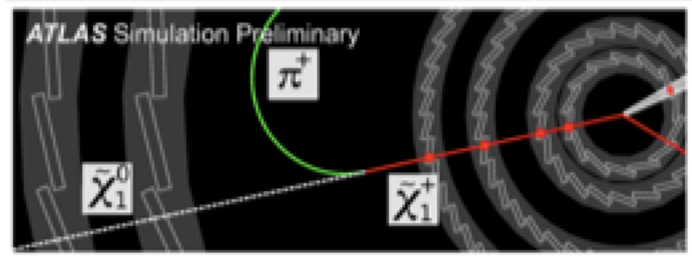
Are we looking at the right place?

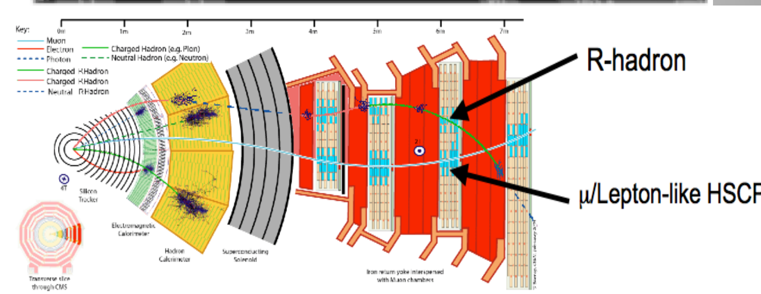
Leave no stone unturned!!

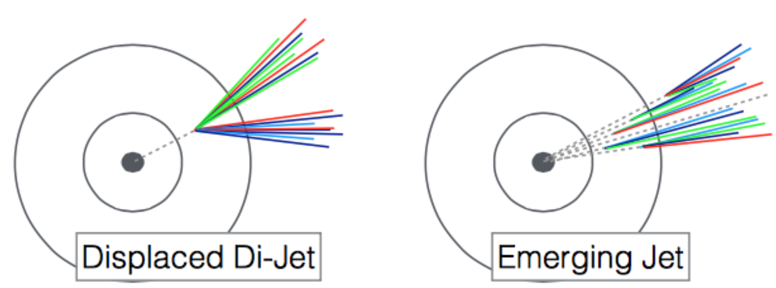
Long Lived Particles

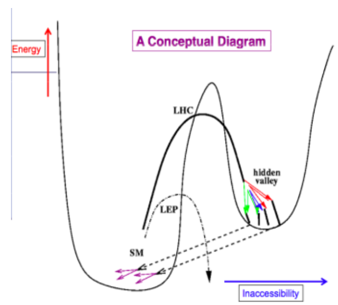
Long lifetimes arise from a hierarchy of scales or a small coupling

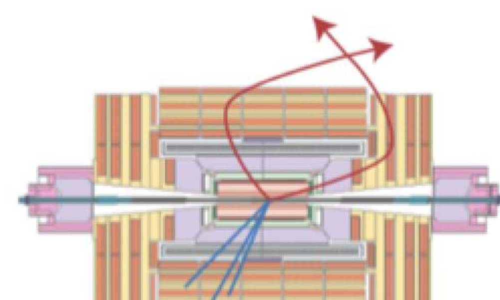
- RP Violating SUSY
- ASMB SUSY
- Gauge Mediated SUSY
- Split SUSY
- Hidden Valleys Models
- Dark QED/Dark Photons
- Monopoles
- Quirk Models
- Dark Matter Models
- Stable Sexaquarks
- Axion-Like Particles
- ….





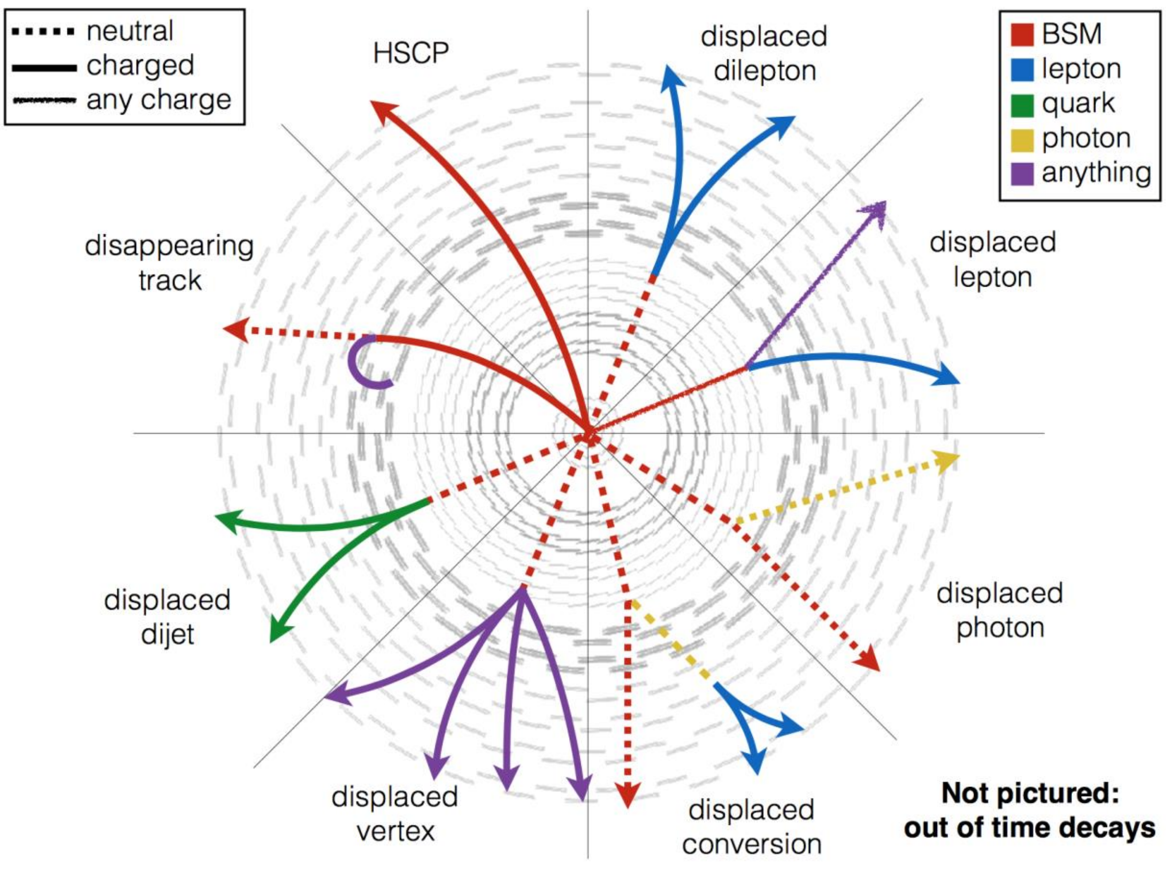






Long Lived Particles @LHC

Signatures



Some of the Challenges

Triggers: Tracking detectors are powerful but difficult to use in trigger

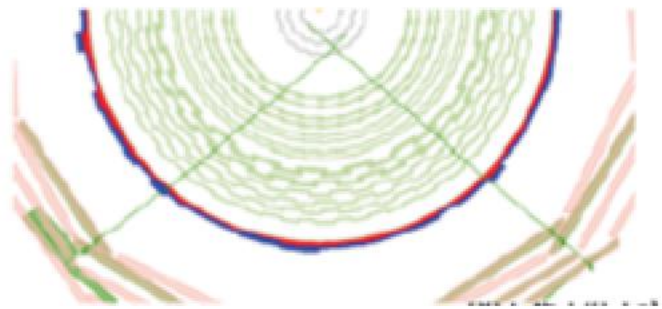
SM backgrounds often low. But need special studies (punch through, secondary interactions, tails, cosmics…)

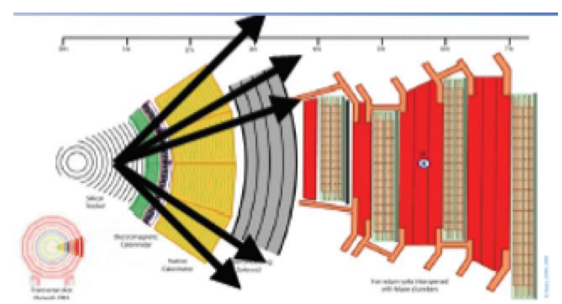
Special reconstruction is often needed

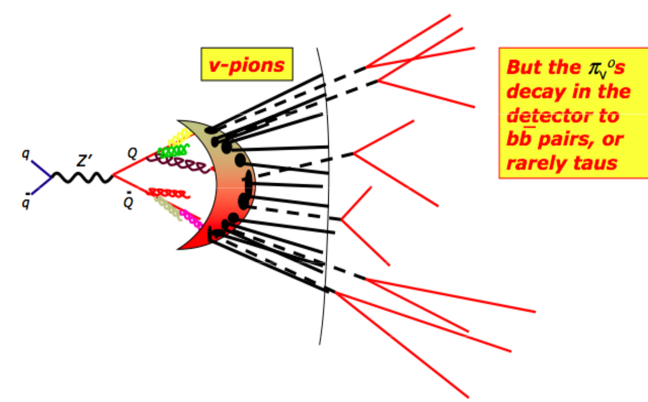
Some detector upgrades for High-Luminosity LHC (>2026) address these issues.

Long Lived Searches Overview

- Displaced jets, dijets, vertices
- Disappearing tracks
- Displaced leptons & lepton jets
- Displaced photons
- Dark photon decays
- Heavy Stable Charged Particles
- Stopped particles
- Emerging jets
- Monopoles stuck in material
- Heavy Neutral Lepton searches
- Strongly Interaction Massive Particles
- …. (others…new ideas…)

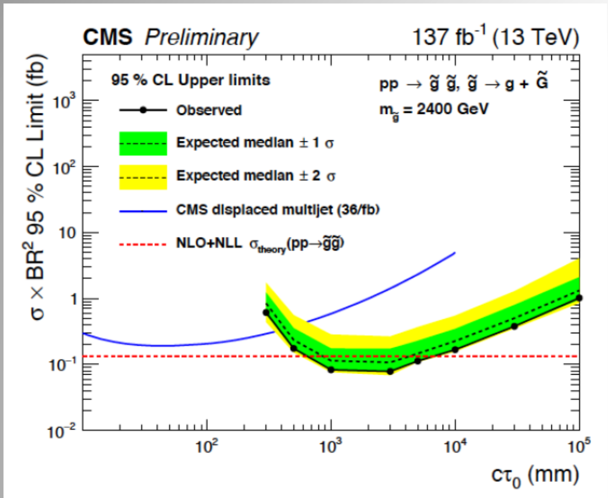




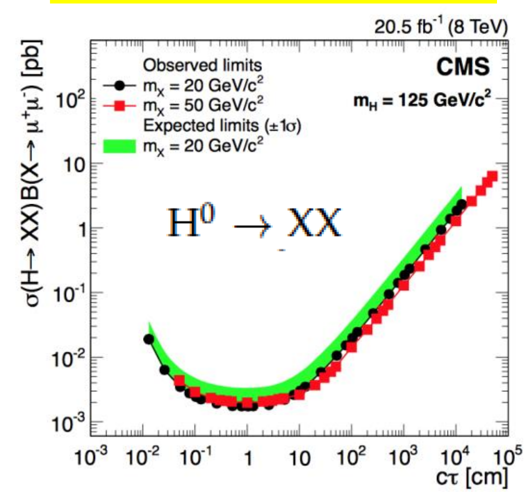


Long Lived Searches: Examples

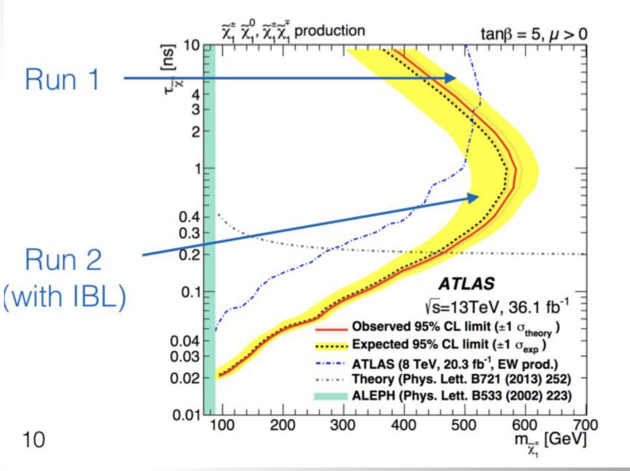
delayed jets



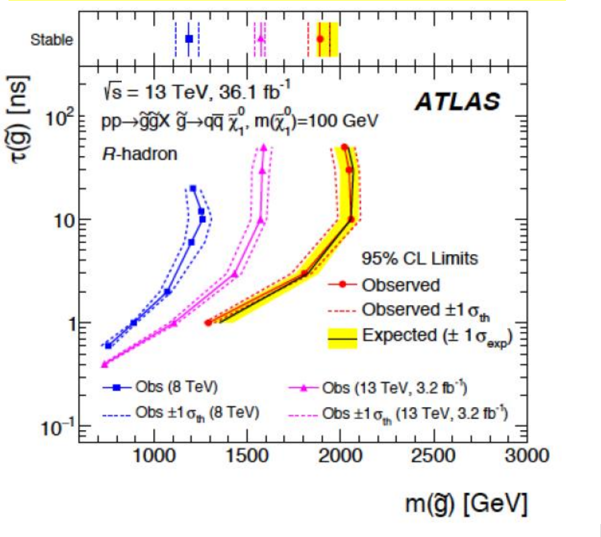
displaced leptons



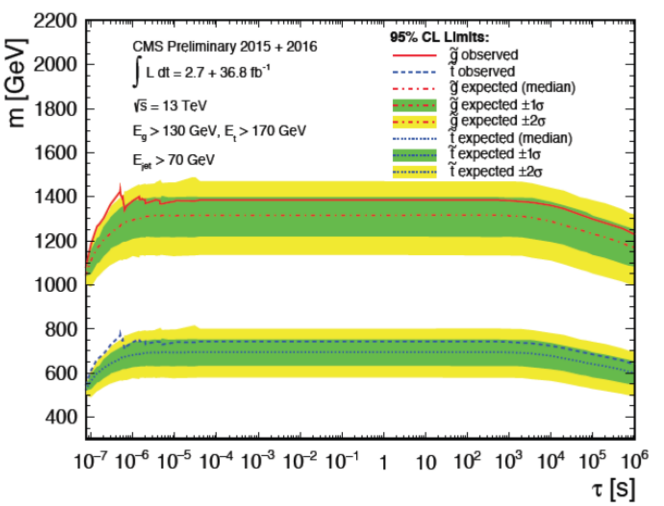
disappearing tracks



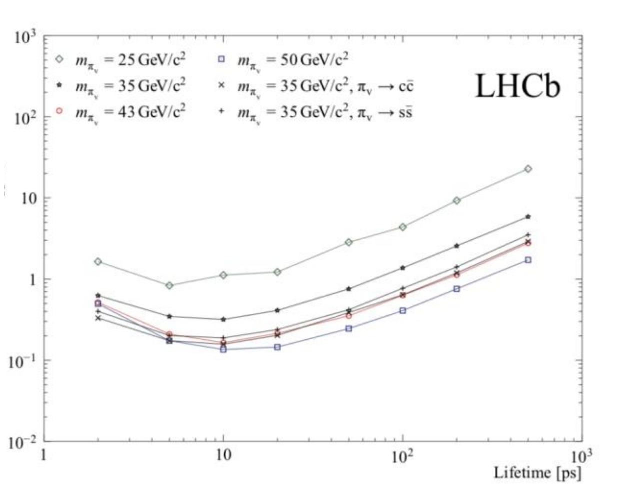
metastable R-hadrons



stopped particles



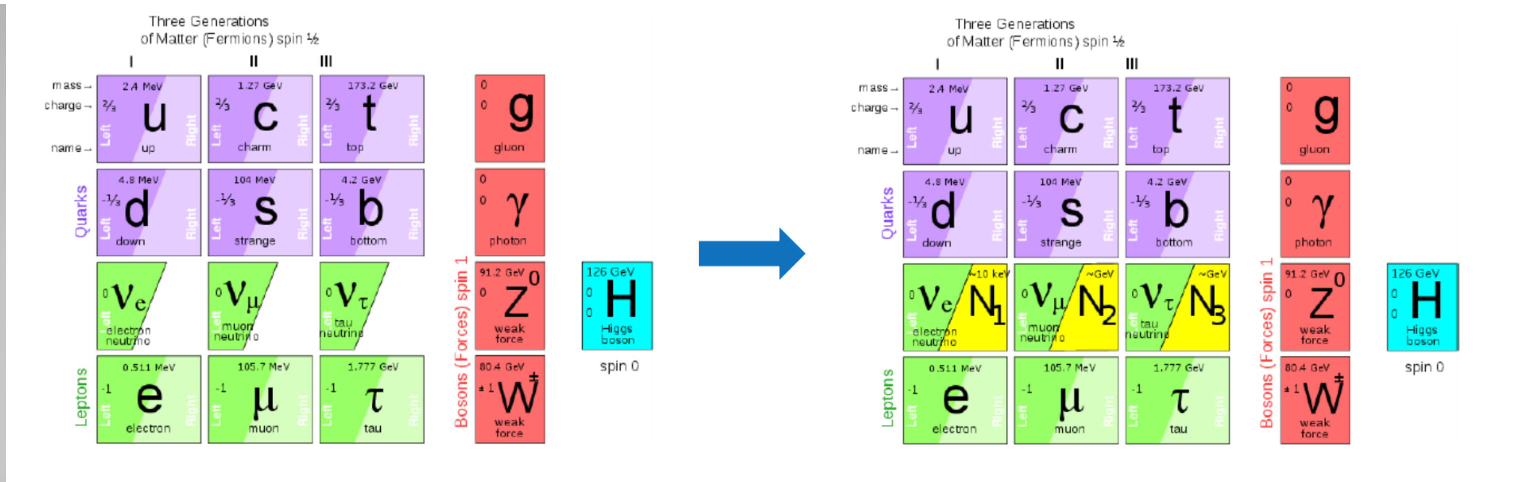
Hidden Valley searches

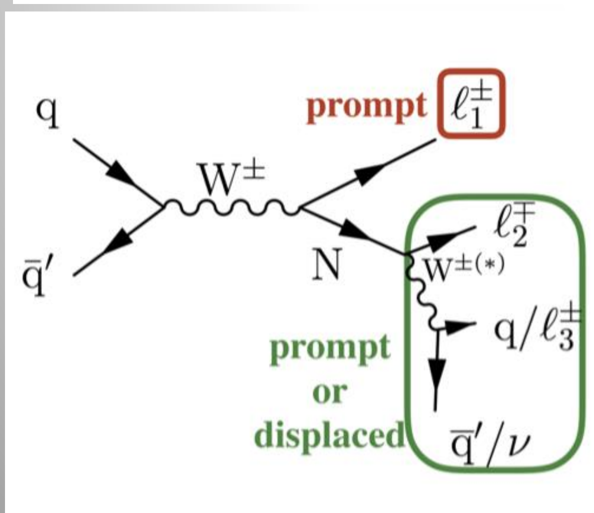


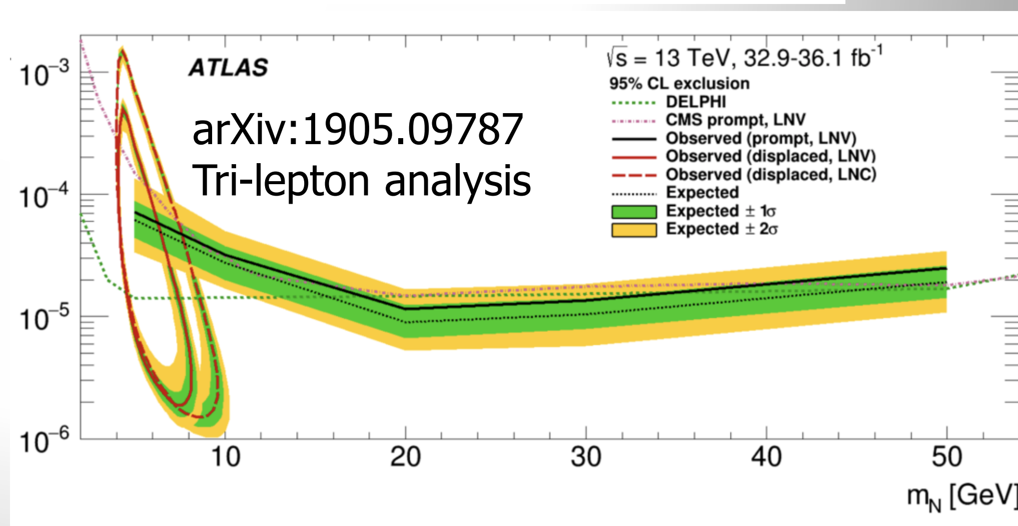
Search for Heavy Neutral Leptons

Neutrino portal: νMSM (Neutrino Minimal Standard Model)

Minimal extension of the SM fermion sector by Right Handed HNLs: N1, N2, N3.



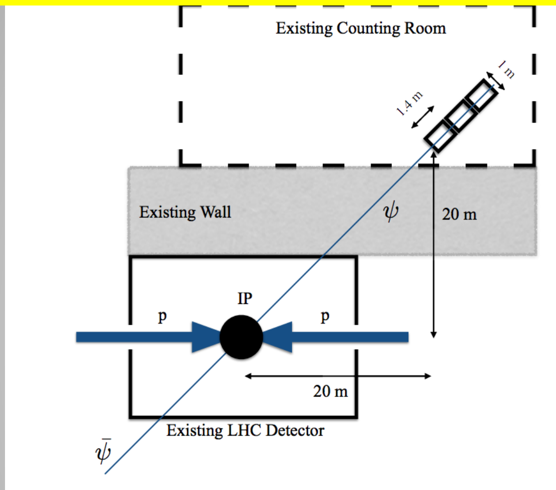




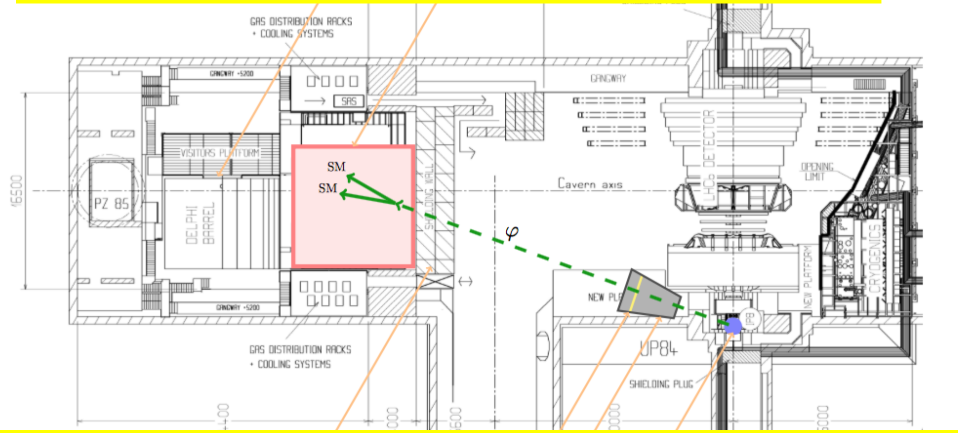
-> HNL hunting also focus of the SHIP experiment proposal

Proposals for New Experiments @LHC

MilliQan: searches for millicharged particles
MAPP: Similar to MoEDAL

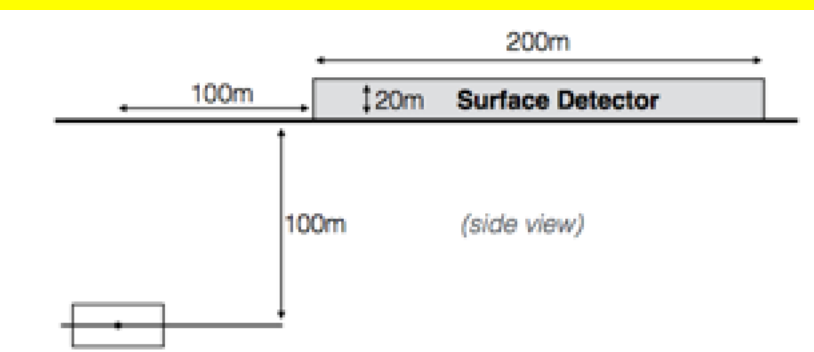


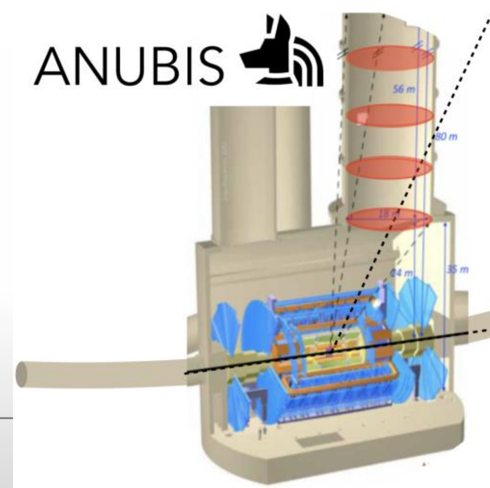
CODEX-b: searches for long lived weakly interacting neutral particles



Also: AL3X ('ALICE' for LLP arXiv.1810.03636).

MATHUSLA: searches for long lived weakly interacting neutral particles

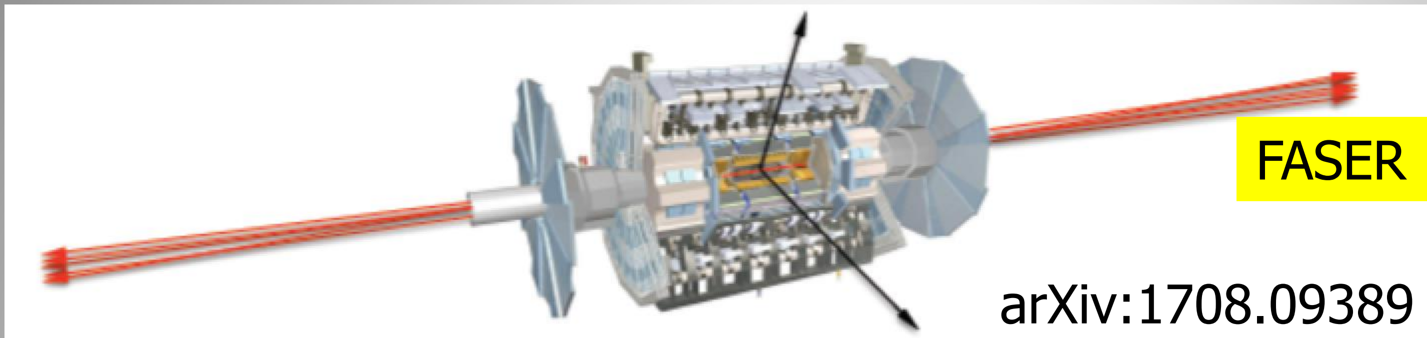


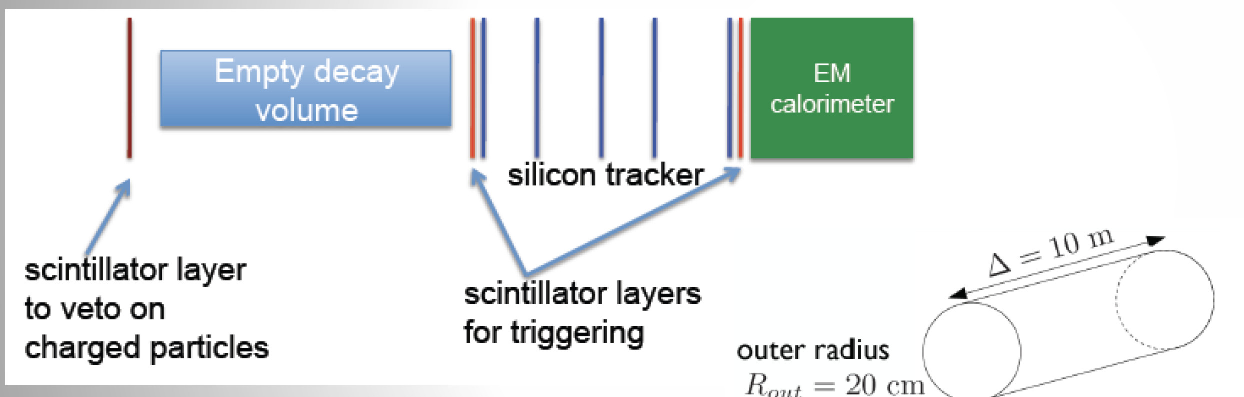


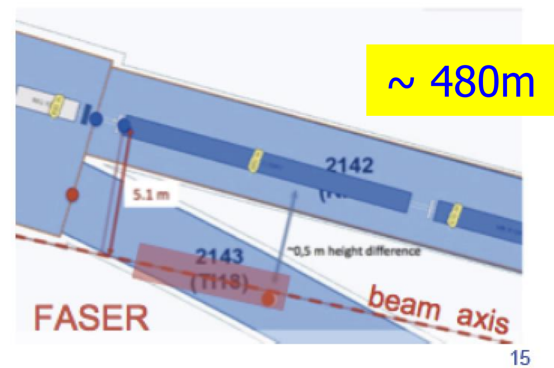
ANUBIS: searches for long lived weakly interacting neutral particles

+ Experiment Proposals for TeV neutrinos

FASER Proposal







- FASER has significant discovery potential for dark photons dark Higgs bosons, heavy neutral leptons (sterile neutrinos), ALPs, other gauge bosons, and many other new particles.

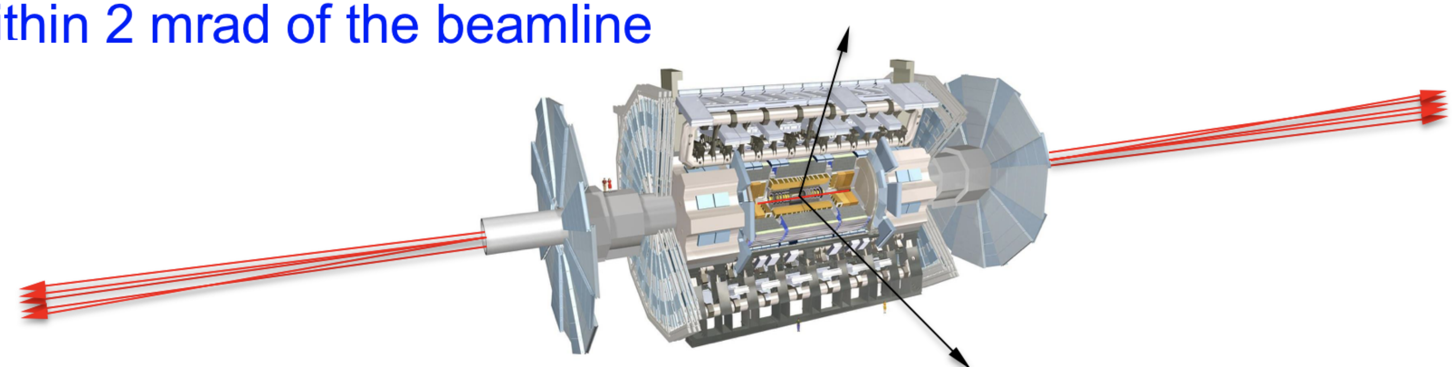
- Currently have in mind an initial veto layer, followed by ~5 tracking layers and EM calorimeter, with volume largely empty and a magnetic field.

FASER: The Idea

- New physics searches at the LHC focus on high p_T. This is appropriate for heavy, strongly interacting particles
  - σ ~ fb to pb → N_{events} ~ $10^3 - 10^6$, produced ~isotropically

- However, if new particles are light and weakly interacting, this may be completely misguided
  - Light → we can produce them in π, *K*, *D*, *B* decays
  - Weakly-interacting → need extremely large SM event rate to see them

- Conclusion: we should go where the pions are: at low p_T along the beamline
  - σ_{inel} ~ 100 mb → N_{events} ~ 10^{17}, and 10% of the pions are produced within 2 mrad of the beamline



FASER Approval

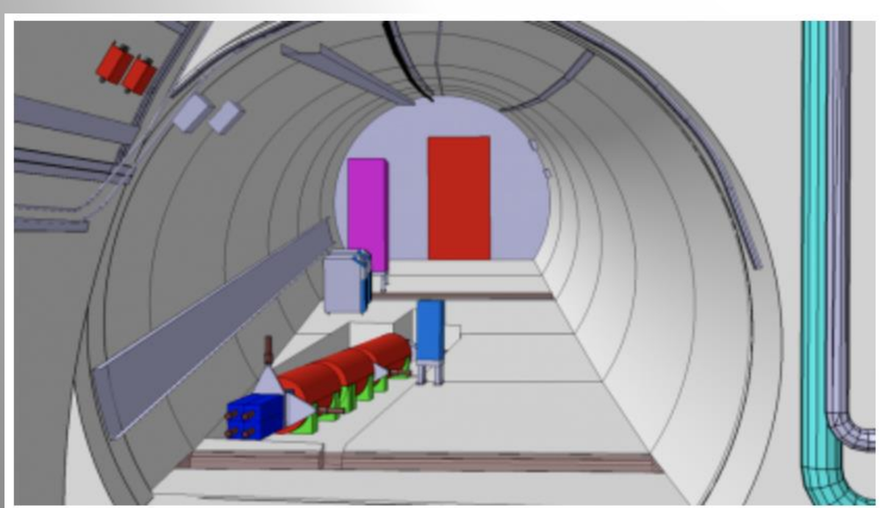
Breaking news: the FASER experiment (phase-I) has been approved March 5th

INTERACTIONS.ORG
PARTICLE PHYSICS NEWS AND RESOURCES

FASER: CERN approves new experiment to look for long-lived, exotic particles

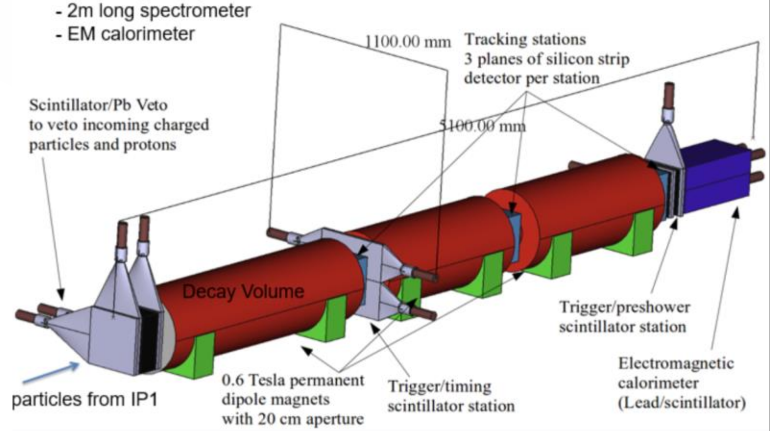
Date Issued
March 5th, 2019

FASER is the 8th LHC experiment



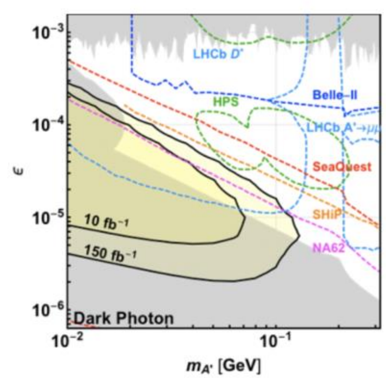
THE FASER DETECTOR

The detector consists of:
- Scintillator veto
- 1.5m long decay volume
- 2m long spectrometer
- EM calorimeter



EXPECTED SENSITIVITY

- Sensitivity for dark photons
  - Assuming no background and 100% signal efficiency
  - Curves only slightly effected by O(1) changes in efficiency



Even with 10/fb (to be collected by end of 2021?) have sensitivity to uncharted territory.
With full Run 3 dataset (150/fb) significant discovery potential.

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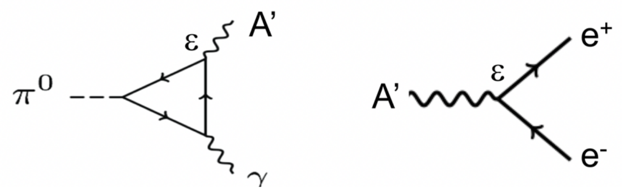
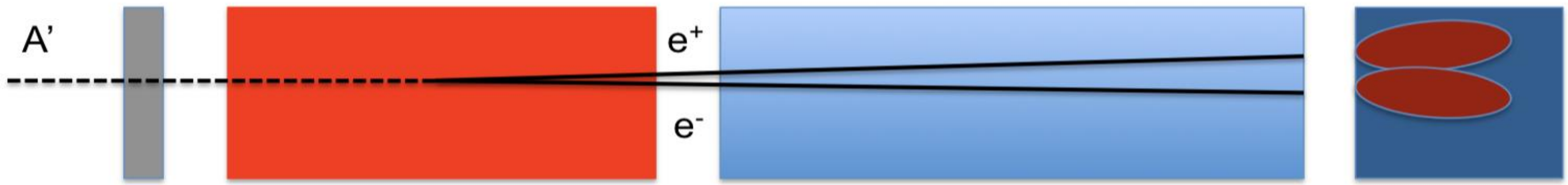
Dark Photon Detection



Signal signature



- The signal is spectacular: 2 ~TeV-energy, oppositely-charged tracks originating in the decay volume and pointing back to IP
- Initial scintillators: veto entering tracks
- Tracker: detect charged tracks
- Magnets: separate the 2 charged tracks sufficiently to resolve them in the tracker

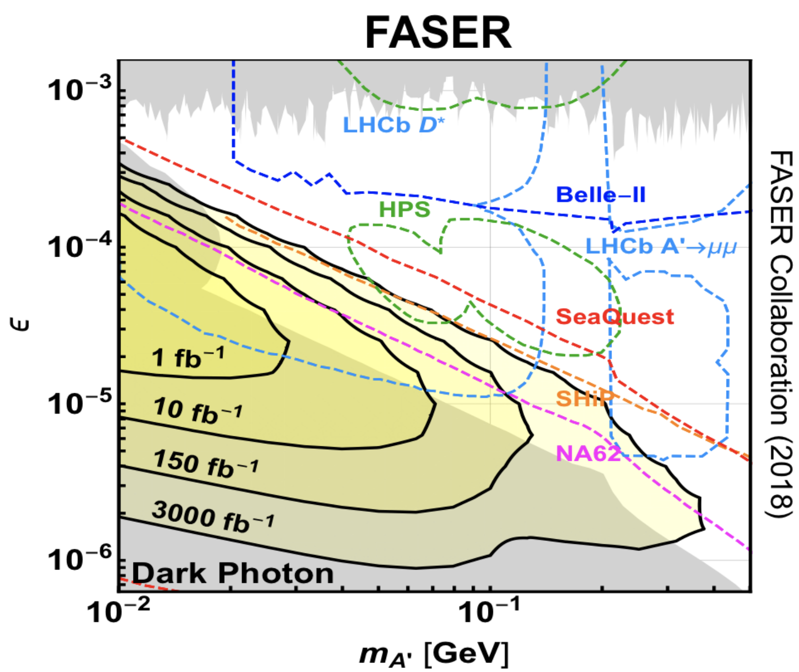
$$h_B \approx \frac{ec\ell^2}{E} B = 2\ \mathrm{mm}\ \left[\frac{1\ \mathrm{TeV}}{E}\right]\left[\frac{\ell}{3\ \mathrm{m}}\right]^2\left[\frac{B}{0.6\ \mathrm{T}}\right]$$

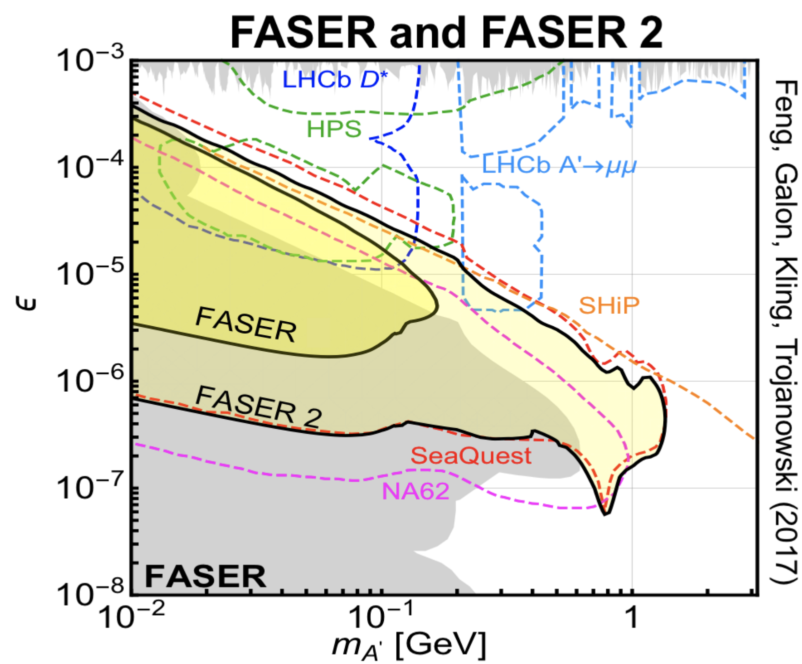
- Calorimeter: differentiate e from μ, detect γ, measure energy

Dark Photon Sensitivity Reach

FASER should be completed before run-3 starts

- FASER: R=10cm, L=1.5m, Run 3;   FASER 2: R=1m, L=5m, HL-LHC





- FASER probes new parameter space with just 1 fb^{-1} starting in 2021
- Without upgrade, HL-LHC extends (L*Volume) by factor of 3000; with possible upgrade to FASER 2, HL-LHC extends (L*Volume) by ~10^6

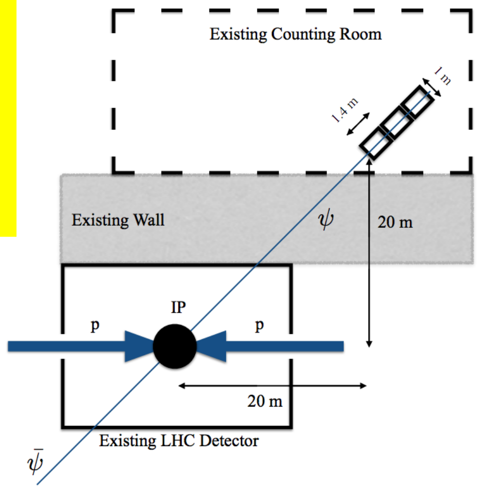
Particles with Milli-Charges?

"New" idea -> Hunting for particles with charges ~ 0.3-0.001e
Baseline paper: arXiv:1410.6816
Proposal for a new experiment/CMS subdetector.
Demonstrator (1%) taking data since mid-2017

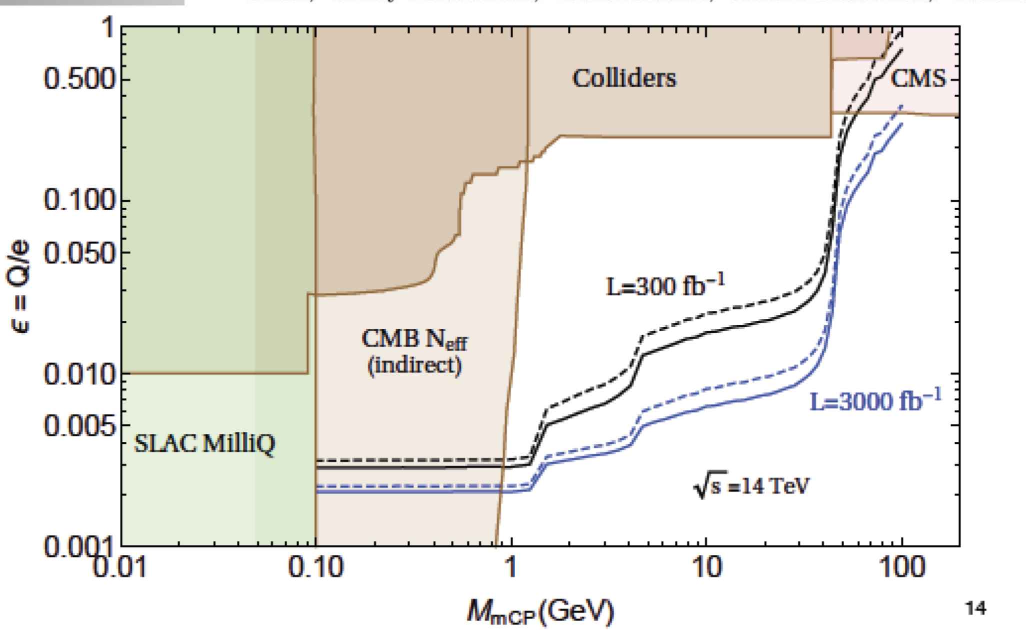
arXiv:1607.04669

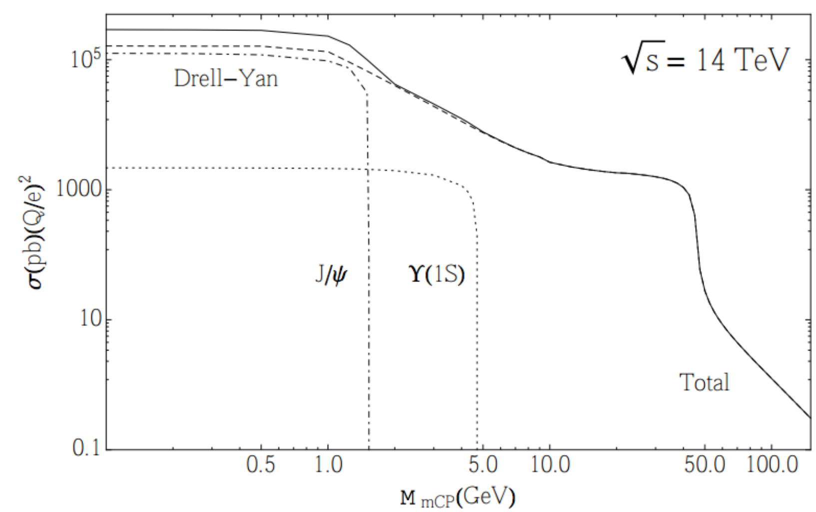
A Letter of Intent to Install a Milli-charged Particle Detector at LHC P5

Austin Ball,[1] Jim Brooke,[2] Claudio Campagnari,[3] Albert De Roeck,[1] Brian Francis,[4] Martin Gastal,[1] Frank Golf,[3] Joel Goldstein,[2] Andy Haas,[5] Christopher S. Hill,[4] Eder Izaguirre,[6] Benjamin Kaplan,[5] Gabriel Magill,[7,6] Bennett Marsh,[3] David Miller,[8] Theo Prins,[1] Harry Shakeshaft,[1] David Stuart,[3] Max Swiatlowski,[8] and Itay Yavin[7,6]



MilliQan Experiment

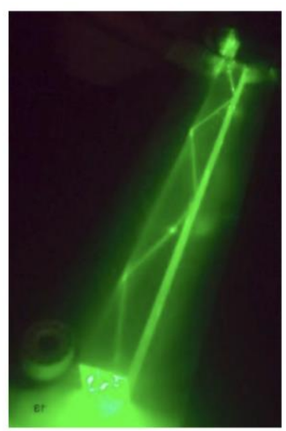


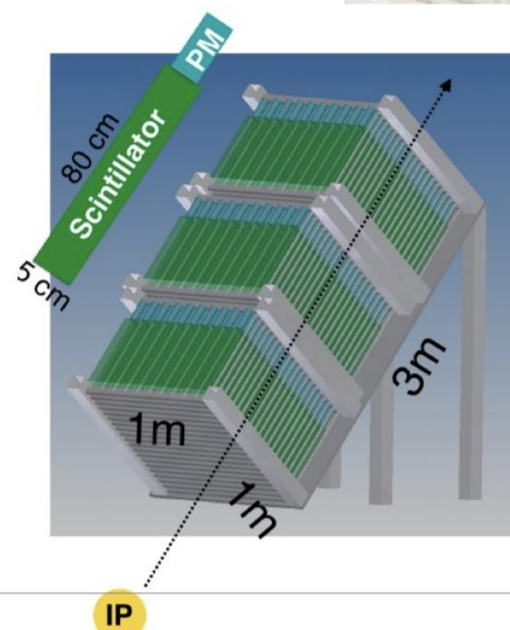


MilliQan Experiment

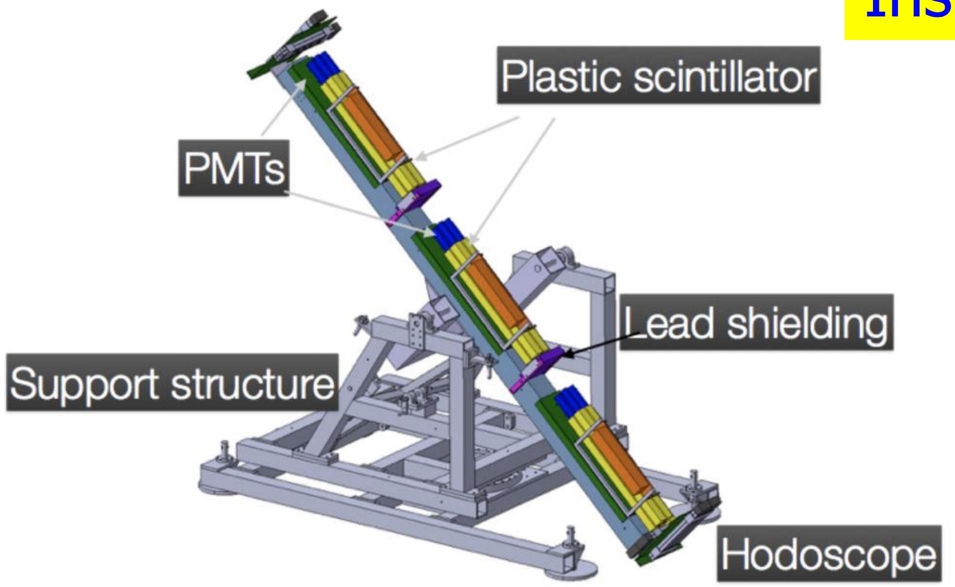
milliQan detector principle

- concept: arXiv:1410.6816; LOI: arXiv:1607.04669
- basic element is 5x5x80 cm^3 plastic scintillator
- attached to photomultiplier tube
- 1x1x3 m^3 in 3 length-layers
- search coincidence of few photons in consecutive scintillators pointing to IP



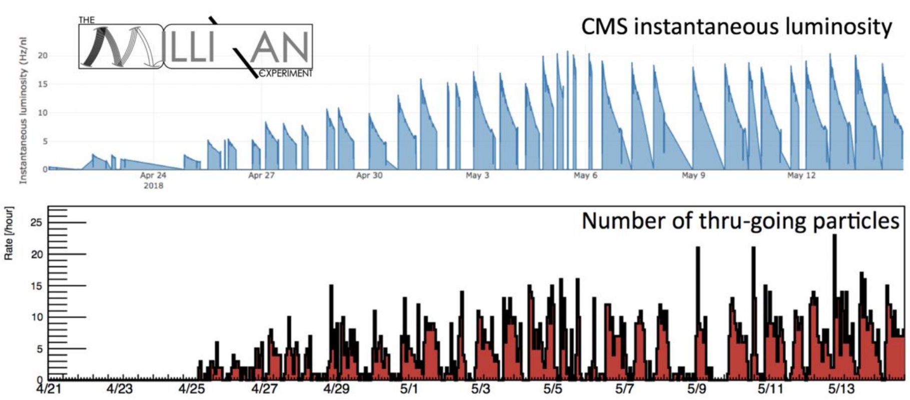


MilliQan Experiment



- In order to verify the feasibility and optimize the design of the experiment thoroughly, ~1% of the detector is installed as a "demonstrator"
- 3 layers of 2x3 scintillator+PMT

Installed demonstrator in 2017



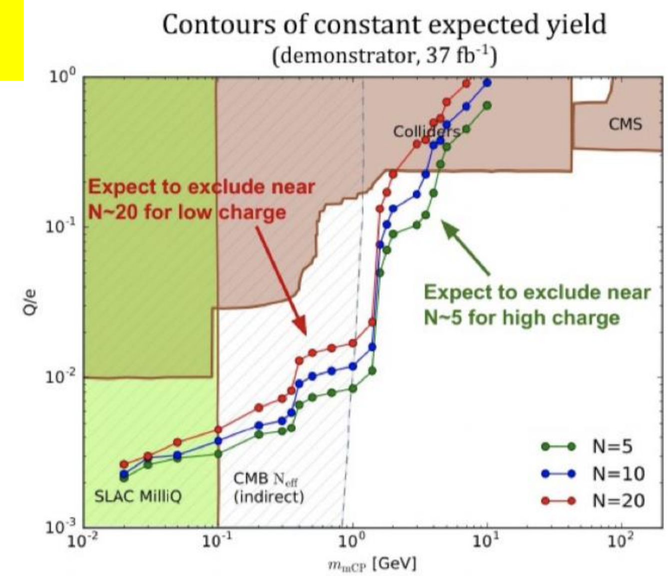
- Took data since September 2017 → ~40 fb^{-1} of data on tape
- Data well understood!
- First physics paper in preparation

MilliQan Experiment

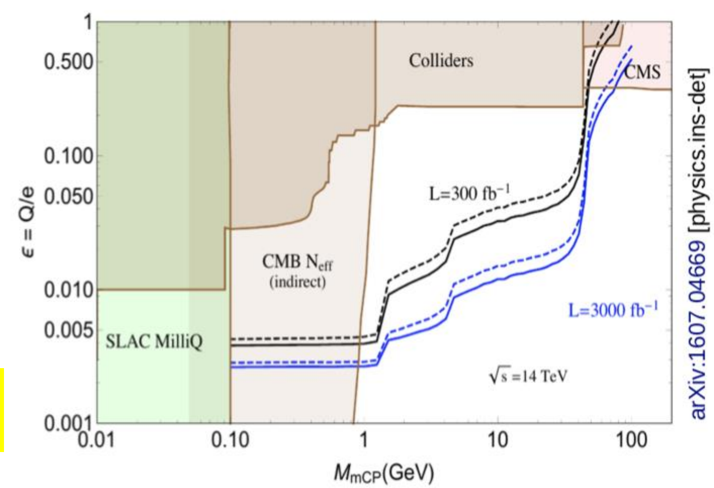
Sensitivity

Projections using the 1% demonstrator and the full detector

- demonstrator analysis coming along
- preview:
  expected limits versus number of B
  - expect to exclude along red line for low charge
  - expect to exclude along green line for high charge
- expect new sensitivity already with demonstrator data



- old background estimate in LoI:
  - 165 events in Run-3 (300/fb)
  - 330 events during HL-LHC (3000/fb)
- update soon

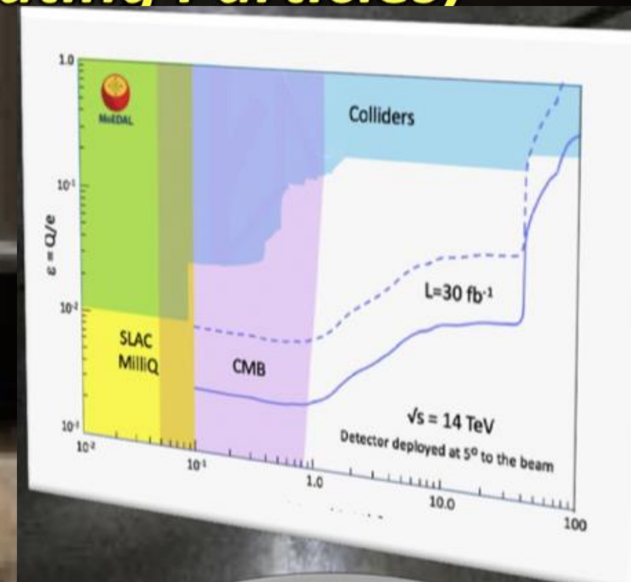


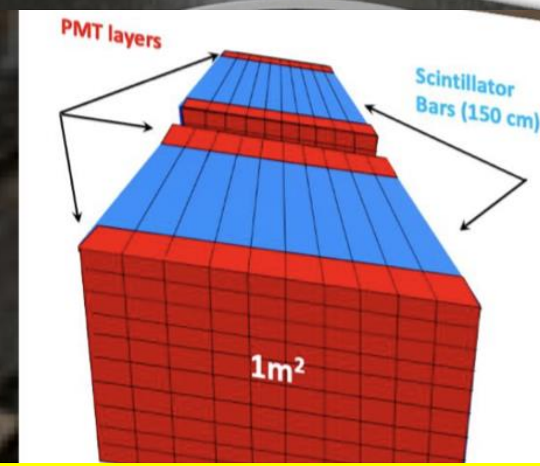
Demonstrator results paper in preparation

MAPP* MoEDAL's Upgrade for RUN-3

*(MoEDAL Apparatus for Penetrating Particles)

- The Milli-charged particle (mQP) detector is a 1m x 1m x (2 x 1.5m) scintillator array, pointing to IP, in well shielded area of LHC Point 8 (LHCb)
  - Placed in UGC8 gallery ~100m underground Positioned at 55m from IP, 50m through rock, in the horizontal beam plane
  - Deployed from 5º to the beam (at 55m) to 25º to the beam (at 26 m)
  - 7-10m decay zones available in from of
  - Uses quadruple coincide between the two scintillator bars) sections (2 PMTs per bar)
  - Active veto against showers in rock
- Under construction during current shutdown
- Due to start data taking in LHC's RUN-3





+scintillator array for decays of long-lived weakly neutrals

MATHUSLA

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

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arXiv:1811-00927

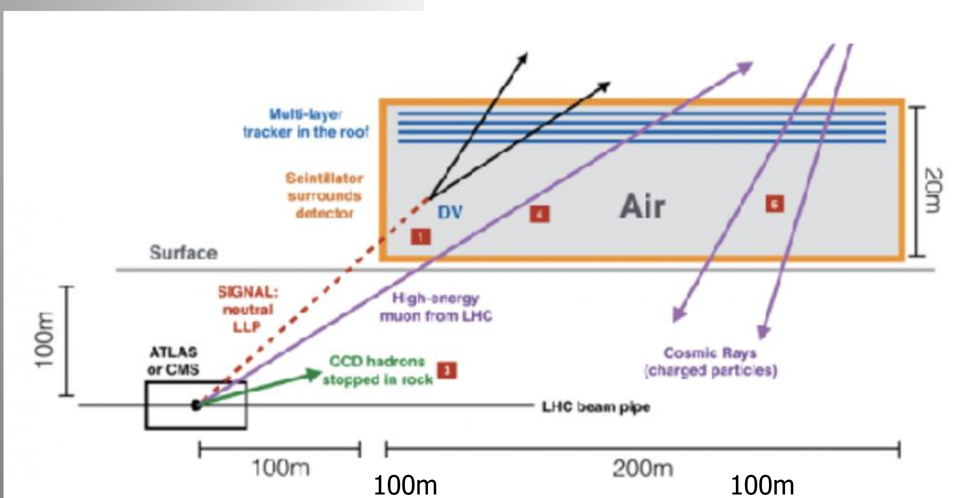
A proposal for a large area surface array to detect ultra long lived particles coming from the pp collisions

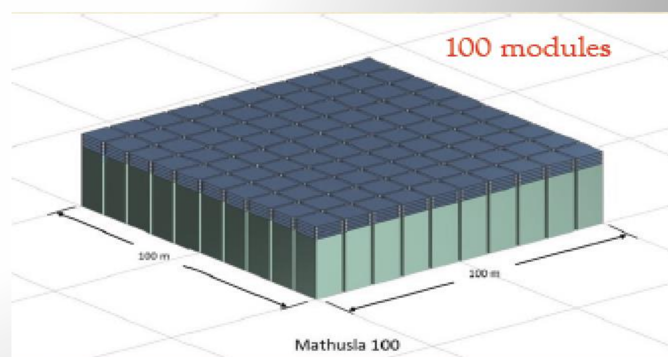
Aim to cover the range

$$c\tau \lesssim 10^7 - 10^8\ \mathrm{m},$$

~ BBN constrained inspired

Physic case arXiv:1806.07396





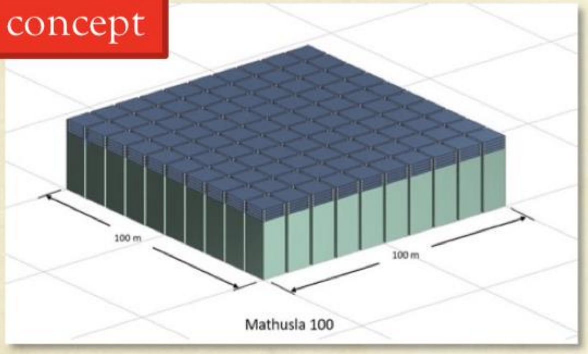
Detector surface array eg above ATLAS or CMS: ~ $(200\mathrm{m})^2$

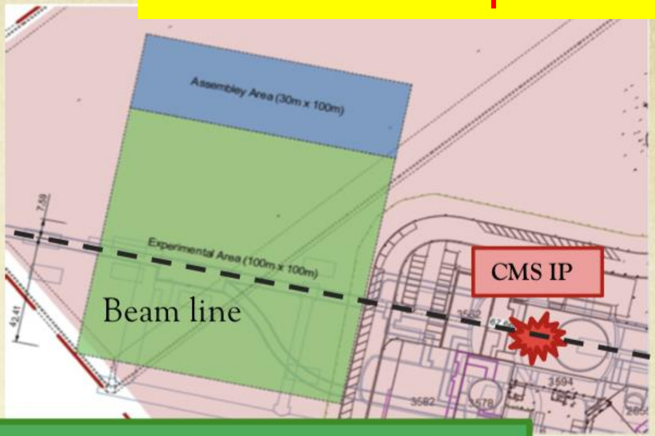
MATHUSLA @ P5

Recent developments

- Worked with Civil Engineers to define the **building and the layout of MATHUSLA at P5**
- **Layout restricted by existing structures** based on current concept and engineering requirements

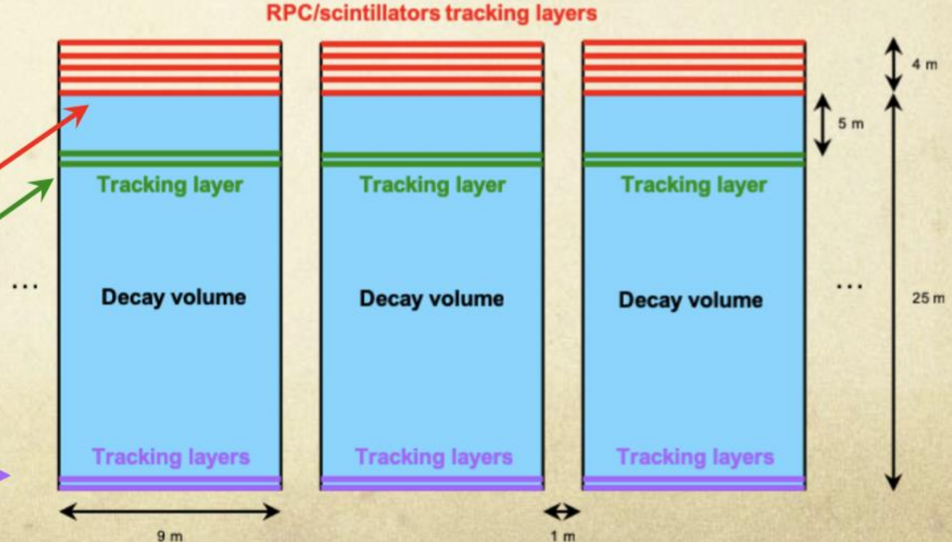
Modular concept





- 68 m to IP on surface and IP ~80m below surface
- ~7.5m offset to the beam line

- Assume ~ 25 meter decay volume
- Individual detector units 9 x 9 x 30 m^3
- 5 layers of tracking/timing detectors separated by 1m
- Additional tracking/timing layer 5m
- Double layer floor detector (tracking/timing)

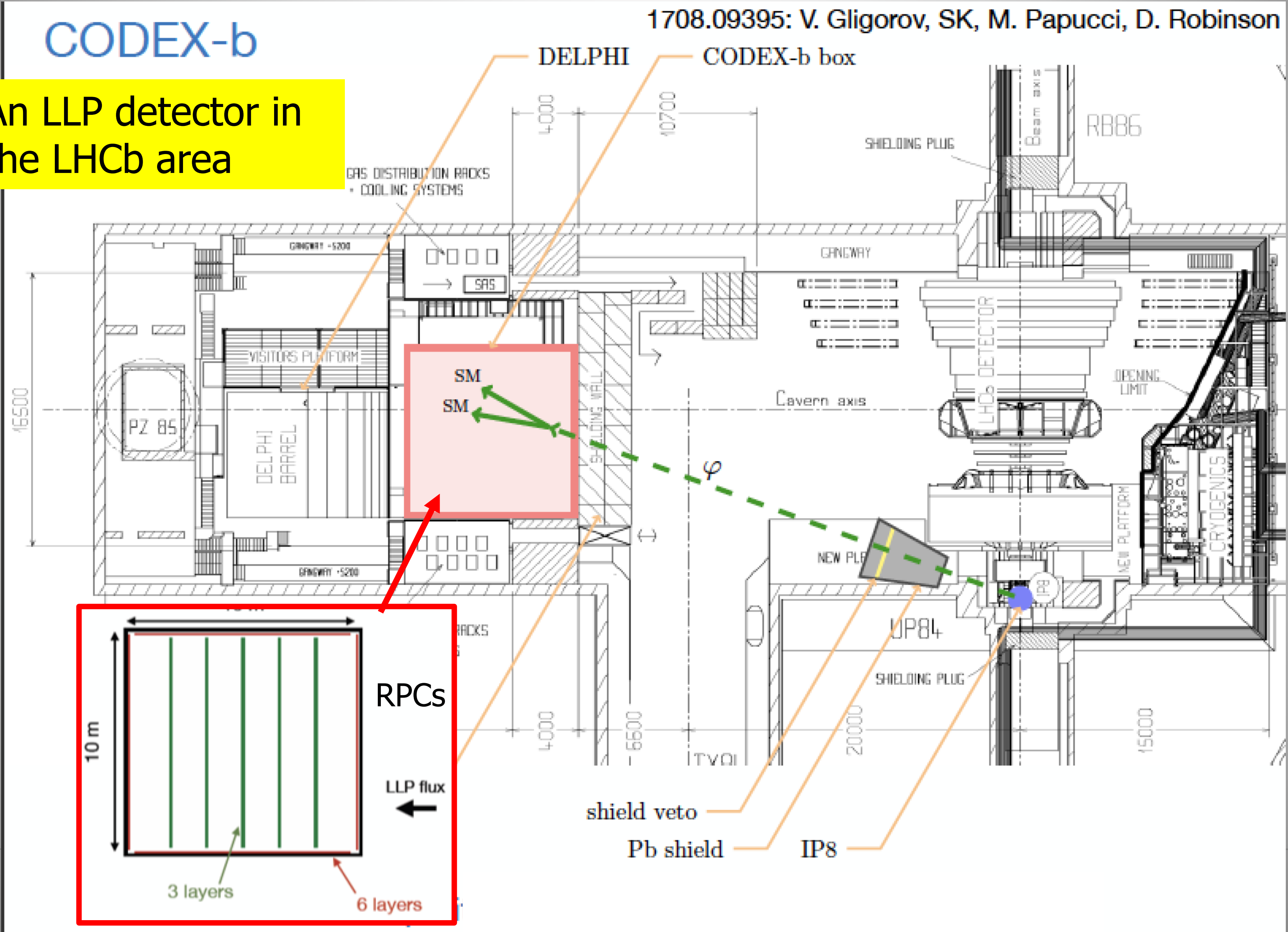


Goal to complete the Technical Design Report (TDR) by end 2020

CODEX-b Proposal

1708.09395: V. Gligorov, SK, M. Papucci, D. Robinson

An LLP detector in the LHCb area

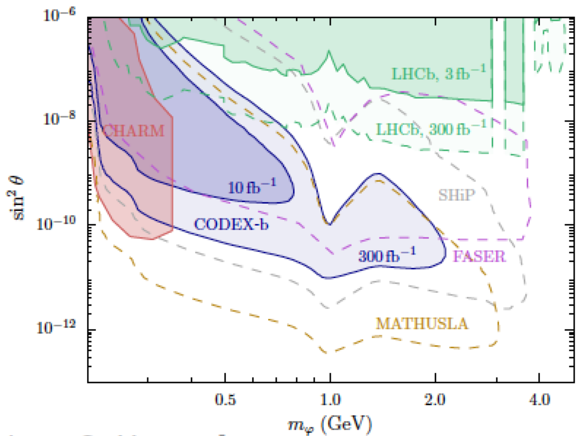


CODEX-b Proposal

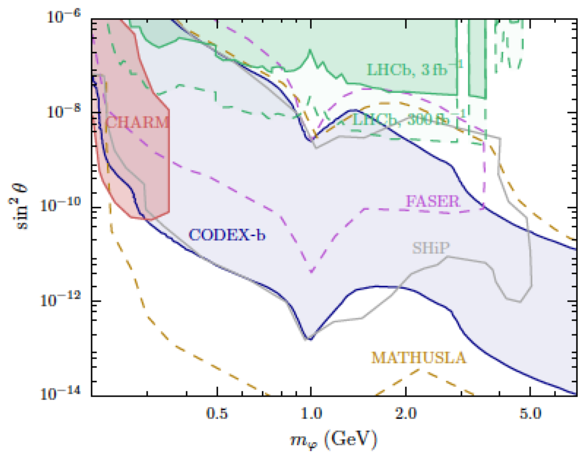
Example: Higgs-scalar mixing

- Minimal extension of Higgs sector: $\mathcal{L} \sim \mu\varphi HH^\dagger + \frac{\lambda}{2}\varphi^2 HH^\dagger$

$\lambda = 0$:

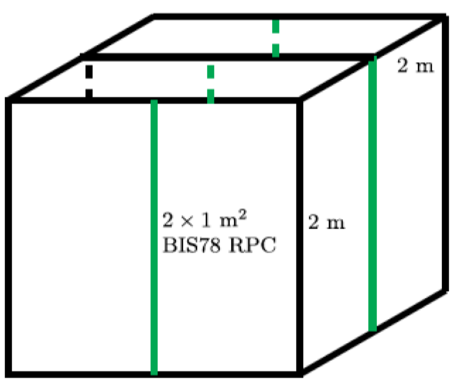


$\lambda = 1.6 \times 10^{-3}$:



[plots: S. Knapen]

- Scalar portal → Dark Higgs/scalars
- Neutrino portal → Heavy Neutral Leptons
- Pseudoscalar portal → Axion-like particles
- Vector portal → Dark photon



- $2 \times 2 \times 2$ m^3 demonstrator for Run 3 ⇒ 1/25 of full detector
- 6 faces + 1 inner station ⇒ 14 BIS78 triplet chambers.
- Enough space already in D1 area of the cavern once DAQ racks shifted out before EOY.

Demonstrator for Run 3

- Main goal: reconstruct K_L^0's in the volume from IP8 during 2021-23.

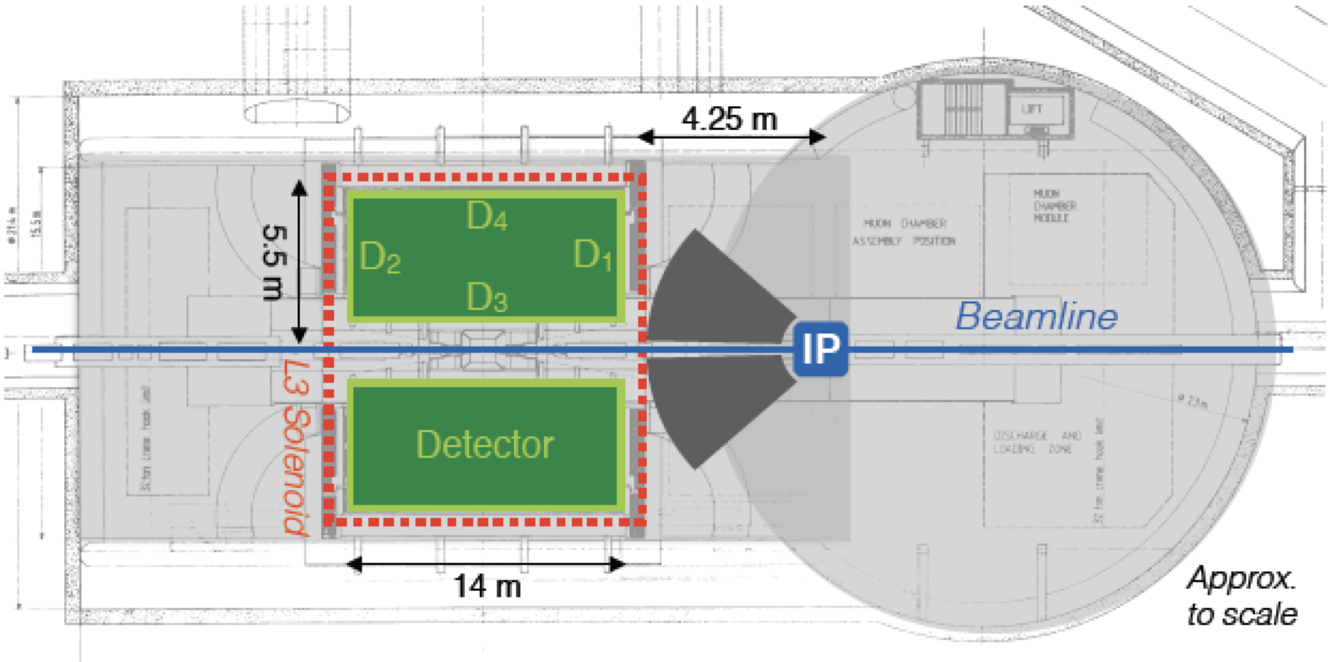
EOI prepared for LHCb in2019

Re-using the ALICE detector?

A Laboratory for Long-Lived eXotics (AL3X)

For LHC Run 5??
So far just an idea

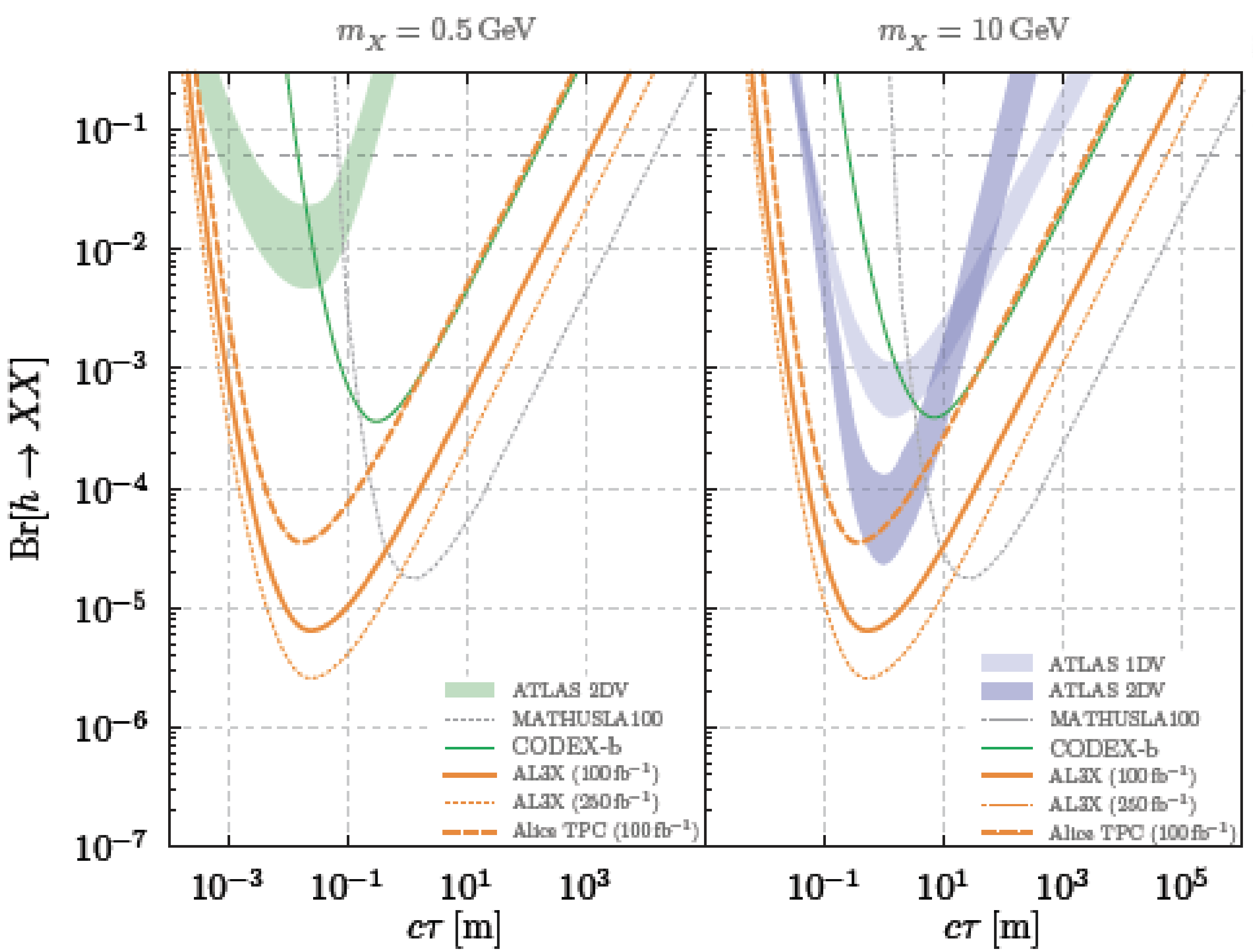
Reuse the L3 magnet and (perhaps) the ALICE TPC

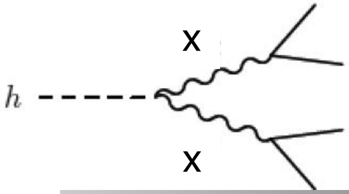


Similar strategy as for CODEX-b: use thick shield with active veto to reduce the backgrounds

V. Gligorov, SK, B. Nachman, M. Papucci, D. Robinson: 1810.03636

Physics Reach: Example

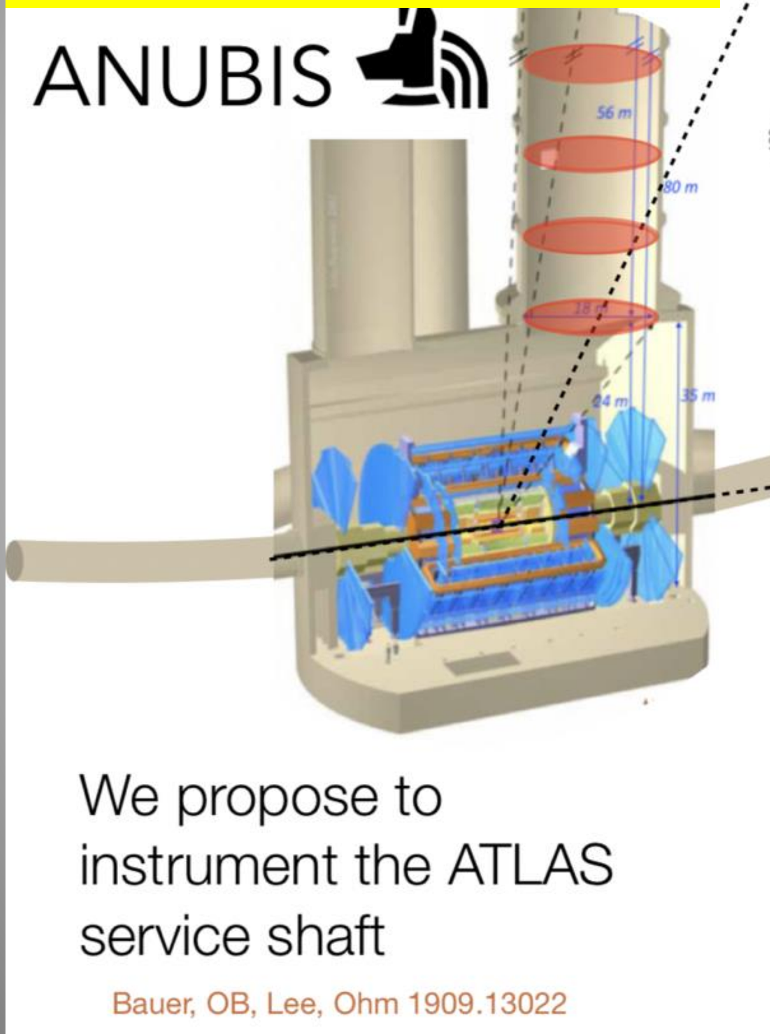


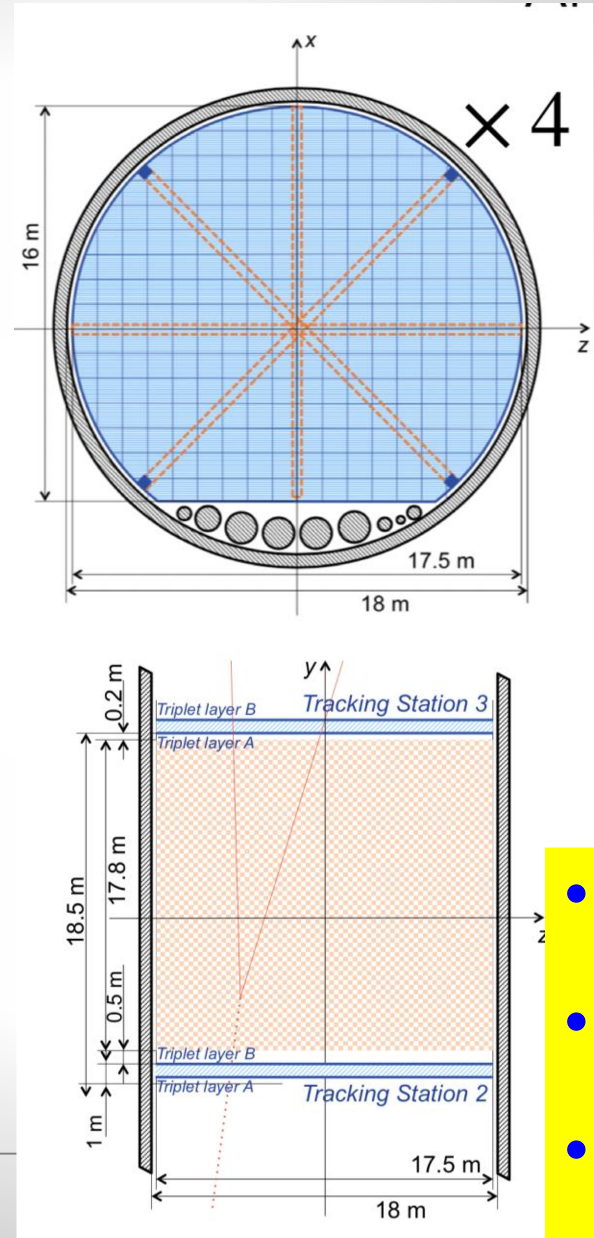


For low masses: MATHUSLA, CODEX-b and AL3X have a leading edge

Proposals for New Experiments @LHC

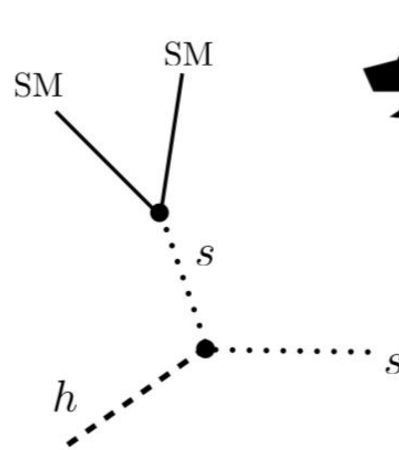
ANUBIS: searches for long lived weakly interacting neutral particles





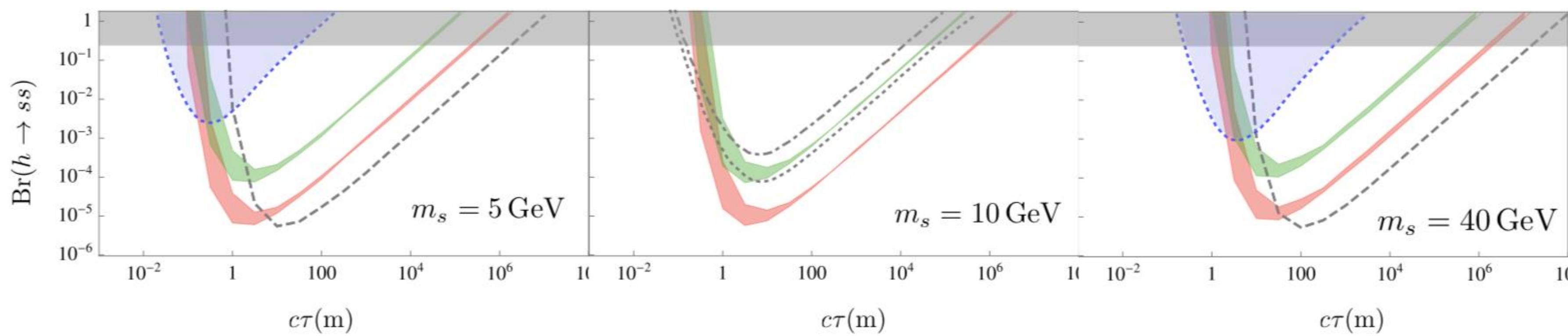
- 4 tracking stations of RPCs
- Propose to have 1x1m^2 test set-up
- Could also be in the CMS shaft

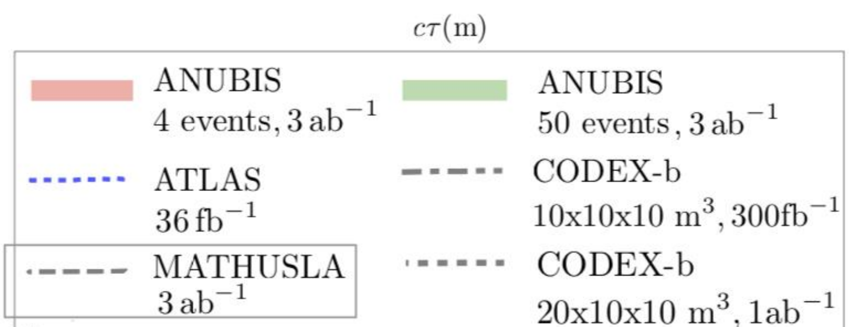
ANUBIS



Sensitivity study for exotic Higgs decays

$$\mathcal{L} = \lambda s^2 H^\dagger H \qquad h \to ss,\, s \to \mathrm{SM\,SM}$$

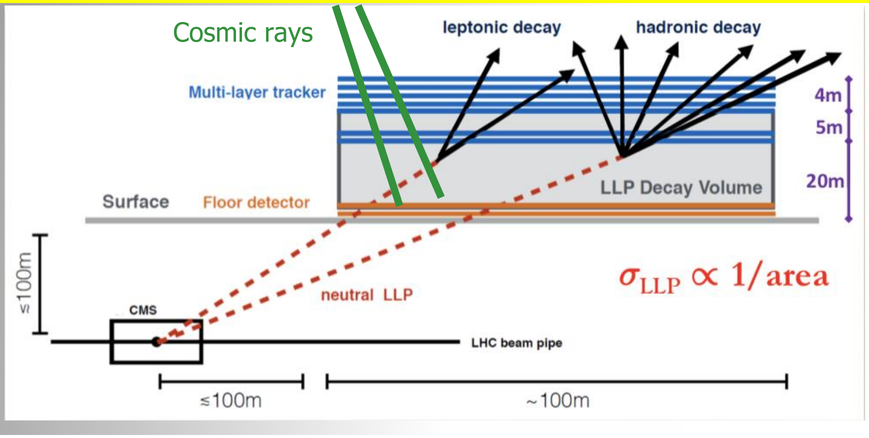




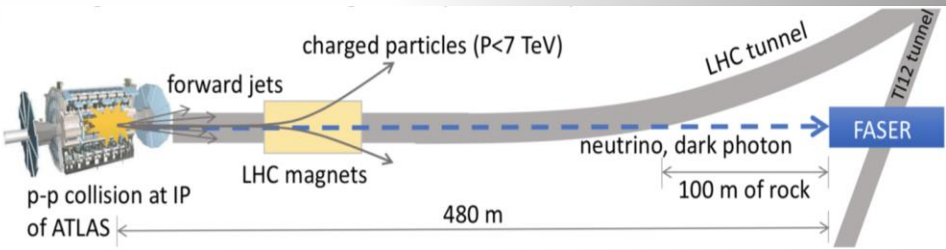
200 x 200 x 20 m³ decay volume →

Cosmic Rays & TeV Neutrinos

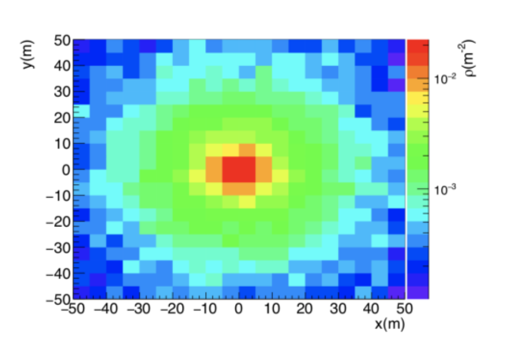
MATHUSLA and ANUBIS 'on surface' Cosmic Ray measurements possible



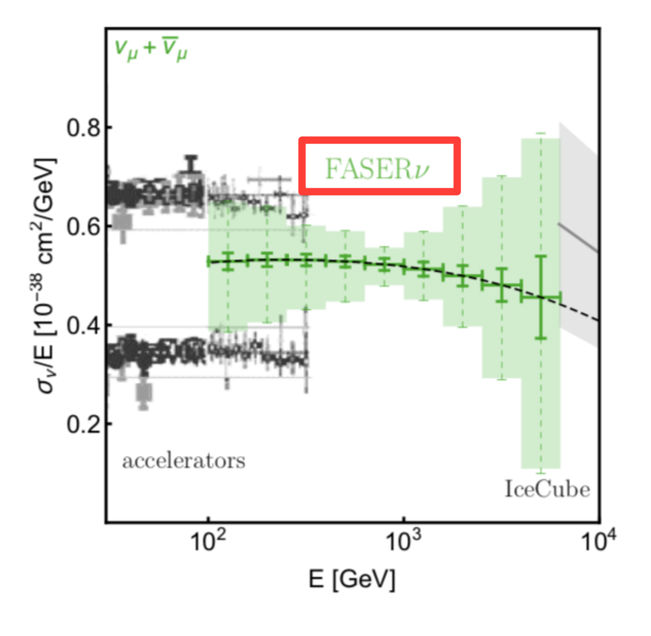
XSEN and FASER-Nu are 400m forward of the IPs and can study TeV-neutrinos with emulsion detectors



Observatory	Full coverage	Spatial resolution	Angular resolution	Energy precision	CR composition capabilities
MATHUSLA-100	100%	Very good	Very good	Good	Limited by statistics
ARGO-YBJ [204]	93%	Very good	Good	Good	Good
KASCADE [146]	< 2%	Good	Good	Good	Very good
HAWC-Outrigger [86]	0.8 – 62%	Good	Good	Good	In investigation
IceTop [88]	0.044%	Good	Good	Good	In investigation
TALE (TA) [89]	$O(1\%)$	Good	Good	Very good	In investigation

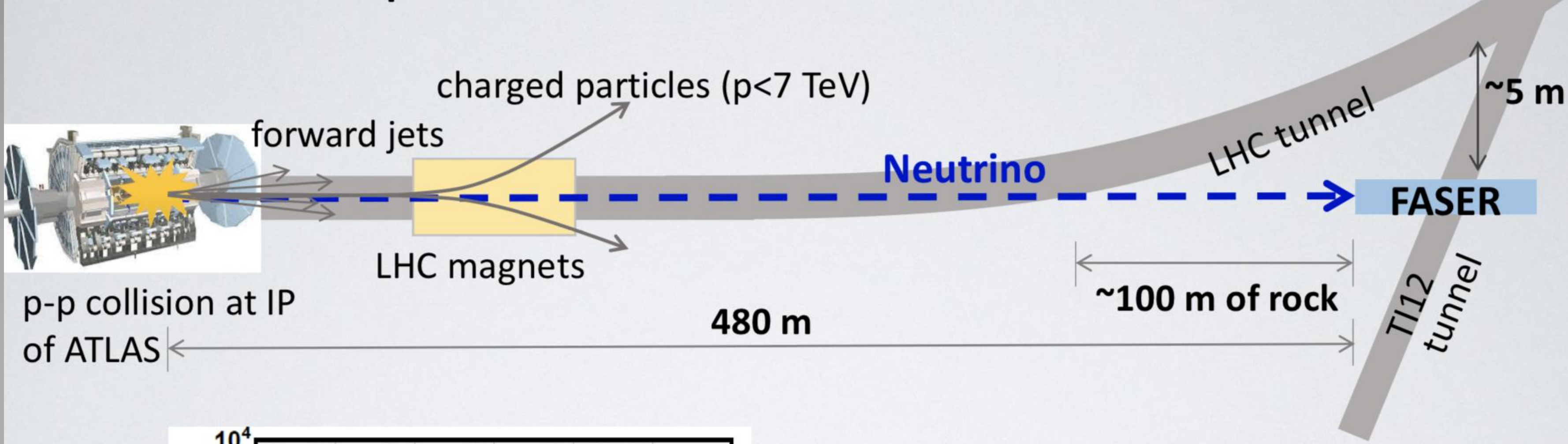


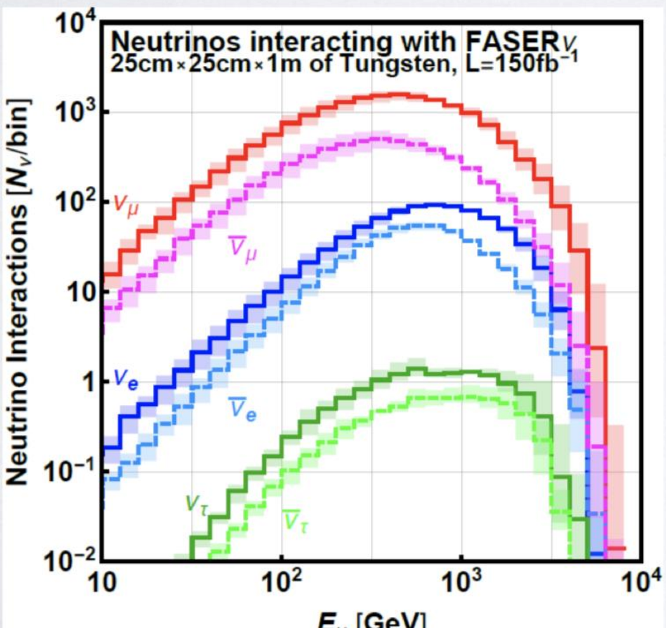
particle density in 10^{15} eV airshower



Neutrinos

Expected neutrino rates at FASER





Expected yields in Run 3 (2021-2023)

	# of CC interactions	Mean energy (GeV)
$\nu_e + \bar{\nu}_e$	1296	827
$\nu_\mu + \bar{\nu}_\mu$	20439	631
$\nu_\tau + \bar{\nu}_\tau$	21	965

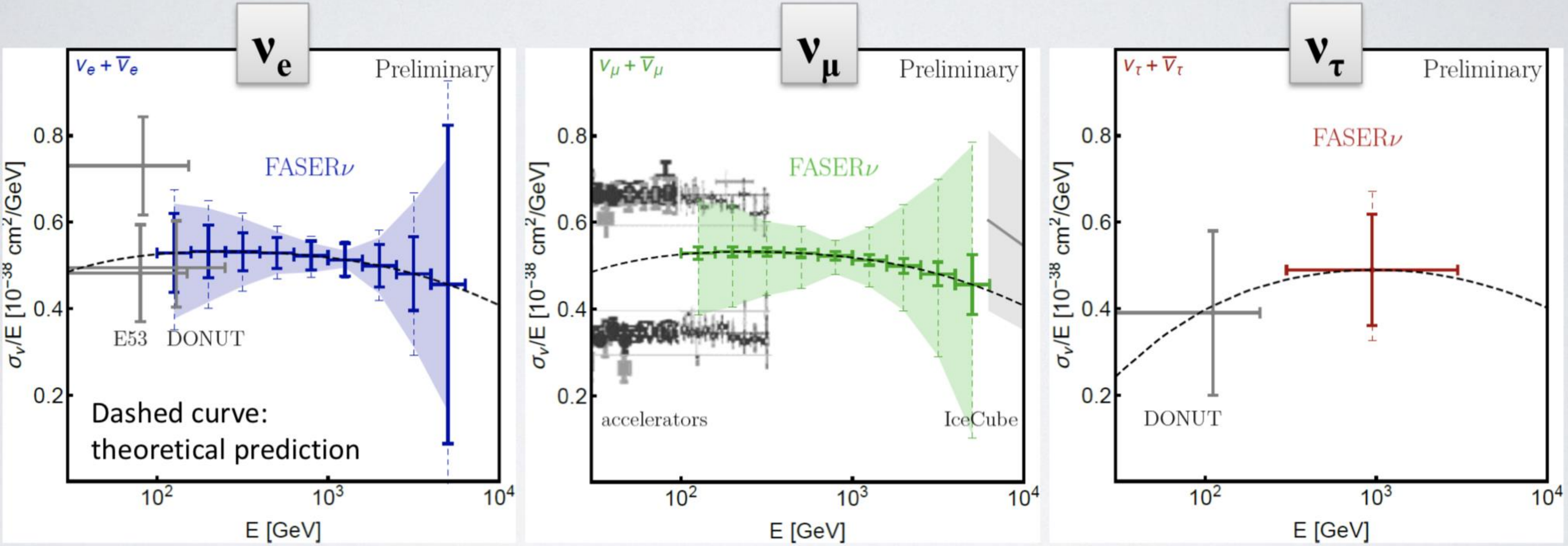
E.g., ν_μ CC cross section in unexplored region 400 GeV < E < 6 TeV, and ν_τ events.

Neutrinos

Prospects for cross section measurements at 14-TeV LHC

in Run3 (150 fb^{-1}) using a 1.2-ton tungsten/emulsion detector

arXiv:1908.02310



Solid error bars: statistical uncertainties.

Dashed error bars: also include uncertainties from neutrino production rate corresponding to the range of predictions obtained from different Monte Carlo generators.

Neutrino Experiments at LHC

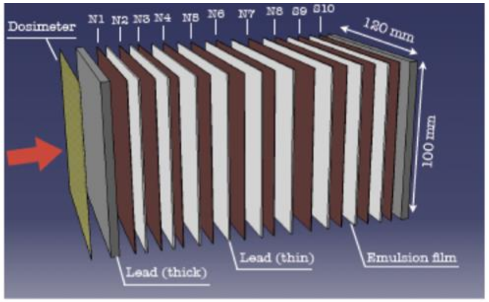
arXiv:1903.06564: a proposal for an emulsion neutrino experiment

Physics Potential of an Experiment using LHC Neutrinos

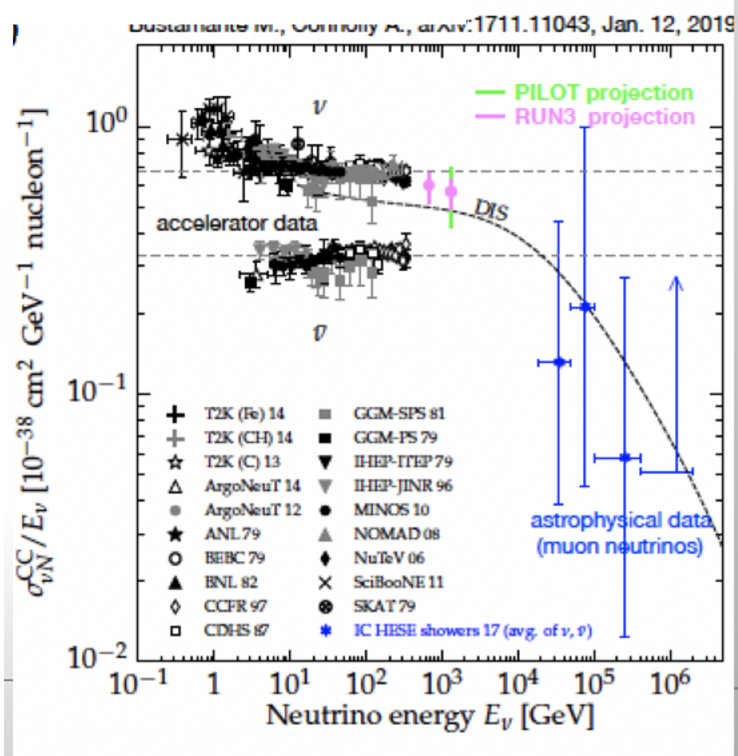
The XSEN experiment

N. Beni[1,2], S. Buontempo[3], T. Camporesi[2], F. Cerutti[2], G.M. Dallavalle[4], G. De Lellis[2,3,5], A. De Roeck[2], A. De Rújula[6], A. Di Crescenzo[3,5], D. Fasanella[4], A. Ioannisyan[2,7], D. Lazic[8], A. Margotti[4], S. Lo Meo[4,9], F.L. Navarria[4], L. Patrizii[4], T. Rovelli[4], M. Sabaté-Gilarte[2], F. Sanchez Galan[2], P. Santos Diaz[2], G. Sirri[4], Z. Szillasi[1,2], C. Wulz [10]

Emulsion detector "OPERA" style

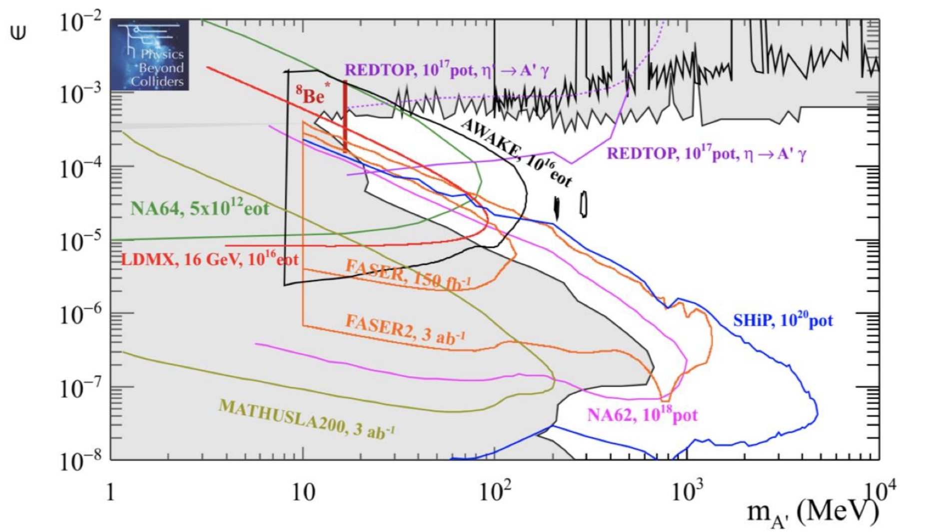


- Phase 1 (PILOT run): 2021, 0.4 ton detector for characterisation of the background, and set-up and tune emulsion handling infrastructure and analysis for 2022-23,
- Phase 2: 2022-23, 1.5 ton detector, 2 sections covering η ranges with different average energy (0.7, 1.2 TeV)
- with 150 /fb can record up to 2000 HE neutrino interactions, up to 100 ν_tau

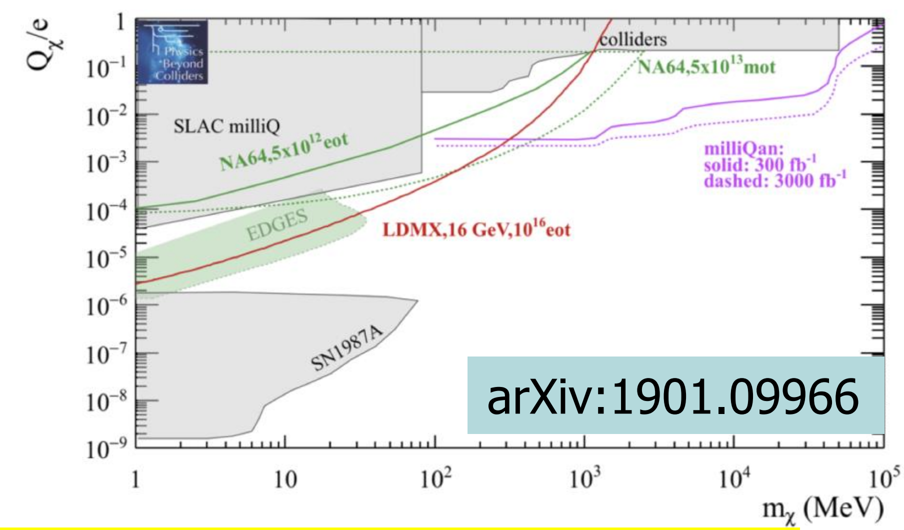


Sensitivity Summaries

Search for dark photons (visible mode)

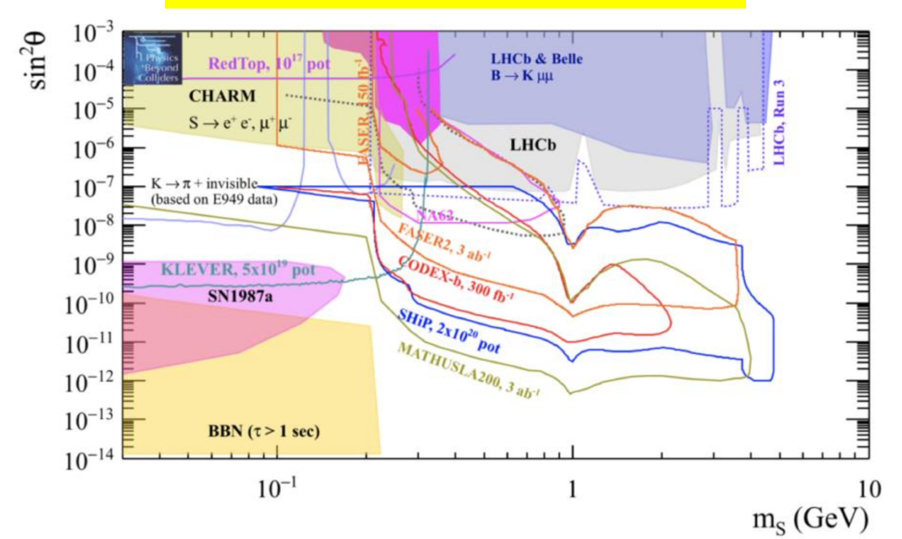


Search for millicharges

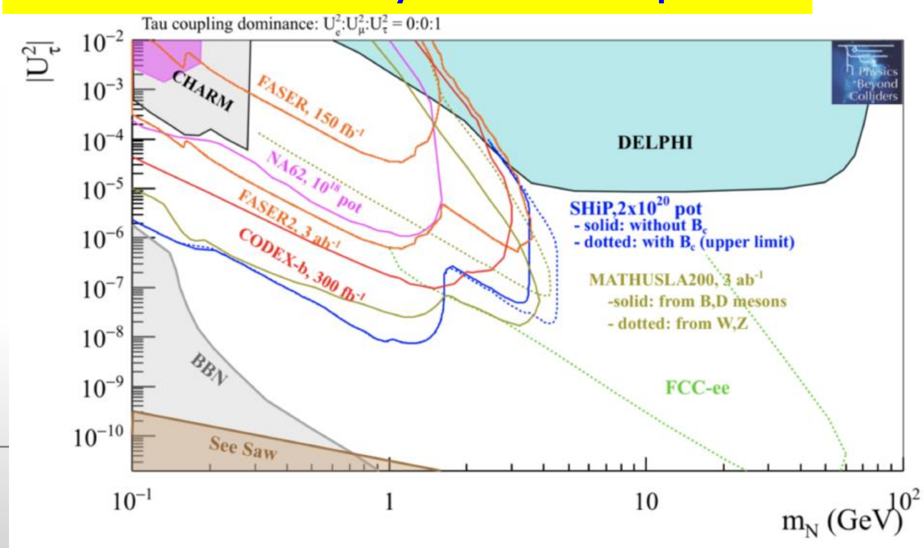


arXiv:1901.09966

Search for dark scalars



Search for heavy neutral leptons



LHC Community White Paper

Web page: https://indico.cern.ch/event/649760

Searches for long-lived particles at the LHC: Second workshop of the LHC LLP Community

17 Oct 2017, 16:00 → 20 Oct 2017, 18:00 Europe/Zurich

Giambiagi Lecture Hall (ICTP, Trieste, Italy)

Albert De Roeck (CERN) , Bobby Samir Acharya (Abdus Salam Int. Cent. Theor. Phys. (IT)) , Brian Shuve (SLAC National Accelerator Laboratory) , James Beacham (Ohio State University (US)) , Xabier Cid Vidal (Universidade de Santiago de Compostela)

Recent workshop: 27-29 November 2019 Ghent

LLP 2017

White paper — chapter statuses and roundtable
[draft here (18 Oct)]

- Simplifed models — First draft done!
- Experimental coverage — First draft essentially done!
- Triggers, upgrades, HL- / HE-LHC opportunities
  — First draft in progress
  —> discussion today [live doc!]
- Re-interpretations / recommendations
  — First draft imminent!
- Backgrounds — First draft imminent!
- Dark showers
  — First draft (summarizing status and advertising for the future) imminent!

White Paper being finalized

Input from ATLAS, CMS, LHCb, proposed specialized experiments and theory
Completed March 2019
(~ 300 pages)

Also meetings with LHC Dark Matter group

Recent Reviews/Reports

arXiv.org > hep-ex > arXiv:1903.04497

High Energy Physics – Experiment

Searching for long-lived particles beyond the Standard Model at the Large Hadron Collider

White paper of the LHC long-lived particle community

arXiv.org > hep-ex > arXiv:1901.09966

Physics Beyond Colliders at CERN: Beyond the Standard Model Working Group Report

J. Beacham, C. Burrage, D. Curtin, A. De Roeck, J. Evans, J. L. Feng, C. Gatto, S. Gninenko, A. Hartin, I. Irastorza, J. Jaeckel, K. Jungmann, K. Kirch, F. Kling, S. Knapen, M. Lamont, G. Lanfranchi, C. Lazzeroni, A. Lindner, F. Martinez-Vidal, M. Moulson, N. Neri, M. Papucci, I. Pedraza, K. Petridis, M. Pospelov, A. Rozanov, G. Ruoso, P. Schuster, Y. Semertzidis, T. Spadaro, C. Vallee, G. Wilkinson

Report of the CERN Physics Beyond Colliders Working group

Collider Searches for Long-Lived Particles Beyond the Standard Model

Lawrence Lee[1], Christian Ohm[2,3], Abner Soffer[4], Tien-Tien Yu[5,6]

arXiv.org > hep-ph > arXiv:1810.12602

Present LHC coverage paper

Summary

- Clearly and increased interest in LLP searches at the LHC in CMS, ATLAS, LHCb, MoEDAL. Many analyses done or in are progress. No signal observed yet, but only top of the iceberg covered so far.
- LLP White Paper released! (LHC). Many ideas for new analyses yet to be analysed for the LHC data
- New ideas for additional small experiments at the LHC to increase the coverage: MilliQan, MAPP, MATHUSLA, CODEX-b, FASER, AL3X, ANUBUS,.. LLPs also focus in the Physics Beyond Collider studies
- Of interest to study in detail the complementarity with LLP searches at Neutrino Near Detectors. Can these be further optimized? (tentative workshop in Pittsburgh spring 2020)
- More opportunities at future projects (FCC…)

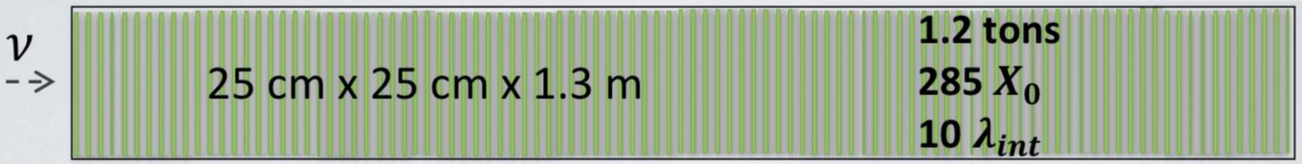
Coming Soon @ CERN

https://indico.cern.ch/event/864648/overview

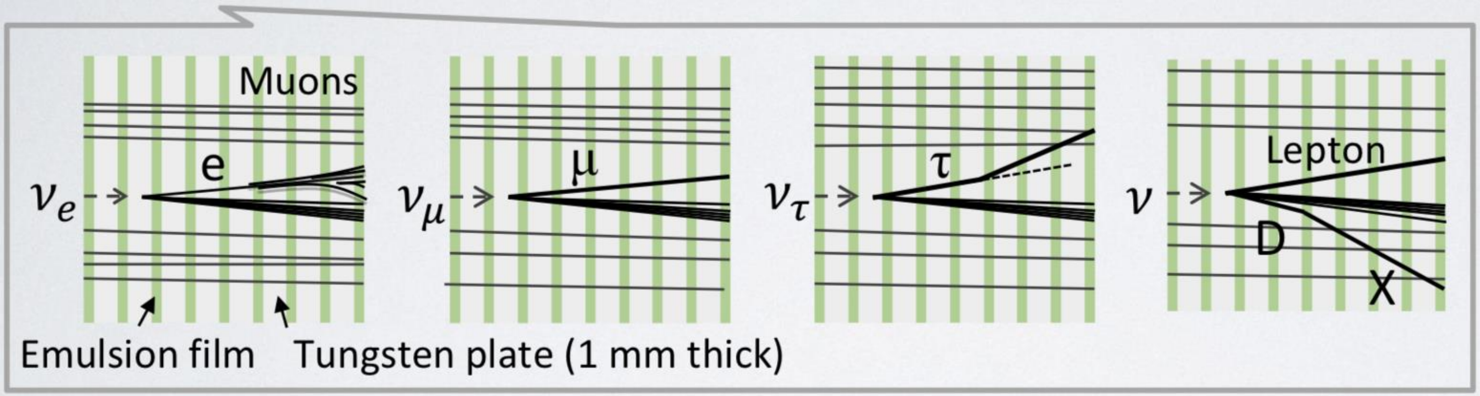
Backup

Neutrinos

Total 1000 emulsion films interleaved with 1-mm-thick tungsten plates



Muon ID: muons are identified by their track length in the detector

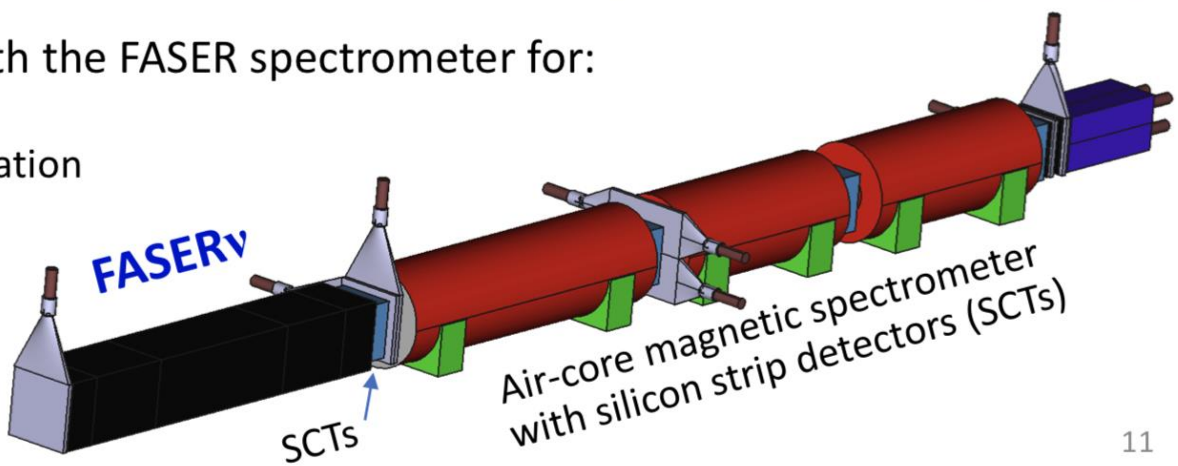


Expected yields in Run3

	# of CC int.
$\nu_e + \bar{\nu}_e$	1296
$\nu_\mu + \bar{\nu}_\mu$	20439
$\nu_\tau + \bar{\nu}_\tau$	21

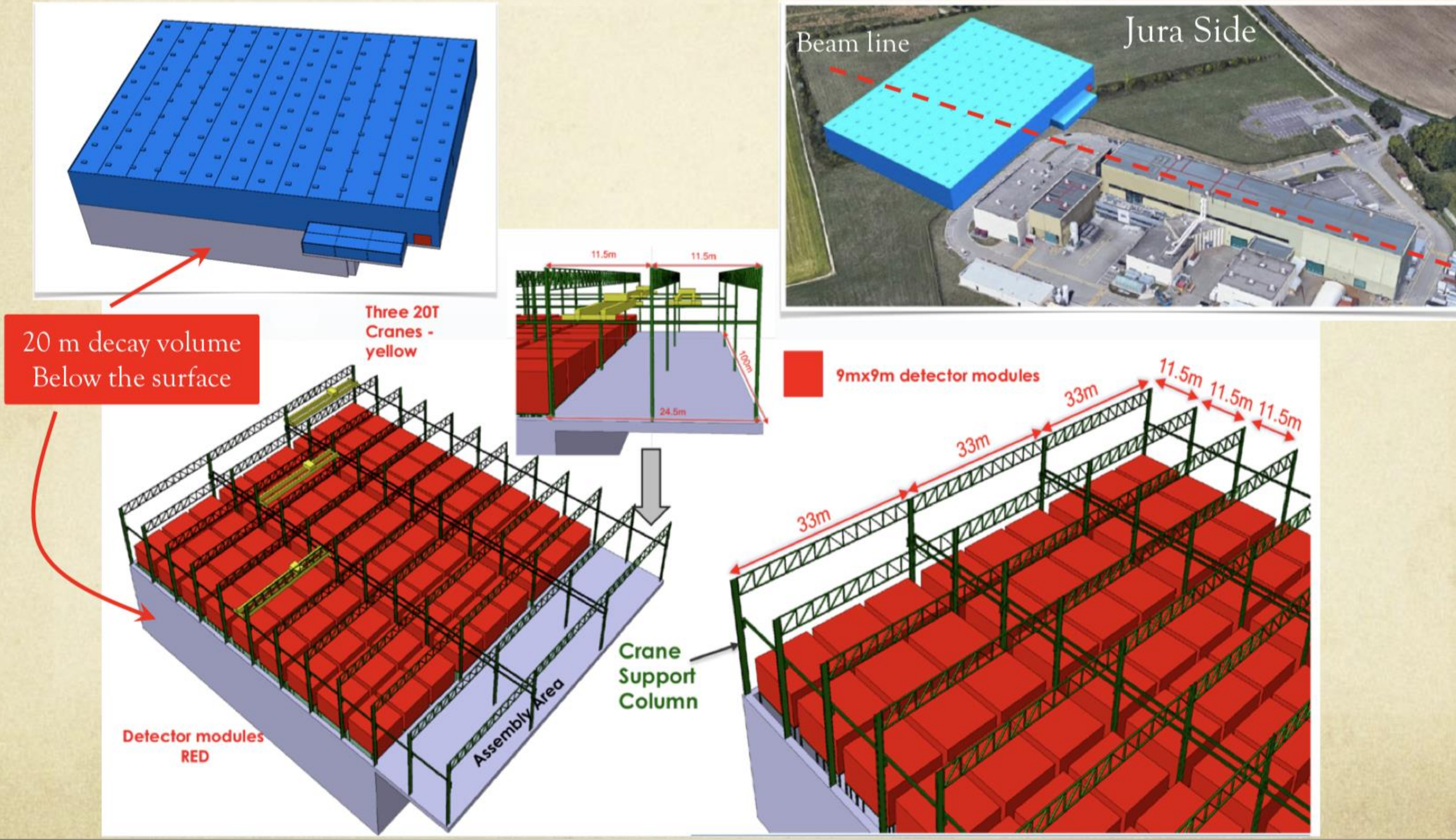
Possibly upgraded to couple with the FASER spectrometer for:

- charge measurement
- improvement of the energy estimation
- background suppression



MATHUSLA @ P5

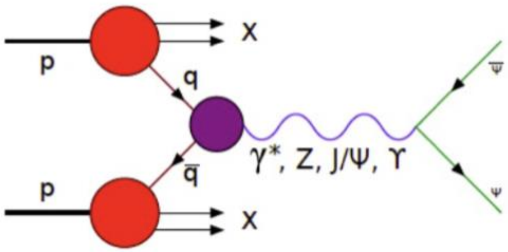
- Worked with Civil Engineers to define the **building and the layout of MATHUSLA at P5**
- **Layout restricted by existing structures** based on current concept and engineering requirements



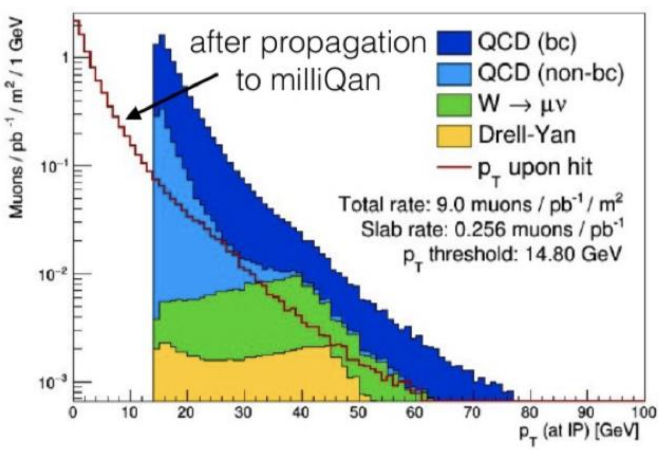
Simulation

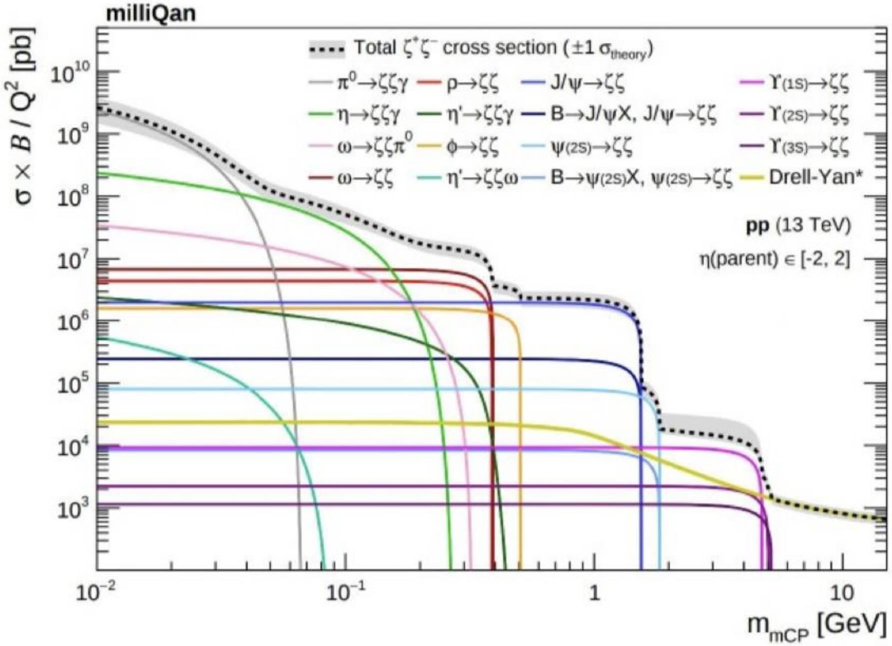
Production and transport simulation

- any process that can make e^+e^- can make millicharged particles
  - low masses dominated by QCD production of π^0, η, ρ, ω, ϕ, then J/ψ and Y
  - above 5GeV it's all Drell-Yan

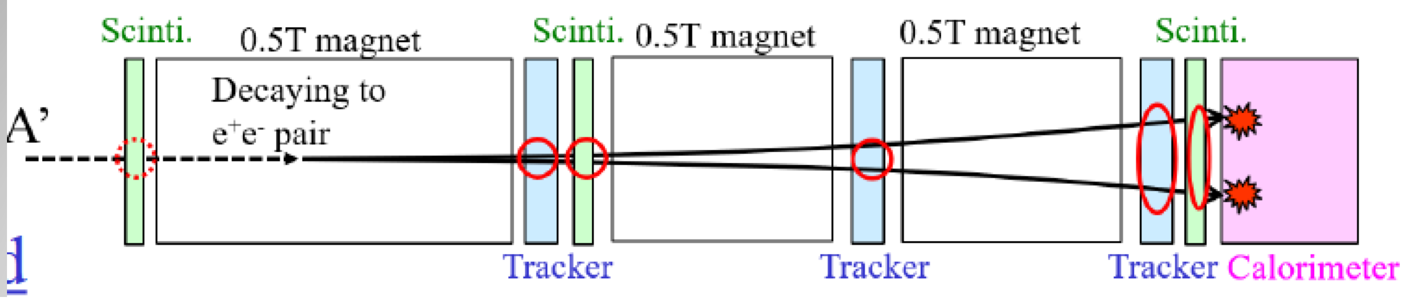


- propagate through CMS material and 17m of rock
  - with multiple scattering and CMS magnetic field





FASER Phase 2

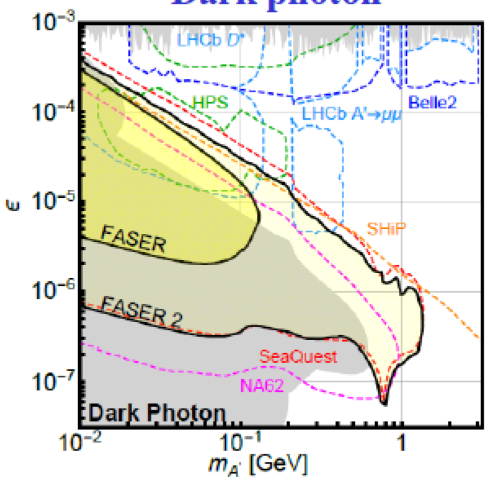


- FASER2 is a potential upgrade to run in HL-LHC with bigger dimensions of the detector.
  - Radius: 1 m
  - Decay volume length: 5 m

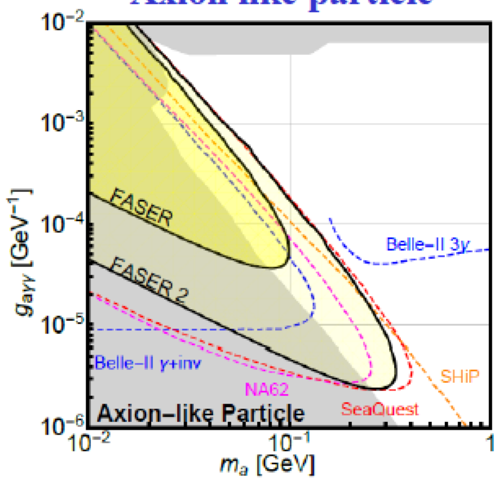
For the HL-LHC run..

- FASER2 can explore much larger parameter space in dark sectors.

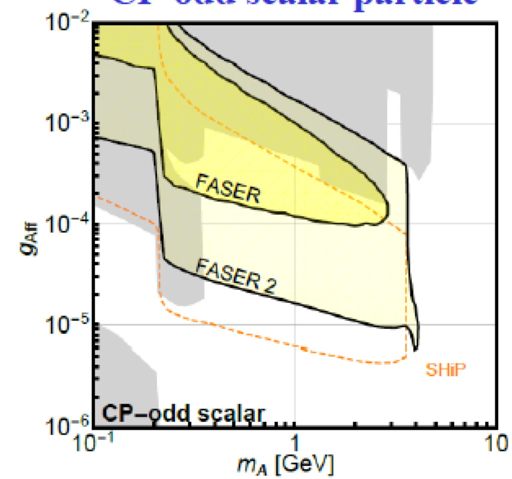
Dark photon



Axion like particle

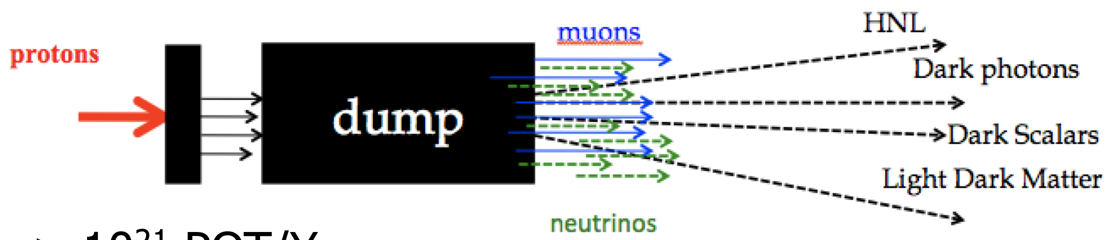


CP-odd scalar particle



Beam Dump Experiments

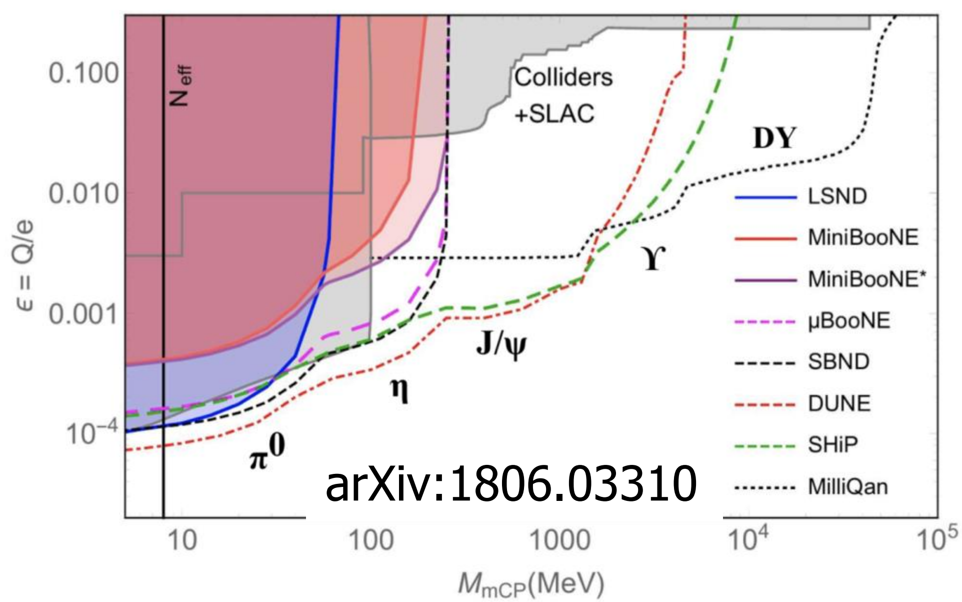
High intensity frontier for low mass particles with very weak couplings
->upcoming neutrino experiments (SBL, LBL) foresee very high intensity beams



> 10^{21} POT/Year

Near Detector:
few 100m away
from the dump

https://indico.fnal.gov/event/18430/



arXiv:1806.03310

These experiments can perform searches for low mass New Physics particles eg
- -HNL/sterile neutrinos
- -dark photons
- -ALPs
- -mini/millicharges

…

<- Example for millicharges
FerMINI @FNAL?

More Milli-Charge Hunting

A proposal for milli-charges at FNAL @ MINOS near detector
Submitted last week.

FerMINI: Fermilab Search for Milicharged Particle

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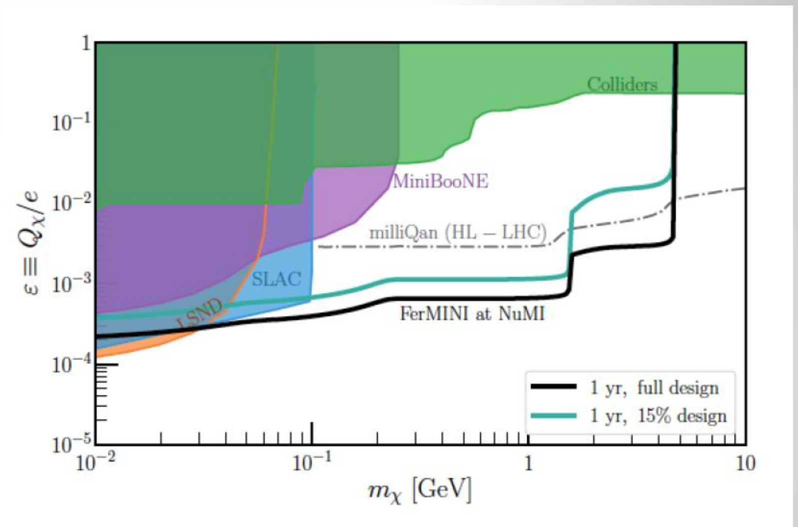
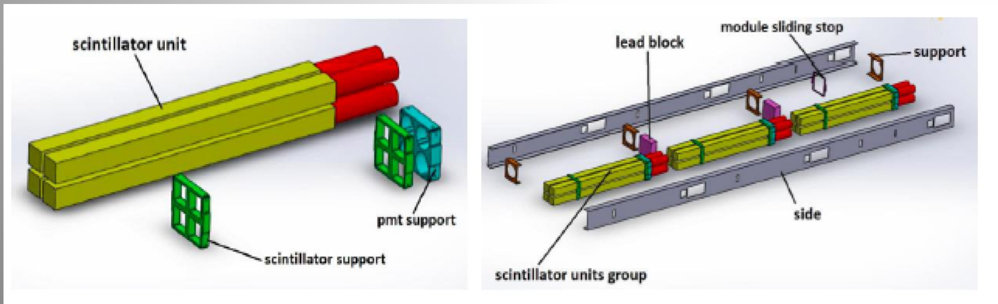
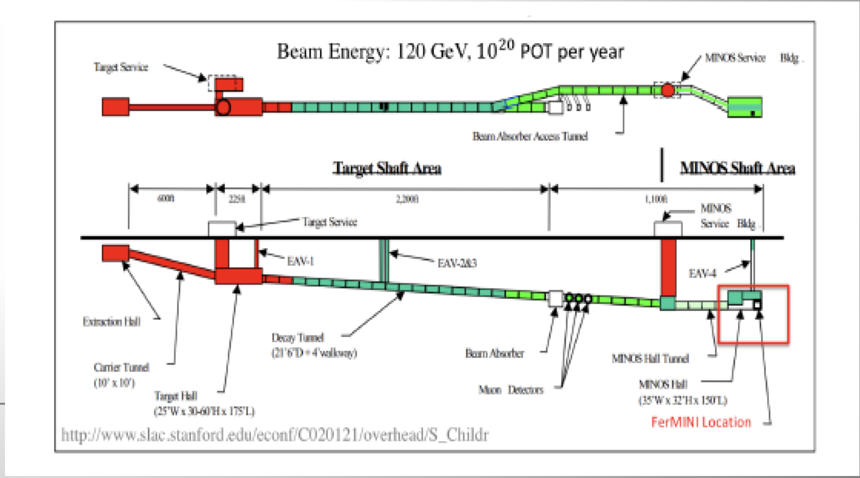
See also: arXiv:1806.03310



Based on the MilliQan design





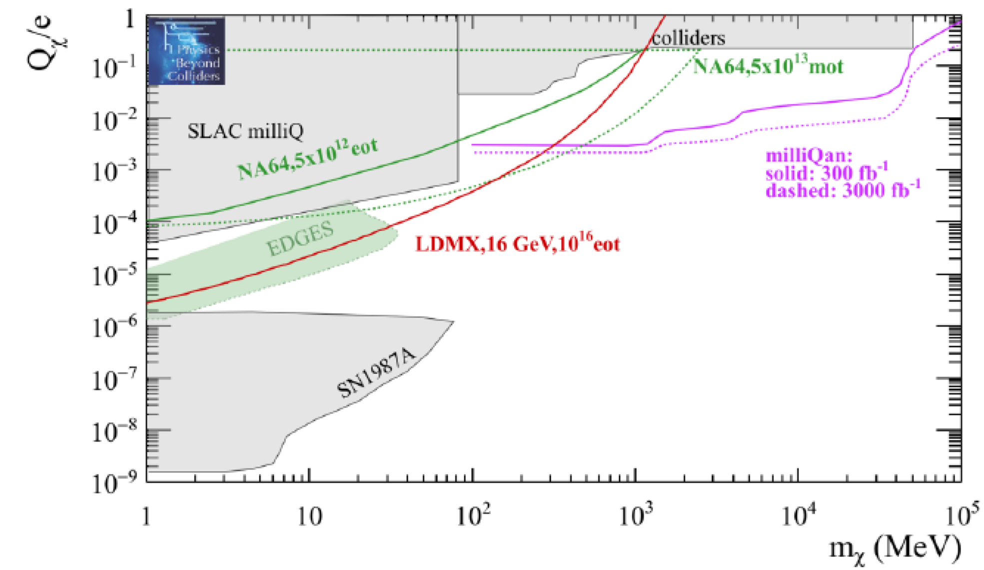
More Milli-Charge Activities

Physics Beyond Collider Study

arXiv:1901.09966

Physics Beyond Colliders at CERN
Beyond the Standard Model Working Group Report

J. Beacham[1], C. Burrage[2,*], D. Curtin[3], A. De Roeck[4], J. Evans[5], J. L. Feng[6], C. Gatto[7], S. Gninenko[8], A. Hartin[9], I. Irastorza[10], J. Jaeckel[11], K. Jungmann[12,*], K. Kirch[13,*], F. Kling[6], S. Knapen[14], M. Lamont[4], G. Lanfranchi[4,15,*,**], C. Lazzeroni[16], A. Lindner[17], F. Martinez-Vidal[18], M. Moulson[15], N. Neri[19], M. Papucci[4,20], I. Pedraza[21], K. Petridis[22], M. Pospelov[23,*], A. Rozanov[24,*], G. Ruoso[25,*], P. Schuster[26], Y. Semertzidis[27], T. Spadaro[15], C. Vallée[24], and G. Wilkinson[28].



Millicharged Particles in Liquid Argon Neutrino Experiments

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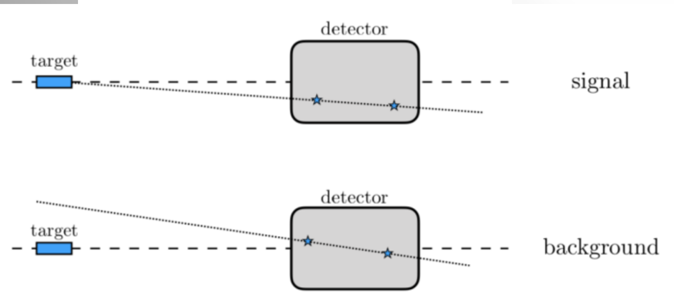
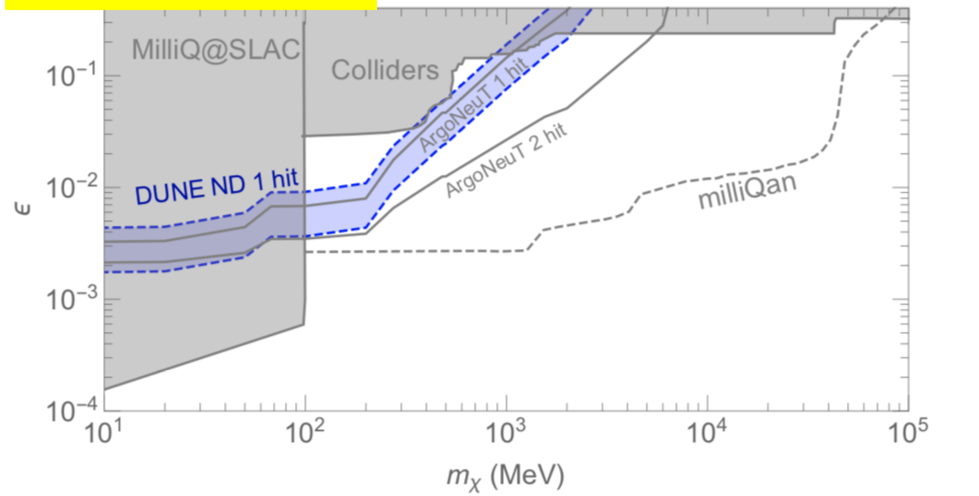
arXiv:1902.03246



LArTPC study



Status of the Various Projects

Simon Knapen FNAL seminar fall 2018

Lifetime frontier

Supplementary detectors

	Higgs decay	B-meson decay	π,η-decay (dark photon)	Progress	Cost
FASER		✔	✔	Approved	$
CODEX-b	✔	✔		sub-collaboration formed	$
SeaQuest			✔	experiment exists	$
AL3X	✔	✔	✔	Proof of concept	$$
MATHUSLA	✔	(✔)		Letter of intent	$$
SHiP with the beamdump facitilty		✔	✔	Technical design report	$$$

MOEDAL: monopoles, already running

MiliQan: milicharged particles, Demonstrator in place