The FASER experiment

A not-so-large LHC experiment in search for new physics in far corners

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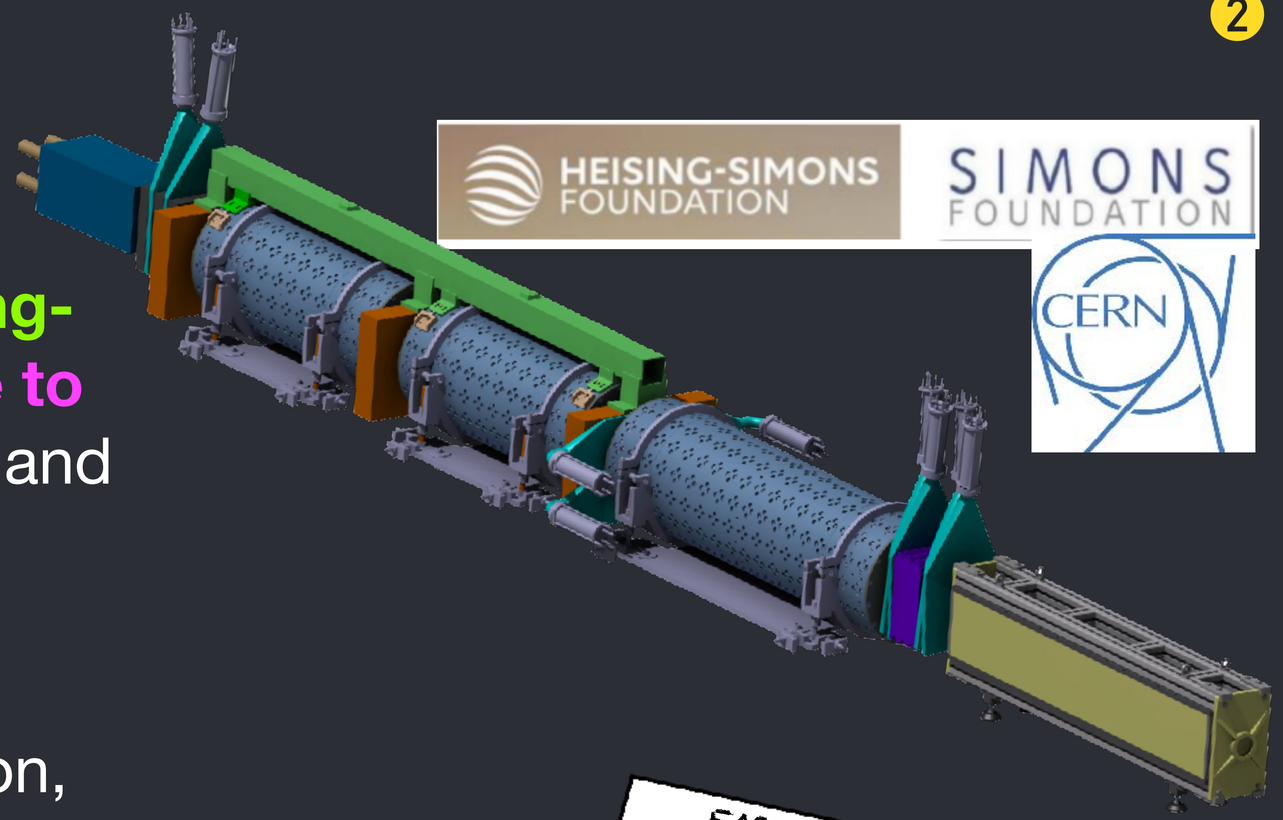
Science coffee seminar, Lund University (Sweden)

13th February 2020

ForwArd Search ExpeRiment

In a nutshell



- An **LHC experiment** to search for **long-lived particles produced at or close to Interaction Point 1** (ATLAS) in Run 3 and beyond.

- **Concept** put forward in 2017 by UCI researchers Jonathan Feng, Iftah Galon, Felix Kling and Sebastian Trojanowski.

- **CERN-approved** March 2019, and to be **fully built & installed in current Long Shutdown.**

- 60 collaborators, 19 institutes, 8 countries.

From a Physics Perspective

Where is New Physics?

- Standard Model largely self-consistent but observations suggest so much more:
  - Dark matter? Neutrino oscillations? Baryon asymmetry?
  - At dawn of LHC, we had promising theories:
    - Supersymmetry
    - WIMP dark matter (thermal production).

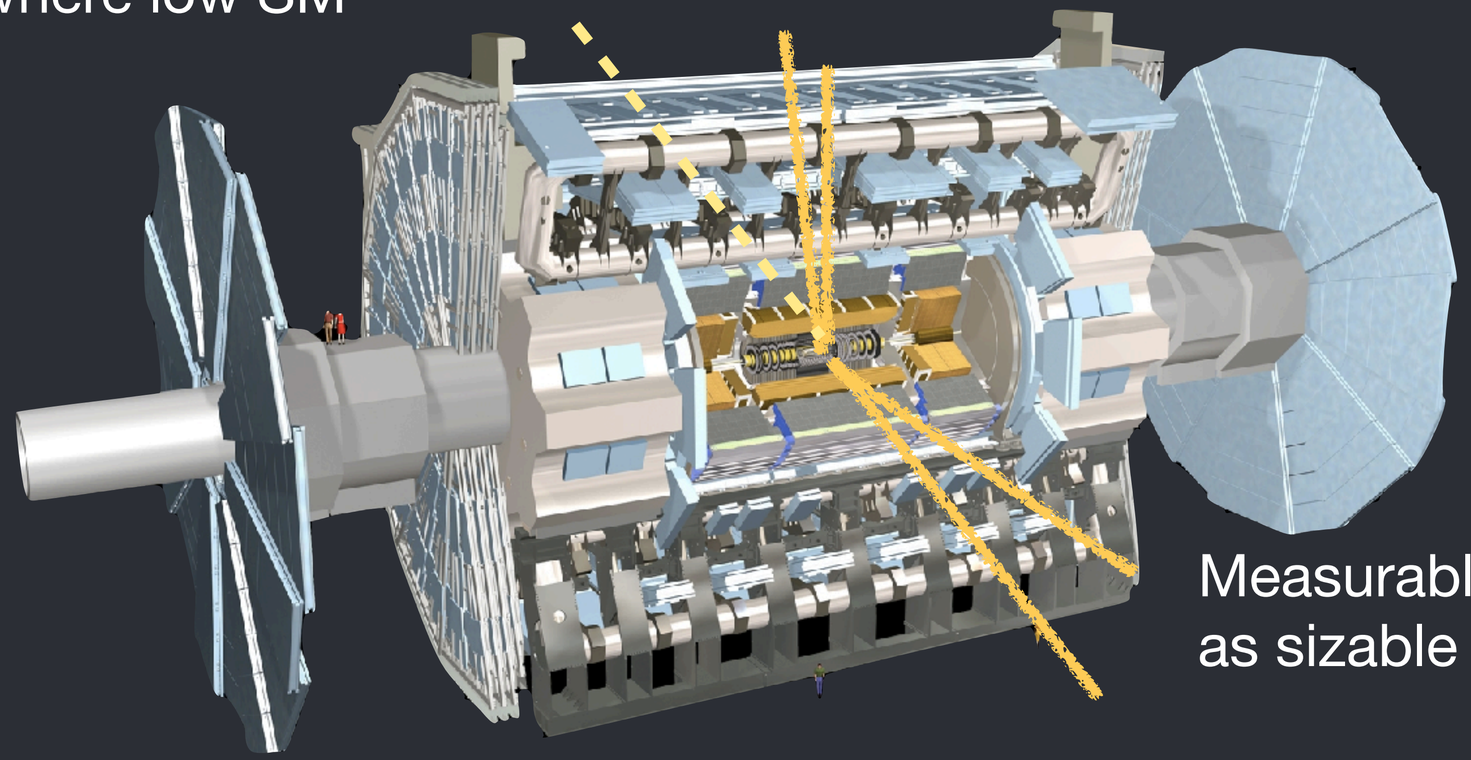
TeV-scale particles

From a Physics Perspective

Heavy and strongly coupled

- Focus at ATLAS & CMS: ~TeV scale particles with electroweak scale couplings

Centrally produced where low SM inelastic background



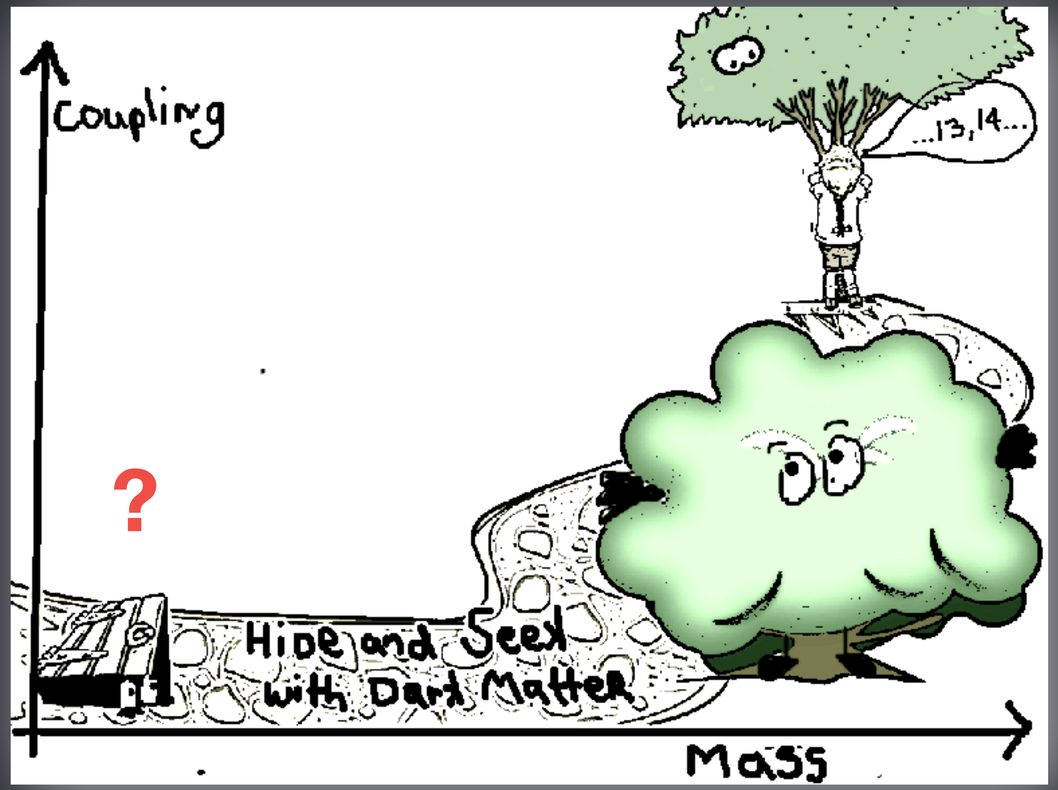
Measurably produced, as sizable coupling.

- No unambiguous signal observed so far. Where else to look?

From a Physics Perspective

Light and feebly coupled

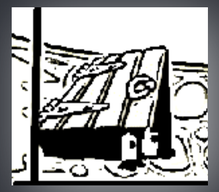
- Motivation for light and feebly coupled particles?



From a Physics Perspective

Light and feebly coupled

- **Hidden sector physics**



  - New mediating particles, couplings to SM via mixing with SM "portal" operator

$$\mathscr{L}_{portal} = \Sigma \mathcal{O}_{SM} \times \mathcal{O}_{HS}$$

- Lowest dimensional renormalisable operators:

DM mediator candidate

DM candidate

Clue to baryogenesis, neutrino oscillations

Portal	Coupling
Dark Photon, A_μ	$-\frac{\epsilon}{2\cos\theta_W} F'_{\mu\nu} B^{\mu\nu}$
Dark Higgs, S	$(\mu S + \lambda S^2) H^\dagger H$
Axion, a	$\frac{a}{f_a} F_{\mu\nu}\tilde{F}^{\mu\nu}$, $\frac{a}{f_a} G_{i,\mu\nu}\tilde{G}_i^{\mu\nu}$, $\frac{\partial_\mu a}{f_a}\overline{\psi}\gamma^\mu\gamma^5\psi$
Sterile Neutrino, N	$y_N L H N$

Ref: [Physics Beyond Colliders Working Group Report]

From a Physics Perspective

Light and feebly coupled - current constraints

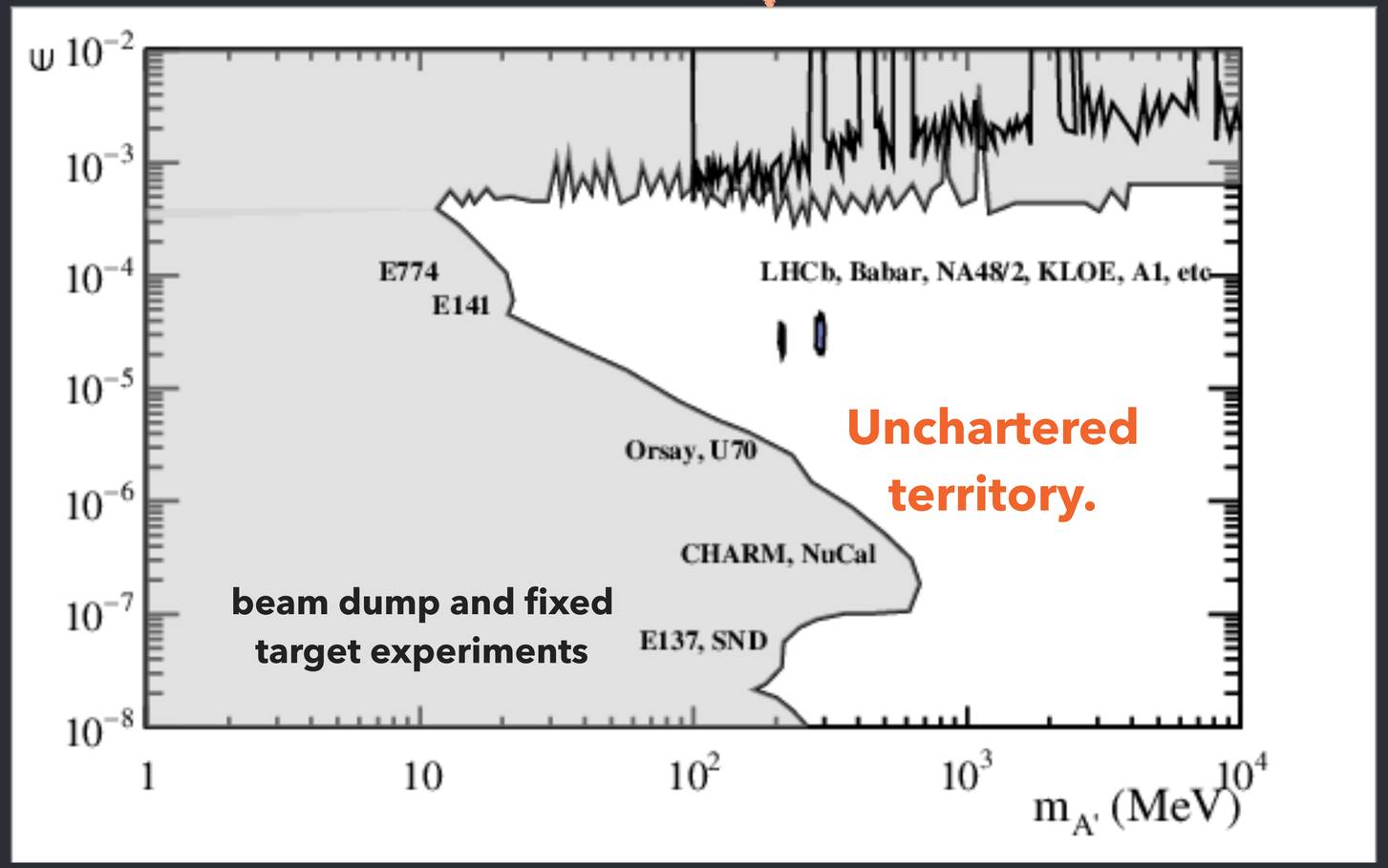
Example: Dark photon to visible decays

Effective Lagrangian

$$\mathscr{L} \supset \frac{1}{2} m_{A'}^2 A'^2 - \epsilon e \Sigma q_f \bar{f} \not{A}' f$$

-> parameter space spanned by **dark photon mass mA'** and **kinetic mixing parameter ε.**

Prompt decay/ resonance searches

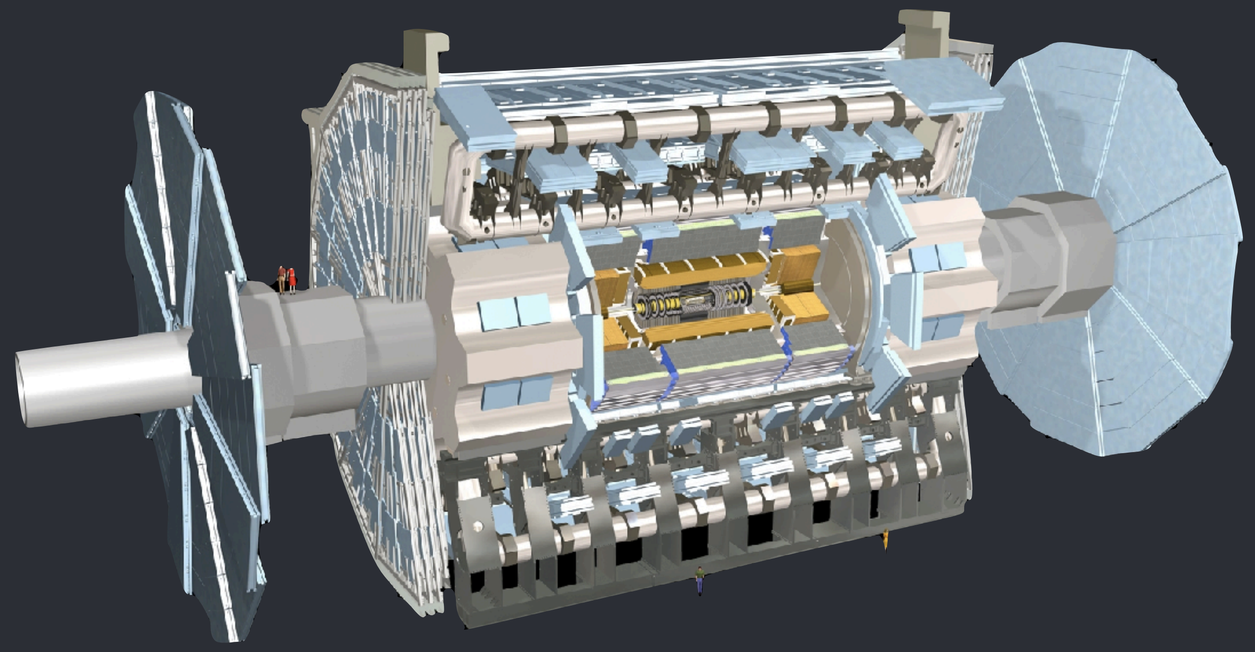


Ref: [Physics Beyond Colliders Working Group Report]

From a Physics Perspective

Light and feebly coupled

- LHC *the* intensity and energy frontier. Where is all the energetic light physics being produced?



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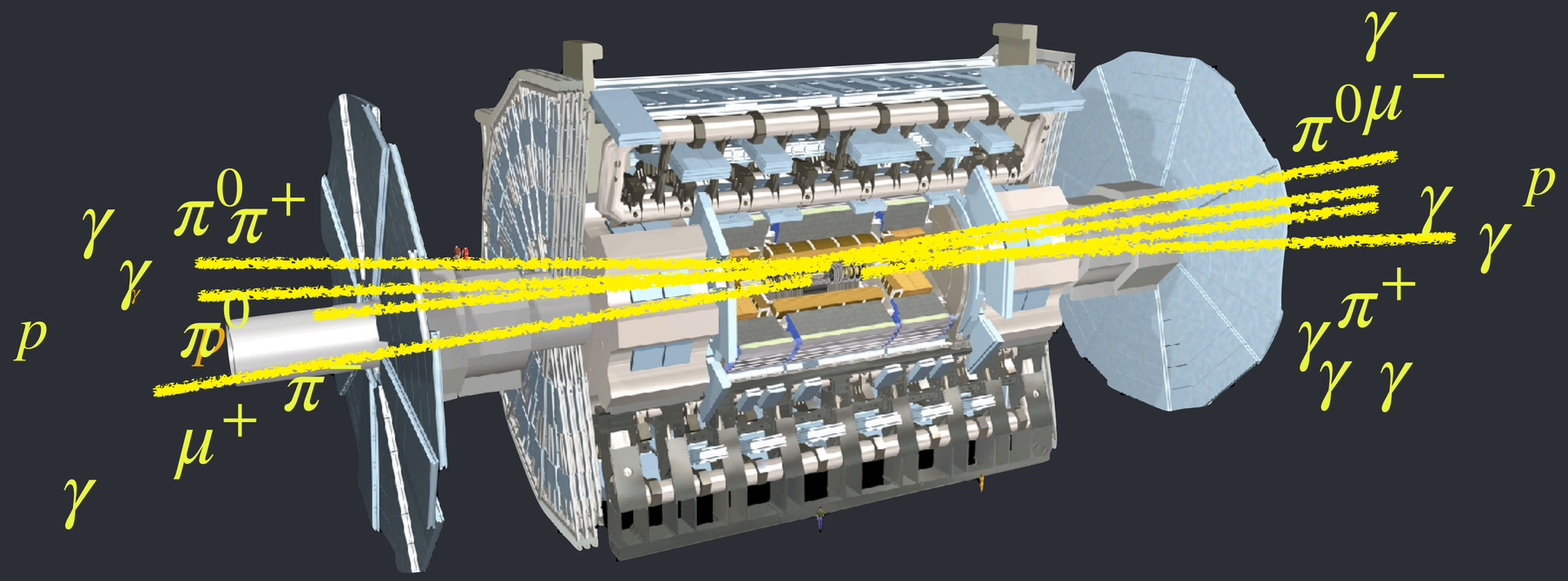

- Answer: Energetic SM inelastic cross-section in forward region.

From a Physics Perspective

Light and feebly coupled

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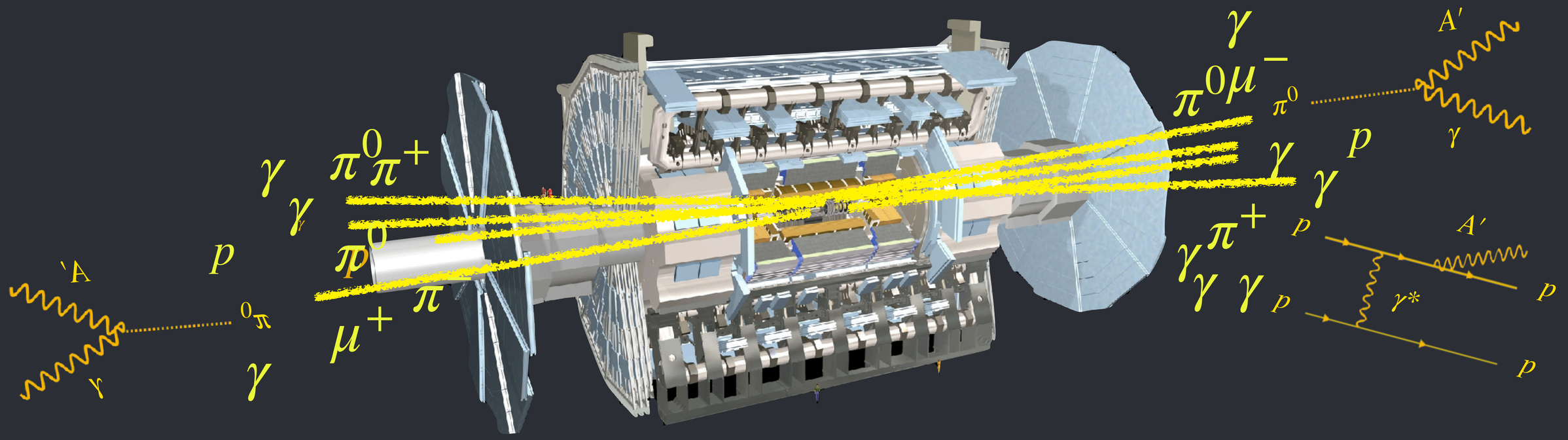


- Answer: Energetic SM inelastic cross-section in forward region.

From a Physics Perspective

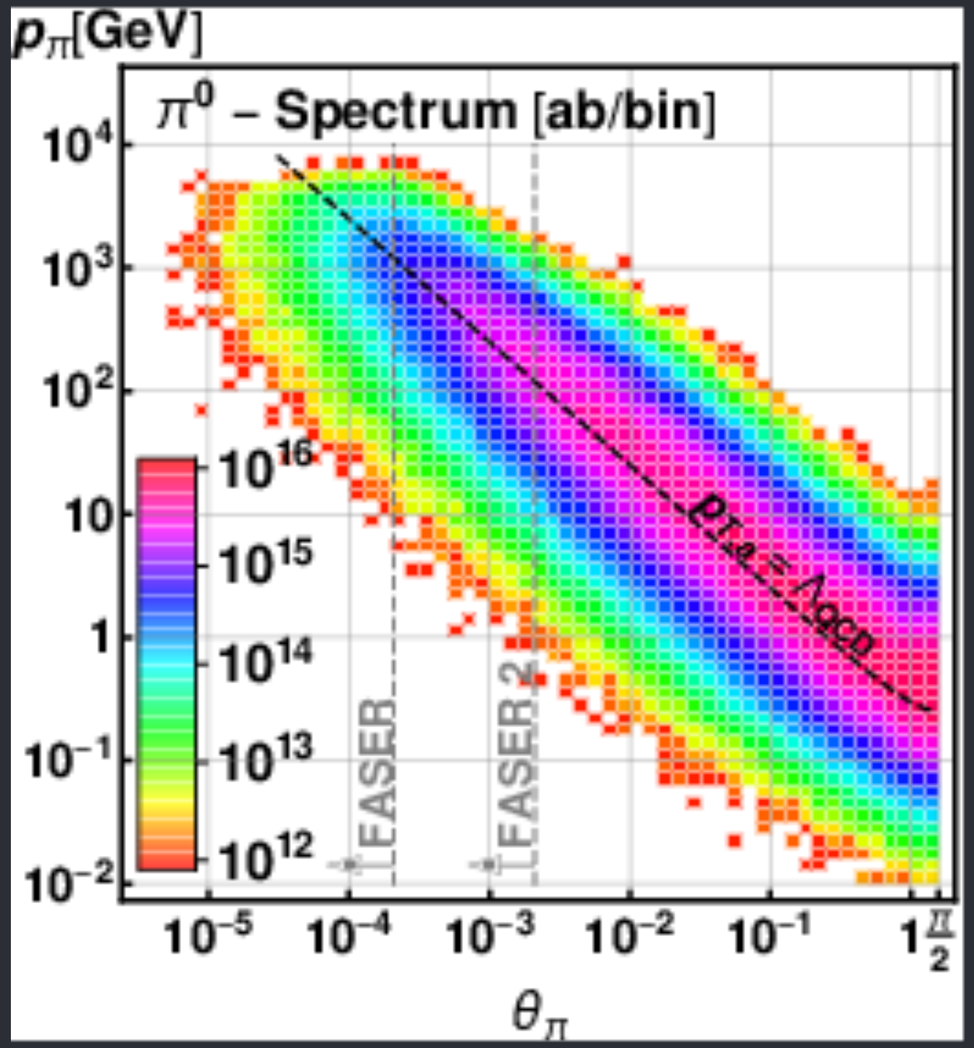
Light and feebly coupled

* Simulation of SM hadron spectra in forward region vastly improved in recent years. "LHC forward Physics" by LHC Forward Physics Working Group

- ~ 10^{16} inelastic scattering events/ hemisphere in Run 3 (150 fb^{-1}) -> large light meson production rates.

$$\theta \sim m_{\pi^0}/E \sim \Lambda_{QCD}/E$$

-> Production rate at small θ to beam axis populated by π0 of >10 GeV momenta (rate a magnitude less for η mesons).



MC event generator: EPOS-LHC

Ref: "Technical Proposal for FASER", FASER coll., 2018

From a Physics Perspective

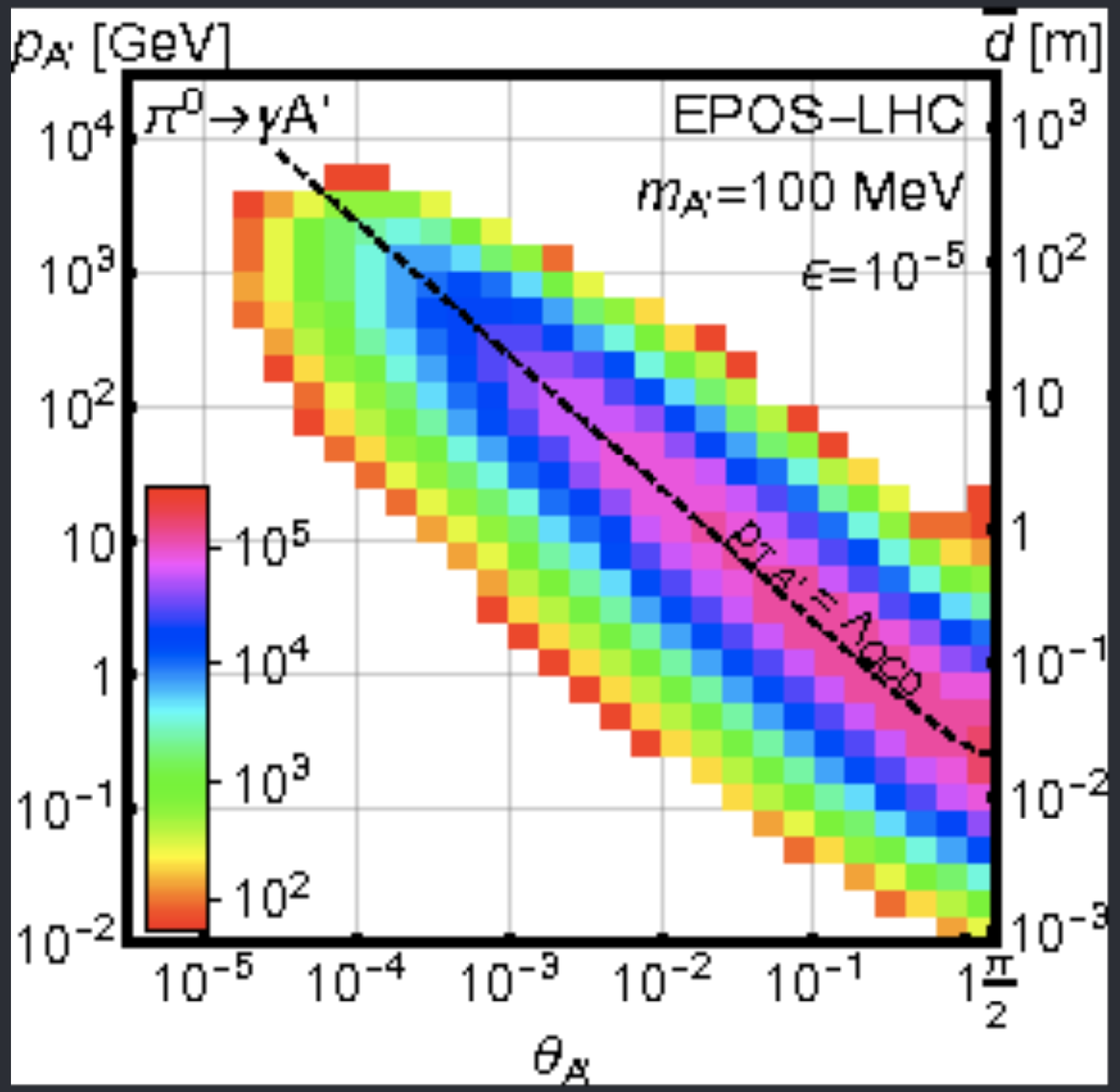
Ref: "Technical Proposal for FASER", FASER coll., 2018

Dark photon example

- Where there are pions there is potential new physics. Signal events/hemisphere in Run 3 ($150 fb^{-1}$):

- Signal suppression roughly ε^2 relative to SM: 1 in every 10^{10} neutral π decay to A'.

- But with large π0 intensity, appreciable rate of high momentum signal in forward region. And once it decays…



From a Physics Perspective

Dark photon signal processes

- A striking signature:

- For dark photon at small angels to beam axis, decay signature is two highly collimated high E (~TeV scale) particles.
- Striking when there is no other background…

From a Physics Perspective

Light and feebly coupled

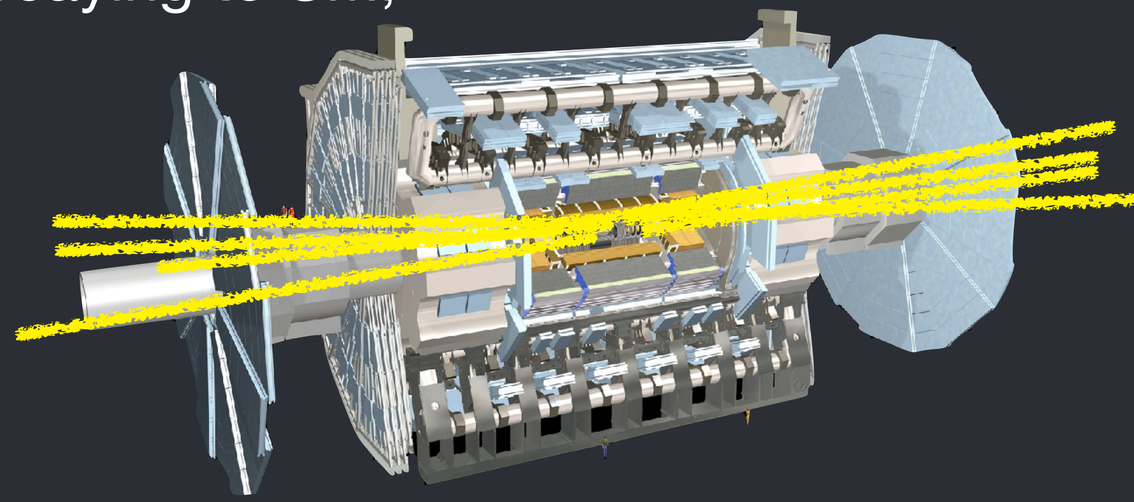
How to search for the hidden sector? **A different set of challenges…**

- Highest production rate in forward direction, where ATLAS not sensitive.
- Extremely weakly interacting: **Rare**, requires ~zero background.

But this offers an advantage: It is long-lived…

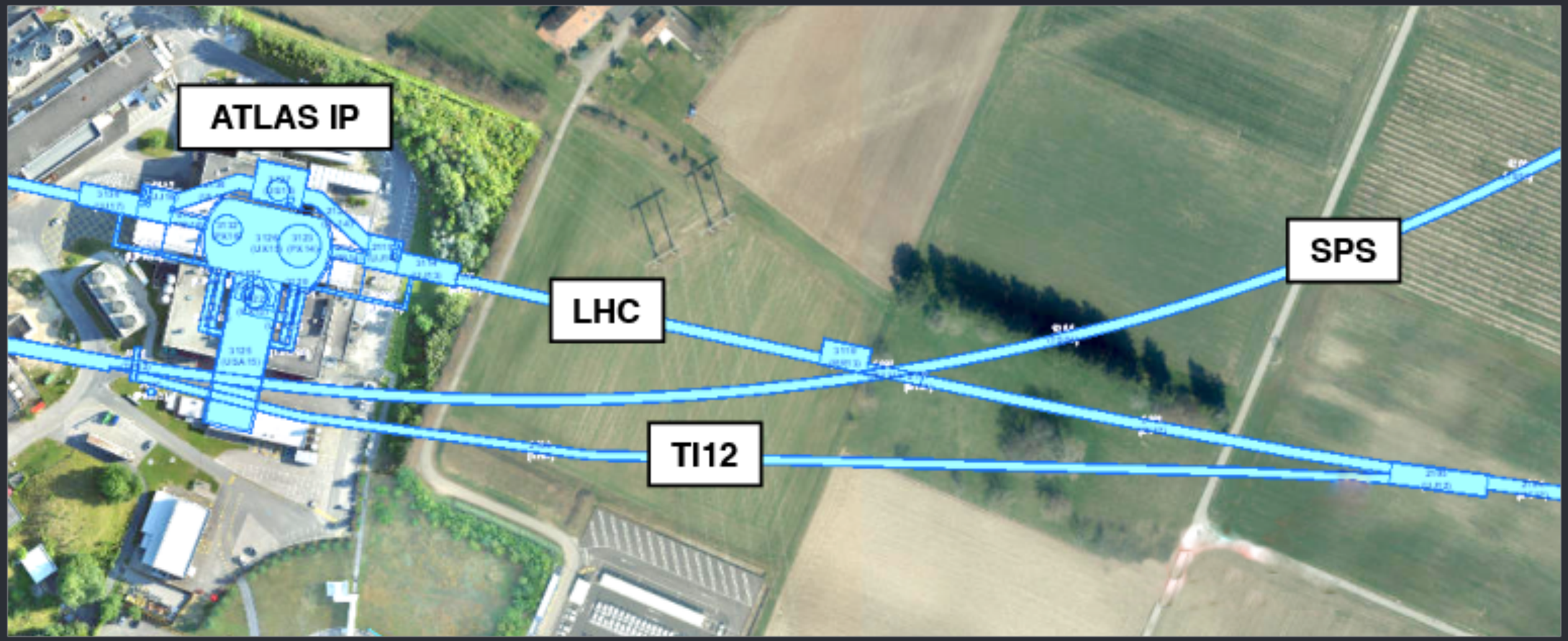
- Can travel considerable distance before decaying to SM,

… traversing any material,
including rock.



From a Technical Perspective

The ideal detector location



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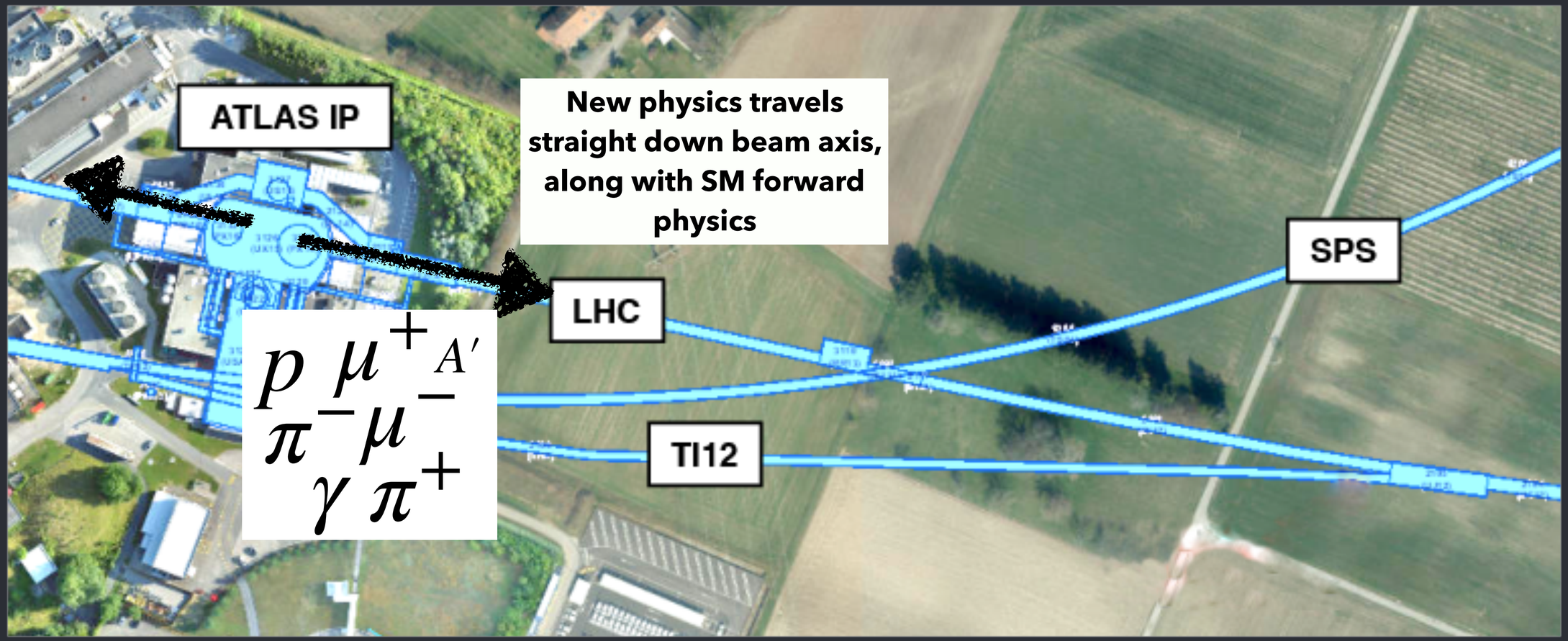

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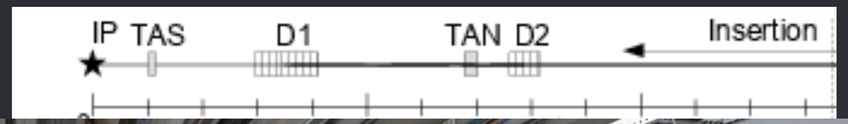
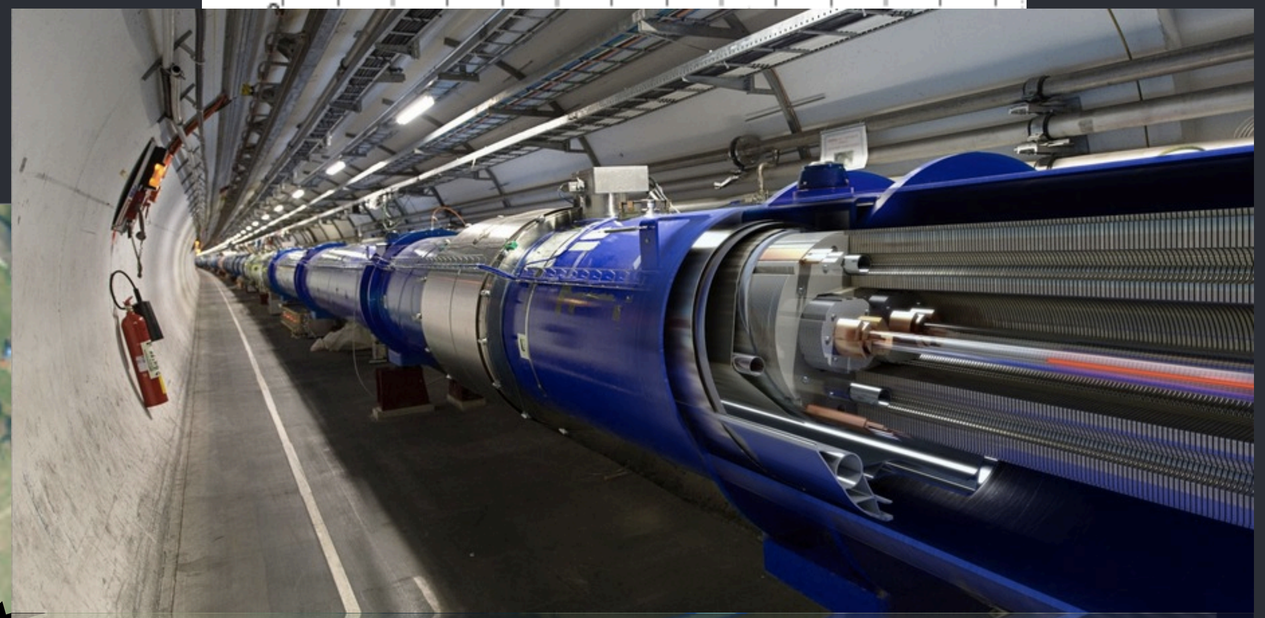
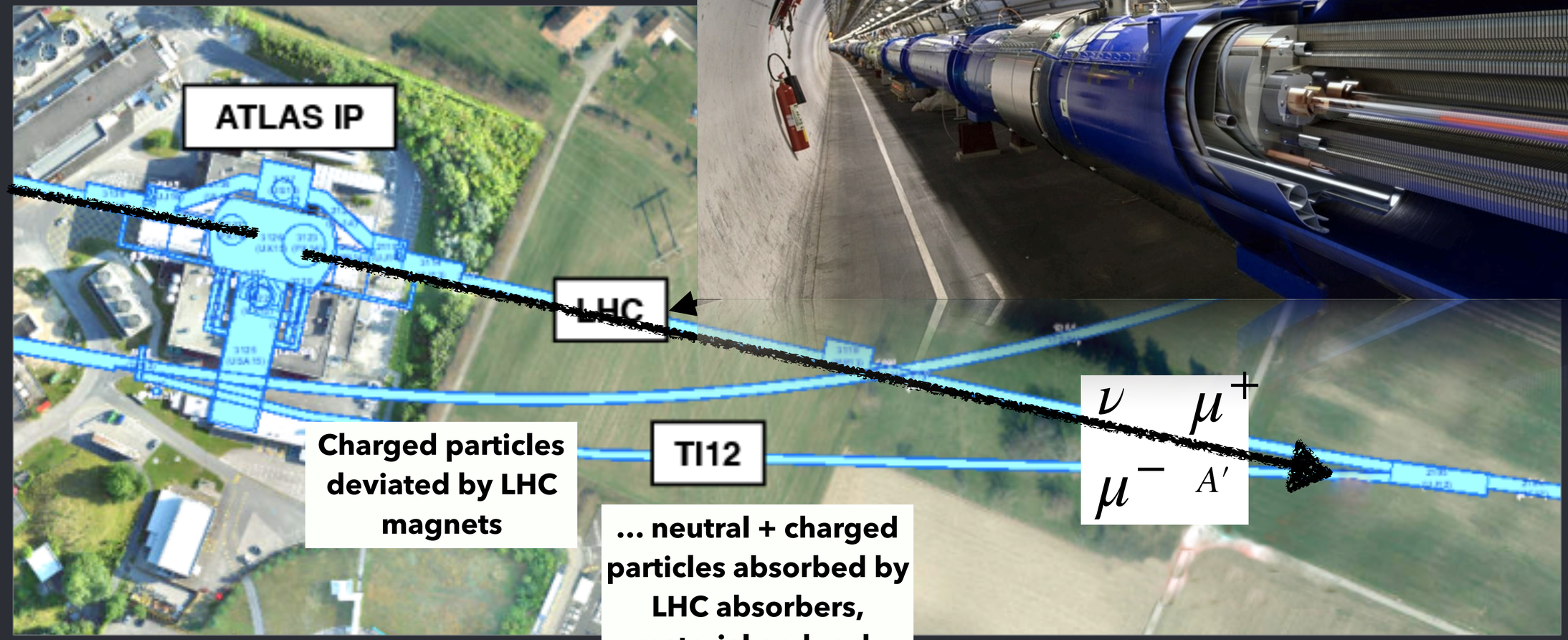




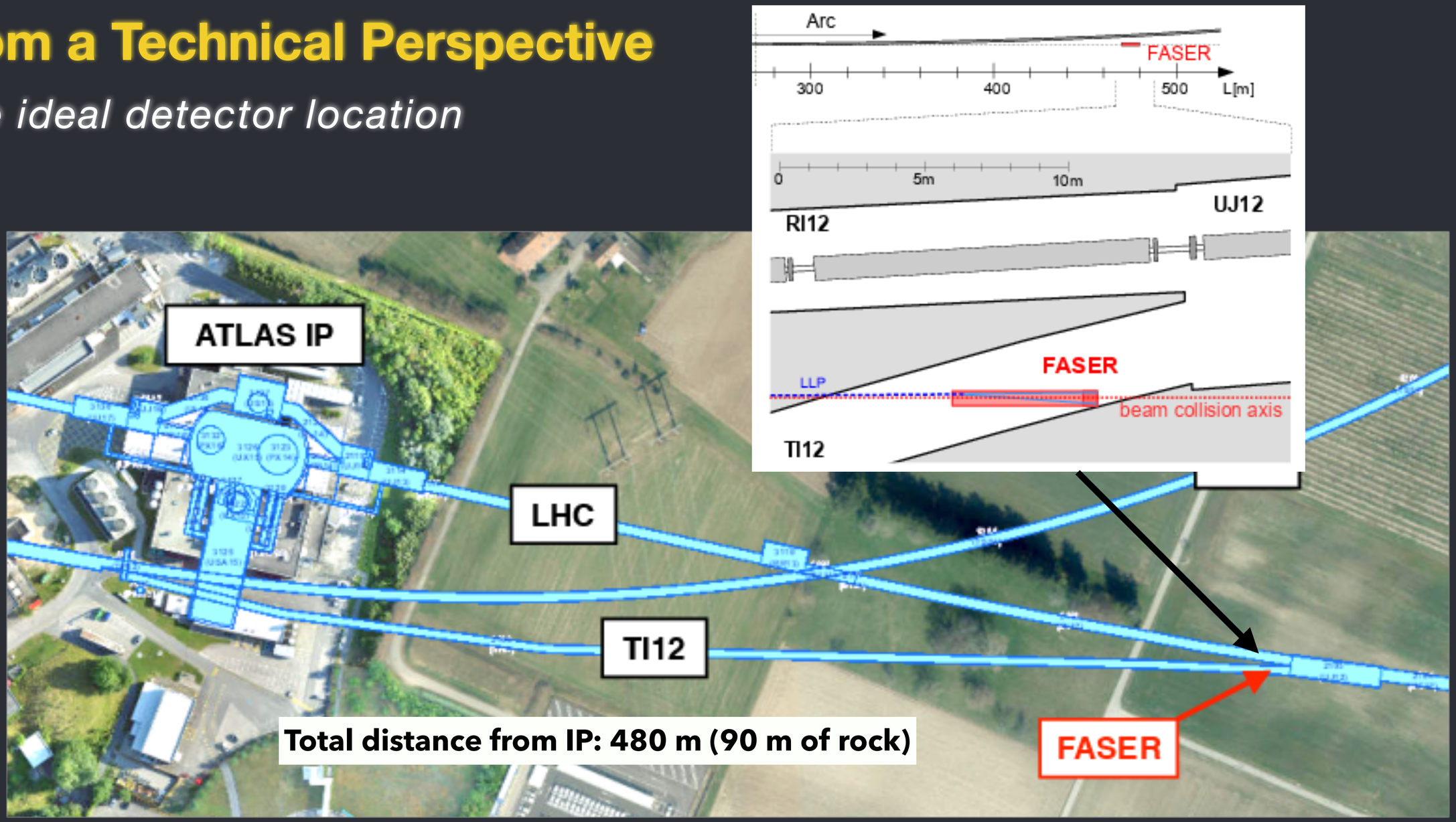


Charged particles deviated by LHC magnets

… neutral + charged particles absorbed by LHC absorbers, material and rock

From a Technical Perspective

The ideal detector location



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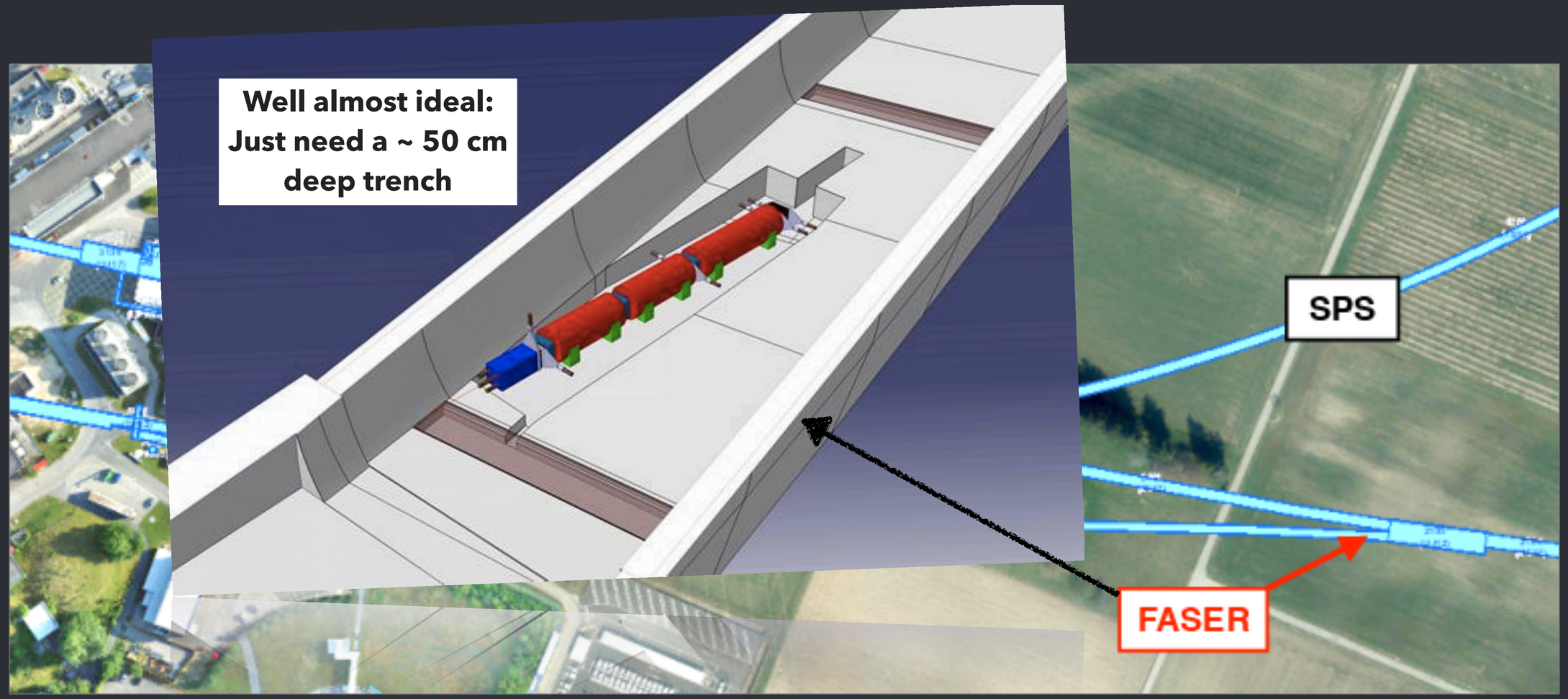
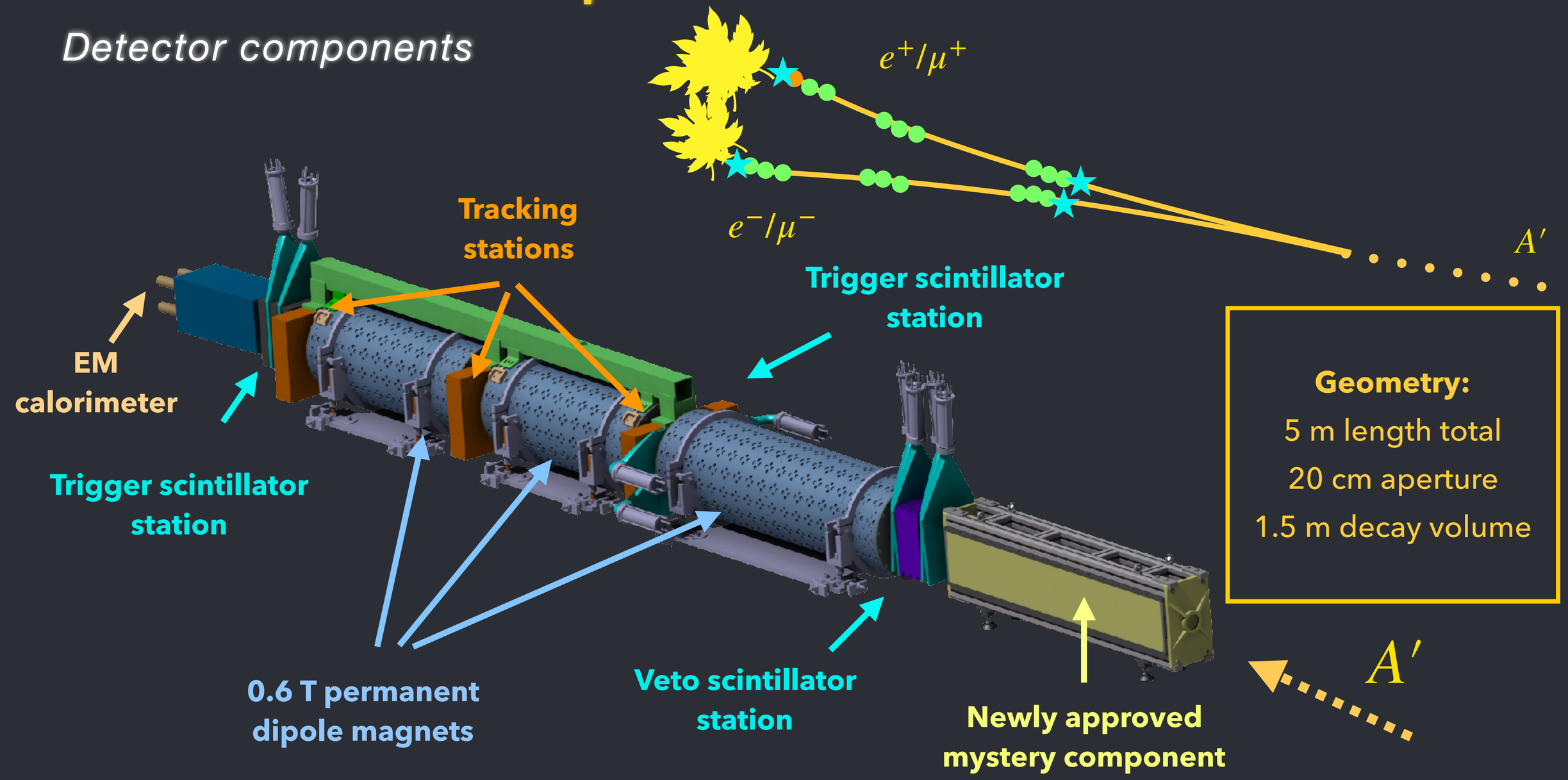


From a Technical Perspective

Detector components



Geometry:

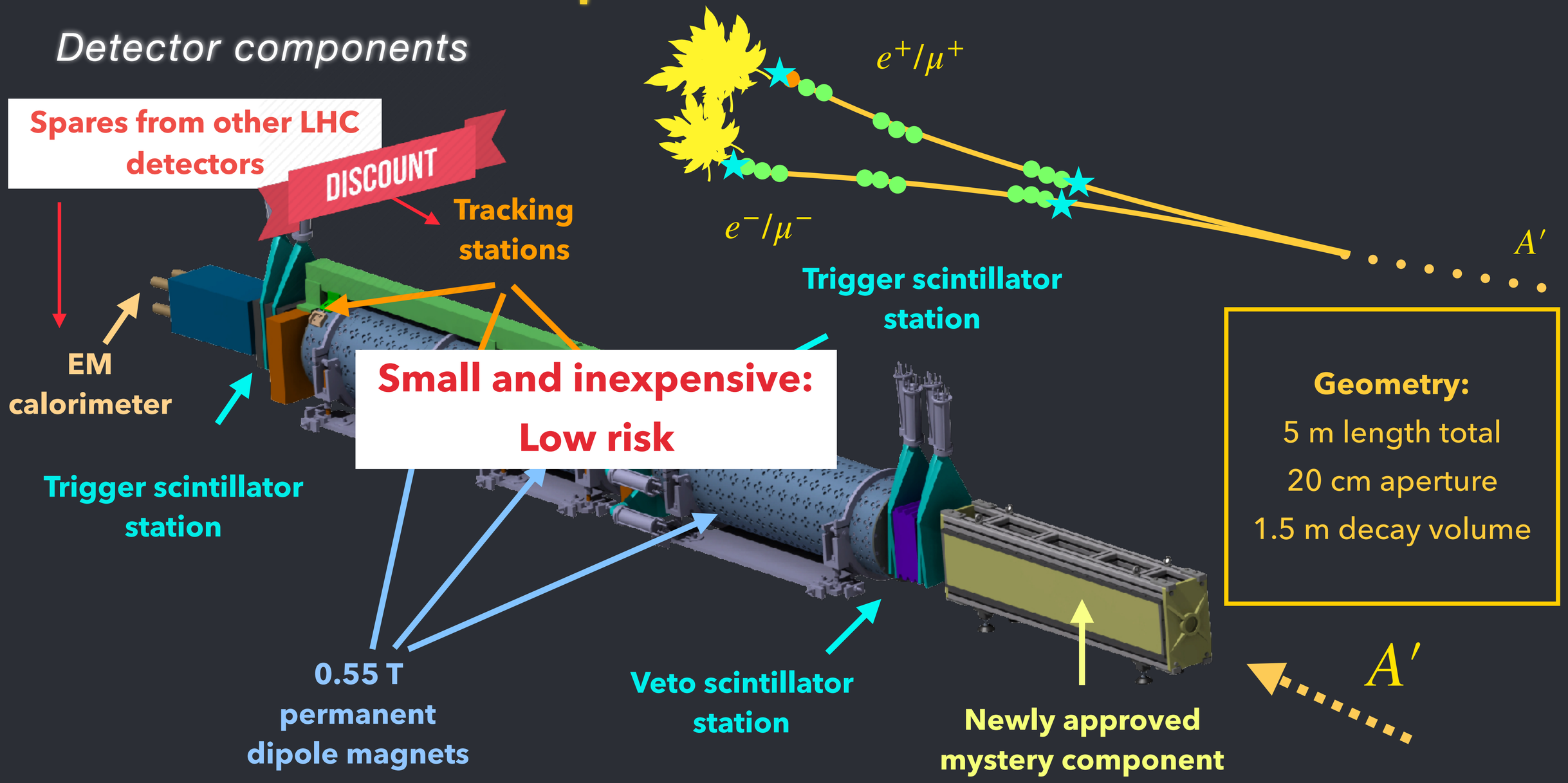
5 m length total

20 cm aperture

1.5 m decay volume

From a Technical Perspective

Detector components

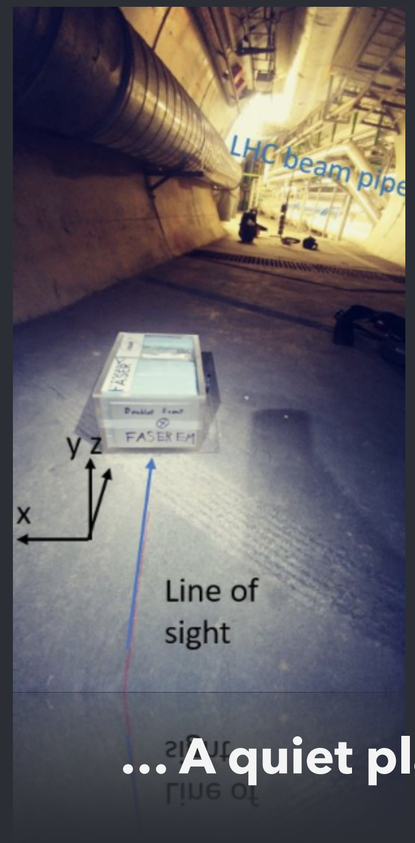


Faser Physics Reach

Determining background rate

Ref: "Technical Proposal for FASER", FASER coll., 2018

- FLUKA simulation, including
  - (i) Particles from IP or produced at IP and interact downstream, e.g. in target for neutral particles (TAN): Specifically, muons & neutrinos.
  - (ii) Particles from showers from off-momentum protons hitting beam pipe.
  - (iii) Particles produced in beam-gas interactions by beam passing FASER in ATLAS direction (no rock shielding).
- In-situ measurements
  - Emulsion detector installed in TI12 during 2018 running to verify FLUKA results.



… A quiet place?

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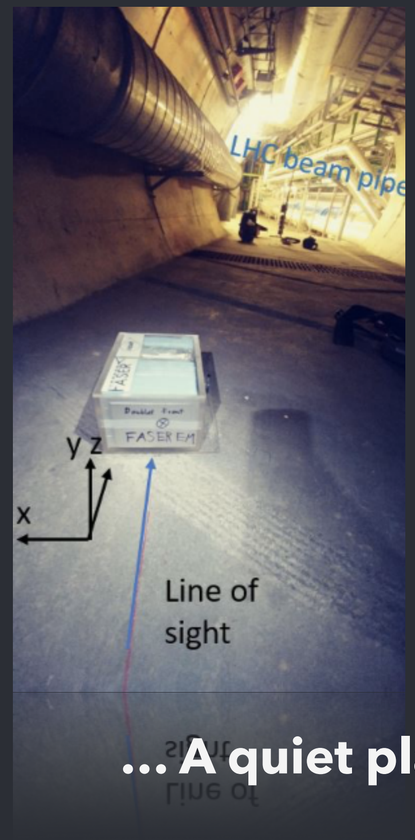
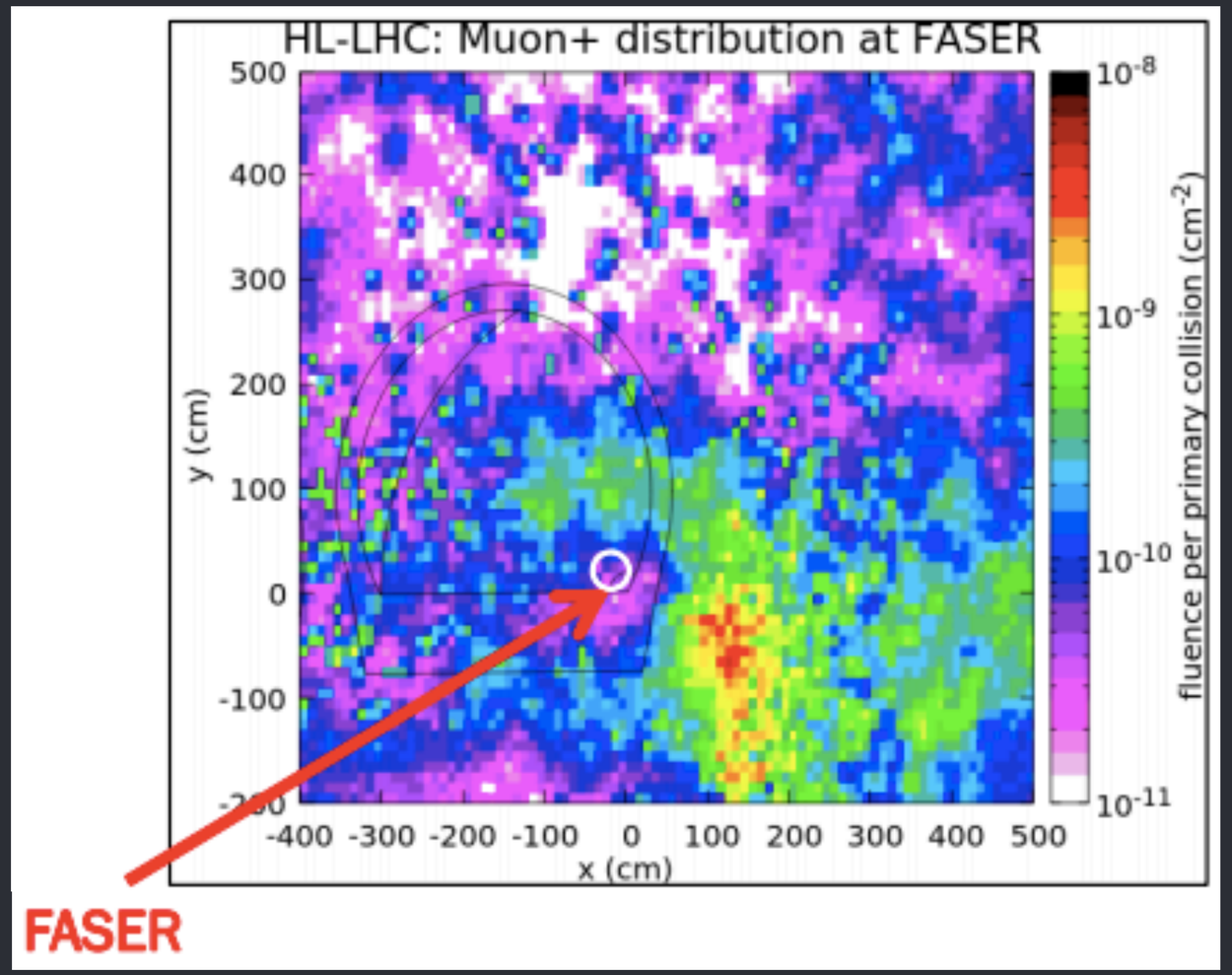


… A quiet place?

Faser Physics Reach

Determing background rate

- Expected rate:
  - Neutrino BG negligible due to low neutrino cross-section and different event kinematics.
  - FLUKA & insitu measurements: 0.4 cm-2 s-1 for > 10 GeV muons, roughly ~ 500 Hz event rate in FASER aperture.
  - 99.9999999999% should effectively be vetoed by first trigger station.
  - **Can assume zero background to first order.**



FLUKA simulation: Magnets very helpfully deflect muons away from beam axis.

Faser Physics Reach

Dark photon to visible decay sensitivity for zero background

Probability of long-lived particle decaying in detector volume:

$$\mathscr{P}(p,\theta) = (e^{-(L-\Delta)/d} - e^{-L/d})\Theta(R - tan\theta L)$$

$$\approx \frac{\Delta}{d} e^{-L/d}\Theta(R - \theta L)$$

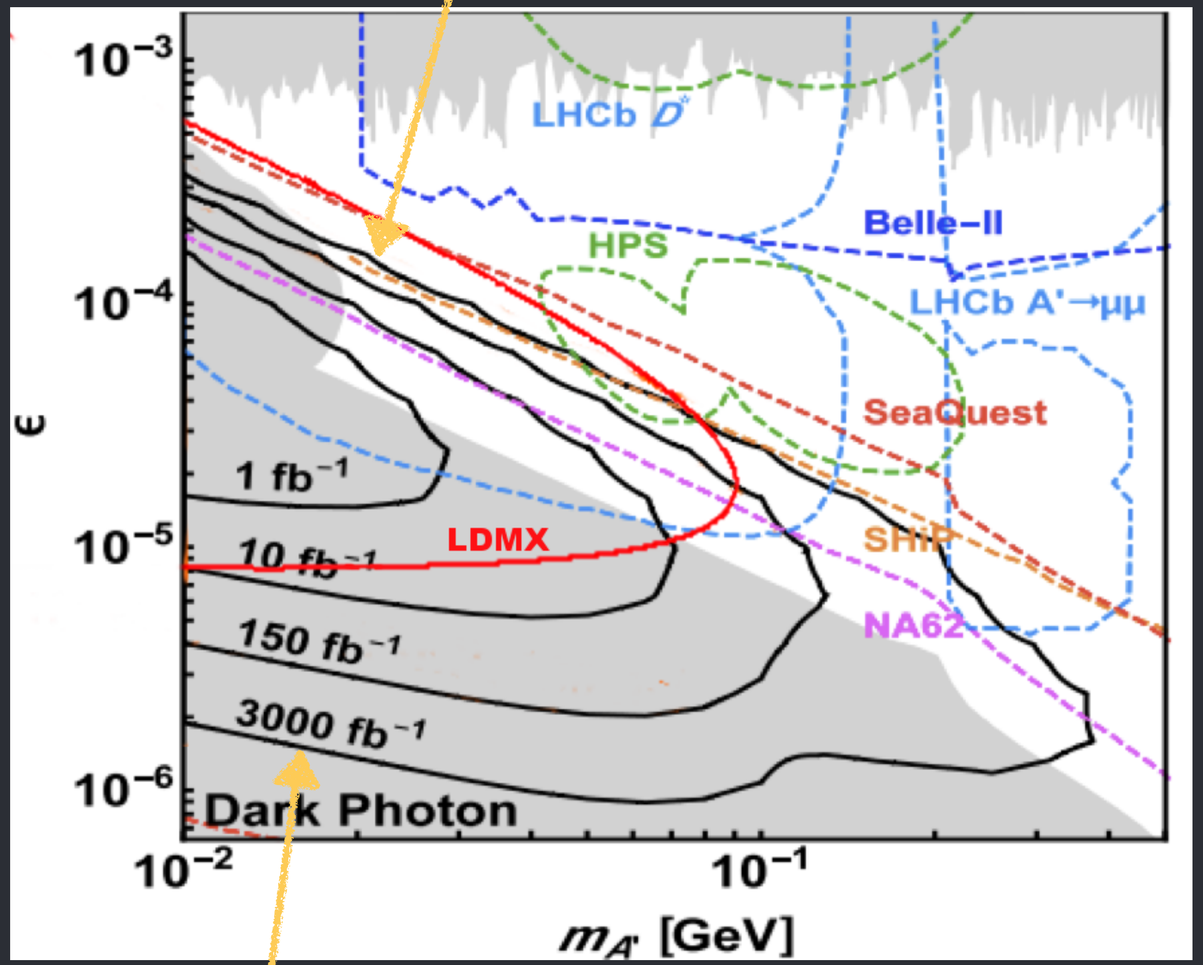
where $d = c\tau\beta\gamma = c\tau p/m$

L, Δ and R are distance from production, decay volume length and aperture radius, respectively. d is decay length in lab frame.

FASER could already break new ground with 10 fb^{-1}…

Ref: "FASER's Physics Reach…", FASER coll., 2018

small lifetime: high boost needed

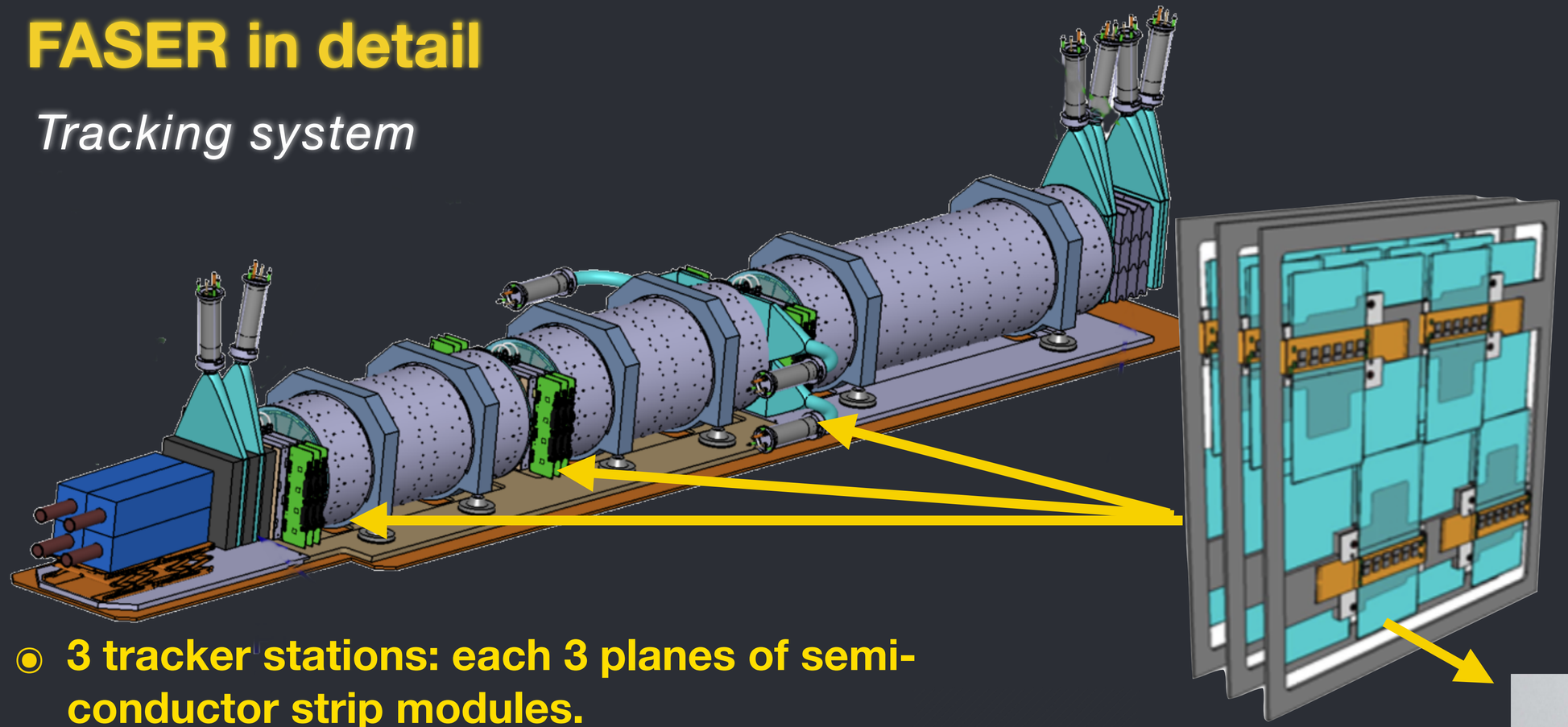


large lifetime: luminosity driven

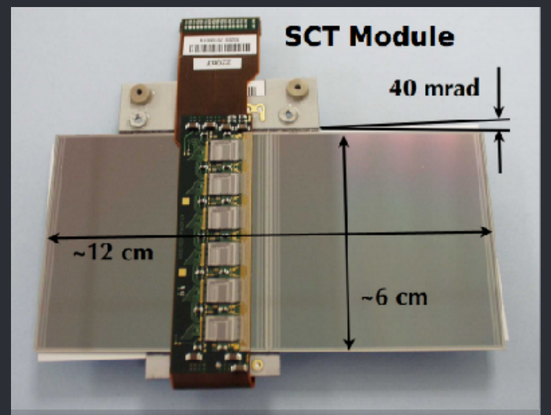
High gain

FASER in detail

Tracking system



24 cm x 24 cm
of active area



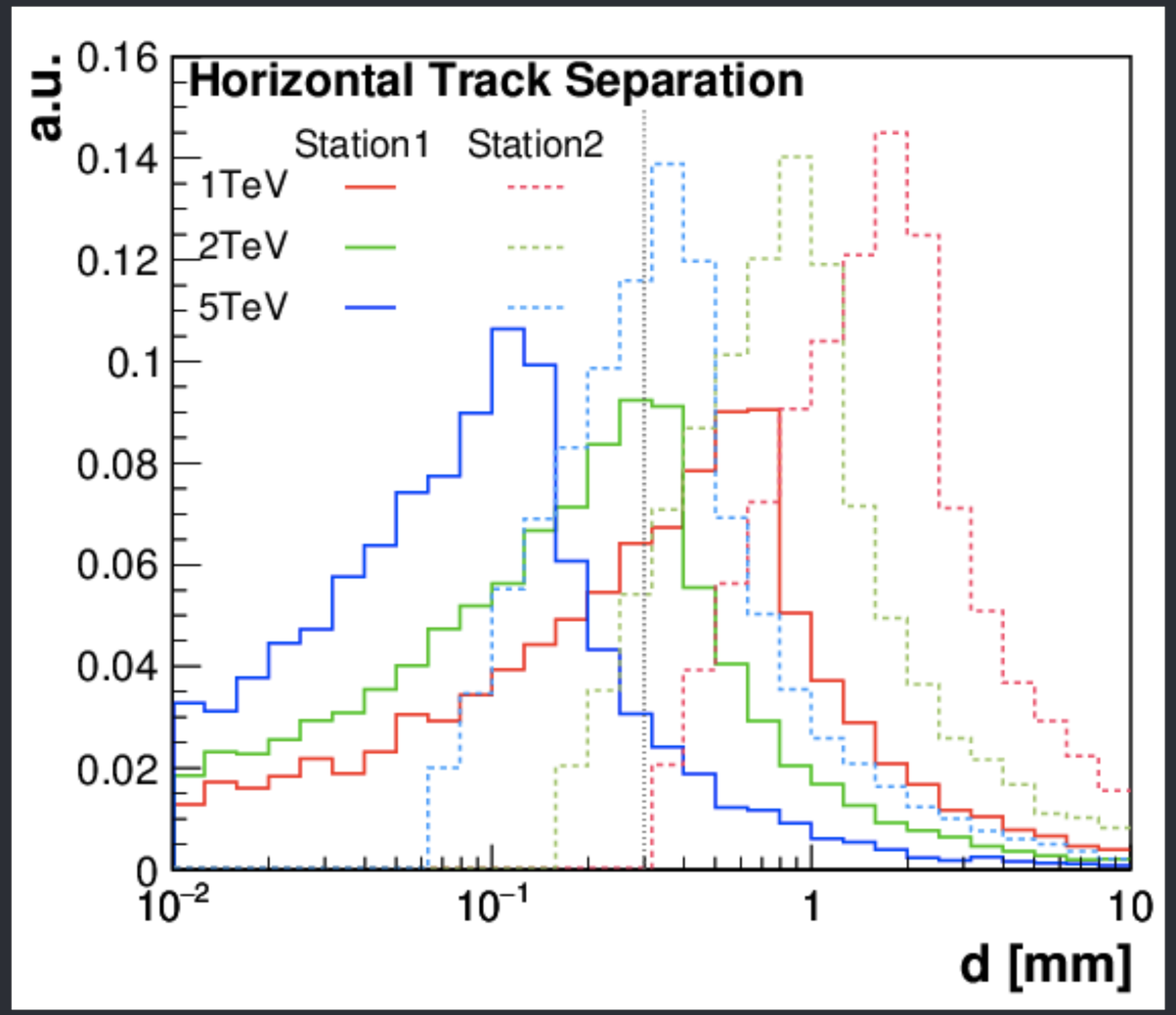
ATLAS SCT module

- **3 tracker stations: each 3 planes of semi-conductor strip modules.**
  - Spare SCT modules donated by ATLAS!
  - Each module two pairs of silicon strip detectors, glued back-to-back: 768 read-out channels/side
  - Oriented modules for precision in bending and non-bending plane.

DISCOUNT

FASER in detail

Tracking system performance requirements



Track separation

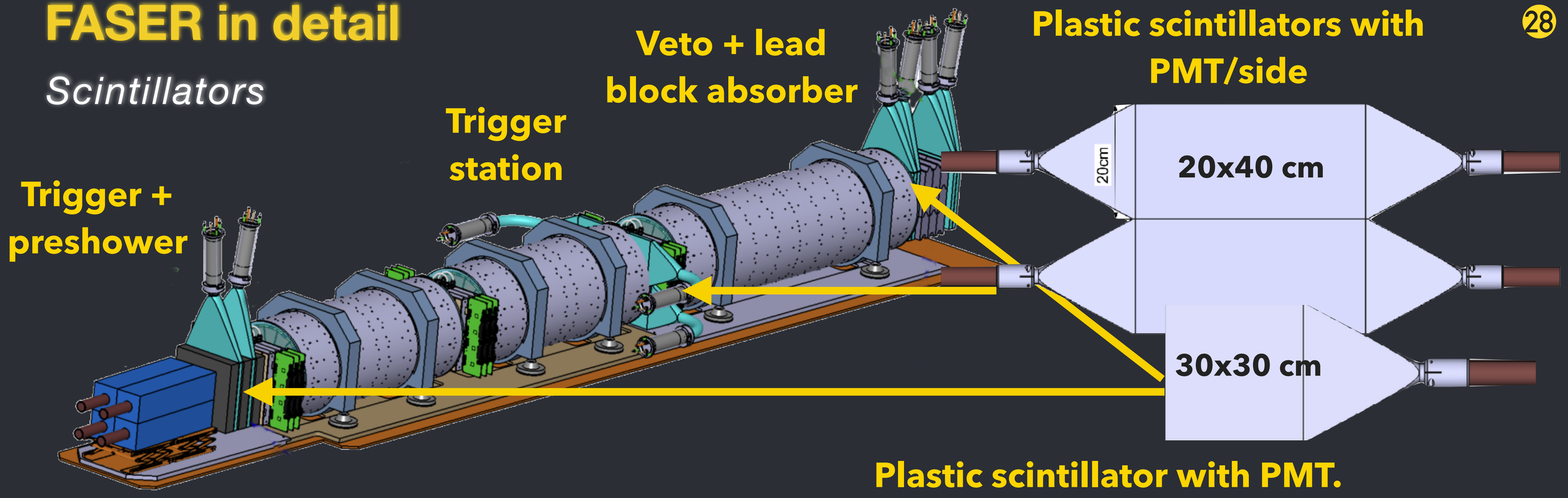
- 300 μm conservative estimate for required separation to create isolated SCT clusters.
- By 2nd tracking station, good track separation achieved across large range in energies.

Track momentum resolution

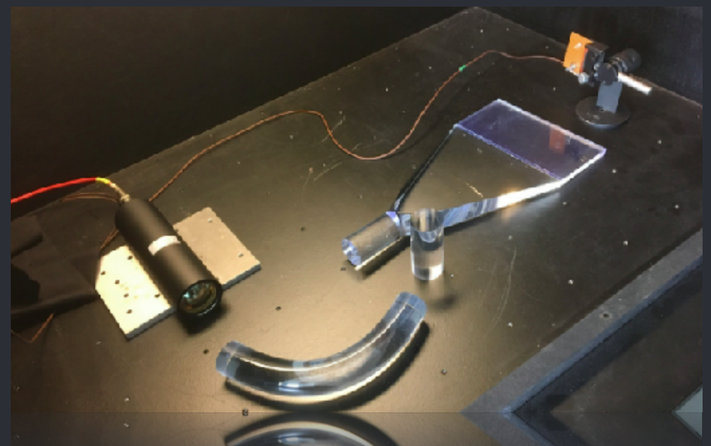
- Do not expect to reconstruct particle masses but still aim for as good as possible to e.g. eliminate low energy (<100 GeV) background.
- Simulations show ~ 3% σ(p)/p for 100 GeV muon tracks.

FASER in detail

Scintillators



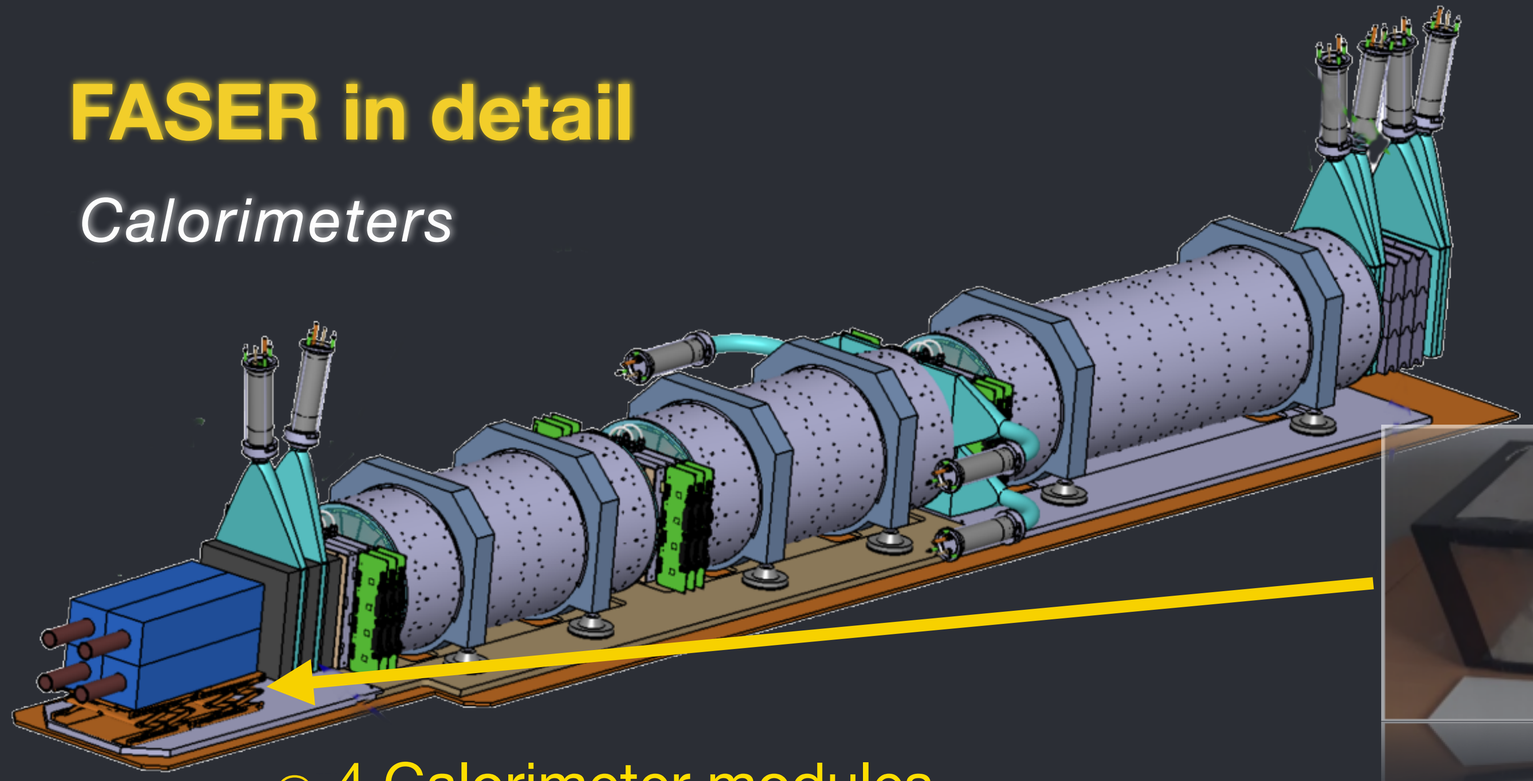
- **Scintillator trigger stations**
  - Including lead block absorber of 20 radiation length to absorb/shower photons radiated by nearby muons.
  - And preshower layer of 2 radiation length lead to convert photons and distinguish from deep-inelastic scattering of neutrinos in calorimeter.

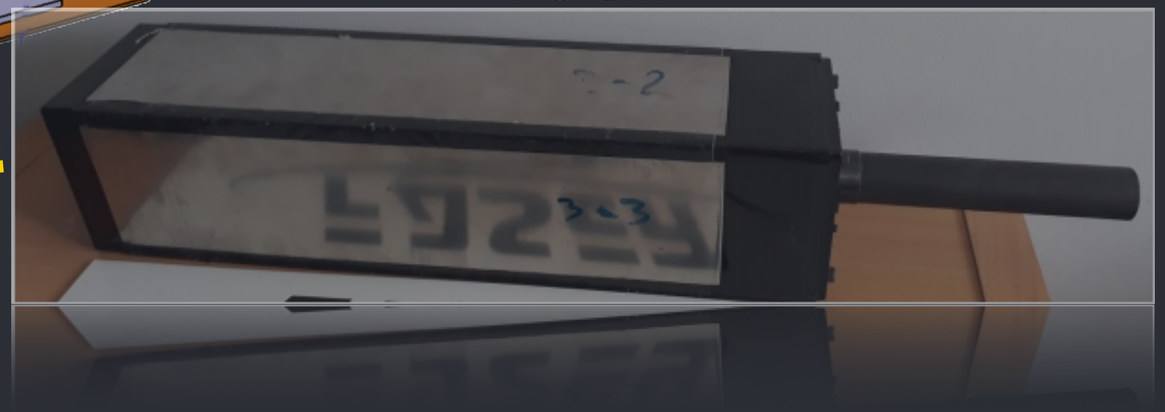


Produced in CERN scintillator lab

FASER in detail

Calorimeters

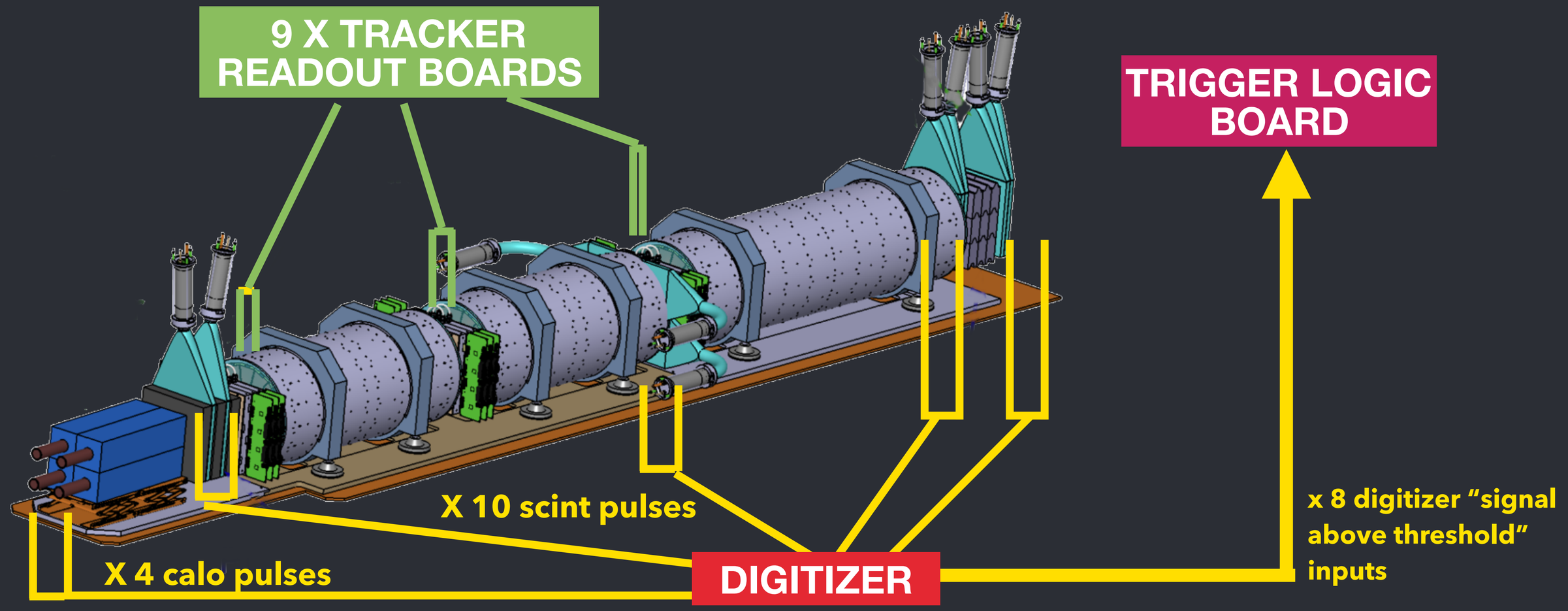




- 4 Calorimeter modules
  - 4 spare outer electromagnetic calorimeter modules donated by LHCb!
  - 66 layers of lead/scintillator, 25 radiation lengths.
  - Read-out via PMT, no longitudinal segmentation.
  - 1% energy resolution for 1 TeV electron, degradation due to leakage of extremely high energy signals expected but tolerable.

FASER in detail

Triggering and data acquisition



FASER in detail

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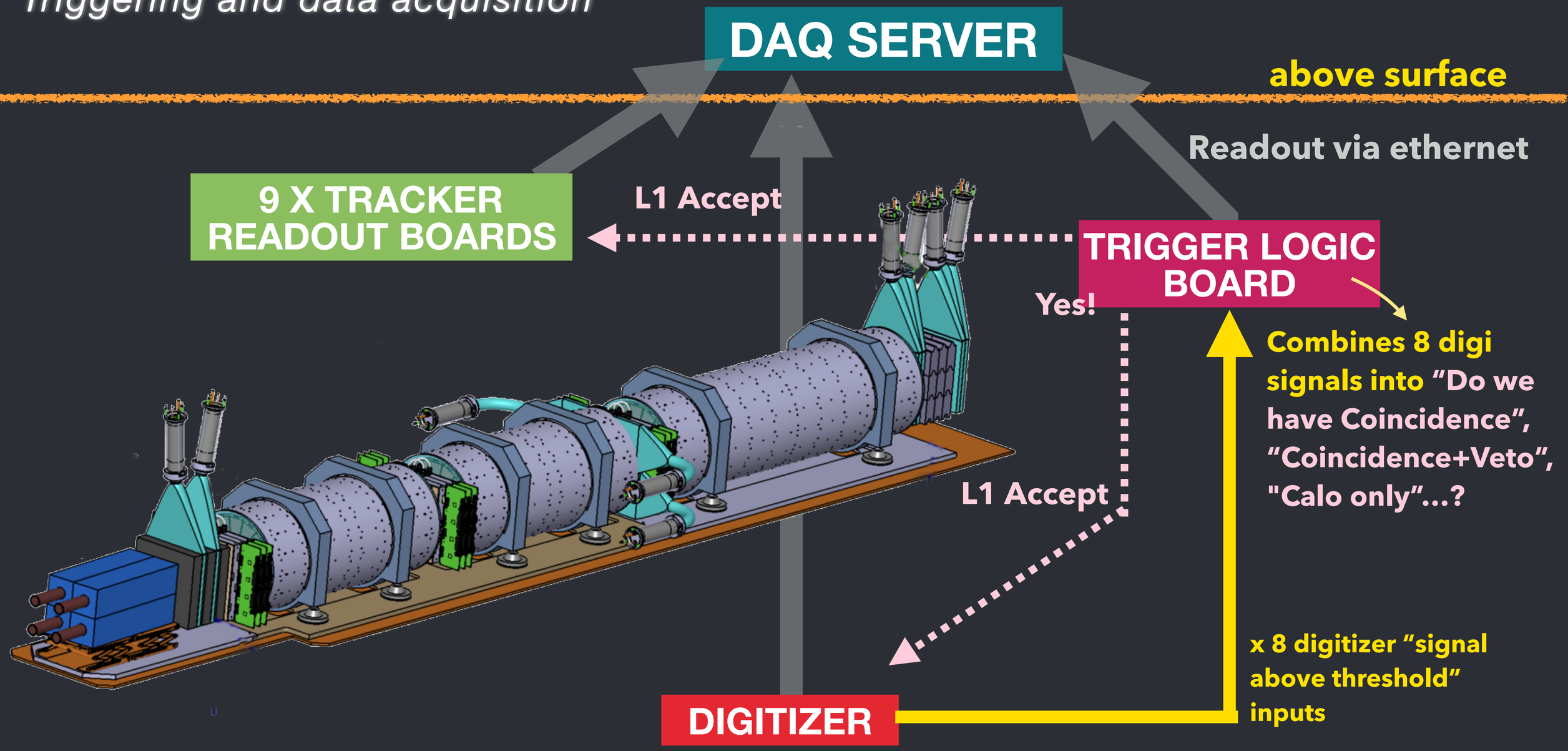
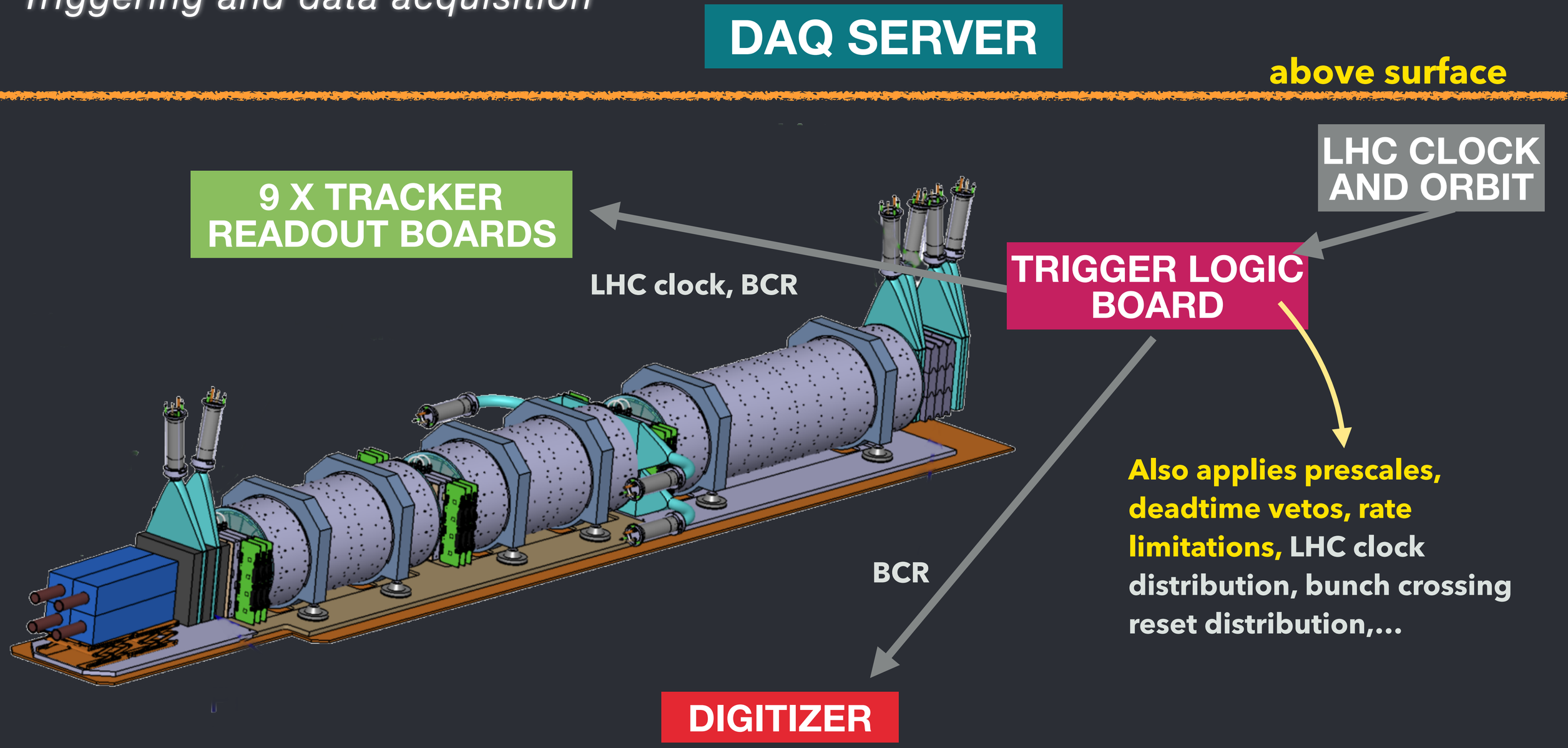


FASER in detail

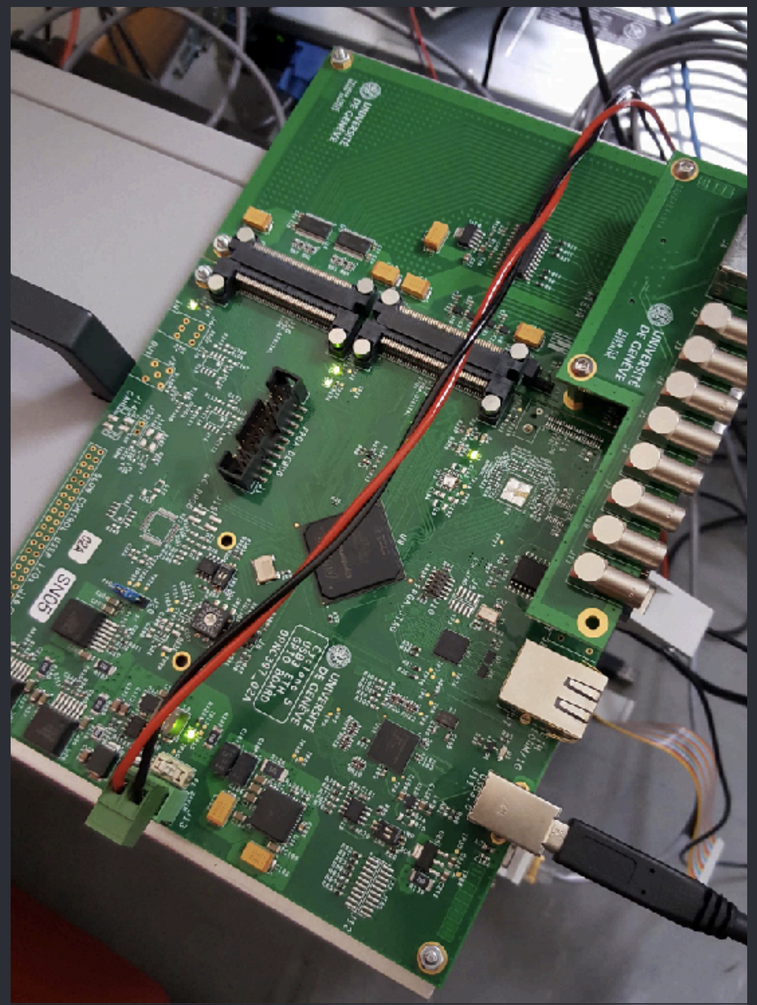
Triggering and data acquisition

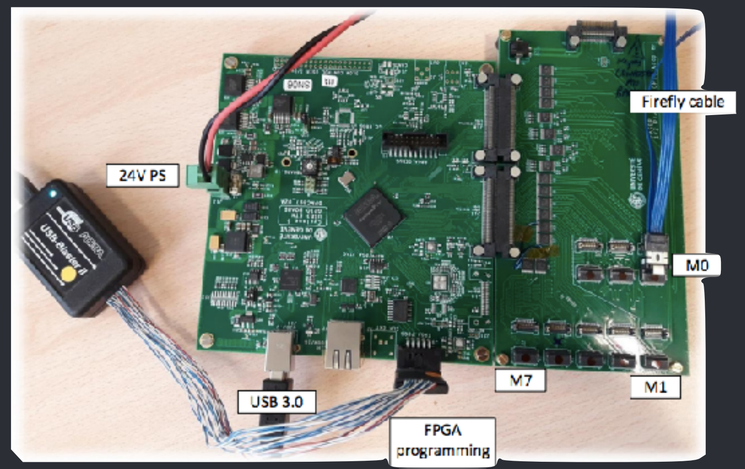


FASER in detail

Triggering and data acquisition

flat cable delivers 8 inputs from digitizer to TLB





- Digitizer: CAEN digitizer card
- Trigger Logic Board (TLB): GPIO board housing an FPGA with complete trigger functionality.
- Tracker Readout Board (TRB): GPIO board housing an FPGA for simple data processing & error handling.

FASER in detail

Triggering and data acquisition

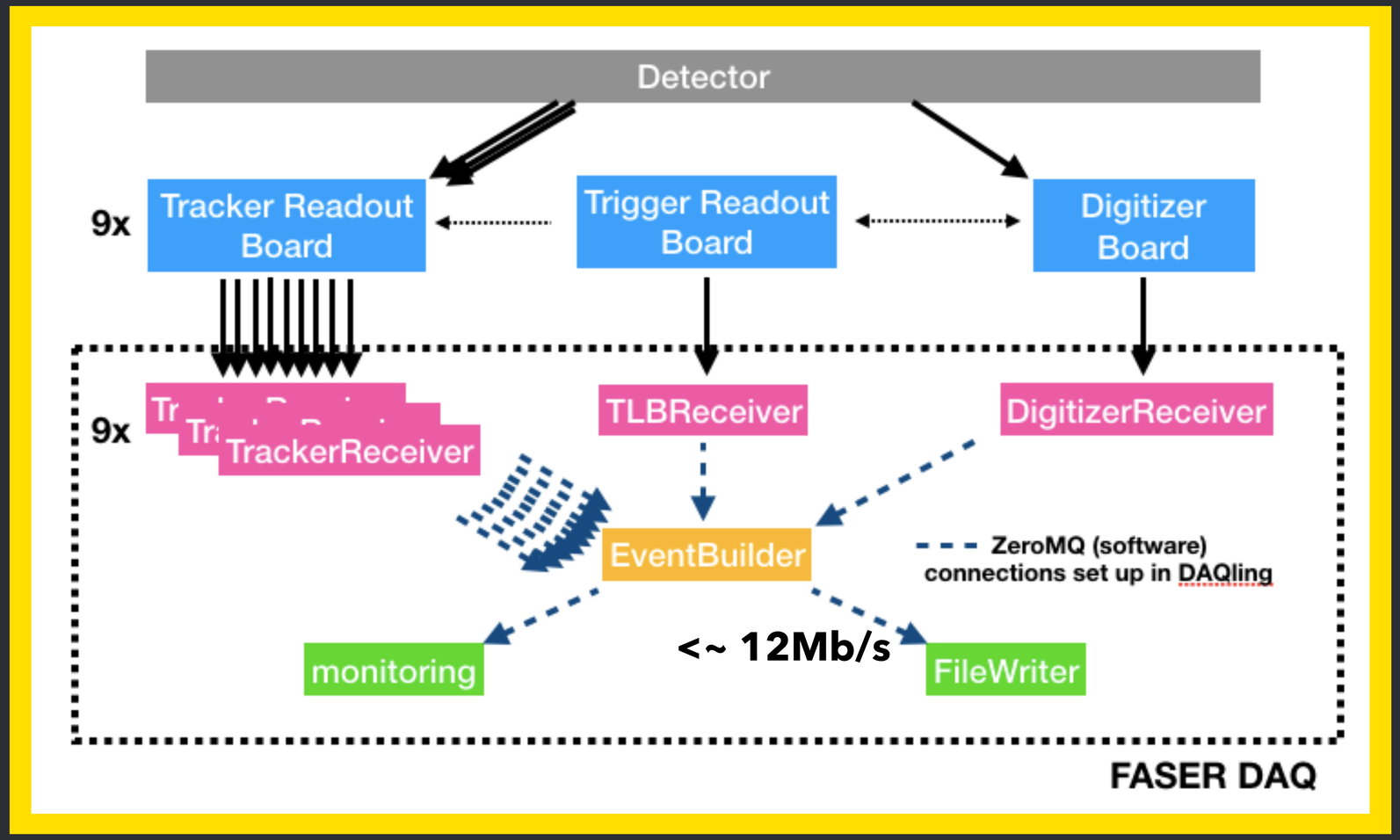
(not their official logo)

- **FASER DAQ framework relies on DAQling,** DAQ core framework for small experiments, developed by CERN Detector Technologies - Detector Interface group (we're one of their first clients!).
- **Software** entirely C++ with python for distribution of commands, configs

EventBuilder:

Combines data fragments from same event. No object reconstruction or event selection

FASER DAQ framework



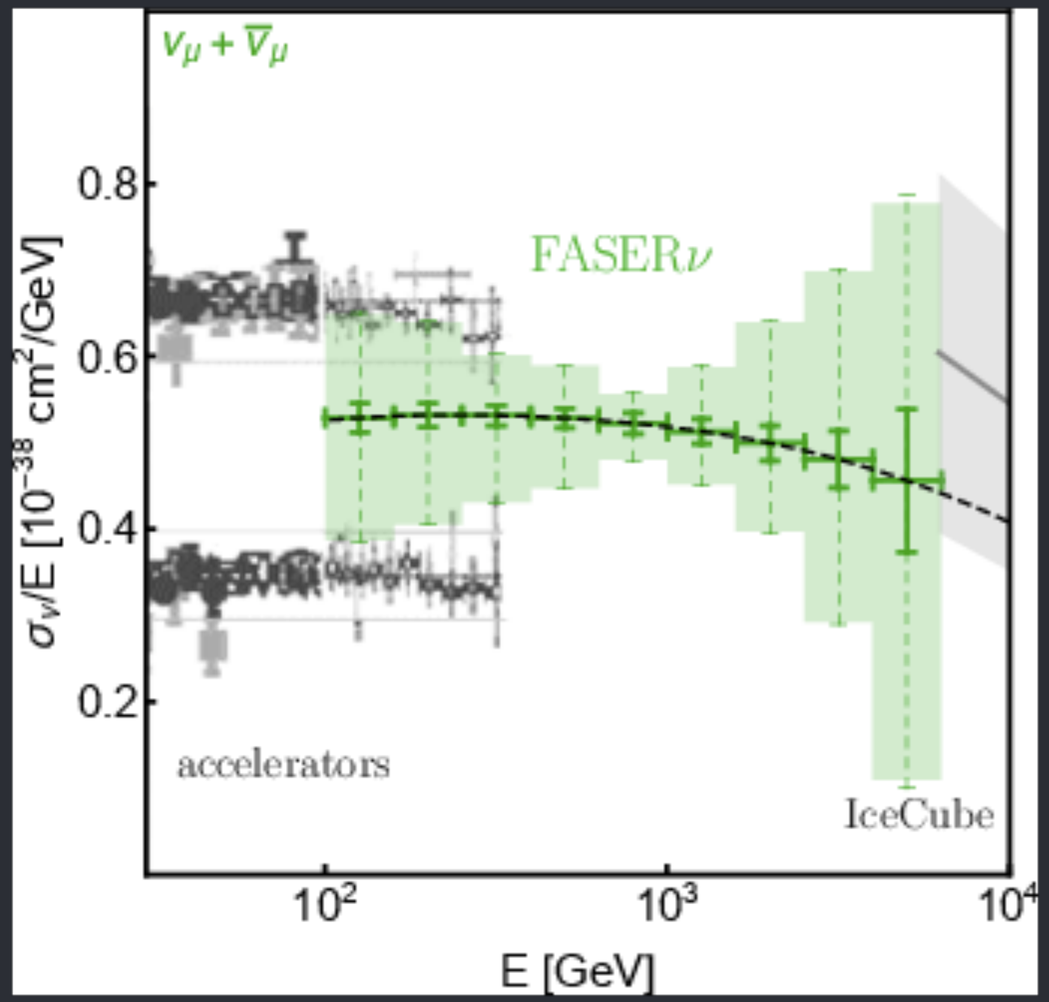
FASER in detail

Triggering and data acquisition

FASERν

FASER neutrino detector (the newly approved mystery component)

- FASERν
  - Approved in December 2019. Recent publication: "Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC"
  - FASER to extend detector to measure SM collider neutrinos for the first time!
  - Extension is a 25 cm x 25 cm x 1.35 m emulsion detector in front of FASER.

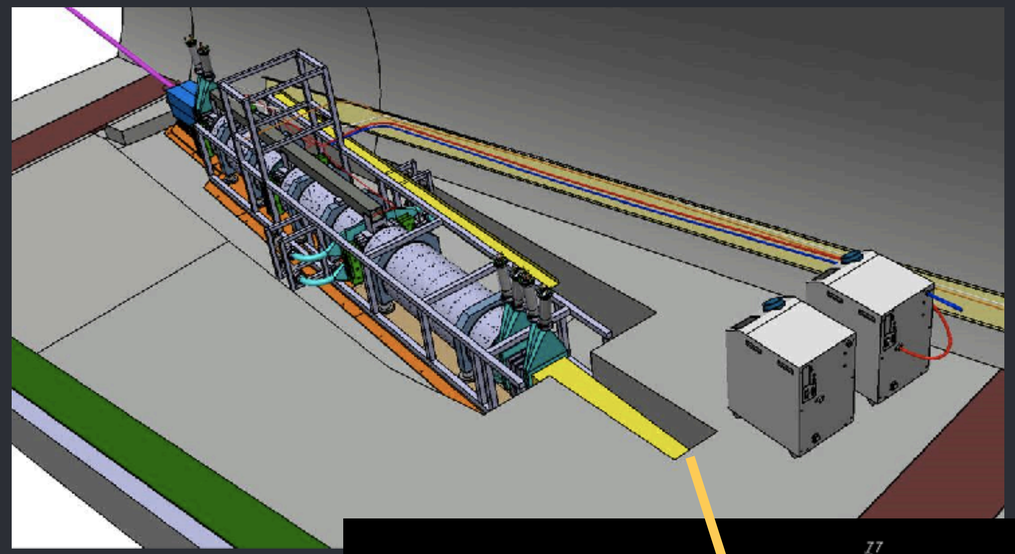


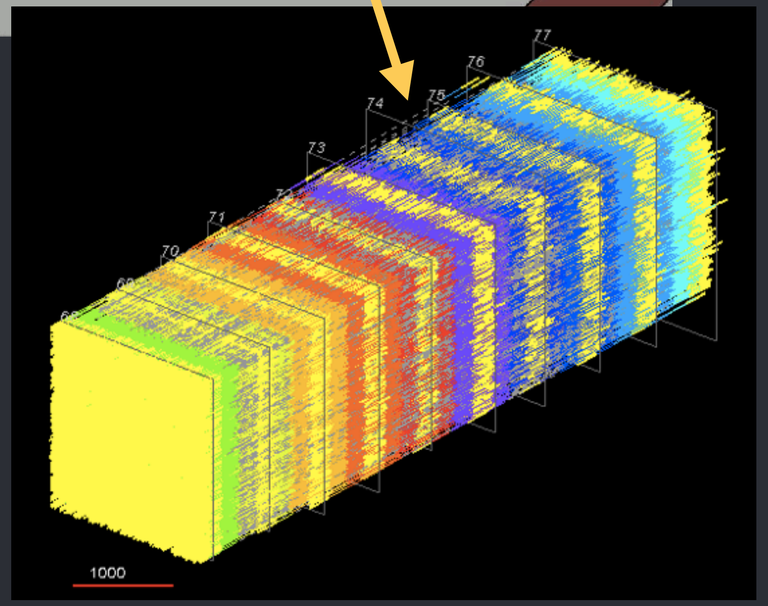
FASERν to set neutrino-nucleon cross-section constraints at whole new neutrino energies. Plots assume 150 fb^{-1} of pp collisions at 14 TeV.

FASERν

FASER neutrino detector (the newly approved mystery component)

- FASERν detector
  - 25 cm x 25 cm x 1.35 m emulsion detector with 1000 emulsion layers interleaved with tungsten plates.
  - Tungsten target mass 1.2 tons.
  - Spatial resolution of 50 nm, but no time resolution.
    - Analysis possible for up to 10^6 tracks/cm^2.
    - Thus emulsion films to be replaced every 10-50 fb^{-1} (during LHC technical stops).

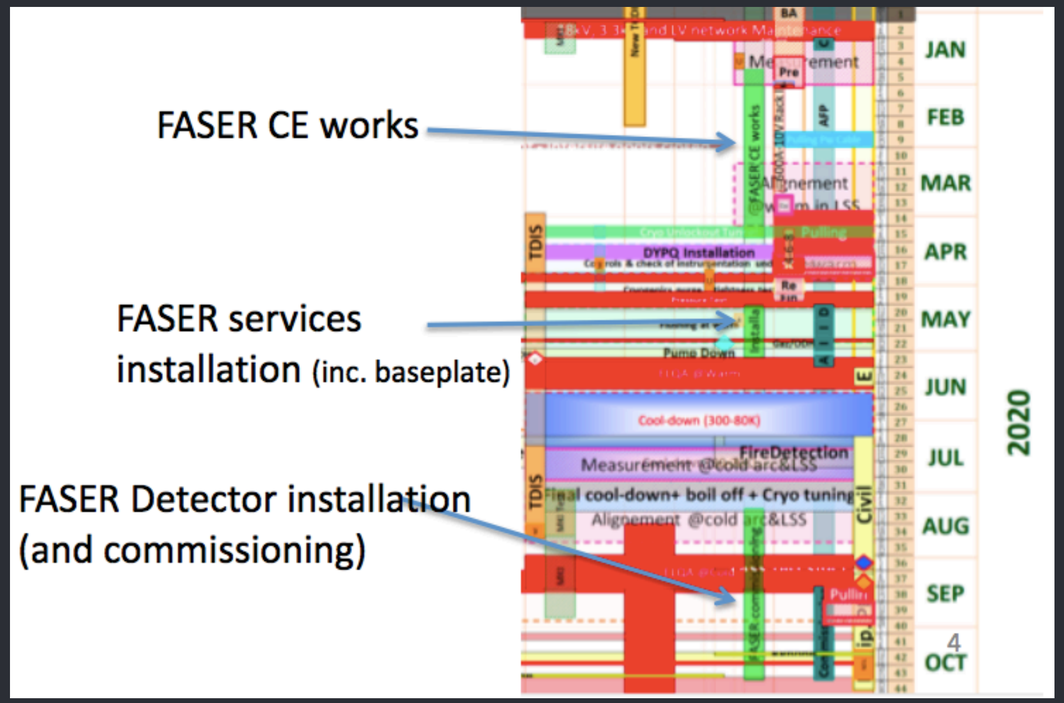




FASER Commissioning

Timeline

- At the whim of LHC schedule.
- FASER civil engineering works happening in tunnel now - April.
- FASER installation of base plate during May.
- FASER **full installation and commissioning mid-July-end October** (barring LHC electric tests in-between)



- Window defined by LHC cool-down and when LHC handed over to LHC operations.

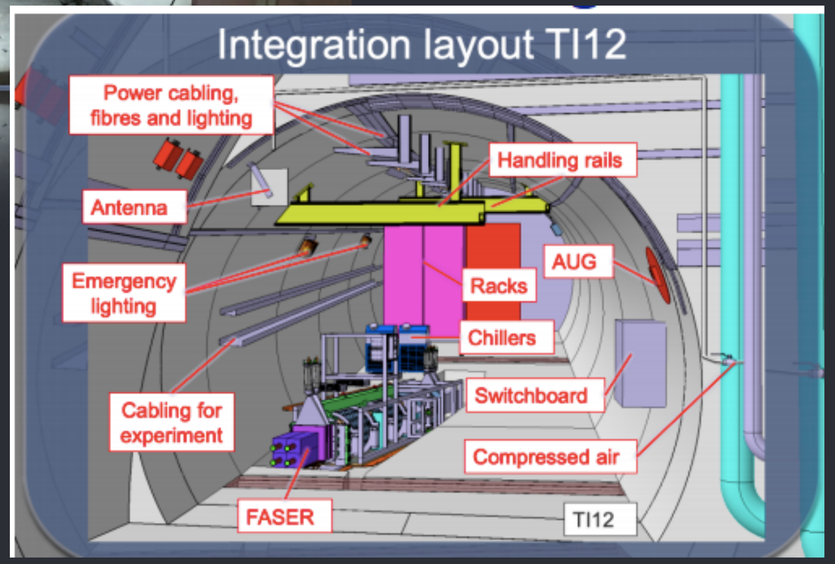
- Data taking to commence in Run 3, 2021.

FASER Commissioning

Civil engineering

TI12 tunnel before and after!

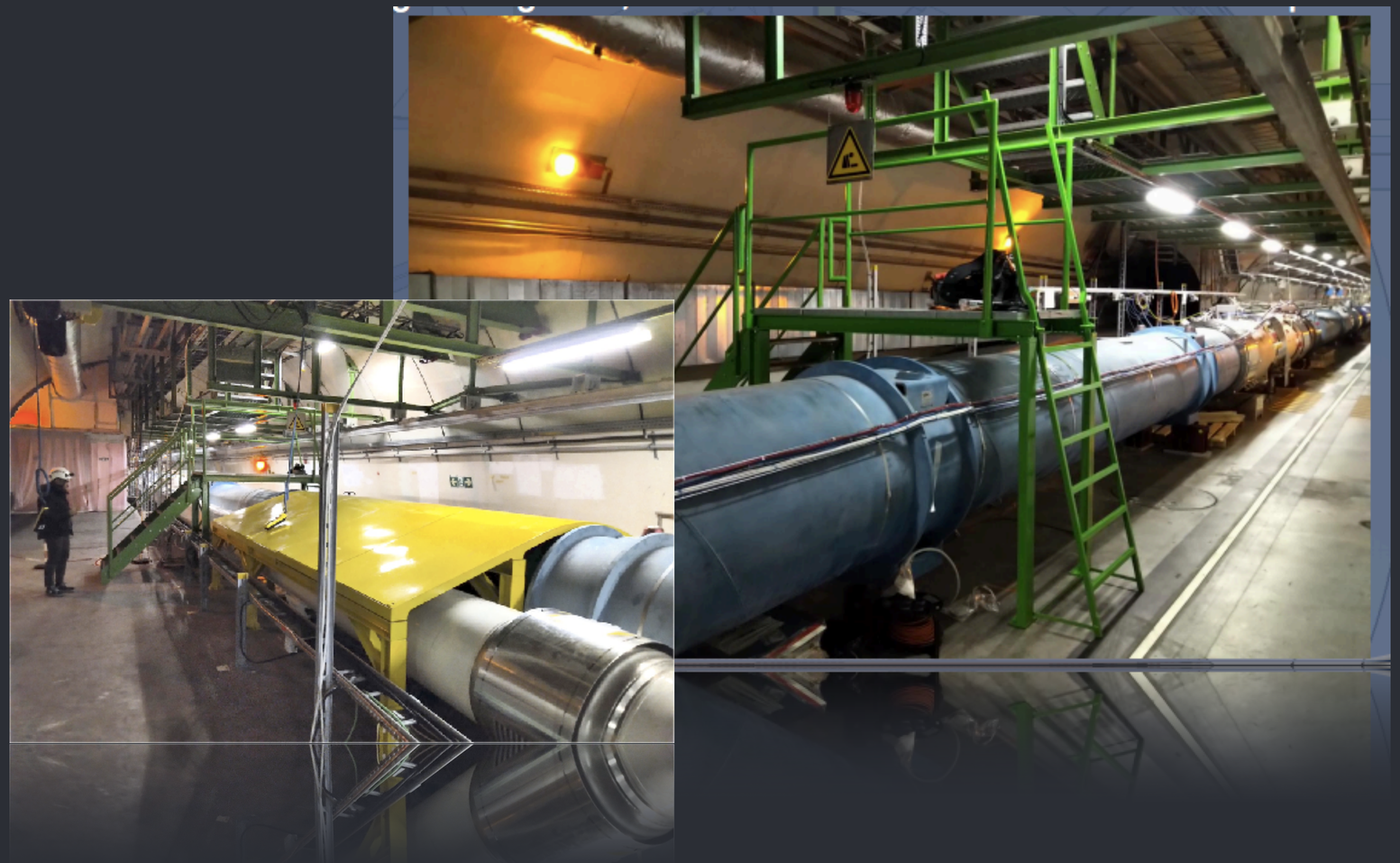
Eventually…

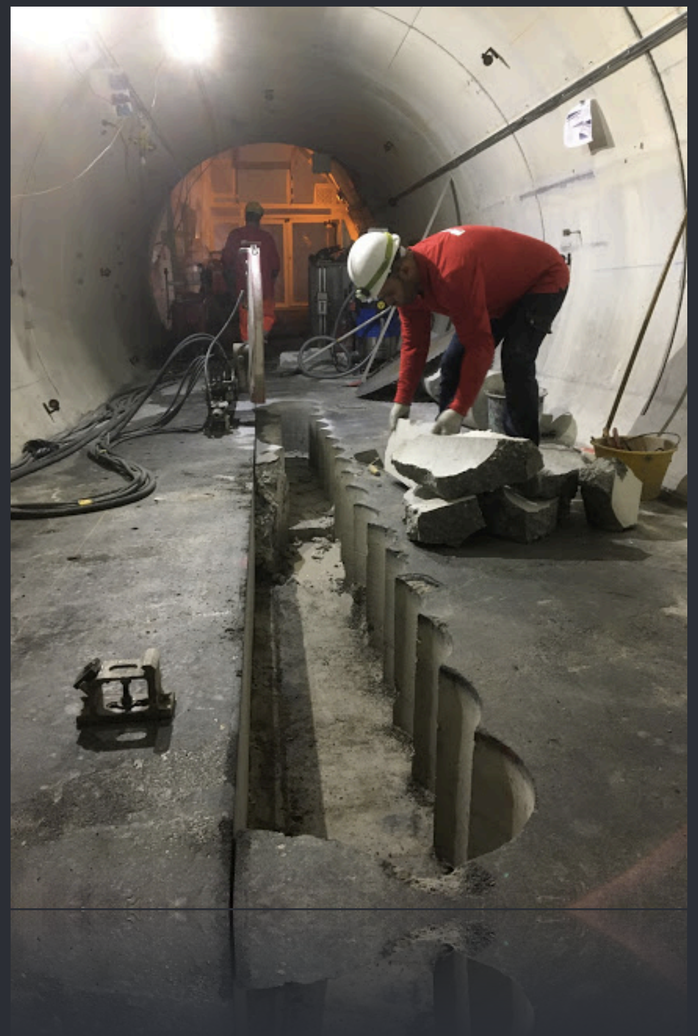


FASER Commissioning

Civil engineering

Gangway, hoist and protection needed to transport across LHC cryogenics distribution line

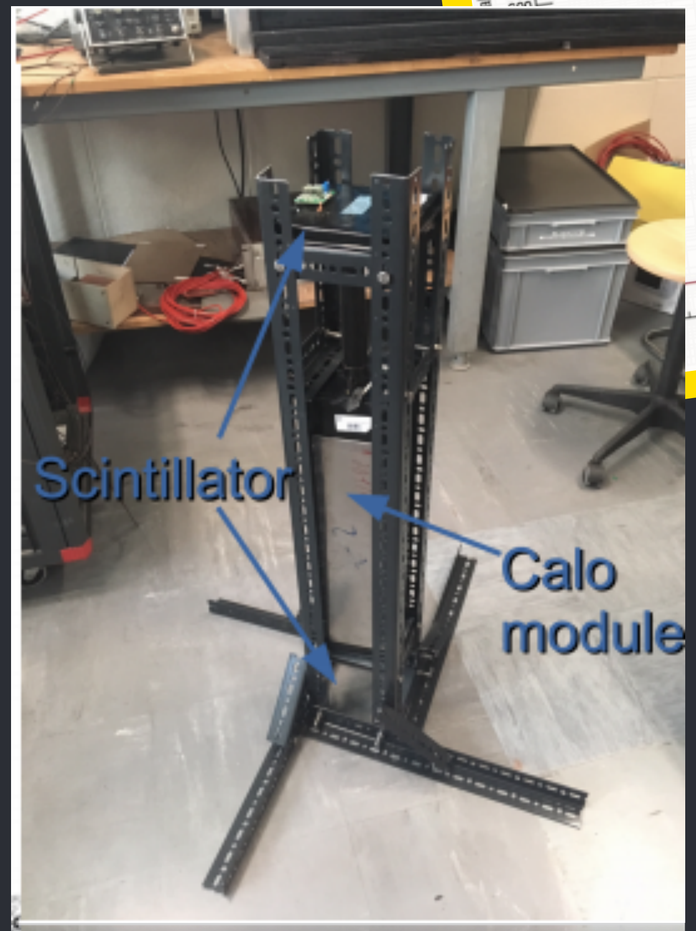




Digging of trench has just begun.

FASER Commissioning

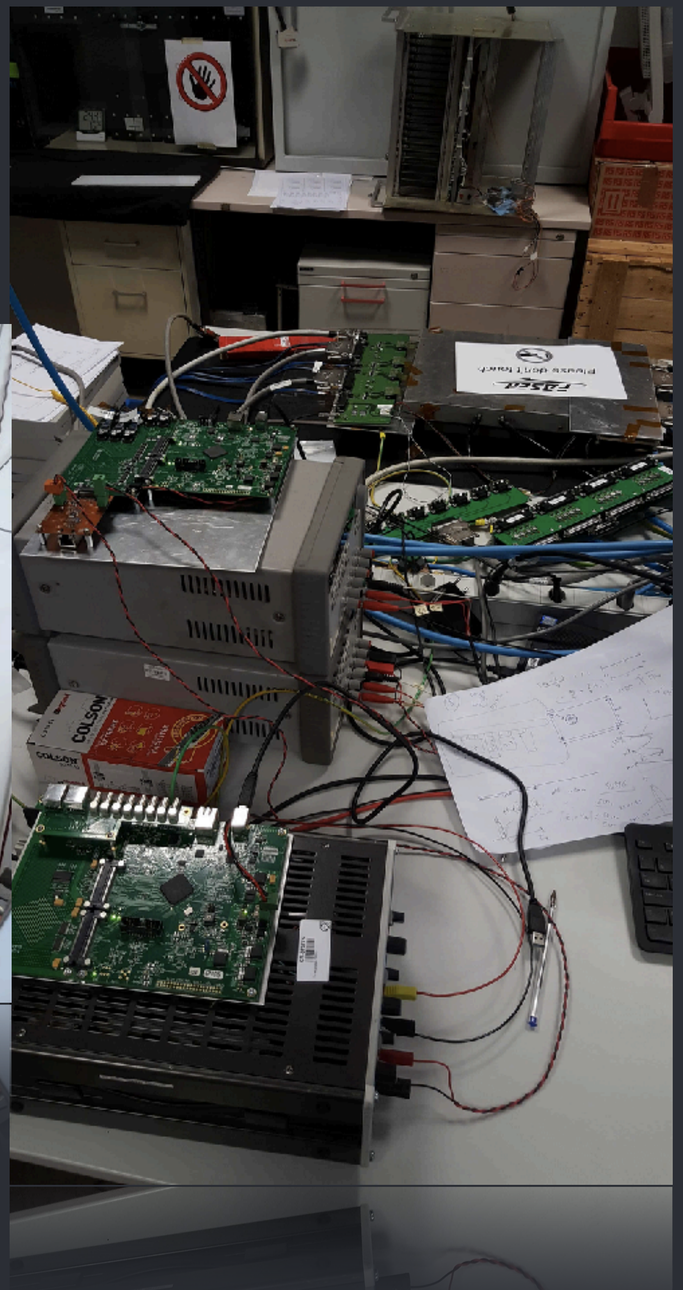
Lab status



Cosmics run using 2 scintillator layers and calo module.

Connection test: TLB-> Digitizer

Connection test: TLB-> TRB -> Tracker modules

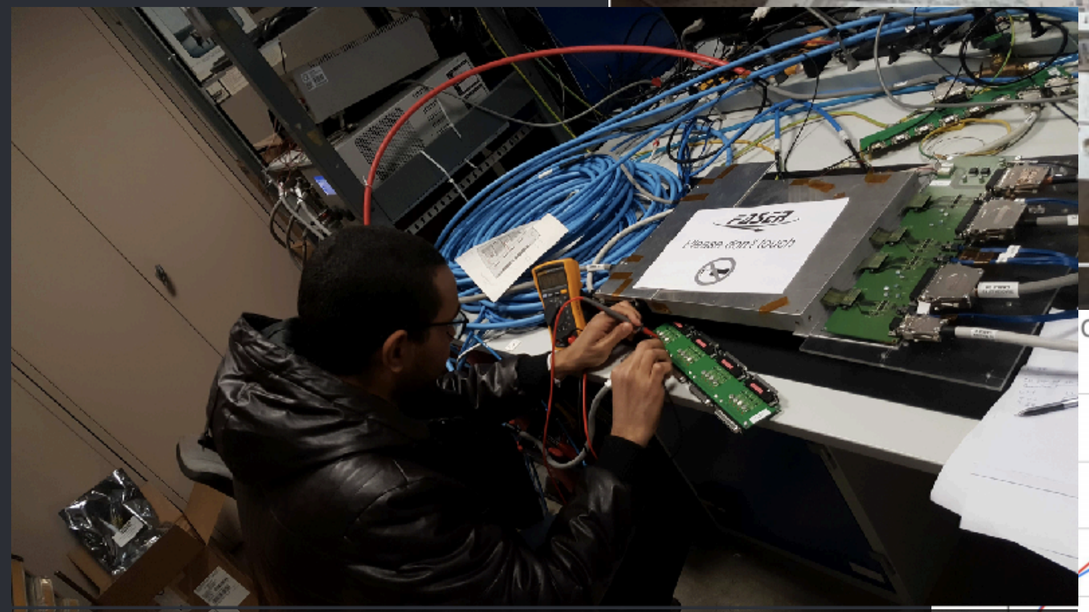


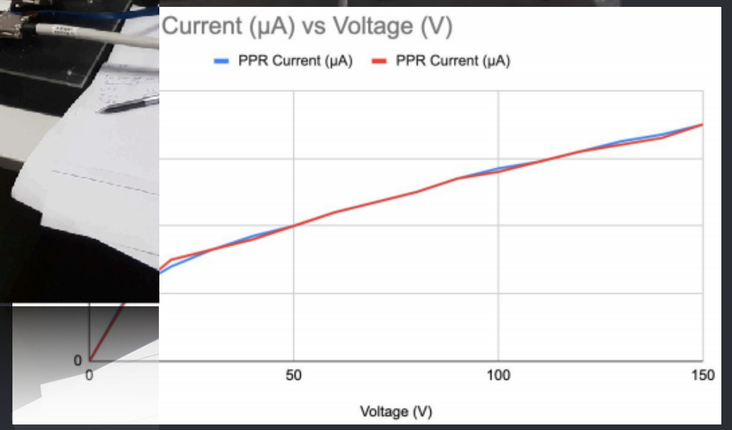
FASER Commissioning

Lab status

Scintillator production

Tracker frames production





Testing of tracker module, temperature and humidity interlock, cooling, low voltage breaks…

Summary

What you now know…

- Not all LHC experiments are **big** and **expensive**.
  - Further reading:

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

- A lot of **LHC luminosity** has formerly remained unexploited -> **Untapped resource** to potential new physics and SM physics at new energies (neutrinos).
- FASER will probe new phase space at **extremely weak couplings** and **light particle masses** for dark photons and axions, dark Higgs and sterile neutrinos…
- FASER still on schedule for data taking beginning of Run 3 and beyond, with exciting upgrades planned.

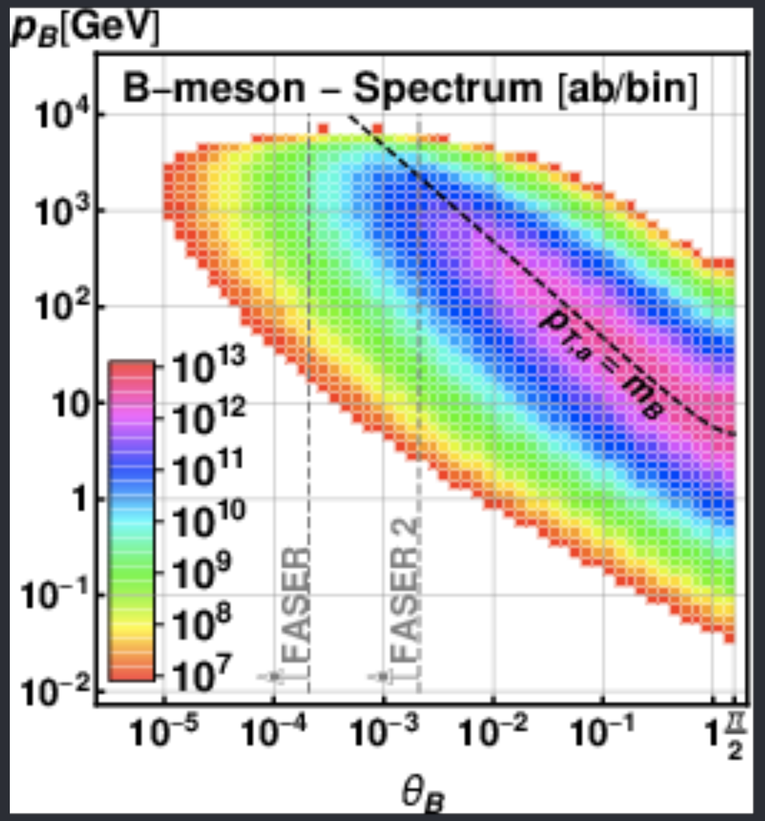
Outlook

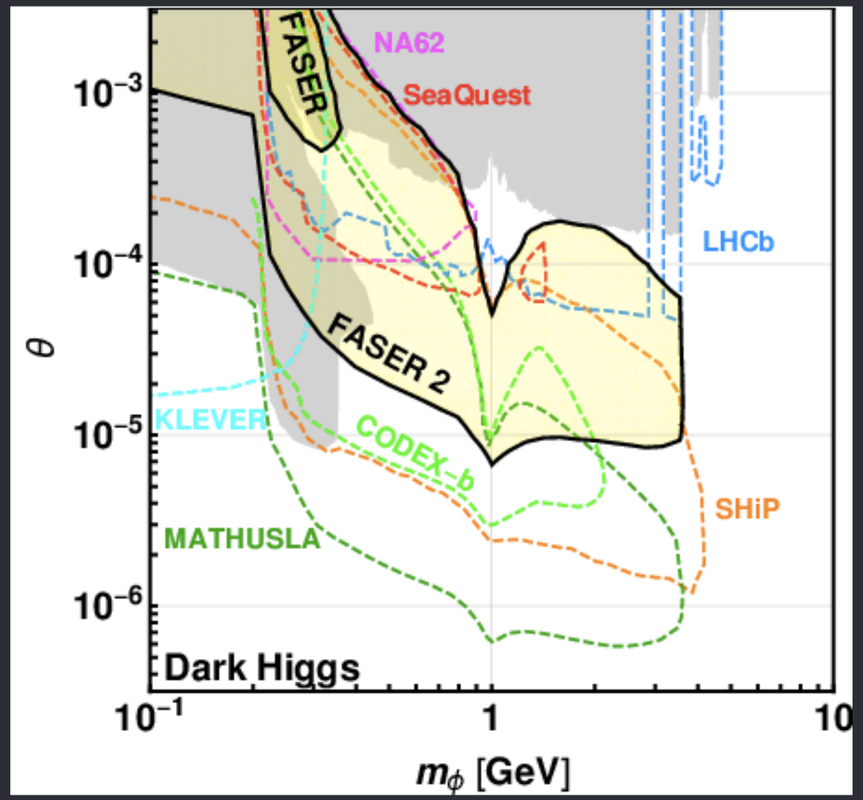
FASER beyond Run 3

- FASER2: Bigger and better. Expanding the aperture of FASER will vastly increase sensitivity to new physics (exact geometry to be decided).

FASER: 150 fb^{-1}, FASER 2: 3 ab^{-1} , with assumed dimensions: R= 1m, Δ= 5 m

Dark Higgs produced mainly in rare decays of B-mesons. Larger spread in p_T for B meson production, thus larger angular acceptance of FASER 2 boosts dark Higgs sensitivity.





Thank you for listening!

The FASER collaboration

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(FASER co-spokespeople)

Henso Abreu (Technion), Yoav Afik (Technion), Claire Antel (Geneva), Akitaka Ariga (Bern), Tomoko Ariga (Kyushu/Bern), Jamie Boyd (CERN), Dave Casper (UC Irvine), Franck Cadoux (Geneva), Xin Chen (Tsinghua), Andrea Coccaro (INFN), Candan Dozen (Tsinghua), Yannick Favre (Geneva), Deion Fellers (Oregon), Jonathan Feng (UC Irvine), Didier Ferrere (Geneva), Iftah Galon (Rutgers), Stephen Gibson (Royal Holloway), Sergio Gonzalez-Sevilla (Geneva), Shih-Chieh Hsu (Washington), Zhen Hu (Tsinghua), Peppe Iacobucci (Geneva), Sune Jakobsen (CERN), Enrique Kajomovitz (Technion), Felix Kling (SLAC), Umut Kose (CERN), Susanne Kuehn (CERN), Helena Lefebvre (Royal Holloway), Lorne Levinson (Weizmann), Ke Li (Washington), Jinfeng Liu (Tsinghua), Chiara Magliocca (Geneva), Josh McFayden (CERN), Sam Meehan (CERN), Dimitar Mladenov (CERN), Mitsuhiro Nakamura (Nagoya), Toshiyuki Nakano (Nagoya), Marzio Nessi (CERN), Friedemann Neuhaus (Mainz), Hidetoshi Otono (Kyushu), Carlo Pandini (Geneva), Hao Pang (Tsinghua), Brian Petersen (CERN), Francesco Pietropaolo (CERN), Michaela Queitsch-Maitland (CERN), Filippo Resnati (CERN), Jakob Salfeld-Nebgen (CERN), Osamu Sato (Nagoya), Paola Scampoli (Bern), Kristof Schmieden (CERN), Matthias Schott (Mainz), Anna Sfyrla (Geneva), Savannah Shively (UC Irvine), Jordan Smolinsky (Florida), Yosuke Takubo (KEK), Ondrej Theiner (Geneva), Eric Torrence (Oregon), Sebastian Trojanowski (Sheffield), Serhan Tufanli (CERN), Dengfeng Zhang (Tsinghua), Gang Zhang (Tsinghua)

We owe many thanks to:

HEISING-SIMONS FOUNDATION SIMONS FOUNDATION CERN

for financial and technical support.

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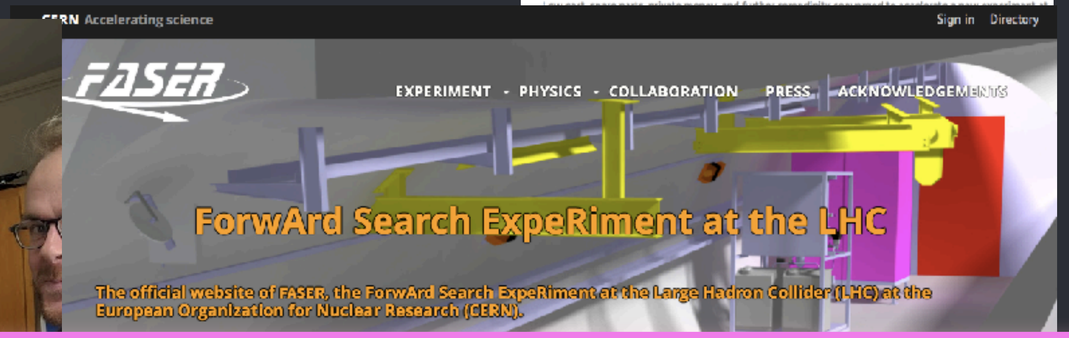
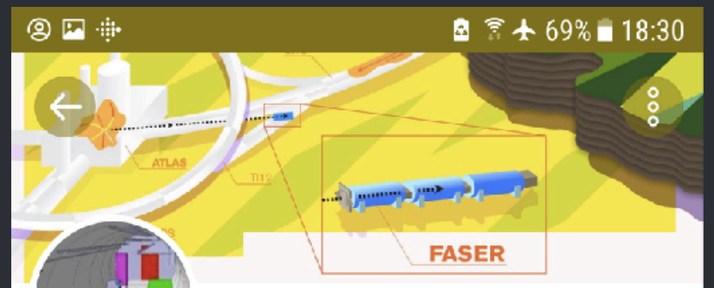




https://faser.web.cern.ch/

News

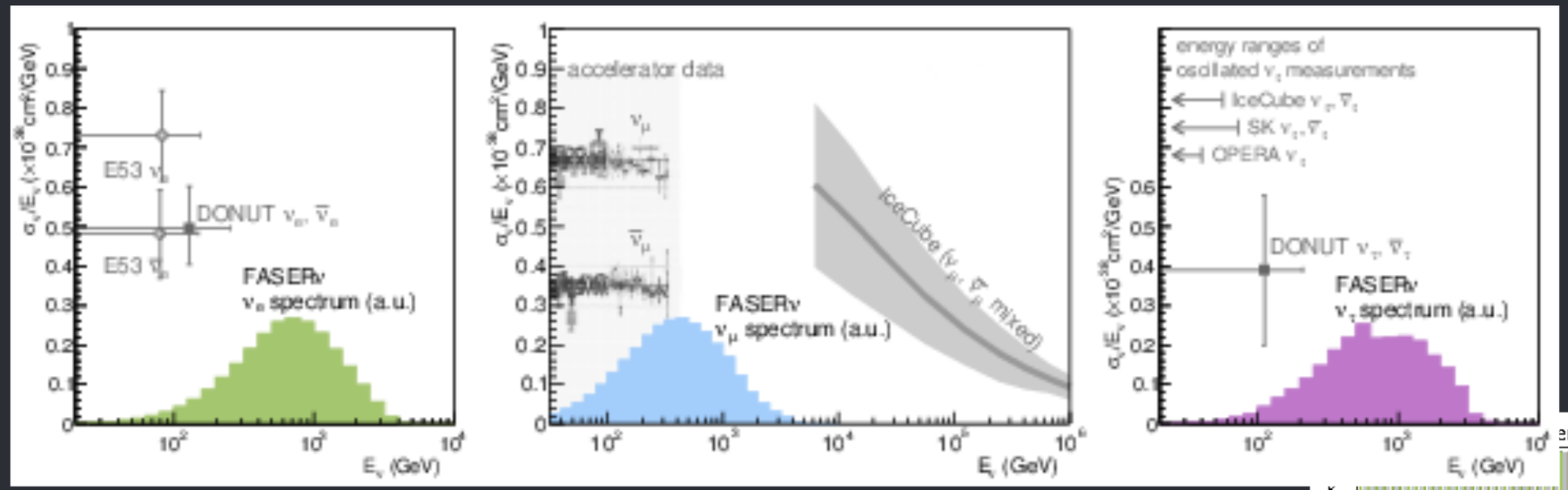
pproves UC
s at the Lar
or will seek clues p

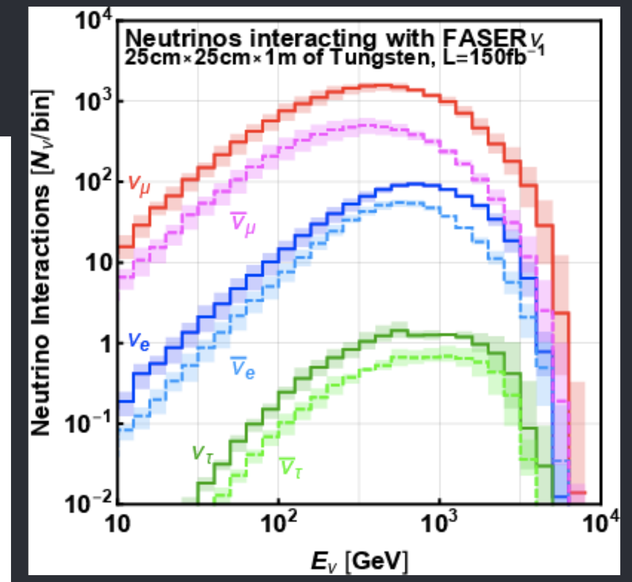
A New Hunt for Undiscovered Dark Matter

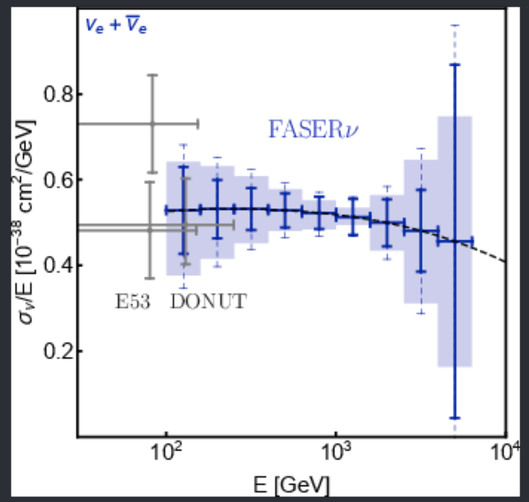
Bonus slides …

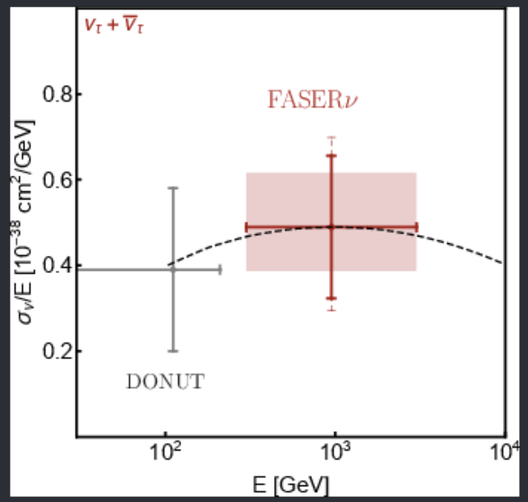
FASERν

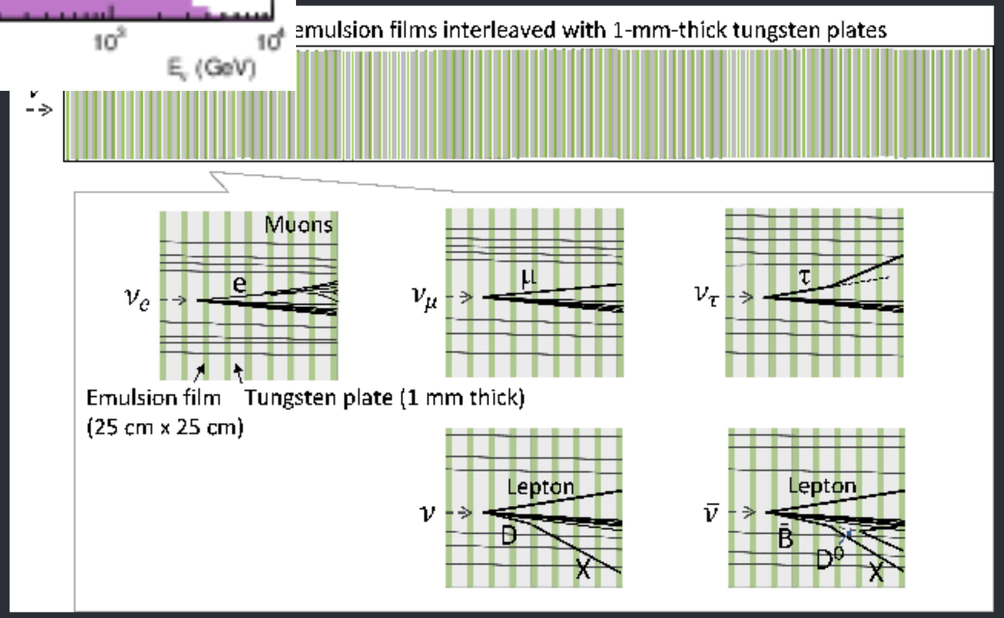
Standard Model neutrino measurements





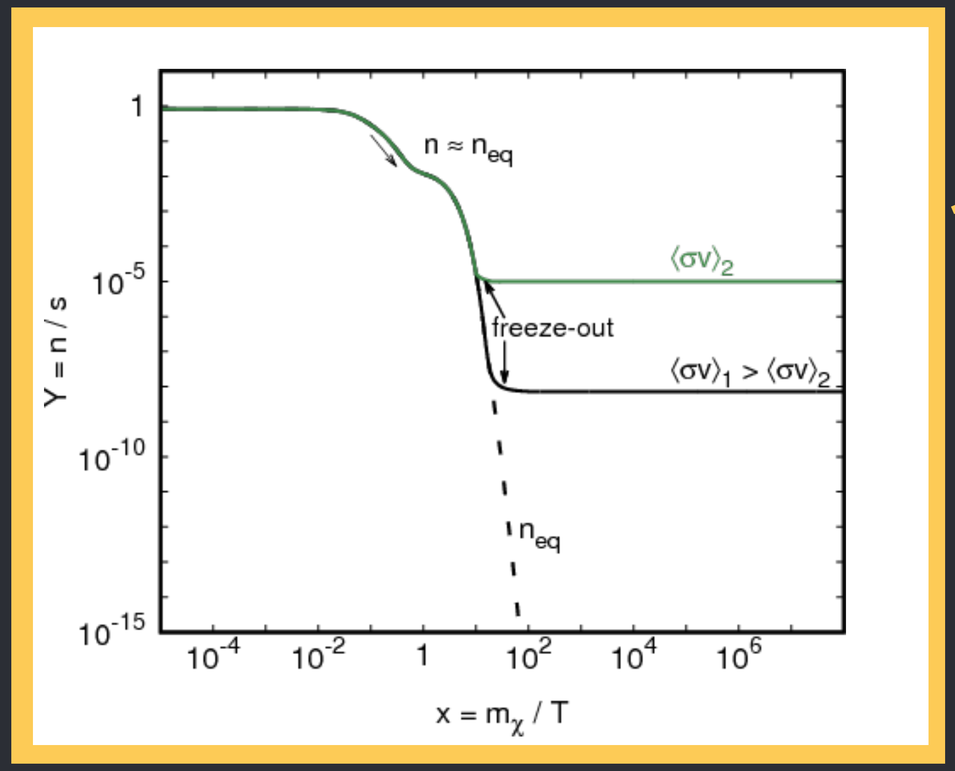






More physics

The WIMPless miracle



$$m_X/g_X^2 \sim m_{\rm weak}/g_{\rm weak}^2$$

- **The "WIMP Miracle":**

  New 0.1-1 TeV DM particle with weak-scale interaction would naturally be thermally produced in early universe resulting in correct DM density to fit today's observations.

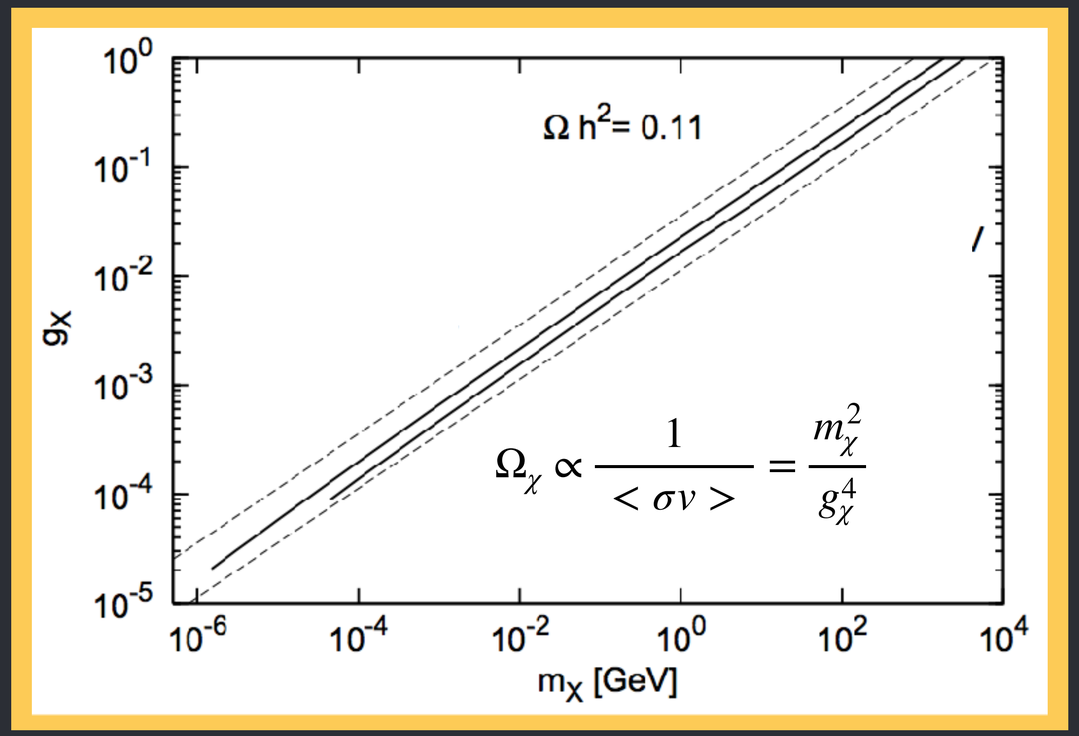
  SUSY readily predicts particles at this mass scale.

References:

- "WIMP dark matter candidates and searches…", L. Roszkowski, E.M. Sessolo, 2018
- "The WIMPless Miracle:…", Feng J., Kumar J., 2008

More physics

The WIMPless miracle



References:

- "WIMP dark matter candidates and searches…", L. Roszkowski, E.M. Sessolo, 2018
- "The WIMPless Miracle:…", Feng J., Kumar J., 2008

- **The "WIMPless Miracle":**

  But it is the ratio m_χ/g^2_χ that matters in obtaining the right DM relic density …

$$m_X/g_X^2 \sim m_{\rm weak}/g_{\rm weak}^2$$

- … So that a larger range in g_χ and m_χ is in fact relevant:

$$10^{-3} \lesssim g_X \lesssim 3$$
$$10\ {\rm MeV} \lesssim m_X \lesssim 10\ {\rm TeV}$$

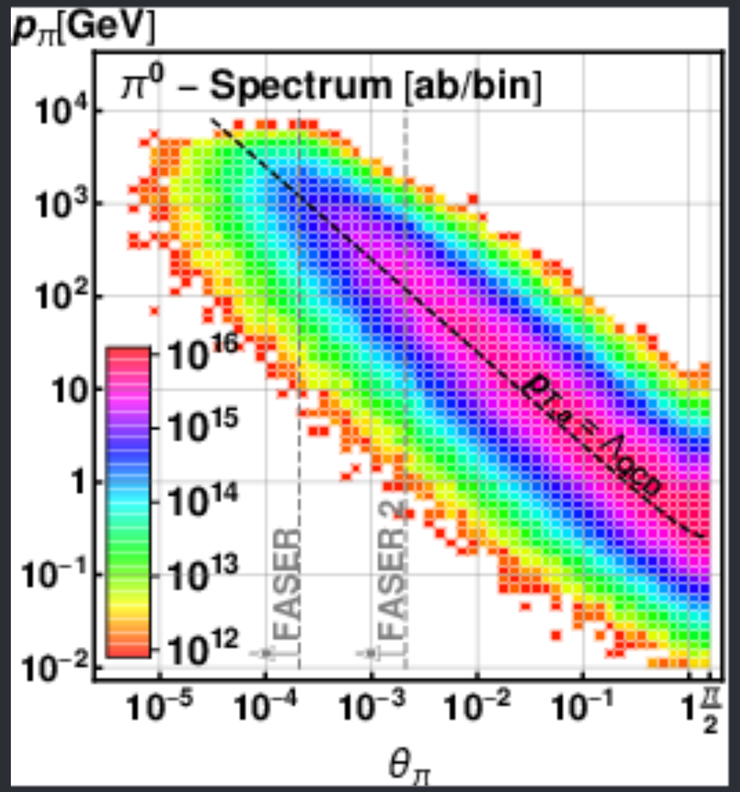
- Bounded by perturbativity limitations and requirement for DM to be non-relativistic at time of freeze-out.

From a Physics Perspective

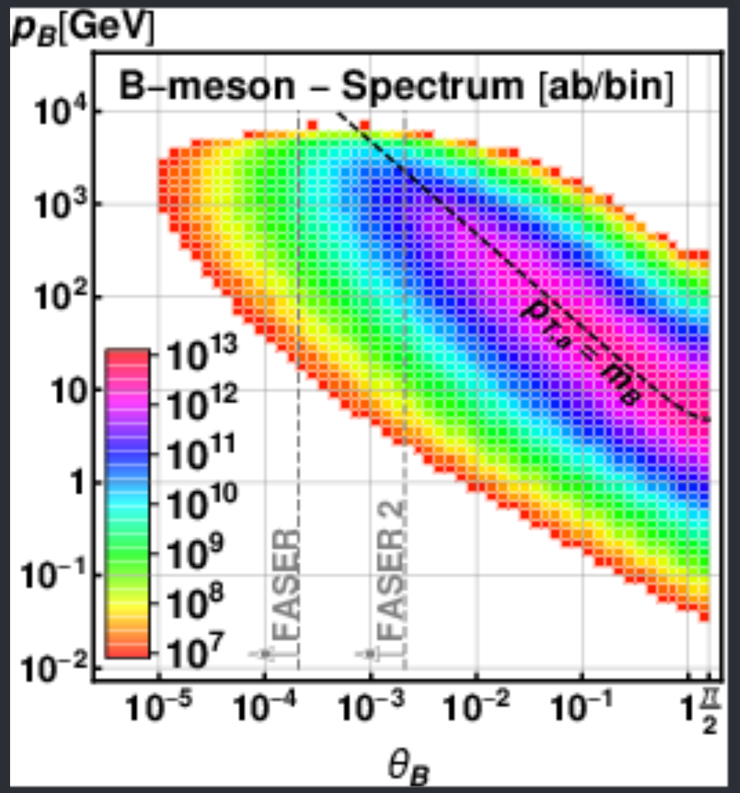
Light and feebly coupled

- ~ 10^{16} inelastic events/hemisphere in Run 3 (150 fb^{-1}) -> large meson production rates.

MC event generator: EPOS-LHC



Production rate for π0 at measurable momenta (>10 GeV) at small θ to beam axis (rate a magnitude less for η mesons).



MC event generator: FONLL, CTEQ6.6

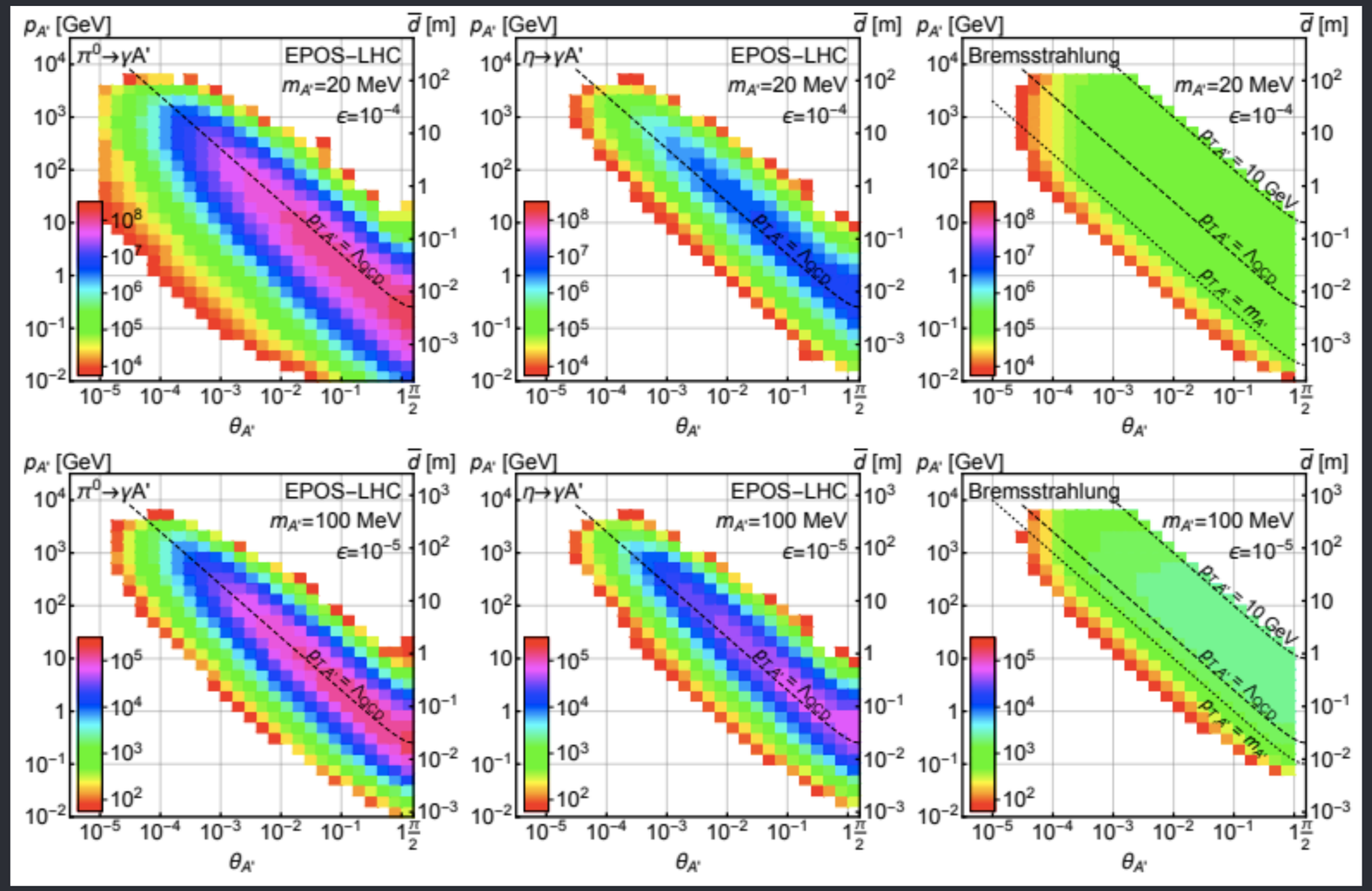
Smaller production rates for heavier mesons.

Ref: "Technical Proposal for FASER", FASER coll., 2018

More physics

Dark photon production rate

- Total number of photons produced in one hemisphere for 300 ifb 13 TeV *pp* collisions for various production modes (no detector decay volume limitation).



More physics

Assumptions in sensitivity plots

- Assumptions by other experiments in sensitivity plots:

NA62 assumes 10^{18} protons on target (POT) while running in a beam dump mode that is being considered for LHC Run 3; SeaQuest assumes 1.44×10^{18} POT, which could be obtained in two years of parasitic data taking and requires additionally the installation of a calorimeter; the proposed beam dump experiment SHiP assumes $\sim 2 \times 10^{20}$ POT collected in 5 years of operation; the proposed electron fixed-target experiment LDMX during Phase II with a beam energy of 8 GeV and 10^{16} electrons on target (EOT); Belle-II and LHCb assume the full expected integrated luminosity of 50 ab^{-1} and 15 fb^{-1}, respectively; HPS assumes 4 weeks of data at JLab at each of several different beam energies; NA64 corresponds to 5×10^{12} EOT with 100 GeV energy; and AWAKE is assumed to be working as a fixed-target experiment with a 10-m-long decay volume and 10^{16} EOT accelerated in a 50 – 100 m long plasma cell to the energy O(50 GeV).

Ref: "FASER's Physics Reach…", FASER coll., 2018

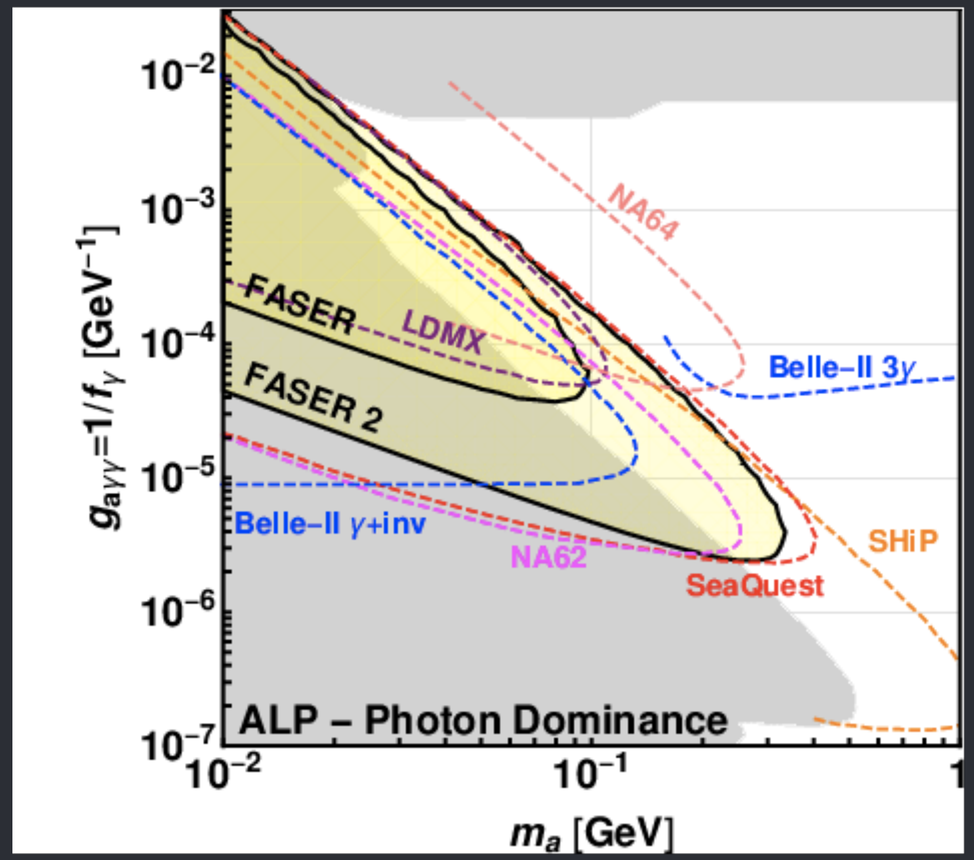
Faser Physics Reach

Axion-like particle production and sensitivity

- Beside production in inelastic events, ALPs may be produced via the Primakoff process at the TAN*.
- ~ 10^{16} photon-TAN interactions in Run 3.

** Target Absorber for Neutrals*

… Giving FASER sensitivity to ALPS with coupling to photons.

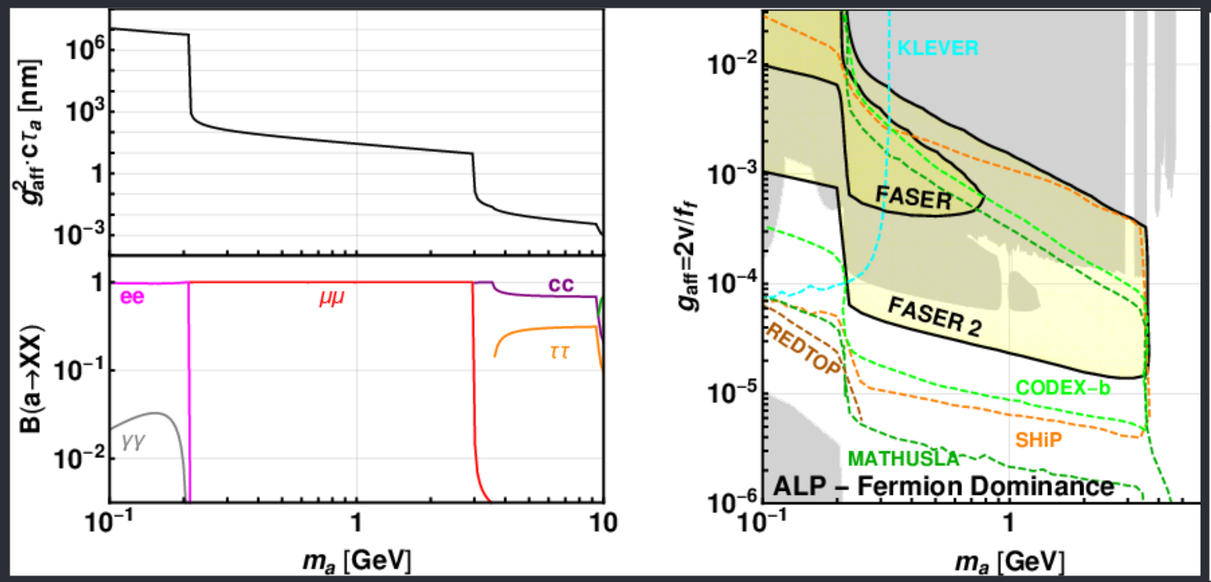


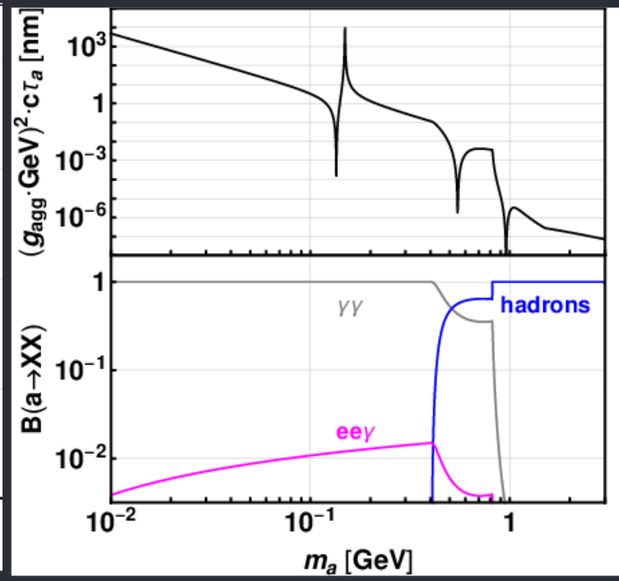
Sensitivity to ALPs with coupling to photons.
FASER 2 a planned extended detector (parameters not confirmed). FASER: 150 fb^{-1}, FASER 2: 3 ab^{-1}, with assumed dimensions R= 1m, Δ= 5 m

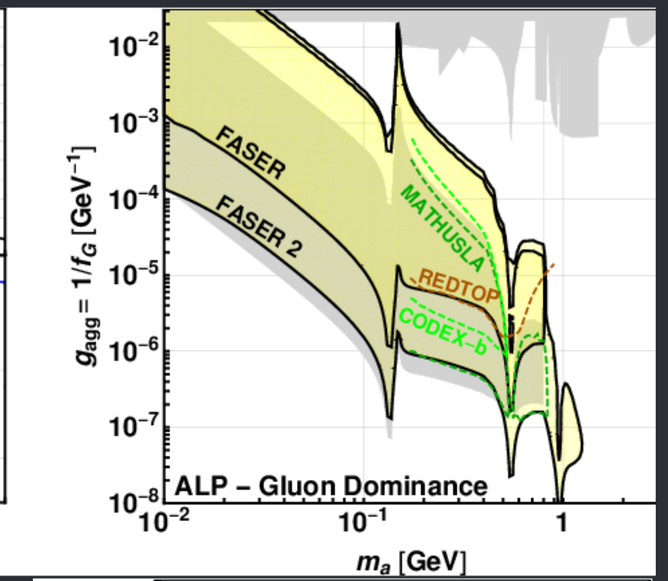
Ref: "FASER's Physics Reach…", FASER coll., 2018

Physics predicted exclusion limits

Axion interactions







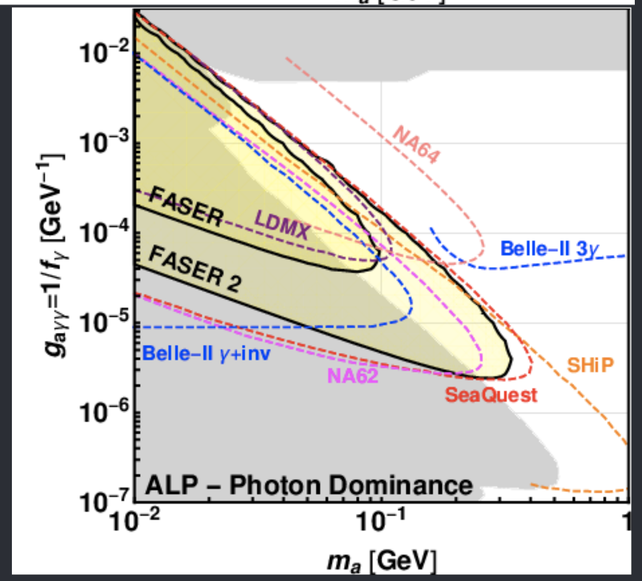
Effective Lagrangian

$$\mathscr{L} = \mathscr{L}_{SM} + \mathscr{L}_{DS} - \frac{1}{2}m_a^2 a^2 - \frac{1}{4}g_{a\gamma\gamma} a F_{\mu\nu}\tilde{F}^{\mu\nu} - \frac{g_s^2}{8} g_{agg} a G^A_{\mu\nu}\tilde{G}^{A\mu\nu} - i\Sigma_f g_{aff}\frac{m_f}{v} a\bar{f}\gamma_5 f$$

largest B.R.:
$a \to \gamma\gamma$

largest B.R.:
$a \to \gamma\gamma$
$a \to hadrons$

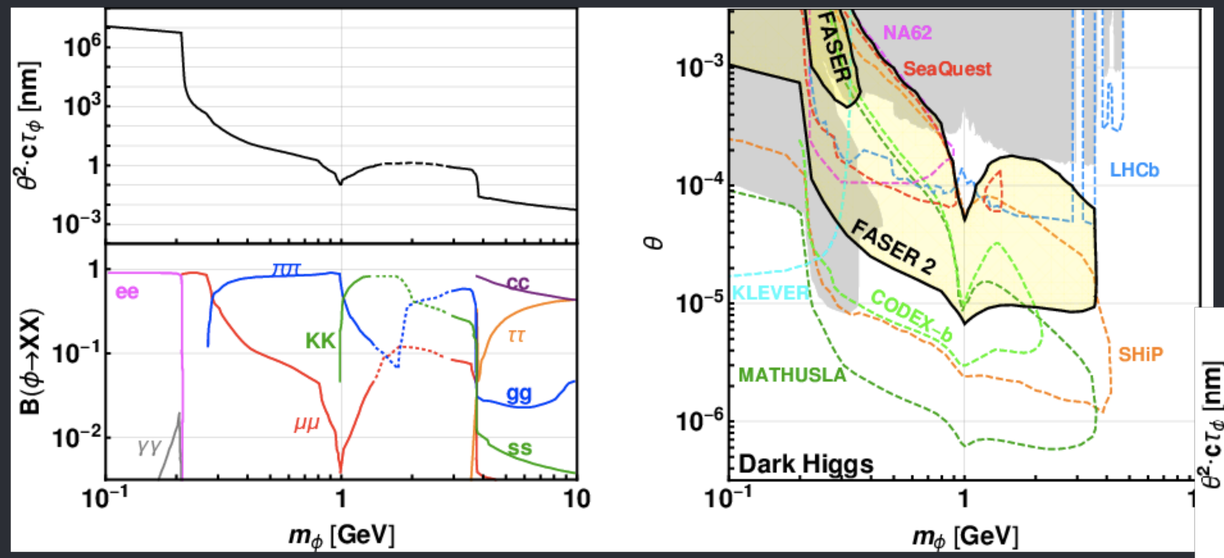
largest B.R.:
$a \to f\bar{f}$

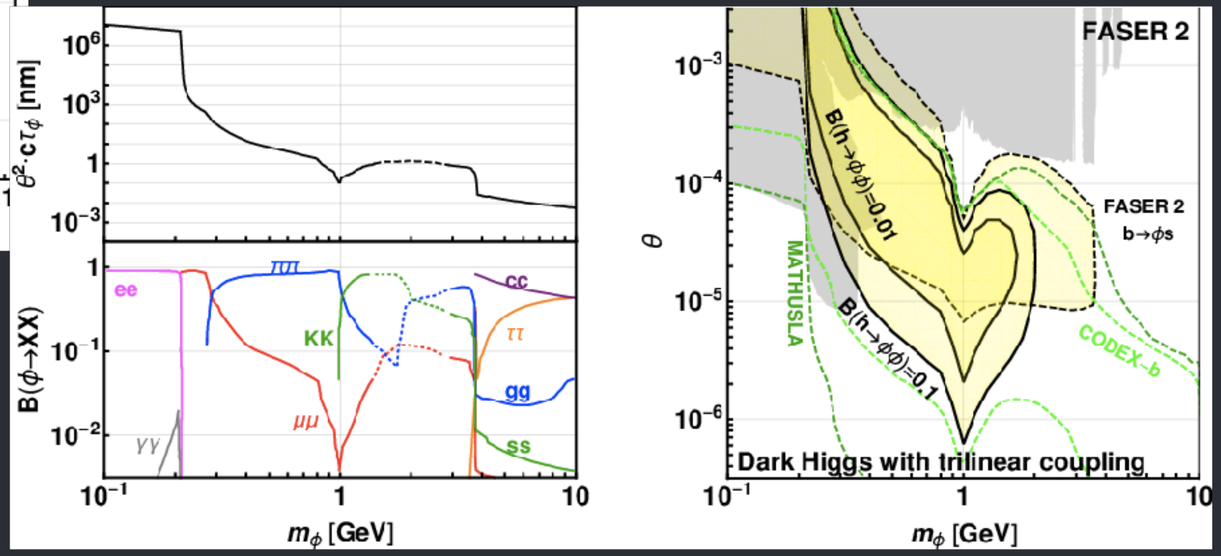


Physics predicted exlusion limits

Dark Higgs

- Sensitivity to dark Higgs without and with trilinear couplings





Effective Lagrangian

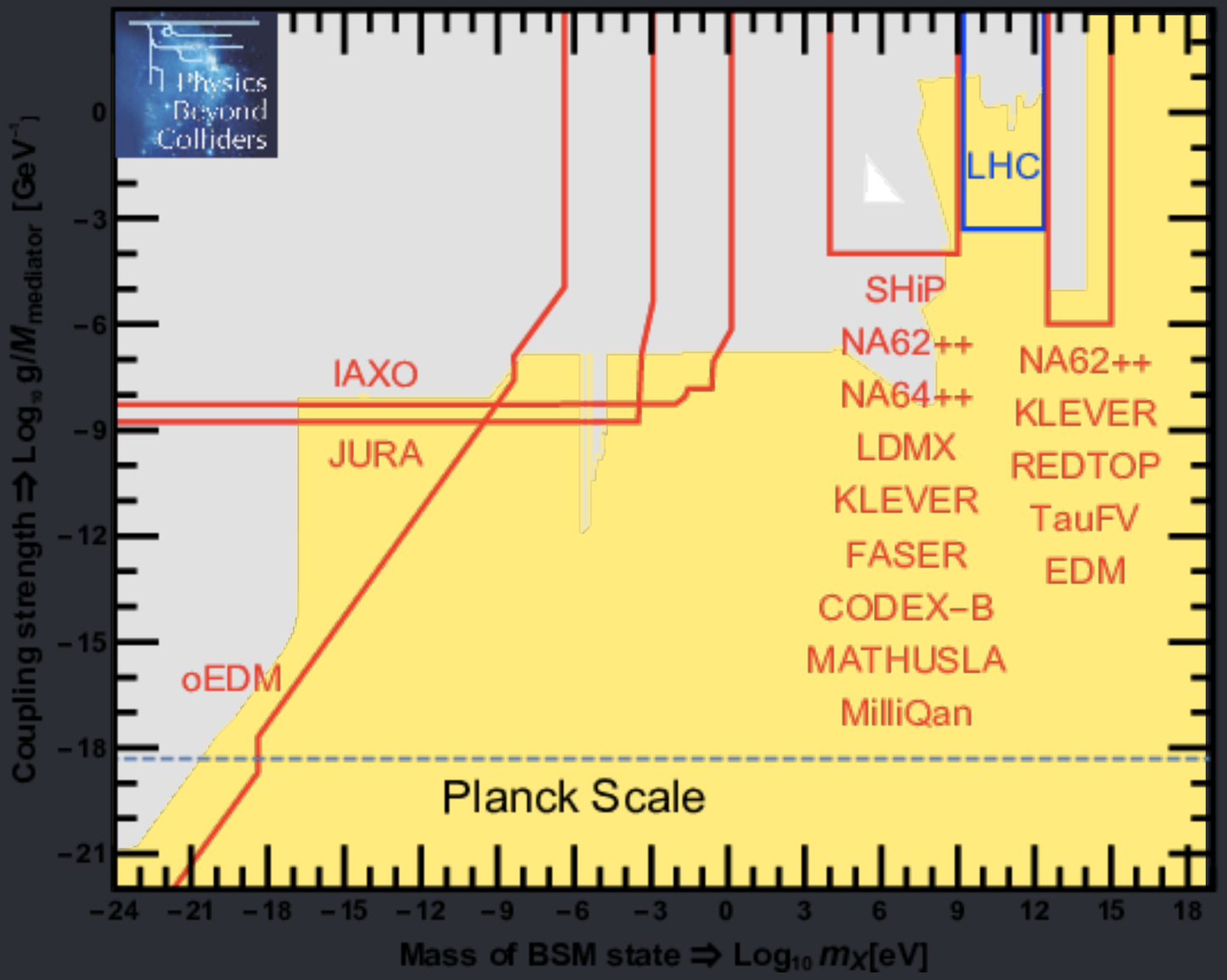
$$\mathscr{L} = -m_\phi^2\phi^2 - sin\theta\frac{m_f}{v}\phi\bar{f}f - \lambda v h\phi\phi + \ldots$$

trilinear couplings $\lambda = 0.0046,\ 0.0015\ (10\,\%, 1\,\%\ B.R.)$

Physics predicted exclusion limits

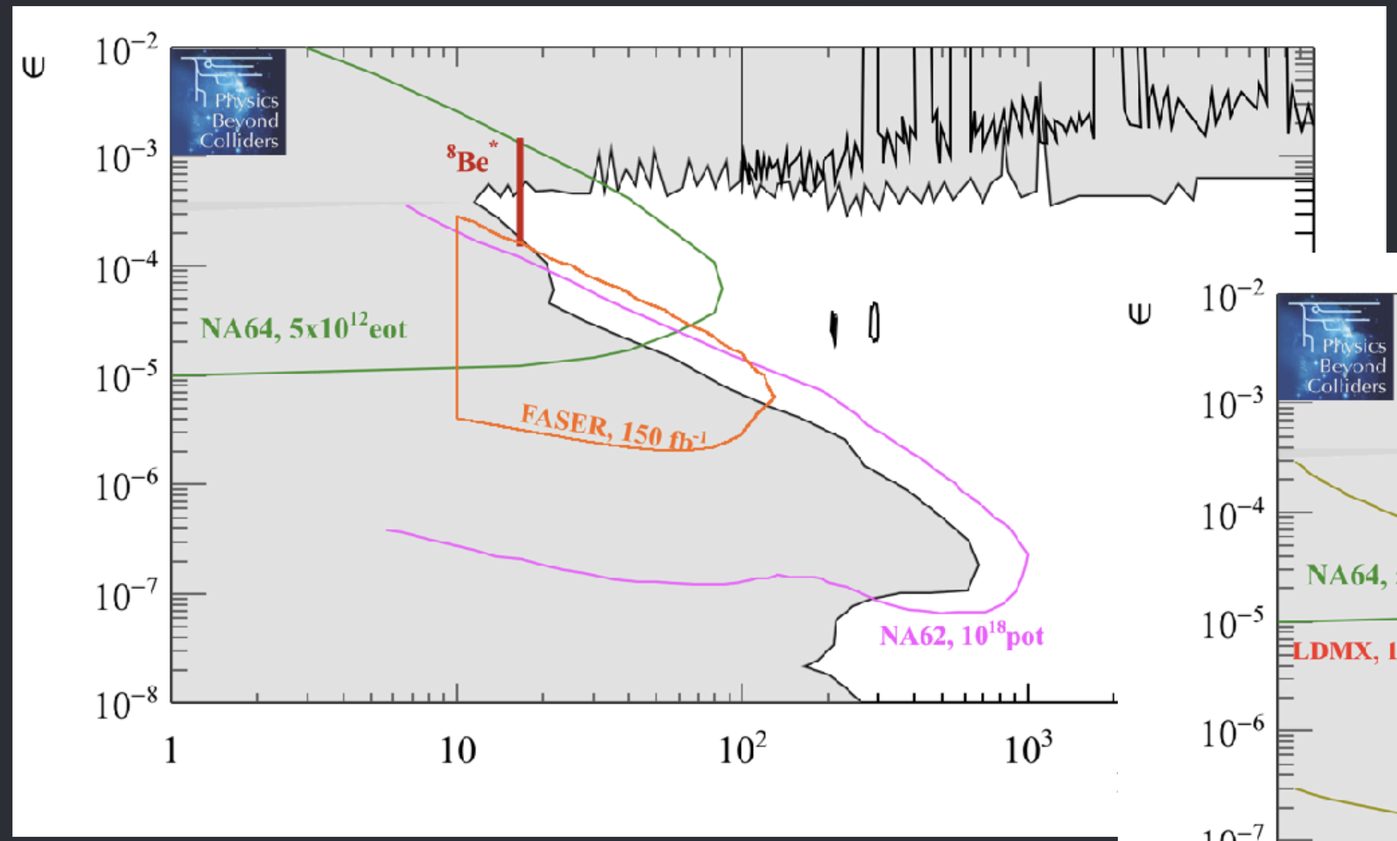
Overview

- Based on selection of specific models.

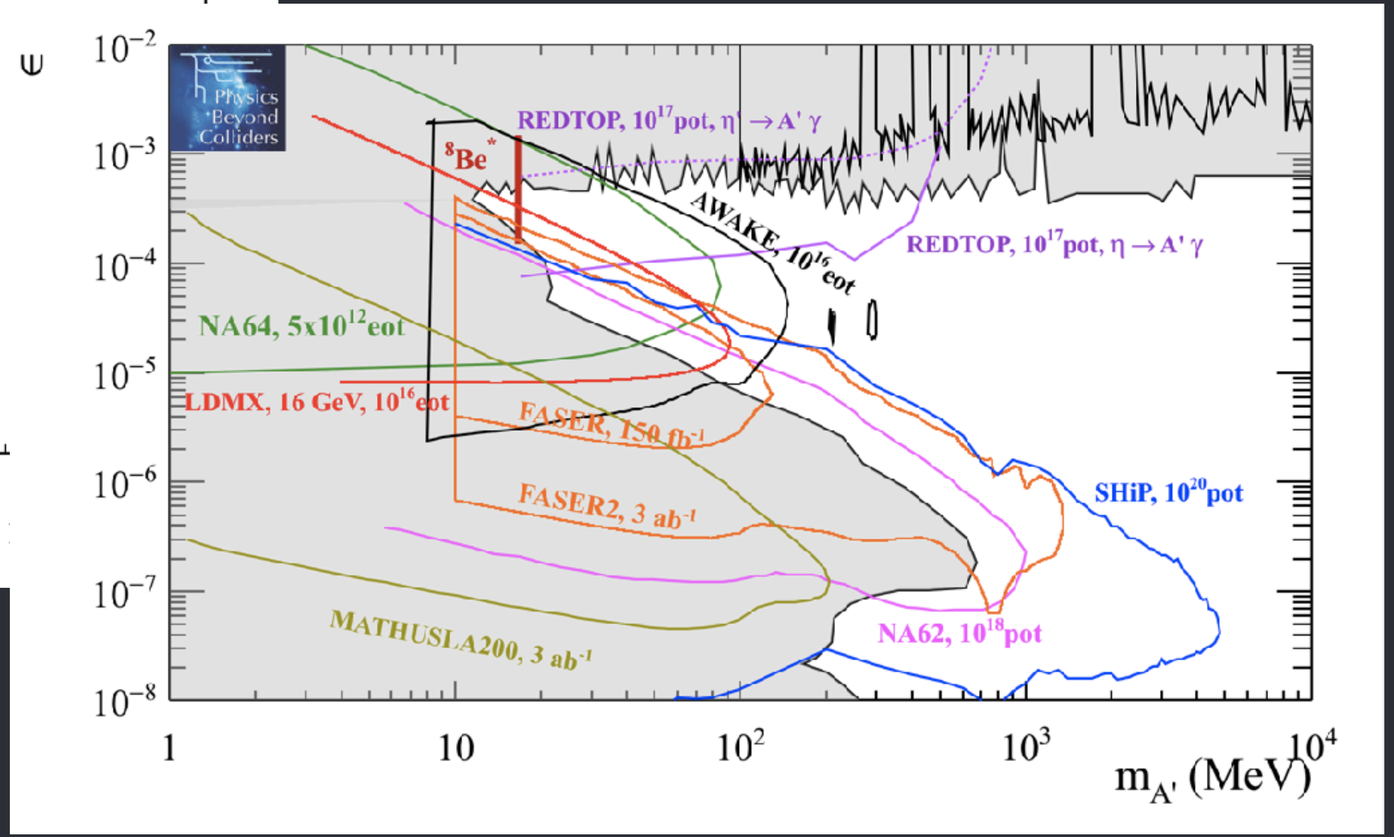


Physics predicted exclusion limits

Dark photon to visible decay



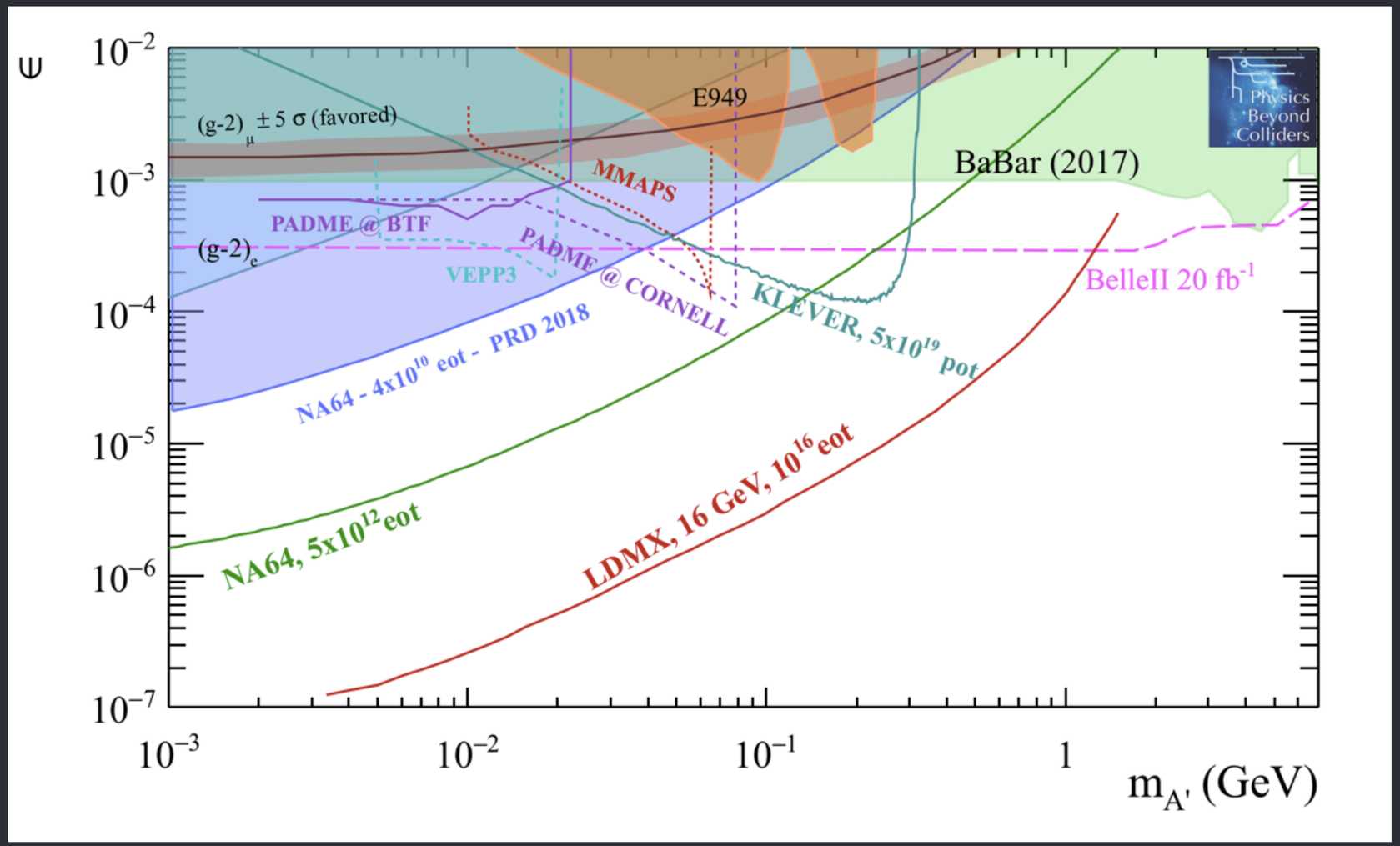
- 5 year timescale



- 10-15 year timescale

Physics predicted exclusion limits

Dark photon to invisible decay



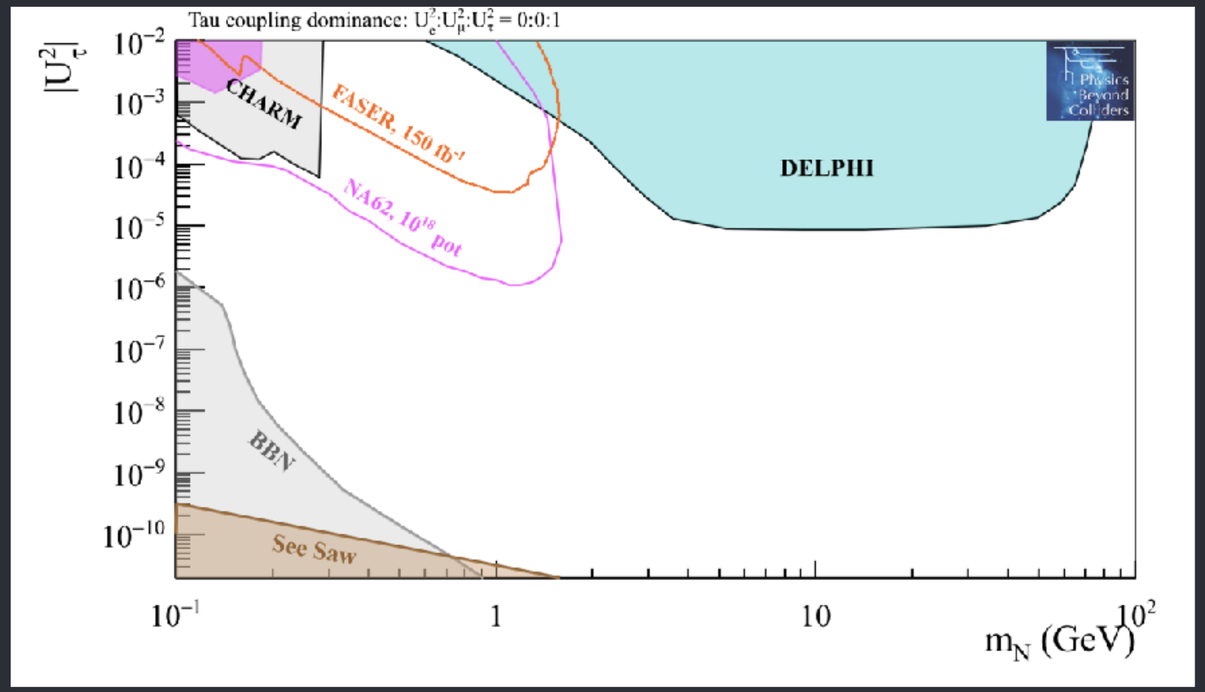
- NA64: 5 year timescale
- LDMX, KLEVER: 10-15 year timescale

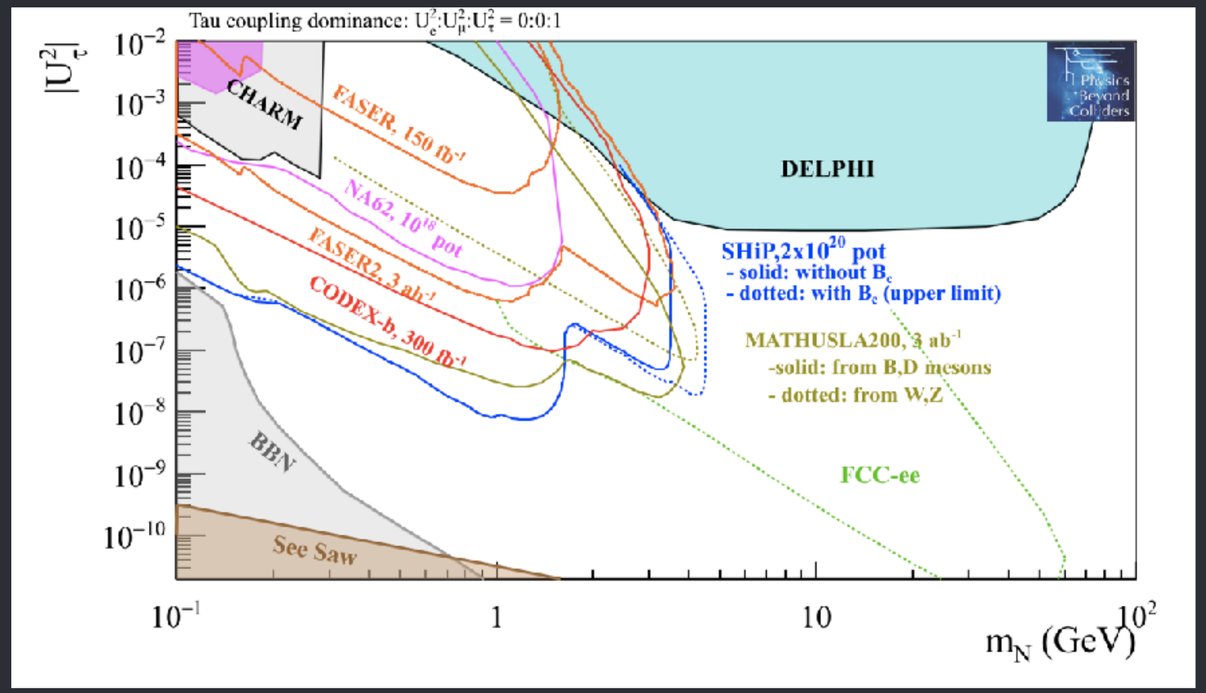
Ref: [Physics Beyond Colliders Working Group Report]

Physics predicted exclusion limits

Heavy Neutral Lepton Current and Future Bounds

- Projected limits on 5 year time scale.





- Projected limits on 10-15 year time scale.

Ref: [Physics Beyond Colliders Working Group Report]

More physics

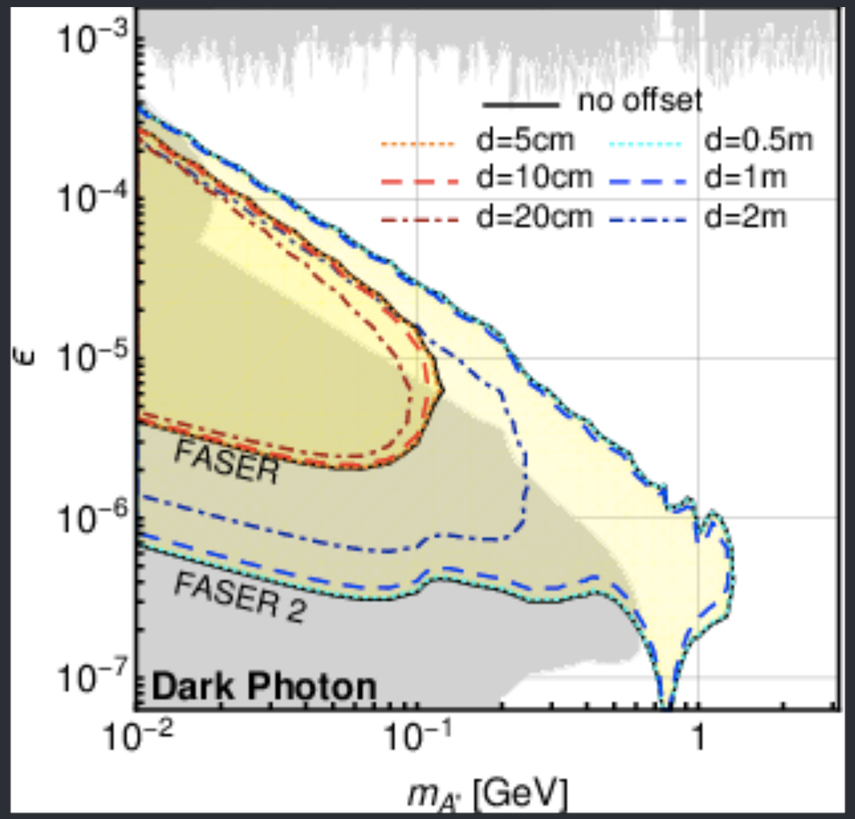
Complete physics programme

Benchmark Model	FASER 1	FASER 2	References
BC1: Dark Photon	√	√	Feng, Galon, Kling, Trojanowski, 1708.09389
BC1': $U(1)_{B-L}$ Gauge Boson	√	√	Bauer, Foldenauer, Jaeckel, 1803.05466; 1811.12522
BC2: Invisible Dark Photon	–	–	–
BC3: Milli-Charged Particle	–	–	–
BC4: Dark Higgs Boson	–	√	Feng, Galon, Kling, Trojanowski, 1710.09387 Batell, Freitas, Ismail, McKeen, 1712.10022
BC5: Dark Higgs with hSS	–	√	Feng, Galon, Kling, Trojanowski, 1710.09387
BC6: HNL with e	–	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC7: HNL with μ	–	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC8: HNL with τ	√	√	Kling, Trojanowski, 1801.08947 Helo, Hirsch, Wang, 1803.02212
BC9: ALP with photon	√	√	Feng, Galon, Kling, Trojanowski, 1806.02348
BC10: ALP with fermion	√	√	1811.12522
BC11: ALP with gluon	√	√	1811.12522

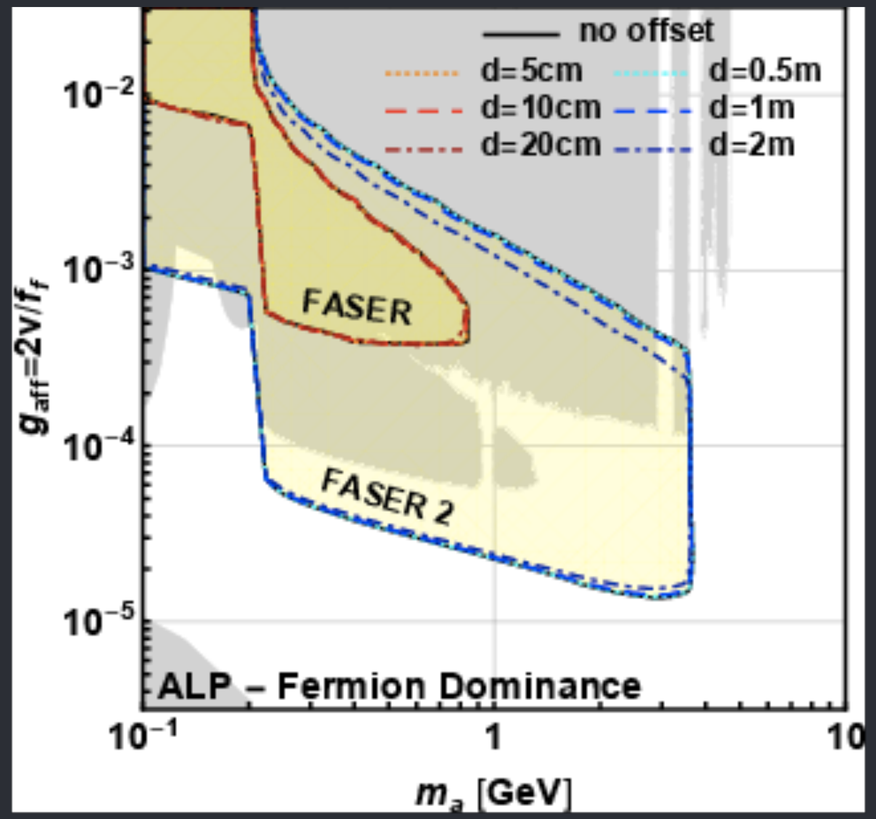
FASER effects on sensitivity

Offset dependence

- LHC crossing angle of 160 μrad , corresponds to shift of collision axis of 7.2 cm.



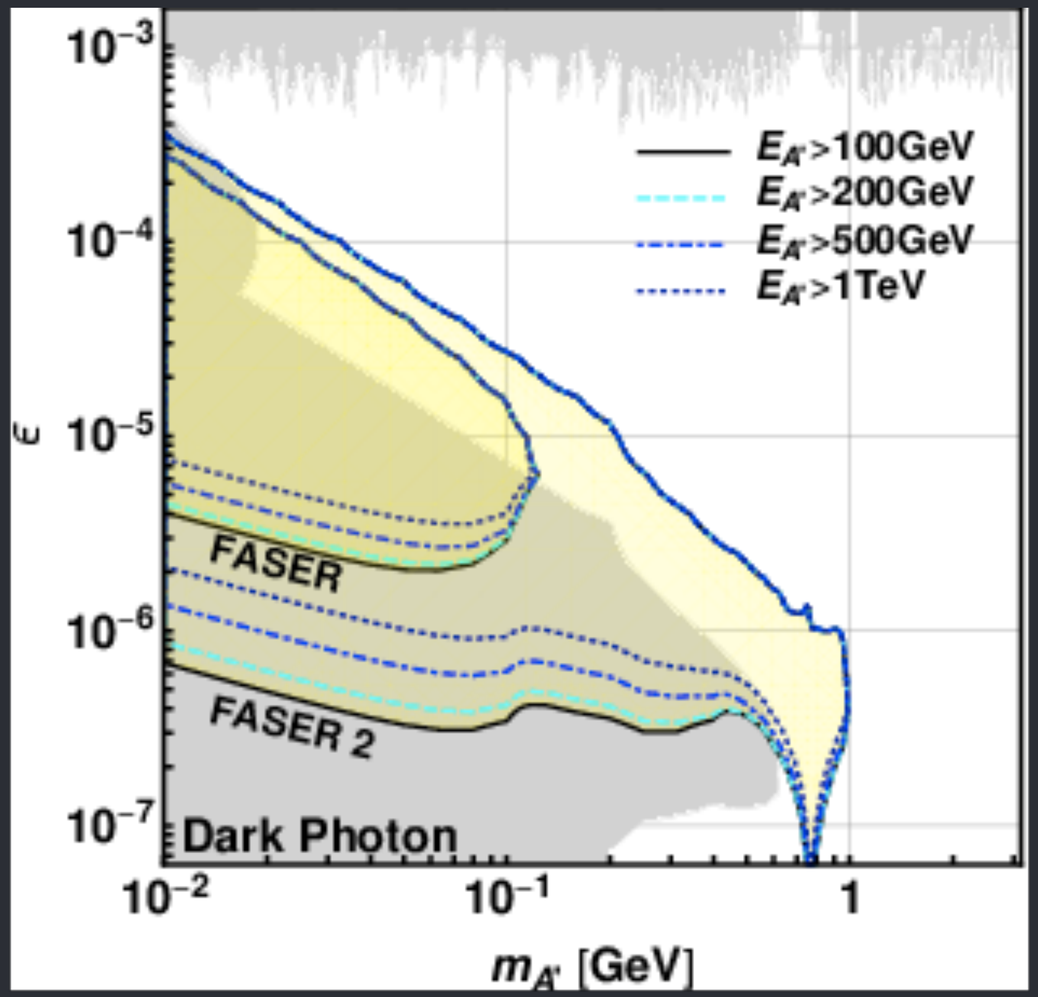
- Dark photon

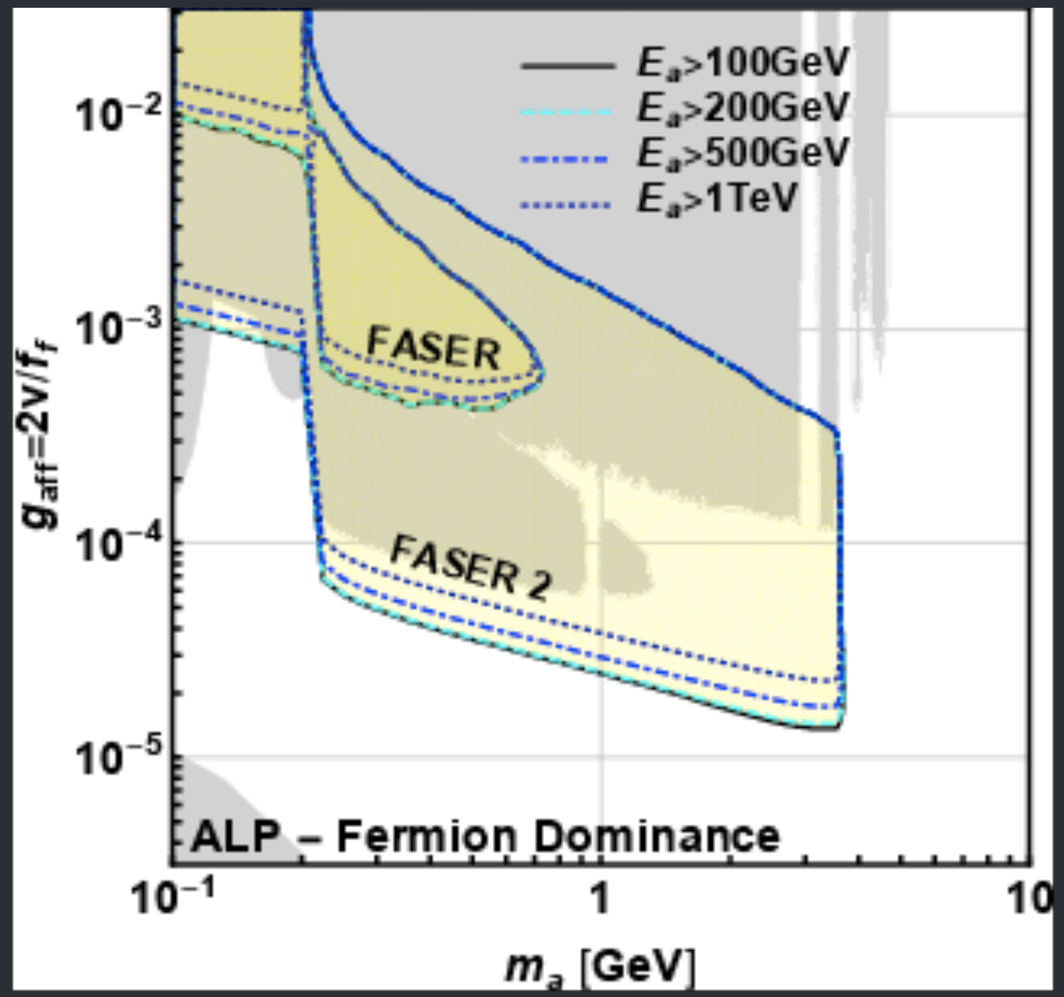


- ALP (fermion dominance)

FASER effects on sensitivity

Energy threshold dependence





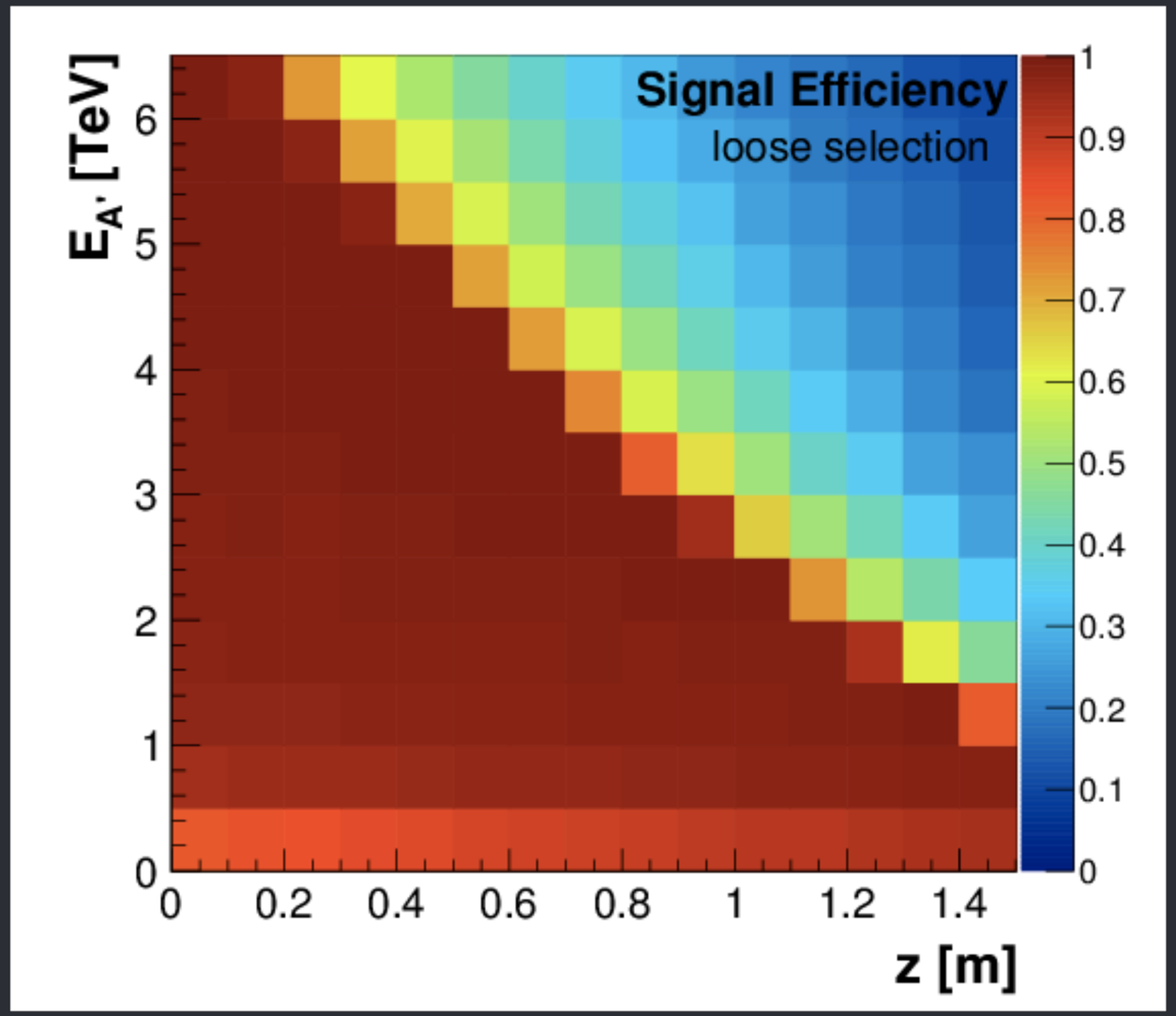
- Dark photon
- Axion, fermion dominance

FASER effects on sensitivity

Signal efficiency

- Signal ε as function of dark photon energy and decay's longitudinal position for mA'=100 MeV, ε = 10^{-5}, track separation > 300 μm for 2nd & 3rd tracker stations.
- More accurate signal ε studies with GEANT simulation ongoing.

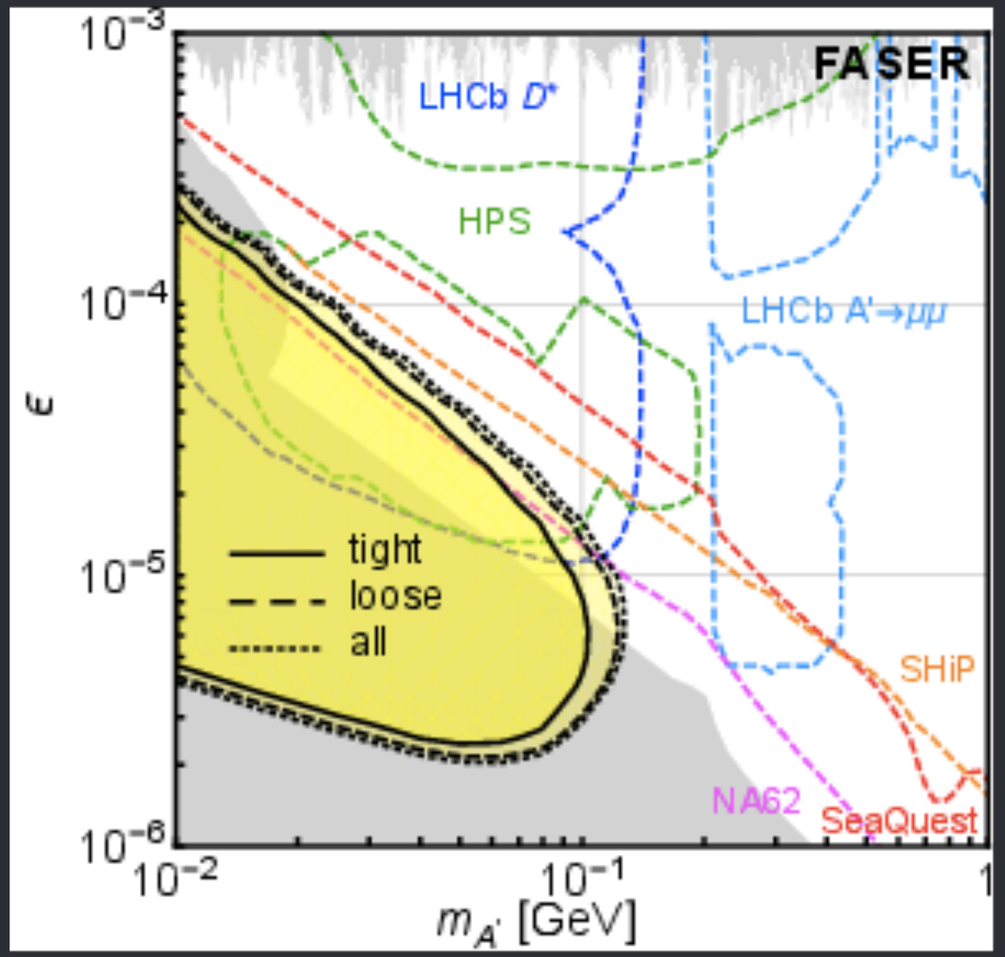
at larger z: decay to close to first tracking station for enough track separation.

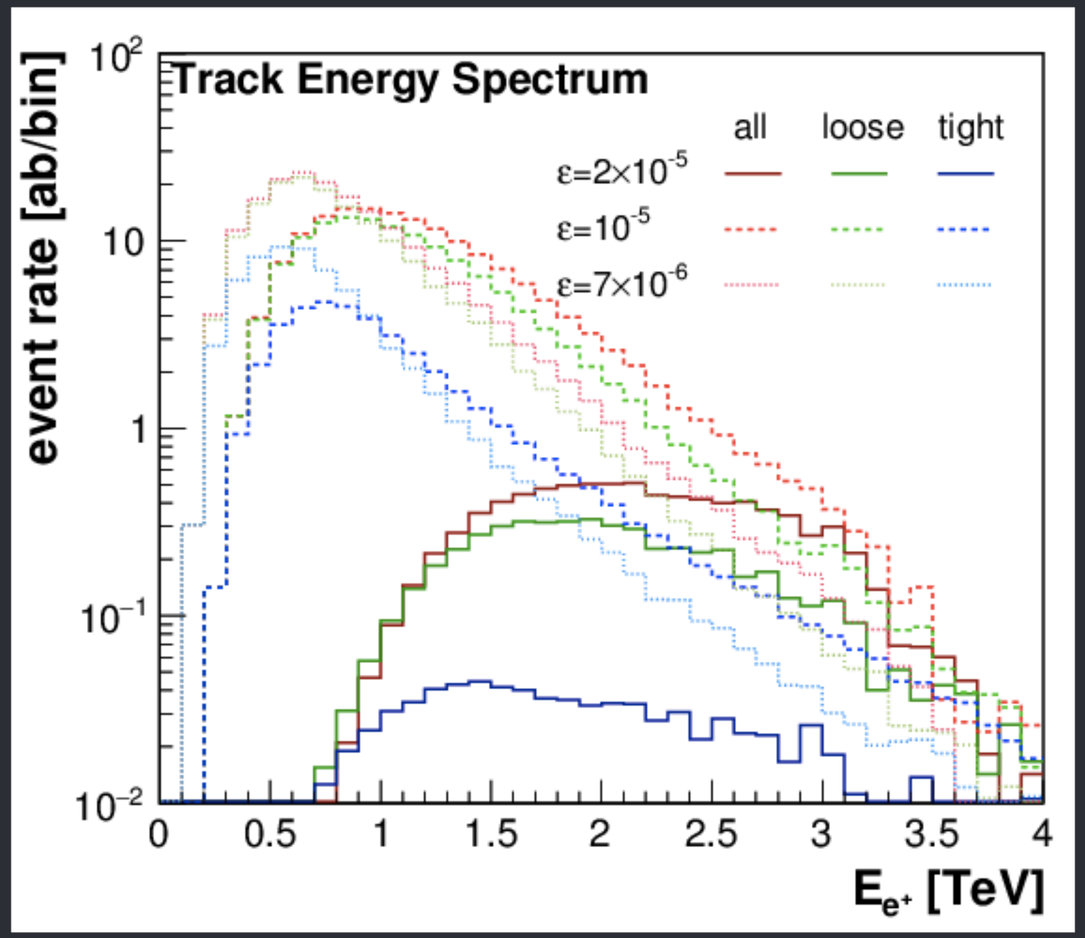


< 500 GeV: drop in ε due to magnet bending.

FASER effects on sensitivity

Dependence on signal selection





- mA'=100 MeV

FASER in detail

Triggering and data acquisition

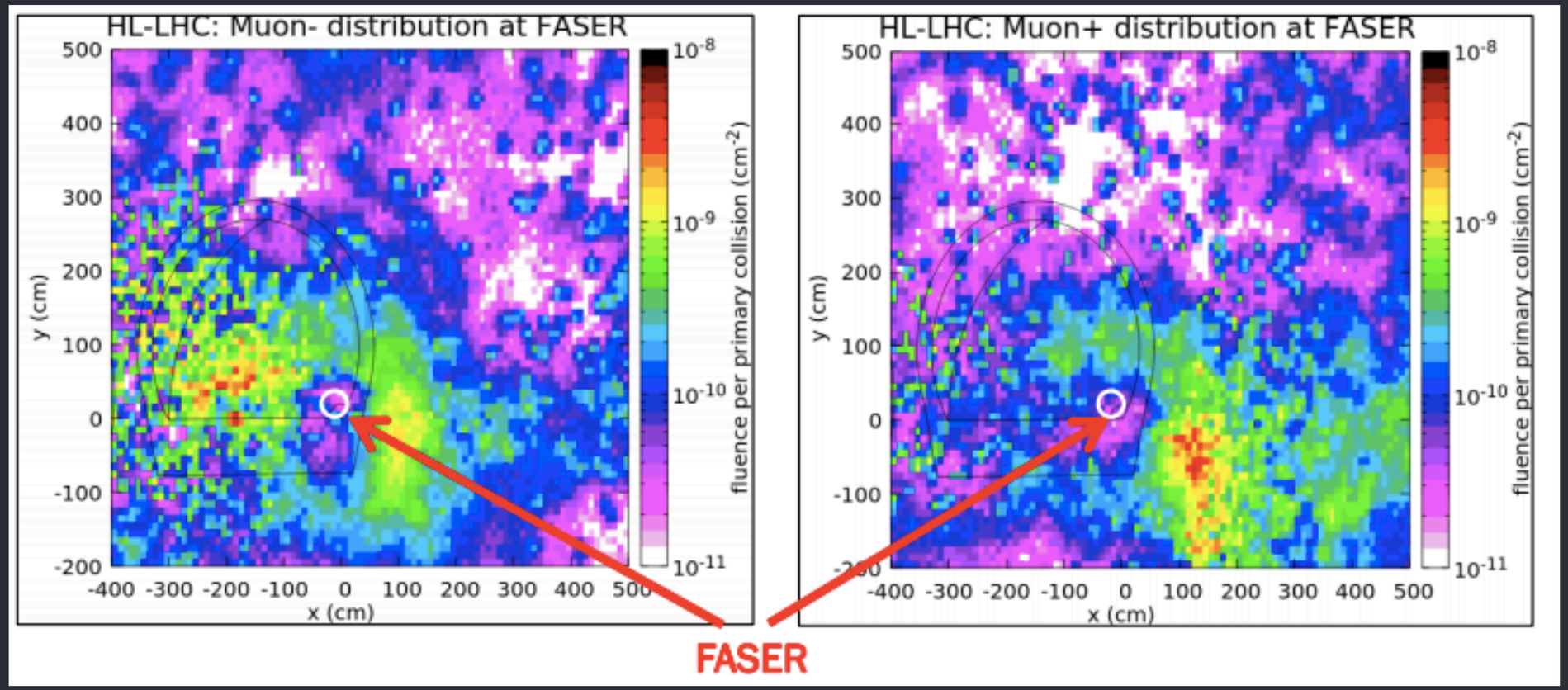
- Expected trigger rate:
  - Veto scintillator: 360 Hz
  - Timing scintillators: 640 Hz
  - Preshower scintillators: 360 Hz
  - Calorimeter (E>100 GeV): < 5 Hz
  - Random trigger: ~10 Hz

Largely overlapping

Faser Physics Reach

Determing background rate

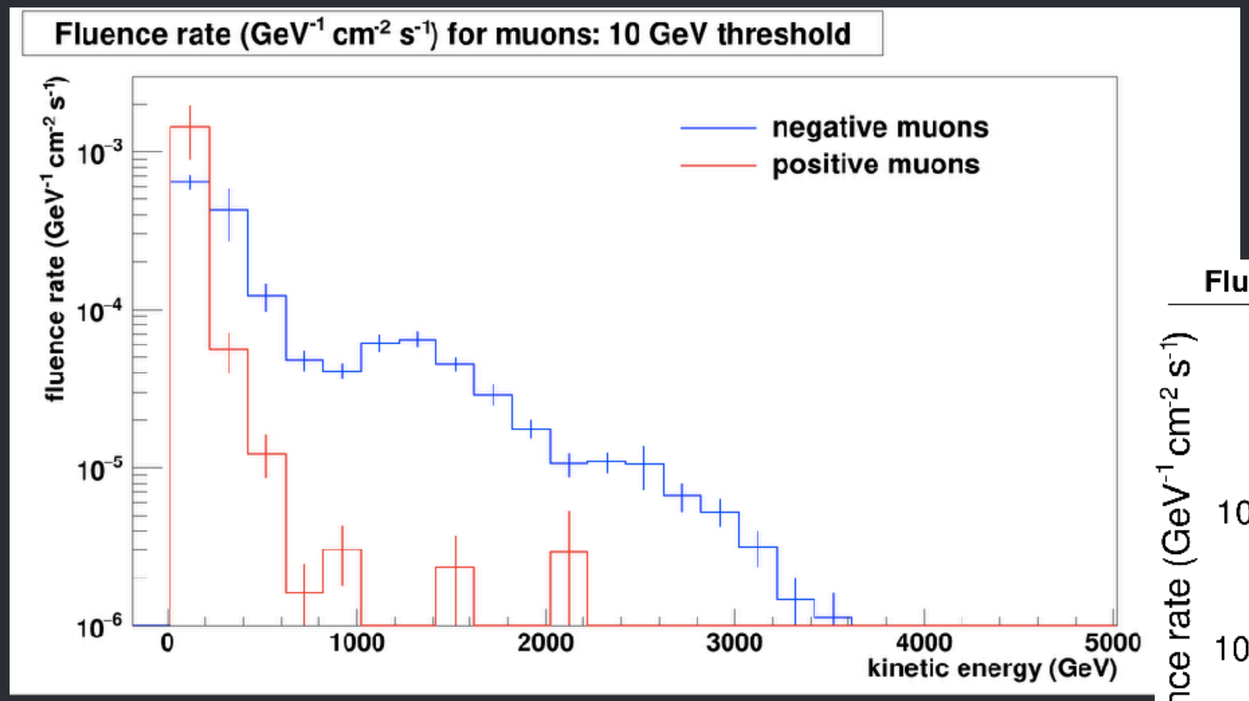
FLUKA simulation: Magnets very helpully deflect muons away from beam axis.

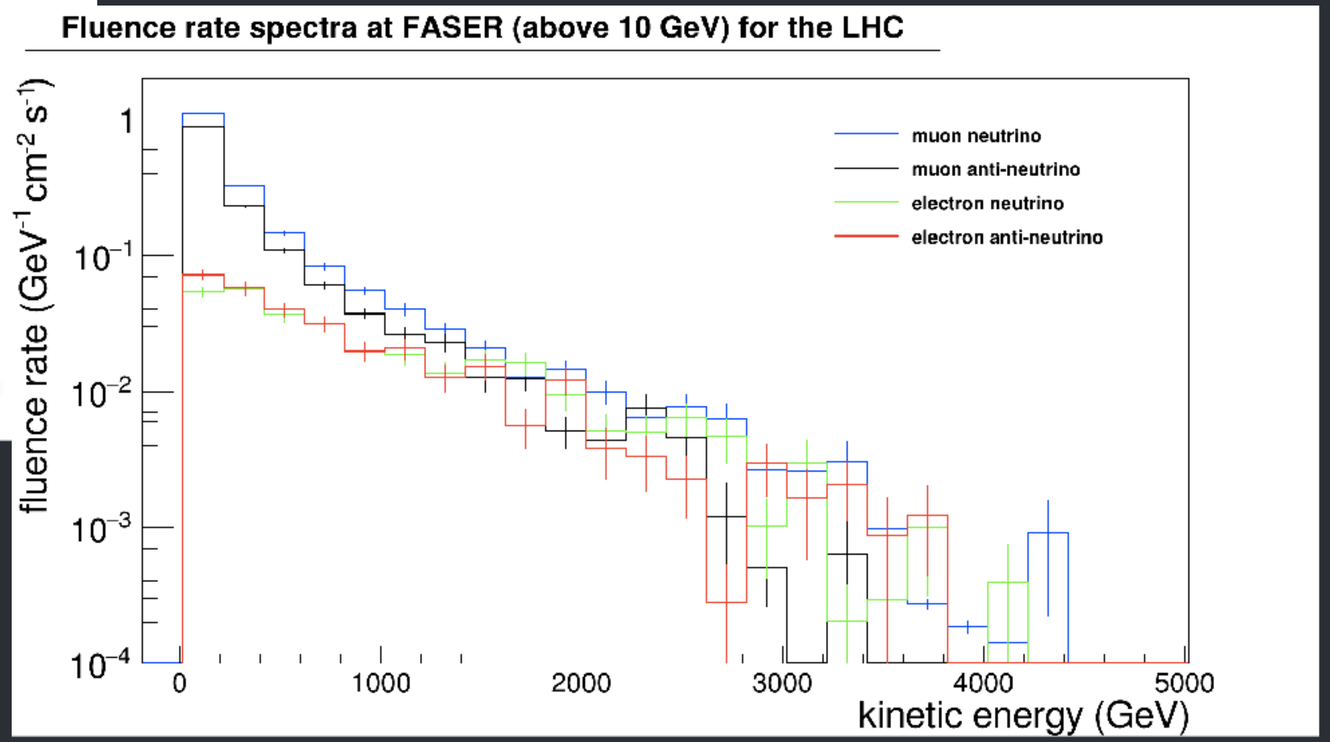


Development of studies with accurate LHC, material and detector simulations ongoing for more accurate determination of background rate.

Faser Physics Reach

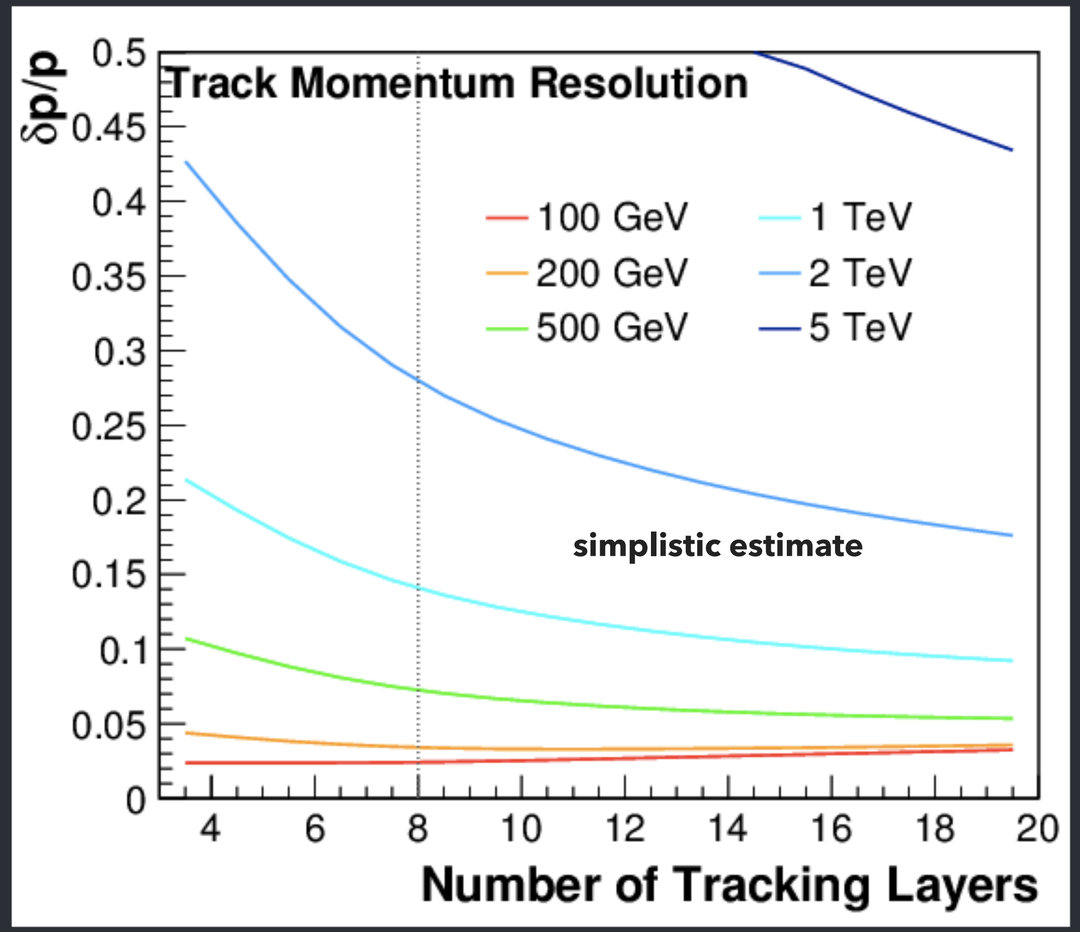
Determing background rate





FASER in detail

Tracking system performance requirements

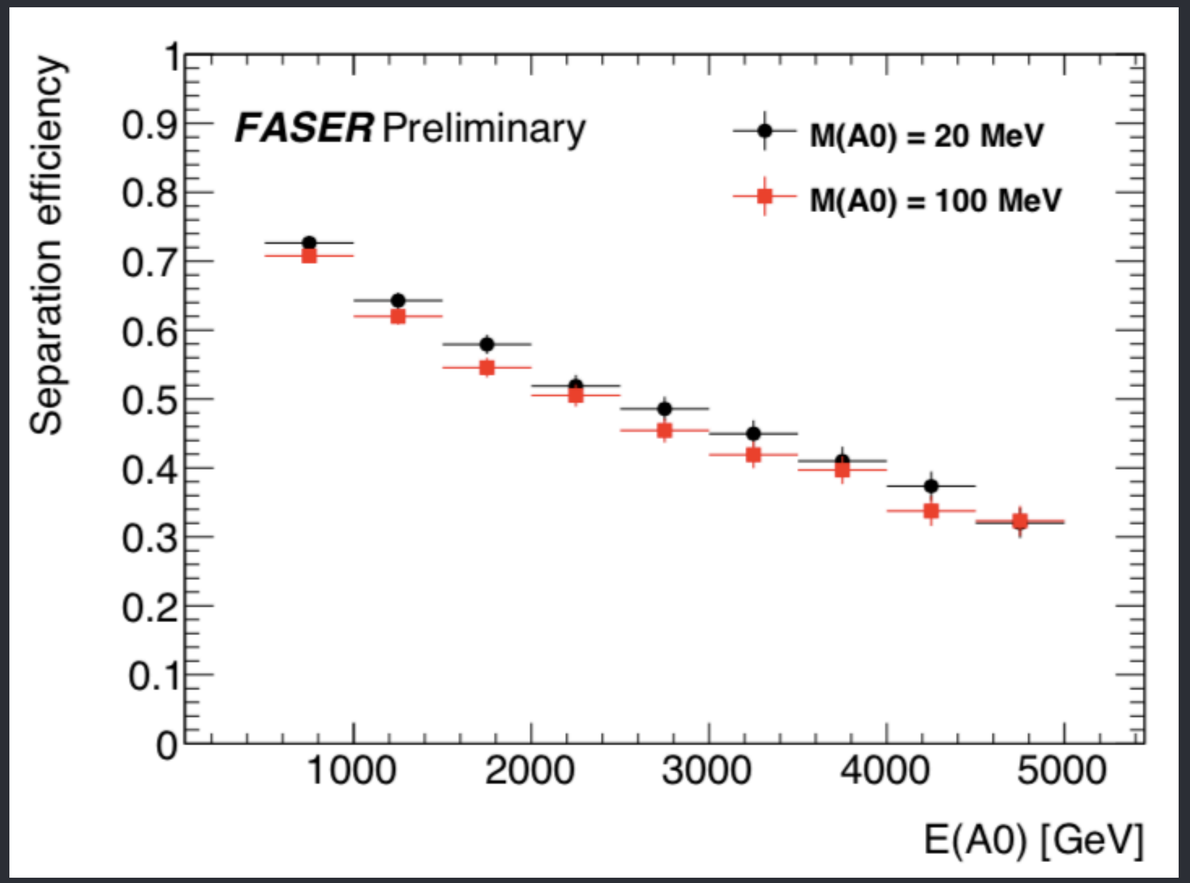


Track momentum resolution

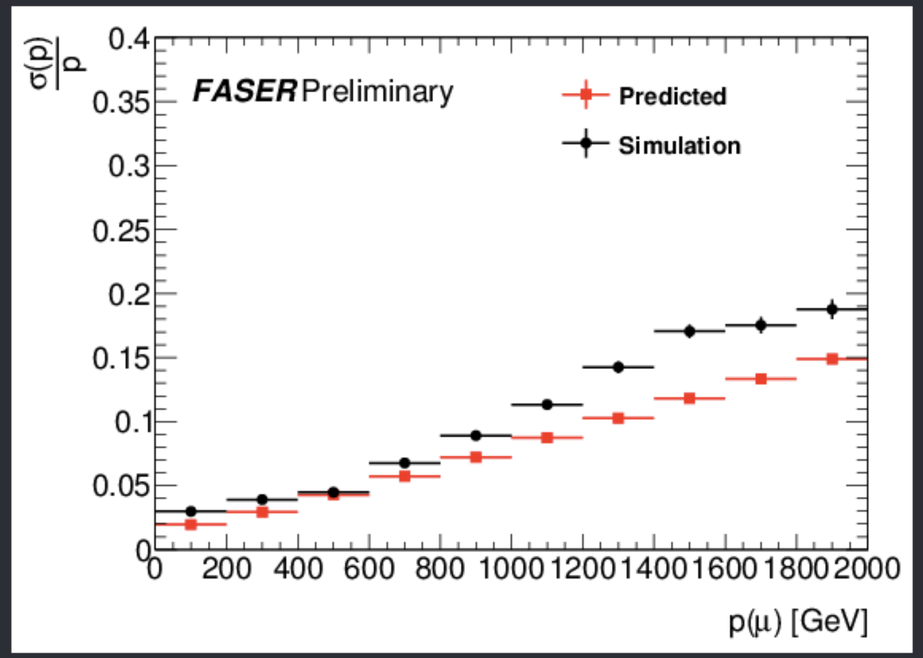
- Idealised momentum resolution: 8 tracking layers good compromise between resolution and costs. For low momenta, expect good resolution.

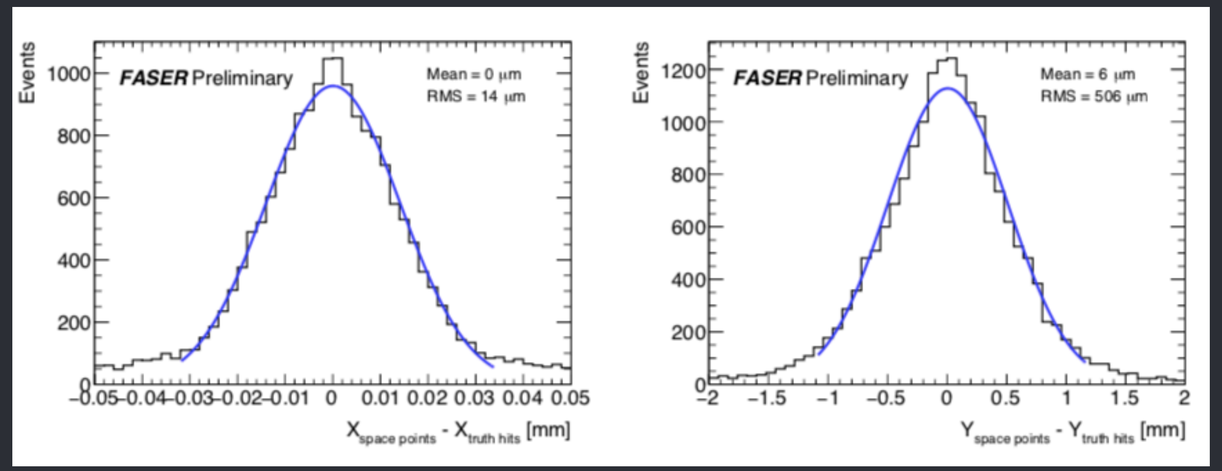
FASER expected performance

Track separation



Preliminary two-track separation efficiency based on isolated space-points in the first tracker plane, for a dark photon of mass M and energy E (simulation)





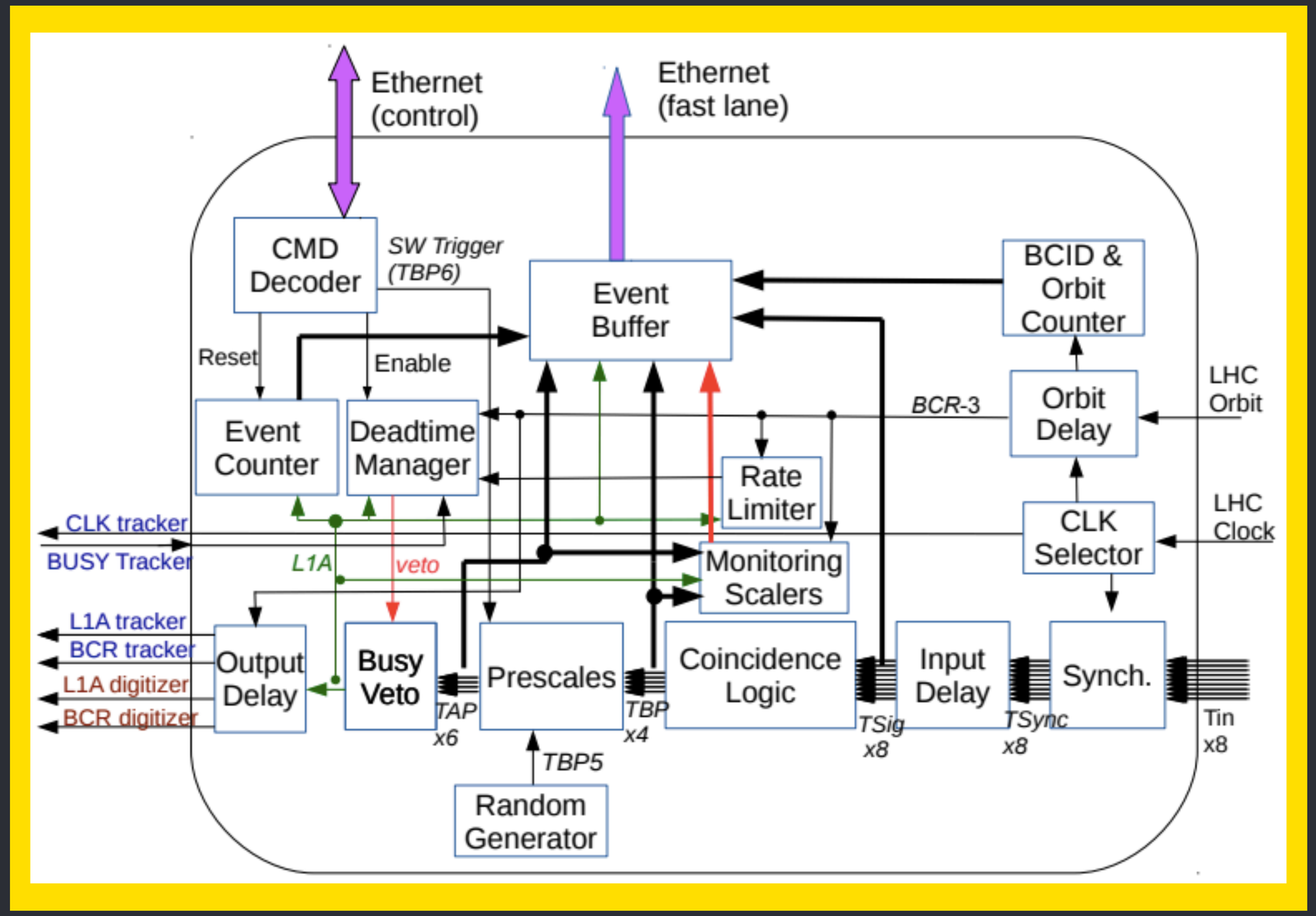
Space point resolutions for simulated dark photon decay

References:

- "FASER Technical Proposal", FASER coll., 2018

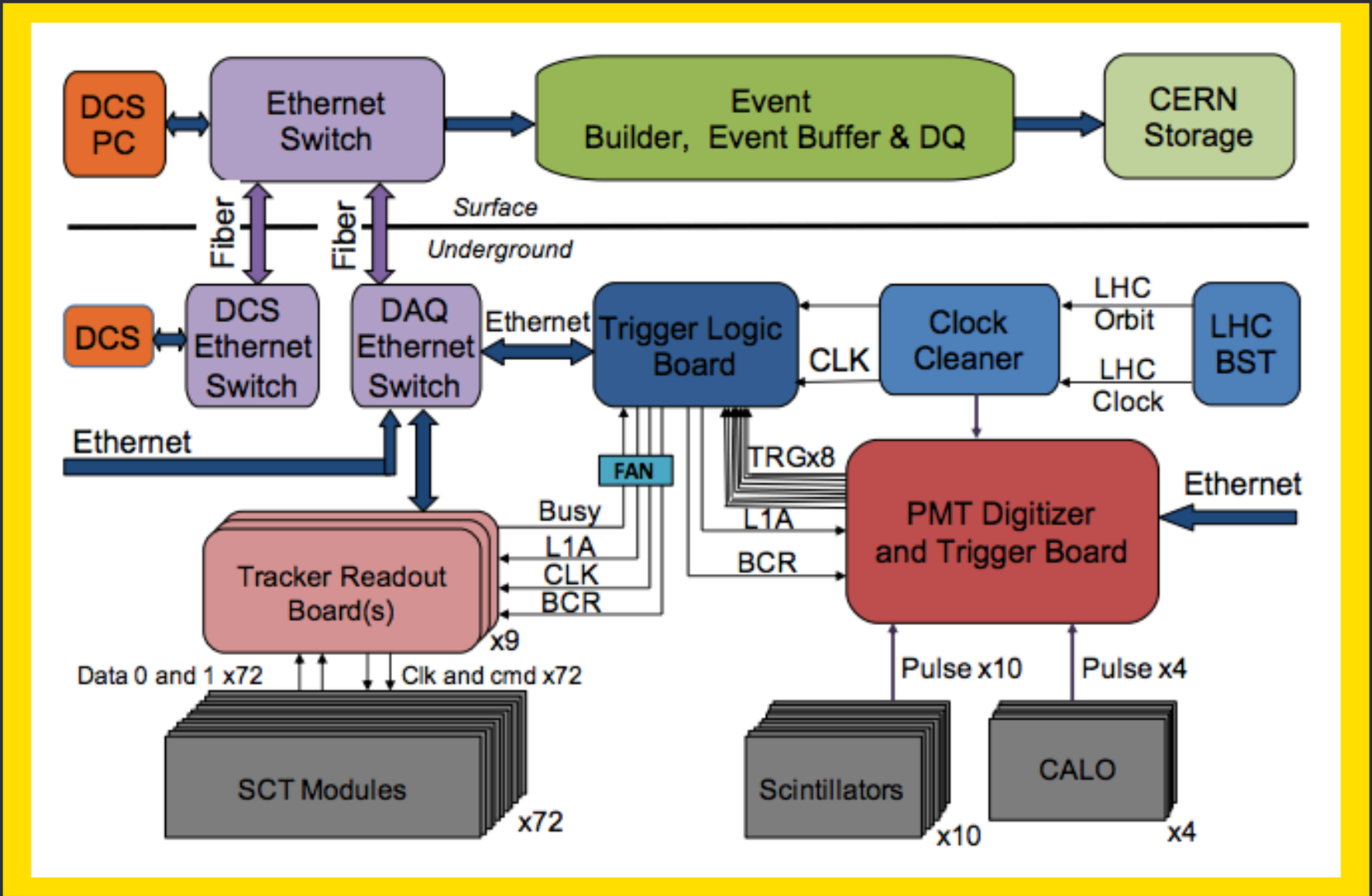
FASER in detail

Triggering and data acquisition



FASER in detail

Triggering and data acquisition

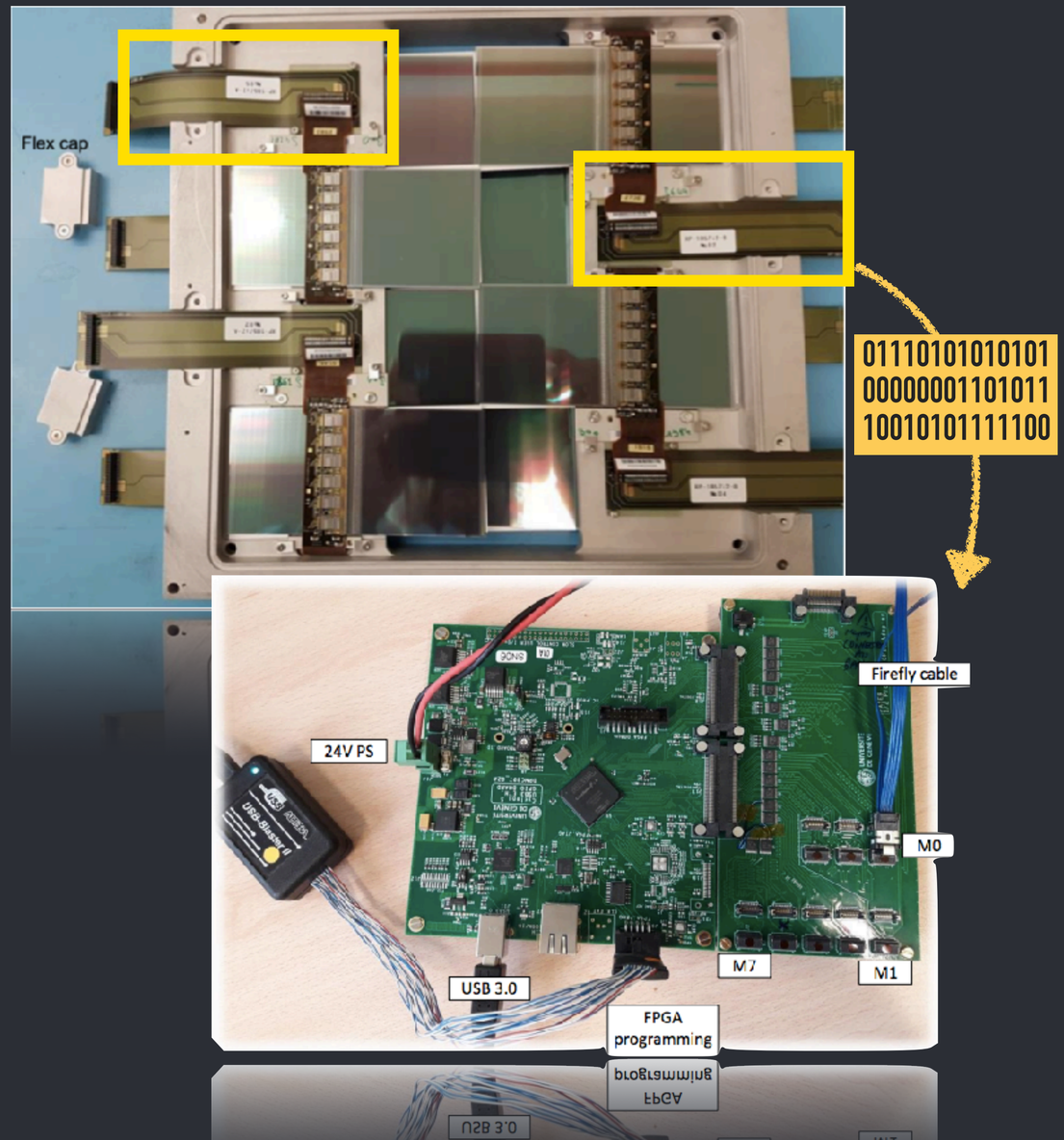


FASER in detail

Tracking system

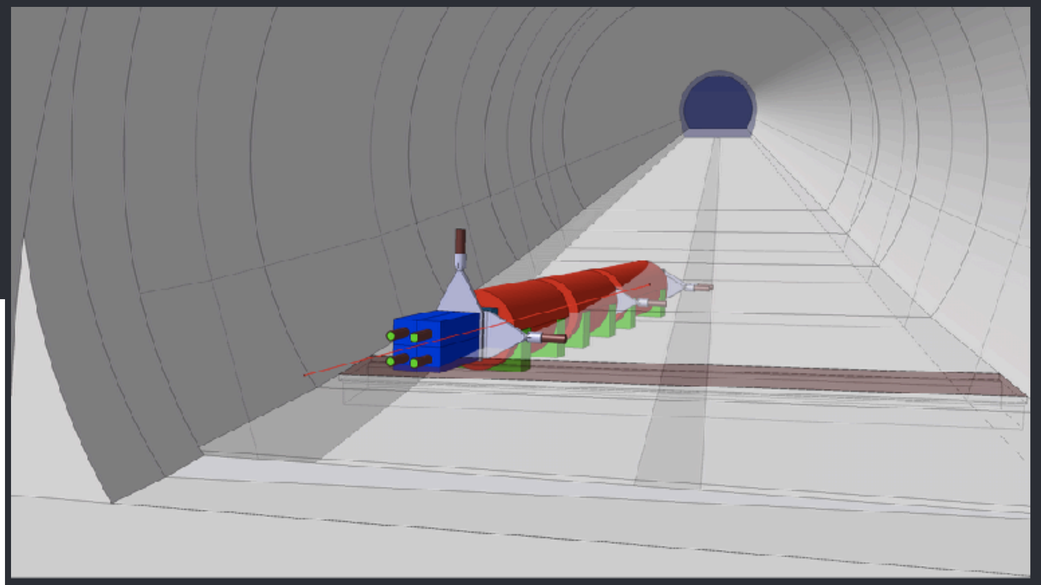
- Read out not big challenge, ~650 Hz rate, roughly 200 bytes/plane:
  - Read-out on custom made flex cables, delivering data to single tracker read-out board/plane.
  - TRB a general purpose (GPIO) board with one FPGA:
    - Simple data processing & error handling.

custom made flex cables

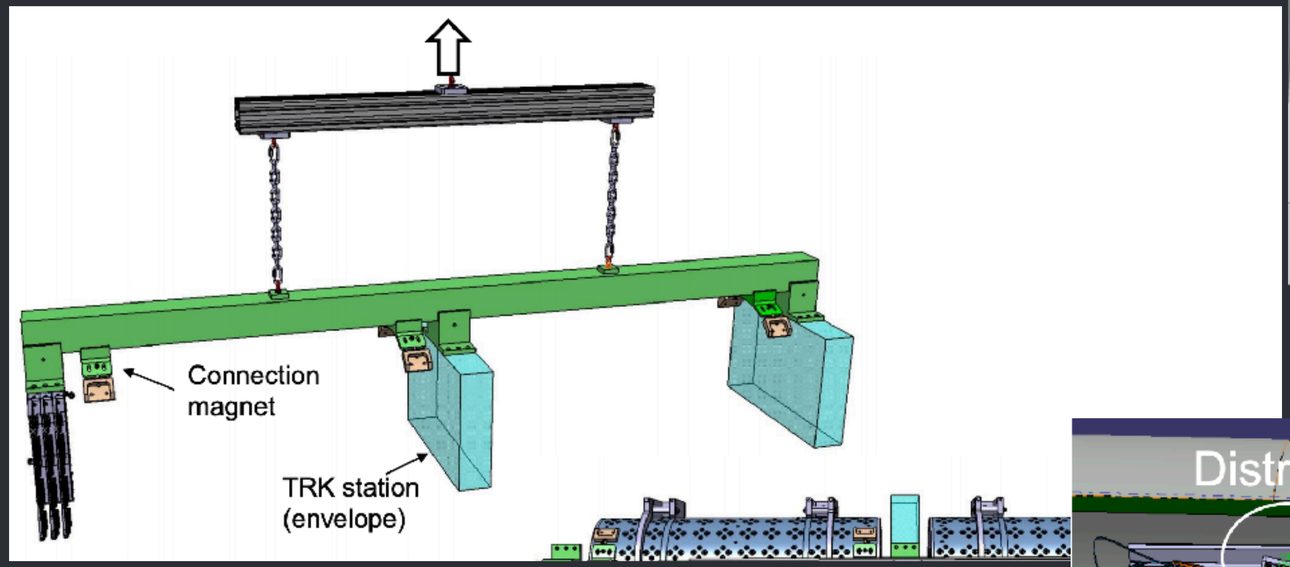


TI12

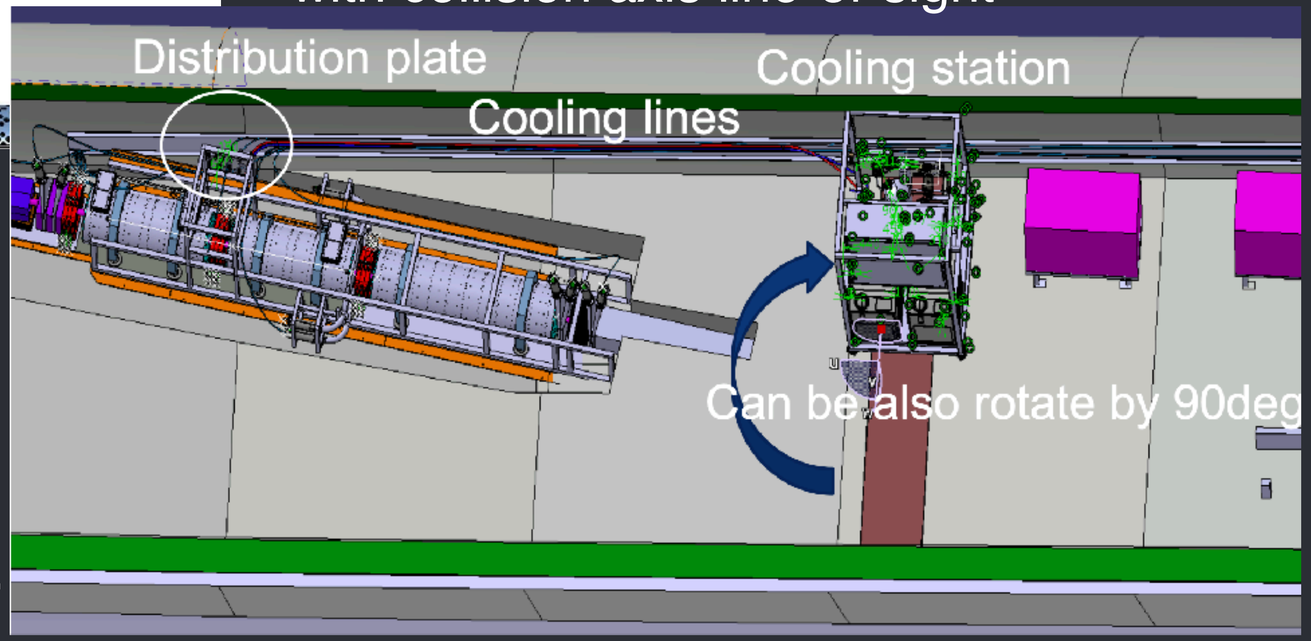
Installation



Trench needed to keep detector aligned with collision axis line-of-sight



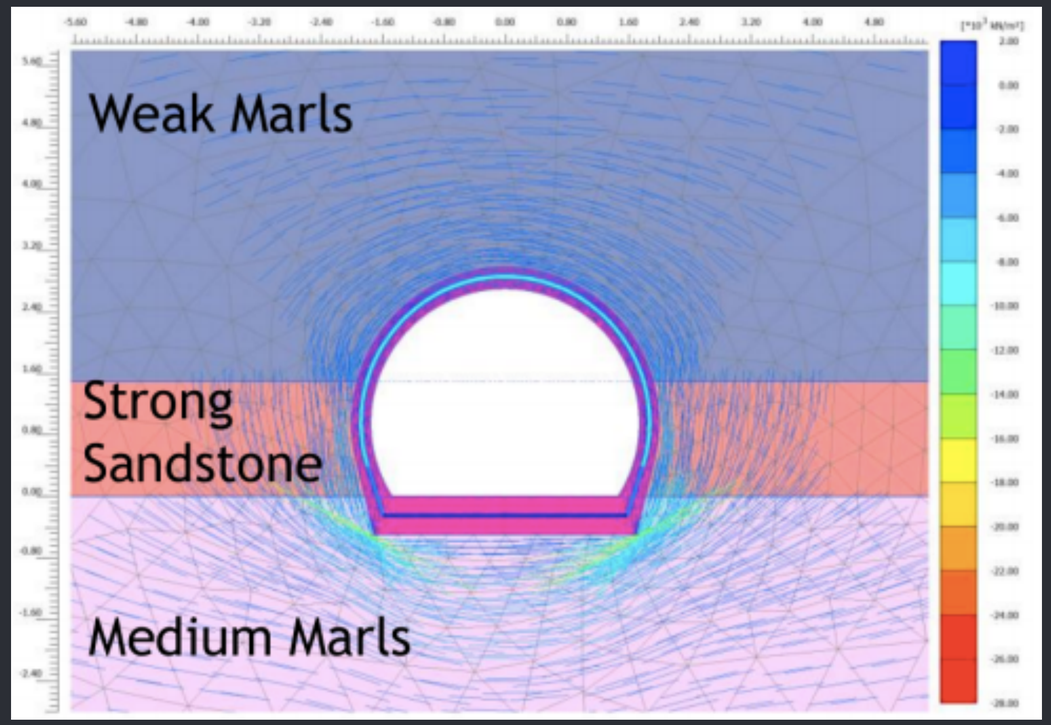
Backbone for insertion of stations into permanent magnets



Water cooling for tracker modules.

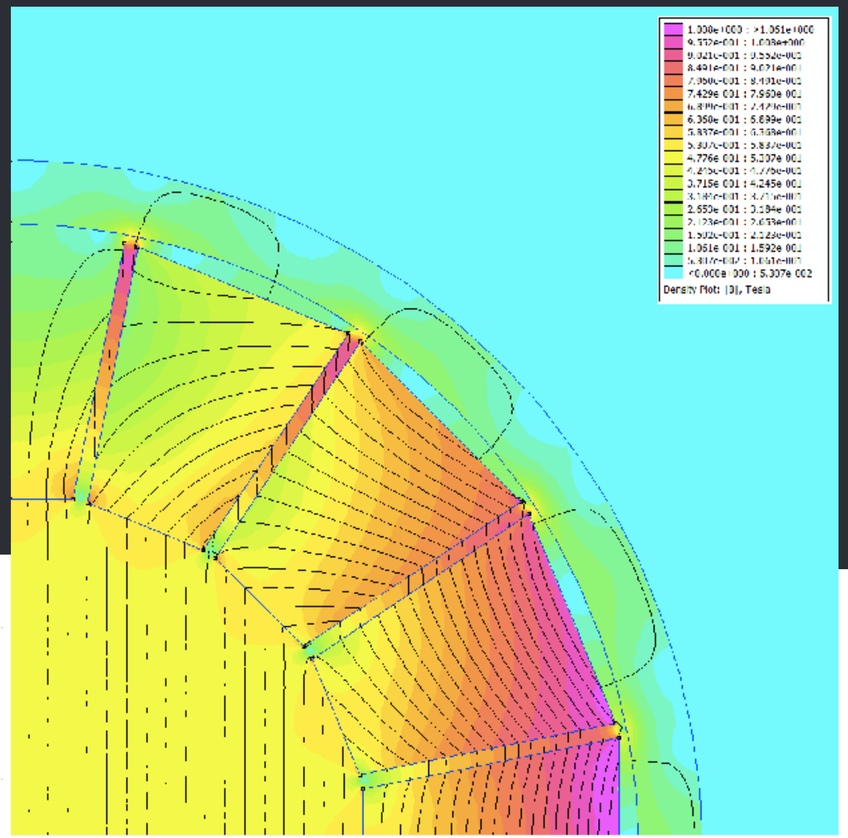
TI12

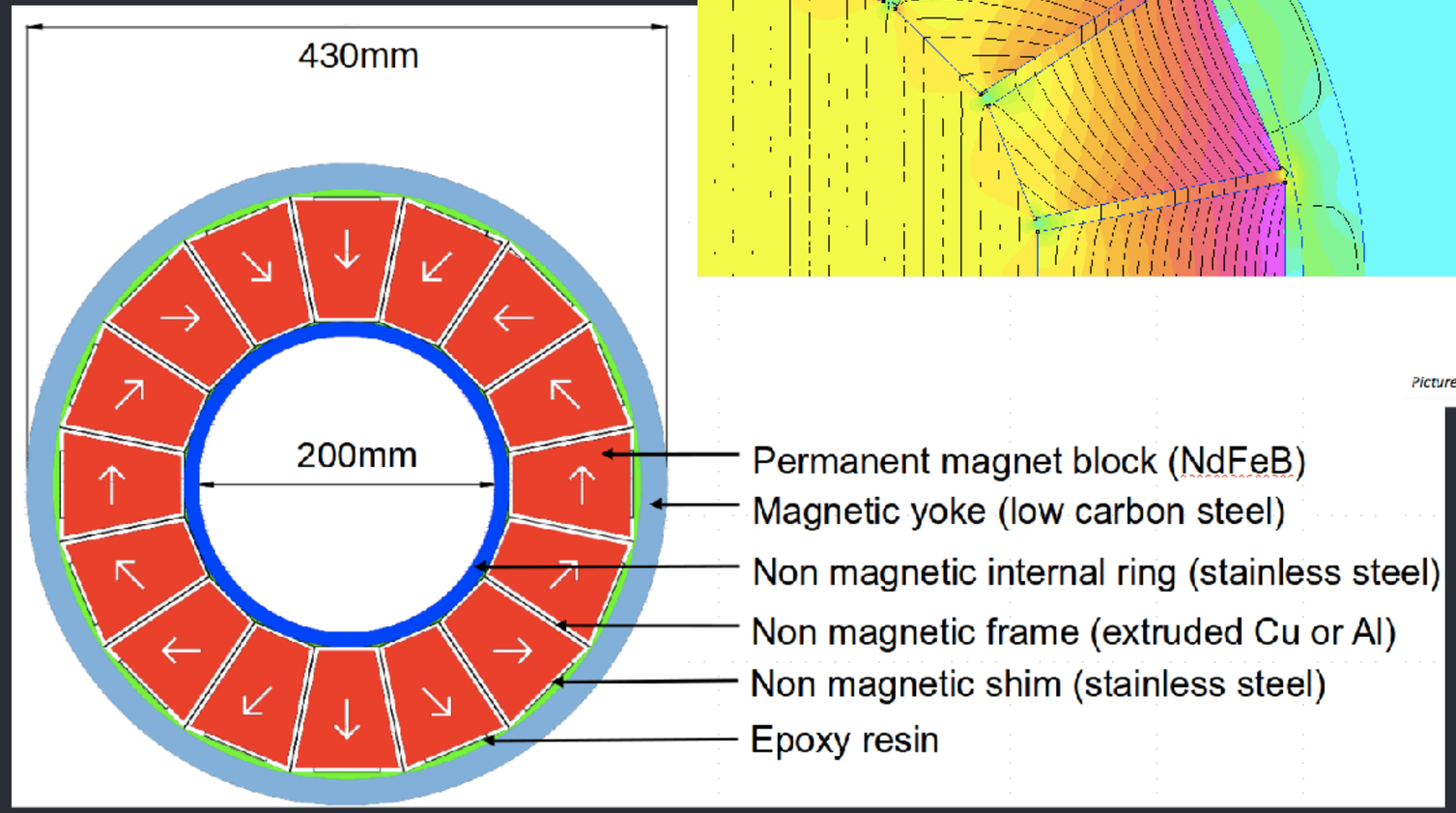
Core testing

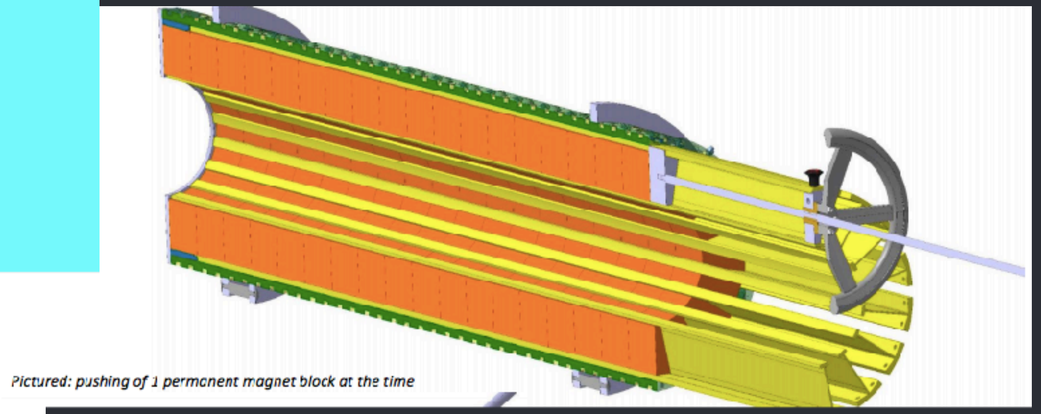


FASER magnet

Design and installation







Pictured: pushing of 1 permanent magnet block at the time

Halbach array design, 0.6 T.
Neodymium

FASER $$$

(more or less up to date)

Tracker costs (readout in TDAQ):

Item	TP	Current	Comments
Module frame	66 kCHF	~46 kCHF	Dropped outer box. Support not incl.
Flex+patch panel	18 kCHF	38 kCHF	5k covered by Kyushu university
Chiller system	15 kCHF	20 kCHF	Chillers alone were 8 kCHF
Power supplies	77 kCHF	83 kCHF	Better HV PSs
TIM	10 kCHF	20 kCHF	Covered by Tsinghua university
Cables	7 kCHF	25 kCHF	Cables are 19 kCHF, added splitter etc.
Total	193 kCHF	232 kCHF	

Calo/Scintillator costs (readout in TDAQ):

Item	TP	Current	Comments
Scintillators	17 kCHF	~17 kCHF	Only 3kCHF for plates confirmed
PMTs (and filters)	32 kCHF	11 kCHF	Calo PMTs donated by LHCb, others half price
HV PS	16 kCHF	9.1 kCHF	Ordered
Cables	3 kCHF	5 kCHF	Use 15m low-loss coax signal cables
Shielding	6.7 kCHF	~5 kCHF	Still to be ordered
LED calib. system	Not incl.	~1 kCHF	Under development
Total	74.7 kCHF	48.1 kCHF	

Work	TP Estimate	Latest estimate	Comments
Hoist in UJ12	17 kCHF	27 kCHF	Installed
Rail/hoist in TI12	33 kCHF		
QRL protection	40 kCHF	10 kCHF	In production
New gangway	Not included	10 kCHF	Installed
Clean-up/prep.	10 kCHF	7.5 kCHF so far	Not complete cost yet
Electrical install.	10 kCHF		
Compressed air	6 kCHF		Partly done
Optical fibers	10 kCHF	~23 kCHF	Need installation of duct
Survey support	Not included	~30 kCHF	Req. still being defined
Other	9 kCHF		
Civil engineering (trench construction)	160 kCHF		Separate CERN budget CERN to pay up 350k

TDAQ costs:

Item	TP	Current	Comments
Trigger boards	5 kCHF	~5 kCHF	
Readout boards	43 kCHF	~52 kCHF	Digitizer, tracker board, minicrate, cables
VME crates	10 kCHF	14 kCHF	Use LHC standard VME crate
PCs	12 kCHF	~12 kCHF	To be ordered with CERN IT etc.
Switches	8.5 kCHF	~11 kCHF	Add switch to split DAQ and DCS
DCS components		~2 kCHF	PDUs, environment monitoring
Total	78.5 kCHF	96 kCHF	

Detector support cost (least mature at the moment):

Item	TP	Current	Comments
Base plate	30 kCHF		
Upper frame	5 kCHF		
Adjustable magnet feet	25 kCHF	0?	Included in magnet support now
Total	60 kCHF		

FASER $$$

(more or less up to date)

Component	Cost estimation (CHF)	Actual cost (CHF)	Status
Permanent magnet blocks	210000	240000	Ordered (CN)
Machining of yoke cylinders	50000	27000	Ordered (NOR)
Production of aluminum guiding profiles	30000	16000 (extruded) 25000 (machined)	Ordered (NL and SP)
Measurement and assembly tooling	30000	6000	Partially ordered (FR)
Contingency	30000		Not yet used
TOTAL COST (1 dipole 1.5 m long + 2 dipoles 1 m long)	**350000 CHF**	**314000 CHF (October 2019)**	

FASERν $$$

Item	Cost [kCHF]
Emulsion gel for 440 m^2	315
Emulsion film production cost for 440 m^2	32
Tungsten plates, 1200 kg (first set)	173
Tungsten plates, 1200 kg (second set)	173
Packing materials	5
Support structure	12
Chemicals for emulsion development	20
Tools for emulsion development	5
Racks for emulsion film storage	5
Computing server	10
Total	**750**
[Emulsion gel for 2024 running]	[135]
[Additional consumables for 2024 running]	[23]
[Total including 2024 running]	**[908]**

TABLE VIII. Cost estimate for the tungsten/emulsion detector.

Item	Cost [kCHF]
SCT modules	0
Tracker mechanics	20
Chiller	0
Connection to EN-CV	2
Tracker Readout Board	5
Powersupplies	31
Cables	11
Flex cable	10
Patch panel	10
Tracker Interlock and Monitoring Board	3
Total	**92**

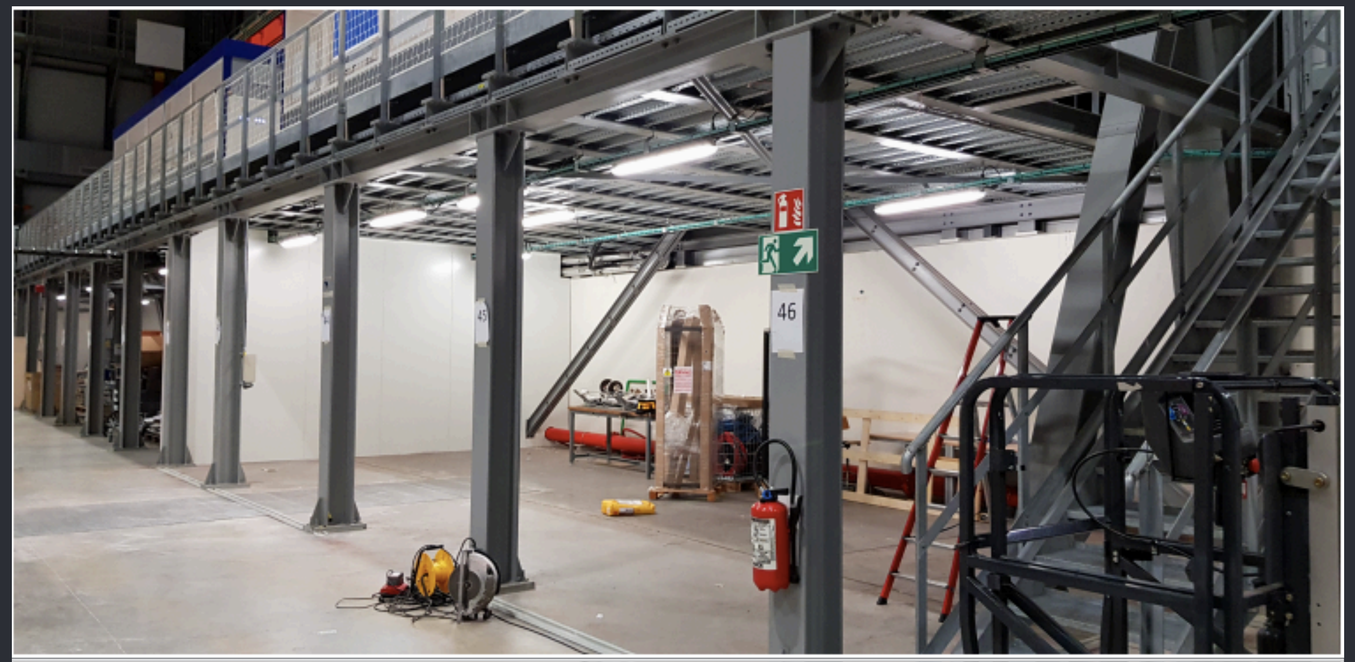
TABLE IX. Cost estimate for the interface detector.

Item	Cost [kCHF]
Transport infrastructure	20
Chemical disposal	20
Computing storage (EOS disk space)	30
Total	**70**

TABLE X. The host lab costs.

FASER dry run

Above surface commissioning



- Until installation in July, FASER components to be assembled and tested in test hall on CERN's Prevessin site.