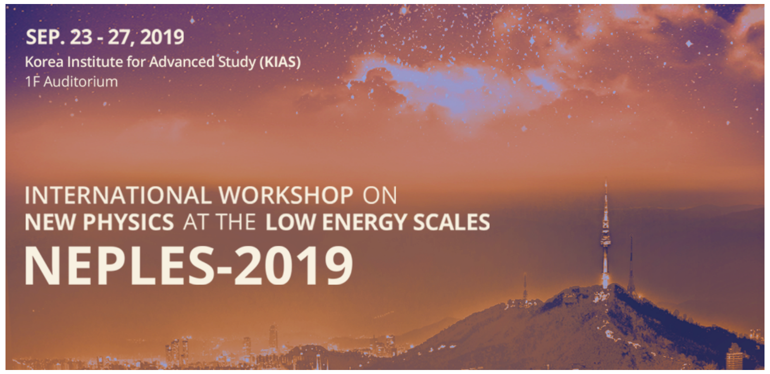

The FASER experiment

Sergio Gonzalez Sevilla
(University of Geneva)

On behalf of the FASER collaboration

FASER

NEPLES-2019, 23rd September 2019, KIAS (Seoul)

Supported by:

SIMONS FOUNDATION

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UNIVERSITÉ DE GENÈVE

Outline

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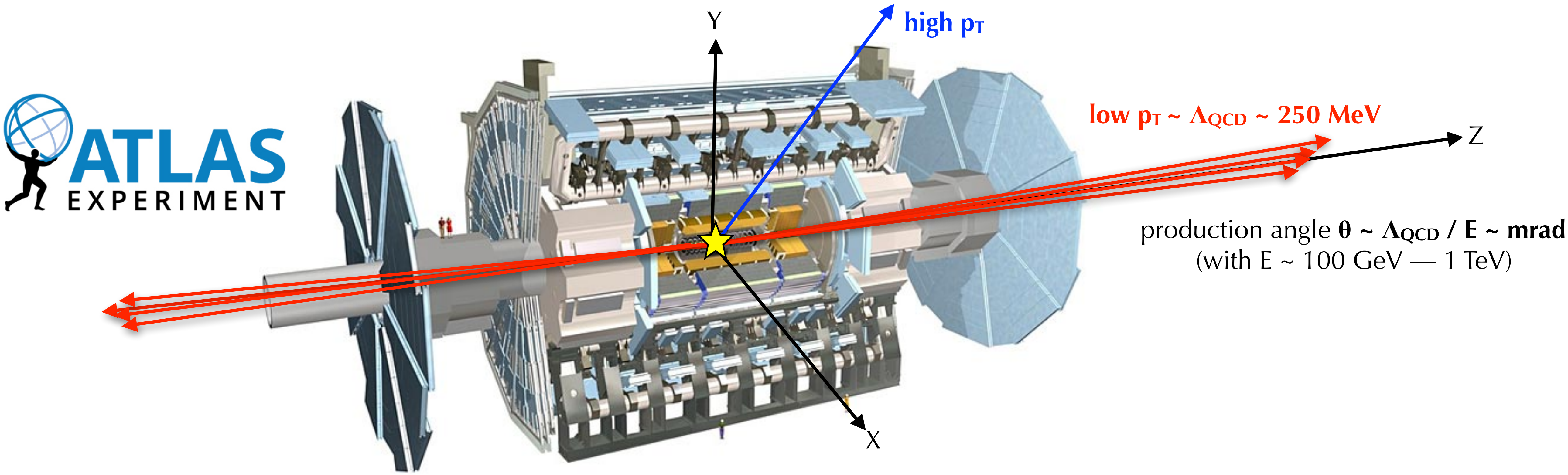
  - Experiment location
- Signal and backgrounds
  - Typical signal and background signatures
  - Background estimation and in-situ measurements
- Detector layout
- Physics potential
  - Sensitivity reach for LLP
  - Neutrino measurements
- Summary

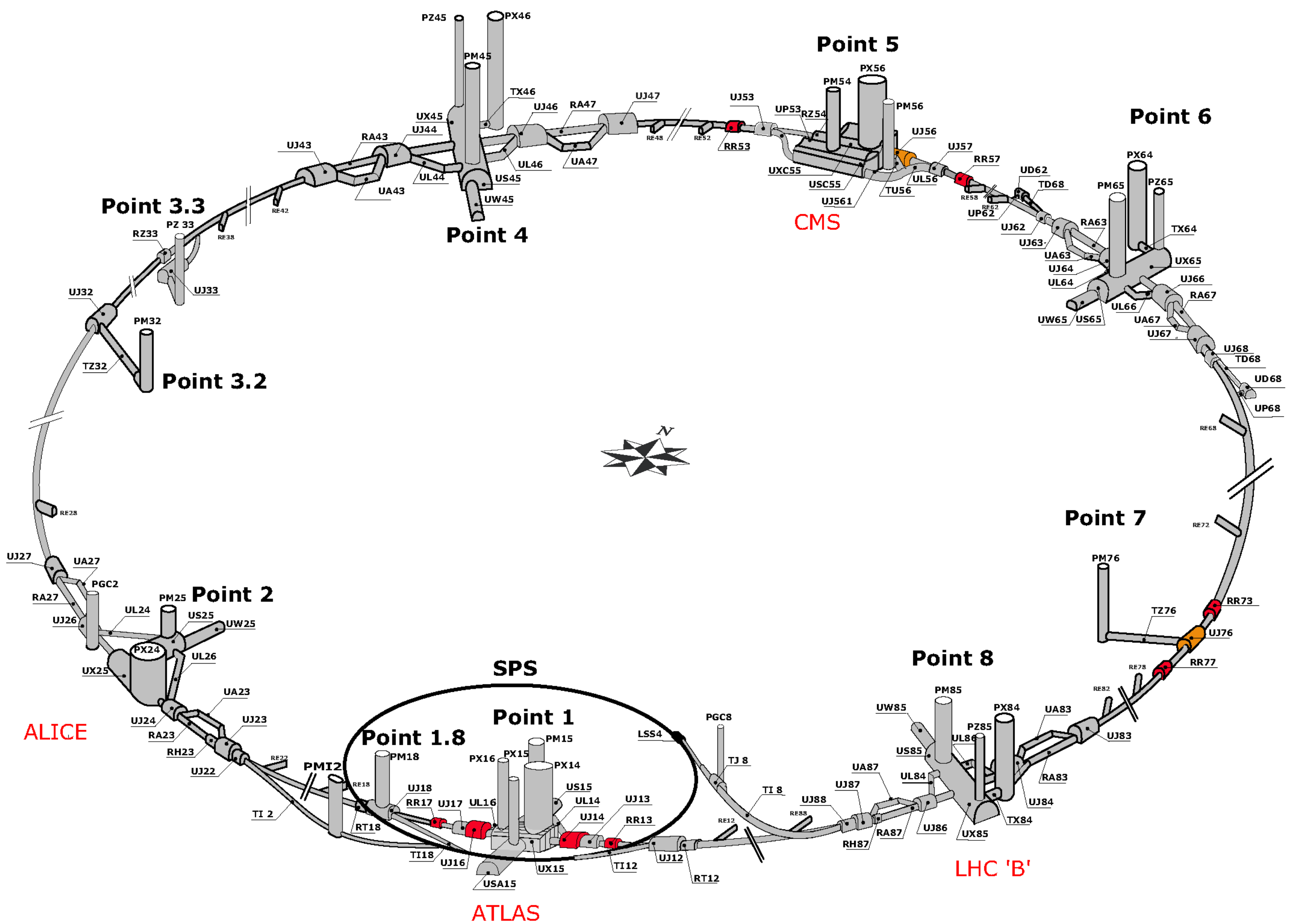
Physics motivation

- General-purpose LHC experiments (ATLAS, CMS) designed to perform measurements in the transverse plane ➡ many NP searches based on signatures from **heavy and strongly interacting** particles (high p_T, large missing E_T)
- In the case of **light and weakly interacting new particles**, these would be mostly produced **at low p_T**, highly collimated in the very forward direction (**θ ~ mrad**)
  - Very large number of low p_T events available at the LHC !!
    - σ_{inel}(13 TeV) ~ 75 mb ➡ **N_{inel} (Run3, 150 fb^{-1}) ~10^{16}**

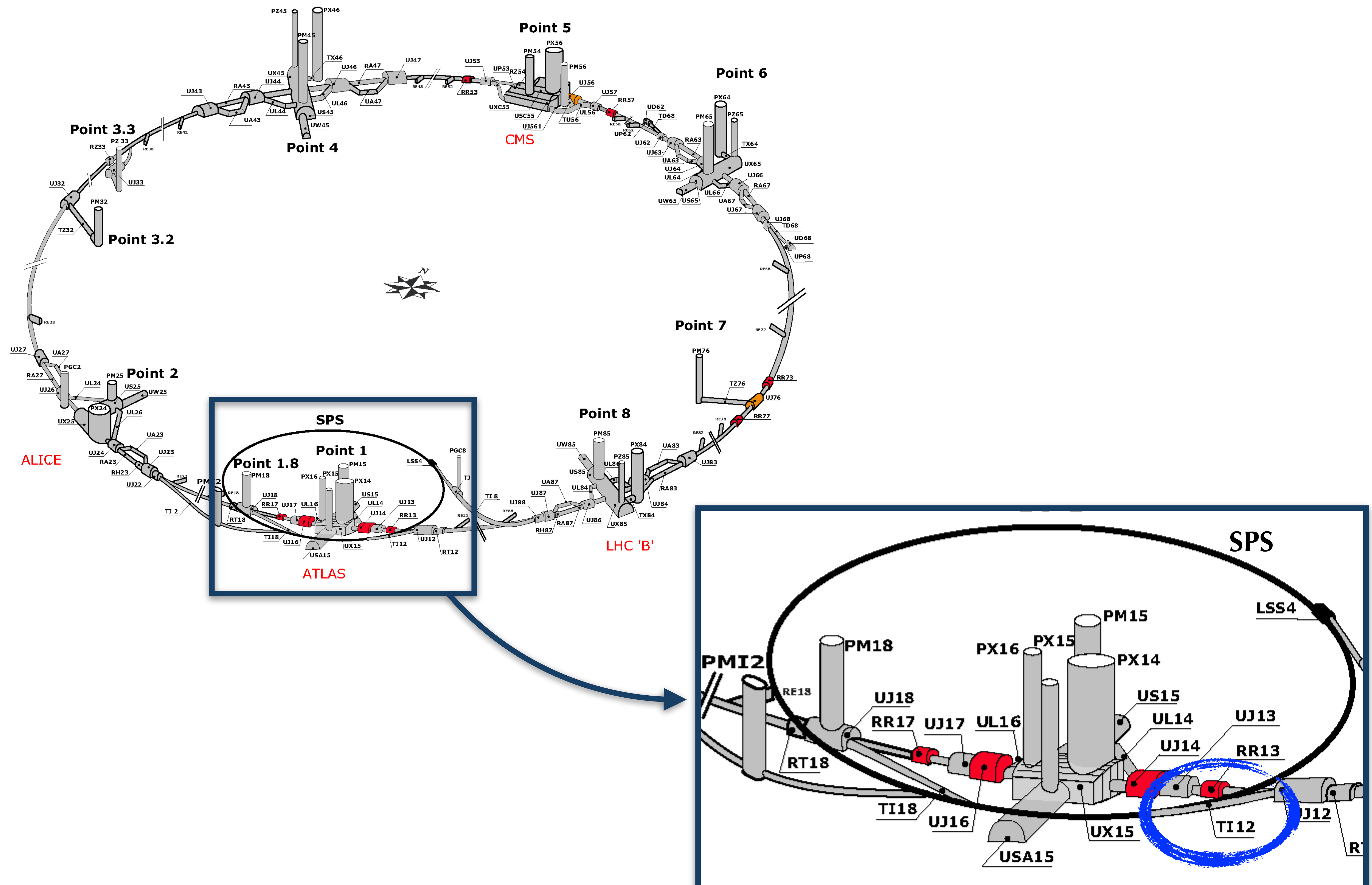


- FASER (the **F**orw**A**rd **S**earch **E**xpe**R**iment) is a small and inexpensive (2M$) experiment that will search for new particles at the LHC
  - located 480 m from IP, along beam collision axis (**line of sight, LOS**)

Experiment location



Experiment location



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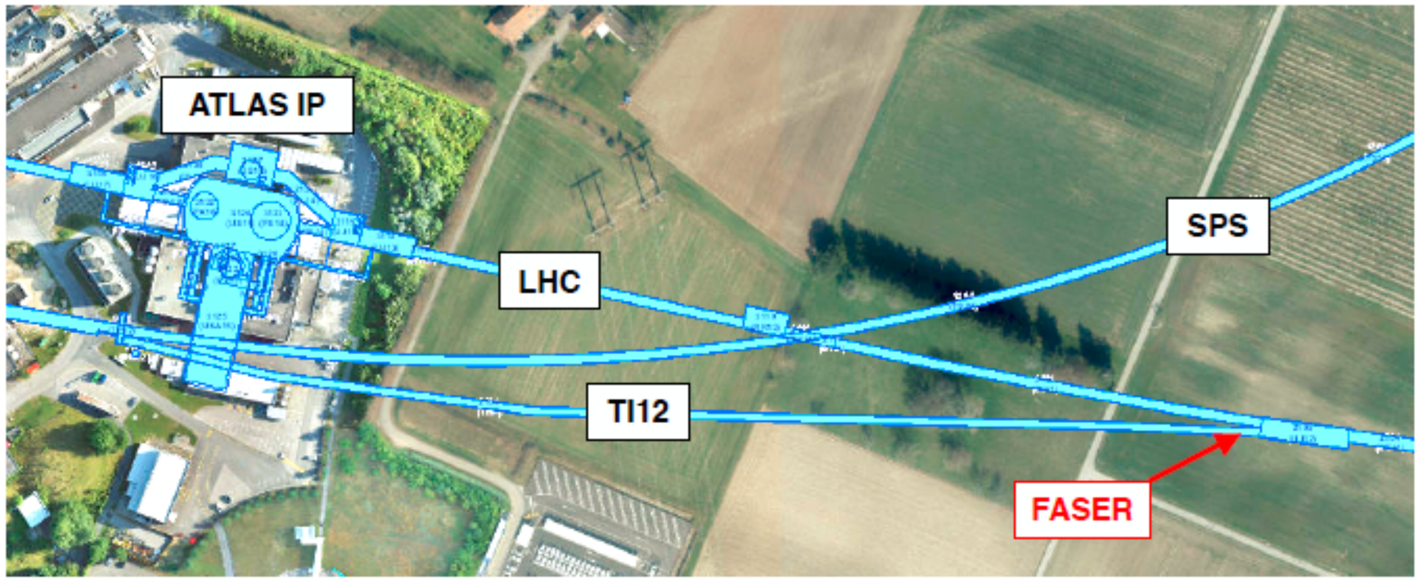
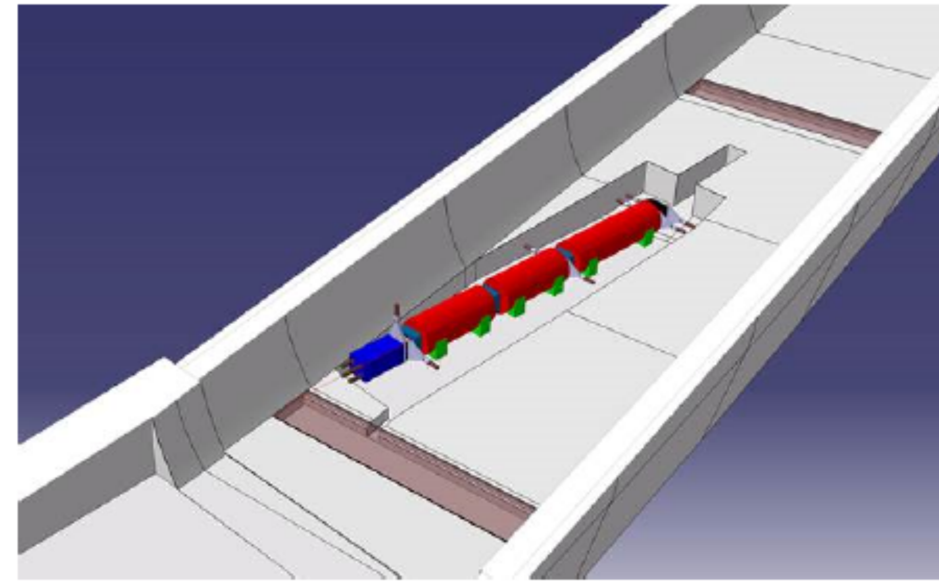
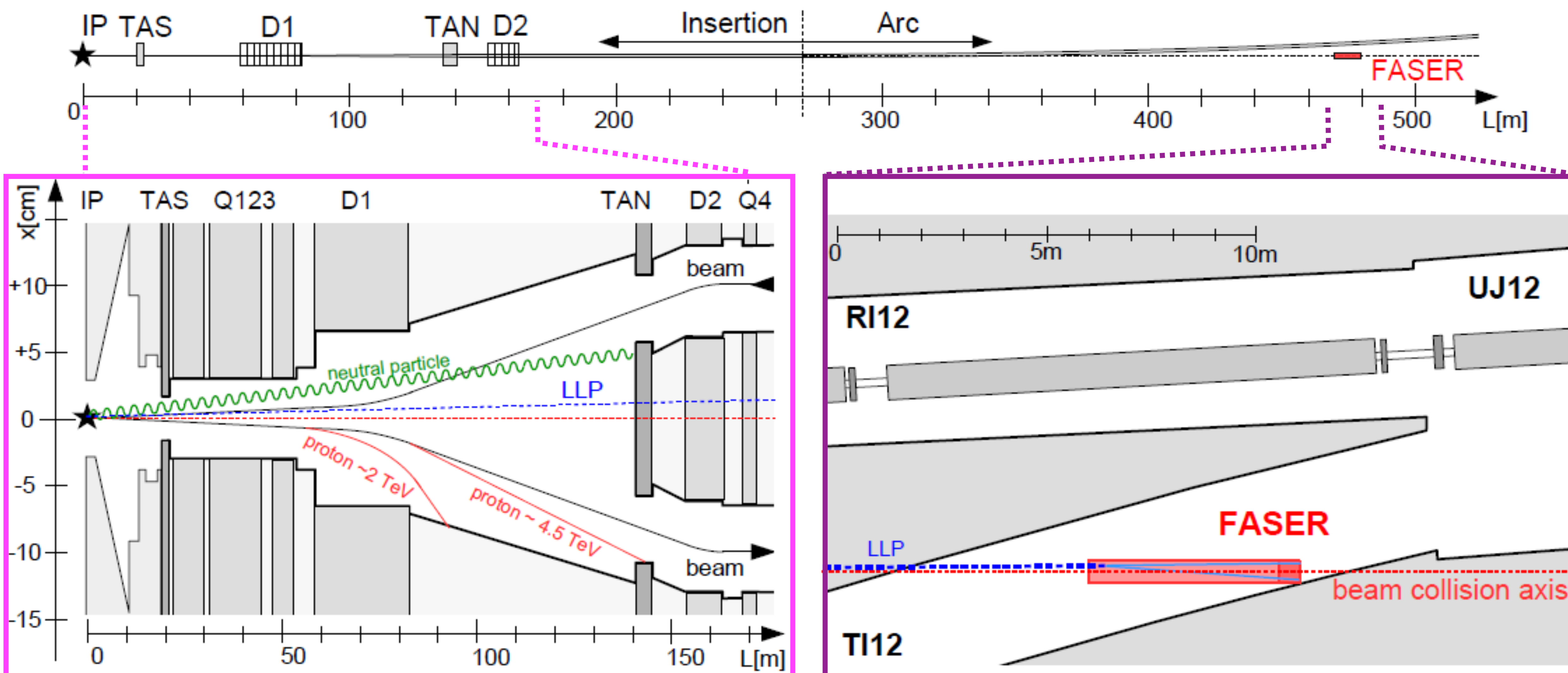
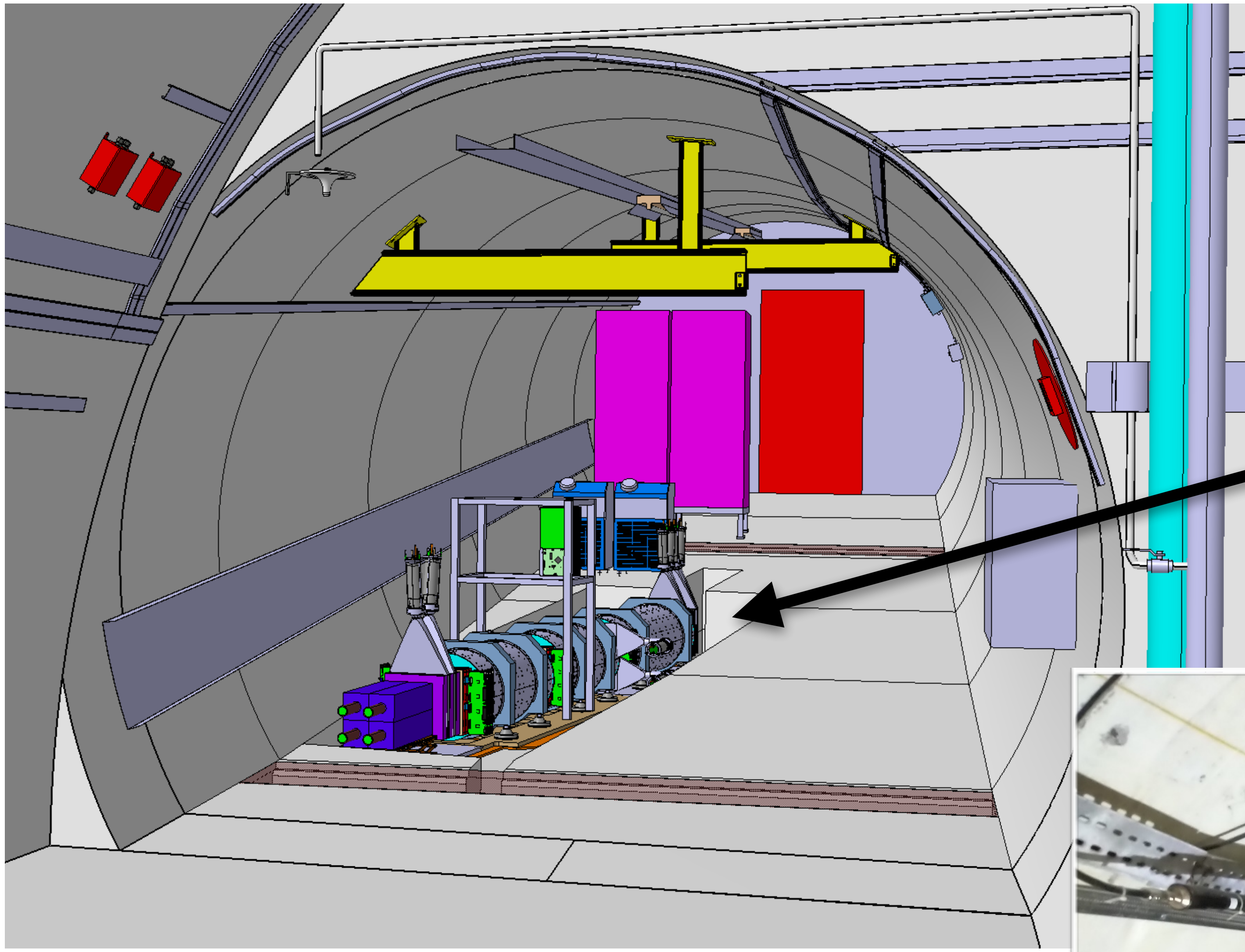






Experiment location

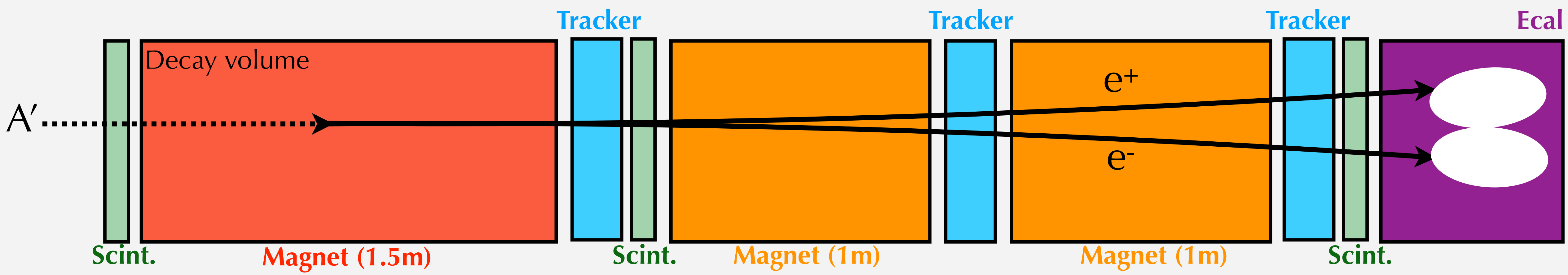


Small digging in TI12 tunnel (< 50 cm) required to align vertically FASER with LOS

Signal and backgrounds

Signal and backgrounds

Ex: pp → A′(→ e^+e^-) + X, with E(A′)~TeV



- Signal signature
  - two very-high energy, oppositely-charged tracks (or γ) originated from a common vertex in the decay volume and with combined momentum pointing back to the IP
  - no signal in the upstream scintillator veto-layer
  - large energy deposited in the em calorimeter

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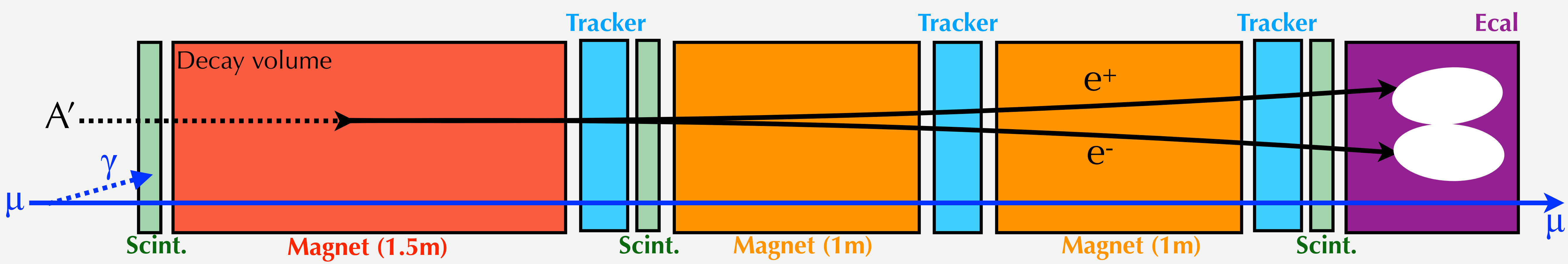

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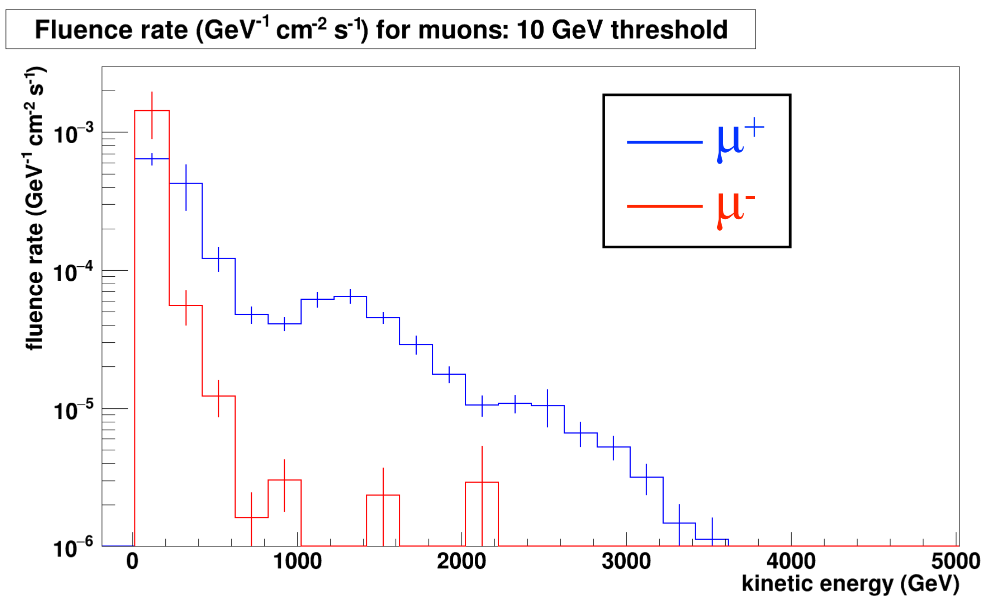
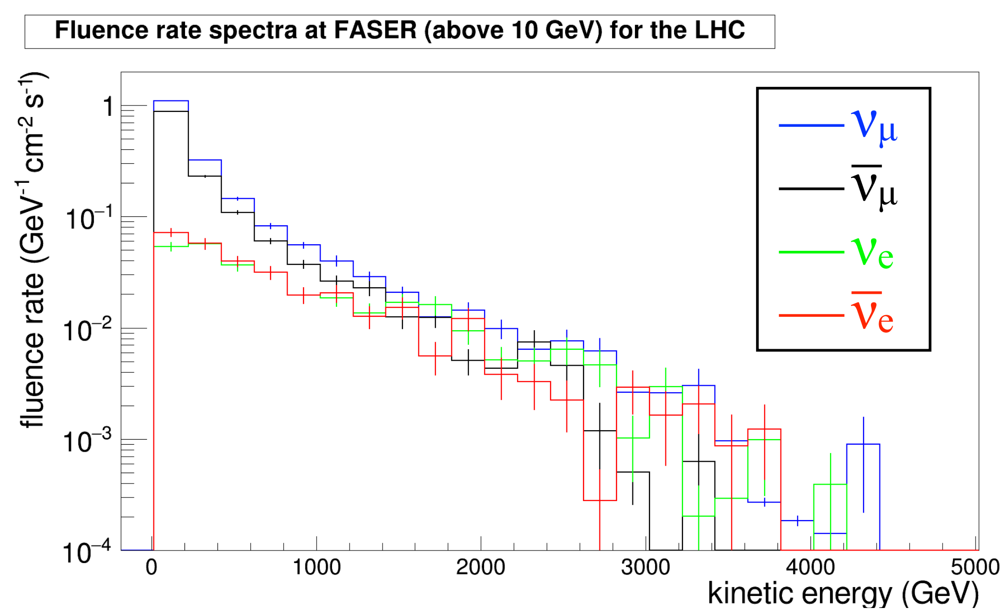
- Backgrounds
  - **FASER's location** (~480m downstream ATLAS IP) **naturally** (rocks, concrete, upstream magnets) **provides an effective suppression for high-energy particles**
  - **Main backgrounds:** muons and neutrinos from the IP
    - muon-associated radiative processes (*e.g.* γ-bremsstrahlung) to be highly suppressed by first scintillator (+ lead-absorber, 20 X_0) veto station

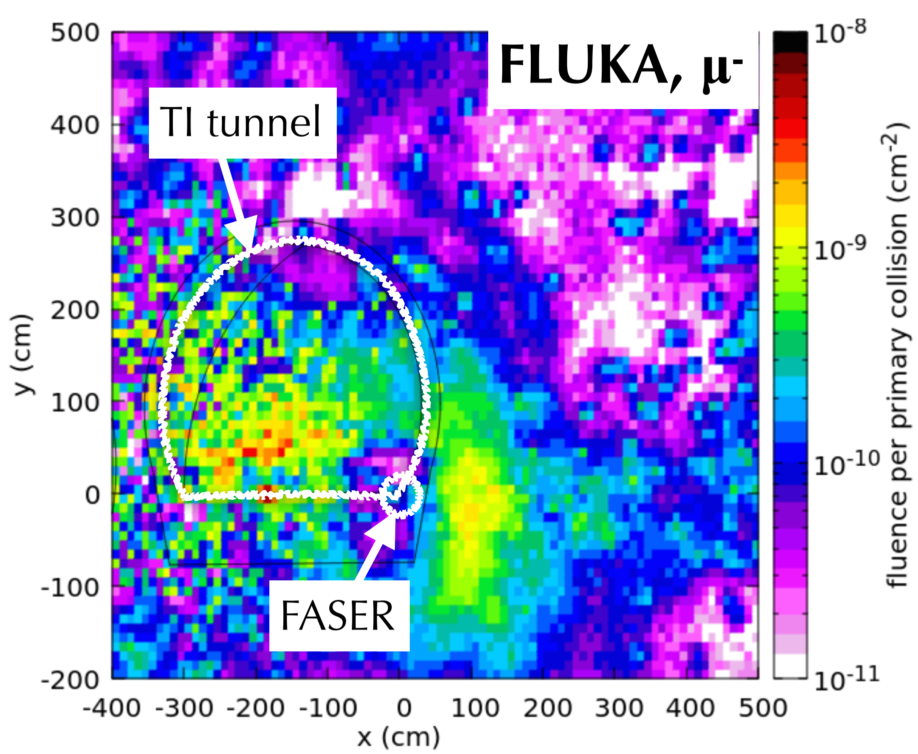
Background estimations

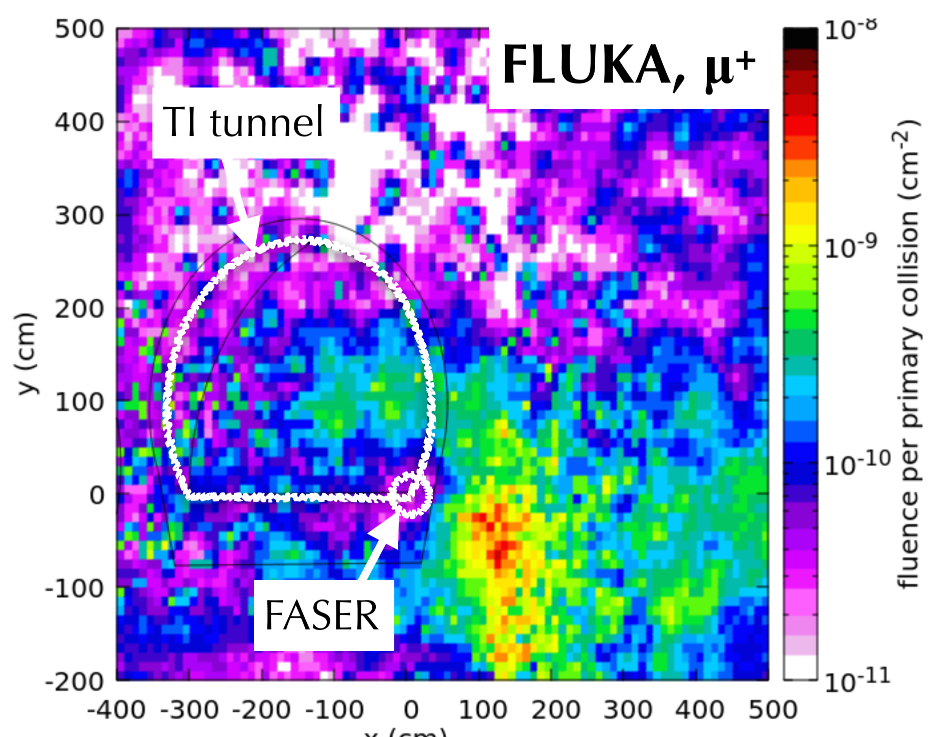
- FLUKA used to estimate the backgrounds expected in FASER. Sources considered:
  1. particles produced at IP
  2. showers from proton losses hitting beam-pipe
  3. beam-gas interactions (from "beam-2" moving towards ATLAS)

  } **negligible** (2 and 3)





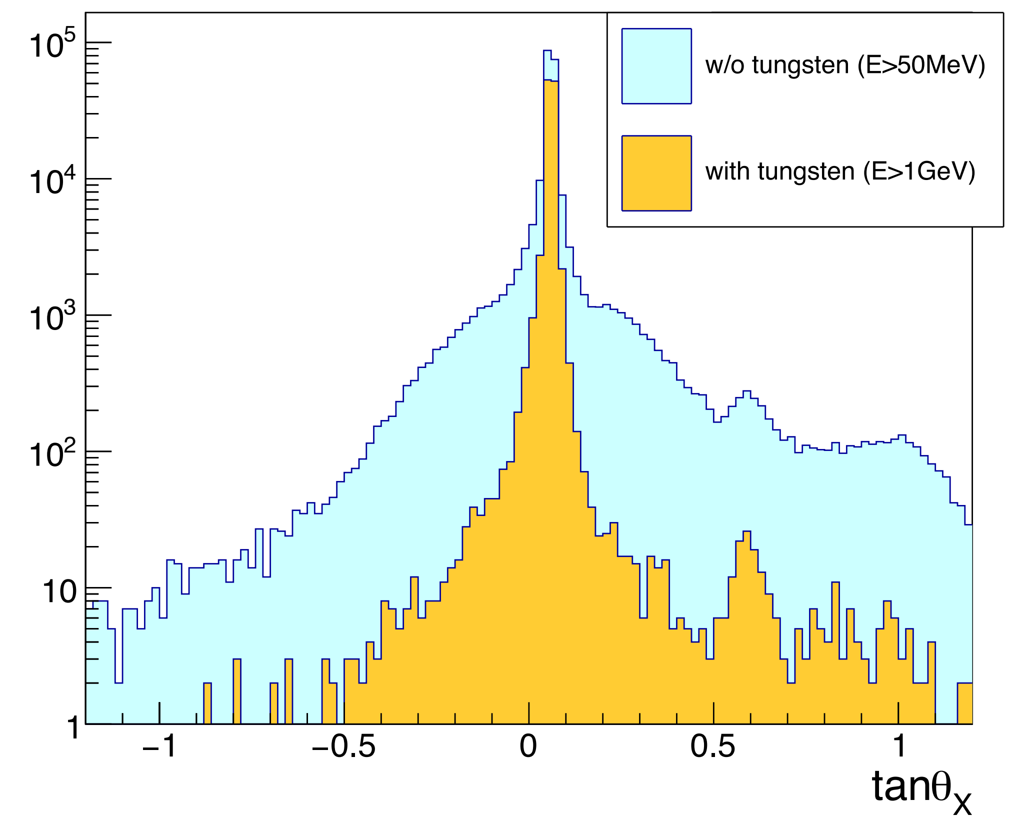




Muons (@L=2×10^{34} cm^{-2} s^{-1})	
Energy threshold [GeV]	Charged Particle Flux [cm^{-2} s^{-1}]
10	0.40
100	0.20
1000	0.06

In-situ measurements

- **Beam background**
  - Emulsion detectors and TimePix3 Beam Loss Monitor installed in the TI12 tunnel in 2018 to measure particle fluxes
  - Conclusions from measurements:
    - ➡ Results fully consistent with FLUKA simulations
    - ➡ Particle flux correlated with the instantaneous luminosity at IP1

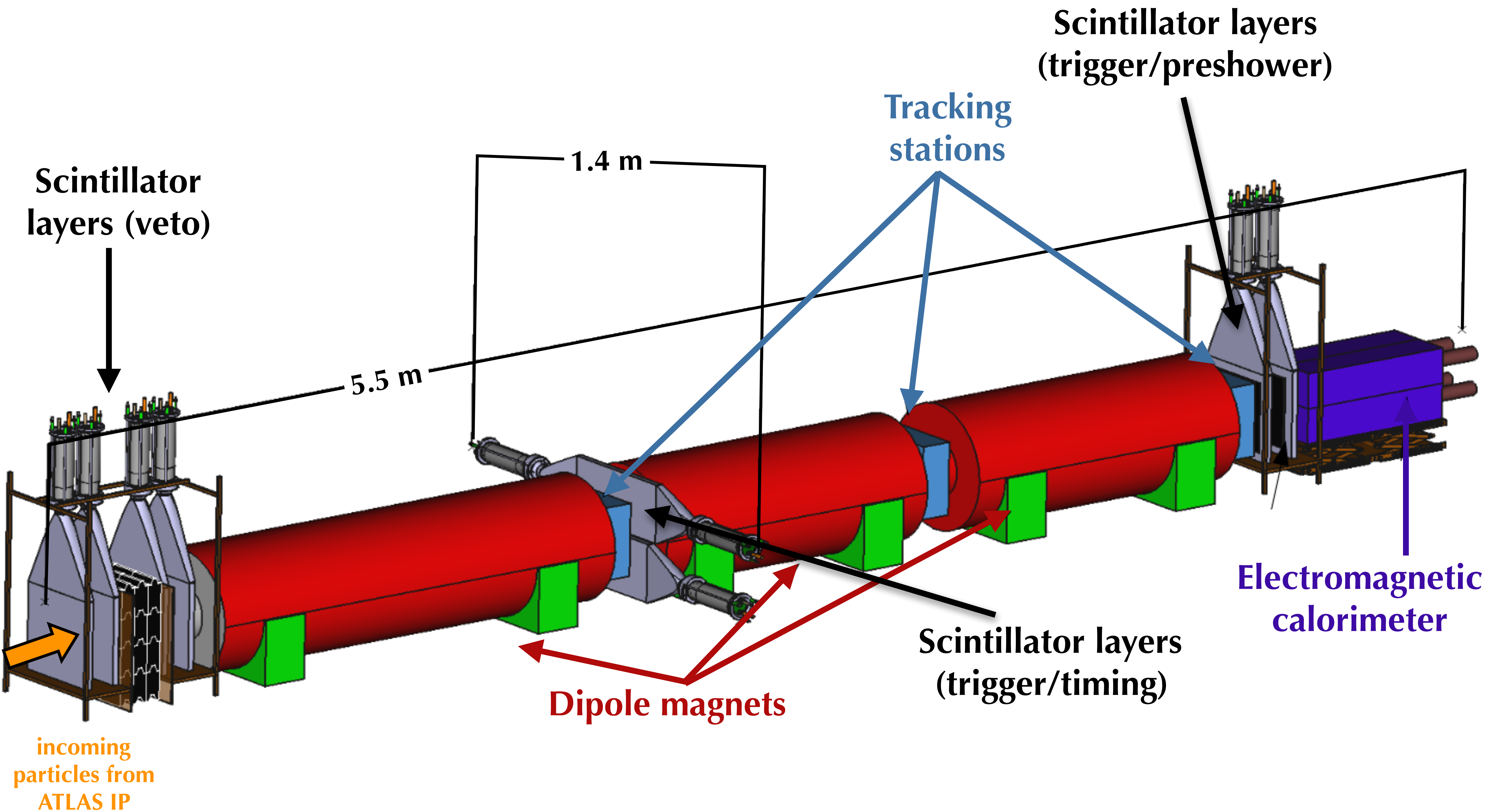


- **Radiation levels**
  - BatMon battery-operated radiation monitoring devices
  - Measurement of high-energy hadron flux and thermal neutron fluence after 3 fb^{-1} 13 TeV pp collisions
  - Results fully consistent with FLUKA simulations
    - D / year < 4 x 10^{-3} Gy
    - Φ / year < 5 x 10^7 [1MeV-n_{eq} / cm^2]

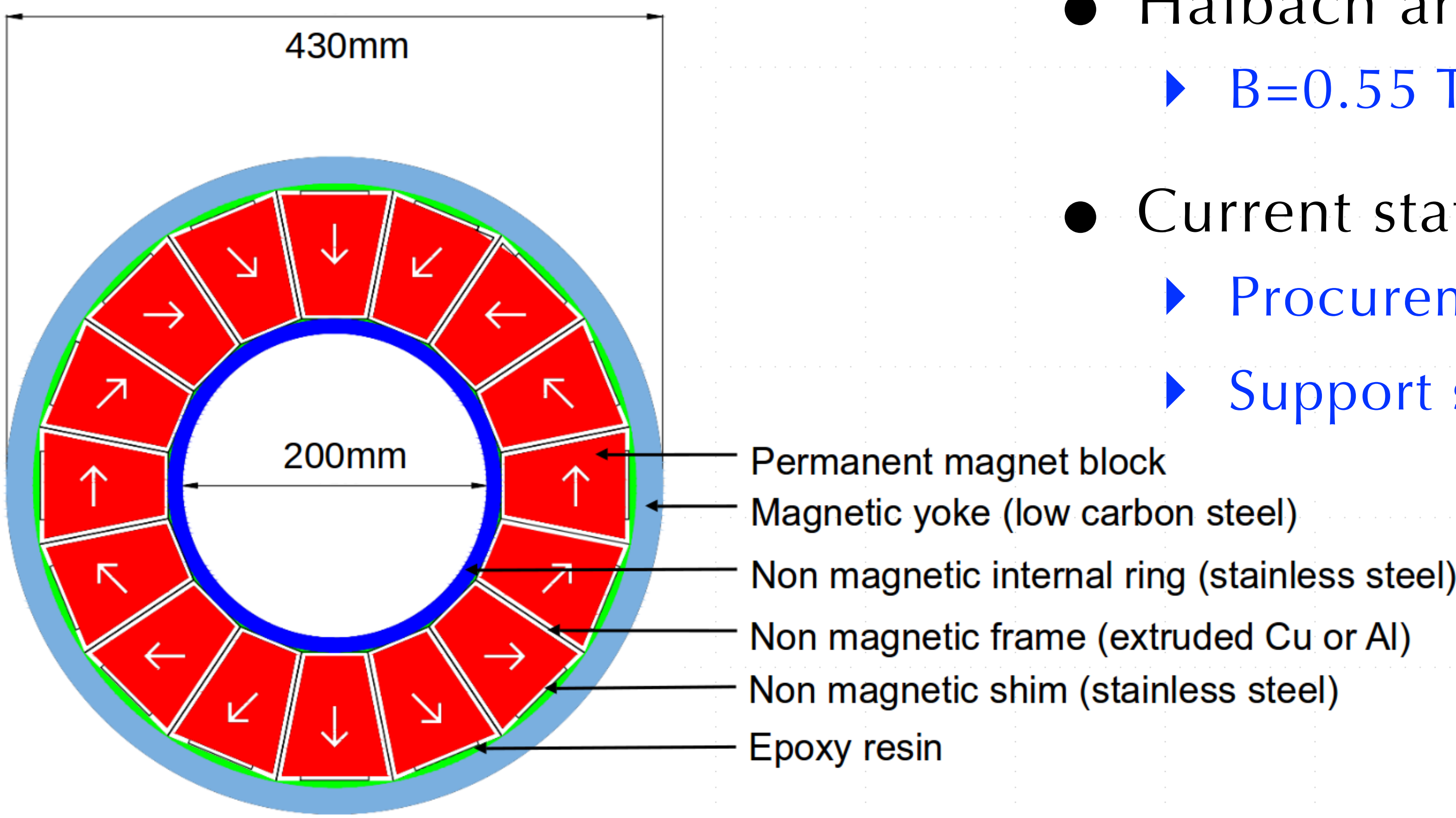
➡ No rad-hard electronics needed in the experiment

Detector layout

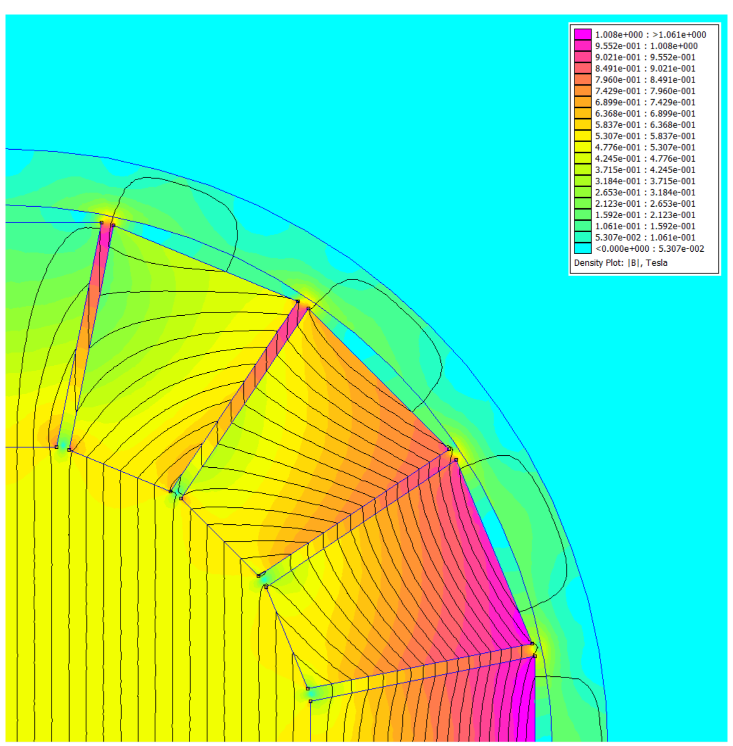
Detector layout

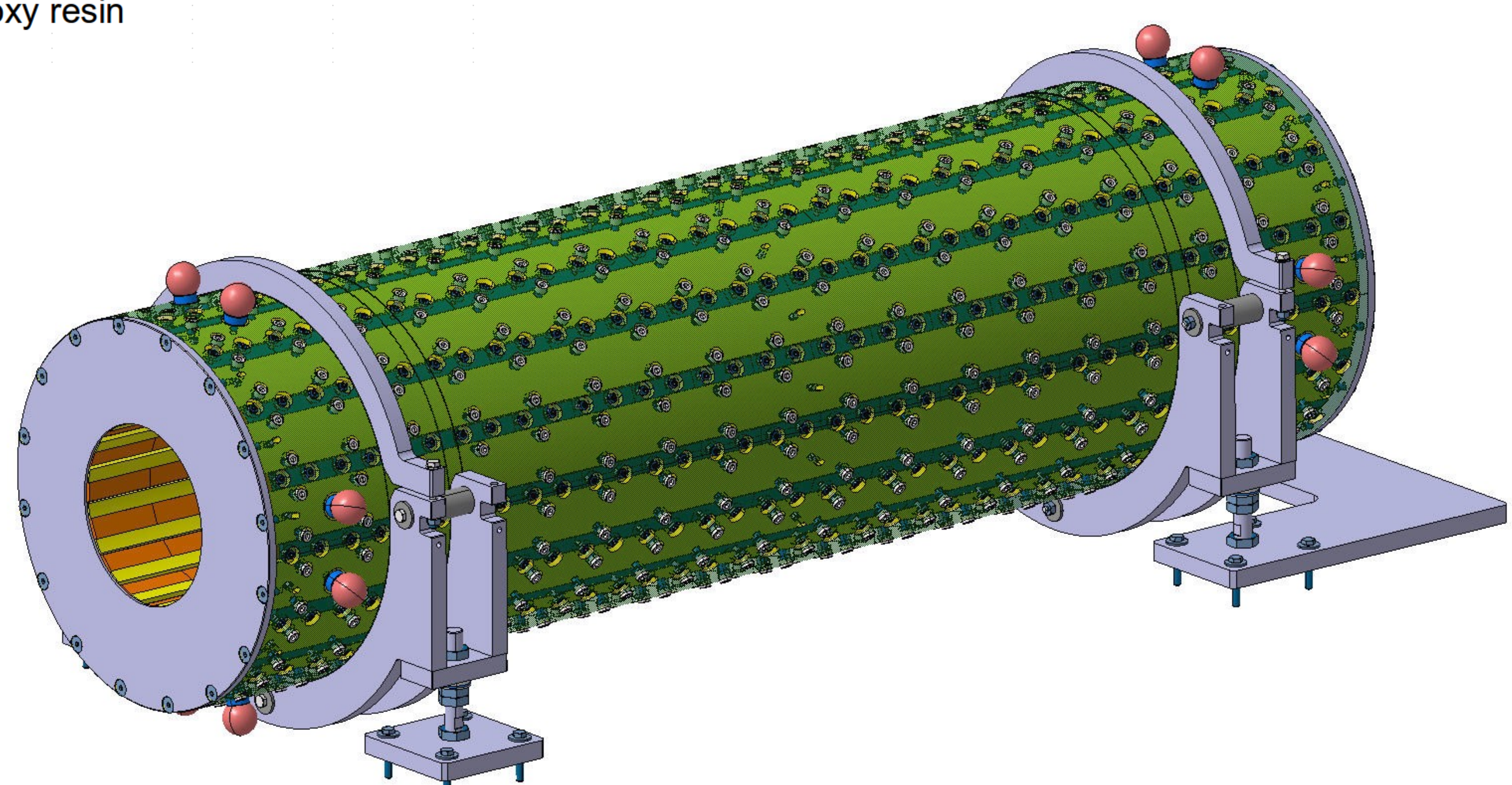


Magnets



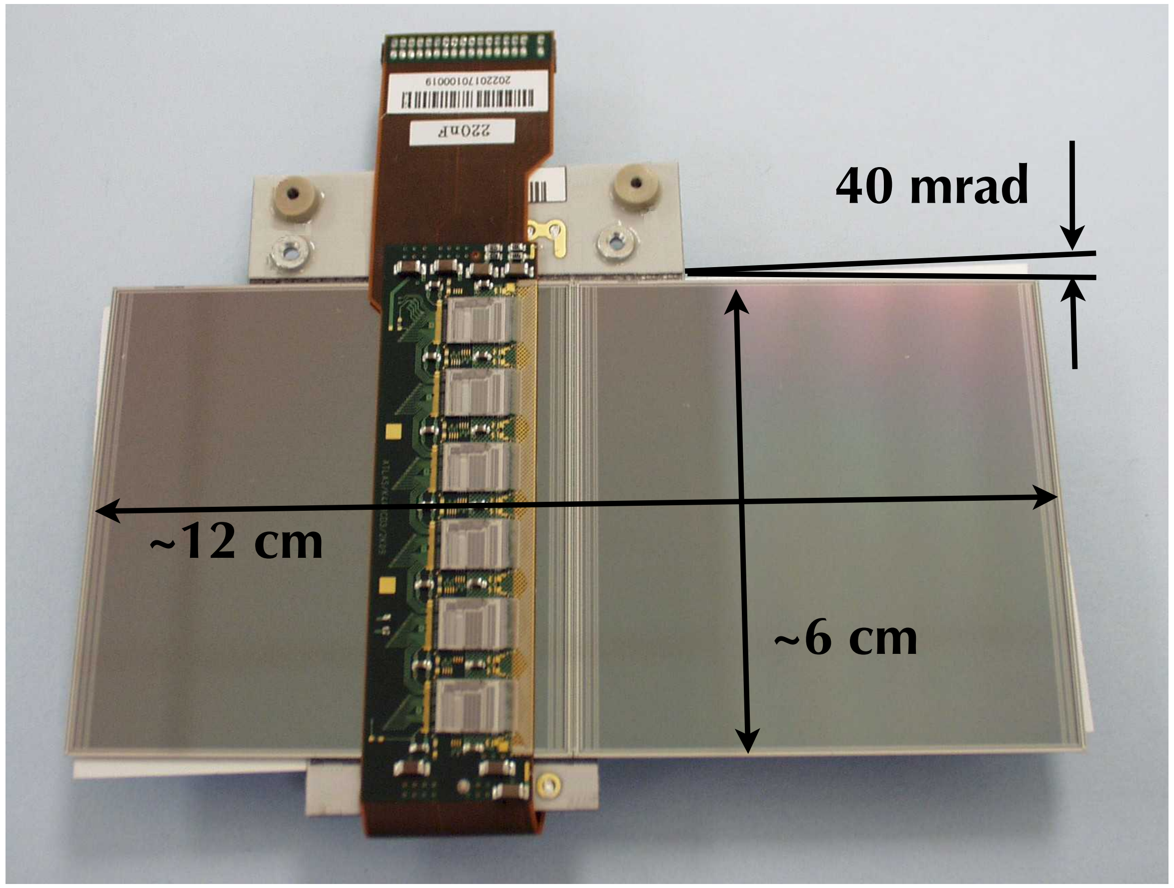
- Halbach array permanent dipole magnets
  - B=0.55 T, 16 blocks
- Current status:
  - Procurement of magnetic blocks underway
  - Support structure under design

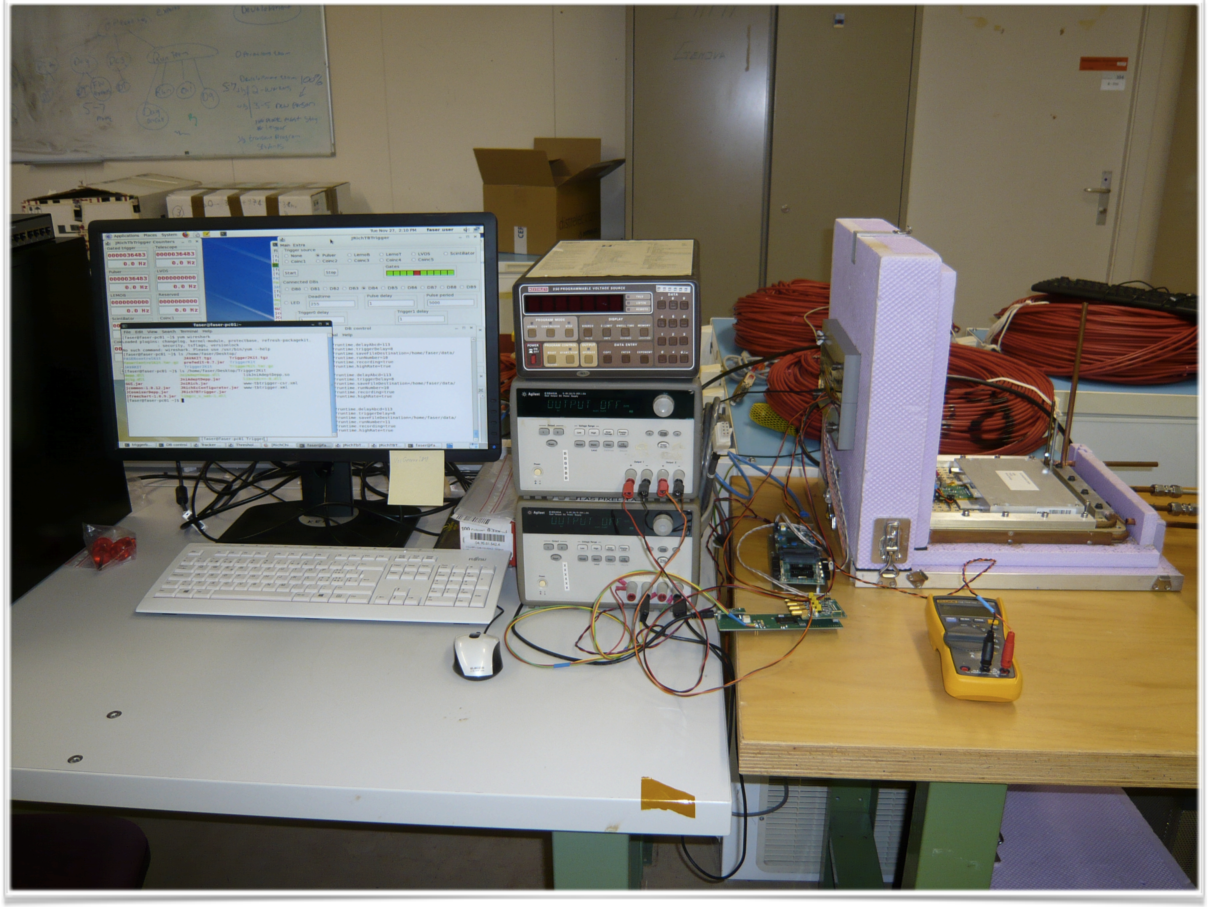




Silicon tracker

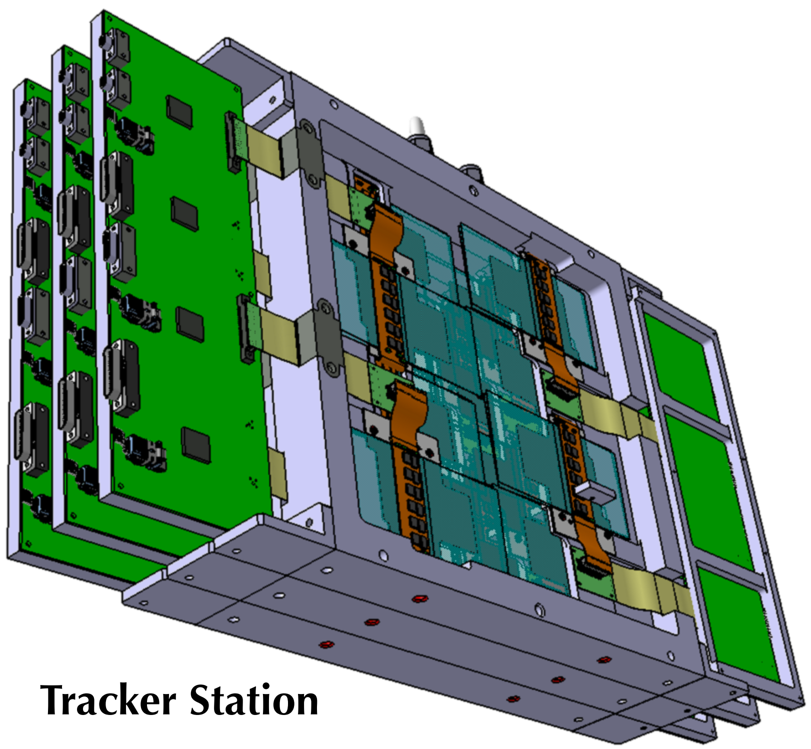
- Tracker using silicon strip modules from the ATLAS Semiconductor Tracker (SCT)
  - 80 spare SCT barrel modules ➡ **many thanks to ATLAS SCT Collaboration !**
  - 2 sides, each with 2 single-sided p-on-n silicon sensors, 40 mrad stereo angle
  - 80 µm strip-pitch, 1536 readout channels / module
- QA of SCT modules performed @CERN in March 2019
  - > 80 modules passing selection criteria (leakage current, noise, # dead / noisy channels)



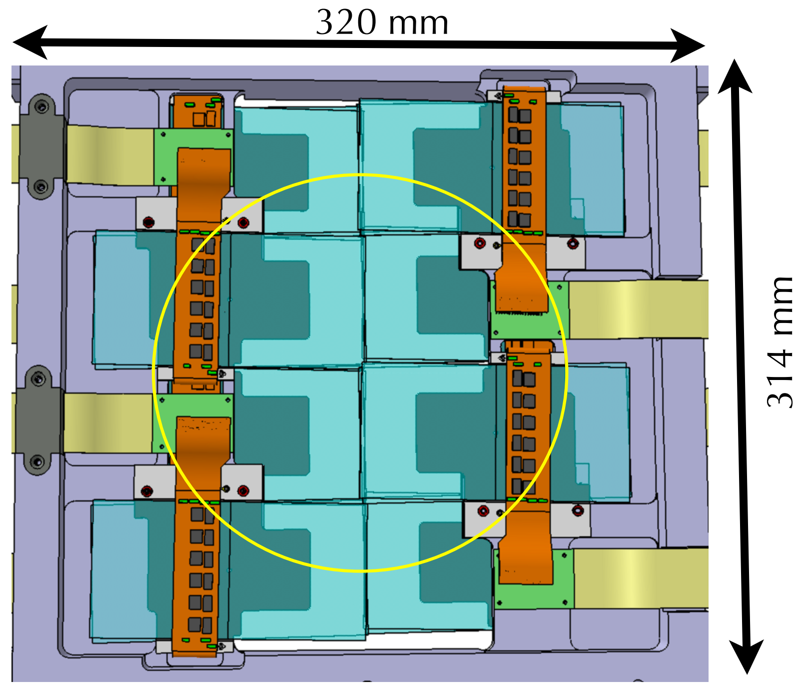


Silicon tracker

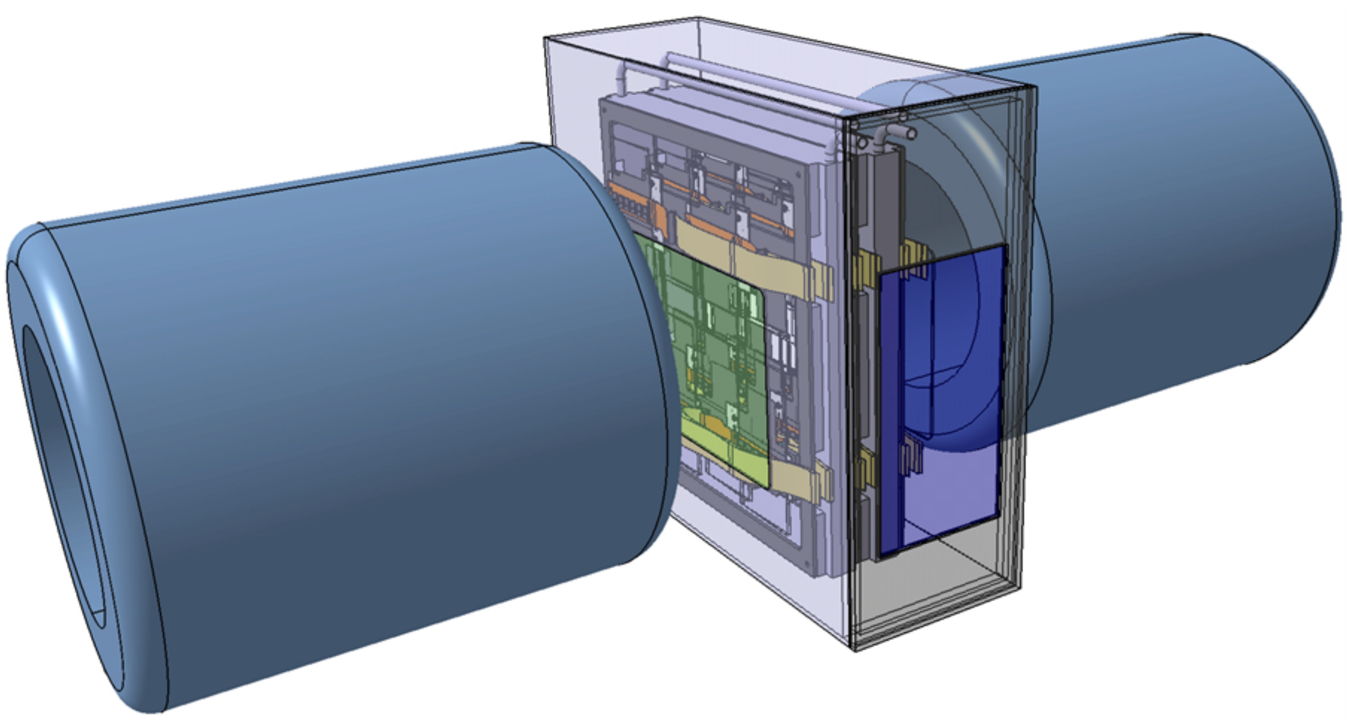
- FASER tracker = 3 stations, each with 3 layers of 8 SCT modules
  - First tests (assembly, thermal performance) on prototype layer on-going

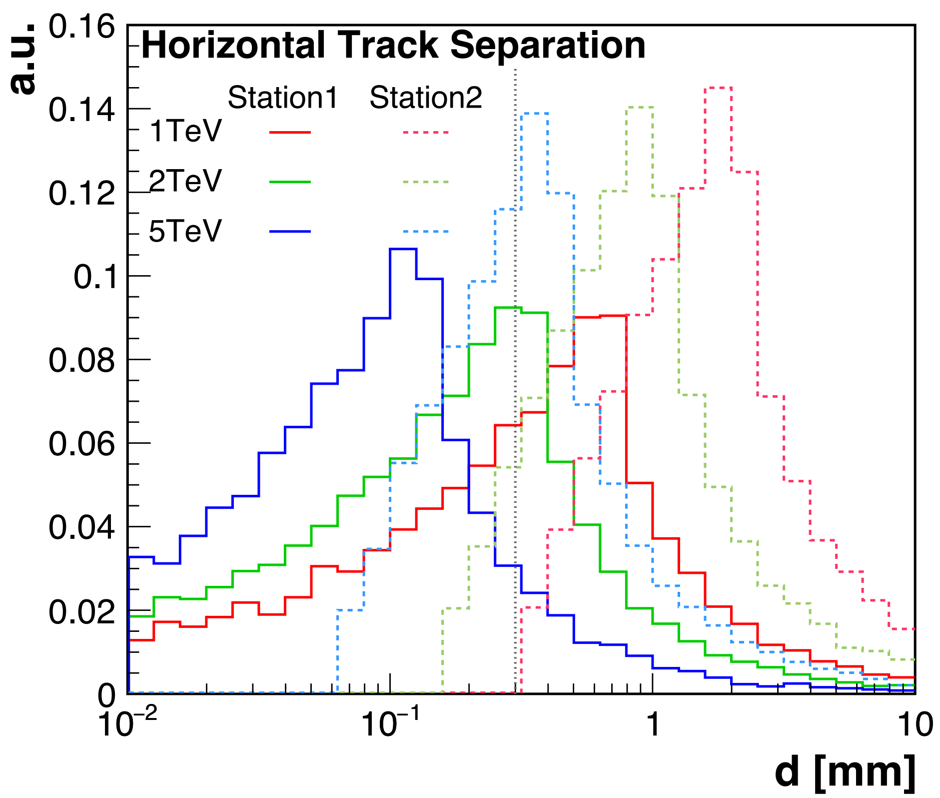


Tracker Station



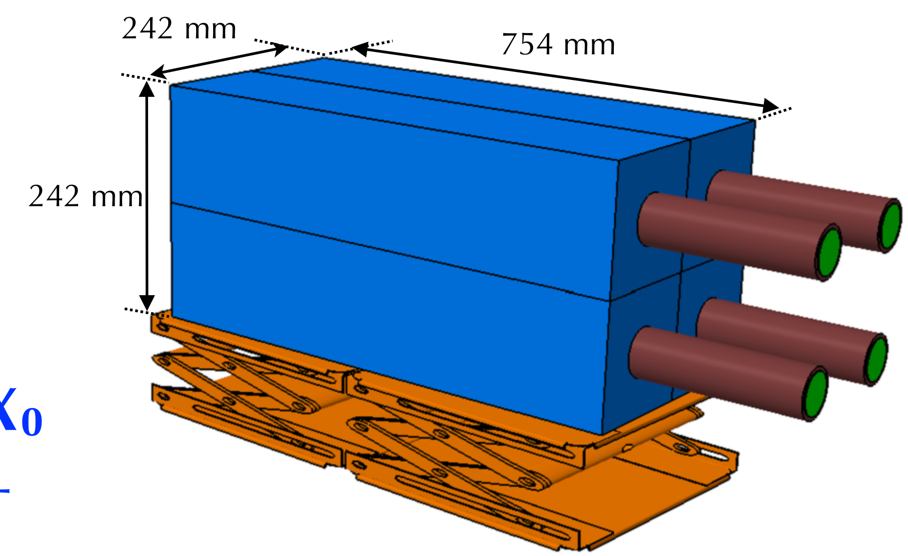
Tracker Layer

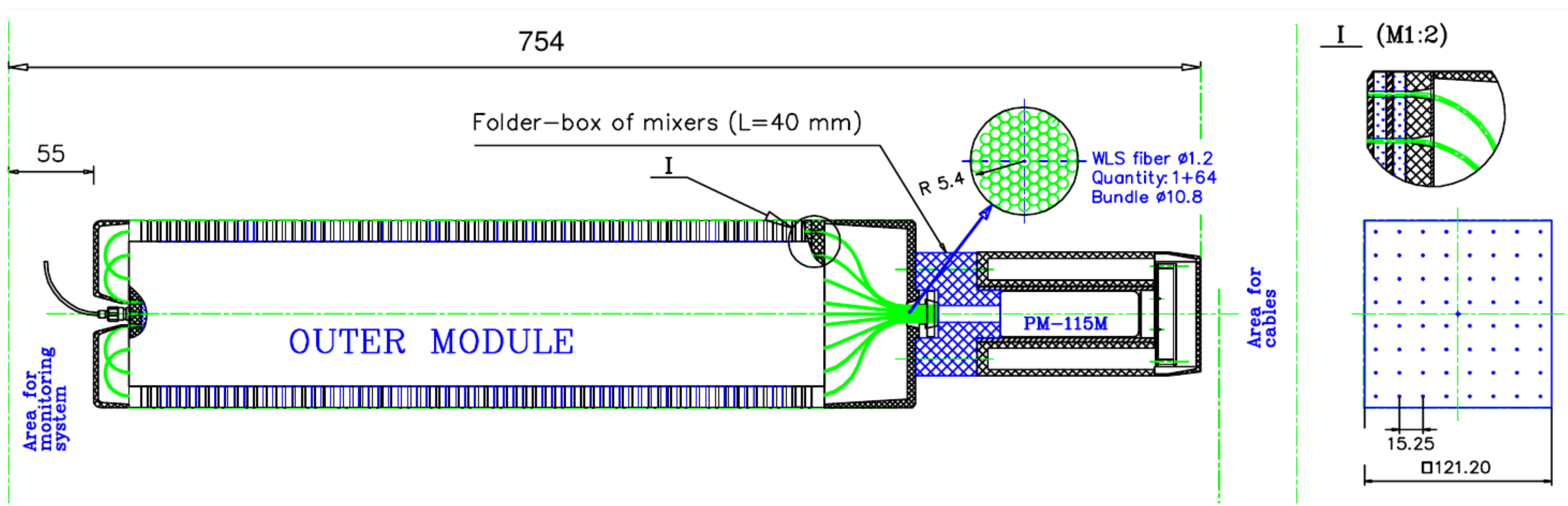




Electromagnetic calorimeter

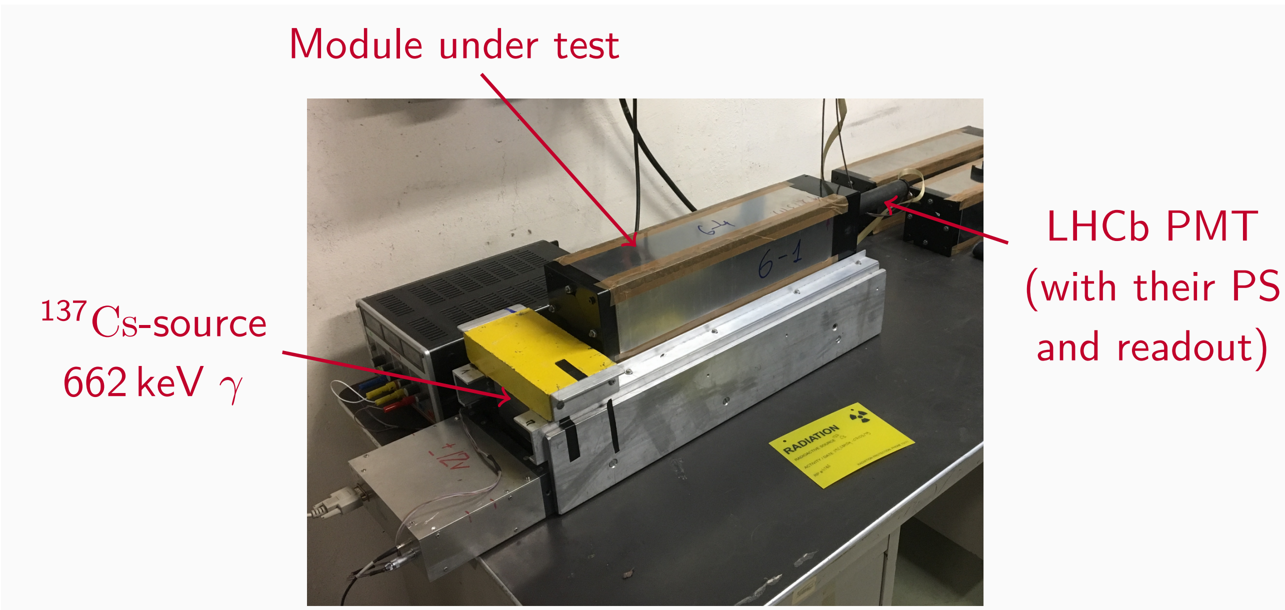
- FASER ECAL built with four spare LHCb Outer Ecal modules ➡ **many thanks to LHCb Collaboration !**
  - **Shashlik layout:** sampling lead/scintillator structure readout by plastic wavelength-shifting (WLS) fibres running parallel to the beam axis
  - 66 layers x (2mm Pb + 4mm plastic scintillator) ➡ **25 X_0**
  - combined light from all layers readout by a single PMT

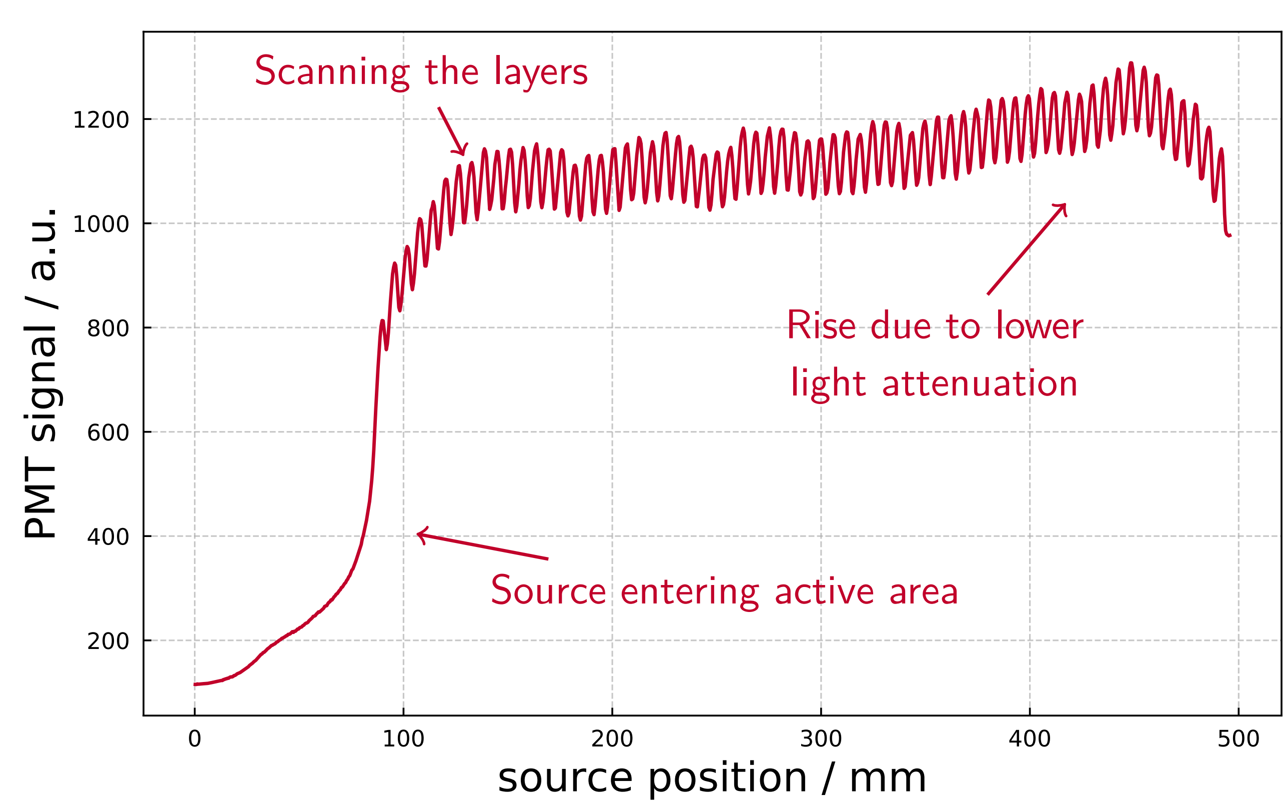


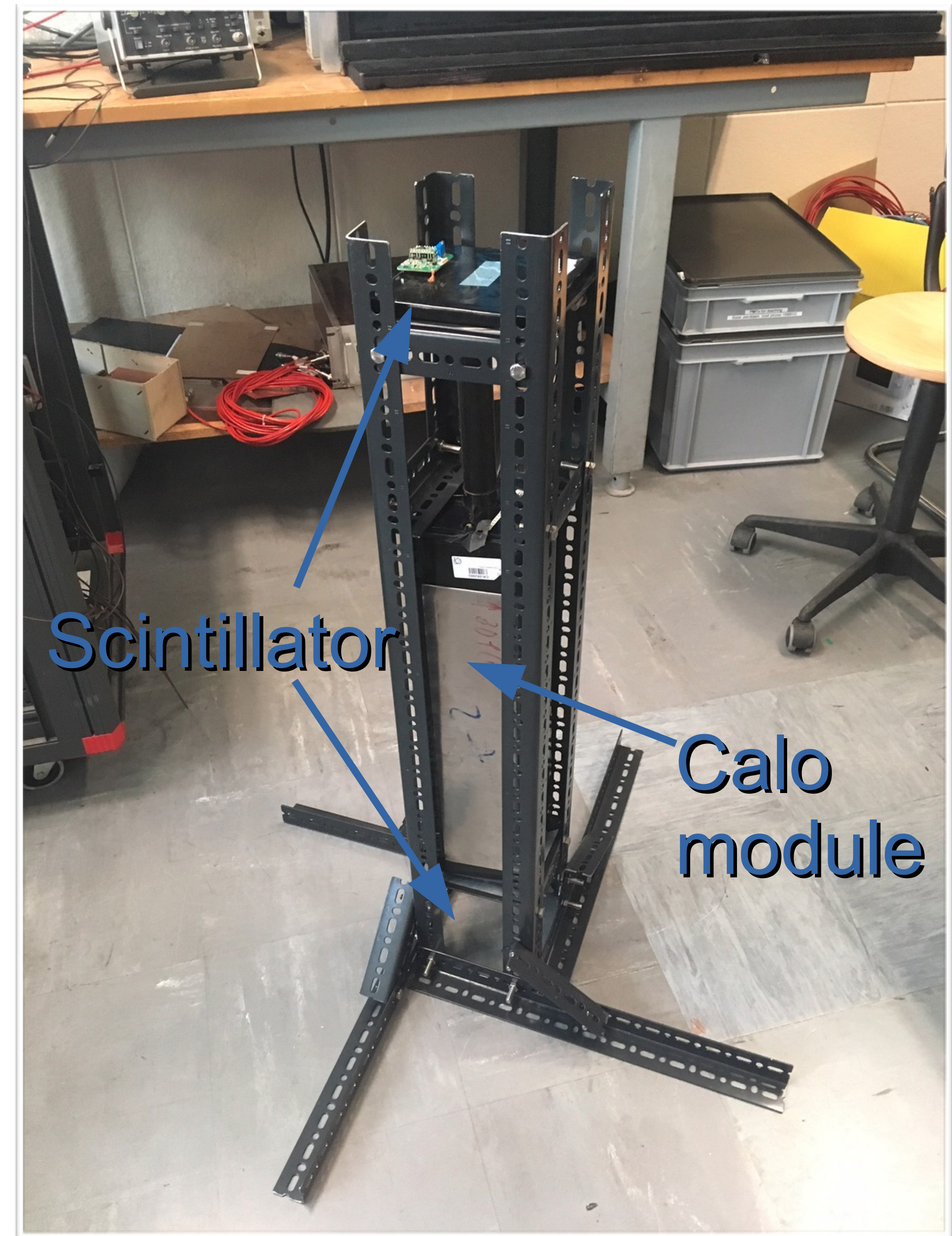


Electromagnetic calorimeter

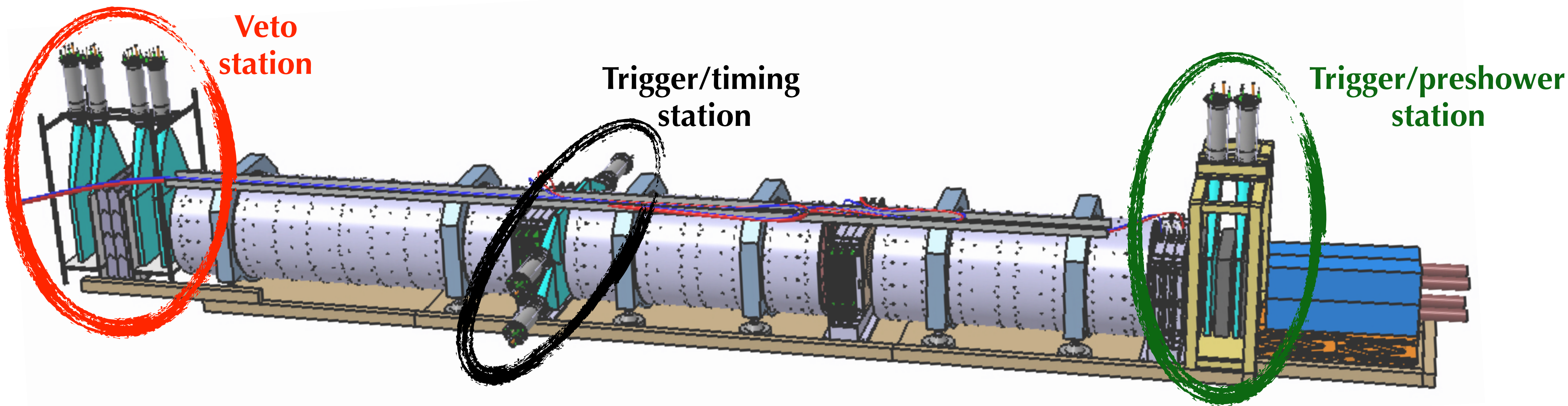
- Calibration / tests using both **^{137}Cs** source and **cosmics**
  - cosmic-ray test stand to allow combined testing of scintillator stations and calorimeter modules







Scintillator layers

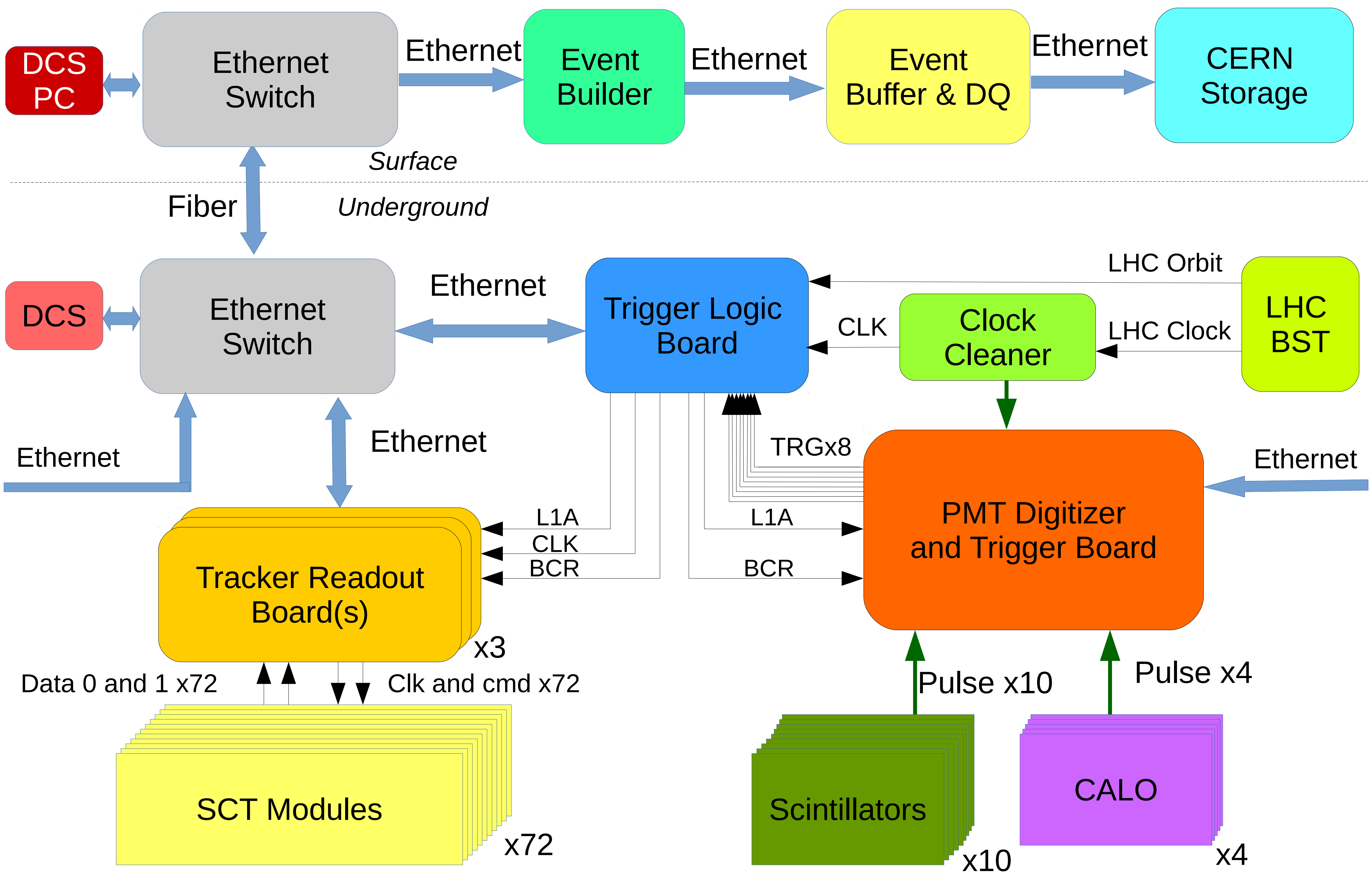


- **Veto station**
  - suppress incoming charged particles (high-energy μ) ➡ **target efficiency per scintillator layer > 99.9%**
  - Pb absorber (20 X_0) for γ-conversion (μ-bremsstrahlung) to be vetoed by the scintillator layers
- **Trigger / timing station**
  - target timing resolution < 1 ns
  - light-guides bent 90^o to reduce overall width

- **Trigger / preshower station**
  - additional trigger signal (coincidence with 1^{st} trigger station)
  - thin radiator layer as preshower + low-Z absorber to reduce calorimeter backsplash

TDAQ

- **Trigger**
  - Signal: Scintillators ⋃ Ecal
  - Rate: ~600 Hz, dominated by muons from ATLAS IP



Physics potential

Benchmark scenarios

- The FASER experiment will search for new light (MeV-GeV mass range) weakly interacting particles ➡ long-lived particles (LLP)
- Sensitivity reach studied under the assumption of a certain number of **benchmark models** and **detector configuration**
  - radius increase in FASER 2 to improve sensitivity to NP particles from heavy mesons (B,D) decays, as more spread out than in the case of light meson (π^0) decays

	Radius [cm]	Decay volume length [m]	Integrated luminosity [fb^{-1}]	Timescale
FASER 1	10	1.5	150	LHC Run3 2021-2023
FASER 2	100	5.0	3000	HL-LHC 2026-2035

FASER 1 is approved and fully funded, though officially FASER 2 not yet

- Further assumptions
  - 100% detection efficiency for all visible decay modes
    - sensitivity curves do not significantly change with O(1) change in efficiency
  - minimal visible energy E >100 GeV
  - no high-energy backgrounds

Benchmark scenarios

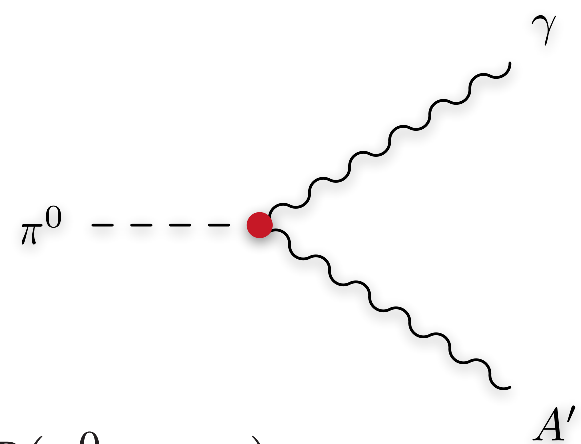
- **FASER physics program is rich**: discovery potential for all candidates with renormalizable couplings (dark photons, dark Higgs bosons, heavy neutral leptons); ALP with all types of couplings (γ, f, g); etc.
  - benchmark models defined by the CERN Physics Beyond Colliders study group

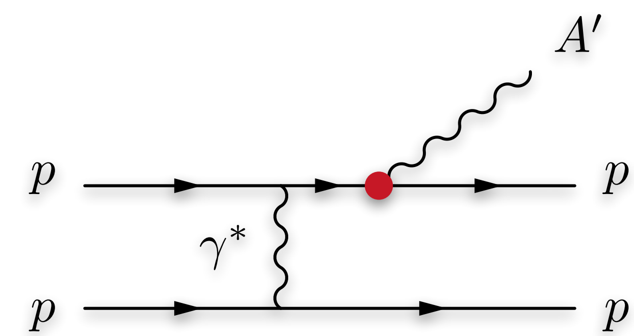
Benchmark Model	FASER	FASER 2	References
BC1: Dark Photon	√	√	Feng, Galon, Kling, Trojanowski, 1708.09389
BC1': $U(1)_{B-L}$ Gauge Boson	√	√	Bauer, Foldenauer, Jaeckel, 1803.05466 FASER Collaboration, 1811.12522
BC2: Invisible Dark Photon	–	–	–
BC3: Milli-Charged Particle	–	–	–
BC4: Dark Higgs Boson	–	√	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	√	√	FASER Collaboration, 1811.12522
BC11: ALP with gluon	√	√	FASER Collaboration, 1811.12522

Dark photon (A′)

- Massive dark photons (**$m_{A'}$**) arising from a **hidden sector** with broken U(1) gauge symmetry ➡ coupled to the SM photon via a small kinetic mixing term (**ε**)

- Production
  - rare decays of light mesons (π^0 / $\eta \rightarrow \gamma A'$)
  - dark bremsstrahlung ($pp \rightarrow ppA'$)





$$B(\pi^0 \rightarrow A'\gamma) = 2\epsilon^2 \left(1 - \frac{m_{A'}^2}{m_{\pi^0}^2}\right)^3 B(\pi^0 \rightarrow \gamma\gamma)$$

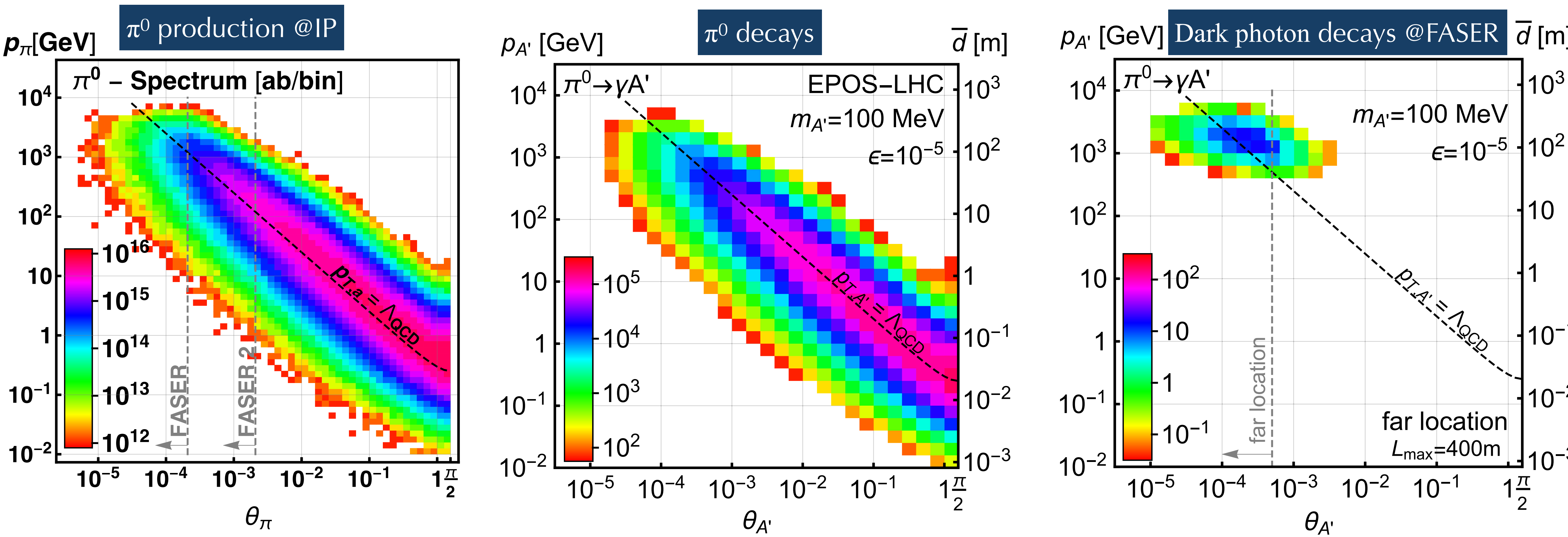
- Decay
  - pair of particles: e^+e^-, $\mu^+\mu^-$ (for $m_{A'} > 2\, m_\mu$), $\pi^+\pi^-$, etc.
  - decay length (in the limit $E_{A'} \gg m_{A'} \gg m_e$):

$$\bar{d} = c\frac{1}{\Gamma_{A'}}\gamma_{A'}\beta_{A'} \approx (80\text{ m})B_e\left[\frac{10^{-5}}{\epsilon}\right]^2\left[\frac{E_{A'}}{\text{TeV}}\right]\left[\frac{100\text{ MeV}}{m_{A'}}\right]^2$$

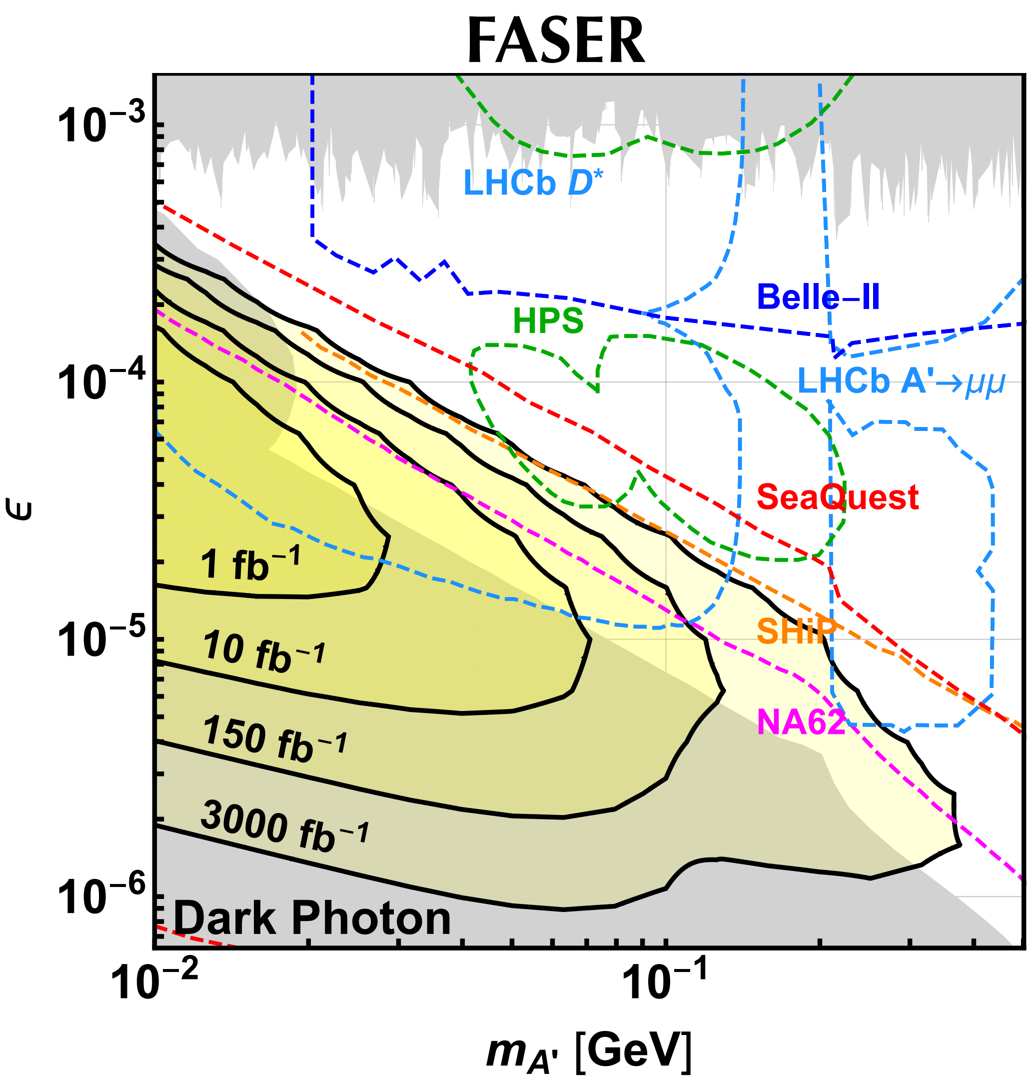
➡ for $m_{A'}$ ~ 10 - 100 MeV and ε~10^{-5} (within FASER reach, see later), dark photons with $E_{A'}$ ~ TeV have a decay length of ~100 m

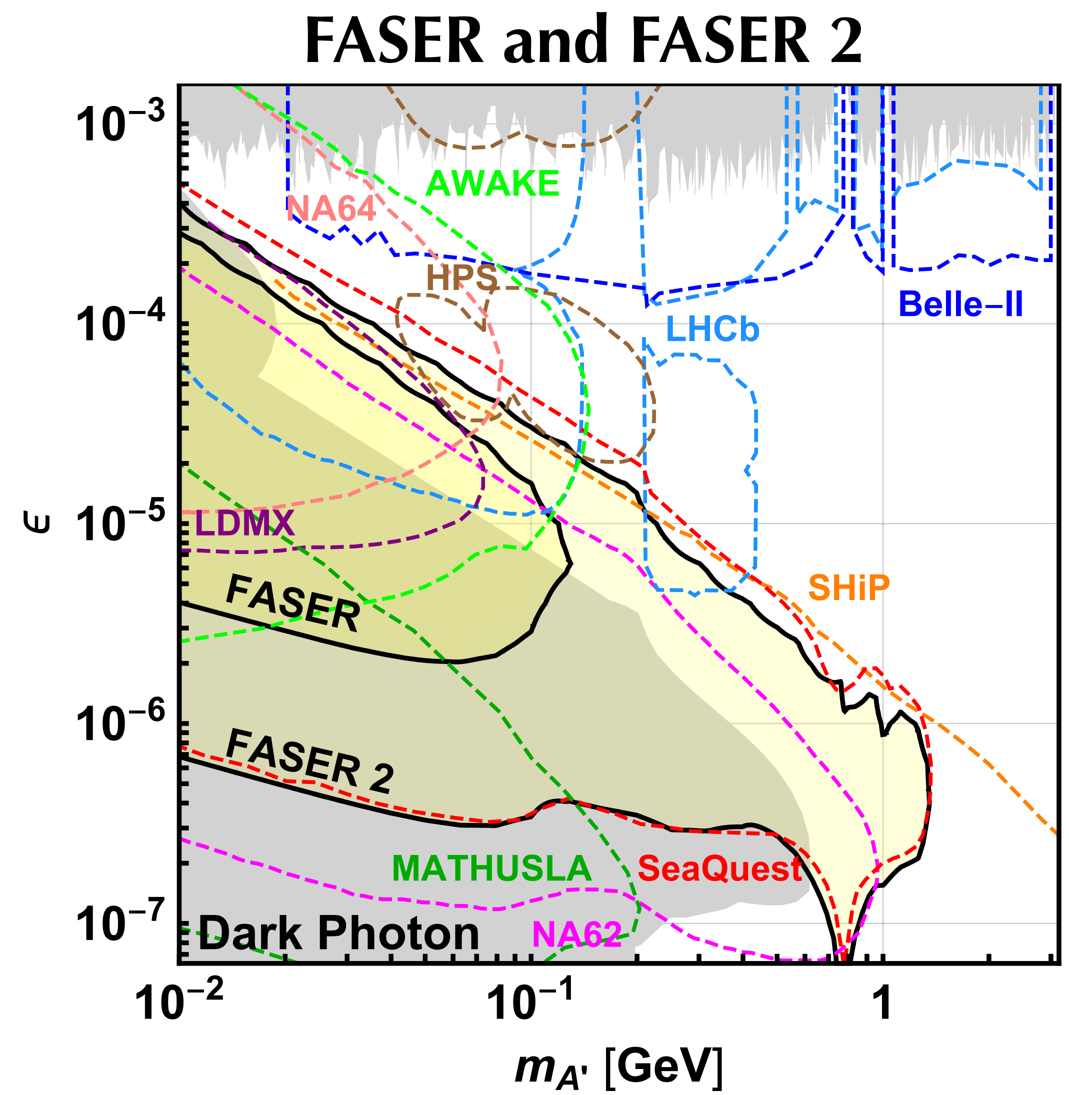
Dark photon (A′)

- Very large π^0 event rates produced in pp collisions
  - 2×10^{17} @LHC Run3 (150 fb^{-1})
  - predictions consistent among different MCs (EPOS-LHC, QGSJET-II-04, SIBYLL 2.3)
    - tuned to match recent LHC data (forward high-E scattering data)
  - 0.6% of π^0 within FASER acceptance
- Even with large suppression ($\varepsilon=10^{-5}$), we **expect $N_{A'}\sim$ 100 signal events** (for $m_{A'}$=100 MeV) **that can be detected with FASER !**
  - (detector acceptance for $A' \to e^+e^- \sim 10^{-3}$)



Dark photon (A′)

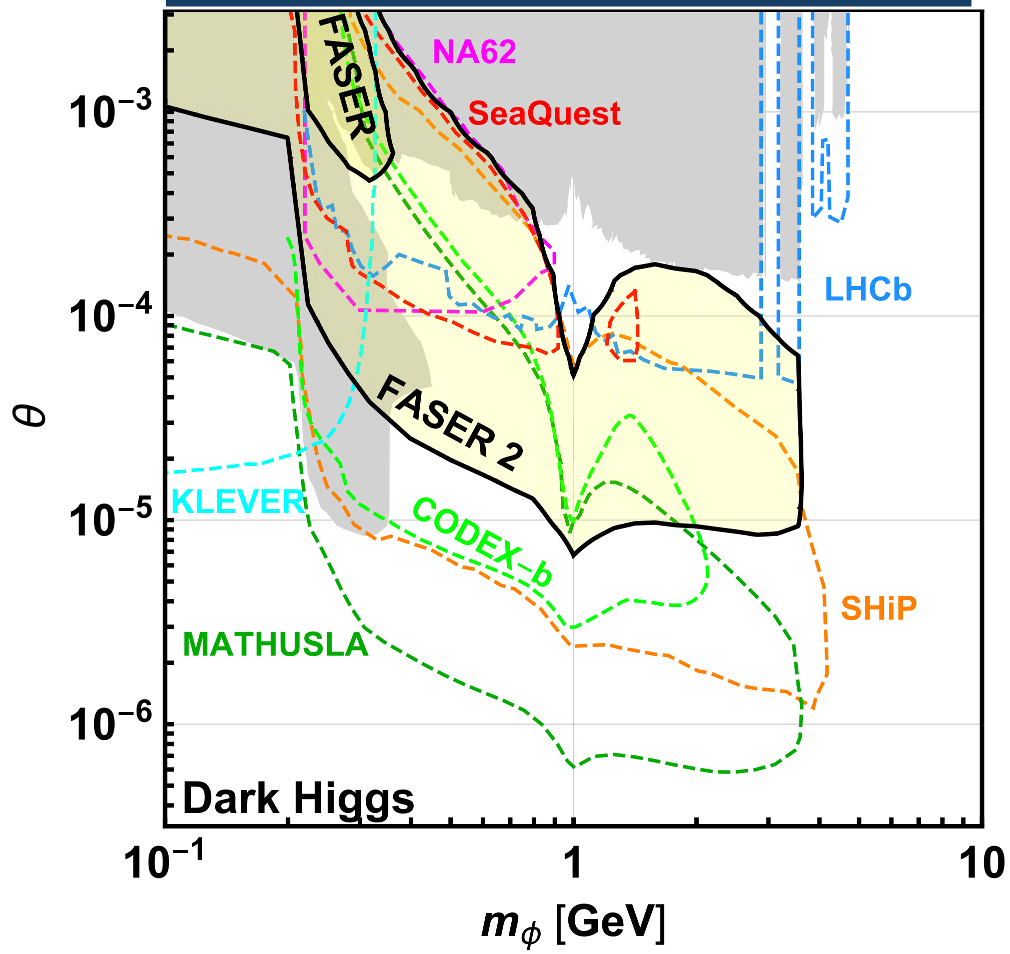




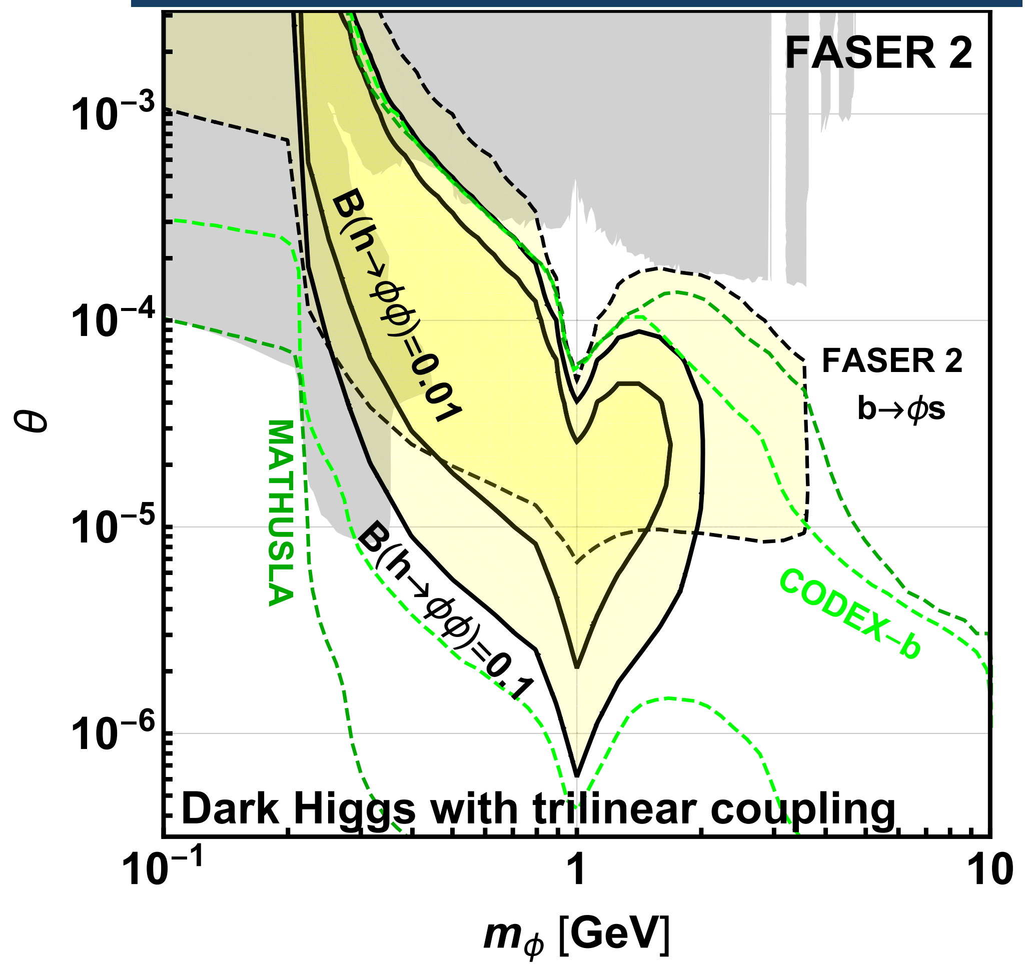
- FASER will already probe new phase-space since the first fb^{-1}
- Large discovery potential after 150 fb^{-1}
- FASER-2:
  - mass reach > GeV
  - ε probed in the range 10^{-7} - 10^{-4}

Dark Higgs (Φ)

Single production (B → X$_s$Φ)



Double production (B → X$_s$ΦΦ)

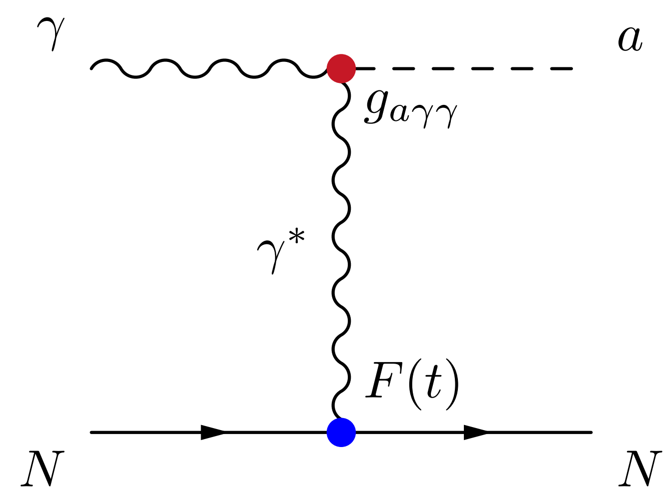


- Dark Higgs boson: single production
  - mainly produced through rare B-decays
  - FASER-2 highly complementary to other proposed experiments
- Dark Higgs boson: double production (large trilinear coupling)
  - probe hΦΦ coupling with sensitivity rivaling the sensitivity from probes of $h^{(*)} \to \Phi\Phi$ at e.g. the HL-LHC ➡ complementary to high energy experiments (LHC, ILC)
  - sensitivity to low values of θ mixing angle

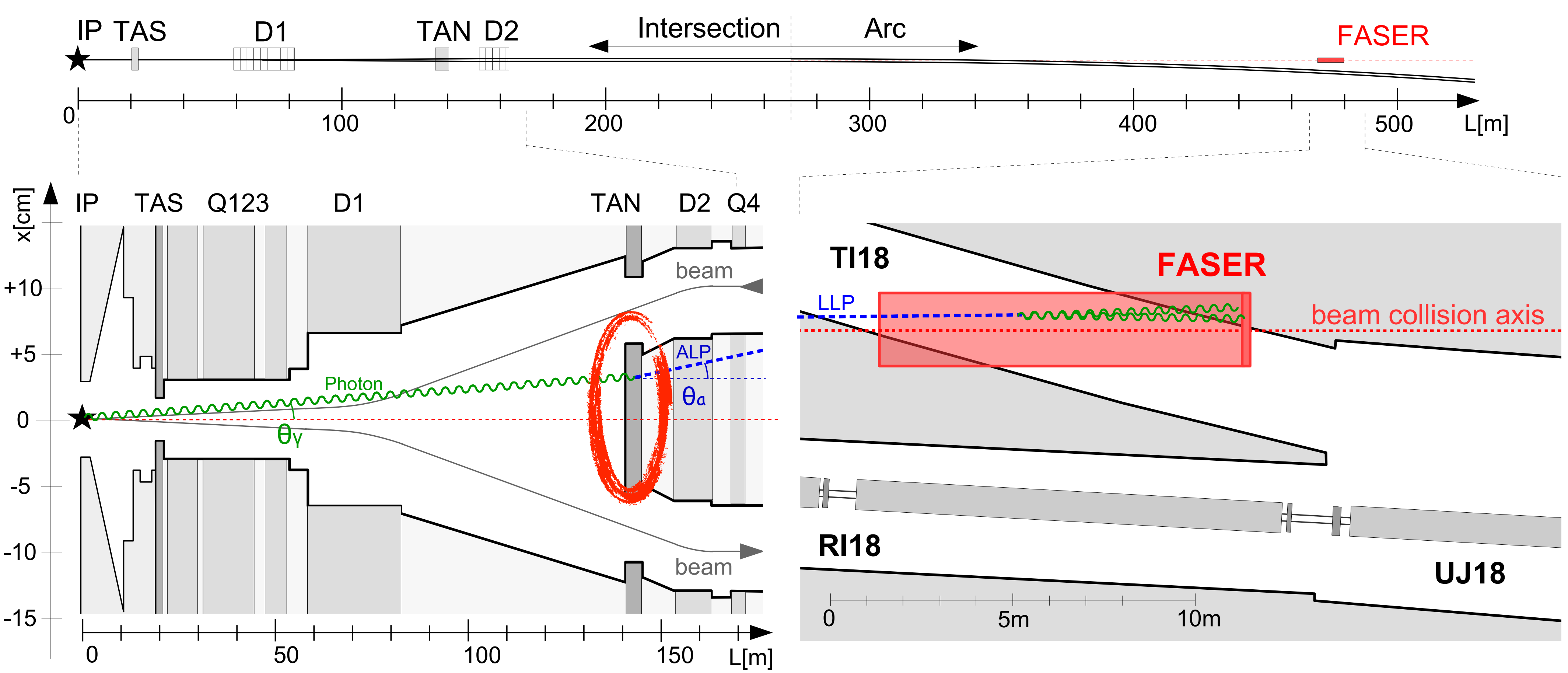
Axion-like particles (a)

- Production of highly energetic ALPs in the very forward region dominated by <u>Primakoff process</u>
  - γ converts into ALP after collision with a nucleus
  - ALP travels ~350 m and decays to γγ

➡ **high-energy beam-dump experiment**

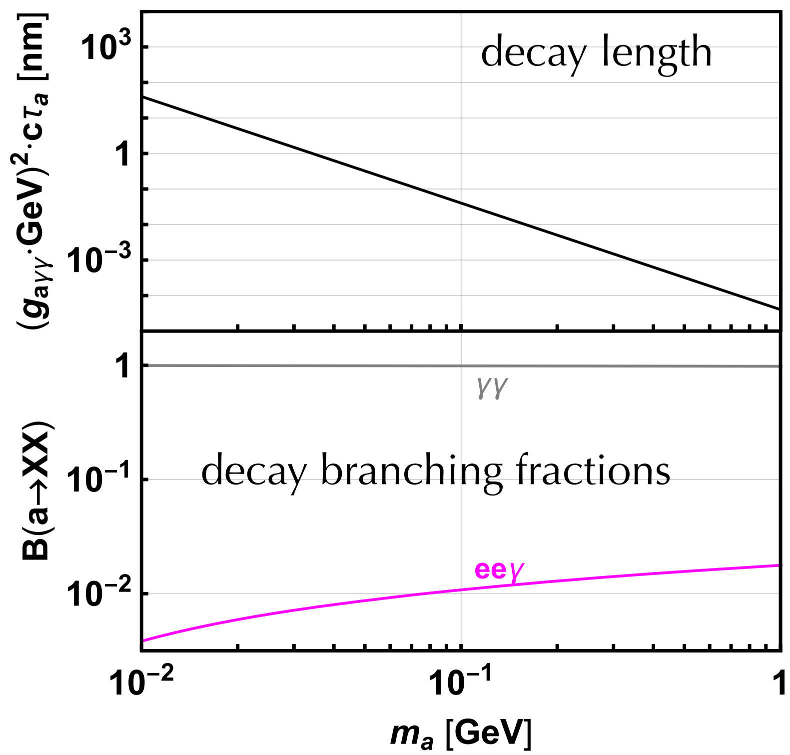


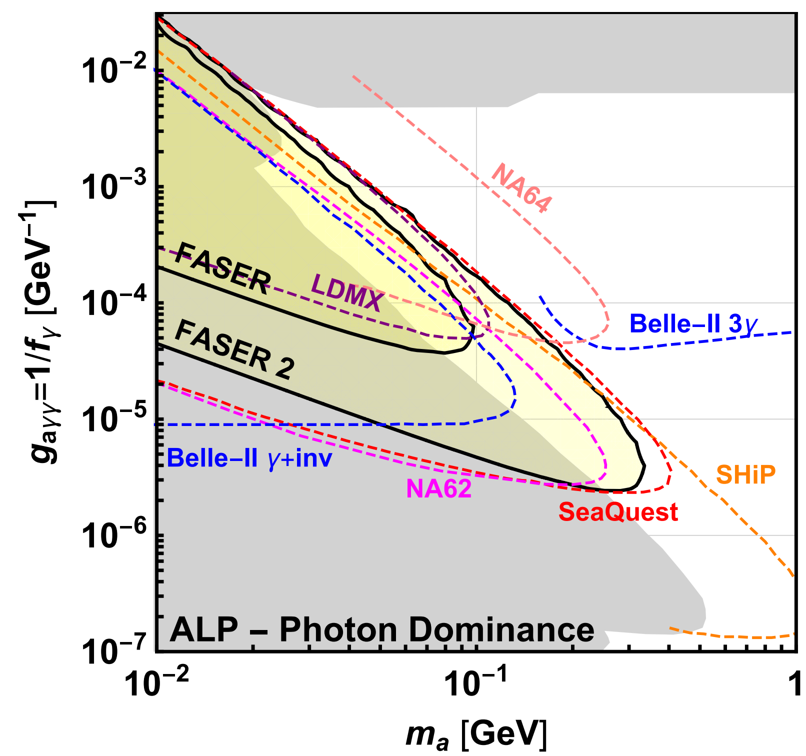
- Not possible to distinguish the two close-by photons from ALP decay, though event signatures with *i)* no charged particle in the tracker and *ii)* >TeV deposited em energy will be ~background free



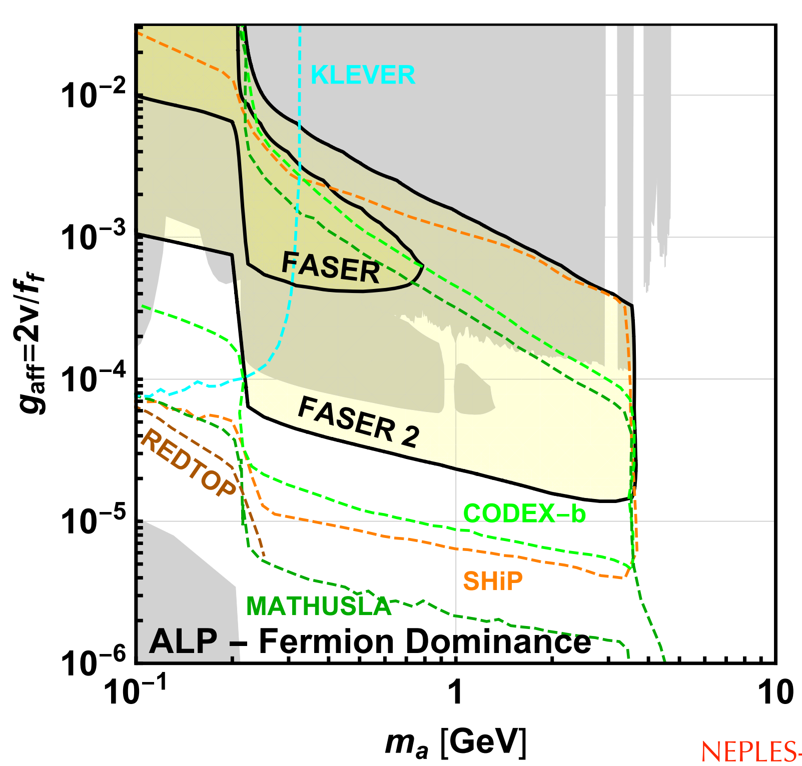
Axion-like particles (a)

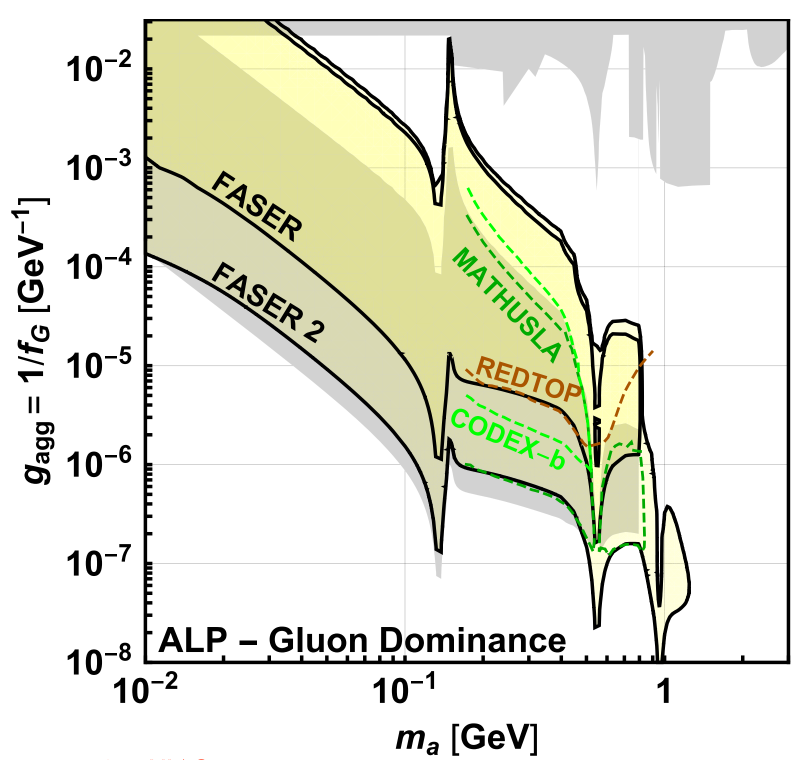
- ALP coupled to photons





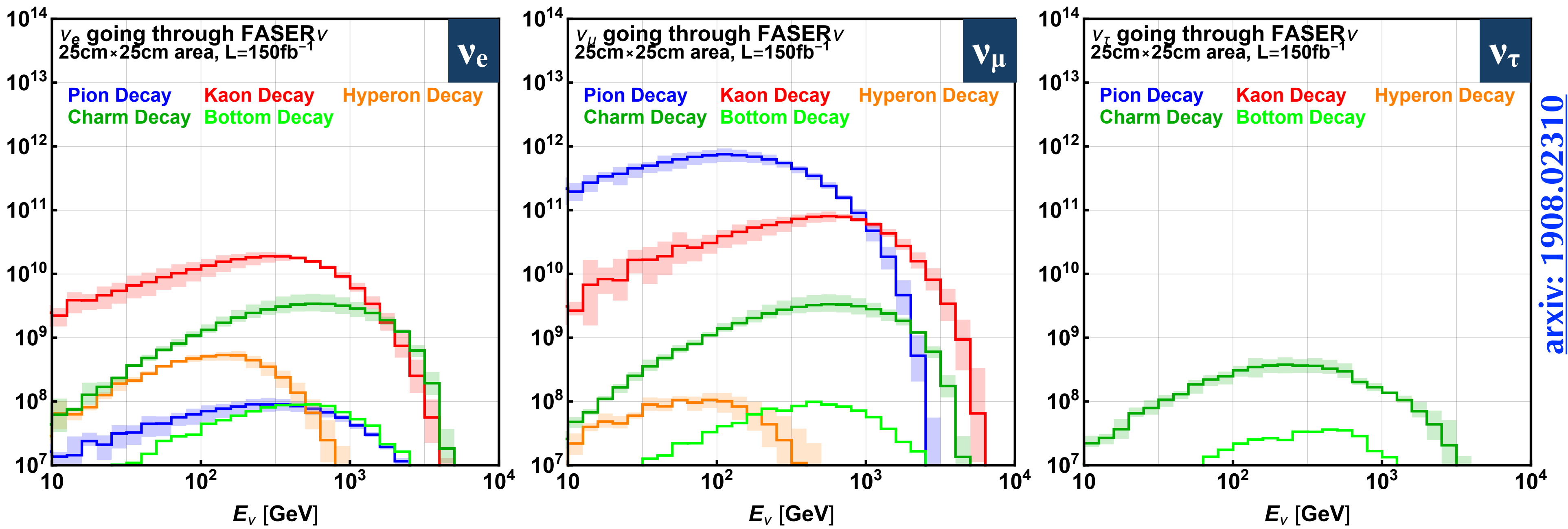
- ALP coupled to fermions and gluons





Neutrinos and FASERν

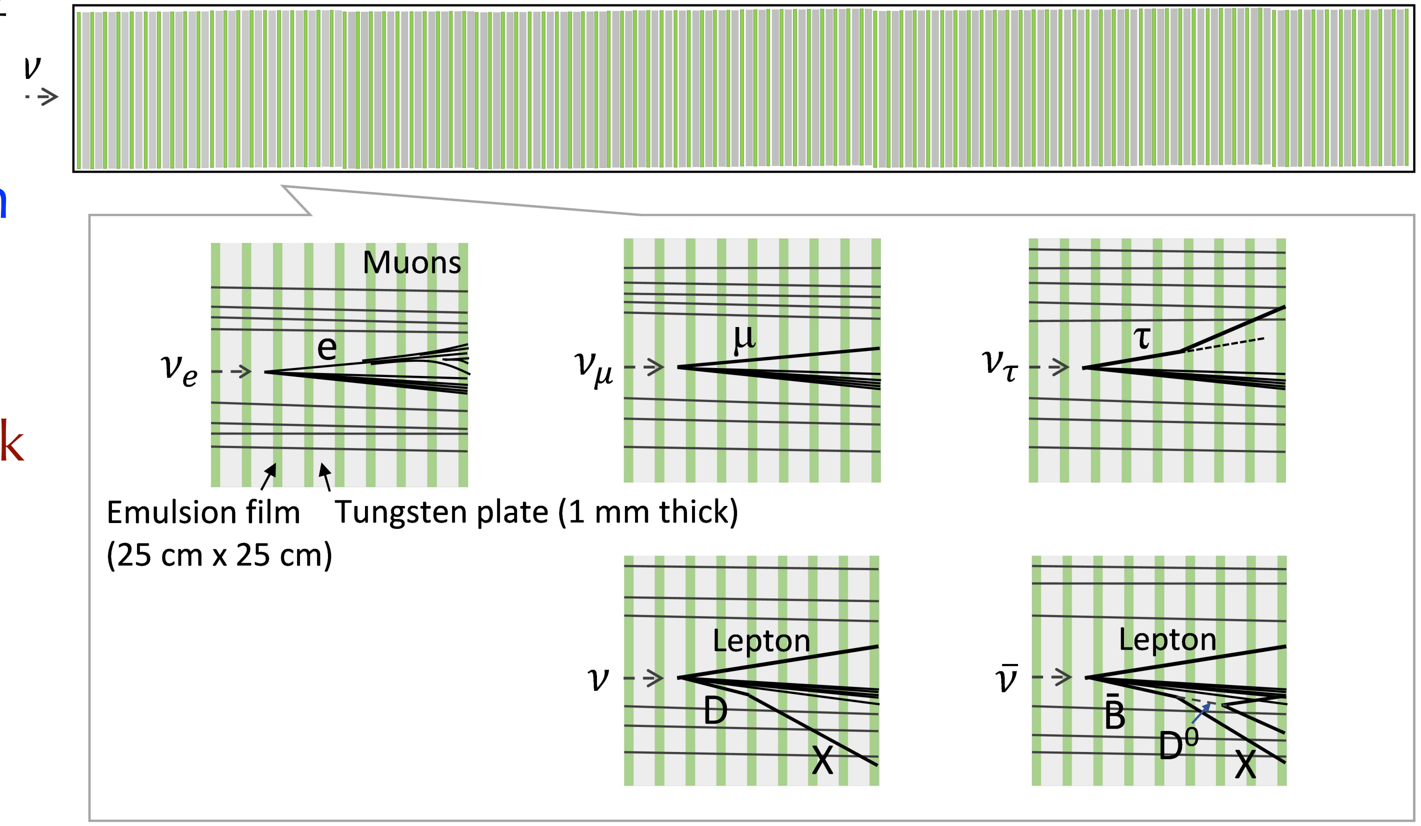
- Very large flux of neutrinos going through FASER ➡ **possibility to perform 1st collider neutrino measurements**



- FASERν: emulsion detector in front of the FASER detector
  - 1000 emulsion films interleaved with 1-mm thick tungsten plates
    - film: 2 x 70 μm-thick emulsion layers (25 x 25 cm²) + 200 μm-thick plastic base

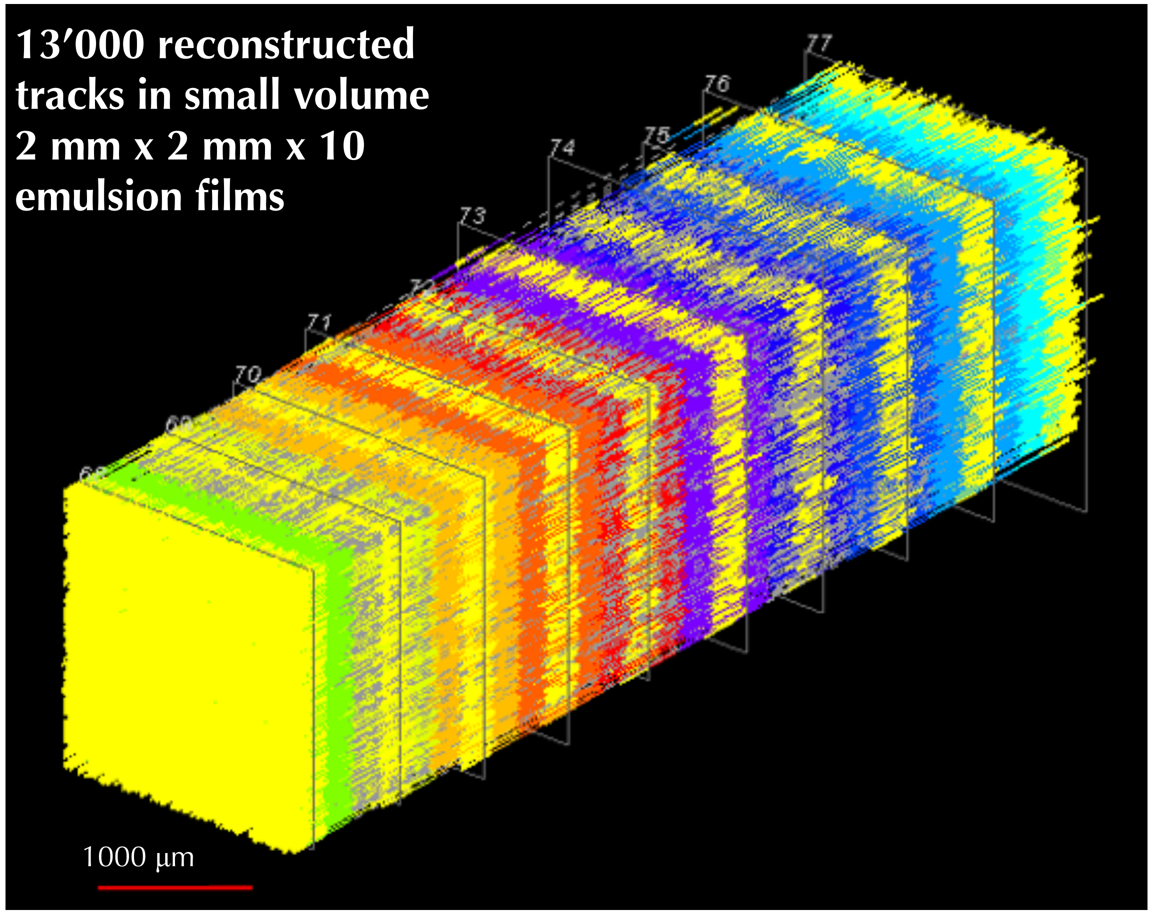
  ☛ **1.2 tons, 285 X_0, 10.1 λ_{int}**

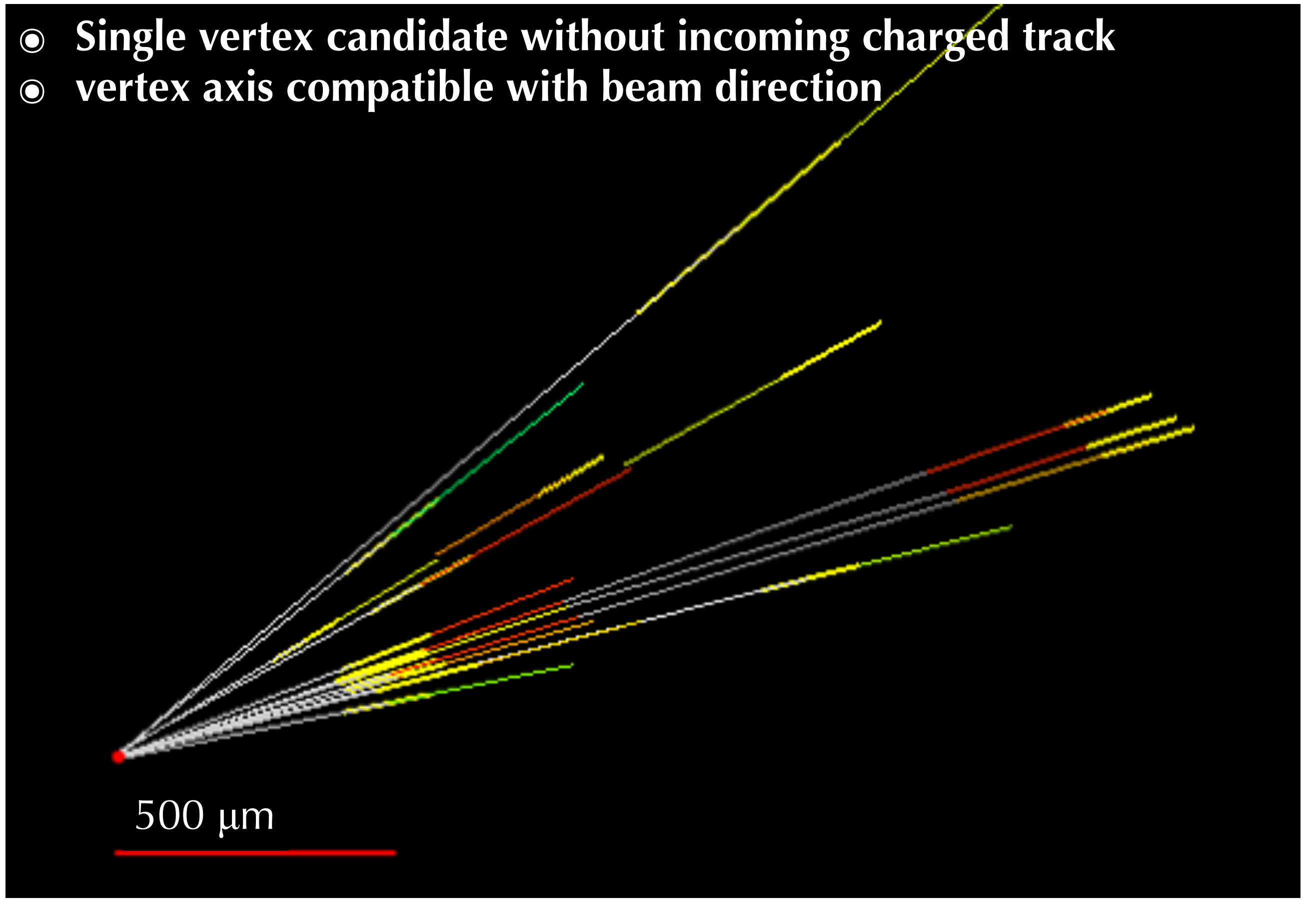
  - exchanged ~3 times / year to control charged particle density



Pilot neutrino detector

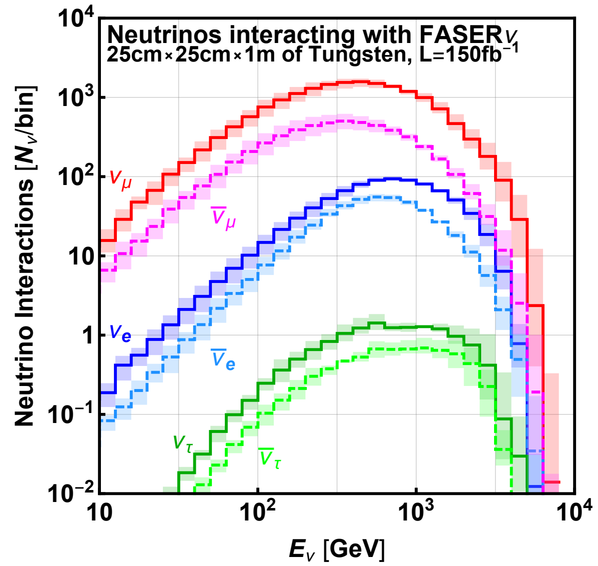
- Pilot neutrino detector installed in TI12 tunnel in 2018
  - Two modules (15 kg each), 12.5 cm x 10 cm / module
    - 100 layers of 1 mm-thick Pb plates
    - 120 layers of 0.5 mm-thick W plates
  - 12.5 fb^{-1} collected data
- Analysis in progress, though so far
  - track density of ~ 3 x 10^5 tracks / cm^2
  - few single vertex candidates already found





FASERν physics goals in LHC Run3 (2021-2023)

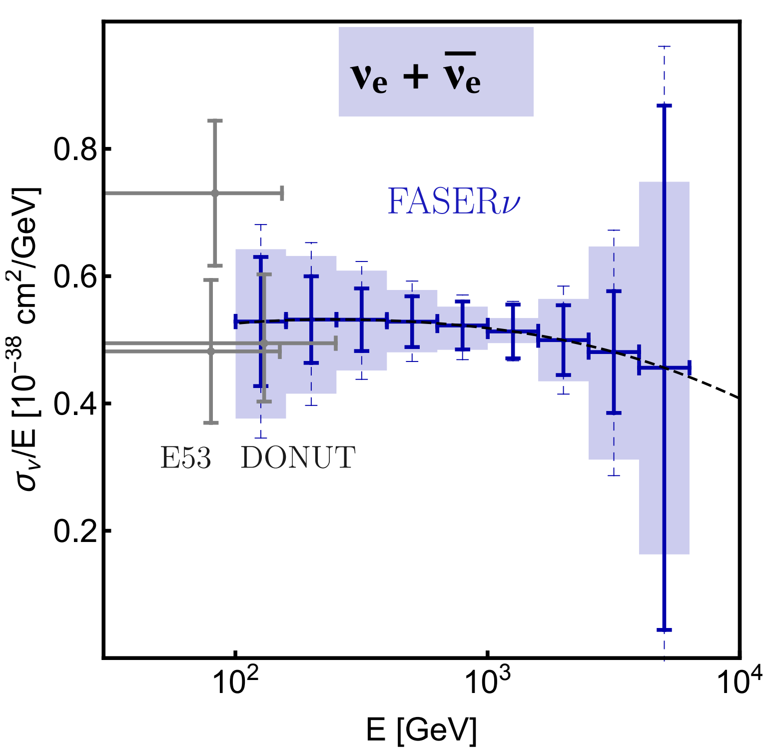
- **Detection of collider neutrinos**

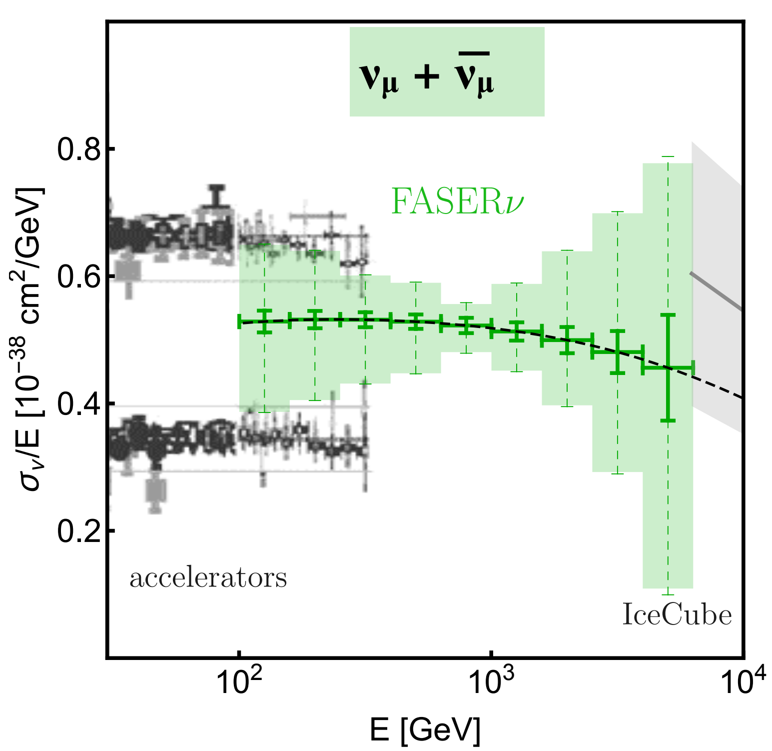


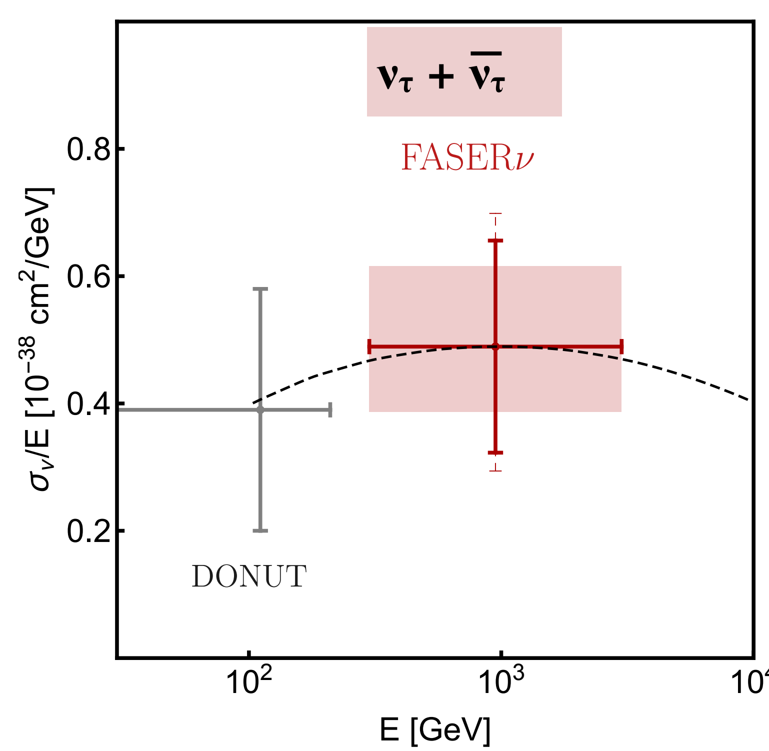
	Interactions	Mean energy
$\nu_e + \bar{\nu}_e$	~1300	~830 GeV
$\nu_\mu + \bar{\nu}_\mu$	~20400	~630 GeV
$\nu_\tau + \bar{\nu}_\tau$	21	965 GeV

Assumptions: tungsten emulsion detector (25 cm x 25 cm x 135 cm), 14 TeV, 150 fb^{-1}, E_ν > 100 GeV

- **Charged current cross section measurements**
  - systematic uncertainties include geometrical acceptance, vertex detection efficiency and lepton identification efficiency





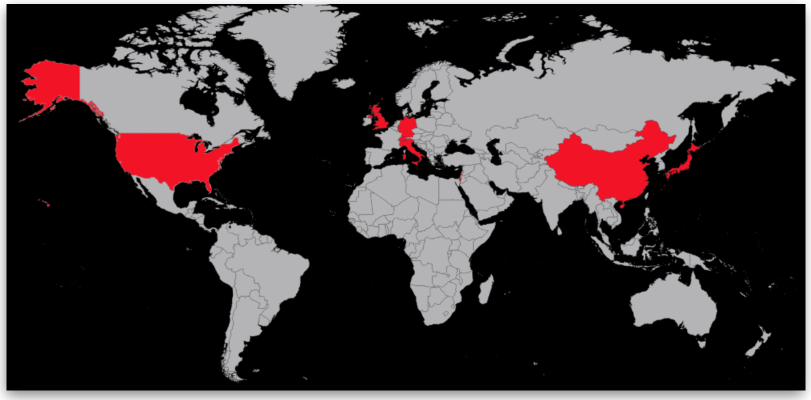


arxiv: 1908.02310

The FASER Collaboration

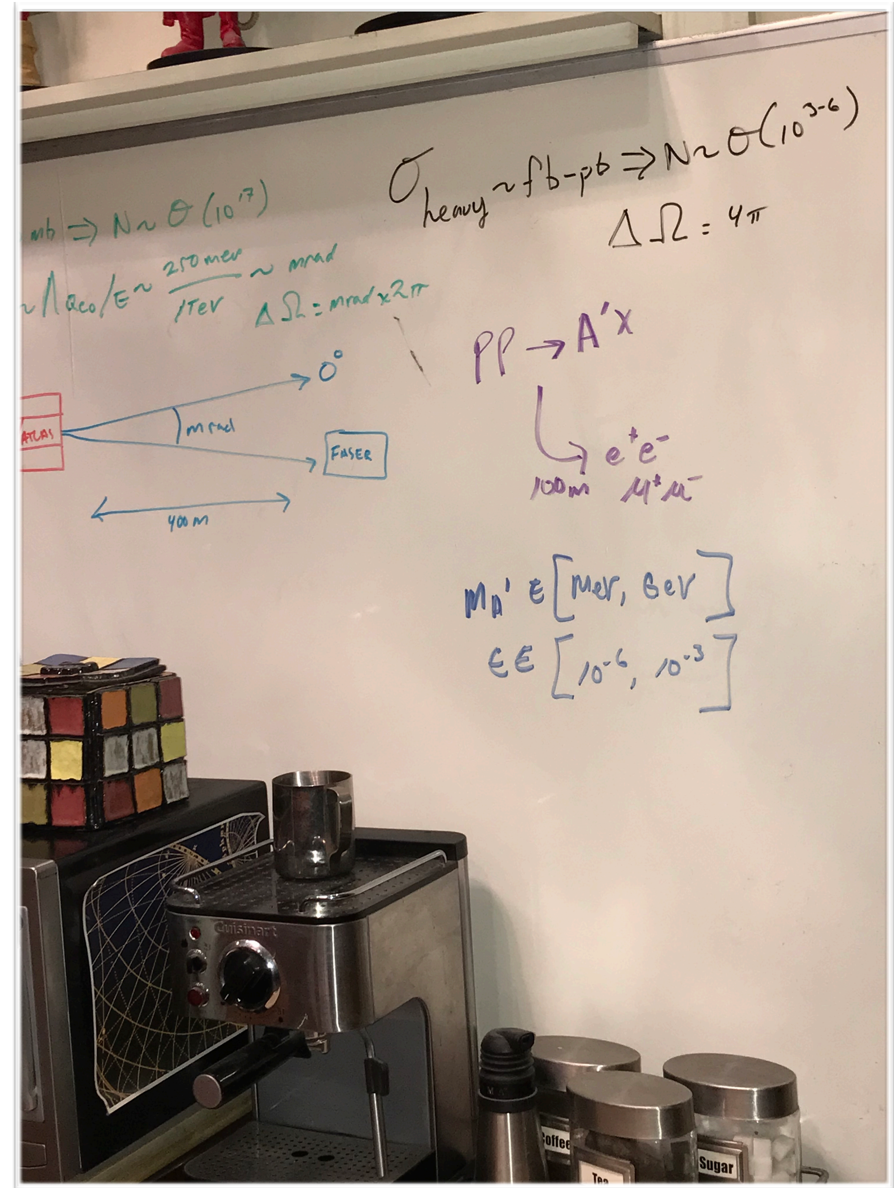
- 46 collaborators, 18 institutions, 8 countries

Henso Abreu (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), **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), **Roland Jansky** (Geneva), **Enrique Kajomovitz** (Technion), **Felix Kling** (SLAC), **Susanne Kuehn** (CERN), **Lorne Levinson** (Weizmann), **Ke Li** (Washington), **Josh McFayden** (CERN), **Sam Meehan** (CERN), **Friedemann Neuhaus** (Mainz), **Hidetoshi Otono** (Kyushu), **Brian Petersen** (CERN), **Helena Pikhartova** (Royal Holloway), **Michaela Queitsch-Maitland** (CERN), **Jakob Salfeld-Nebgen** (CERN), **Osamu Sato** (Nagoya), **Kristof Schmieden** (CERN), **Matthias Schott** (Mainz), **Anna Sfyrla** (Geneva), **Savannah Shively** (UC Irvine), **Jordan Smolinsky** (UC Irvine), **Aaron Soffa** (UC Irvine), **Yosuke Takubo** (KEK), **Eric Torrence** (Oregon), **Sebastian Trojanowski** (Sheffield), **Dengfeng Zhang** (Tsinghua), **Gang Zhang** (Tsinghua)



The FASER Collaboration

Jonathan Feng (UC Irvine) — FASER co-spokeperson



the BIG BANG THEORY

Summary and outlook

- FASER is a small and cheap experiment that will search for light and weakly interacting new particles at the LHC
  - installed 480 m downstream the ATLAS IP along the line-of-sight
  - Detector: decay volume (1.5 m) + spectrometer (3.5 m), spare silicon microstrip detectors for tracking (ATLAS SCT) and spare em calorimeter modules (LHCb)

- Thanks to the **Simons foundation** and to the **Heising-Simons foundation** for securing the funding for this project, and **CERN** (civil engineering and preparation works)

- Extremely fast turnaround time
  - LOI submitted to LHCC in July 2018
  - Experiment approved by CERN on March 2019
  - All parts designed. Production / procurement of required items in-progress
    - QA and sub-systems commissioning to follow
  - Assembly and full-detector commissioning during 2020
  - **Data-taking during LHC Run3 (2021-2023), target 150 fb^{-1}**

Summary and outlook

- FASER to complement current LHC's physics program
  - exploit large number of highly boosted low pT inelastic events
  - dark photons, dark Higgs, ALP, etc.
  - Neutrino physics possible with addition of emulsion detectors (FASERν)

- Possible upgrade (FASER-2) for the HL-LHC
  - increase decay volume (1m) and overall spectrometer (5m)
  - further civil-engineering needed to extend existing tunnel

Additional information

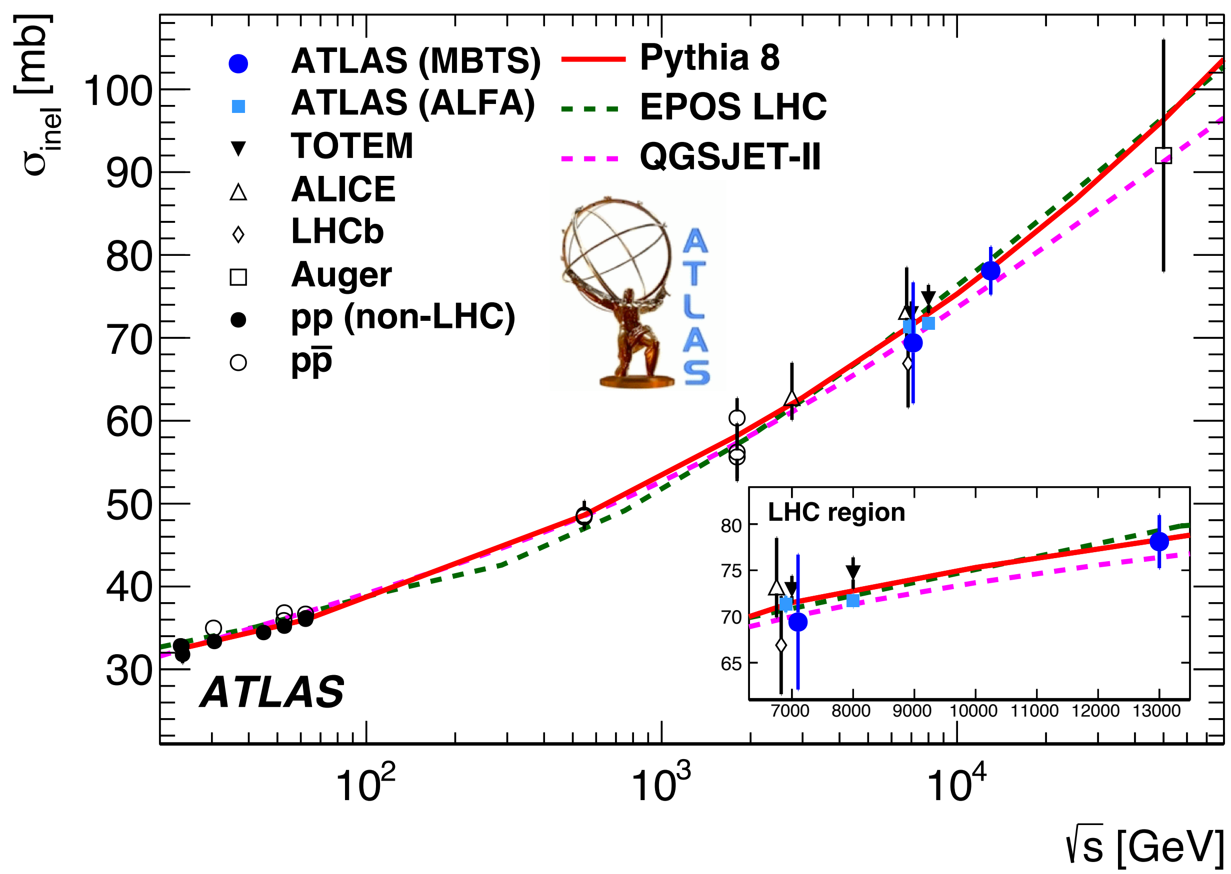
- FASER Collaboration
  - “Letter of Intent for FASER: ForwArd Search ExpeRiment at the LHC”, arXiv:1811.10243
  - “Technical Proposal for FASER: ForwArd Search ExpeRiment at the LHC”, arXiv:1812.09139
  - “FASER's Physics Reach for Long-Lived Particles”, arXiv:1811.12522
  - “FASER: ForwArd Search ExpeRiment at the LHC (Input to the European Particle Physics Strategy)”, arXiv:1901.04468
  - “Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC”, arXiv:1908.02310

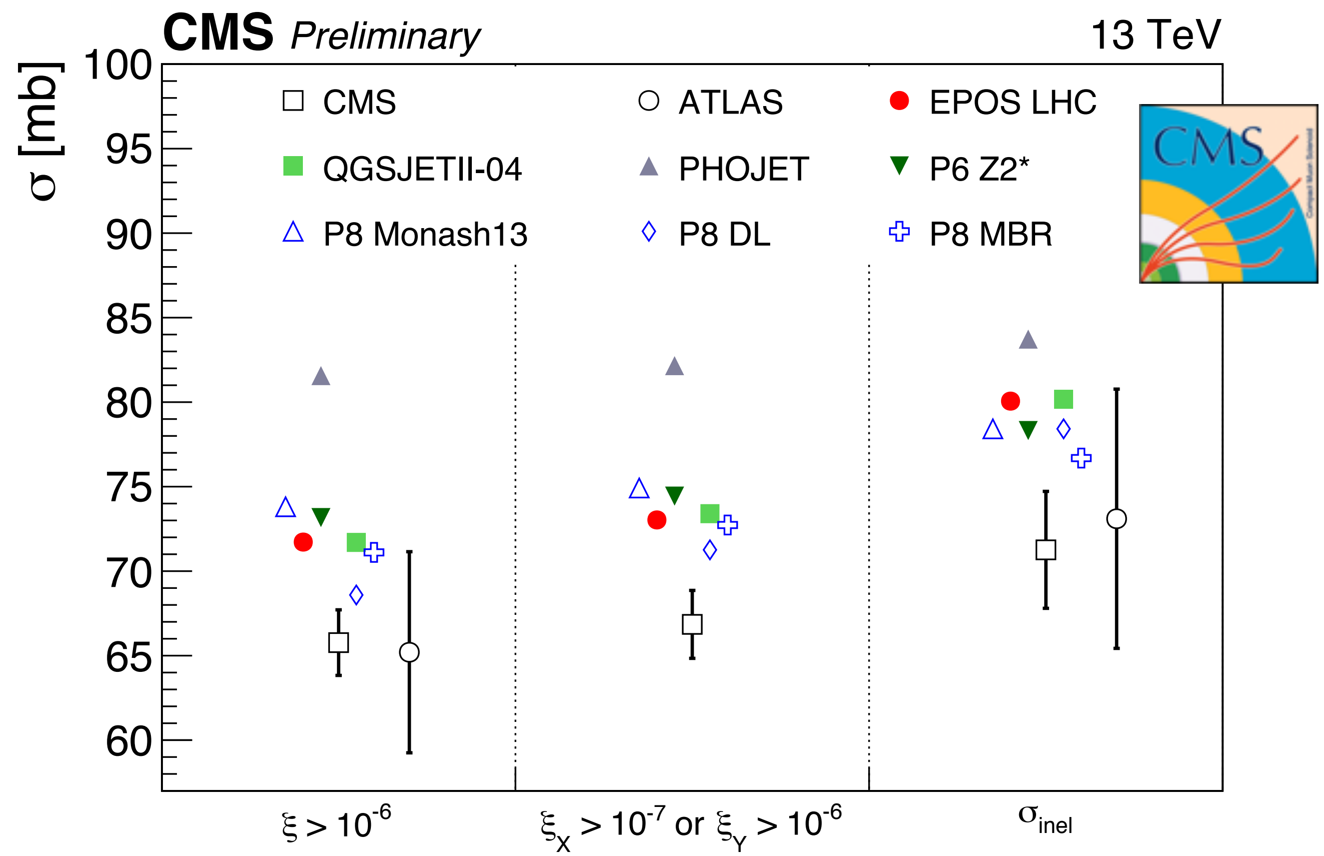
https://twiki.cern.ch/twiki/bin/view/FASER/WebHome

Thanks for your attention !

Backup

Inelastic pp cross section at 13 TeV





$\sigma_{\rm inel} = 78.1 \pm 0.6\ (\text{exp.}) \pm 1.3\ (\text{lum.}) \pm 2.6\ (\text{extrap.})\ \text{mb.}$

arxiv: 1606.02625

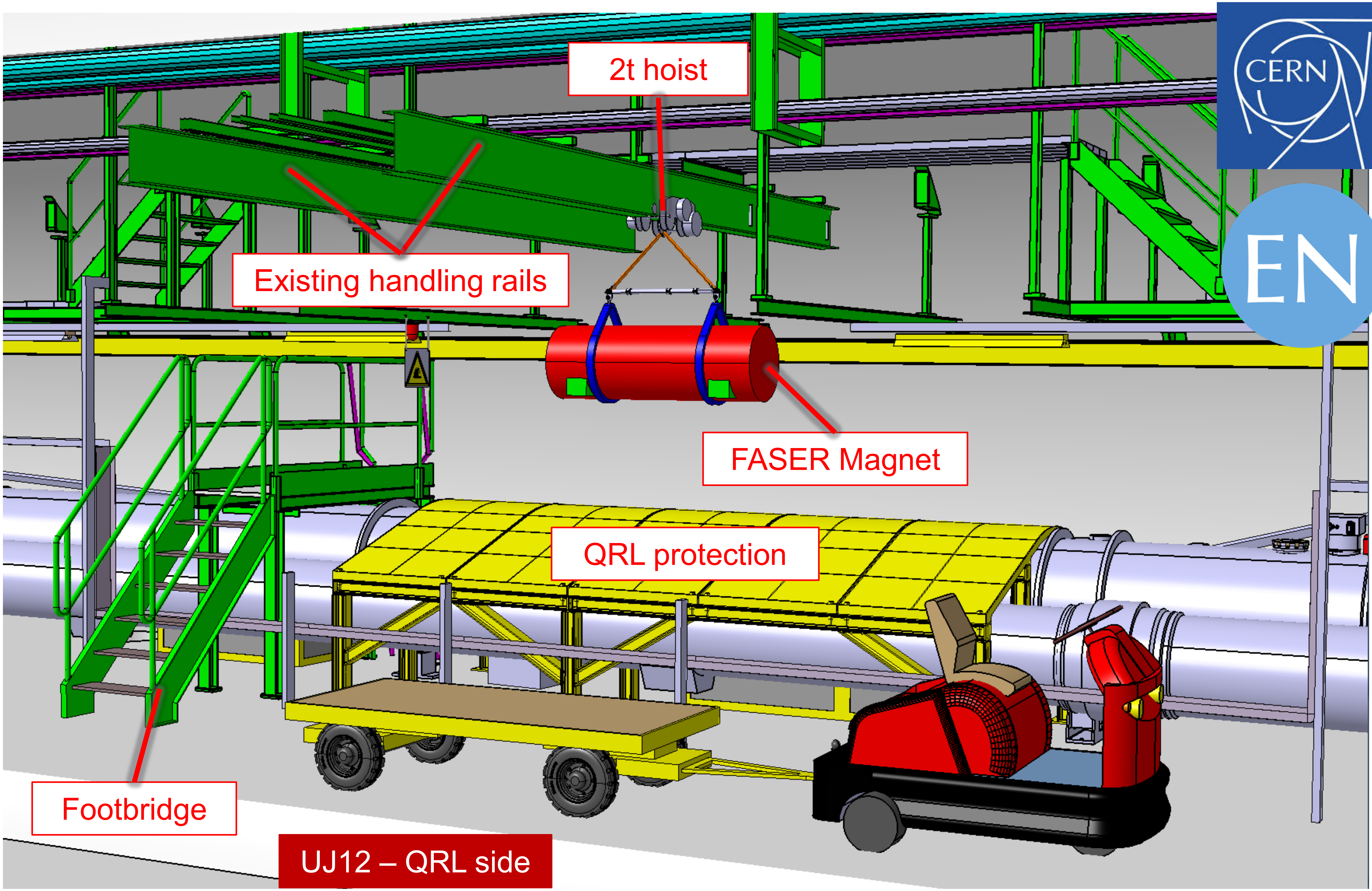
$\sigma_{\rm inel} = 71.26 \pm 0.06\ (\text{stat.}) \pm 0.47\ (\text{sys.}) \pm 2.09\ (\text{lum.}) \pm 2.72\ (\text{ext.})\ \text{mb.}$

arxiv: 1607.02033

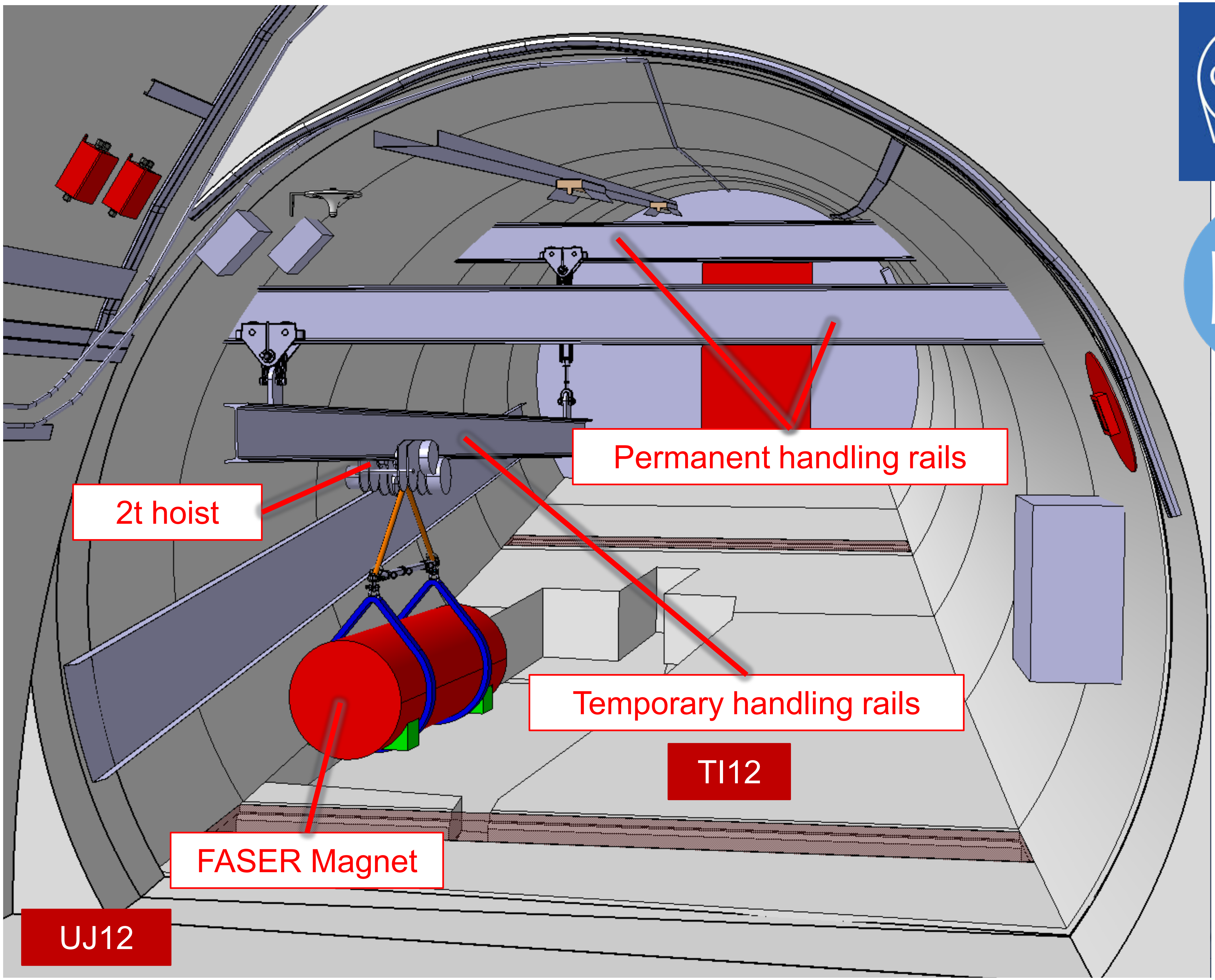
NB: in the CMS measurement the final $\sigma_{\rm inel}$ is obtained using a model dependent extrapolation of the measured cross section in different phase-space regions, corresponding to different detector acceptances on stable-particle level:

- $\xi > 10^{-6}$ for the offline HF OR detector-level selection (energy deposit > 5 GeV in any of the Hadronic Forward calorimeters)
- $\xi_X > 10^{-7}$ or $\xi_Y > 10^{-6}$ for the offline HF OR CASTOR offline selection (energy deposit > 5 GeV in any of the HF calorimeters or an energy deposit > 5 GeV in the very forward CASTOR calorimeter). The acceptance assymmetry comes from the fact that CASTOR is only located at the minus sign of the interaction point.

FASER installation in TI12

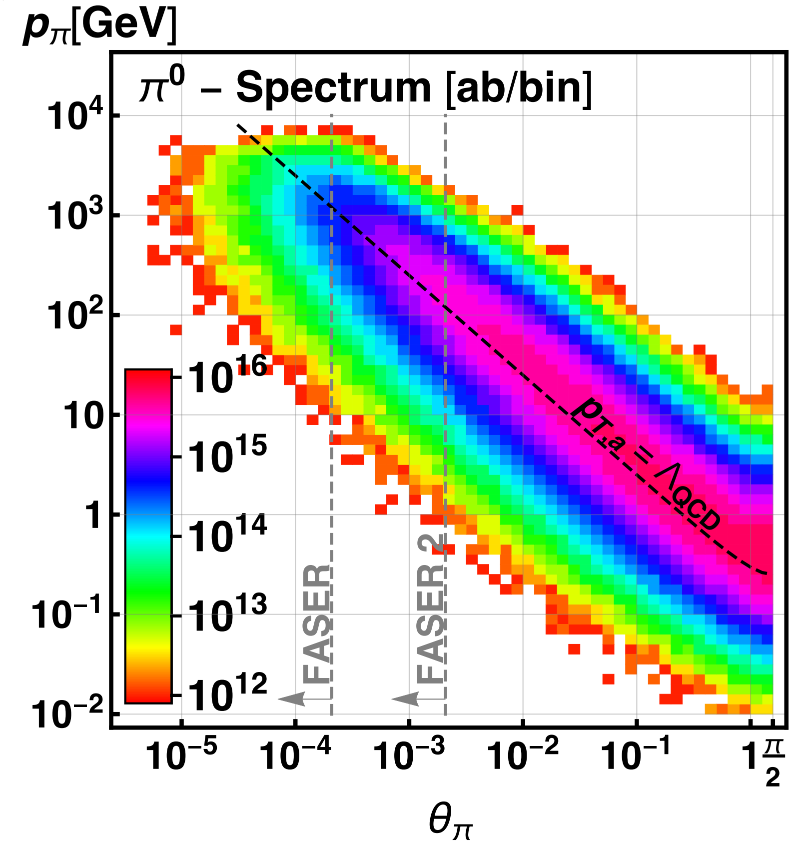


FASER installation in TI12



Neutrino-induced backgrounds (1/2)

- Forward-going neutrinos are dominantly produced by in-flight $\pi^{\pm}$ decays
  - distribution of $\pi^{\pm}$ similar to that of π^0
  - requiring E>1 TeV and $\theta \lesssim 0.5$ mrad (so that the produced neutrinos reach FASER) $N_{\pi\pm} \sim 10^{15}$ for 300 fb^{-1}



1. **The probability that a pion decays before the D1 magnet** (required as otherwise the pion be deflected and the produced neutrino will miss the detector) **is:**

$$P_\pi = 1 - \exp\left(-\frac{L_{\rm D1} m_{\pi^\pm}}{p_{\pi^\pm}\tau_{\pi^\pm}}\right) \approx 10^{-3}\left[\frac{\rm TeV}{p_{\pi^\pm}}\right]$$

with $L_{D1} \sim$ 59-83 m being the distance between the IP and D1, $\tau_{\pi\pm} \sim 2.6 \times 10^{-8}$ s and $m_\pi \sim$ 140 MeV.

2. **The probability that the resulting ν interacts with the detector volume is:**

$$P_\nu \simeq \Delta\,\sigma(E_\nu)\,\rho_{\rm det} N_A \simeq 6\times 10^{-12}\left[\frac{\sigma(E_\nu)}{10^{-35}\,{\rm cm}^2}\right]\left[\frac{0.1\,{\rm m}^2}{A_{\rm det}}\right]\left[\frac{M_{\rm det}}{1\,{\rm kg}}\right]$$

where $\rho_{det} = M_{det} / (A_{det}\Delta)$ is the average density of the target material, M_{det}, A_{det} and Δ are the mass, transverse area and length of the detector and $\sigma(E_\nu)$ is the neutrino-nucleus cross section.

J. Feng et al., "ForwArd Search ExpeRiment at the LHC", Phys. Rev. D97 no. 3, (2018) 035001, arXiv:1708.09389

Neutrino-induced backgrounds (2/2)

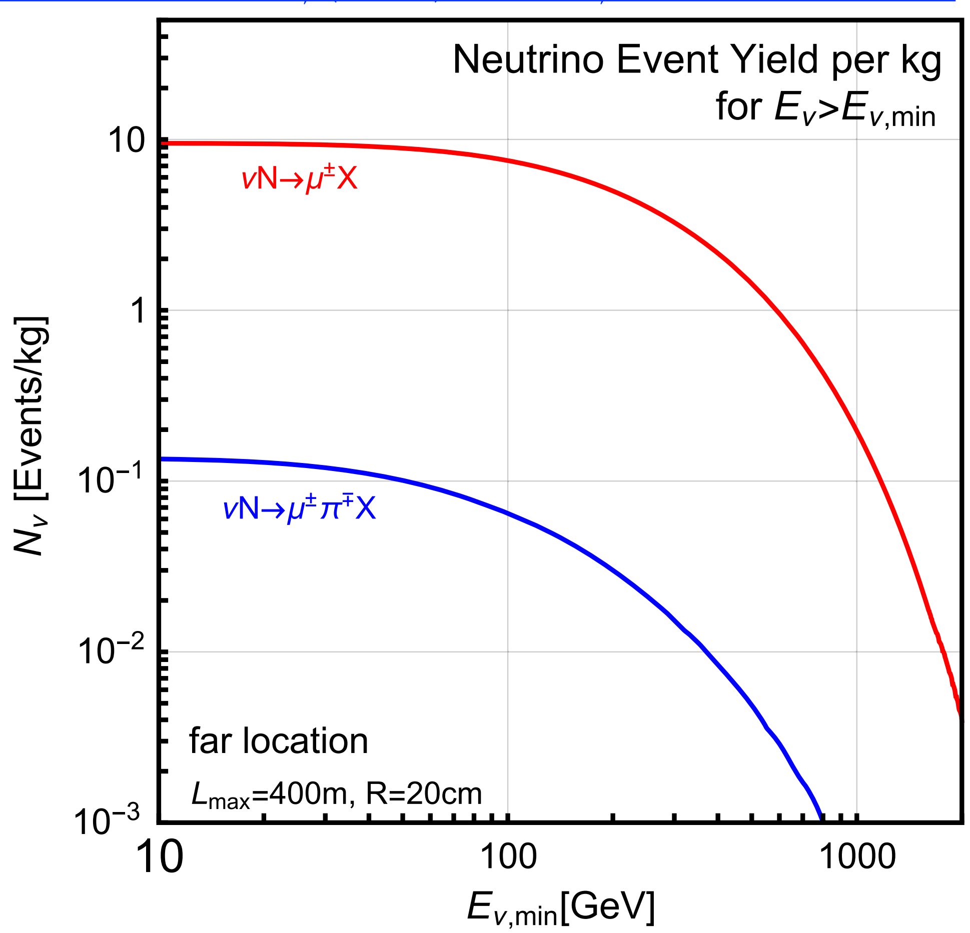
$\sigma(E_\nu)$ is normalized to the charged-current (CC) cross section for neutrinos with $E_\nu \sim 200$ GeV, which is the average energy produced in the decay of TeV pions

➡ the number of charged leptons (from neutrino CC events, $\nu_l N \rightarrow lX$) is expected to be $N_\pi P_\pi P_\nu \sim 10$ per kg of detector mass (for 300 fb^{-1})

J. Feng et al., "ForwArd Search ExpeRiment at the LHC", Phys. Rev. D97 no. 3, (2018) 035001, arXiv:1708.09389

- **Analytical calculation in excellent agreement with MC simulations:**
  - ~ 10 events per kg of detector mass ($E_\nu \sim 200$ GeV)
  - ~ 0.1 events per kg of detector mass ($E_\nu \sim 1$ TeV)

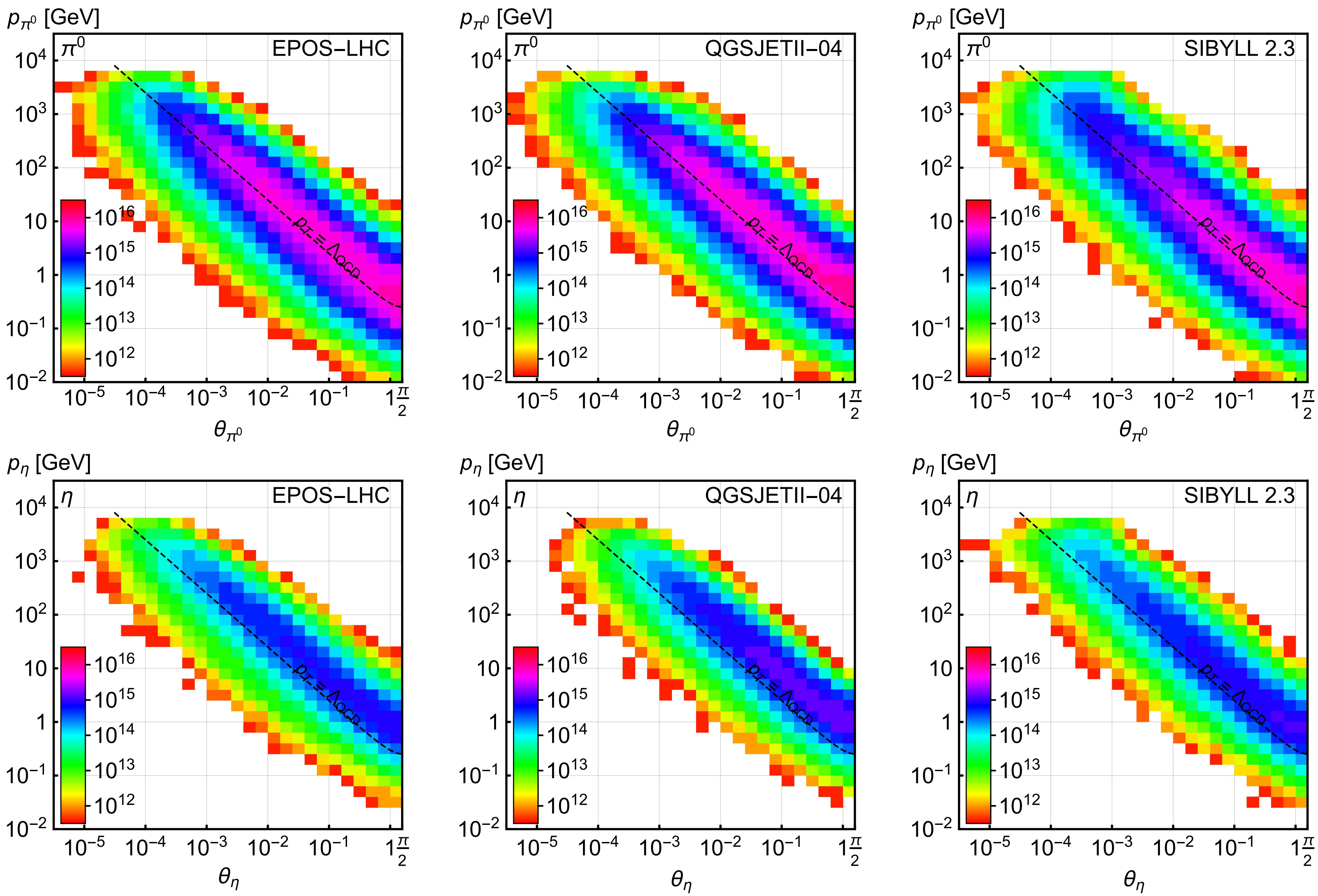
➡ considering the small mass of the first tracking station (~500 g) and of the air in the decay volume (~ 60 g), one expects at most few ~ 100 GeV CC evens (much less with TeV energies)



➡ Neutrino-induced backgrounds are negligible

Light neutral meson production

- Comparison of EPOS-LHC, QGSJET-II-04 and SIBYLL 2.3



J. Feng et al., "ForwArd Search ExpeRiment at the LHC", Phys. Rev. D97 no. 3, (2018) 035001, arXiv:1708.09389

FIG. 3. Distribution of π^0 (top) and η (bottom) mesons in the (θ, p) plane, where θ and p are the meson's angle with respect to the beam axis and momentum, respectively. The different panels show results from the simulation codes EPOS-LHC [52] (left), QGSJET-II-04 [53] (center), and SIBYLL 2.3 [54,55] (right). The total number of mesons is the number produced in one hemisphere $(0 < \cos\theta \leq 1)$ in 13 TeV pp collisions at the LHC with an integrated luminosity of 300 fb^{-1}. The bin thickness is 1/5 of a decade along each axis. The dashed line corresponds to $p_T = p \sin\theta = \Lambda_{\text{QCD}} \simeq 250$ MeV.

Dependence on beam collision axis offset

arxiv: 1811.12522

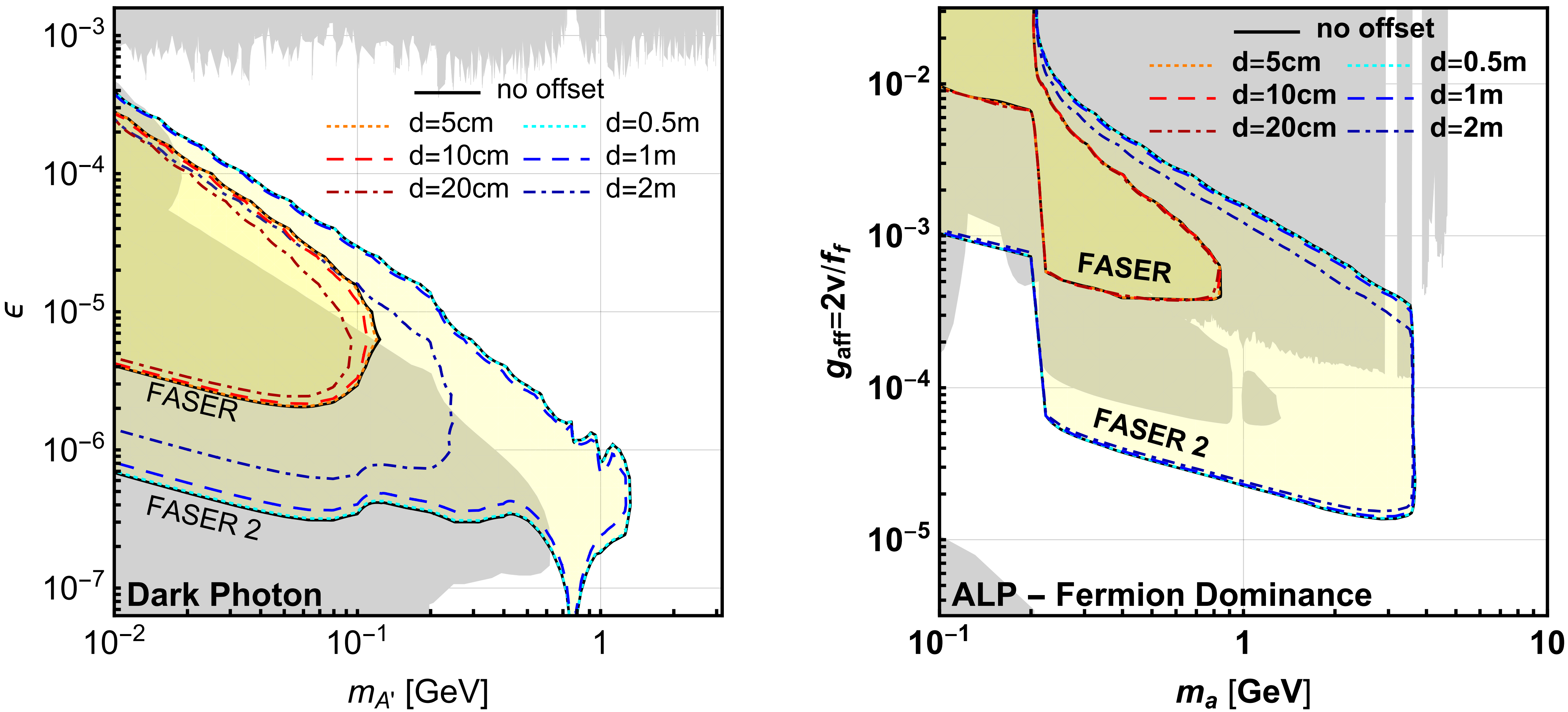


FIG. 19. FASER reach for dark photons (left) and ALPs with dominantly fermion couplings (right) for different offsets *d* between the beam collision axis and the center of FASER.

Dependence on MC generators and PDFs

arxiv: 1811.12522

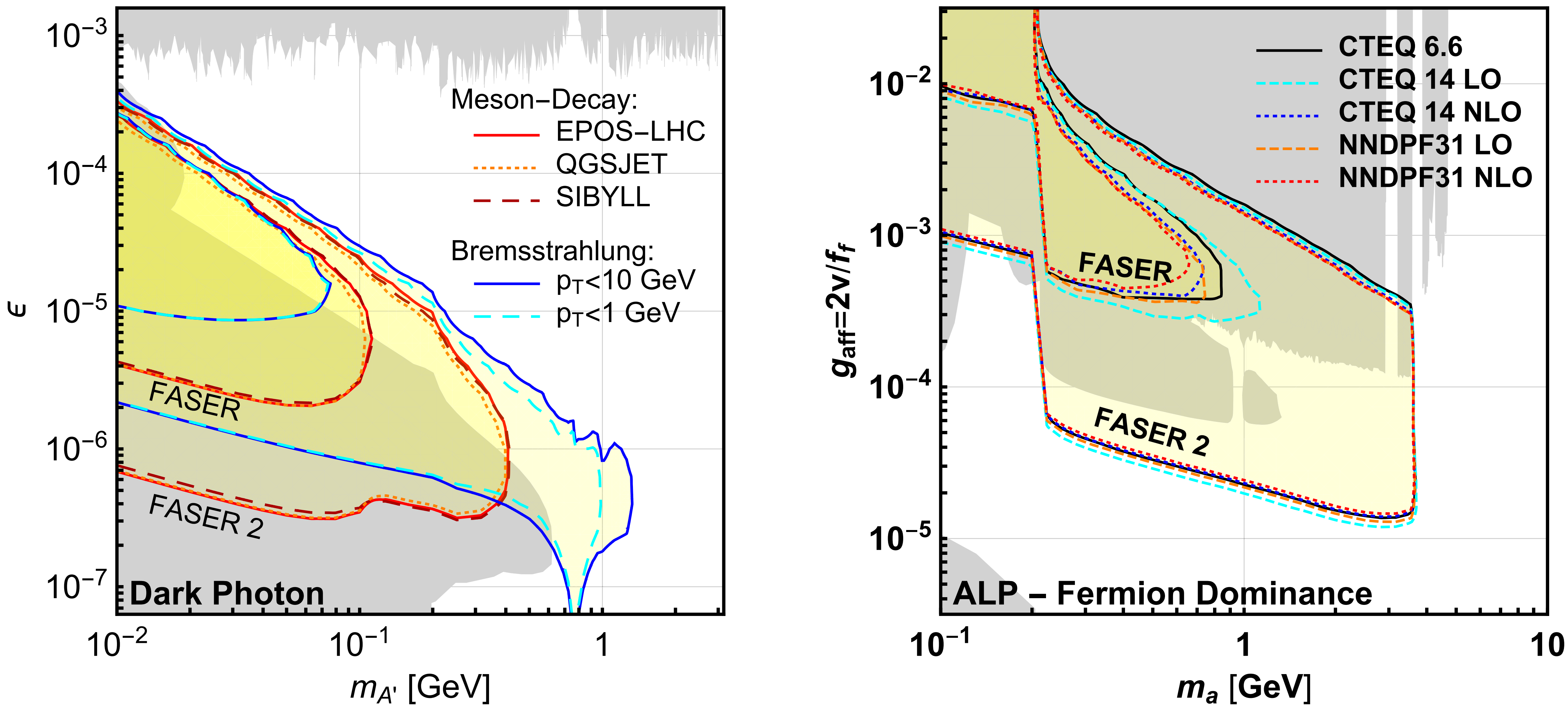


FIG. 20. FASER reach for dark photons (left) and ALPs with dominant couplings to fermions (right). For the dark photon, we vary the forward Monte Carlo generators used to produce the light meson spectrum as well as the validity on the transverse momentum of the dark photon used in the bremsstahlung approximation. For the ALPs, we change the PDF used to estimate the forward *B*-meson spectra in FONLL.

Dependence on energy threshold

arxiv: 1811.12522

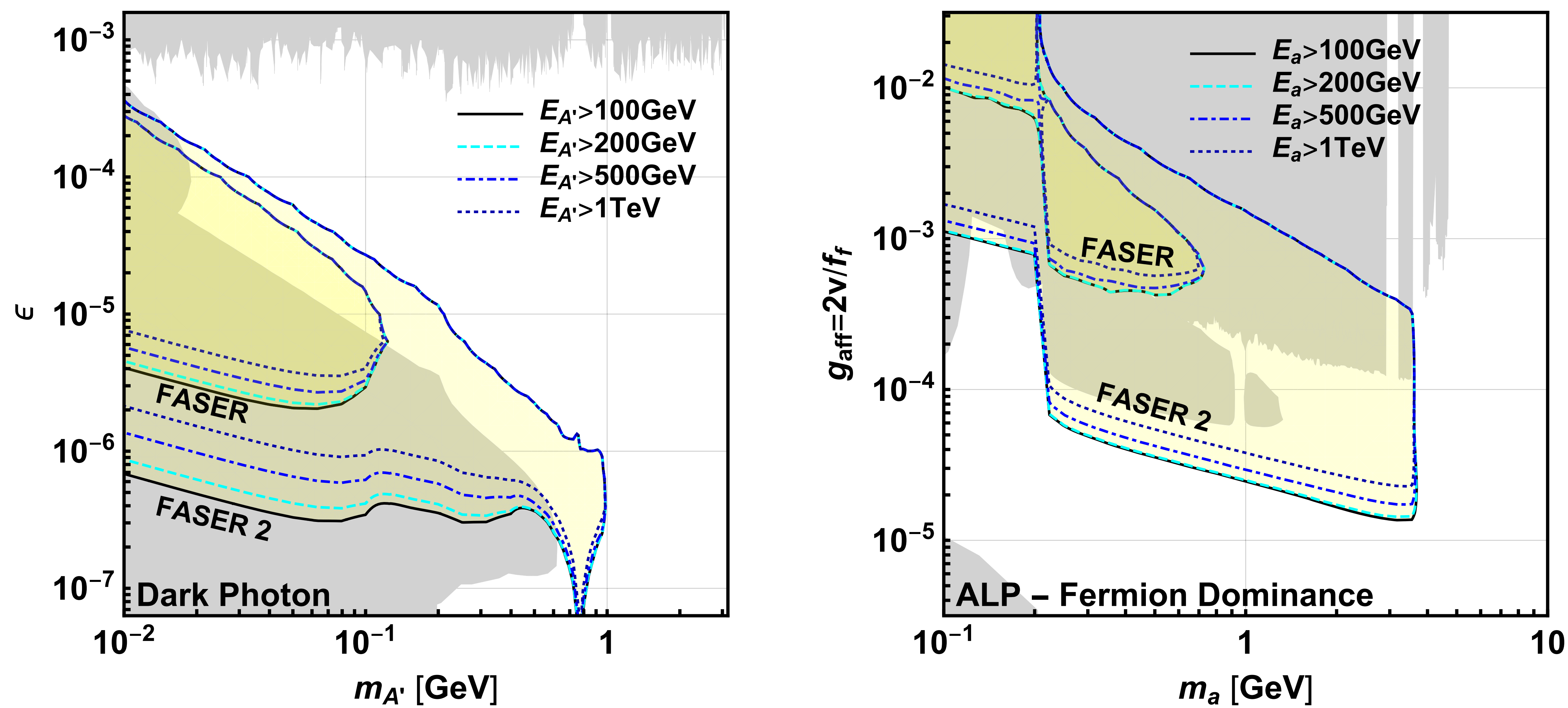
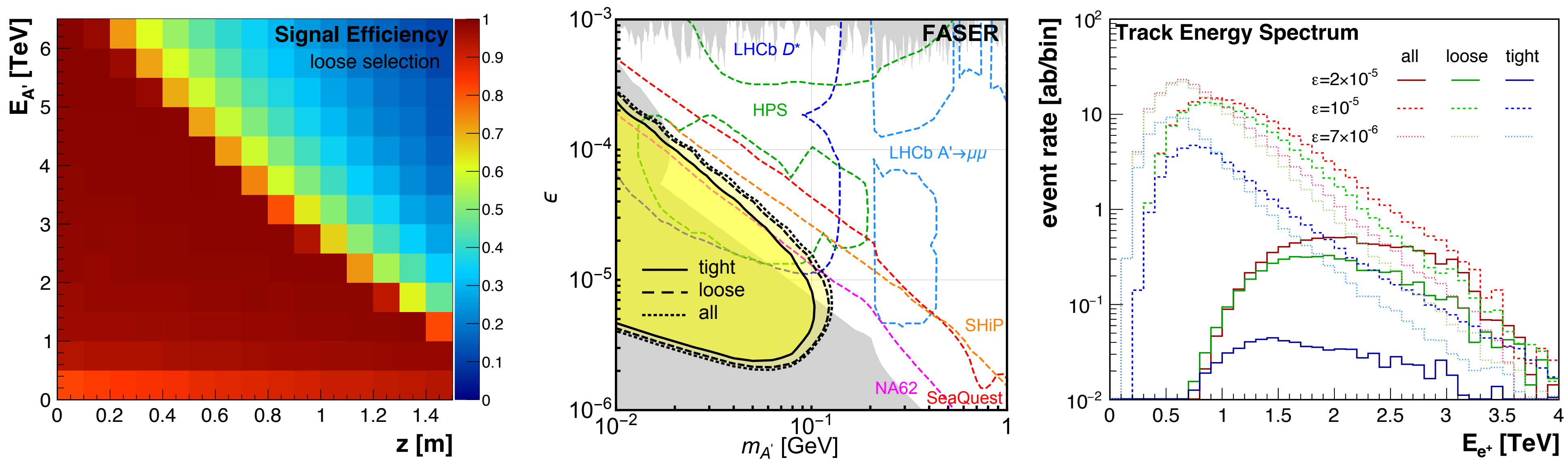


FIG. 21. FASER reach for dark photons (left) and ALPs with dominant couplings to fermions (right) for different LLP energy threshold cuts.

Dependence on signal efficiency

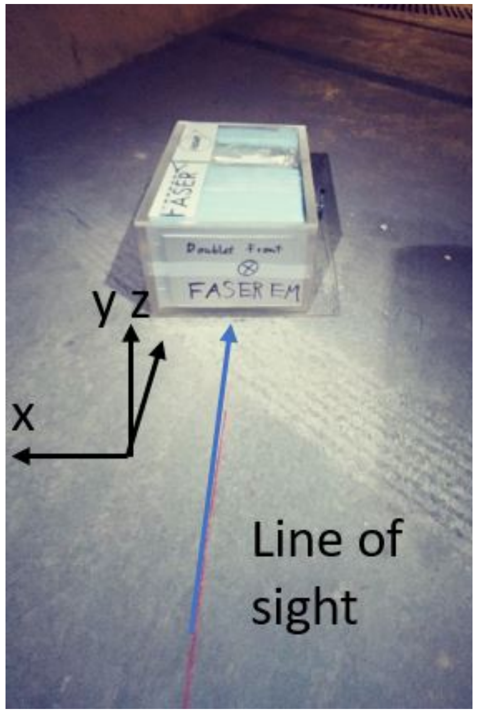
- Example: dark photon decay to e+e-, with decay products required to be
  - completely enclosed in the tracker within R=10 cm
  - separated by more than =0.3 mm in the bending plane of the tracking stations
- Selection criteria:
  - Loose: tracks sufficiently separated in tracking stations #2 and #3
  - Tight: tracks sufficiently separated in tracking stations #1, #2 and #3

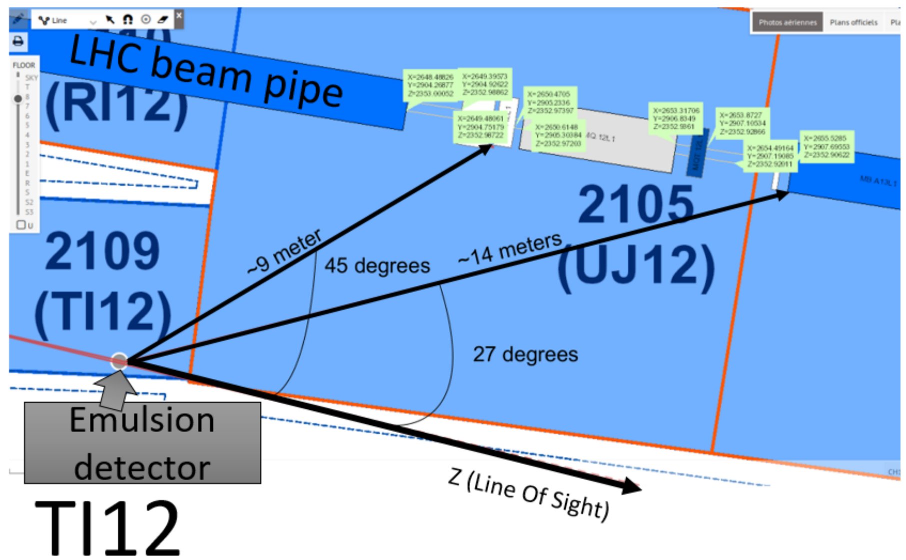


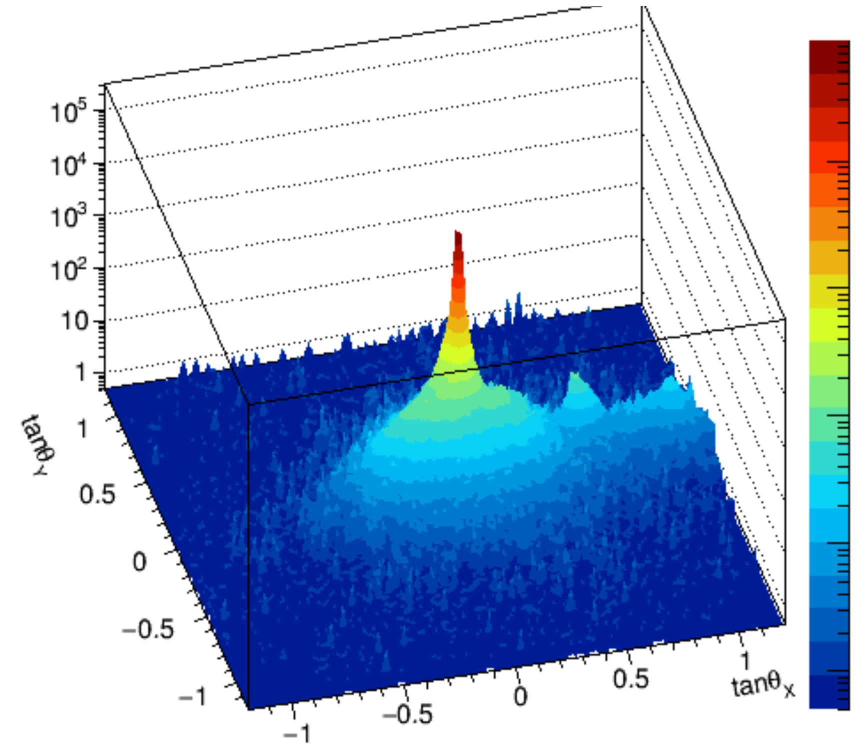
arxiv: 1811.10243

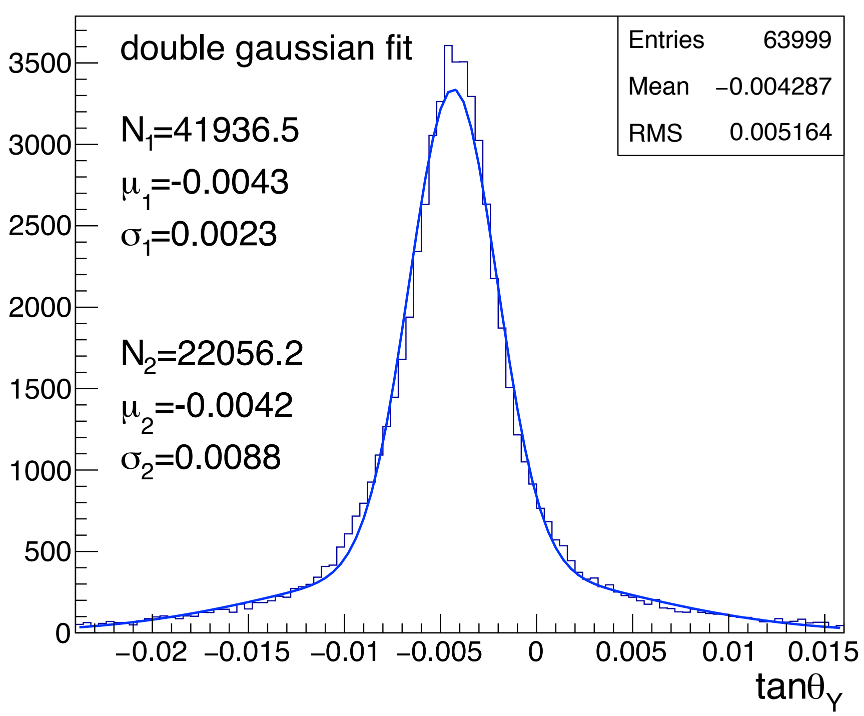
FIG. 6. Left: Signal efficiency for the loose selection criterion as a function of dark photon energy and the decay's longitudinal position, averaged over the transverse position, for the dark photon benchmark point $m_{A'} = 100$ MeV and $\epsilon = 10^{-5}$. Center: FASER dark photon reach without signal efficiencies (dotted), with loose selection cuts (dashed), and tight selection cuts (solid). The "all" and "loose" curves are almost indistinguishable. Right: Energy spectrum of dark photon decay products in FASER for $m_{A'} = 100$ MeV and $\epsilon = 2 \times 10^{-5}$ (solid), $\epsilon = 10^{-5}$ (dashed) and $\epsilon = 0.7 \times 10^{-5}$ (dotted). We show the spectrum for all dark photons decaying in FASER (red), and those passing the loose (green) and tight (blue) selection cuts.

Beam background in-situ measurements









Period	Luminosity $[10^{34}\ s^{-1}\ cm^{-2}]$	Counting Rate $[s^{-1}]$	Counting Rate/Luminosity $[10^{-34}\ cm^{2}]$
No beam	-	0.16	-
Beam (no collisions)	-	0.55	-
Collisions	1.8	7.0	4.0
Collisions	1.3	4.8	3.8
Collisions	0.8	3.3	4.2
Collisions	0.6	2.7	4.3
Collisions	0.5	2.2	4.1

TABLE III. Preliminary results from the TimePix detector installed in TI18, indicating that the main particle rate is proportional to luminosity in IP1. This also shows a small, but significant, increase in rate with non-colliding beam, compared to no beam in the machine. Beam (no collisions) corresponds to a full machine (2556 bunches) at the start of a physics fill, providing a total intensity of 2.7×10^{14} protons per beam.