Looking forward to new physics with FASER: ForwArd Search ExpeRiment at the LHC

Sebastian Trojanowski
University of Sheffield

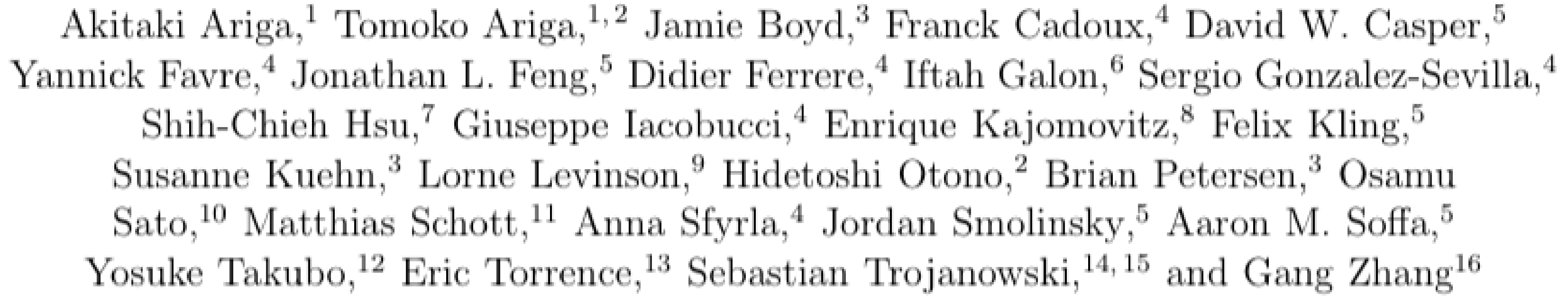
LHC Working Group on Forward Physics and Diffraction
CERN, December 18, 2018

(FASER group see https://twiki.cern.ch/twiki/bin/viewauth/FASER/WebHome)

Email to the group: faser-all@cern.ch

arXiv:1708.09389;1710.09387;1801.08947;1806.02348 (PRD,with J.L.Feng,I.Galon,F.Kling)
FASER Collaboration: arXiv:1811:10243 Letter of Intent (CERN-LHCC-2018-030)
arXiv:1811.12522 (physics case)

FASER COLLABORATION



Akitaki Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3] Franck Cadoux,[4] David W. Casper,[5] Yannick Favre,[4] Jonathan L. Feng,[5] Didier Ferrere,[4] Iftah Galon,[6] Sergio Gonzalez-Sevilla,[4] Shih-Chieh Hsu,[7] Giuseppe Iacobucci,[4] Enrique Kajomovitz,[8] Felix Kling,[5] Susanne Kuehn,[3] Lorne Levinson,[9] Hidetoshi Otono,[2] Brian Petersen,[3] Osamu Sato,[10] Matthias Schott,[11] Anna Sfyrla,[4] Jordan Smolinsky,[5] Aaron M. Soffa,[5] Yosuke Takubo,[12] Eric Torrence,[13] Sebastian Trojanowski,[14,15] and Gang Zhang[16]

九州大学
KYUSHU UNIVERSITY

THE UNIVERSITY OF CALIFORNIA IRVINE

UNIVERSITY OF WASHINGTON 1861

CERN

名古屋大学
NAGOYA UNIVERSITY

RUTGERS THE STATE UNIVERSITY OF NEW JERSEY 1766

SCHOLA GENEVENSIS 1559

The University Of Sheffield.

Weizmann Institute of Science

TECHNION ISRAEL INSTITUTE OF TECHNOLOGY

UNIVERSITÄT BERN

UNIVERSITY OF OREGON

OUTLINE

- Motivation behind the intensity frontier searches for light long-lived particles (LLPs)

- FASER: ForwArd Search ExpeRiment at the LHC

- Remarks about FASER physics program

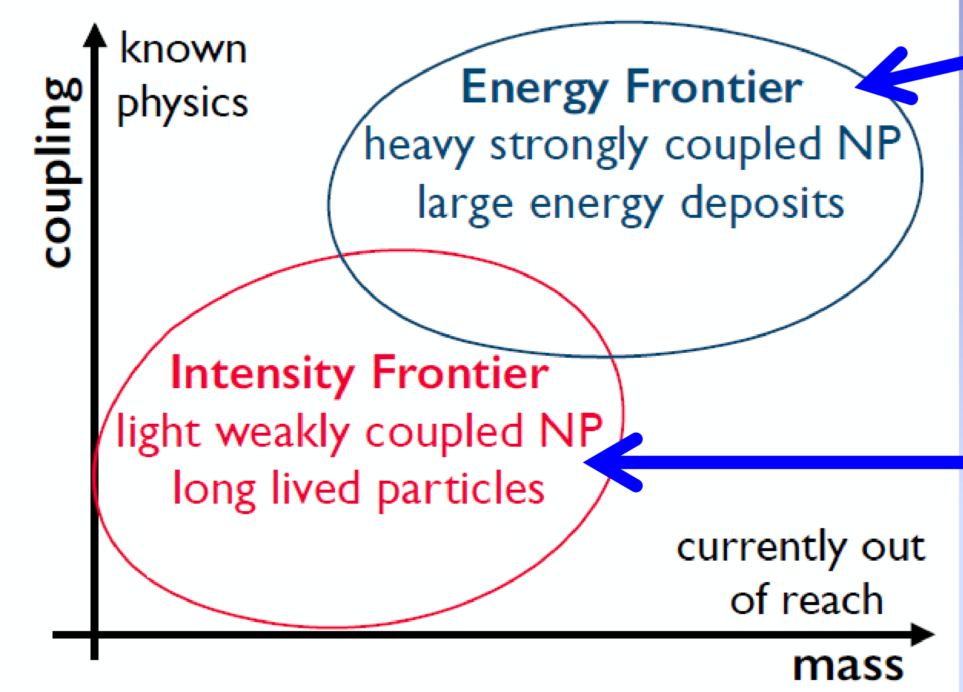
  -- dark photons,

  -- axion-like particles,
  -- possible measurements for SM neutrinos
  -- … and many other models

- Background: simulations & in-situ measurements

- Concluding remarks

MOTIVATION

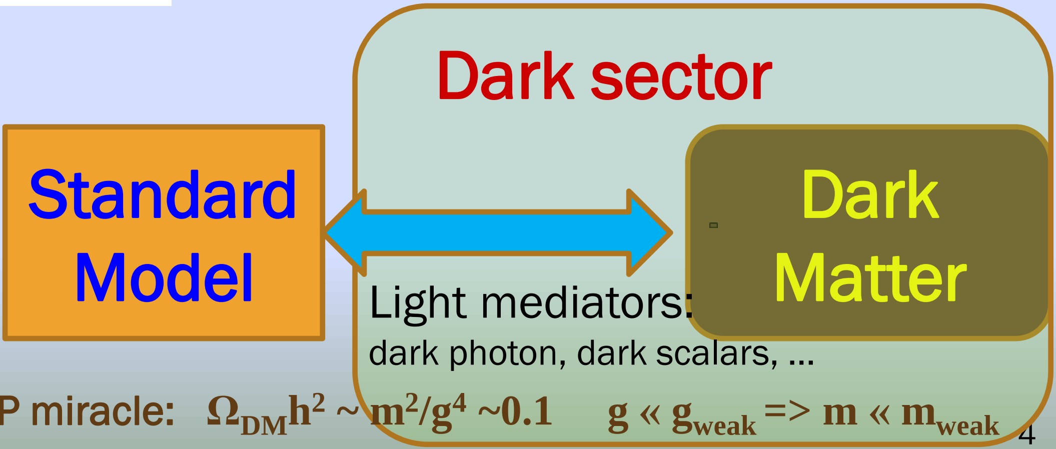


<u>heavy</u> and <u>strongly-coupled new physics</u>
e.g. SUSY, extra dimensions, ...

here also missing energy
searches for heavy WIMP DM

Light and very weakly coupled new physics:
-- requires large „luminosities" (statistics)
-- new particles decay back to SM, but with highly displaced vertices
-- SM BG needs to be highly suppressed

Exciting physics:
-- cosmology
(dark matter, inflation, bariogenesis,...)
-- neutrino masses
(GeV-scale heavy neutral leptons)
-- $(g-2)_{\mu}$
-- ...



Dark sector

Standard Model

Dark Matter

Light mediators:
dark photon, dark scalars, ...

Generalized WIMP miracle: $\Omega_{DM}h^2 \sim m^2/g^4 \sim 0.1$ $\quad g \ll g_{weak} \Rightarrow m \ll m_{weak}$

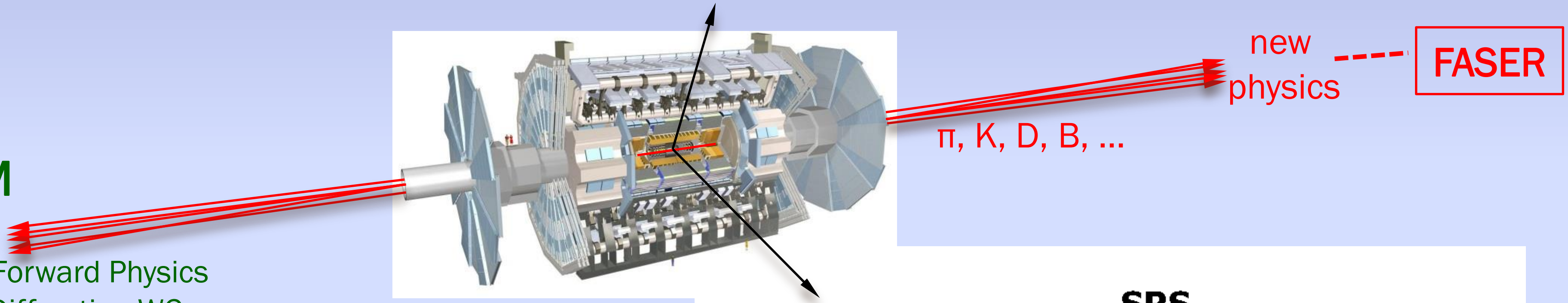
FASER - IDEA

FASER – newly proposed, small (**~0.05 m^3**) and inexpensive (**~1.5M$**) detector to be placed few hundred meters downstream away from the ATLAS IP

to harness large, currently „wasted" forward LHC cross section

σ_{inel} ~ 75 mb, e.g., $N_\pi \sim 10^{17}$ at 3 ab^{-1}

(for comparison **σ ~ fb – pb,** e.g., $N_H \sim 10^7$ at 300 fb^{-1} in high-p_T searches)



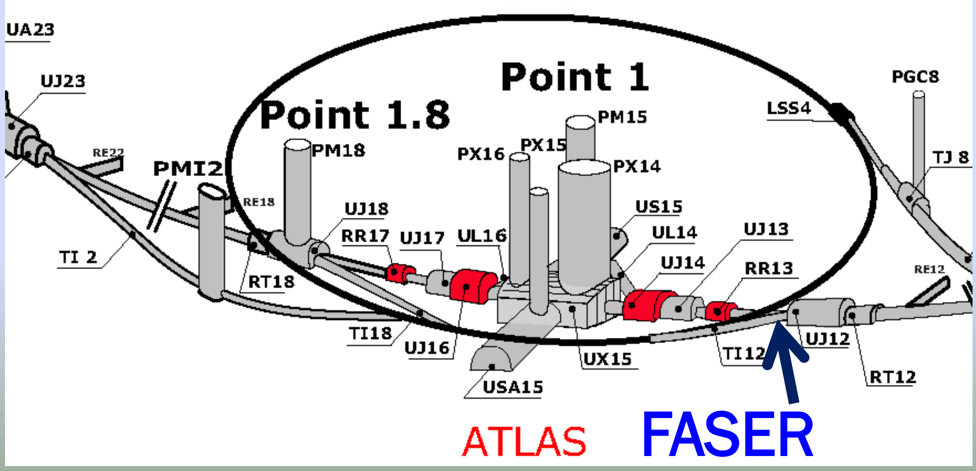
SM

LHC Forward Physics
and Diffraction WG

π, K, D, B, …

new
physics

FASER

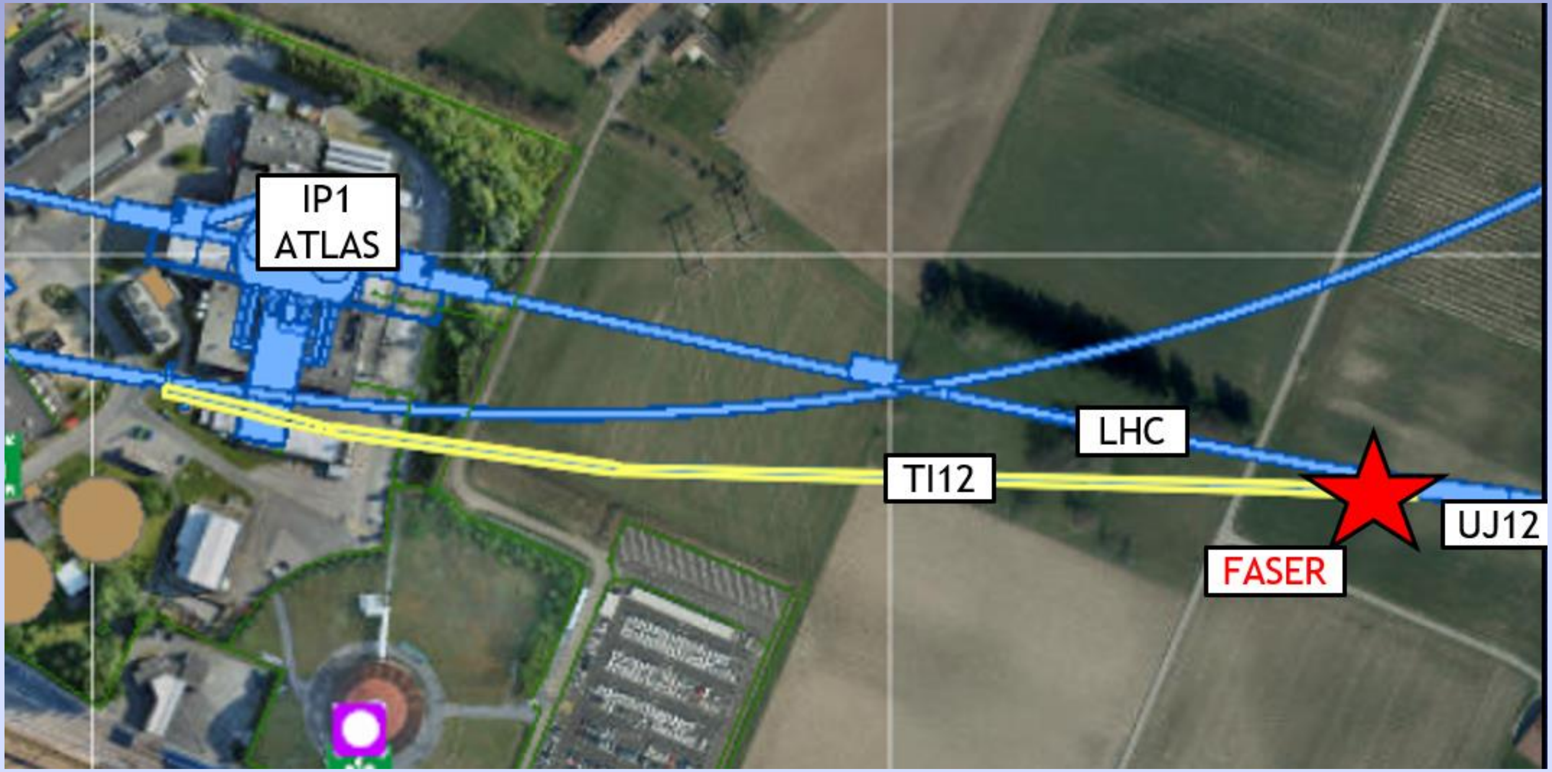


ATLAS FASER

FASER will complement ATLAS/CMS by searching for new Light Long-Lived Particles

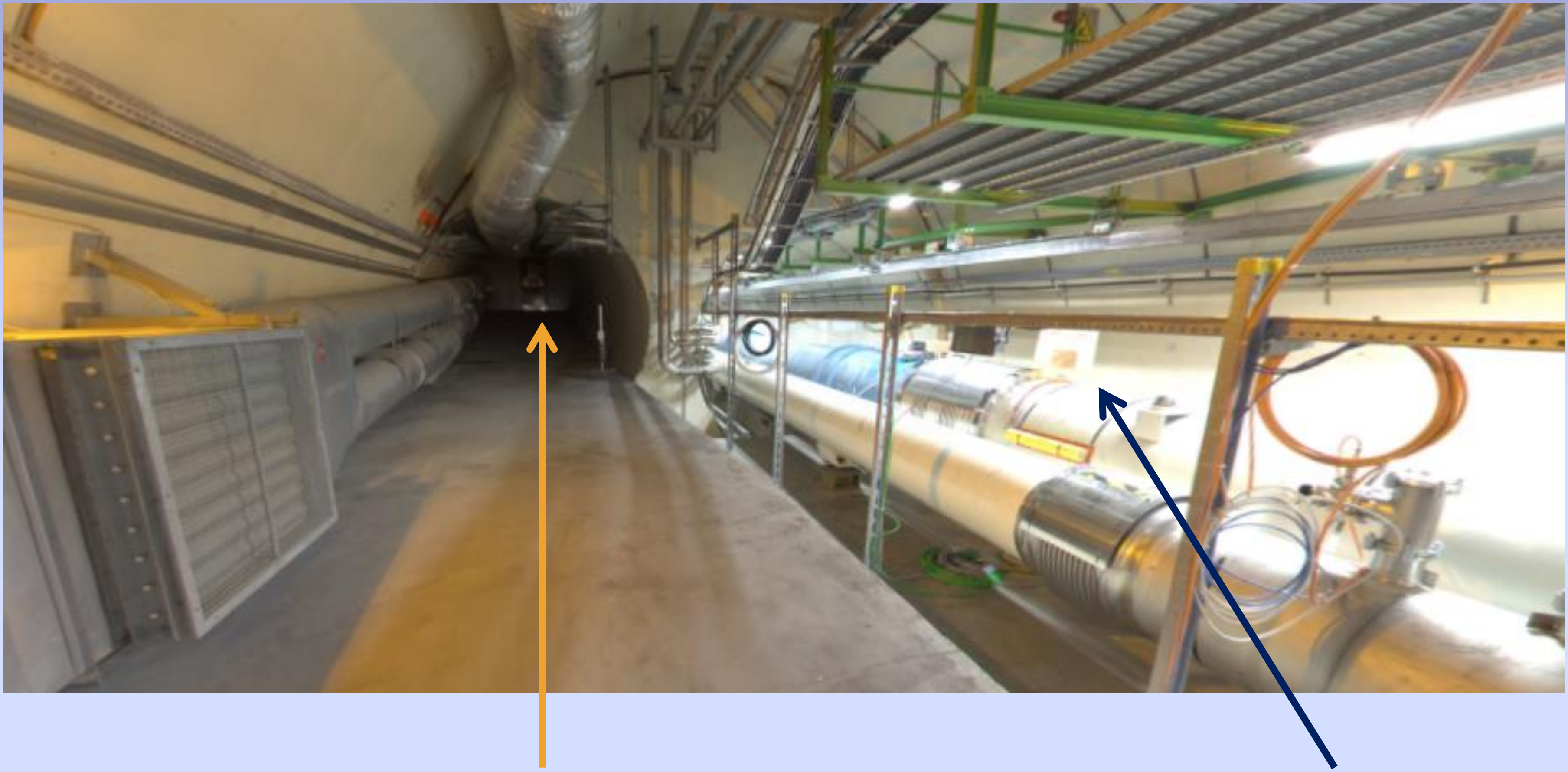
(part of Physics Beyond Colliders Study Group at CERN)

FASER LOCATION – TUNNEL TI12



- promising location in a side tunnel TI12 (former service tunnel connecting SPS to LEP)
- about **L ~ 480m** away from the IP along the beam axis
- space for a **few-meter-long** detector
- precise position of the beam axis in the tunnel up to **mm precision** (CERN Engineering Dep
- corrections due to beam crossing angle (for 300μrad the displacement is ~7 cm)

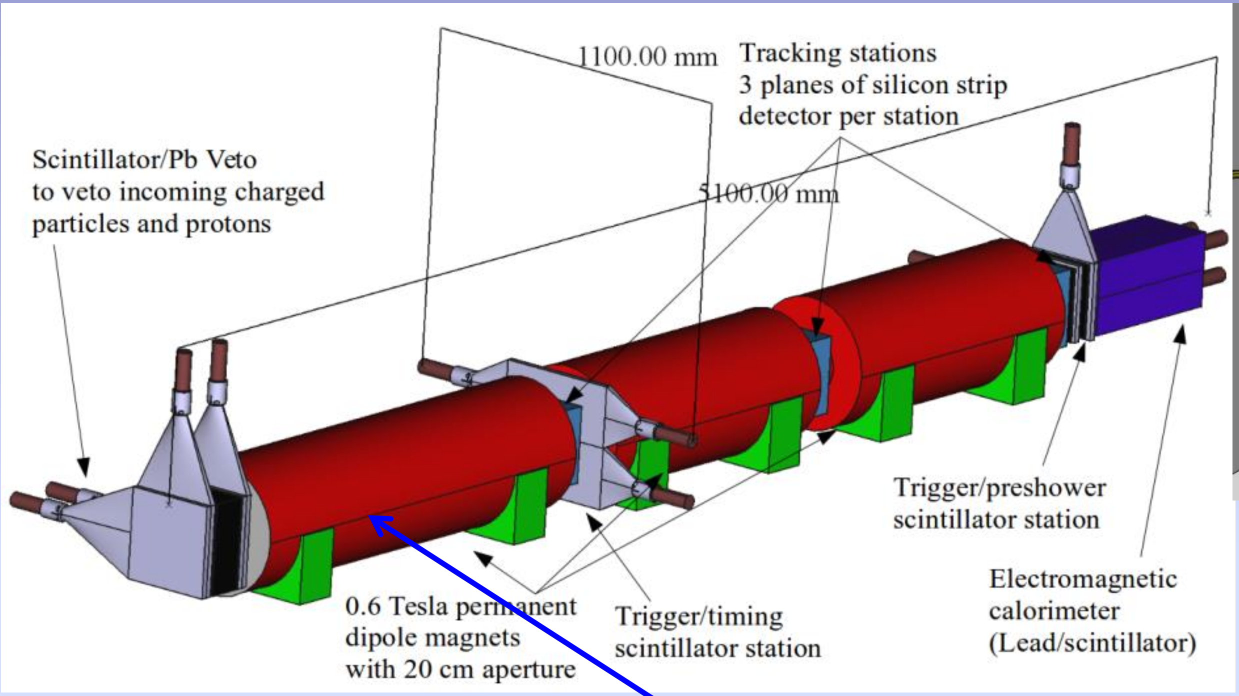
TUNNEL TI12

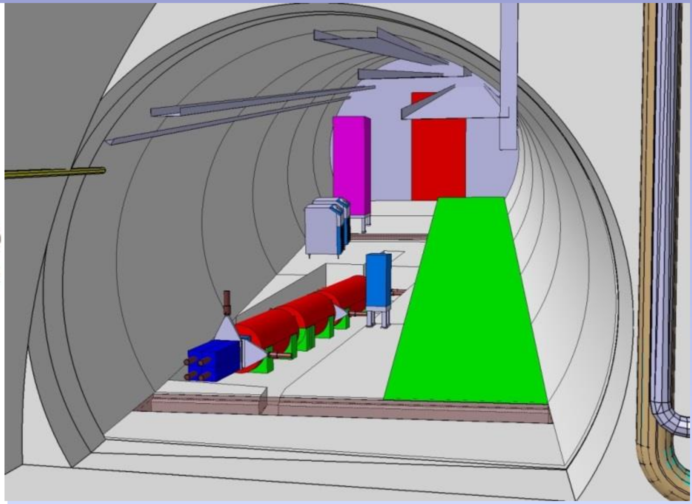


new physics
(hidden in the dark)

main LHC tunnel

BASIC DETECTOR LAYOUT

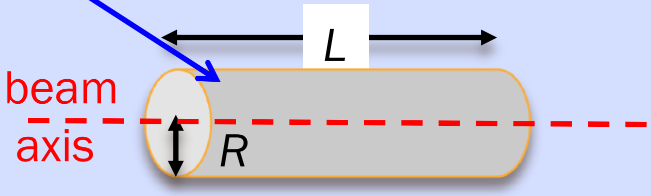




Plans for recycling existing spare modules:
- ATLAS SCT modules (Tracker)
- LHCb ECAL modules (Calorimeter)

(save money & time)

- cylindrical decay volume



- 2 stages of the project:

FASER 1: $L = 1.5$ m, $R = 10$ cm, V = 0.05 m^3, 150 fb^{-1} (Run 3)

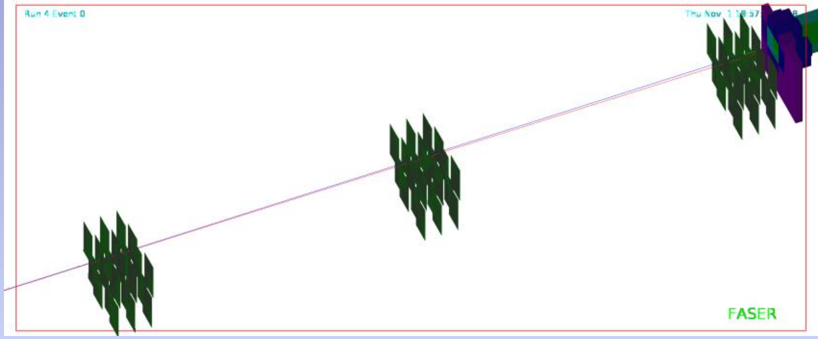
FASER 2: $L = 5$ m, $R = 1$ m, V = 16 m^3, 3 ab^{-1} (HL-LHC)

SIGNAL DETECTION

Signal is a pair of oppositely charged high-energy particles e.g. 1 TeV A’ -> e^+e^-

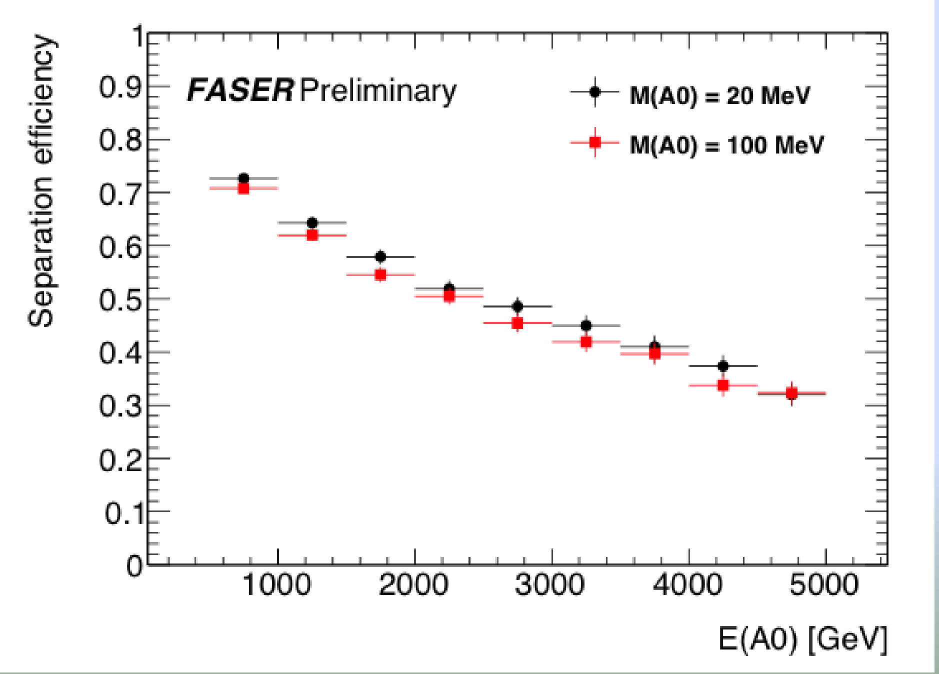
In the following we assume 100% detection efficiency
for a better comparison with other experiments

Ongoing work on full detector simulations

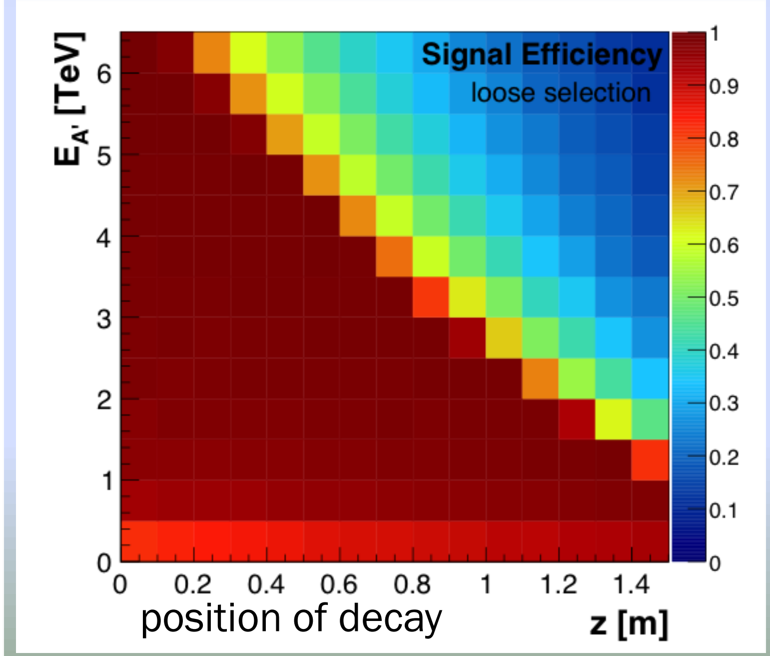


CHARGED TRACK SEPARATION EFFICIENCY

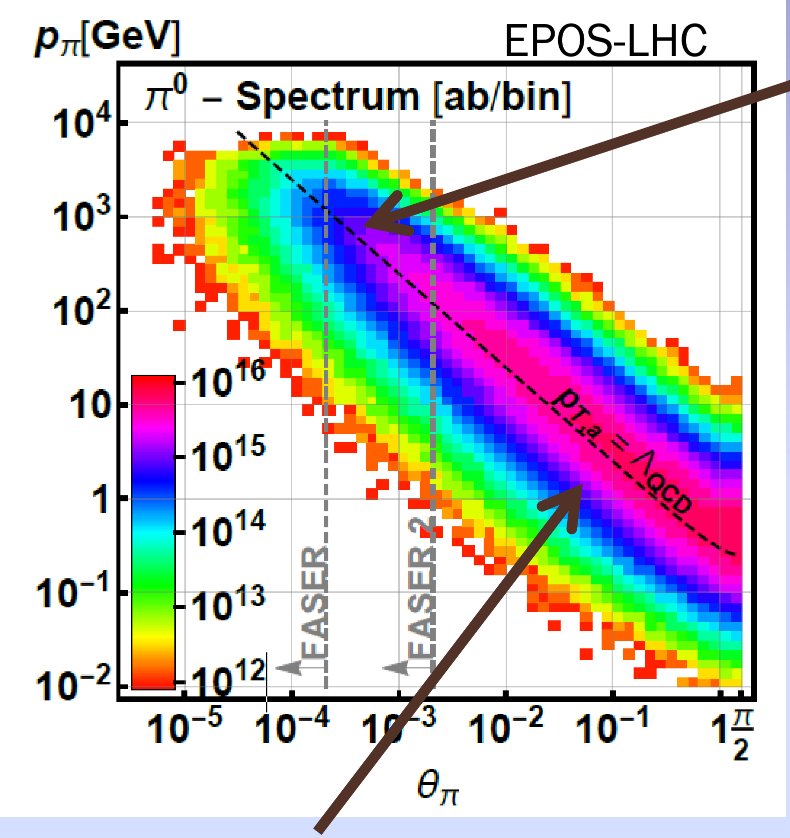
1st tracking station



2nd/3rd tracking station (separation > 0.3mm)



EXAMPLE OF LHC/FASER KINEMATICS
LLP FROM PION PRODUCTION AT THE IP



Hard pions highly collimated along the beam axis since their $p_T \sim \Lambda_{QCD}$ e.g. for $E_{\pi 0} \geq 10$ GeV

~ 1.7% of π_0s go towards FASER

~ 24% of π_0s go towards FASER 2

This can be compared to the angular size of both detectors with respect to the total solid angle of the forward hemisphere (2 π) :

~ (2×10^{-6})% for FASER

~ (2×10^{-4})% for FASER 2

Soft pions going towards high-p_T detectors:

- produced LLPs would be too soft for triggers
- large SM backgrounds

LLPs produced from B mesons in FASER 2

$p_T \sim m_B$ ⇒ larger angular spread

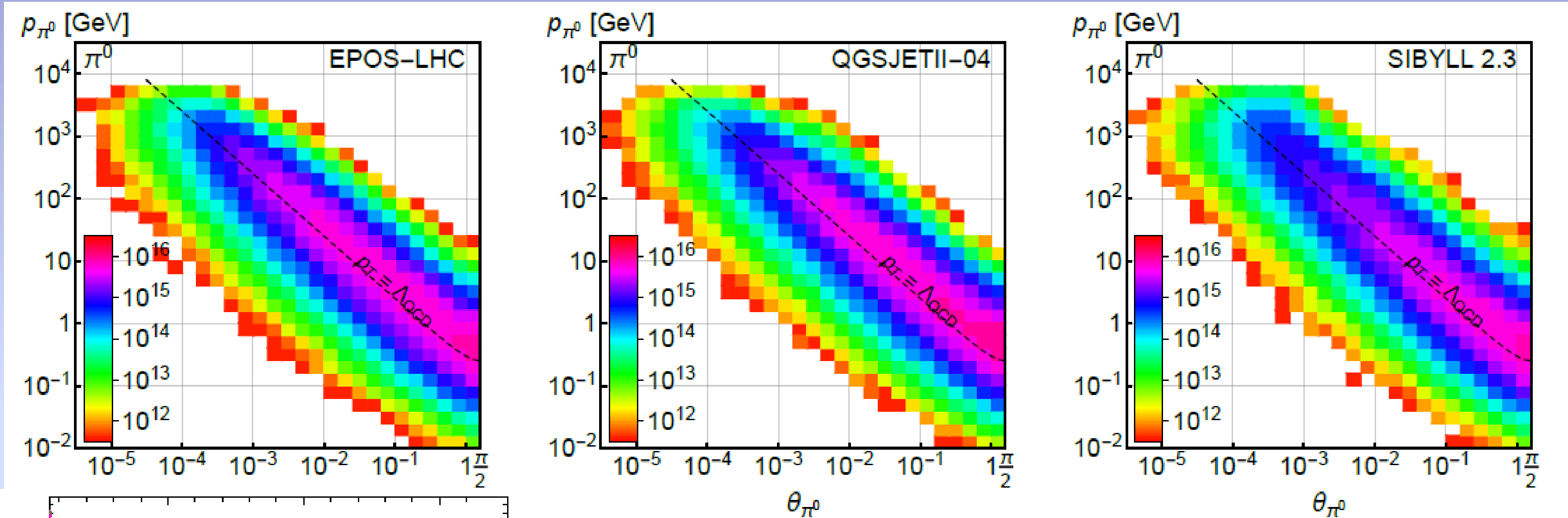
⇒ target for FASER 2

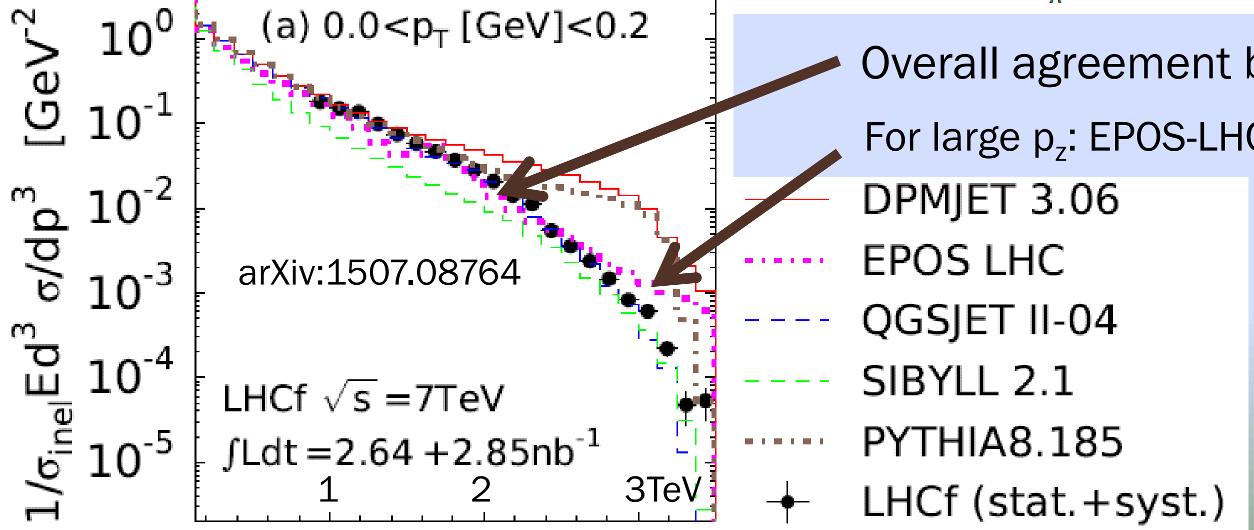
at FASER energies: $N_B/N_\pi \sim 10^{-2}$

$(10^{-7}$ for typical beam dumps)

COMPARISON – VARIOUS MC TOOLS

CRUCIAL CONTRIBUTION FROM LHC FORWARD PHYSICS AND DIFFRACTION WG





Overall agreement between MC and data

For large p_z: EPOS-LHC gives some overestimate

QGSJET II, SIBYLL lower estimates

THESE DISCREPANCIES HAVE VERY LITTLE IMPACT ON FASER SENSITIVITY

(see next slides)

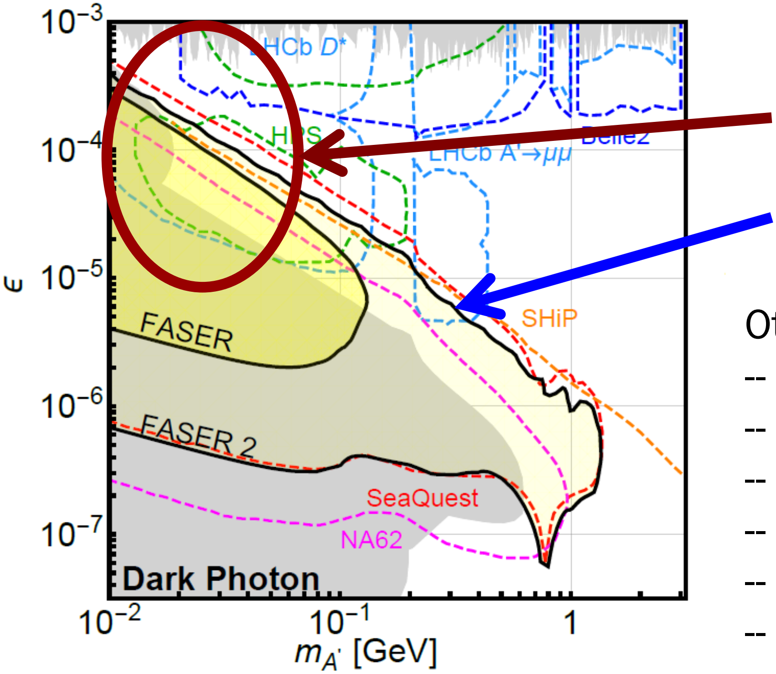
DARK PHOTON

1708.09389, PRD 97 (2018) no.3, 035001

- (broken) dark $U(1)$ gauge group,
- kinetic mixing with the SM photon: $\epsilon\, F^{\mu\nu}\, F'_{\mu\nu}$,
- after field redefinition:

$$\mathcal{L} \supset -\frac{1}{4}\, F^{\mu\nu} F_{\mu\nu} - \frac{1}{4}\, F'^{\mu\nu} F'_{\mu\nu} + \frac{1}{2}\, m^2_{A'}\, A'_\mu A'^\mu + \sum \bar{f}(i\not{\partial} - \epsilon\, e q_f\, A')f$$

- production: π^0 and η decays, bremsstrahlung,
  direct production in $q\bar{q}$ scatterings
- decays: dominantly into e^+e^- and $\mu^+\mu^-$ up to ~ 500 MeV,
  then various hadronic decay modes



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

A' as a DM-SM mediator

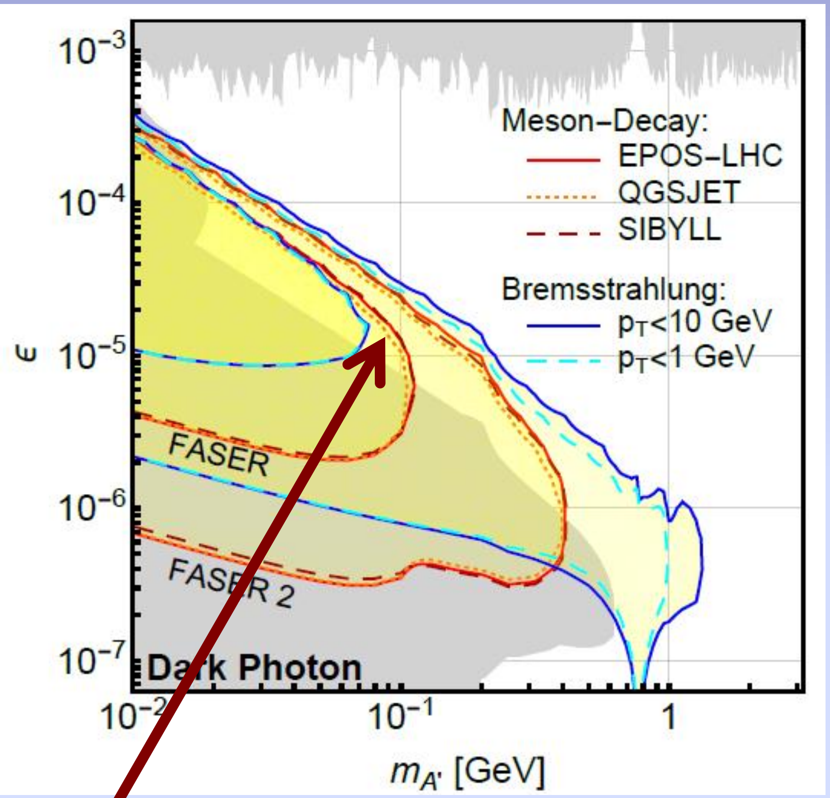
FASER 2 comparable to proposed large SHiP detector

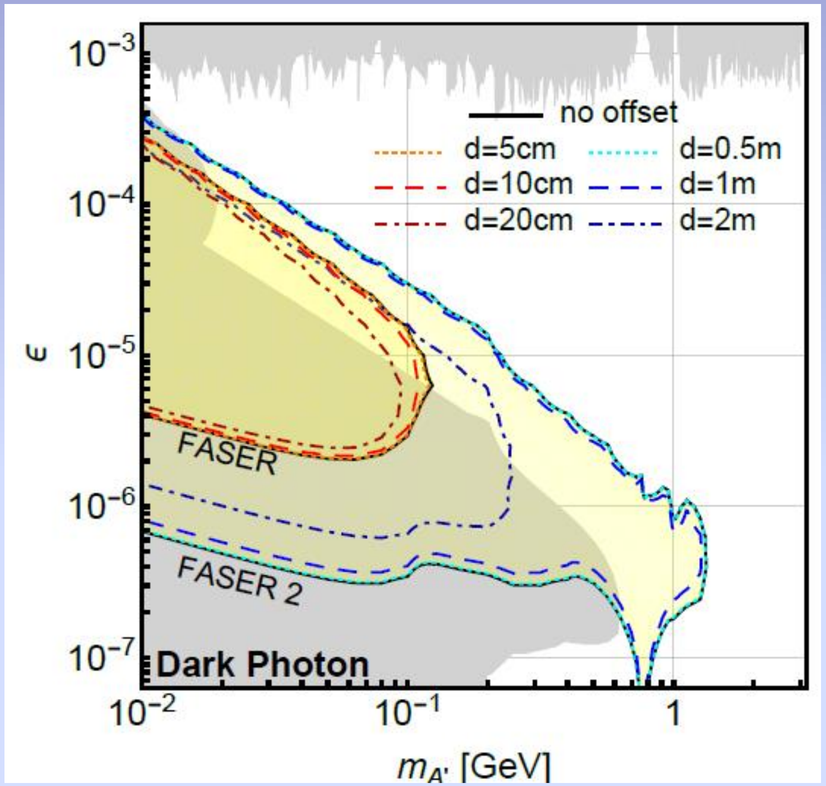
Other models include e.g.:

Physics case: 1811.12522

-- B-L gauge bosons
-- dark Higgs boson J. L. Feng, I. Galon, F. Kling, ST, 1710.0938
-- heavy neutral leptons F. Kling, ST, ;1801.08947
-- ALPs J. L. Feng, I. Galon, F. Kling, ST, 1806.02348
-- inelastic DM A. Berlin, F. Kling, 1810.01879
-- RPV SUSY D. Dercks, J. de Vries, H. K. Dreiner, Z. S. Wang 1810.03617

DARK PHOTON REACH – VARIOUS MC TOOLS & OFFSET





Almost impreceptible differences in reach for various MC tools

FASER reach unaffected by a small offset as long as the beam collision axis goes through the detector

$\bar{d} \sim \varepsilon^{-2}$

$$N_{\rm sig} \propto \mathcal{L}^{\rm int}\, \epsilon^2\, e^{-L_{\rm min}/\bar{d}} \quad \text{for} \quad \bar{d} \ll L_{\rm min}$$

no of events grows exponentially with a small shift in ε

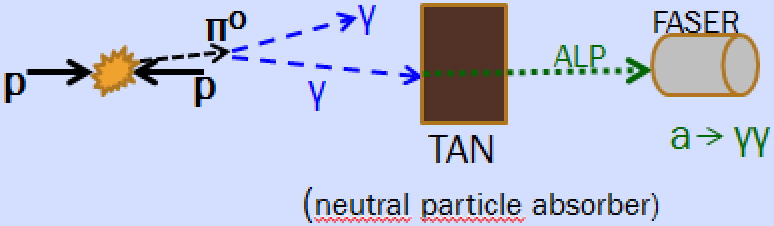
ALPS AT FASER – LHC AS A PHOTON BEAM DUMP

1806.02348, PRD 98 (2018) no.5, 055021

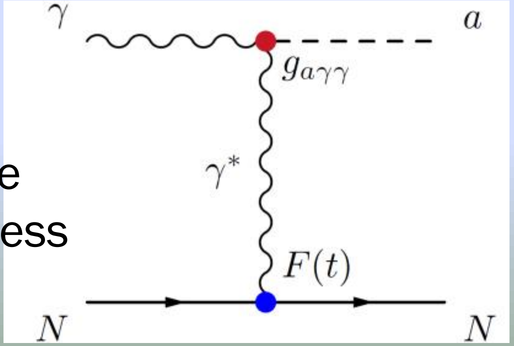
- similarly to the QCD axion, they can appear as pseudo-Nambu-Goldstone bosons in theories with broken global symmetries
- suppressed dim-5 couplings to gauge bosons $(1/\Lambda) a V^{\mu\nu} \tilde{V}_{\mu\nu}$,
- dim-5 couplings to fermions also allowed $(\partial_\mu a/\Lambda) \bar{f} \gamma_\mu \gamma_5 f$,
- interesting pheno scenario – dominant $a\gamma\gamma$ coupling

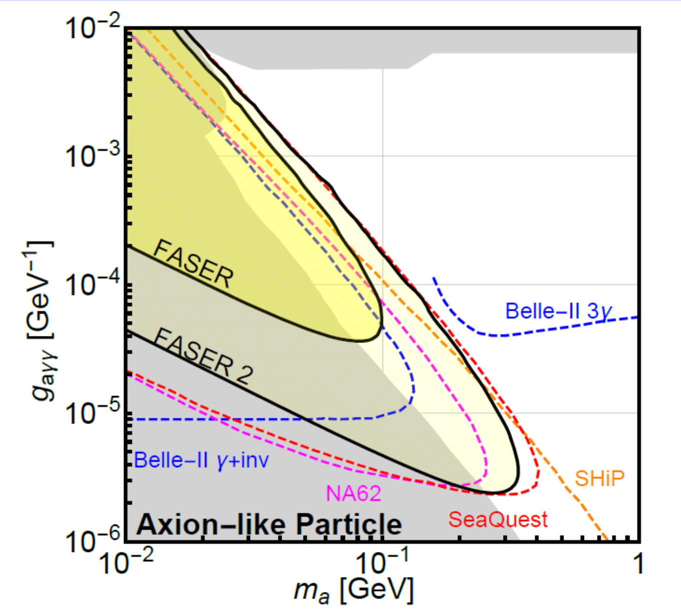
B. Döbrich *et al*, JHEP 1602 (2016) 018

Photon beam dump (also „light shining through a wall")



ALPs produced in the Primakoff process





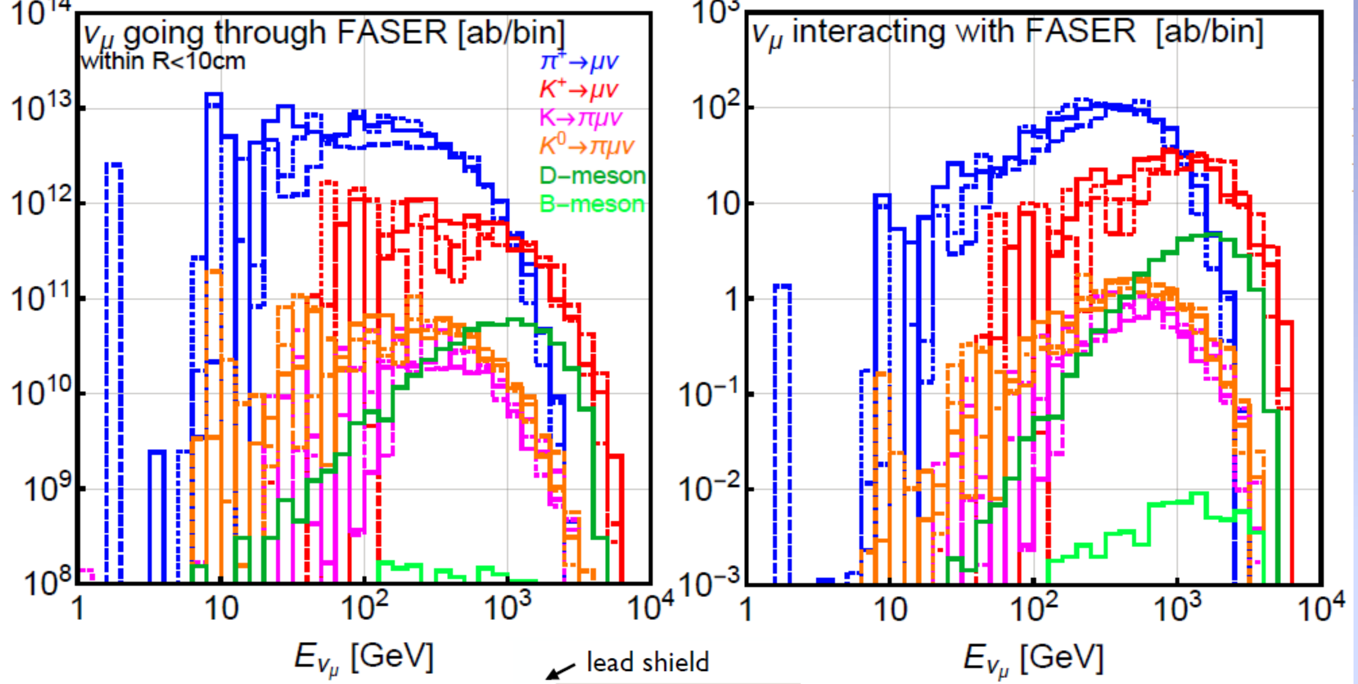
SM NEUTRINOS IN FASER

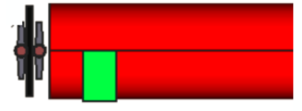
J. Feng, F. Kling, J. Smolinsky
(further work in progress)

Few cm thick lead plate will be put between several front veto layers (in front of FASER)

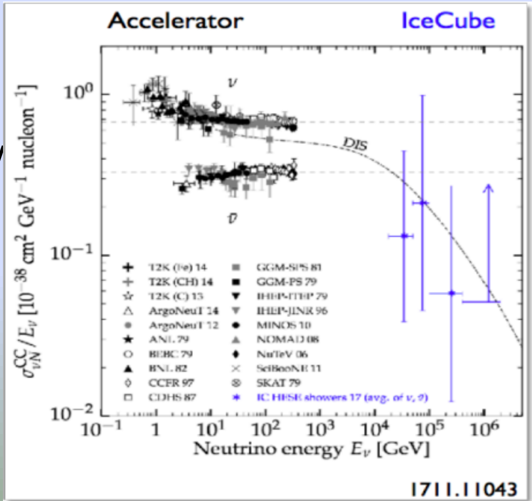
Incoming neutrinos can CC interact inside the lead plate producing muon μ, with no counterpart in layers in front of the plate

Potentially hundreds of events in FASER





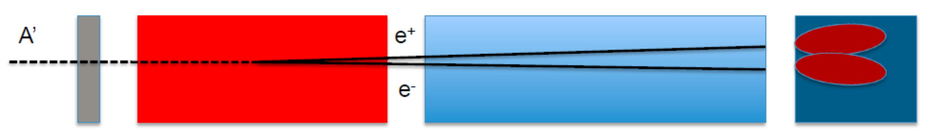
Measurement of the neutrino CC scattering cross section for E_ν ~TeV



Further possibilities are also explored
e.g. measurements of ν_τ employing emulsion detectors

A. Ariga, T. Ariga, O. Sato

BACKGROUNDS – SIMULATIONS (FLUKA)



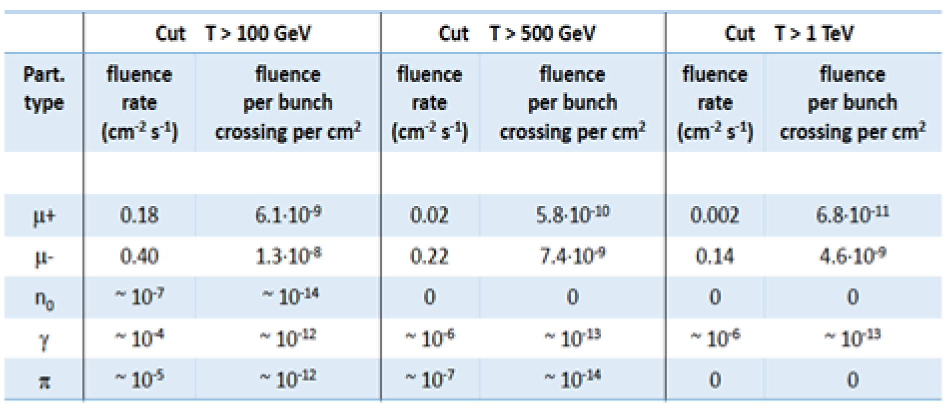
Spectacular signal:

-- two opposite-sign, high energy (few hundred GeV) charged tracks,
-- that originate from a common vertex inside the decay volume,
-- and point back to the IP (+no associated signal in a veto layer in front of FASER),
-- and are consistent with bunch crossing timing.

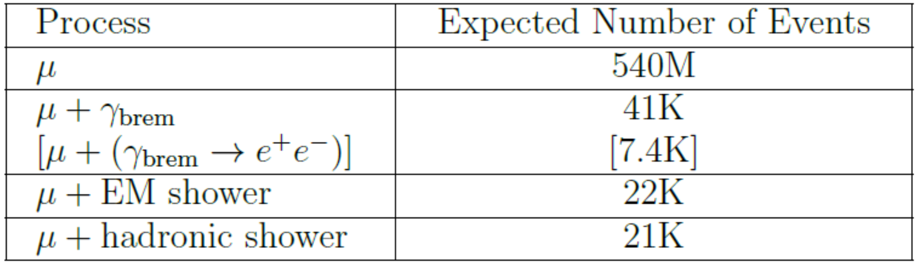
- Neutrino-induced events: low rate + highly asymmetric momentum distribution
- Very small activity close to FASER from diffractive proton losses
- The radiation level in TI18 is low (<10^{-2} Gy/year), encouraging for detector electronics.
- Proton showers in a nearby Disperssion Suppresor lead to negligible BG after ~90m of rocks in front of FASER
- Muons coming from the IP – front veto layers

Other particles: detailed simulations, highly reduced rate (shielding + LHC magnets)

study by the members of the CERN FLUKA team:



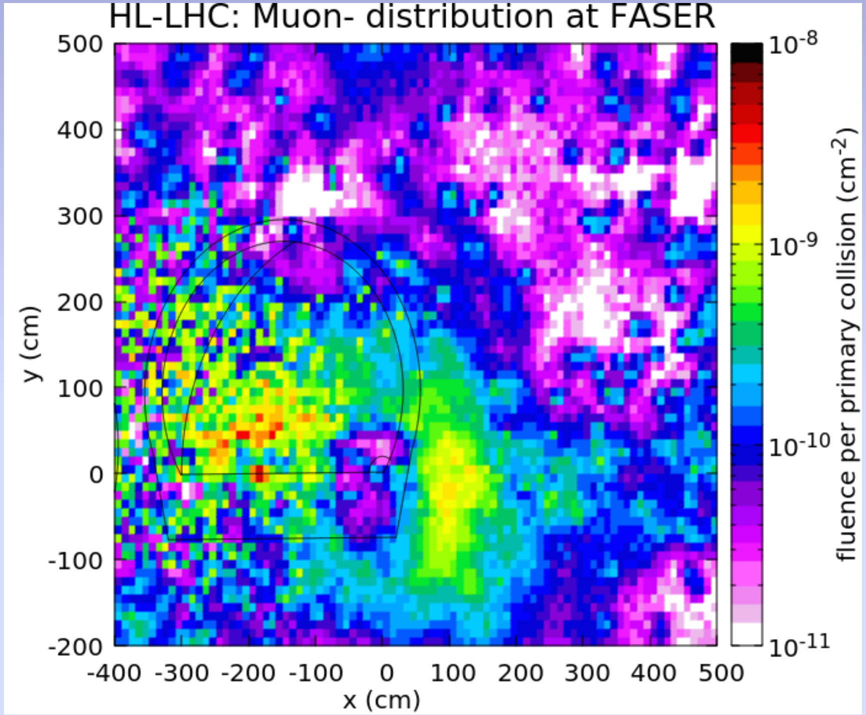
	Cut T > 100 GeV		Cut T > 500 GeV		Cut T > 1 TeV	
Part. type	fluence rate ($cm^{-2}\,s^{-1}$)	fluence per bunch crossing per cm^2	fluence rate ($cm^{-2}\,s^{-1}$)	fluence per bunch crossing per cm^2	fluence rate ($cm^{-2}\,s^{-1}$)	fluence per bunch crossing per cm^2
$\mu+$	0.18	$6.1 \cdot 10^{-9}$	0.02	$5.8 \cdot 10^{-10}$	0.002	$6.8 \cdot 10^{-11}$
$\mu-$	0.40	$1.3 \cdot 10^{-8}$	0.22	$7.4 \cdot 10^{-9}$	0.14	$4.6 \cdot 10^{-9}$
n_0	$\sim 10^{-7}$	$\sim 10^{-14}$	0	0	0	0
γ	$\sim 10^{-4}$	$\sim 10^{-12}$	$\sim 10^{-6}$	$\sim 10^{-13}$	$\sim 10^{-6}$	$\sim 10^{-13}$
π	$\sim 10^{-5}$	$\sim 10^{-12}$	$\sim 10^{-7}$	$\sim 10^{-14}$	0	0

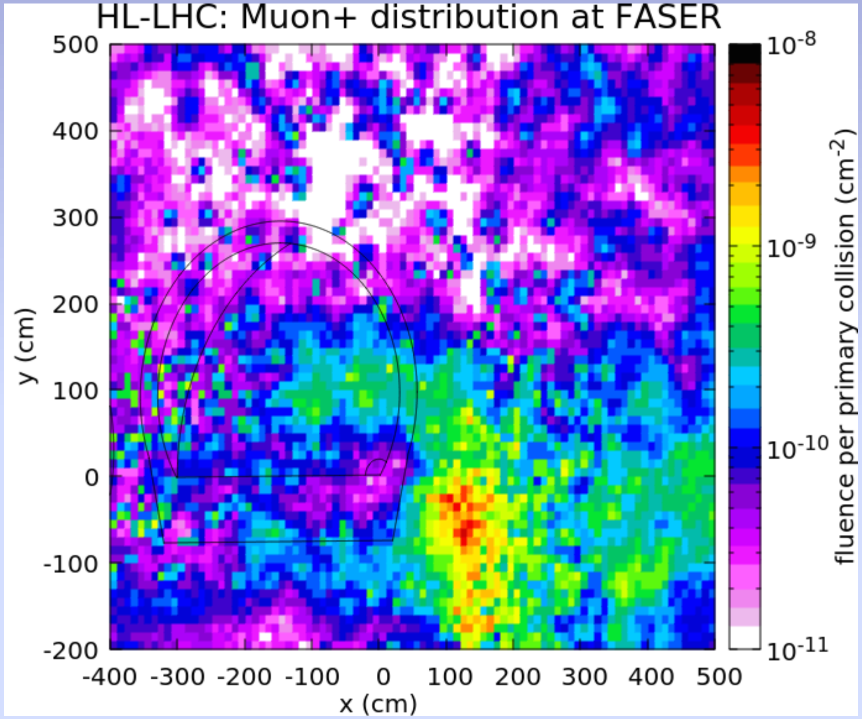


Process	Expected Number of Events
μ	540M
$\mu + \gamma_{\text{brem}}$ $[\mu + (\gamma_{\text{brem}} \to e^+e^-)]$	41K [7.4K]
μ + EM shower	22K
μ + hadronic shower	21K

BACKGROUNDS – SIMULATIONS (2)

Cross section of the tunnel containing FASER





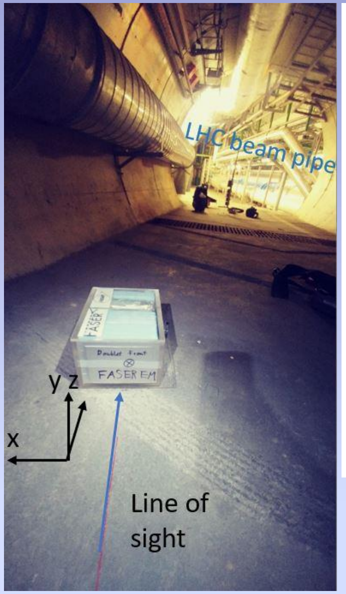
Muon flux reduced at FASER location (helpful role of the LHC magnets)

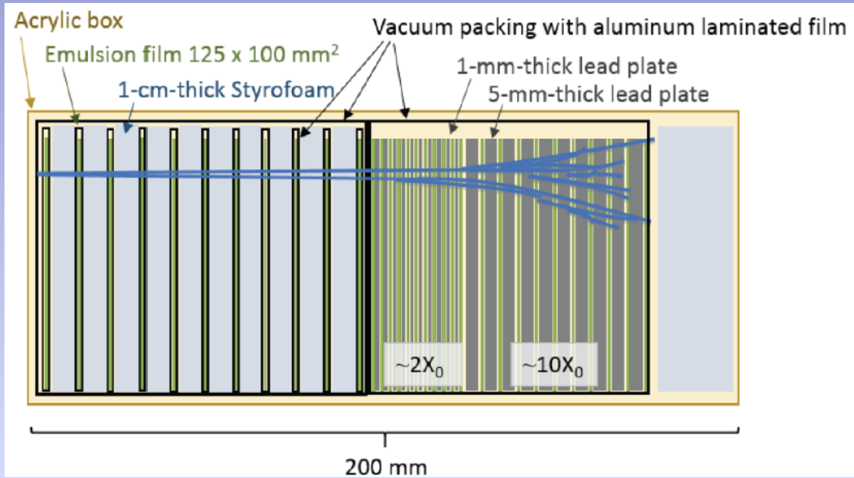
BACKGROUNDS – IN-SITU MEASUREMENTS

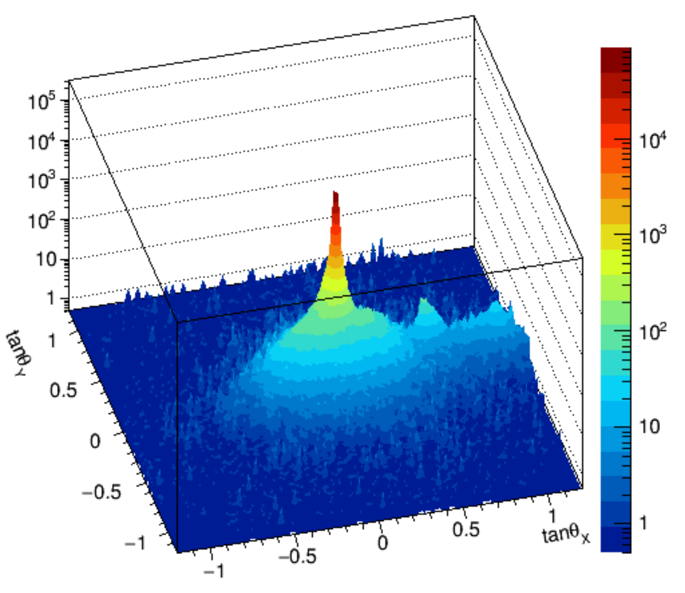
- Emulsion detectors – focusing on a small region around the beam axis (FASER location)
- BatMons (battery-operated radiation monitors)

First analyses show that given uncertainties results are consistent with FLUKA simulations

More work ongoing to refine simulations and analyse in-situ measurements







PRACTICALLY ZERO BG SEARCH

FASER – GROWING COLLABORATION

Sep 2017: First paper, J. Feng, I. Galon, F. Kling, ST, PRD 97 035001 (2018)

...within ~year FASER grew to an international collaboration recognized at CERN

Currently: 27 active members from **15** institutions in **8** countries,

Spokespersons: Jonathan L. Feng (UC Irvine), Jamie Boyd (CERN)

During LHC Run 2 (2018): detailed BG simulations (CERN Eng Dep) + in-situ measurements

Sep 2018: FASER Letter of Intent -- accepted by the LHC Committee

TECHNICAL PROPOSAL

FASER

FORWARD SEARCH EXPERIMENT AT THE LHC

Akitaki Ariga,[1] Tomoko Ariga,[1,2] Jamie Boyd,[3,*] Franck Cadoux,[4] David W. Casper,[5] Francesco Cerutti,[3] Salvatore Danzeca,[3] Liam Dougherty,[3] Yannick Favre,[4] Jonathan L. Feng,[5,†] Didier Ferrere,[4] Jonathan Gall,[3] Iftah Galon,[6] Sergio Gonzalez-Sevilla,[4] Shih-Chieh Hsu,[7] Giuseppe Iacobucci,[4] Enrique Kajomovitz,[8] Felix Kling,[5] Susanne Kuehn,[3] Mike Lamont,[3] Lorne Levinson,[9] Hidetoshi Otono,[2] John Osborne,[3] Brian Petersen,[3] Osamu Sato,[10] Marta Sabaté-Gilarte,[3,11] Matthias Schott,[12] Anna Sfyrla,[4] Jordan Smolinsky,[5] Aaron M. Soffa,[5] Yosuke Takubo,[13] Pierre Thonet,[3] Eric Torrence,[14] Sebastian Trojanowski,[15] and Gang Zhang[16]

Currently: longer Technical Proposal submitted to the LHC Committee

very important and positive feedback

possible approval: March 2019

CERN Research Board

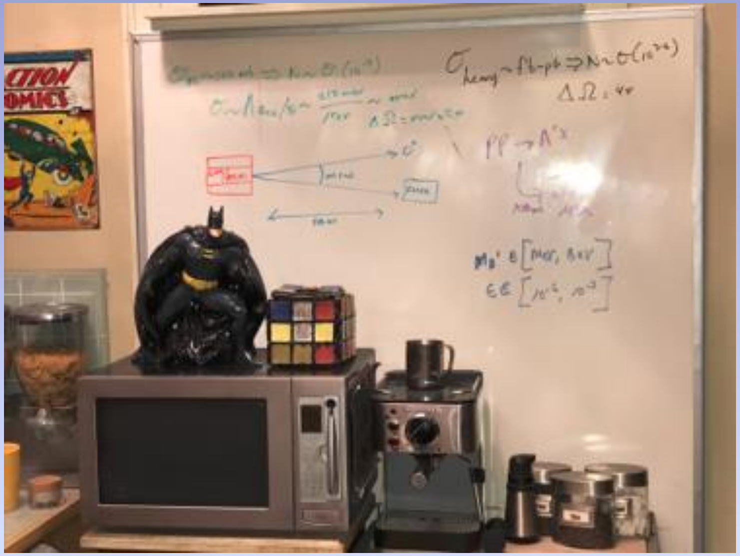
PLAN:

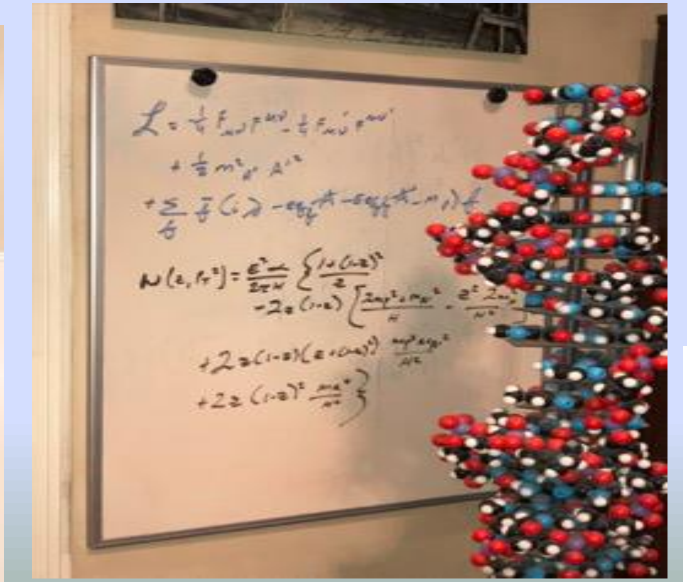
-- Install detector during Long Shutdown 2
(work beginning in early 2019)

-- **Data taking during LHC Run 3 (2021-23)**

-- **FASER 2 (major upgrade for HL-LHC)**

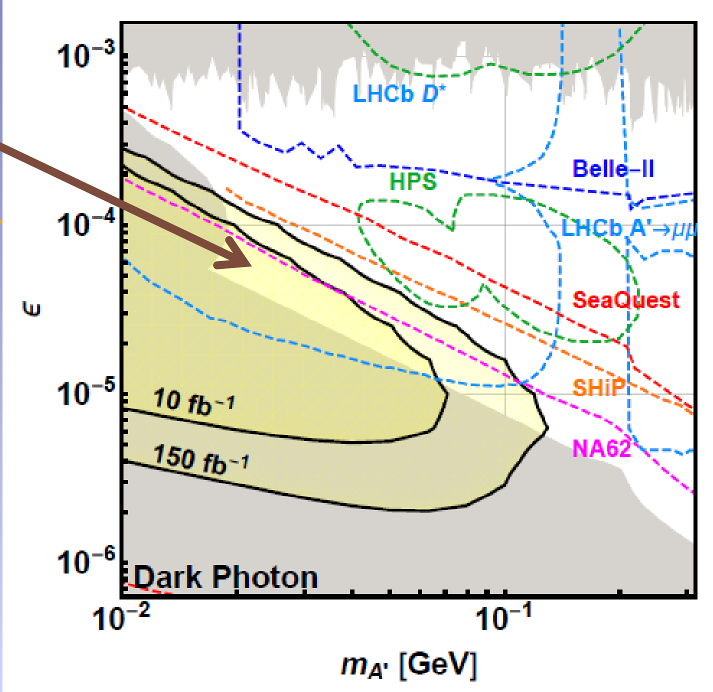
FASER IN POPULAR CULTURE





related article

LA Times



New physics reach even after first 10fb^{-1} (end of 2021?)

CONCLUSIONS

- Intensity frontier searches – exciting new physics !!!

- **FASER** is a newly proposed, small and inexpensive experiment to be placed at the LHC to search for Light Long-lived Particles (LLPs) to complement the existing experimental programs at the LHC, as well as other proposed experiments,

- FASER & LHC Committee: Letter of Intent accepted, Technical Proposal submitted

- **FASER would not affect any of the existing LHC programs and do not have to compete with them for the beam time etc.**

- Rich physics prospects:

- popular LLP models (dark photon, dark Higgs boson, GeV-scale HNLs, ALPs…),
- Many connections to DM and cosmology
- Invisible decays of the SM Higgs,
- Measurments of SM neutrinos

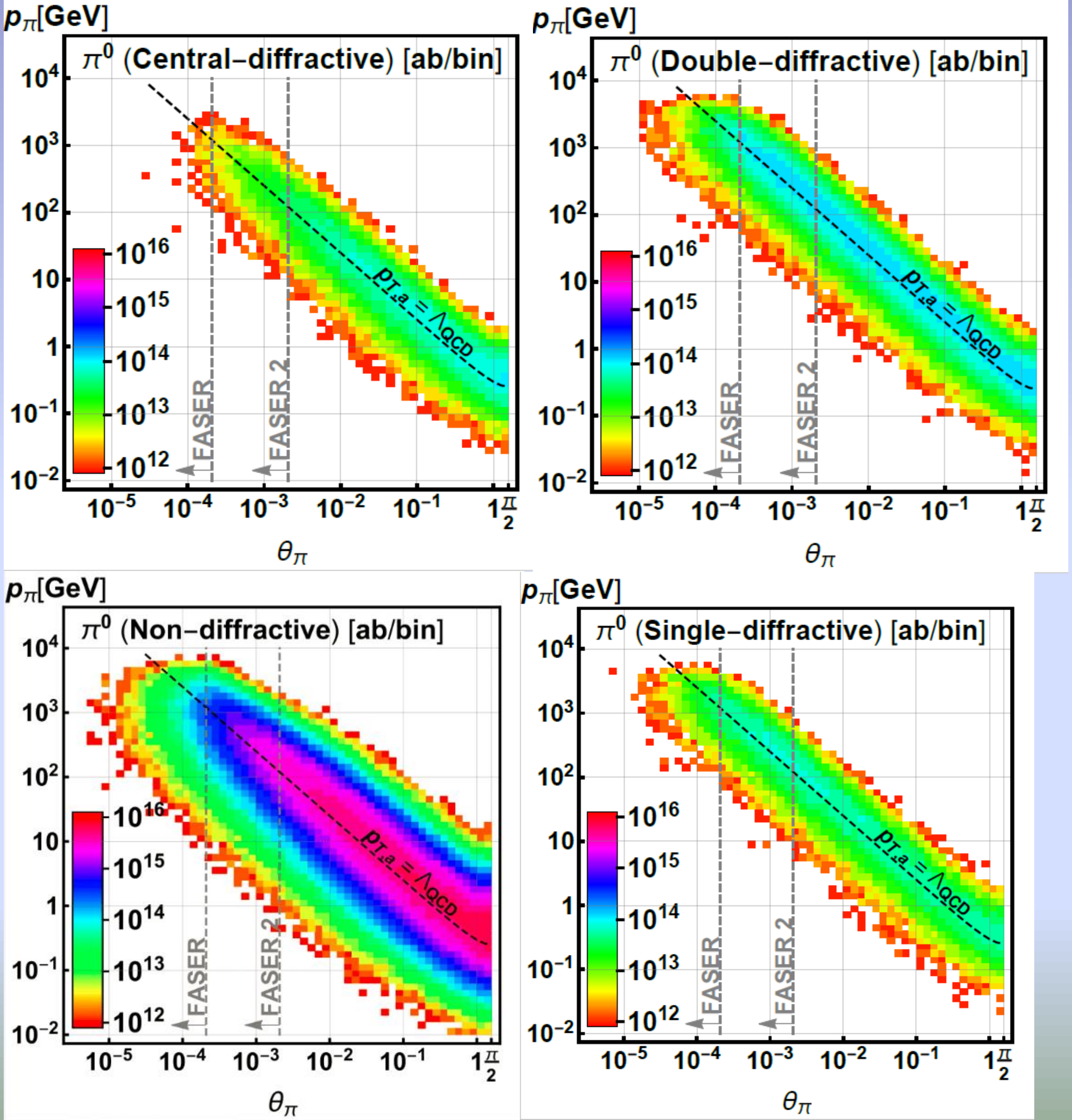
- Possible timeline:

  Install FASER 1 in LS2 (2019-20) for Run 3 (150 fb^{-1})
  - R = 10 cm, L = 1.5 m, Target dark photons, B-L gauge bosons, ALPs…

  Install FASER 2 in LS3 (2023-25) for HL-LHC (3 ab^{-1})
  - R = 1 m, L = 5 m, Full physics program: dark vectors, ALPs, dark Higgs, HNLs…

BACKUP

INELASTIC P-P COLLISIONS

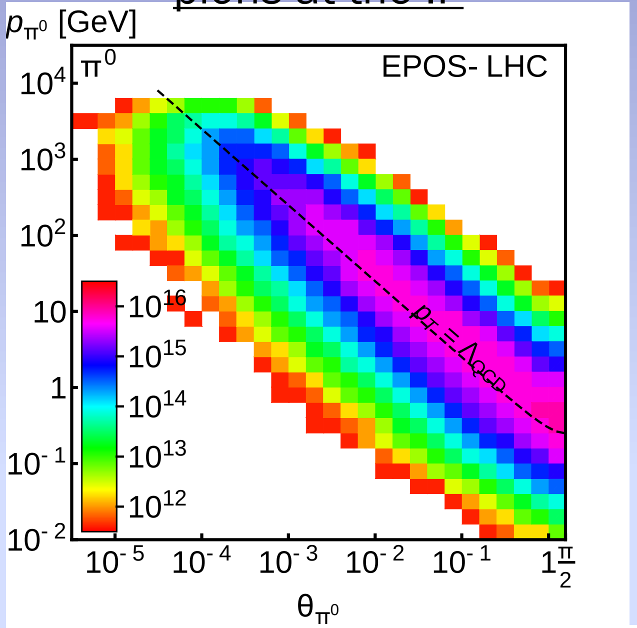


EPOS-LHC

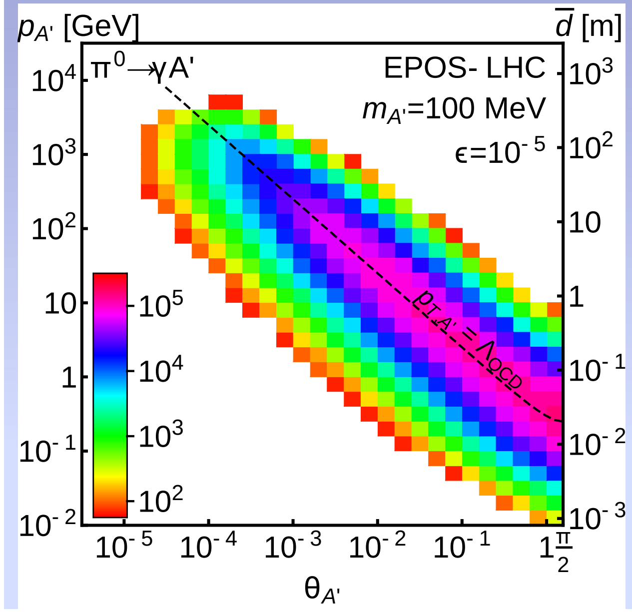
1708.09389

DARK PHOTONS AT FASER – KINEMATICS

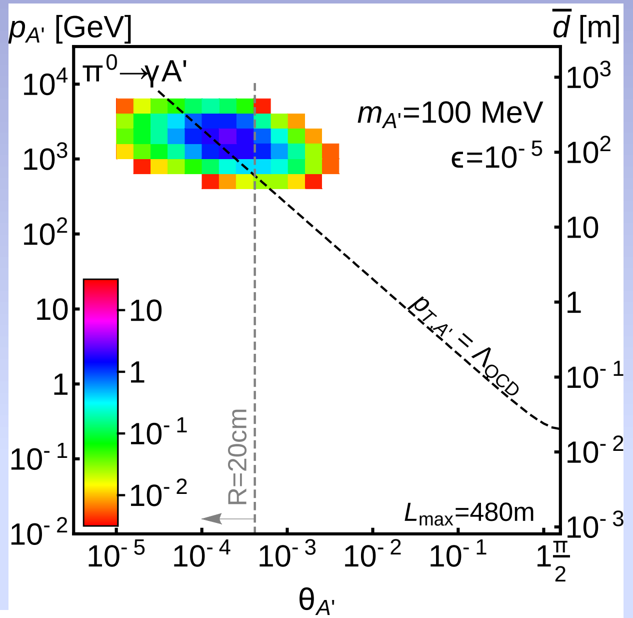
pions at the IP



A's at the IP



A's decaying in FASER



- Monte Carlo fitted to experimental data (LHCf, ALFA)
- typically $p_T \sim \Lambda_{QCD}$
- for E~TeV ⇨ p_T/E ~0.1 mrad
- even ~10^{15} pions per (θ,p) bin

- $\pi^0 \to A'\gamma$
- high-energy π^0
  ⇨ collimated A's
- $\varepsilon^2 \sim 10^{-10}$ suppression but still up to 10^5 A's per bin

- only highly boosted A's survive until FASER
  $E_{A'}$ ~TeV
- further suppression from decay in volume probability
- still up to **$N_{A'}$ ~100 events** in FASER, mostly within **r<20cm**

DARK HIGGS BOSONS

1710.09387, PRD 97 (2018) no.5, 055034

– Dark Higgs boson: additional hidden real scalar field ϕ,

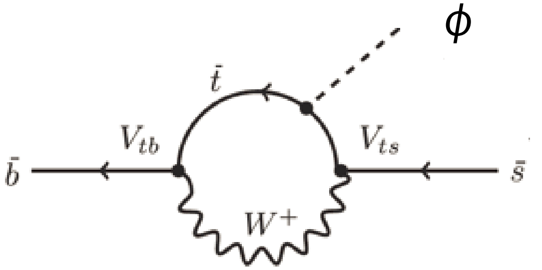
– often adopted phenomenological parametrization:

$$\mathcal{L} \supset -m_\phi^2\,\phi^2 - \sin\theta\,\frac{m_f}{v}\,\phi \bar{f} f - \lambda v h \phi\phi$$

– Higgs-like couplings suppressed by θ^2,

– production: B and K decays, $h \to \phi\phi$,

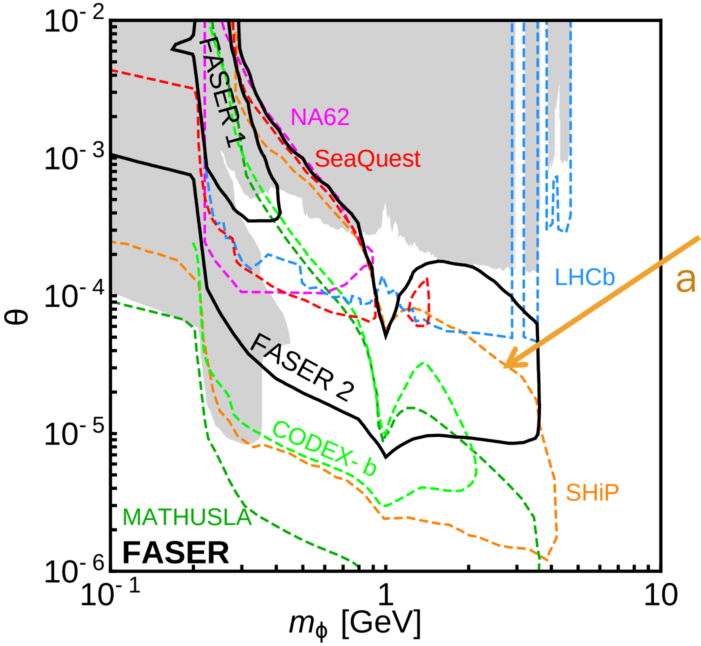
– decays: into the heaviest kinematically allowed states: $\mu^+\mu^-$, $\pi\pi$, KK, ...



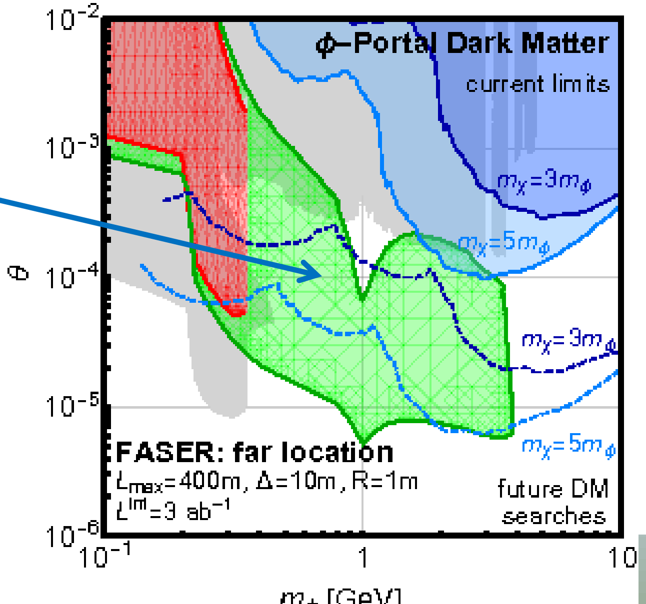
- at FASER energies: **N_B/N_π ~10^{-2}** (10^{-7} for typical beam+dumps)
- Typical p_T ~m_B ⇨ improved reach for FASER 2 (R=1m)

Dark Higgs-DM portal $\mathcal{L} \supset -\frac{1}{2}\kappa\,\phi\,\bar{X}X$

$\langle\sigma v\rangle \sim \kappa^4$ → κ fixed by relic density



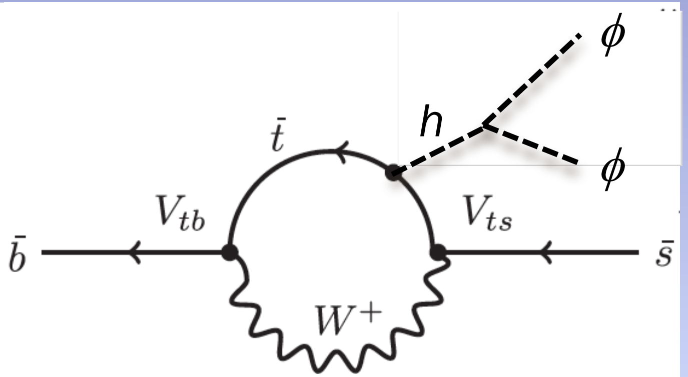
complementarity between FASER and other proposed experiments (large boost, probing lower τ)



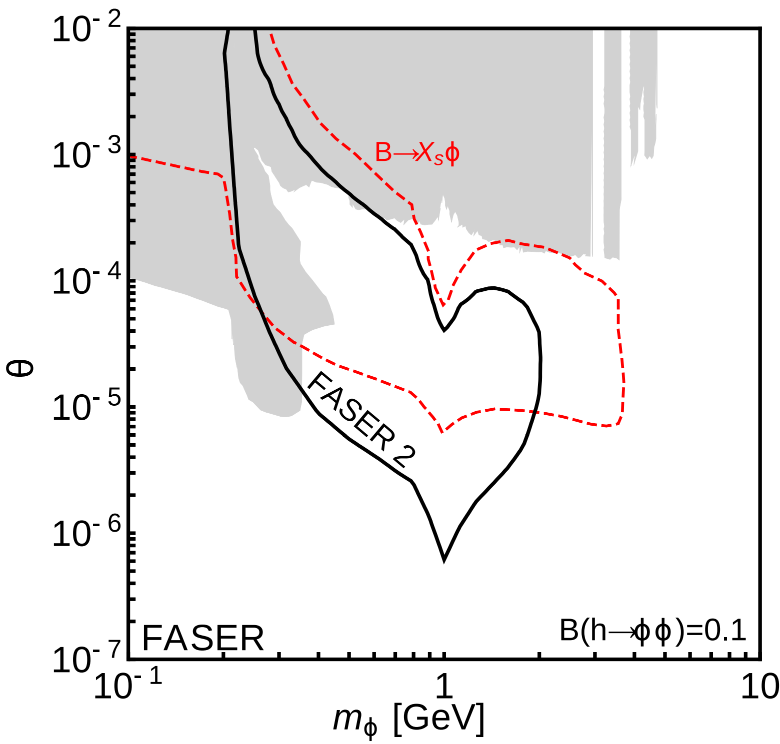
1710.09387

PROBING INVISIBLE DECAYS OF THE SM HIGGS

$\mathcal{L} \supset -\lambda v h \phi \phi$



- trilinear coupling
  ➡ invisible Higgs decays h → $\phi\phi$
- far-forward region: efficient production via off-shell Higgs, B → $X_s h^*(\rightarrow \phi\phi)$
- can extend the reach in θ up to 10^{-6} for $B(h \rightarrow \phi\phi) \sim 0.1$
- up to ~100s of events

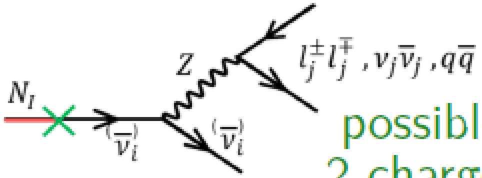


HEAVY NEUTRAL LEPTONS

- seesaw mechanism, e.g., for type-I seesaw

$$\mathcal{L} = \mathcal{L}_{\mathrm{SM}} + i\,\bar{\tilde{N}}_I \partial\!\!\!/ \tilde{N}_I - F_{\alpha I}\,\bar{L}_\alpha\,\tilde{N}_I\,\tilde{\Phi} - \frac{1}{2}\bar{\tilde{N}}{}_I^{c}\,M_I\,\tilde{N}_I + \mathrm{h.c.}$$

- popular model: νMSM with the lightest N_1 being a DM candidate possibly consistent with 3.5 keV excess and two heavier HNLs, $N_{2,3}$, detectable in LLP searches,
- typically considered in searches for LLPs, possibly a primary motivation to build SHiP
- they mix with the SM (active) neutrinos,
- phenomenologically they behave like *heavy* or *sterile* neutrinos with masses m_{N_I} and mixing angles U_{eI}, $U_{\mu I}$, $U_{\tau I}$
- HNLs can decay into lighter SM particles ⇒ signatu



possible
2 charged
tracks

HEAVY NEUTRAL LEPTONS AT FASER

1801.08947

Typical simplified approach:

- we focus on only one HNL leaving a signature in FASER
- we vary as free parameters

$$m_N, \quad U_{eN}, \quad U_{\mu N}, \quad U_{\tau N}, \quad \text{where only one } U_{\ell N} \neq 0 \text{ at a time.}$$

B and D **meson decays** – we consider about ~ 20 production channels, dominant ones dictated by the CKM suppression, kinematics and fragmentation fractions

$$D^{0,\pm} \to N\, e^{\pm}\, K^{\mp,0,(*)},\ D_s^{\pm} \to N\, e^{\pm}, \ldots$$

$$B^{0,\pm} \to N\, e^{\pm}\, D^{\mp,0,(*)},\ B^{\pm} \to N\, e^{\pm},$$

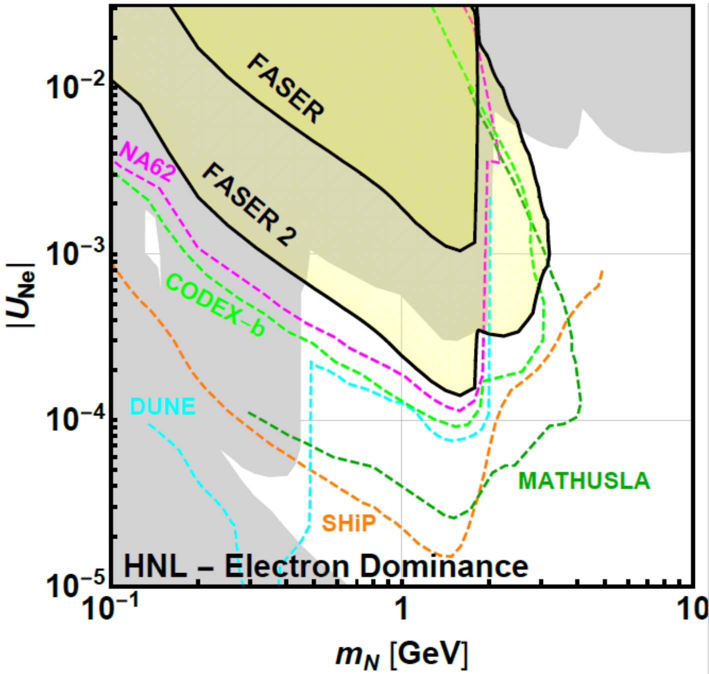
$$B_c^{\pm} \to N\, e^{\pm}, \ldots$$

Decay modes:

$\text{BR}(N \to 3\nu) \sim 10\% - 20\%$ invisible

$\text{BR}(N \to \nu\, l_1^+\, l_2^-) \sim 20\%$ $(\text{BR}(N \to \nu\, e^+\, e^-) \sim$ few percent$)$

$\text{BR}(N \to \text{hadrons}) \sim 60\% - 70\%$, various final states



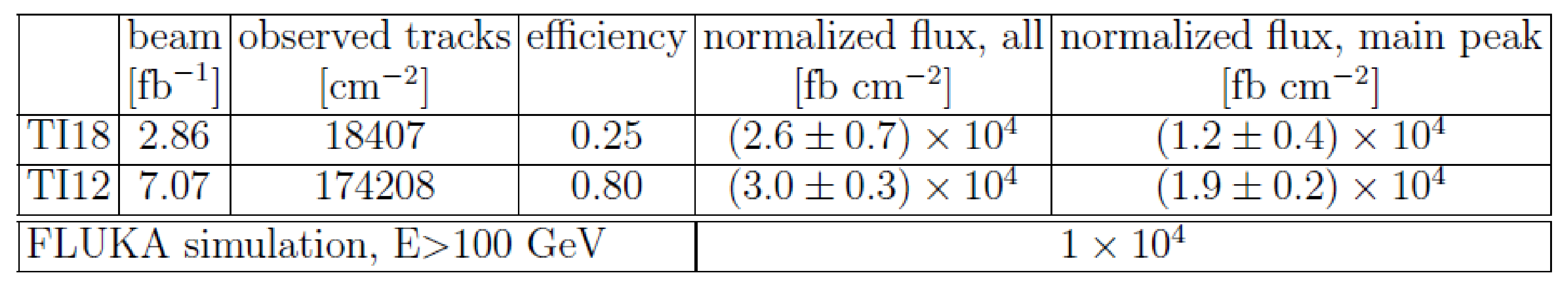
FASER 2

$\Rightarrow$ up to $\sim 10^3$ events for $m_N \gtrsim m_D$

$\Rightarrow$ for $m_N \lesssim m_D$ possible $\sim 10^1$-10^2 events

POSSIBLE LOCATIONS (TI12 vs TI18)

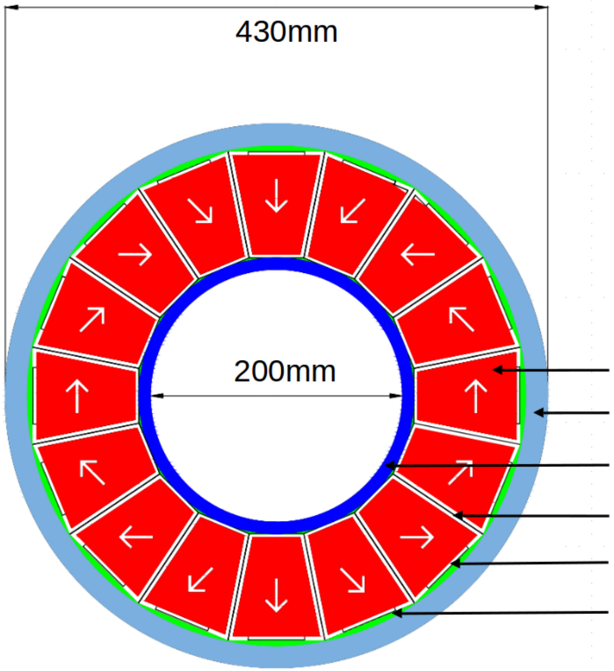
- When designing the detector 2 main possible locations were considered: tunnels TI12 and TI18 on two sides of the ATLAS IP (~480m away from the IP)
- Both are former service tunnels connecting SPS and the main LHC tunnel
- Both are currently unused
- Both slope steeply upwards when leaving the main LHC tunnel (SPS is shallower than LHC)
- In both cases the line-of-sight (along the beam collision axis) is below the tunnel floor as it enters the tunnel, and then emerges from the floor
- Lowering of the floor up to 460mm is possible to maximize the detector length (CERN survey team)
- The tunnels do have identical geometry:
  about 5m long detector can be fit in tunnel TI12
  about 3m long detector can be fit in tunnel TI18
- Based on this the preferred location is the tunnel TI12
- BG measurements have been performed in both locations (below fluxes within 10 mrad)



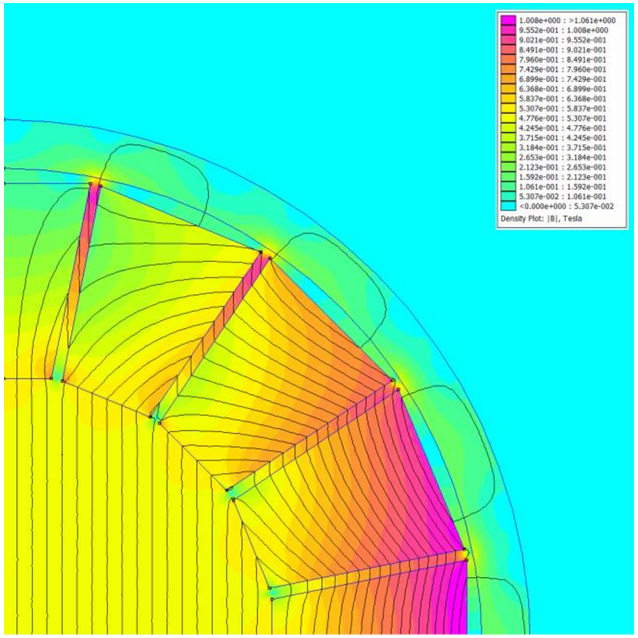
	beam [fb^{-1}]	observed tracks [cm^{-2}]	efficiency	normalized flux, all [$\mathrm{fb\ cm}^{-2}$]	normalized flux, main peak [$\mathrm{fb\ cm}^{-2}$]
TI18	2.86	18407	0.25	$(2.6 \pm 0.7) \times 10^4$	$(1.2 \pm 0.4) \times 10^4$
TI12	7.07	174208	0.80	$(3.0 \pm 0.3) \times 10^4$	$(1.9 \pm 0.2) \times 10^4$
FLUKA simulation, E>100 GeV				1×10^4	

See talk: J. Boyd at the LHCC Open Session 28/11/2018

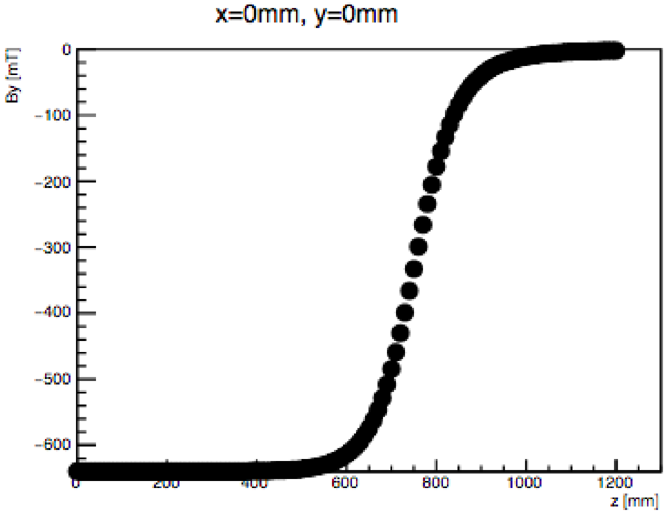
FASER MAGNET



Permanent magnet block (NdFeB)
Magnetic yoke (low carbon steel)
Non magnetic internal ring (stainless steel)
Non magnetic frame (extruded Cu or Al)
Non magnetic shim (stainless steel)
Epoxy resin

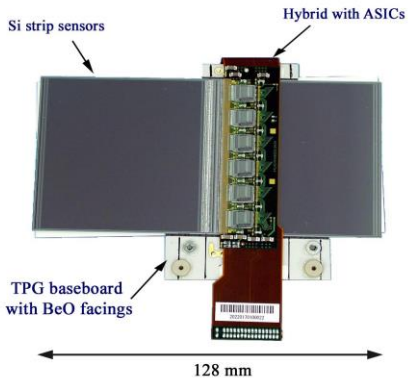


- The FASER magnets are 0.6T permanent dipole magnets based on the Halbach array design
  - Thin enough to allow the LOS to pass through the magnet center with minimum digging to the floor in TI12
  - Minimized needed services (power, cooling etc..)
- To be constructed by the CERN magnet group
  - Cost 450kCHF

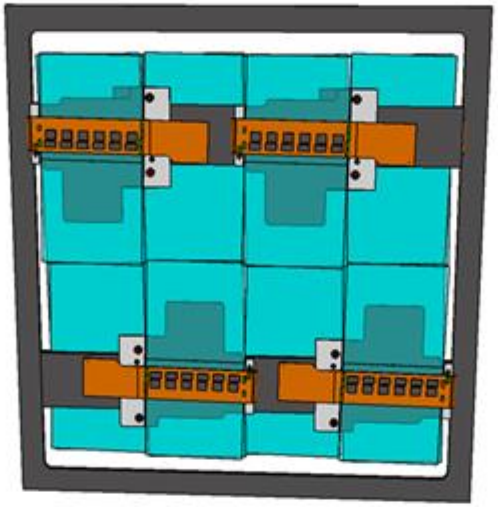


FASER TRACKER

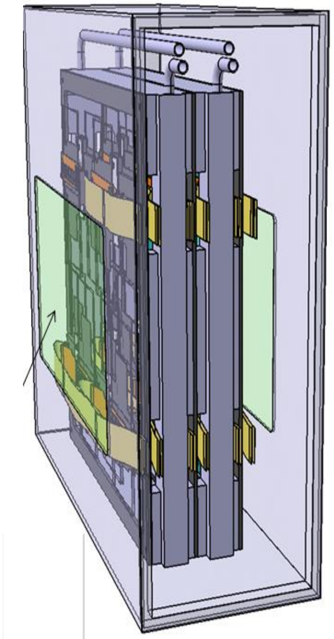
- The FASER Tracker will be made up of 3 tracking stations
- Each containing 3 layers of double sided silicon micro-strip detectors
  - Spare ATLAS SCT modules will be used
    - 80μm strip pitch, 40mrad stereo angle
    - Many thanks to the ATLAS SCT collaboration!
- 8 SCT modules give a 24cm x 24cm tracking layer
- 9 layers (3/station, 3 stations) => 72 SCT modules needed for the full tracker
  - 10^5 channels in total
- Due to the low radiation in TI12 the silicon can be operated at room temperature, but the detector needs be cooled to remove heat from the on-detector ASICs
- Tracker readout using FPGA based board from University of Geneva (already used in Baby MIND neutrino experiment)



SCT module



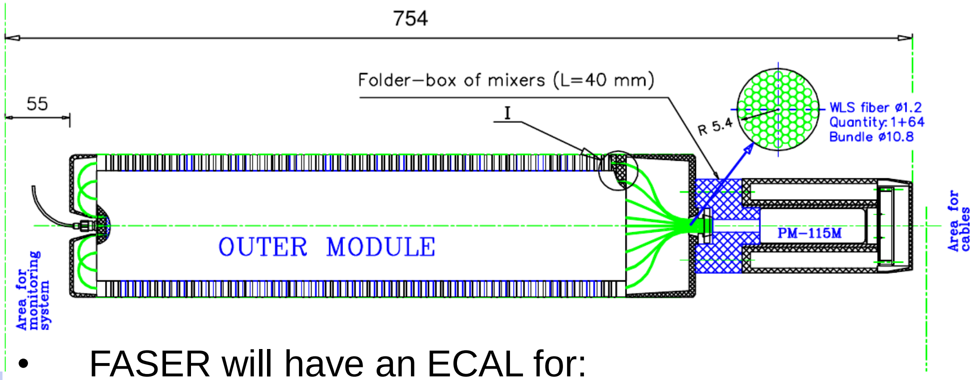
Tracking layer

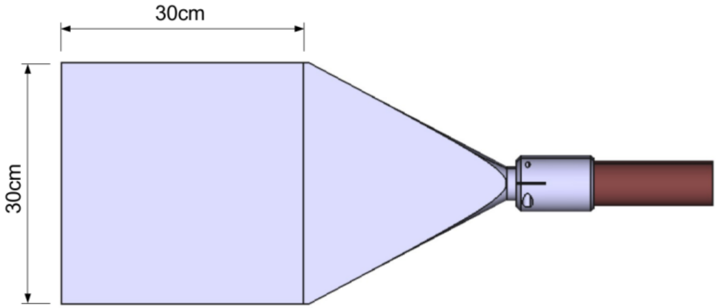


Tracking station

See talk: J. Boyd at the LHCC Open Session 28/11/2018

CALORIMETER / SCINTILLATORS

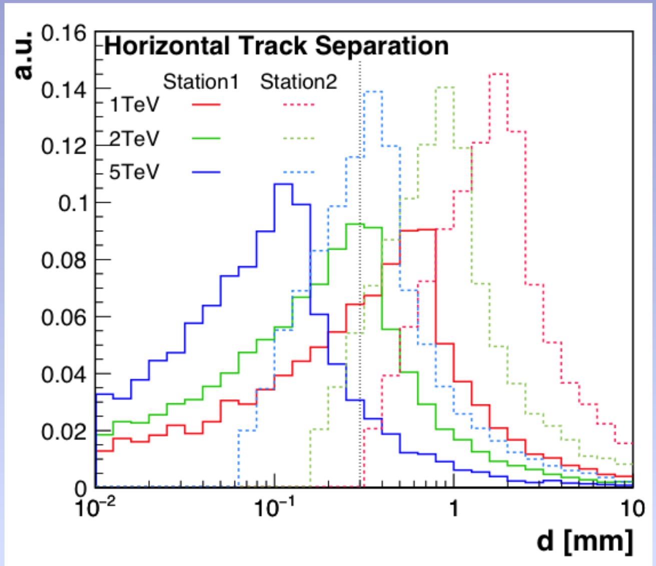


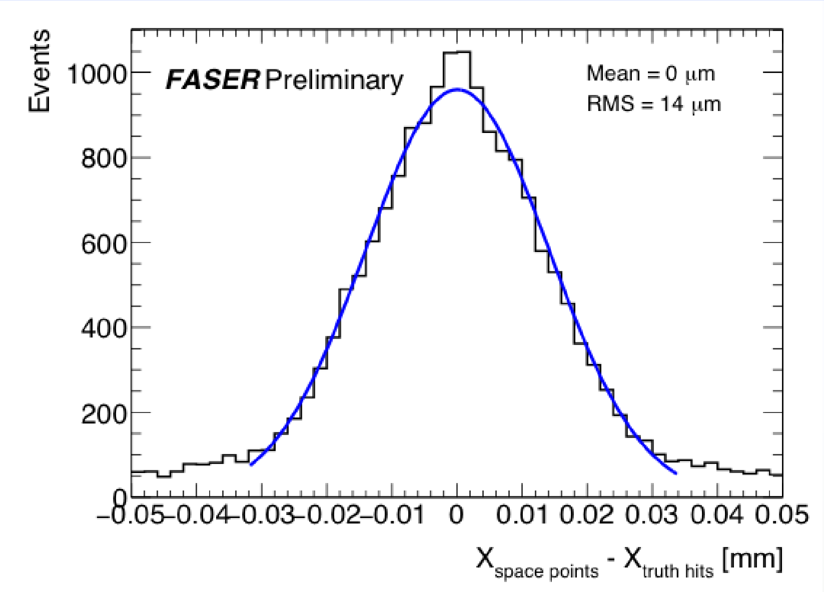


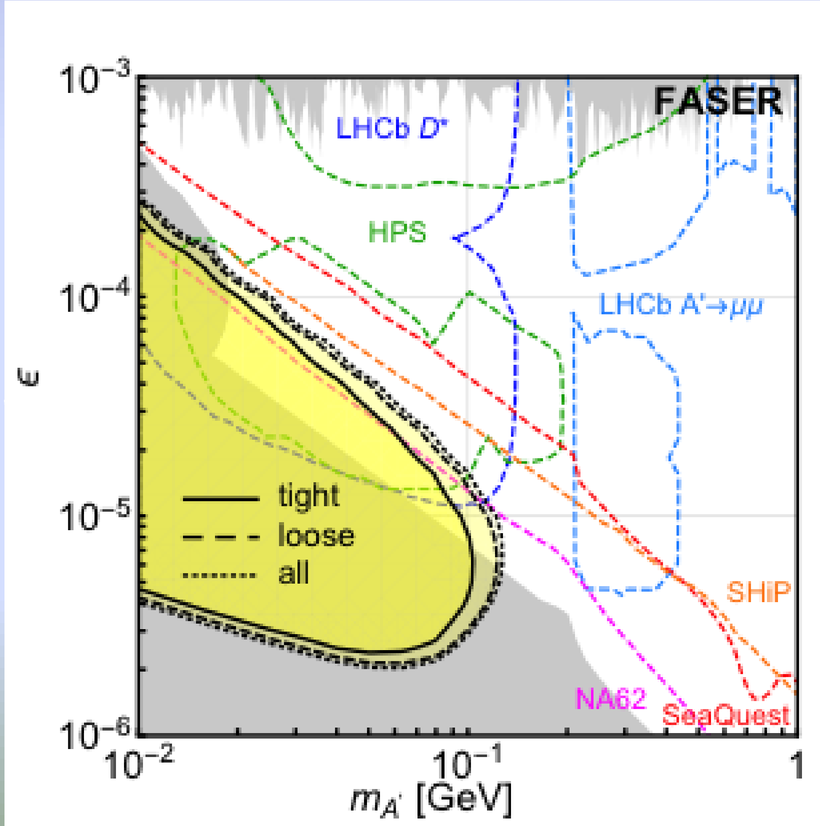
- FASER will have an ECAL for:
  - measuring the EM energy in the event
  - electron/photon identification
  - triggering
- Will use 4 spare LHCb outer ECAL modules
  - Many thanks to LHCb for allowing us to use these!
  - 66 layers of lead/scintillator, light out by wavelength shifting fibres, and readout by PMT (no longitudinal shower information)
    - 25 radiation lengths long
  - dimensions: 12cmx12cm – 75cm long (including PMT)
  - Provides ~1% energy resolution for 1 TeV electrons
    - Resolution will degrade at higher energy due to not containing full shower in calorimeter
- Scintillators used for vetoing charged particles entering the decay volume, and for triggering
  - To be produced at CERN scintillator lab
  - Require extremely efficient charged particle veto (eff>99.99%) – achievable with the current design

MORE ABOUT TRACK SEPARATION

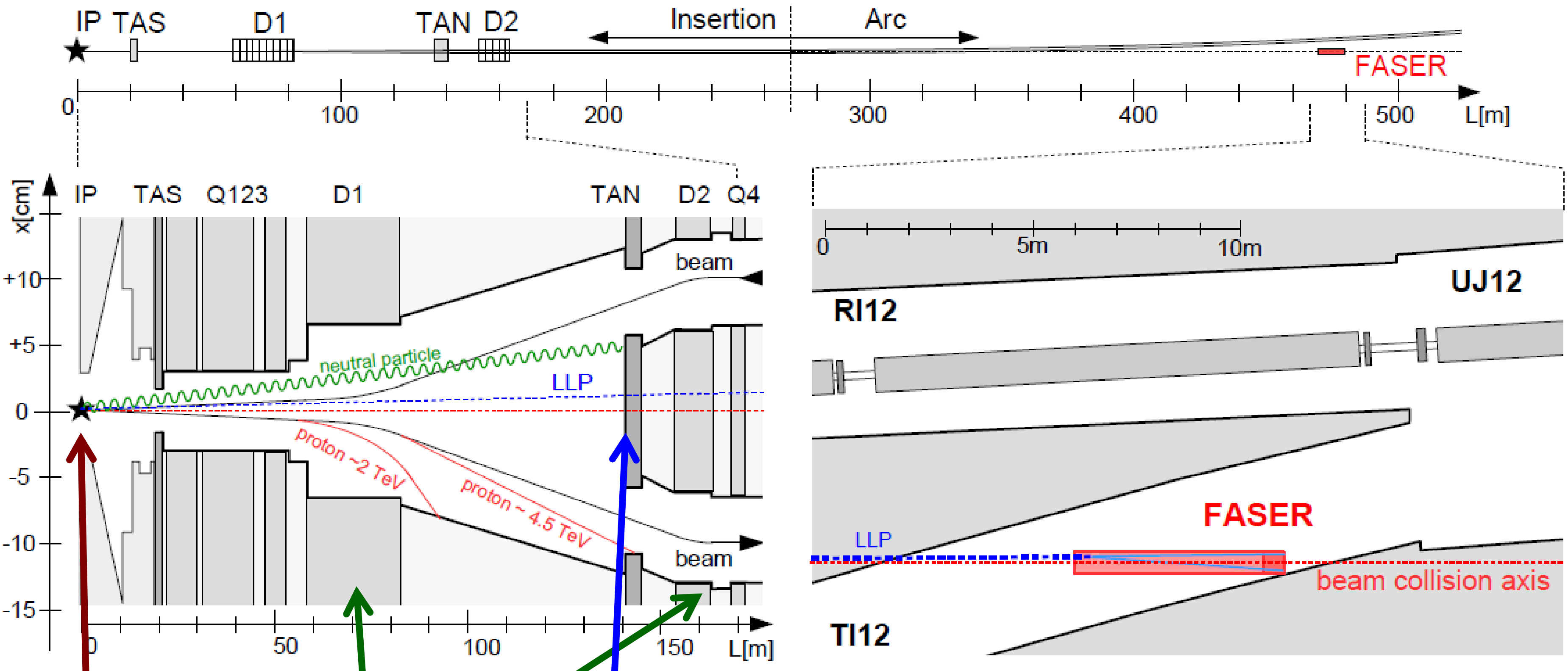
GEANT 4







FASER AND SURROUNDING LHC INFRASTRUCTURE



ATLAS Interaction Point (IP)

Strong LHC dipole magnets

TAN
Neutral Particle Absorber
~140m away from the IP

FASER location
tunnel TI12
~480m away from the IP