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FASER: ForwArd Search ExpeRiment at the LHC

Sebastian Trojanowski
University of Sheffield

HEP phenomenology joint Cavendish-DAMPT seminar
University of Cambridge, March 07, 2019

The University Of Sheffield.

Science & Technology Facilities Council | UK Research and Innovation

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
arXiv:1812.09139 Technical Proposal (CERN-LHCC-2018-036)
arXiv:1901.04468 Input to the European Particle Physics Strategy

FASER APPROVAL

related article

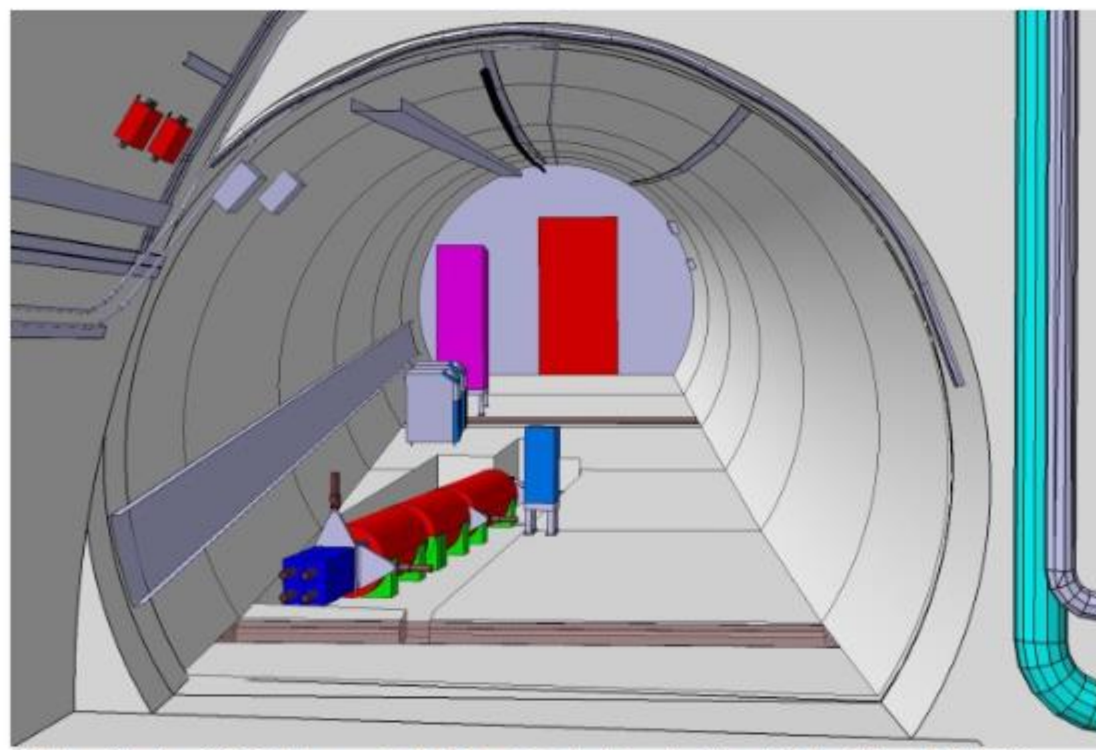
symmetry
dimensions of particle physics

Voir en français

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

The experiment, which will complement existing searches for dark matter at the LHC, will be operational in 2021

5 MARCH, 2019 | By Cristina Agrigoroae



A 3D picture of the planned FASER detector as seen in the TI12 tunnel. The detector is precisely aligned with the collision axis in ATLAS, 480 m away from the collision point (Image: FASER/CERN) (Image: CERN)

Geneva. Today, the CERN Research Board approved a new experiment designed to look for light and weakly

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

FASER COLLABORATION

Spokespersons: J. Boyd, J. L. Feng

- The FASER Collaboration: 30 collaborators, 16 institutions, 8 countries

  Akitaka Ariga (Bern), Tomoko Ariga (Kyushu/Bern), Jamie Boyd (CERN), Dave Casper (UC Irvine), Franck Cadoux (Geneva), Andrea Coccaro (Genova), Yannick Favre (Geneva), Jonathan Feng (UC Irvine), Didier Ferrere (Geneva), Iftah Galon (Rutgers), Sergio Gonzalez-Sevilla (Geneva), Shih-Chieh Hsu (Washington), Peppe Iacobucci (Geneva), Enrique Kajomovitz (Technion), Felix Kling (UC Irvine), Susanne Kuehn (CERN), Lorne Levinson (Weizmann), Josh McFayden (CERN), Friedemann Neuhaus (Mainz), Hidetoshi Otono (Kyushu), Brian Petersen (CERN), Osamu Sato (Nagoya), Matthias Schott (Mainz), Anna Sfyrla (Geneva), Jordan Smolinsky (UC Irvine), Aaron Soffa (UC Irvine), Yosuke Takubo (KEK), Eric Torrence (Oregon), Sebastian Trojanowski (Sheffield), Gang Zhang (Tsinghua China)

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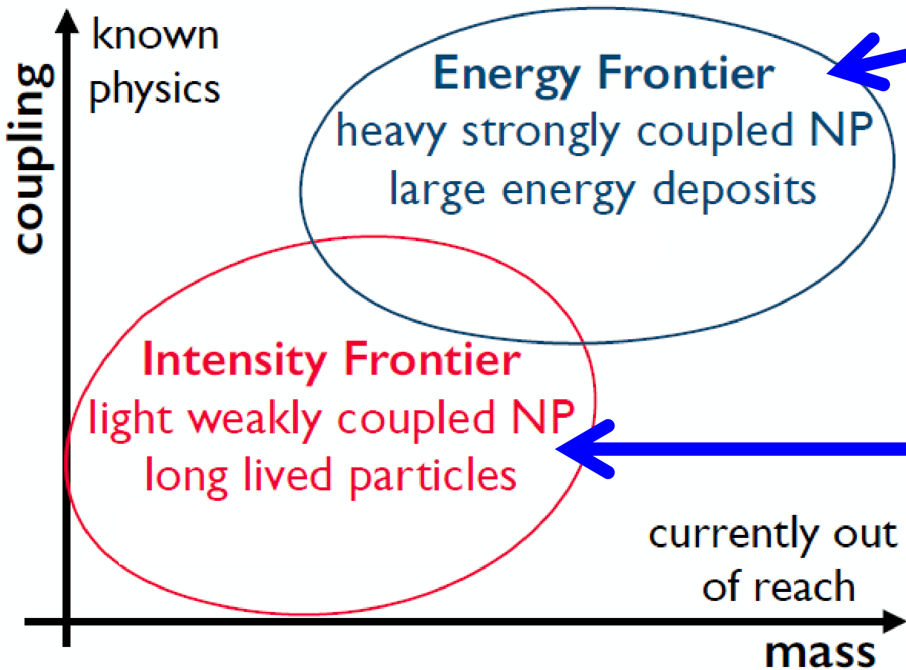
OUTLINE

- Motivation behind the intensity frontier searches for light long-lived particles (LLPs)
- FASER: ForwArd Search ExpeRiment at the LHC (idea, basic detector design)
- Remarks about FASER physics program
  - -- dark photons,
  - -- axion-like particles,
  - -- light scalars and heavy neutral leptons,
  - -- possible measurements for SM neutrinos,
  - -- ... and many other models

→ more experimental details:
Jamie Boyd talk at LHCb week
(remotely, right after this seminar)

- Background: simulations & in-situ measurements
- Concluding remarks

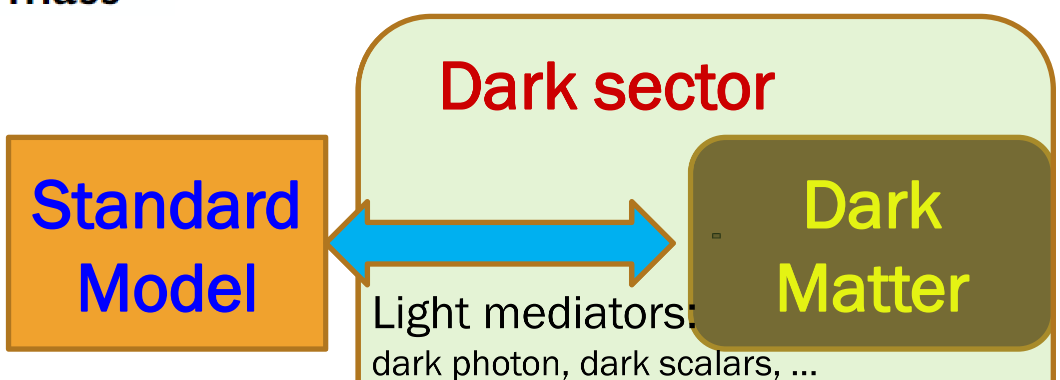
MOTIVATION



heavy and strongly-coupled new physics
e.g. SUSY, extra dimensions, ...
here also missing energy searches for heavy WIMP DM, magnetic monopoles,...

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)
-- $(g-2)_\mu$
-- …



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

„The WIMPless Miracle..." J.L. Feng, J. Kumar, Phys.Rev.Lett. 101 (2008) 231301

HIDDEN SECTOR PORTALS

- new „hidden" particles are SM singlets
- interactions between the SM and „hidden" sector arise due to mixing through some SM portal

$$\mathcal{L}_{\rm portal} = \sum O_{\rm SM} \times O_{\rm DS}$$

B. Patt, F. Wilczek, 0605188
B. Batell, M. Pospelov, A. Ritz, 0906.5614

Renormalizable portals

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	$y_N L H N$

PBC report, 1901.09966

FASER

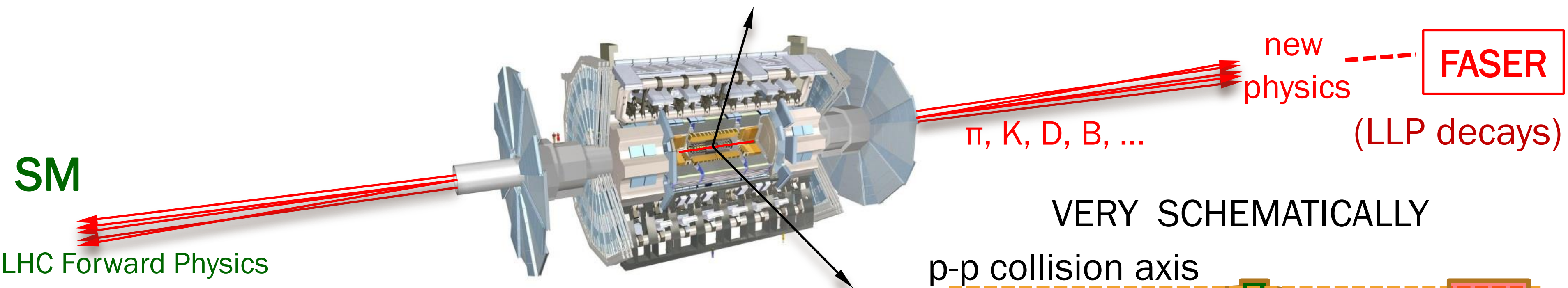
FASER - IDEA

FASER – newly proposed, small (**~0.05 m³**) and inexpensive (**~1M$**) experiment detector to be placed few hundred meters downstream away from the ATLAS IP

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

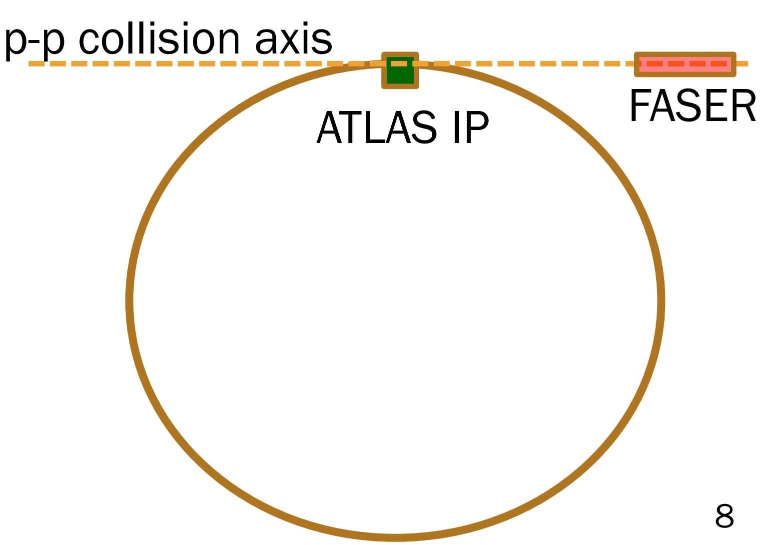
σ_{inel} ~ 75 mb, e.g., $N_{\pi} \sim 10^{17}$ at 3 ab^{-1}

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



LHC Forward Physics and Diffraction WG

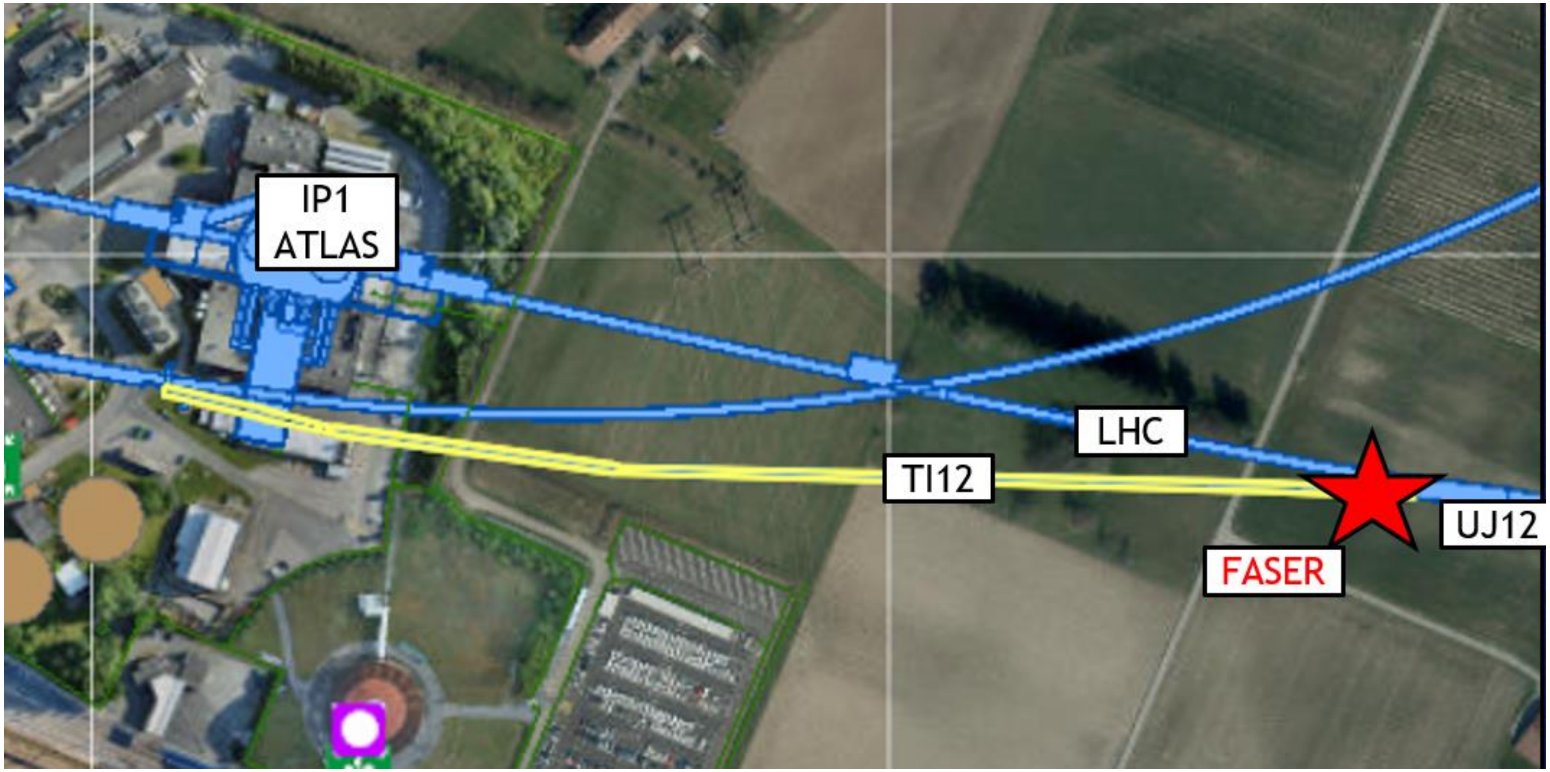
VERY SCHEMATICALLY



FASER will complement ATLAS/CMS by searching for highly-displaced decays of new Light Long-Lived Particles

(part of Physics Beyond Colliders Study Group at CERN)

FASER LOCATION – TUNNEL TI12



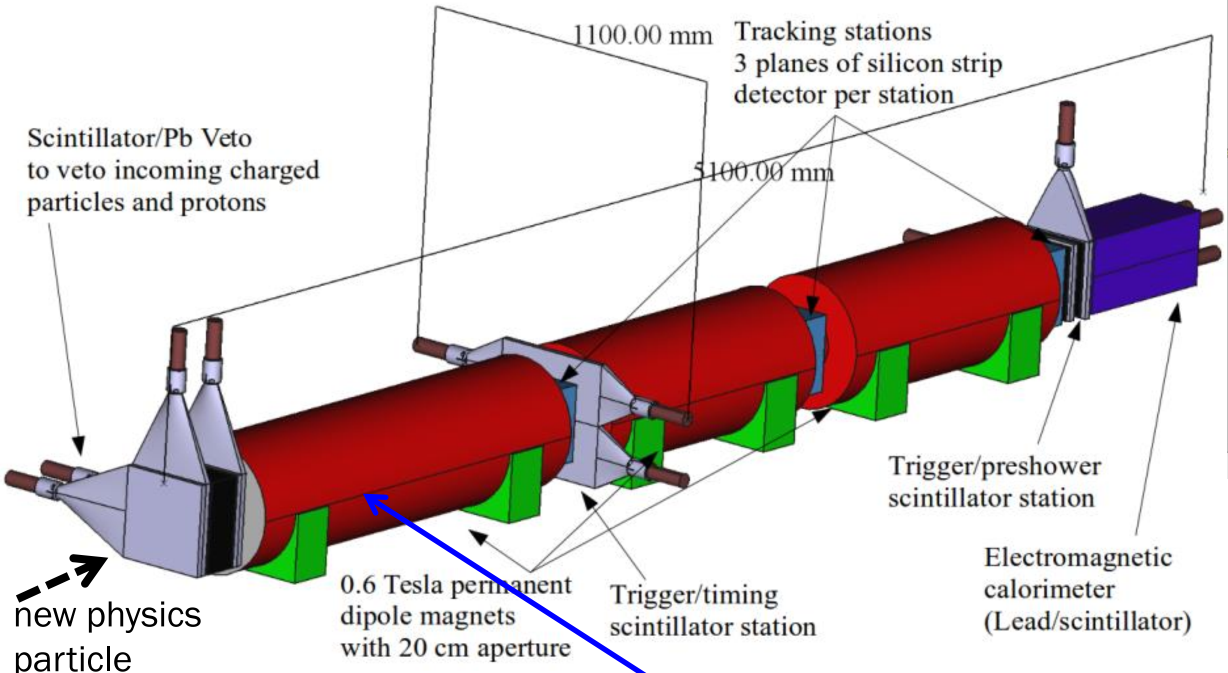
- location in a side tunnel TI12 (former service tunnel connecting SPS to LEP)
- **L ~ 485m** away from the IP along the beam axis
- space for a **5-meter-long** detector
- precise position of the beam axis in the tunnel up to **mm precision** (CERN Engineering Dep)
- corrections due to beam crossing angle (for ~300μrad the displacement is ~7-8 cm)

TUNNEL TI12

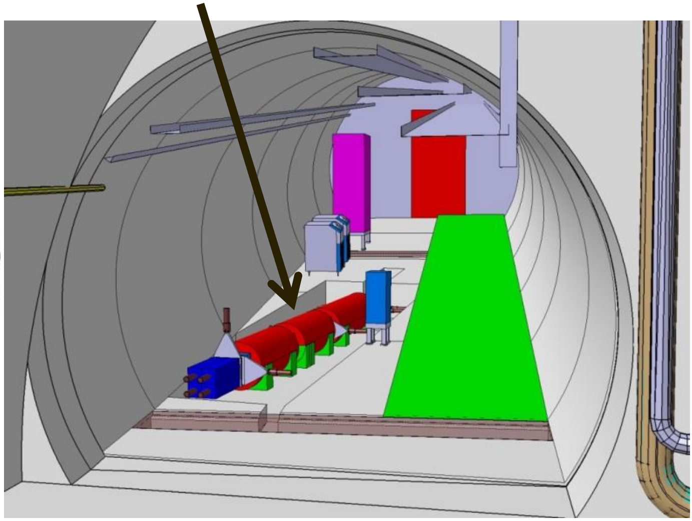
new physics
(hidden in the dark)

main LHC tunnel

BASIC DETECTOR LAYOUT



small civil engineering
(max 50cm digging)

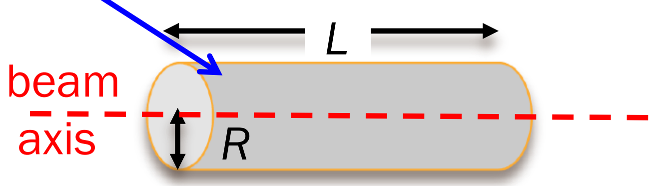


Thank you !!!

Recycling existing spare modules:

- ATLAS SCT modules (Tracker)
- LHCb ECAL modules (Calorimeter)

- cylindrical decay volume



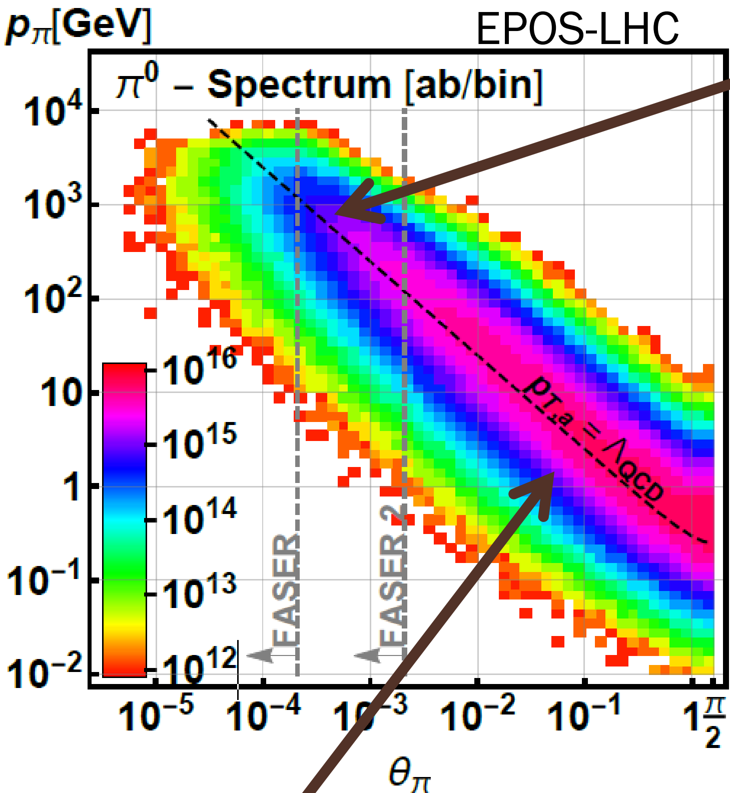
- 2 stages of the project:

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

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

FASER PHYSICS

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

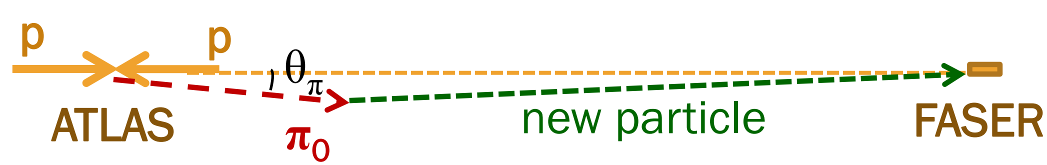
~ 1.7% of π_0s go towards FASER

~ 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 (2π) :

~ (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)

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

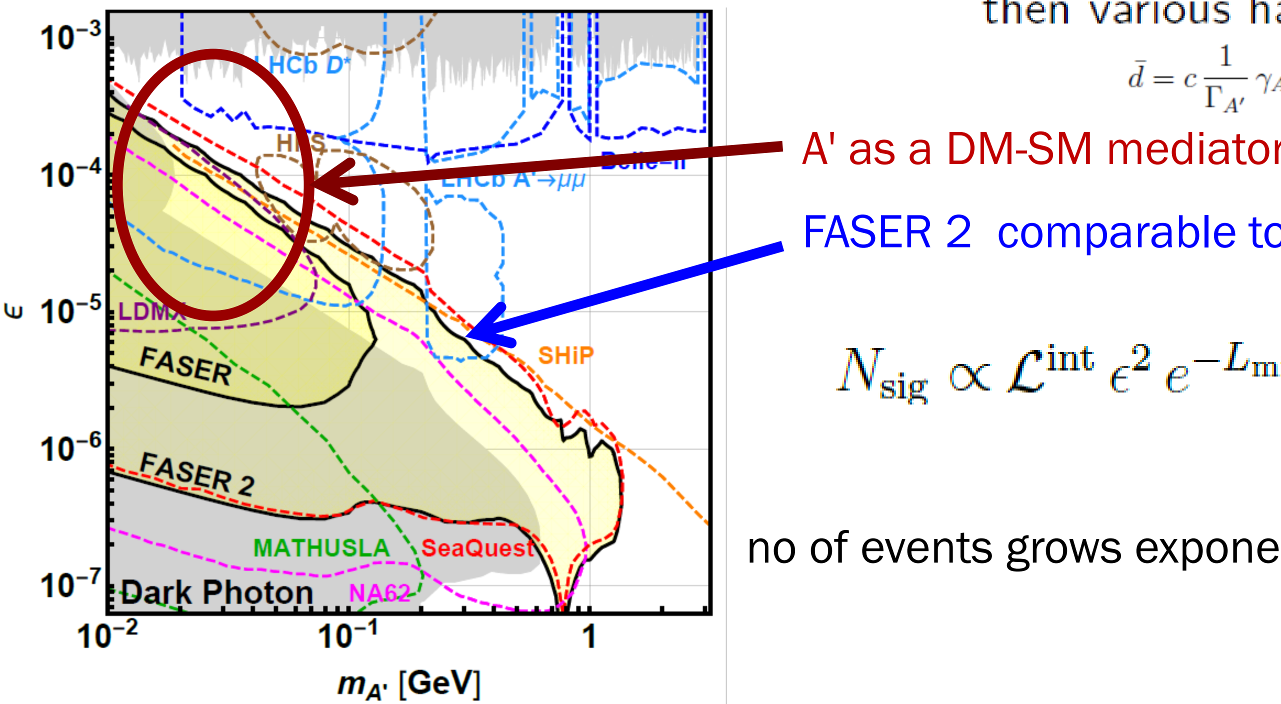
DARK PHOTON

- (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

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

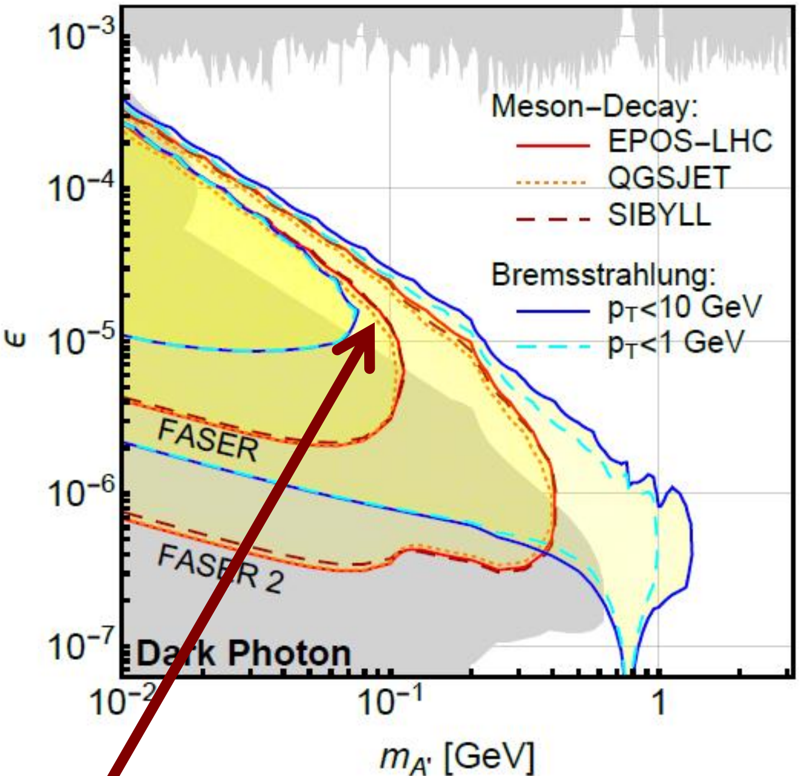


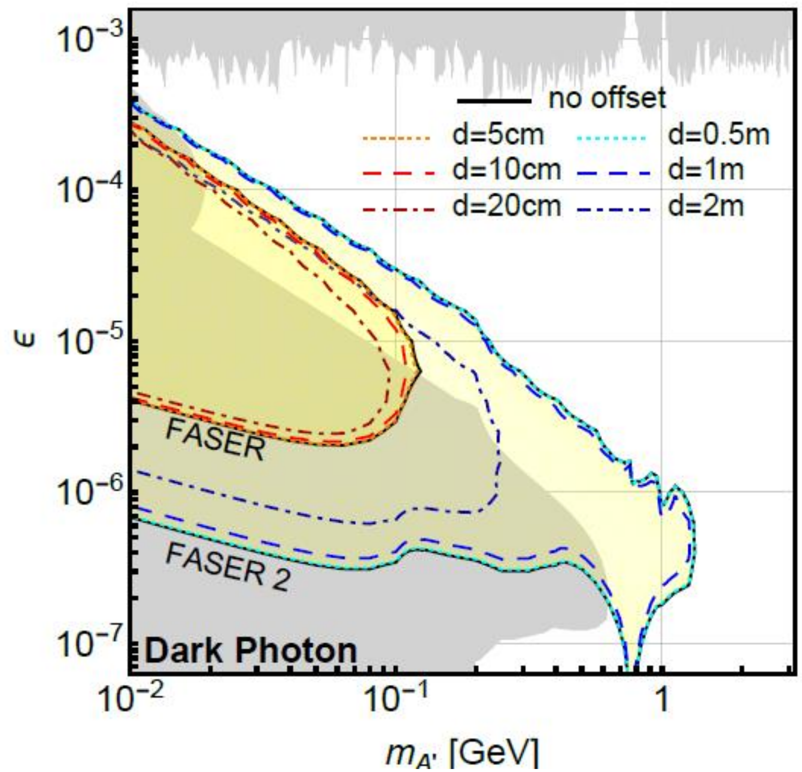
$$N_{\text{sig}} \propto \mathcal{L}^{\text{int}} \, \epsilon^2 \, e^{-L_{\min}/\bar{d}} \quad \text{for} \quad \bar{d} \ll L_{\min}$$

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

no of events grows exponentially with a small shift in ε

DARK PHOTON REACH – VARIOUS MC TOOLS & OFFSET





Almost impreceptible differences in reach for various MC tools

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

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

no of events grows exponentially with a small shift in ε

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

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

ALPS AT FASER – LHC AS A PHOTON BEAM DUMP

– similarly to the QCD axion, they can appear as pseudo-Nambu-Goldstone bosons in theories with broken global symmetries

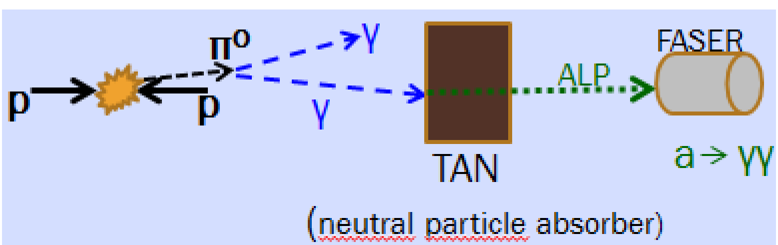
– suppressed dim-5 couplings to gauge bosons $(1/\Lambda) a V^{\mu\nu}\tilde{V}_{\mu\nu}$,

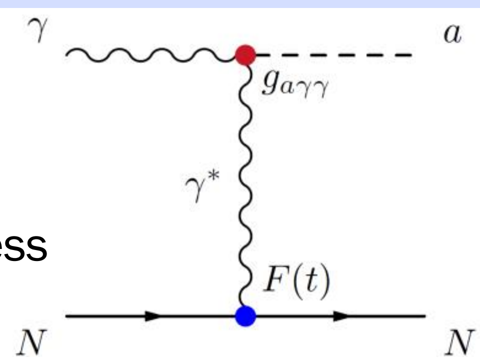
– dim-5 couplings to fermions also allowed $(\partial_\mu a/\Lambda)\bar{f}\gamma_\mu\gamma_5 f$,

– interesting pheno scenario – dominant $a\gamma\gamma$ coupling

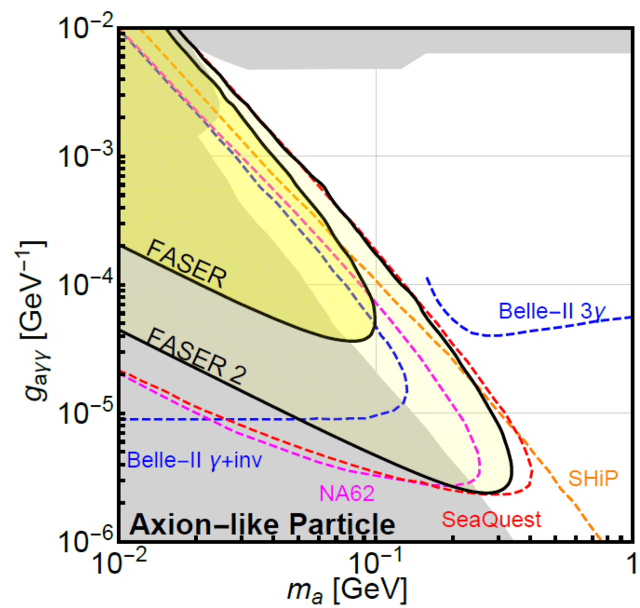
B. Döbrich *et al*, JHEP 1602 (2016) 018

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





ALPs produced in the Primakoff process



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

DARK HIGGS BOSONS

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

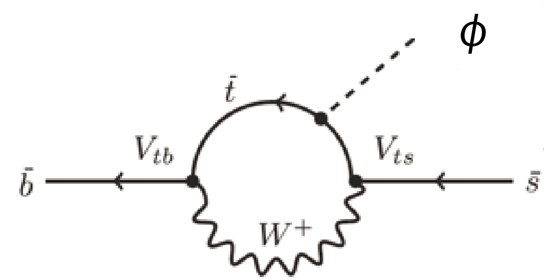
– often adopted phenomenological parametrization:

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

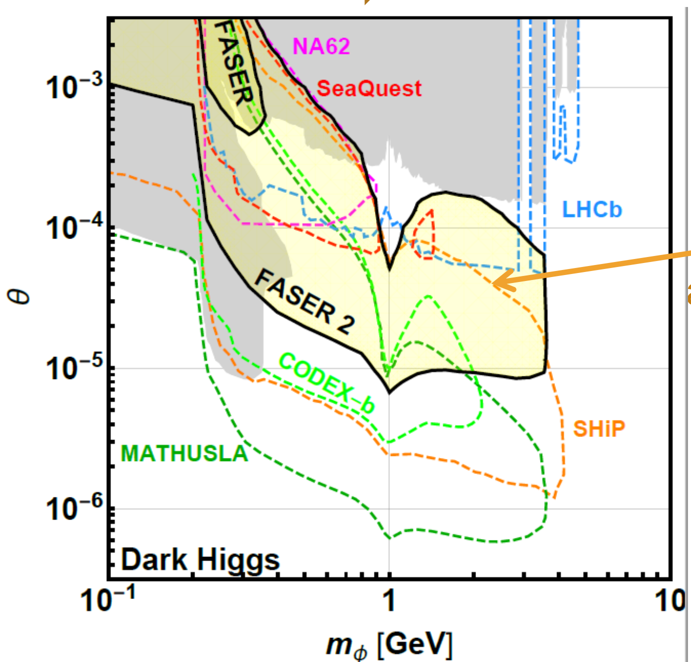
– Higgs-like couplings suppressed by θ^2,

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

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



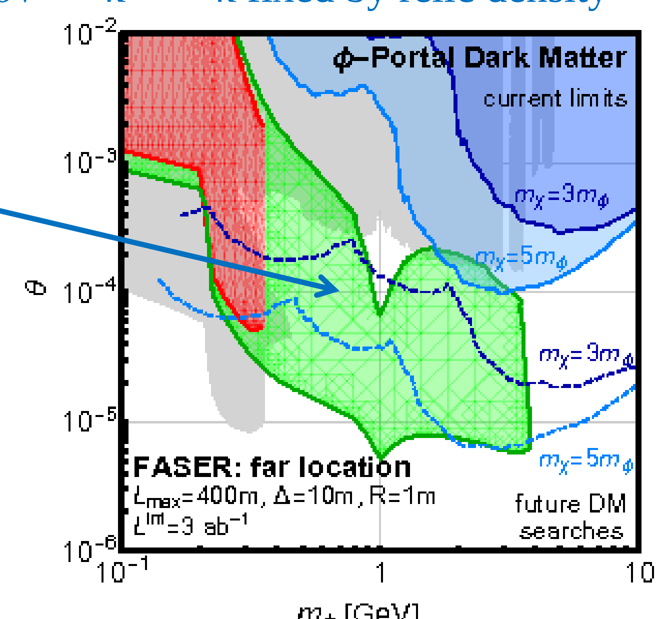
- at FASER energies: **N_B/N_π ~10^{-2}** (10^{-7} for typical beam+dumps)
- Typical p_T ~m_B ⇨ improved reach for FASER 2 (R=1m)



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

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

<σv> ~ κ^4 → κ fixed by relic density

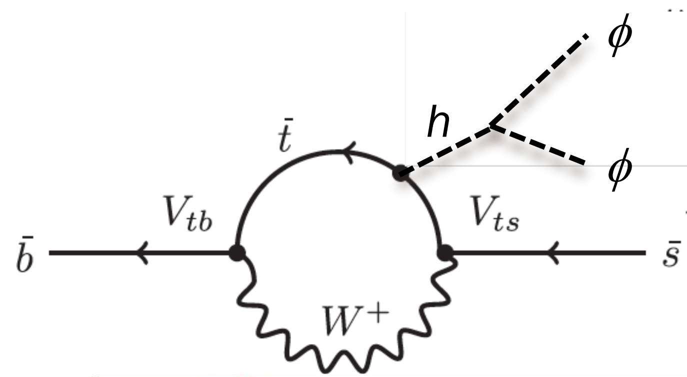


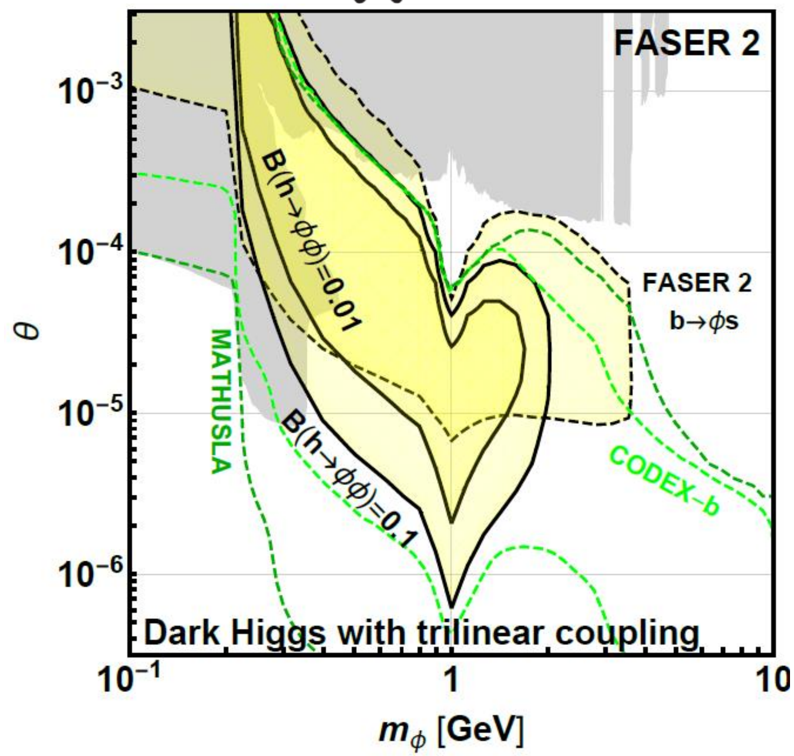
1710.09387, PRD 97 (2018) no.5, 055034

PROBING INVISIBLE DECAYS OF THE SM HIGGS

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

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





1801.08947, PRD 97 (2018) no.9, 095016

HEAVY NEUTRAL LEPTONS

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

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

- once Higgs gets vev, they mix with active (SM) neutrinos

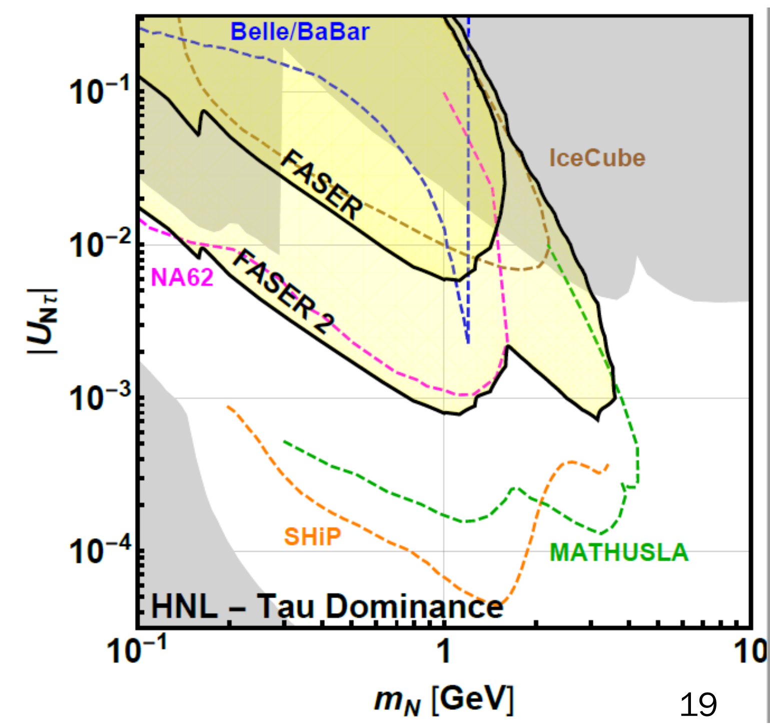
Mixing angles: $U_{eI}\,,\ U_{\mu I}\,,\ U_{\tau I}$

- production in B and D meson decays

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

- decay back into lighter SM particles (visible BR often 80-90%)

possible 2 charged tracks



1811.12522, (physics case)

MORE MODELS OF NEW PHYSICS

(table refers to the benchmark scenarios of the Physics Beyond Colliders CERN study group)

Benchmark Model	Label	Section	PBC	Refs	FASER	FASER 2
Dark Photons	V1	IV A	BC1	[7]	✓	✓
$B-L$ Gauge Bosons	V2	IV B	—	[30]	✓	✓
$L_i - L_j$ Gauge Bosons	V3	IV C	—	[30]	—	—
Dark Higgs Bosons	S1	V A	BC4	[26, 27]	—	✓
Dark Higgs Bosons with hSS	S2	V B	BC5	[26]	—	✓
HNLs with e	F1	VI	BC6	[28, 29]	—	✓
HNLs with μ	F2	VI	BC7	[28, 29]	—	✓
HNLs with τ	F3	VI	BC8	[28, 29]	✓	✓
ALPs with Photon	A1	VII A	BC9	[32]	✓	✓
ALPs with Fermion	A2	VII B	BC10	—	✓	✓
ALPs with Gluon	A3	VII C	BC11	—	✓	✓

Other models & FASER sensitivity studies e.g.:

- RPV SUSY (D. Drecks, J. de Vries, H.K. Dreiner, Z.S. Wang, 1810.03617)
- Inelastic dark matter (A. Berlin, F. Kling, 1810.01879)

SM NEUTRINOS IN FASER

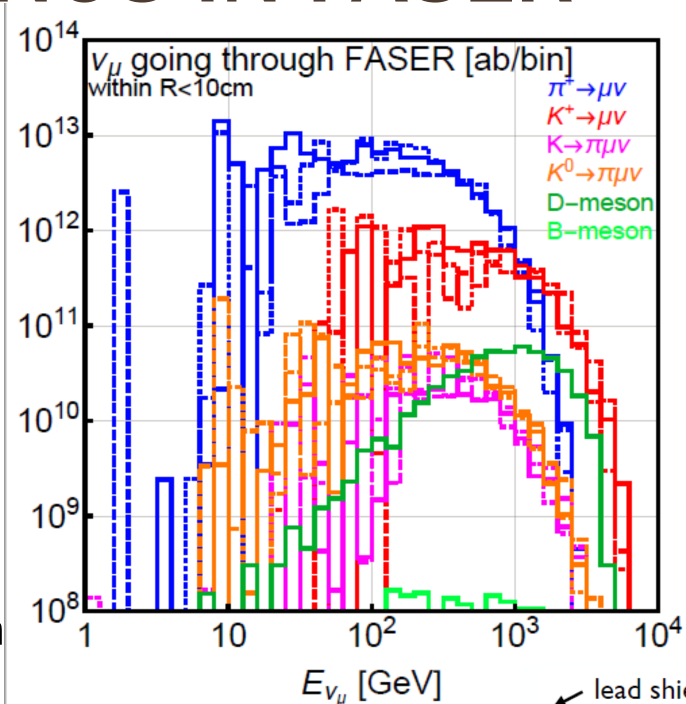
A. Ariga, T. Ariga, B. Petersen, J. Feng, F. Kling, H. Otono, O. Sato, J. Smolinsky, C. Wilkinson, …

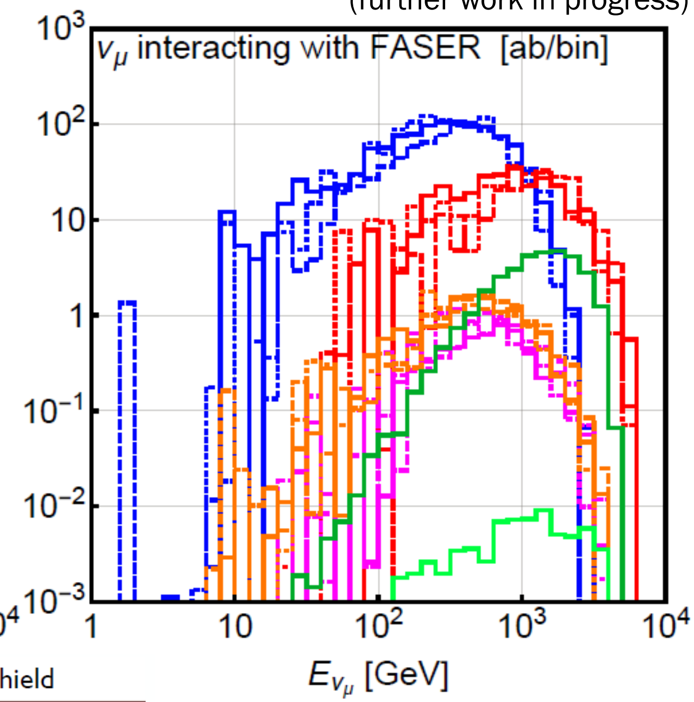
(further work in progress)

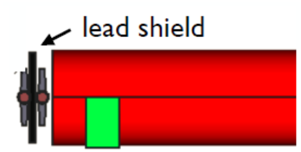
Ideas currently explored:

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

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

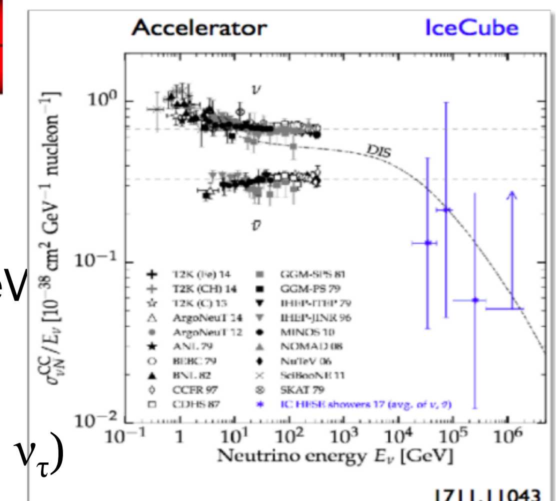






Potentially hundreds of events in FASER

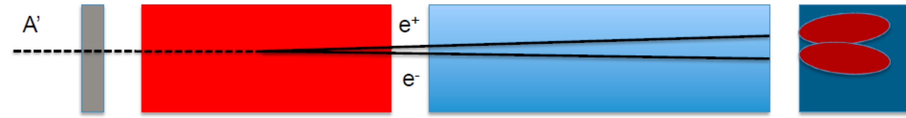
Measurement of the neutrino CC scattering cross section for E_ν ~TeV



2) Employing emulsion detectors
– additional information about kinematics (e.g. measurements of ν_τ)

SM BACKGROUNDS

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

- 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

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
μ^+	0.18	$6.1\cdot10^{-9}$	0.02	$5.8\cdot10^{-10}$	0.002	$6.8\cdot10^{-11}$
μ^-	0.40	$1.3\cdot10^{-8}$	0.22	$7.4\cdot10^{-9}$	0.14	$4.6\cdot10^{-9}$
n_0	~ 10^{-7}	~ 10^{-14}	0	0	0	0
γ	~ 10^{-4}	~ 10^{-12}	~ 10^{-6}	~ 10^{-13}	~ 10^{-6}	~ 10^{-13}
π	~ 10^{-5}	~ 10^{-12}	~ 10^{-7}	~ 10^{-14}	0	0

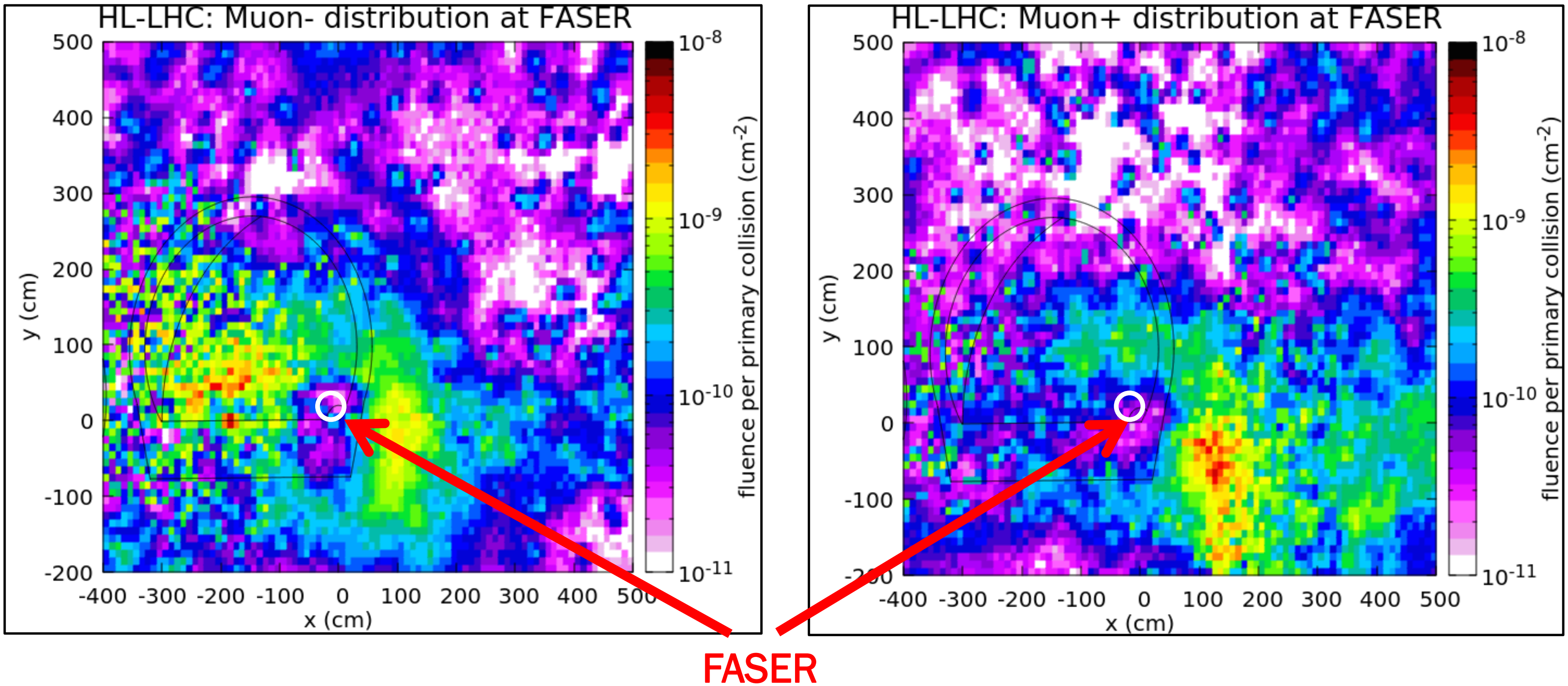
- Muons coming from the IP – front veto layers

Expected trigger rate ~650 Hz

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

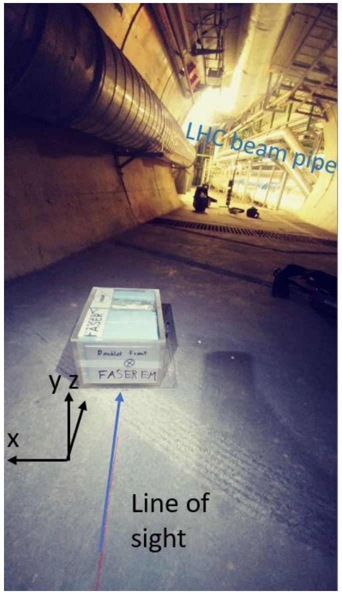


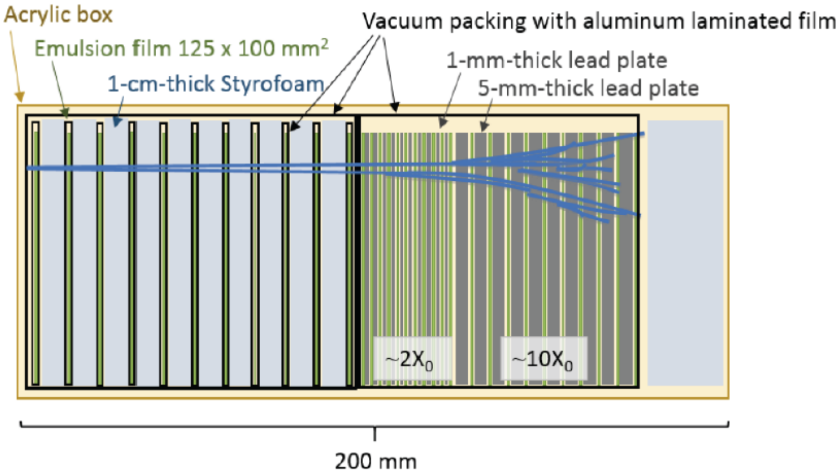
At FASER location:

muon flux reduced along the beam collision axis (helpful role of the LHC magnets)

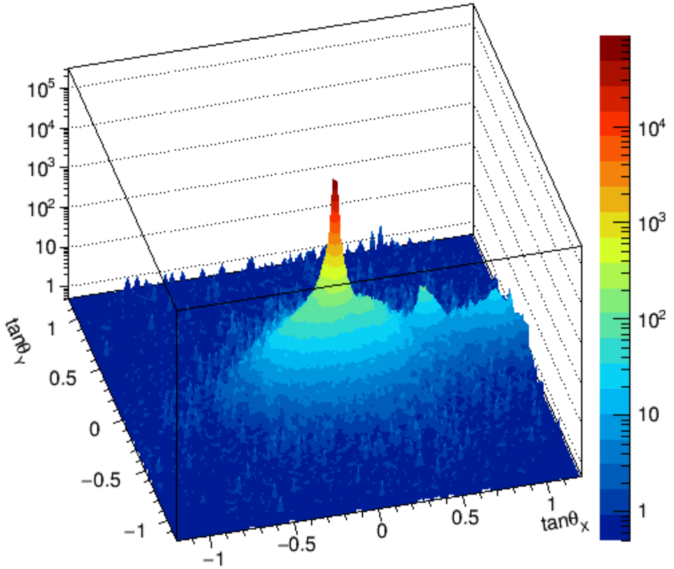
BACKGROUNDS – IN-SITU MEASUREMENTS

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





Analyses show that results are consistent with FLUKA simulations



PRACTICALLY ZERO BG SEARCH

SUMMARY

FASER TIMELINE

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

...within ~1.5 year FASER grew to an international collaboration recognized at CERN

Currently: ~30 active members from ~**16** institutions in ~**8** countries,
Spokespersons: Jamie Boyd (CERN), Jonathan L. Feng (UC Irvine)

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

Dec 2018: Technical Proposal recommended by the LHC Committee for a full approval

Dec 2018/Jan 2019: fundings granted for the detector (Heisig-Simons and Simons foundations)

Mar 2019: **FASER fully approved by the CERN Research Board**

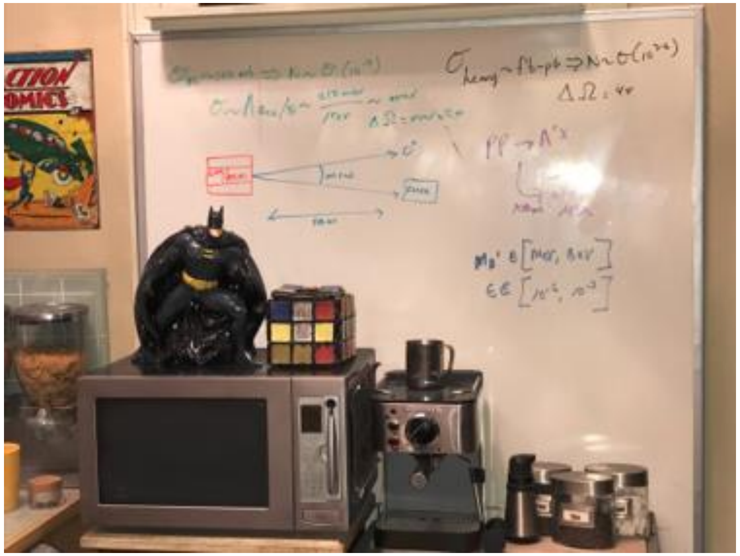
PLANS:

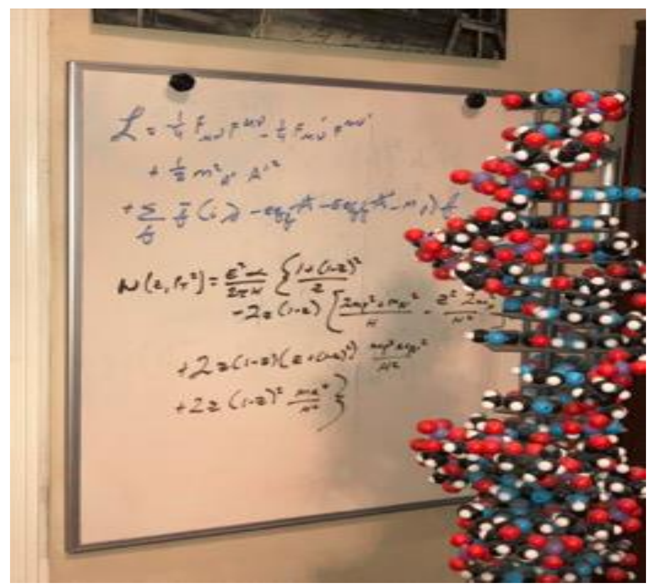
-- Final detector design, manufacture, installation and commisioning during Long Shutdown 2 (ongoing work)

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

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

FASER IN POPULAR CULTURE

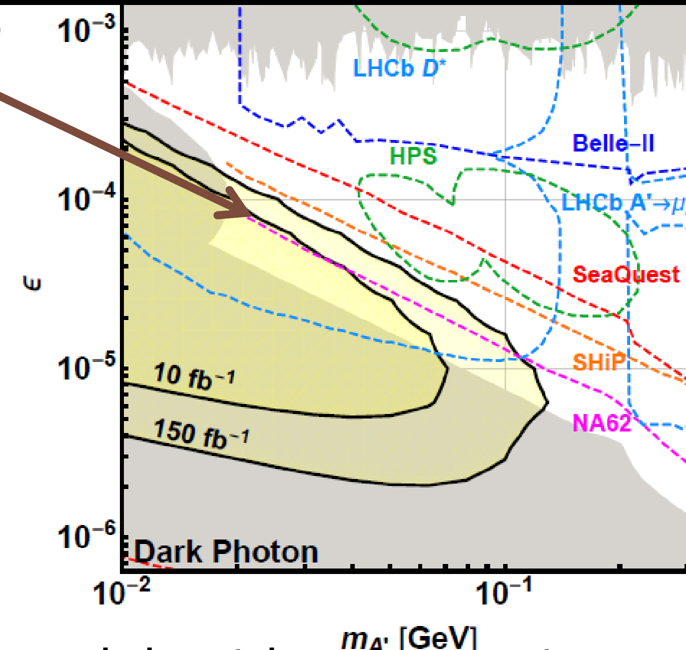




related article

LA Times

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



CONCLUSIONS

- Light Long-lived Particles (LLPs) – exciting new physics !!!

- **FASER** is a newly proposed, <u>small and inexpensive</u> experiment to be placed at the LHC to search for light long-lived particles to complement the existing experimental programs at the LHC, as well as other proposed experiments,

- FASER is fully approved by the CERN Research Board

- **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

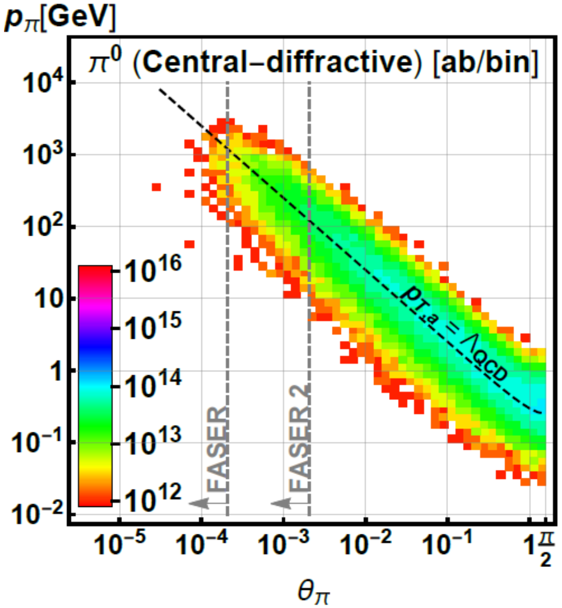
- Possible timeline:

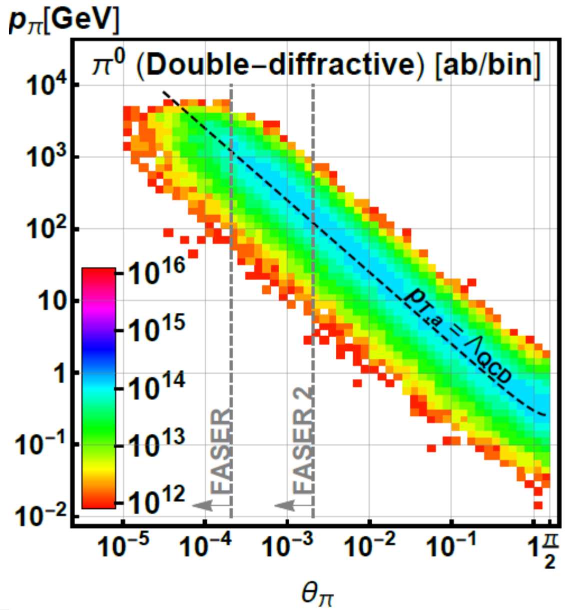
  Install FASER 1 in LS2 (2019-20) for Run 3 (150 fb^{-1})
  - R = 10 cm, L = 1.5 m, Target dark photons, B-L gauge bosons, ALPs, HNLs(τ)…

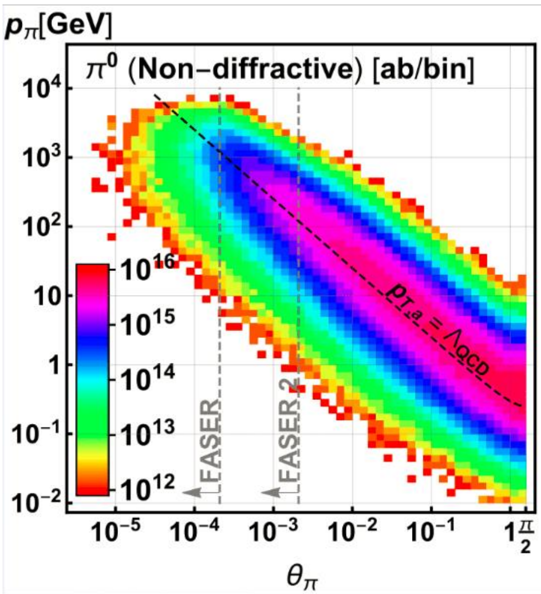
  Install FASER 2 in LS3 (2023-25) for HL-LHC (3 ab^{-1})
  - R = 1 m, L = 5 m, Full physics program: dark vectors, ALPs, dark Higgs, HNLs…

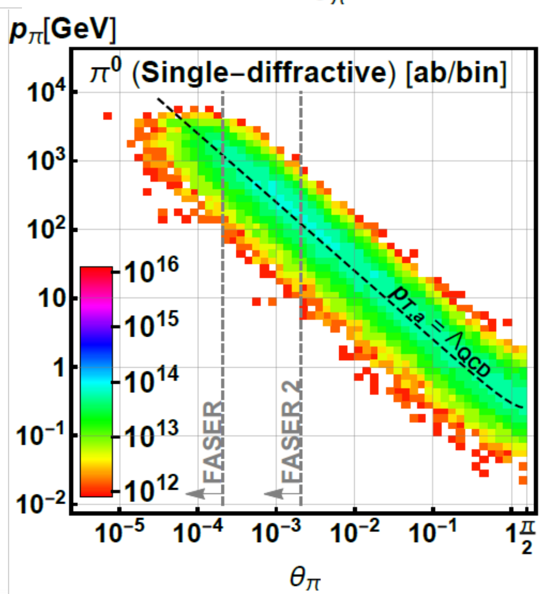
BACKUP

INELASTIC P-P COLLISIONS







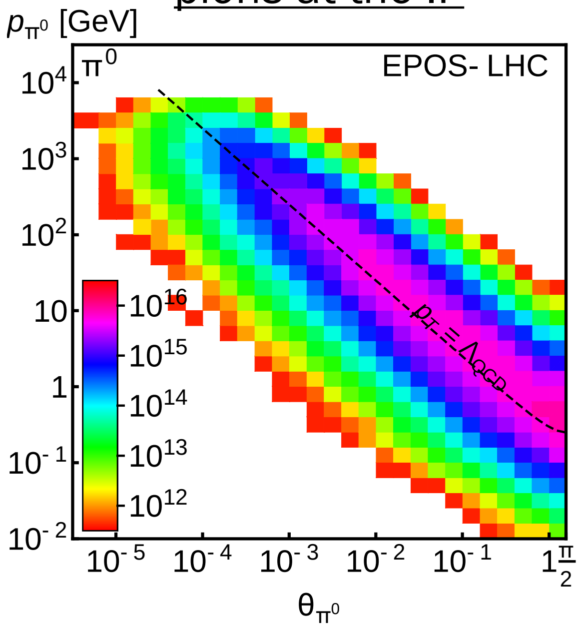


EPOS-LHC

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

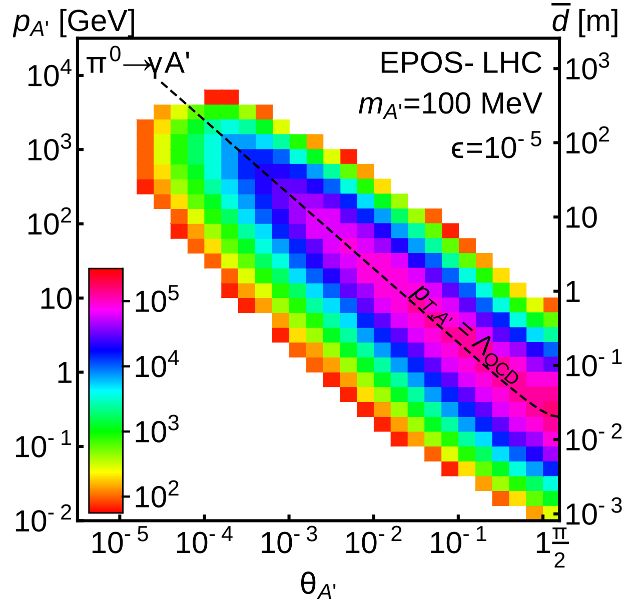
DARK PHOTONS AT FASER – KINEMATICS

pions at the IP



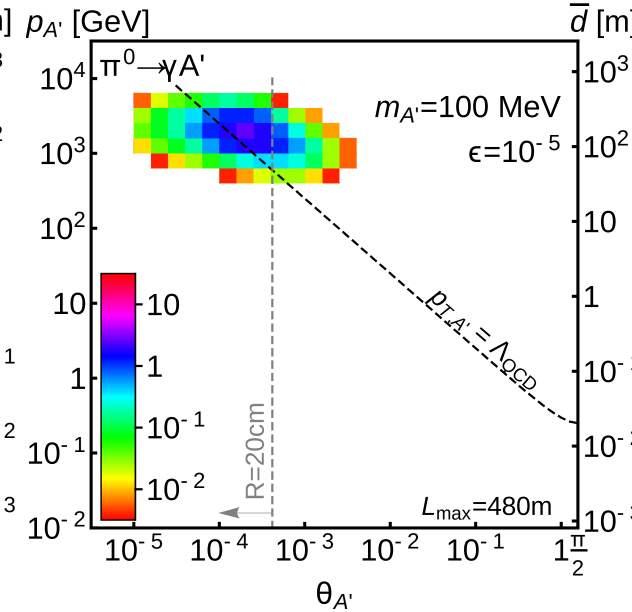
- Monte Carlo fitted to experimental data (LHCf, ALFA)
- typically $p_T \sim \Lambda_{QCD}$
- for E~TeV ⇨ p_T/E ~0.1 mrad
- even ~10^{15} pions per (θ,p) bin

A's at the IP



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

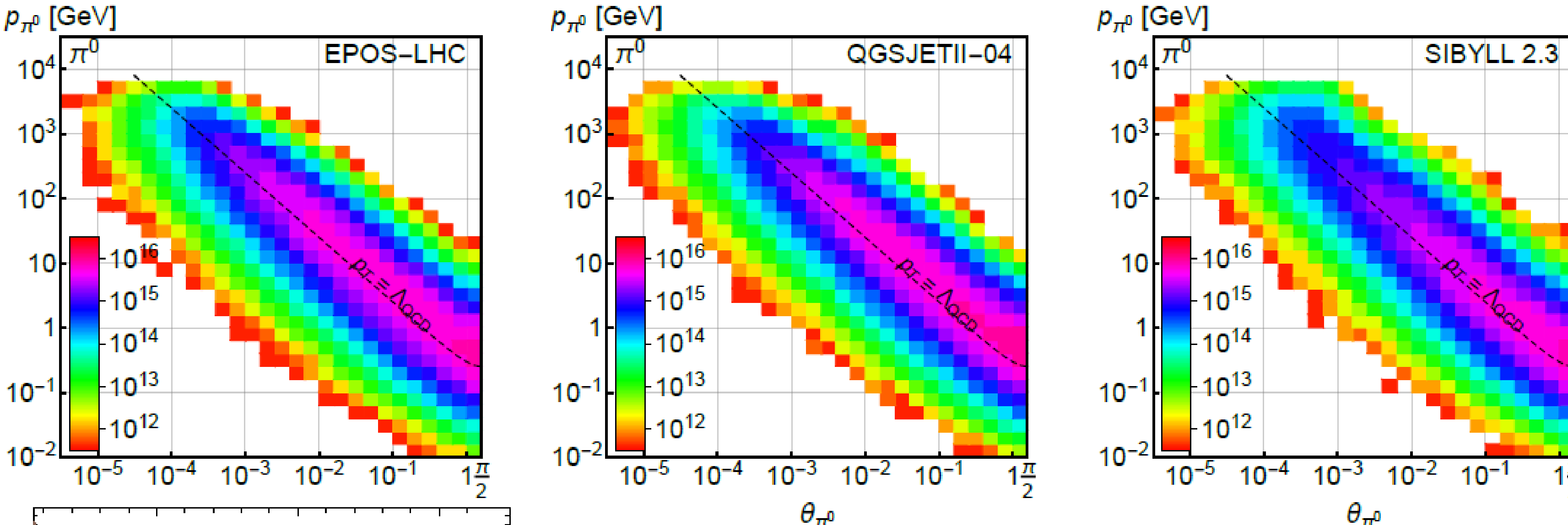
A's decaying in FASER

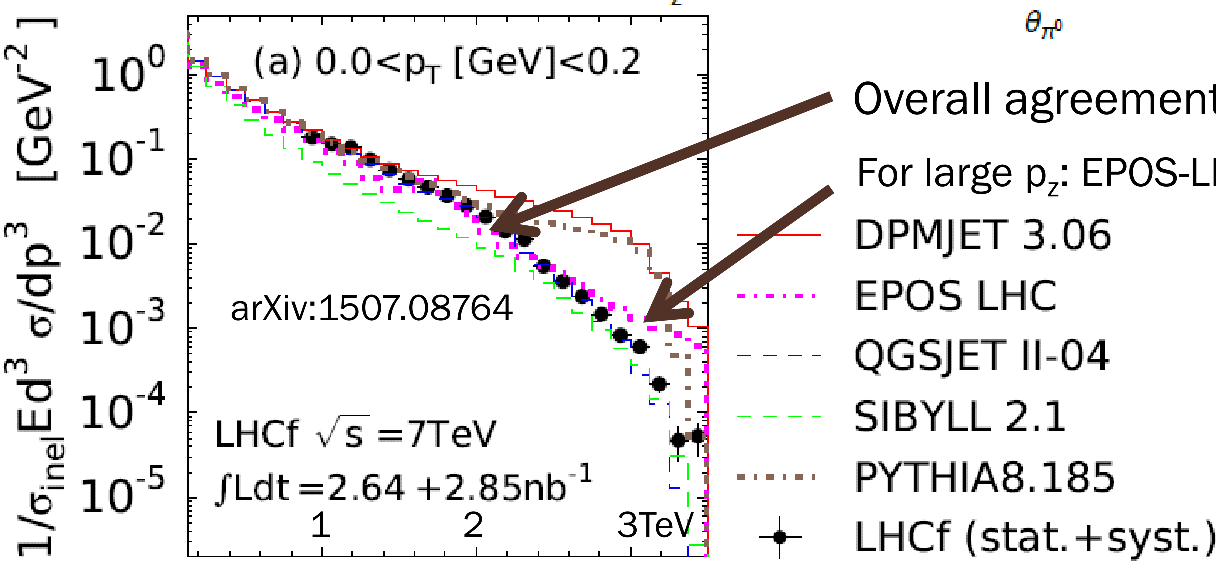


- only highly boosted A's survive until FASER
  $E_{A'}$ ~TeV
- further suppression from decay in volume probability
- still up to **$N_{A'}$ ~100 events** in FASER, mostly within **r<20cm**

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)

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:

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

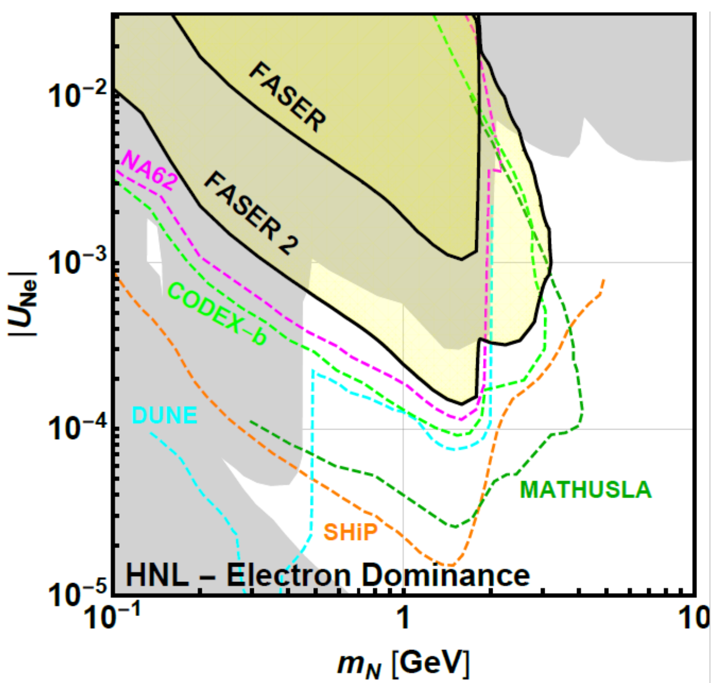
$\mathrm{BR}(N \to \nu\, l_1^+\, l_2^-) \sim 20\%$ ($\mathrm{BR}(N \to \nu\, e^+ e^-) \sim$ few percent)

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

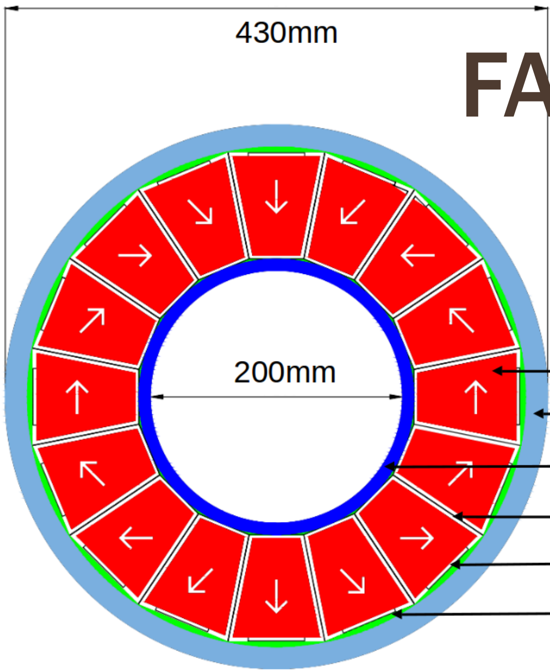
FASER 2

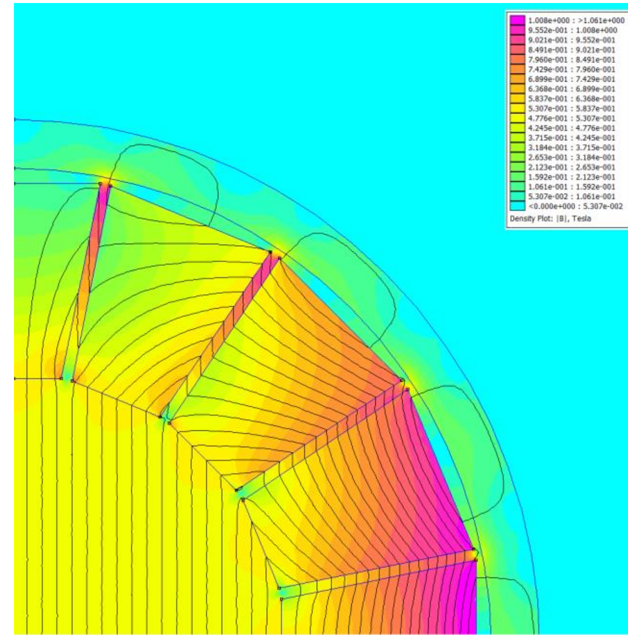
$\Rightarrow$ up to $\sim 10^3$ events for $m_N \gtrsim m_D$

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

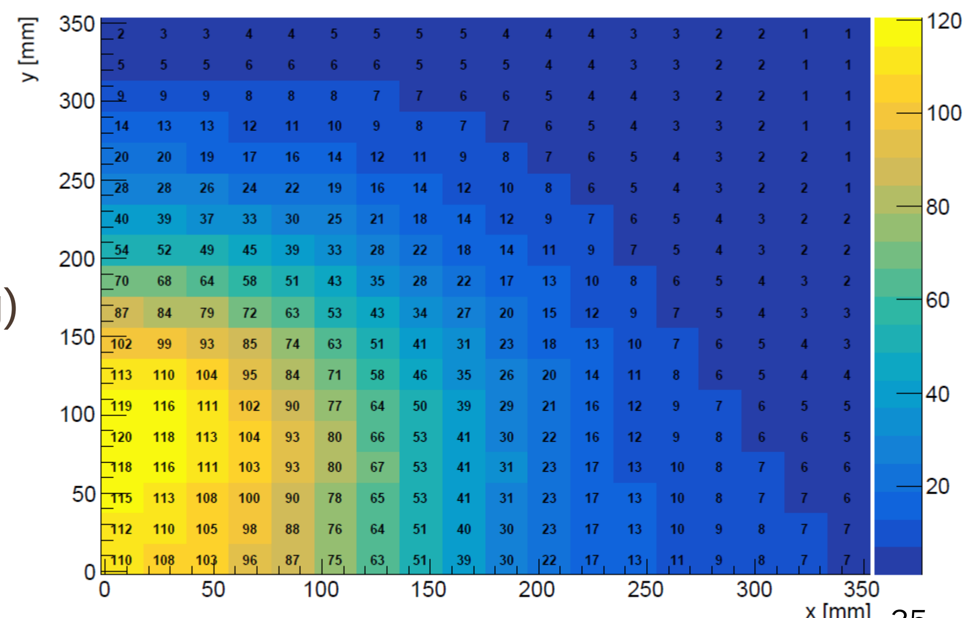


FASER MAGNET





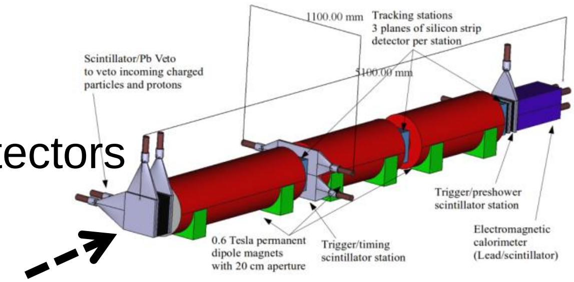
|B| [mT] at z=1100 mm



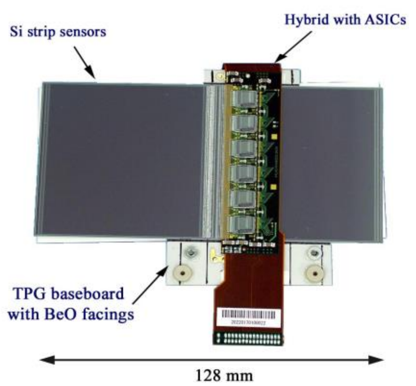
- 0.55T permanent dipole magnets based on the Halbach array design
  - LOS to pass through the magnet center
  - minimum digging to the floor in TI12
  - minimized needed services (power,cooling)

- manufacture: CERN magnet group
- stray field around scintillator PMTs ~5mT
  → shielding (mu-metal)

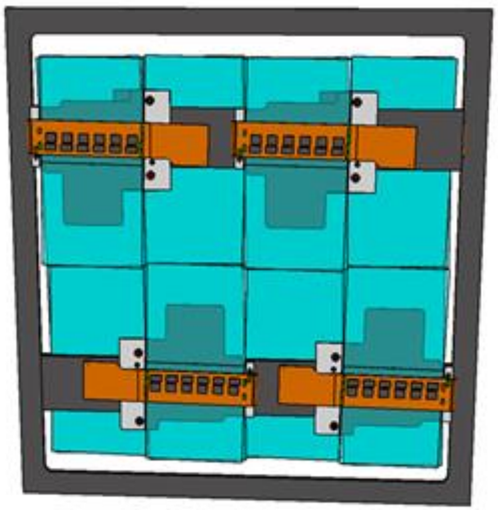
FASER TRACKING STATIONS



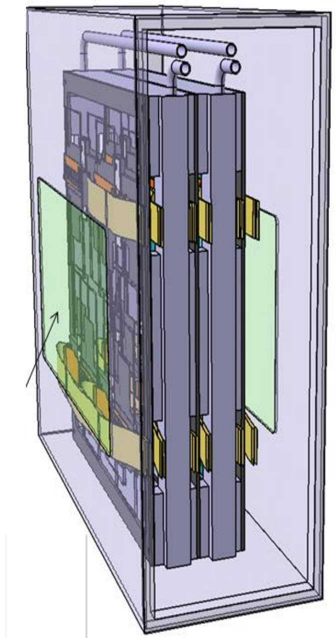
- The FASER Tracker will be made up of 3 tracking stations
- Each containing 3 layers of double sided silicon micro-strip detectors
- Spare ATLAS SCT modules will be used
  - 80μm strip pitch, 40mrad stereo angle
  - Many thanks to the ATLAS SCT collaboration!
- 72 SCT modules needed for the full tracker
- Due to the low radiation in TI12 the silicon can be operated at room temperature, but the detector needs to 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

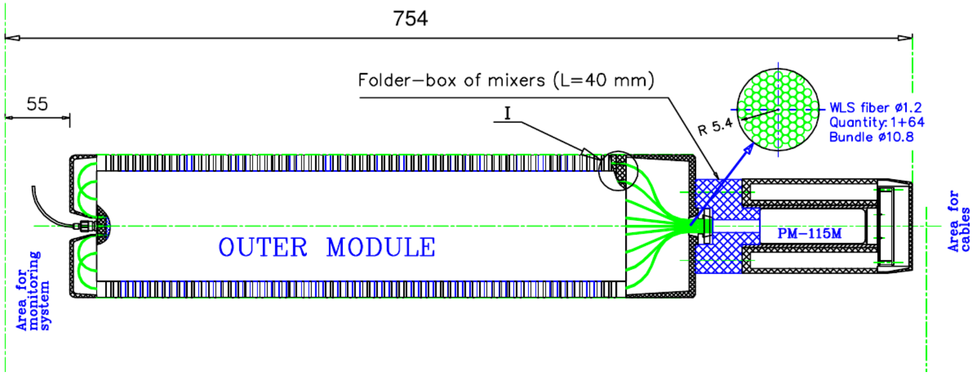


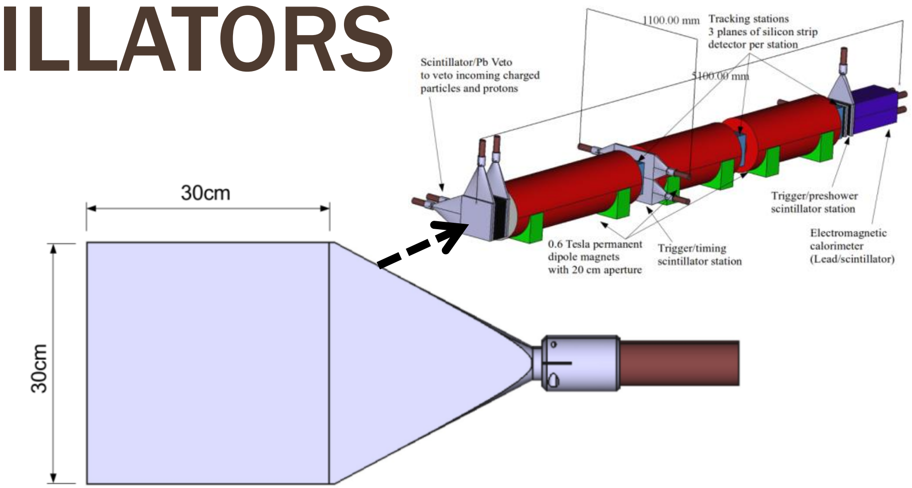
Tracking layer



Tracking station

CALORIMETER & SCINTILLATORS





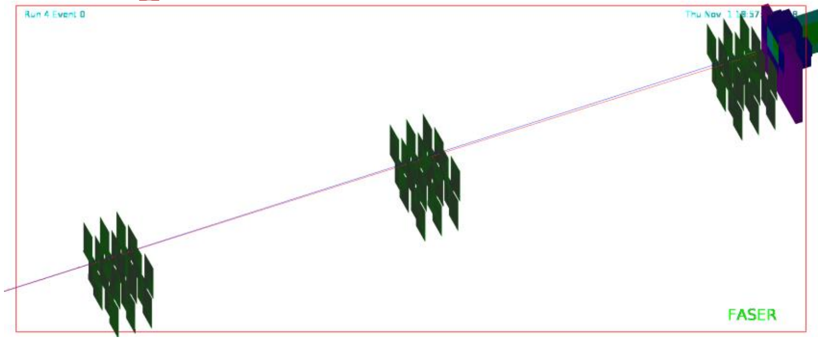
- FASER will have an ECAL:
  measuring the EM energy in the event (up to 1% accuracy in energy ~1 TeV)
- Will use 4 spare LHCb outer ECAL modules
  - Many thanks to LHCb Collaboration for allowing us to use these!
  - 66 layers of lead/scintillator (2mm lead, 4mm plastic scintillator)
    - 25 radiation lengths long
    - no longitudinal shower information
    - Resolution will degrade at higher energy due to not containing full shower in calorimeter
- Scintillators used for vetoing charged particles entering the decay volume, for triggering and as a preshower
  - To be produced at CERN scintillator lab
  - Vetoing: achievable extremely efficient charged particle veto (eff>99.99%)
  - Trigger: also timing the signal with respect to timing of the pp interactions
  - Preshower: thin radiator in front, photon showering (disentangling from ν interactions in ECAL)

SIGNAL DETECTION

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

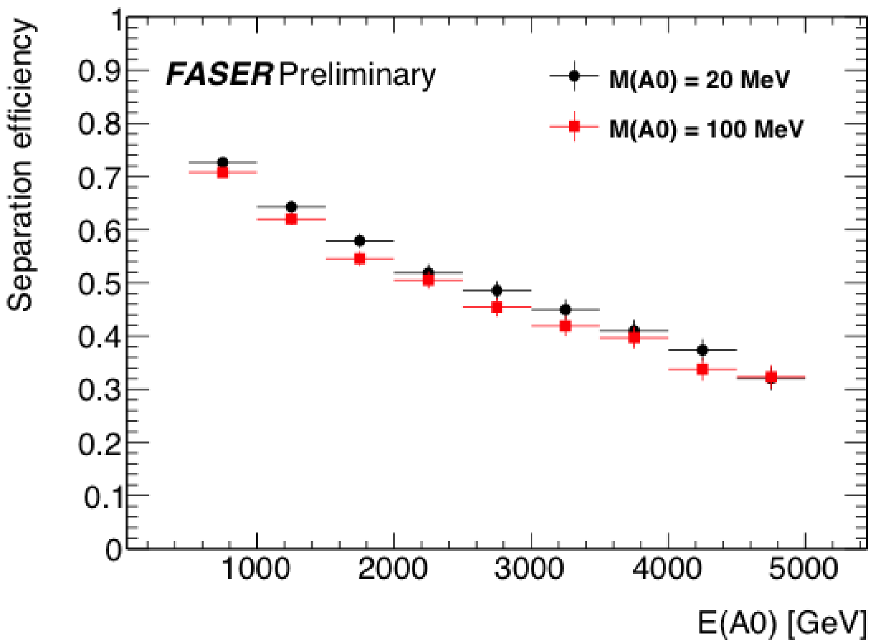
In the following we assume 100% detection efficiency for a better comparison with other experiments

Ongoing work on full detector simulations

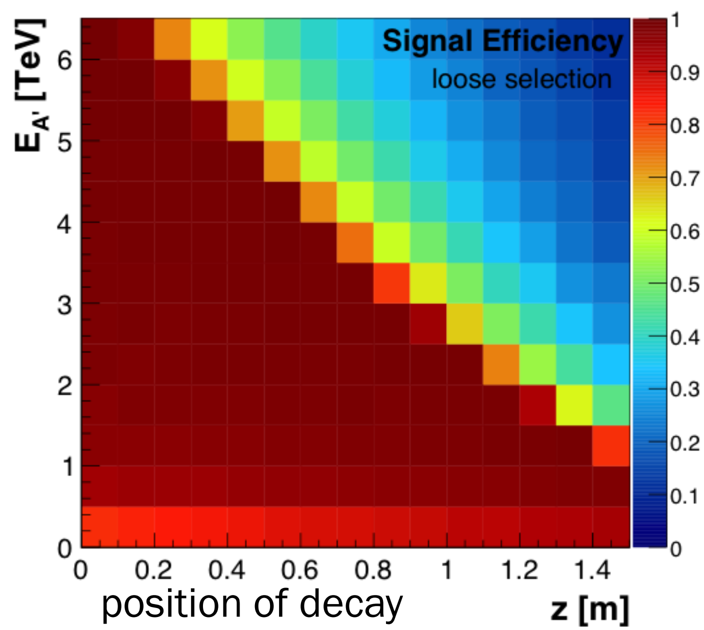


CHARGED TRACK SEPARATION EFFICIENCY

1st tracking station

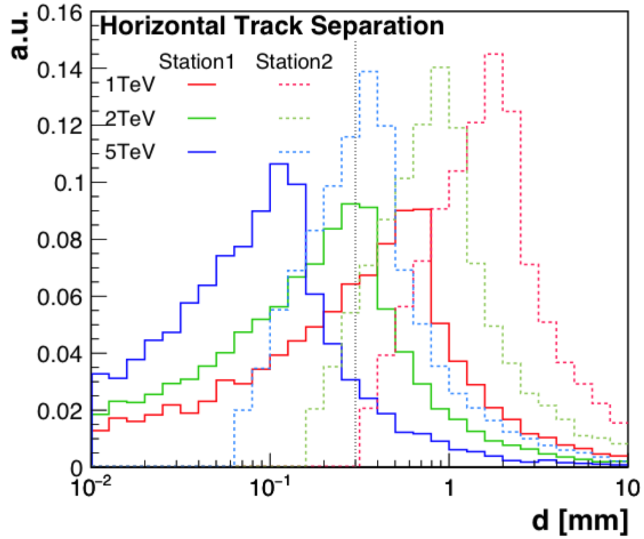


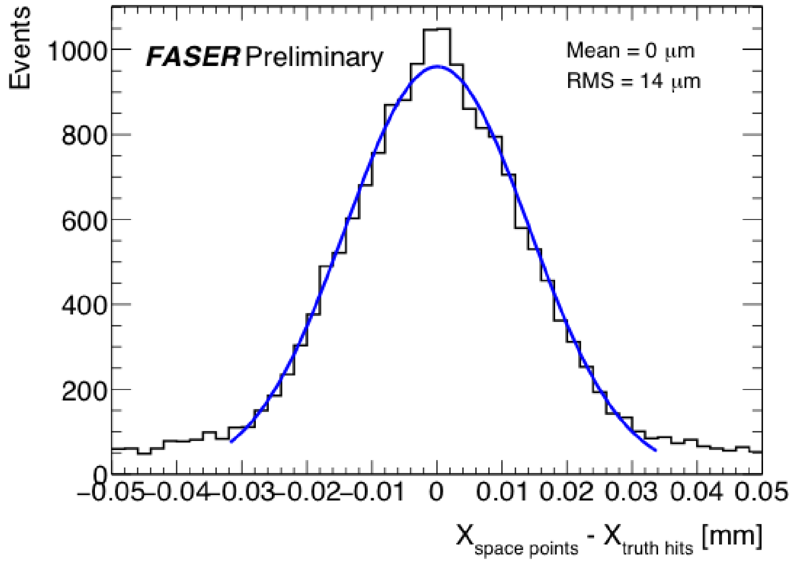
2nd/3rd tracking station (separation > 0.3mm)

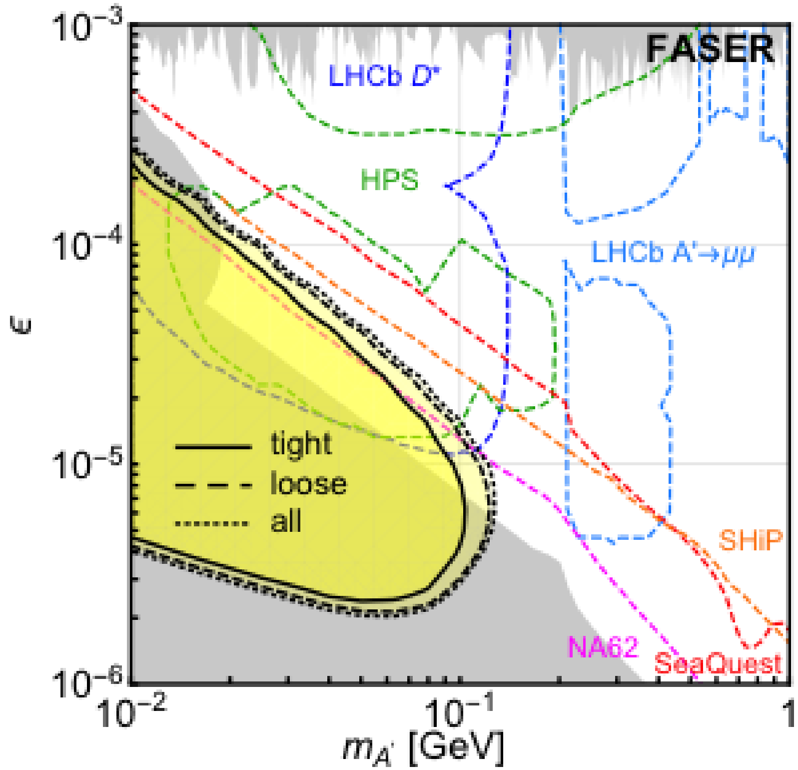


MORE ABOUT TRACK SEPARATION

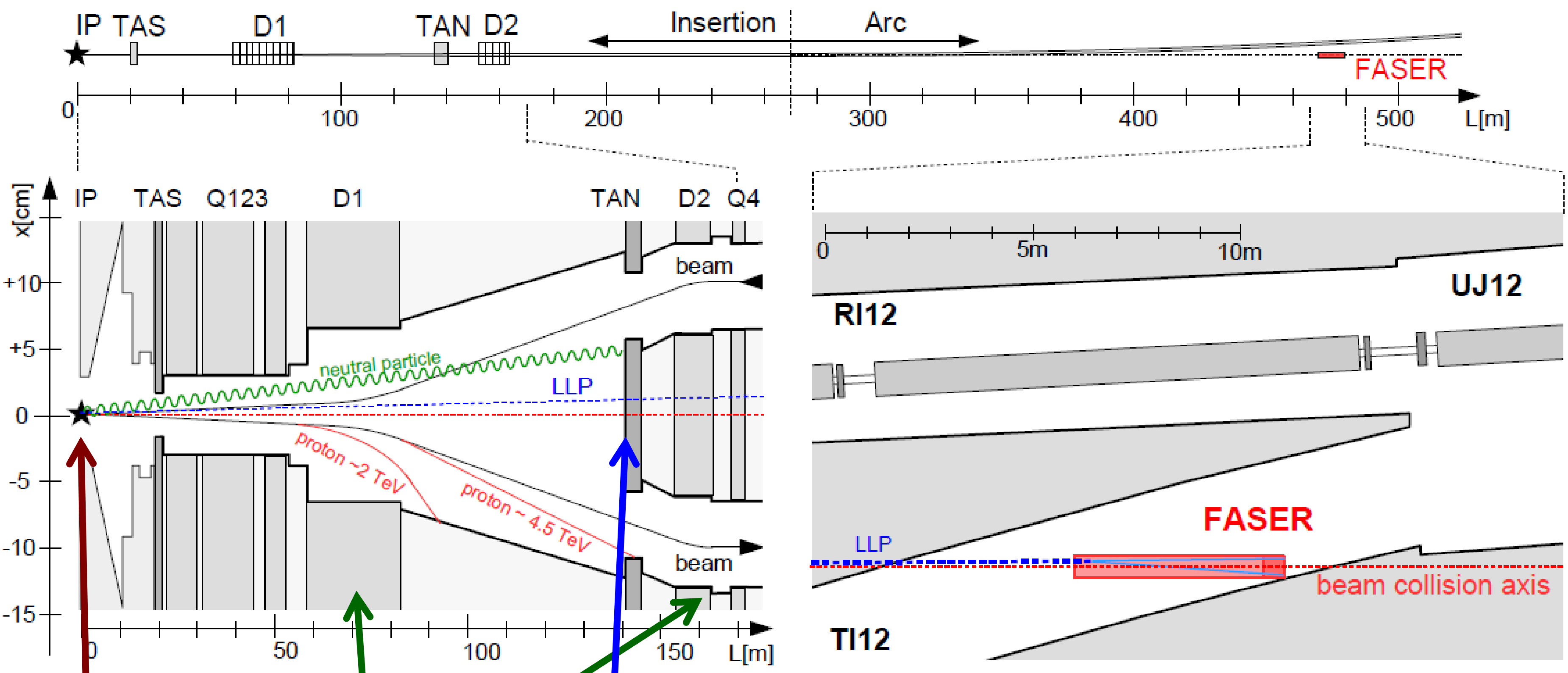
GEANT 4







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

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 [fb cm^{-2}]	normalized flux, main peak [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