FASER
FORWARD SEARCH EXPERIMENT AT THE LHC

Physics Beyond Colliders Working Group Meeting

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

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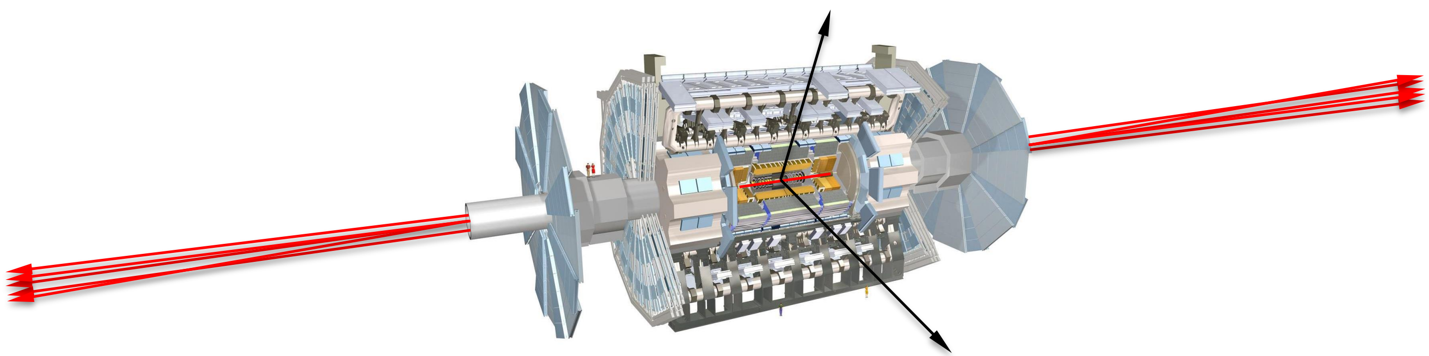
FASER

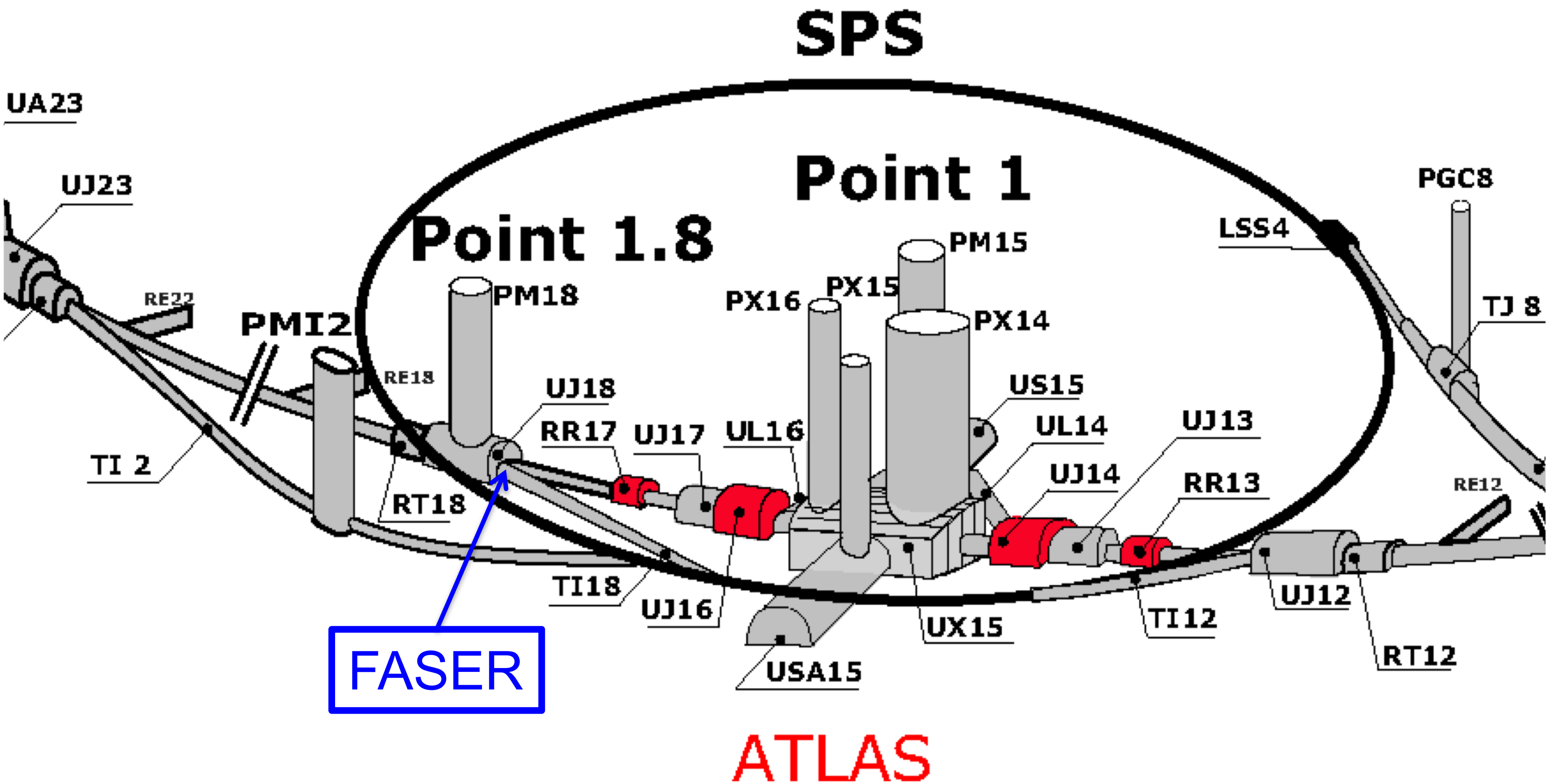
- New physics searches at the LHC have traditionally focused on high p_T. This is appropriate for heavy and strongly-interacting particles.
  - σ ~ fb to pb → N ~ $10^3 – 10^6$ in 3 ab^{-1}, produced ~isotropically

- However, if new particles are light and weakly-interacting, this may be completely misguided. Such particles may be produced, e.g., in π, K, B decays, so we should go where these particles are: low p_T .
  - σ_{inel} ~ 100 mb → N_π ~ 10^{17} in 3 ab^{-1}, $\theta \sim m_\pi$ / TeV ~ 0.1 mrad



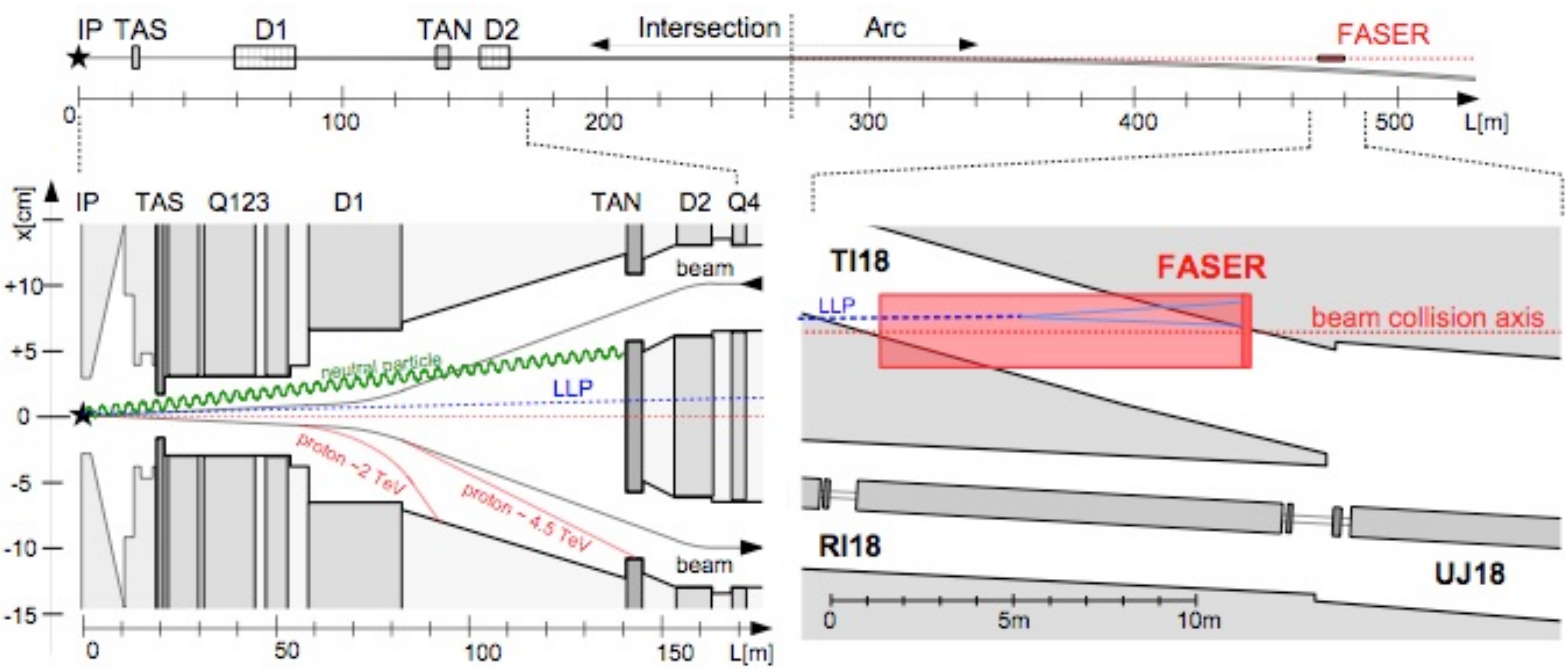
- These light, weakly-interacting particles are long-lived and collimated. This motivates a small (~1 m^3) and inexpensive experiment placed in the very forward region of ATLAS/CMS, a few 100 m downstream.

FASER LOCATION



LONG LIVED PARTICLES IN FASER

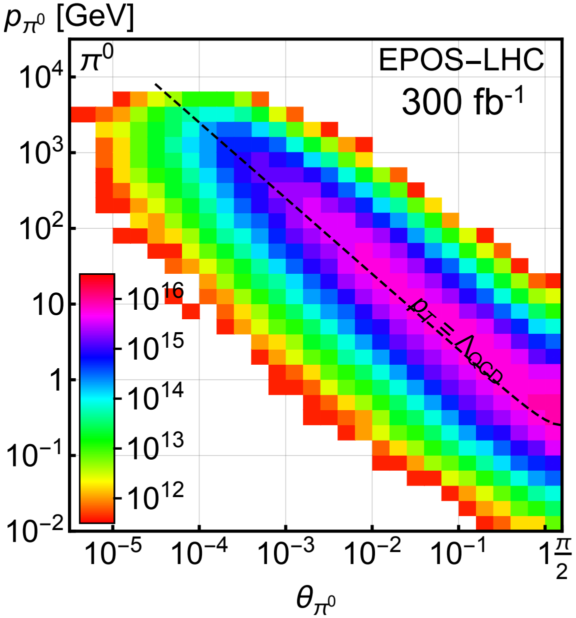
- LLP starts at IP, travels through TAN and other very forward infrastructure, then leaves the LHC tunnel, travels through 90m of rock, and decays to two highly energetic (~TeV) charged tracks in FASER.



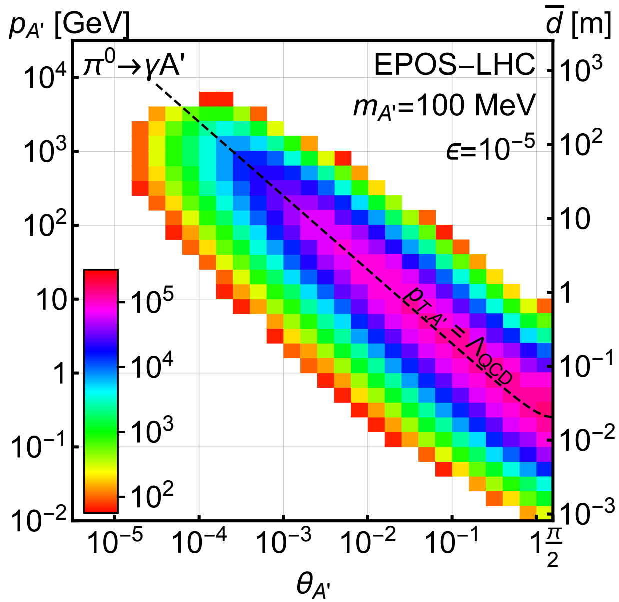
- FASER will be placed on the beam collision axis ("on-axis"); if the beam crossing angle = 300 μrad, the on-axis location at FASER shifts by 7 cm.

AN EXAMPLE: DARK PHOTONS AT FASER

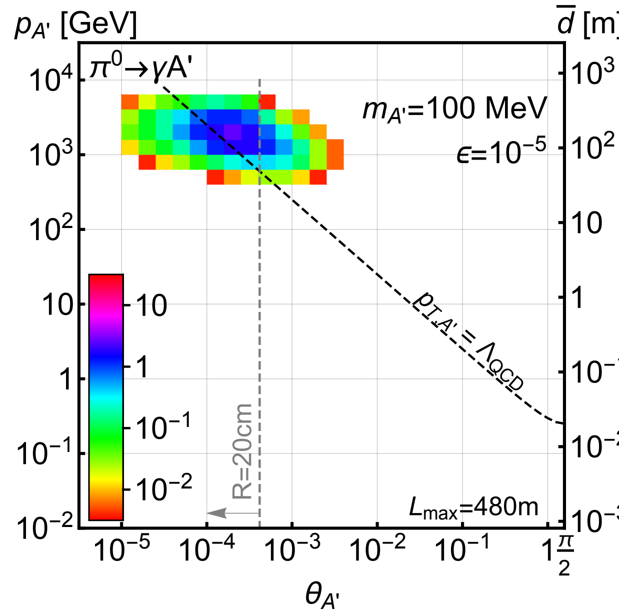
Pions at the IP



A's at the IP



A's decay in [480m, 483m]

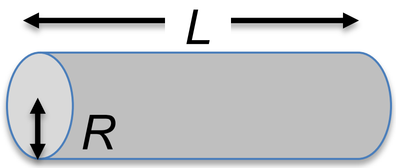


- Simulations greatly refined by LHC data
- Production is peaked at $p_T \sim \Lambda_{QCD} \sim 250$ MeV
- Enormous event rates: $N_\pi \sim 10^{15}$ per bin

- Production is peaked at $p_T \sim \Lambda_{QCD} \sim 250$ MeV
- Rates highly suppressed by $\varepsilon^2 \sim 10^{-10}$
- But still $N_{A'} \sim 10^5$ per bin

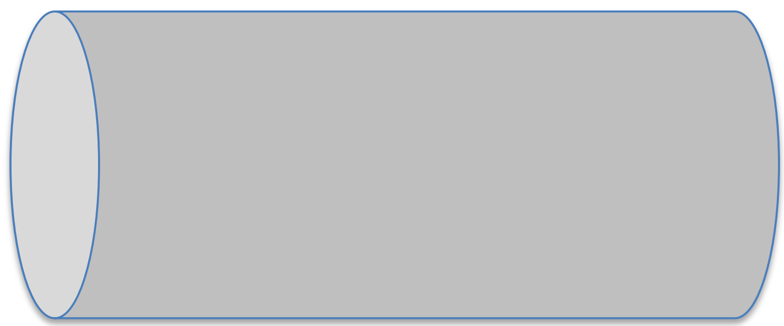
- Only highly boosted ~TeV A's decay in FASER
- Rates again suppressed by decay requirement
- But still $N_{A'} \sim 100$ signal events, and almost all are within 20 cm of "on axis"

FASER SENSITIVITY REACHES



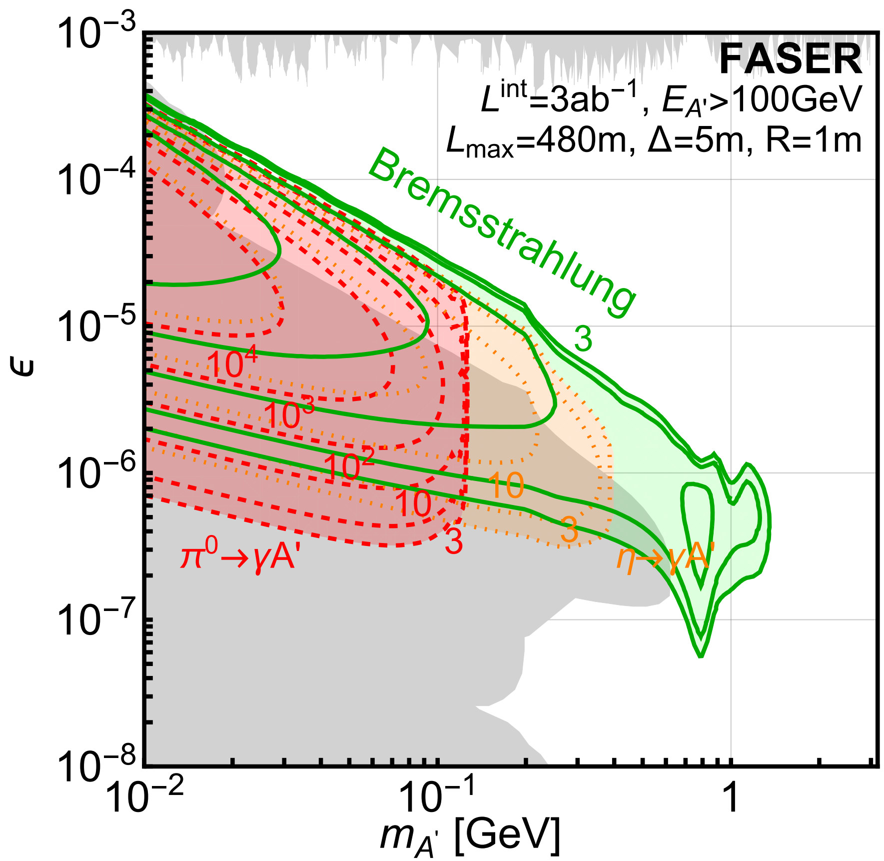
- Present results for 2 simple cases
- FASER 1: L = 3 m, R = 10 cm, V = 0.1 m^3, 150 fb^{-1} (Run 3)

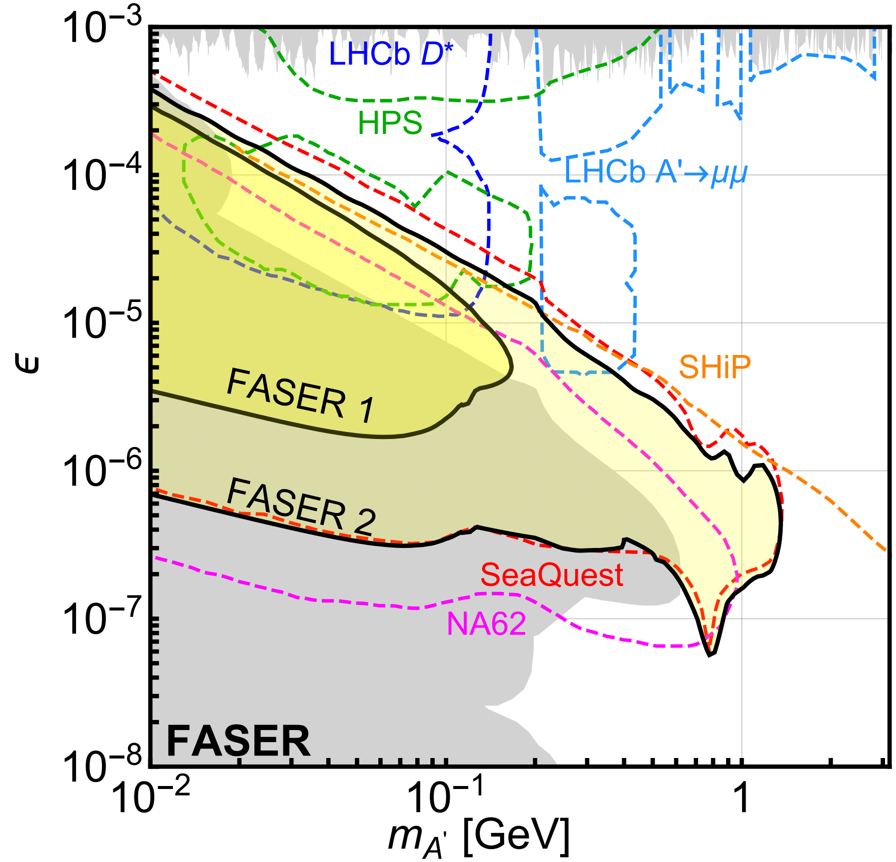
- FASER 2: L = 5 m, R = 1 m, V = 16 m^3, 3 ab^{-1} (HL-LHC)



- Larger and smaller detectors are certainly possible, but these give a feel for the range of sizes and their implications for physics reach.
- Below, FASER contours are updated for PBC; other experiments' contours are their full reaches from the literature.

BC1: DARK PHOTON SENSITIVITY REACH



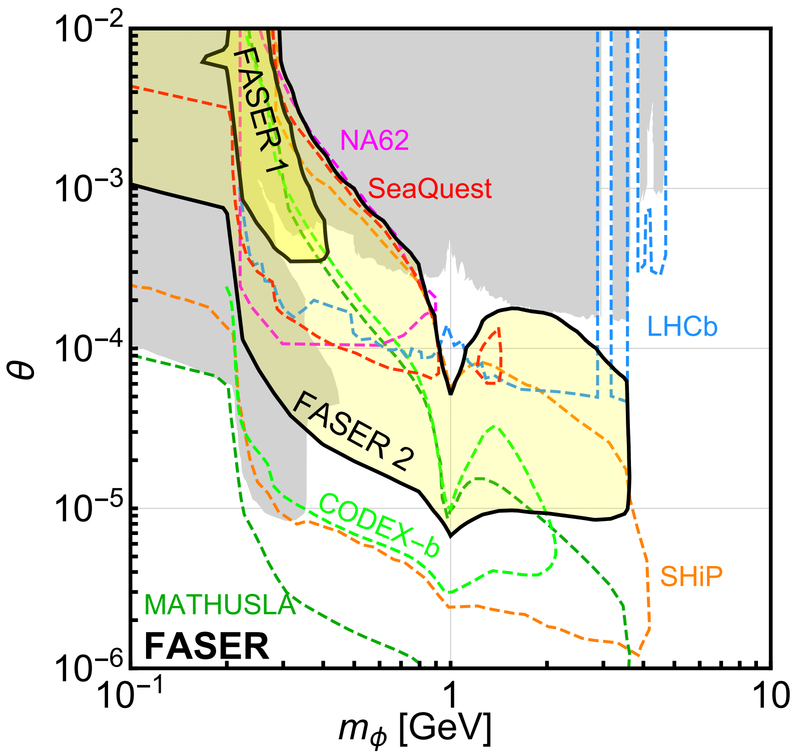


- For low ε, FASER is not competitive with SHiP.

- For high ε, FASER may have world-leading sensitivity. Note: contours are very closely spaced: ~50% signal efficiency, N=3 vs.10, e^+e^- vs. e^+e^- + $\mu^+\mu^-$, L=3m vs. 5m, … each lead to nearly imperceptible shifts in reach.

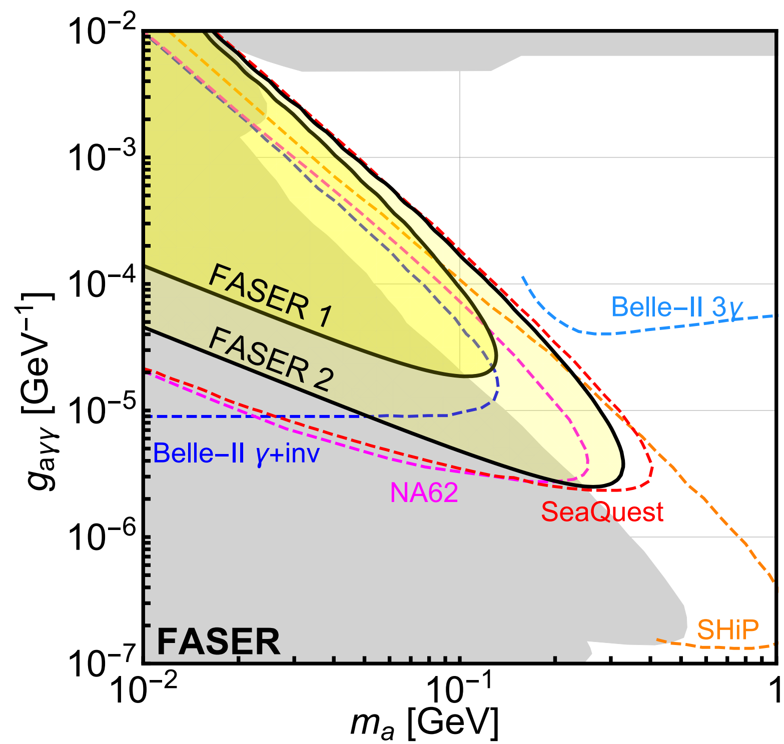
SENSITIVITY REACH FOR OTHER MODELS

- **BC4: DARK HIGGS BOSON**



- Dark Higgs produced in B decays. $N_B/N_\pi \sim 10^{-2}$ at FASER ($N_B/N_\pi \sim 10^{-7}$ at beam dumps)
- Reach is complementary to other proposed experiments

- **BC9: ALP WITH PHOTON**



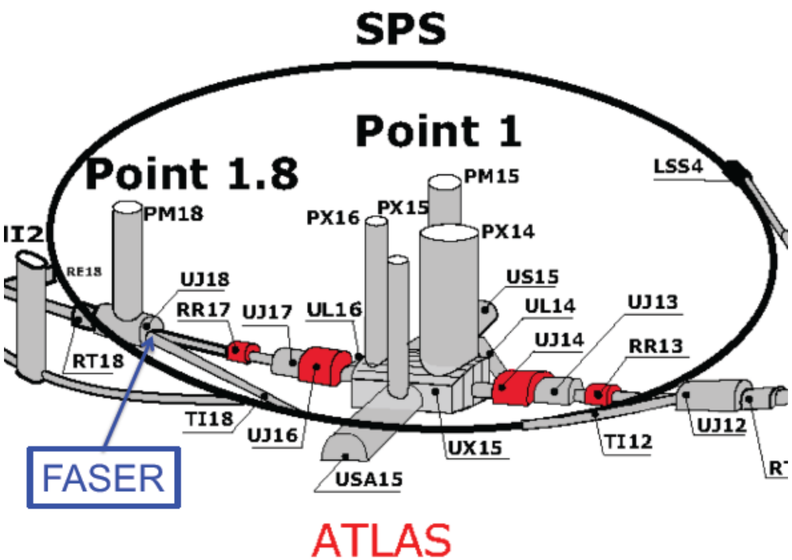
- ~TeV photon from IP collides with TA(X)N, creates ALP through Primakoff, and a → γγ in FASER
- Requires calorimeter

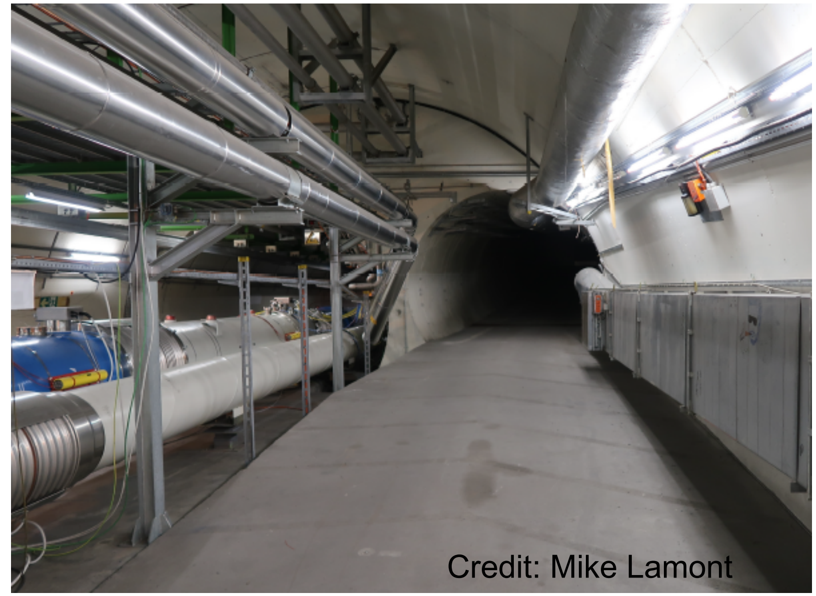
PBC BENCHMARK SUMMARY

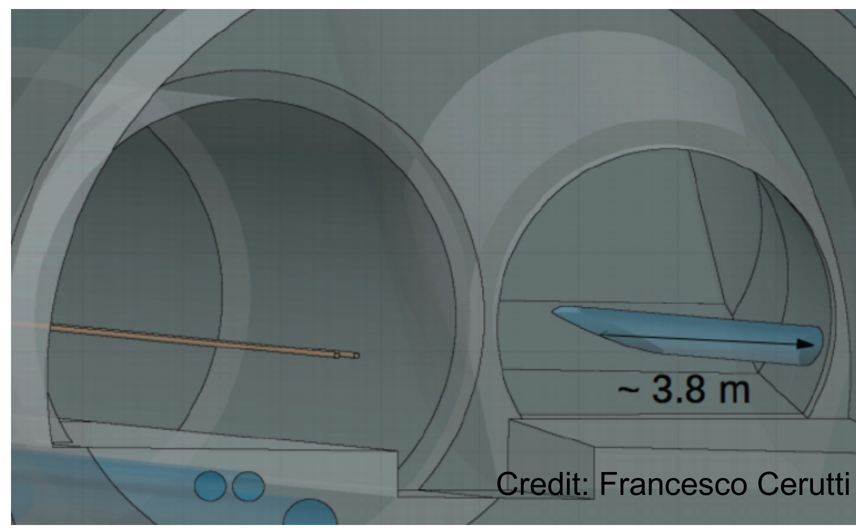
- FASER has a full physics program: can discover all candidates with renormalizable couplings (dark photon, dark Higgs, HNL); ALPs with all types of couplings (γ, f, g); and examples that are not PBC benchmarks.

Benchmark Model	FASER 1	FASER 2	References
BC1: Dark Photon	√	√	Feng, Galon, Kling, Trojanowski, 1708.09389
BC1': $U(1)_{B-L}$ Gauge Boson	√	√	Bauer, Foldenauer, Jaeckel, 1803.05466; PBC
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	√ (cal)	√ (cal)	Feng, Galon, Kling, Trojanowski, 1806.02348
BC10: ALP with fermion	√	√	PBC
BC11: ALP with gluon	[√]	[√]	[PBC]

FASER LOCATION





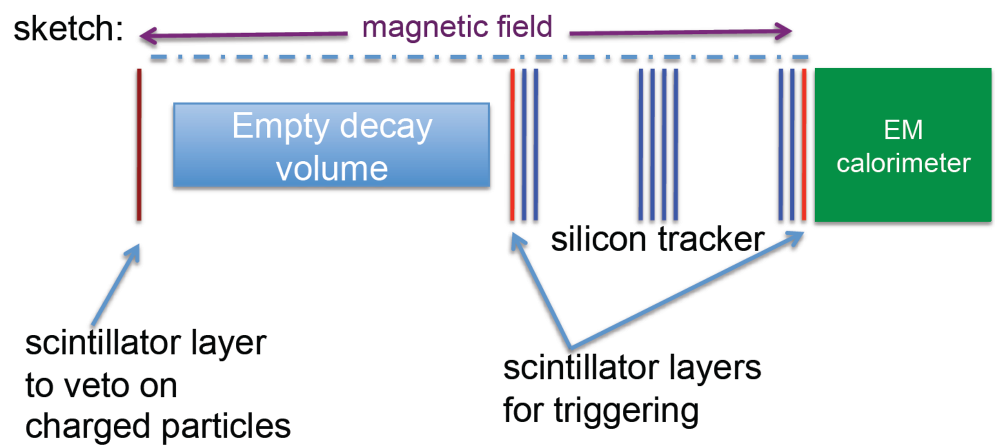


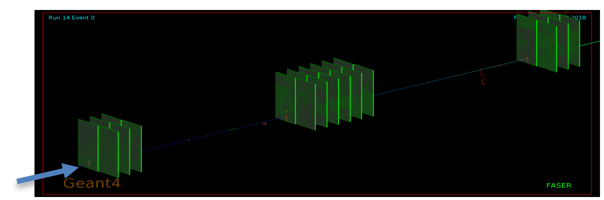
DETECTOR LAYOUT

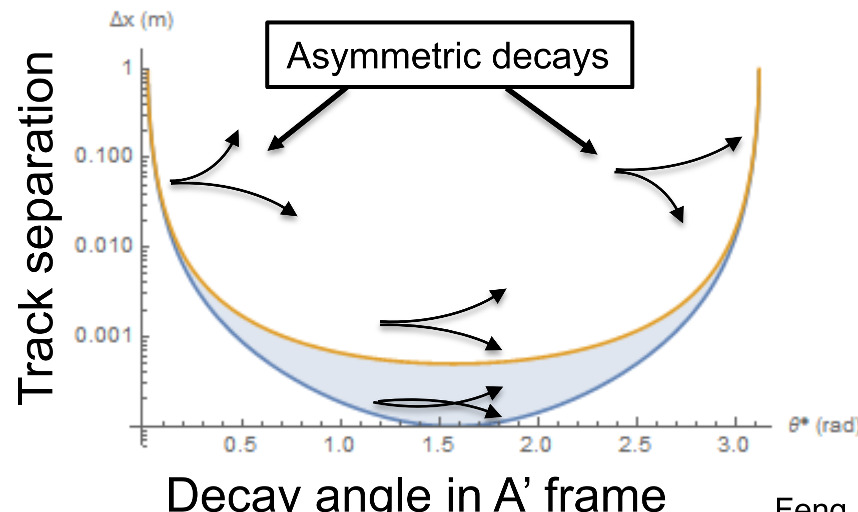
- Currently being optimized with Geant4 study: length of decay volume vs. length of tracker volume, number and placement of tracking layers, strength and region of magnetic field.

- E.g., 1 TeV A' → e^+e^- : even a 0.5 T magnetic field over 1m is sufficient to separate ~50% of the charged tracks by > 1 mm, and some much more (asymmetric decays).

- Considering permanent dipole magnetic (no services).

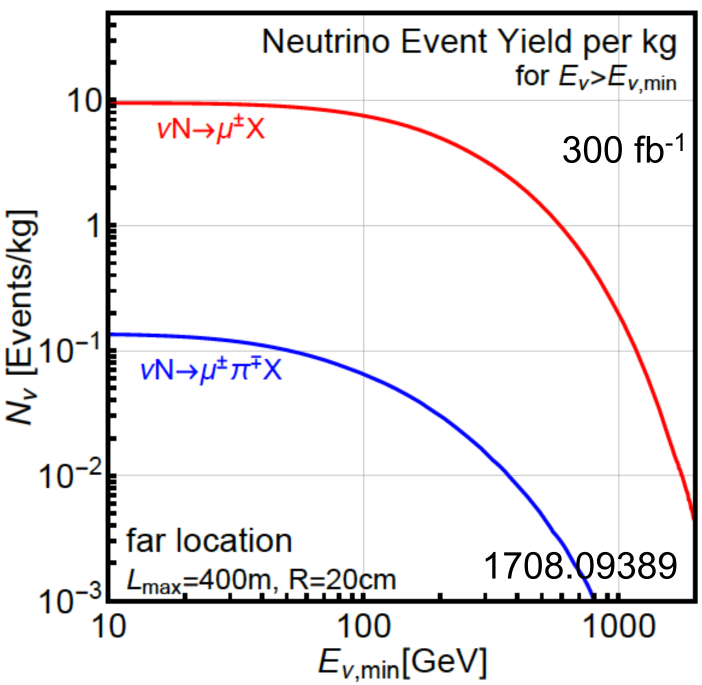






BACKGROUNDS

- The signal is striking: two opposite-sign, high energy (E > 500 GeV) charged particles that originate from a common vertex in a small, empty decay volume, point back to the IP through 90 m of rock, and are consistent with bunch crossing timing.
- Of course, neutrinos and muons get through, but the resulting backgrounds appear to be negligible.



	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	$\sim10^{-7}$	$\sim10^{-14}$	0	0	0	0
γ	$\sim10^{-4}$	$\sim10^{-12}$	$\sim10^{-6}$	$\sim10^{-13}$	$\sim10^{-6}$	$\sim10^{-13}$
π	$\sim10^{-5}$	$\sim10^{-12}$	$\sim10^{-7}$	$\sim10^{-14}$	0	0

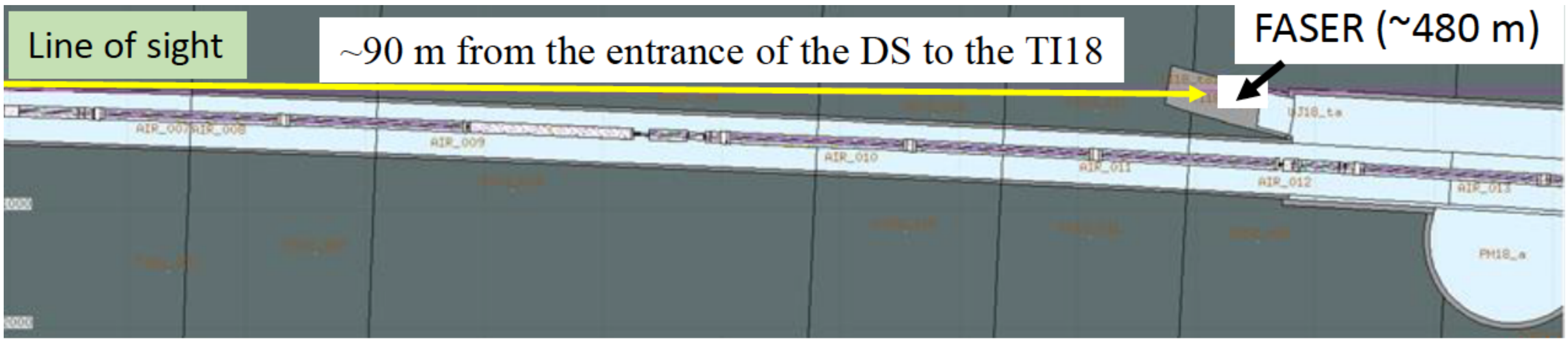
- HL-LHC conditions:
  - Luminosity: $5\cdot10^{34}$ ($cm^{-2}\ s^{-1}$)
  - Cross section p-p collision: 85 mb
  - Pile-up: 140 (events/bunch crossing)

5-10% uncertainty

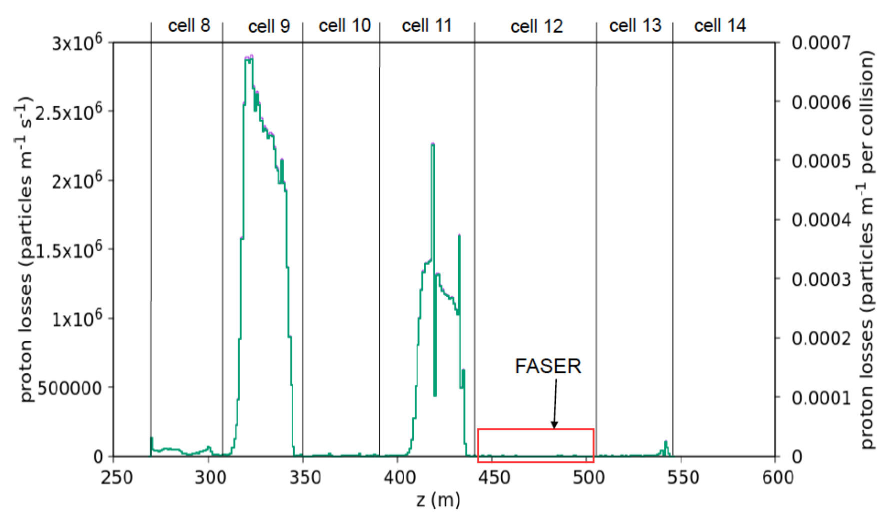
FLUKA study: Marta Sabate-Gilarte, Francesco Cerutti, Andrea Tsinganis

MORE BACKGROUNDS

- Recent FLUKA study finds that proton showers in dispersion suppressor and beam-gas background (from “beam 2”) are also negligible.



Proton-loss map in the DS

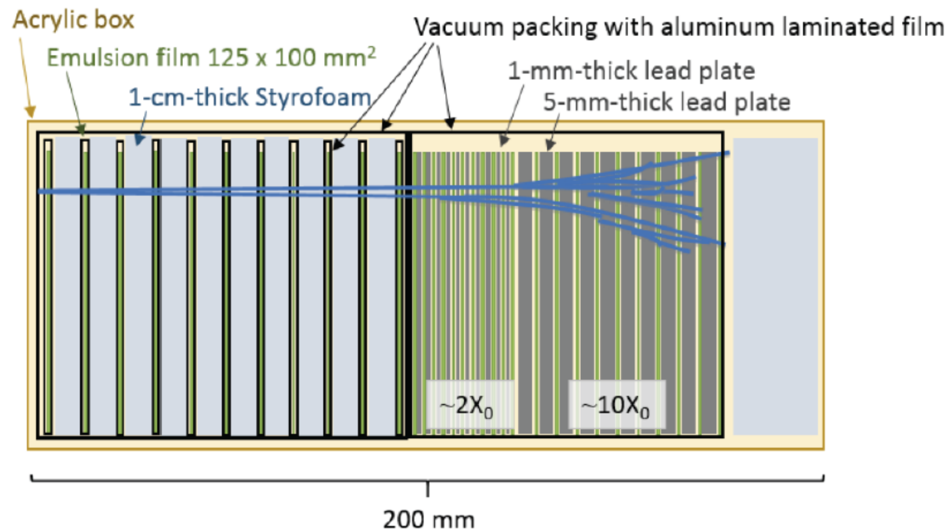


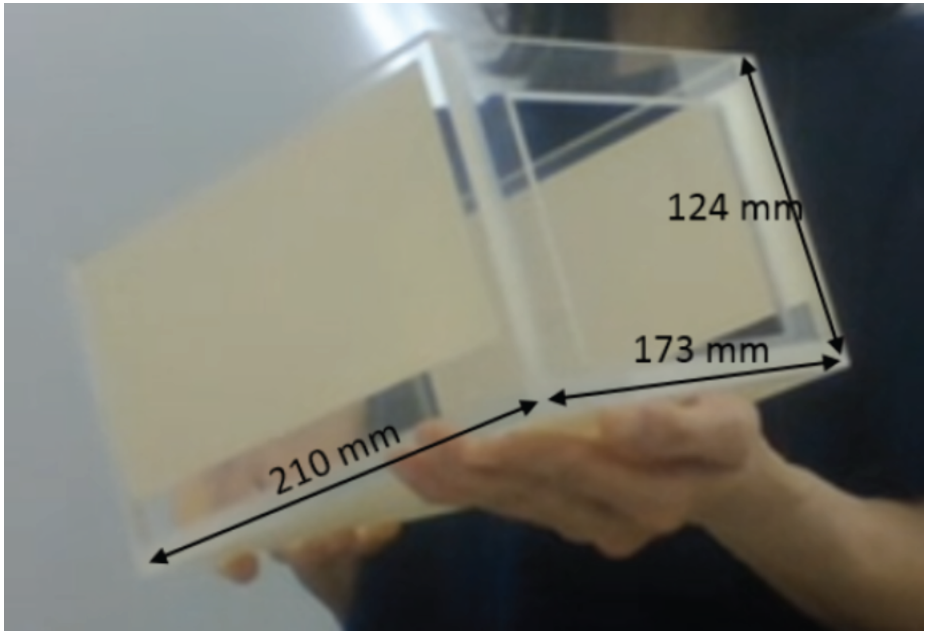
- The dispersion of the machine means activity close to FASER from diffractive proton losses is very small. It would be orders of magnitude higher 50m along LHC in either direction. The radiation level in TI18 is low ($<10^{-2}$ Gy/year), which is encouraging for detector electronics.

Marta Sabate-Gilarte, Francesco Cerutti, Andrea Tsinganis

IN SITU MEASUREMENTS

- In Technical Shutdown 1 (TS1, next week), we will begin the first in situ measurements at the FASER site.
- CERN survey team will map out and mark the "on-axis" line in TI18 to ~mm accuracy.
- An emulsion detector has been prepared and will be placed at the FASER location in TS1, removed in TS2 (or before).
- A BatMon (battery-operated radiation monitor) will also be installed.





SUMMARY AND TIMELINE

- FASER is an opportunity for a small and inexpensive experiment to search for a full range of light and weakly-interacting particles, complementing other experiments. FASER collects data when ATLAS collects data, but is independent (requires only bunch crossing timing).
- TS1 (next week): installation of BatMon, emulsion detector for validation of FLUKA study, first in-situ measurements.
- Currently pursuing funding options and seeking CERN approval. If successful, a possible timeline and plan is

  Install FASER 1 in LS2 (2019-20) for Run 3 (150 fb^{-1})
  - R = 10 cm, L = 3 m, requires lowering floor by 50cm in existing tunnel
  - Target dark photons, B-L gauge bosons, ALPs, etc.

  Install FASER 2 in LS3 (2023-25) for HL-LHC (3 ab^{-1})
  - R = 1 m, L = 5 m, requires some extension of existing tunnel
  - Full physics program: dark photons, B-L, ALPs, dark Higgs, HNLs, etc.

BACKUP

FASER GROUP

Contact

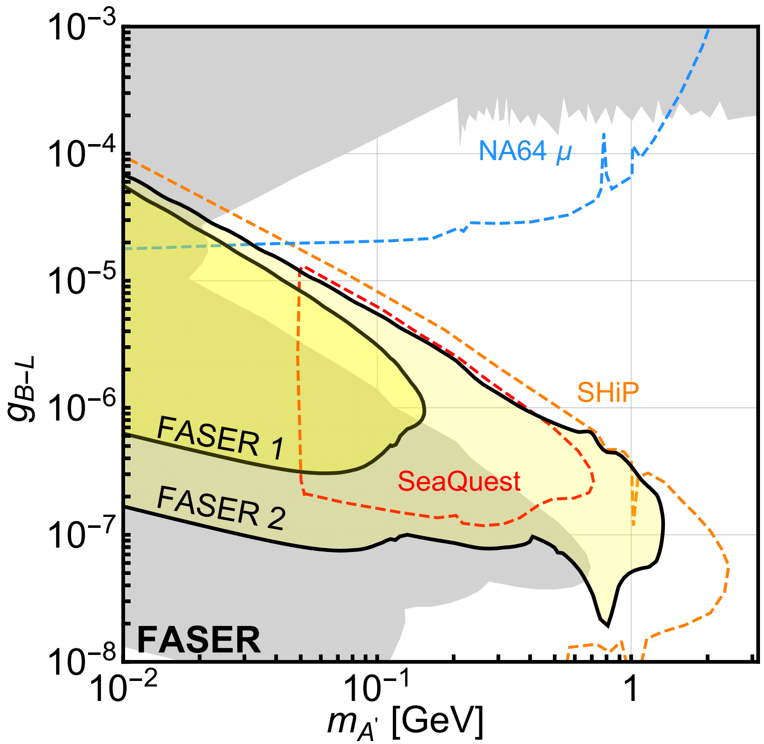
FASER e-group is: faser-all@cern.ch Active members:

- Jonathan Feng (UCI, theorist) (contact with PBC BSM group)
- Iftah Galon (Rutgers, theorist)
- Sebastian Trojanowski (UCI, theorist)
- Felix Kling (UCI, theorist)
- Dave Casper (UCI, experimentalist)
- Jamie Boyd (CERN, experimentalist) (contact with PBC accelerator group)
- Brian Petersen (CERN, experimentalist)
- Shih-Chieh Hsu (Washington, experimentalist)
- Hidetoshi Otono (Kyushu, experimentalist)
- Aaron Soffa (UCI, experimentalist)
- Akitaka Ariga (Bern, experimentalist)
- Tomoko Ariga (Kyushu/Bern, experimentalist)
- Osamu Sato (Nagoya, experimentalist)

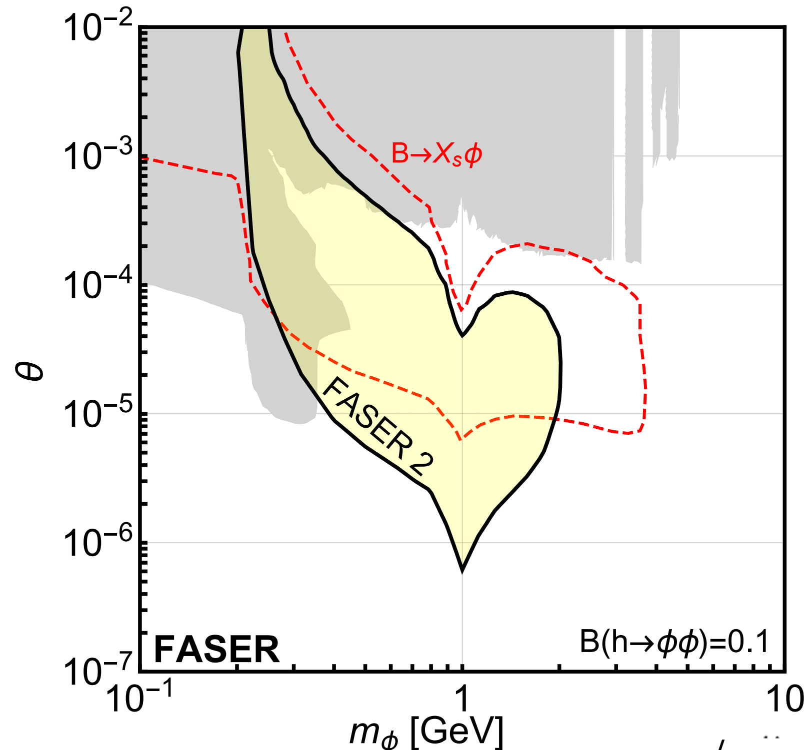
More info: https://twiki.cern.ch/twiki/bin/viewauth/FASER/WebHome

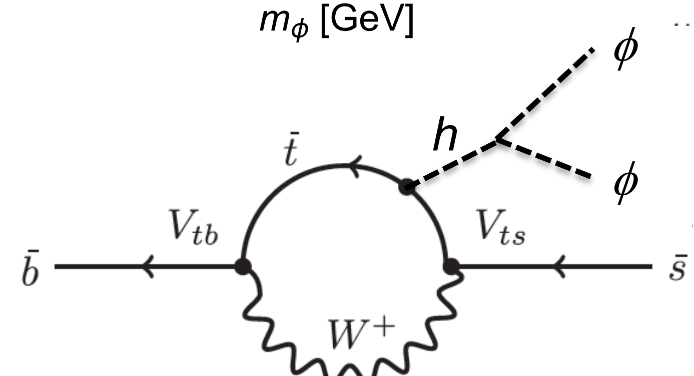
SENSITIVITY REACH FOR OTHER MODELS

- **BC1*: $U(1)_{B-L}$ GAUGE BOSON**



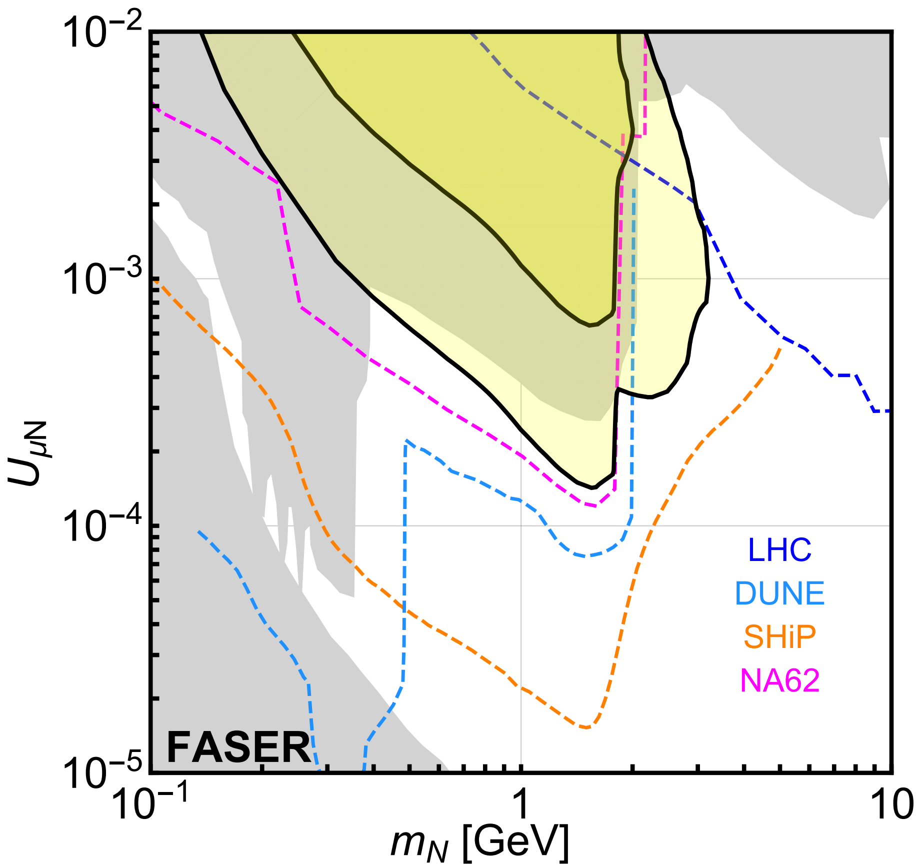
- **BC5: DARK HIGGS WITH hSS**



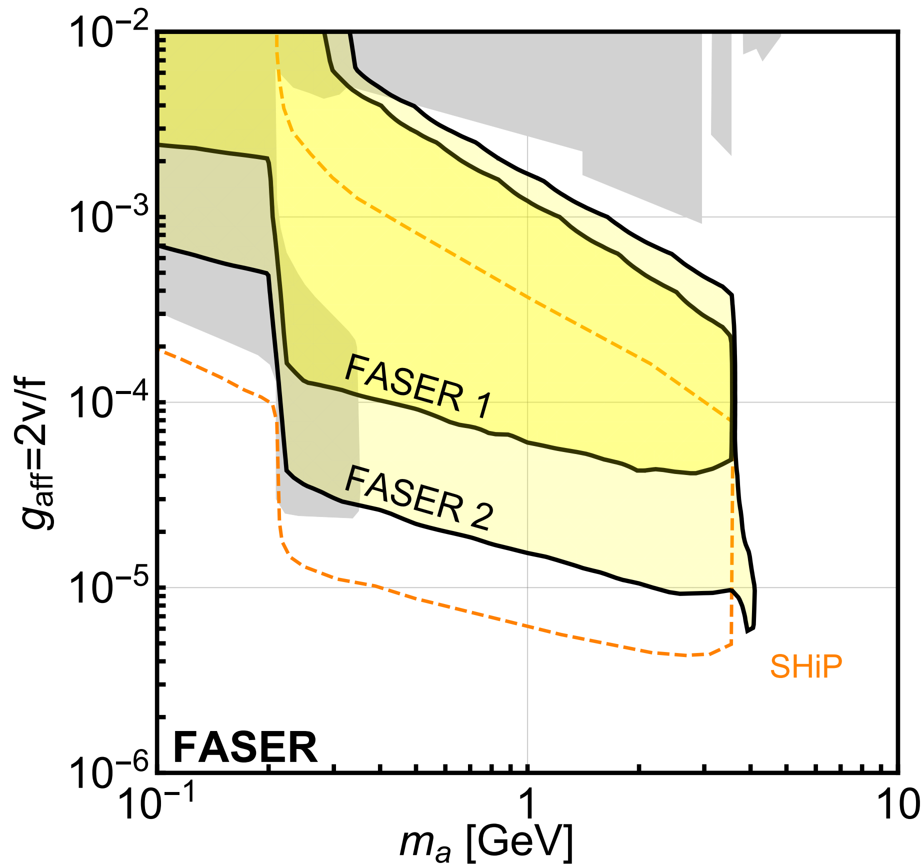


SENSITIVITY REACH FOR OTHER MODELS

- **BC6/7/8: HNL WITH e/μ/τ**



- **BC10: ALP WITH FERMIONS**



- $p_T \sim m_D, m_B$
- Reach similar for all 3 scenarios