LHCP2021

The Ninth Annual Conference on Large Hadron Collider Physics

ONLINE

7-12 June 2021 Paris (France), Sorbonne Université (IN2P3/CNRS,IRFU/CEA)

Searches for Long-lived Particles & Neutrinos with New detectors at the LHC

FASER(ν), SND@LHC, MoEDAL-MAPP

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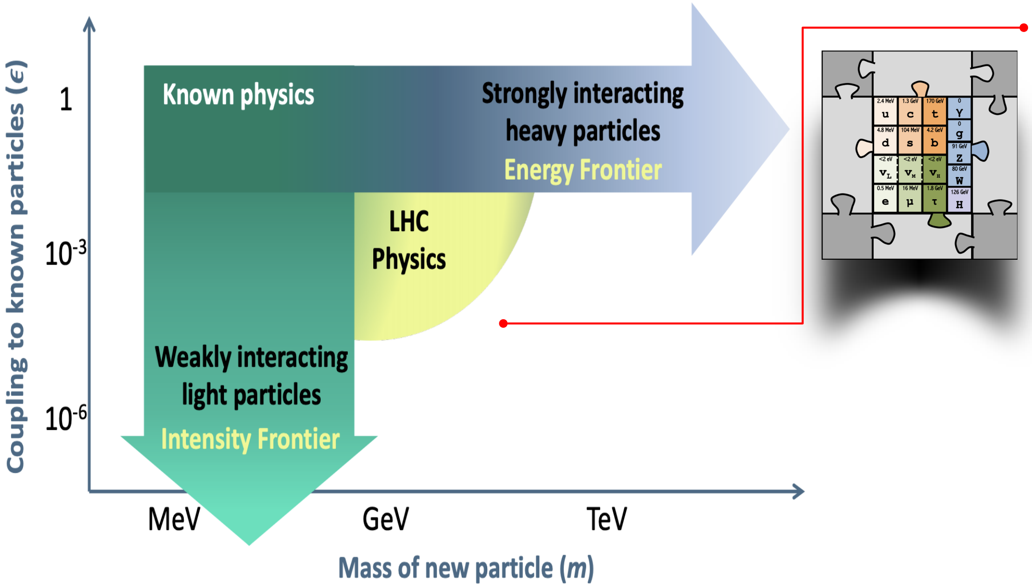
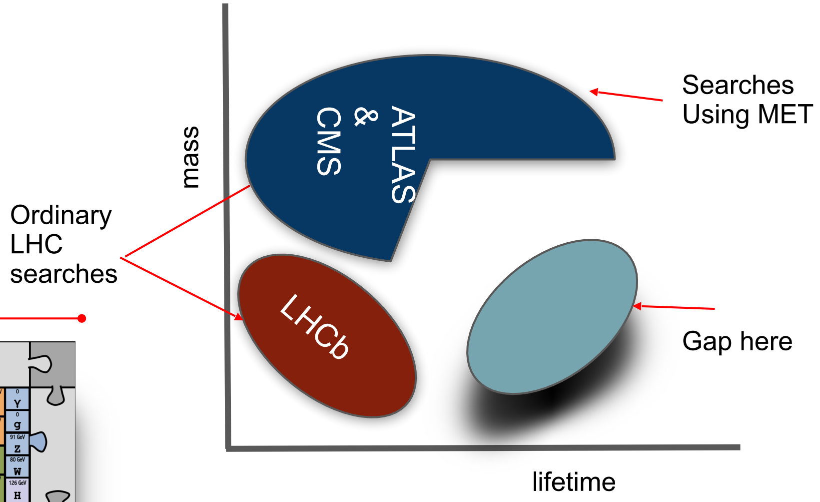
CERN

The landscape of new particles at colliders

LHC experiments typically focus on heavy, strongly interacting particles

- Require large transverse momenta of detected particles
- Produced ~isotropically and at relatively low rates



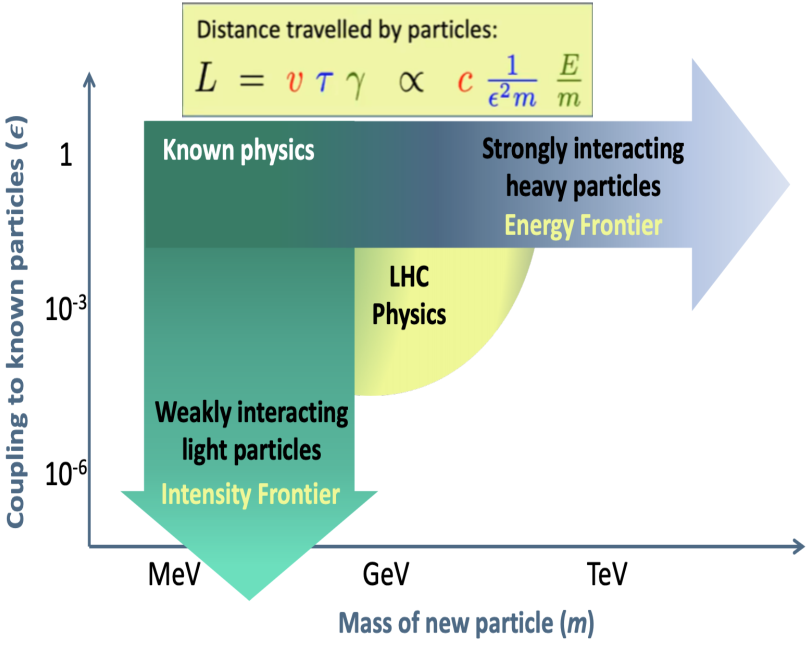


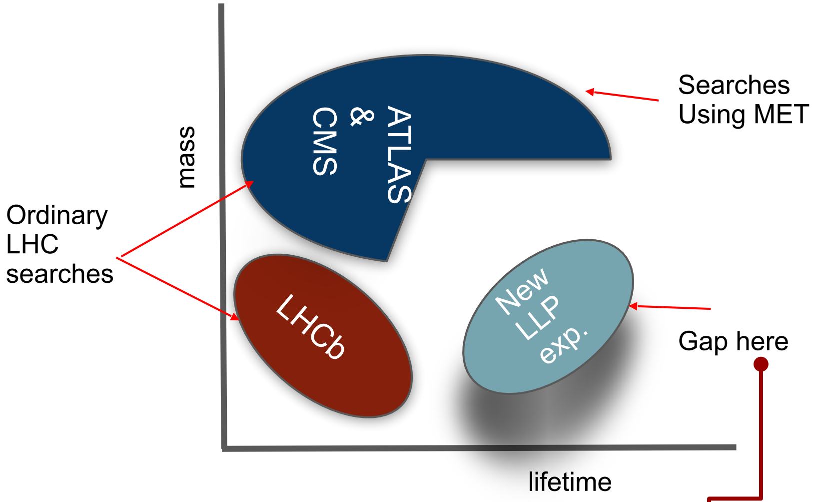
The landscape of new particles at colliders

"**LIFETIME**" A characteristic of weakly interacting particles

Distinct signatures

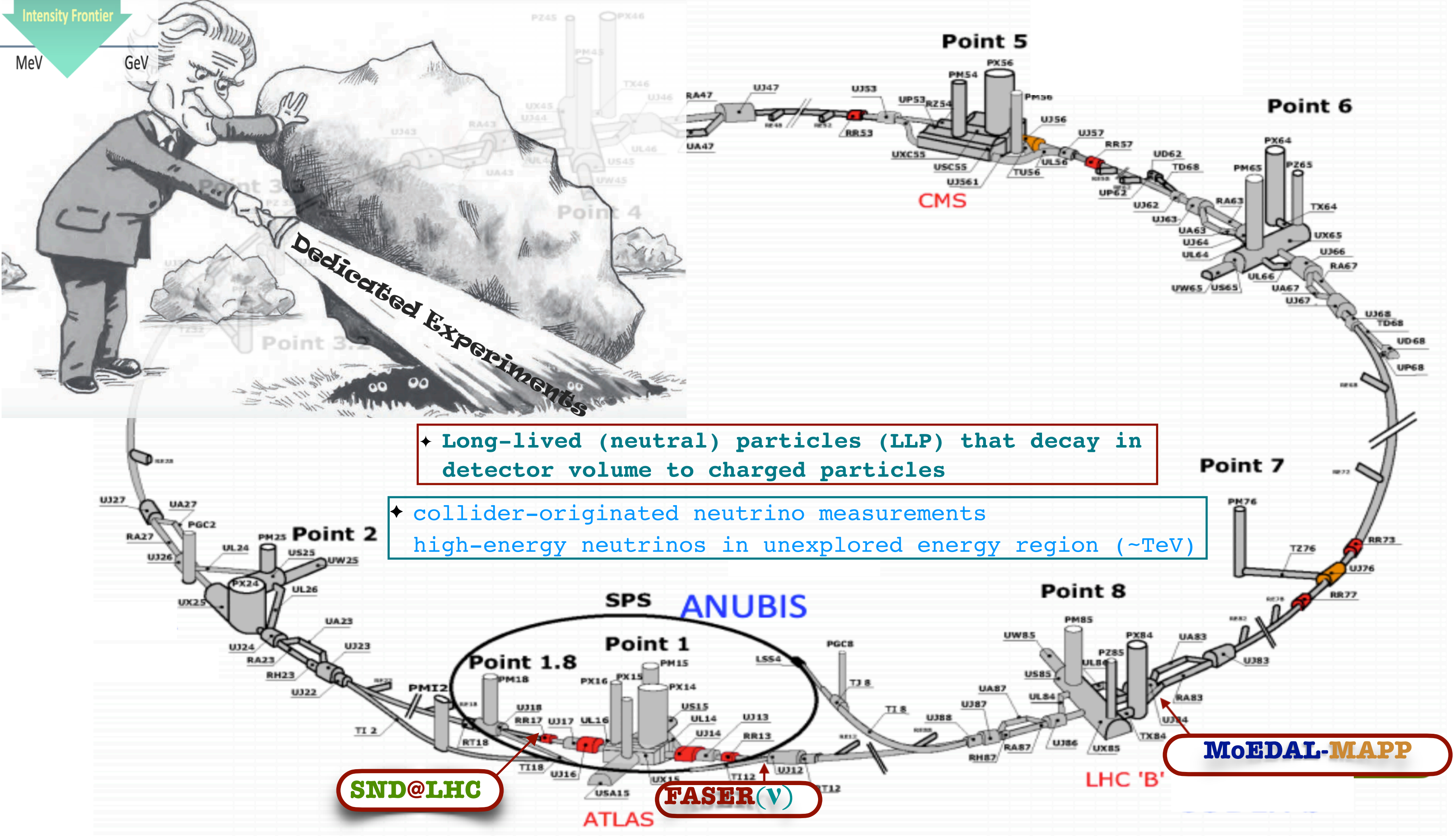
Opportunity for exploration!





- Motivated by the lack of results in "traditional" searches and new physics scenarios

Explosion of ideas!
Build a new detector to profit the LHC collisions to find elusive LLPs and TeV neutrino (and muon) beams.
Perfect detector would
- ➔ Have 0 background
- ➔ Have 100% coverage
- ➔ Be very cheap (no civil works needed.)


Intensity Frontier
MeV
GeV
Dedicated Experiments
Point 5
CMS
Point 6
✦ Long-lived (neutral) particles (LLP) that decay in detector volume to charged particles
Point 7
✦ collider-originated neutrino measurements
high-energy neutrinos in unexplored energy region (~TeV)
Point 2
SPS
ANUBIS
Point 8
Point 1
Point 1.8
LHC 'B'
MoEDAL-MAPP
SND@LHC
FASER(ν)
ATLAS

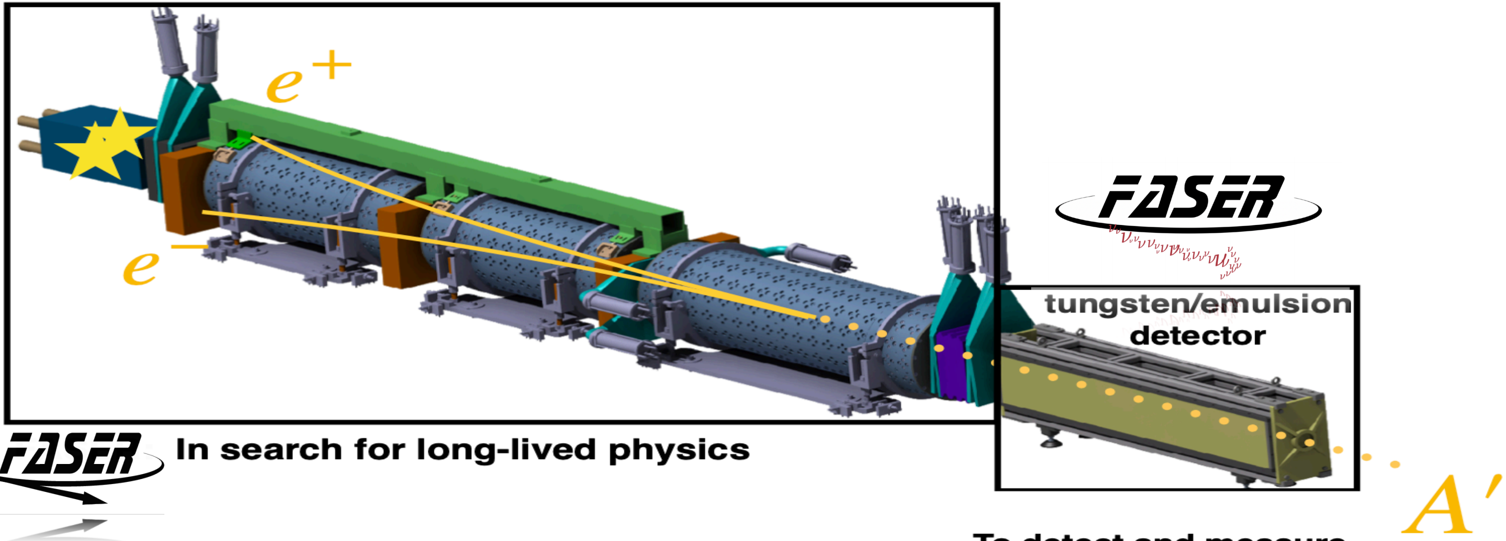
Run 2	Long Shutdown 2	Run3

CERN Approved March 2019

Construction and commissioning by collaboration of 64 people (20 institutes, 8 countries)

FORWARD SEARCH EXPERIMENT

From searches for weakly interacting particles to first measurements of collider neutrinos



FASER In search for long-lived physics

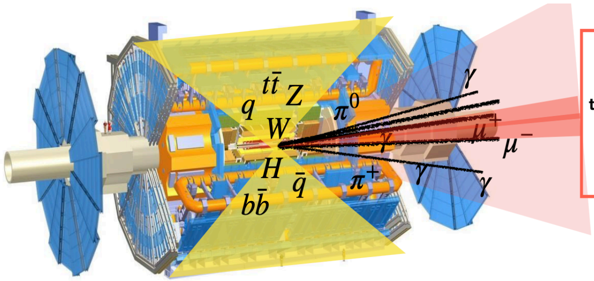
To detect and measure collider neutrinos.

Overview

Searches for new weakly-interacting light long-lived particles

- ❖ New particles produced in decays of light mesons,
- ❖ copiously present at zero angle,
- ❖ escaping detection in ATLAS/CMS

➢ **2×10^{-6} % solid angle but still O(10^{15}) π^0 in RUN 3!**

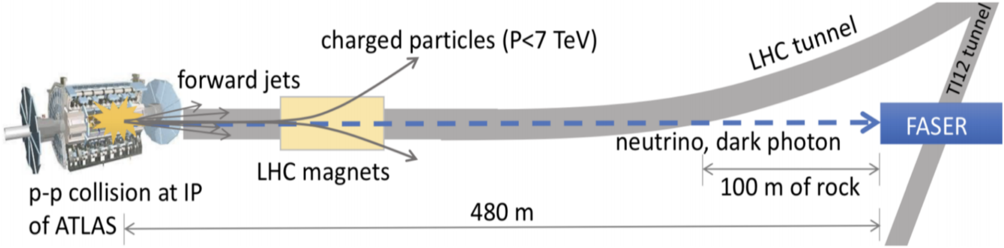


FASER to search for light particles with extremely weak couplings by tapping into unused LHC luminosity: <u>SM inelastic events</u>

σ_{inel}(13 TeV) ~ 75 mb, N_{inel} (Run3, 150 fb^{-1}) ~10^{16}

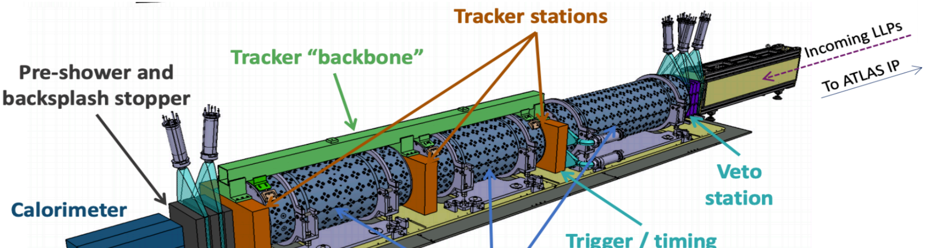
(mostly in forward region)

- ‣ situated along the beam collision axis line of sight (LOS) in TI12 tunnel (former injection tunnel for LEP)
- ‣ 480 m from IP1 (ATLAS) with Transverse radius of 10 cm covering the mrad regime (η>9.1)
- ‣ After beams start to bend
- ‣ A few meters from the LHC beam line



- **Distinctive detector signature:~ TeV long-lived particles produced in the forward region**

pp → LLP + X, LLP travels ~ 480m, LLP → $e^+e^-, \mu^+\mu^-, \pi^+\pi^-, \gamma\gamma, \ldots$



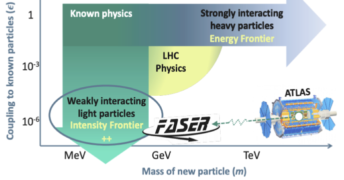
Geometry:
Length: 5 m
Aperture: 20 cm
Length of decay volume: 1.5 m

<u>An almost perfect location</u>

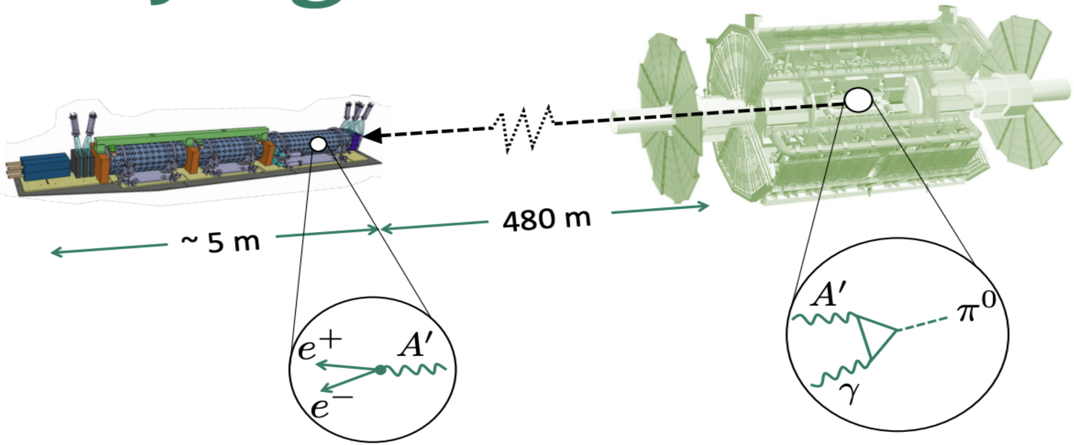
- Shielded by LHC components and rock
  - ✓ Low radiation levels
    - ‣ no radiation-hard electronics needed

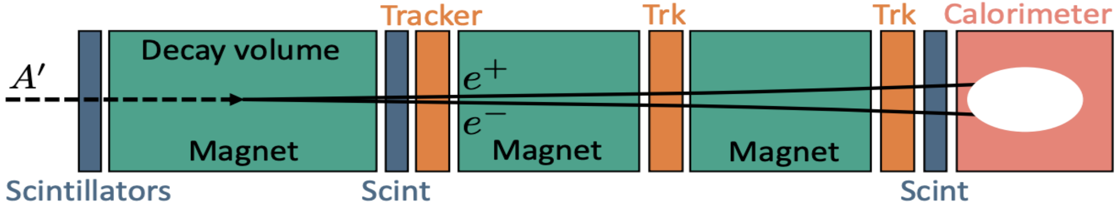
Example Physics Studies

Searches for new weakly-interacting light long-lived particles



Key signatures



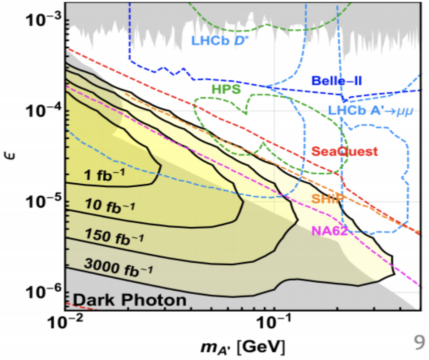


Dark photon (A')

Ballpark numbers for A':

- Momentum of 1 TeV
- Mass of 100 MeV

Decay products collimated requirements for magnetic field & high resolution tracker



Assuming 3 signal events and no backgrounds

Anna Sfyrla

Physics potential: Phys. Rev. D 99, 095011

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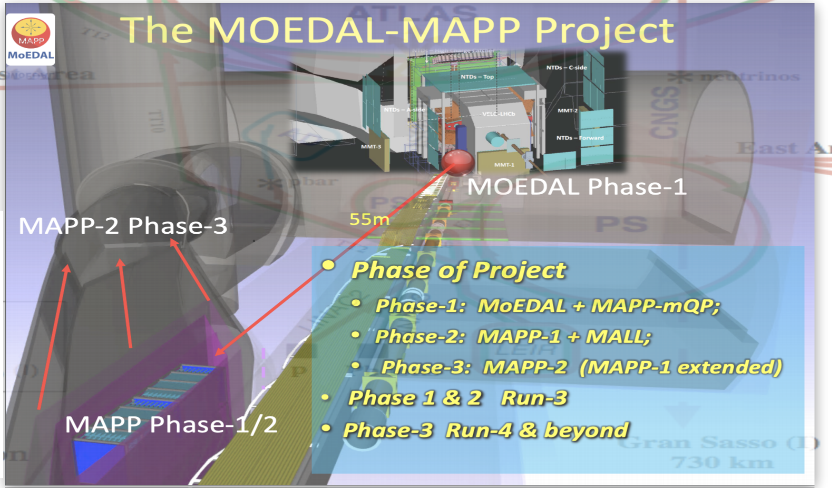
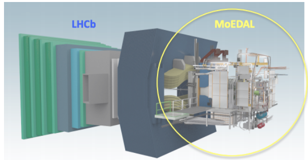
MAPP-MoEDAL Aparatus for Penetrating Particles

The LHC's First Dedicated Search Experiment





MoEDAL-The Monopole and Exotics Detector at the LHC

BSM scenarios through searches for :

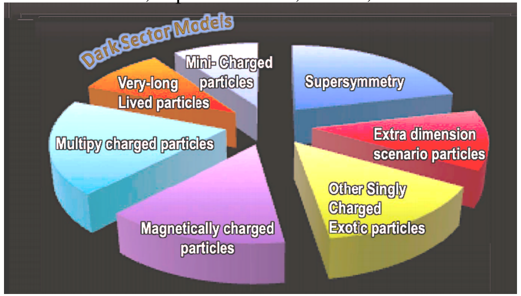
- highly ionizing particles, such as magnetic monopoles
- multiply electrically charged particles, as avatars of new physics.

MoEDAL physics program
Int. J. Mod. Phys. A29 (2014) 1430050

Overview

The LHC's First Dedicated Search Experiment

IJMPA, September 2014, Vol. 29, No. 23



✦ MAPP the MoEDAL Experiment will be sensitive to 3 clear avatars of new physics:

- ✦ Highly ionizing particles (HIPs)
- ✦ Mini-charged Particles (mQPs)
- ✦ Long-lived Particles (LLPs)

Consists of 2 sub detectors

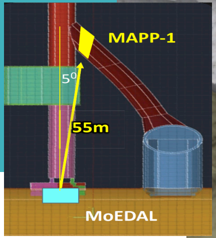
- **MAPP-LLP:** The very long-lived weakly interacting particle detector
- **MAPP-mQP**: The core milli-charged particle detector
  - Particles with charges <<1e

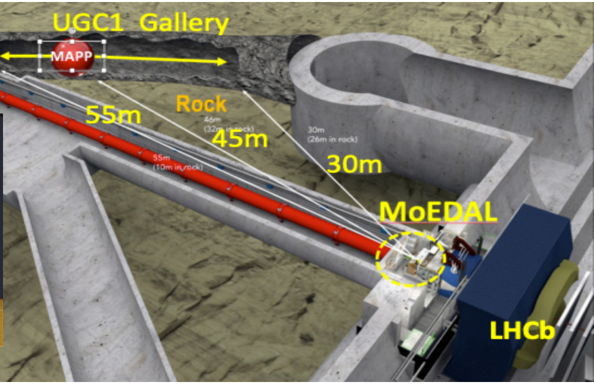
Deployed in the UGC8 Galery adjacent to MoEDAL's intersection point IP8

- ~55m away from the IP
- @ an angle of 5^0w.r.t beam axis

Protected by

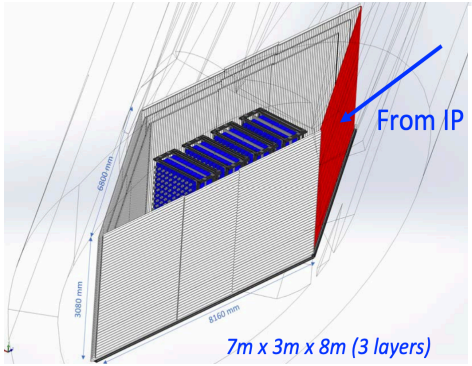
- 100m of rock overburden
- 25 m of rock from IP

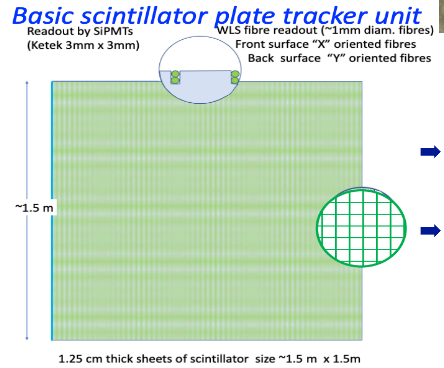




❖ MAPP-1 (mQP+LLP) for RUN 3

"Box-within-a-box" structure to detect charged tracks from neutral-particle decays



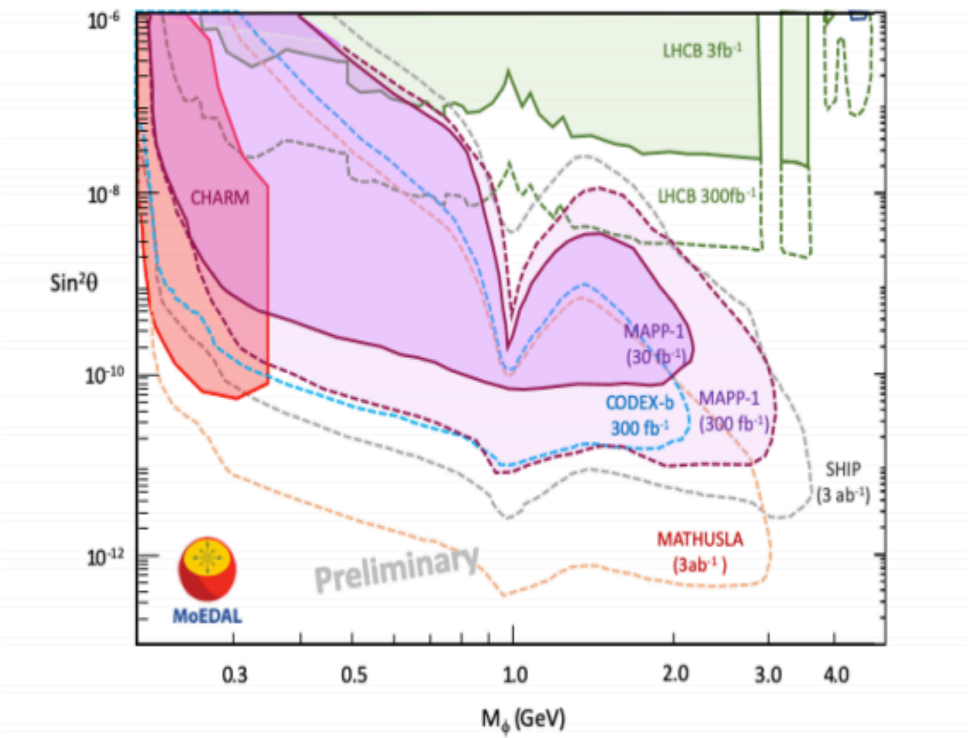


- ➡ Constructed of 3 nested boxes formed from scintillator strip hodoscope planes
- ➡ The readout structure are scintillator strips in an x-y configuration readout by SIMPs

MAPP-LLP EXAMPLE PHYSICS STUDIES

The LHC's First Dedicated Search Experiment

DARK HIGGS Scenario



Benchmark Process:

- Reach for MAPP-1 (30 fb^{-1} /300 fb^{-1}) for the scenario where the Higgs mixing portal admits inclusive
  - $B \rightarrow Xs\phi$ decays

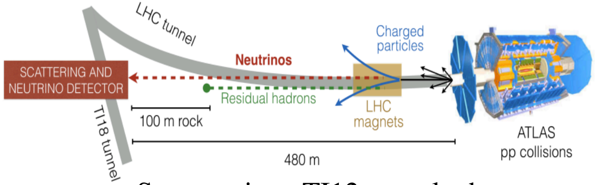
where ϕ is a light CP-even scalar that mixes with the Higgs, with mixing angle $\theta \ll 1$

Promising physics reach for MAPP-LLP also for R-parity violating SUSY and sterile neutrino models [e.g. Dreiner et al, 2008.07539 & 2010.07305, respectively

Neutrinos at the LHC

Neutrinos detected from many sources, but not from colliders.

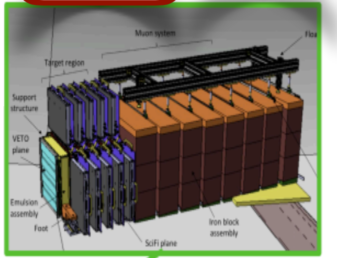
- ATLAS provides an intense and strongly collimated beam of TeV-energy neutrinos along beam collision axis.
  - huge flux of neutrinos in the forward direction,mainly from: π, K and D meson decay
- The neutrino beam passes through the side tunnels TI12 and TI18,~480 m downstream from ATLAS,
  - shielded by ~100 m of rock from the IP,
    - providing a natural location for LHC neutrino experiments



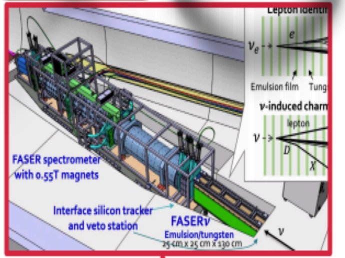
Symmetric to TI12 tunnel where FASER is located

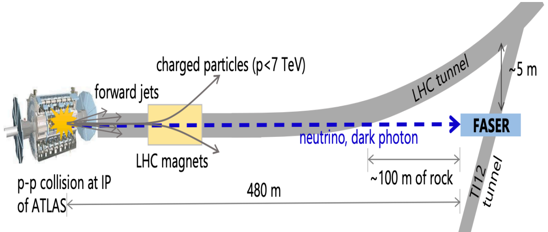
Angular acceptance: $7.2<\eta< 8.6$

SND@LHC off-axis



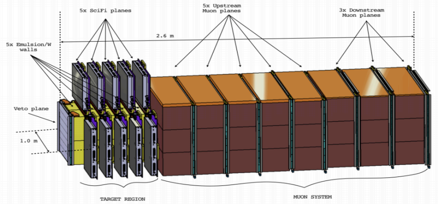
FASER(ν) On-axis



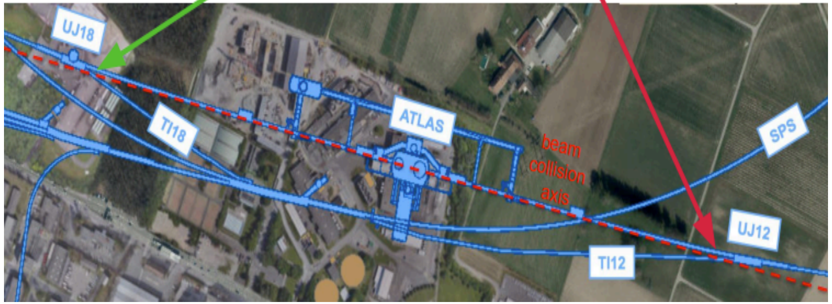


- FASERν : will be placed in front of the FASER main detector

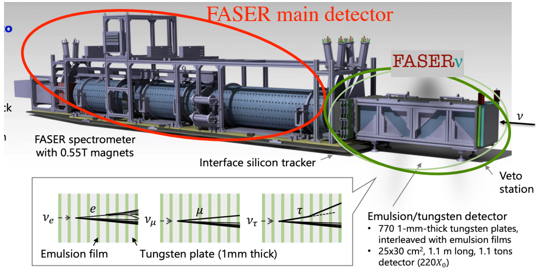
0.8- ton emulsion based detector



identification and measurement of the three neutrino flavours, νe, $\nu\mu$, $\nu\tau$ detection of feebly interacting particles



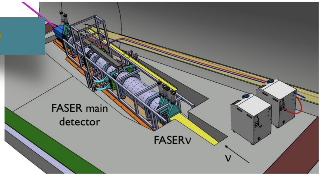
1.2- ton emulsion based detector

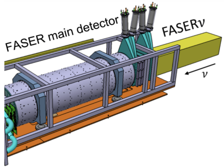


- distinguish all flavor of neutrino interactions.

FASERν in FASER

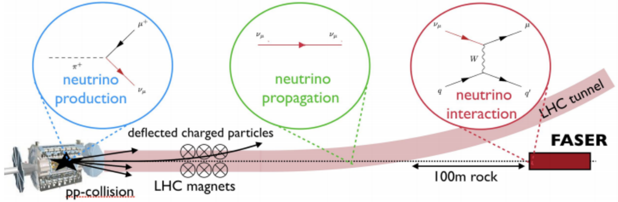
approved in Dec.2019





Measurement at highest man-made neutrino energies

- A high-intensity beam of neutrinos will be produced in the far-forward direction.
- FASERν will be centered on the LOS (in the FASER trench) to maximizes fluxes of all neutrino flavors
  - expect to collect ~10000 CC interactions (distinguishing the flavors) in LHC-Run3 (2022-2024). {F.Kling, Forward Neutrino Fluxes at the LHC, [arXiv:2105.08270}](arXiv:2105.08270)

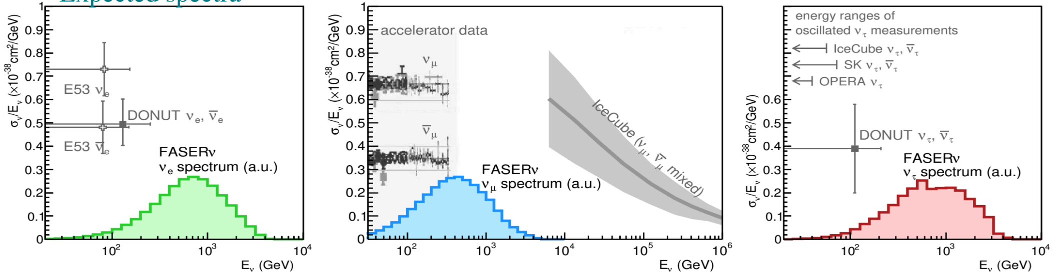


Will be installed in October for Run3!

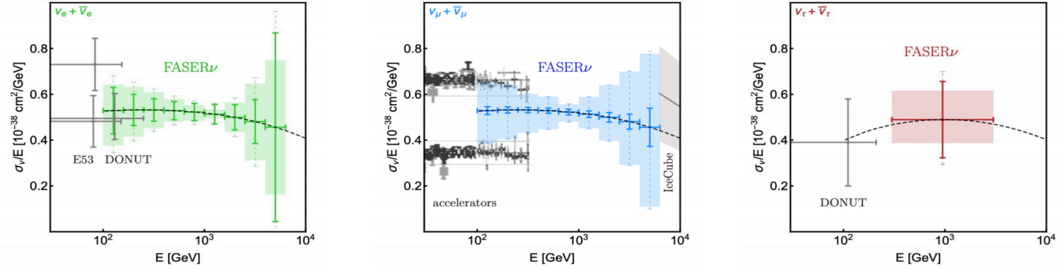
Aims :

- Detect collider neutrinos for the first time
- Probe neutrino interactions in an energy range where neutrino cross sections are unconstrained, especially tau neutrinos
- Probe BSM neutrino physics…

Expected spectra



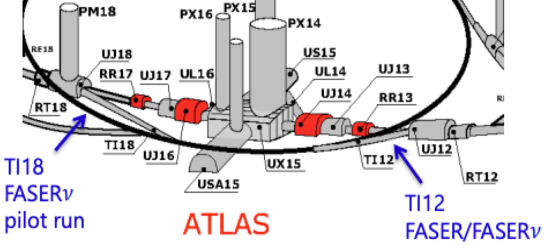
- Expected cross section reach: extends current measurements already with 150/fb^{-1}



FASER Collaboration, Eur. Phys. J. C 80 (2020) 61, arXiv:1908.02310

Pilot Run in 2018 (LHC Run-2)

Aim: demonstrate neutrino detection at the LHC for the first time



- Performed measurements in the tunnels TI18 and TI12, 480 m from the ATLAS IP.
- For neutrino detection, a 30 kg emulsion detector was installed in TI18 and 12.2 fb^{-1} data was collected.
  - Analyzed target mass 11 kg
  - 18 neutral vertices were selected
  - by applying # of charged particle ≥ 5, etc.
  - Expected signal $3.3^{+1.7}_{-0.9}$ events, BG 11.0 events

First neutrino interaction candidates at the LHC, arXiv:2105.06197


UCI-TR-2021-04, KYUSHU-RCAPP-2020-04, CERN-EP-2021-087

First neutrino interaction candidates at the LHC

(FASER Collaboration)

(Dated: May 14, 2021)

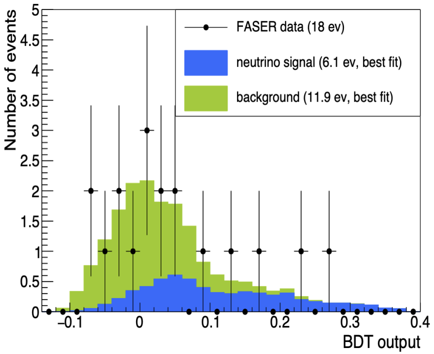
FASERν at the CERN Large Hadron Collider (LHC) is designed to directly detect collider neutrinos for the first time and study their cross sections at TeV energies, where no such measurements currently exist. In 2018, a pilot detector employing emulsion films was installed in the far-forward region of ATLAS, 480 m from the interaction point, and collected 12.2 fb^{-1} of proton-proton collision data at a center-of-mass energy of 13 TeV. We describe the analysis of this pilot run data and the observation of the first neutrino interaction candidates at the LHC. This milestone paves the way for high-energy neutrino measurements at current and future colliders.

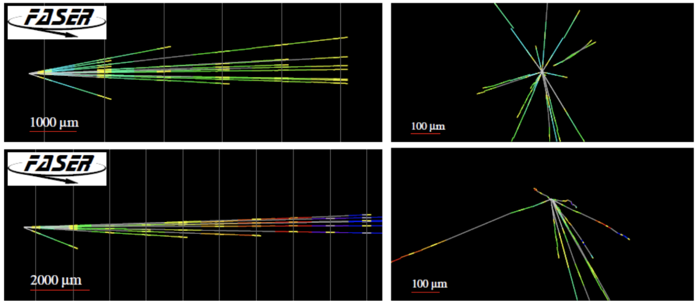
I. INTRODUCTION

There has been a longstanding interest in detecting neutrinos produced at colliders [1–6], but to date no collider neutrino has ever been directly detected. Proton-proton (pp) collisions at a center-of-mass energy of 14 TeV during LHC Run-3, with an expected integrated luminosity of 150 fb^{-1}, will produce a high-intensity beam of $\mathcal{O}(10^{12})$ neutrinos in the far-forward direction with mean interaction energy of about 1 TeV. FASERν [7] is designed to detect these neutrinos and study their prop-

arXiv:2105.06197v1 [hep-ex] 13 May 2021

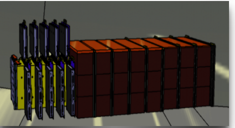
This result demonstrates detection of neutrinos at the LHC!





In BDT, an excess of neutrino signal is observed. Statistical significance 2.7σ from null hypothesis

preparing for data taking in LHC Run-3!



SND@LHC-Scattering and Neutrino Detector

approved in March 2021

- SND@LHC A newly proposed, compact and stand-alone experiment designed to: measuring neutrinos produced at the LHC in an unexplored pseudo-rapidity region
- searching for feebly interacting particles (FIP) through scattering off atoms in the detector target

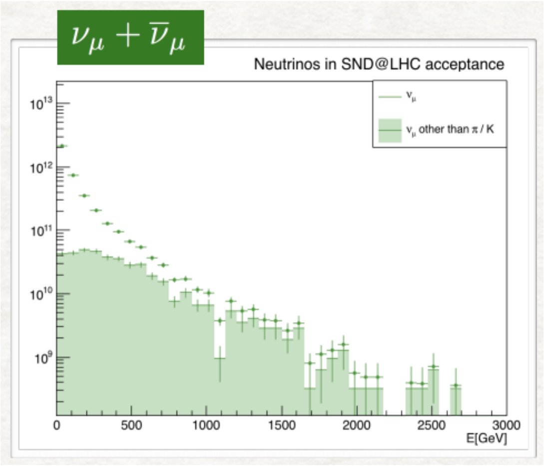
Detector optimised for neutrino searches in a region where they act as a probe of heavy (mostly charm) quark production

- BSM searches possible (relying on the topology and on the time-offlight measurements), sensitivity under evaluation

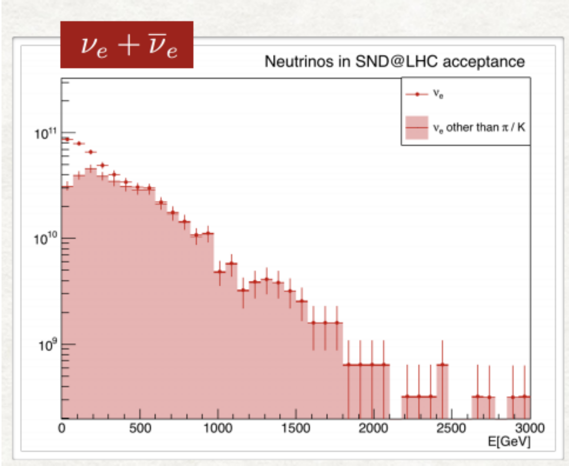
LEPTON FLAVOUR UNIVERSALITY TEST

- The identification of three neutrino flavours in the SND@LHC detector offers a unique possibility to test the Lepton Flavor Universality (LFU)

- **Data taking will start in early 2022**



- The measurement of the $\nu e/\nu\mu$ ratio can be used as a test of the LFU for E>600 GeV



- Sensitive to ν-nucleon interaction x-section ratio of two neutrino species

SND@LHC: Technical Proposal

SUMMARY

External LLP detectors for the LHC can probe deep into LLP parameter space, for both scalar-portal-FIPs and general LLPs.

❖ FASER (Run3)

- Refurbishment of TI12 to be an experimental site was completed in Winter 2020.
- All detectors have been installed in TI12 as of March 2021
- Already starting to collect cosmic-ray data.
- Aiming to start data taking in LHC Run-3 from 2022 for:
  - discovery of a light weakly- coupled particle in MeV-GeV range

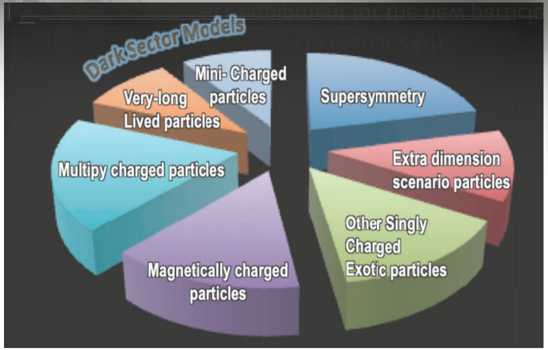
❖ FASER2 (HL-LHC)

- Potential to increase sensitivity with FASER 2 upgrade for HL-LHC:
  ➡opportunity to probe more benchmarks

❖ MoEDAL-MAPP (Run3)

will be sensitive to 3 clear avatars of new physics: HIPs, mQPs and LLPs

- Successful mQP prototype tested during LHC Run 2.
- Full detector planned for LHC Run 3.
- ❖ **MoEDAL-MAPP-1** is planned for 2022/UGC1 gallery must be upgraded to house MAPP in 2021/22.
- Envisage approval in 2022 and the start of data taking in 2023.



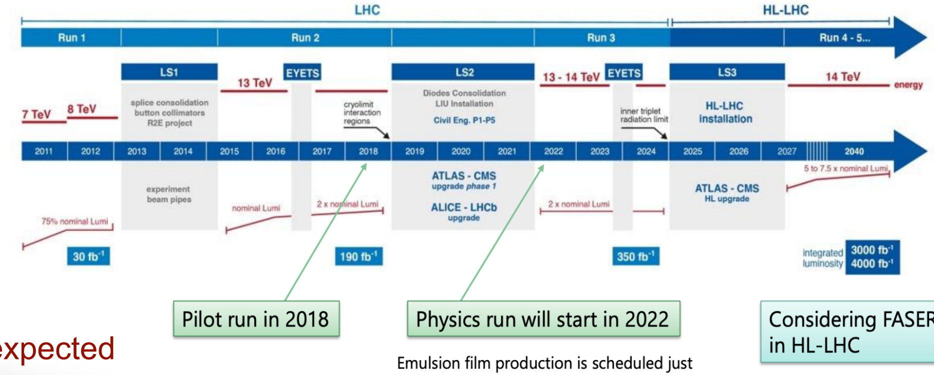
❖ **MoEDAL-MAPP-2 (HL-HLC) installed for Run-4 will give a greater fiducial volume for the LLP search**

SUMMARY

FASERν & SND@LHC will make measurements of neutrinos produced at a particle collider for the first time ~ open a new frontier in neutrino physics ~

❖FASERν (Run 3) ▸ Will register neutrinos from a collider for the first time

- Design and strategy are all defined
  - **Will be installed in October 2021.**
- Neutrino analysis from Pilot run available
- First neutrino interaction candidates at the LHC submitted to journal: arXiv:2105.06197



Emulsion film production is scheduled just before each installation (3 times per year).

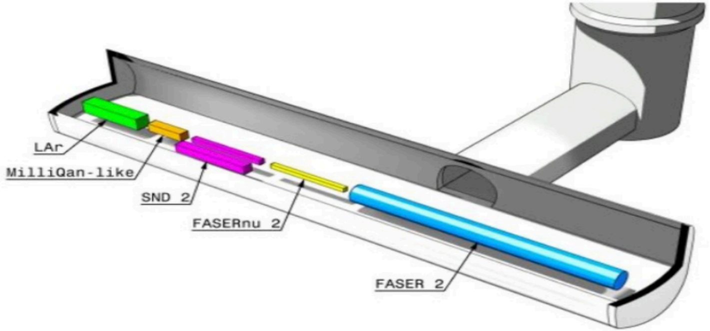
- **Aiming data-taking at LHC Run3 in (2022-2024).**
  ~10000 n CC interactions (distinguishing the flavours) are expected

❖FASERν2 (HL-LHC) ▸ Planning neutrino measurements in the HL-LHC era.

- A large detector for precision $\nu\tau$ physics with 10-30 tons of target

❖SND@LHC **recently approved (March 2021)**

- aiming to register ~2000 n CC interactions (distinguishing the flavours) in 2022-2024
- Detector under construction
- **Data taking will start in early 2022**
- Possible extensions beyond Run3 would highly benefit from the development of a Forward Physics Facility



Thank you for your attention!

Special Thanks to: Vasiliki Mitsou
Jamie Boyd,
Jonathan Lee Feng,
Zhen Hu,
Xabier Cid Vidal,
Emma Torro Pastor,
Niki Saoulidou,
Josef Francisco Zurita

References

FASER collaboration:

- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC
- First neutrino interaction candidates at the LHC
- Technical Proposal arXiv:1812.09139
- FASER's Physics Reach for Long-Lived arXiv:1811.12522
- Detecting and Studying High-Energy Collider Neutrinos with FASER at the LHC arXiv:1908.02310

+several theory papers:
More information: https://faser.web.cern.ch/physics/publications

MoEDAL-MAPP:

- Webpage:https://moedal.web.cern.ch/moedal-detector
- LLP2021 workshop: James Pinfold
- Snowmass21-EF9_EF8
- MoEDAL – a new light on the high-energy frontier
- MoEDAL physics results and future plans:Vasiliki A. Mitsou
- MoEDAL, FASER and future experiments targeting dark sector and long-lived particles

SND@LHC:

- Letter of intent: LHCC-I-037, 27 Aug 2020
- Technical proposal: LHCC-P-016, 22 Jan 2021
- Experiment approval: Grey Book database, 17 Mar 2021
- Experiment website: http://snd-lhc.web.cern.ch/

B A C K U P

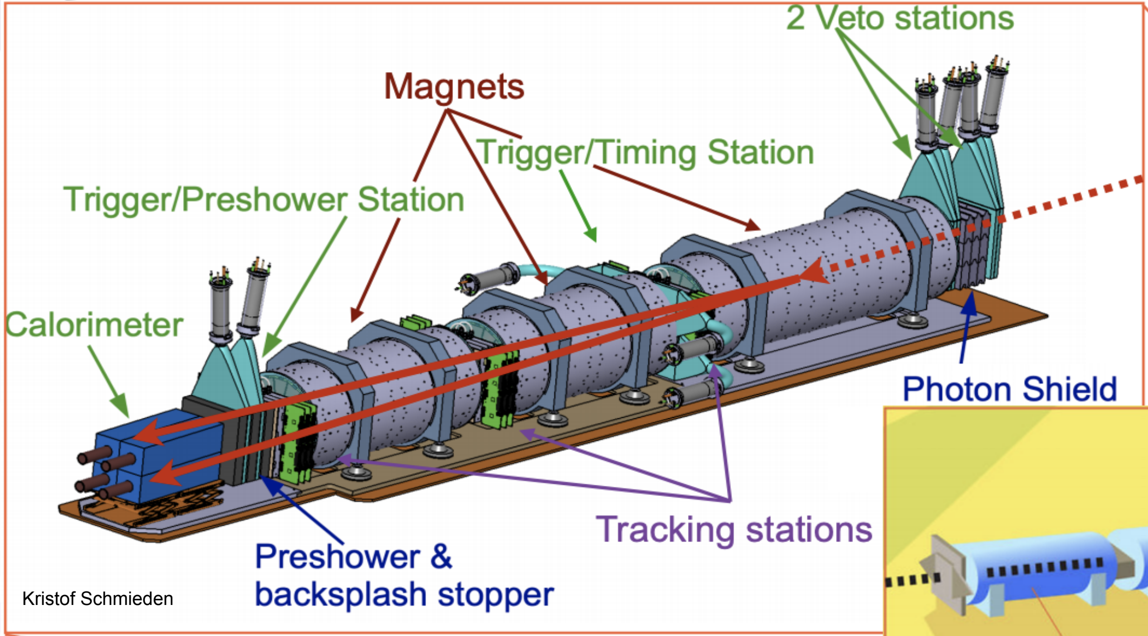
FASER Timeline

Detector Design

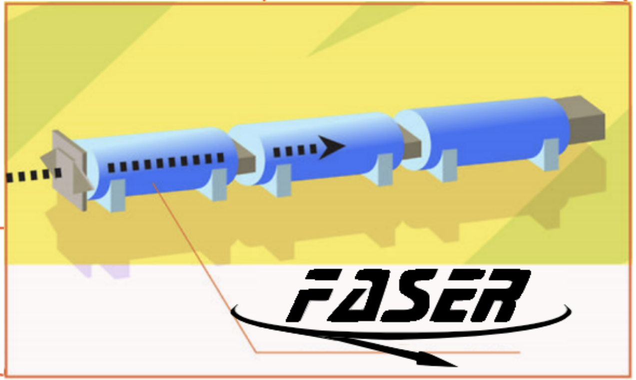
Searches for new weakly-interacting light long-lived particles

arXiv:1812.09139

FASER: tracker and calorimeter, detects LLP decay to pair of TeV charged tracks



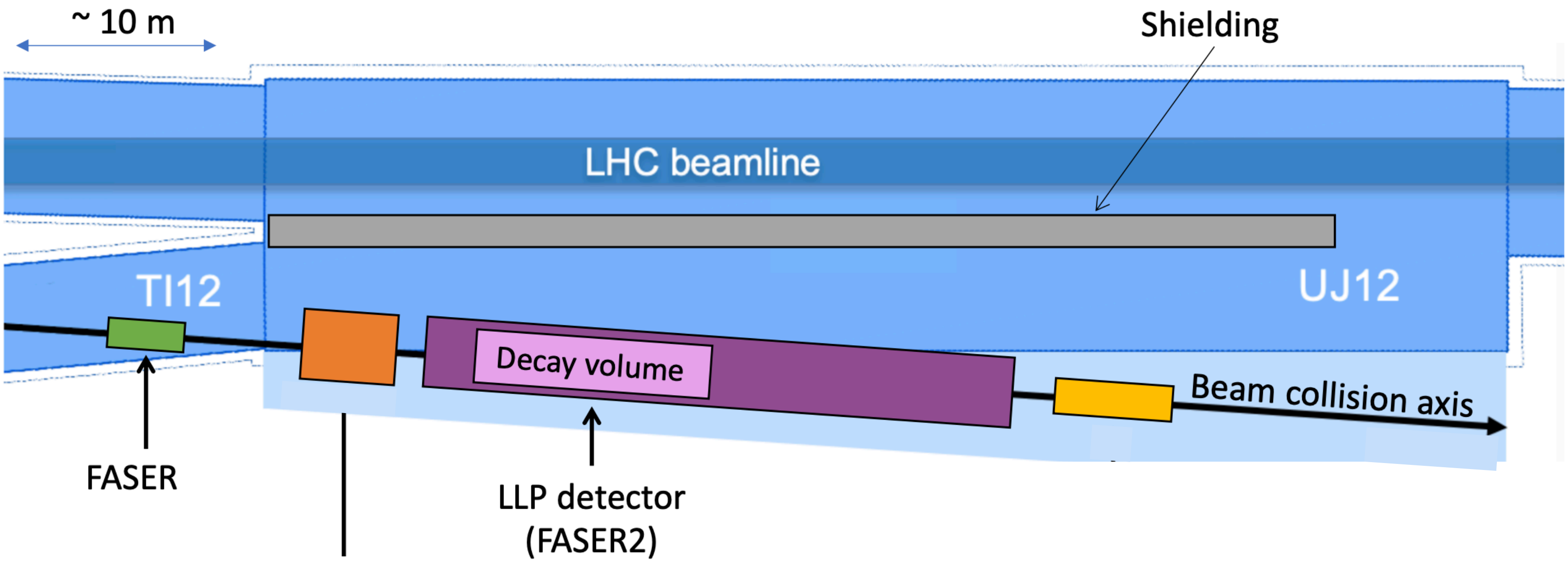
- 1.5-meter magnetized decay volume
- 2-meter magnetic spectrometer
  - Three tracking stations
- Electromagnetic calorimeter
- Three scintillator stations for triggering, veto and precise timing
- Aperture (10 cm radius) and length strongly constrained by available space



Many Thanks !!!
Recycling existing spare modules:
ATLAS SCT modules (Tracker)
LHCb ECAL modules (Calorimeter)

BEYOND FASER ?-backup

Searches for new weakly-interacting light long-lived particles



Anna Sfyrla

Physics potential: Phys. Rev. D 99, 095011

Beyond FASER ? FASER2

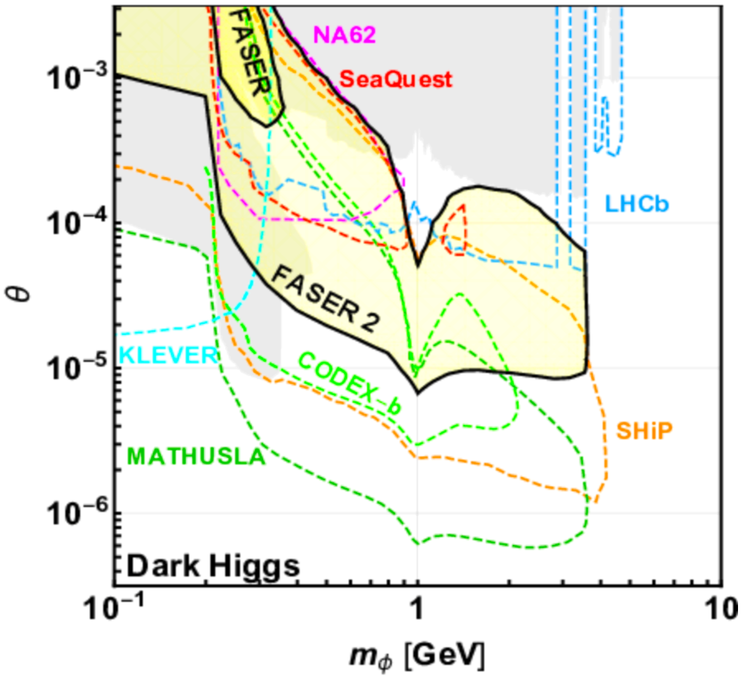
FASER 2 is a **speculative** extension for the HL-LHC

upgrade to FASER 2 in LS3 (2023-25) for HL-LHC (2026-35, 3 ab^{-1})

Detector benchmarks:
- FASER: R=10cm, L=1.5m, Run-3
- FASER-2: R=1m, L=5m, HL-LHC

Potential to increase sensitivity with FASER 2 upgrade for HL-LHC

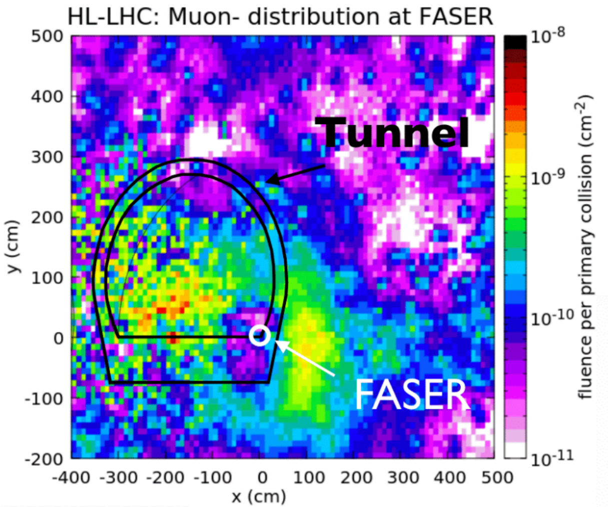
Benchmark Model	Label	Section	PBC	Refs	FASER	FASER 2
Dark Photons	V1	IV A	BC1	[7]	√	√
$B-L$ Gauge Bosons	V2	IV B	—	[30]	√	√
$L_i - L_j$ Gauge Bosons	V3	IV C	—	[30]	—	—
Dark Higgs Bosons	S1	V A	BC4	[26, 27]	—	√
Dark Higgs Bosons with hSS	S2	V B	BC5	[26]	—	√
HNLs with e	F1	VI	BC6	[28, 29]	—	√
HNLs with 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	—	√	√
Dark Pseudoscalars	P1	VIII	—	[36]	—	√

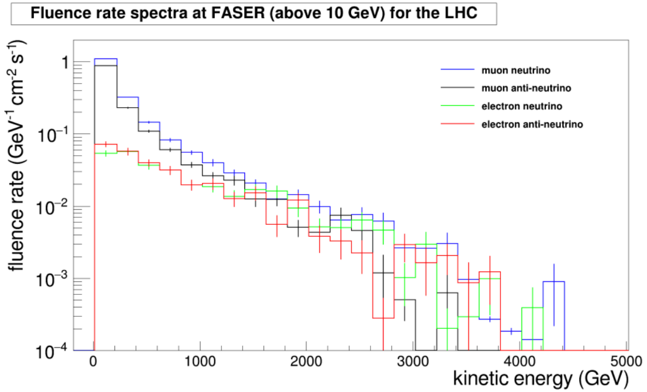


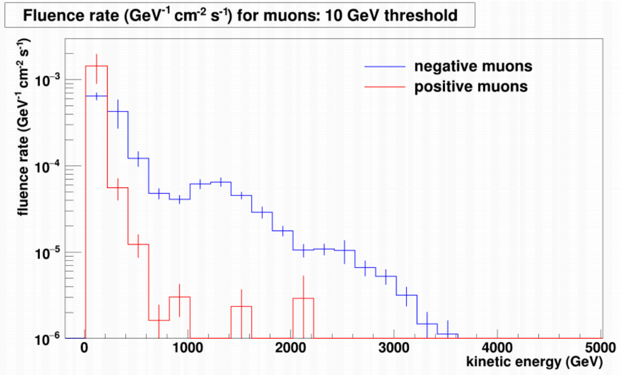
Increased detector radius to 1 m allows sensitivity to particles produced in heavy meson (B, D) decays increasing physics case beyond just increased luminosity

Beam backgrounds

- FLUKA simulations and *in situ* measurements used to assess expected backgrounds.
  - IP1 collisions (shielded by 100m rock)
  - Off-orbit protons hitting beam pipe aperture near TI12 } *Minor*
  - Beam-gas interactions
- Low particle flux along beam axis due to LHC optics.







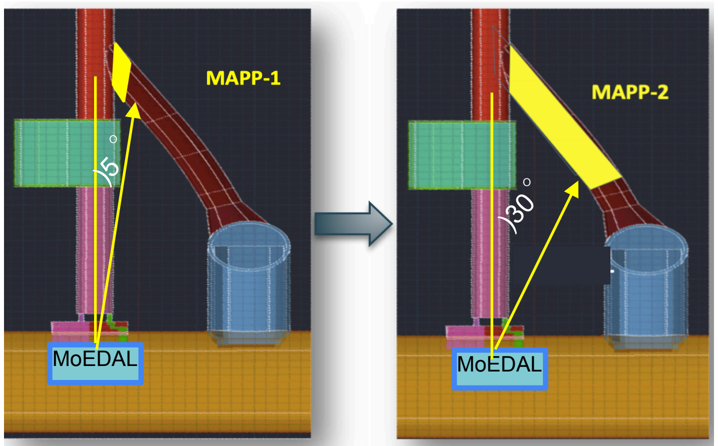
Muon charge asymmetry due to LHC magnets

Muons (@L=2x10^{34} cm^{-2} s^{-1})	
Energy threshold [GeV]	Charged Particle Flux [cm^{-2} s^{-1}]
10	0.40
100	0.20
1000	0.06

M. Queitsch-Maitland: FASER

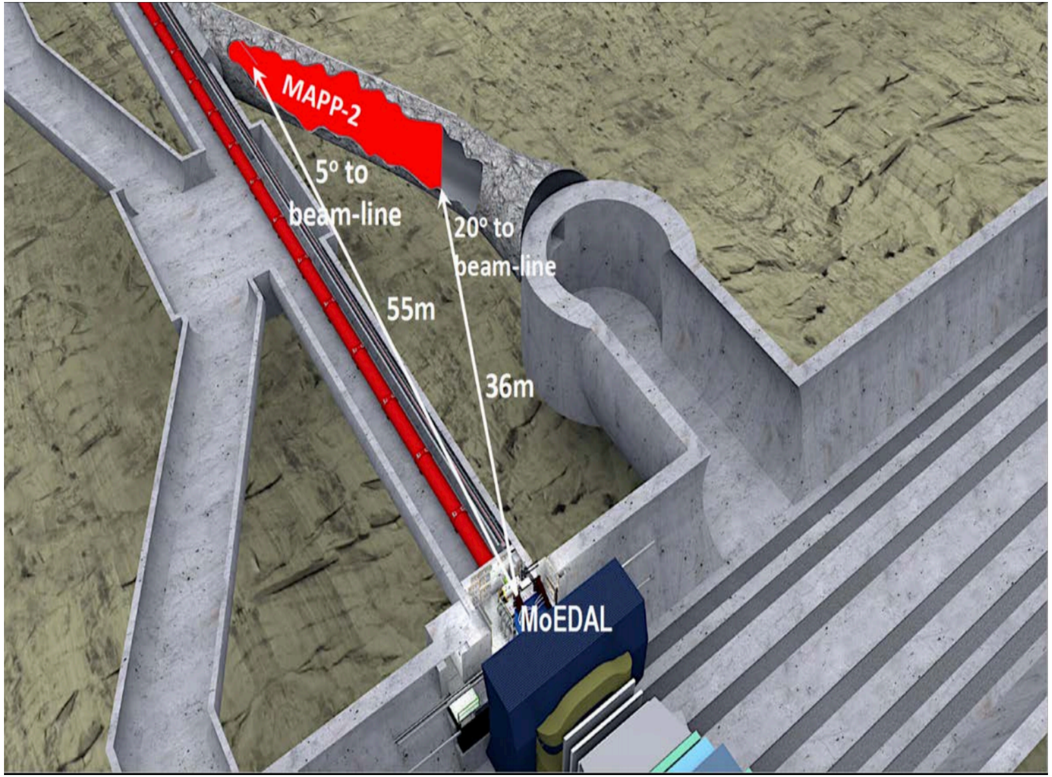
MAPP-2 FOR HL-LHC

- MAPP-2 is an extension fo MAPP1 down the UGC1 gallery
- The MAPP-1 technology would be used to provide a cost effective approach
- MAPP-2 extends MAPP1's sensitivity



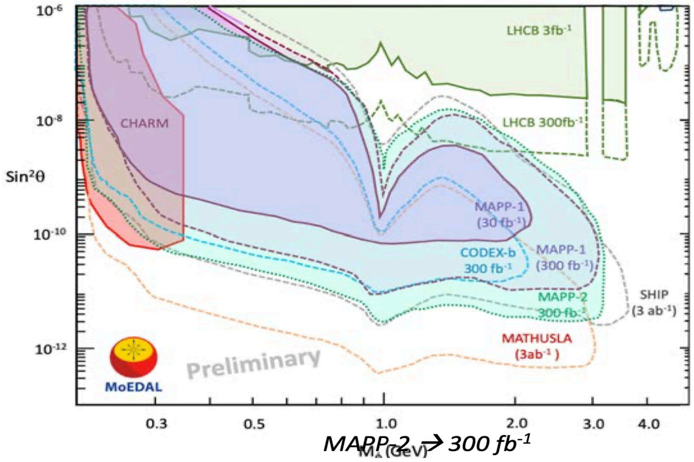
Run 3, 30 fb^{-1}

HL-LHC, 300 fb^{-1}



MAPP-2 EXAMPLE PHYSICS STUDIES

- Using the same Higgs mixing portal benchmark
- So that is competitive with the SHIP's



- Pair production of right-handed neutrinos from the decay of an additional neutral Z0 boson in the gauged B-L model- Phys. Rev.D100(2019),035005

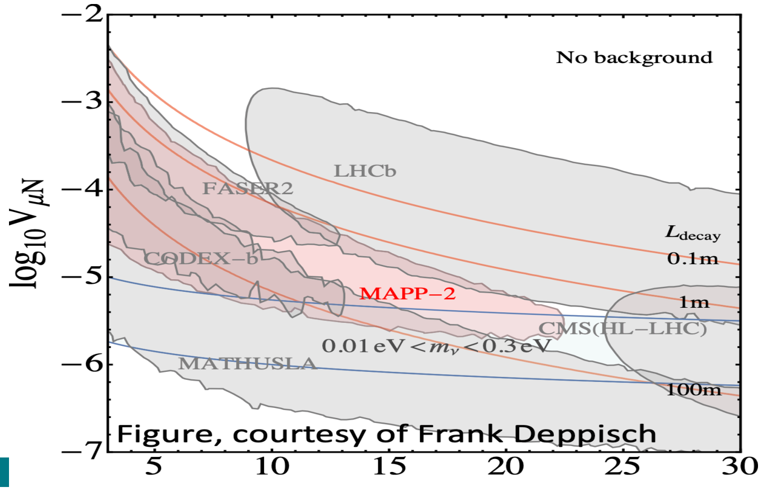
- Luminosity assumed in figure:

MAPP-2 → *300* fb^{-1}

CODEX-b → *300* fb^{-1}

FASER-2 → *3*Ab^{-1}

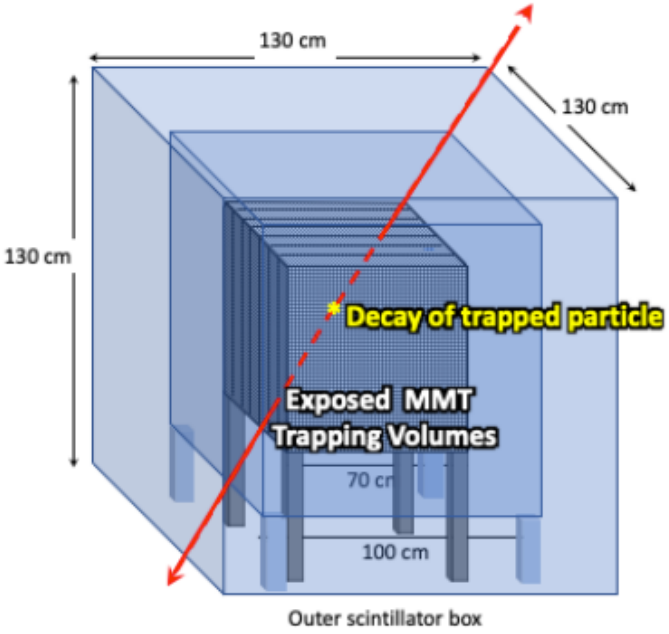
MATHUSLA → *3* Ab^{-1}



MALL- Monopole Aparatus to search for very Long Lived charged particles

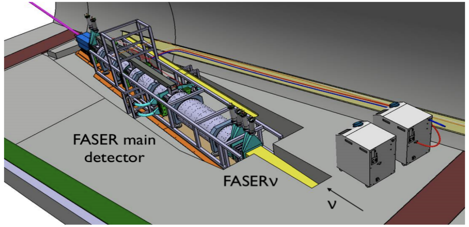
❖ **Push the search for the decays of new charged, massive and very long-lived long-lived particles**

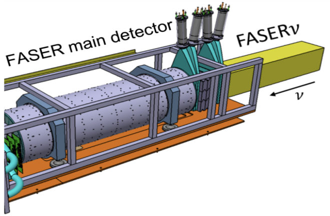
- After exposure and SQUID scan, MoEDAL MMTs will be monitored for decaying electrically charged particles possibly trapped in their volume.
- Sensitive to charged particles (e, μ, had.) and to photons with energy as small as 1~GeV • Estimated MALL probed lifetimes ~10 yrs.
- MALL planned to be installed during Run-3 at the UGC1 gallery of IP8



FASERν Detector

approved in Dec.2019

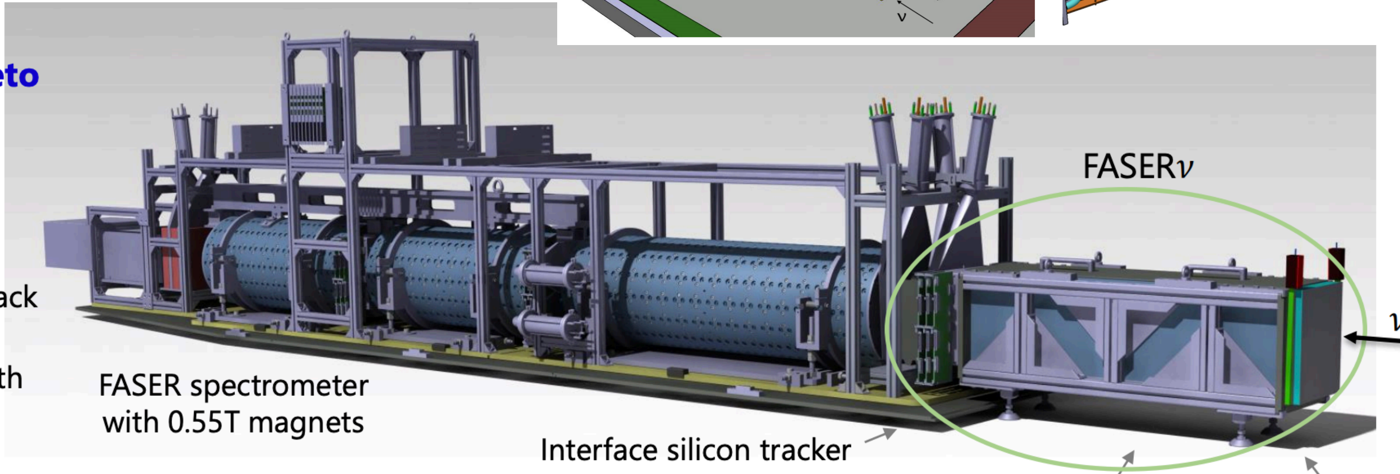


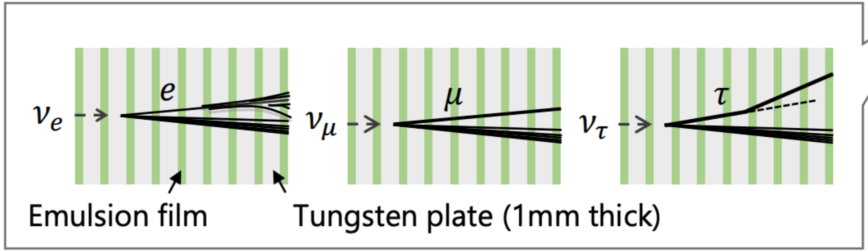


Emulsion/tungsten detector, interface silicon tracker, and veto station will be placed in front of the FASER main detector.

Allow to distinguish **all flavor of neutrino interactions.**

- **Muon identification** by their track length in the detector ($8\lambda_{int}$)
- **Muon charge identification** with hybrid configuration → distinguishing ν_μ and $\bar{\nu}_\mu$
- **Neutrino energy** measurement with ANN by combining topological and kinematical variables





Emulsion/tungsten detector

- 770 1-mm-thick tungsten plates, interleaved with emulsion films
- 25x30 cm^2, 1.1 m long, 1.1 tons detector ($220X_0$)

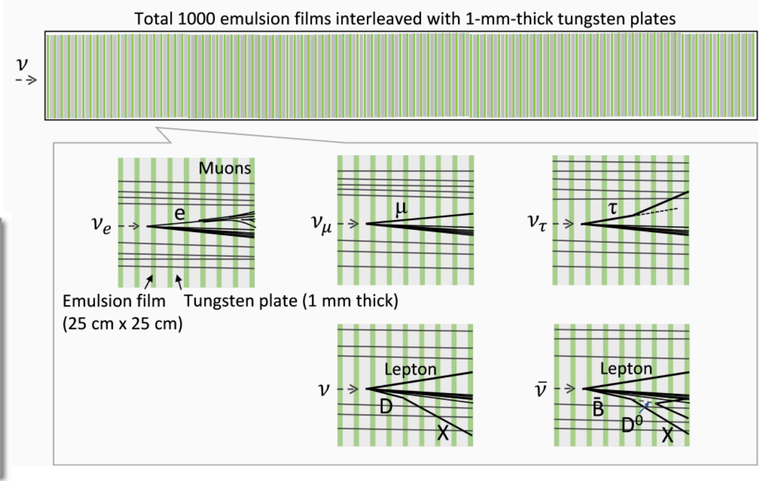
FASERν Detector

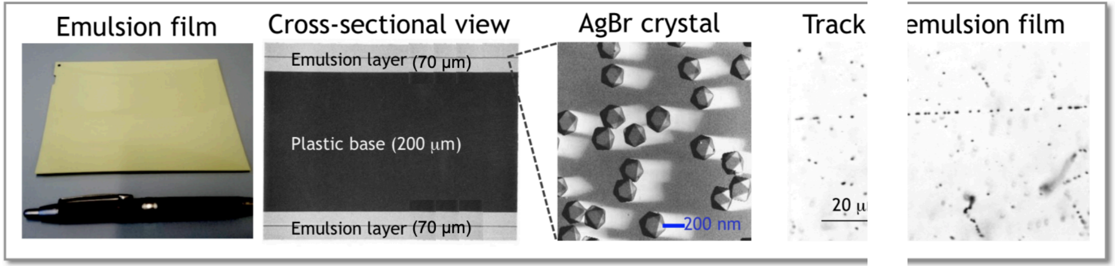
approved in Dec.2019

	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 100 cm), 14 TeV, 150 fb^{-1}, E_ν > 100 GeV

- FASERν: tungsten emulsion detector in front of FASER
  - 3D tracking detector, 50 nm precision, no timing
  - Total mass 1.2 tons, 285 X_0, 10.1 λ_{int}
- Needs to be exchanged every ~3 months (during technical stops) to control track density $\lesssim 1 \times 10^6$ tracks/cm³
- To be installed before data taking in 202
  - 10 emulsion detectors in total needed 2021-20 data.





dispersed in gelatin media

FASERν Neutrino Expectation

Expected neutrino event rate in LHC Run-3

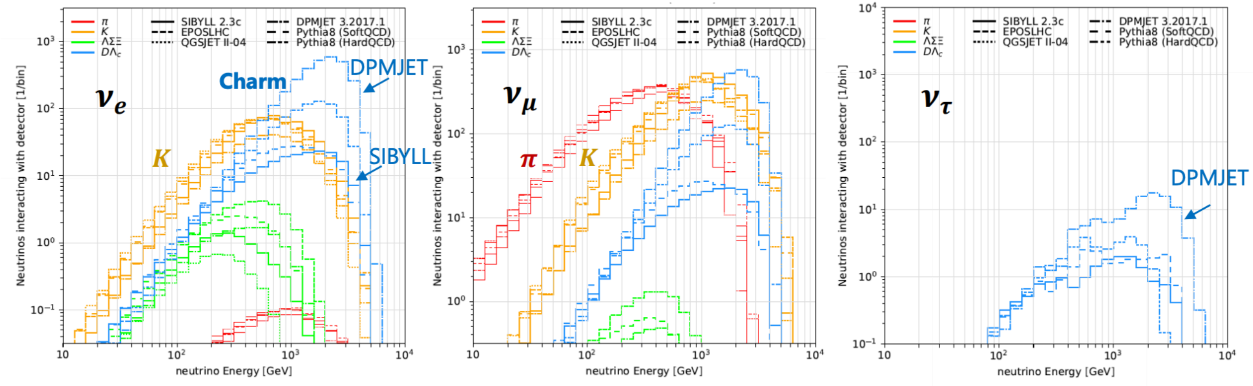
- A high-intensity beam of neutrinos will be produced in the far-forward direction.
- FASERν will be centered on the LOS (in the FASER trench) to maximizes fluxes of all neutrino flavors.

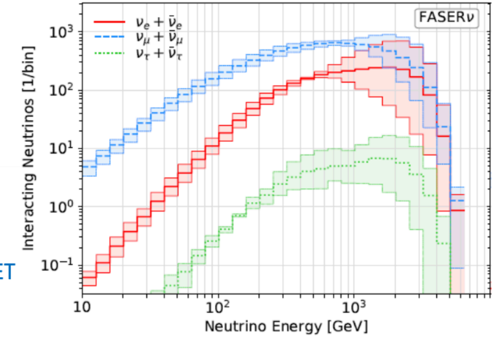
F. Kling, Forward Neutrino Fluxes at the LHC, arXiv:2105.08270

Expected number of CC interactions in FASERν during LHC Run-3 (150 fb^{-1})

Generators		FASERν		
light hadrons	heavy hadrons	$\nu_e + \bar{\nu}_e$	$\nu_\mu + \bar{\nu}_\mu$	$\nu_\tau + \bar{\nu}_\tau$
SIBYLL	SIBYLL	1343	6072	21.2
DPMJET	DPMJET	4614	9198	131
EPOSLHC	Pythia8 (Hard)	2109	7763	48.9
QGSJET	Pythia8 (Soft)	1437	7162	24.5
Combination (all)		2376^{+2238}_{-1032}	7549^{+1649}_{-1476}	$56.4^{+74.5}_{-35.1}$
Combination (w/o DPMJET)		1630^{+479}_{-286}	7000^{+763}_{-926}	$31.5^{+17.3}_{-10.3}$

Differences between the generators checked with the same propagation model (RIVET-module)





Tomoko Ariga: Detecting and studying high-energy neutrinos with FASERν at the LHC

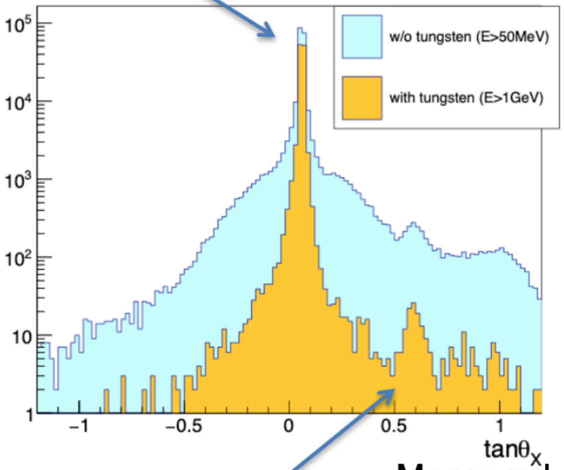
FASERν Pilot run

- Emulsion and Timepix detectors exposed to 12 fb^{-1} in 2018
- Primary goal was to verify muon flux and backgrounds in TI12 & TI18 tunnels
- Secondary goal was to look for neutrinos…

30 kg Emulsion Detector in TI18

particles from IP1

Rates in TI12



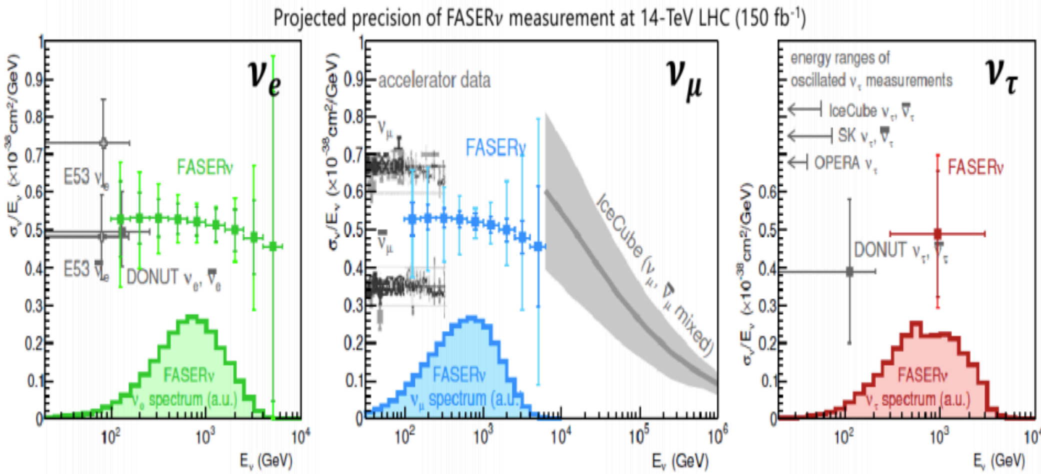
particles from LHC beam line

Measured angle in emulsion detector

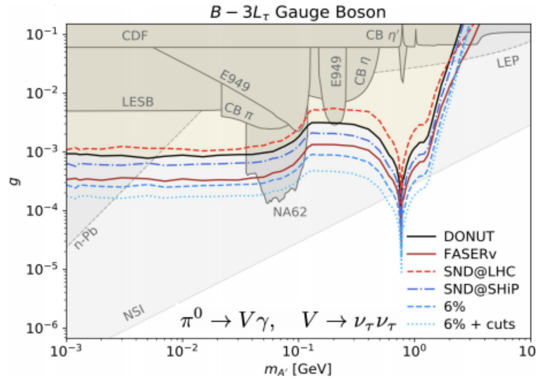
Physics Potential

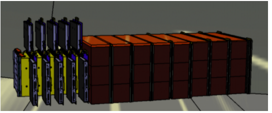
- Measure neutrino cross-section for all species in collider-energy range (100GeV-TeV)

- FASERν will detect ~10 tau neutrino interactions.
  - Thousands of tau neutrino events possible at HL-LHC, allowing for precision studies of tau neutrino properties
- FASERν will record neutrino interaction event shapes with high precision.
  - This could be useful for validation/tuning of neutrino event generators.
- SM neutrino oscillations are expected to be negligible at FASERν. However, sterile neutrinos with mass ~40eV can cause oscillations.
  - FASERν could act as a *short-baseline neutrino experiment.*



- The tau neutrino flux small in SM. A new light weakly coupled gauge bosons decaying into tau neutrinos could significantly enhance the tau neutrino flux.

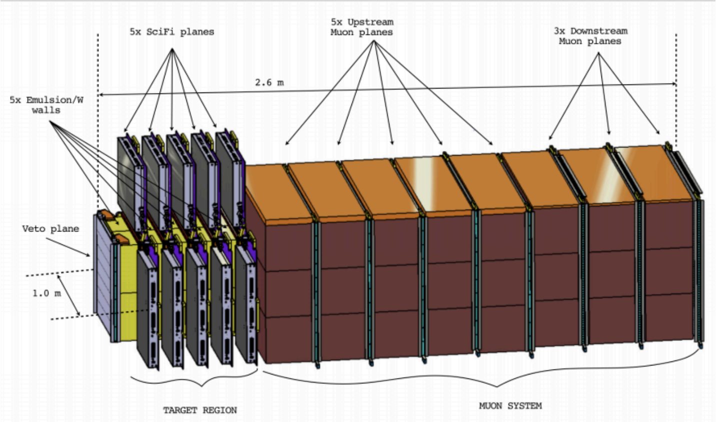




Scattering and Neutrino Detector

SND@LHC: Technical Proposal

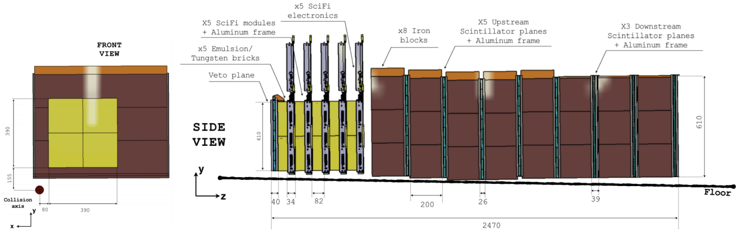
- SND@LHC is a compact experiment proposed to make measurements with neutrinos of all three neutrino flavours from the LHC in the pseudo-rapidity range of $7.2 < \eta < 8.6$.
- This range of pseudo-rapidity is currently unexplored , and a large fraction of the corresponding neutrinos originate from charmed-hadron decays.
- Together with the FASERν experiment, SND@LHC will first observe the neutrinos produced by a collider
- SND@LHC is sensitive to Feebly Interacting Particles (FIP) through scattering off atoms in the detector target.
- The direct-search strategy gives the experiment sensitivity in a region of the FIP mass-coupling parameter space that is complementary to other indirect searches

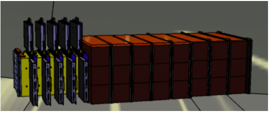


SND Detector

- Hybrid detector optimised for the identification of three neutrino flavours and for the detection of feebly interacting particles
- VETO PLANE: tag penetrating muons
- TARGET REGION: - Emulsion cloud chambers (Emulsion+Tungsten) for neutrino interaction detection - Scintillating fibers for timing information and energy measurement
- MUON SYSTEM: iron walls interleaved with plastic scintillator planes for fast time resolution and energy measurement

- target: 830 kg of tungsten
- angular acceptance: $7.2 < \eta < 8.6$, off-axis location
- electromagnetic calorimeter: $\sim 84X_0$, sampling every $17X_0$
- hadronic calorimeter: $\sim 10\lambda$ (muon system alone – 8λ), sampling every λ

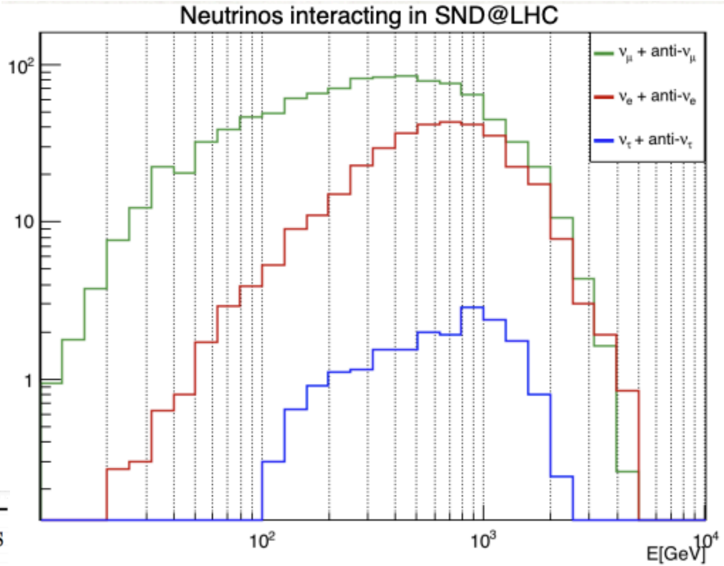




SND@LHC Neutrino Expectation

NEUTRINO EXPECTATIONS

- Expectations in 150 fb-1 ‣ Upward crossing angle
Neutrino production in LHC pp collisions performed with DPMJET3 embedded in FLUKA
- Particle propagation towards the detector through FLUKA model of LHC accelerator
-



Flavour	Neutrinos in acceptance $\langle E \rangle$ (GeV)	Neutrinos in acceptance Yield	CC neutrino interactions $\langle E \rangle$ (GeV)	CC neutrino interactions Yield	NC neutrino interactions $\langle E \rangle$ (GeV)	NC neutrino interactions Yield
ν_μ	145	2.1×10^{12}	450	730	480	220
$\bar{\nu}_\mu$	145	1.8×10^{12}	485	290	480	110
ν_e	395	2.6×10^{11}	760	235	720	70
$\bar{\nu}_e$	405	2.8×10^{11}	680	120	720	44
ν_τ	415	1.5×10^{10}	740	14	740	4
$\bar{\nu}_\tau$	380	1.7×10^{10}	740	6	740	2
TOT		4.5×10^{12}		1395		450

Ideas in view of a future forward facility at HL-LHC

- 2 fully active detectors, both forward but off-axis
- 1: η region ~ 8
- 2: η region ~ 4.5
- No shield from other experiments
- Shielded locations (from LHC IP) desirable, similar to TI18
- SND2 to be located closer to improve the acceptance (keeping the same η)

Useful link to LHCb measurements
Sensitive to neutrinos from W, Z decays