Physics Opportunities with High Energy Neutrinos at the HL-LHC

Dark Sectors and Light Long-Lived Particles Cross Frontier Meeting

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Felix Kling

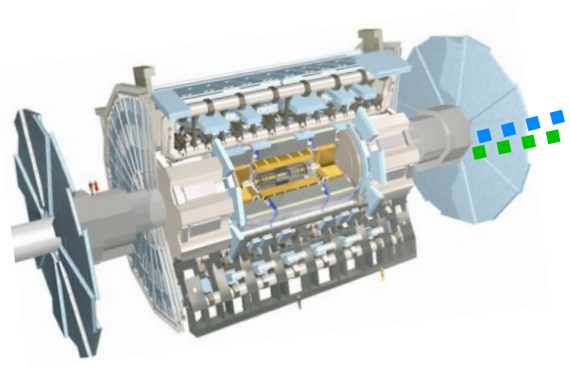
HEISING-SIMONS FOUNDATION
SIMONS FOUNDATION
SLAC NATIONAL ACCELERATOR LABORATORY

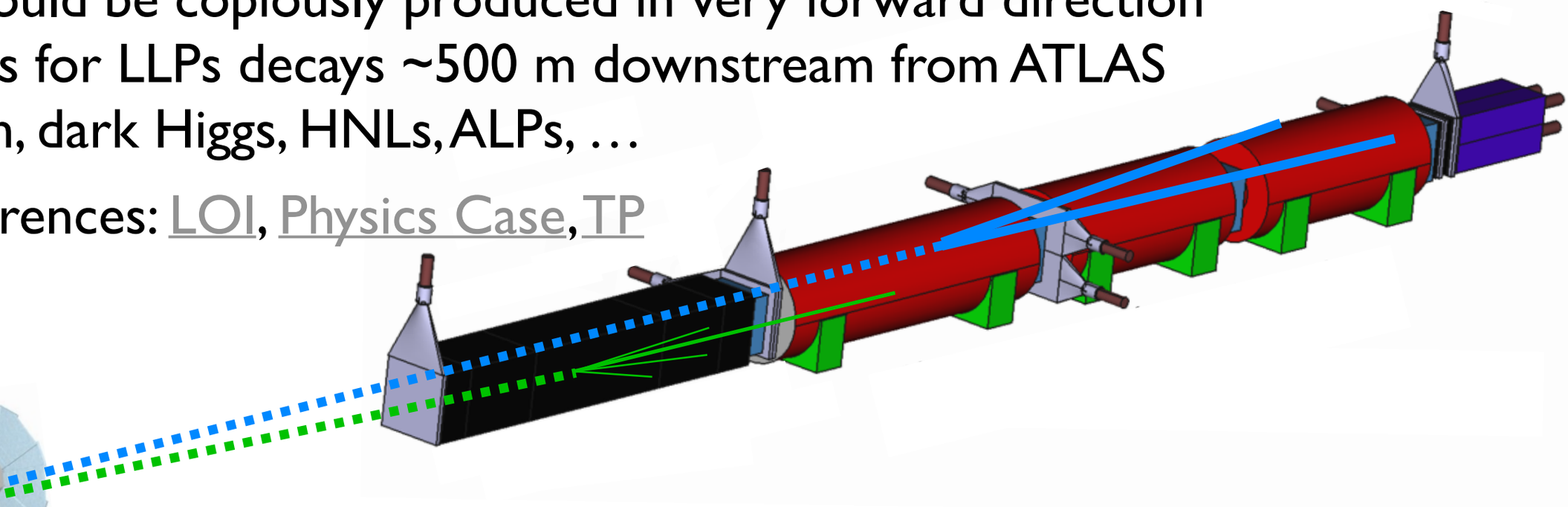
send questions to: felixk@slac.stanford.edu

The FASER experiment

Long-Lived Particle Searches

* light LLPs could be copiously produced in very forward direction
* FASER looks for LLPs decays ~500 m downstream from ATLAS
* dark photon, dark Higgs, HNLs, ALPs, …
* FASER References: LOI, Physics Case, TP





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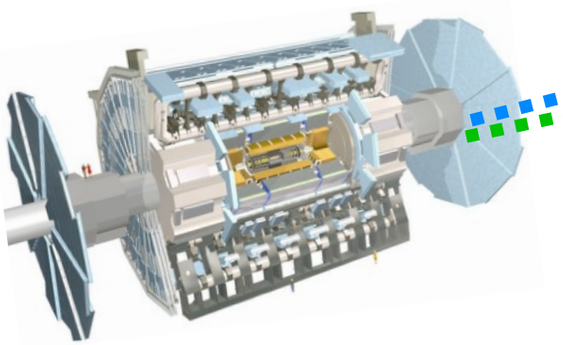

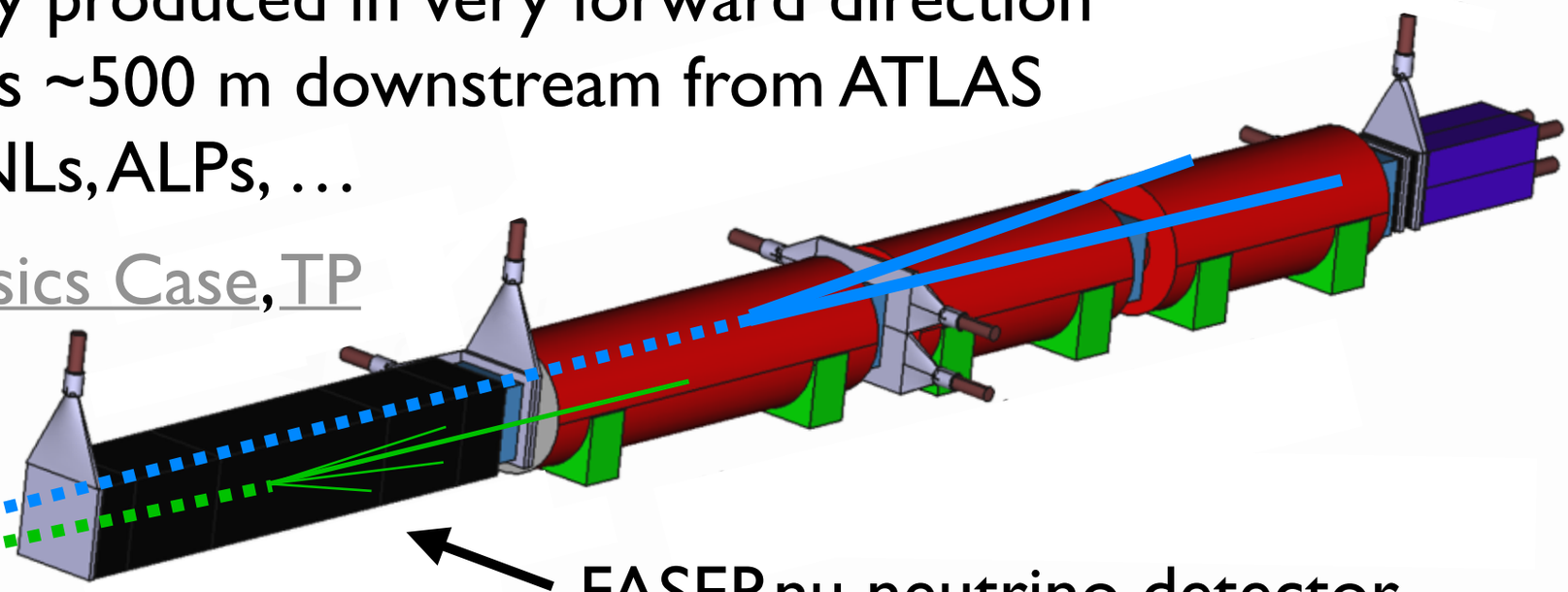

FASERnu neutrino detector

Neutrino Measurements

* ATLAS provides intense forward neutrino beam
  i) collimated ii) E ~ TeV iii) all flavors: $\pi \rightarrow \nu_\mu$, $K \rightarrow \nu_e$, $D \rightarrow \nu_\tau$
* FASERnu will see ~10^4 ν_μ, ~10^3 ν_e, ~10 ν_τ during LHC Run 3
* FASERnu References: Proposal, TP

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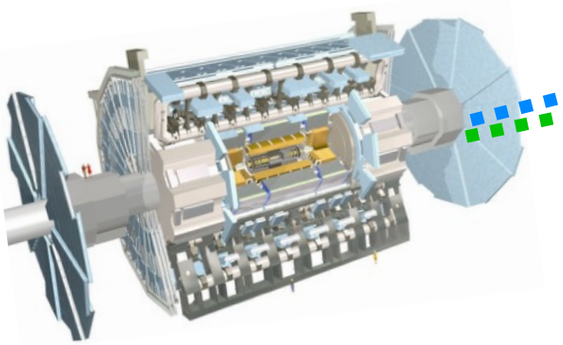

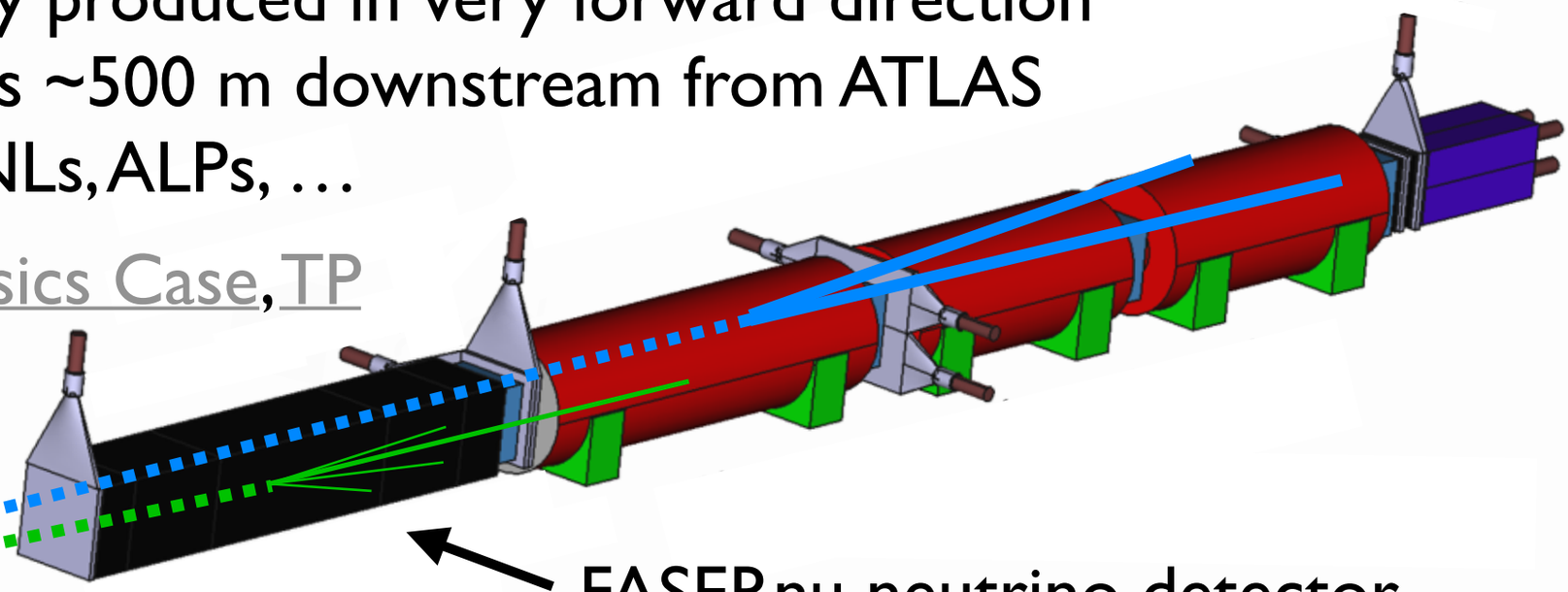

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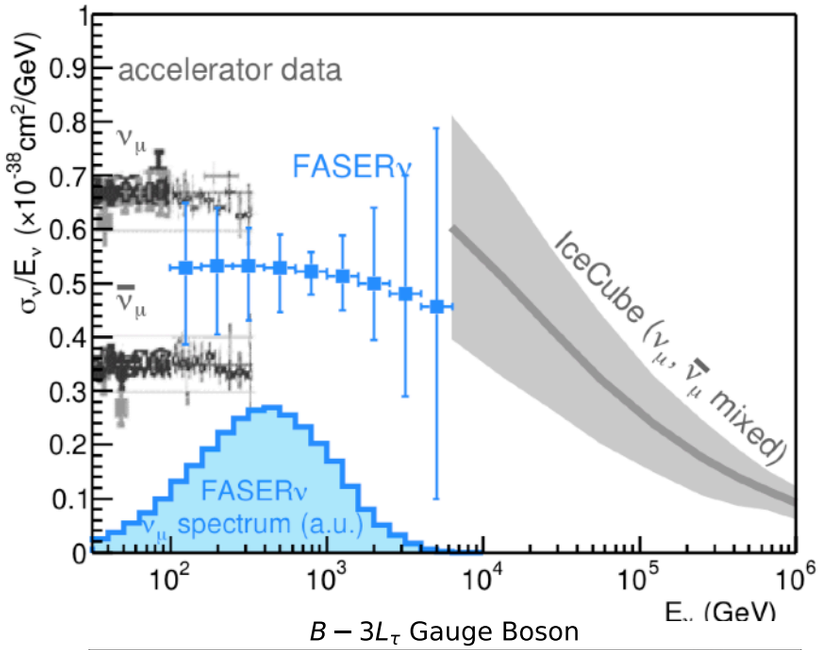
FASERnu paves the way for a high-energy neutrino program at colliders.
What is the physics potential for forward neutrino physics at the LHC?
What detector would we need at the HL-LHC era?

LHC Neutrino Physics Potential

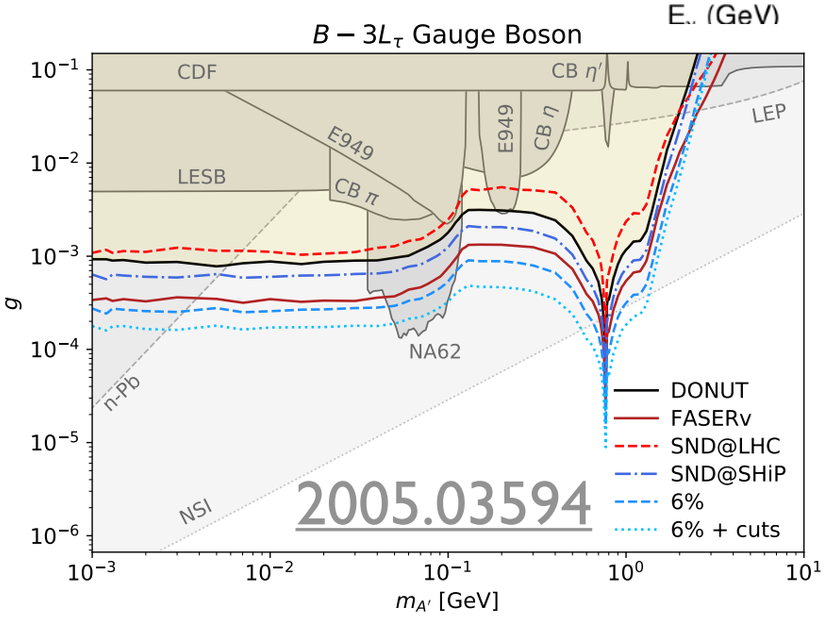
Neutrino Cross Sections at TeV energies

* first measurement of DIS neutrino interaction cross section at TeV energies
* additional sensitivity to neutrino-electron scattering, neutrino tridents or NSI



Tau Neutrino Physics

* 20 ν_τ at FASERnu, thousands possible at HL-LHC
* ν_τ cross section over a wide range of energies
* ν_τ flux as a laboratory for new physics
* test lepton universality in neutrino interactions
* ν_τ c $\rightarrow \tau$ b as a probe B-decay anomalies b$\rightarrow$c τ ν_τ
* ν_τ magnetic moment



Event Shapes, Kinematics and PDFs

* high spatial resolution of emulsion detector resolves shape of ν-interaction
* valuable input for MC tuning (GENIE)
* ν s $\rightarrow$ ℓ c as probe of strange quark PDF
* sensitivity to nuclear effects, variety of nuclear targets possible
* sensitivity to new physics effects, e.g. neutrino-philic forces

LHC Neutrino Physics Potential

Forward Particle Production

* mostly unconstrained by existing LHC detectors
* $\pi \rightarrow \nu_\mu$, $K \rightarrow \nu_e$: improve and validate hadronic interaction models used in cosmic ray physics
* $D \rightarrow \nu_\tau$: constrains forward charm production
  - prompt atmospheric neutrino flux at IceCube
  - sensitive to intrinsic charm and gluon PDF at low x

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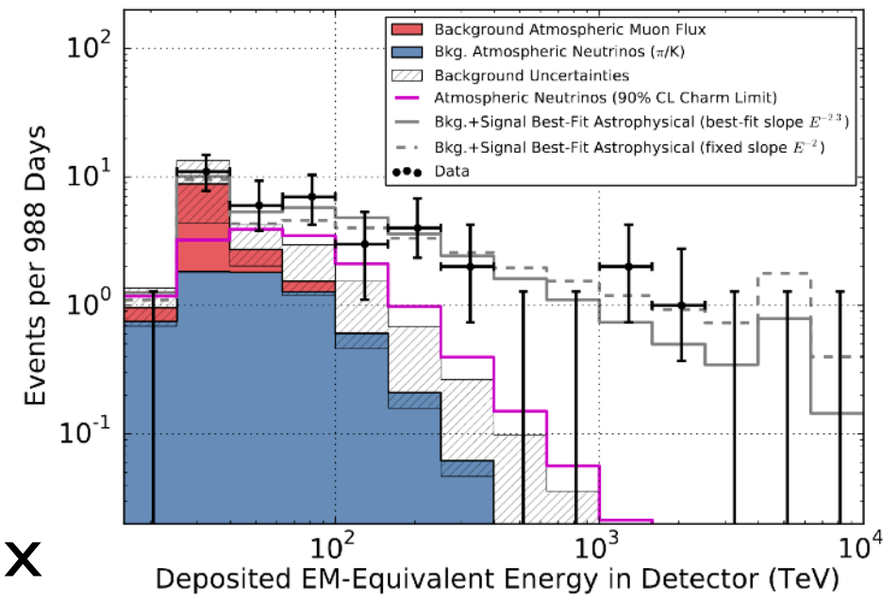
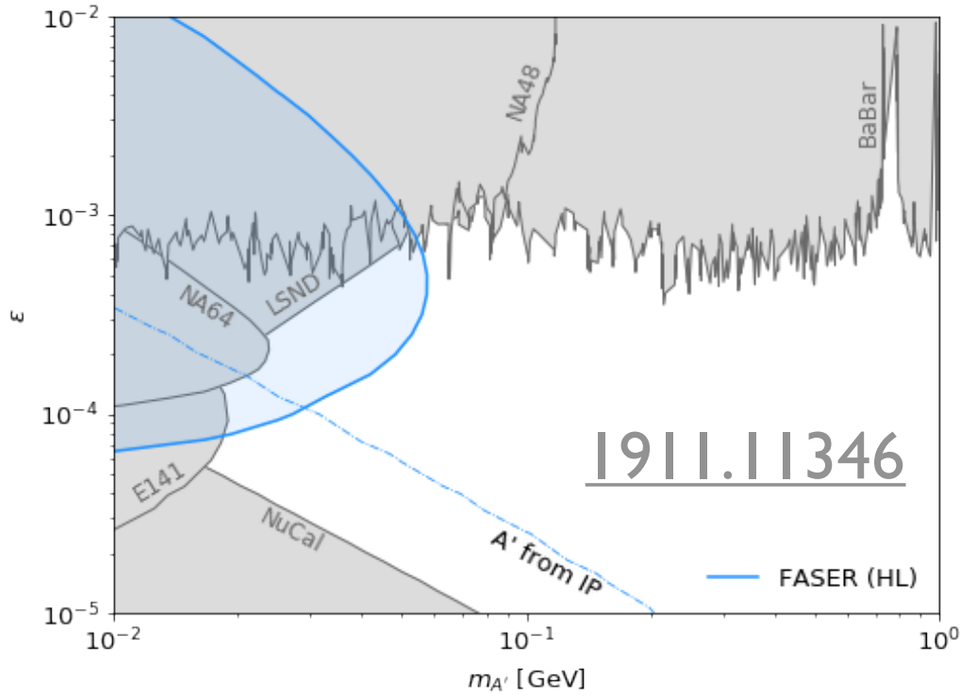


Sterile Neutrino Oscillations

* use forward neutrino detector as short baseline experiment
* sterile neutrinos with mass ~40eV can cause oscillations

Further BSM Prospects

* $\pi \rightarrow \gamma A' \rightarrow \gamma XX$ produces DM beam with TeV energies directed at FASERnu: search for DM scattering in neutrino detector
* secondary LLP production in FASERnu with LLP decay in FASER
* sizable flux of TeV muons: use FASERnu as high-energy muon beam dump facility



Snowmass and Outlook

- FASERnu will soon measure the first neutrinos at the LHC. It also paves the way for a high-energy forward neutrino physics program at the HL-LHC as well as future colliders, and motivated a dedicated Forward Physics Facility.

  * See Jonathan's talk

- We propose a detector with roughly ten times the mass of FASERnu operating at the HL LHC. With 3ab^{-1} of luminosity, such a detector would collect roughly ~$10^5 \nu_e$, ~10^6 ν_μ and ~10^3 ν_τ at TeV energies. This opens up many new opportunities for neutrino physics, new physics searches and QCD, significantly extending the LHC's physics program.

- We would like to invite the Snowmass community to help us explore the physics potential of this program.

- See Snowmass LOI SNOWMASS21-NF0-EF0-IF0-006