

# Probing the Intensity Frontier at the LHC

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DM@LHC 2020

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# **Part 1: DM at the LHC**

# **Part 2: Neutrinos at the LHC**

# DM at the LHC: iDM

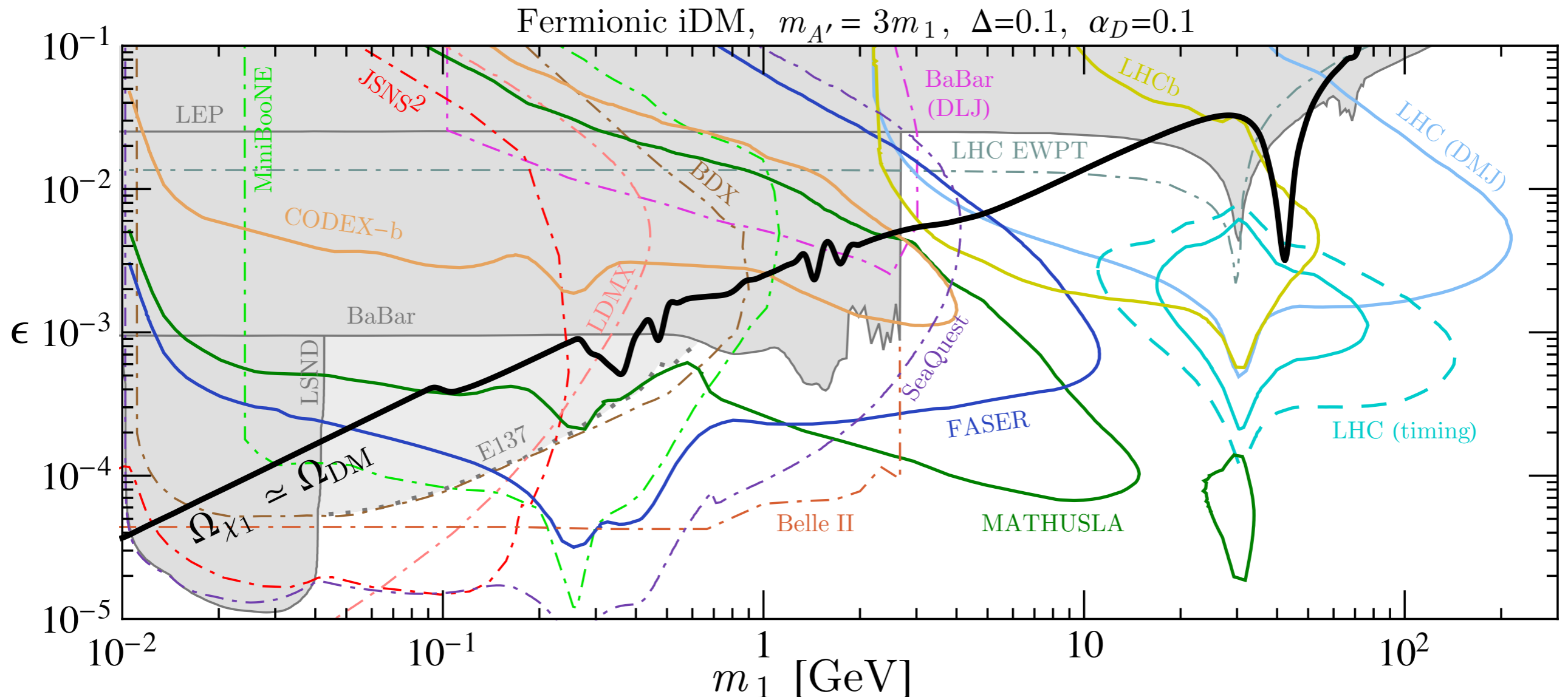
- concrete DM example with LLP: inelastic DM

\* two dark particles  $\chi_i$ , coupled non-diagonally to  $A'$

\* phenomenological lagrangian:

$$\mathcal{L} \subset \frac{1}{2} m_{A'} A'_\mu A'^\mu - \bar{\chi}_i (i\partial\!\!\!/ - m_i) \chi_i + \bar{f}_i (i\partial\!\!\!/ - \epsilon e q_i A'_\mu) f + i e_D A'_\mu \bar{\chi}_1 \gamma^\mu \chi_2$$

\* mass splitting: avoids direct detection constrains



# DM at the LHC: iDM

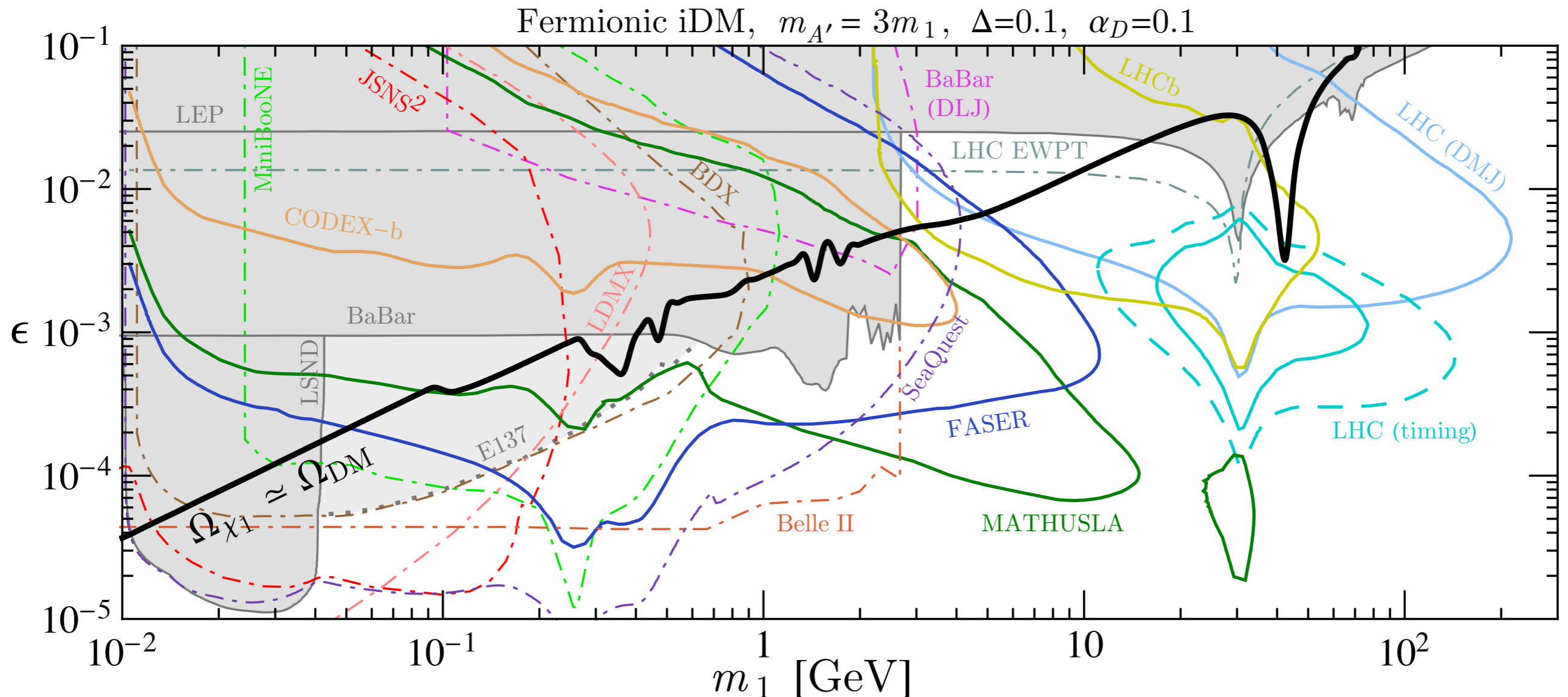
## Intensity frontier experiments

- \* dedicated experiments
- \* b-factories
- \* neutrino experiments
- \* nuclear physics experiments

## LHC

- \* far detectors
- \* displaced muon jets
- \* timing

[Berlin, FK [1810.01879](#)]



# DM at the LHC: iDM

- some updates on **SeaQuest**:

\* SeaQuest (E906): run with A' trigger in 2017;

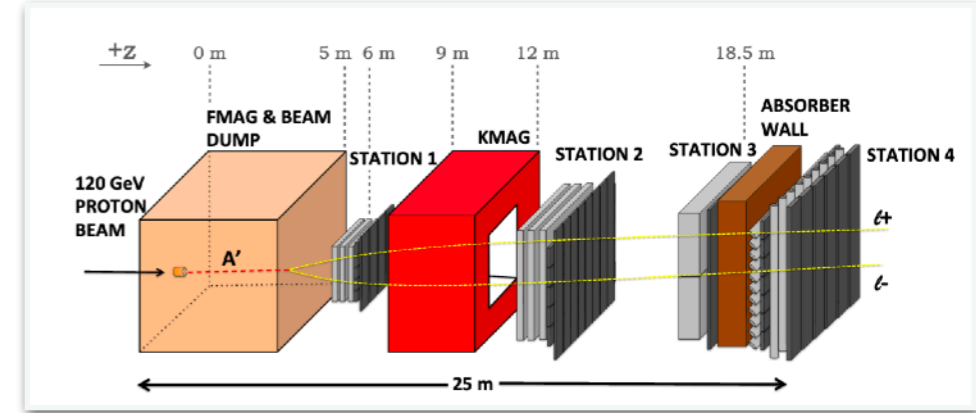
no physics results expected

\* SpinQuest (E1039): run 2020-2022;

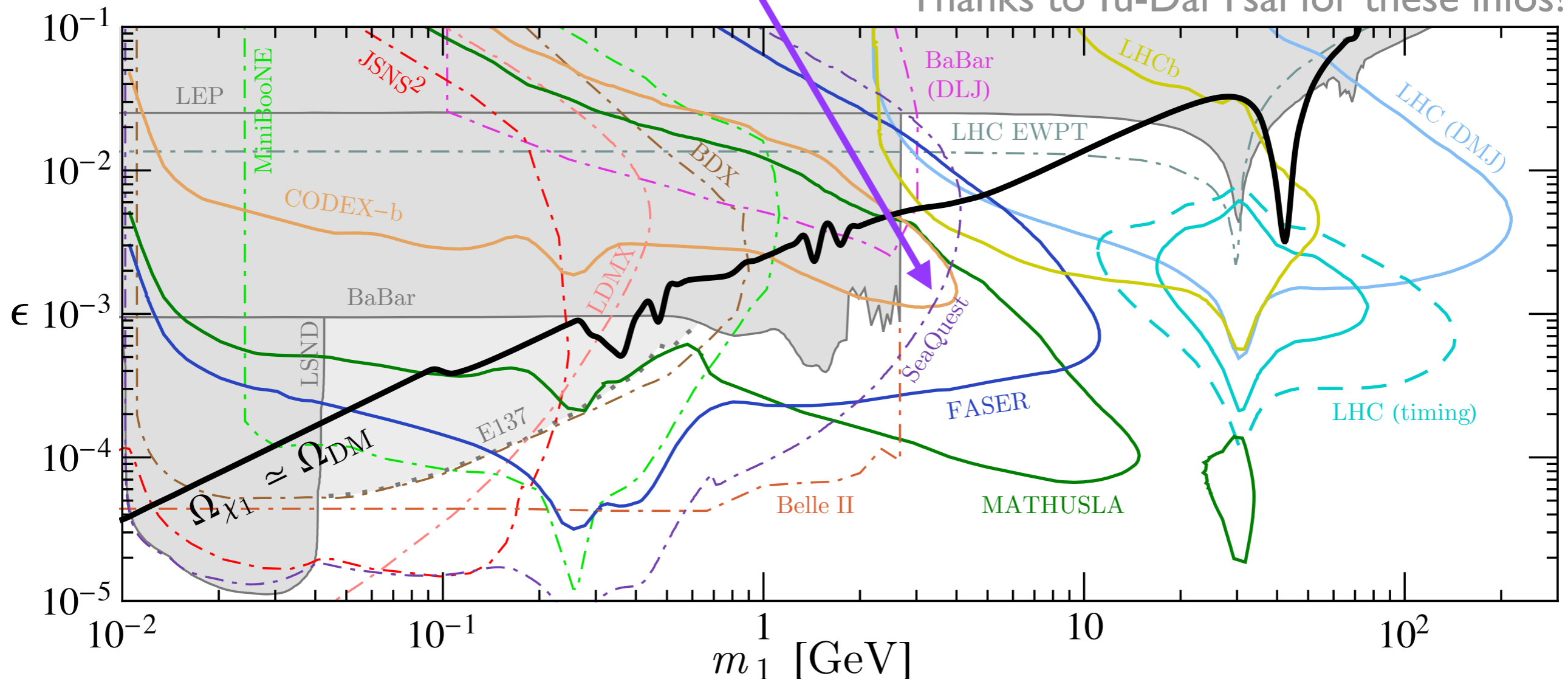
A' searches in di-muon channel

\* DarkQuest: add EMCAL in main detector, see [1804.00661](#), conduct when beam is off

\* LongQuest: add EMCAL 10 m behind main detector, see [1908.07525](#)



Thanks to Yu-Dai Tsai for these infos!

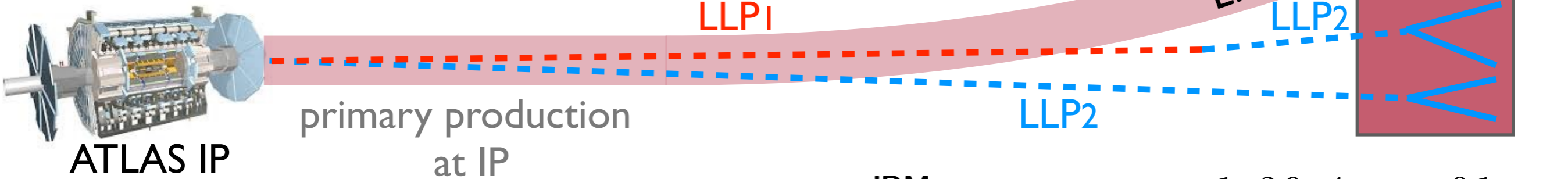


# DM at the LHC: secondary production

- secondary LLP production

[K. Jodłowski, FK, L. Roszkowski, S. Trojanowski: [1810.01879](https://arxiv.org/abs/1810.01879)]

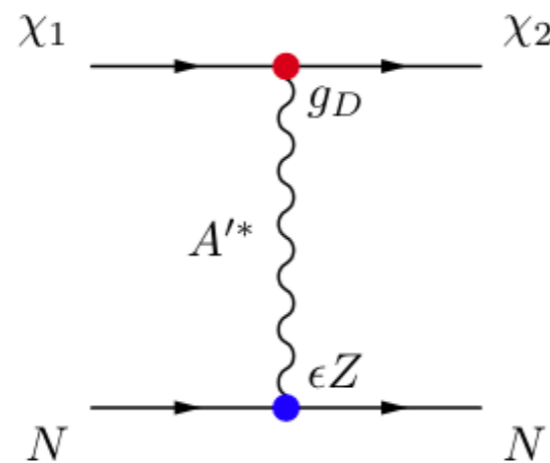
- \* additional production mode, occurring close to detector
- \* extends reach to smaller lifetimes
- \* for FASER, SHiP and MATHUSLA



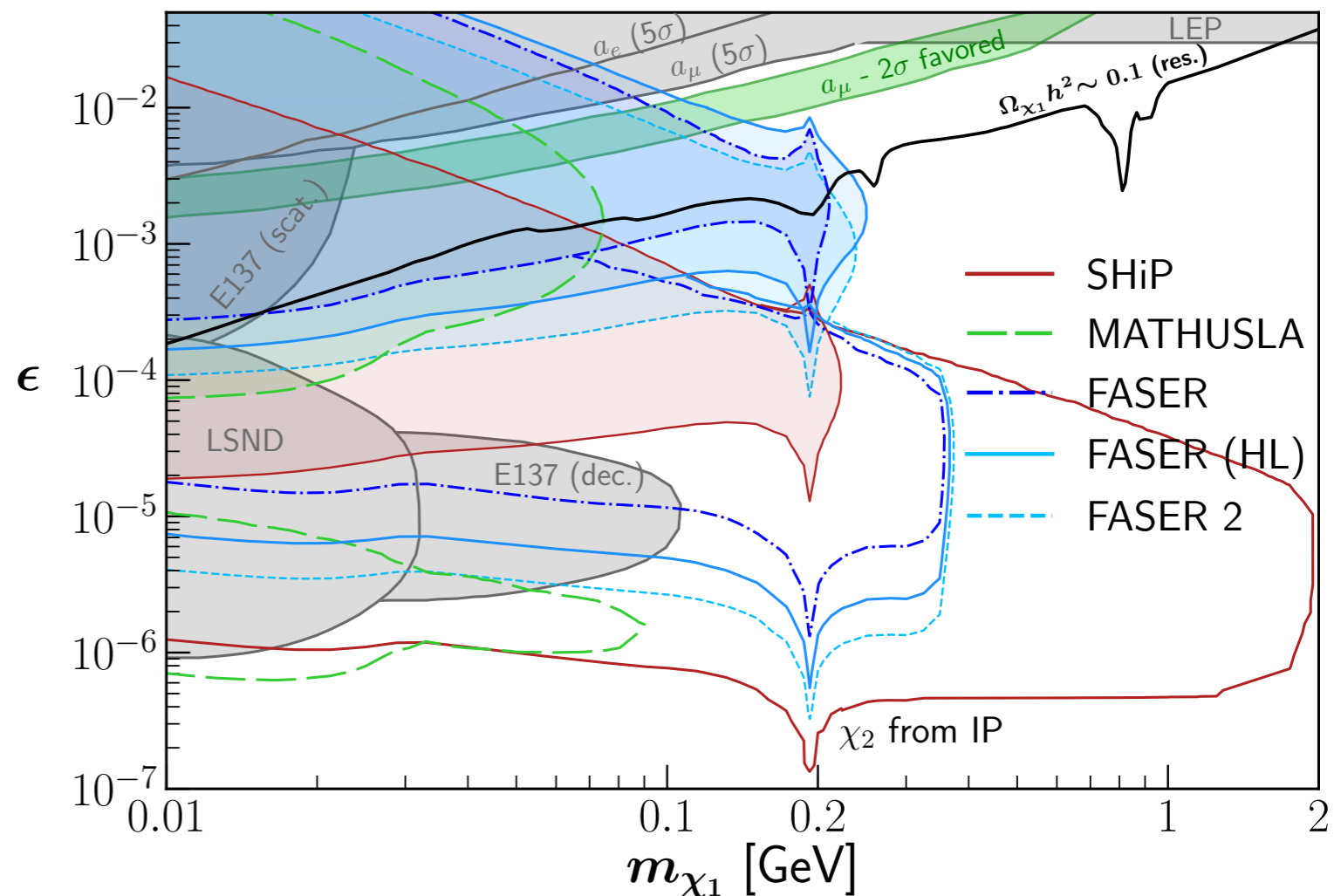
- inelastic DM

- \*  $X_1 = \text{LLP}_1, X_2 = \text{LLP}_2$
- \* primary production  $\pi^0 \rightarrow \gamma X_1 X_2$
- \* secondary production:  $X_1 N \rightarrow X_2 N$
- \* decay:  $X_2 \rightarrow X_1 e e$

- \* enhanced reach
- \* relevant for DM, Be8, g-2



iDM:  $m_{\chi_1} : m_{\chi_2} : m_{A'} = 1 : 2.9 : 4, \alpha_D = 0.1$

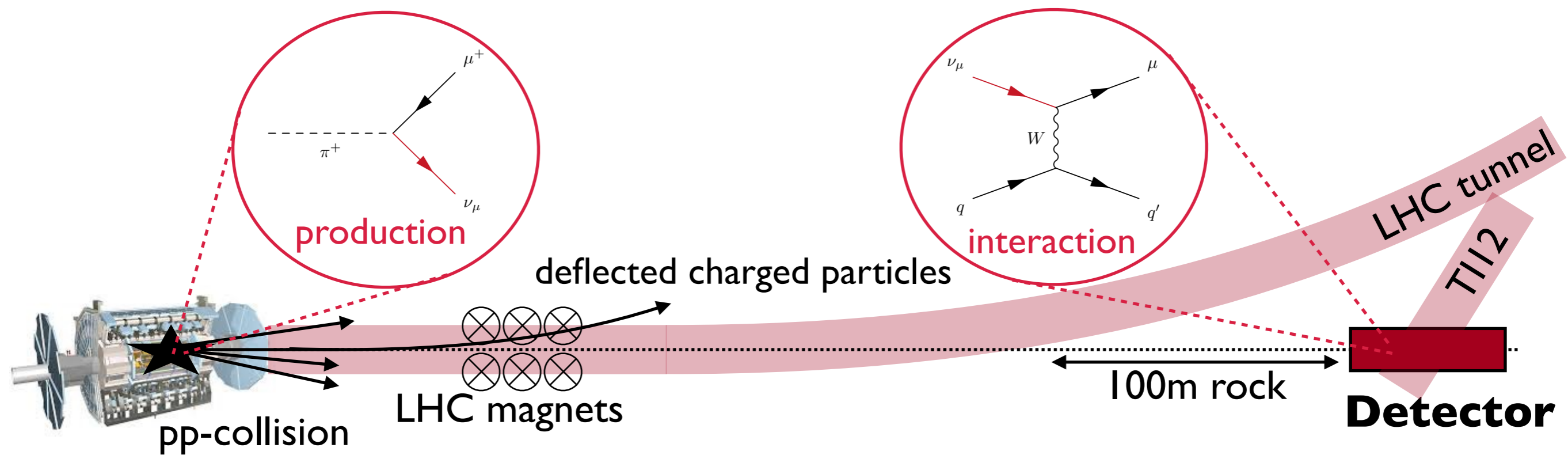


# **Part 1: DM at the LHC**

# **Part 2: Neutrinos at the LHC**

# Neutrinos at the LHC

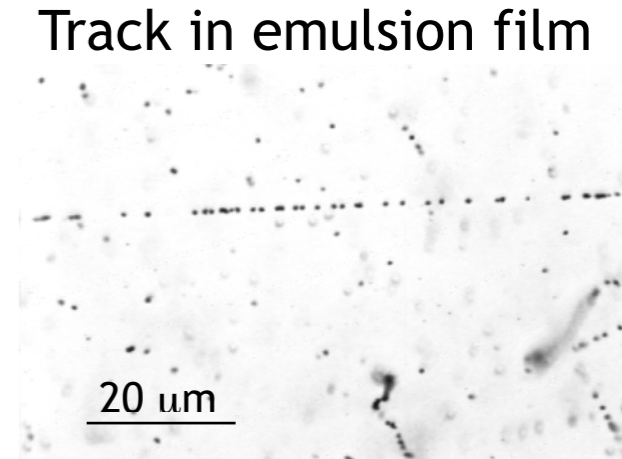
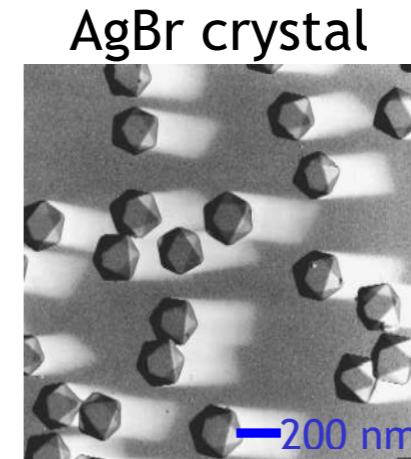
- neutrinos detected from many sources, but not from colliders
- many neutrinos at LHC produced in  $\pi$ , K, D meson decay
  - provides intense energetic collimated neutrino beam in forward direction
  - \*  $\sim 10^{12}$  neutrino in LHC Run 3
  - \*  $E \sim \text{TeV}$
  - \*  $\theta \sim \text{mrad}$
  - \* all flavors
- 480m downstream from ATLAS, this beam passes through (unused) side tunnel
  - place neutrino detector directly into this beam





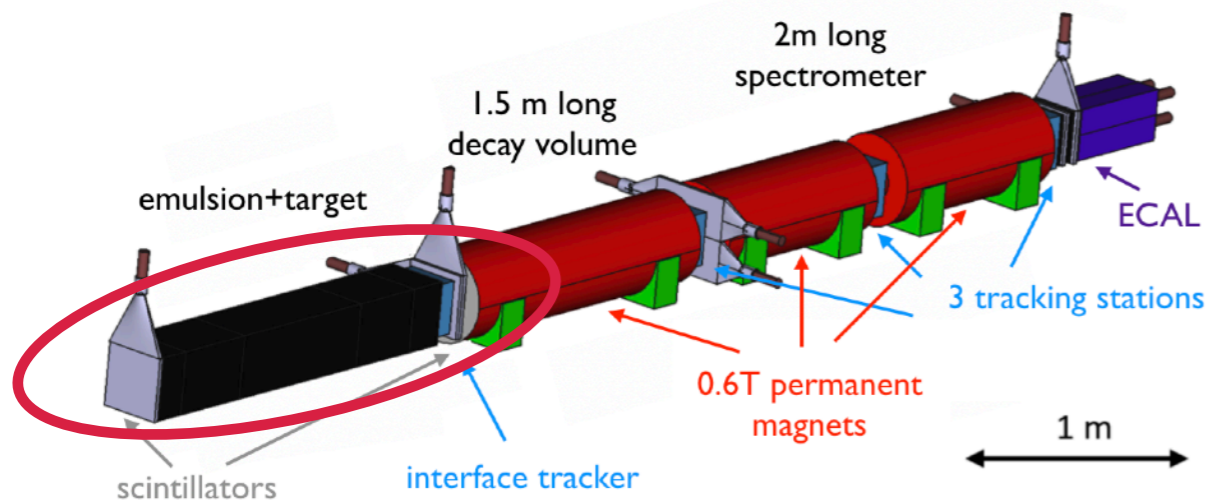
# Neutrinos at the LHC

- two recent proposals for LHC neutrino detectors
  - emulsion detector technology
    - \* 3D tracking devices with 50 nm spatial precision
    - \* flavor identification
    - \* energy measurements



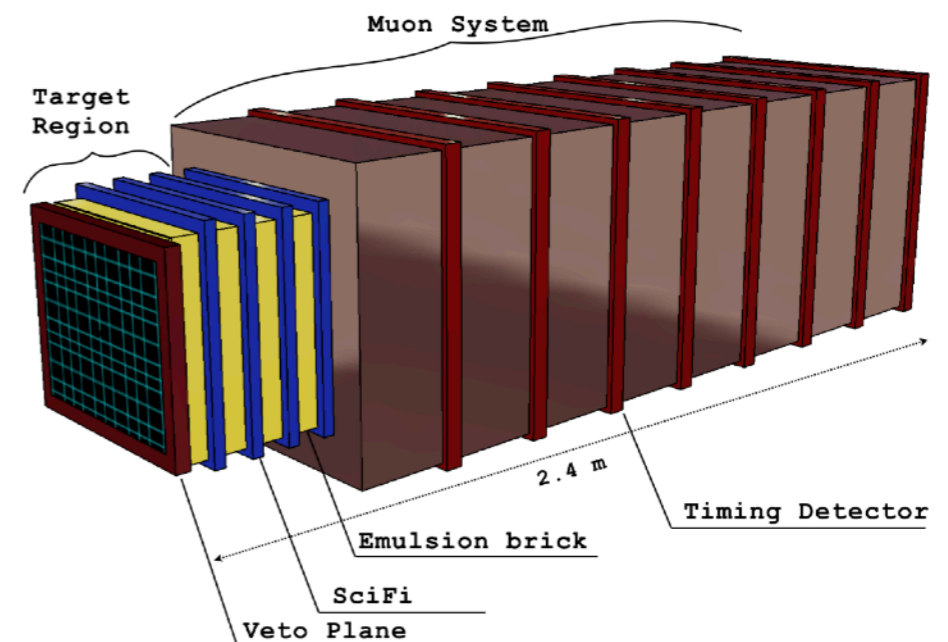
## FASERv

- \* tungsten target with 1.2 ton mass
- \*  $\sim 20000 \nu_\mu$ ,  $\sim 2000 \nu_e$ ,  $\sim 20 \nu_\tau$
- \* Letter of Intent: [1908.02310](#)
- \* Technical Proposal: [2001.03073](#)
- \* approved and funded

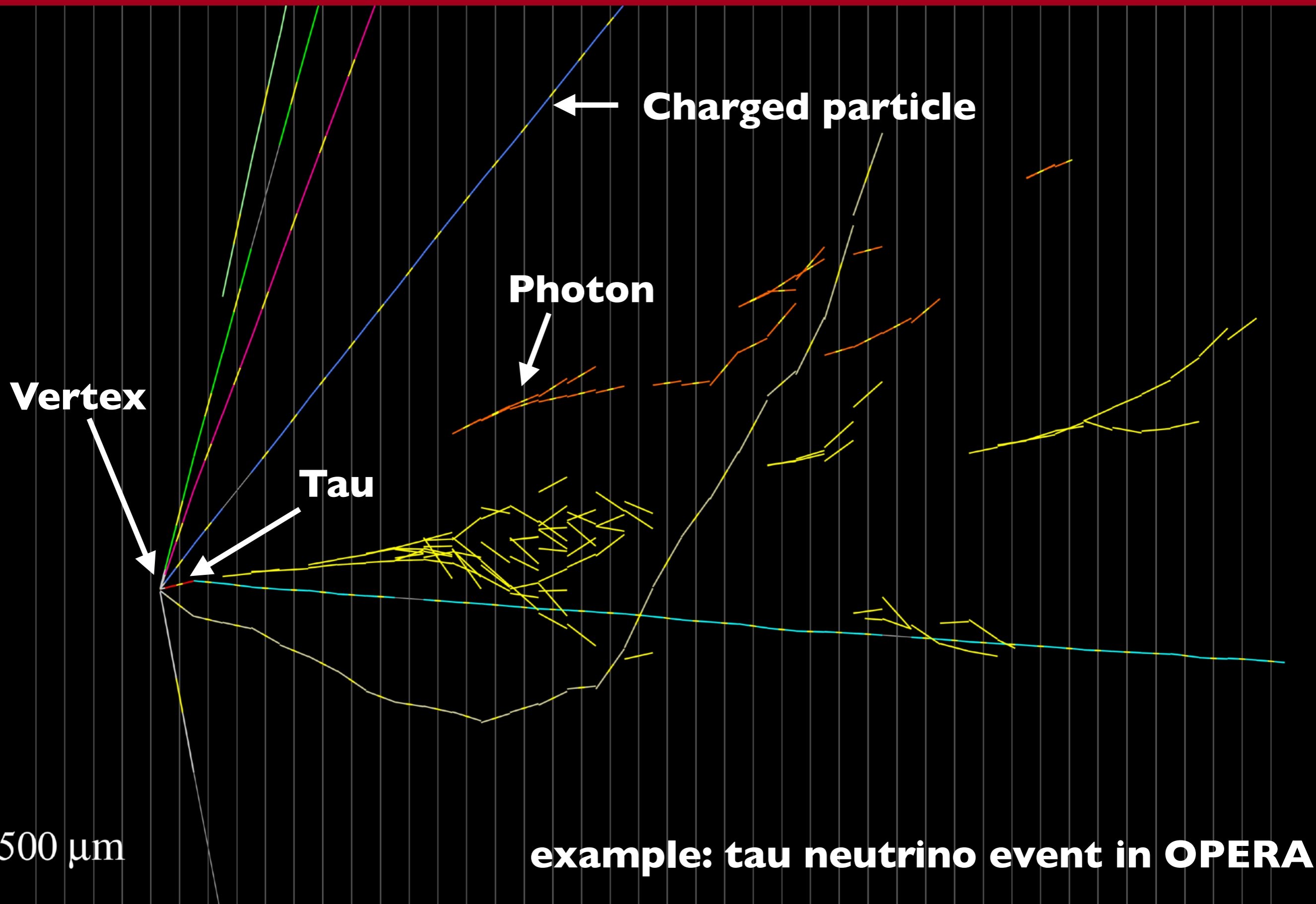


## SND@LHC

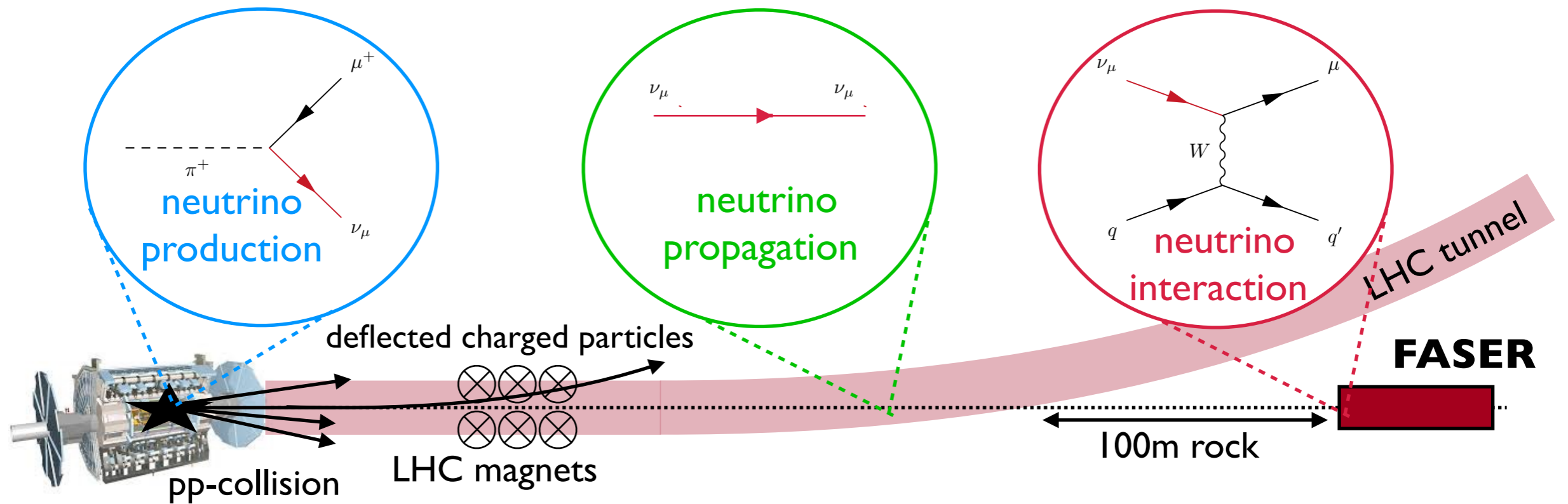
- \* lead tungsten target with 380 kg mass
- \*  $\sim 1000 \nu_\mu$ ,  $\sim 100 \nu_e$ ,  $\sim 10 \nu_\tau$
- \* Letter of Intent: [2002.08722](#)



# Emulsion Detectors



# LHC Neutrino Physics Potential



In the following, I will present some ideas\*.

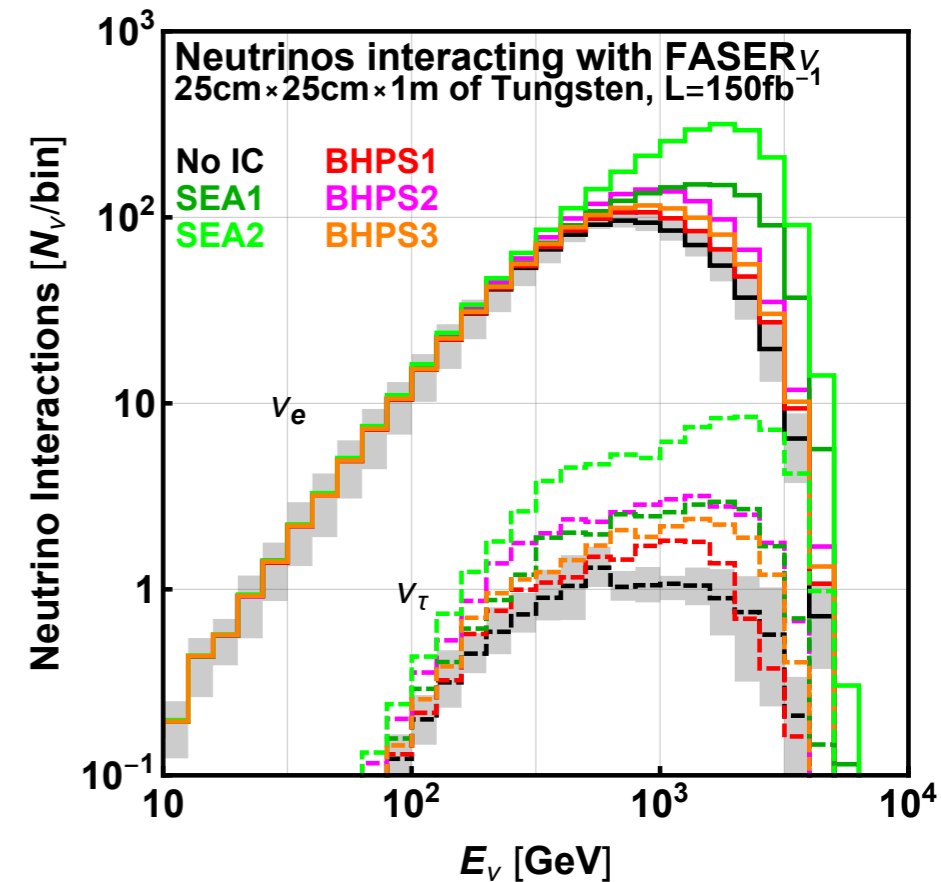
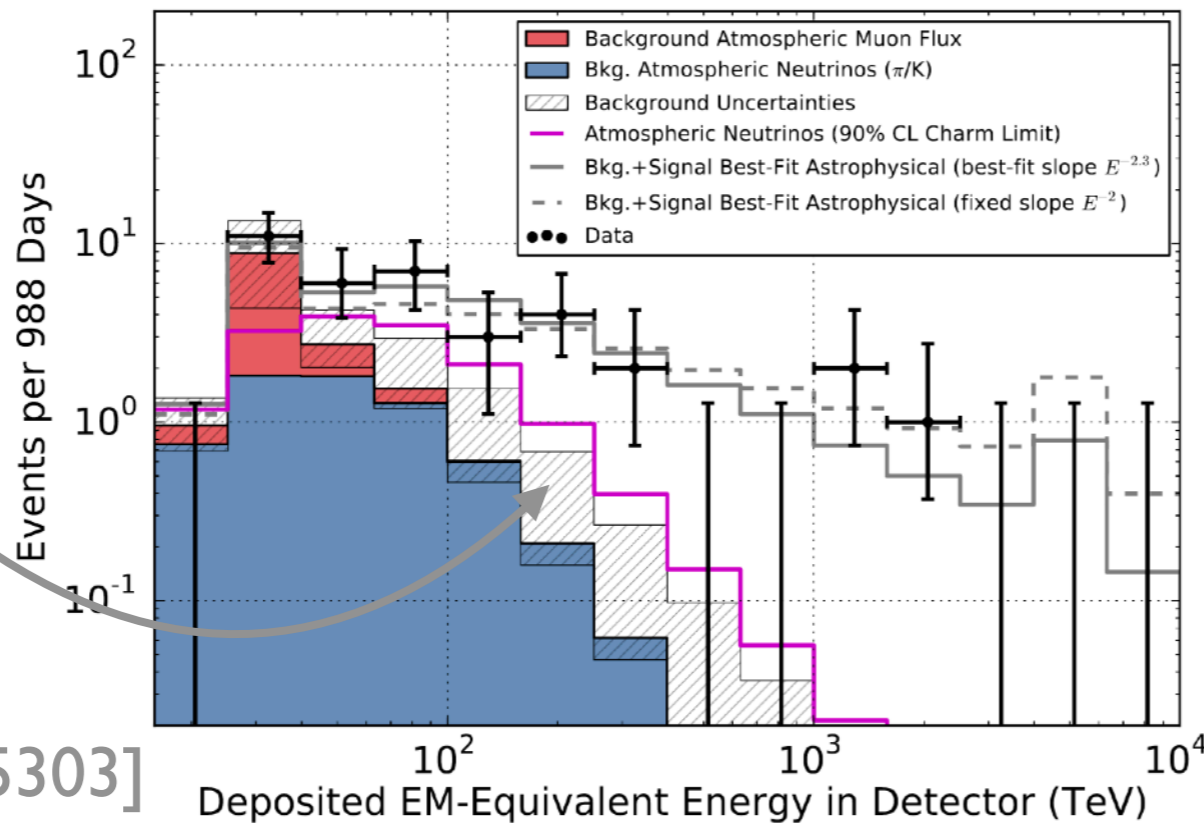
Most of them were not investigated in detail yet.

\* Warning: not all ideas will work

# LHC Neutrino Physics Potential

## Neutrino Production

- use observed neutrino spectrum to measure neutrino production rate
- validate/improve/constrain **hadronic interaction models** or **PDFs**
  - \* used for LHC and cosmic rays physics
  - \* example: **intrinsic charm**
  - \* important input for HE neutrino observatories (similar CM energy)



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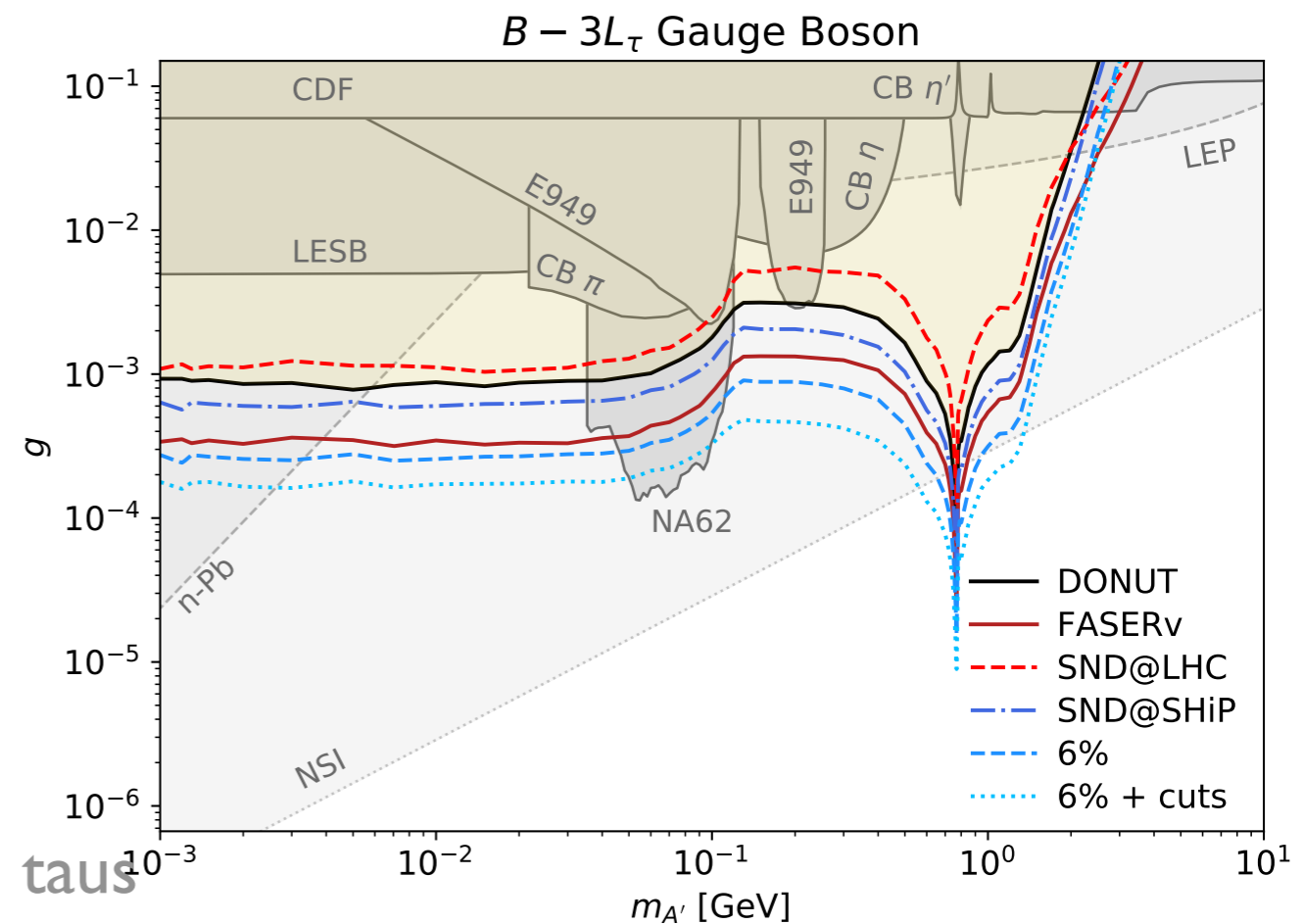
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## - **BSM** tau neutrino **production modes**

- \* tau neutrino flux small in SM
- \* new light weakly coupled particles could decay into tau neutrinos

$$\pi^0 \rightarrow V\gamma, \quad V \rightarrow \nu_\tau \nu_\tau$$

example: vector boson  
with coupling to quarks and taus  
[FK, [2005.03594](#)]



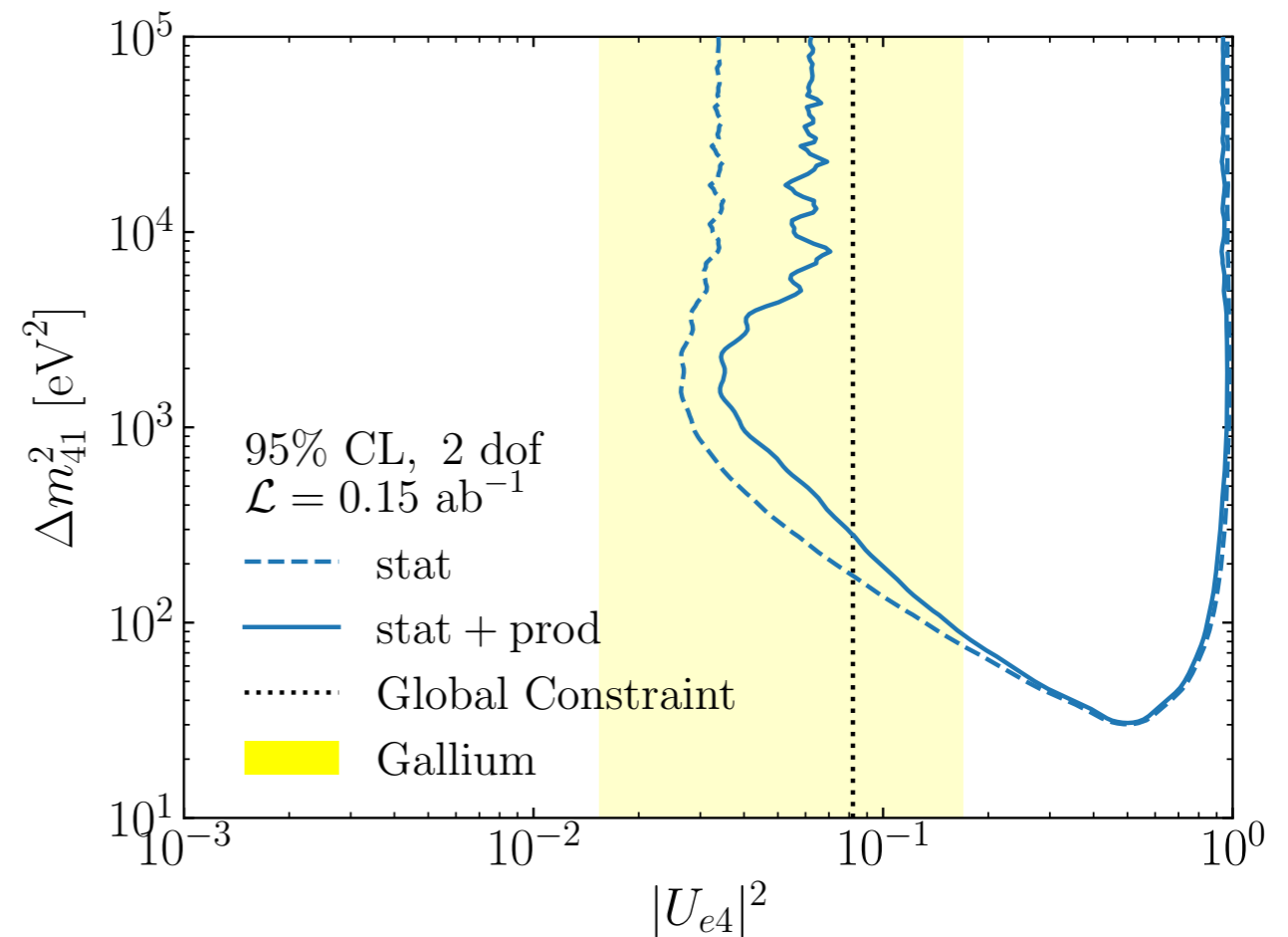
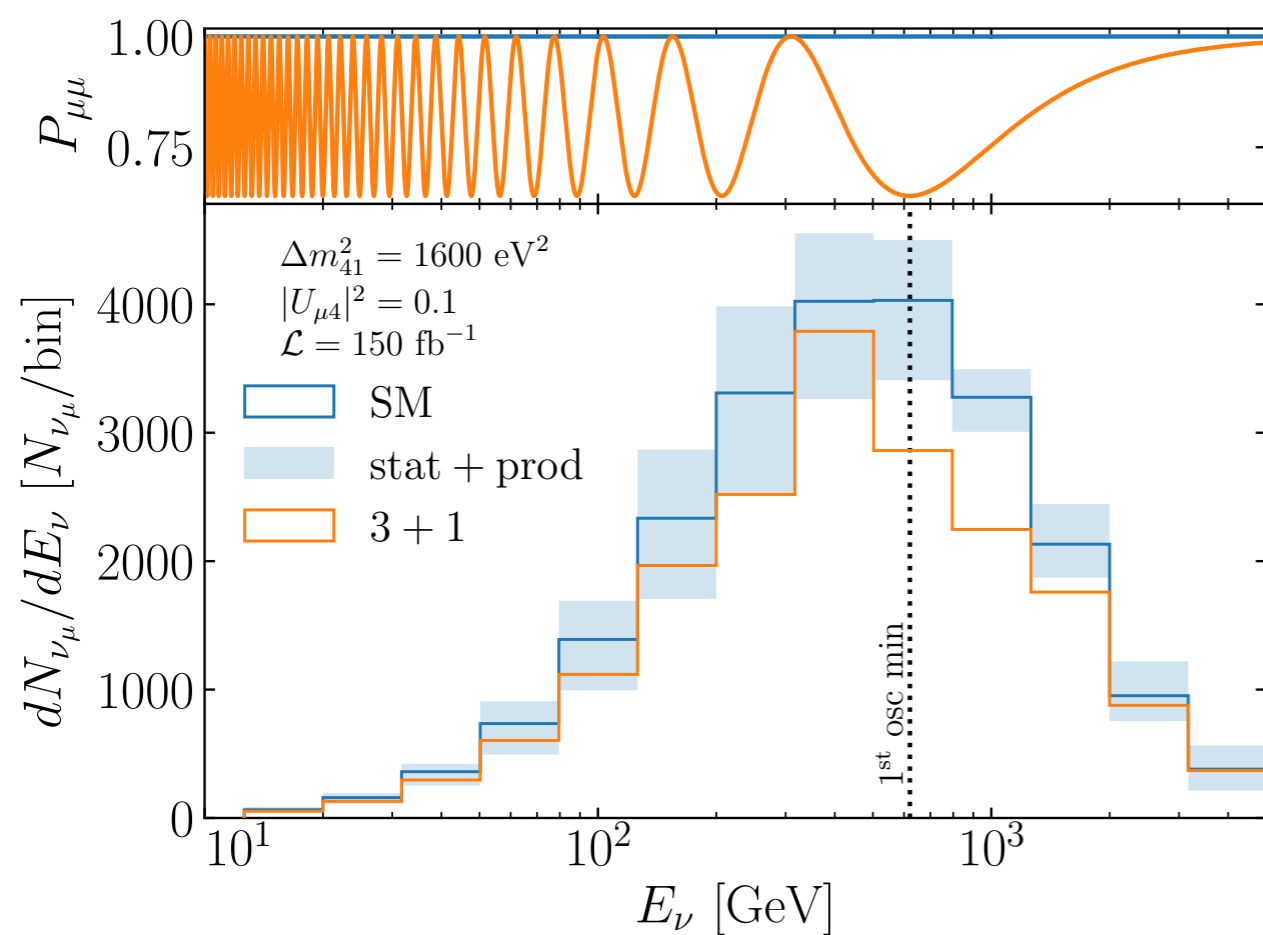
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# LHC Neutrino Physics Potential

## Neutrino Propagation

- no oscillations in SM
- maybe we can use FASERv as short-baseline experiment
- **sterile neutrinos** with mass  $\sim 40\text{eV}$  can cause **oscillations**
- \* changes shape of energy spectrum

- how about **NSI**?  $\mathcal{L} \sim \epsilon_{ij}^f (\bar{\nu}_i \gamma_\mu \nu_j) (\bar{f} \gamma^\mu f)$

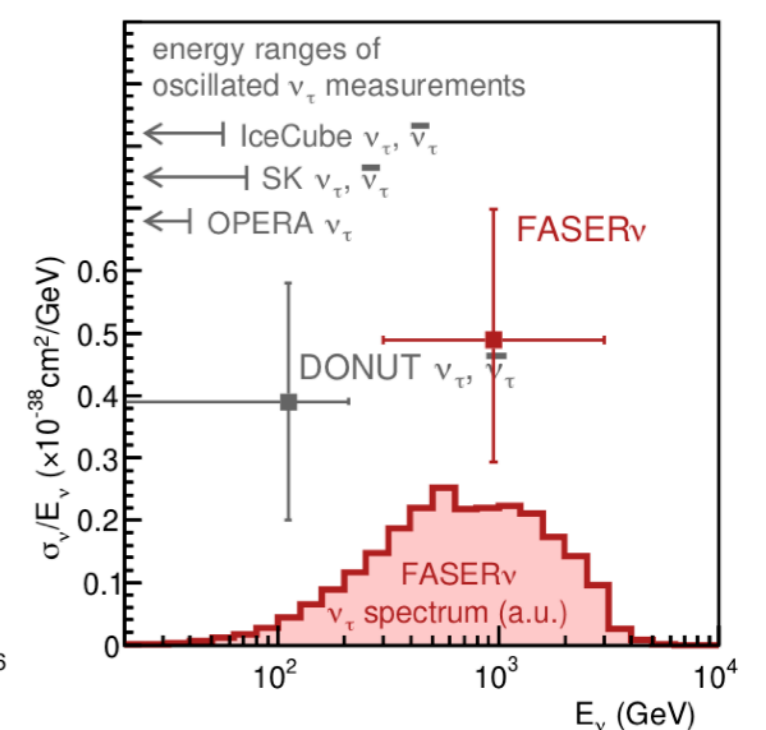
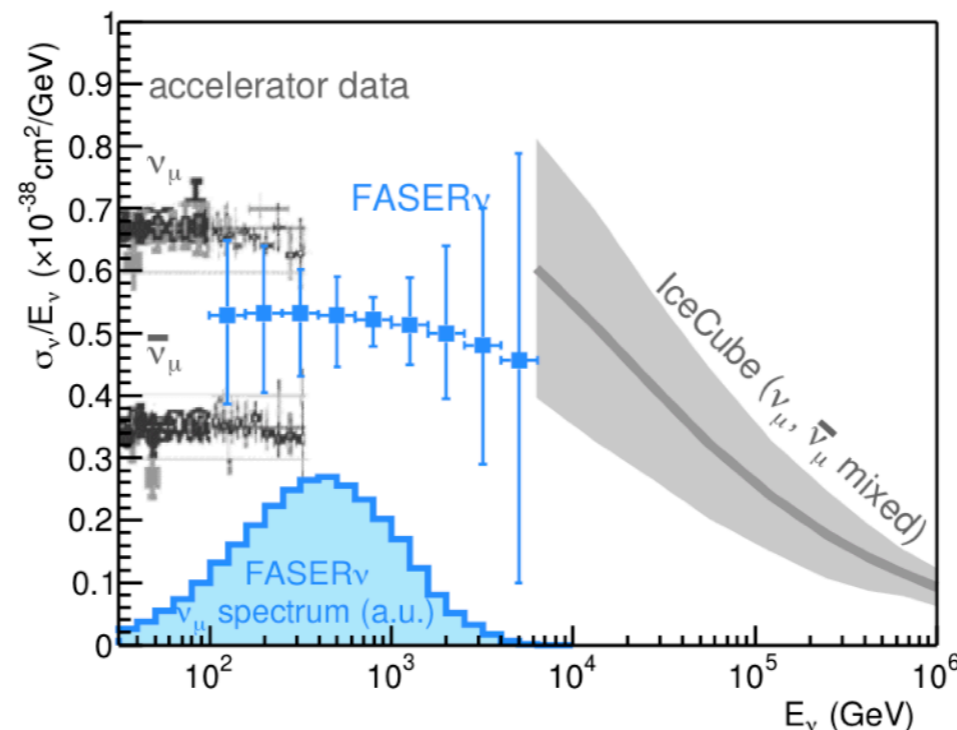
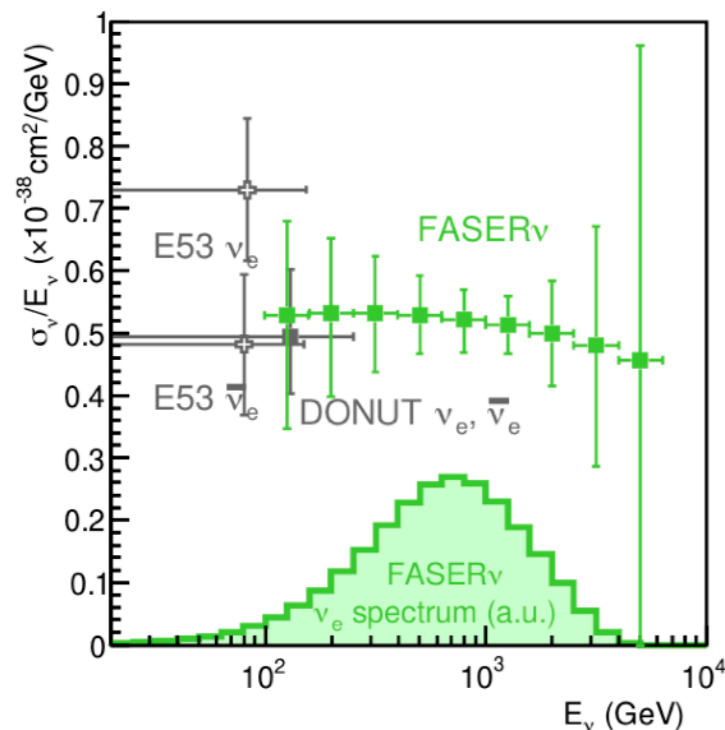


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# LHC Neutrino Physics Potential

## Neutrino Interactions

- use observed neutrino spectrum to measure **neutrino interaction XS**
  - \* high energy  $E \sim \text{TeV}$
  - \* all 3 neutrino flavors
  - \* DIS regime
  - \* first sensitivity estimate

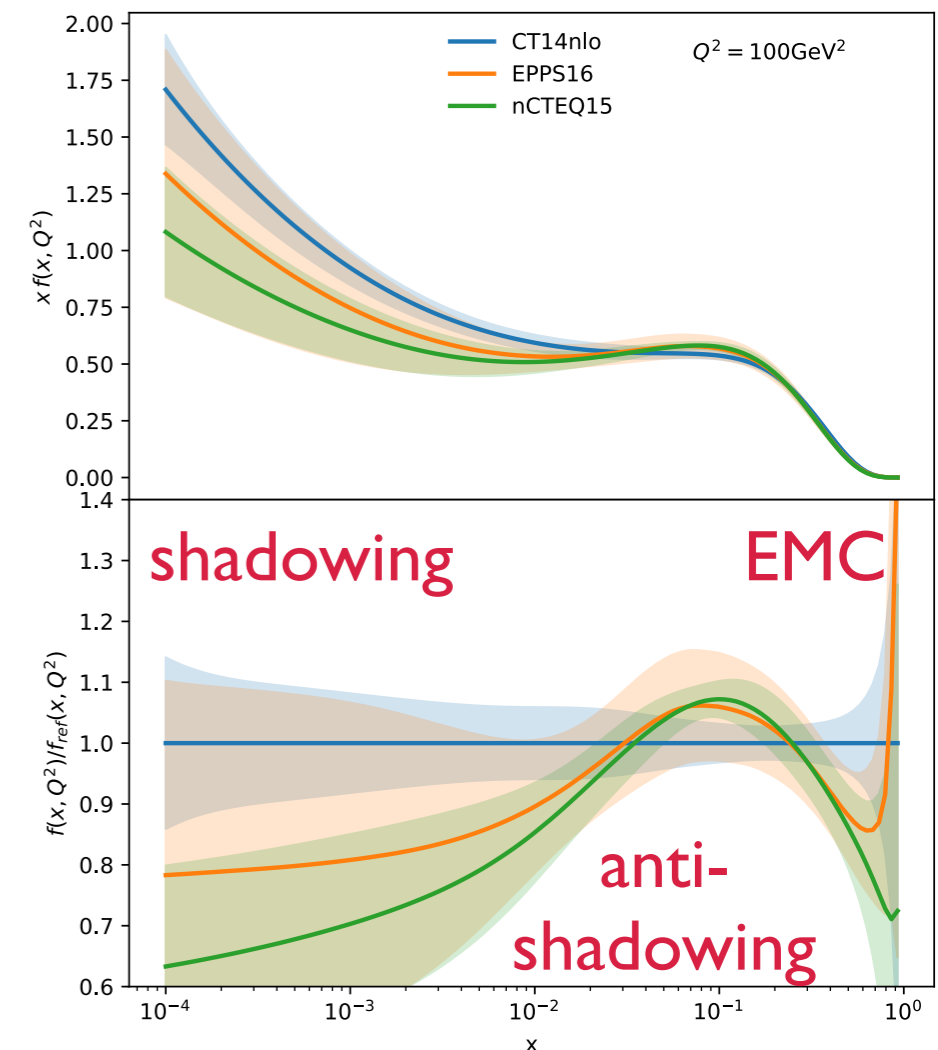


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- nuclear effects in tungsten target: input for **nPDFs**
  - \* shadowing, anti-shadowing, EMC
- event shapes & neutrino **generator tuning**



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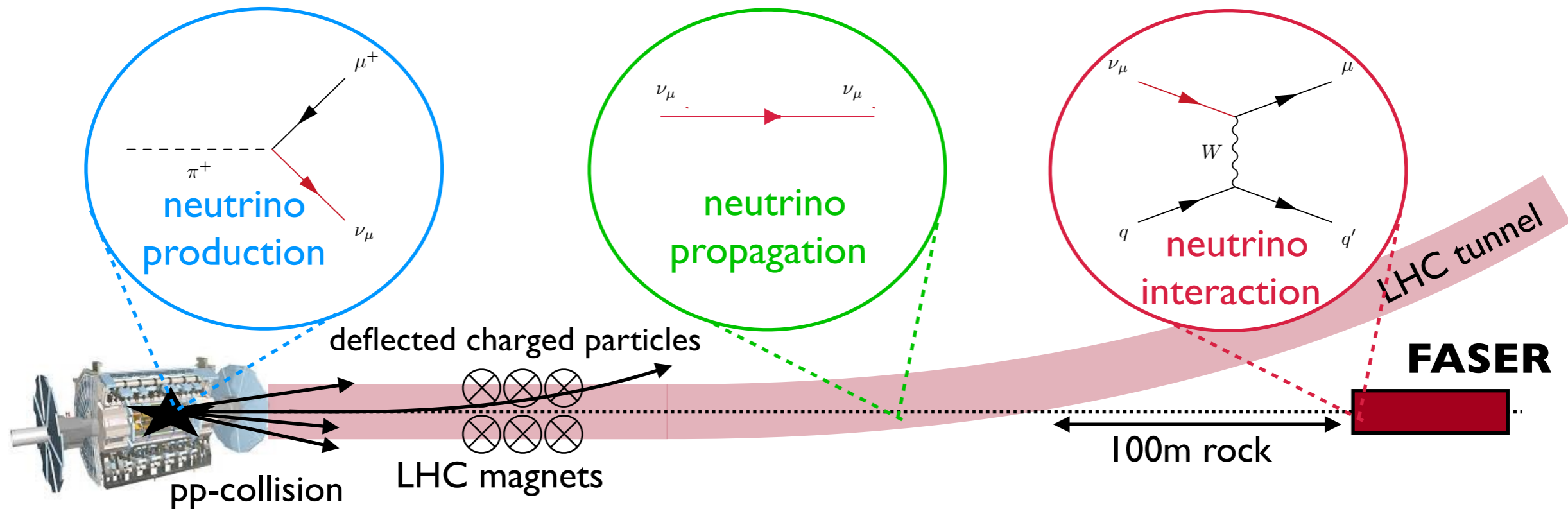
# LHC Neutrino Physics Potential

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  - \* first sensitivity estimate
- nuclear effects in tungsten target: input for nPDFs
  - \* shadowing, anti-shadowing, EMC
- event shapes & neutrino **generator tuning**
- charm associated neutrino interactions
  - \*  $\sim 10\%$  of events have charm in final state
  - \* was used at CHORUS to measure **strange PDFs**,  $V_{dc}$ , **charm fragmentation**
- bottom associated neutrino interactions
  - \* strongly suppressed in SM:  $O(0.1)$  events expected
  - \* sensitivity to BSM models explaining **b-physics anomalies** (probably not)

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# LHC Neutrino Physics Potential



hadronic interaction models

PDFs

intrinsic charm

light weakly interacting particles

sterile neutrino oscillations

NSI

+ many more ideas

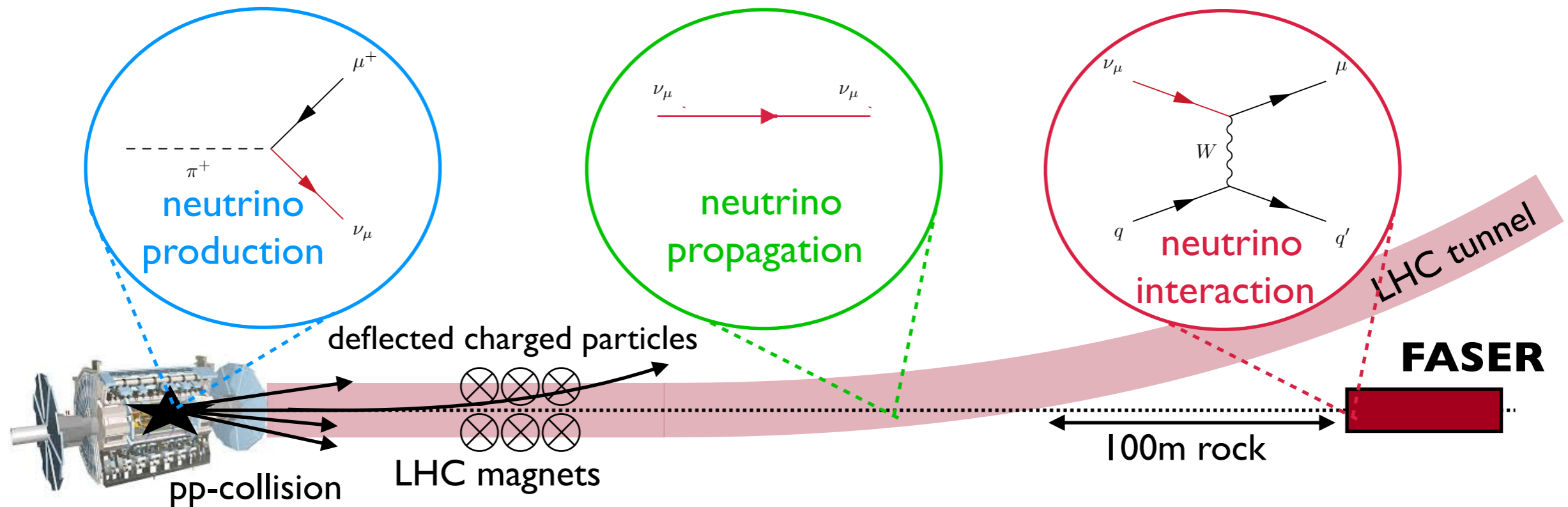
neutrino cross section measurements

strange and nuclear PDFs

neutrino generator tuning

heavy flavor associated neutrino interactions

# LHC Neutrino Physics Potential



Physics potential studies have just started.  
More detailed studies needed - and you can help!

Let's think big: Snowmass 2021 just started.  
Bigger + better detectors possible at HL-LHC

**That's it**