New Physics Opportunities
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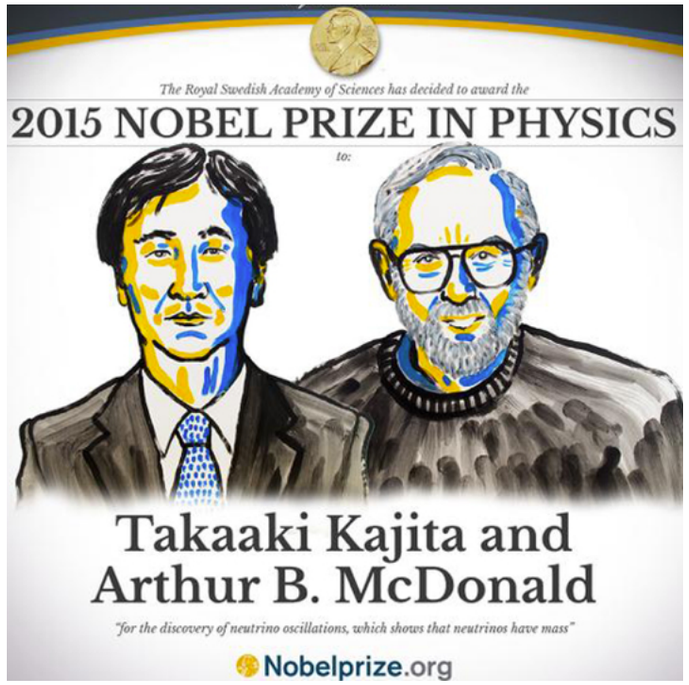
Pedro A. N. Machado

November 2019

pmachado@fnal.gov

Why BSM in neutrino experiments?



The existence of non-zero neutrino masses, inferred from neutrino oscillation measurements, is the only laboratory-based evidence of physics beyond the standard model

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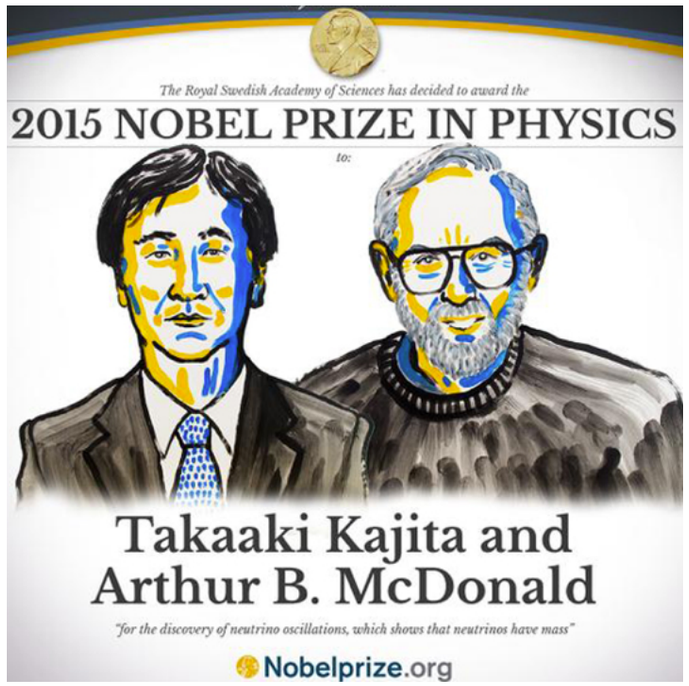
Why BSM in neutrino experiments?



The existence of non-zero neutrino masses, inferred from neutrino oscillation measurements, is the only laboratory-based evidence of physics beyond the standard model

Where do neutrino masses come from?

Do neutrinos communicate with DM?

Are neutrinos their own antiparticle?

Is lepton number conserved?

What is going on in LSND/ MiniBooNE?

...

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I did this talk thinking about LArTPCs,

but maybe it is general enough

Some examples of opportunities that could benefit from timing

1. Precision physics ($\sin^2\theta_W$)
2. Dark matter searches
3. Sterile neutrino searches
4. Long lived particles

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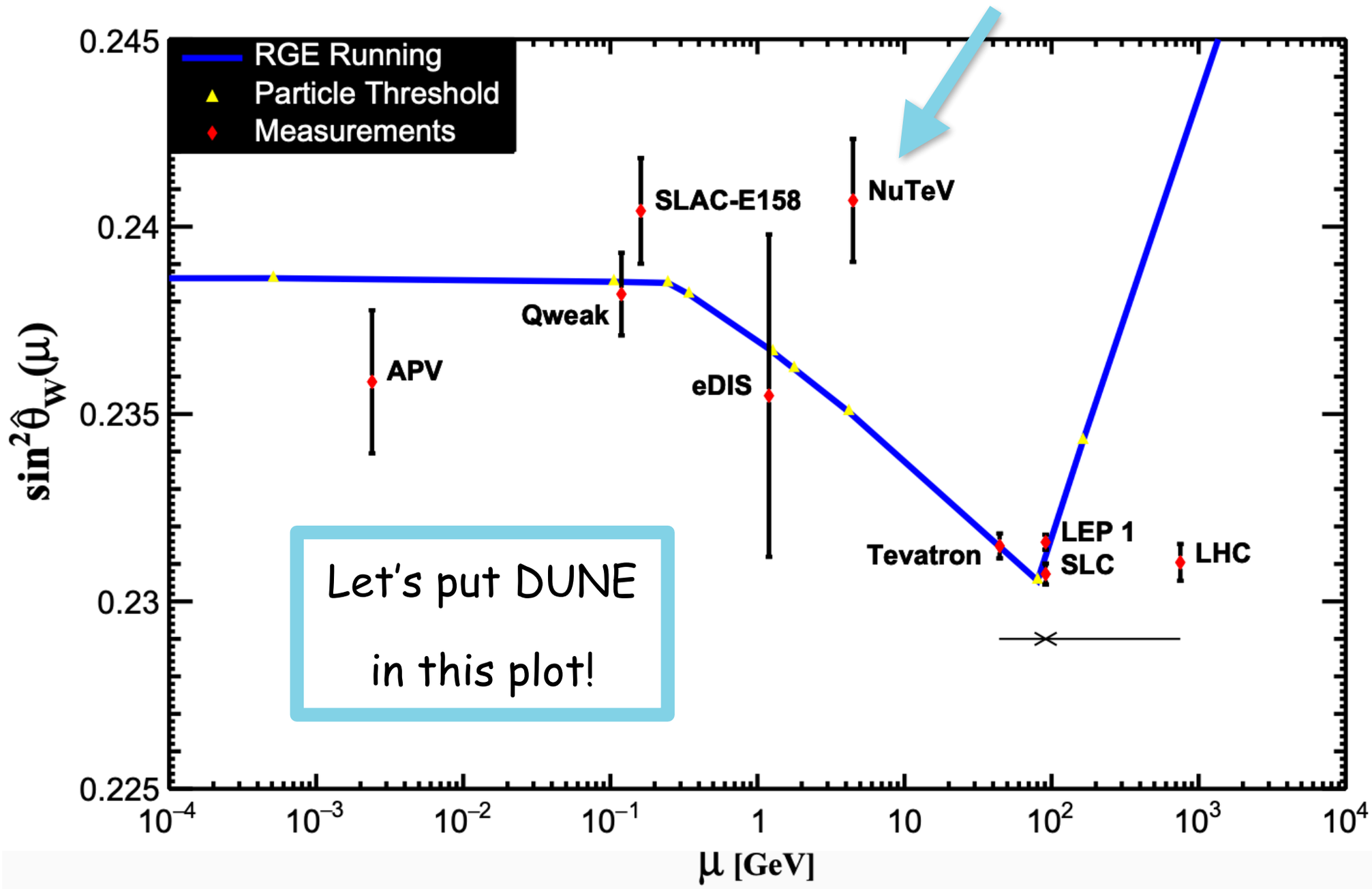
Precision physics - measuring $\sin^2\theta_w$ at DUNE

De Gouvêa M Perez-Gonzalez Tabrizi, so appear soon!

Only neutrino data point



Let's put DUNE in this plot!

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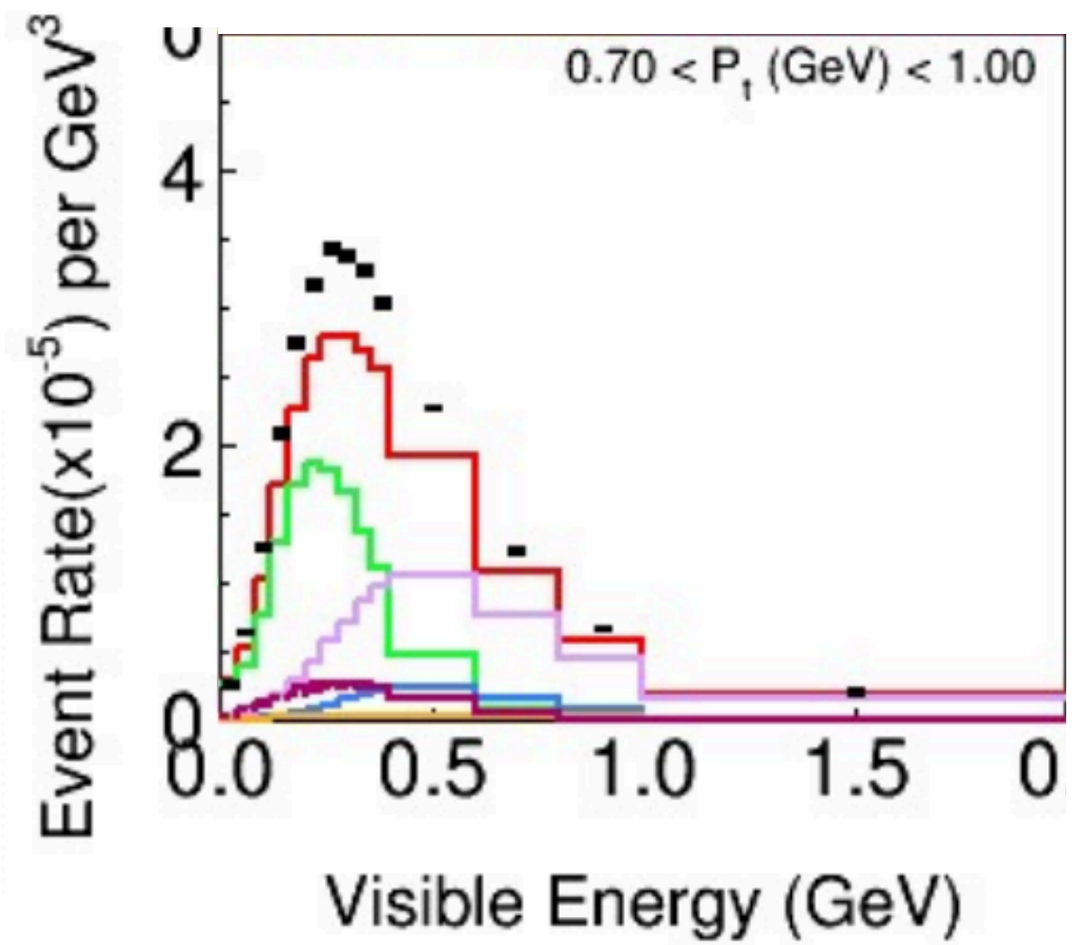
Can we do ν-N scattering?

Have you seen Minerva wine and cheese talk on Oct 25???



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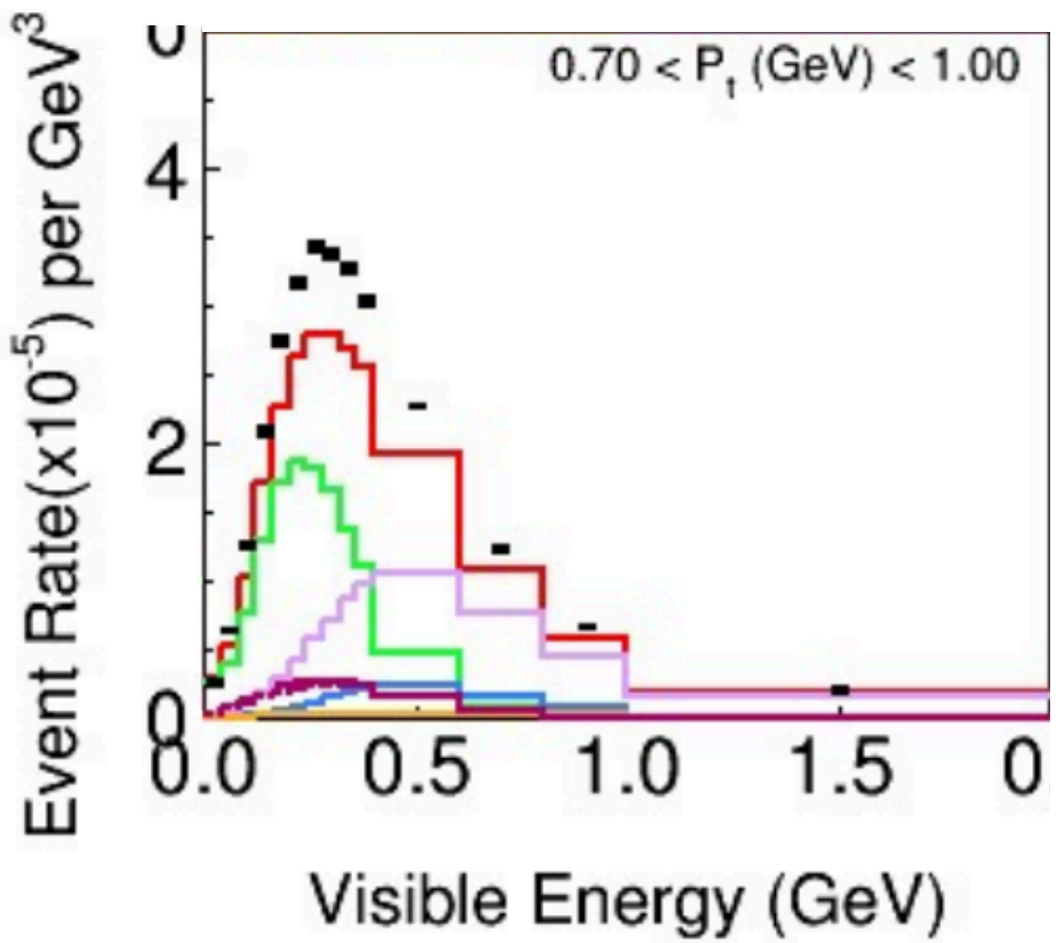
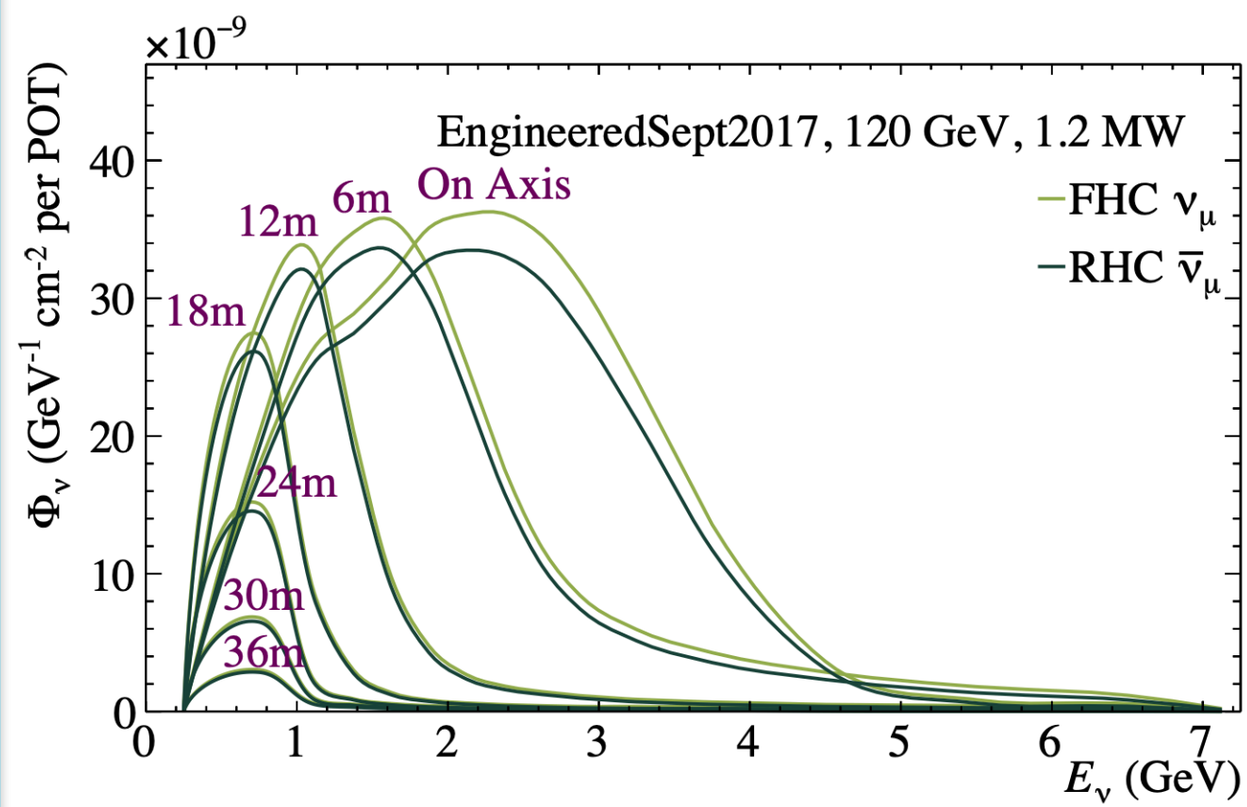


What about ν-e scattering?

Reasonable stats in DUNE

Flux uncertainties? PRISM!



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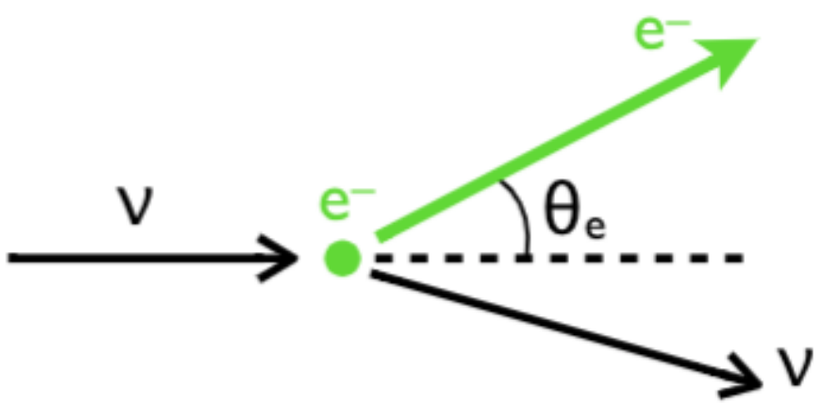

$$\frac{d\sigma}{dE_R} \simeq 1.72 \times 10^{-41} \left\{ g_1^2 + g_2^2 \left(1 - \frac{E_R}{E_\nu}\right)^2 \right\} \frac{\text{cm}^2}{\text{GeV}}$$

ν_α	g_1	SM	g_2	SM
ν_e	$1+(g_V+g_A)/2$	$1/2+s_W^2$	$(g_V-g_A)/2$	s_W^2
$\nu_{\mu,\tau}$	$(g_V+g_A)/2$	$-1/2+s_W^2$	$(g_V-g_A)/2$	s_W^2
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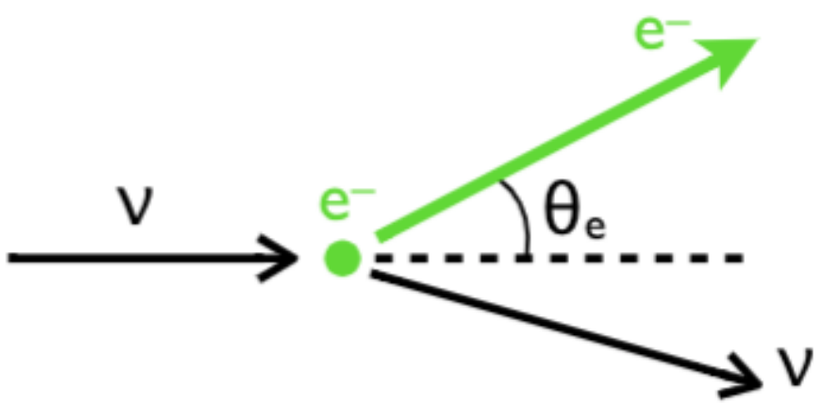

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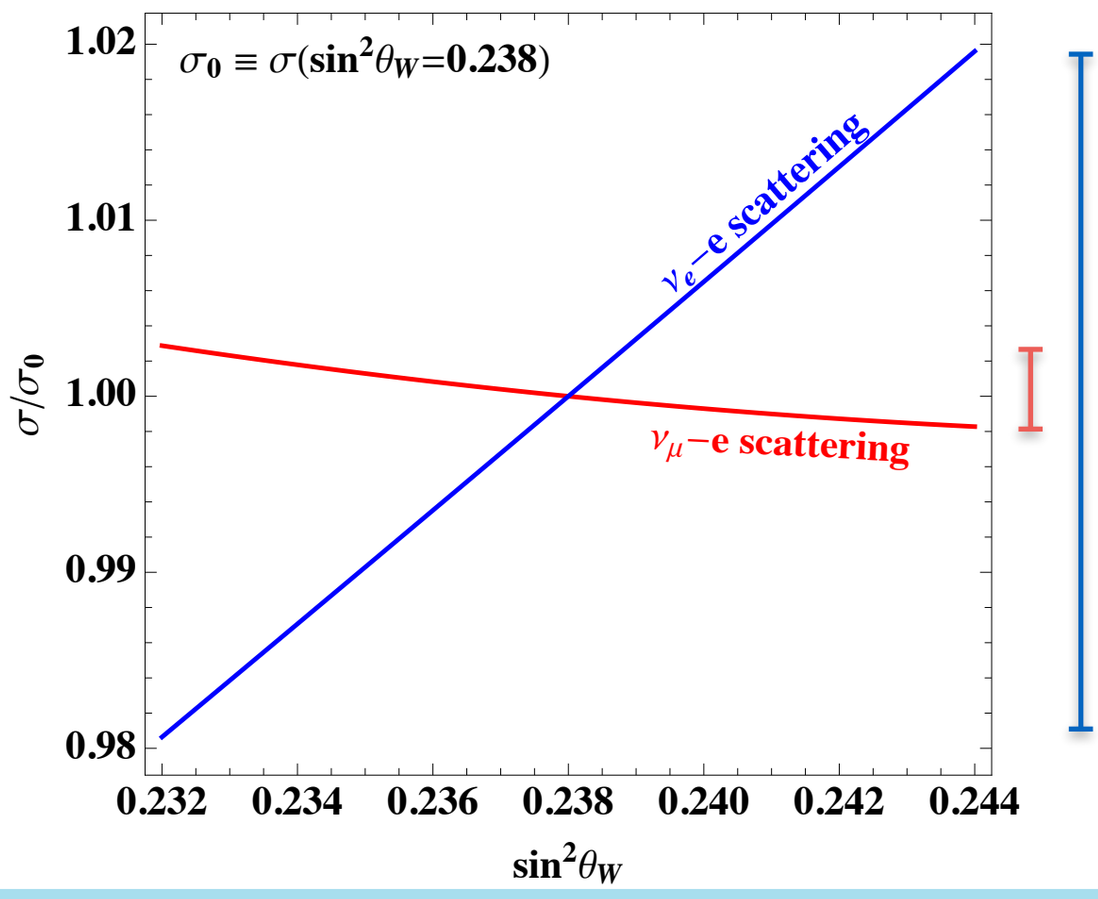

ν_e change is 10 times larger!

This happens at the differential cross section level

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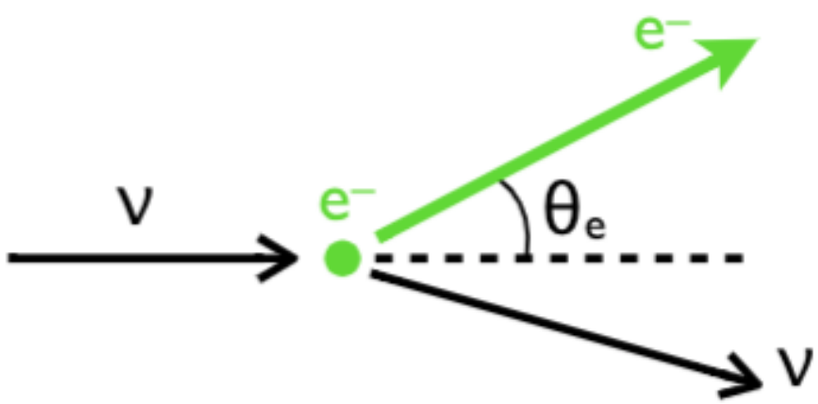

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ν_μ scattering: $\sin^2\theta_W$ almost an overall normalization

ν_e scattering: Interesting, but depends on ν_e contamination?

ν_e contamination grows as one goes off-axis

(ν_e contamination is late in time as well)

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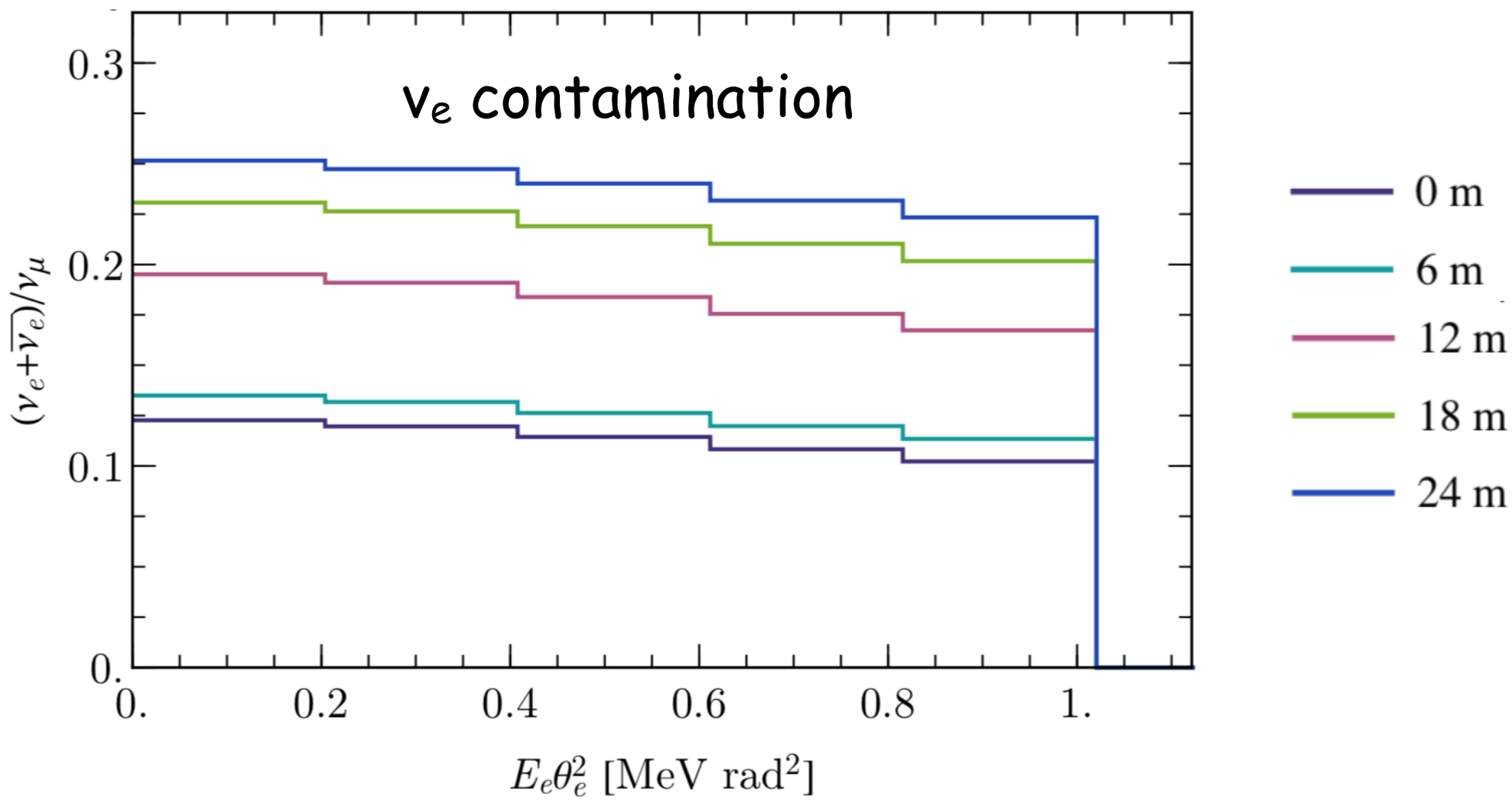

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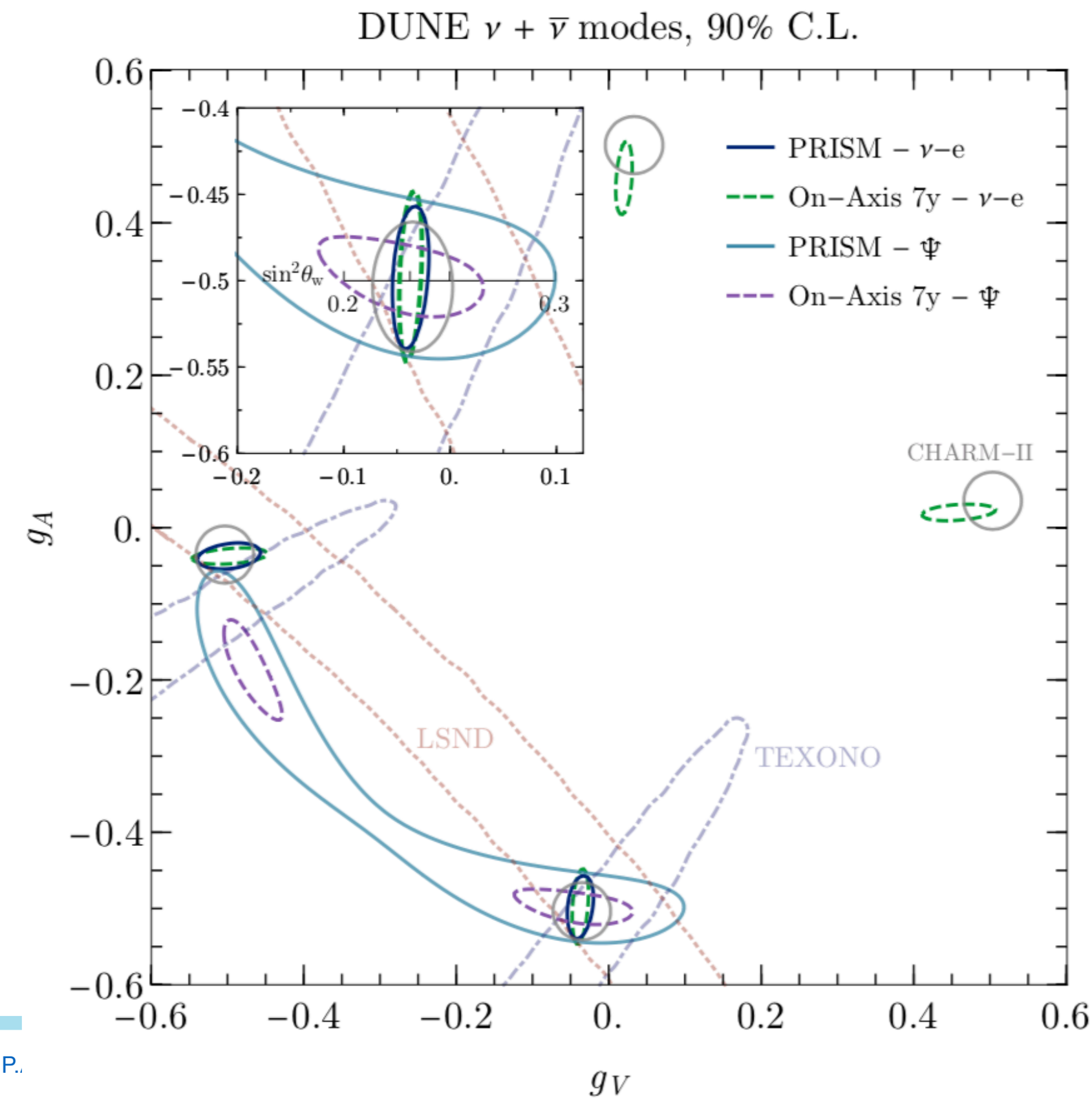

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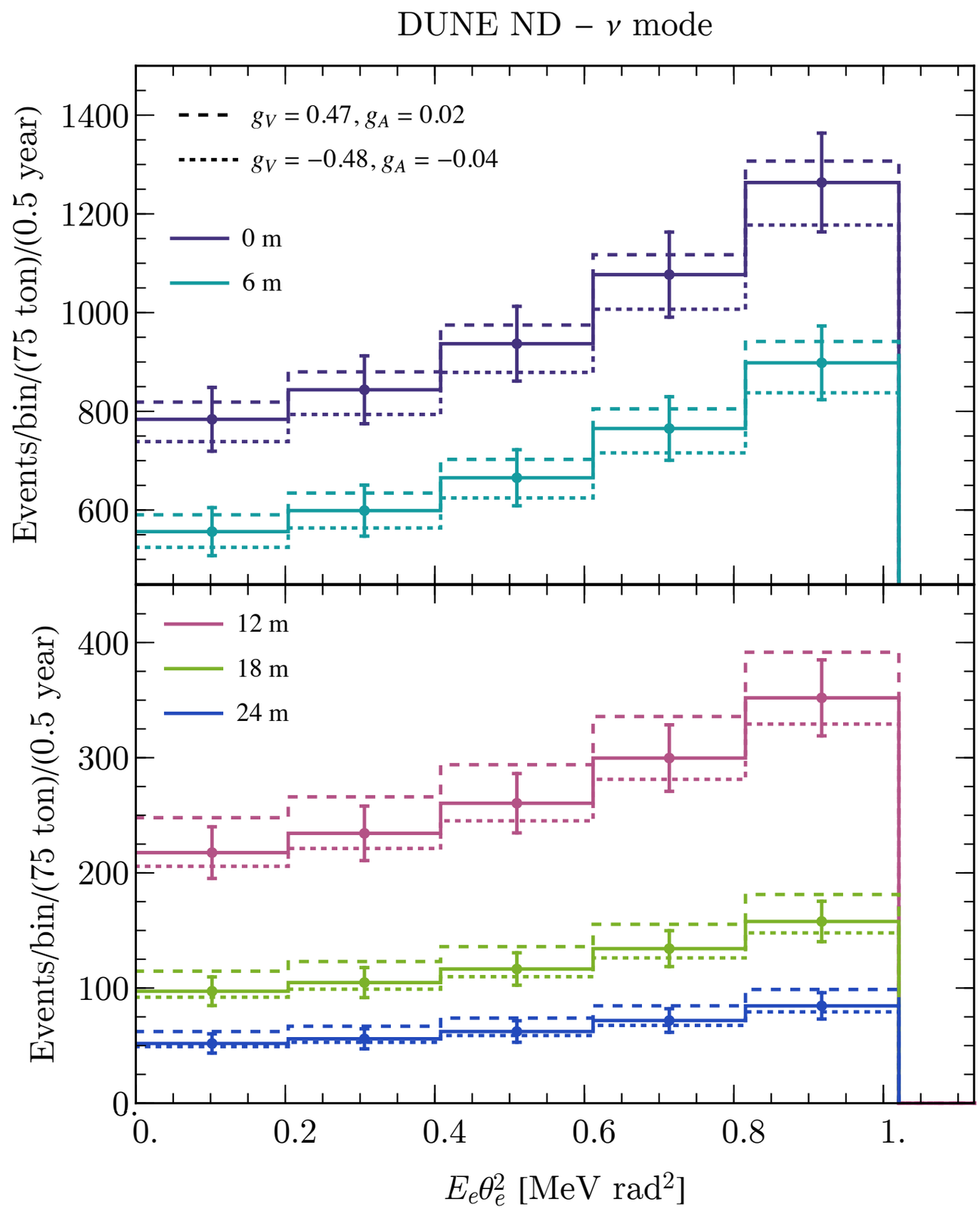

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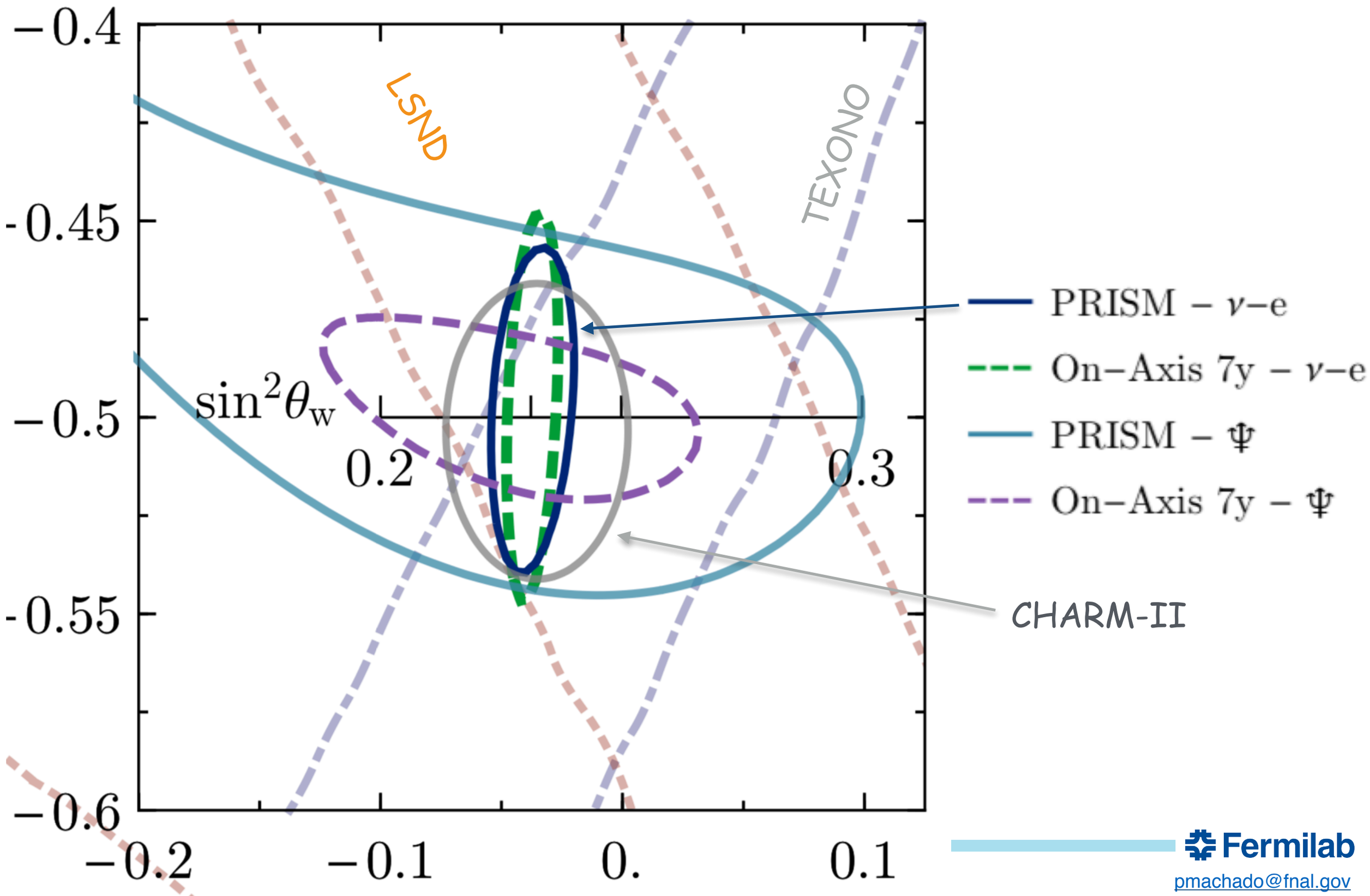

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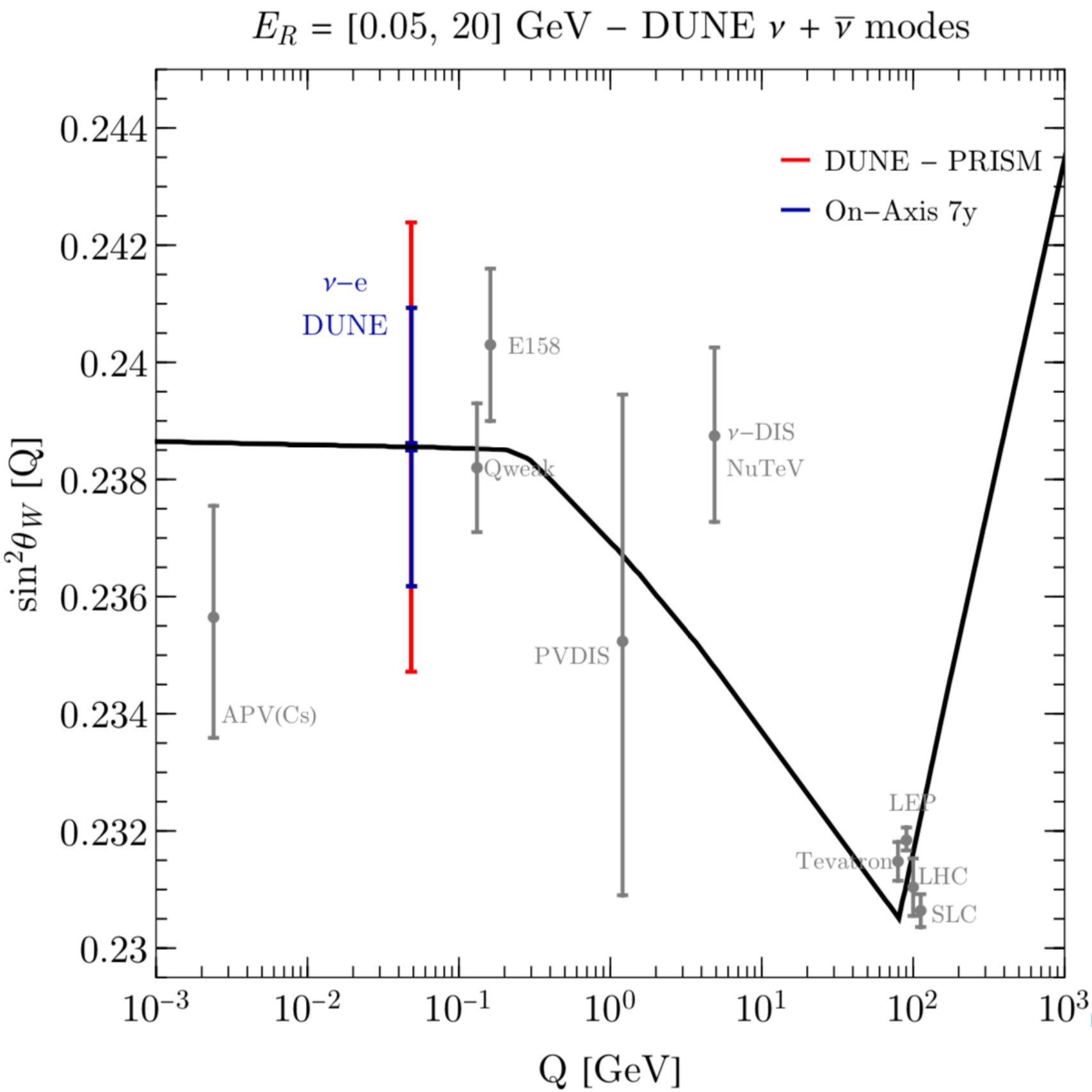

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I did this talk thinking about LArTPCs,

but maybe it is general enough

Some examples of opportunities that could benefit from timing

1. Precision physics ($\sin^2\theta_w$)
2. Dark matter searches
3. Sterile neutrino searches
4. Long lived particles

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Light DM

We are talking about new physics below the ~GeV scale

DM interacts with gauge boson A'

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Light DM

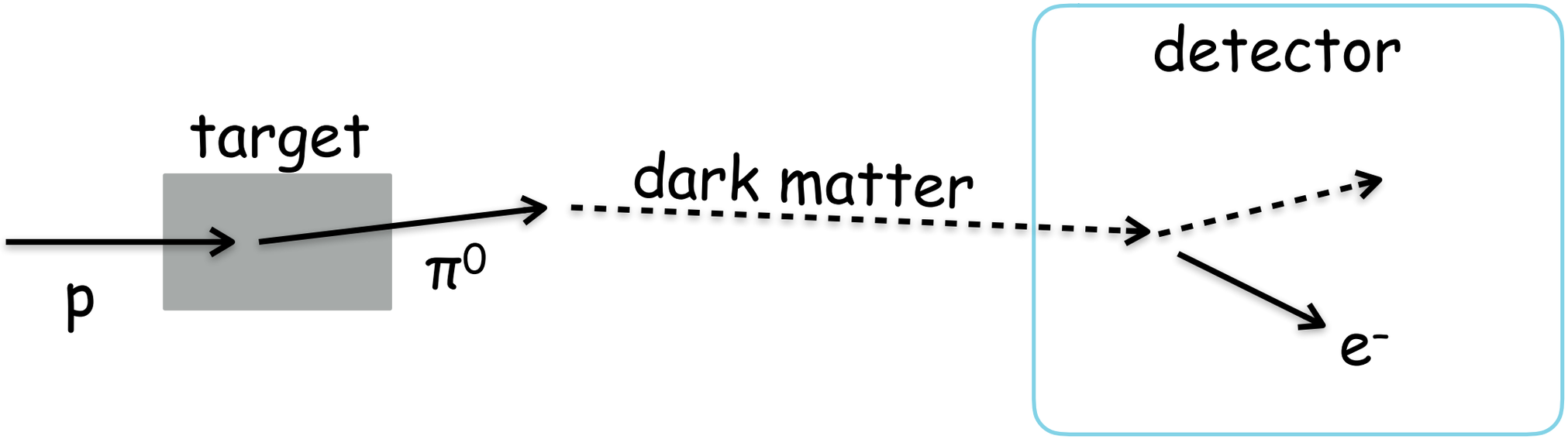
We are talking about new physics below the ~GeV scale

DM interacts with gauge boson A'

A' mixes with our photon via the kinetic term ==> dark photon

Anything that decays to photon can go to A' followed by A' to XX

Neutrino beams are perfect!



Battell et al 0906.5614, de Niverville et al 1107.4580, et al' 1205.3499, et al" 1807.06501, Izaguirre et al 1307.6554, Coloma et al 1512.03852, Jordan et al 1806.05185, de Romeri et al 1903.10505, ...

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Light DM

We are talking about new physics below the ~GeV scale

DM interacts with gauge boson A'

A' mixes with our photon via the kinetic term ==> dark photon

Anything that decays to photon can go to A' followed by A' to XX

Neutrino beams are perfect!

but...

neutrinos are the background!!!

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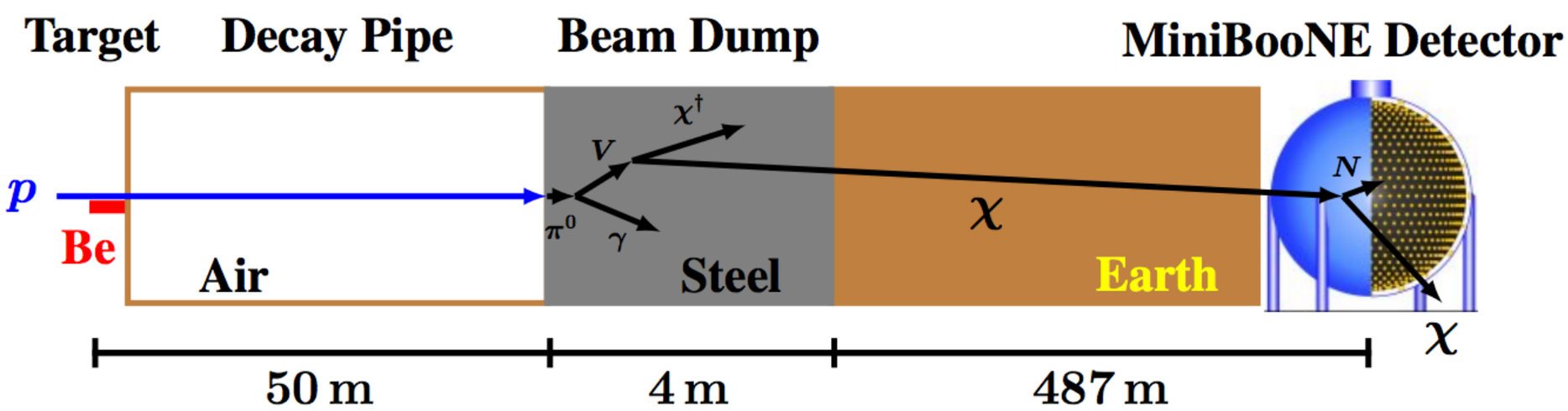
Light DM

Possible solution: turn neutrinos off (i.e. run in beam dump mode)

Dark matter search in nucleon, pion, and electron channels from a proton beam dump with MiniBooNE

(The MiniBooNE-DM Collaboration)

arXiv:1807.06137



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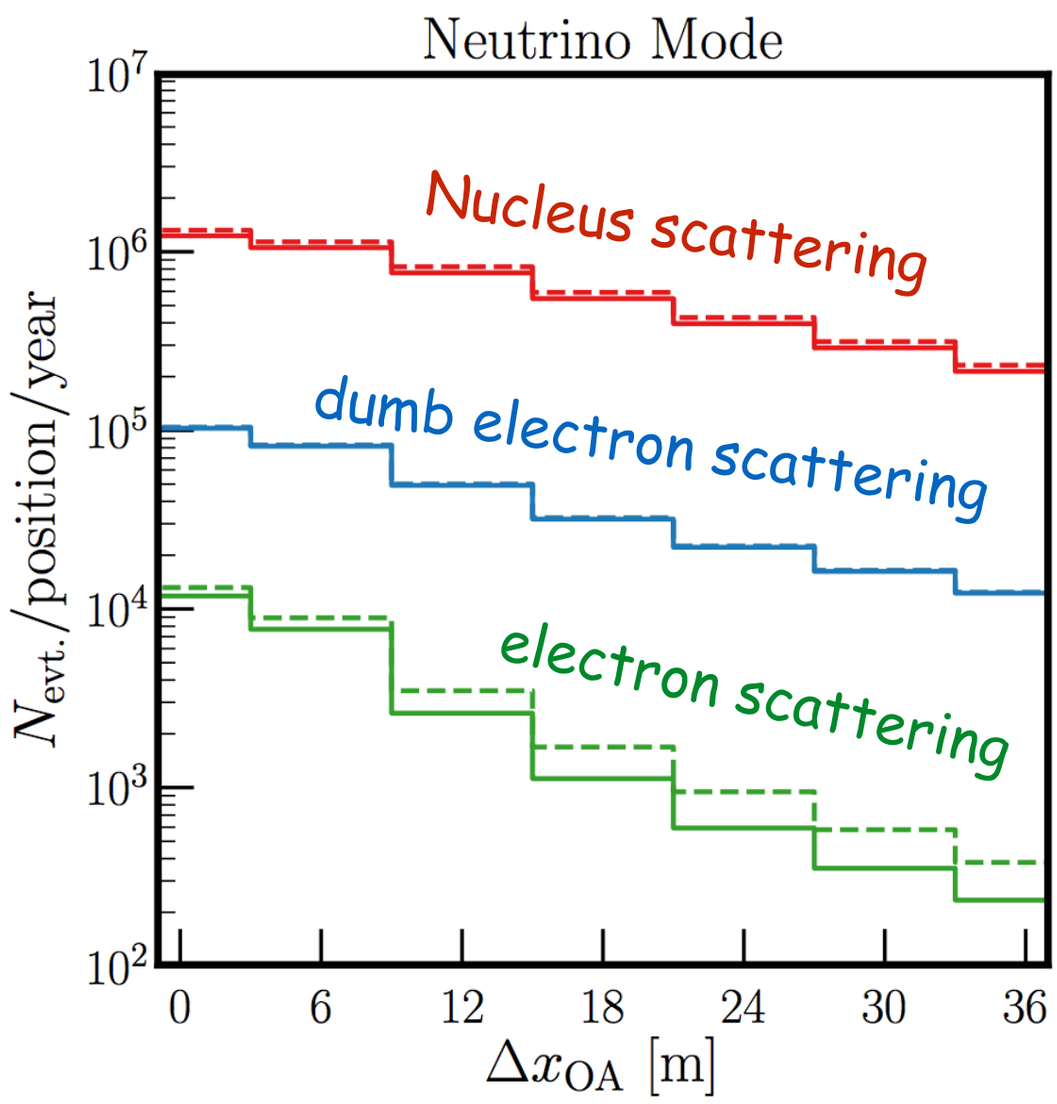
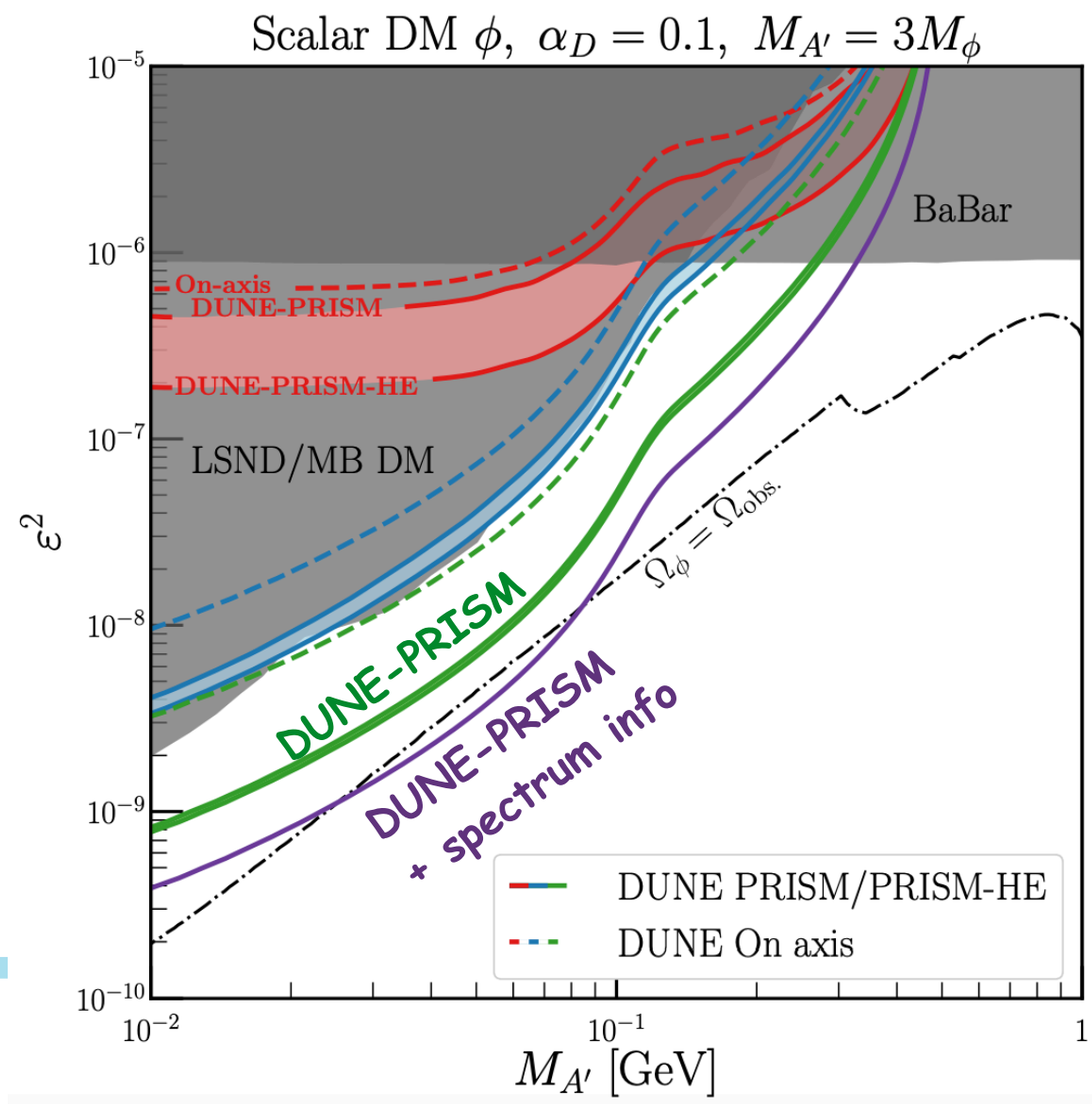
Light DM

Solution 2: go off-axis





de Romeri Kelly M 1903.10505

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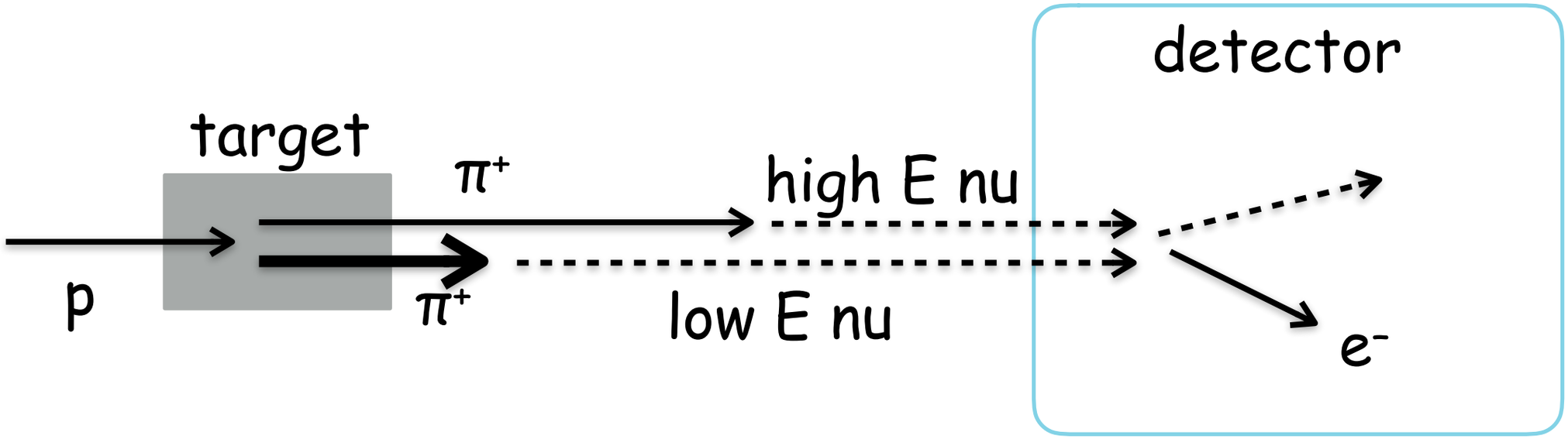
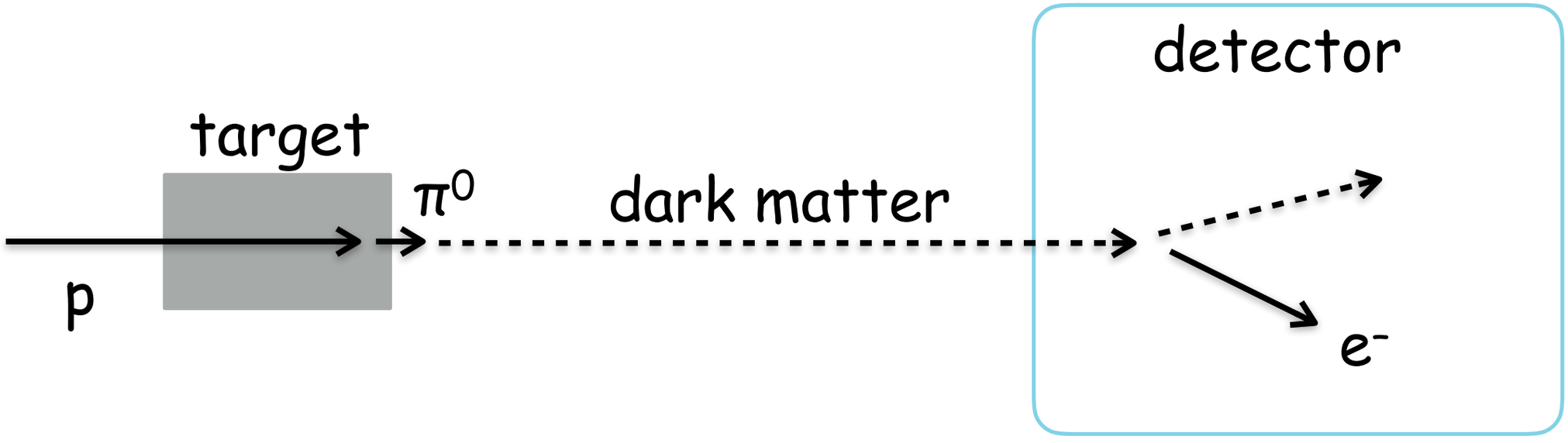
Light DM

Solution 3: Timing? Do we want a dedicated study?

Do we have the necessary info?





Time vs energy structure to distinguish DM vs neutrinos?

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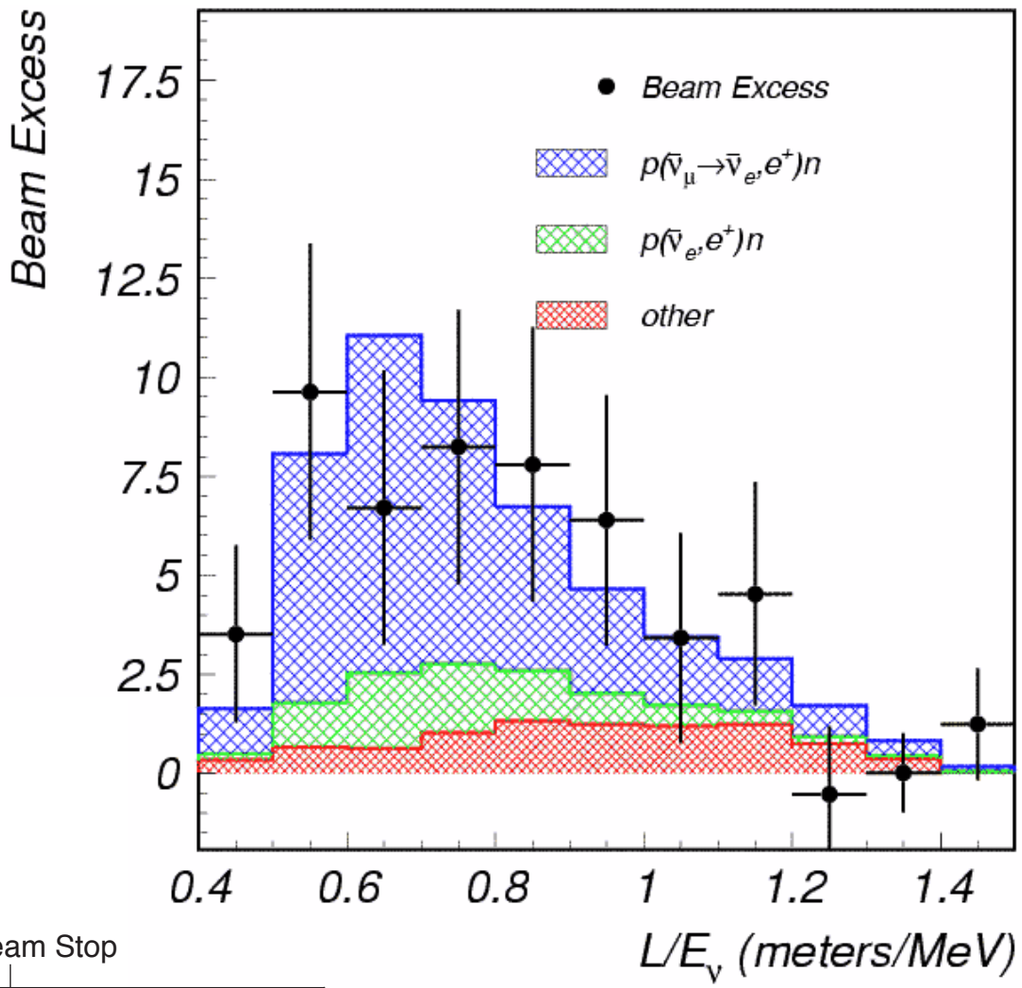
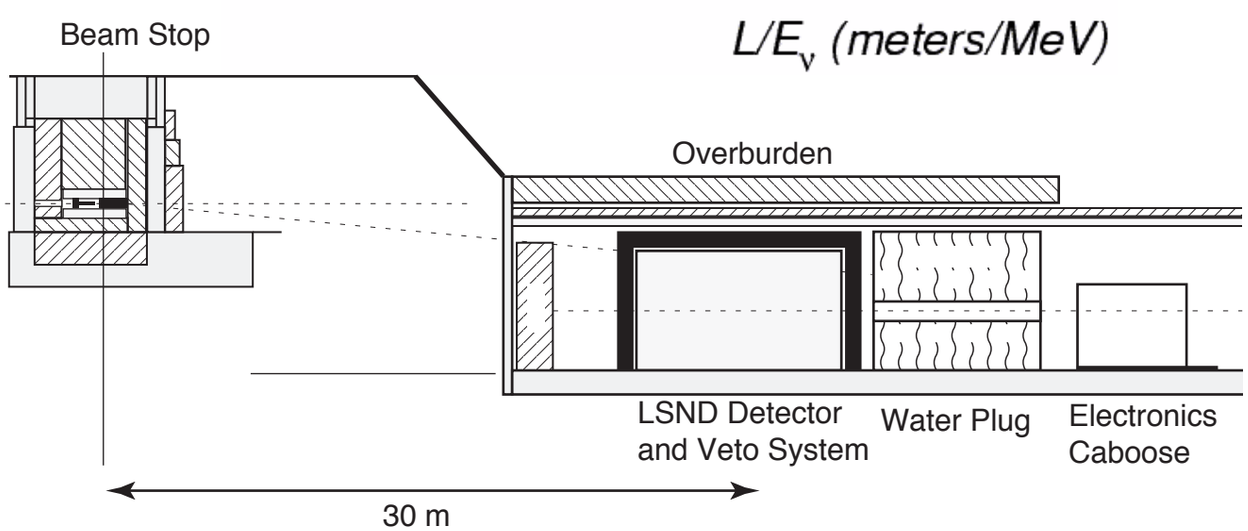
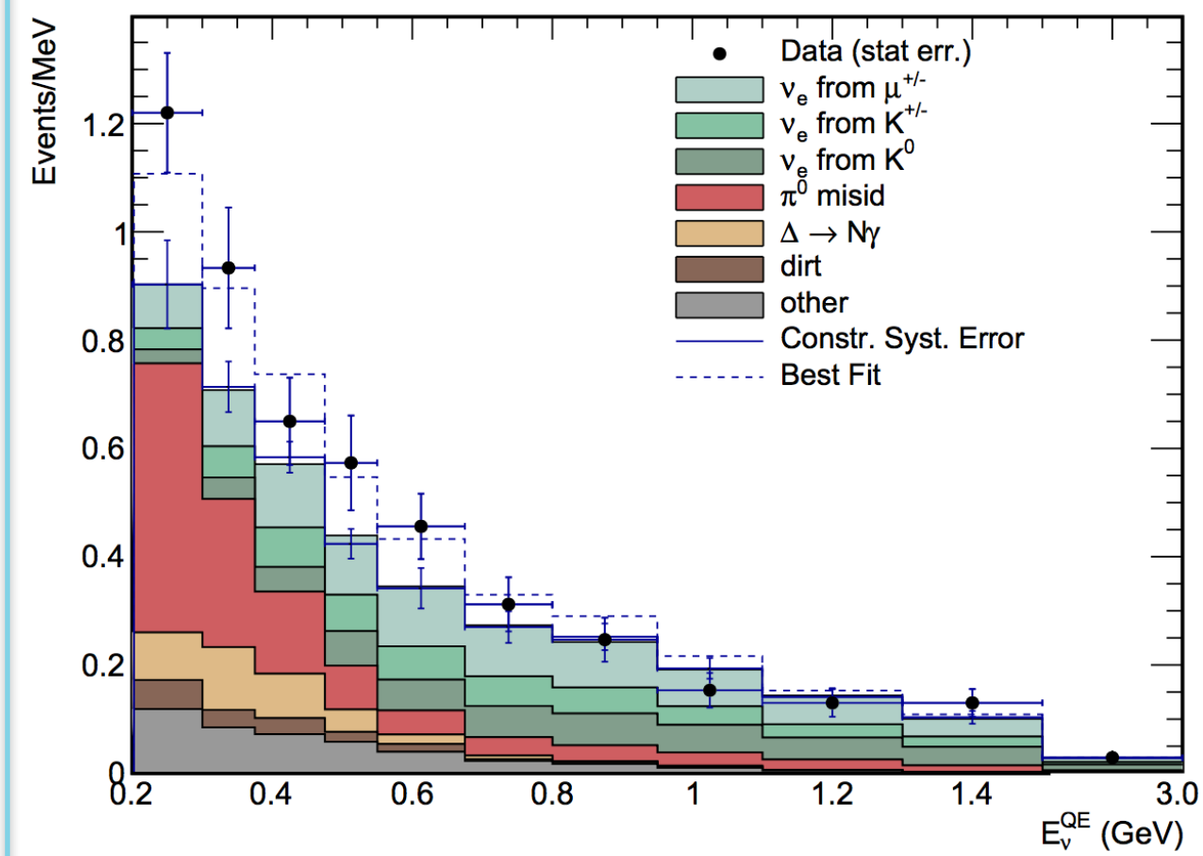
Sterile neutrino searches

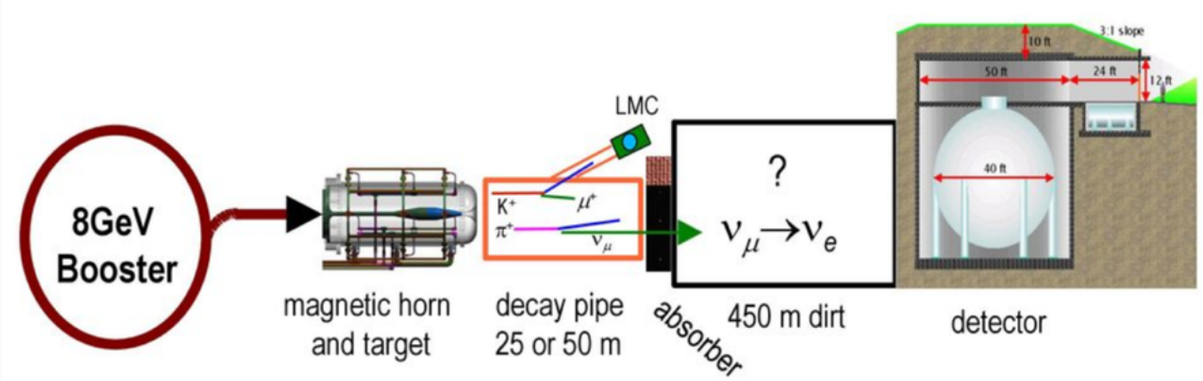
LSND





MiniBooNE





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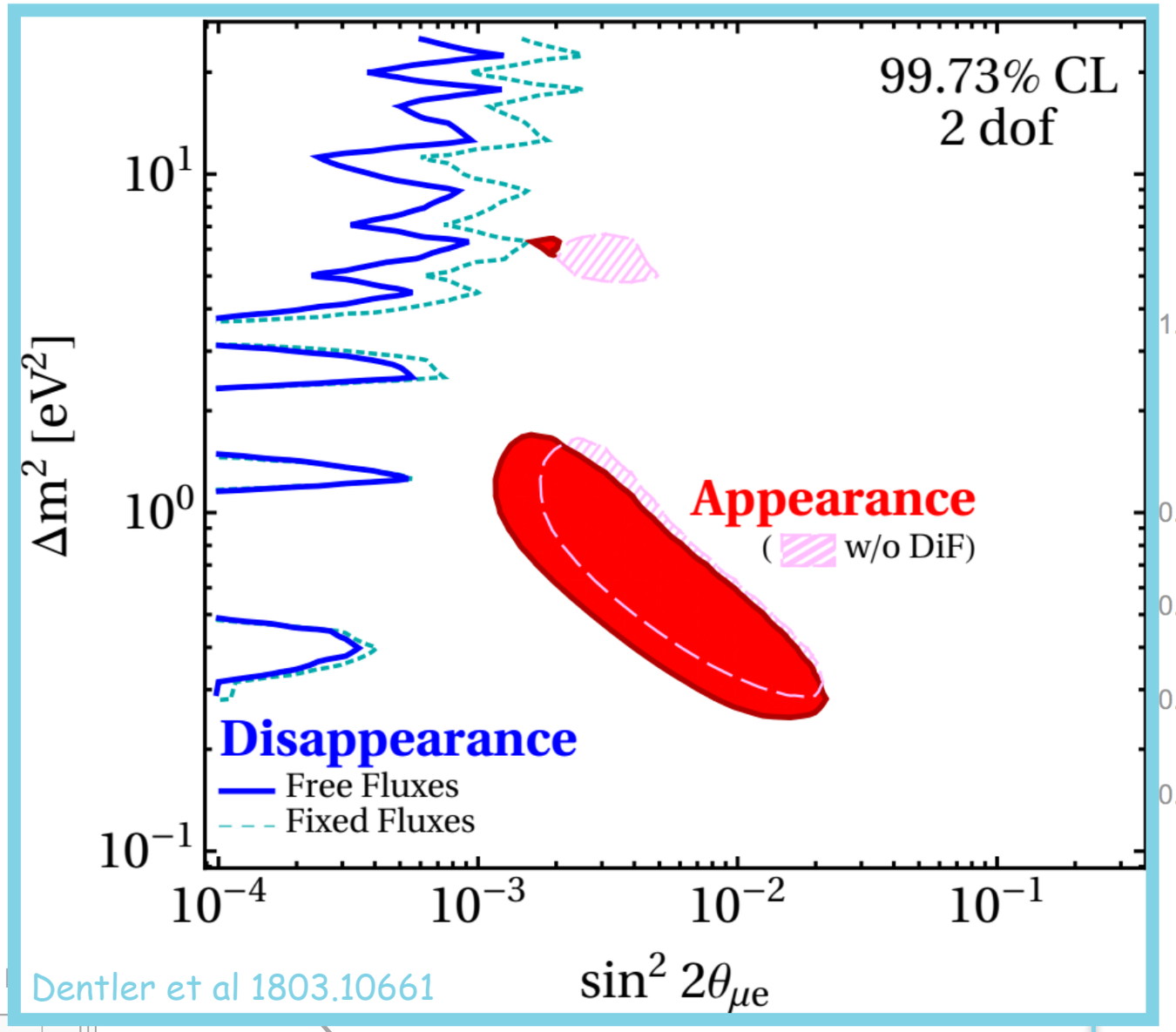
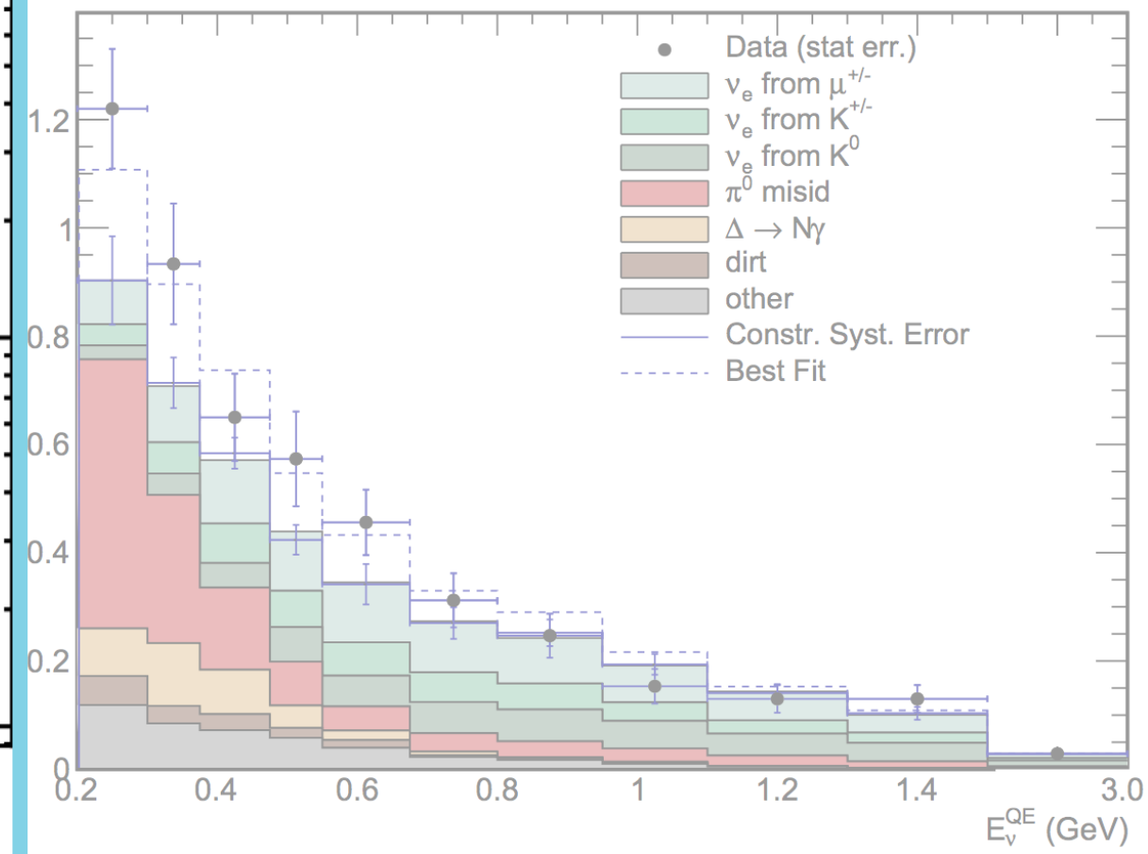
Sterile neutrino searches



Dentler et al 1803.10661

MiniBooNE



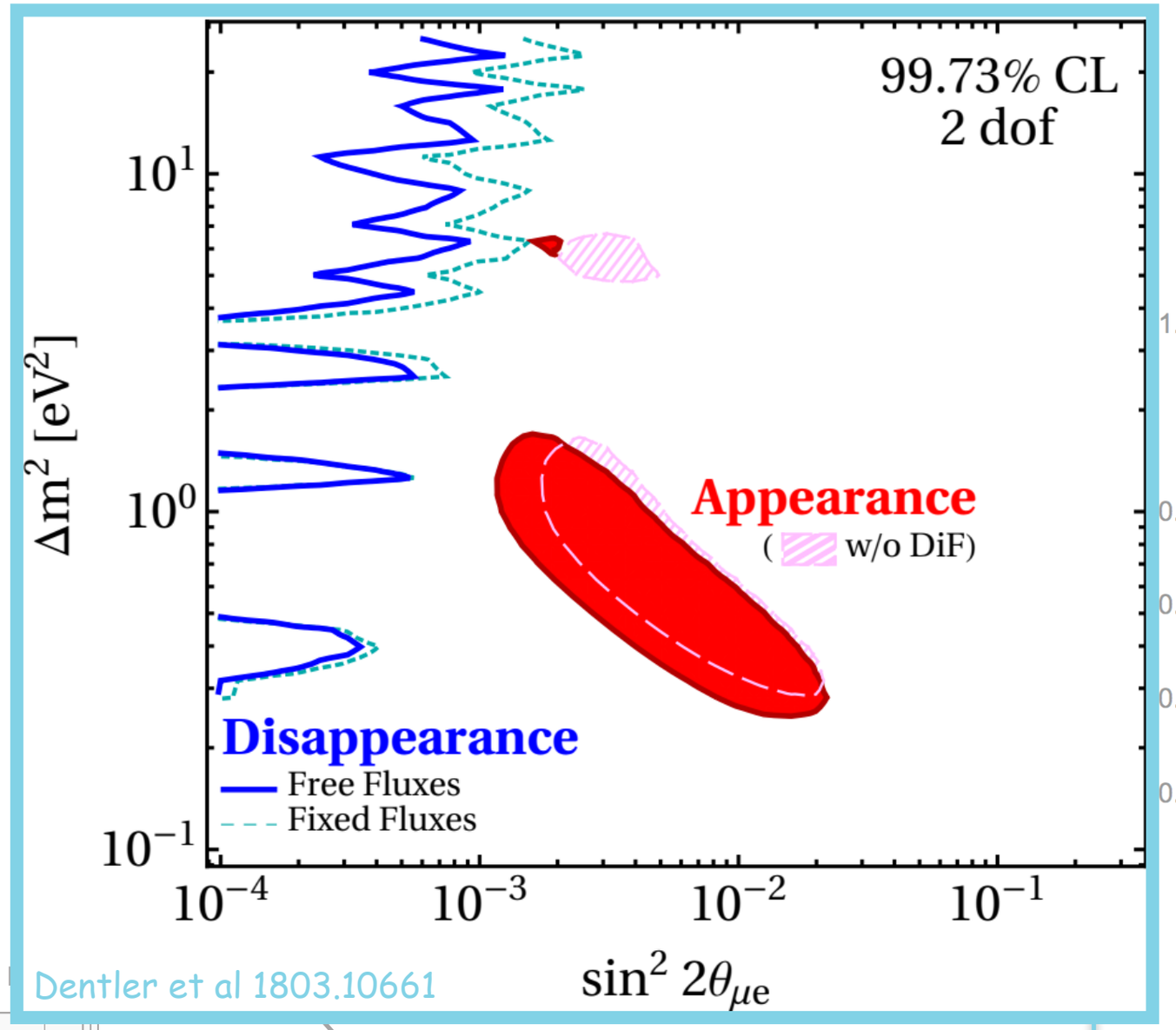
+ Extremely significant (over 5σ)

+ Sterile neutrinos provide a good fit of LSND+MiniBooNE

+ Sterile neutrinos are a simple, minimal model

- Extraordinary tension with other data set (4.7σ)

Sterile neutrino searches



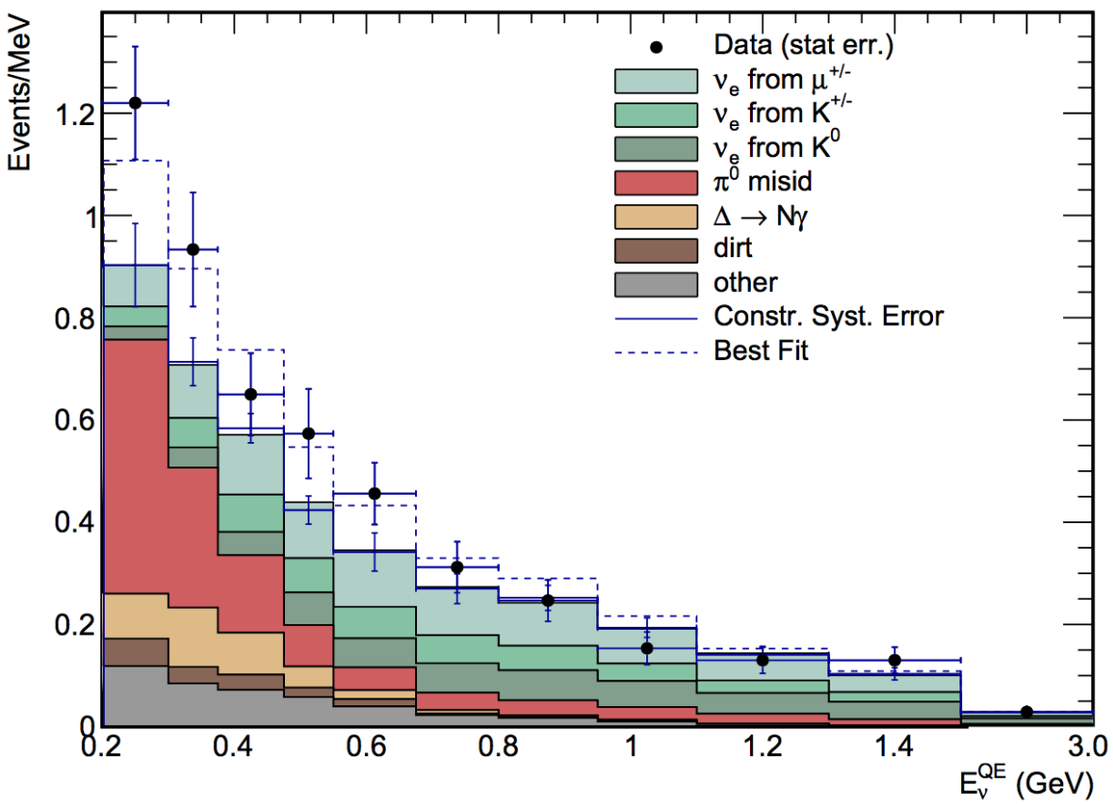
Dentler et al 1803.10661

MiniBooNE

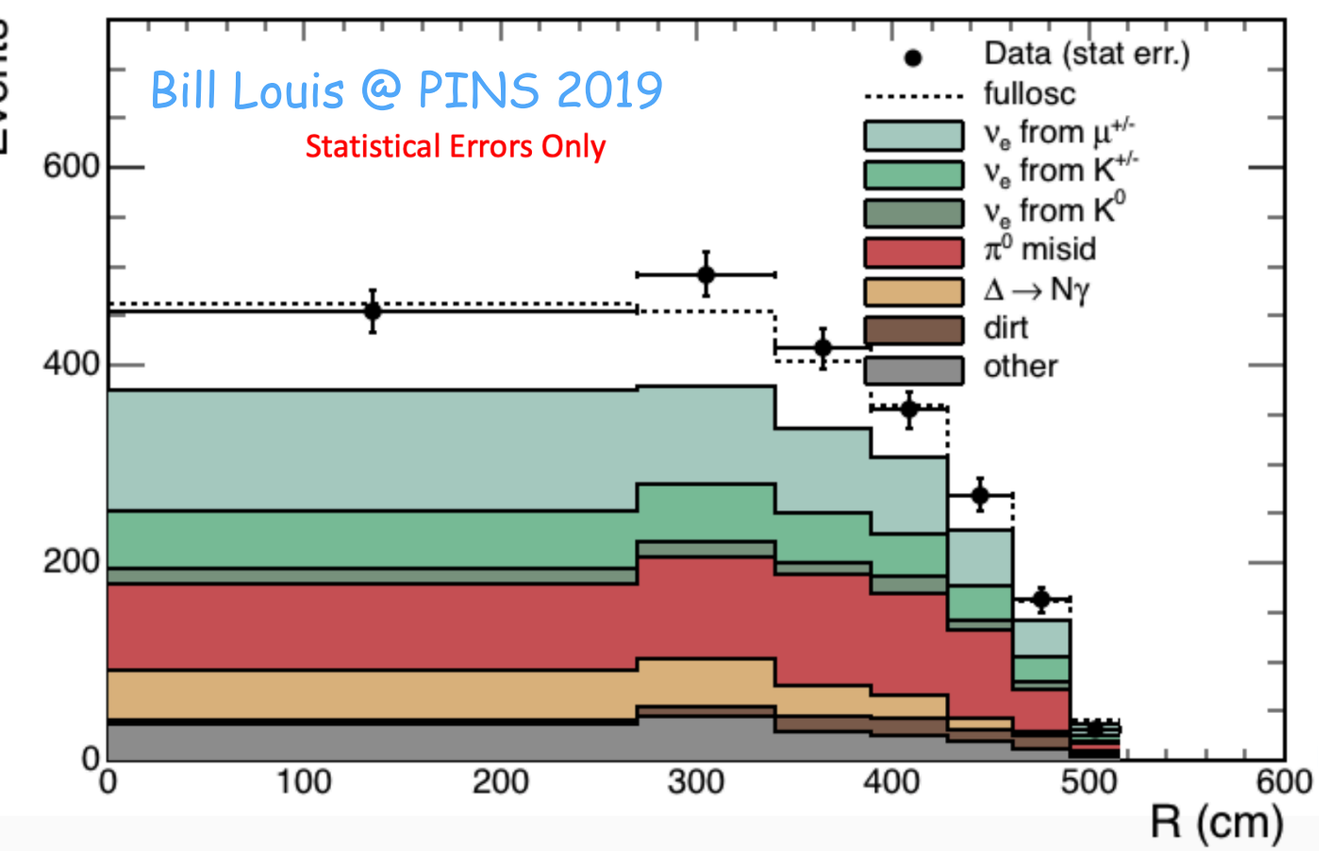
Take home message:
If there is appearance, there needs to be both disappearances!

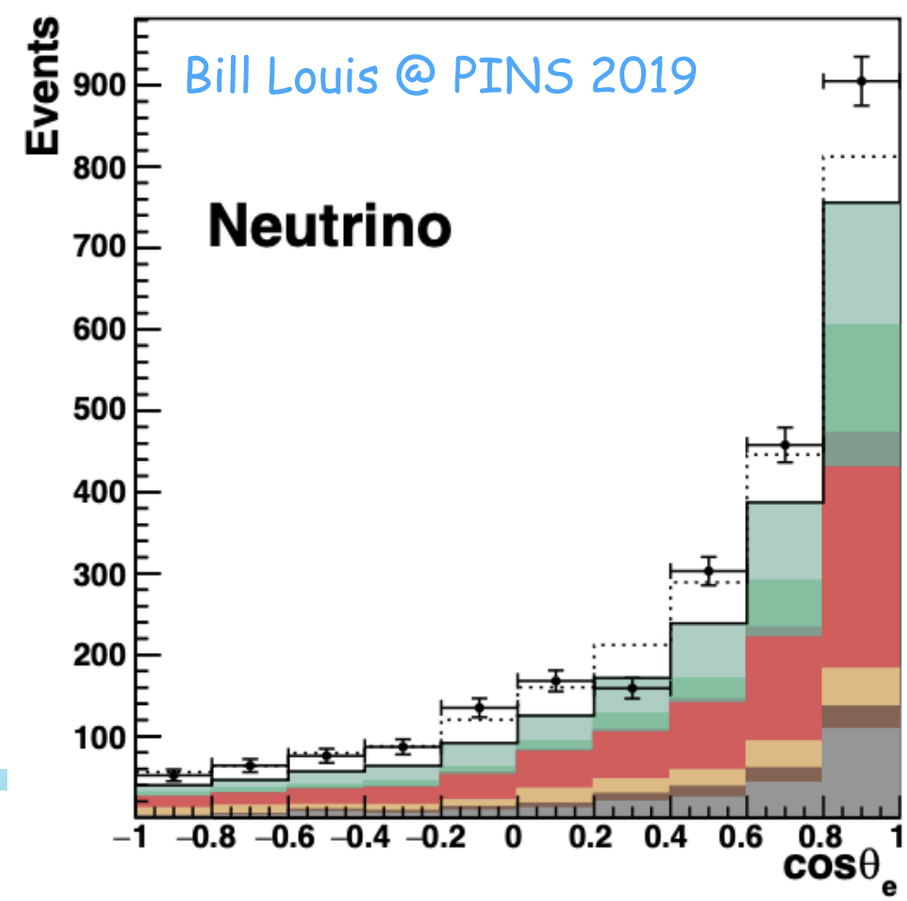
+ Extremely significant (over 5σ)
+ Sterile neutrinos provide a good fit of LSND+MiniBooNE
+ Sterile neutrinos are a simple, minimal model
- Extraordinary tension with other data set (4.7σ)

Sterile neutrino searches



Anatomy of the excess:
Several distributions, looking for consistency among them





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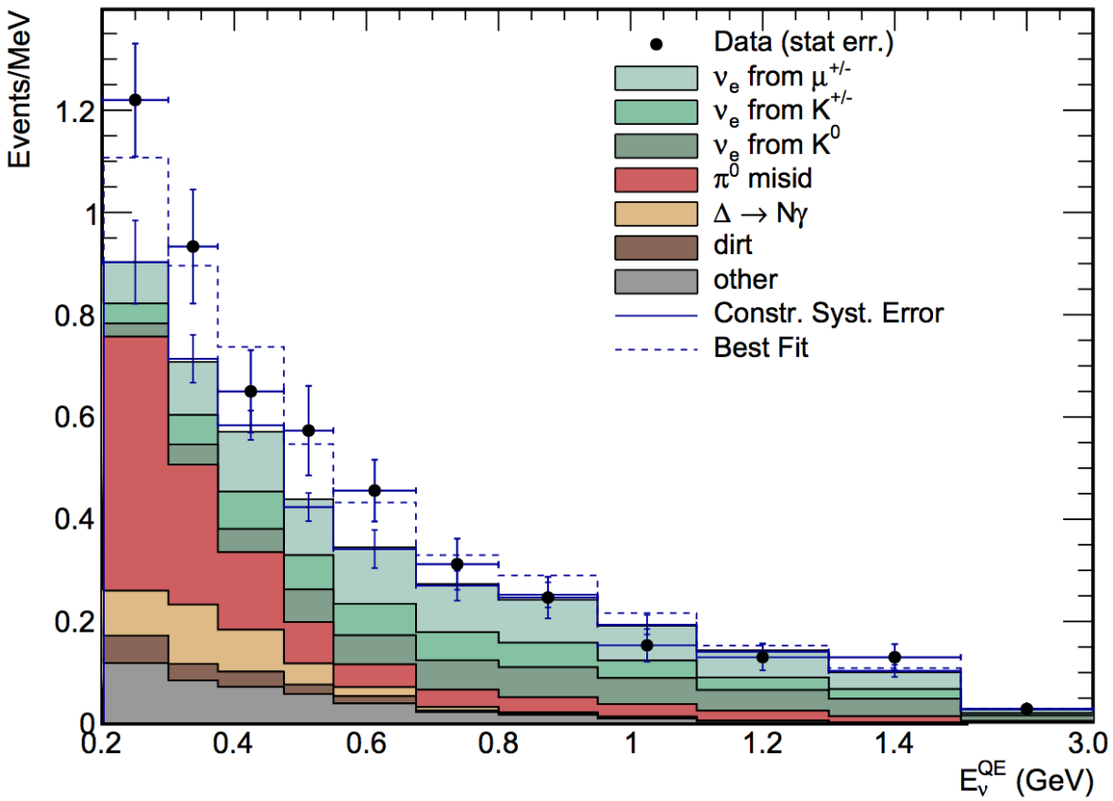
Sterile neutrino searches



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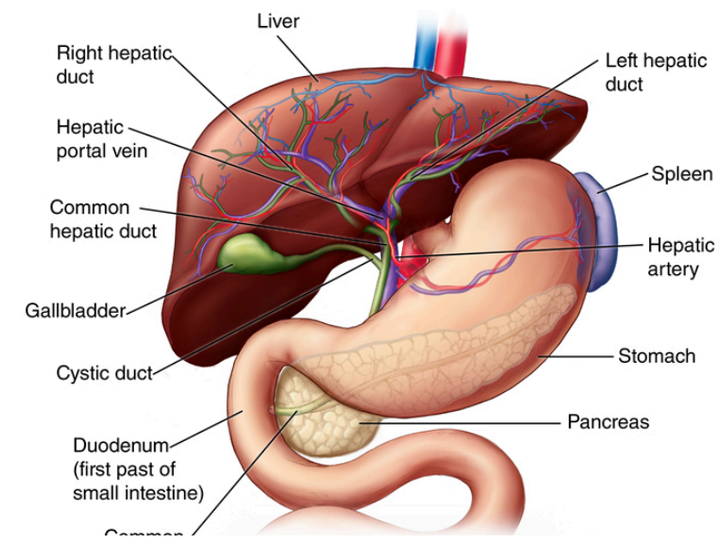
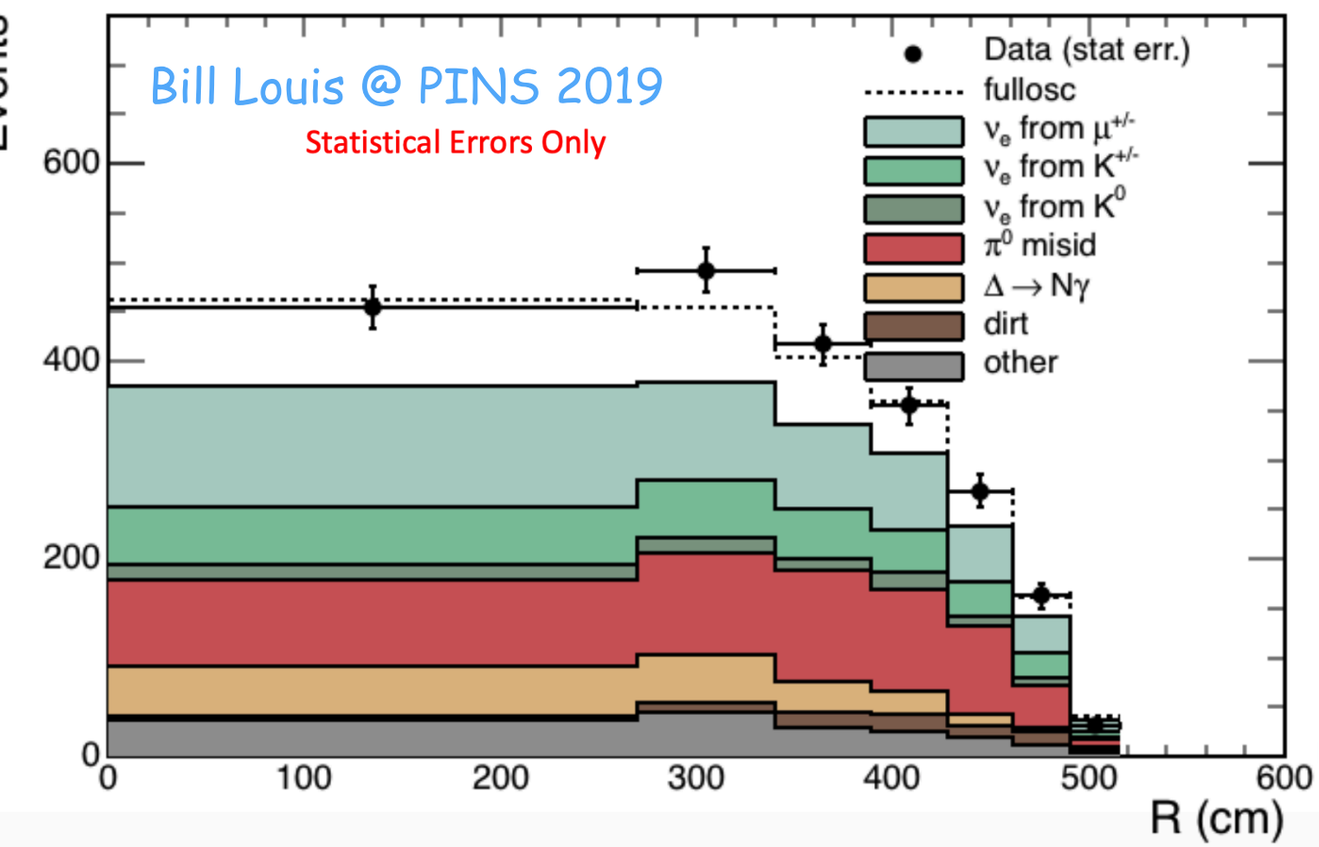
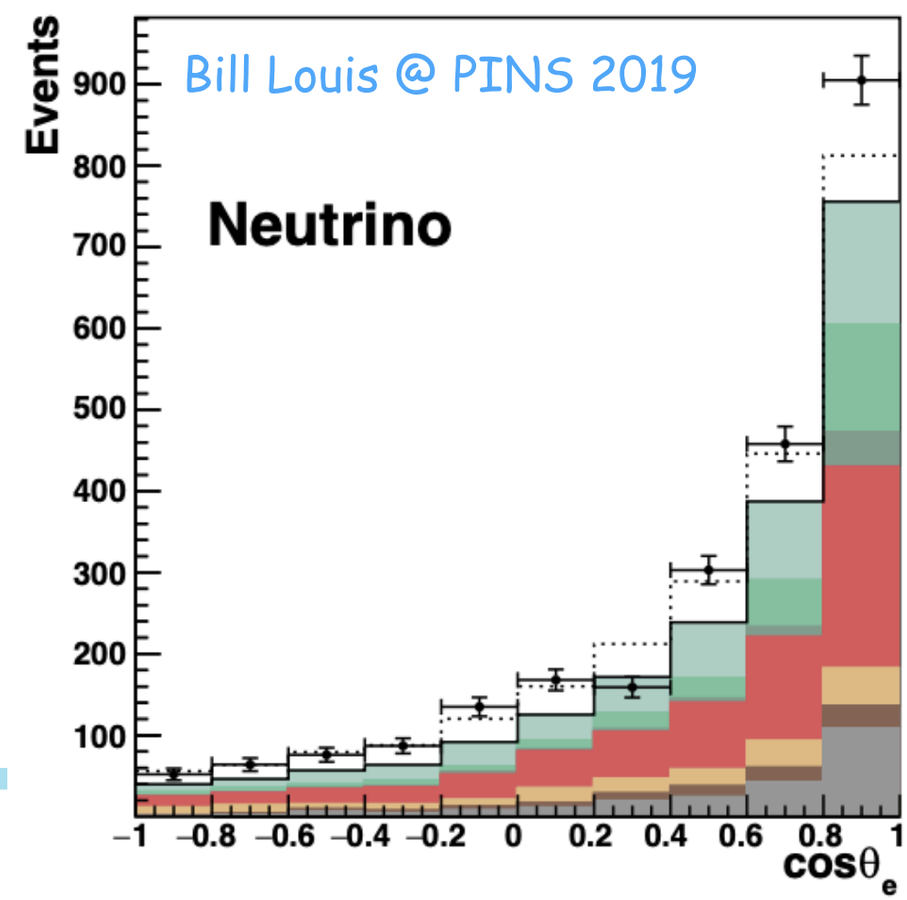
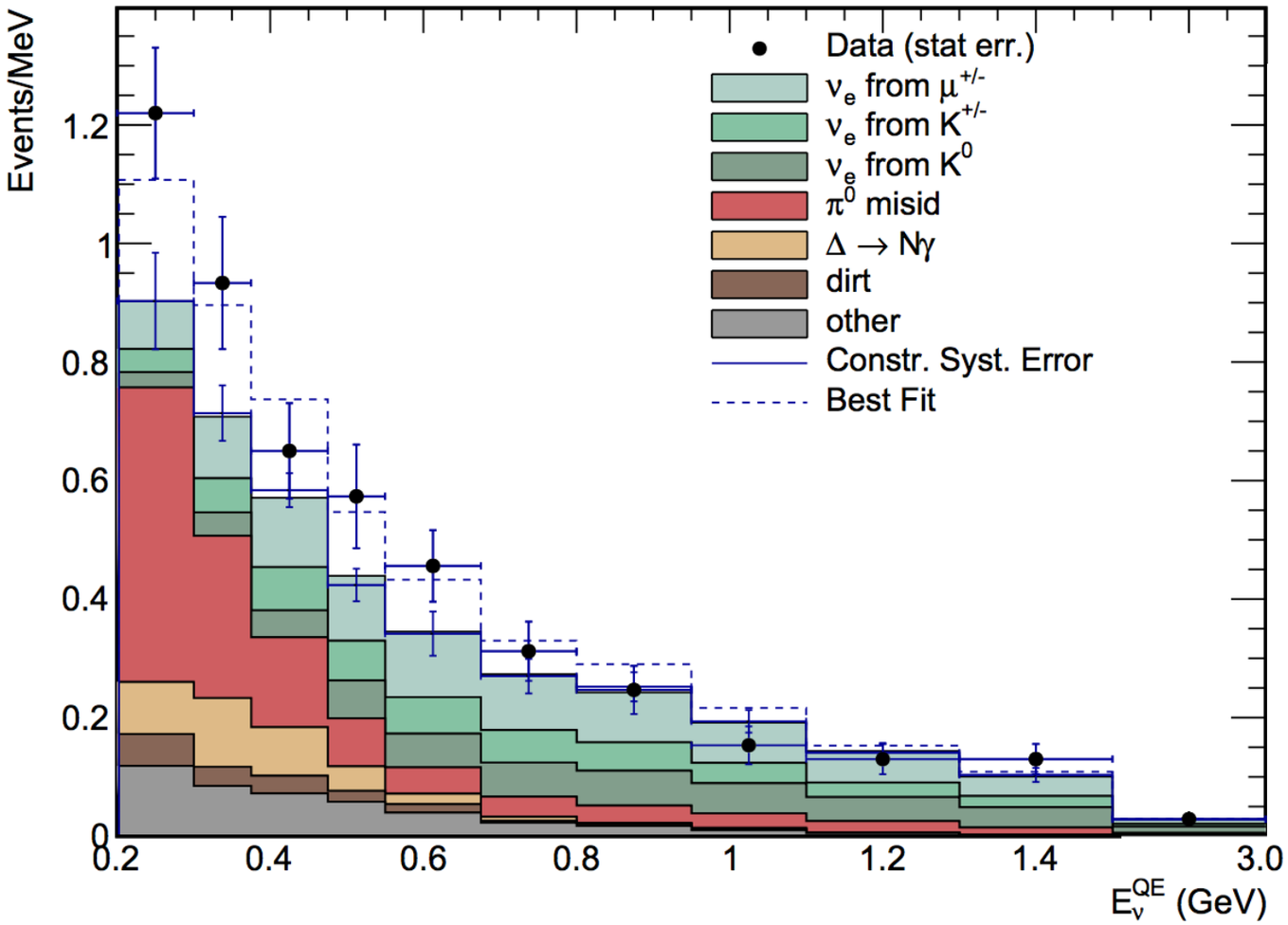
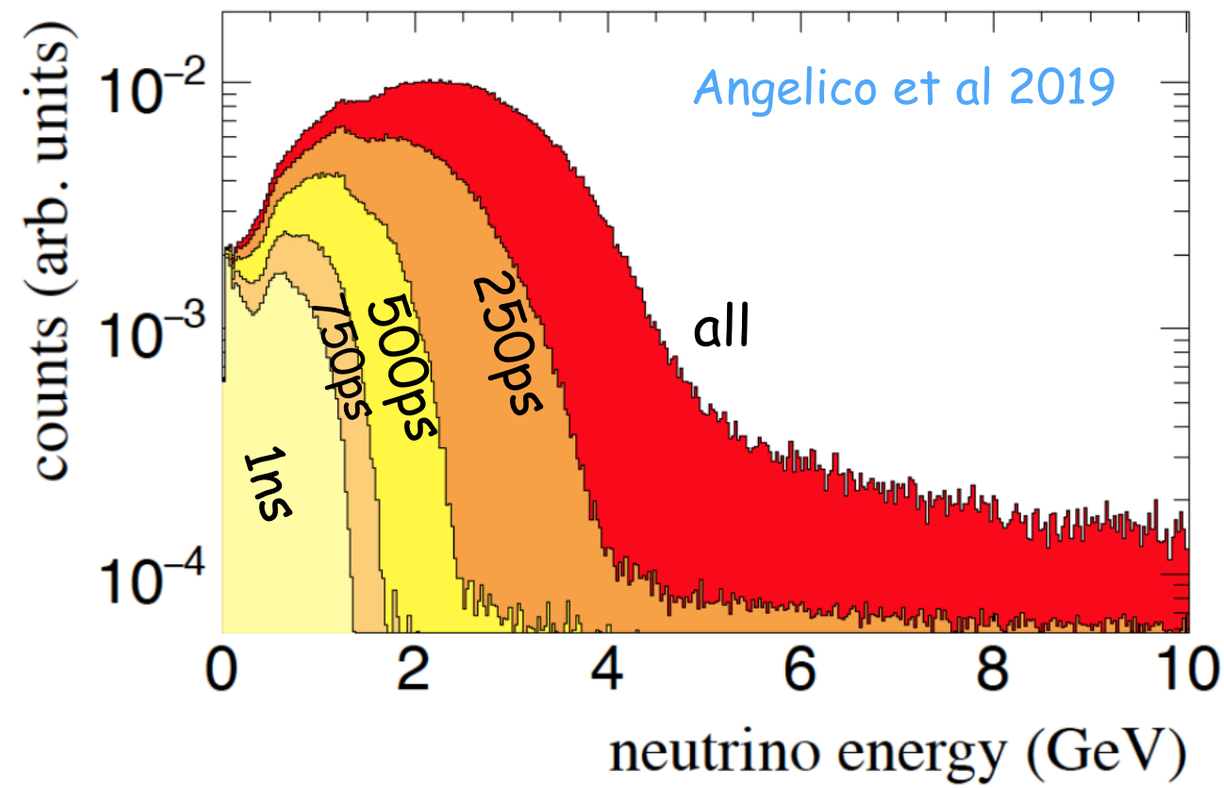






Backgrounds and timing?





Distribution of excess in time could be interesting

Are these high energy events migrating to low E?

Do they look like ν_e from $\mu^{\pm}$, $K^{\pm}$ or K^0?

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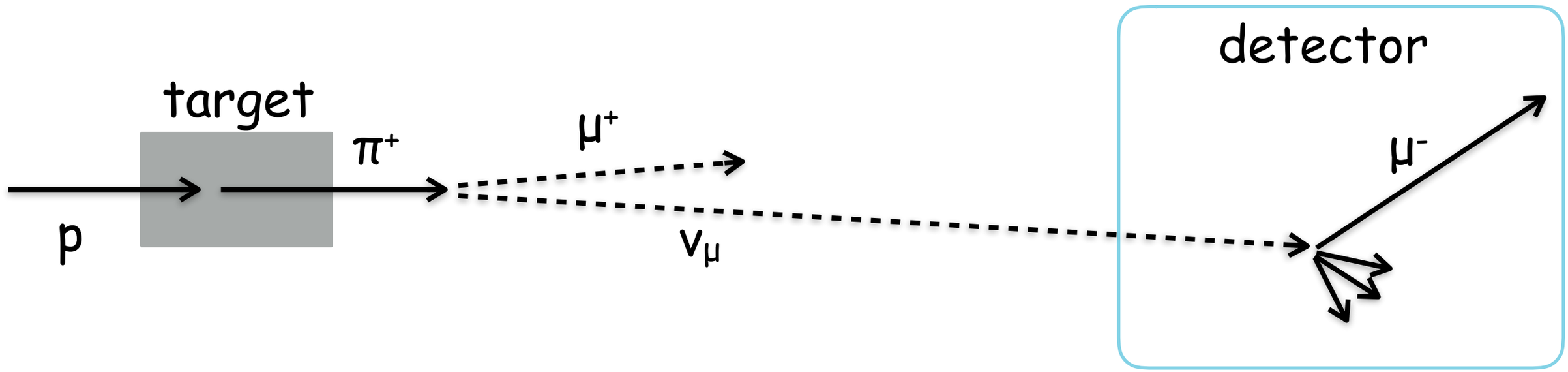
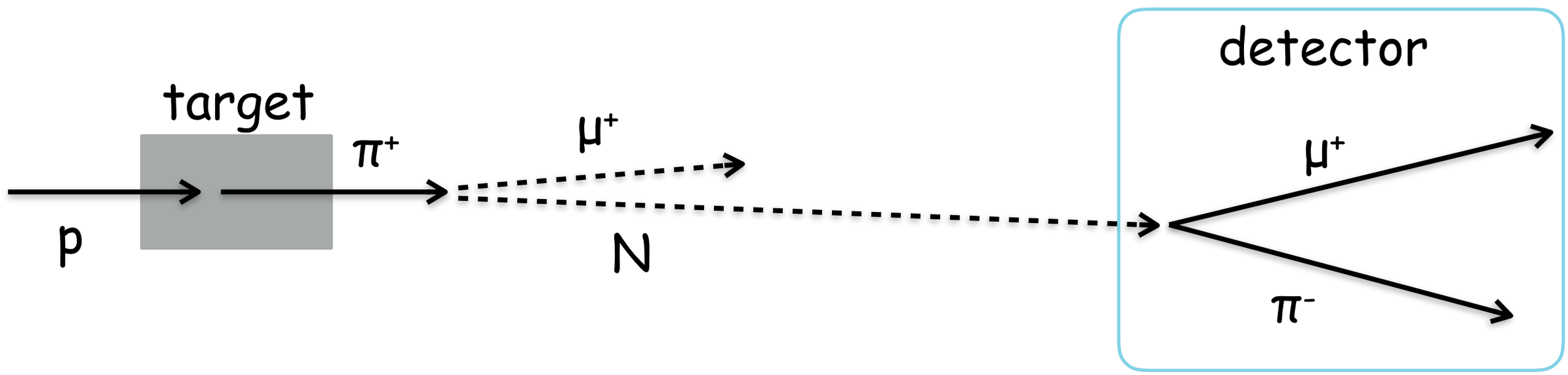
Long lived particles





Next few slides are taken from Yun-Tse Tsai @ PONDD 2018

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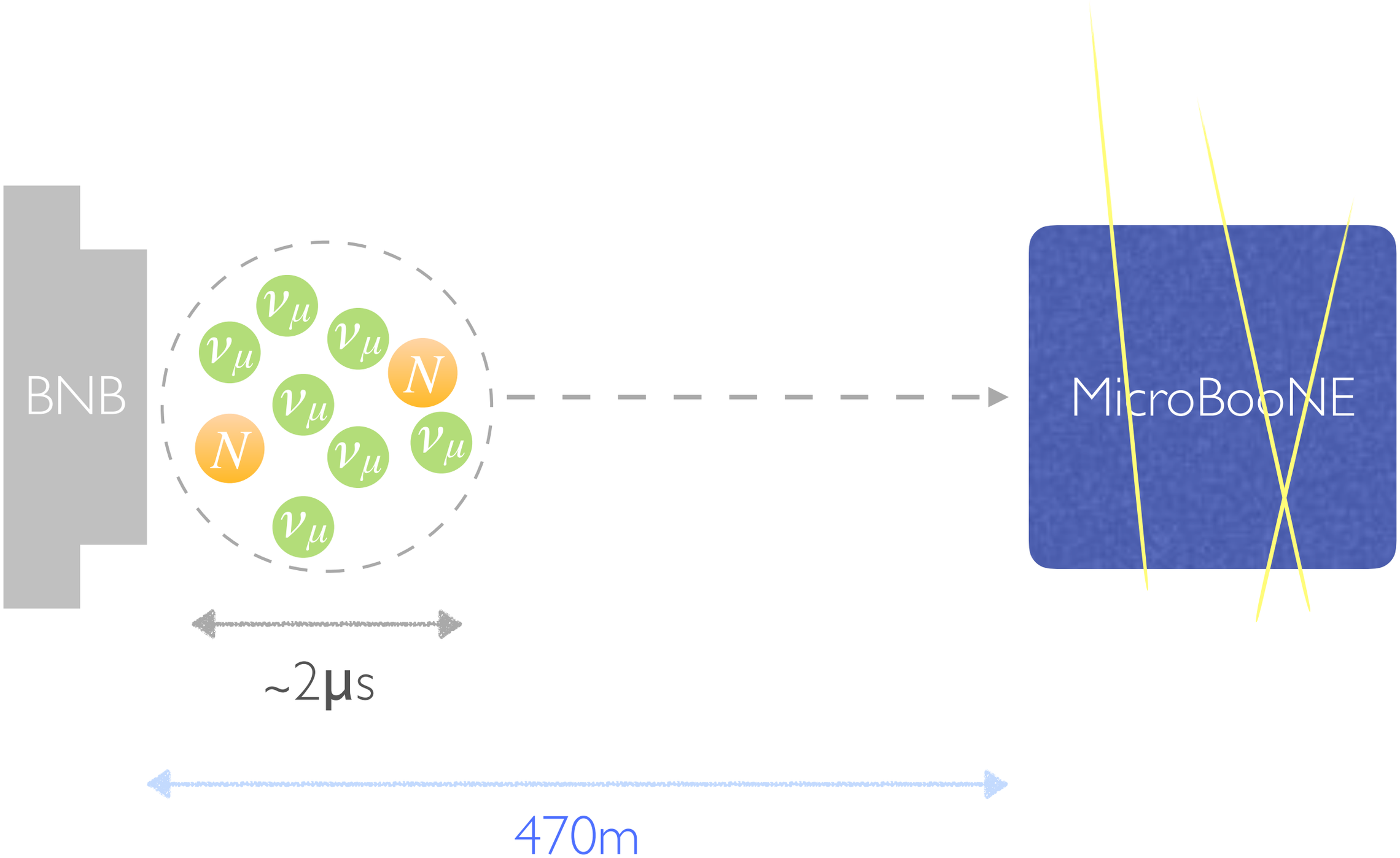
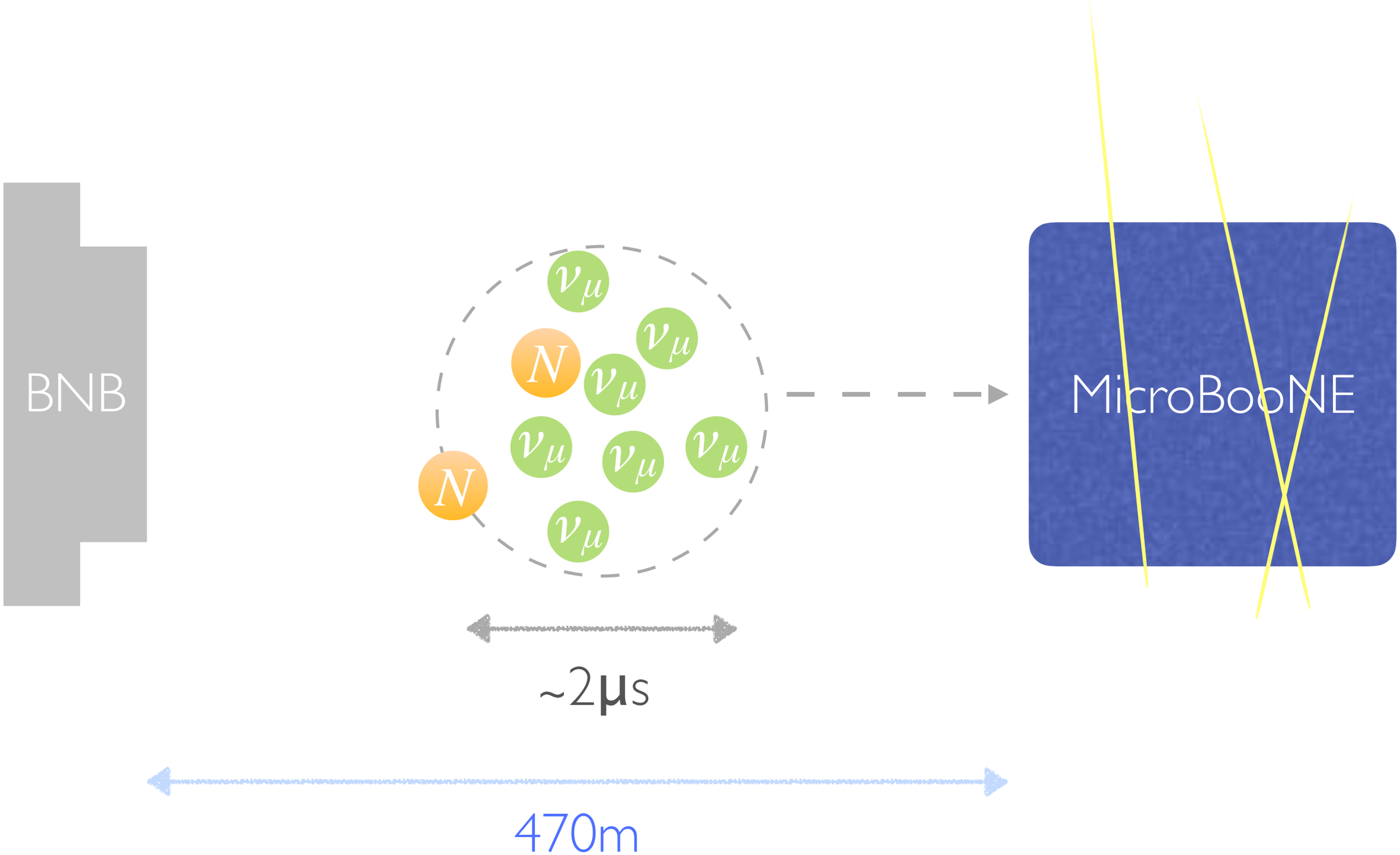
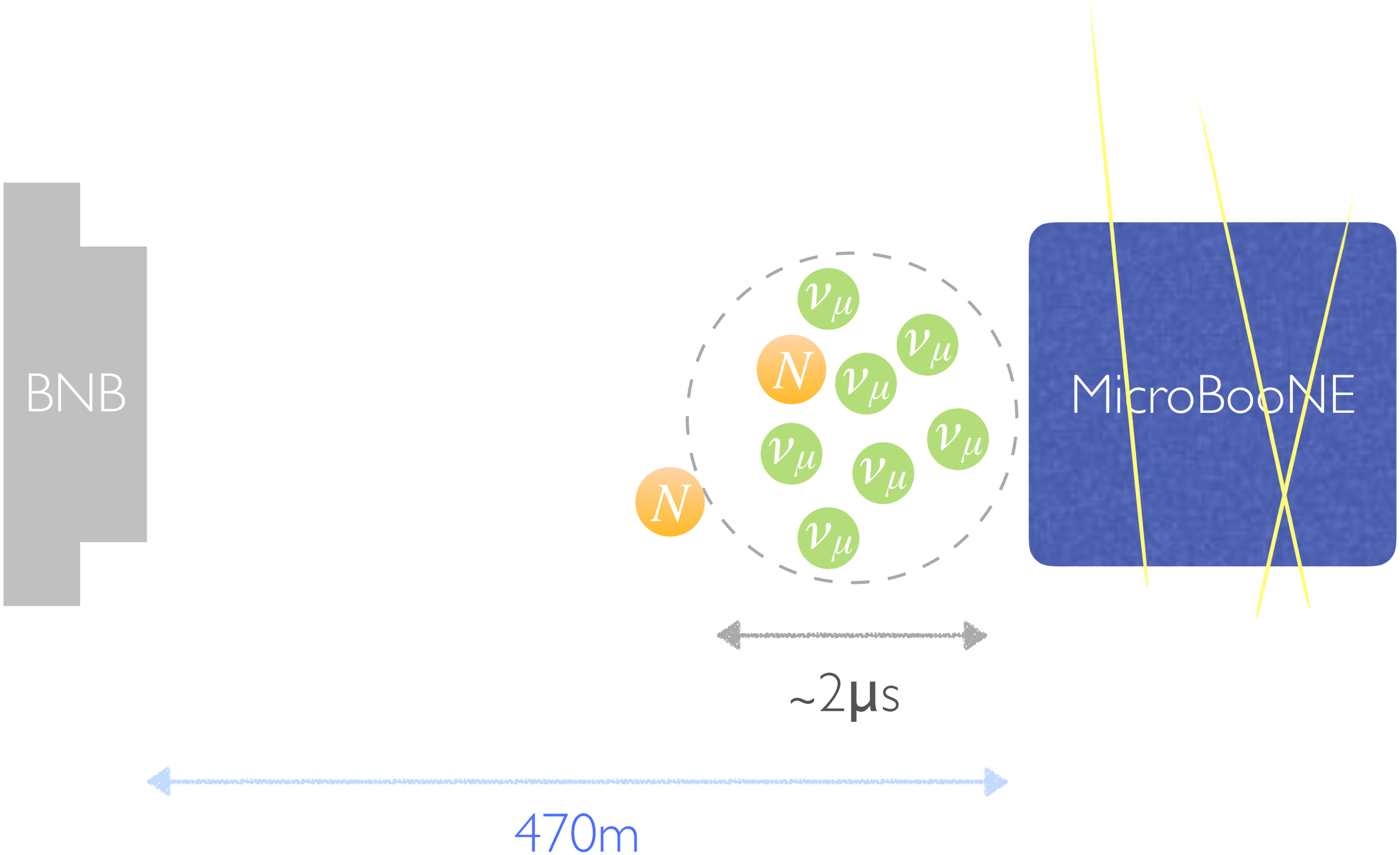
Time of Flight



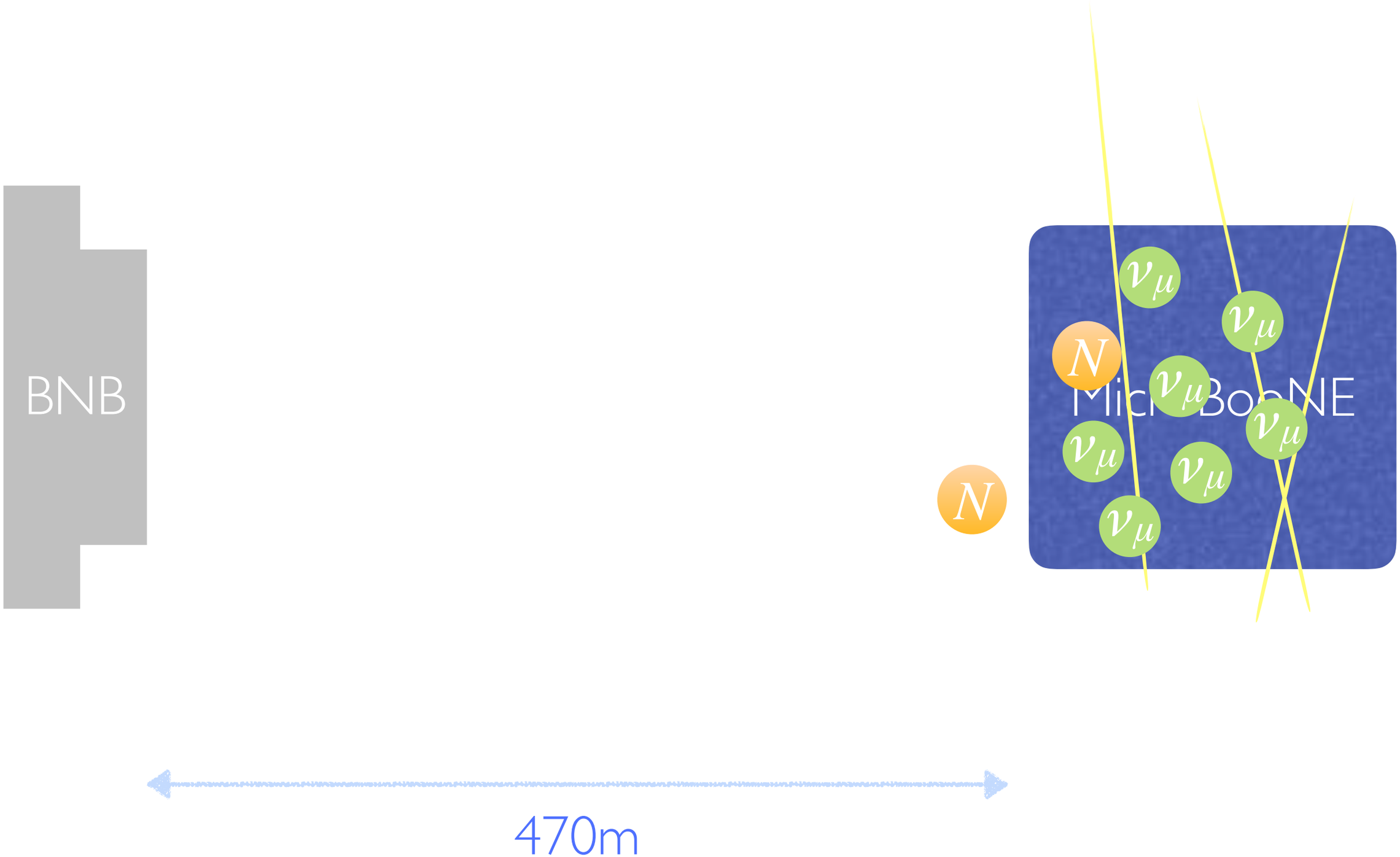
Time of Flight



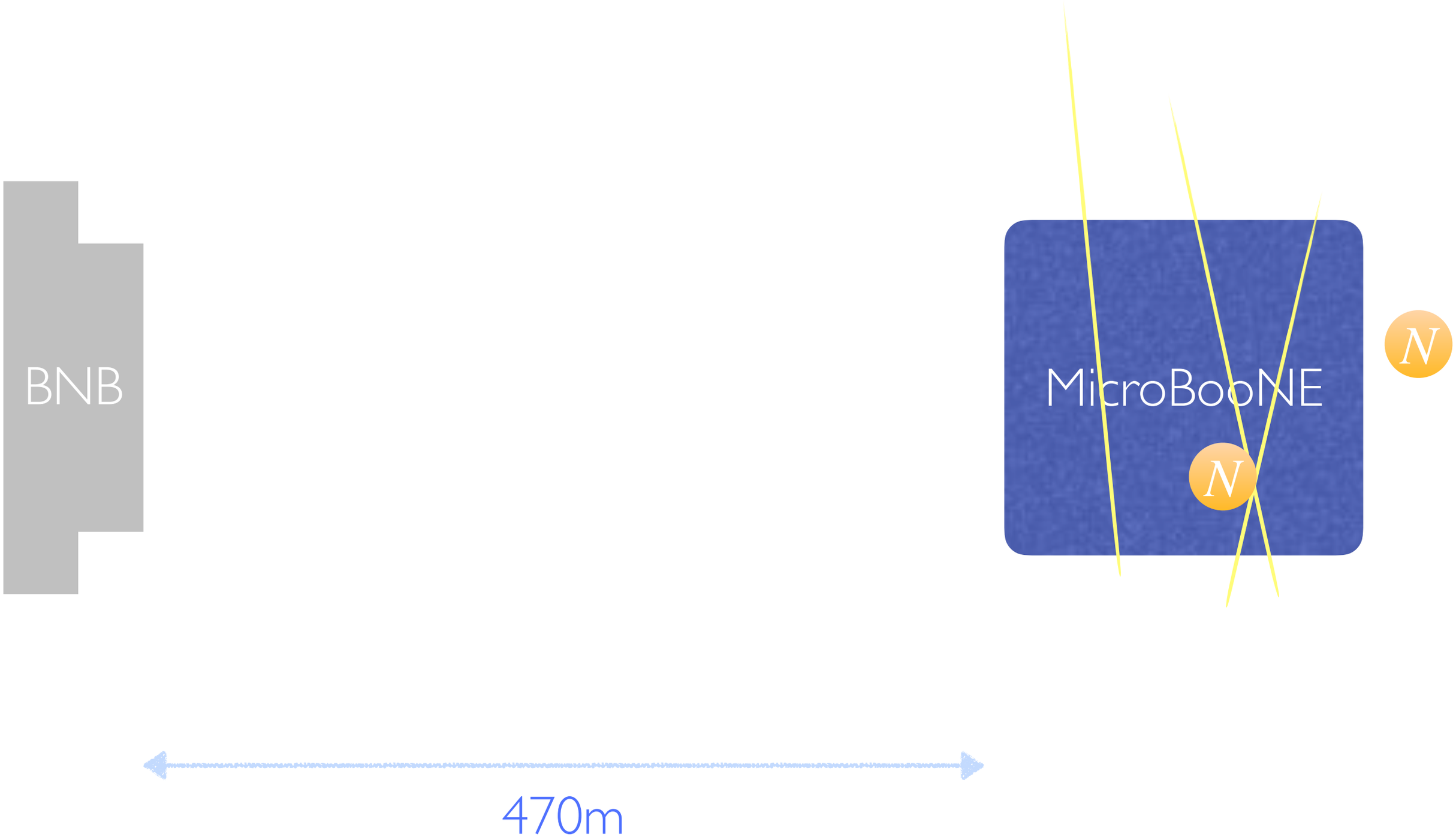
Time of Flight



Time of Flight

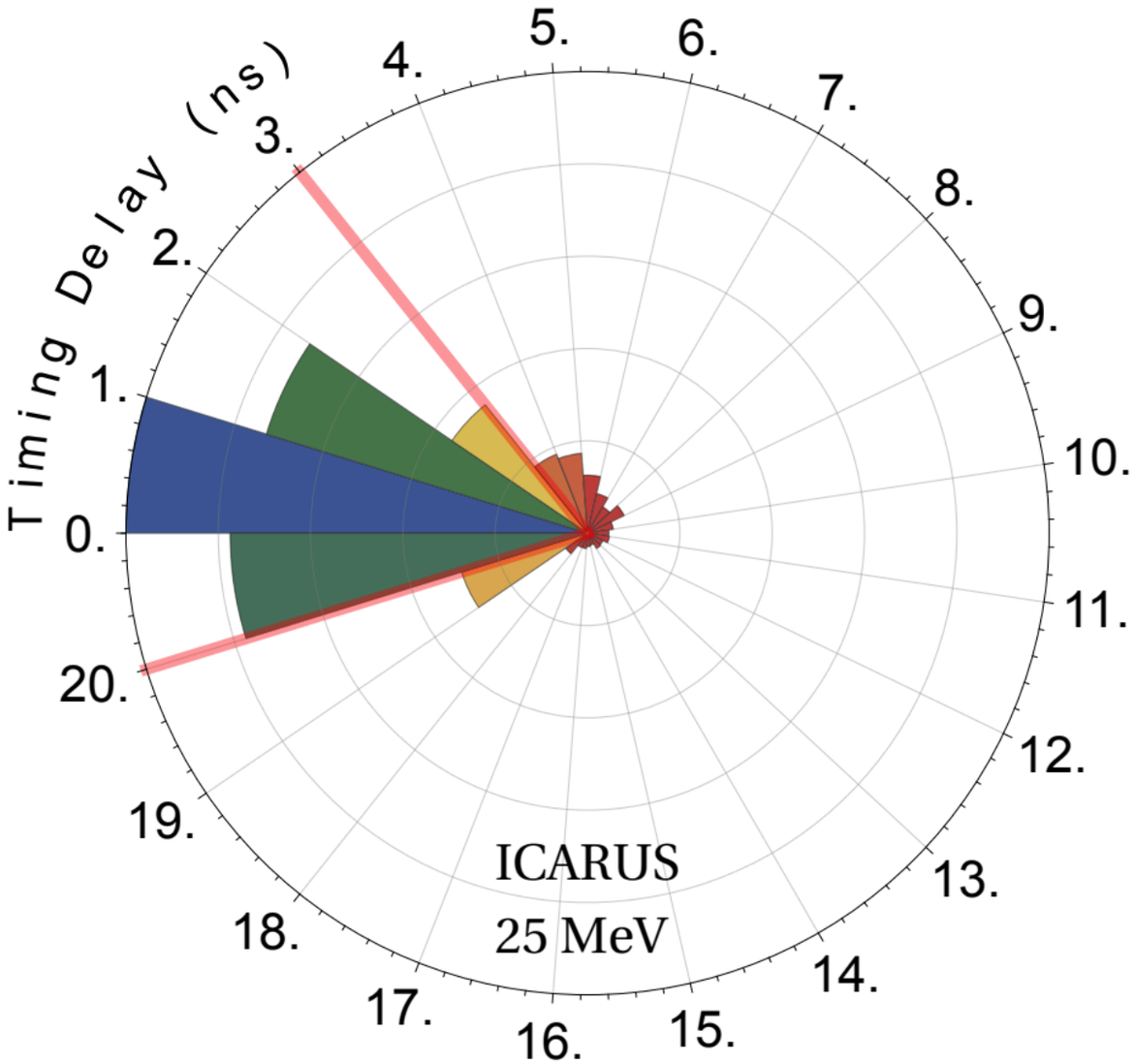


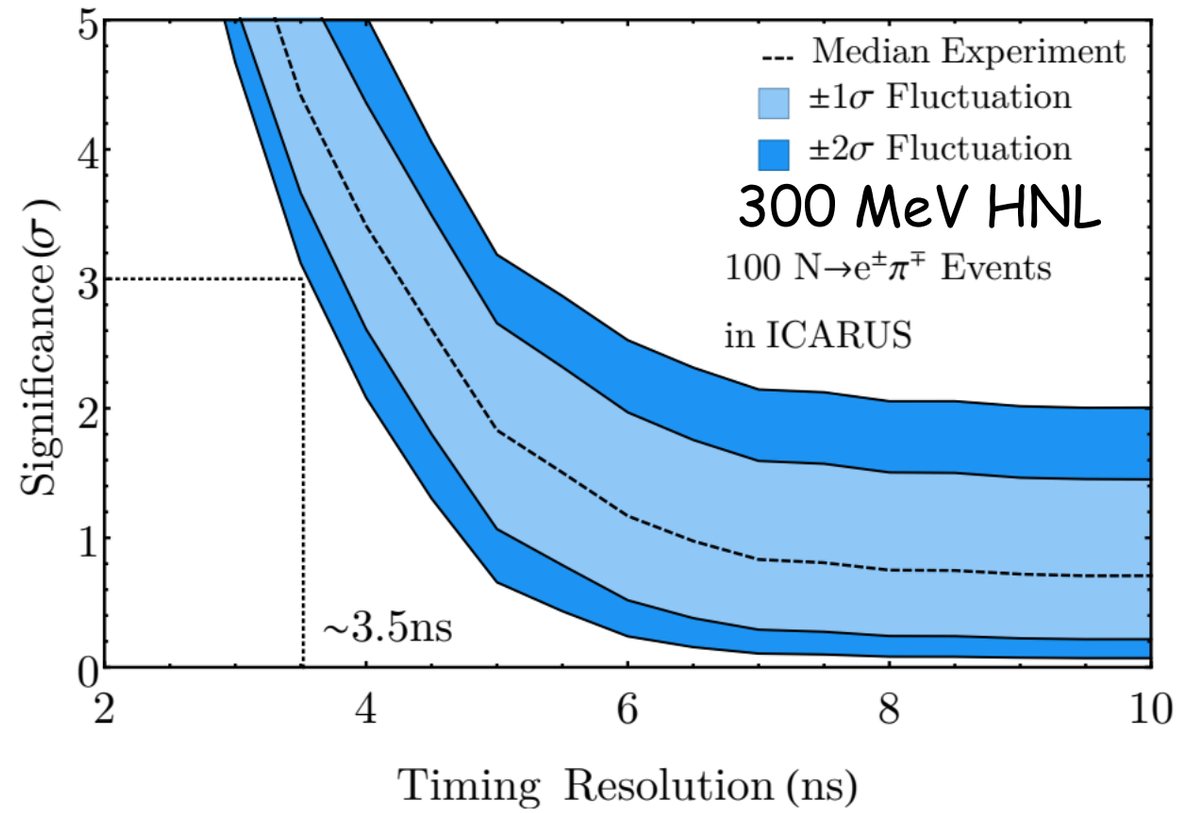
Time of Flight

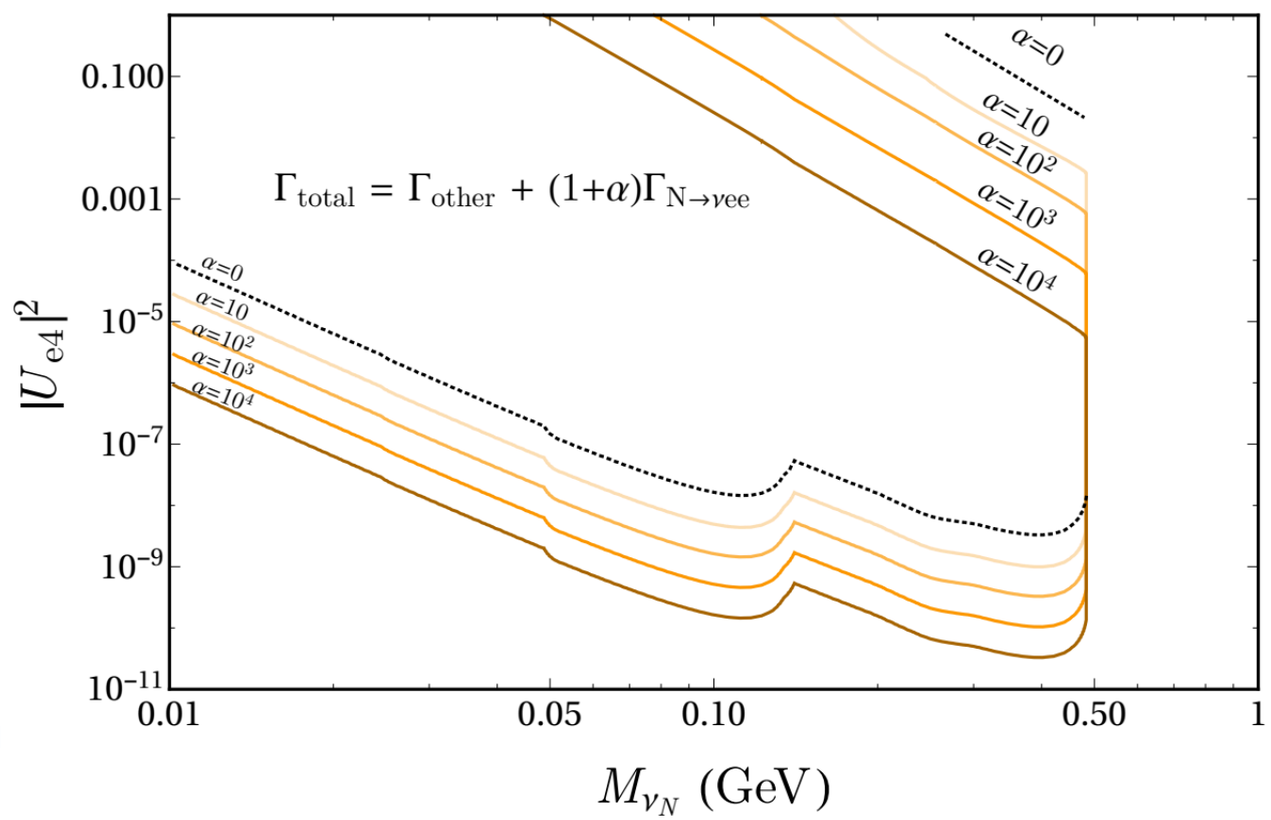


Long lived particles

Ballett et al 2016

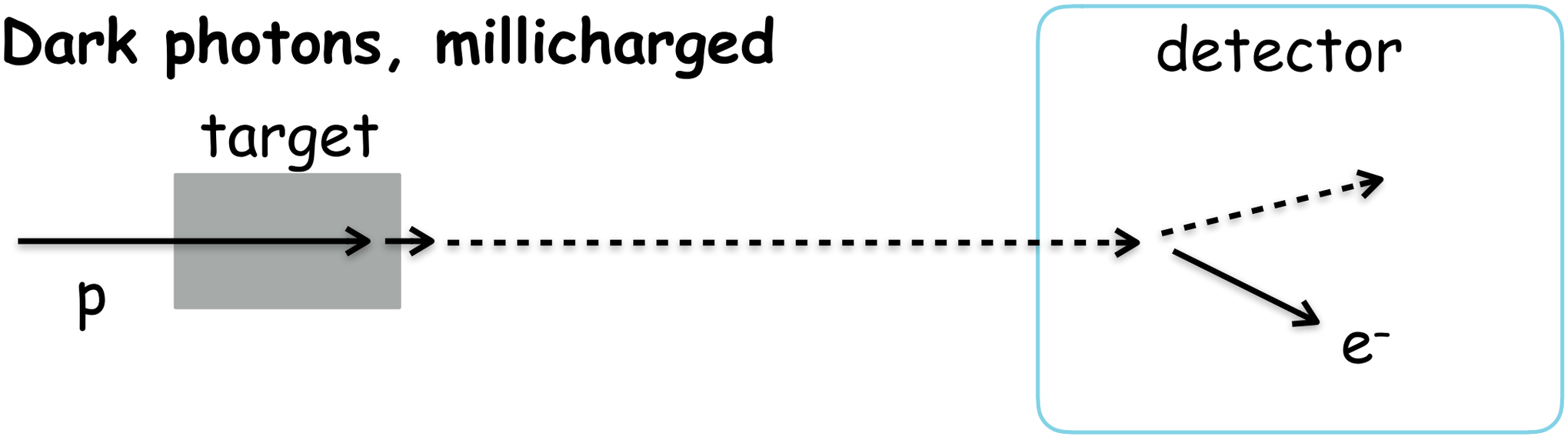




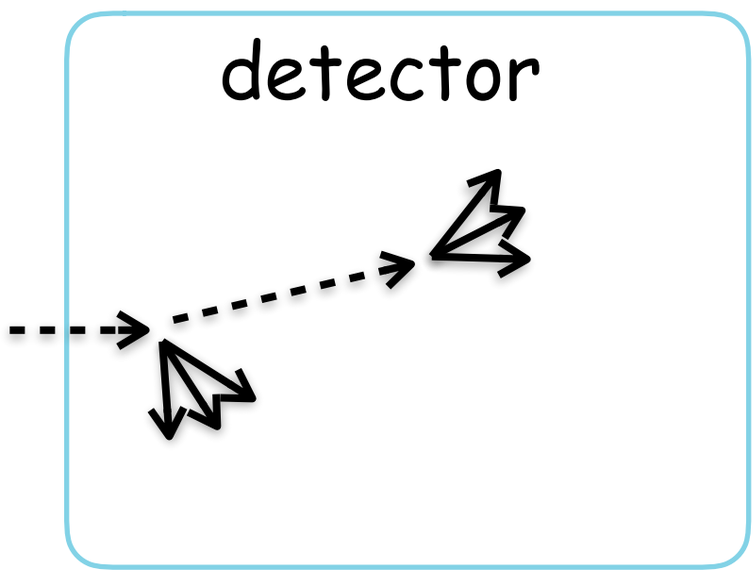


Few other scenarios and possibilities

Dark photons, millicharged

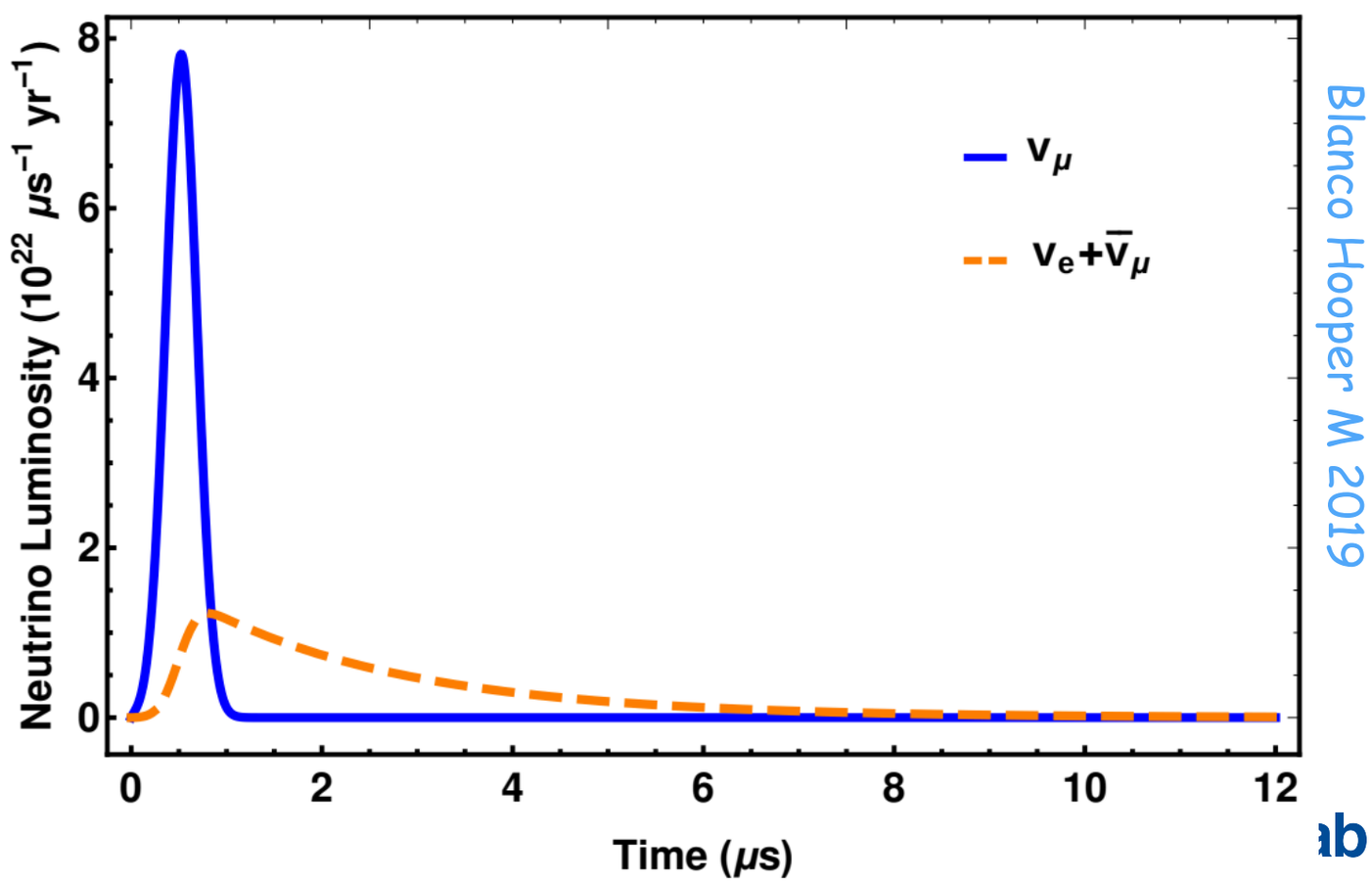


Dark neutrinos



Neutrino speed

πDAR and KDAR



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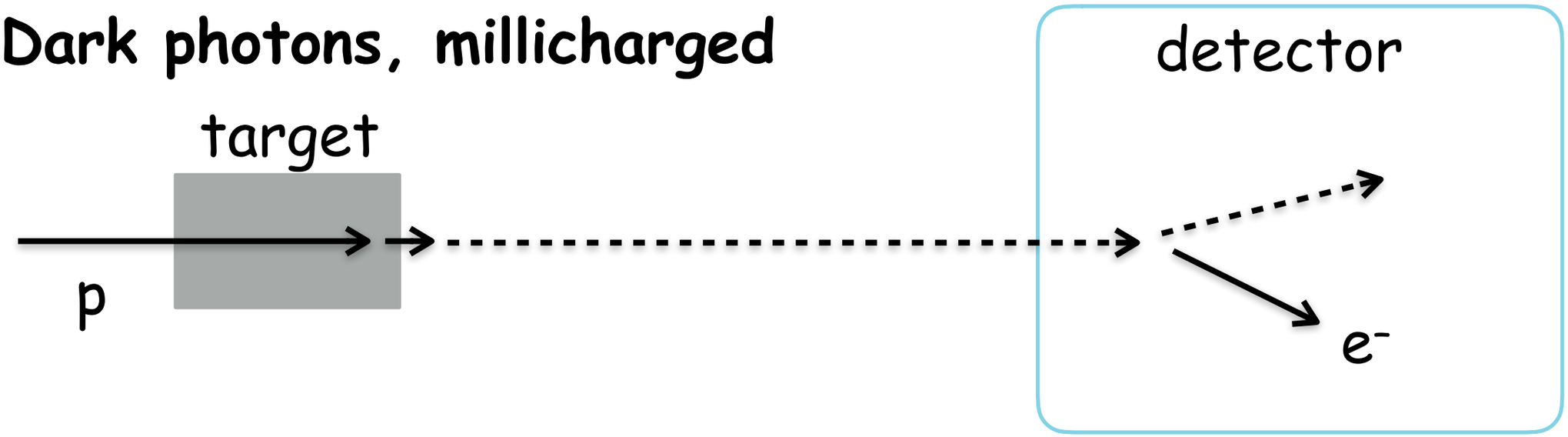
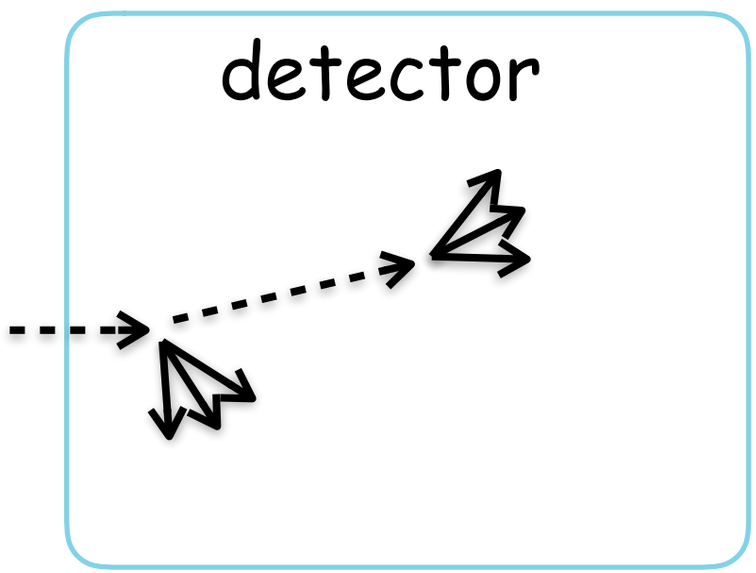
pmachado@fnal.gov

Few other scenarios and possibilities

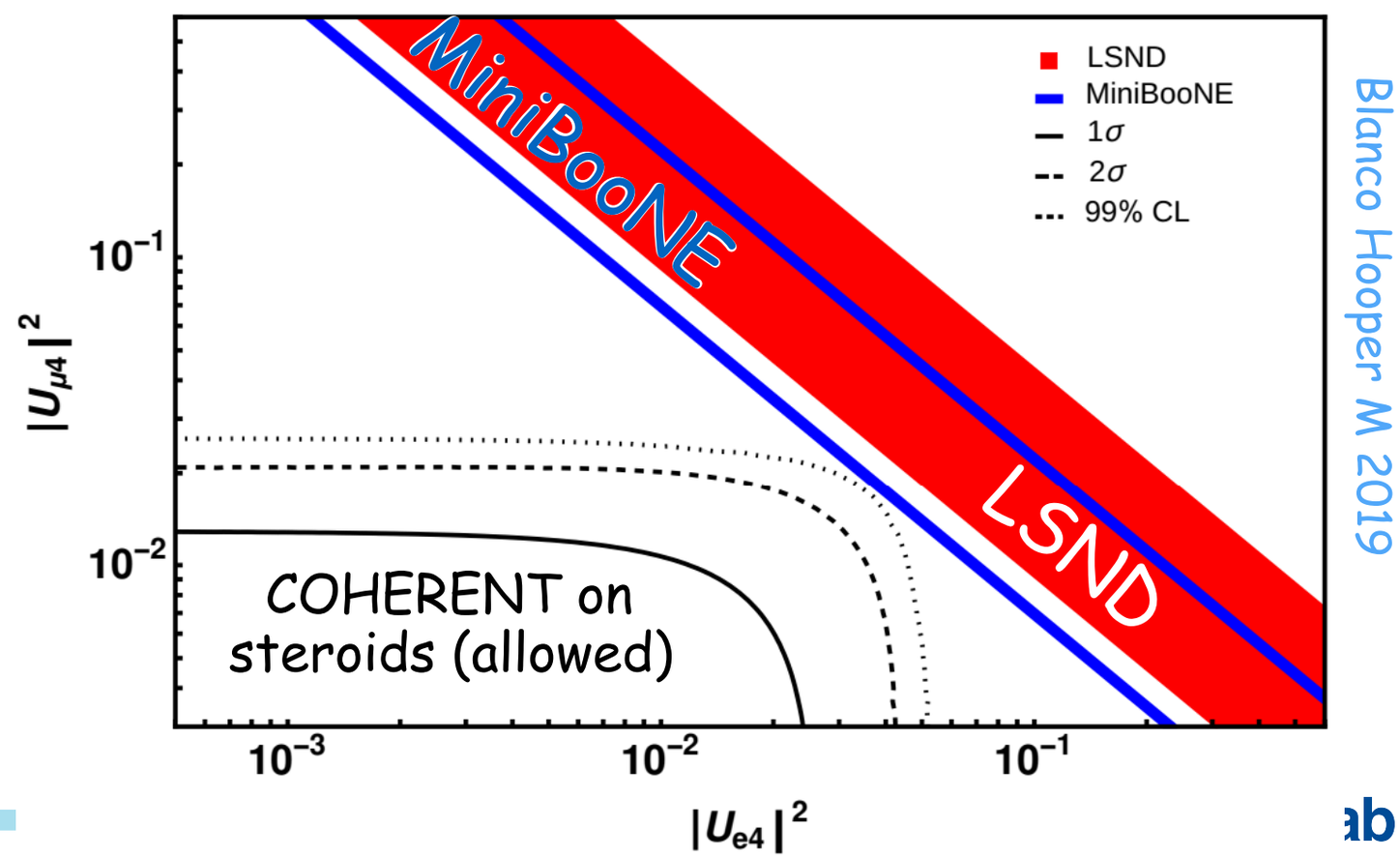
Dark photons, millicharged



Dark neutrinos



πDAR and KDAR



Neutrino speed

pmachado@fnal.gov

Conclusions

Improved timing may help SM and BSM physics case

Large stats ==> timing anatomy

We need more studies to prove the physics case, happy to help

Timing vs PRISM or timing + PRISM?

pmachado@fnal.gov