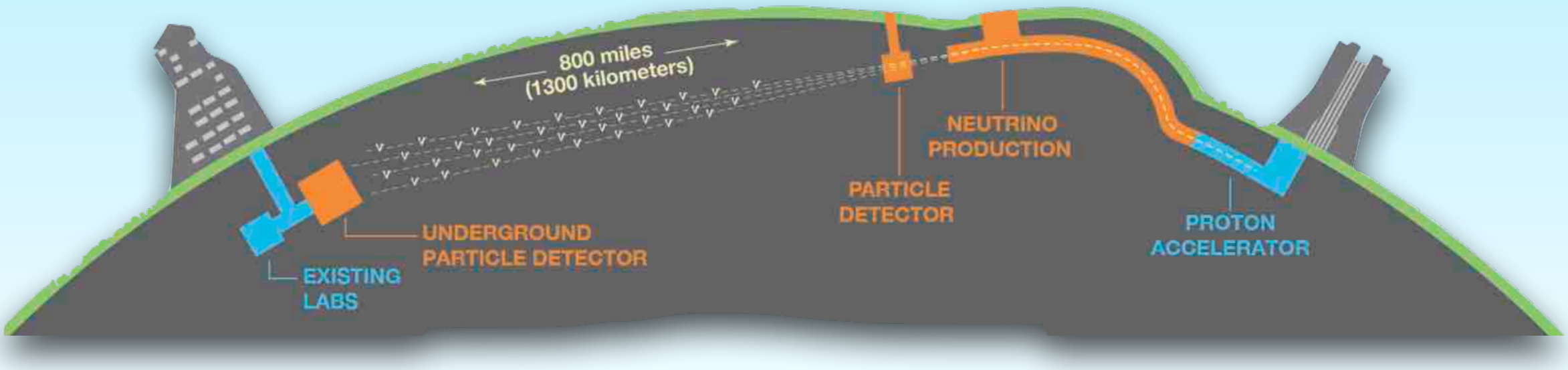
A ν_τ appearance search analysis in DUNE (Deep Underground Neutrino Experiment)

PhD day

-

27th January 2021



DEEP UNDERGROUND NEUTRINO EXPERIMENT

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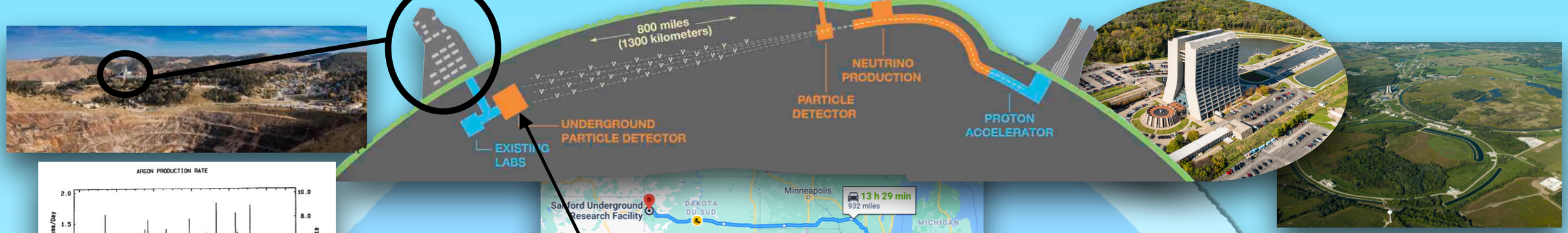
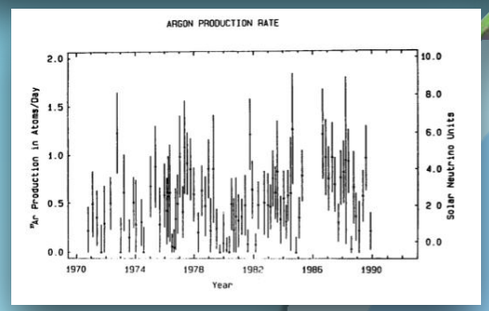
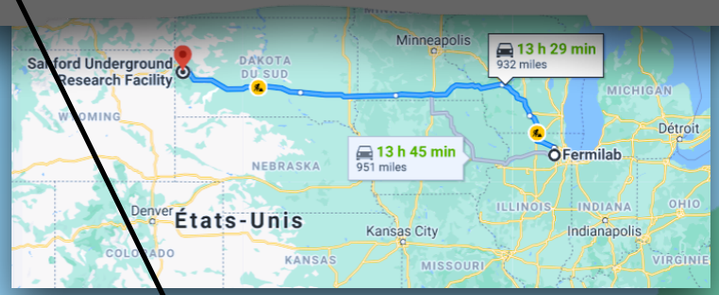




https://doi.org/10.1016/0146-6410(94)90004-3



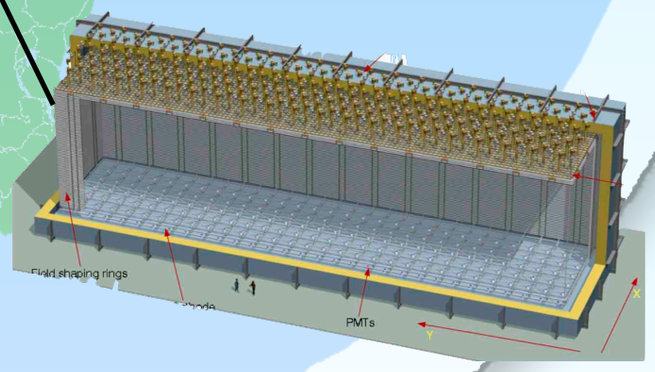
DUNE (Deep Underground Neutrino Experiment)

Long-baseline experiment between Fermilab (~Chicago, Illinois) and Sanford Underground Research Facility (South Dakota, ~Far West).

Neutrinos produced at Fermilab are shot at ~5° downard, run over 1285 km in Earth, and come out at Sanford (1.5 km underground, actually).

They first travel through a « near detector », installed at Fermilab.

Four 10-kTon detector modules at Sanford to detect neutrino events. Size = 66 x 19 x 18 m³.
(~1 Dirac building)



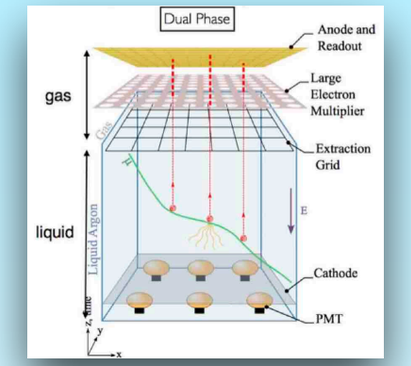
LBNE	LBNE—>DUNE	Site excavation starts	ProtoDUNEs (CERN) start operating	FD site complete	Beam data taking
2010	2015	2017	2019/2020	2024	2026

LArTPC (Liquid Argon Time Projection Chamber) in a nutshell

Idea originated from 1977, C. Rubbia (Nobel Prize, but not for that): argon described as a promising target for future neutrino experiments.

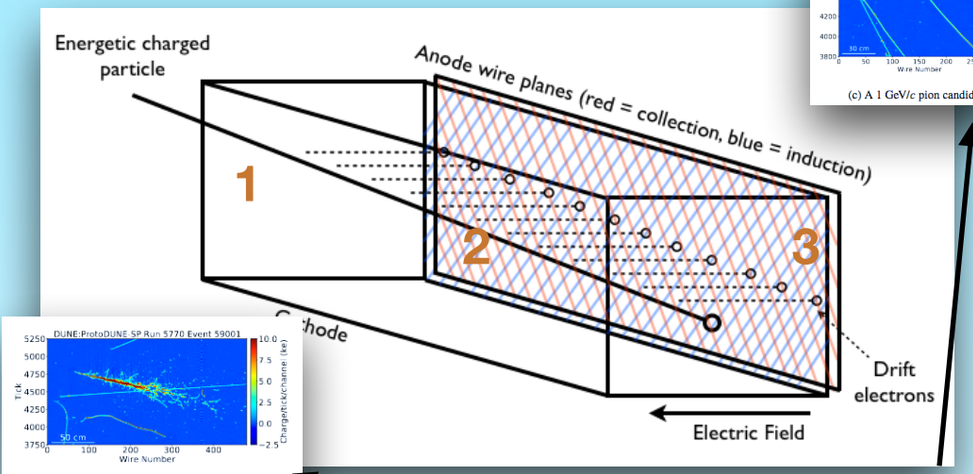
Allows **precise energy** reconstruction of charged particles.

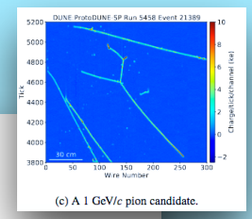
IP2I team involved in the deployment of the novel double-phase LArTPC technology. The anode plane is in a thick layer of gas, allowing for signal gain increase.



Currently, ProtoDUNEs (far detector prototypes, 6x6x6 m3) at CERN testing the O(10.000 tons) scaling detector mass and deepening charged hadron energy deposition in matter.

The working principle





(c) A 1 GeV/*c* pion candidate.

(b) A 6 GeV/*c* electron candidate.

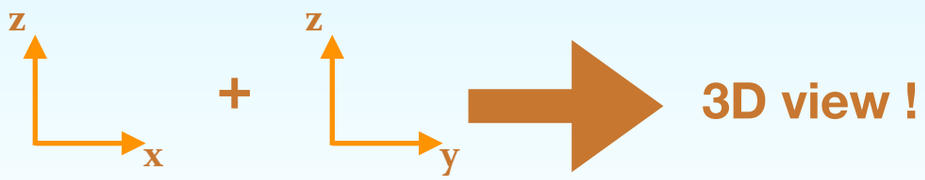
https://arxiv.org/pdf/2007.06722.pdf

1°/ Charged particles ionise argon.

2°/ Free electrons derive thanks to a strong external electrical field.

3°/ Electrons are detected/captured by several planes of stripes, allowing for 2-D projection views of the same events.

4°/ Event reconstruction process uses the time of flight of electrons as the third coordinates.



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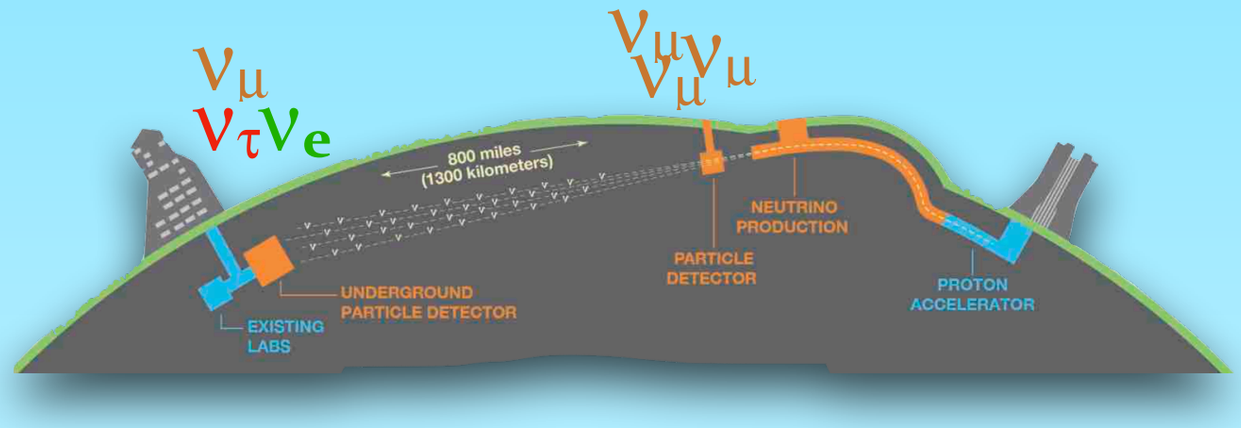
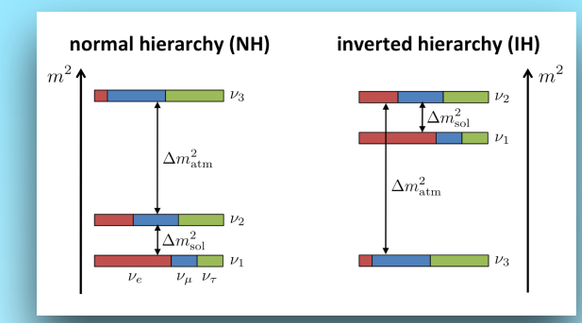
DUNE scientific program



Neutrino oscillation, more scpecifically the parameters θ_{23} and δ_{CP}, thanks to $\nu_\mu \rightarrow \nu_e$ oscillation channel.

(v3-flavour phenomenology ($\nu_\mu \rightarrow \nu_\tau$ research))

Proton decay research program.



Mass hierarchy measurement (normal ordering favoured at 3σ).

Supernova ν_e detecting program, if one were to explode in our Milky Way (O(5000) events/supernova).

ν_τ physics at DUNE

10.1103/PhysRevD.100.016004

- Unprecedented sensitivity to the $\nu_\mu \rightarrow \nu_\tau$ channel ; O(100-1000) events at DUNE Far Detectors (runtime experiment) vs O(20) today.

Useful for hypothesis testing →

1. **Non unitary lepton mixing matrix**
2. **3+1 neutrino paradigm**
3. **Non-standard neutrino neutral current**

- Complementary to $\nu_\mu \rightarrow \nu_e$, θ_{23} constrain, cross-section measurement

BUT: non-trivial appearance search ; cross-section killed because of τ mass

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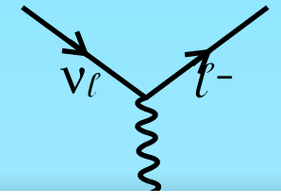
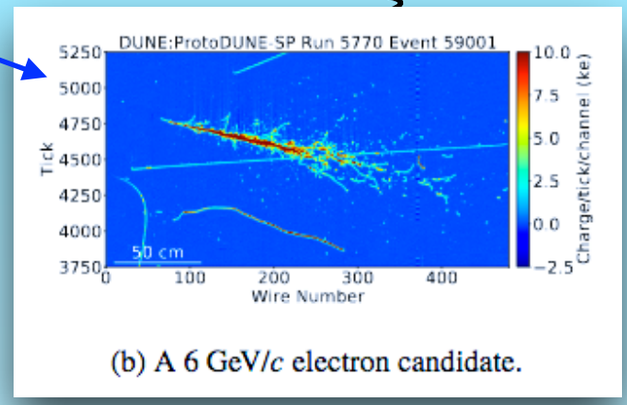
Detecting ν_τ physics at DUNE - 1

- **Neutrino flavour identification**: charged-current interaction (i.e coupling with the charged lepton). Look for the presence of a charged lepton in the final state. e^- —> electromagnetic shower, μ^- —> long straight track. **What about the τ ?**





(b) A 6 GeV/*c* electron candidate.

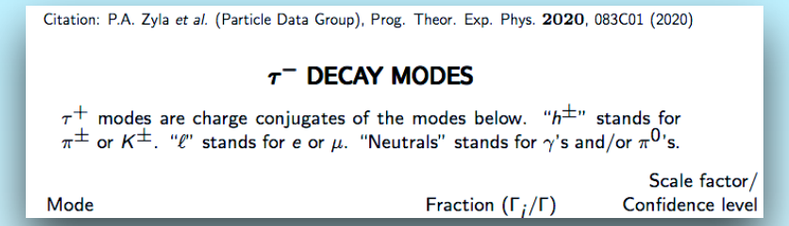
https://arxiv.org/pdf/2007.06722.pdf

DUNE ν energies O(1 GeV) + **τ half-life** + **Doing the math**

= τ mean length of flight before decay O(100 μm) < detector spatial resolution (~3 mm)

Without special care, the ν_τ sample is lost

- **Idea**: rely on the τ decay products !


Citation: P.A. Zyla *et al.* (Particle Data Group), Prog. Theor. Exp. Phys. **2020**, 083C01 (2020)

τ^- DECAY MODES

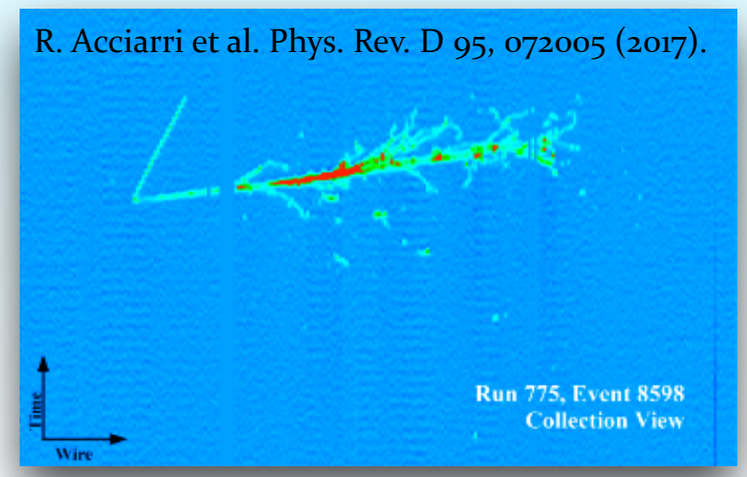
τ^+ modes are charge conjugates of the modes below. "$h^\pm$" stands for $\pi^\pm$ or $K^\pm$. "ℓ" stands for e or μ. "Neutrals" stands for γ's and/or π^0's.

Mode	Fraction (Γ_i/Γ)	Scale factor/ Confidence level

Particle Data Group

5 pages long...

- **Solution**: develop a specific S/B analysis for "as many as" decay modes possible. In reality try to cover as many branching ratio as possible, pickink most promising decay modes.



ν_eCC candidate, according to ν_e + Ar —>e^- + hadron(s)

Tell me, what would a ν_τ + Ar —> (τ^-)+hadron(s)—> ν_τ + e^- + ν_e + hadrons' look like ?

Detecting ν_τ physics at DUNE - 1

Going through the kinematics of ν_eCC like events

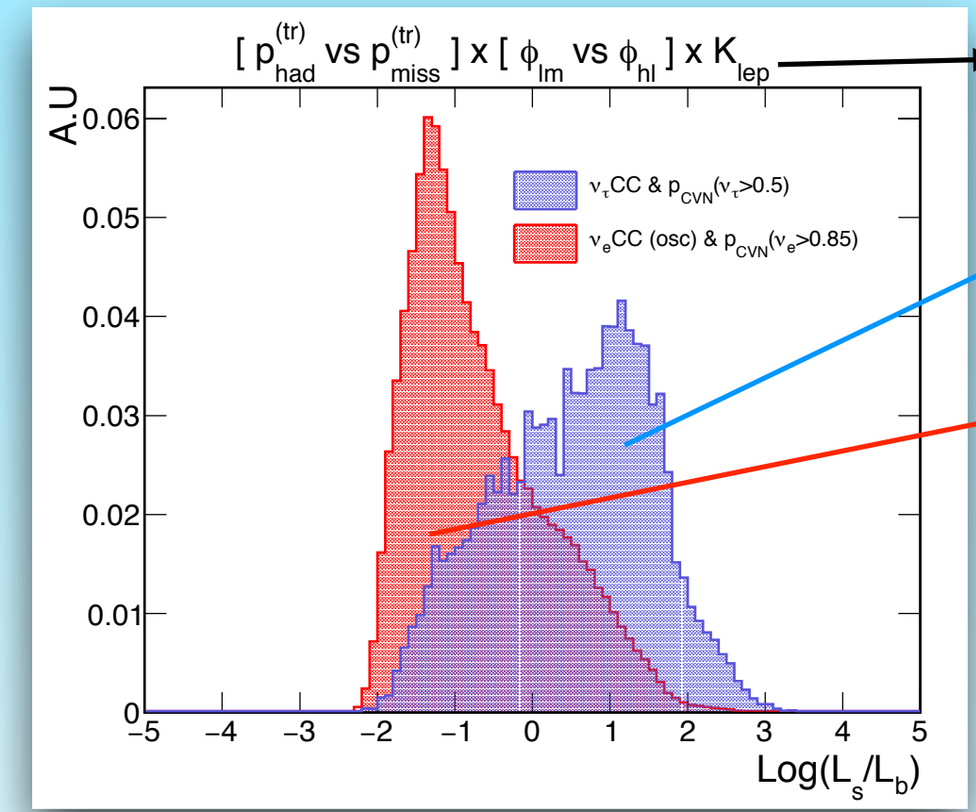
Look into the simulations files of the DUNE Technical Design Report (2019/2020)

Specify kinematic variables of neutrino events, build p.d.f for S and B

Go over the simulation files, for S and B and perform a **flavor test hypothesis** (Pseudo likelihood)

Pick the kinematic variables with the best discriminating power and define cuts

Show semi-realistic S/sqrt(B)

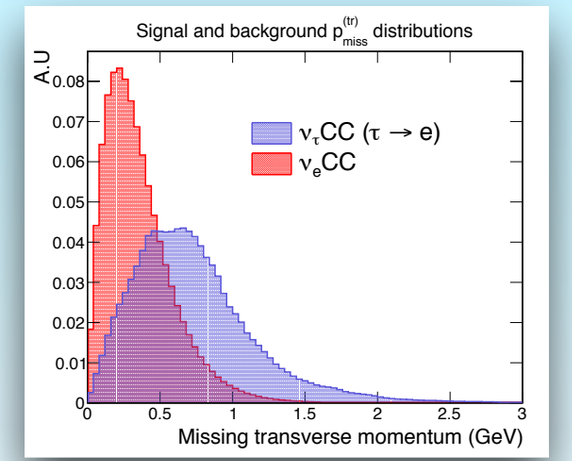


A plot I made for the τ—>e decay mode

Messy notations of kinematic variables

Pseudo-likelihood of ντ events

Pseudo-likelihood of neutral current events.



- **Get back home with numbers:** 3.5 years, expected to select ~20 ν_τ events while having ~220 ν_e background contamination. Note: DUNE has the possibility of using a higher neutrino energy beam (after some years of running) that would increase the ν_τ statistics.

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Conclusion / Discussion

DUNE is the only long-baseline neutrino experiment sensitive to the three active neutrino falvours. Good potentialities for physic measurements (3-flavour phenomenology).

I developped kinematical selection methods to identify τ neutrino events, each specific to the τ decay channel (namely τ—>e (17.8%) competing with ν_eCC and τ—>ρ (25.5%) competing with NC). Branching ratios in brackets.

Good knowledge of neutrino interaction, final state kinematics reconstruction and cross- required

Question ?