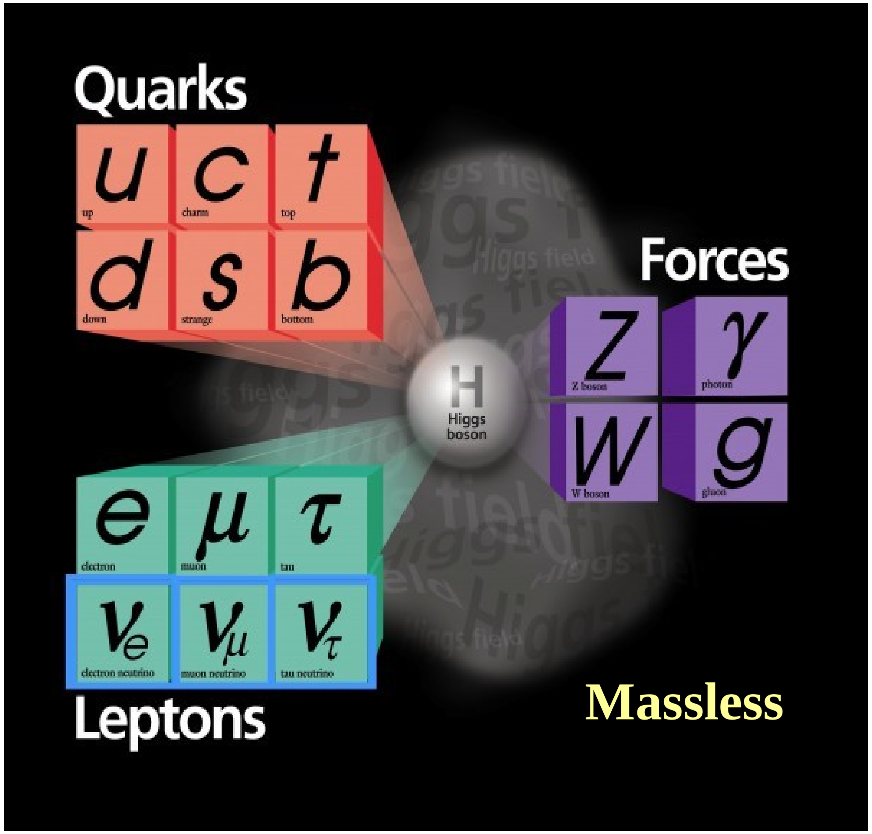
Event-by-event neutrino-hydrogen interactions with a hydrocarbon-gas TPC

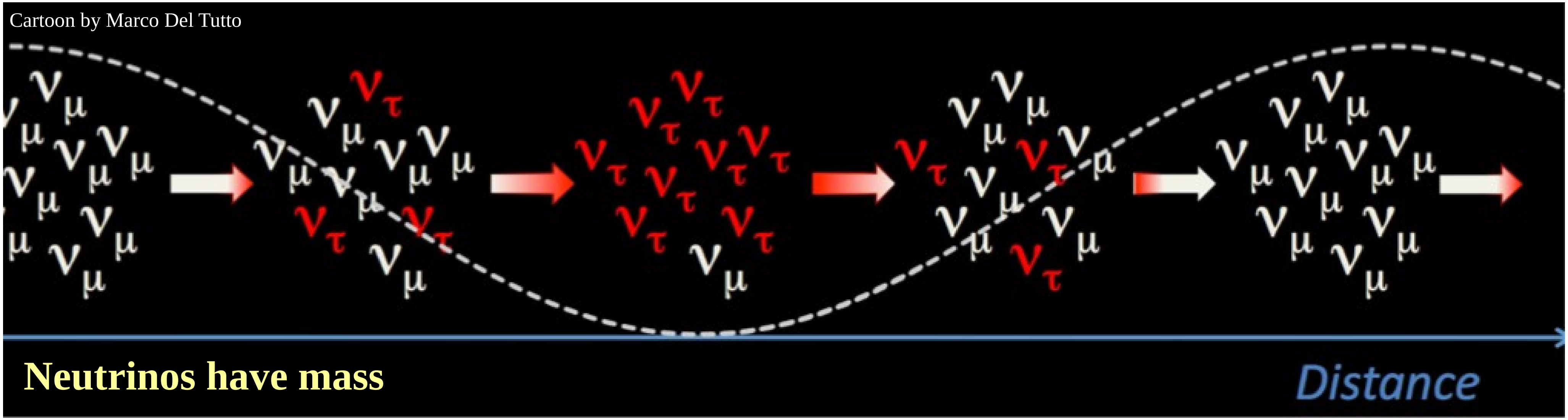
Xianguo LU/ 卢显国
University of Oxford

TPC Mini Workshop
CERN, 12 July 2019

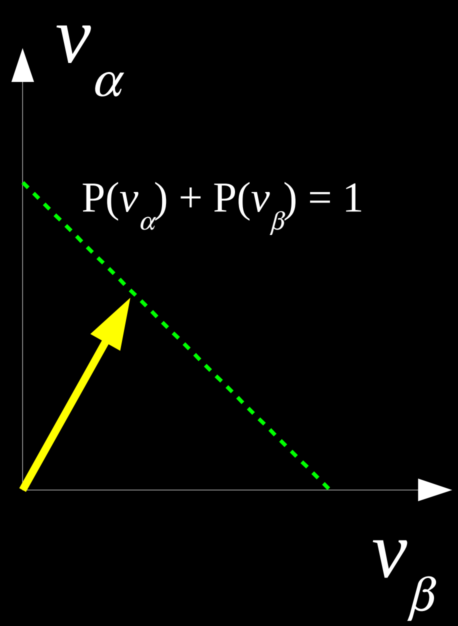
Wiki
By François Haffner

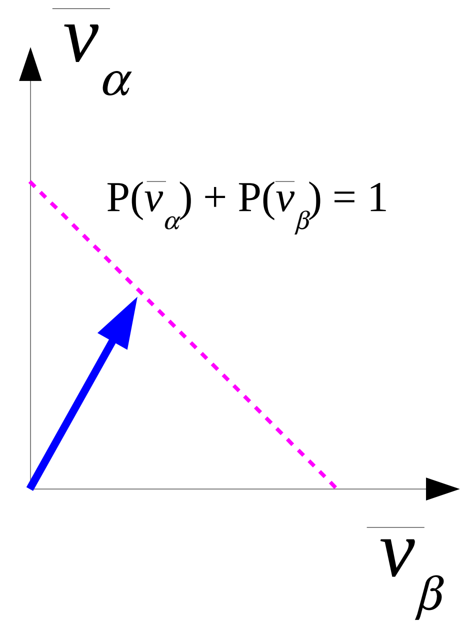
Physics Beyond Standard Model
via
Neutrino Oscillations





Neutrino Oscillations



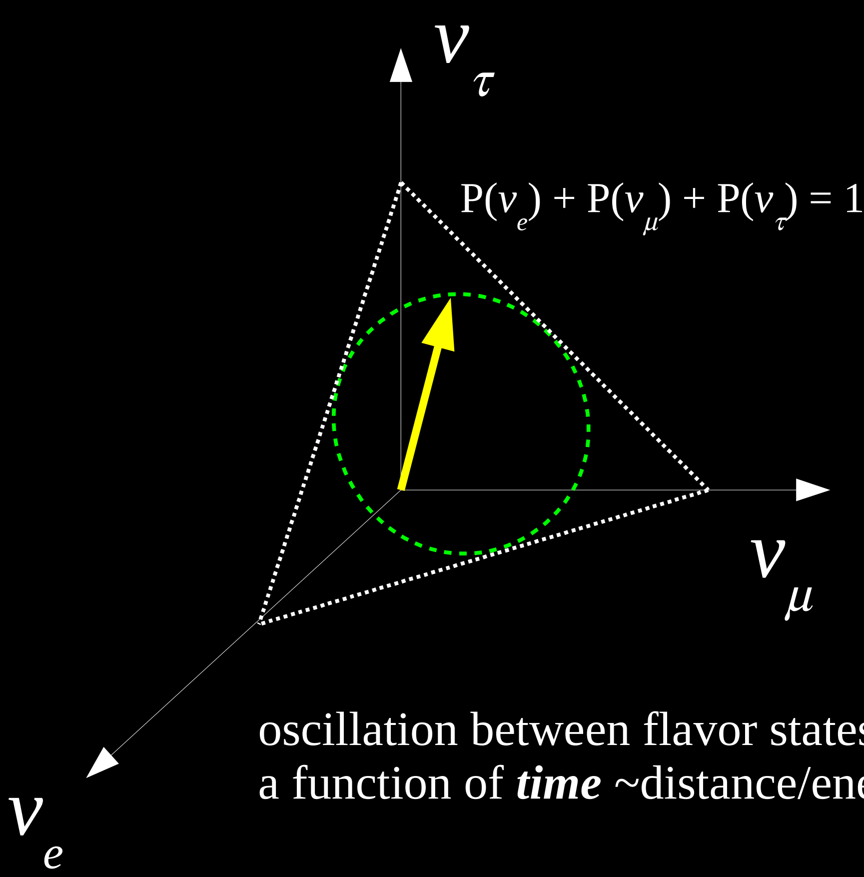


oscillation between flavor states as
a function of ***time*** ~distance/energy

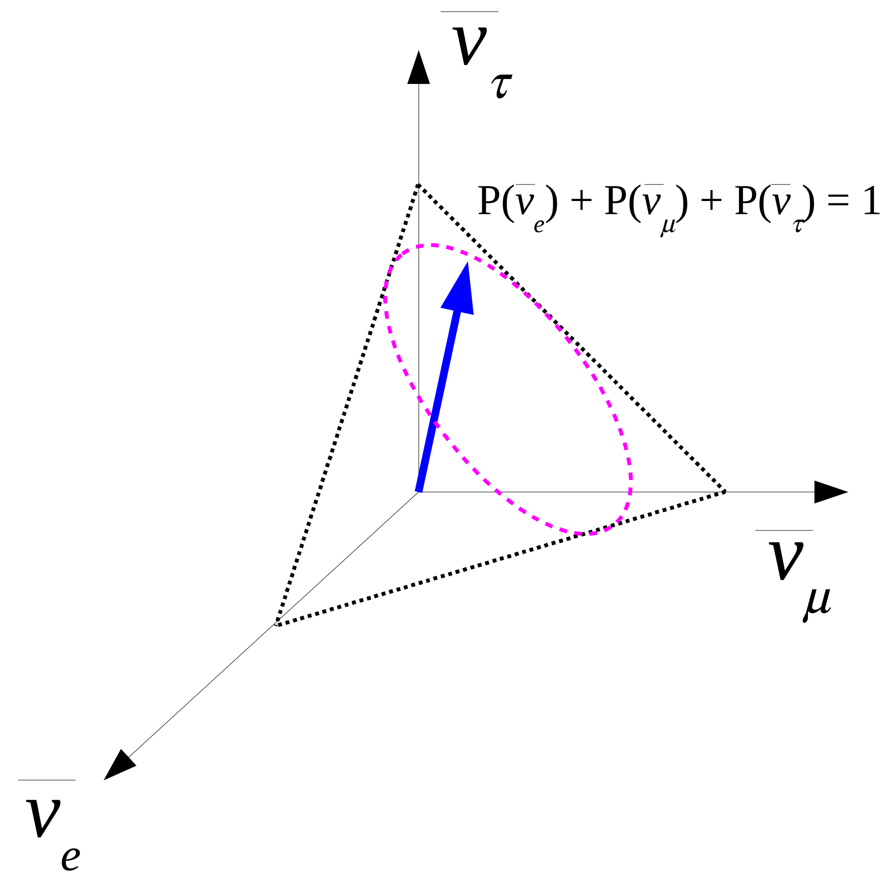
Only 2 flavors, same oscillation behavior

Neutrino Oscillations

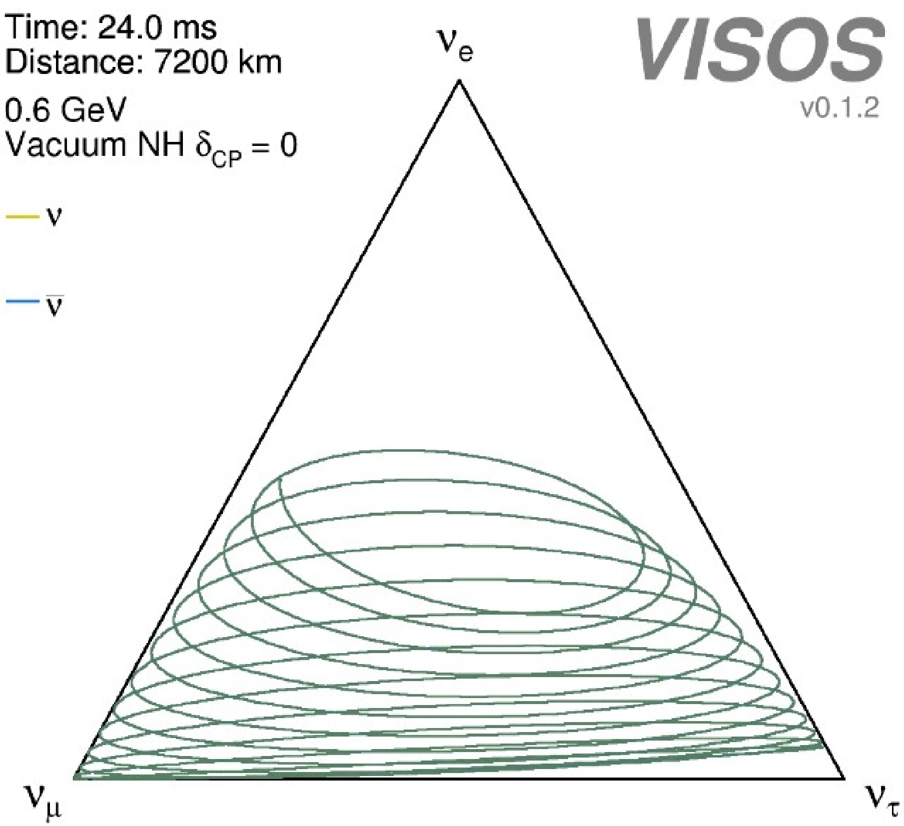
*3-flavor paradigm

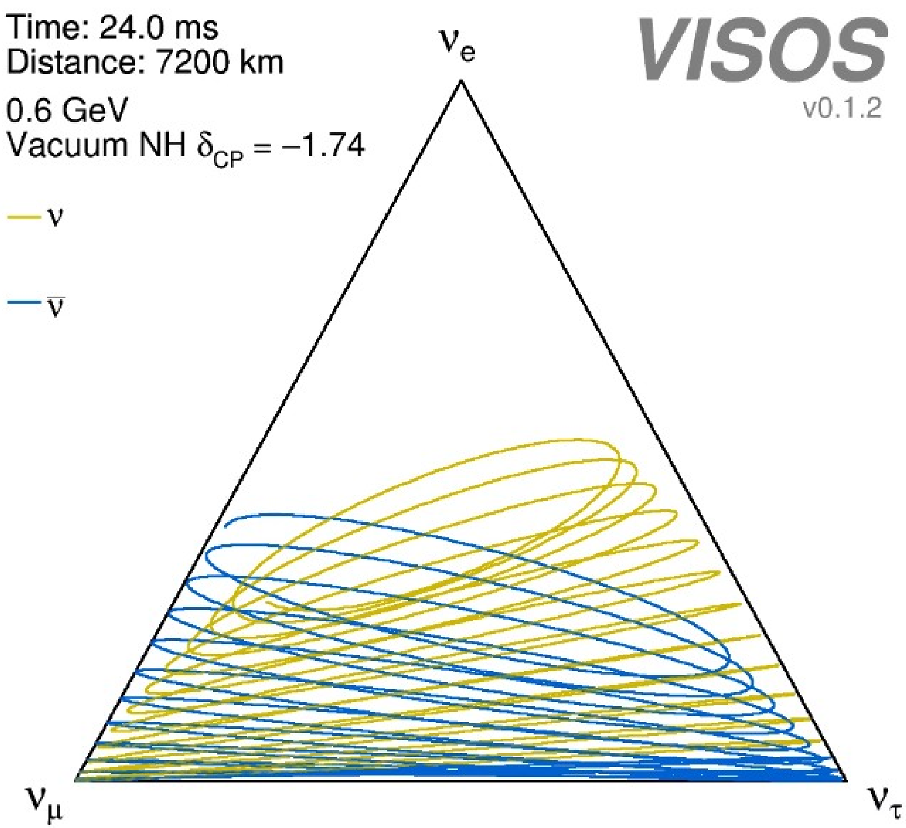


oscillation between flavor states as a function of ***time*** ~distance/energy



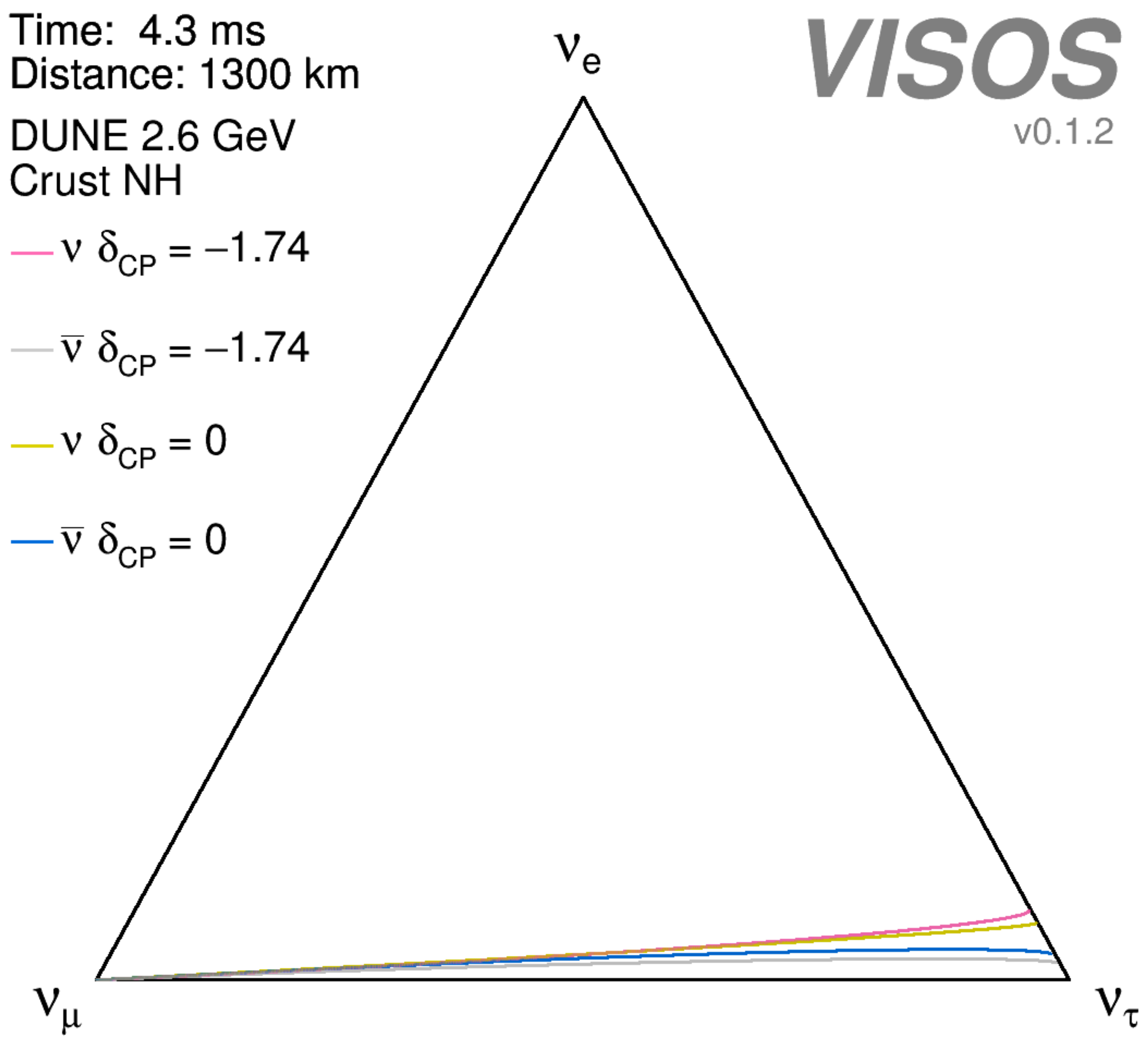
Neutrino Oscillations





More in http://www-pnp.physics.ox.ac.uk/~luxi/visos

Neutrino Oscillations

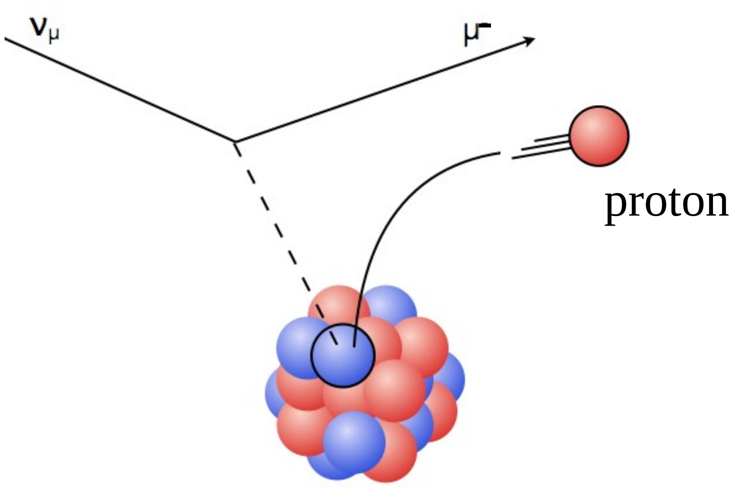


More in http://www-pnp.physics.ox.ac.uk/~luxi/visos

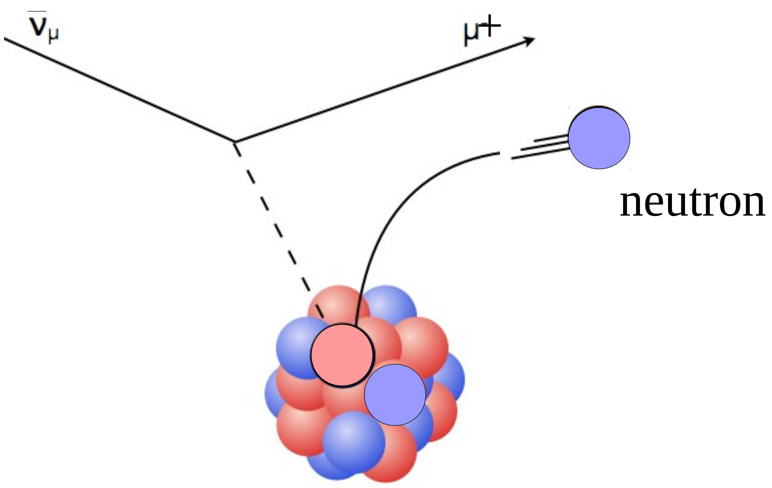
Oscillation Measurements

– ν and $\bar{\nu}$ interactions

Cartoon by Marco Del Tutto



neutrino



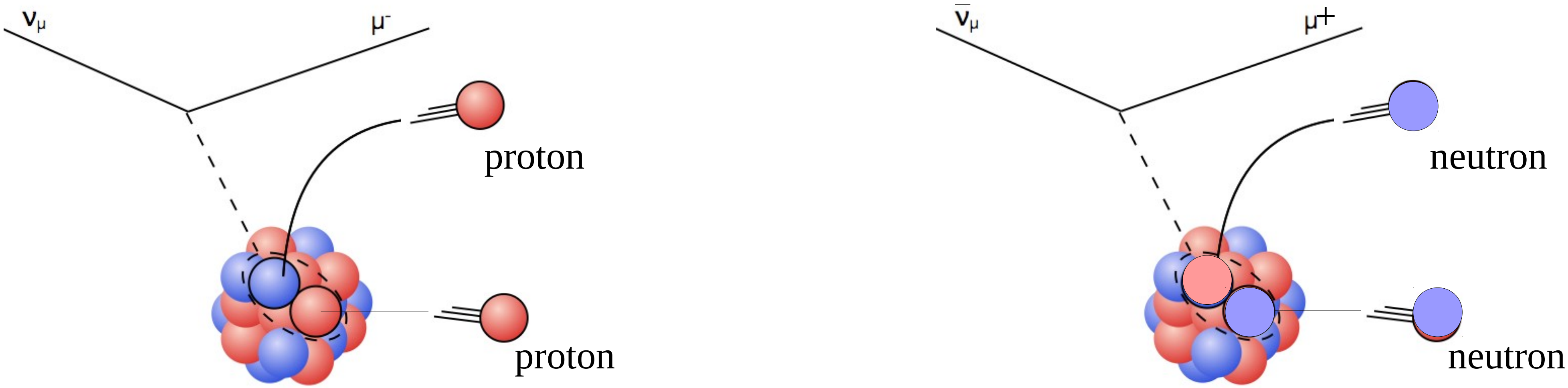
antineutrino

Intrinsic difference in ν and $\bar{\nu}$ event rates without CPV

Oscillation Measurements

– ν and $\bar{\nu}$ interactions

Cartoon by Marco Del Tutto



neutrino

antineutrino

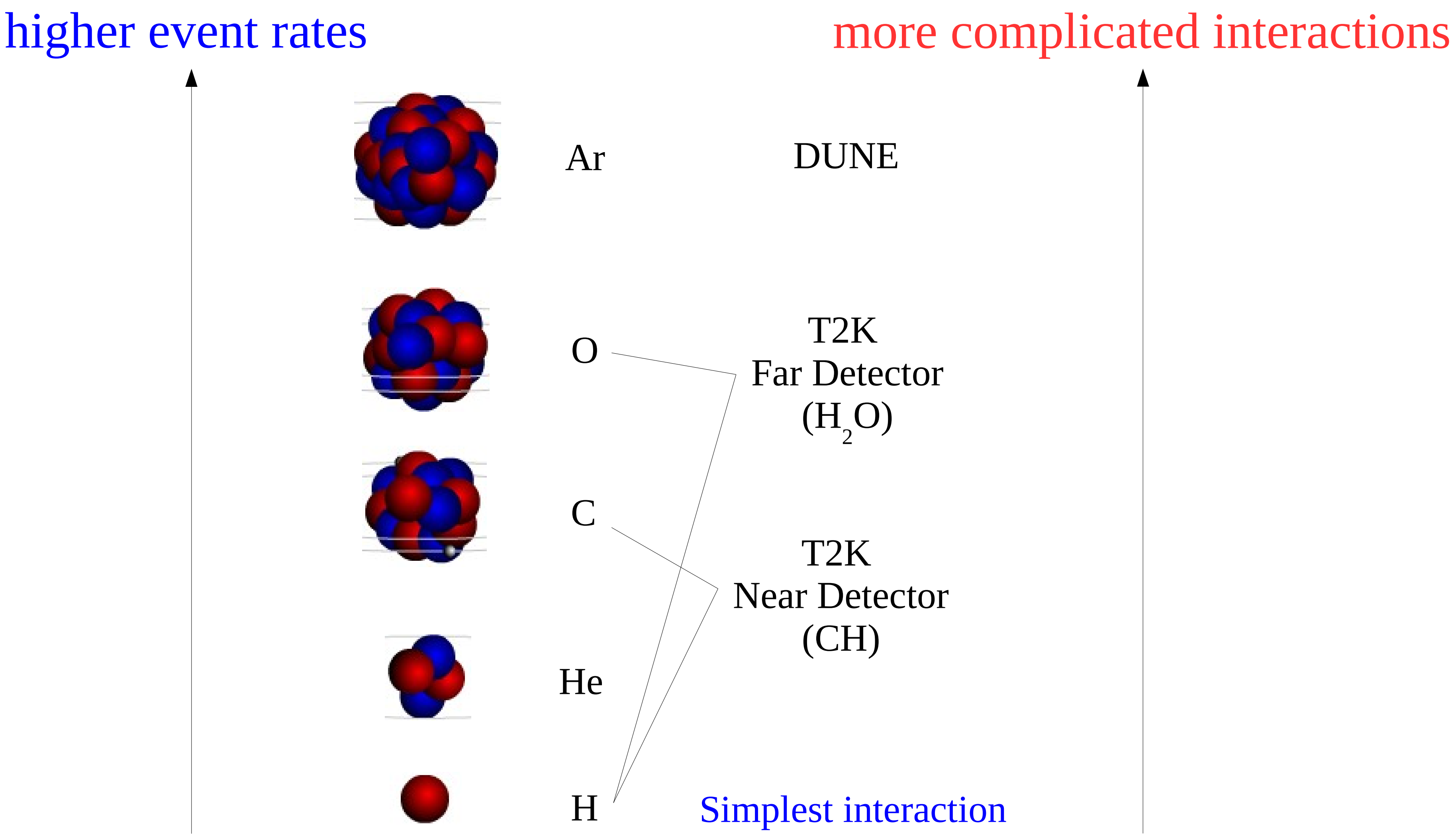
Nuclear effects like “2p2h” make it worse

Nuclear effects: all effects due to target A>1

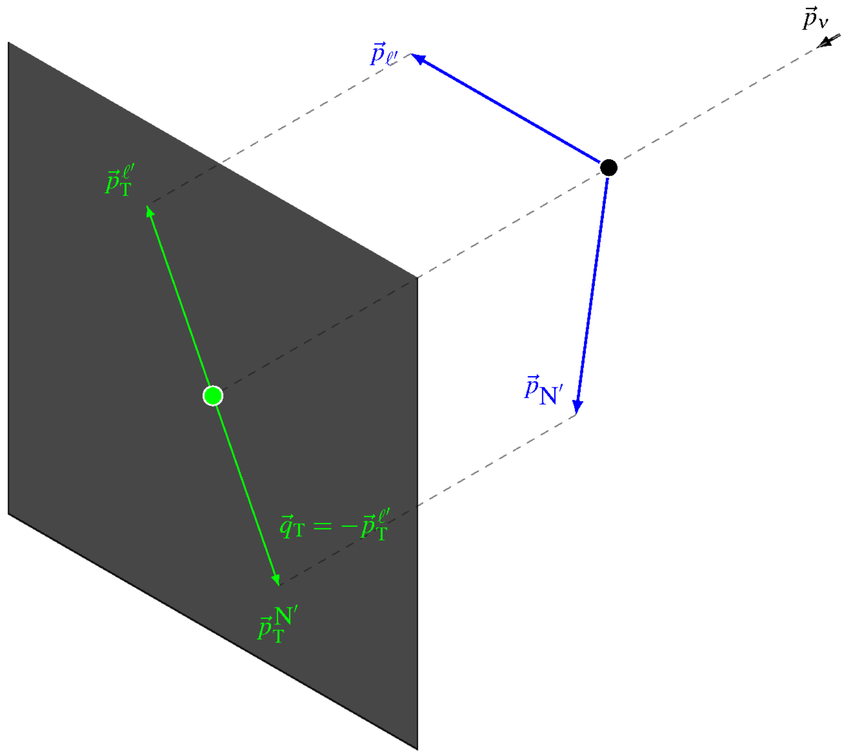
Proton and neutron have VERY different experimental signatures

Oscillation Measurements

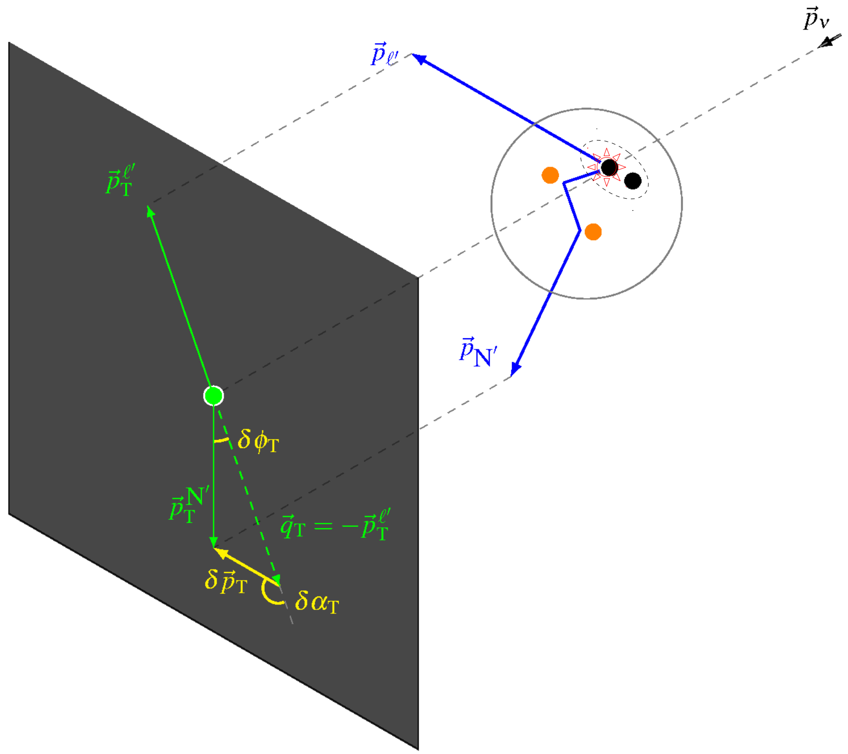
– ν and $\bar{\nu}$ interactions



Transverse Kinematic Imbalance (TKI) to study interaction details with nuclei



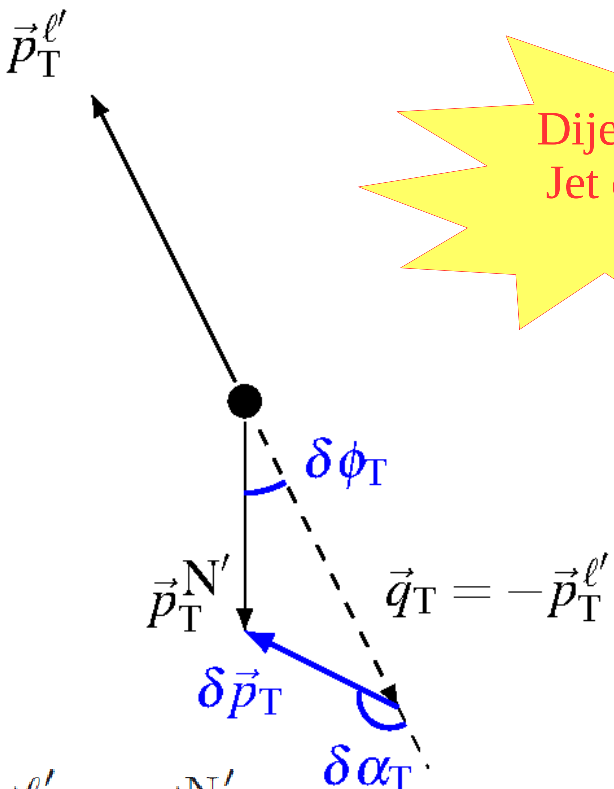
Stationary nucleon target



Nuclear target
(A>1)

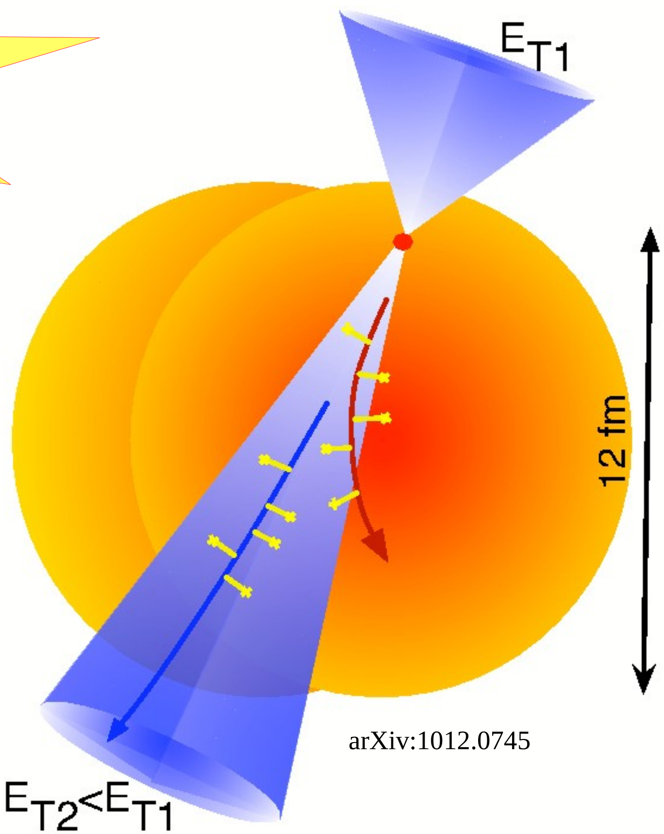
Fermi motion
Final-state interactions

Transverse Kinematic Imbalance (TKI) to study interaction details with nuclei



$$\delta\vec{p}_T \equiv \vec{p}_T^{\ell'} + \vec{p}_T^{N'}$$

Dijet imbalance / Jet quenching

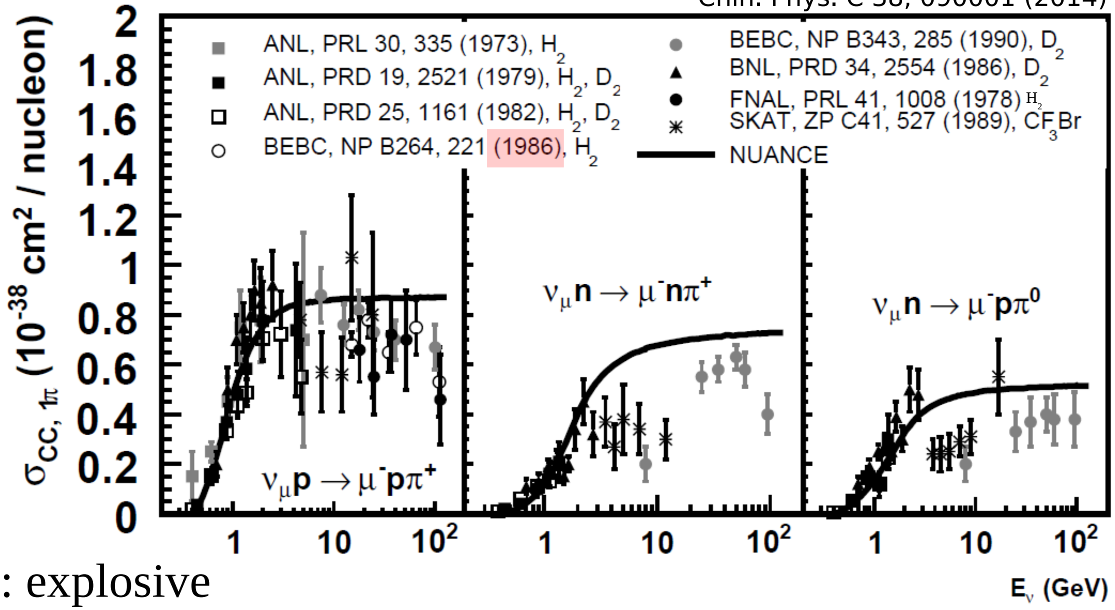


arXiv:1012.0745

Neutrino-Hydrogen Interactions – Review

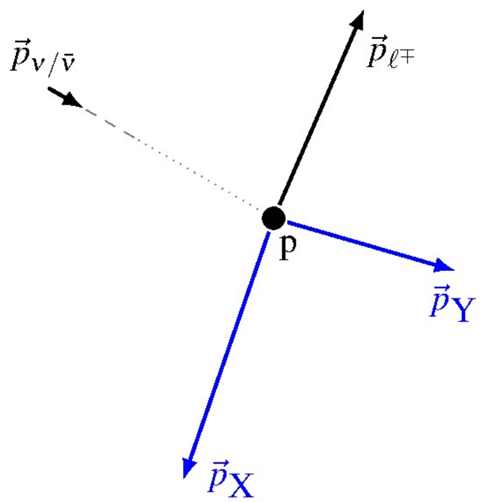
- Pure hydrogen
  - Technical requirement: bubble chamber (historical: 73, 79, 78, 82, 86)

Chin. Phys. C 38, 090001 (2014)



  - Safety issue: explosive
    - Due to buoyancy, more dangerous for underground experiments
- Neutrino interactions on hydrogen:
  - In the last ~30 years there has been no new measurement
  - No nuclear effects → much desired for flux constraint and nucleon cross section input for oscillation analysis
  - Nucleon structure → new frontier of hadron physics

Neutrino-Hydrogen Interactions

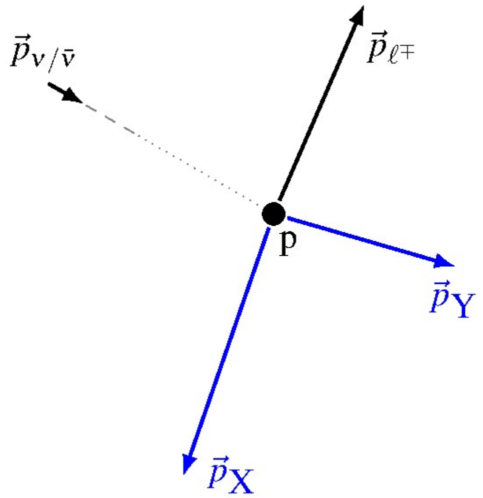


l p interaction → 3 charged particles:
l p → l' X Y

[XL, et al. Phys. Rev. D 92, 051302 (2015),
XL, JPS Conf. Proc. 12, 010034 (2016)]

Neutrino-Hydrogen Interactions

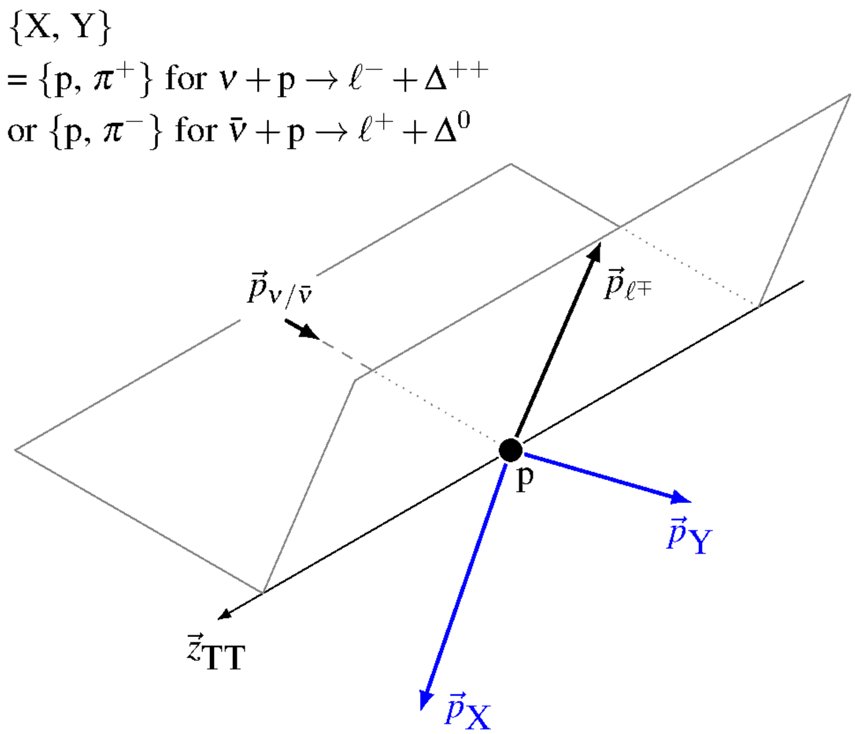
$\{X, Y\}$
$= \{p, \pi^+\}$ for $\nu + p \to \ell^- + \Delta^{++}$
or $\{p, \pi^-\}$ for $\bar{\nu} + p \to \ell^+ + \Delta^0$



l p interaction → 3 charged particles:
l p → *l'* X Y

[XL, et al. Phys. Rev. D 92, 051302 (2015),
XL, JPS Conf. Proc. 12, 010034 (2016)]

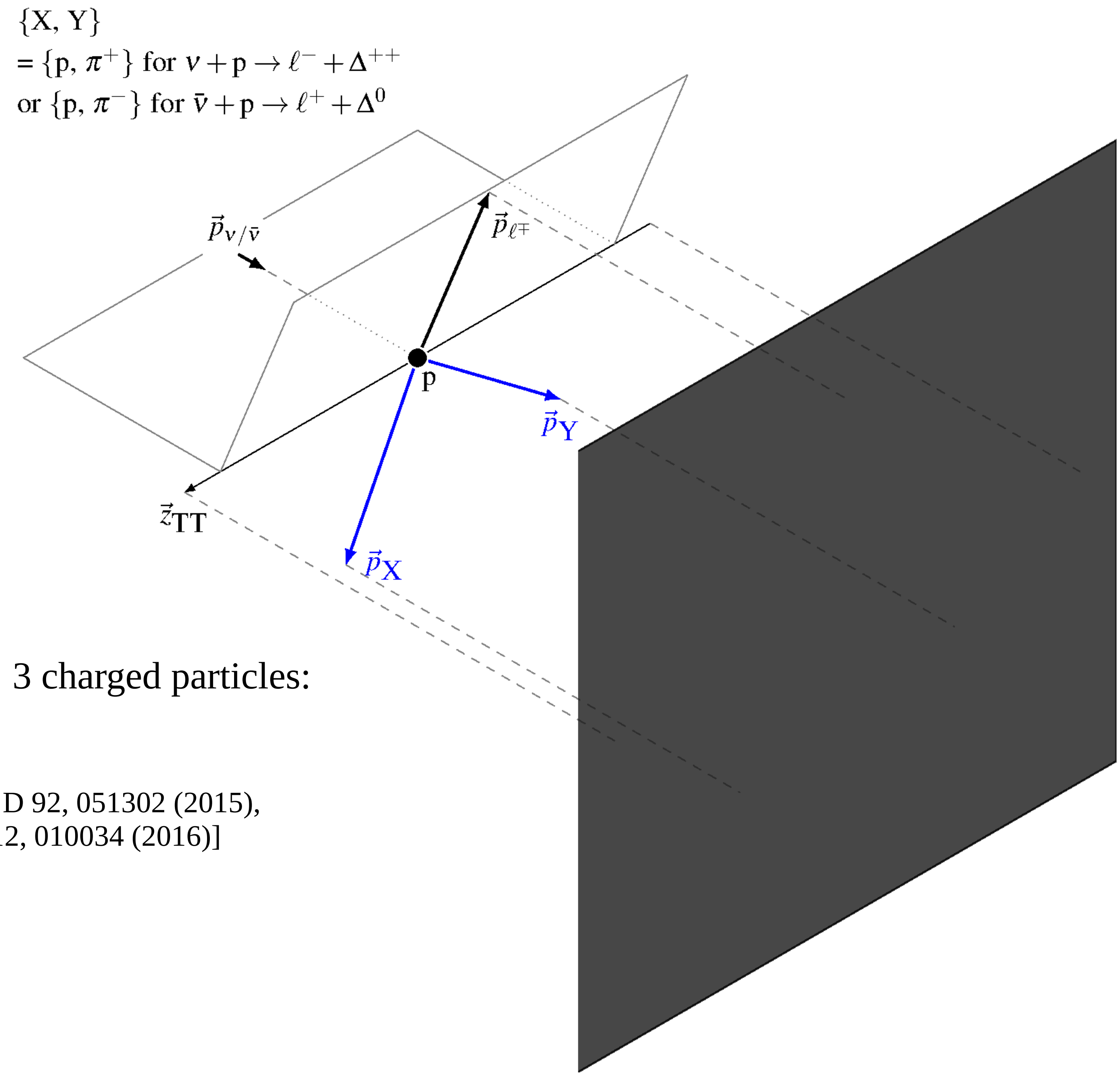
Neutrino-Hydrogen Interactions



l p interaction → 3 charged particles:
l p → *l'* X Y

[XL, et al. Phys. Rev. D 92, 051302 (2015),
XL, JPS Conf. Proc. 12, 010034 (2016)]

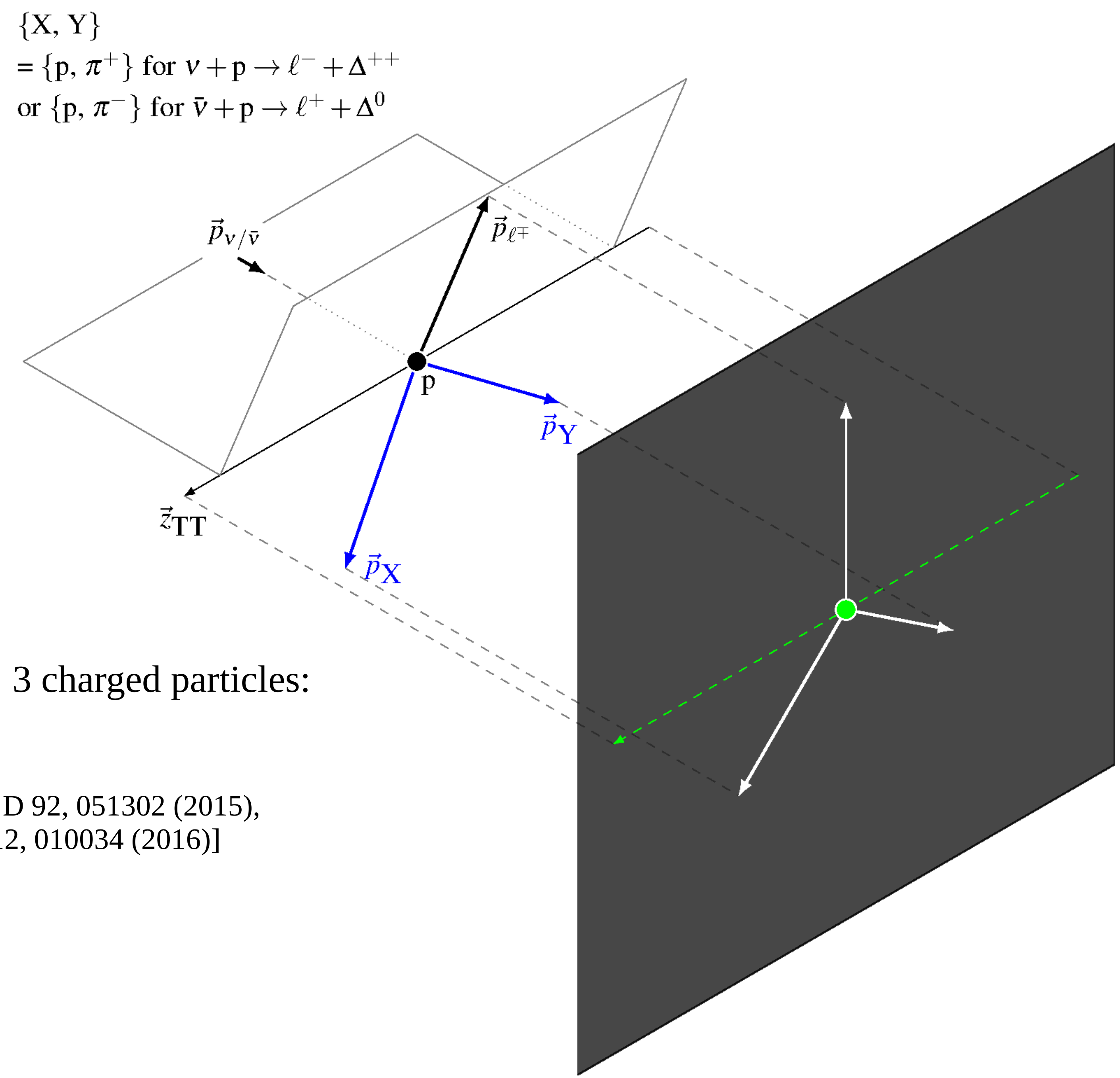
Neutrino-Hydrogen Interactions



l p interaction → 3 charged particles:
l p → *l'* X Y

[XL, et al. Phys. Rev. D 92, 051302 (2015),
XL, JPS Conf. Proc. 12, 010034 (2016)]

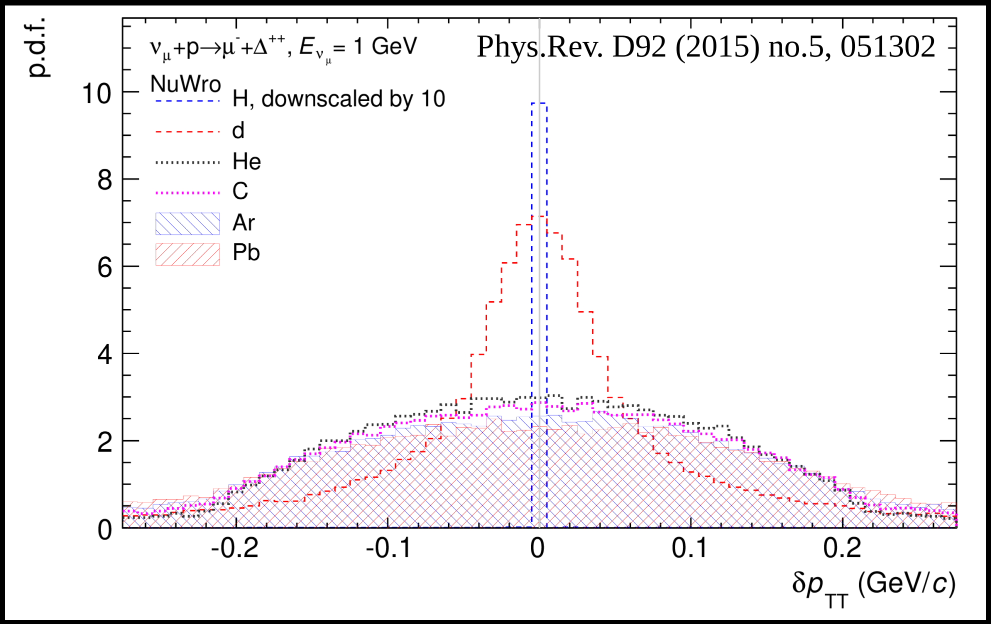
Neutrino-Hydrogen Interactions

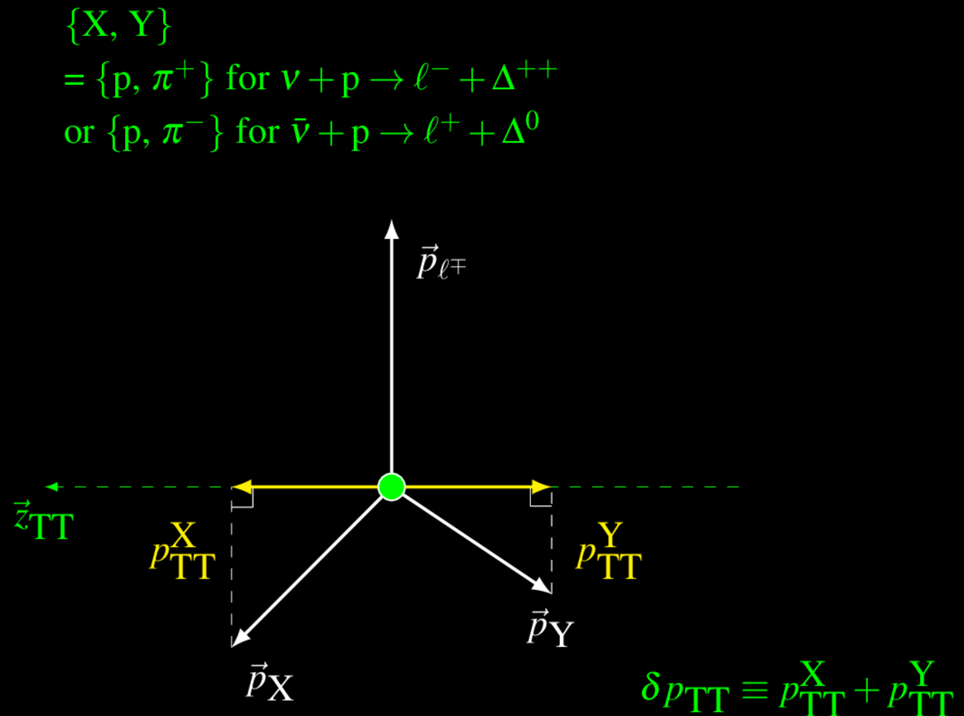


l p interaction → 3 charged particles:
l p → *l'* X Y

[XL, et al. Phys. Rev. D 92, 051302 (2015),
XL, JPS Conf. Proc. 12, 010034 (2016)]

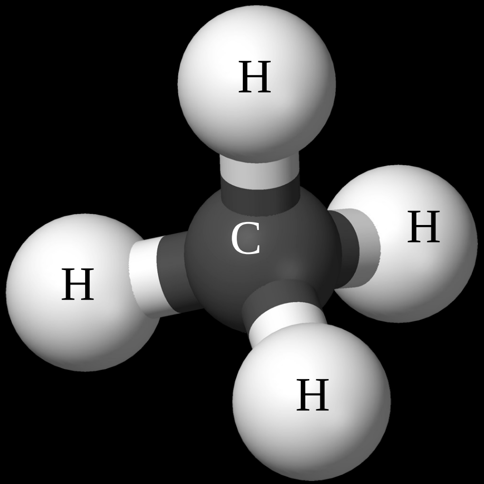
Neutrino-Hydrogen Interactions



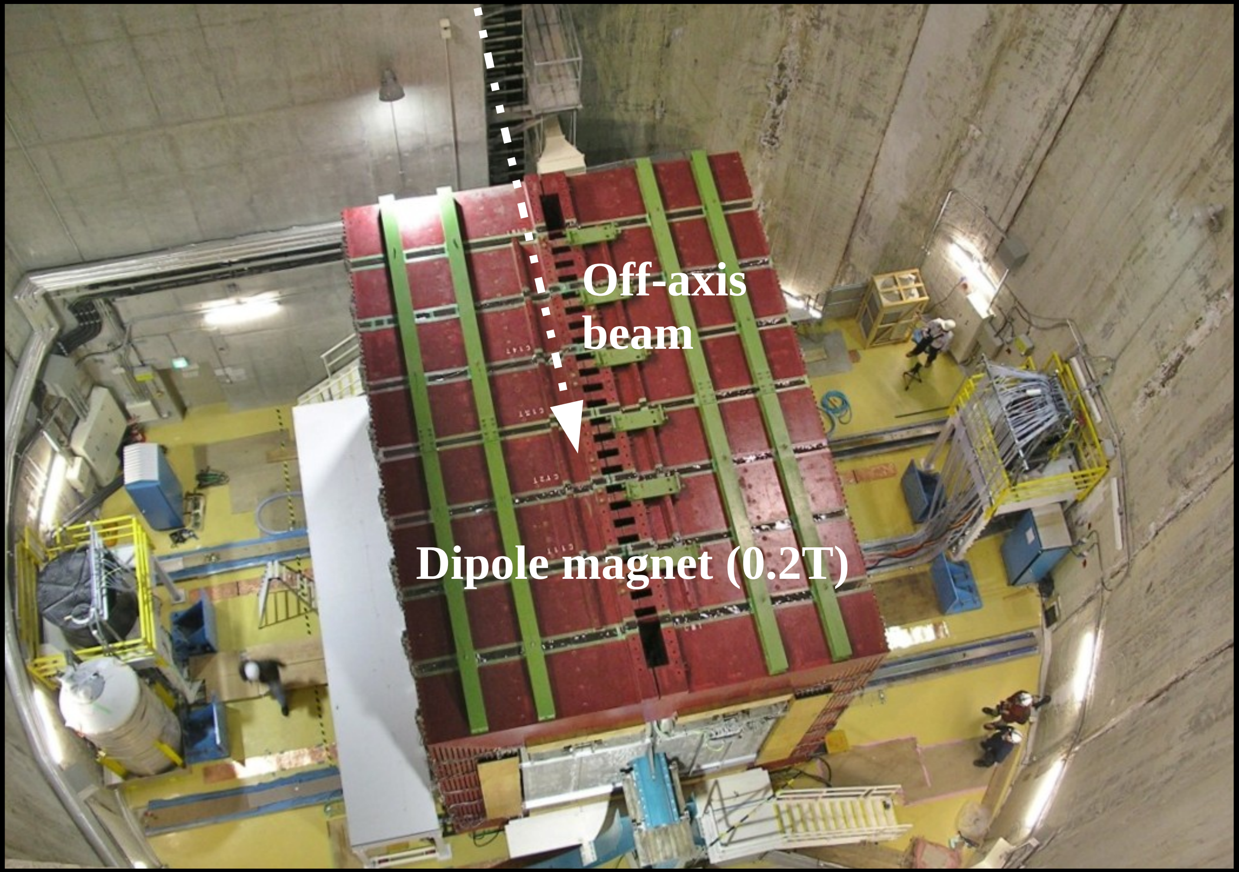


Double-transverse momentum imbalance δp_{TT}

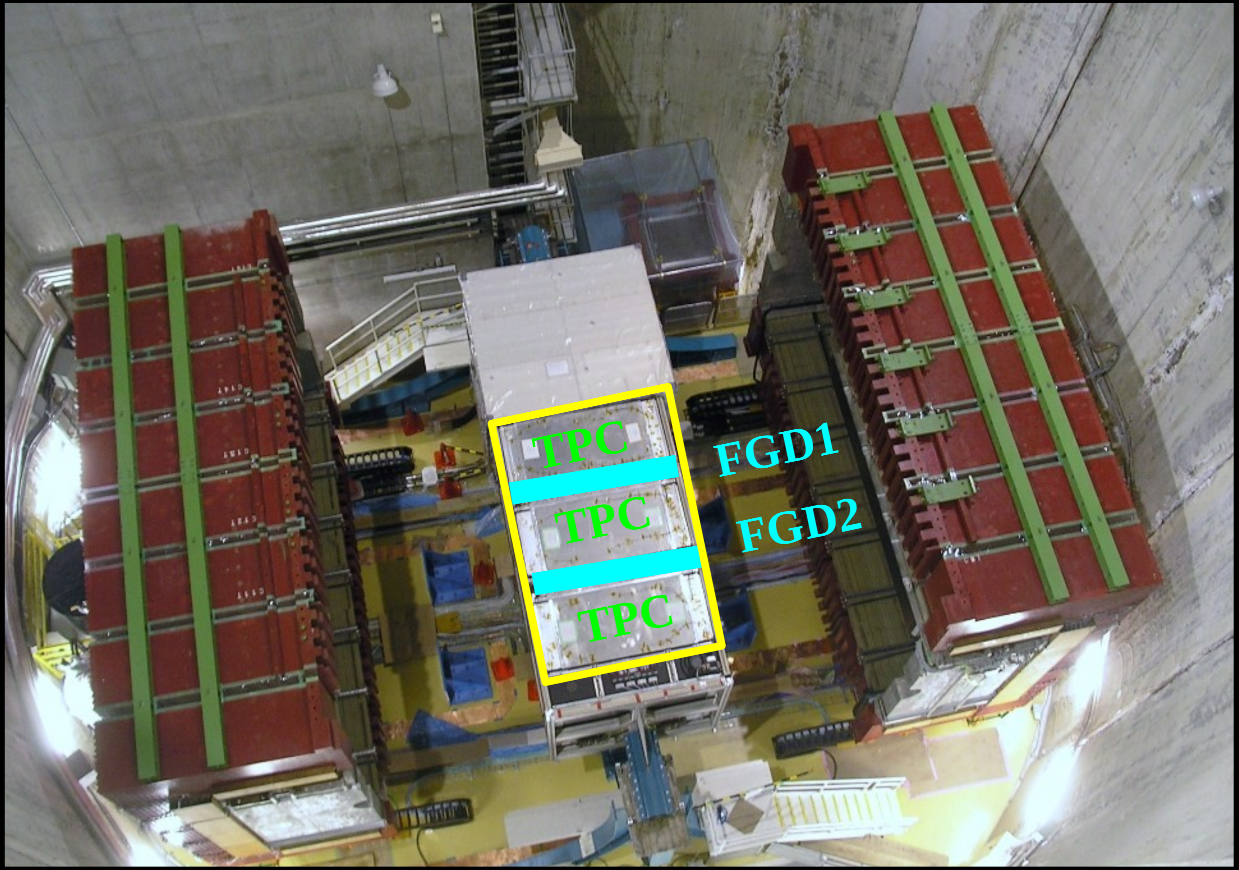
- H: 0
- Heavier nuclei: irreducible symmetric broadening
  - by Fermi motion O(200 MeV) and FSI
- CH_n: νH interaction can be extracted
  - νH δp_{TT}~O(<10MeV) after detector smearing
  - νC δp_{TT}~ 200 MeV



T2K off-axis near detector (ND280)



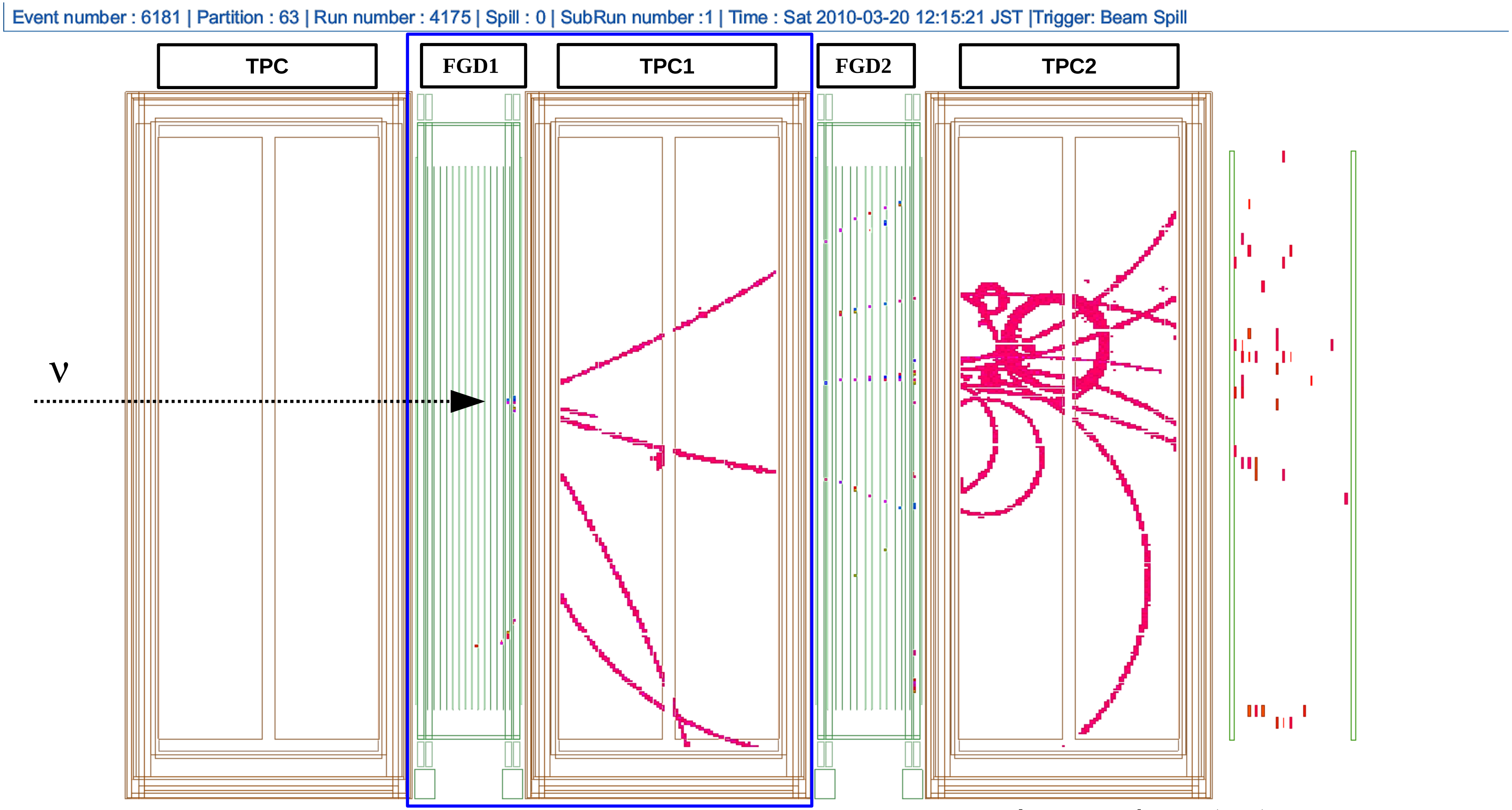
T2K off-axis near detector (ND280)



Tracker:

- FGD: Fine-Grained Detector
  1. CH target **(same as DUNE 3DST)**
  2. CH + H_2O target
- Time Projection Chamber (TPC)

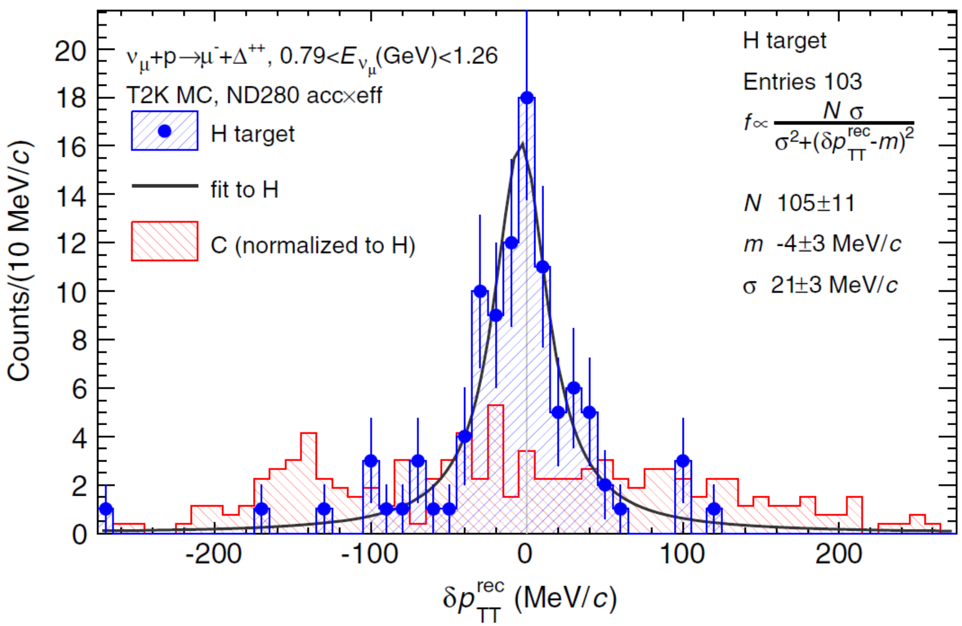
T2K off-axis near detector (ND280)



Nucl.Instrum.Meth. A659 (2011) 106-135

Neutrino-Hydrogen Interactions
– T2K example

Phys.Rev. D92 (2015) no.5, 051302

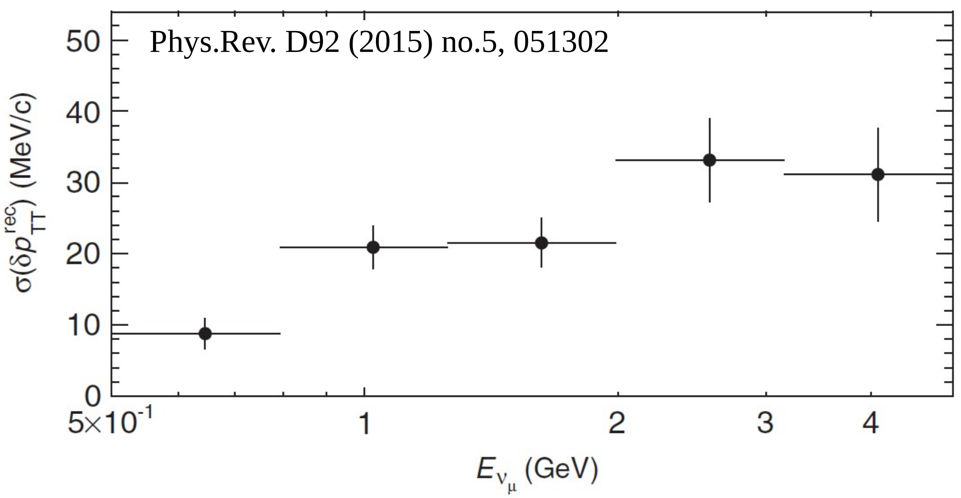


In T2K

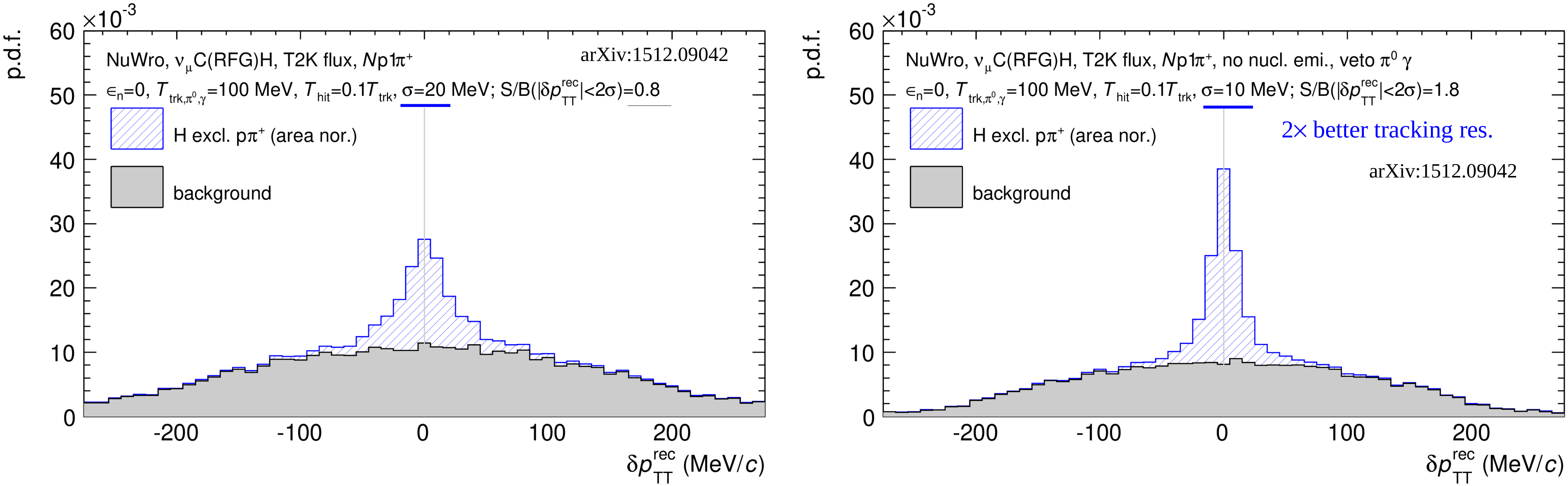
- TPC pT resolution ~10% @ 1GeV

→ δp_{TT} resolution ~ 23 MeV

- Tracking performance varies with neutrino energy



Neutrino-Hydrogen Interactions – Perspective

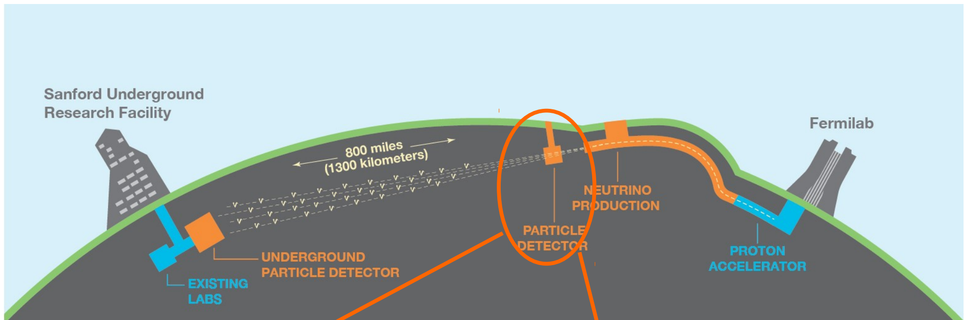


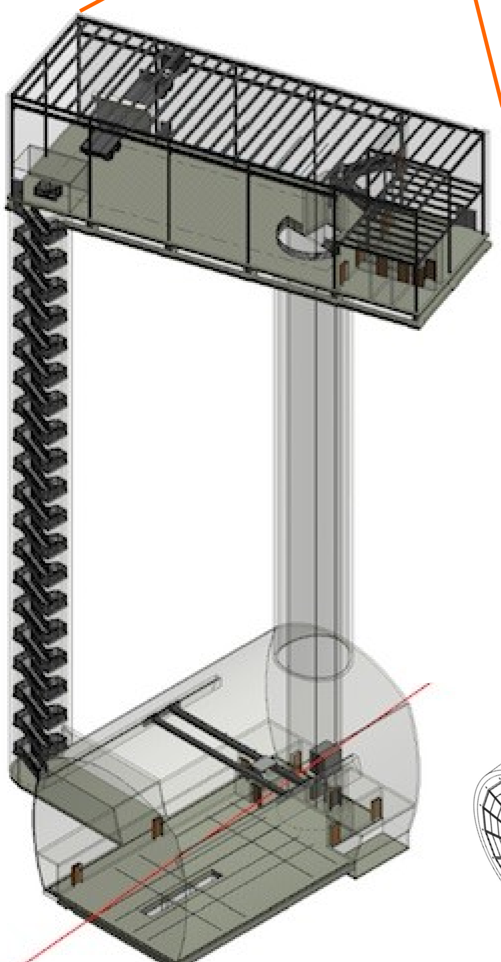
Toy simulation of T2K performance (T2K neutrino flux on **CH** target)

- Realistic detector resolution as T2K gas TPC (~10% at 1 GeV/c)

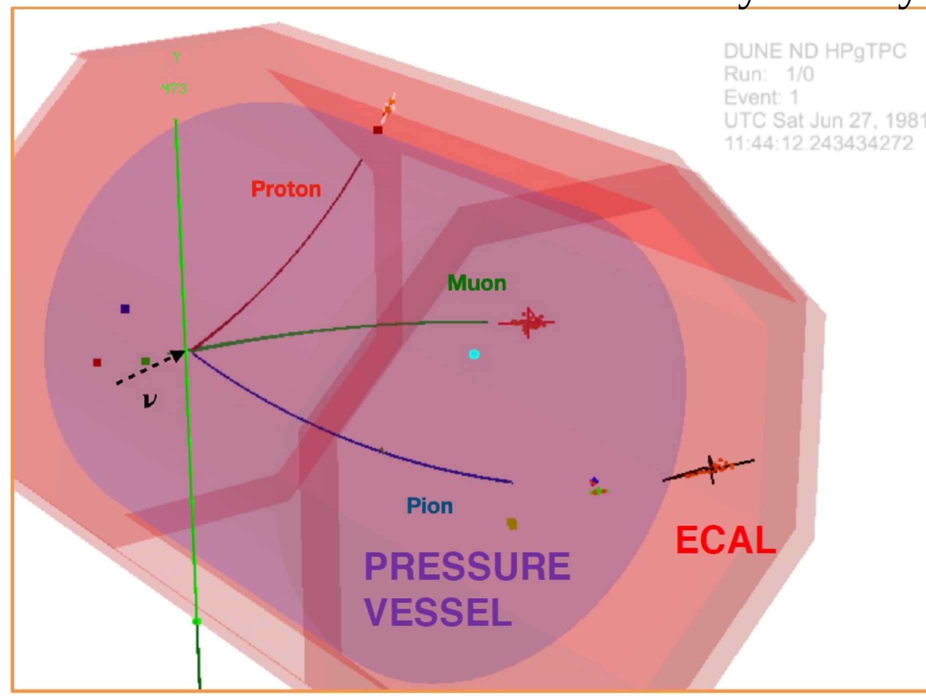
- When tracking resolution improves, only signal distribution gets narrower, background still wide due to Fermi motion and FSI! → Signal/background improves

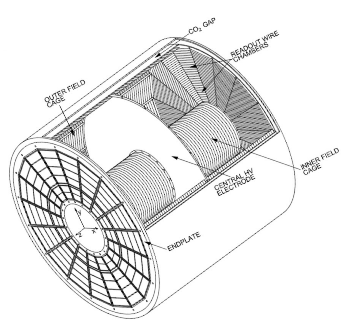
Neutrino-Hydrogen Interactions – Perspective





See Jen's talk yesterday





DUNE Near Detector

High-Pressure gas Time Projection Chamber (HPgTPC) Model: ALICE TPC

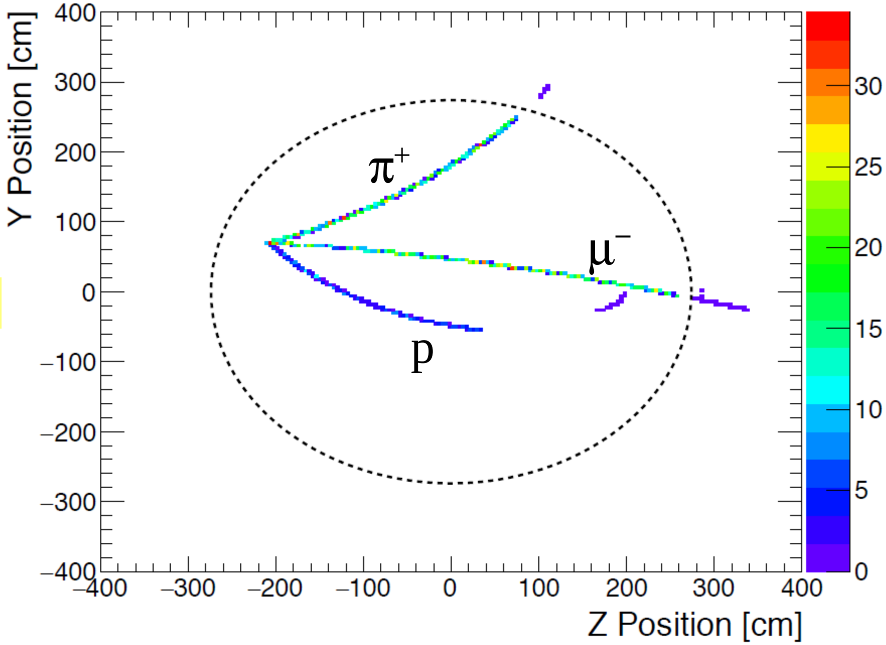
Xianguo Lu, Oxford

Neutrino-Hydrogen Interactions
– Perspective

Z-Y Projection: Sample event - ν_μCC

See Alan's talk yesterday

Test event



- State-of-the-art tracking resolution in gas TPC
  ALICE TPC (~1% at 1 GeV/c, 10 times better compared to T2K)
  → S/B = 8 on CH target
  (recap T2K ~10% at 1 GeV/c, S/B = 0.8)

- DUNE Near Detector
  High Pressure gas TPC
  can achieve 95% νH purity with
  50% He + 50% CH_4
  or
  50% He + 50% C_2H_6
  → S/B = 24 or 20

Name	Formula	Signal rate	Background rate	S/B
pure hydrogen	H_2	1 (ref.)	-	-
polystyrene (solid)	$(C_8H_8)n$ or CH	-	-	0.17
P-10	90% Ar + 10% CH_4	0.2	8.4	0.02
P-50	50% Ar + 50% CH_4	1	6	0.17
helium-methane (50:50)	50% He + 50% CH_4	1	2	0.5
helium-ethane (50:50)	50% He + 50% C_2H_6	1.5	3.5	0.43

*By optimizing proton/neutron ratio, we gain a factor of ~3 improvement in S/B.

For less superb tracking resolution, e.g. 2% at 1 GeV/c, namely only 5 times better than T2K

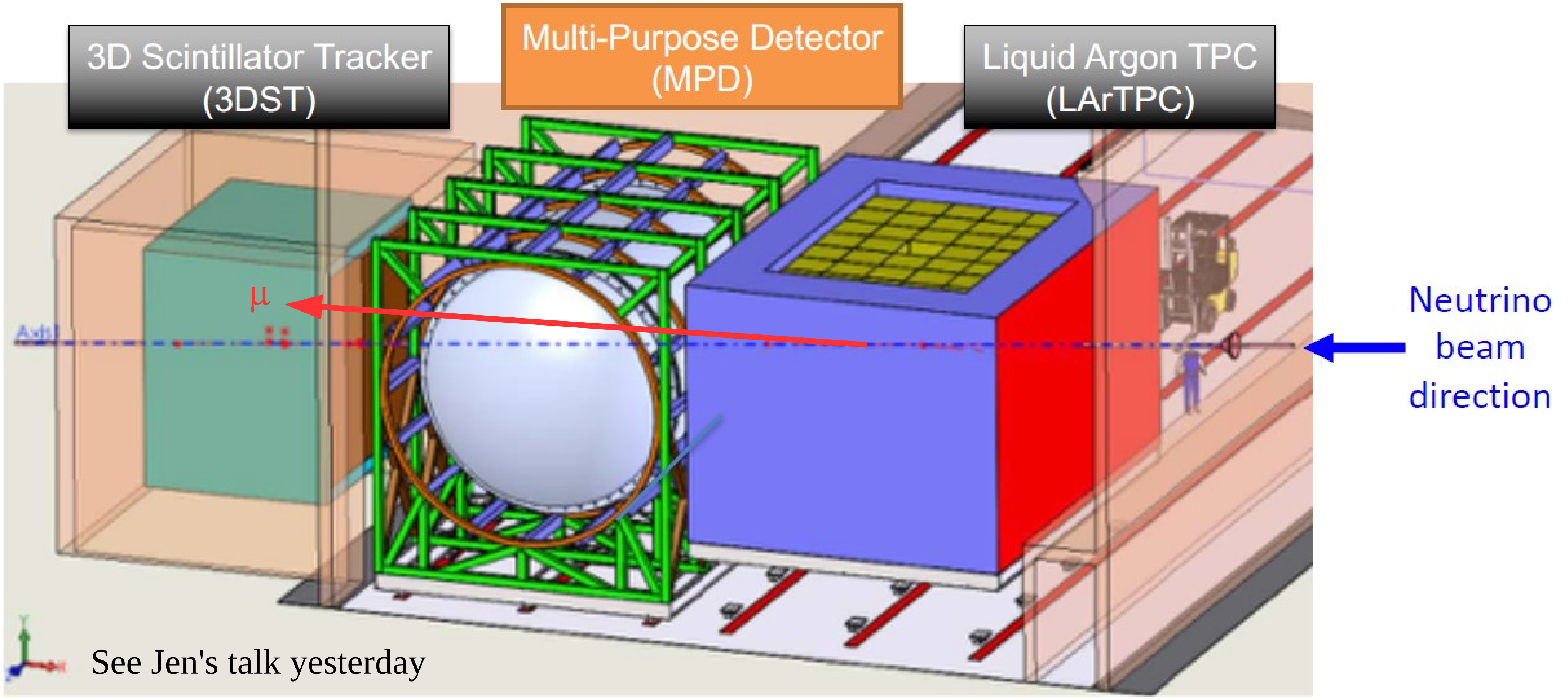
- S/B = 10 → purity = 90%

ν-H Discussions (1/2)

- Previous estimation needs to be corrected for
  - Kinematic distributions at DUNE energy
    - Pion and proton momentum will saturate for E_ν>1GeV (form factor effect)
  - Track topology
    - Inclination angle
  - TPC tracking performance with different gas at different pressure
    - Drift & attachment, gain, multiple scattering
      - 50% He + 50% CH_4 <Z>=6, 1/3 of argon (Z=18); <A>=10, ¼ of argon (A=40)
      - 10 atm, $\rho \sim \times$ 10/4 = 2.5 times of 1 atm argon
      - $1/X_0 \sim Z^2/A=4/9$, $\sqrt{(\rho/X_0)} = \sqrt{(10/9)}$, similar to 1 atm argon
- Do we have good simulation of gas properties?
  - Do we need new measurements?

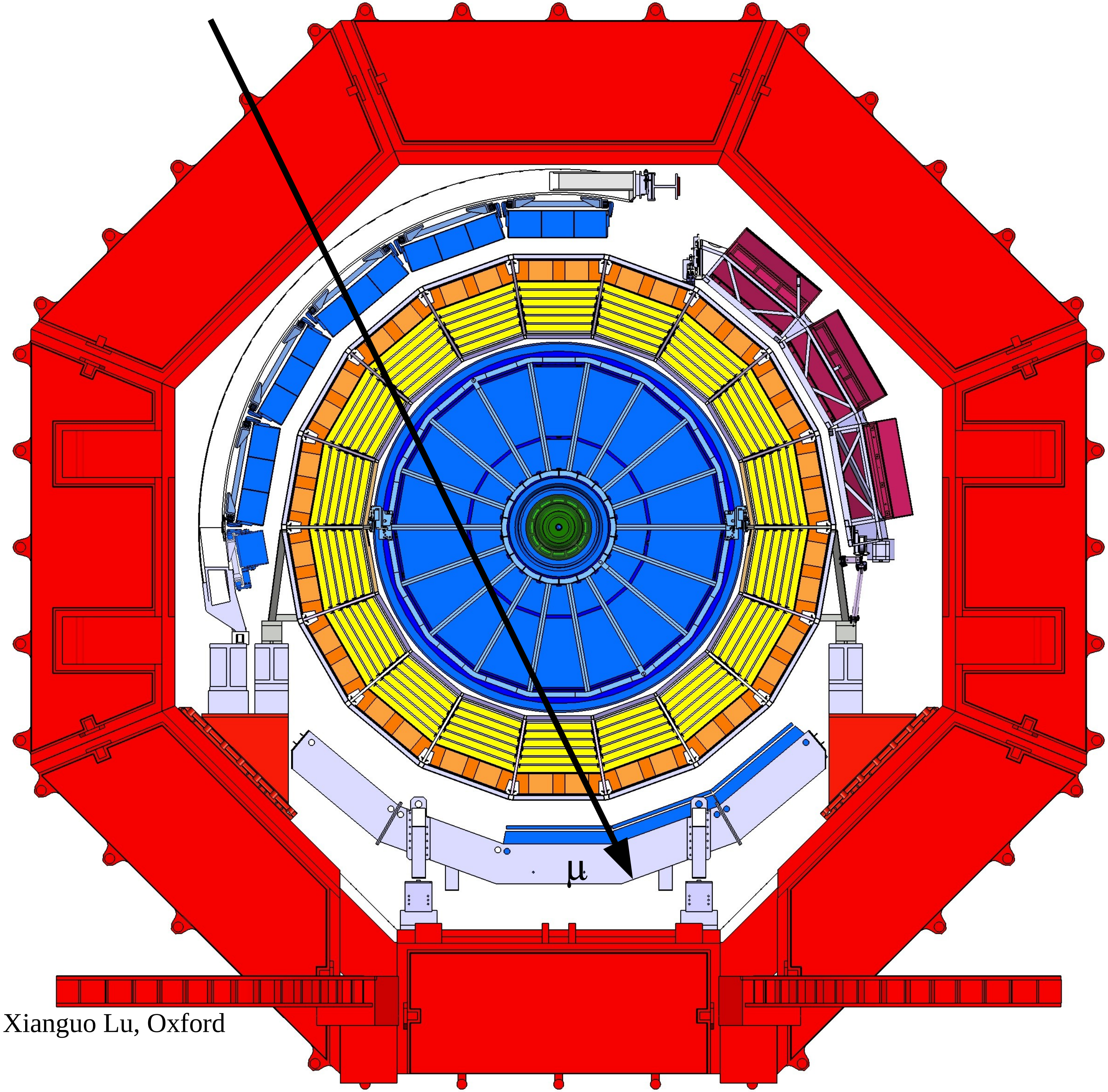
General Discussions (2/2) – Event Topology

DUNE HPgTPC spectrometer muons



See Jen's talk yesterday

General Discussions (2/2) – Event Topology



We can use ALICE cosmic muons to mock DUNE HPgTPC spectrometer muons:

Data exist, just need to modify (slightly?) ALICE TPC standalone tracking?

BACKUP

END