Interactions in He-CH_4 mixture: Transverse variable analysis in *20'*

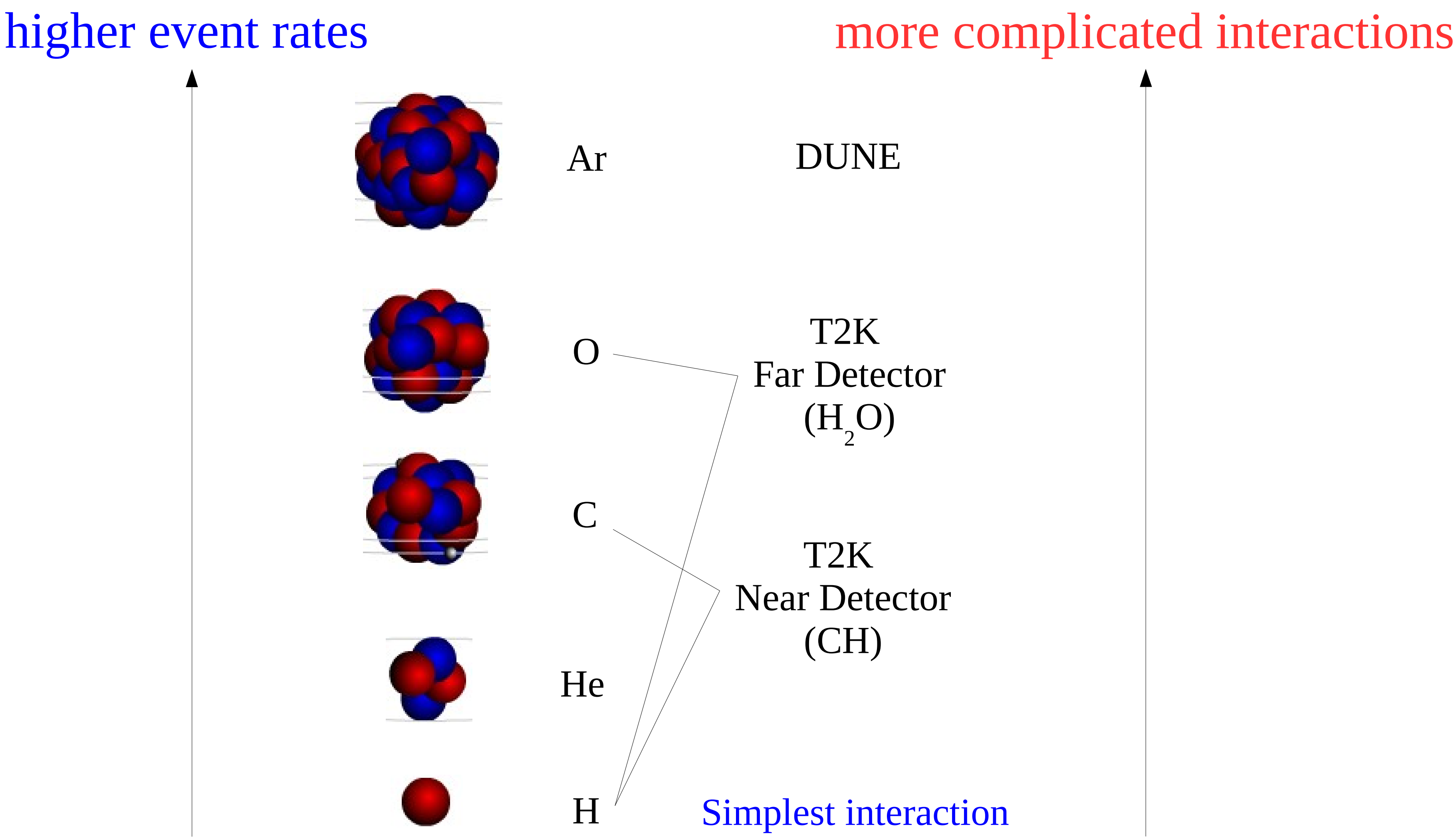
– Ideas for νH interactions in HPgTPC

Xianguo LU/ 卢显国
University of Oxford

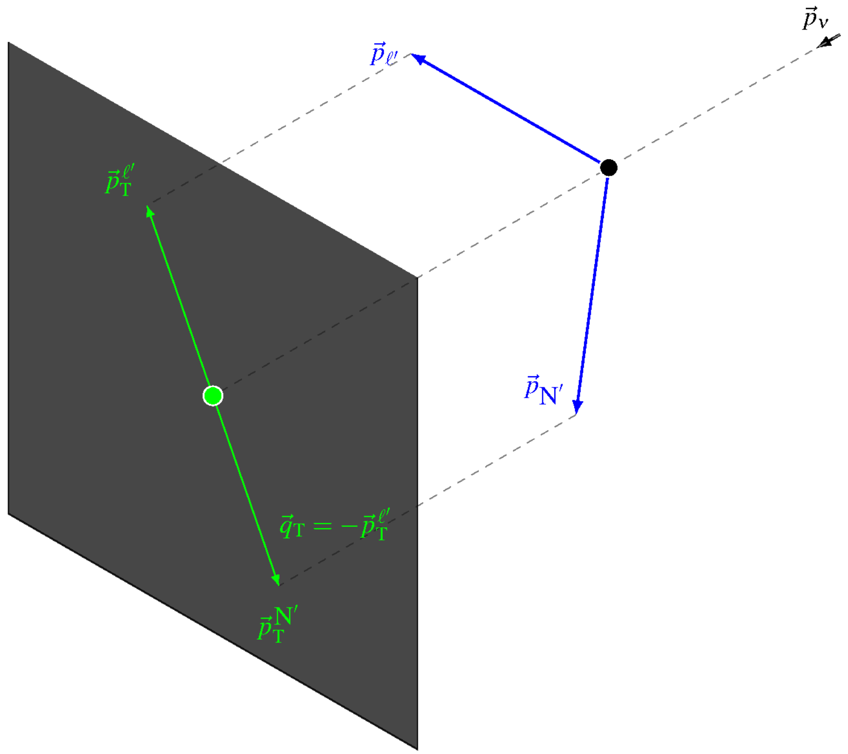
6th DUNE Near Detector Workshop
22nd October 2019

Oscillation Measurements

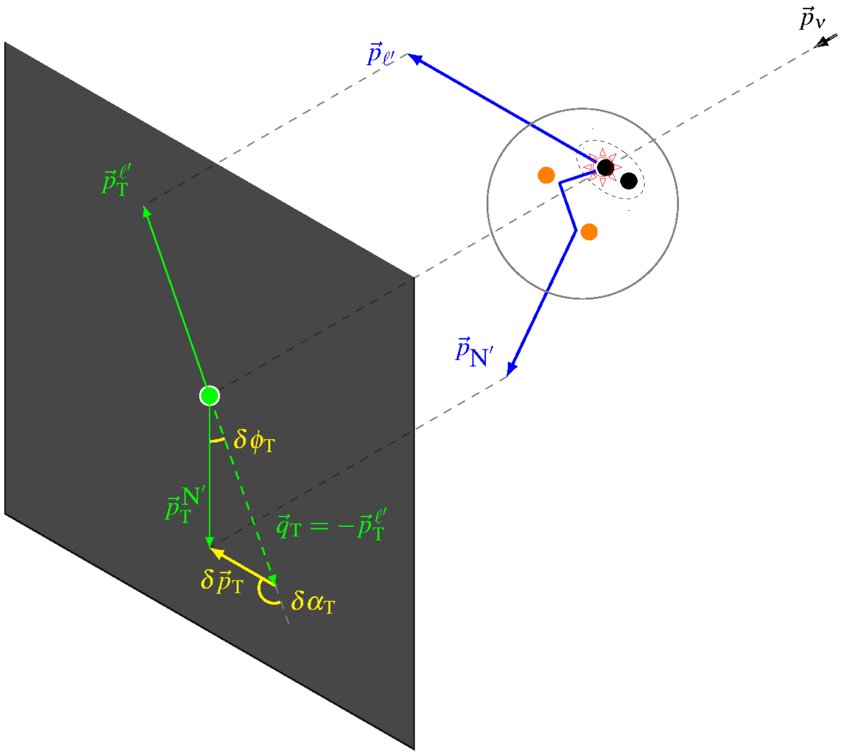
– ν and $\bar{\nu}$ interactions



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



Stationary nucleon target



Nuclear target
(A>1)

Fermi motion
Final-state interactions
Pion absorption
2p2h
...

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

Single-TKI

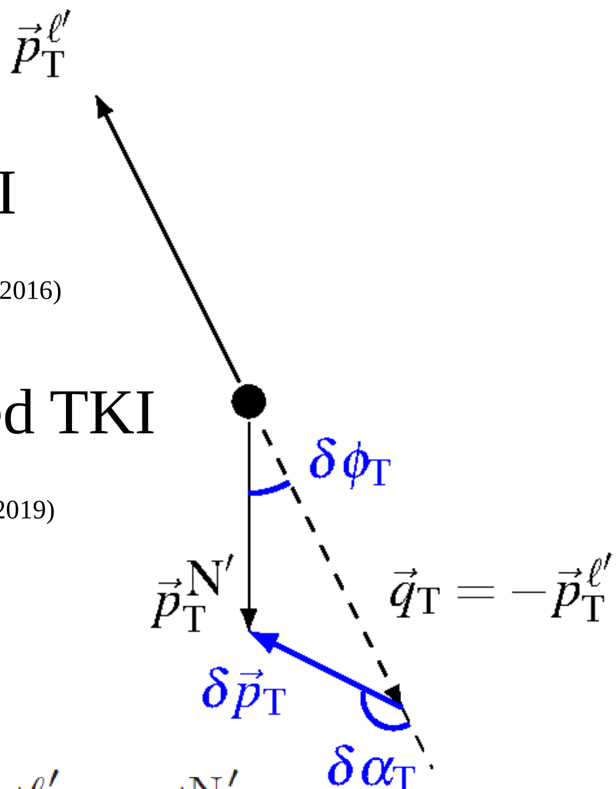
N': proton

Phys.Rev. C94, 015503 (2016)

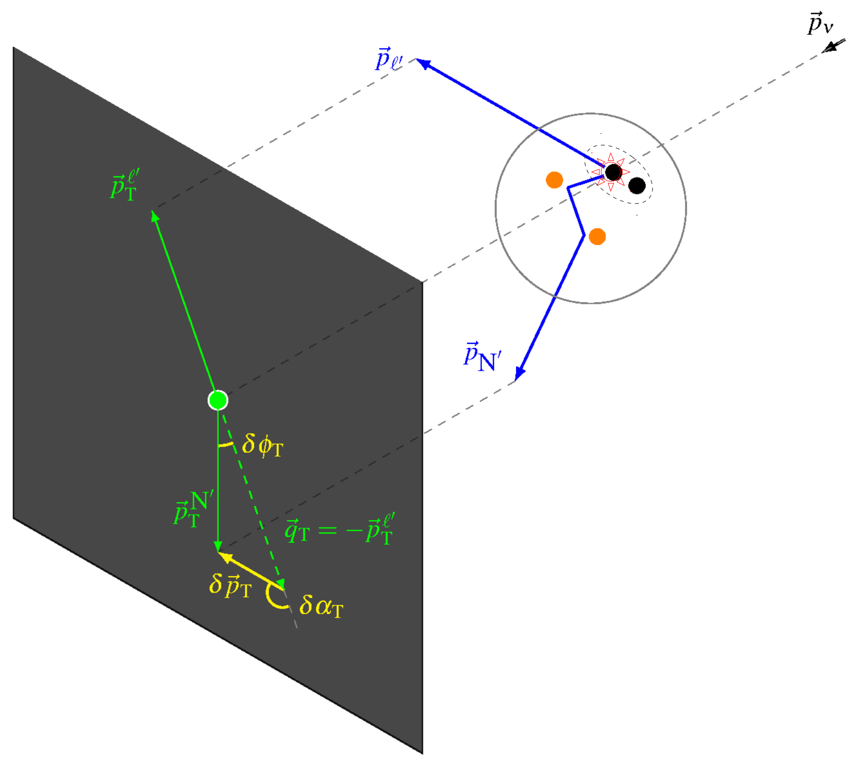
Generalized TKI

N': proton+pion

Phys.Rev. C99, 055504 (2019)



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



Nuclear target (A>1)

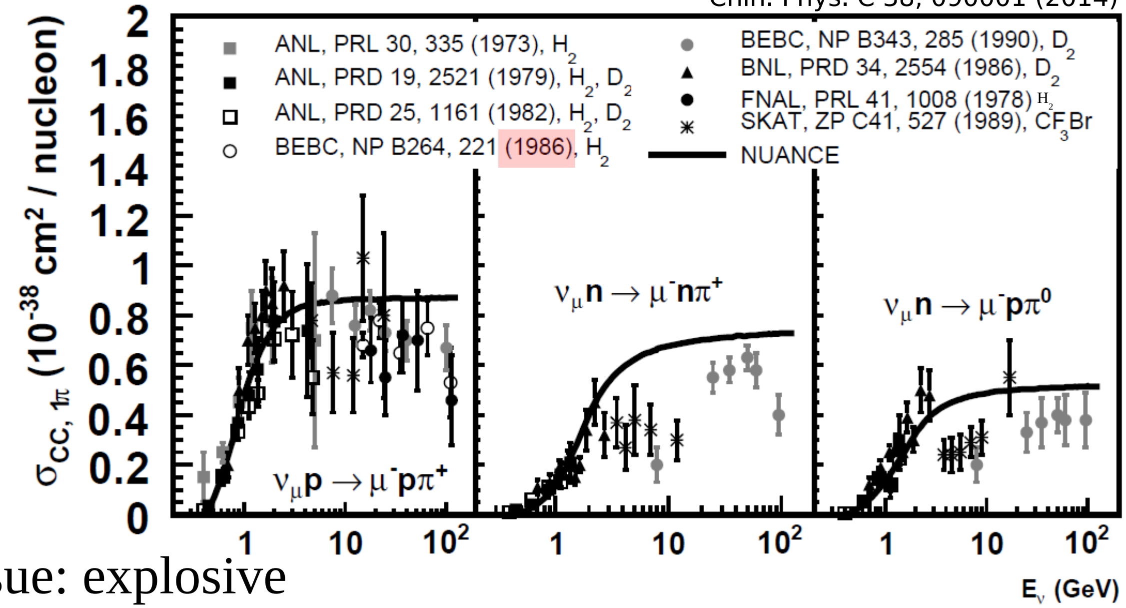
Fermi motion
Final-state interactions
Pion absorption
2p2h
...

Nuclear effects are interesting, but we still wish to get rid of them...

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

Teddy could hear Chuck beside him taking slow breaths, waiting for his cue.
Teddy said, 'Like you said, I choose not to think about it too much.'
'Mmm.' The guy nodded. He stroked the stubble on his chin. 'We hear things in here. You wouldn't think so, right? But we do. A new guy comes in, he tells us things. The guards talk. You orderlies, you talk. We know, we know. About the outside world. About the H-bomb tests, the atolls. You know how a hydrogen bomb works?'
'With hydrogen?' Teddy said.
'Very good. Very clever. Yes, yes.' The guy nodded several times. 'With hydrogen, yes. But, also, also, not like any other bombs. You drop a bomb,

Shutter Island By Dennis Lehane

… the danger of hydrogen is well known

Xianguo Lu, Oxford

Neutrino-Hydrogen Interactions – Review

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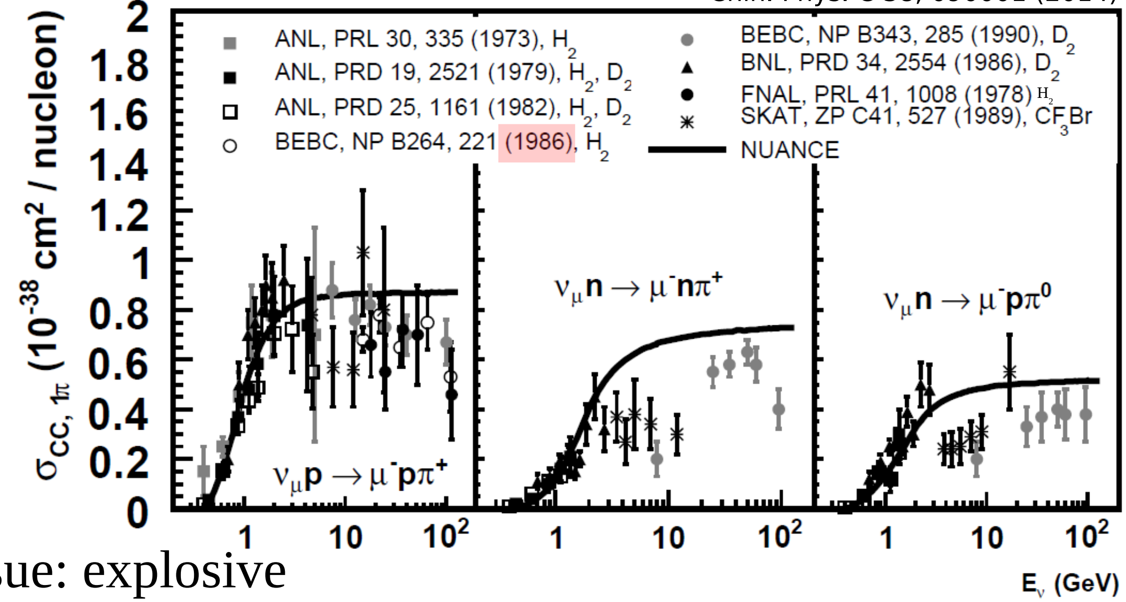
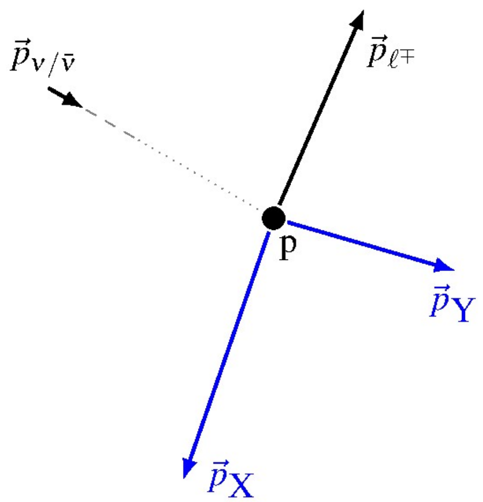


  - Safety issue: explosive
    - Due to buoyancy, more dangerous for underground experiments
- Neutrino interactions on hydrogen:
  - In the last ~30 years there has been no new measurement
  - No nuclear effects → much desired for flux constraint and nucleon cross section input for oscillation analysis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

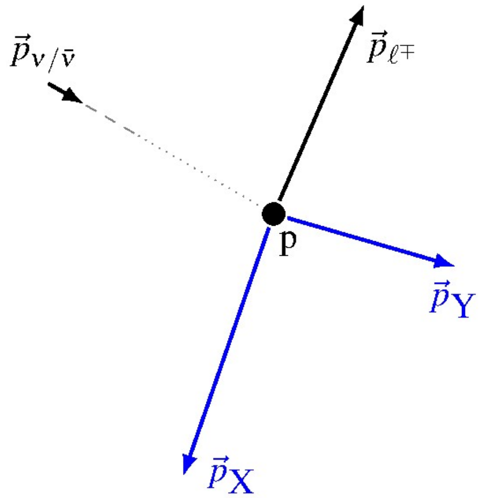
Neutrino-Hydrogen Interactions



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

Neutrino-Hydrogen Interactions

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



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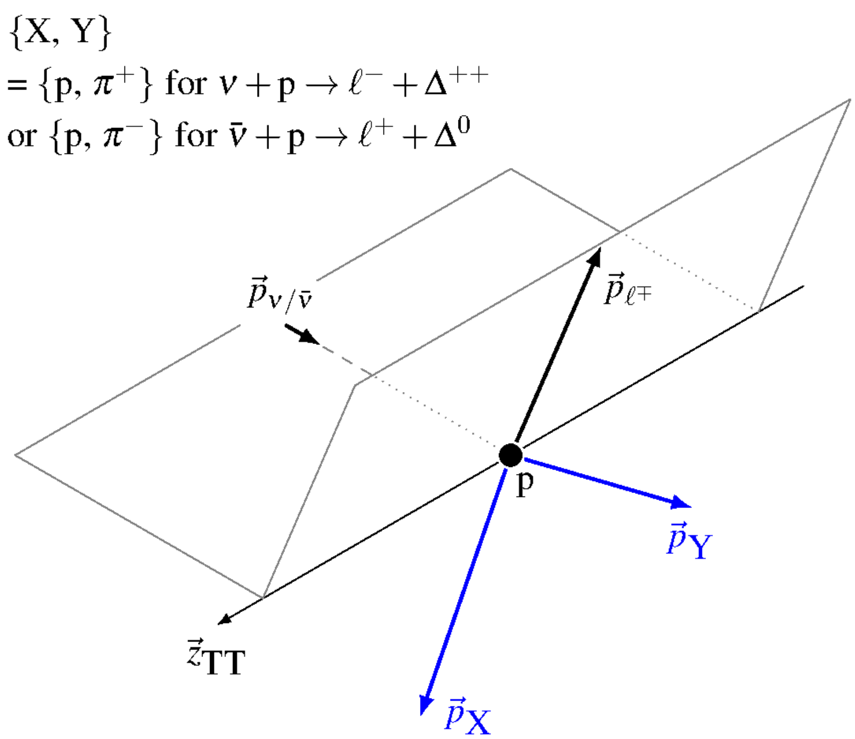
Neutrino-Hydrogen Interactions



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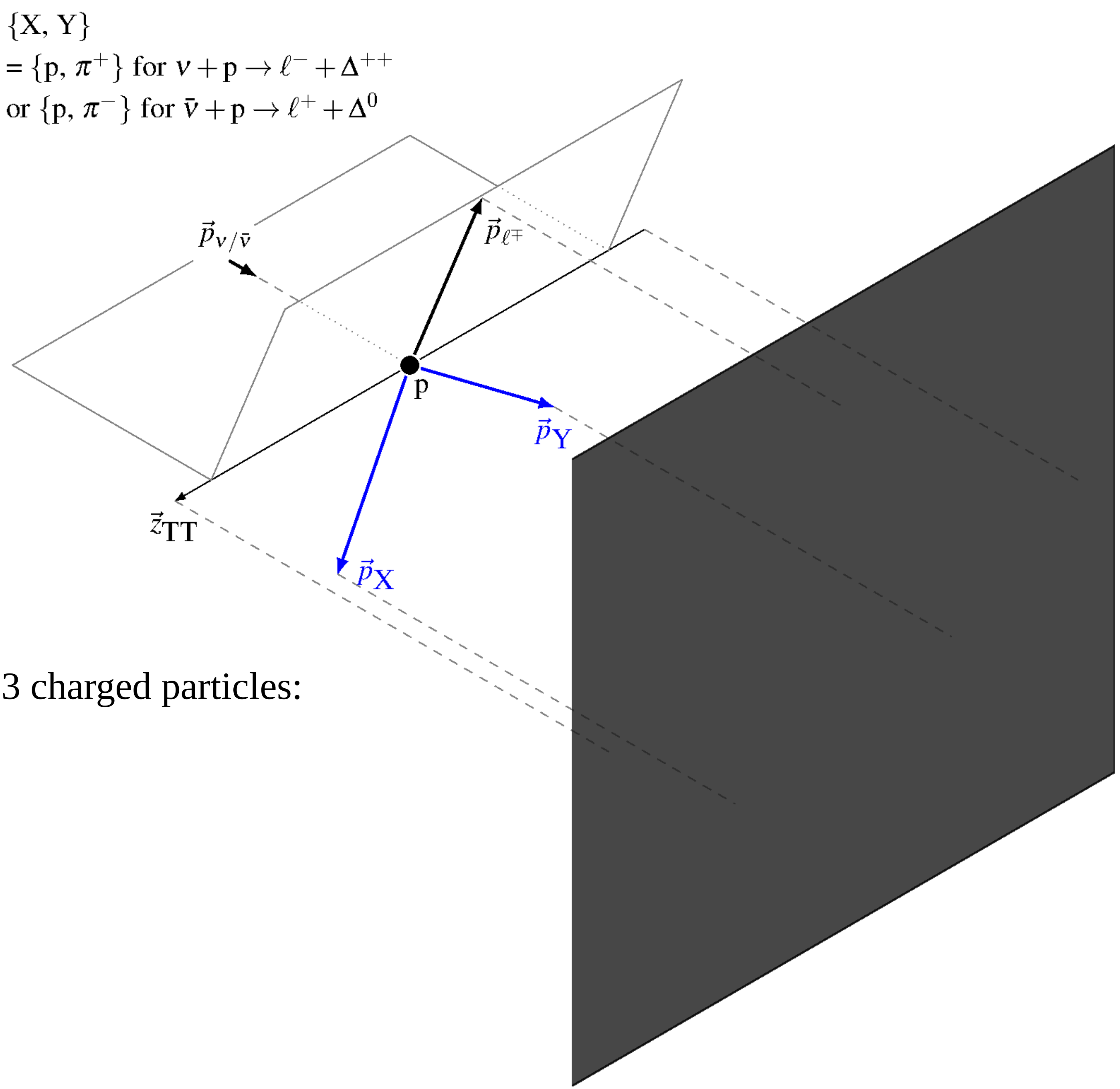

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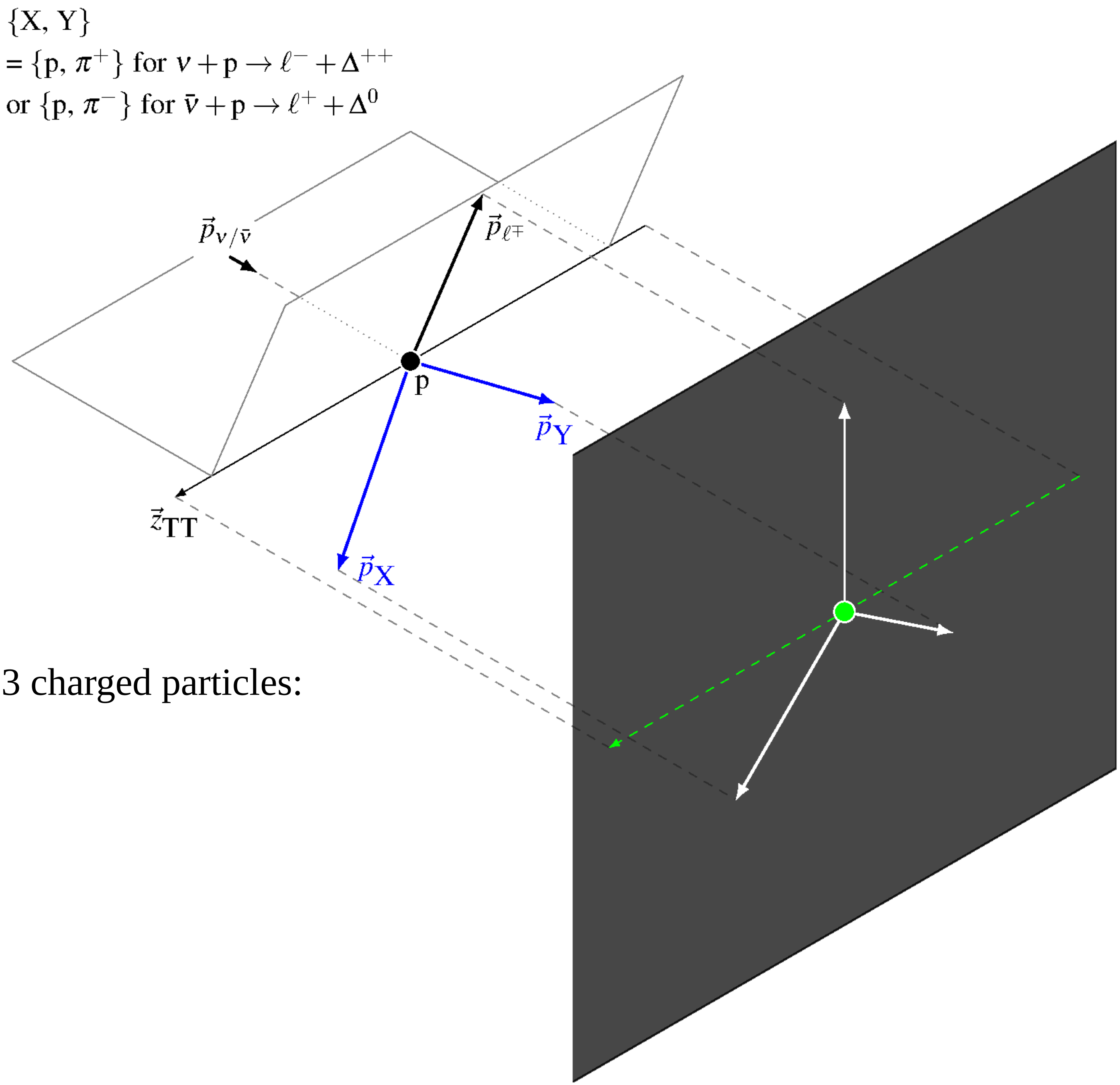

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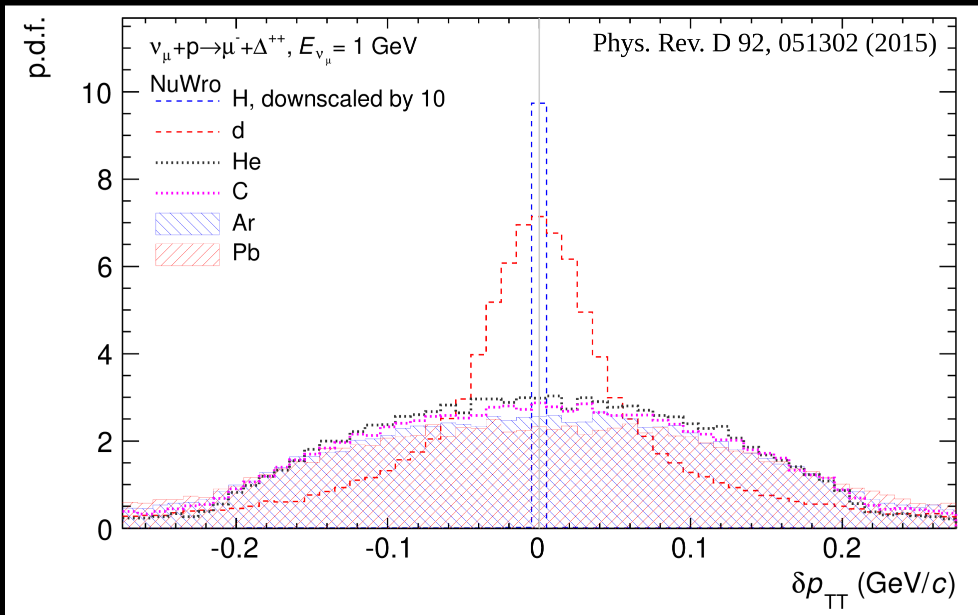
Neutrino-Hydrogen Interactions



$\{X, Y\}$
$= \{p, \pi^+\}$ for $\nu + p \to \ell^- + \Delta^{++}$
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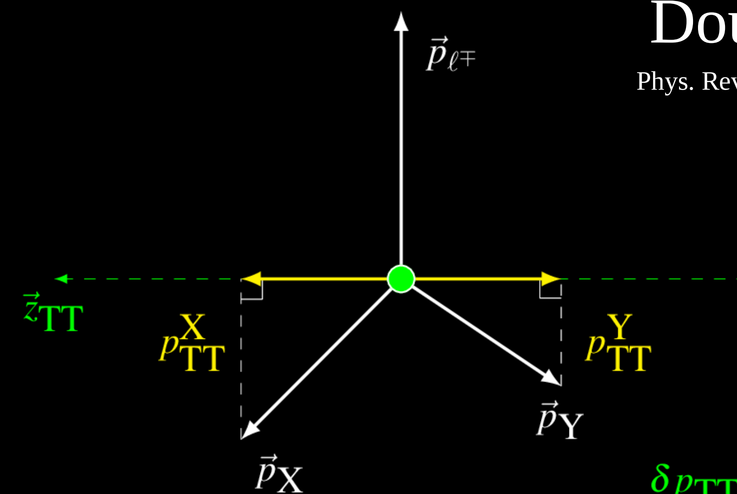
Double-TKI

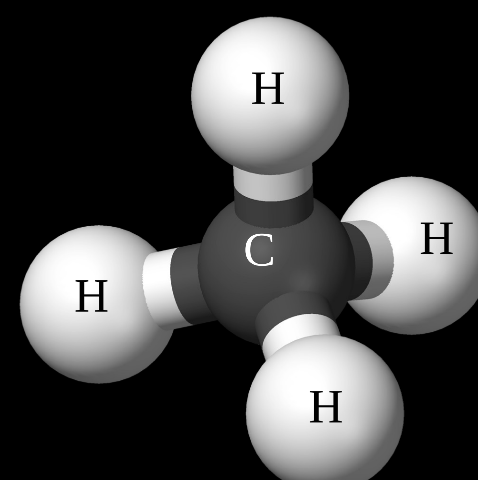
Phys. Rev. D 92, 051302 (2015)



$\delta p_{TT} \equiv p_{TT}^{X} + p_{TT}^{Y}$

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



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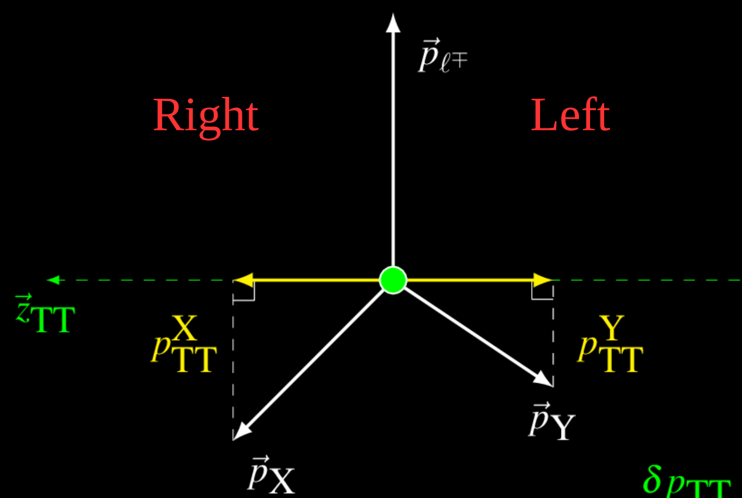
N.B., to be right or not to be right, that is the question

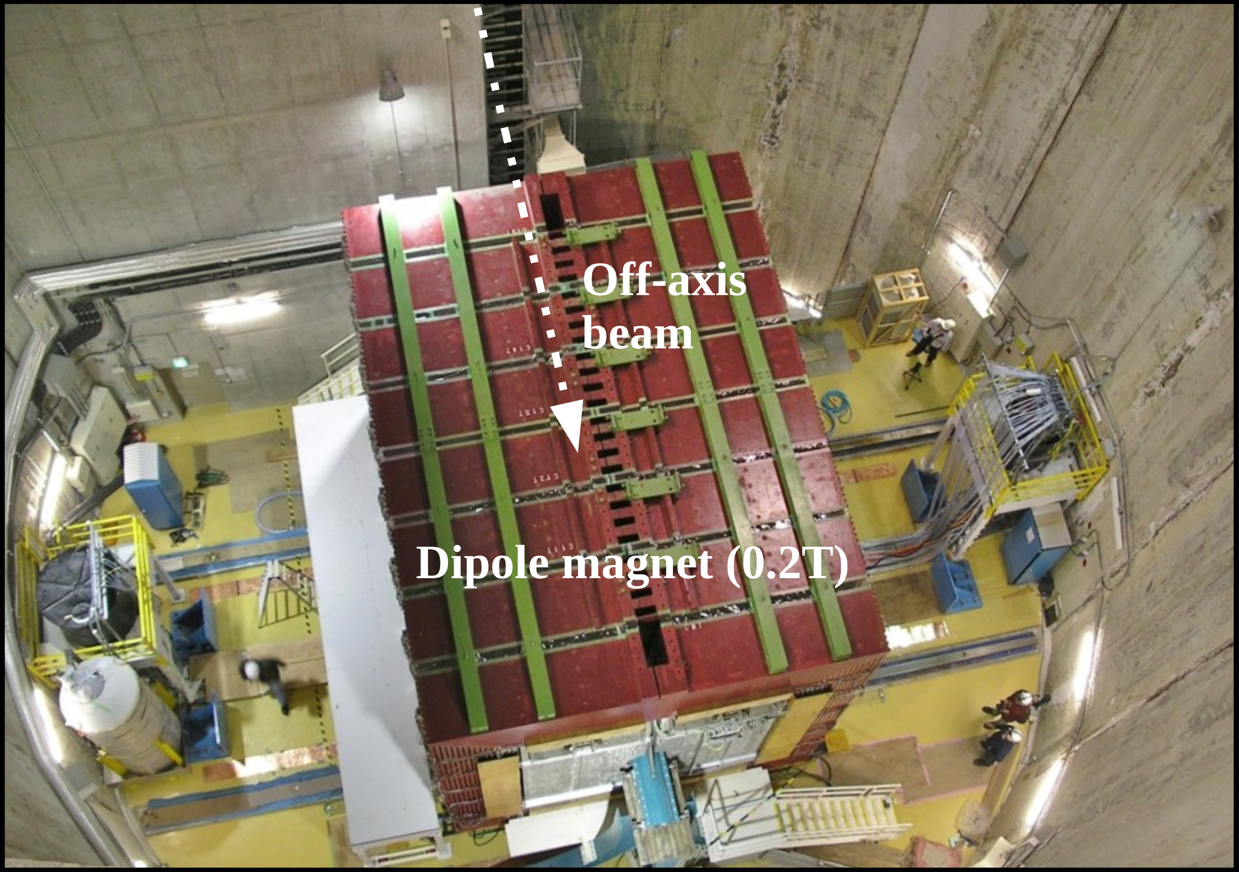
$\{X, Y\}$
$= \{p, \pi^+\}$ for $\nu + p \to \ell^- + \Delta^{++}$
or $\{p, \pi^-\}$ for $\bar{\nu} + p \to \ell^+ + \Delta^0$



$\delta p_{\mathrm{TT}} \equiv p_{\mathrm{TT}}^{\mathrm{X}} + p_{\mathrm{TT}}^{\mathrm{Y}}$

Proton left-right asymmetry could tell us about absorbed-pion in CC0pi
[arXiv:1907.11212, PRD in press]

T2K off-axis near detector (ND280)



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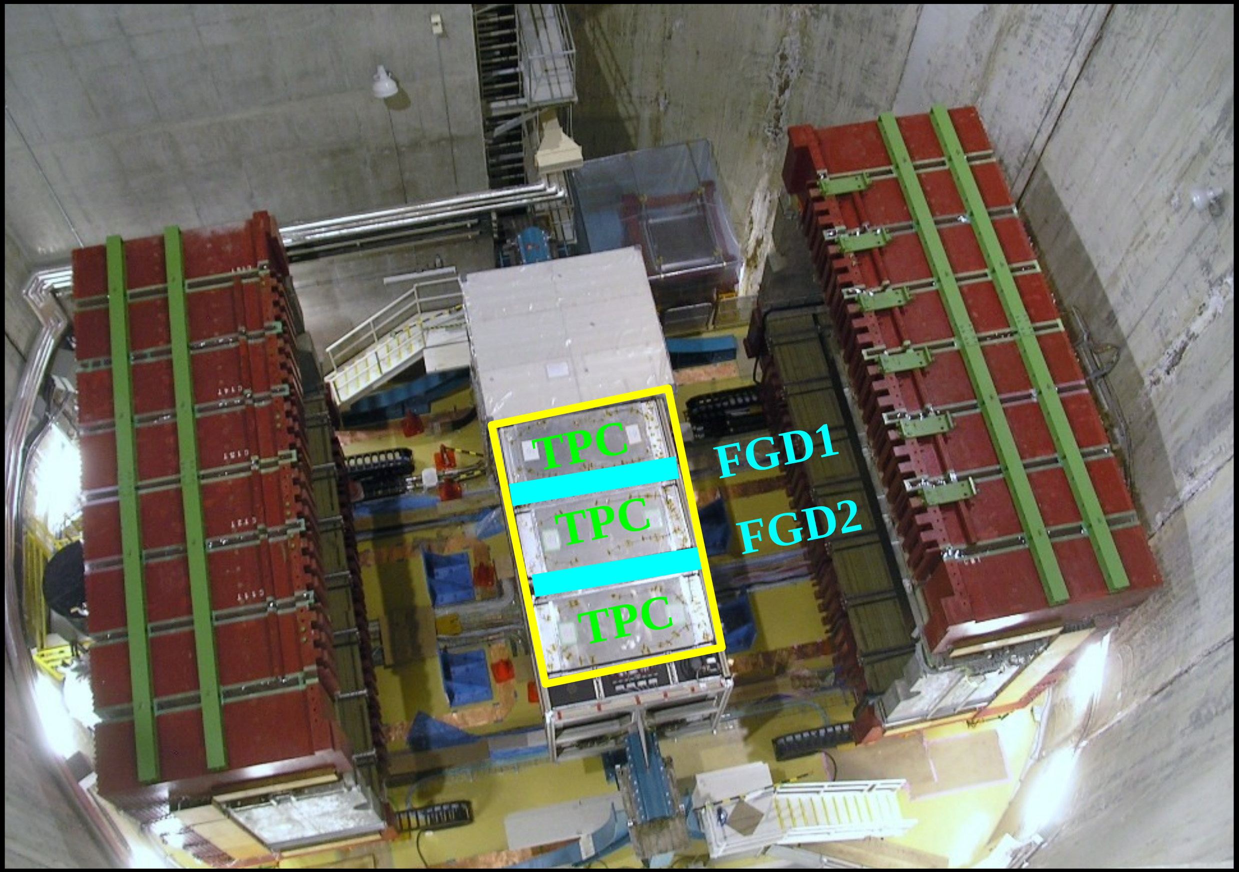
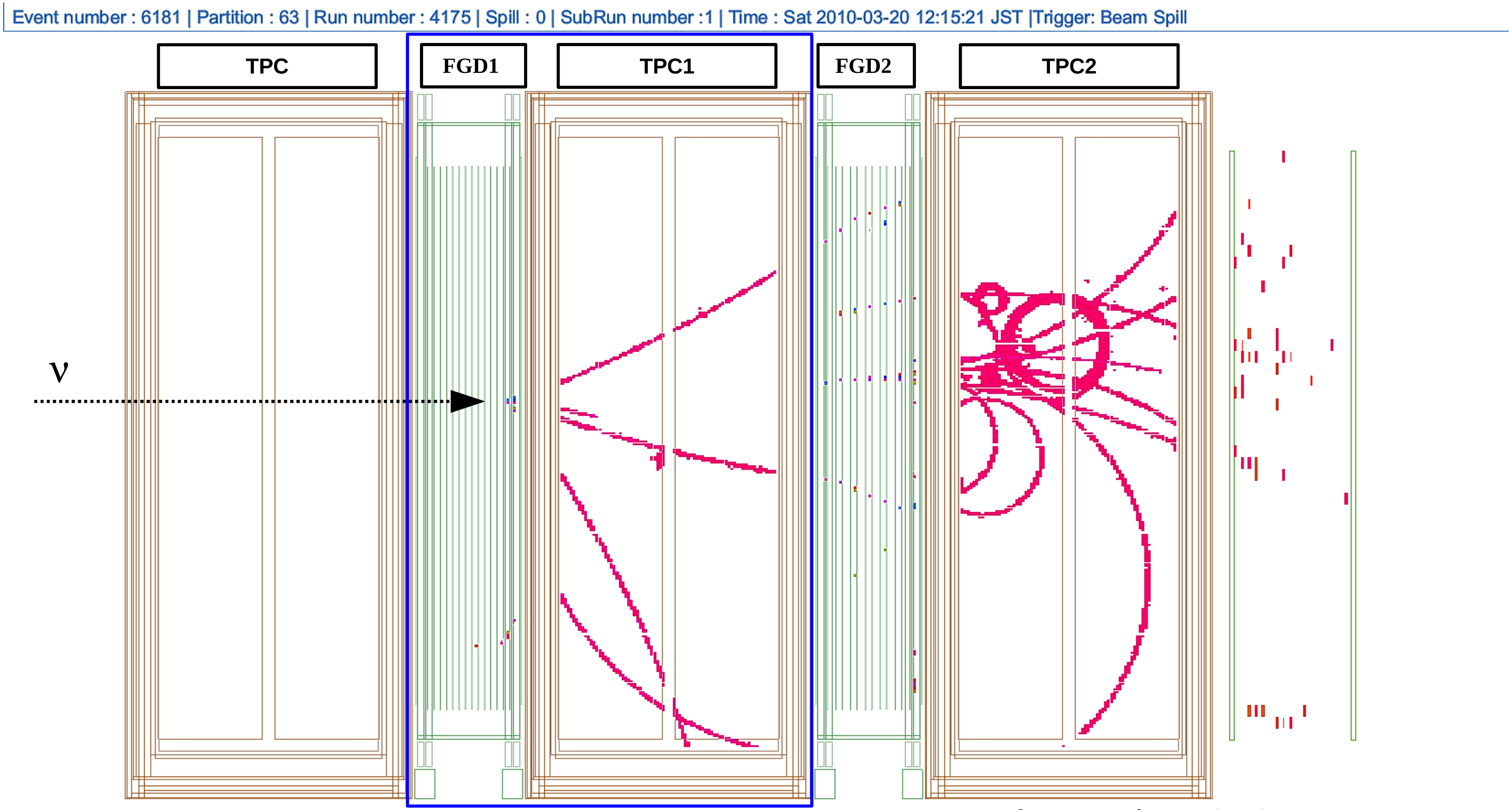


Tracker:
- FGD: Fine-Grained Detector
  1. CH target **(similar to 3DST)**
  2. CH + H_2O target
- Time Projection Chamber (TPC)

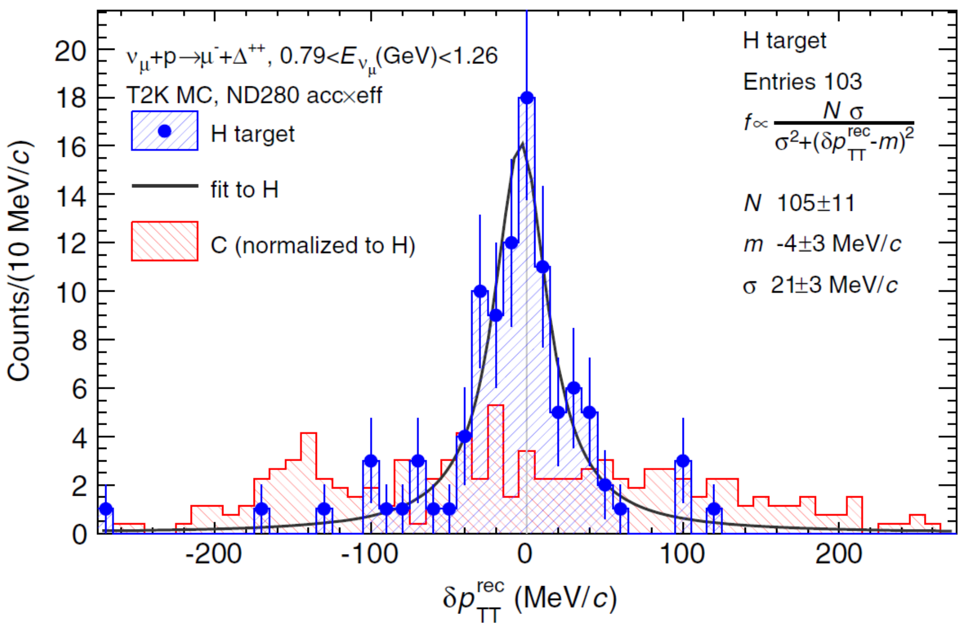
T2K off-axis near detector (ND280)



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

Neutrino-Hydrogen Interactions – T2K example

Phys. Rev. D 92, 051302 (2015)

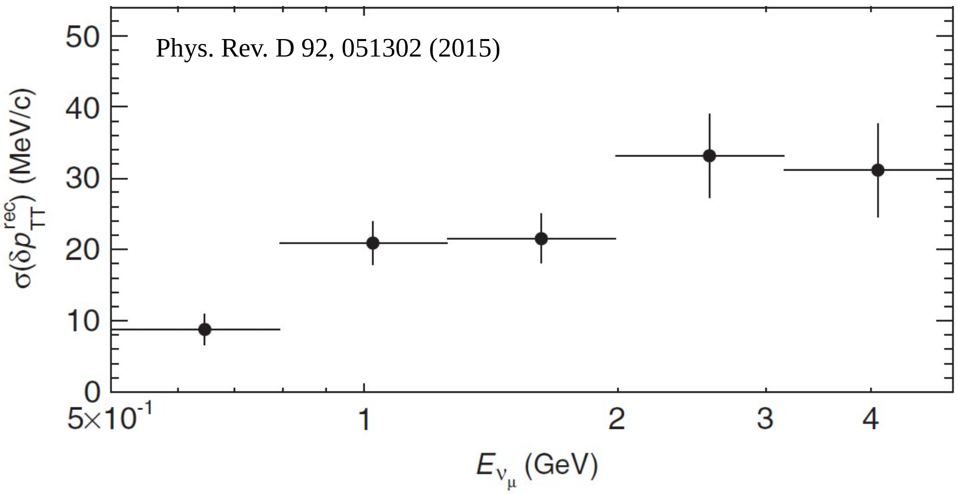


In T2K

- TPC pT resolution ~10% @ 1GeV

→ δp_{TT} resolution ~ 23 MeV

- Tracking performance varies with neutrino energy



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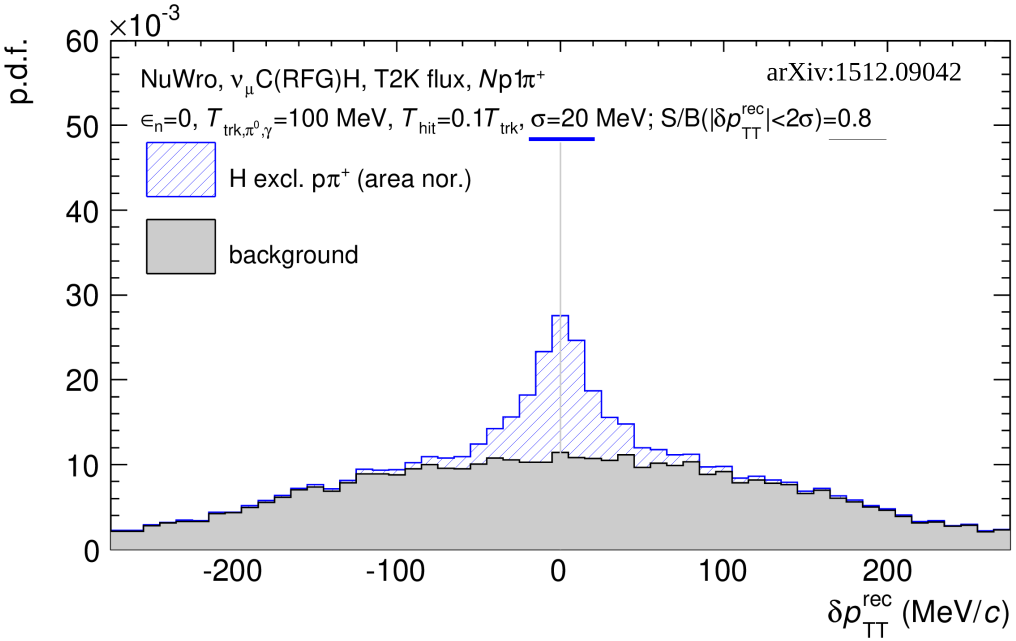
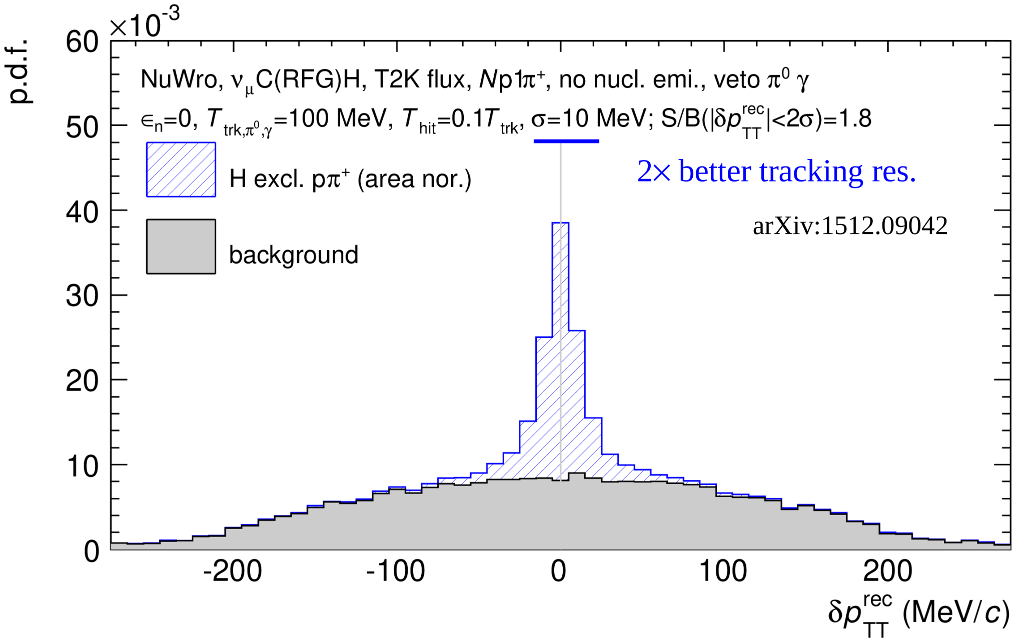
Neutrino-Hydrogen Interactions
– Perspective



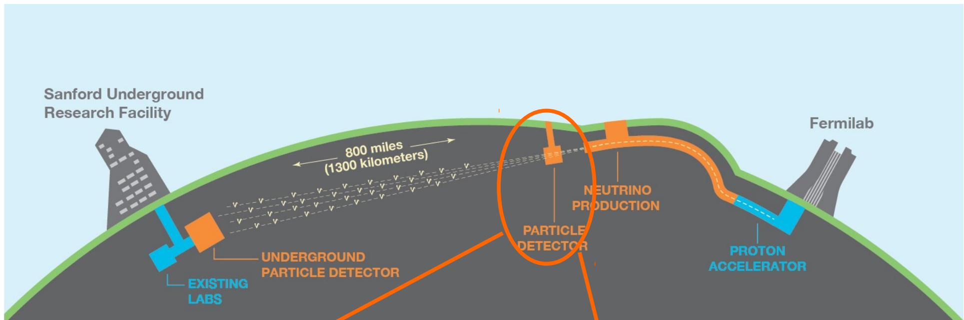


Toy simulation of T2K performance (T2K neutrino flux on **CH** target)

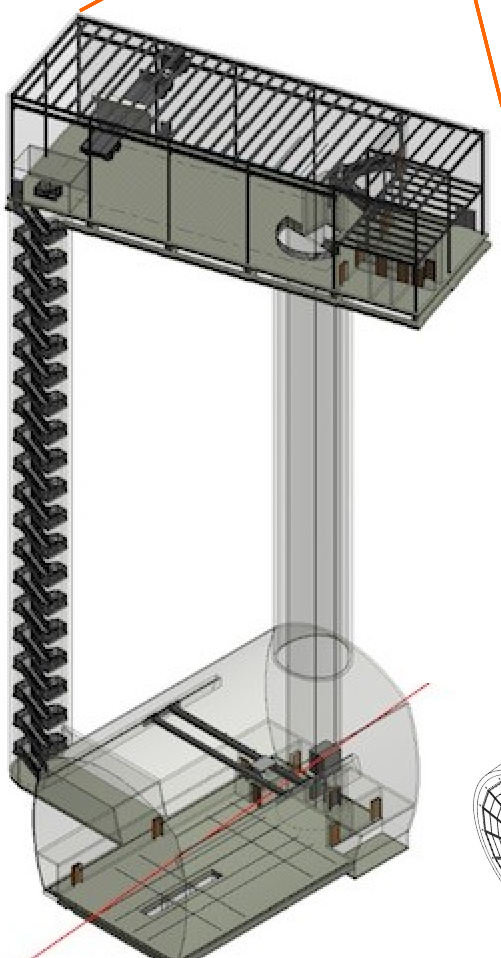
- Realistic detector resolution as T2K gas TPC (~10% at 1 GeV/c)

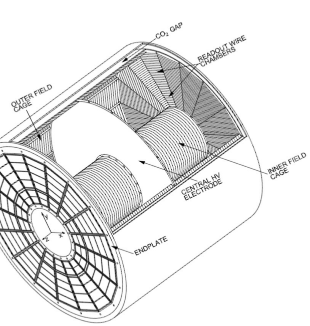
- When tracking resolution improves, only signal distribution gets narrower, background still wide due to Fermi motion and FSI! → Signal/background improves

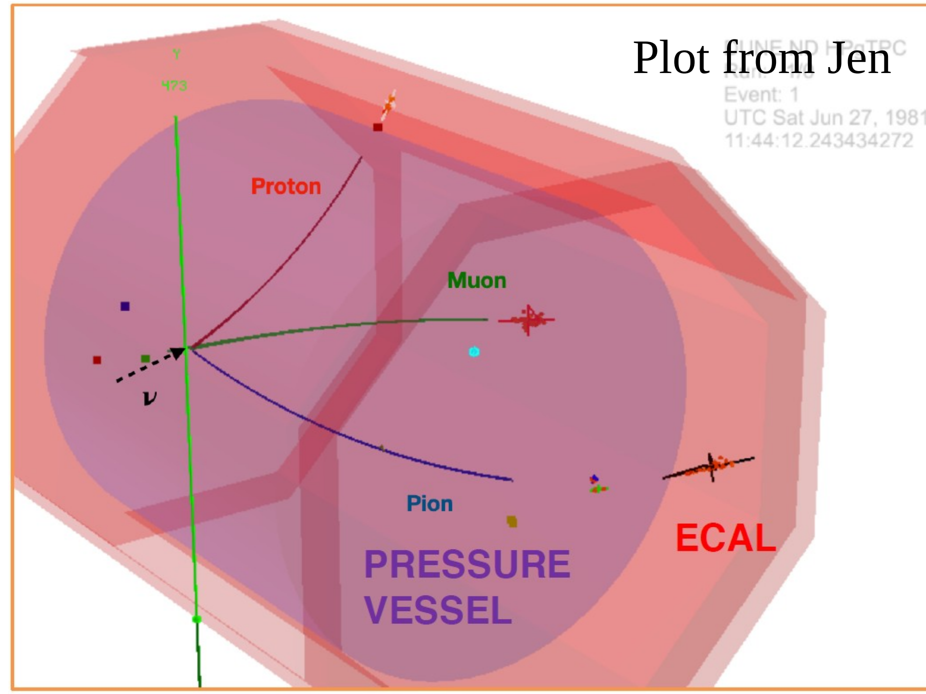
Neutrino-Hydrogen Interactions – Perspective



ND





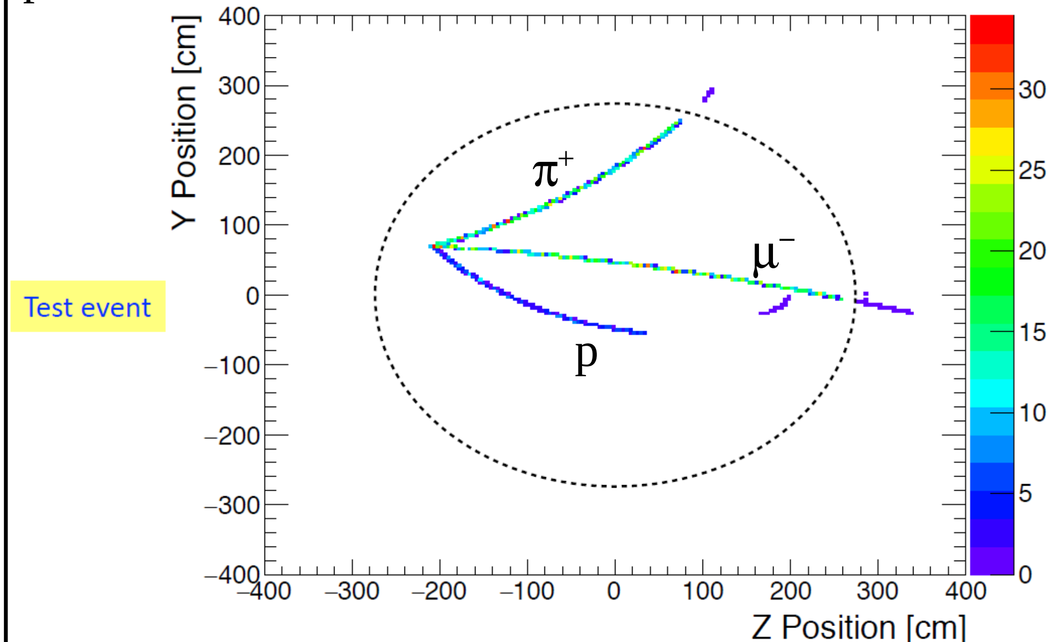


HPgTPC
Model: ALICE TPC

Neutrino-Hydrogen Interactions – Perspective

Z-Y Projection: Sample event - ν_μCC

plot from Alan



- 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, respectively)

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 free/bound-proton 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

- Previous estimation needs to be corrected for
  - Kinematic distributions at DUNE energy
    - In resonant production, pion and proton momenta increase only slowly with E_ν>1GeV (energy transfer saturates due to form factor effect)
  - Track topology
    - Inclination angle w.r.t. readout pad geometry
  - TPC tracking performance with different gas at different pressure
    - Drift & attachment, gain, multiple scattering
      - 50% He + 50% CH_4 $\langle Z \rangle=6$, 1/3 of argon (Z=18); $\langle A \rangle=10$, ¼ of argon (A=40) → "Carbon-10"
      - 10 atm, $\rho \sim \times 10/4 = 2.5$ times of 1 atm argon
      - $1/X_0 \sim Z^2/A=4/9$, $\sqrt{(\rho/X_0)} = \sqrt{(10/9)}$, radiation length similar to 1 atm argon
- Do we have good simulation of gas properties?
  - Do we need new measurements?

BACKUP

END