The T2K TPC

Dean Karlen / U. Victoria & TRIUMF

ECFA LC Workshop – Durham, England

September 1-4, 2004

Outline

- Introduction to the T2K experiment and long baseline neutrino physics
- Near detector concept for the T2K experiment
  - tracker – builds on the LC TPC R&D
- T2K Schedule
  - current status of the project
  - opportunity to participate in a large TPC project before the LC detector construction begins

T2K neutrino project

- The J-PARC 50 GeV proton accelerator at Tokai, currently under construction, will be the highest intensity proton beam
  - $1.5 B budget over 7 years for phase 1

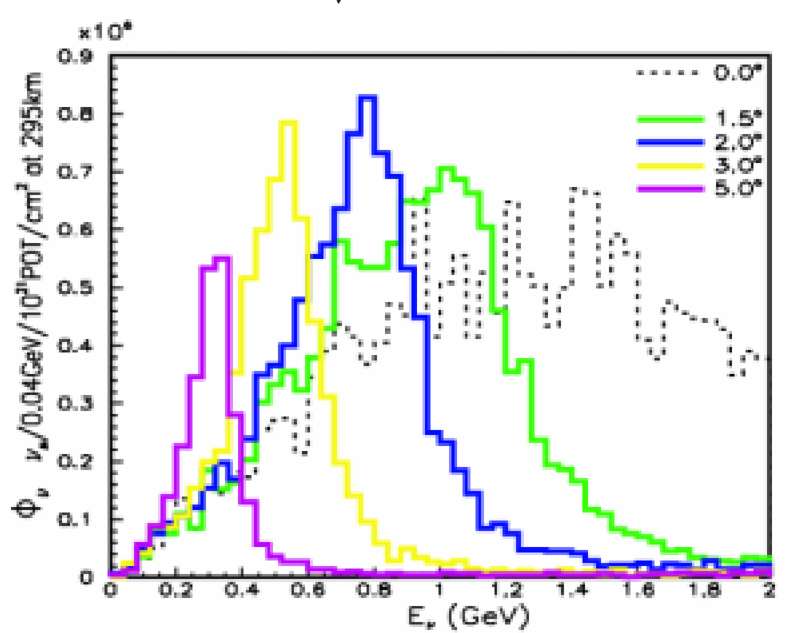
- A neutrino beamline directed towards the Super Kamiokande detector was approved by the Japanese government in December 2003.
  - $160 M budget

T2K collaboration

- January 2004: First official collaboration meeting at KEK

Geography – Off axis beam

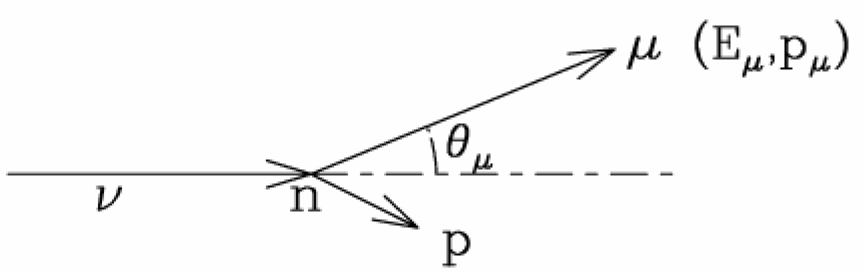
- For the 300 km baseline, the first neutrino oscillation maximum occurs at E_ν ~ 0.7 GeV



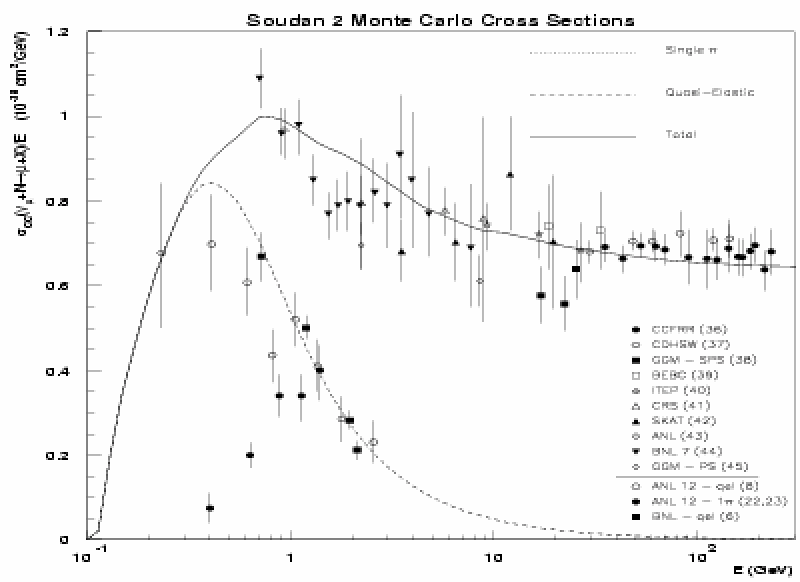
  - an off axis angle of about 2.5° gives a narrow band beam with peak energy ~ 0.7 GeV

Neutrino energy reconstruction

- Use the quasi-elastic charged current process
  - dominates the cross section for low E_ν

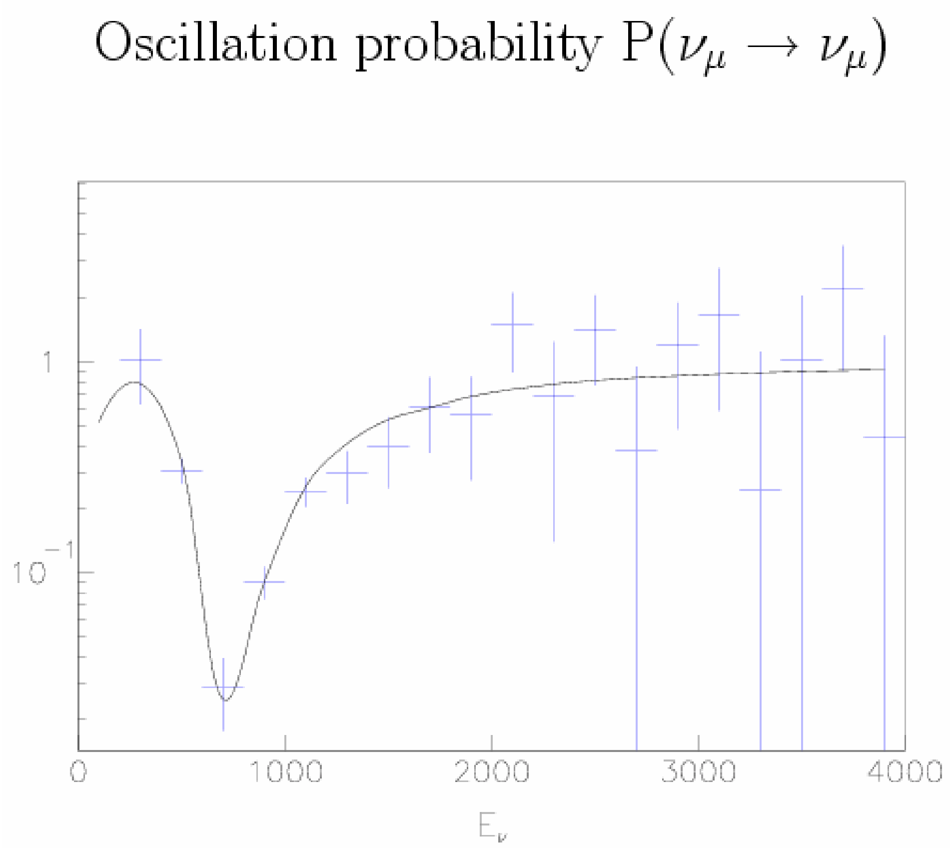


$$E_\nu = \frac{m_N E_l - m_l^2/2}{m_N - E_l + p_l cos\theta_l}$$



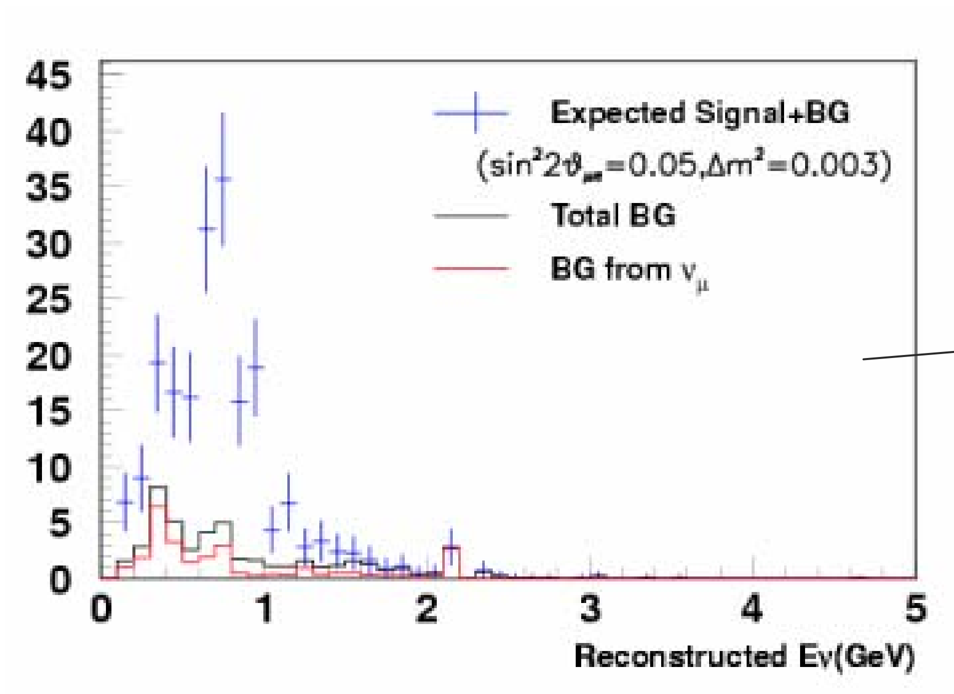
Muon neutrino disappearance

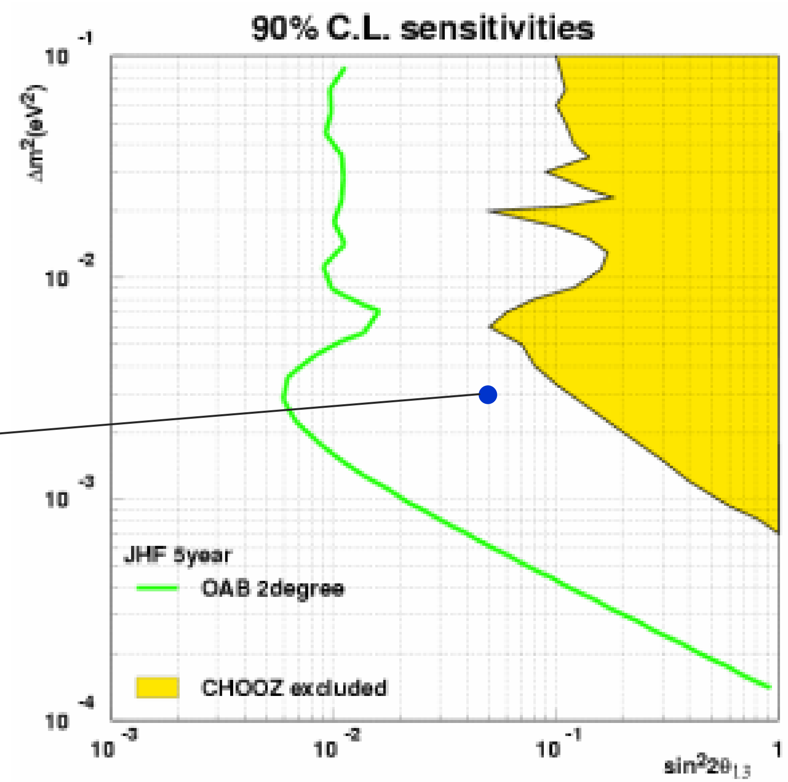
- Precise measure of θ_{23}, Δm_{23}
- Is $\sin^2 2\theta_{23} = 1$?



Electron neutrino appearance

- Observe ν_e events at SK (single electrons)
- Sensitive to θ_{13}

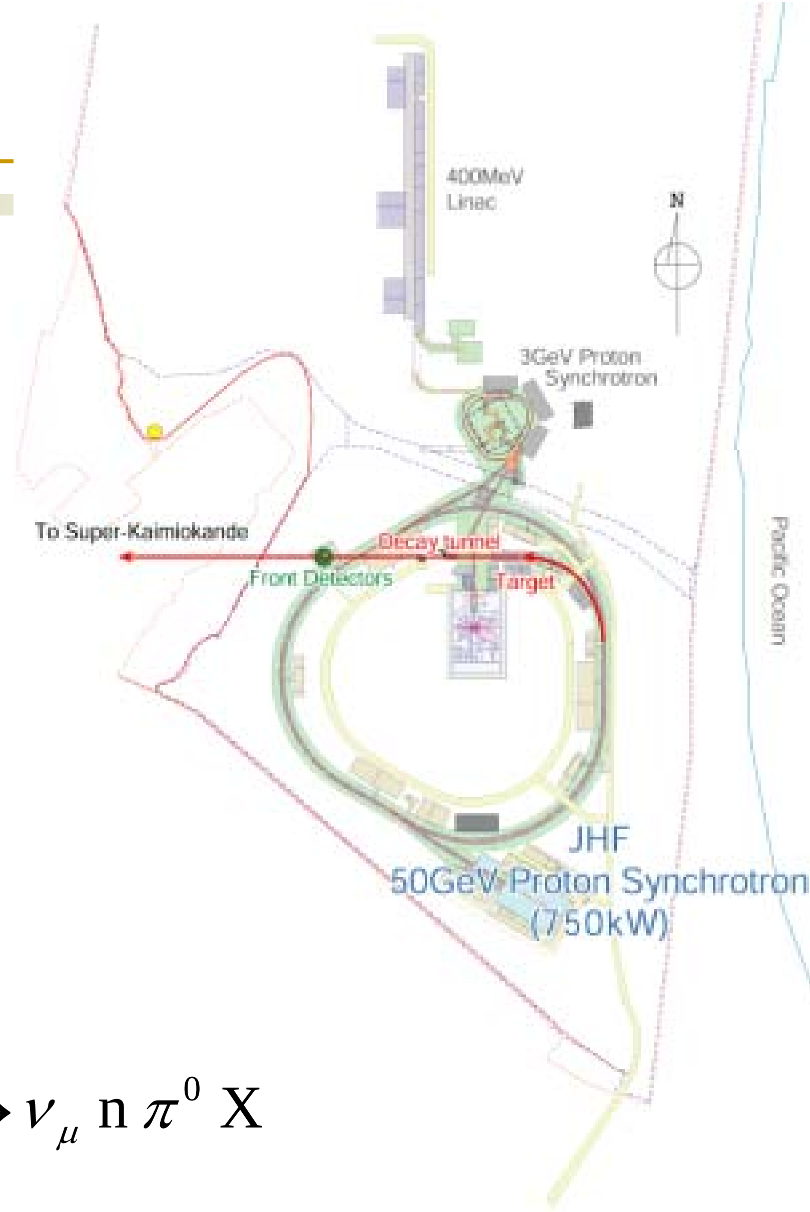




The Near Detector

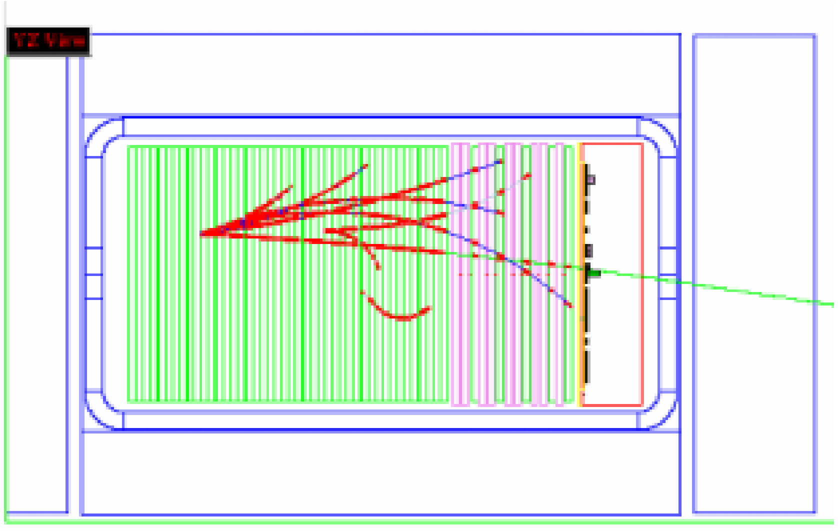
- Located 280 m downstream of the production target
- Purpose:
  - measure energy spectrum and flux × cross – sections for ν_μ reactions on Oxygen
  - Important processes:

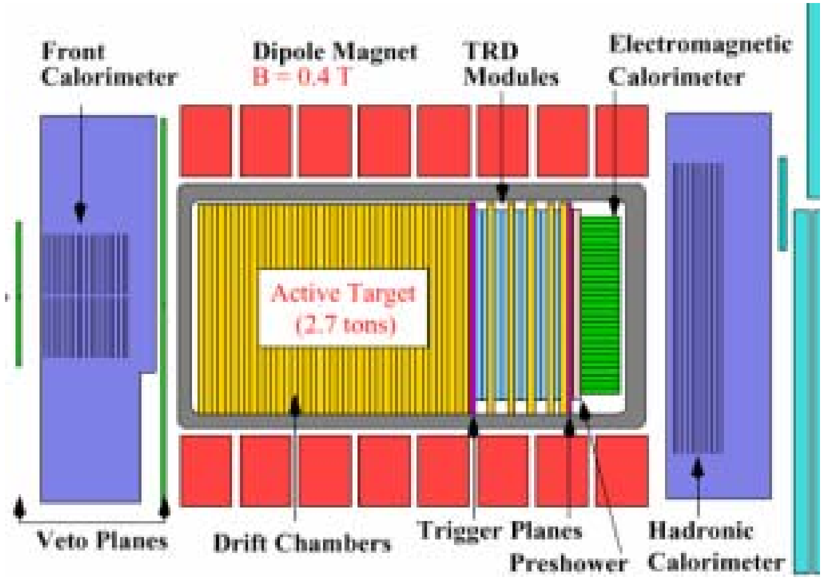
$$\nu_\mu\, \mathrm{n} \rightarrow \mu\, \mathrm{p}\, \mathrm{X} \qquad \nu_\mu\, \mathrm{n} \rightarrow \nu_\mu\, \mathrm{n}\, \pi^0\, \mathrm{X}$$



Near Detector concept

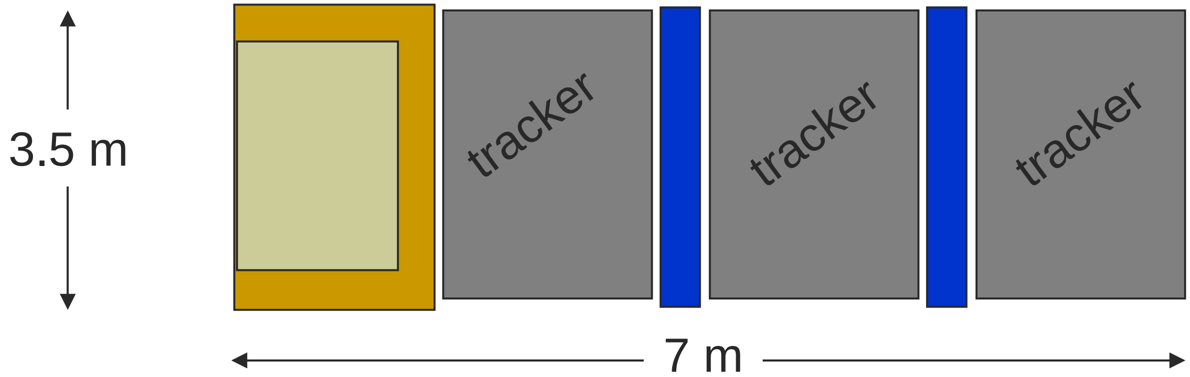
- Will use the UA1 magnet… most recently used for the NOMAD experiment
  - 7 m × 3.5 m × 3.5 m interior volume
  - 0.2 T → 600 kW





Near Detector Concept

- Neutral current section:
  - Use 5-10 Ton of segmented scintillator, surrounded by EM-calorimeter to measure π^0 production
- Charged current section:
  - Use active target (scintillator or scintillator+water) with a charged particle detector to measure μ momentum and other reaction products



Tracker design criteria

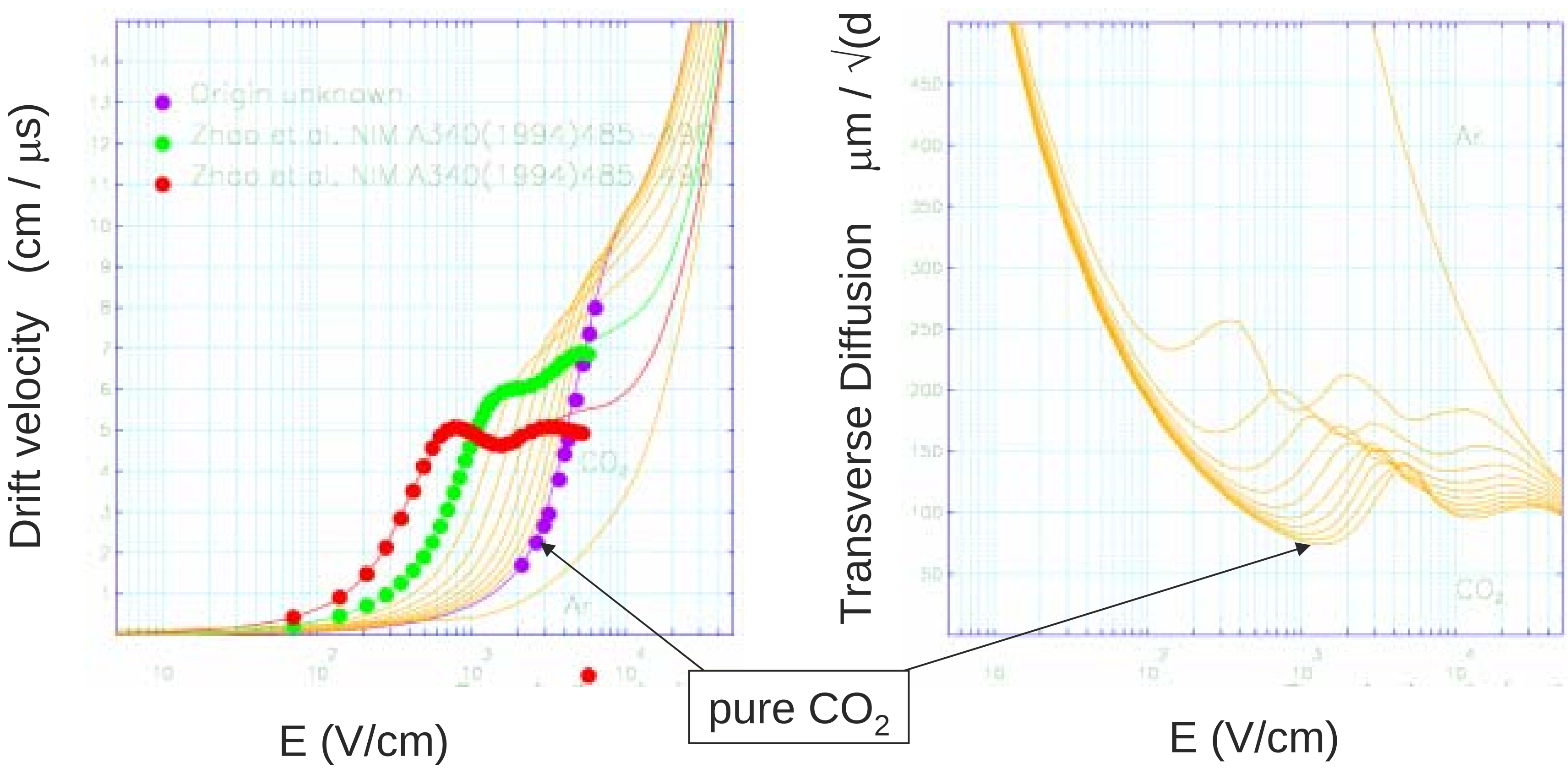
- Design criteria for the tracker:
  - Good point resolution
    - good muon momentum resolution
  - Good two particle resolution
    - better pattern recognition for more complicated events
  - Low mass
    - to reduce multiple scattering – better momentum resolution
    - to reduce dead & non-0_2 target material – neutrino cross section measurements
  - Simple, proven design
    - to be built in timely manner – there is little time for R&D

TPC tracker is baseline choice

- Excellent resolution
- Fine granularity
- Low mass
- Proven technology
- The TPC gas itself can be used as an additional oxygen rich target:
  - eg. 2.5 m × 2.5 m × 1 m volume of CO_2 = 12.5 kg
  - 4 such modules (50 kg) would provide about 5000 events per year, with very fine granularity
    - similar statistics as SK

CO_2 gas properties

- very slow at low fields
- very low diffusion
  trans. diff. ~ long. diff.



TPC with CO_2

- For a modest field: 200 V/cm (140 cm drift)
  - ~ 30 kV maximum potential – no problem
  - v ~ 1.5 mm/μs → ~1 ms maximum drift time
    - no problem given the beam spill interval (seconds)
    - electronics can be “slow” (cheaper, less noise)
    - very small lorentz angle: ~ 2° at 0.5 T
  - minimum ionizing electon-ion pairs: ~91/cm
  - diffusion: ~ 150 μm / √cm → 1.7 mm max σ
    - diffusion limits space resolution to ~0.3 mm per 4 mm sample
  - gain: lower, but probably acceptable
  - inexpensive and non-flammable
  - a good target material, rich in Oxygen

Magnetic field distortions

- Because drift velocity is so slow, the sensitivity to the magnetic field direction is very low:
  - example: (Following notes by J. Va'vra)
    - here $\omega\tau \sim 0.02$

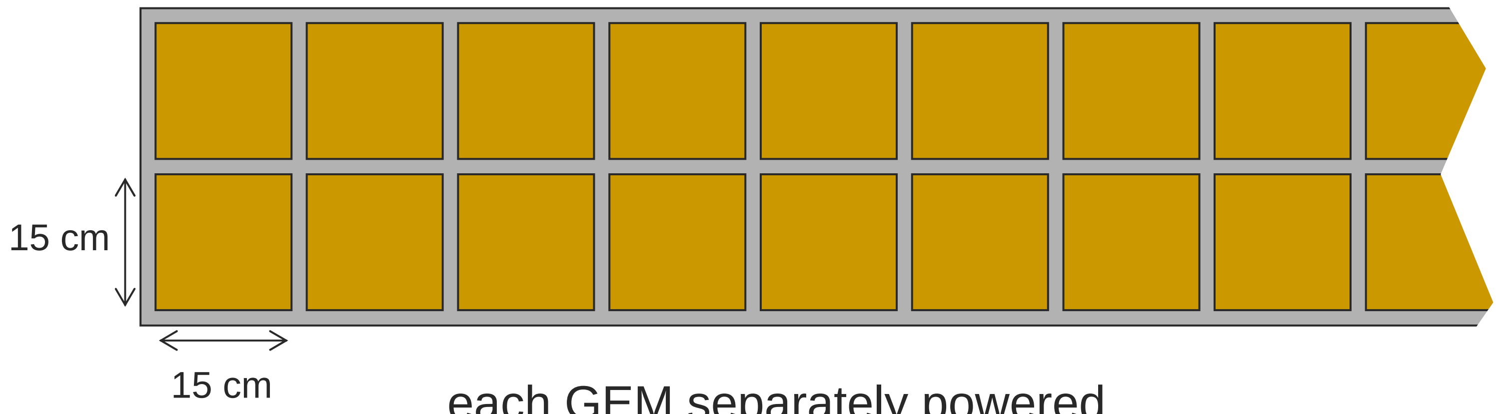
$$\mathbf{E} = (E_x, 0, 0) \quad \mathbf{B} = (B_x, 0, B_z) \quad |B_z| << |B_x|$$

$$v_x \approx v \qquad v_y \approx \omega\tau \frac{B_z}{B_x} v \qquad v_{yz} \approx (\omega\tau)^2 \frac{B_z}{B_x} v$$

  - If B_z / B_x ~ 1% for full 125 cm drift distance, the offset in y is only 0.3 mm
  - ample cosmics can be used to develop corrections

GEMs for TPC endplate

- Andy White (UT Arlington) is negotiating with 3M for GEMs for their hadron calorimeter prototypes
  - The design is ideal for ND280m TPC:

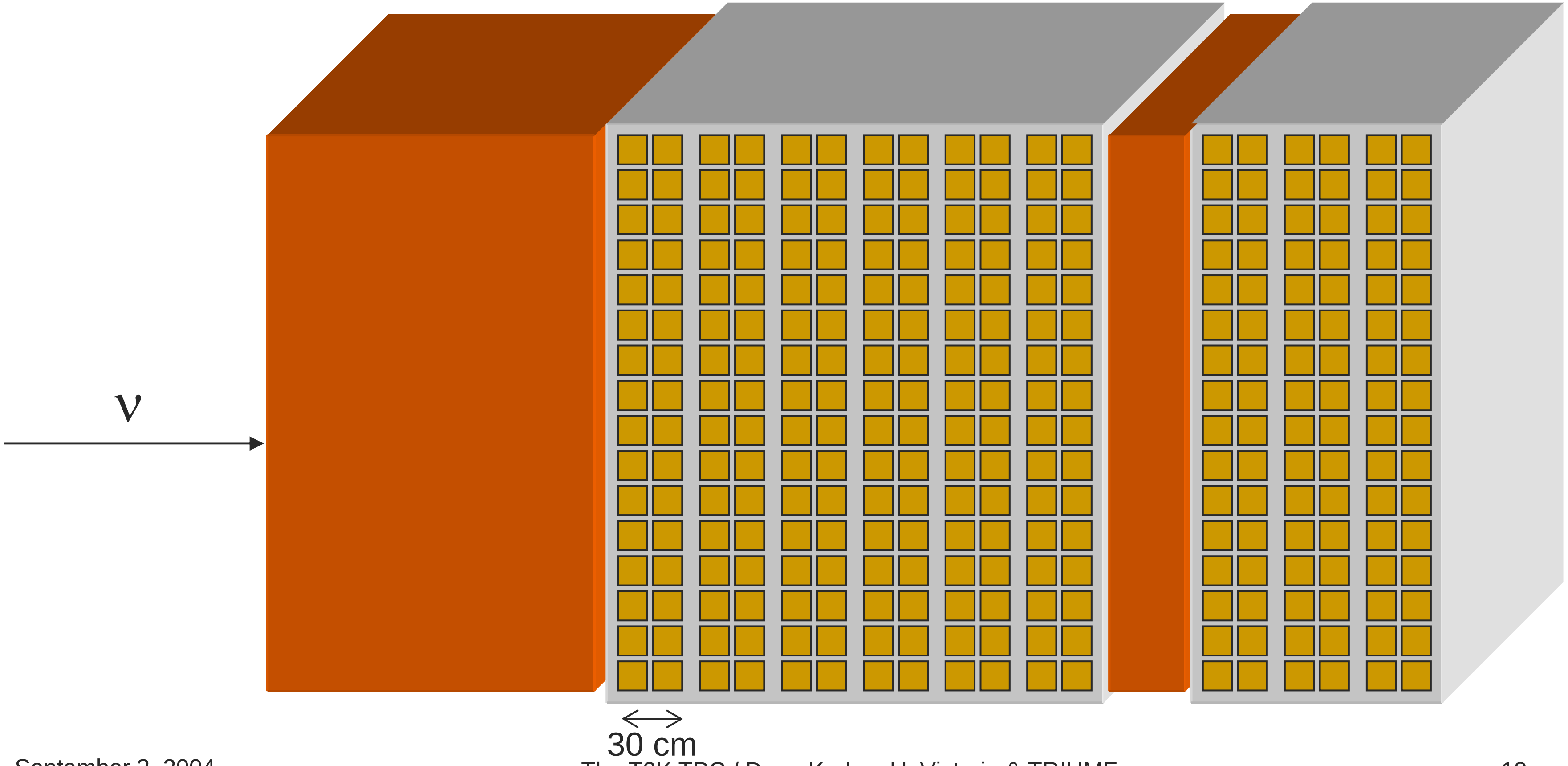


each GEM separately powered

  - ND would need at most 50 m^2 – small compared to the full LC HCAL requirements of 4000 m^2

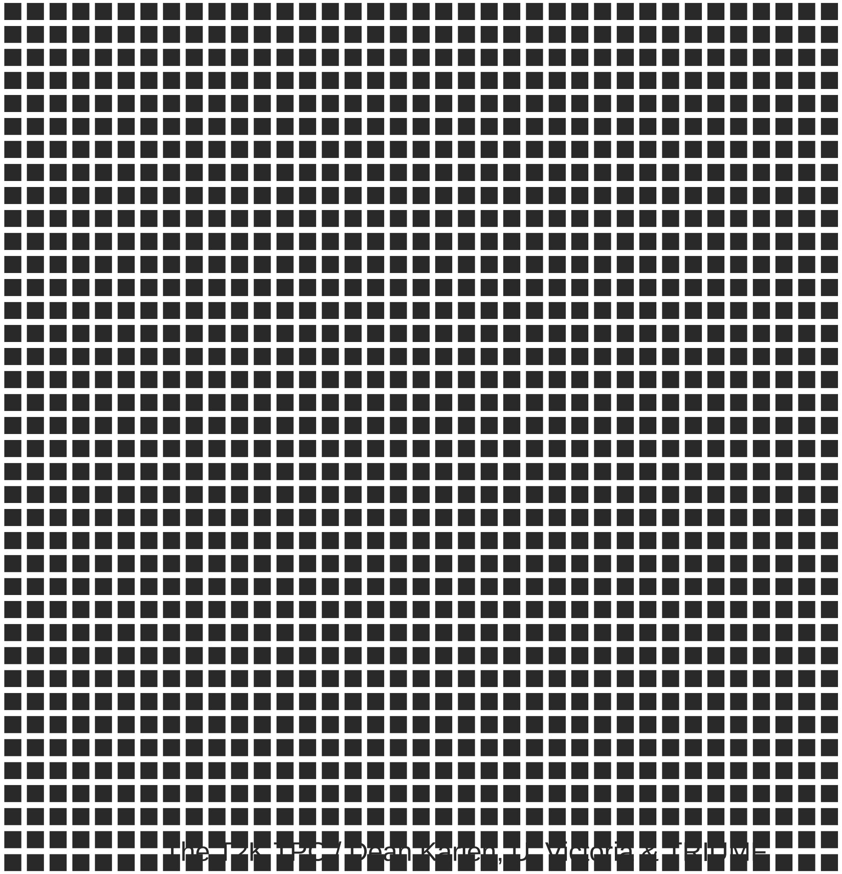
Near detector TPC concept

- GEMs or micromegas foils ~ 30 cm
  - figure below exaggerates the gaps between foils



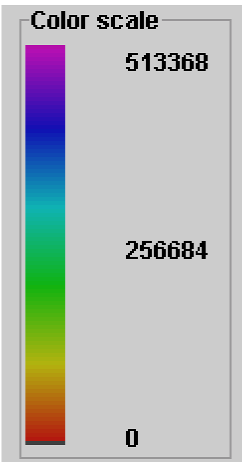
Pad readout: an example

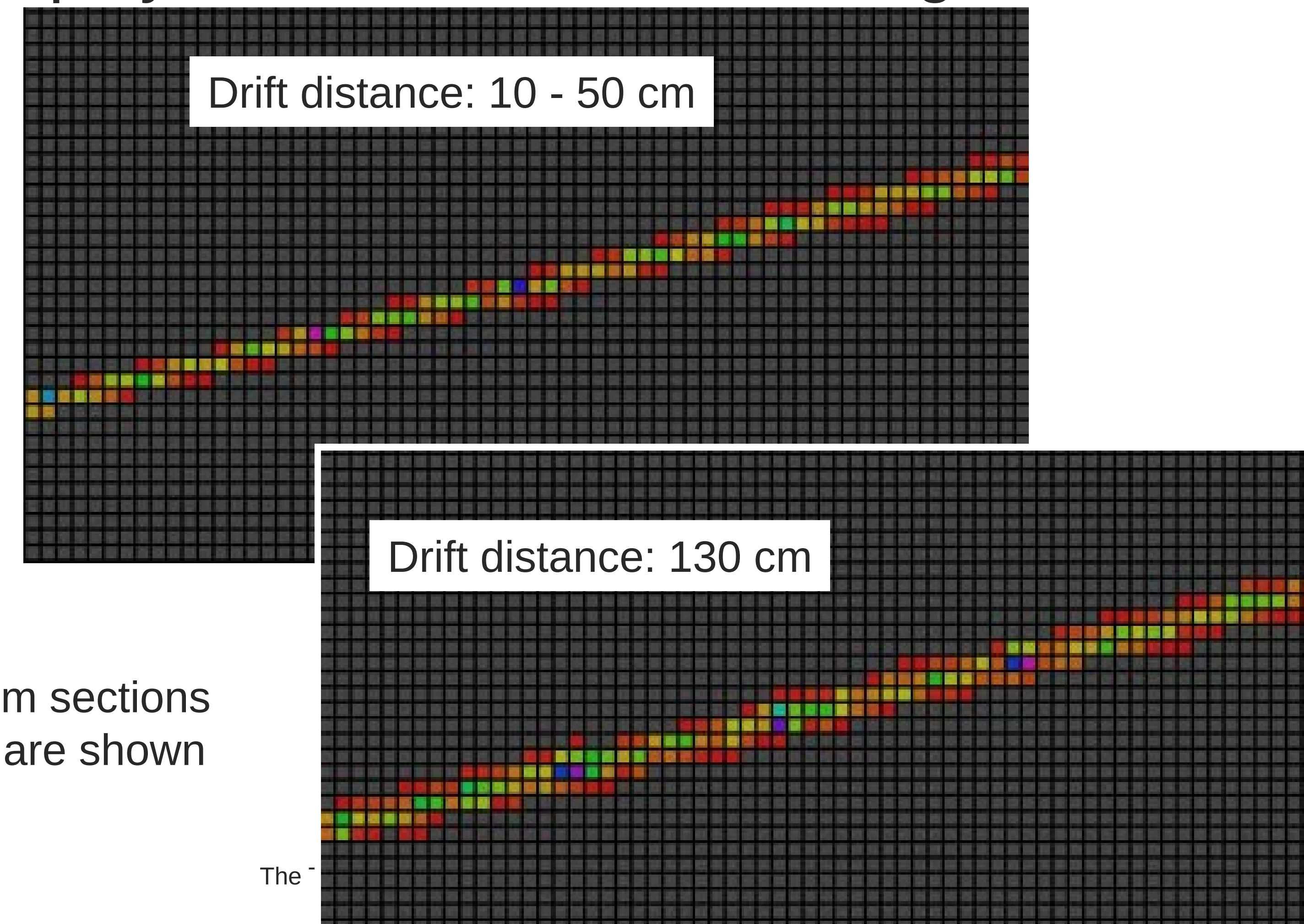
- Behind each GEM have a rectangular array of 4mm x 4mm pads:



Simulation of a GEM TPC

- Event displays with a minimum ionizing track:





only 25 cm sections
of tracks are shown

Muon momentum resolution

- Using parameterizations in PDG, ignoring multiple scattering in gas:

$$\sigma_{1/r} \approx \frac{\sigma_x}{L^2}\sqrt{\frac{720}{N+4}}$$

  - For L = 1 m, 4 mm samples, σ = 0.3 mm, B = 0.2 T

$$\frac{\delta p_\perp}{p_\perp} \approx 0.01 p_\perp [\mathrm{GeV}]$$

  - For L = 0.5 m, 8 mm samples, σ = 0.3 mm, B = 0.2 T

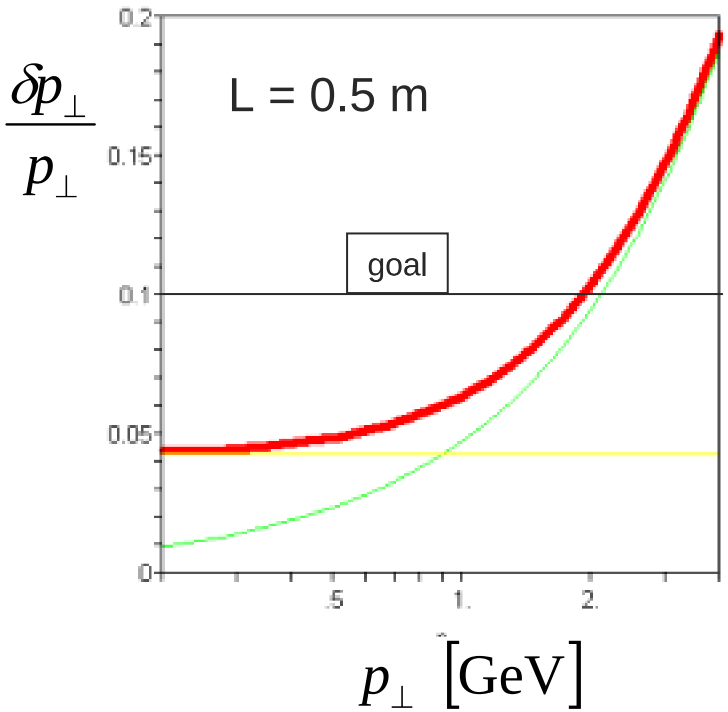
$$\frac{\delta p_\perp}{p_\perp} \approx 0.05 p_\perp [\mathrm{GeV}]$$

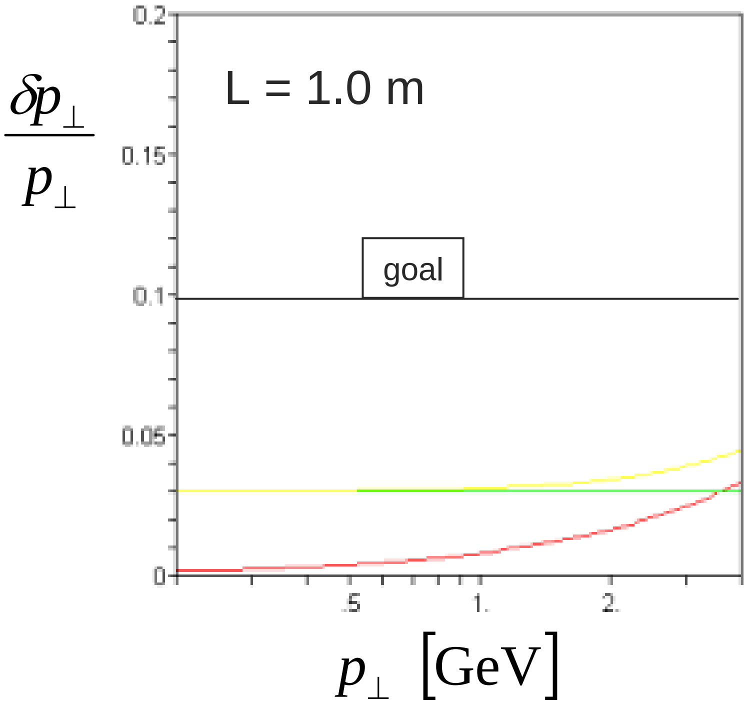
Multiple scattering in CO_2

- Parameterization:

$$\sigma_{1/r}^{ms} \approx \frac{0.016}{\beta\ p[\mathrm{GeV}]\cos^2\lambda\sqrt{L\ X_0}}$$

$$\cos\lambda = 0.5$$





Neutrino events in gas target

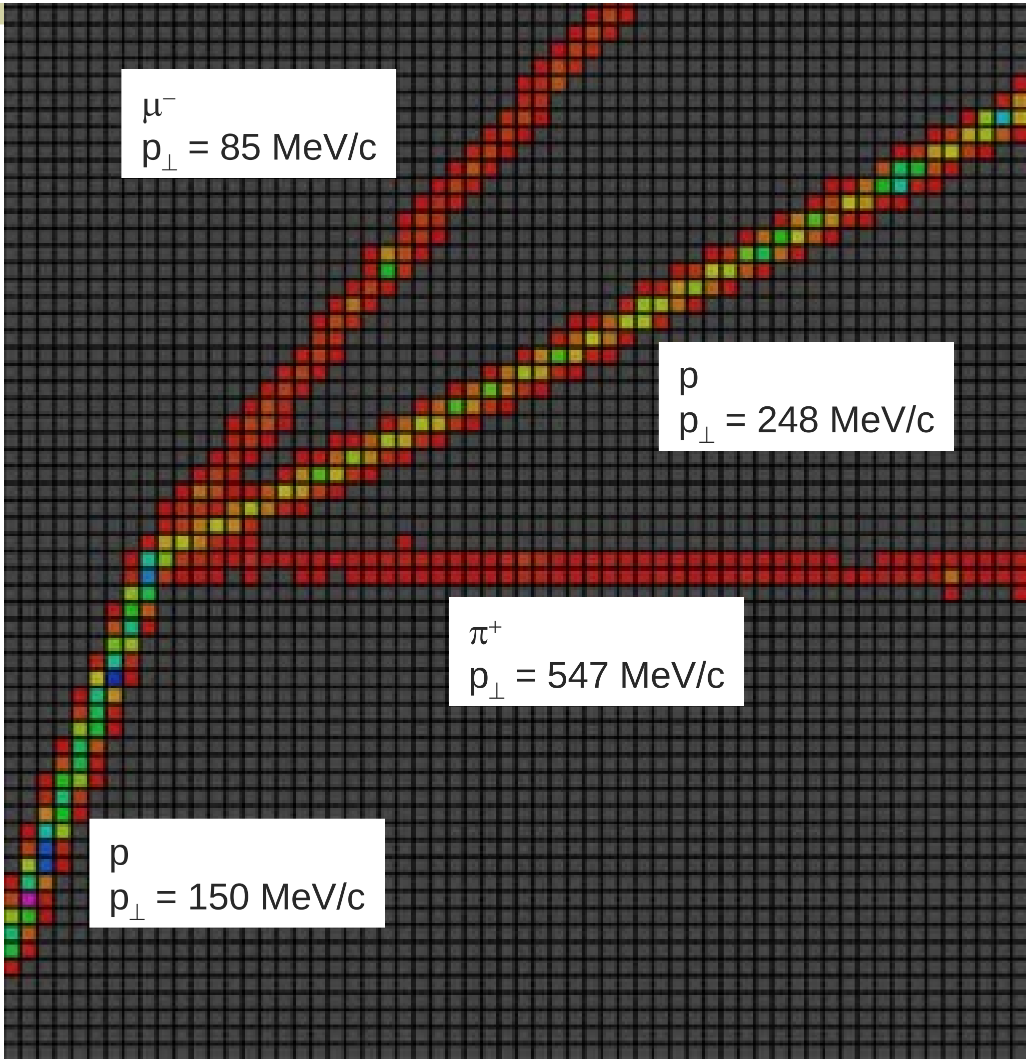
- To see what events in the gas target look like, a sample of NEUT events were generated randomly in the gas volume
  - following images show some of the first 10 events in a small gas volume, 25 cm x 25 cm x 140 cm
  - GEANT was used to generate dE in 1 mm steps, insert the produced electrons into GEM-TPC simulation package
  - Charge collected by 4 mm × 4 mm pads

Event 1

4 mm x 4 mm pads
color: relative signal amplitude:

ν

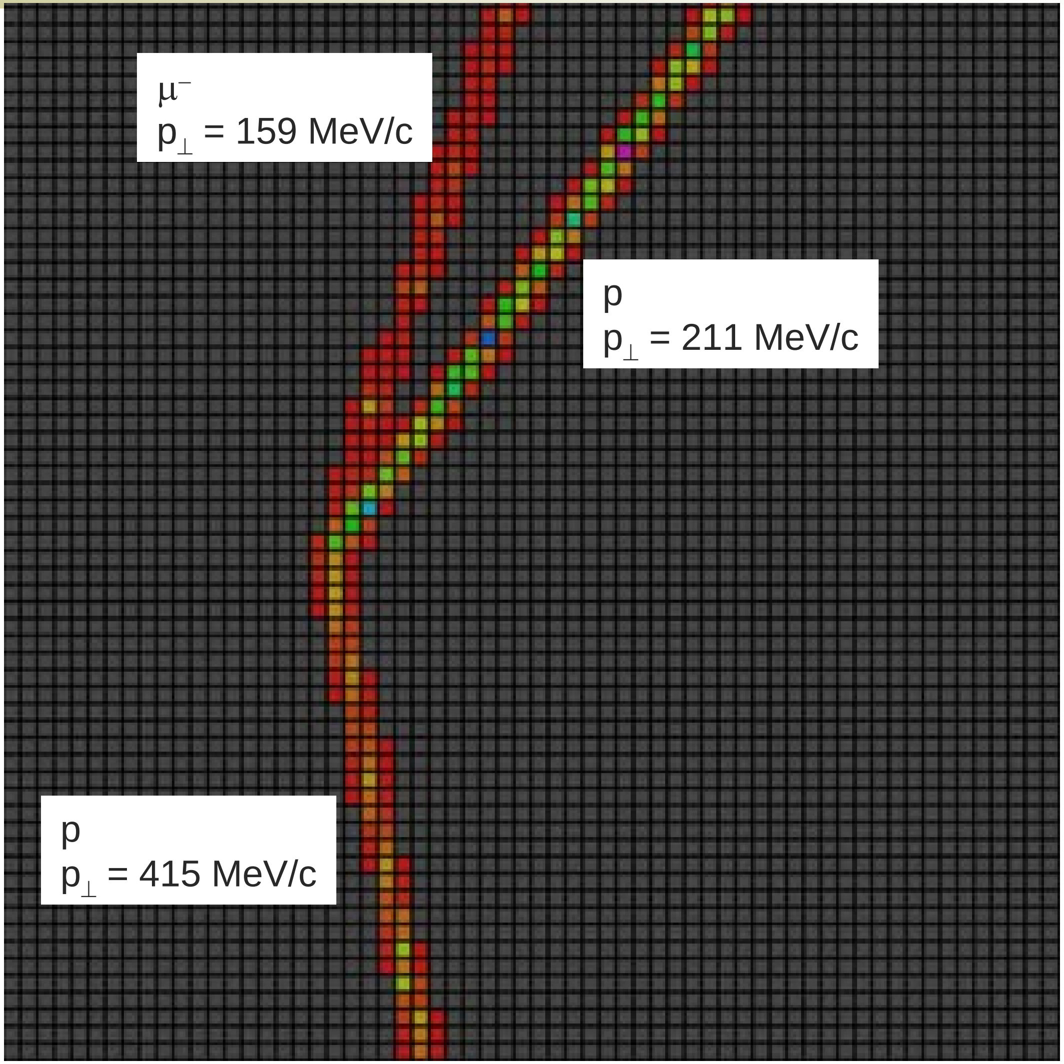
E = 742 MeV



Event 2

ν

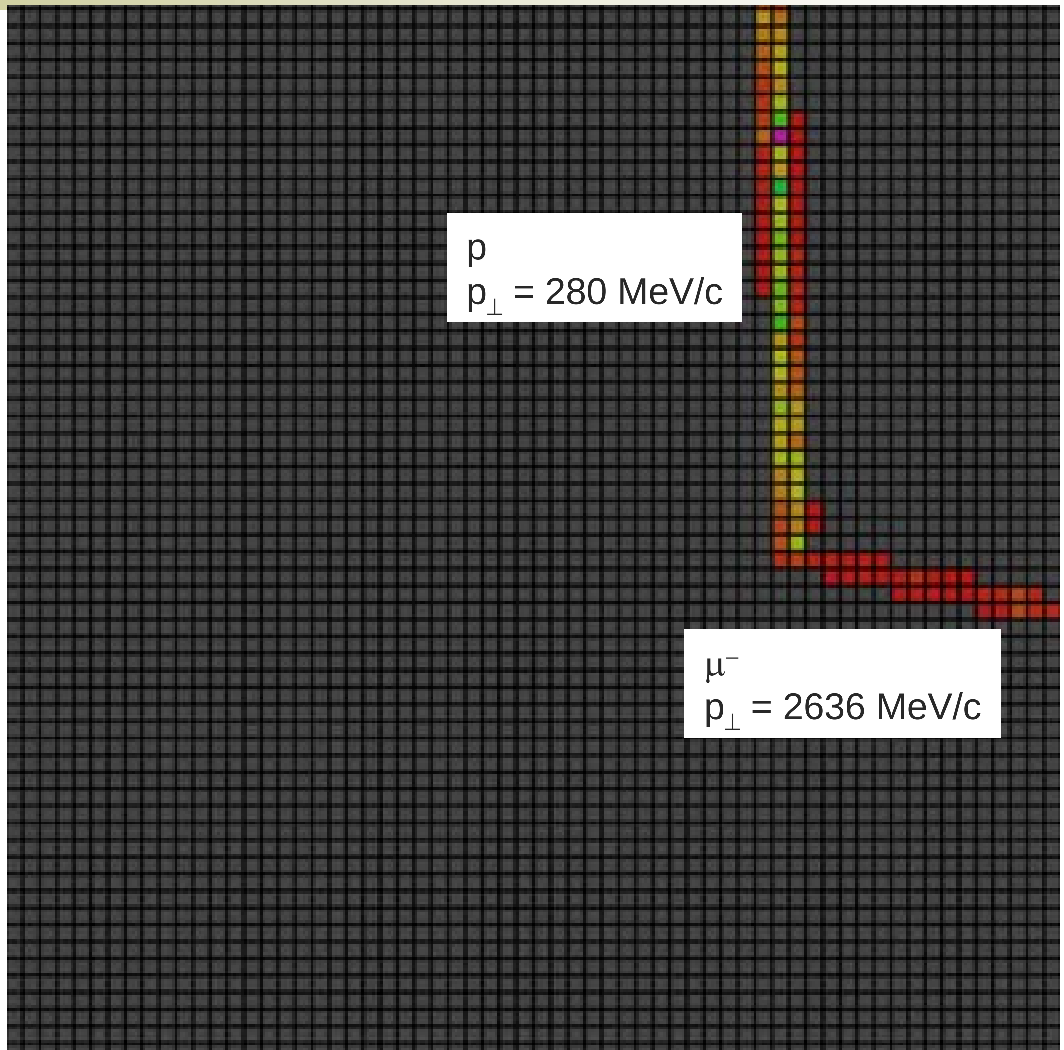
E = 352 MeV



Event 4

ν

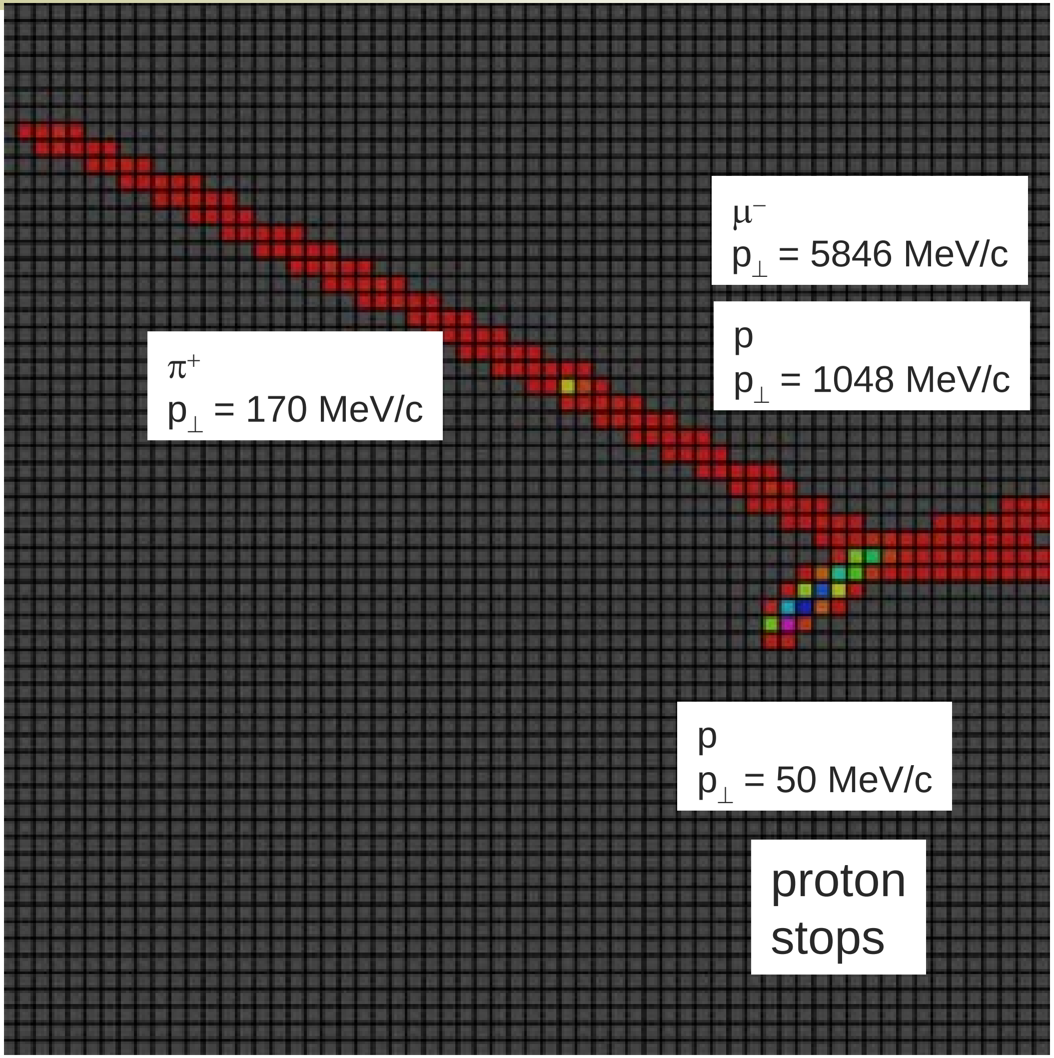
E = 2727 MeV



Event 6

ν

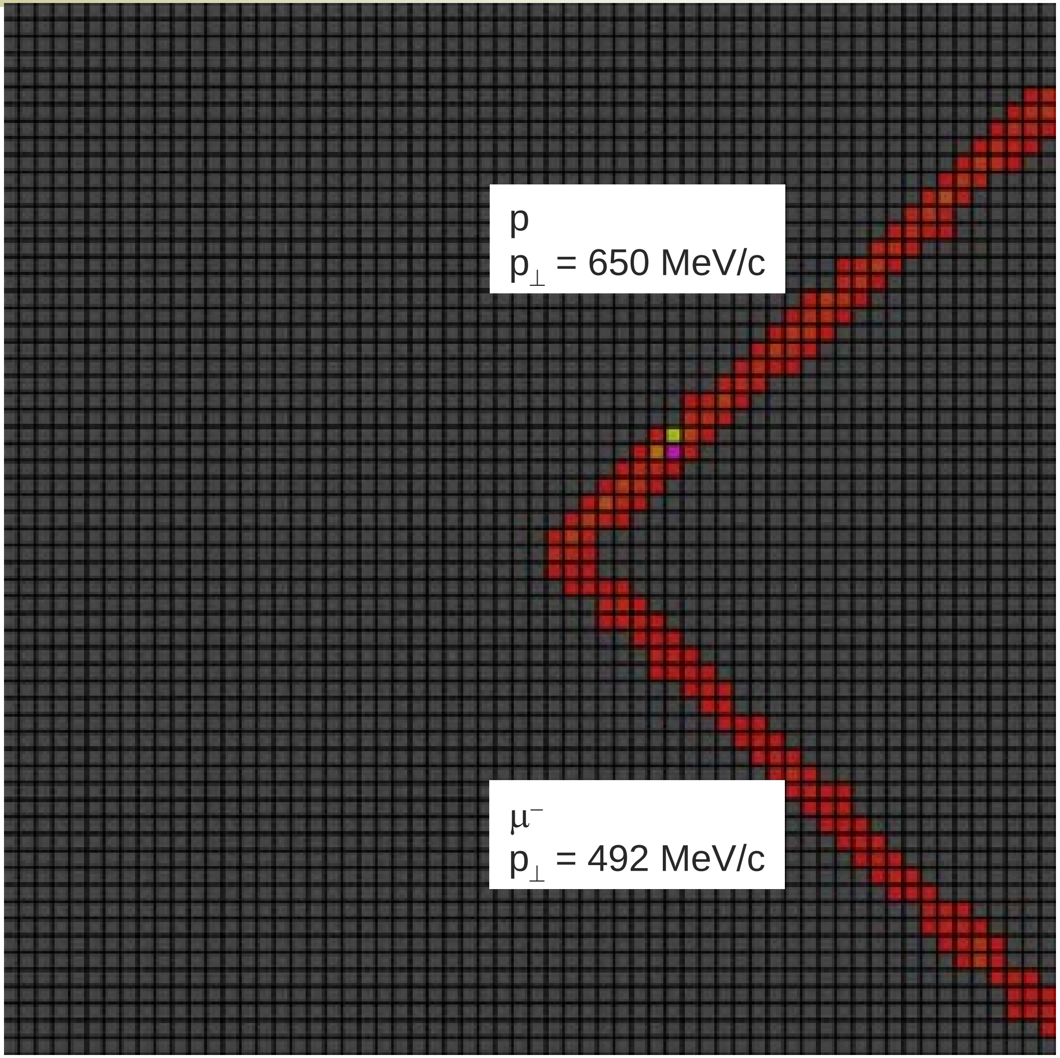
$E = 6572$ MeV



Event 7

ν

E = 722 MeV

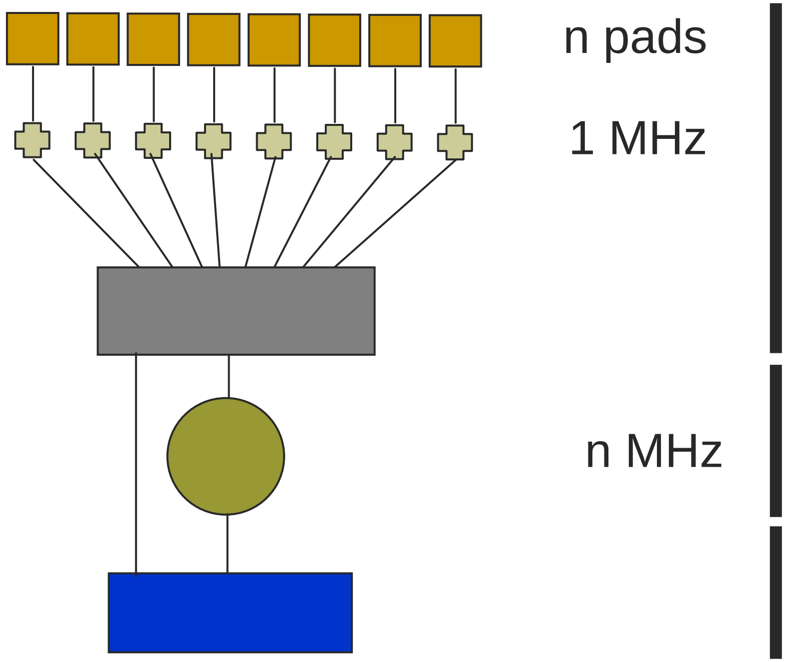


Electronics considerations

- At most 1 million pads (4mm x 4mm) needed to instrument the TPCs (both sides).
  - occupancy is extremely small
    - for a live time frame of 1 ms there are 10^9 voxels
      - very safe against background hits that accumulate in 1ms
    - multiplexing possible
  - slow shaping & sampling times can be used:
    - 1 μs sampling $\rightarrow$ 2 mm resolution in drift direction
    - faster ADCs can be used to sample many pads
    - $2/channel readout possible in ASIC (?)

Multiplexing

- To reduce the number of A/D elements, multiplex in time:



  - Put as much on back of readout pad board as possible
  - Total cost ~ $2 /channel

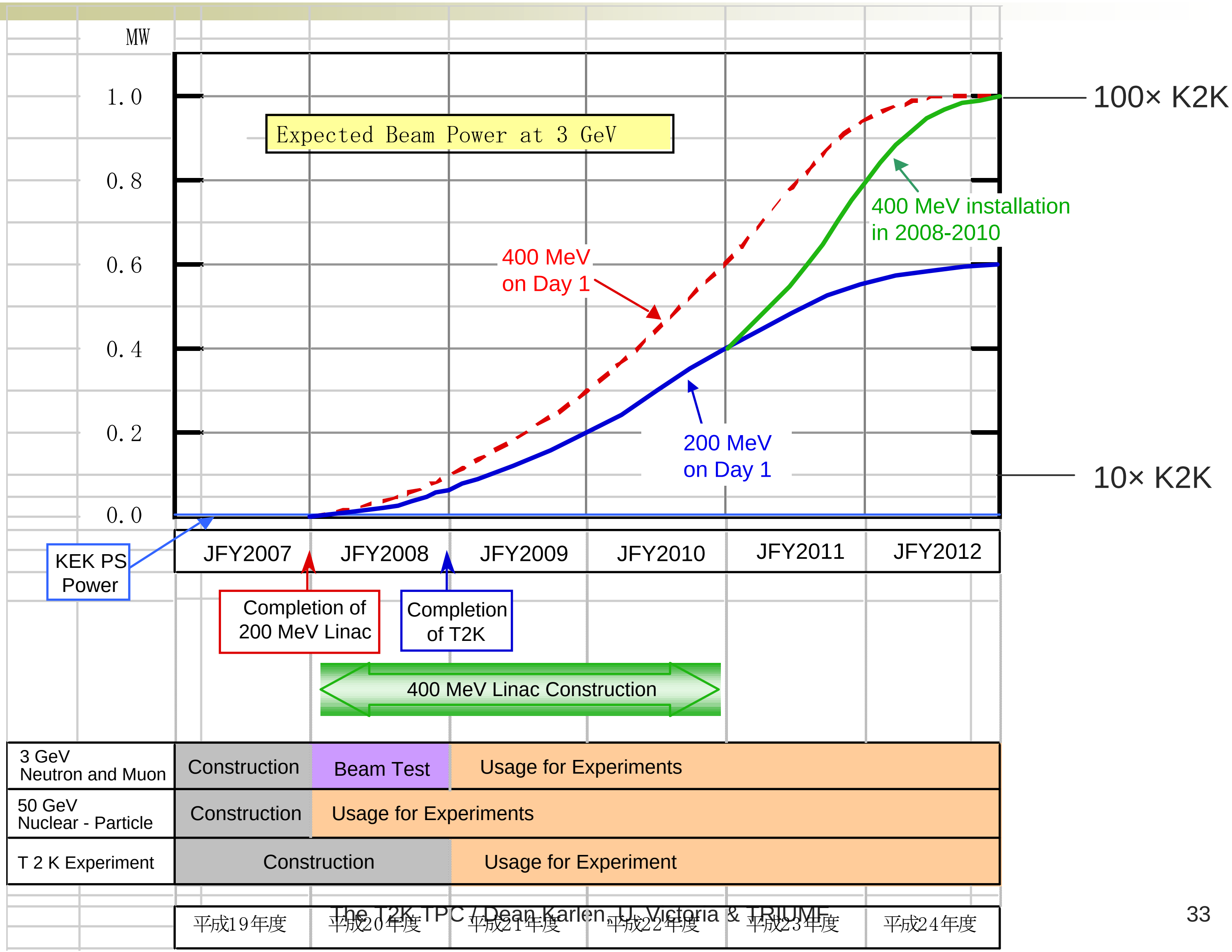
R&D required for proof of concept

- Field cage design
  - needs more thought… simply use wires
- Need to build a long drift prototype
  - 140 cm drift, 30 cm x 30 cm
  - test field cage design, look for attachment
  - use high density, slow electronics
    - discrete components to prove concept for ASIC design
  - demonstrate space point resolution in test beam
- Significant effort and costs…
  - substantial effort needs to begin now

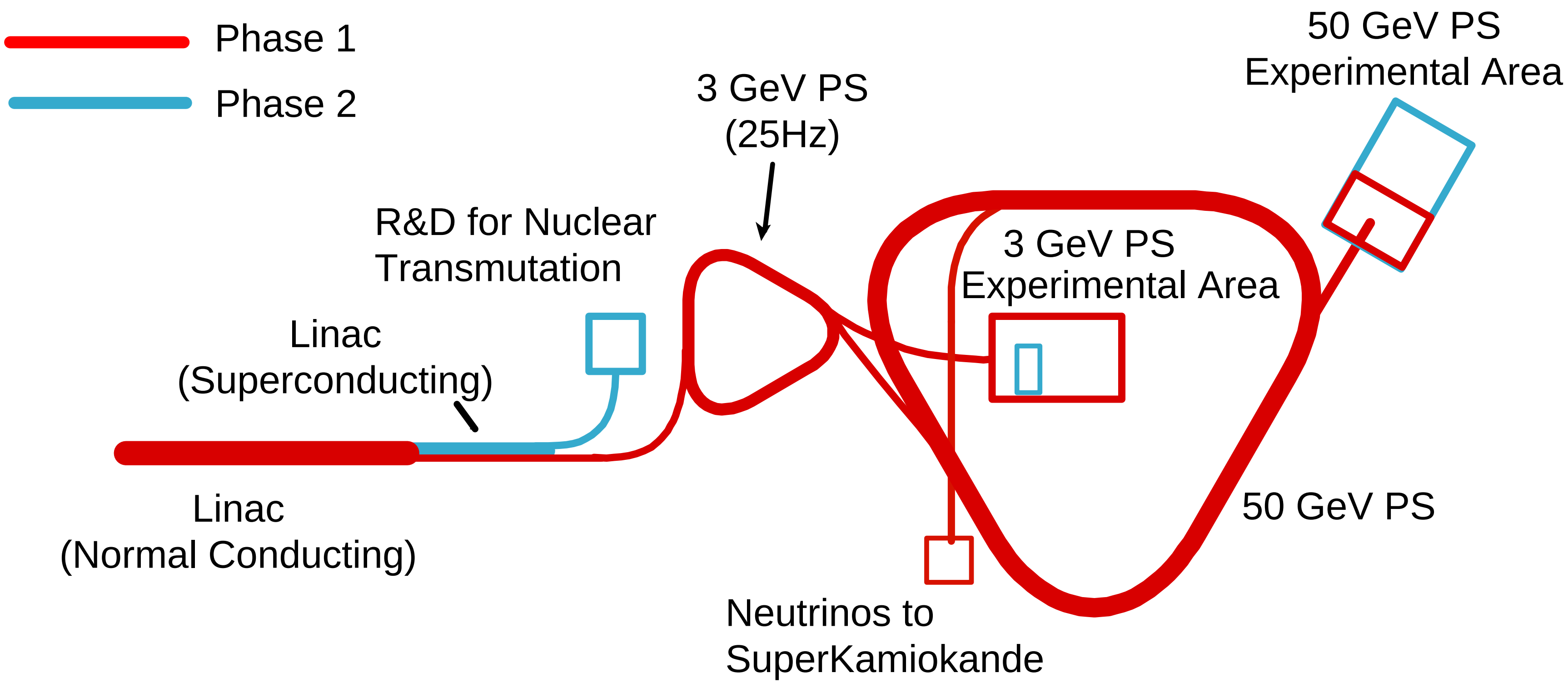
ND TPC as an international project?

- The TPC project can be naturally divided amongst several collaborating institutions:
  - Gas vessel and field cage:
    - Design and construction of vessel, field cage, and central cathode
    - HV and field cage resistor chain
  - GEM amplification
    - Design of GEM frames, mounting of GEMs into frames
    - HV distribution
  - Pad readout boards
    - Pad geometry design, construction of boards
    - ASIC design, fabrication, installation ($$$)

T2K schedule



J-PARC facility construction




Linac area


3 GeV area


50 GeV area


Feb 2004

Near detector organization

- Led by Tsuyoshi Nakaya (Kyoto) with working groups:
  - **Tracking group** (mainly TPC+Magnet+FGD)
    convener: Akira Konaka (TRIUMF, CANADA)
    deputy-convener: Pier Loverre (Rome, Italy)
  - **EM group** (mainly EM cal, side MRD, π^0 detector)
    convener: Kevin McFarland (Rochester, USA)
    deputy-convener: Dave Wark (Imperial, UK)
  - **Neutrino Beam Monitor group** (on-axis det., muon monitor)
    convener: Tsuyoshi NAKAYA (Kyoto, Japan)
  - **Software/Physics simulation group**
    convener: Federico Sanchez (Barcelona, Spain)
    deputy-convener: Clark McGrew (Stony Brook, USA)

Near detector near term goals

- End-November 2004:
  - agree upon near detector baseline design
  - first-order cost estimate
- February 2005:
  - draft “technical design report”

Upcoming meetings

- December 6-8, Rome
  - Near Detector working group meeting
  - Newcomers encouraged to attend
- February 21-23, KEK
  - Near Detector working group meeting
- February 24-26, KEK
  - T2K collaboration meeting

Summary

- The T2K project is an exciting physics opportunity that gets underway before LC construction begins
- The near detector TPC builds on the LC TPC R&D
  - we are well through the R&D phase
  - an excellent large scale "prototype" for the LC TPC
- Much work needs to be done
  - needs to begin right away!
- I encourage you to join this effort!