TPC Report

D. Karlen
T2K ND280m meeting
December 7, 2004
Rome
Outline

- Review of current TPC concept as outlined in the TPC feasibility report (December 6, 2004)
  
  [http://particle.phys.uvic.ca/~karlen/t2k](http://particle.phys.uvic.ca/~karlen/t2k)
  
  - Performance goals
  - Baseline detector design concepts and options
    - gas choice, gas containment and field cage, gas system
    - gas amplification and electronic readout
    - expected performance
  - TPC working group
  - Prototype plans
  - Budget and milestones

- Include results from recent studies (not found in the feasibility report)
Performance goals

- Primary goal for TPC is to accurately measure the muon momenta from CCQE events, in order to reconstruct the neutrino spectrum
  - At the peak neutrino energy, the neutrino energy resolution is limited by 10% due to Fermi motion
    - this sets the scale for muon momentum resolution – it should be better than about 10% at 1 GeV and below.

- Other goals
  - good reconstruction efficiency for more complex final states, and to distinguish extraneous particles
  - good particle identification ($\rho$, $e$, $\pi/\mu$)
  - special target for study of low energy products
Baseline design concepts

Geometry

- ~3 modules, 2.5 x 2.5 x 1 m³ outer dimensions
Gas choice

- Optimal gas parameters for T2K TPC:
  - low diffusion, good primary statistics, low density, low neutron cross section, saturated drift velocity, small Lorentz angle, no attachment losses, good gain, good quenching, high breakdown voltage, non-reactive, non-aging, inflammable, non-toxic, low cost, easy to purify, well proven
  - and, if possible, large component of “gas target” contains the element Oxygen or a nearby element
### Ar CO₂ vs Ne CO₂

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<th>Property (CO₂ &gt; 10%)</th>
<th>Ar</th>
<th>Ne</th>
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<td>good primary statistics</td>
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<td>small Lorentz angle</td>
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<td>no attachment losses (depends on O₂ and CO₂)</td>
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<td>well proven</td>
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<tr>
<td>target elements near Oxygen</td>
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Gas choice

- We do not need to choose Ar vs. Ne now
  - prototype studies can gain experience with both
  - TPC design not strongly influenced by Ar vs. Ne
    - stronger influence is on choice of CO$_2$ concentration
Gas choice

Higher CO$_2$ concentration gives:

- lower diffusion ✓
- slower drift velocity
- more Oxygen target ✓
- higher attachment from O$_2$ contamination ✗
  - CO$_2$ plays a role in stabilizing vibrationally excited ions…
    
    \[ e^- + O_2 \rightarrow O_2^- \]
    \[ O_2^- \rightarrow e^- + O_2 \]
    \[ O_2^- + CO_2 \rightarrow O_2^- + CO_2 \]

- 10% CO$_2$ needs O$_2$ \~~ 10 ppm
- 100% CO$_2$ needs O$_2$ \~~ 0.1 ppm
Gas choice

- Propose that we ensure TPC design works for CO$_2$ at 10-20%, and leave option open for higher concentrations for now
  - Note: gas for COMPASS GEMs: Ar CO$_2$ (70:30)

- Higher CO$_2$ concentration means:
  - need much tighter gas containment
  - preference for higher drift fields
Gas containment and field cage

Drift fields under consideration:
- ~ 200 V/cm for low CO₂ concentration
- 200 – 400 V/cm for intermediate/high CO₂ levels
  - maximum central cathode potential ~ 50 kV

Limited time for design and prototype studies
- borrow from existing design concepts
  - NA49/ALICE, STAR
Gas containment and field cage

A number of options to choose from:

- Field defining strip elements:
  - mylar strips suspended away from walls (ALICE/NA49)
    - no charging between strips (less concern for T2K?)
  - strips on walls (STAR/ALEPH/DELPHI…)
    - easier construction?

- Wall materials:
  - nomex honeycomb with insulating skins
    - low density
  - G10 with ribs
    - smaller gap, higher breakdown voltage
  - other options?
Gas containment and field cage

... choices (cont.)

- Main voltage standoff:
  - solid insulator
    - less total space required (higher breakdown field)
    - mechanical design easier
  - gas envelope
    - safer – less likely to develop a permanent fault (which would render the TPC dead)
    - easier to provide uniform field within drift volume
    - an additional barrier for O₂ contamination
    - provides thermal insulation for drift volume – reducing thermal gradients (non-saturated drift velocities)
New - Field cage and tracking acceptance

- Federico presented results from a detailed study comparing the acceptance for two extremes in field cage design:

![Diagram showing field cage design for ALICE and HARP/NA49]
Relative efficiency for HARP/ALICE:

- **Muons:**
  - ![Graph](image1.png)

- **Protons:**
  - ![Graph](image2.png)

- In general: ALICE about 10-20% lower acceptance
New results: Electrostatic simulations

- Juergen Wendland (UBC postdoc) is using FEMLAB to simulate different field cage designs
  - ALICE/NA49 and STAR-like ideas

- comparisons:
  - field uniformity in the drift volume
  - absence of high field regions in gas (concern for breakdown)

- all results shown for 400 V/cm drift field
  - the maximum drift field under consideration
ALICE and STAR-like simulation

- ALICE Geometry:
  - Inner surface of outer wall at ground
  - 75 mm of CO$_2$ envelope
  - inner wall 30 mm
    - 13 mm strips on each side of inner wall with 270 mm pitch
  - field cage 30 mm from inner wall
    - 15 mm pitch of field cage, 2mm gap

- STAR-like Geometry:
  - Inner surface of outer wall at ground
  - 75 mm of CO$_2$ envelope
  - inner wall 30 mm
    - 13 mm strips on inner side and outer side of inner wall, pitch 15 mm, outer strips offset by one half pitch
Field uniformity: ALICE

uniformity is worse than stated in ALICE TDR (still to be understood). would improve with smaller pitch of electrodes on wall
Field uniformity: STAR-like

uniformity is much better: pitch on walls much smaller than ALICE
High field regions: ALICE

Surface: Electric field, norm  Contour: Electric potential

7 kV/cm

Max: 7.00e5 x10^5  Max: 4.13e4 x10^4

gas envelope

inner wall

mylar strips

central cathode
High field regions: STAR

7 kV/cm

higher field in gas envelope than ALICE
lower fields near surfaces than ALICE
Very high field regions: ALICE

Surface: Electric field, norm

20 kV/cm

Max: 2.00e6
Min: 0
Very high field regions: STAR-like

no regions of very high field

20 kV/cm
ALICE and STAR-like comparison

- The STAR-like design has better uniformity and safer high field regions
- Actual STAR design would probably improve performance even further:
  - double sided strips:
    - complicates FEA simulation: new distance scale:
      - 50 µm kapton gap
No gas-envelope study

- Use STAR double sided strips on inside of wall, outside of wall grounded
  - cannot simulate entire TPC, due to memory limitations
  - early stage of study – needs more checks
Field uniformity: No gas envelope

Field is much less uniform
Very high field regions: No gas envelope

Surface: Electric field, norm

20 kV/cm

Max: 2.00e6 x 10^6

Min: 0
Gas containment and field cage

- Appears that field strips on wall can provide good field uniformity without high field regions
  - is charge-up between strips a concern for the T2K environment?
- Gas envelope improves field uniformity in drift volume
  - “wasted” space appears without it anyway
- Propose to focus on a design with a gas envelope and with field defining strips on walls
Gas system

- A recirculation system will be necessary to maintain O₂ levels below 10 ppm or lower
  - typically 20% of volume to flow per hour
  - typically 1% fresh gas introduced
  - since detector is well below surface, pumps may be necessary to ensure good flow rate

- Ar and CO₂ are denser than air – the asphyxiation risk needs to be considered in the design of the experimental hall

- Gas services need to be provided on surface – gas lines to the detector area
Gas amplification

- Existing large TPCs have used wire arrays to provide gas gain at the endplates
  - requires significant tension, wires can break
- Extensive R&D effort in past several years on micropattern gas detectors for TPC readout
  - gas electron multipliers and micromegas devices
  - give significant improvement to TPC performance
  - commercial providers for large area devices coming on line
- Given benefits and expertise of group – propose to use MPGD readout
Gas Amplification

- Propose to leave option open between GEM and micromegas for now – has limited impact on detector mechanical design
  - decide sometime in 2005 on basis of:
    - experience of groups with large scale prototypes
    - cost and supply of devices
    - simplicity in readout module design
    - demonstrated performance
    - robustness
    - flexibility on gas choice
    - impact on electronics design
Gas amplification

Following COMPASS design of 30 x 30 cm$^2$ GEM foils, TPC could take a form as:
Pad readout system

- Pads located after MPGD amplification collect the electrons – pattern of charge sharing and time of arrival is used to reconstruct the particle momentum

- Number and size of pads determine electronics requirements – a full simulation of pad geometries is underway
New - Pad geometry study

- From experience with GEM-TPC prototype studies for ILC, 2 mm wide pads can achieve space point resolution of 100 μm for a 7 mm sample in a low diffusion gas
Pad geometry study

For T2K TPC

- higher diffusion gas
- 300 – 400 mm space point resolution sufficient to achieve performance goals
- no preferred direction

- as a result – first suggestion was to have square pads, 4 mm on a side populate entire TPC active area
Pad geometry study

To characterize the performance of the TPC for different pad geometries:

- GEANT simulation of muon propagation and energy loss in a 60 cm wide gas volume in 0.2 T field
  - energy losses in 1 mm segments are saved to flat files
- Specialized GEM-TPC simulation program:
  - energy losses converted to electron/ion pairs
  - electrons drift, diffuse, pass through GEM holes, are amplified, diffuse, get collected on pads, pad signals generated, digitized, and signals stored in data files
- GEM-TPC data analysis program:
  - read data files, signals converted to charge estimates
  - likelihood track fit performed to estimate track parameters
  - momentum resolution determined
Comparison of prototype and simulation

- agreement is reasonably good

- **B = 0, Dt = 700 μm/√cm**

- **B = 0.9 T, Dt = 170 μm/√cm**

- **B = 1.5 T, Dt = 110 μm/√cm**

- Projection for 1250 mm target = 0.3 mm
Pad geometry study

- Two muon samples
  - low momentum: from Neut CCQE interactions at edge of 60 cm wide drift volume
  - high momentum: 8 GeV generated +/- 10° to ν beam direction
  - interaction points at drift distances of 10, 60, 120 cm
  - gas diffusion of 180 and 300 μm/√cm
  - electron statistics ~ 90 e/cm (Ar,CO₂) : (Ne 45 e/cm)
  - radiation length: 180 m (CO₂) : (Ar 110 m, Ne 350 m)

- Several pad geometries
  - 4 mm x 4 mm, 8 mm x 8 mm, 2 mm x 8 mm, mixtures of pad designs, sparse readout designs
4 mm x 4 mm pads – event #3

muon $p_t = 0.367$ GeV
recon $p_t = 0.368$ GeV

$D = 180 \, \mu m/\sqrt{cm}$
4mm x 4mm: CCQE events at 60 cm

\[ \sigma_{pt} / pt \text{ vs } pt \]

\[ \Delta pt / pt \text{ vs } \phi \text{ pt } < 0.8 \text{ GeV/c} \]

December 7, 2004
Resolution vs. pad size

- for 4x4 mm$^2$ pads, $p$ resolution is about 3-4%
  - dominated by multiple scattering: independent of $p_t$

- consider using much larger pads: 8mm x 8mm:
8mm x 8mm : CCQE events at 60 cm

True pt

pt (GeV/c)

σ_{pt} / pt vs pt

σ_{pt} / pt vs φ
pt < 0.8 GeV/c
Resolution vs. diffusion

- Even with 8 mm x 8 mm pads, 5-6% resolution for $D = 180 \, \mu m/\sqrt{cm}$

- Consider effect of larger diffusion
  - $D = 180 \, \mu m/\sqrt{cm} \rightarrow D = 300 \, \mu m/\sqrt{cm}$
4x4 mm$^2$: CCQE at 60 cm, $D = 300 \mu$m/$\sqrt{\text{cm}}$
8x8 mm$^2$: CCQE at 60 cm, D = 300 μm/\sqrt{cm}$

True pt:

pt (GeV/c)

$\sigma_{pt}/pt$ vs pt

$\Delta pt/pt$

$\sigma_{pt}/pt$ vs $\phi$
ppt < 0.8 GeV/c
Resolution for high energy muons

➤ Test of point resolutions…
  • any strong physics reason to have good resolution for high momentum particles?
8 GeV/c muons at 60 cm, D = 180 μm/√cm

\[ \Delta pt / pt \]

\[ 4x4 \text{ mm}^2 \]

\[ 0/200 \text{ wrong charge} \]

\[ \sigma_{pt} / pt \text{ vs } \phi \]

\[ 4x4 \text{ mm}^2 \]

\[ a : 30.472 \]
\[ \text{mean} : -0.079779 \]
\[ \text{sigma} : 0.237688 \]

\[ 8/200 \text{ wrong charge} \]

\[ 8x8 \text{ mm}^2 \]

\[ \sigma_{pt} / pt \text{ vs } \phi \]

\[ 8x8 \text{ mm}^2 \]

\[ a : 19.548 \]
\[ \text{mean} : -0.088903 \]
\[ \text{sigma} : 0.32579 \]
Expected resolutions

- Assuming 300 µm point resolution, the standard formulas reproduce full simulation reasonably well.

150 points
4x4 pads

75 points
8x8 pads
Other pad ideas (CCQE 60 cm, D=180)

- 2 x 8 mm²
- 4 x 4 mm² separated by 32 mm
- 1 x 6, 5 x 6 mm²
- mix separated by 28 mm

\[
\sigma_{pt} / pt = 0.045
\]
\[
\sigma_{pt} / pt = 0.070
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\[
\sigma_{pt} / pt = 0.037
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\[
\sigma_{pt} / pt = 0.062
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Pad geometry: general observations

- Square pads give better resolution
  - $4 \times 4 \text{ mm}^2 \rightarrow \sigma_{pt} / pt = 0.032$
  - $8 \times 8 \text{ mm}^2 \rightarrow \sigma_{pt} / pt = 0.052$
- Populate entire area with pads
- Resolution better than requirements
  - may be possible to reduce magnetic field?
    - if so - advantageous to use Ne over Ar?
- Continue this study to define electronics requirements
  - channel count, noise, dynamic range...
Readout electronics

- It appears that 8 mm x 8 mm pads will give sufficient information to determine momentum to desired accuracy
  - about 75K channels per TPC module
  - power and costs can be reduced by going to an ASIC front end
    - for relatively slow gases, 1 µs sampling may be sufficient – further reducing power and complexity of readout
  - given limited cable space, it would be best to do digitization / zero-suppression on detector
- Frédéric Druillole (SACLAY) presented initial ideas for design – faster readout, with SCA, <1 mm²/channel, ~10 mW/channel: ~1kW/TPC module
# TPC working group interests

- Open to additional groups...

<table>
<thead>
<tr>
<th></th>
<th>Mechanical design</th>
<th>Gas system</th>
<th>Gas studies</th>
<th>Gas containment</th>
<th>Field cage</th>
<th>Gas amplification</th>
<th>High voltage</th>
<th>Readout electronics</th>
<th>Simulation</th>
<th>Test beam studies</th>
<th>Reconstruction software</th>
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TPC prototype efforts

- Canadian group making plans for prototype gas containment and field cage
  - start with small container for gas issues only
  - then move to 125 cm drift, 60 cm x 30 cm
  - test field cage design, look for attachment
  - use high density, slow electronics
    - discrete components to prove multiplex concept for ASIC design
  - demonstrate space point resolution in test beam
TPC prototype efforts

- The University of Geneva and INFN groups are acquiring 2000 channels of ALICE readout
  - test GEM readout pad boards on HARP field cage
- SACLAY to build micromegas readout modules for HARP and/or Canadian prototype TPCs
- SACLAY also requesting funds for ASIC prototyping
Budget estimates

- TPC is not well enough defined to do a detailed costing. Some of the larger expenditures are indicated below:
  - Field cage
    - scale down by surface area from ALICE - $350K/module
    - very conservative estimate – expect it to be lower than this
  - Gas amplification
    - quote from CERN for GEMs: $60K per TPC/module, assuming triple GEM readout
  - Electronics
    - could be largest single item – roughly $1-2M expected (US costing), $0.2-0.3M (French costing)
Project milestones

- **October/November 2004:**
  - Submit grant request to Canadian funding agency for prototype studies.
  - Begin design of prototype electronics based on discrete components

- **January 2005:**
  - Complete designs of prototype module and electronic readout based on discrete components
  - Begin construction of Canadian TPC prototype modules

- **April 2005:**
  - Order all items for Canadian prototype.
  - Begin ASIC design work.

- **September 2005:**
  - Complete draft design of all TPC components – gas vessel and gas system, field cage, amplification region. Submission of construction grant request to Canadian funding agency.
Project milestones

- **Fall 2005:**
  - Complete construction of long drift prototype and prototype readout electronics.
  - Begin tests of prototype with cosmics and TRIUMF test beams.

- **April 2006:**
  - Complete design of all TPC components.
  - Begin construction of full-scale TPCs.

- **Fall 2008:**
  - Complete construction, delivery to Japan.

- **January 2009:**
  - Begin installation and integration with Near Detector
Summary

- Good progress being made on many of the basic design parameters for the TPC
  - The field cage simulation is progressing – a solution using field strips on wall and a gas envelope appears to work well
  - The pad density requirements appear to be lower than the original guess – easier electronics
  - A conservative operating point with low CO$_2$ concentration (10%) has been demonstrated by earlier TPCs – and will meet p resolution goal

- TPC feasible? Yes