A High Resolution Neutrino Experiment in a B-Field for Project-X

S.R. Mishra, R. Petti, C. Rosenfeld

University of South Carolina, USA

10th International Workshop on Neutrino Factories, Super beams and Beta beams
Valencia, July 3, 2008
PHYSICS GOALS

- Determination of the relative abundance, the energy spectrum, and the detailed topology (complete hadronic multiplicity) of the four neutrino species in NuMI: $\nu_\mu$, $\bar{\nu}_\mu$, $\nu_e$, and $\bar{\nu}_e$ CC-interactions.

- An ‘Event-Generator Measurement’ for the LBL$\nu$ experiments including single and coherent $\pi^0$ ($\pi^+$) production, $\pi^\pm/K^\pm/p$ for the $\nu_e$-appearance experiment, and a quantitative determination of the neutrino-energy scale.

- Measurement of the weak-mixing angle, $\sin^2 \theta_W$, with a precision of about 0.2%, using independent measurements:
  - $\nu(\bar{\nu})$-q (DIS);
  - $\nu(\bar{\nu})$-$e^-$ (NC);
  - NC elastic scattering on proton.
  Direct probe of the running of $\sin^2 \theta_W$ within a single experiment.

- Precise determination of the exclusive processes such as $\nu$ quasi-elastic, resonance, $K^0/\Lambda/D$ production, and of the nucleon structure functions.

- Search for weakly interacting massive particles with electronic, muonic, and hadronic decay modes with unprecedented sensitivity.
MASSIVE CALO (NuTeV)

PRECISE TRACKER (NOMAD)

HiResMv: order of magnitude higher segmentation

Missing transverse momentum
PROPOSED DETECTOR

Fiducial Mass
\[\sim 7.4 \text{ tons}\]

- Build upon the NOMAD experience:
  - Simple inner detector combining high resolution tracking & particle identification;
  - Low density design with target embedded.

- Side coverage of EM calorimeter needed for \(\pi^0\) detection

\[\Rightarrow \text{Will describe the STT detector in the following}\]
THE STRAW TUBE TRACKER

✦ Build upon NOMAD experience

✦ The ATLAS TRT technology allows to improve upon limitations of the NOMAD design while keeping all the advantages of a low density - $\rho = 0.1 g/cm^3$ - detector:

- Small cylindrical drift tubes insensitive to track angles;
- More sampling points along the track ($\times 6 \perp$ beam axis and $\times 2$ along the beam axis) $\implies$ efficient proton reconstruction down to 250 MeV/c
- $dE/dx$ and Transition Radiation (TR) for particle identification $\implies$ proton and electron identification with little background

✦ Mass of the active target is completely dominated by the radiators (85% of total mass) and can be tuned to achieve desired events & momentum resolution

✦ Basic design for the proposed detector after COMPASS

- Operate with Xe/CO$_2$ gas mixture;
- As baseline calculate radiator thickness in order to give same density as in NOMAD ($1X_0 = 5 m$);
- Arrange radiators and straws in "modules".
**EXPECTED STATISTICS**

- Expect $30 \times 10^{20}$ protons/year on target assuming $365/\pi$ days/year

- 3(4) years $\nu(\bar{\nu})$ run in tandem with the Long Baseline neutrino oscillation experiments (LBL$\nu$)

$\Rightarrow$ No need for a dedicated beam

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Events</th>
<th>Cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive $\nu_\mu$-CC</td>
<td>$140 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>$\nu_\mu$-QE</td>
<td>$12 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>Inclusive $\nu_\mu$-NC</td>
<td>$19 \times 10^6$</td>
<td>FV &amp; $E_{H_{\text{had}}} \geq 3$ GeV</td>
</tr>
<tr>
<td>Coherent-$\pi^0$</td>
<td>$0.7 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>Coherent-$\pi^+$</td>
<td>$1.4 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>IMD</td>
<td>$15 \times 10^3$</td>
<td>FV &amp; $E_\nu \geq 11$ GeV</td>
</tr>
<tr>
<td>$\nu_\mu$-$e$ NC</td>
<td>$31 \times 10^3$</td>
<td>FV &amp; $E_e \geq 0.1$ GeV</td>
</tr>
<tr>
<td>$\nu_e$-CC</td>
<td>$2 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>$\bar{\nu}_e$-CC</td>
<td>$0.3 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$-CC</td>
<td>$3.5 \times 10^6$</td>
<td>FV</td>
</tr>
</tbody>
</table>

**Table 1: Expected Events in a 3-Year $\nu$-Run.**

<table>
<thead>
<tr>
<th>Interaction</th>
<th>Events</th>
<th>Cuts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inclusive $\bar{\nu}_\mu$-CC</td>
<td>$50 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$-NC</td>
<td>$4 \times 10^6$</td>
<td>FV &amp; $E_{H_{\text{had}}} \geq 3$ GeV</td>
</tr>
<tr>
<td>Coherent-$\pi^0$</td>
<td>$0.4 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>Coherent-$\pi^+$</td>
<td>$0.8 \times 10^6$</td>
<td>FV</td>
</tr>
<tr>
<td>$\bar{\nu}_\mu$-$e$ NC</td>
<td>$17 \times 10^3$</td>
<td>FV &amp; $E_e \geq 0.1$ GeV</td>
</tr>
</tbody>
</table>

**Table 2: Expected Events in a 4-Year $\bar{\nu}$-Run.**
Neutrino radiography of one drift chamber

Reconstructed $K^0$ mass

- **NOMAD:** charged track momentum scale known to < 0.2%
  - hardonic energy scale known to < 0.5%
- **HiRes$\nu$:** $200 \times$ more statistics and $12 \times$ higher segmentation
**EXPECTED PERFORMANCE**

- **Space point resolution** better than 200 µm (in ATLAS 130 µm).

- **Momentum resolution** for $\rho = 0.1 g/cm^3$ and $B = 0.4T$:
  - Multiple scattering contribution $0.05$ for $L = 1m$ ($B = 0.4T$, default radiator)
  - Measurement error ($B = 0.4T$)
    \[
    \frac{\sigma(p)}{p} = \frac{\sigma(x)p}{0.3BL^2} \sqrt{\frac{720}{N + 4}}
    \]
    which gives $0.006$ for $L = 1m$ and $p = 1$ GeV/c ($N = 50$ if along beam direction)

- **Full reconstruction of charged particles and γ’s**

- **Identify e,π,K,p from dE/dx.** Use Transition Radiation for electron identification with Xe filling. Full reconstruction and ID of protons down to 250 MeV/c.

- **Reconstruction of electrons down to 80 MeV from curvature in magnetic field ($B = 0.4T$)**
✧ **Reconstruction of** $\pi^0$:

- 50% of $\pi^0$ with at least one converted $\gamma$;
- 25% of $\pi^0$ with both photons converted.

⇒ Use events with at least one converted $\gamma$ to reconstruct the pointing direction

✧ **Electromagnetic calorimeter surrounding the STT:**

- Compact 15-20 $X_0$ in 50 cm;
- Fine grained longitudinal segmentation ($\gamma$ direction);
- Transverse segmentation not so critical for $\pi^0$ reconstruction if we require one converted $\gamma$;
- Energy resolution about $10%/\sqrt{E}$;

⇒ Sampling calorimeter with Pb as absorber

✧ **The Muon Range Detector (MRD), outside of the magnetic field, provides a coverage of forward and side regions.** Resistive Plate Chambers (RPC) for muon detection.
**MEASUREMENT OF $\sin^2 \theta_W$ FROM $\nu N$ DIS**

- *Ratio of NC and CC in both $\nu$-N and $\bar{\nu}$-N Deep Inelastic Scattering.* Paschos-Wolfenstein relation allows a reduction of systematic uncertainties:

$$R^- \overset{\text{def}}{=} \frac{\sigma^\nu_{NC} - \sigma^\nu_{NC}}{\sigma^\nu_{CC} - \sigma^\nu_{CC}}$$

**Large statistics available in HiResM$\nu$:**
- $19 \times 10^6$ NC events with $E_{\text{had}} > 3.0$ GeV in $\nu$ mode;
- $6 \times 10^6$ NC events with $E_{\text{had}} > 3.0$ GeV in $\bar{\nu}$ mode.

- *Expected total uncertainty $\sim 0.2\%$. Model systematics constrained by dedicated measurements:*
  - Charm production from both dileptons ($\sim 200k \, \mu\mu$) and exclusive charmed hadrons ($6 \times 10^6$ charm events);
  - Structure function measurement and QCD analysis of HiResM$\nu$ data (PDFs, High Twists, etc.)

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>$\delta s^2_W/s^2_W$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statistics</td>
<td>0.0008</td>
</tr>
<tr>
<td>Experimental systematics</td>
<td>0.0010</td>
</tr>
<tr>
<td>Model systematics</td>
<td>0.0014</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>0.0019</strong></td>
</tr>
</tbody>
</table>
Relative uncertainties for *NuTeV analysis* (published) and expectations for *HiResM*:

<table>
<thead>
<tr>
<th>Source of uncertainty</th>
<th>$\delta X/X$</th>
<th>$\delta R^\nu/R^\nu$</th>
<th>$\delta R^\bar{\nu}/R^\bar{\nu}$</th>
<th>$\delta X/X$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data statistics</strong></td>
<td>0.00593</td>
<td>0.00176</td>
<td>0.00393</td>
<td></td>
</tr>
<tr>
<td><strong>Monte Carlo statistics</strong></td>
<td>0.00044</td>
<td>0.00015</td>
<td>0.00025</td>
<td></td>
</tr>
<tr>
<td><strong>Total Statistics</strong></td>
<td><strong>0.00593</strong></td>
<td><strong>0.00176</strong></td>
<td><strong>0.00393</strong></td>
<td><strong>0.0008</strong></td>
</tr>
<tr>
<td>$\nu_e, \bar{\nu}_e$ flux ($\sim 1.7%$)</td>
<td>0.00171</td>
<td>0.00064</td>
<td>0.00109</td>
<td>0.0001</td>
</tr>
<tr>
<td>Energy measurement</td>
<td>0.00079</td>
<td>0.00038</td>
<td>0.00059</td>
<td>0.0004</td>
</tr>
<tr>
<td>Shower length model</td>
<td>0.00119</td>
<td>0.00054</td>
<td>0.00049</td>
<td>n.a.</td>
</tr>
<tr>
<td>Counter efficiency, noise</td>
<td>0.00101</td>
<td>0.00036</td>
<td>0.00015</td>
<td>n.a.</td>
</tr>
<tr>
<td>Interaction vertex</td>
<td>0.00132</td>
<td>0.00056</td>
<td>0.00042</td>
<td>n.a.</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td></td>
<td></td>
<td></td>
<td>0.0008</td>
</tr>
<tr>
<td><strong>Experimental systematics</strong></td>
<td><strong>0.00277</strong></td>
<td><strong>0.00112</strong></td>
<td><strong>0.00141</strong></td>
<td><strong>0.0010</strong></td>
</tr>
<tr>
<td>$d,s\rightarrow c, s$-sea</td>
<td>0.00206</td>
<td>0.00227</td>
<td>0.00454</td>
<td>0.0011</td>
</tr>
<tr>
<td>Charm sea</td>
<td>0.00044</td>
<td>0.00013</td>
<td>0.00010</td>
<td>n.a.</td>
</tr>
<tr>
<td>$r = \sigma^\nu/\sigma^\nu$</td>
<td>0.00097</td>
<td>0.00018</td>
<td>0.00064</td>
<td>0.0005</td>
</tr>
<tr>
<td>Radiative corrections</td>
<td>0.00048</td>
<td>0.00013</td>
<td>0.00015</td>
<td>0.0001</td>
</tr>
<tr>
<td>Non-isoscalar target</td>
<td>0.00022</td>
<td>0.00010</td>
<td>0.00010</td>
<td>N.A.</td>
</tr>
<tr>
<td>Higher twists</td>
<td>0.00061</td>
<td>0.00031</td>
<td>0.00032</td>
<td>0.0003</td>
</tr>
<tr>
<td>$R_L$</td>
<td><strong>0.00141</strong></td>
<td><strong>0.00115</strong></td>
<td><strong>0.00249</strong></td>
<td><em>(F_2,F_T,x_F_3)</em> 0.0005</td>
</tr>
<tr>
<td><strong>Model systematics</strong></td>
<td><strong>0.00281</strong></td>
<td><strong>0.00258</strong></td>
<td><strong>0.00523</strong></td>
<td><strong>0.0014</strong></td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>0.00711</strong></td>
<td><strong>0.00332</strong></td>
<td><strong>0.00672</strong></td>
<td><strong>0.0019</strong></td>
</tr>
</tbody>
</table>
**MEASUREMENT OF** $\sin^2 \theta_W$ **FROM** $\nu$-$e$  

- **Ratio** of $\nu e \rightarrow \nu e$ and $\bar{\nu} e \rightarrow \bar{\nu} e$ *NC elastic scattering*, which is free from hadronic uncertainties:
  
  \[
  R_{\nu e} \overset{\text{def}}{=} \frac{\sigma(\bar{\nu} - e^-)}{\sigma(\nu - e^-)}
  \]

  Statistics available in HiResM$\nu$:
  - $31 \times 10^3$ *NC events in* $\nu$ *mode*;
  - $17 \times 10^3$ *NC events in* $\bar{\nu}$ *mode*.

- **Expected total uncertainty** $\sim 0.56\%$ *dominated by statistics*. **Systematic uncertainties** reduced by $\nu/\bar{\nu}$ ratio and detector design:
  - High resolution $e$ tracking and charge measurement avoid background extrapolation (*CHARM II*);
  - Electron energy measurement cancel in the ratio;
  - Absolute fluxes determined by inverse muon decay at high energy. Relative fluxes from low-$\nu^0$ method in conjunction with MIPP hadroproduction data.
RELEVANCE OF THE $\sin^2 \theta_W$ MEASUREMENT

✦ Sensitivity expected from $\nu$ scattering in HiResM\nu comparable to the Collider precision:
  - **FIRST** single experiment to directly check the running of $\sin^2 \theta_W$:
    - elastic $\nu$-$e$ scattering and $\nu$N DIS have different scales
  - **different scale** of momentum transfer with respect to LEP/SLD (off $Z^0$ pole)
  - direct measurement of neutrino couplings to $Z^0$
    ➞ Only other measurement LEP $\Gamma_{\nu\nu}$

✦ NuTeV measured $\sin^2 \theta_W$ by comparing NC and CC rates for BOTH $\nu$ and $\bar{\nu}$:

$$R^\nu = \frac{\sigma_{\nu NC}}{\sigma_{\nu CC}}$$

$$R^{\bar{\nu}} = \frac{\sigma_{\bar{\nu} NC}}{\sigma_{\bar{\nu} CC}}$$

⇒ A discrepancy of $3\sigma$ with respect to SM in the NEUTRINO data
**ADDITIONAL CHANNELS**

- Ratio of **NC elastic scattering neutrino-nucleus to CC quasi-elastic scattering for both \( \nu \) and \( \bar{\nu} \) \((\sin^2 \theta_W)\):

  \[
  R_{\nu} = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu^- p)}; \quad R_{\bar{\nu}} = \frac{\sigma(\bar{\nu} p \rightarrow \bar{\nu} p)}{\sigma(\bar{\nu} p \rightarrow \mu^+ n)}
  \]

  Excellent proton reconstruction and ID in HiResM\(\nu\):
  - Expect \(\sim 1.5 \times 10^6 \ \nu \) NC and \(\sim 800k \ \bar{\nu} \) NC events;
  - Significant reduction of systematics from NC/CC ratios.

- Extract value of axial mass \(M_A\) from the CC sample:
  - Intermediate \(Q\) scale between \(\nu N\) DIS and \(\nu-e\) scattering;
  - Systematics to check:
    - nuclear effects, form factors \((Q^2\) dependence), neutrons

- Additional constraints to electroweak parameters could be provided by the study of coherent-like NC processes. The statistical precision on NC coherent \(\pi^0\) production expected in HiResM\(\nu\) is \(\sim 0.2\%\).
PHYSICS POTENTIAL

✦ About NuMI and Service to LBL
1: The energy scale and relative flux of $\nu_\mu$ Flux in NuMI
2: The $\bar{\nu}_\mu$ relative to $\nu_\mu$ as a function of $E_{\nu}$ in NuMI
3: Relative abundance of $\nu_e$ and $\bar{\nu}_e$ -vs- $\nu_\mu$ and $\bar{\nu}_\mu$ in NuMI
4: An empirical parametrization of $K^0_L$ yield in NuMI using the $\nu_\mu$ data
5: Redundancy check on the MIPP $\pi^+, K^+, \pi^-, K^-$, and $K^0_L$ yields in NuMI using the $\nu_\mu$, $\bar{\nu}_\mu$, $\nu_e$, and $\bar{\nu}_e$ induced charged current interactions

✦ Neutral-Pion Production in $\nu$-Interactions
6: Coherent and single $\pi^0$ production in $\nu$-induced neutral current interactions
7: Multiplicity and energy distribution $\pi^0$ production in neutral current and charged current processes as a function of hadronic energy
8: The cross section of $\pi^0$ production as a function of $X_F$ and $P_T$ in the $\nu$-CC interactions

✦ Charged-Pion, Kaon and Proton Production in $\nu$-Interactions
9: Coherent and single $\pi^\pm$ production in $\nu$-induced charged current interactions
10: Charged $\pi/K/p$ production in the the NC and CC interactions as a function of hadronic energy
11: Cross section of $\pi^\pm/K^\pm/p$ production as a function of $X_F$ and $P_T$ in the $\nu$-CC interactions

✦ Neutrino-Electron Scattering
12: Measurement of inverse muon decay and absolute normalization of the NuMI flux above $E_{\nu} > 11$ GeV with $\leq 1\%$ precision
13: The $\nu_\mu$-$e^-$ and $\bar{\nu}_\mu$-$e^-$ neutral current interaction and determination of $\sin^2\Theta_W$
14: Measurement of the chiral couplings, $g_L$ and $g_R$ using the $\nu_\mu$-$e^-$ and $\bar{\nu}_\mu$-$e^-$ NC interactions

Roberto Petti
USC
ν-Nucleon Neutral Current Scattering
15: Measurement of NC to CC ratio, $R^\nu$, as a function of hadronic energy $0.25 \leq E_{\text{Had}} \leq 20$ GeV
16: Measurement of NC to CC ratio, $R^\nu$ and $R^\bar{\nu}$, for $E_{\text{Had}} \geq 3$ GeV and determination of the electroweak parameters $\sin^2 \theta_W$ and $\rho$.

Non-Scaling Charged and Neutral Current Processes
17: Measurement of $\nu_\mu$ and $\nu_\mu$ quasi-elastic interaction and determination of $M_A$
18: Measurement of the axial form-factor of the nucleon from quasi-elastic interactions
19: Measurement of $\nu_\mu$ and $\nu_\mu$ induced resonance processes
20: Measurement of resonant form-factors and structure functions
21: Study of the transition between scaling and non-scaling processes
22: Constraints on the Fermi-motion of the nucleons using the 2-track topology of neutrino quasi-elastic interactions
23: Coherent $\rho^\pm$ production in $\nu$-induced charged current interactions
24: Neutral current elastic scattering on protons $\nu(\bar{\nu})p \rightarrow \nu(\bar{\nu})p$
25: Measurement of the strange quark contribution to the nucleon spin $\Delta s$
26: Determination of the weak mixing angle from NC elastic scattering on protons

Inclusive Charged Current Processes
27: Measurement of the inclusive $\nu_\mu$ and $\nu_\mu$ CC cross-section in the range $0.5 \leq E_\nu \leq 40$ GeV
28: Measurement of the inclusive $\nu_e$ and $\nu_e$ CC cross-section in the range $0.5 \leq E_\nu \leq 40$ GeV
29: Measurement of the differential $\nu_\mu$ and $\nu_\mu$ CC cross-section as a function of $x_{bj}$, $y_{bj}$ and $E_\nu$.
30: Determination of $x F_3$ and $F_2$ structure functions in $\nu_\mu$ and $\nu_\mu$ CC and the QCD evolution
31: Measurement of the longitudinal structure function, $F_L$, in $\nu_\mu$ and $\nu_\mu$ charged current interactions and test of QCD
32: Determination of the gluon structure function, bound-state and higher twist effects
33: Precise tests of sum-rules in QPM/QCD
34: Measurement of $\nu_\mu$ and $\bar{\nu}_\mu$ charged current differential cross-section at large-$x_{bj}$ and $-y_{bj}$
35: Measurement of scaled momentum, rapidity, sphericity and thrust in (anti)neutrino CC
36: Search for rapidity gap in neutrino charged current interactions.
37: Verification of quark-hadron duality in (anti)neutrino interactions
38: Verification of the PCAC hypothesis at low momentum transfer
39: Determination of the behavior of $R = \sigma_L/\sigma_T$ at low momentum transfer
40: Precision tests of the Conservation of the Vector Current

✦ Nuclear Effects
41: Measurement of nuclear effects on $F_2$ in $\nu(\bar{\nu})$ scattering from ratios of Pb,Fe and C targets
42: Measurement of nuclear effects on $xF_3$ in $\nu(\bar{\nu})$ scattering from ratios of Pb,Fe and C targets
43: Study of (anti)shadowing in $\nu$ and $\bar{\nu}$ interactions and impact of axial-vector current
44: Measurement of axial form-factors for the bound nucleons from quasi-elastic interactions on Pb, Fe and C targets
45: Measurement of hadron multiplicities and kinematics as a function of the atomic number

✦ Semi-Exclusive and Exclusive Processes
46: Measurement of charmed hadron production via dilepton ($\mu^-\mu^+$, and $\mu^-e^+$) processes
47: Determination of the nucleon strange sea using the (anti)neutrino charm production and QCD evolution
48: Measurement of $J/\psi$ production in neutral current interactions
49: Measurement of $K^0_S$, $\Lambda$ and $\bar{\Lambda}$ production in (anti)neutrino CC and NC processes
50: Measurement of exclusive strange hadron and hyperon production in (anti)neutrino CC and NC
51: Measurement of the $\Lambda$ and $\bar{\Lambda}$ polarization in (anti)neutrino charged current interactions
52: Inclusive production of rho0(770), f0(980) and f2(1270) mesons in (anti)neutrino charged current interactions

53: Measurement of backward going protons and pions in neutrino CC interactions and constraints on nuclear processes

54: D*+ production in neutrino charged current interactions

55: Determination of the D^0, D^+, D_s, Λ_c production fractions in (anti)neutrino interactions

56: Production of K*(892)+- vector mesons and their spin alignment in neutrino interactions

✦ Search for New Physics and Exotic Phenomena

57: Search for heavy neutrinos using electronic, muonic and hadronic decays

58: Search for eV (pseudo) scalar penetrating particles

59: Search for the exotic Theta+ resonance in the neutrino charged current interactions

60: Search for heavy neutrinos mixing with tau neutrinos

61: Search for an anomalous gauge boson in pi0 decays at the 120 GeV p-NuMI target

62: Search for anomaly mediated neutrino induced photons

63: Search for the magnetic moment of neutrinos

64: A test of ν_μ–ν_e universality down to 10^{-4} level

⇒ More than 100 physics papers on a broad range of topics
SUMMARY

✦ The Project-X with HiResMν offers a unique opportunity to do neutrino physics: for oscillation studies and for standard model physics

- Well established technologies (no R&D required) based upon ATLAS and COMPASS designs;
- Dipole design based upon NOMAD and LHCb;
- Calorimetry and Muon Range Detector based on conventional detectors.

✦ Outstanding Physics potential for HiResMν at Project-X:

- Ultimate Near Detector for Long Baseline Neutrino Oscillation experiments;
- Precise measurement of $\nu_\mu, \bar{\nu}_\mu, \nu_e, \bar{\nu}_e$ as a function of $E_\nu$ & detailed topology;
- Measurement of $\sin^2 \theta_W$ in neutrino interactions to a precision comparable to LEP/SLC & check of NuTeV anomaly. Direct probe of running of $\sin^2 \theta_W$;
- Measurement of strange sea contribution to the nucleon spin $\Delta s$;
- Precision tests of the structure of the weak current: PCAC, CVC;
- Strange sea and charm production;
- Measurement of Nuclear effects in neutrino interactions;
- Precision measurements of cross-sections and particle production;
- Studies of QCD and hadron structure of nucleons and nuclei;
- Search for weakly interacting massive particles and other exotic phenomena;
- etc., etc. .....

Roberto Petti

USC
Backup slides
THE ATLAS TRT TECHNOLOGY

✦ Compact design combining tracking & particle identification in the same detector:
  ● Radiator foils for Transition Radiation (TR) for electron identification ($\gamma > 1000$);
  ● Drift straw tubes for tracking (400k channels with 4mm diameter filled with Xe/CO$_2$/O$_2$);
  ● Low density $1X_0 \sim 5\ m$.

✦ Electronic readout chain developed to match the challenging rate & radiation problems in ATLAS:
  ● Drift time measurement;
  ● Signal pulses are fed to discriminators with Low (tracking) and High (electron ID) Thresholds (no analog readout of charge).

✦ Standard resolution achieved on space points 130 $\mu$m at testbeam.

✦ Straw Tracker also built for the COMPASS detector, where only the drift time information is used (tracking without particle identification).
Use the same global mechanics as in COMPASS (established and well tested design). The design of the tracking modules would be the following:

- Straw diameter 1 cm;
- Straw walls 60μm Kapton or Mylar (one wall $2 \times 10^{-4} X_0$);
- Gas in each straw $9 \times 10^{-5} X_0$;
- Wire W gold plated 30μm diameter;
- Wire tension around 90g;
- Default radiator thickness $\sim 3mm$ (foils for TR);
- Straws are arranged in double layers glued together (epoxy glue) and inserted within Al mechanical frames (or C-fibre);
- Thickness of frames 4 cm (2 straws / 4 cm);
- Total of 125 modules to cover 5 m, arranged by alternating vertical and horizontal orientation;
- Analog readout at both ends of straws to solve ambiguities in the association of hits.
**MEASURING NUCLEAR EFFECTS**

- **Best procedure would be to measure the A dependence with few points (e.g. C, Fe, Pb):**
  - Determine ratios of structure functions of different nuclei: $F_2$ AND $xF_3$;
  - Comparisons with charged leptons.

- **Use 1mm ($0.18X_0$) Pb plates in front of three straw modules (providing 6 space points) without radiators in the upstream part of the detector:**
  - Total Pb target mass for one such module $\sim$ 70 kg;
  - **OPTION**: possible to install other materials (Fe, etc.) downstream by keeping a constant thickness in $X_0$. 

Roberto Petti
USC
The maximum drift time for a Xe/CO$_2$ gas mixture is 125 ns for a distance of 5mm (lower for Ar), as measured in testbeam.

The STT can resolve individual beam bunches.

Possible a self-triggering scheme in which hits are stored in pipelines (can use FE ADC - e.g. 8 bit - to operate in digital domain) waiting a later decision:
- ATLAS FE has pipeline $256 \times$ clock;
- Avoid trigger based upon geometrical acceptance (problem in NOMAD).

Depending upon the background rate, it should be possible to read and timestamp everything within one spill and to take a decision later in the cycle.

In addition, calorimetric trigger (complementary)
Perform a global fit to the charged lepton DIS and Drell-Yan data samples with $Q^2 > 1.0 \text{ GeV}^2$ and $W > 1.8 \text{ GeV}$ is used. The leading twist is calculated in the NNLO approximation, with parton distributions evolved from $Q^2_0 = 9 \text{ GeV}^2$.

The dynamical twist-4,6 terms, $H_{2,T}^{τ4,τ6}(x)$, are parameterized in a model-independent way by cubic splines with values at $x = 0.1, 0.3, 0.5, 0.7, 0.9$ which are fitted from data.

Few external constraints are imposed:

- $H_{2,T}^{τ4,τ6}(0) = 0$ since no clear evidence for saturation effects is found at HERA;
- $H_{2,T}^{τ6} = 0$ at $x > 0.5$ due to the impossibility to extract them out of the resonance region.
Many indications twist-6 terms extracted from data are fake. Perform new fits with $H_{2,T}^{\tau 6} = 0$ in the full kinematic region.

After dropping twist-6 terms the shape and magnitude of twist-4 contributions to $F_2$ and $F_T$ are comparable.

The upper limit on the magnitude of twist-6 terms turns out to be $\sim 0.02$ GeV$^2$, well below twist-4 terms.

Out of the resonance region the high twist contributions correspond to $\leq 10\%$ of the total structure functions, indicating a convergence of the OPE expansion.
The excess in SLAC data for $R = \sigma_L/\sigma_T$ at $x \sim 0.2$ with respect to the QCD predictions was considered as evidence of the large high twist contribution to $R$ and $F_L$ (Miramontes 92).

Our results show instead such excess is connected with the discrepancy between SLAC and BCDMS and can be hardly attributed to the high twist contributions.
The High Twist on $F_2$ and $F_T$ extracted from CHORUS neutrino cross-section data are consistent with the ones from charged lepton after rescaling for the charge.

Simultaneous extraction of HT in $xF_3$ from neutrino data

NUCLEAR EFFECTS

- Detailed phenomenological model describing nuclear corrections to structure functions

  - Introduce 3 general parameters, common to all nuclei
  - Extract parameters from e and μ DIS data on He,Li,Be,C,Al,Ca,Fe,Cu,Ag,Sn,Au,Pb from BCDMS,EMC,E139,E140,E665,NMC
  - Shadowing at small x (coherent) with meson dominance + leading twist
  - Off-shell, binding energy, Fermi motion at large x in convolution approach
  - Nuclear pion excess
  - Non-isoscalarity (isovector) correction
  - Independent correction for $F_T$, $F_2$ and $xF_3$

⇒ Data from charged lepton scattering bound uncertainties