Near detectors for νSTORM

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Near detector physics goals

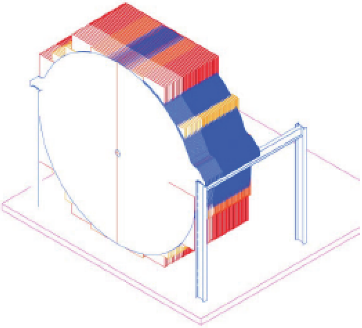
- Measurement of absolute ν flux as a function of E_ν, and relative abundance of four ν species (ν_e, $\overline{\nu}_e$, ν_μ, $\overline{\nu}_\mu$):
  - Reduce systematics on sterile neutrino searches at νSTORM.
  - ... and exploit νSTORM's unique 1% precision on ν flux for...
- 'Event-generator measurements' for the LBLν experiments:
  - Background to oscillations at LBLν experiments.
- Precision measurements of ν cross-sections:
  - Inclusive CC and Exclusive QE, Resonance;
  - Neutral current; NC-QE;
  - ν-e scattering.
- Precision determination of the exclusive processes such as ν QE, resonance, $K^0/\Lambda/D$ production and of the nucleon structure functions;
- Dark matter searches: weakly interacting massive particles with electronic, muonic and hadronic decay modes with unprecedented sensitivity.

Near detector requirements

- Should be capable of handling high multiplicity events;
- Magnetic detector necessary especially for $\overline{\nu}$ exposure;
- Energy resolution as good as far detector;
- Likely consist of several detectors (sub-detectors) to cover flux normalization and cross-section measurements;
- ... a near detector facility:
  - Covers physics goals;
  - Test beam area is a test bed for future ν detectors;
- ....NearBIND, HiResMν and $\gamma\nu$det options are presented here.

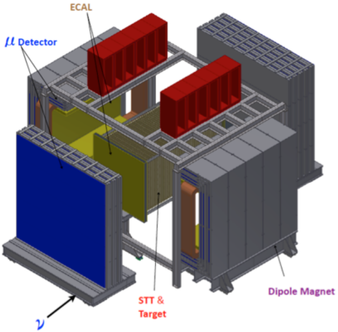
A magnetized iron neutrino near detector

- NearBIND at a near detector facility (20-50 m) would be a scaled version of SuperBIND at (1500 m);
  - 200 T;
  - dia. 3 m, length 6 m;
  - 1.5 cm Fe plates.
- NearBIND can be placed downstream of a "cross-section" detector:
  - Contributes to reconstruction of events occurring in the "cross-section" detector;
  - Provides an independent sample of events for SuperBIND physics.



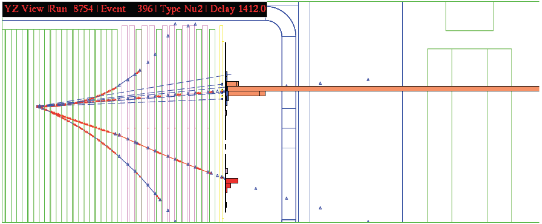
The HiResMNu concept

- Derived from NOMAD;
- ND option for LBNE:
  - 3.5 $\times$ 3.5 $\times$ 7.5 m Straw Tube Tracker (STT);
  - 4 π ECAL in a Dipole B-field (0.4T);
  - 4 π μ detector (RPC) in Dipole and downstream
  - Pressurized Ar target ($\times$5 FD stat).



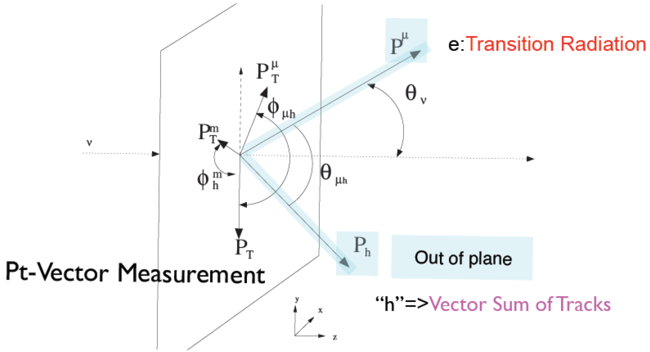
A $\overline{\nu}_e$ CC candidate in NOMAD

- e^-/e^+ ID using TRD, ECAL;
- μ from ν_μ and e from ν_e are Tracks: determined with very high precision;
- Universality equivalence: μ-$\nu_\mu \leftrightarrow$ e-ν_e;
- Uniquely resolve μ^- (ν_μ) from μ^+ ($\overline{\nu}_\mu$), e^- (ν_e) from e^+ ($\overline{\nu}_\mu$).



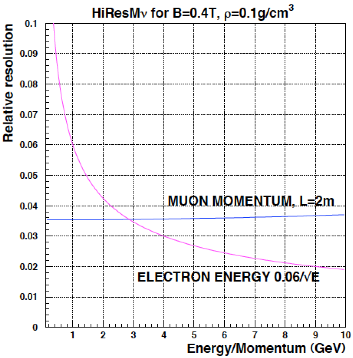
Kinematics in HiResMNu

- Pt vector:
  - Powerful constraint on Eν scale and ν vs $\overline{\nu}$ interactions;
  - NC vs CC ID;



Resolutions in HiResMNu

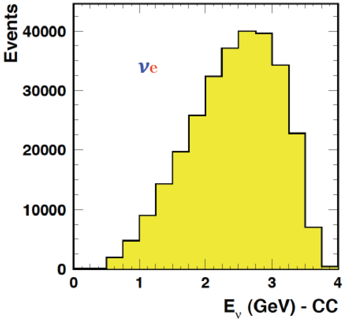
- $\rho = 0.1$ g/cm^3;
- Space point res. = 200 μm;
- Time res. = 1 ns;
- CC events vertex Δ(X,Y,Z) = O(250 μm);
- Energy in downstream ECAL = 6%/sqrtE
- μ angle res. ($\sim$2 GeV) = O(3 mrad)
- E_μ res. ($\sim$2 GeV) = $\sim$3.5 %
- E_e res. ($\sim$2 GeV) = $\sim$4.5 %

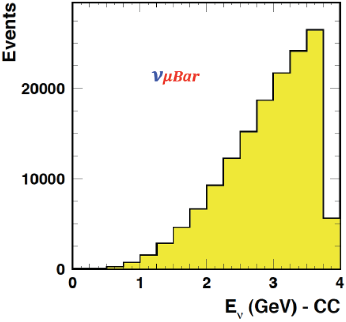


Expected statistics at nuSTORM

- 1e21 POT;
- Fiducial mass: 7 tons.

			QE	Res	Dis
μ+:	νμBar-CC:	1.5 x 10**5	34%	56%	10%
	νe-CC:	2.8 x 10**5	33%	65%	2% (?)





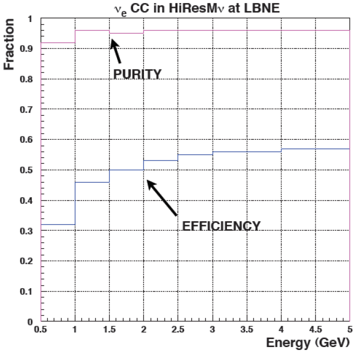
Identification of ν_e CC interactions

- HiResMν can distinguish e^- from e^+ in STT;

  $\Longrightarrow$ recons. e as bending tracks not showers;
- e ID against charged hadrons from both TR and dE/dx;

  $\Longrightarrow$ TR π rejection of 10^{-3} for $\epsilon \sim 90\%$;
- Multi-dim. likelihood functions to reject non-prompt backgrounds (π^0 in ν_e CC and NC);

  $\Longrightarrow$ On average $\epsilon = 55\%$ and $\eta = 99\%$ at LBNE;



ν_μ-QE Analysis

- Example of a ν interaction in a high-res. ND as a calibration of FD;
- Key is 2-Track (μ, p) signature: proton reconstr. is THE critical issue.

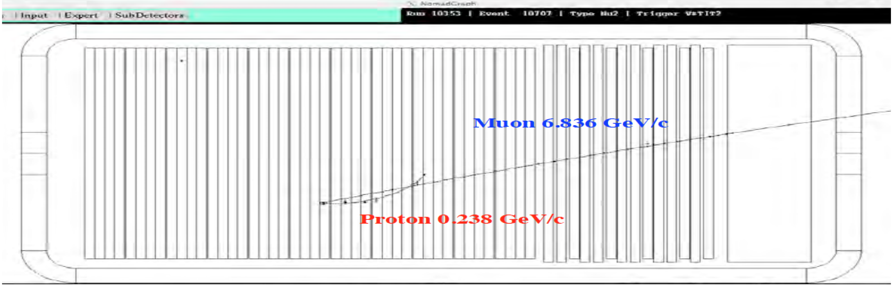


Figure 15: A ν_μ-QE candidate in NOMAD

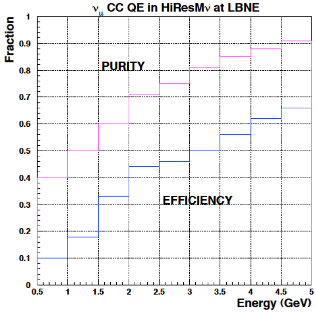
Reconstruction of CCQE interactions (LBNE spectrum)

- Protons easily identified by the large dE/dx in STT and range:

  $\Longrightarrow$ Min. range to reconstruct p track parameters 12 cm $\Rightarrow$ 250 MeV
- Analyze BOTH 2-track and 1-track events to constrain FSI, Fermi motion and nuclear effects:

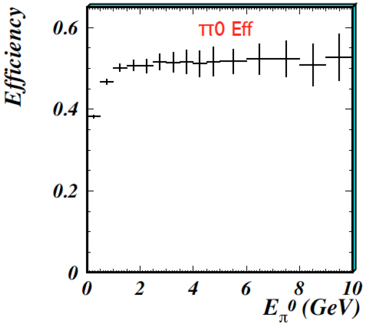
  $\Longrightarrow$ Min. range to reconstruct p track parameters 12 cm $\Rightarrow$ 250 MeV
- Use multi-dim likelihood functions to reject DIS and Res backgrounds:

  $\Longrightarrow$ On av. $\epsilon = 52\%$ and $\eta = 82\%$ for CCQE at LBNE
- For νSTORM $\epsilon = 40\%$ with $\eta = 70\%$

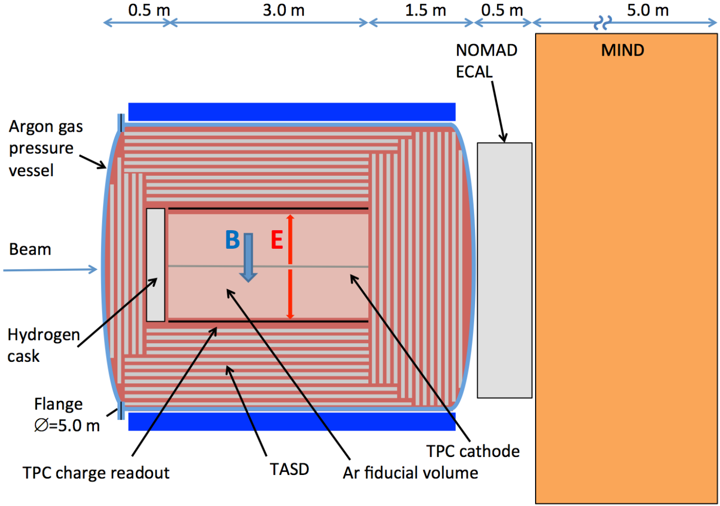


π^0 reconstruction

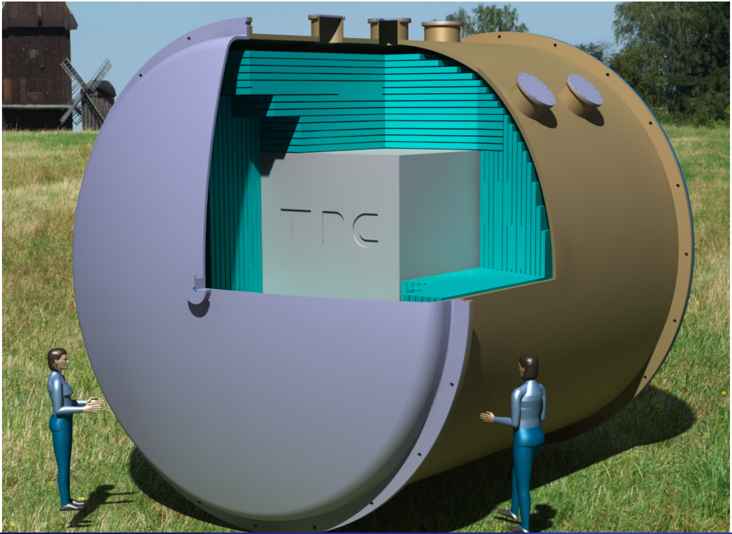
- Clean π^0 and γ signatures in STT;
- ν-NC and CC $\rightarrow \pi^0 \rightarrow \gamma\gamma$;
  - 50% of the $\gamma \rightarrow e^+e^-$ will convert in the STT, away from the primary vertex
- γ ID;
  - e^-/e^+ ID: TR;
  - kinematic cut: mass, opening angle.
- At least one converted γ in STT;
- Another γ in the downstream and side ECAL.



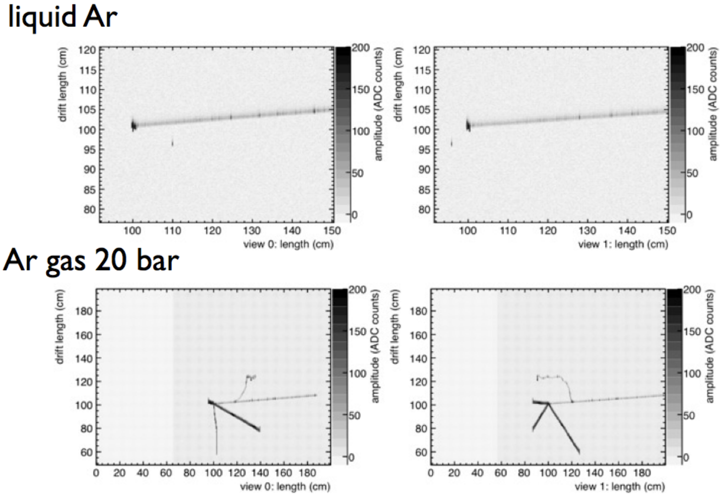
GAs ModulAr NEUtrino DETector ($\gamma\nu$det)



TPC and plastic scintillators embedded in gas pressure vessel

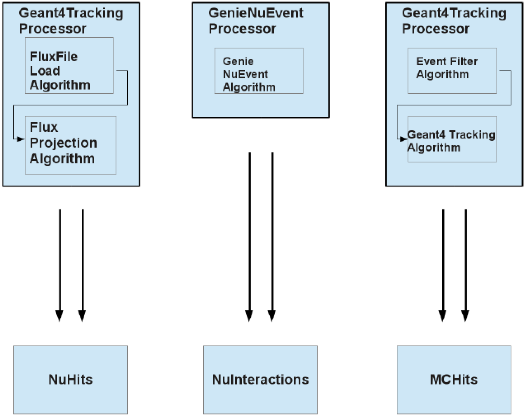


Vertex in argon gas...



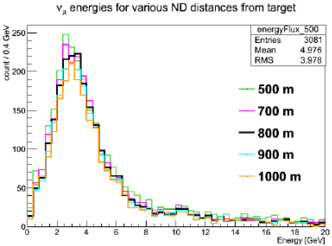
Software framework: T. Stainer & Y. Karadzhov

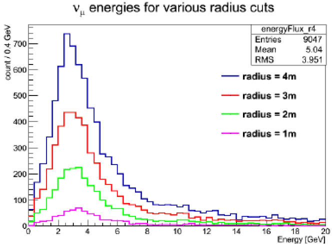
- Code available at https://launchpad.net/lbno-nd



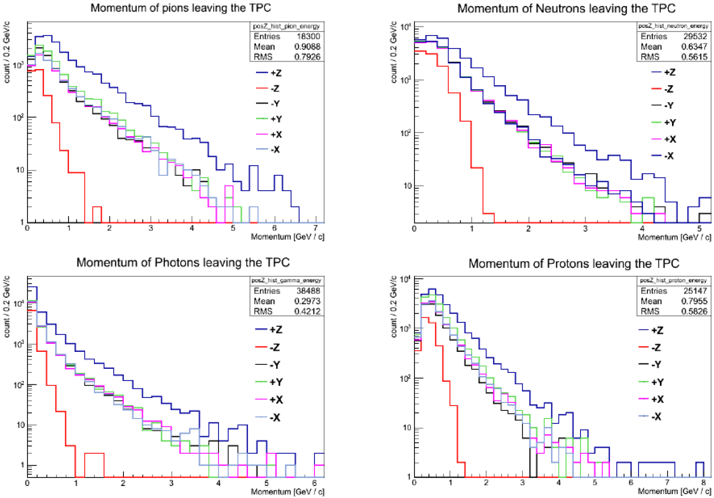
Simulation parameters

- Flux file (Fluka) from P. Velten for 10^6 p.o.t;
- ND is 800 m from target;
- 10^5 ν_μ only simulated, $E_\nu <$ 10 GeV;
- Interactions only in TPC: 2.4 x 2.4 x 3.0 m, 605 kg;
- Uniform 0.5 T dipole field across TPC.



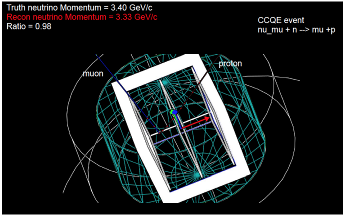


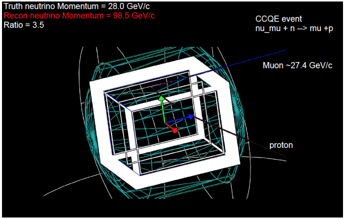
Particles leaving the 6 TPC faces



Basic momentum reconstruction in (only) the TPC

- Only tracks with hits (Edep points) are recorded;
- Event criteria: non-zero p and TPC tracks with at least 3 hits.
- Calculate sagitta from truth momentum;
- $s = BL^2/(26.7*p)$;
- $ds = 300$ microns;
- $B = 0.5$ T;
- Smear and recalculate value;
- Sum all momenta $->$ reconstructed ν momentum;
- 20 cm fiducial cut;

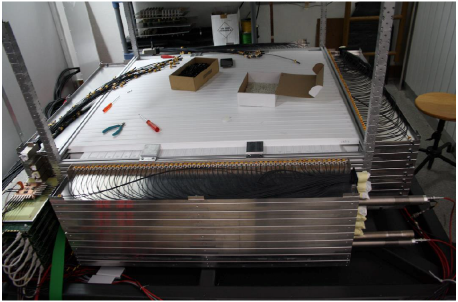


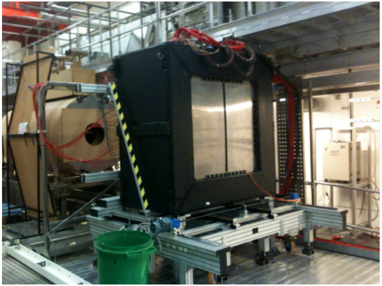


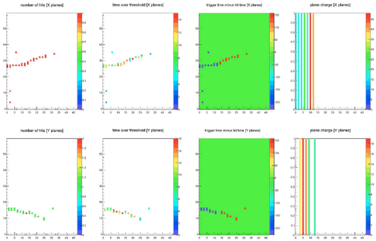
Event rates

- LBNO: events in TPC for 1.77e20 POT;
  - 1.09e6 interactions in TPC;
  - 6.7e5 good events;
  - 3.8e4 CCQE events;
- Corresponds to 3.55e7/100T/1e21POT.
- c.f. nuSTORM 2.15e6/100T/1e21POT at 50m;
- μ per spill in TPC at 800m ($\mu/m^2/spill$):
  - 0.025 from ν interactions inside TPC;
  - 6.11 from ν interactions outside TPC;
  - 9 from target that reach TPC.

MICE EMR commissioned at UNIGE summer 2013, installed at RAL September 2013



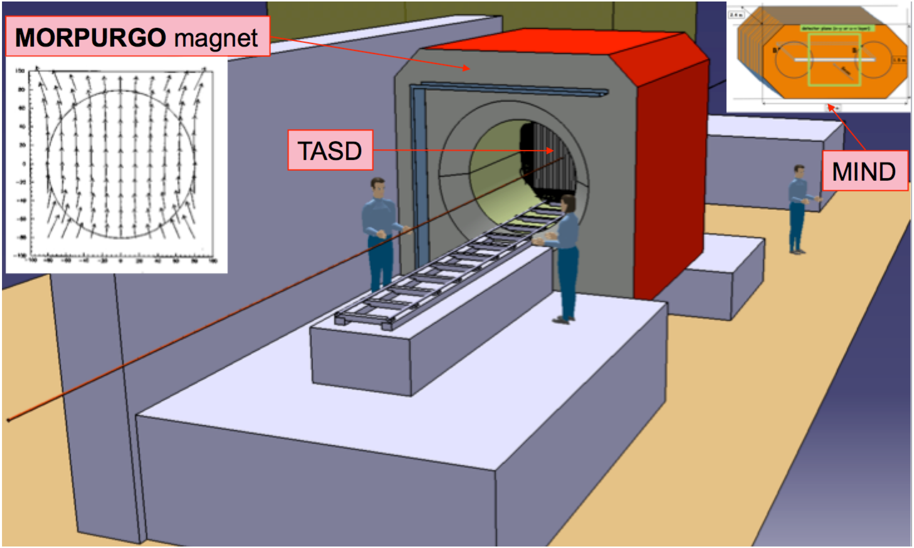




AIDA WP8.5.2: MIND and TASD test beam prototypes

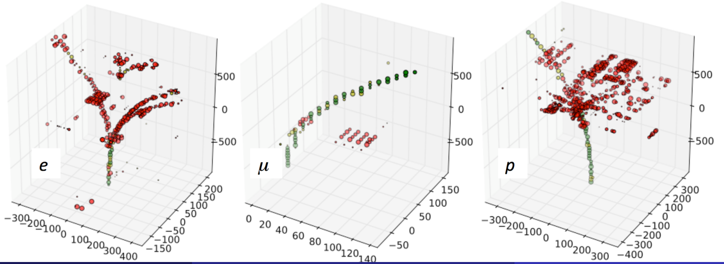
- Magnetised Iron Neutrino Detector (MIND):
  - Muon charge identification, for wrong sign muon signature of a neutrino oscillation event: golden channel at a NF: requires correct sign background rejection of 1 in 10^4: test beam 0.8 to 5 GeV/c;
  - Hadronic shower reconstruction for identification of charged current neutrino interactions and rejection of neutral current n.i.: test beam protons/pions 0.5 to 9 GeV/c.
- Totally Active Scintillating Detector (TASD):
  - Stopping properties of pions and muons up to 200 MeV/c (MICE EMR);
  - Electron and muon charge separation inside a magnetic field, in particular electron charge ID in electron neutrino interaction for the platinum channel at a neutrino factory: 0.5 to 5 GeV/c.
- Test beam: electrons, muons and hadrons (pions, protons), 0.5 to 5.0 GeV/c, at H8 beam line in North Area at CERN 2015.

TASD and MIND on the H8 beam line: CERN North Area



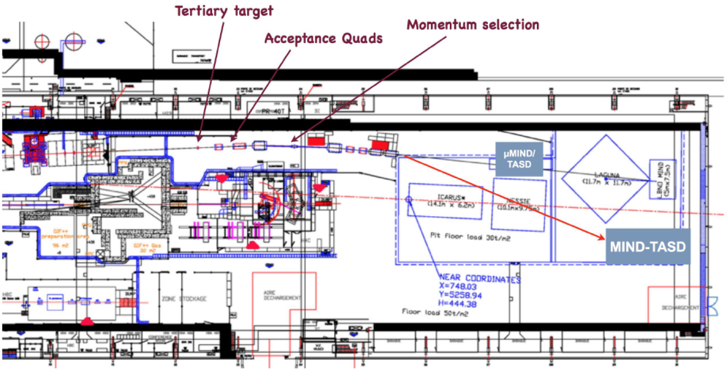
AIDA MIND and TASD simulations

- TMVA of the baby-MIND:
  - SuperBIND μ ID by range: not in baby-MIND
  - Need to rely on other PID metrics: MICE-EMR?
  - Clear differentiation between e, π, μ;
  - Training baby-MIND on μ, π, p, e.
- TASD simulations;
  - 50 plastic scintillator detector modules;
  - Variable distance 0-2.5cm;
  - Targets can be inserted in gaps between modules.



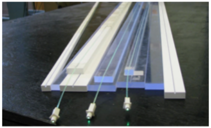
EHN1: Extension to North Area building for neutrino detector prototypes

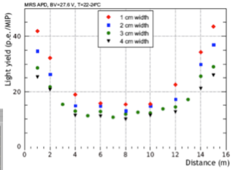
- WA105: Laguna LBNO proto: LAr and MIND;
- WA104: ICARUS proto: LAr;
- WA104: NESSIE proto: MIND-like and Air core magnet;

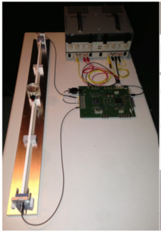


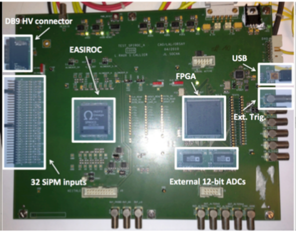
Plastic scintillator bars with SiPM readout

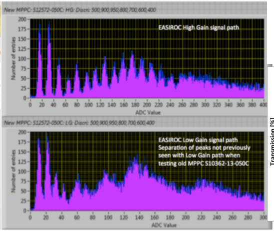
- Extruded scintillator slabs produced by Uniplast + connectors INR;
- Kuraray Y11 wavelength shifting fiber;
- Optical glue tests and selection;
- Photosensor comparison;
- Electronics: EASIROC tests.

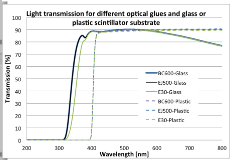












Summary

- Near detector facility at νSTORM:
  - Likely that more than one detector will be needed to fully address physics goals;
  - The ND facility is also a test bed for neutrino detector prototyping;
- Emphasis on precision neutrino interaction measurements (1% precision on ν flux)
- Several detector options:
  - NearBIND;
  - HiResMν;
  - $\gamma\nu$det;
  - Bubble chamber with CCD readout...
- Simulation, design and prototyping work:
  - Common software framework;
    $\Longrightarrow$Needed to optimize designs and compare;
  - Projects for test beam activities (AIDA, CERN-WA105).

Thanks

- Sanjib Mishra, Alain Blondel, Alessandro Curioni, Yury Kudenko, Ian Taylor, Tom Stainer, Yordan Karadzhov, Ryan Bayes, Franck Cadoux... are gratefully acknowledged for contributions to the slide materials