Magnetized Iron Neutrino Detectors (MIND) at LBNO

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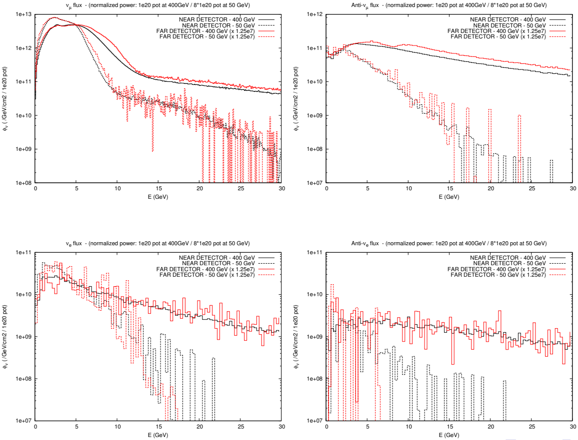
Magnetized Iron Neutrino Detectors

- MINDs past/present/future: CDHS(1250t-1976)/MINOS(980t & 5400t-2005)/LBNO/νSTORM/Neutrino Factory:
  - Compact (high density), high stats;
  - Good event containment;
  - Good charge ID (one "obvious" way to get charge info, B field);
  - Relatively cheap (CHF/ton), robust, maintainability;
  - Ideal for ν_μ studies with $E > 1GeV$.
- Not great for $E < 1GeV$, or for ν_e, or for reconstructing complex vertex:
  - ... but can be used as a tail catcher to reconstruct high E μ from events occurring upstream in higher spatial res. (sub)detectors.

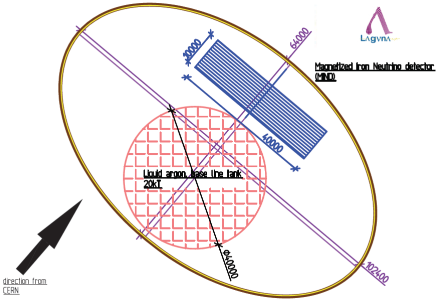
The LBNO neutrino beams

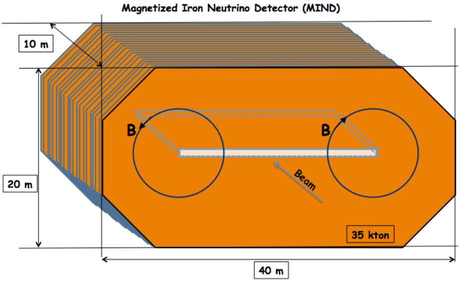
- ν beams optimized for far detector:
  - first and second maxima, $3 < E_\nu < 6$ GeV and $1.2 < E_\nu < 1.8$ GeV;
  - primary protons: 400 vs 50 GeV options (target outside/inside horn).



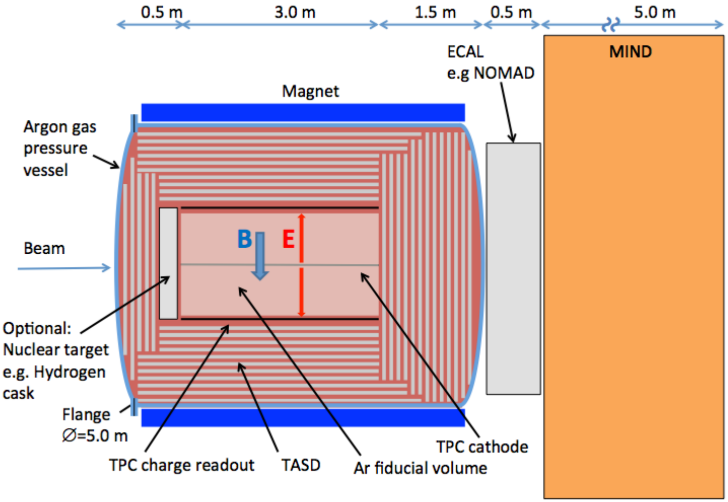
LBNO MIND at the far detector location

- LBNO far detector facility 2300 km from ν source at CERN;
  - 20 kt LAr TPC for phase 1;
  - 35 kt MIND downstream of the LAr.

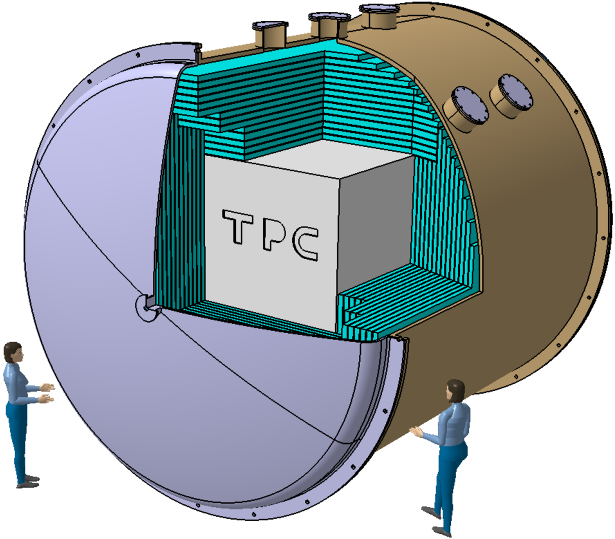




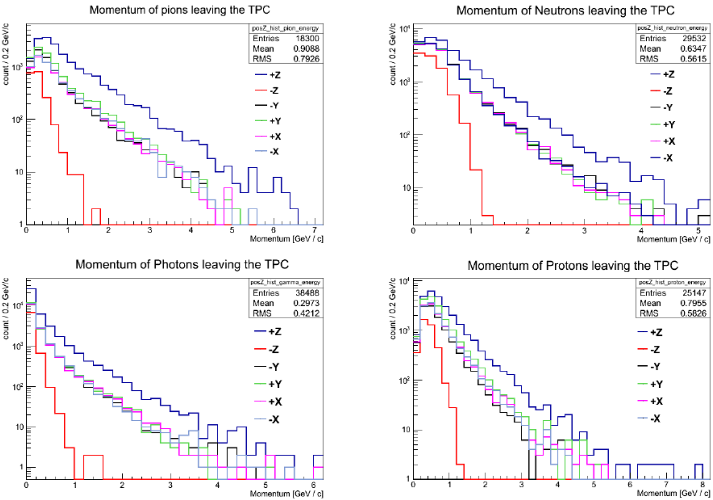
LBNO near detector concept



LBNO near detector Argon gas pressure vessel

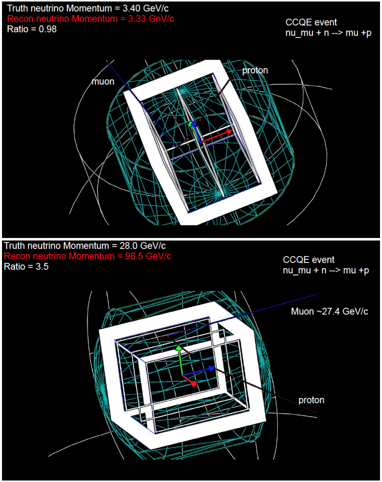


LBNO near detector: spectra of particles leaving the 6 TPC faces



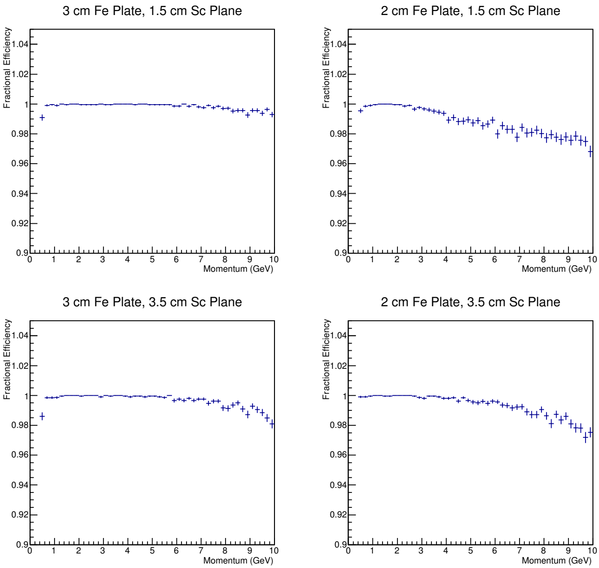
Basic momentum reconstruction in (only) the TPC

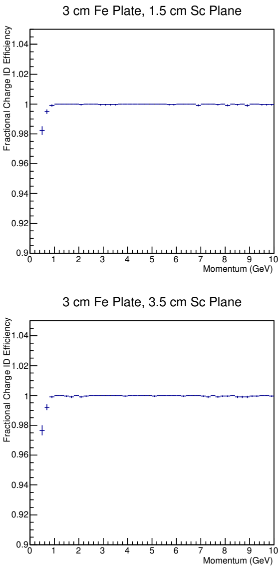
- Only tracks with hits (Edep points) are recorded;
- Event criteria: non-zero p and TPC tracks with at least 3 hits.
- Calculate sagitta from truth momentum;
- $s = BL^2/(26.7*p)$;
- $ds = 300$ microns;
- $B = 0.5$ T;
- Smear and recalculate value;
- Sum all momenta $->$ reconstructed ν momentum;
-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



MIND (& TASD) prototyping

- Totally Active Scintillating Detector (TASD):
  - Stopping properties of π and μ (MICE EMR at RAL);
  - e and μ charge separation inside a B field, in particular e charge ID in ν_e interactions for the platinum channel at a NF: 0.5 - 5 GeV/c (MORPURGO).
- MIND:
  - μ charge ID, for wrong sign μ signature of a ν oscillation event: golden channel at νSTORM, NF: requires correct sign background rejection of 1 in 10^4: test beam 0.8 to 5 GeV/c (babyMIND);
  - Hadronic shower reconstruction for identification of charged current ν interactions and rejection of neutral current ν interactions: test beam p/π 0.5 to 9 GeV/c (babyMIND).
- Technology:
  - Better computing and new software tools are leading to better capabilities for event reconstruction BUT... Need test beam data to benchmark new reconstruction techniques;
  - Improvements in components (e.g. photosensors, electronics);
  - Review and update costing models for planned large detectors.


3 cm Fe Plate, 1.5 cm Sc Plane
2 cm Fe Plate, 1.5 cm Sc Plane
3 cm Fe Plate, 3.5 cm Sc Plane
2 cm Fe Plate, 3.5 cm Sc Plane
Fractional Efficiency
Momentum (GeV)
0.9
0.92
0.94
0.96
0.98
1
1.02
1.04
0 1 2 3 4 5 6 7 8 9 10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0.9
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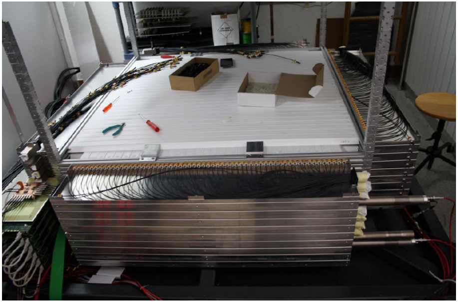
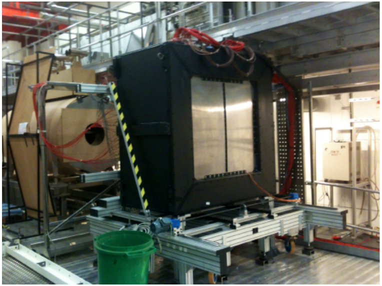
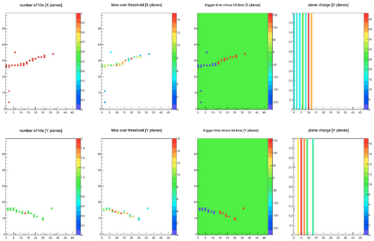
0 1 2 3 4 5 6 7 8 9 10

MICE Electron Muon Ranger (EMR): commissioned at UNIGE summer 2013, installed at RAL September 2013

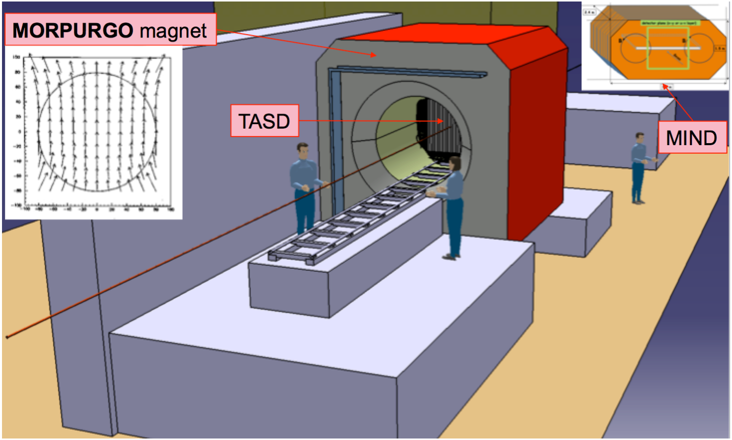




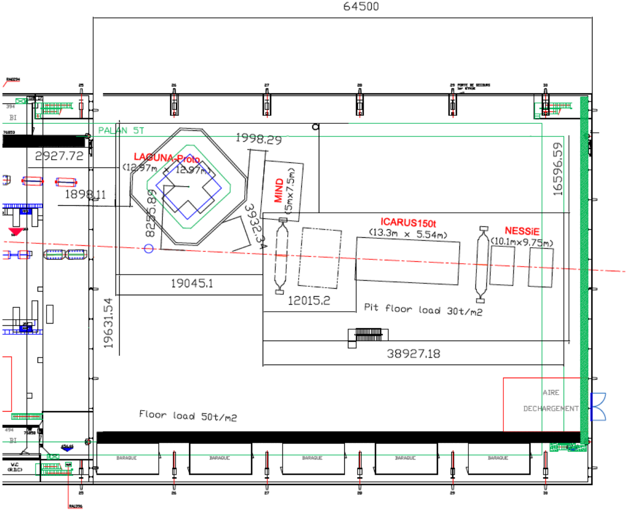


MIND and TASD: H8 beamline in North Area

- Beam tests 2015;
- Requires beamline (studied by AIDA WP8.2.1).

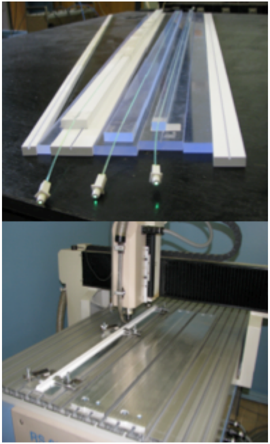


MIND downstream of LAr at EHN1: WA105, being discussed for MoU



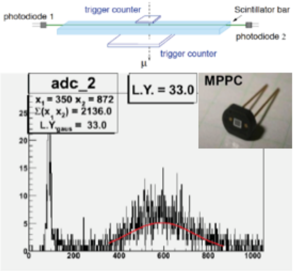
Manufacturing plastic scintillator slabs: INR

- Extruded scintillator slabs produced at Uniplast company, Vladimir, Russia:
  - polysterene-based, 1.5% paraterphenyl (PTP) and 0.01% POPOP.
- Slabs are etched with a chemical agent (Uniplast) to create a 30-100 μm layer that acts as a diffusive reflector;
- Counters of three different sizes for tests:
  - $895 \times 7 \times 10 mm^3$;
  - $895 \times 7 \times 20 mm^3$;
  - $895 \times 7 \times 30 mm^3$.
- WLS fiber embedded in 2 mm-deep groove.



Plastic scintillator cosmic tests

- Tests carried out to determine basic light yield and timing properties;
- Light collection: Kuraray wavelength shifting fiber, 1.0 mm diameter, $\sim$1 m long, embedded in groove with Toshiba TSF451-50M silicon grease;
- Light readout: Hammamatsu MPPC on both sides;
- Cosmic telescope:
  - two trigger counters;
  - upper one: $7 \times 7\ cm^2$ (L.Y.) and $2 \times 2\ cm^2$ (timing);
  - lower one: $10 \times 24\ cm^2$.
  - measurement at counter center: light yield per MIP.



	MPPC
Number of pixels	667
Active area	$1.3\times1.3\ mm^2$
Pixel size	$50\times50\ \mu m^2$
Gain	0.7×10^6
PDE at 525 nm	30-35%
Dark rate, thr = 0.5 p.e.,22C	<500 kHz
Pulse width	<100 ns
Cross-talk	10-20%
After pulses	10-20%
Sensitivity to magnetic field	no

Light yield: slabs with no chemical reflector

Slab width [mm]	**MPPC 1 L.Y.** [p.e.]	**MPPC 2 L.Y.** [p.e.]	$\Sigma_{L.Y.}$ **[1+2]** [p.e.]
No chemical reflector, no Tyvek paper reflector			
10	15.7	15.8	31.5
20	15.5	13.6	29.1
30	12.8	11.5	24.3
With Tyvek paper reflector, still no chemical reflector...			
20 + Tyvek	41.8	34.8	76.6

- Light attenuation length in bars is $\sim$8 cm;
- Tyvek paper reflector: factor 2.5;
- T2K SMRD tests experience: L.Y. $>$ 12 p.e. (sum of both ends) allows to achieve 99% detection efficiency.

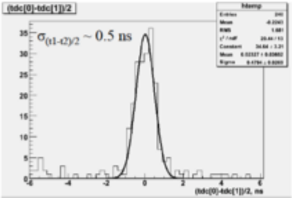
Light yield: slabs with chemical reflector

Slab width [mm]	**MPPC 1 L.Y.** [p.e.]	**MPPC 2 L.Y.** [p.e.]	$\Sigma_{L.Y.}$ **[1+2]** [p.e.]
Chemical reflector			
10	46.0	36.8	82.8
20	39.7	35.7	75.4
20	32.6	28.2	60.8
30	31.2	26.6	57.8
Chemical reflector, w/o optical grease			
20 - grease	25.7	22.1	47.8
Chemical reflector + Tyvek paper reflector			
20 + Tyvek	49.3	44	93.3

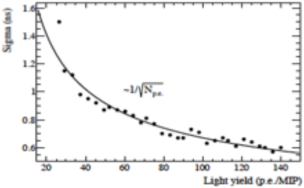
- $\sim \times$ 2.5 effect of chemical reflector;
- $\sim$ 60 % effect of optical grease;
- $\sim$ 20 % effect of additional Tyvek reflector.

Timing characteristics

- Timing estimation with small 2 $\times$ 2 cm^2 upper trigger counter;
- $\sim$ 0.5 p.e. TDC threshold to suppress time-walk effects;
- Two-sided readout $\rightarrow (t_1 - t_2)/2$ to estimate timing;
- Timing is mostly determined by fiber decay constant:
  - $\tau_{fiber} \sim 12$ ns;



$\sigma_{(t1-t2)/2}$ vs L.Y. according to T2K SMRD test-bench results

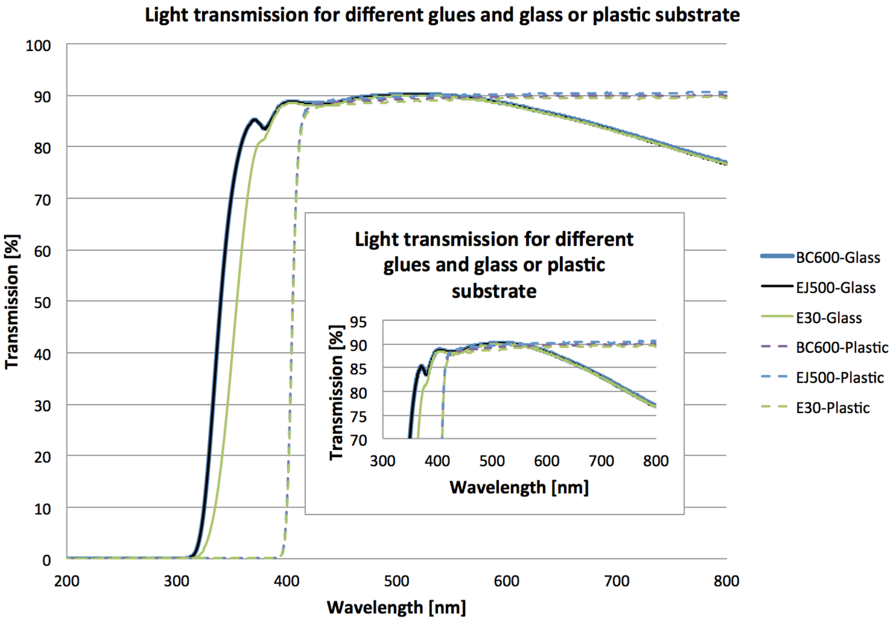


Optical glue tests

- Optical glues:
  - Bicron BC-600: reference in HEP;
  - EJ-500: proposed by CERN PH-DT-DD;
  - Aqua E-30: fibers on MICE-EMR;
  - Araldite Cristal: connectors on MICE-EMR.
- Glue on glass and plastic substrates:
  - Standard: glue thickness 40 μm;
  - U-shaped TEFLON spacer: glue thickness 200 μm.
- Light transmission tests with Perkin Elmer Lambda 650 UV/VIS spectrometer.

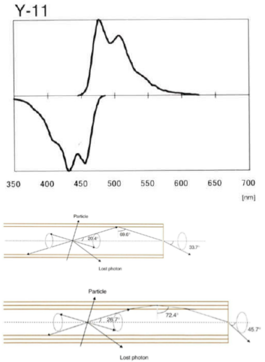
At room temperature (20°C) the resin takes 3 to 4 hours to set and 24 hours to harden, although it takes several days to achieve maximum hardness.

EJ-500 is fully cured at room temperature (20°C) with a working life of 60 minutes. The mixed cement takes 3-4 hours to set and 24 hours to harden, although it takes several days to achieve complete cure. It may also be used to cement metal or ceramic parts to plastic scintillators or PMMA light guides.

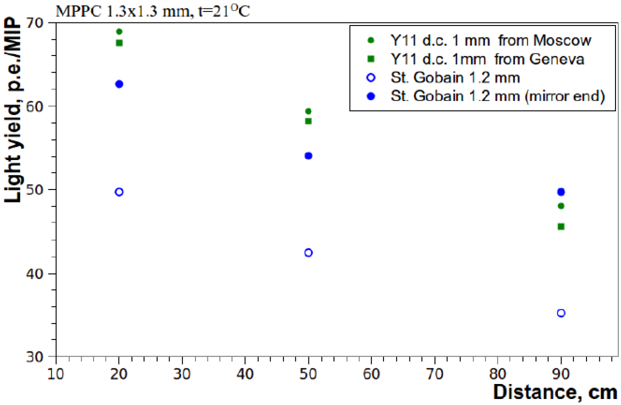

Light transmission for different glues and glass or plastic substrate
Transmission [%]
100
90
80
70
60
50
40
30
20
10
0
200
300
400
500
600
700
800
Wavelength [nm]
Light transmission for different glues and glass or plastic substrate
Transmission [%]
95
90
85
80
75
70
300
400
500
600
700
800
Wavelength [nm]
BC600-Glass
EJ500-Glass
E30-Glass
BC600-Plastic
EJ500-Plastic
E30-Plastic

Wavelength shifting fiber (WLS) options

- WLS fiber options:
  - Kuraray Y11 double-clad, 1.0 mm diameter;
  - St. Gobain double-clad, 1.2 mm diameter.
- Multi-clad fiber has 50% higher light yield than single clad fiber due to better trapping efficiency;
- Light yield 30% better for Kuraray Y11;
- Opted for the Kuraray Y11 fiber.



Light yield for the different WLS fibers



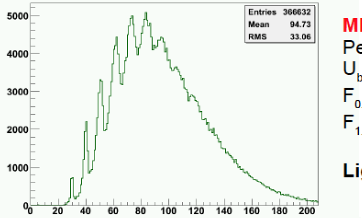
- 3 fibers tested with open end, with cosmic triggers at 20, 50, 90 cm;
- Then one measurement on St. Gobain with Al Mylar mirror on open end.

Specifications of photosensor options

Parameters	MPPC	ASD-SiPM1C-40	ASD-SiPM1S-100
Pixel size, μm	50	40	40
Pixel number	667	660	100
Sens. area, mm	1.3×1.3	$\oslash 1.2$	1.3×1.3
Gain	$\sim 7.5 \times 10^5$	1.6×10^6	10^7
Dark rate, MHz	< 1	~ 3	~ 5
Bias voltage, V	~ 70	$30 - 50$	$30 - 50$

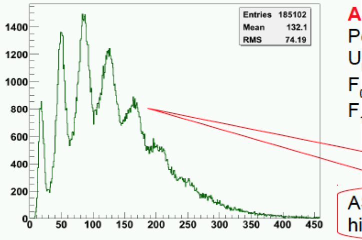
Photosensor charge spectra

Green LED flash light is sent through a monochromator and collimator to a SiPM.
ADC gate is 150 ns. Wavelength is 520 nm. Temperature is 25°C.



MPPC response to LED signal.
Pedestal and up to 8 p.e. peaks can be separated
U_{bv}=69.2 V (specified by Hamamatsu)
$F_{0.5}$=900 kHz
$F_{1.5}$=90 kHz

Light yield is about 5 p.e.



ASD-SiPM1C-40 response to LED signal.
Pedestal and up to 5 p.e. peaks can be separated
U_{bv}=47.2 V (3.6 V overvoltage)
$F_{0.5}$=3630 kHz
$F_{1.5}$=490 kHz

Light yield is about 3 p.e.

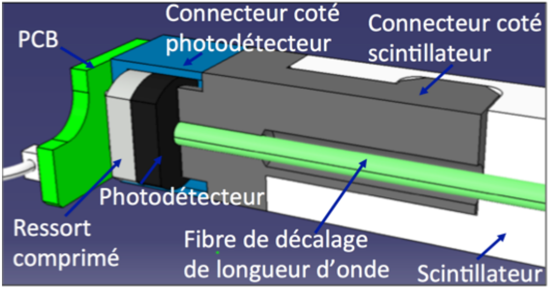
ASD sensor produces well separated peaks even at high dark rate

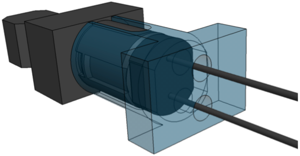
Summary of photosensor characterisation

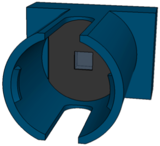
Parameters	MPPC	ASD-SiPM1C-40	ASD-SiPM1S-100
Sens. area, mm^2	1.69	1.13	1
Overvoltage, V	1.4	3.6	2.1
Dark rate, MHz	0.9	3.6	3.7
Crosstalk, %	10	13.4	12.4
Pulse shape	good	good	long tails
Peak separation	good	good	bad
PDE at 520 nm, %	25.6	11	13.3

- Final choice of photosensor not made!
- Tests planned of newly developed devices. e.g low dark count and low after pulse MPPCs, also precision low cross talk MPPCs.

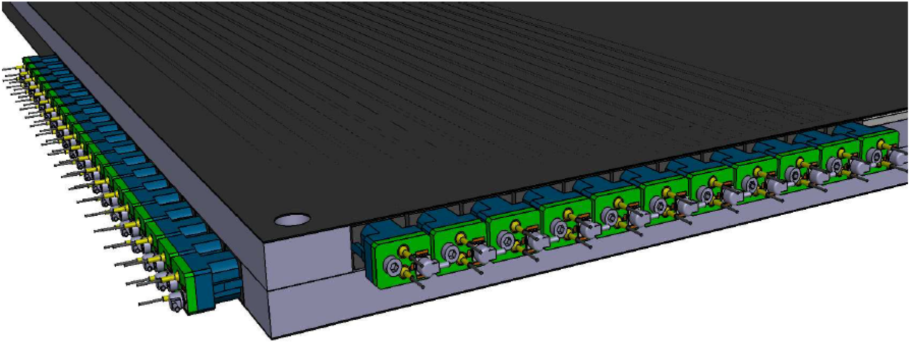
Photosensor connector





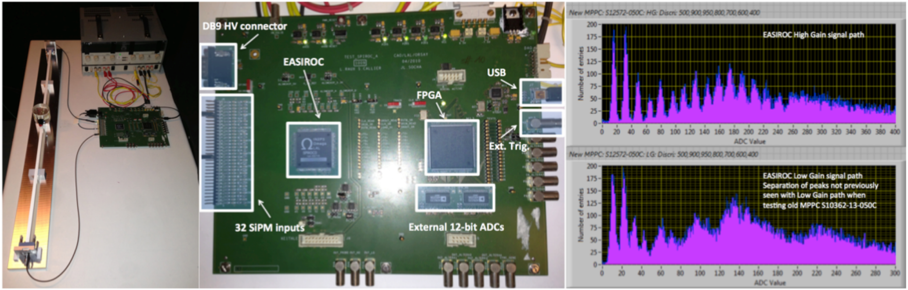


Detector module design



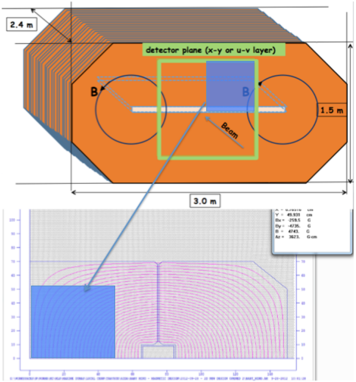
Electronics

- Baseline design with EASIROC chip;



Measuring B-field in-situ

- Slit in steel, few mm...
- fill with non-magnetic material (e.g. SS316L);
- Insert probe to measure field at various points along slit;
- Small distortion of field lines;
- Measurements validate simulated field across whole detector;
- 23000 At with slot c.f. 4000 At without slot.



Summary

- Several future facilities plan MIND-type detectors.
  - Two at LBNO: one near, one far.
- Progress in software reconstruction techniques:
  - These are being applied to Neutrino Factory and νSTORM analyses;
  - Must be benchmarked against test beam data on hardware that is well characterized;
  - Applicable to LBNO.
- Advances in technology (e.g. photosensors, electronics) are being tracked in order to:
  - better gauge potential gains these bring to the field;
  - update costing models for the large detectors.
- We plan beam tests of MIND-type detectors in the near term 2015-2020:
  - at the H8 beamline in the North Area at CERN;
  - at the new EHN1 facility in combination with LAr under WA105.