AIDA

Advanced European Infrastructures for Detectors at Accelerators

AIDA TASD and MIND Detectors

E. Noah - 21.09.2012

On behalf of AIDA WP8.5.2 co-workers

Outline

- The AIDA project
- Planned neutrino facilities
- AIDA TASD and MIND detectors
- MIND Magnetisation
- Plastic scintillators
- SiPM characterisation
- Electronics – EASIROC
- UNIGE MICE EMR experience

The AIDA project

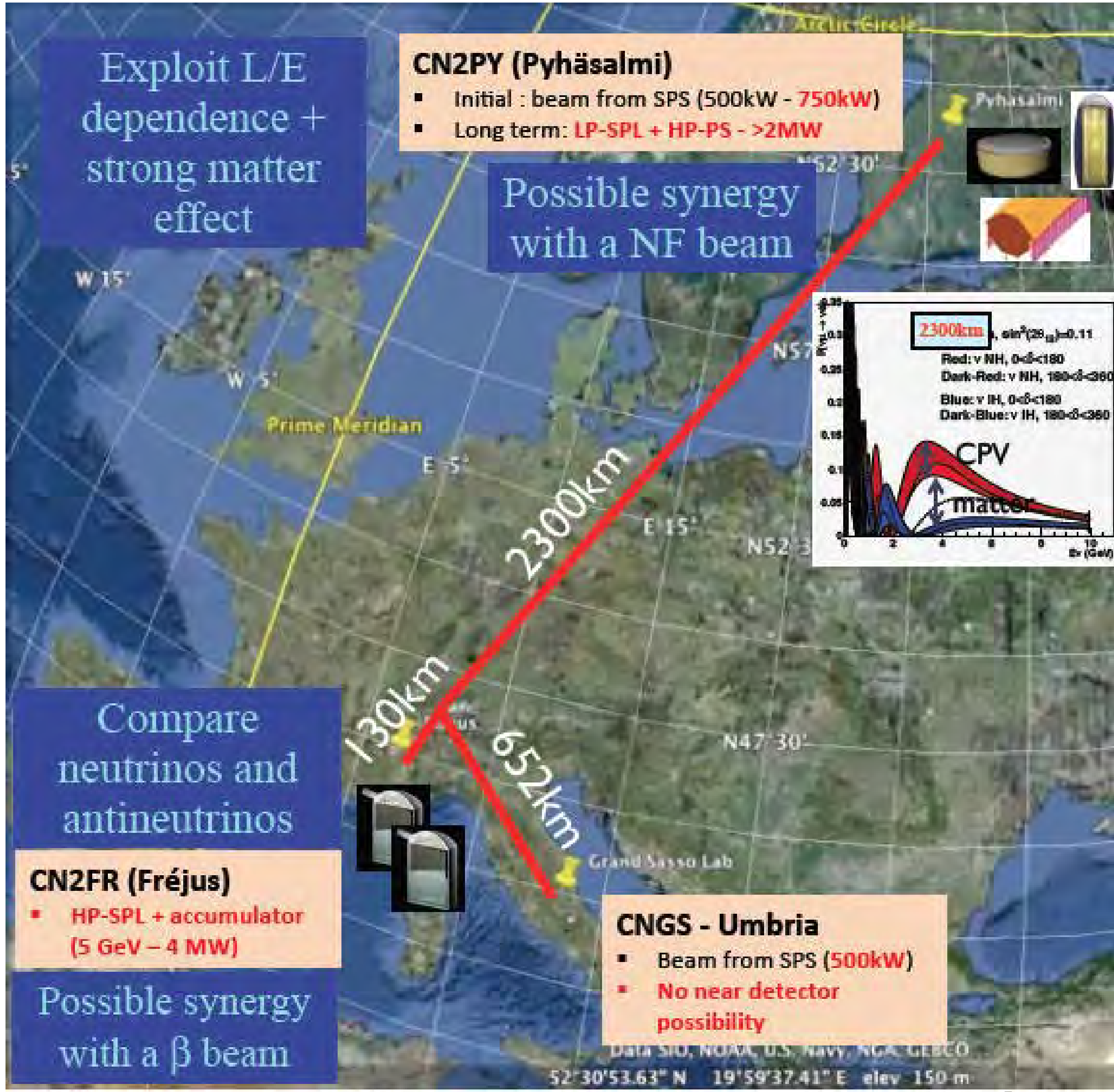
- Advanced European Infrastructures for Detectors at Accelerators:
  - Part EU-funded **4-yr project** under FP7 Research Infrastructures programme.
  - Timeline: **02/2011 – 01/2015**
- Aim:
  - **Upgrade**, **improve** and **integrate** key European research infrastructures.
  - Develop **advanced detector technologies** for future particle accelerators.

Accelerator-based neutrinos

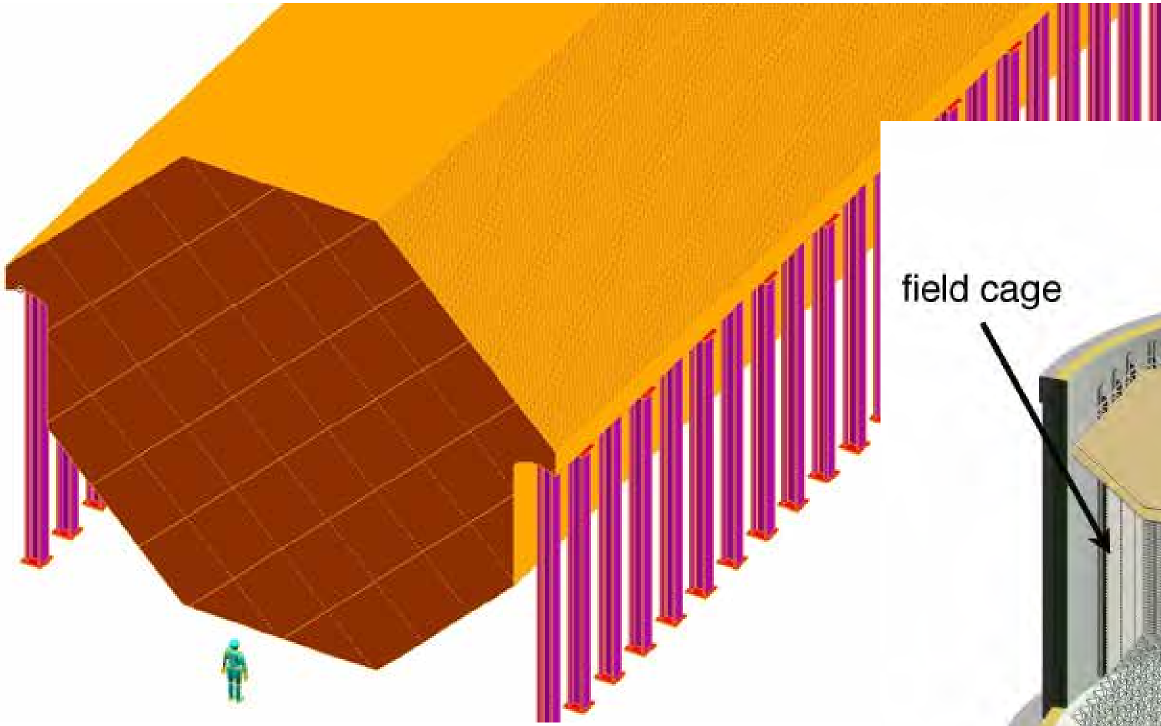
- Two recent proposals (in Europe):
  - One short-baseline experiment at CERN-SPS (SPSC-P-347: 15th March 2012): neutrino beam to search for sterile neutrinos with the ICARUS T600 Lar TPC @ 1600m + T150 @ 300m from proton target.
  - One long-baseline experiment at CERN-SPS (SPSC-EOI-007-LBNO: 28th June 2012): Investigate all flavour oscillations (n_m to n_m, n_m to n_t, n_m to n_e) with neutrinos and antineutrinos, explicitely testing the existence of CP-violation and conclusively determining mass hierarchy for any value of d_{CP}.
- Both instrumented with liquid argon detectors and magnetised iron detectors.

CN2PY

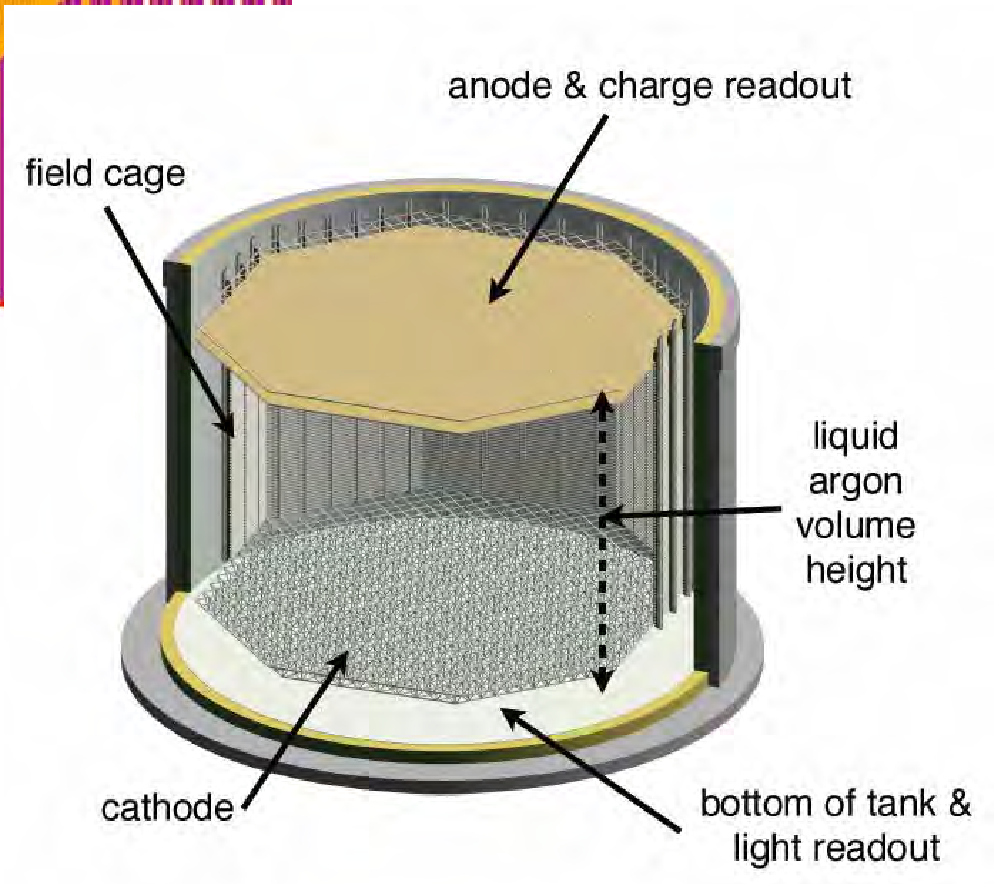
Mine closure 2018



LBNO Detectors

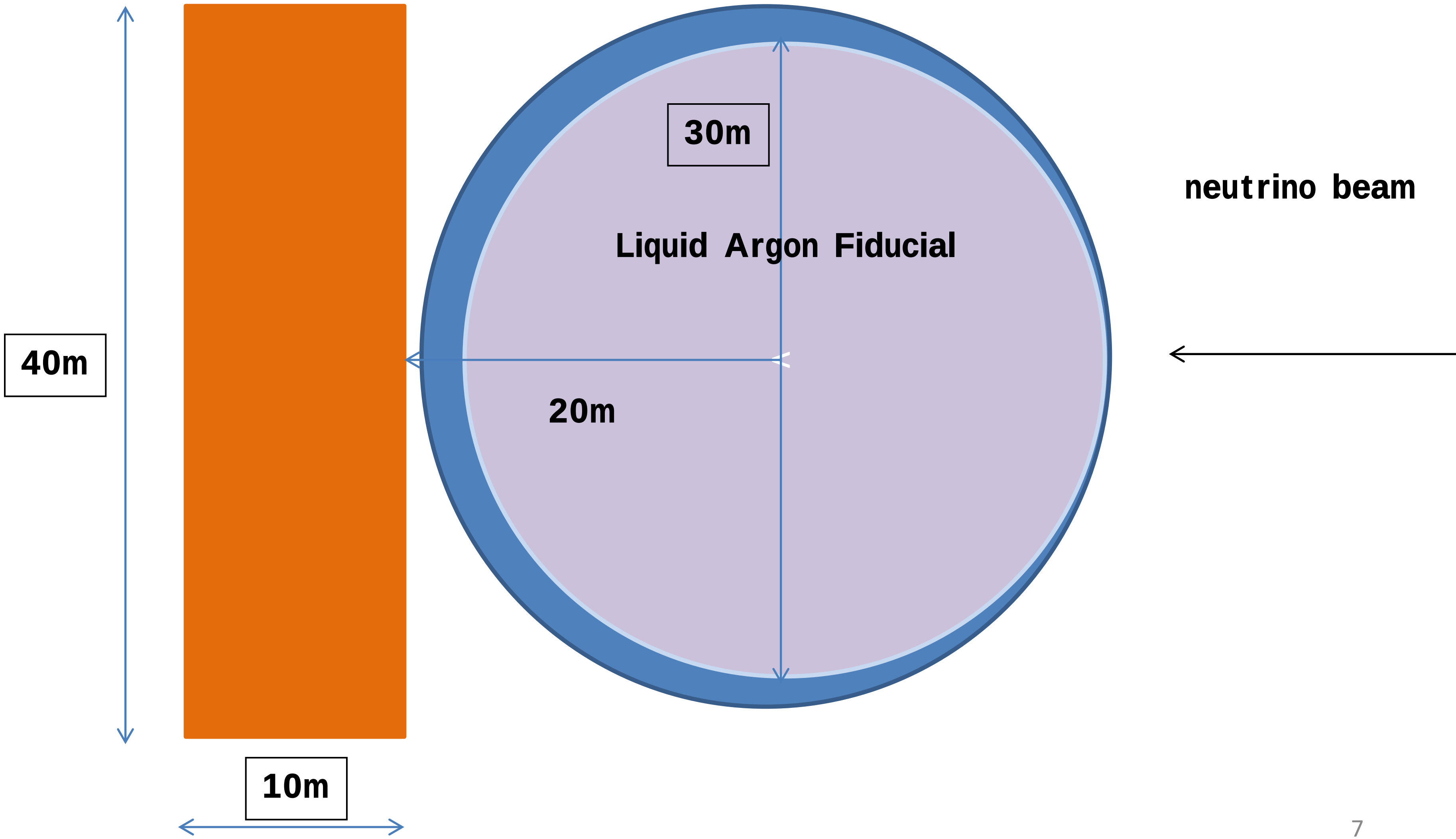


MIND detector =
Neutrino Factory baseline detector
as of the NF-IDR
(Interim Design Report)
100kton Magnetized Iron detector
(1.5 T toroidal field)
Scintillator read out with
Wave Length Shifting fibers and SiPMTs

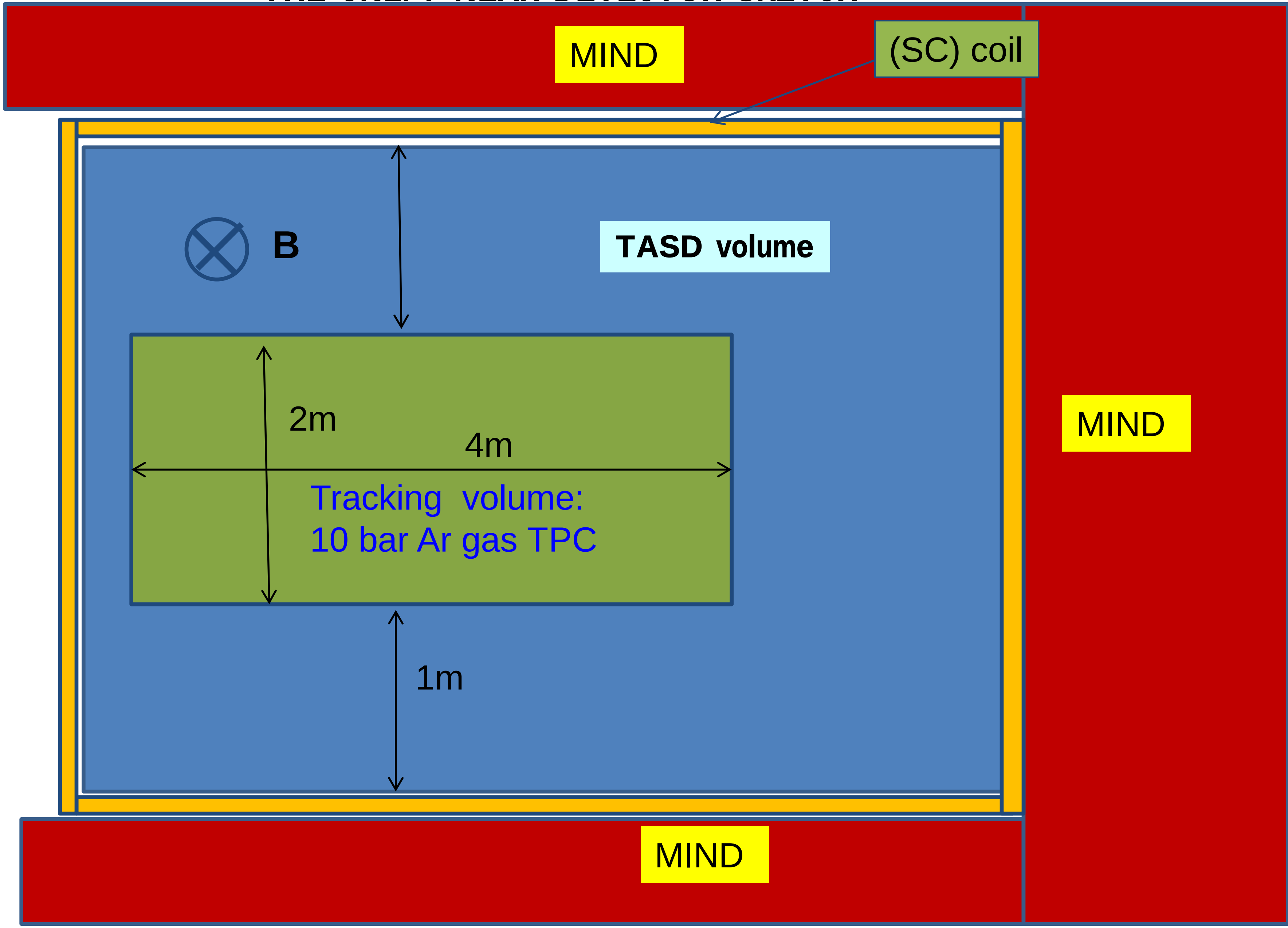


20kton Glacier detector
Liquid Argon TPC
with 2-phase readout (LEM)

LBNO Far Detectors: Top View



THE CN2PY NEAR DETECTOR SKETCH



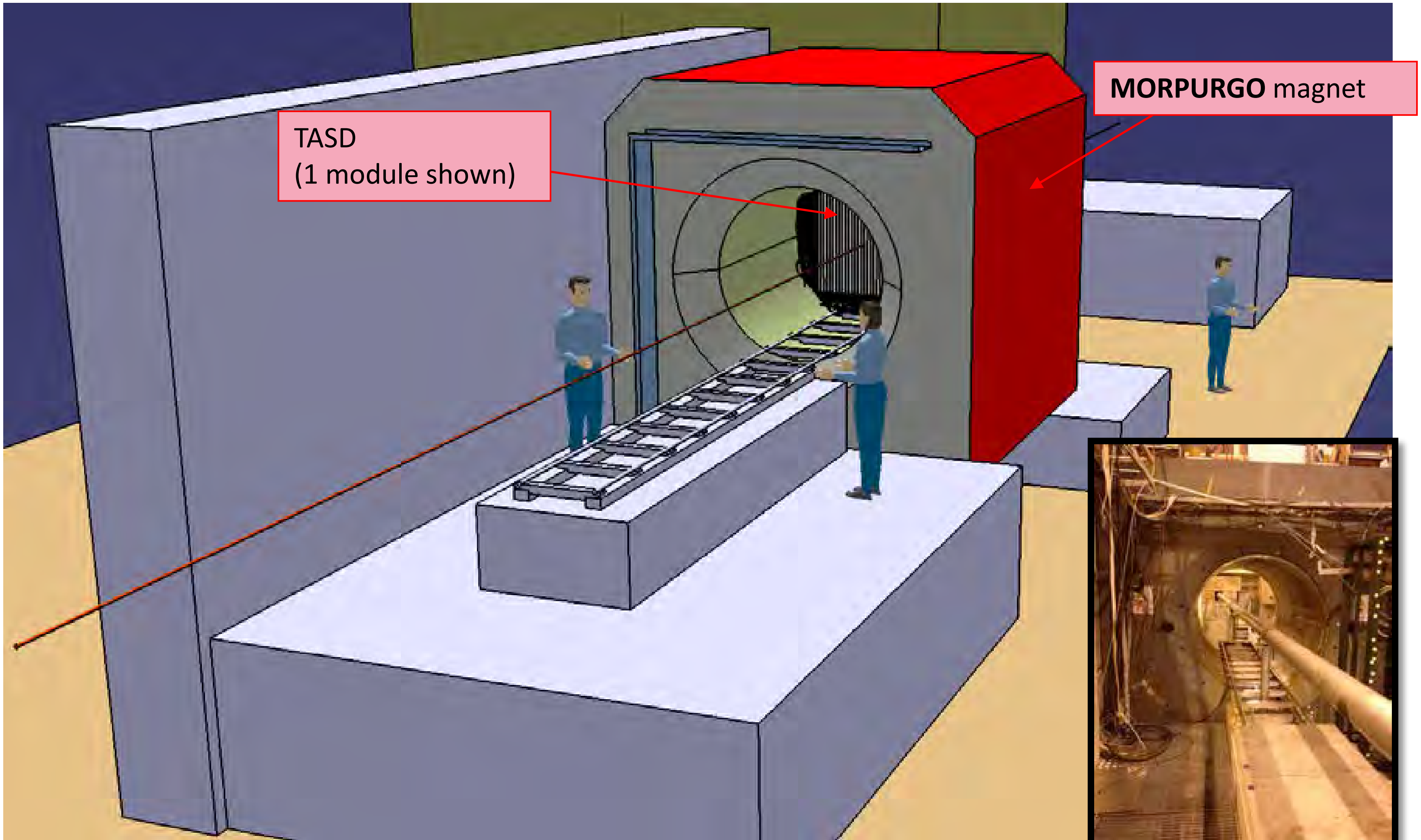
Excerpt from LBNO SPSC-EOI-007

Based on the expertise present at CERN and in European and in international research groups, and building upon the results of several years of EU-funded design studies, we are confident that the technology for the beam and detectors is sufficiently mature to allow for an early start to realizing the facility. We are **calling on CERN** to promptly **support** and engage in the **prototyping** of the **near and far detector components**, to **investigate** options for campaigns of **detector performance characterization** and calibration with **test beams** in the **North Area**, and engage in a collaborative effort with the LBNO Collaboration that should lead to a full engineering design of the CN2PY beam and to an LBNO Proposal by the end of 2014.

AIDA TASD and MIND

- Totally Active Scintillating Detector
  - **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 NF: 0.5 – 5 GeV/c (**AIDA – MORPURGO**).
- Magnetised Iron Neutrino Detector
  - **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 (**AIDA – baby-MIND**).
  - **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 (**AIDA – baby-MIND**).

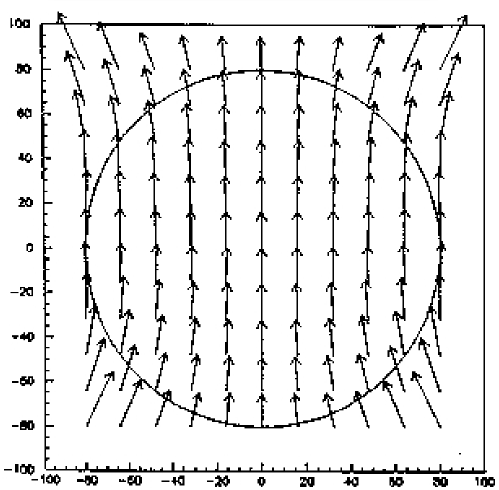
General layout: TASD



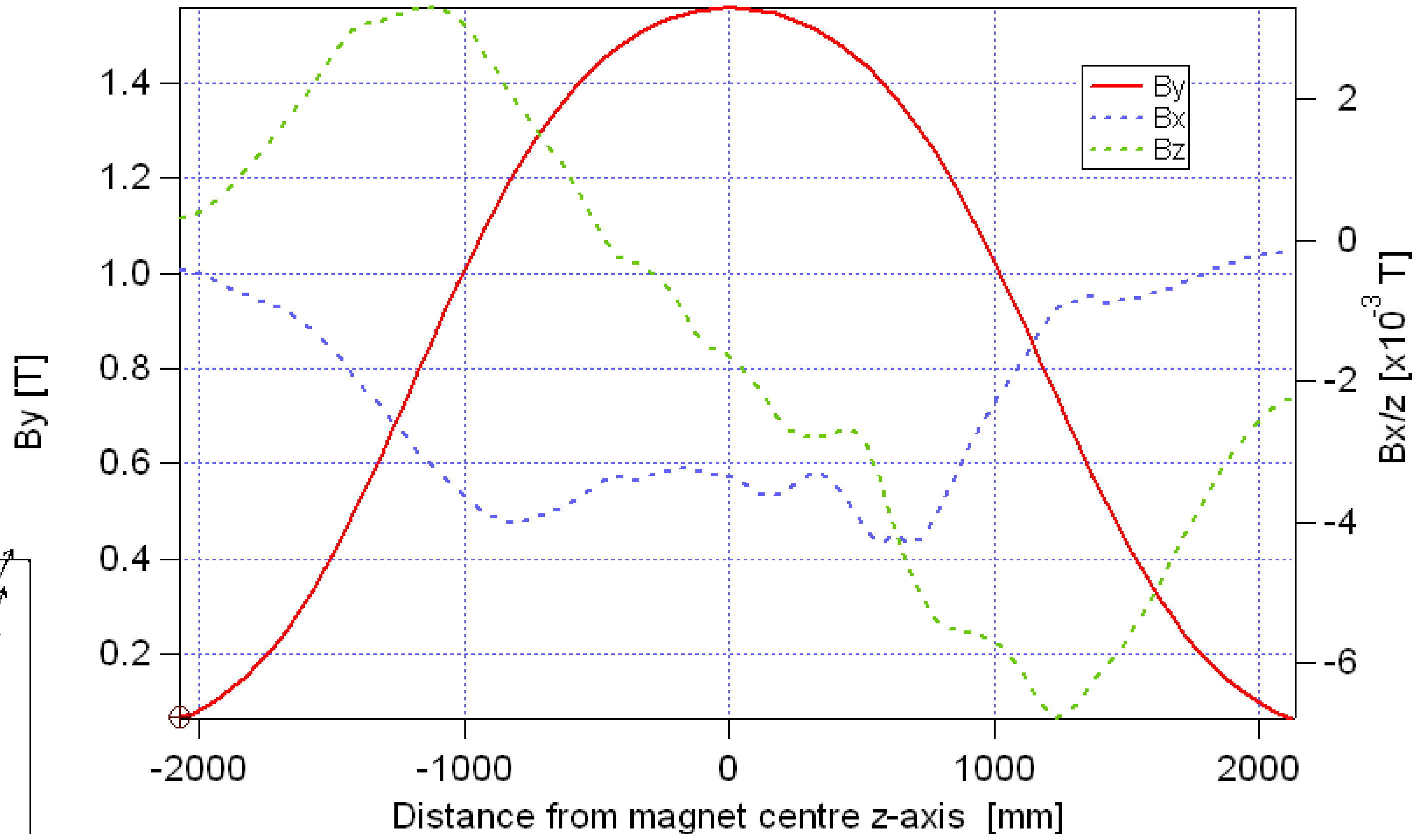
TASD Parameters

Parameter	Symbol	Unit	Nominal Value	Range Min	Range Max
Detector global dimensions					
Detector width	w_{det}	m	1.0	0.9	1.1
Detector height	h_{det}	m	1.0	0.9	1.1
Detector depth	d_{det}	m	0.75	-	-
Detector depth with gaps	d_{gap}	m	197.5	-	-
Plastic scintillator					
Number of planes per module (xy or uv)	-	-	2	1	2
Number of modules	n_{module}	-	50		
Gap between planes within module		cm	0	0	0.05
Module envelope thickness	t_{env}	cm	0.05	0	0.05
Scintillator bar length	l_{sci}	cm	90.0	80.0	100.0
Scintillator bar width	w_{sci}	cm	1.0	1.0	3.0
Scintillator bar height	h_{sci}	cm	0.7	0.6	1.0
Bars per module	n_{bars_mod}	-	180		
Total number of bars	n_{bars_tot}	-	9000		

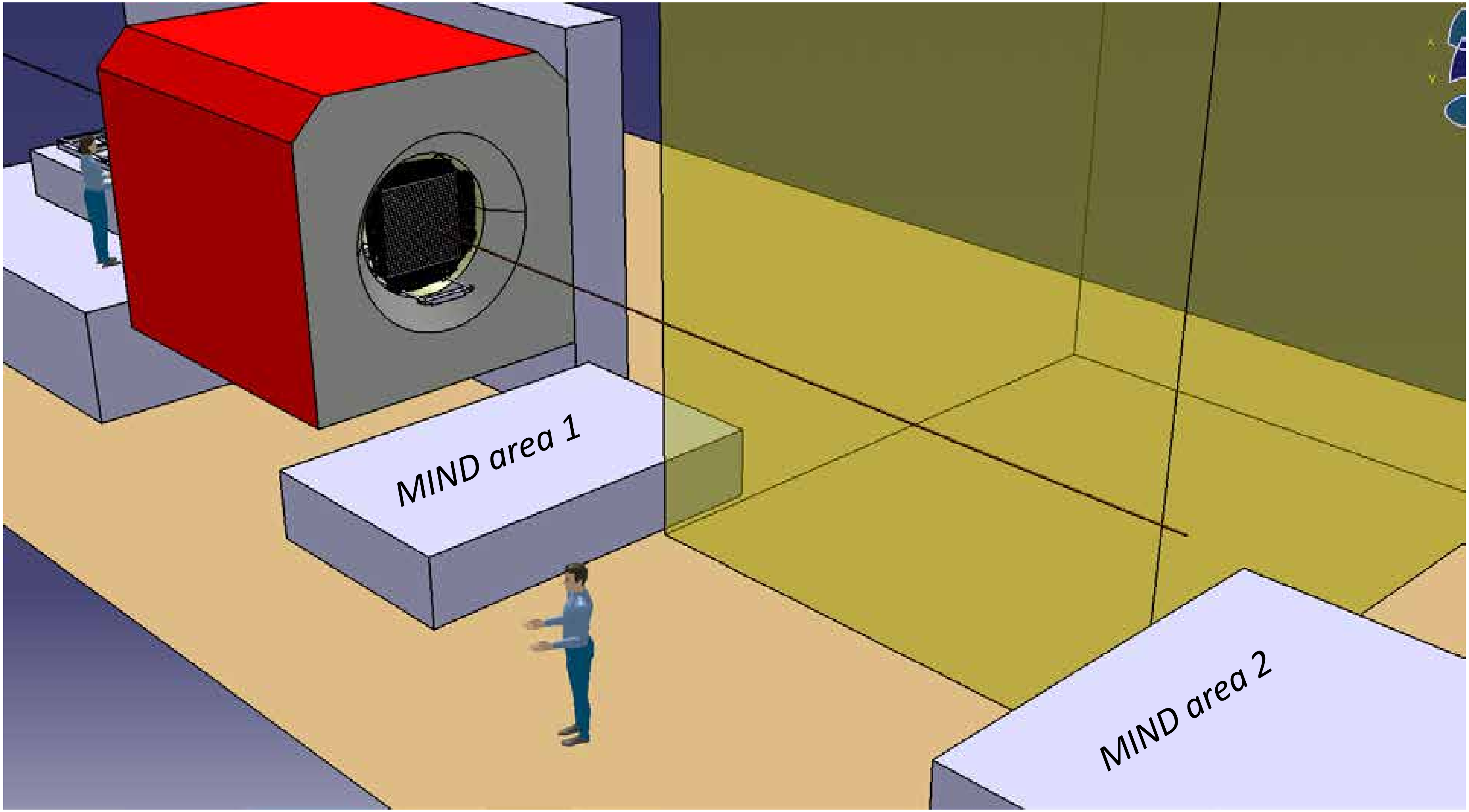
Morpurgo magnet B-field



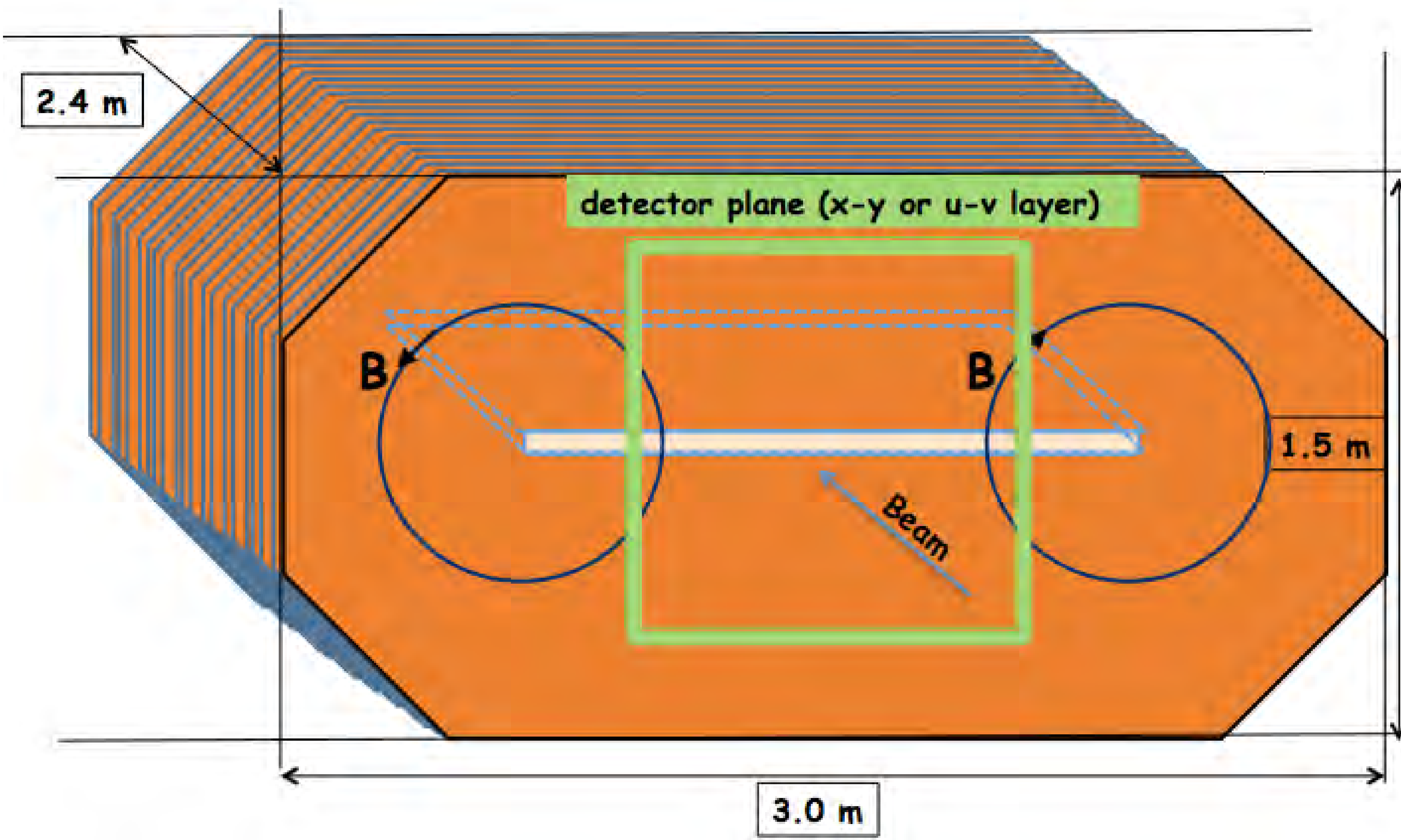
X-Y slice



General Layout: Baby-MIND



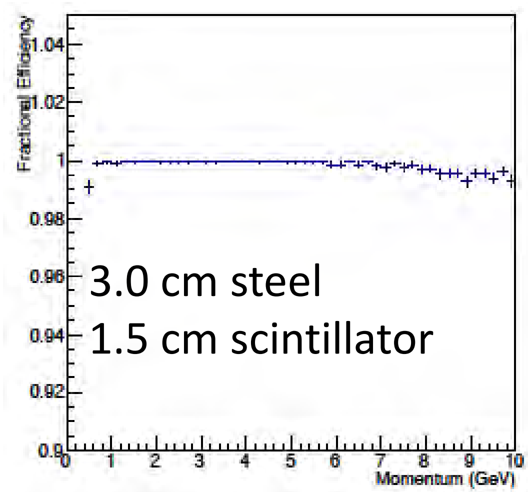
Baby-MIND Dimensions

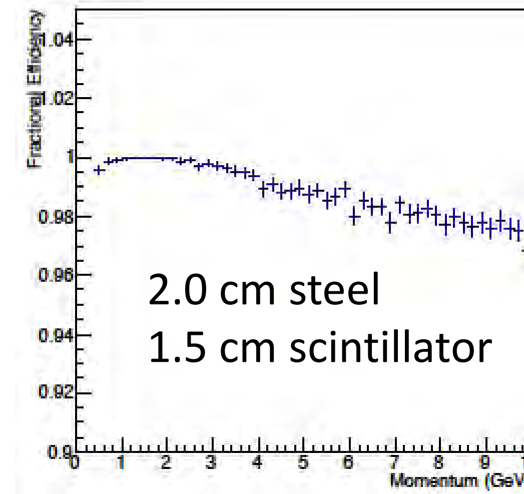


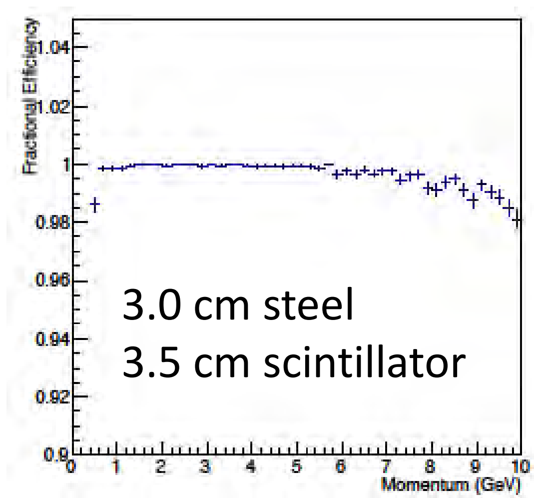
Baby-MIND Steel Selection

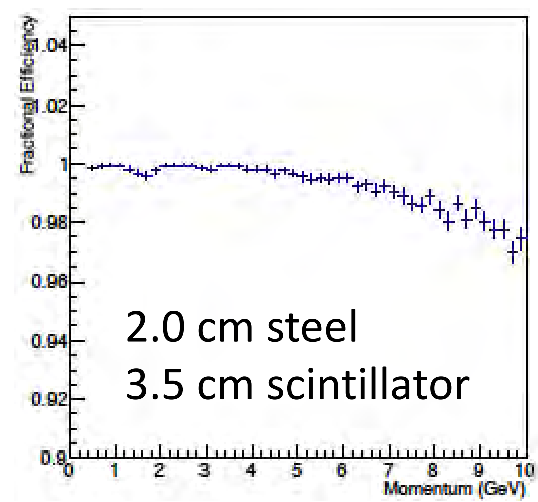
R. Bayes

- Muon reconstruction efficiencies are good for all scenarios considered here, slightly better for 3.0 cm steel, 1.5 cm scintillator.
- Charge I.D. efficiencies are identical for all scenarios.
- Cost...
  - ARMCO: 5.4 CHF/kg.
  - AISI1010
  - AISI1006 (MINOS)







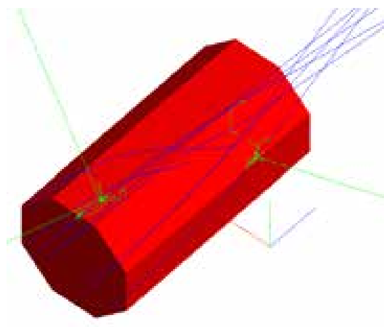


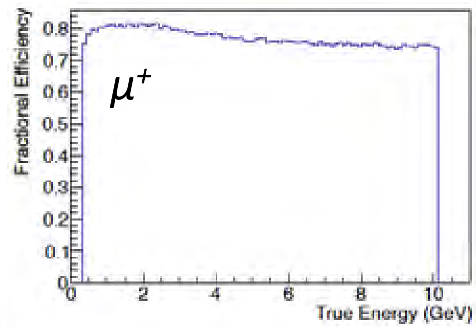
MIND Proto Simulations

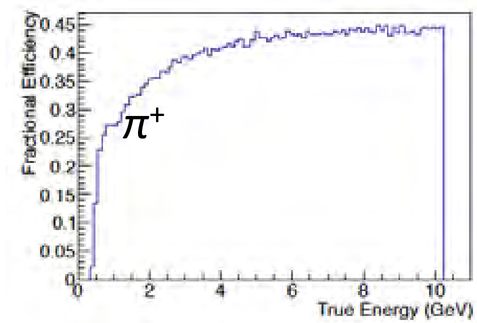
R. Bayes

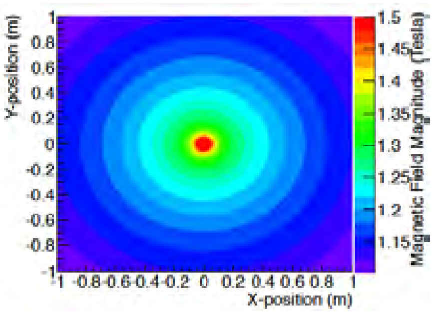
MIND Prototype

- 1 m × 1 m × 2 m
- 3 cm Fe
- 2 cm scintillator
- 7 cm dia. copper STL (for scattering)
- Toroidal B-field 100 kA



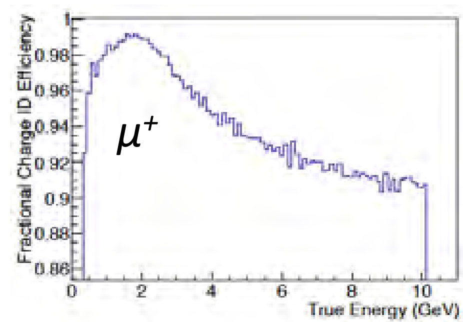


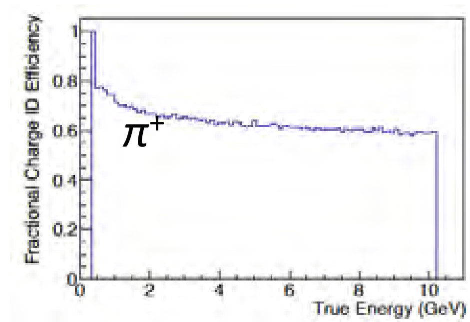




10 μ^+ events é :

- Generated at random on X-Y plane at Z=L/2
- 1 million events per simulation



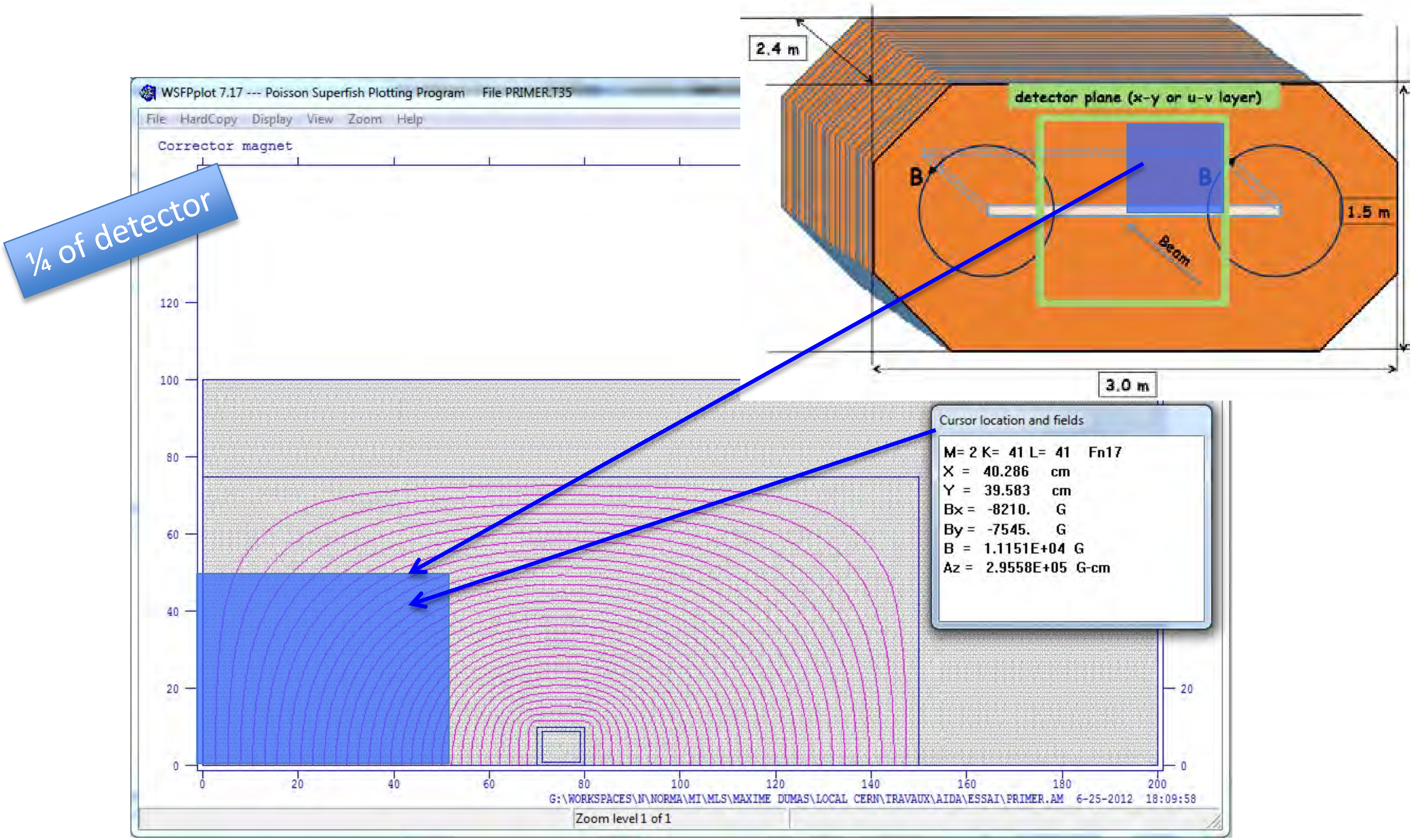


Particle	Detector - MIND	Reconstruction efficiency	Charge identification efficiency
μ^+	Prototype	80% (1GeV) 75% (10GeV)	99% (1GeV) 91% (10GeV)
μ^+	Far	81% (Flat 1 to 25GeV)	99.5% (1GeV) 98% (25GeV)
μ^-	Prototype	60% (1GeV) to 64% (10GeV)	92% (1GeV) to 83% (10GeV)
π^+	Prototype	13% (1GeV) to 45% (10GeV)	80% (1GeV) to 60% (10GeV)
π^-	Prototype	11% (1GeV) to 42% (10GeV)	75% (1GeV) to 55% (10GeV)

Baby-MIND Magnetisation

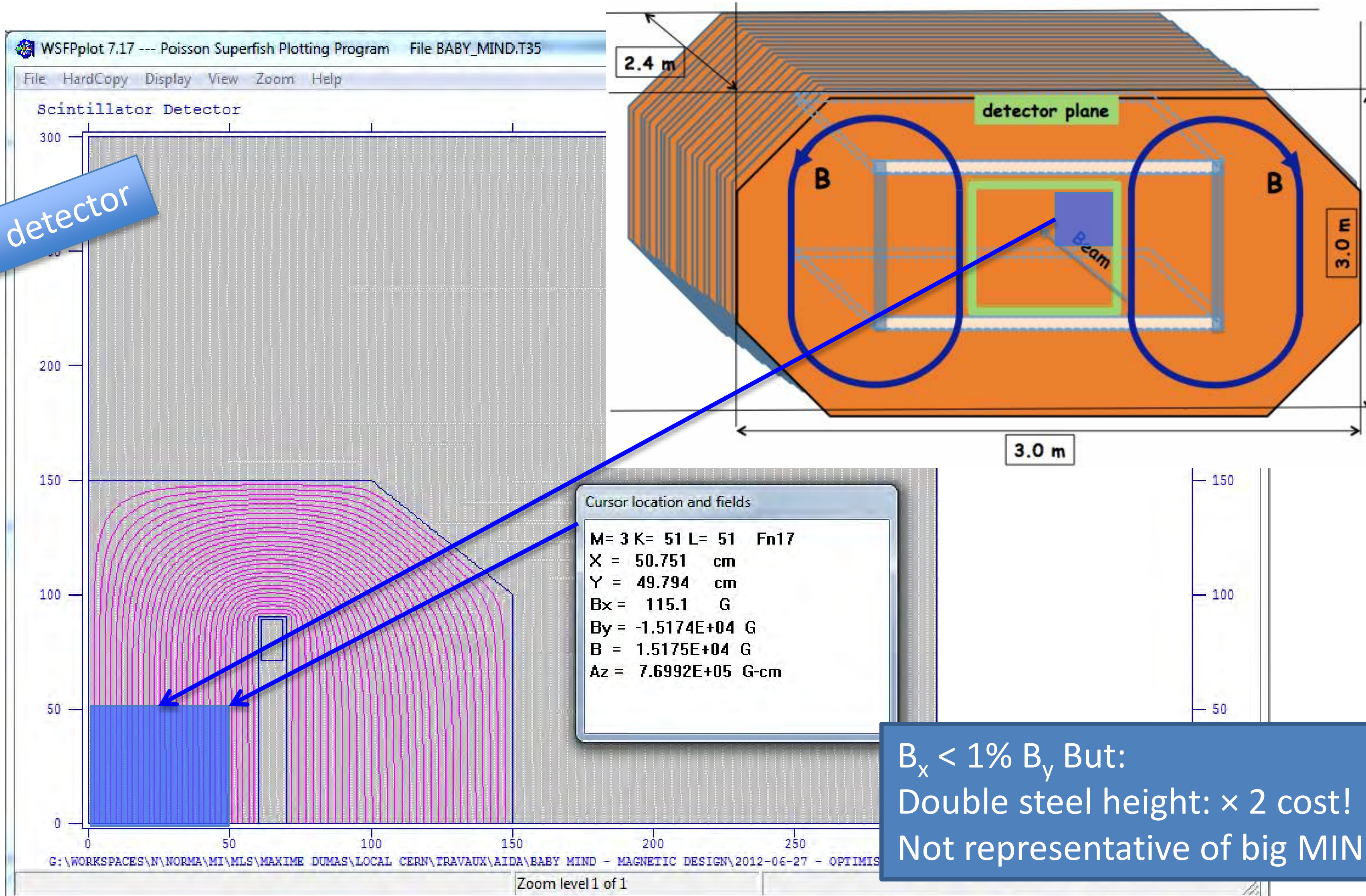
- Magnetic field requirements:
  - field nominal value: 1.5 T ± 20%.
  - knowledge of field in volume of interest to precision of 1e-4.
  - ~~Bx component < 1% of By within steel, along projection of plas. sci.~~
  - field uniformity within steel along projection of plastic scintillator vol.: 10%.
  - field value outside MIND volume: maximum = 100 Gauss.
- Power supply parameters:
  - if possible should match existing power supplies at CERN that could be borrowed for this application,
  - if above point not possible, then optimise for cost (purchase and operation).
- Ongoing evaluation by CERN TE-MSC-MNC:
  - Study A: First optimisation of basic parameters
  - Study B: One coil vs. Two coils
  - Study C: Normal conducting vs superconducting.

One coil – no slots



M. Dumas, J. Bauche

Two coils - with slot



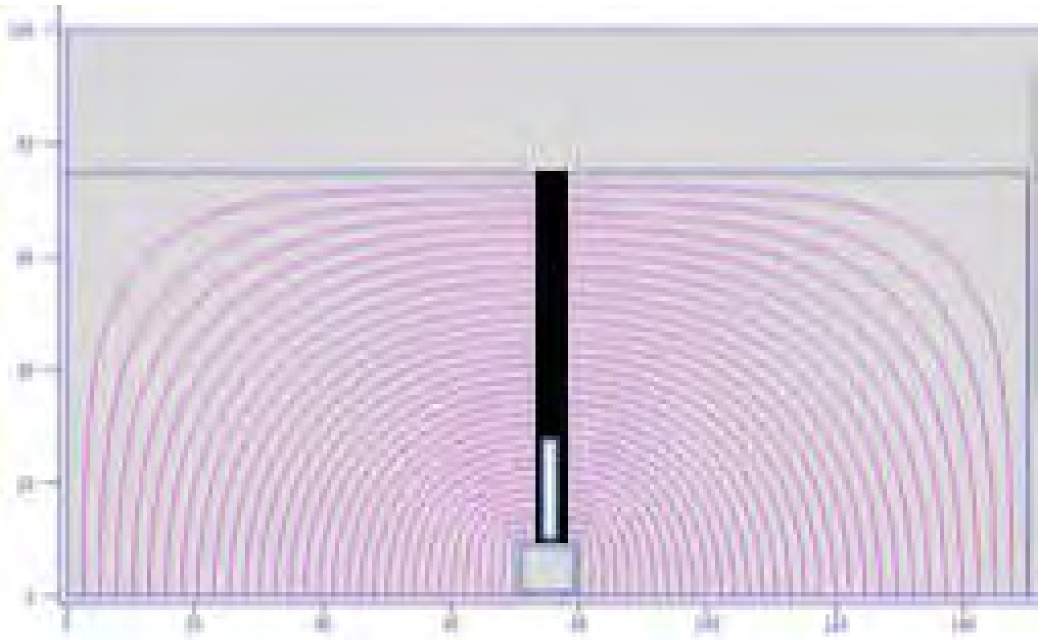
¼ of detector

$B_x < 1\% B_y$ But:
Double steel height: × 2 cost!
Not representative of big MIND

M. Dumas, J. Bauche

Measuring B-field

- 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.
- Use measurements to cross-check and validate simulated field across whole detector.
- ~23000 At with slot c.f. 4000 At without slot.

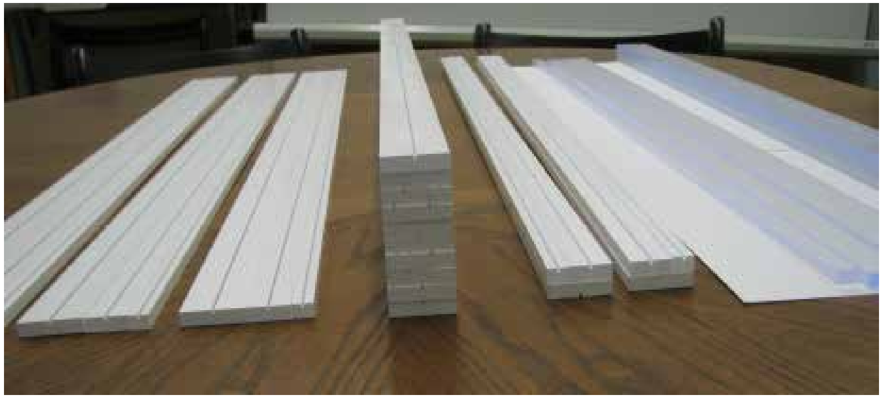


M. Dumas, J. Bauche

Plastic scintillators

Prototyping at INR RAS:

- Extruded scintillator slabs produced at **Uniplast company**, Vladimir, Russia
  - polysterene based, 1.5% of paraterphenyl (PTP) and 0.01% of POPOP
- Plastics initially used for **T2K SMRD** detector counters production
- Counter **surface** is etched with a **chemical agent** (Uniplast) to create a 30-100 μm layer that works as **diffusive reflector**
- Counters of **three** different **sizes**:
  - $895 \times 7 \times 10\ \mathrm{mm}^3$
  - $895 \times 7 \times 20\ \mathrm{mm}^3$
  - $895 \times 7 \times 30\ \mathrm{mm}^3$
- 2 mm deep **grooves** to embed fibers:
  - **three** different types of **fiber**
  - Fiber diameter: 1.0 mm, 1.2 mm, 1.5 mm
  - Groove width: 1.1 mm, 1.3 mm, 1.7 mm



A. Izmaylov, A. Khotjantzev, Y. Kudenko, O. Mineev

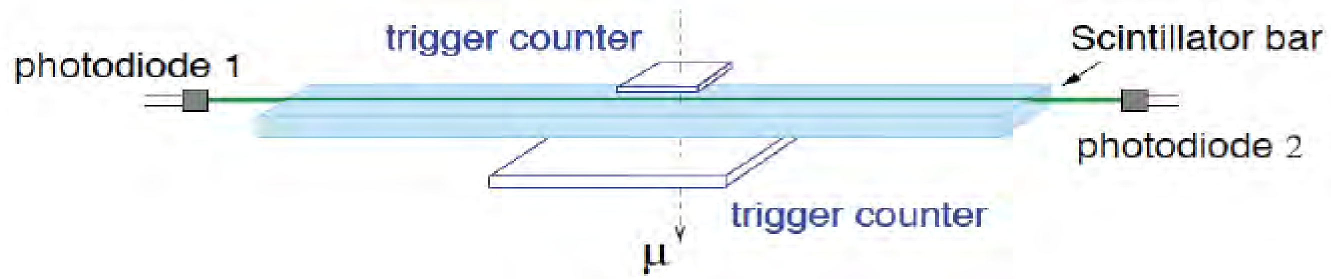
Cosmic telescope tests

Light collection:

- **Kuraray** WLS fiber (200 ppm, S-type, 1.0 mm dia)
- Toshiba TSF451-50M **silicone grease** used to **embed fiber**
- Photosensors (two-sided readout): 667-pixel avalanche photo-diodes **Hamamatsu MPPC** (~55k MPPCs used in **T2K ND**)
- HV from Hamamatsu, **gain of 7.5×10^5** for 25°C
- Note!: no correction for cross-talk + after-pulses (~15% in total)

Cosmic telescope:

- two trigger counters
- upper one: 7×7 cm^2 (L.Y. checks) and 2×2 cm^2 (timing)
- lower one: 10 x 24 cm^2
- measurements at counter center: L.Y. per cosmic MIPs



Light yield with no chemical reflector

Counter width	MPPC 1 L.Y. [pe]	MPPC 2 L.Y. [pe]	ΣL.Y. [pe]
No chemical reflector/ No Tyvek			
10 mm	15.7	15.8	31.5
20 mm	15.5	13.6	29.1
30 mm	12.8	11.5	24.3
No chemical reflector/ Tyvek reflector 100-120 μm			
20 mm	41.8	34.8	76.6

Tyvek effect
× 2.5

- **Light attenuation** length in bars ~**8 cm**.
- **T2K SMRD** experience: L.Y. > **12 p.e.** (sum of both ends) allows to achieve **99%** detection efficiency.
- **Highest L.Y.** for **smallest width**.

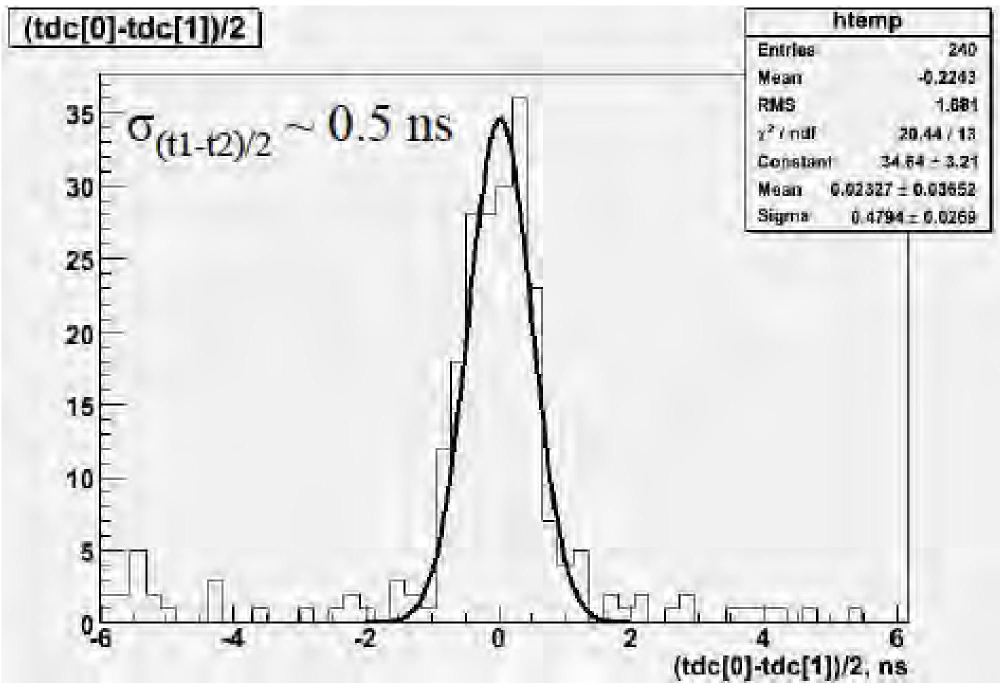
Light yield with chemical reflector

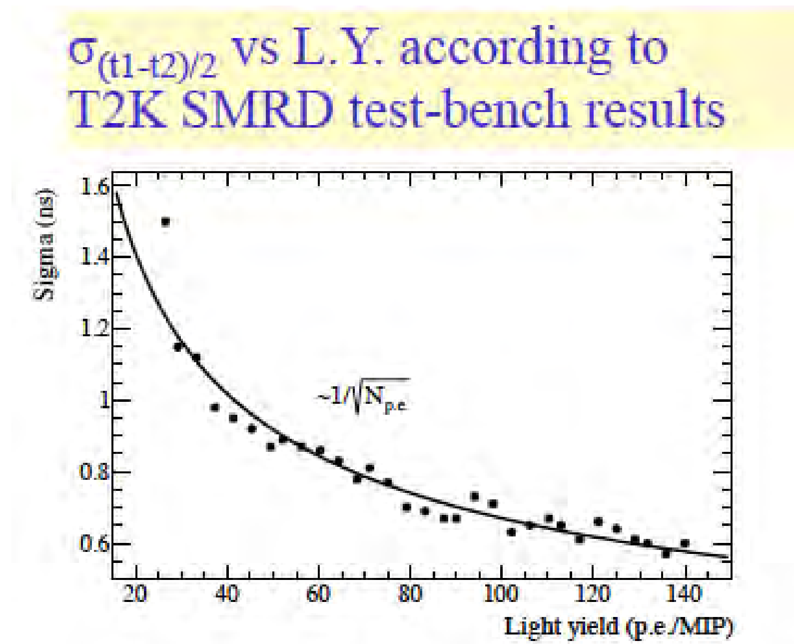
Counter width	MPPC 1 L.Y. [pe]	MPPC 2 L.Y. [pe]	ΣL.Y. [pe]
Chemical reflector/ Optical grease			
10 mm	46.0	36.8	82.8
20 mm	39.7	35.7	75.4
30 mm	31.2	26.6	57.8
Chemical reflector/ no optical grease			
20 mm	25.7	22.1	47.8
Chemical reflector/optical grease/Tyvek reflector			
20 mm	49.3	44.0	93.3

- **× 2.5 effect** of **chemical reflector** compared with no chemical reflector.
- **60%** effect of **optical grease** (same expected with **optical glue**).
- **20%** effect of additional **Tyvek reflector**.

Timing characteristics

- Timing dominated by fiber decay constant: $t_{fiber} \sim 12$ ns.
- 0.5 p.e. TDC threshold to suppress timewalk effects.
- Two-sided readout è $(t_1-t_2)/2$ combination to estimate timing.





SiPM Characterisation

- Have a basic modelling approach to:
  - Compare experimental measurements with semi-empirical processes – fitting of raw data...
  - Extract parameters from experimental measurements for digitisation
- Steps:
  - Response of SiPM to single photon
  - Estimate number of photoelectrons produced
  - Combine single photon response with multi-photon input
  - SiPM output and path to digitisation

Energy deposition in scintillator

10 GeV/C

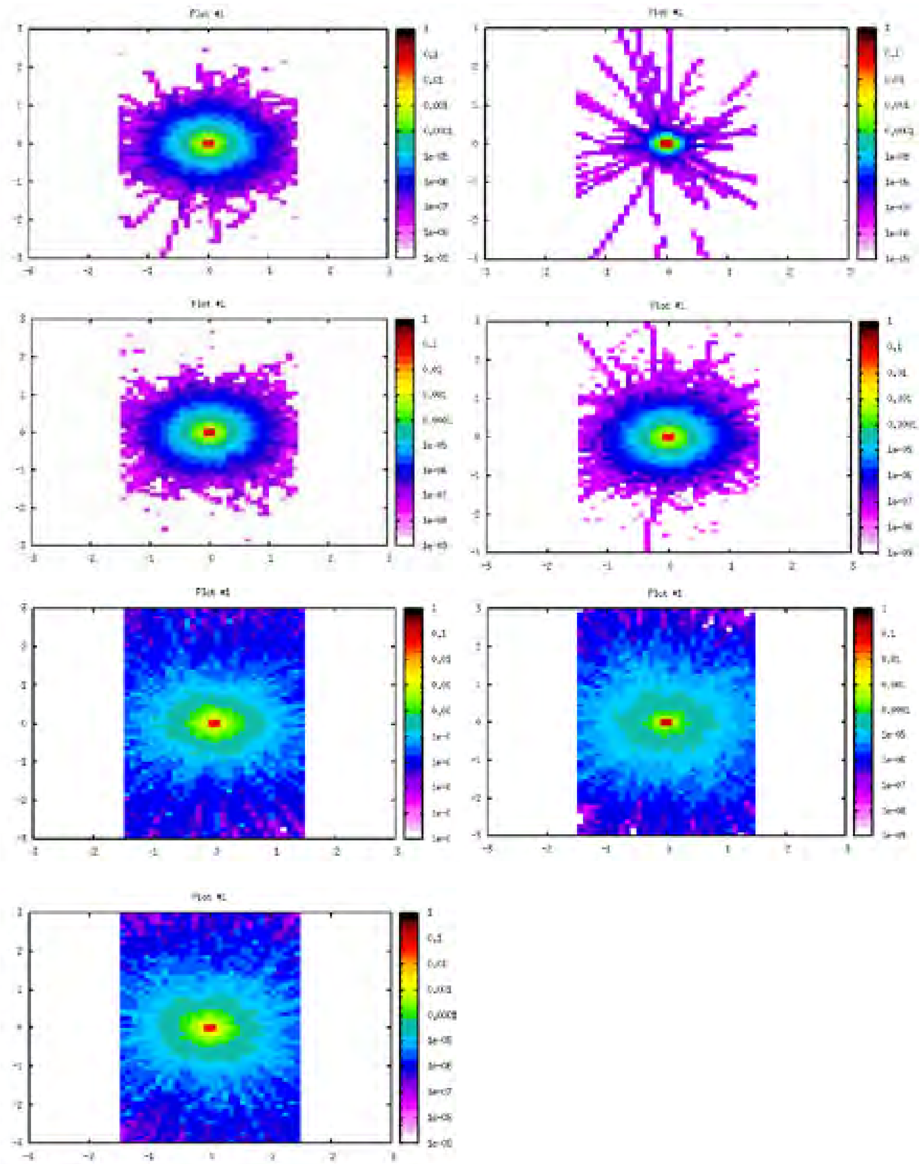
0.1 GeV/C

m

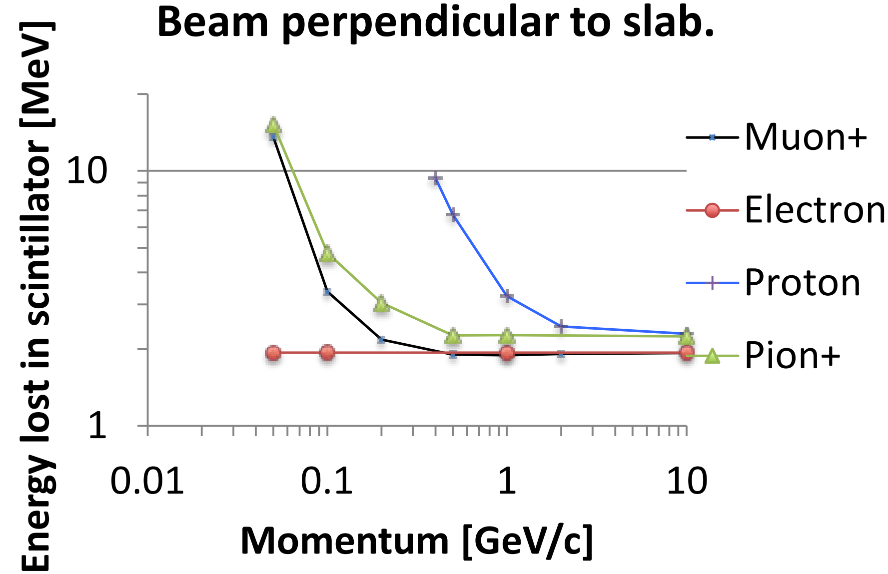
e

p

p



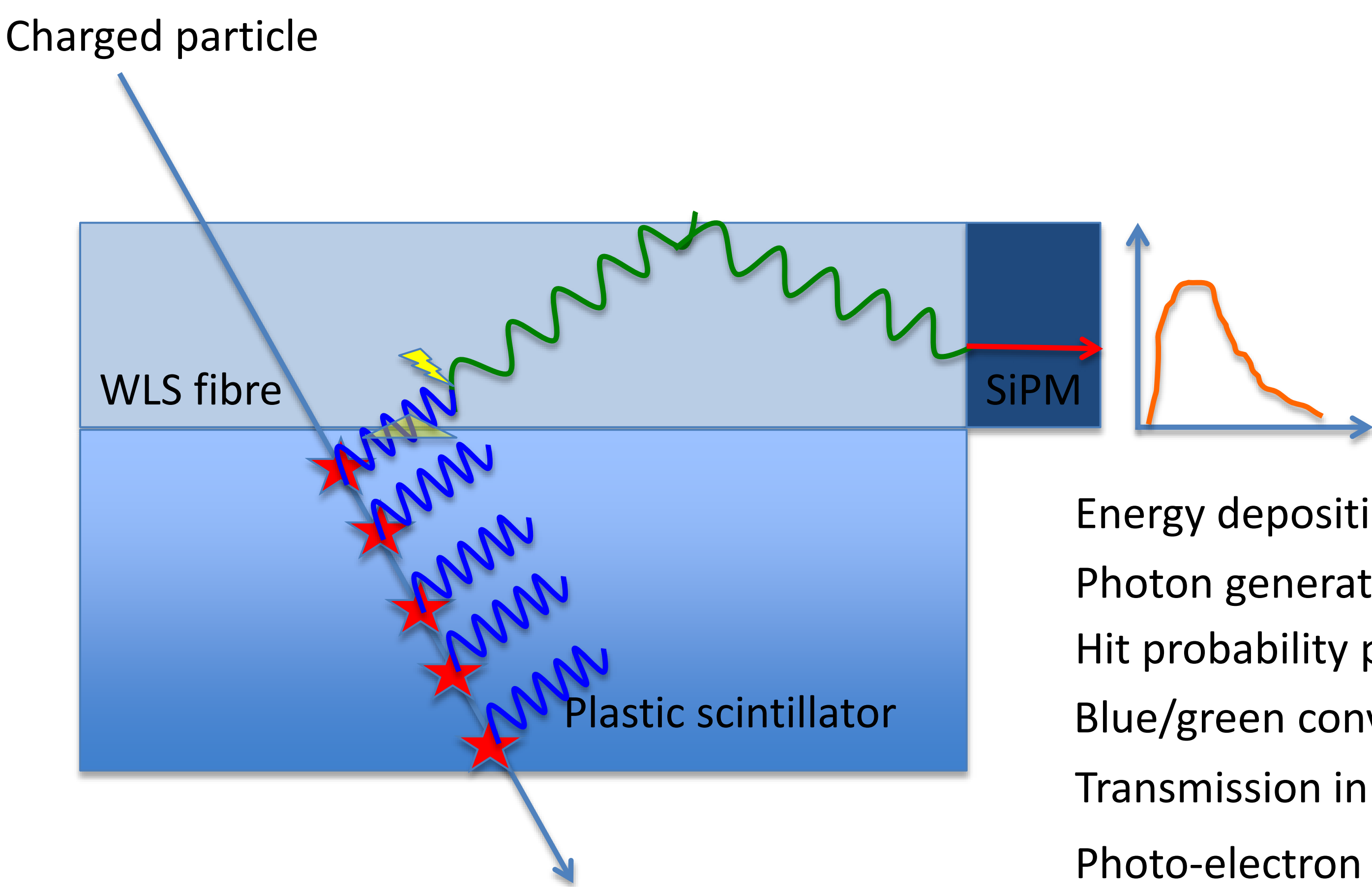
Energy deposited in a 1cm deep plastic scint: Beam perpendicular to slab.



L.Y. estimates

Parameter	Unit	AIDA [Perpendicular]	AIDA [MAX]
Energy deposition			
Track length	[cm]	0.70	1.00
Peak Edep/cm	[MeV/cm]	8.82	8.82
Peak Edep	[MeV]	6.17	8.82
Edep/MIP/cm	[MeV/MIP/cm]	2.00	2.00
Edep/MIP	[MeV/MIP]	1.40	2.00
Photon conversion			
Photon yield	[ph/MeV]	1.25E+04	1.25E+04
Photon yield per bar	[ph]	7.72E+04	1.10E+05
Photon efficiency	%	5.00E-03	5.00E-03
Photons on SiPM	[ph]	3.86E+02	5.51E+02
MRS APD case (PDE = 35%)			
Light yield	[p.e./MeV]	21.4	21.4
Total light yield	[p.e./bar]	132.1236	**188.748**

Processes leading to SiPM output



Energy deposition

Photon generation in p.s.

Hit probability p.s. to WLS

Blue/green conversion in WLS

Transmission in WLS

Photo-electron conversion

SiPM output

Number of photons incident on SiPM

$$n_{phe}(x) = k(x) E_{dep}$$

$$k(x) = k_{d.i.} k_{att}(x)$$

$$k_{d.i.} = Y_{photon} P_H P_{Trans} P_Q$$

Initial photon yield ~ 1.25e4/MeV

Integral of SiPM quantum efficiency ~ 20% (check)

Probability that blue photon from p.s. hits WLS

$$P_H = \frac{d_f / w_s + h_s}{(d_f / w_s + h_s) + \left(1 - e^{-(w_s + hs)/\Lambda_s}\right) + (1 - R_s)}$$

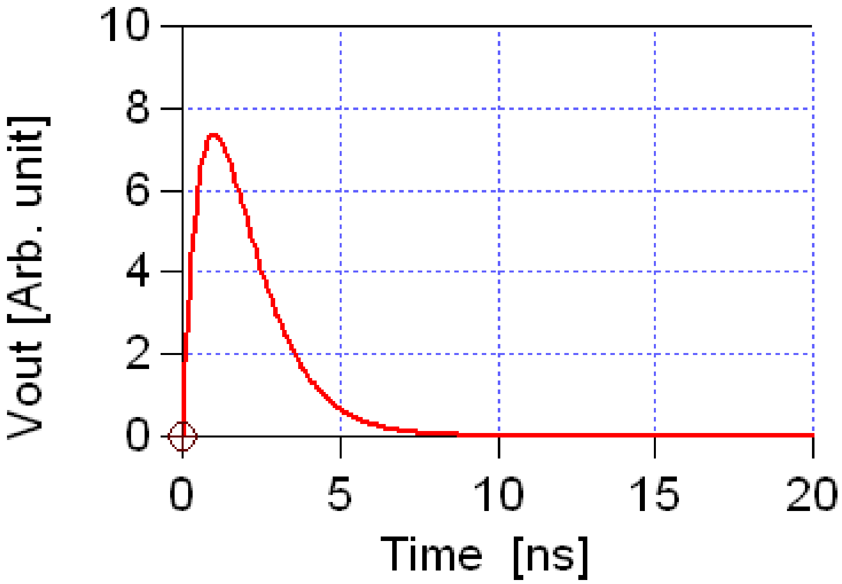
Probability that green photon propagates in WLS by total internal reflection

$$P_{Trans} = \frac{1}{2}(1 - n_{clad} / n_{core})$$

SiPM Single photon response

- Assume for time being that SiPM circuit is similar to PMT circuit (later derive more appropriate approximation) i.e.:
  - Single high-pass filter $t_1 = C_1 R_1$
  - Series of low-pass filters $t_2 = C_2 R_2$

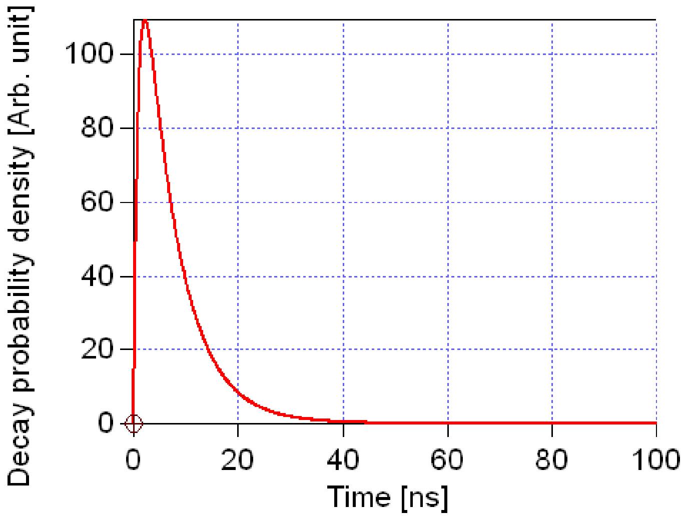
$$v^{1p.e.}(t) = \frac{QR}{\tau\Gamma(1+\alpha)}\left(\frac{t}{\tau}\right)^{\alpha} e^{-t/\tau}$$



Time distribution

- Three main contributions:
  - Decay times in scintillator and WLS
  - Propagation delay
  - Internal SiPM transit time
- Decay time distribution:
  - Random variable that is the sum of independent random times
  - Characteristic decay times: t_p and t_f

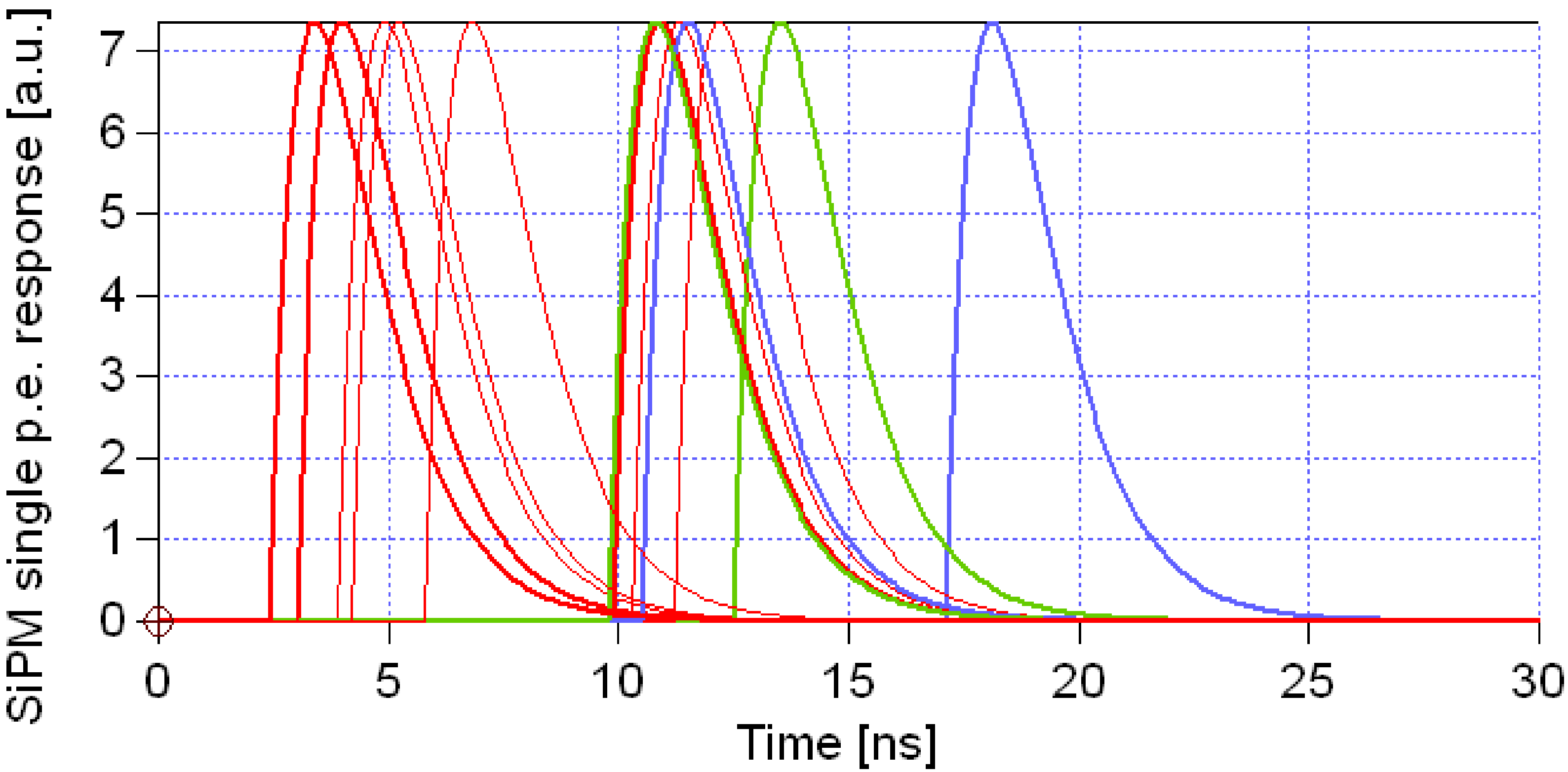
$$P_D(t^{decay}) = \frac{e^{-t/t_p} - e^{-t/t_f}}{t_p - t_f}$$



SiPM Output

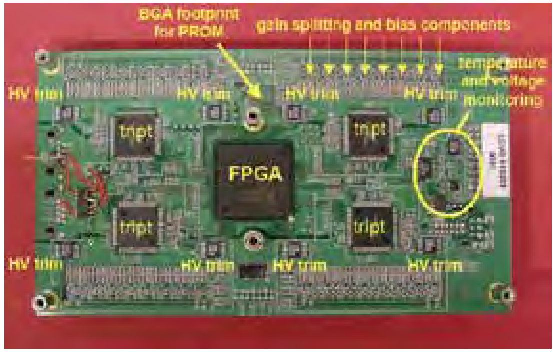
- Sum over all photoelectrons of SiPM response to single photoelectron.

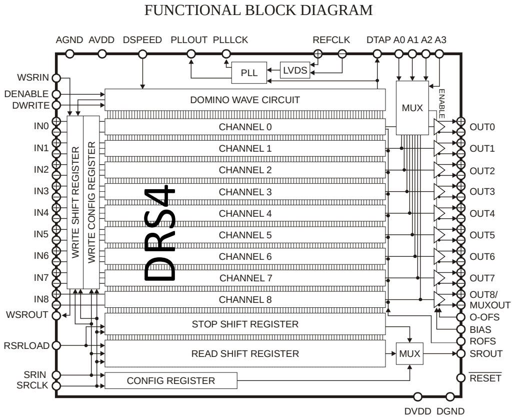
$$v^{tot}(x,t) = \sum_{i=1}^{n_{phe}} v(t - t_i)$$



TASD and baby-MIND Electronics

- Secondary/Tertiary beam from SPS:
  - Slow extraction: < 100000 particles/(10s spill) every 60s
- Electronics: 1000-10000 samples/s
- Dynamic range: estimate 500 p.e. (100 p.e./MIP)
- Number of channels: ~10000 ch.
- Allowable noise level: 0.5 p.e.
- Timing res.: TBD
- Cost: 15 CHF/channel
- Options:
  - DRS4/5 (PSI, NA61 development)
  - MAROC/EASIROC (MICE EMR)
  - ~~TRIP-t (T2K ND280)~~





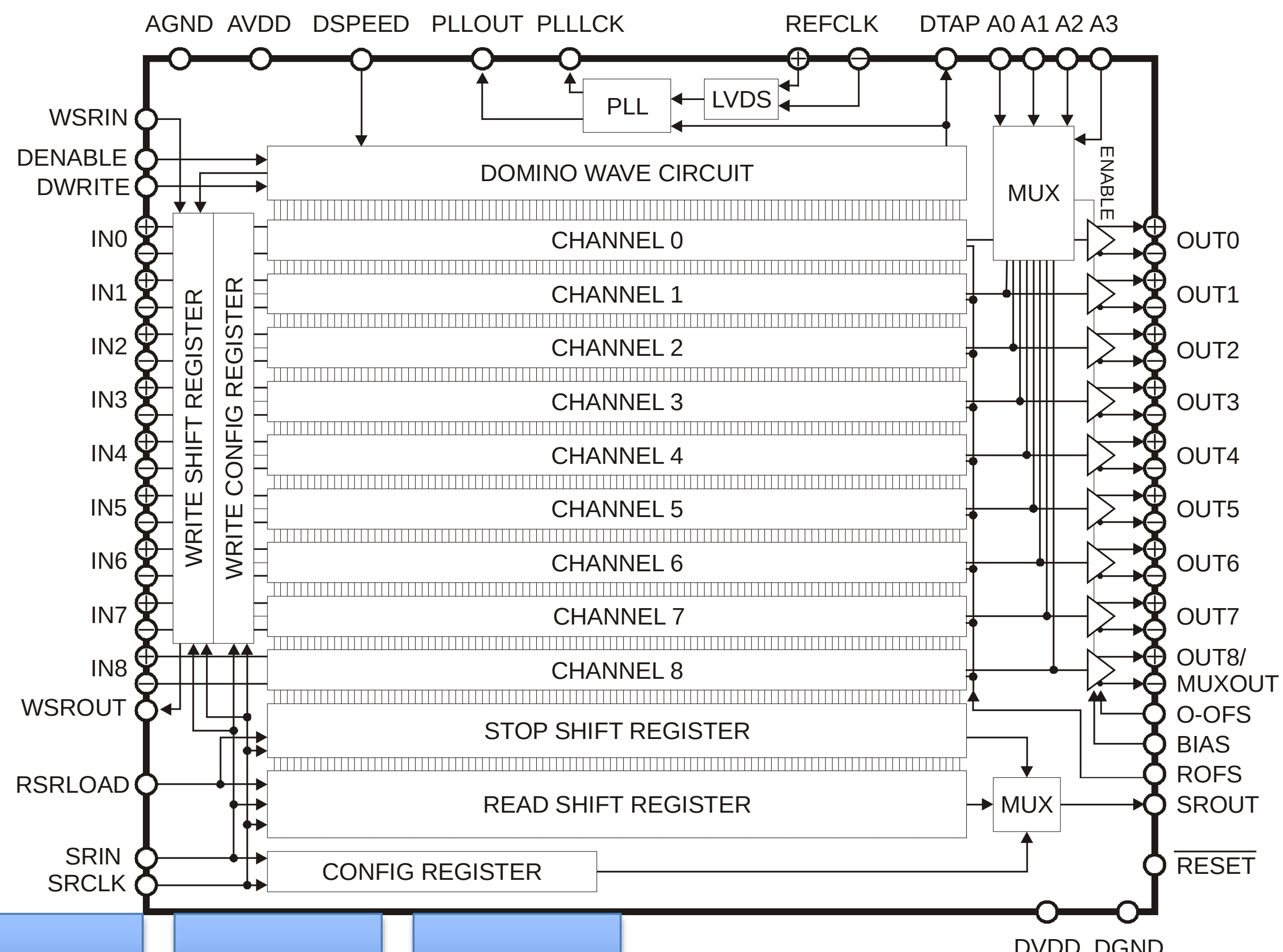
E. Noah – nuSTORM Workshop – Fermilab – 21/09/2012

DRS4

S. Bravar

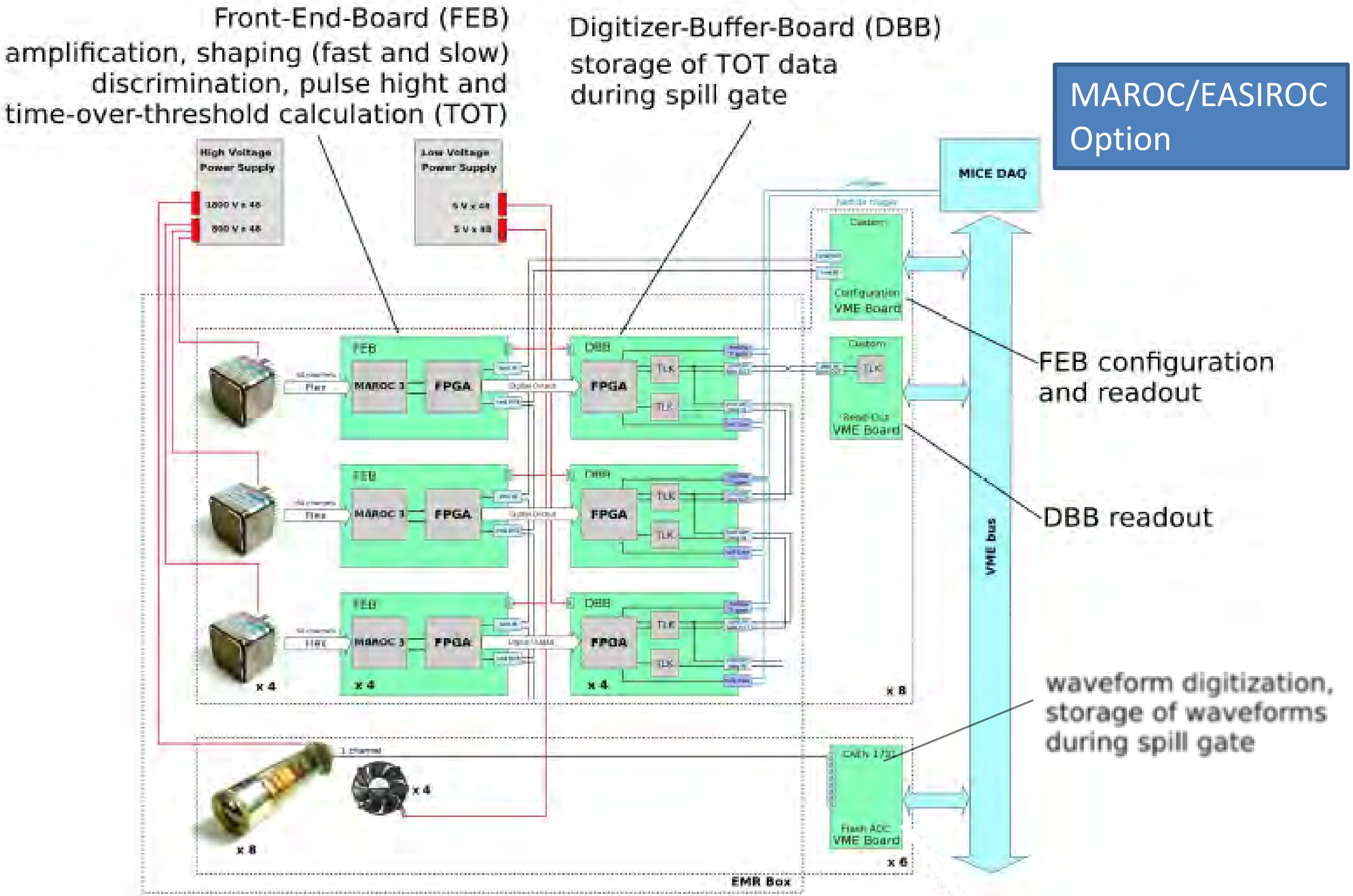
- Fabricated in 0.25 mm 1P5M MMC process (UMC), 5 x 5 mm2, radiation hard
- 8+1 ch. each 1024 bins, 4 ch. 2048, ..., 1 ch. 8192
- Passive differential inputs/outputs
- Sampling speed 700 MHz ... 5 GHz
- On-chip PLL stabilization
- Readout speed 30 MHz, multiplexed or in parallel

FUNCTIONAL BLOCK DIAGRAM



SiPM → Ampli → DRS → ADC → FPGA

MICE EMR Electronics



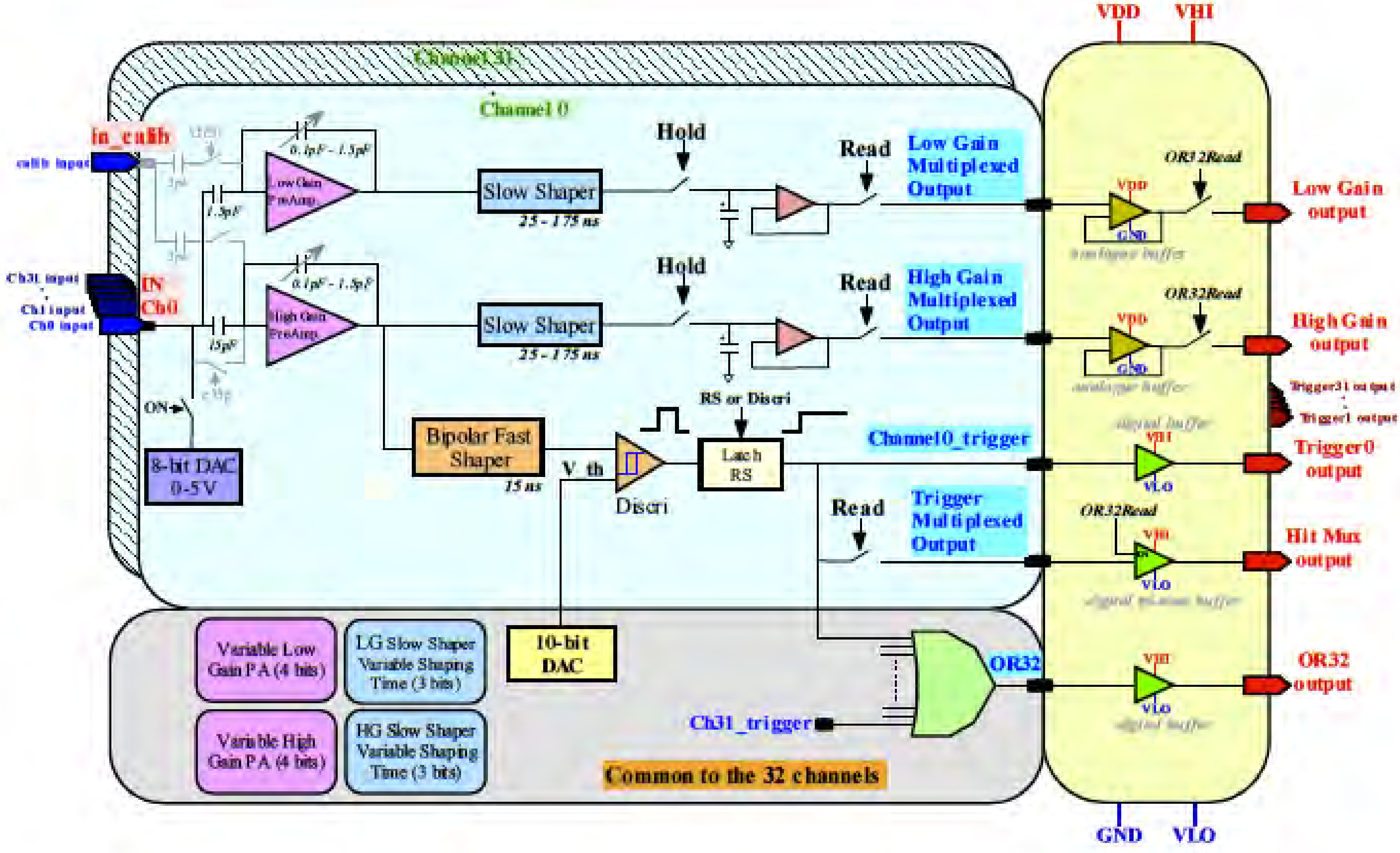
Omega Micro Chips - LAL

	MAROC	SPIROC	EASIROC	HARDROC	MICROROC	SKIROC	PARISROC	SPACIROC
Technology	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe	0.35μ SiGe
Packages available	• Naked • QFP240	• Naked • TQFP208	• Naked • TQFP160	• Naked • TQFP160	• Naked • QFP160	• Naked • QFP240	• Naked • QFP160	• Naked • CQFP240
Detector compliant	PMT, MAPMT, SiPM, μmegas, RPC	PMT, MAPMT, SiPM, μmegas, RPC, GEM, PIN	PMT, MAPMT, SiPM, μmegas, RPC, GEM, PIN	PMT, MAPMT, SiPM, μmegas, RPC	μmegas	RPC, GEM, PIN	PM matrix	MAPMT
Optimized for	MAPMT	SiPM	SiPM	RPC	μmegas	PIN	PM matrix	MAPMT
Nmber of channels	64	36	32	64	64	64	16	64
Kind of measurement	• Threshold • Charge	• Threshold • Charge • Time	• Threshold • Charge	• Threshold • Charge	• Threshold • Charge	• Threshold • Charge	• Threshold • Charge • Time	• Threshold • Charge
Outputs	64 triggers, 1 mux charge (analogue), 1 mux charge digitized	1 digital formatted output, 1 mux charge (analogue)	32 triggers, 2 mux charge (anlogue), 1 mux trigger	1 digital formatted output, 1 mux charge (analogue)	1 digital formatted output, 1 mux charge (analogue)	1 digital formatted output, 1 mux charge (analogue)	16 triggers, 1 digital formatted output, 1 mux trigger	64 triggers, 9 mux charge
Input Polarity	Negative	Positive	Positive	Negative	Negative	Positive	Negative	Negative

EASIROC Description

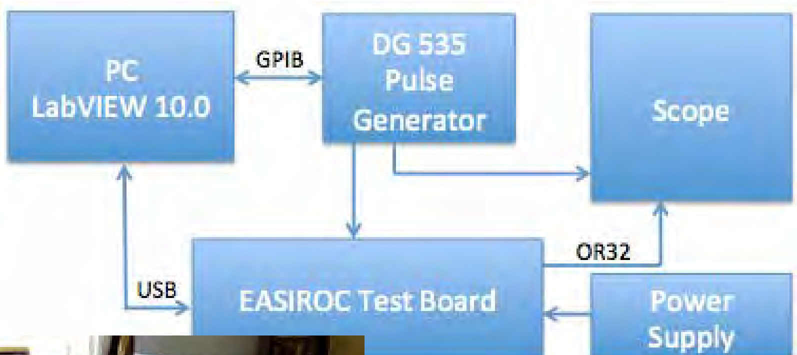
- Number of channels: 32
- Analogue core :
  - Internal input 8-bit DAC (0-4.5V) for individual SiPM gain adjustment
  - Individually addressable calibration injection capacitance
  - Energy measurement : 14-bit dynamic range
    - 2 tuneable gains followed by 2 adjustable shapers
    - Analogue memory (Track & Hold cell) for low gain and high gain
    - Common 10-bit DAC for threshold adjustment
    - Variable shaping time: from 25 ns to 175 ns
    - from 160 fC à 320 pC (ie. 1 pe à 2000 pe @ SiPM gain = 10^6)
    - pe/noise ratio : ~10 @ SiPM gain 10^6
  - Trigger output
    - pe/noise ratio on trigger channel : ~ 25
    - Fast shaper : ~15ns
    - Trigger on 50 fC (ie. 1/3 pe @ SiPM gain = 10^6)

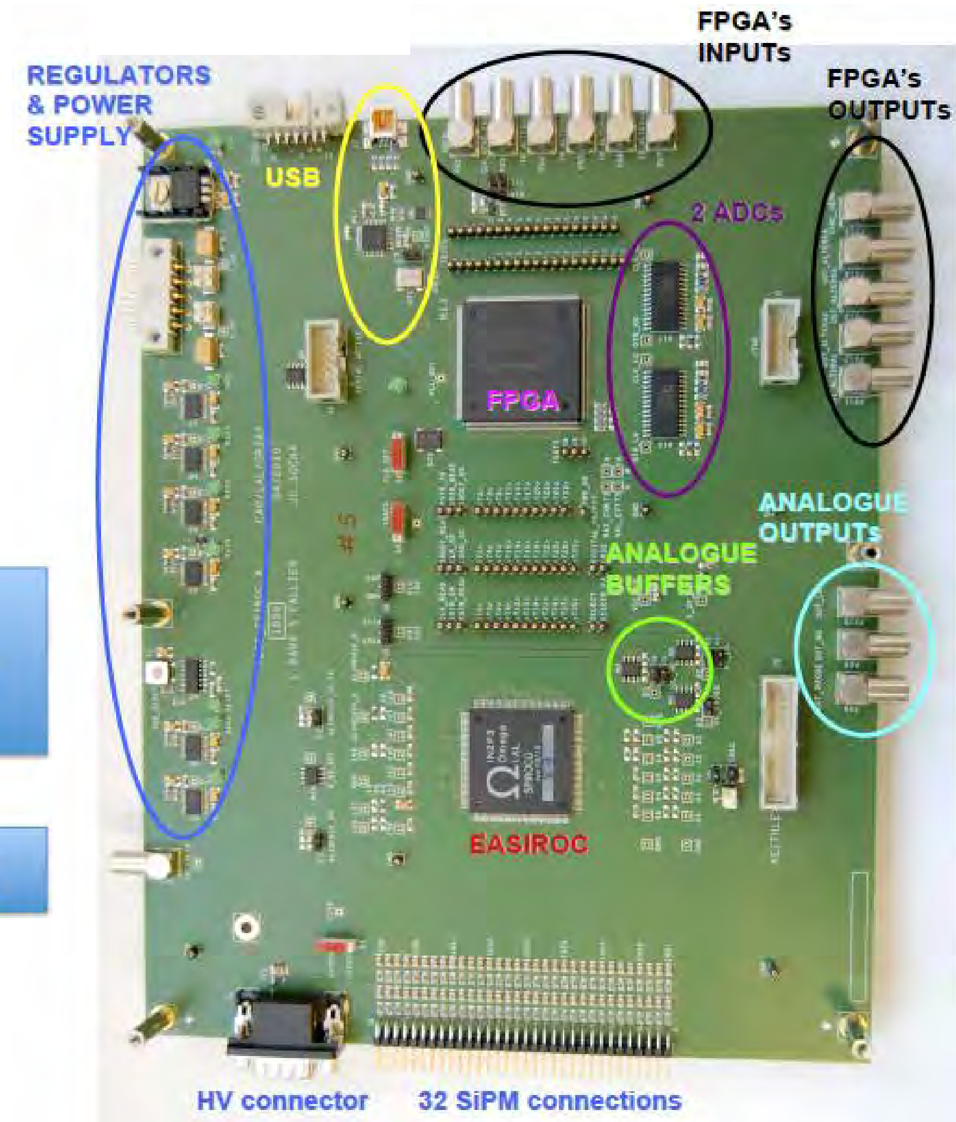
EASIROC Schematic



EASIROC Evaluation Board

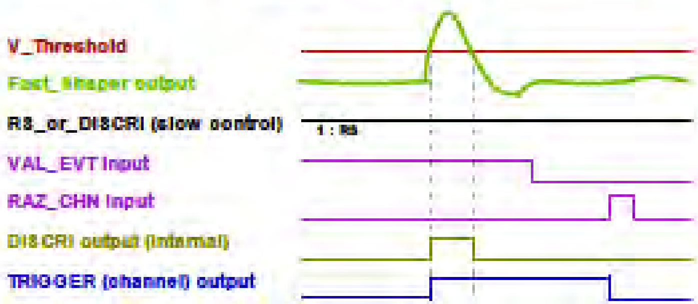
- Enables tests of most of the functionality of the EASIROC.
- Full access to slow control 456 bits.
- Pins on I/O allow for easy monitoring.
- External ADCs for analogue signal tests.



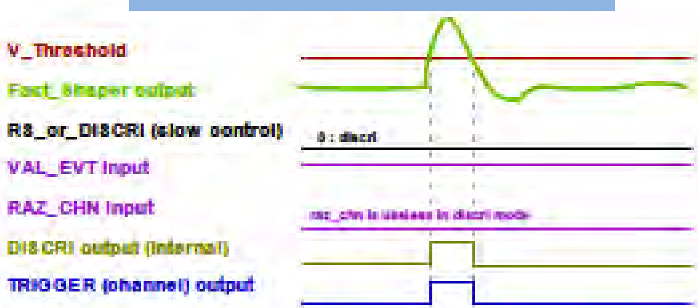


Trigger Output

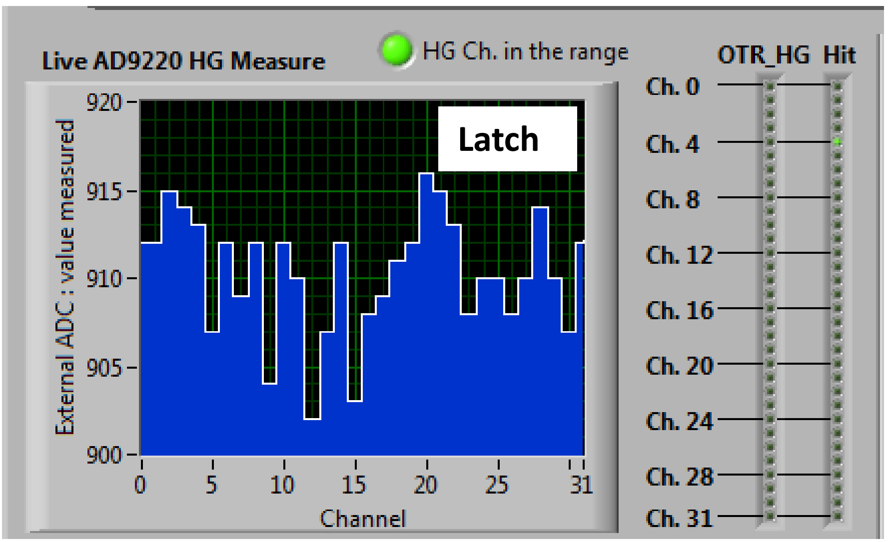
Val Evt signal effect

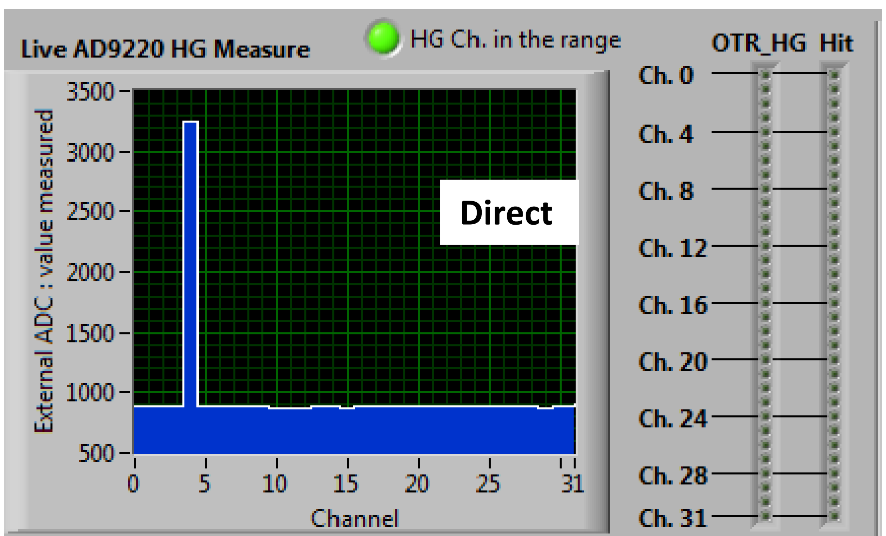


Trigger output using latch

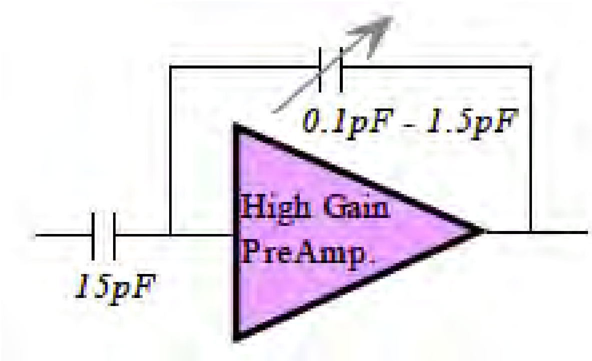


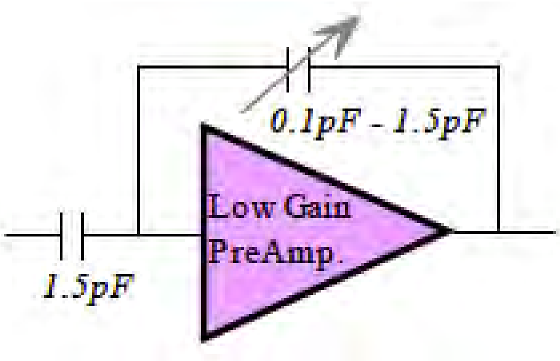
Trigger output in direct discriminator mode

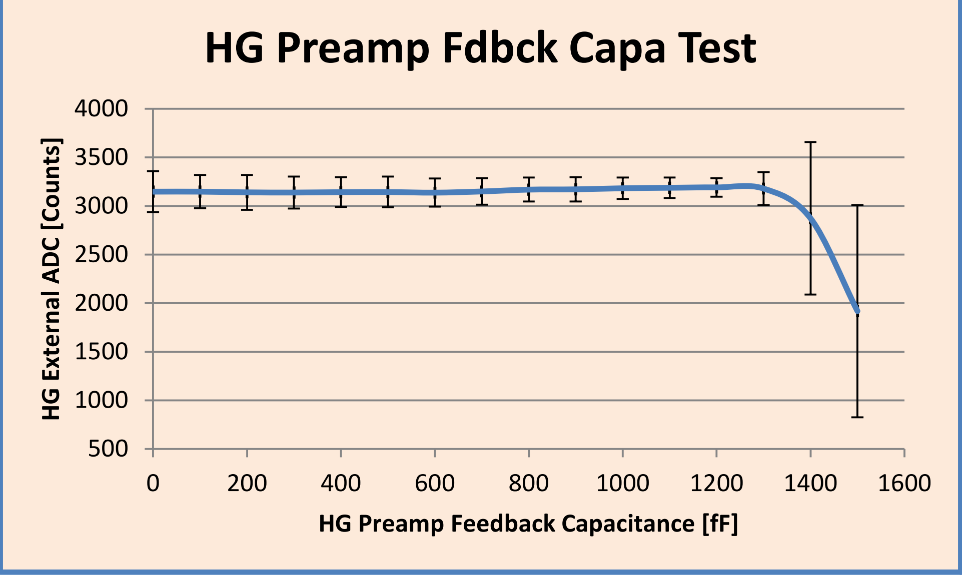


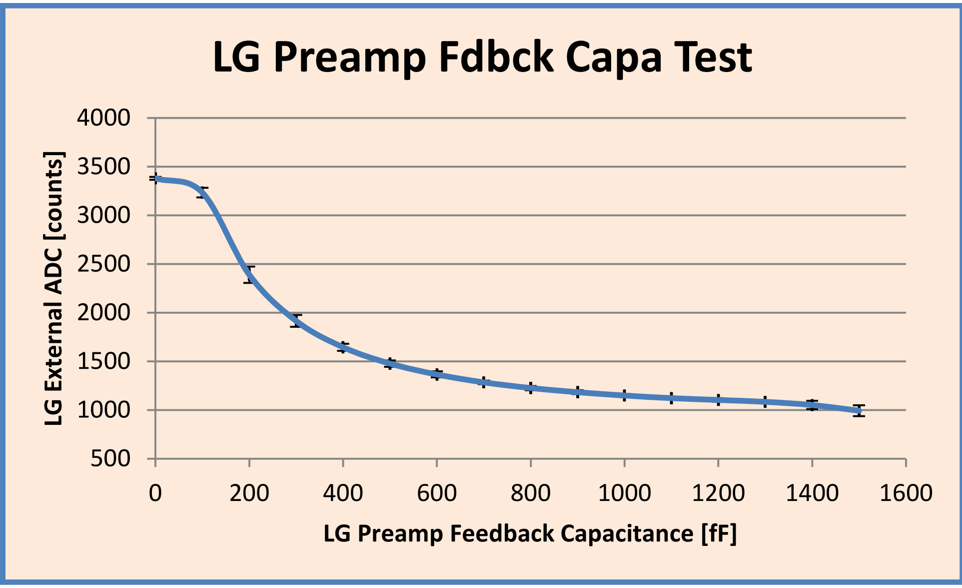


Preamp Feedback Tests

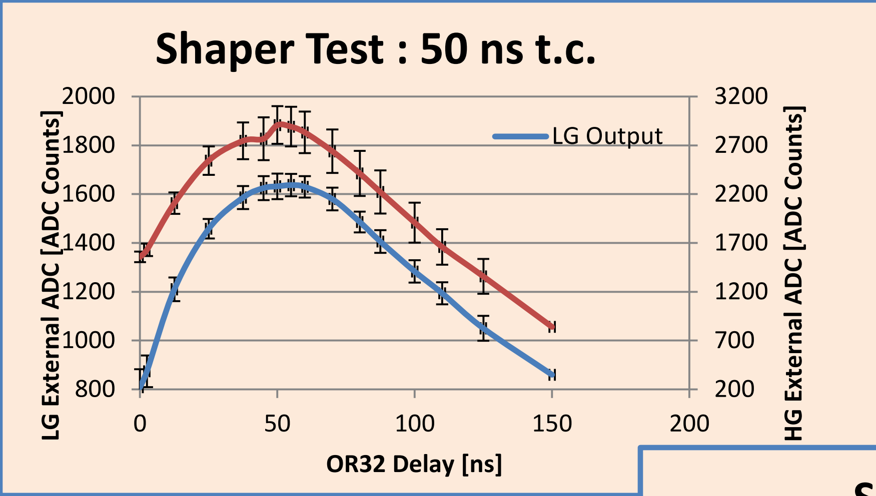




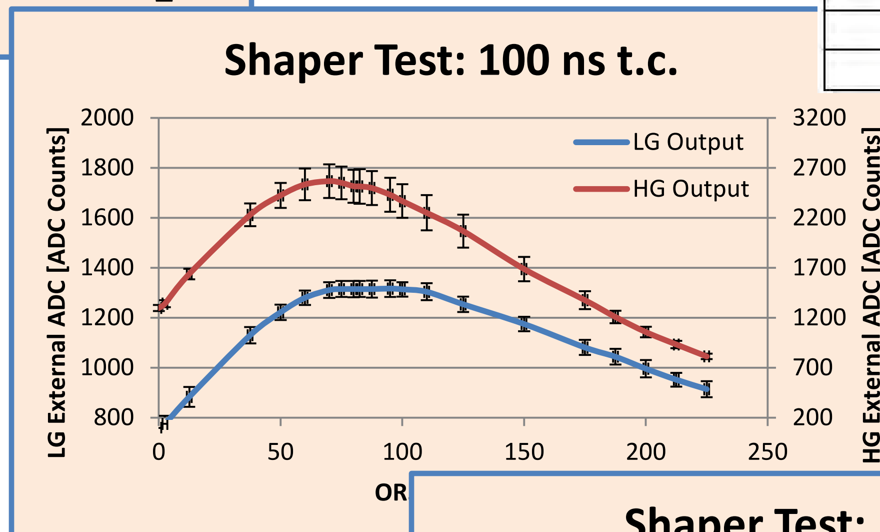


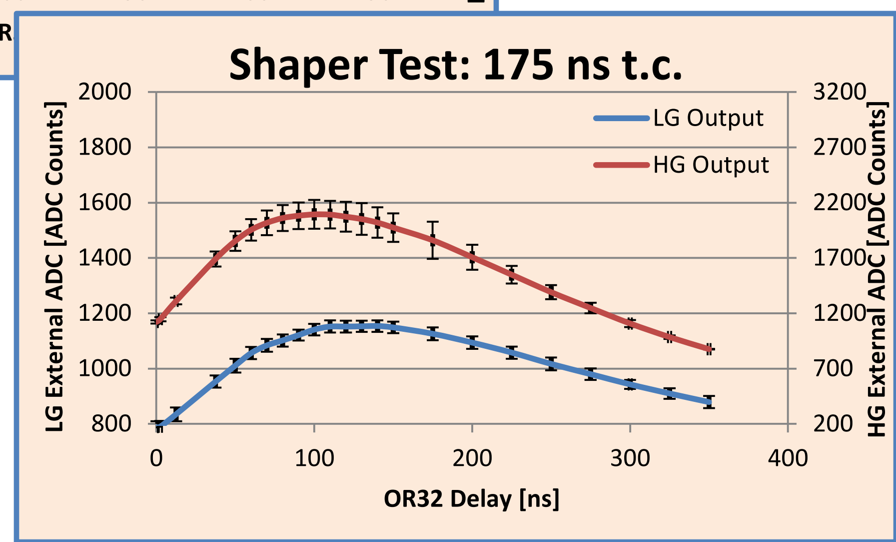


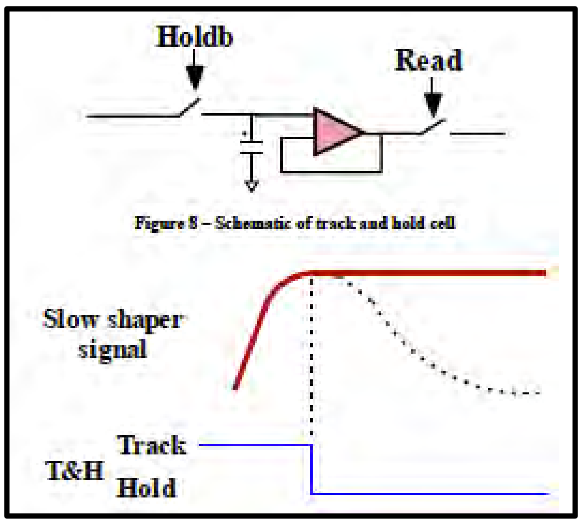
Shaper Tests



Slow control value	Peaking time value
1 (001)	25 ns
2 (010)	50 ns
3 (011)	75 ns
4 (100)	100 ns
5 (101)	125 ns
6 (110)	150 ns
7 (111)	175 ns



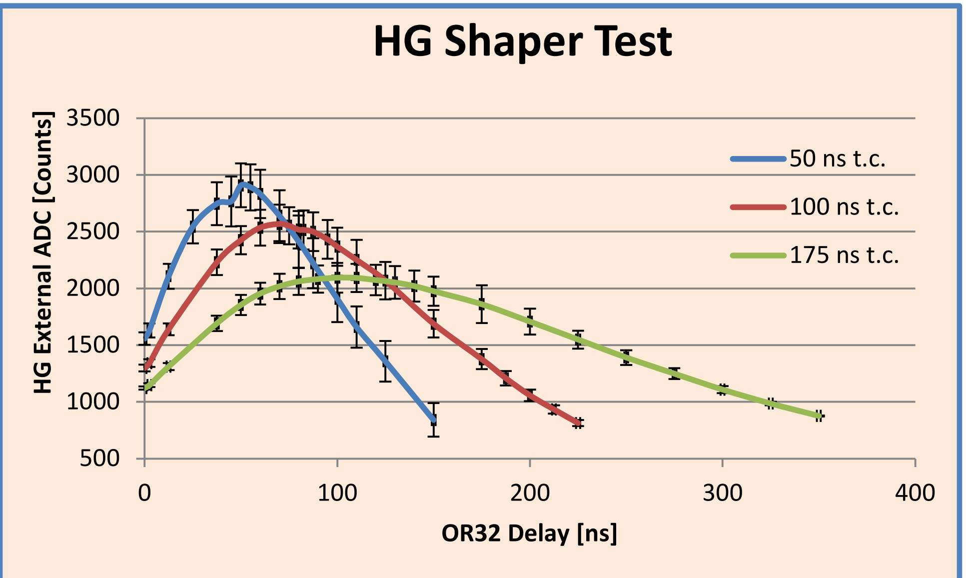


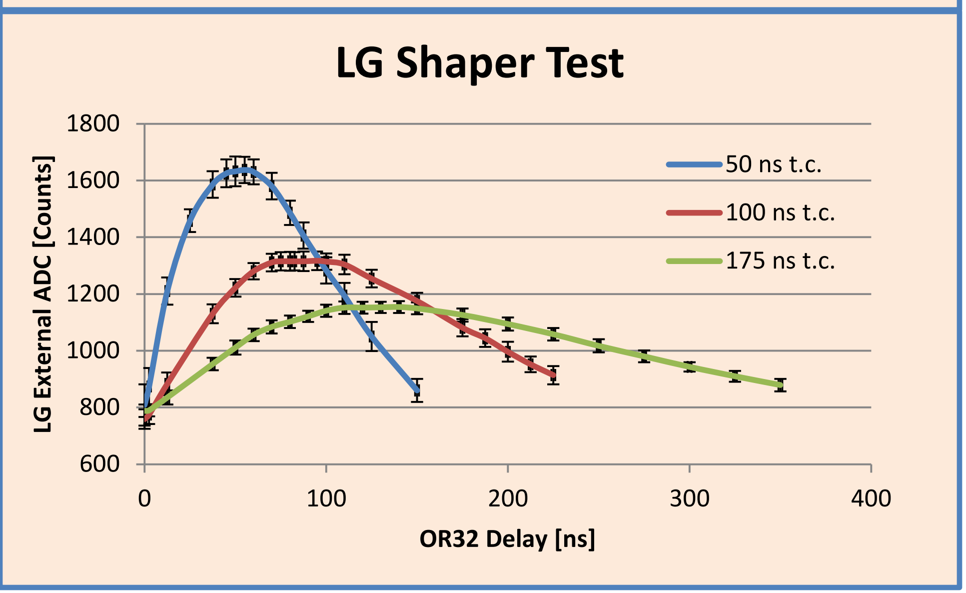


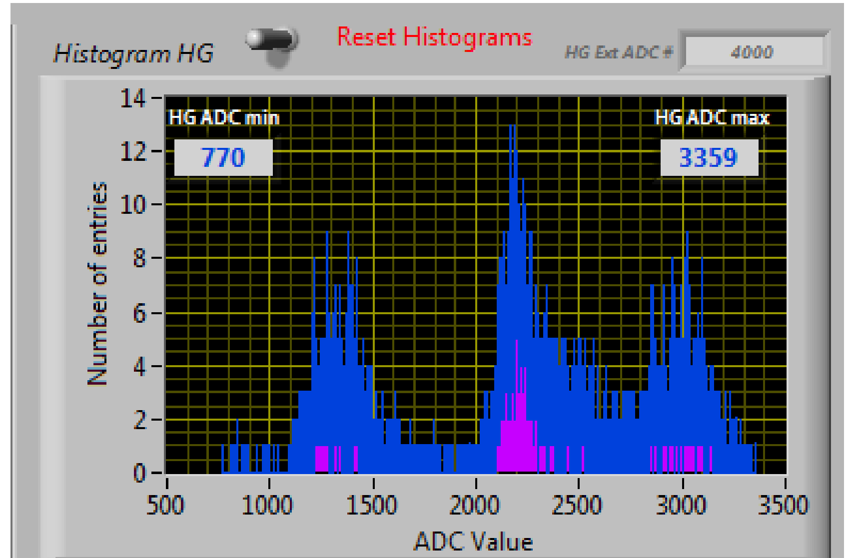
T&H is OR32 with programmable delay through FPGA

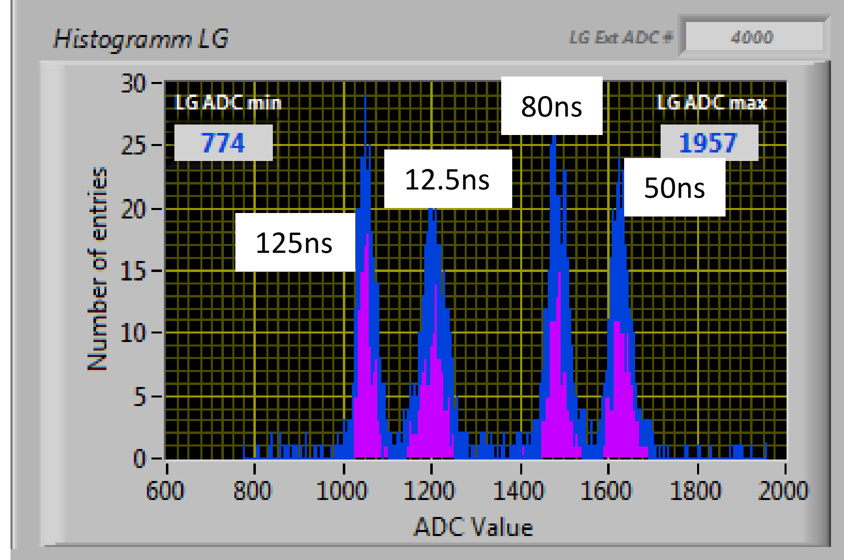
Shaper Tests

50 ns time constant

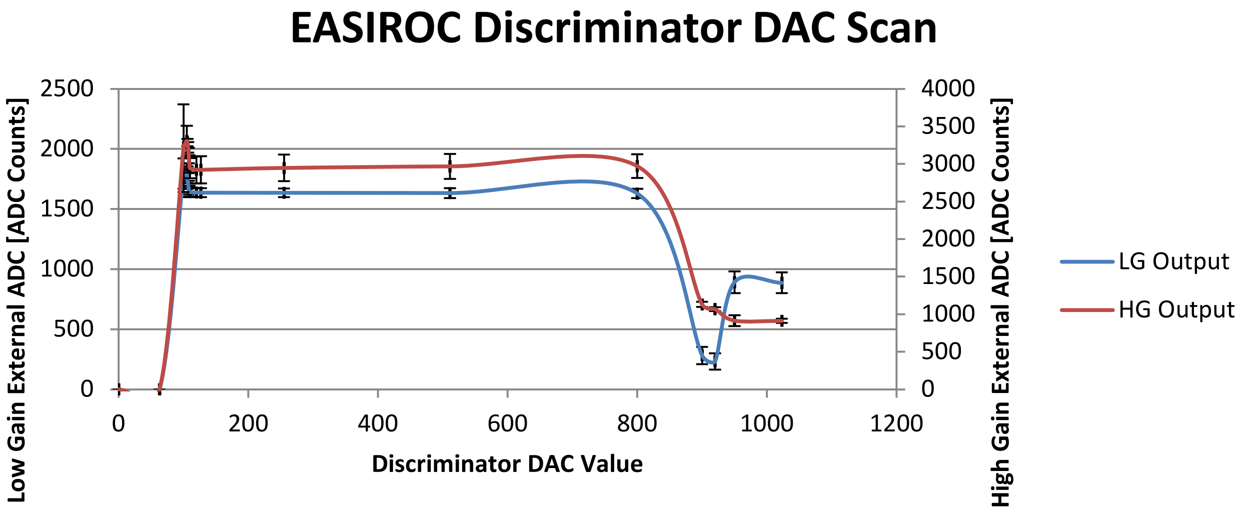


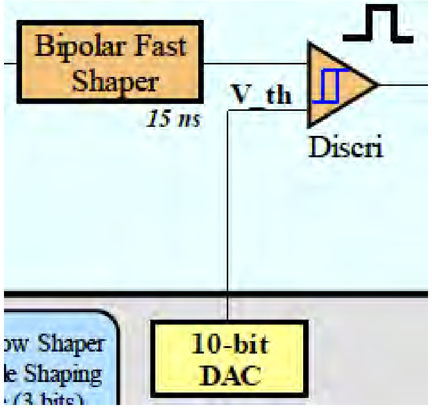


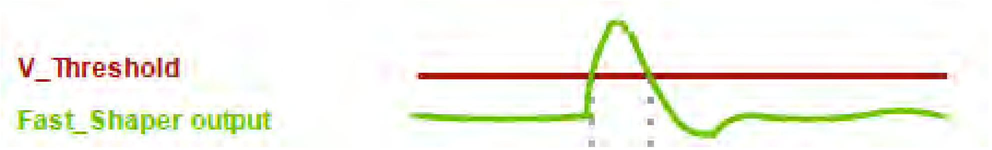




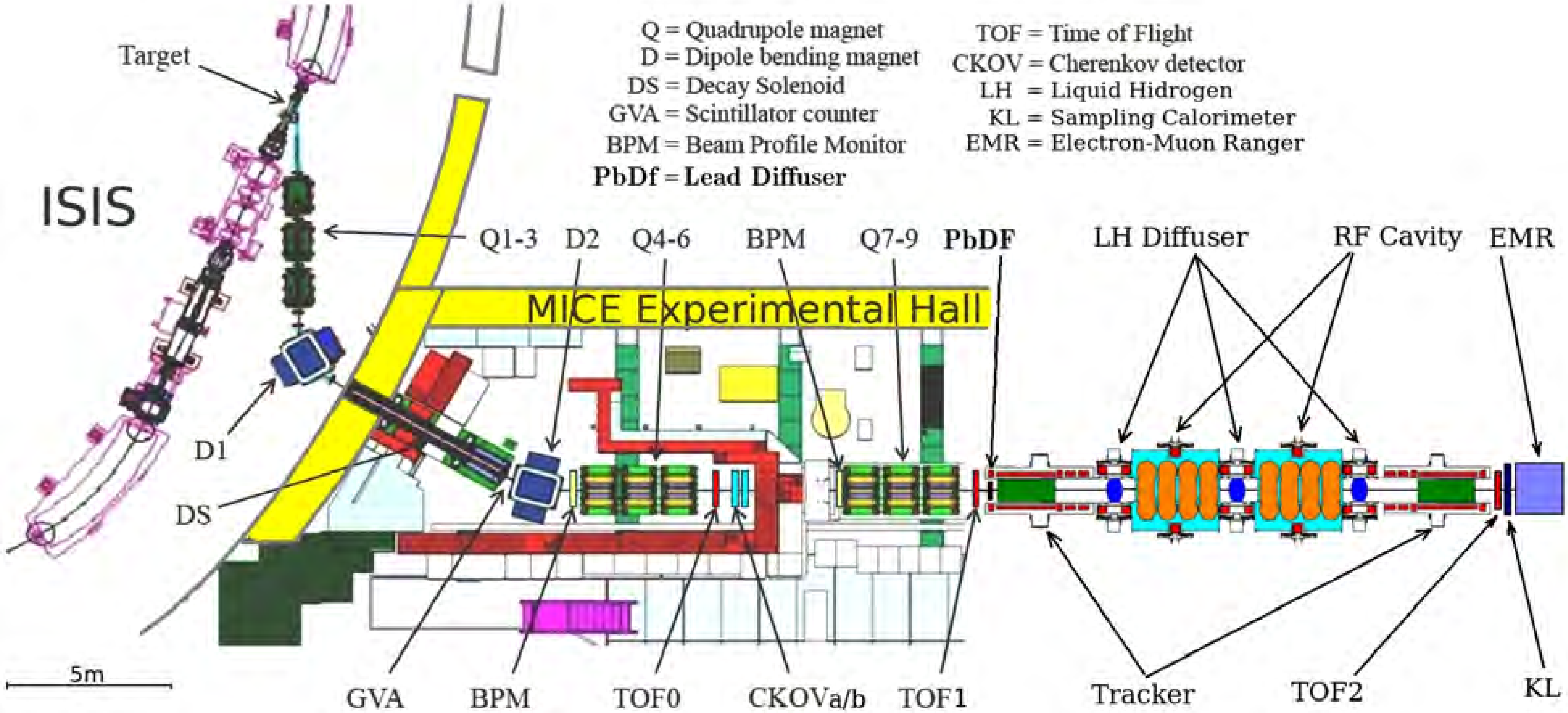
Discriminator DAC Scan



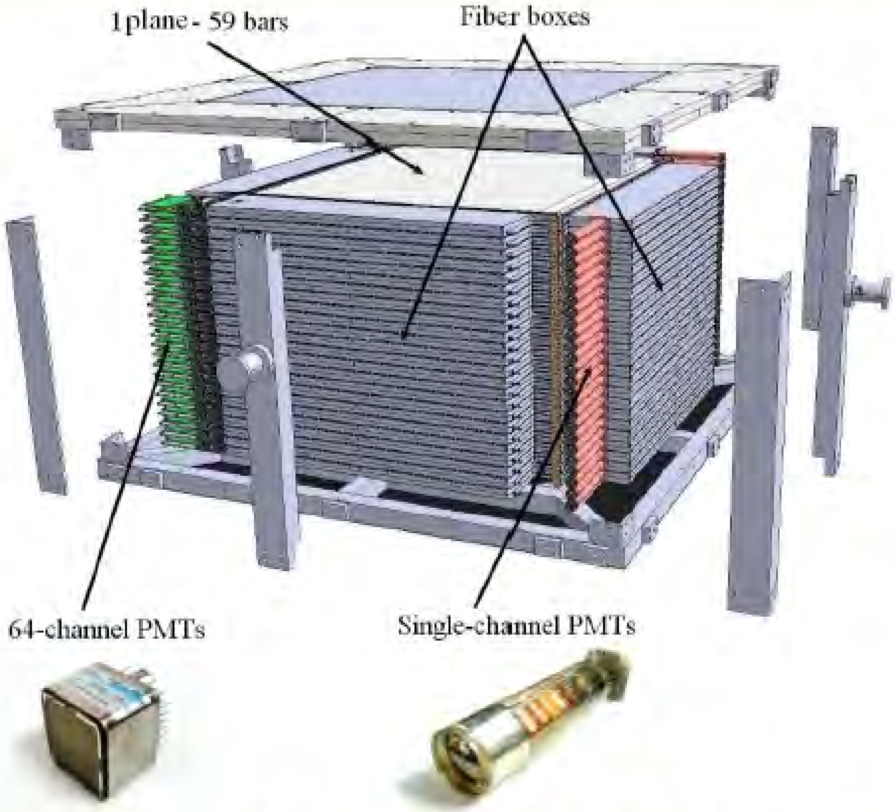




Muon Ionisation Cooling Experiment (MICE)



MICE EMR

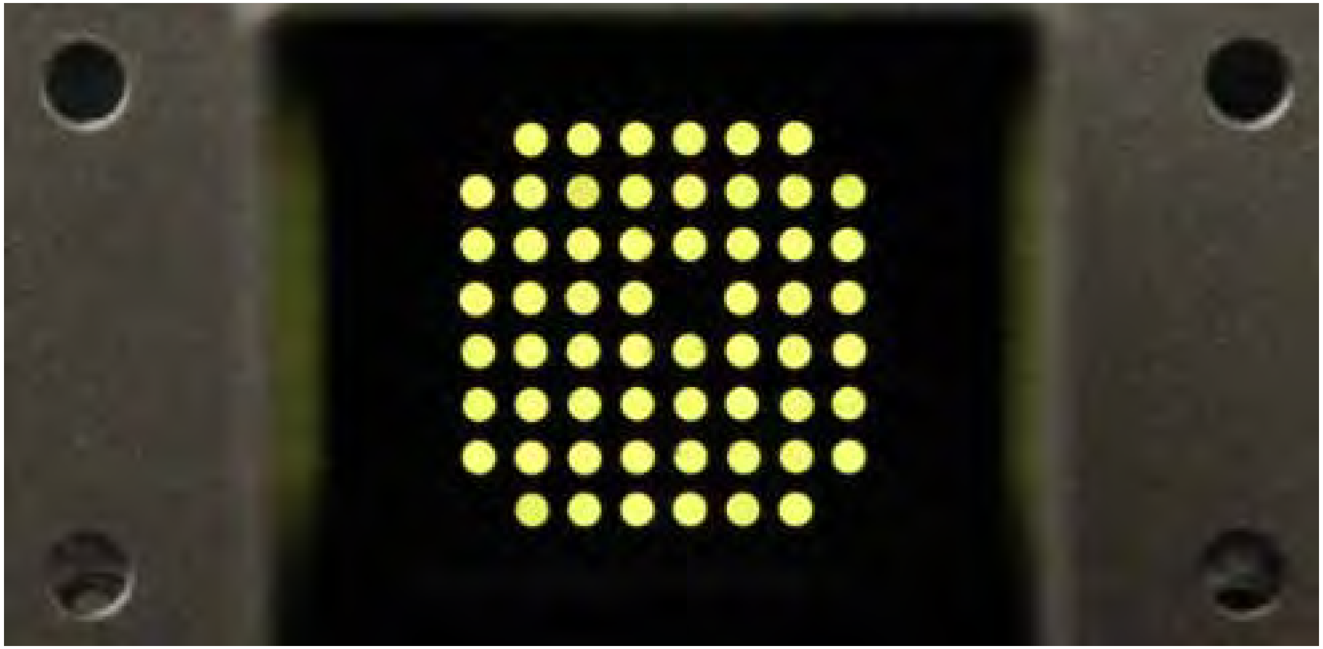


EMR detector is designed to fully stop muons from the MICE cooling channel, provide distinct signatures for muons and electrons and measure their range.

Characteristics

- 24 modules (module = 2 X&Y planes)
- 59 triangular scintillator bars per plane → 2832 bars
- light is collected by WLS fiber transfered to PMTs by light guide
- total energy per plane is detected by single-channel PMT (PHILIPS)
- energy in every bar is detected by 64-channel PMT (HAMAMATSU)
- readout is performed by custom made electronics based on MAROC/FPGA ISICs and CAEN fADC
- custom made buffer board stores all hits (time over threshold) within MICE spill gate; pulse hight information is available at low rate

EMR construction/commissioning



R. Asfandiyarov

Outlook

- **Work ongoing** to “freeze” a number of parameters for **production**:
  - Magnetisation of MIND (**steel** Oct. 2012)
  - **Scintillator** slabs (Dec. 2012)
  - **SiPMs** (April 2013)
  - **Electronics** (Aug. 2013)

- **Simulations**:
  - **Baby-MIND Geant4**: similar methodology to MIND/SuperBIND.
  - **TASD Geant4**: similar environment to MICE EMR.
  - MIND and TASD **Fluka**: planned for comparison...

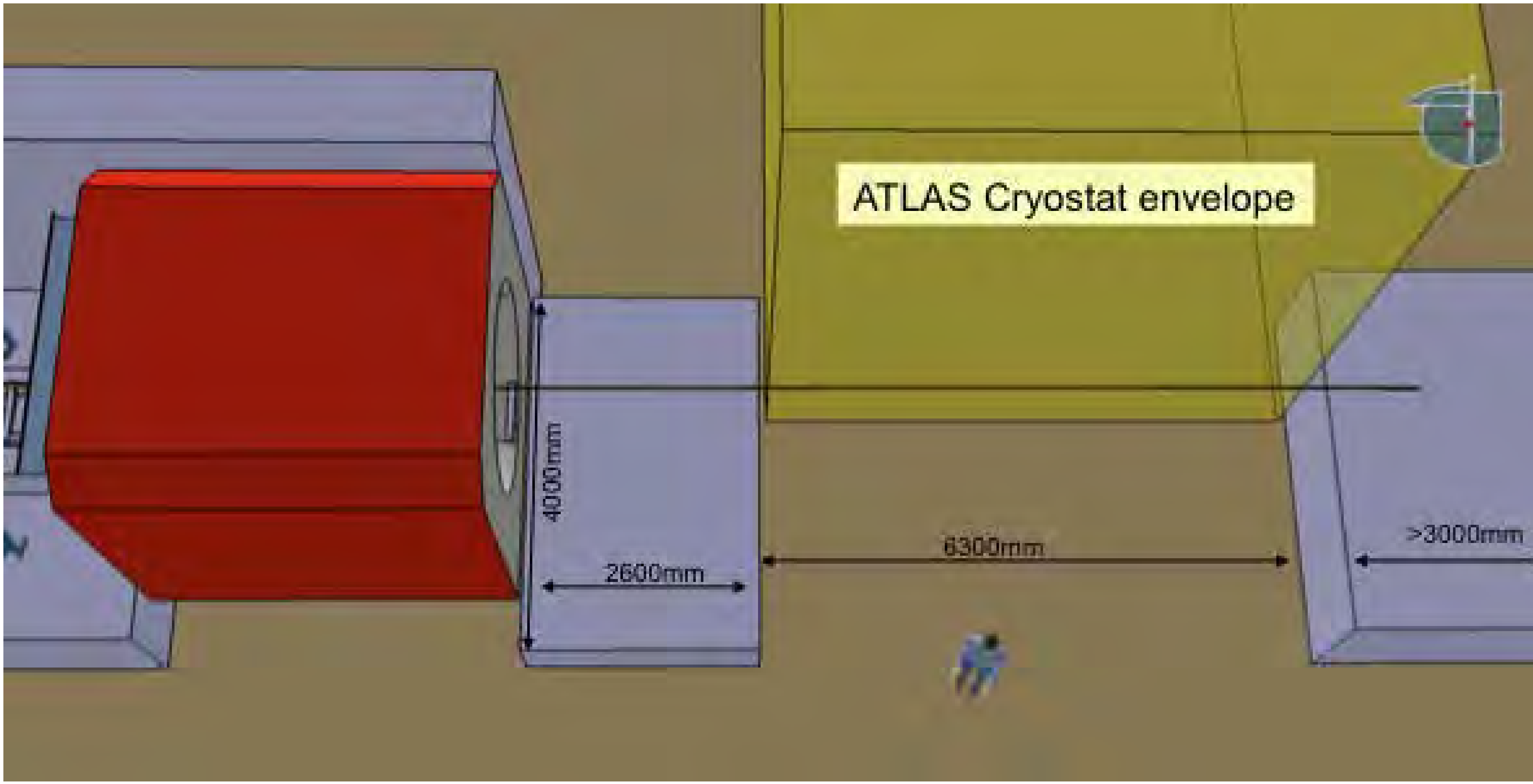
Summary: what we are here for...

Discuss collaboration on:

- Construction of TASD and MIND-type detectors:
  - **Magnetisation** of the MIND (STL?, in-situ measurement of B-field, cost of steel, mechanics).
  - **SiPM** procurement/integration (novel approaches e.g. digital SiPM, connector design, cost/ch).
  - **Electronics** (options, cost/ch).
- Simulation:
  - Simulation **framework**.
  - **Methodology** (e.g. hadronic shower reconstruction in B-field).
- Use of AIDA detectors as **test beds** for **nuSTORM** detector activities (in the spirit of the MINOS CalDet experiments...).

Back-up slides

General Layout: Baby MIND



Baby-MIND parameters I/II

Parameter	Symbol	Unit	Nominal Value	Range Min	Range Max
Detector global dimensions					
Detector width	w_{det}	m	3.0	2.5	4.0
Detector height	h_{det}	m	1.5	1.0	2.0
Detector depth	d_{det}	m	2.33	2.0	3.0
Steel plates					
Number of plates	n_{steel}	-	67		
Steel width	w_{steel}	m	3.0	2.5	4.0
Steel height	h_{steel}	m	1.5	1.0	2.0
Steel thickness	t_{steel}	cm	2.0	2.0	5.0
Number of slots for coil	n_{slots}	-	2	2	4
Slot for coil: width	w_{slot}	cm	10.0		
Slot for coil: height	h_{slot}	cm	20.0		
Support structure		-	TBD		
Gap between steel plates					
Number of gaps	n_{gaps}		66		
Gap thickness	t_{gap}	cm	1.3	1.2	2.0
Material	-	-	air + plastic		

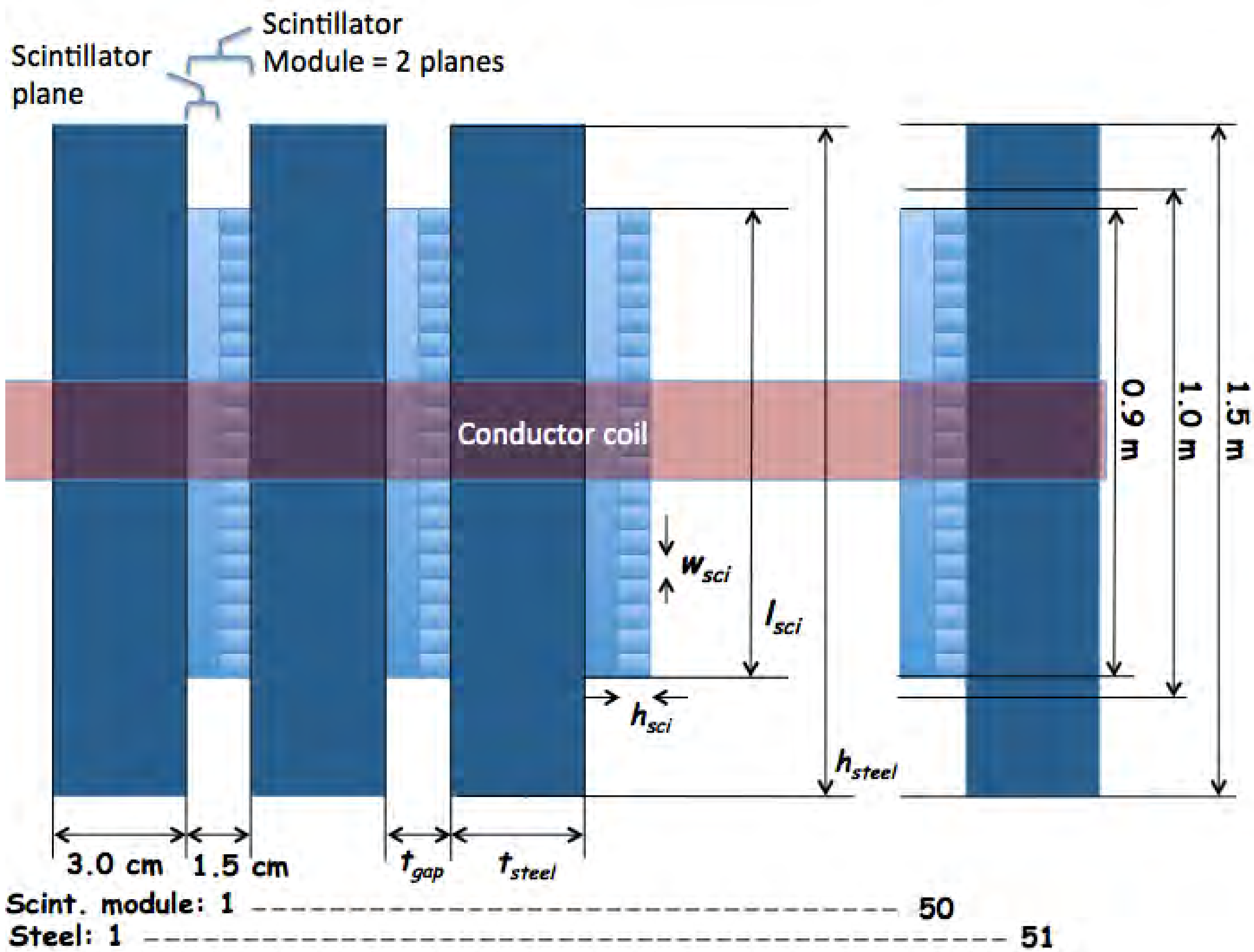
Baby-MIND parameters II/II

Parameter	Symbol	Unit	Nominal Value	Range Min	Range Max
Plastic scintillator					
Material	-	-	Polystyrene		
Number of planes per module (xy or uv)	-	-	2	1	2
Number of modules	n_{module}	-	66		
Gap between planes within module		cm	0	0	0.05
Module envelope thickness	t_{env}	cm	0.05	0	0.05
Scintillator bar length	l_{sci}	cm	90.0	80.0	100.0
Scintillator bar width	w_{sci}	cm	1.0	1.0	3.0
Scintillator bar height	h_{sci}	cm	0.7	0.7	1.0
Bars per plane	n_{bars_pla}	-	90		
Bars per module	n_{bars_mod}	-	180		
Total number of bars	n_{bars_tot}	-	11880		
Light readout and conversion					
Light readout optical fibres		-	WLS		
Total length of fibre	l_{fibre}	m	15000	15000	20000
Readout device	-	-	SiPM		
Readout from One/Two sides	-	-	1		

Basic parameters for magnetisation

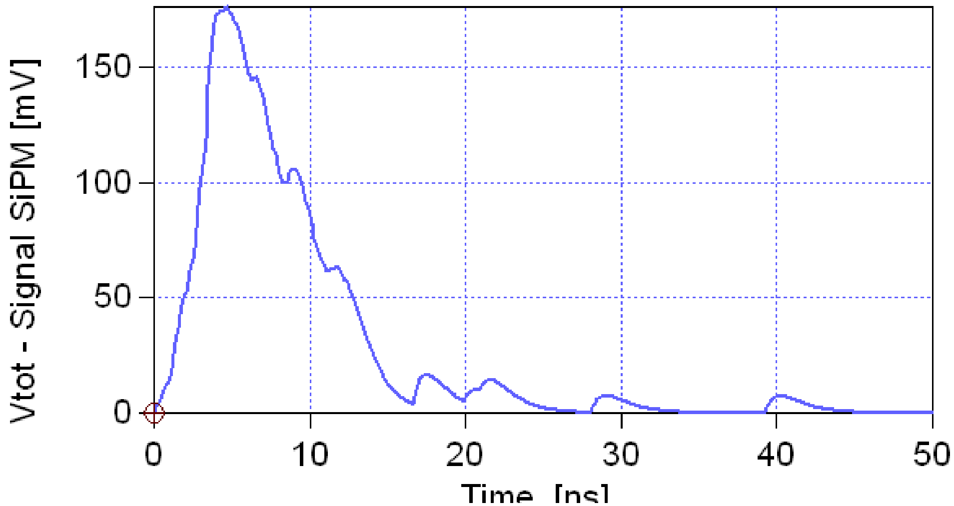
Coil and P.S. parameters	Units	AIDA baby-MIND	INO Full	INO Prototype
Coil dimension 1	cm	2.6	20	2.6
Coil dimension 2	cm	10	100	10
Coil height	m		15	
Total single turn length	m	8	46	4.7 x 2
Total coil length	m	800	92000	940
Density of copper	kg/m3	8940	8940	8940
Coil volume	m3	0.021	9.2	0.024
Coil weight	kg	185.952	82248	218
Amp-turns	Amp-turns		40000	4000x2
Number of turns		20 x 5	20 x 100 x 2	5 x 20 x 2
Conductor size	cm	0.5 x 0.5	1 x 1	0.5 x 0.5
Current 10 A	Amps	40	10	40
Resistance	Ohm	0.5376	15.6	0.64
Voltage	Volts	21.504	156	25.6
Power dissipation	kW	0.86016	3.1	1.02
Coil inductance	Henry		1710	10
Rise in temperature of coil	oC		4	
Rise in temperature of iron surface	oC		2	
Stored magnetic energy	MJ		5.3	0.01
Characteristic magnetisation time	s		110	16

Baby-MIND scintillator modules

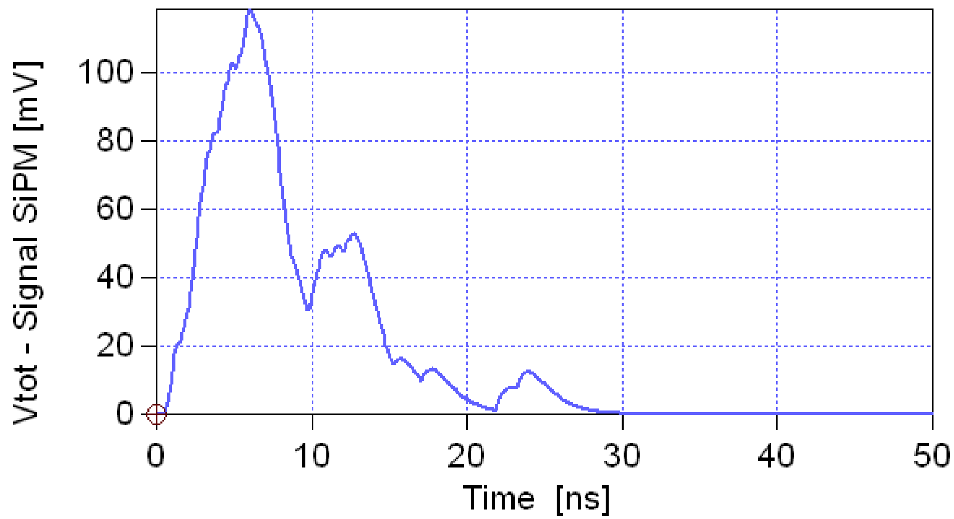


Example outputs

- Yield=1.25e4/MeV
- 2 MeV/MIP
- n_{clad}=1.6
- n_{core}=1.49
- t_s=1ns
- t_f=6.5ns
- P_Q=20%



- w_s=2cm
- h_s=3cm
- d_f=0.15cm
- Edep=6MeV
- P_H=13%
- P_{Trans}=3.7%



- W_s=1cm
- H_s=0.6cm
- d_f=0.10cm
- Edep=1.2MeV
- P_H=43%
- P_{Trans}=3.7%