UNIVERSITÀ DEGLI STUDI DI BARI ALDO MORO

INFN Istituto Nazionale di Fisica Nucleare Sezione di Bari

XXXI CICLO DI DOTTORATO

Dottoranda: INTONTI ROSARIA ANNALISA

‘Development of a P-Terphenil beam monitor for the far detector of T2K (Super-Kamiokande) Linac calibration’

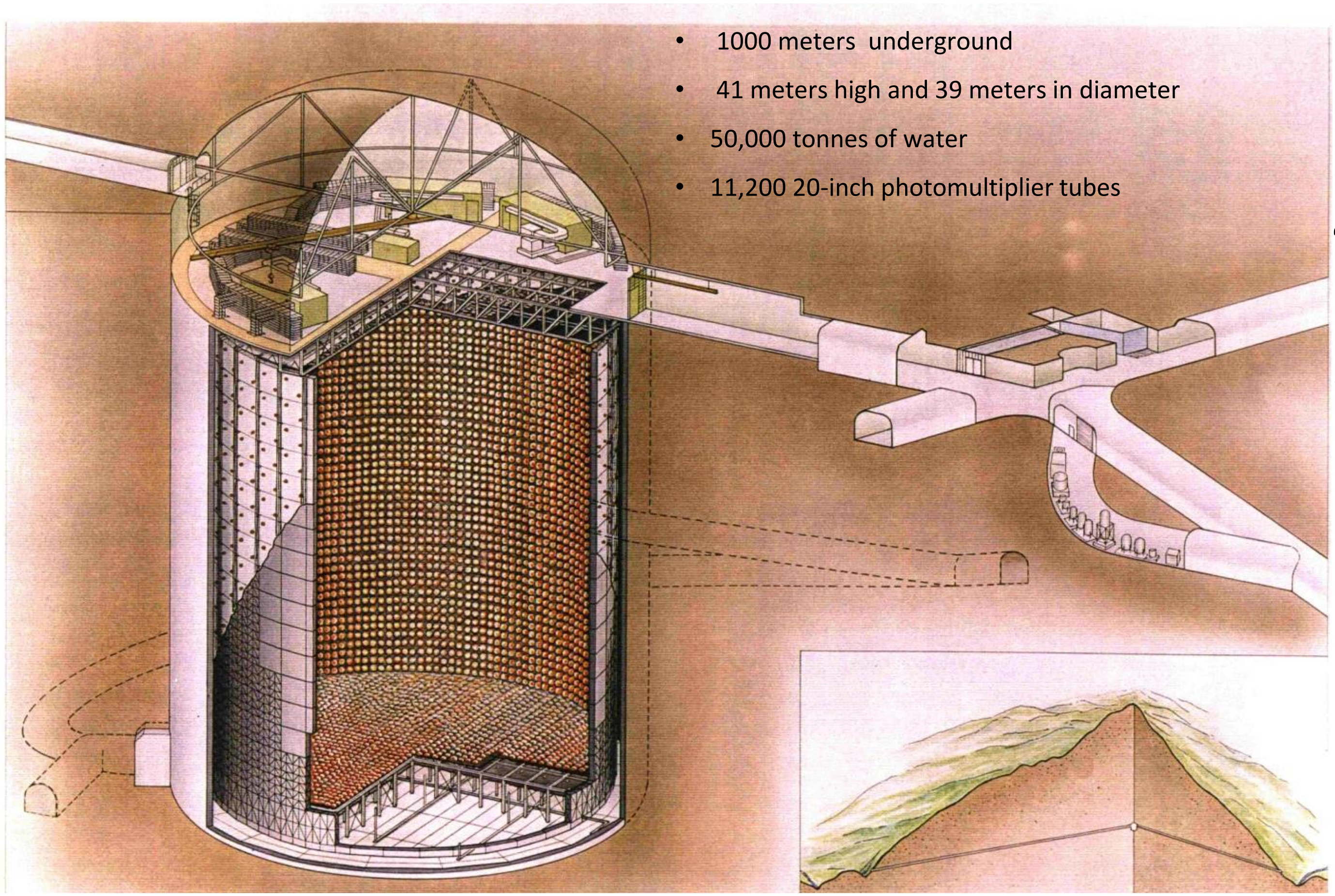
Tutori: PROF. BERARDI VINCENZO
DOTT. RADICIONI EMILIO

Outline

- Super-Kamiokande
- Overview of the calibration system in Super-Kamiokande
- P-Terphenyl beam monitors for the SK Linac calibration
- Activity:
  1) Calibration campaign at S-K
  2) P-therpenyl attenuation length
  3) detector simulation codes in Geant4
- Conclusion
- PhD schools and publications

Super-Kamiokande

- 1000 meters underground
- 41 meters high and 39 meters in diameter
- 50,000 tonnes of water
- 11,200 20-inch photomultiplier tubes



Physics topics in Super-Kamiokande:

1) Long baseline neutrino oscillation

2)Solar neutrino

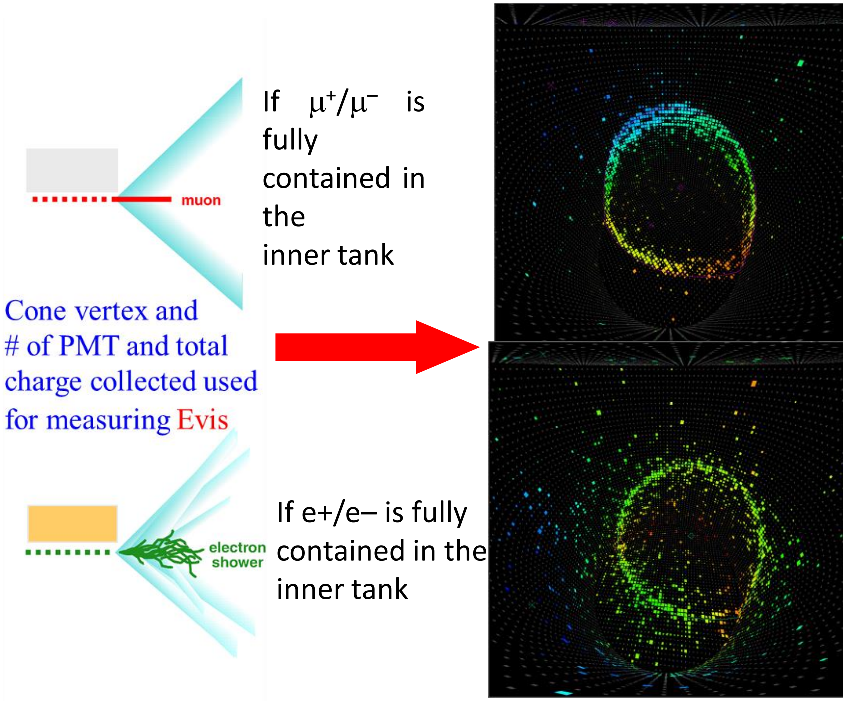
3)Atmospheric neutrino

4)Neutrinos from supernova burst

5)Nucleon decay

6)Massive neutrino dark matter search

7)Gamma-ray burst search



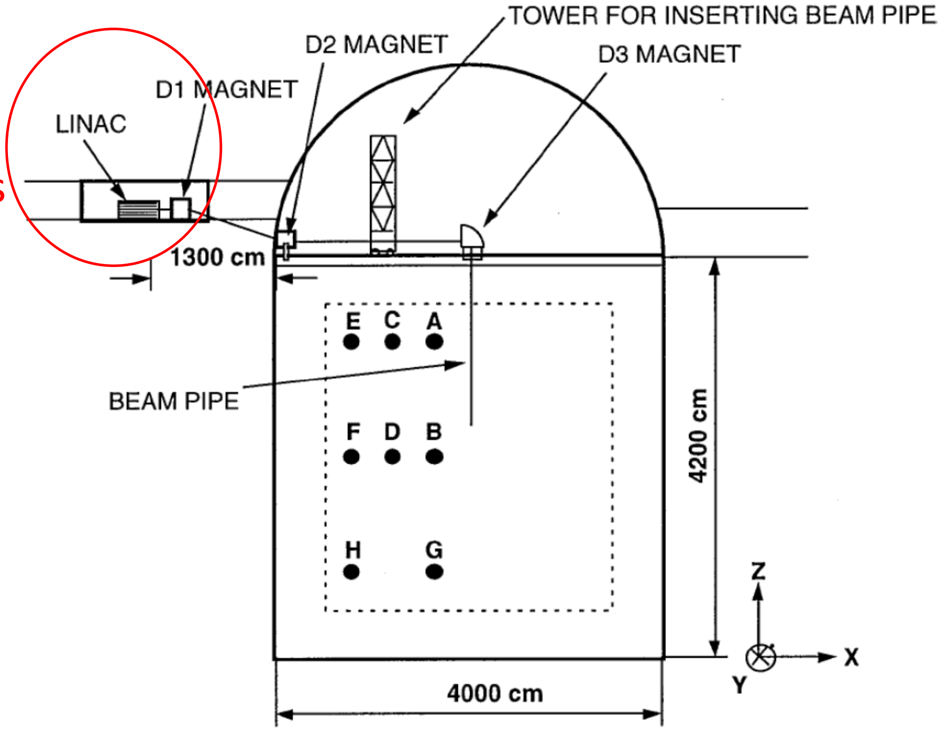
Measure Cherenkov rings produced by $e^{\pm}$ and $\mu^{\pm}$

Super-Kamiokande Calibration

Needed for:

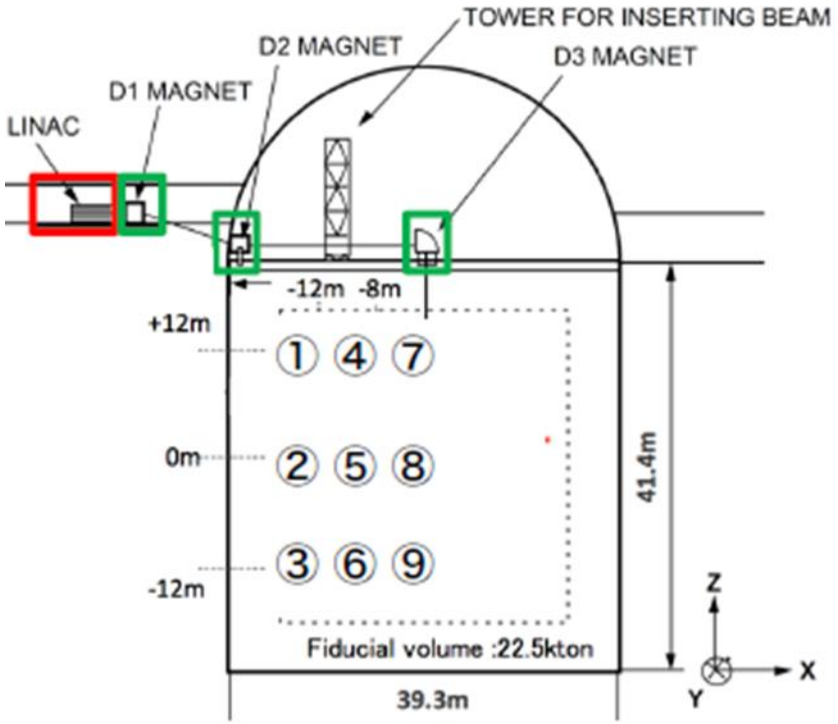
1-Estimation of the number of photo-electrons and of the arrival timing on each PMT.
2-Understanding the water quality in detail.
3- Estimating of the uncertainty of reconstruction, such as energy, position, direction etc.
4-Monitoring the long term stability for PMT gain.

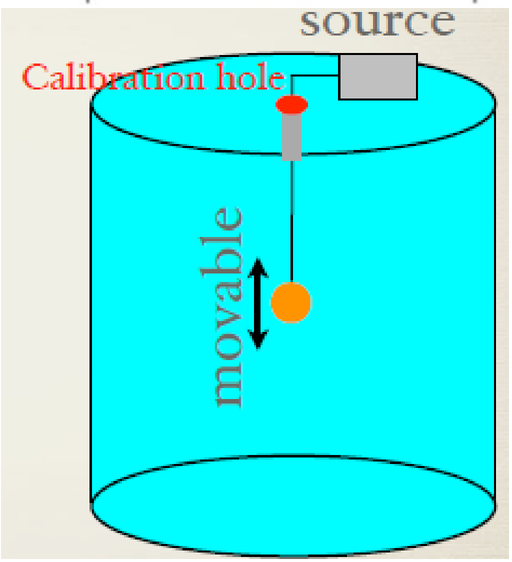
Use electron LINAC: "**The LINAC festival**" is held once per year, takes ~4weeks



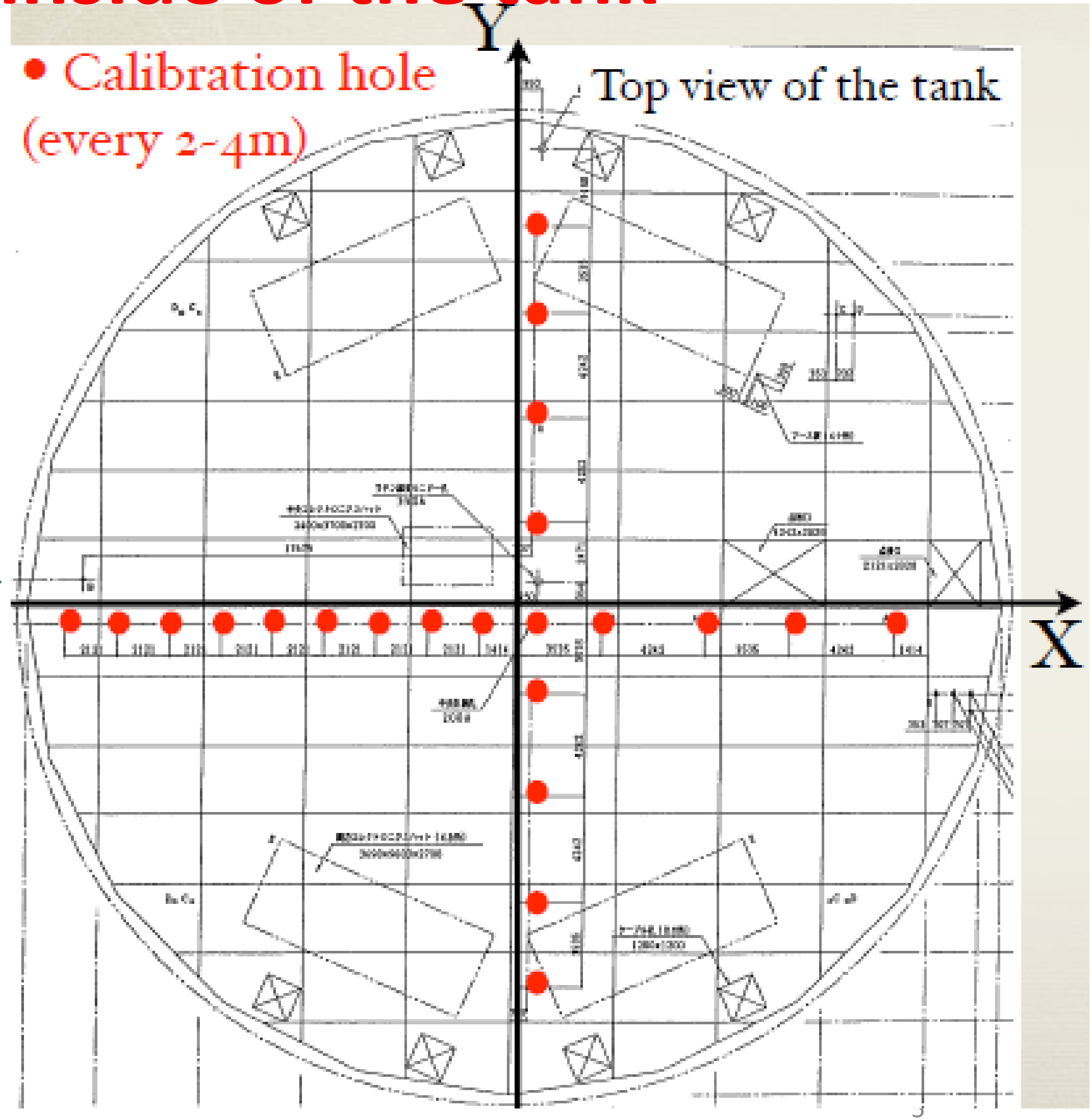
-tunable energy (4~18MeV)
-Known direction
-individual triggered single electron
-Mono-energetic electrons are selected from this spectrum
-A 1 mm thick, 24 mm diameter plastic scintillator (the "trigger counter"), mounted 17 mm above a titanium window and supplies a trigger signal

Access to the inside of the tank

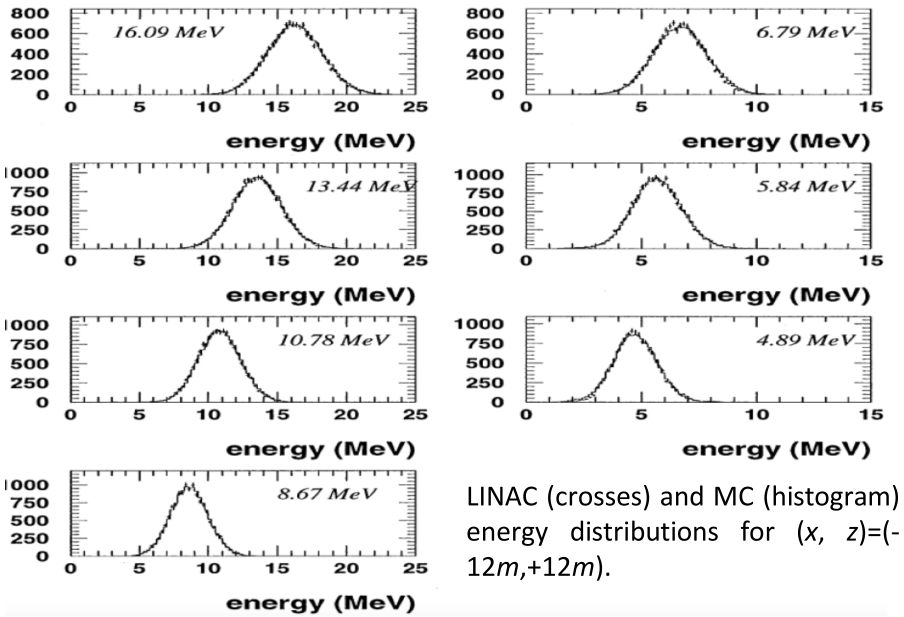




LINAC positioning in relation to the tank and data collecting



Takes about one month for a “complete” detector scan and ~6 people working: 9 positions, 5-7 beam momenta



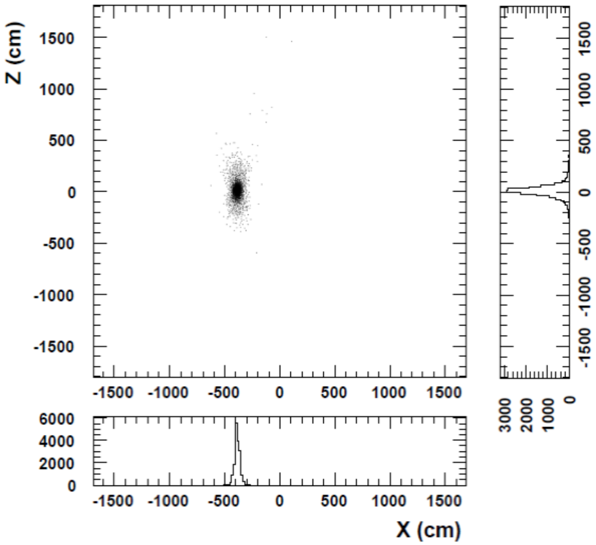
LINAC (crosses) and MC (histogram) energy distributions for (x, z)=(-12m,+12m).

-takes about 0.5-1 days to install/align beam pipe, about 0.5 days to vacuum

-takes about 3h to take one measurement for each beam momentum: 1.5h to tune the beam, 1h to take data (assuming 60Hz bunch frequency), 0.5h to take control samples for backgrounds and measure beam momentum in Ge detector

Results for the year 2018 calibration campaign

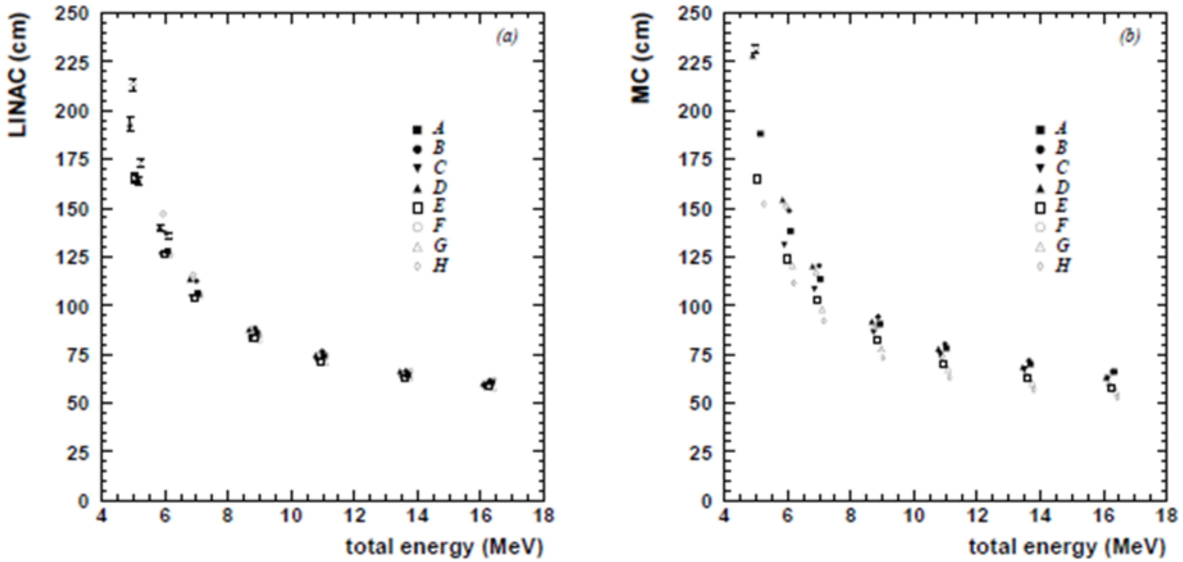
	Position[cm]			Target beam energy [MeV]					
2017	x [cm]	y [cm]	z [cm]	5	6	8	12	15	18
①	-1237	-70.7	1197	●	-	●	●	●	●
②	-1237	-70.7	-6	●	-	●	●	●	●
③	-1237	-70.7	-1209	●	●	●	●	●	●
④	-813.1	-70.7	1197	●	●	●	●	●	●
⑤	-813.1	-70.7	-6	●	-	●	●	●	●
⑥	-813.1	-70.7	-1209	●	●	●	●	●	●
⑦	-388.9	-70.7	1197	●	●	●	●	●	●
⑧	-388.9	-70.7	-6	-	●	●	●	●	●
⑨	-388.9	-70.7	-1209	●	-	●	●	●	●



Position vertex a (x,z)=(-4m,0m), beam energy to 15MeV/c

The analysis of this last calibration data outlet is almost completed, but a first estimate has made it possible to evaluate THE VERTEX POSITION RESOLUTION depending on an energy scale position:

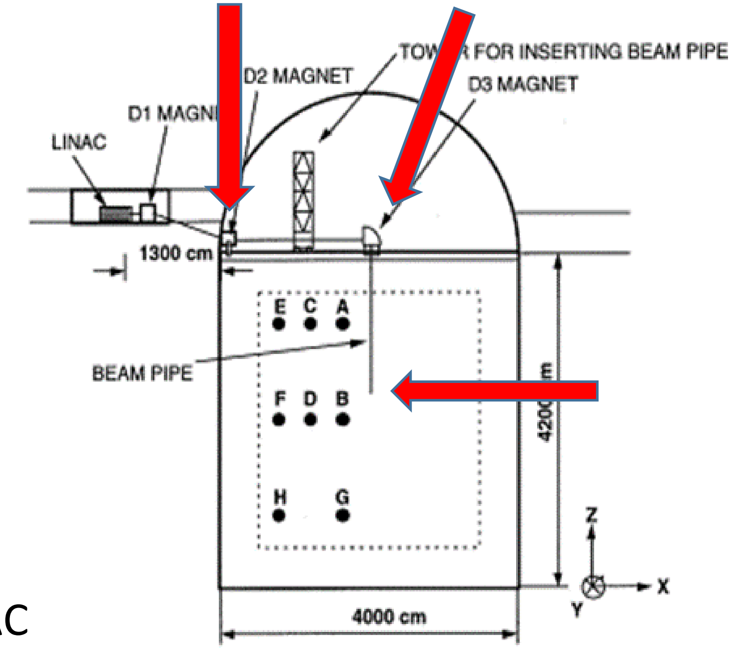
Total energy (MeV)	Vertex resolution(cm)
5	121±21
6	133±8
8	108±5
12	73±2
15	65±2
18	50±2



Vertex position resolutions of (a) LINAC and (b) MC.

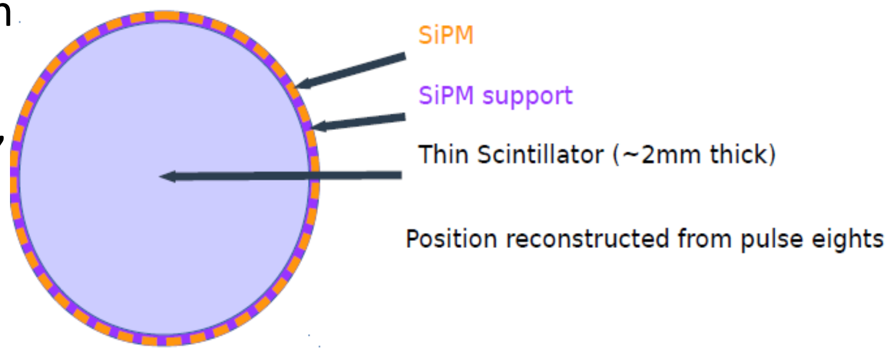
P-Terphenyl beam monitors for the SK Linac calibration

3 position-sensitive devices to provide a complete characterization of the beam shape and position in real-time!!!



List of requirements for a position-sensitive device to be installed in the SK LINAC

- Position resolution: ~ 1mm
- Moved in and out the beam by a remotely-operated manipulation system, even when mounted in the final (underwater) vertical section
- Amount of material in the beam equivalent to the one of the present monitors, and possibly less
- Minimal cabling for power and data
- Larger active area (~ 2cm diameter)



3 monitors based on the concept of a gamma-camera around a scintillator disk of ~ 2cm diameter.

Why P-Terphenyl?

C6H5C6H4C6H5

Organic scintillators fast decay time and their low Z, while inorganic for high light yields

a para-terphenyl based detector has a mix of properties of the two categories that can be optimal for energy and position measurements of low energy charged particles.

1) P-terphenyl is an aromatic hydrocarbon isomer, formed by three benzene rings in ortho position.
2) P-terphenyl is an organic material commonly used as a dopant for organic scintillators.
3) Pure terphenyl is a white crystalline solid, insoluble in water.
4) Crystals of this material have a LY that strongly depends on the doping: LY can be significantly increased at the cost of shortening the Light Attenuation Length (λ).

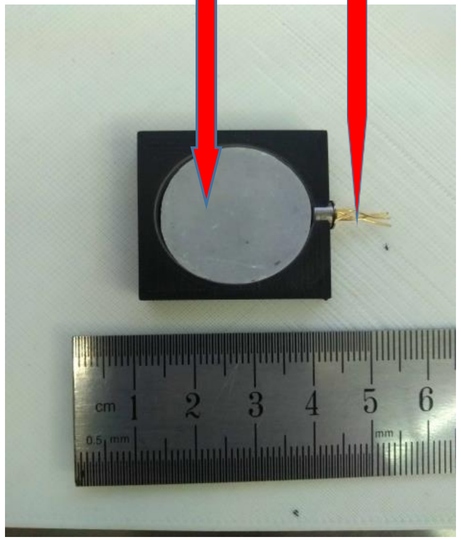
LY and λ parameters are crucial

Research activity: experimental measurements (1)

P-Terphenil characteristics

SiPM (MicroFC 10035 X18)

-Density 1.23 g/cm3
-HC ratio 0.778
-Luminescence max 420 nm
-Refractive index 1.65
-Light yield 27,000 ph/MeV
-Decay time 3.7 ns



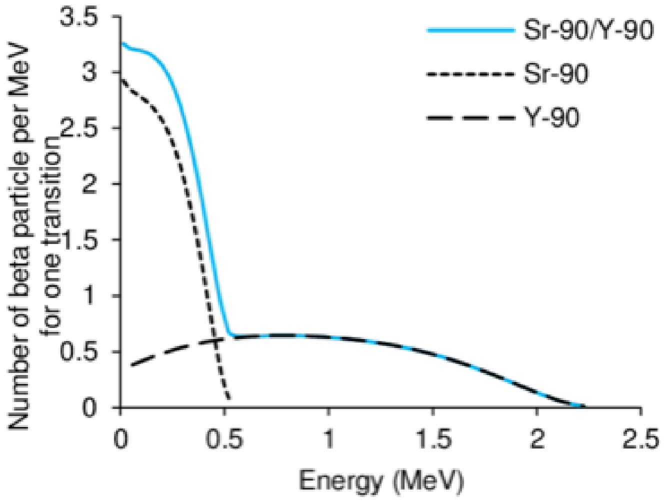
TO-18 Packaged SiPM
1x1 mm size
576 microcell of 35um (fill factor 64%)
Temp stability 21.5mV/°C
Breakdown voltage ~24.65V
Bias over-voltage 1-5 V
Wavelenght 300-800nm, peak 420nm
PDE 31%-41%
Gain 3 106
Dark current rate 30KHz (<96KHz)

A monocrystal P-Terphenil disk, 26mm diam, 4mm tick read by a 1x1mm SiPM

Research activity: experimental measurements (2)

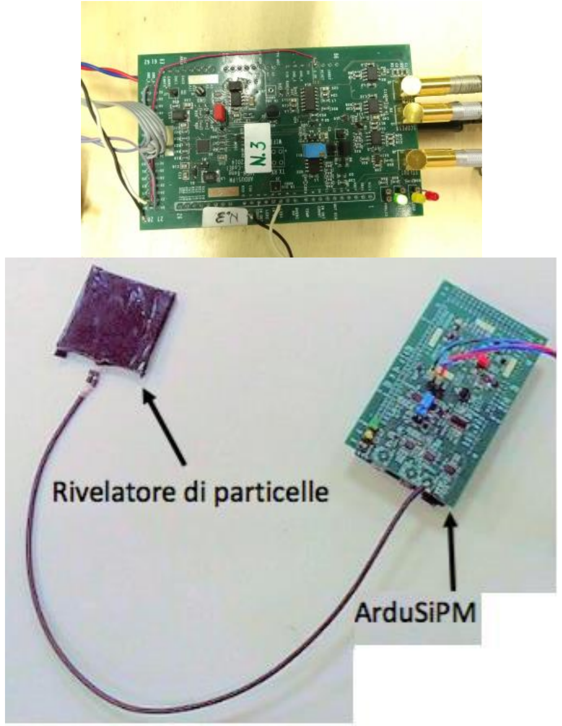
Sr90-Y90 radioactive source

74 KBq nominal
Sr90 end point: Ekin=0.53 MeV, g=2.05, E=1.05 MeV
Y90 end point: Ekin=2.23 MeV, g=5.37, E=2.74 MeV



ArduSiPM INFN Roma

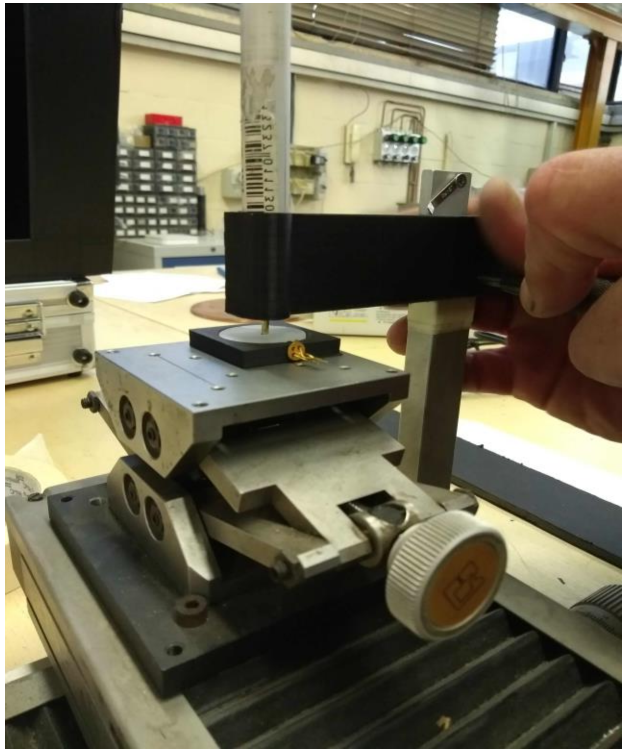
readout&control
bias setting and preamp



Research activity: experimental measures (3)

Stage

An XY micrometric stage, adjustable in Z to move the detector



Black box

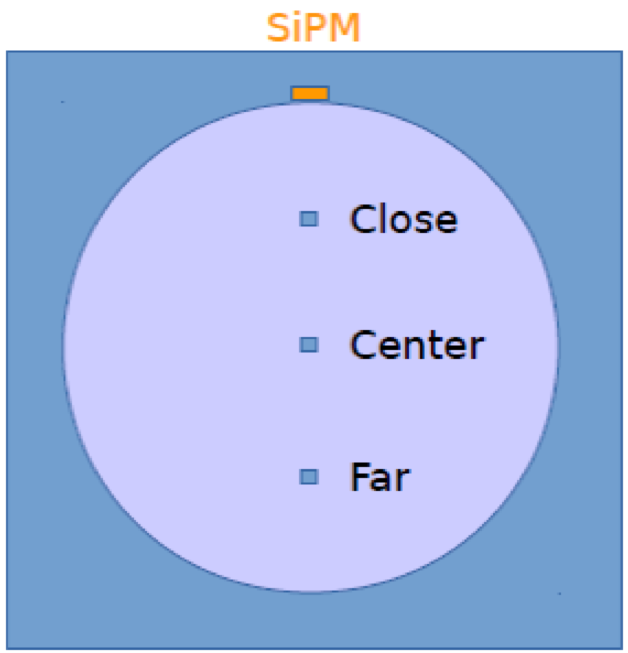
A Black box with a LEMO feed-through XxYxZcm (inner)

Research activity: experimental measurements (4)

We to data with 1mm- , 3mm-, 4mm-thickness disks to find the best detector performance!!!

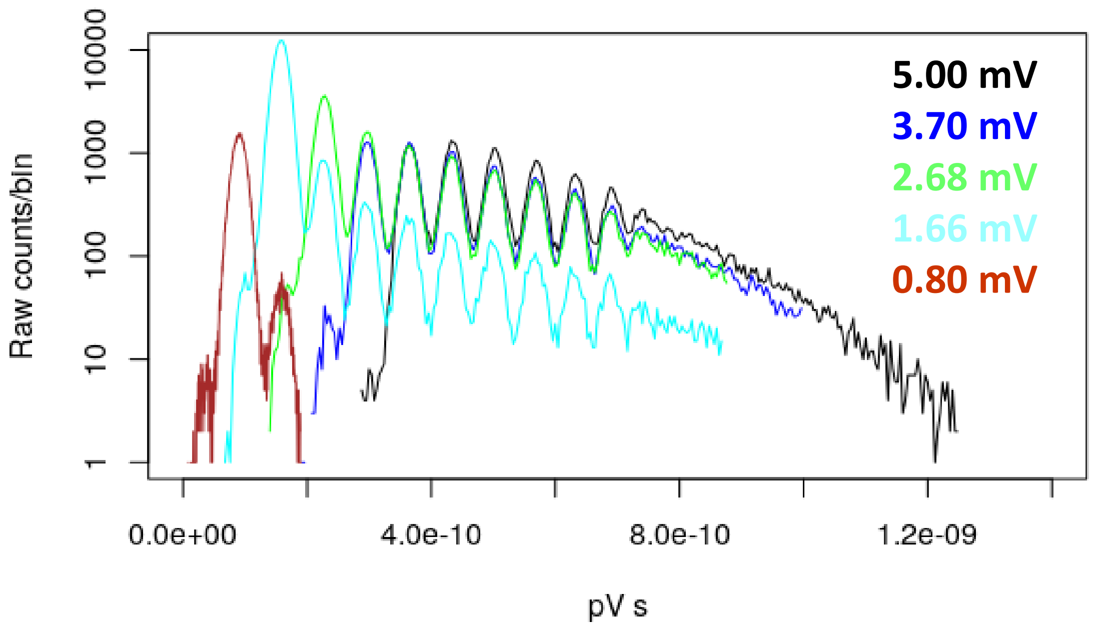
Data points taken at three distances:

Source at 0,05mm over the scintillator
Close = Center - 7mm
Far = Center + 7mm



Research activity: experimental measurements (5)

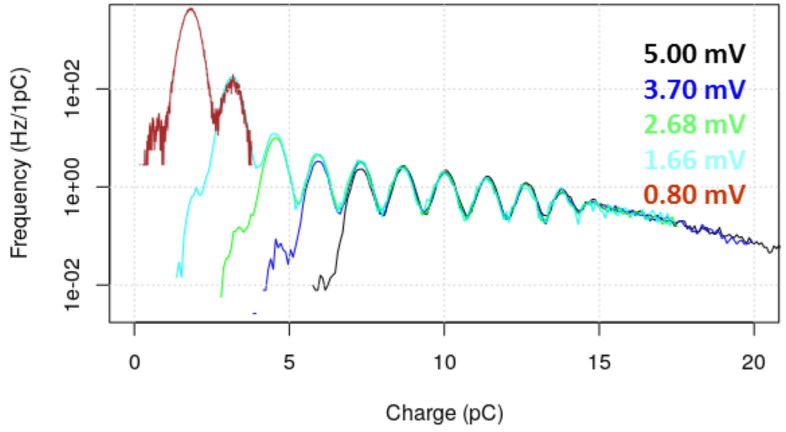
For a 4mm-thick p-therphenil disk



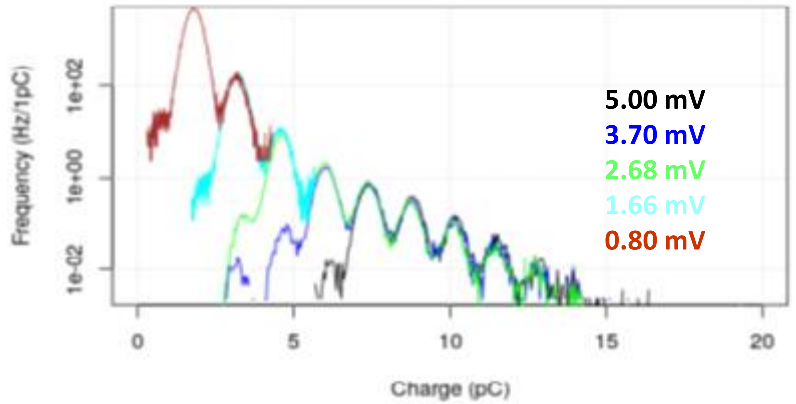
RAW COUNTS: Close position to SiPM

Raw Amplitude•Time integral counts from scope (pV •s)
→ transform to Charge(pC)
→ use counts integral of the dataset at highest threshold (5 mV, black histogram, for which the frequency was measured) to normalise counts to frequency
→ use the integral in the overlapping ranges to normalise datasets taken at different thresholds

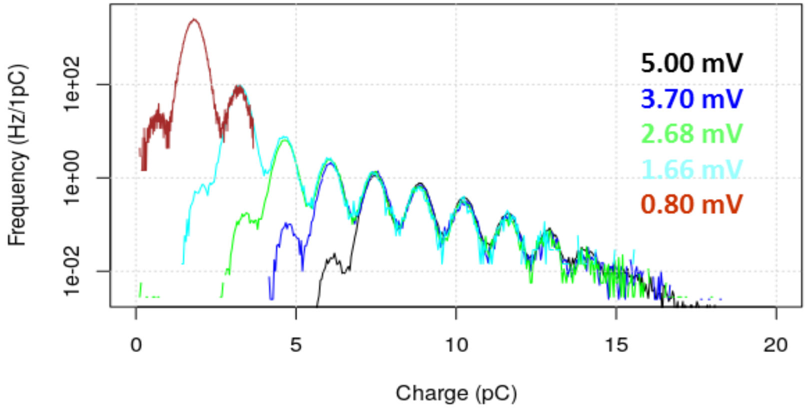
Research activity: experimental measurements (6)



Close position (~7mm from SiPM)

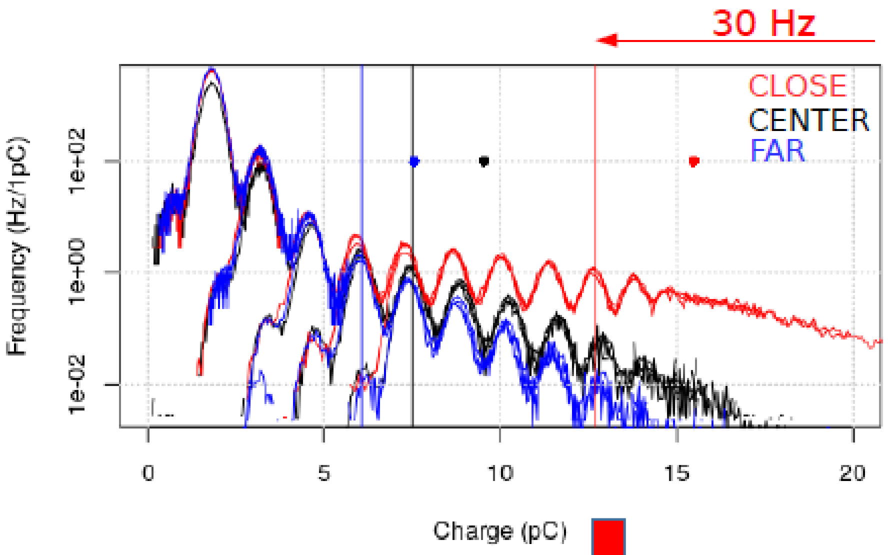


Far position (~21mm from SiPM)



Center Position (~14mm from SiPM)

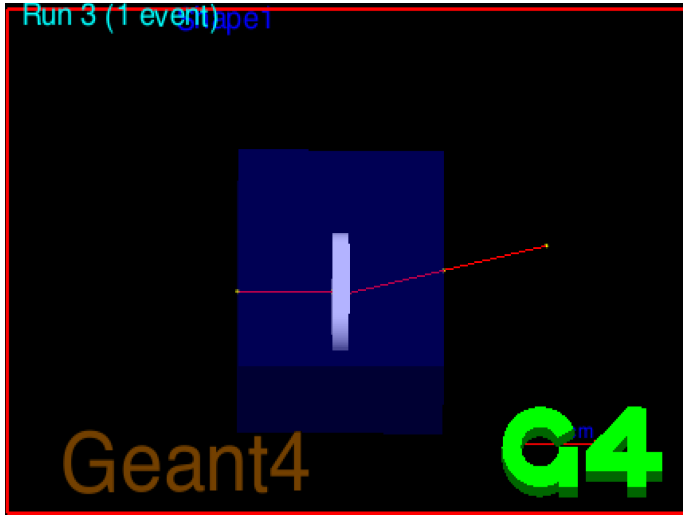
Compute the average charge for the upper tails of each distribution corresponding to 30Hz (arbitrarily chosen)



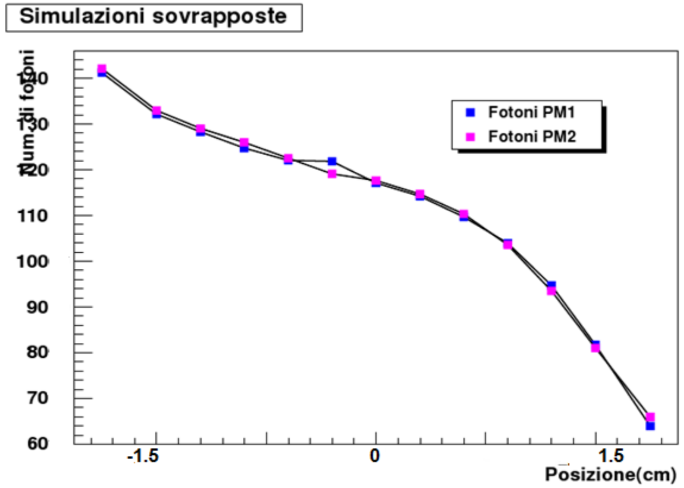
	Average 30Hz
CLOSE	15.48
CENTER	9.53
FAR	7.56

The attenuation length λ for p-terphenyl is of the order of one cm, compatible with the size of the new monitors for the calibration of SK, verifying that a scintillator disc of this new material (p-terphenyl) and with this geometry can be used for our purposes!!!

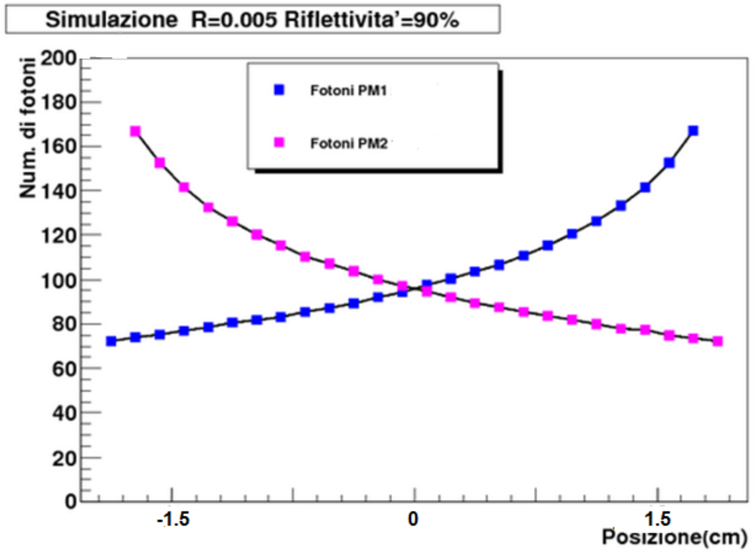
Detector simulation (1)



1) Geometry
2) New Material (p-terphenil)
3) Beam (e- from 4 MeV to 18 MeV)

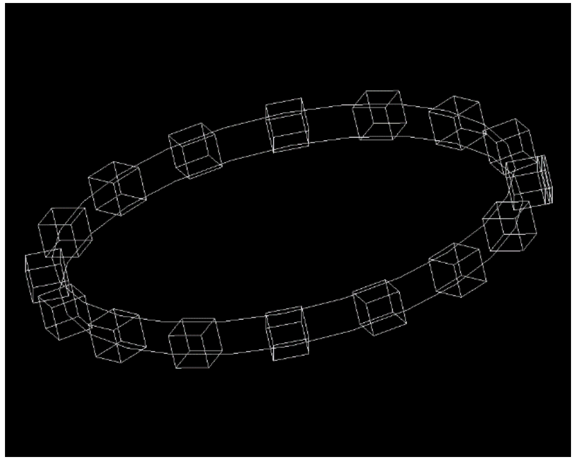


Number of photons for position
Beam energy 5 MeV, in CLOSE position (near the SiPM)

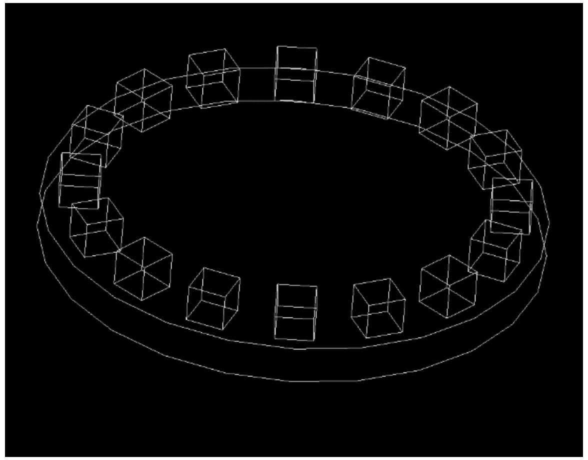


Number of photons revealed by two SiPM as a function of the source position depending on the value of the roughness R=0.005 and reflectivity=90%.

Detector simulation (2)



Configuration SIDE



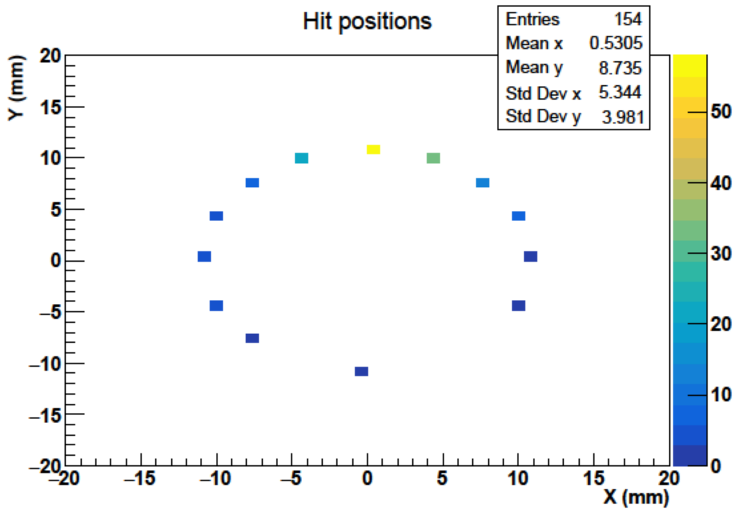
Configuration UP

POSIZIONE SIPM	N°SIPM	SPESSORE SCINT (mm)	DIAMETRO SCINT (cm)
SIDE	12-16	1-2-3-4-5	2.6
UP	12-16	1-2-3-4-5	2.6

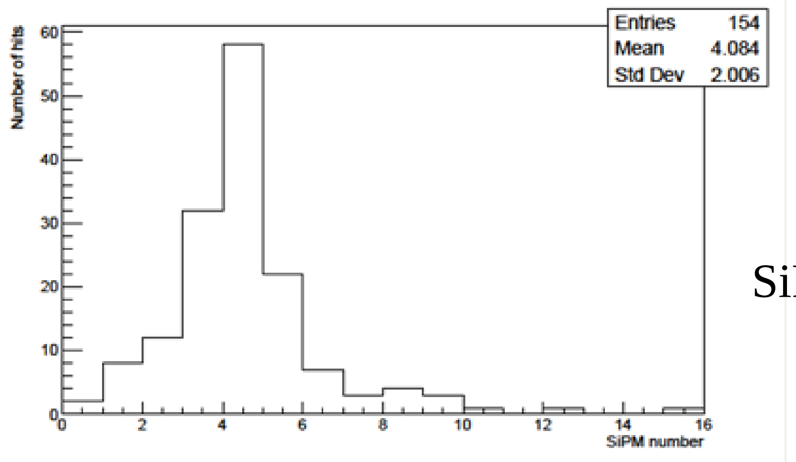
Simulation codes and measurements on a series of discs of sparkling material of different thicknesses, diameter and light collection characteristics, in order to optimize the desired performances!!!

Detector simulation (3)

30 simulations for each energy and for each beam position

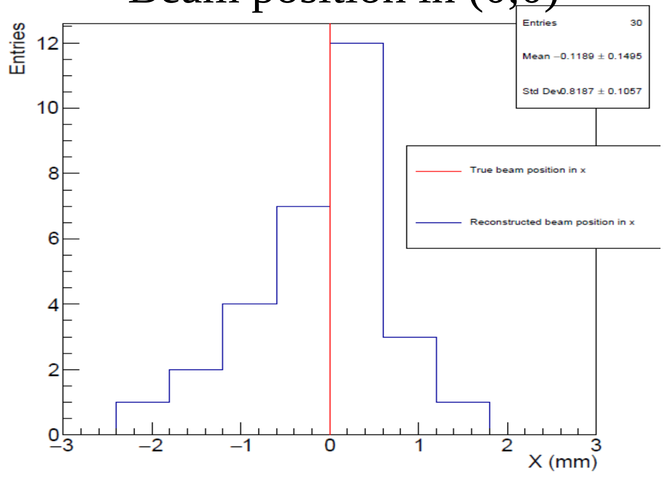


Number of photons into 16 SiPMs (configuration UP)

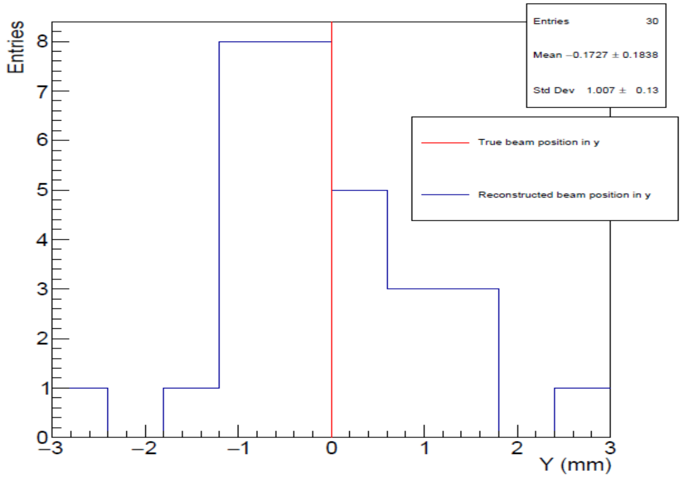


Number of hits in 16 SiPMs(configuration UP)

Beam position in (0,0)



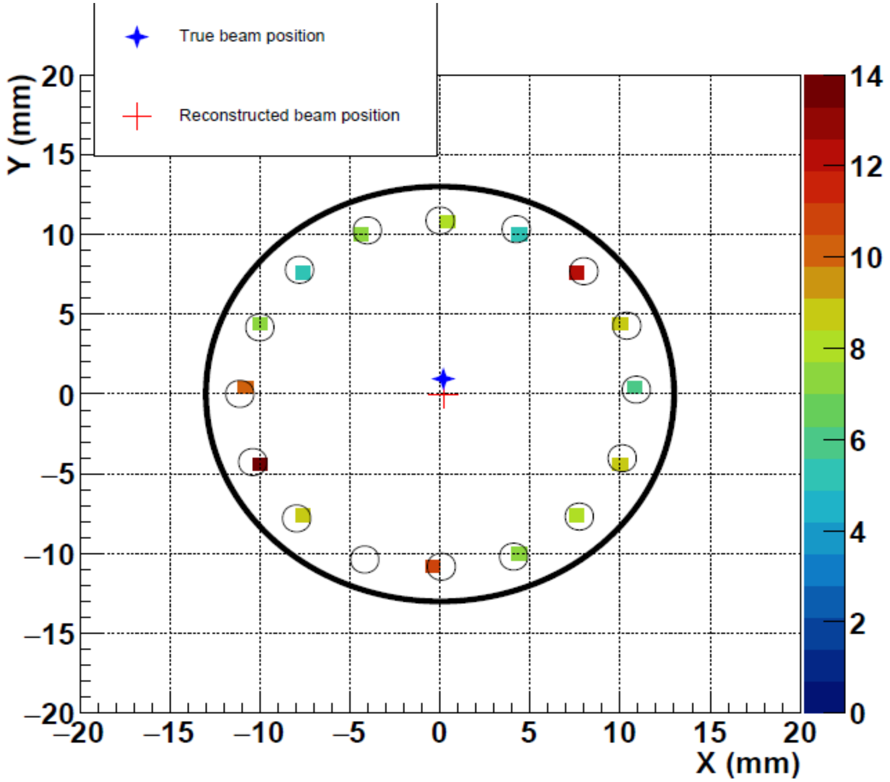
Reconstruction position in x and for 30 simulations resolution in x=0.84±0.15 mm



Reconstruction position in y and for 30 simulations resolution in y=1.04±0.18mm

Detector simulation (4)

Xrec = (w1X1 + w2X2+…)/(w1 + w2+…)

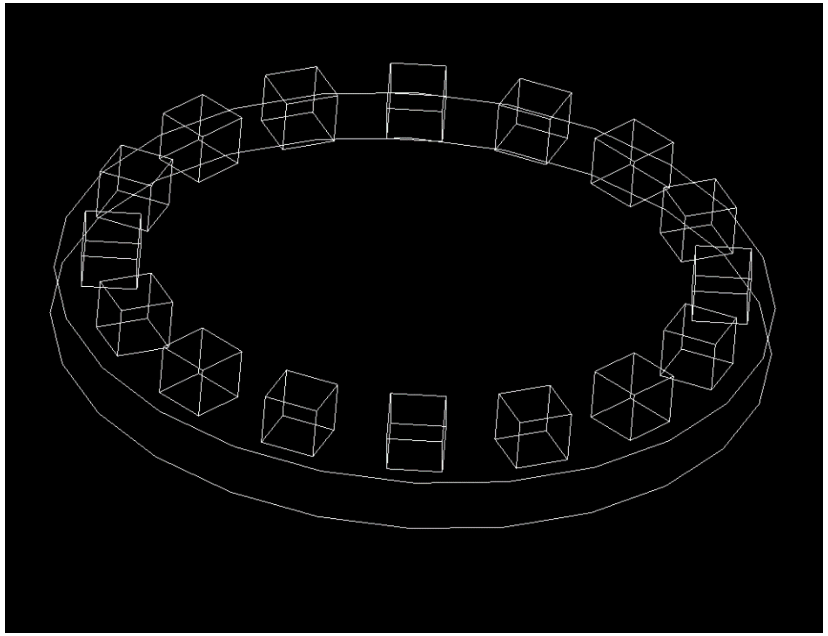


Resolution on beam position: 1.34±0.24 mm

Conclusion

THE BEST CONFIGURATION

1) A monocrystal P-Terphenil disk
2) Thickness 5mm
3) Diameter 2.6cm
4) 16 SiPMs
5) Configuration UP



POSITION ERROR
~ 1mm

A possible timeline is:

1) test of a first prototype with radio-active sources and a low-energy electron beam

2) construction of the additional beam monitors and associated mechanics

3) The 3 final beam monitors for the installation in the SK LINAC

PhD schools and publications (2016-2017)

1. VII International Course "Detectors and Electronics for High Energy Physics, Astrophysics, Space Applica-tions and Medical Physics" INFN National Laboratories of Legnaro, 3-7 April 2017
2. XIV Seminar on "Software for Nuclear, Subnuclear and Applied Physics", ALGHERO, 4-9 June 2017

1. First measurement of the νμ charged-current cross section without pions in the final state on a wa-ter target -T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Aug 22, 2017. 15 pp. -e-Print: arXiv:1708.06771
2. Measurement of neutrino and antineutrino oscillations by the T2K experiment including a new ad-ditional sample of ve interactions at the far detector - T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Jul 4, 2017. 50 pp. - e-Print: arXiv:1707.01048 [hep-ex]
13
3. Measurement of ν¯μν¯μ and νμνμ charged current inclusive cross sections and their ratio with the T2K off-axis near detector - T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Jun 13, 2017. 15 pp. - Published in Phys.Rev. D96 (2017) no.5, 052001 - DOI: 10.1103/PhysRevD.96.052001
4. Measurement of the single π0 production rate in neutral current neutrino interactions on water - T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Apr 24, 2017. 17 pp. - e-Print: arXiv:1704.07467 [hep-ex]
5. Updated T2K measurements of muon neutrino and antineutrino disappearance using 1.5××102121 protons on target - T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Apr 21, 2017. 9 pp. - Pub-lished in Phys.Rev. D96 (2017) no.1, 011102 - DOI: 10.1103/PhysRevD.96.011102 - e-Print: arXiv:1704.06409
6. Search for Lorentz and CPT violation using sidereal time dependence of neutrino flavor transitions over a short baseline - Ko Abe (Kamioka Observ.) et al.. Mar 3, 2017. 9 pp. - Published in Phys.Rev. D95 (2017) no.11, 111101 - DOI: 10.1103/PhysRevD.95.111101
7. Combined Analysis of Neutrino and Antineutrino Oscillations at T2K - T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Jan 2, 2017. 9 pp. - Published in Phys.Rev.Lett. 118 (2017) no.15, 151801 - DOI: 10.1103/PhysRevLett.118.151801

8. Dinucleon and Nucleon Decay to Two-Body Final States with no Hadrons in Super-Kamiokande Super-Kamiokande Collaboration (S. Sussman (Boston U.) et al.). Nov 29, 2018. 7 pp.e-Print: arXiv:1811.1243
9. Measurement of the neutrino-oxygen neutral-current quasielastic cross section using atmospheric neutrinos at Super-Kamiokande Super-Kamiokande Collaboration (L. Wan (Tsinghua U., Beijing, Dept. Eng. Phys.) et al.). Jan 16, 2019. 11 pp. Published in Phys.Rev. D99 (2019) no.3, 032005
10. Irradiation and performance of RGB-HD Silicon Photomultipliers for calorimetric applications F. Acerbi (Fond. Bruno Kessler, Povo) et al.. Jan 24, 2019. 16 pp. Published in JINST 14 (2019) no.02, P02029
11. Search for CP violation in Neutrino and Antineutrino Oscillations by the T2K experiment with 2.2×1021 protons on target -T2K Collaboration (K. Abe (Kamioka Observ.) et al.)- Jul 20, 2018 - 9 pages-e-Print: arXiv:1807.07891 [hep-ex]
12. Atmospheric Neutrino Oscillation Analysis with Improved Event Reconstruction in Super-Kamiokande IV Super-Kamiokande Collaboration (M. Jiang (Kyoto U.) et al.). Jan 10, 2019. 42 pp. Published in PTEP 2019 (2019) no.5, 053F01
13. Hyper-Kamiokande Design Report -Hyper-Kamiokande Collaboration (K. Abe (Yokohama Natl. U. & Kamioka Observ. & Tokyo U., IPMU) et al.) May 9, 2018 - 333 pages, e-Print: arXiv:1805.04163 [physics.ins-det] |
14. A beam monitor based on MPGD detectors for hadron therapy-P.R. Altieri, D.Di Benedetto, G. Galetta, R.A. Intonti, A. Mercadante, S. Nuzzo, P. Verwilligen 2018 - 4 pages EPJ Web Conf. 174 (2018) 01011 (2018) DOI: 10.1051/epjconf/201817401011 Conference: C15-10-12
15. Characterization of nuclear effects in muon-neutrino scattering on hydrocarbon with a measurement of final-state kinematics and correlations in charged-current pionless interactions at T2K - T2K Collaboration (K. Abe et al.) Feb 14, 2018 - 46 pages Phys.Rev. D98 (2018) no.3, 032003 (2018-08-10) DOI: 10.1103/PhysRevD.98.032003 e-Print: arXiv:1802.05078 [hep-ex]
16. Search for Neutrinos in Super-Kamiokande Associated with the GW170817 Neutron-star Merger-Super-Kamiokande Collaboration (Y. Hayato (Kamioka Observ. & Rutherford) et al.) Feb 12, 2018 - 8 pages Astrophys.J. 857 (2018) no.1, L4 (2018-04-09) DOI: 10.3847/2041-8213/aabacae-Print: arXiv:1802.04379 [astro-ph.HE]
17. Measurement of inclusive double-differential νμ charged-current cross section with improved acceptance in the T2K off-axis near detector T2K Collaboration (K. Abe (Kamioka Observ.) et al.). Jan 16, 2018. Published in Phys.Rev. D98 (2018) 012004 DOI: 10.1103/PhysRevD.98.012004 e-Print: arXiv:1801.05148 [hep-ex]

Thank you for your attention