BOREXINO - Status and Calibration

International Workshop on "Double Beta Decay and Neutrinos"

Osaka, June 12, 2007

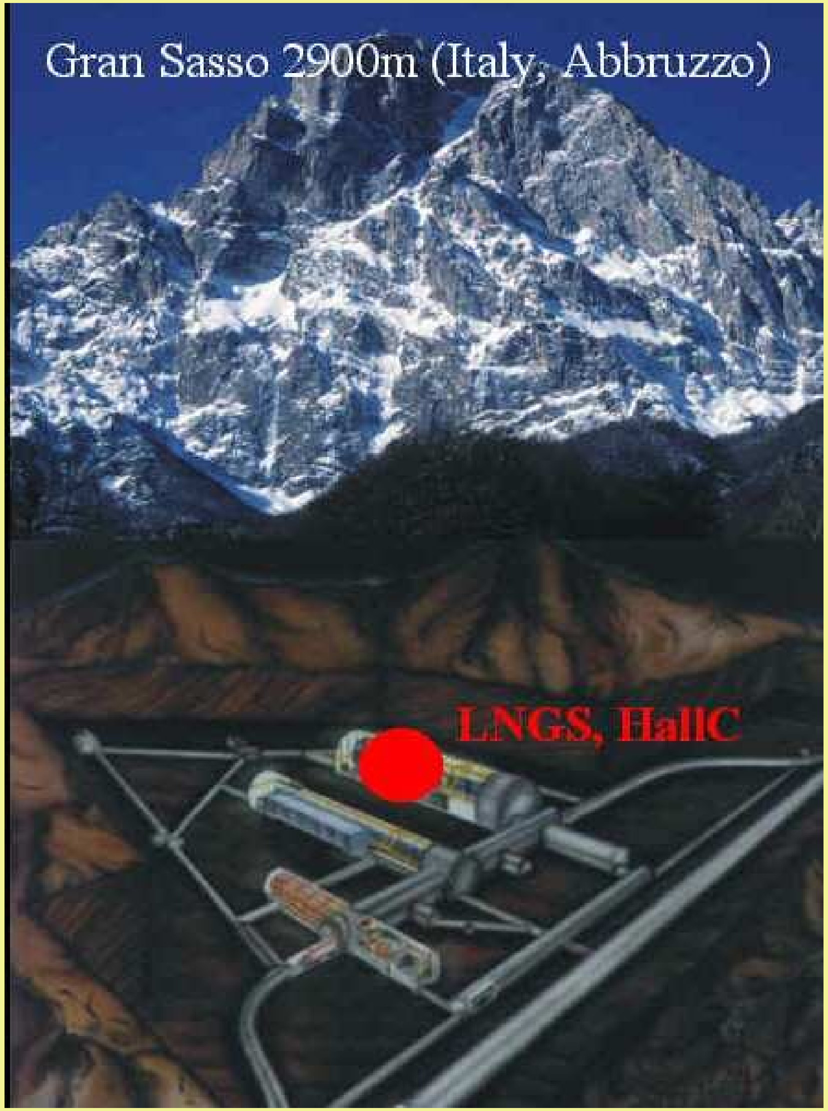
Christian Grieb for the Borexino Collaboration
Virginia Tech

Borexino Collaboration

- College de France (France)
- Technische Unversität München (Germany)
- JINR Dubna (Russia)
- Kurchatov Institute Moscow (Russia)
- MPI Heidelberg (Germany)
- Jagellonian University Cracow (Poland)
- INFN – Milano (Italy)
- INFN – Genova (Italy)
- INFN – Perugia (Italy)
- INFN – LNGS (Italy)
- Princeton Univeristy (USA)
- Virginia Tech (USA)

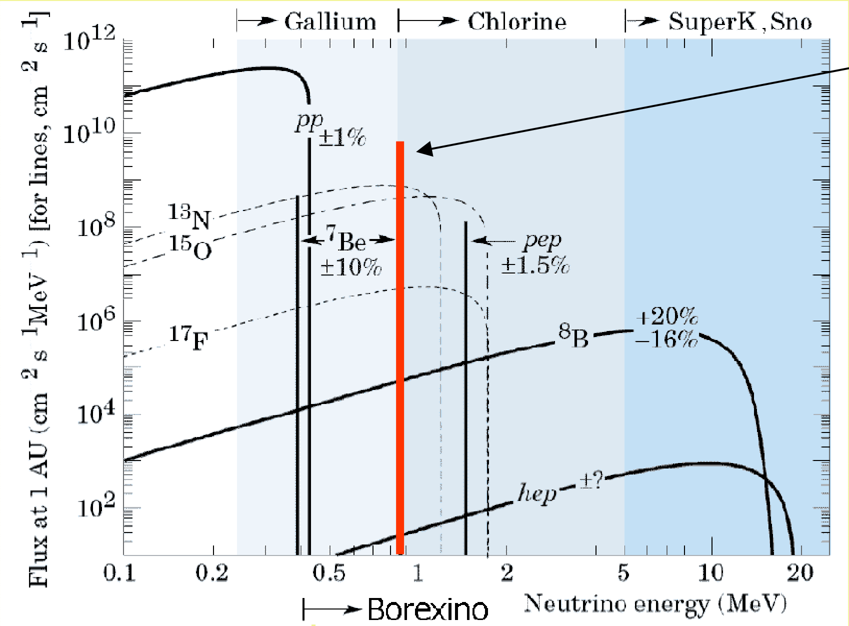
} NSF funded

Borexino



- Designed to spectroscopically measure low energy solar neutrinos, especially ^{7}Be
- Liquid Scintillator Spectrometer
- $\nu + e^{-} \rightarrow \nu' + e^{-\prime}$
  - Charged Current
  - Neutral Current

Signal in Borexino

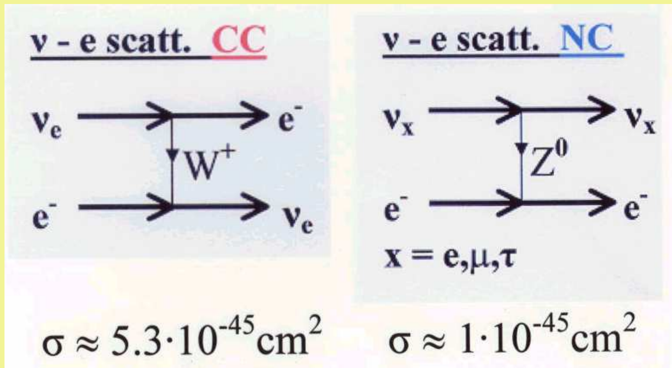


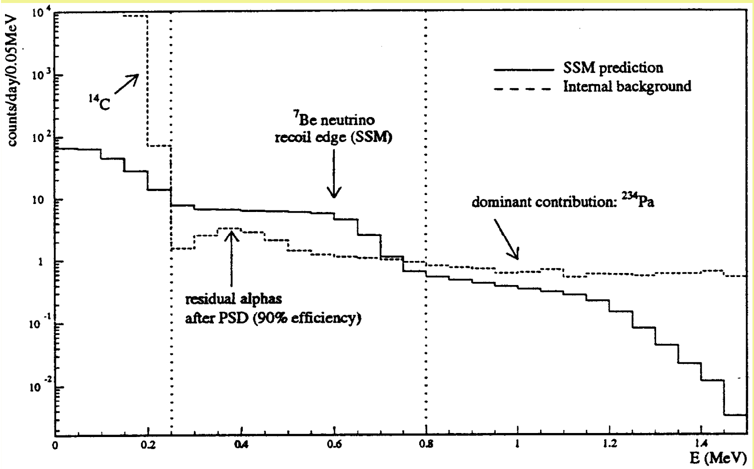
$^{7}\mathbf{Be} + \mathbf{e}^{-} \rightarrow {}^{7}\mathbf{Li} + \nu_{e}$

Monochromatic E_{ν}=862 keV

Φ_{SSM}=4.8x10^{9} ν/sec/cm^{2}

$\nu_e \longleftrightarrow \nu_x$



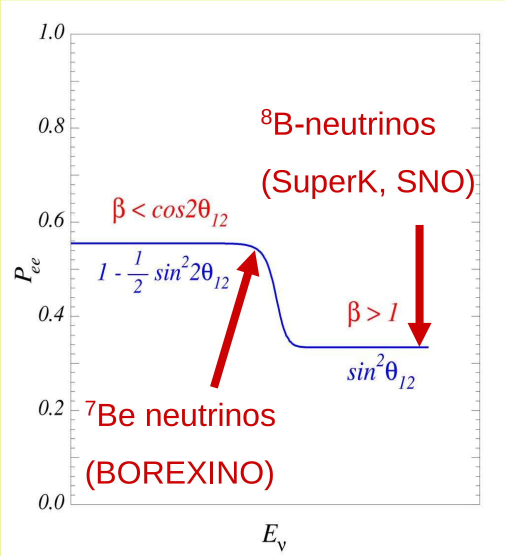


Expected rate (LMA) is ~35 counts/day between 0.25-0.8 MeV

Science in Borexino

- Measure ^{7}Be solar neutrinos (0.25-0.8 MeV)
  - Measured vs MSW-LMA predicted event rate
  - 1/r^2 solar signature

- Study CNO and pep (~1-2 pep ev/d) neutrinos (0.8-1.3 MeV) (rejection of ^{11}C cosmogenic background – proven in CTF hep-ex/0601035)
- Geoneutrinos (10 – 30 ev/year)
- Supernova Neutrinos (~120 ev from GC supernova)
- Double beta decay with Xenon? (Phys.Rev.Lett. 72:1411,1994)
- ...



Publications (since 2002)

- The Nylon Scintillator Containment Vessels for the Borexino Solar Neutrino Experiment.
  - J. Benziger *et al.* Feb 2007 physics/0702162
- CNO and pep neutrino spectroscopy in Borexino: Measurement of the deep-underground production of cosmogenic C11 in an organic liquid scintillator
  - H. Back et al. (Borexino Collaboration), Phys.Rev.C74:045805 (2006)
- Supernova neutrino detection in Borexino.
  - M.E. Monzani Jun 2006. Published in Nuovo Cim.C29:269-280 (2006).
- Search for electron antineutrino interactions with the Borexino counting test facility at Gran Sasso.
  - By Borexino Collaboration (M. Balata *et al.*). Eur.Phys.J.C47:21-30 (2006).
- Experimental scintillator purification tests with silica gel Chromatography.
  - Ludwig Niedermeier, Christian Grieb, Lothar Oberauer, Gunther Korschinek, Franz von Feilitzsch, Nuclear Instruments and Methods in Physics Research A 568 (2006)
- Cosmogenic 11C production and sensitivity of organic scintillator detectors to pep and CNO neutrinos.
  - Cristiano Galbiati, Andrea Pocar, Davide Franco, Aldo Ianni, Laura Cadonati, Stefan Schönert
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- Radon permeability through nylon at various humidities used in the Borexino experiment.
  - M. Wójcik, G. Zuzel.
    Nuclear Instruments and Methods in Physics Research A 524 (2004) 355 365.
- New experimental limits on violations of the Pauli exclusion principle obtained with the Borexino Counting Test Facility
  - European Physical Journal C37 (2004) 421.
- Ultra-traces of 226Ra in nylon used in the Borexino solar neutrino experiment.
  - G. Zuzel, M. Wójcik, C. Buck, W. Rau, G. Heusser.
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- A Sampling Board Optimized for Pulse Shape Discrimination in Liquid Scintillator Applications
  - G. Ranucci, R. Dossi, P. Inzani, G. Korga, P. Lombardi, E. Meroni, and M. E. Monzani
    IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 4, AUGUST 2004
- The measurements of 2200 ETL9351 type photomultipliers for the Borexino experiment with the photomultiplier testing facility at LNGS
  - A.Ianni, P.Lombardi, G.Ranucci, O.Ju.Smirnov
    arXiv:physics/0406138; Nucl.Instrum.Meth. A537 (2005) 683-697
- The photomultiplier tube testing facility for the Borexino experiment at LNGS
  - A.Brigatti, A.Ianni, P.Lombardi, G.Ranucci, O.Ju.Smirnov
    arXiv:physics/0406106; Nucl.Instrum.Meth. A537 (2005) 521-536
- Precicision measurements of time characteristics of the 8'' ETL9351 series photomultiplier
  - O.Ju.Smirnov, P.Lombardi, G.Ranucci
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- Light concentrators for Borexino and CTF.
  - ", L. Oberauer (Munich, Tech. U.) , C. Grieb (Munich, Tech. U. & Virginia Tech.) , F. von Feilitzsch (Munich, Tech. U.) , I. Manno (Budapest, RMKI), Nucl.Instrum.Meth.A 530:453-462 (2004).
- A multiplexed optical-fiber system for the PMT calibration of the Borexino experiment.
  - B.Caccianiga, D.Franco, D.Giugni, P.Lombardi, S.Malvezzi, J.Maneira, G.Manusardi,L.Miramonti, G.Ranucci O.Smirnov
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- Search for the Solar pp- neutrinos with an unpgrade of CTF detector
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- Study of the neutrino electromagnetic properties with the Prototype of the Borexino Detector
  - Physics Letters B 563 (2003) 37.
- New limits on nucleon decays into invisible channels with the BOREXINO Counting Test Facility
  - Physics Letters B 563 (2003) 23.
- Search for electron decay mode $e \rightarrow \gamma + \nu$ with prototype of Borexino detector.
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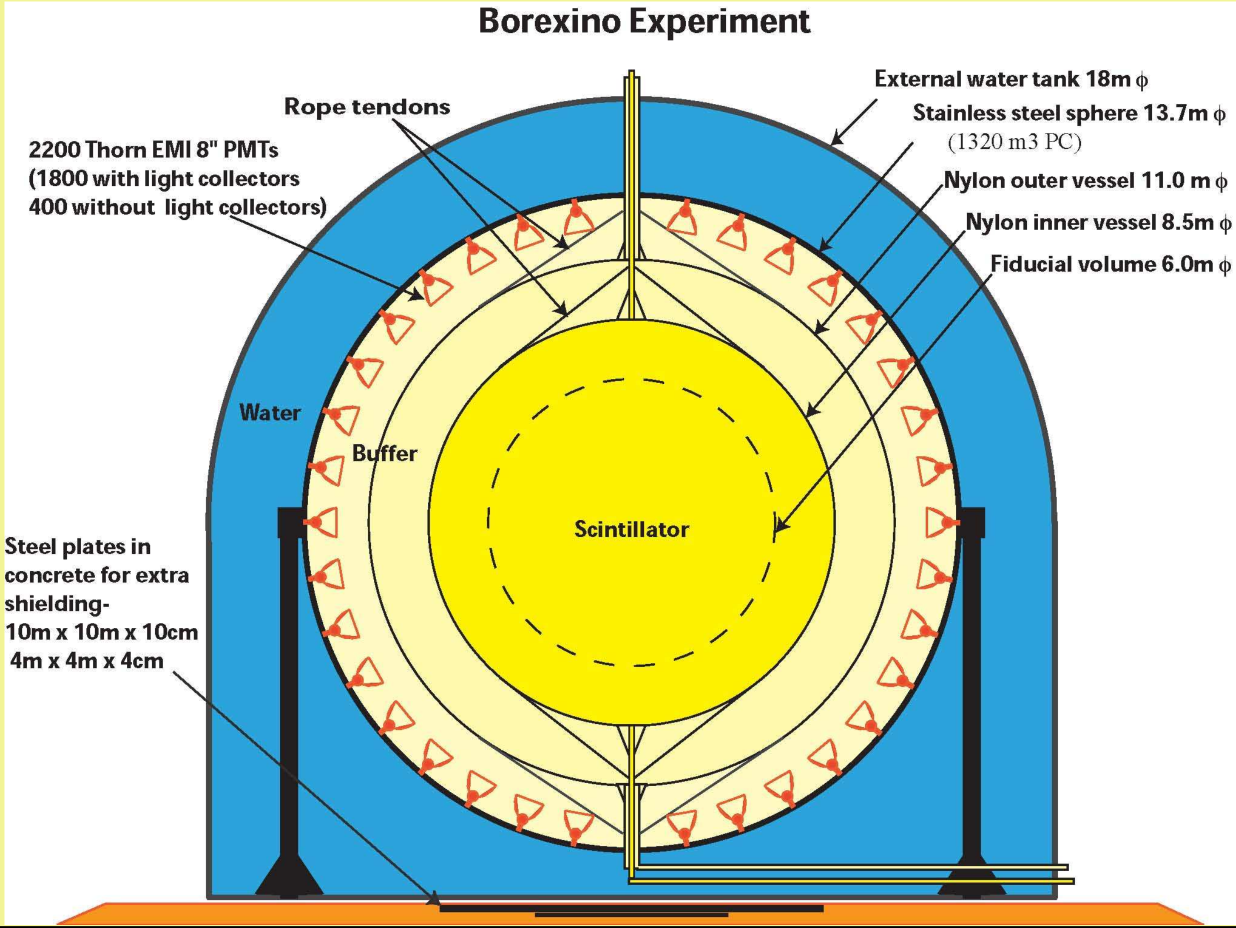
- Measurements of extremely low radioactivity levels in BOREXINO.
  - Astroparticle Physics 18 (2002) 1.
- Science and Technology of Borexino: A Real Time Detector for Low Energy Solar Neutrinos
  - Astroparticle Physics 16 (2002) 205.
- Search for neutrino radiative decay with a prototype Borexino detector
  - Derbin A., Smirnov O.
    JETP Lett. Vol 76, No 7 (2002) 409-413.
- Resolutions of a large volume liquid scintillator detector.
  - O. Ju. Smirnov.
    Instruments and Experimental Techniques, 2003 No 2
- Effects of absorption and reemission of photons in large scintillation counters on the quantities measured by an observing phototubes.
  - G. Ranucci.
    Nuclear Instruments and Methods A487 (2002) 535.

Schematic View of the Borexino Detector

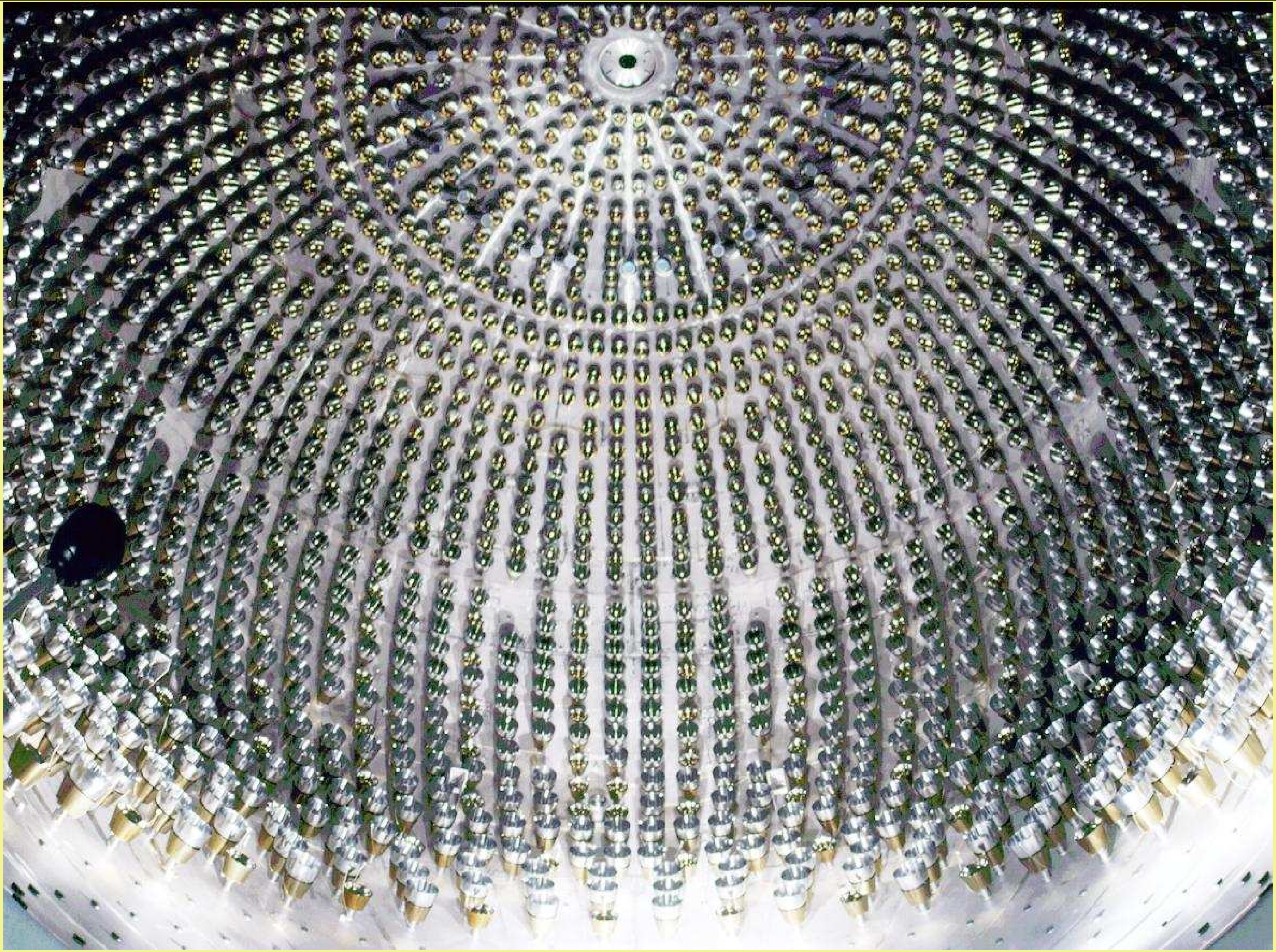
Main challenge in Borexino: Radiopurity → Shell Structure

Components of the detector:

- Scintillator: 1,2,4-Trimethylbenzene (PC) + PPO (1.5 g/l) (300 t, 100 t fiducial mass)
- Nylon inner vessel (d = 8.5 m) - Nylon outer vessel
- Buffer liquid: PC + DMP (1040 ton)
- Stainless steel sphere (d = 13.7 m)
- ~2200 inner phototubes – ~1800 with light guides
- Outer Muon veto: 210 PMTs + tyvek panels
- External buffer of ultra-pure water
- Water Tank
- Calibration equipment
- Electronics and DAQ

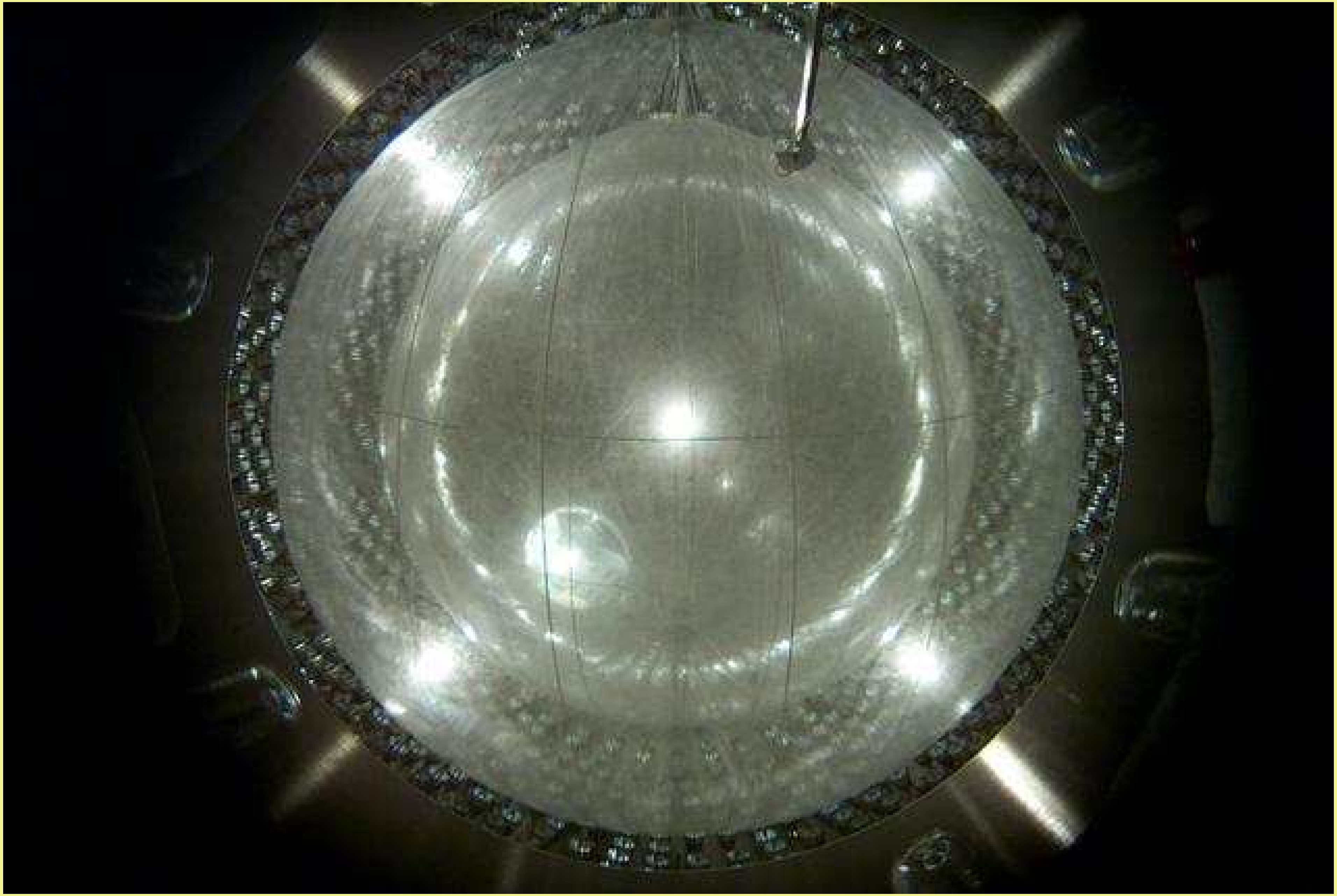


View of SSS with PMTs and Light Guides Installed

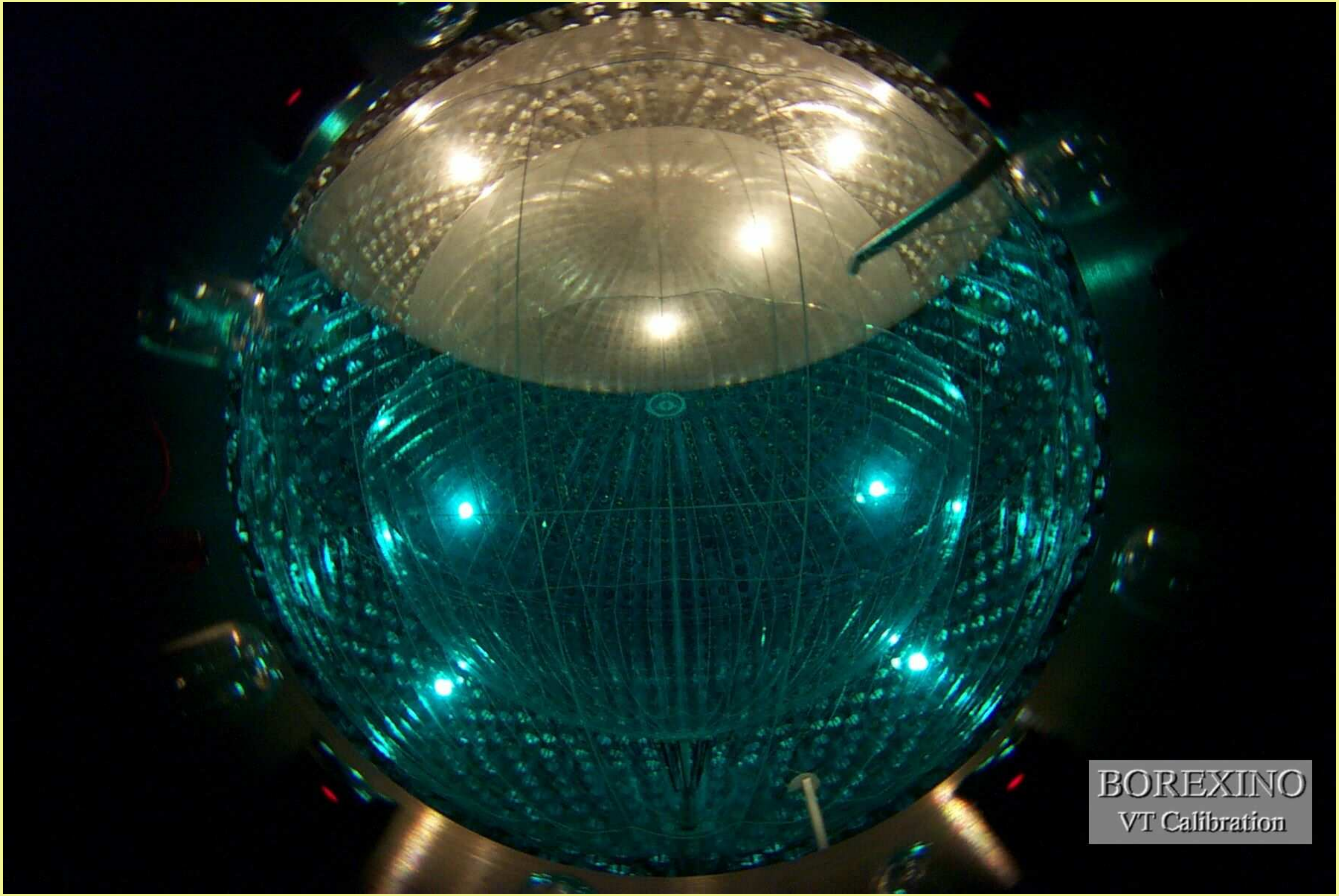


Nylon Vessels in SSS prior to inflation (2004)

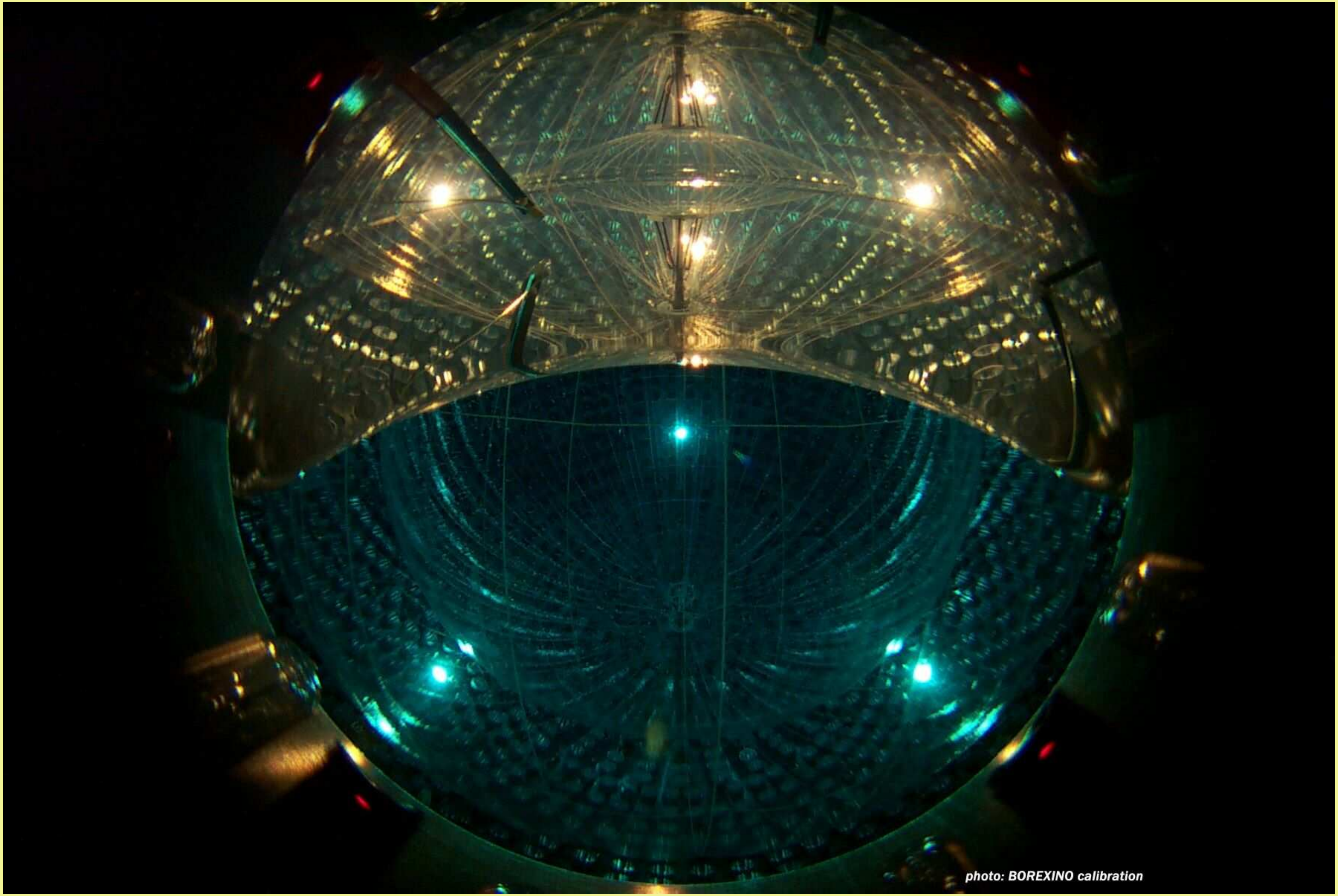
Inflated Nylon Vessels in SSS



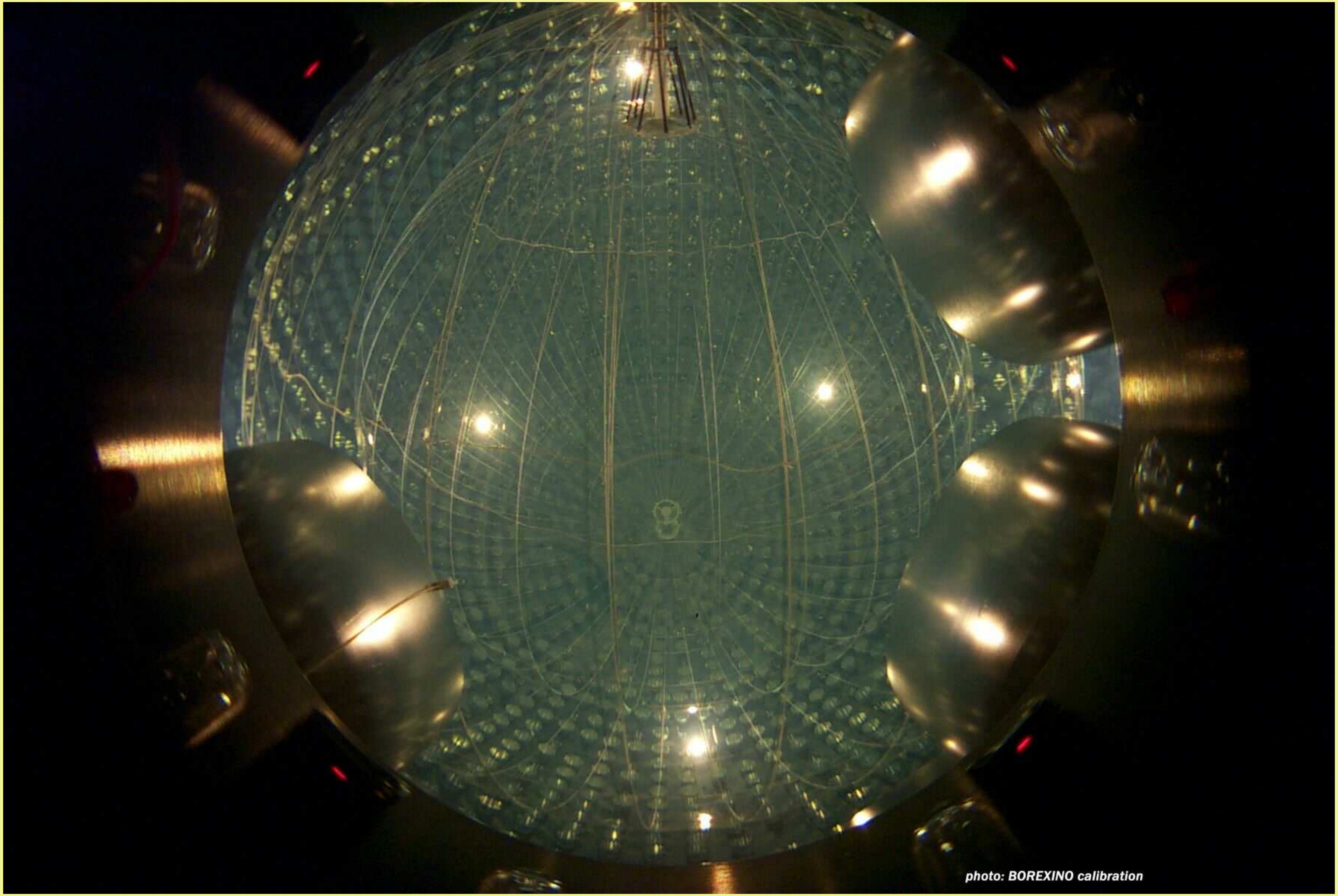
Filling with Ultrapure Water



Water (on top) is replaced by Scintillator



May 15, 2007: Borexino completely filled with Scintillator!



Motivation for Calibration

Precision neutrino science:

- Systematics need to be known
- 1/r^2 solar signature

Challenges in Borexino:
No event signature (only spectroscopic)

A. Radiopurity

Requirements defined design, construction and filling

B. Energy

Quenching – different energy response to α,β,γ ⇨Cal. sources

C. α/β separation (pulse shape discrimination)

is critical due to ^{210}Po + other α sources at low energies
spatial and energy dependence ⇨Cal. sources

D. Fiducial Volume ⇨Cal. sources

Definition of absolute mass
Solar signal 1/r^2 (Stability of FV over time)
Characterization of external background

Borexino Calibration

A variety of calibration and monitoring systems are planned:

- Making use of intrinsic radioactivity (^{14}C, Radon BiPo, neutron capture,…)
- Laser pulses distributed to all PMT’s with a fiber optics splitting system
  - ⇨ Timing calibration
  - ⇨ Gain adjustment via detection of the single photoelectron peak
- External sources (Th) located in the SSS close to the light guides
  - ⇨ Check the stability over time of the overall detector response
- Internal sources inside the scintillator (Virginia Tech Source Calibration System)
  - ⇨ Position reconstruction calibration
  - ⇨ Energy calibration (and spatial dependence)
  - ⇨ α/β Discrimination (“ “)

Borexino Calibration

• CCD Cameras with capability to precisely locate objects inside the detector; a ≤ 2% uncertainty in the fiducial volume definition translates into ~ ±2 cm (part of the Virginia Tech Source Calibration System)

• Laser beams with different wavelengths through the buffer and laser excitation of the scintillator

⇨ Stability monitoring of the optical properties

⇨ Tuning of Monte Carlo

• Blue LED's + fibers for the outer muon veto detector

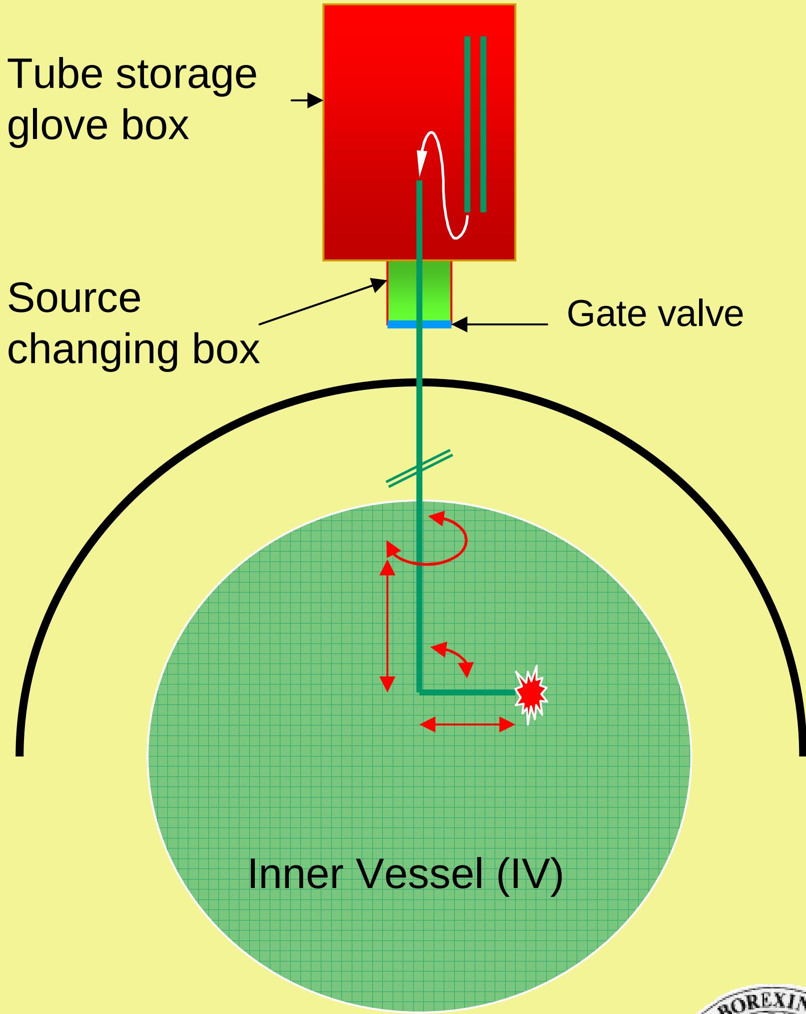
Source Calibration System for Borexino

Novel approach to source calibration system:

A) Mechanical insertion to approximate position

B) Precise optical position determination

Source Insertion System (SIS)

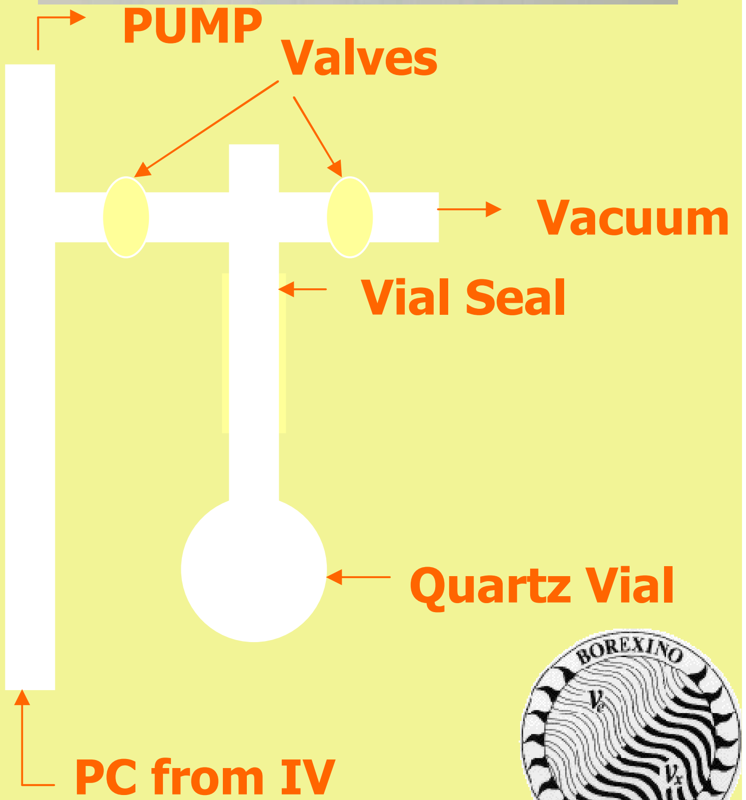


- Maps out cylinders in IV
- Neutrally buoyant in scintillator
- Source changing is box at same pressure as IV
- Only *approximate* source position

Source Insertion System

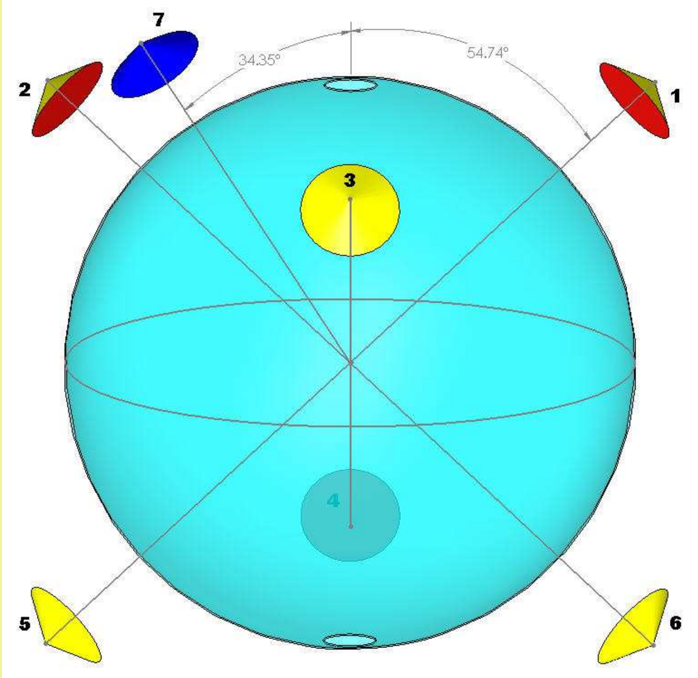
Calibration Sources

- Possible α-sources:
  ^{238}U (4.2 MeV), ^{232}Th (4.0 MeV), ^{222}Rn (5.6 MeV), ^{210}Po (5.4 MeV)
- Radon was used in the Borexino Counting Test Facility (CTF)
- U and Th have long half lives
  ⇨ Contamination concern
- Radon has short half life
  ⇨ Higher energy



- Sources are made with scintillator from inner vessel (IV)
- Vial is evacuated and loaded with source material
- Scintillator is then pumped from IV
- When it is sure that the scintillator being pumped is from the IV, source is loaded with scintillator

The Optical Source Locating System



Goals:

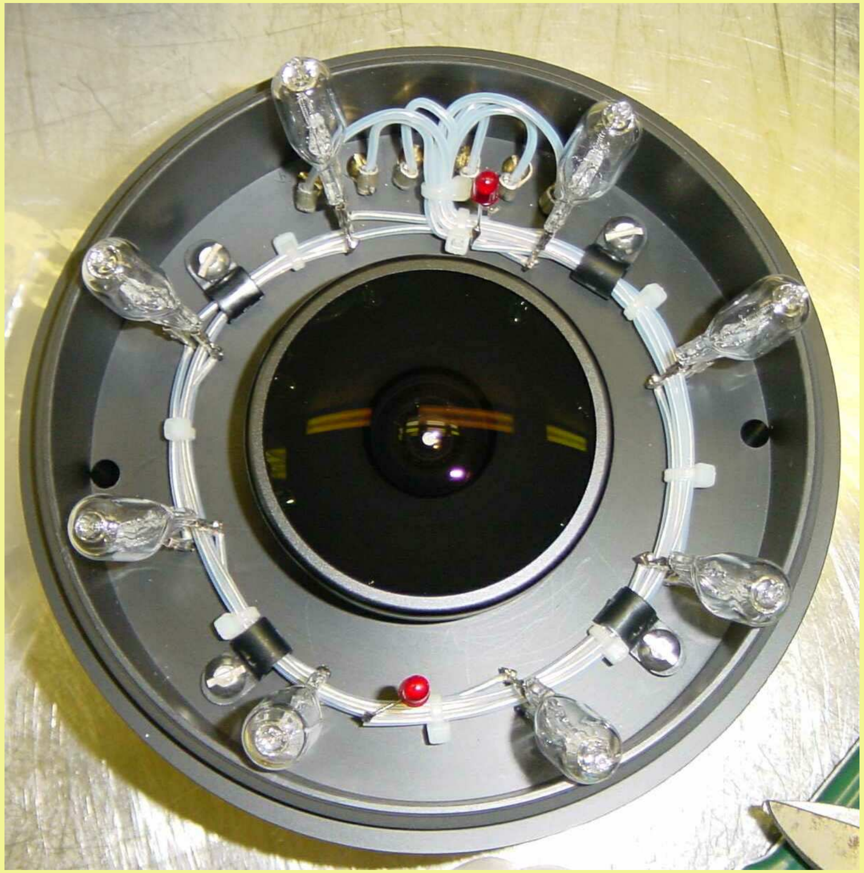
- Locate Internal Sources to +/- 2cm
- Locate Internal Fiber Optics
- Monitor Vessel Shapes
- Provide Photos for PR

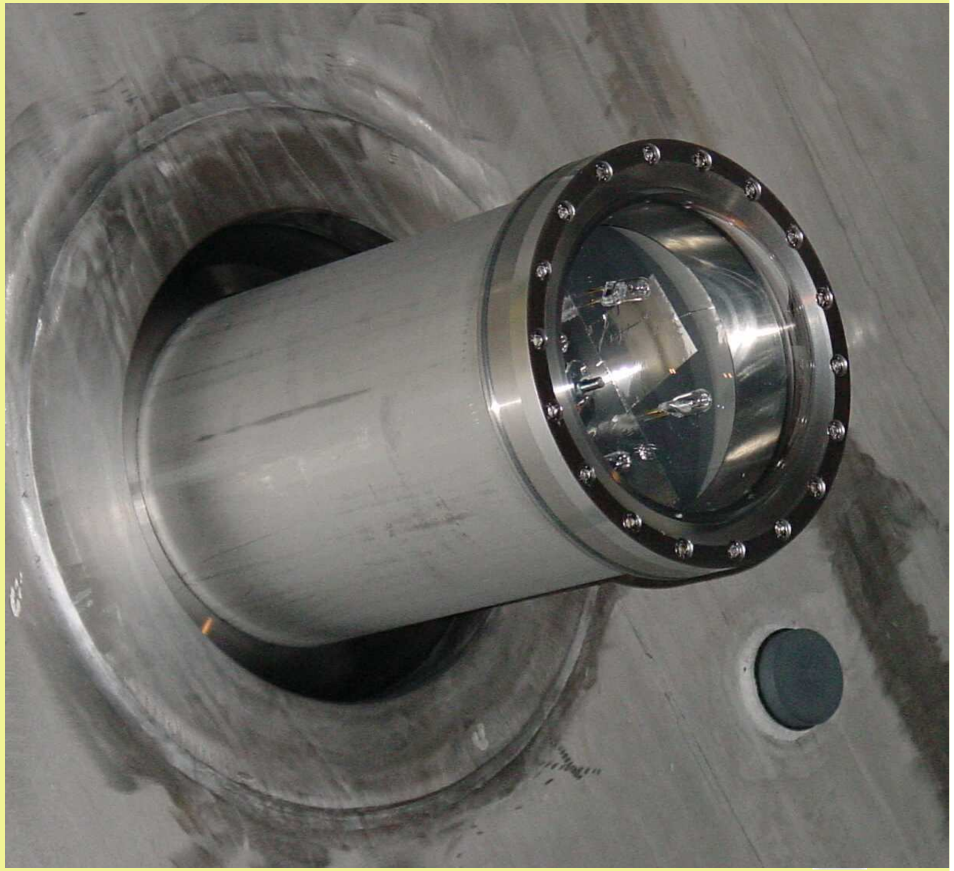
Strategy:

- Mount cameras at approximately orthogonal positions and use triangulation to reconstruct position
- Use LEDs (with PMTs on, but trigger disabled) on objects to locate
- 7 cameras ➔ 14 independent numbers to determine x,y,z

Source Locating System

- Camera Kodak DC290 with additional fish-eye lens
- Mounted in Stainless steel housings
- The Borexino Counting Test Facility (CTF) was equipped with 3 cameras
- Borexino has 7 cameras installed

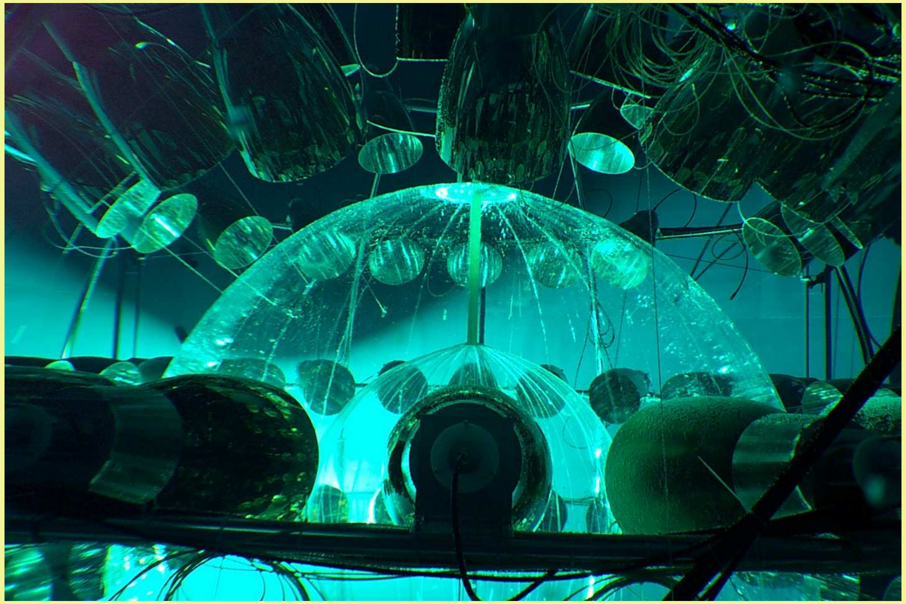


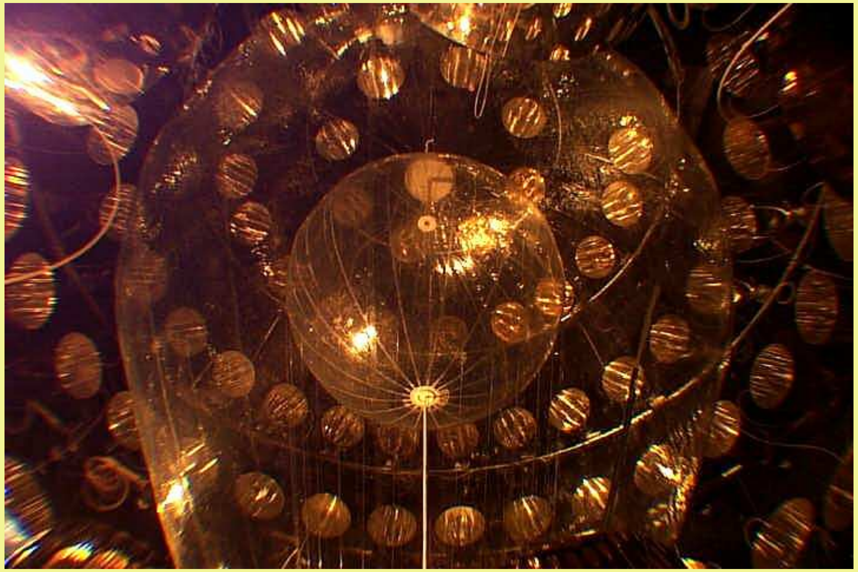


Pictures from the CTF

Featured in:

- Alitalia in-flight magazine
- INFN 50th anniversary book

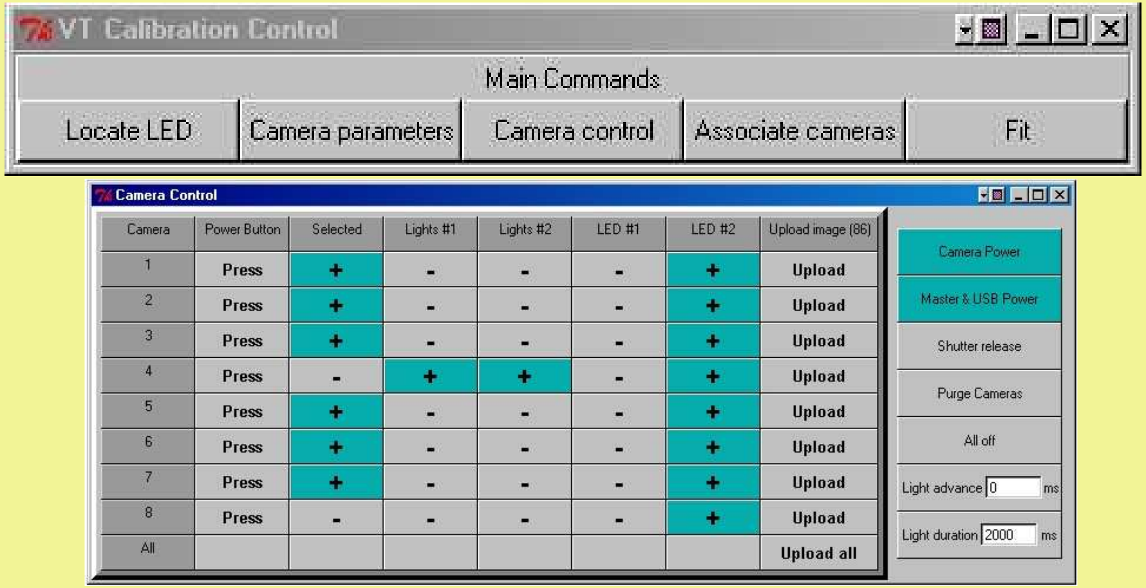




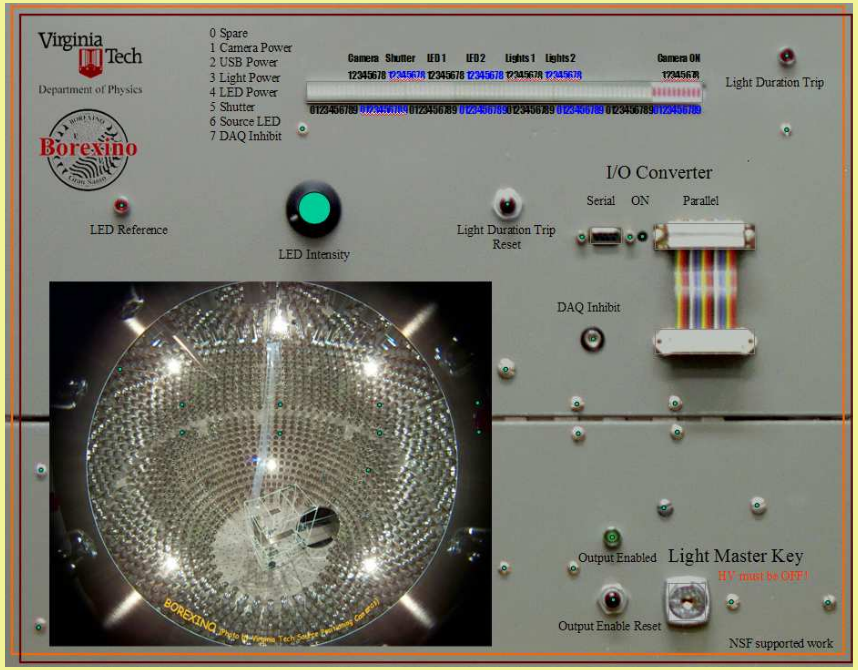
- Cover of “Proceedings of the 5th International Topical Workshop at LNGS on Solar Neutrinos: Where Are the Oscillations?”
- Italian Photography Magazines

Control of Cameras and Lights

Software:



Hardware:



Cameras & Lights are controlled remotely, fully automated

Challenges

- Cameras are not pin-hole
- Cameras are multi-lens systems that project 3d space onto a 2d image
- CCD image plane may not be perpendicular to optical axis, lenses may be misaligned
- Installed Orientation of camera must be determined with pixel accuracy

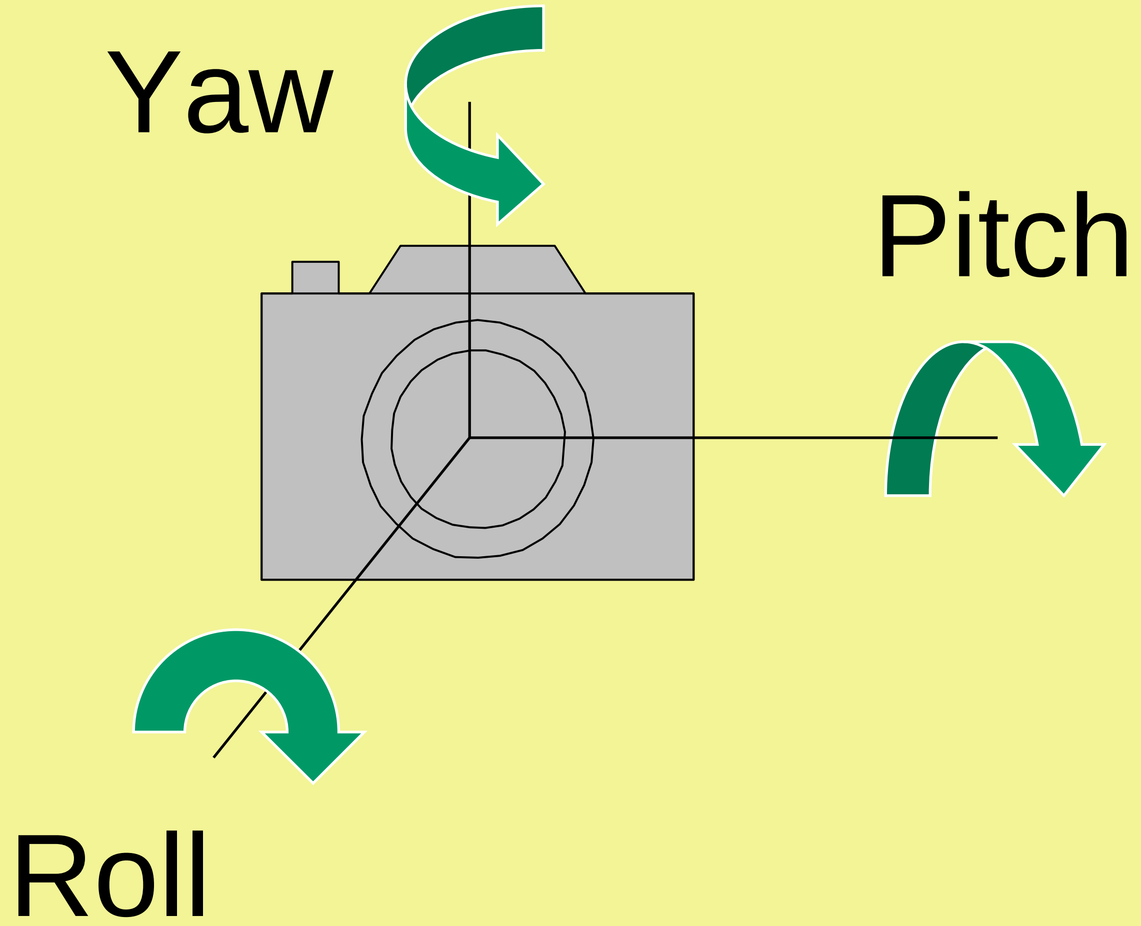
⇒ The resulting image is distorted

Corrections are necessary

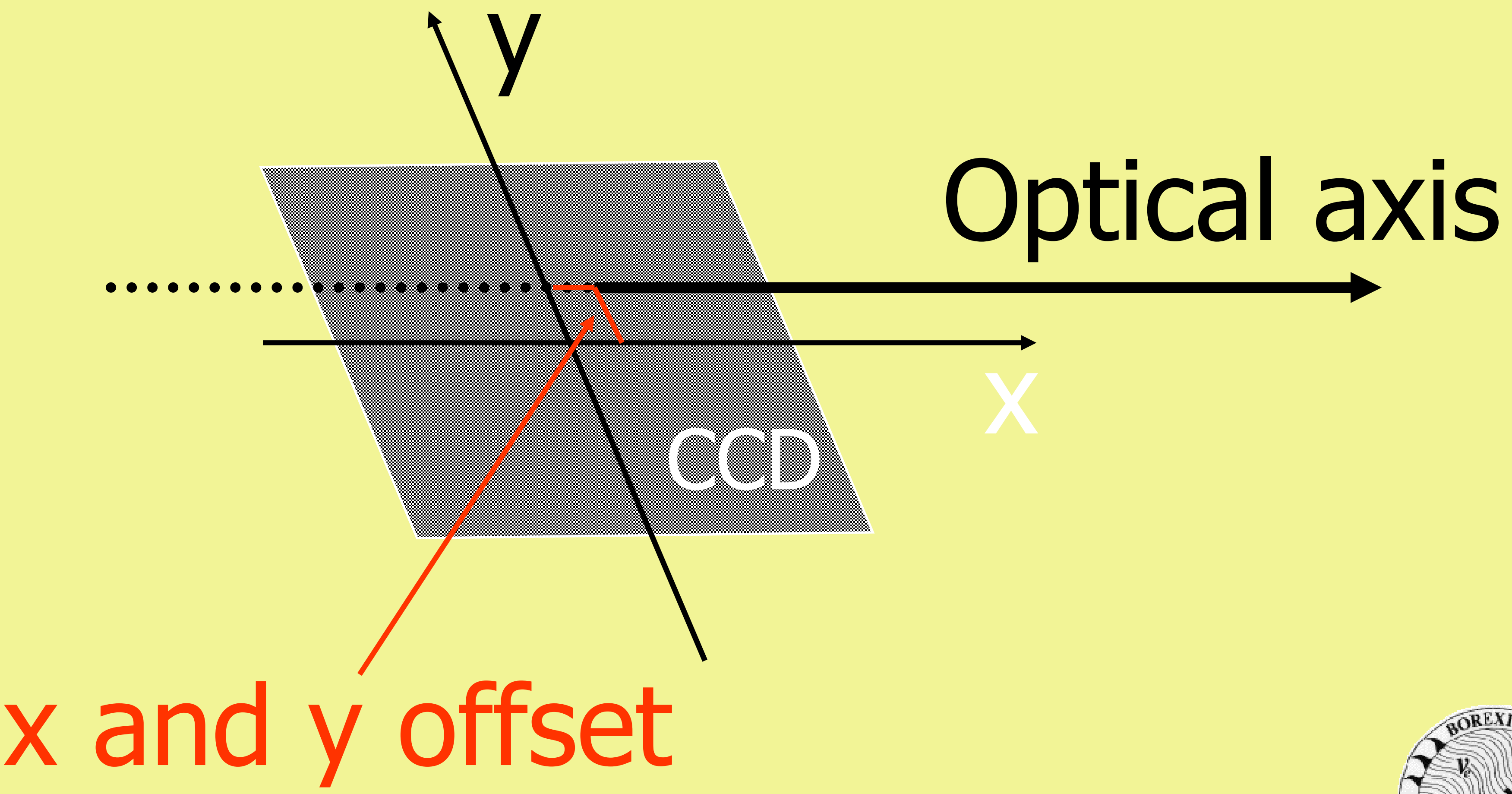
Camera Calibration - Strategy

- Each camera/lens system must be calibrated
- Fit camera roll, pitch, yaw
- Fit CCD x, y pixel offsets and scale
- Fit lens parameters
- Use known positions of PMTs

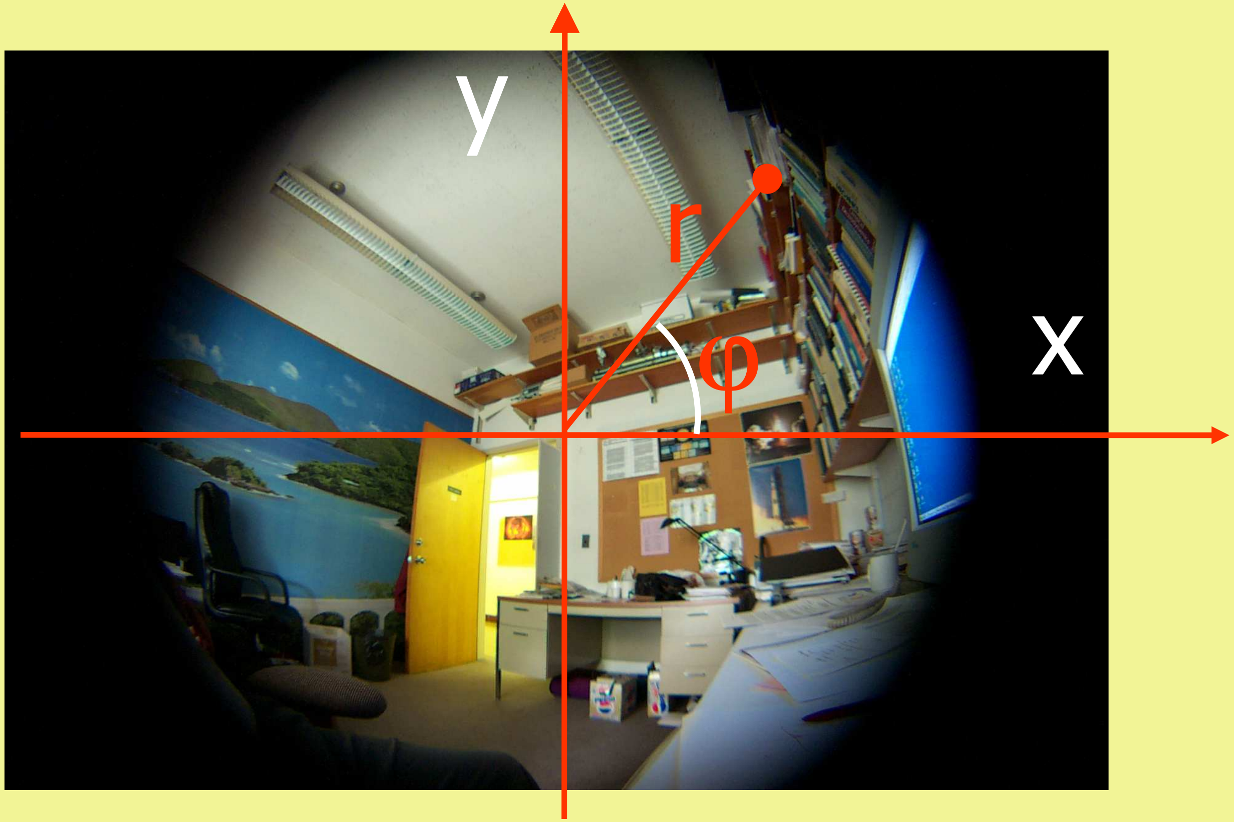
Roll, Pitch and Yaw



CCD Offset and Scale



Radial & Decentering Correction for Optical Distortion



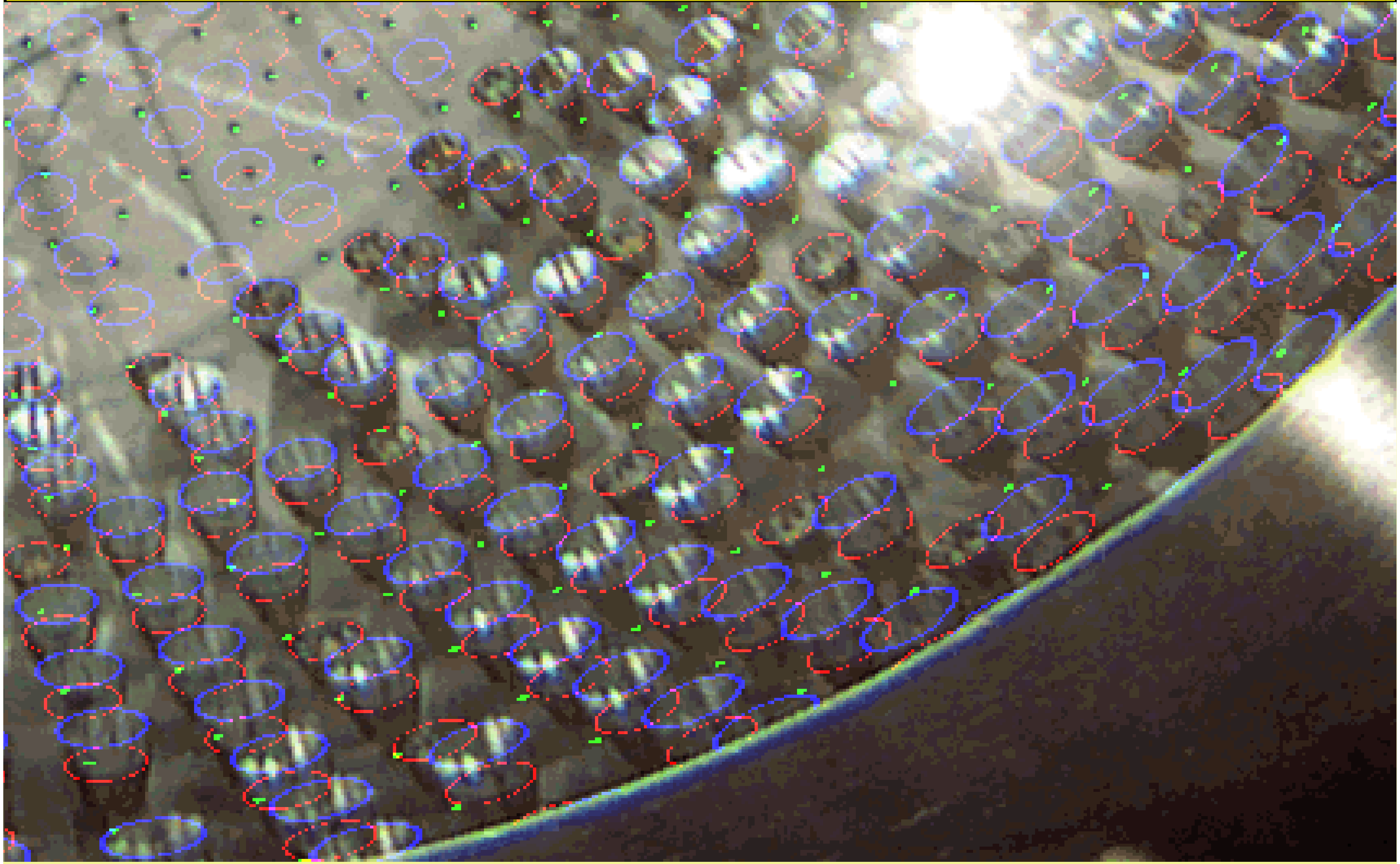
Radial correction:

$$r' = \sum_i c_i r^i$$

Decentering correction:

$$\begin{pmatrix} x \\ y \end{pmatrix}'' = \begin{pmatrix} r' \cos\varphi \\ r' \sin\varphi \end{pmatrix} + \begin{pmatrix} p_1\left(r'^2 + 2r'^2 \cos^2\varphi\right) \\ p_2\left(r'^2 + 2r'^2 \sin^2\varphi\right) \end{pmatrix} + \begin{pmatrix} 2p_2 r'^2 \cos\varphi \sin\varphi \\ 2p_1 r'^2 \cos\varphi \sin\varphi \end{pmatrix}$$

Camera Calibration

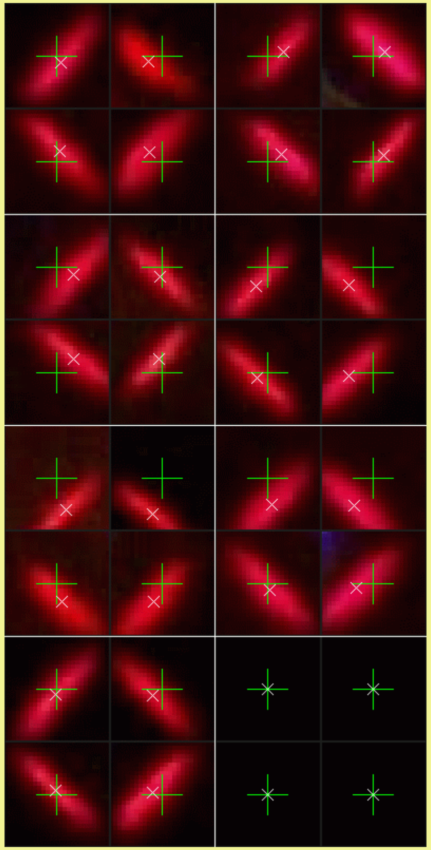


About 100 calibration pts / camera

Additional Correction: “Tweak”

Problem:

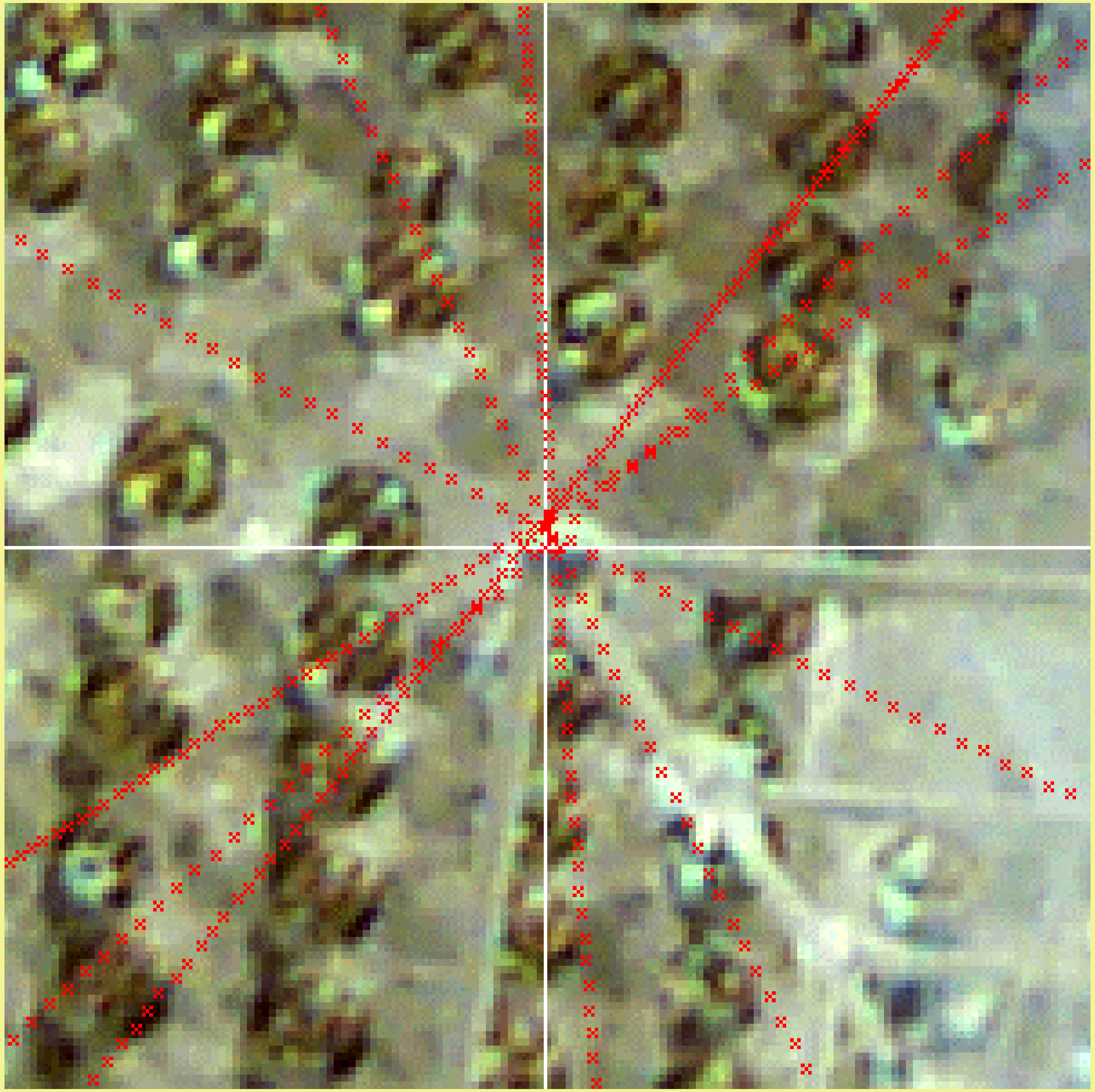
- Consumer Kodak camera DC290 with Nikon lens
- Focus and zoom not locked
- Each picture has x,y shift and scale factor which need to be corrected for on a case-by-case basis (without this one gets only +/- 5 cm position)



Solution:

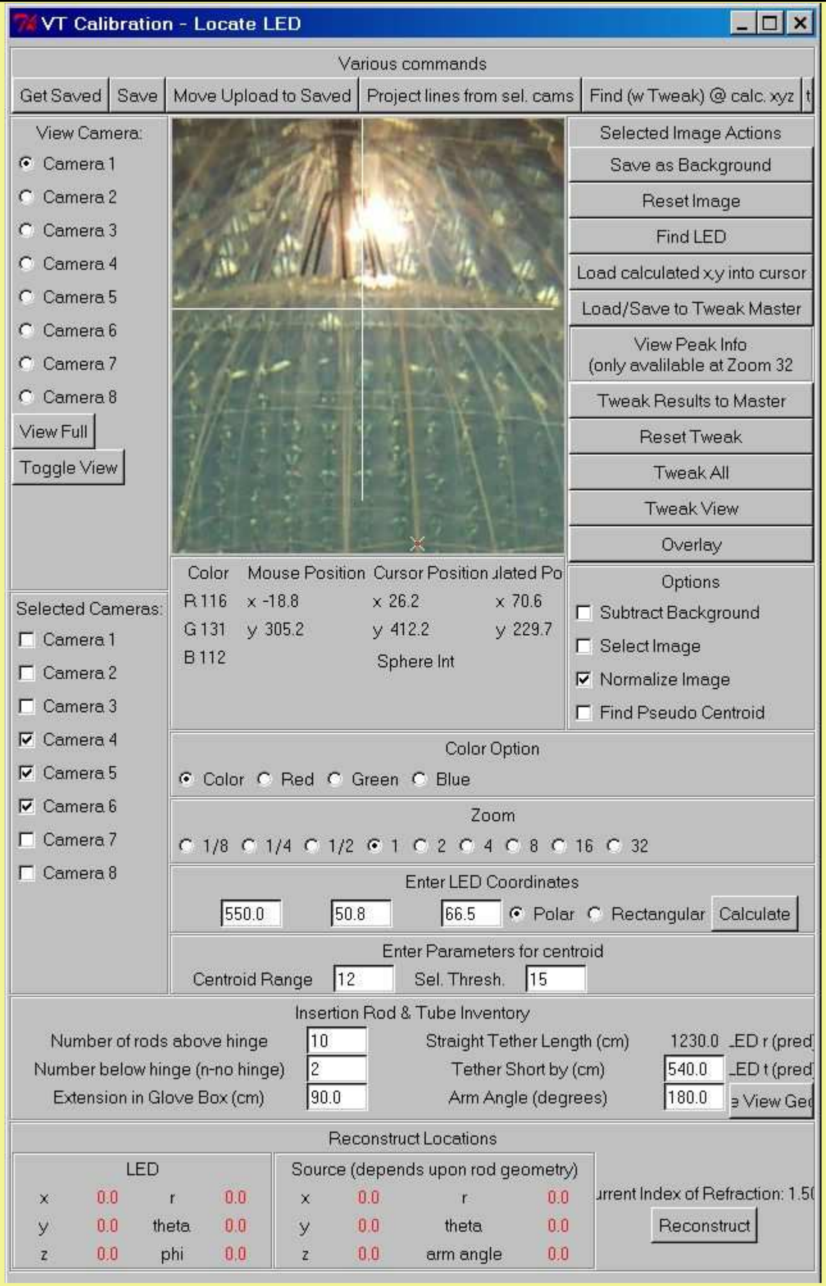
- Turn on in-camera LEDs for every picture. Use two points (four numbers) to correct scale and shift.
- The software can do this correction automatically, by finding known reference LEDs

Source Locating System



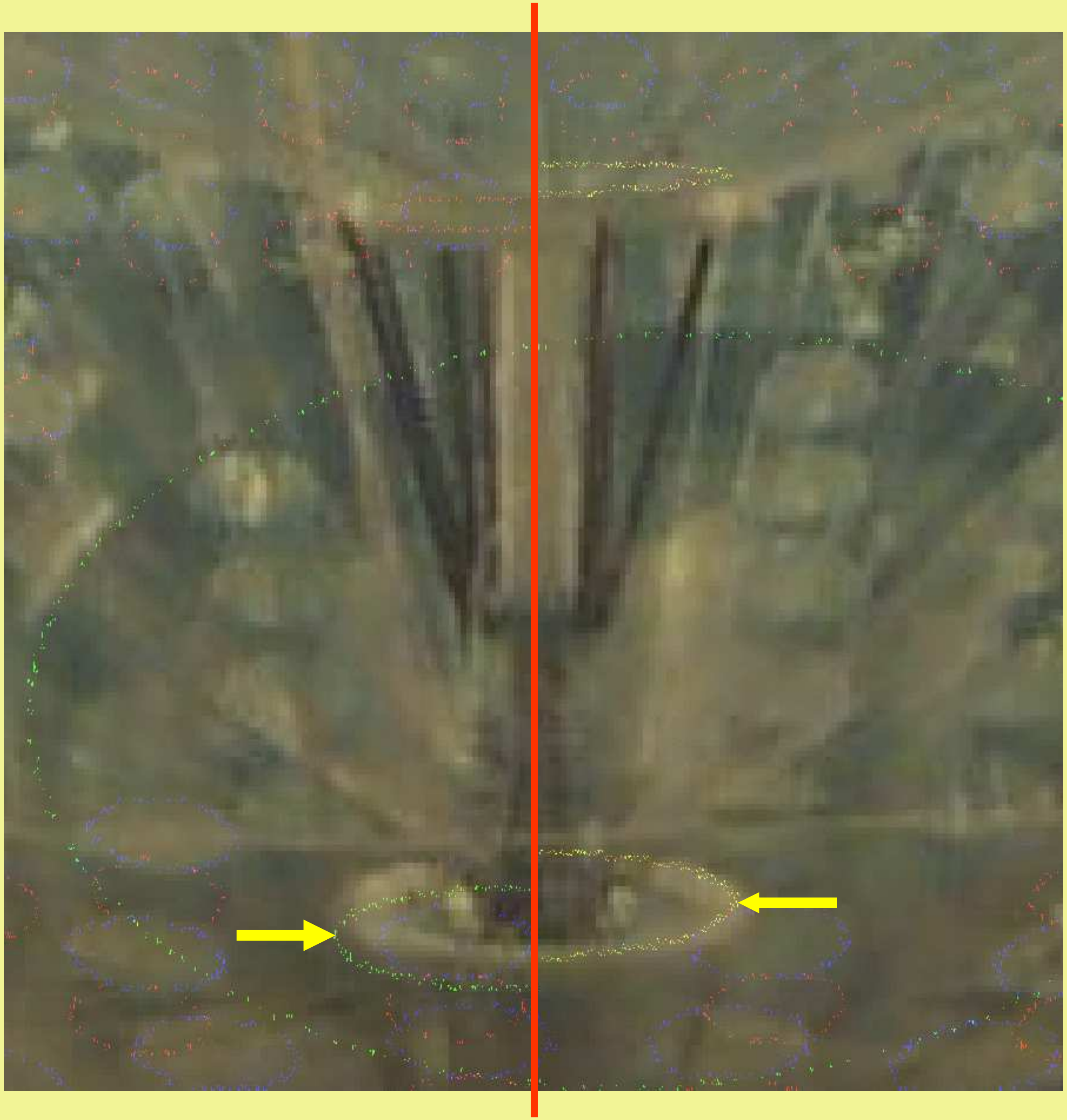
Projection of rays from the six 'other' cameras. Their intersection should ideally be at a single point.

Calibration Software Position Reconstruction Window



Largely automated system for source position reconstruction

VT Calibration System already in Use



Finding the Location of Nylon Vessel South Pole

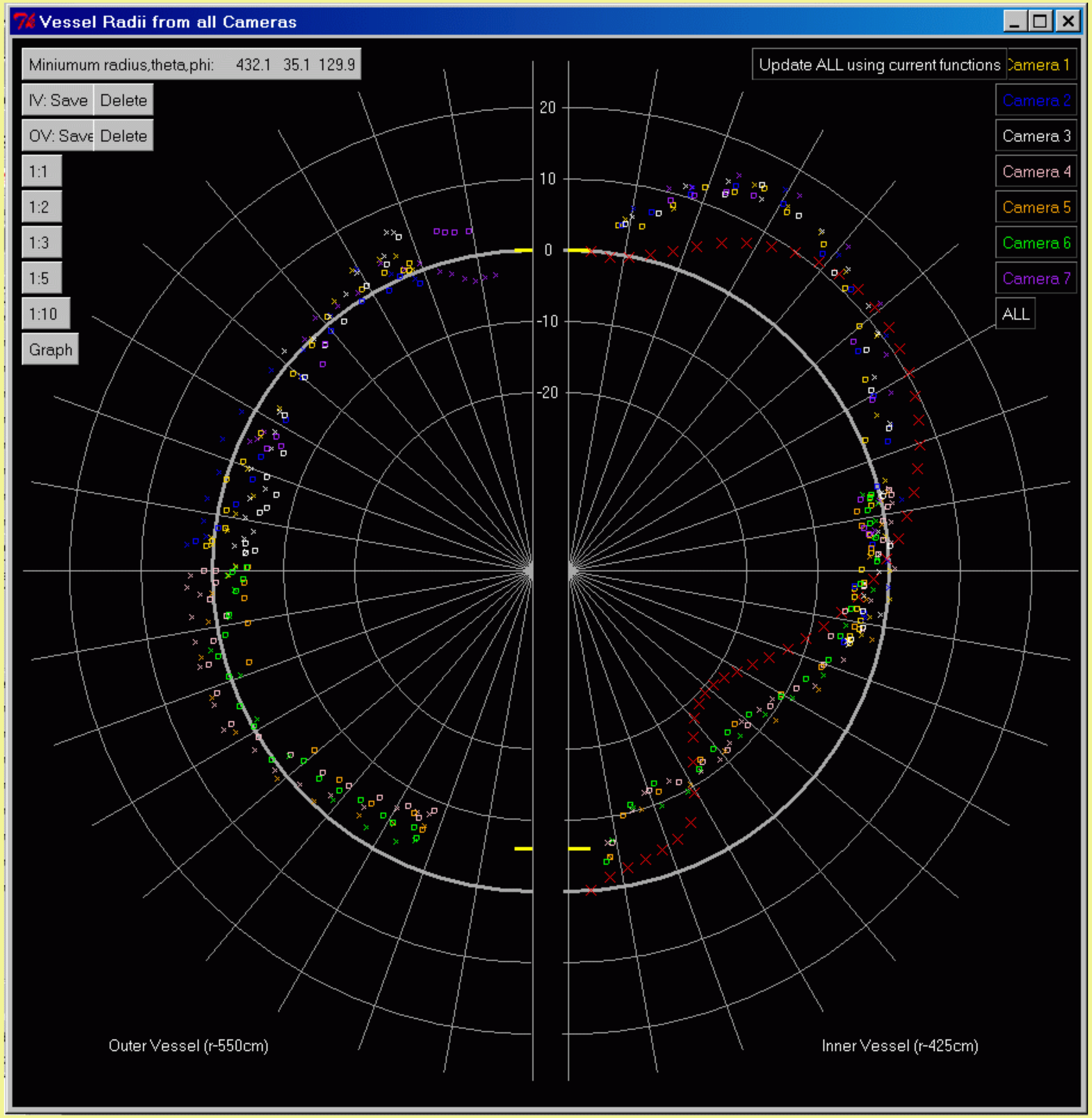
VT Calibration System already in Use

Determining the shape of the Nylon Vessels

Mark tangential interface of vessels

⇨ Calibration Software finds Position in space

VT Calibration System already in Use



Result:

Radii of Inner & Outer Vessel as a function of Φ

- Buoyancy is visible
- Use vessel shape for Position reconstruction
- Monitor vessel shape Over time (Background Interpretation)

Conclusions and Status

Borexino:

- The detector is filled & running.

VT Source Calibration System:

- The Source Locating System is fully operational
- With 7 cameras, +/- 2 cm seems obtainable ⇒ Fiducial Volume +/- 2%
- System is tested and works
- First uses to determine the Shape & Position of the vessels successful
- To be done:
  - Final Installation of Source Insertion Box
  - Production of calibration sources