Title: Latest results from ZEPLIN-III, a liquid xenon dark matter detector. And a status update on SNOLab.

Date: Jun 12, 2009 03:50 PM

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Abstract: The ZEPLIN-III liquid xenon dark matter detector has completed its first underground science run, with a final exposure after cuts of 128kg.days of data. This has led to a limit on the spin-independent cross section of 7.8e-8pb for a 60GeV mass WIMP. The required techniques to derive this limit will be outlined, including data stability, detector calibrations, analysis techniques and selection efficiencies. Future plans for ZEPLIN-III will be Outlined. In addition, as a reflection of a new position, the current status of the SNOLab facility will be described, outlining the construction progress, current status of the first experimental suite and future plans and opportunities.

Latest results from ZEPLIN-III: a liquid-xenon dark matter detector

N.J.T.Smith
STFC Rutherford Appleton Laboratory

The ZEPLIN-III Collaboration:

- University of Edinburgh
- Imperial College London
- STFC Rutherford Appleton Laboratory
- LIP, Coimbra
- ITEP Moscow

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And a status update on SNOLAB:

A New International Facility for AstroParticle-Physics Research

- Overview and Status of the facility
- Current Scientific programme

Nigel Smith

SNOLab

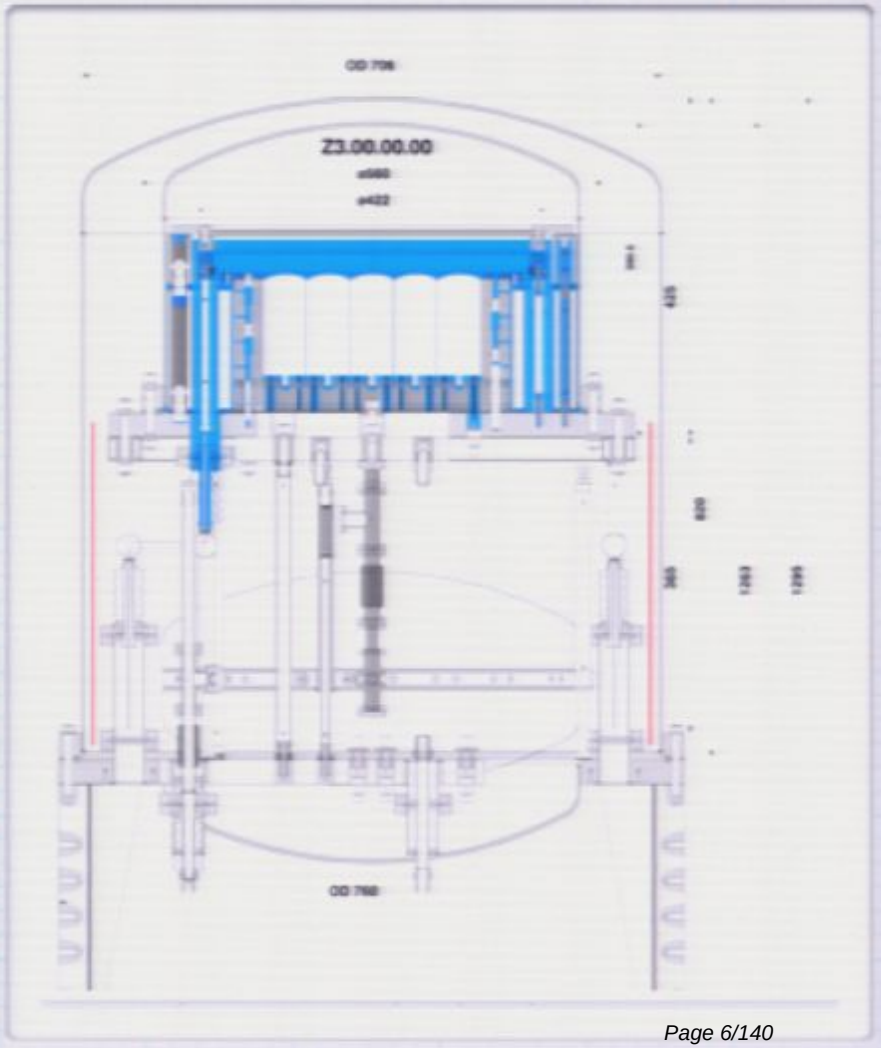
Slides 'borrowed' directly from Tony Noble, Queen's University

The Boulby facility

Depth 1100 m, 2.8 km water equivalent

ZEPLIN III

- PMTs in liquid to improve light collection
- 31 small PMTs for fine position sensitivity
- 12kg target mass
- 3.5 cm drift depth – high E-field (3.9kV/cm)
  - provides strong n/ γ discrimination
- 0.5 cm electroluminescent gap
- open plan – no surfaces - reduced feedback
- Low-background xenon (40 yr old - low Kr)
- All copper construction - electron beam welded



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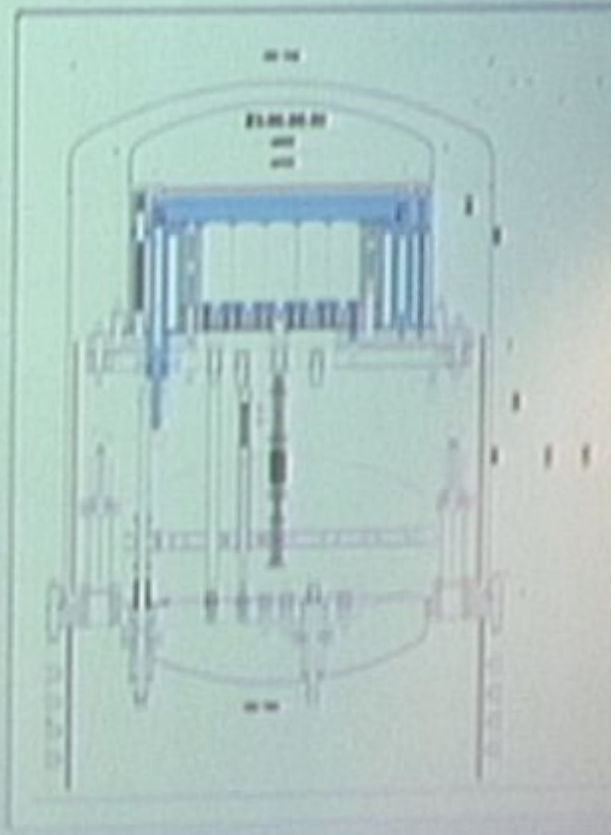

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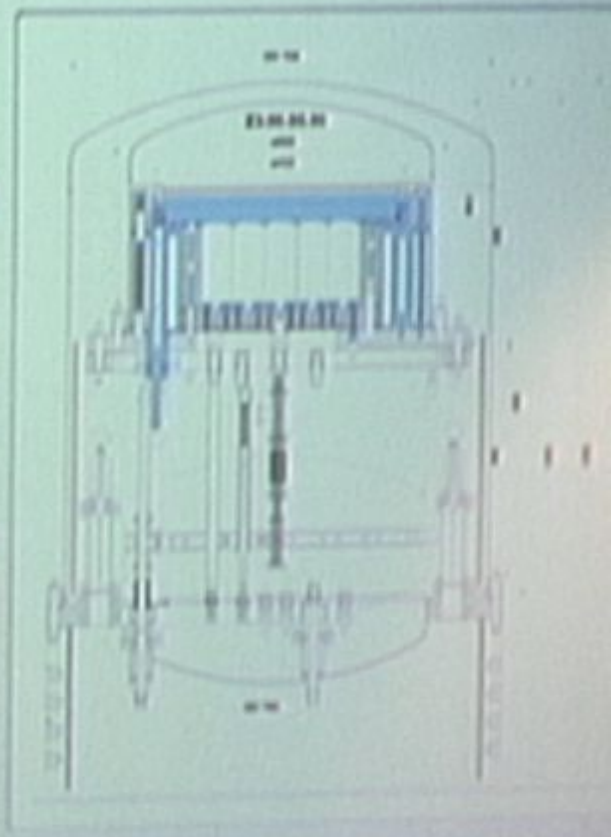

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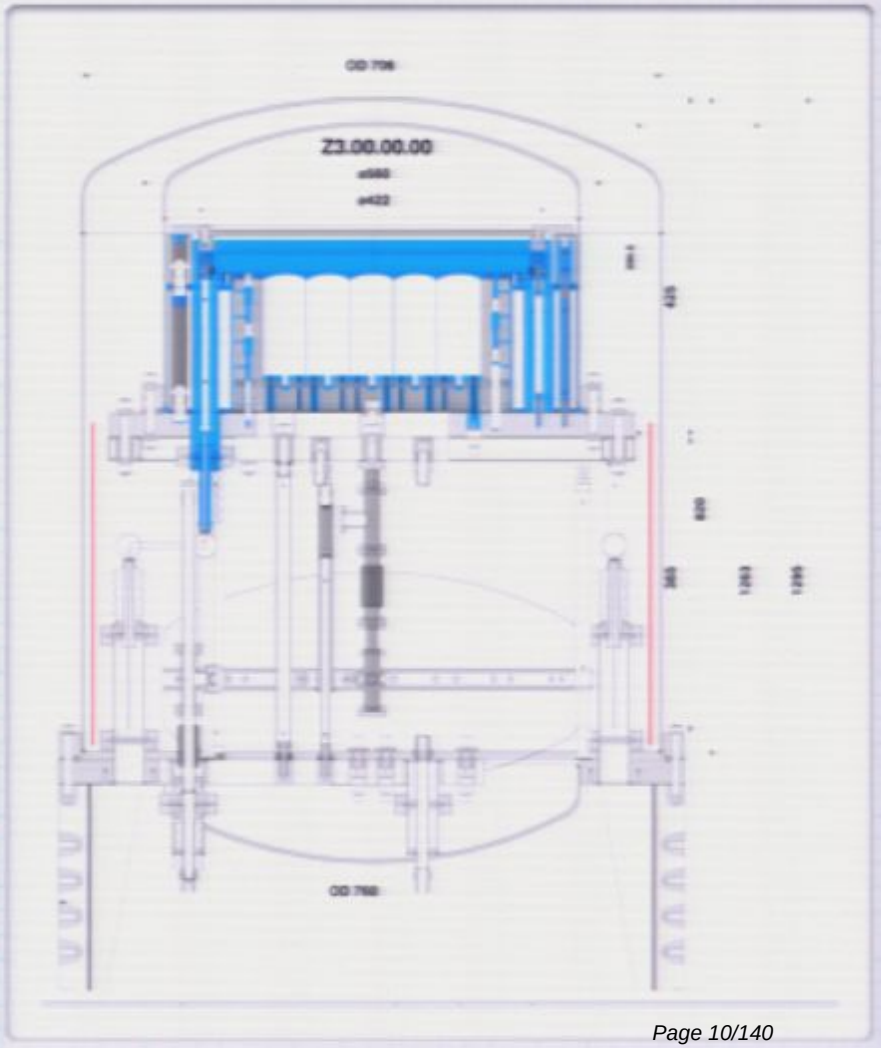

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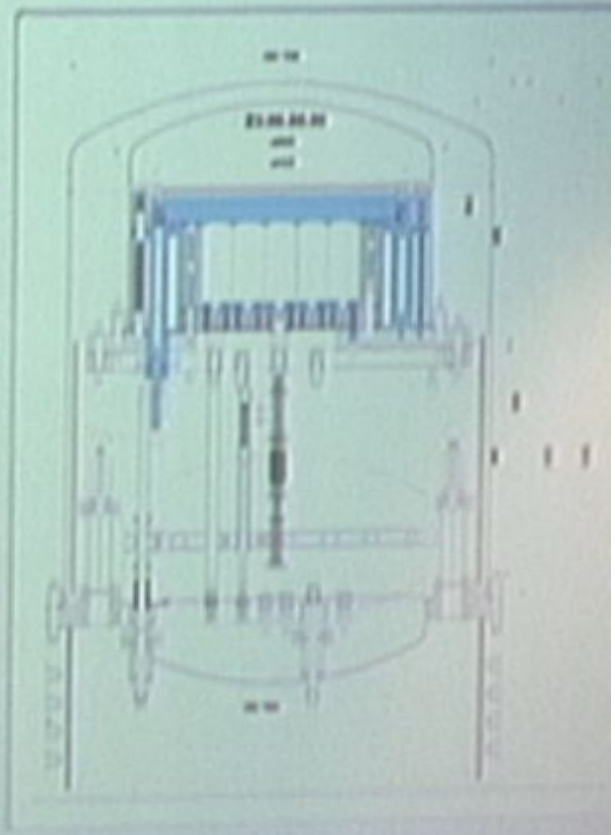

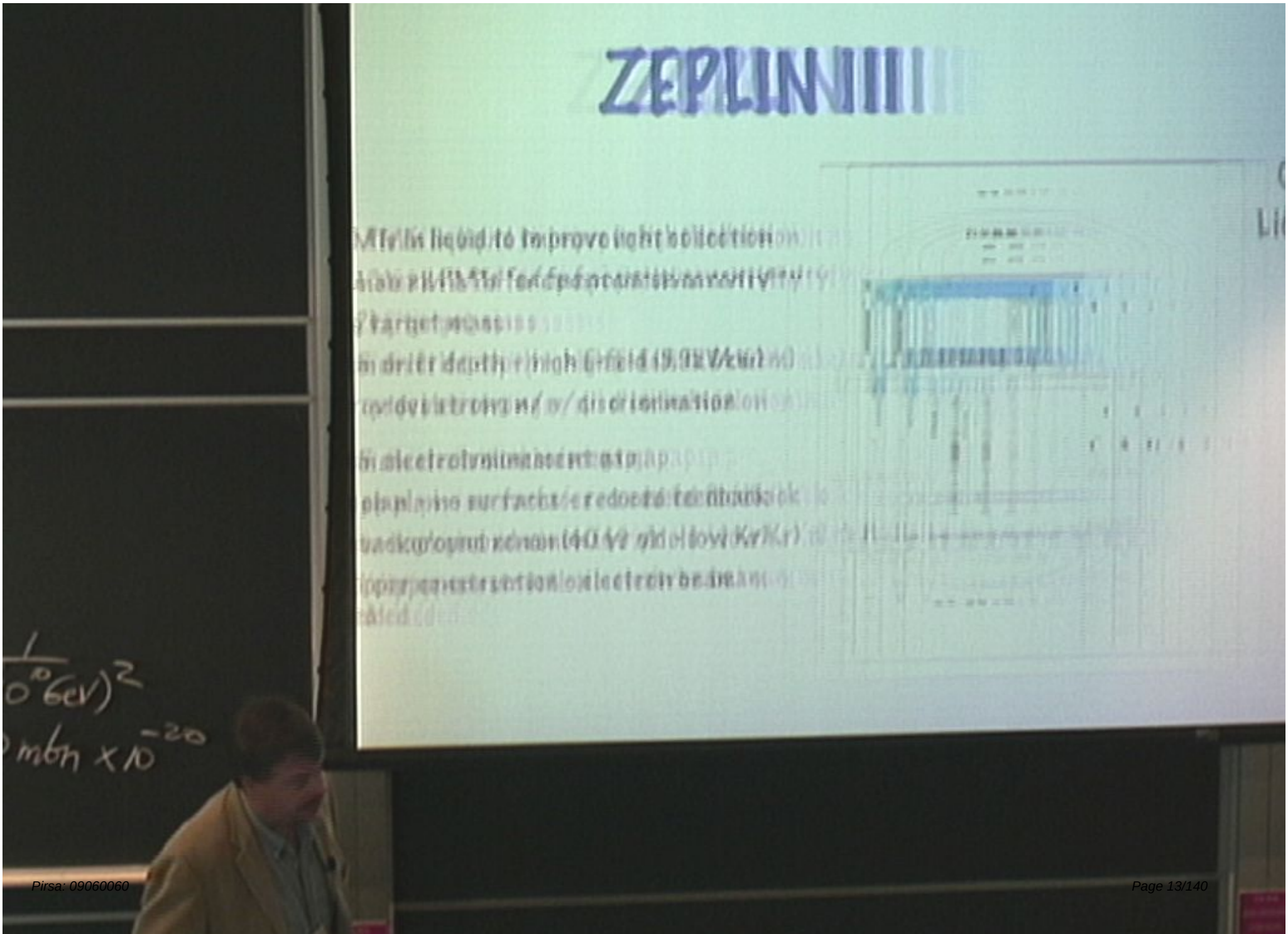
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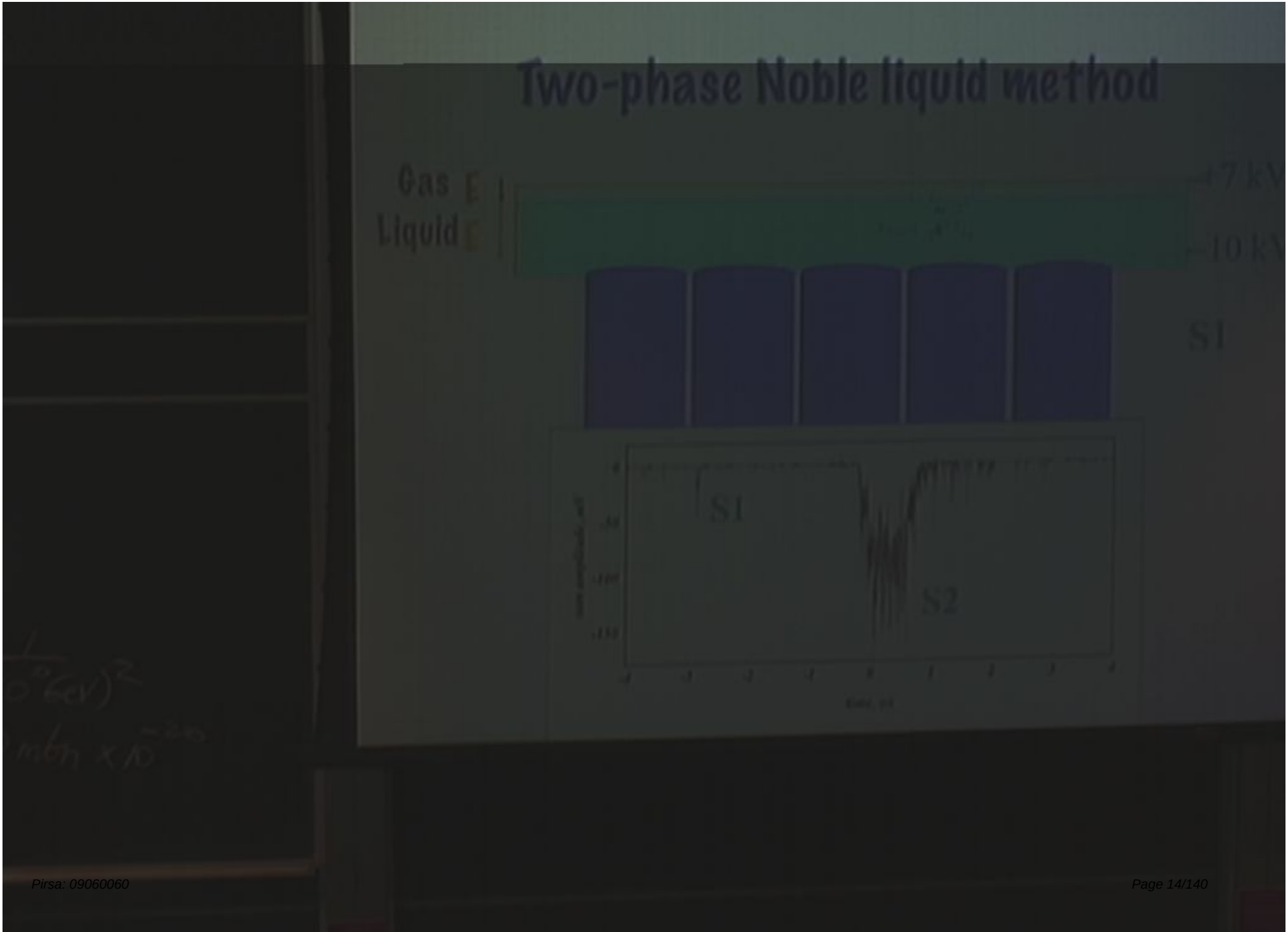
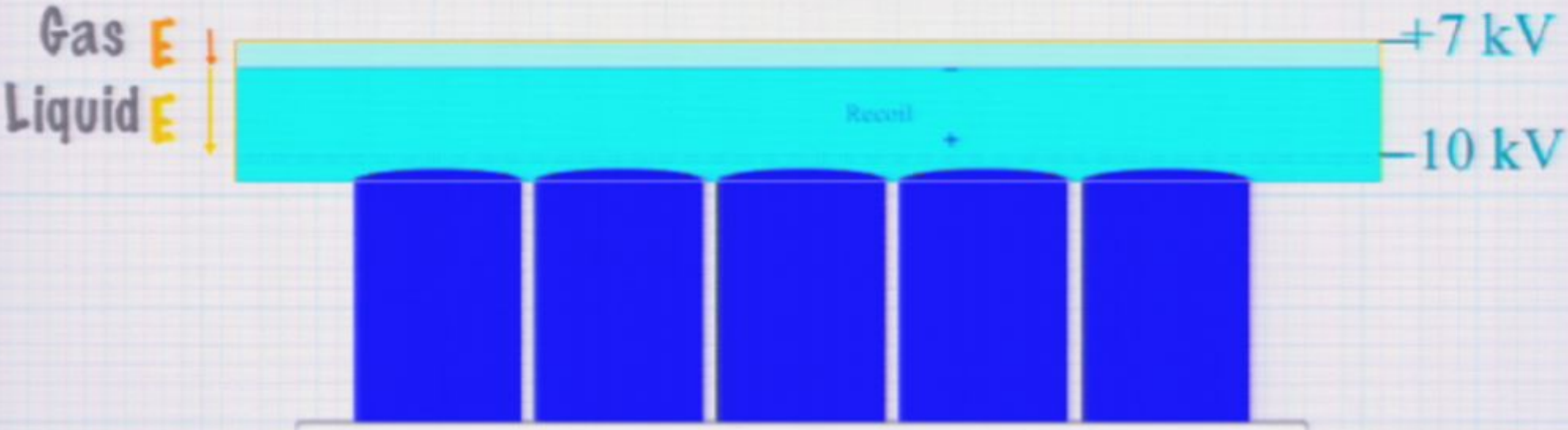
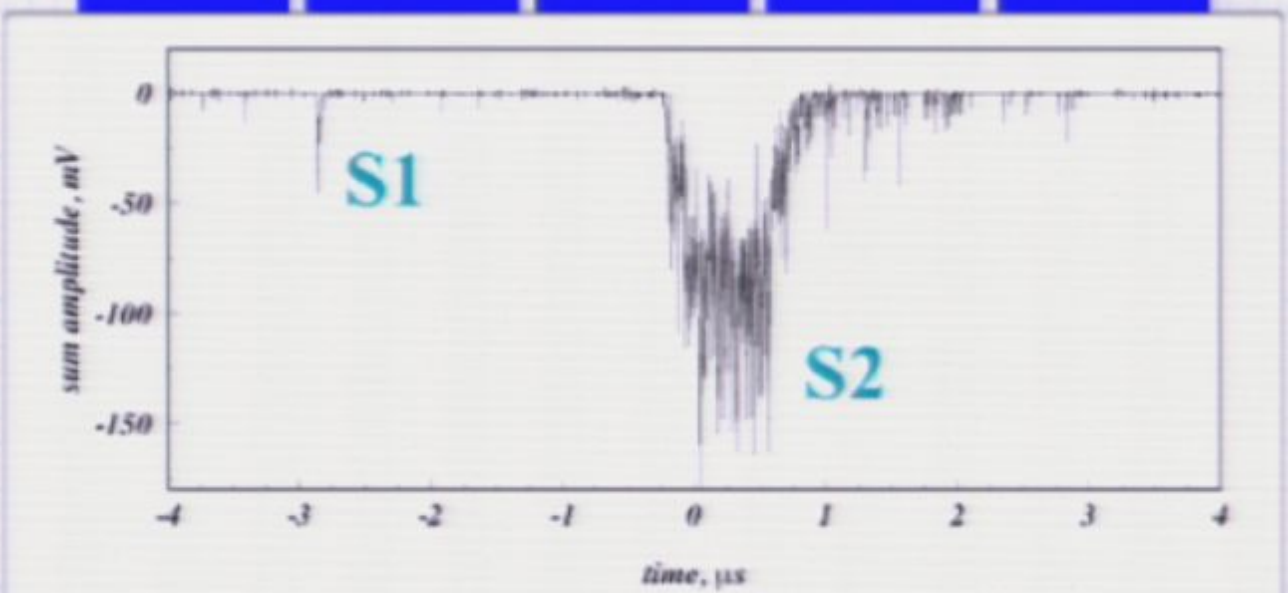
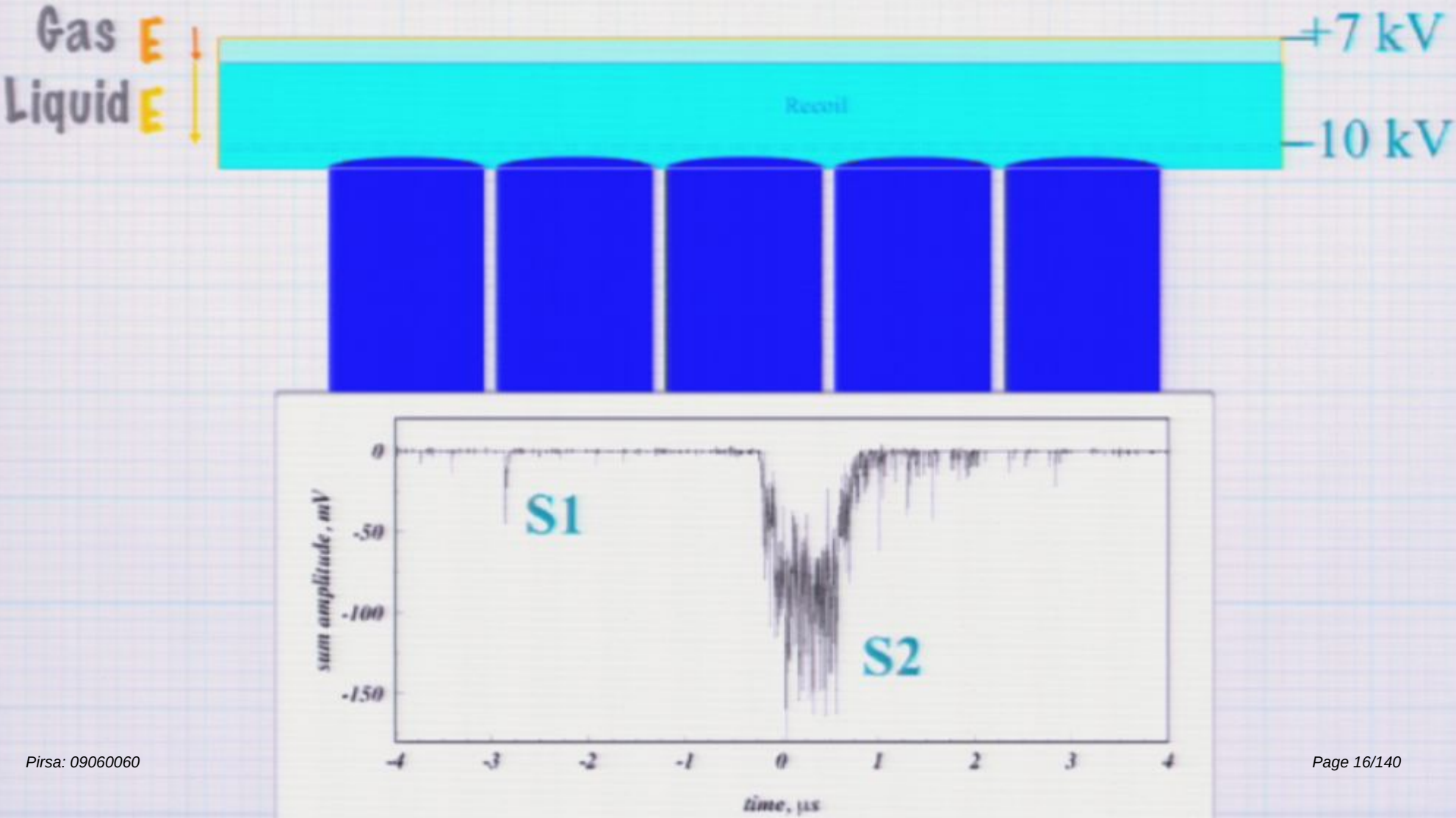

Two-phase Noble liquid method
Gas
Liquid
S1
S2

Two-phase Noble liquid method





Two-phase Noble liquid method



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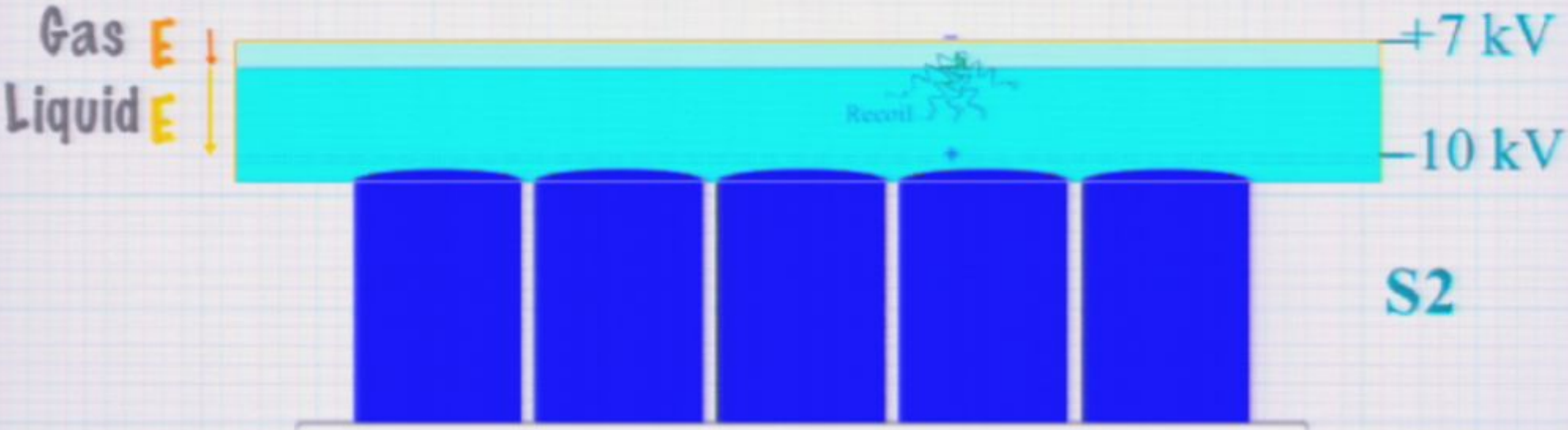

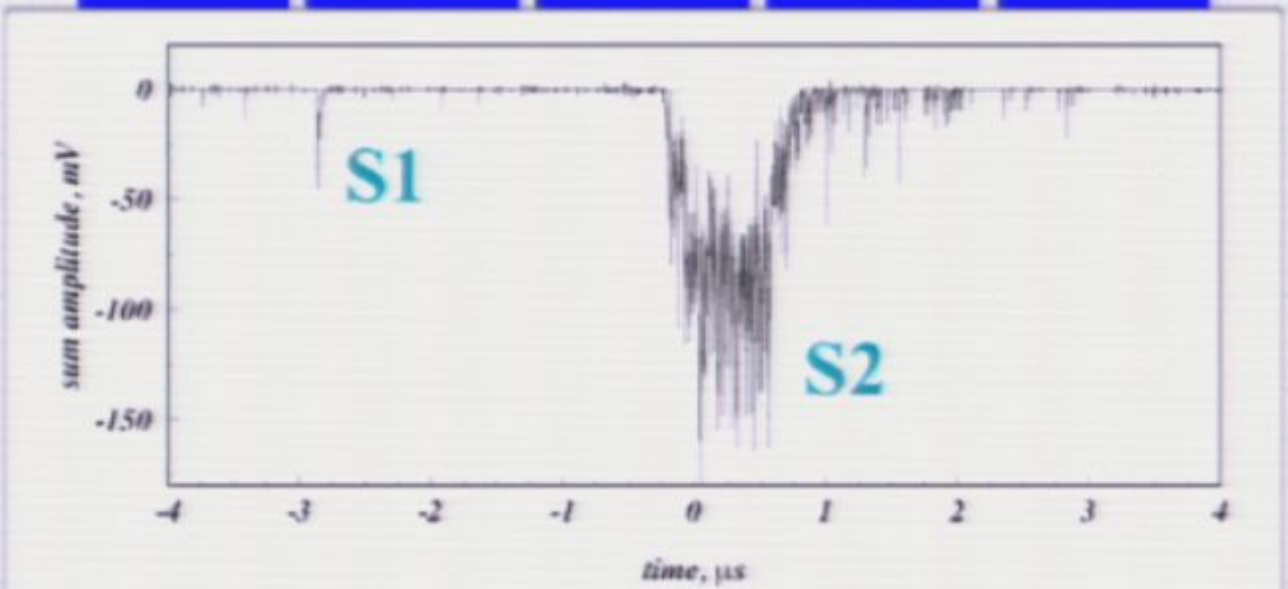

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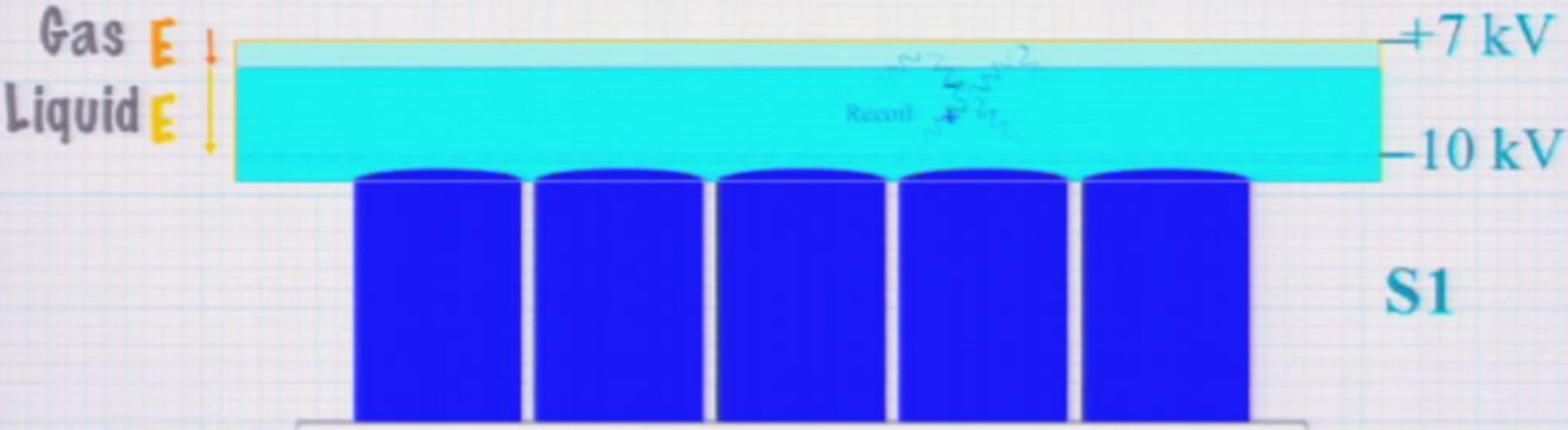

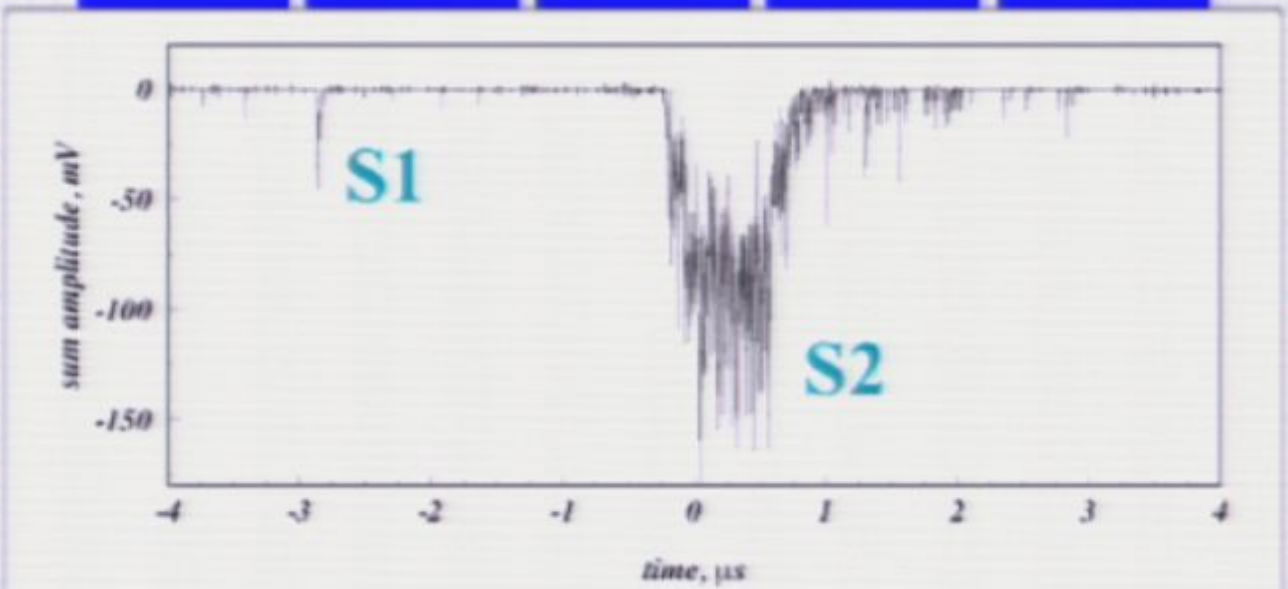

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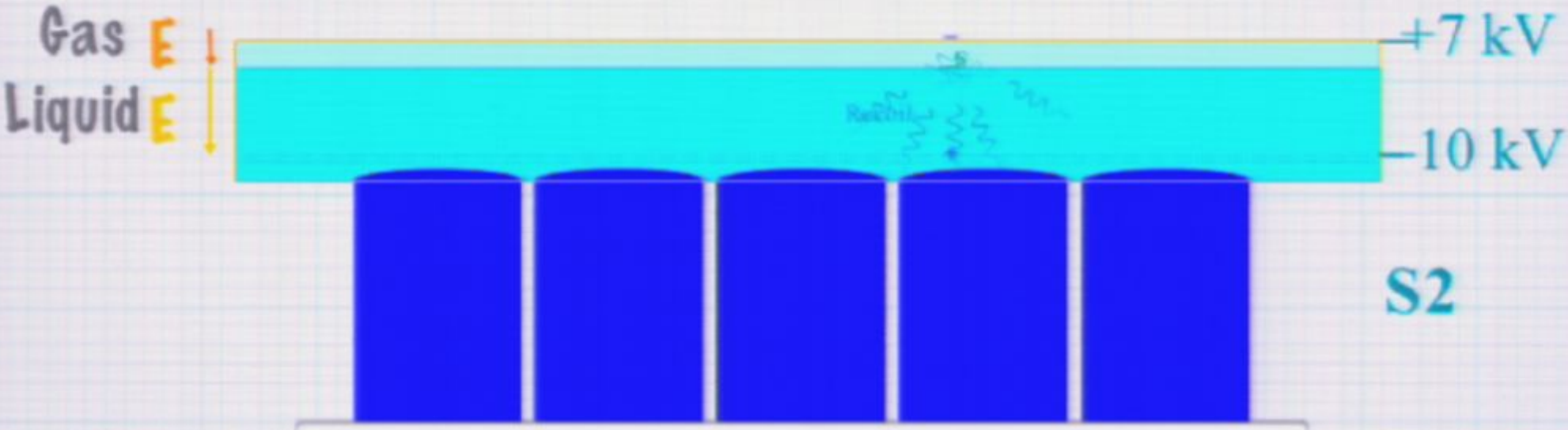
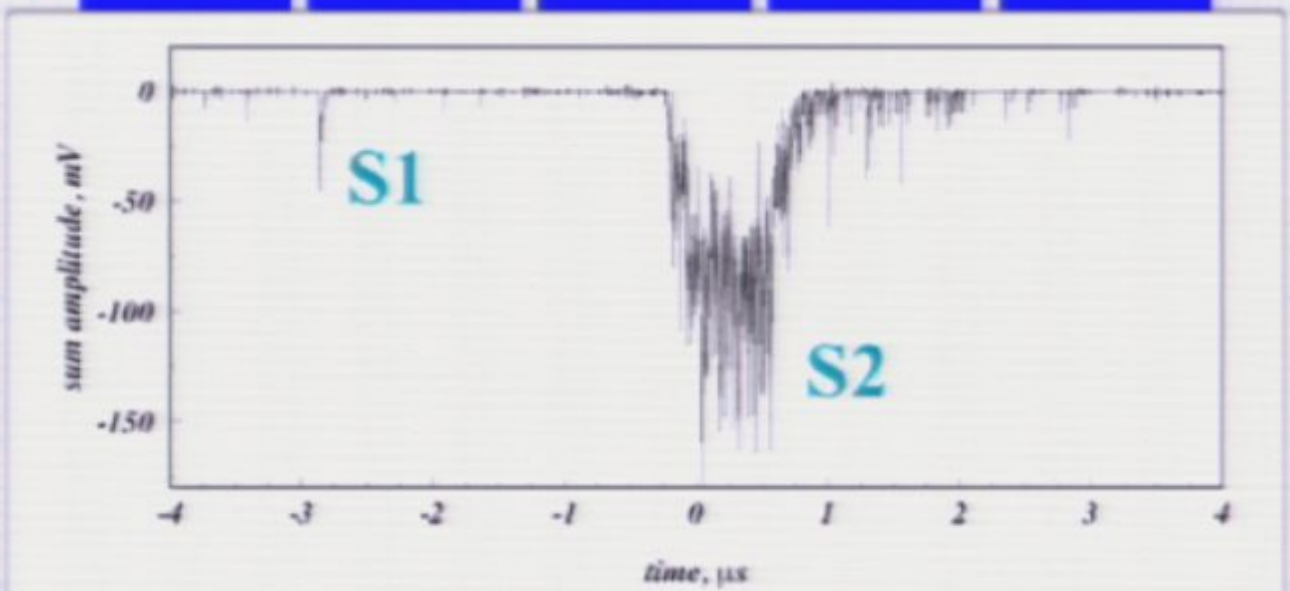
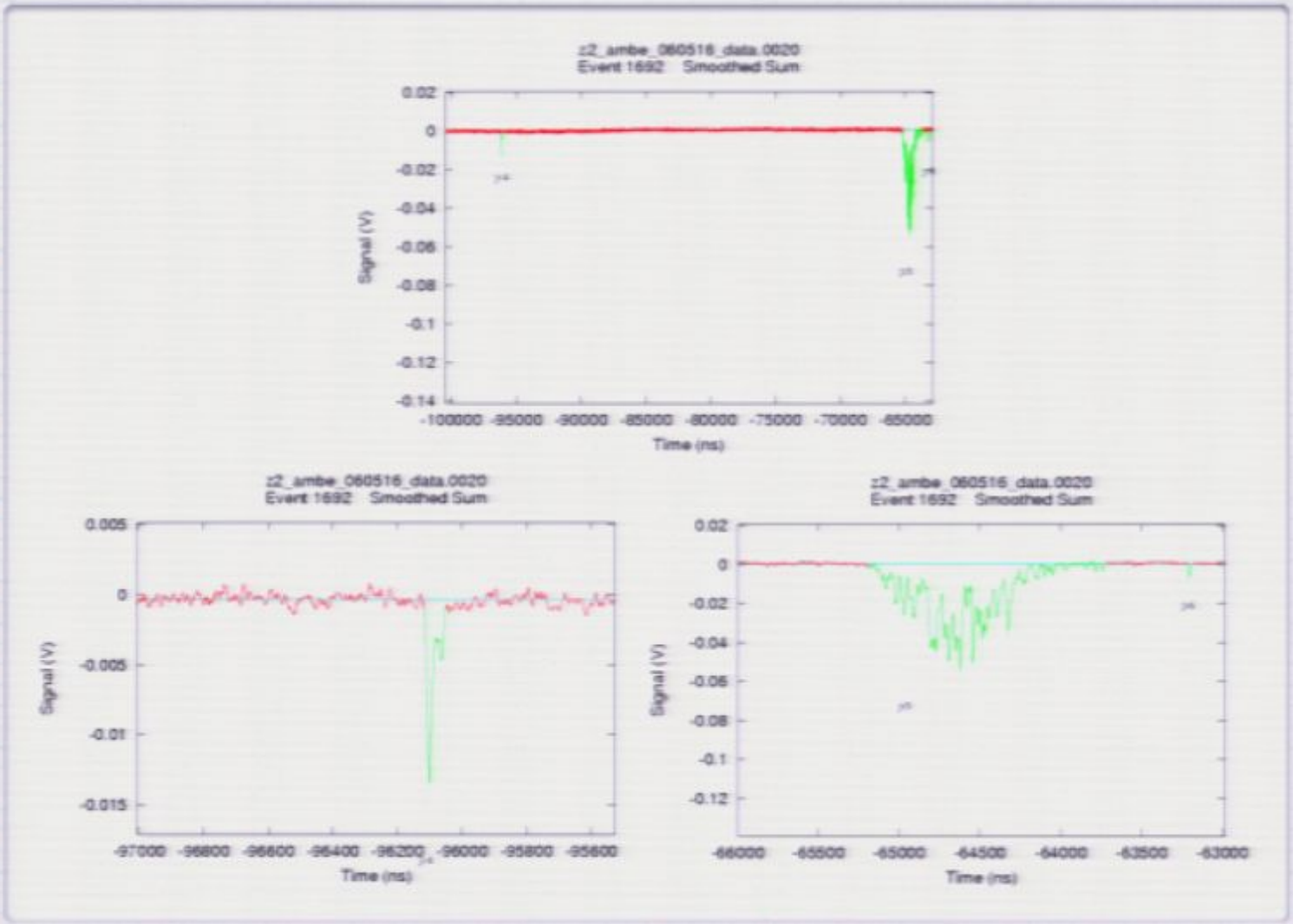




Neutron/Gamma pulses



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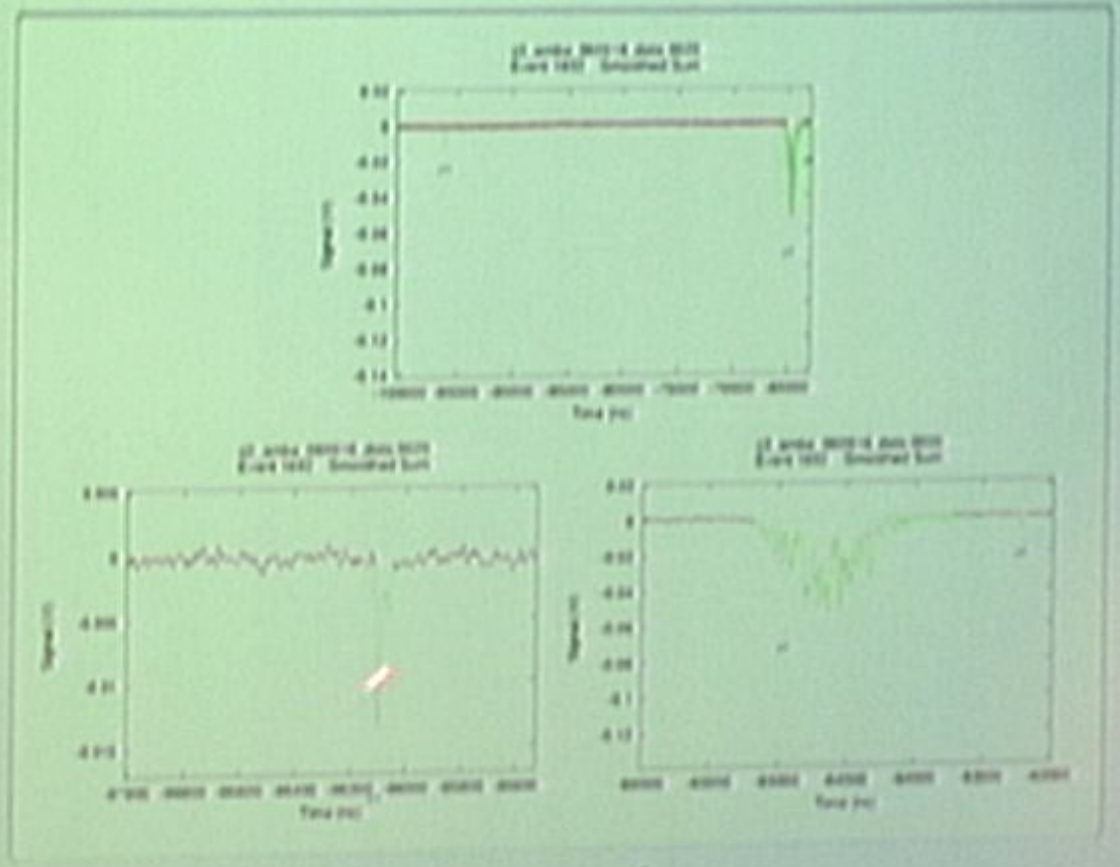

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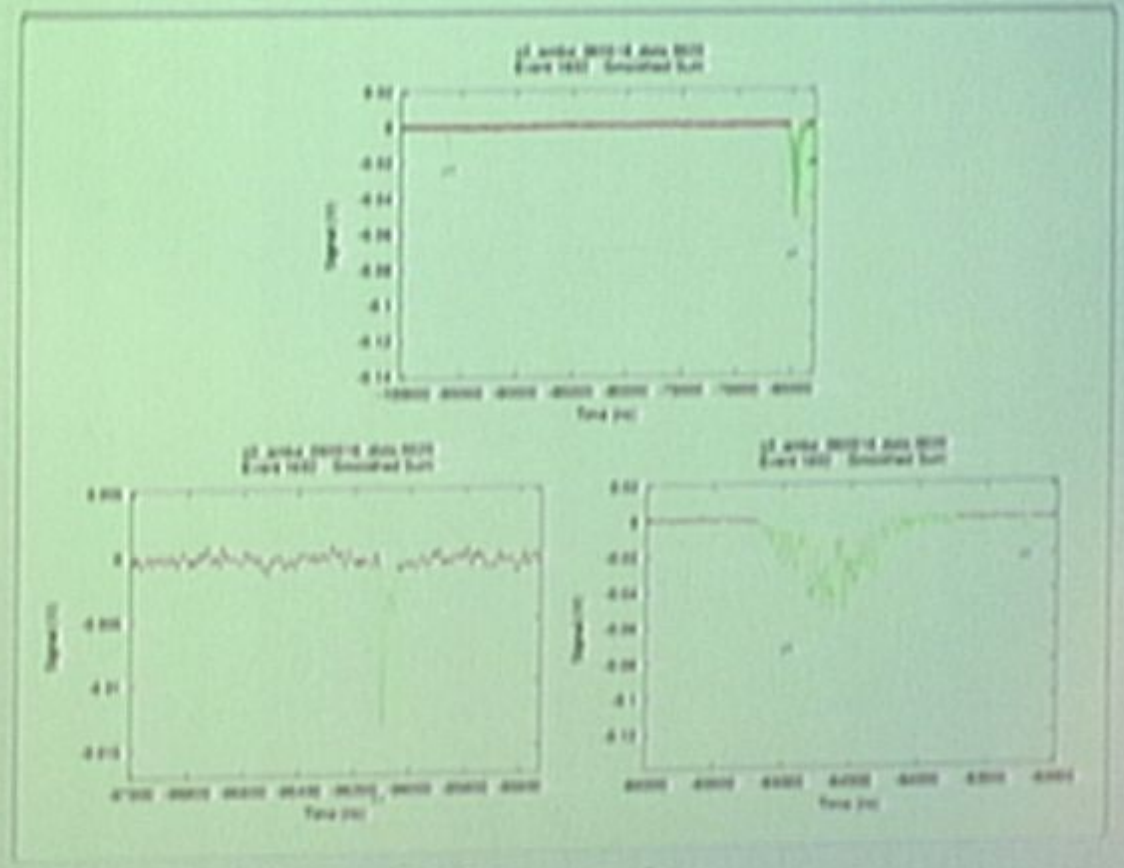

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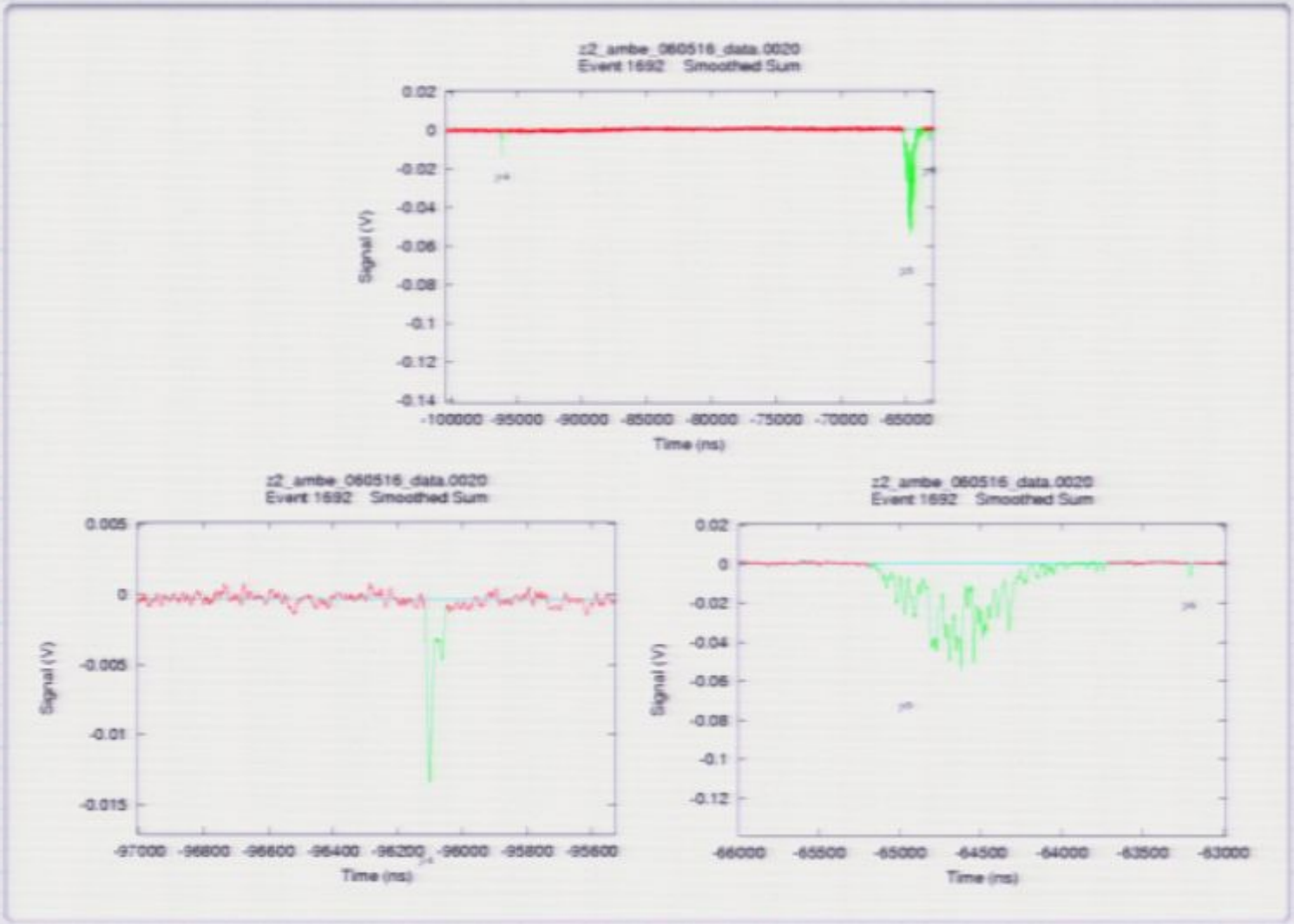

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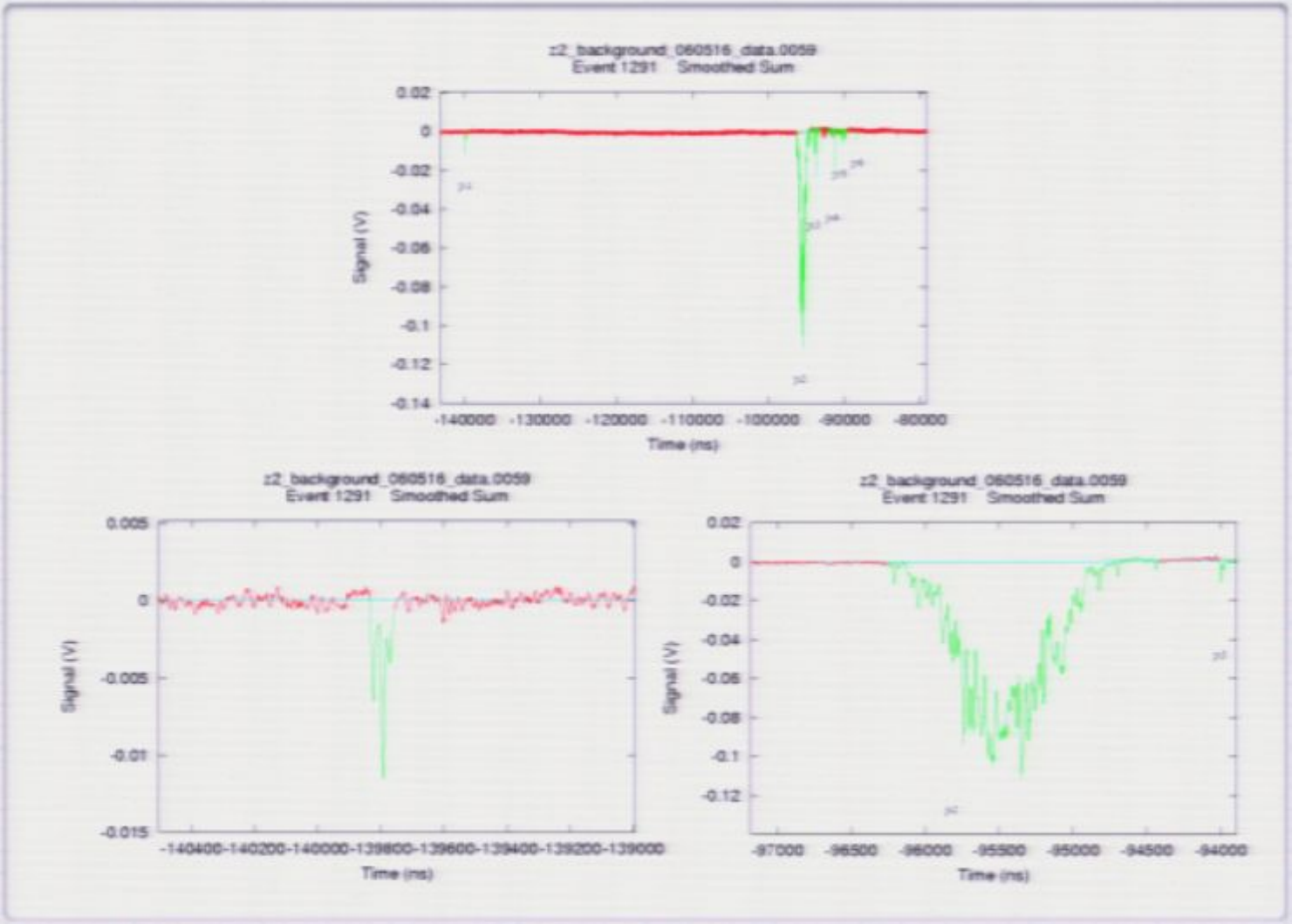

Gamma pulse

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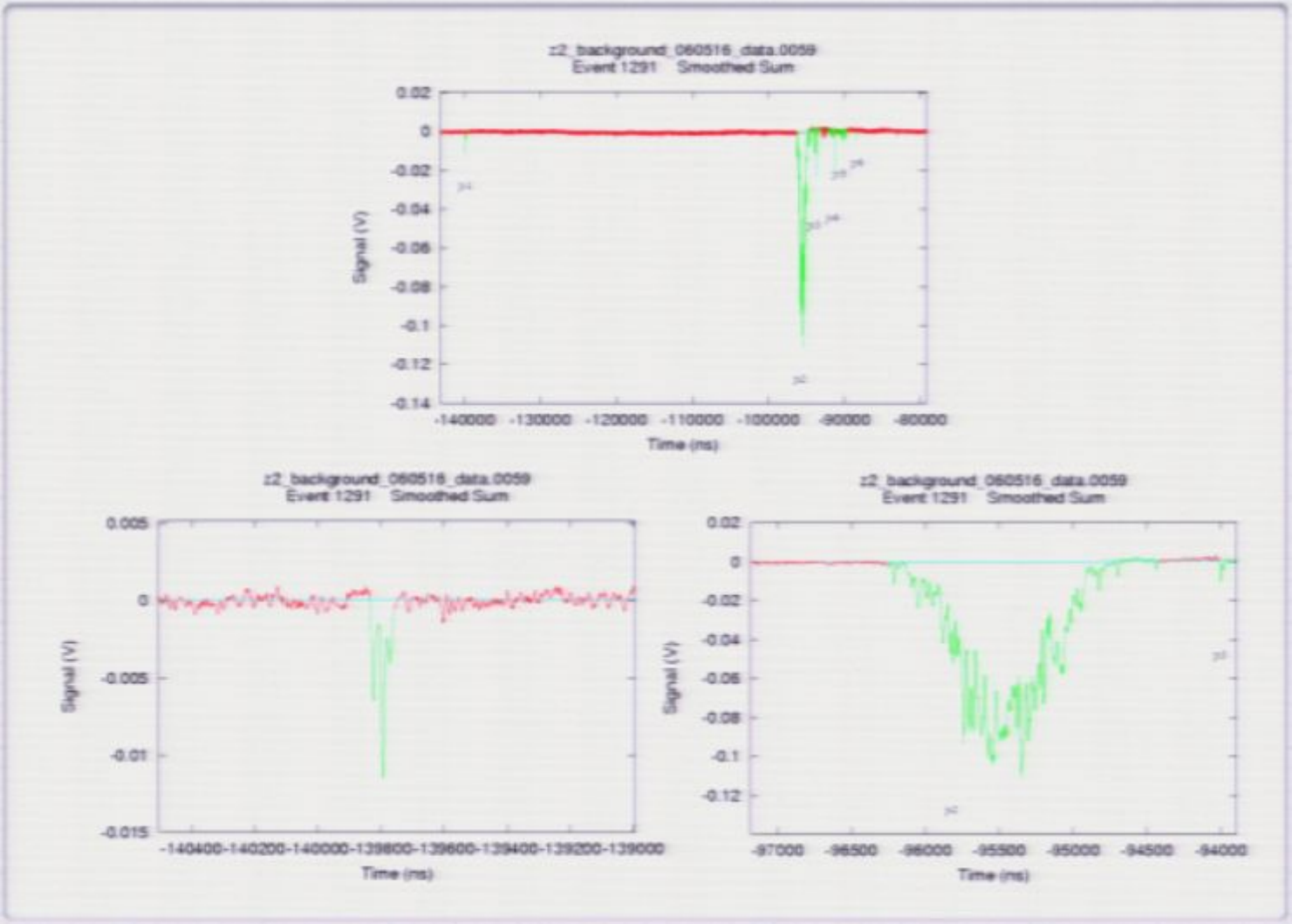

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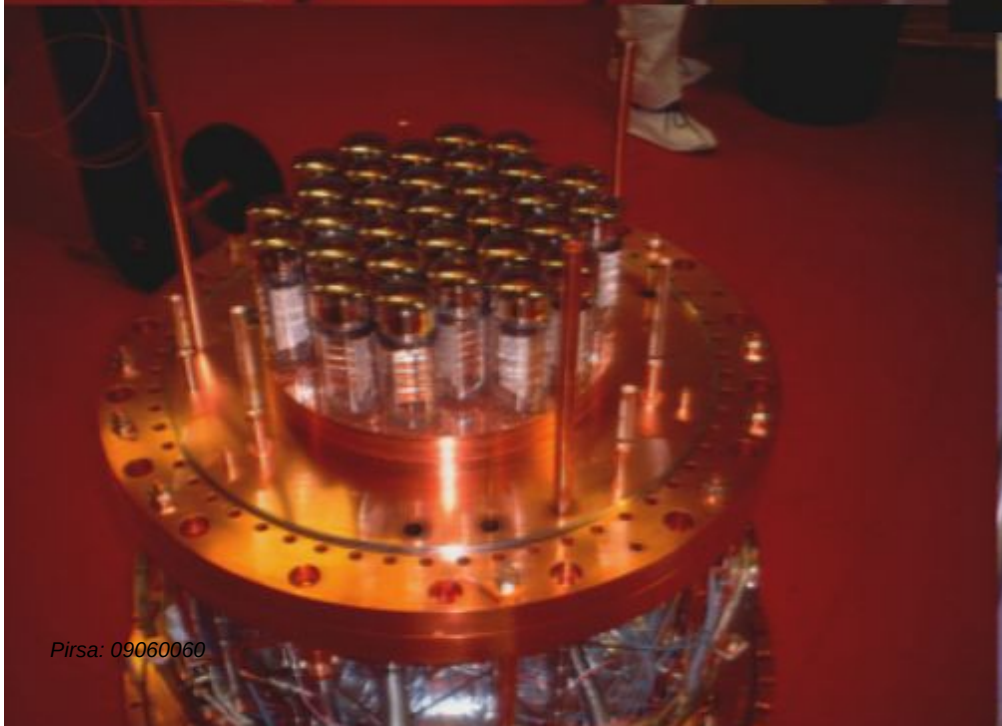
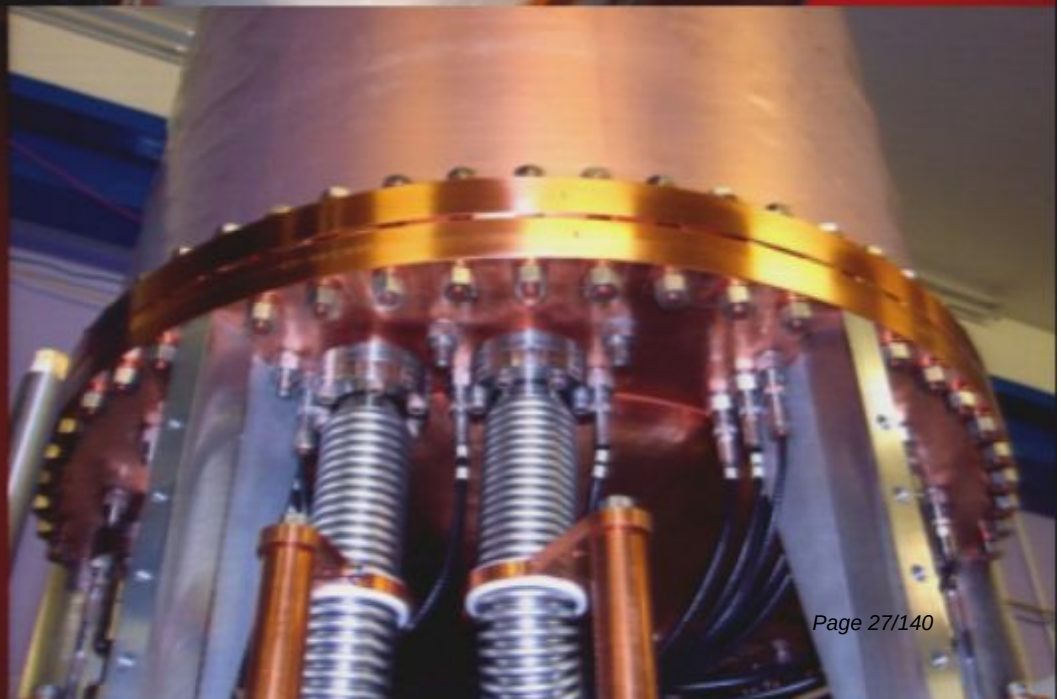
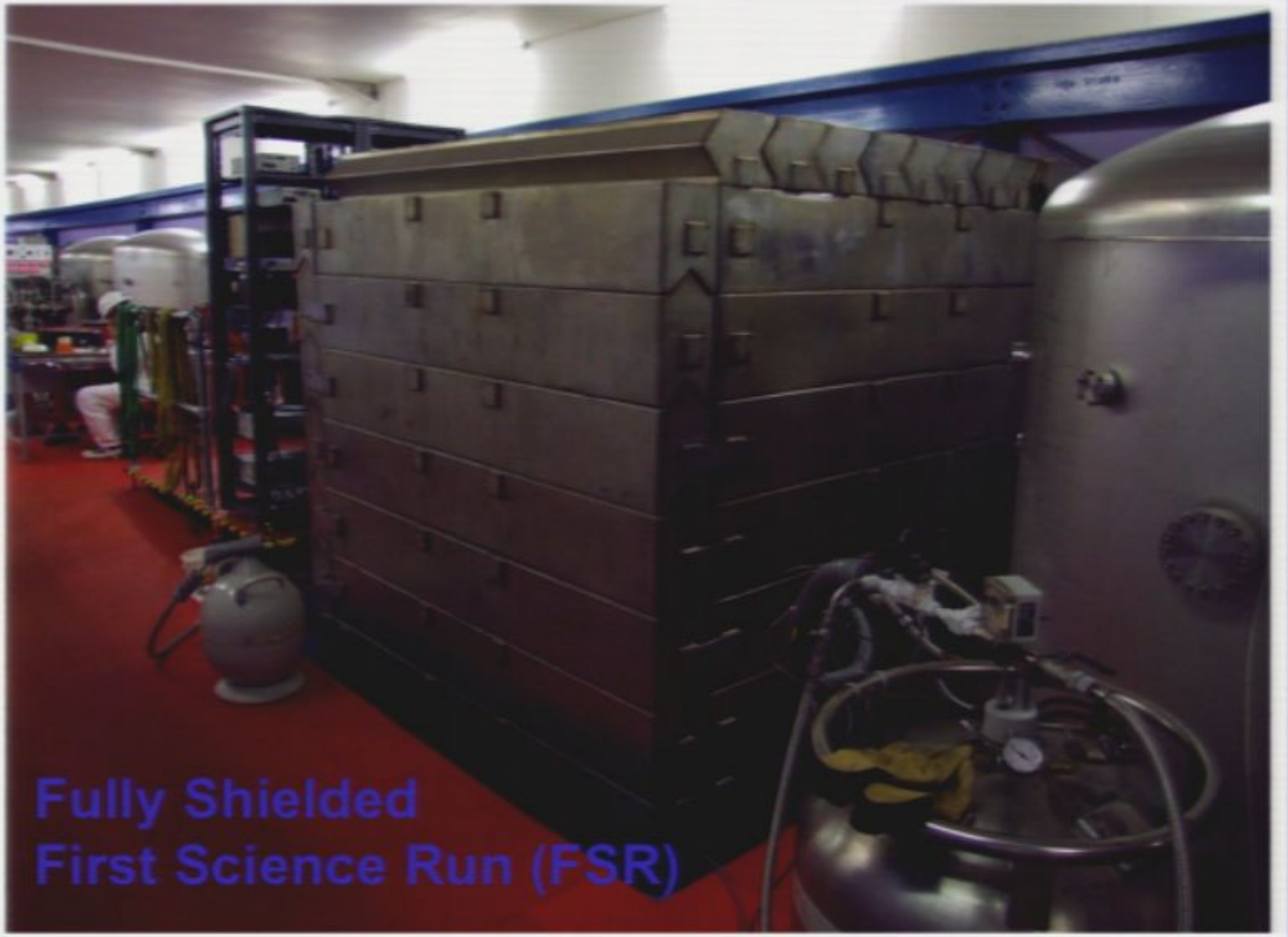


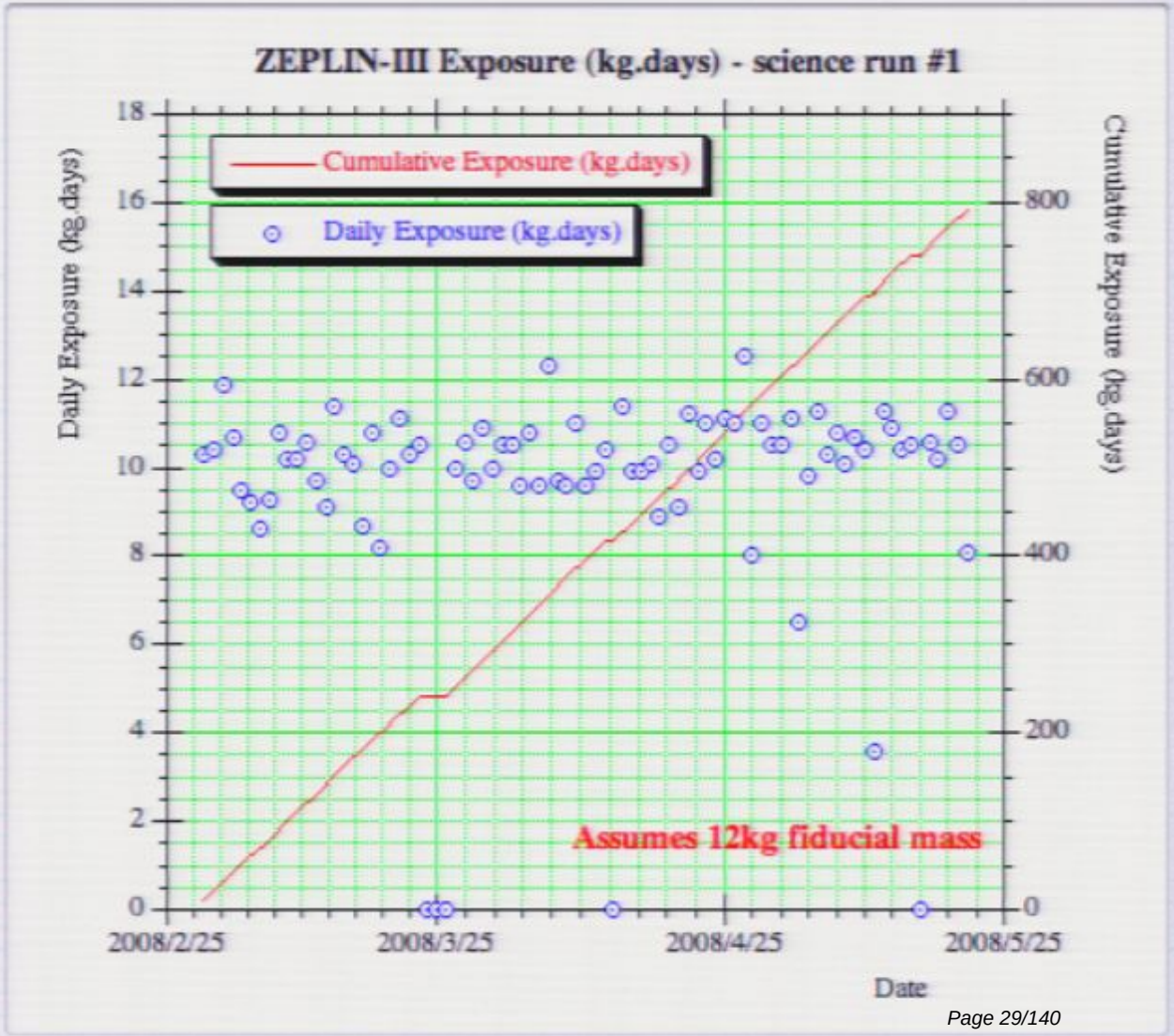


2008: February 28th .... May 21st



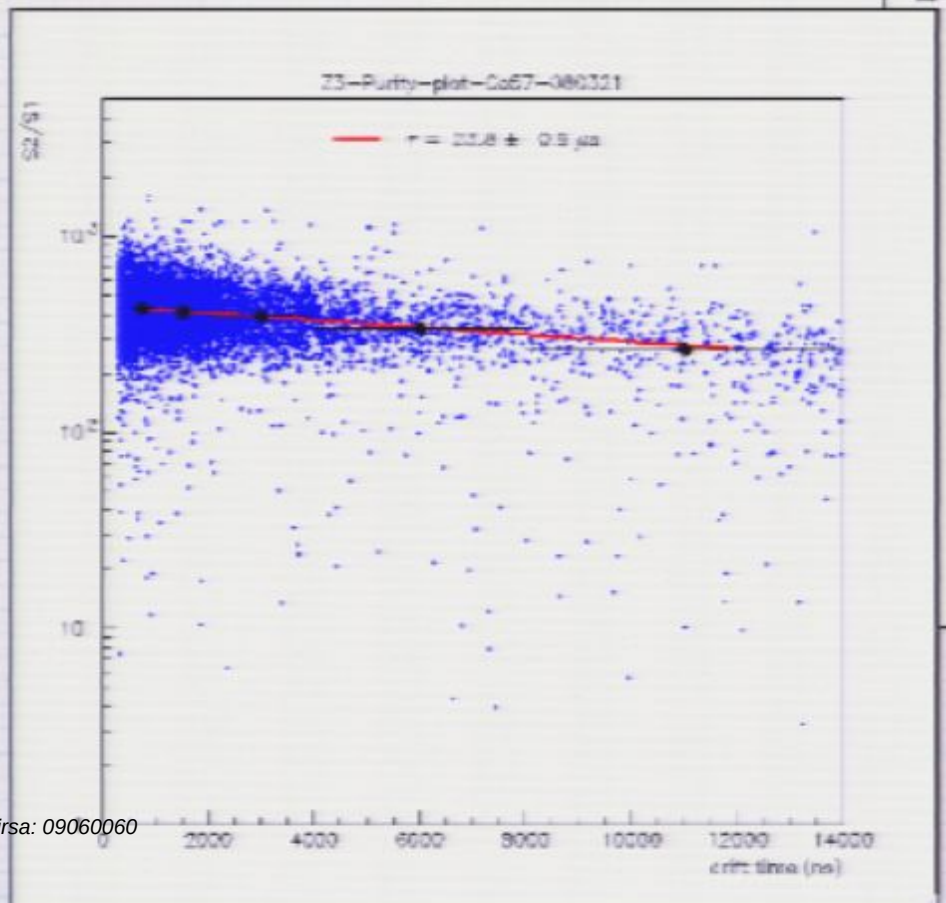
First science run

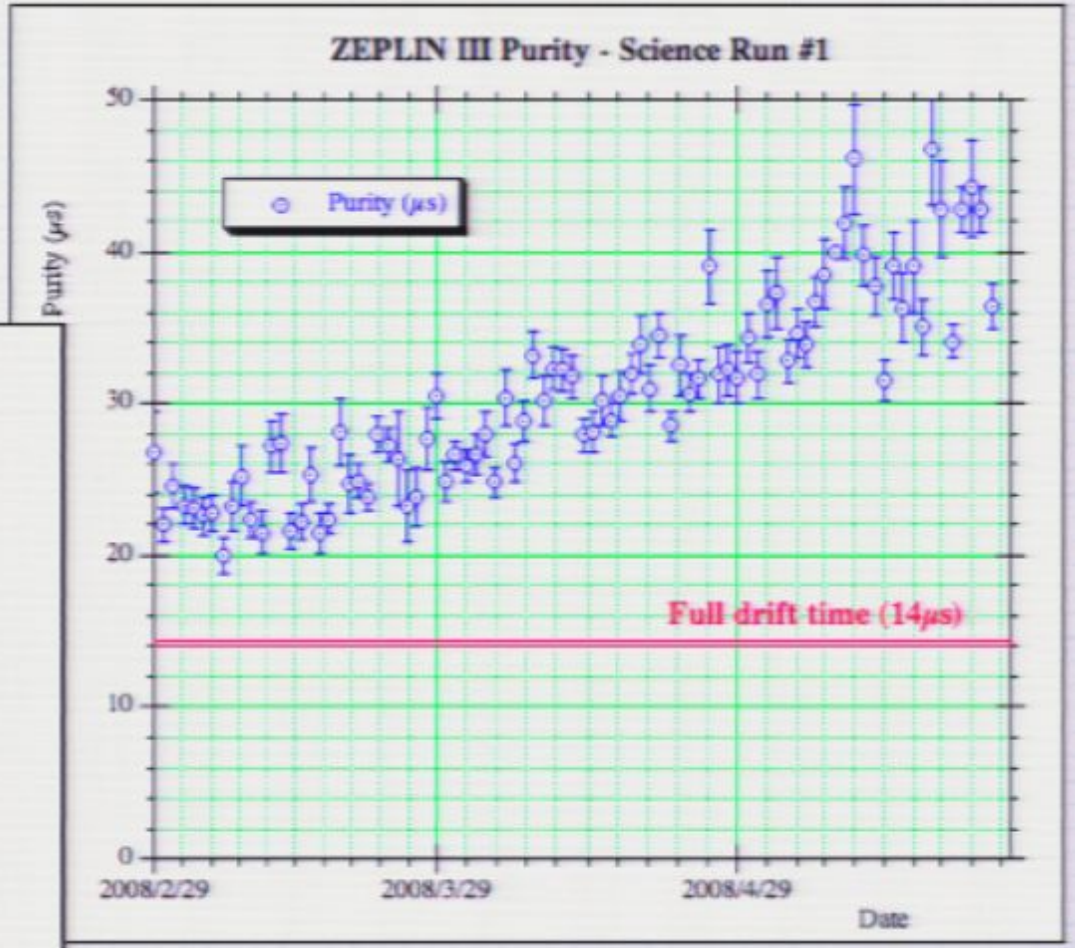
- Science run taken from 29th Feb - 21st May
- Gamma (energy) calibrations performed daily
- Gamma (Compton) and Neutron calibrations performed at run start and end
- raw exposure of 847 kg.days from the 12 kg target volume



Purity Evolution

- Daily monitor with ^{57}Co source for stability measurement
- S2/S1 as a function of depth
- Cross check against FSR & ^{137}Cs





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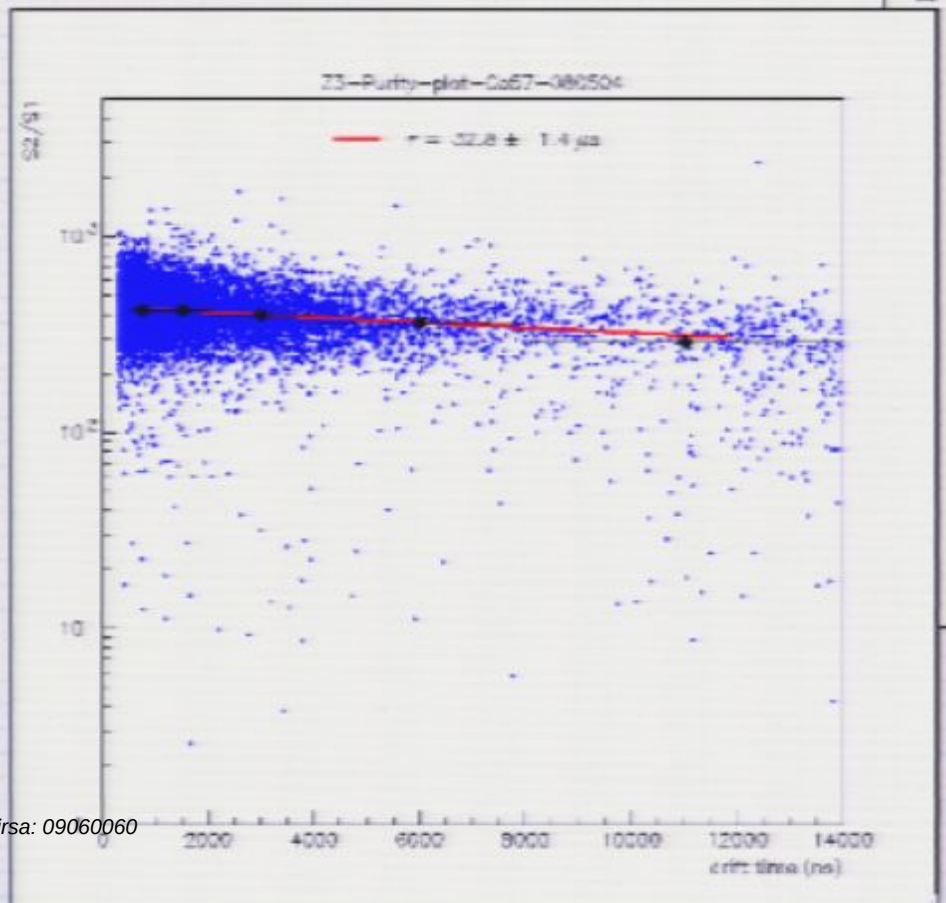

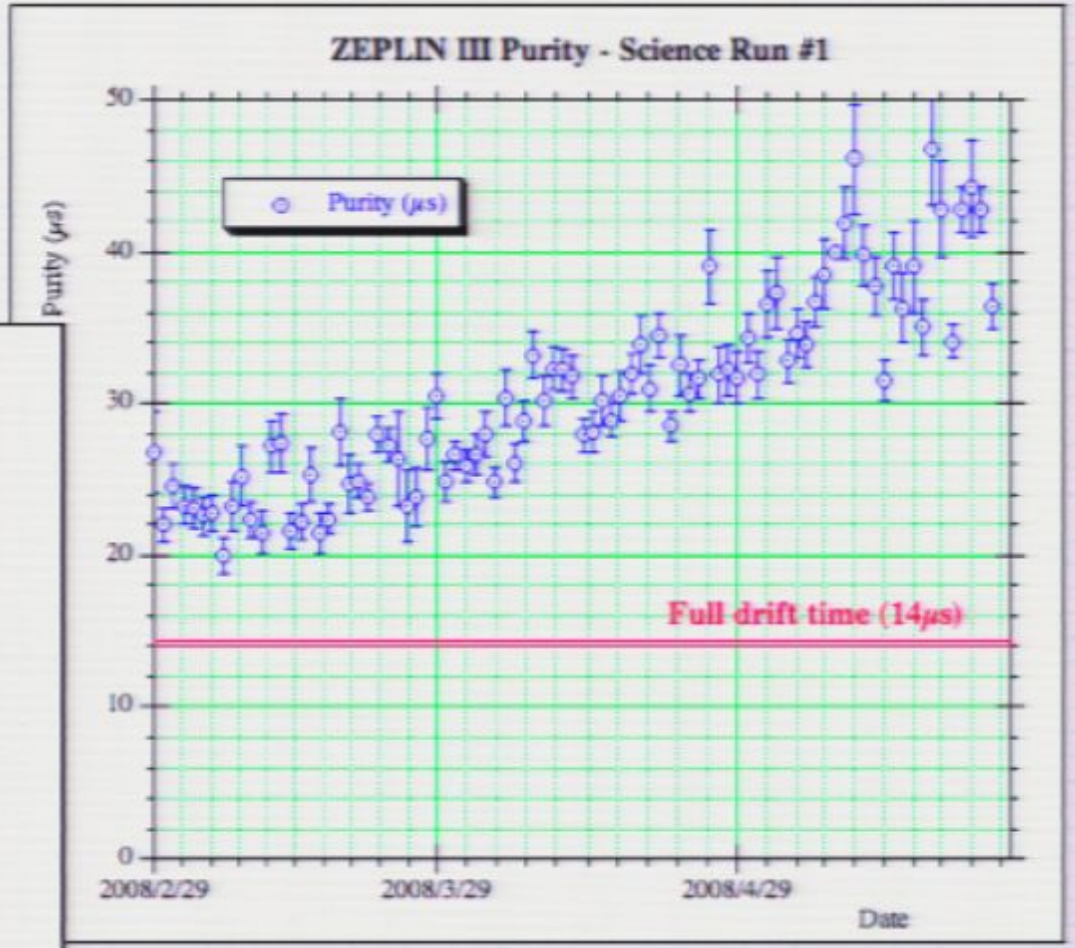

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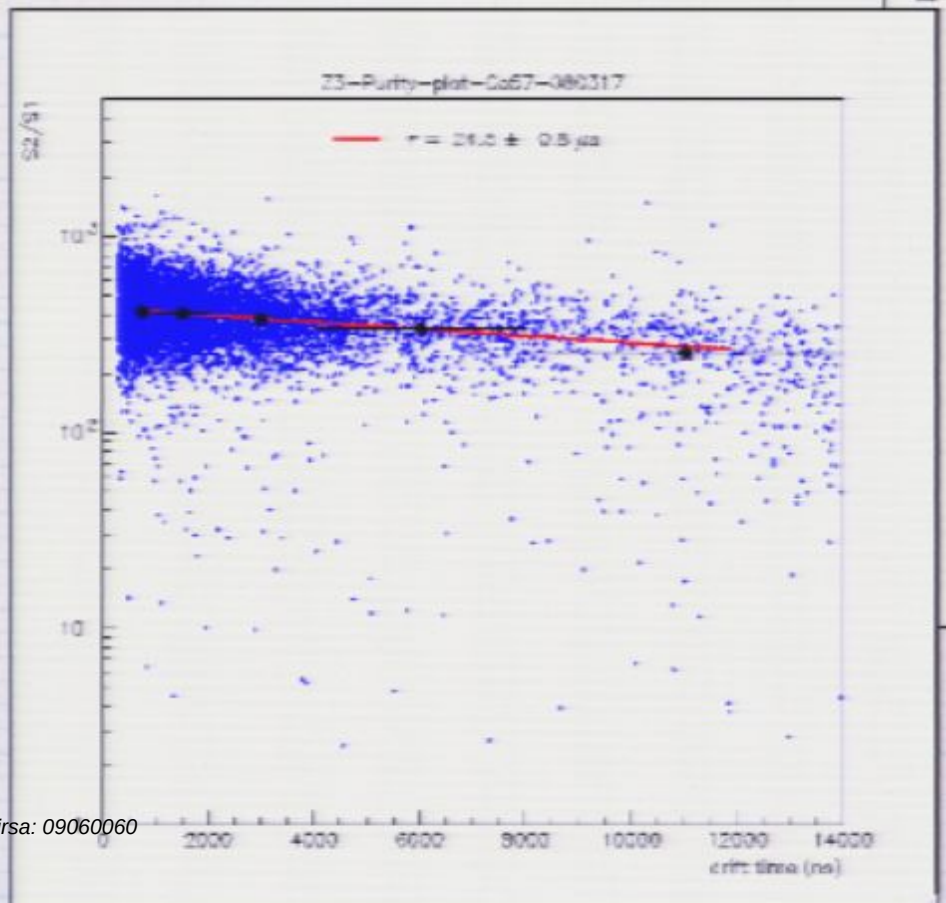

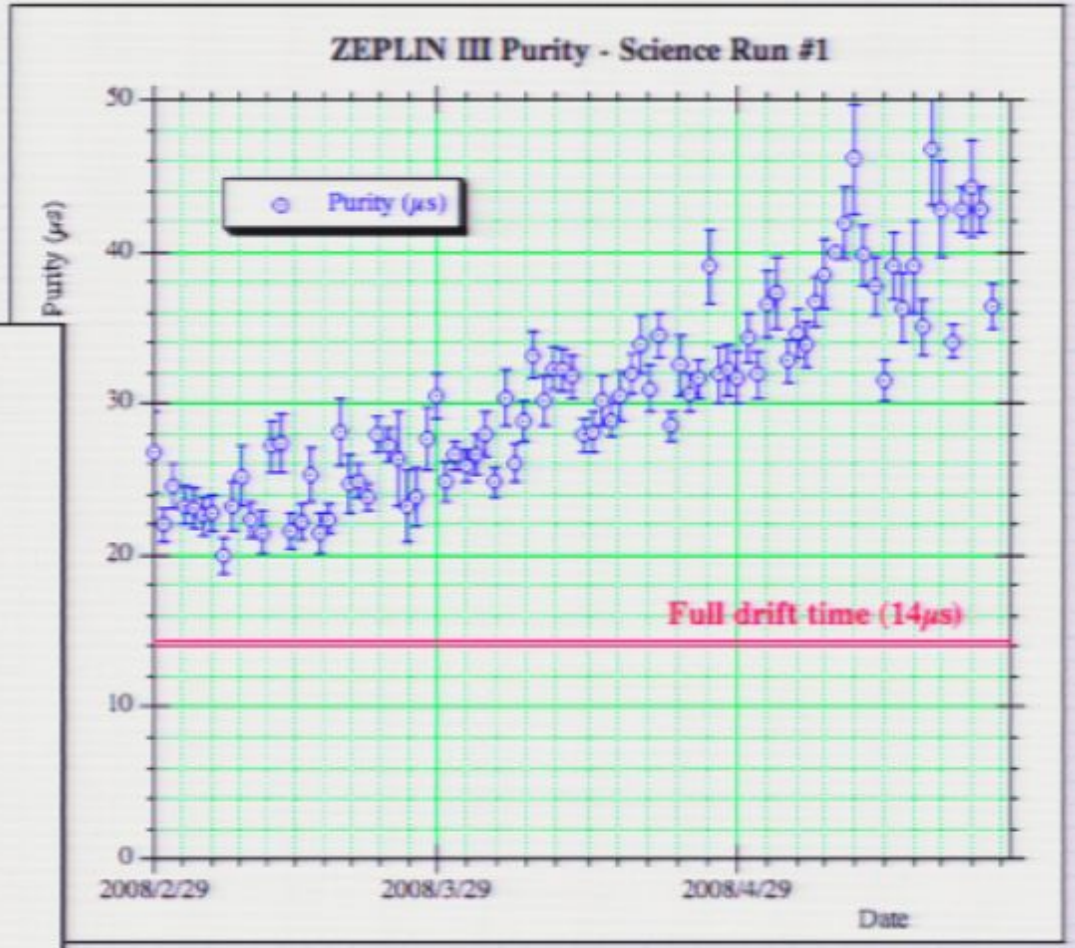

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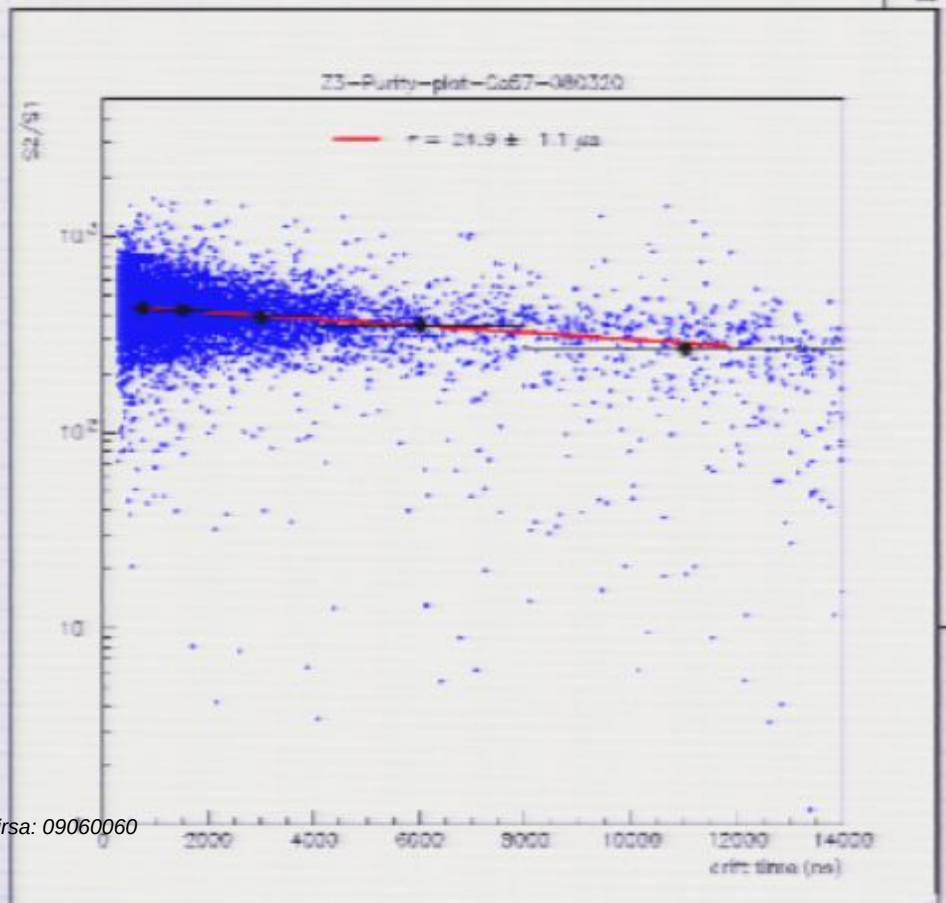

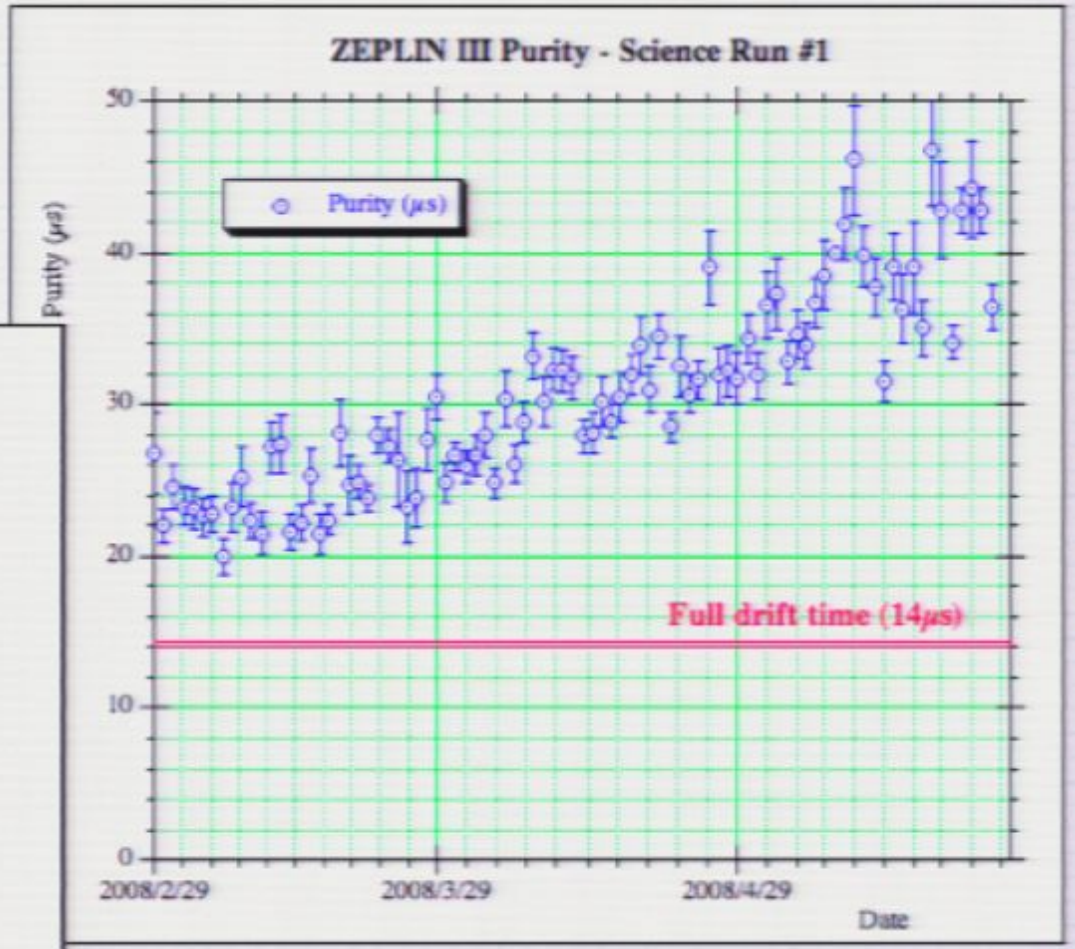

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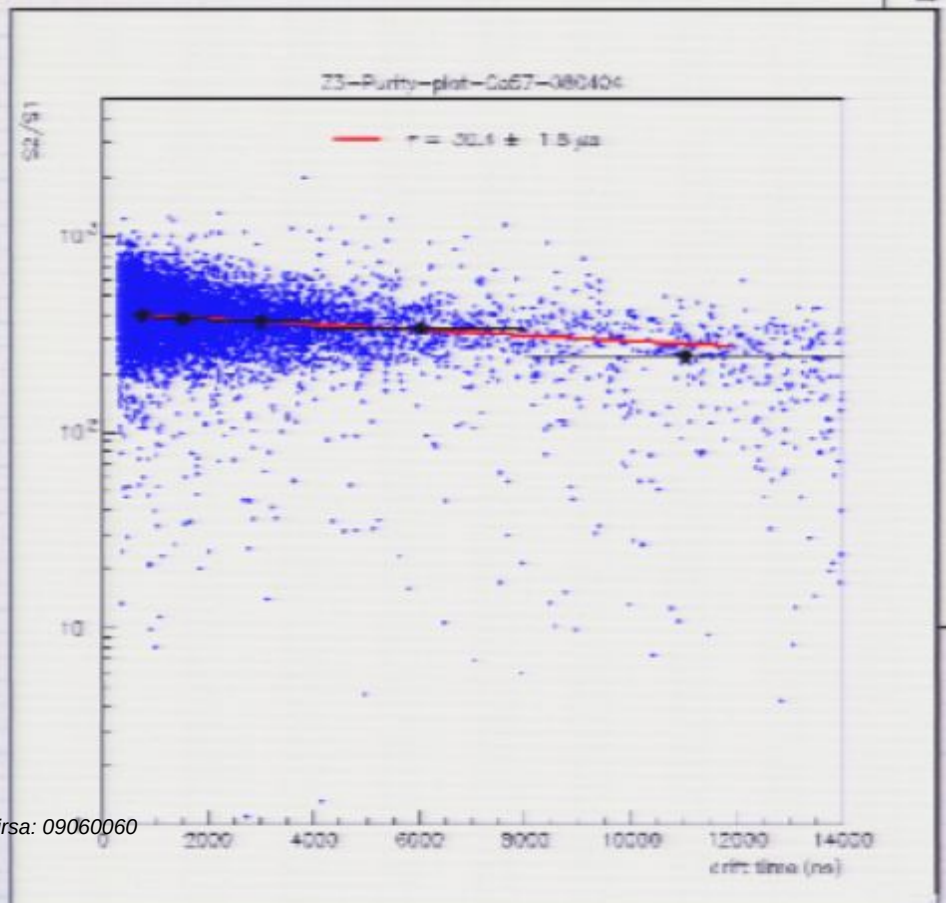

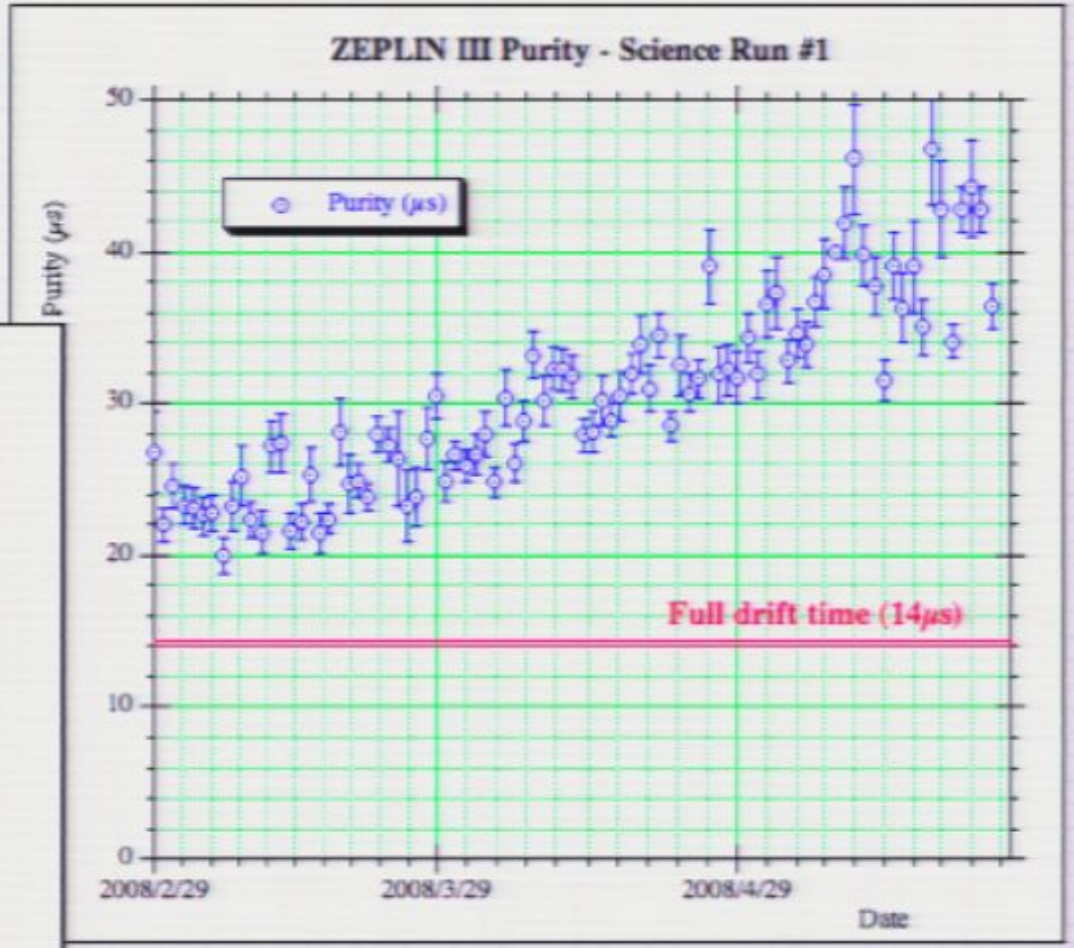

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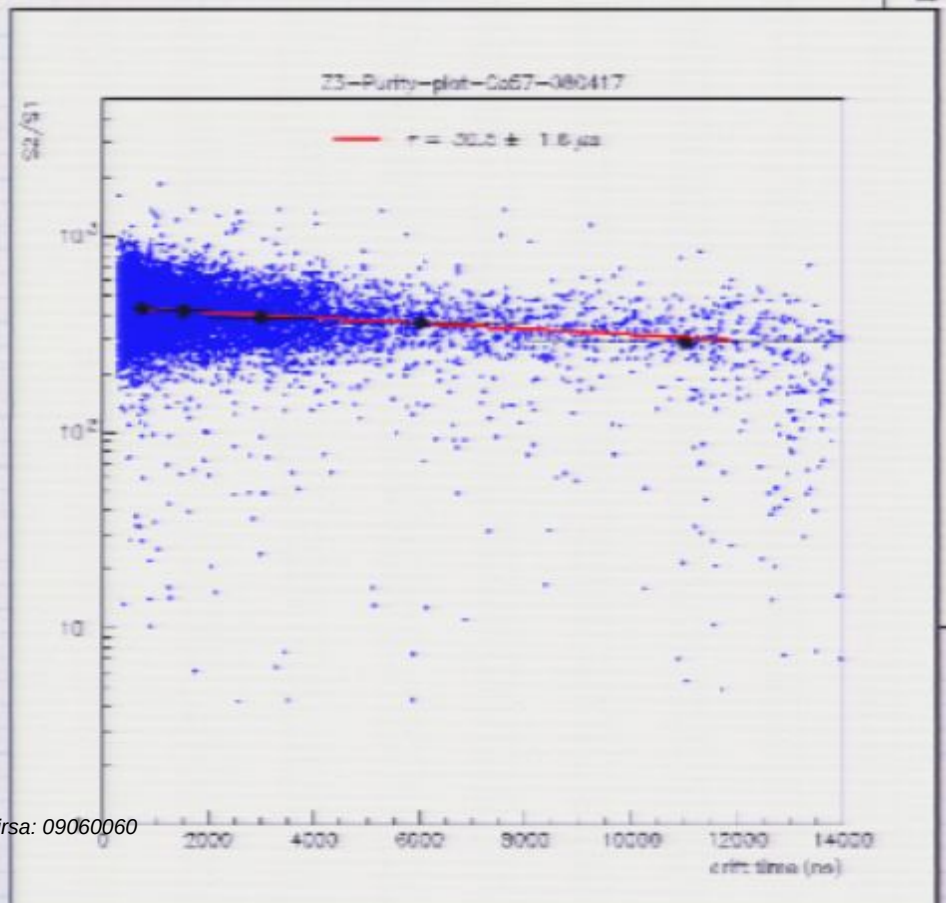

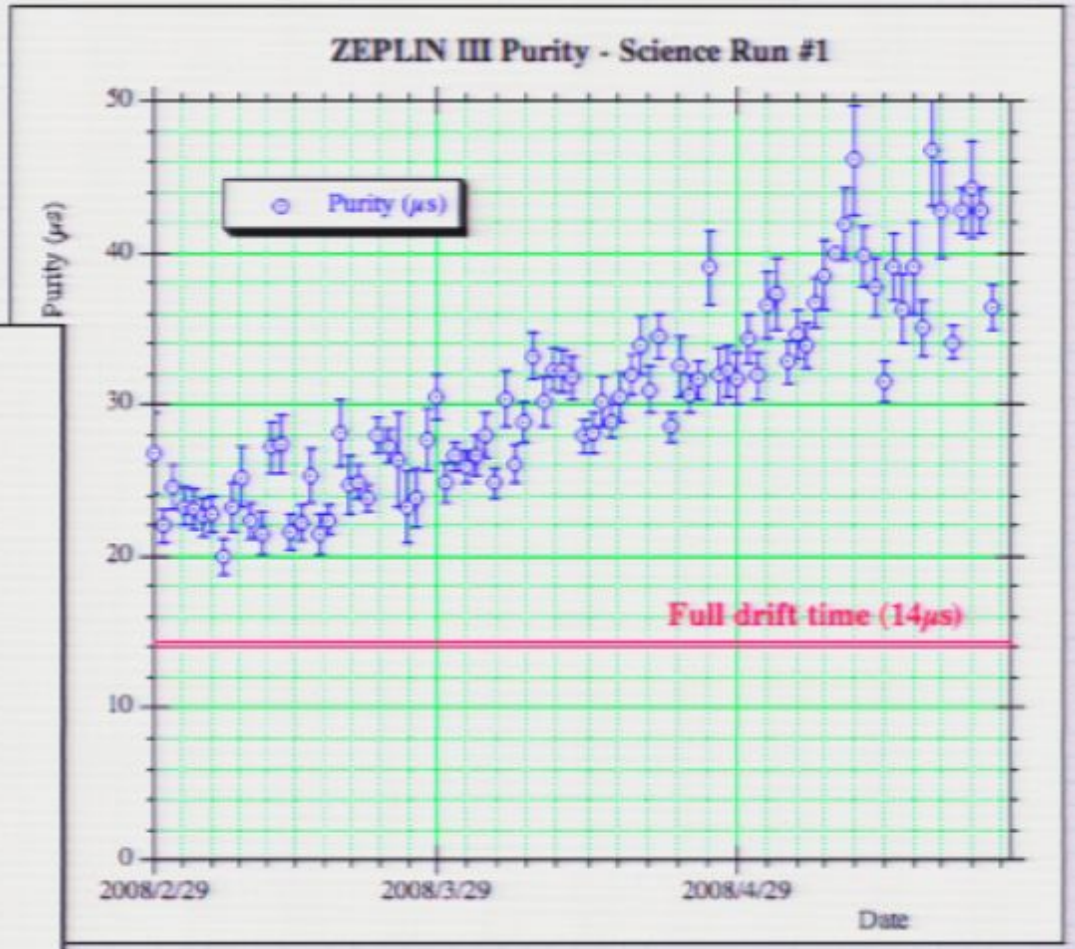

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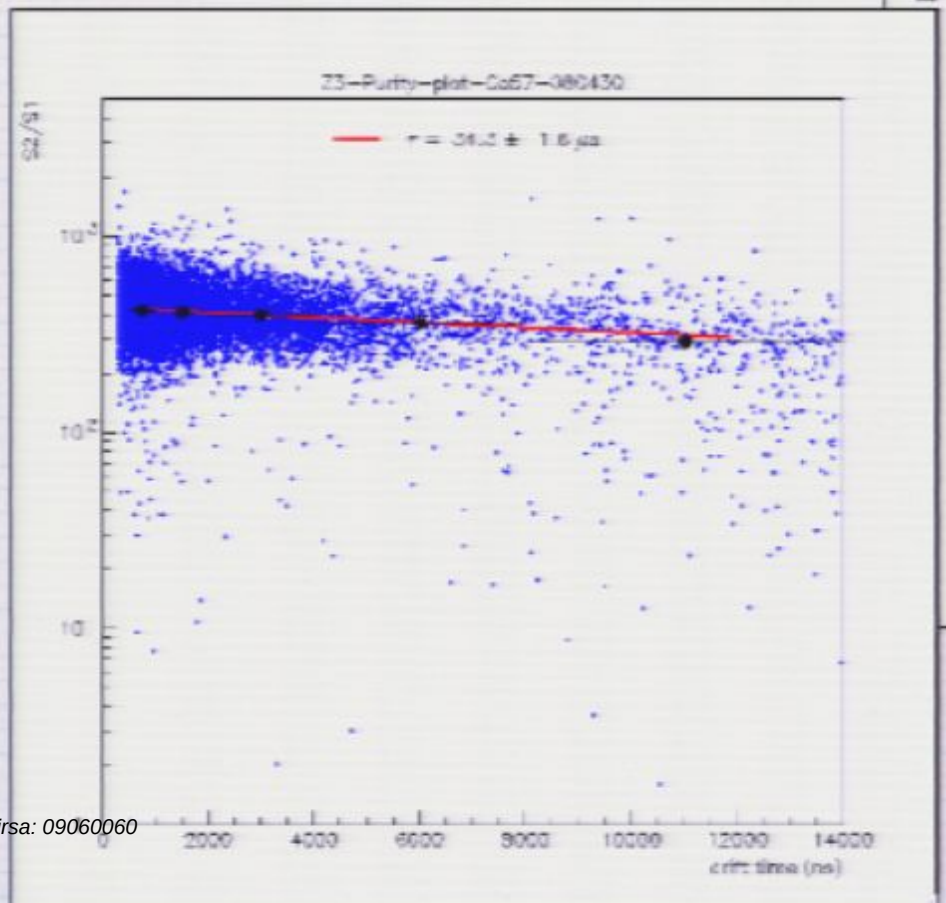

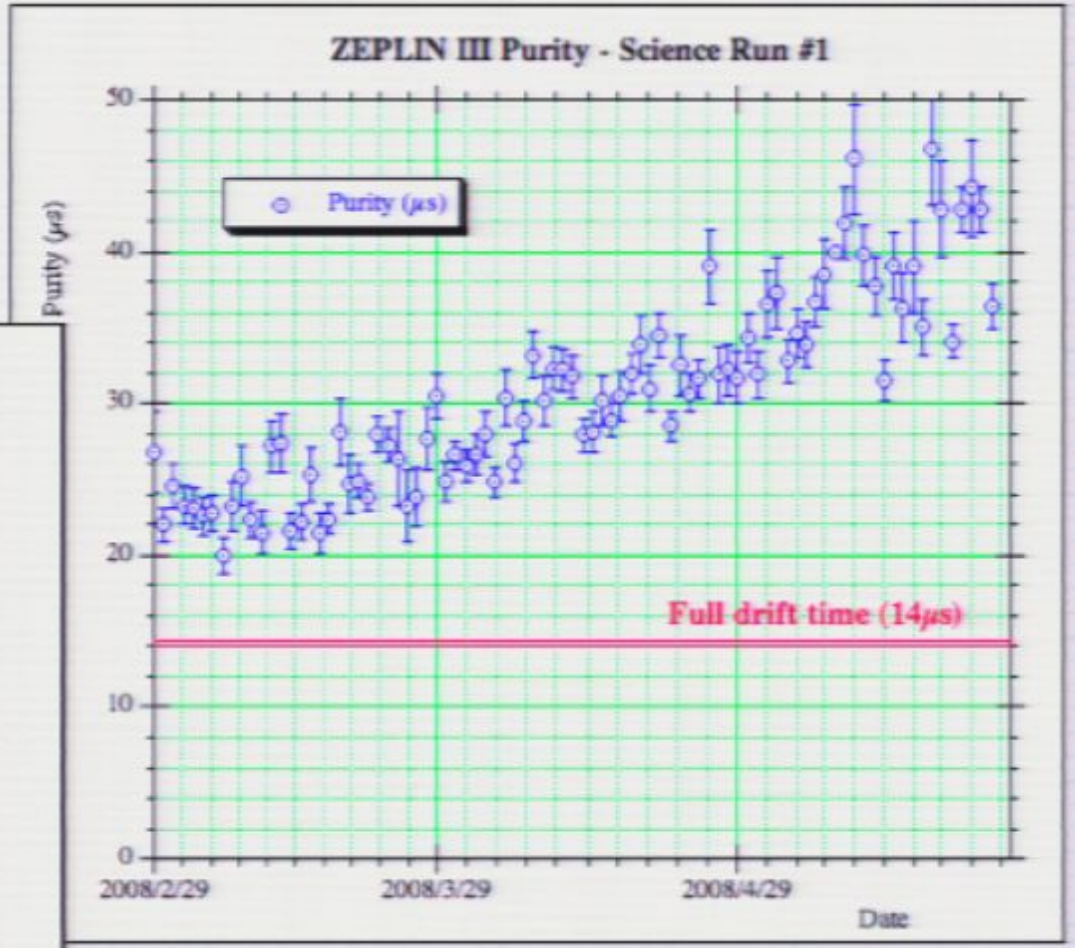

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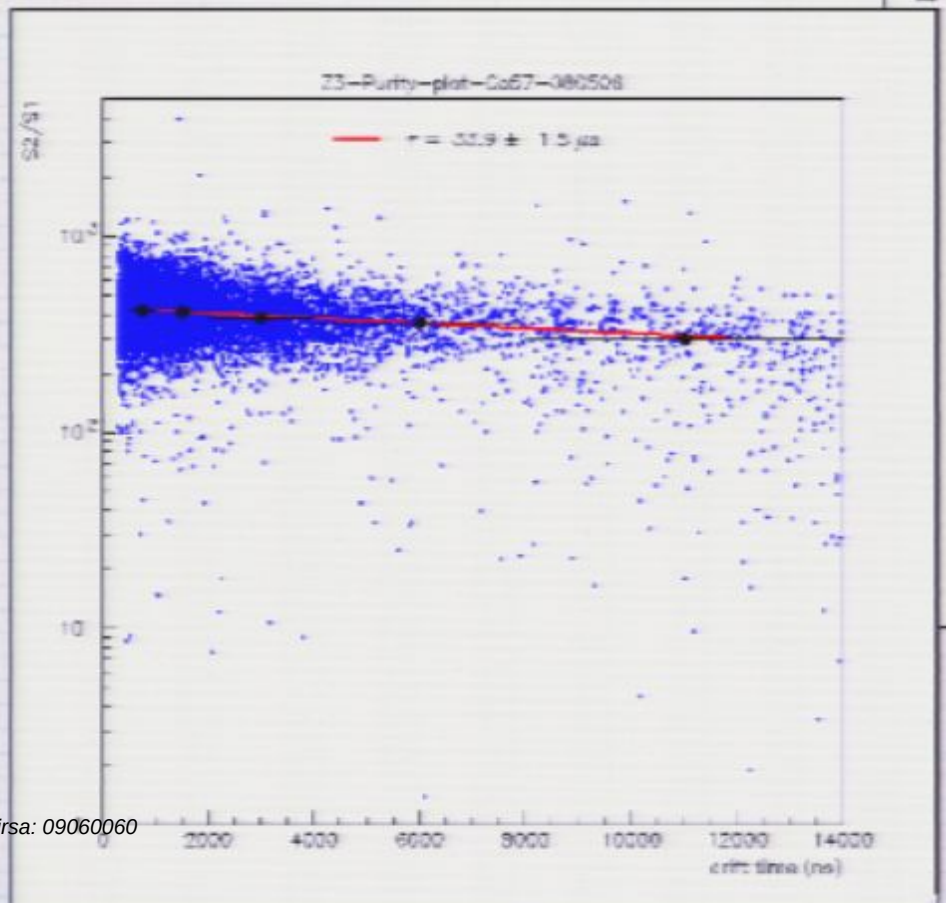

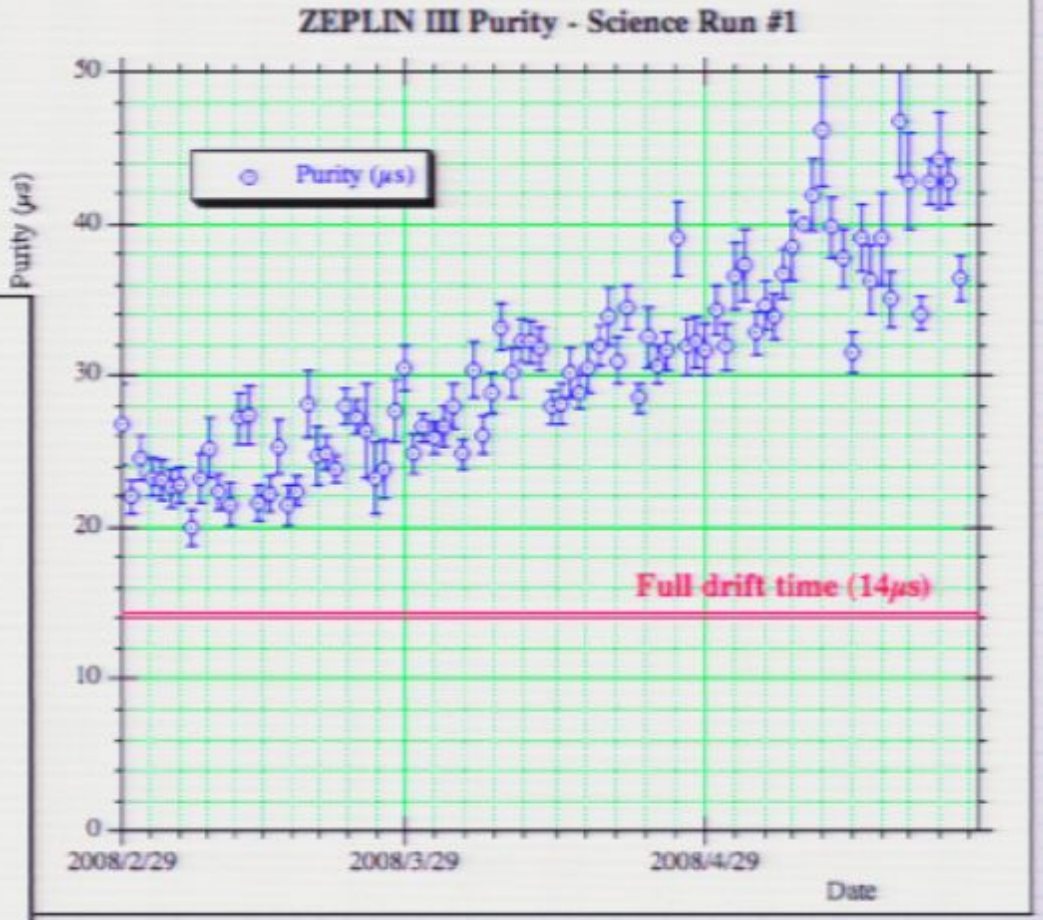

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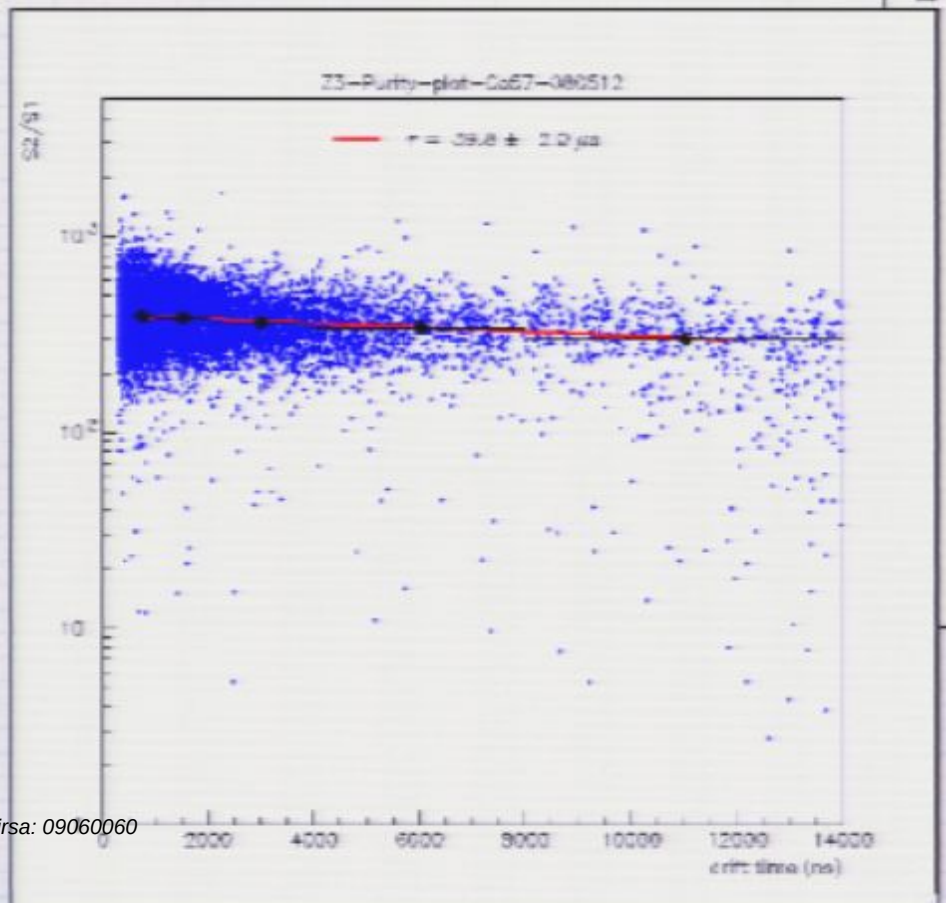

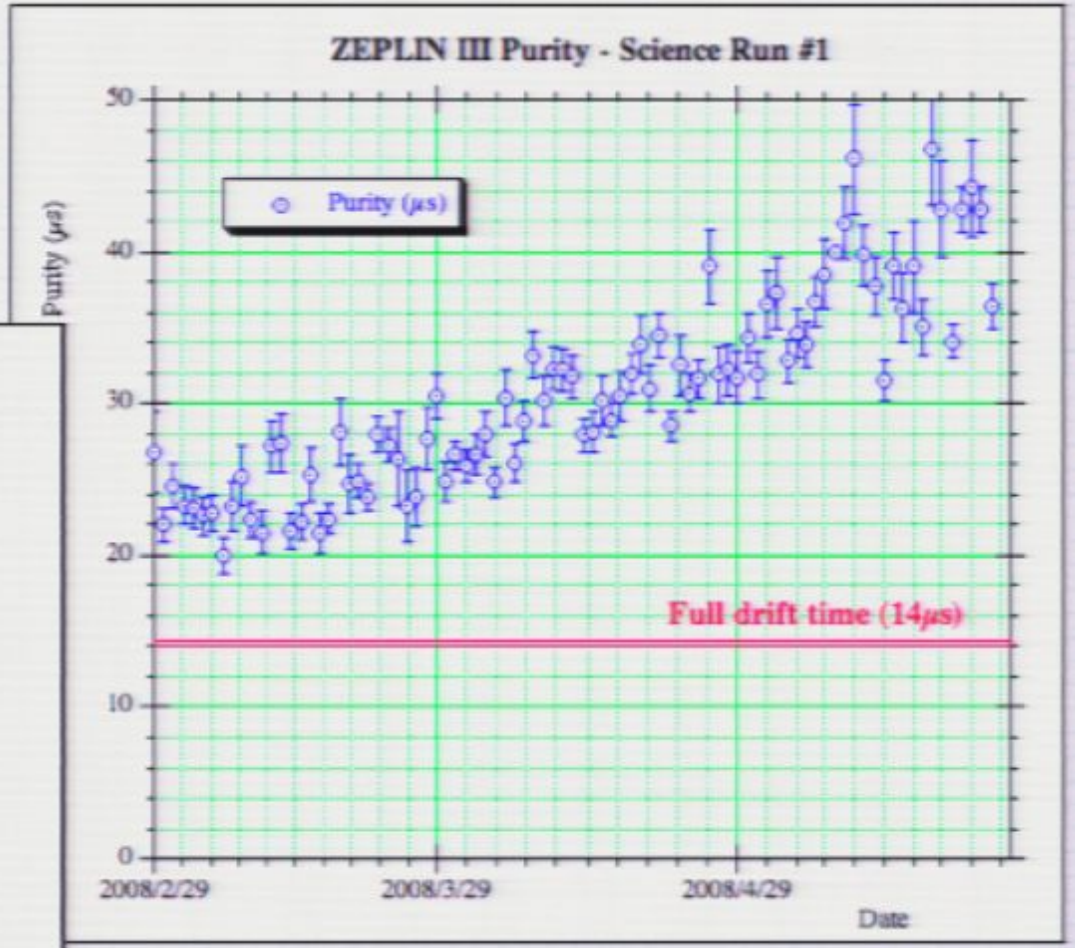

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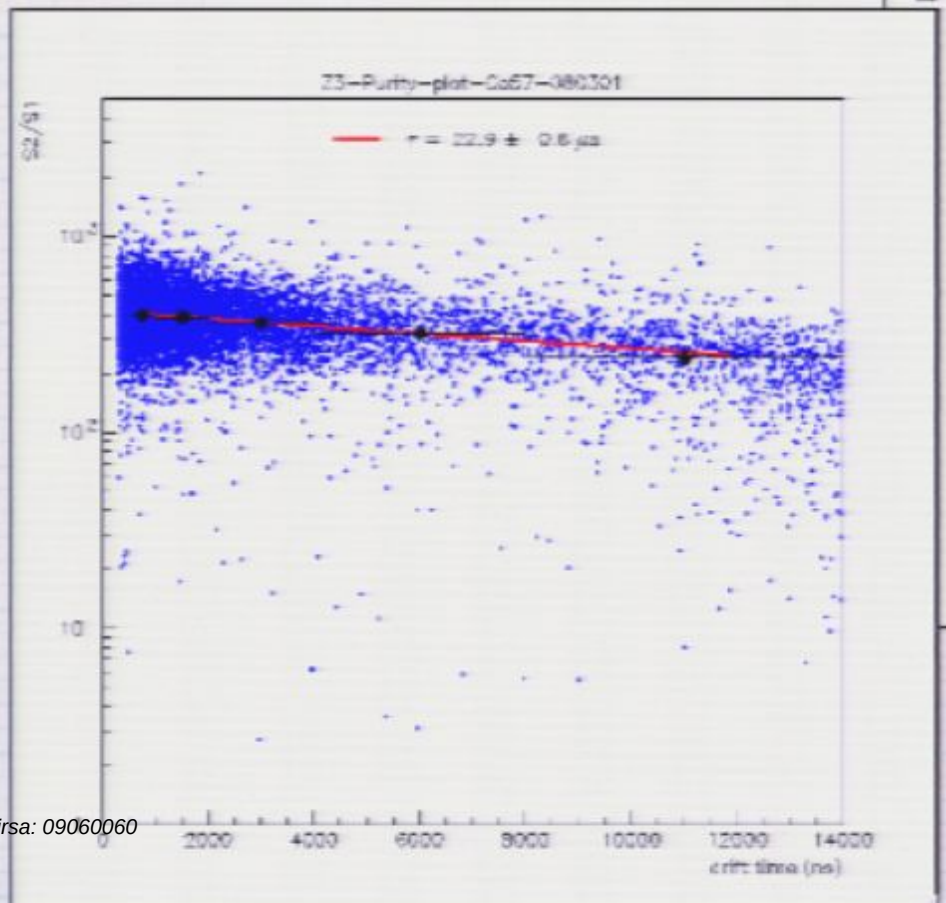

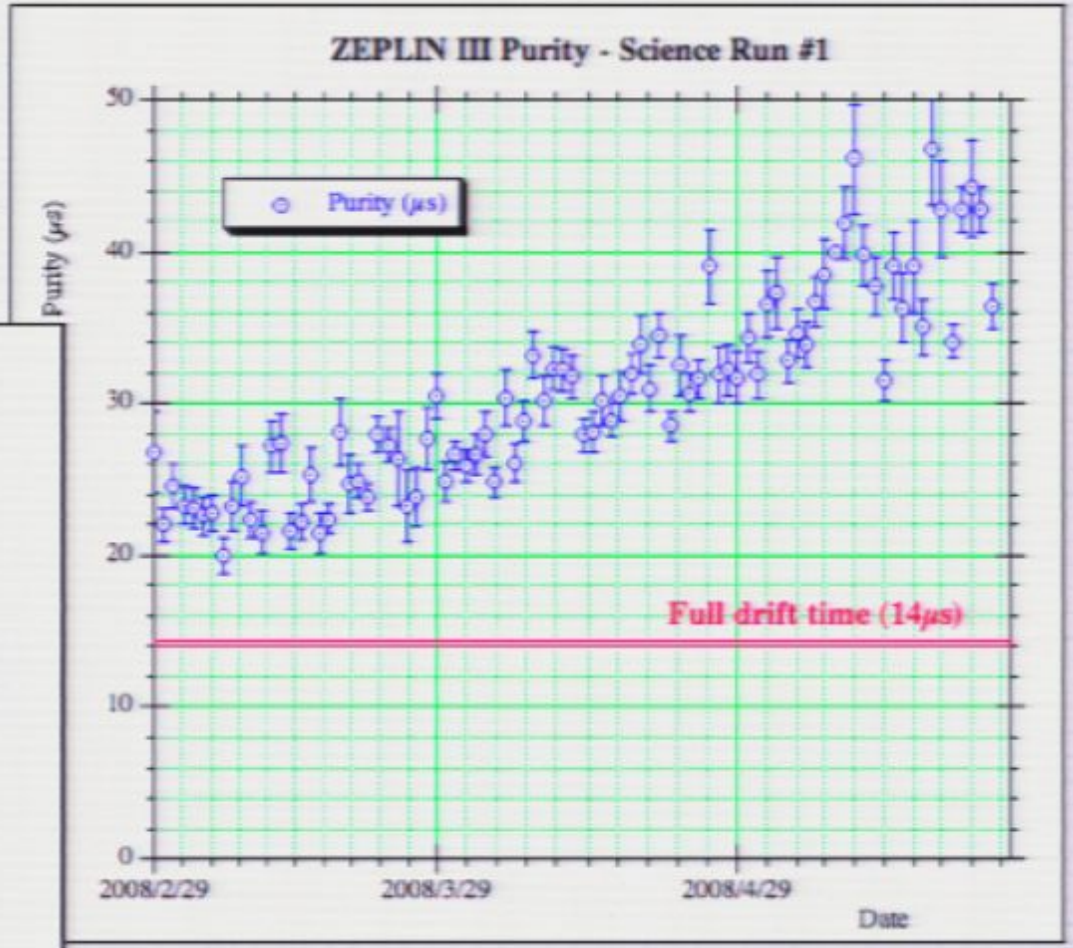

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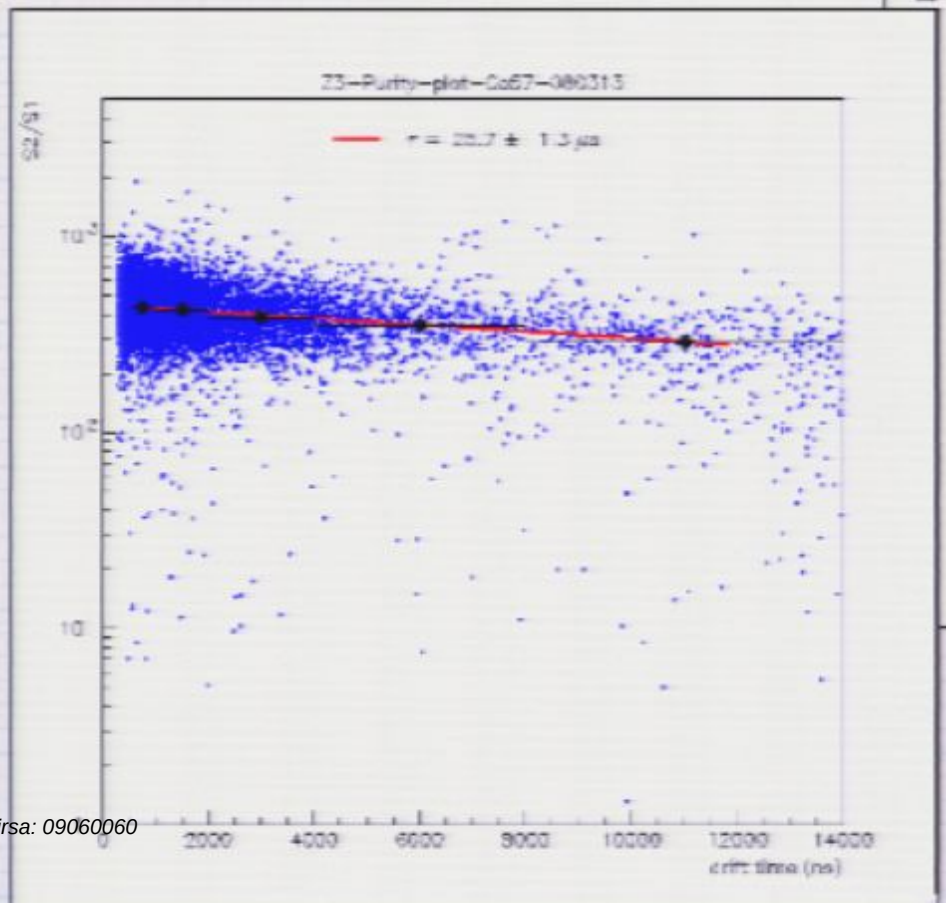

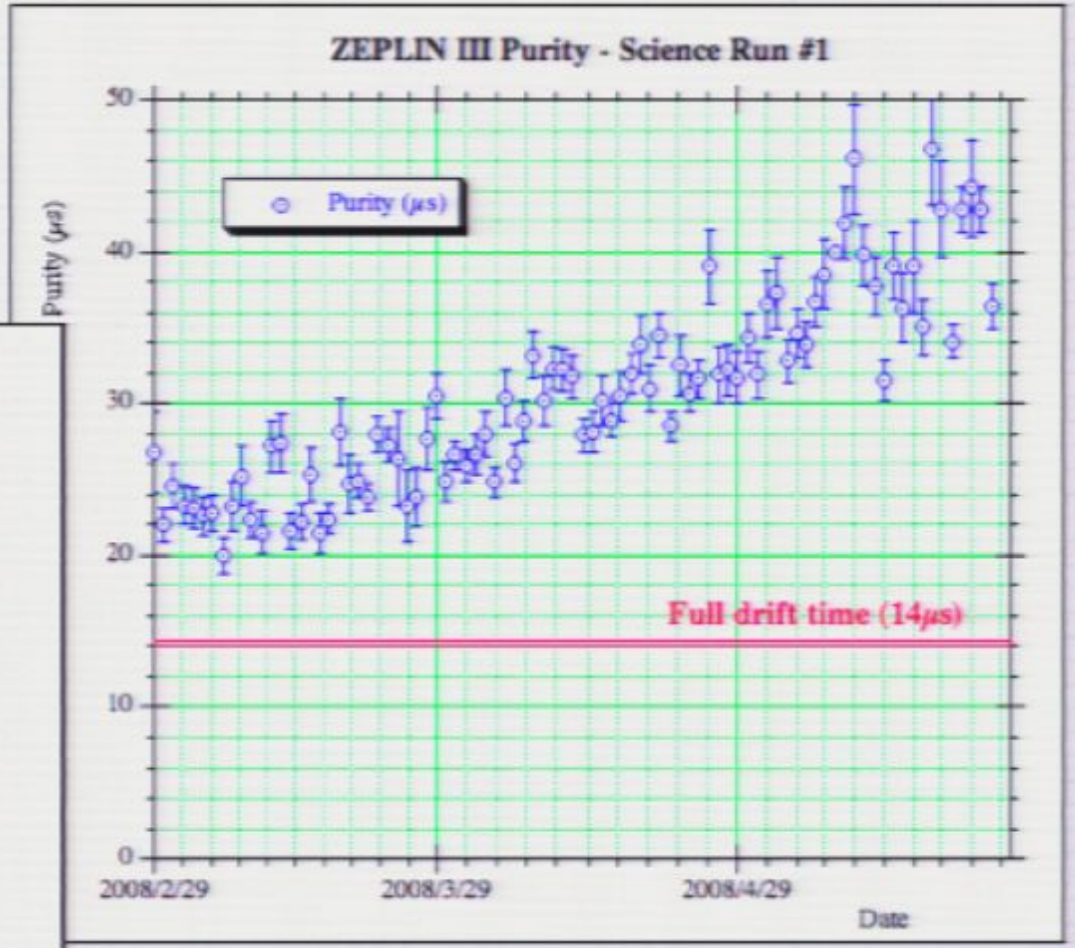

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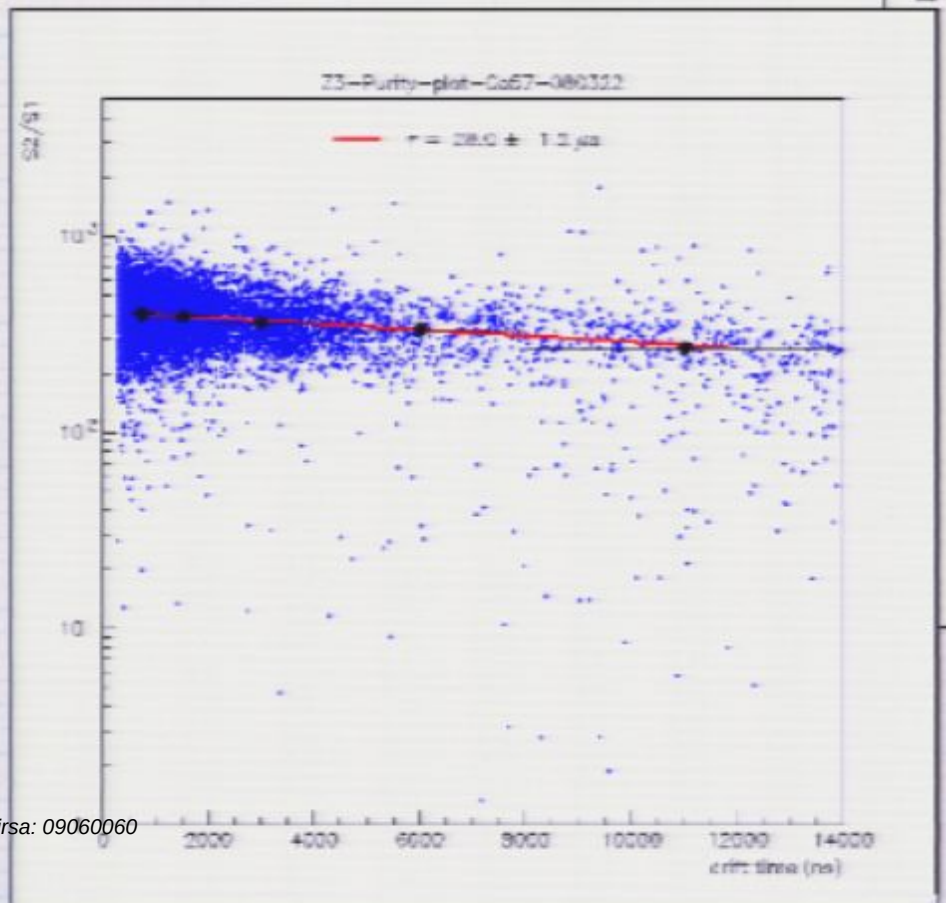

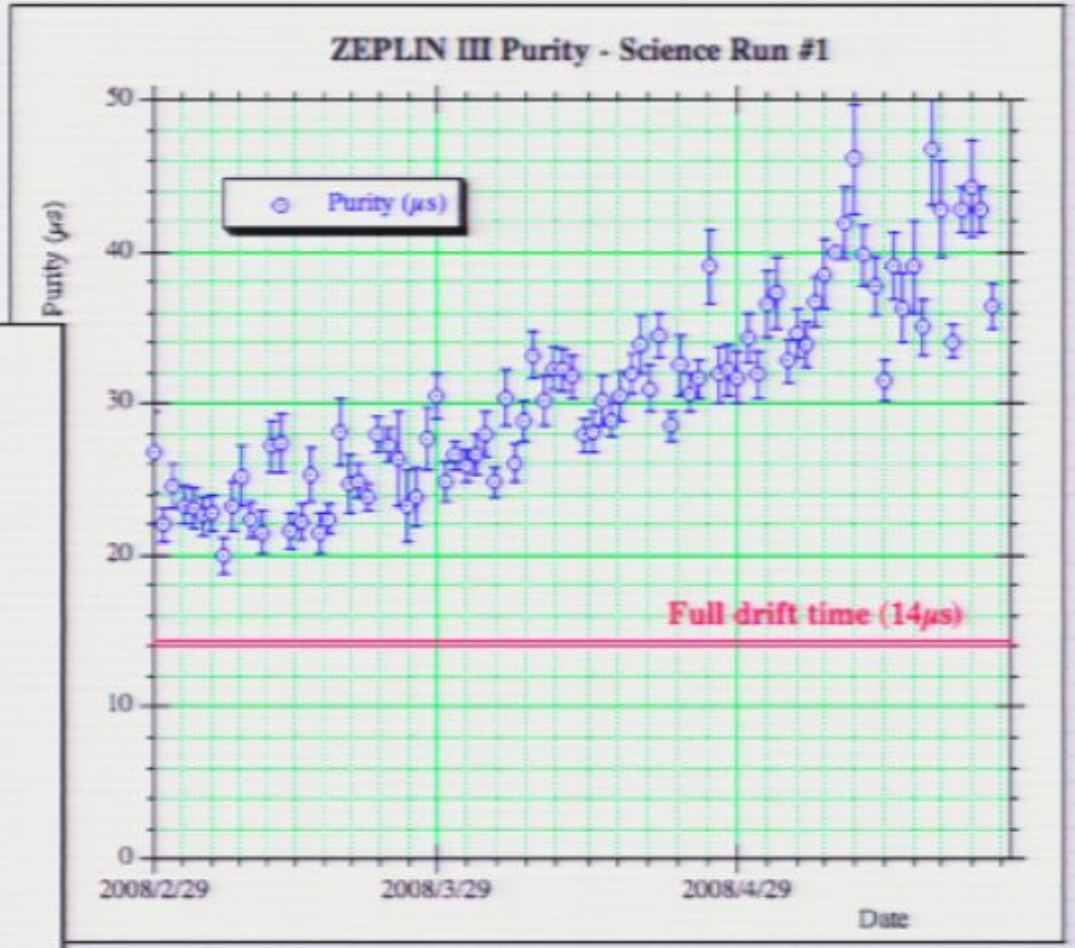

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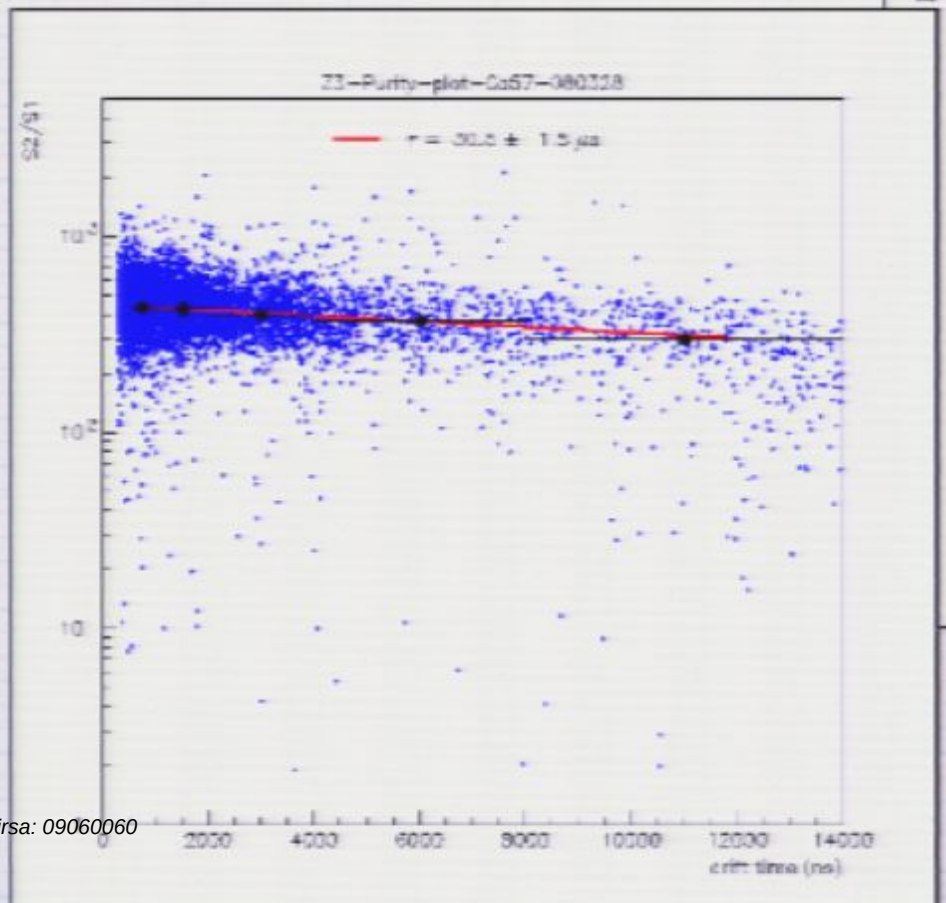

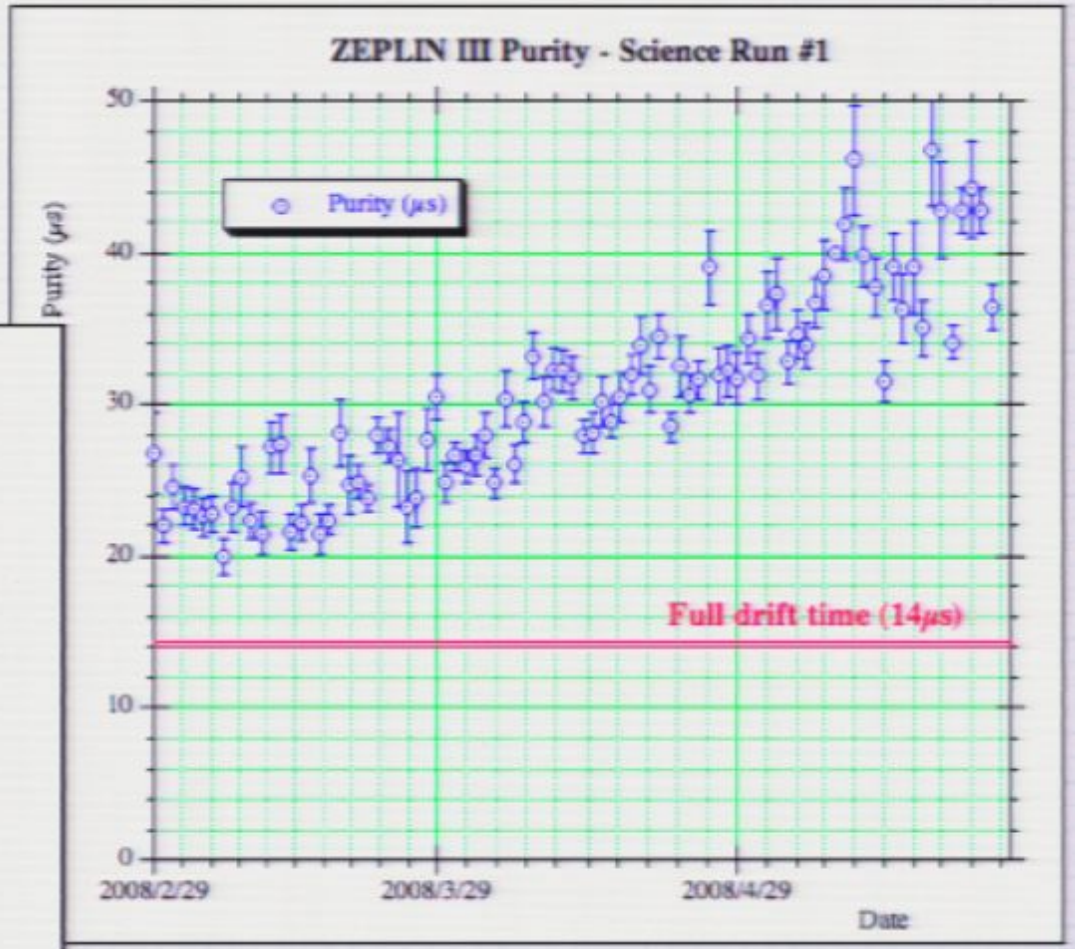

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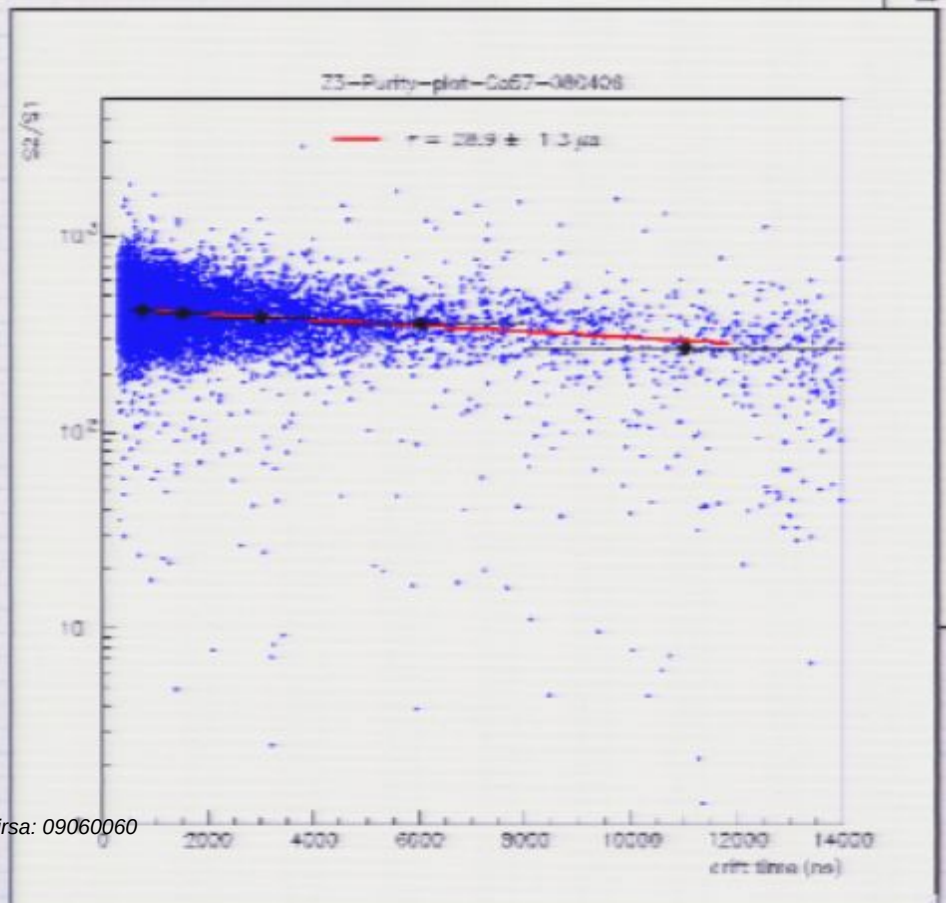

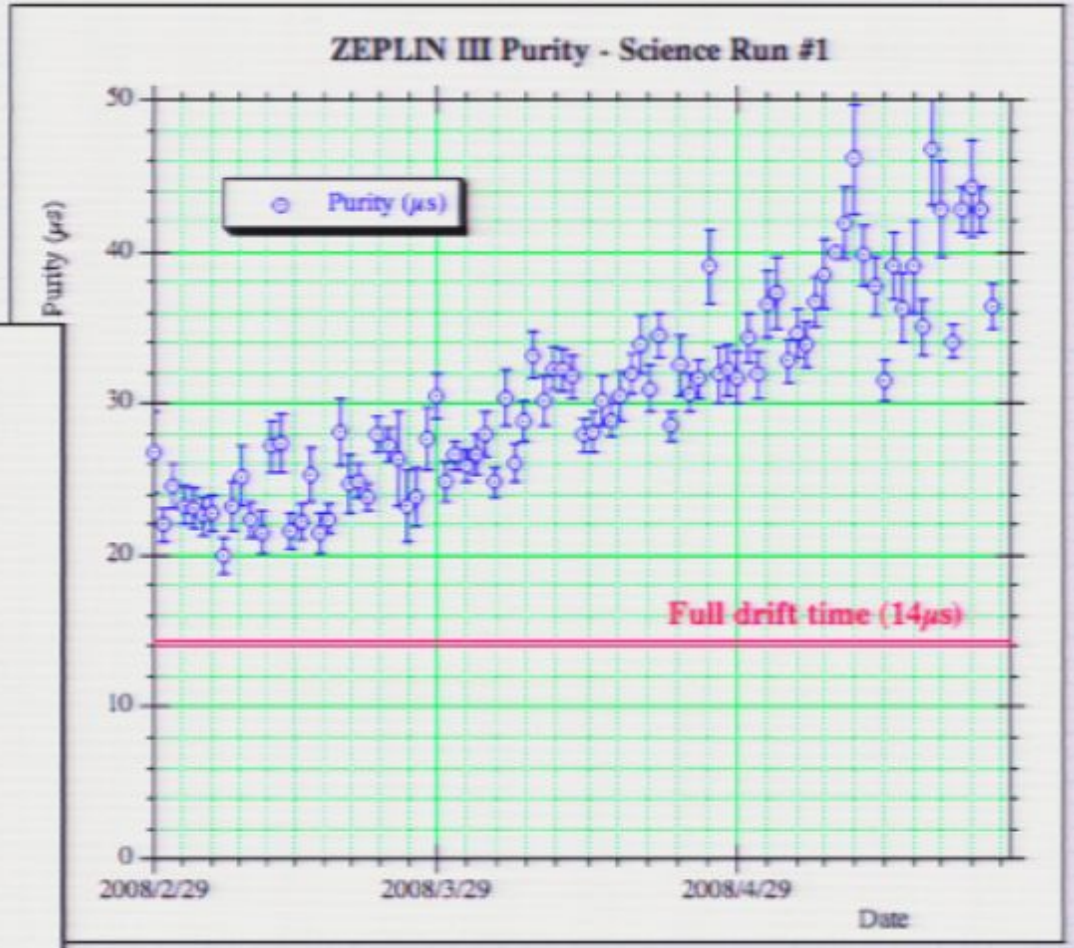

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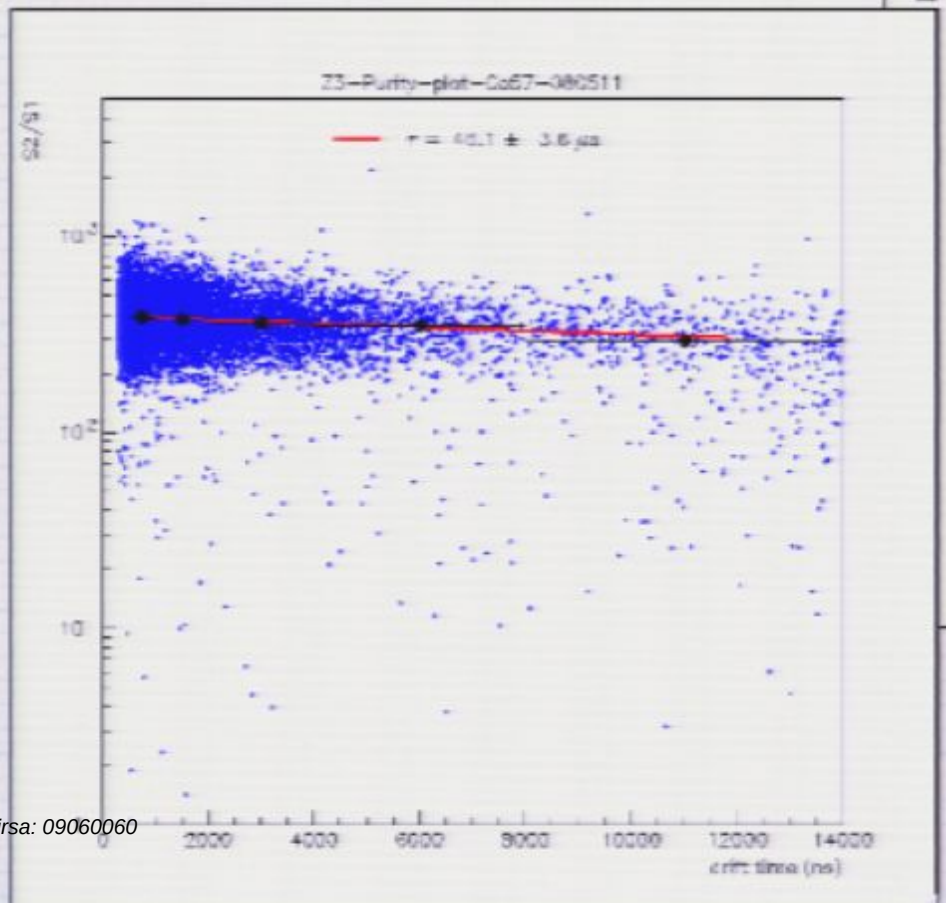

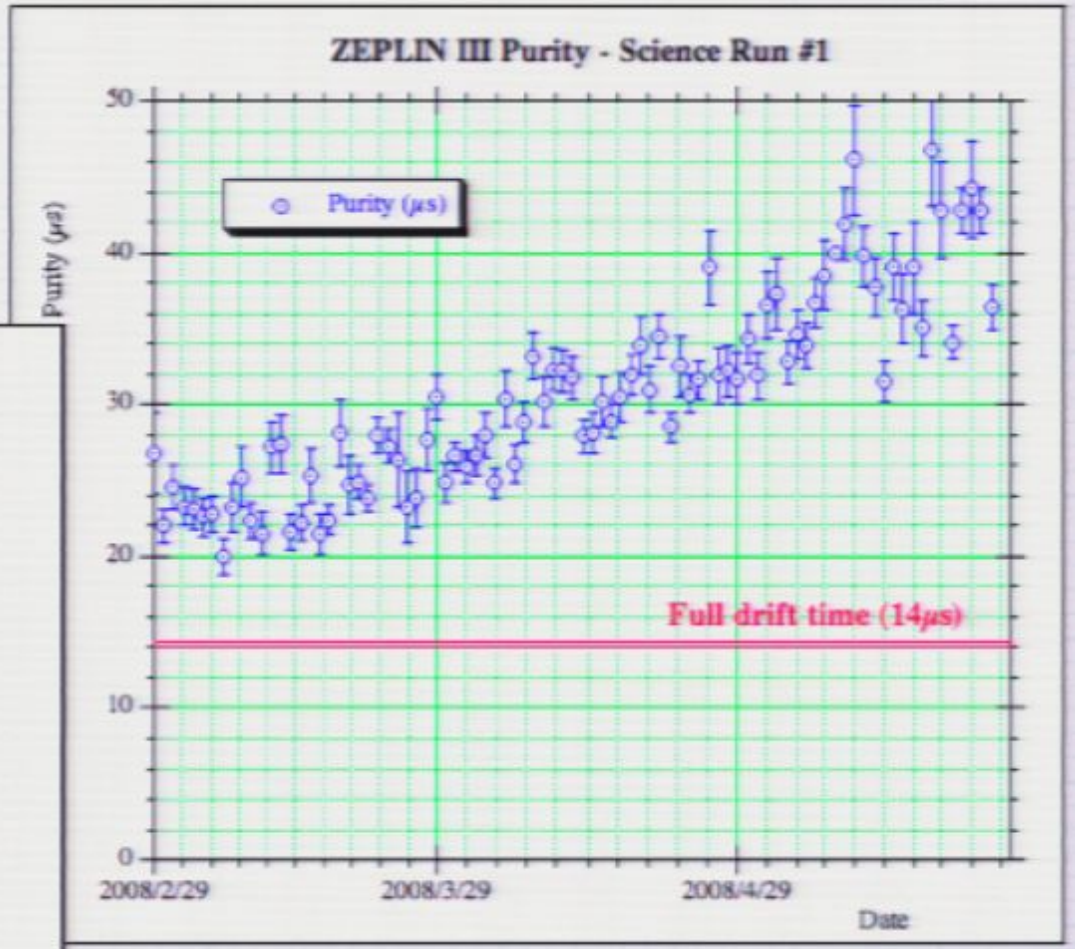

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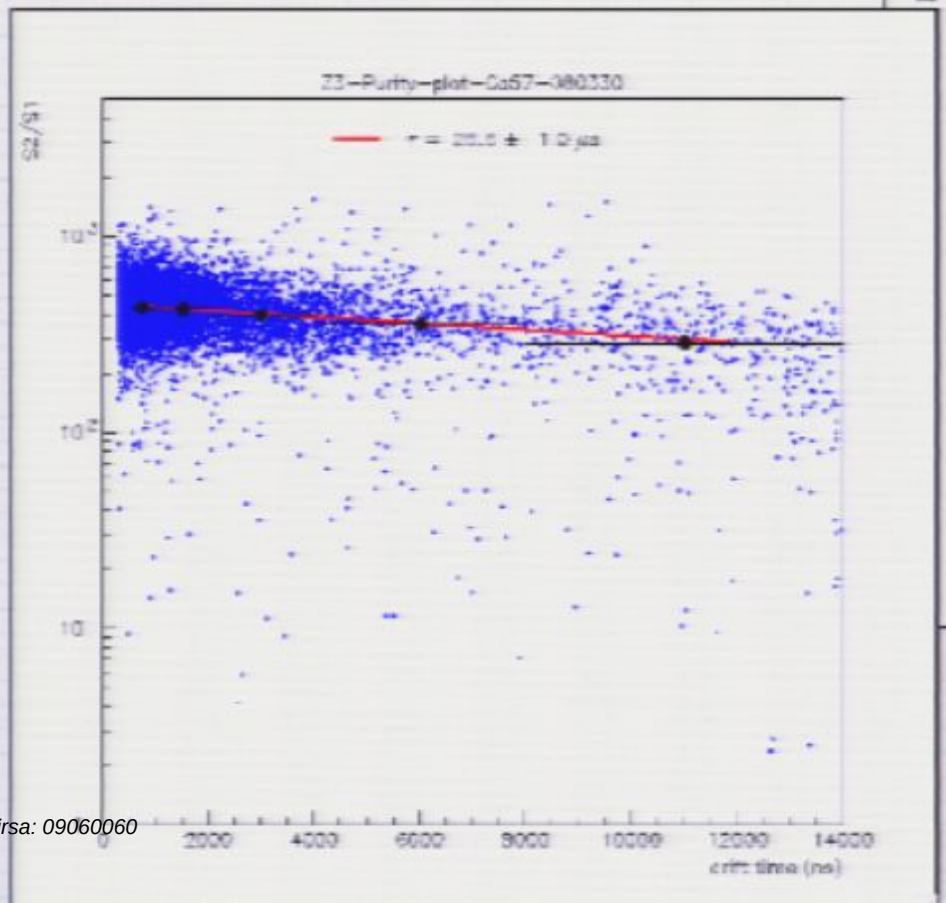

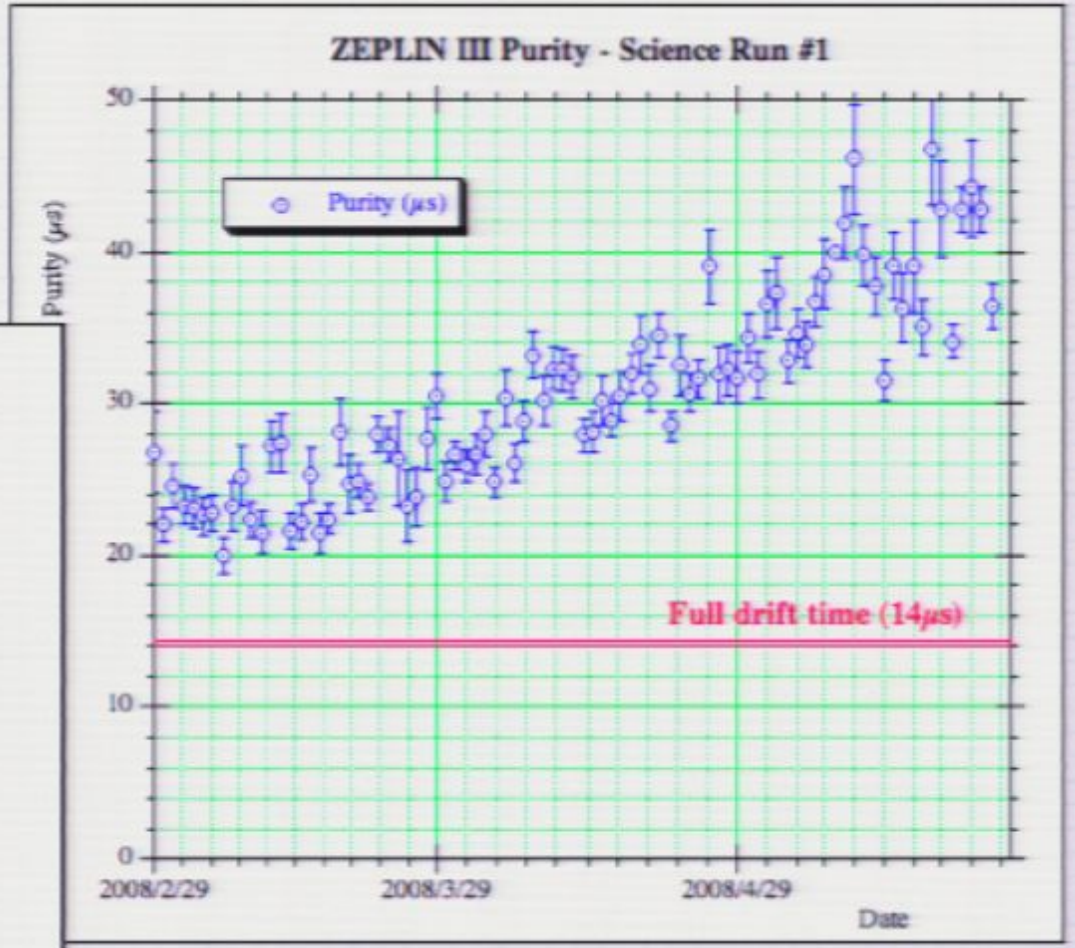

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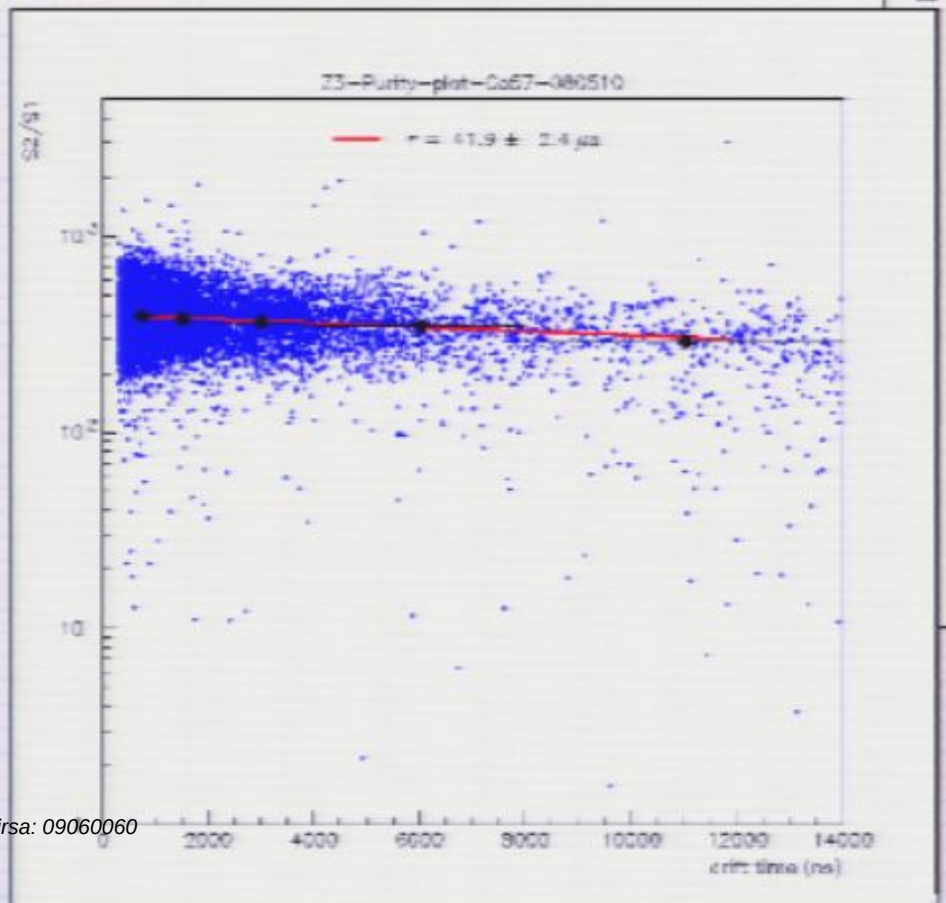

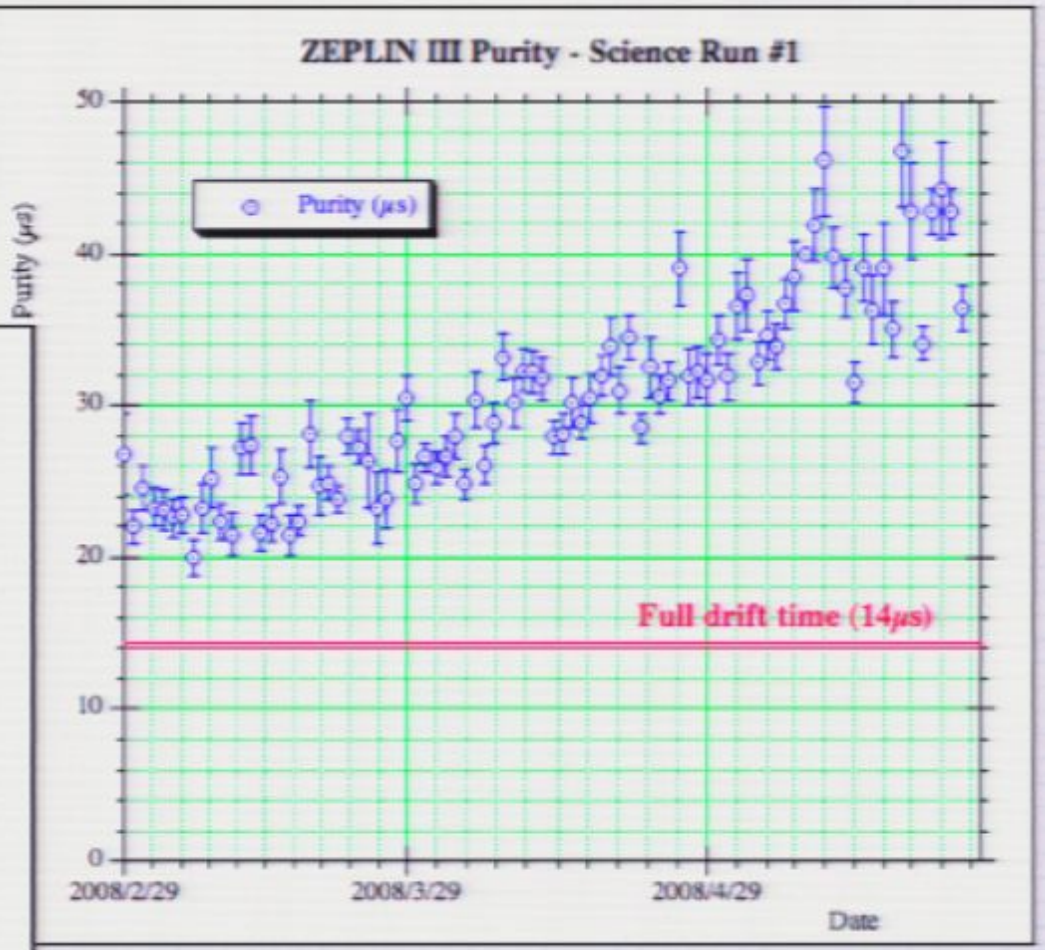

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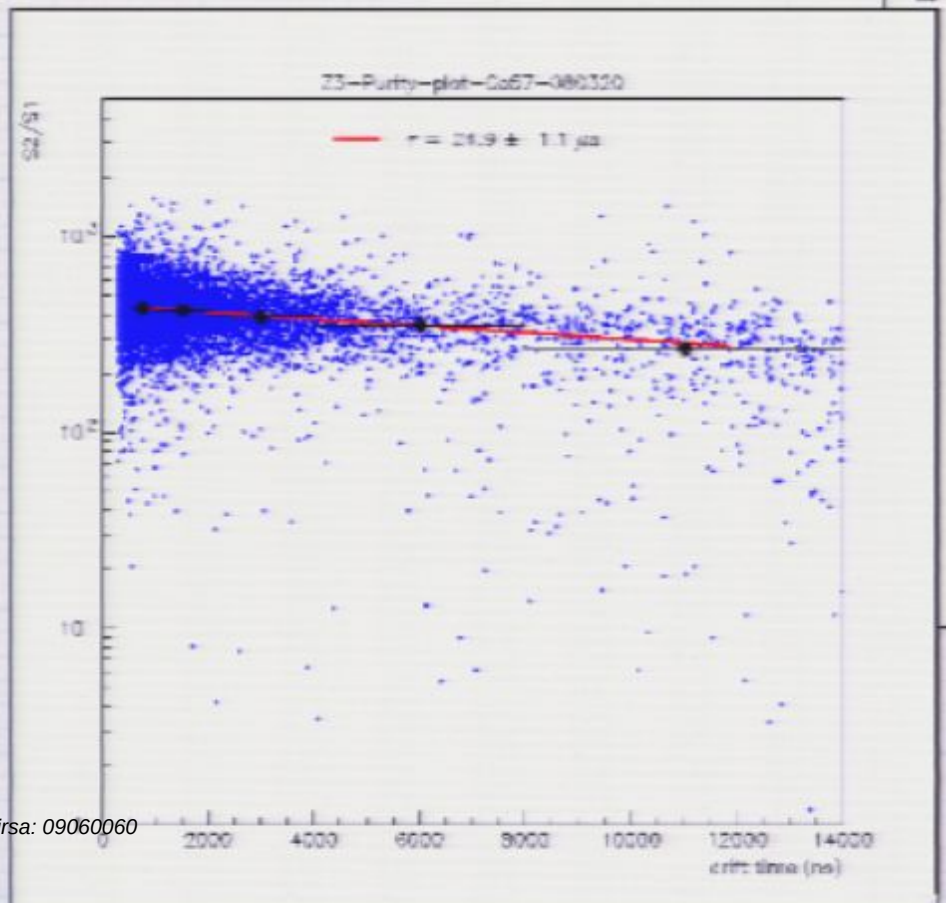

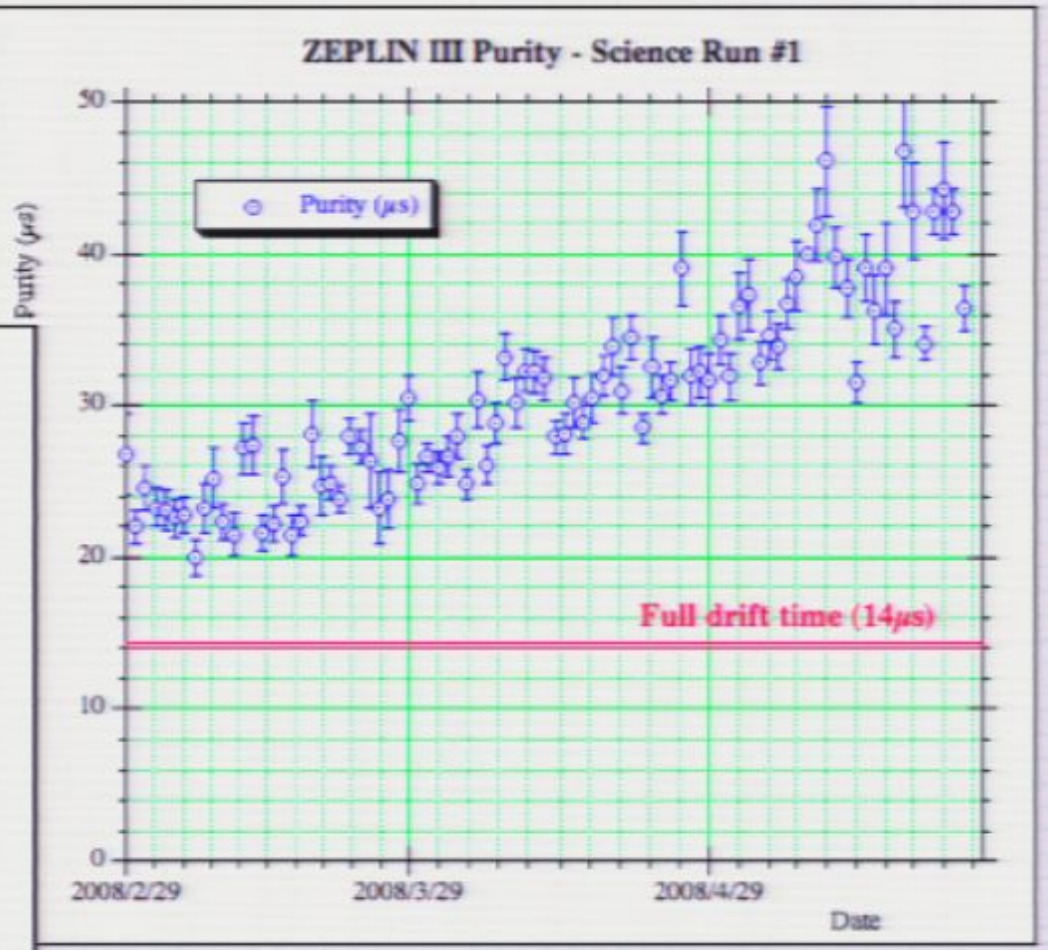

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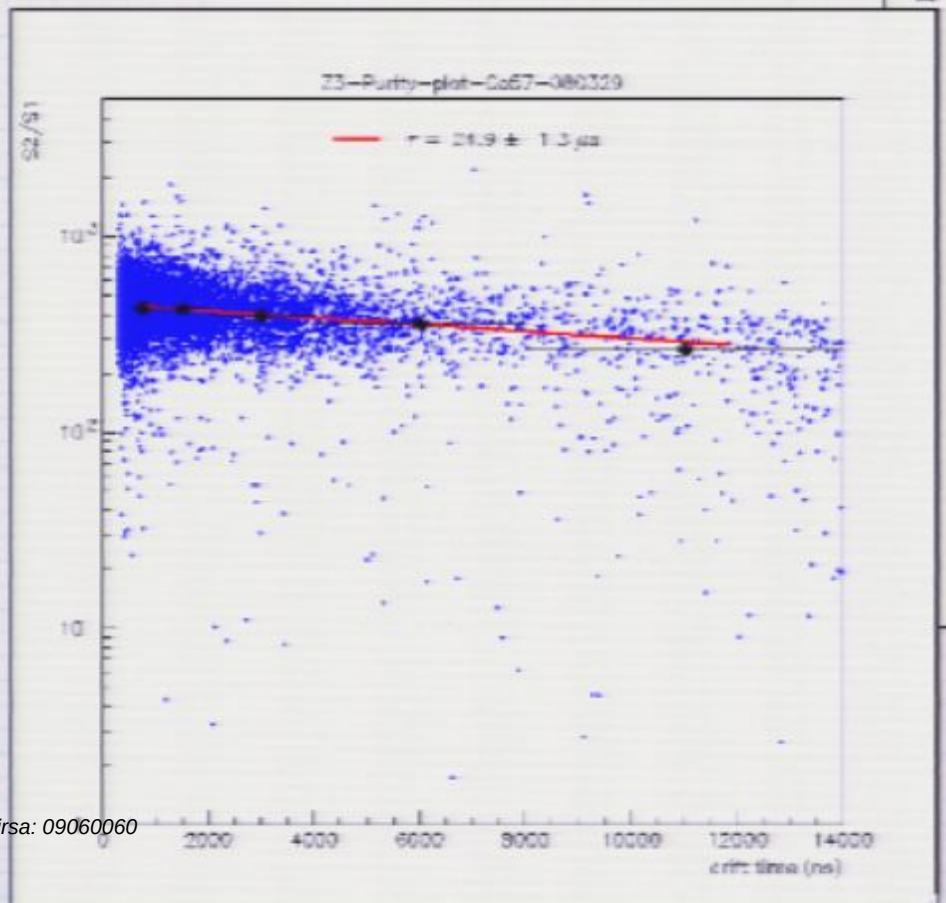

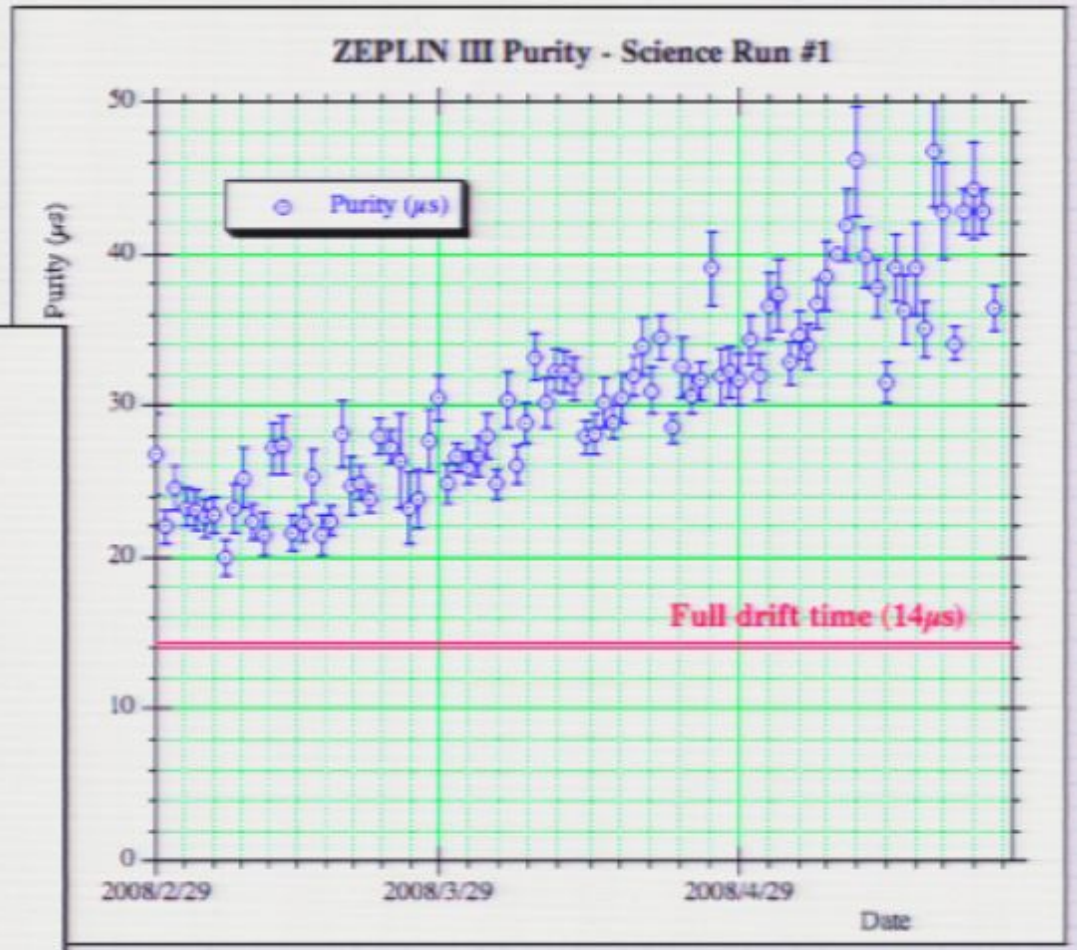

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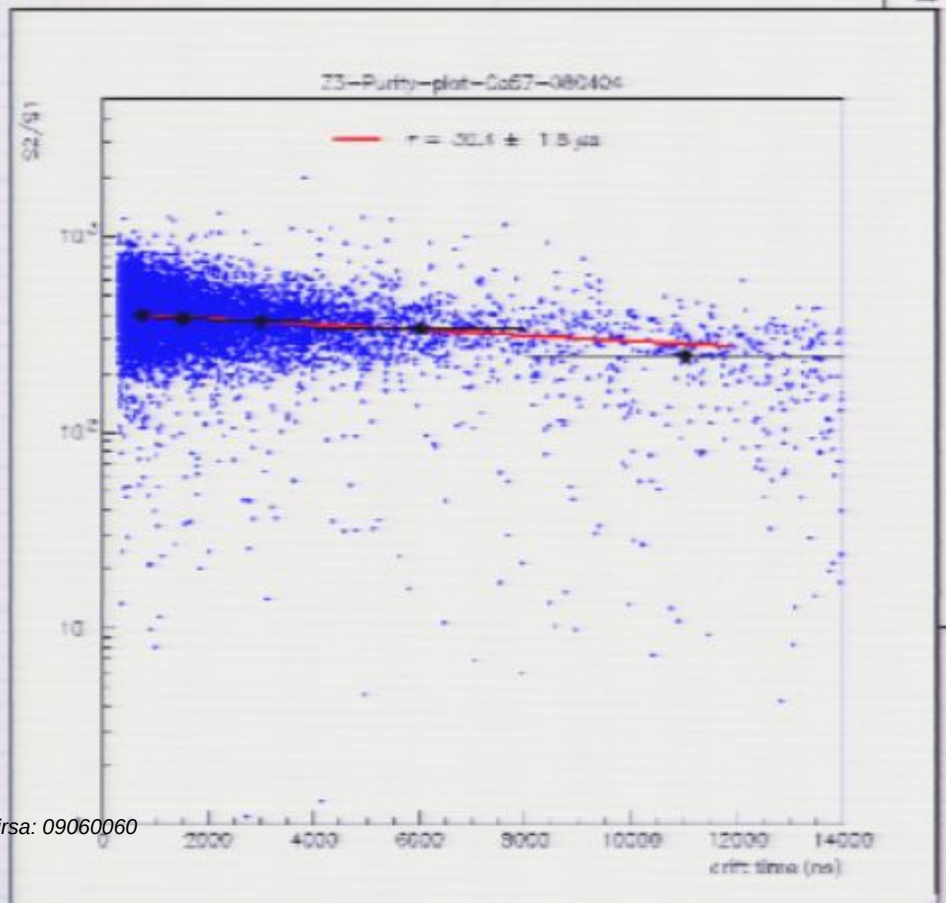

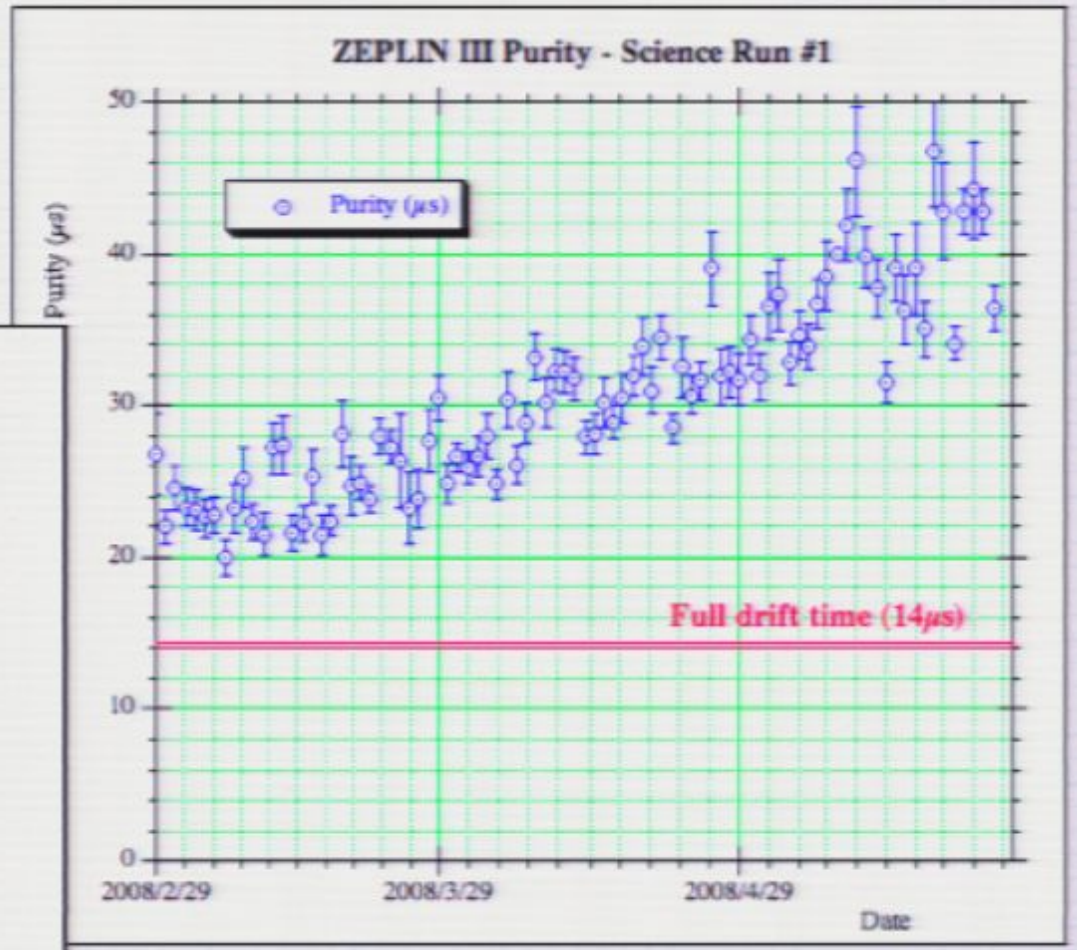

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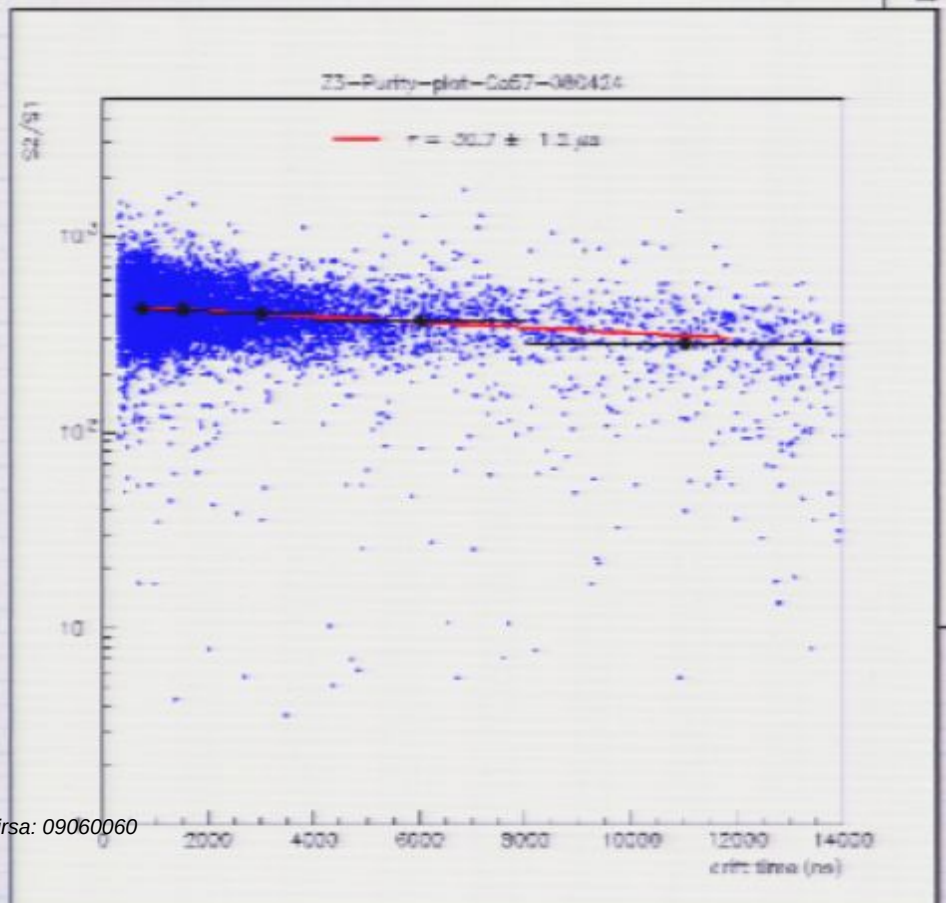

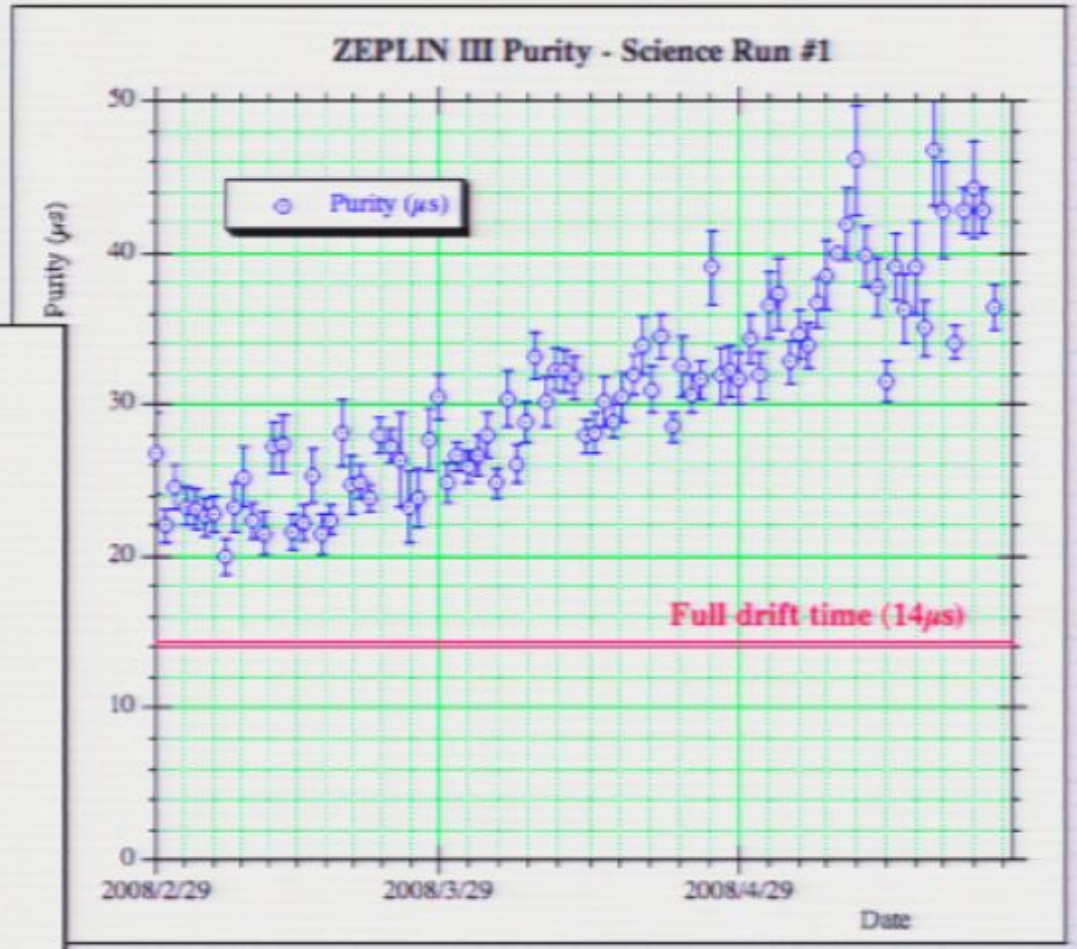

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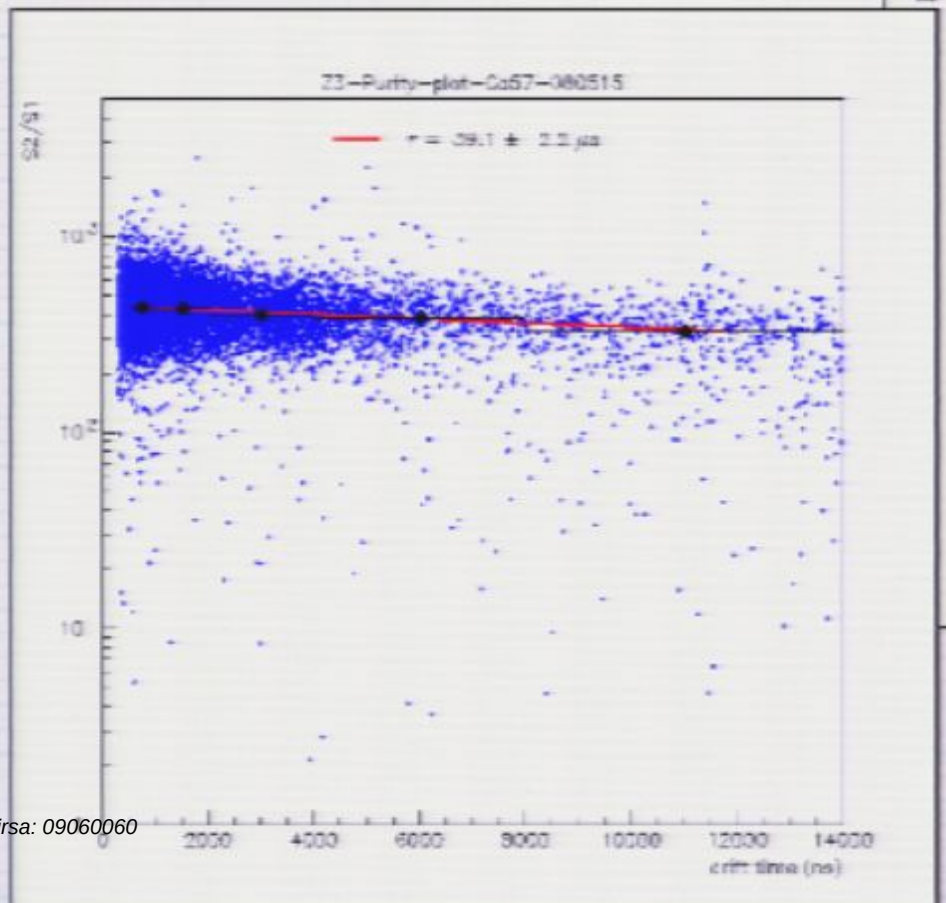

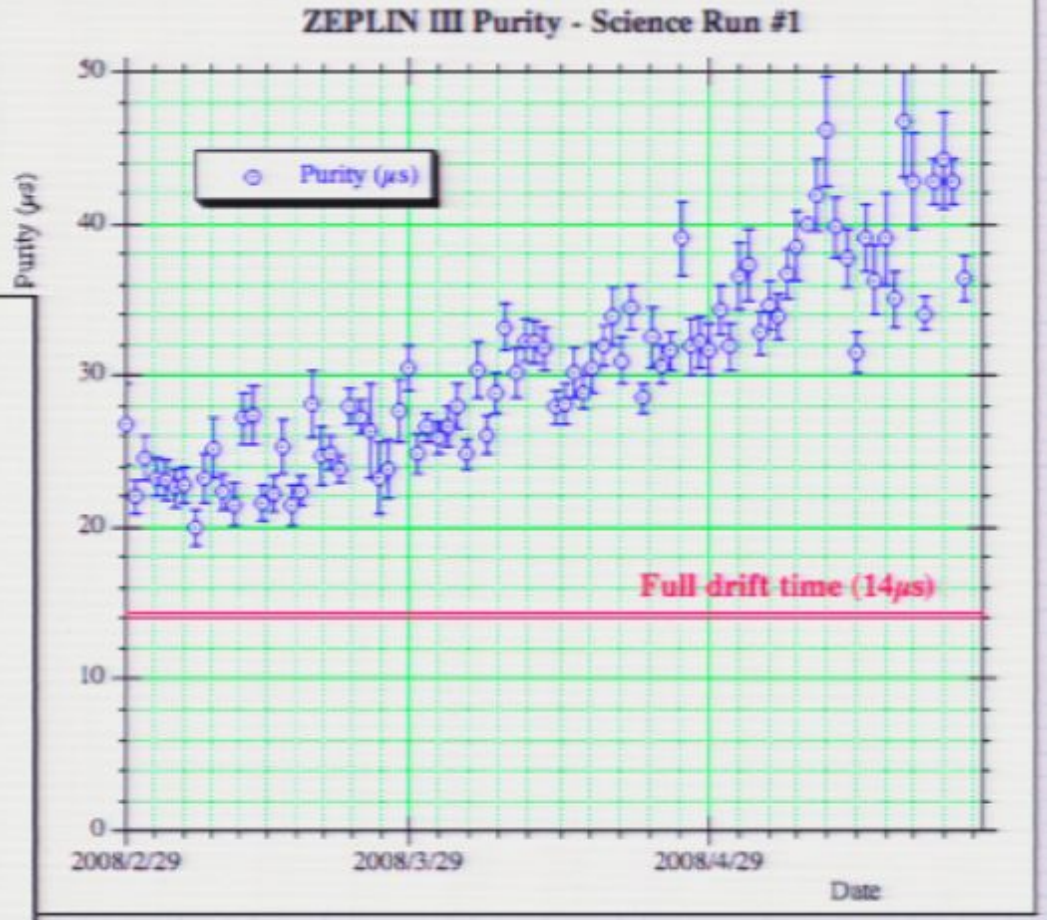

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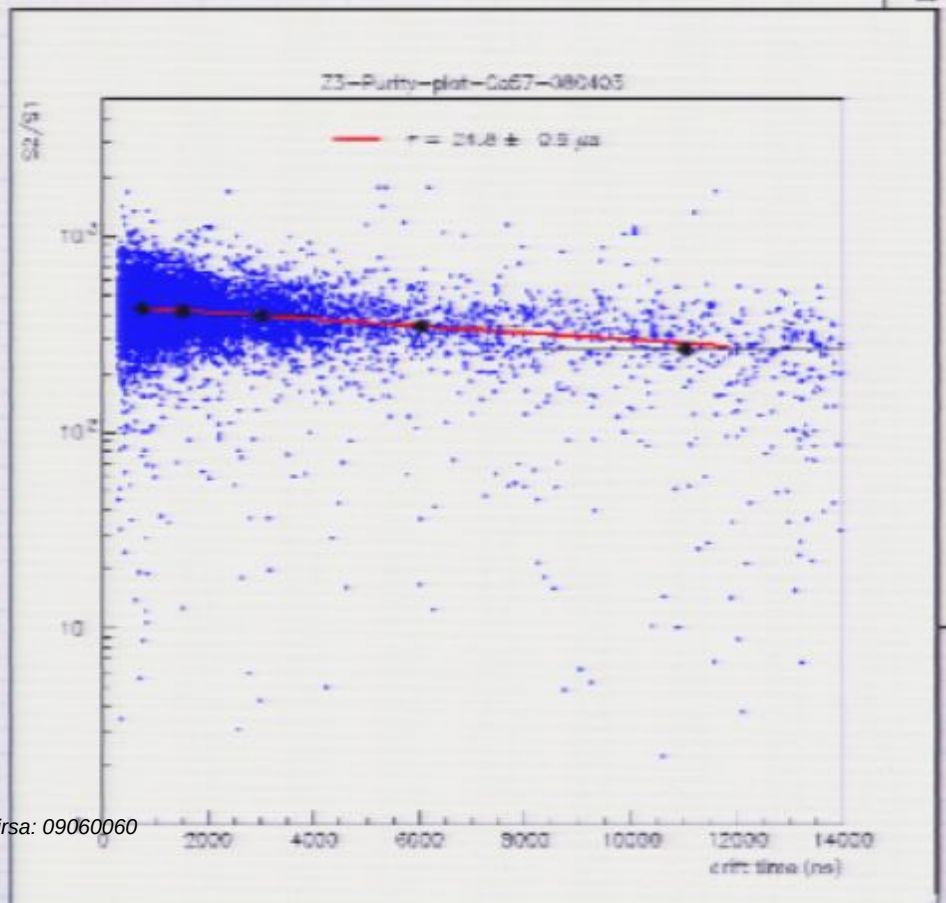

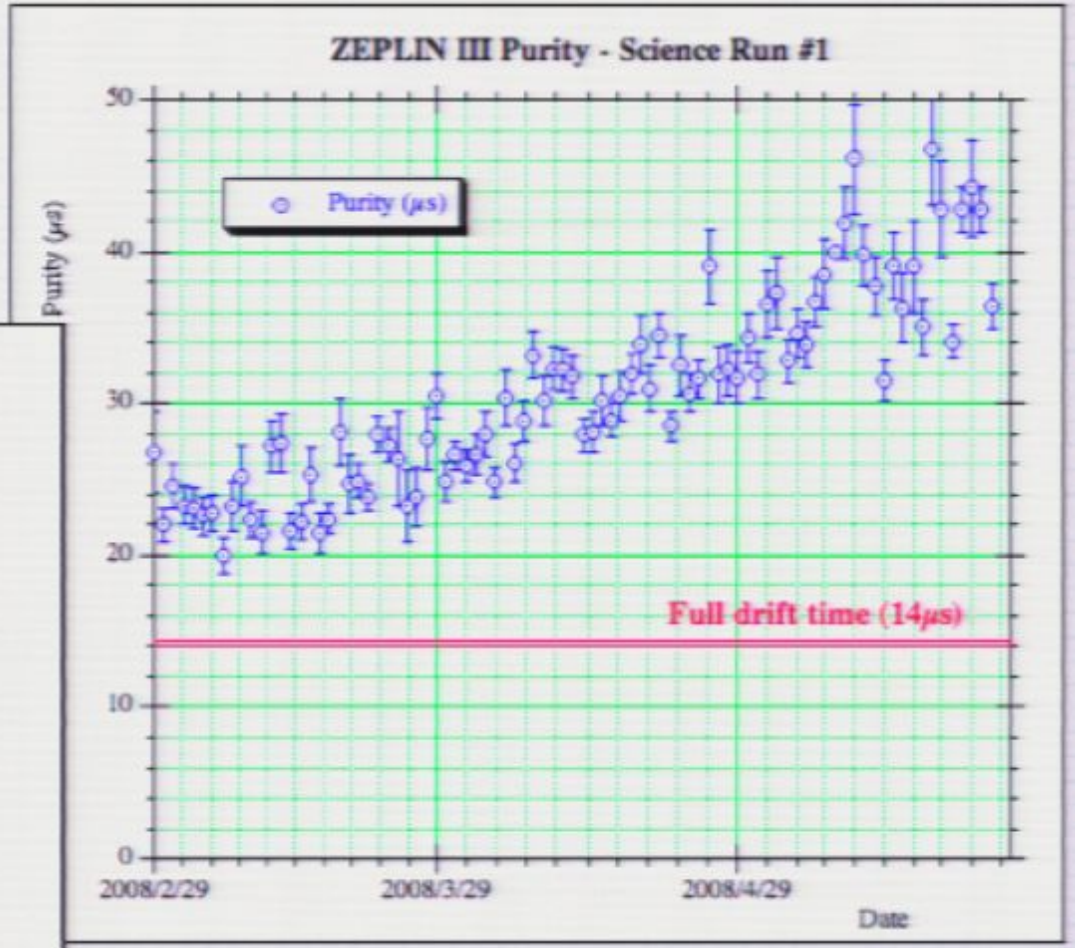

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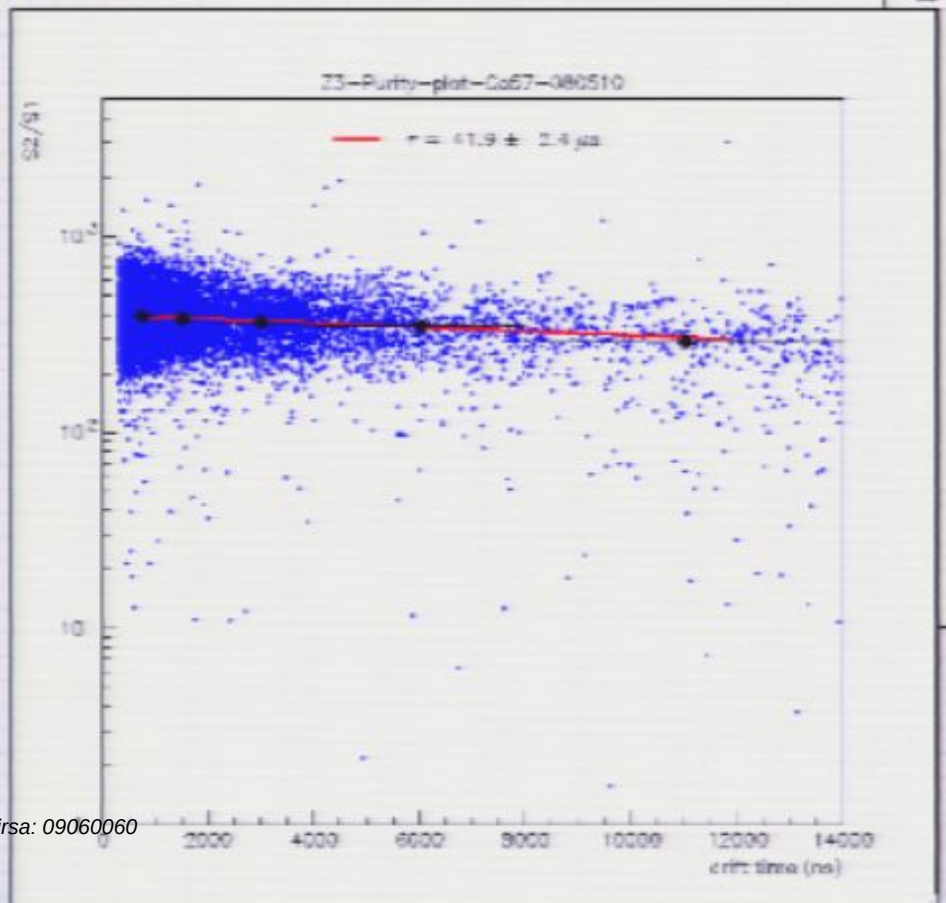

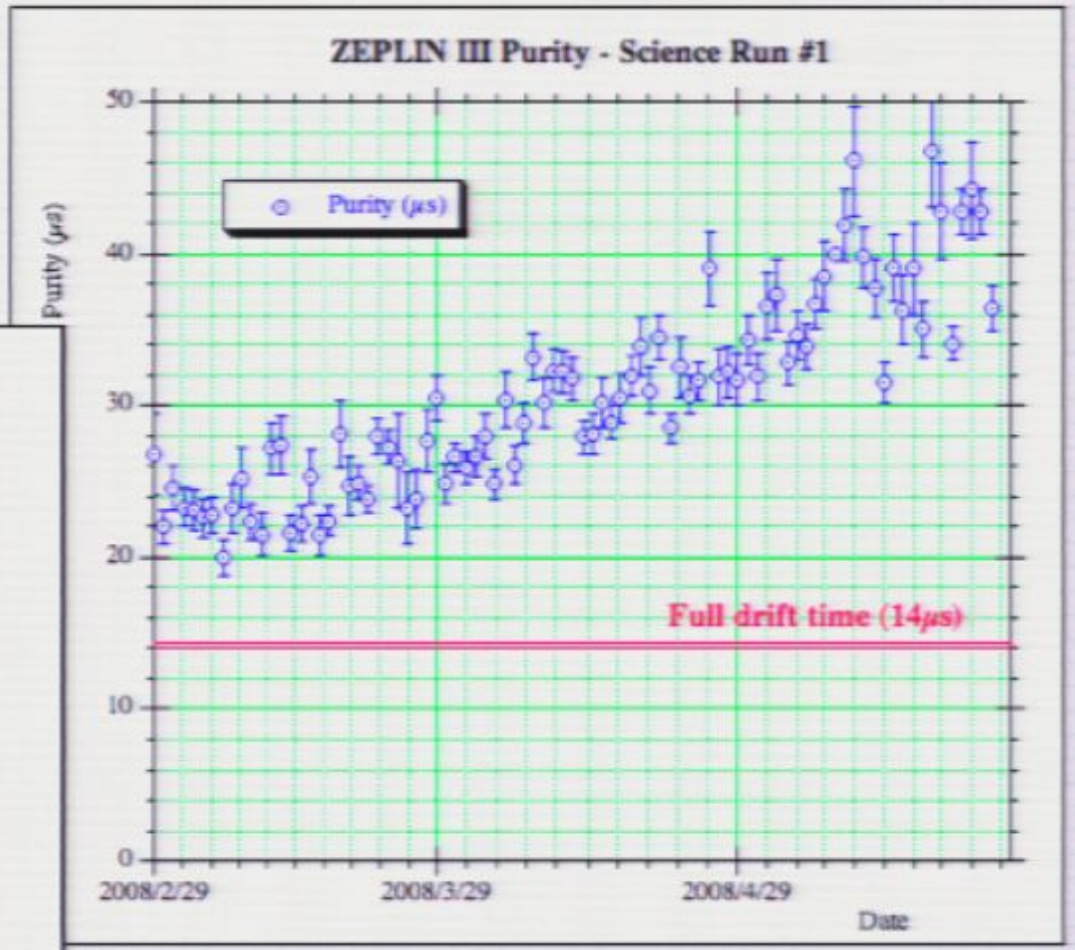

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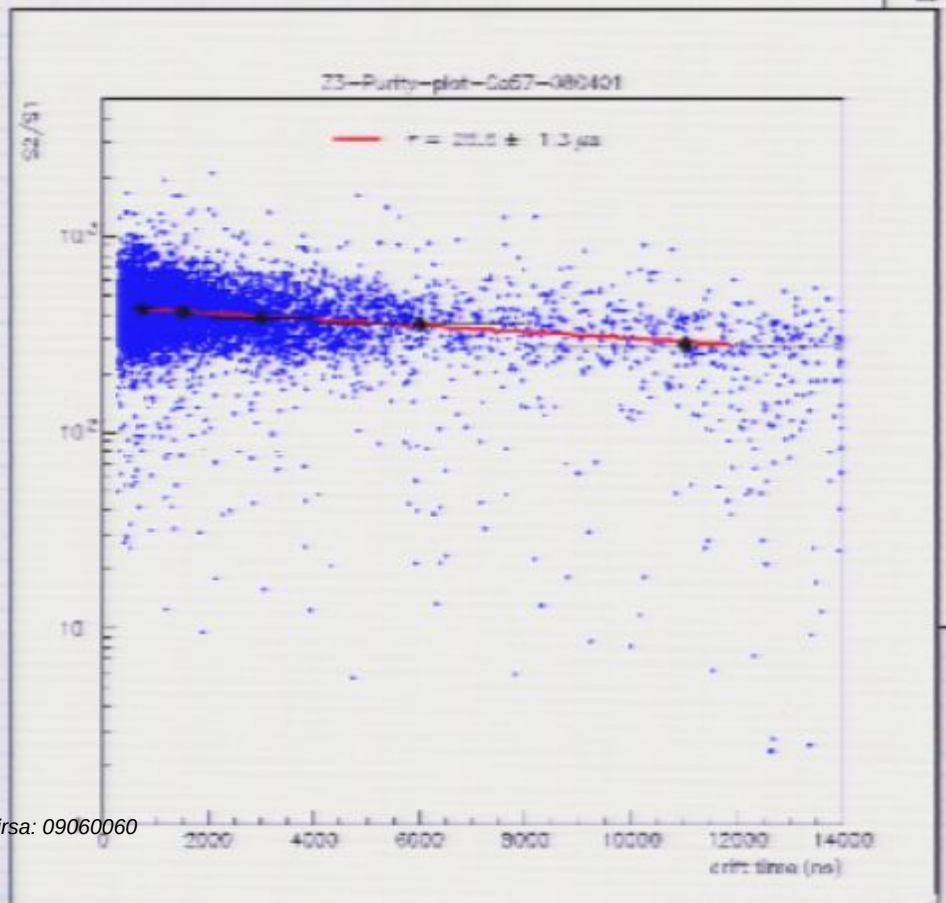
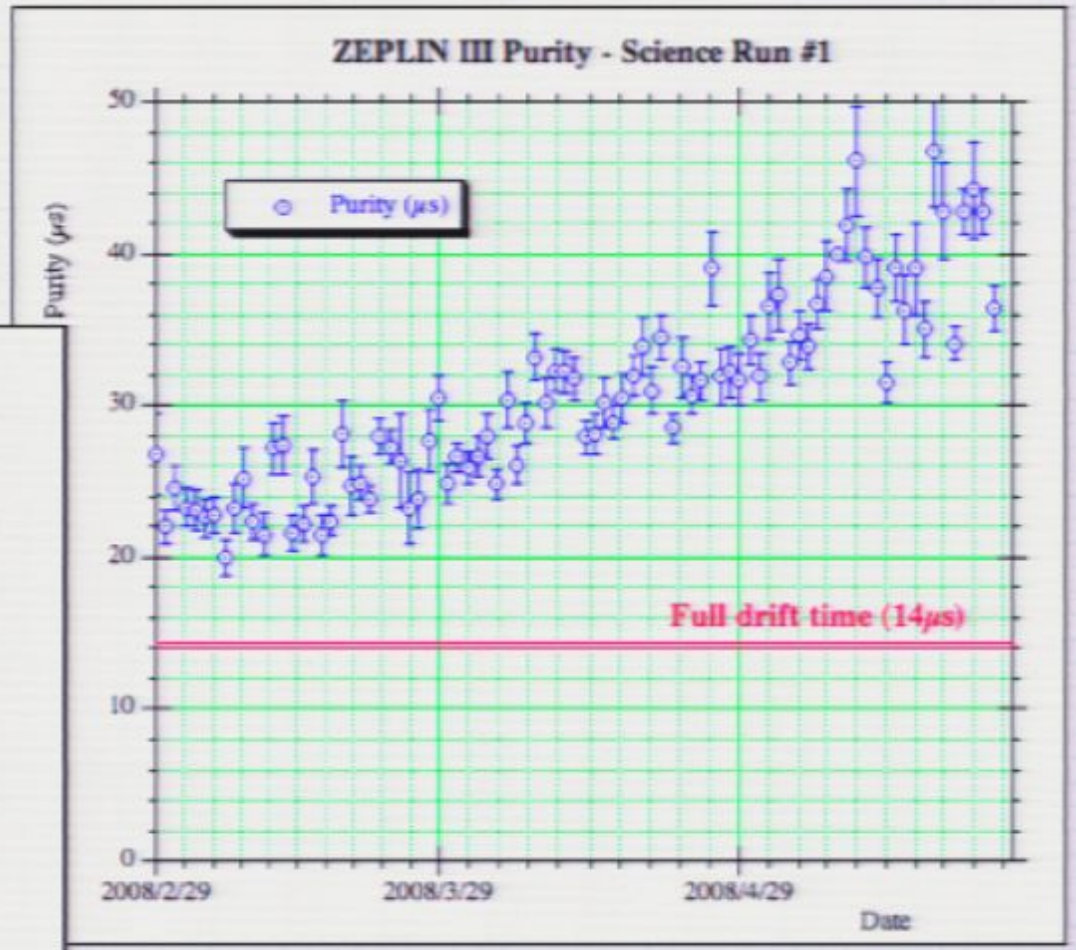
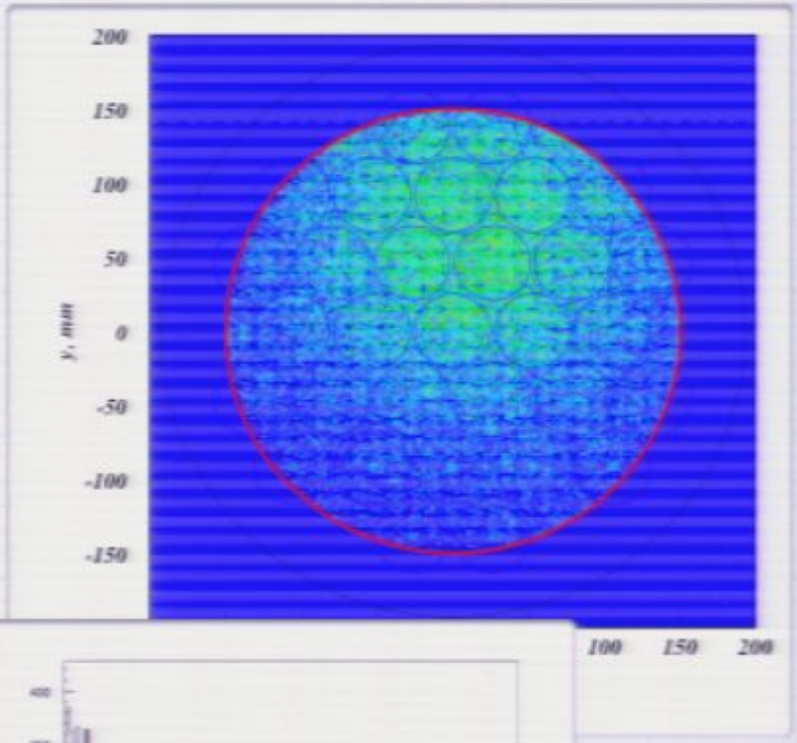


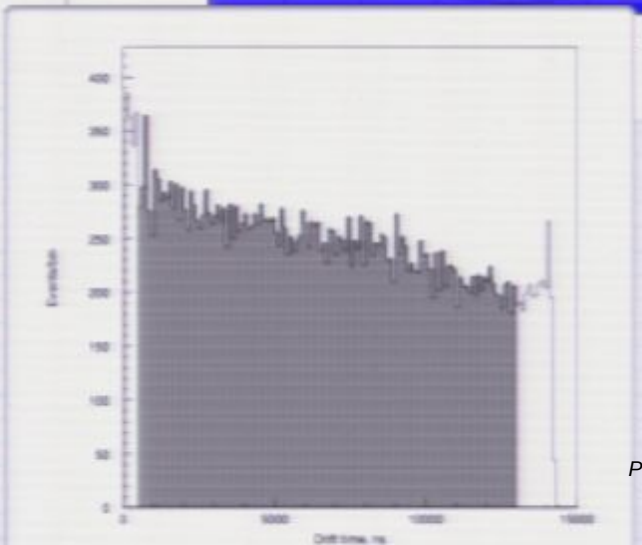


Fiducial volume

- Position reconstruction from drift time (z) and S1,S2 relative signals (x,y)
- Initial position from corrected centroid algorithm
- Final positions from
  - event template matching
  - least squares minimisation to response profile
- Defines fiducial volume with 150mm radius and 12.5µs drift
- Final fiducial exposure 453.6 kg.days

^{57}Co x,y reconstruction





Drift time cuts

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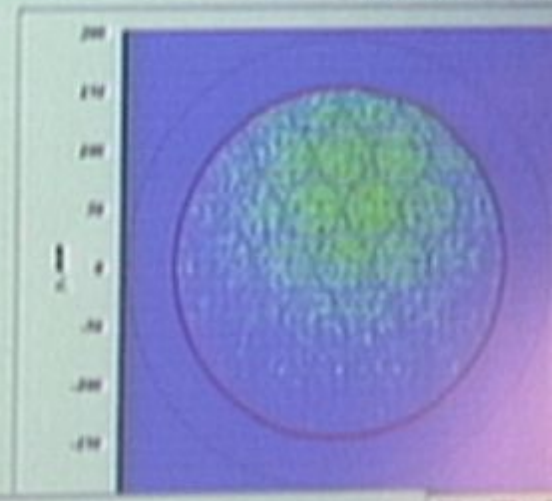

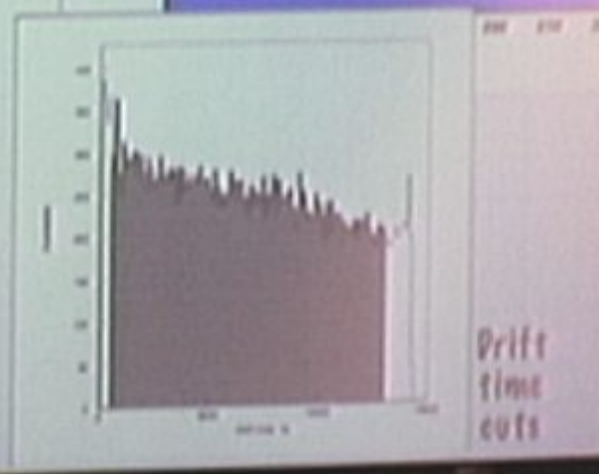

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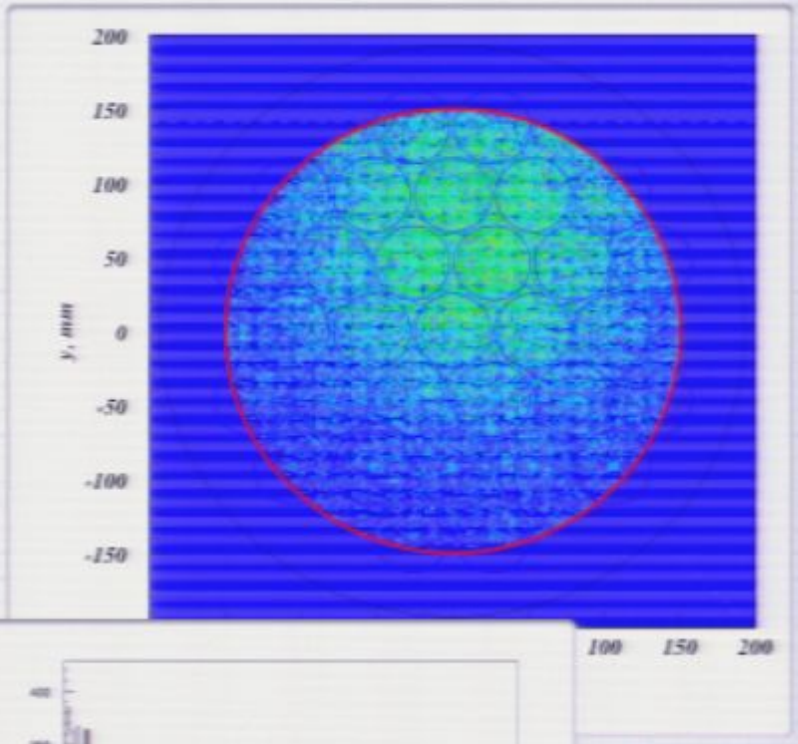
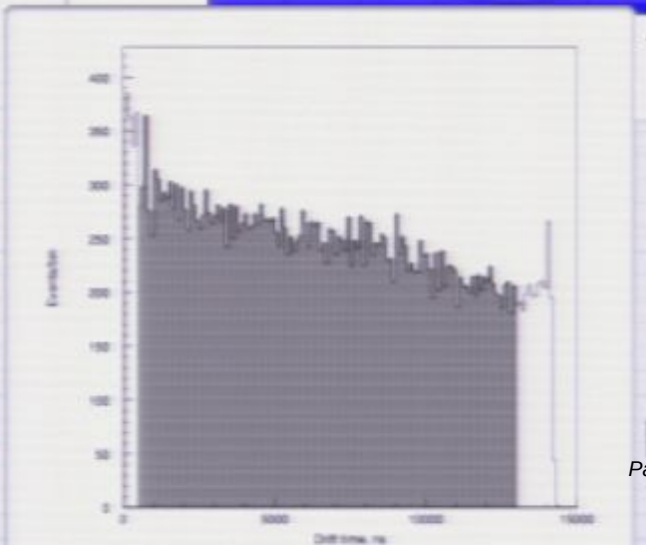


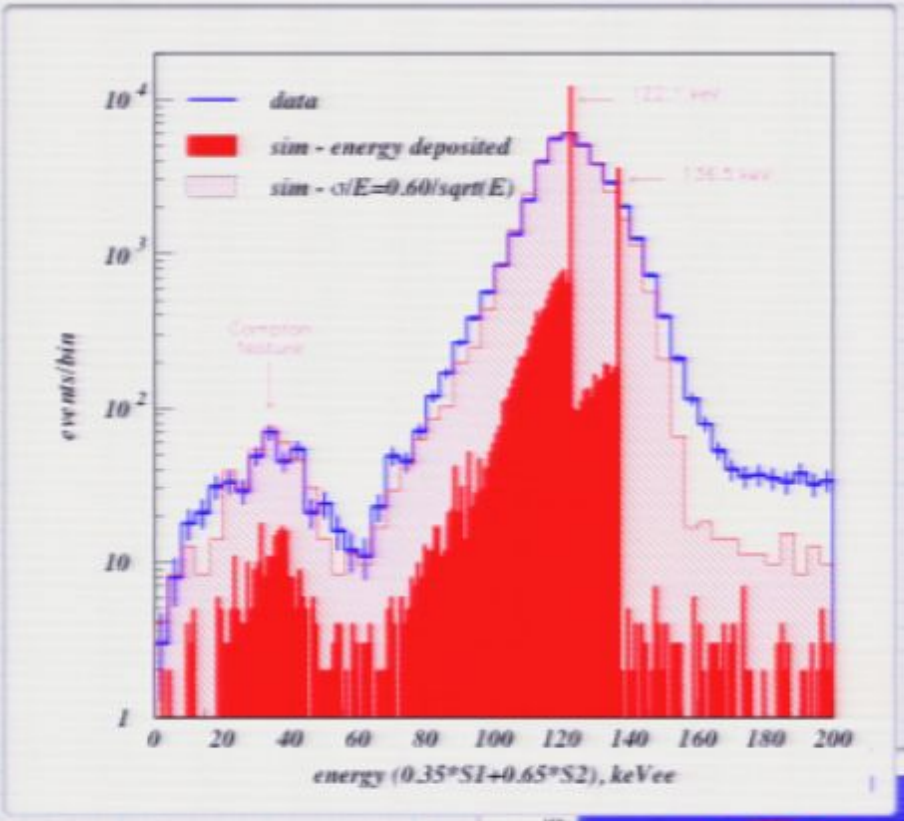


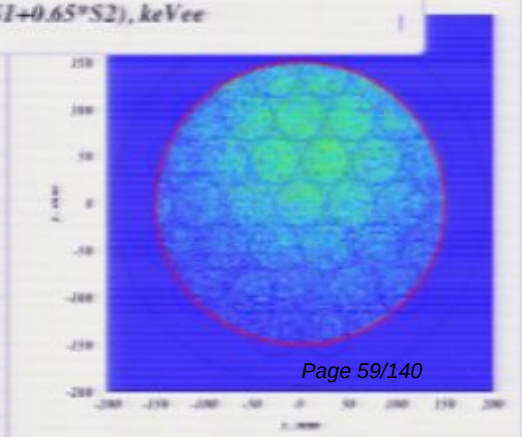
Drift time cuts

^{57}Co Calibration

- Daily ^{57}Co calibration for stability checks and scintillation response
- Light yield 1.8 p.e./keVee at operating field of 3.9kV/cm
- Full volume resolution (after flat fielding) of σ = 5.4%

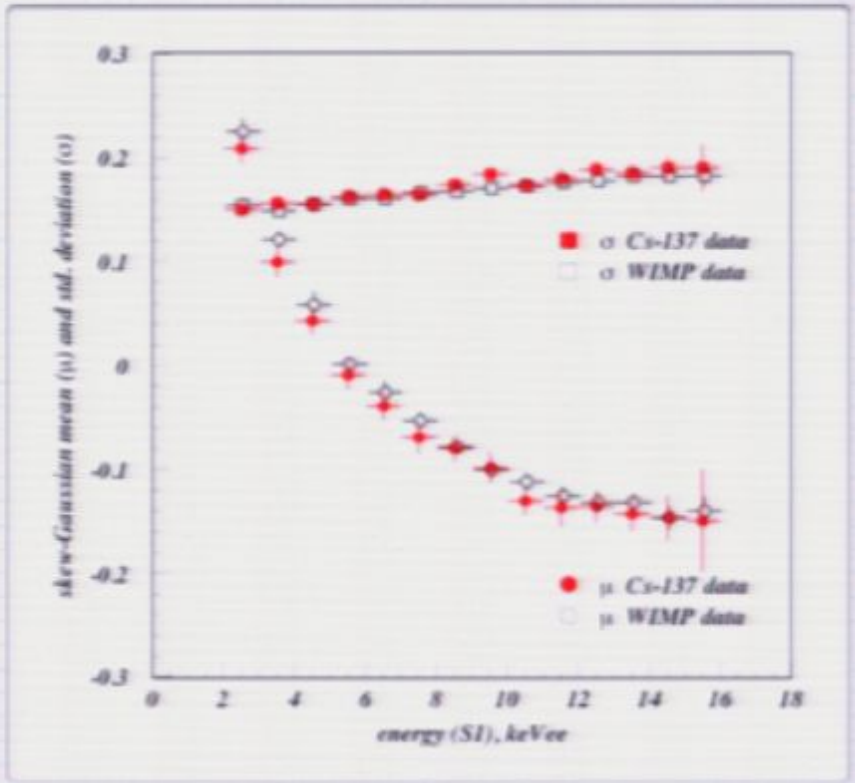
  @122keV in correlated signal
- S1 only σ = 16.3% @ 122keV
- S2 only σ = 8.8% @ 122keV
- Comparison to G4 simulation shows expected Compton feature at ~35keV





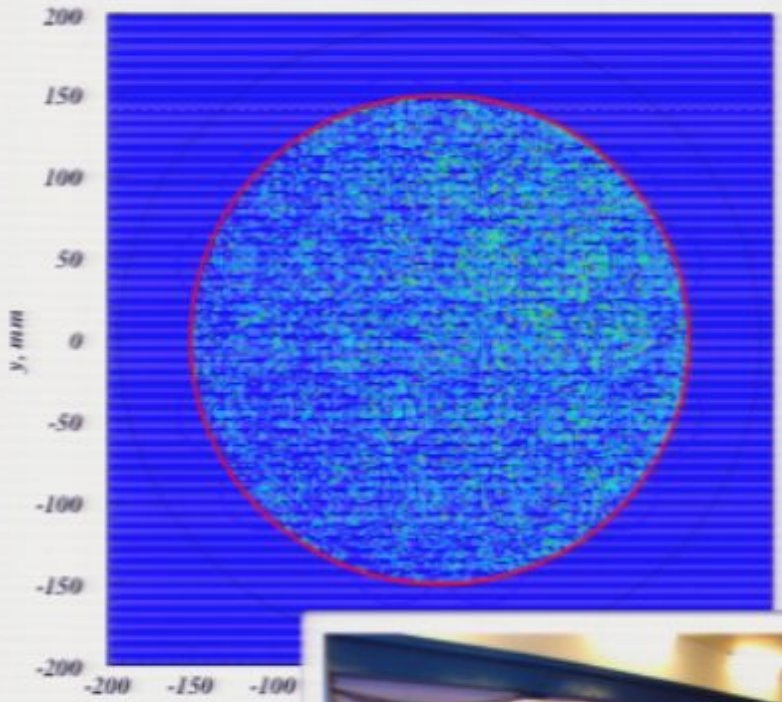
Compton Calibrations

- ^{137}Cs Calibration at run start and end
- Run end main calibration
  - 122 hours data
- Same analysis techniques applied
- Demonstrates good agreement between fit parameters for Compton gammas and FSR data
- Low S2/S1 tails showed enhanced population of MSSI 'living-dead' events
  - Double scatters, one in region without field - 2x S1, 1x S2
  - Used to refine rejection algorithms for these events
  - Gamma leakage defined from FSR data



Neutron Calibrations

- AmBe Calibrations at run start and run end
- Total calibration time ~5 hours
- Uniform x, y distribution, slight enhancement towards source position



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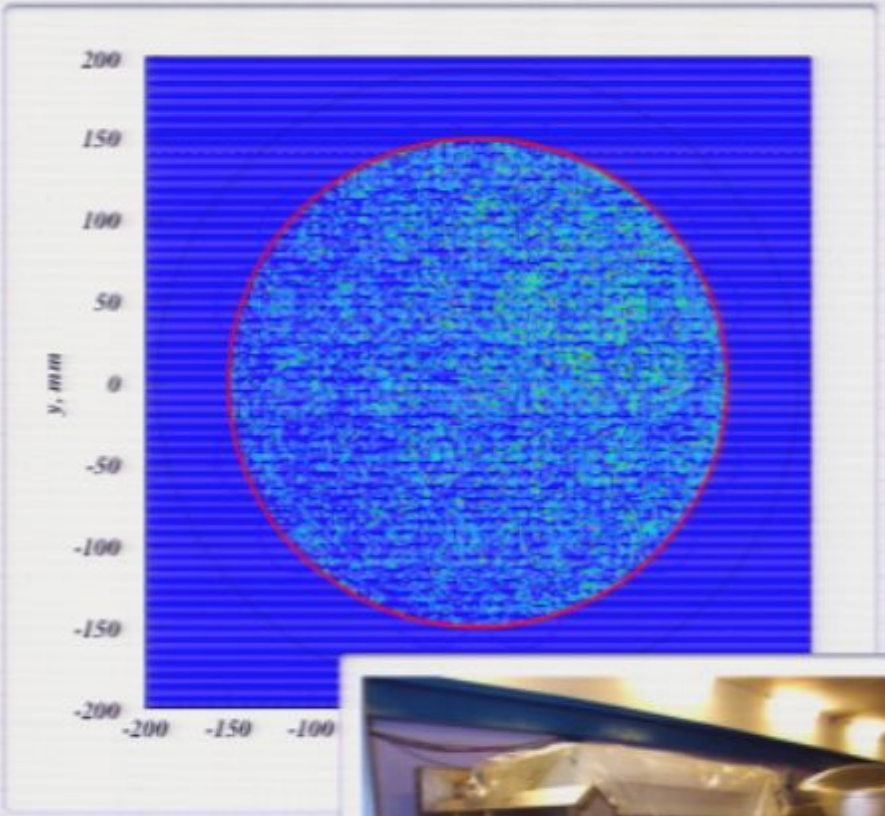

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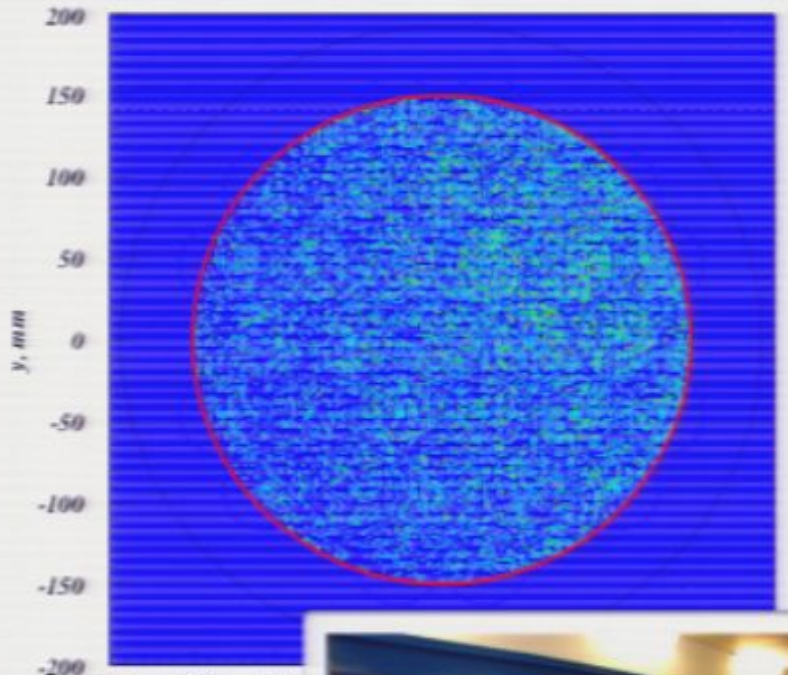

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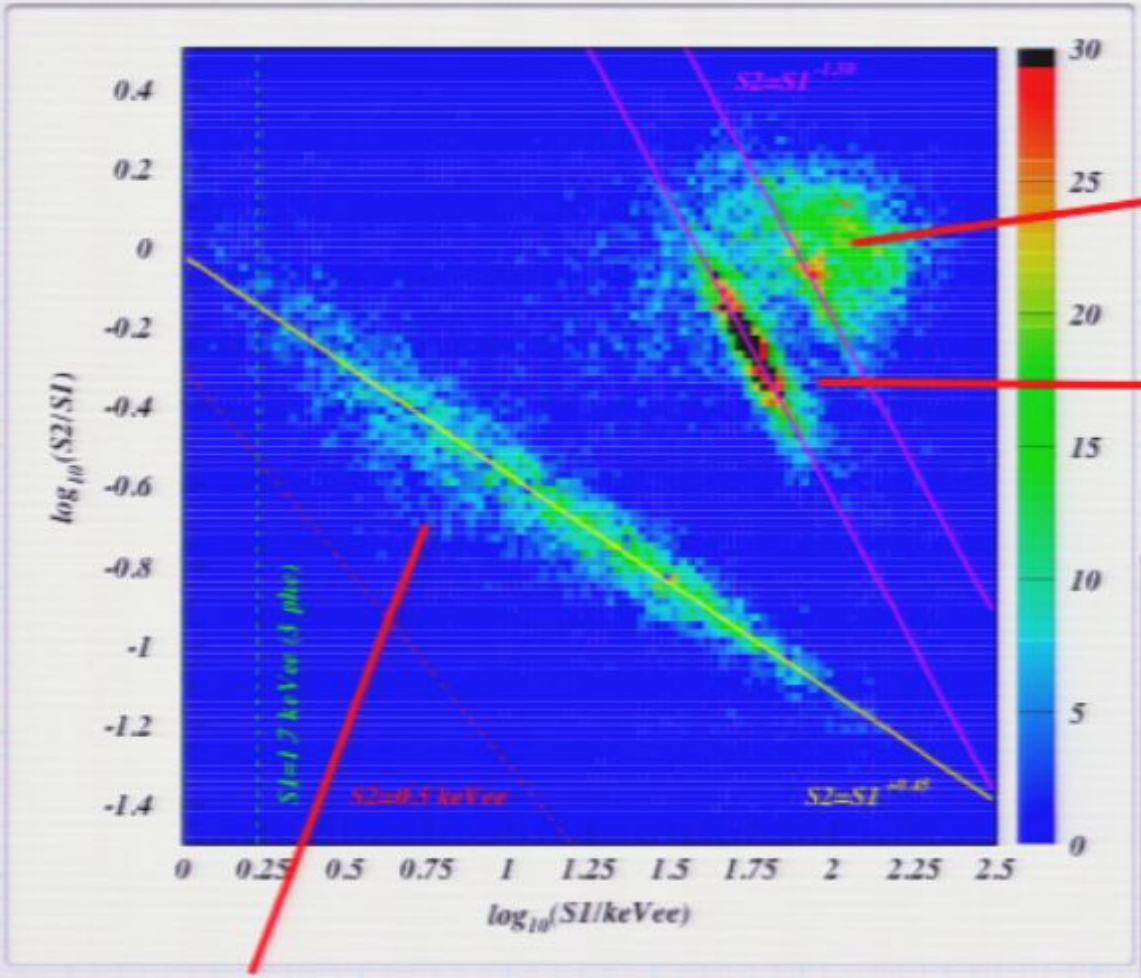
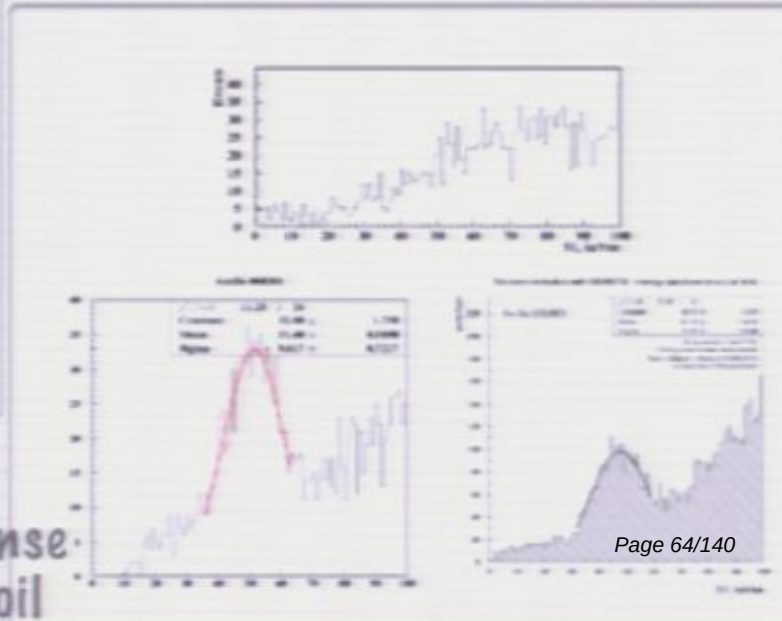


S1 & S2 thresholds shown

Gamma recoils

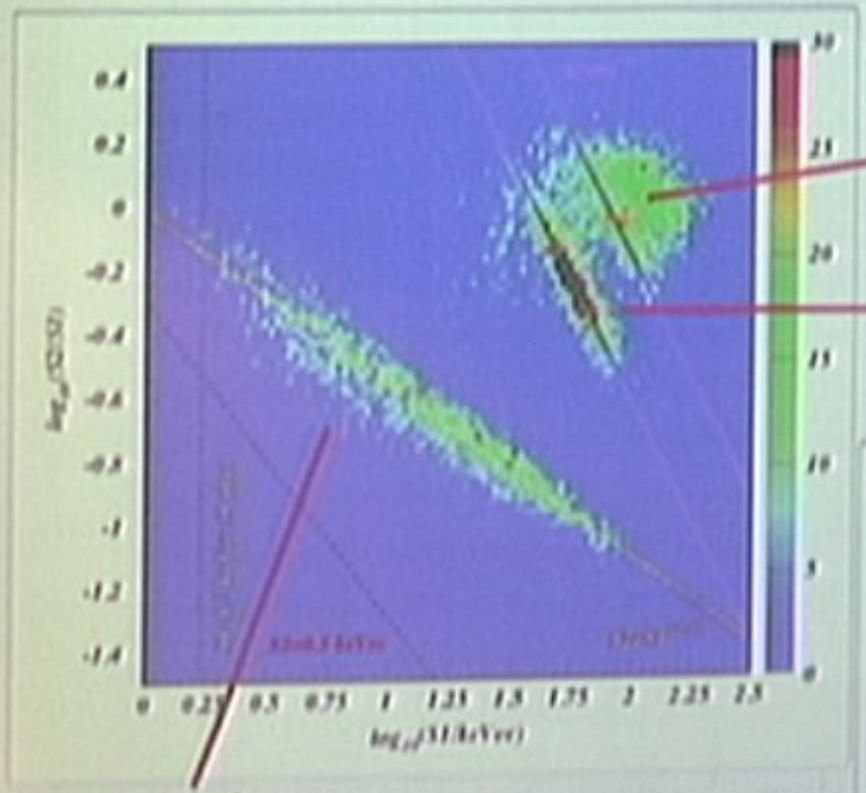
Inelastic recoils
(^{129}Xe)

Elastic nuclear recoils



S1, E* and simulated response for 40keV$_{ee}$ inelastic recoil

Neutron calibration



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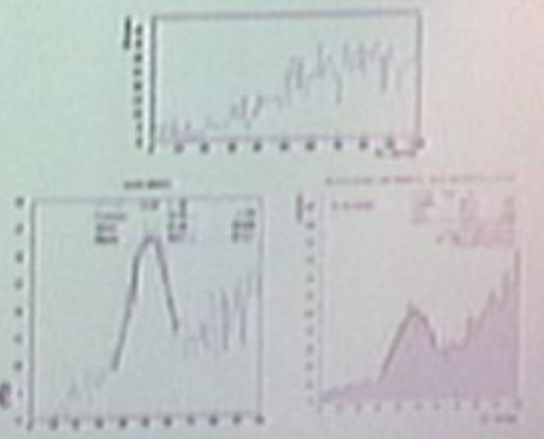

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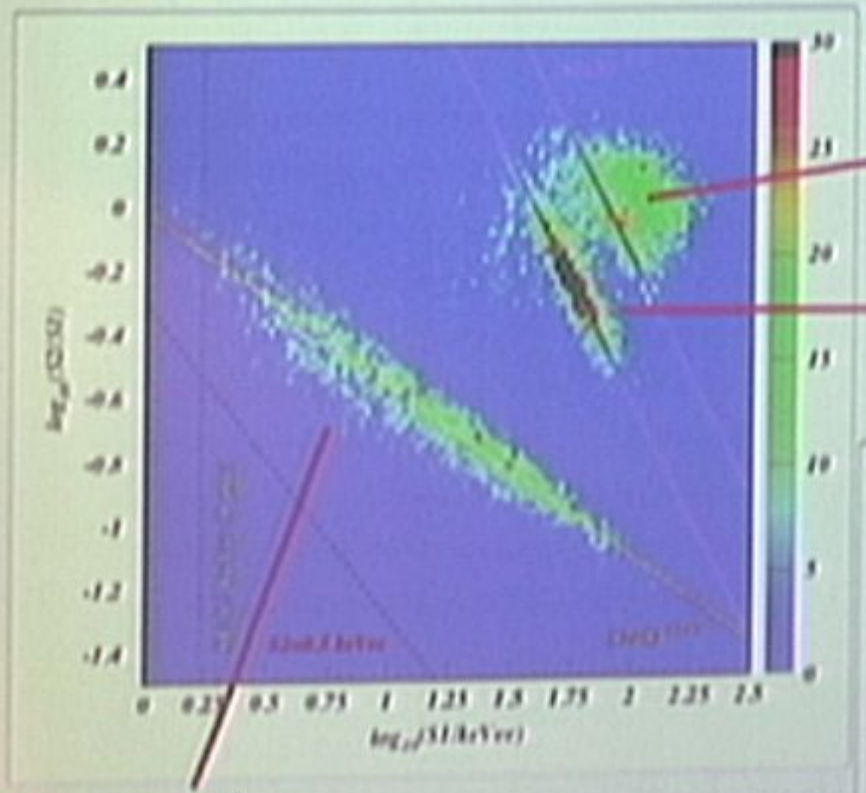

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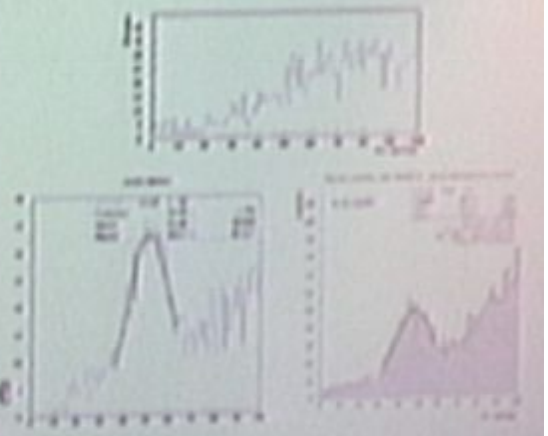

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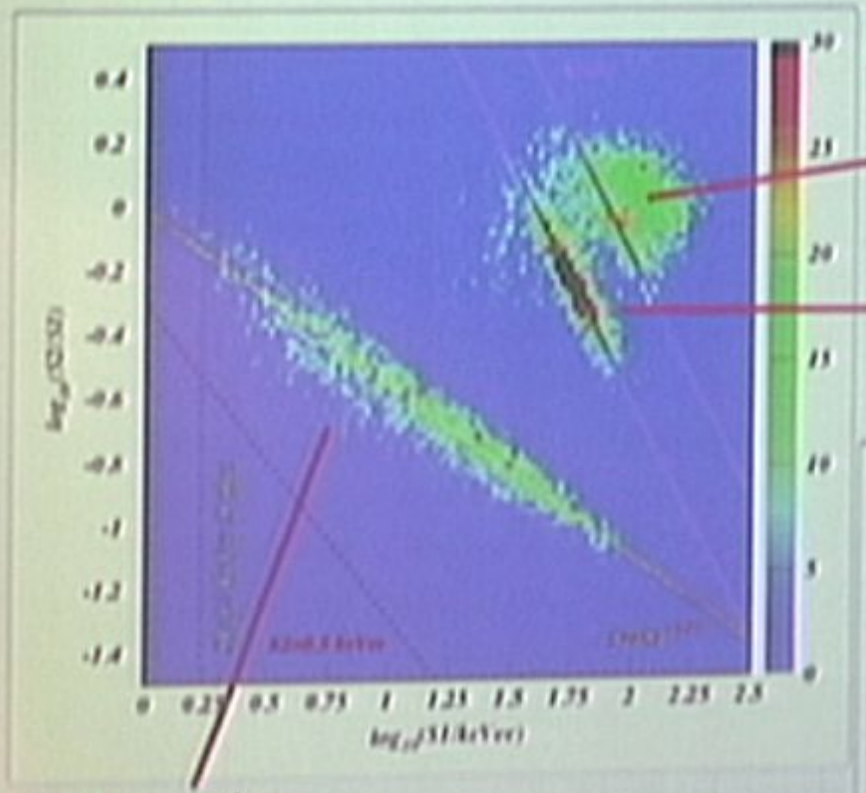

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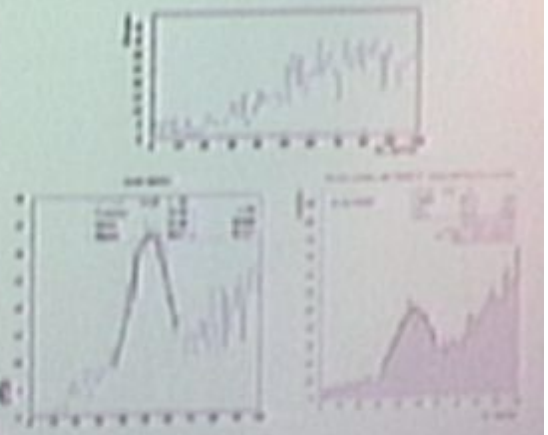

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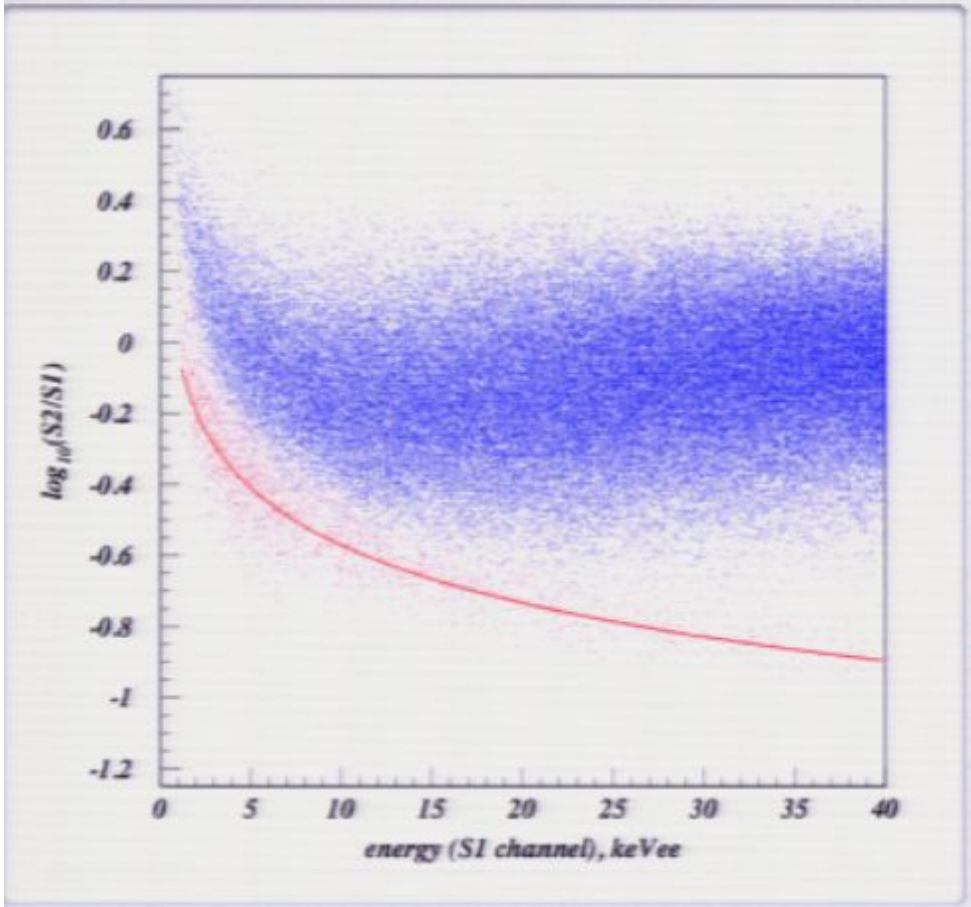
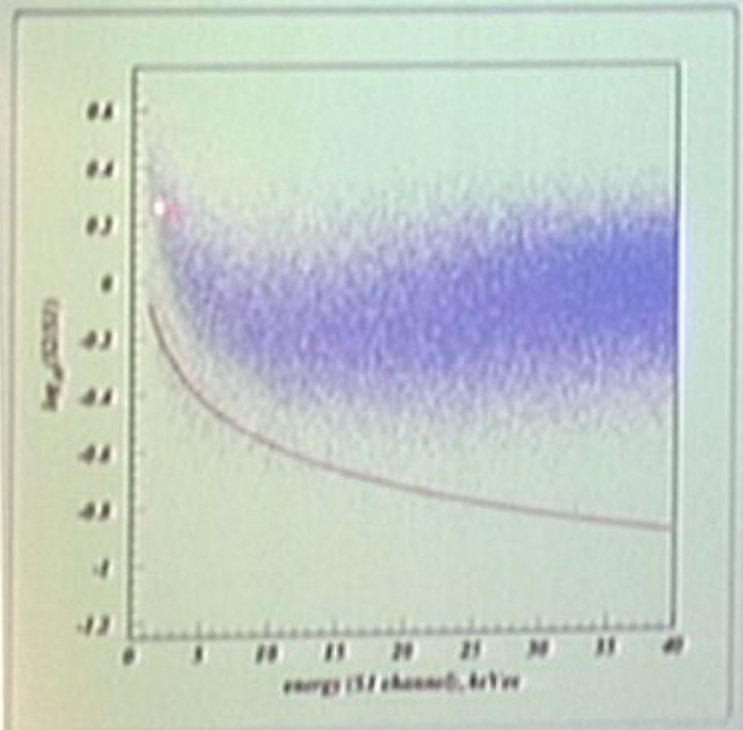
Discrimination Power



- Comparison of scatter plots for AmBe and ^{137}Cs datasets
- Plots show $\log_{10}(S2/S1)$
  - strictly, ratio of energy determination through S2 and S1
- Discrimination defined as leakage of gammas below 50% nuclear recoil line is ~ 10^3

Discrimination Power



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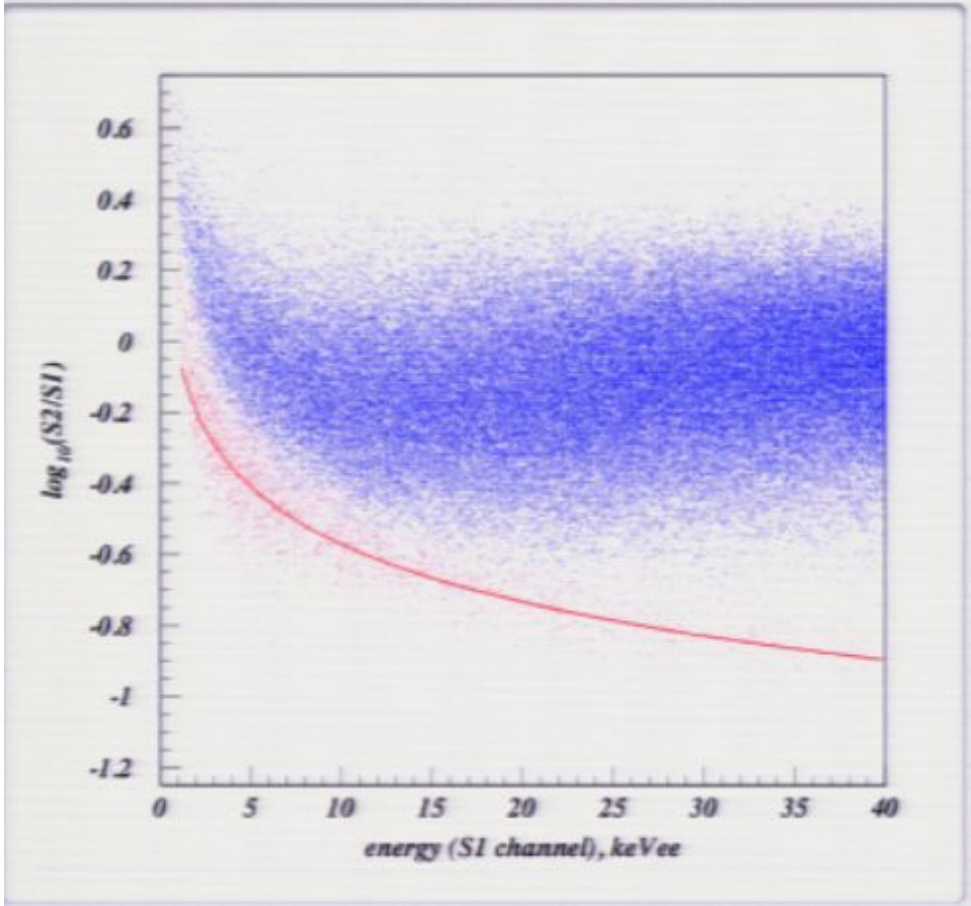
- Discrimination defined as leakage of gammas below 50% nuclear recoil line is ~ 10^3

Discrimination Power



- Comparison of scatter plots for AmBe and ^{137}Cs datasets
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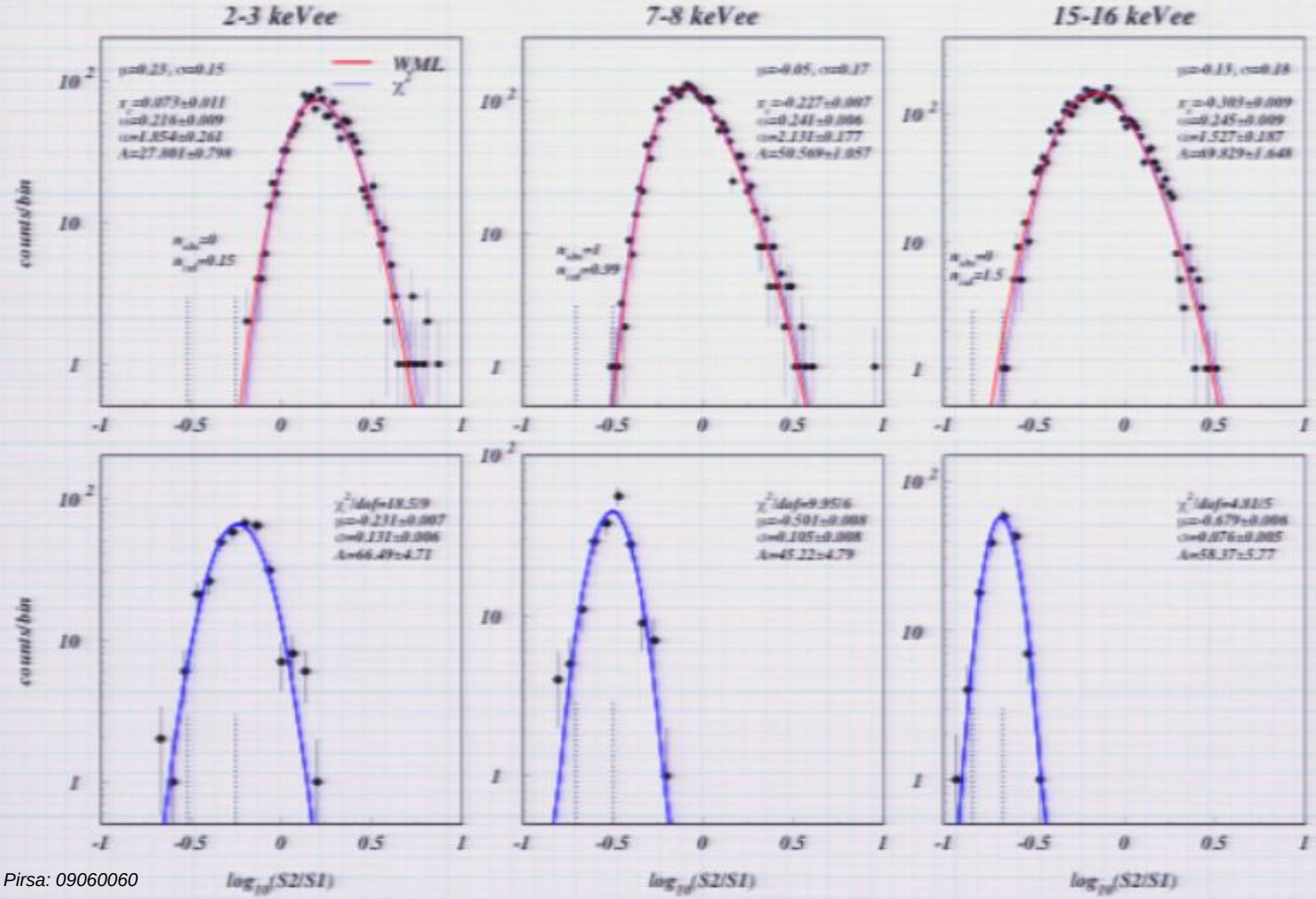

FSR Data

Neutron calibration

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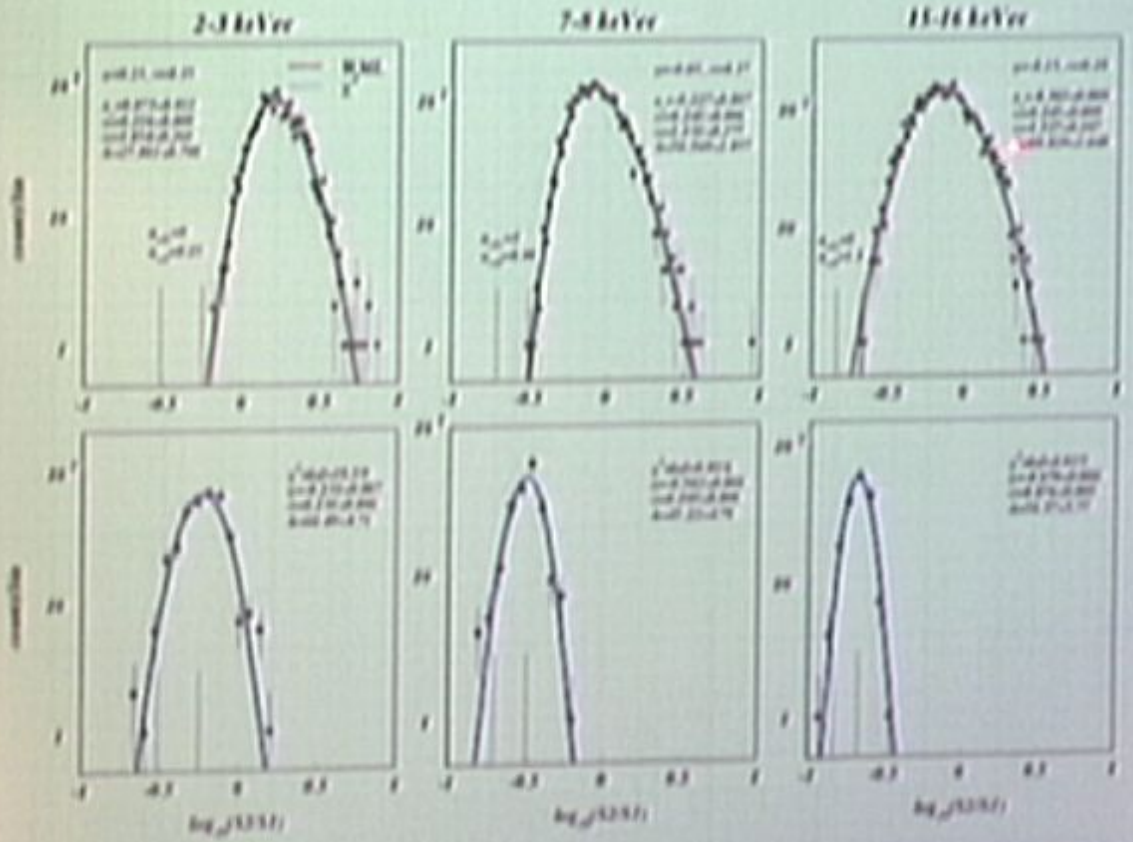

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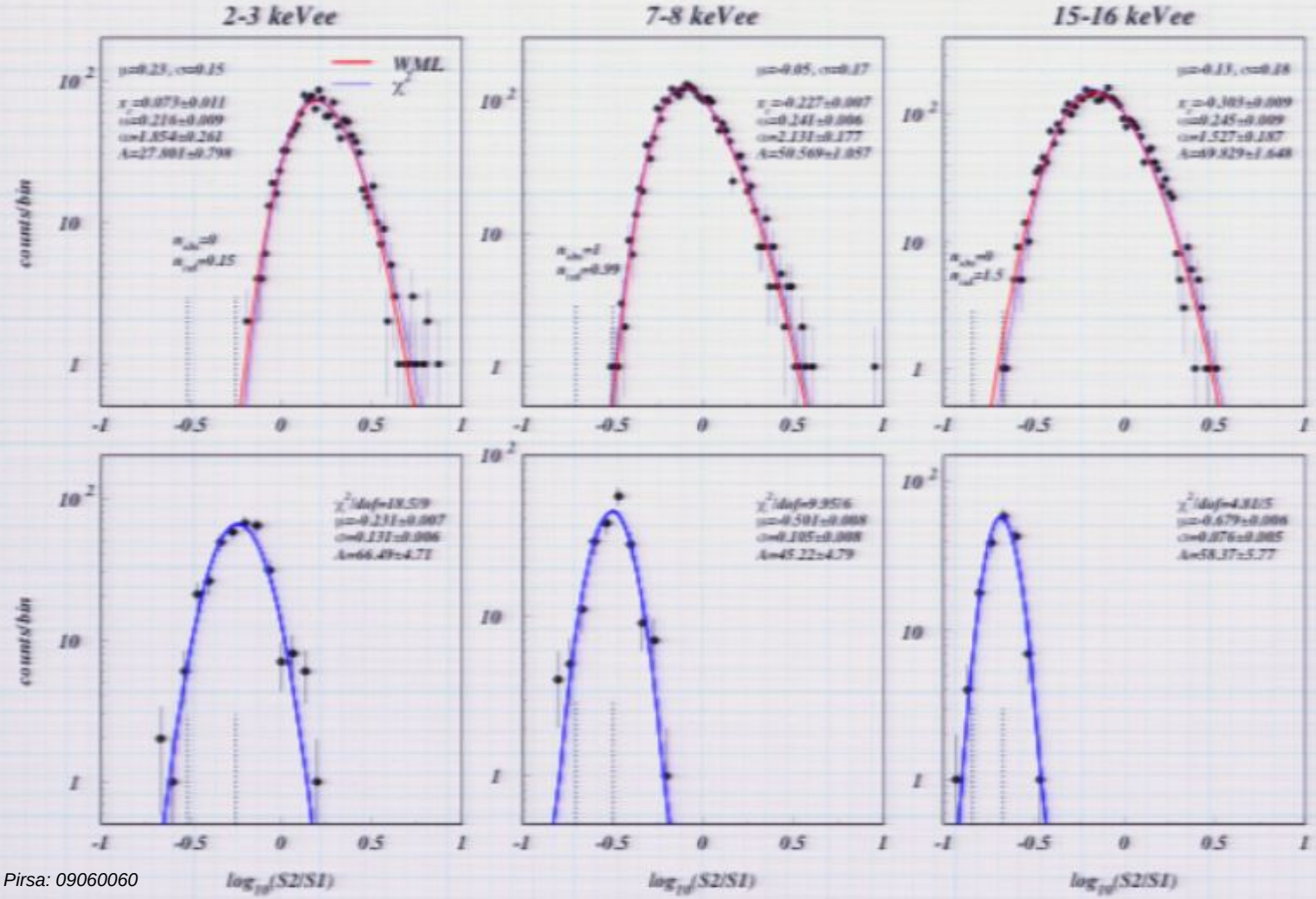

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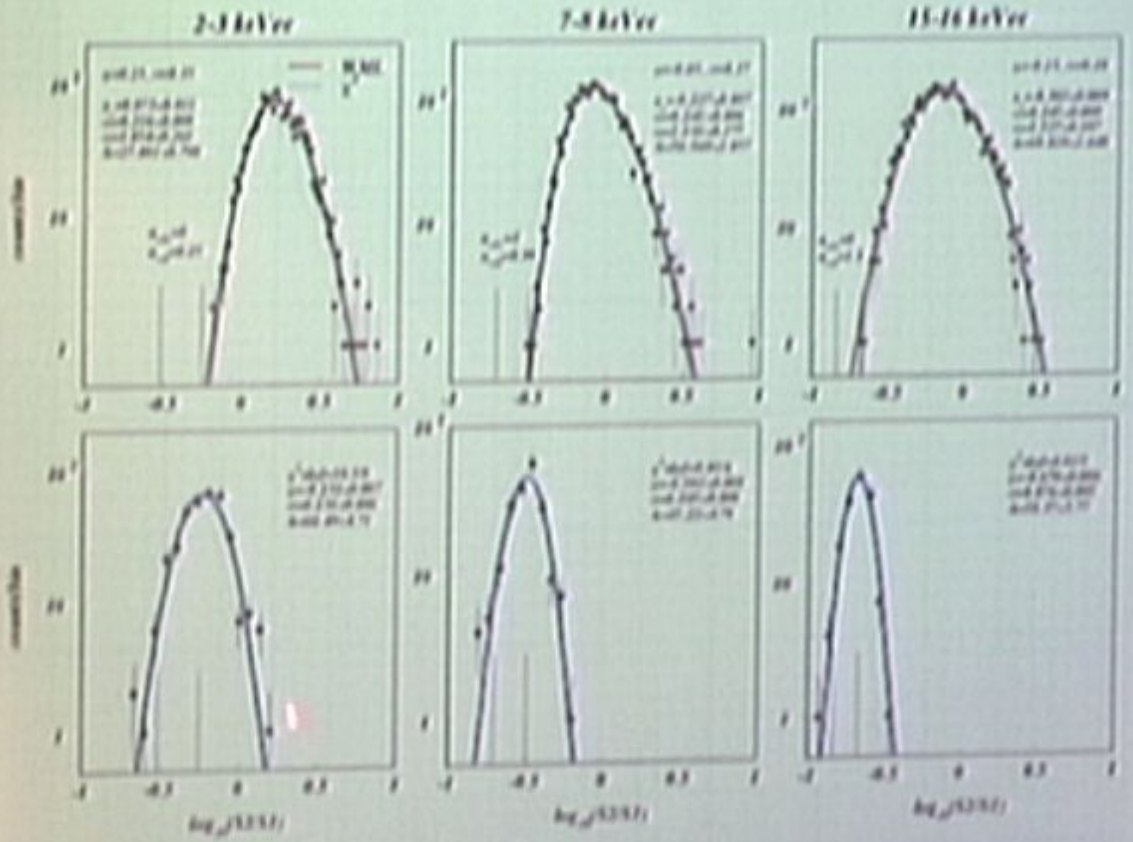

FSR Data

Neutron calibration

Defining the search box

- Energy defined between 2 and 16 keV_{ee}
- S2/S1 region is defined between mean of nuclear recoil band and -2 σ of n.r. band (blind)
- Selection cuts (partially blind)
  - 'Golden' event selection - one S1, one S2
  - Waveform quality cuts
  - Pulse quality cuts
  - Fiducial volume definition
  - Event quality cuts (to remove MSSI 'living-dead' events)
- Fiducial mass of 6.52kg, fiducial exposure of 453.6 kg.days
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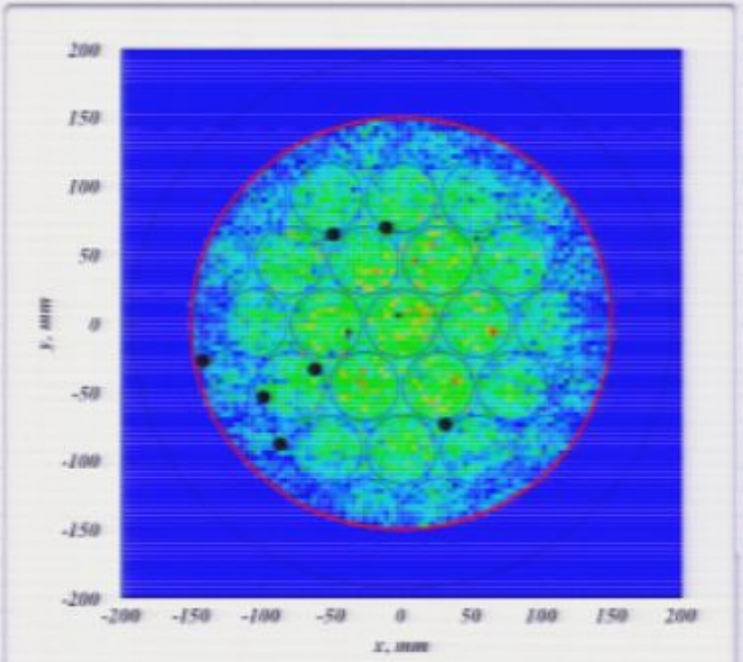
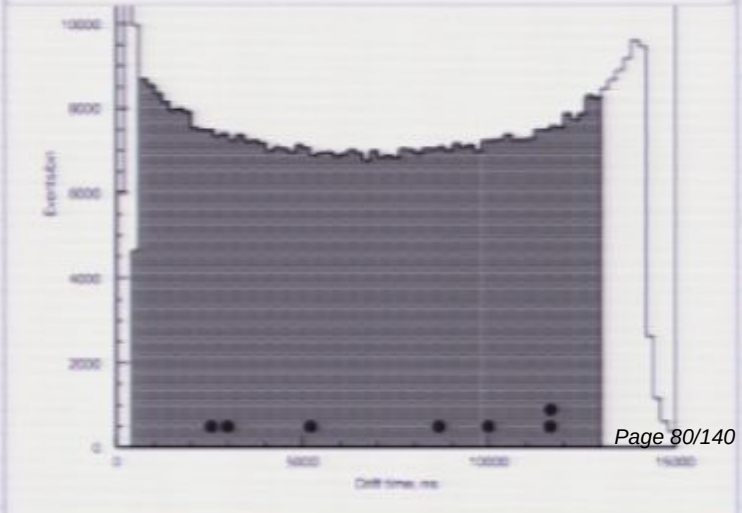
FSR Science Data

- 83 days operation @ 84% livetime
- Expect 1.2±0.6 neutron events (from PMTs) within this dataset
- Golden rule for selection is to extract single scatter events
- Secondary selection rules on event topology (S1, S2) to remove 'living-dead' events
- 7 Events within search box observed, extrapolation from leakage fits gives 11.3±3.0 expected
- No systematics in spatial or temporal distributions





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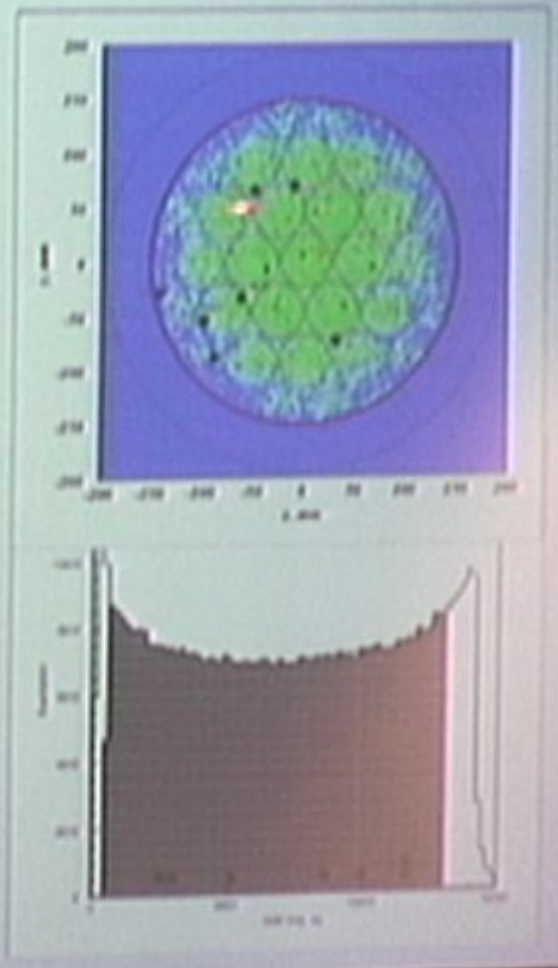

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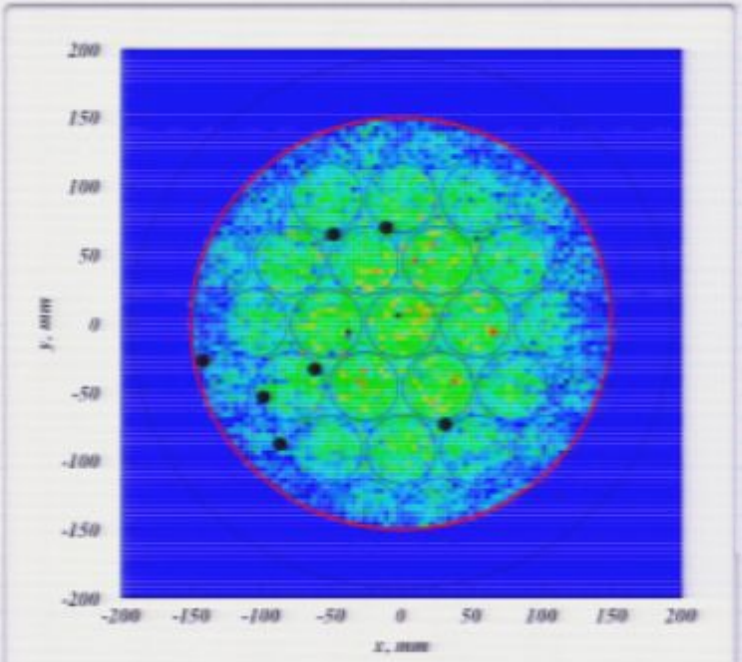
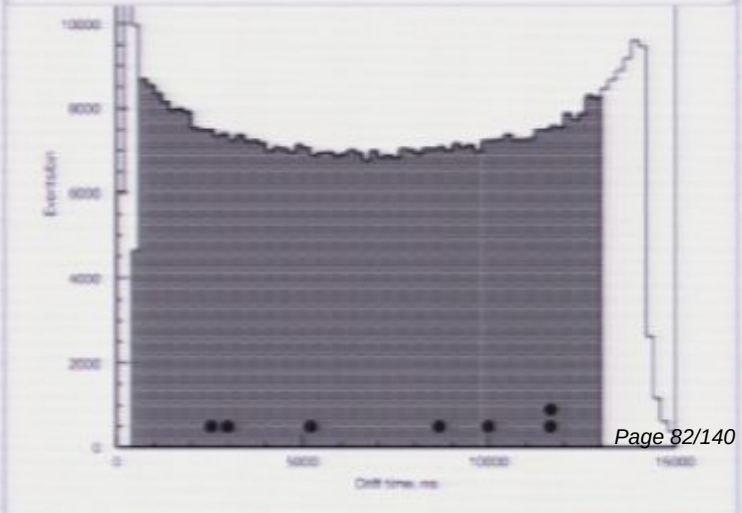
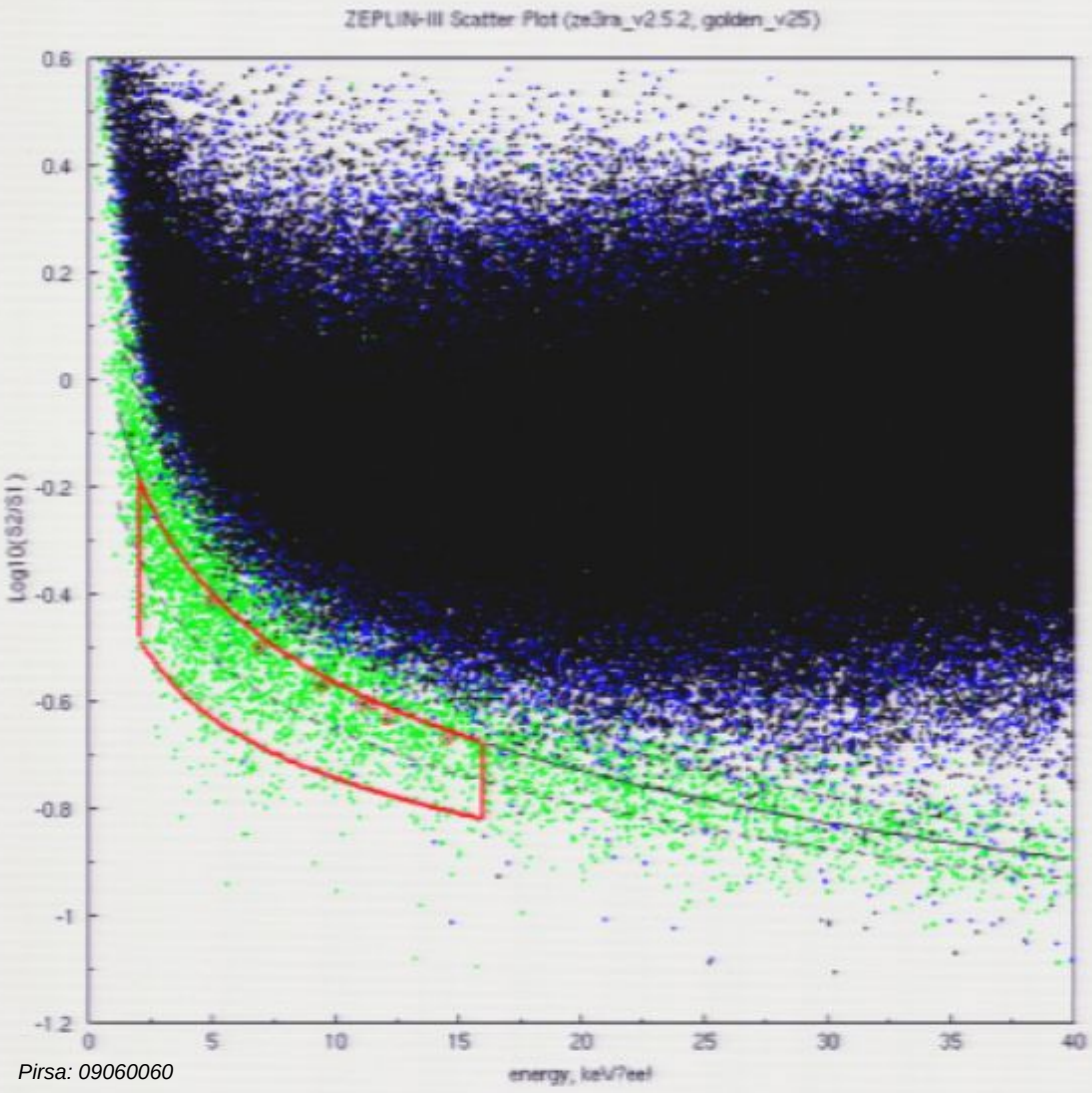




Data Transforms



- Blue - ^{137}Cs
- Green - AmBe
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- $\log_{10}(S2/S1)$ vs $Energy_{e.e.}$
- Strictly ordinate is $\log_{10}(E_{S2}/E_{S1})$

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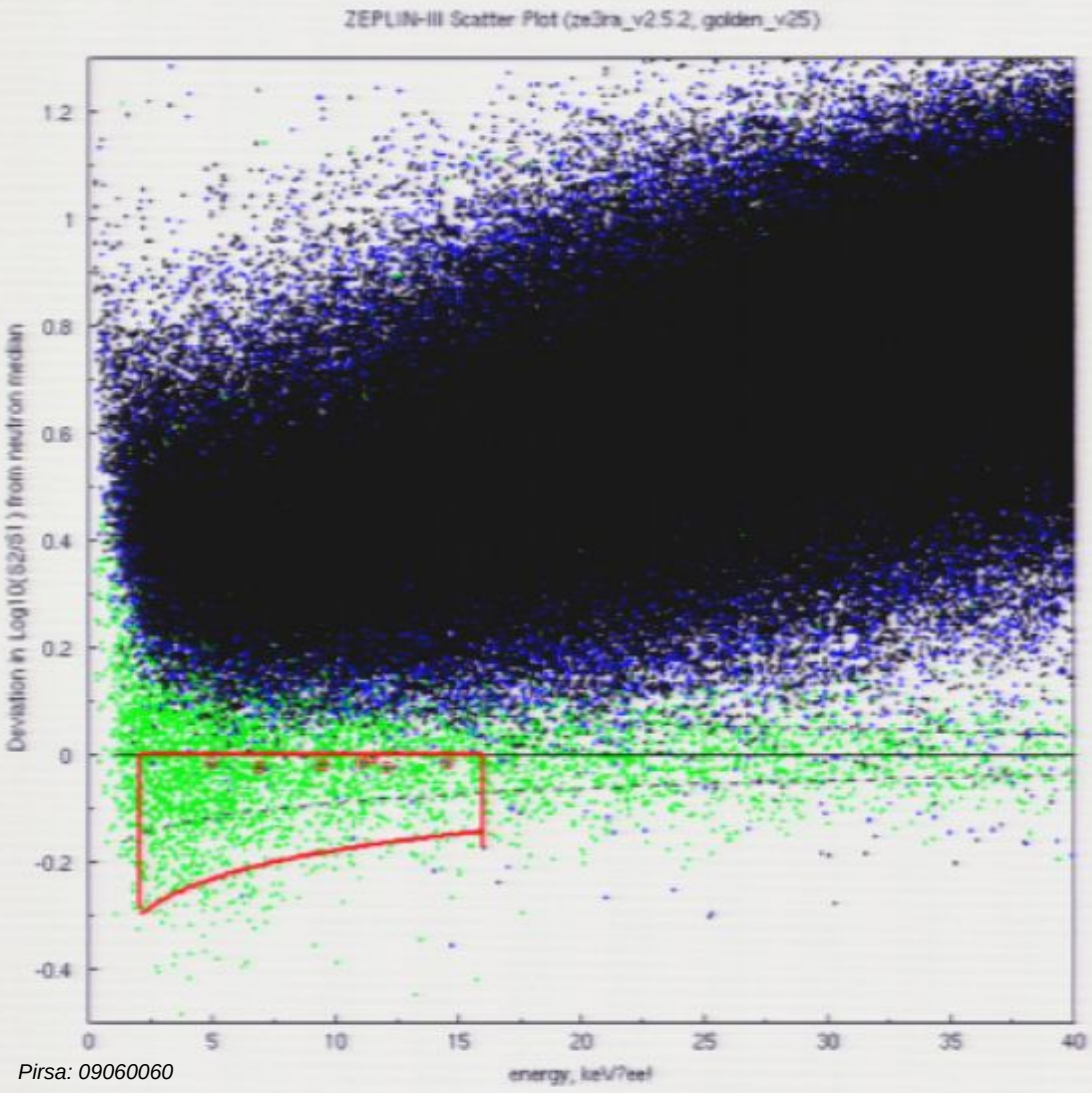

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- Deviation from mean neutron $\log_{10}(S2/S1)$ vs $Energy_{e.e.}$
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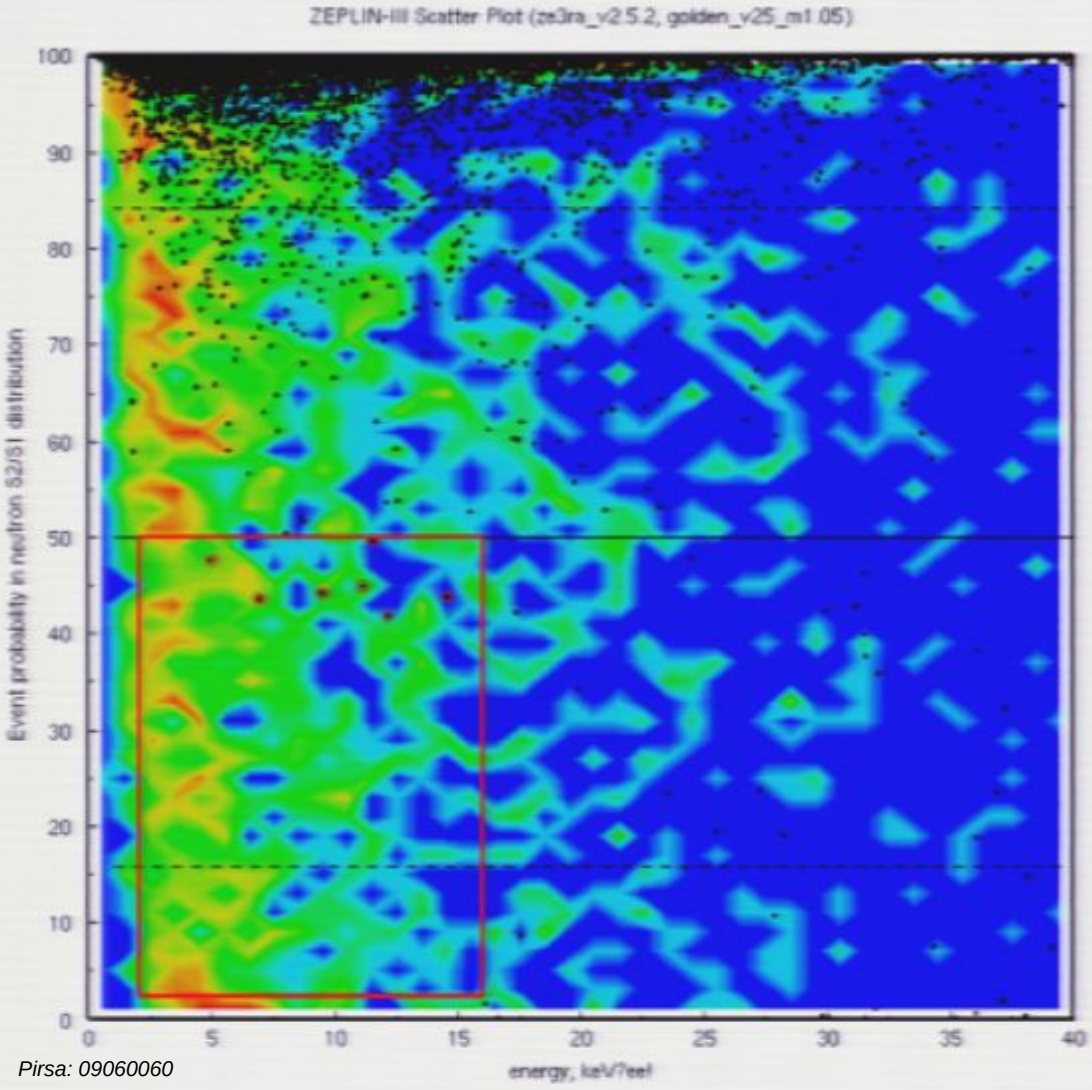

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- Event nuclear recoil probability vs Energy$_{e.e.}$
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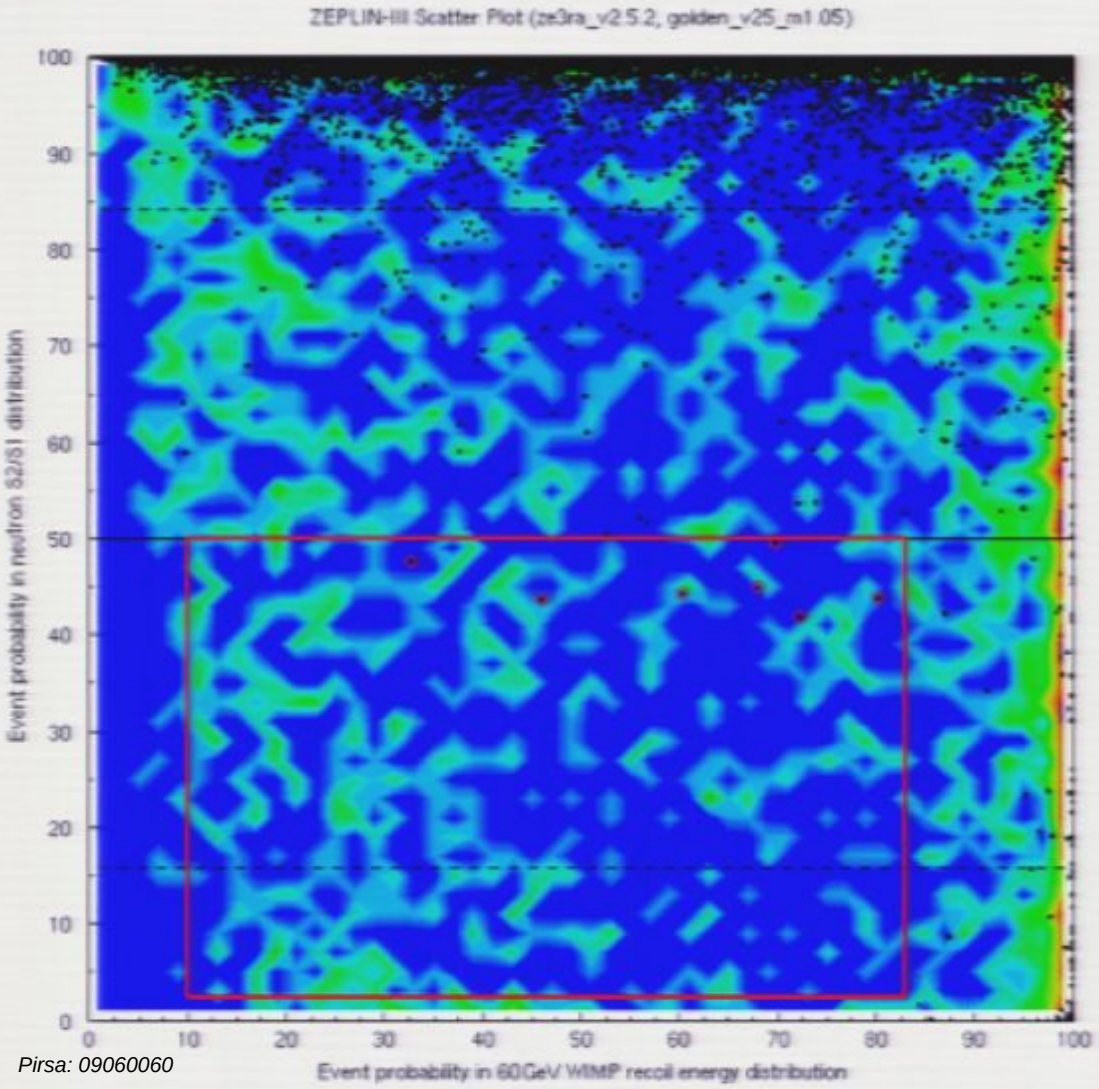

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- Event nuclear recoil probability vs probability in 60GeV WIMP recoil spectrum
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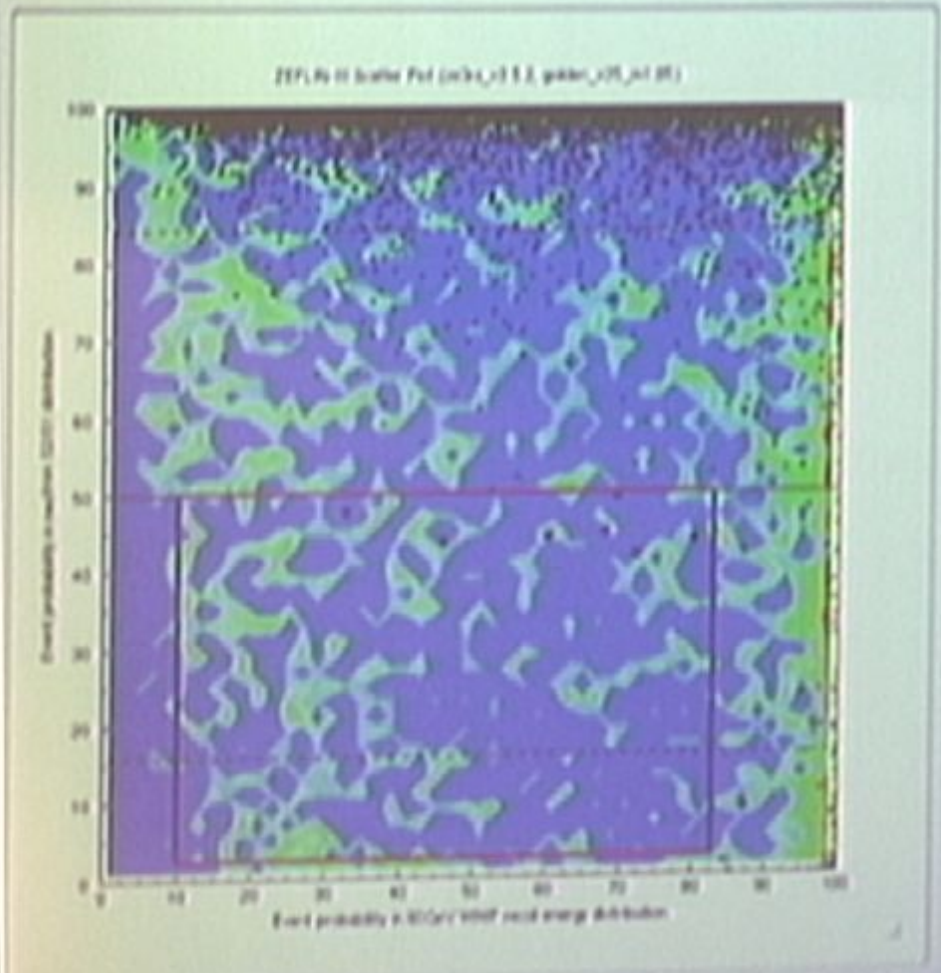

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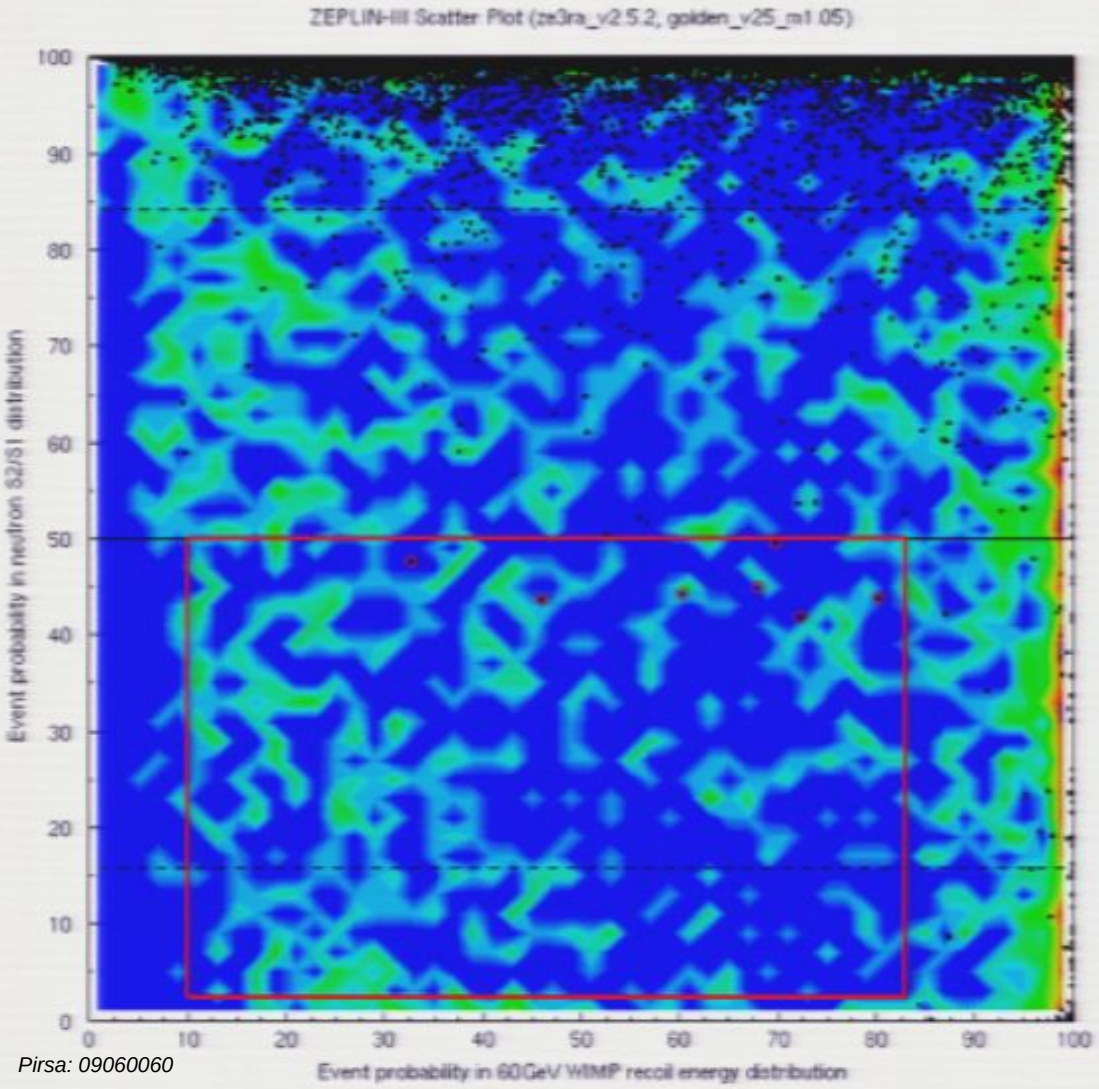

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Trigger & Efficiencies

- Efficiencies calculated from a variety of sources
  - Data scanning
  - Direct calculations
  - Hardware studies and tests
- S1 trigger (3-fold) determined at 1.7 keV_{ee}
- S2 trigger (11 electrons) at 0.2 keV_{nr}

Energy-independent efficiencies		
Effect	Efficiency	Method of calculation
Deadtime	91.7%	Measured
Hardware saturation cut	100%	On-Off comparison
ZE3RA pulse finding	96.0%	Event scanning
Event reconstruction	91.9%	Event scanning
Living-dead cuts	73.0%	On-Off comparison
WIMP-box acceptance	47.7%	

Energy-dependent efficiencies		
Effect	Threshold	Method of calculation
Hardware trigger	< 1 keV_{ee}	Additional dataset Event scanning Pulser measurements
Software S2 criteria	< 1 keV_{ee}	Calculation Scatter plots
Software S1 3-fold requirement	1.7 keV_{ee}	Calculation Scatter plots

Low energy scale - L_{eff}

- Mis-match observed between nuclear recoil calibration (AmBe) and G4 simulation
- Many studies to determine if efficiency loss, simulation failure, etc.
- Can be matched by varying L_{eff} (or S_n) below ~6keV$_{ee}$, from higher energy value of 0.19 & 0.9
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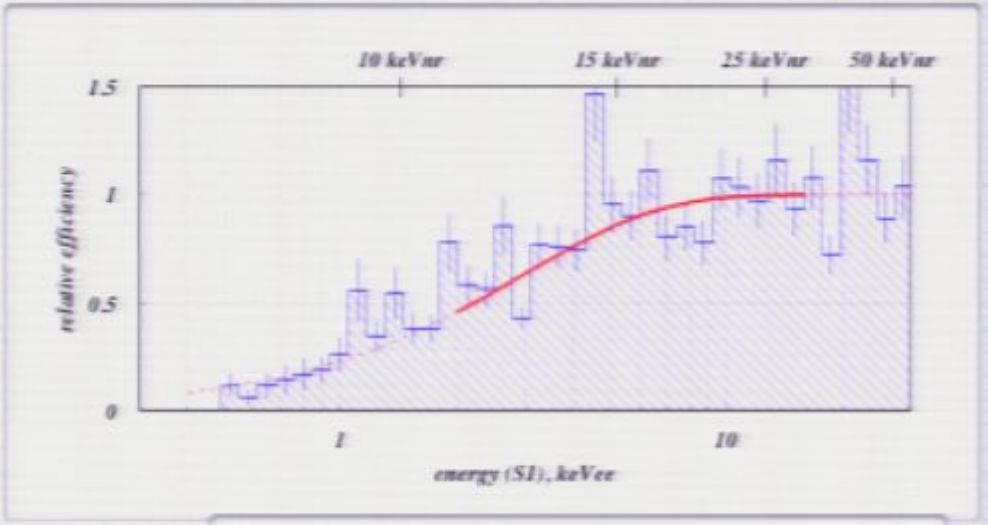

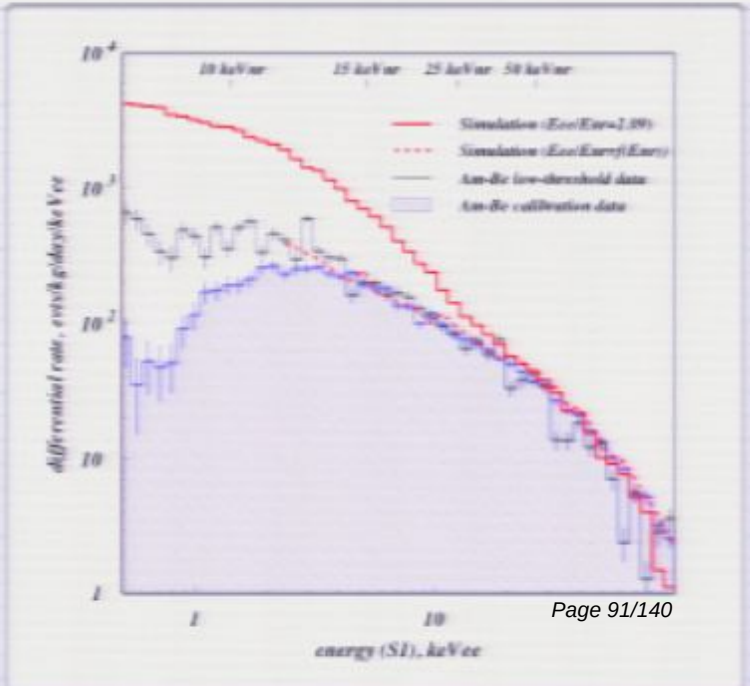

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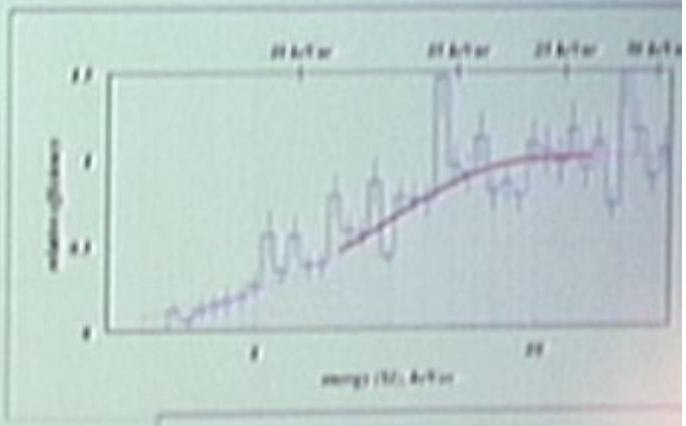

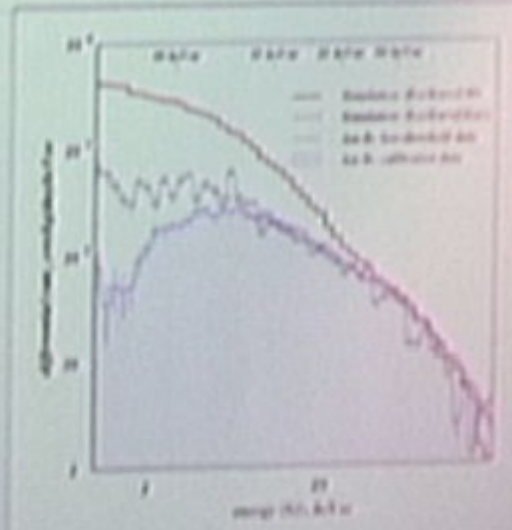

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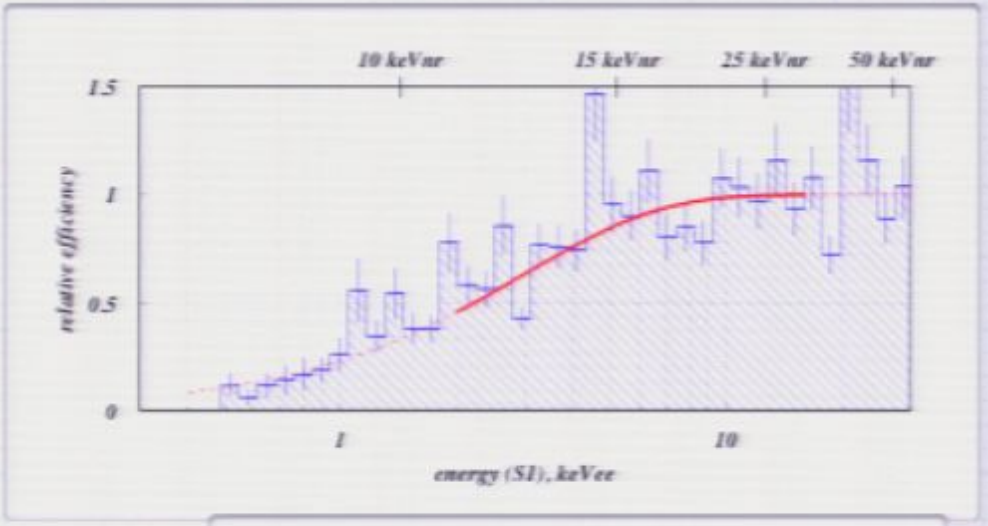

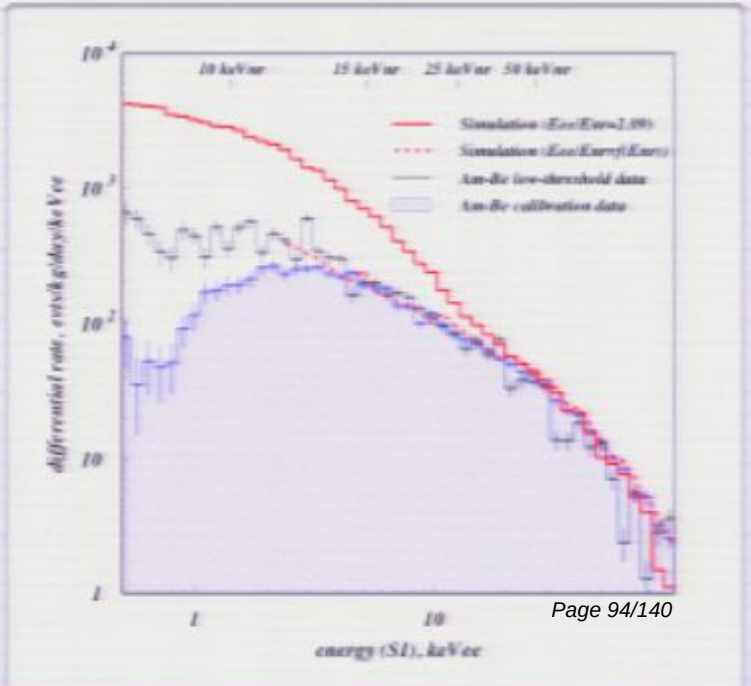

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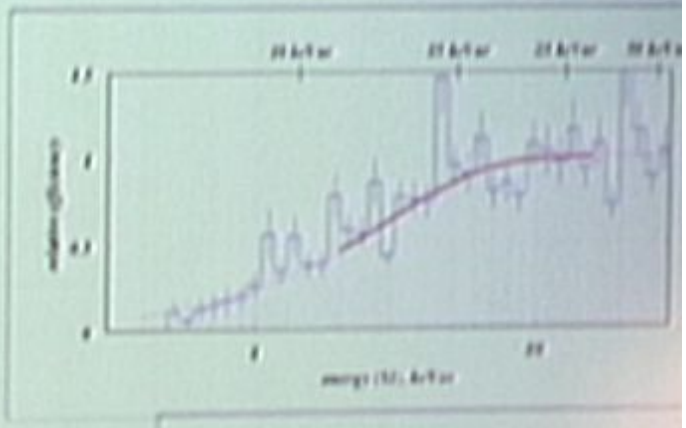

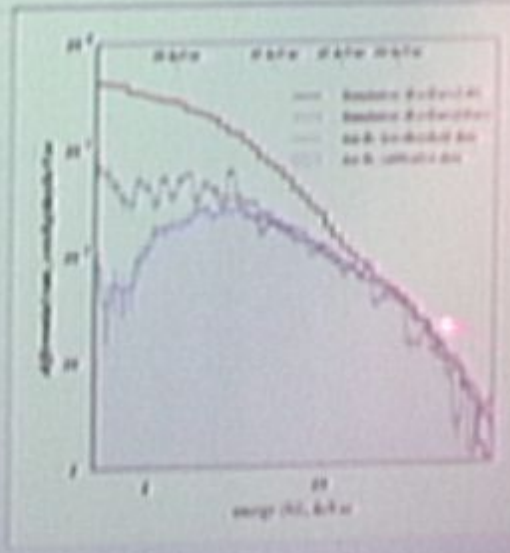

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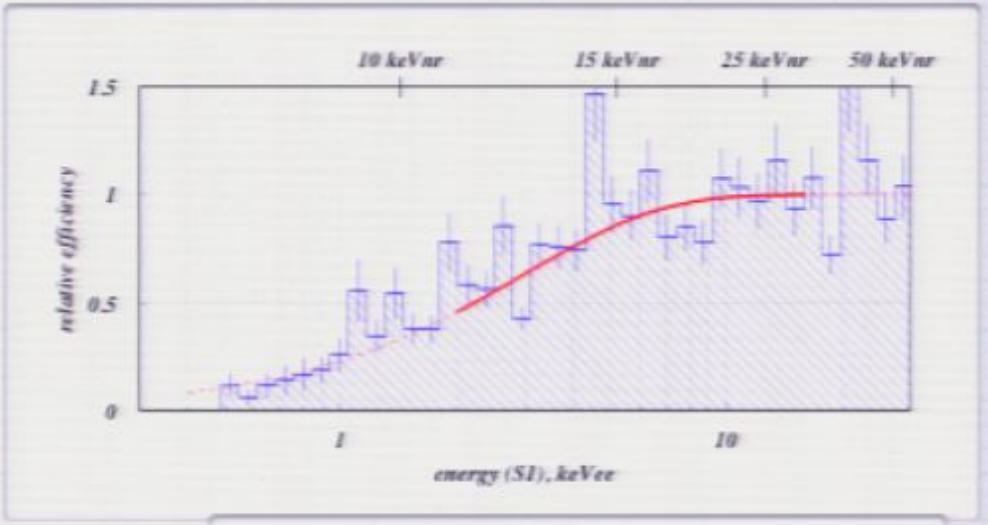

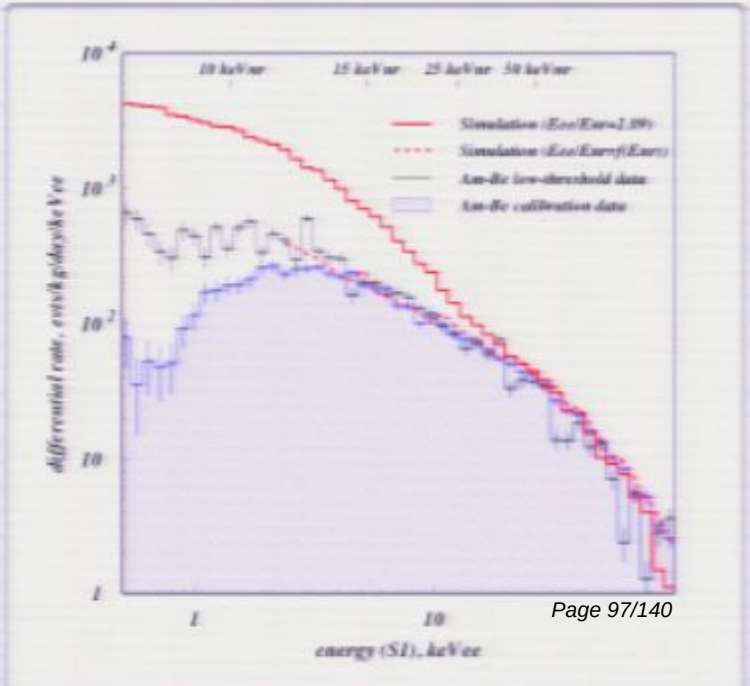

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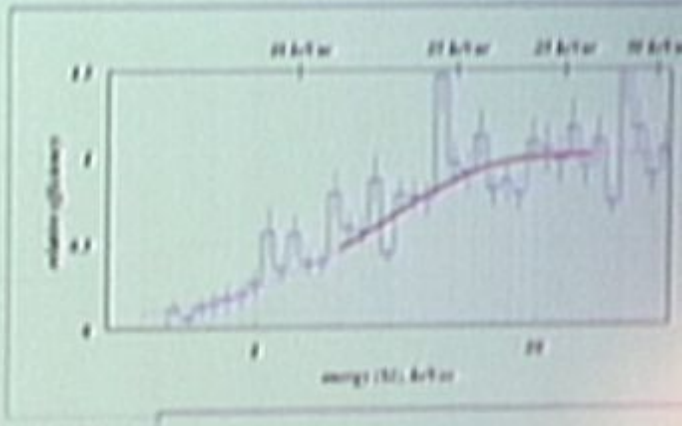

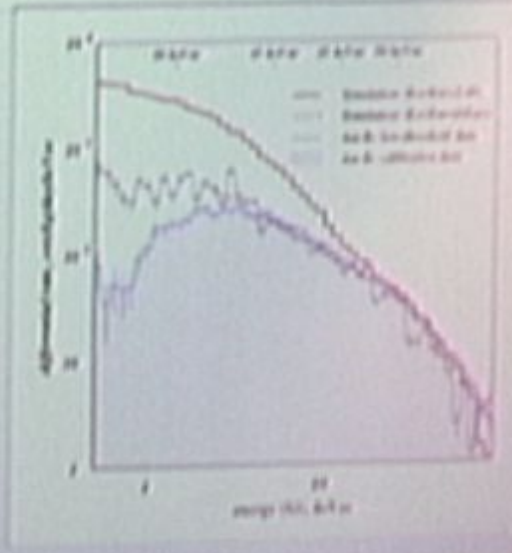

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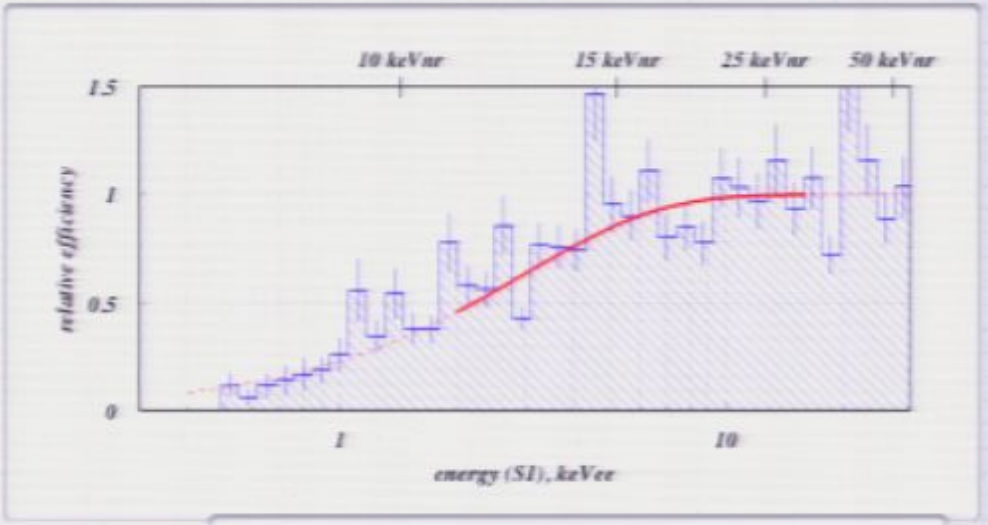

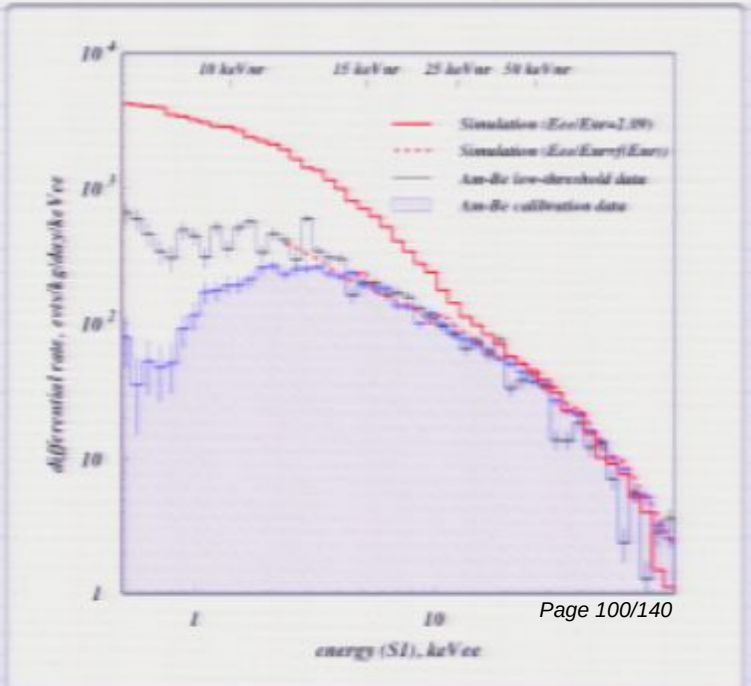

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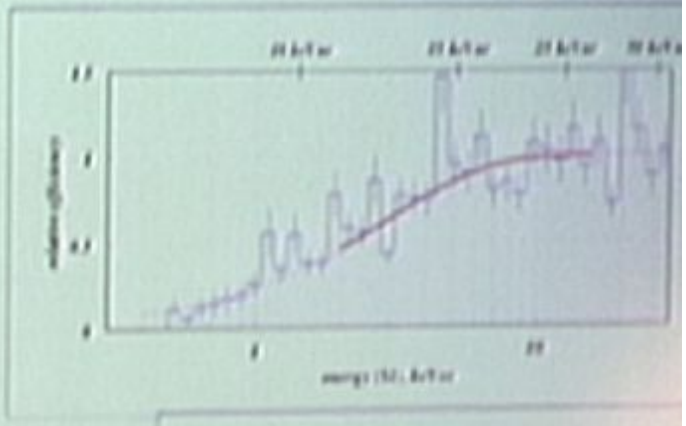

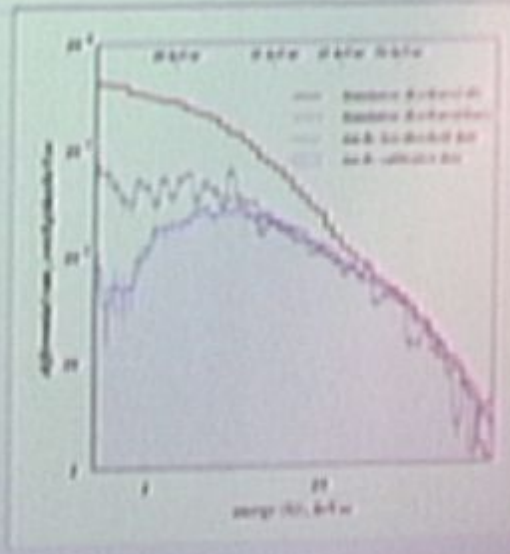

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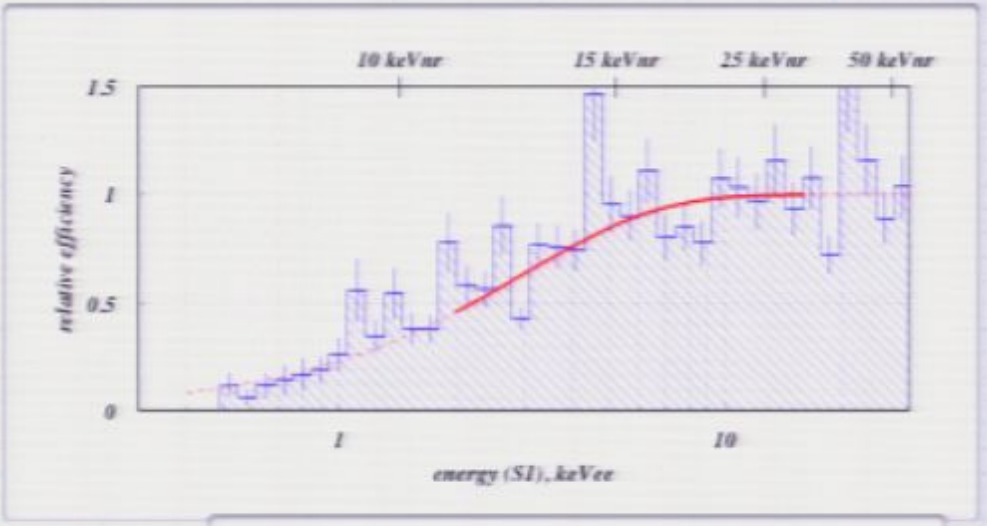

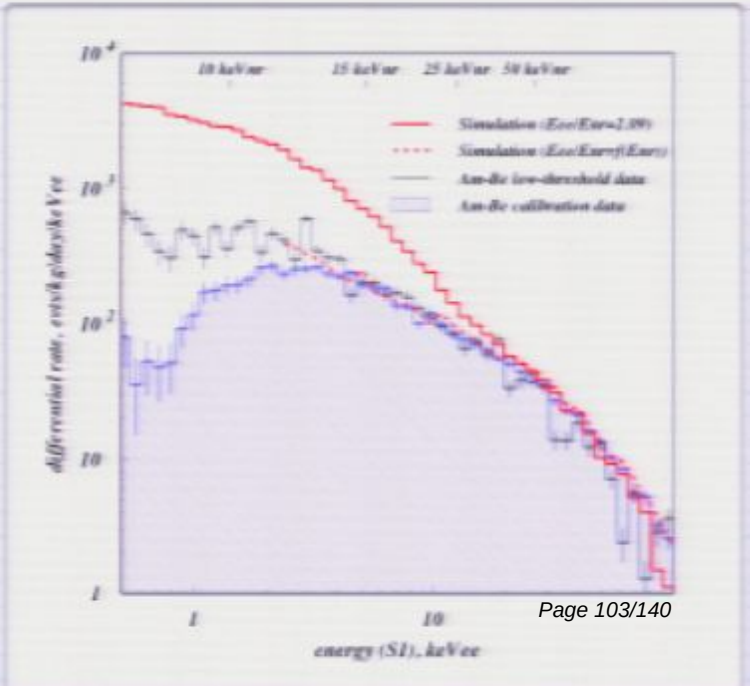

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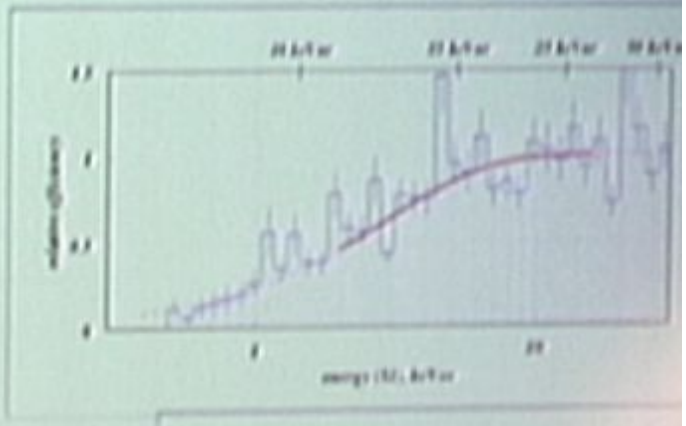

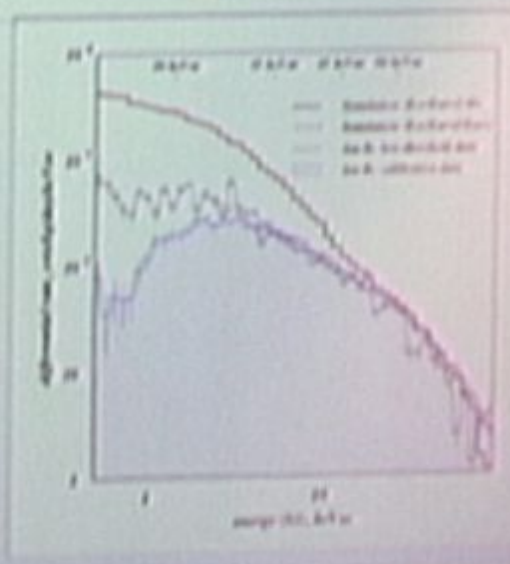

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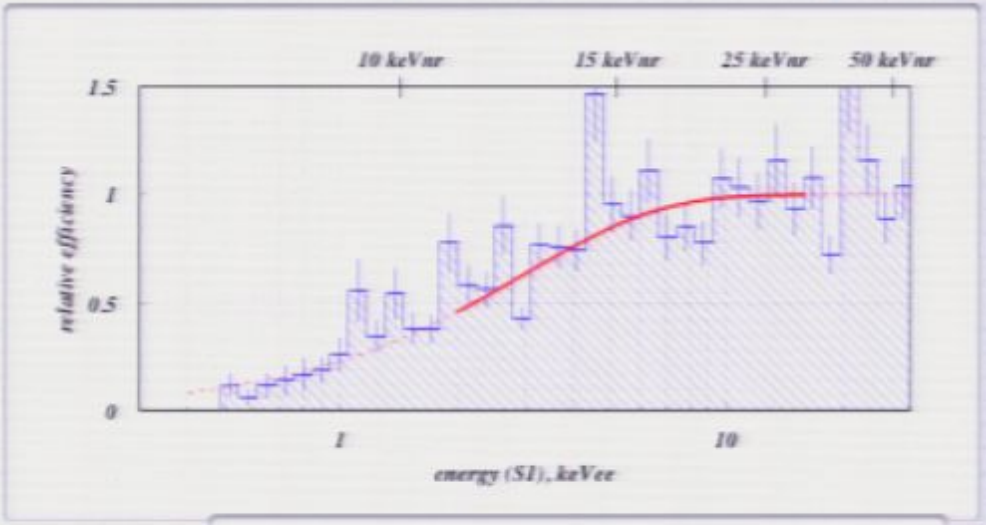

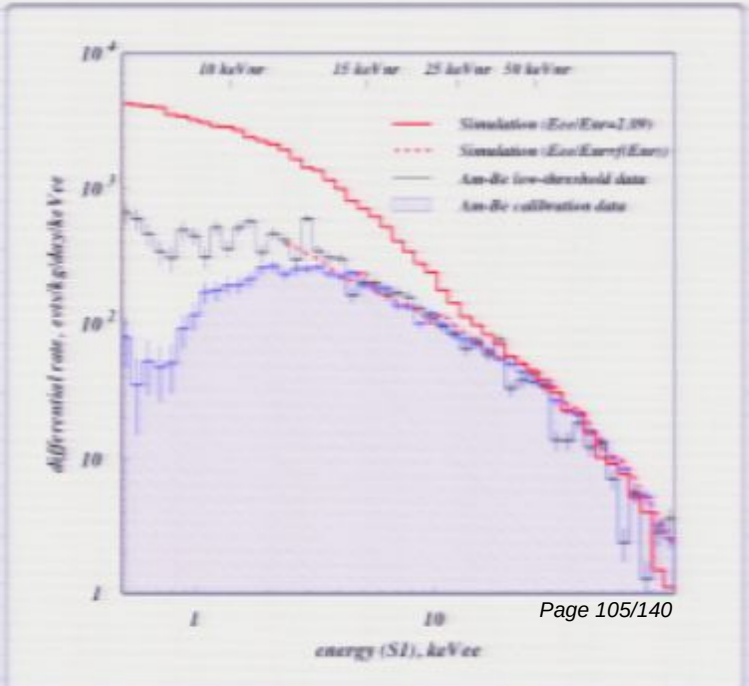

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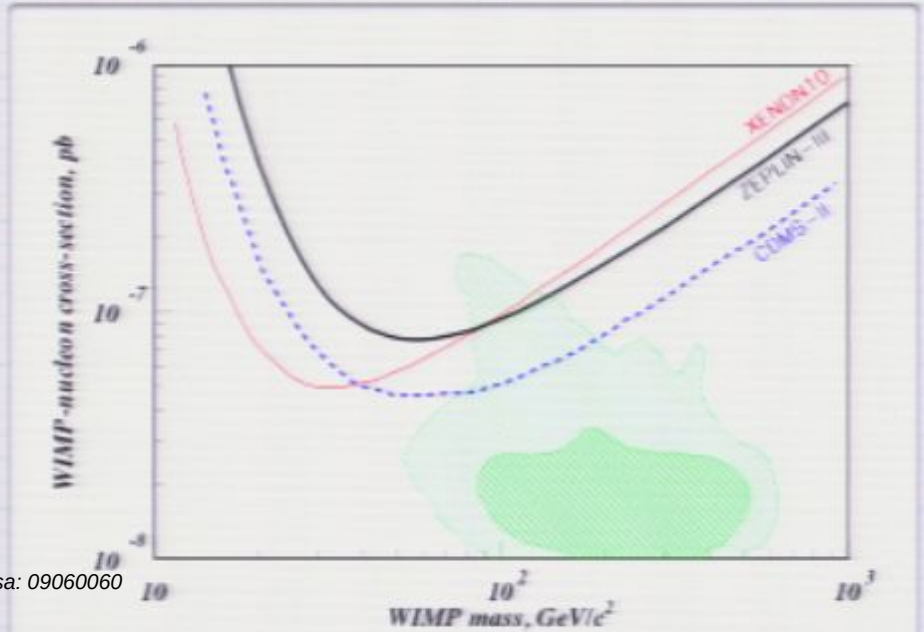
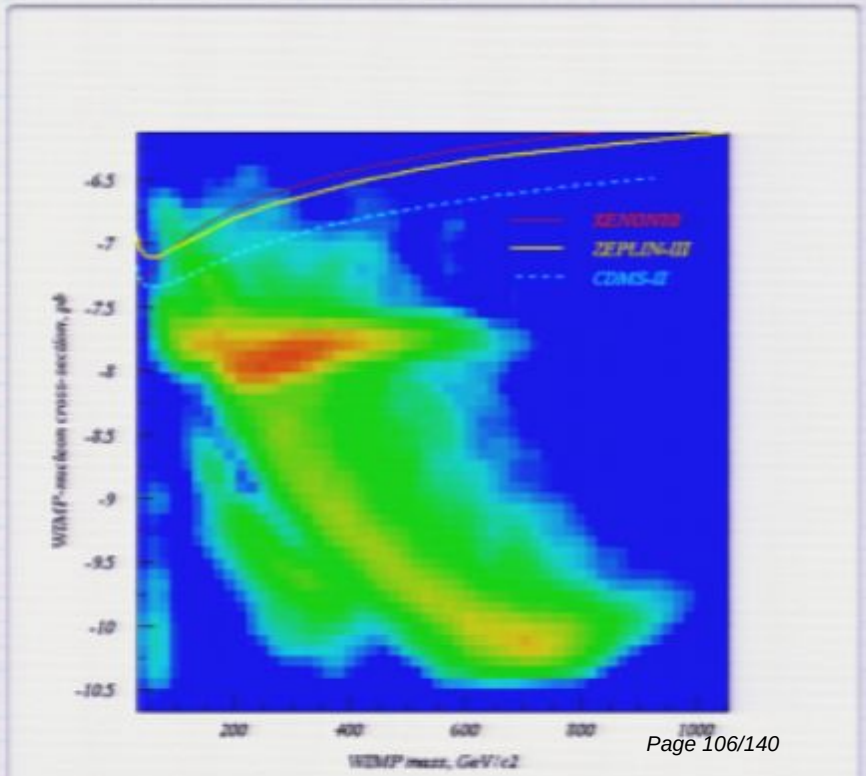
S.I. Cross-section limit

- 7 events observed in search box, most likely signal is zero events
- BML analysis gives 90% c.l. of 2.9 events (at 60GeV WIMP)
- Translates to 7.8×10^{-8}pb @60GeV
- 'canonical' halo model

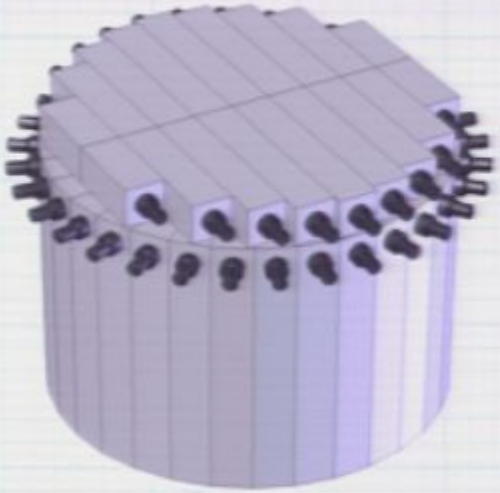
ρ_{dm}=0.3 GeVcm^{-3}, v_o=220 km/s,
v_{esc}=600 km/s and v_{Earth}=232 km/s

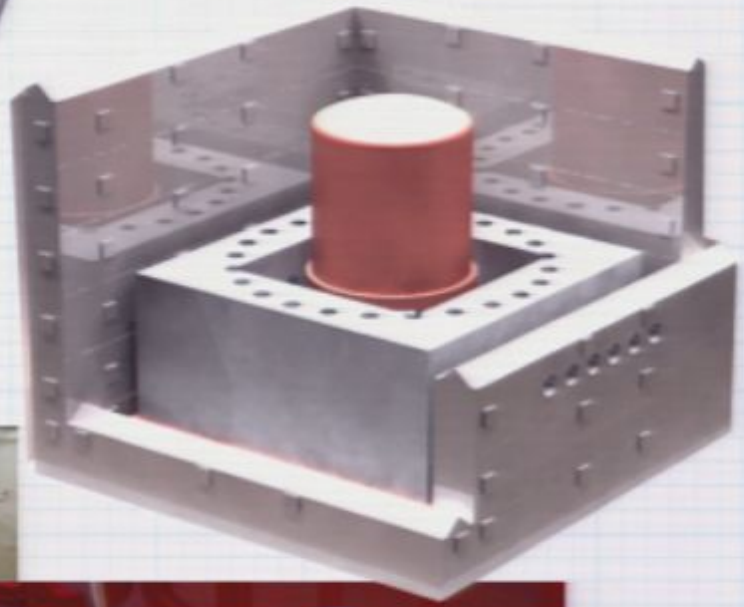




Future Plans

- Second science run using lower background PMTs
  - events mainly from PMT array
- Active Compton gamma and neutron veto installation





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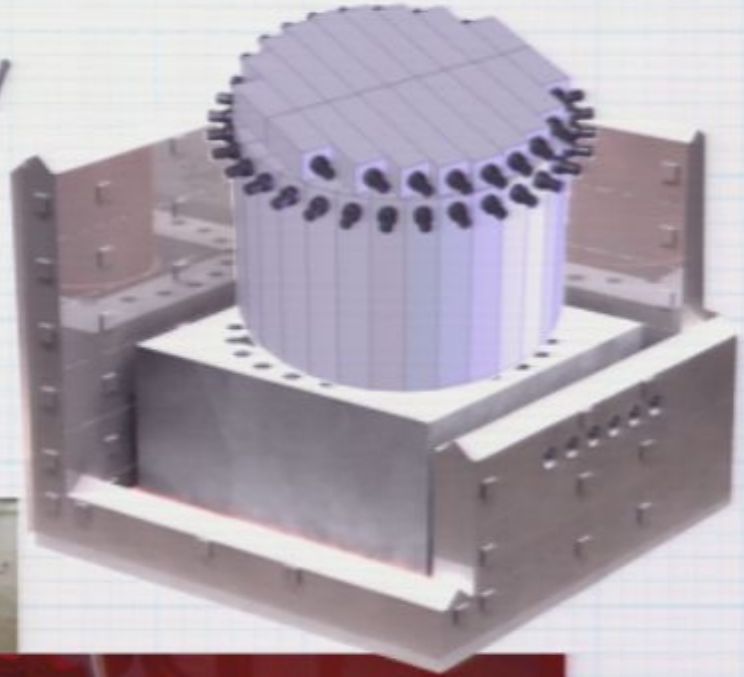
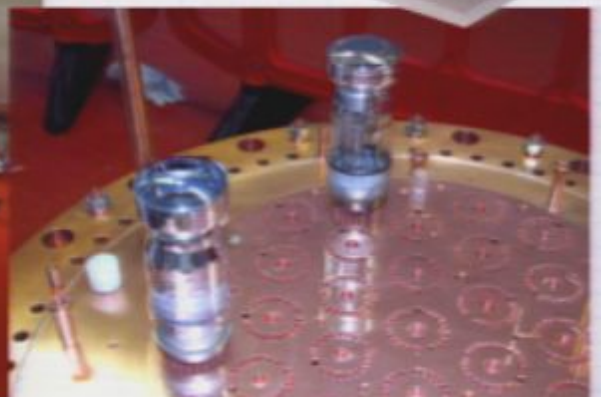




ZEPLIN-III Summary

- ZEPLIN-III successfully deployed in first stage configuration
- Detector operated stably during 2008
- First science run completed
  - 847 kg.days total exposure, 453.6 fidcual
  - 126.7 kg.days exposure after all cuts
  - Effective threshold 1.7 keV_{ee}
- Full analysis completed
    - 90% c.l. Limit at 7.8 $x10^{-8}$ pb @ 60GeV WIMP mass
    - Non-linearity in energy sale identified below ~5keV_{ee}
- Upgrades planned this year
  - PMT upgrade - lower background
  - Veto - tag background, provide diagnostics

The Motivation for SNOLAB:

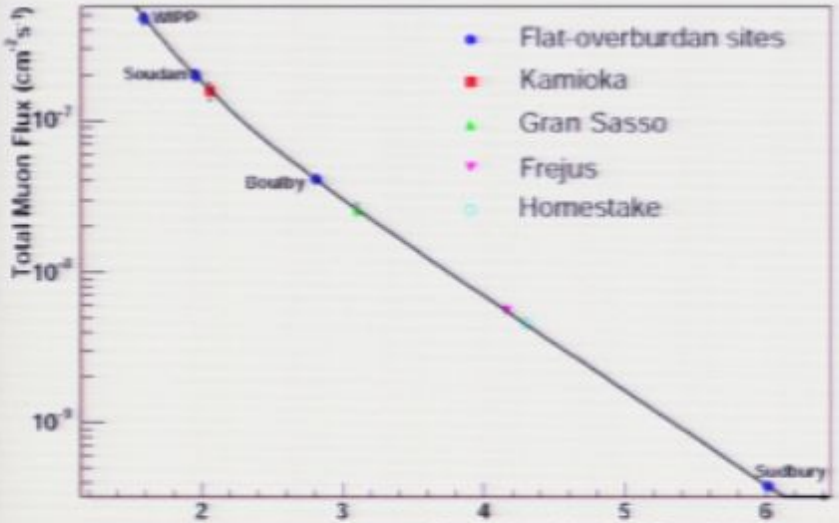
- To promote an International programme of Astroparticle Physics
- To provide a very deep experimental laboratory to shield sensitive experiments from penetrating Cosmic Rays
- To provide a very clean laboratory: Entire lab at better than class 2000 to mitigate against contamination of experiments.
- To provide infrastructure support to the experiments
- Focus on dark matter, double beta decay, solar & SN experiments requiring depth and cleanliness of SNOLAB. Also provide space for prototyping of future experiments.
- Large scale expt's = ktonne, not Mtonne.
- Goal has been to create a significant amount of space for an active experimental programme to support current generation of experiments as early as possible.

SNOLAB

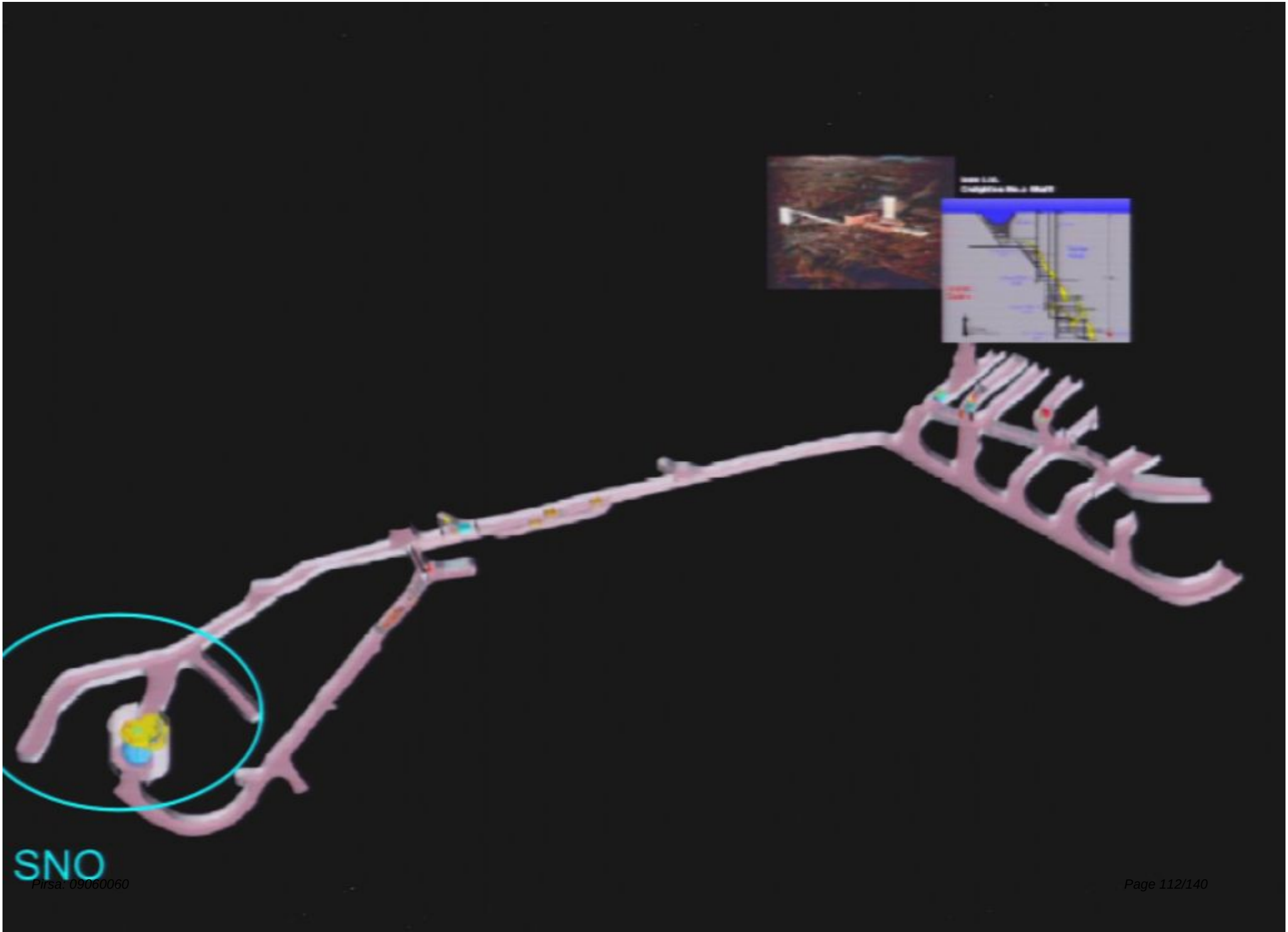
Surface Facility

2km overburden (6000mwe)

Muon Flux = 0.27/m^2/day



Underground Lab Clean Room


SNO

SNOLAB Underground facilities

Laboratory Space

	Excavation Area	Volume	Clean Rm Area	Volume	Laboratory Area	Volume
Existing	20,049 ft²	582,993 ft³	12,196 ft²	470,360 ft³	8,095 ft²	412,390 ft³
	1,863 m²	16,511 m³	1,133 m²	13,321 m³	752 m²	11,679 m³
Existing + Phase I	65,340 ft²	1,367,488 ft³	41,955 ft²	1,049,393 ft³	26,117 ft²	837,604 ft³
	6,072 m²	38,728 m³	3,899 m²	29,719 m³	2,427 m²	23,721 m³
Existing	77,636 ft²	1,647,134 ft³	53,180 ft²	1,314,973 ft³	32,877 ft²	1,043,579 ft³
+ Phase I&II	7,215 m²	46,648 m³	4,942 m²	37,241 m³	3,055 m²	29,555 m³

SNO: 752 m² lab space single experiment

SNOLAB: 3,055 m² lab space ~4 large experiments, several medium/small

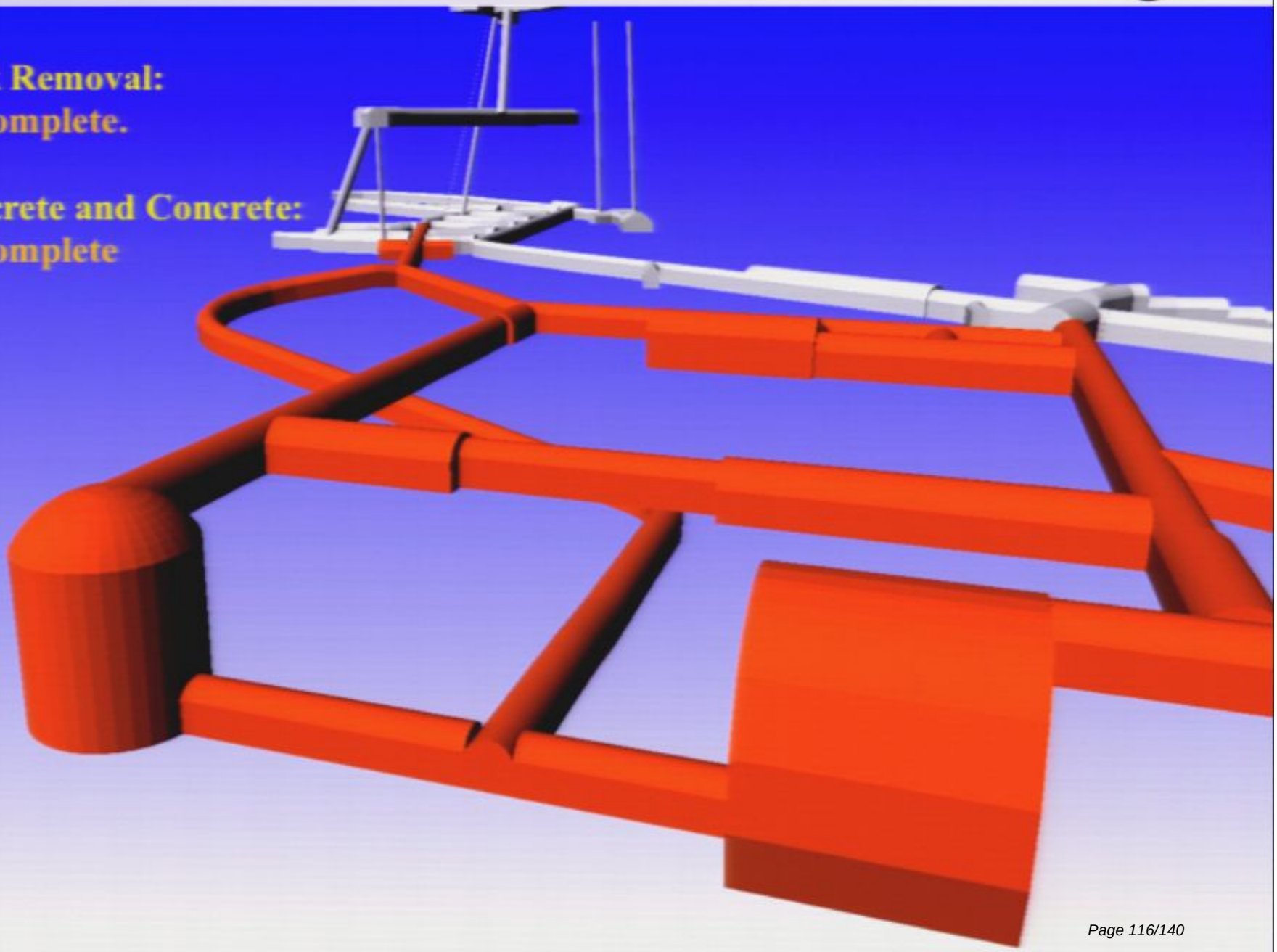
4 x the space

Surface Facilities

Excavation Status

Rock Removal:
Complete.

Bolting, Shotcrete and Concrete:
Complete




Lab Entry


Lab Entry
FEATHERLITE


Lab
Entrance


Personnel
Facility

SNO Access Drift


Lunch
Room


Cube Hall


Cryopit


Ladder
Labs


Personnel
Area

Chiller Room

SNOLAB Schedule

- Underground Construction (Cube Hall, Cryopit, Ladder Labs, Lab Entrance)
  - Excavation 100% complete.
  - Outfitting began June 2007. Now essentially complete.
  - Spaces available now for experimental infrastructure installation..
  - Final infrastructure (Chiller, MPC, waste water plant) commissioned
  - Commissioning and final cleaning started in November, 2008. Ongoing with installation of experiments.

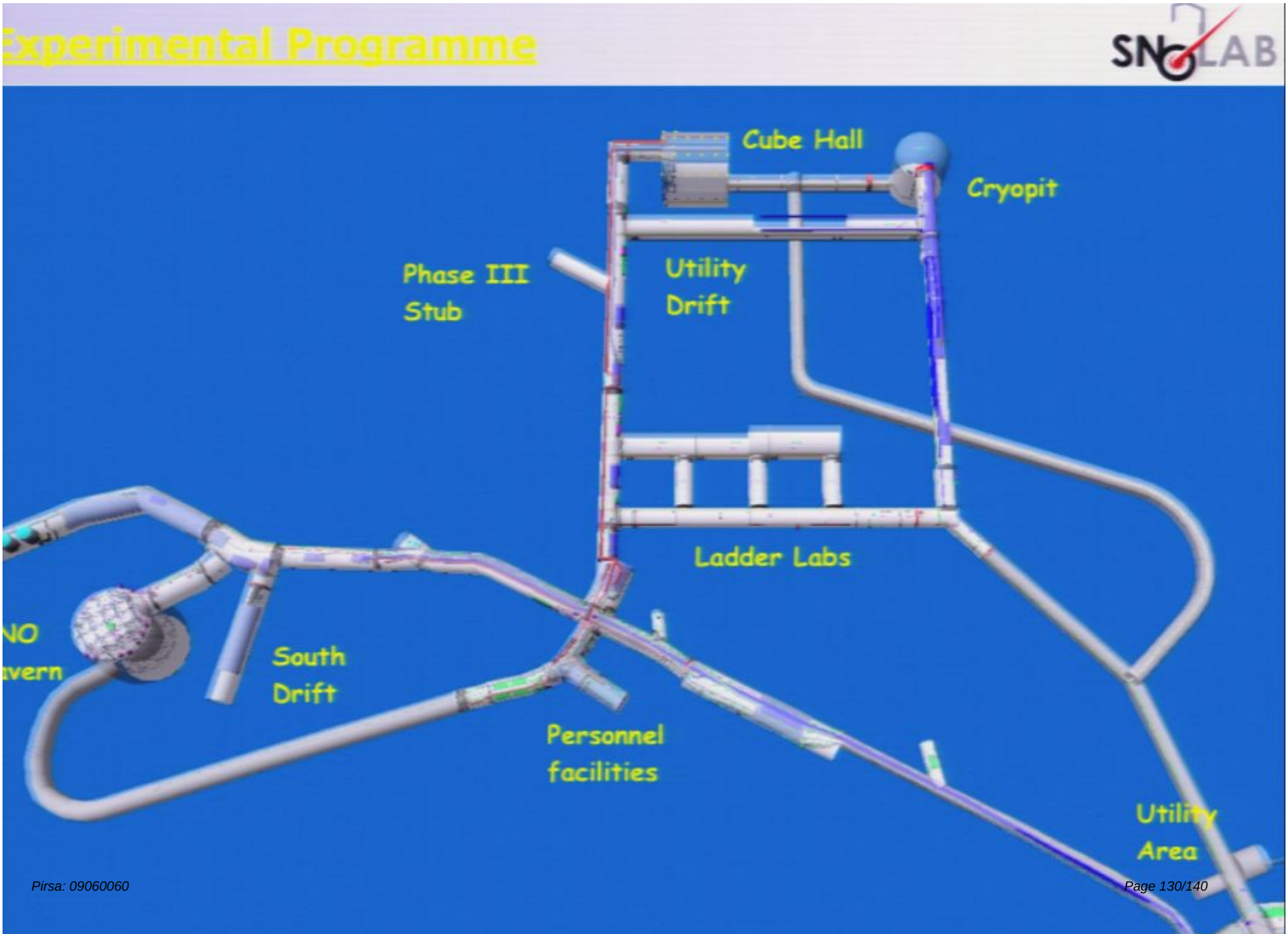
- Surface Facility
  - Operational since 2005.

- Experimental Programme
  - Initial assignments of space underground.
  - Current allocations to: PICASSO, DEAP I, SNO+, DEAP/CLEAN, MiniCLEAN SuperCDMS, HALO.
  - Anticipated or under discussion: EXOgas 200, COUPP, 2-phase LAr, low background counters to measure ^{39}Ar, future Cobra upgrade…

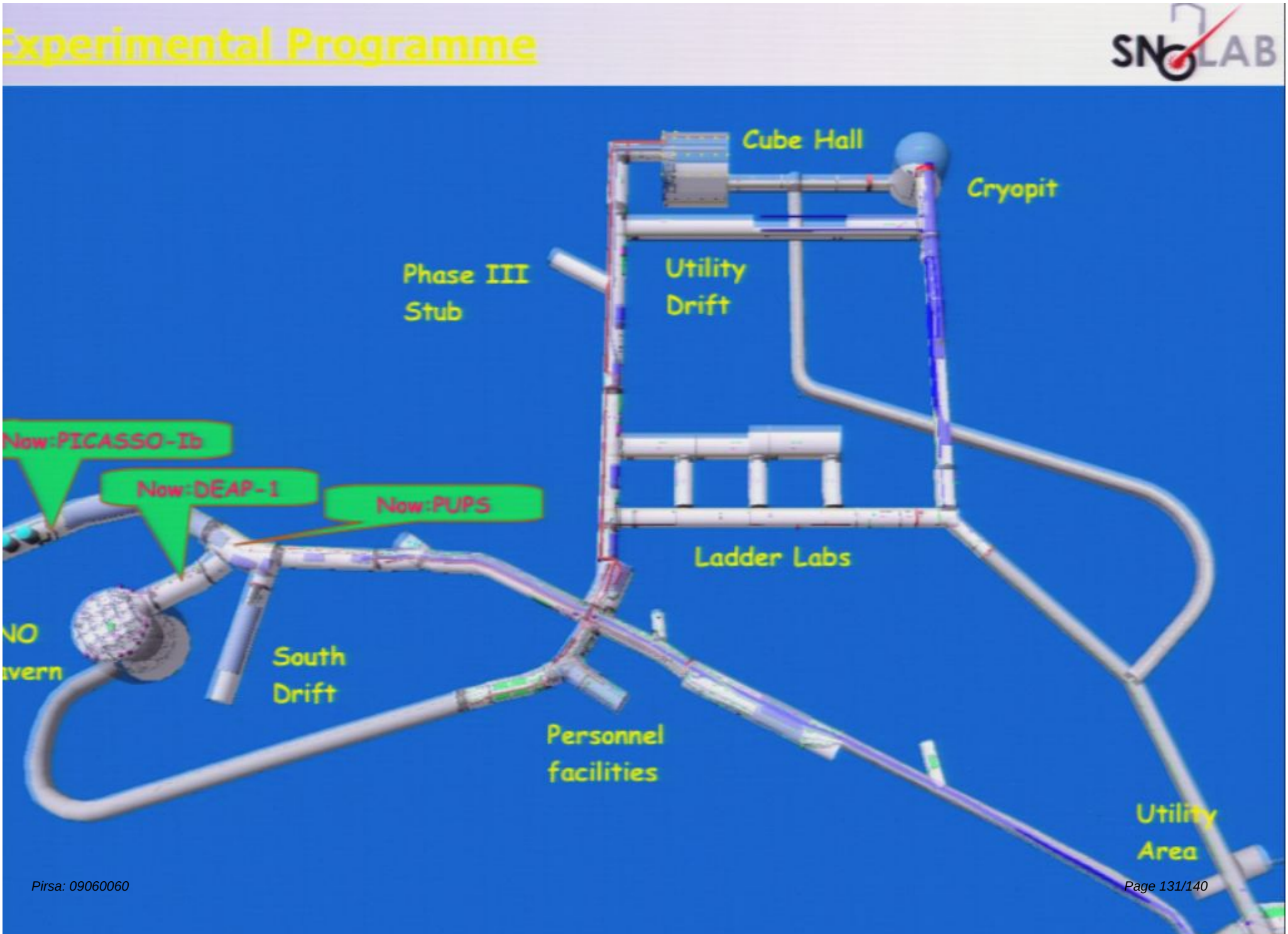
Experimental Programme

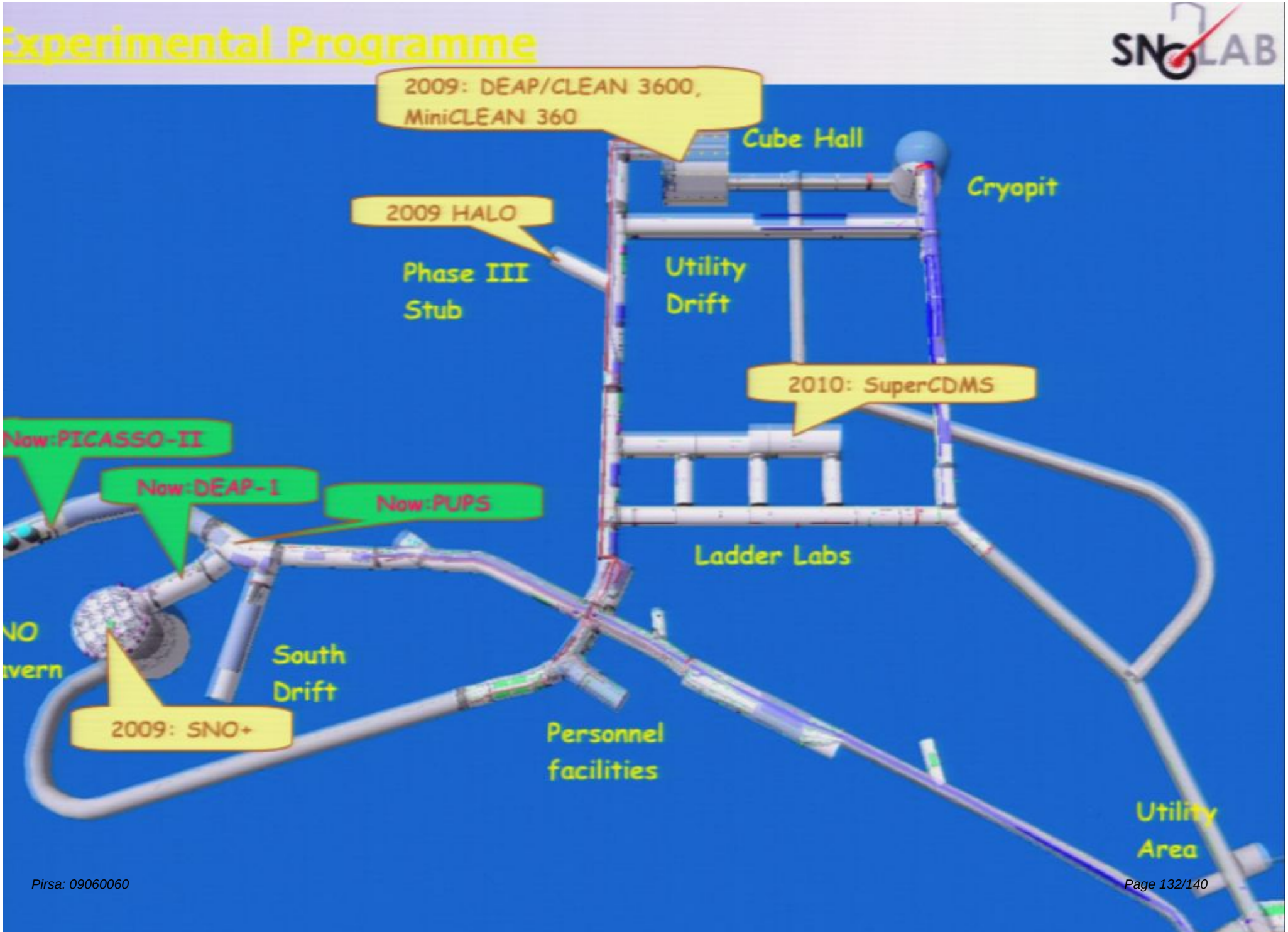
Experiment	Solar Nu	0nuBB	Dark Matter	Super nova	GeoNu	Other	Space Allocated	Status
SNO+	X	X		X	X		SNO Cavern	Install 2009
PICASSO			X				SNO Utility Room	Running
DEAP-1			X				SNO Control Room	Running
MiniCLEAN 360			X				Cube Hall	Install 2009
DEAP/CLEAN 3600			X				Cube Hall	Install 2009
EXO		X						Install 2010?
SuperCDMS			X				Ladder Labs	Install 2010?
HALO				X				Install 2009
PUPS						Seismic	Various Locations	Running

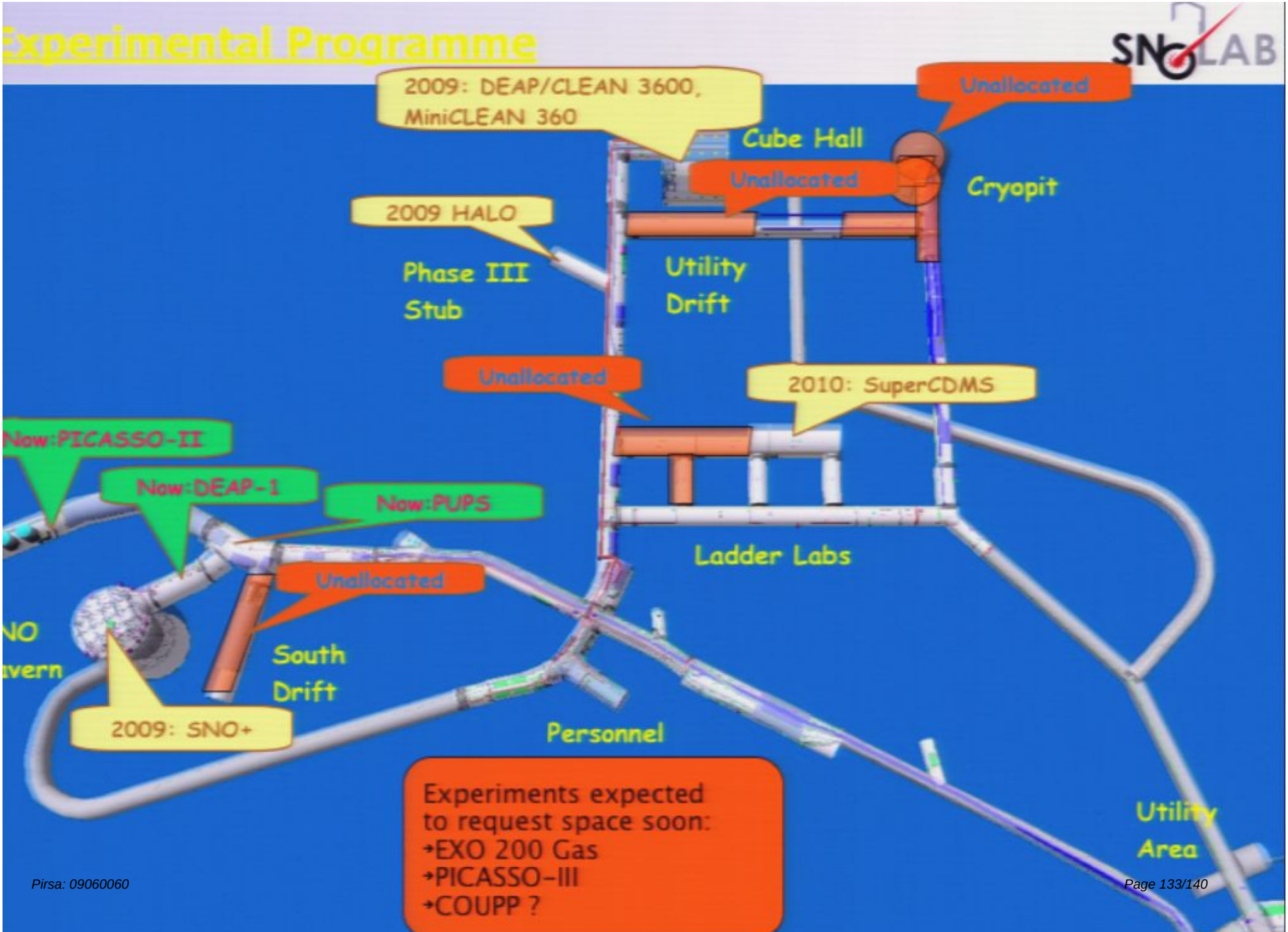
Experimental Programme



Experimental Programme




Experimental Programme
SNOLAB
2009: DEAP/CLEAN 3600, MiniCLEAN 360
Cube Hall
Cryopit
2009 HALO
Phase III Stub
Utility Drift
2010: SuperCDMS
Now:PICASSO-II
Now:DEAP-1
Now:PUPS
Ladder Labs
NO
avern
South Drift
2009: SNO+
Personnel facilities
Utility Area


Experimental Programme
SNOLAB
2009: DEAP/CLEAN 3600, MiniCLEAN 360
Unallocated
Cube Hall
Unallocated
Cryopit
2009 HALO
Phase III Stub
Utility Drift
Unallocated
2010: SuperCDMS
Now:PICASSO-II
Now:DEAP-1
Now:PUPS
Ladder Labs
Unallocated
South Drift
2009: SNO+
Personnel
Experiments expected to request space soon:
→EXO 200 Gas
→PICASSO-III
→COUPP ?
Utility Area

Status of Experiments

Dark Matter at SNOLAB

Noble Liquids: Deap I, MiniClean, & DEAP/Clean :

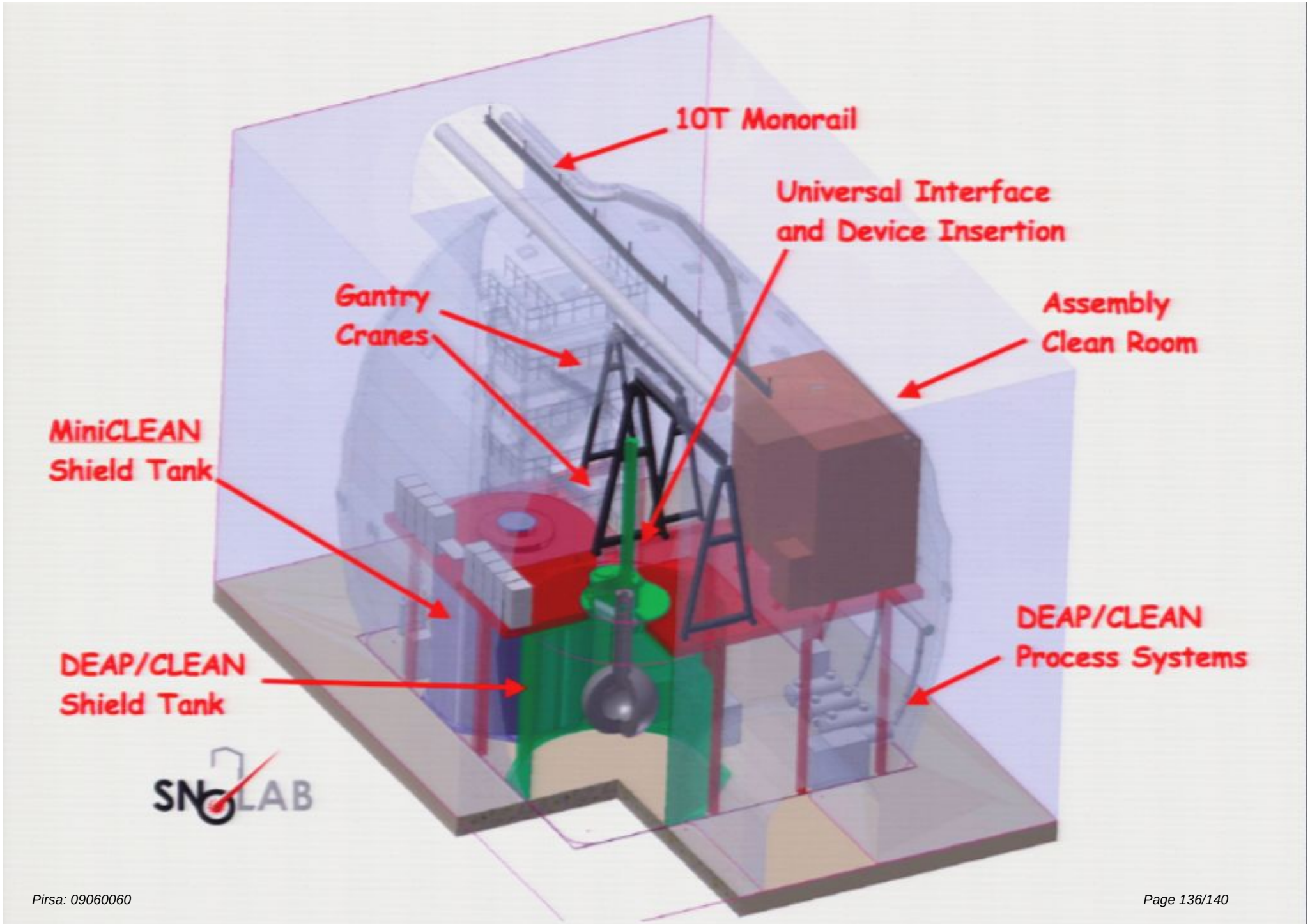
- Single Phase Liquid Argon.
- Uses pulse shape discrimination
- Prototype DEAP I Installed in SNOLAB now. Very successful demonstration of PSD. To be followed by MiniClean, Deap/CLEAN
- Will measure Spin Independent cross-section.

Superheated Liquids: PICASSO: COUPP ?

- Superheated droplet detector. Insensitive to MIPS radioactive background at operating temperature.
- PICASSO Currently Operational in existing SNO lab. Next phase will need SNOLAB space.
- Will measure Spin Dependent cross-section.

Solid State: SuperCDMS :

- State of the art Ge crystals with ionization and phonon readout.
- Has led the field for many years. Currently operational in Soudan. Next phase will benefit from SNOLAB depth to reach desired sensitivity.
- Most sensitivity to Spin Independent cross-section


10T Monorail
Universal Interface
and Device Insertion
Gantry
Cranes
Assembly
Clean Room
MiniCLEAN
Shield Tank
DEAP/CLEAN
Process Systems
DEAP/CLEAN
Shield Tank
SNOLAB

Example Program: 0uββ at SNOLAB

SNO+ : $^{150}Nd \rightarrow {}^{150}Sm + e^- + e^-$

Uses existing SNO detector. Heavy water replaced by scintillator loaded with ^{150}Nd. Modest resolution compensated by high statistical accuracy.

Requires engineering for AV hold down and purification plant. Technologies already developed. ~Ready to go. Capital Funding Decision June 2009.

Easily obtain best limits or confirm claim within first year of running.

EXO$_{gas}$: $^{136}Xe \rightarrow {}^{136}Ba^{++} + e^- + e^-$

Ultimate detector = large volume Xe Gas TPC

Developing technique to tag Ba daughter. Electron tracking capability.

Prototype soon.

Future large scale detector with Ba tagging likely to have best sensitivity.

Other

SNO+ :

- Will also measure solar neutrino pep, geo-neutrinos, Supernovae bursts and reactor neutrinos. Installation began in 2009

HALO: Dedicated Supernova watch experiment

- Preparing materials for underground installation
- All materials now at SNOLAB (Pb, Neutron counters, DAQ ...) Installation complete in 2009.

PUPS: Seismicity Deep Underground

- Currently operational
- Goal is to study seismic wave propagation deep underground, thereby avoiding complications due to reflections at surface...

Summary

- SNOLAB has great potential to address many of the most fundamental questions in subatomic physics today.

- Lab is ready now to begin installation of experiment specific infrastructure.
  - Construction schedule a few months ahead of schedule…→ more infrastructure
  - Skilled technical staff, engineering and scientific support.

- Several smaller sized programs (PICASSO, DEAP-1, PUPS) already operational

- Dark Matter programme: Diverse targets and sensitivities.

– DEAP/CLEAN	Spin Indep	Ar	10^{-46}
– SuperCDMS	Spin Indep	Ge	10^{-45}
	Spin Dep	Ge	neutron
– Picasso	Spin Dep	F	proton

- Neutrinoless double beta decay programme:

– SNO+	Nd	High statistics and clean
– EXO	Xe	Gas TPC with tagging

SNOLAB is open for business!
Highest priority now is to get experiments fully funded.
designed, reviewed and installed.

We welcome new proposals !!
We are looking for new Students and Postdocs
We welcome sabbatical visits