HERON: Projected precision & plans

Real time

PP & ^{7}Be solar ν flux studies

$$\nu_x + e \rightarrow \nu_x + e$$

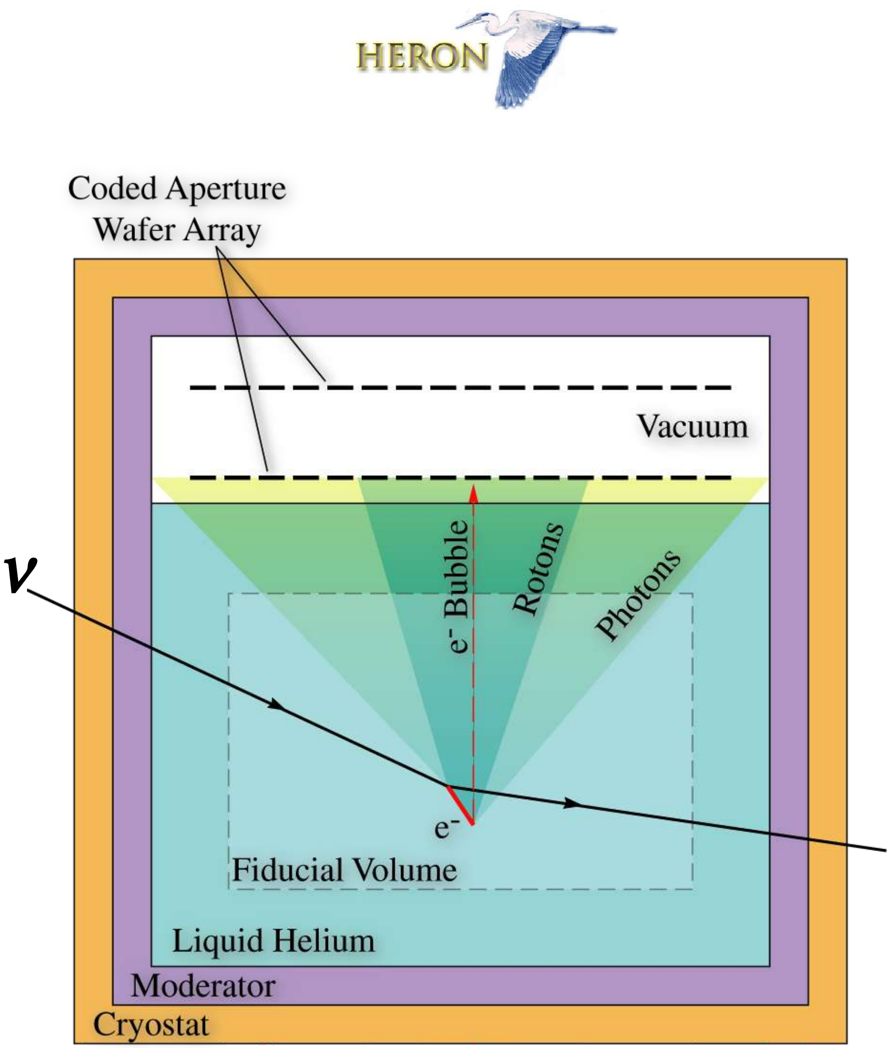
Meat: Test stellar models by PP luminosity in ν's

Gravy: > Improve knowledge of sin^2 $_{12}$, $_{13}$

> Test MSW-LMA $P_{ee}(E_\nu)$

> 'MaVan'; other new physics (e.g., μ_ν)?

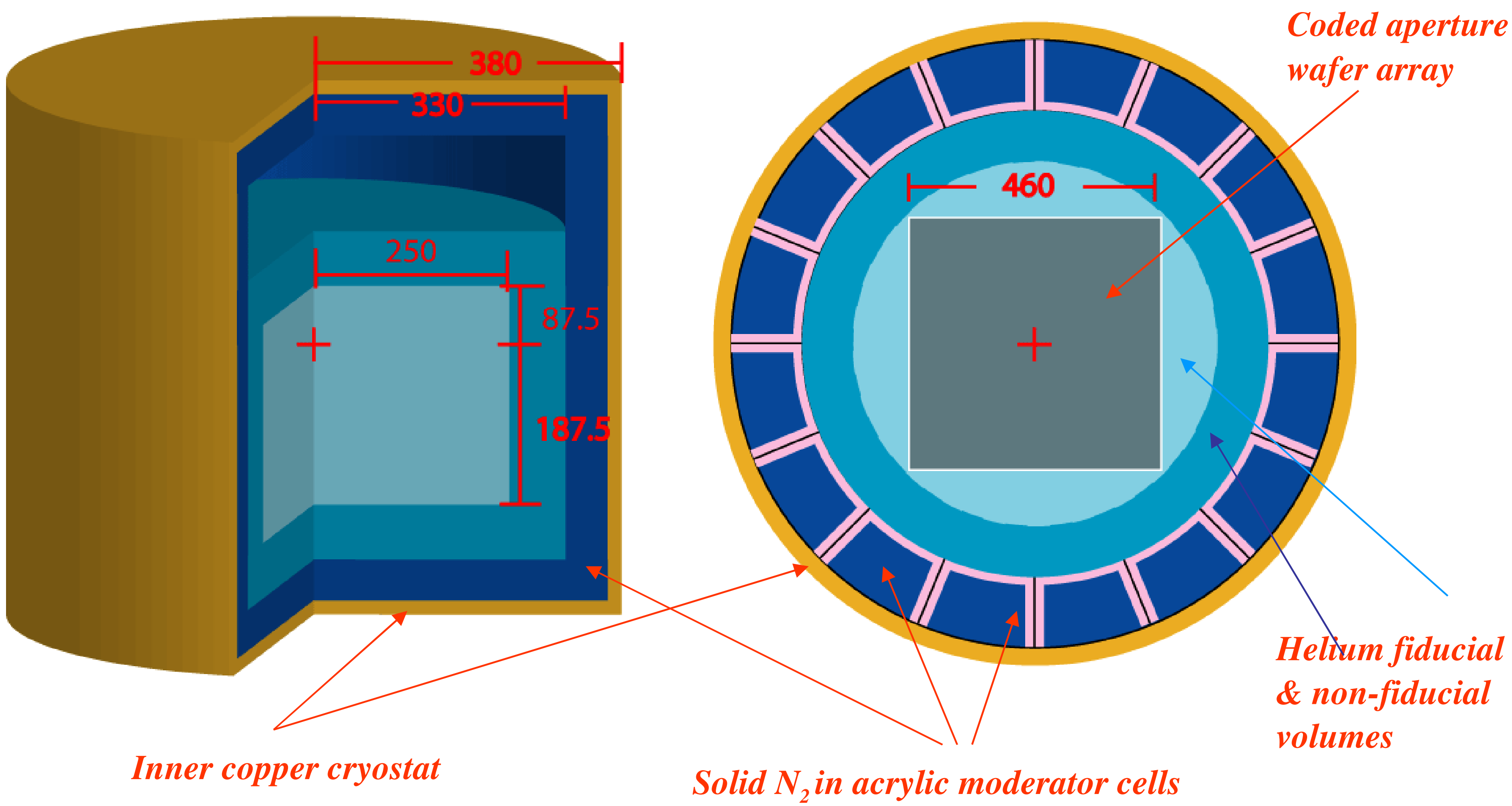
Requires unprecedented control of systematics (< 1 - 3%) & large samples



General Properties

- Total Helium mass 22 tonnes at 50mK.
- No internal backgnd (superfluid self-cleaning).
- Scintillation/rotons or Scintillation/e-bubbles.
  (complement & redundancy)
- Scintillation: 35% of E_e into 16 eV UV
  ($\lambda_{Rayl.} > 200$ meter; self-transparent).
- Detection:2400wafer calorimeters above liquid.
- Event location: coded aperture array; few cm.).
- Fiducial volume variable:
  2.5 evts/(day-tonne) LMA (pp+Be) $E_e > 45$ keV .
- Helium immune to muon spallation/capture.
- External gamma backgrounds control :
  Deep site & Shielding
  Material select + moderator solid N_2
  Gamma physics in Helium → n-Comptons
  Event signature (coded aperture)
  Fiducial cuts

CRYOSTAT & MODERATOR



Estimating precision for flux measurement

Role of coded aperture:

Distinguishes point sources from distributed sources by likelihood
(scintillation photons pattern & no. of drifted recoil e-bubble)

Measures event energy calorimetrically (photons)

Measures point source position accurately
(photons with cruder check from e-bubble)

Quantities for extended LL separation of bckgnd, pp & Be:

Energy spectra (E)

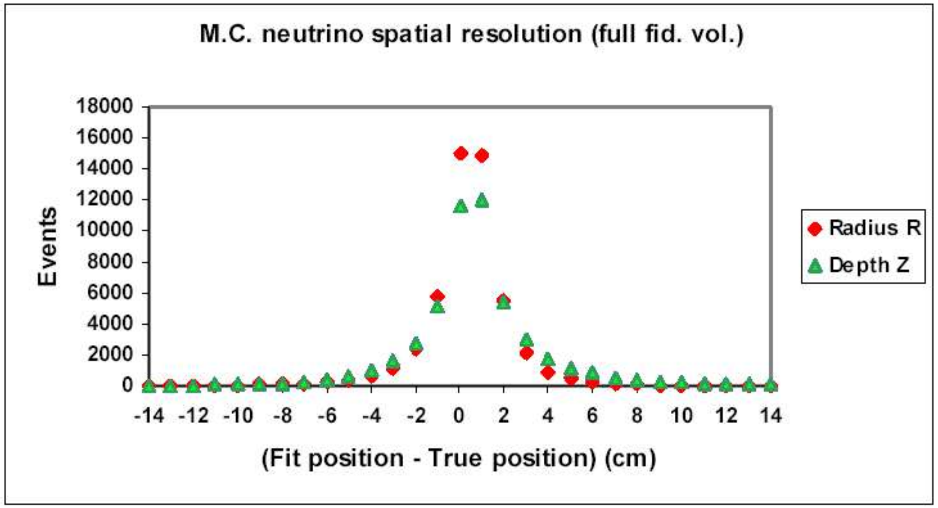
Event spatial distributions (Z, R^2)

Point-like source quality factors (LL, "ddL" (norm. LL))

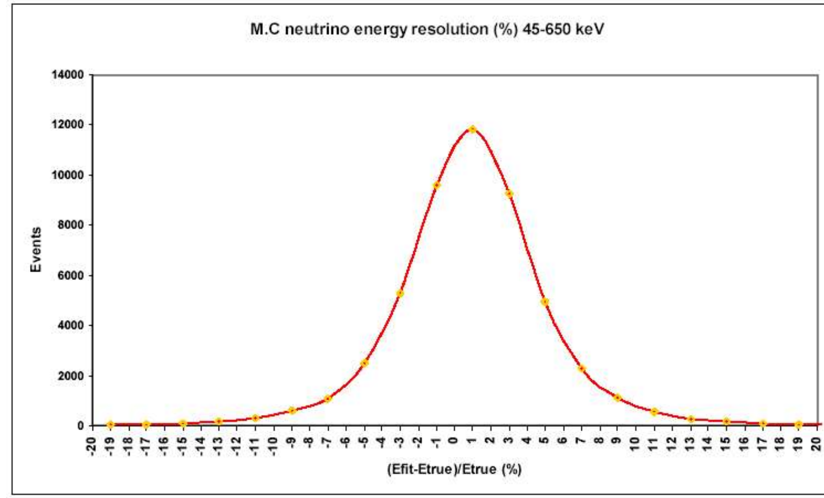
Restriction of number drifted e's detected ("<3 over 5 keV")

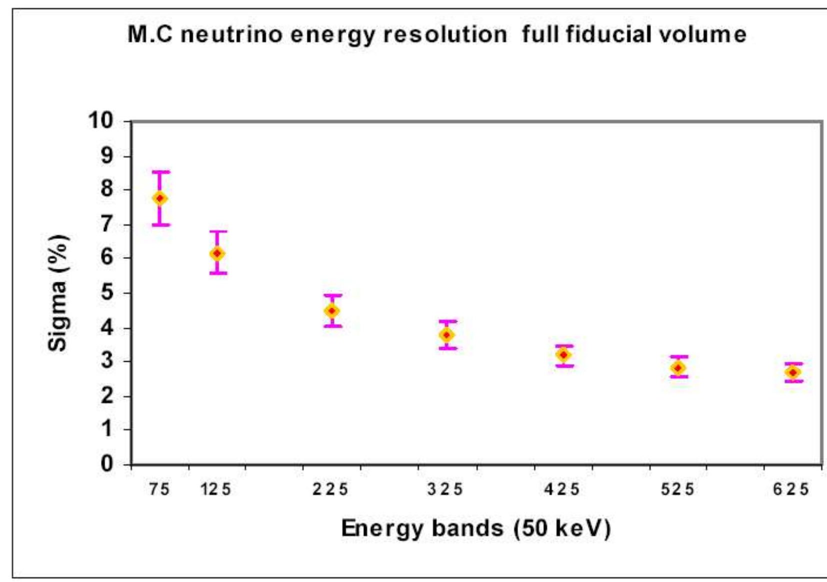
Resolutions:

Spatial



Energy





Resolutions (sigma) for E_e > 45 keV

	In fid. vol.	60 cm beyond fid. vol.
X	1.62 cm	2.1 cm
Y	1.54 cm	1.7 cm
Z	2.46 cm	0.4 cm (top), 6.0 cm (bott.)

"Standard" fiducial vol. (54 m³):
R < 250 cm; -187.5 < Z < 87.5 cm

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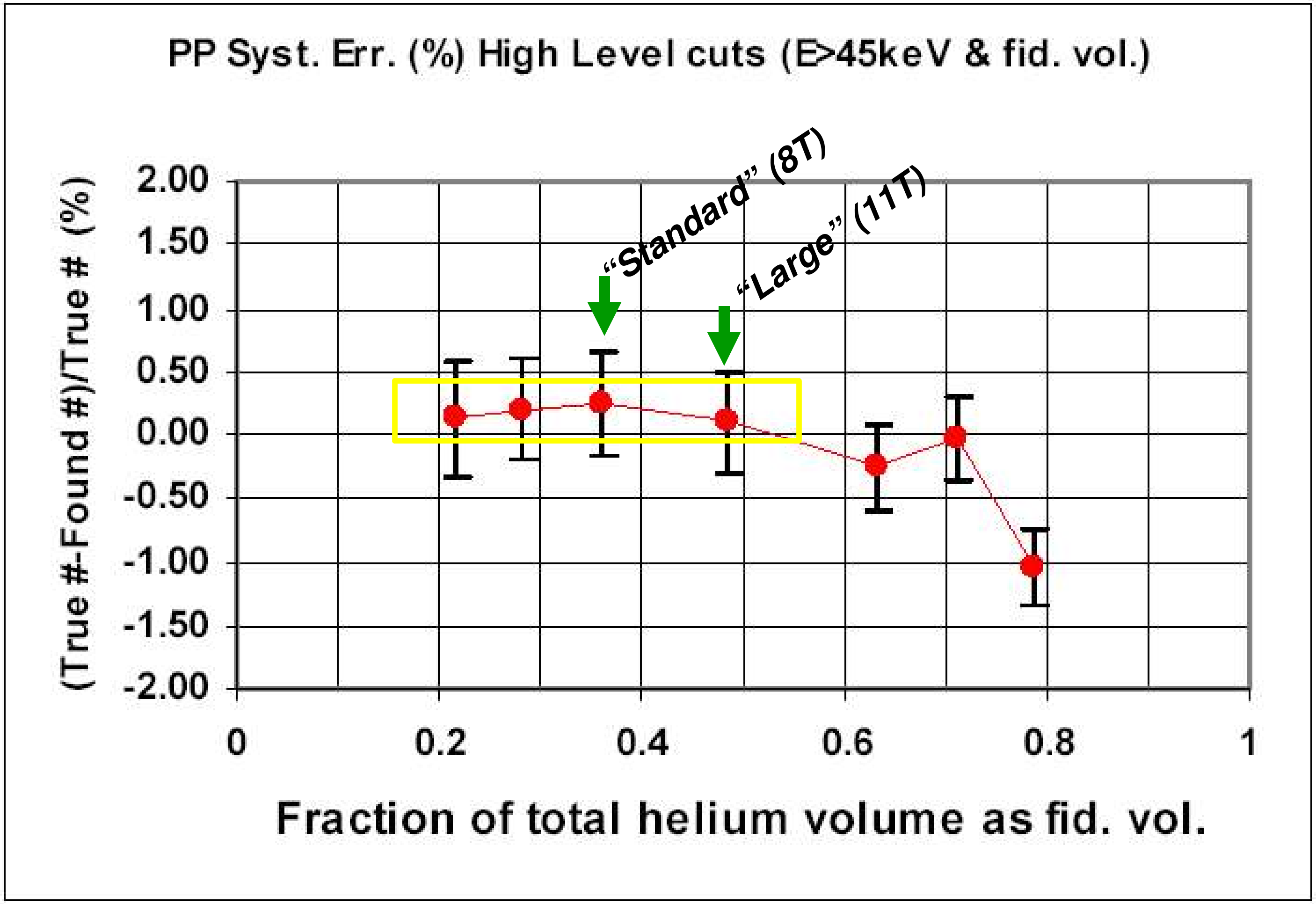
High level cuts (E_{recoil}>45keV; R^2; Z; n_e<3)



High level cuts (% bckgnd remain)

- *> $N_{e(5keV)}$ < 3 → 33.3 %*
- *> E_{fit} > 45 keV → 17.1 %*
- *> Std. Fid. → 1.25%*

Need to construct pdf's and understand possible correlations

Simulating multi-year experiments

Major computational task:

> GEANT simulation of radioactive chains through detector.
(U/Th, K, cosmogenics from cryostat, acrylic, nitrogen
with activities from ββ , SNO, KamLAND)

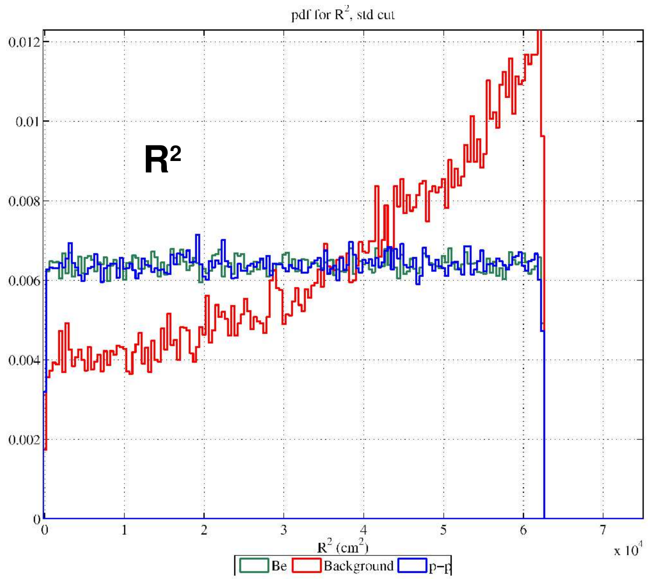
> Full coded aperture-based reconstruction of all events in He.
(Y.H. Huang)

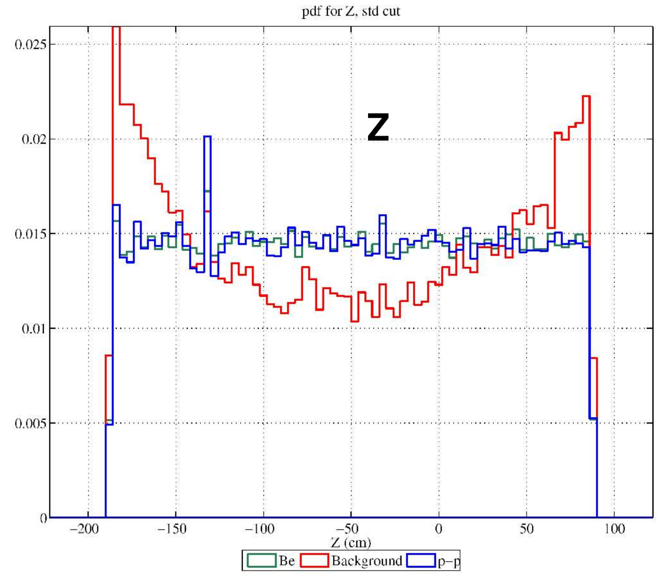
>To save computation time: analytic methods as much as possible.
(4.5 years-equivalent of backgrounds)

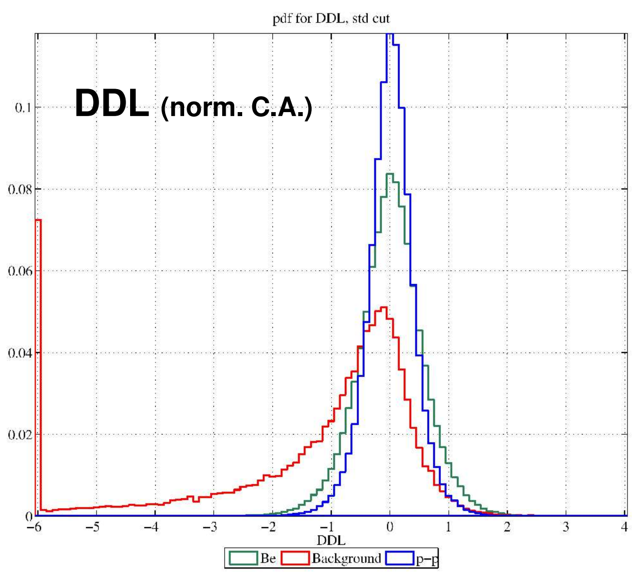
> Evaluate later small non-analytic effects (UV multiple reflections)

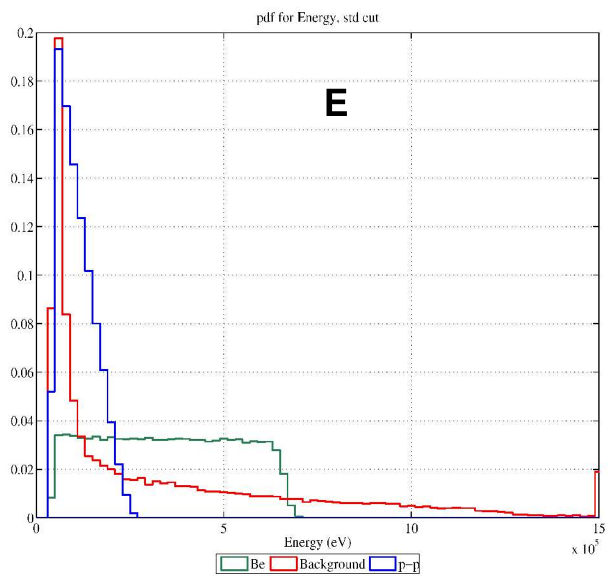
> Construct p.d.f.'s of measured variables (E, R^2, Z, LL, DDL)

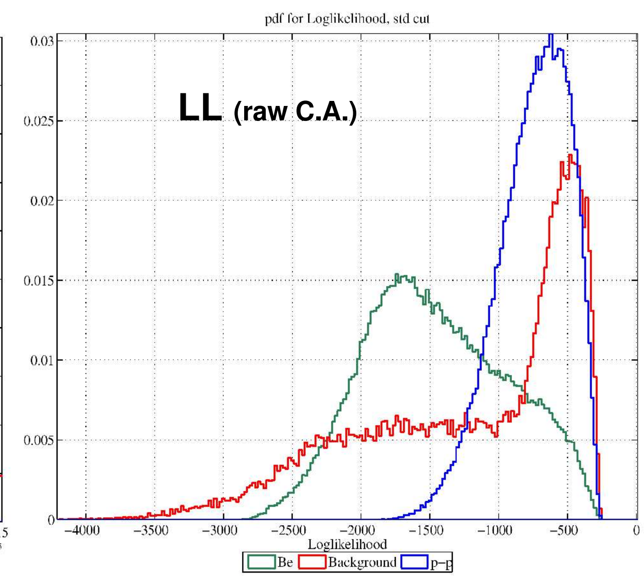
> Create large pool of bckgnd, pp & Be for creating "data" mixes
to test signal extraction procedures.











Available PDF's

(^{7}Be -- Bckgnd -- PP --)

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Procedures for flux extraction:

- **Data rates:**

  Signal: PP=1.85 Be=0.64 events/day-tonne

  for $\delta m^2 = 7.9 \times 10^{-5}\ eV^2\ \sin^2 \Theta_{12} = 0.31$

  Background: 5.16 events/day-tonne

- **Apply extended-LL method for 8 tonne and 11 tonne:**

$$extLL = -(N_{pp} + N_{Be} + N_{Bkg}) + \sum_j \ln(N_{pp}P_{pp}(v_j) + N_{Be}P_{Be}(v_j) + N_{Bkg}P_{Bkg}(v_j))$$

($P(v_j)$ are pdf's for either v_j = E, LL, R^2, Z or ddL)

- **Find solutions, errors and correlations among all 5 pdfs and two different fiducial volumes.**

HERON Error Budget(s)

	3 months PP	3 months 7Be	3 months Total nu's	1 year PP	1 year 7Be	1 year Total nu's	5 year PP	5 year 7Be	5 year Total nu's
	%	%	%	%	%	%	%	%	%
Energy scale (45keV thresh)	0.62	0.15	0.5	0.62	0.15	0.5	0.62	0.15	0.5
Fid. Vol. & Thresh. Cuts (resolution)	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Internal background	0	0	0	0	0	0	0	0	0
Density non-uniformity in target vol.	0	0	0	0	0	0	0	0	0
Cross sections	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Dead time correction	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Bckgnd/PP/7Be separation (PDF's):									
E	4.54	13.86	5.36	2.27	6.93	2.68	1.02	3.10	1.20
LL	5.74	17.65	7.04	2.87	8.82	3.52	1.28	3.95	1.57
DDL			4.19			2.10			0.94
R2			12.67			6.33			2.83
Z			18.30			9.15			4.09
TOTAL SYSTEMATIC:									
(by PDF-type) E	4.59	13.86	5.39	2.37	6.94	2.74	1.22	3.11	1.33
LL	5.78	17.65	7.06	2.95	8.83	3.57	1.45	3.96	1.67
DDL			4.23			2.17			1.10
R2			12.68			6.36			2.89
Z			18.31			9.17			4.13
STATISTICS:	2.72	4.63	3.38	1.36	2.31	1.69	0.61	1.03	0.76
EVENTS:	1350	467	3769	5400	1868	15076	27000	9340	75380

- ***Provides independent channels to PP, Be (& ν_{total}) flux with high precision.***
- ***Check: Independent of fiducial volume over range of volumes.***

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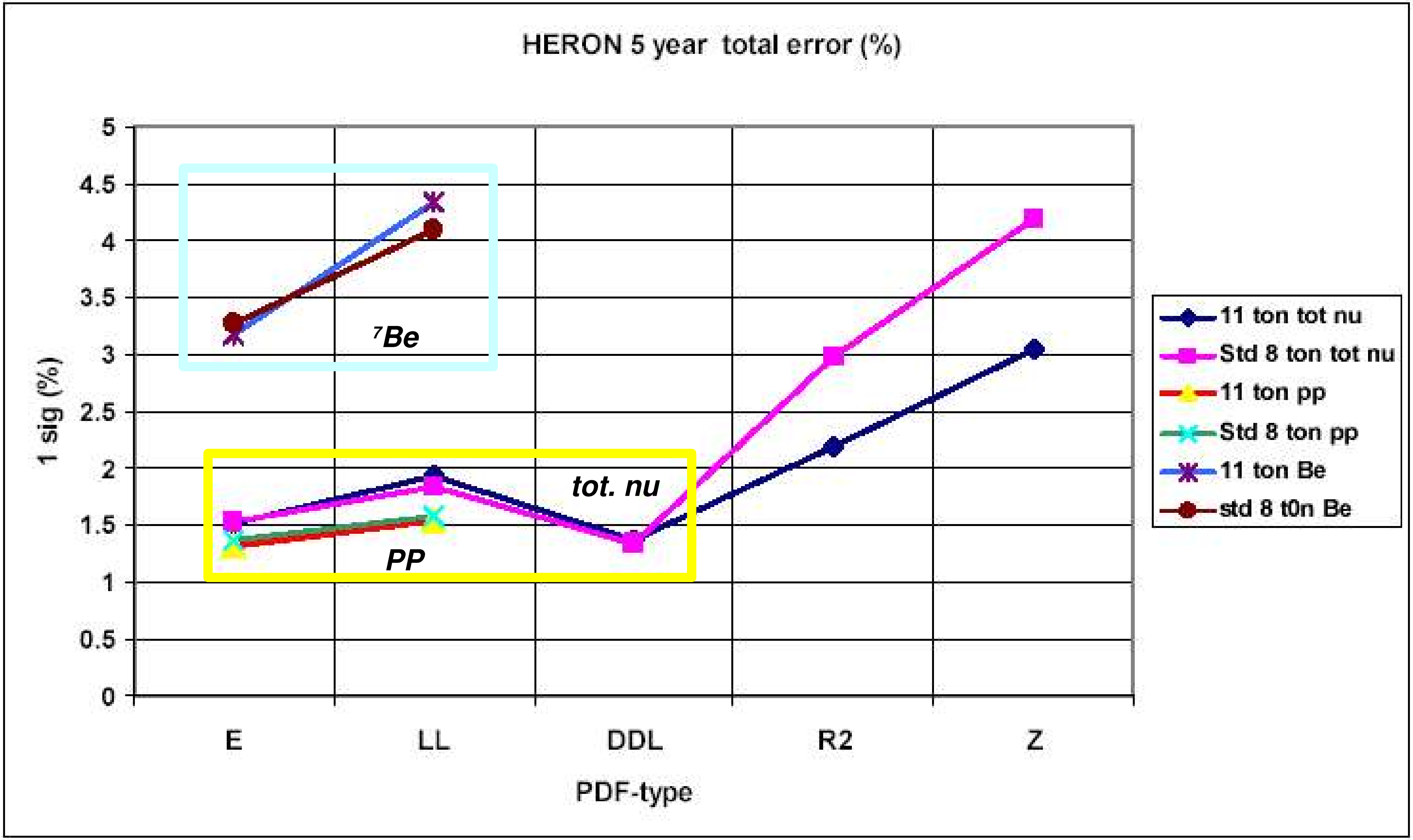
Comparison of different size fiducial volumes:



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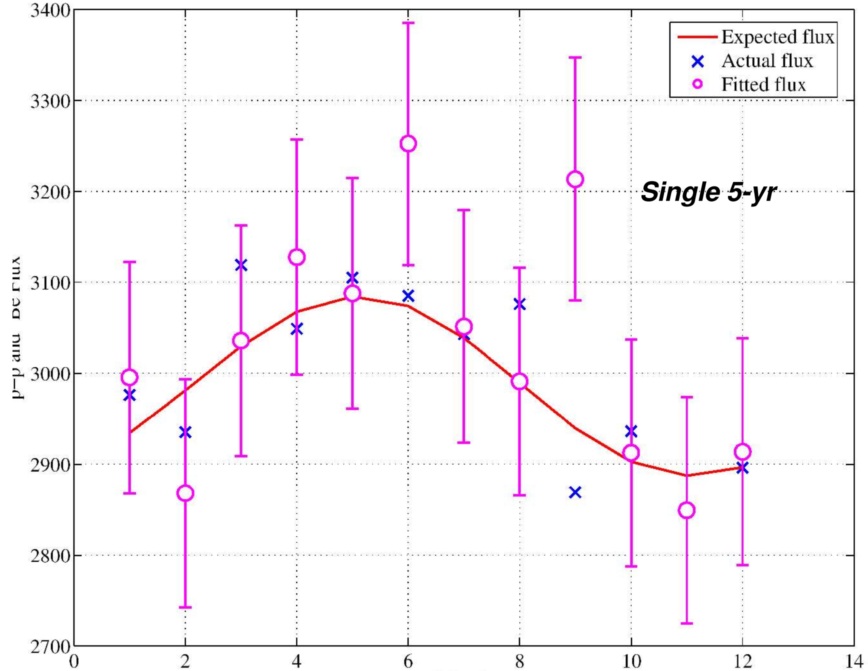
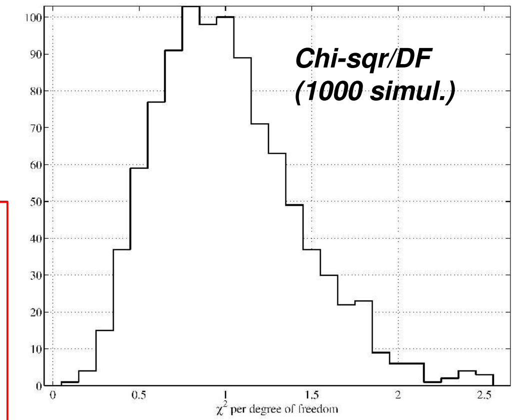
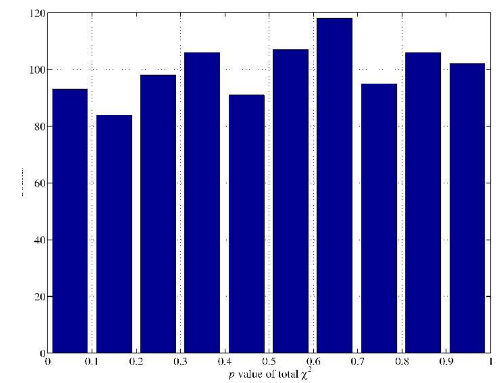


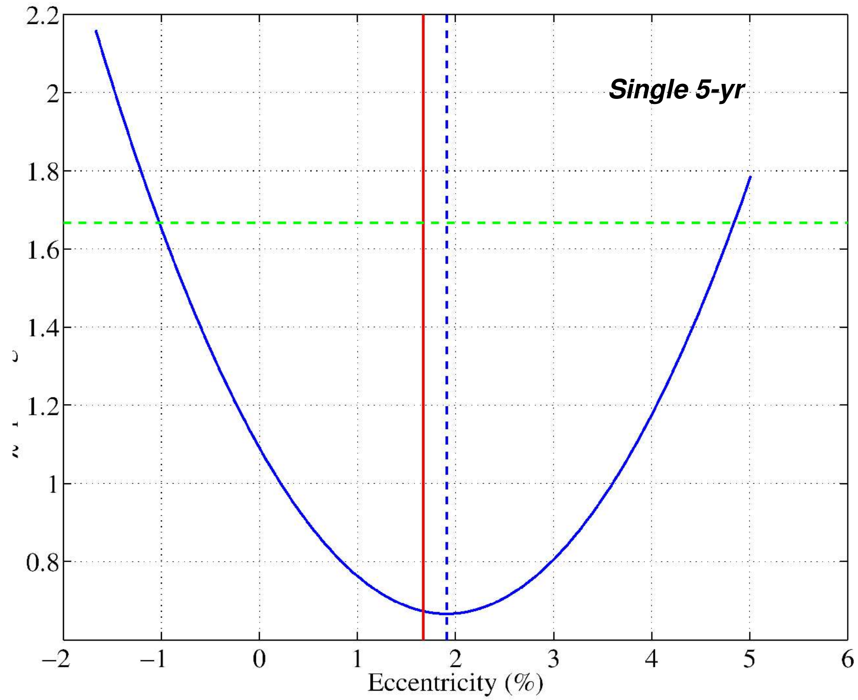
HERON

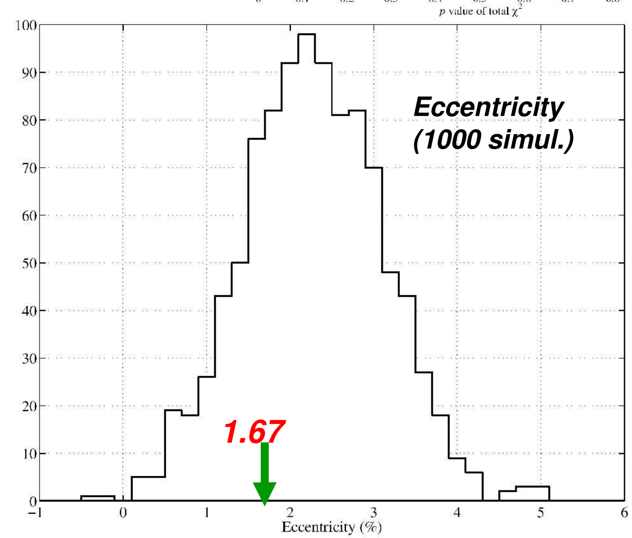
Modulation by eccentricity of annual Solar orbit

(1000 simulations Bckgnd, pp & Be)









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Summary, Plans and Conclusions:

- On basis of prototype experiments & simulations predict performance sufficient to measure PP flux to <1.5% , ^{7}Be to <4% and meet other physics goals if full scale HERON were to be built.

- Still need to wrap-up experiments on e-bubbles; further simulation details.

- Essential – and major – next step: Engineer & build a large scale prototype.
  - Need to know if superfluid design of this type can be built & costed.
  - Scale version a cryogenic engineering task of significant complexity & cost.
  - Not within the capability of university groups alone.

- Community has very exciting future program in ν physics:
  - Attested by long list of particle/nuclear topics, priorities, $$'s.
  - Presently, testing the solar model with ν's a very tough sell.

- Our decision, reluctantly:
  - Do not pursue the large scale prototype at this time.
  - Wrap-up present experiments.
  - Mothball the project and archive.

Very good documentation: >20 publications, 7 PhD theses on physics processes

Supplemental slides

on HERON not covered in this talk

Detection of PP and ^{7}Be Solar Neutrino Elastic Scattering in Superfluid Helium

H. Eguchi, Y.H. Huang, Y.H. Kim, R.E. Lanou H.J. Maris, A.N. Mocharnuck, G.M. Seidel, B. Sethumadhavan and W. Yao

Department of Physics, Brown University

With collaboration on wafer calorimetry by:

C. Enss, A. Fleischmann and J. Schonefeld

Kirchhoff Institut, Universitat Heidelberg

S.R. Bandler (NASA-Goddard) and S. Romaine (CfA-Harvard)

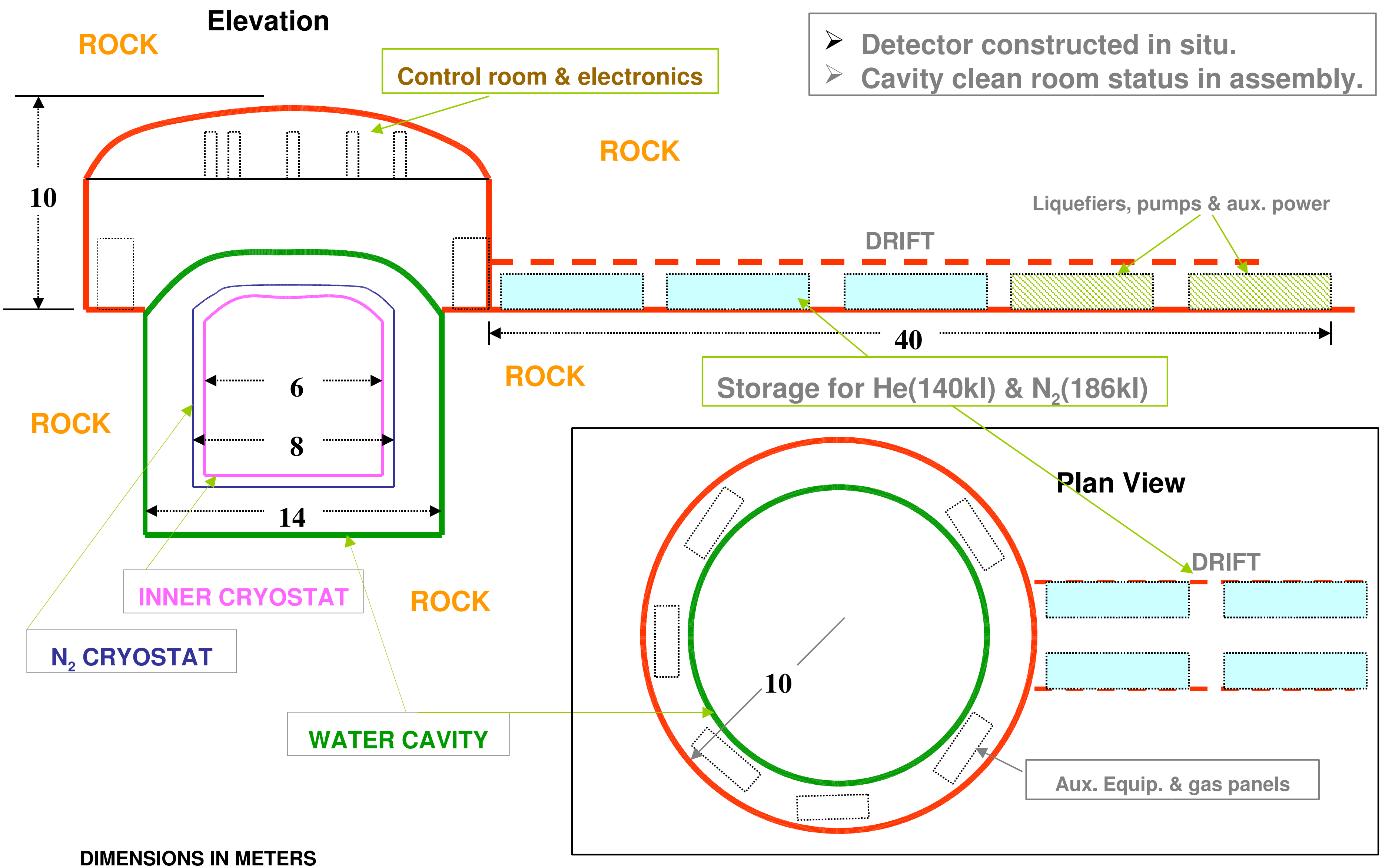
With collaboration on engineering & computation on simulations :

K.T. Lesko and A.W. Poon

Lawrence Berkeley National Laboratory

Sketch of possible space configuration for HERON (6000mwe)

- Detector constructed in situ.
- Cavity clean room status in assembly.



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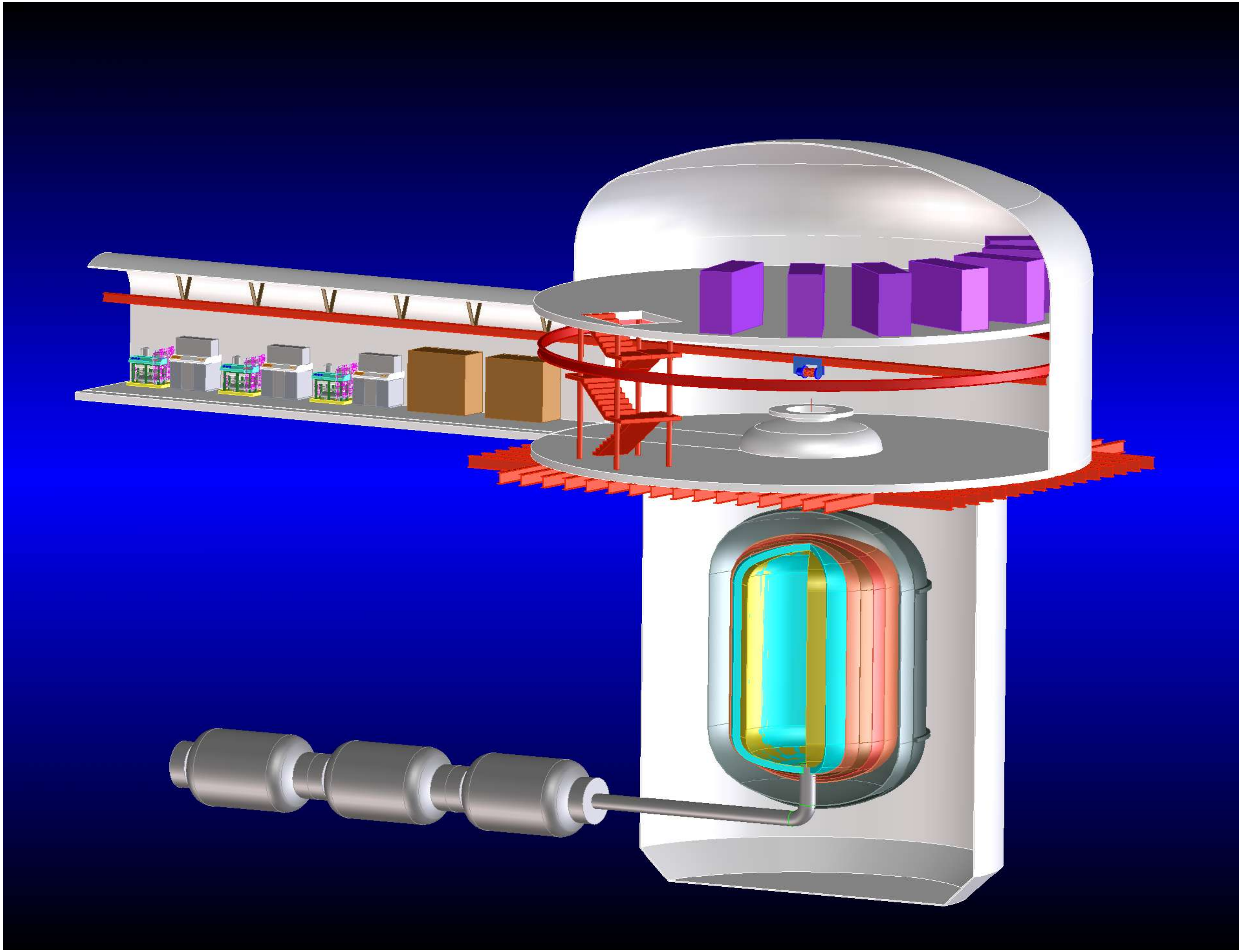
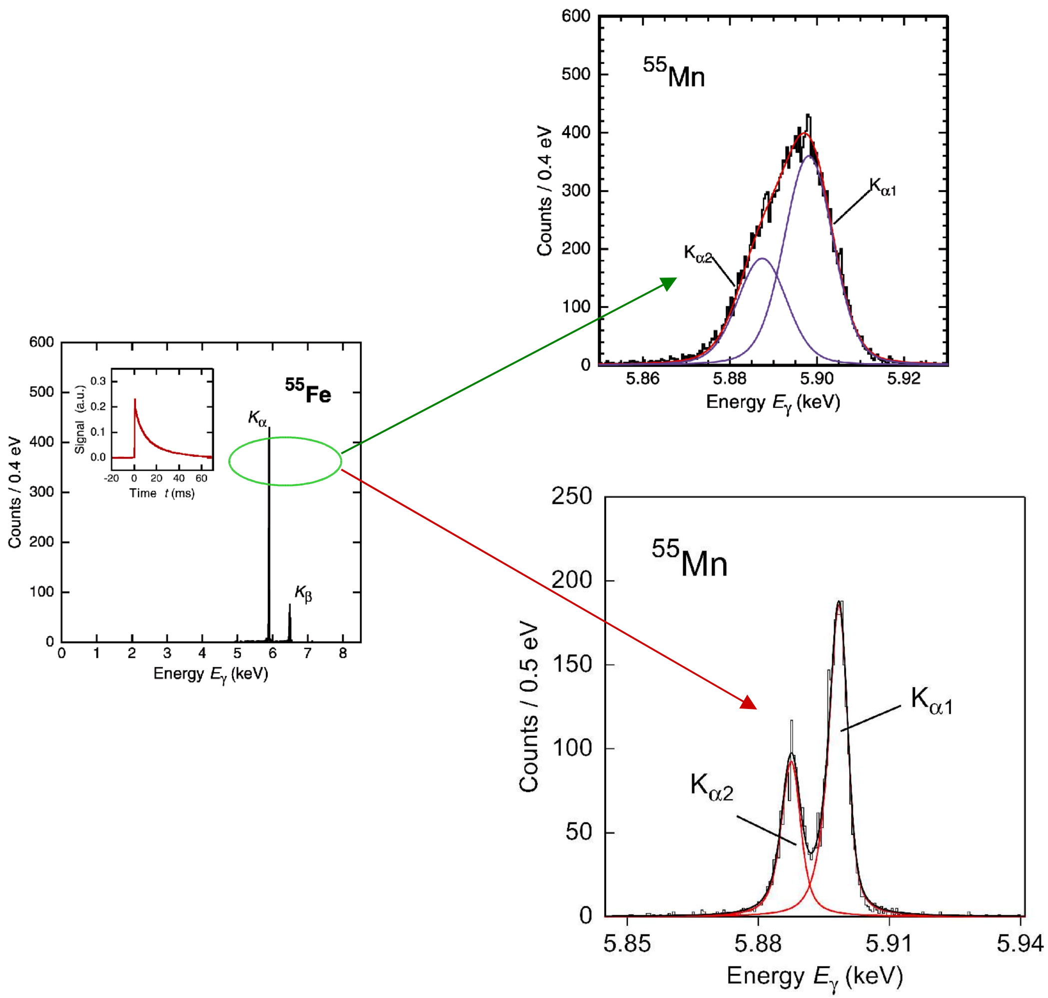


WAFER SENSITIVITY (single 16 eV photons and e-bubble/phonons)

Progress on metallic magnetic sensors for use on wafers:

- **MMS's were developed at Brown and Heidelberg for astrophysics.**
- **New results from Heidelberg collaborators.**



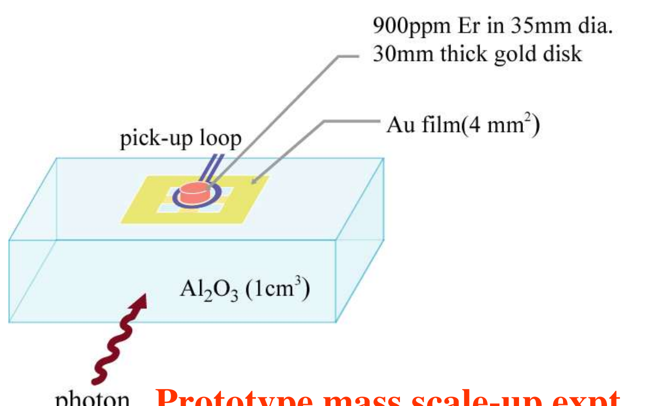
Last year at LowNu-III (9.6 eV)

April '03

New world record 3.4 eV for energy dispersive resolution.

(Implications for a CNO expt. with ^{7}Li)

Progress on scaling up to heat capacity of full scale wafers:

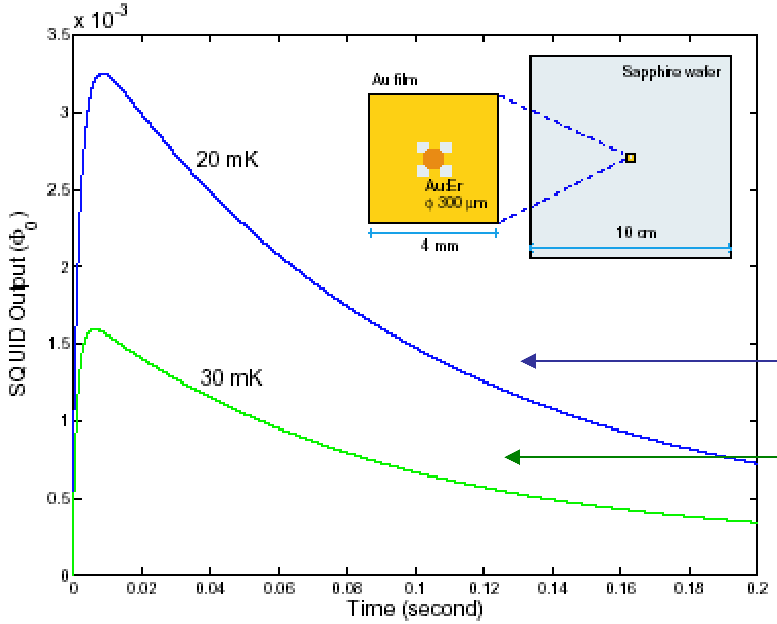


Prototype mass scale-up expt,

At LowNu-III:

- Expt. to measure physics quantities for scale-up
- Energy transfer processes (electron-phonon, athermal/thermal, Kapitiza)
- Relative heat capacities
- Thermal links time constants

Results allow simulation of full scale wafer performance:



- Sapphire wafer 10x10x0.04 cm
- Metallic magnetic sensor (Er:Au) @ 50 gauss

- Single 16 eV photon:

factor 15 (20 mK)

above thermal & SQUID noise

factor 4 (30 mK)

- Sensitivity good; decay time needs work.

ELECTRON DRIFT IN SUPERFLUID HELIUM ("e-bubbles")

- ***What is the fate of the recoil electron in the superfluid & can we use it?***

- ***Unusual but well established properties of e^- in liquid ^4He***

  (Sanders, Reif, Packard, Donnelly, Rayfield, Williams, Landau, Fetter ----)

- ***Stopped e^- trapped in "bubble"-void:***
  - ***Pauli principle; high zero point energy (1 eV).***
  - ***R ~ 18 Å***
  - ***~500 He atoms displaced. $F = M^* a$***
  - ***$M^* \sim 243\, m_{He}$ → $a = +2g$!***
  - ***If un-impeded would rise to surface ala "anti- free-fall".***
  - ***Held at free surface by image charge potential unless released.***

- ***Some considerations on velocities & releasing:***
  - ***Thermal phonons, ^3He limit attainable velocity. v(T).***
  - ***In superfluid, vortex generation limits to < 40 m/s.***
  - ***Modest electric fields can control velocity and release charges at surface.***

- ***Can we make use of this and why would we want to?***
  - ***Use in conjunction with scintillation fast trigger and event signature.***
  - ***e^- from ν event in single wafer vs. multi-wafer for distributed Compton bckgnds.***
  - ***Time delay & wafer hits give redundant position info.***
  - ***e^- signal can be made larger than roton signal. A comparison of alternatives.***

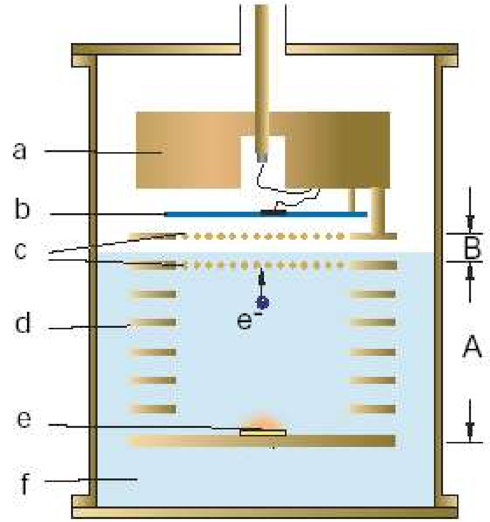
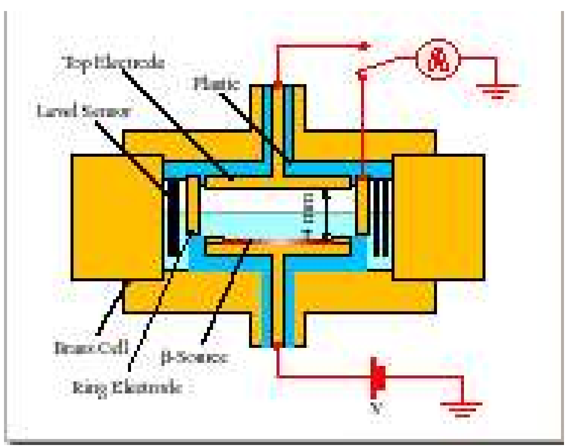
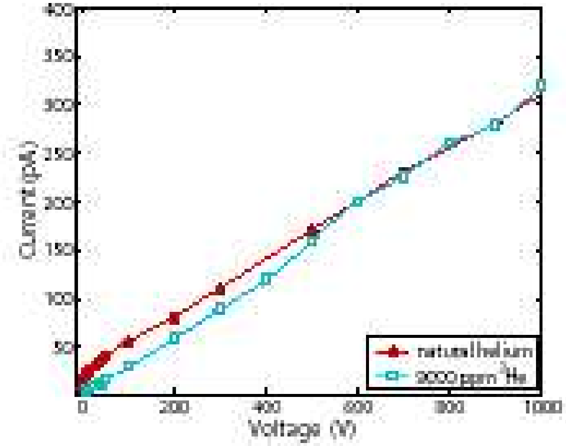
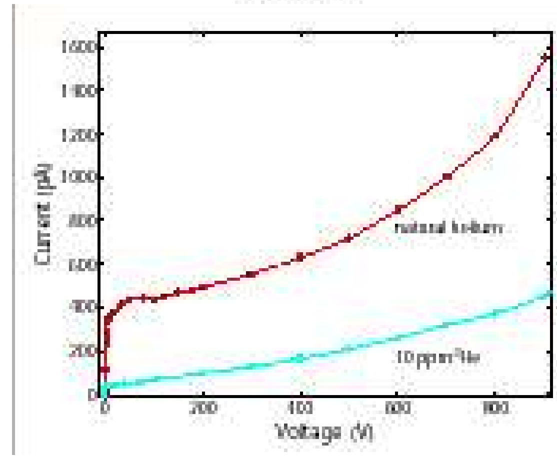
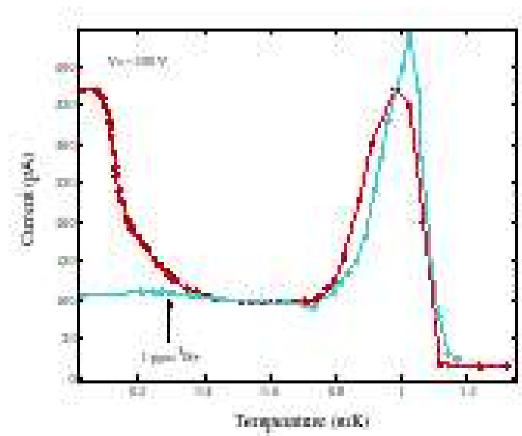


Figure 1. Experimental setup. a, helium free stage. b, calorimeter. c, grid electrodes. d, drifting field electrode rings. e, electron source. f, superfluid helium.

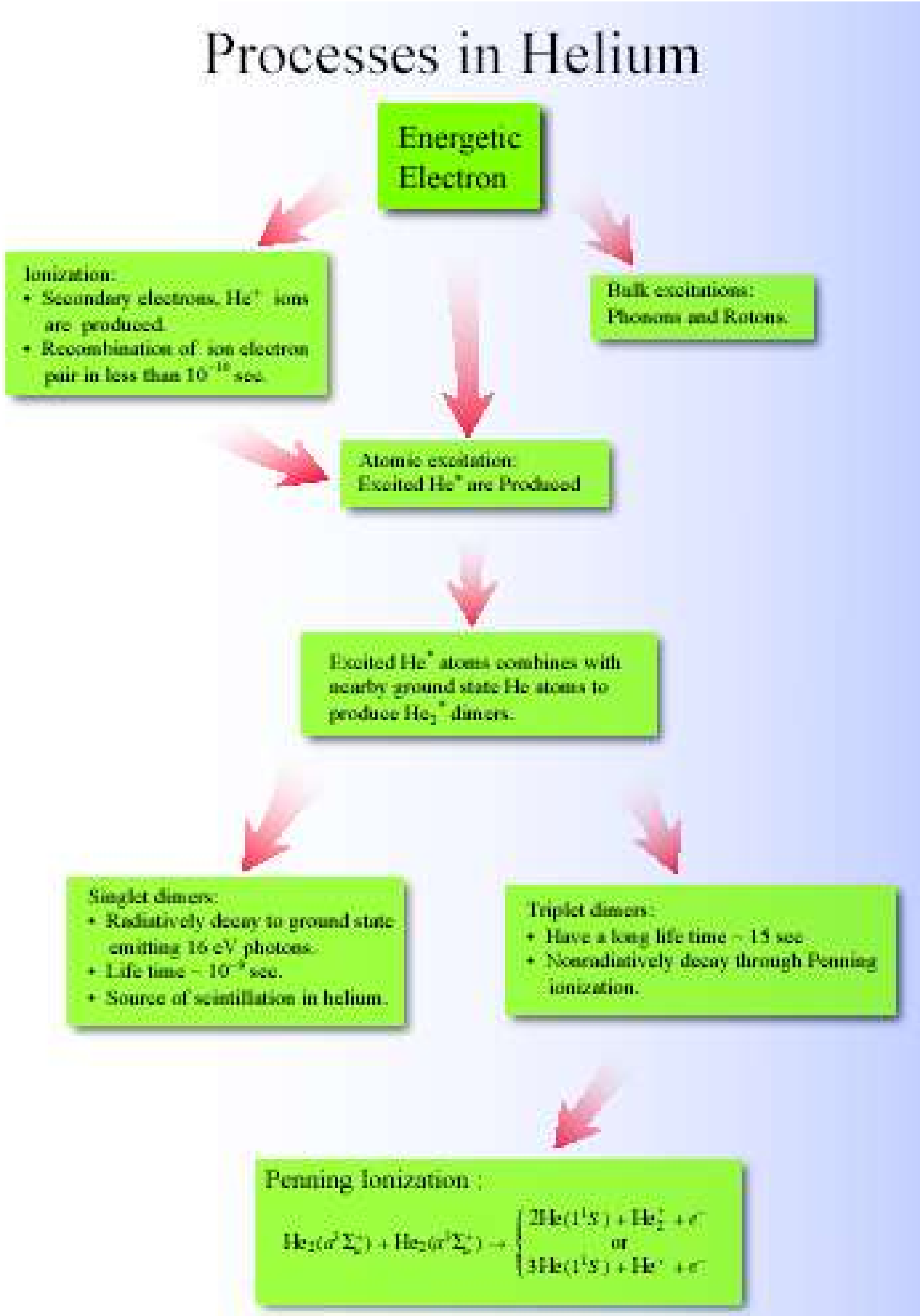






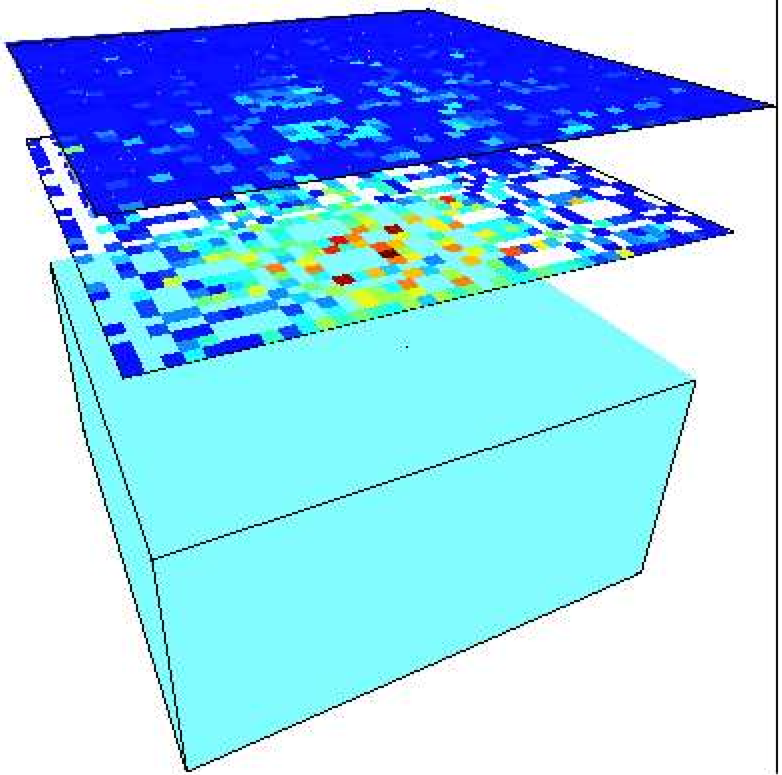


from B. Sethumadhavan poster



from B. Sethumadhavan poster

The HERON Coded Aperture



HERON's mask of choice is a URA array. However there are differences compared to typical coded aperture imaging:

- ✗ Low statistics:

  ~10/hole, not hundreds or thousands.

- ✗ Complex math:

  3-dimensinal instead of 2-d; difficult to apply Green's function approach.

- ✗ Noise:

  Container walls will contribute greatly to background.

- ✓ Simpler source geometry:

  We only expect to deal with one or a few source points.

- ✓ More sensors:

  The mask itself can be made of detectors.

From Y.H. Huang seminar

Loglikelihood

Since Green's function is difficult to derive for HERON's geometry, a loglikelihood is used instead:

$$\mathcal{L}(\mathbf{x}) \equiv \ln\left(\prod_{i} \frac{1}{n_i!}\left(\frac{\omega_i(\mathbf{x})}{\Omega(\mathbf{x})}\right)^{n_i}\right)$$

where

$\omega_i(\mathbf{x})$: Solid angle for the i^{th} detector

$\Omega(\mathbf{x})$: Total solid angle

n_i : Photon counts on i^{th} detector

$\mathcal{L}$ represents the probability of given light pattern comes from a single source located at $\mathbf{x}$. Compared with Green's function approach:

- Instead of direct reconstruction, searching algorithms were developed to find global minimum of $\mathcal{L}$.
- More flexible, easier to implement.

From Y.H. Huang seminar

	E_bg	E_pp	E_be	ddl_bg	ddl_pp	ddl_be	ll_bg	ll_pp	ll_be	r2_bg	r2_pp	r2_be	z_bg	z_pp	z_be
E_bg	1.000	-0.753	-0.787	0.054	-0.005	-0.016	0.722	-0.610	-0.549	-0.054	0.019	-0.017	-0.026	0.000	0.002
E_pp	-0.753	1.000	0.186	-0.036	0.048	-0.029	-0.506	0.758	0.077	0.017	-0.021	0.020	0.002	0.009	-0.009
E_be	-0.787	0.186	1.000	-0.047	-0.038	0.050	-0.604	0.201	0.748	0.065	-0.010	0.007	0.037	-0.008	0.005
ddl_bg	0.054	-0.036	-0.047	1.000	0.146	-0.497	0.003	-0.001	-0.004	-0.117	-0.004	0.009	-0.020	-0.034	0.035
ddl_pp	-0.005	0.048	-0.038	0.146	1.000	-0.931	0.048	0.025	-0.098	0.011	-0.006	0.005	0.044	0.049	-0.053
ddl_be	-0.016	-0.029	0.050	-0.497	-0.931	1.000	-0.043	-0.022	0.087	0.034	0.006	-0.008	-0.031	-0.031	0.033
ll_bg	0.722	-0.506	-0.604	0.003	0.048	-0.043	1.000	-0.785	-0.816	-0.012	0.007	-0.006	-0.001	0.005	-0.005
ll_pp	-0.610	0.758	0.201	-0.001	0.025	-0.022	-0.785	1.000	0.283	0.005	-0.012	0.012	-0.018	0.011	-0.010
ll_be	-0.549	0.077	0.748	-0.004	-0.098	0.087	-0.816	0.283	1.000	0.013	0.001	-0.002	0.019	-0.018	0.017
r2_bg	-0.054	0.017	0.065	-0.117	0.011	0.034	-0.012	0.005	0.013	1.000	-0.368	0.331	-0.007	-0.008	0.009
r2_pp	0.019	-0.021	-0.010	-0.004	-0.006	0.006	0.007	-0.012	0.001	-0.368	1.000	-0.999	0.012	-0.011	0.010
r2_be	-0.017	0.020	0.007	0.009	0.005	-0.008	-0.006	0.012	-0.002	0.331	-0.999	1.000	-0.012	0.011	-0.010