The NPDGamma Experiment at the SNS

- **Motivation**

  Weak Interaction between quarks

  Radiative capture of polarized cold neutrons in protons

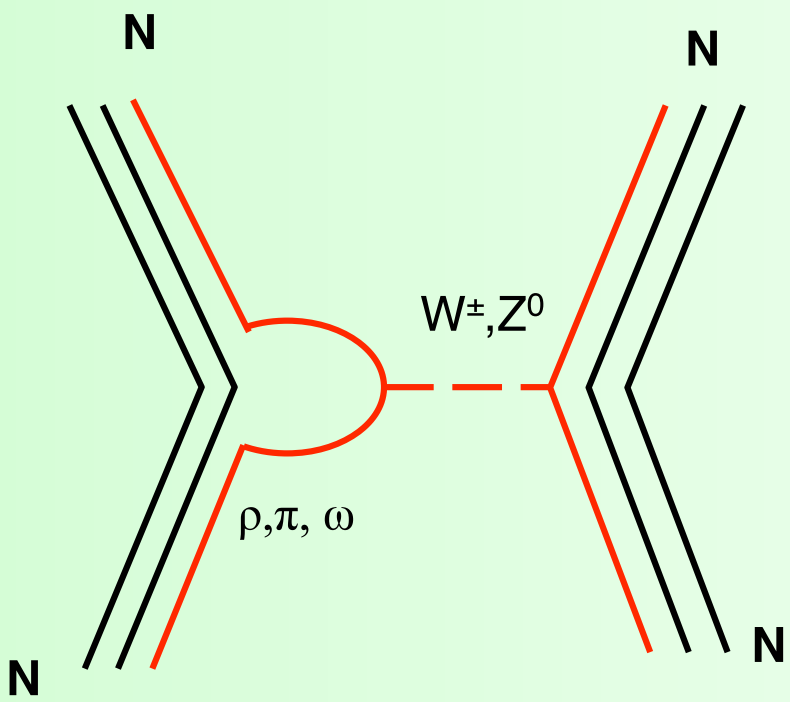
- **NPDGamma experiment at the SNS**

  Status report

- **Summary and Outlook**

5th International Symposium on Symmetries in Subatomic Physics, Groningen, June 18-22, 2012

Hadronic Weak Interaction (HWI)



- Probe of *qq* correlations in hadrons (range W-Z exchange << N size).

- Natural scale ~ x 10^{-7}, set by relative size of meson vs boson exchange amplitudes.

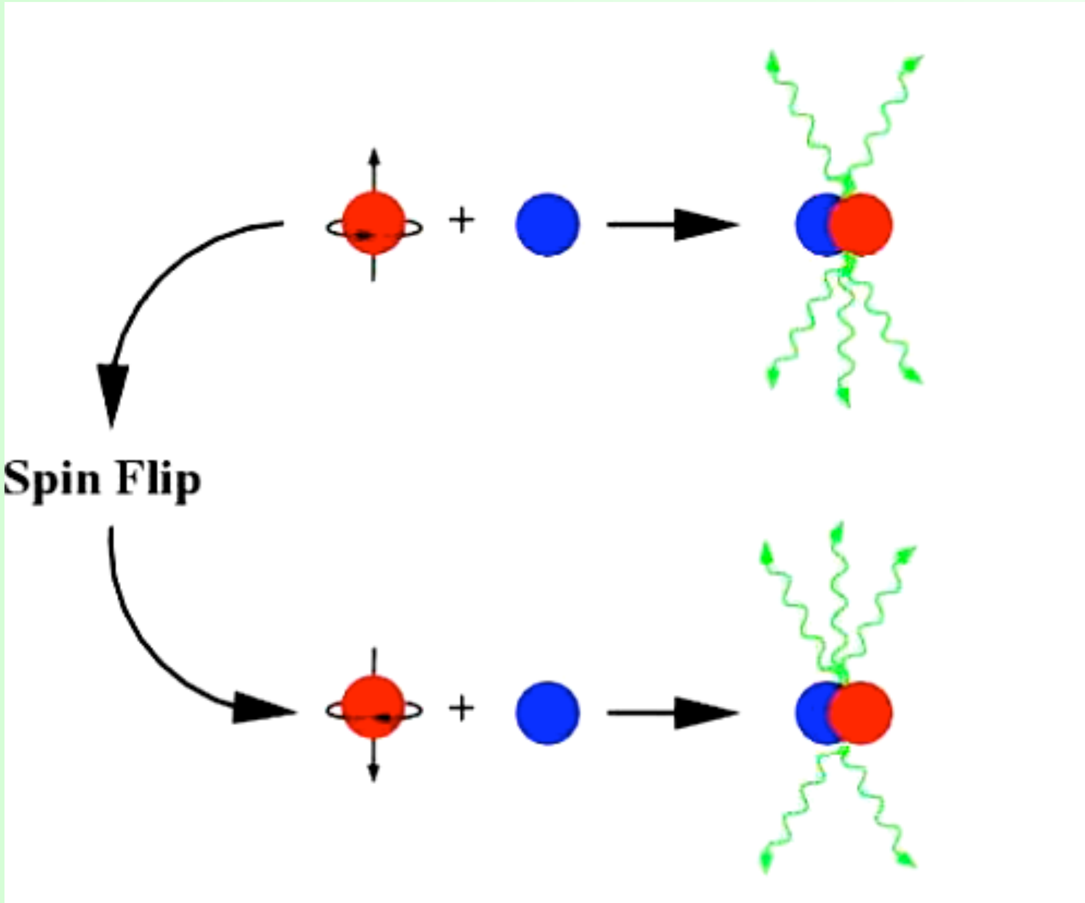
- At low energy, the weak *NN* is sensitive to qq neutral current effects.

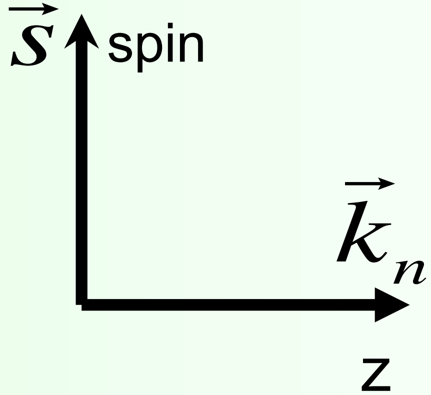
- Induce parity-odd effects in electron scattering, nuclear decays, compound nuclear resonances, and atomic structure (nuclear anapole moments).

- Above QCD scale Λ = 1 GeV, at the quark level, the *qq* weak interaction can be written in a current-current form (ΔI= 0, 1, 2).

- At the nucleon level, below Λ, five independent weak transition amplitudes (ΔI= 0, 1, 2) are present in NN elastic scattering at low energy.

The PV γ-ray asymmetry in $\vec{n} + p \rightarrow d + \gamma$ is dominated by the *ΔI=1* parity-odd transition amplitude ($^3S_1$-$^3P_1$) expected from the HWI between nucleons.





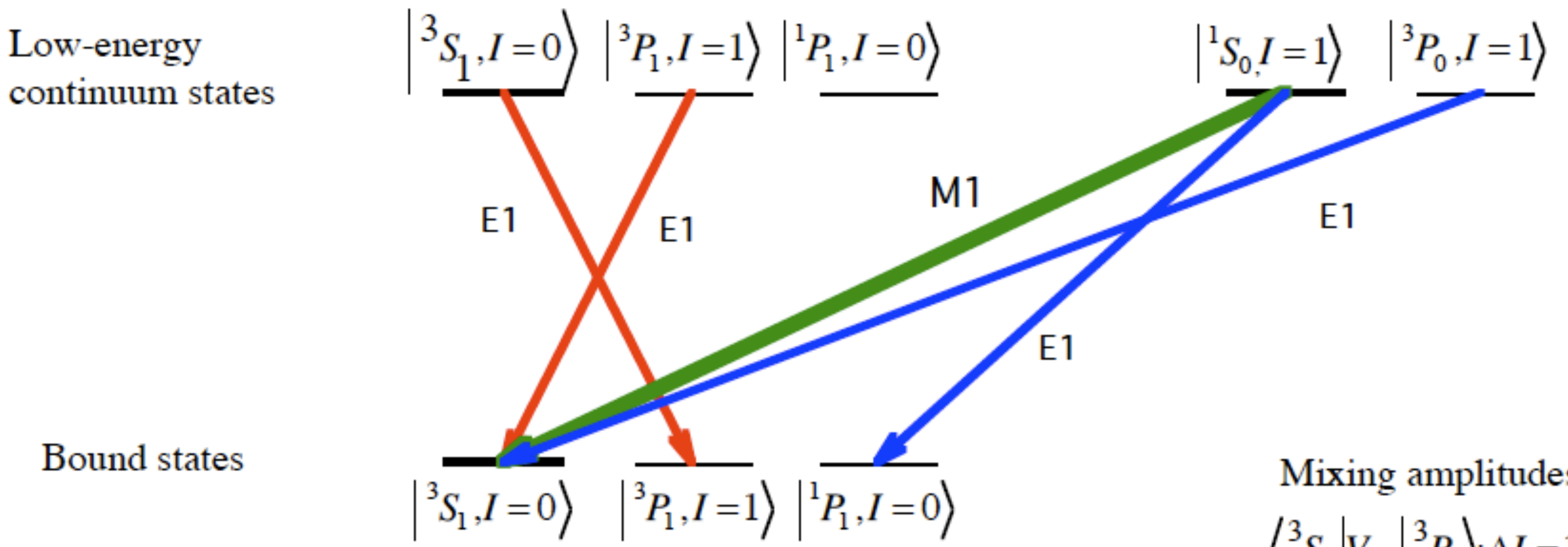
$$\cos\theta = \hat{s} \cdot \hat{k}_\gamma$$

$$\vec{s} \cdot \vec{k}_\gamma$$

$$\vec{s} \cdot (\vec{k}_n \times \vec{k}_\gamma)$$

$$\frac{d\sigma}{d\Omega} \propto \frac{1}{4\pi}(1 + A_{\gamma,UD}\cos\theta + A_{\gamma,LR}\sin\theta)$$

Simple Level Diagram of *n-p* System; $\vec{n}+p\rightarrow d+\gamma$ is primarily sensitive to the Δ*I* = 1 component of the weak interaction



Mixing amplitudes:

$\langle ^3S_1 | V_W | ^3P_1 \rangle; \Delta I = 1$

$\langle ^3S_1 | V_W | ^1P_1 \rangle; \Delta I = 0$

$\langle ^1S_0 | V_W | ^3P_0 \rangle; \Delta I = 2$

- Weak interaction mixes in *P* waves to the singlet and triplet *S*-waves in initial and final states.
- Parity conserving transition is $M1$.
- Parity violation arises from mixing in *P* states and interference of the $E1$ transitions.
- A_γ is coming from $^3S_1$ - $^3P_1$ mixing and interference of $E1$-$M1$ transitions - $\Delta I = 1$ channel.

Hadronic Weak Interaction Models

1. **DDH model** – uses valence quarks to calculate effective PV meson-nucleon coupling directly from SM via 7 weak meson coupling constants

$$f_\pi^1, h_\rho^0, h_\rho^1, h_\rho^{1'}, h_\rho^2, h_\omega^0, h_\omega^1$$

- Observables can be written as their combinations

$$A = a_\pi^1 f_\pi^1 + a_\rho^0 h_\rho^0 + a_\rho^1 h_\rho^1 + a_\rho^2 h_\rho^2 + a_\omega^0 h_\omega^0 + a_\omega^1 h_\omega^1$$

	$n+p \blacktriangleright d+\gamma$ A_γ (ppm)	$n+d \blacktriangleright t+\gamma$ A_γ (ppm)	n-p φ_{PV} (μrad/m)	n-^4He φ_{PV} (μrad/m)	p-p $\Delta\sigma/\sigma$ (ppm)	p-^4He $\Delta\sigma/\sigma$ (ppm)
f_π	-0.107	-0.92	-3.12	-0.97		-0.340
h_ρ^0		-0.50	-0.23	-0.32	0.079	0.140
h_ρ^1	-0.001	0.103		0.11	0.079	0.047
h_ρ^2		0.053	-0.25		0.032	
h_ω^0		-0.160	-0.23	-0.22	-0.073	0.059
h_ω^1	0.003	0.002		0.22	0.073	0.059

$f_\pi \sim 4.5 \times 10^{-7}$

Weak π–nucleon coupling (long range)

$A_\gamma \approx -0.11 f_\pi^1$

HWI Models - Continued

2. Effective Field Theory

– developed by Holstein, Ramsey-Musolf, van Kolck, Zhu and Maekawa

– model-independent

- NN potentials are expressed in terms of 12 parameters, whose linear combinations give us 5 low energy coupling constants
  - connect to 5 parity-odd S-P NN amplitudes

$\lambda_t, \lambda_s^{I=0,1,2}, \rho_t$ Corresponding to

$$^1S_0 \rightarrow {}^3P_0 \quad (\Delta I = 0,1,2)$$

$$^3S_1 \rightarrow {}^1P_1 \quad (\Delta I = 0)$$

$$^3S_1 \rightarrow {}^3P_1 \quad (\Delta I = 1)$$

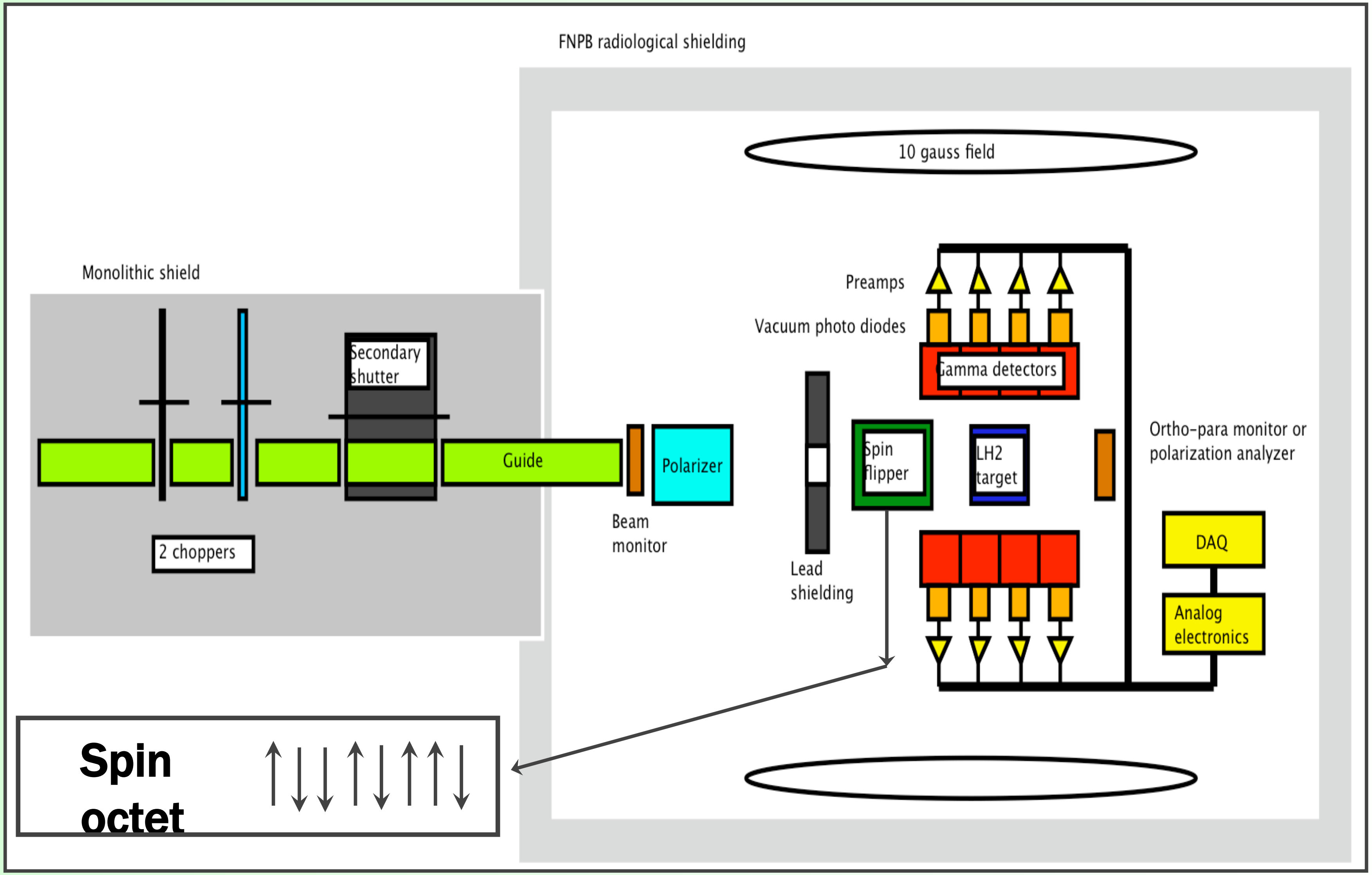
$$A_\gamma^{\vec{n}p} \approx -0.27\tilde{C}_6^\pi - 0.09 m_N \rho_t$$

3. Lattice QCD (NEW)

– J. Wasem, PRC C85 (2012)

$$h^1_{\pi NN} = 1.099 \pm 0.505 {}^{+0.058}_{-0.064} \; [\times 10^{-7}]$$

NPDGamma – Experimental Setup



LANSCE Results and Improvements for SNS

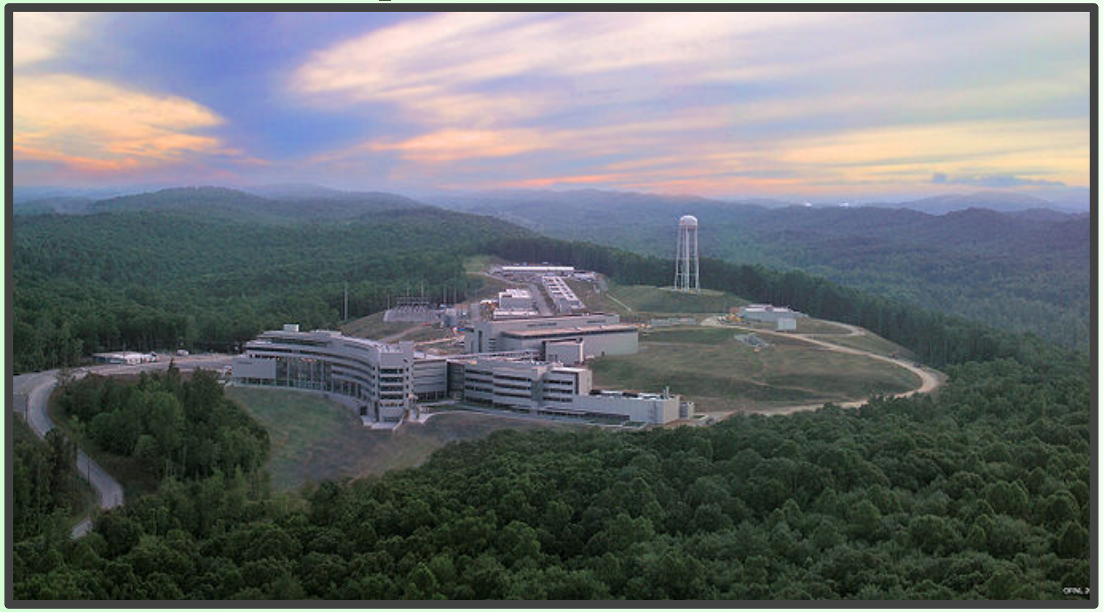
$$A_{\gamma,UD} = \left[-1.2 \pm 2.1(stat.) \pm 0.2(sys.)\right] \times 10^{-7}$$

$$A_{\gamma,LR} = \left[-1.8 \pm 1.9(stat.) \pm 0.2(sys.)\right] \times 10^{-7}$$

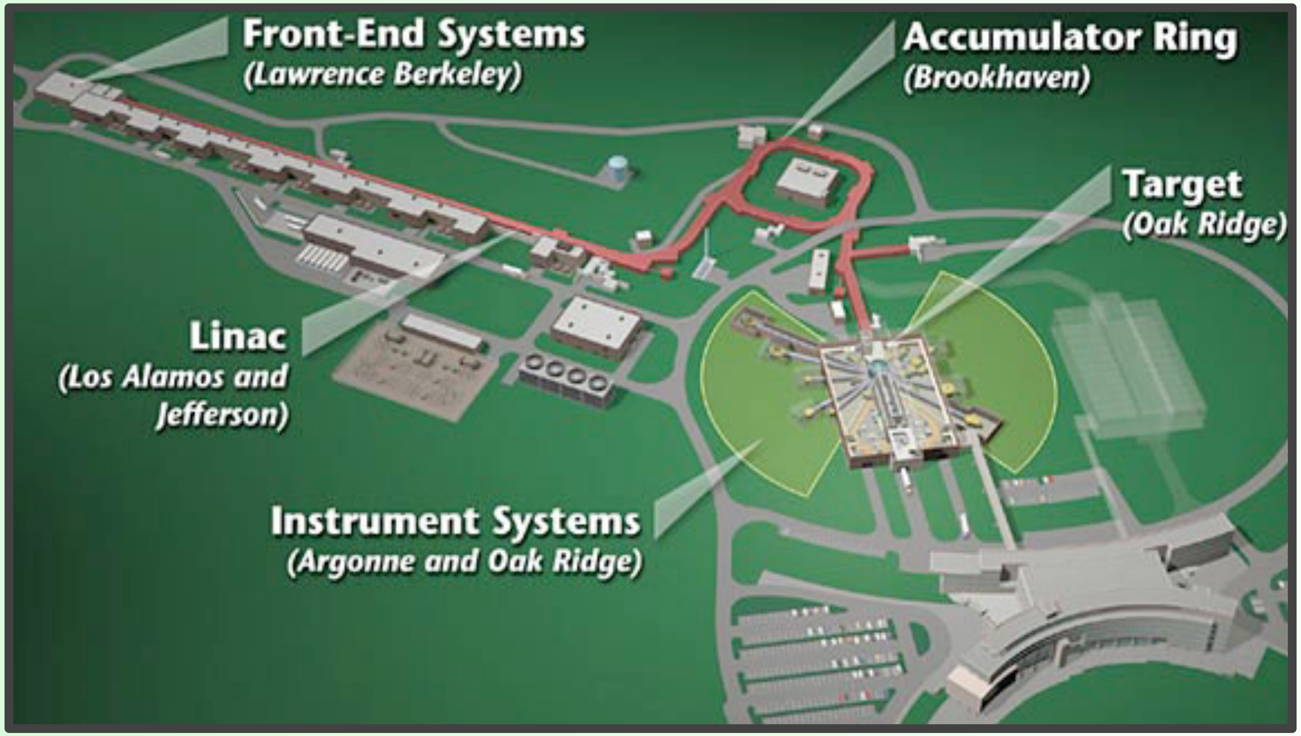
M.T. Gericke et al., Phys. Rev **C83**, 015505 (2011)

Sensitivity	$2x10^{-7}$	$1x10^{-8}$
Polarizer	^3He polarizer (average 55% NP)	SuperMirror Polarizer (95% NP)
FOM (NP^2)	$8.9x10^7/s$	X200 improvement
Target	16L, LH_2	New and improved, thinner windows

Spallation Neutron Source at ORNL

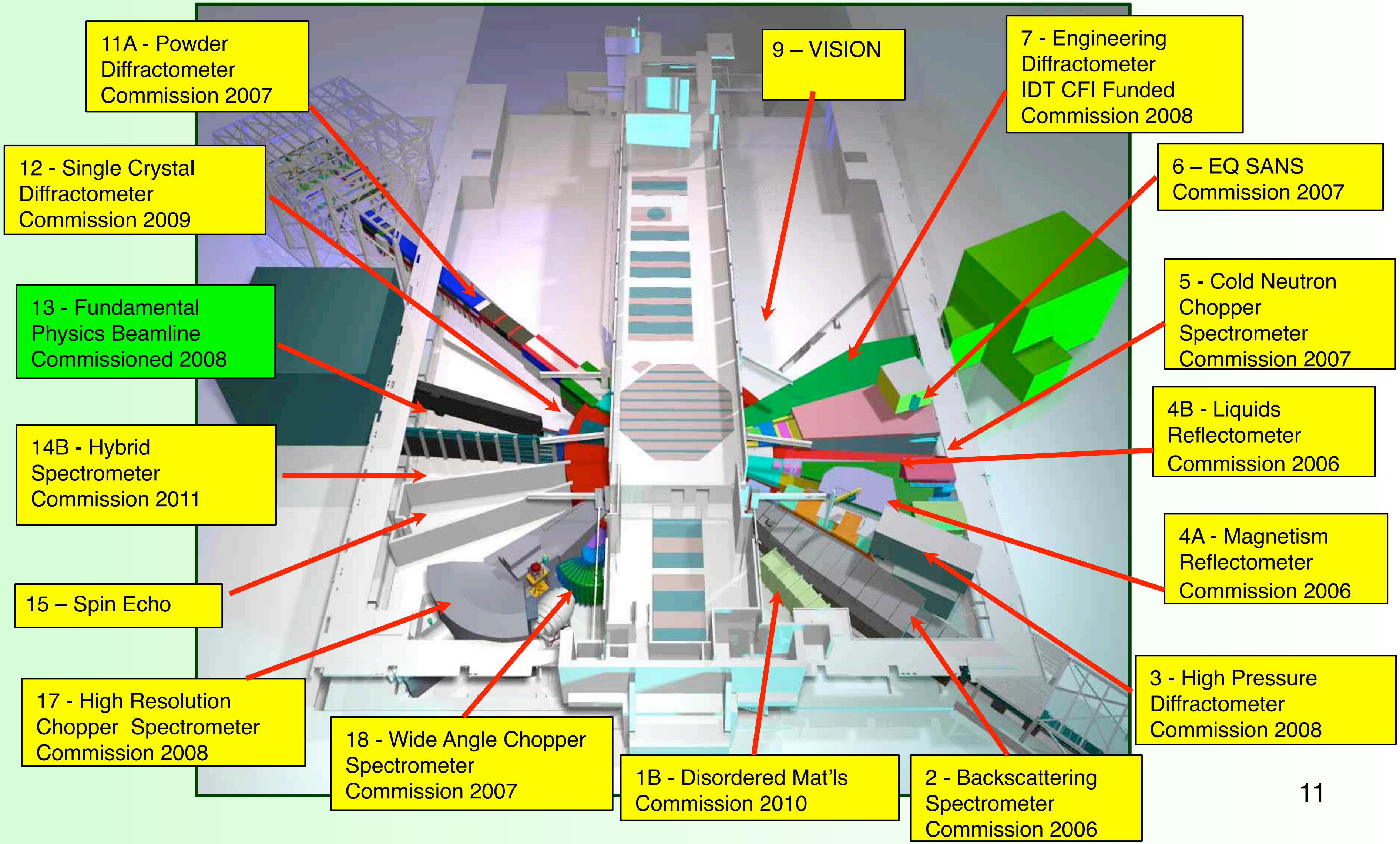


- 1.4 GeV protons, 60Hz
- Hg Spallation target → neutrons
- H_2 moderator
- 17 m SM guide, curved

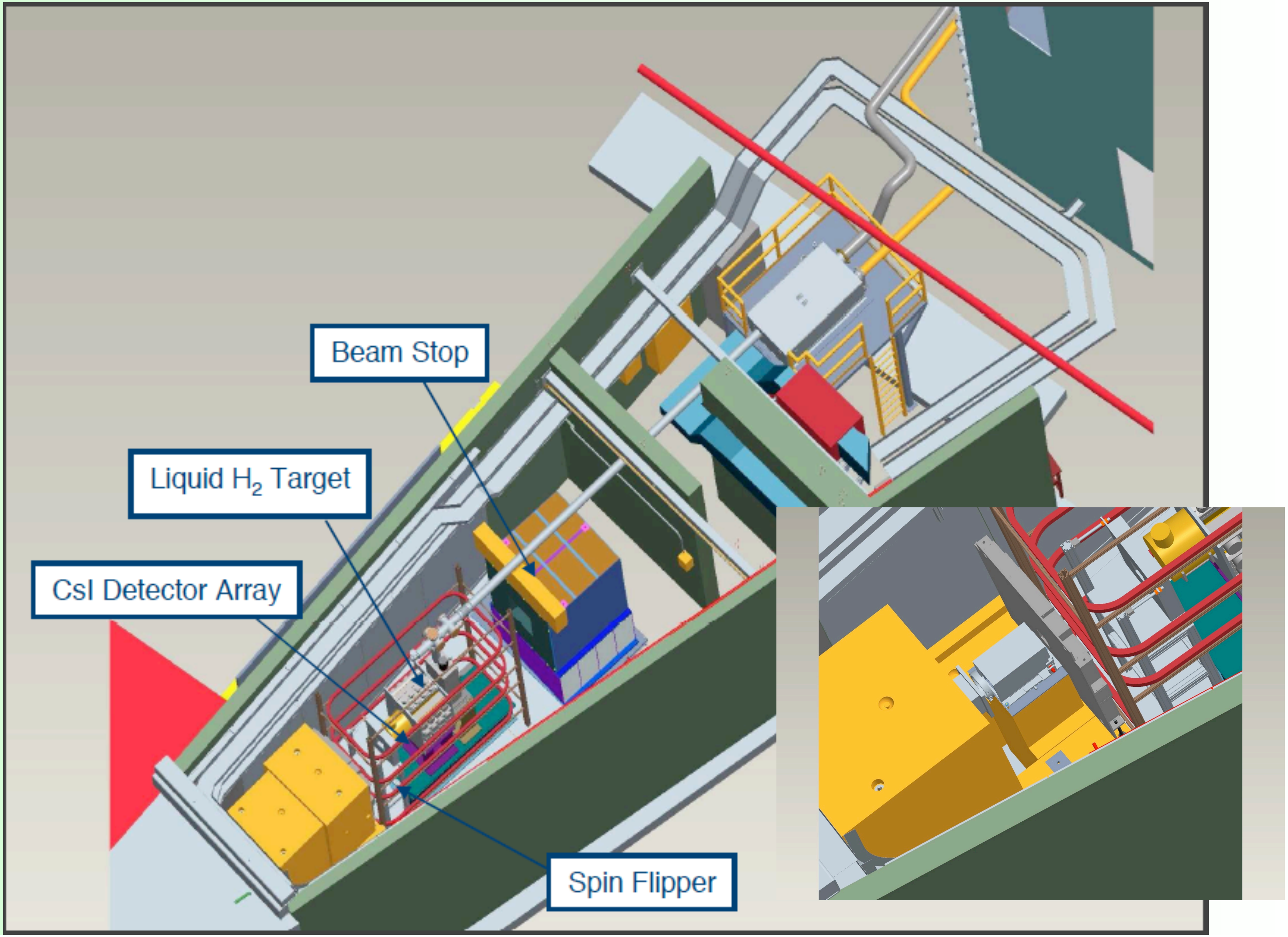


Spallation Neutron Source at ORNL

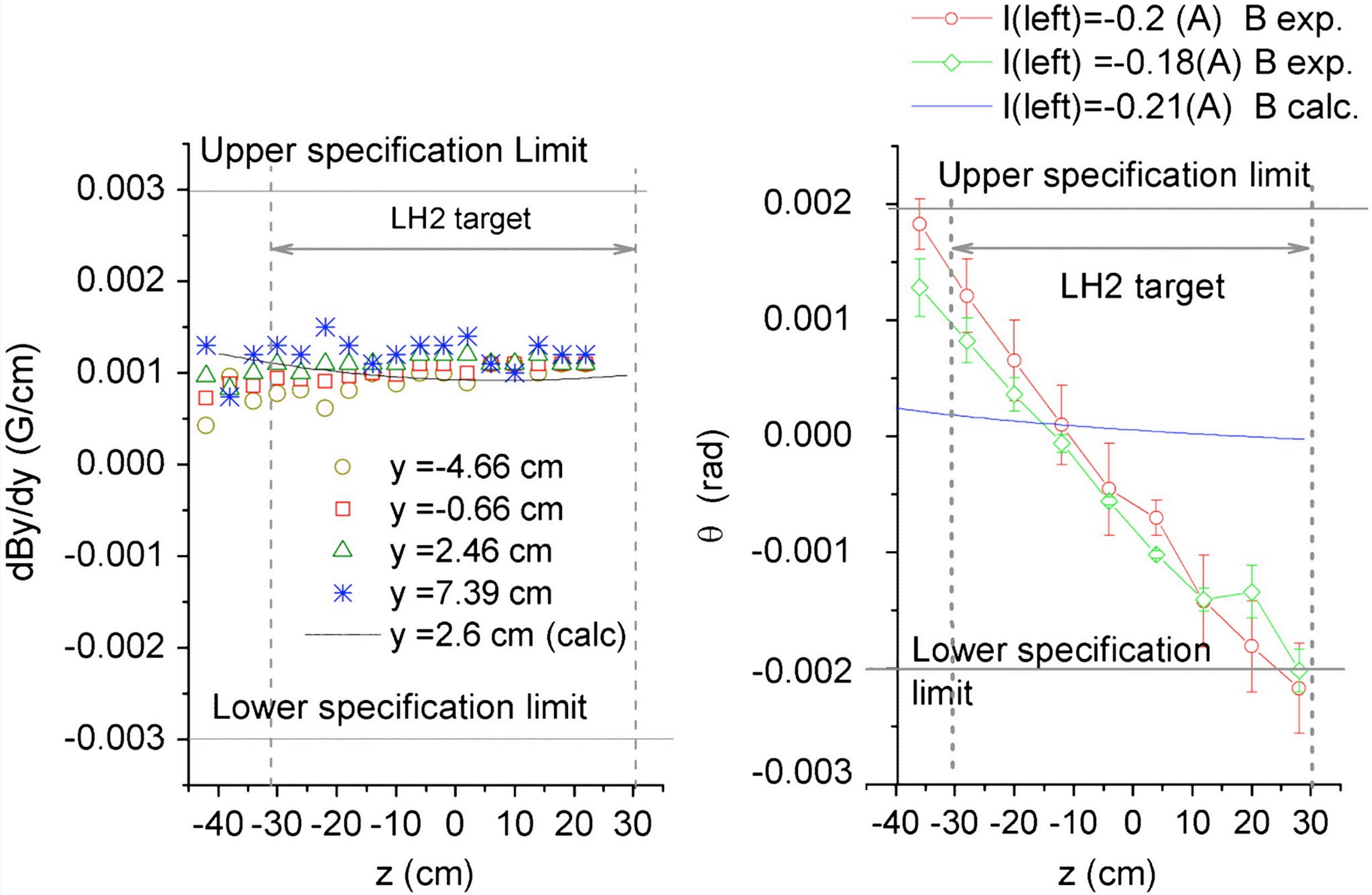
Reached 1MW of power – September, 2009



The NPDGamma Experiment at the SNS



Magnetic Field Measurements

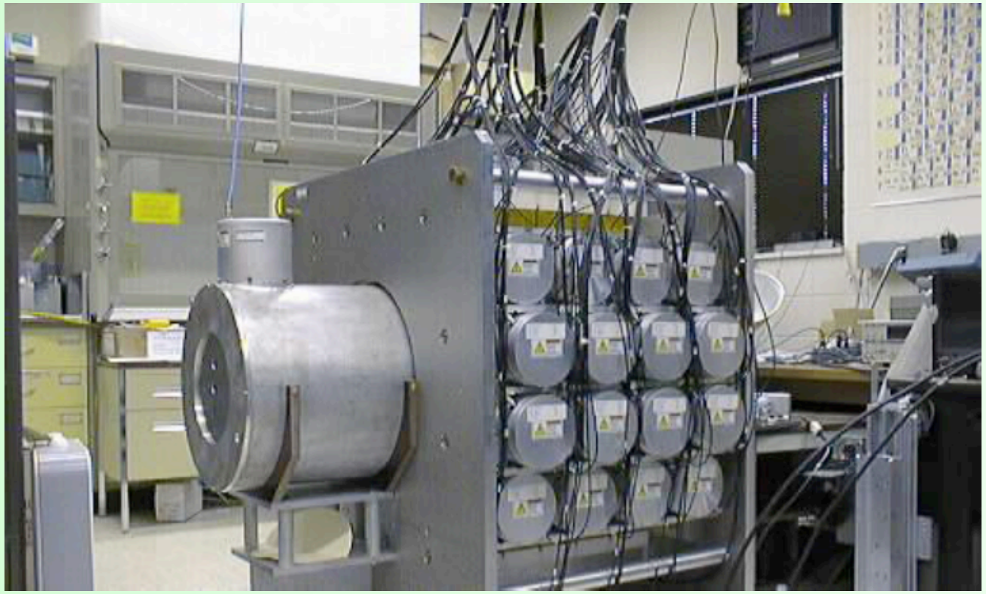


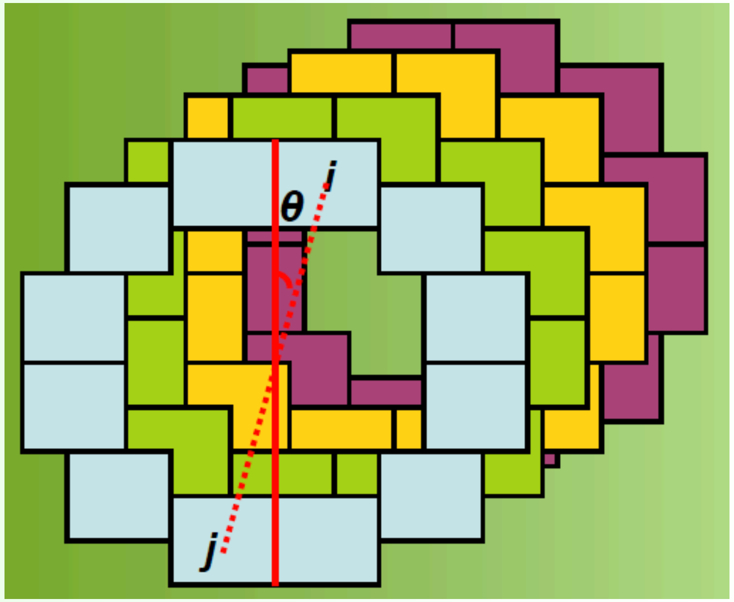
S. Balascuta *et al*, NIMA **671**, 137-143 (2012)

Photon CsI Detector System

There are 48 detectors arranged in 4 rings.

~ 3π geometrical solid angle.





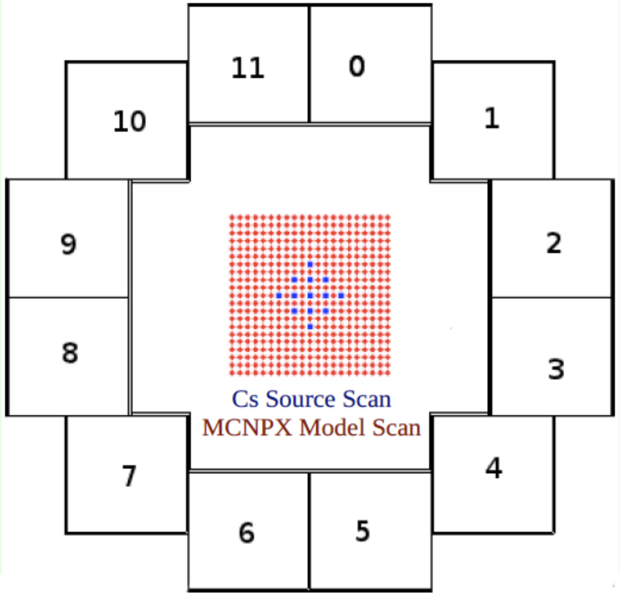
$$A_{raw} = \frac{Y^{\uparrow} - Y^{\downarrow}}{Y^{\uparrow} + Y^{\downarrow}}$$

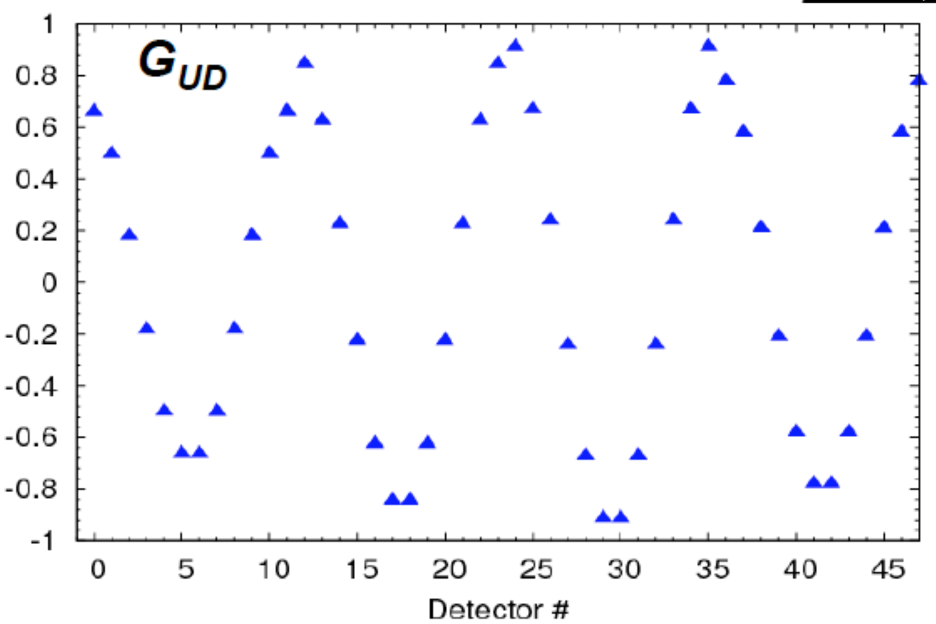
$$A_{raw} = \frac{1}{2}\left(\frac{Y_i^{\uparrow} - Y_j^{\uparrow}}{Y_i^{\uparrow} + Y_j^{\uparrow}} + \frac{Y_j^{\downarrow} - Y_i^{\downarrow}}{Y_j^{\downarrow} + Y_i^{\downarrow}} \right)$$

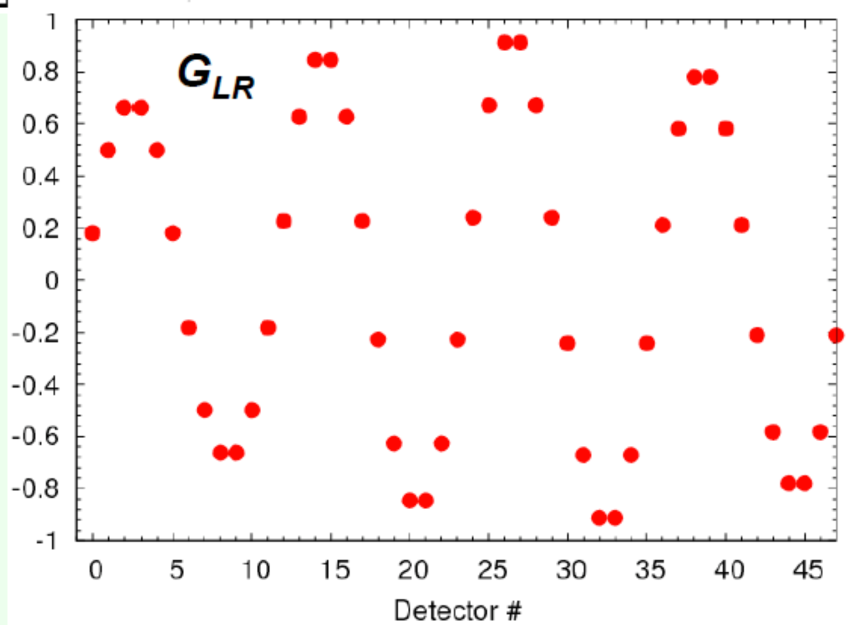
Detector Geometrical Factors

Up-Down (parity violating) $G_{UD} = \langle \hat{k}_\gamma \cdot \hat{\sigma}_n \rangle = \langle \hat{k}_\gamma \cdot \hat{y} \rangle = \langle \sin(\theta) \sin(\varphi) \rangle$

Left-Right (parity allowed) $G_{LR} = \langle \hat{k}_\gamma \cdot (\hat{\sigma}_n \times \hat{k}_n) \rangle = \langle \hat{k}_\gamma \cdot \hat{x} \rangle = \langle \sin(\theta) \cos(\varphi) \rangle$

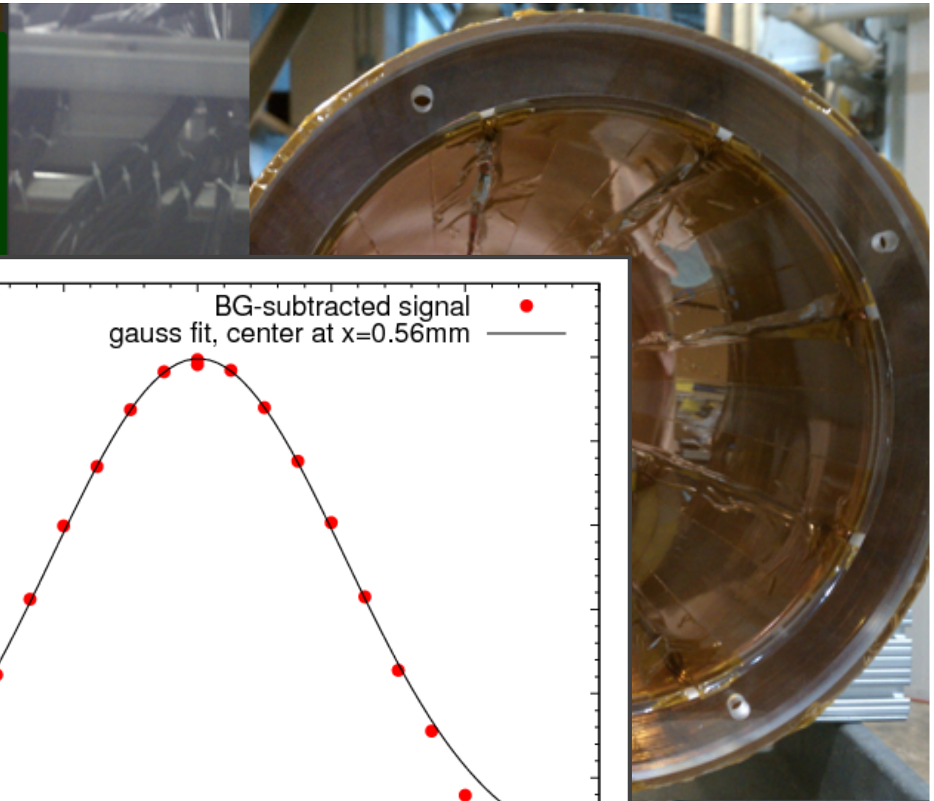


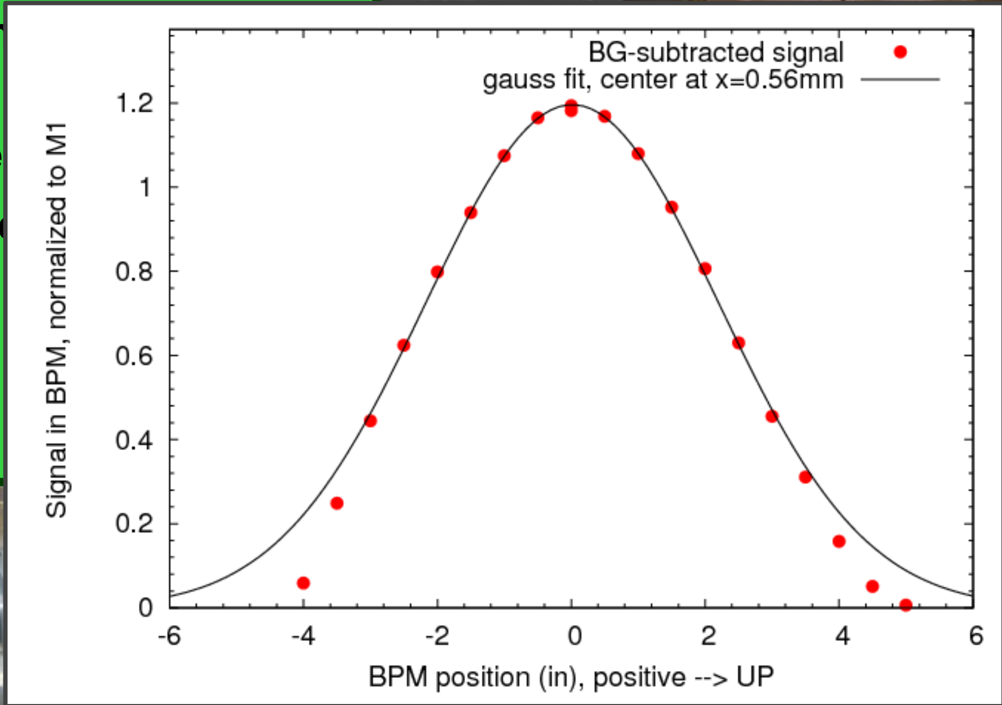


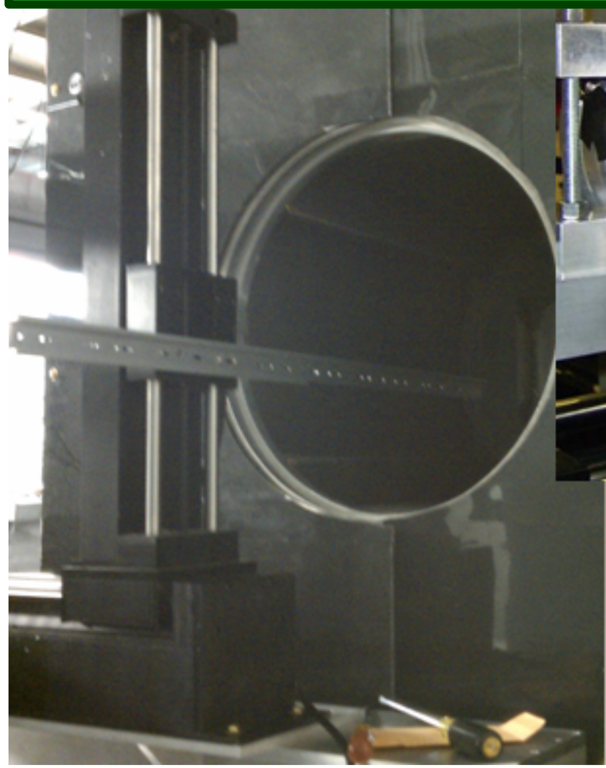


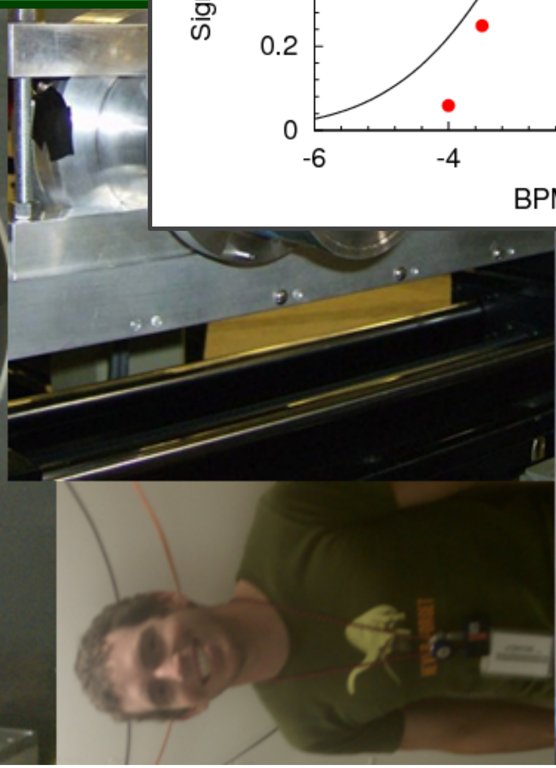
Commissioning Phases I and II (began Dec, 2010)

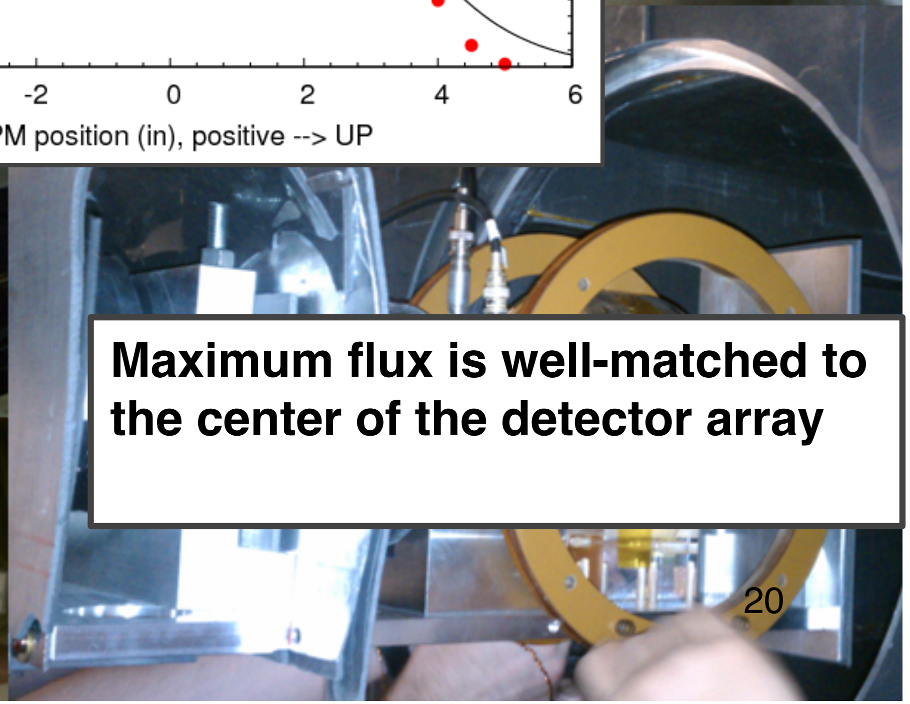
- *Beam profile measured*
- **Flux confirmed**
- **Detailed studies of new shieldin**
performed
- **Polarization of beam establishe**
- **Precision measurements of det**
completed
- **Al and Chlorine data collection**





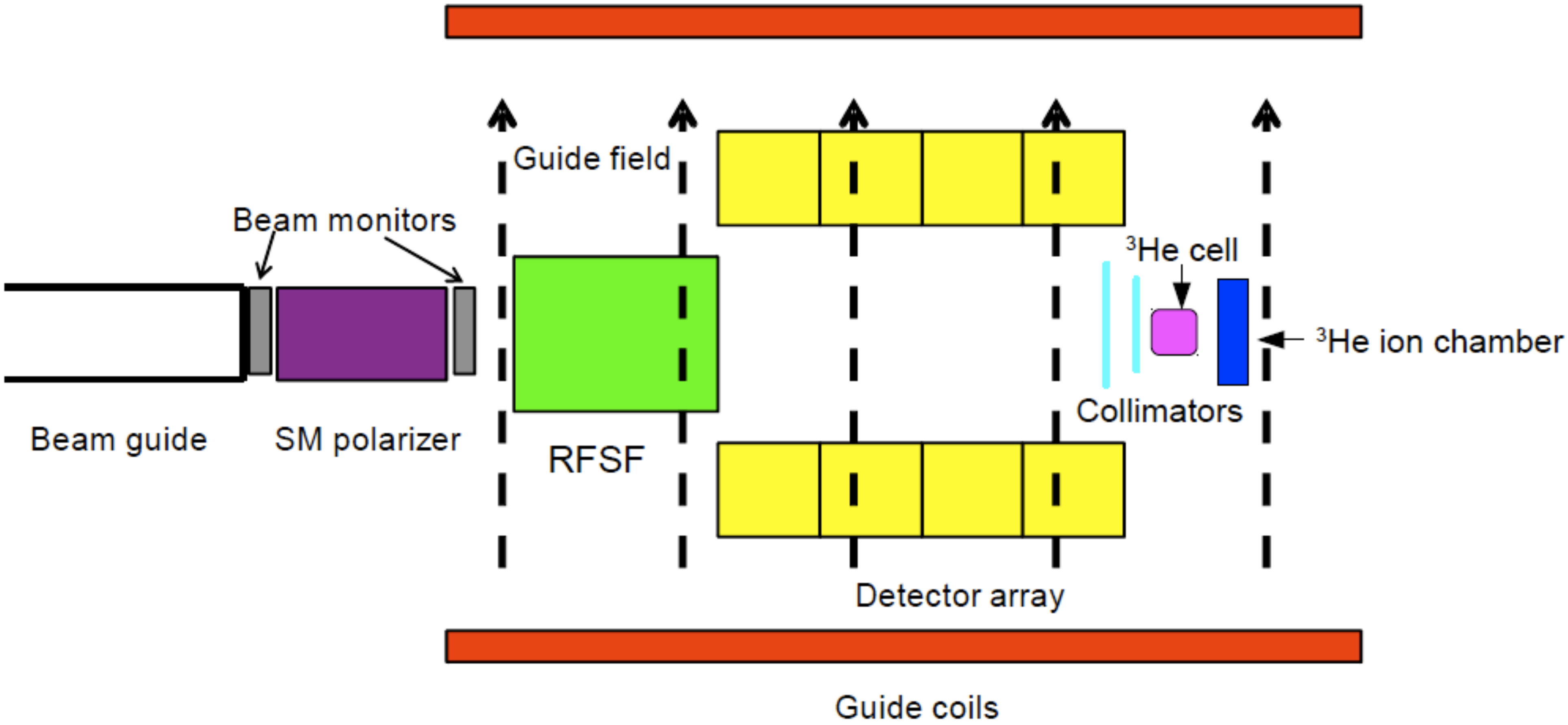




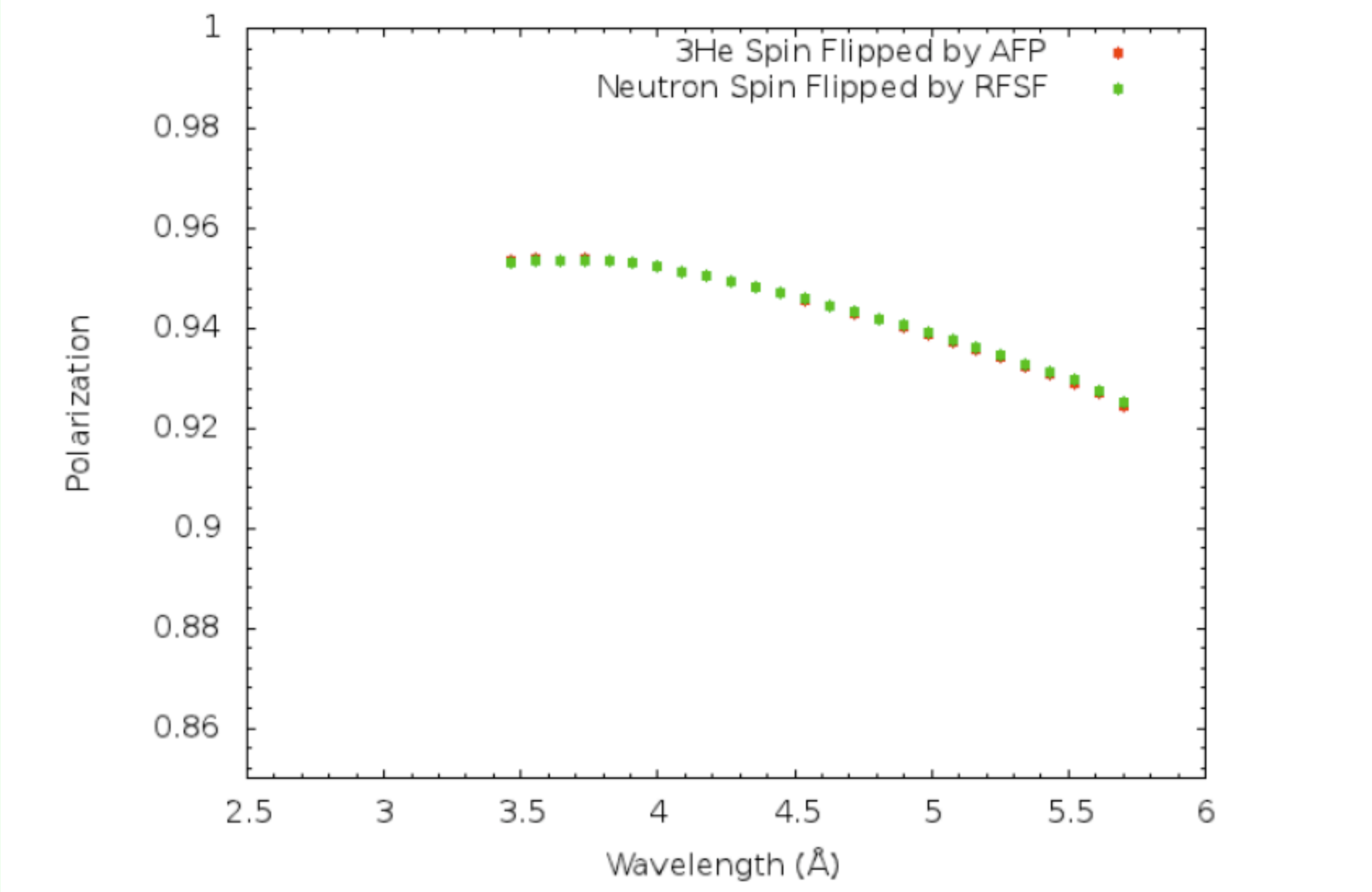


Maximum flux is well-matched to the center of the detector array

Beam Polarization Measurements



Beam Polarization Measurements



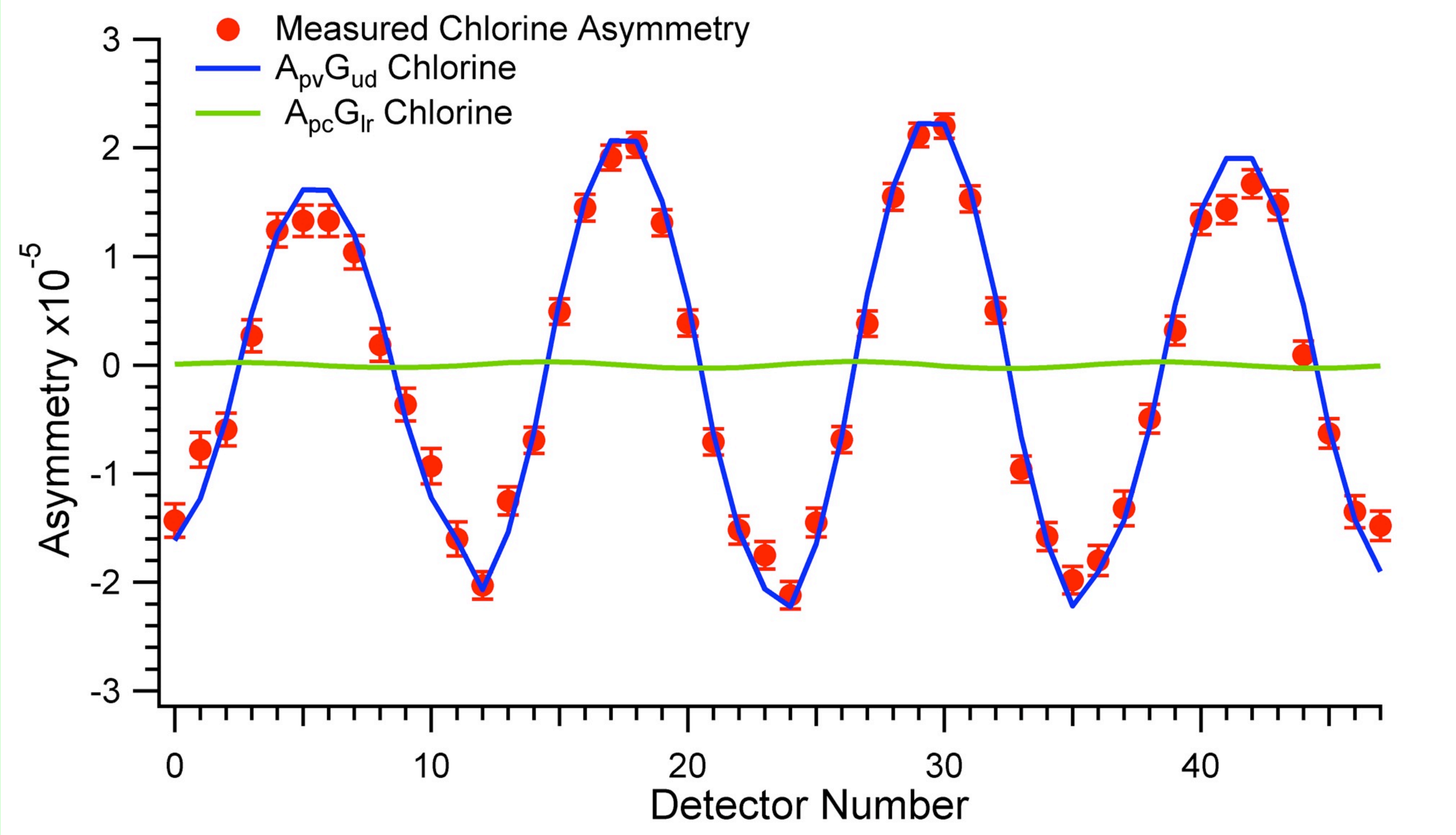
A_γ from ^{35}Cl and ^{27}Al

- ^{35}Cl PV asymmetry is well known, it is enhanced (10^{-5}), and it is used as an initial check and to test important experimental systematics.

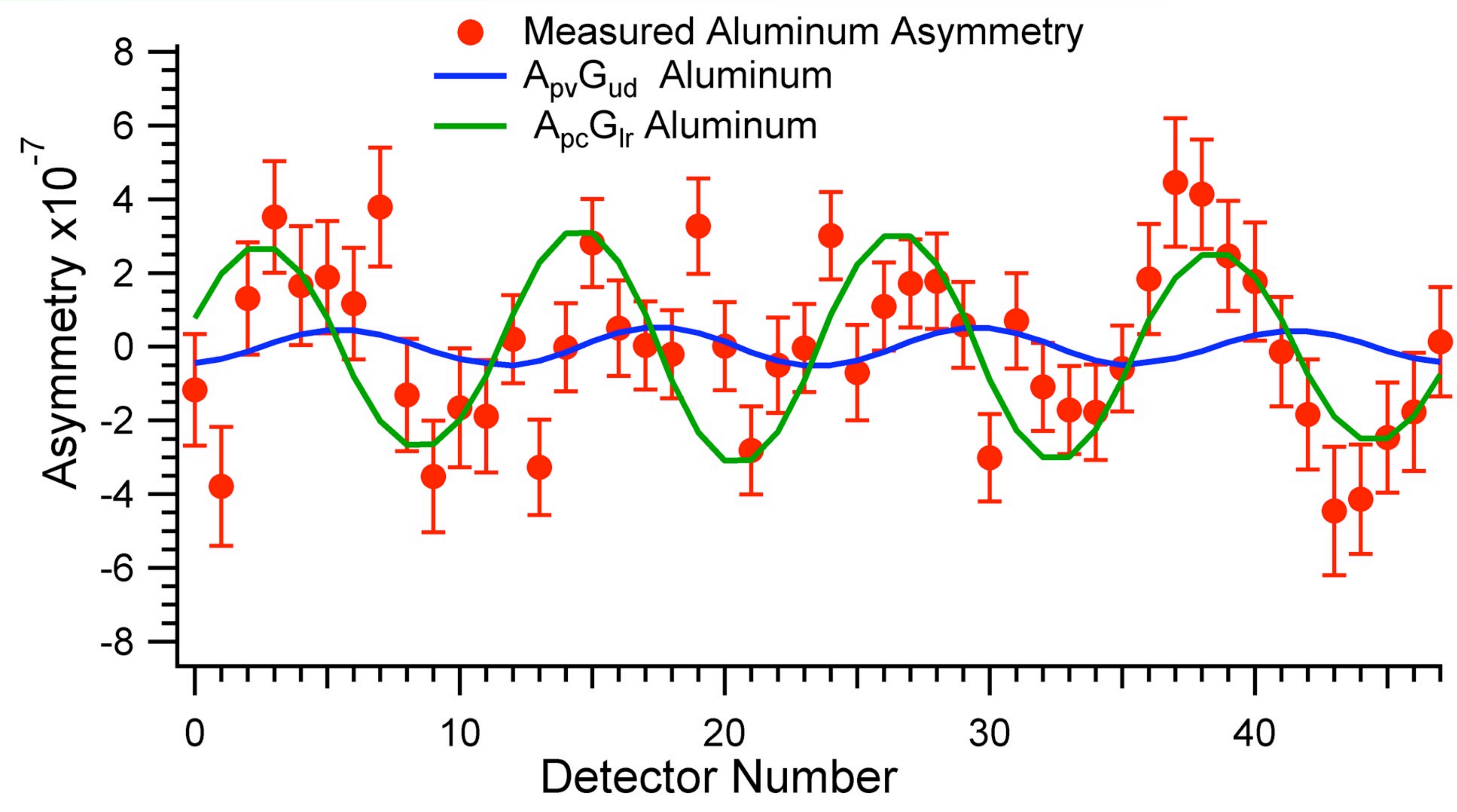
- ^{27}Al is the largest source of background in NPDGamma and the PV asymmetry needs to be measured to about 3×10^{-8} .

$$\sqrt{\left\langle A_\gamma^2 \right\rangle} = 1.3\times10^{-7}$$

^{35}Cl PV (up-down) and PC (left-right) Asymmetries



^{27}*Al* PV (up-down) and PC (left-right) Asymmetries



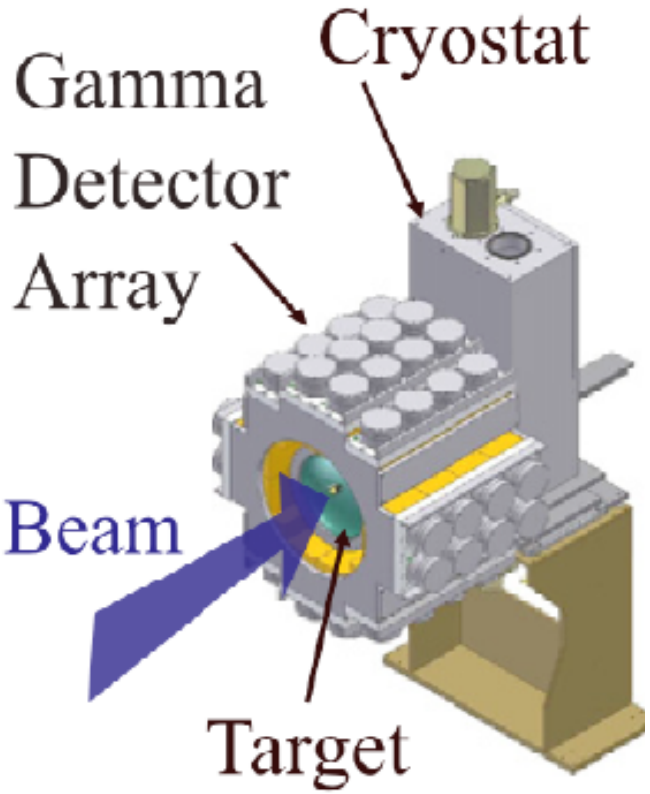
^{27}*Al* PV (up-down) and PC (left-right) Asymmetries

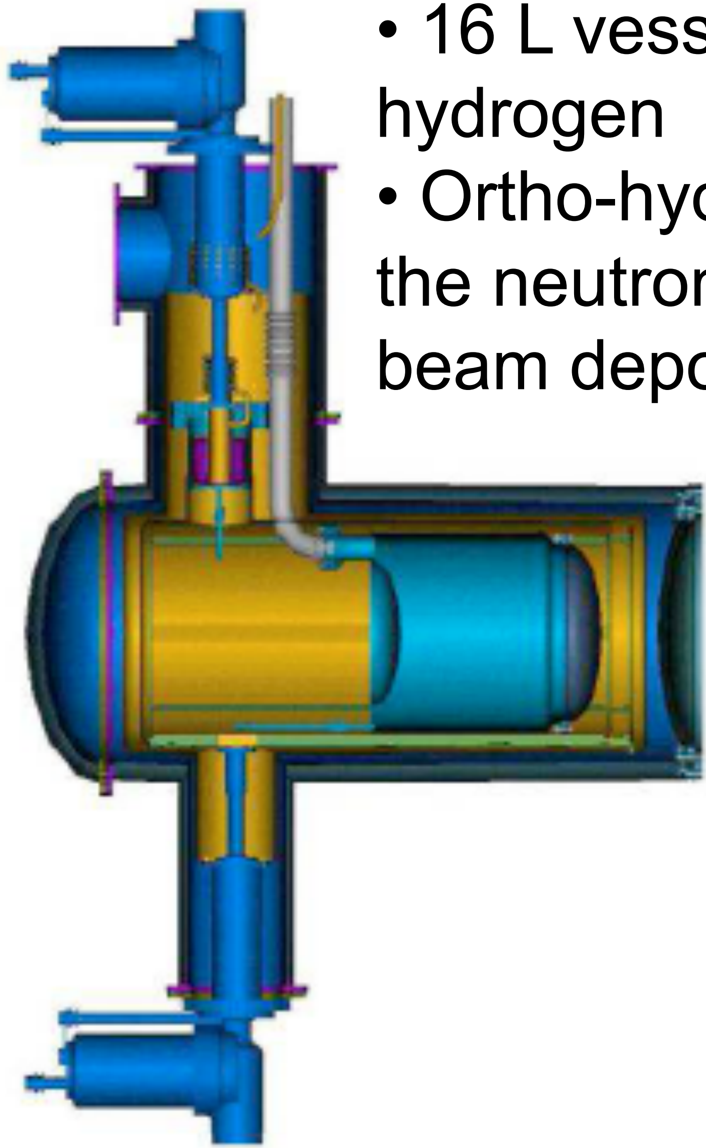
• The PV result is the most precise up to now. The statistical errors are $< 4\times10^{-8}$. This will be the first statistically significant measurement of the asymmetry in the NPDGamma reaction.

• The PC (left-right) result is statistically significant and somehow surprising. Three factors :

- Stern-Gerlach effect (B-field)
- Mott-Schwinger effect (spin-orbit)
- Direct reaction

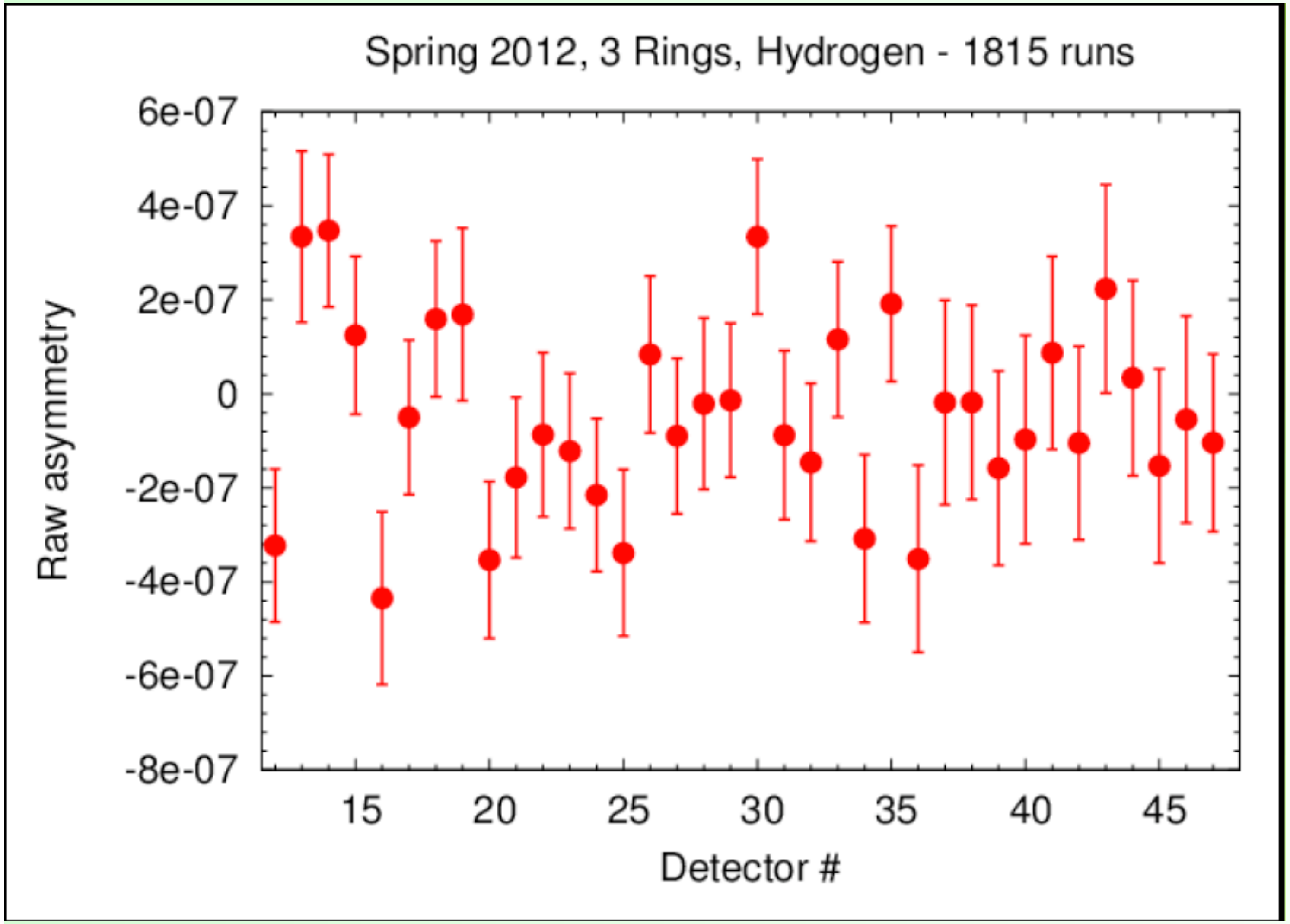
Liquid Para-Hydrogen Target





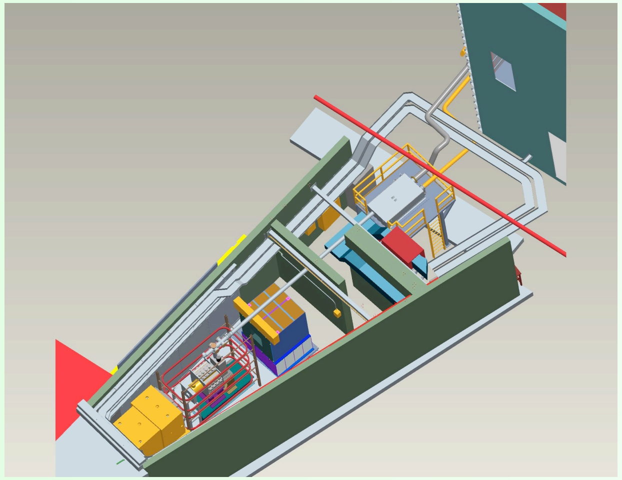
- 16 L vessel of para-hydrogen
- Ortho-hydrogen scatters the neutrons and leads to beam depolarization

Production Data on Hydrogen- so far



- Raw asymmetry
- No BG subtraction
- Fit to the geometric factors shows current sensitivity of ***5.6x10^{-8}***

Status of the NPDGamma experiment



- Numerous improvements to the experiment allow for the first measurement of A_γ that will test theoretical predictions
  - Predicted size: $5x10^{-8}$ (DDH) - NPDGamma will make a 20% measurement ($1x10^{-8}$)

- Results from Cl and Al out soon.
- Production Hydrogen Data is underway !

The NPDGamma collaboration

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