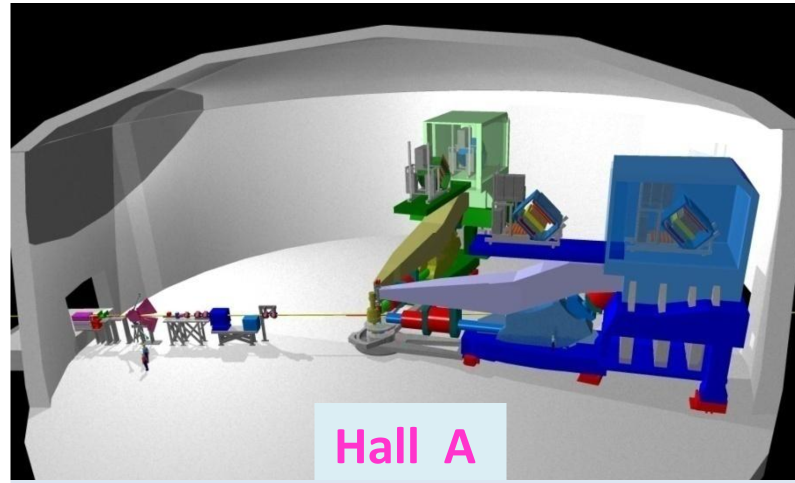
Parity-Violating Measurements of the Weak Charge of ^{208}Pb (PREX) & ^{48}Ca (CREX)

…. and possible future measurements

Hall A at Jefferson Lab

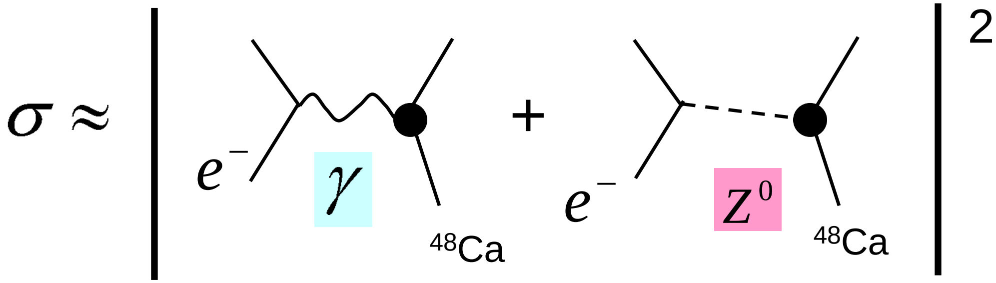


High Resolution Spectrometers (HRS)

Parity Violating Asymmetry

Elastic scattering of electrons

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim 10^{-4} \times Q^2$$



A_{PV} from interference

Parameter	PREX-II (Pb)	CREX (Ca)
Beam Energy (GeV)	1.0	2.2
Angle	5^0	4^0
Asymmetry (ppm)	0.6	2.2
Asy Stat. Error	3%	2.4%
Error in R_N (fm)	0.06	0.02
Beam Time (days)	35	45

septum magnet

1% polarimetry

CREX / PREX : Z^0 of weak interaction : sees the neutrons

	proton	neutron
Electric charge	1	0
Weak charge	0.08	1

T.W. Donnelly, J. Dubach, I. Sick
Nucl. Phys. A 503, 589, 1989

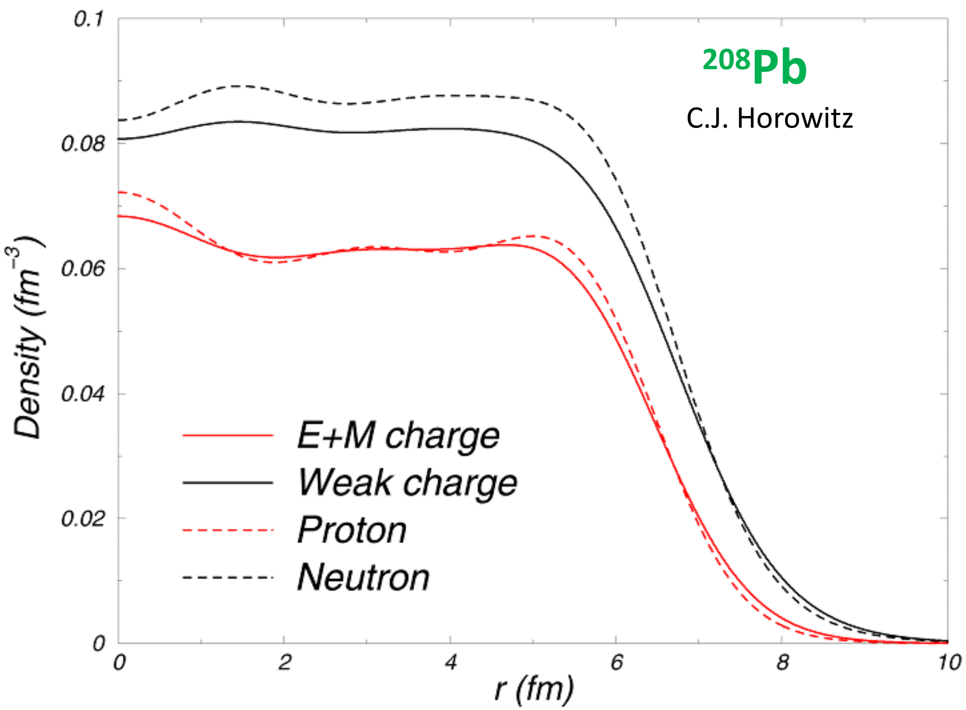
C. J. Horowitz, S. J. Pollock, P. A. Souder, R. Michaels
Phys. Rev. C 63, 025501, 2001

Neutron form factor

$$F_N(Q^2) = \frac{1}{4\pi} \int d^3r \; j_0(qr) \; \rho_N(r)$$

Parity Violating Asymmetry

$$A = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}} \left[\underbrace{1 - 4\sin^2\theta_W}_{\approx 0} - \frac{F_N(Q^2)}{F_P(Q^2)} \right]$$



PREX II and CREX

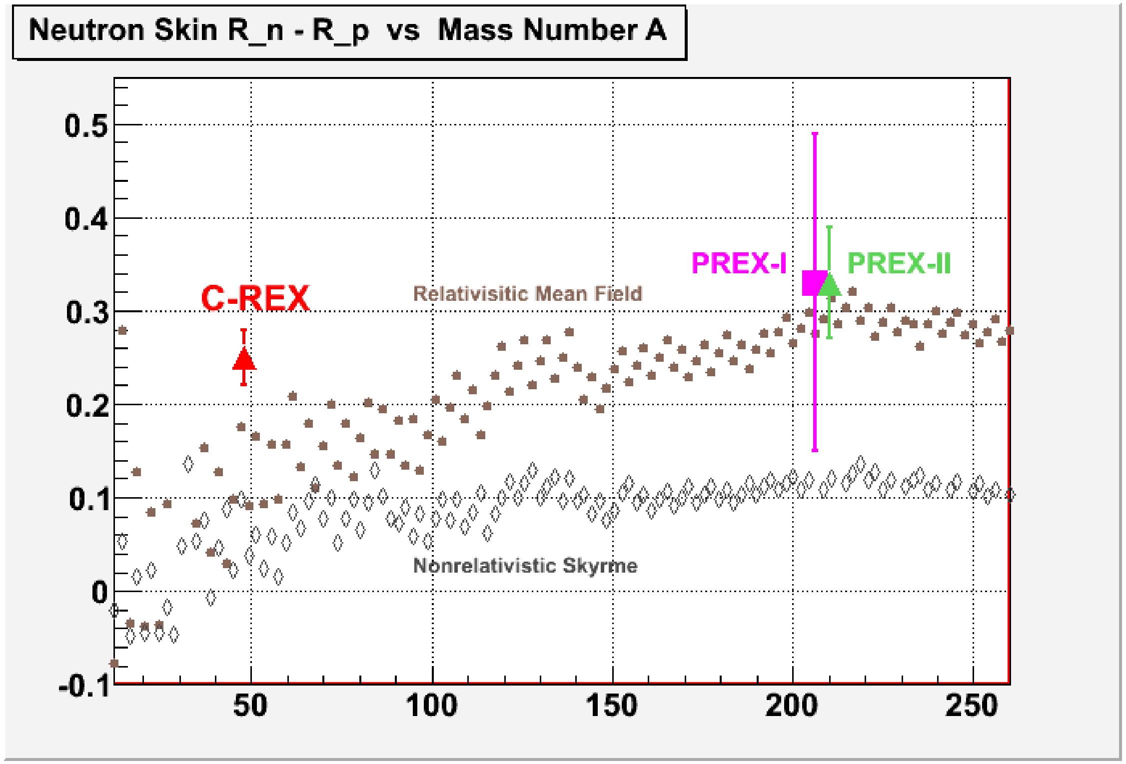
^{208}Pb ^{48}Ca

^{208}Pb skin *approximates* infinite nuclear matter ~ small neutron star

^{48}Ca smaller, optimizes at higher Q^2 (*a natural 11 GeV expt*).

Lots of neutrons, sensitive to 3N force

Tests micrscopic models for neutrons.



Want doubly-magic nuclei: little coupling to inelastic -- "clean"

Want neutrons : weak interaction couples to neutrons

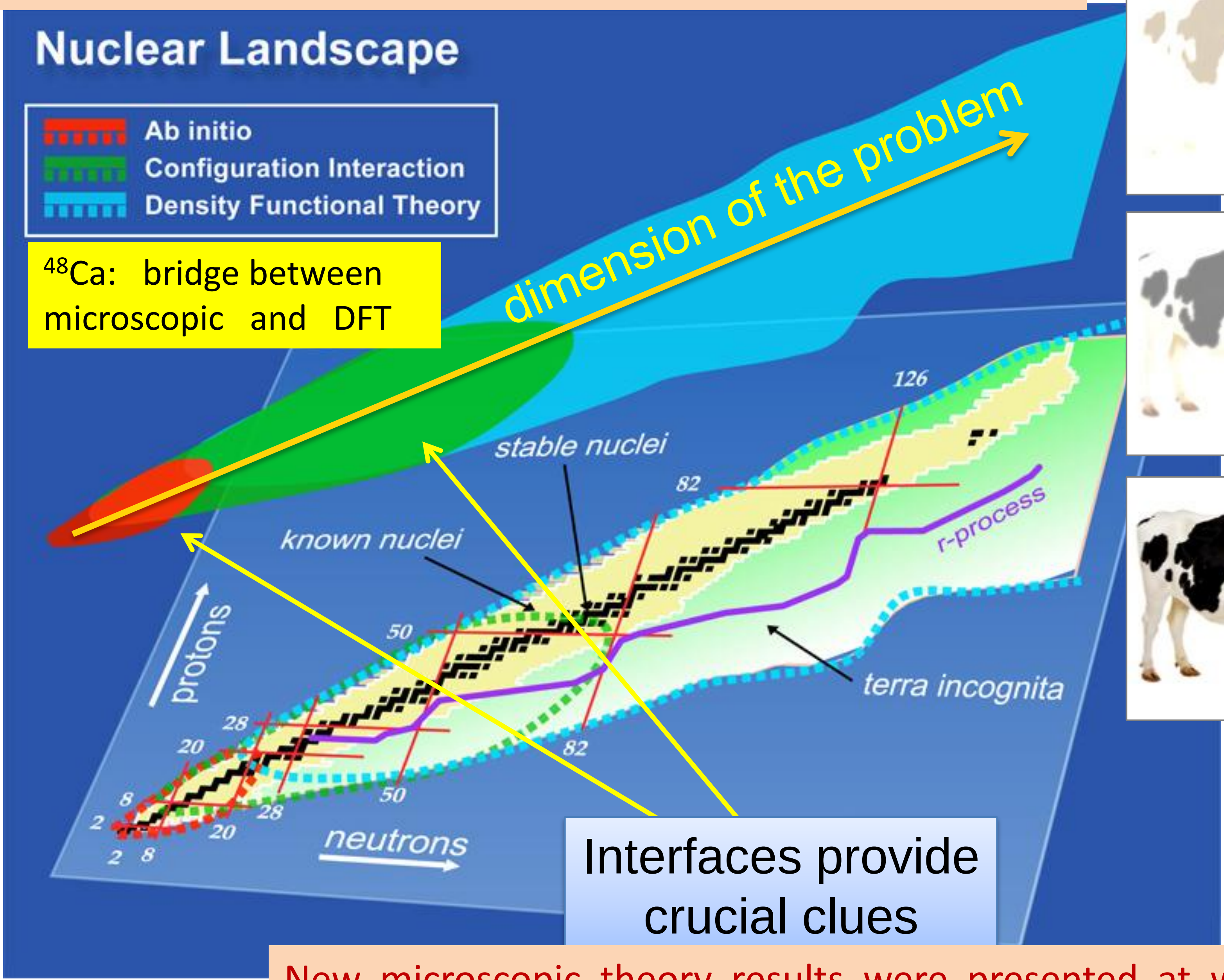
C-REX Workshop

http://www.jlab.org/conferences/crex/program.html

at JLab March 17 – 20, 2013

40 Participants from several fields 19 talks & discussion

Witek Nazarewicz's at Workshop: **Why C-REX after PREX ?**



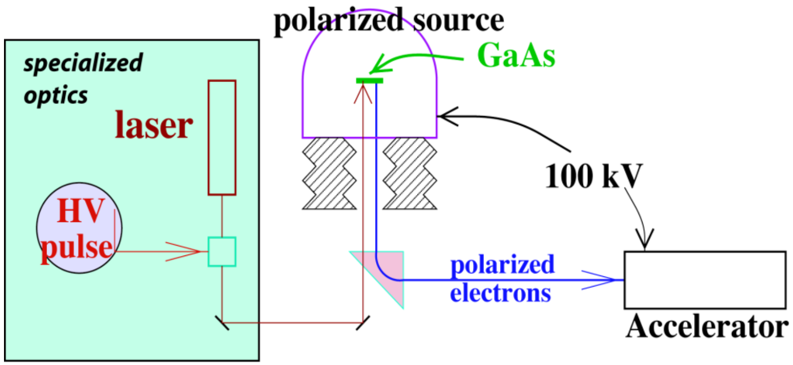
^{48}Ca: bridge between microscopic and DFT

Interfaces provide crucial clues

New microscopic theory results were presented at workshop.

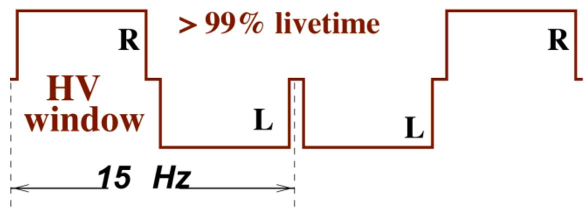
How to do a Parity Experiment

(integrating method)



rapid, random, helicity flipping

Rapid, Random Helicity Flips



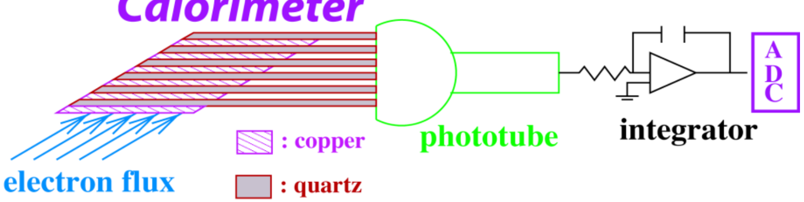
Measure flux F for each window

$$A_{\text{window pair}} = \frac{F_R - F_L}{F_R + F_L}$$

Flux Integration Technique:

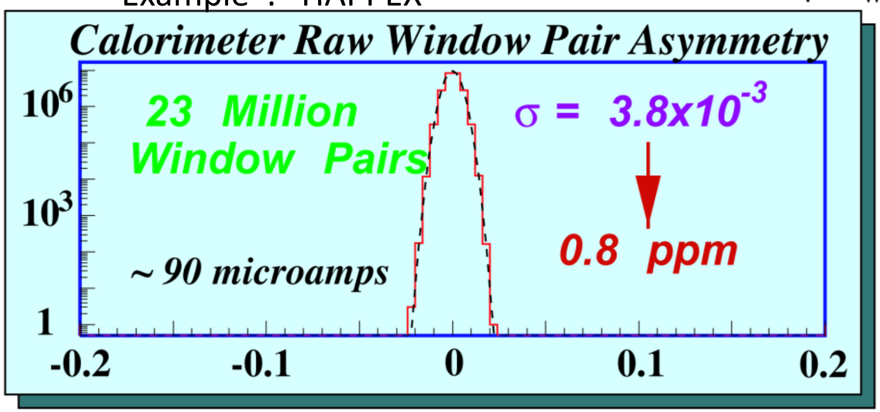
HAPPEX: 2 MHz

PREX: 500 MHz



Signal Average N Windows Pairs: $A \pm \frac{\sigma(A)}{\sqrt{N_{\text{windows}}}}$

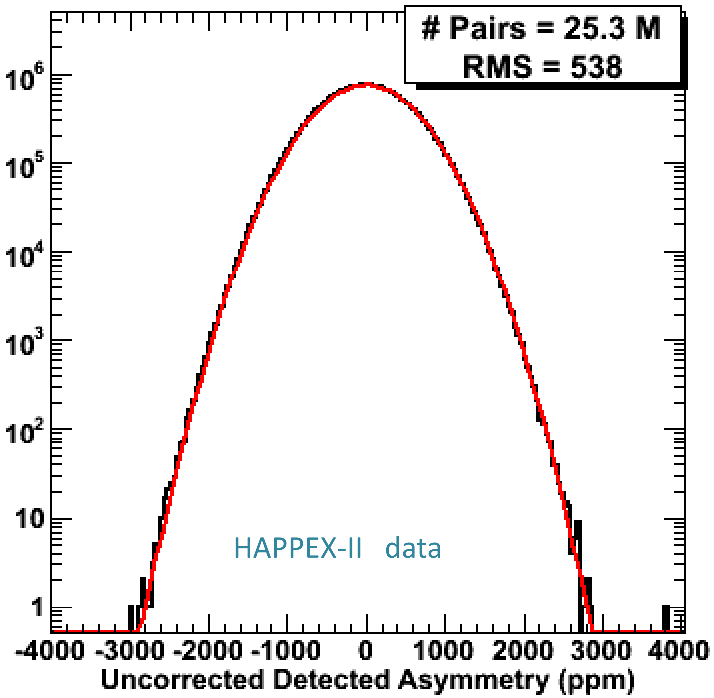
Example : HAPPEX



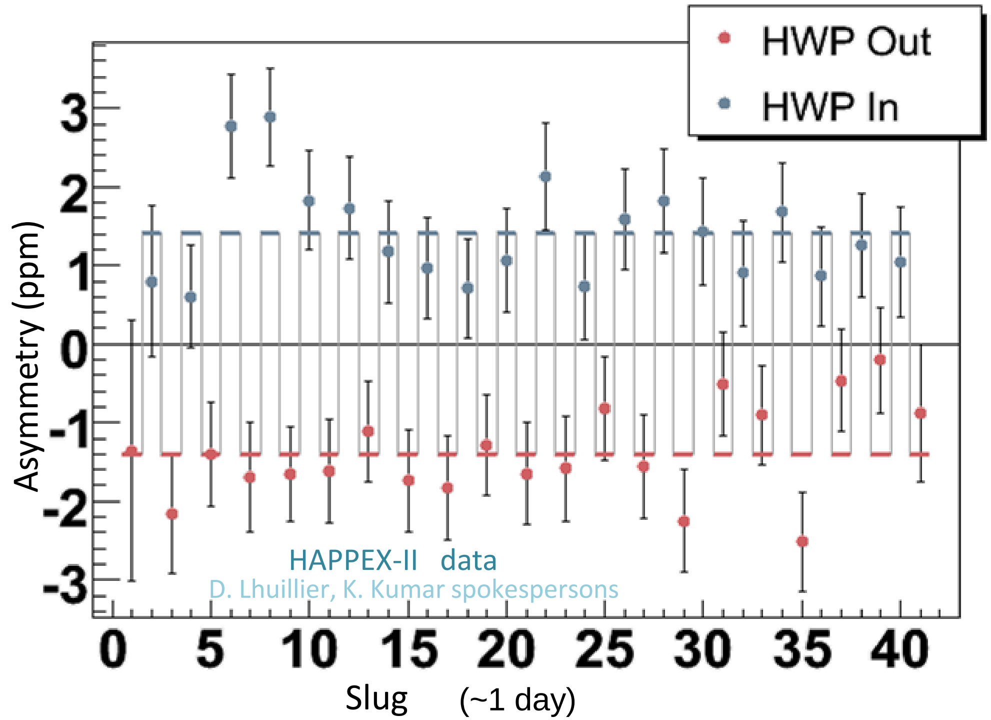
No non-gaussian tails to +/- 5σ

Small beam-related Systematics -- thanks to Jlab beam quality

- Offline asymmetries nearly identical to online.
- Corrections tiny (here, 3 ppb)
- Errors are statistical only



Parity Violating Asymmetry



A_{raw} = -1.58 ppm ± 0.12 (stat) ± 0.04 (syst)

(HWP = optical element used to flip beam helicity, helps suppress some systematics)

Parity Quality Beam : *Unique Strength of JLab*

Helicity – Correlated Position Differences

$< X_R - X_L >$ *for helicity L, R*

Plotted below

$$A_{raw} = A_{det} - A_Q + \alpha\, \Delta_E + \Sigma \beta_i\, \Delta x_i$$

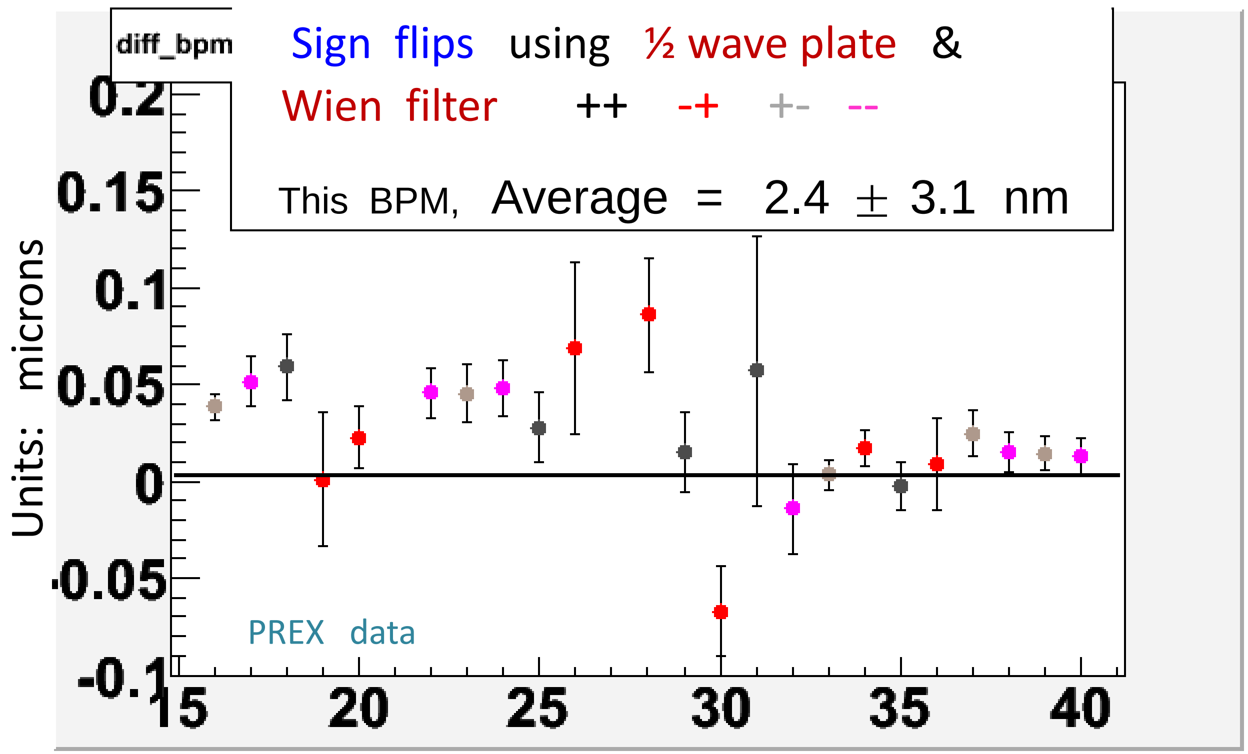
Measured separately

Points: Not sign-corrected. 20-50 nm diffs. with pol. source setup & feedback

Sign flips provide further suppression : Average with signs = what experiment feels

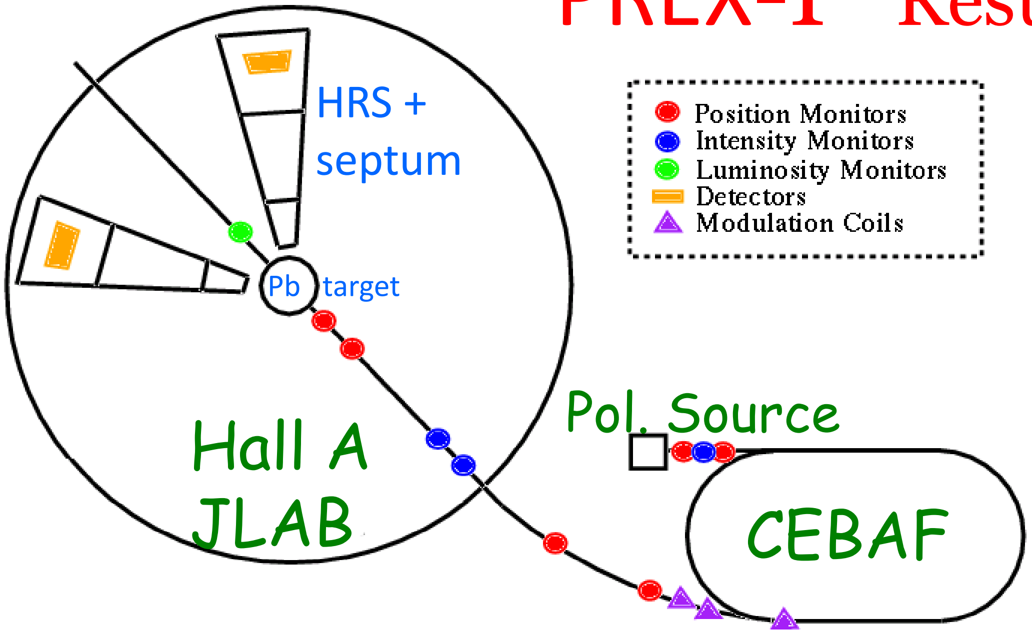
achieved

< 5 nm



Slug # (~ 1 day)

PREX-I Results



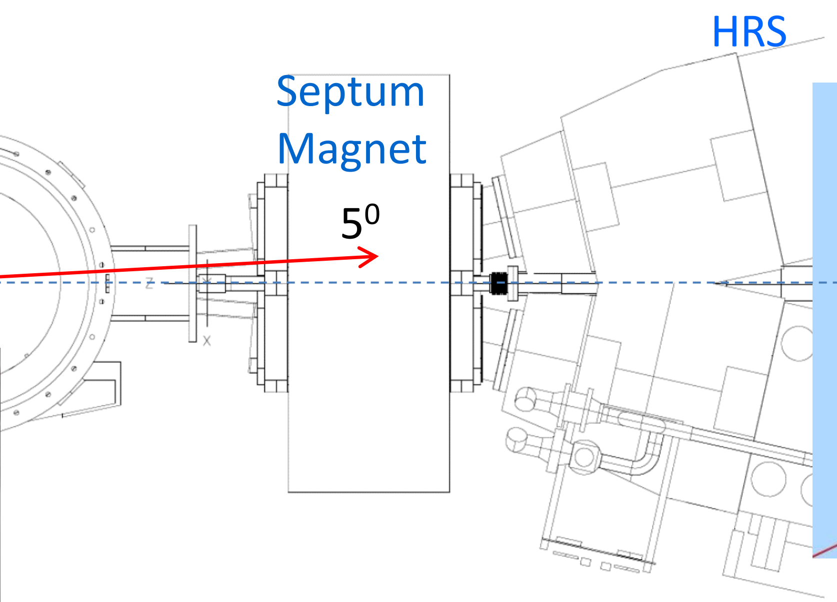
PRL 108 (2012) 112502

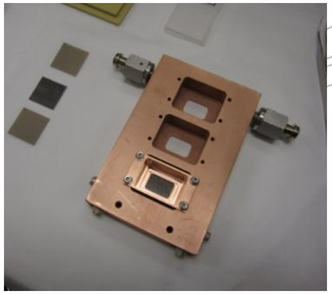
Physics Asymmetry

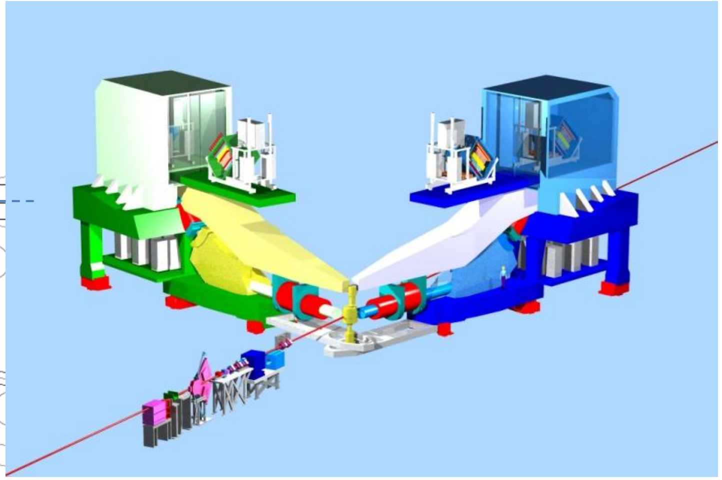
$$A = 0.656 \; ppm \pm 0.060\,(stat) \pm 0.014\,(syst)$$

→ Statistics limited (9%)

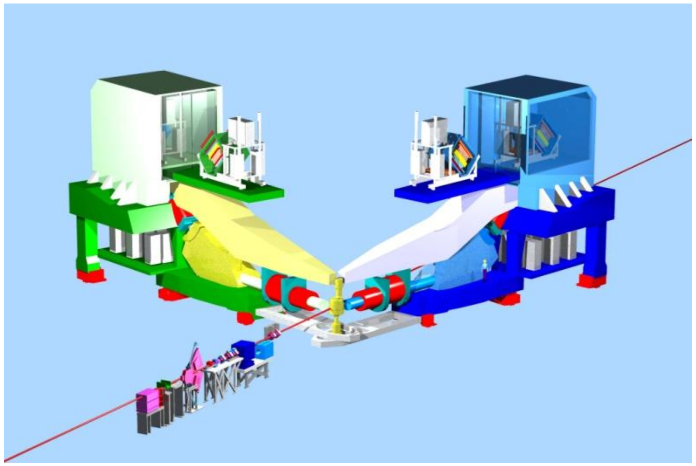
→ Systematic error goal achieved ! (2%)



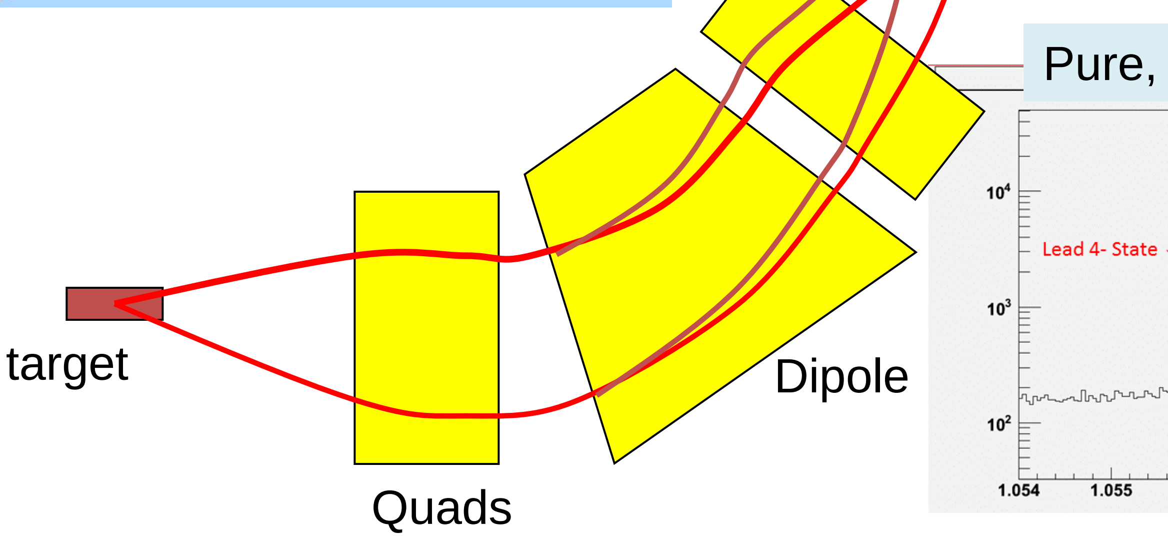


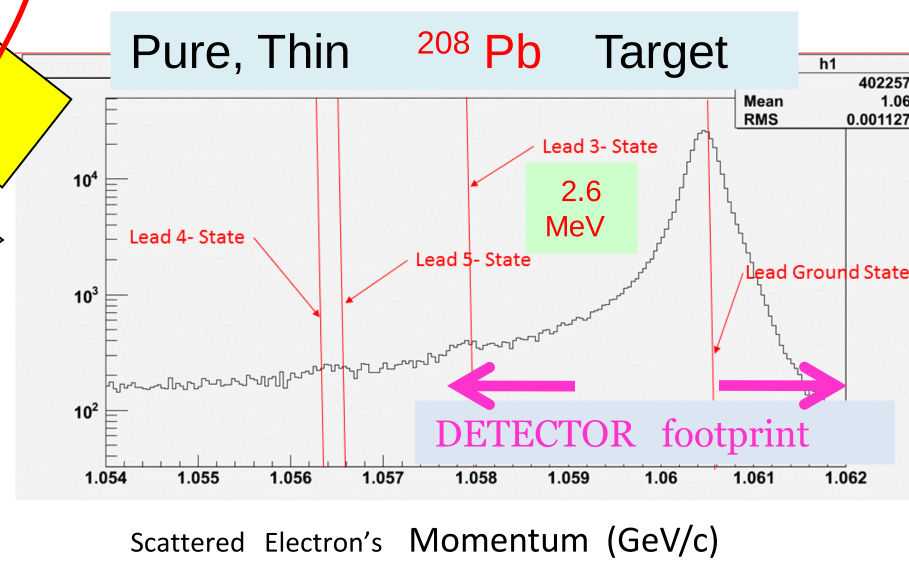


Hall A High Resolution Spectrometers

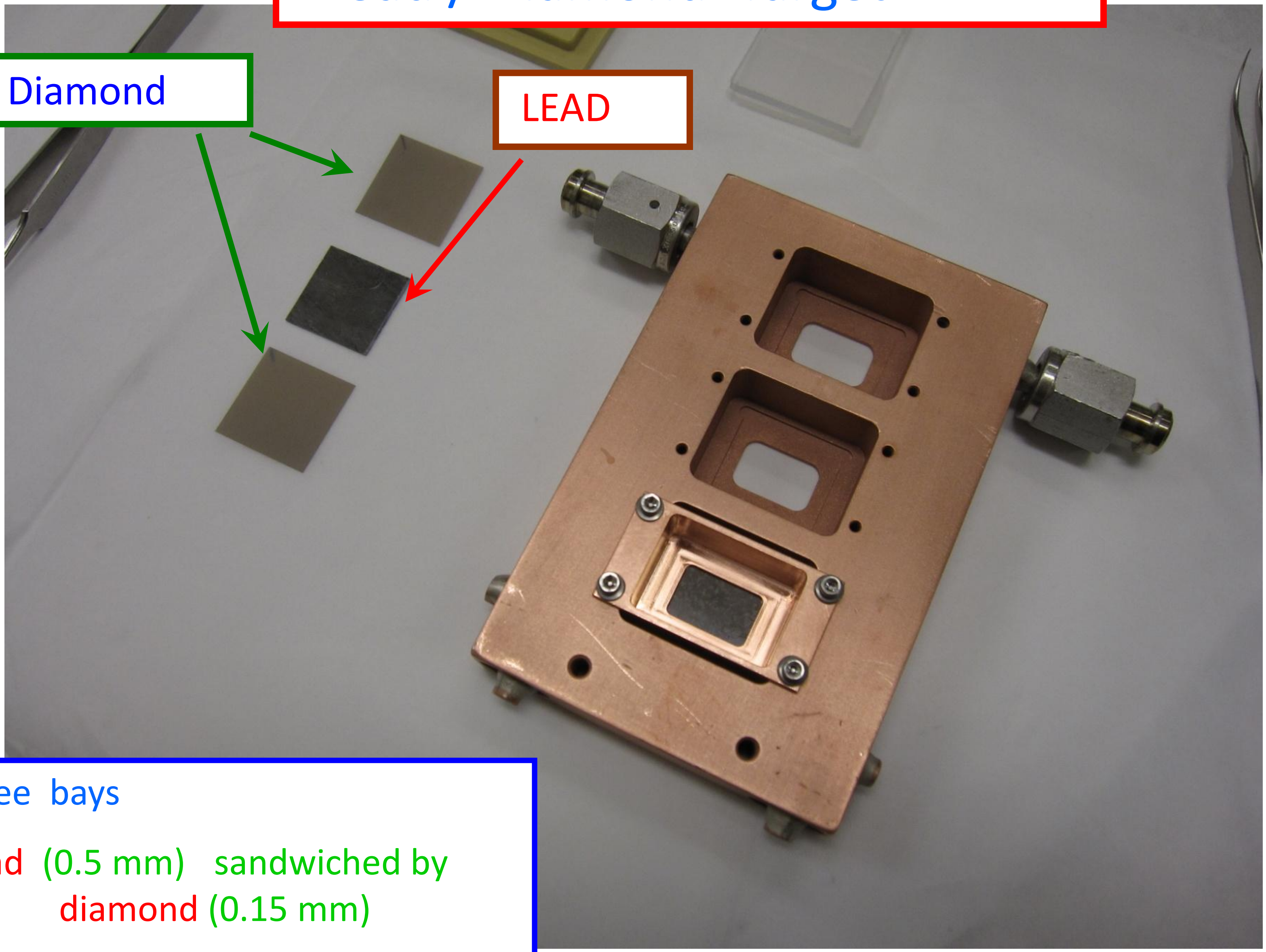


- Resolve Elastic Scattering
- Discriminate Excited States



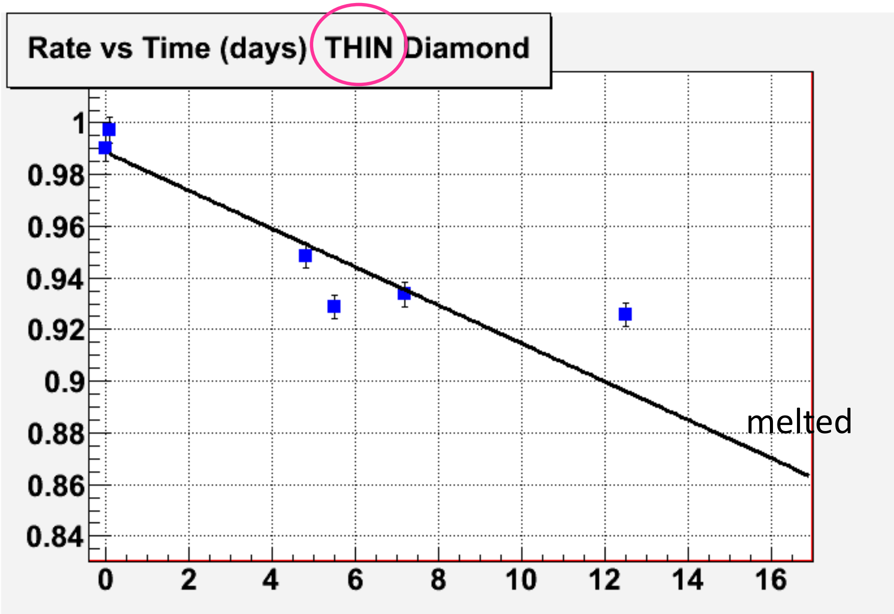


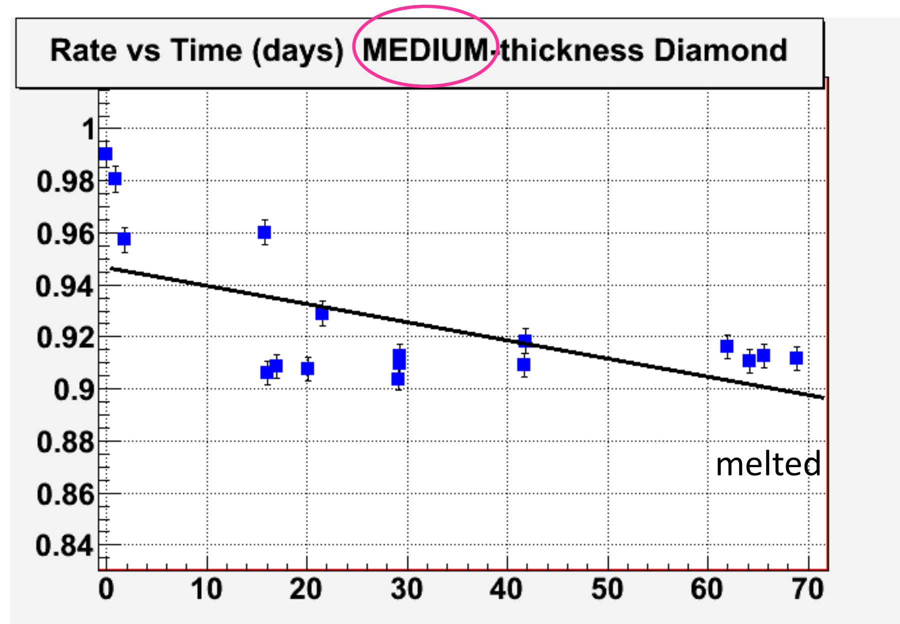
Lead / Diamond Target

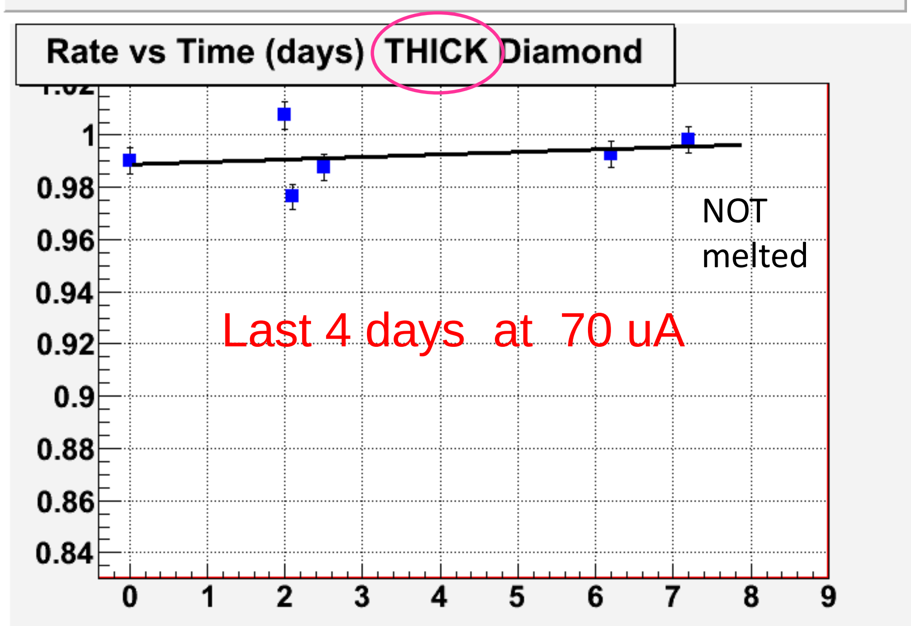


- Three bays
- Lead (0.5 mm) sandwiched by diamond (0.15 mm)
- Liquid He cooling (30 Watts)

Performance of Lead / Diamond Targets







Targets with thin diamond backing (4.5 % background) degraded fastest.

Thick diamond (8%) ran well and did not melt at 70 uA.

→ Solution: Run with 10 targets.

PREX-I Result

Systematic Errors

Error Source	Absolute (ppm)	Relative (%)
Polarization (1)	0.0083	1.3
Beam Asymmetries (2)	0.0072	1.1
Detector Linearity	0.0076	1.2
BCM Linearity	0.0010	0.2
Rescattering	0.0001	0
Transverse Polarization	0.0012	0.2
Q^2 (1)	0.0028	0.4
Target Thickness	0.0005	0.1
^{12}C Asymmetry (2)	0.0025	0.4
Inelastic States	0	0
TOTAL	**0.0140**	**2.1**

(1) Normalization Correction applied

(2) Nonzero correction (the rest assumed zero)

Physics Asymmetry

$$A = 0.656 \ ppm \pm 0.060\,(stat) \pm 0.014\,(syst)$$

→ Statistics limited (9%)

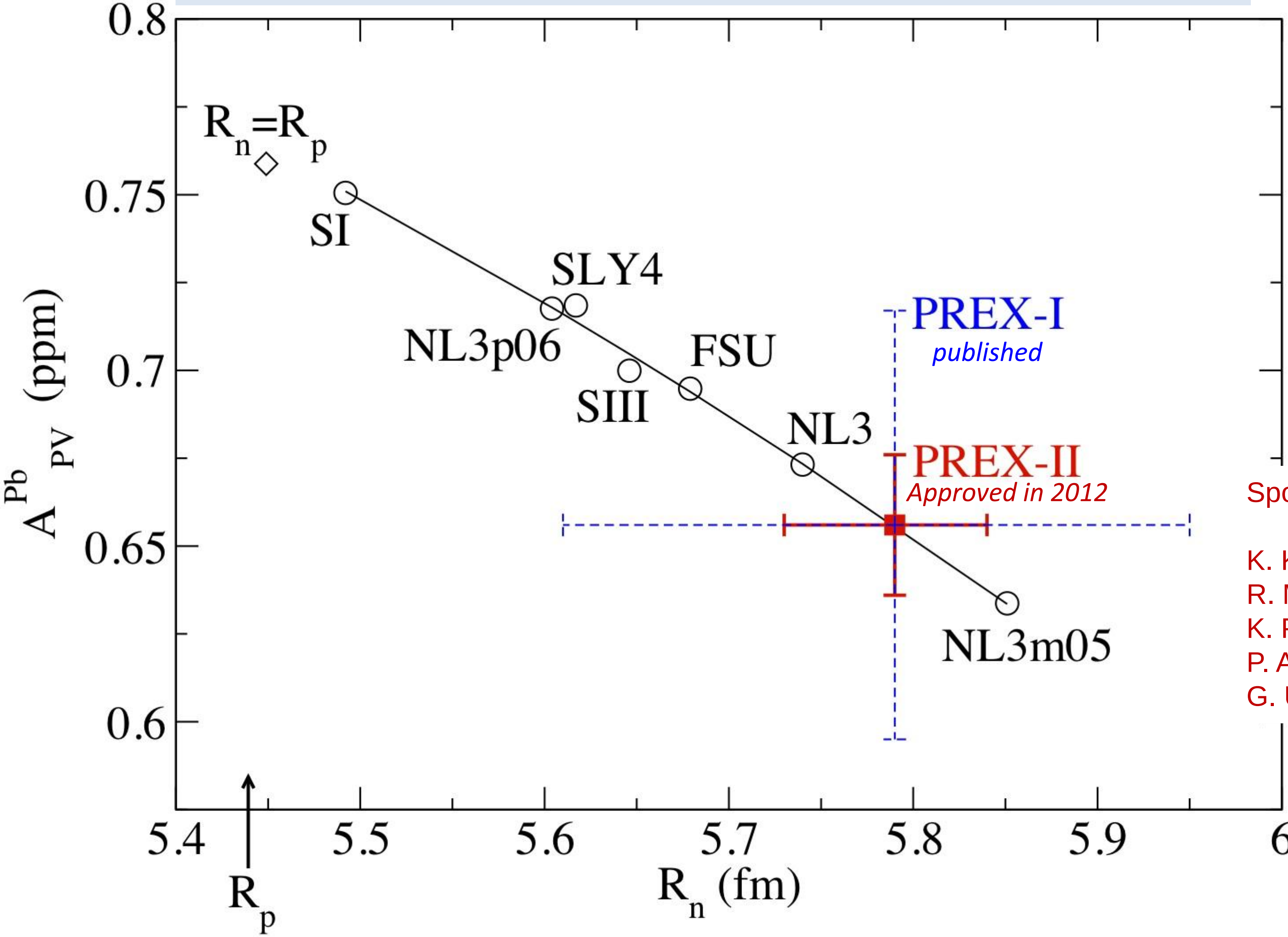
→ Systematic error goal achieved ! (2%)

PRL 108, 112502 (2012)
PRC 85, 032501(R) (2012)

PREX: Asymmetry leads to R_N

Establishing a neutron skin at ~95 % CL

Neutron Skin = R_N - R_P = 0.33 + 0.16 - 0.18 fm



Spokespersons

K. Kumar
R. Michaels
K. Paschke
P. A. Souder
G. Urciuoli

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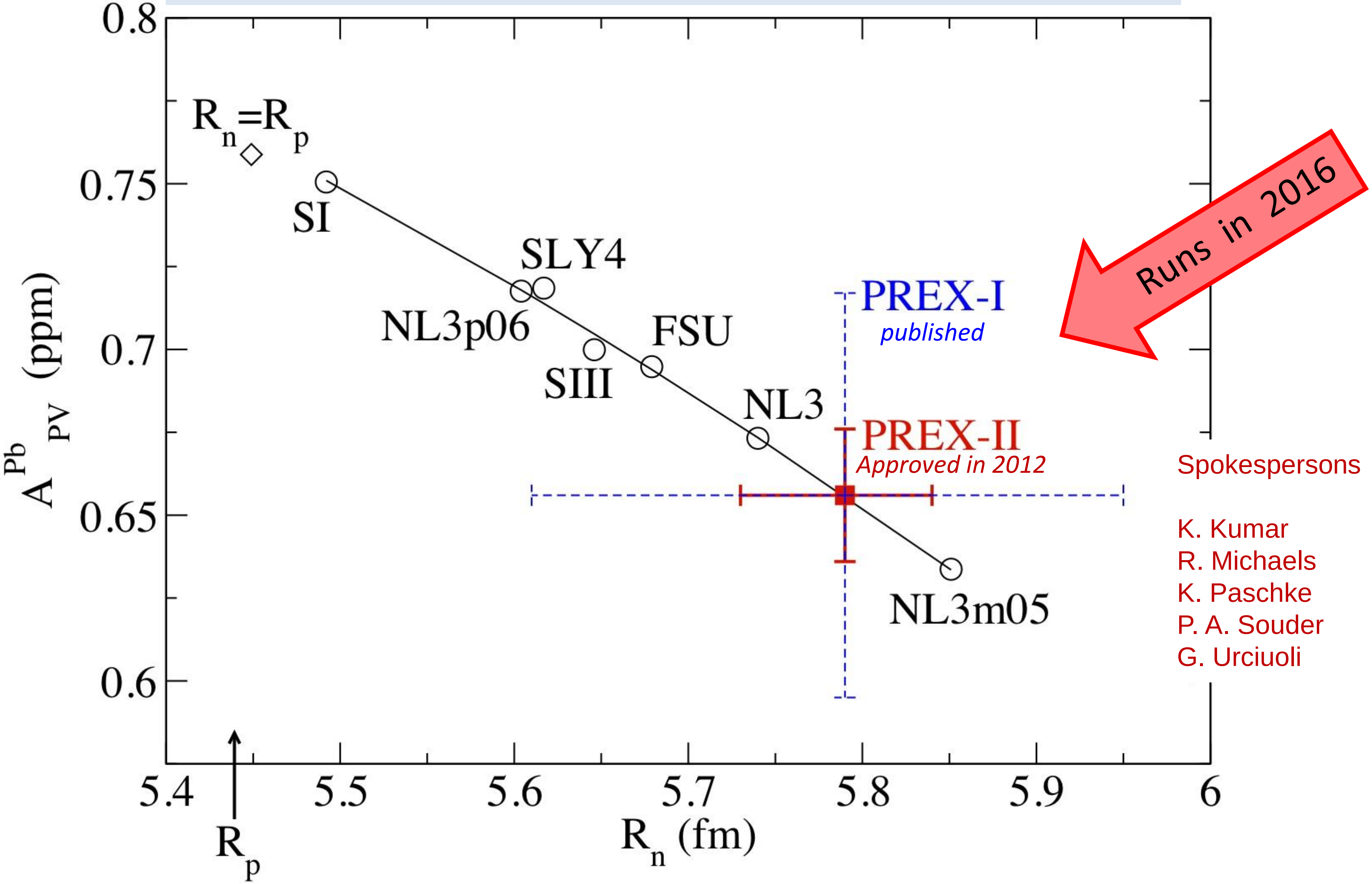

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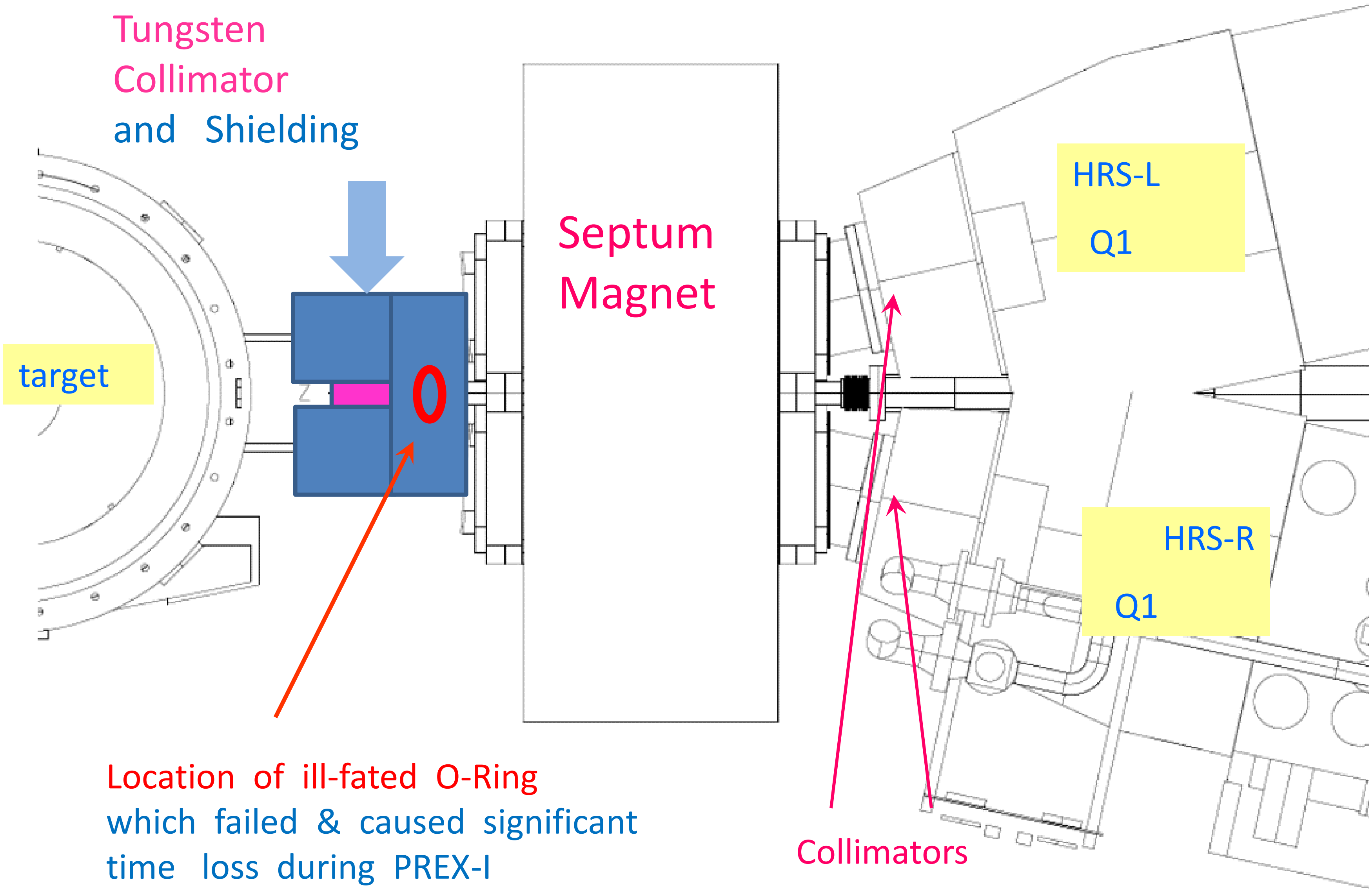
Improvements for PREX-II

Region downstream of target



→ PREX-II to use all-metal seals

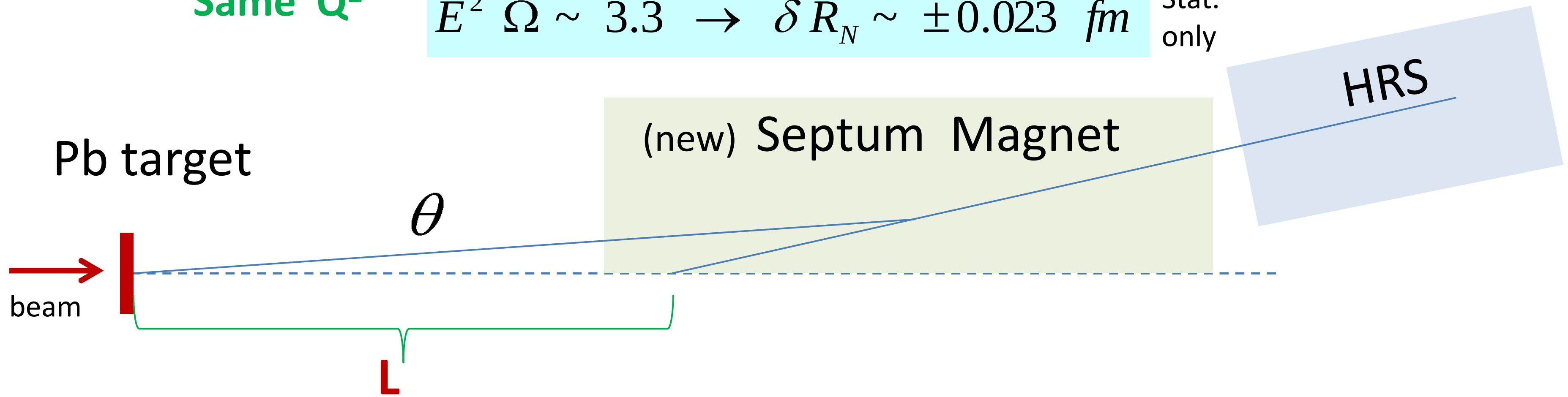
Chuck asks : " What about a **PREX-III** ? "

2.2 GeV - 1-pass JLab beam energy (**2 month** run)

Same Q^2

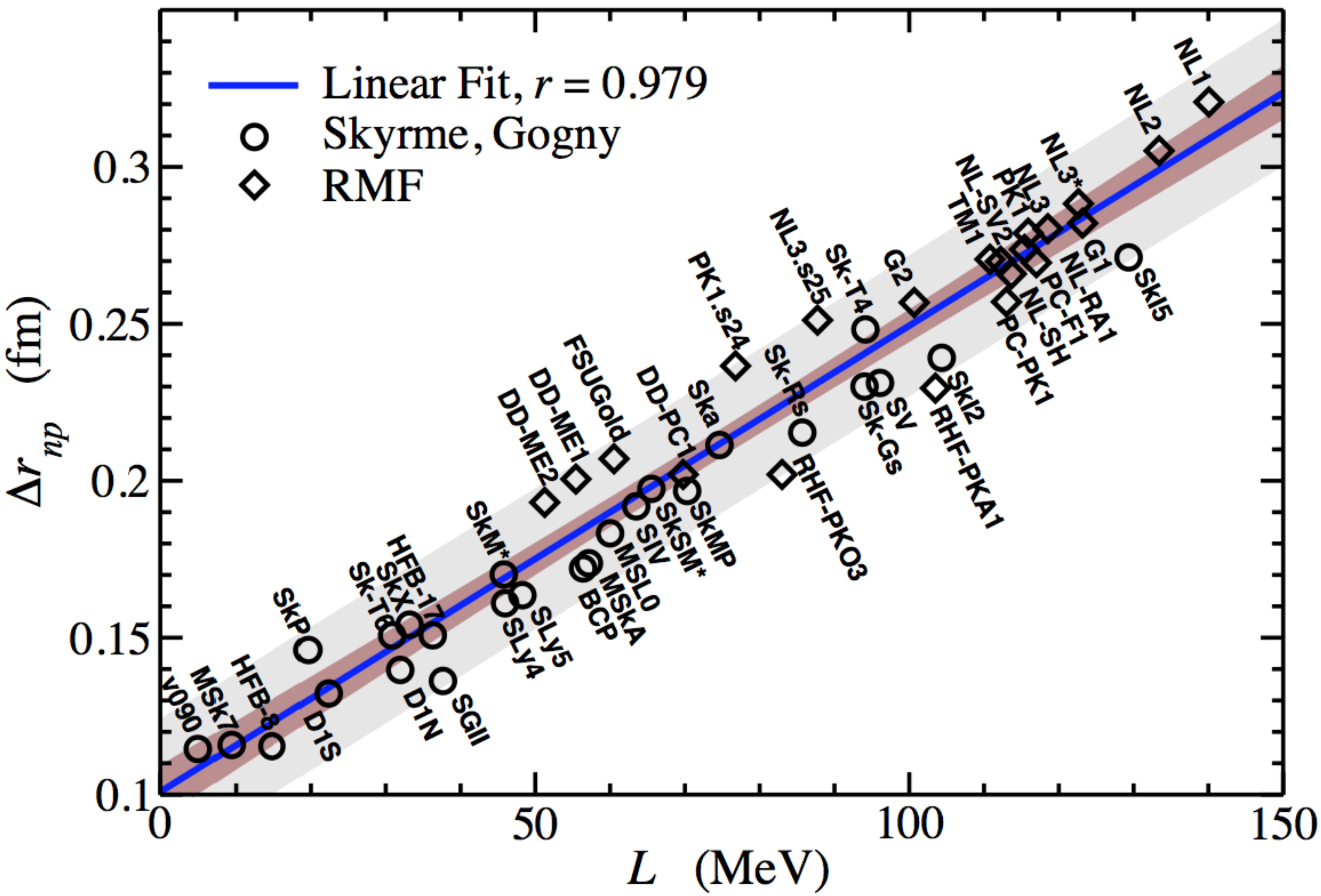
$$E^2\,\Omega \sim 3.3 \;\rightarrow\; \delta R_N \sim \pm 0.023\ fm$$

Stat. only



quantity	PREX-II or CREX	new PREX-III	comment
Energy, angle	1.05 GeV, 5^0	2.2 GeV, 2.4^0	same Q^2
L	1.36 m (CREX)	2 m	Re-engineer beamline
Septum, Acceptance Ω	1 m x 11.3 kG 2.9 msr (CREX)	1.7 m x 19 kG $\Omega \sim 2\ msr$	new magnet, more windings
Q^2 Error	0.4 %	1.7 %	Problem: need << 1 %
Polarimetry	1 %	< 1 %	Easier at higher E

[nucl-th]1308.1008 X. Vinas, M. Centelles, X. Roca-Maza, M. Warda



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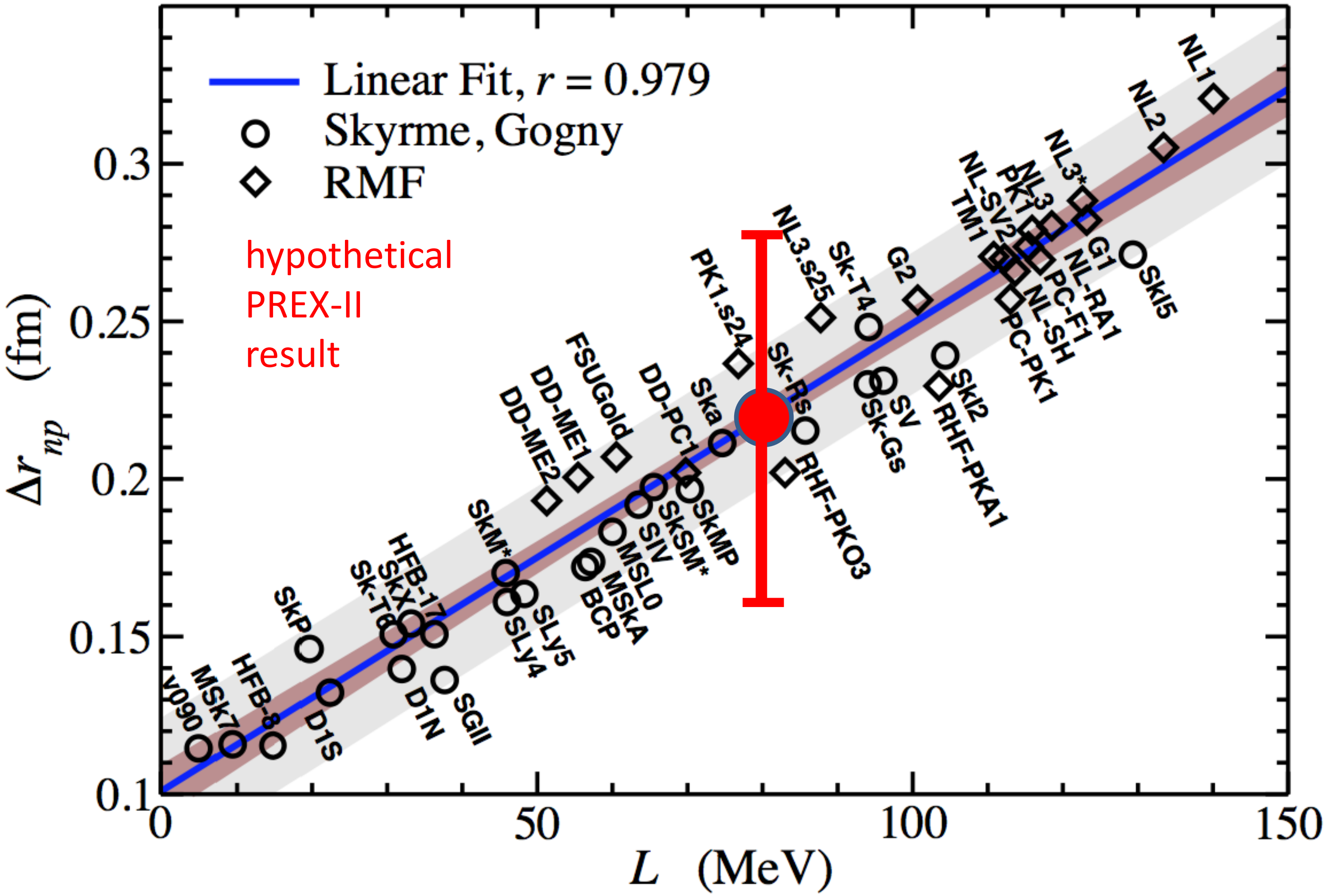
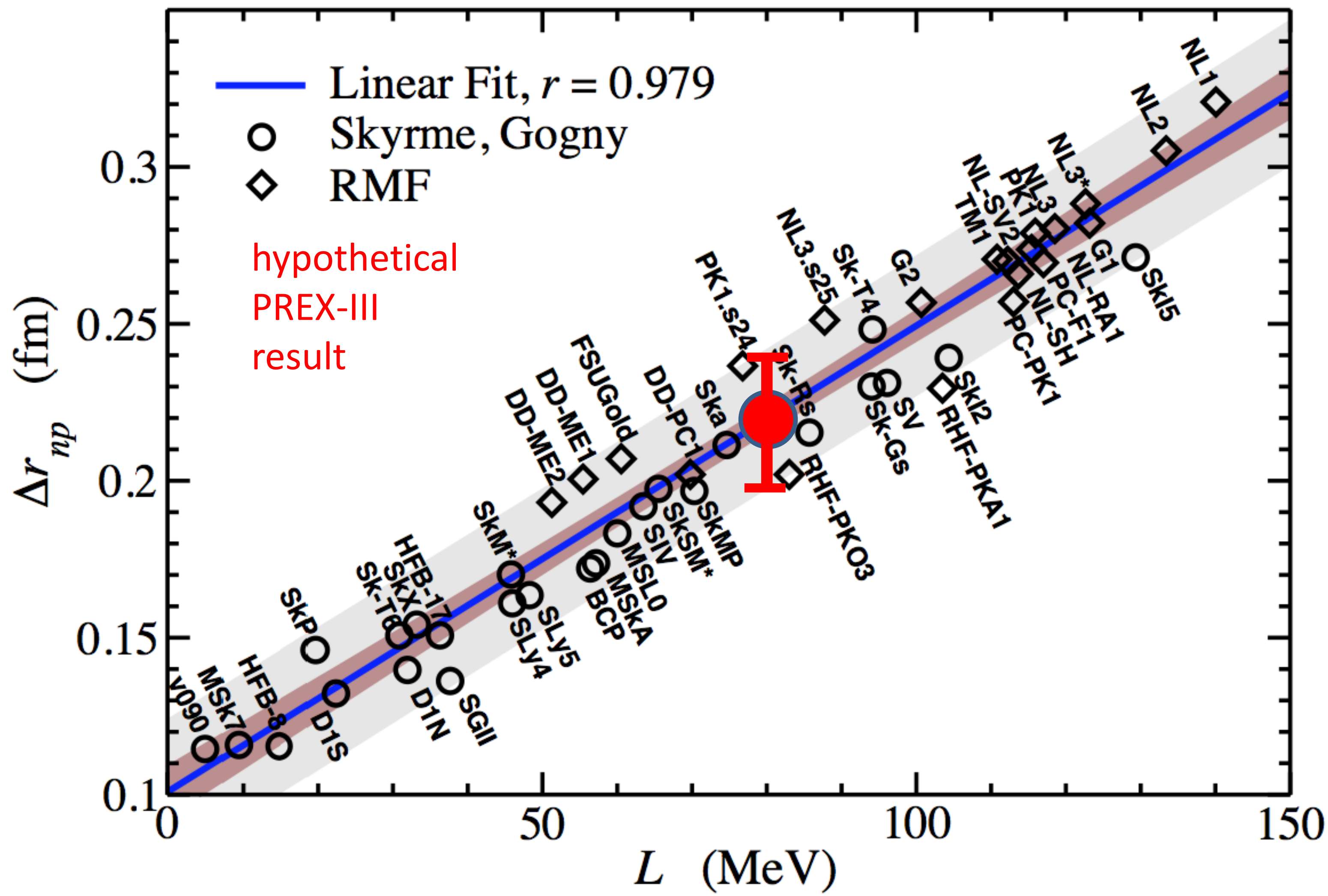
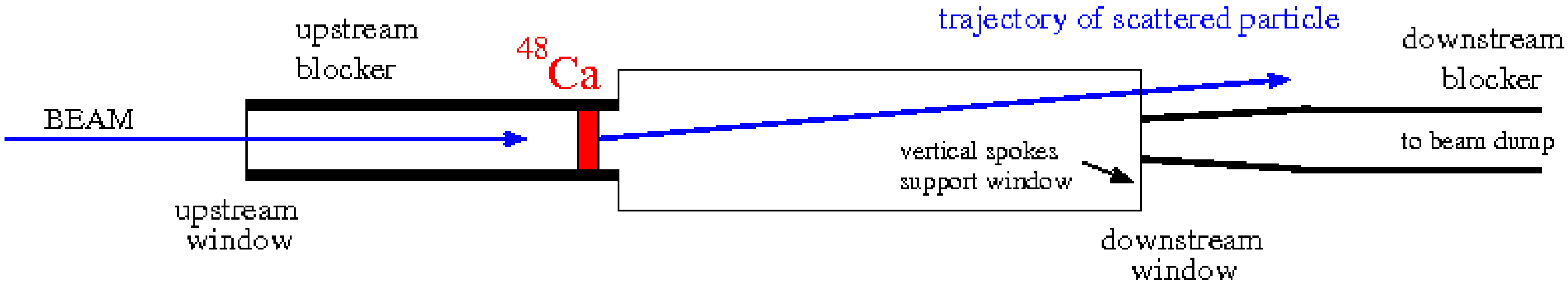


[nucl-th]1308.1008 X. Vinas, M. Centelles, X. Roca-Maza, M. Warda



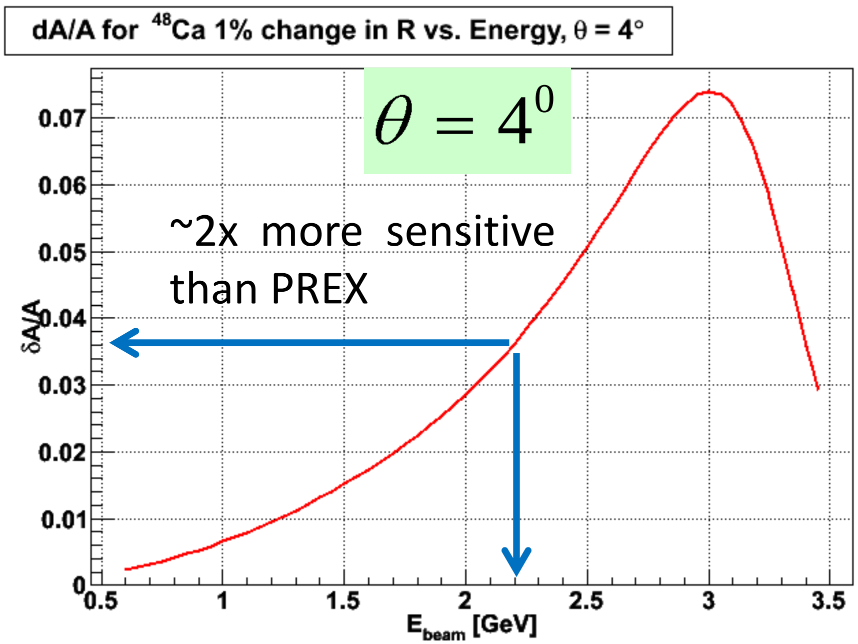
CREX Target

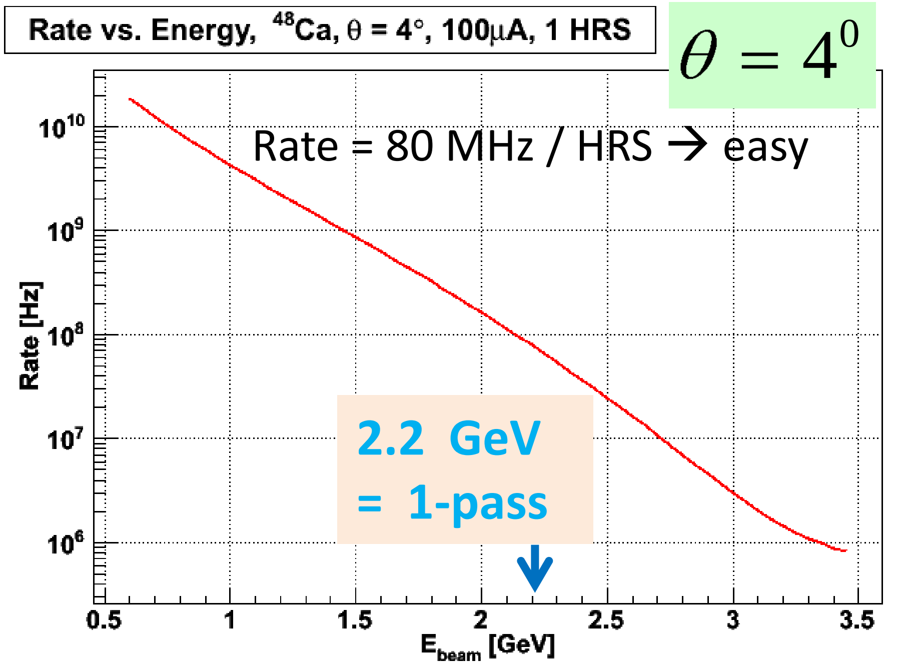
- **Isotopically pure ^{48}Ca**
- Vacuum seal to trap atoms if beam destroys target
- Higher thermal conductivity and melting point than lead : should take 100 uA.
- Similar to target used in E08014 (at 40 uA)

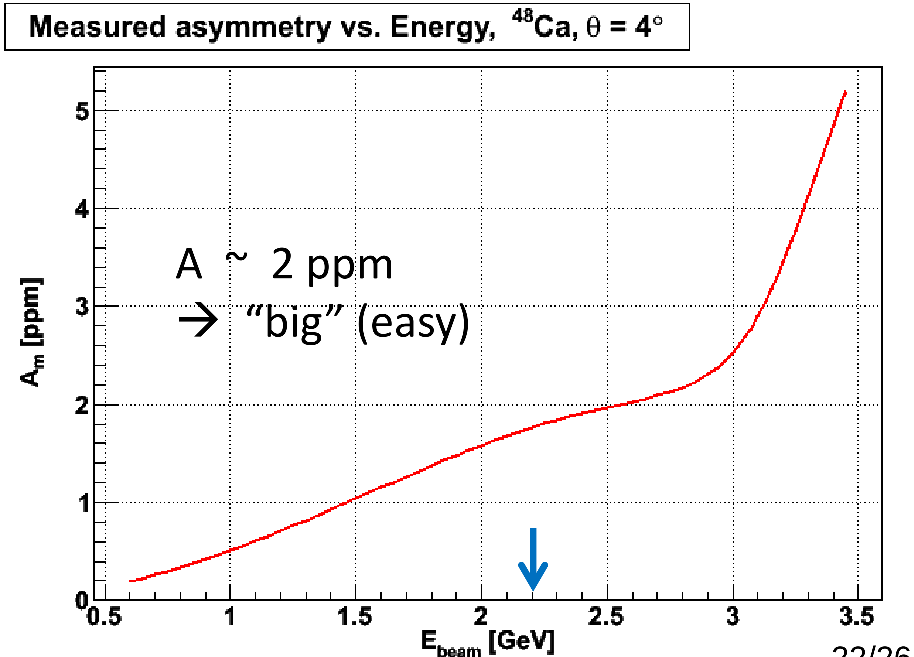


CREX: Optimization of Kinematics

Sensitivity of Asymmetry (A) to change in R_N

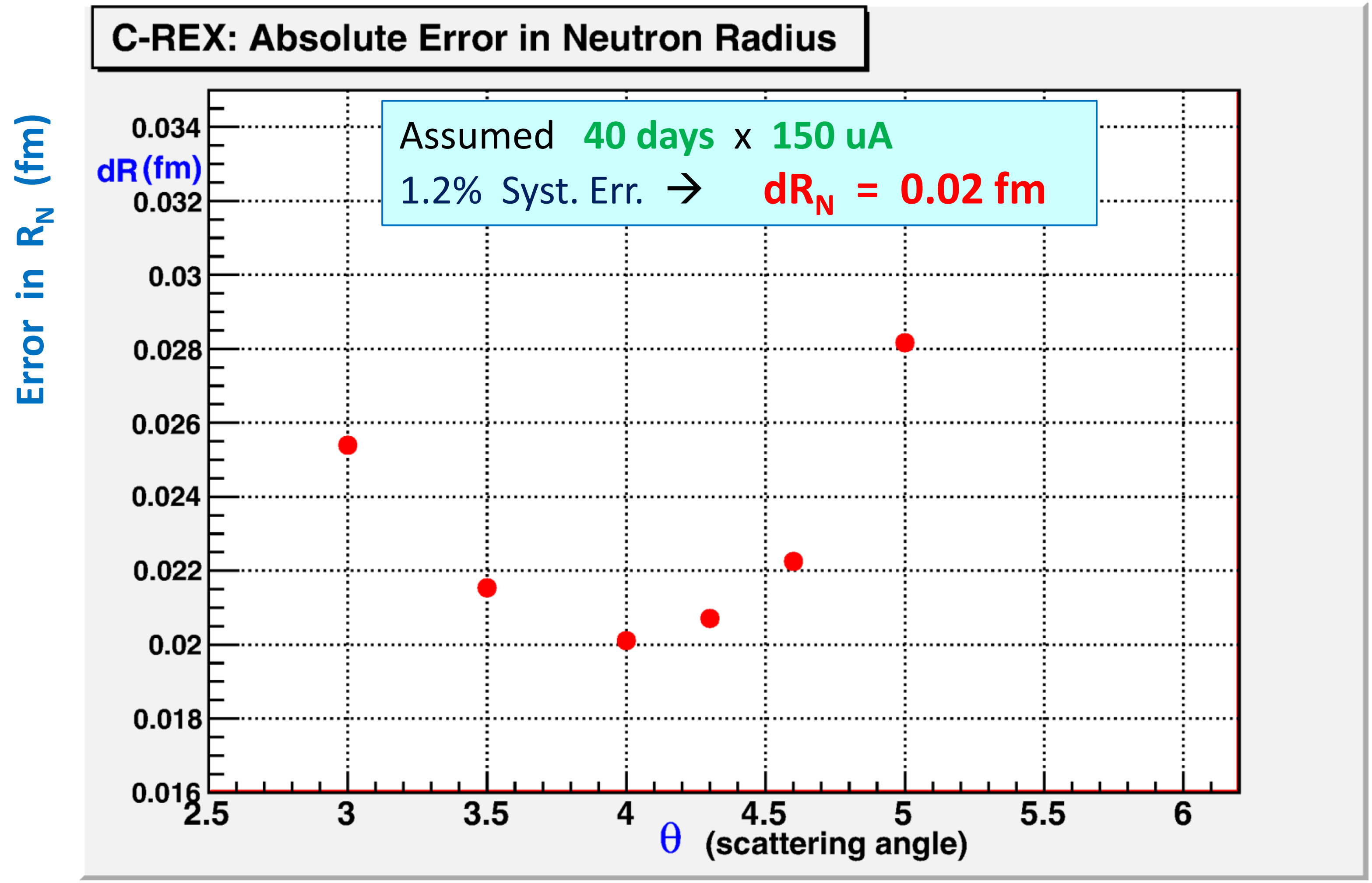






CREX -- choice of kinematics $E = 2.2\,GeV\,,\ \theta = 4^0$

Optimization of FOM equivalent to **minimum error in R_N**

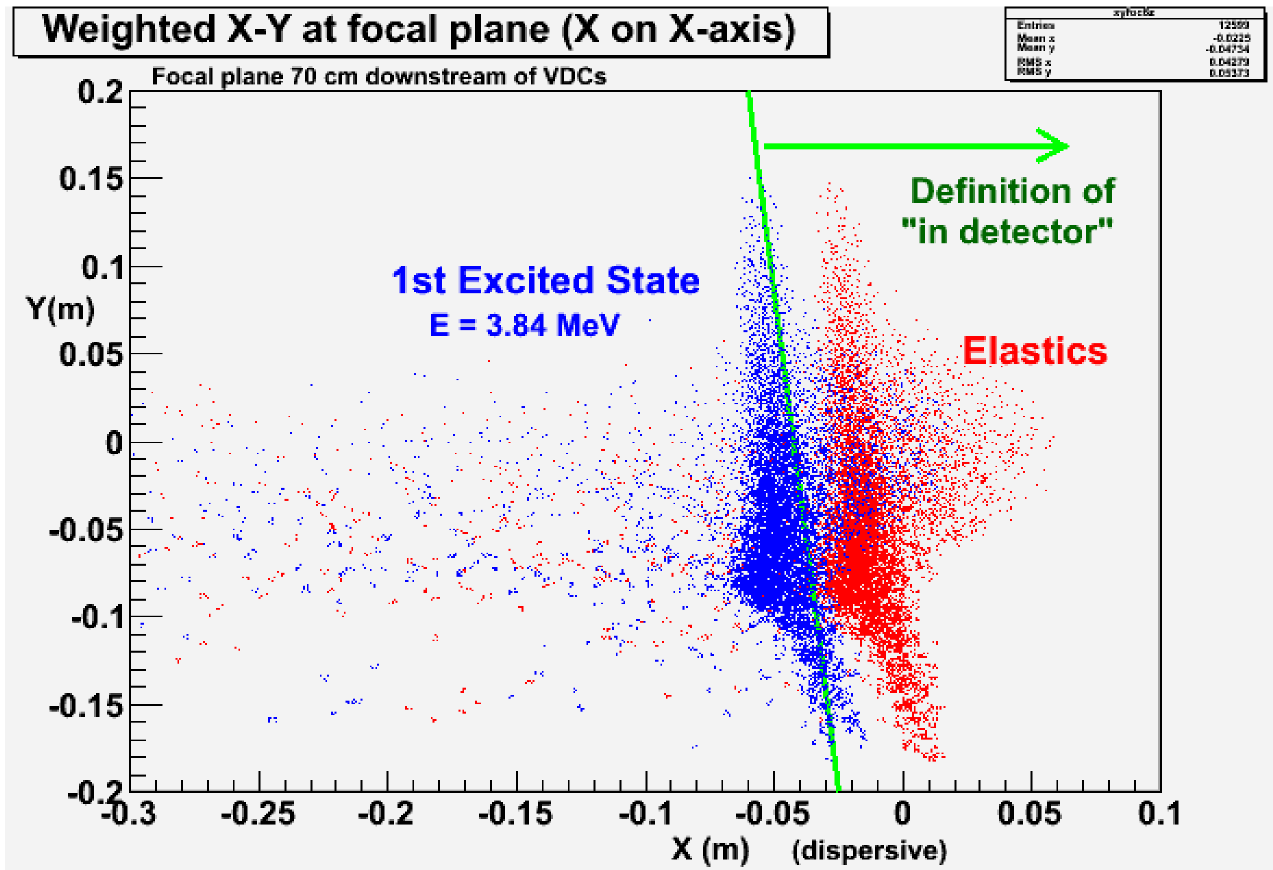


Inelastic Contributions -- background   Correction $dA = f * A_{state}$

For ^{48}Ca : 1st state f = 0.19%, 2nd state f = 0.18%, next 8 states f_{tot} = 0.03%

Need estimates for A_{state} and further optimization of HRS tune

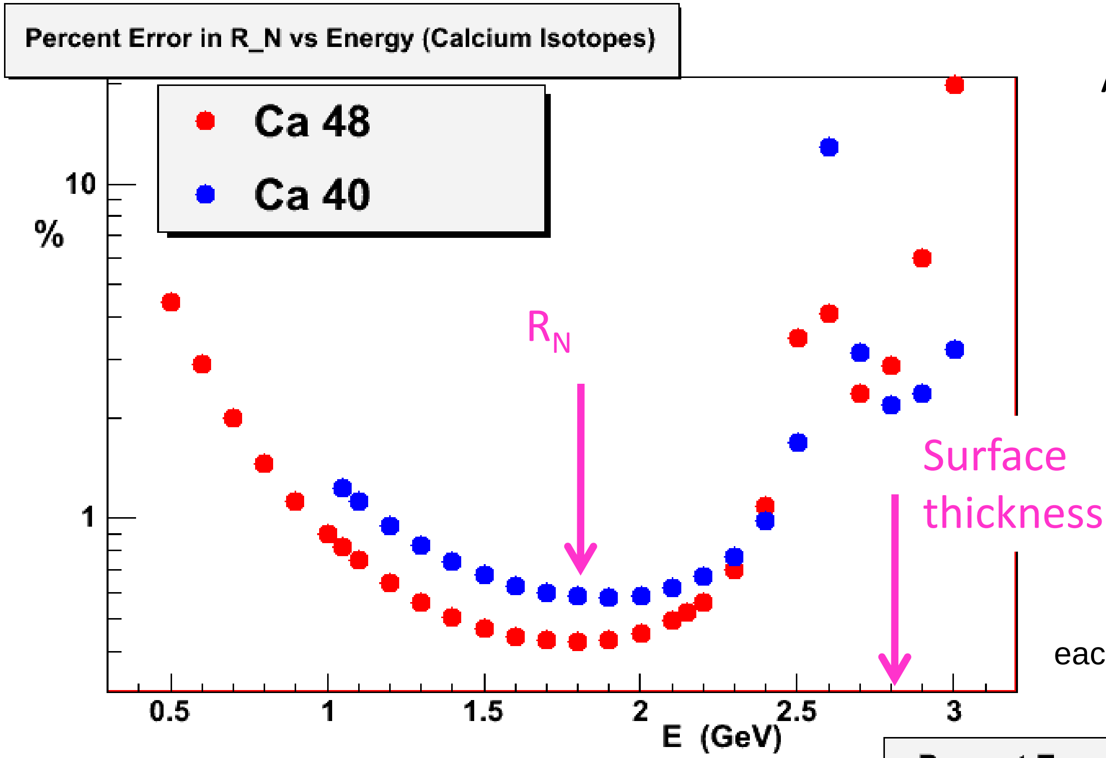
Simulated Events in HRS



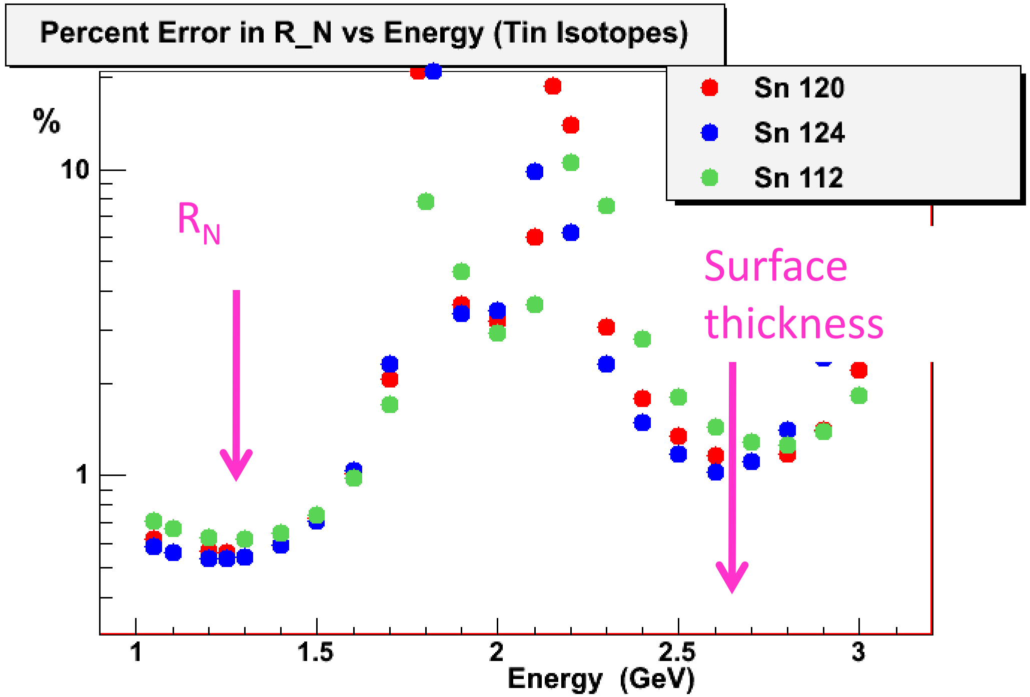
After PREX / CREX ....

Other Nuclei ?

and Shape Dependence ?



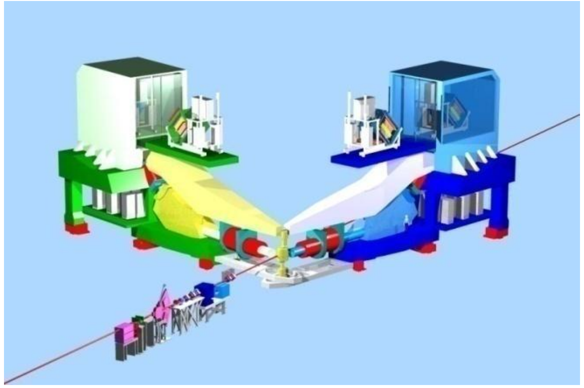
each point 30 days



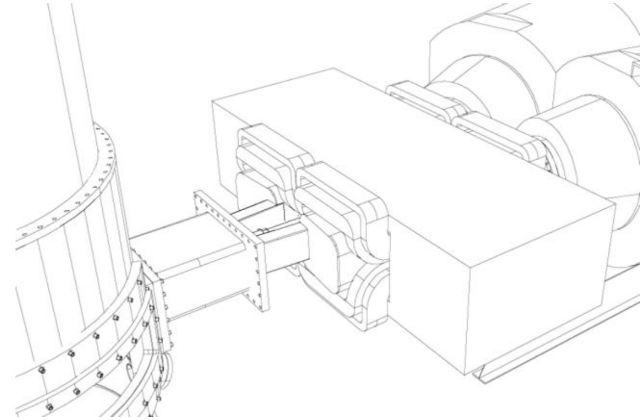
Parity Violating Electron Scattering Measurements of Neutron Densities

Shufang Ban, C.J. Horowitz, R. Michaels

J. Phys. G39 014104 2012



Possible Future PREX - type Program ?



Each point 30 days, except PREX-III 60 days   stat. error only

Nucleus	E (GeV)	dR_N / R_N	comment
^{208}Pb	1	1 % (0.06 fm)	**PREX-II** (approved by JLab PAC, A rating)
^{48}Ca	2.2 (1-pass)	0.02 fm	**CREX** natural 12 GeV exp't (approved, A-)
^{208}Pb	2.2 (1-pass)	0.02 fm	**PREX-III** discussed today
^{48}Ca	2.6	2 %	surface thickness
^{40}Ca	2.2 (1-pass)	0.6 %	basic check of theory
tin isotope	1.8	0.6 %	apply to heavy ion ?
tin isotope	2.6	1.6 %	surface thickness

Not yet proposed (last five rows)

Shufang Ban, C.J. Horowitz, R. Michaels J. Phys. G39 014104 2012

PREX / CREX : Summary

- Fundamental Nuclear Physics with many applications
- PREX-I achieved a 9% stat. error in Asymmetry (original goal : 3 %)
- Systematic Error Goals Achieved !!
- PREX-II approved to reach original goals (runs in 2016)
- CREX approved (unscheduled)