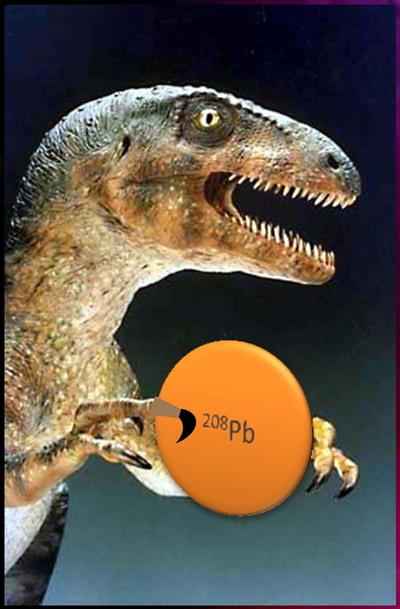
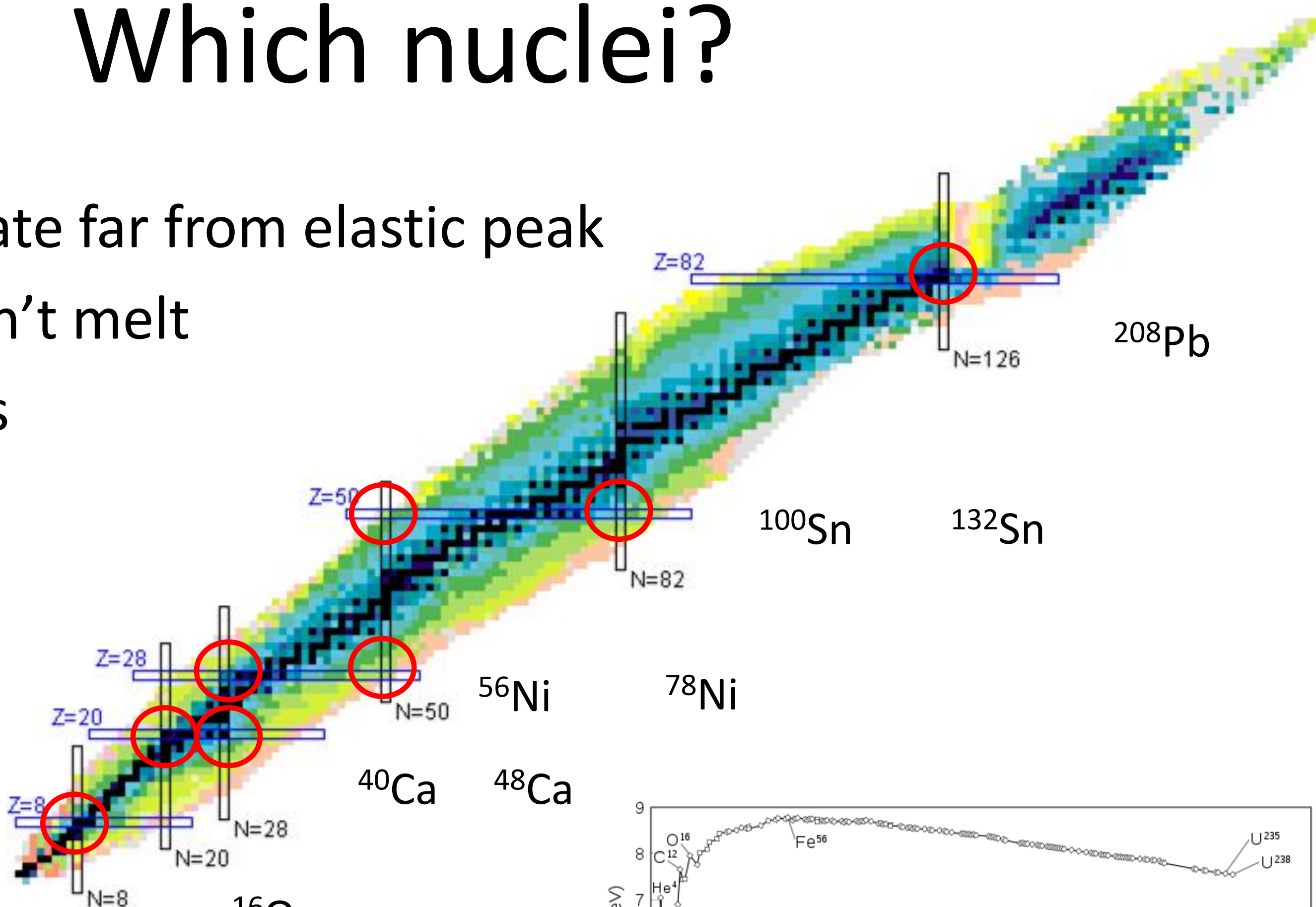
CREX
Ca **R**adius **Ex**periment

Juliette Mammei



Which nuclei?

- First excited state far from elastic peak
- Target that won’t melt
- Neutron excess
- Doubly-magic
- Stable



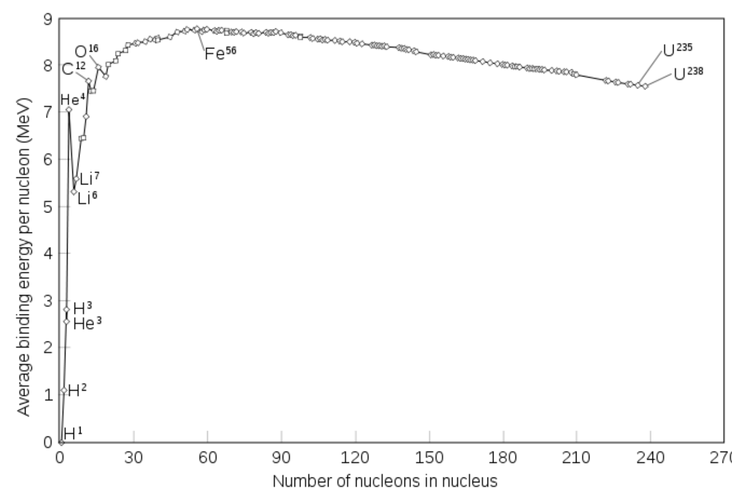
^{208}Pb

^{100}Sn ^{132}Sn

^{56}Ni ^{78}Ni

^{40}Ca ^{48}Ca

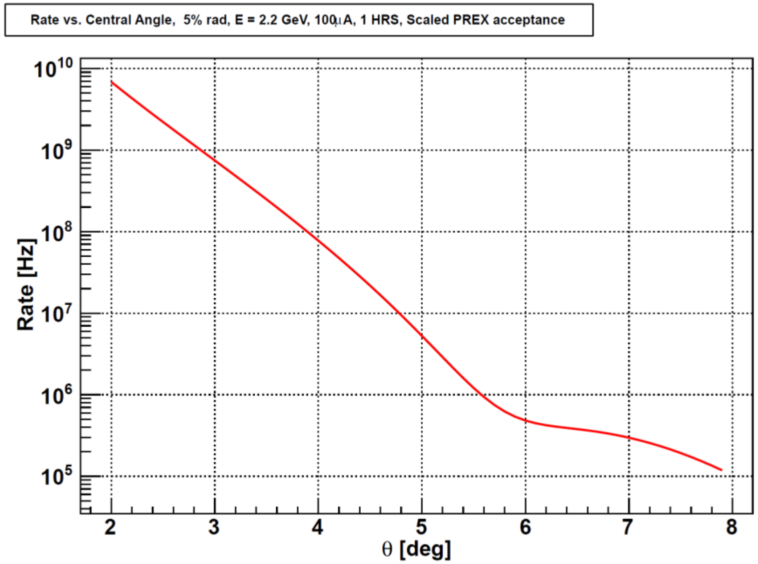
^{16}O

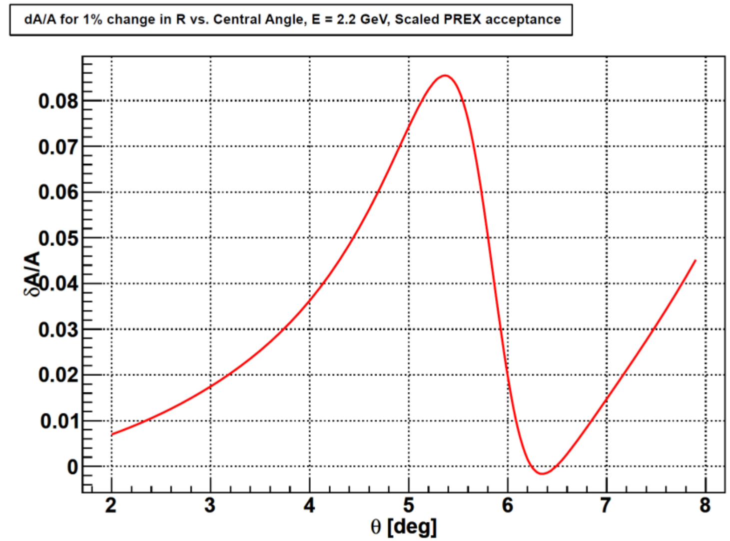


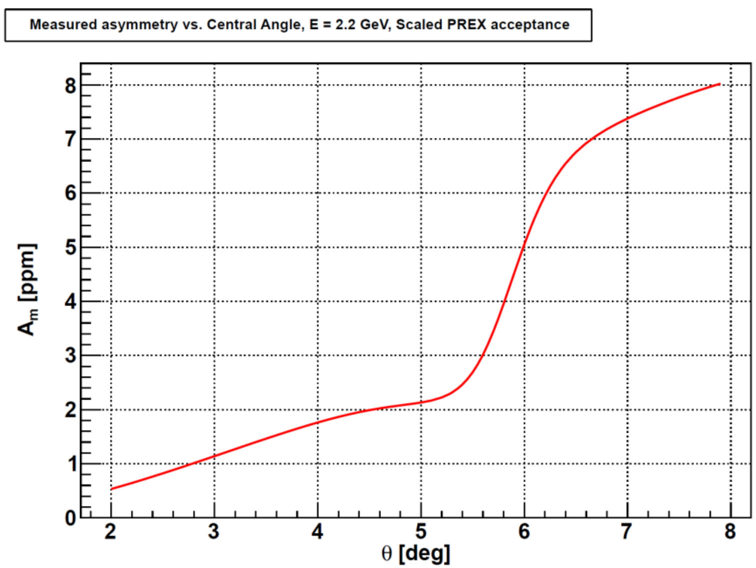
$$\frac{E}{A} \approx -a_v + \boxed{a_4}\left(\frac{N-Z}{A}\right)^2 + a_s / A^{1/3} + \ldots$$

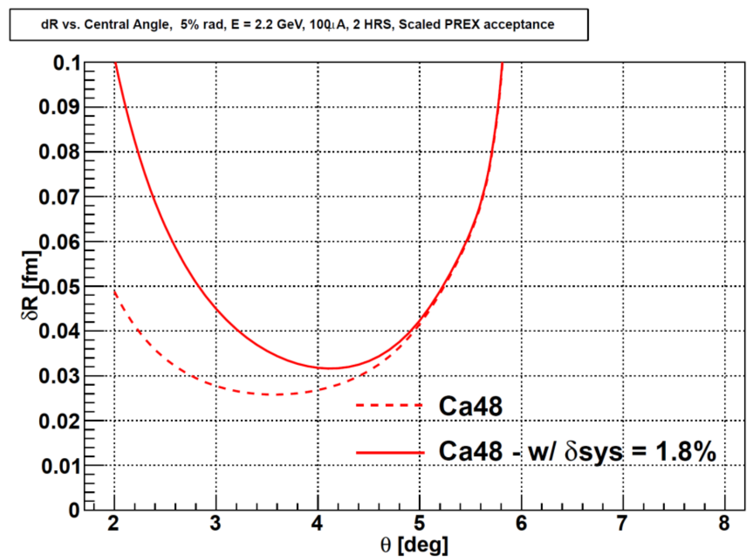
energy cost for unequal #p & #n

Choosing the angle

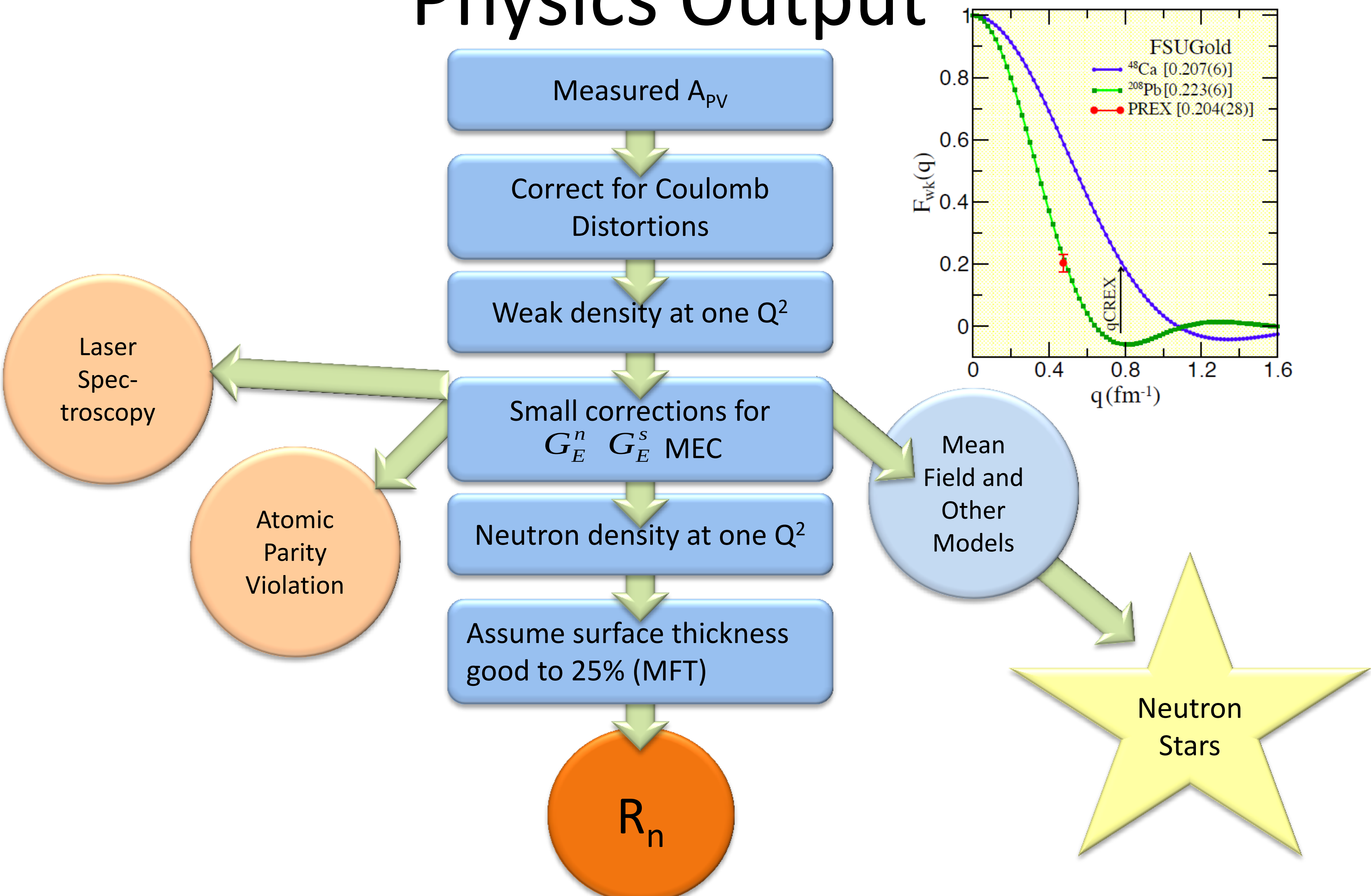




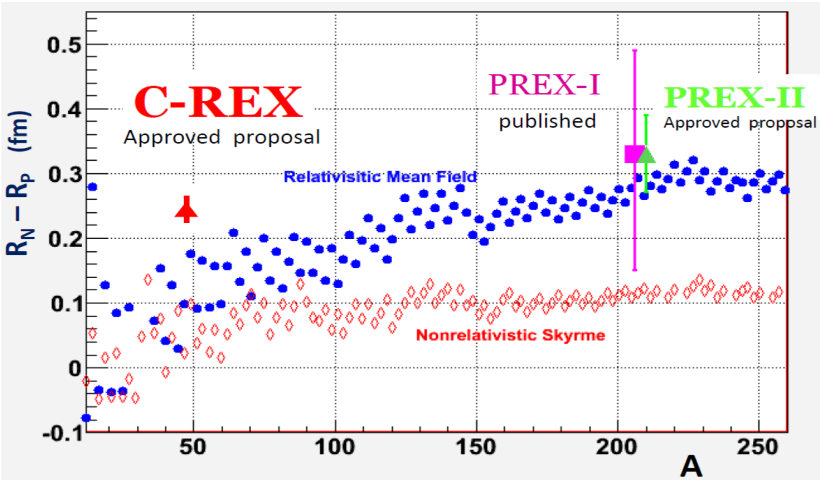


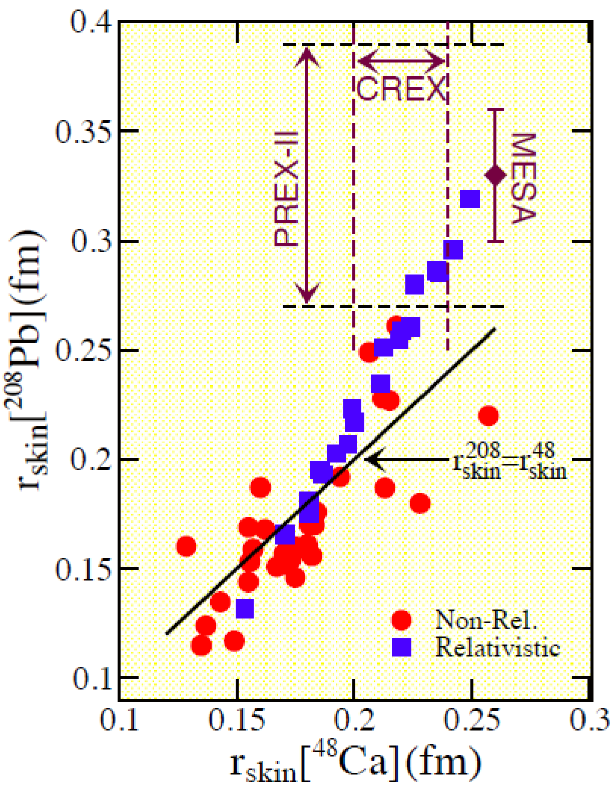


Physics Output



Why both?





^{208}Pb more closely approximates infinite nuclear matter

The ^{48}Ca nucleus is smaller, so can be measured at a Q^2 where the figure of merit is higher

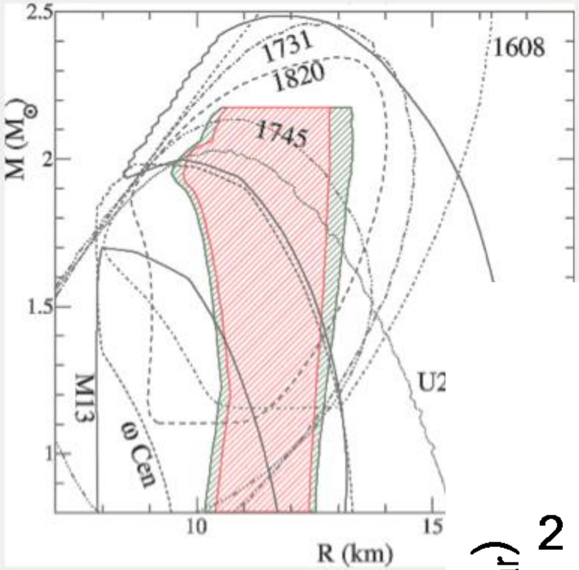
and are expected to be correlated, but the correlation depends on the correctness of the models

The structure of ^{48}Ca can be addressed in detailed microscopic models

Measure both and - test nuclear structure models over a large range of A

Neutron Stars

Mass and Radius Results

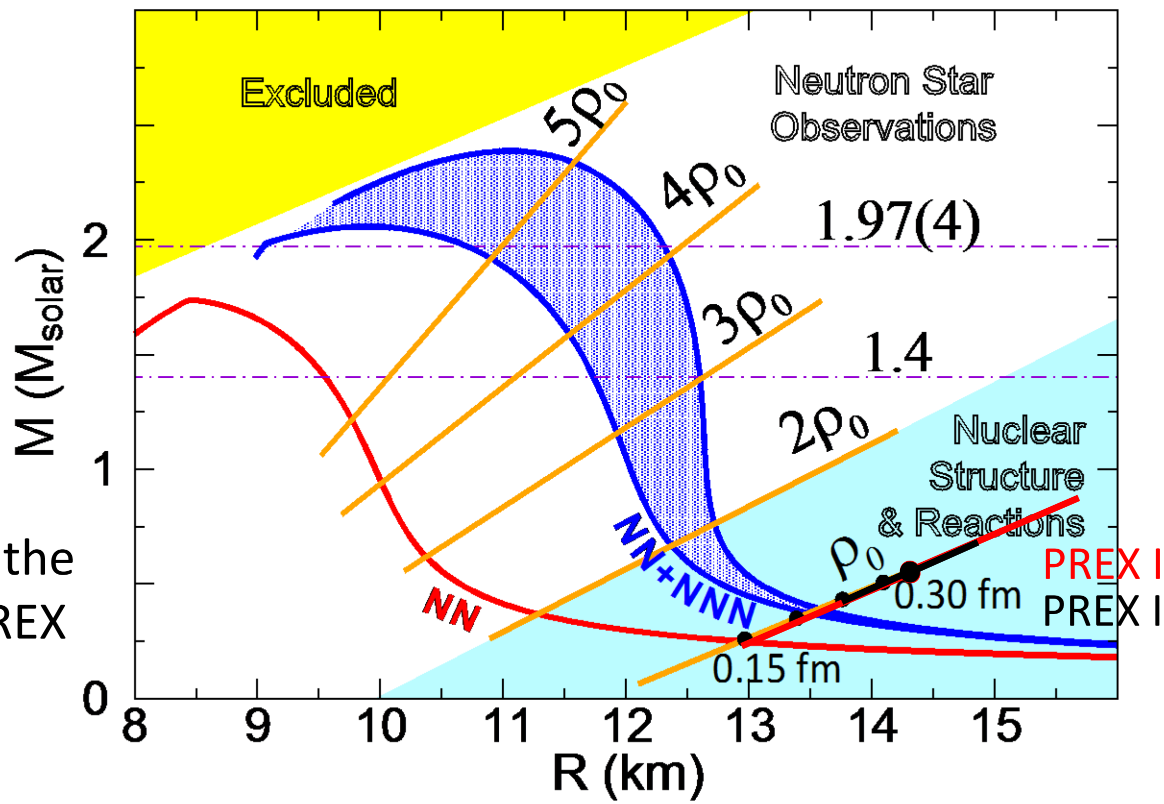


Steiner, Lattimer, and Brown

- Range of radii for a 1.4 solar mass star: 10.4 and
- All neutron stars have nearly the same radius

Using models, one can relate the neutron star radius to the neutron skin of heavy nuclei

Gandolfi et al. PRC85, 032801 (2012)



Including 3N forces can change the model predictions; CREX and PREX will help constrain the models

Measuring A_{PV} with ES

- unpolarized target
- high current
- highly polarized beam

$$A_{PV} = \frac{A_{sig}}{P_{beam}}$$

$$A_{sig} = \frac{A_{corr} - A_{back}\, f_{back}}{f_{sig}}$$

$$A_{corr} = A_{meas} - \sum_{i=1}^{N} \frac{1}{2Y}\left(\frac{\partial Y}{\partial P_i}\right)\Delta P_i$$

where $\Delta P_i = P_+ - P_-$

$$A_{meas} = \frac{Y_+ - Y_-}{Y_+ + Y_-}$$

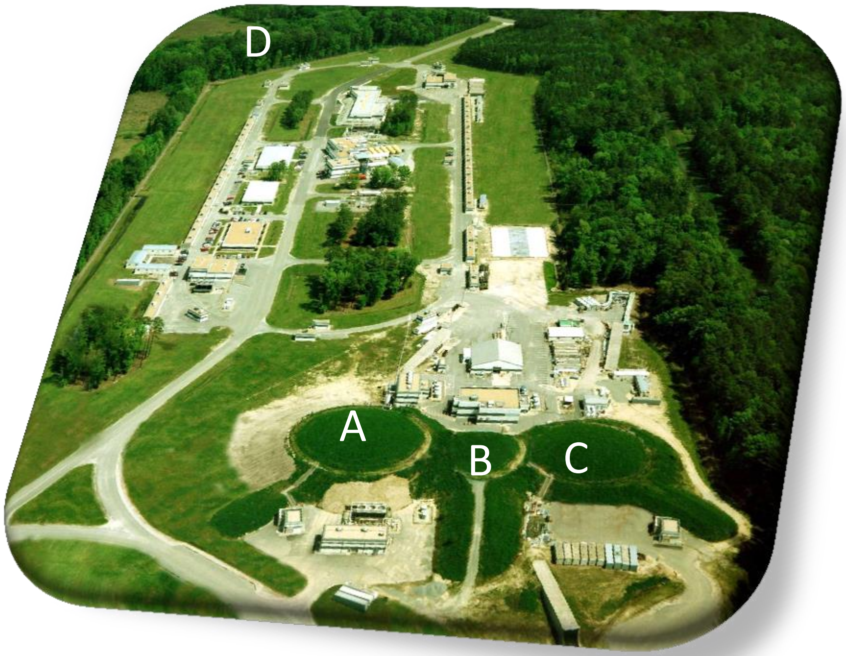
- polarimetry
- elastic electrons from target (resolution of the spectrometers)
- beam property monitoring
- active feedback to minimize helicity correlations
- rapid helicity reversal
- slow helicity reversal as a cross check

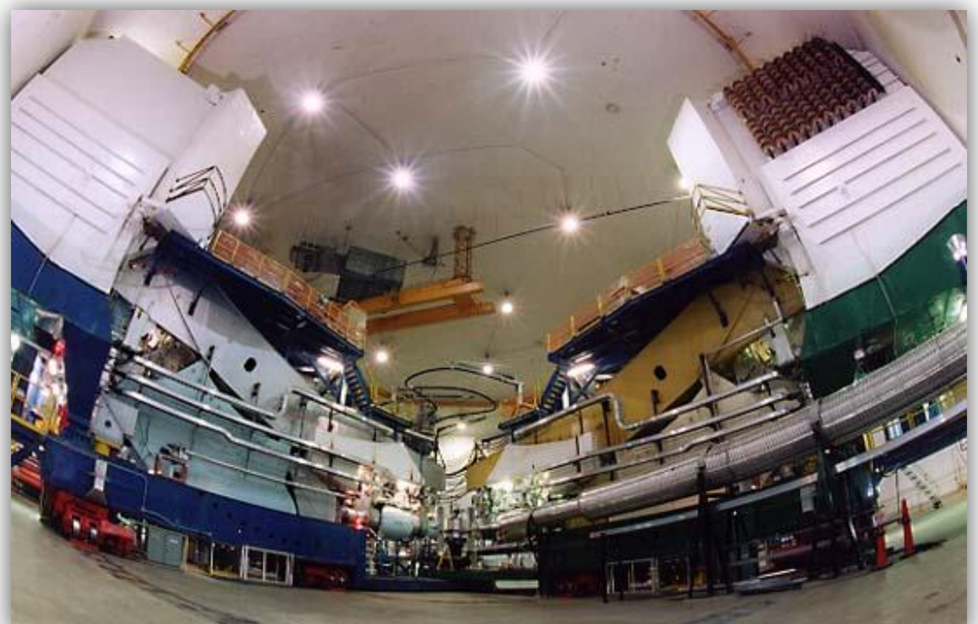
CREX

2.2 GeV electron beam, 50-70 µA

high polarization, ~89%

helicity reversal at 120 Hz





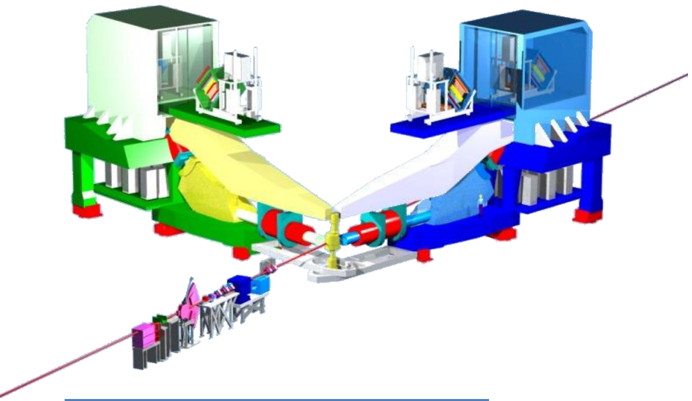
~5 mm thick Ca target

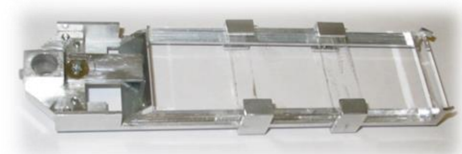
4° scattered electrons

$Q^2 = 0.022\ GeV^2/c^2$

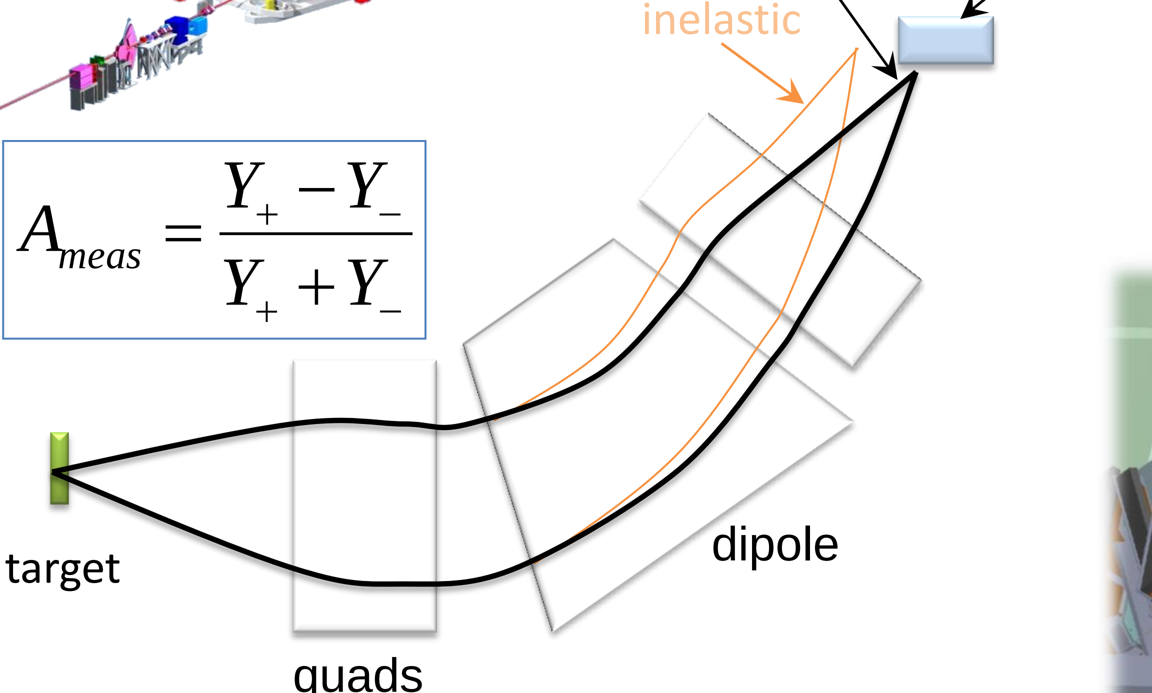
thick and thin quartz detectors

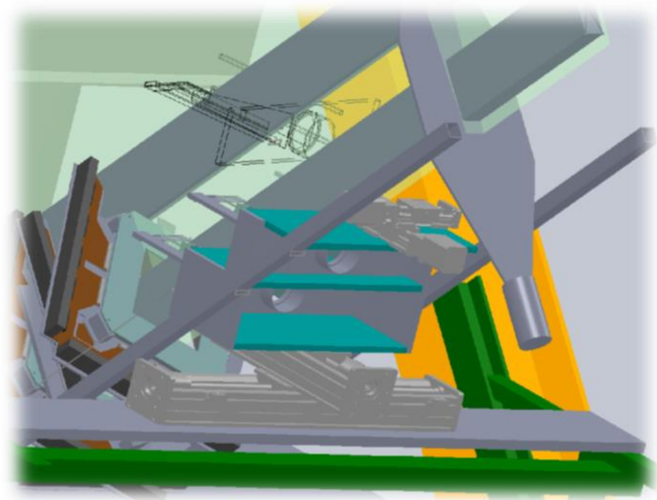
Hall A High Resolution Spectrometers





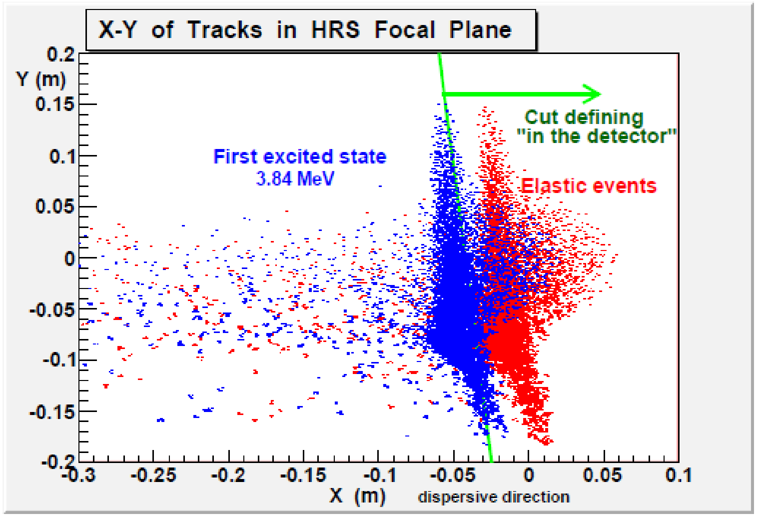
$$A_{meas} = \frac{Y_+ - Y_-}{Y_+ + Y_-}$$



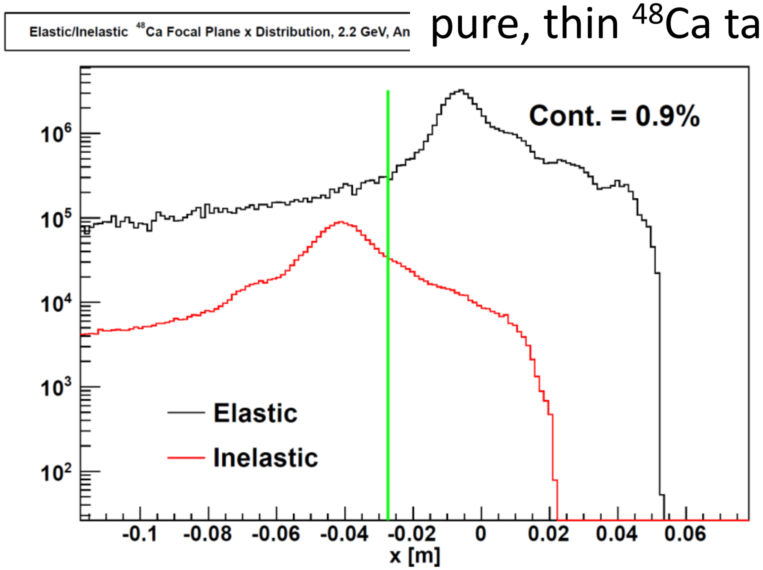


Optics considerations

- Can refine optics – find a tune for
  - Septum
  - Quads
  - Dipole
- Need to consider effect of higher order multipoles in septum
- May need to use shims for CREX (for field shaping)



pure, thin ^{48}Ca target



like momentum

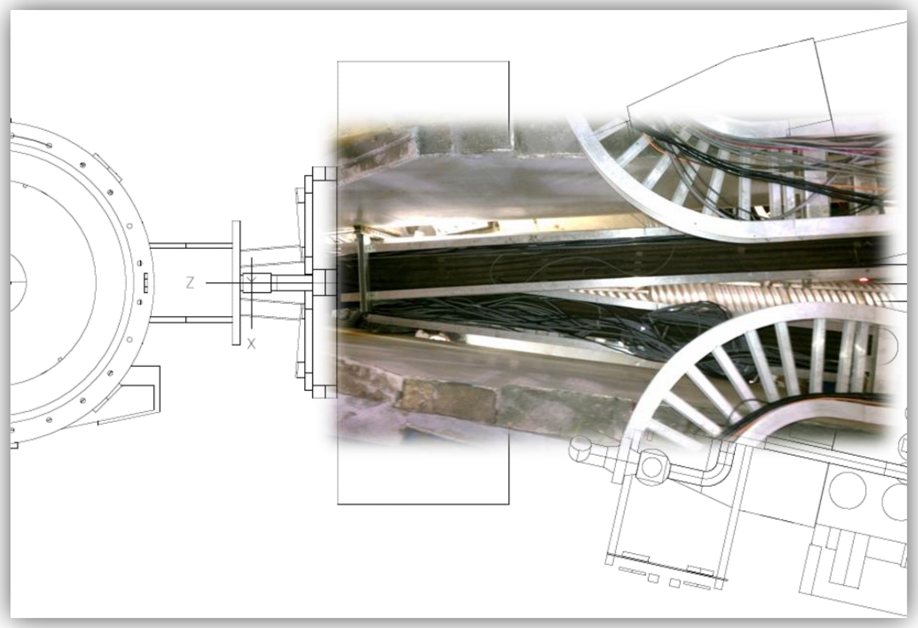
The septum

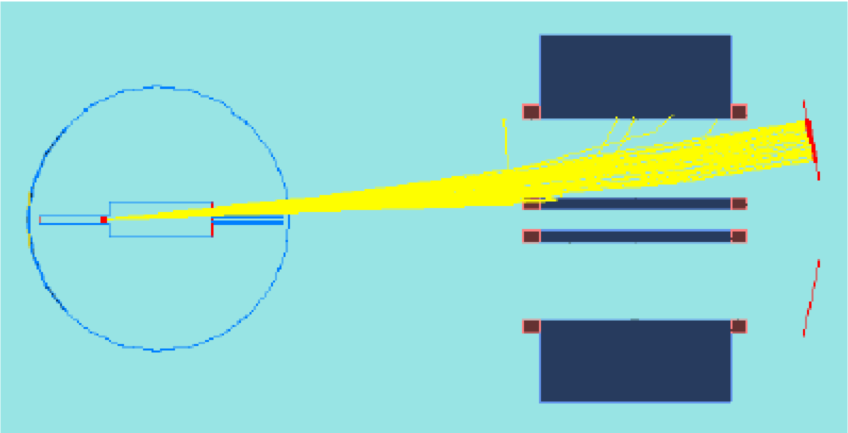
HRS only goes down to 12.5°, need septum to "pre-bend"

- Need higher $\int \vec{B} \cdot d\vec{\ell}$
  - Energy higher (1.06 → 2.2 GeV)
  - Lower lowest angle (4.6° → 3°)

$$\alpha[rad] = \frac{\int \vec{B} \cdot d\vec{\ell}\ [Tm]}{3.33E[GeV]}$$

- Difficulties
  - Saturation in the yoke
  - Water cooling
- Consequences
  - Tune for CREX
  - magnetic shielding



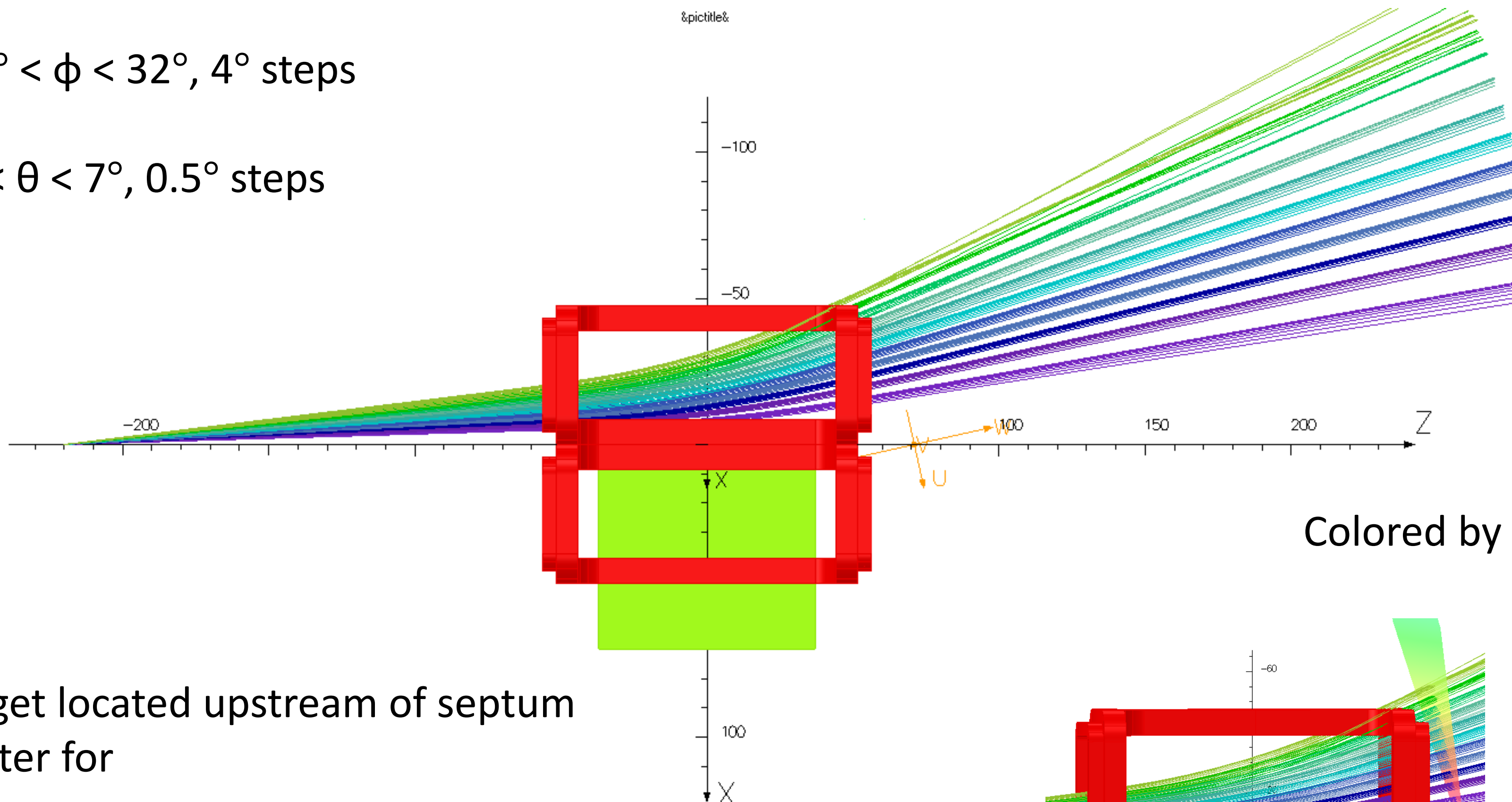


TOSCA simulations

Tracks are generated for:

-32° < ϕ < 32°, 4° steps

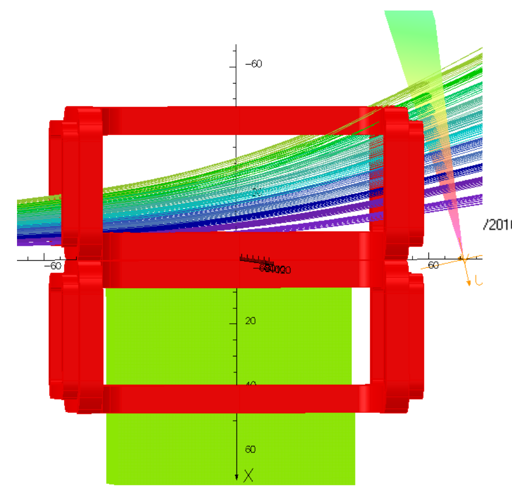
2° < θ < 7°, 0.5° steps



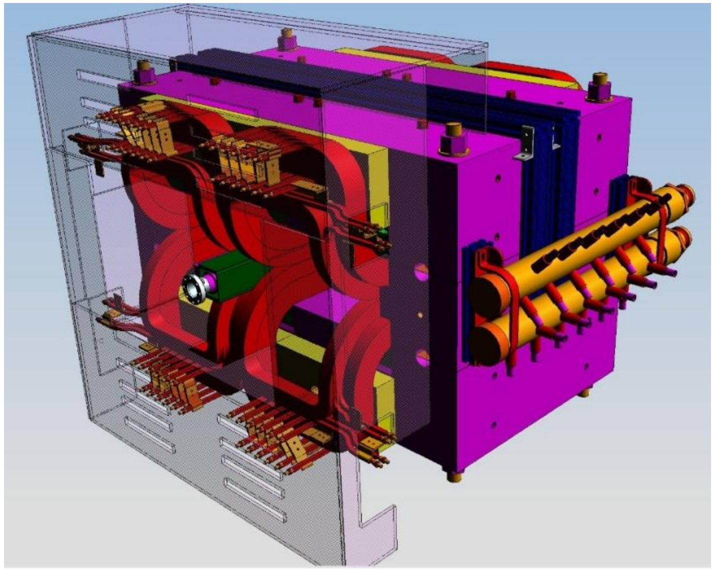
Colored by θ

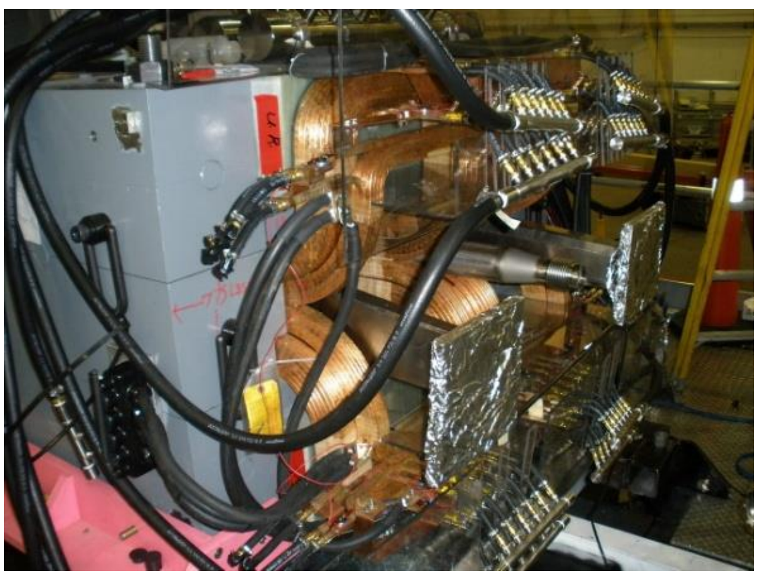
Target located upstream of septum center for

PREX: -175.211 cm
CREX: -175.211 - 45 cm



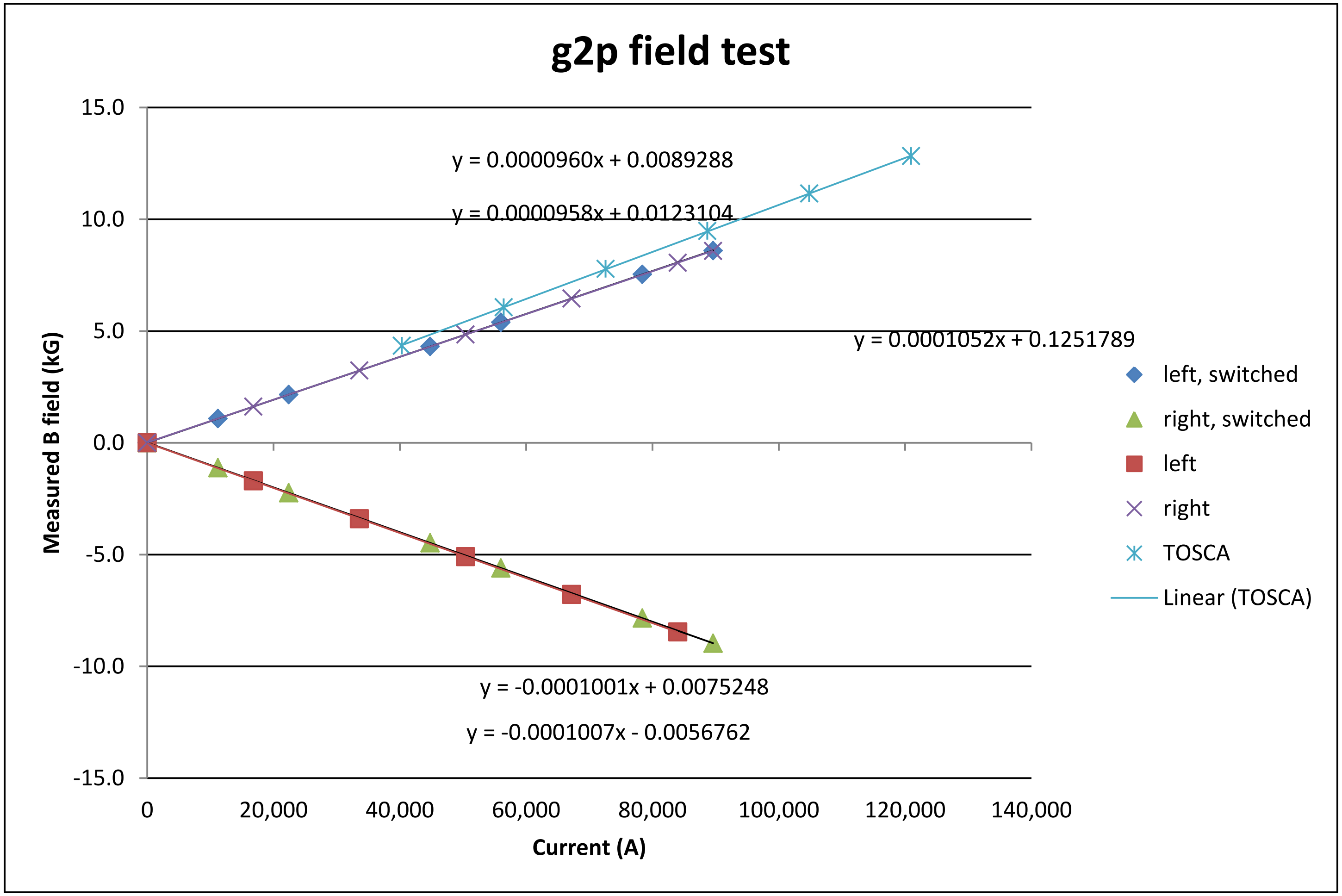
Septum Design

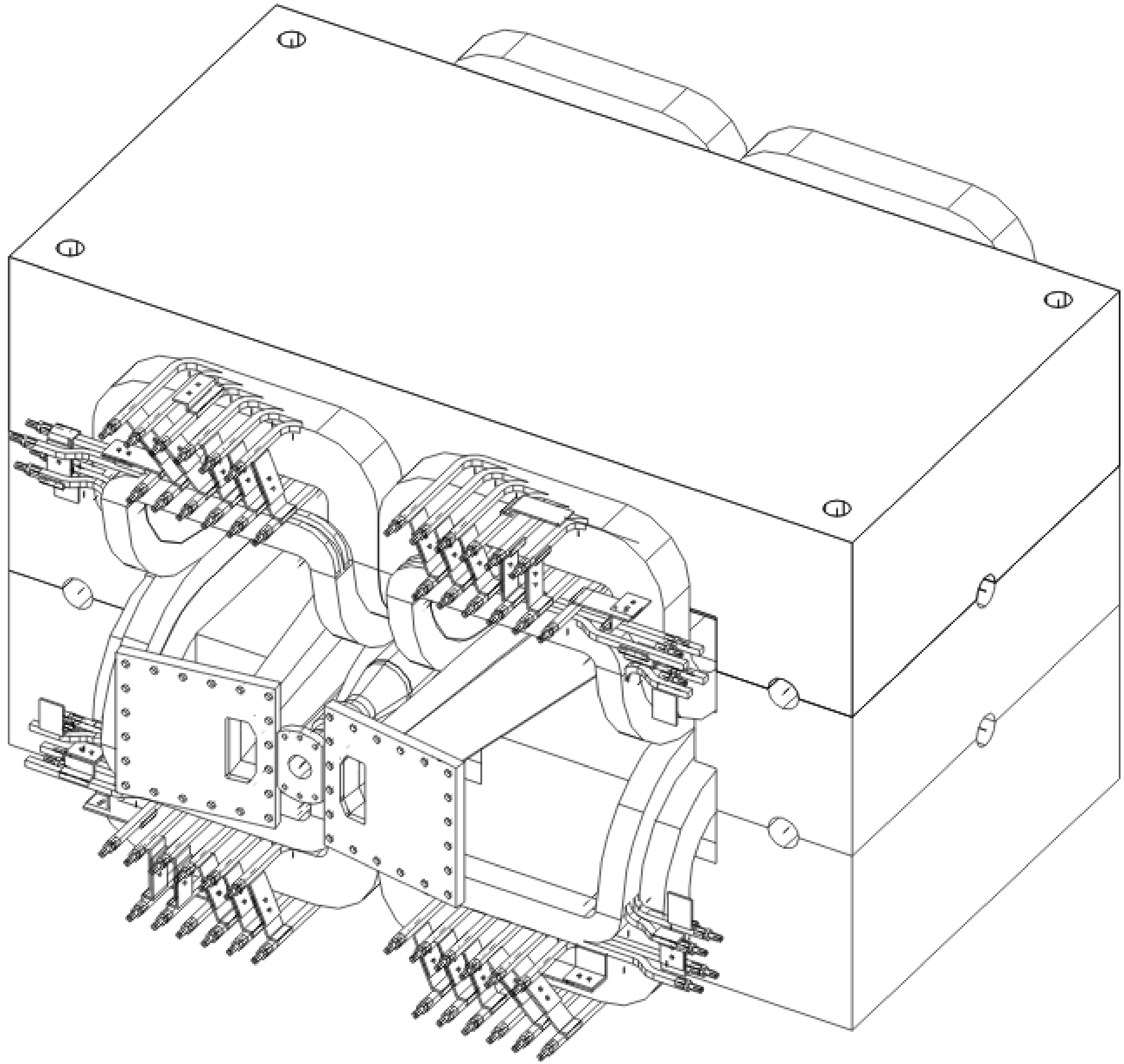


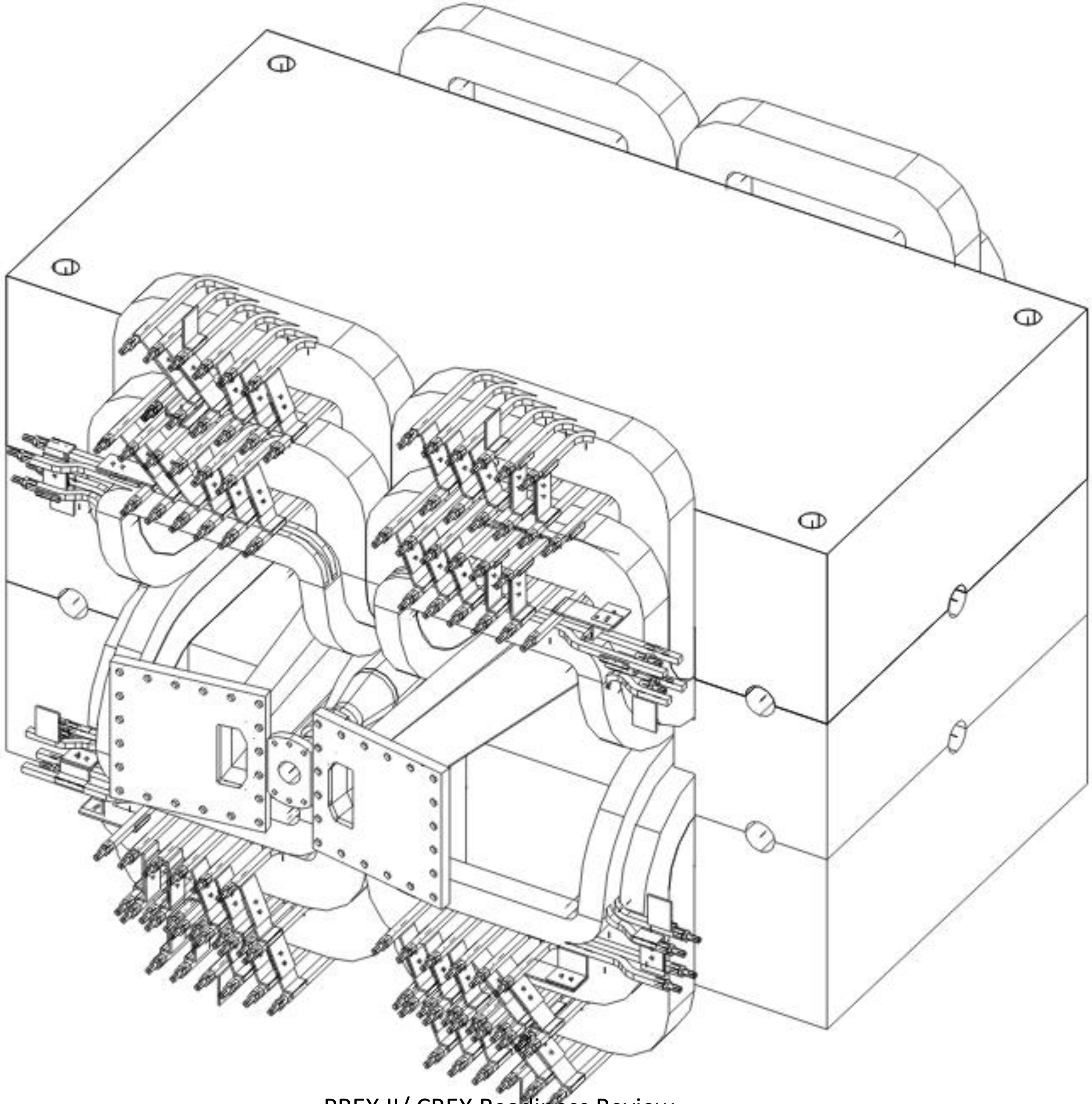


	PREX (2 coils)	CREX (3 coils)	PREX (3 coils)
J (A/cm²)	(600) 1021	(858) 1455	(343) 584
A (cm²)	323	564	564
NI (A)	193536	484217	193536
$\int \vec{B} \cdot d\vec{\ell}$	0.486	1.21	0.4855
I_1 (A)	12096	17293	6912
I_2 (A)	36288	51880	20736
I_3 (A)	0	51880	20736
Total I (A)	193536	484217	193536
I_{PS} (A)	756	1081	432
V(V)	176	449	176
P(kW)	133	486	76
FR (gal/min)	25.17	45.99	14.37
<P> (psi)	127.19	154.75	19.36
R/L (Ω/cm)	2.38E-06	2.44E-06	2.38E-06
ΔT (°C)	20	40	20

Current Tests



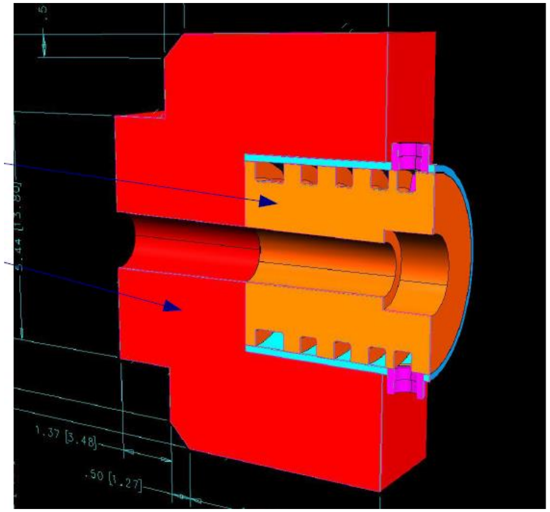


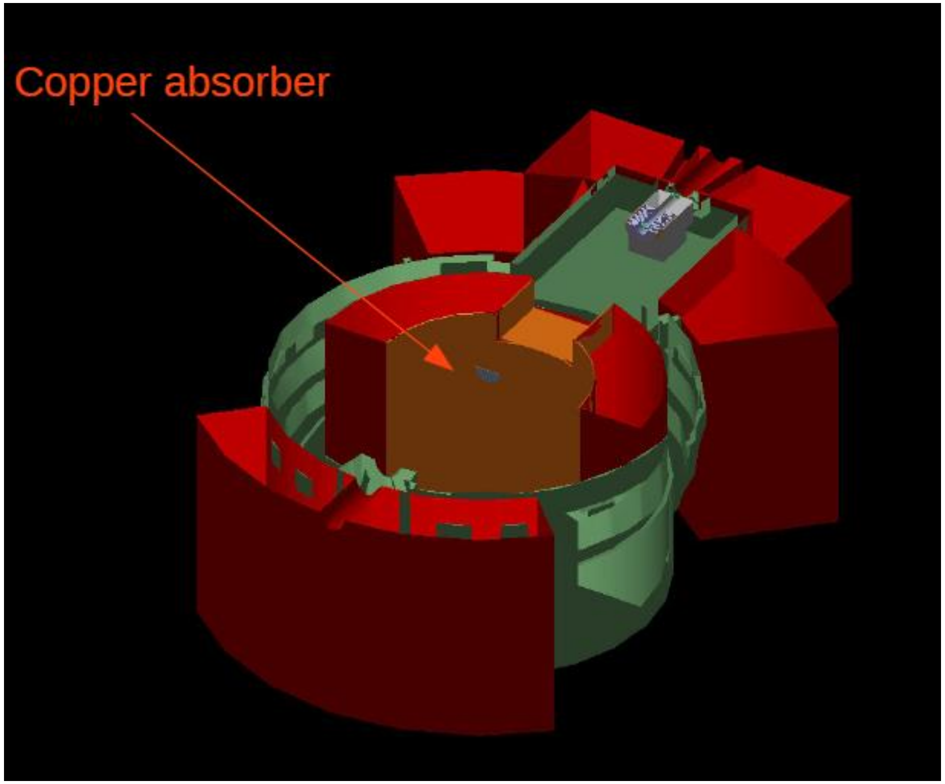


Collimator

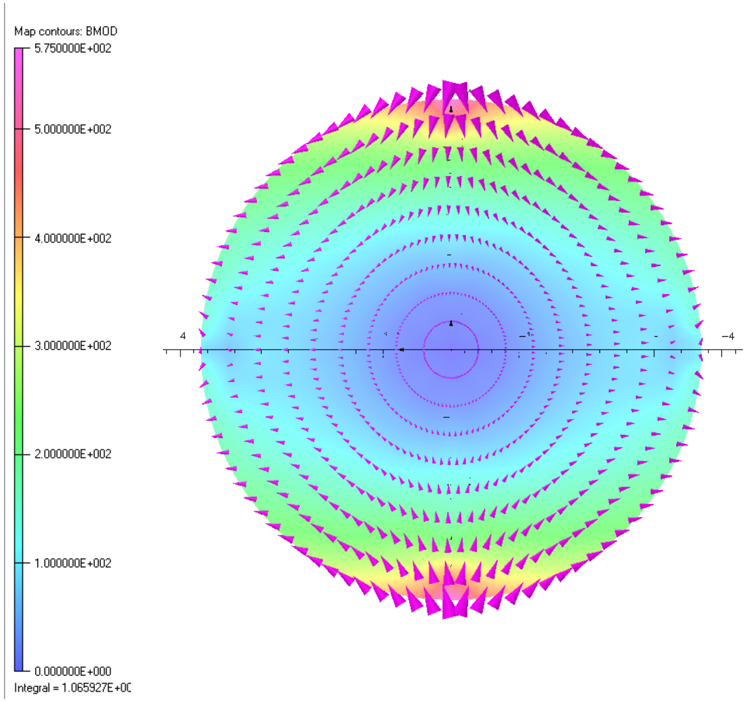
The collimator is placed about 85 cm from the target and intercepts scattered electrons from 0.78° to 3.8°

- Water cooled Cu-W inner cylinder in a W box
- 2.1 kW power

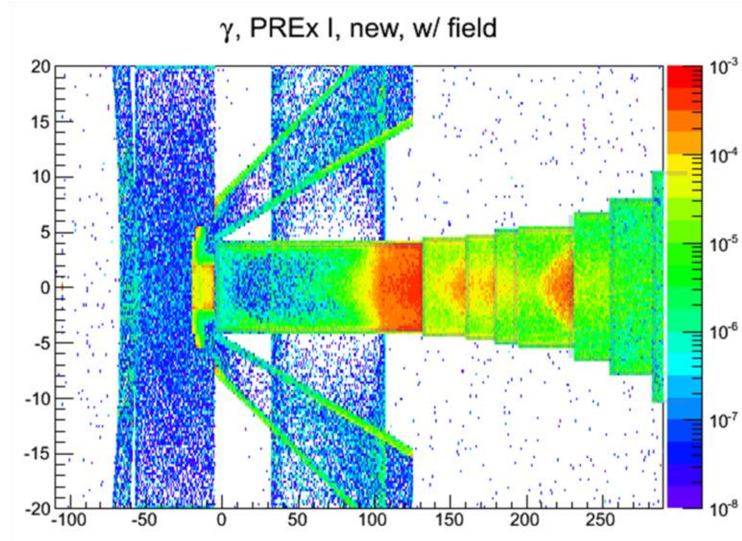


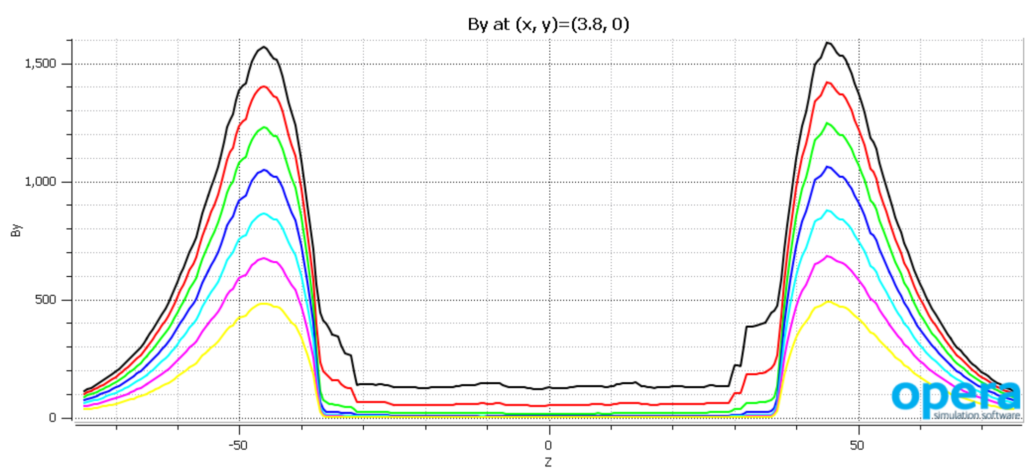


Magnetic shielding



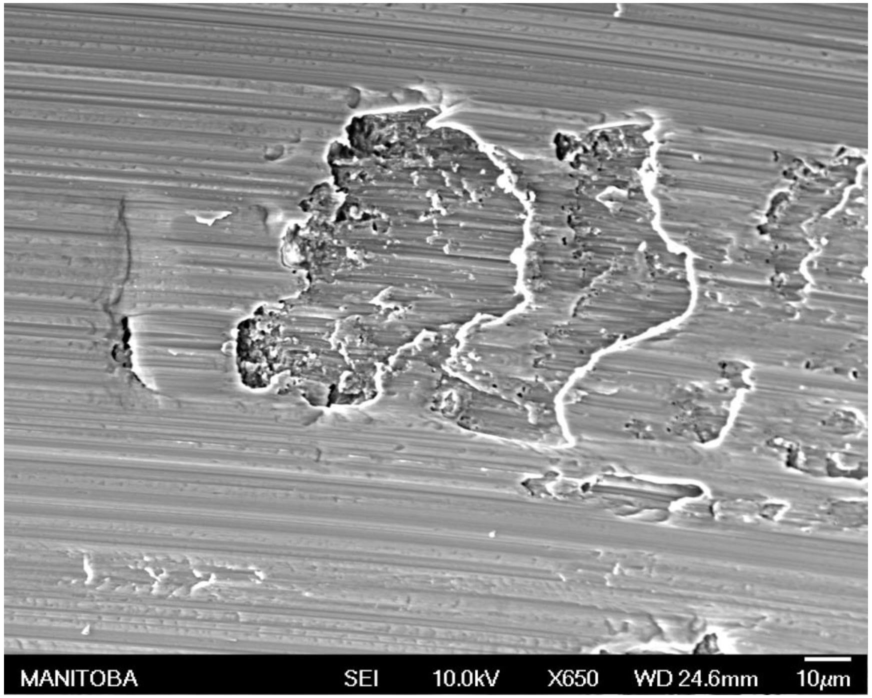
No shield

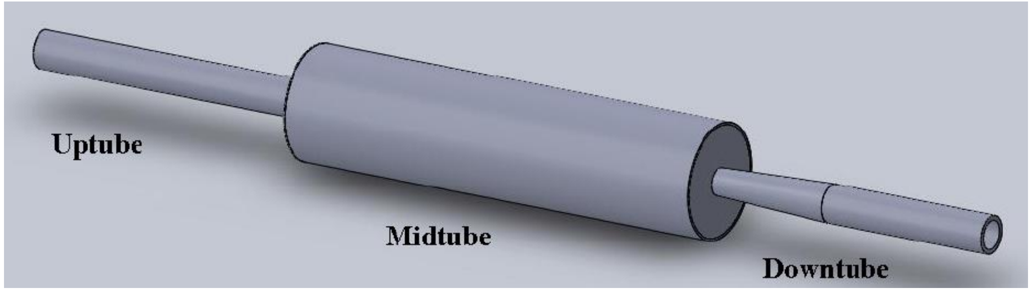




Target

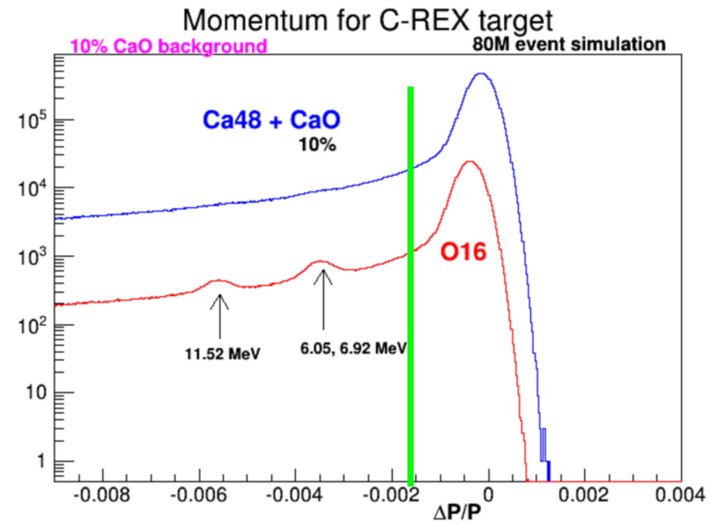
- Isotopically pure ^{48}Ca target from Oak Ridge
- Clean
- Measure contamination
- Increase thickness

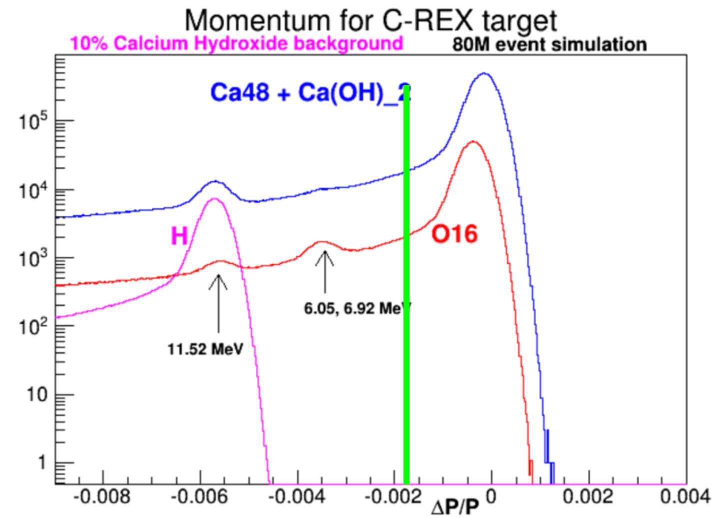




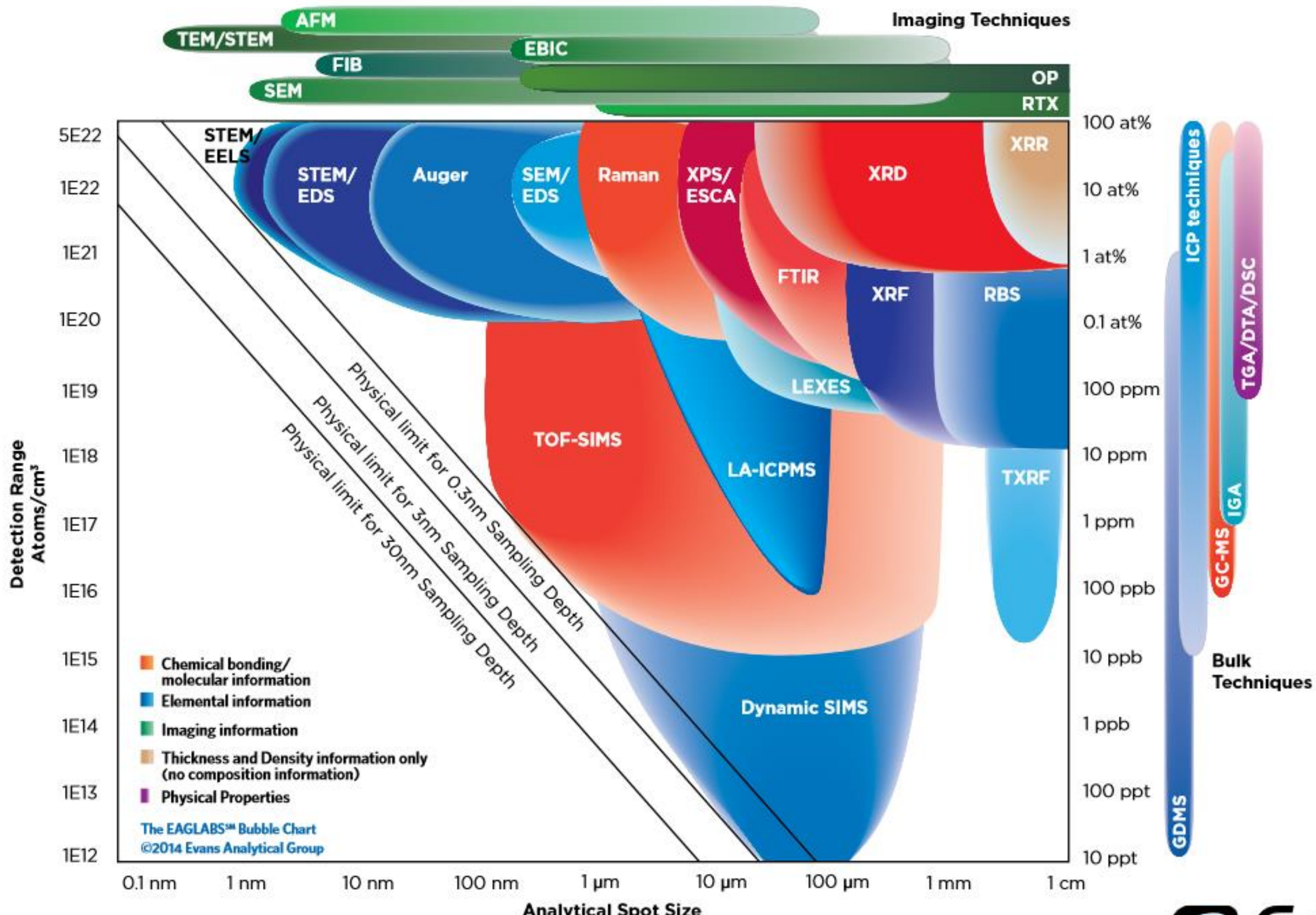
Contamination

- Oxides, nitrides, carbides…
- Preliminary tests with natural calcium
  - Can't measure hydrogen
  - Only "surface" carbon
  - No nitrogen
- Need more controlled tests with better precision
  - Preparing lumps
  - Oxidizing
  - Scraping
  - Measuring



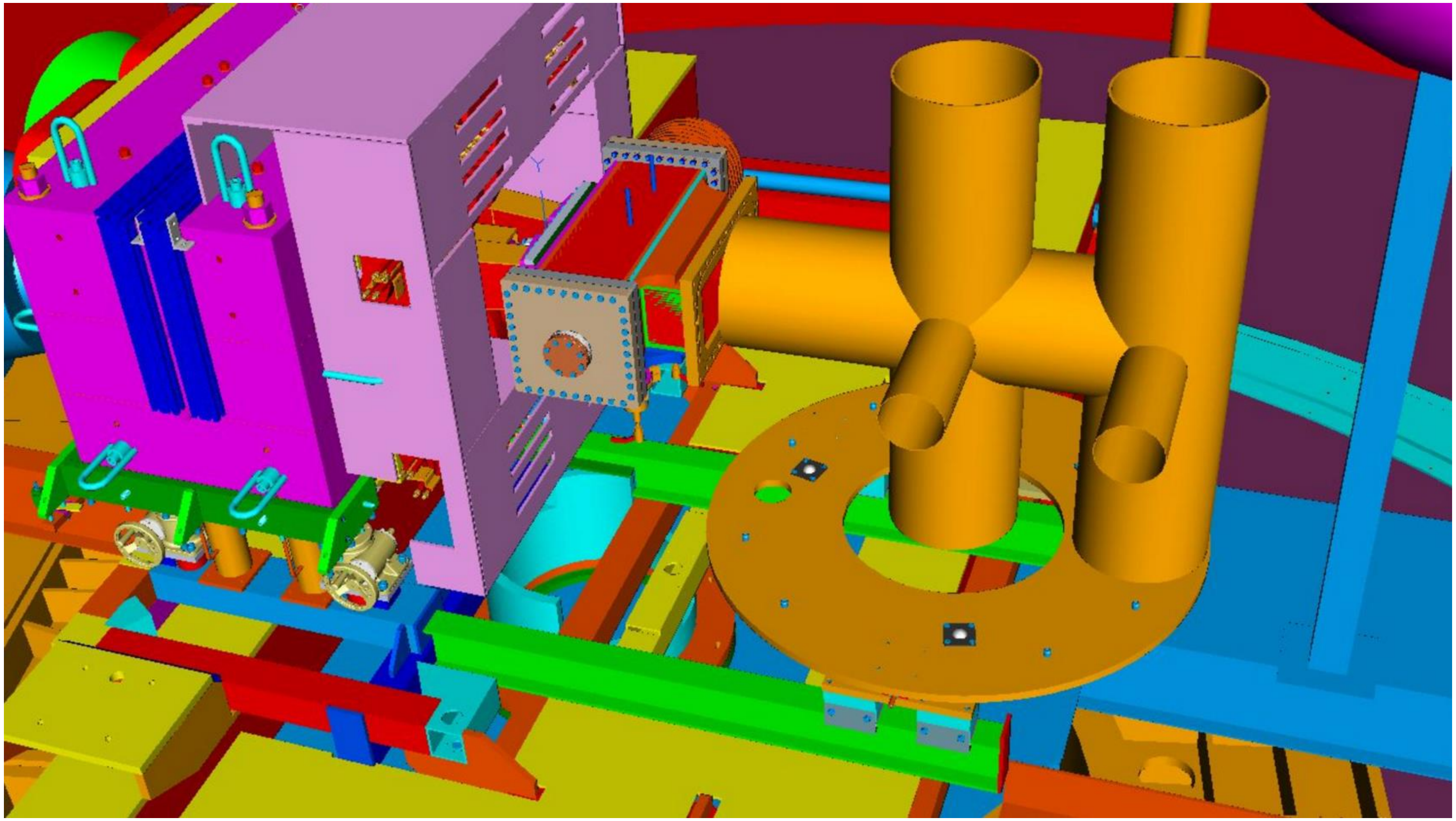


Analytical Resolution vs Detection Limit



www.eag.com/mc

Running PREX/CREX



CREX Uncertainties

$$A_{PV} = 0.656\ ppm \pm\ 0.060(stat) \pm 0.013(syst)$$ → $$R_n - R_p = 0.33^{+.16}_{-.18}\ fm$$

Systematic Error	PREX II (achieved in PREX I)	CREX
	Relative (%)	Relative (%)
Polarization (1)	1.3	0.8
Beam Asymmetries (2)	1.1	0.3
Detector Linearity	1.2	0.3
Beam current normalization	0.2	0.1
Transverse Polarization	0.2	0.1
Q^2 (1)	0.5	0.8
Target Contamination/Backing	0.4	0.2
Inelastic States	<0.1	0.2
TOTAL	**2.1**	**1.2**

PREX ~0.06 fm

CREX ~0.02 fm

(1) Normalization Correction applied
(2) Nonzero correction (the rest assumed zero)

→ Statistics limited (9%)

→ Systematic error goal achieved !

Challenges unique to CREX

- Run CREX/PREX II together
  - Same collimator, septum, target ladder, shielding
- Septum
  - Higher current needed
  - Optics
  - Residual quadrupole field
- Target
  - oxidized
  - thermal considerations
- Radiation
  - compare to PREX

All under control

Extra Slides

Breakdown

- KK: Historical perspective, description of observable, experimental technique, PREX-I result
- Kent: Description of improvements, status of preparations, projected experimental statistical and systematic errors
- Juliette: Advantages of Ca-48, description of technical challenges, status of preparations, projected statistical and systematic errors.
- Bob: Possible ways to measure additional Q2 points for Ca-48, and (perhaps one additional Q2 point on Pb-208?)
- Paul: Discussion of how to go from Bob's investigations to realistic experimental designs?