Fundamental Symmetries
and
Weak Interaction through Parity Violation

(Particularly with Polarized Electron Scattering)

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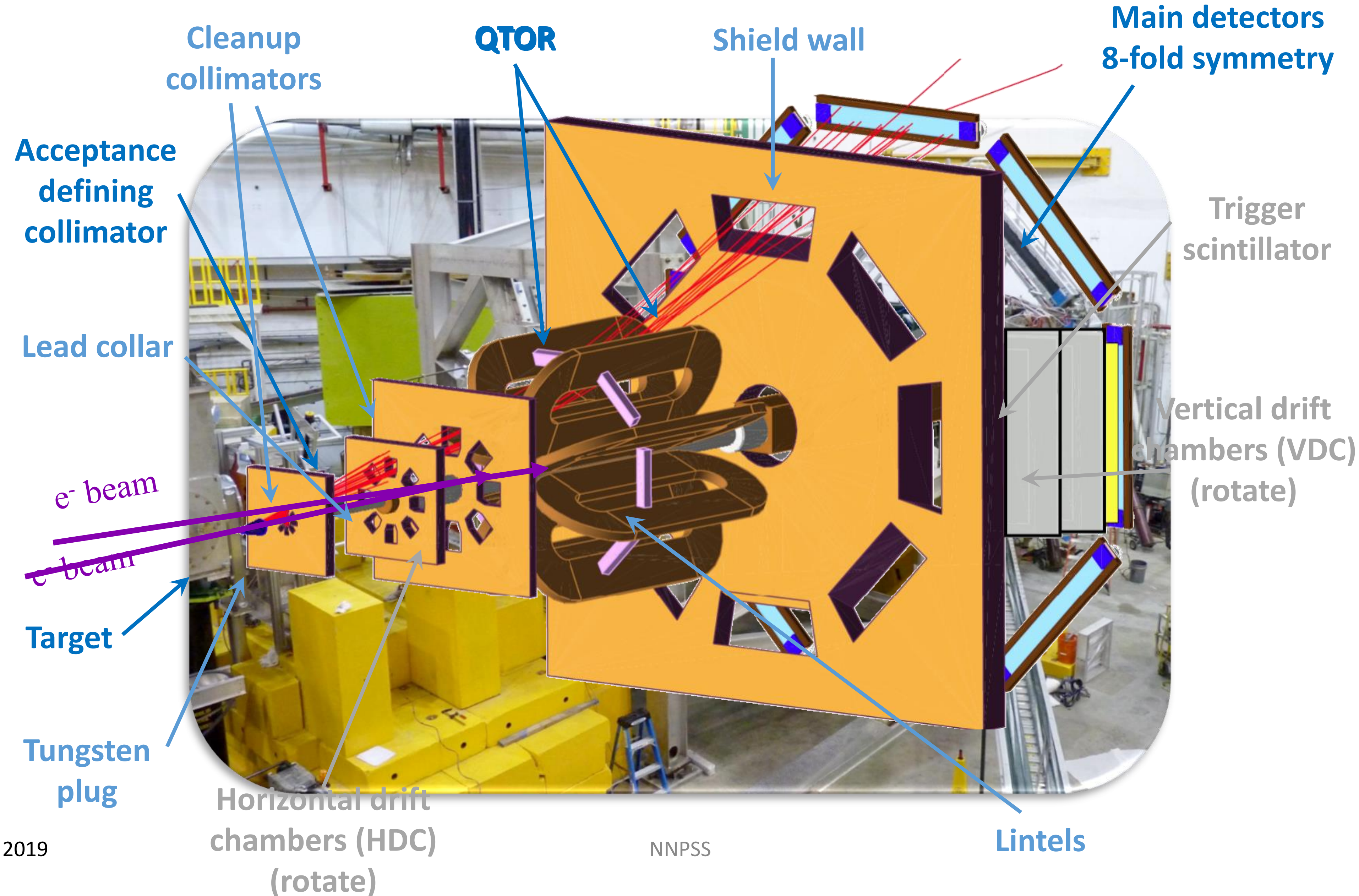
Qweak

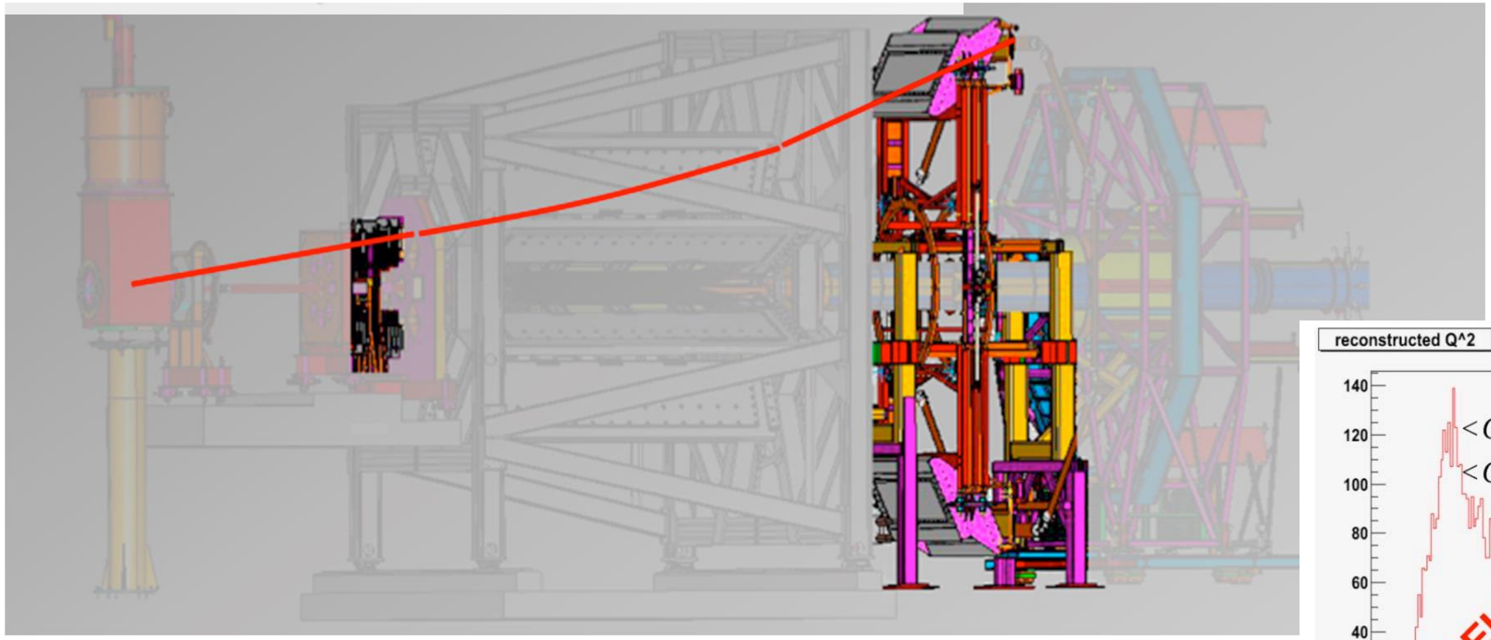


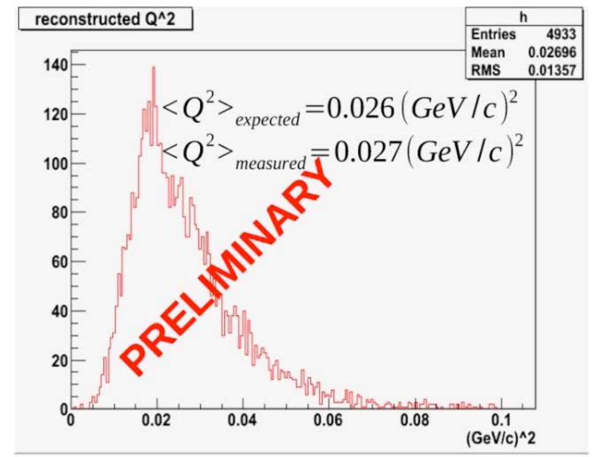
Cleanup collimators
QTOR
Shield wall
Main detectors 8-fold symmetry
Acceptance defining collimator
Trigger scintillator
Lead collar
Vertical drift chambers (VDC) (rotate)
e^- beam
~~e^- beam~~
Target
Tungsten plug
Horizontal drift chambers (HDC) (rotate)
Lintels

Determining the Kinematics

Required uncertainty on Q^2 is 0.5%; combination of tracking and simulation

$$A_{PV} = -\frac{Q^2 G_F}{4\sqrt{2}\pi\alpha}\left[Q_W^p + F(\theta, Q^2)\right]$$

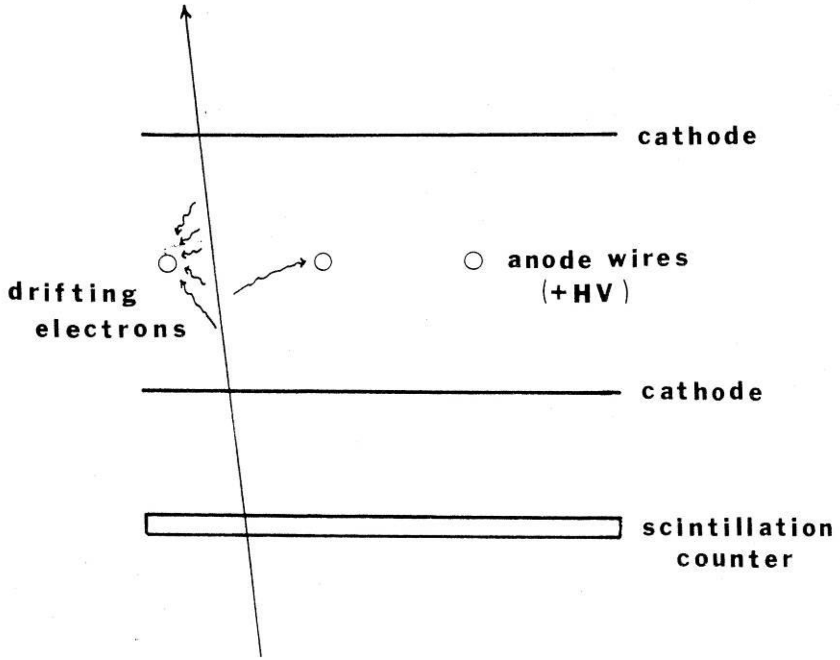


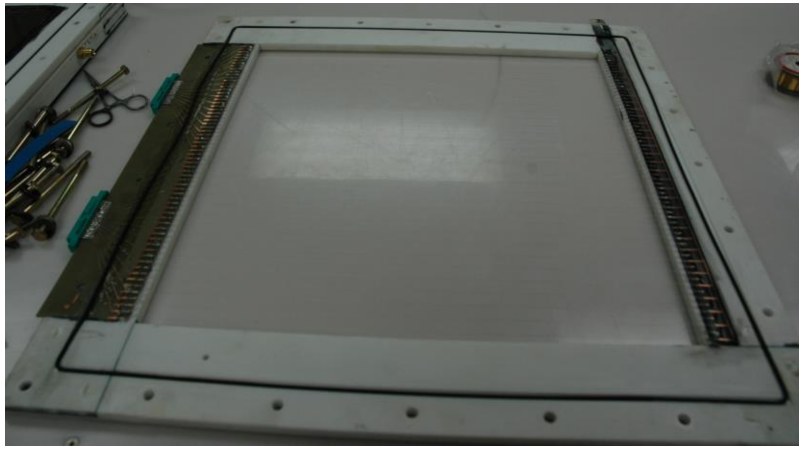


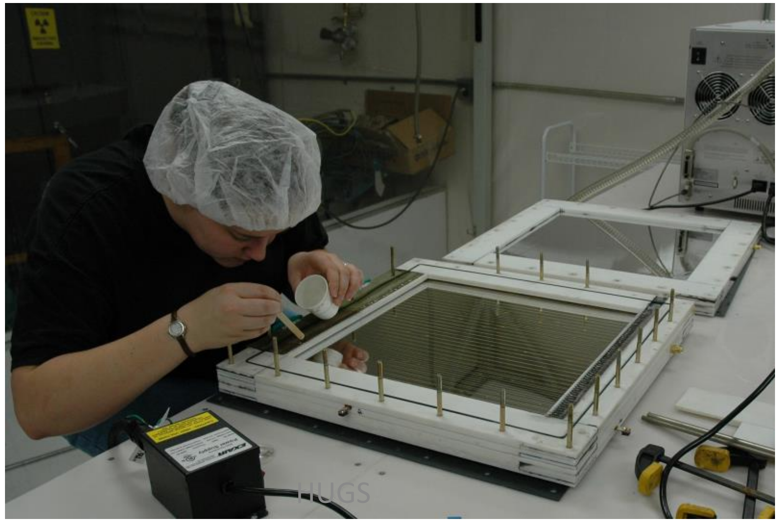
Need momentum and scattering angle + energy loss to vertex:

- Region 2 HDCs → scattering angle and vertex in target
- Region 3 VDCs → partial track from QTOR exit to detector
- “Swim” electrons through the QTOR magnetic field to match partial tracks and find p
- Map out main detector light response for single track to determine light-weighted $<Q^2>$
- Data to benchmark simulation (confirm treatment of energy loss, radiative corrections, etc.)

Drift Chambers: Used to precisely locate charged particles



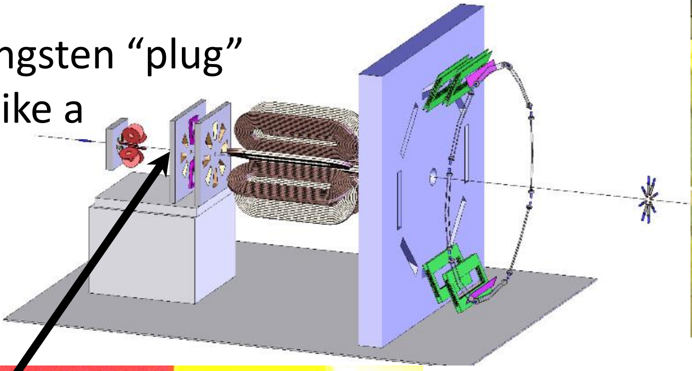


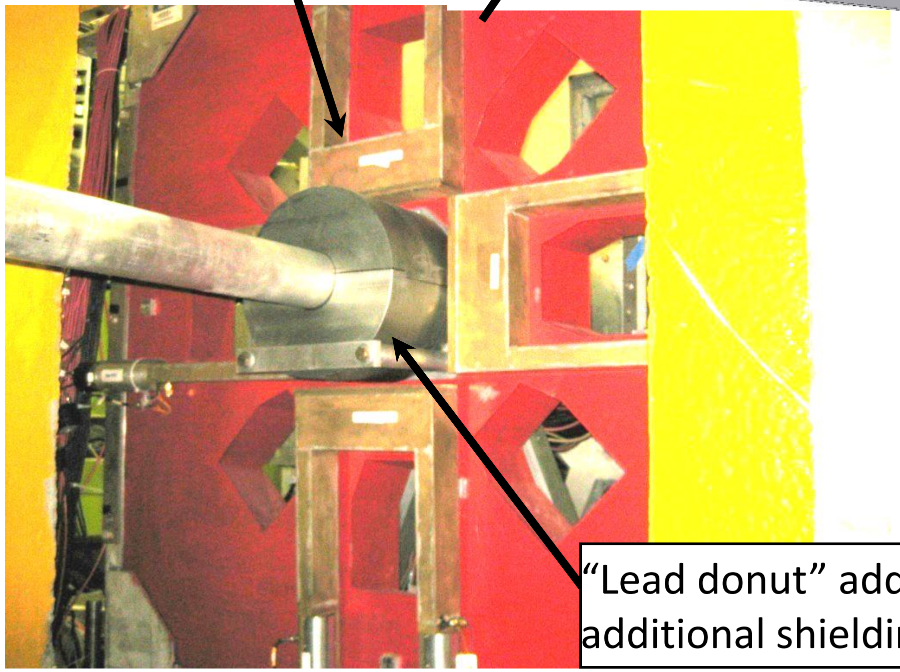


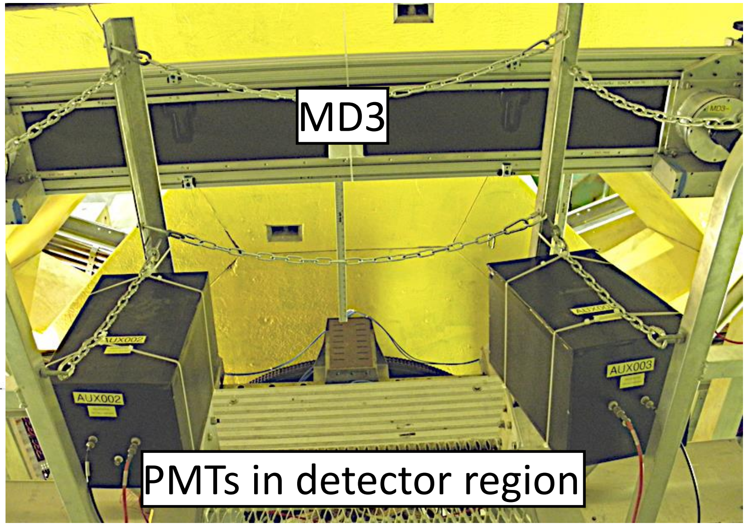
Background Detectors

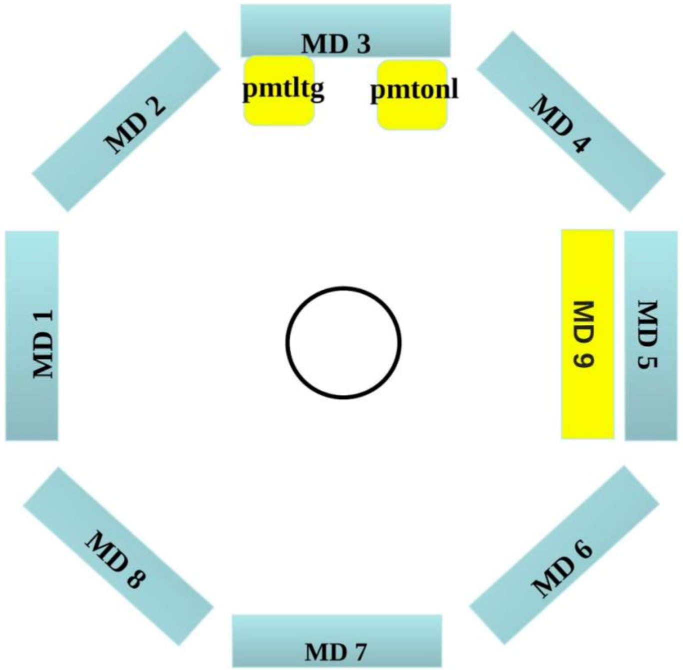
upstream luminosity monitors (US lumi)**:**
4 detectors at ~5 degrees 100 GHz / detector

50-60% of signal from Tungsten "plug" scattering (i.e. functions like a background detector)





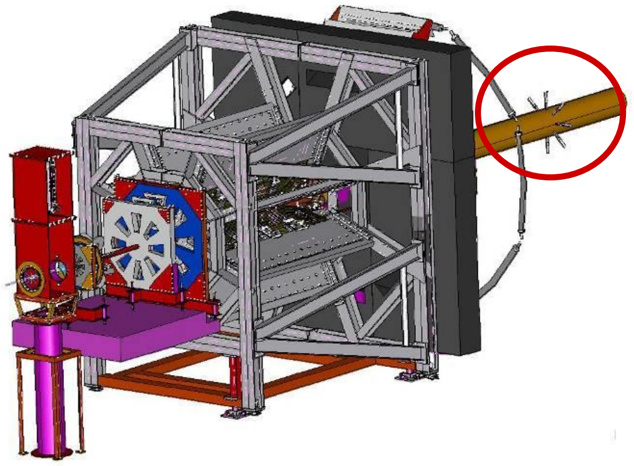




"Lead donut" added for additional shielding.

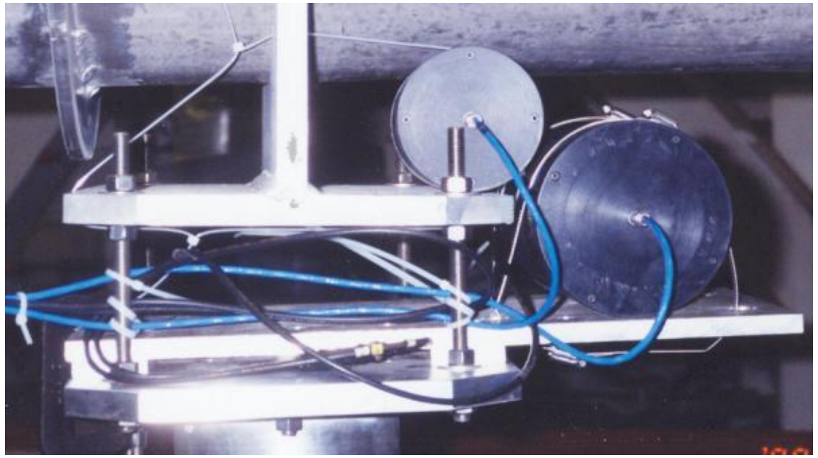
The Q^{p}_{Weak} Luminosity Monitor

- Luminosity monitor → Symmetric array of 8 quartz Cerenkov detectors
- Placed in location where physics asymmetry is expected to be VERY small; useful as a "null" asymmetry monitor



Some prototyping:

Before beam:



After beam (radiation damage!):

What could go wrong?

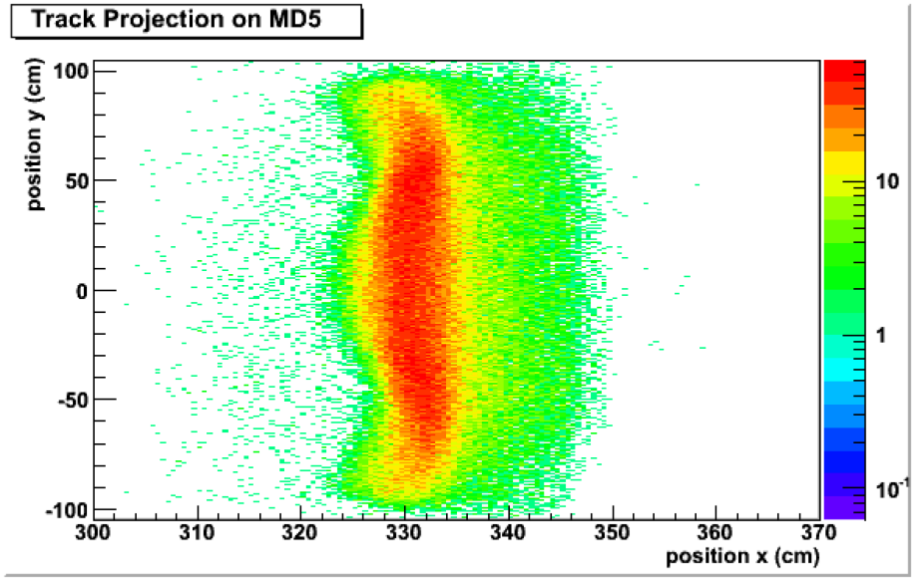


FIG. 5.22: Top: Typical VDC track projection (octant 5) to the primary quartz detectors weighted by the response of the sum of their PMTs. The color scale is the number of photoelectrons measured by both PMTs. The shape of the detectors is clearly visible. Bottom: The same projection as above with no weighting. The color scale indicates the number of tracks in a pixel.

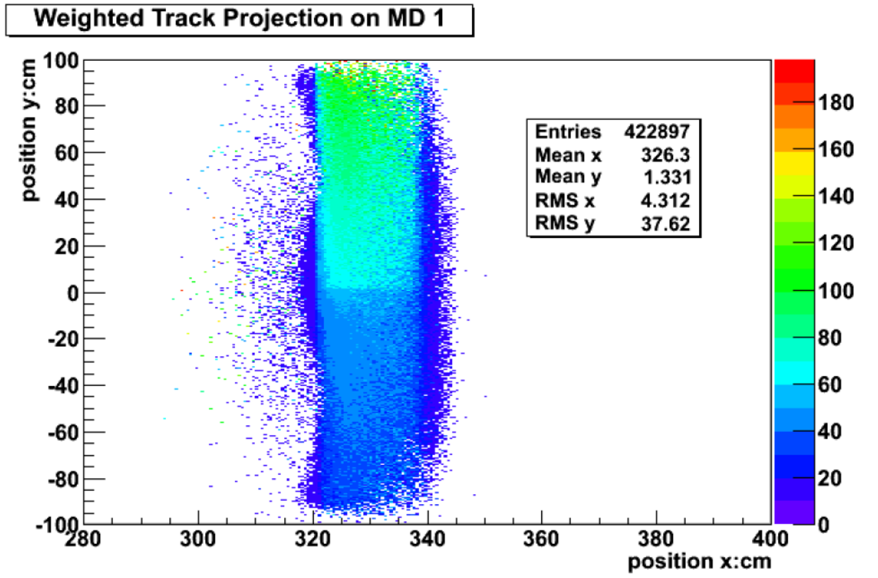


FIG. 5.23: VDC track projection to the primary quartz detectors, weighted by the response of only one of the PMTs on the primary quartz detector in octant 1. The number of photoelectrons drastically changes when going over the glue joint at the center of the y axis. The color axis is number of photoelectrons measured by only one PMT.

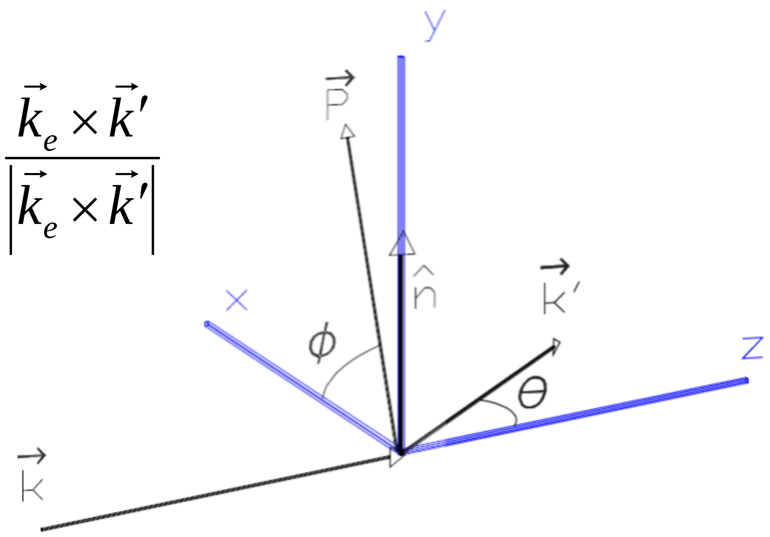
Geometrical Symmetry

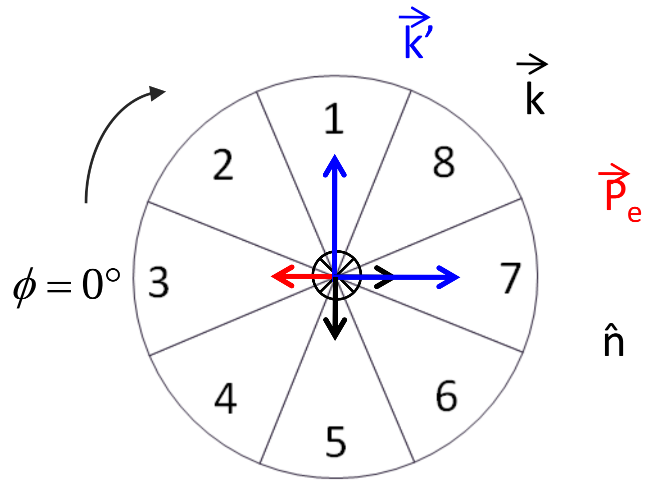
Transverse

Reduce sensitivity to beam fluctuations

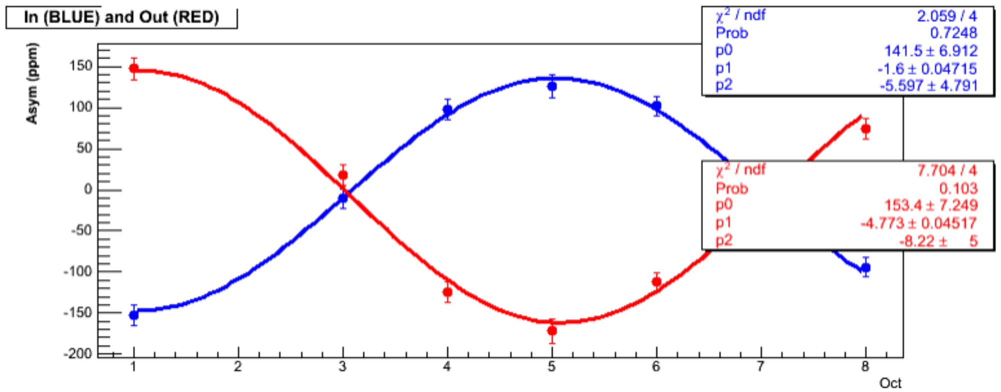
$$K_T = A_T \frac{P_T}{P} A_S$$

$$\hat{n} = \frac{\vec{k}_e \times \vec{k}'}{\left|\vec{k}_e \times \vec{k}'\right|}$$

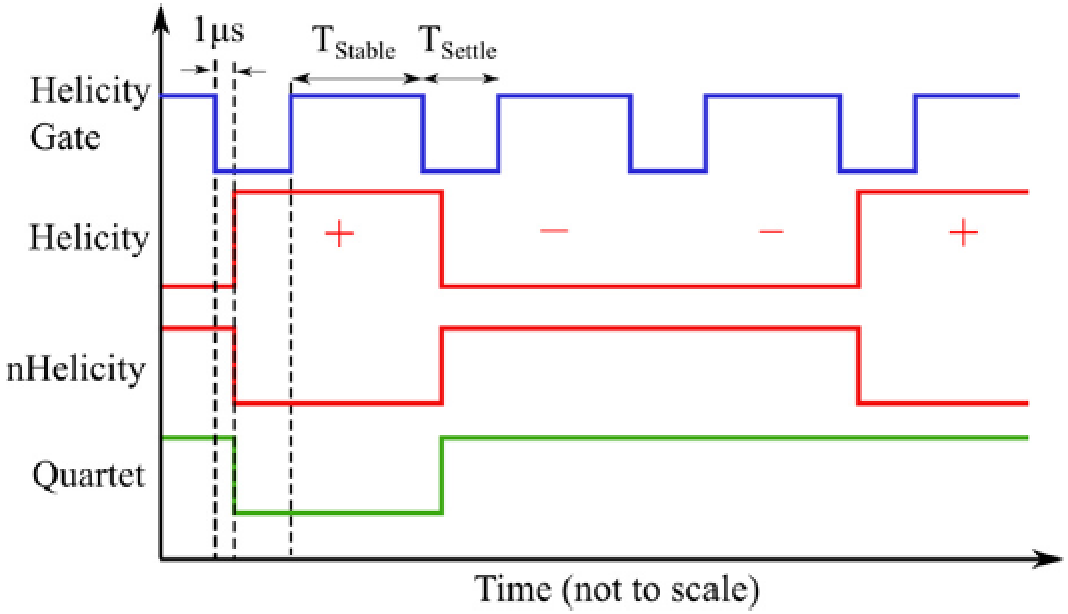




$$A_{\perp}^{m} = \frac{\sigma_{\uparrow} - \sigma_{\downarrow}}{\sigma_{\uparrow} + \sigma_{\downarrow}} = A_n \vec{p}_e \cdot \hat{n} = -A_n \sin(\phi + \phi_0)$$



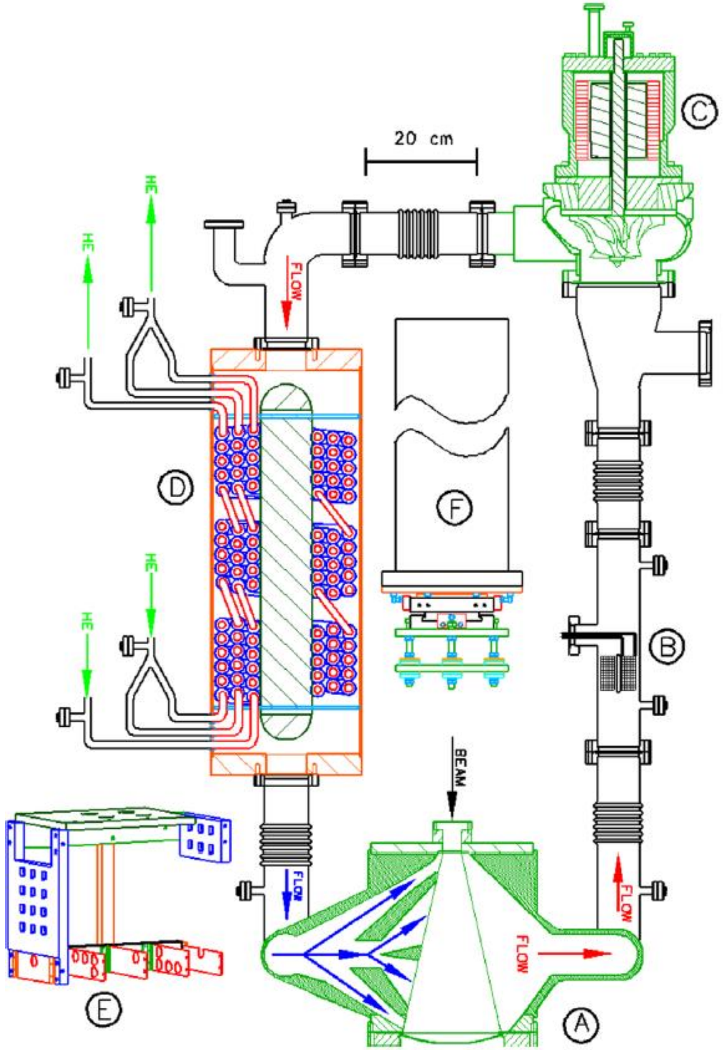
Pockells Cell Ringing

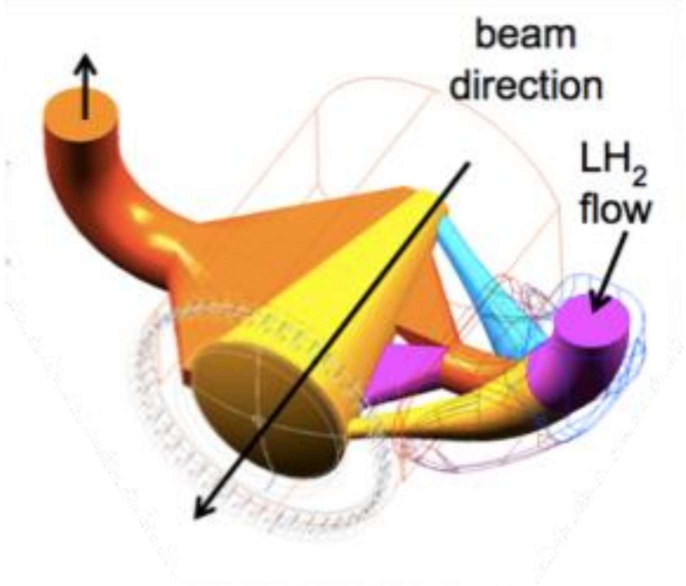


g. 5. Timing diagram of the helicity signals from the polarized source. See text for tails. The scale of the horizontal axis is exaggerated to show details of the signal timing.

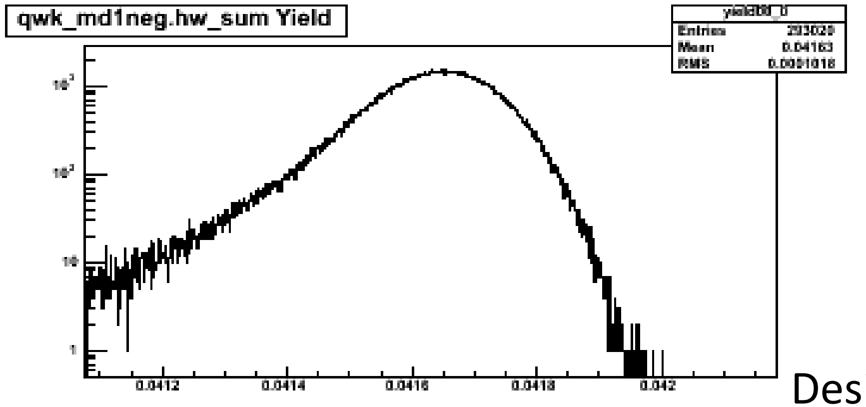
Qweak Target

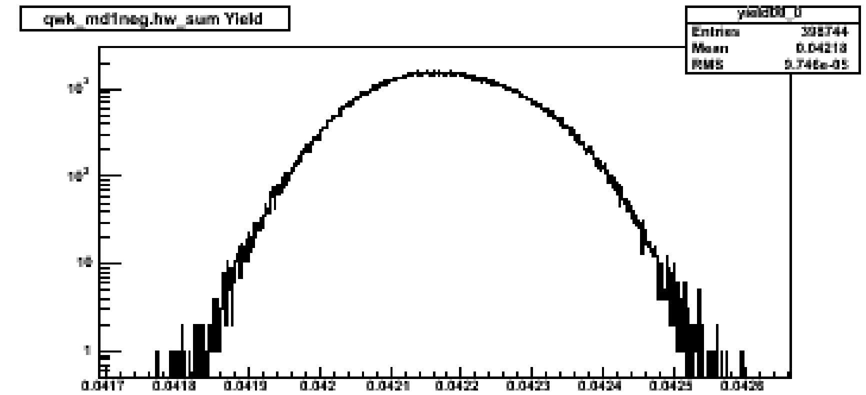
World's **highest power** cryogenic target ~2.5 kW!



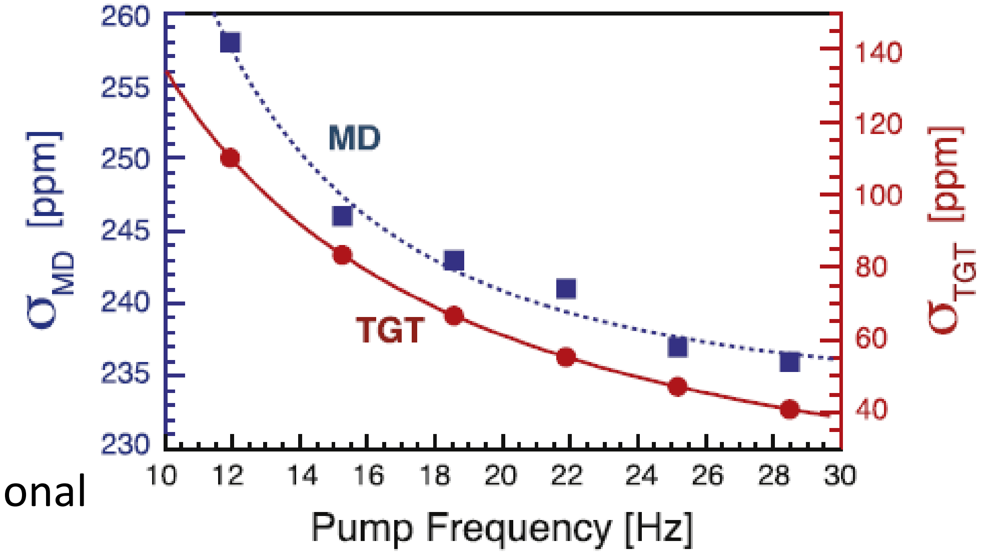


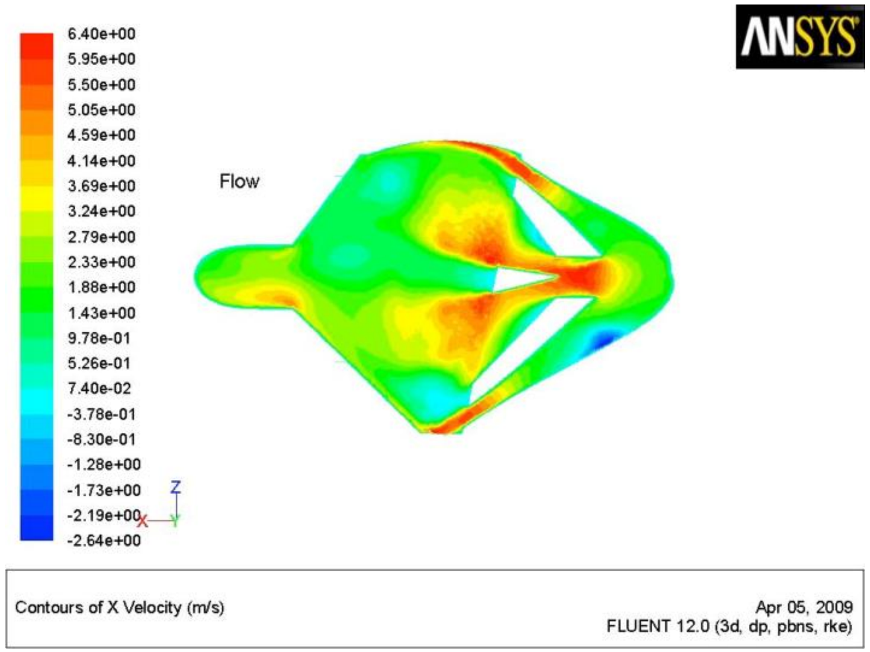
Target Studies



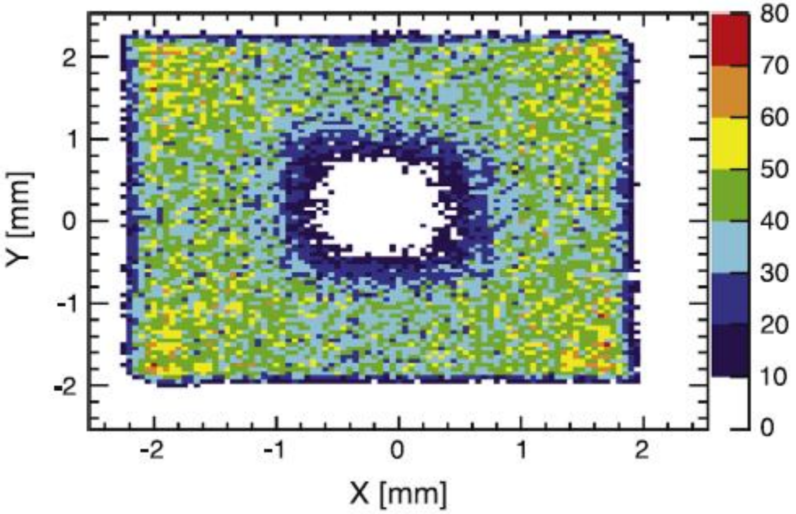


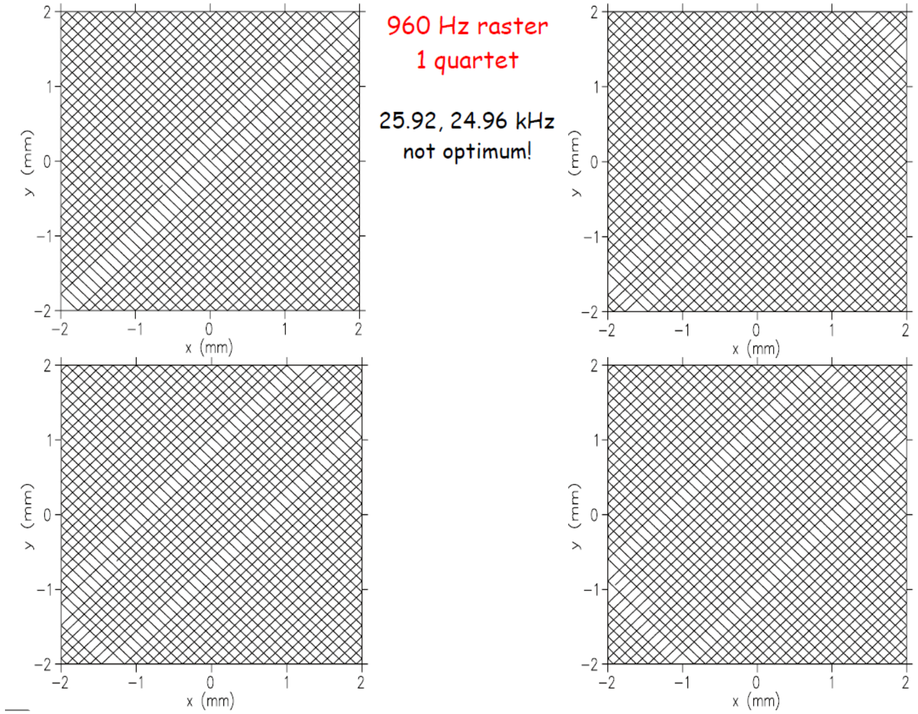
Designed with computational fluid dynamics (CFD) to reduce density fluctuations

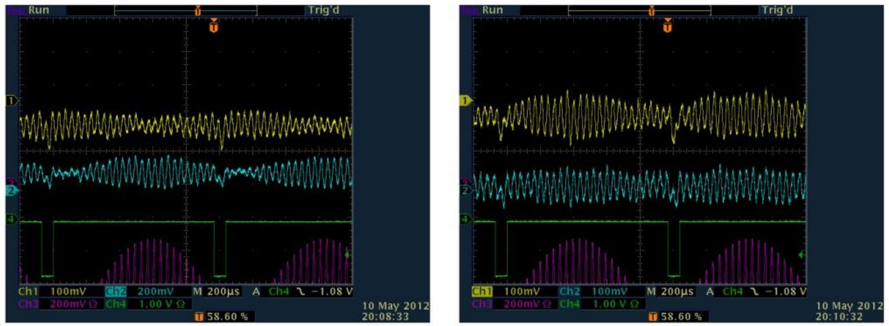




Raster synch (PREX)



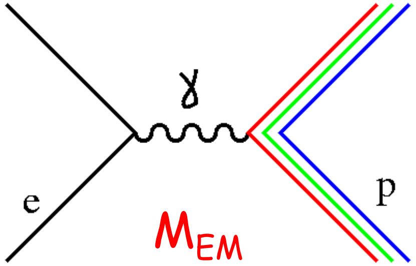




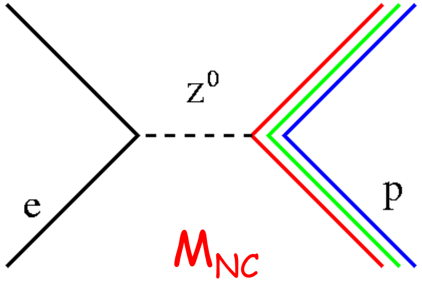
(c) MD3 pos and neg

(d) MD4 pos and neg

Weak Charges of the Nucleons



As $Q^2 \to 0$



measures Q^p – proton's electric charge

measures Q^p_{weak} – proton's weak charge

	Q^γ
u	+2/3
d	–1/3

$$Q^p_{EM} = 2\left(+\frac{2}{3}\right) + 1\left(-\frac{1}{3}\right) = +1$$

$$Q^n_{EM} = 1\left(+\frac{2}{3}\right) + 2\left(-\frac{1}{3}\right) = 0$$

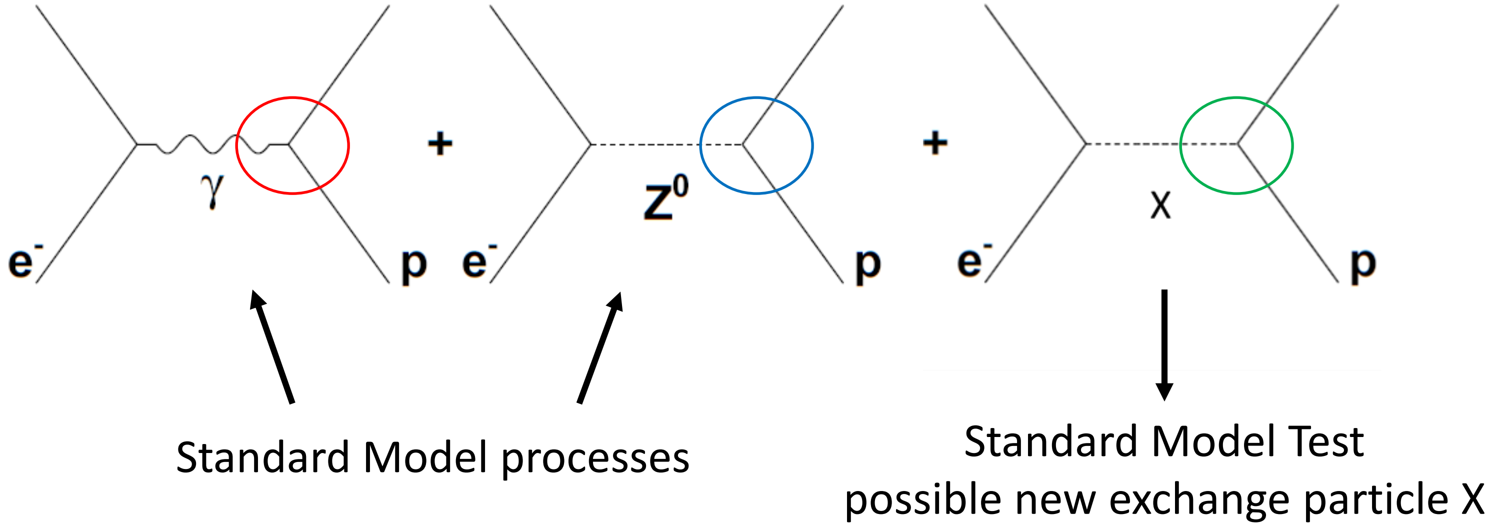
$$Q^p_{weak} = 2\left(1 - 8/3\sin^2\theta_W\right) + 1\left(-1 + 4/3\sin^2\theta_W\right)$$
$$= 1 - 4\sin^2\theta_W \approx 0$$

$$Q^n_{weak} = 2\left(-1 + 4/3\sin^2\theta_W\right) + 1\left(1 - 8/3\sin^2\theta_W\right)$$
$$= -1$$

Neutral Weak Coupling

$\vec{e} + p \rightarrow e + p$

E_{beam} = 1.165 GeV
$\theta \sim 7.9°$
$Q^2 \sim 0.025$ GeV²/c²



$Q^2 \rightarrow 0$
measure charge of proton

$Q^2 \rightarrow 0$
measure weak charge of proton

$Q^2 \rightarrow 0$
measure coupling of new physics to proton

$$Q^p = 2Q^u + Q^d$$
$$= 2\left(+\tfrac{2}{3}\right) + \left(-\tfrac{1}{3}\right)$$

$$Q_W^p = 2Q_W^u + Q_W^d$$
$$= 2\left(1 - \tfrac{8}{3}\sin^2\theta_W\right) + \left(-1 + \tfrac{4}{3}\sin^2\theta_W\right) \approx 0$$

The Physics

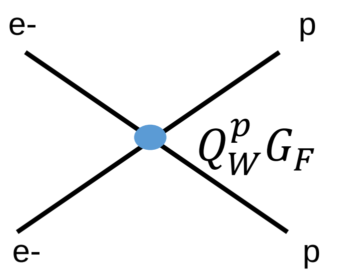
$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \frac{-G_F Q^2}{4\pi\alpha\sqrt{2}}\left[Q_W^p + F(\theta, Q^2)\right] \approx 280 \pm 7\ ppb$$

nucleon structure,
~30% of asymmetry

$$\delta A_{\rm PV} \approx \pm 2.6\ \%$$
$$\Longrightarrow\ \delta Q_W^p \approx \pm 4\ \%$$
$$\Longrightarrow\ \delta(\sin^2\theta_W) \approx \pm 0.3\ \%$$

Coupling constants

$$\mathcal{L}_{ep}^{PV} = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV}$$



$$\mathcal{L}_{NEW}^{PV} = -\frac{G_F}{\sqrt{2}}\bar{e}\gamma_\mu\gamma_5 e\sum_q C_{1q}\bar{q}\gamma^\mu q + \frac{g^2}{4\Lambda^2}\bar{e}\gamma_\mu\gamma_5 e\sum_f h_V^q \bar{q}\gamma^\mu q$$

Mass scale

$$\frac{\Lambda}{g} \sim \frac{1}{2\sqrt{\sqrt{2}G_F\left|\ Q_W^p\right|}}$$

4% Qweak uncertainty

$$\rightarrow \mathbf{2.3\ TeV}$$

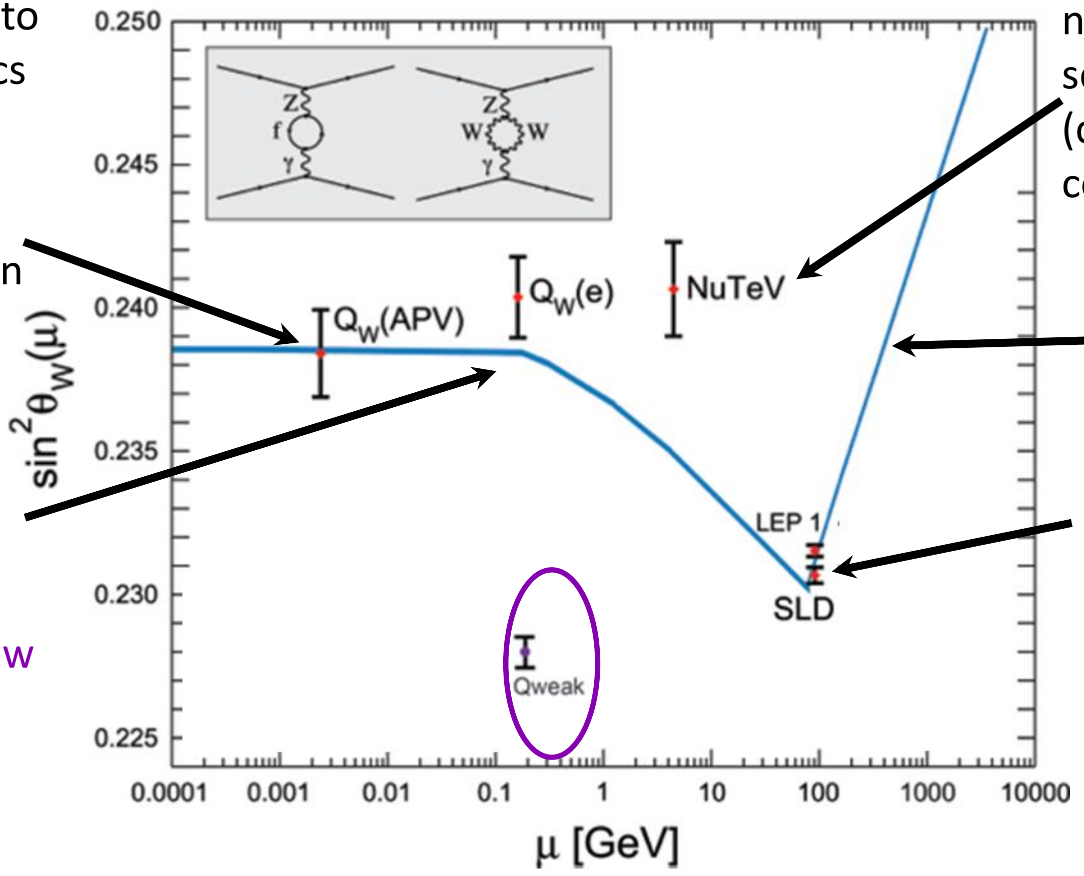
Weak mixing angle

Each experiment is differently sensitive to potential new physics

$6S \rightarrow 7S$ ^{133}Cs atomic transition

Parity violating moller scattering

Qweak will test a new set of couplings to new physics



neutrino deep-inelastic scattering cross-sections (controversial hadronic corrections not included)

Standard Model electroweak fit with uncertainty

Colliders

Qweak projected final uncertainty (arbitrary position)

Contact Interaction Models

Use four-fermion contact interaction to parameterize the effective PV electron-quark couplings (mass scale and coupling)

For electron-quark scattering:

$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha}(g_A^e g_V^i + \beta g_V^e g_A^i)$$

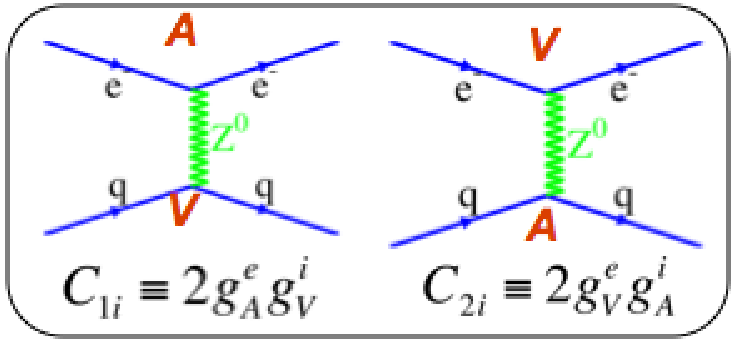
Qweak is particularly sensitive to C_{1q}

New physics interaction:

$$\sigma \propto |M_\gamma + M_Z + M_{\text{new}}|^2$$
$$\sim |M_\gamma|^2 + 2M_\gamma M_Z^* + 2M_\gamma M_{\text{new}}^*$$

new Z', leptoquarks, SUSY ...

$$\frac{1}{Q^2 - M^2} \xrightarrow{Q^2 \ll M^2} \frac{1}{M^2}$$



Small θ Large θ

4% measurement of the proton weak charge probes TeV scale new physics

$$\frac{\Lambda}{g} \sim \left(\sqrt{2}G_F \Delta Q_W^p\right)^{-\frac{1}{2}} \sim O(\text{TeV})$$

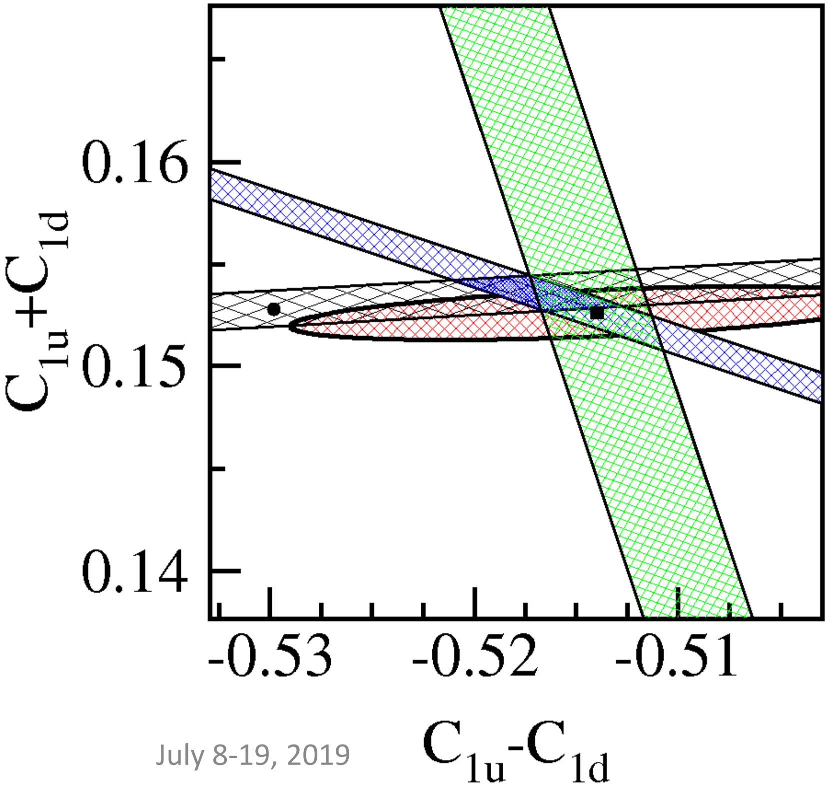
Erler, Kurylov, and Ramsey-Musolf, PRD 68, 016006 2003

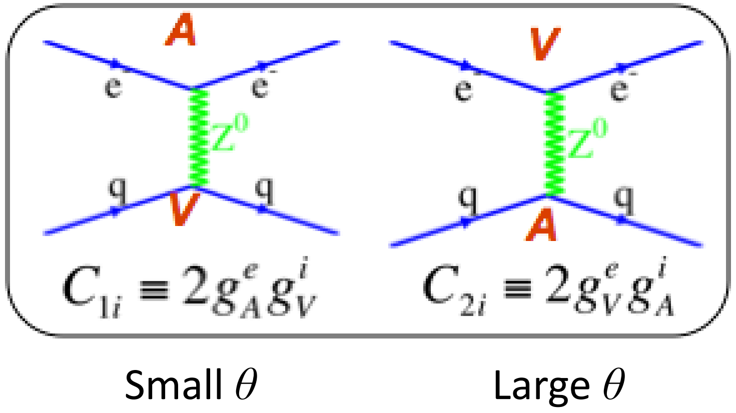
Neutral Weak Quark Couplings

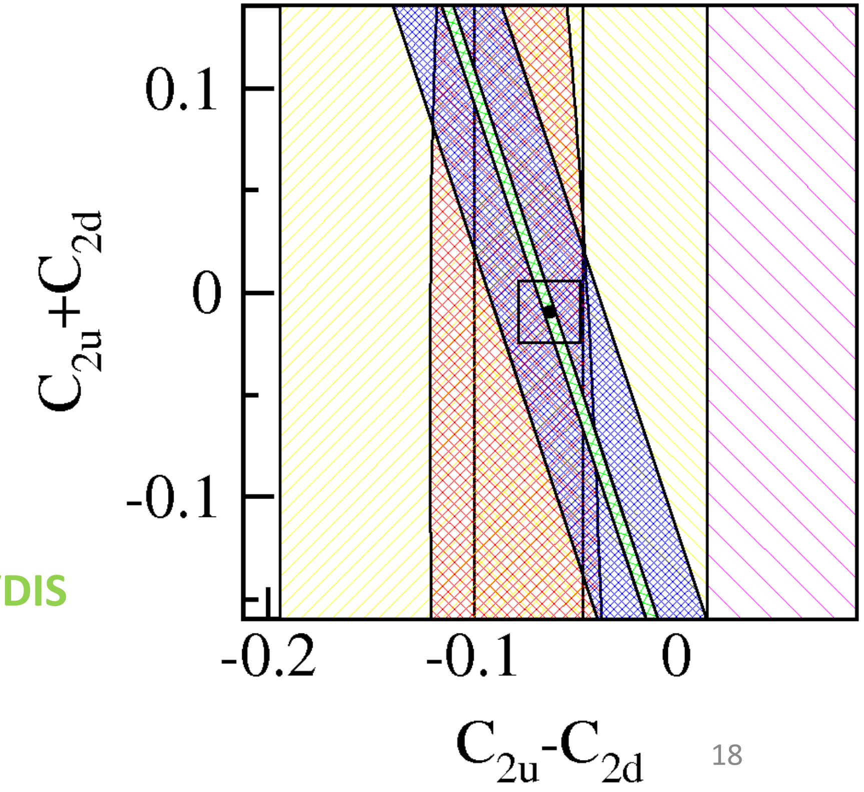
$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha}(g_A^e g_V^i + \beta g_V^e g_A^i)$$

Red ellipses are PDG fits

Blue bands represent expected data: Qweak (left) and PVDIS-6GeV (right)

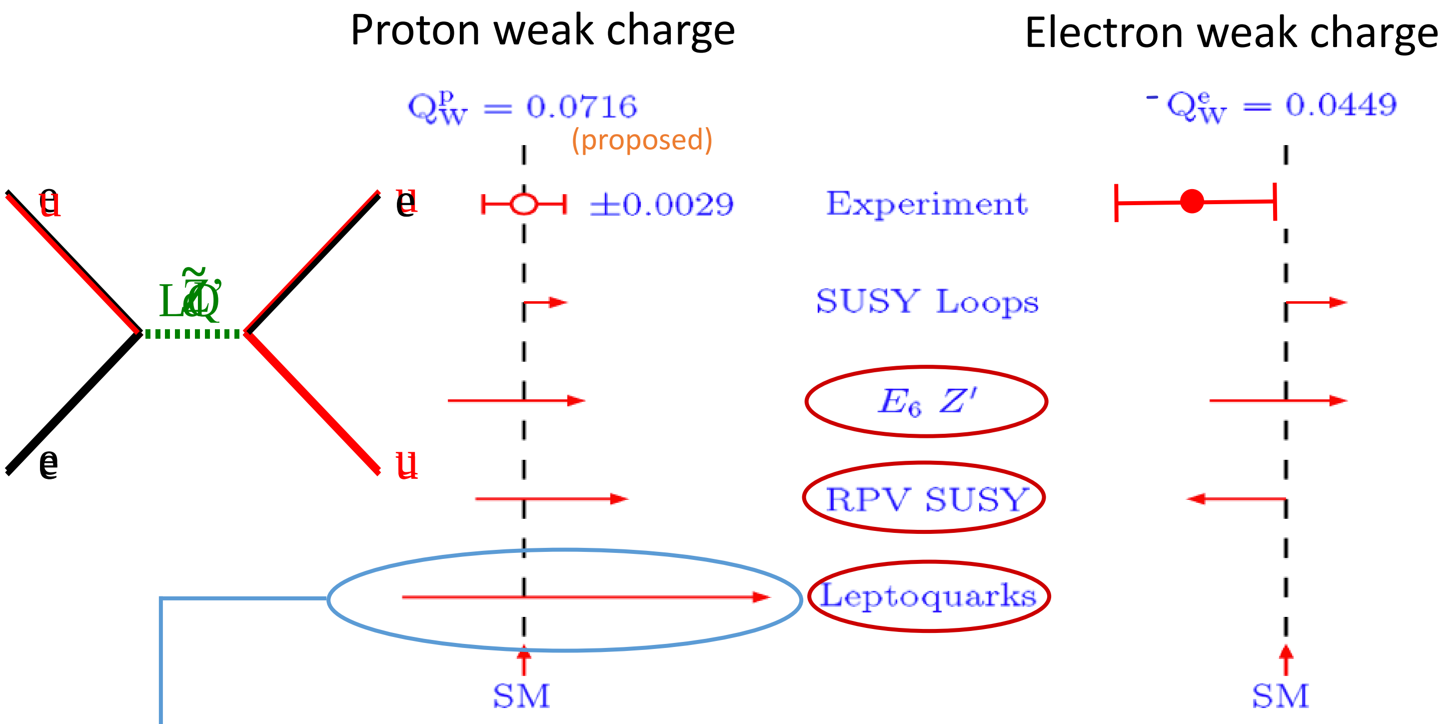






Green bands are proposed SOLID PVDIS

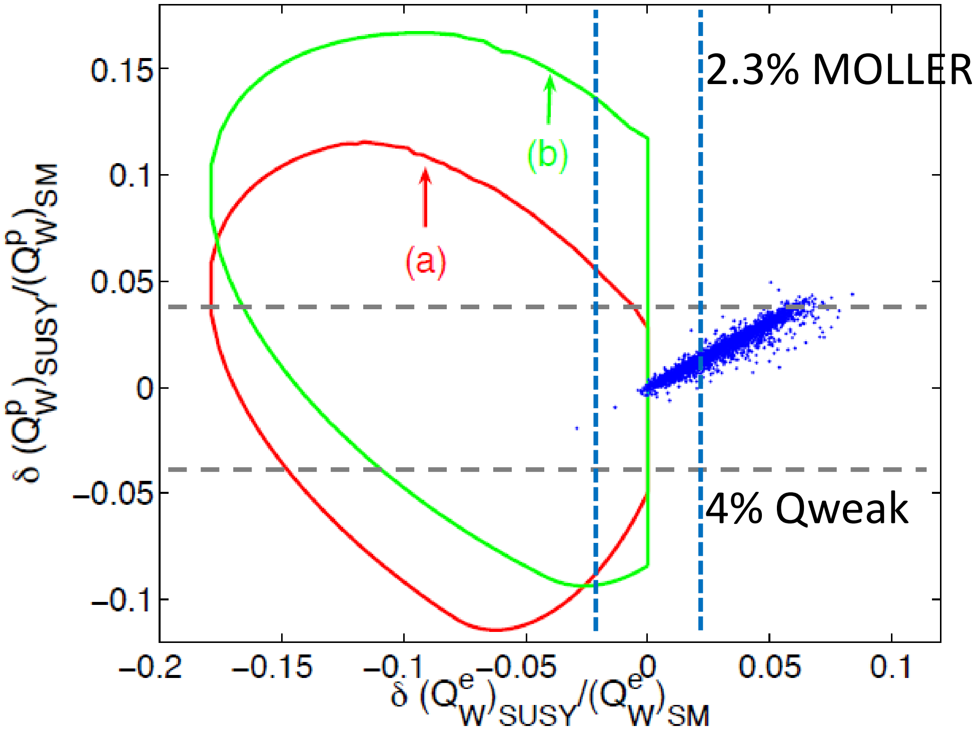
Complementary Diagnostics



Erler, Kurylov, Ramsey-Musolf, PRD 68, 016006 (2003)

- Qweak measurement will provide a stringent stand alone constraint on Lepto-quark based extensions to the SM
- Q^p_{weak} (semi-leptonic) and E158 (pure leptonic) together make a powerful program to search for and identify new physics

Other Models



Ramsey-Musolf, Su

SUSY and RPV SUSY

If RPC, possible dark matter candidate

Doubly-charged scalars

(reach of **5.3 TeV** compared to 3 TeV at LEP2)

Asymmetry Extraction

$C_{\mathrm{beam}} = -42.2 \pm 12.8$ ppb

$$A_{\mathrm{msr}} = -204.6 \pm 30.5 \text{ ppb}$$

(14.9 % rel)

$$A_{\mathrm{PV}} = \frac{\frac{A_{\mathrm{msr}}}{P} - \Sigma f_i A_i}{1 - \Sigma f_i}$$

$P = 88.95 \pm 1.83$ %

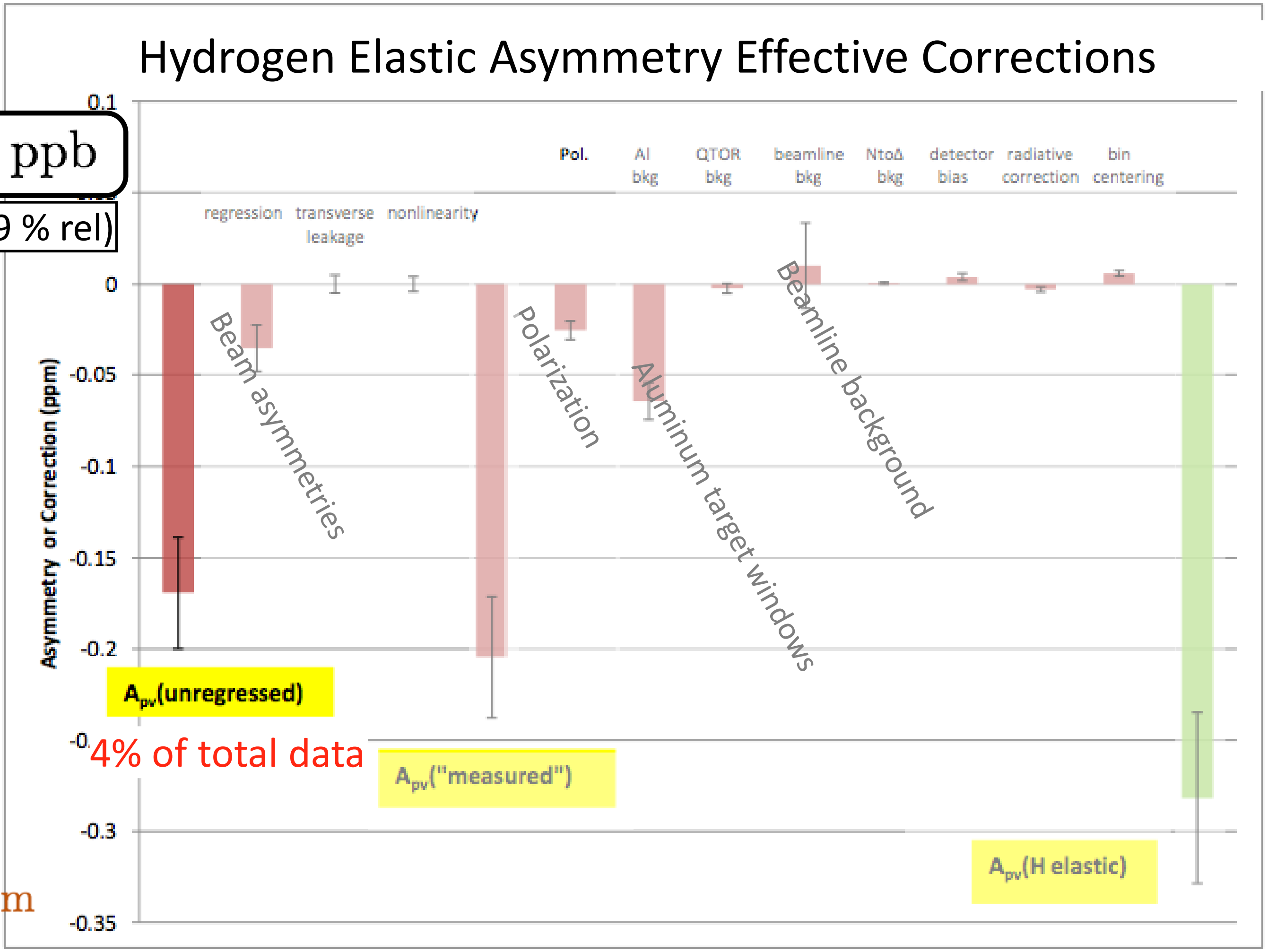
(2% rel)

$C_{\mathrm{Al}} = -64 \pm 10$ ppb

$f_{\mathrm{Al}} = 3.23 \pm 0.24$ %

$A_{\mathrm{Al}} = 1.76 \pm 0.26$ ppm

$C_{\mathrm{beamline}} = -10.2 \pm 23.5$ ppb



$$A_{\mathrm{PV}} = -281.2 \pm 35.1(\mathrm{stat}) \pm 29.6(\mathrm{syst}) \text{ ppb}$$

(16.3 % rel)

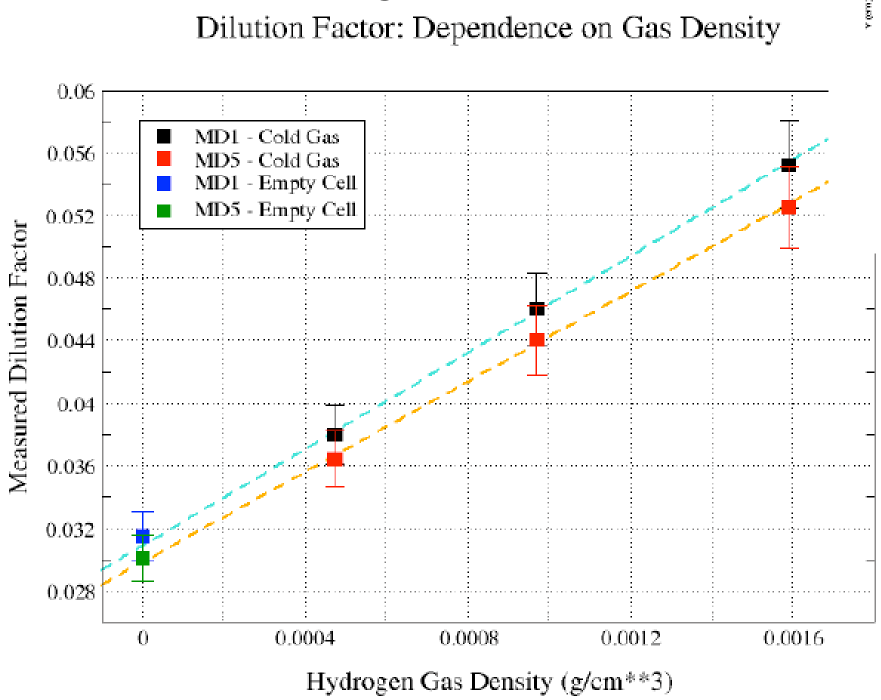
Ex. Aluminum Window Background

$$C_{\text{Al}} = -64 \pm 10 \text{ ppb}$$

Large asymmetry and high fraction make this a big effect; correction driven by measurement

$$f_{\text{Al}} = 3.23 \pm 0.24 \ \%$$

Rate from windows measured with empty target (actual windows)
Corrected for effect of hydrogen using simulation and data driven models of elastic and QE scattering

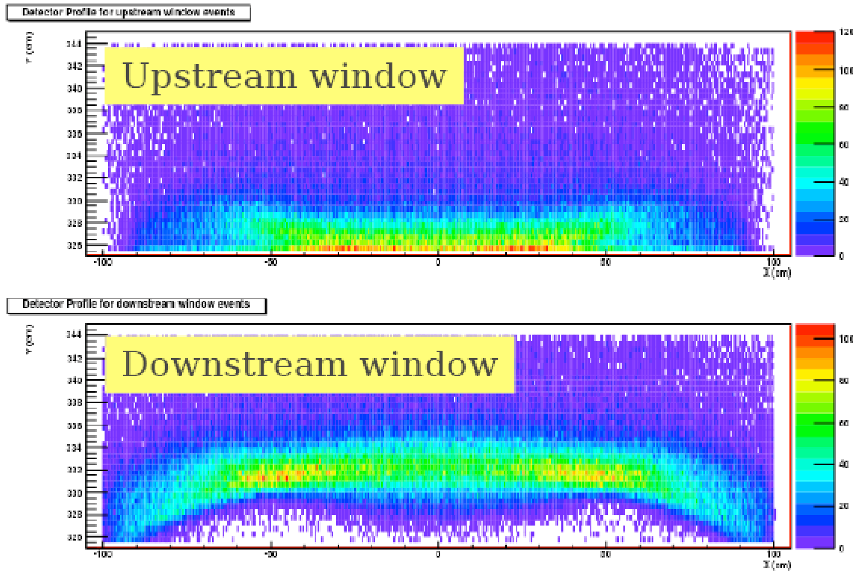


$$A_{\text{Al}} = 1.76 \pm 0.26 \text{ ppm}$$

Asymmetry measured from thick Al target
Measured asymmetry agrees with expectation from scaling

$$A_{PV}(^{N}_{Z}X) = -\frac{Q^2 G_F}{4\pi\alpha\sqrt{2}}\left[Q_W^p + \left(\frac{N}{Z}\right) Q_W^n\right]$$

Simulated e- profile at detector:



Electroweak Corrections

$$Q_W^p = [1+\rho_{NC}+\Delta_e][1-4\sin^2\hat{\theta}_W(0)+\Delta'_e] + \square_{WW} + \square_{ZZ} + \square_{\gamma Z}$$

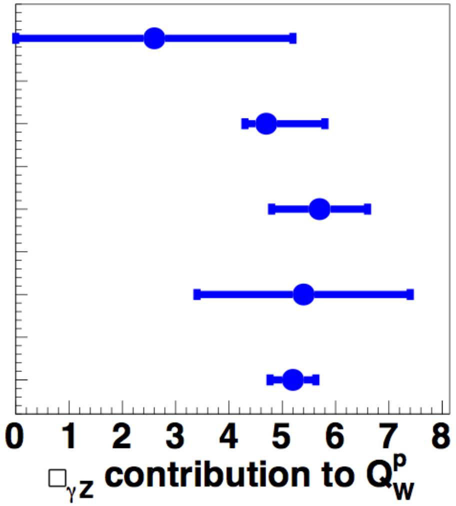
Uncertainty on this calculation only important at final precision ~7% correction

Rapid progress in data driven theoretical work is decreasing uncertainties:

Estimates of γZ contribution at Qweak kinematics

Gorchtein & Horowitz *PRL 102, 091806 (2009)*	0.0026 ± 0.0026
Sibirtsev, Blunden & Melnitchouk, Thomas *PRD 82, 013011 (2010)*	$0.0047^{+0.0011}_{-0.0004}$
Rislow & Carlson *arXiv:1011.2397 (2010)*	0.0057 ± 0.0009
Gorchtein, Horowitz & Ramsey-Muslof *arXiv:1102.3910 (2011)*	0.0054 ± 0.0020
Hall, Blunden, Melnitchouk, Thomas & Young *Private communication (2012)*	0.0052 ± 0.00043

(calculation constrained by PVDIS data)



Calculations are primarily dispersion theory type - error estimates can be firmed up with data!
Inelastic parity-violating asymmetries:

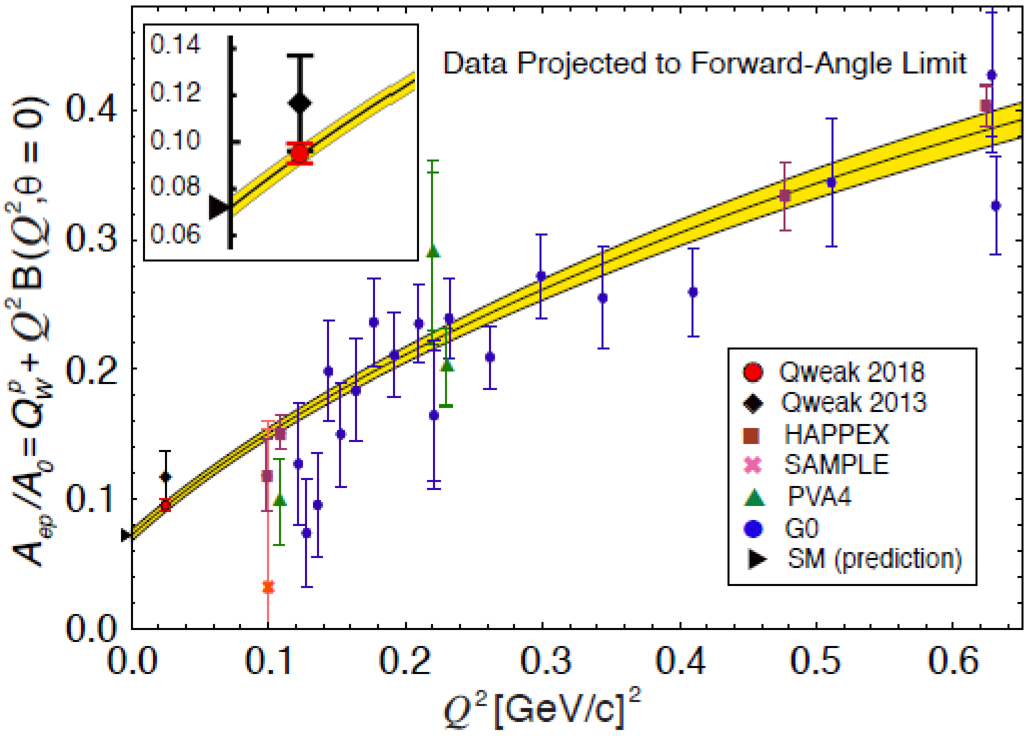
- PVDIS at 6 GeV (JLAB E08-011); resonance region asymmetries
- Qweak: inelastic asymmetry data taken at W ~ 2.3 GeV, Q^2 = 0.09 GeV^2

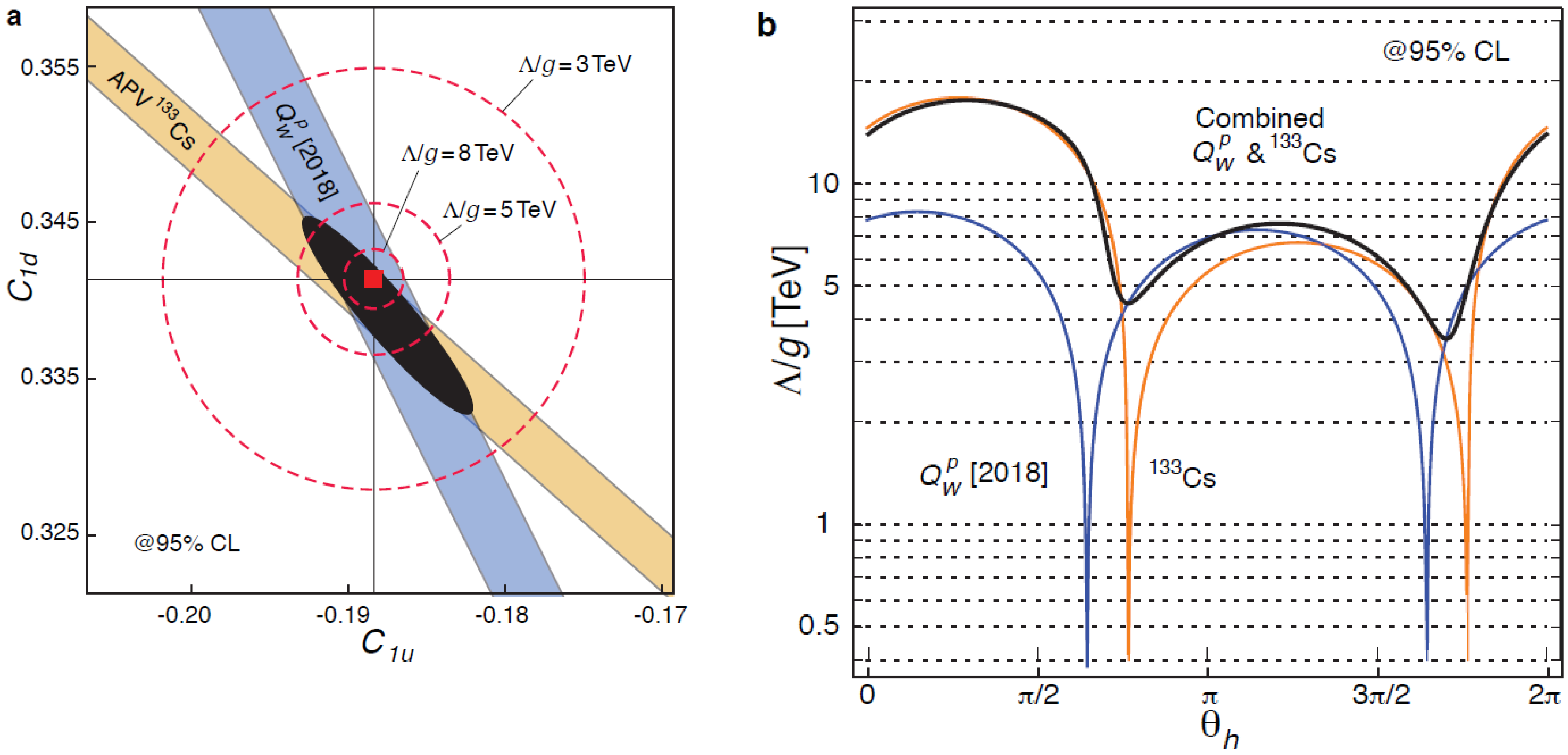
Reduced Asymmetry

in the forward-angle limit (θ=0)

$$A_0 = -\frac{Q^2 G_F}{4\sqrt{2}\pi\alpha} \qquad \overline{A^p_{\rm LR}} = \frac{A_{LR}}{A_0} \xrightarrow{\theta\to 0} [Q^p_W + Q^2 B(Q^2)]$$

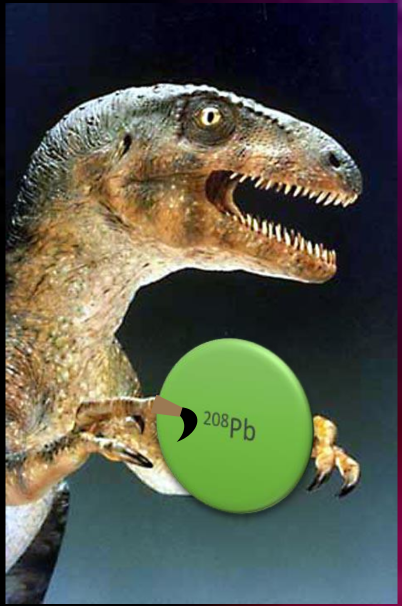
Hadronic part can be extracted through global fit of PVES data.




a
0.355
0.345
0.335
0.325
-0.20
-0.19
-0.18
-0.17
C_{1d}
C_{1u}
APV 133Cs
Q_W^p [2018]
$\Lambda/g = 3$ TeV
$\Lambda/g = 8$ TeV
$\Lambda/g = 5$ TeV
@95% CL
b
@95% CL
Combined
Q_W^p & 133Cs
10
5
1
0.5
Λ/g [TeV]
Q_W^p [2018]
133Cs
0
π/2
π
3π/2
2π
θ_h

The **P**b **R**adius **Ex**periment and the **C**a **R**adius **Ex**periment

Juliette Mammei



Neutron Rich Matter

At the heart of many fundamental questions in nuclear physics and astrophysics:

- What are the high density phases of QCD?
- Where did the chemical elements come from?
- Structure and properties of celestial bodies
- Neutron distribution effect on spectroscopy, dark matter measurements

Can be studied with astrophysical observations (X-rays, neutrinos, gravity waves) and in new facilities like the Facility for Rare Isotope Beams (FRIB)

Many of these methods have complications from strong interaction dependencies

Measurement of the mean radius of the neutron density distribution in a heavy nucleus, $R_{n,}$ could provide key insight

Neutron Stars

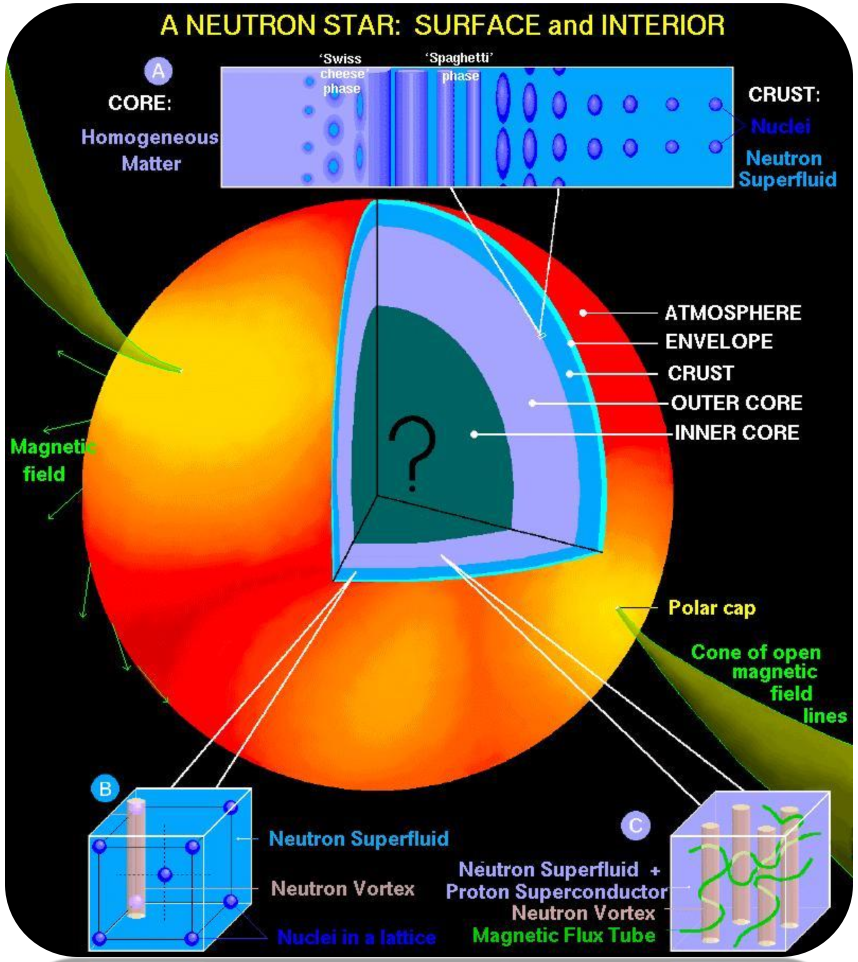


Fig from: D. Page. J.M. Lattimer & M. Prakash, Science 304 (2004) 536.

A typical neutron star is 1.5 solar masses, $M_\odot$, has a radius of 12 km, and a density as high as 5-10 times that of lab nuclei

Crust is 10 billion times stronger than steel

The interface between the crust and the outer core consist of regions with different void structures (spaghetti, lasagna, ziti) called *pasta*!

What we don't know is:

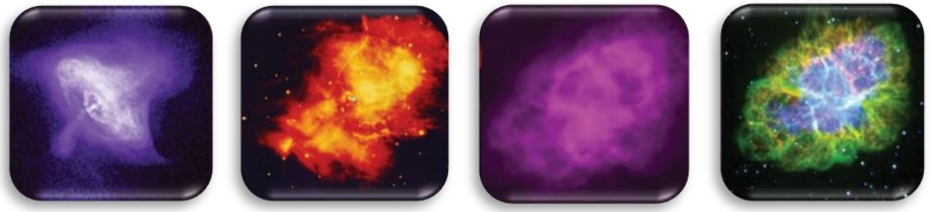
maximum mass of a neutron star
radius of 1.4 $M_\odot$ neutron star

Does the direct URCA process (emission of a $\nu_e \bar{\nu}_e$ pair) occur in neutron stars?

Neutron Stars

Equation of State

The equation of state (EOS) is the pressure as a function of density $P(\rho)$



Crab Nebula (X-ray, infrared, radio, visible)

URCA cooling

$$n \rightarrow p + e^- + \bar{\nu}_e$$

$$p + e^- \rightarrow n + \nu_e$$

Resulting in the emission of $\nu_e \bar{\nu}_e$ a pair, cooling the star

Using hydrostatics in general relativity, and astrophysics observations of:

- Luminosity, L
- Temperature, T
- Mass M (from pulsar timing)

$$L = 4\pi\sigma_B r_{NS}^{\ 2}\ T^4$$

(with corrections)

$$f(r_{NS}, M)$$

If $R_n \uparrow$ and $r_{NS} \downarrow$ - quark matter?

If $R_n \uparrow$, then $\rho_t \downarrow$ - affects solid crust

r_{NS} from combined observations predicts R_n-R_p ~0.15 +/- .02 fm

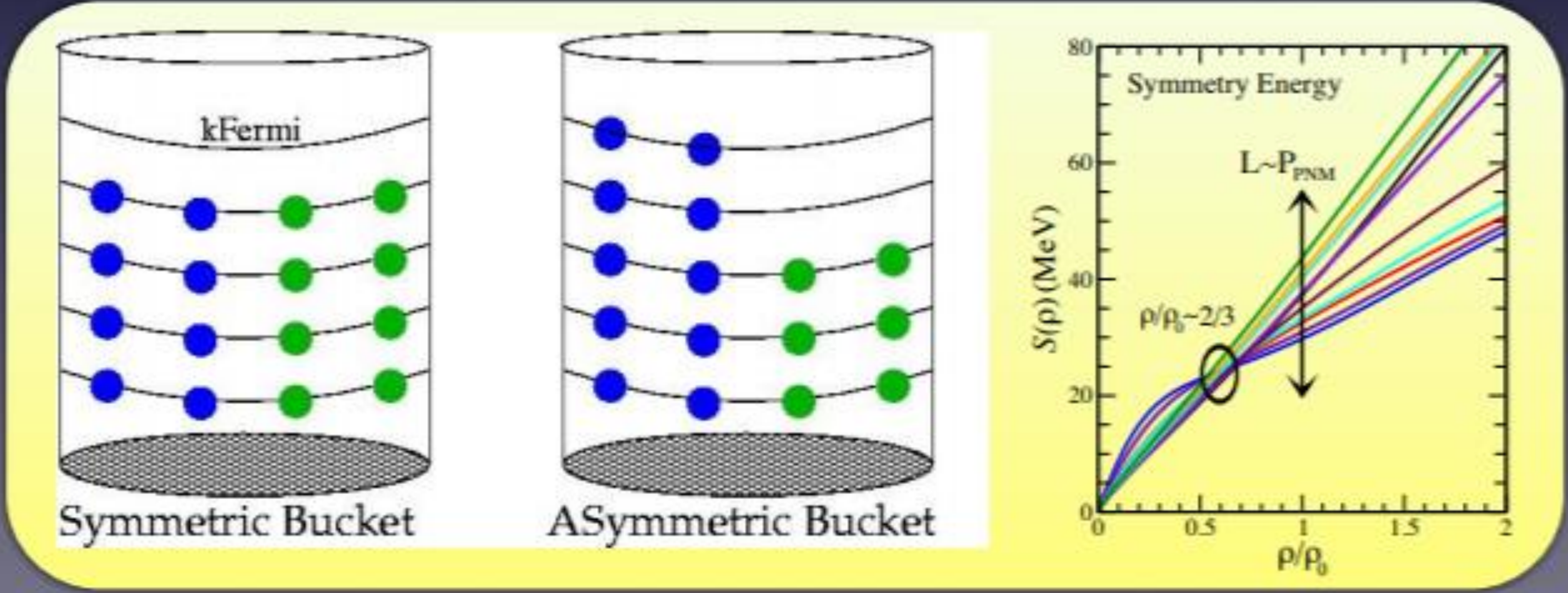
Steiner, Lattimer and Brown arXiv:1005.0811

The Equation of State of Neutron-Rich Matter

- Two conserved charges: proton and neutron densities (no weak interactions)
- Equivalently; total nucleon density and asymmetry: ρ and α=(N-Z)/A
- Expand around nuclear equilibrium density: $x=(\rho-\rho_0)/3\rho_0$; $\rho_0 \simeq 0.15$ fm-3

$$\mathcal{E}(\rho,\alpha) \simeq \mathcal{E}_0(\rho) + \alpha^2 \mathcal{S}(\rho) \simeq \left(\epsilon_0 + \frac{1}{2}K_0 x^2\right) + \left(J + Lx + \frac{1}{2}K_{\rm sym} x^2\right)\alpha^2$$

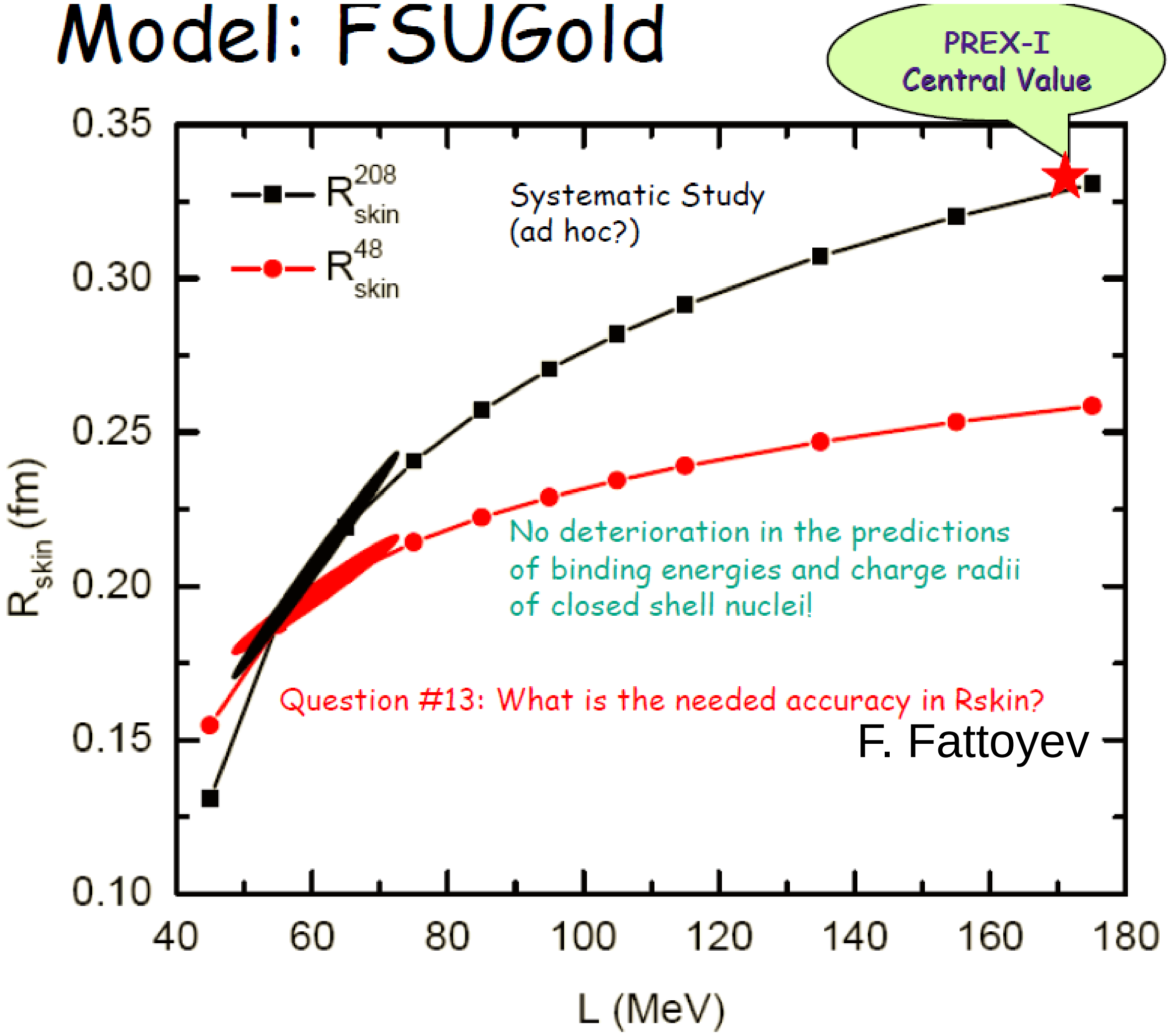
- Density dependence of symmetry energy poorly constrained!!
  "L" symmetry slope ~ pressure of pure neutron matter at saturation



Credit: J. Piekarawicz

CREX Workshop Summary

Model: FSUGold



- BE and charge radii well described (isoscalar)
- Isovector sector unconstrained by data
- Slope of asymmetry energy with density, L, is primarily isovector
- The things we know the best are unaffected by wildly different values of L
- You need neutron-rich matter (isovector)
  - ^{208}Pb is uniform nuclear matter – addresses L (but do we know everything we need from this?)
  - ^{48}Ca interpolate to intermediate A (big lever arm)

$$L = 3\rho_0 \frac{\partial c_{\rm sym}(\rho)}{\partial \rho}\bigg|_{\rho_0}$$

Need ^{48}Ca to address in ab initio and DFT (bridge!)

- ab initio calculations can't be done in ^{208}Pb
- 3N forces

How *on Earth* can we learn about neutron stars?

Same forces.

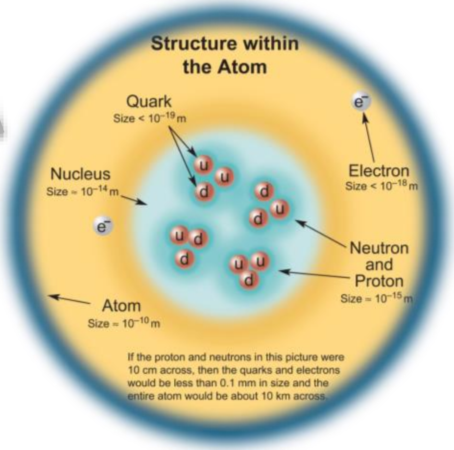
Same particles.

Same equation of state.

18 orders of magnitude in size!

(10 km to 5.5 fm)

55 orders of magnitude in mass!



A whole lot closer to home.

Other ways to get R_n

- Proton-Nucleus Elastic scattering
- Pion, alpha, d Scattering
- Pion Photoproduction
- Heavy ion collisions
- Rare Isotopes (dripline)

} Involve strong probes

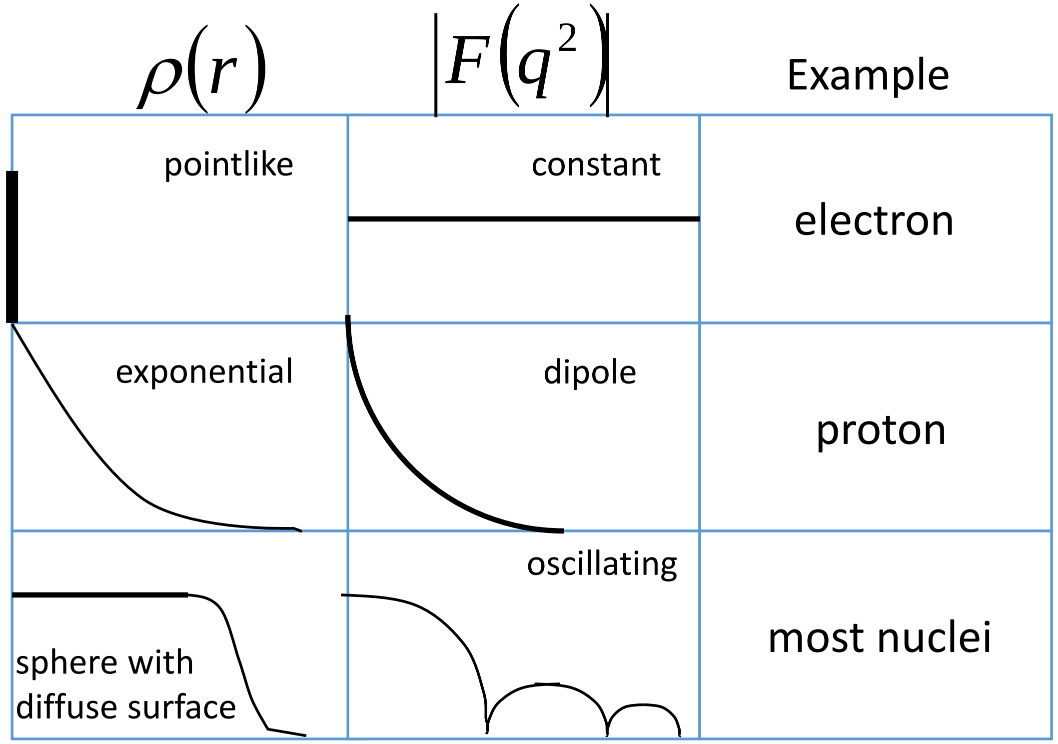
- Magnetic scattering → Most spins couple to zero.
- **PREX/CREX** → Weak interaction
- Theory → MFT fit mostly by data *other than* neutron densities

Form Factors

$$\left(\frac{d\sigma}{d\Omega}\right) = \left(\frac{d\sigma}{d\Omega}\right)^{*}_{Mott} \cdot \left|F\left(q^2\right)\right|^2$$

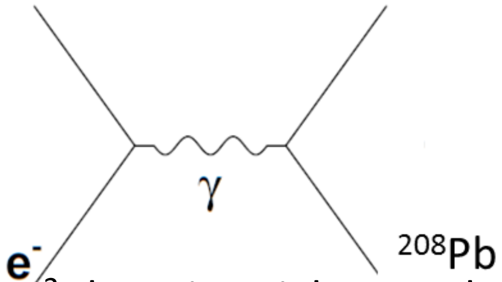
Mott scattering describes electron scattering, including the spin of the electrons

The Fourier transform of the "form factor" $F(Q^2)$ gives the density as a function of radius



Adapted from Particles and Nuclei, Povh, Rith, Scholz, Zetsche

The "radius" of Pb

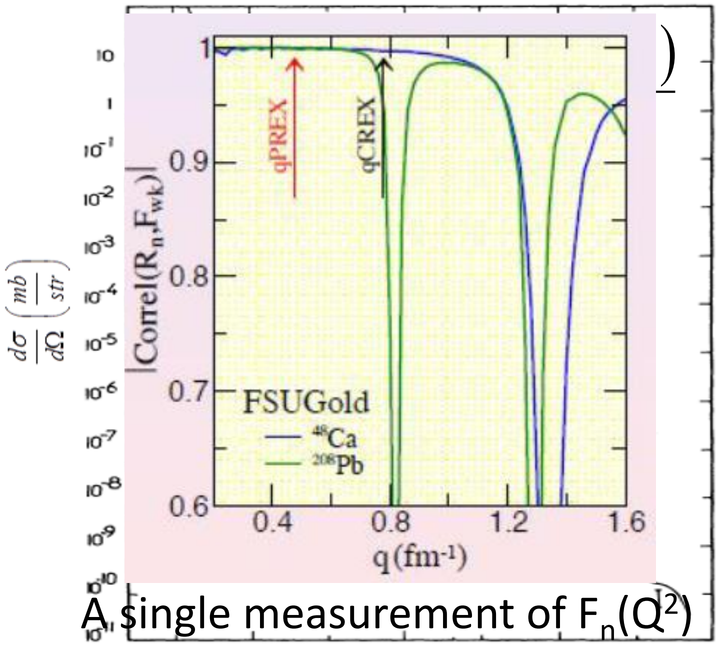


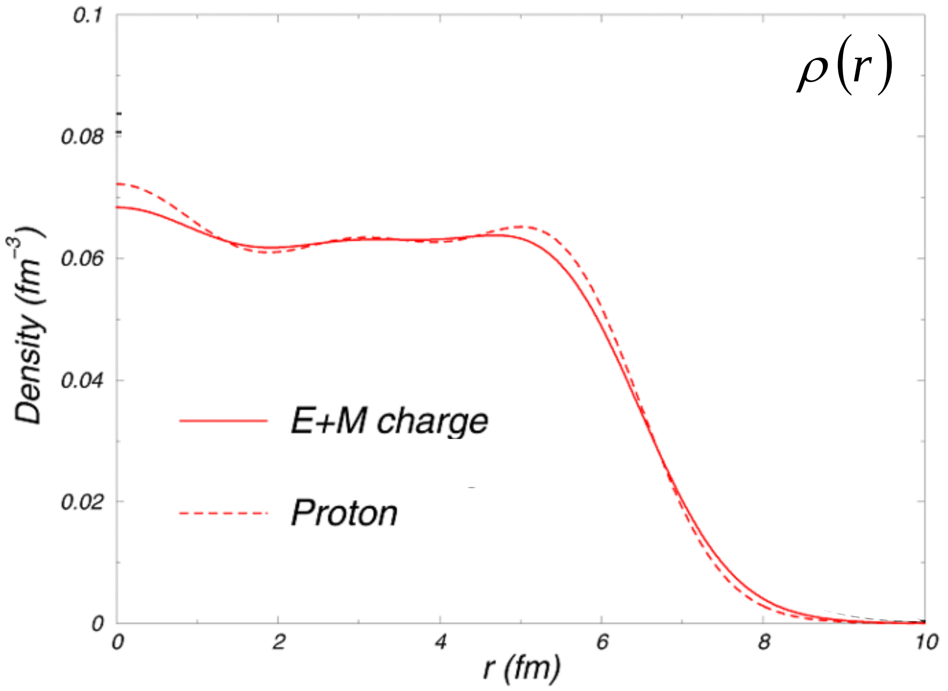
$$Q^p_{weak} = 1 - 4\sin^2\theta_W \approx 0$$

$$Q^n_{weak} = -1$$

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

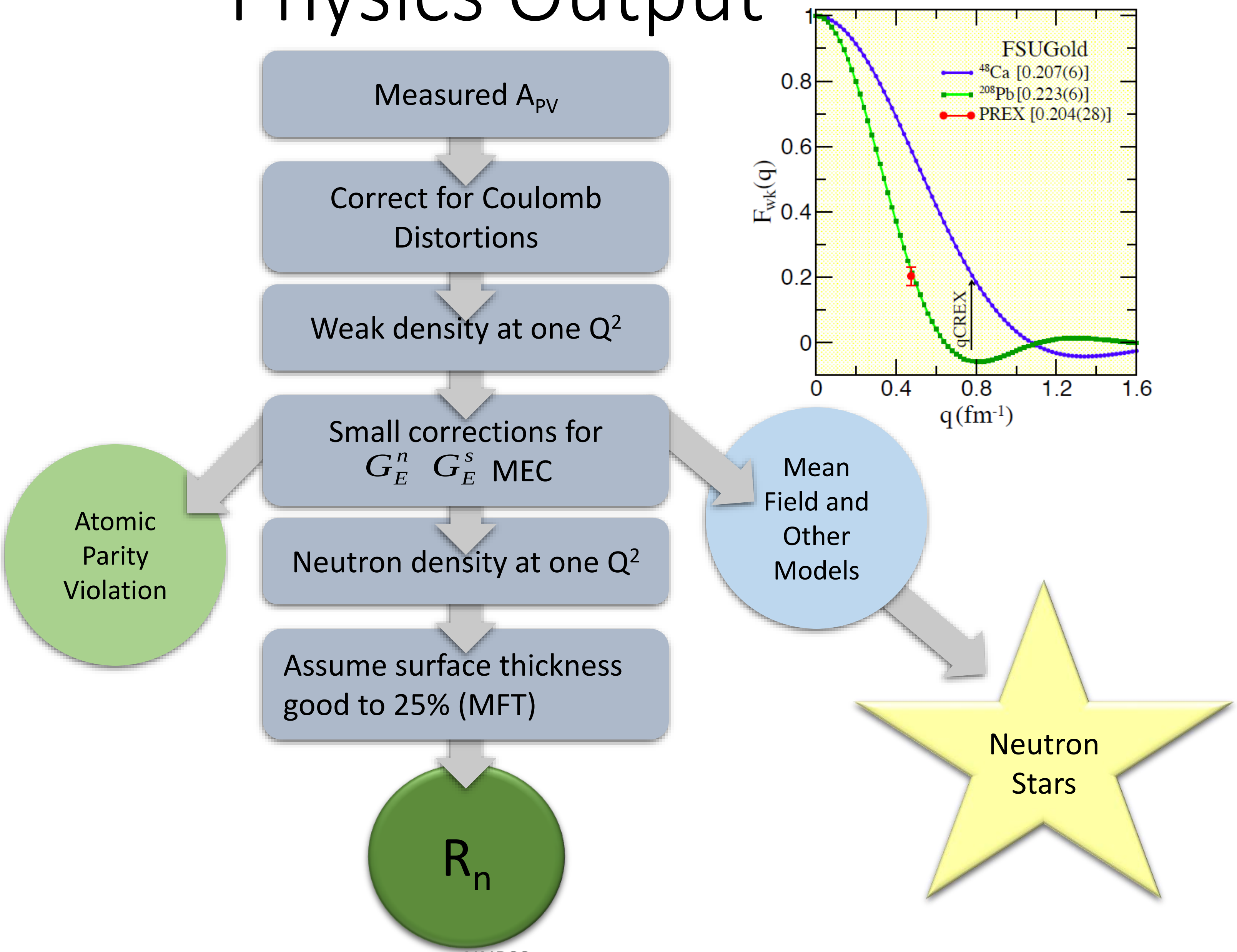
At low Q^2 there is a tight correlation between R_n and $F_n(Q^2)$





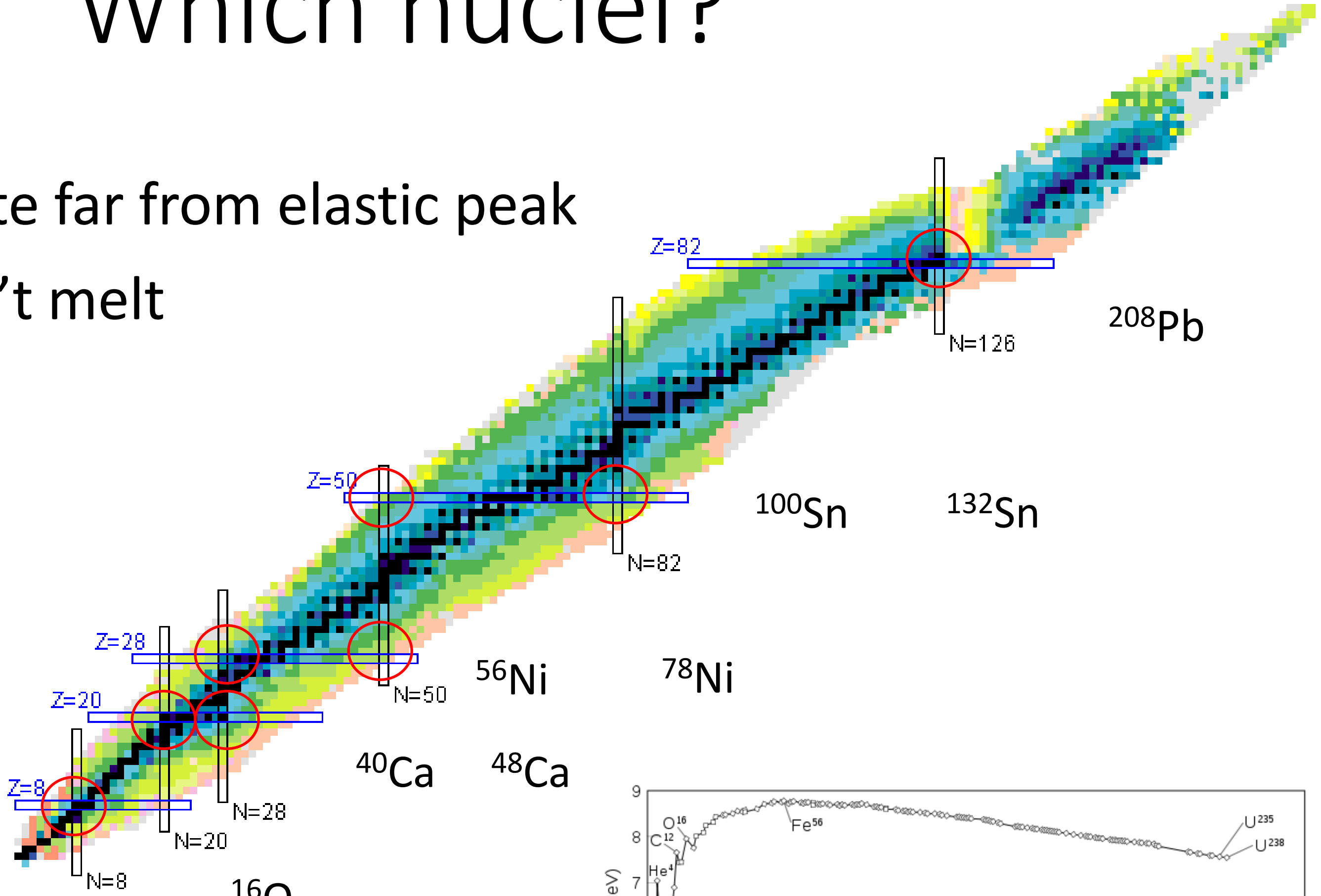
A single measurement of $F_n(Q^2)$ translates to a measurement of R_n via mean-field nuclear models.

Physics Output



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

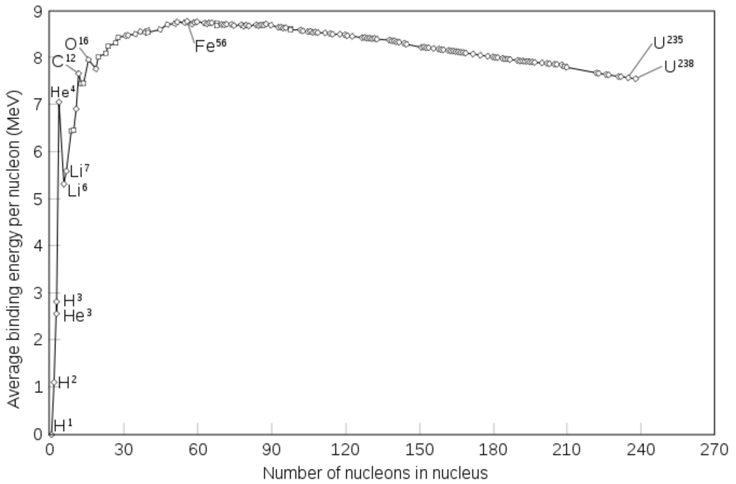
^{56}Ni ^{78}Ni

^{40}Ca ^{48}Ca

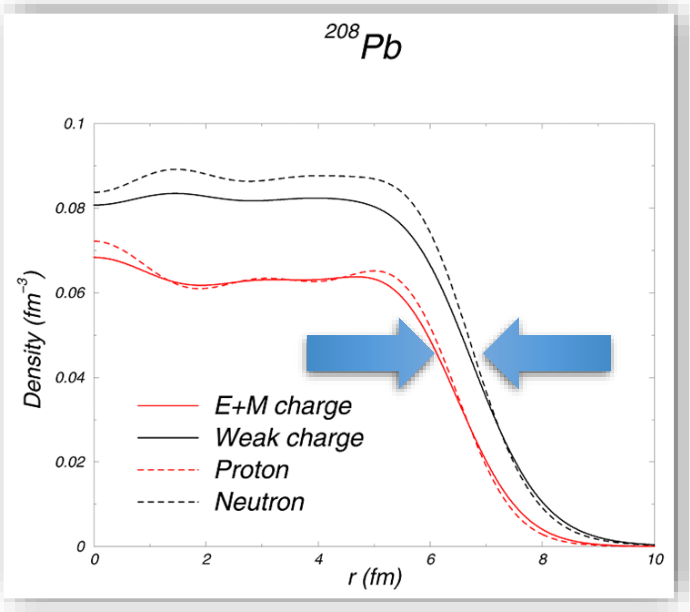
^{16}O

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

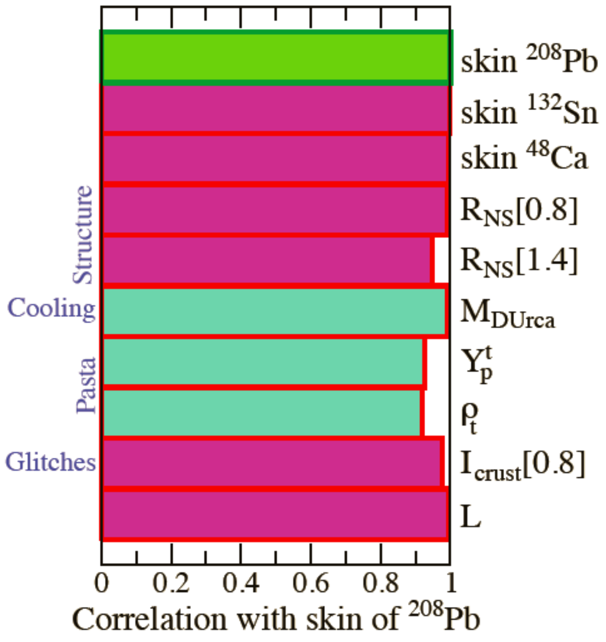
energy cost for unequal #p & #n

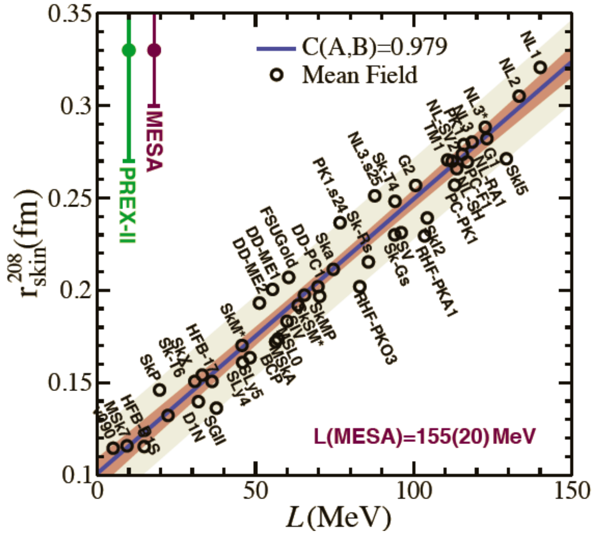


Neutron skin of Pb



C.J. Horowitz





There is a tight correlation between the neutron skin of Pb, *actually*

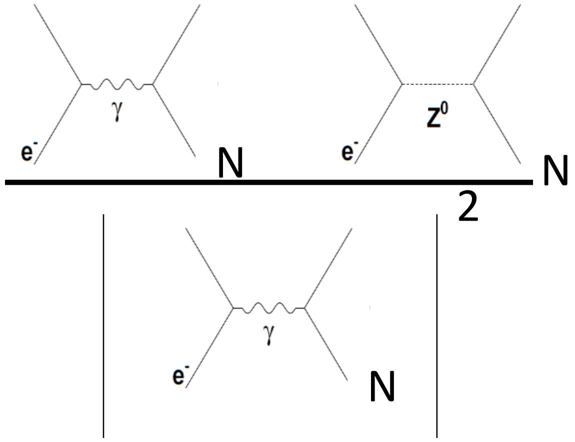
$$R_n - R_p = \sqrt{\langle r_n^2 \rangle} - \sqrt{\langle r_p^2 \rangle}$$

and the symmetry energy
and
the EOS of neutron matter

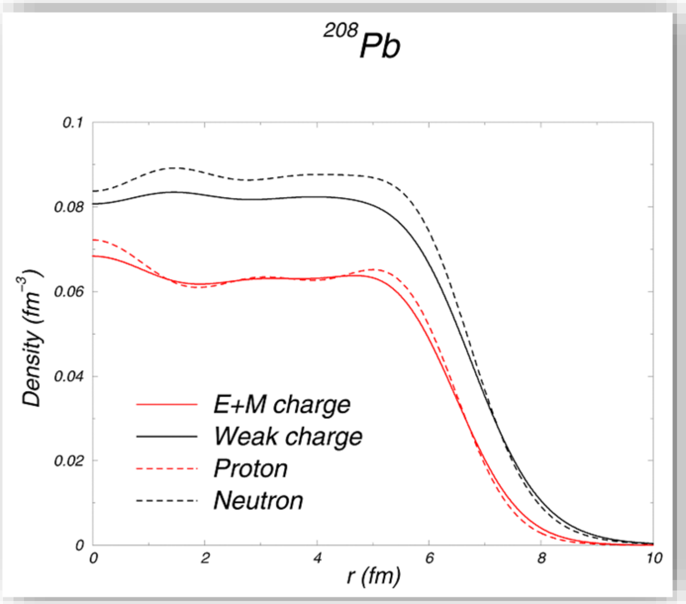
Density dependence of symmetry energy L

PV Asymmetry

$$A_{PV} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_+ - \left(\frac{d\sigma}{d\Omega}\right)_-}{\left(\frac{d\sigma}{d\Omega}\right)_+ + \left(\frac{d\sigma}{d\Omega}\right)_-} \approx$$



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



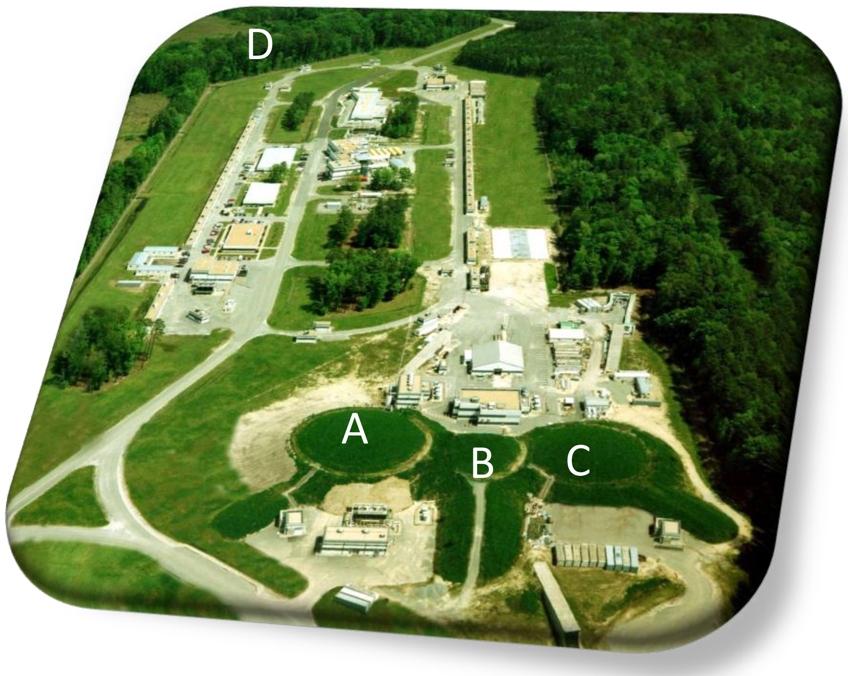
$$F_{n,p}(Q^2) = \frac{1}{4\pi}\int d^3r\ j_0(qr)\ \rho_{n,p}(r)$$

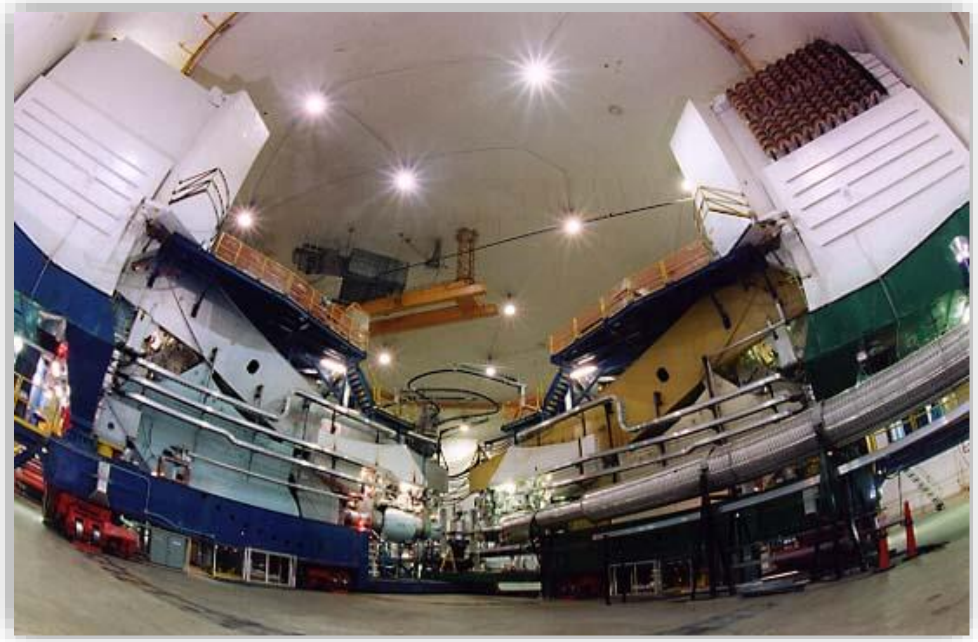
PREx (CREx)

1 GeV electron beam, 50-70 µA
(2.2) GeV electron beam, 150 µA

high polarization, ~89%

helicity reversal at 120 Hz





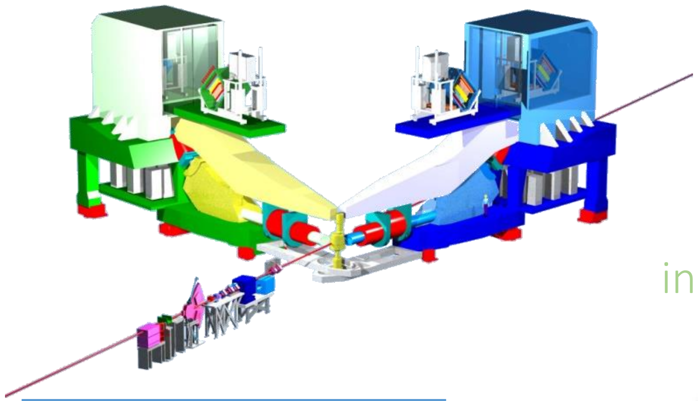
0.5 mm thick Pb target
(5) mm thick Pb (Ca) target

5° scattered electrons
(4°) scattered electrons

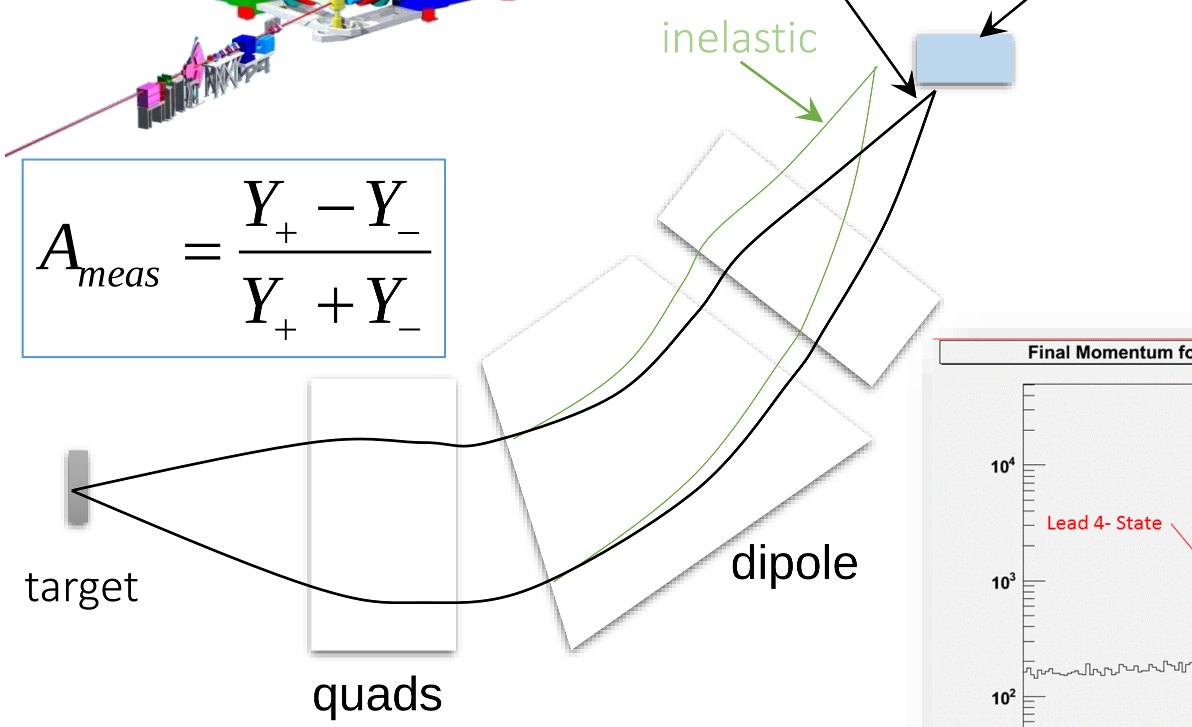
Q^2 =0.0088 GeV^2/c^2
(0.022) GeV^2/c^2

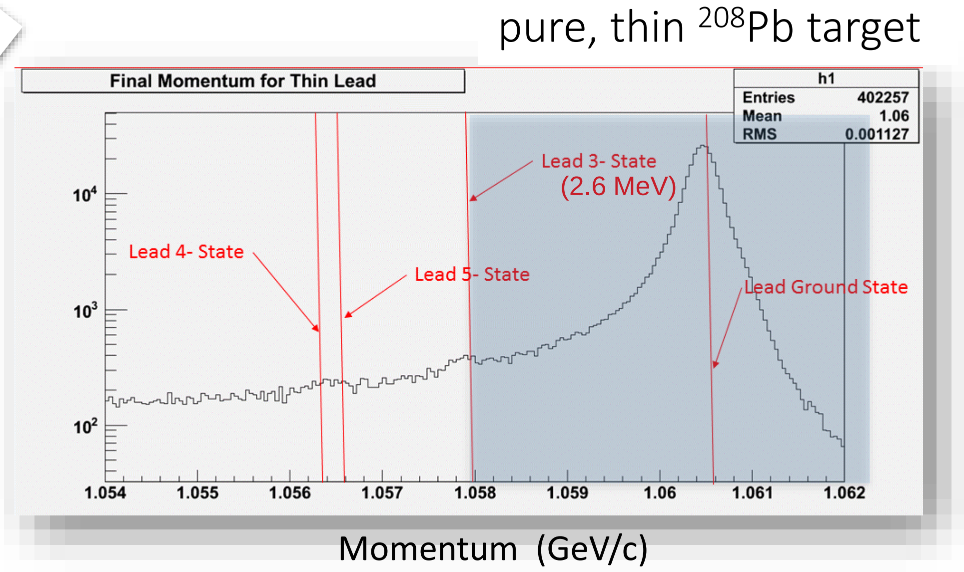
thick and thin quartz detectors

Hall A High Resolution Spectrometers

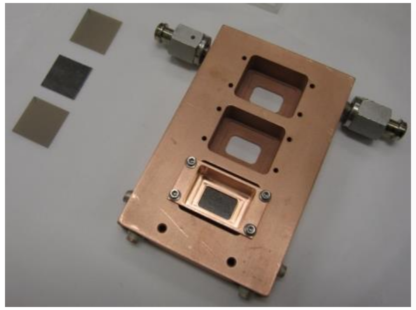


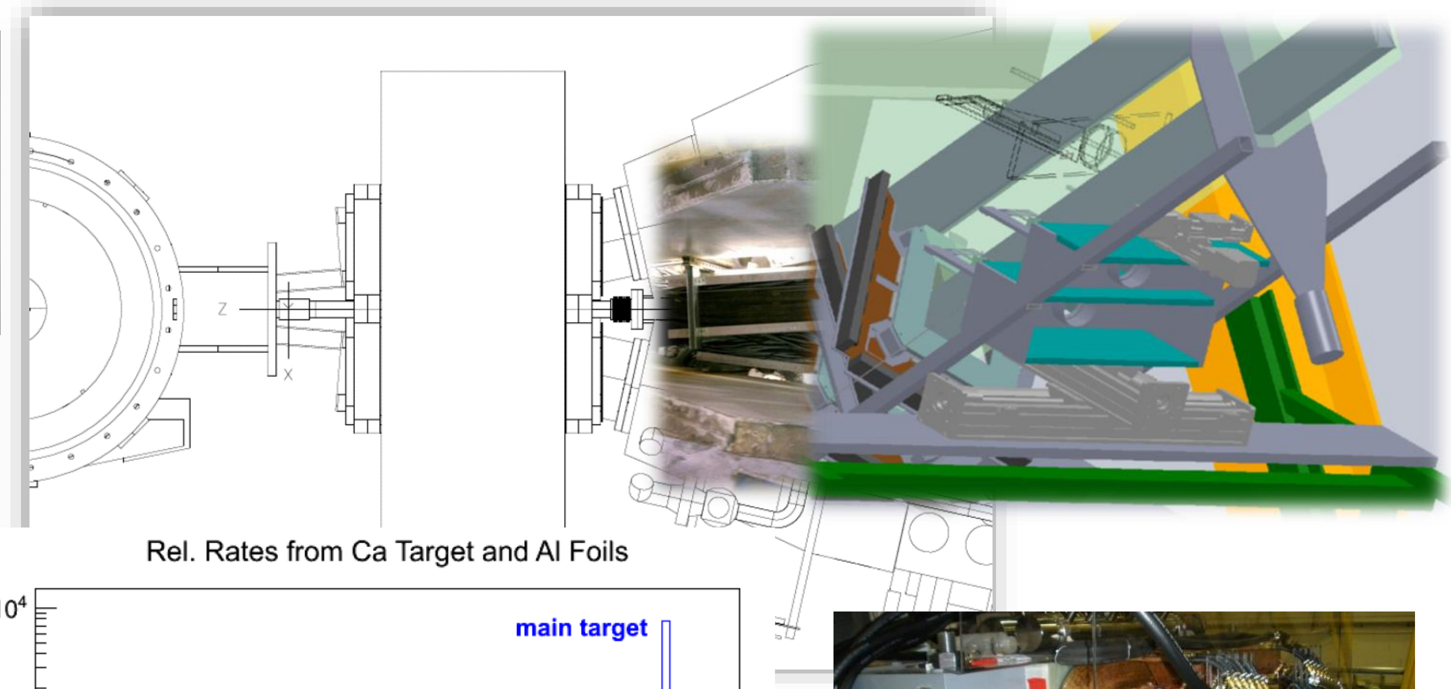
$$A_{meas} = \frac{Y_+ - Y_-}{Y_+ + Y_-}$$

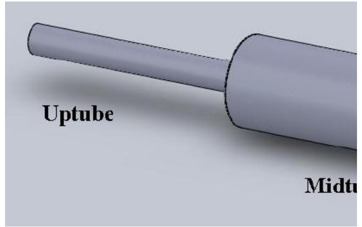


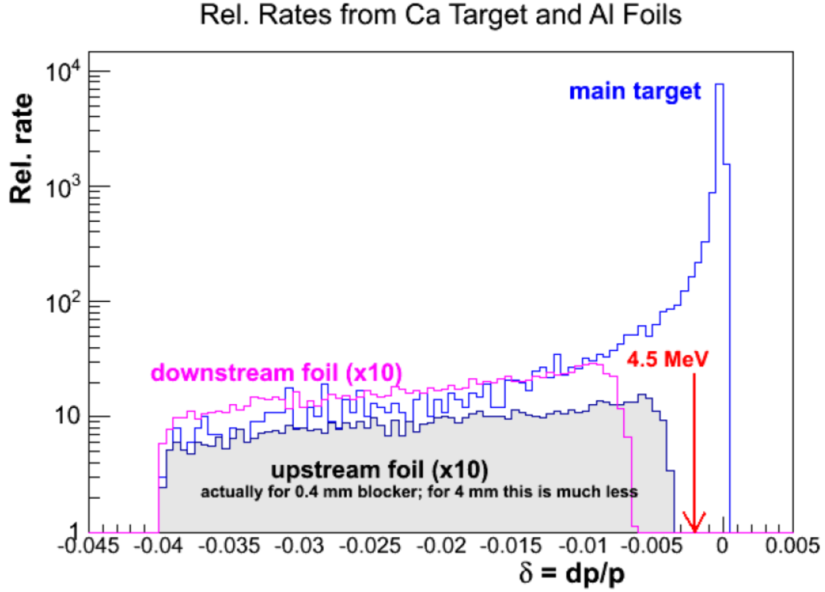


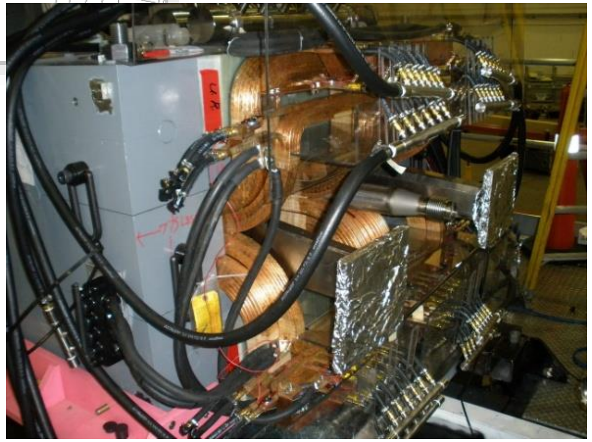
PREx (CREX) Apparatus



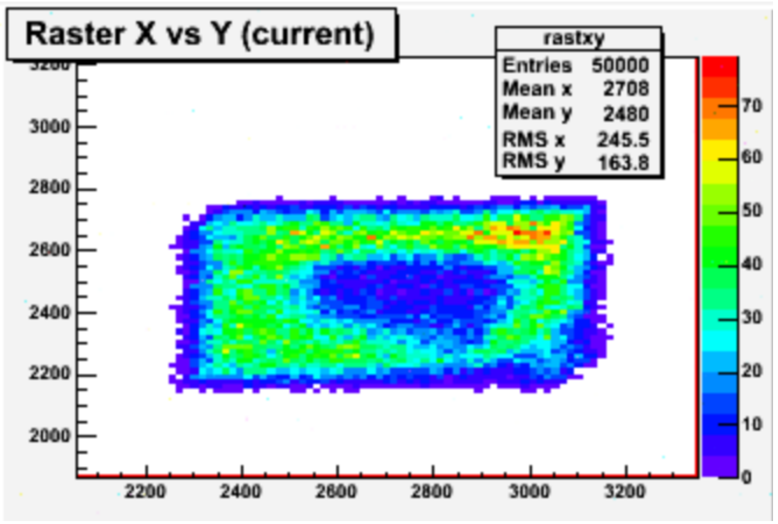




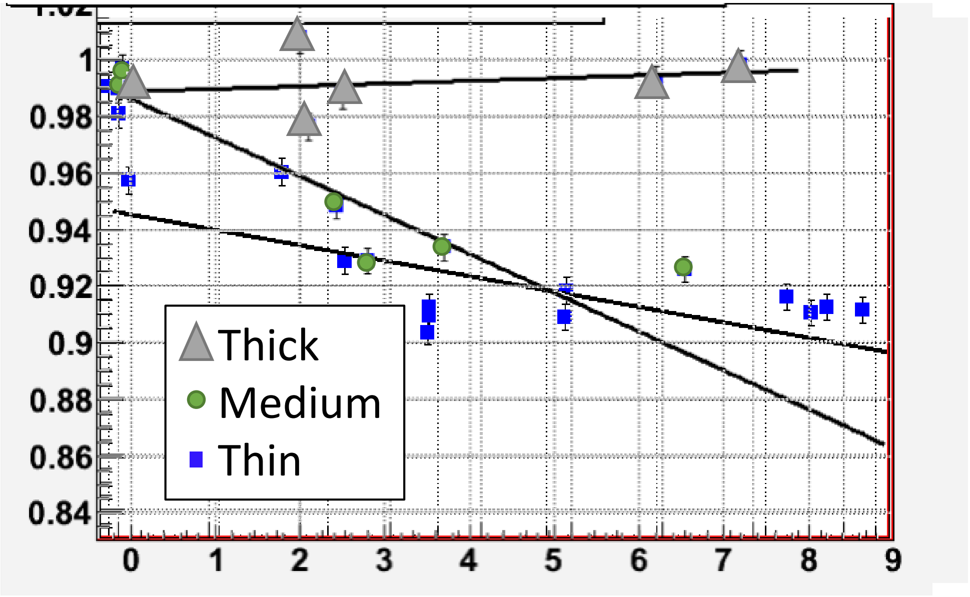


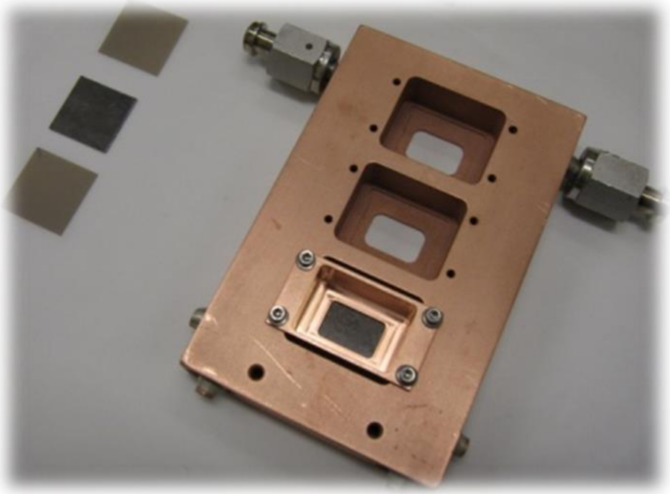


Target Performance



Normalized Rate vs. Time



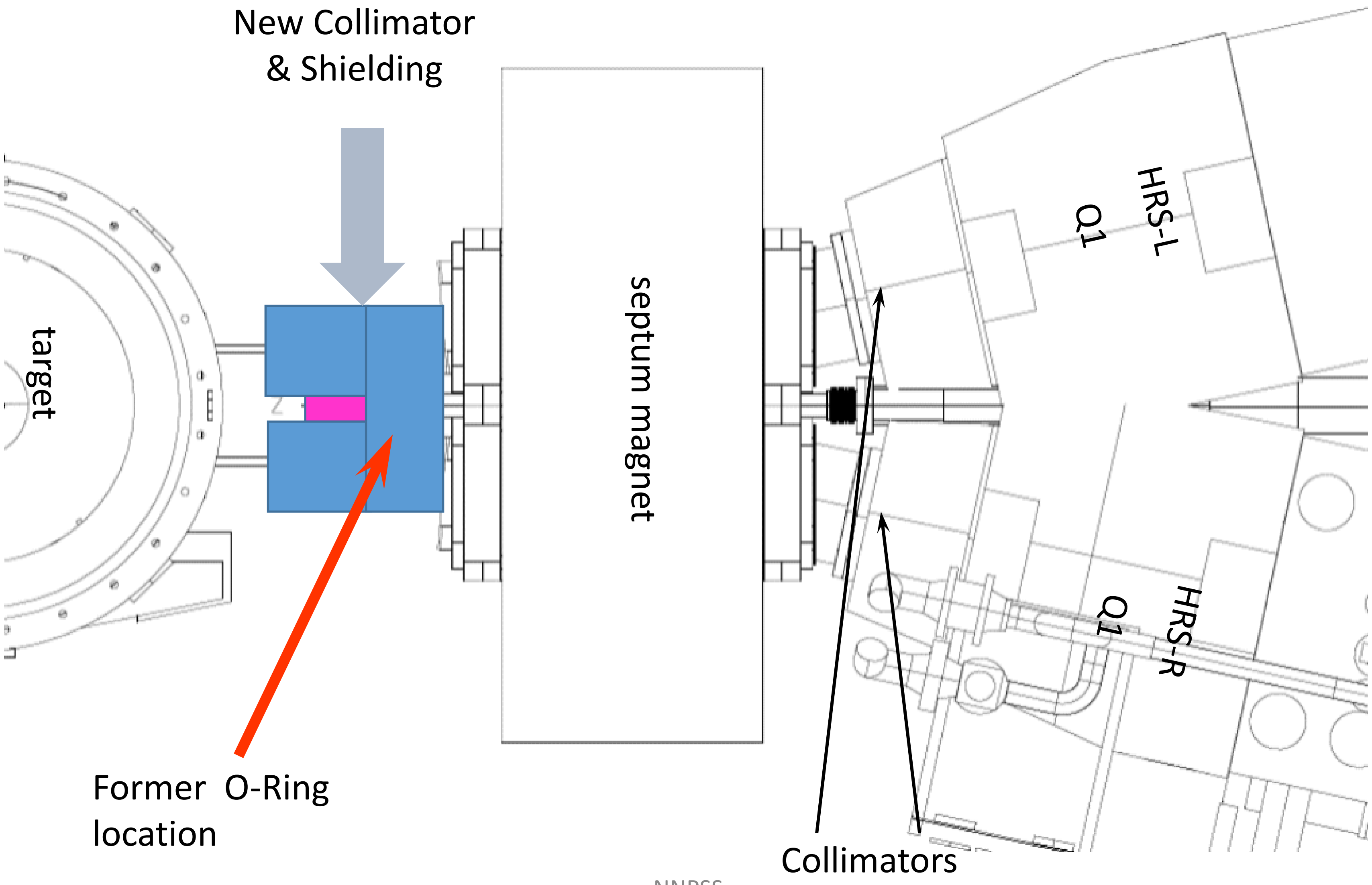


Targets with thin diamond backing (4.5% bkgd) degraded fastest.

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

Solution: Run with 10 targets.

Region Near the Septum



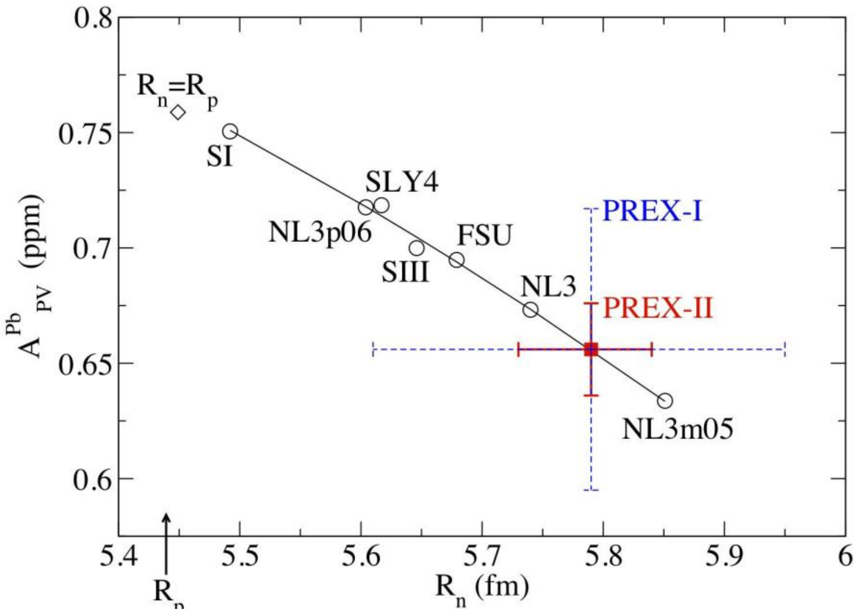
PREx I Results

$$A_{PV} = 0.656\ ppm \pm\ 0.060(stat) \pm 0.013(syst)$$

$$R_n - R_p = 0.33^{+16}_{-18}\ fm$$

Systematic Error	Absolute (ppm)	Relative (%)
Polarization (1)	0.0071	1.1
Beam Asymmetries (2)	0.0072	1.1
Detector Linearity	0.0071	1.1
Beam current normalization	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	0.0130	2.0

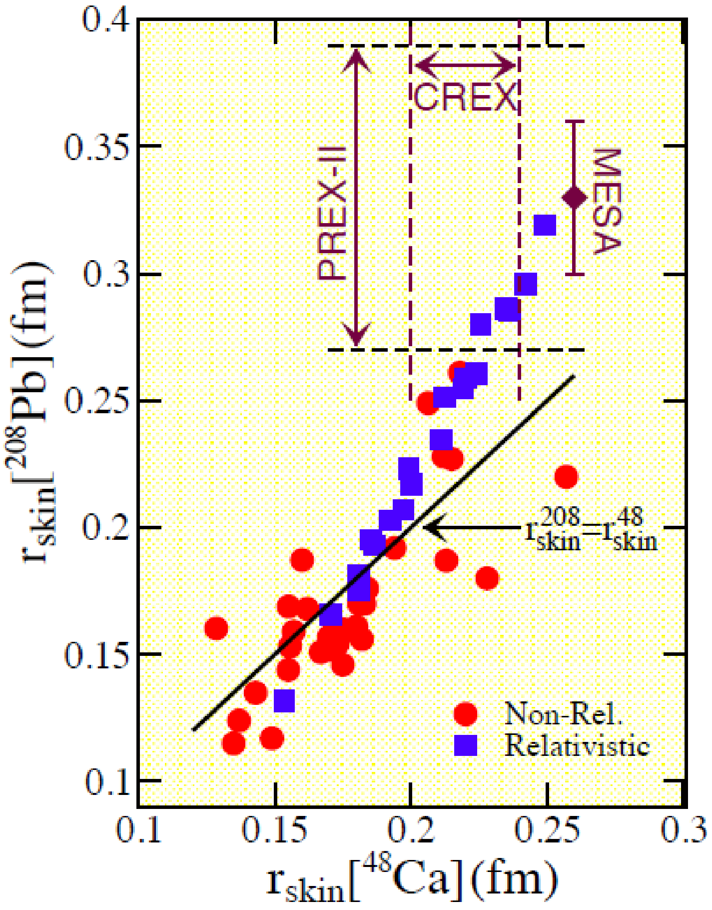
(1) Normalization Correction applied
(2) Nonzero correction (the rest assumed zero)



→ Statistics limited (9%)

→ Systematic error goal achieved !

PREx II/CREX



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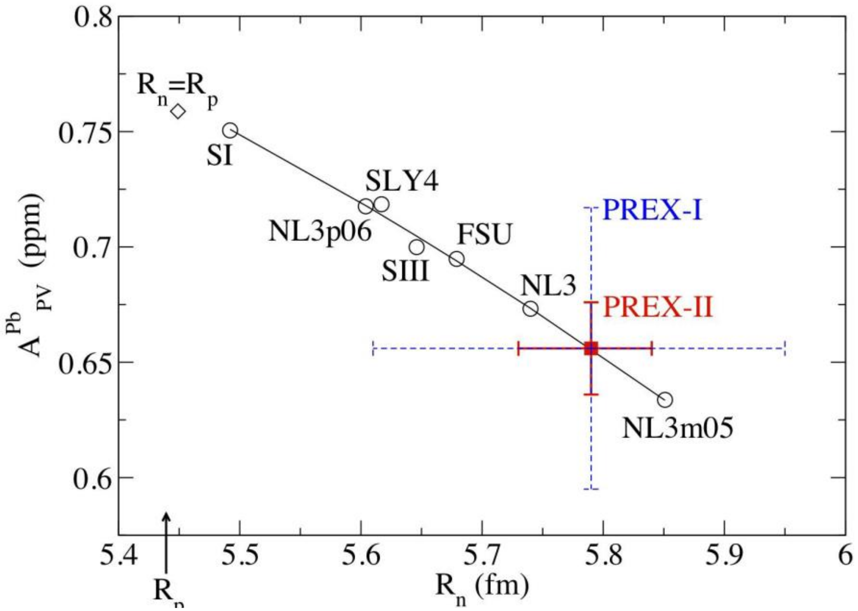


→ Statistics limited (9%)

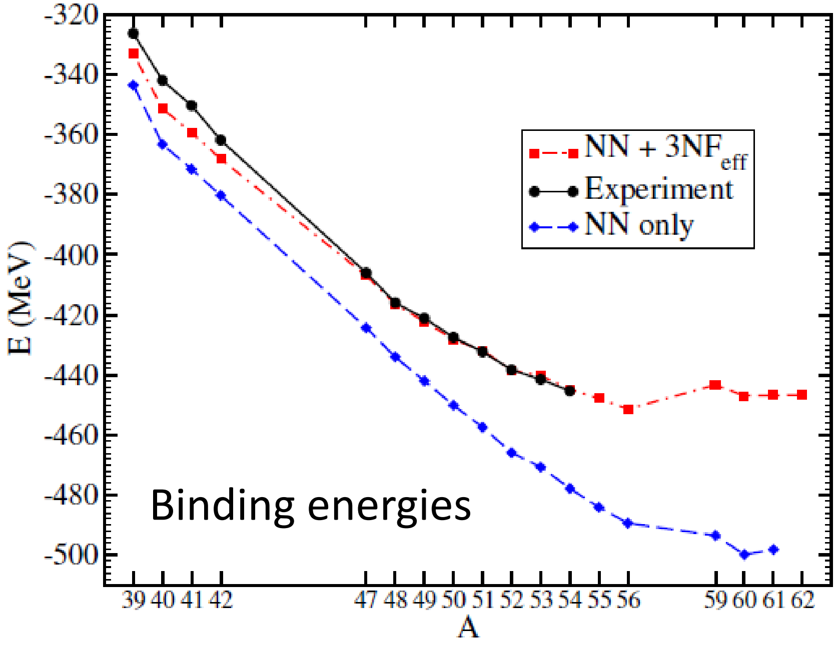
→ Systematic error goal achieved !

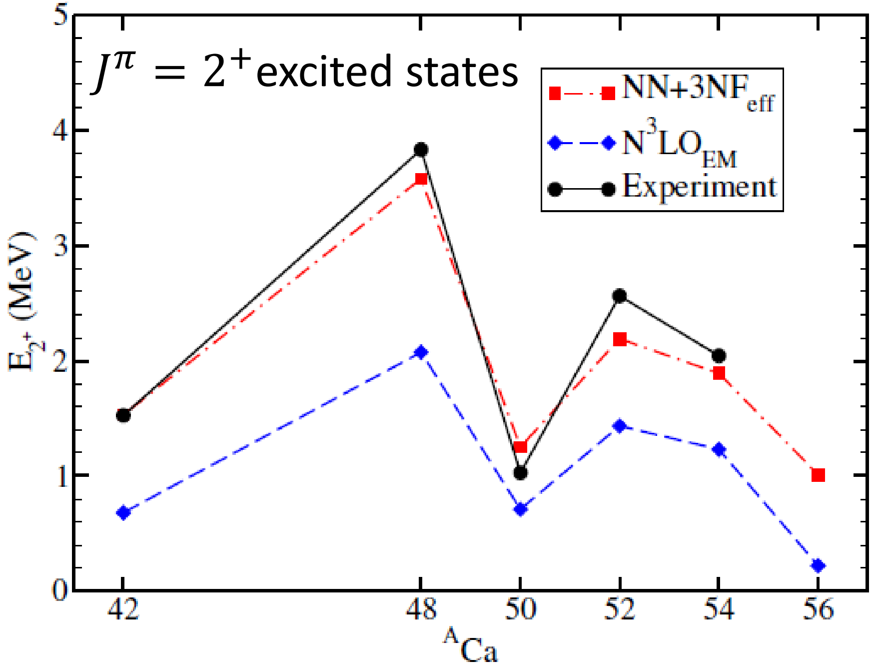
3 nucleon forces

Ab-initio coupled-cluster calculations

3N forces needed for ^{48}Ca to *be* doubly-magic

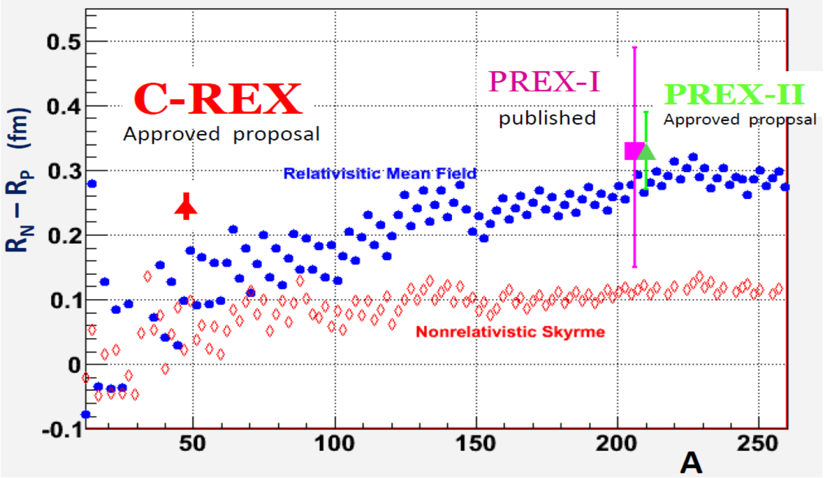
G. Hagen, et. Al, arXiv:1312.7872v1 [nucl-th] 30 Dec 2013





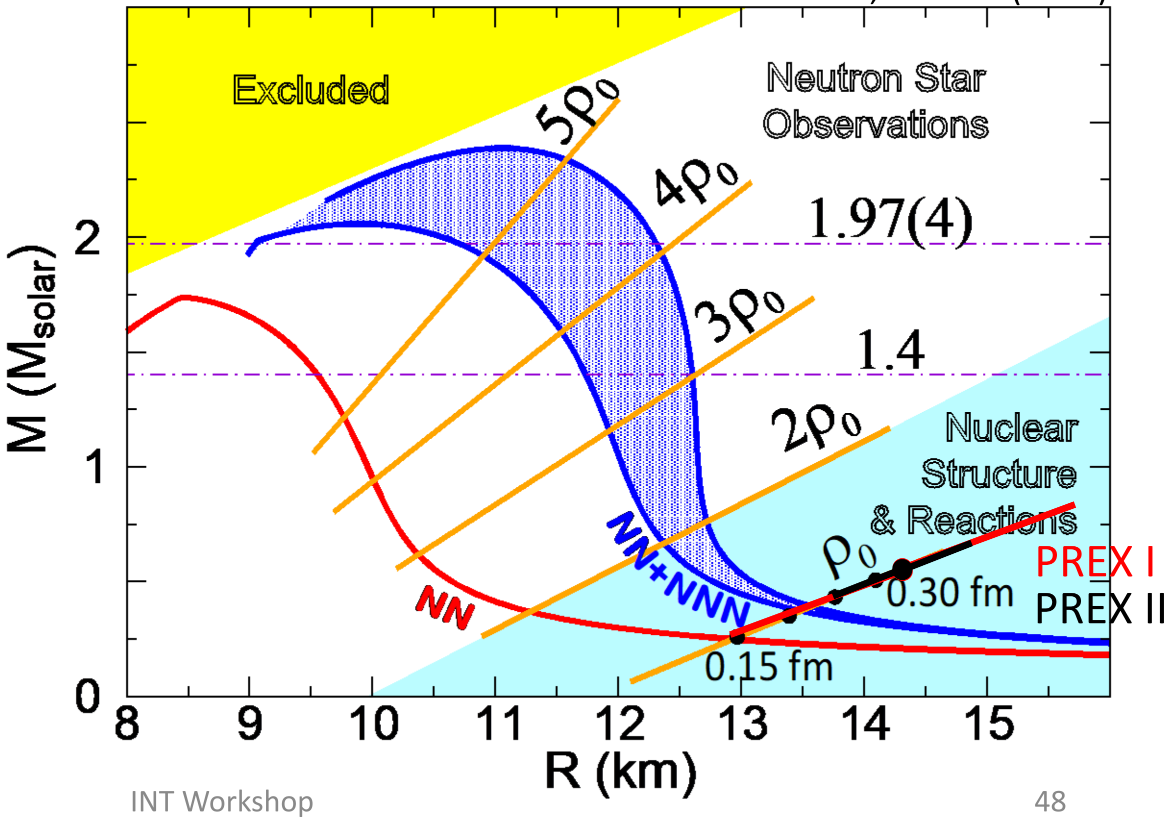
Can do microscopic calculations for ^{48}Ca that we can't do for lead (yet?)

Why both?



Measure both R_n^{Pb} and R_n^{Ca} test nuclear structure models over a large range of A

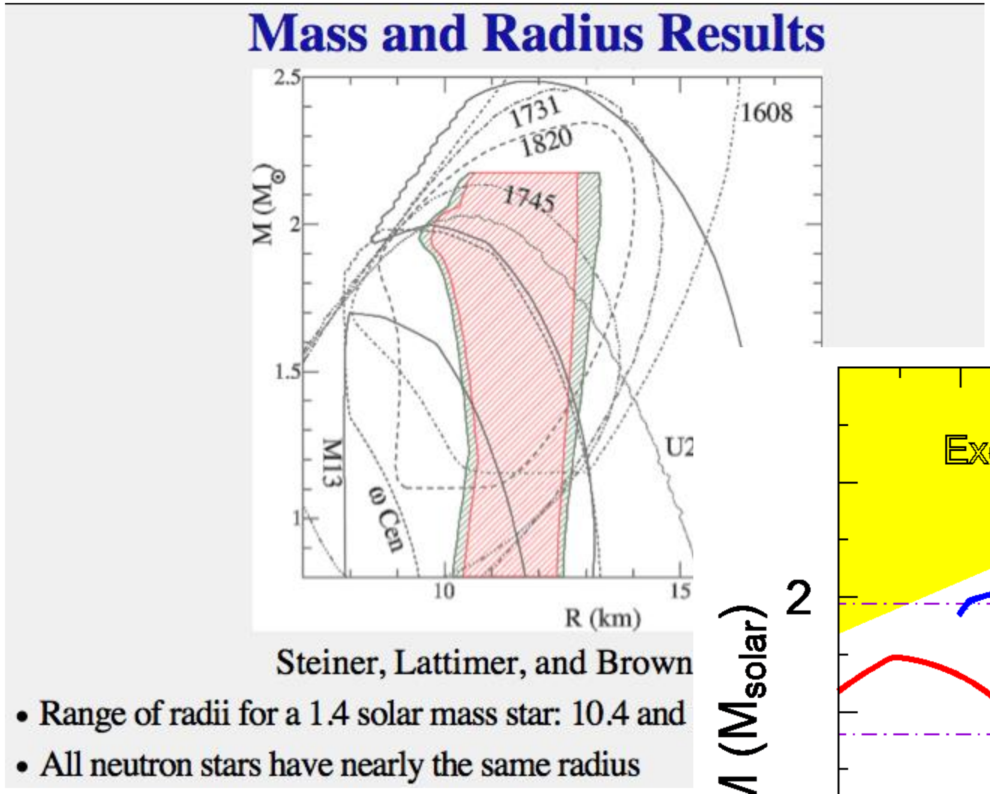
Gandolfi et al. PRC85, 032801 (2012)



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

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

Neutron Stars



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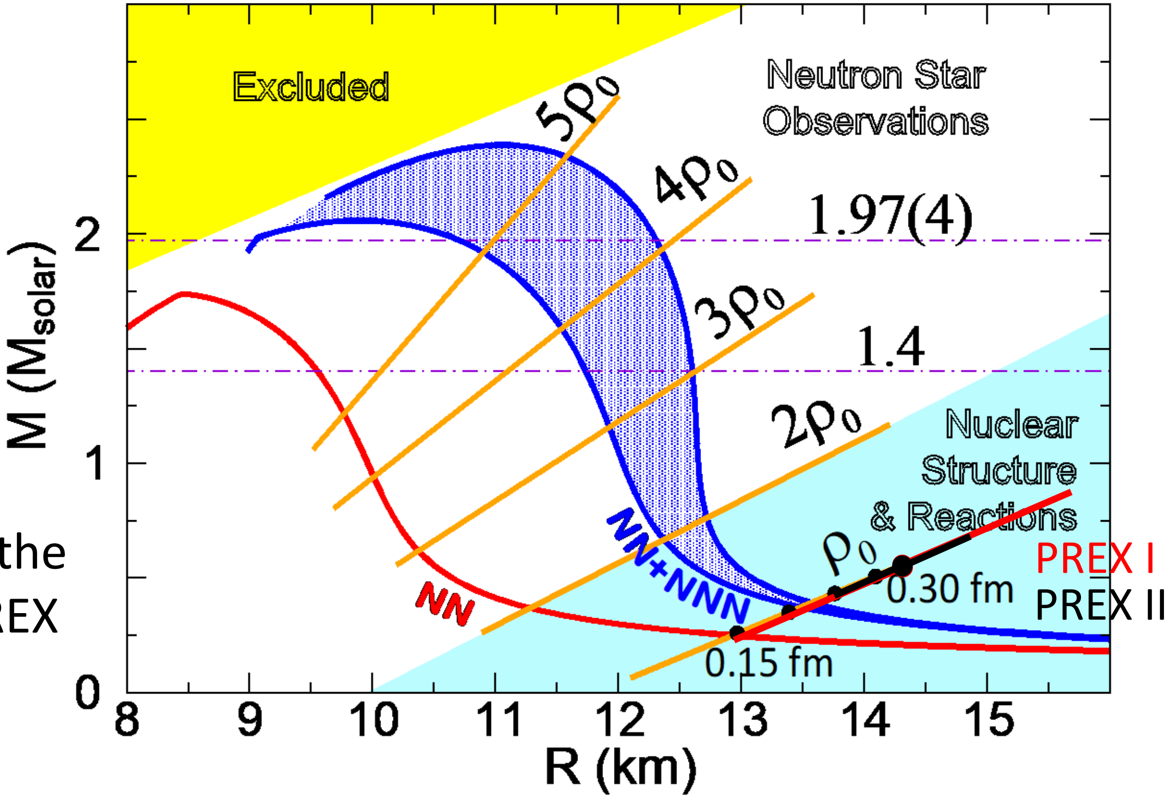
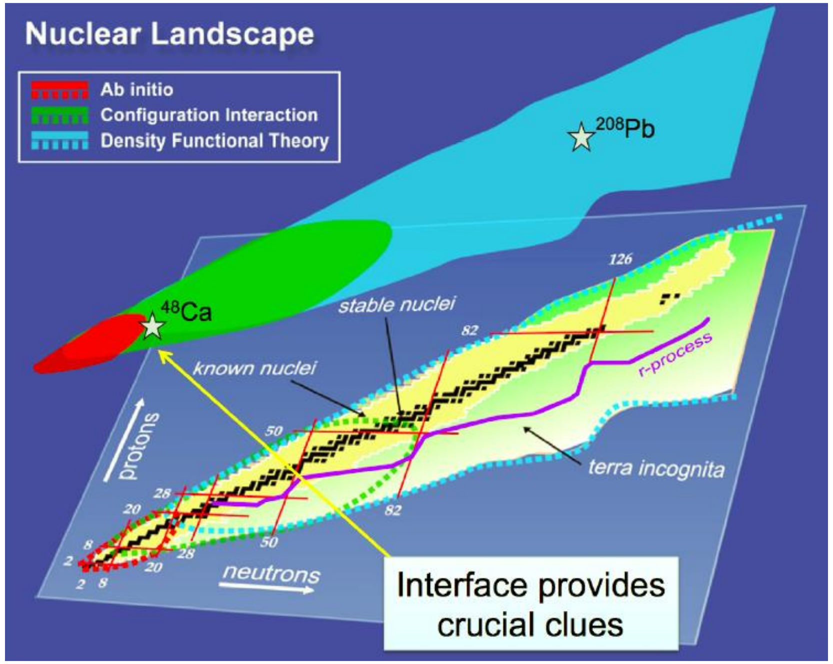
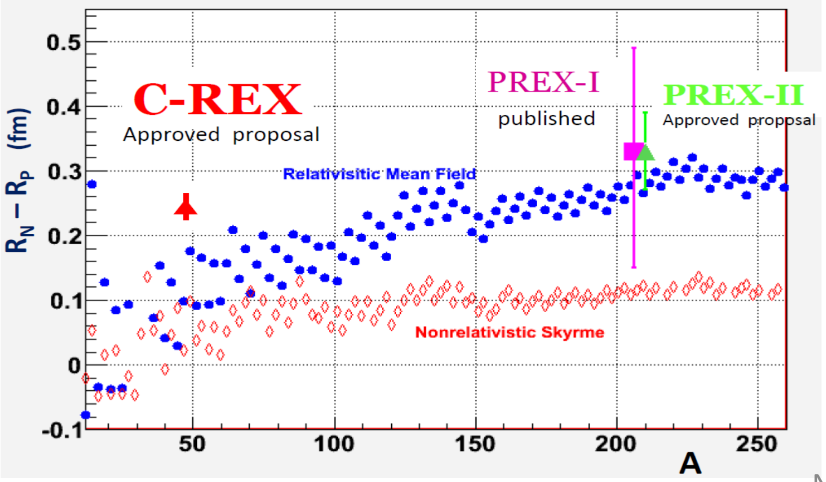


Including 3N forces can change the model predictions; CREX and PREX will help constrain the models

PREX and CREX





Theory from P. Ring et al. Nucl. Phys. A 624 (1997) 349

^{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

R_n^{208} and R_n^{48} 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 R_n^{208} and R_n^{48} - test nuclear structure models over a large range of A

MOLLER

Spectrometer Elements

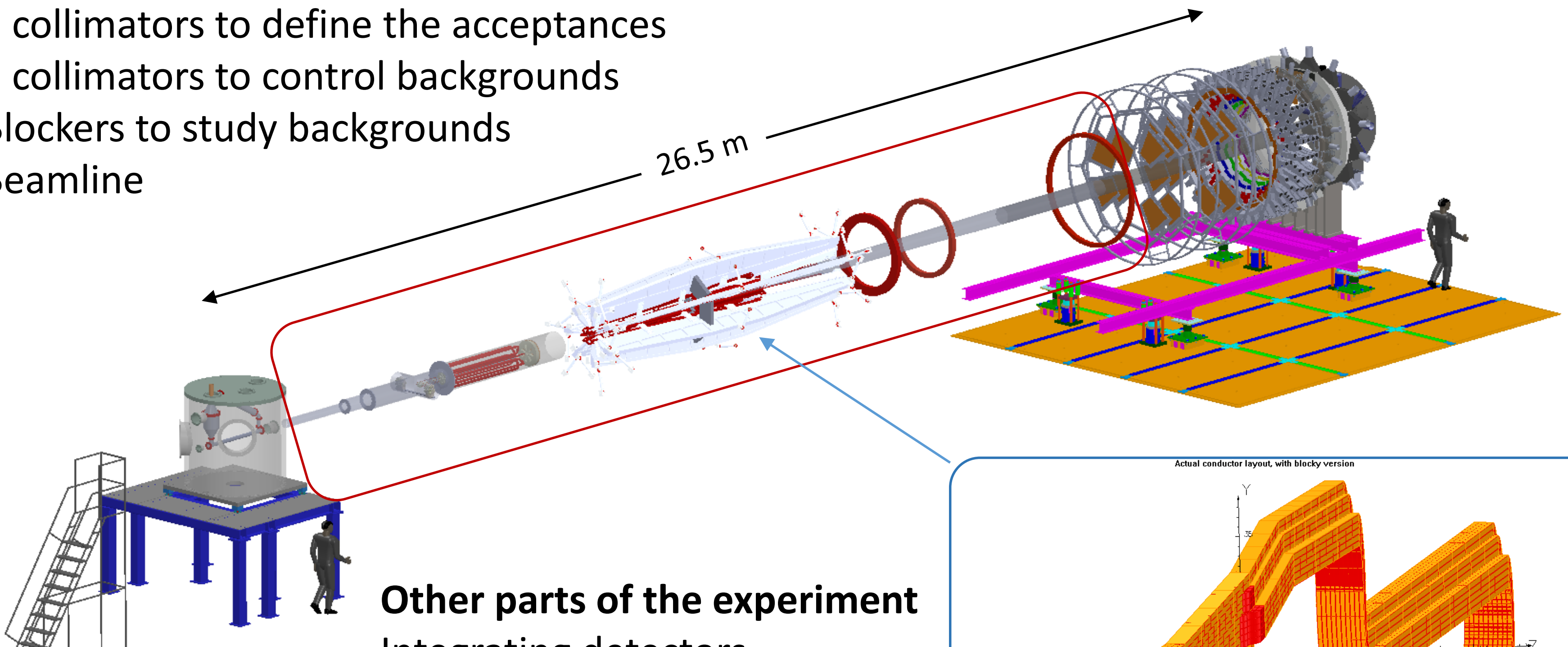
Two resistive toroidal magnets

2 collimators to define the acceptances

2 collimators to control backgrounds

Blockers to study backgrounds

Beamline



Other parts of the experiment

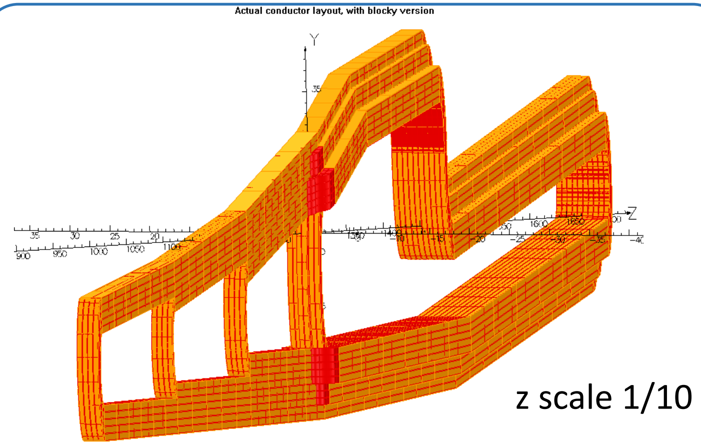
Integrating detectors

Tracking detectors

Target

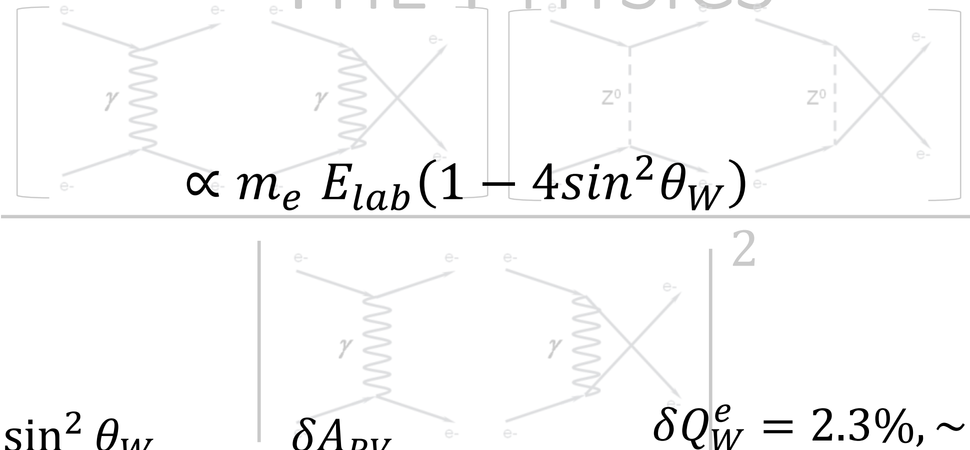
Shielding

Beam monitors



Single coil of downstream (hybrid torus)

The Physics



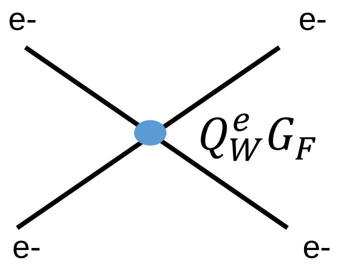
$$A_{PV} = \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-} \approx \propto m_e\ E_{lab}(1 - 4sin^2\theta_W) = 35.6\ \pm\ 0.73\ ppb$$

$$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W} \simeq .05\frac{\delta A_{PV}}{A_{PV}}$$

$\delta Q_W^e = 2.3\%, \sim 5 \times smaller$

$than\ E158\ (\delta Q_W^e = 10.9\%)$

$$\boldsymbol{\mathcal{L}_{e_1e_2}^{PV} = \mathcal{L}_{SM}^{PV} + \mathcal{L}_{NEW}^{PV}}$$



$$g_{ij} = g_{ij}^*$$

$$e_{L,R} = \frac{1}{2}(1 \mp \gamma_5)\psi_e$$

Coupling constants

$$\mathcal{L}_{NEW}^{PV} = \sum_{i,j=L,R} \frac{g_{ij}^2}{2\Lambda_{ij}^2}\bar{e}_i\gamma_i e_i \bar{e}_j \gamma^j\ e_j$$

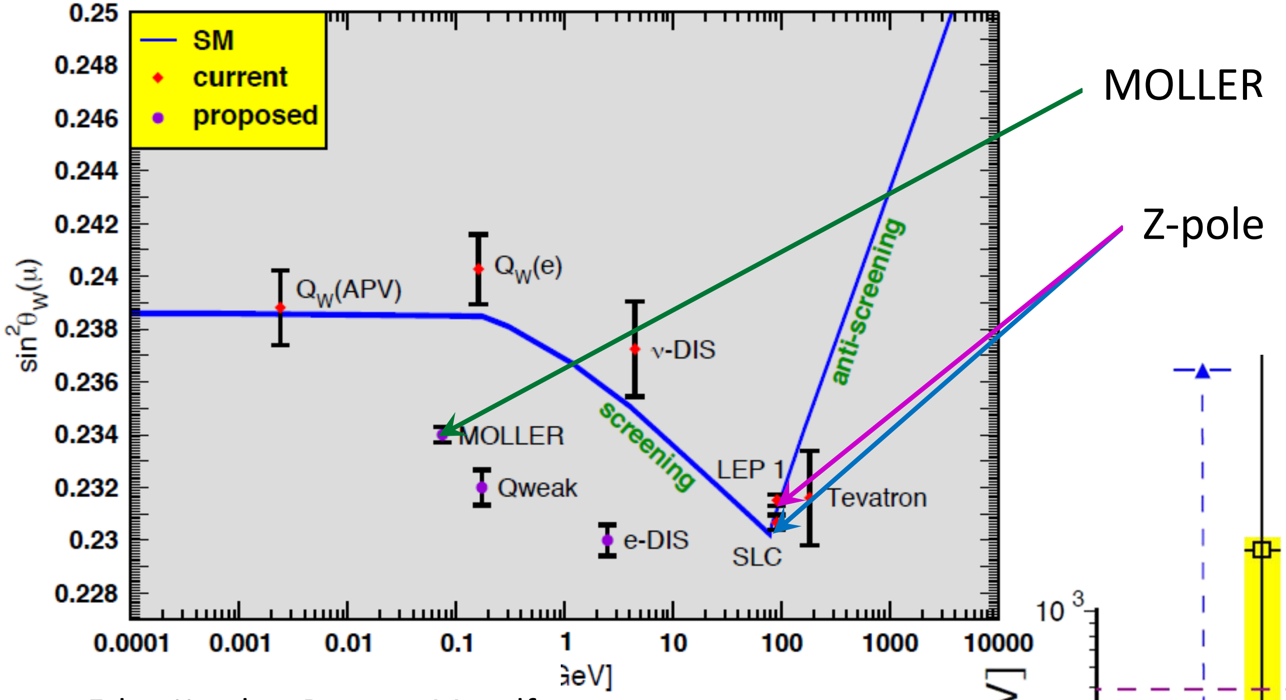
Mass scale

$$\frac{\Lambda}{\sqrt{|g_{LL}^2 - g_{RR}^2|}} = \frac{\Lambda}{\sqrt{\sqrt{2}G_F|\Delta Q_W^e|}}$$

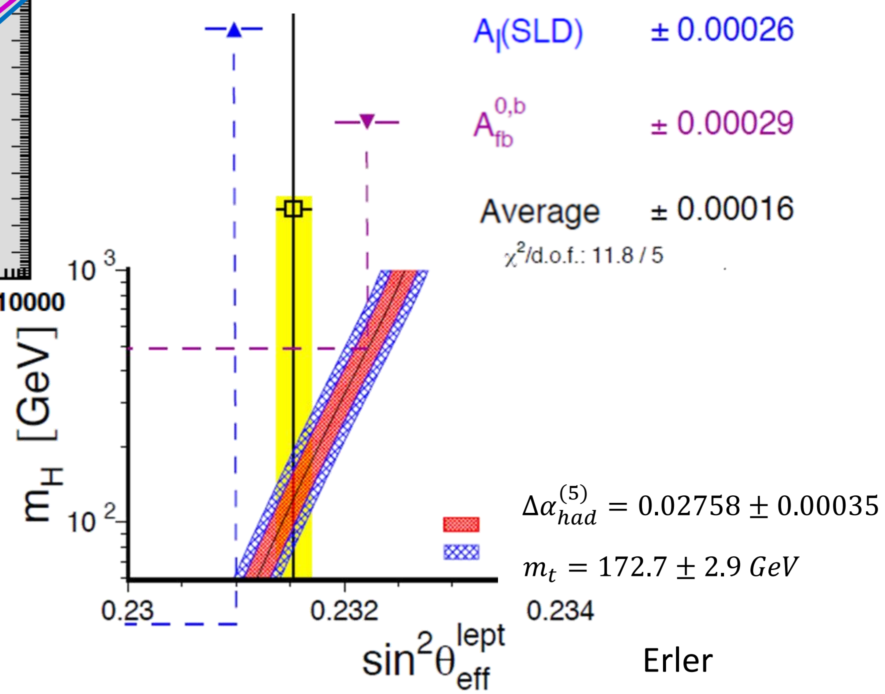
2.3% MOLLER uncertainty

$\rightarrow \boldsymbol{7.5\ TeV}$

MEASUREMENT OF $\sin^2\theta_W$



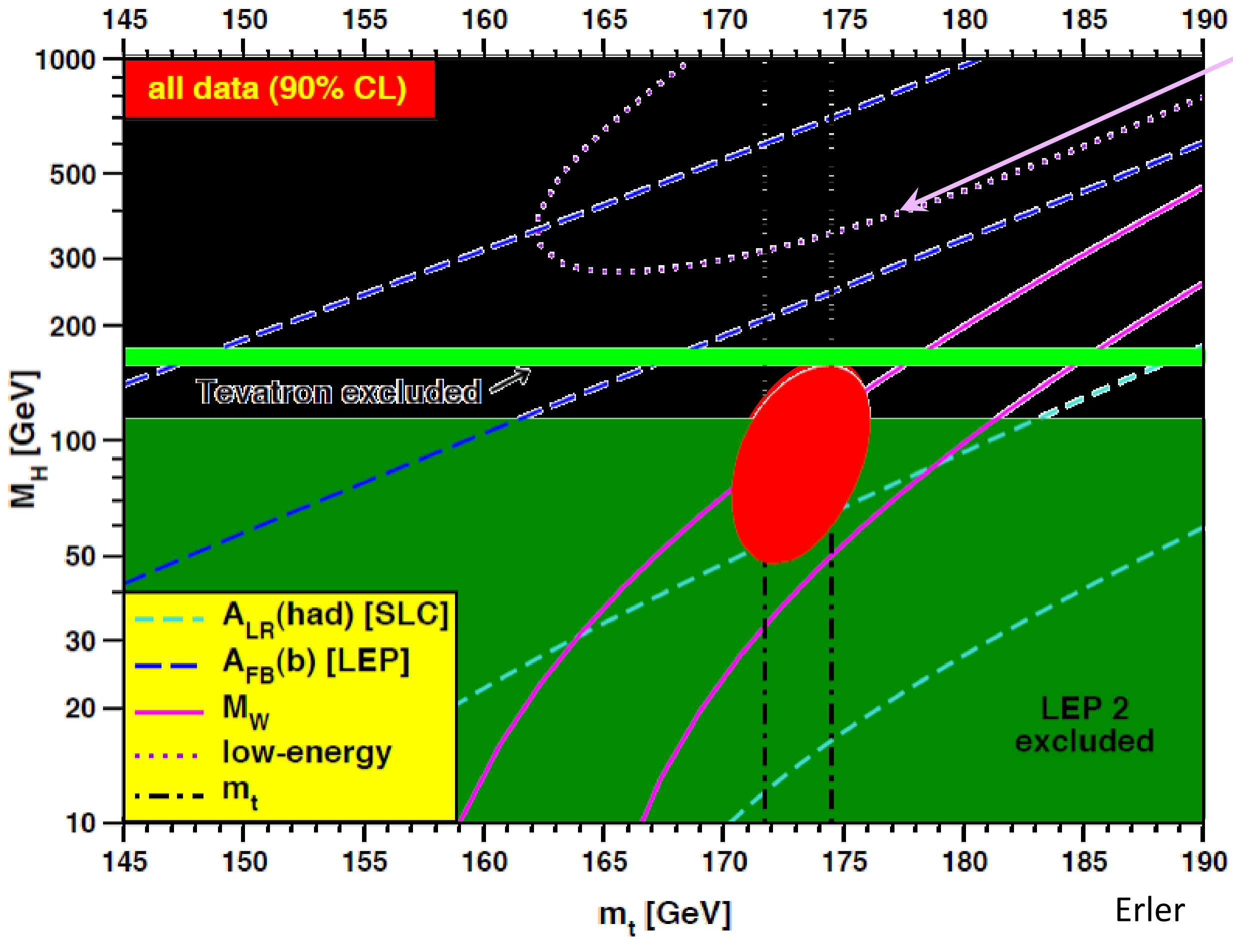
Erler, Kurylov, Ramsey-Musolf



Erler

Higgs Mass

MOLLER would dominate this ellipse



Erler

All precision EW data

Direct Searches (Excluded)

Tevatron

LEP2

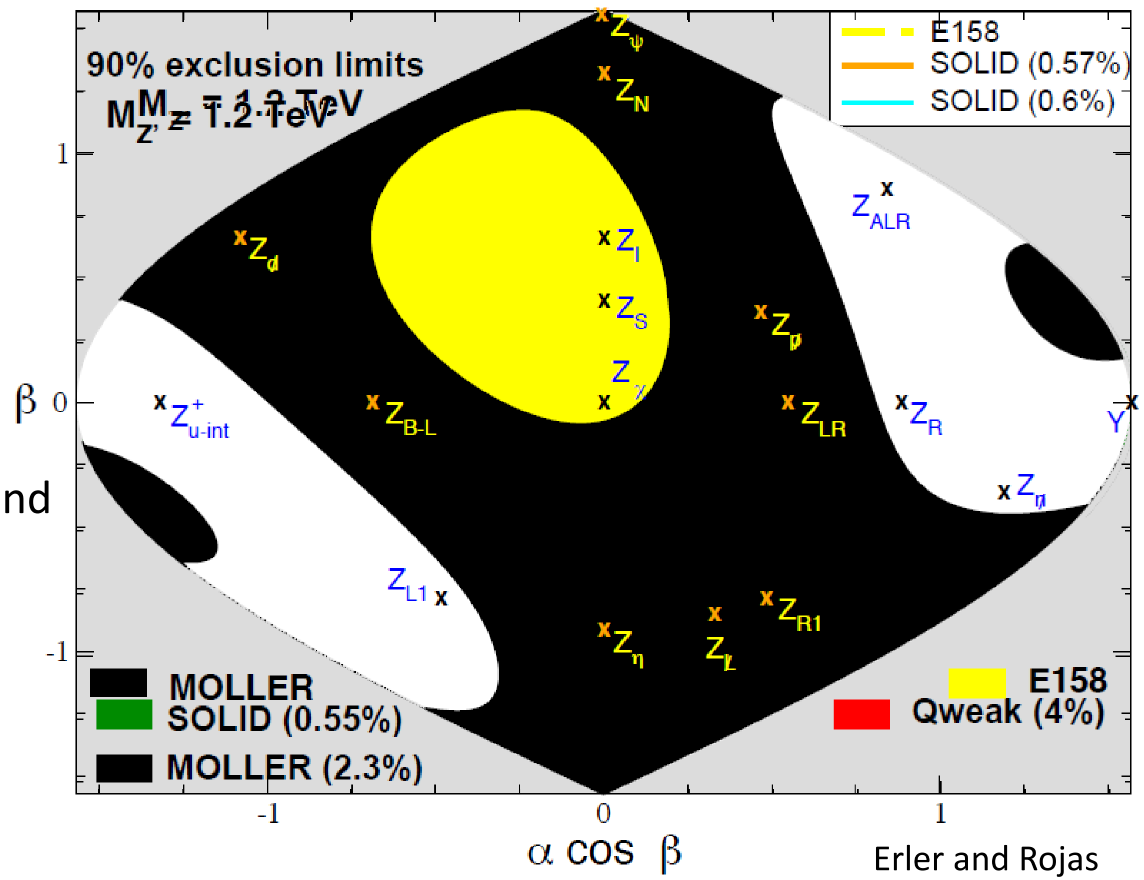
COMPLEMENTARY TO THE LHC - Z′

Assume LHC discovers a new spin 1 gauge boson with M =1.2 TeV

Halfway between SM and E158 central value

If the SM value is measured

MOLLER can distinguish between models

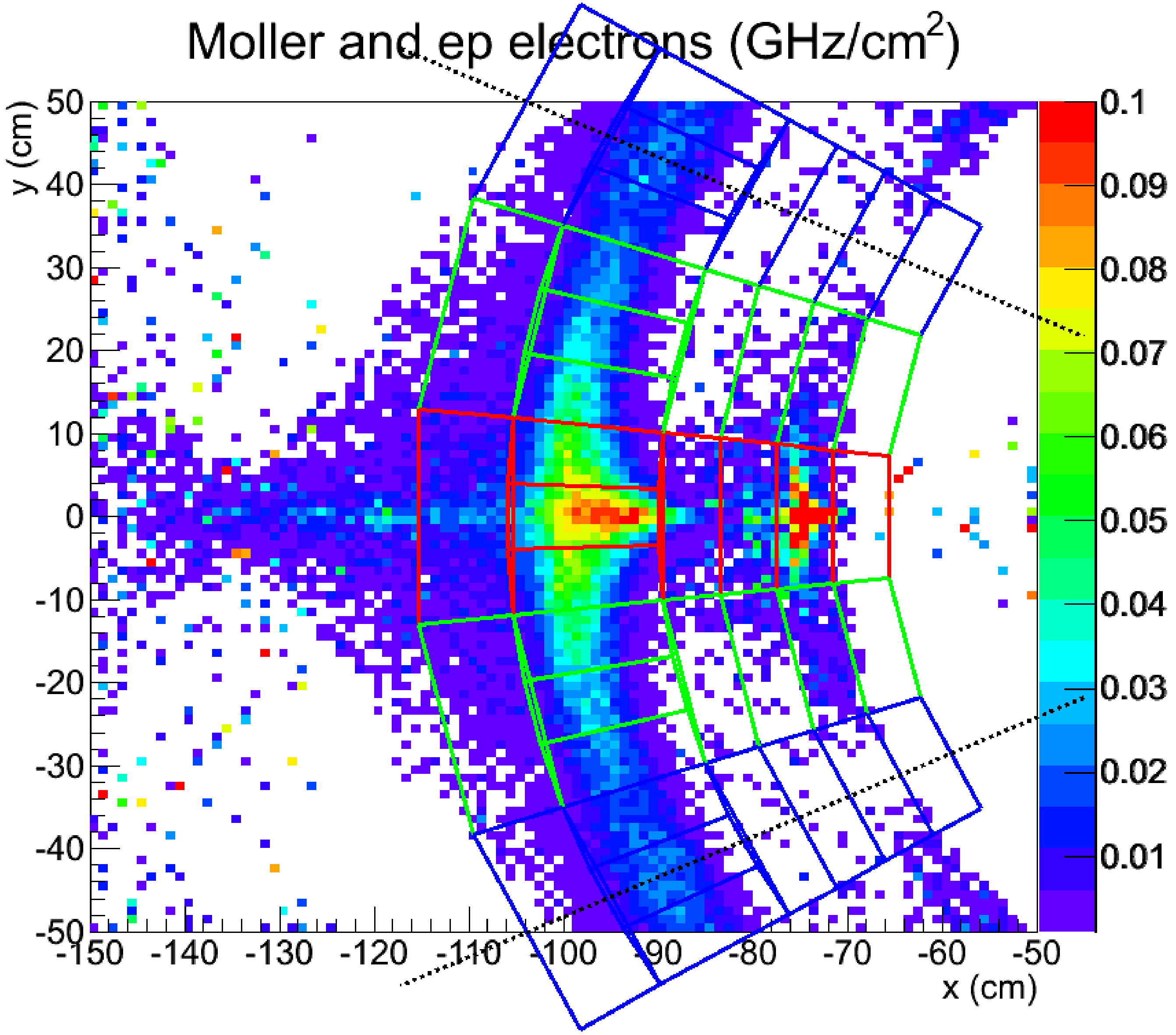


Erler and Rojas

$\alpha = 0 \rightarrow E6\ models, \alpha \neq 0$ describes kinetic mixing

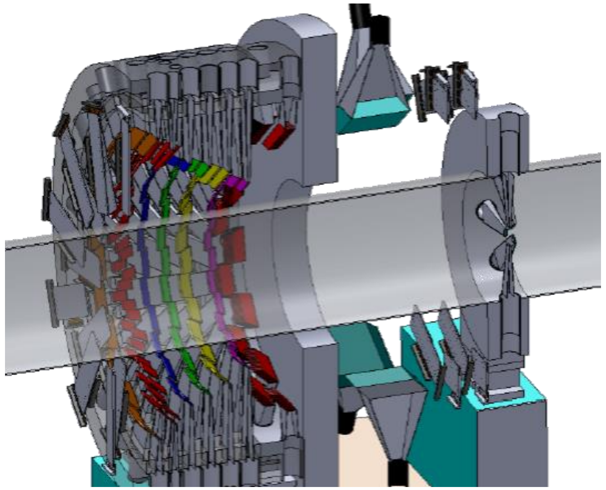
$\beta = 0 \rightarrow SO(10)(including\ those\ based\ on\ LR\ symmetry)$

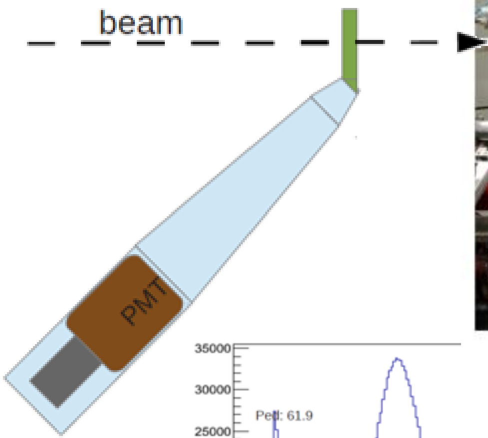
DETECTOR ARRAY

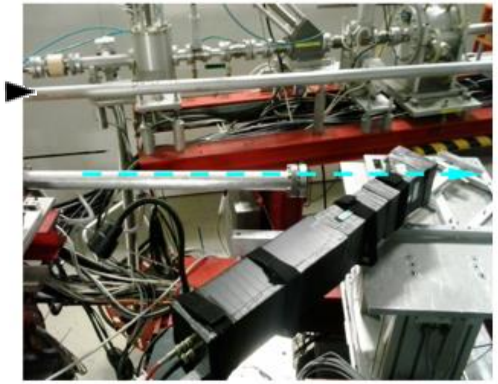


x (cm)

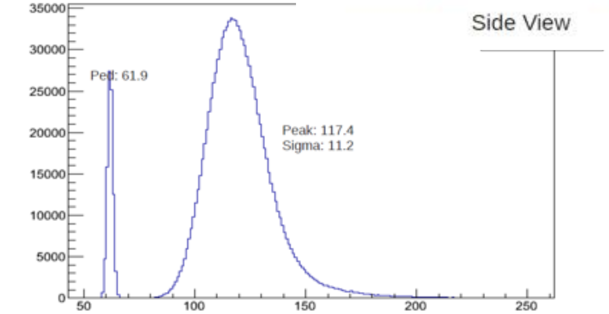
(Rate weighted 1x1cm^2 bins)







Side View



- Simulation expectation: 37 PE (for 1.5 cm thick quartz)
  25 PE (for 1.0 cm thick quartz)
  (ref. p.21, DocDB#76-v1)