From deep inside to outer space: exploring neutron skins

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on Nuclear Physics
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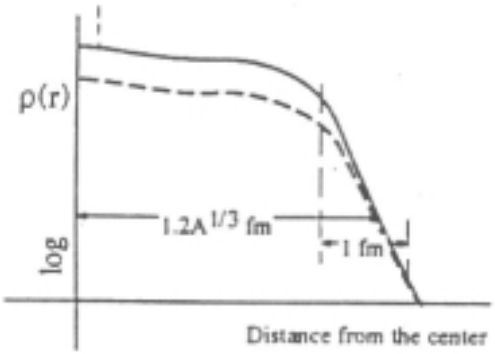
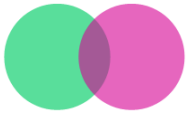
JG|U SFB 1044 PRISMA

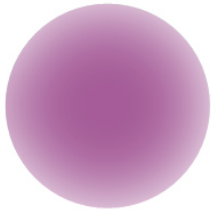
short reminder

stable nuclei





neutron proton



short reminder

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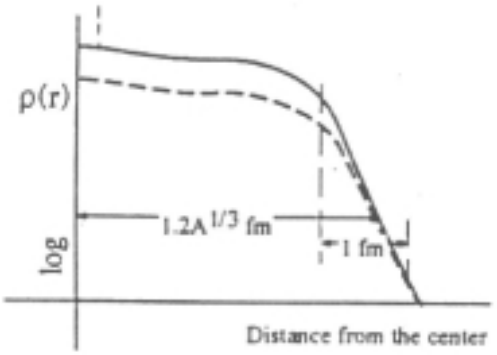
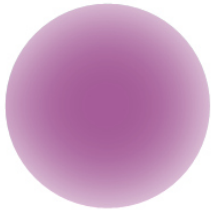
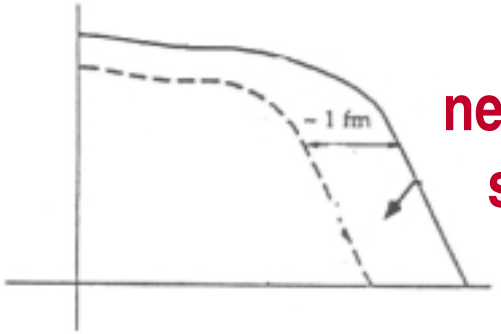




neutron rich nuclei



neutron skin

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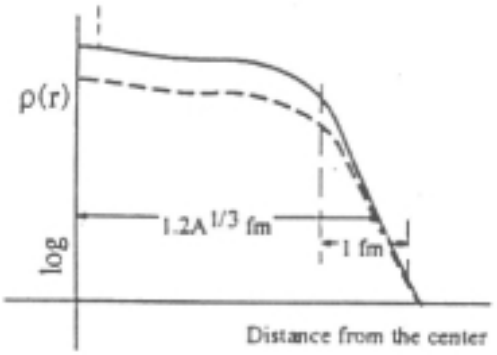

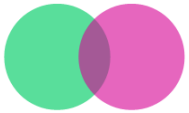

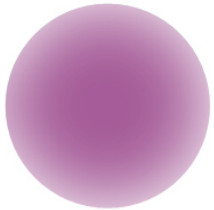

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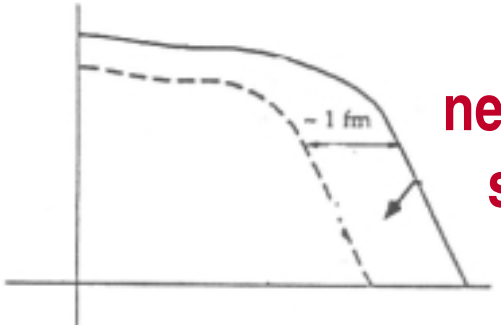

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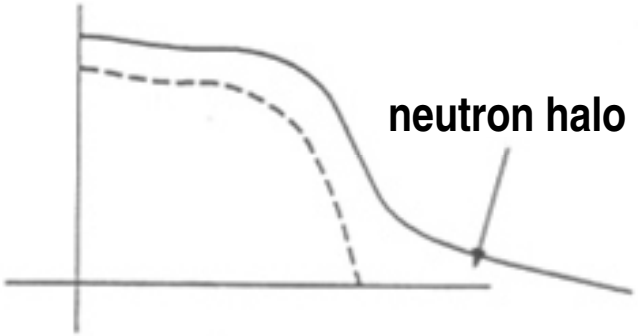

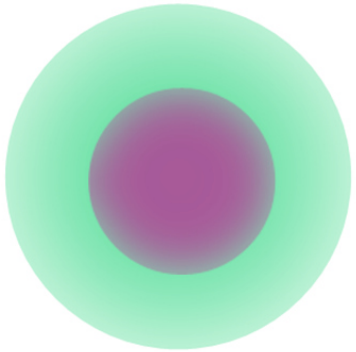

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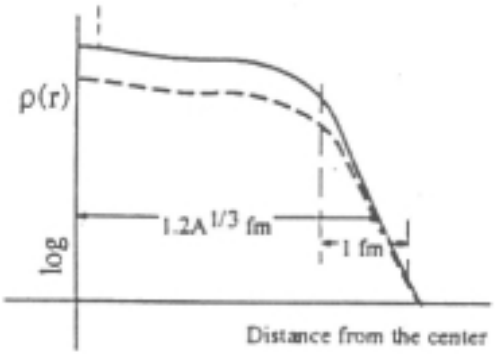

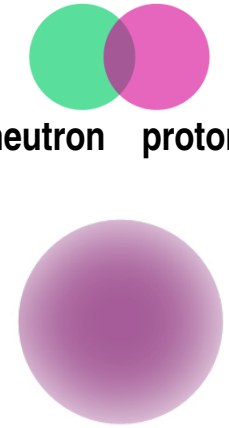

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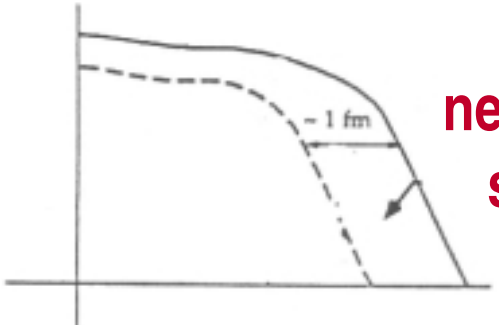

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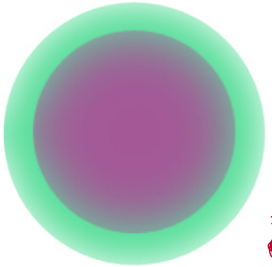
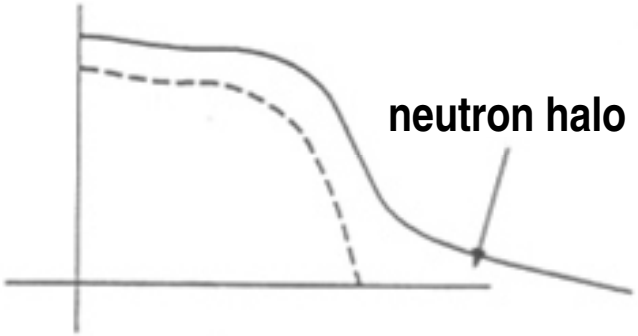
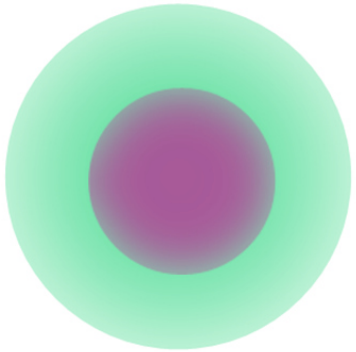
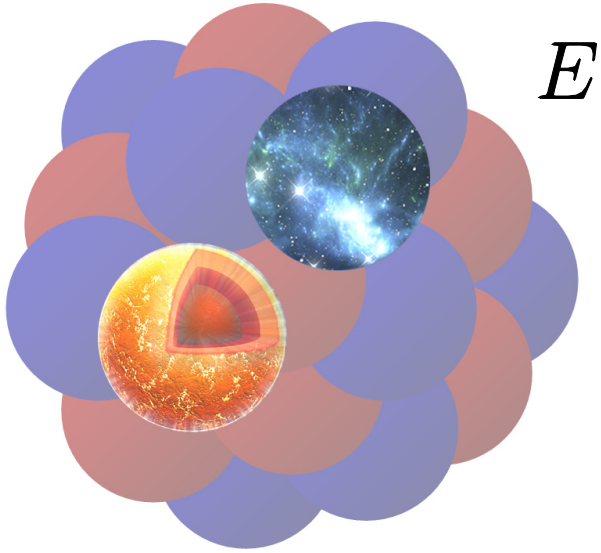


pressure forces neutrons out against surface tension





Equation Of State



$$E(\rho,\delta) = E(\rho,0) + E_{sym}(\rho)\,\delta^2 + \mathcal{O}(\delta)^4$$

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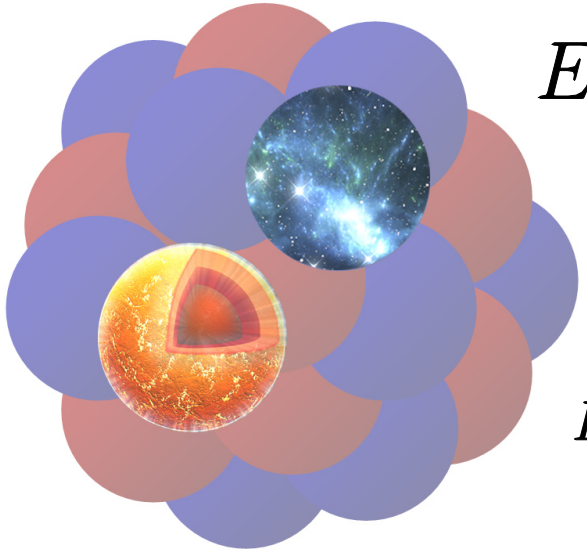

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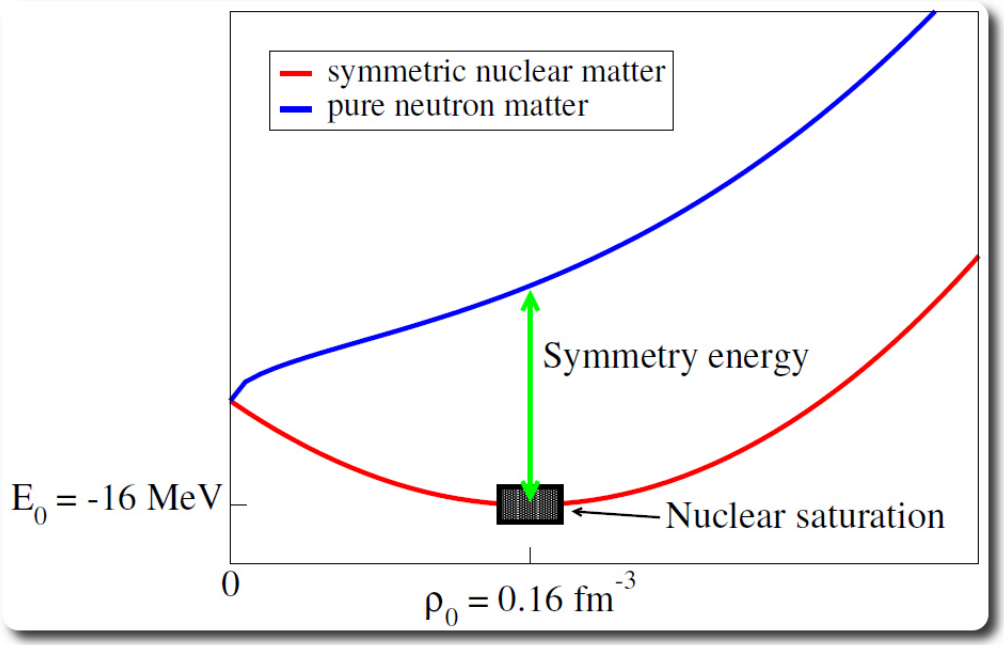
symmetry energy

$$E_{sym}(\rho) = \left[S_v + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2\right] + \ldots$$



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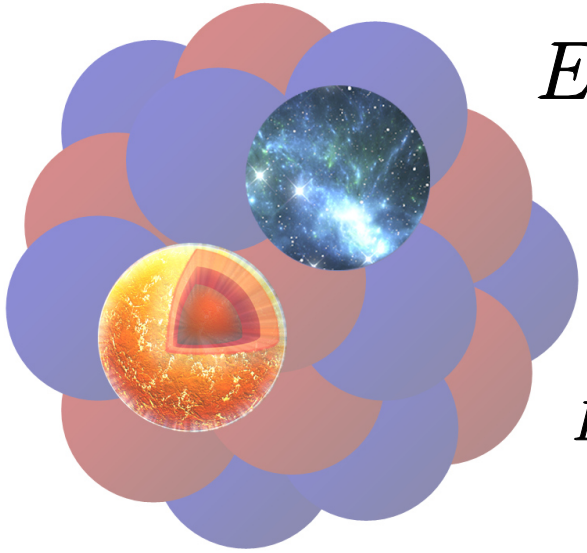

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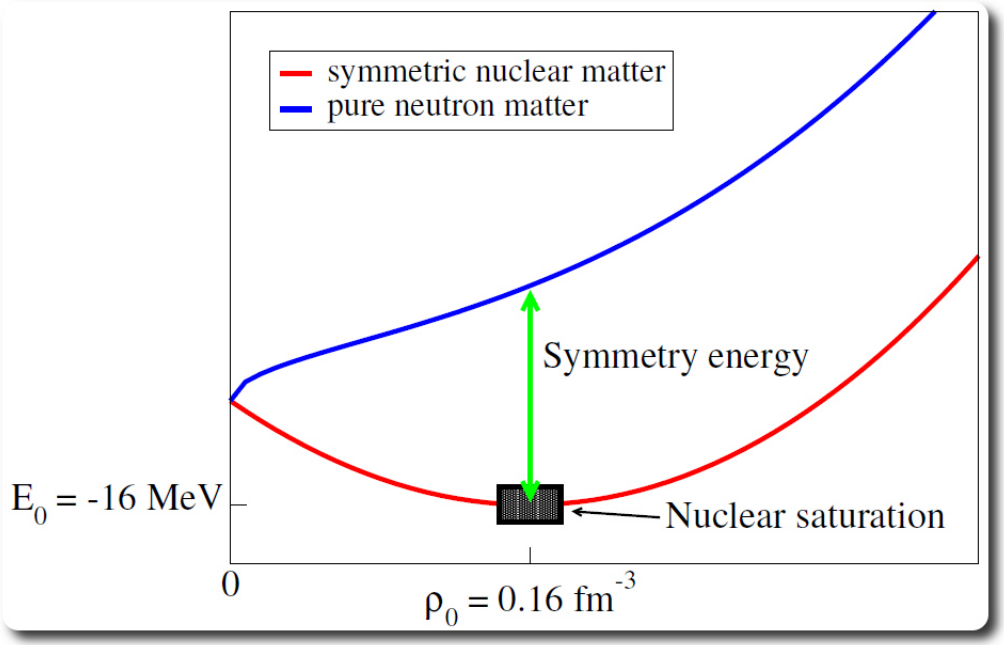
$$L = 3\rho_0 \left.\frac{\partial E_{sym}(\rho)}{\partial \rho}\right|_{\rho_0}$$

curvature parameter

$$K_{sym} = 9\rho_0^2 \left.\frac{\partial^2 E_{sym}(\rho)}{\partial \rho^2}\right|_{\rho_0}$$



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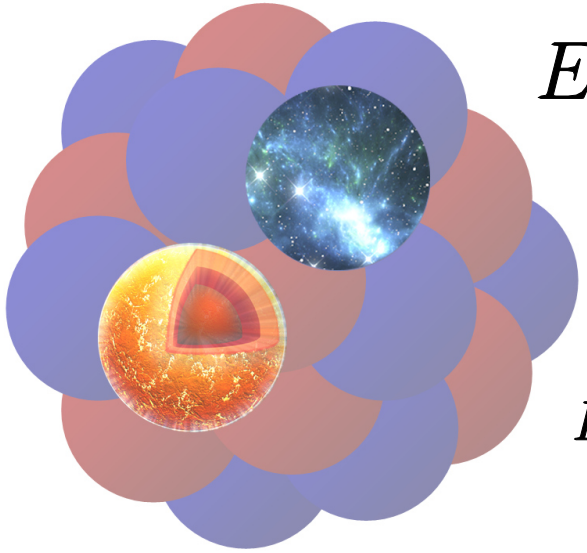

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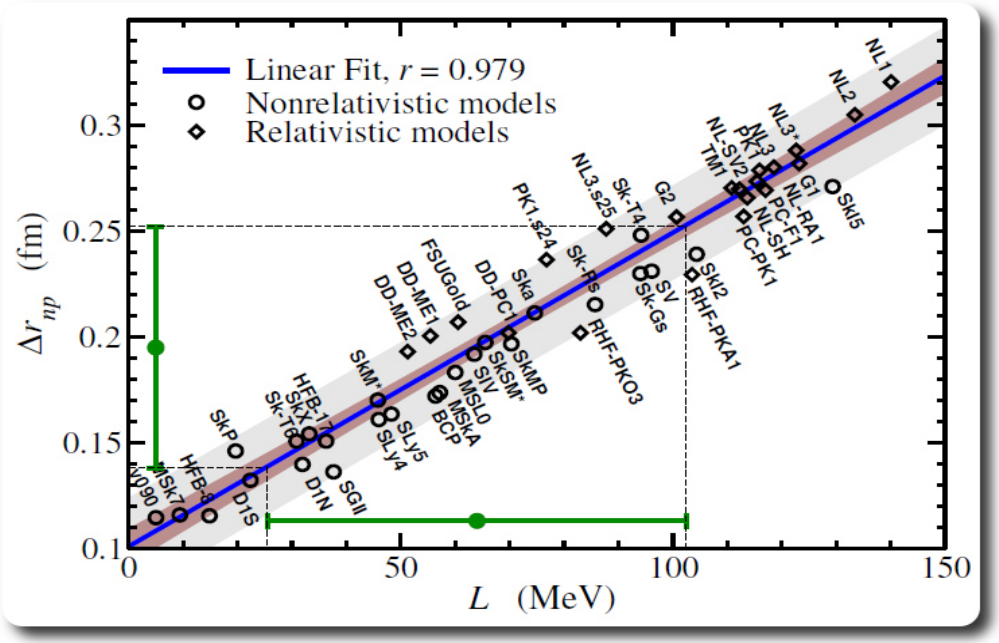
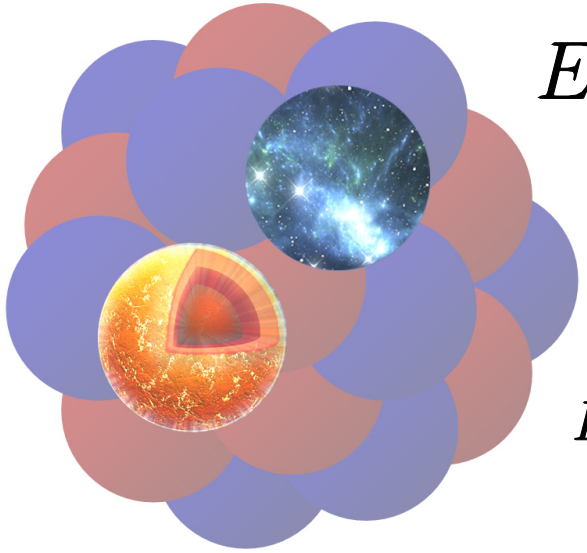


X. Roca-Maza et al., PRL 106 (2011) 252501

Equation Of State



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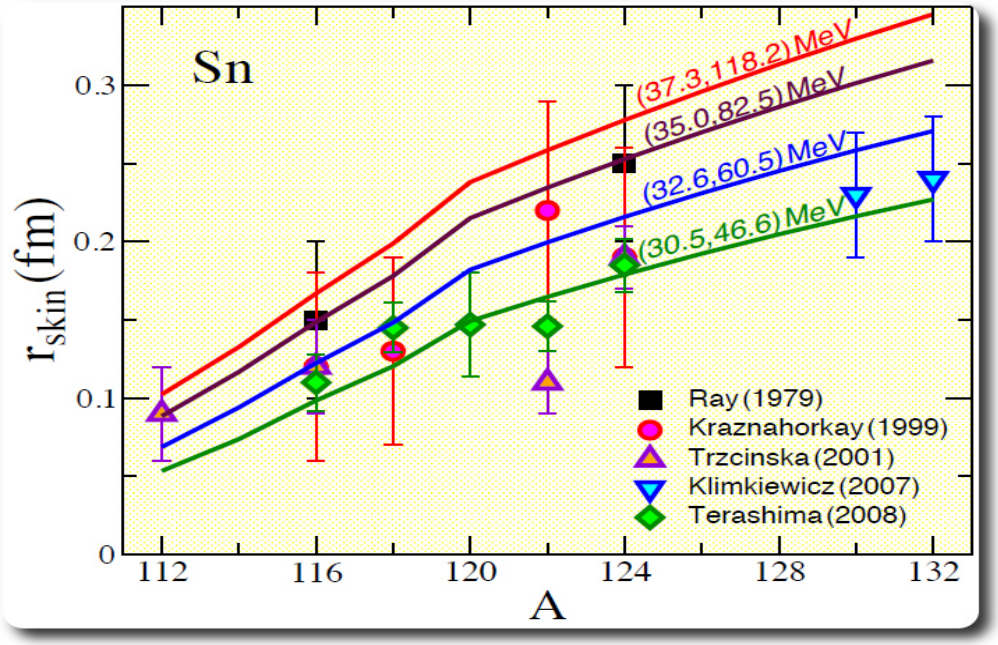
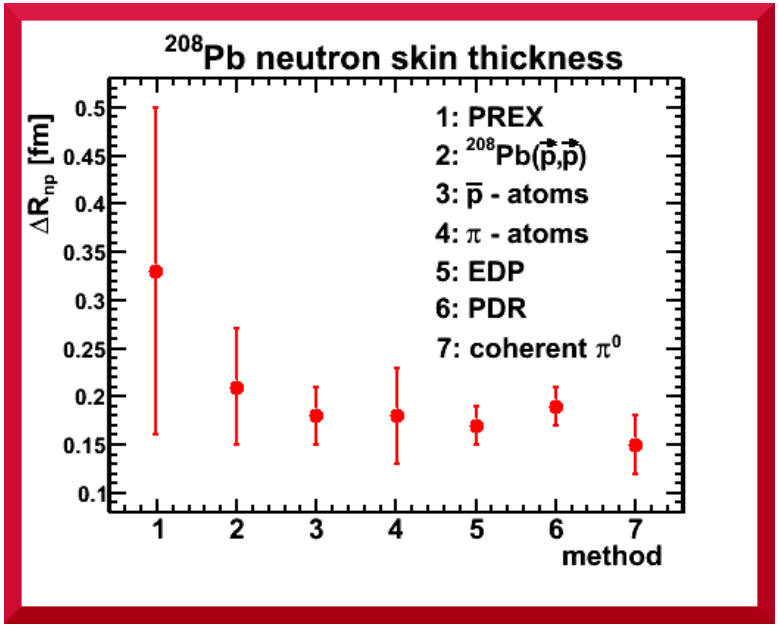


J. Piekarewicz, ICNT2013

state of affairs

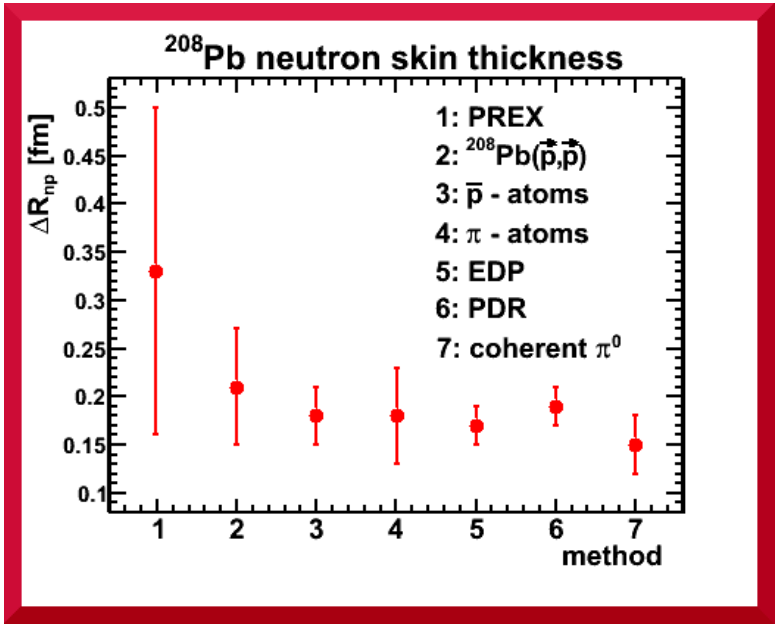


diverse experiments
but consistent results

are model dependeces clearly understood?

ultimate accuracy: ±0.03 fm?

state of affairs



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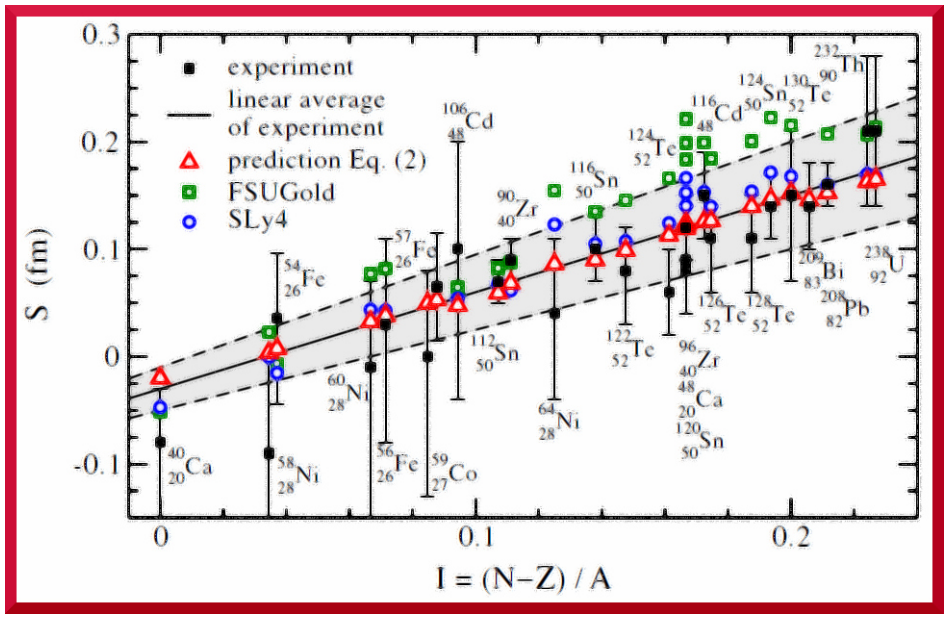
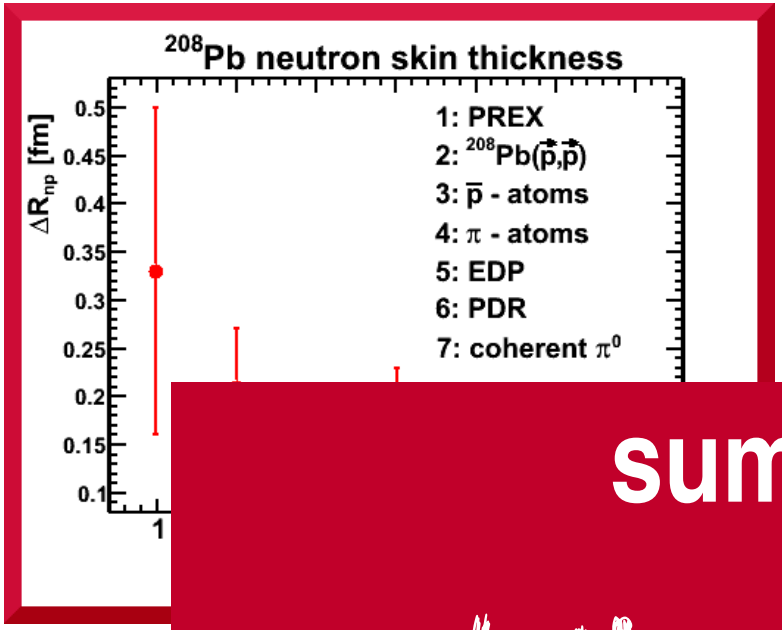
evolution along isotop chain

sensitive to S_v and L



M. Centelles et al., PRL 102 (2009) 122502

state of affairs



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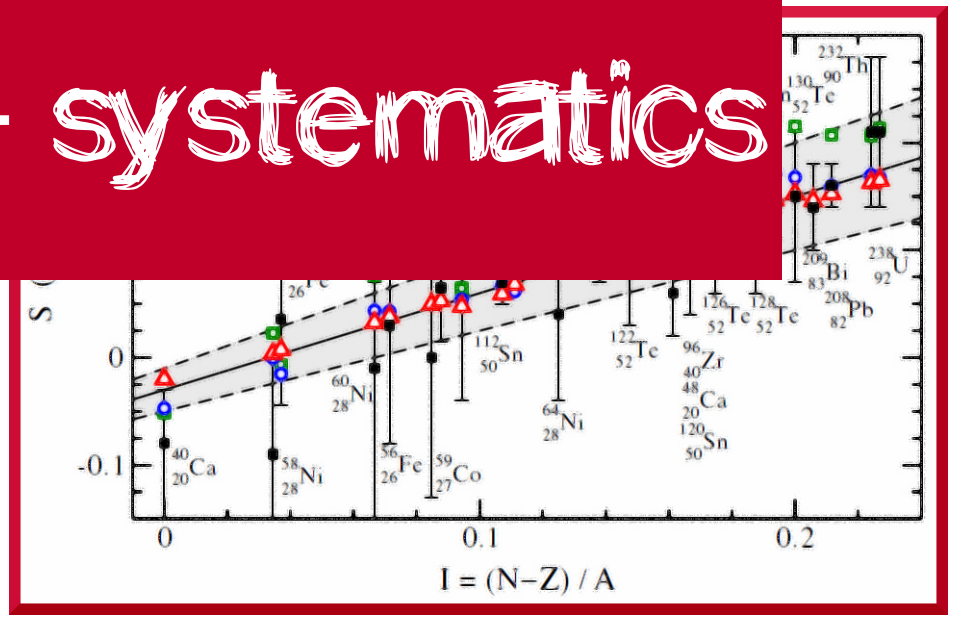
summing up:

resolution + systematics

n?

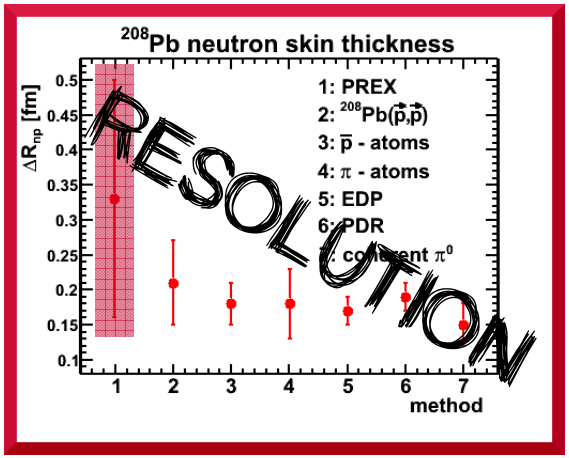
evolution along isotop chain

sensitive to S_v and L

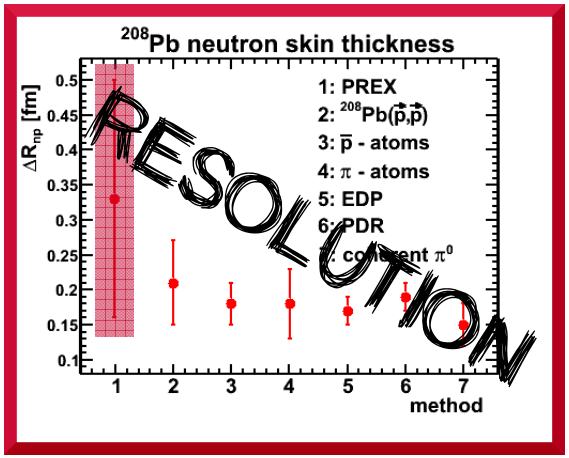


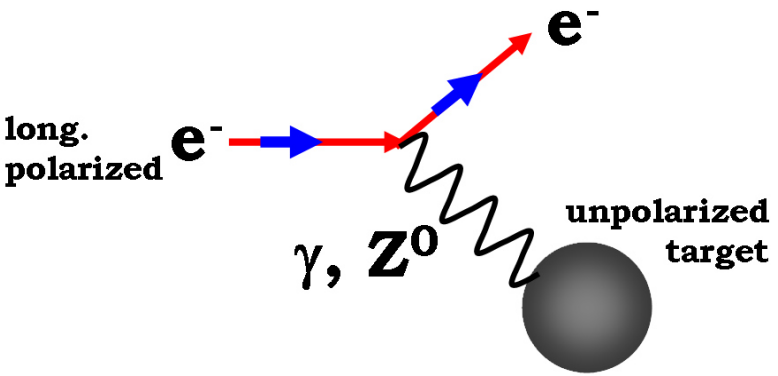
M. Centelles et al., PRL 102 (2009) 122502

least model dependent method: PV e^- scattering



least model dependent method: PV e⁻ scattering





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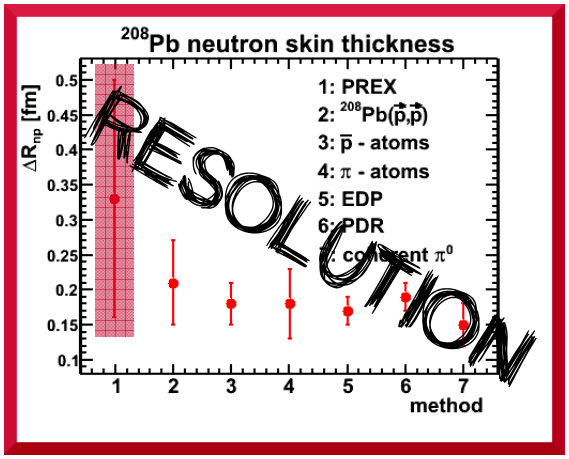

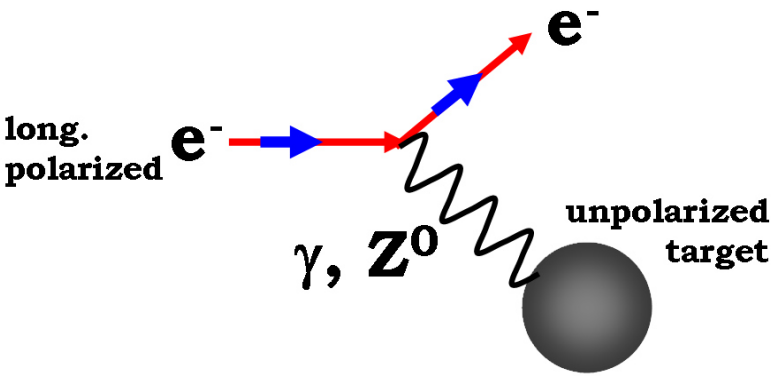

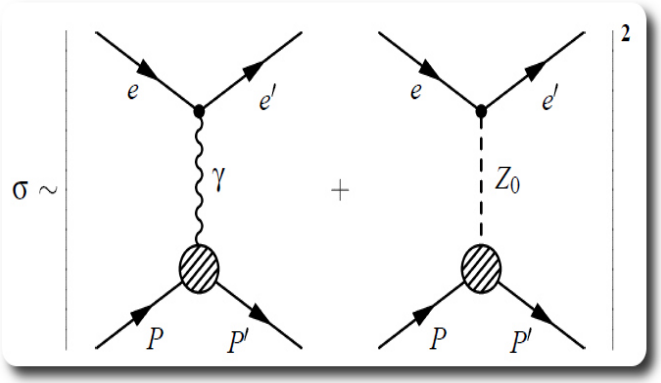

$$\sigma \propto |\mathcal{M}_\gamma|^2 + 2\,|\mathcal{M}_\gamma \mathcal{M}_{Z^0}| + |\mathcal{M}_{Z^0}|^2$$

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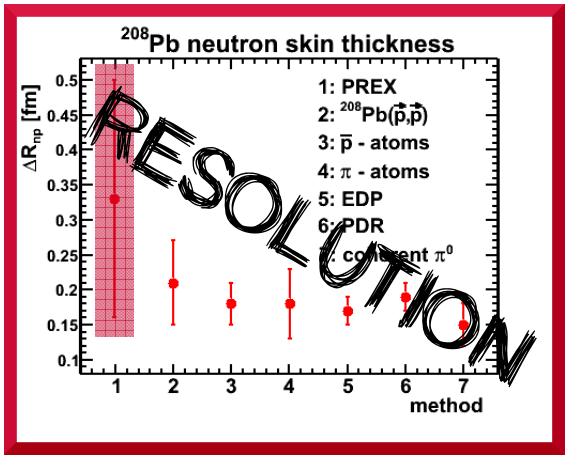

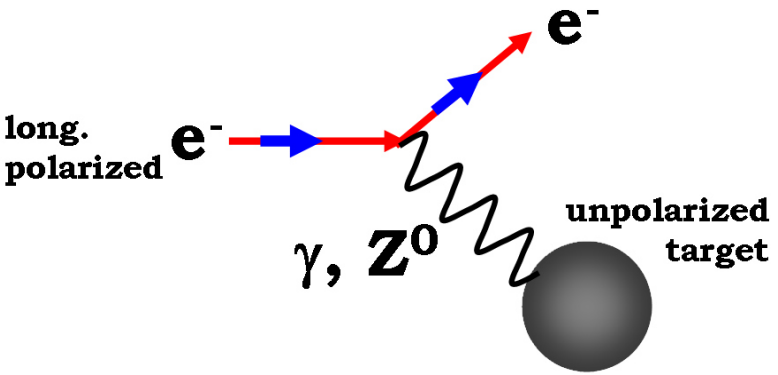

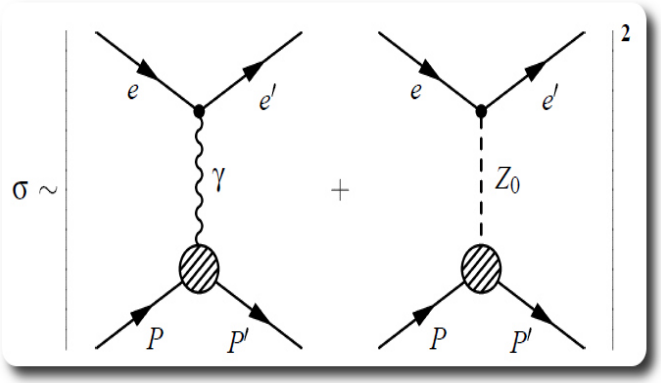

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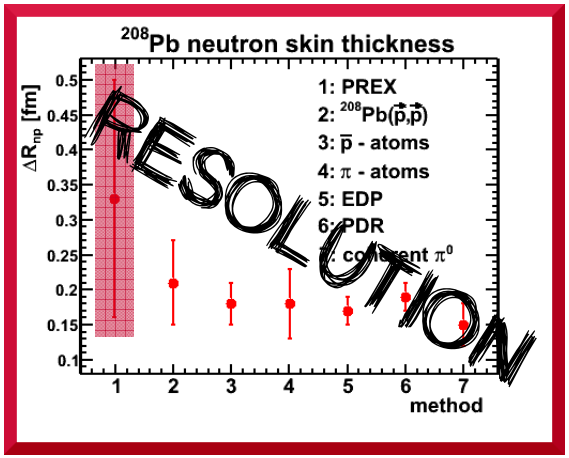

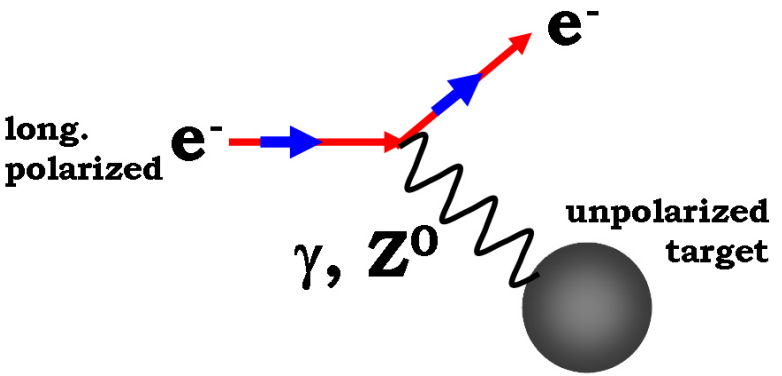

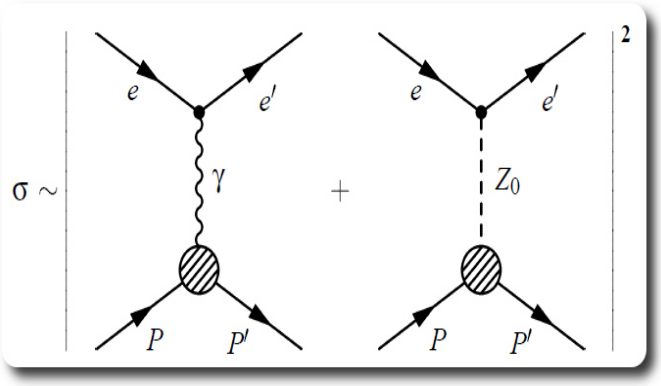

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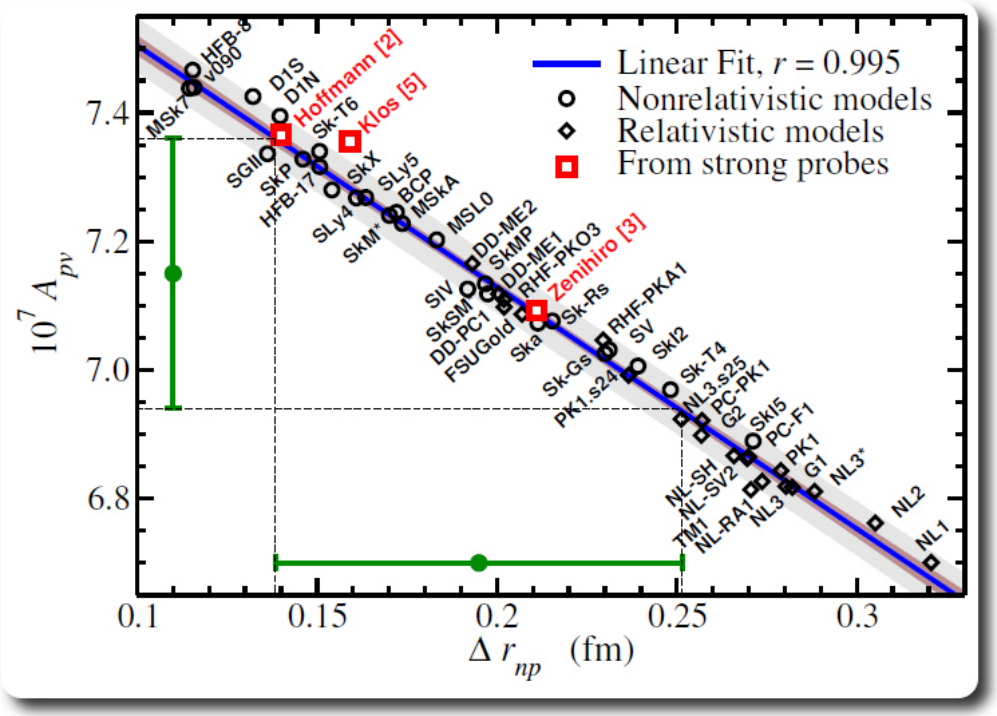

X. Roca-Maza et al., PRL 106 (2011) 252501

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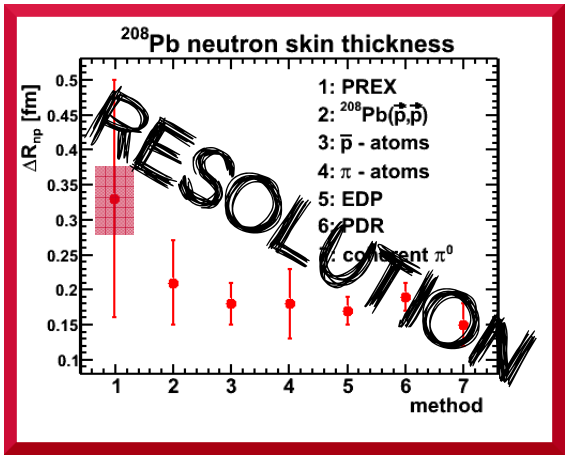

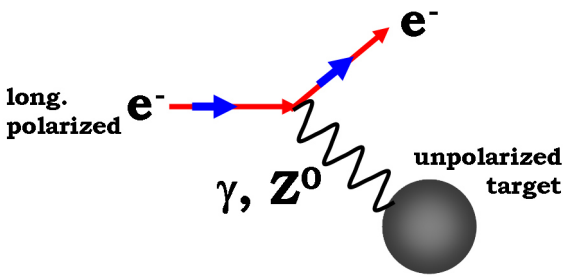

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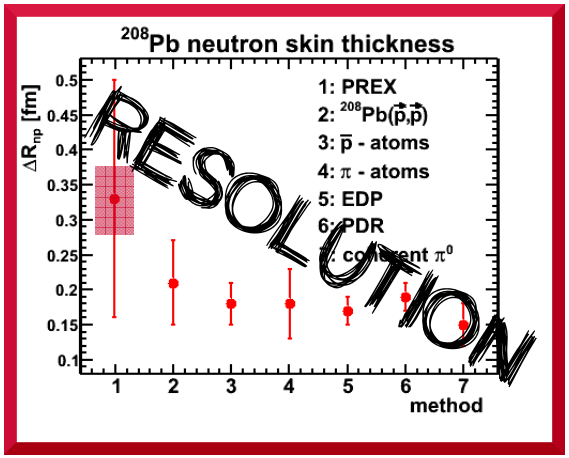
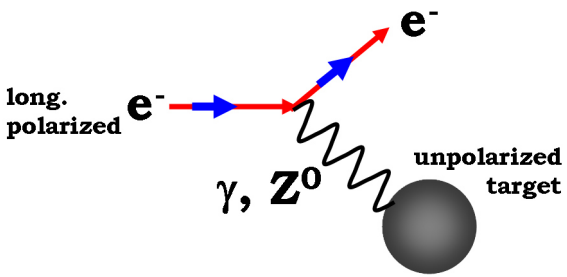


Proposal to Jefferson Lab PAC 38

APPROVED

PREX-II: PRECISION PARITY-VIOLATING MEASUREMENT OF THE NEUTRON SKIN OF LEAD



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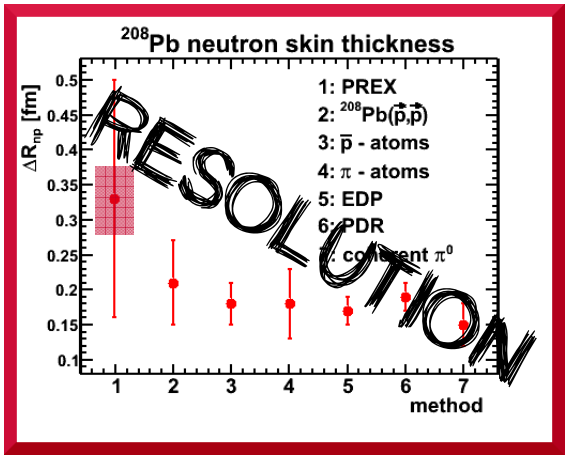

Proposal to Jefferson Lab PAC 38

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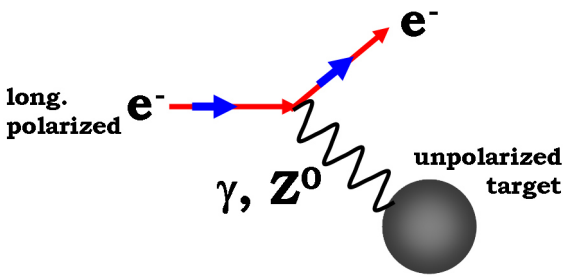
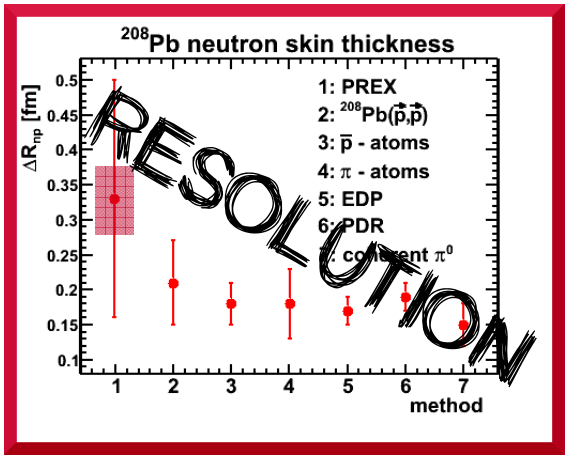
Proposal to Jefferson Lab PAC 40

CREX: PARITY-VIOLATING MEASUREMENT of the WEAK CHARGE DISTRIBUTION of ^{48}Ca to 0.02 fm ACCURACY

APPROVED



least model dependent method: PV e⁻ scattering



Proposal to Jefferson Lab PAC 38

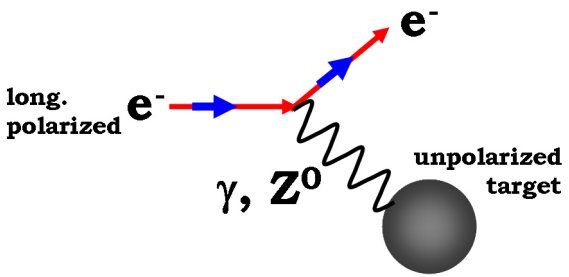
PREX-II: PRECISION PARITY-VIOLATING MEASUREMENT OF THE NEUTRON SKIN OF LEAD

APPROVED

Proposal to Jefferson Lab PAC 40

CREX: PARITY-VIOLATING MEASUREMENT of the WEAK CHARGE DISTRIBUTION of ^{48}Ca to 0.02 fm ACCURACY

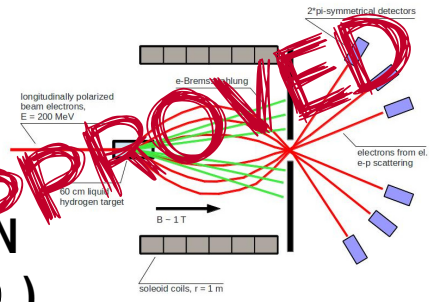
APPROVED



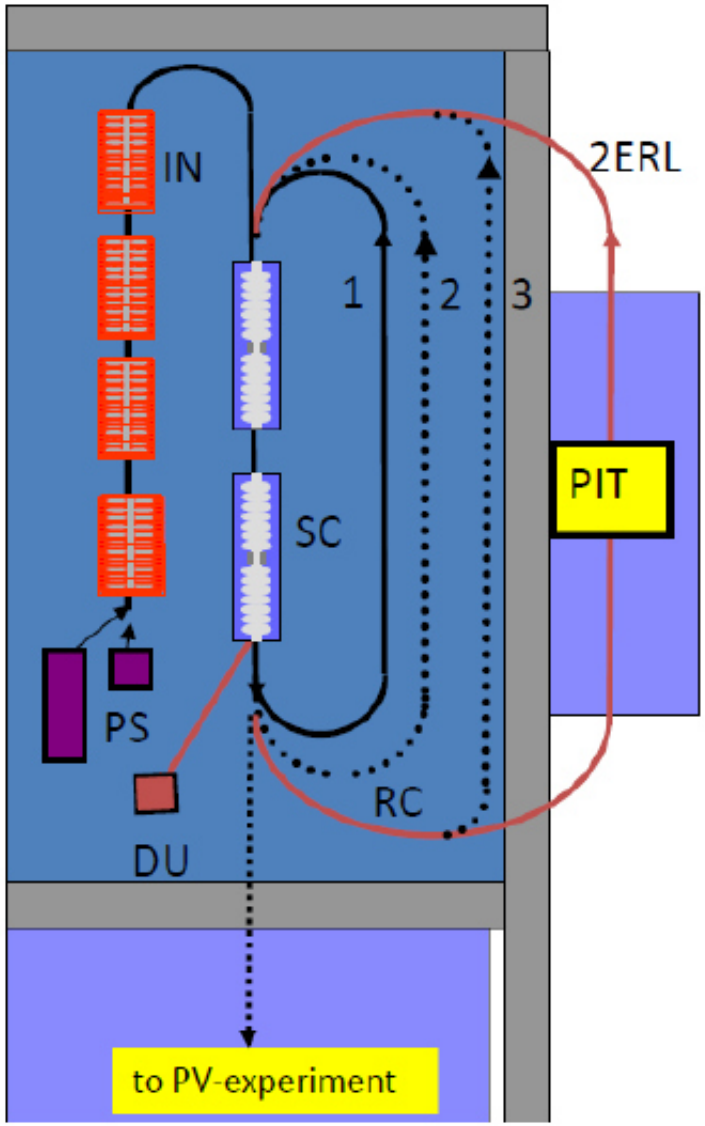
P2 @ MESA

A HIGH-PRECISION DETERMINATION OF THE WEAK MIXING ANGLE $\sin^2(\theta_W)$

APPROVED



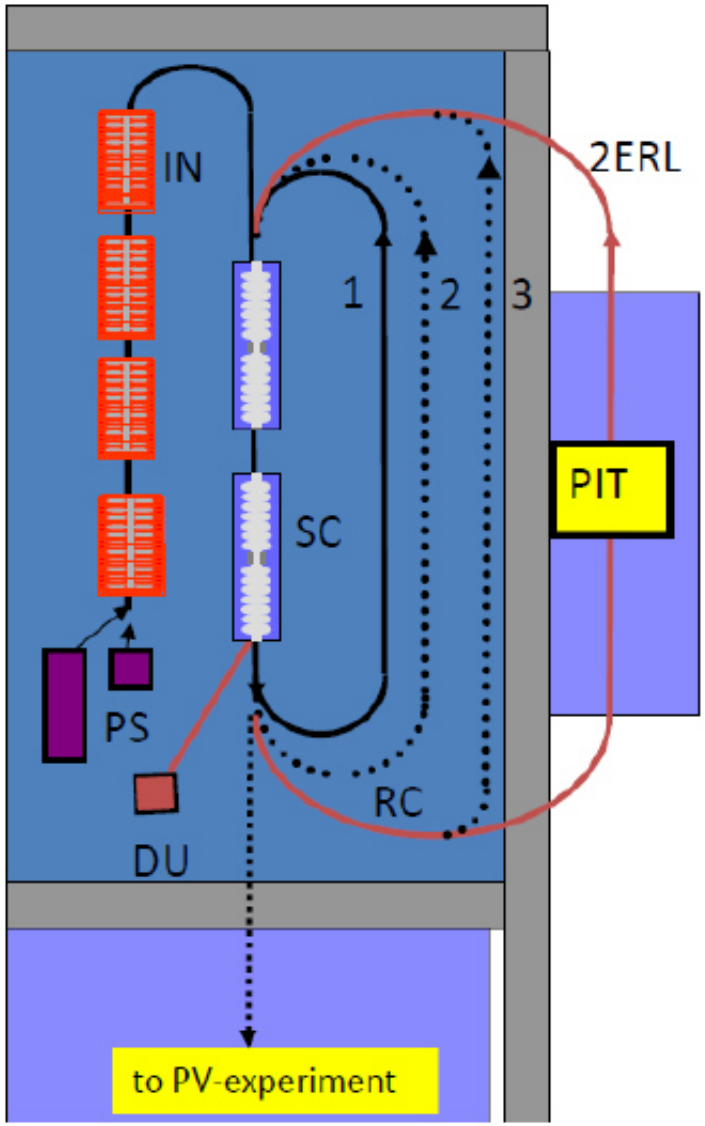
P2@MESA: go for ultimate precision



Mainz energy recovering superconducting accelerator

1.3 GHz c.w. beam
normal conducting injector LINAC
superconducting cavities in recirculation beamline

P2@MESA: go for ultimate precision



Mainz energy recovering superconducting accelerator

1.3 GHz c.w. beam
normal conducting injector LINAC
superconducting cavities in recirculation beamline

EB-mode (external beam):
150 MeV @ 300 μA (pol.)

ERL-mode (energy recovering mode):
100 MeV @ 10mA (unpol.)

P2@MESA: go for ultimate precision

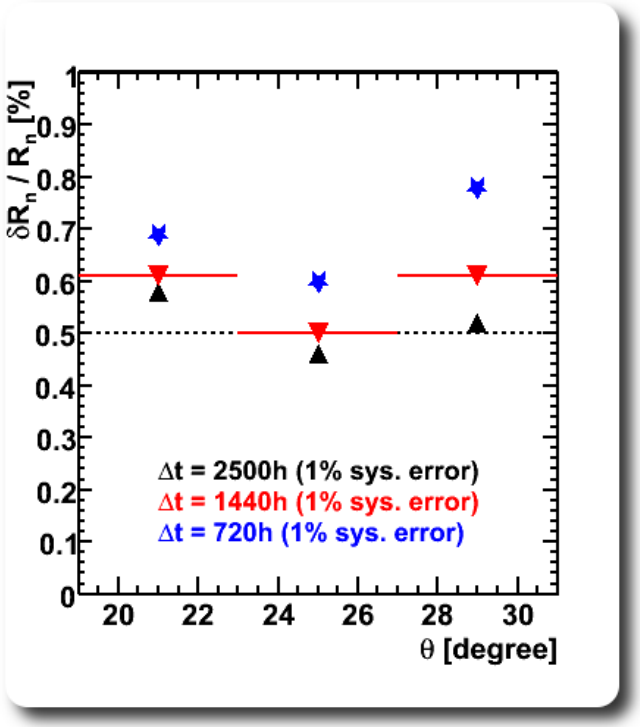
GOAL:

$dR_n/R_n \approx 0.5\%$

P2@MESA: go for ultimate precision

GOAL:

$dR_n/R_n \approx 0.5\%$

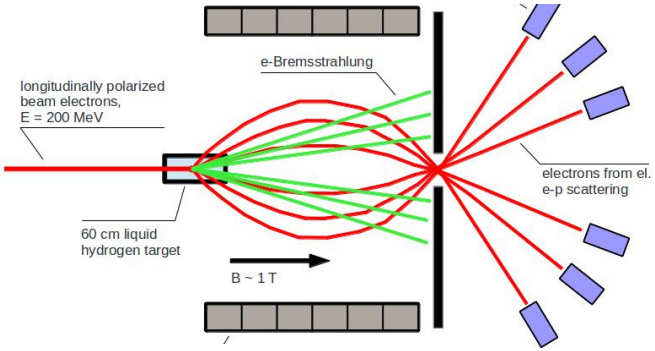


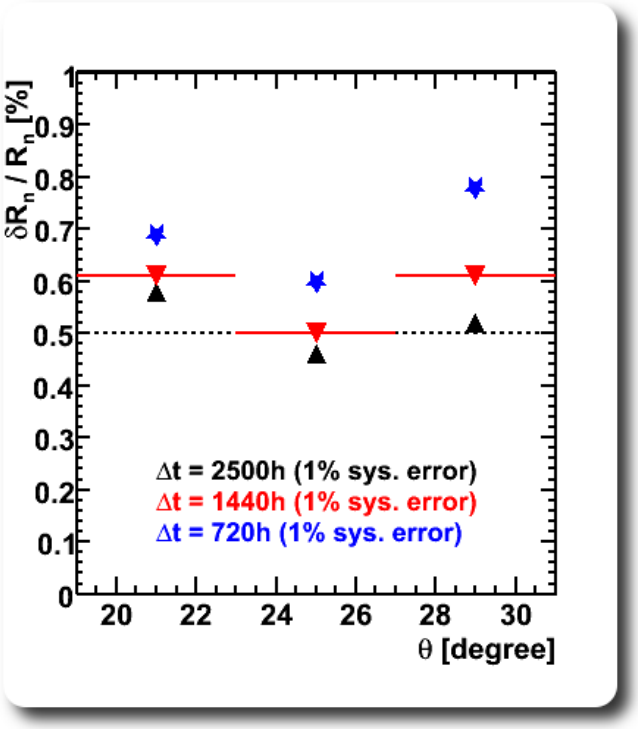
P2@MESA: go for ultimate precision

full azimuthal coverage (solenoid)

GOAL:

$dR_n/R_n \approx 0.5\%$





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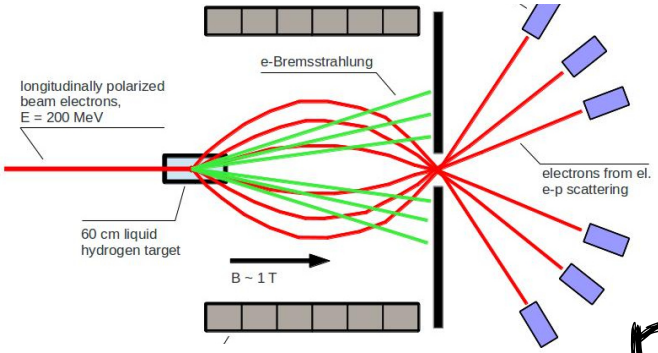
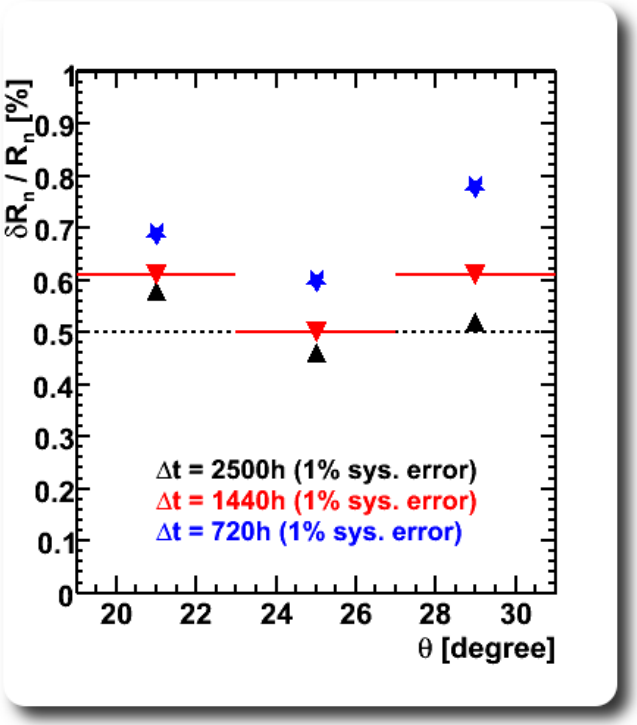
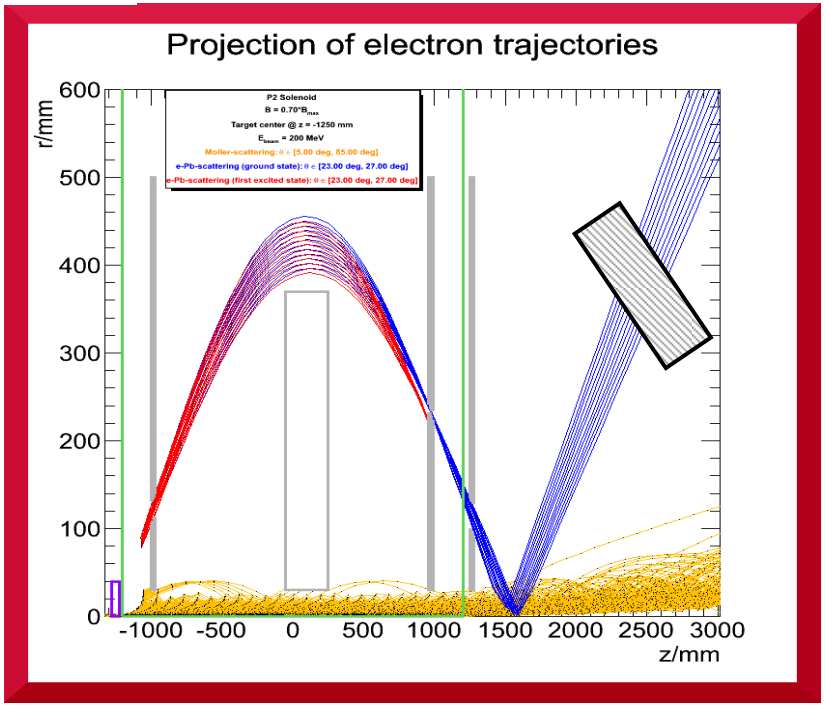


resolve elastic!

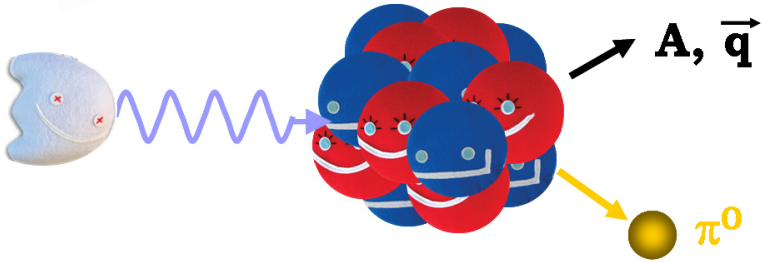




Dominik Becker

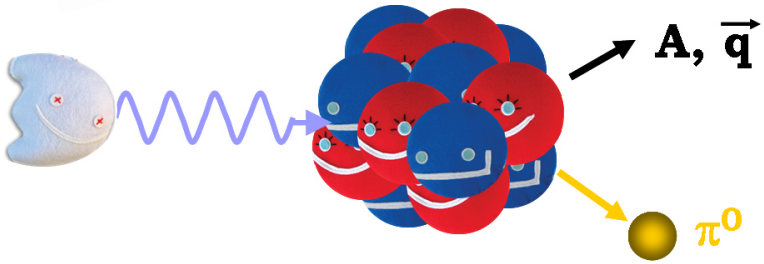
QaD method: coherent π^0 photoproduction

QaD method: coherent π^0 photoproduction

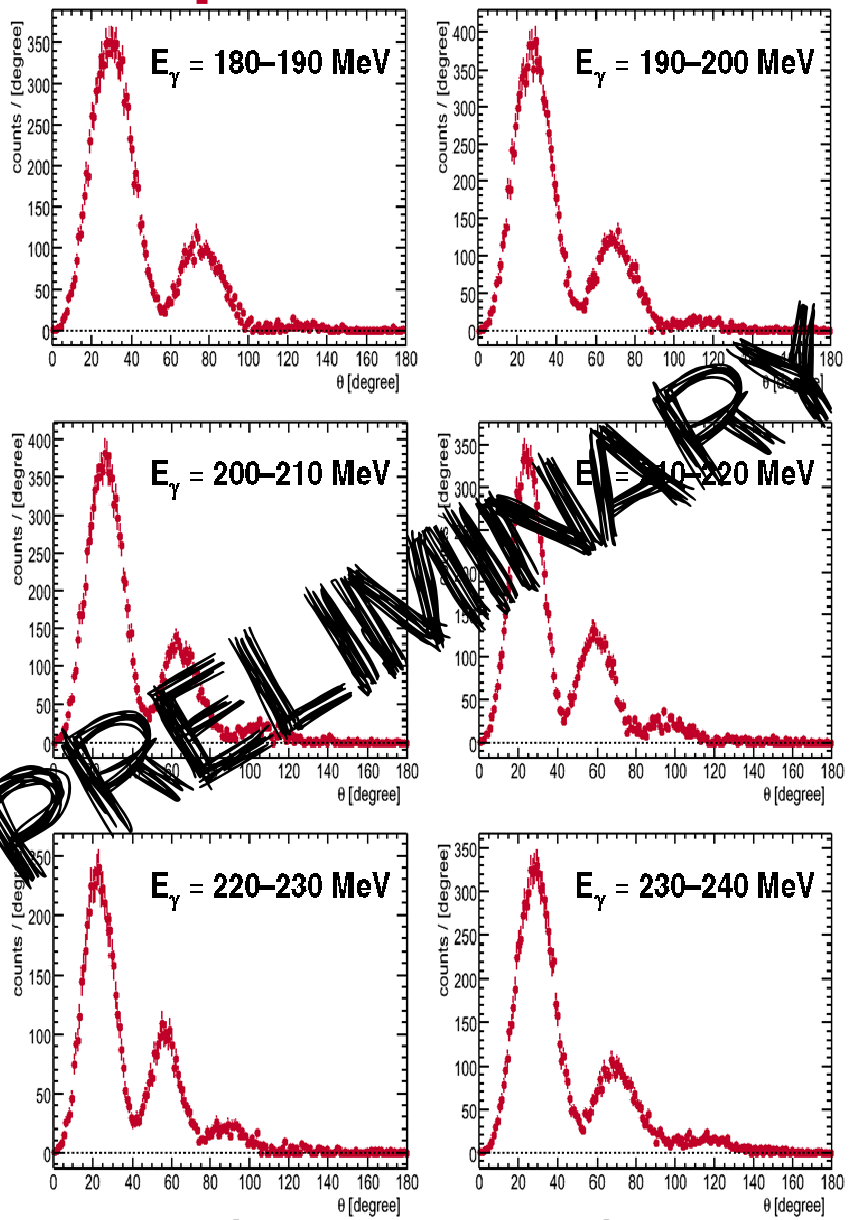


$$\gamma + A_{(g.s.)} \longrightarrow \pi^0 + A_{(g.s.)}$$
$$\hookrightarrow \gamma\gamma$$

QaD method: coherent π^0 photoproduction

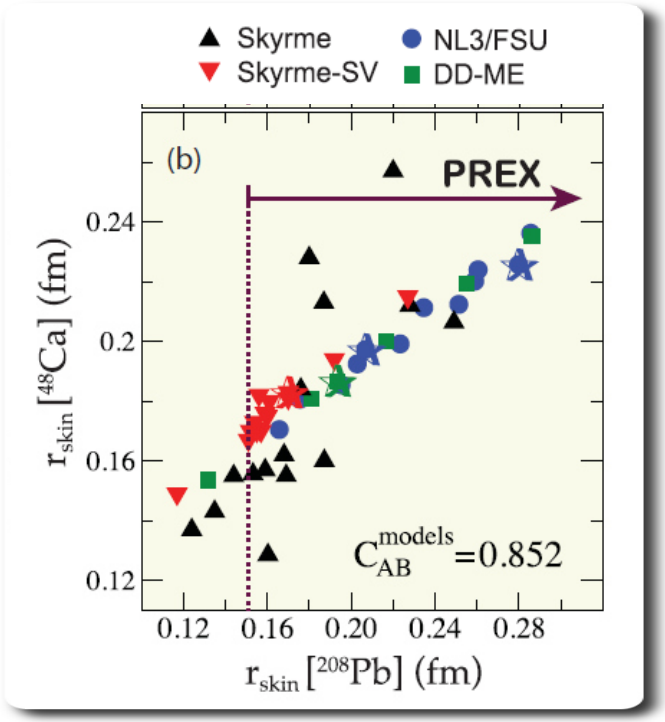


$$\gamma + A_{(g.s.)} \longrightarrow \pi^0 + A_{(g.s.)}$$
$$\hookrightarrow \gamma\gamma$$



more details: M. Isabel Ferretti

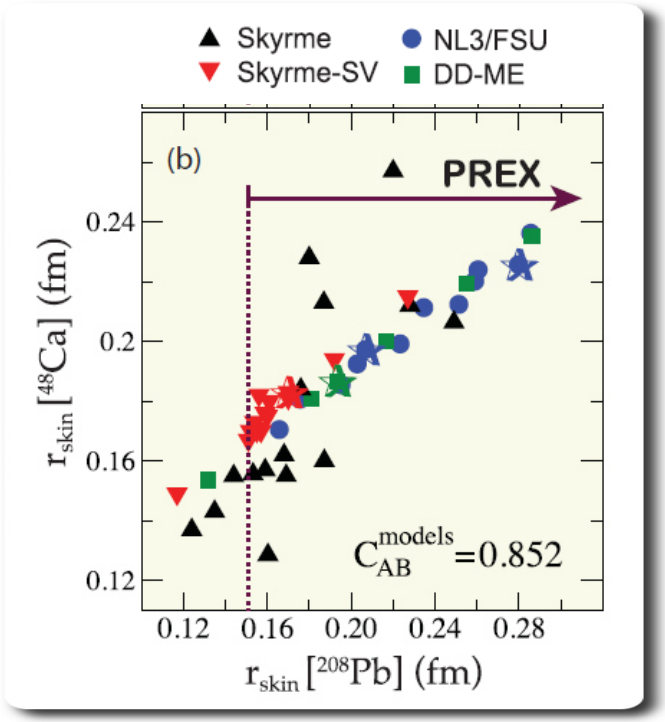
can we do something in addition?



J. Piekarewicz et al., Phys. Rev. C 85 (2012) 041302

^{48}Ca vs. ^{208}Pb

can we do something in addition?

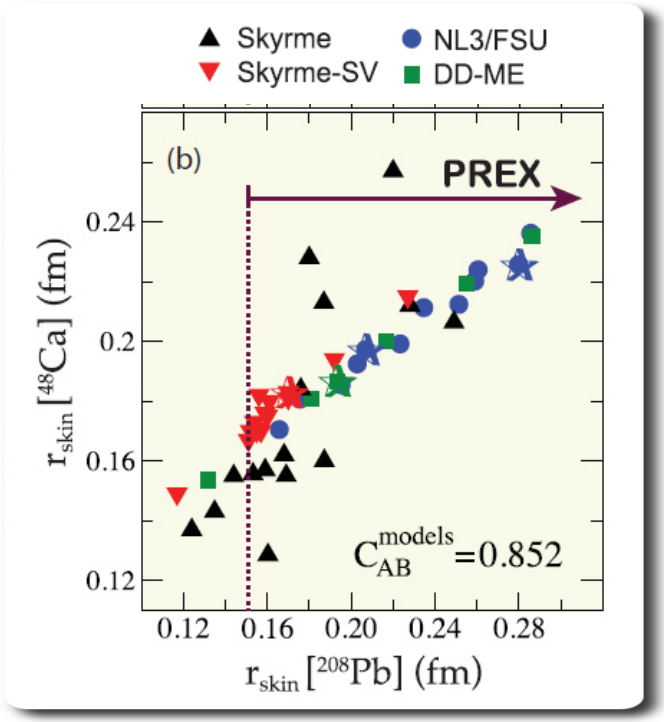


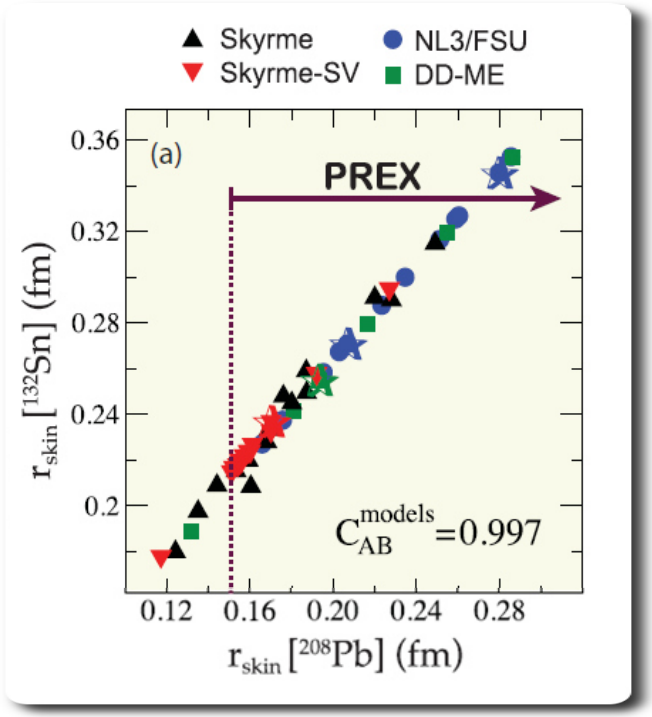
J. Piekarewicz et al., Phys. Rev. C 85 (2012) 041302

^{48}Ca vs. ^{208}Pb

CREX

can we do something in addition?





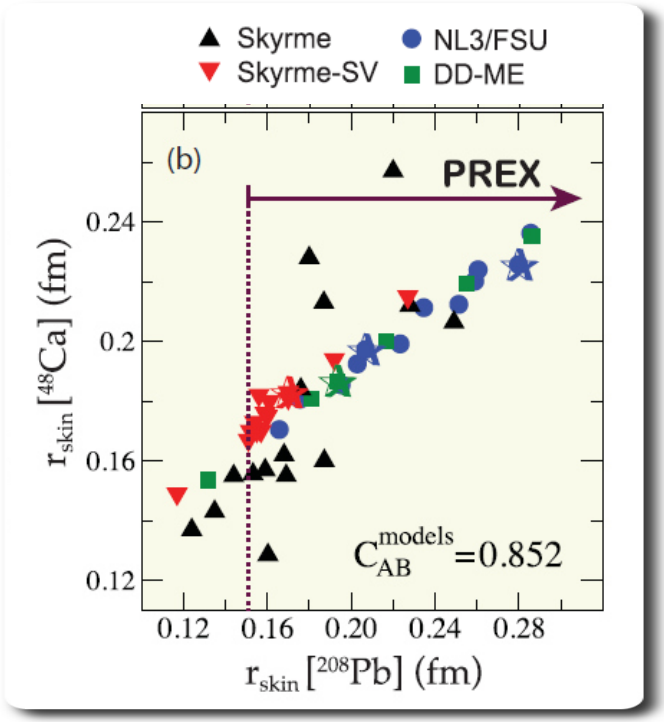
J. Piekarewicz et al., Phys. Rev. C 85 (2012) 041302

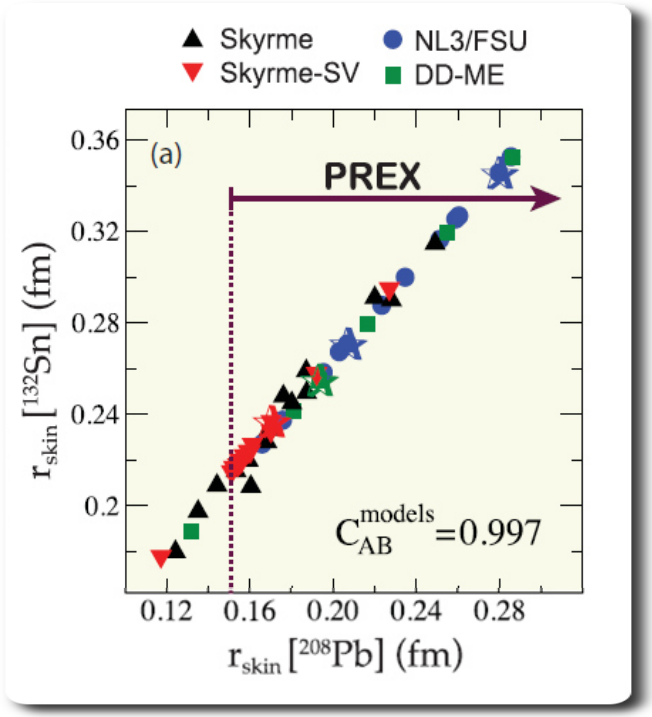
^{48}Ca vs. ^{208}Pb

^{132}Sn vs.^{208}Pb

CREX

can we do something in addition?





J. Piekarewicz et al., Phys. Rev. C 85 (2012) 041302

^{48}Ca vs. ^{208}Pb

CREX

^{132}Sn vs.^{208}Pb

better FOM at low energy!

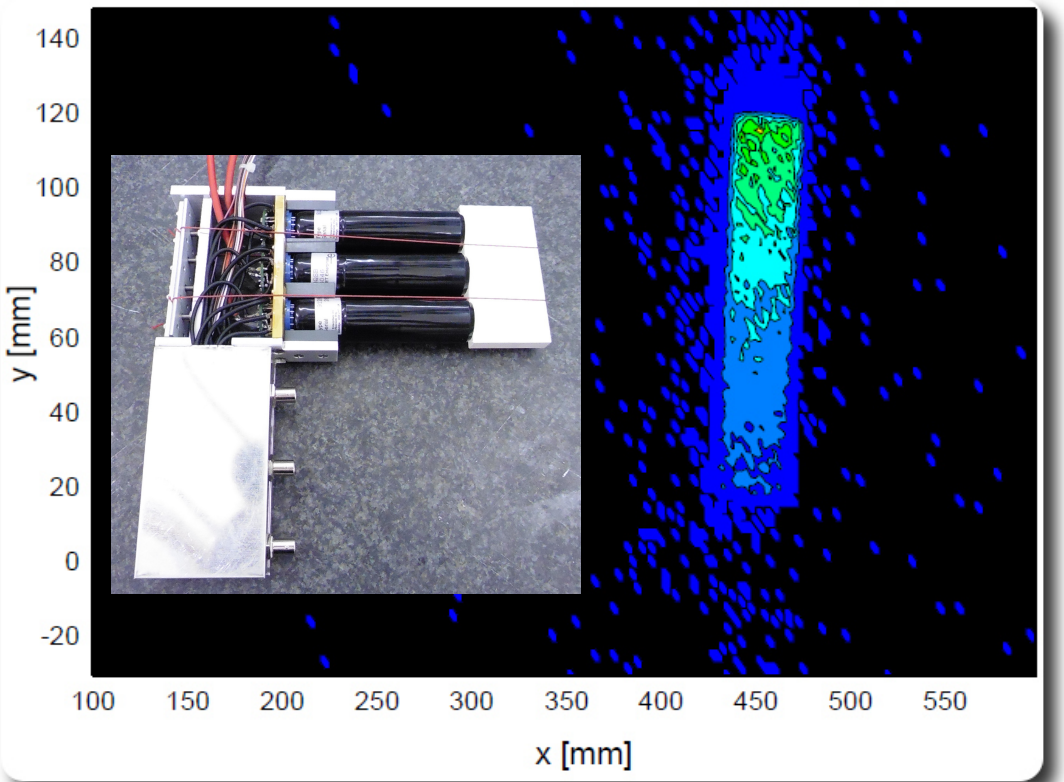
A1 @MAMI

A1@MAMI: intermezzo

Proof-of-principle:

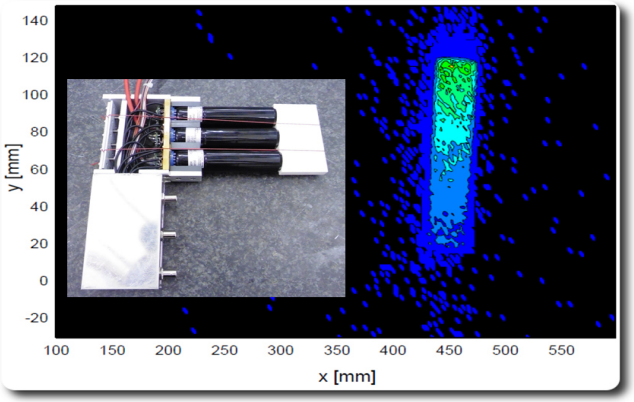
PVES ^{12}C

(commissioning 09/2014)



Alexey Tyukin

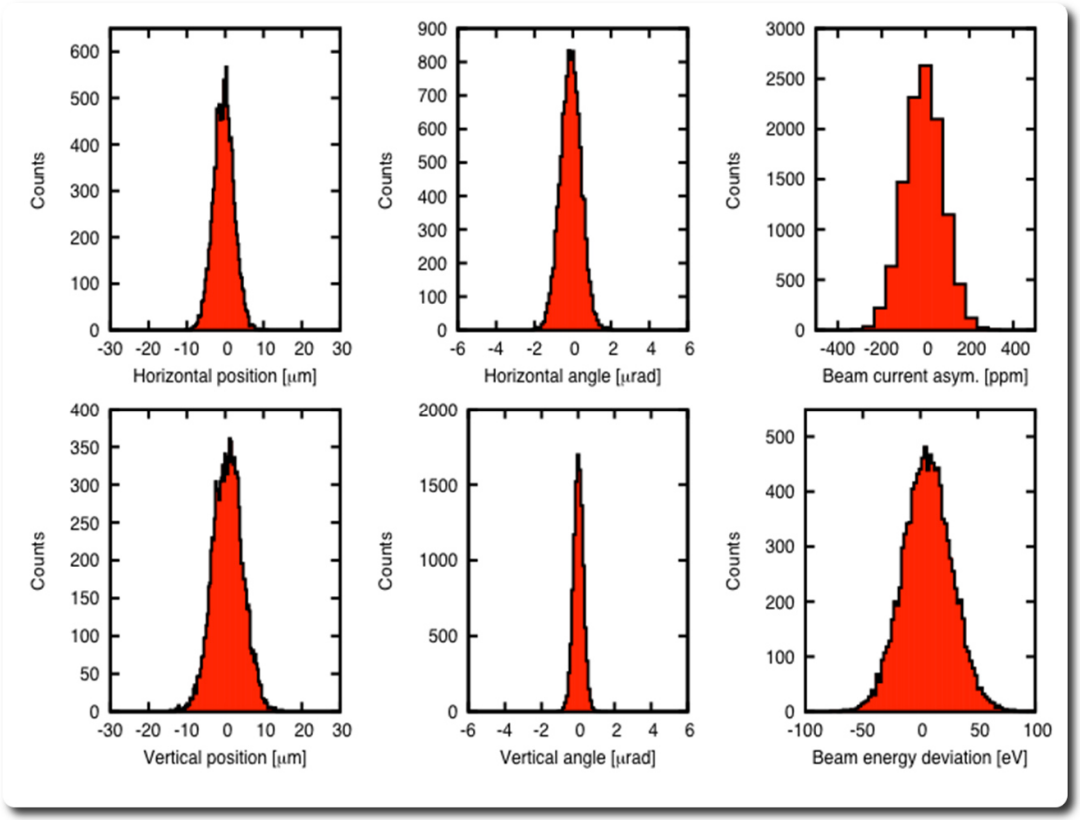
A1@MAMI: intermezzo



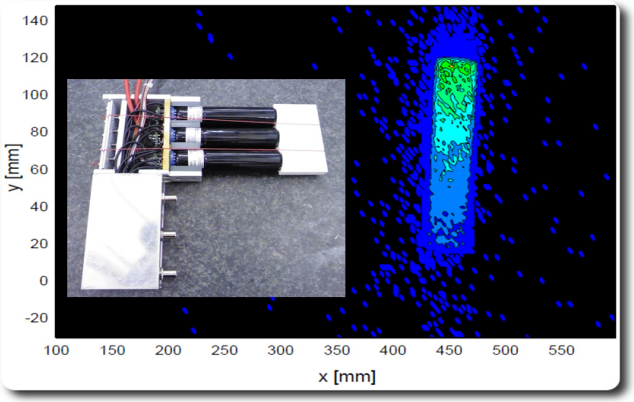
Proof-of-principle:

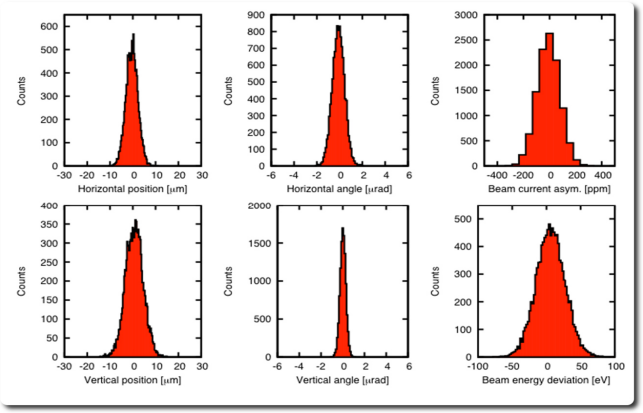
PVES ^{12}C

(commissioning 09/2014)



A1@MAMI: intermezzo





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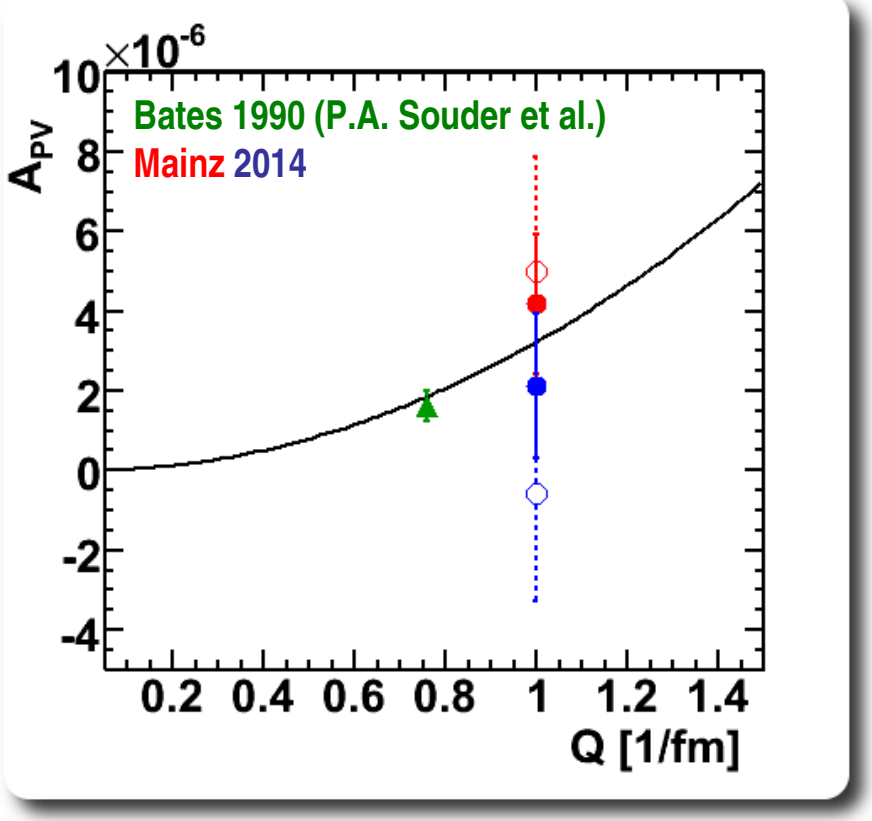
PVES ^{12}C

(commissioning 09/2014)



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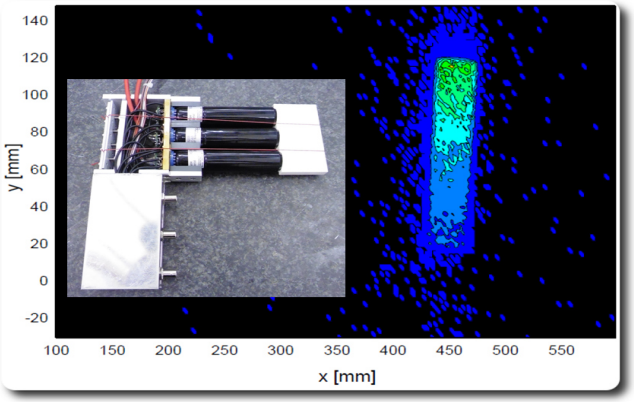
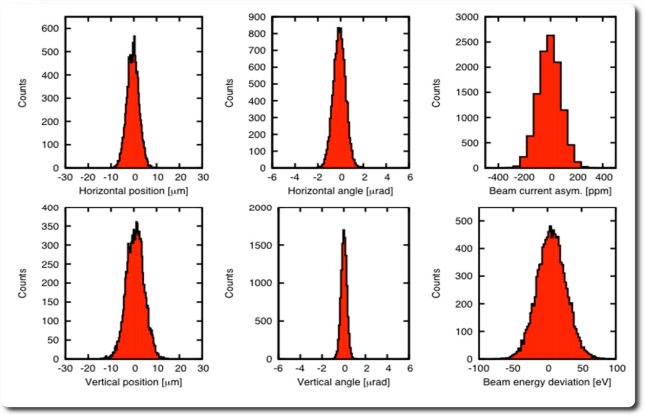
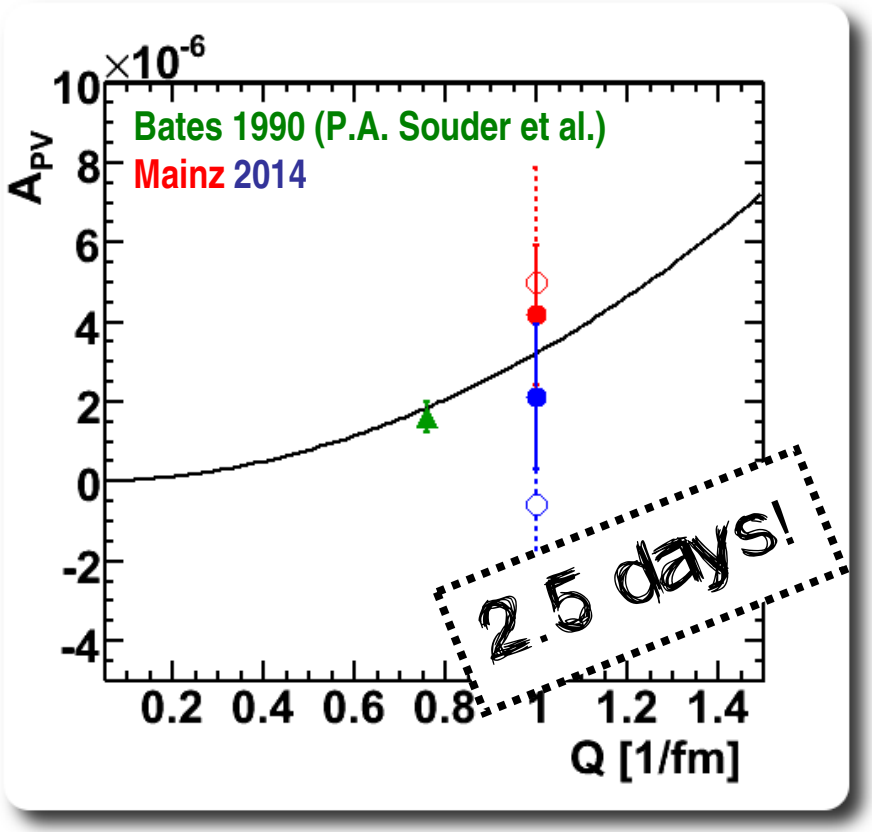




Proof-of-principle:

PVES ^{12}C

(commissioning 09/2014)



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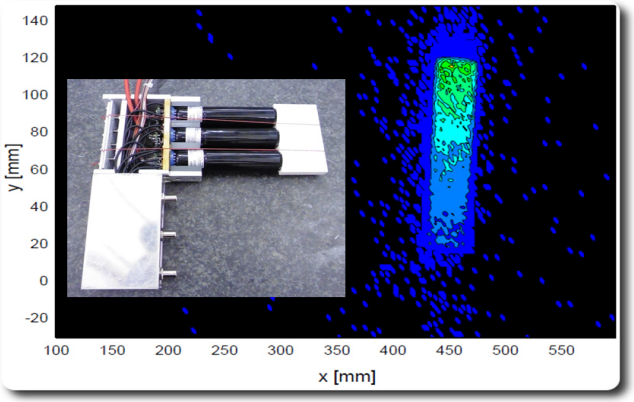
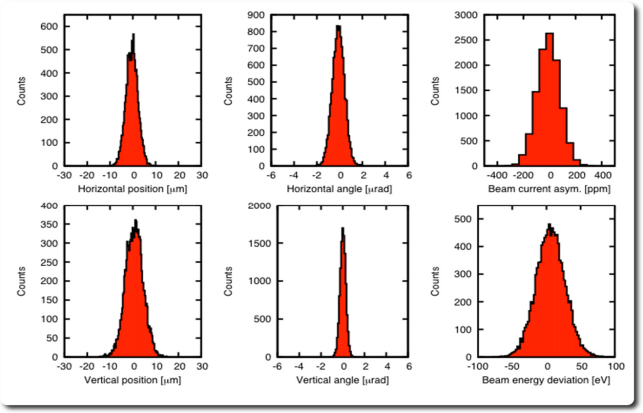
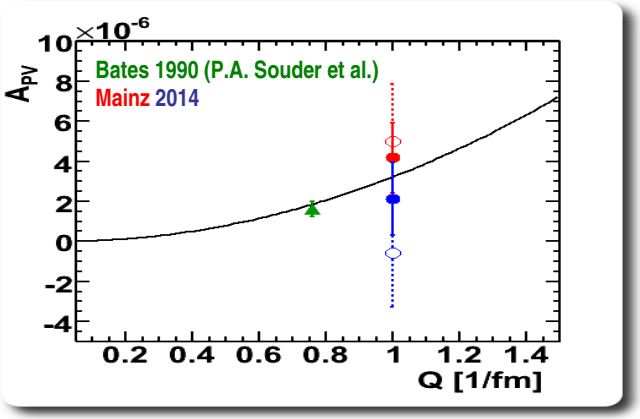




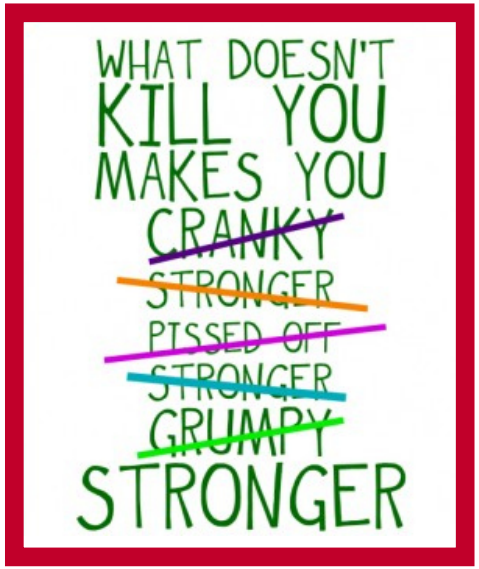


Proof-of-principle:

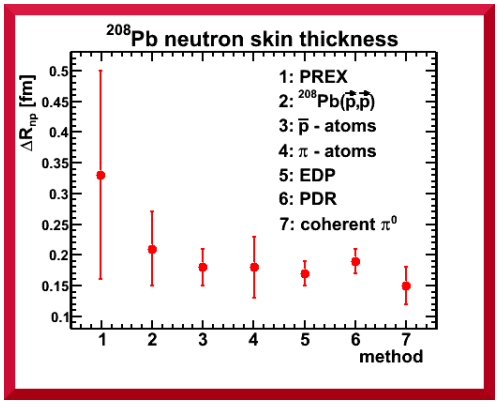
PVES ^{12}C

(commissioning 09/2014)

looking forward to challenging times

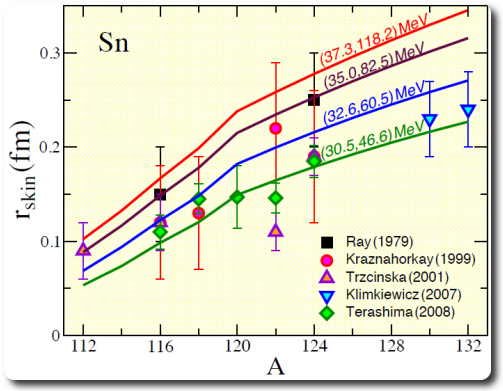


conclusions



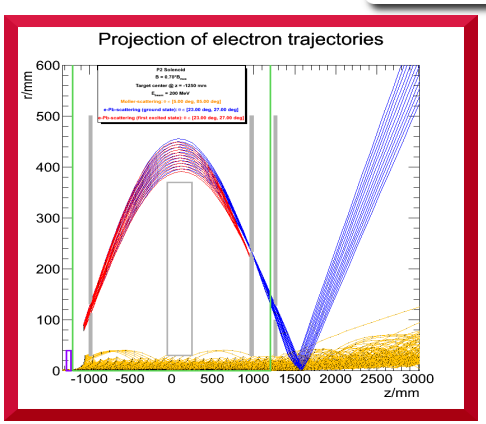
remarkable consistency

model dependencies under control?

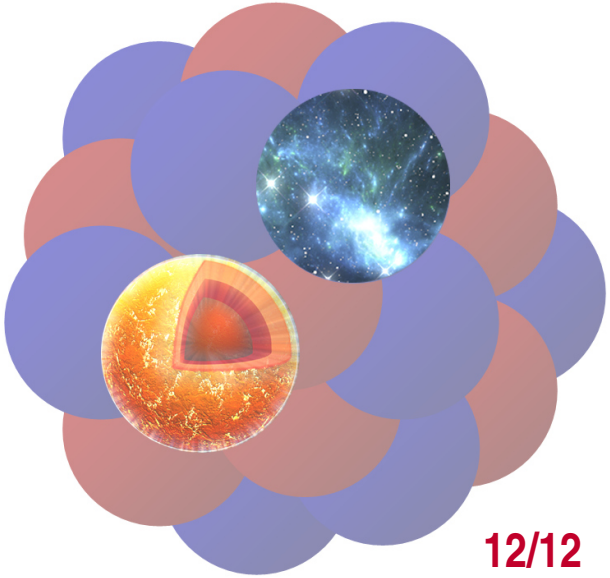


combine efforts from

theory & experiment



Mainz { PRECISION / SYSTEMATICS

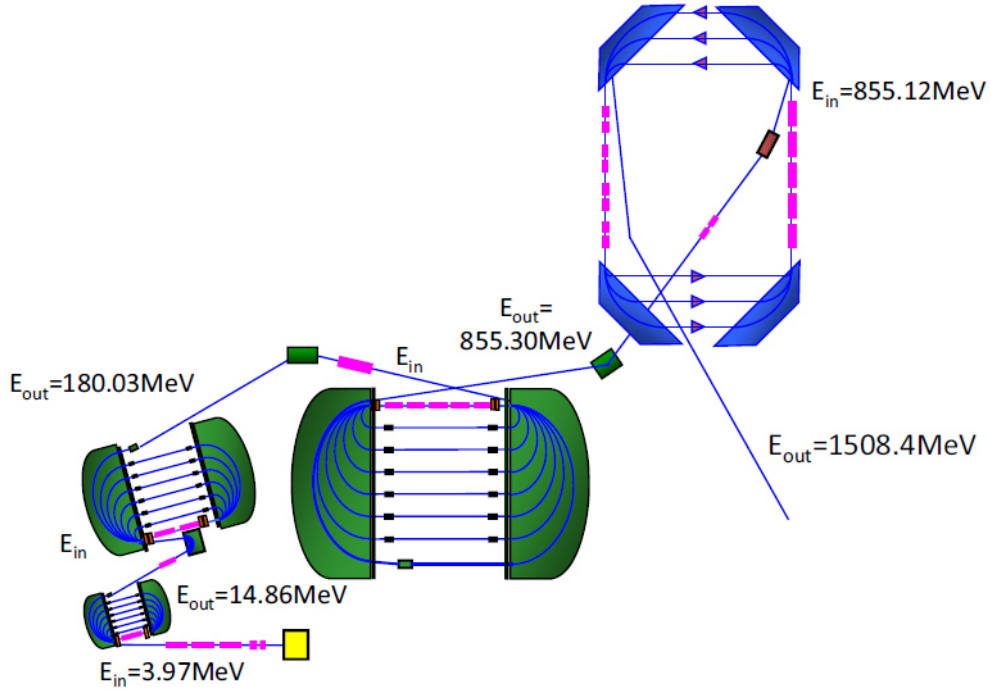


backup slides

QaD method: coherent π^0 photoproduction

RECIPE:

(1) high quality accelerator

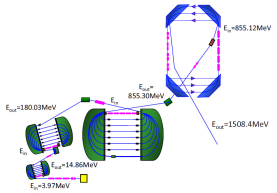


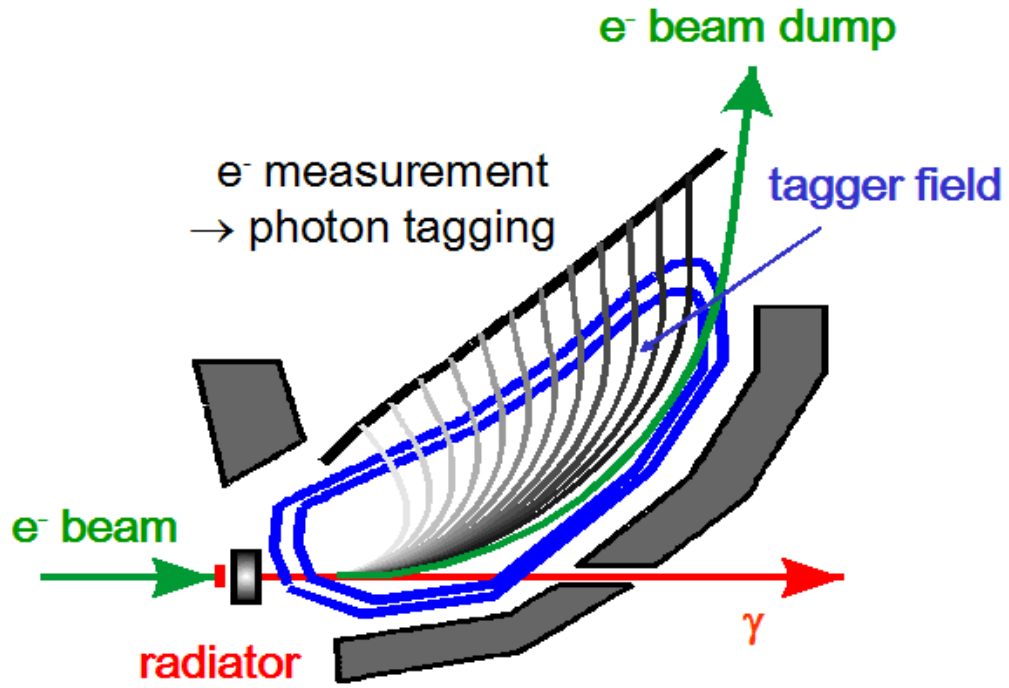
QaD method: coherent π^0 photoproduction

RECIPE:

(1) high quality accelerator

(2) tagged photon facility





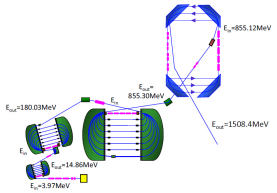
QaD method: coherent π^0 photoproduction

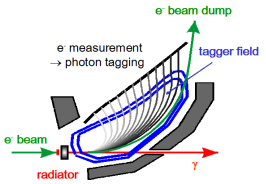
RECIPE:

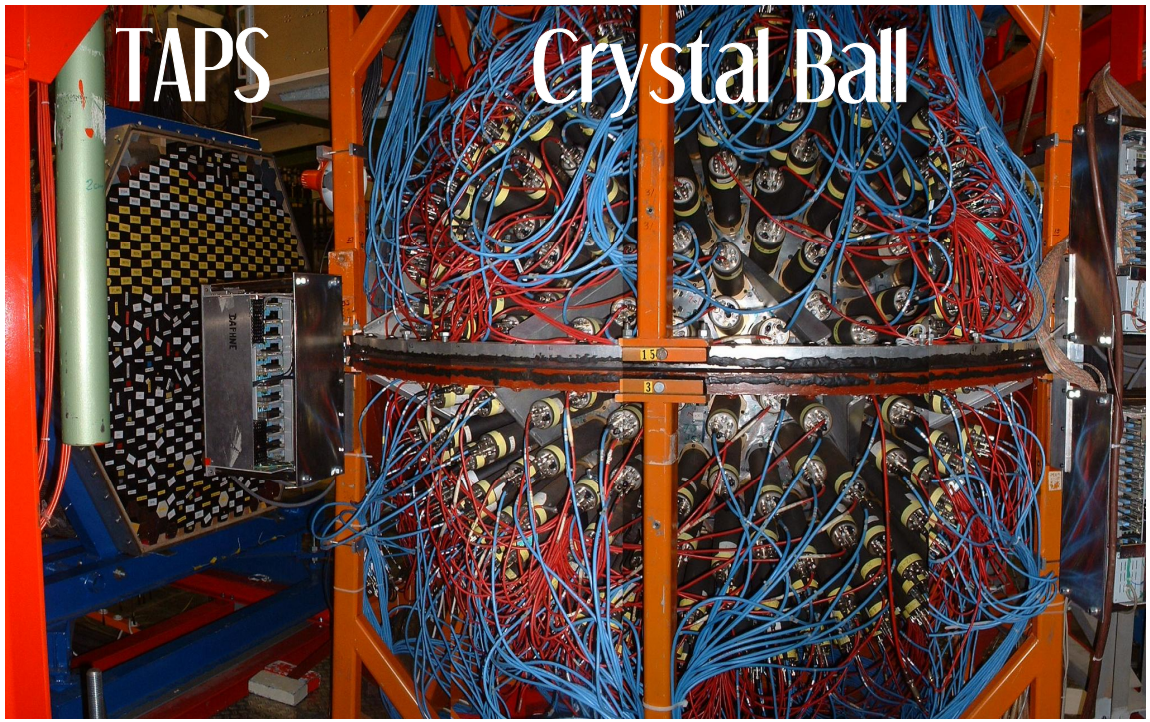
(1) high quality accelerator

(2) tagged photon facility

(3) 4π detector system







coherent π^0 photoproduction @ A2

$$\frac{d\sigma}{d\Omega}(\mathbf{PWIA}) = \frac{s}{m_N^2} \times \frac{1}{2}\frac{q_\pi^*}{k^*} \left|F_2\left(E_\gamma^*, \theta_\pi^*\right)\right|^2 \sin^2\left(\theta_\pi^*\right) \times A^2 F^2\left(q\right)$$

separation of coherent and incoherent events:
DE ≈ 1.5-3 MeV

FSI:
complex optical potential tuned to p-A scattering
NPA 660, 423 (1990)
correction modest at low p momenta

campaign in 2012:

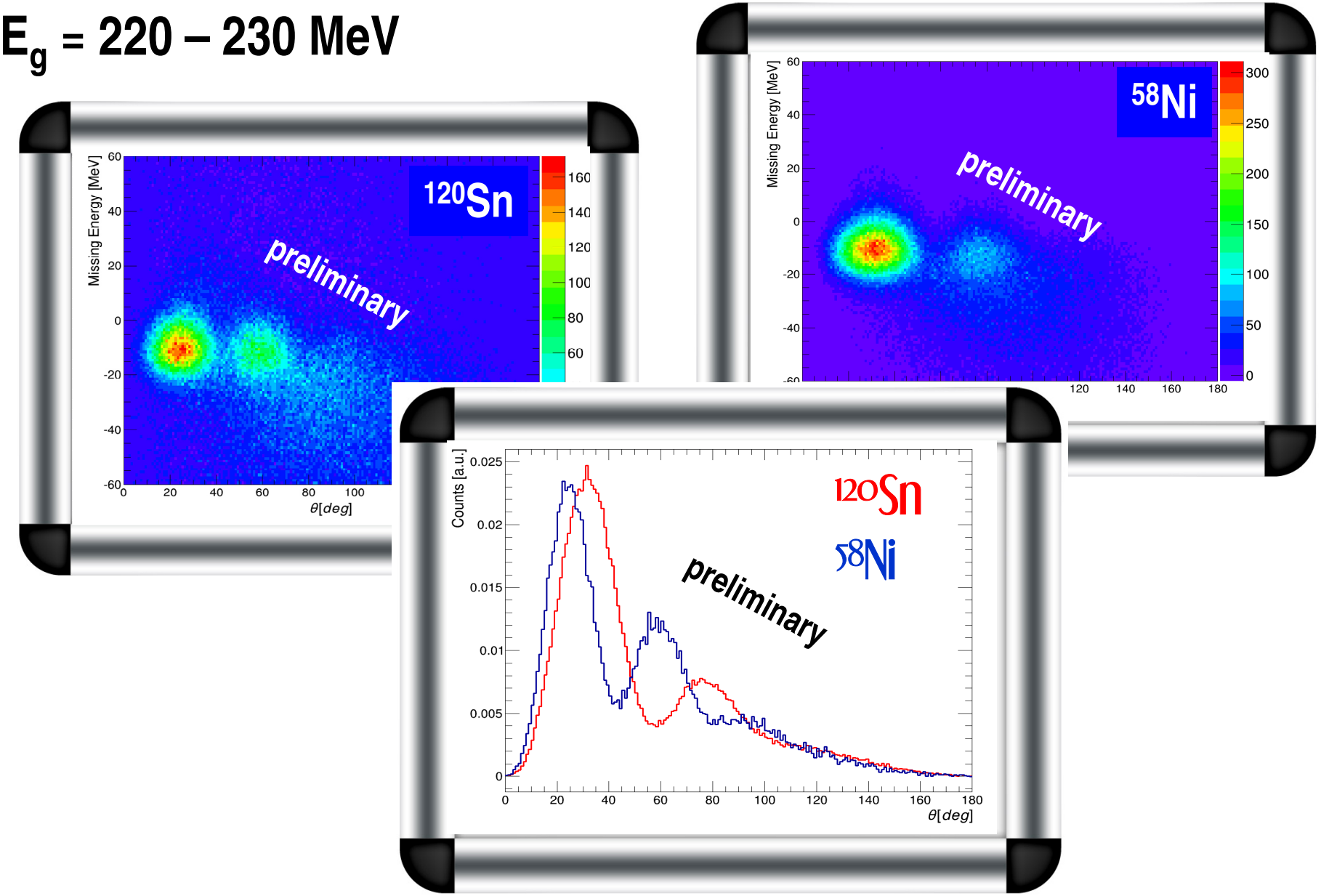
evolution along isotopic chain

plus measurement on

(N/Z: 1.07 to 1.54)

coherent π^0 photoproduction @

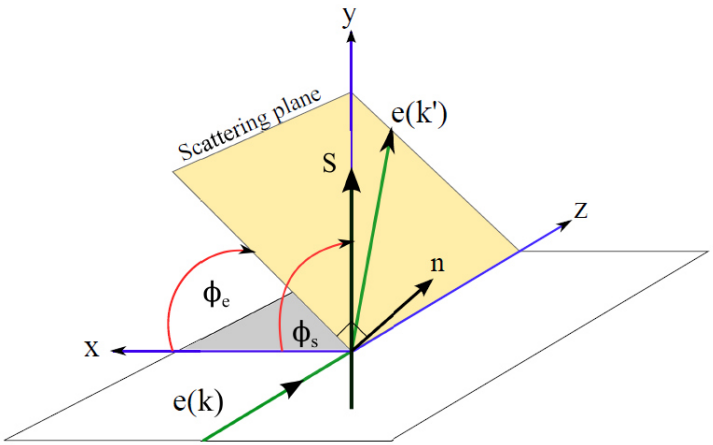
E_g = 220 – 230 MeV



program 1: transverse Asymmetry A_n

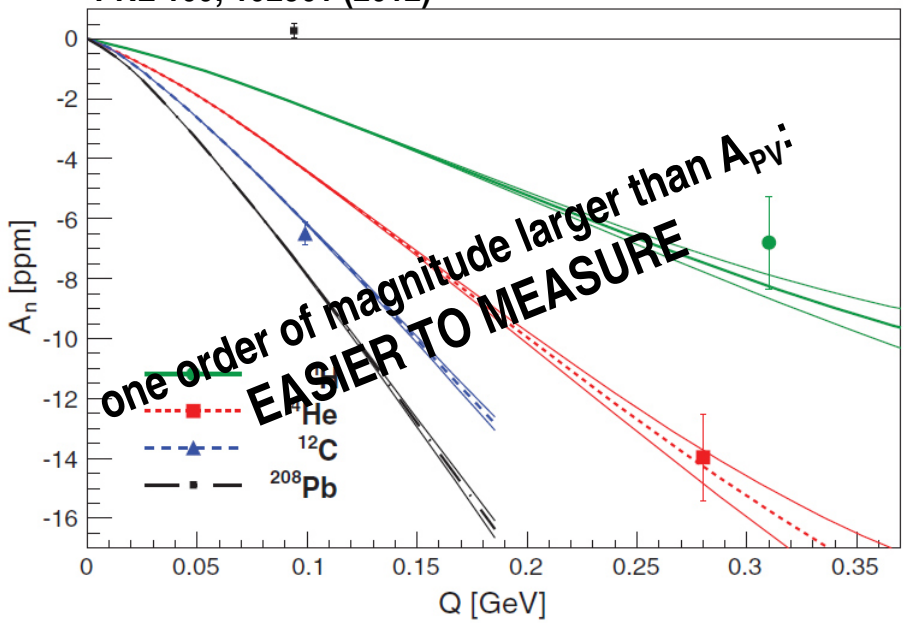
direct probe of two or more photon exchange:
A_n is zero at first Born approximation
(forbidden by time reversal symmetry)

A_n can contribute to the extracted A_{PV}
if beam asymmetry has
transverse component



$$A_n^m = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = A_n \vec{S}_e \cdot \hat{n} = -A_n \left|\vec{S}\right| \sin(\phi_e - \phi_s)$$

PRL 109, 192501 (2012)



new theoretical calculations
treating dispersion corrections
and Coulomb distortion
simultaneously

+

systematic set of A_n

N_{skin} landscape: theory

Brueckner-Hartree-Fock (BHF)

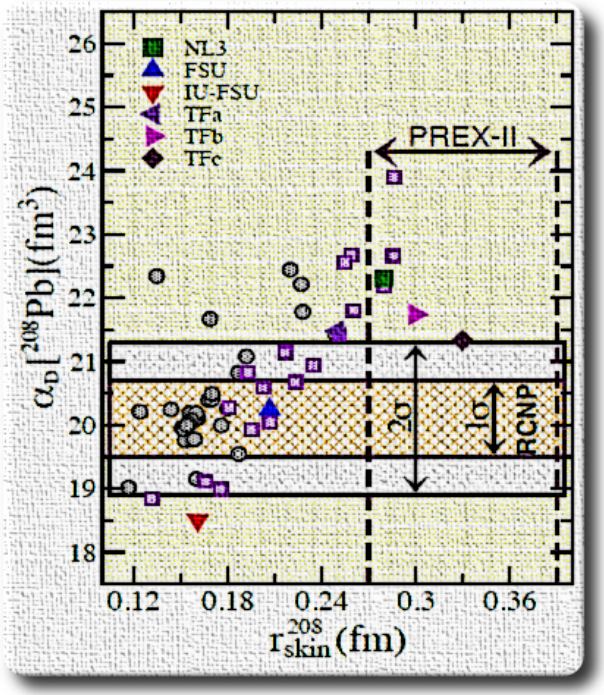
Phys. Rev. C 80, 045806 (2009)

Quantum Monte Carlo (QMC)

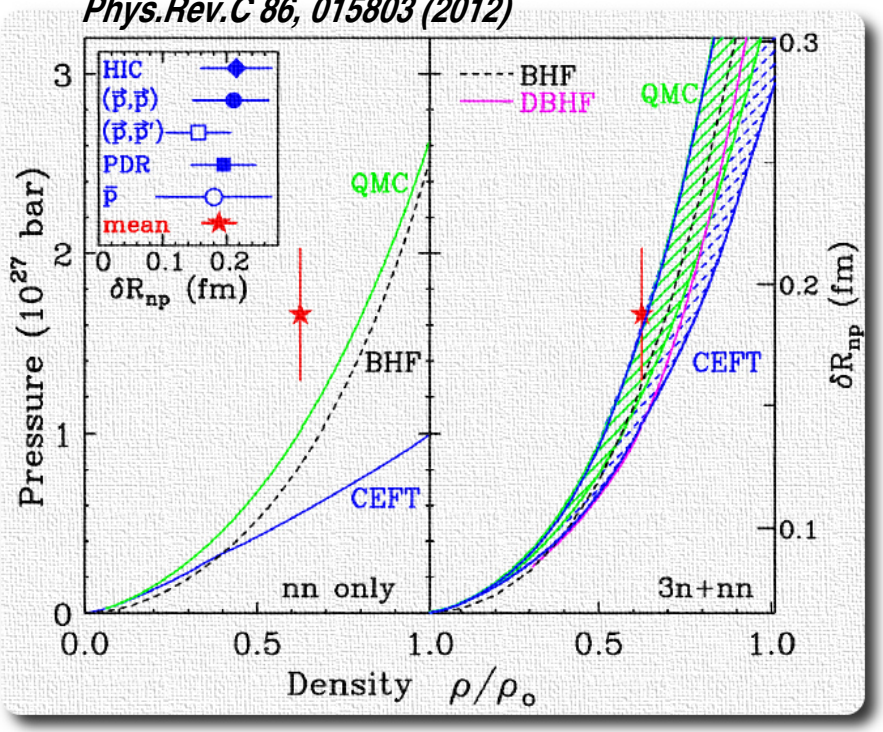
Phys. Rev. C 85, 032801(R) (2012)

Chiral effective field theory (CEFT)

Phys. Rev. Lett. 105, 161102 (2010)



Phys.Rev.C 86, 015803 (2012)



are models with large neutron skins really incompatible with available laboratory or astrophysical data?

Phys. Rev. Lett. 111, 162501 (2013)

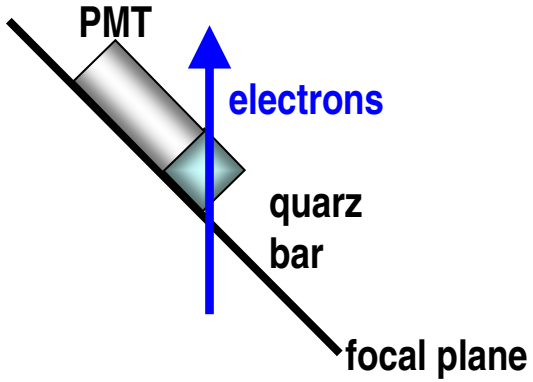
parity violation program @ A1

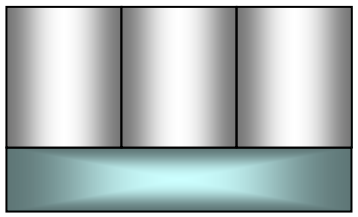
start with „easy“ target: carbon …

… plenty of other challenges:

- beam stability
- Polarimetry
- polarization at several mA
- low noise electronics
- high rates

pilot experiment scheduled for July 2014:



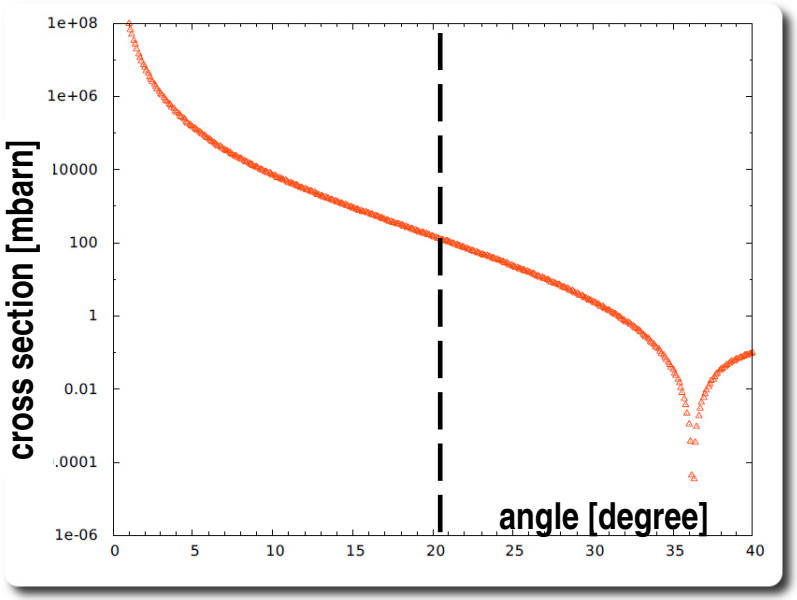


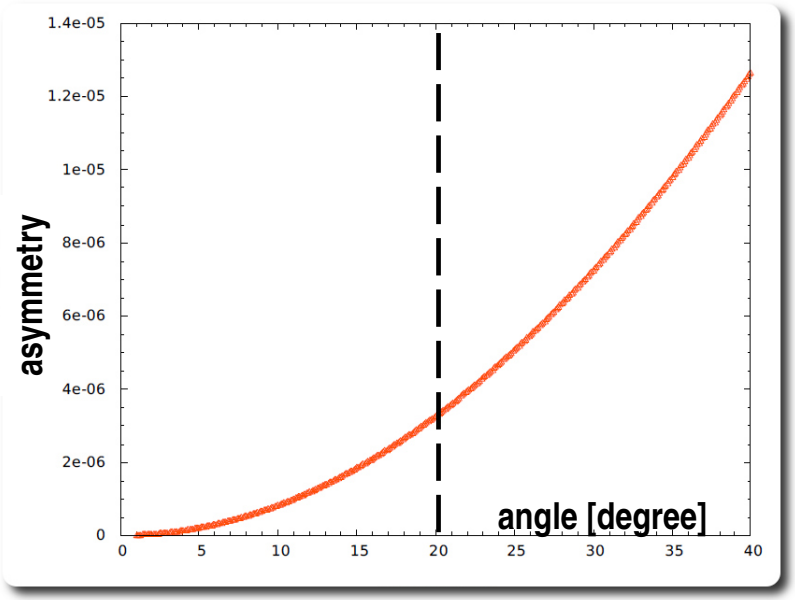
quarz bar:
(10 x 50 x 100) mm^3

PMTs with
quarz window!

parity violation program @

carbon measurement





E = 570 MeV

I = 20 mA

q = 20°

asymmetry: 3.260 ppm

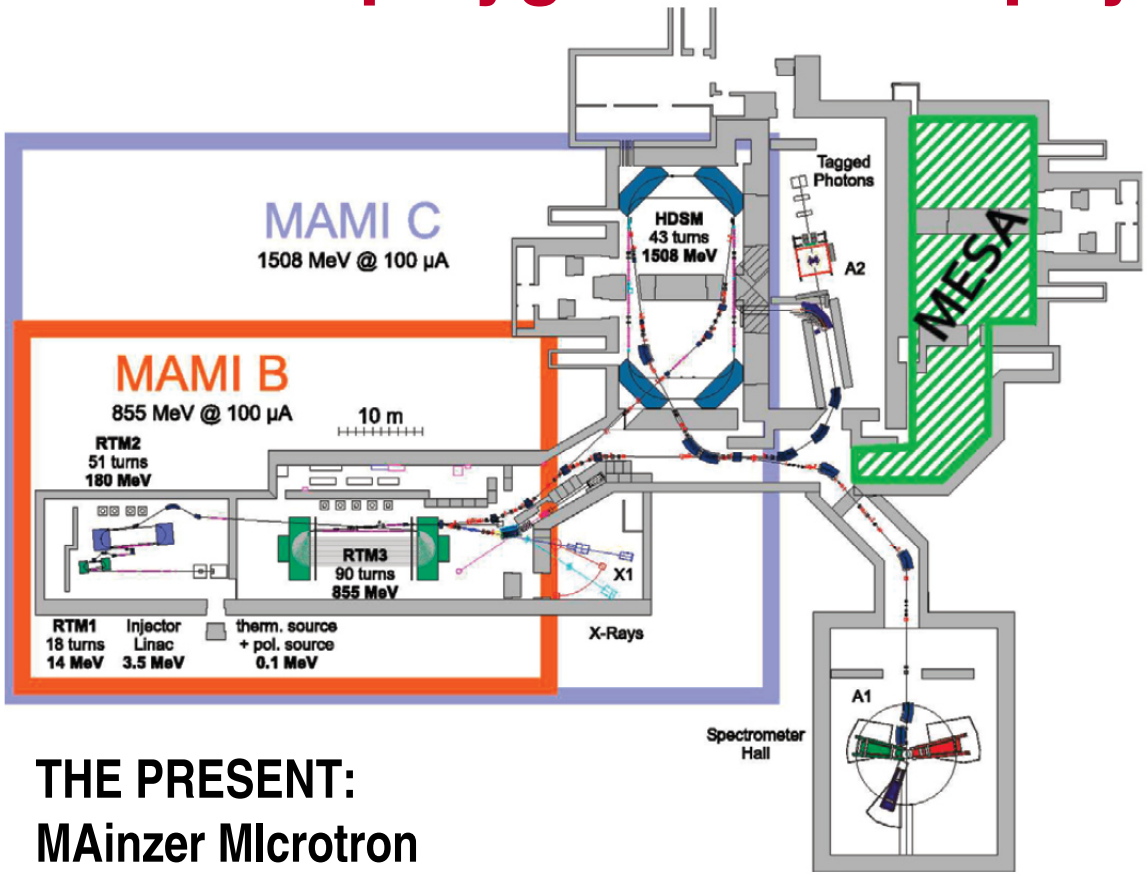
the complete program:

transverse asymmetry A_n

^{208}Pb measurement

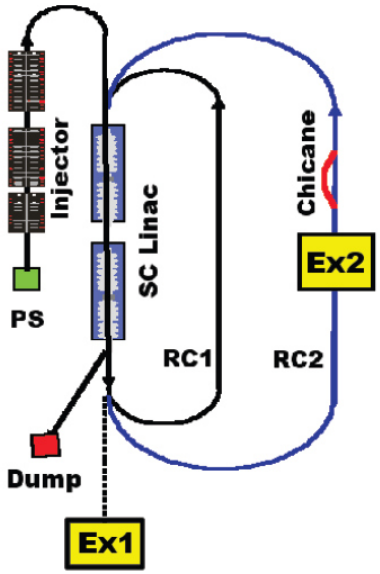
^{120}Sn measurement

the best playground for a phycisist



THE PRESENT:
MAinzer MIcrotron

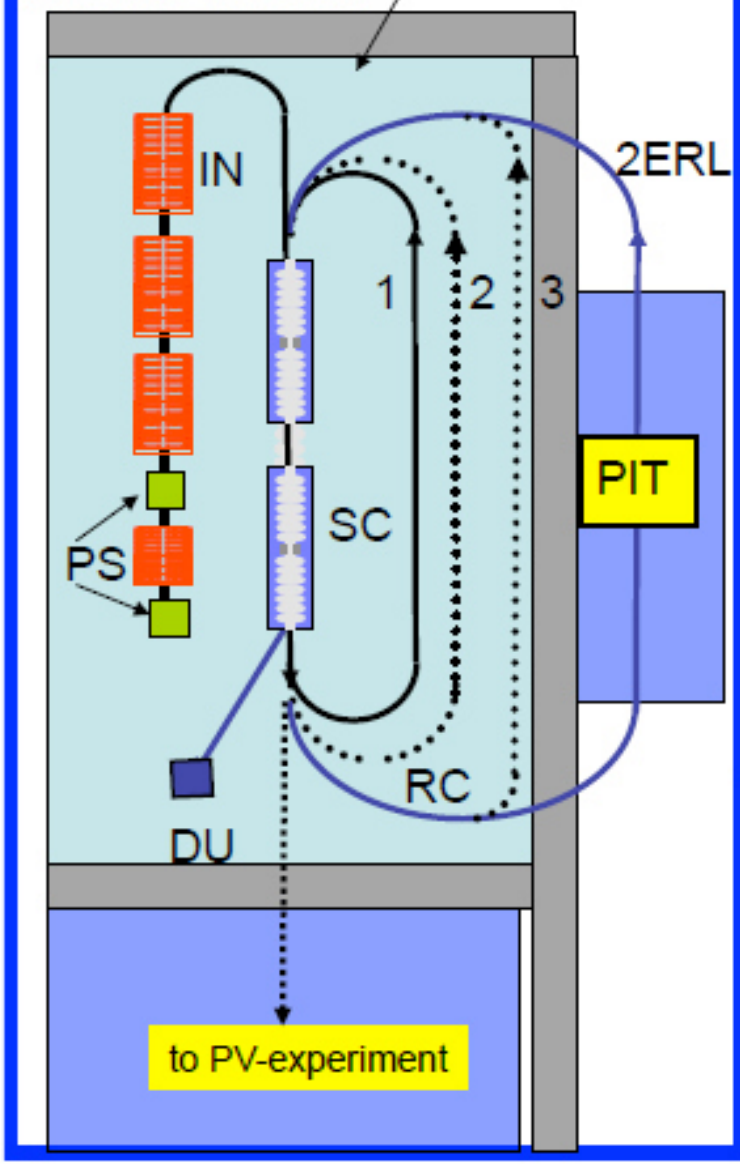
THE FUTURE:
MESA



beam energy:	intensity:
E_{max}: 1.6 GeV	up to 100mA
resolution:	polarization:
s_E < 100keV	up to 80% @ 40mA

EB-mode:
200 MeV @ 150 mA (pol.)

ERL-mode:
100 MeV @ 10mA (unpol.)



KEY:

PS: Photosources: 100keV polarized
(EB, ERL (low charge)),
500keV unpolarized (ERL, high charge)

IN: 5 MeV – NC injector

SC: 4 Superconducting cavities
Energy gain 50 MeV per pass.

1-3 Beam recirculations for EB
Orbit 1 common to ERL and EB,
Orbit 2 could be separate for ERL and EB

PIT: Pseudo Internal target (ER-experiment)

PV: Parity violation experiment (EB-mode)

DU: 5 MeV beam dump in ERL-mode

Existing walls: 2-3m thick shielding

EXPERIMENTAL BEAM PARAMETERS:

1.3 GHz c.w.

EB-mode: 150 μA, 200 MeV polarized beam
(liquid Hydrogen target L~10^{39})

ERL-mode: 10mA, 100 MeV unpolarized beam
(Pseudo-Internal Hydrogen Gas target, L~10^{35})