exploring neutron skins:

current program and future perspectives at Mainz

Michaela Thiel

Institut für Kernphysik, Johannes Gutenberg-Universität Mainz

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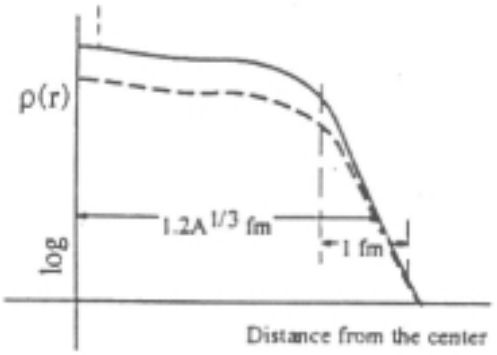
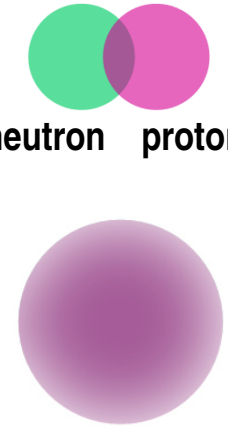
Kraków, Poland

JG|U SFB 1044 PRISMA

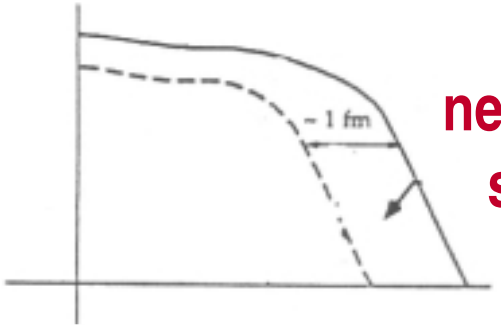
short reminder

stable nuclei

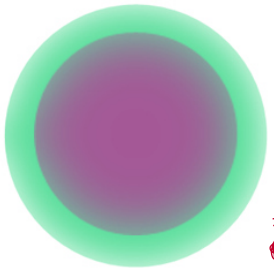




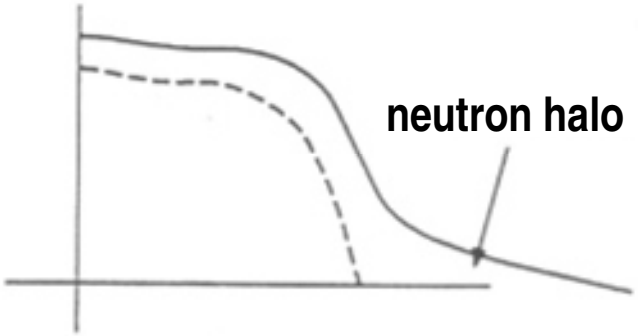
neutron rich nuclei

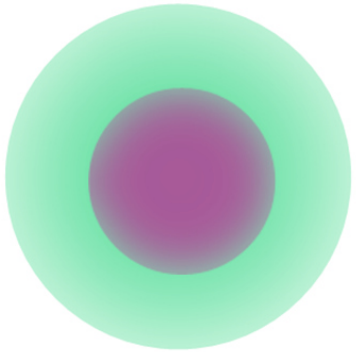


neutron skin

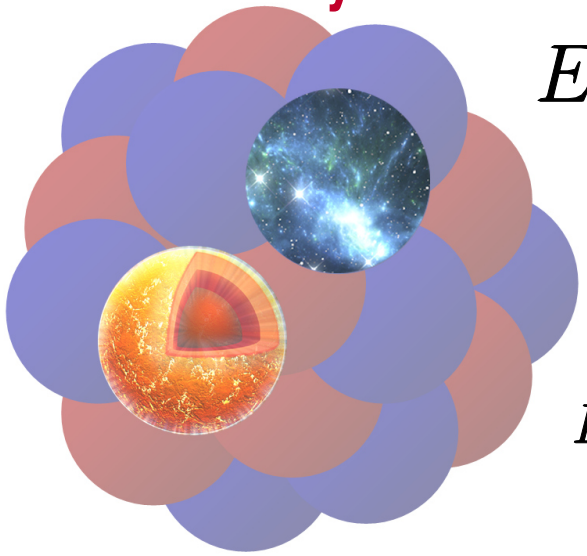


pressure forces neutrons out against surface tension





EOS, E_{sym} und N_{Skin}



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

symmetry energy

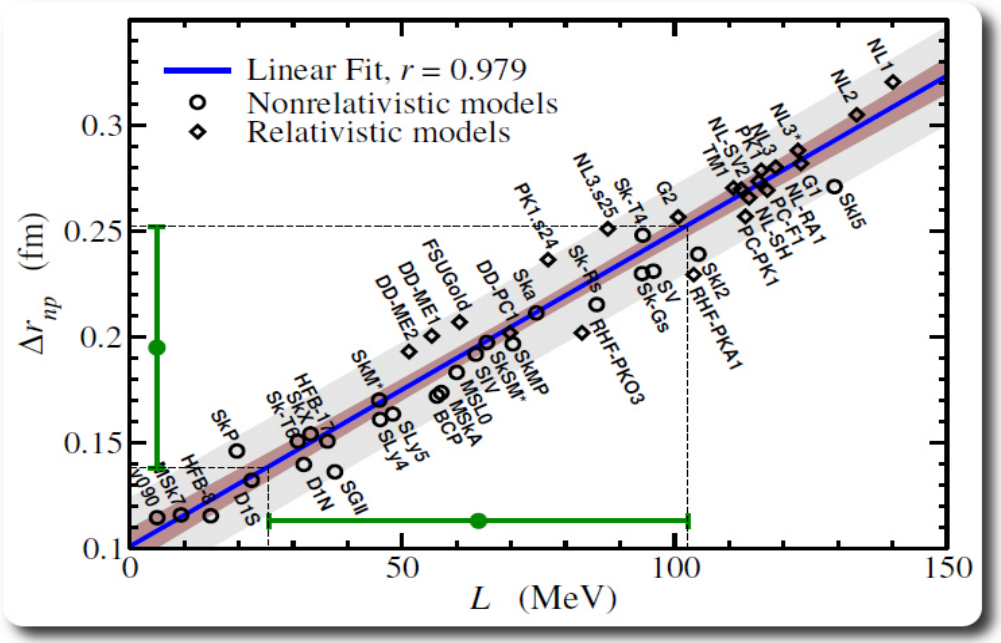
$$E_{sym}(\rho) = \left[S_v + \frac{L}{3}\left(\frac{\rho-\rho_0}{\rho_0}\right) + \frac{K_{sym}}{18}\left(\frac{\rho-\rho_0}{\rho_0}\right)^2\right] + \ldots$$

slope parameter

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

curvature parameter

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



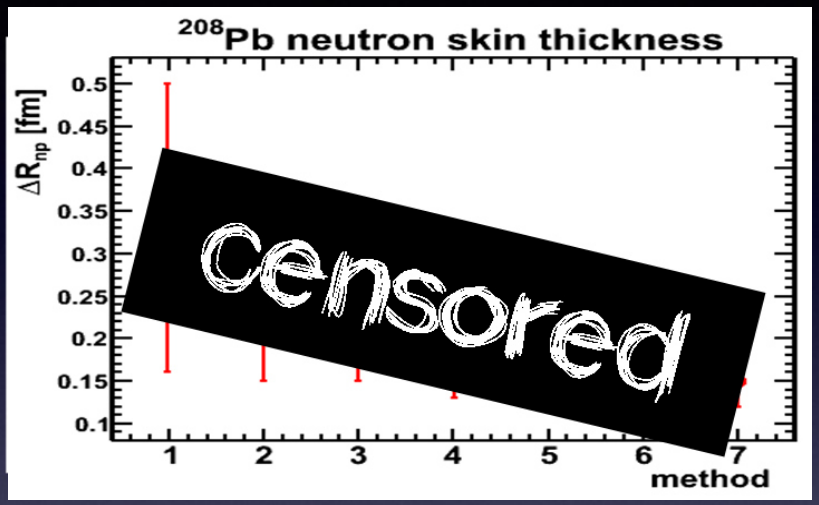
X. Roca-Maza et al., PRL 106 (2011) 252501

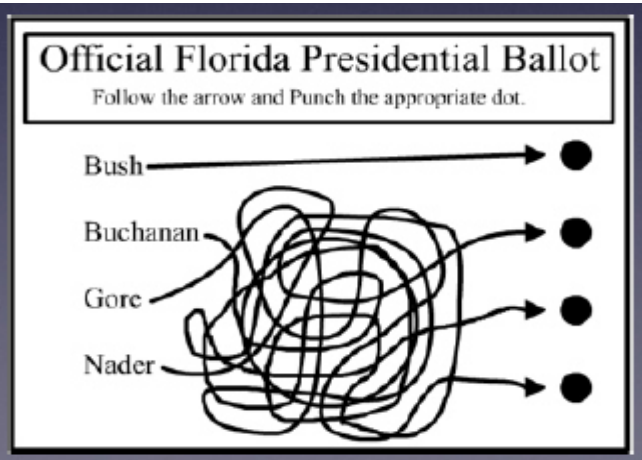
MITP workshop @ Mainz: concluding remarks I

From Measurable Observables to the Neutron Skin

- What is actually measured?
  Cross section, asymmetry, spin observables, …
- How is the measured observable connected to the neutron skin?
- What are the assumptions implicit in making this connection?
  Impulse approximation, off-shell ambiguities, distortion effects, …
- How sensitive is the extraction of the neutron radius/skin to these assumptions?
- Quantitative assessment of both statistical and systematic errors

All observables are equal, but some observables are more equal than others … Pedigree!





courtesy of Jorge Piekarewicz

model dependences: a difficult thing to deal with

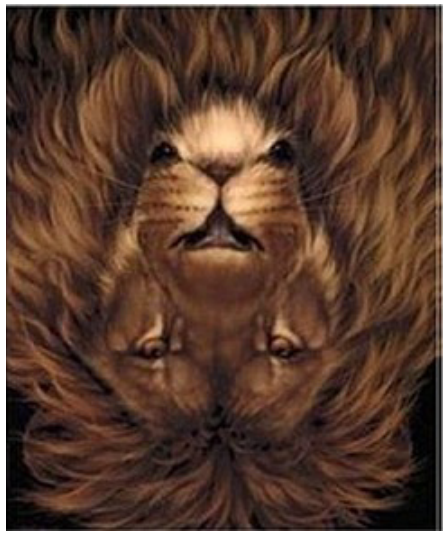
data

extract

object of desire

tool

OR



model 1

model 2

conclusion:

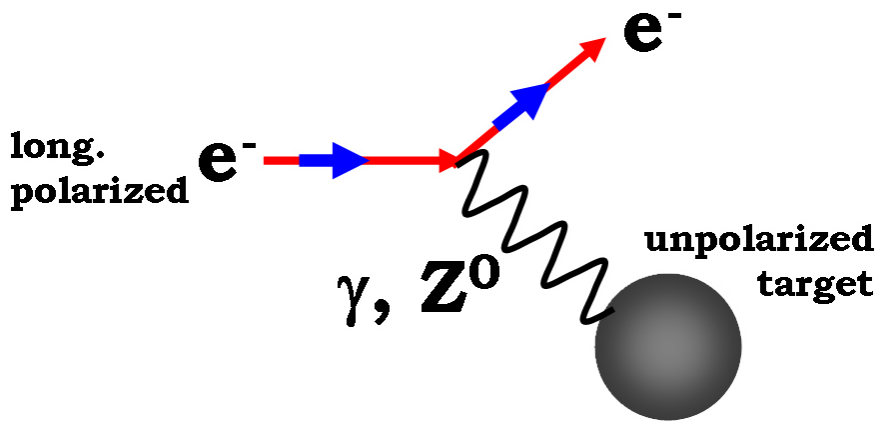
use

least model

dependent

method!

parity violating electron scattering



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

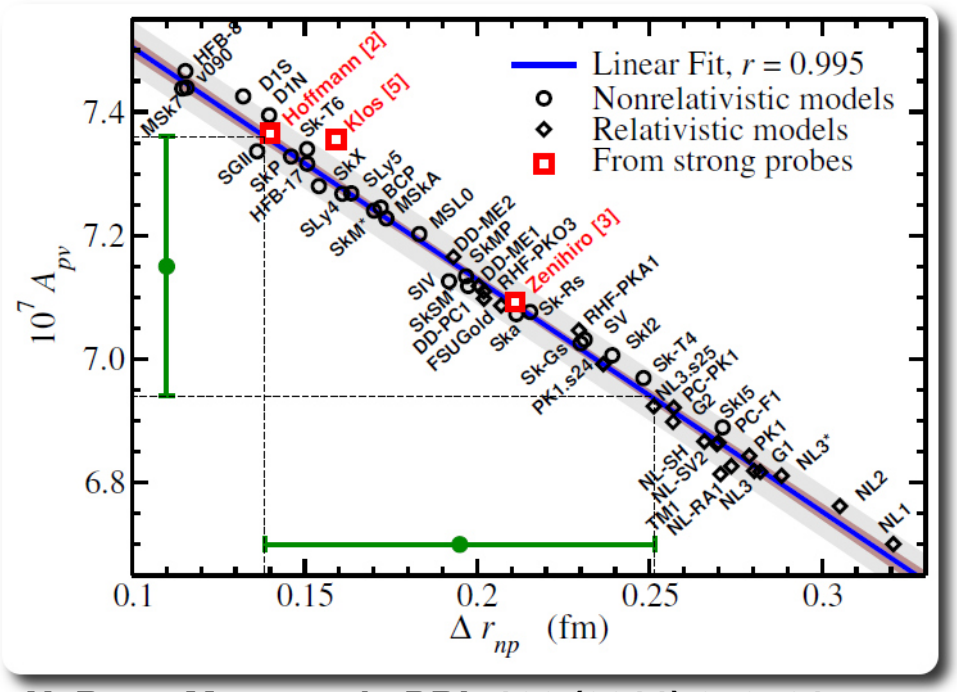
$$A_{PV} = \frac{\sigma^R - \sigma^L}{\sigma^R + \sigma^L}$$

PREX:

[S. Abrahamyan et al., PRL 108 (2012) 112502]

$A_{PV} = 0.656 \pm 0.060(\text{stat}) \pm 0.014(\text{syst})\text{ppm}$

$\Delta r_{np} = 0.33^{+0.16}_{-0.18}\,\text{fm}$

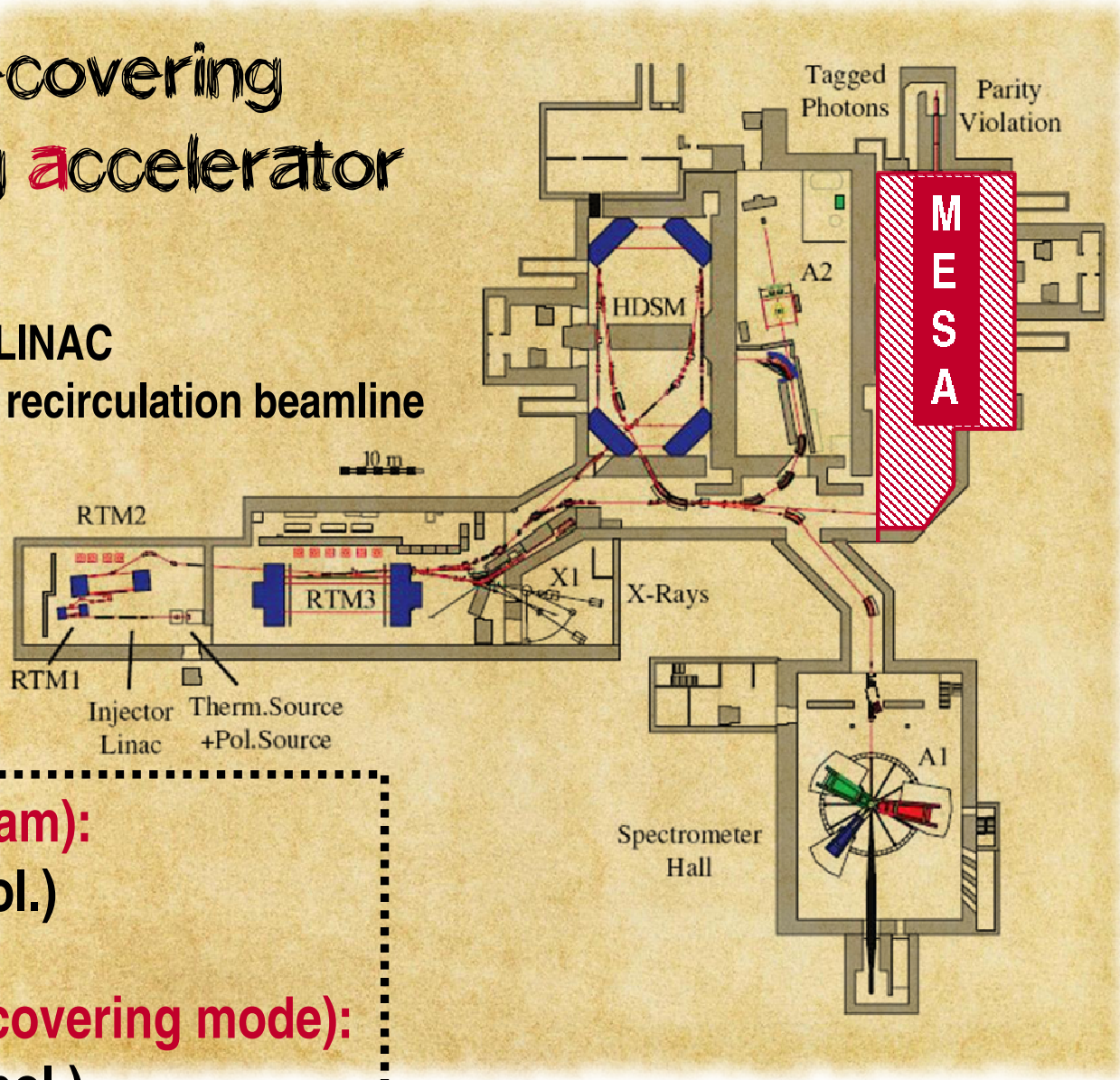


X. Roca-Maza et al., PRL 106 (2011) 252501

the stage

Mainz energy recovering superconducting accelerator

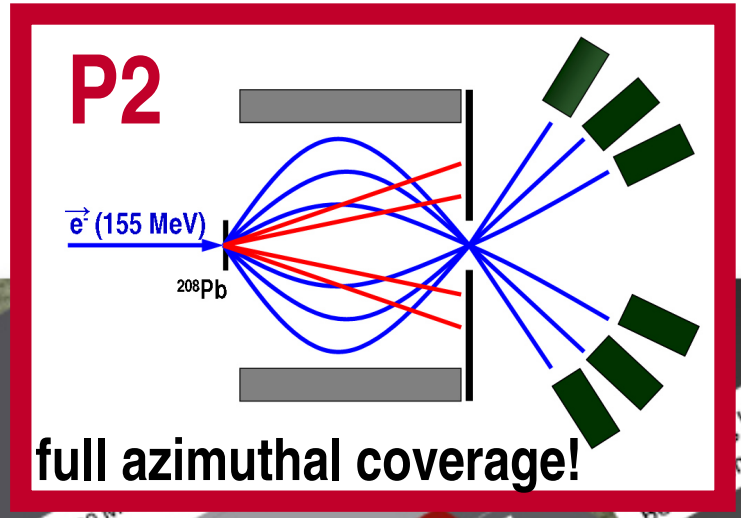
1.3 GHz c.w. beam
normal conducting injector LINAC
superconducting cavities in recirculation beamline

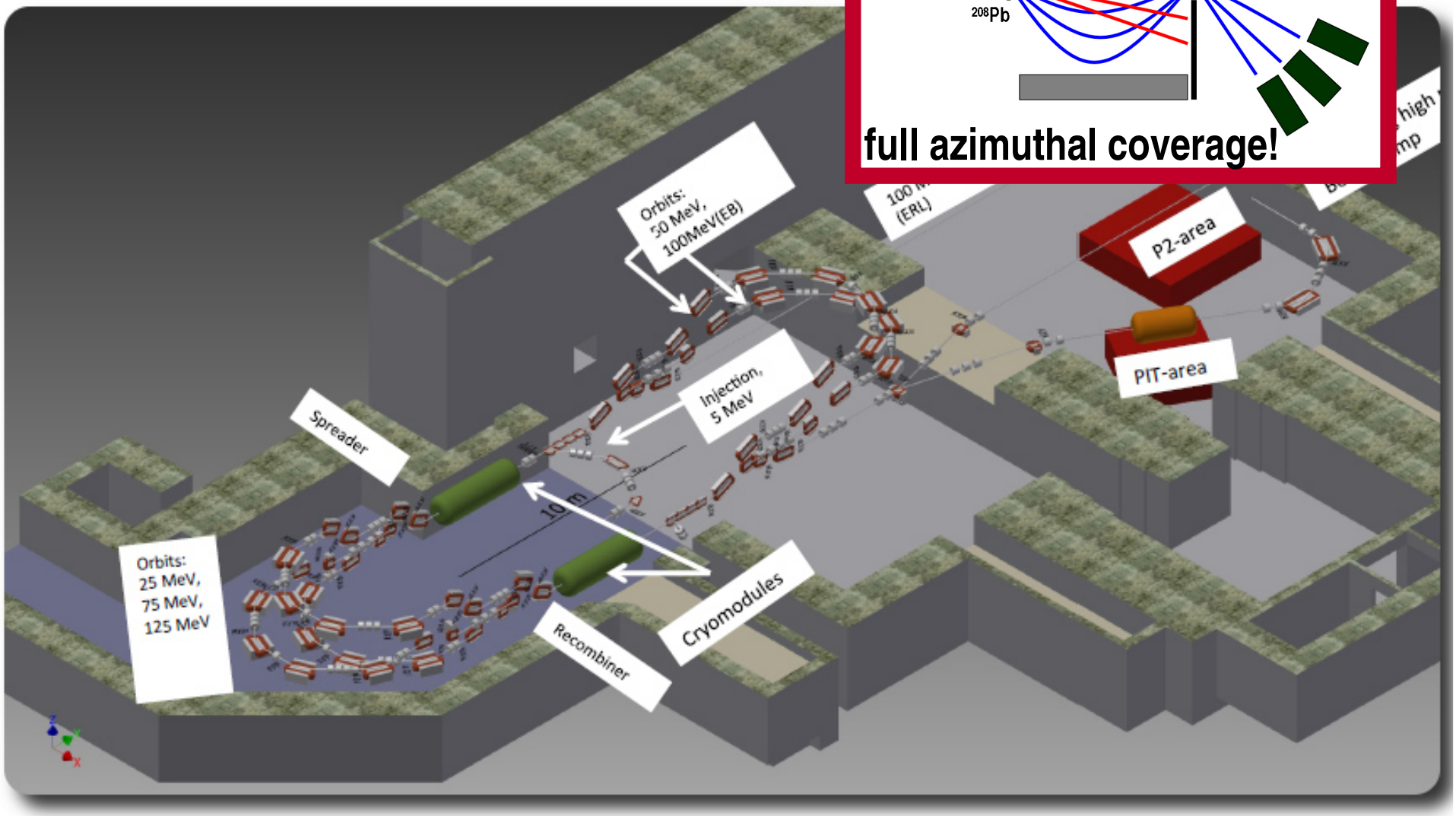


EB-mode (external beam):
155 MeV @ 300 μA (pol.)

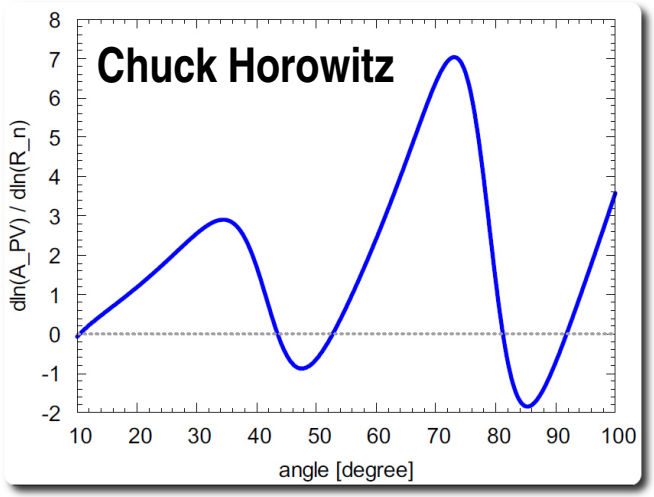
ERL-mode (energy recovering mode):
100 MeV @ 10mA (unpol.)

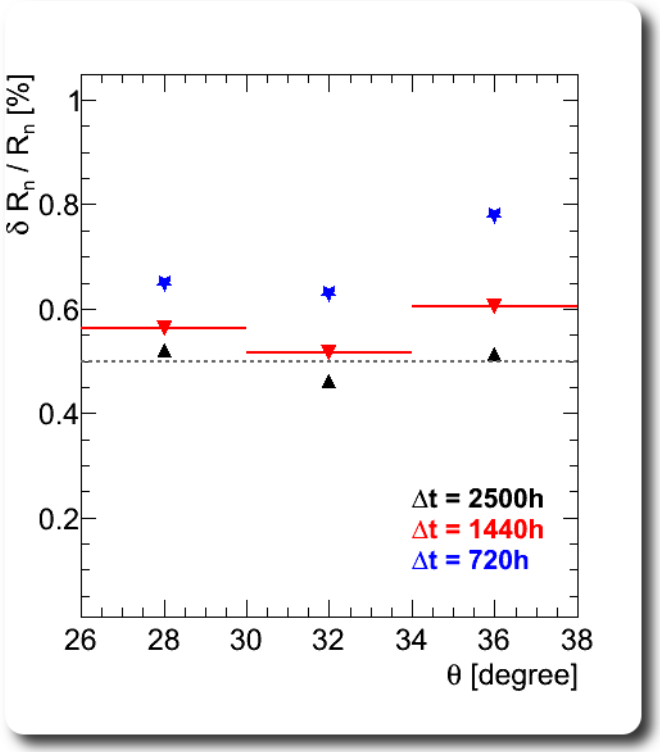
MESA


P2
e⃗ (155 MeV)
208Pb
full azimuthal coverage!


Orbits:
50 MeV,
100MeV(EB)
100 M
(ERL)
P2-area
PIT-area
Injection,
5 MeV
Spreader
10 E
Orbits:
25 MeV,
75 MeV,
125 MeV
Recombiner
Cryomodules

P2@MESA: go for ultimate precision

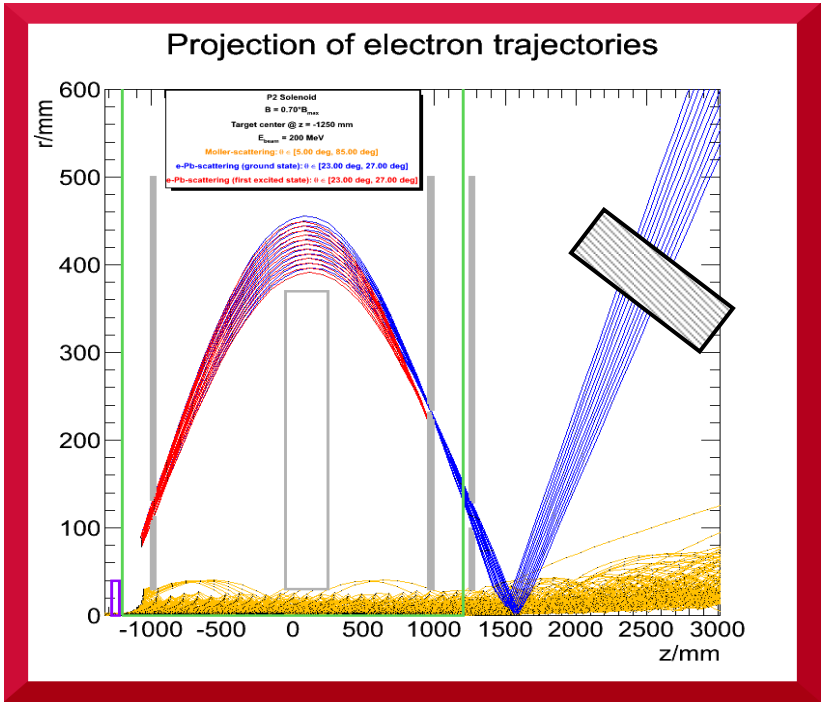




GOAL:

dR_n/R_n (^{208}Pb)≈ 0.5 %

resolve elastic!



future programs

PREX-II

reduce stat. error

CREX

^{48}Ca

MESA

additional Q^2 point for ^{208}Pb

JG|U

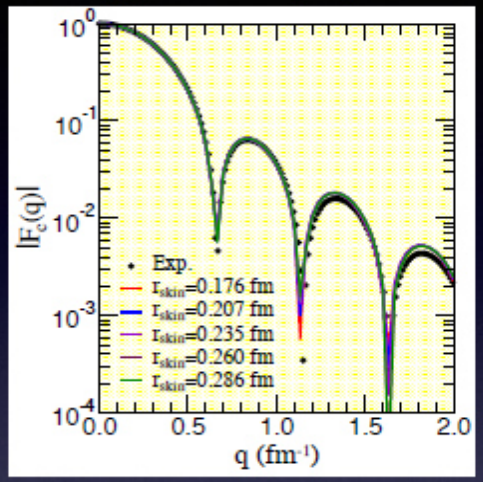
Chuck Horowitz, Zidu Lin
arXiv: 1505.06358 (2015)

MITP workshop @ Mainz: concluding remarks II

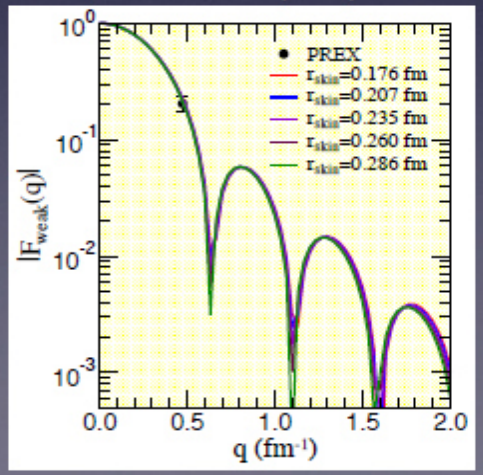
Theory Informing Experiment

- **Quantitative assessment of both statistical and systematic errors; theory must provide error bars!**
  Uncertainty quantification and covariance analysis (theoretical errors & correlations)
- **Precision required in the determination of the neutron radius/skin?**
  - As precisely as "humanly possible" - fundamental nuclear structure property
  - To strongly impact Astrophysics?
  - What astrophysical observables to benchmark?
- **Is there a need for a systematic study over "many" nuclei?**
  PREX, CREX, SREX, ZREX, ...
- **Is there a need for more than one Q-square point?**
  Radius and diffuseness ... the whole form factor?

$R_{ch} = 5.5012(13)$ fm

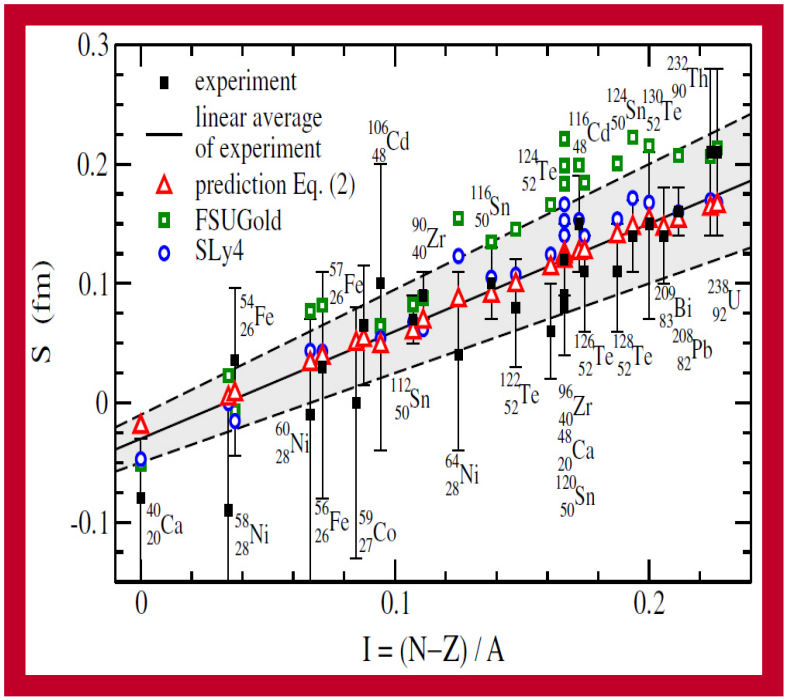


$R_{wk} = 5.826(181)$ fm



courtesy of Jorge Piekarewicz

do we need more than one point?



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

YES

can we do more than one point?

YES

infinite money and time available?

YES

NO

PV e⁻ scattering

QaD

set absolute scale

the stage

Mainz Microtron

up to E = 1.6 GeV

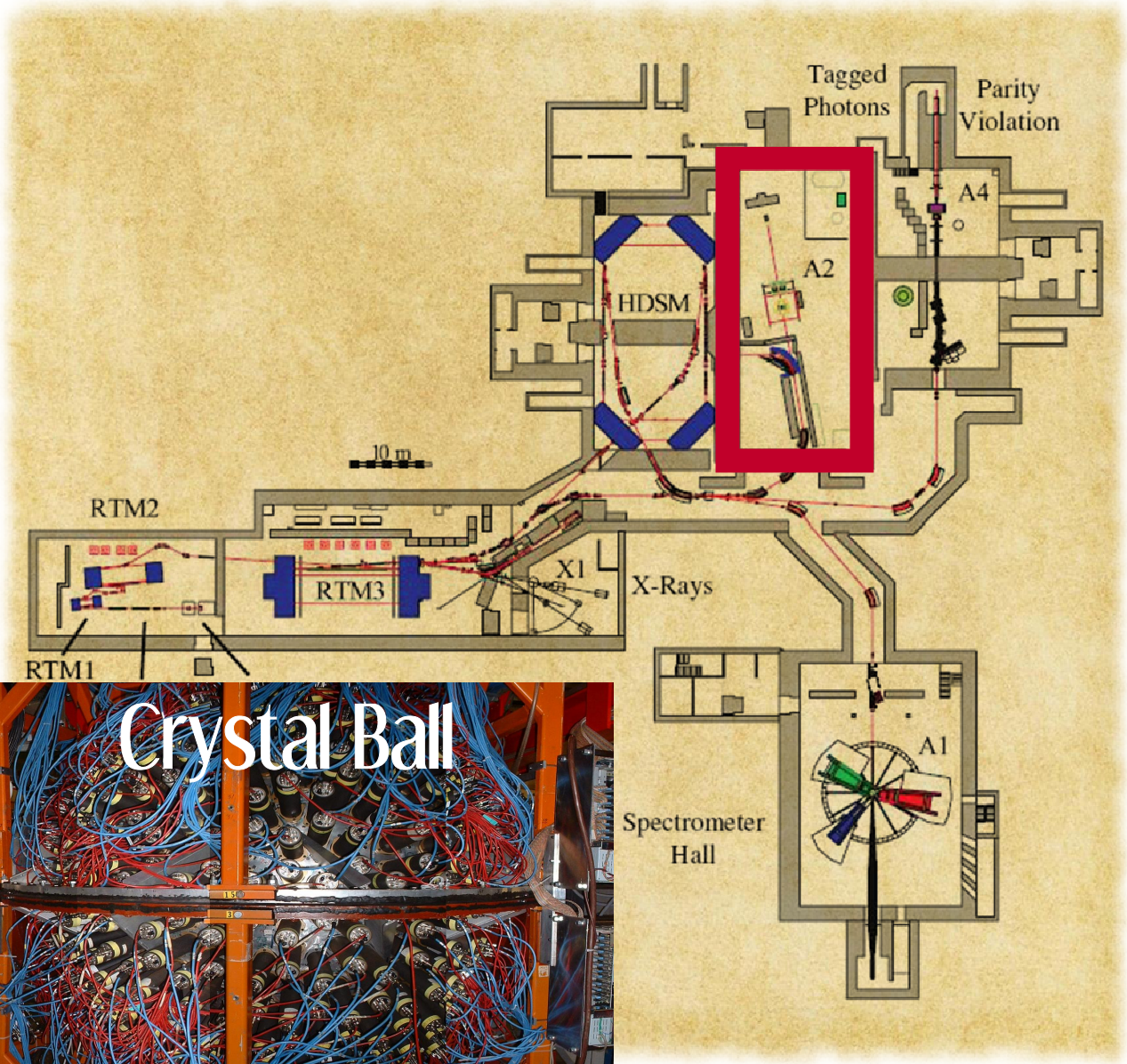
HIGH

resolution

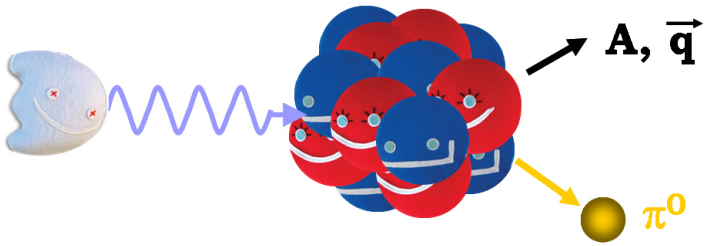
σ_E < 0.1 MeV

reliability

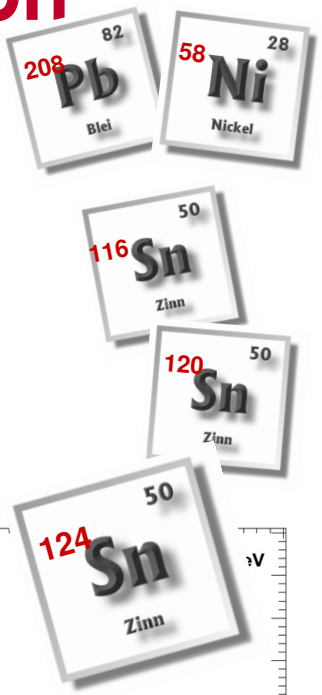
85% (7000 h/a)

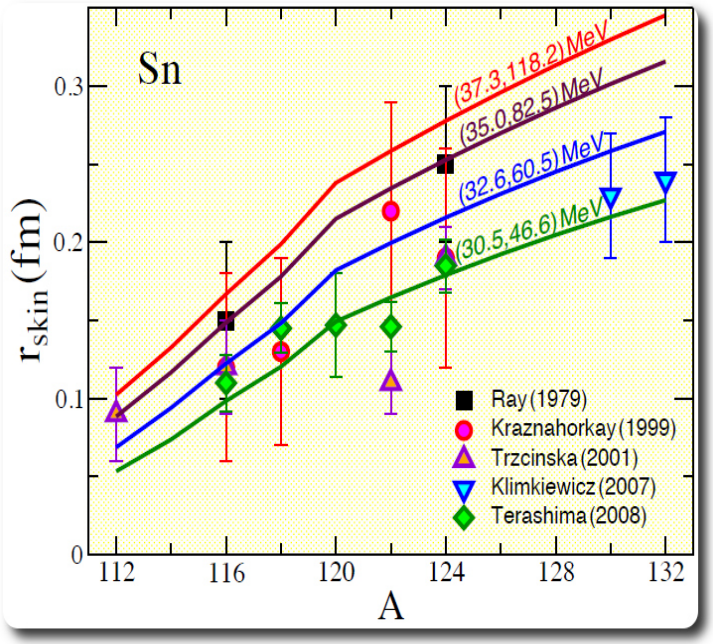


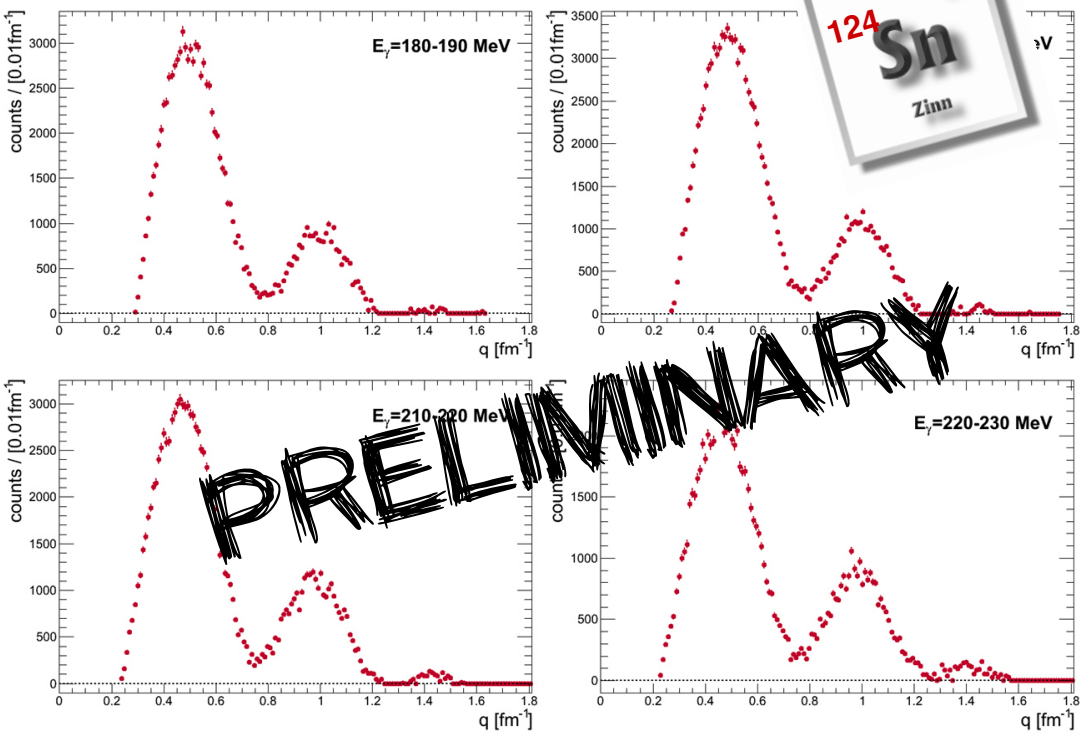
QaD method: coherent π^0 photoproduction



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







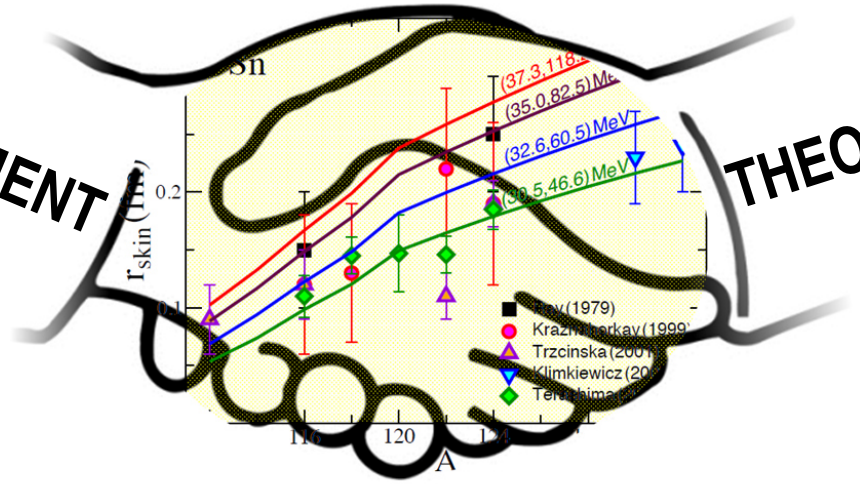
PRELIMINARY

Jorge Piekarewicz, ICNT2013

M. Isabel Ferretti Bondy

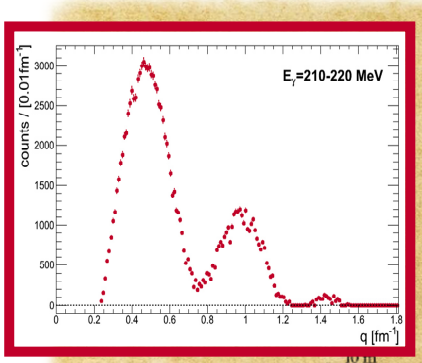
conclusions

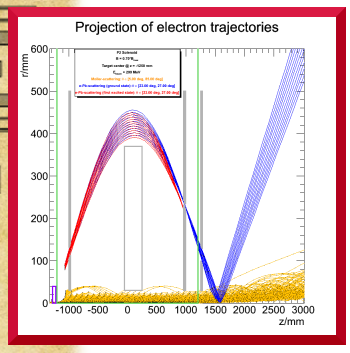
EXPERIMENT

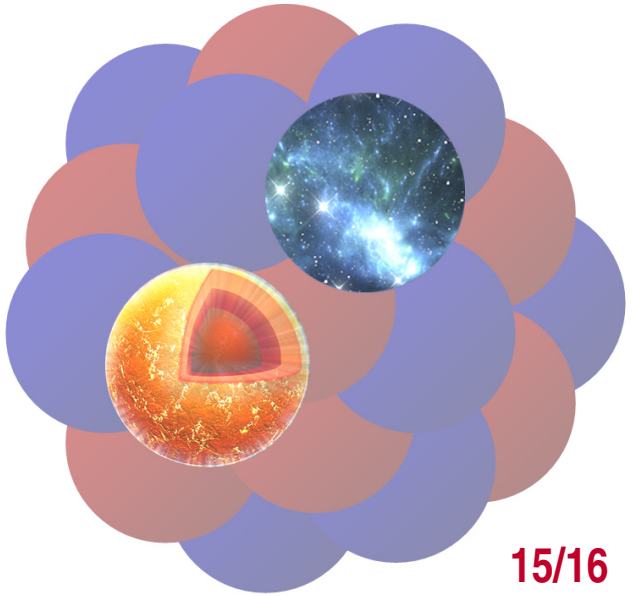


THEORY

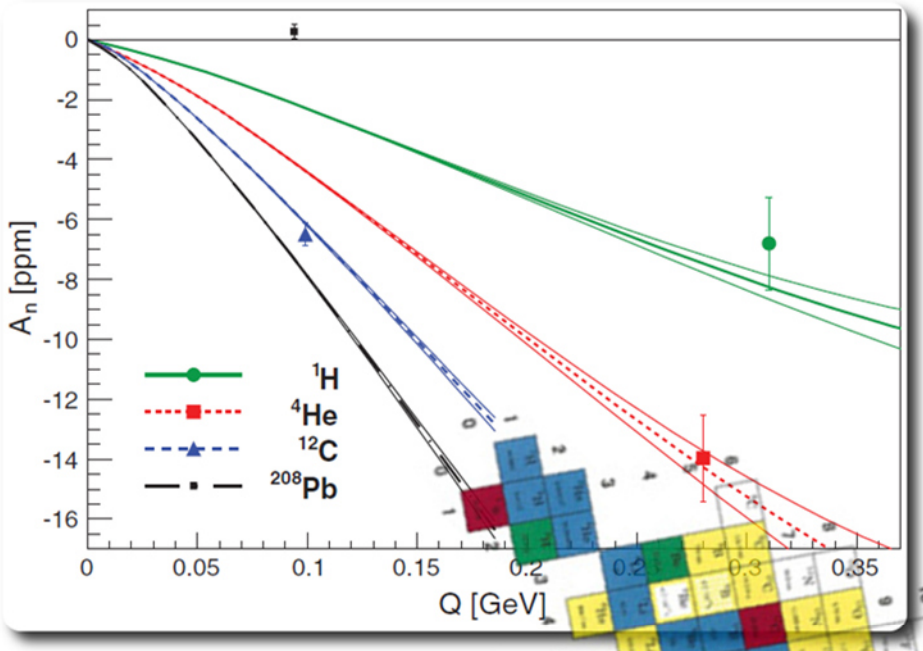
PRECISION@ MESA
SYSTEMATICS@ MAMI







A1@MAMI: transverse asymmetry



KEEP BEING AWESOME AND LET'S HAVE MORE FUN!!!

constrain systematic error in PVES

new calculations with Coulomb distortions and dispersion corrections

first test at A1@MAMI investigating ^{12}C and ^{58}Ni