From outer space to deep inside: exploring neutron skins of nuclei

PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

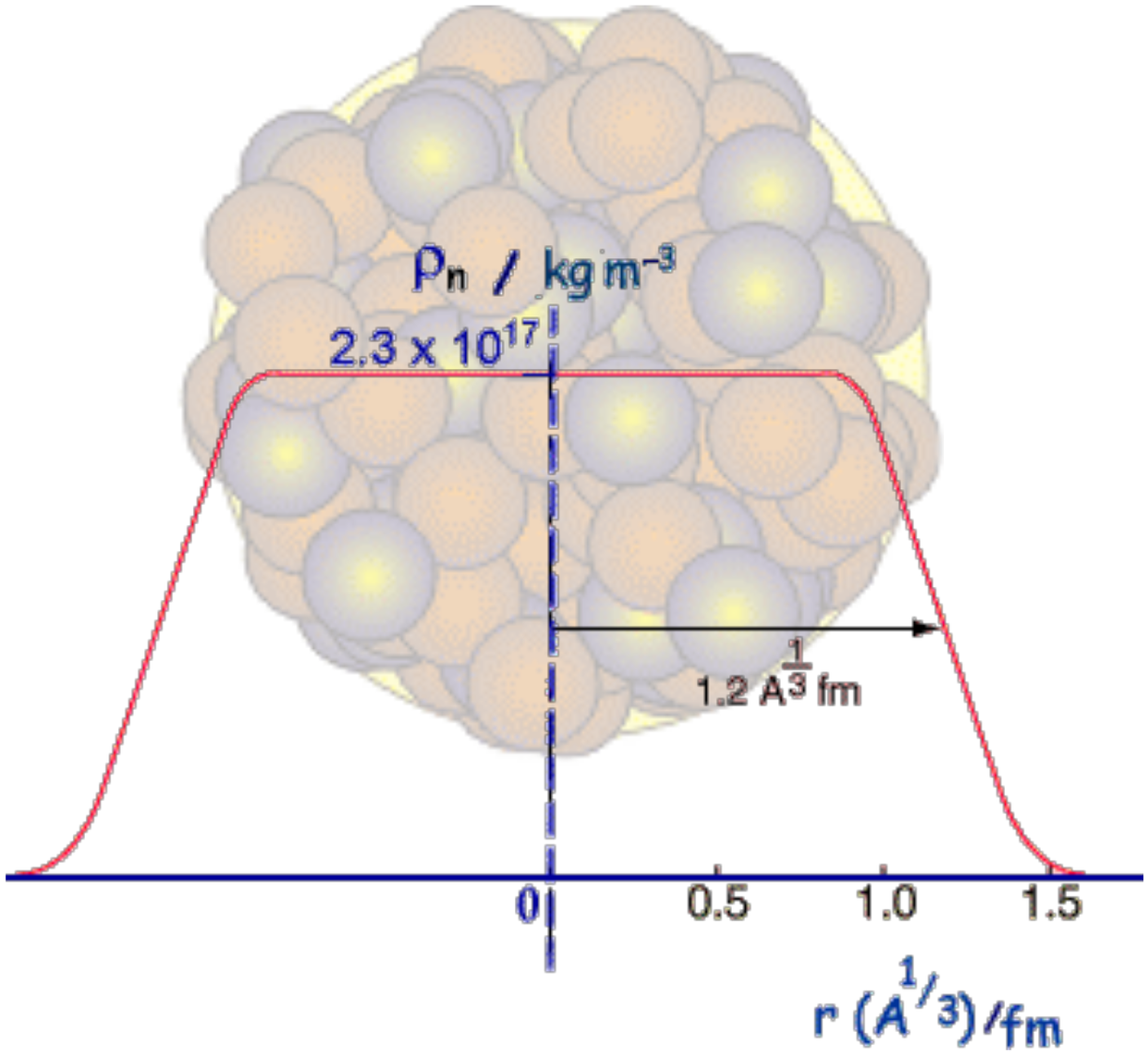
JG|U

New Vistas in Low-Energy Precision Physics (LEPP)

4-7 April 2016
Kupferbergterrasse Mainz

Neutron Skin for beginner

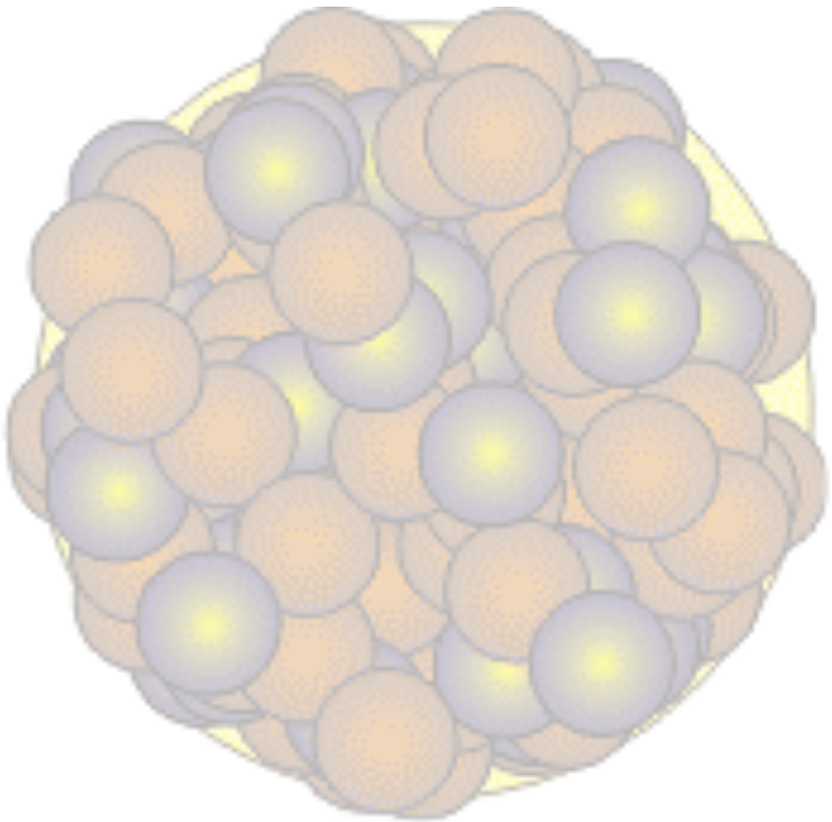
Nuclear charge radii



Where do the neutrons go?

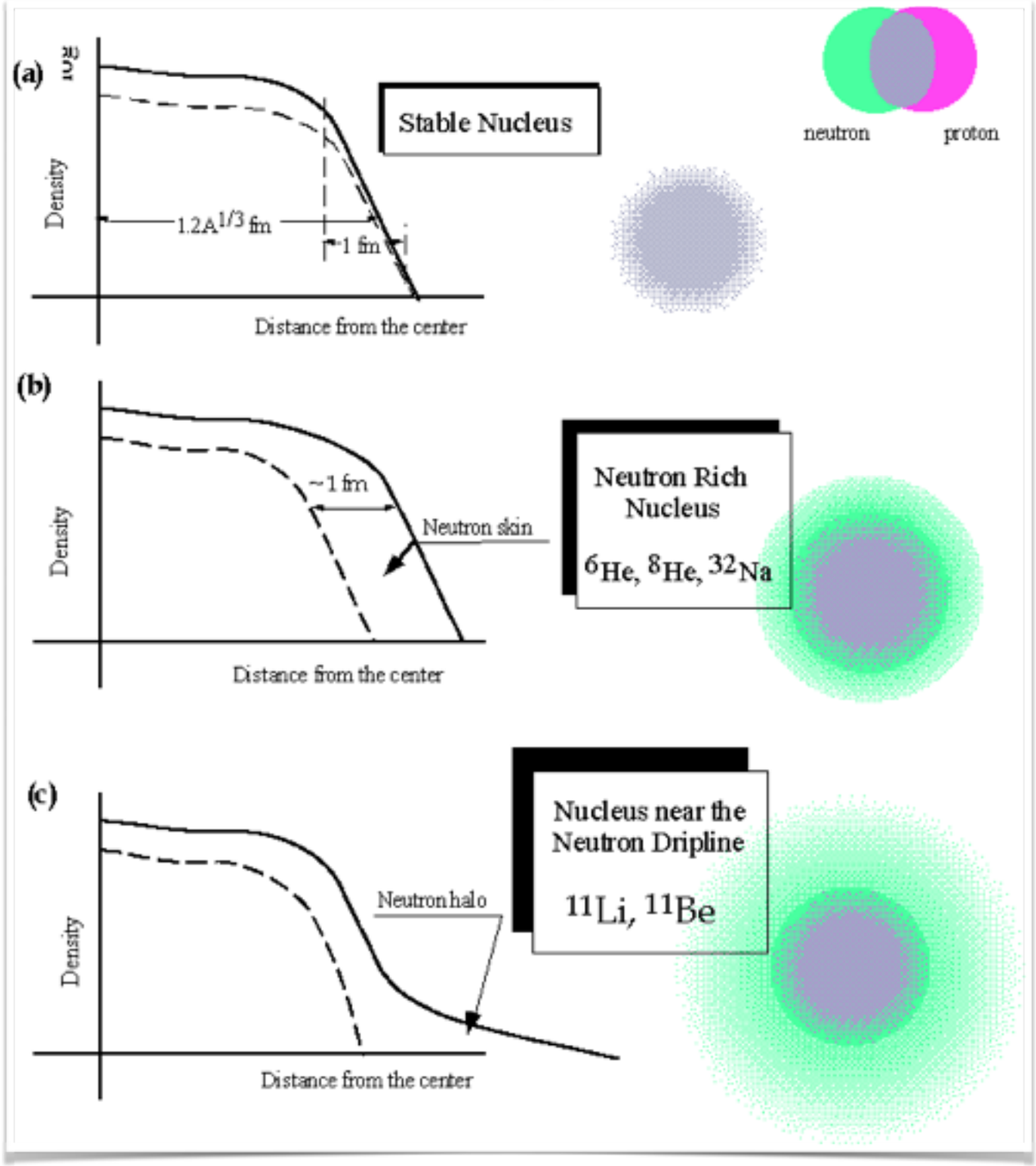
Neutron Skin for beginner

Where do the neutrons go?

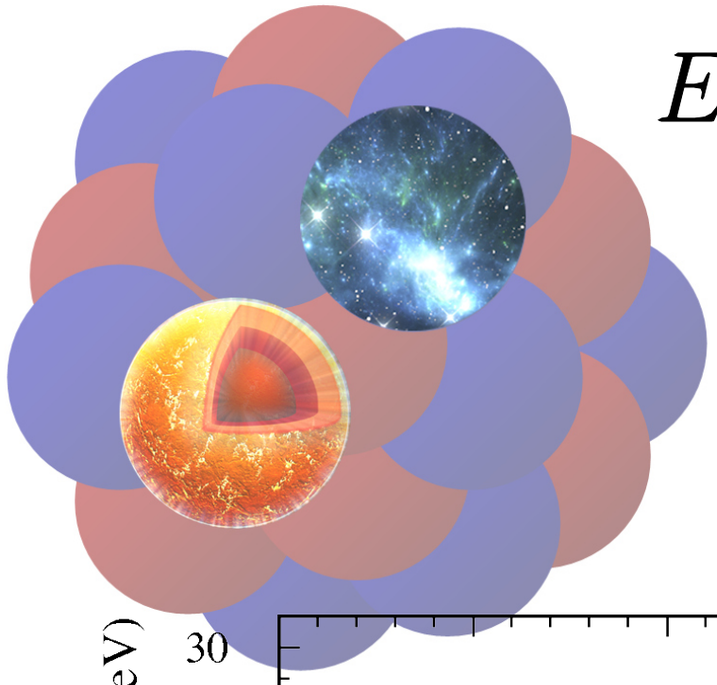


Pressure forces neutrons out against surface tension

→ EOS

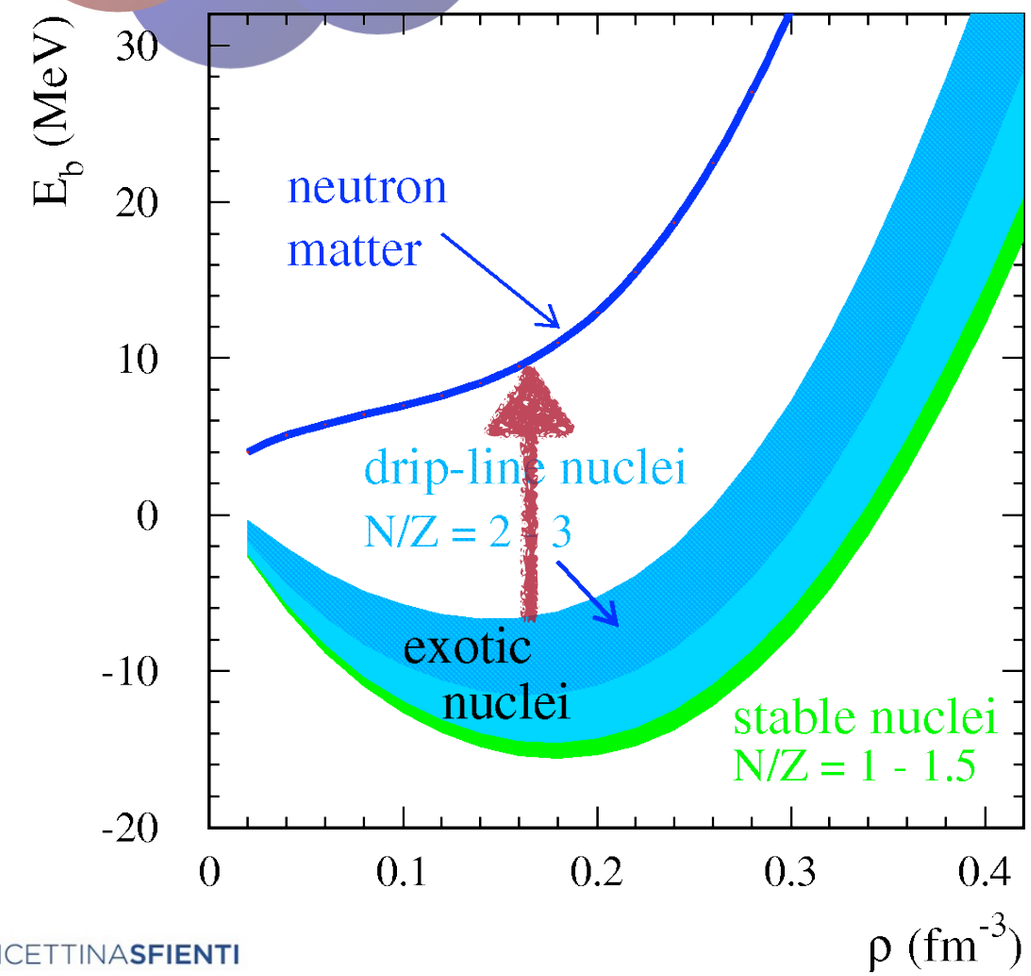


18-OM smaller 55-OM lighter ... same EOS



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

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



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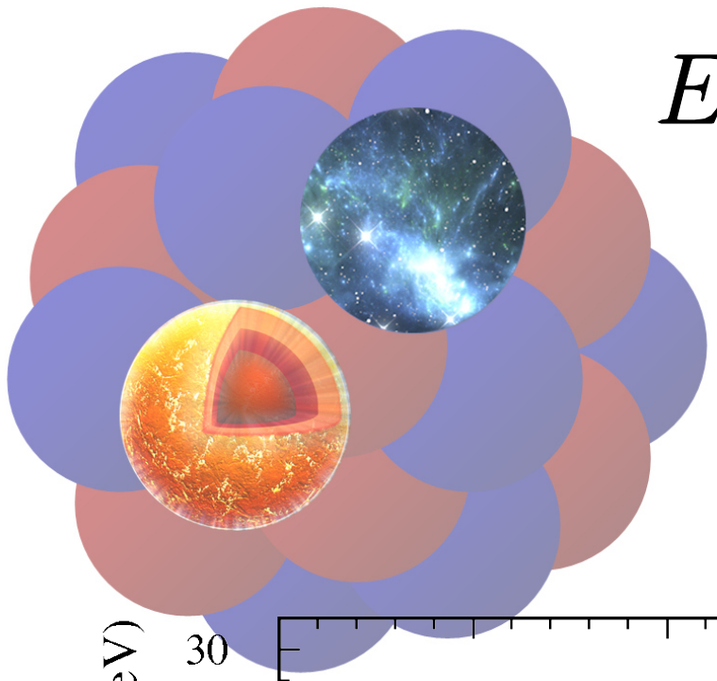

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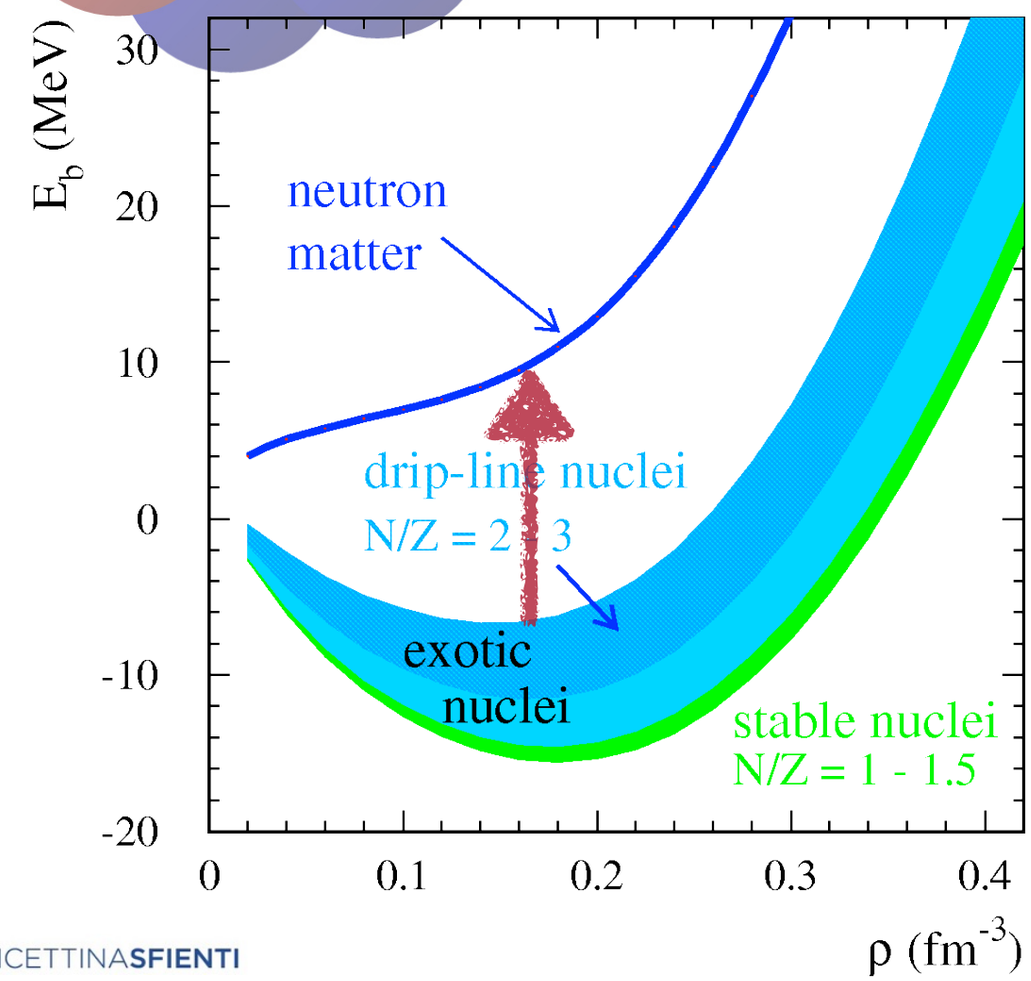

slope parameter

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

curvature parameter

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

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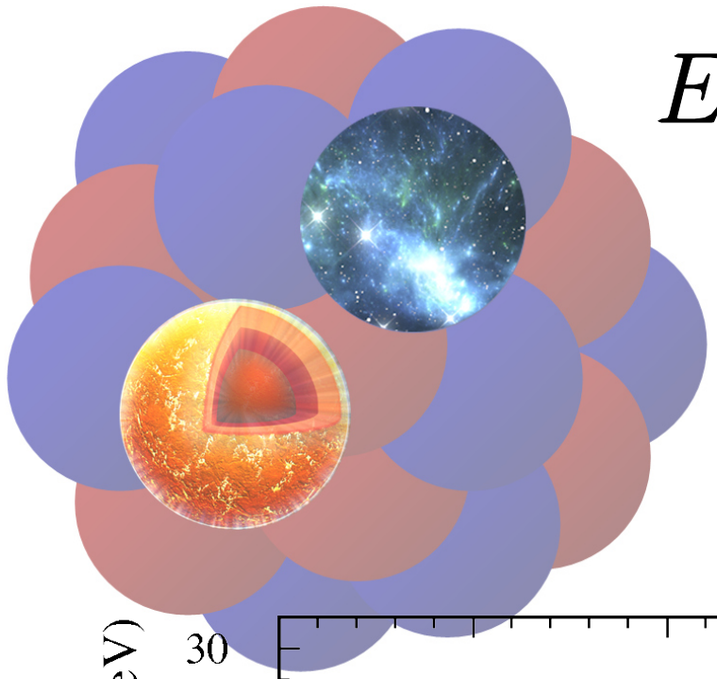

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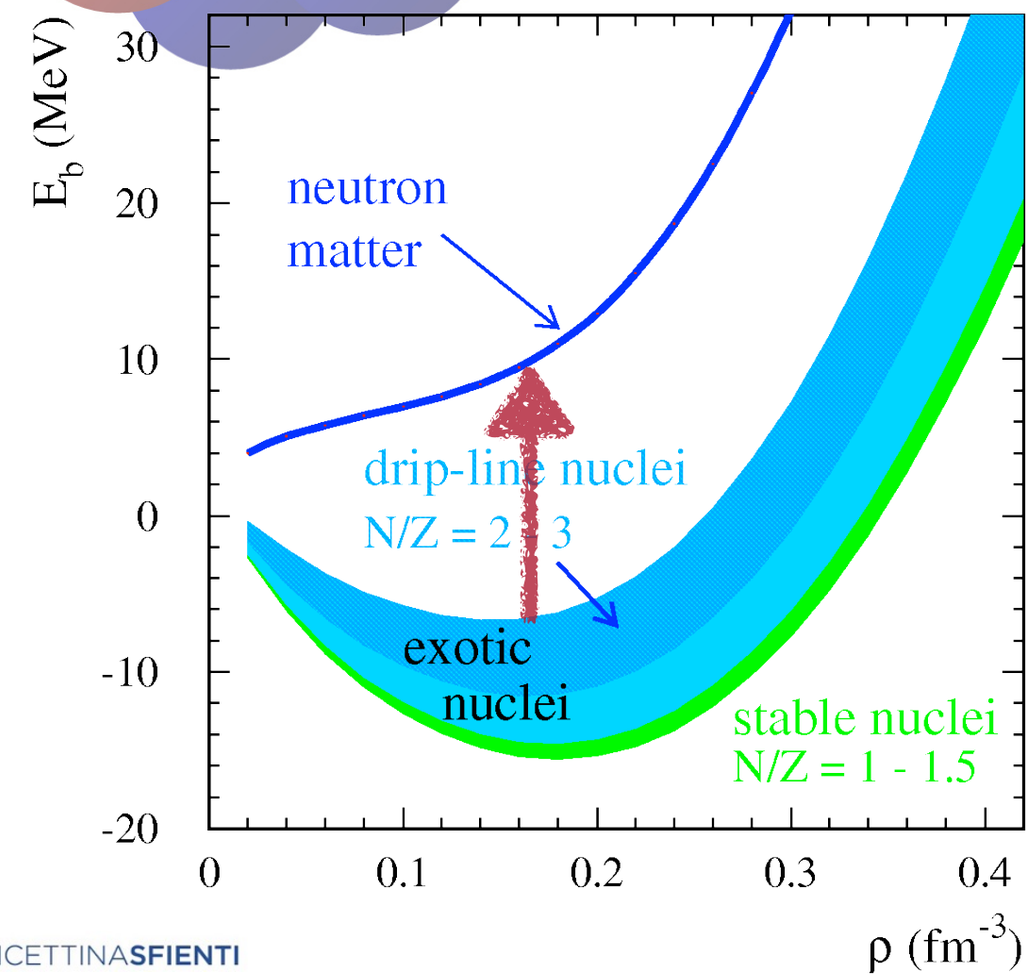
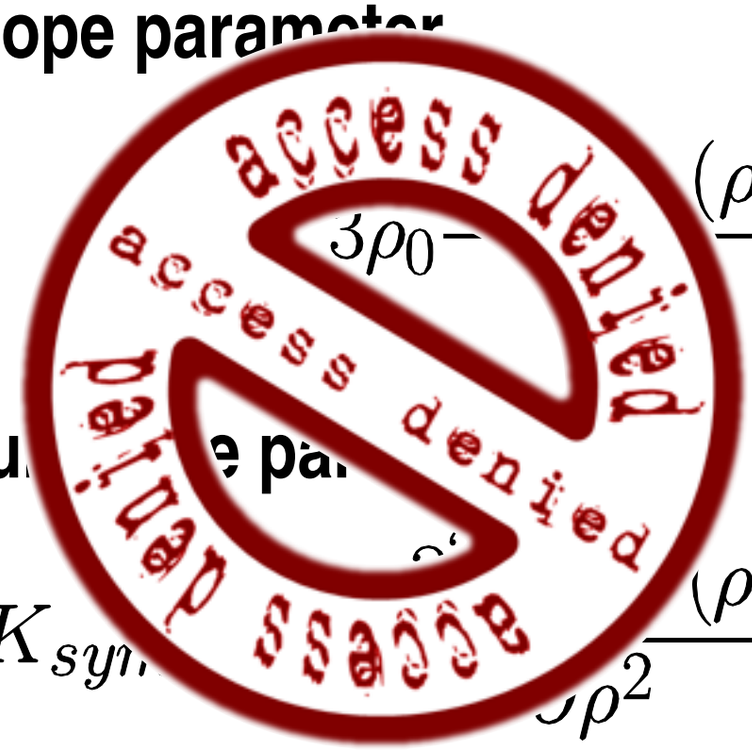


slope parameter

$$3\rho_0 - \left.\frac{(\rho)}{}\right|_{\rho_0}$$

curvature parameter

$$K_{sym} \left.\frac{(\rho)}{}\right|_{\rho_0}$$



CONCETTINASFIENTI

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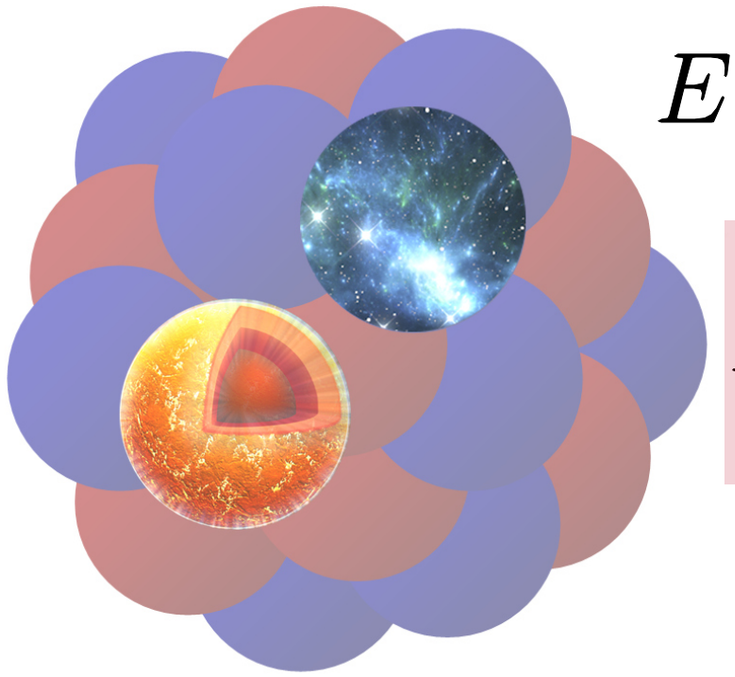

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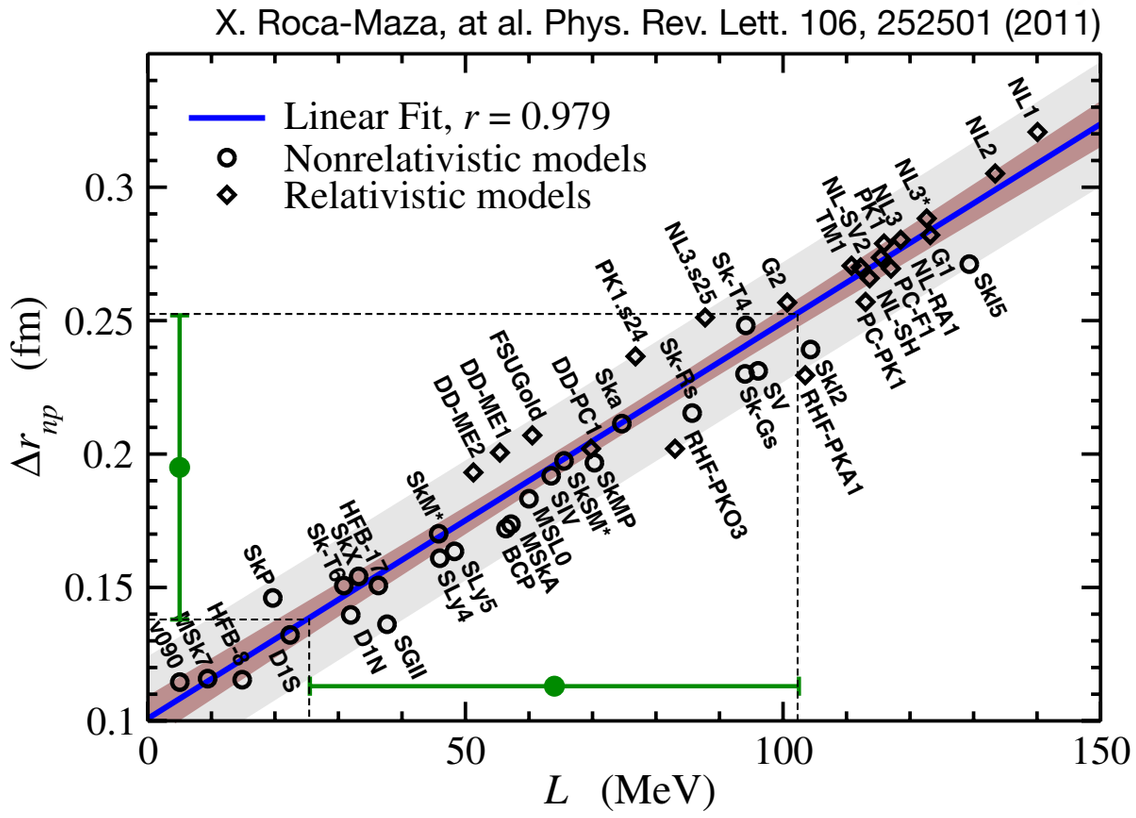

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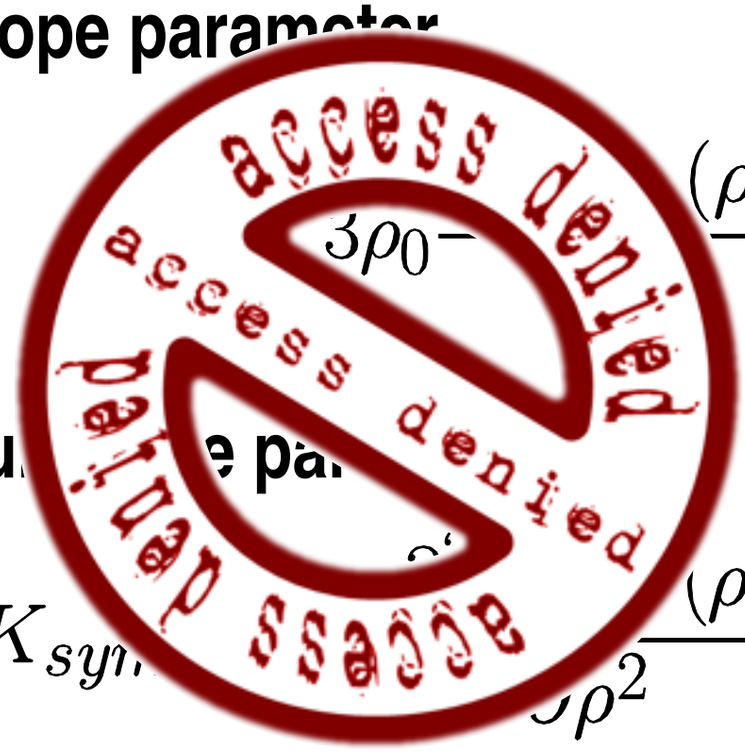


$$3\rho_0 - \left.\frac{(\rho)}{}\right|_{\rho_0}$$

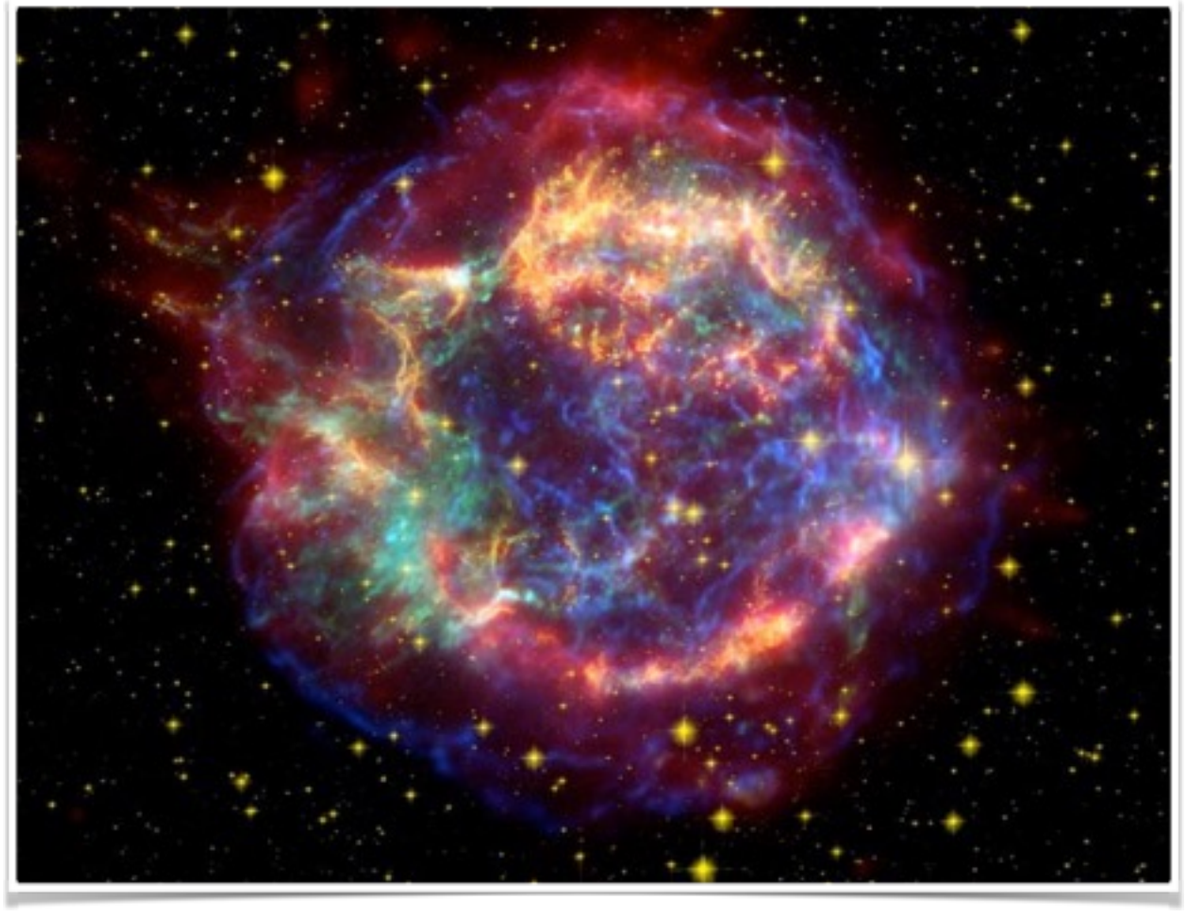
cu e pa

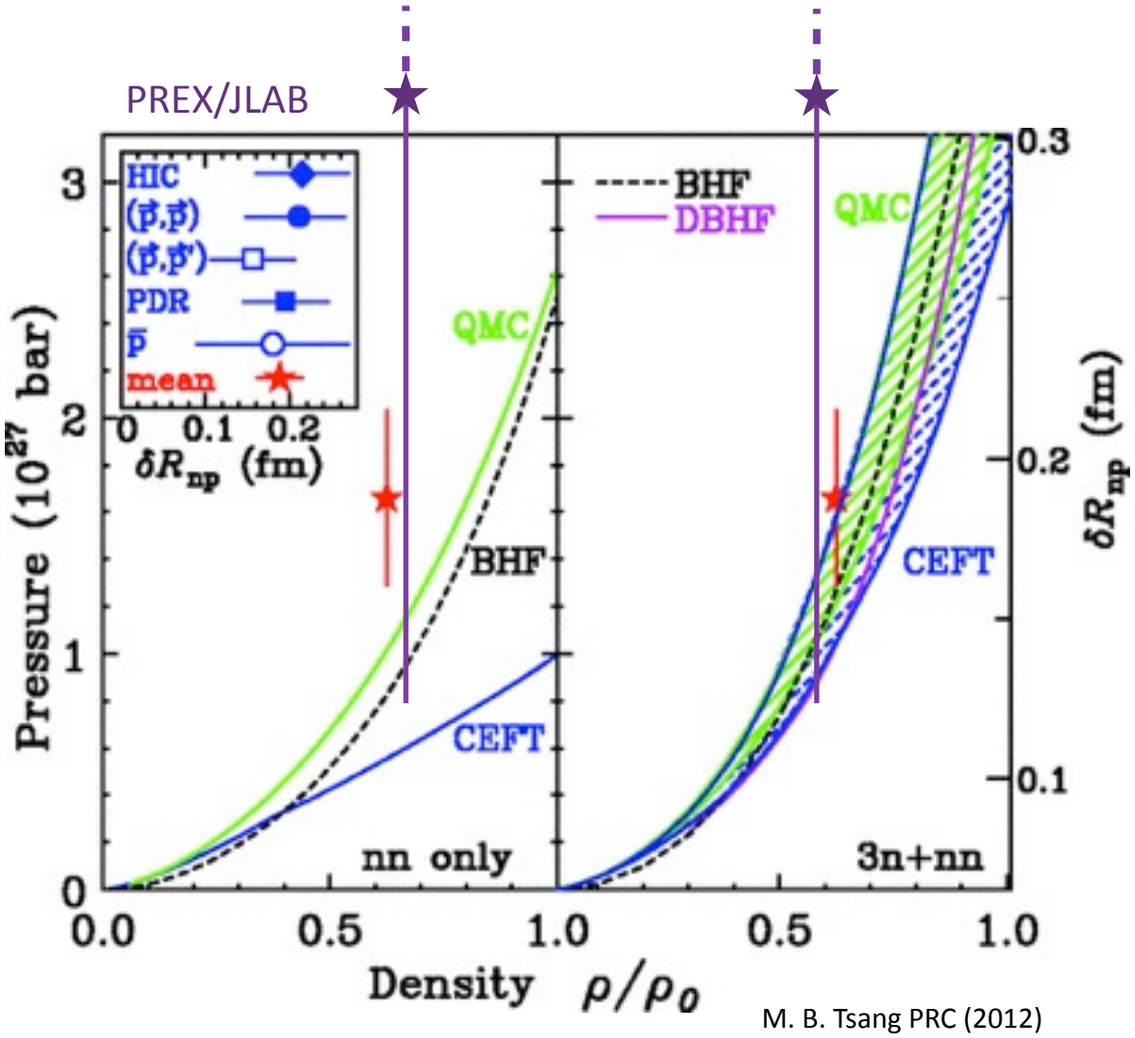
$$K_{sym} \qquad 9\rho^2 \left.\frac{(\rho)}{}\right|_{\rho_0}$$

CONCETTINASFIENTI

...from deep inside to outer space ...

Neutron skins constrain the EOS [@low ρ]





M. B. Tsang PRC (2012)

Pressure @ low ρ ⟶ Crust thickness

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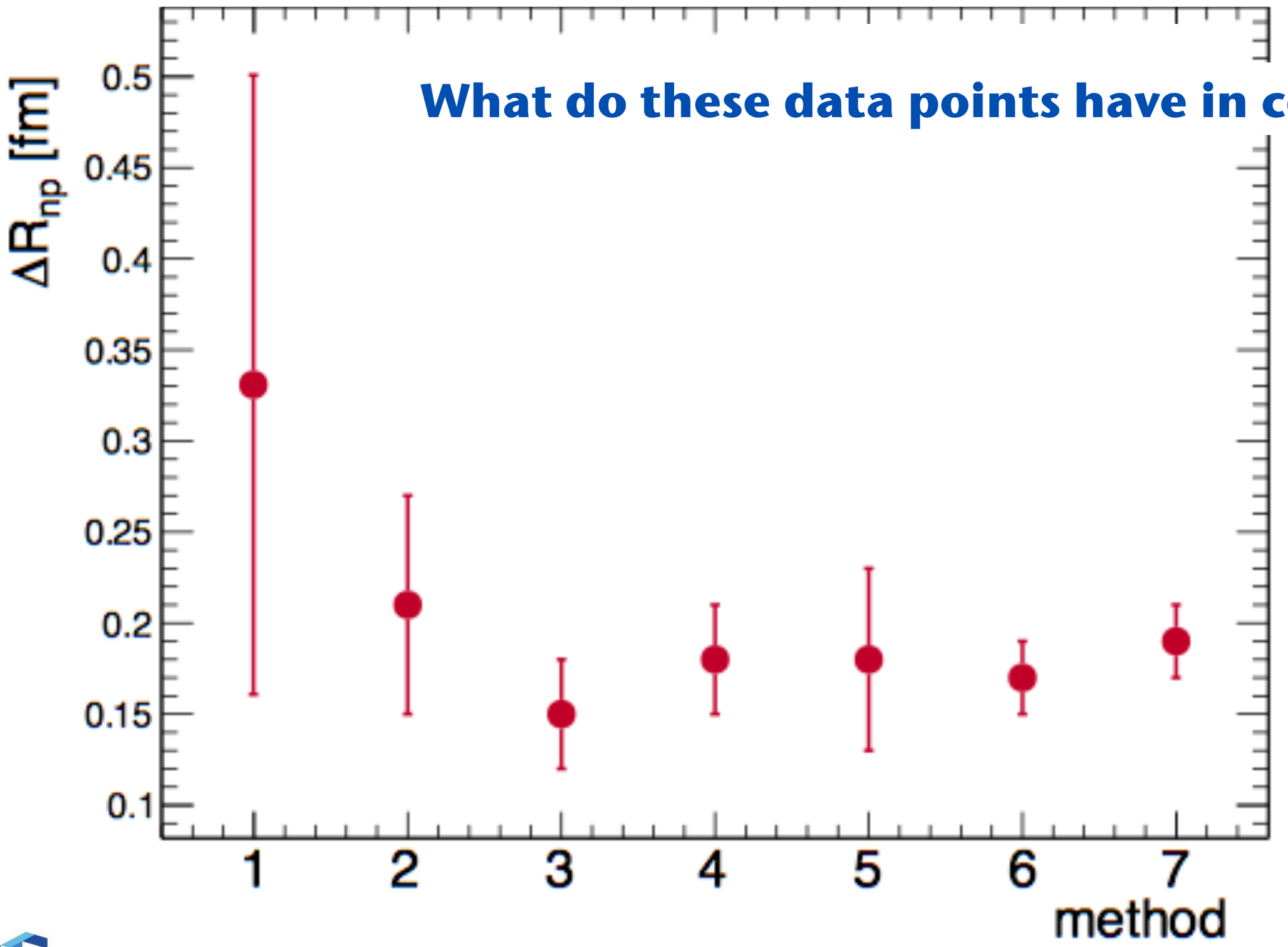
The answer to the ultimate question



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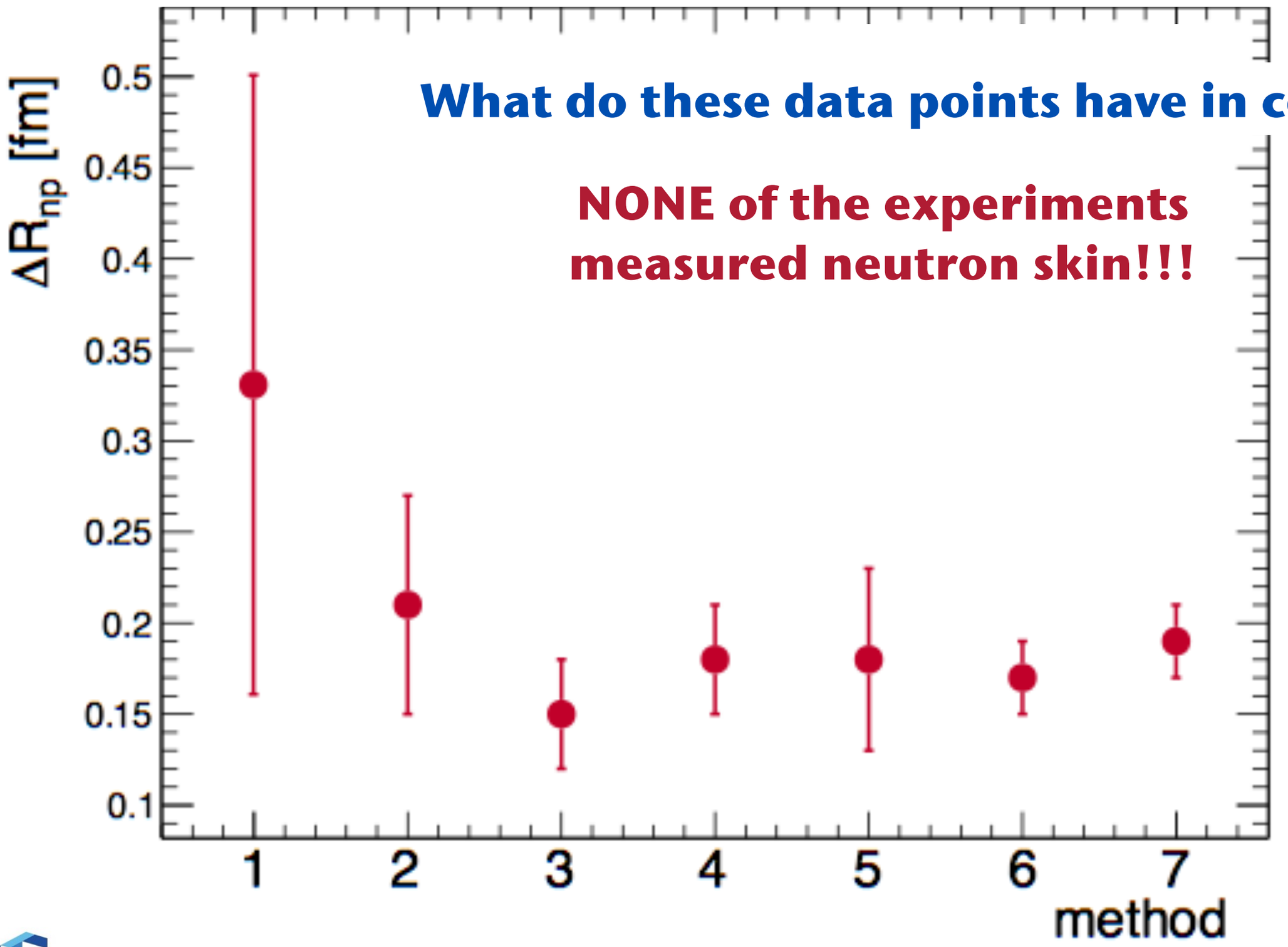


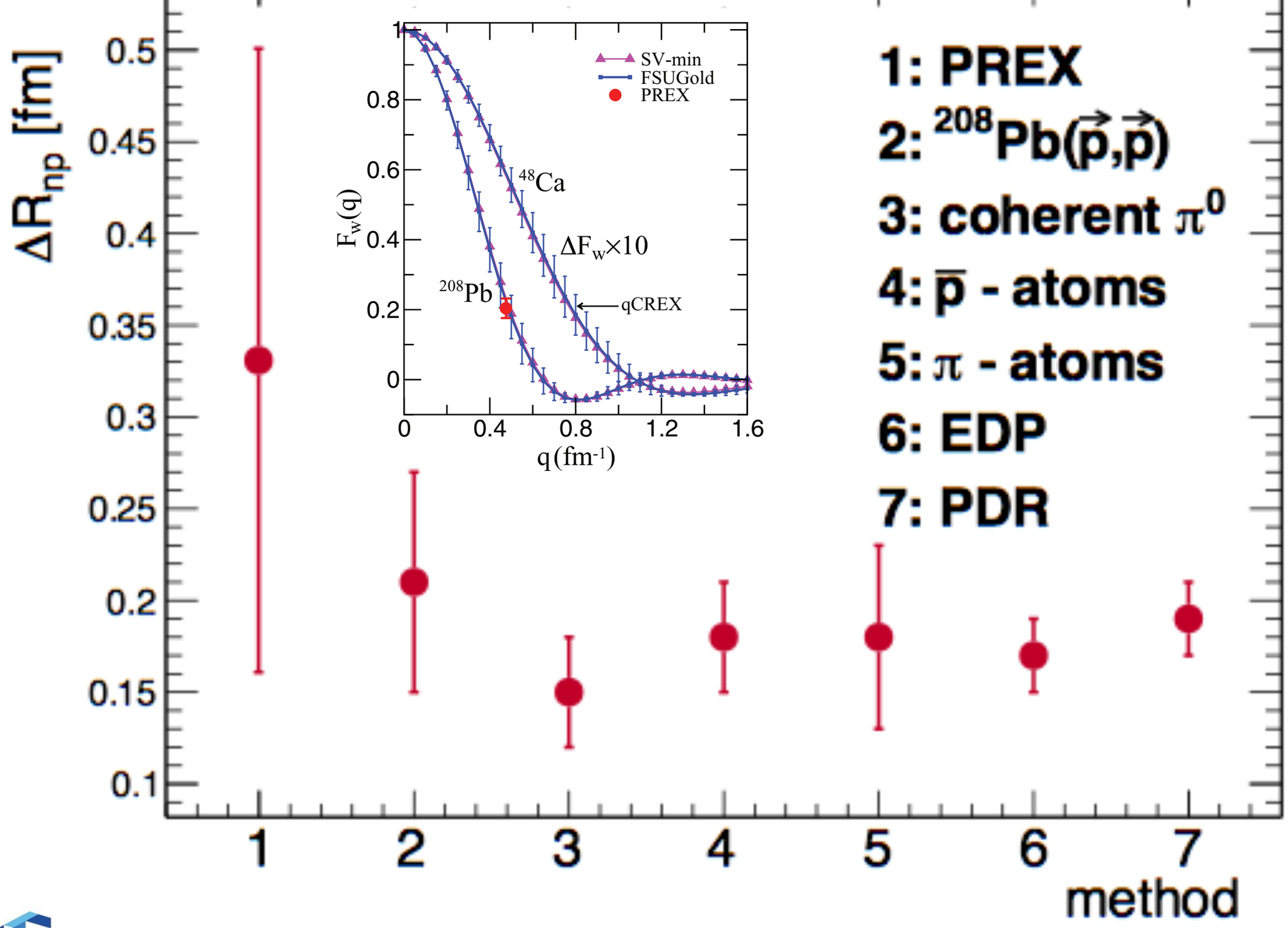
What do these data points have in common?

NONE of the experiments measured neutron skin!!!

WHY?

....do we produce these plots in the first place?!?!

PHYSICAL REVIEW C88, 034325 (2013)



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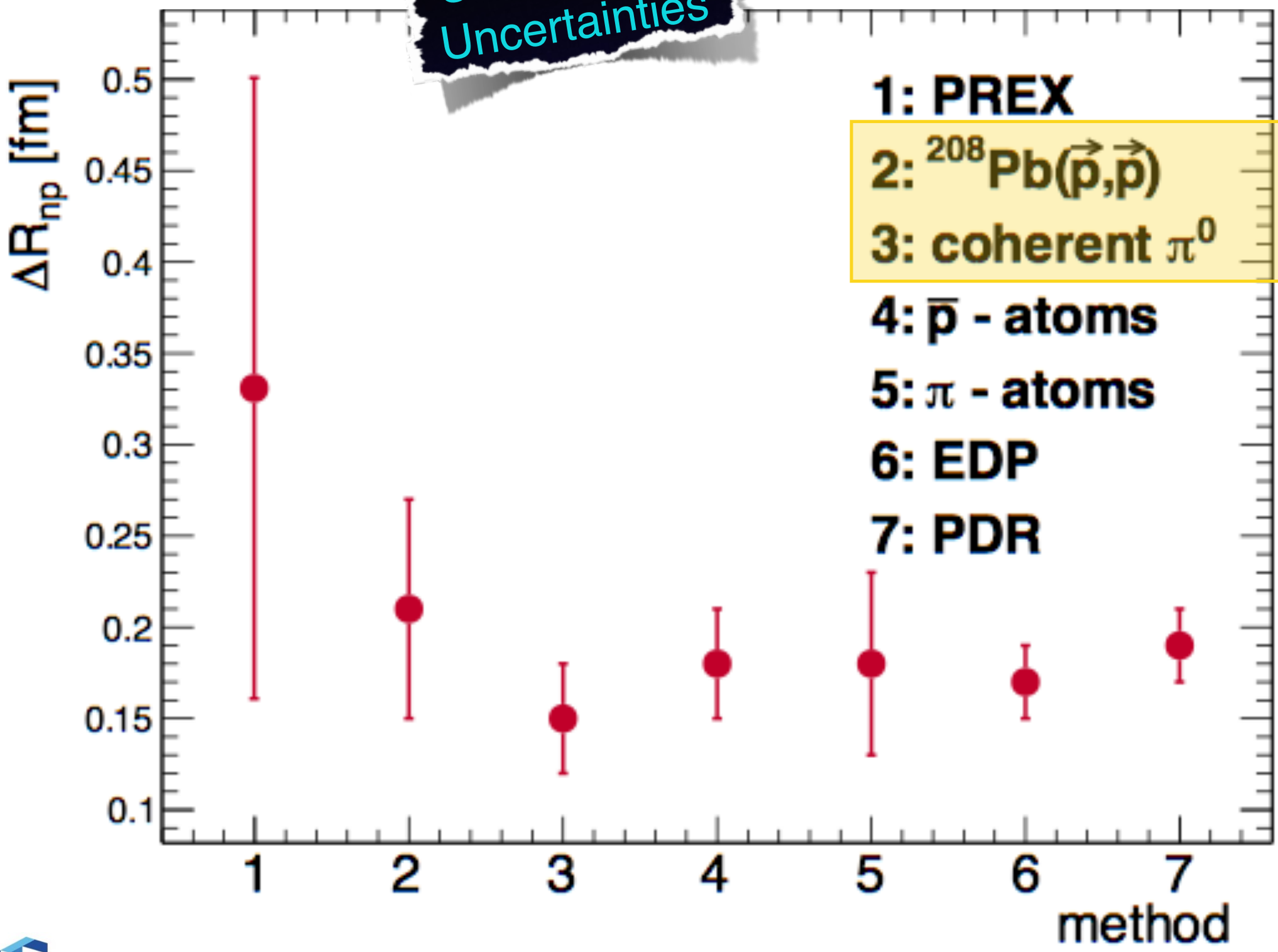
WHAT?

Uncontrolled Uncertainties

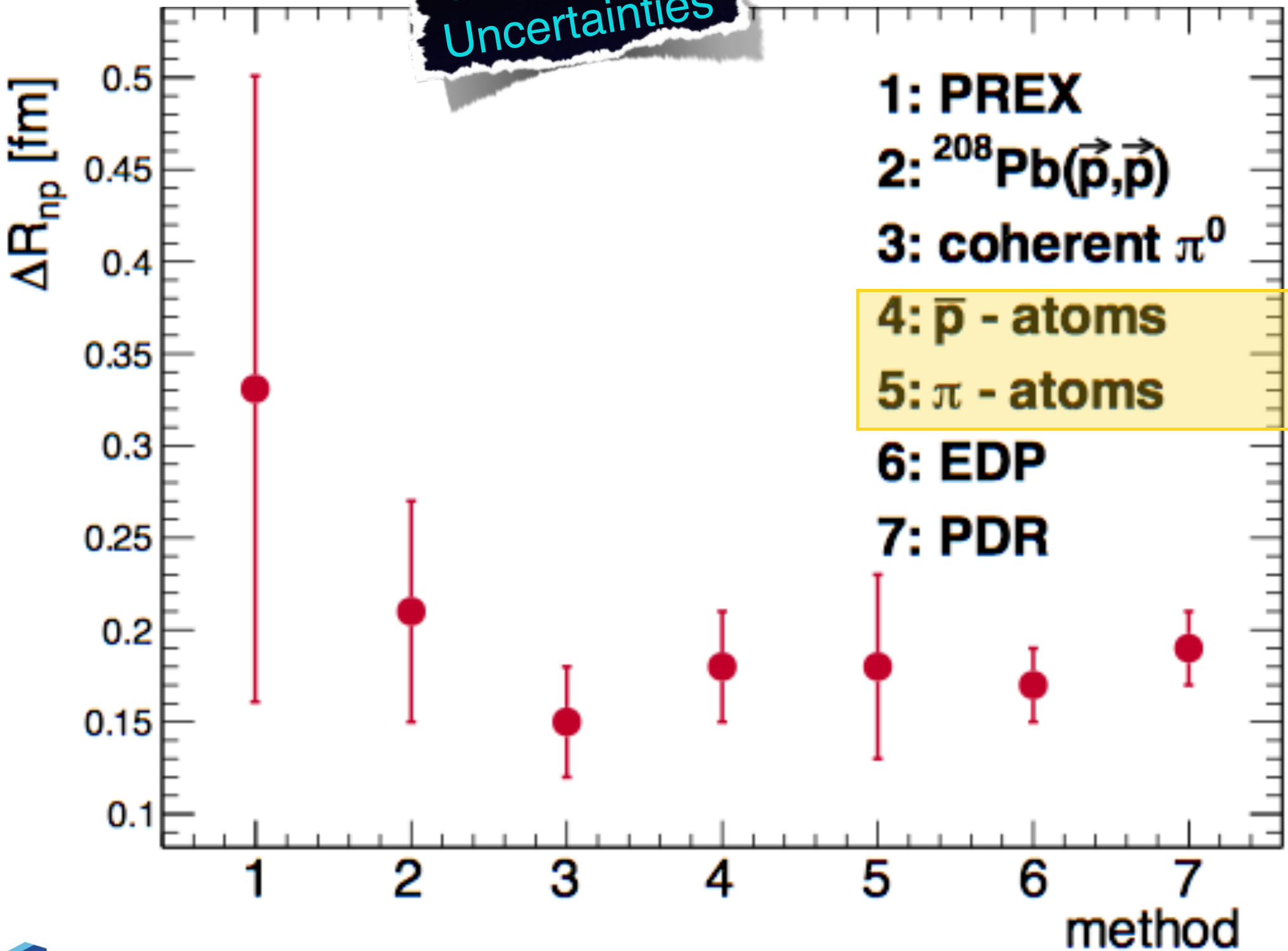


ISI + FSI

(SYST)$_{THEO}$??

WHAT?

Uncontrolled Uncertainties



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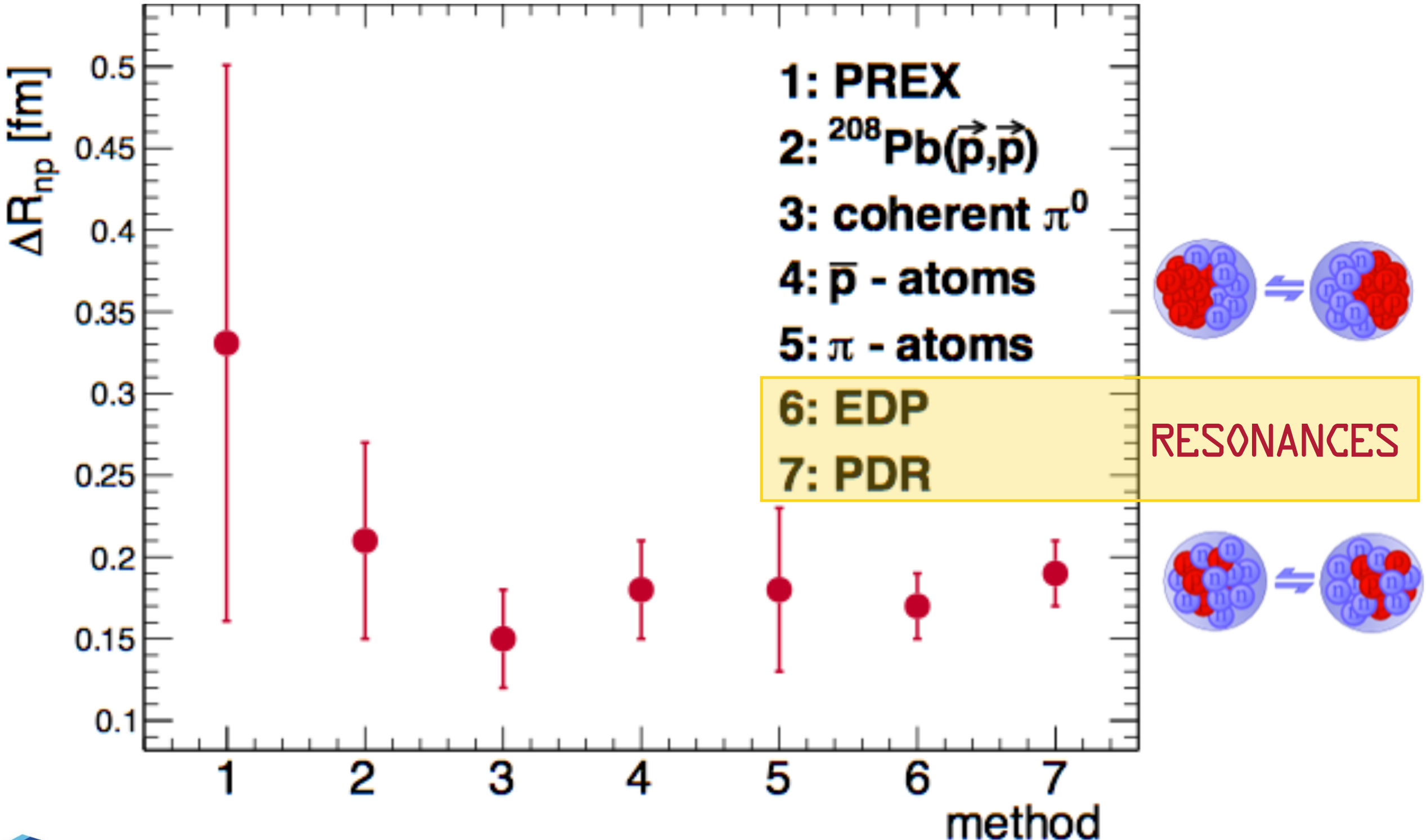
WHAT?



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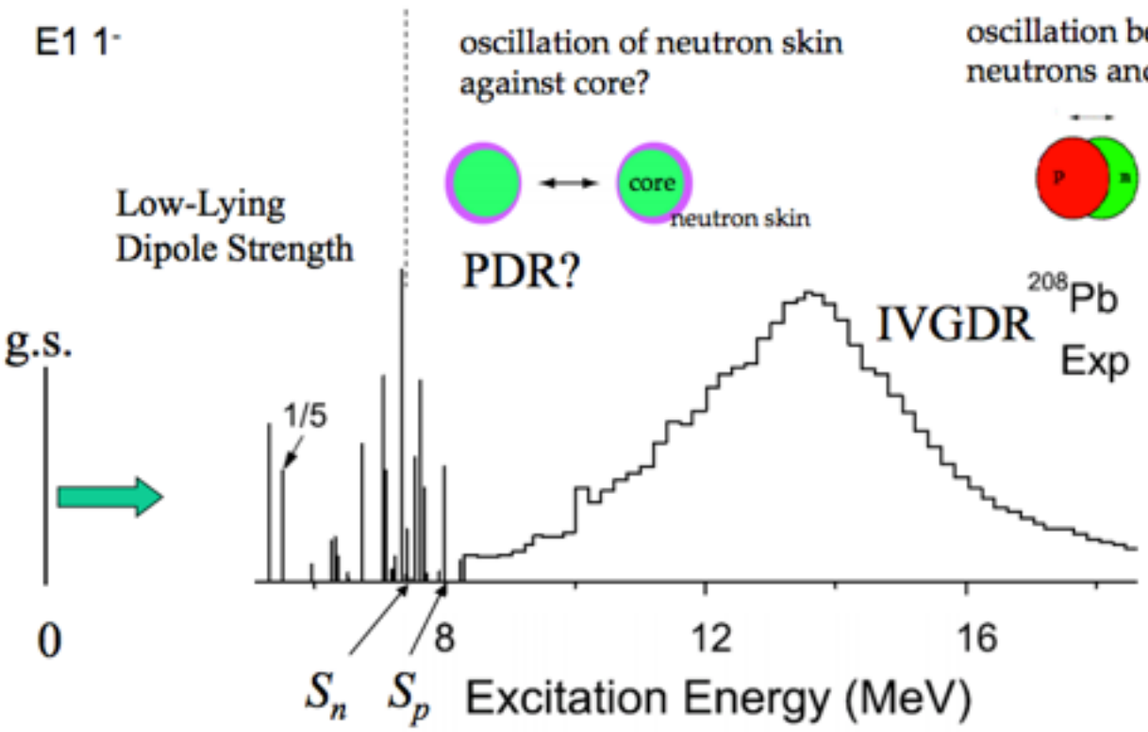
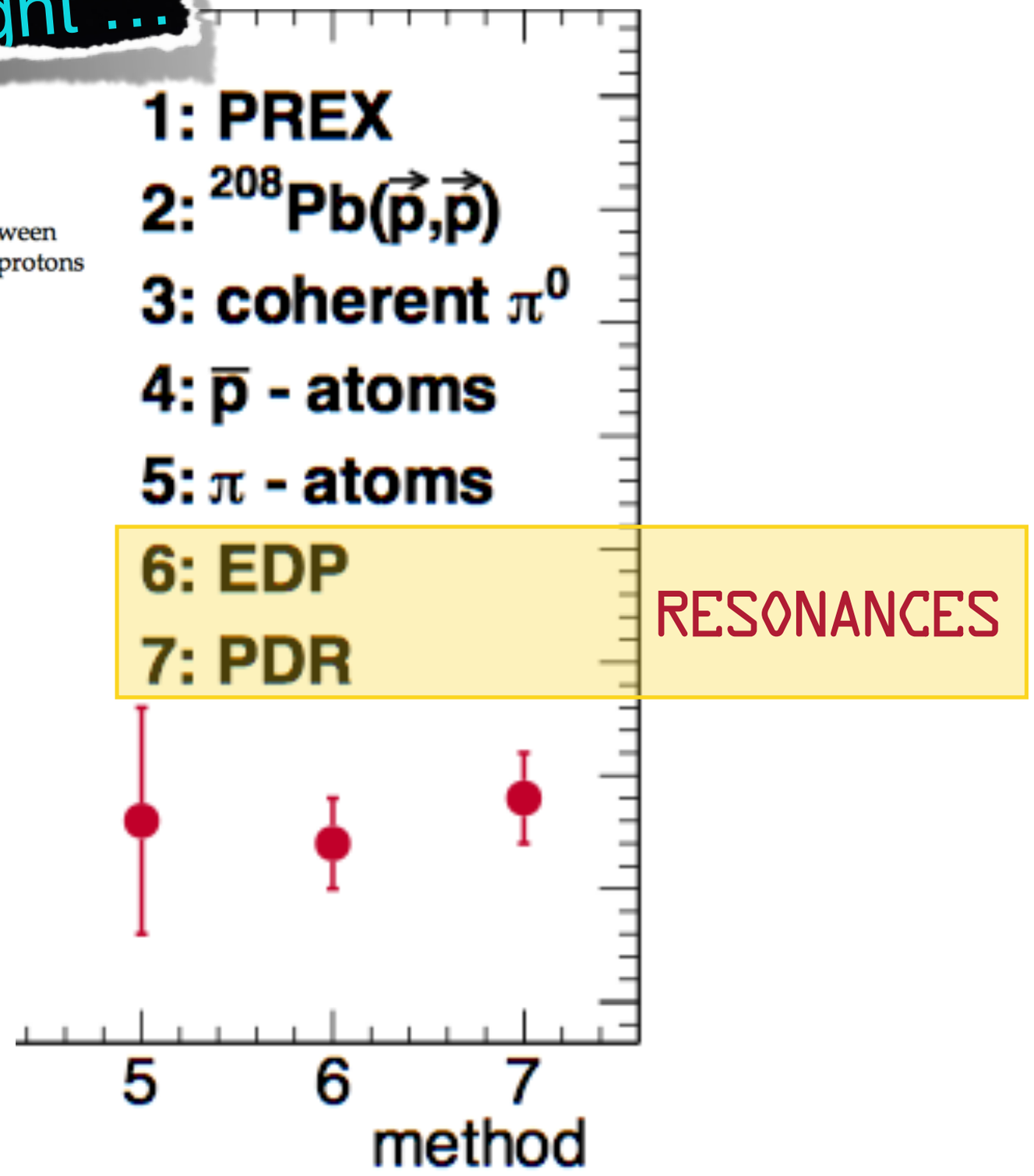
WHAT?

Enormous progress in sight …



$$\alpha_D = \frac{\hbar c}{2\pi^2}\int\frac{\sigma_{abs}}{\omega^2}d\varpi = \frac{8\pi}{9}\int\frac{dB(E1)}{\omega}$$

A. Tamii et al., Phys. Rev. Lett. 107, 062502 (2001)



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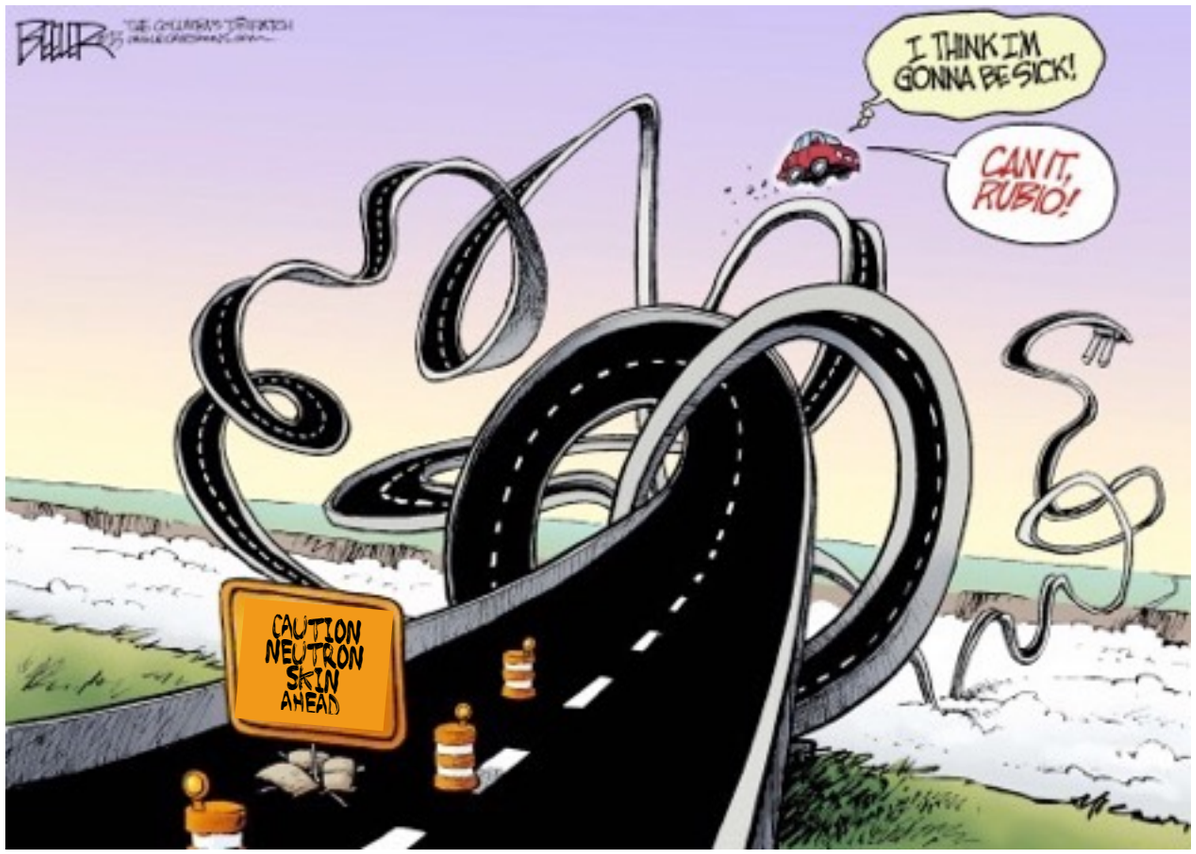
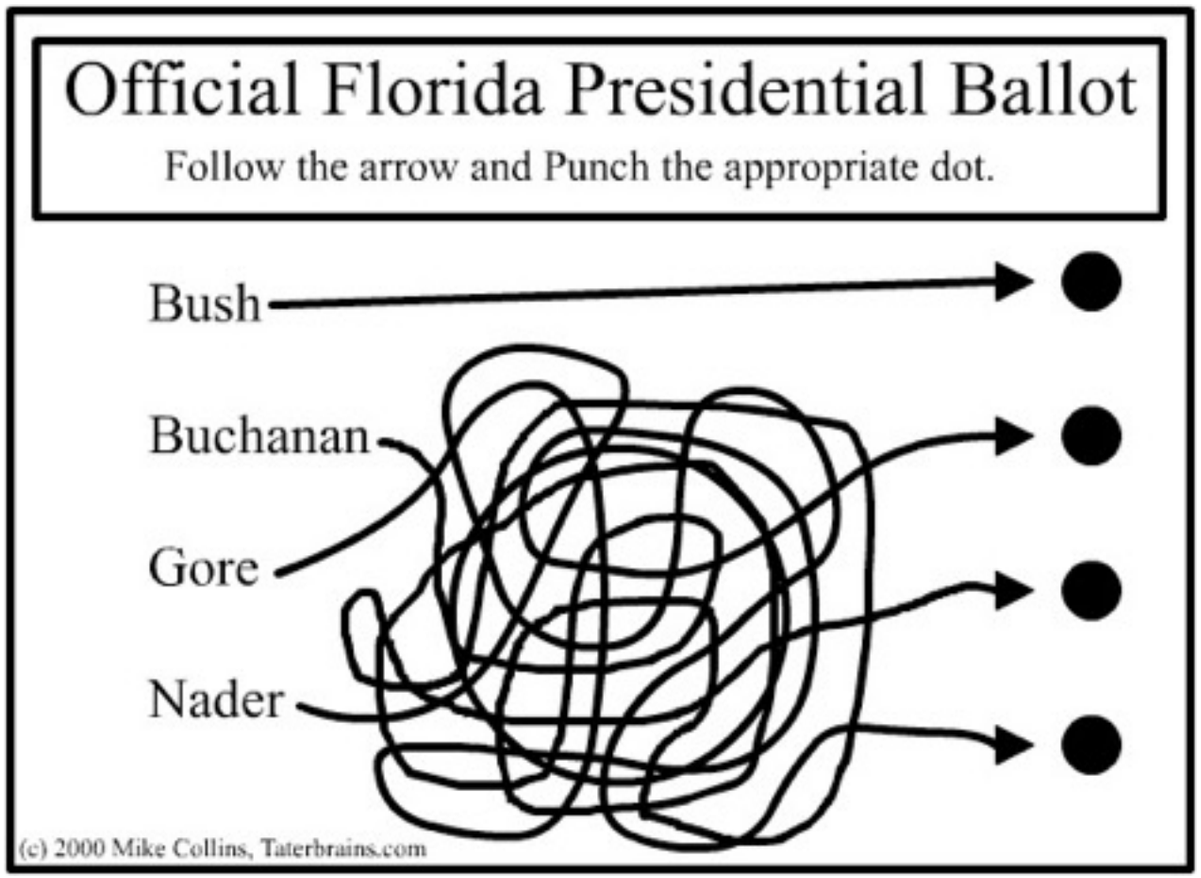
The long winding road ....



...FROM MEASURABLE OBSERVABLES TO THE NEUTRON SKIN

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

The long winding road ....



...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

Theory informing experiment

...FROM MEASURABLE OBSERVABLES TO THE NEUTRON SKIN

- Quantitative assessment of both statistical and systematic errors; theory must provide error bars!
  Uncertainty quantification and covariance analysis (theoretical errors & correlations)

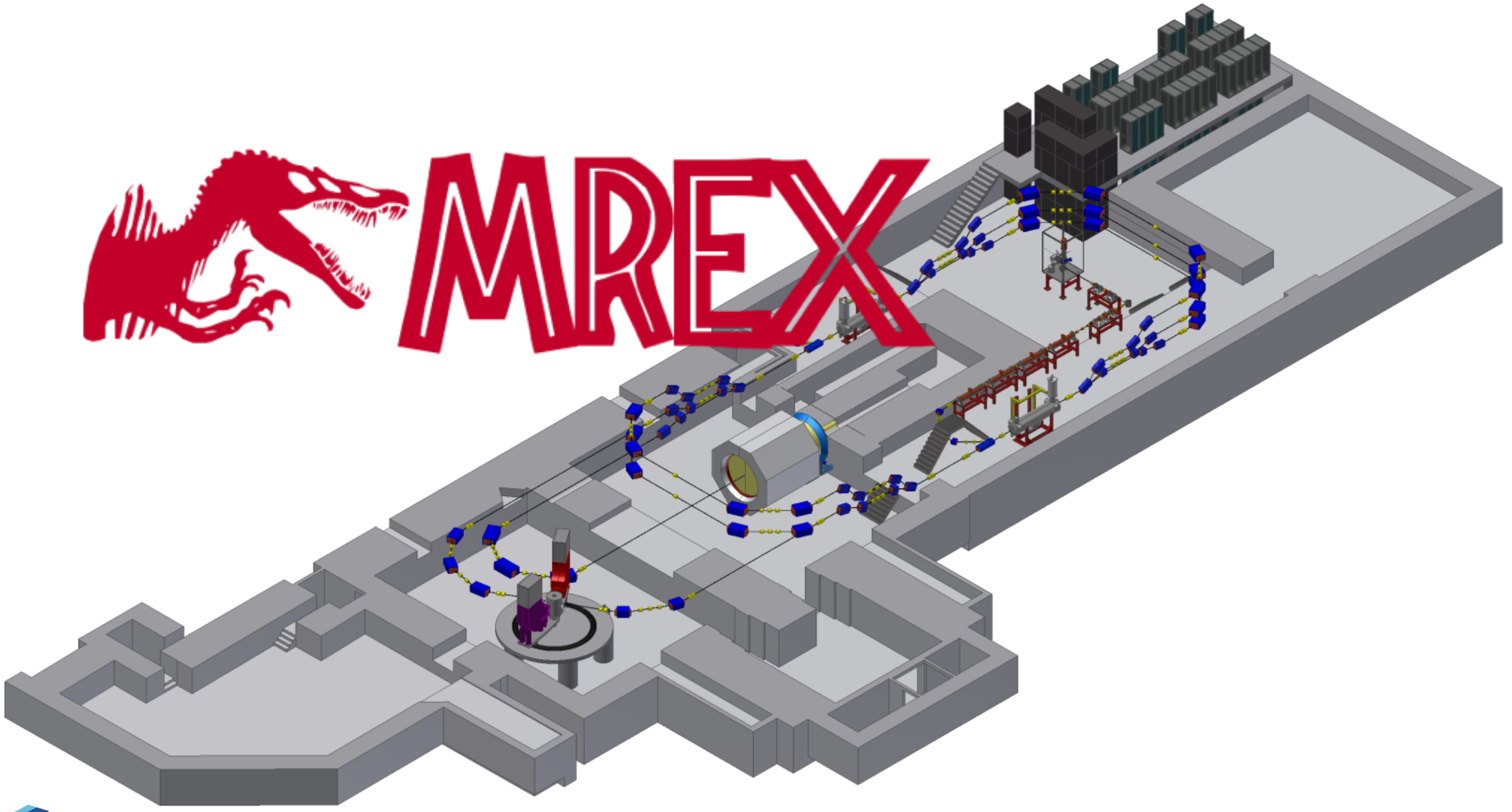
- Precision required in the determination of the neutron radius/skin?
  - As precisely as "humanly possible" - fundamental nuclear structure property
  - To strongly impact Astrophysics?
  - What astrophysical observables to benchmark?

- Is there a need for more than one Q-square point?
  Radius and diffuseness … the whole form factor?

- Is there a need for a systematic study over "many" nuclei?
  PREX, CREX, SREX, ZREX, …

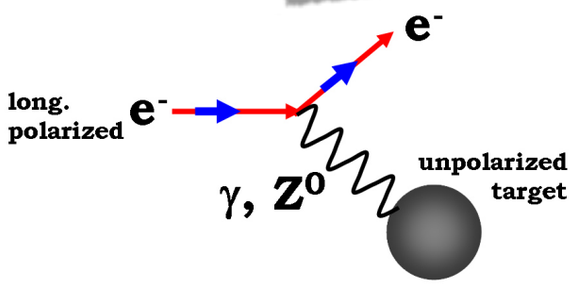
Neutron Skin@Mainz

MESA: Parity Violation



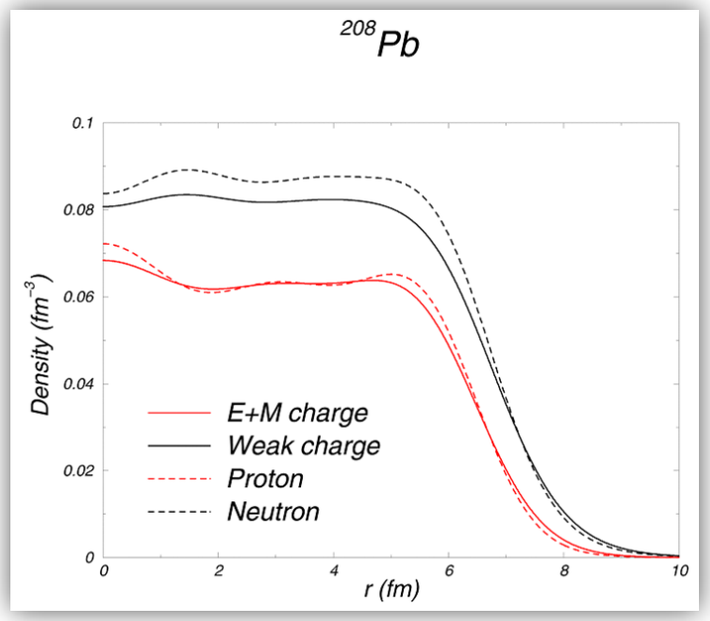
Enormously Clean … Extraordinarily Expensive!

PVES



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

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



MREX

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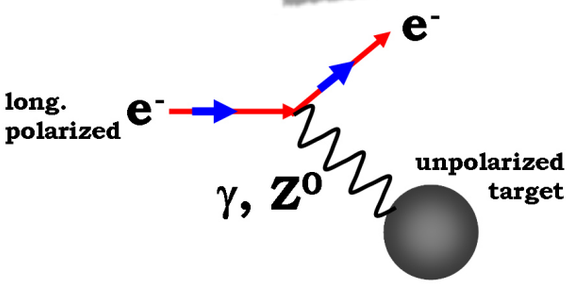

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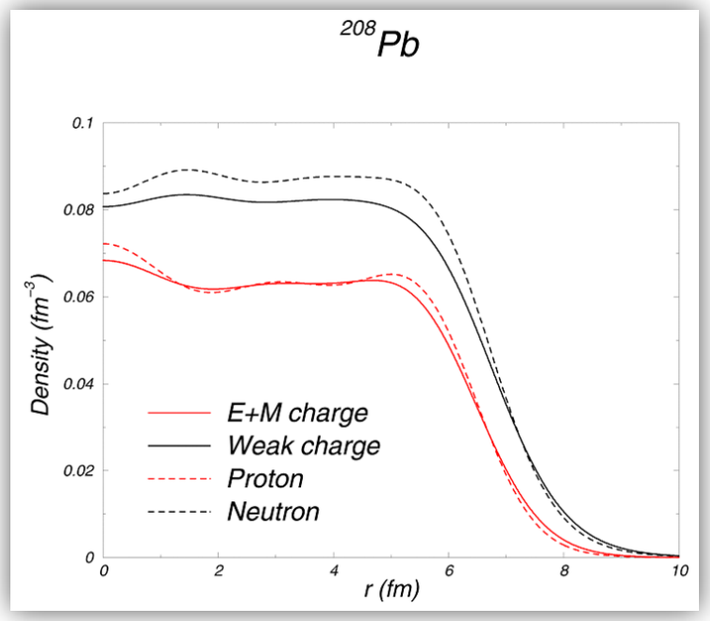

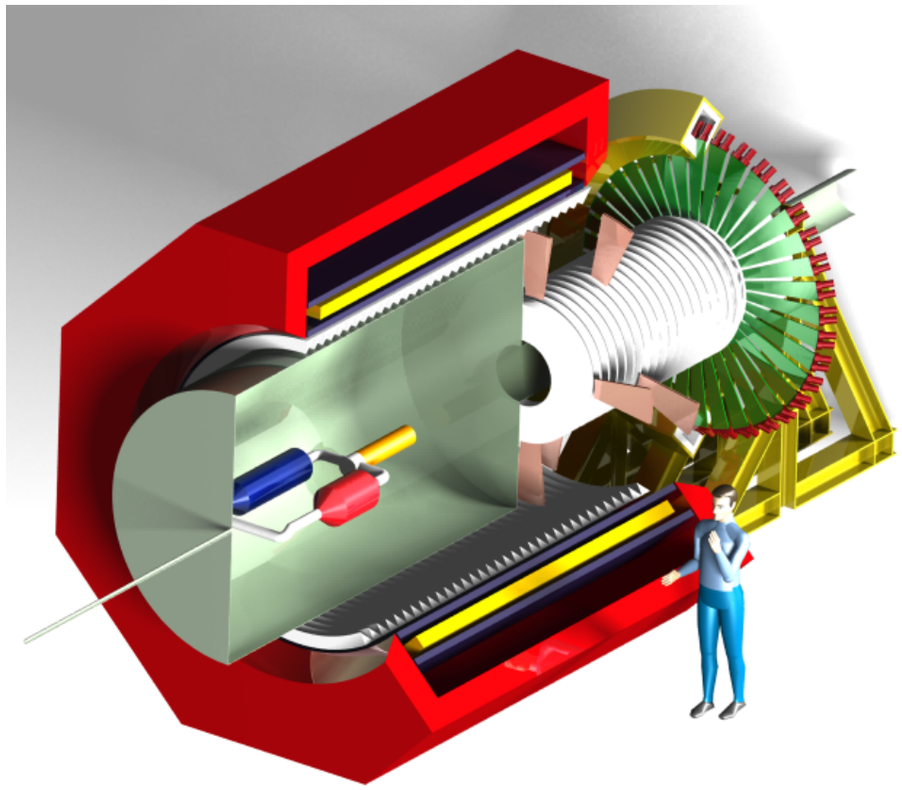

Full azimuthal coverage⇔**4xstat**

MREX

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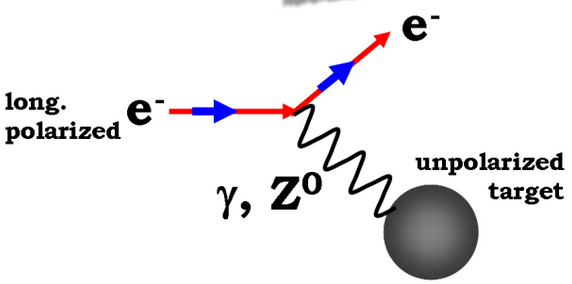

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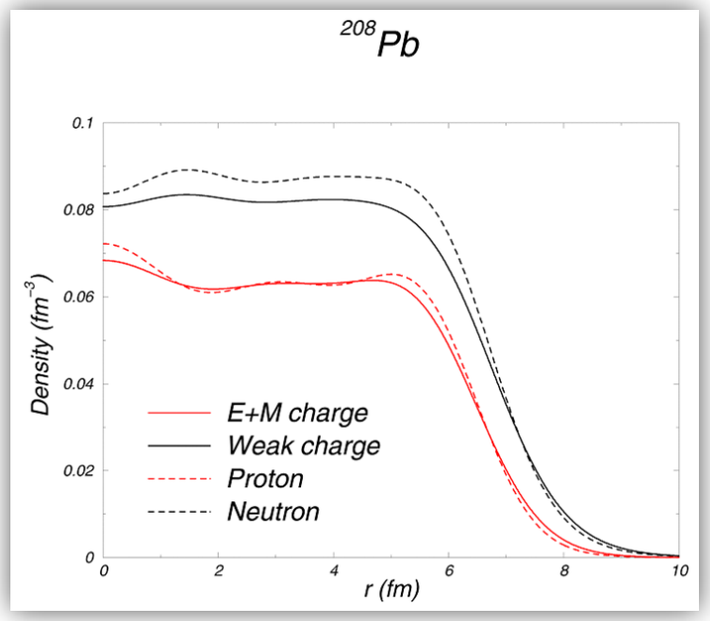

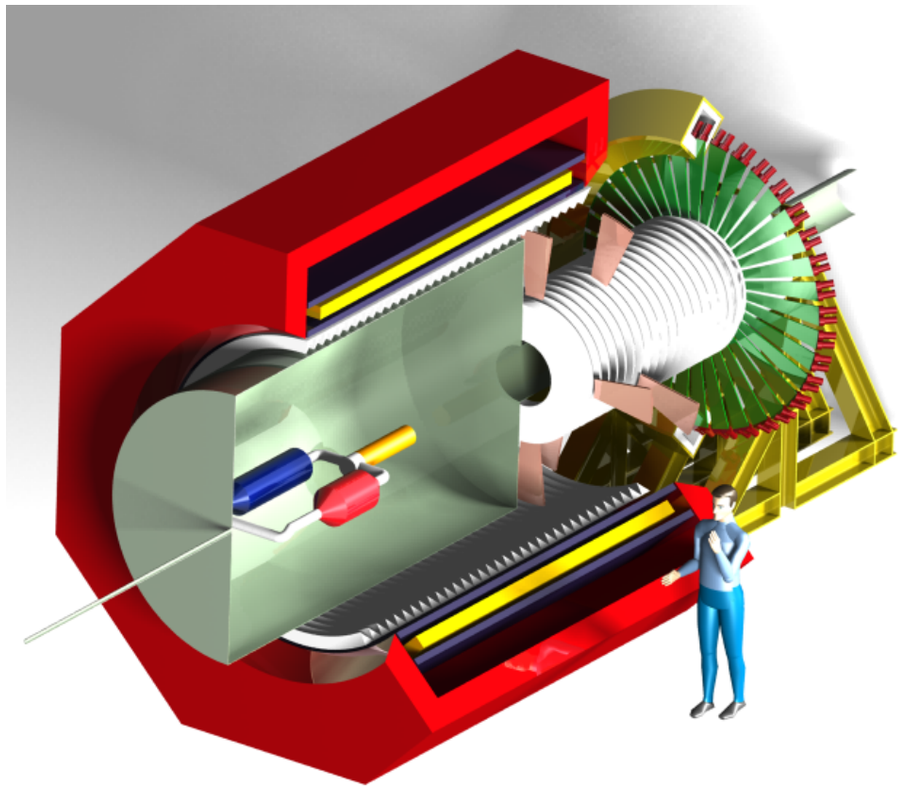

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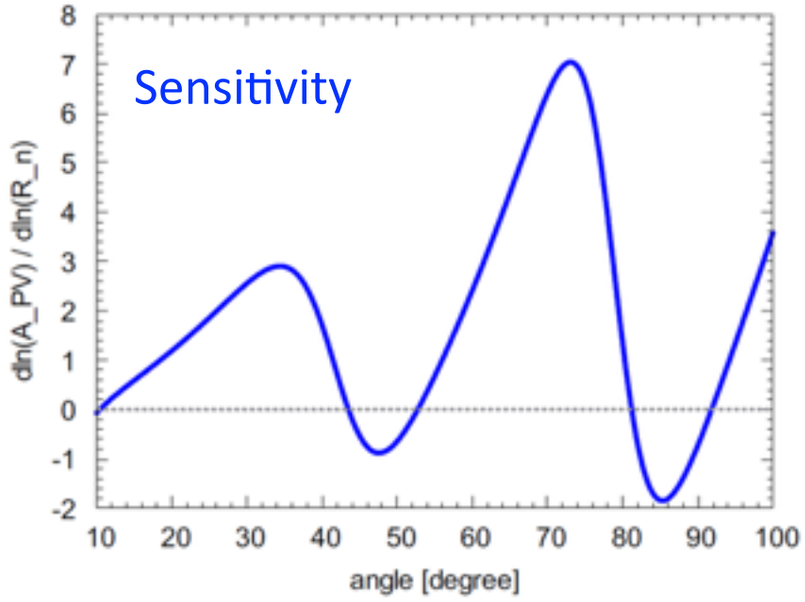

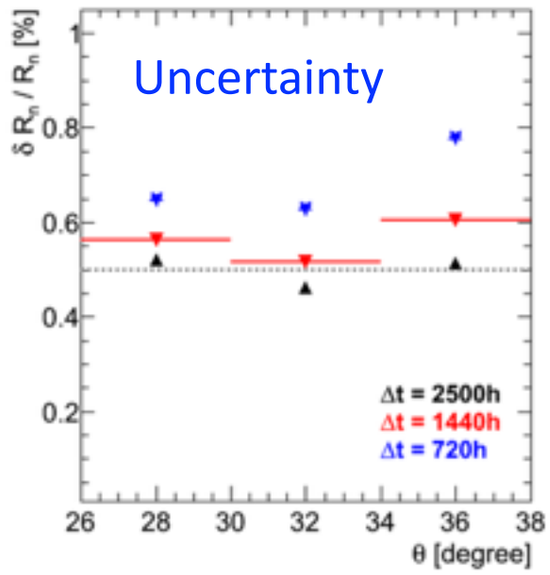

Assuming same PREX luminosity:

Δθ=4° : Rate=8.25 GHz, A_{PV}=0.66 ppm

1440h ➜ $\delta R_n/R_n$ = 0.5%

(assuming 1% syst. $\delta A_{PV}/A_{PV}$)

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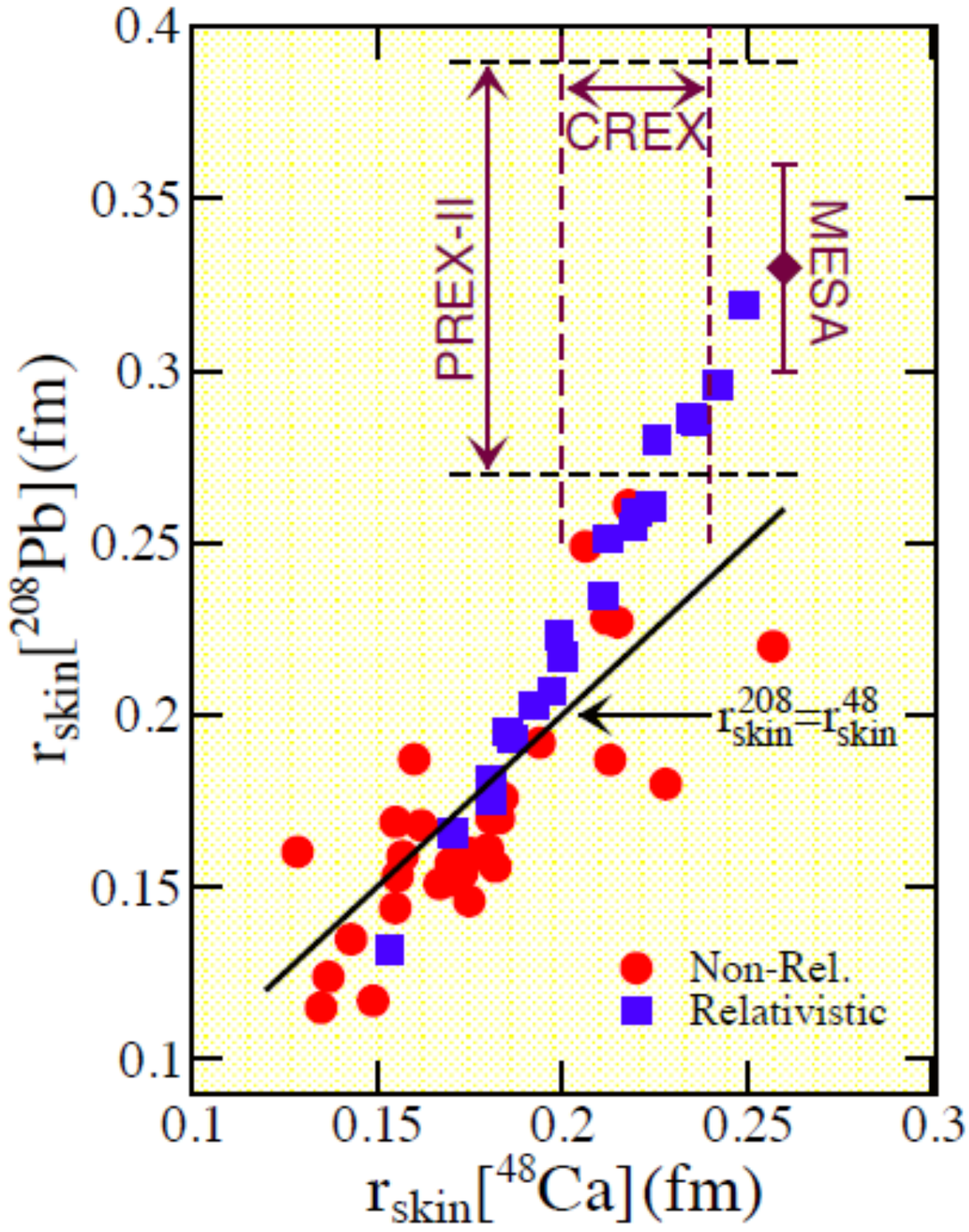
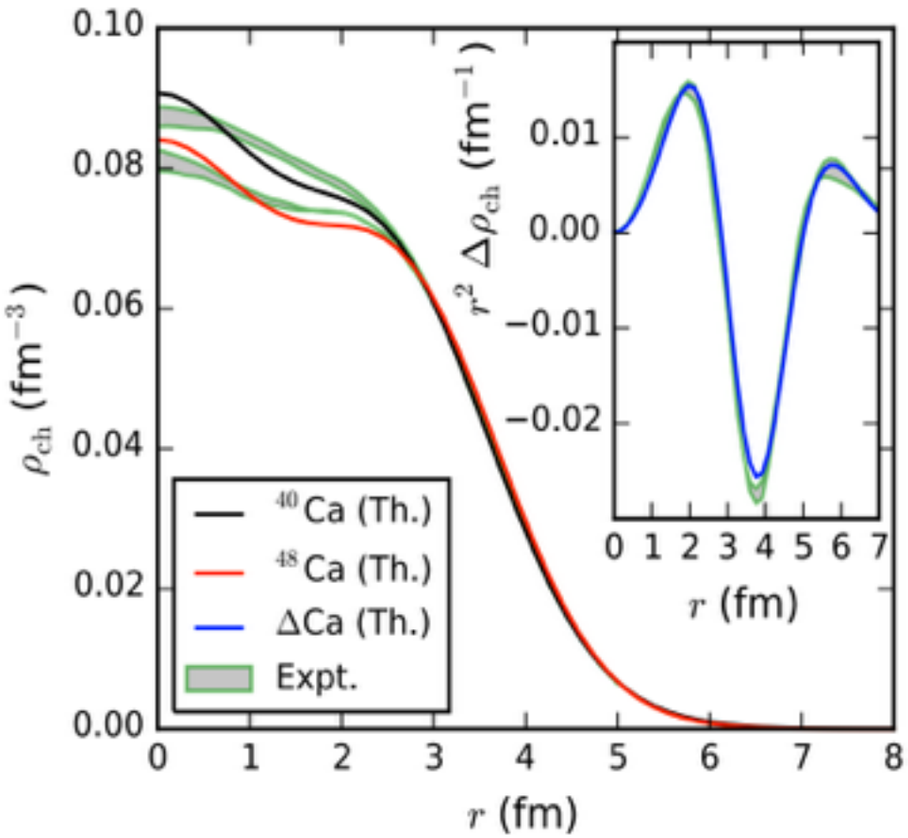
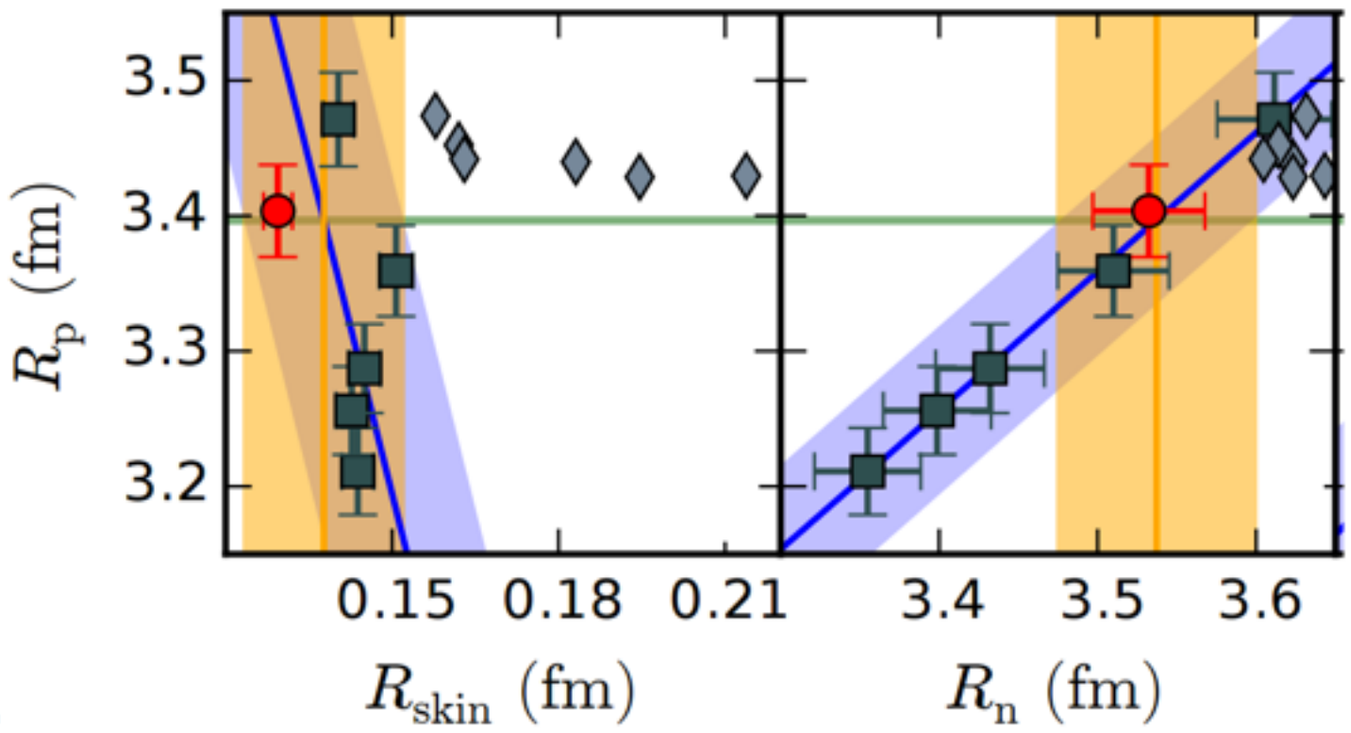
1st possibility: ^{208}Pb





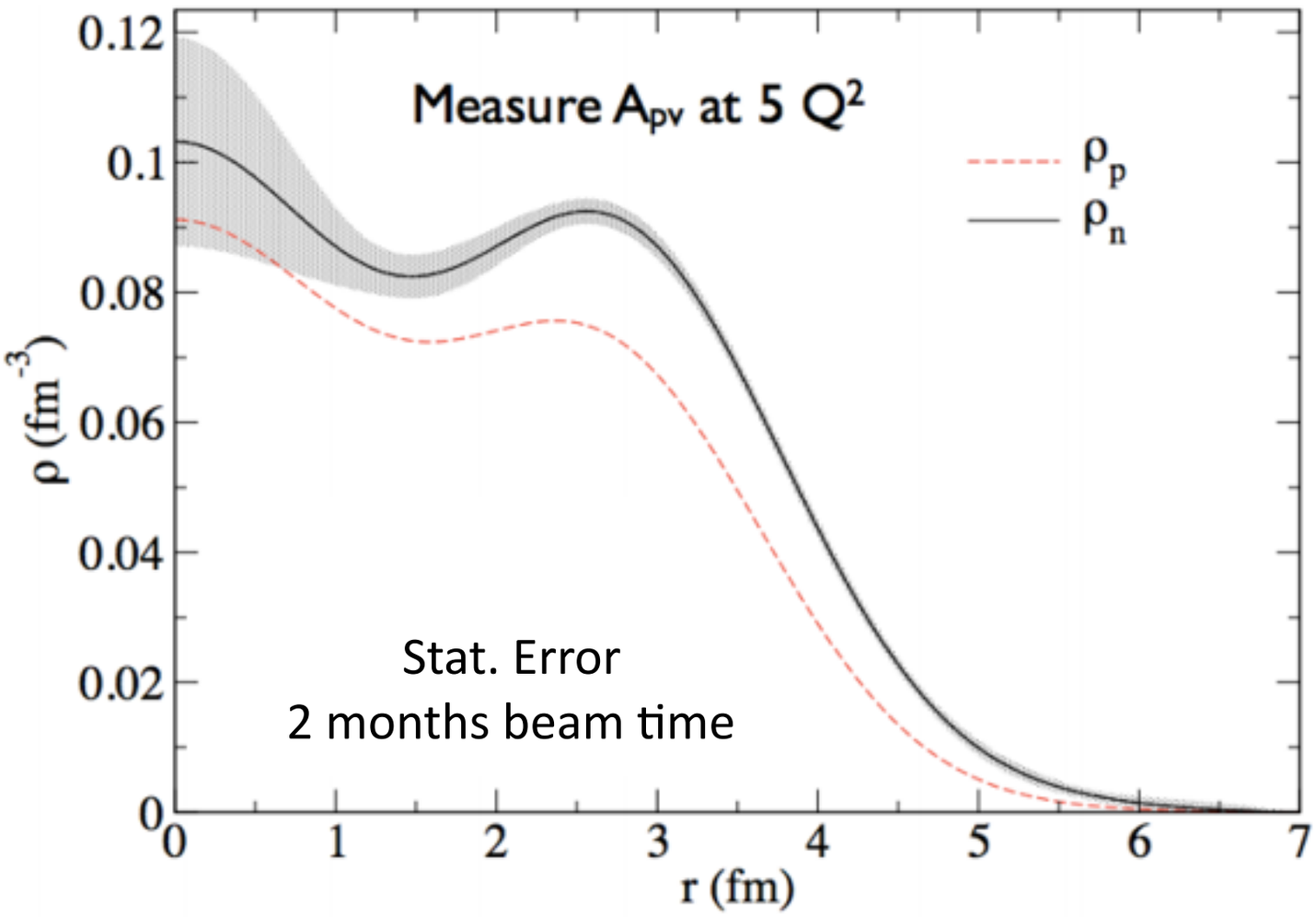


1st possibility: **^{208}Pb**

2nd possibility: **^{48}Ca**

G. Hagen et al.,
Nature Physics 12, 186–190 (2016)

C. J. Horowitz, Phys. Rev. C 92, 014313 (2015)



1st possibility: ^{208}Pb

2nd possibility: ^{48}Ca

3rd possibility:

more Q^2 points

Mainz Institute for Theoretical Physics

Neutron Skins of Nuclei

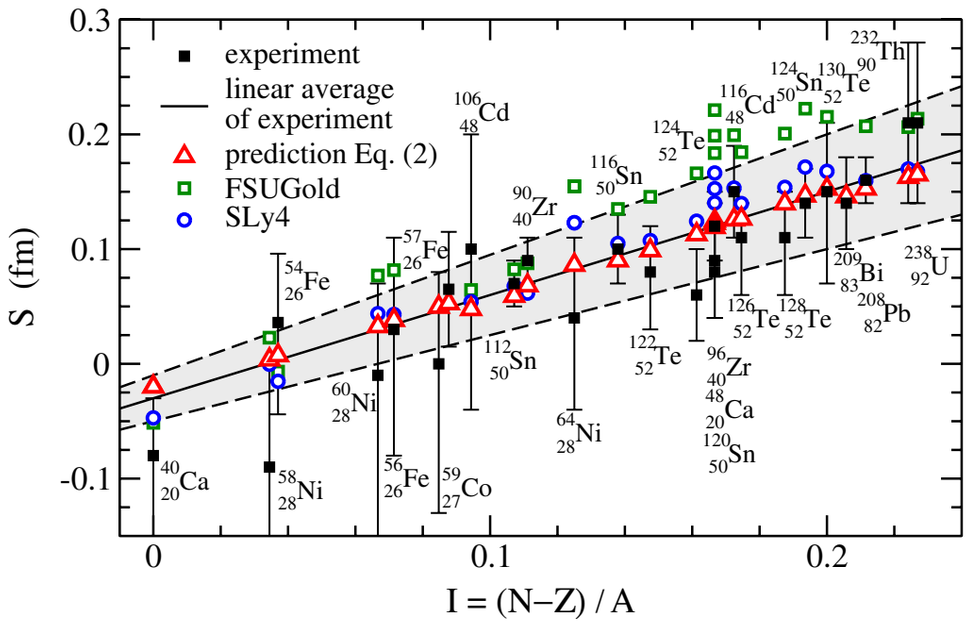
17-27 May 2016
Mainz Institute for Theoretical Physics, Johannes Gutenberg University
Europe/Berlin timezone

CONCETTINASFIENTI

The long winding road ....

- Is there a need for a systematic study over “many” nuclei?
  PREX, CREX, SREX, ZREX, …

M. Centelles, et al Phys. Rev. Lett. 102, 122502 (2009)



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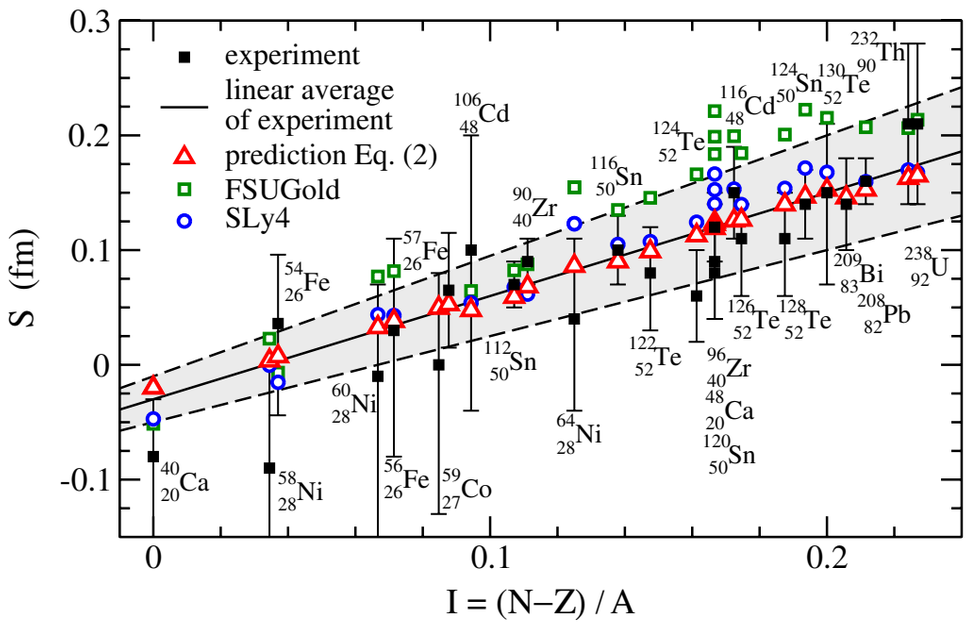


```
IF (YES) {
   IF (MONEY==∞ && TIME ==∞){
      (PVES)
            } ELSE {
         (INDIRECT METHOD)}
   }
```

CONCETTINASFIENTI

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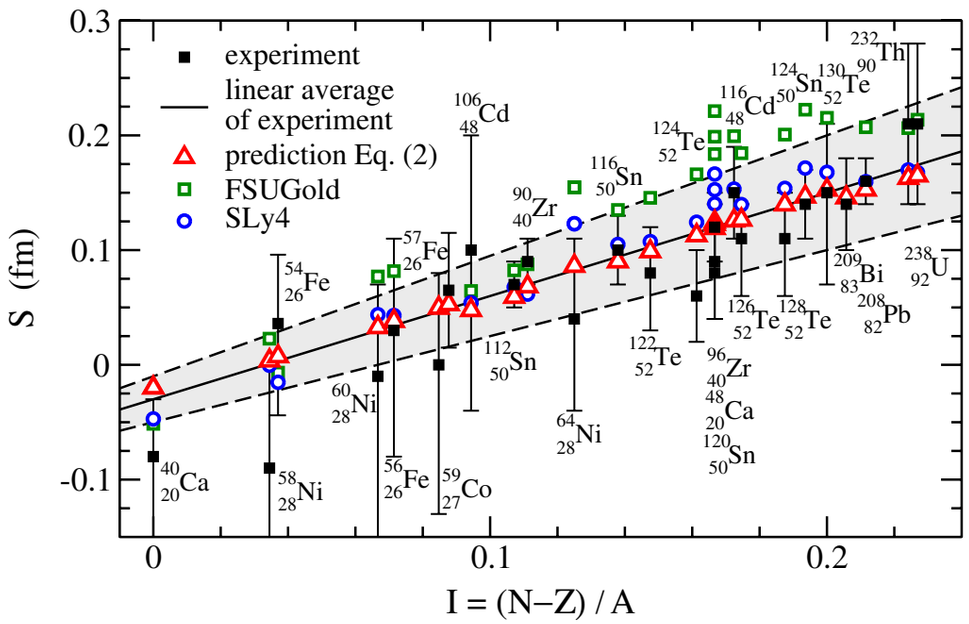


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Neutron skin extraction:

⇒ Nuclear structure away from stability

⇒ Experiment informing theory

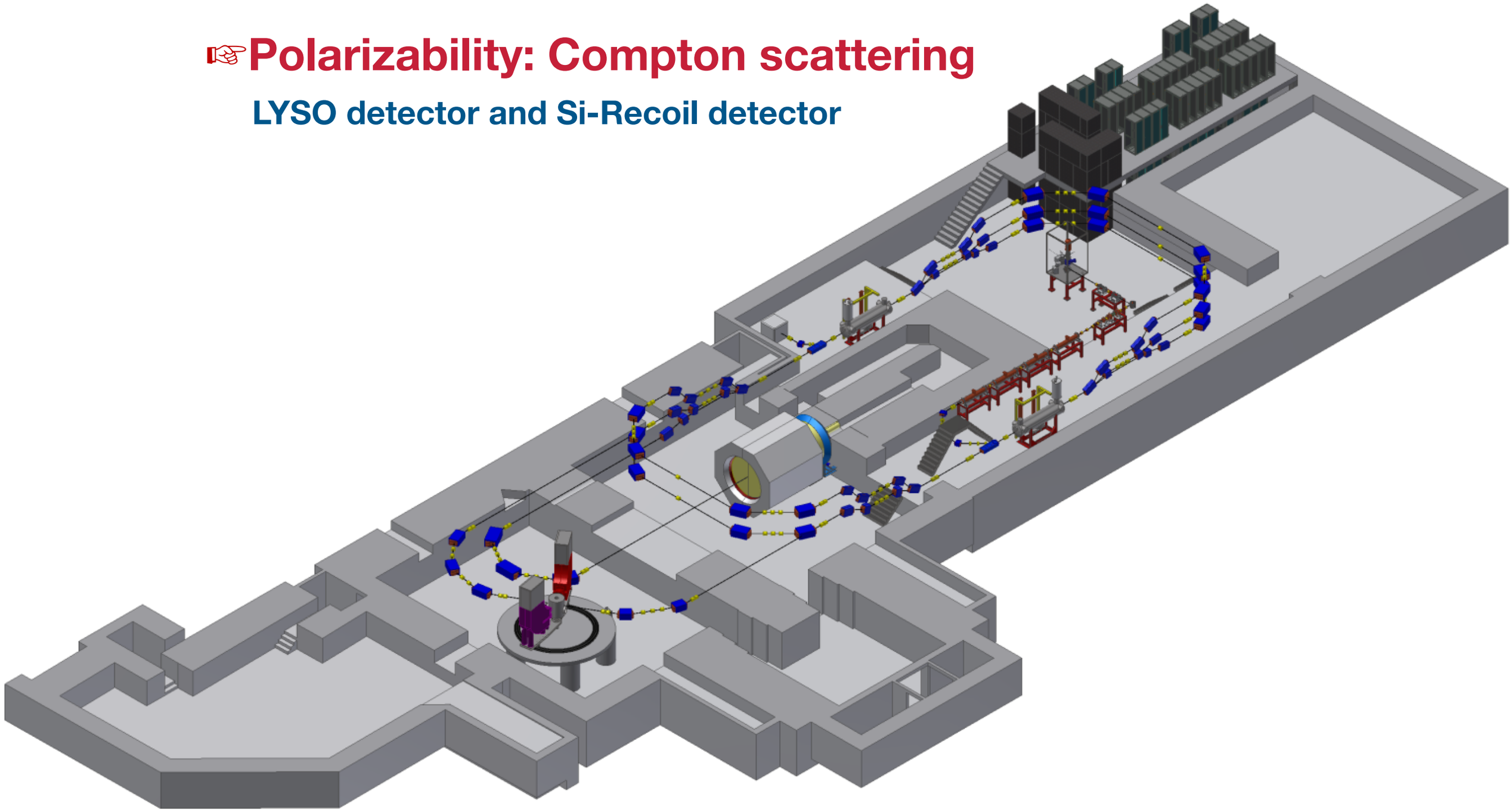
CONCETTINASFIENTI

Neutron Skin@Mainz

MAGIX: Internal Target

☞Polarizability: Compton scattering

LYSO detector and Si-Recoil detector

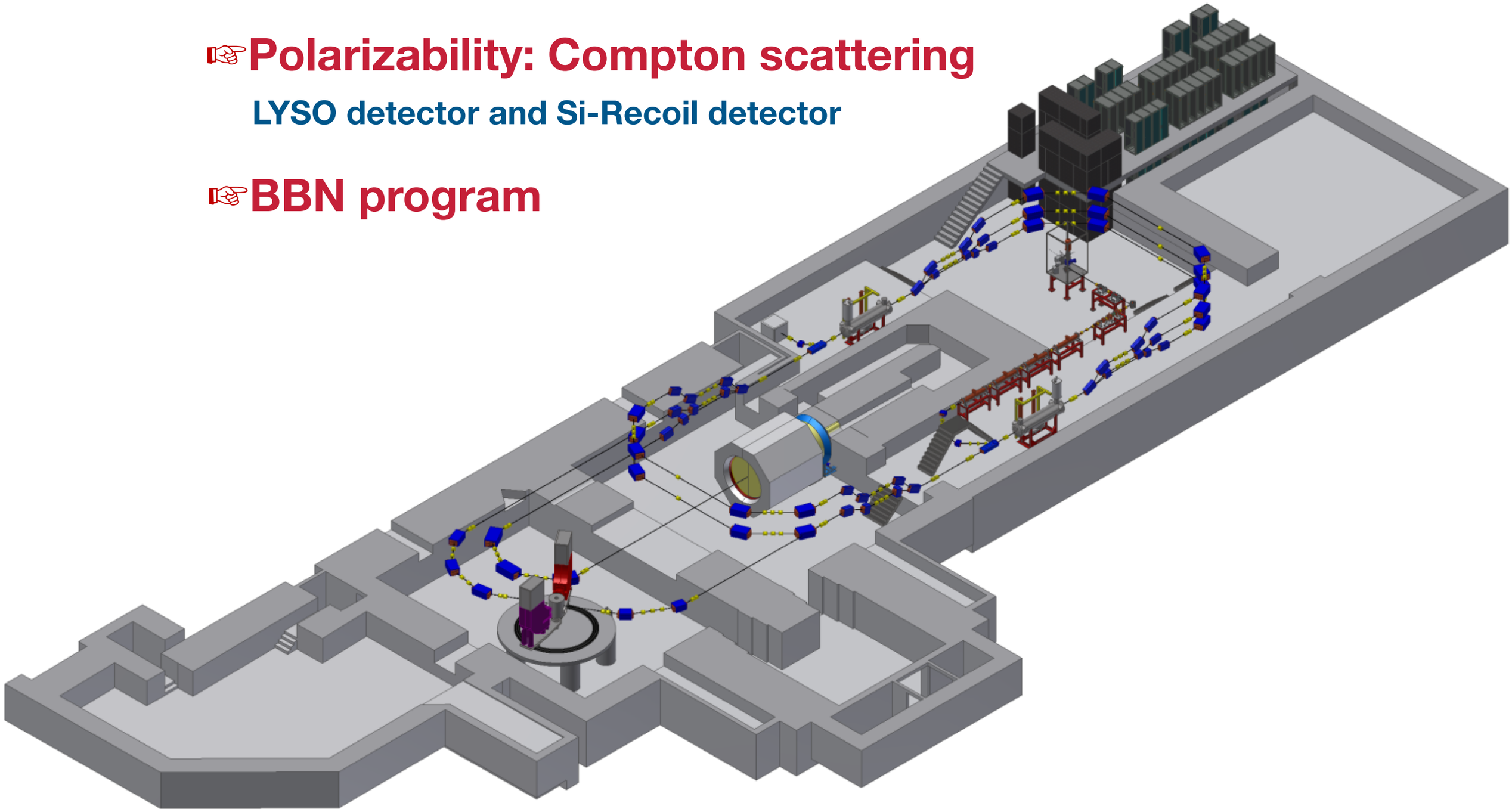


CONCETTINASFIENTI

Neutron Skin@Mainz

MAGIX: Internal Target

- ☞ **Polarizability: Compton scattering**
  - LYSO detector and Si-Recoil detector
- ☞ **BBN program**



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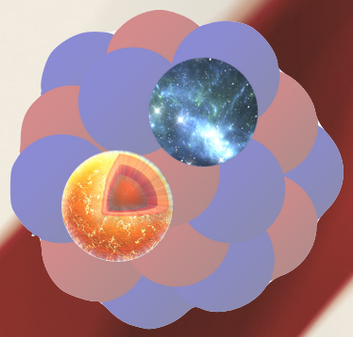
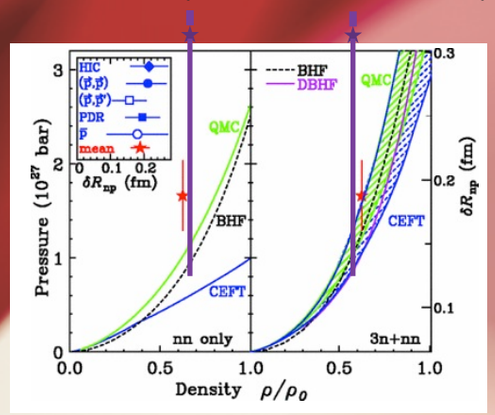
From outer space to deep inside: exploring neutron skins of nuclei





The Good...

PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

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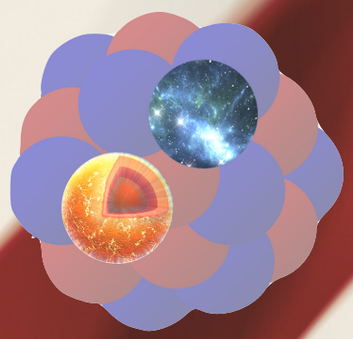
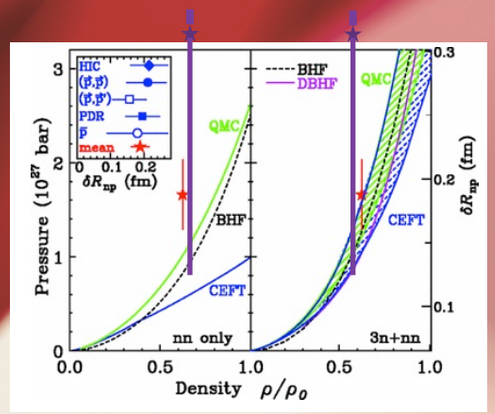
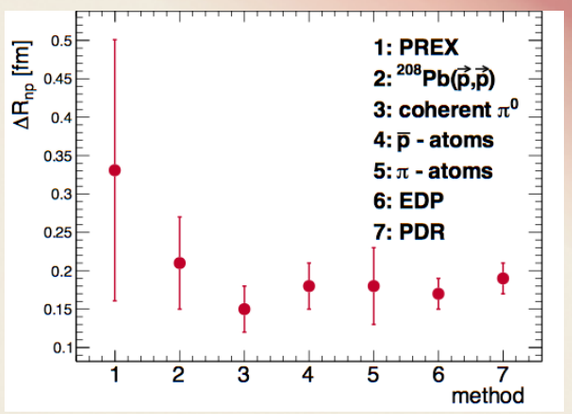
CONCETTINASFIENTI

From outer space to deep inside: exploring neutron skins of nuclei





The Good...



The Bad...

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PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

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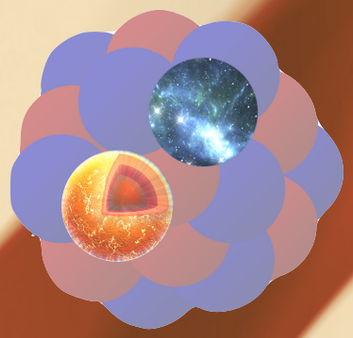
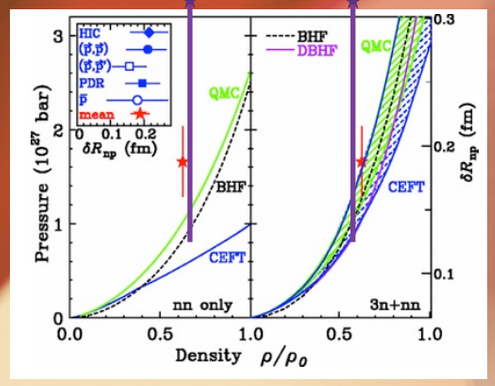
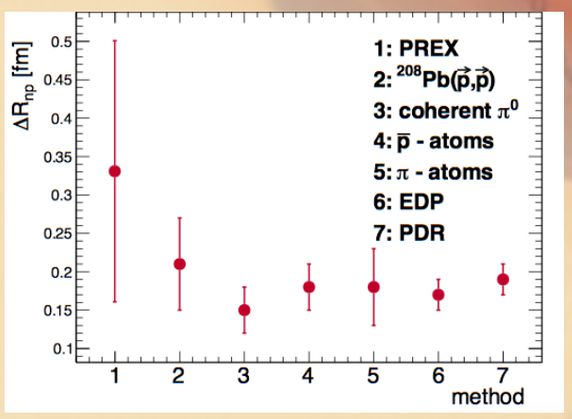
From outer space to deep inside: exploring neutron skins of nuclei





The Good...



The Bad...

AND THE UGLY

CONCETTINASFIENTI

PRISMA

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THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

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