Status and Prospect of Ru measurements @ Mainz

PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

JG|U

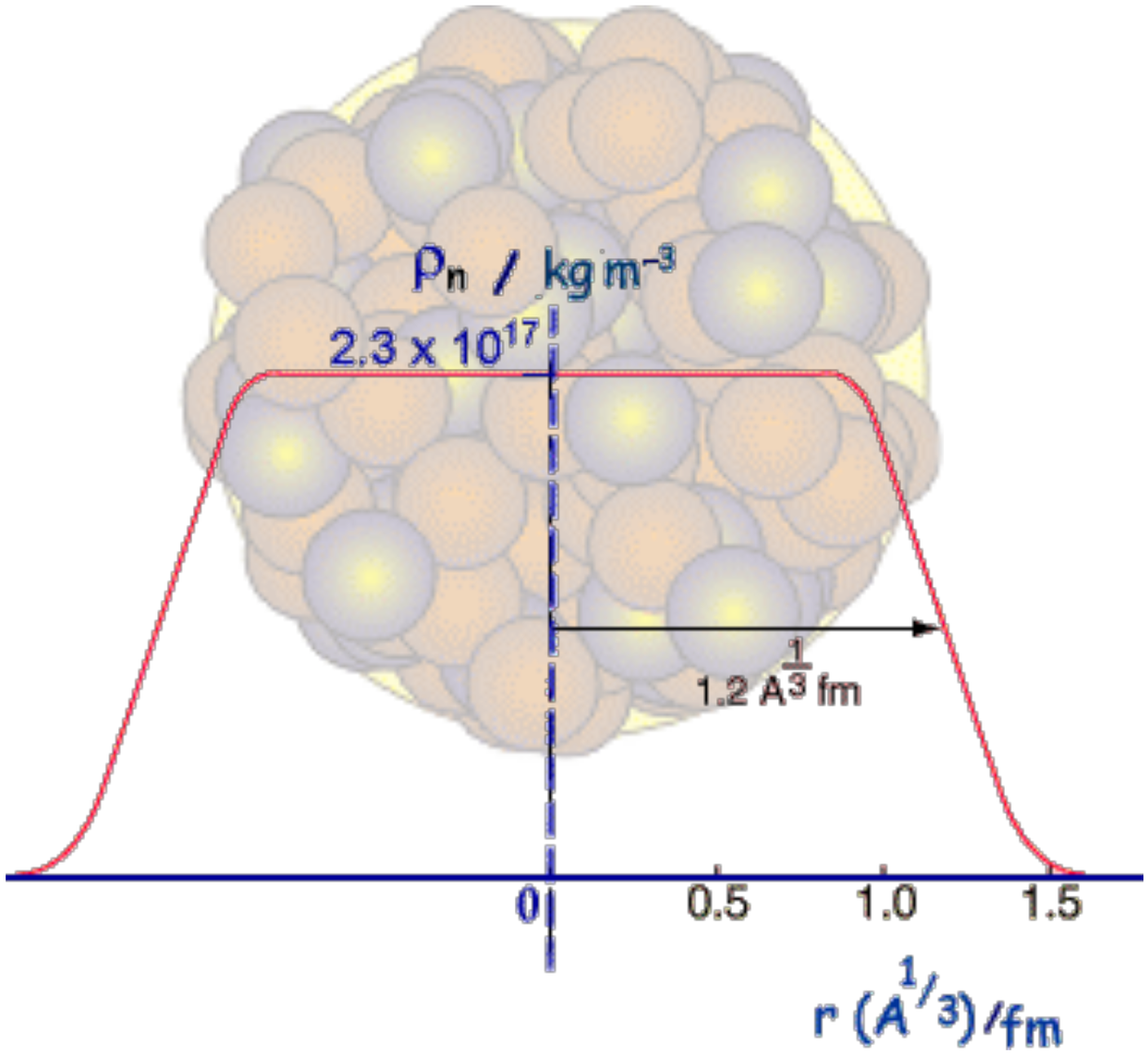
NUSYM 2017

7th international symposium on nuclear symmetry energy

SEPTEMBER 4TH – 7TH / GANIL, CAEN, FRANCE

Neutron Skin for beginner

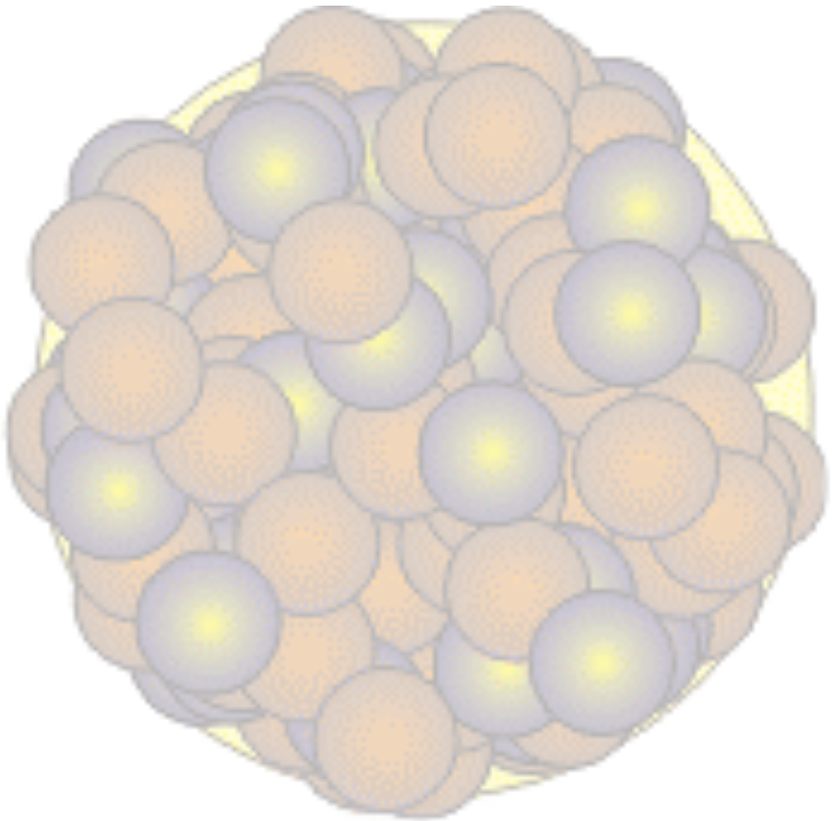
Nuclear charge radii



Where do the neutrons go?

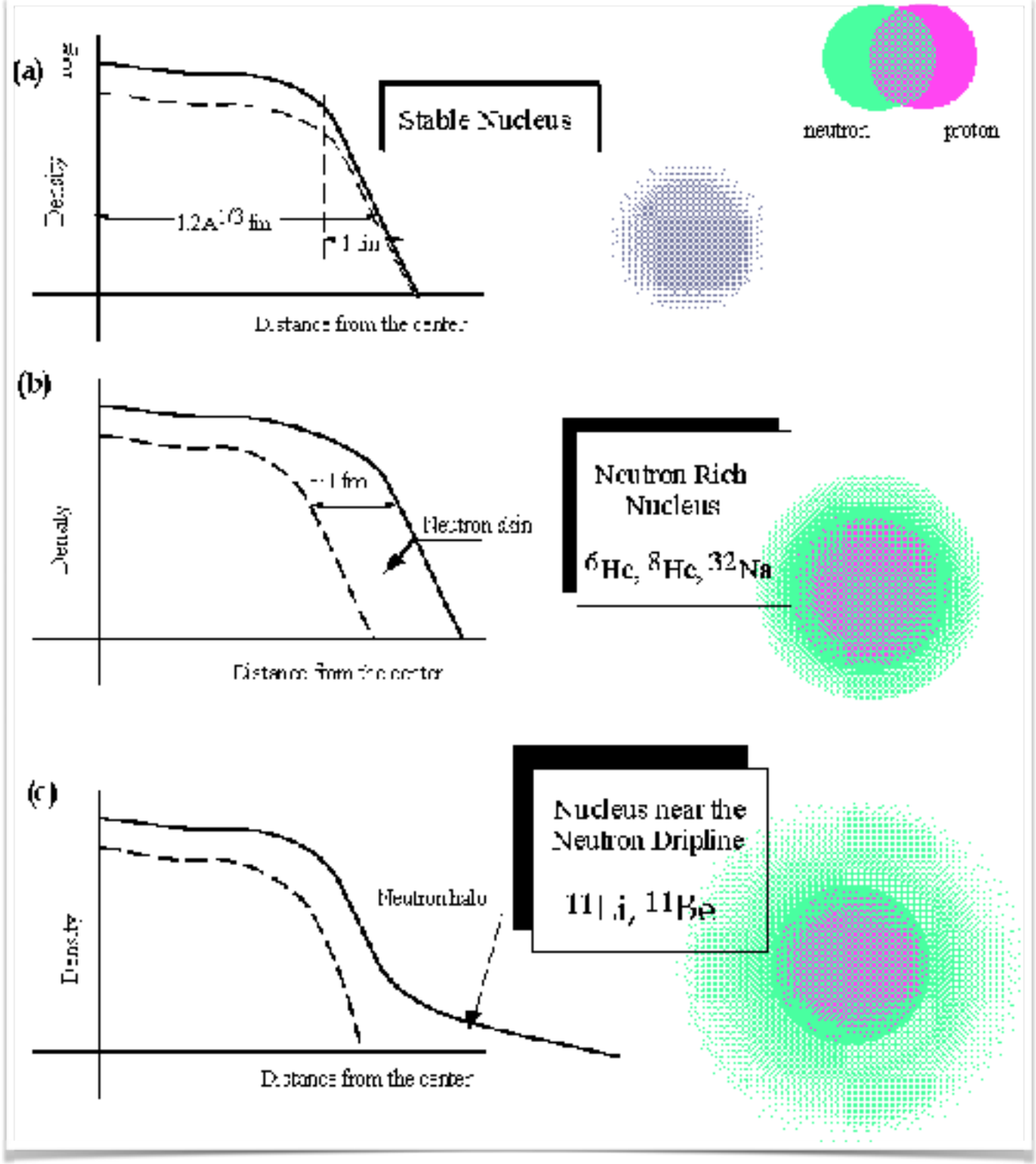
Neutron Skin for beginner

Where do the neutrons go?

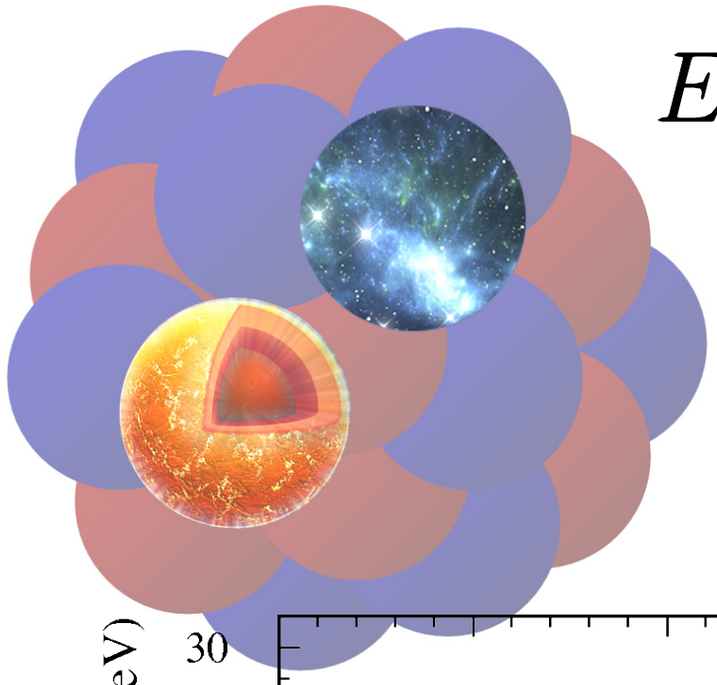


Pressure forces neutrons out against surface tension

→ EOS

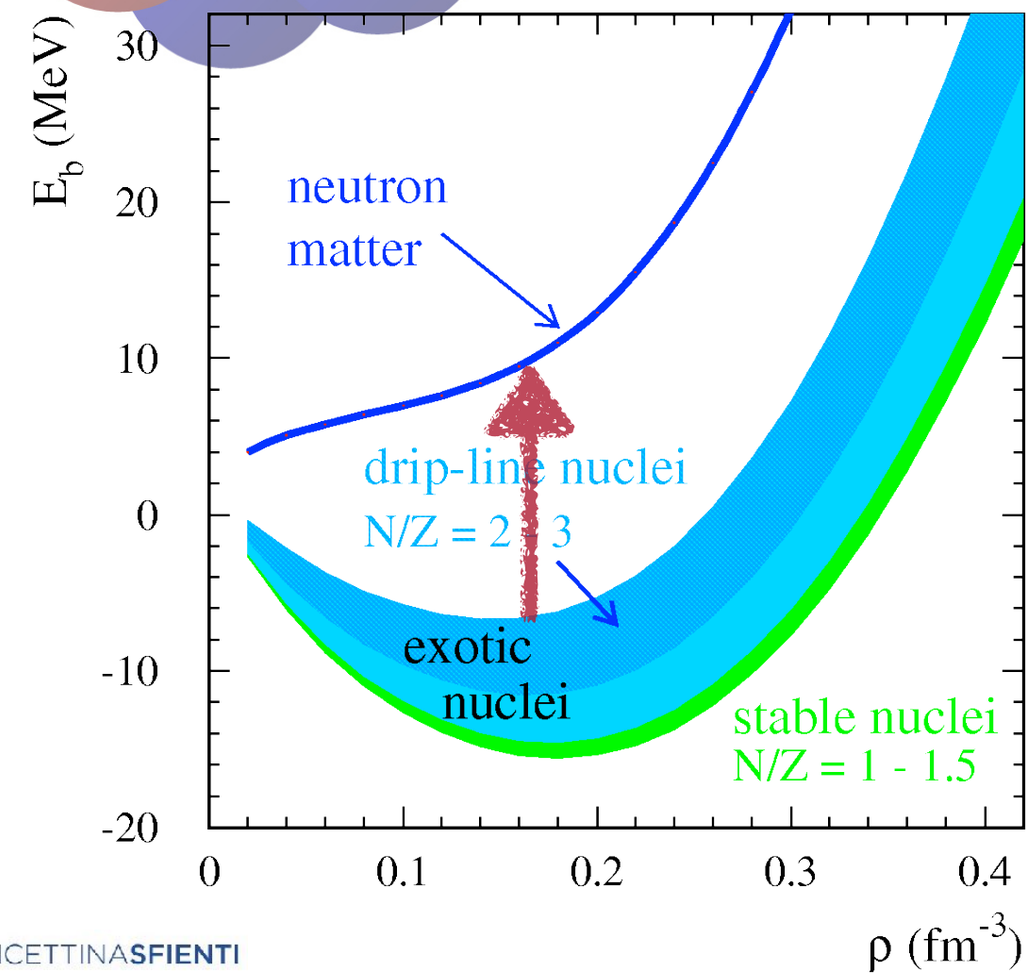


“The Search for the Nuclear Symmetry Energy” (HW)



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

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



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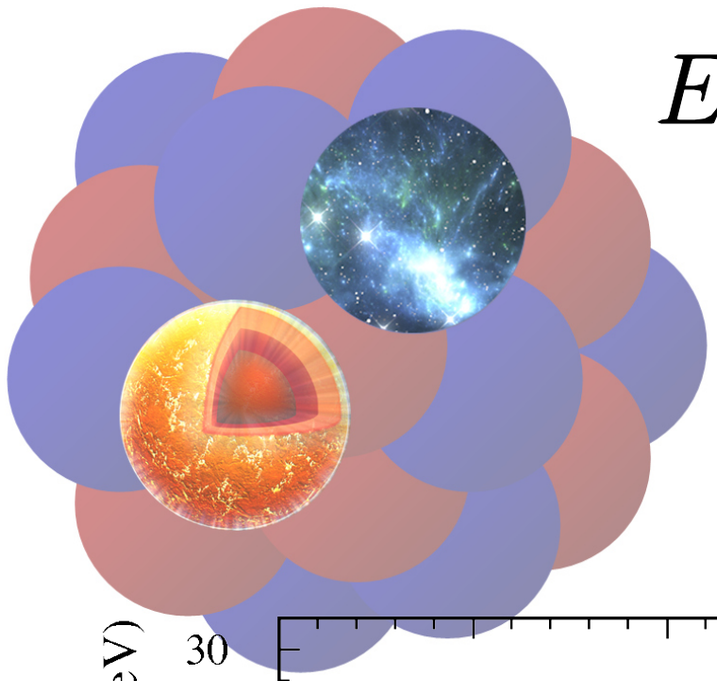

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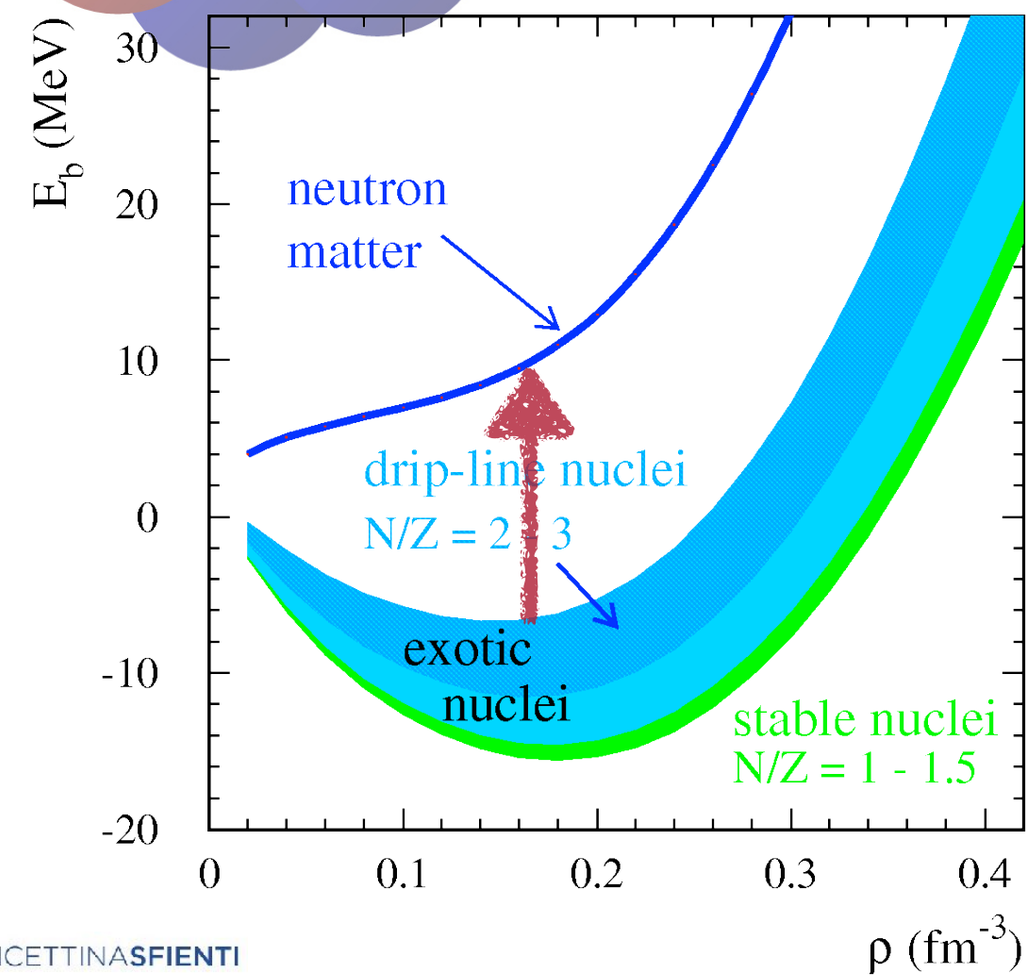


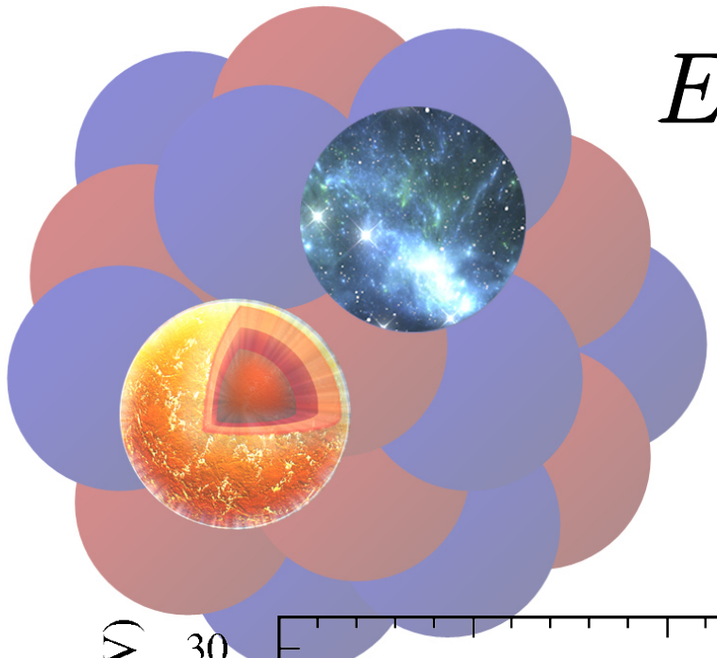
slope parameter

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

curvature parameter

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

...the (blind!?) search for the Nuclear Symmetry Energy



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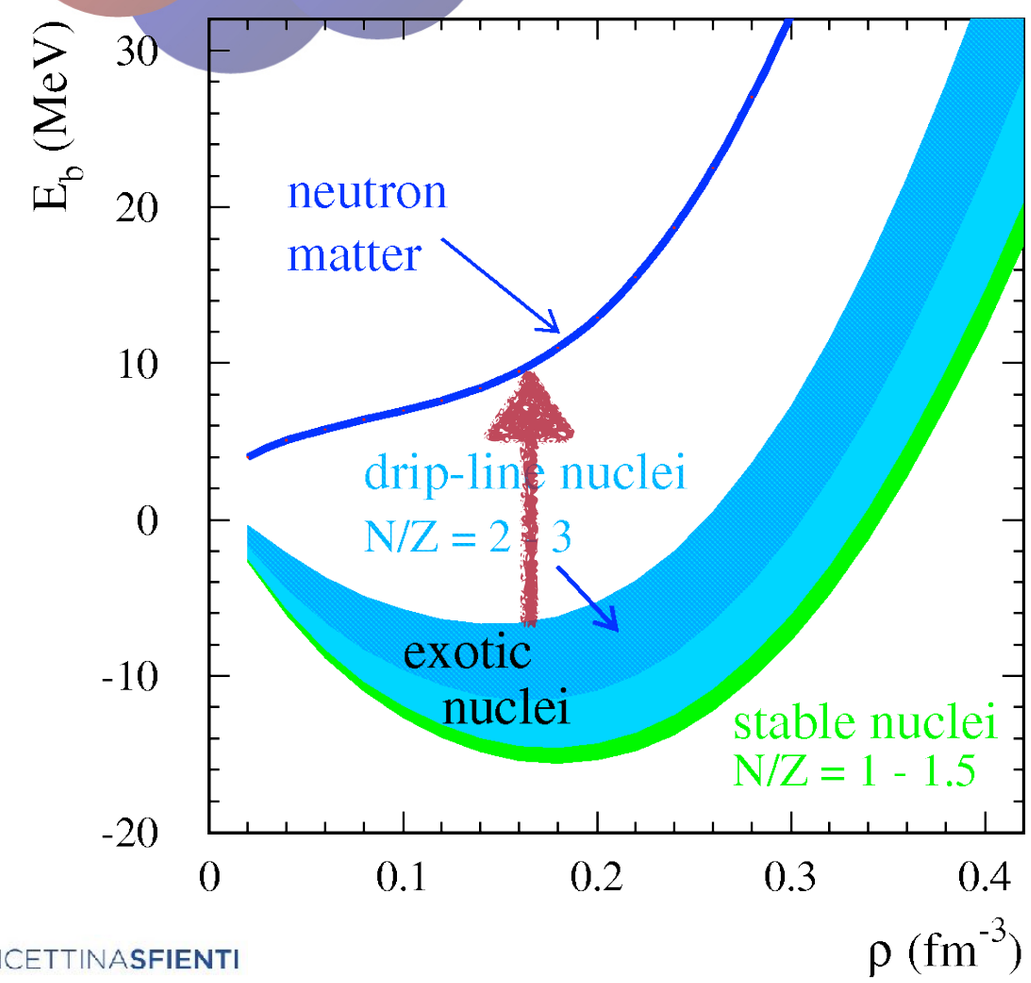
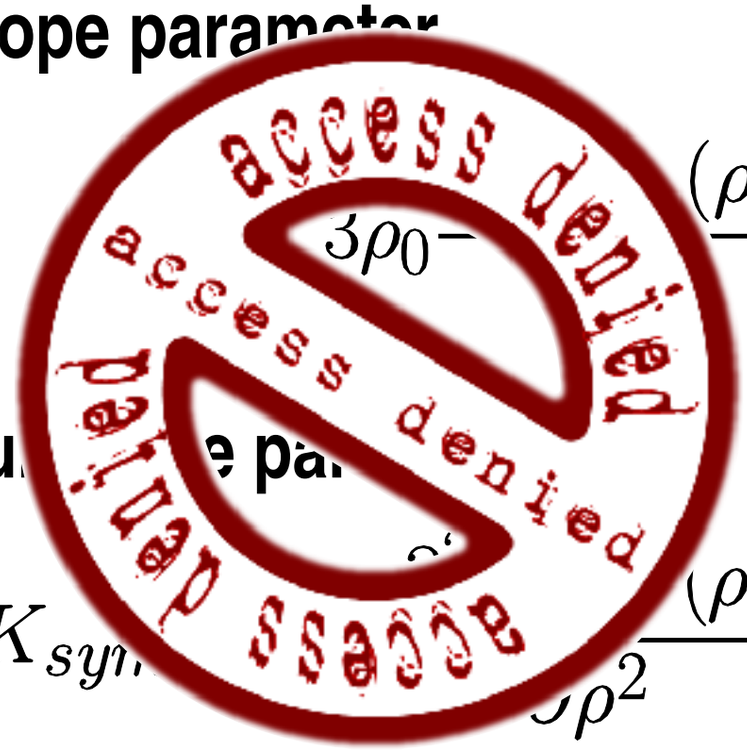


slope parameter

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

cu e pa

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



CONCETTINASFIENTI

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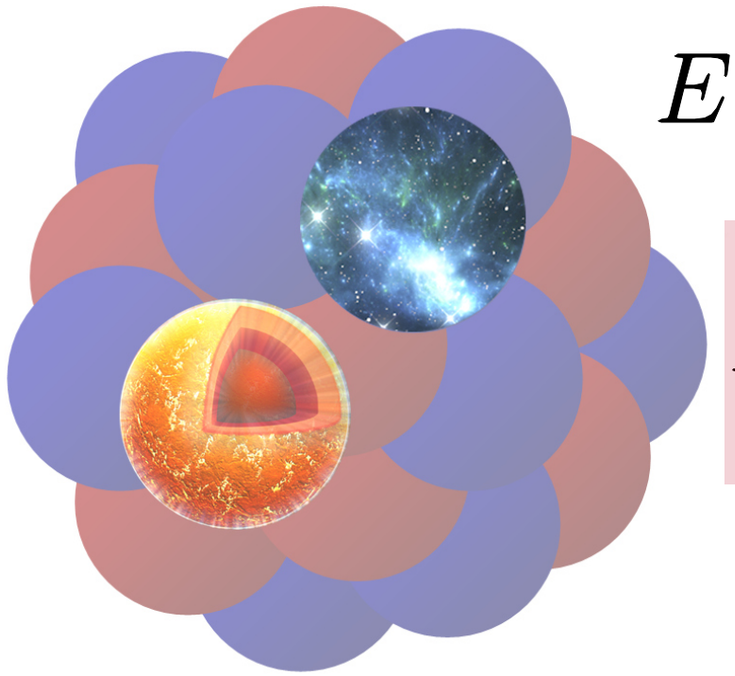

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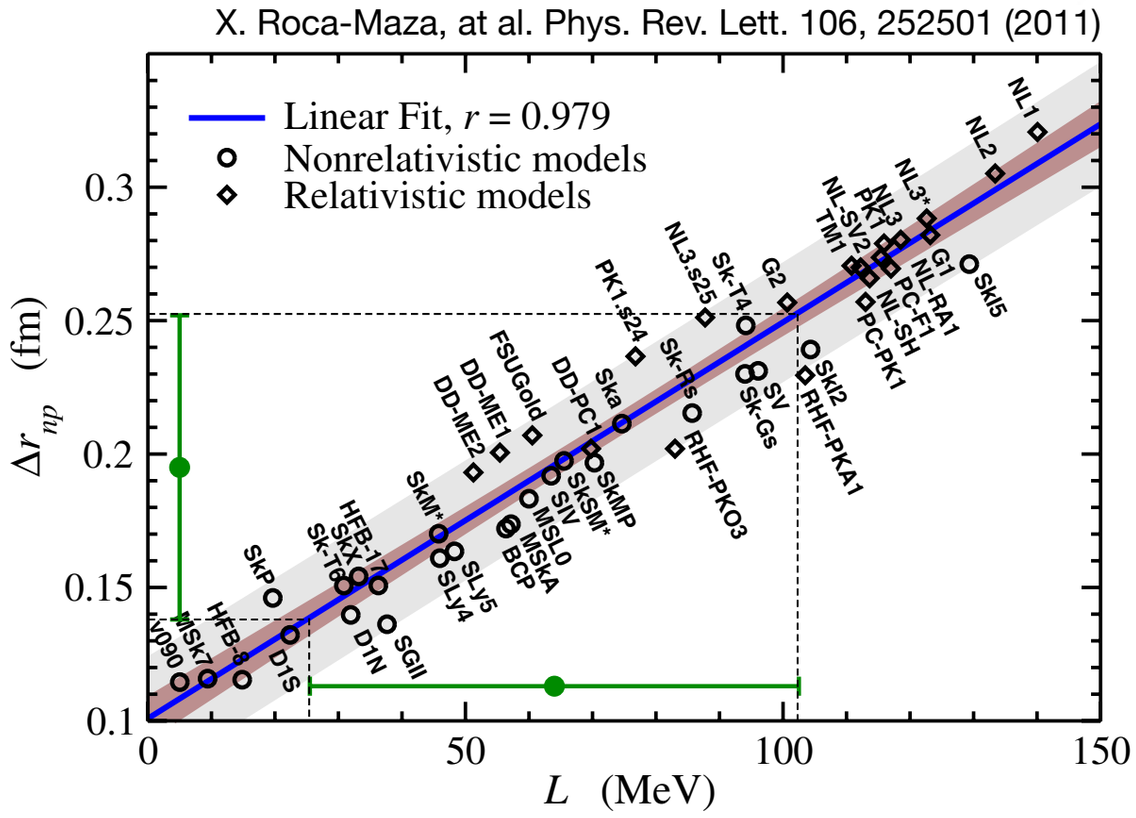
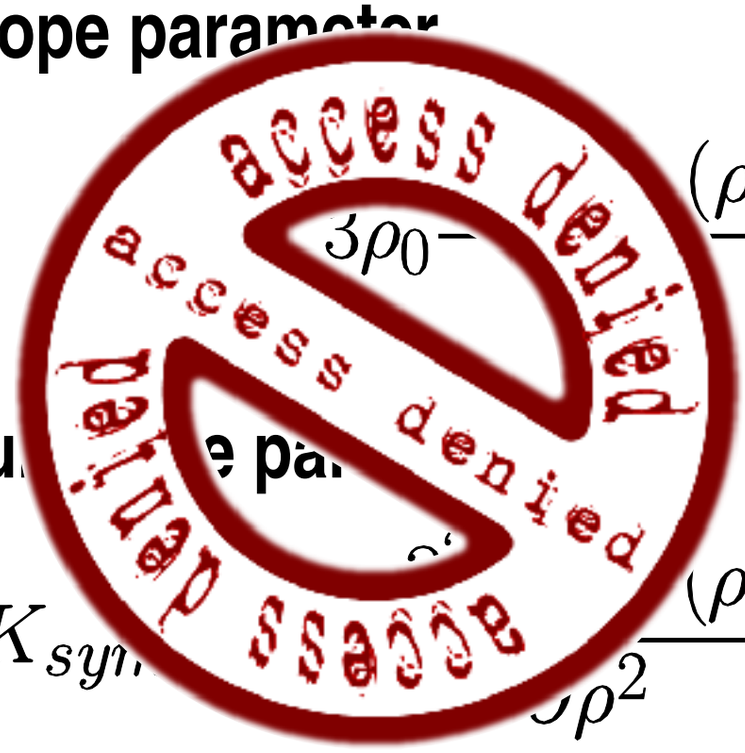


slope parameter

curvature parameter

$$K_{sym} = 9\rho^2 \frac{\partial^2 E_{sym}(\rho)}{\partial \rho^2}\bigg|_{\rho_0} - 3\rho_0 \frac{\partial E_{sym}(\rho)}{\partial \rho}\bigg|_{\rho_0}$$



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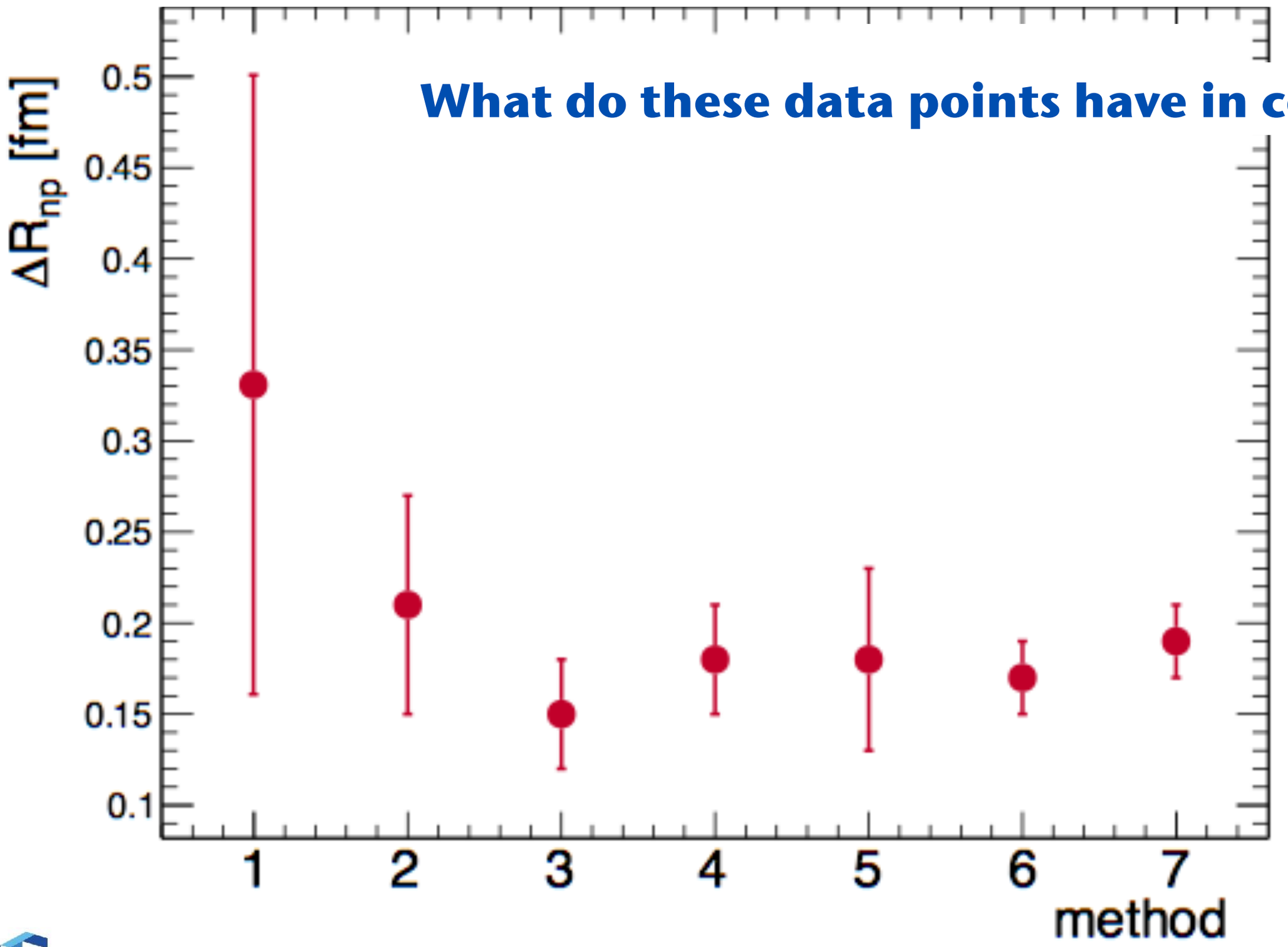
The answer to the ultimate question



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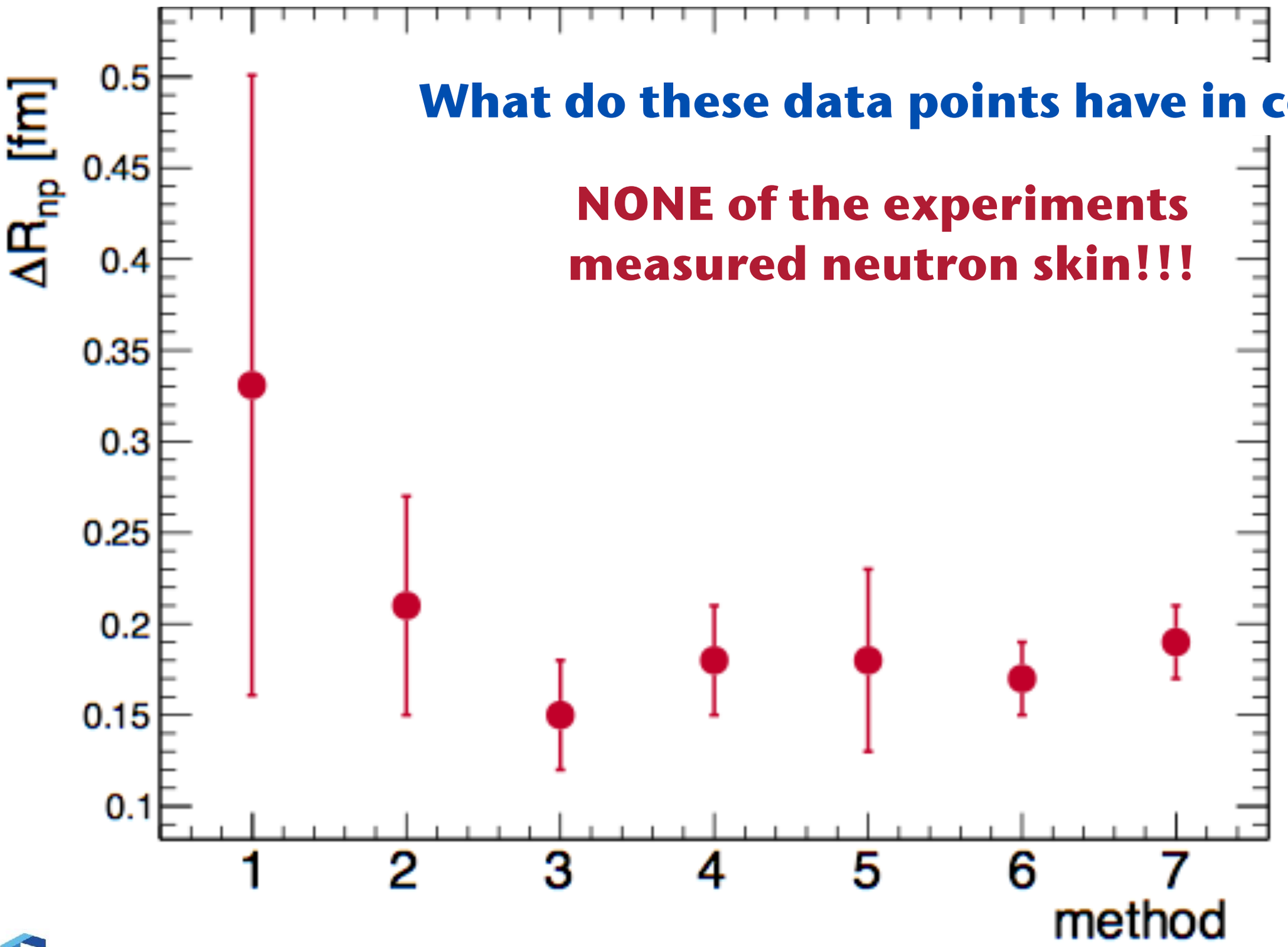
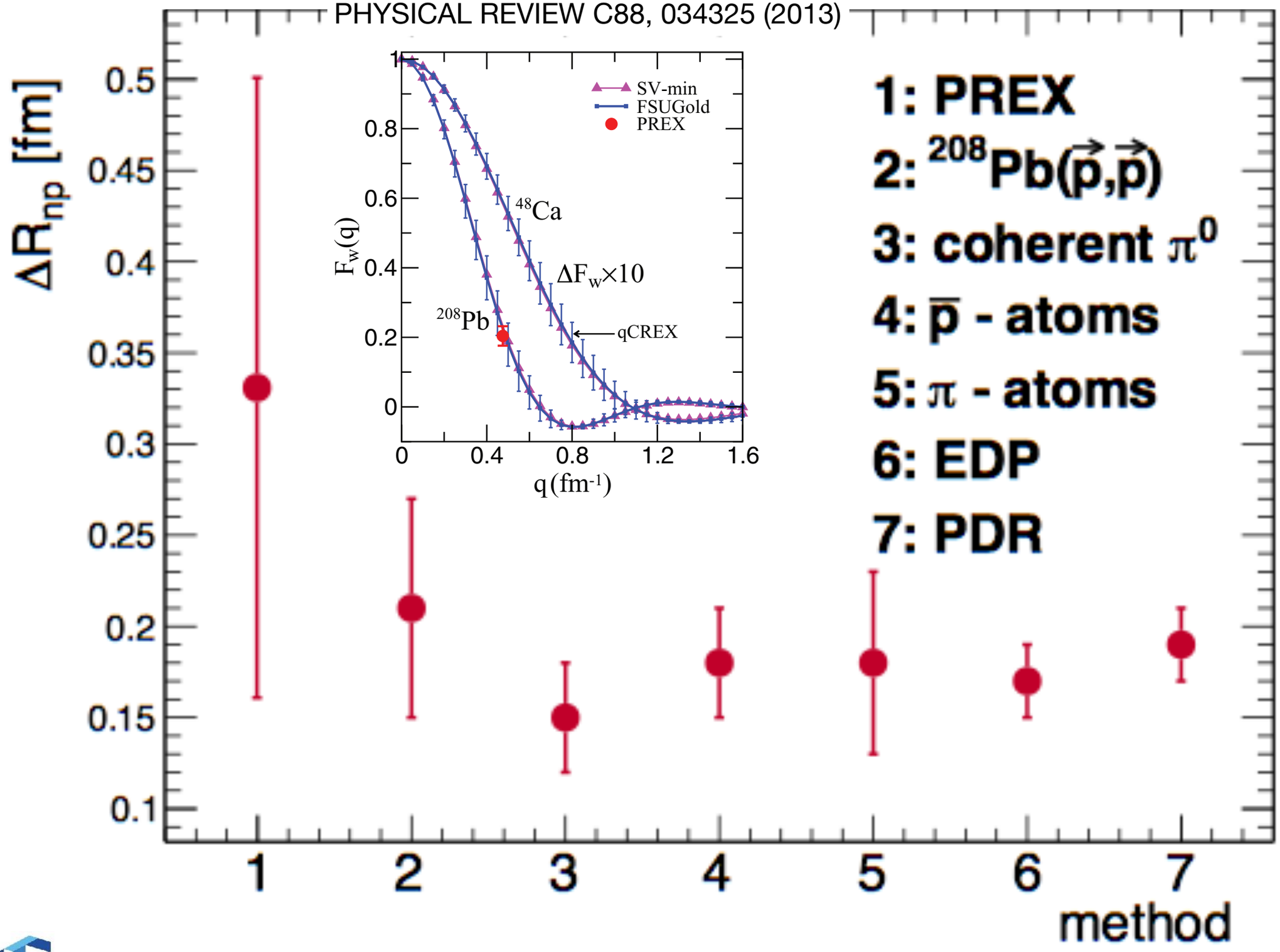


What do these data points have in common?

NONE of the experiments measured neutron skin!!!

WHY?

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



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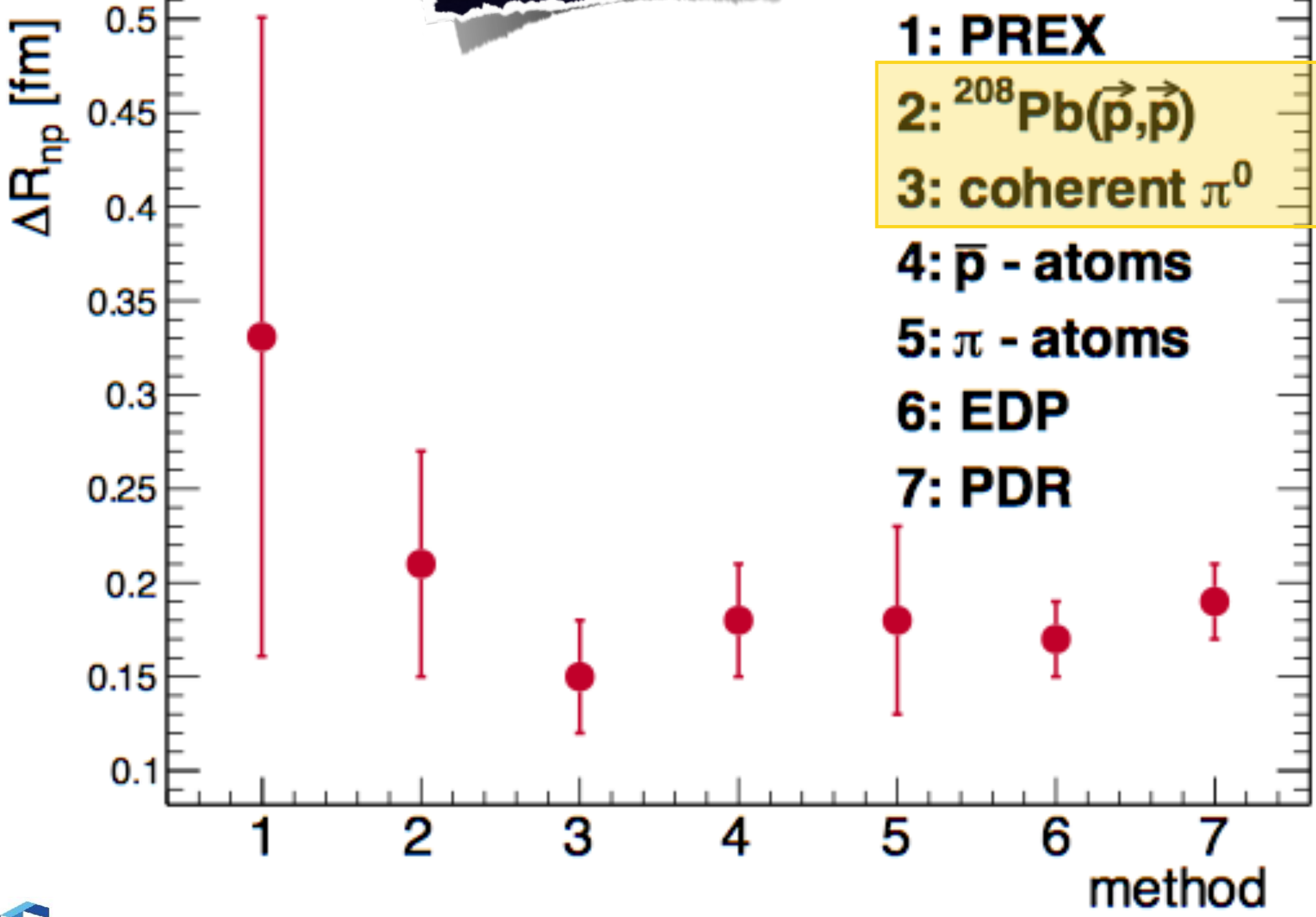
WHAT?

Uncontrolled Uncertainties

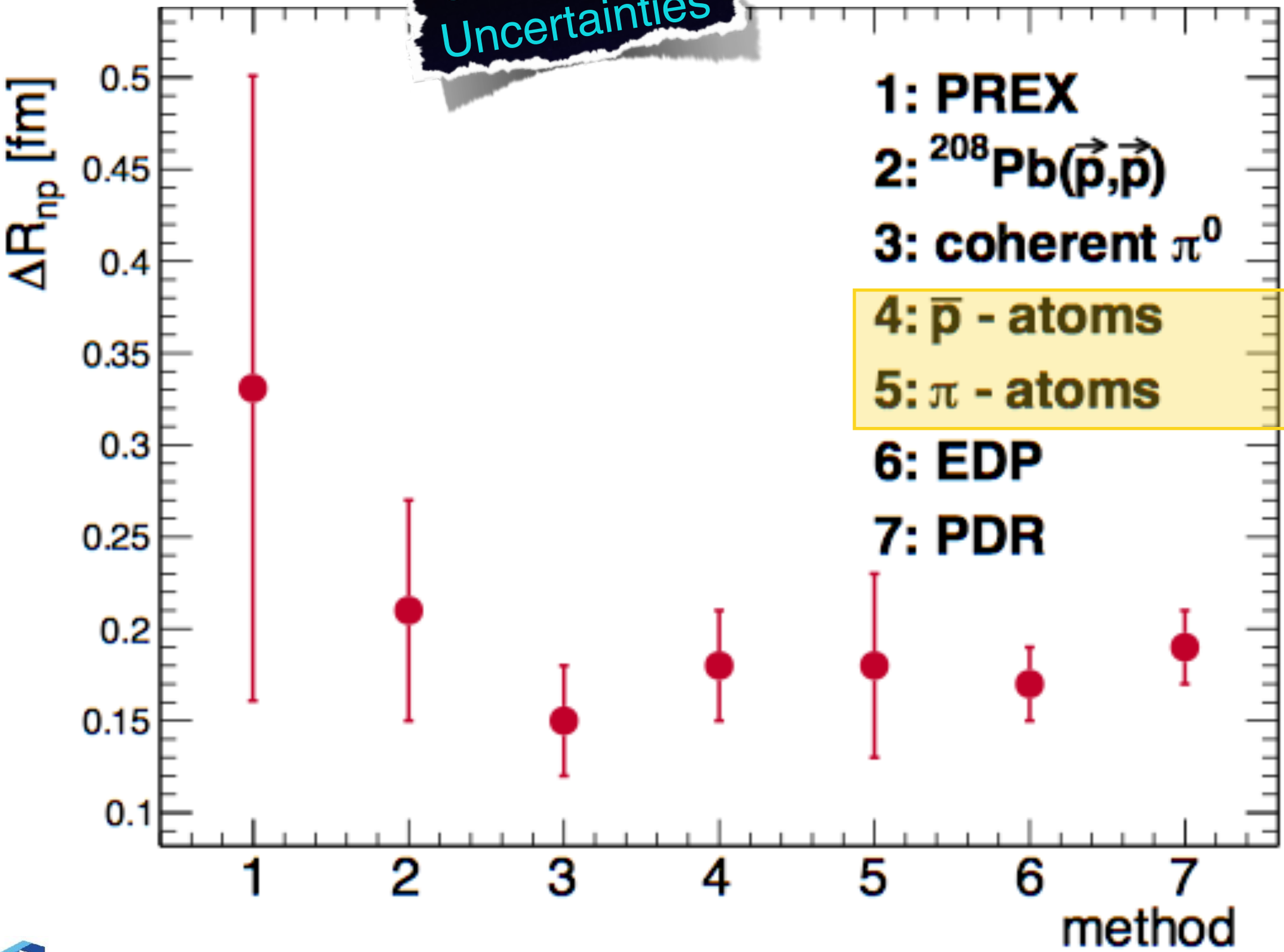


ISI + FSI

(SYST) THEO??

WHAT?

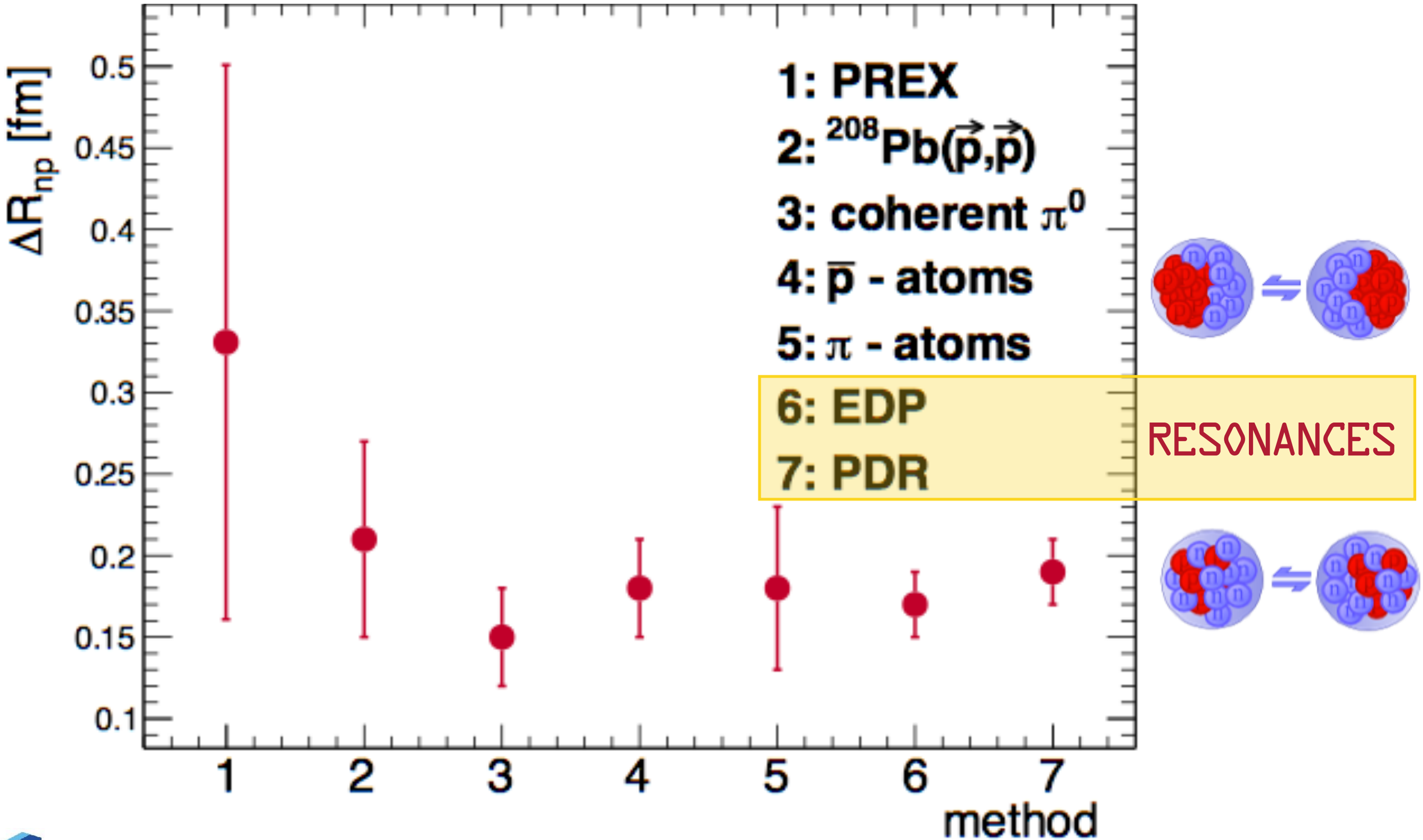
Uncontrolled Uncertainties



(SYST) THEO??

CONCETTINASFIENTI

WHAT?



RESONANCES

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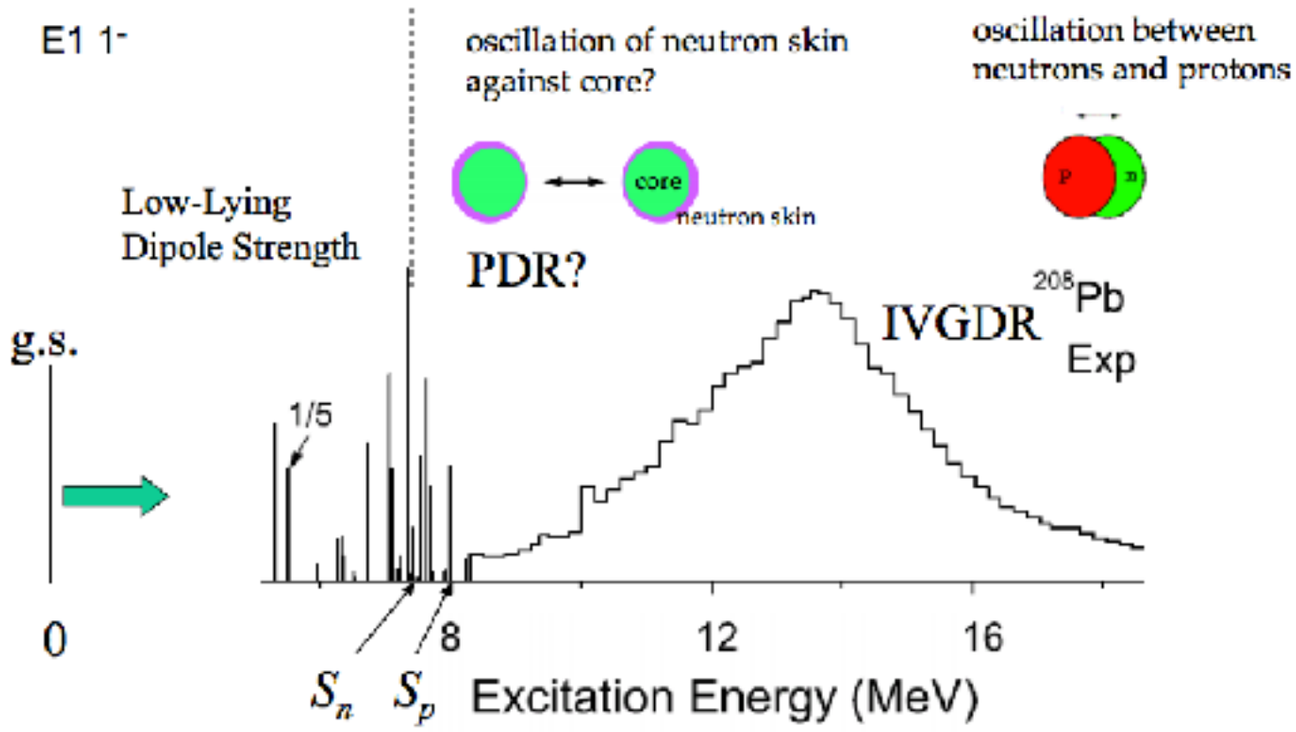
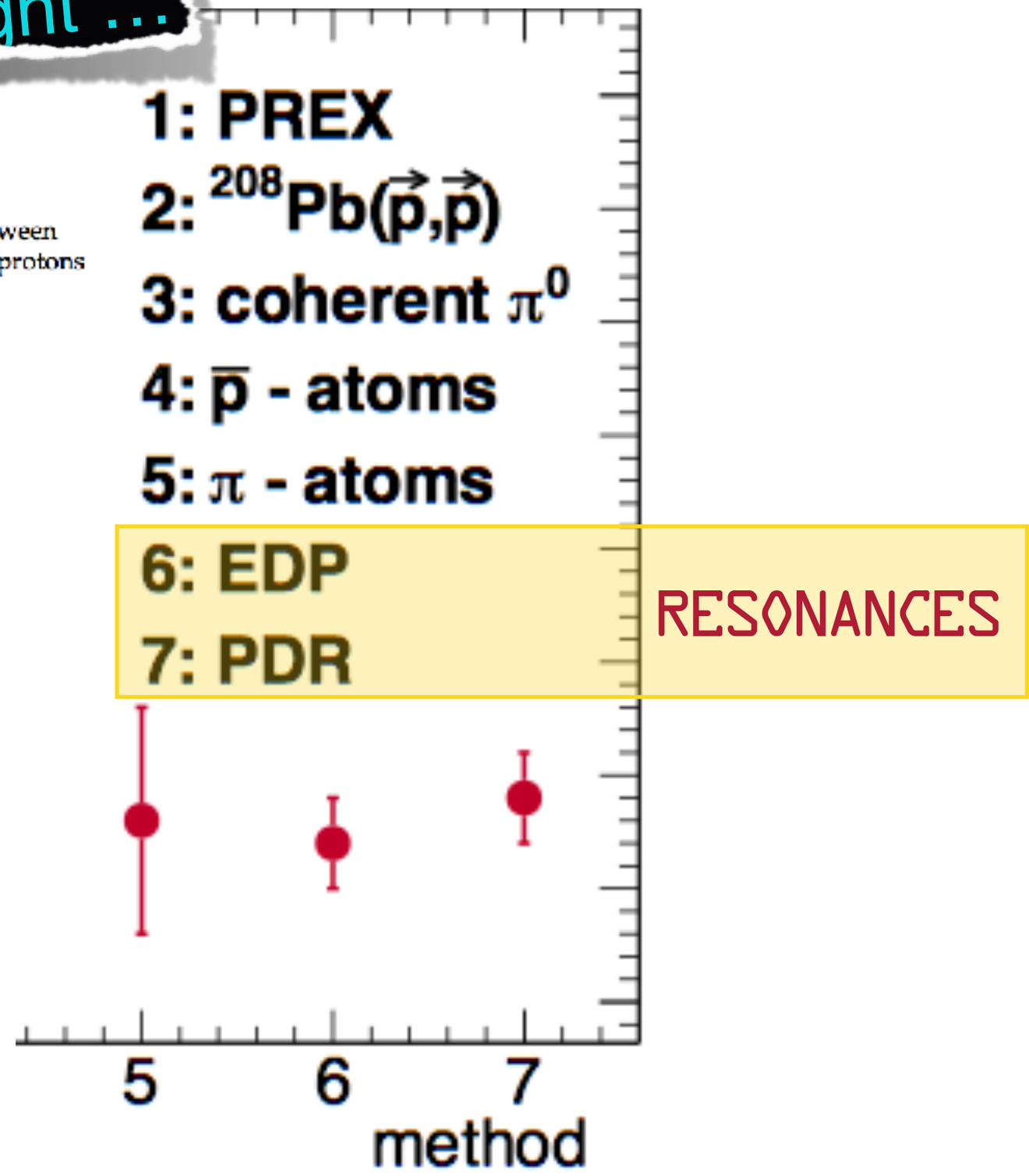
WHAT?

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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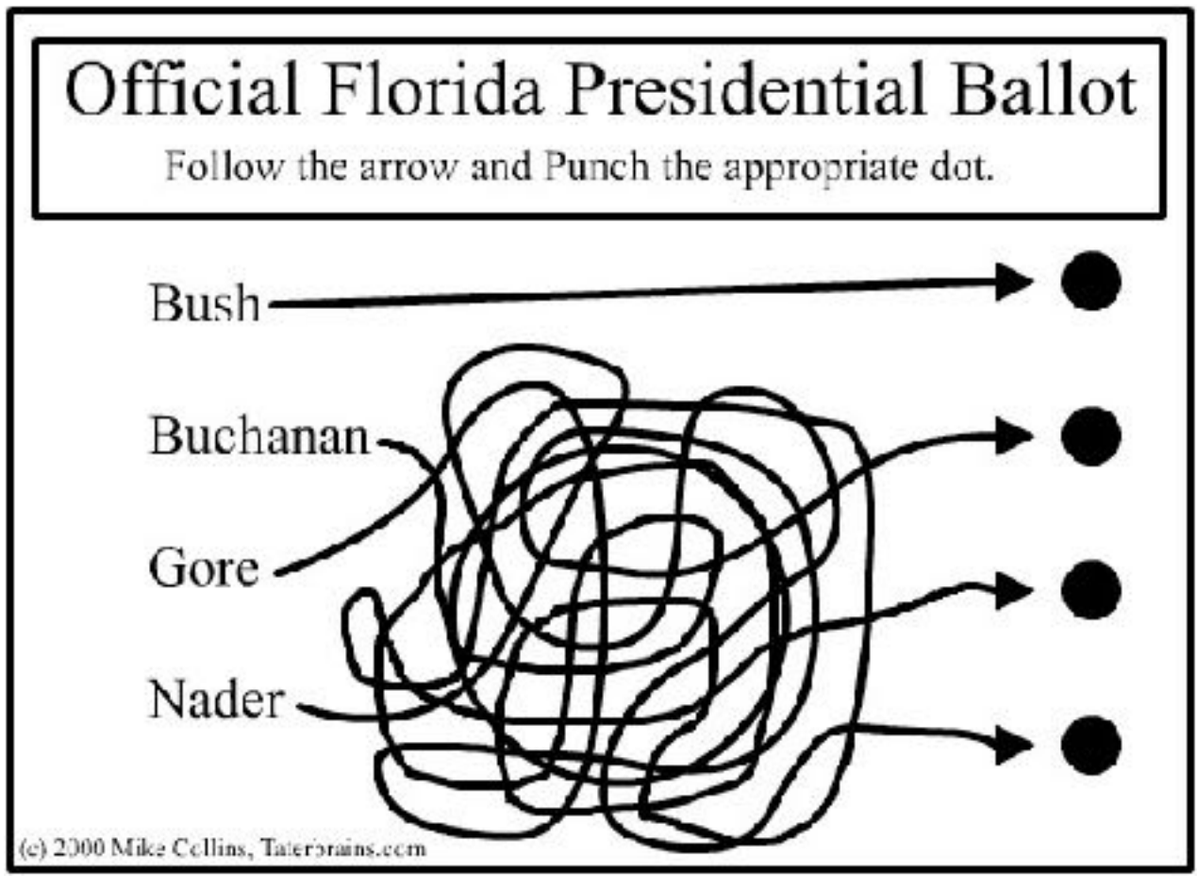
The long winding road ....

...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

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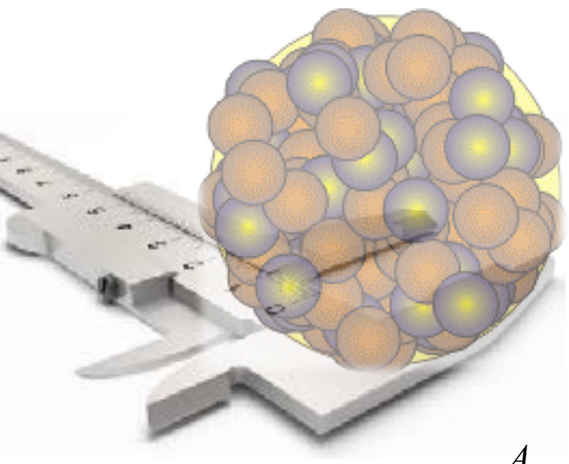
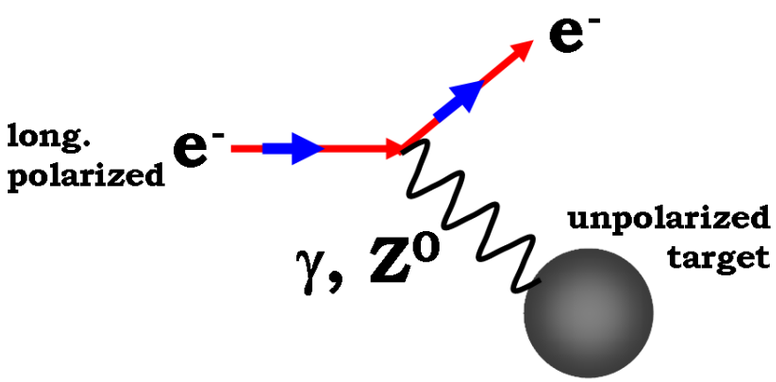
mitp Mainz Institute for Theoretical Physics

Neutron Skins of Nuclei: from laboratory to stars

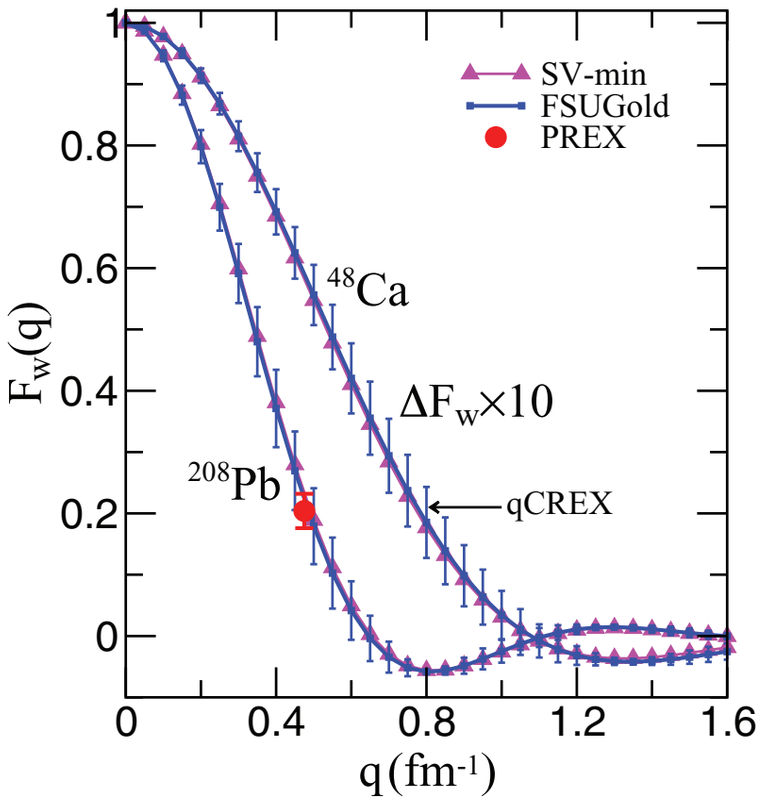
C. Horowitz, J. Piekarewicz, CS (to appear JPG)

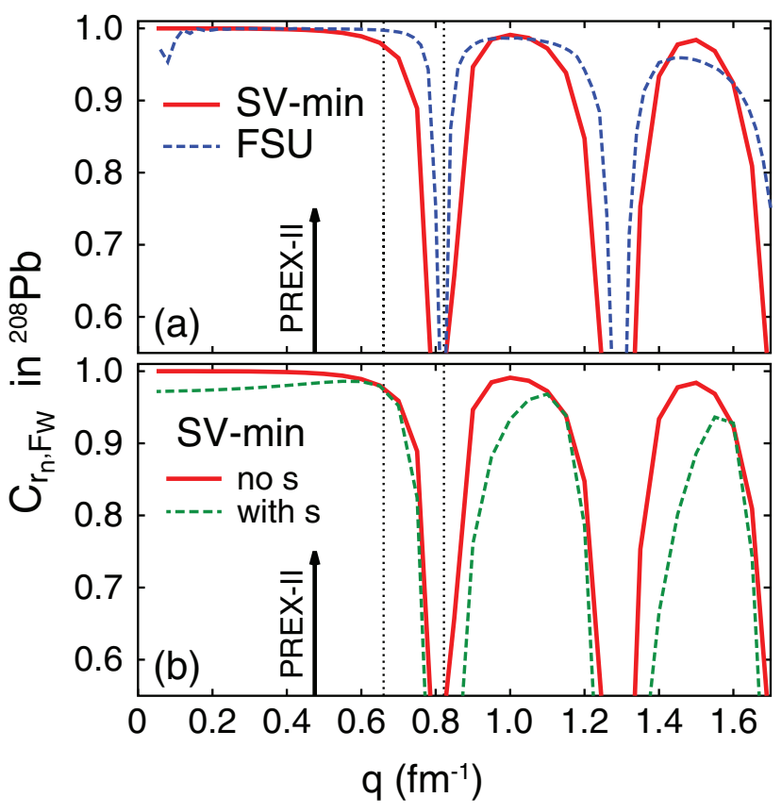
The shortest of the roads …



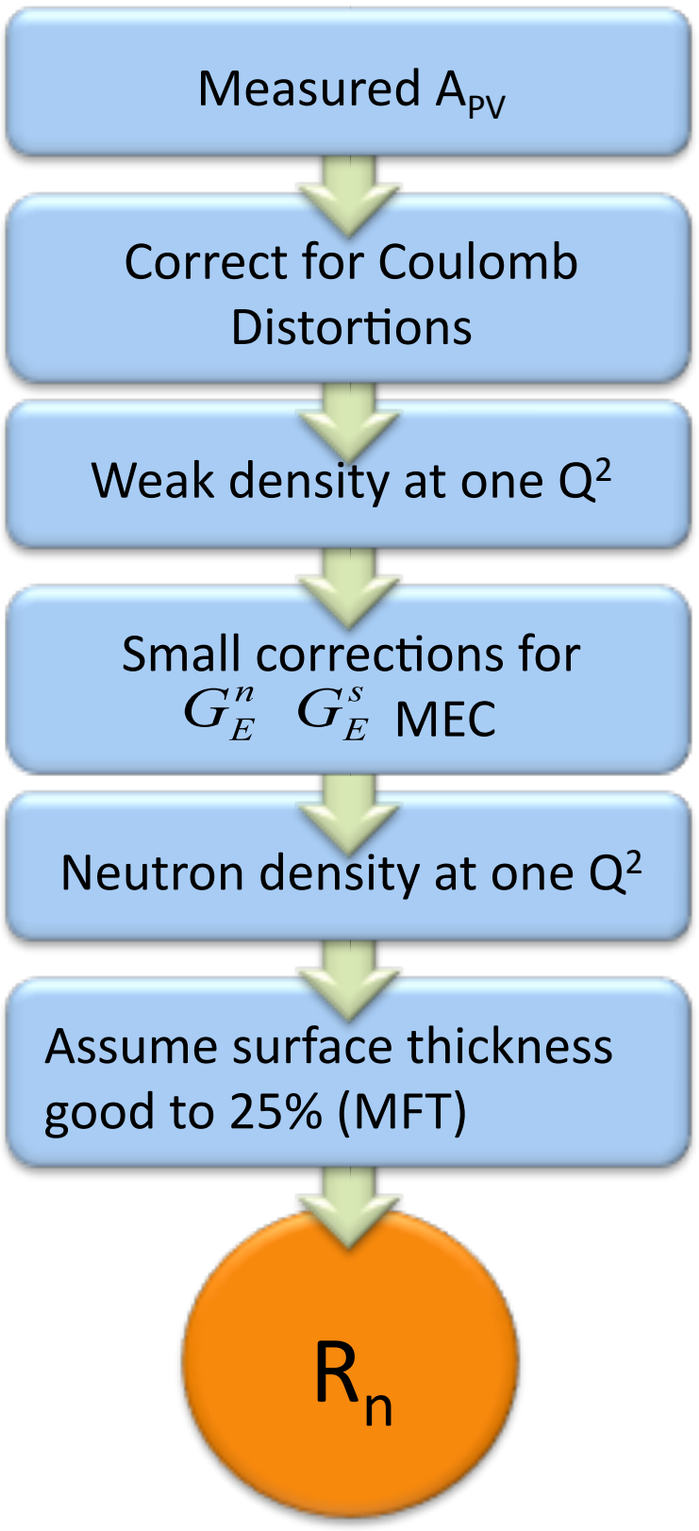


$$A_{PV} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[\underbrace{1-4\sin^2\theta_W}_{\approx 0} - \frac{F_n(Q^2)}{F_p(Q^2)}\right]$$





PHYSICAL REVIEW C88, 034325 (2013)

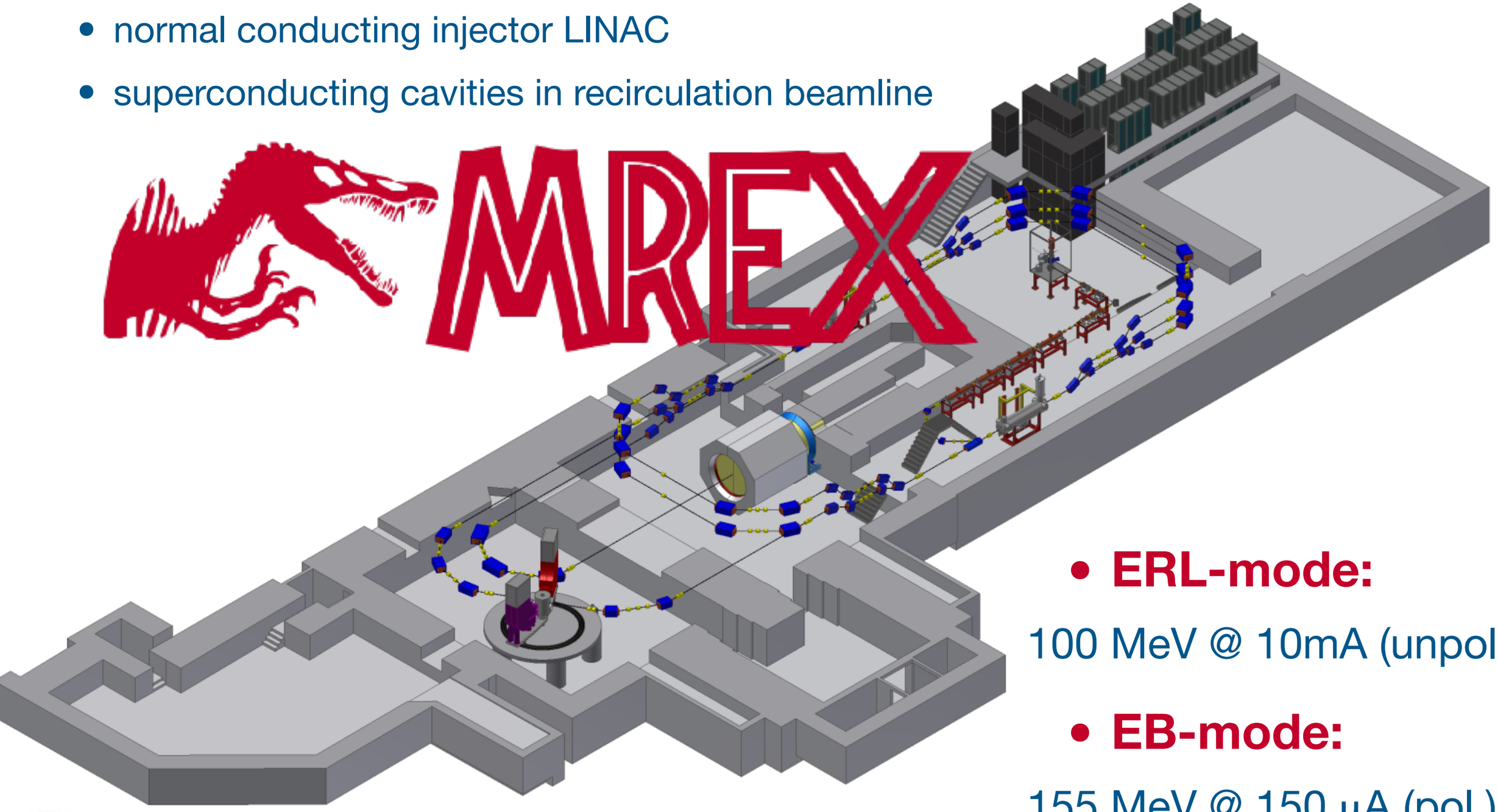


Neutron Skin@Mainz

MESA

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

MAGIX



- **ERL-mode:**

100 MeV @ 10mA (unpol.)

- **EB-mode:**

155 MeV @ 150 μA (pol.)

Neutron Skin@Mainz

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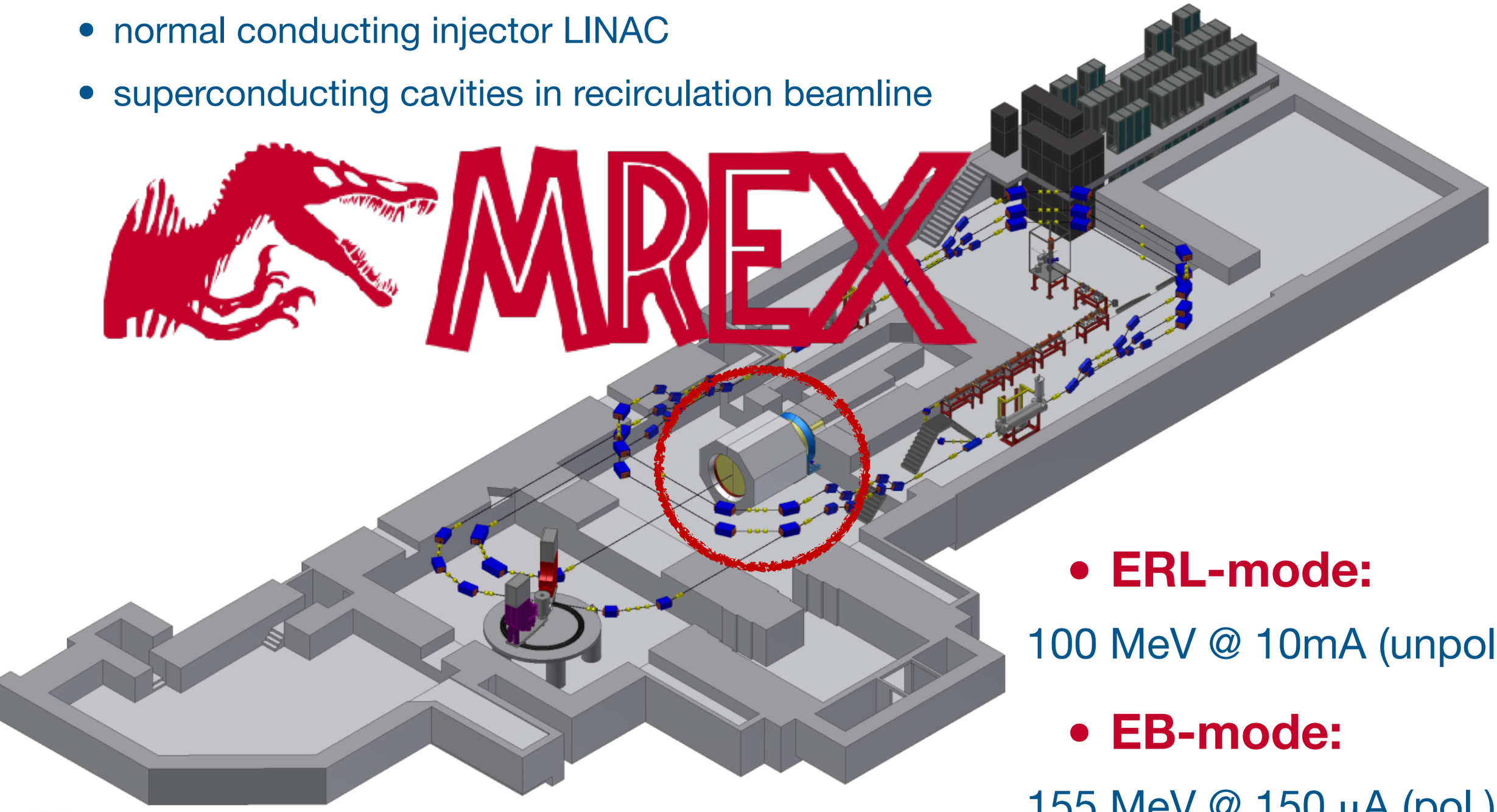

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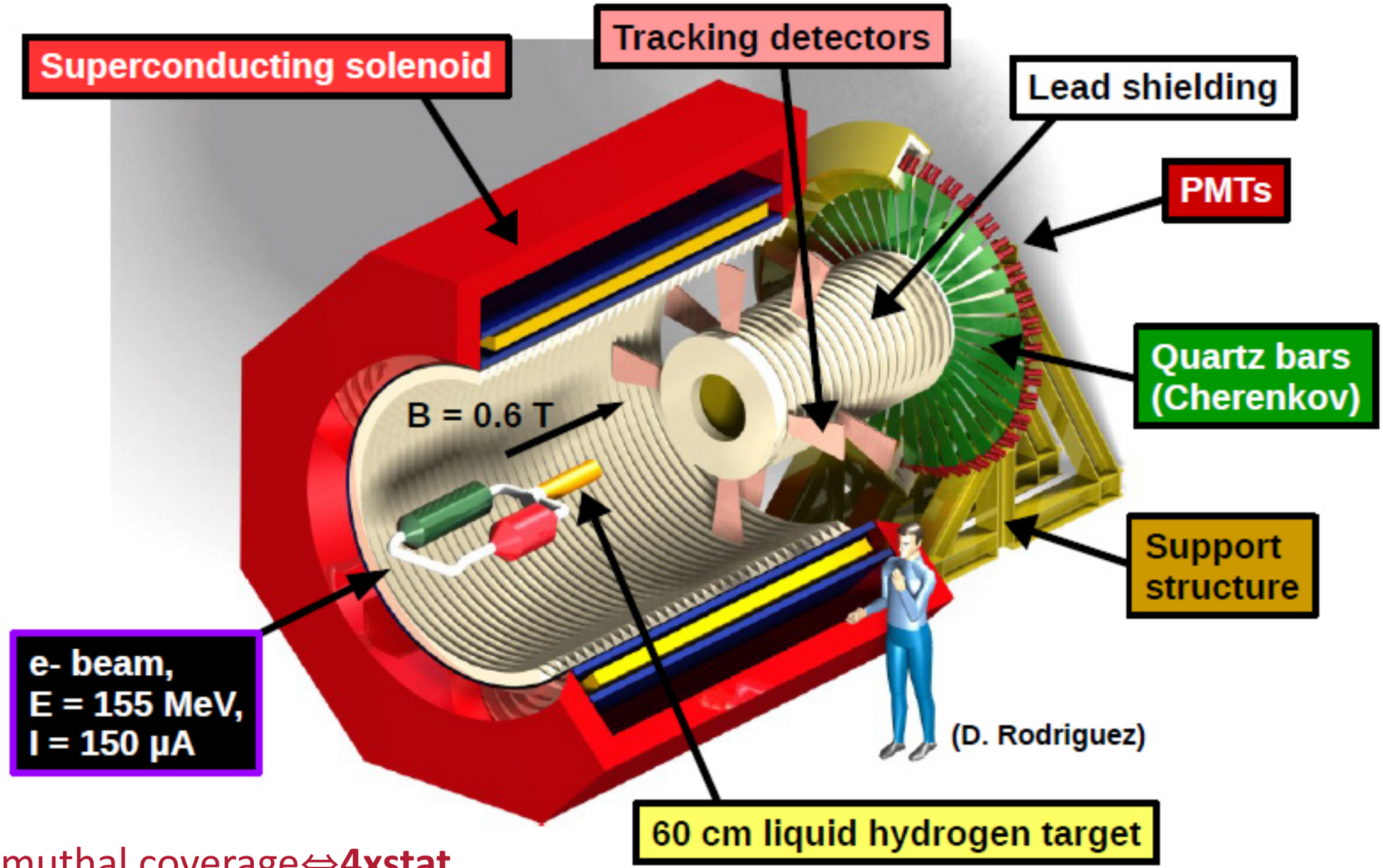
MREX



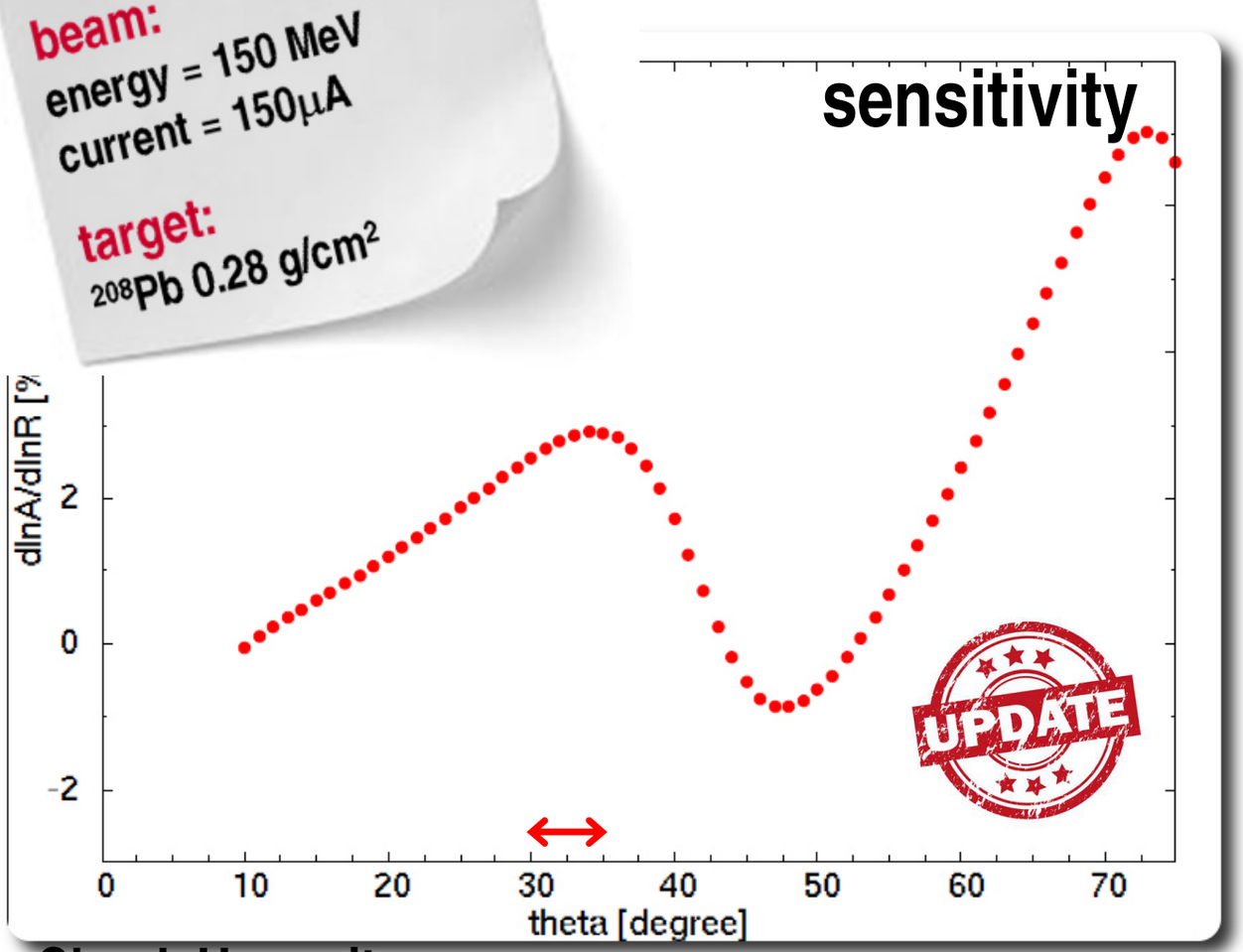
Full azimuthal coverage⇔**4xstat**

MREX

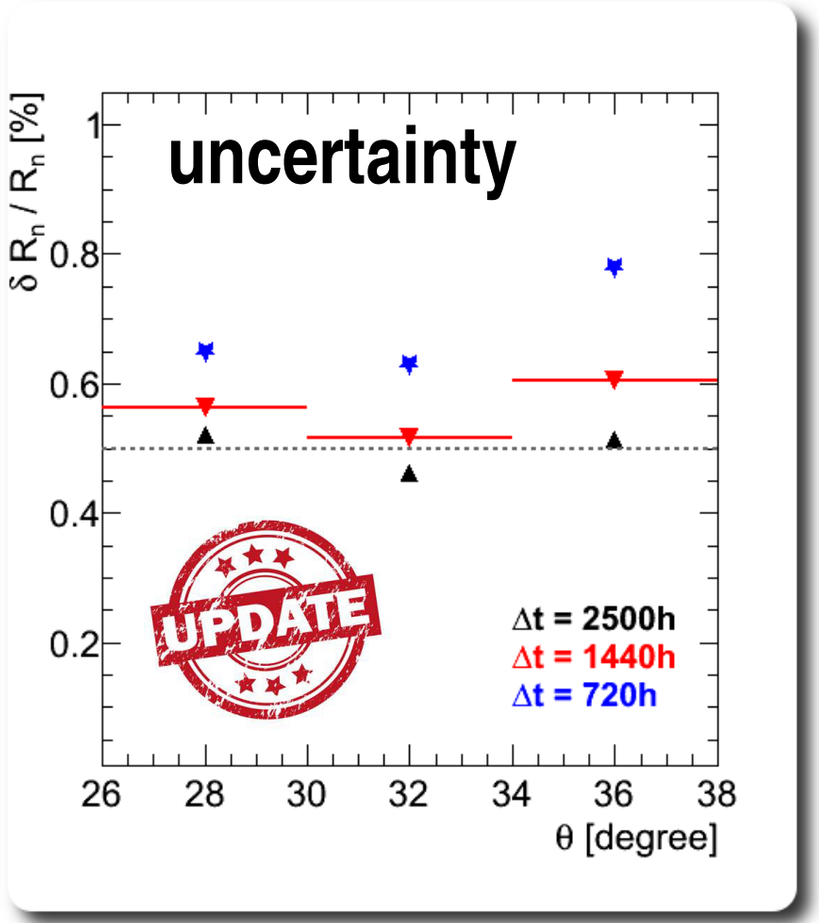
General condition:

beam:
energy = 150 MeV
current = 150μA

target:
^{208}Pb 0.28 g/cm^2



Chuck Horowitz



Michaela Thiel

$\Delta\theta$=4° : expected rate = 8.25 GHz, A_{PV} = 0.66 ppm, P = 85%, Q ≈ 86 MeV

1440h → $\delta R_n/R_n$ = 0.52% (^{208}Pb @ 155 MeV)

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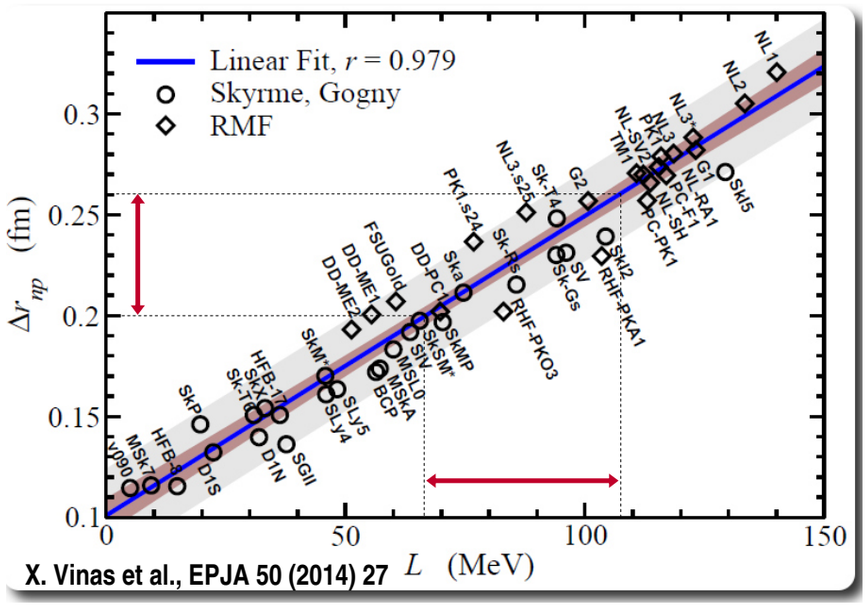
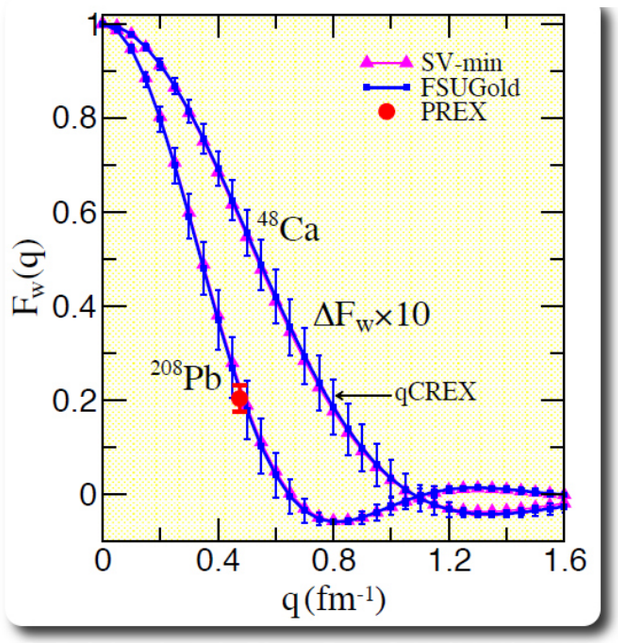


X. Vinas et al., EPJA 50 (2014) 27



P.-G. Reinhard et al.. Phys. Rev. C 88 (2013) 034325

➢ **PREX-II & CREX Results needed**

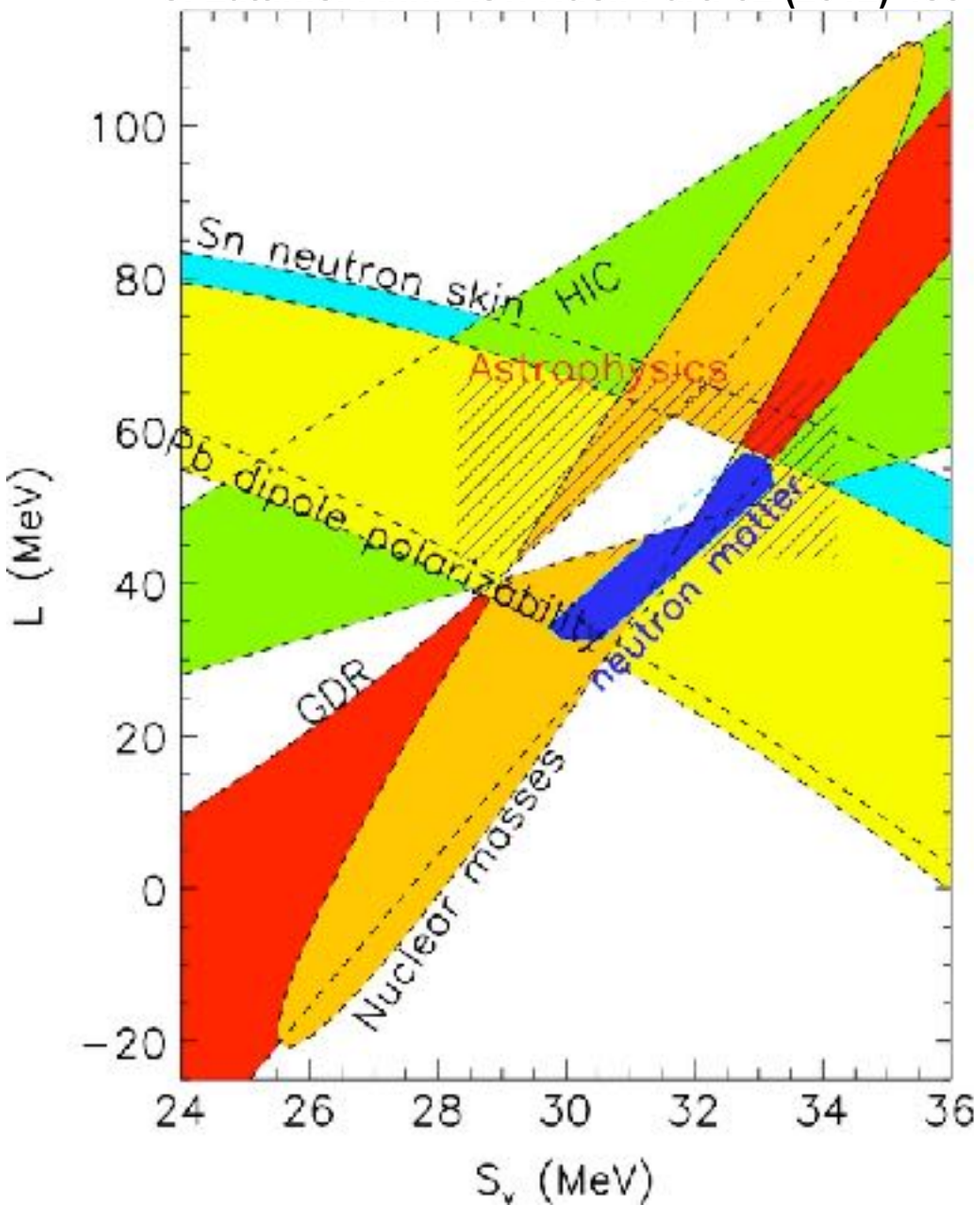
➢ **$\delta R_n/R_n$ = 0.5%**

→ **L ± 20 MeV**

	^{208}Pb @ MREX	^{48}Ca @ MREX	PREX-II	CREX
E_{beam}	155 MeV / 105 MeV	155 MeV / 105 MeV	≈ 1 GeV	2.2 GeV
Q	86 MeV / 58 MeV 0.44 fm^{-1} / 0.29 fm^{-1}	143 MeV / 75 MeV 0.73 fm^{-1} / 0.38 fm^{-1}	86 MeV 0.44 fm^{-1}	154 MeV 0.78 fm^{-1}
$\delta A_{PV}/A_{PV}$	1.3%	1.3%	3.6%	2.4%
$\delta R_n/R_n$	**0.52%**	**0.38%**	**1.0%**	**0.5%**

The long winding road ....

J. Lattimer Ann. Rev. Nucl. Part. 62 (2012) 485



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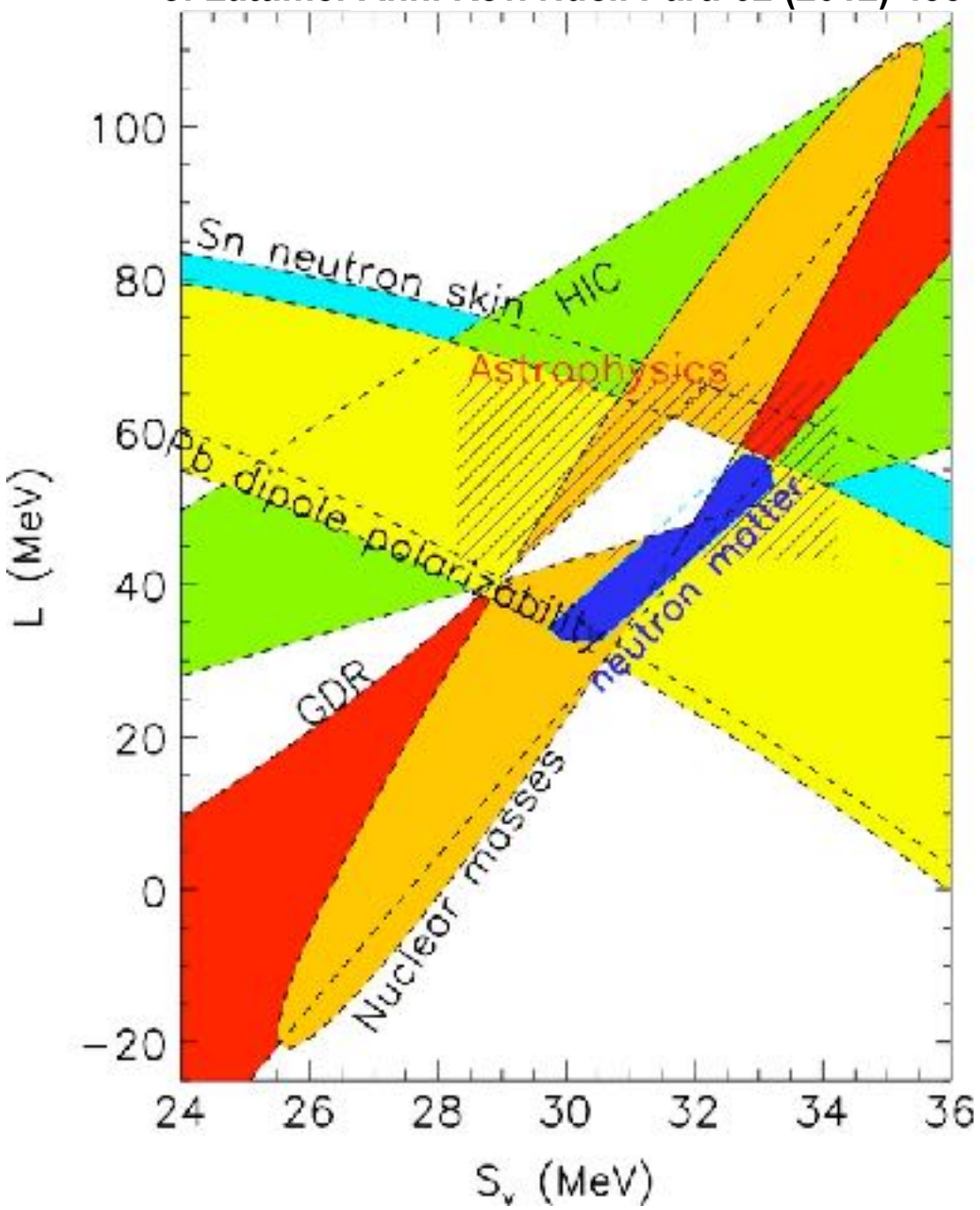

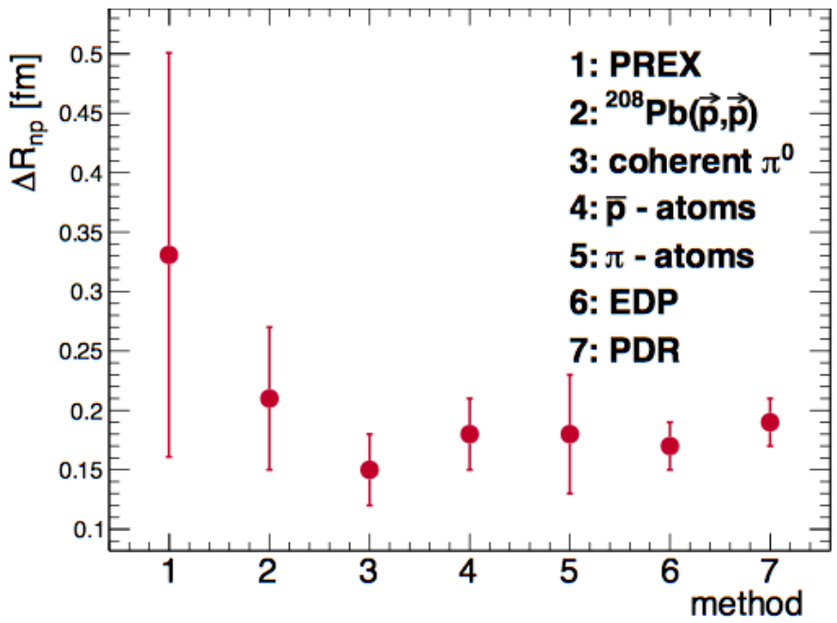

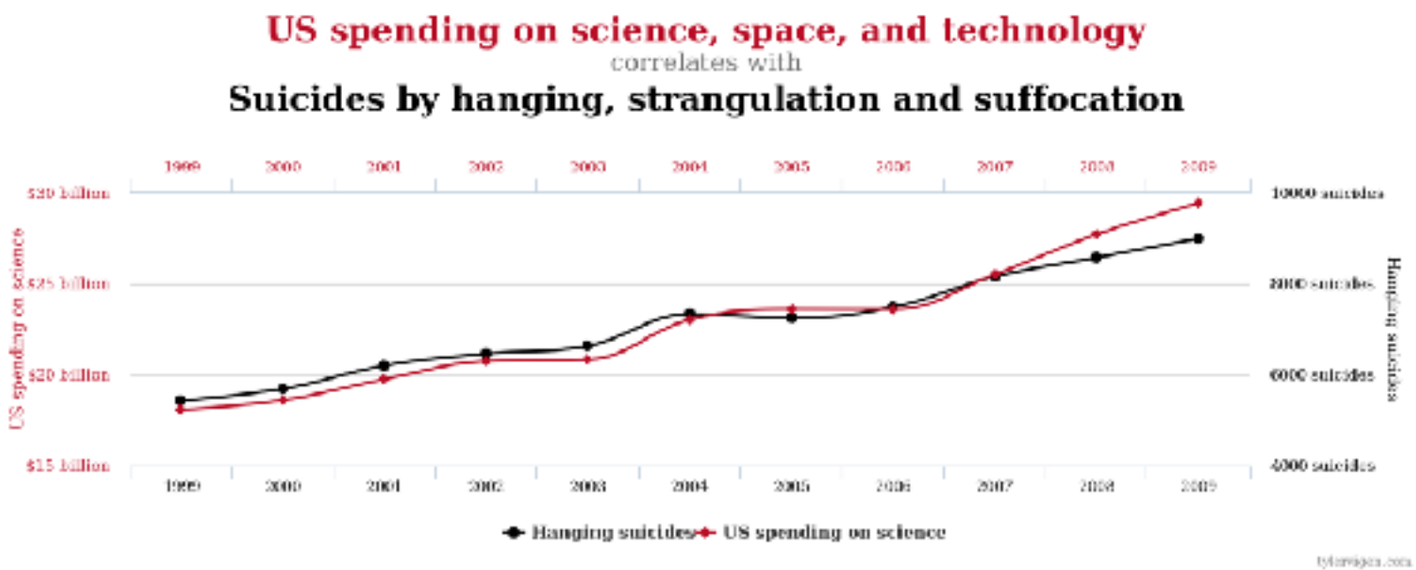

.... could not lead to Rome...

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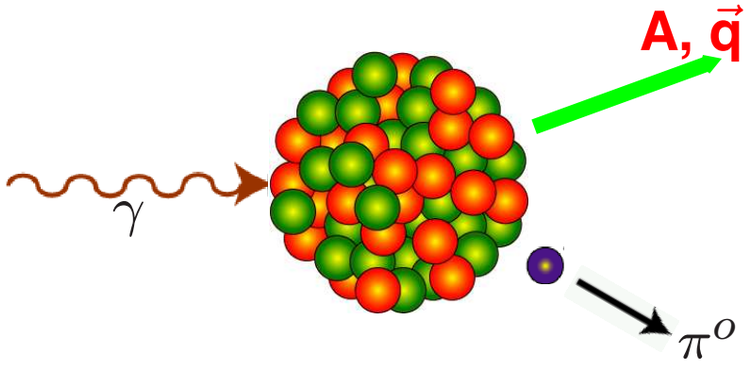
One MZ-Example

Coherent π^0 photoproduction: easy and quick *(A2 Coll. Phys. Rev. Lett. 112, 242502)*



… *shine light* on the nucleus!

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

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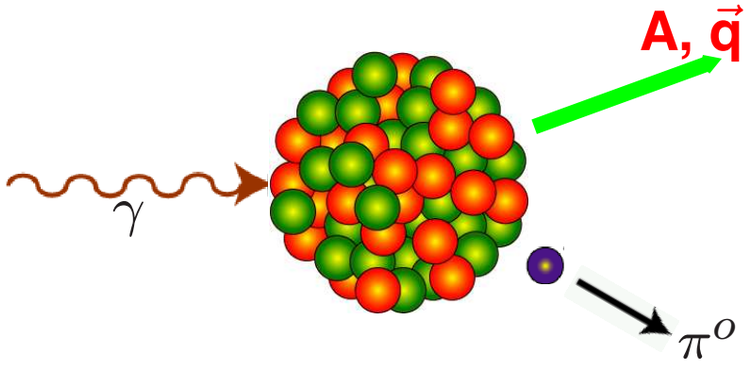

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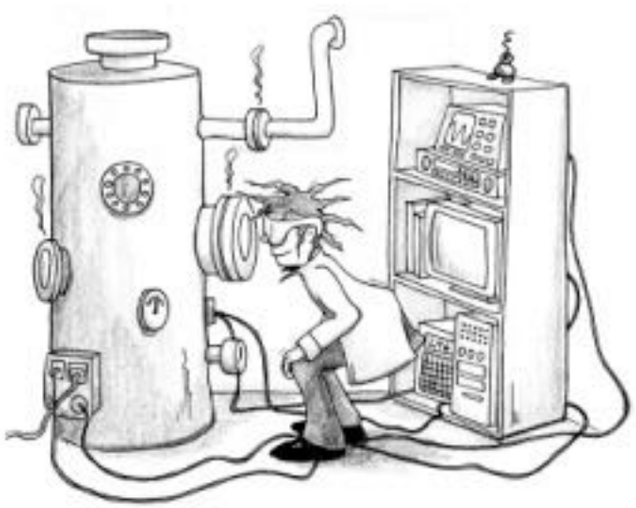

Photon probe interaction well understood: No ISI

π^0 meson produced with ≈ probability on **p AND n**

TO DO: Reconstruct π^0 from $\pi^0 \rightarrow 2\gamma$ decay

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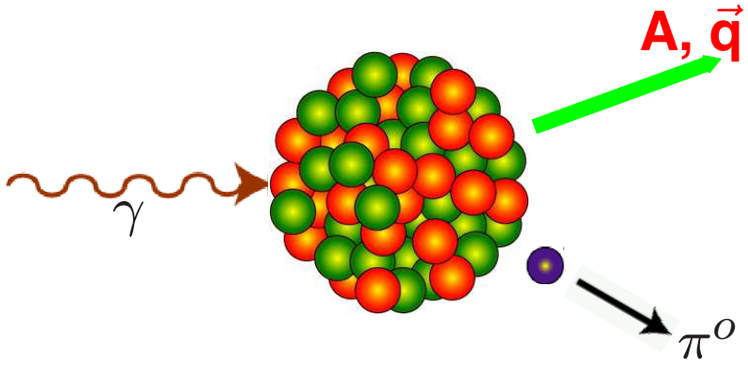

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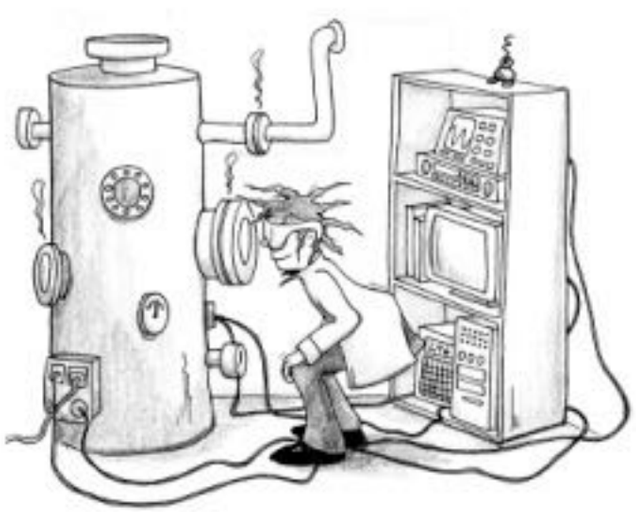

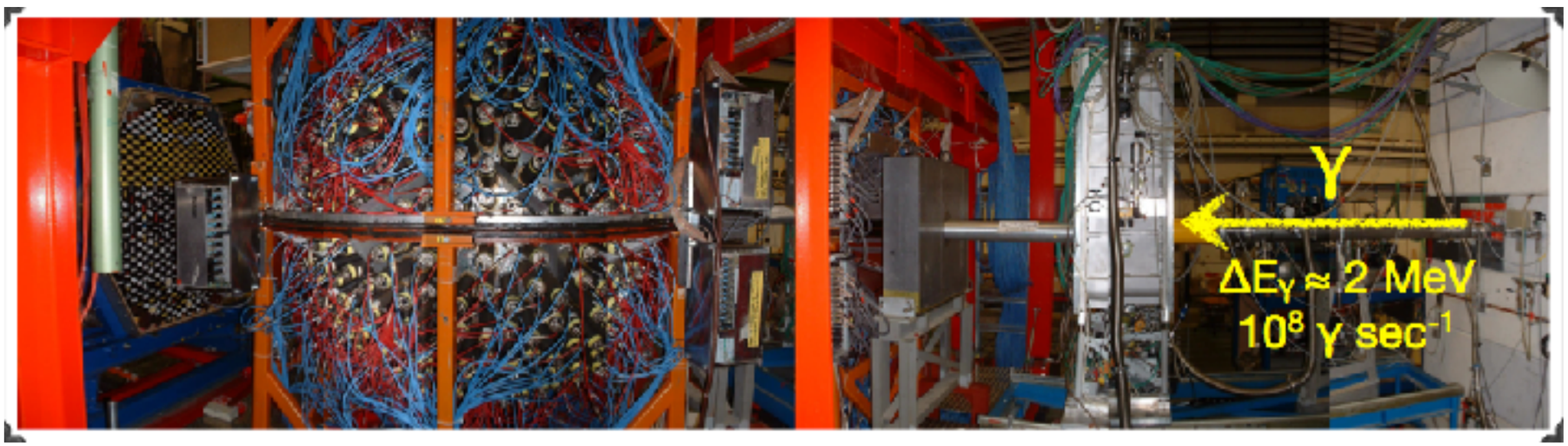

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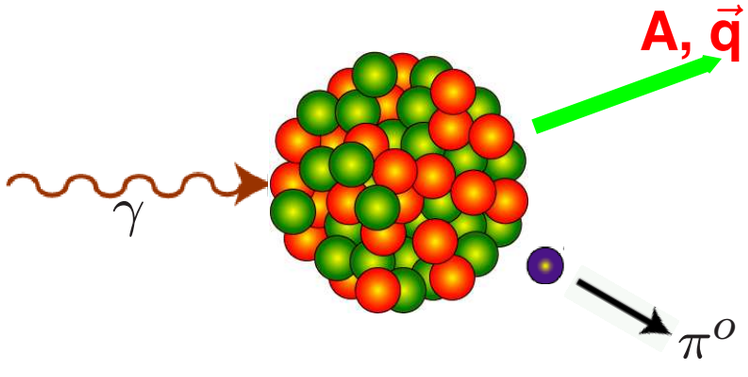
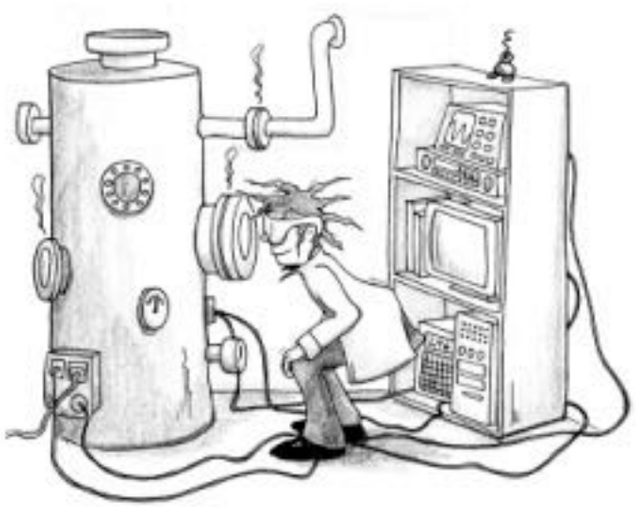
One MZ-Example

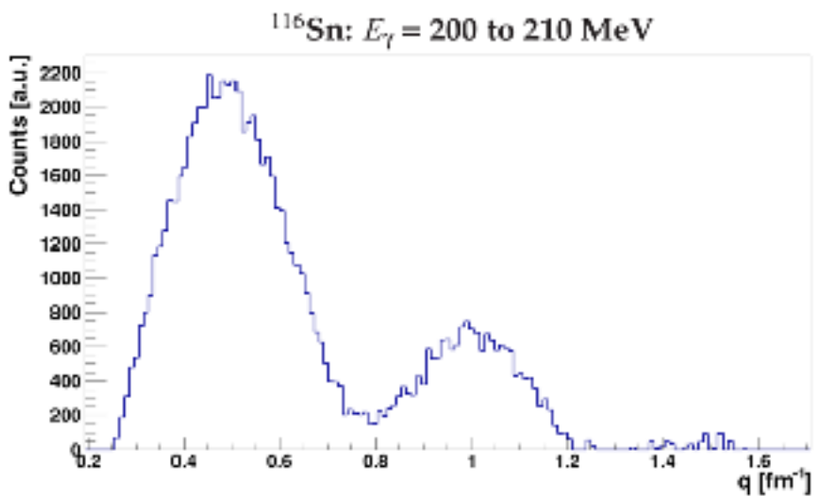
Coherent π^0 photoproduction: easy and quick *(A2 Coll. Phys. Rev. Lett. 112, 242502)*

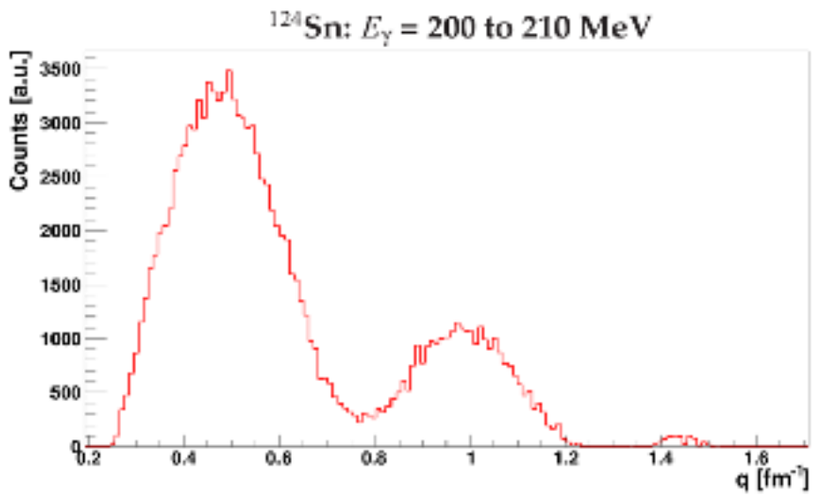


… *shine light* on the nucleus!

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







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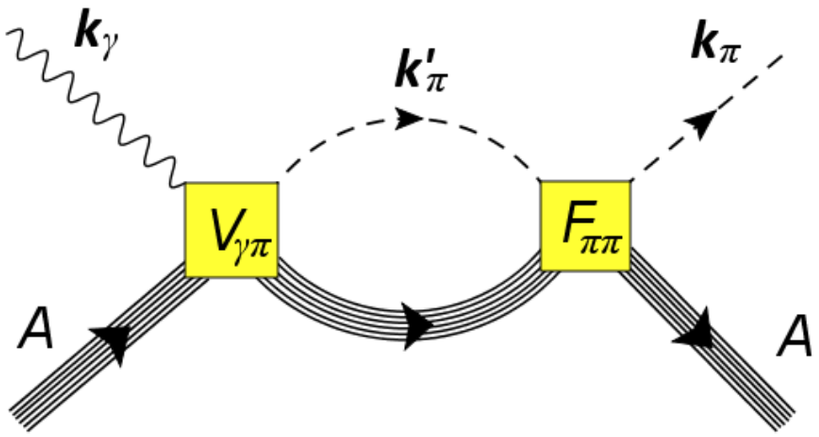
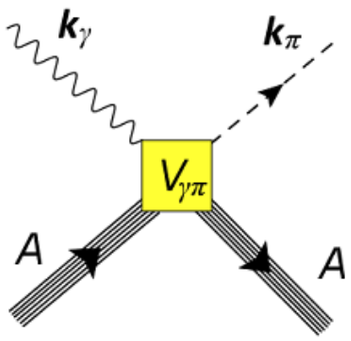
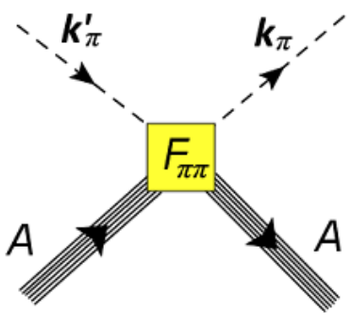
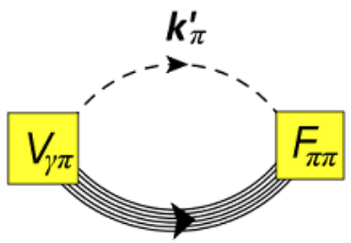
One MZ-Example

P. Capel, F. Colomer, S. Tsaran, M. Vanderhagen









- Working code for PWIA amplitudes for photoproduction $V_{\pi\gamma}^{(\lambda)}(\mathbf{k}_\pi, \mathbf{k}_\gamma)$
- Working code for scattering matrix $F_{\pi A}$ of π^0
  - Resolution of the Lippmann-Schwinger equation
  - Singularity of Coulomb solved : better constrains on $U^{\mathrm{Nucl}}(k', k)$
- ☐ DWIA amplitudes calculation
  - Off-shell photoproduction amplitudes $V_{\pi\gamma}^{(\lambda)}(\mathbf{k}'_\pi, \mathbf{k}_\gamma)$
- ☐ Devise a better form for $U^{\mathrm{Nucl}}(k', k)$

+ Treatment of Resonances,

+ Use Effective Potentials (J. Piekarewicz)

+ Sensitivity of $\sigma_{\mathrm{coherent}}$ to neutron density

+ Benchmark theory with A/Z and Z variation

...it is a long way till Rome ...

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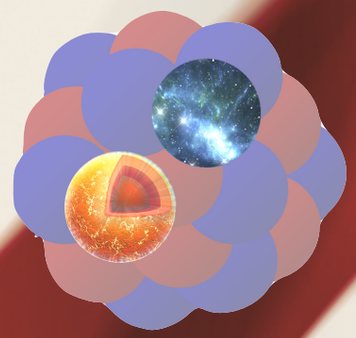

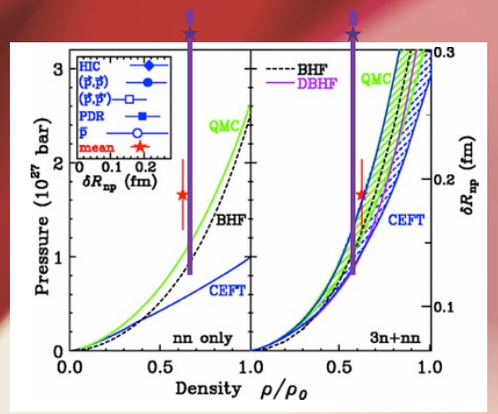

The Good...

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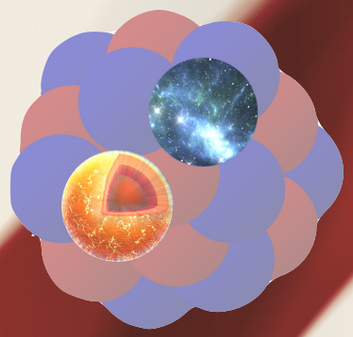
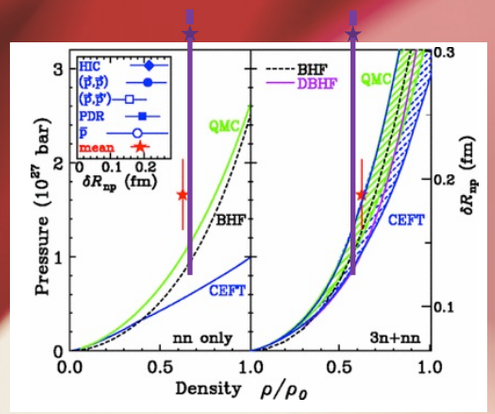
PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

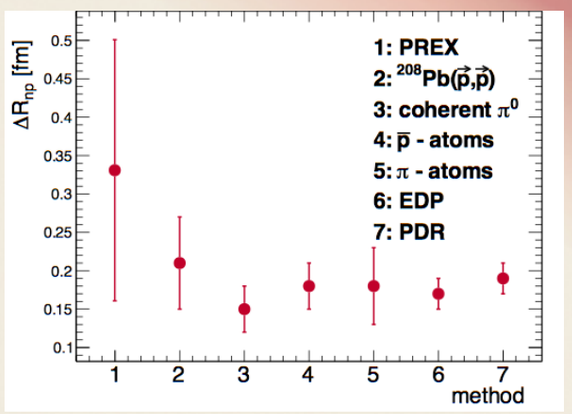
JG|U

Status and Prospect of Rn Measurements at Mainz





The Good...



The Bad...

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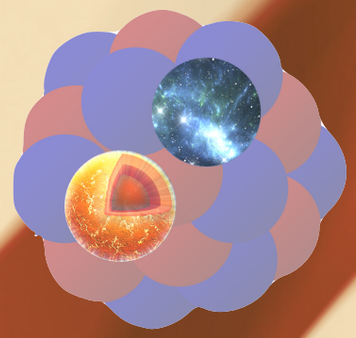
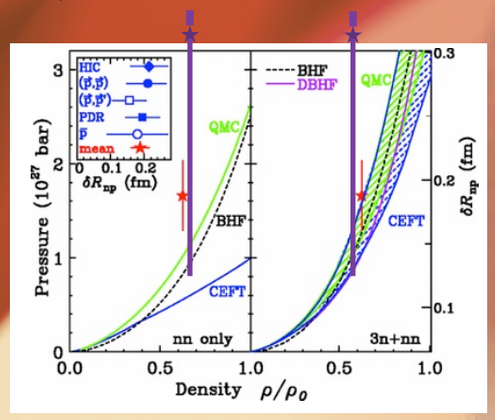
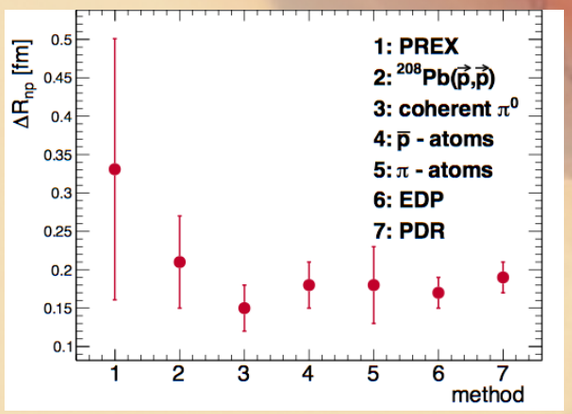
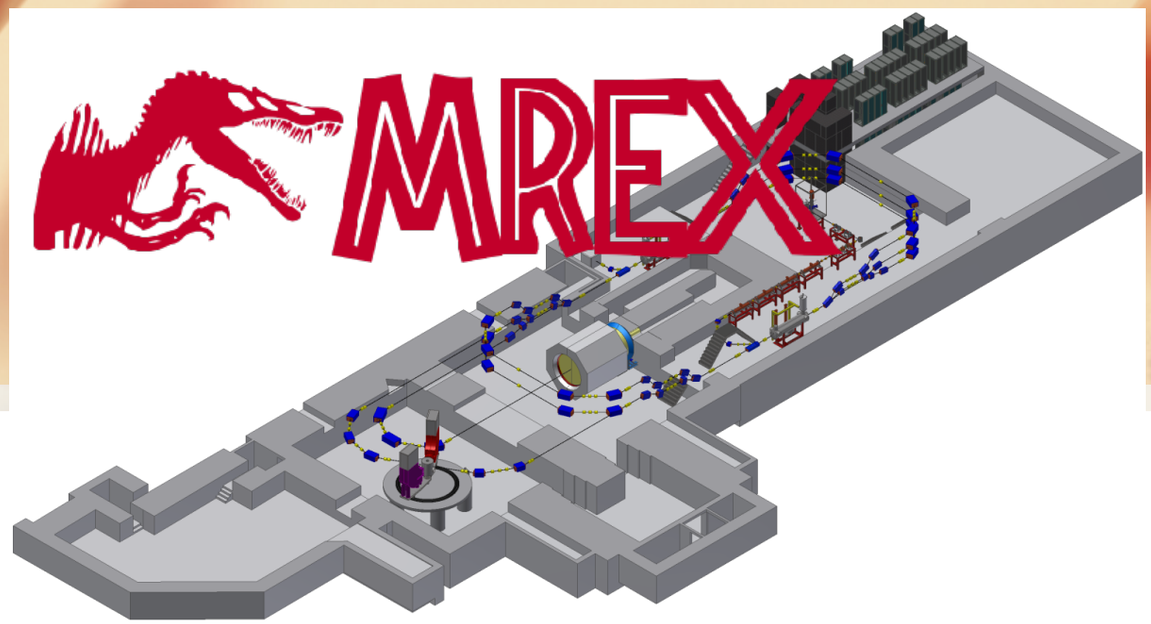




The Good...



The Bad...



...AND THE UGLY

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SFB 1044
THE LOW-ENERGY FRONTIER
OF THE STANDARD MODEL

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56th International Winter Meeting on Nuclear Physics

22-26 January 2018 Bormio, Italy

Long-standing conference bringing together researchers and students from various fields of subatomic physics.

The conference location is Bormio, a beautiful mountain resort in the Italian Alps.

DEADLINES

October 29: Student's fellowship application

October 29: Registration and abstract submission

December 1 : Notification of abstract acceptance and accommodation

We missed you!

PRISMA

SFB 1044 THE LOW-ENERGY FRONTIER OF THE STANDARD MODEL

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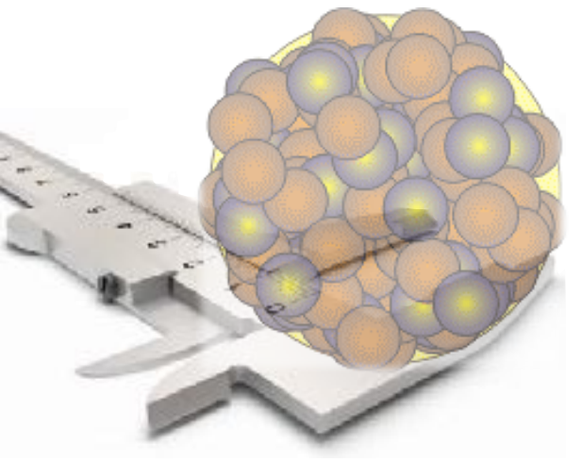
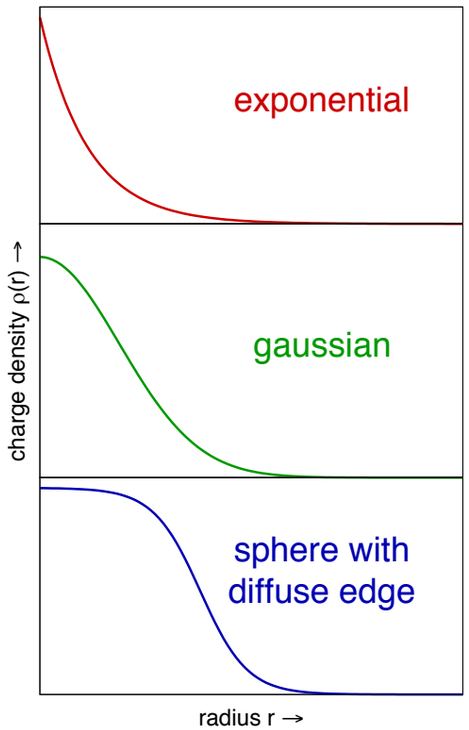
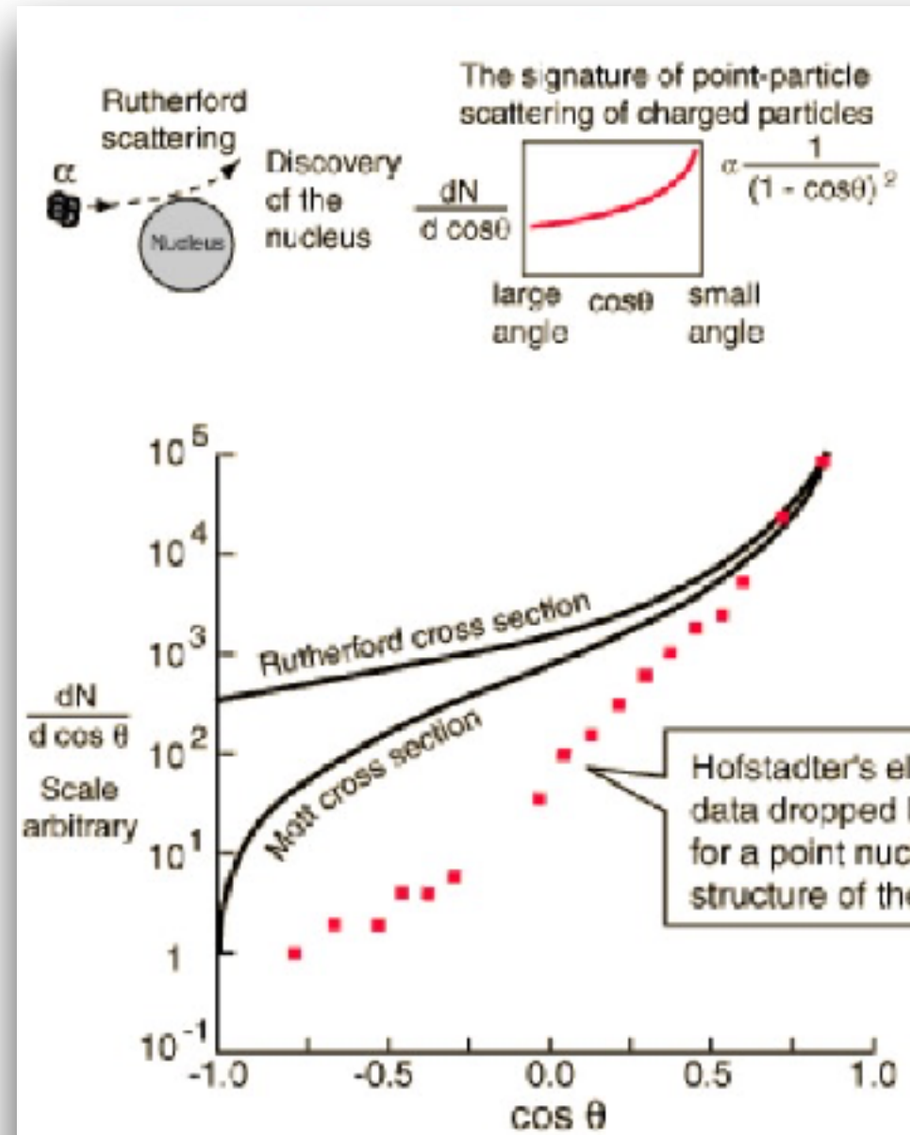
Trivial? It is a long winding road ...







Rutherford Scattering

$$\frac{d\sigma}{d\ \cos\theta} = \frac{\pi}{2} z^2 Z^2 \alpha^2 \left(\frac{\hbar c}{KE}\right)^2 \frac{1}{(1-\cos\theta)^2}$$

+ relativistic electrons
+ nuclear recoil
+ magnetic moments
= Mott Scattering

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

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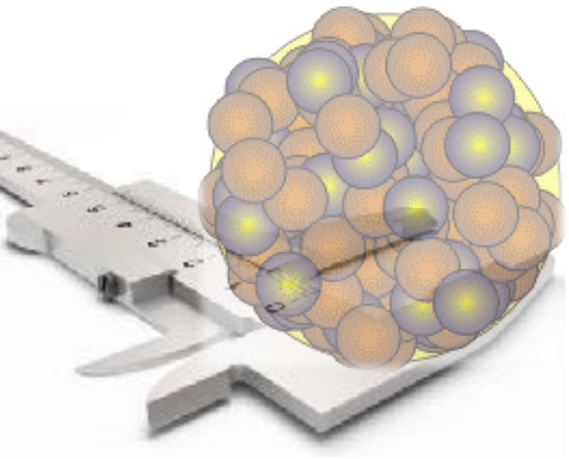
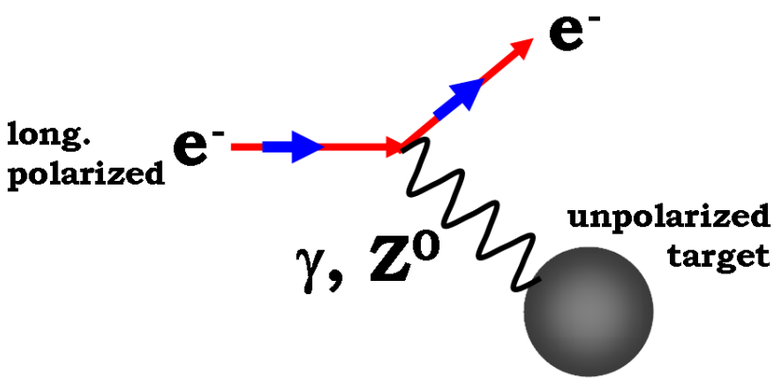
Trivial? It is a long winding road …





electric charge	1	0
weak charge	≈0.07	1

Non-PV e-scattering

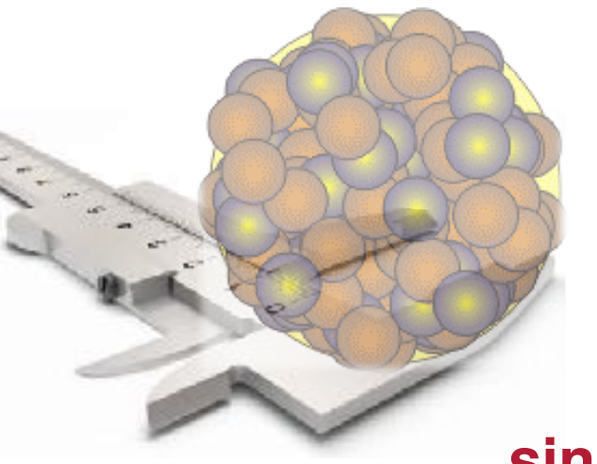
Electron scattering γ exchange provides R_p through nucleus FFs

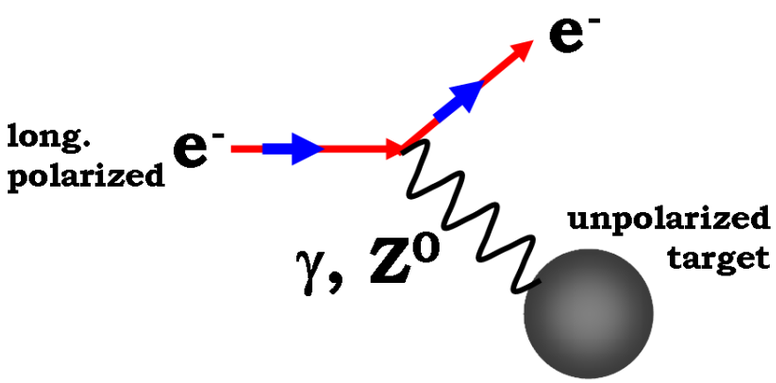
PV e-scattering

Electron also exchange Z, which is parity violating

Primarily couples to neutron

Trivial? It is a long winding road ...





electric charge	1	0
weak charge	≈0.07	1

...since...

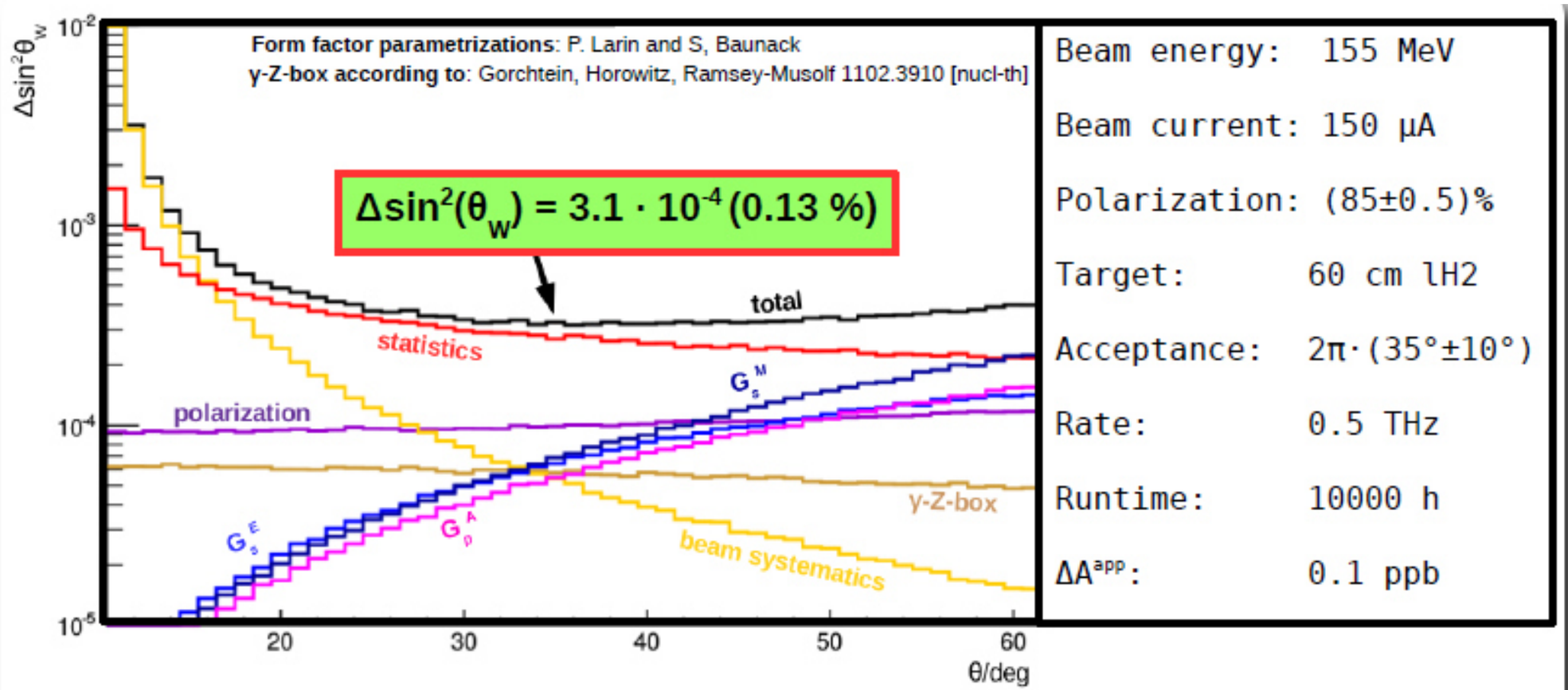
$$\sigma \propto \left| \gamma + Z^0 \right|^2$$

...to measure ...

....construct ....

$$A_{PV} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_+ - \left(\frac{d\sigma}{d\Omega}\right)_-}{\left(\frac{d\sigma}{d\Omega}\right)_+ + \left(\frac{d\sigma}{d\Omega}\right)_-} \approx \frac{2\,\mathrm{Re}\left[\gamma^* Z^0\right]}{\left|\gamma\right|^2} = \frac{G_F Q^2}{2\pi\alpha\sqrt{2}}\left[\underbrace{1 - 4\sin^2\theta_W}_{\approx 0} - \frac{F_n(Q^2)}{F_p(Q^2)}\right]$$

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



<A^exp> = -28.35 ppb | <Q²> = 4.49e-3 GeV²/c²

	Total	Statistics	Polarization	Apparative	FF	Re(□_γZA)
Δsin²(θ_w)	3.1e-4 (0.13 %)	2.6e-4 (0.11 %)	9.7e-5 (0.04 %)	7.0e-5 (0.03 %)	1.4e-4 (0.04 %)	6e-5 (0.03 %)
ΔA^exp/ppb	0.44 (1.5 %)	0.38 (1.34 %)	0.14 (0.49 %)	0.10 (0.35 %)	0.11 (0.38 %)	0.09 (0.32 %)

Dominik Becker

ΔA(sys) ≈ 0.8%

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)

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

- 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, …

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Mainz Institute for Theoretical Physics

Neutron Skins of Nuclei: from laboratory to stars

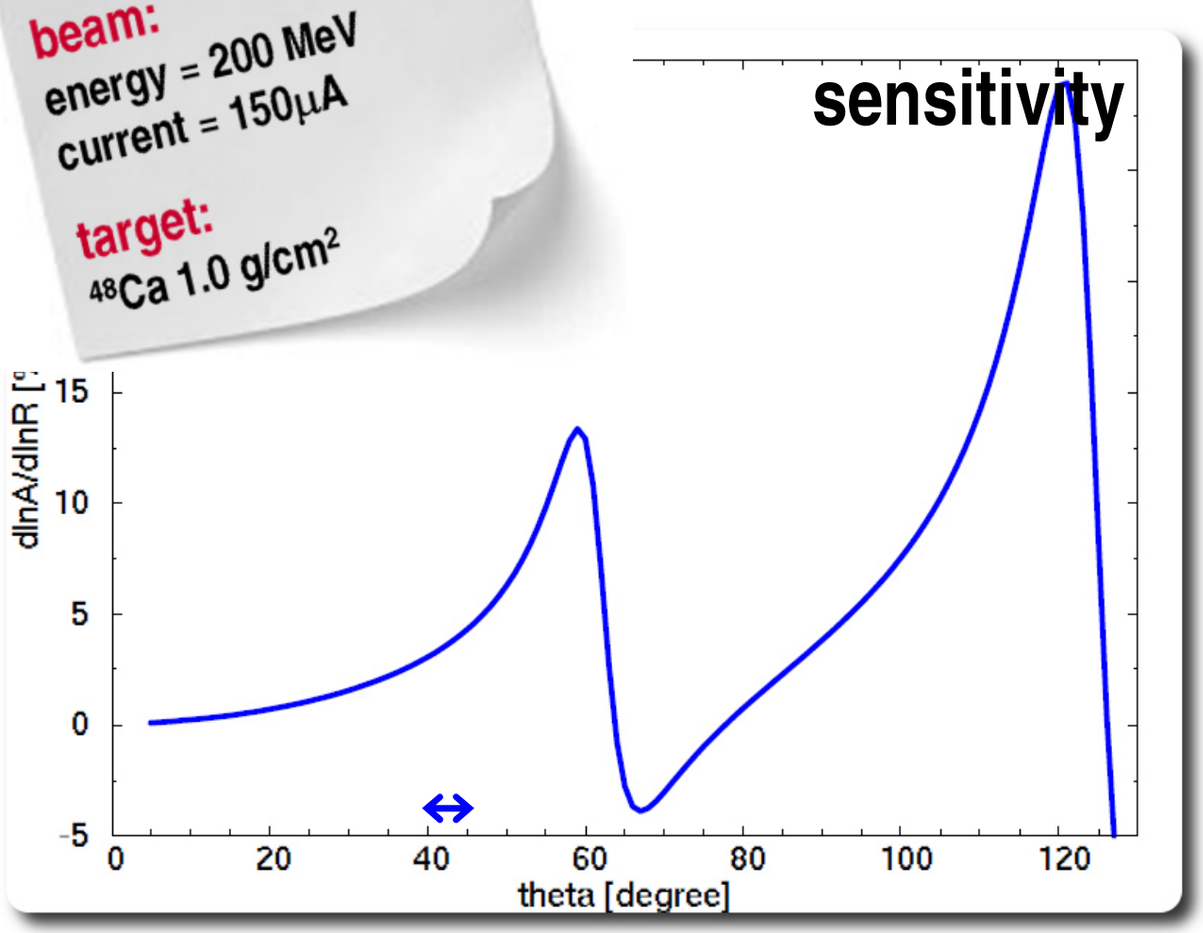
C. Horowitz, J. Piekarewicz, CS (to appear JPG)

MREX

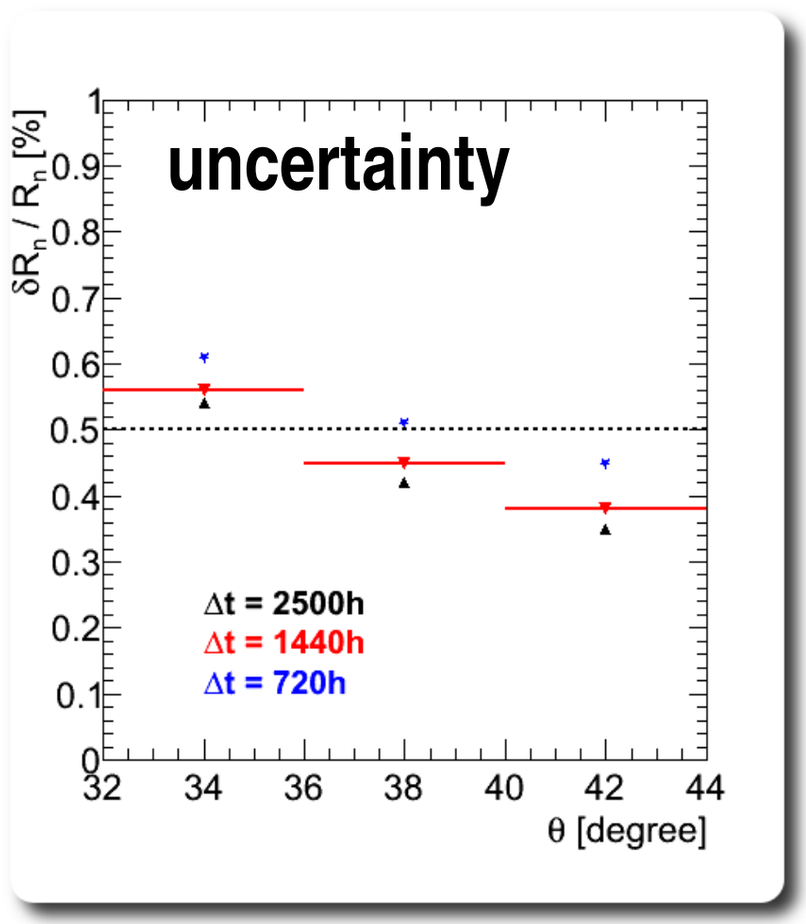
General condition:

beam:
energy = 200 MeV
current = 150μA

target:
^{48}Ca 1.0 g/cm^2



Chuck Horowitz



Michaela Thiel

$\Delta\theta$=4° : expected rate = 0.87 GHz, A_{PV} = 2.14 ppm, P = 85%, Q ≈ 143 MeV

1440h → $\delta R_n/R_n$ = 0.38% (^{48}Ca @ 200 MeV)

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