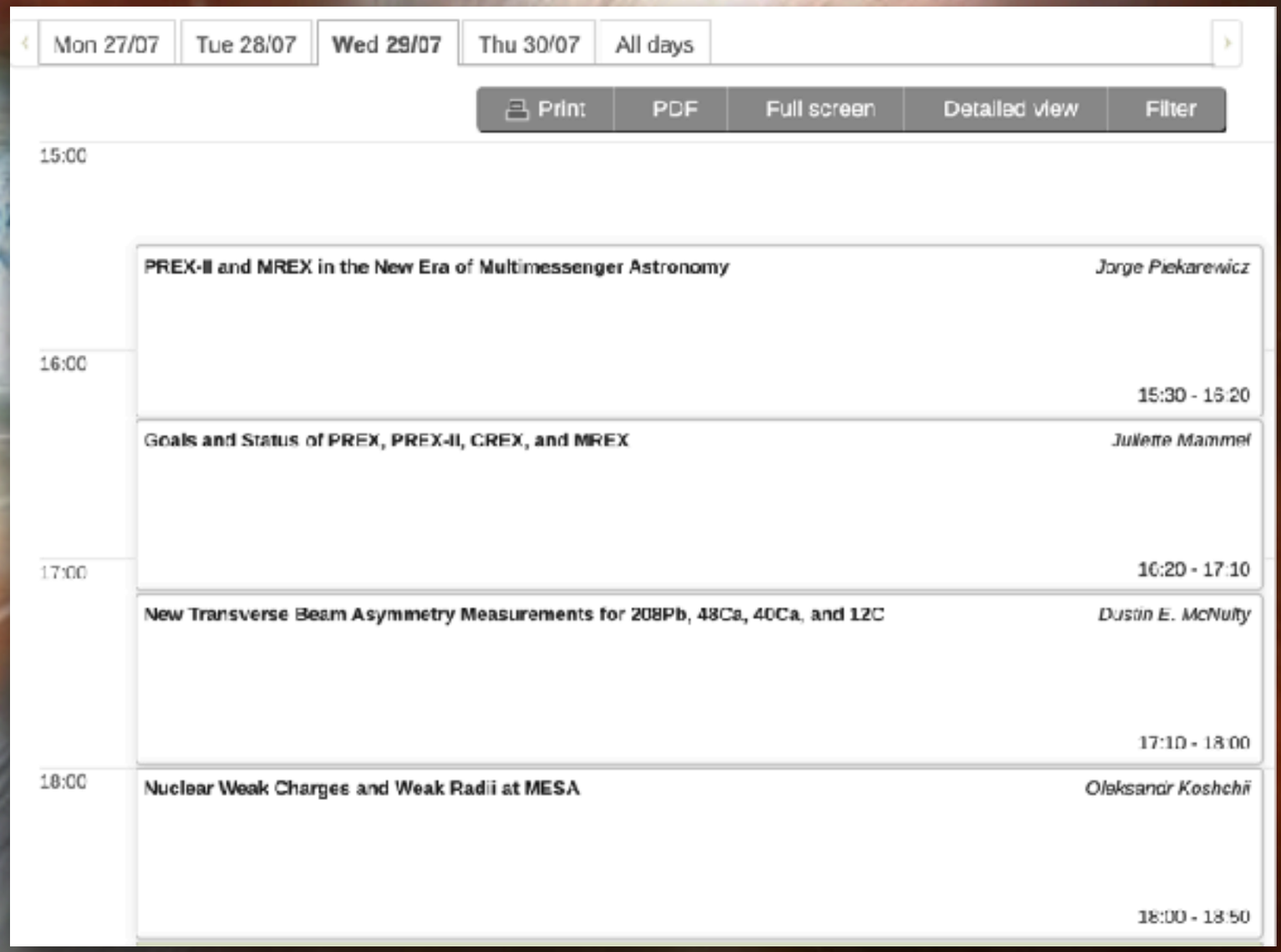
Per aspera ad astra ...

Perspective on EOS studies in the Laboratory

Concettina Sfienti
Johannes Gutenberg-Universität - Institut für Kernphysik, Mainz

Per aspera ad astra ...

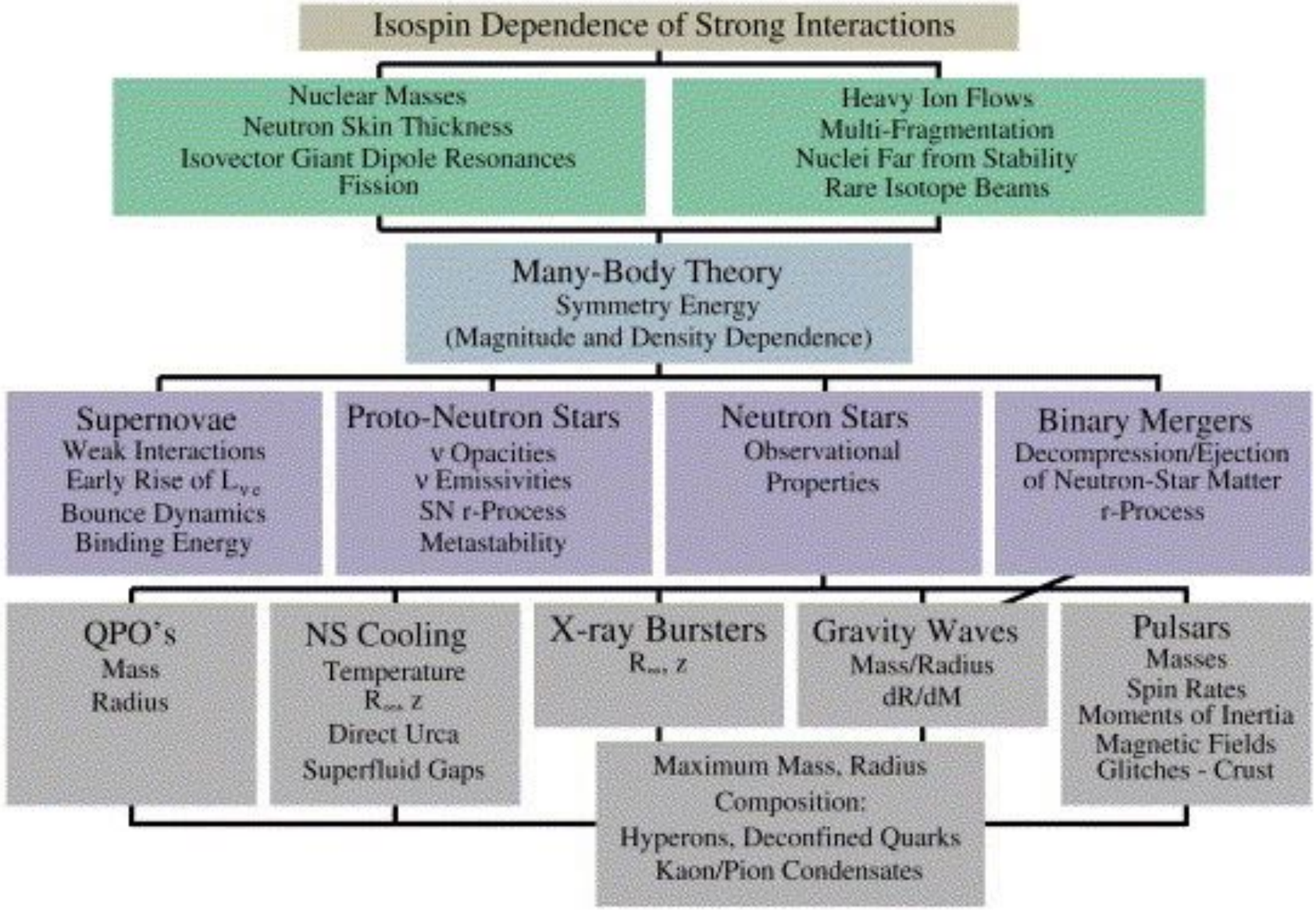
Omen Nomen



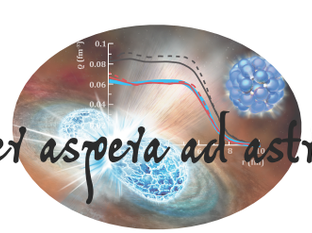
Concettina Sfienti

Johannes Gutenberg-Universität - Institut für Kernphysik, Mainz

Once upon a time...

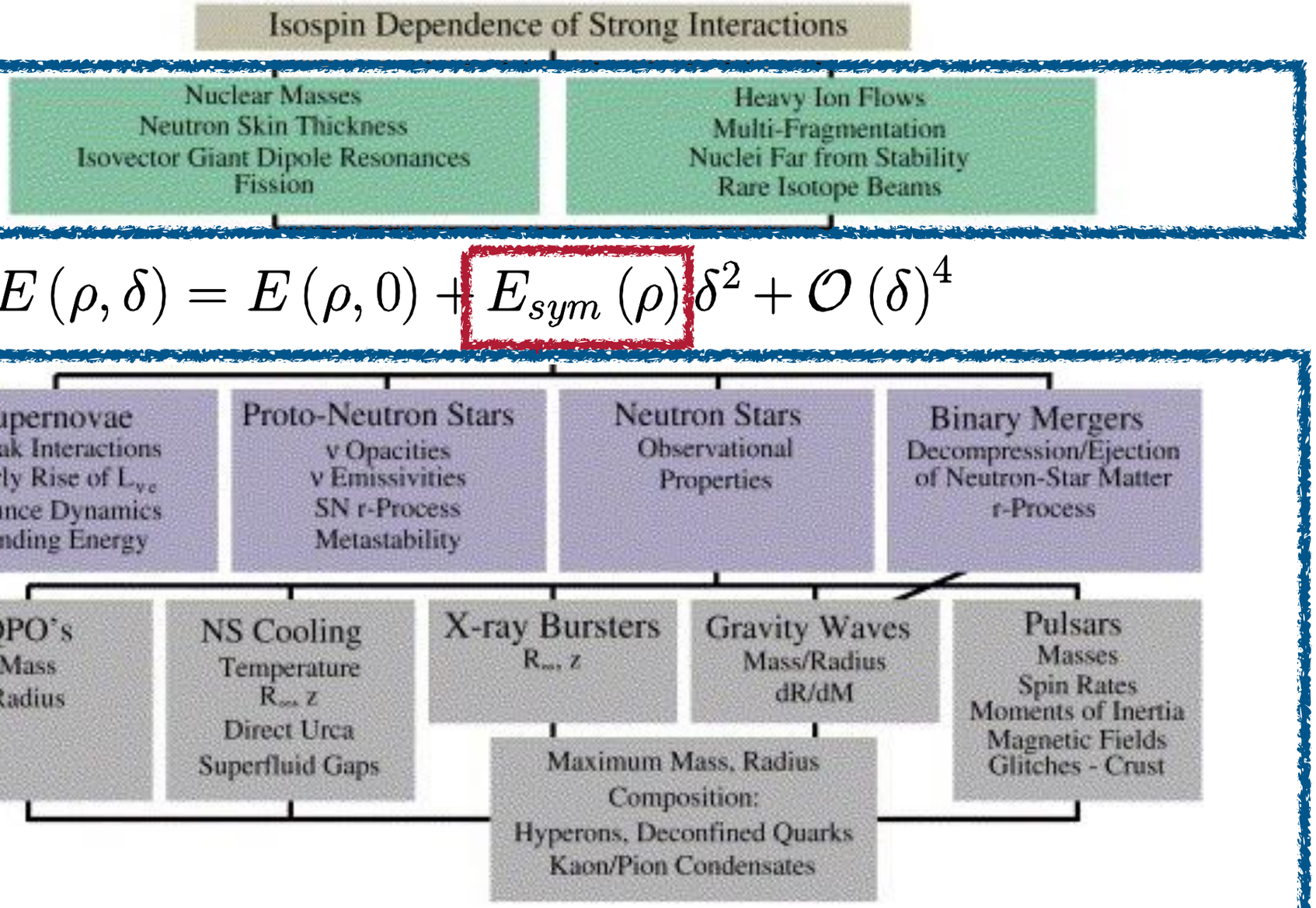


A.W. Steiner, M. Prakash, J.M. Lattimer and P.J. Ellis, Physics Reports, 411 (2005) 325



... per aspera ad astra ...

“Multi-messengers Physics”



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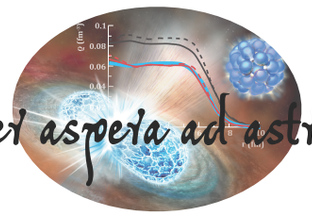
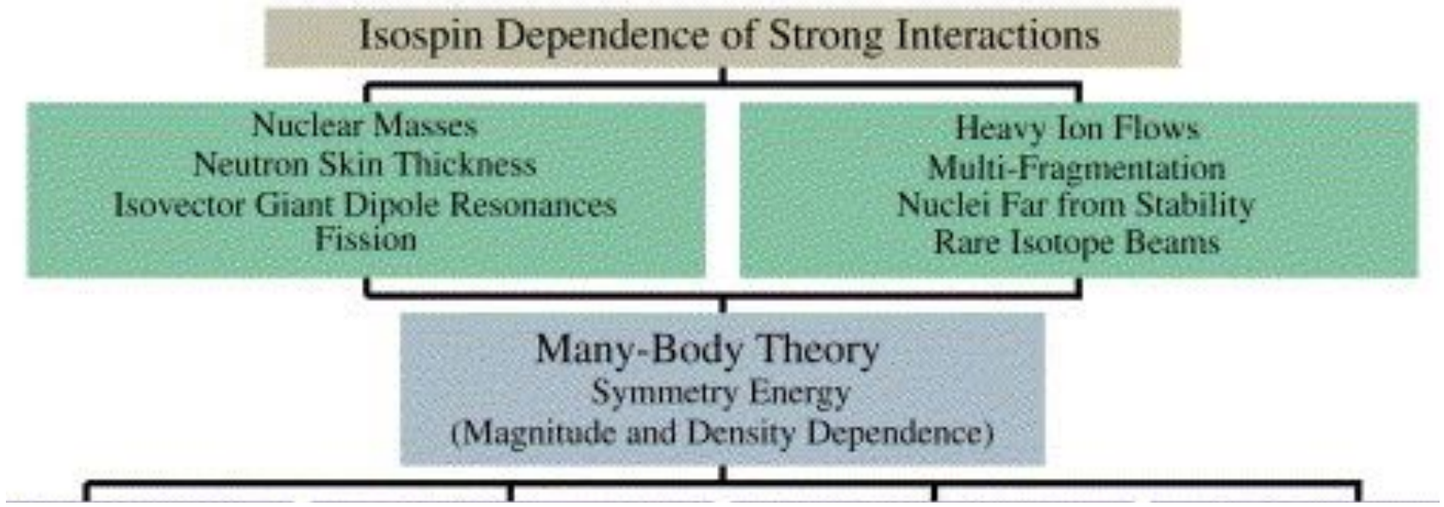


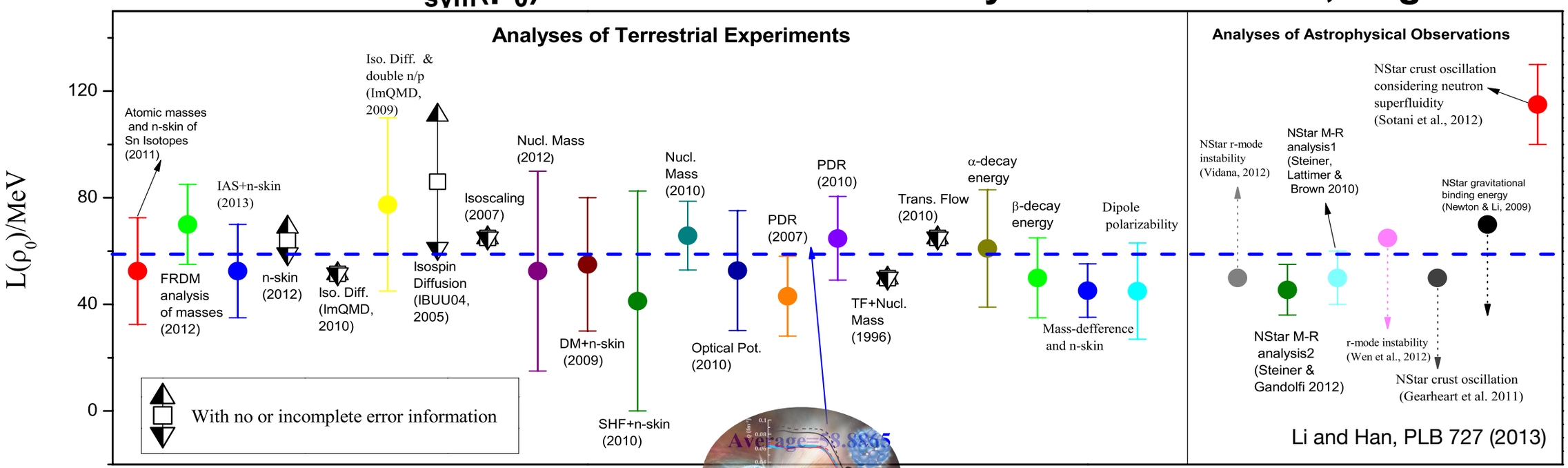
... per aspera ad astra ...

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



Observable + Model = S_v,L

Constraints on $E_{sym}(\rho_0)$ and L based on 29 analyses of some data, Aug. 2013



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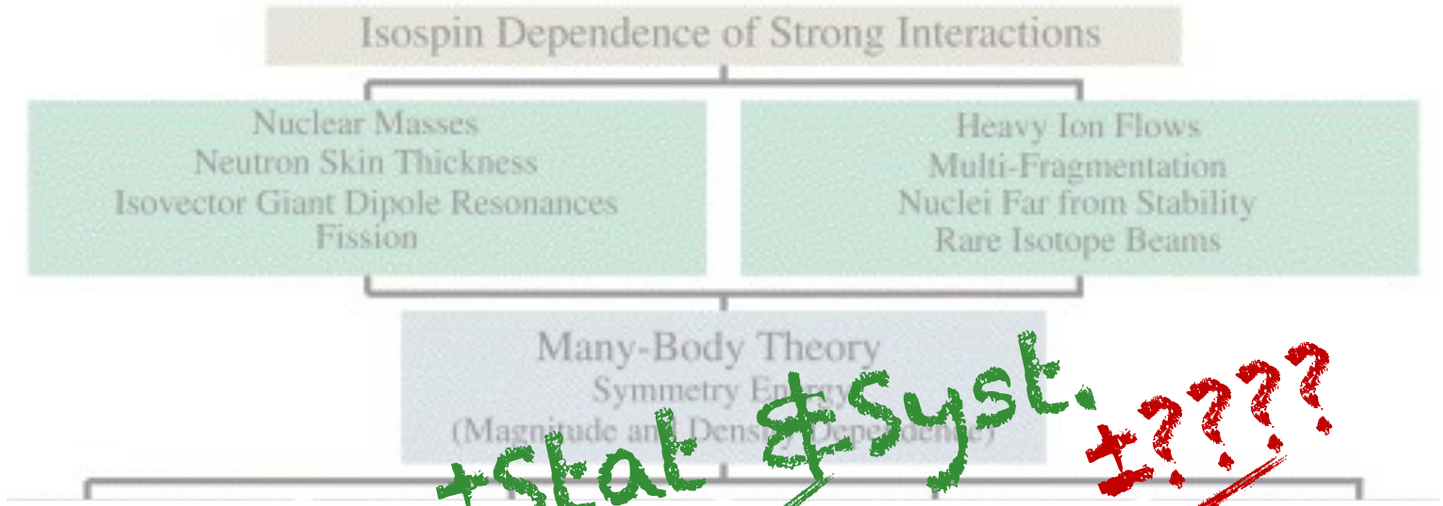

±stat & Syst. ±????

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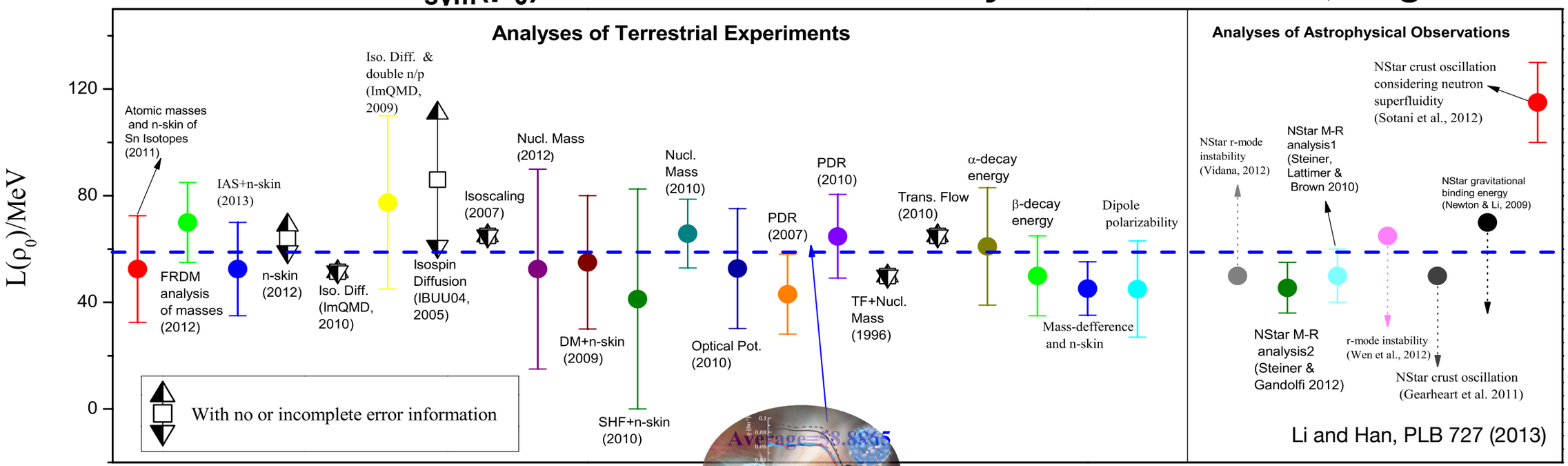

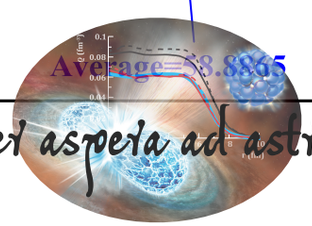

... per aspera ad astra ...

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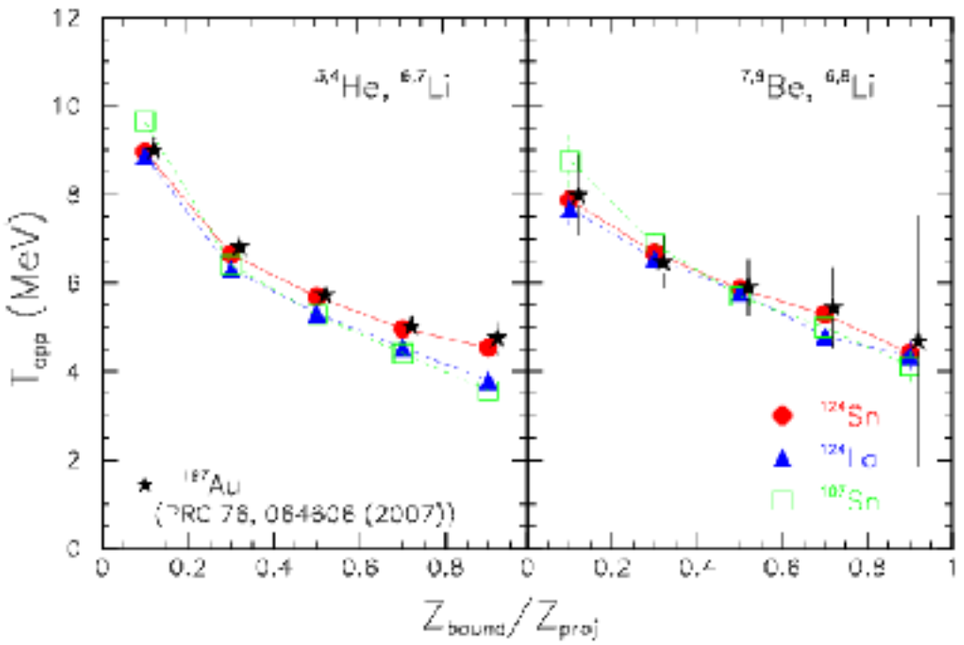
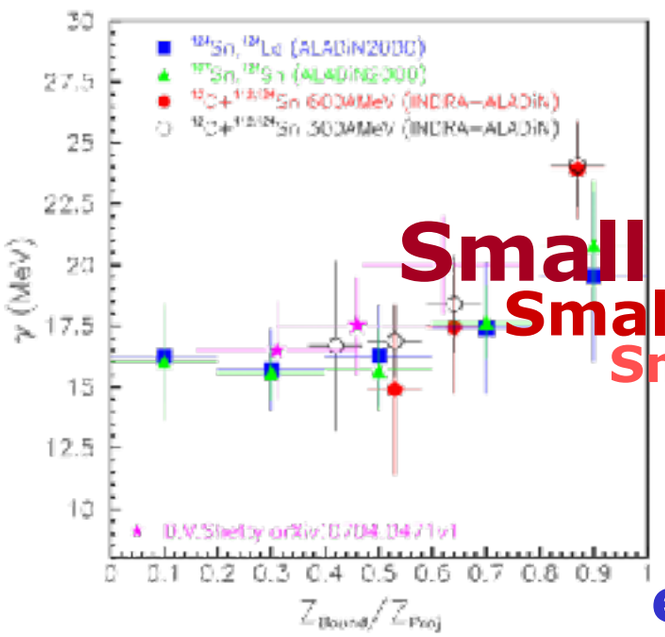
...the (blind!?) search for the Nuclear Symmetry Energy

CS et al., Phys. Rev. Lett. **102**, 152701 (2009)





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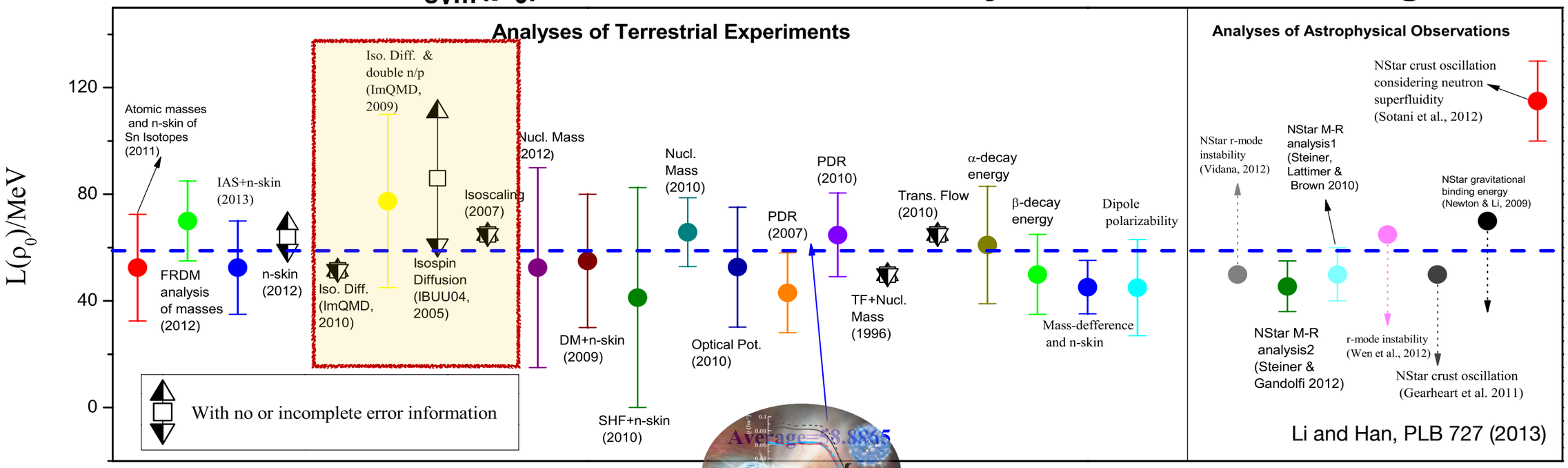
Constraints on $E_{sym}(\rho_0)$ and L based on 29 analyses of some data, Aug. 2013



Li and Han, PLB 727 (2013)

... per aspera ad astra ...

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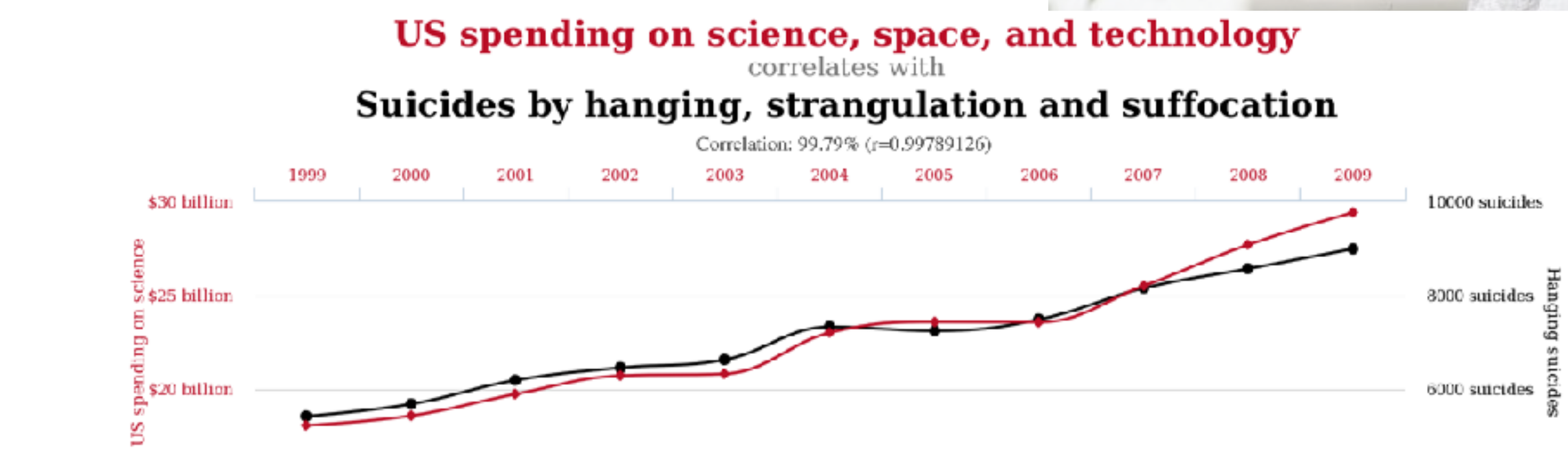
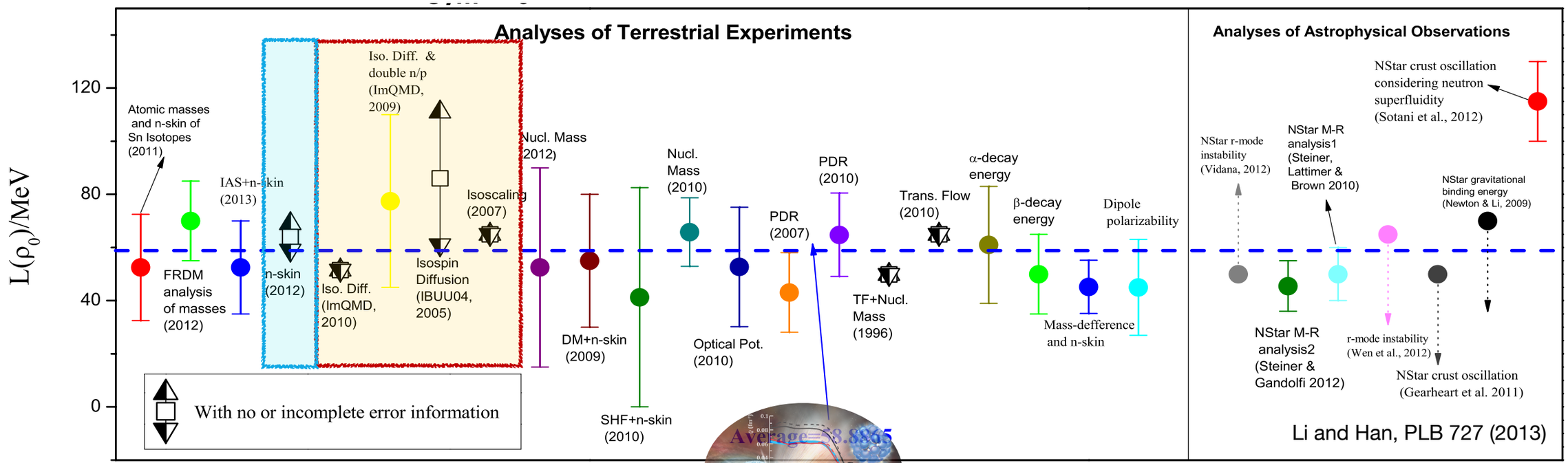
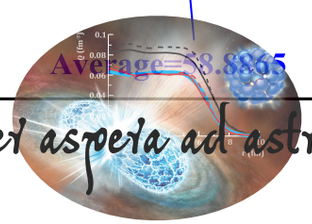




... per aspera ad astra ...



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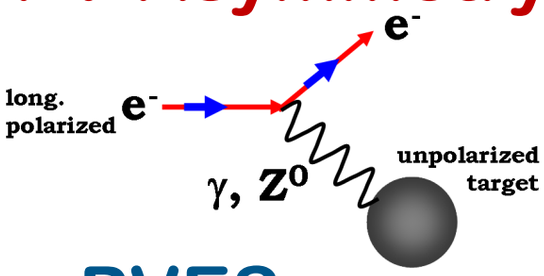
#MakeHumansSmartAgain

The stairway to heaven

(or the highway to hell, depending on your level of optimism)

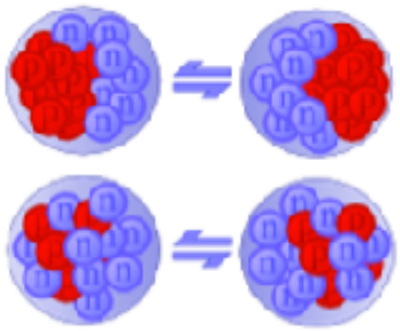
(Personal selection)

PV-Asymmetry



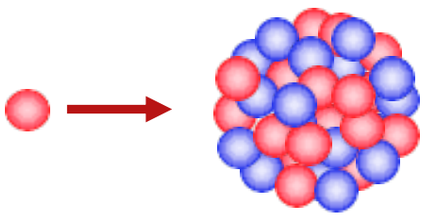
PVES

Resonance Strength

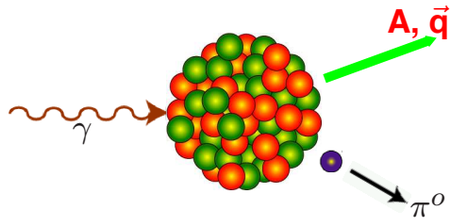


Collective Excitation

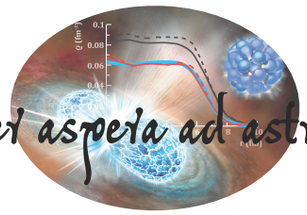
Cross-section



Hadronic Probes



EM Probes



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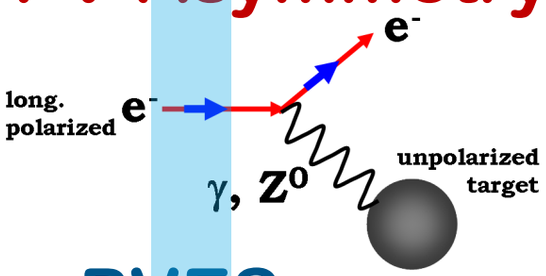
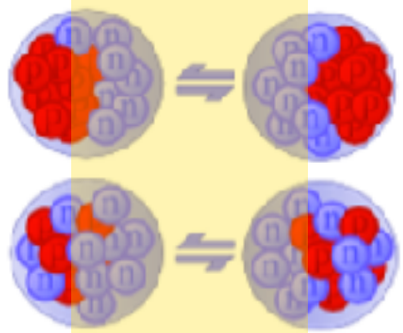


PVES

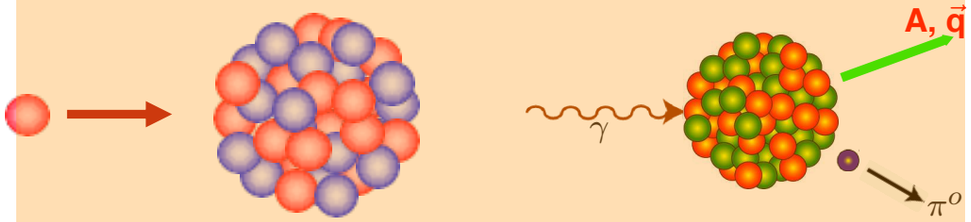
Resonance Strength



Collective Excitation

????..

Cross-section

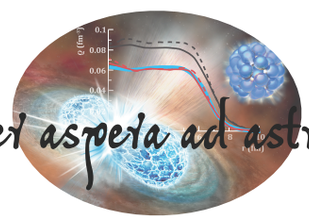


Hadronic Probes

EM Probes

Theo. uncertainties (a.u)

... per aspera ad astra ...



The stairway to heaven

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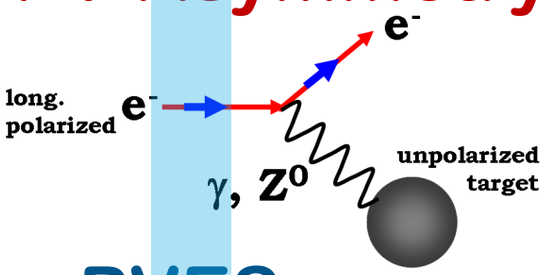
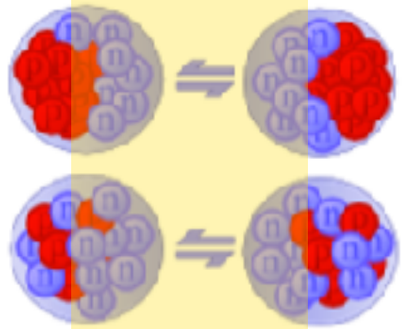
Experimental Challenges
(in unit of frustration)

PV-Asymmetry



PVES

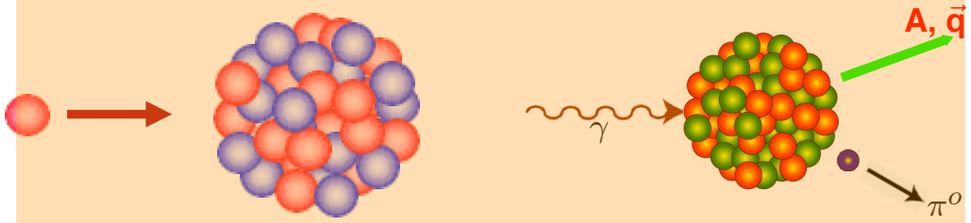
Resonance Strength



Collective Excitation

????..

Cross-section



Hadronic Probes

EM Probes

Theo. uncertainties (a.u)

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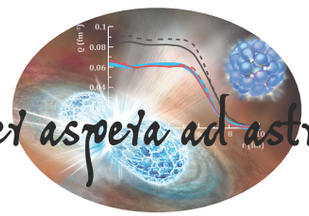

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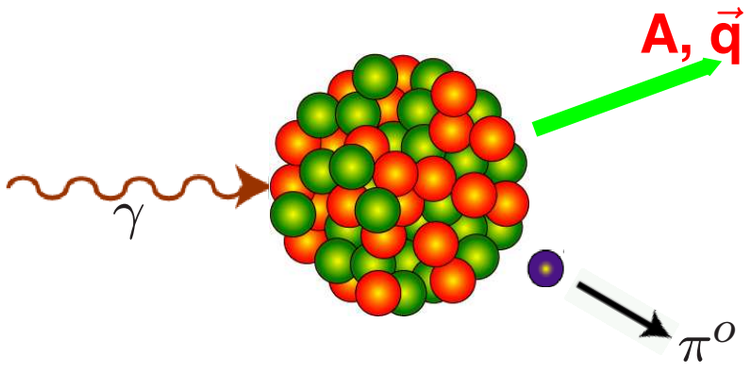
#MakeHumansSmartAgain

One MZ-Example

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



... *shine light* on the nucleus!

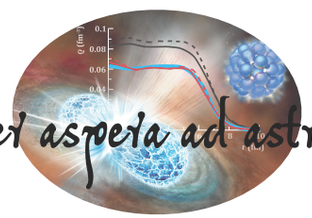
$$\gamma + A_{(g.s.)} \rightarrow \pi^0 + A_{(g.s.)}$$
$$\hookrightarrow \gamma\gamma$$

Advantages:

- Same amplitude for n and p
  - $\rightarrow$ Sensitivity to nucleon dist.
- Photon is neutral
  - $\rightarrow$ Whole volume is probed
- Quick measurement

Drawbacks:

- Final state interactions
  - $\rightarrow$ Model dependence
- Delta resonance region
  - $\rightarrow$ Model dependence



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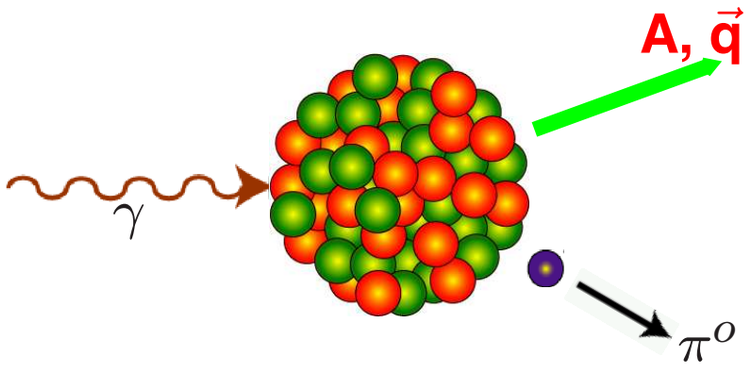

Featured in Physics Editors' Suggestion

… *shine light* on the nucleus!

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$$\hookrightarrow \gamma\gamma$$

Neutron Skin of ^{208}Pb from Coherent Pion Photoproduction

C. M. Tarbert *et al.* (Crystal Ball at MAMI and A2 Collaboration)
Phys. Rev. Lett. **112**, 242502 – Published 18 June 2014

Physics See Synopsis: Neutron Skin Turns Out to Be Soft

tagger at the MAMI electron beam facility. On exploitation of an interpolated fit of a theoretical model to the measured cross sections, the half-height radius and diffuseness of the neutron distribution are found to be $c_n = 6.70 \pm 0.03(\text{stat.})$ fm and $a_n = 0.55 \pm 0.01(\text{stat.})^{+0.02}_{-0.03}(\text{sys.})$ fm, respectively, corresponding to a neutron skin thickness $\Delta r_{np} = 0.15 \pm 0.03(\text{stat.})^{+0.01}_{-0.03}(\text{sys.})$ fm. The results give the first successful extraction of a neutron skin thickness with an electromagnetic probe and indicate that the skin of ^{208}Pb has a halo character. The measurement provides valuable new constraints on both the structure of nuclei and the equation of state for neutron-rich matter.

… per aspera ad astra …

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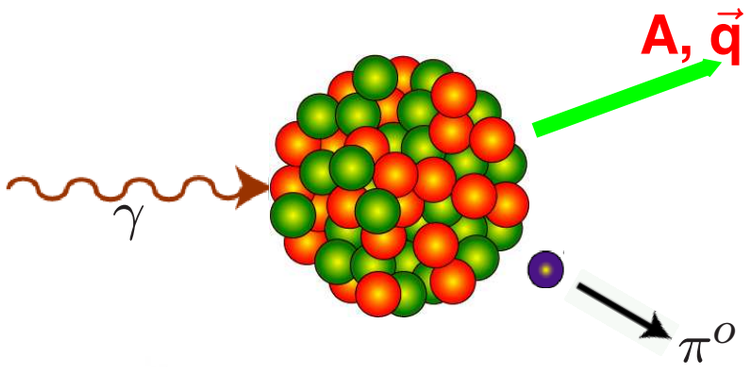
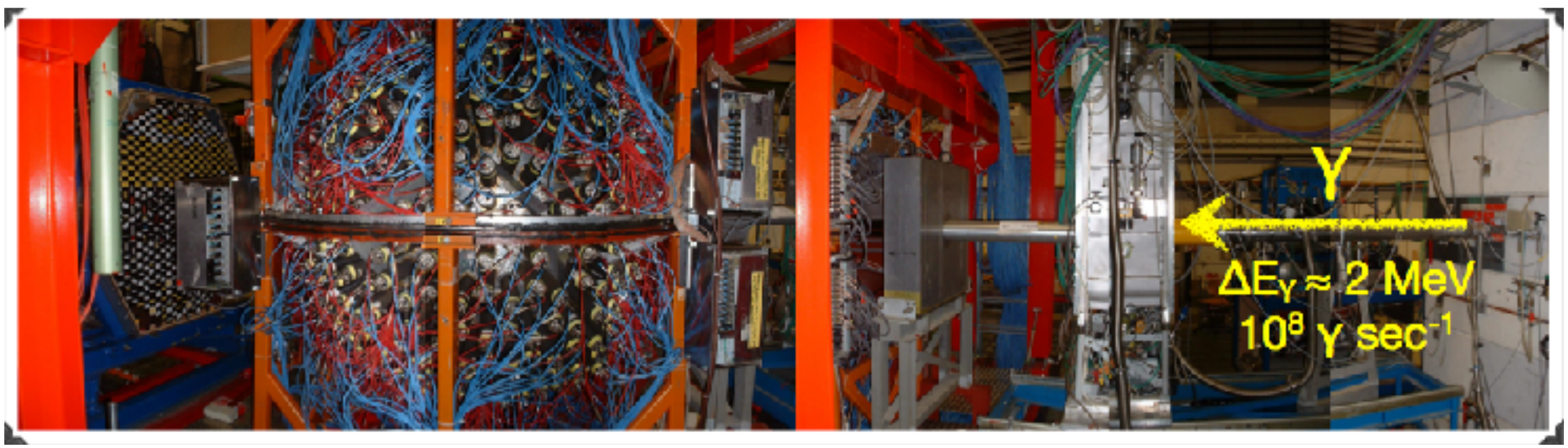
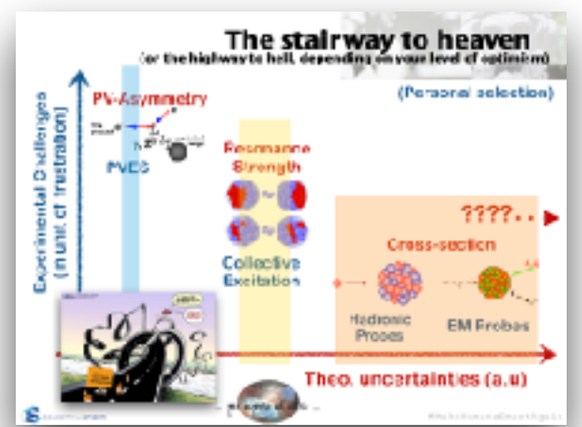


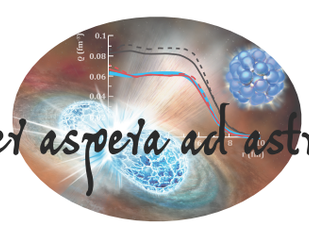
... *shine light* on the nucleus!

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

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







... per aspera ad astra ...

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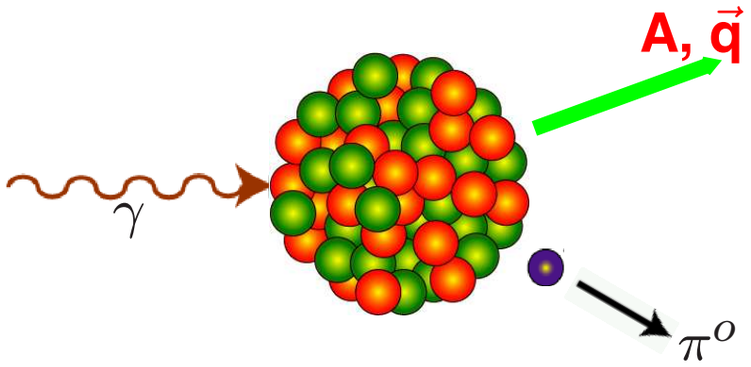
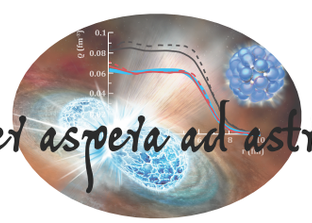


... *shine light* on the nucleus!

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

$$\frac{d\sigma}{d\Omega}(\mathrm{PWIA}) \propto sin^2\left(\theta^*_\pi\right) A^2 F^2\left(q\right)$$

... per aspera ad astra ...



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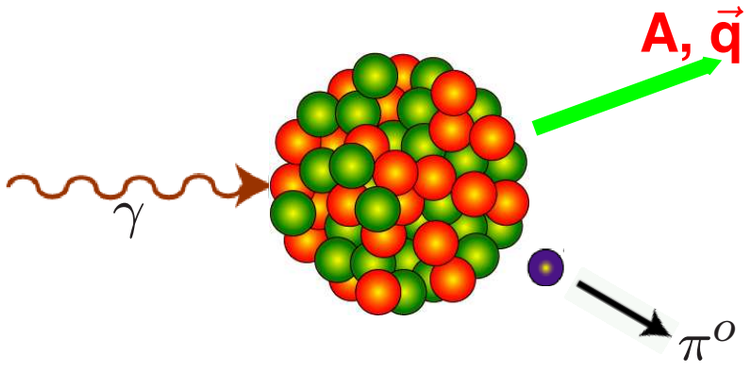

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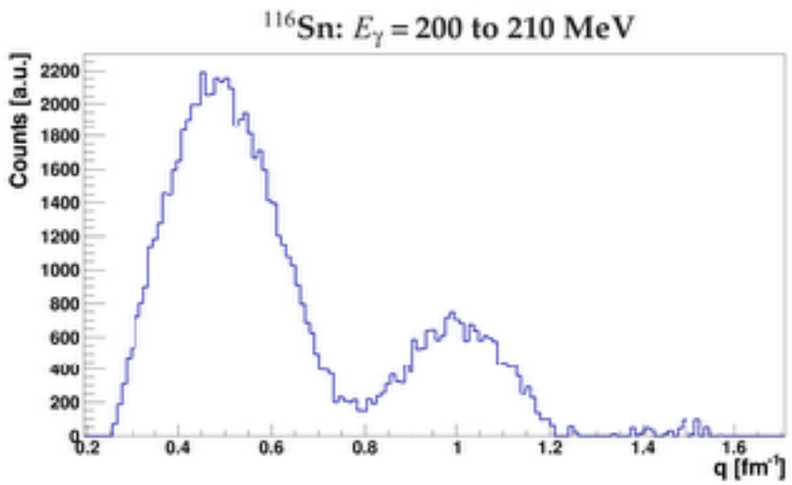
My perspective:



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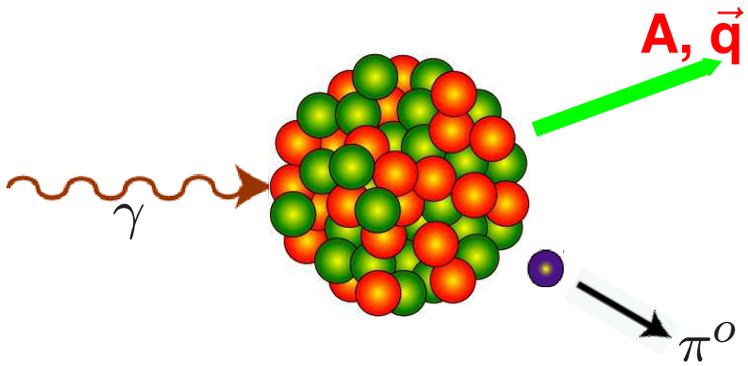
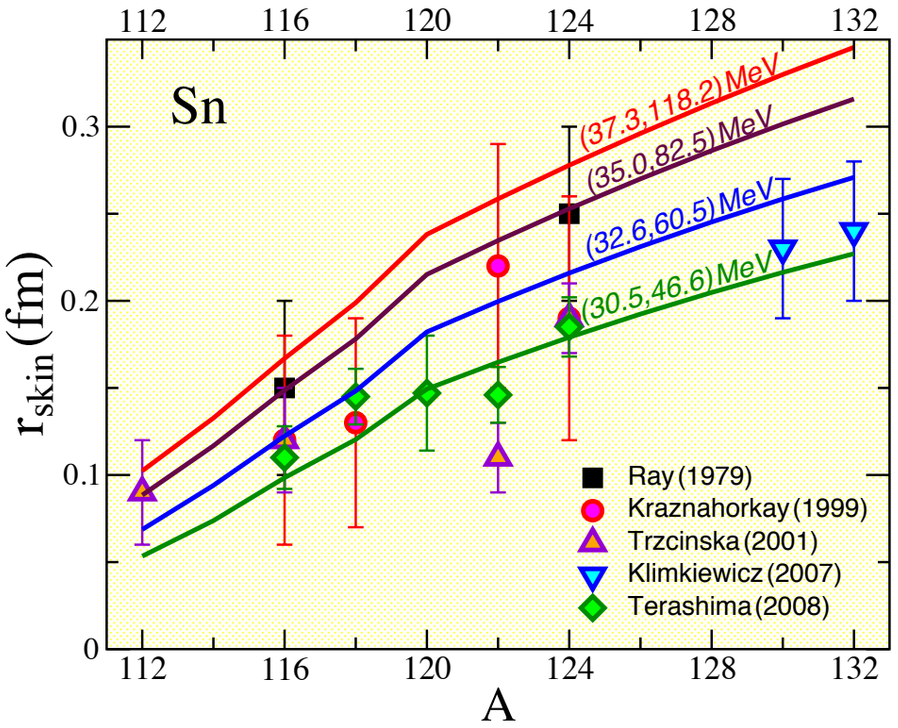
One MZ-Example

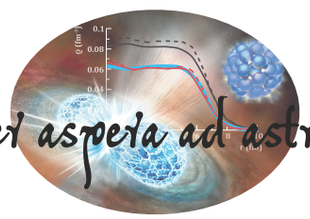
Coherent π⁰ photoproduction: easy and quick *(A2 Coll. Phys. Rev. Lett. 112, 242502)*



PhD M. Ferretti-Bondy (exp), F. Colomer (theo), S. Tsaran (theo)



J. Piekarewicz et al.



... per aspera ad astra ...

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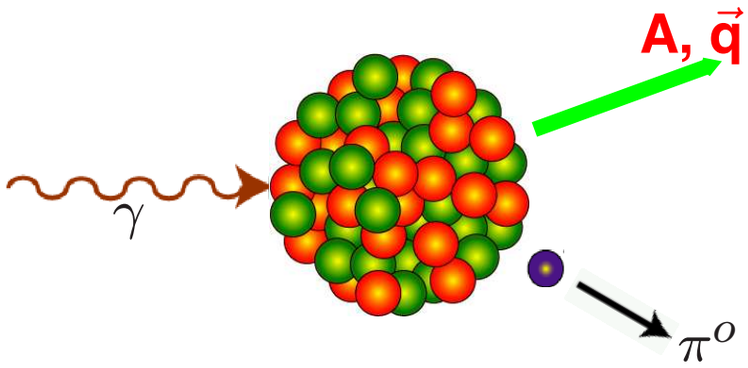

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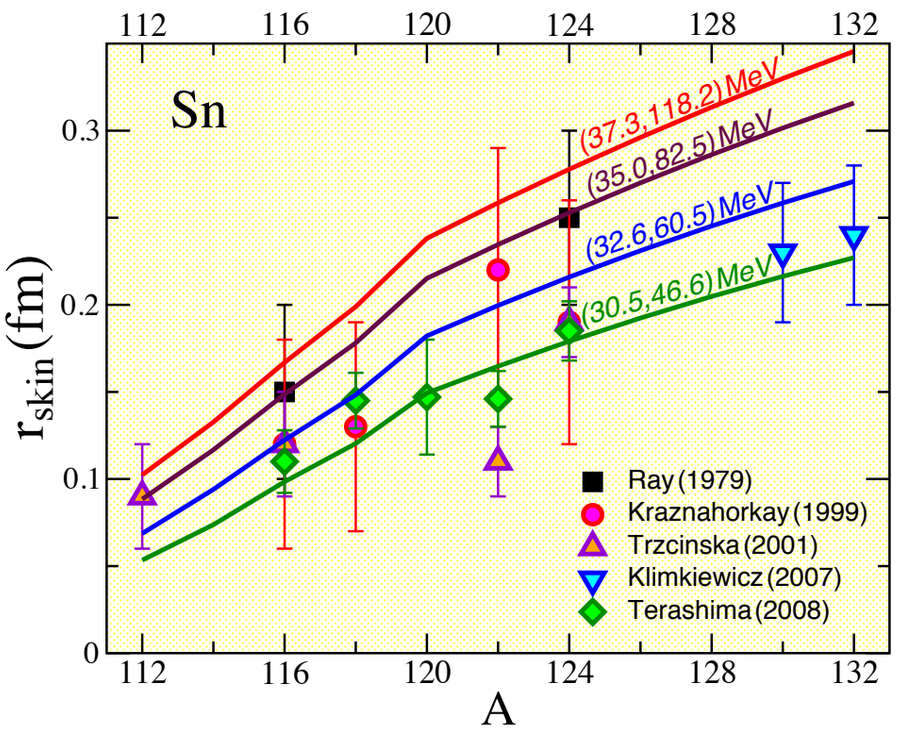
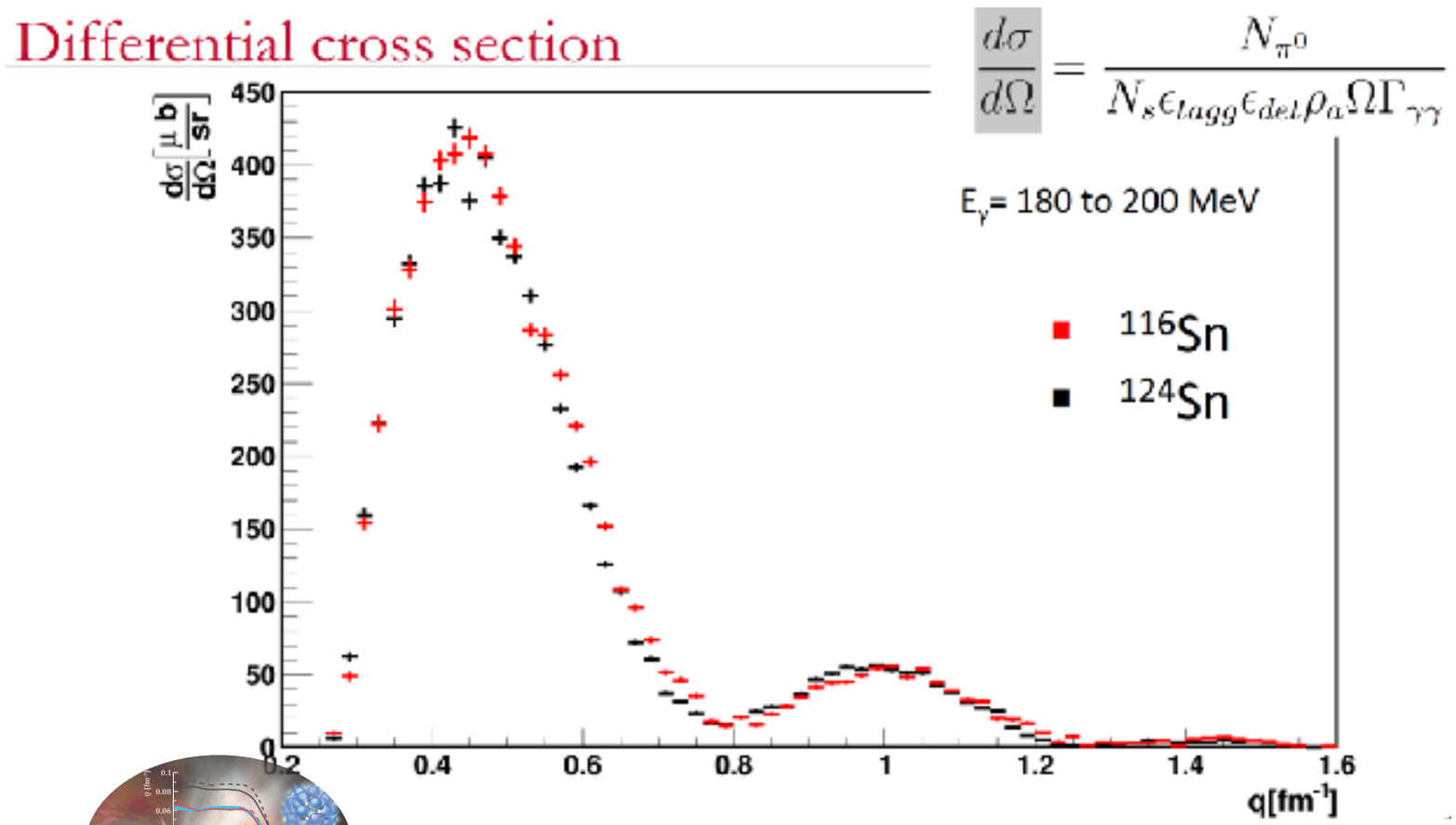
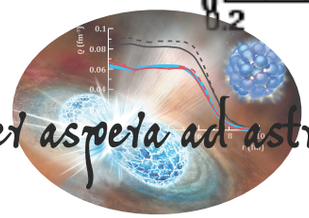


J. Piekarewicz et al.





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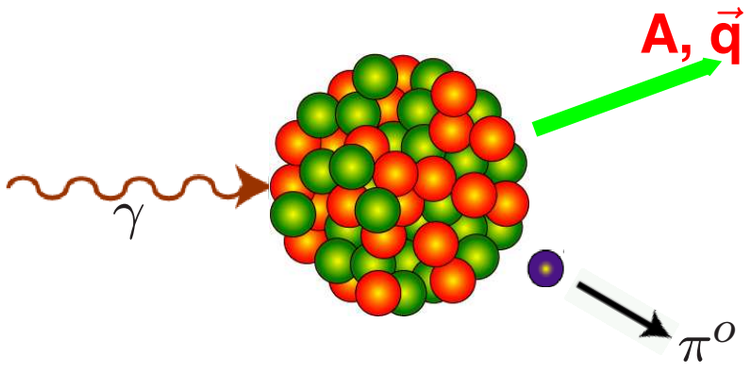
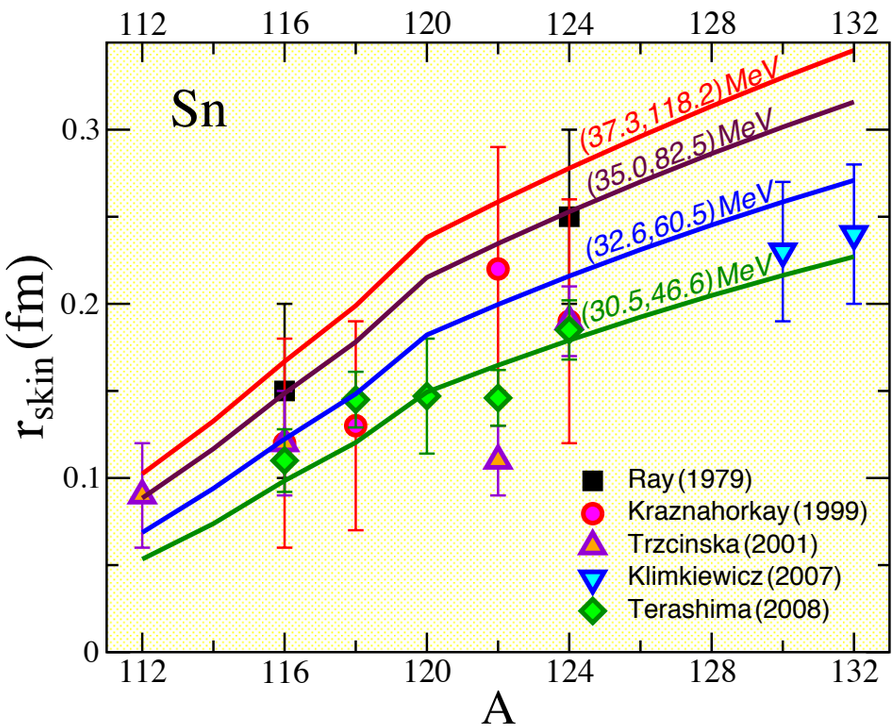
One MZ-Example

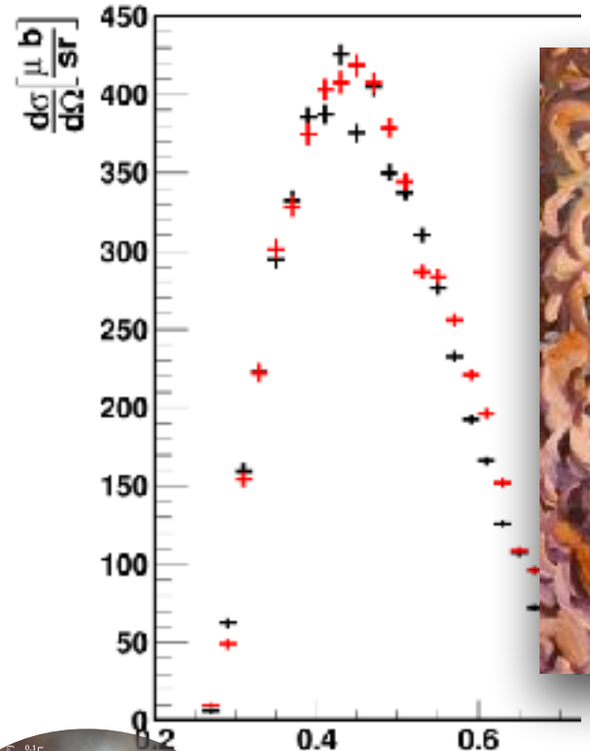
Coherent π^0 photoproduction: easy and quick *(A2 Coll. Phys. Rev. Lett. 112, 242502)*



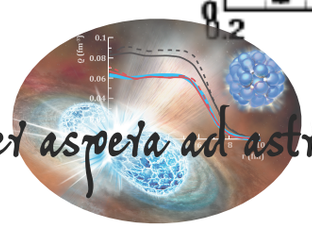
PhD M. Ferretti-Bondy (exp), F. Colomer (theo), S. Tsaran (theo)



J. Piekarewicz et al.



... per aspera ad astra ...



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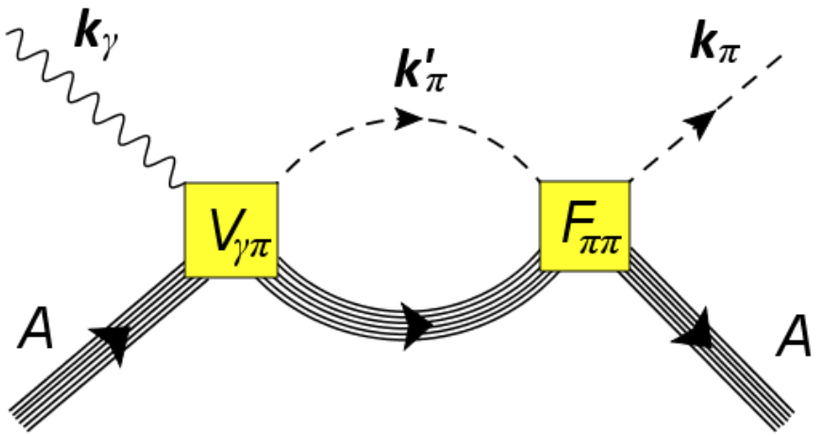
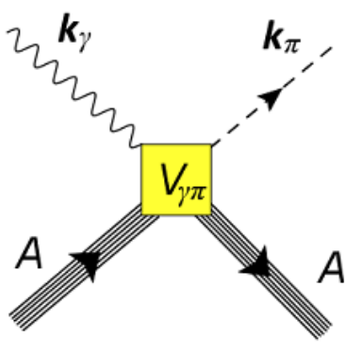
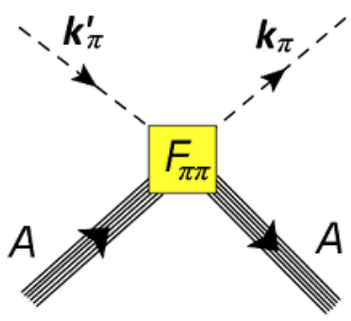
One MZ-Example

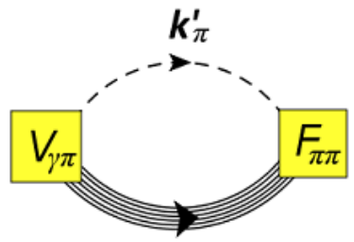
P. Capel, F. Colomer, S. Tsaran, M. Vanderhagen



- 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 $U^{\mathrm{Nucl}}(k', k)$







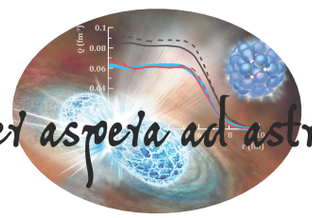
+ a.o. Treatment of Resonances,

+ Use Effective Potentials (J. Piekarewicz)

  FSU000 (NSkin = 0.284 fm)

  FSU040 (NSkin = 0.189 fm)

“ …at the extremes of models that I feel comfortable do not "brake" the nuclear chart. “ (JP)



... per aspera ad astra ...

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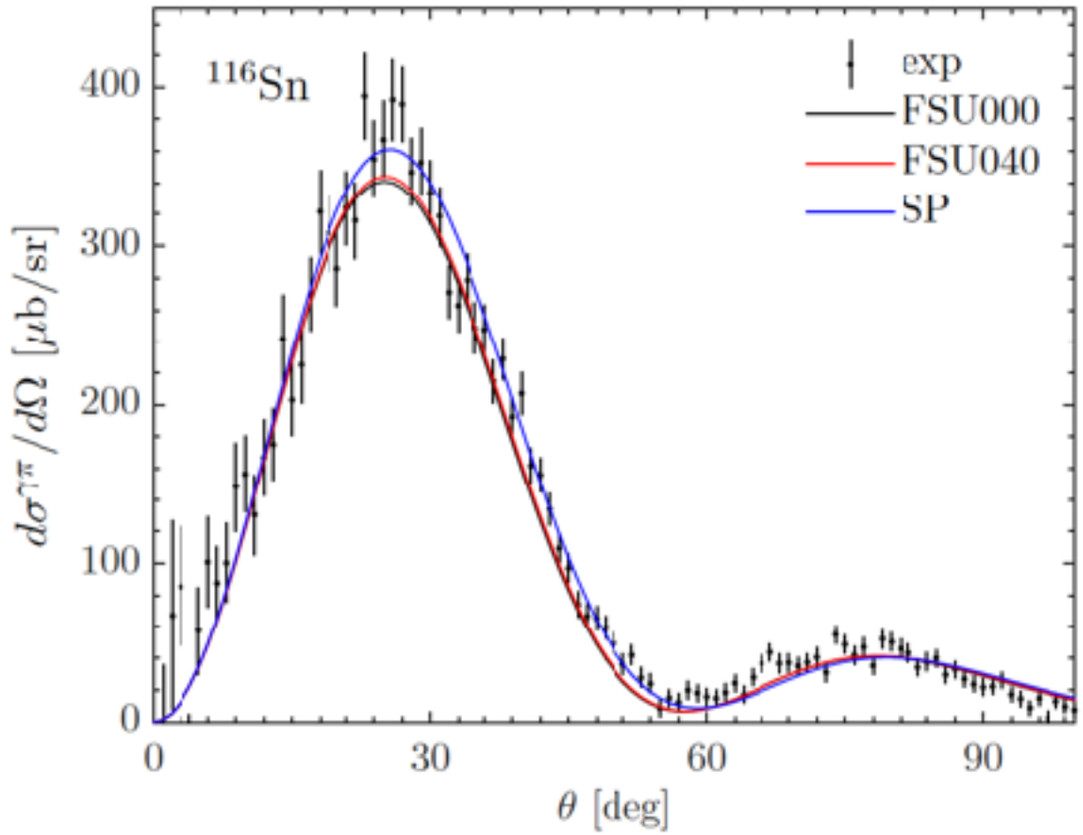
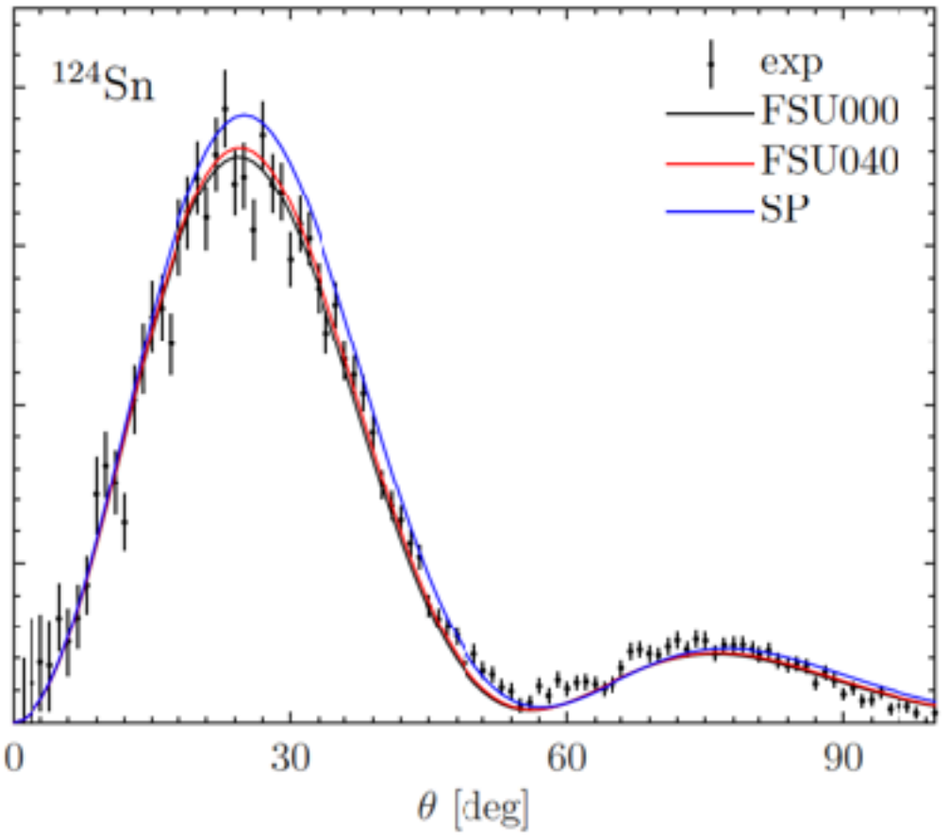
One MZ-Example

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

F. Colomer PhD Thesis (2020) to be published





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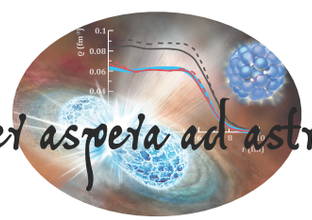

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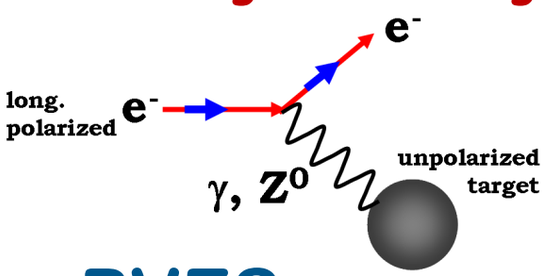
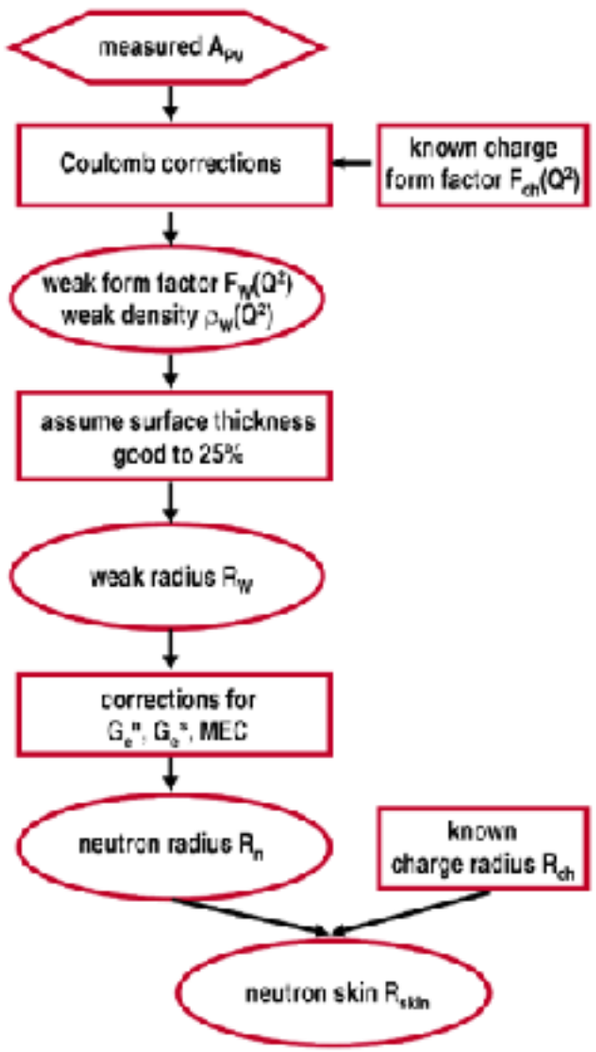
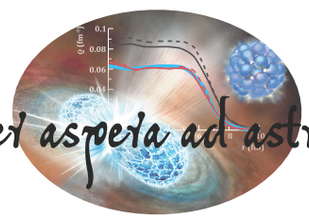
The -REX family

PV-Asymmetry



PVES



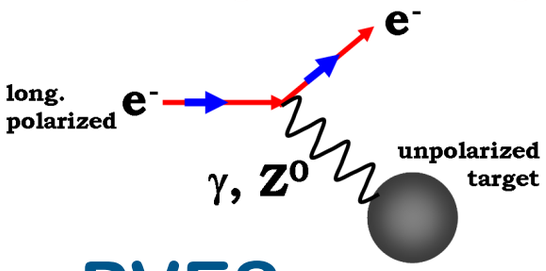


... per aspera ad astra ...

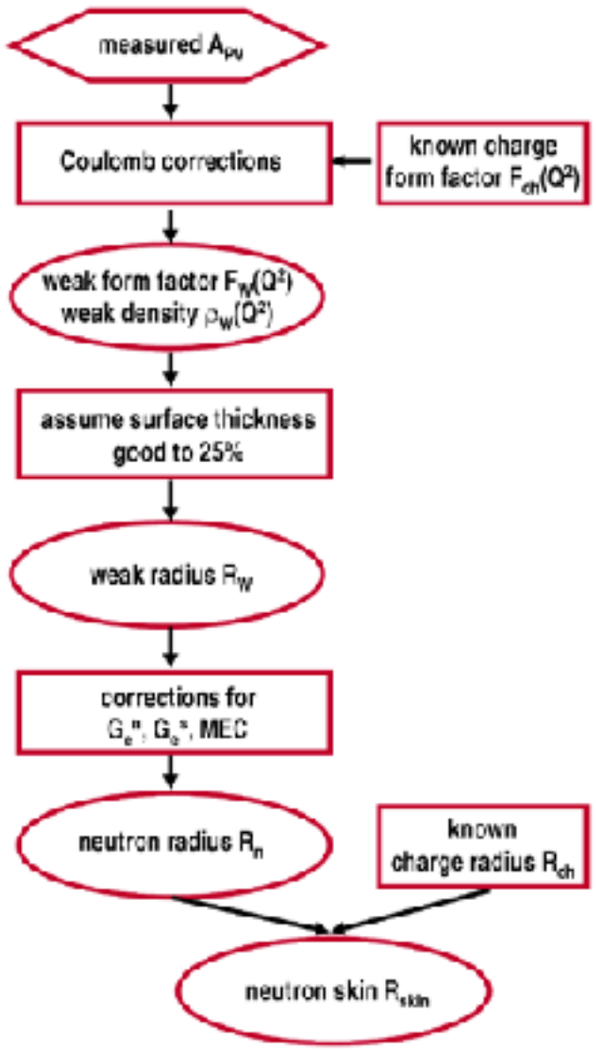
The -REX family

MREX

PV-Asymmetry

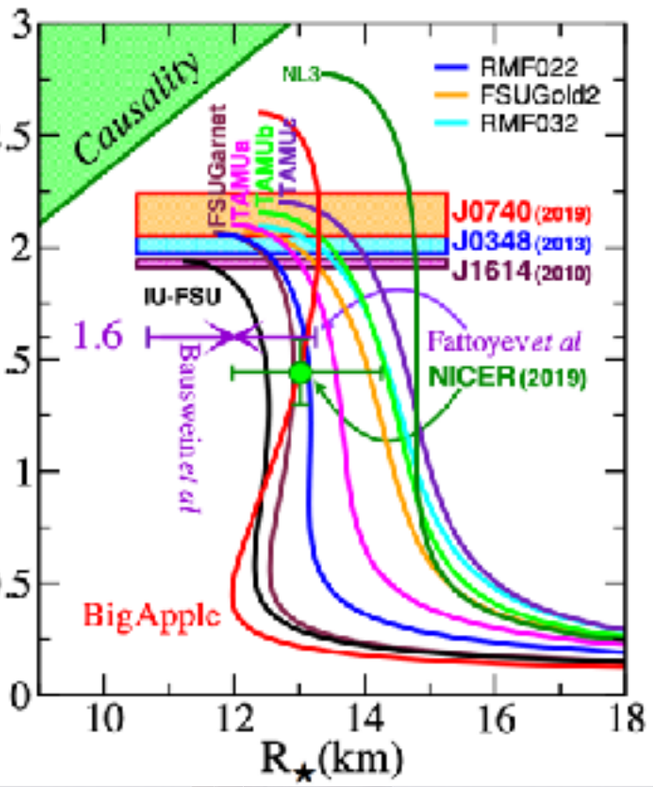


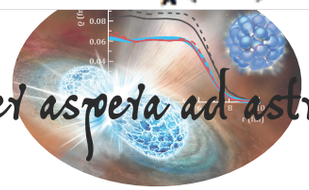
PVES



P2@MESA: 2023+
Commissioning (^{12}C): 2023-2024
First Weinberg Run: 2024-2025
MREX: 2025+

What if in 2025+ there is no need for a 0.5% measurement?





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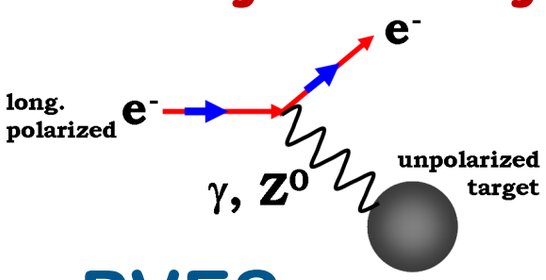
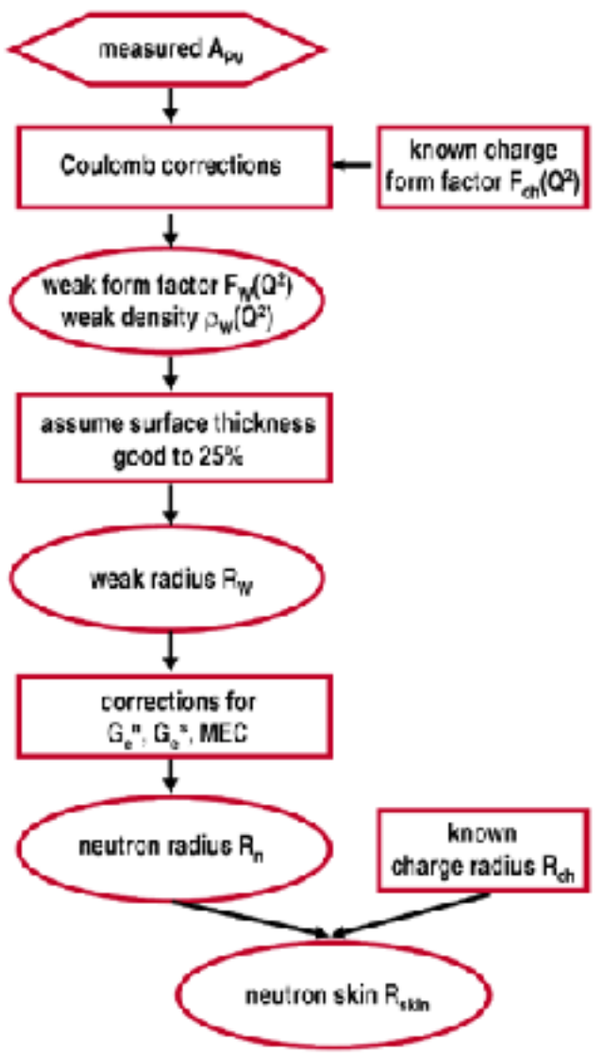
The -REX family

MREX

PV-Asymmetry



PVES



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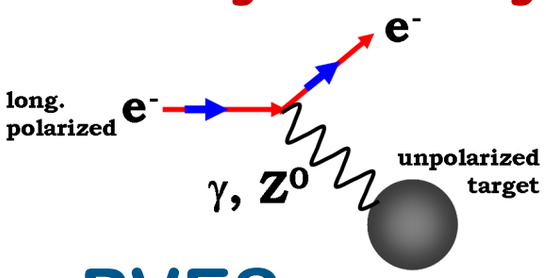
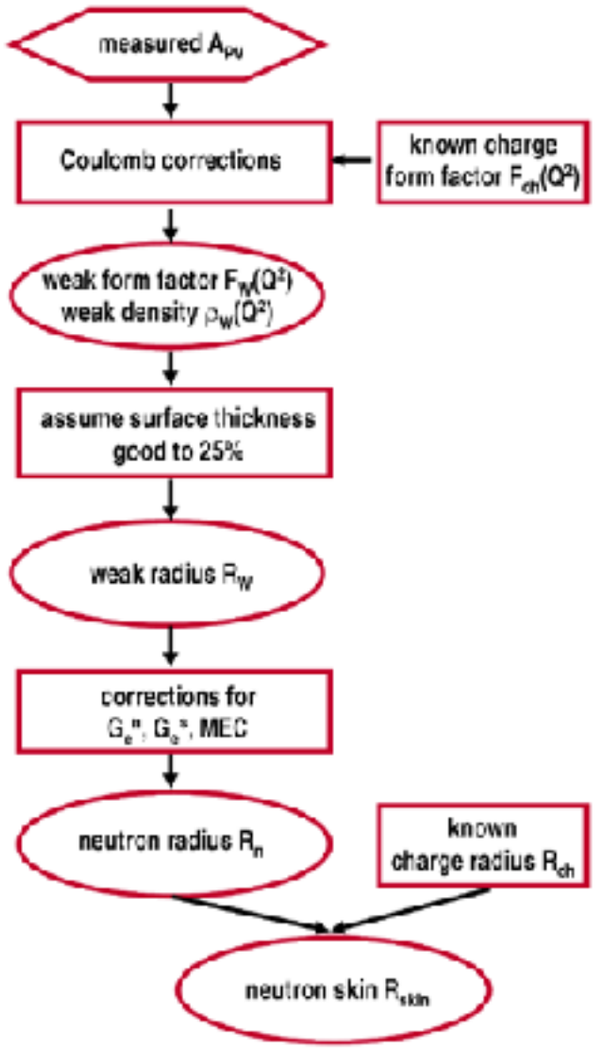
Chen, Piekarewicz arXiv:2006.08405

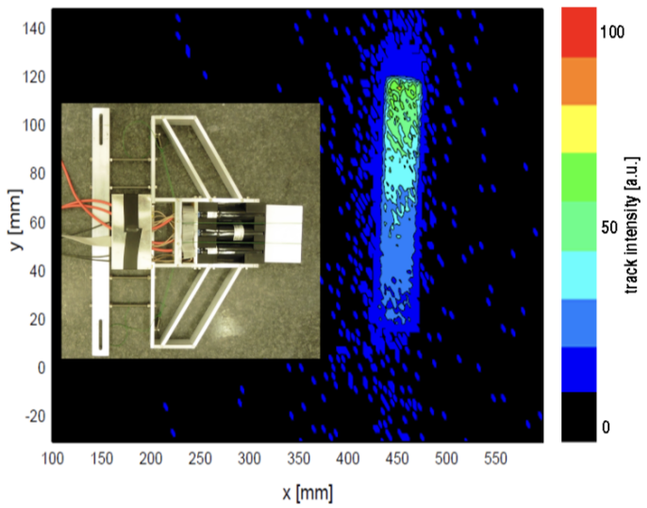
Medium-Range Program@MAMI

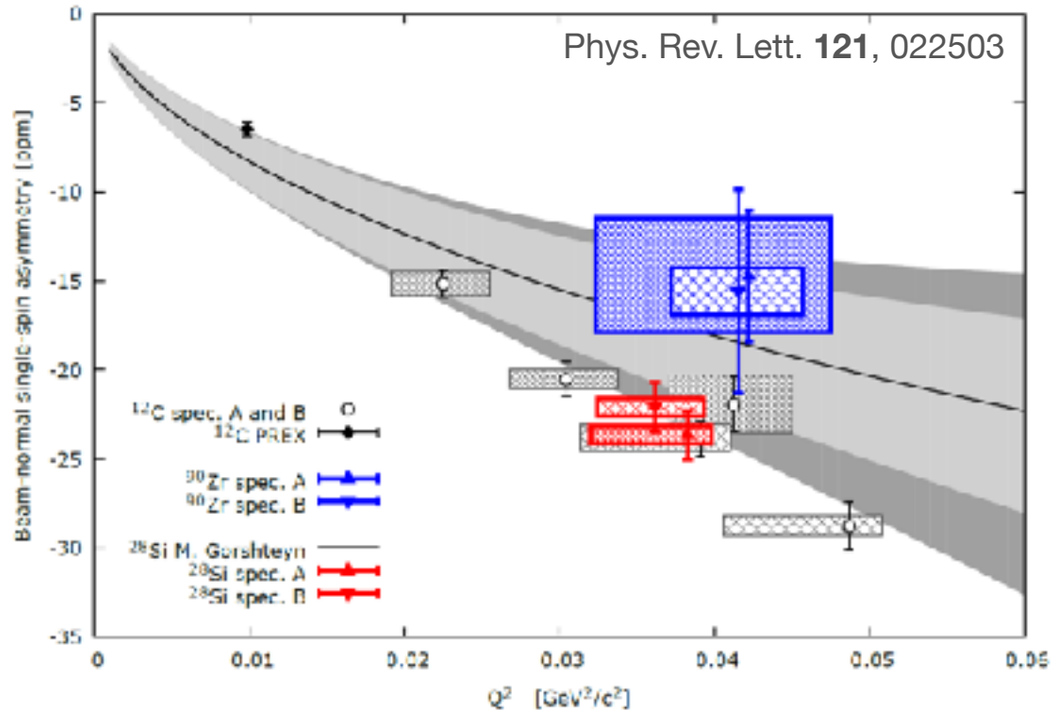
PV-Asymmetry

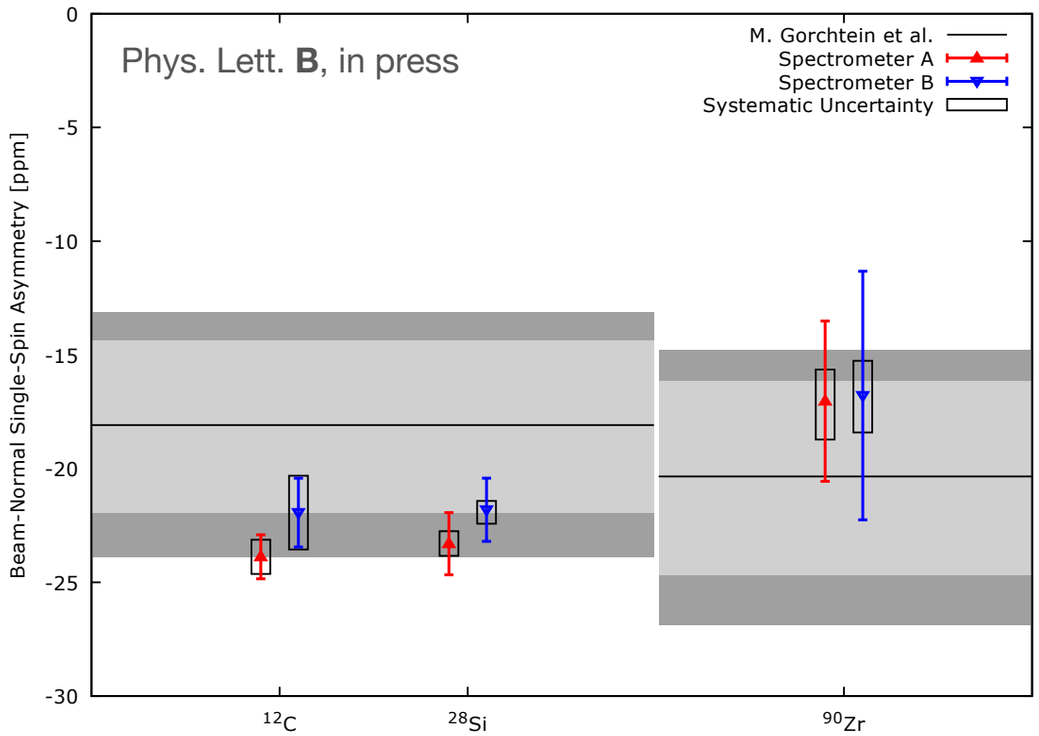


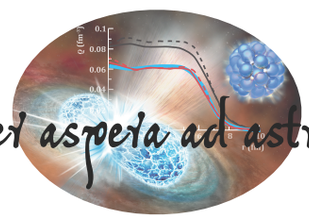
PVES











... per aspera ad astra ...

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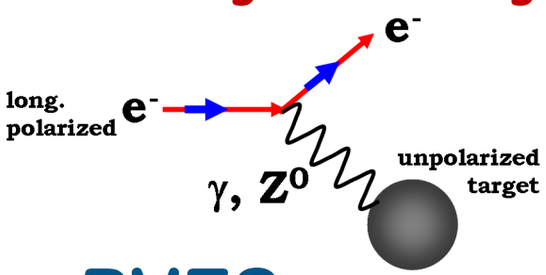
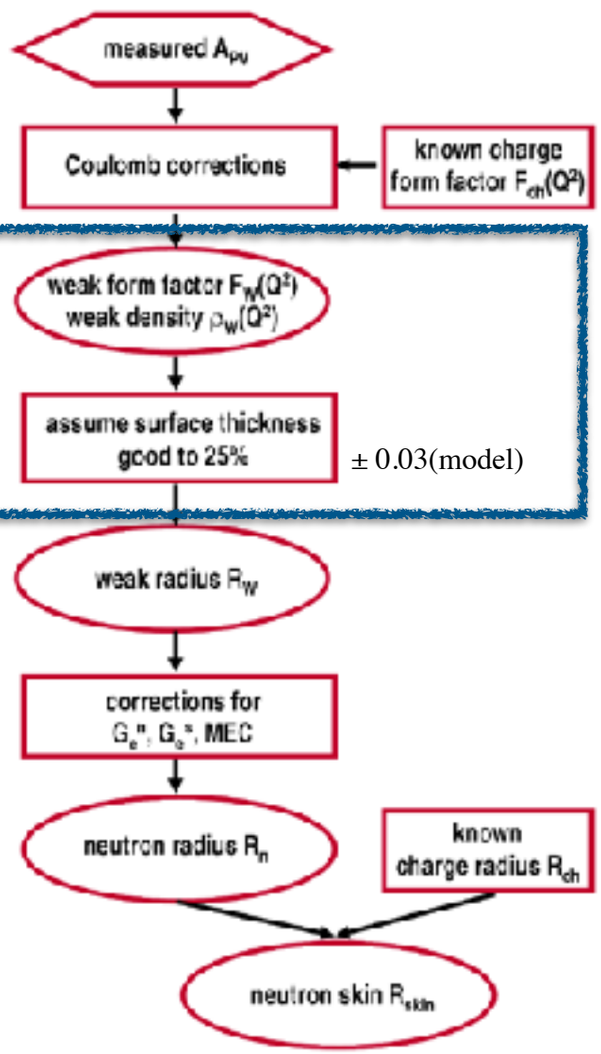
Medium-Range Program@MAMI

PV-Asymmetry



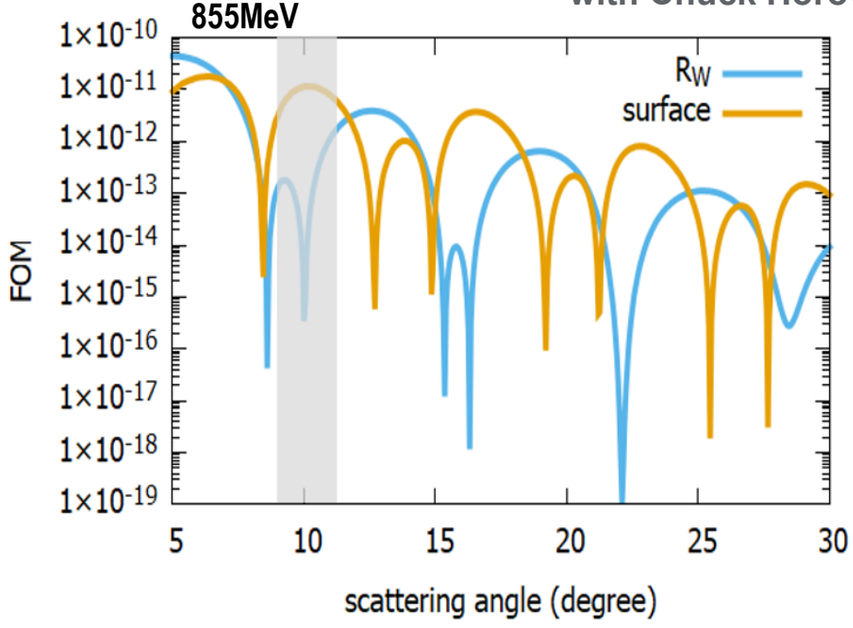
PVES

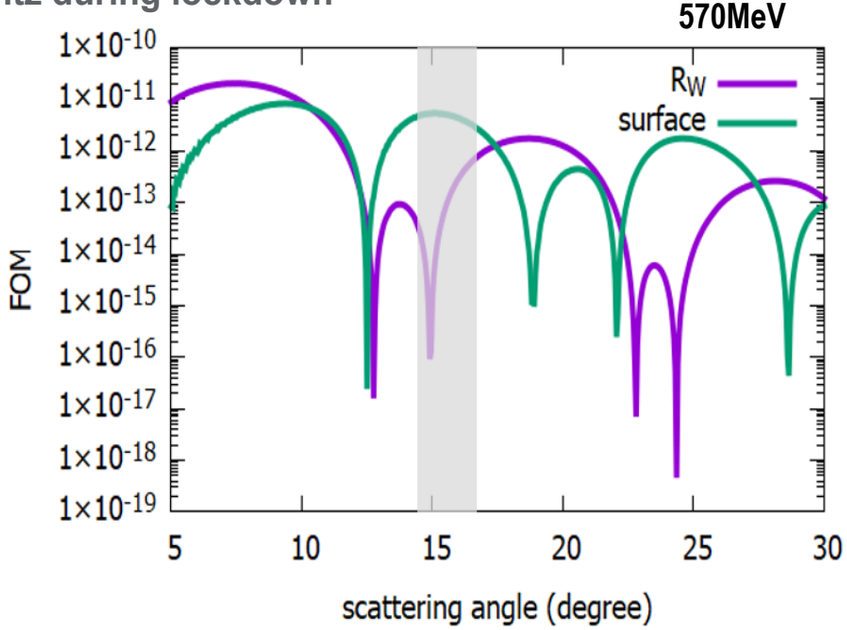


Scenario 1:						
E_{Beam}	I_{Beam}	Scattering Angle θ		Four-Momentum Transfer Q^2		Running Time
		SpecA	SpecB	SpecA	SpecB	
855 MeV	20 µA	23.50°	10.35°	0.12 GeV^2/c^2	0.02 GeV^2/c^2	78 days

Scenario 2:						
E_{Beam}	I_{Beam}	Scattering Angle θ		Four-Momentum Transfer Q^2		Running Time
		SpecA	SpecB	SpecA	SpecB	
570 MeV	20 µA	24.4°	15.2°	0.06 GeV^2/c^2	0.02 GeV^2/c^2	166 days

with Chuck Horowitz during lockdown





… per aspera ad astra …

10% measurement of surface thickness

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...per astra da astra ....

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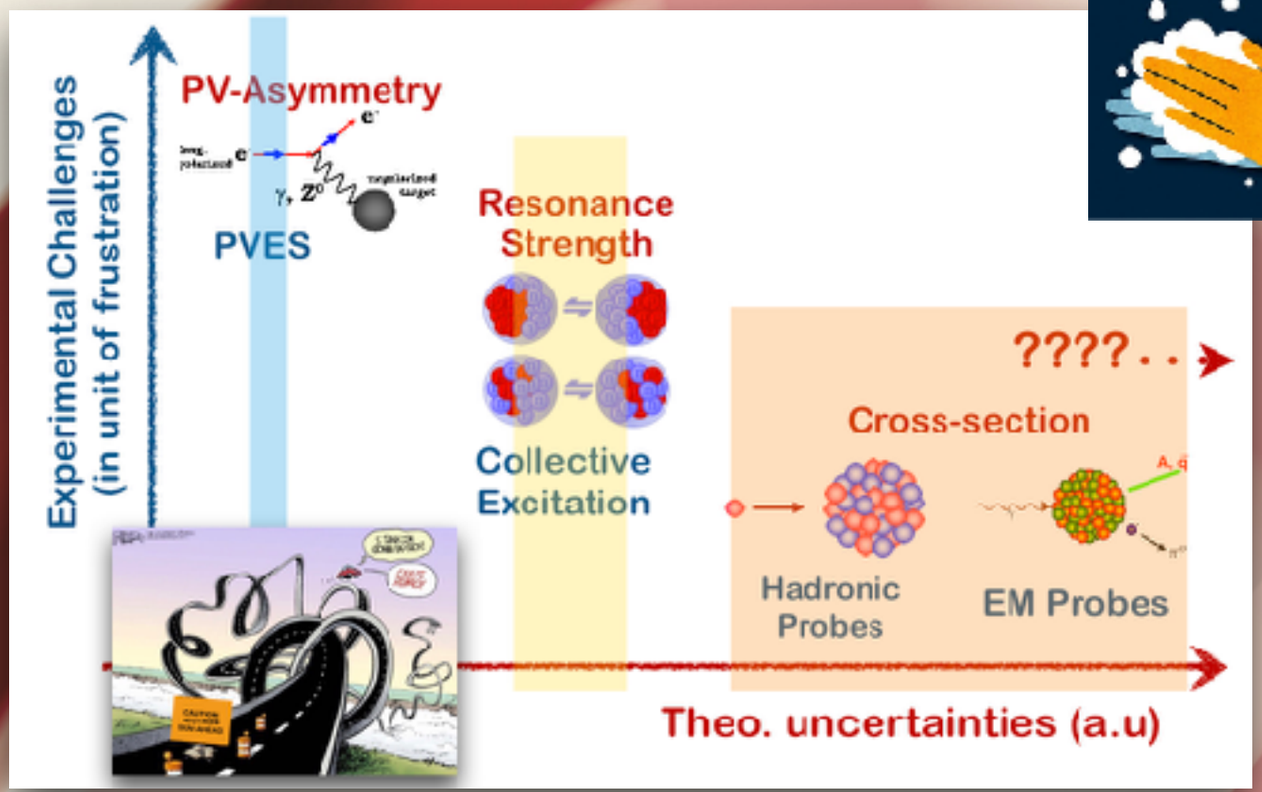
... per aspera ad astra ...

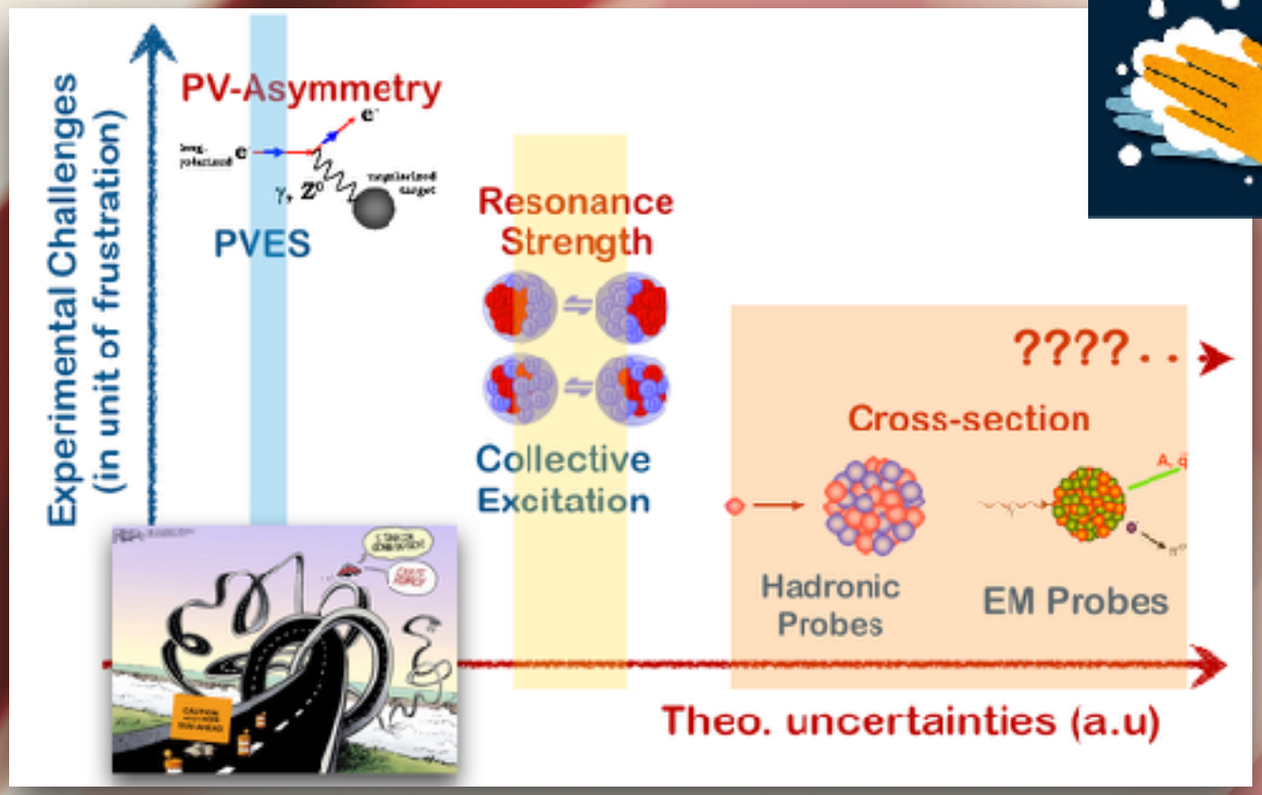
JG|U

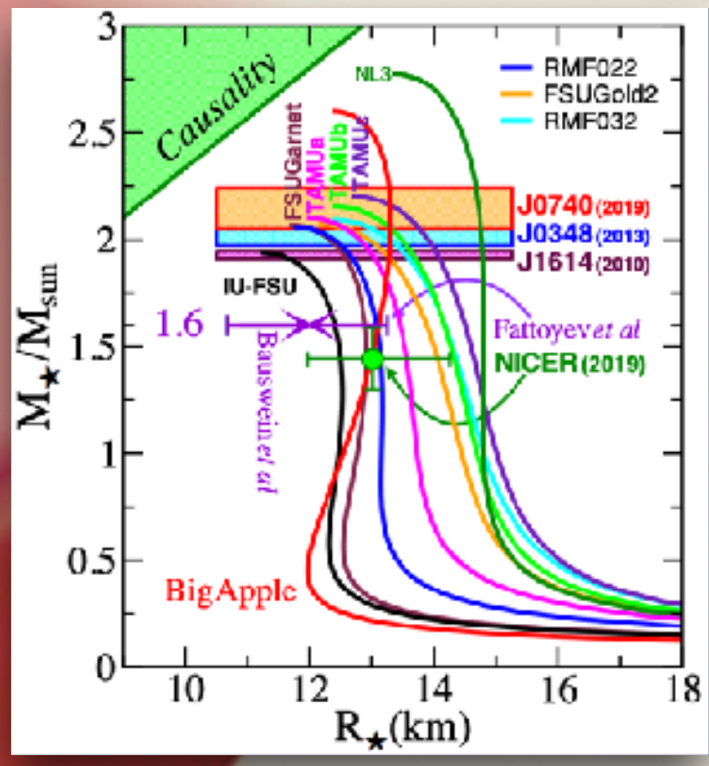
...since MITP2016 cleaning in progress

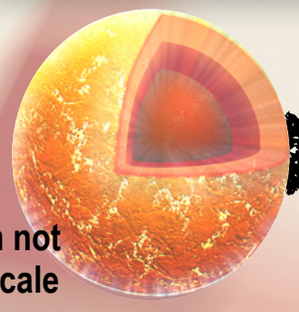


...per astra da astra ....

...since MITP2016 cleaning in progress

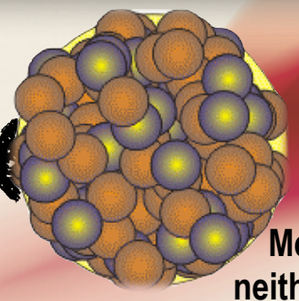






I am not to scale

KEEP DISTANCE

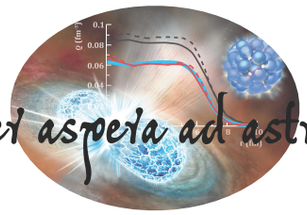


Me neither!

JP: "MREX measures pure neutron matter at saturation density and nobody can do it better"

..waiting eagerly for a new plot of my (second) favourite theory colleagues!

...Omen Nomen



... per aspera ad astra ...