Per aspera ad astra ...

Neutron-skin "measurements"

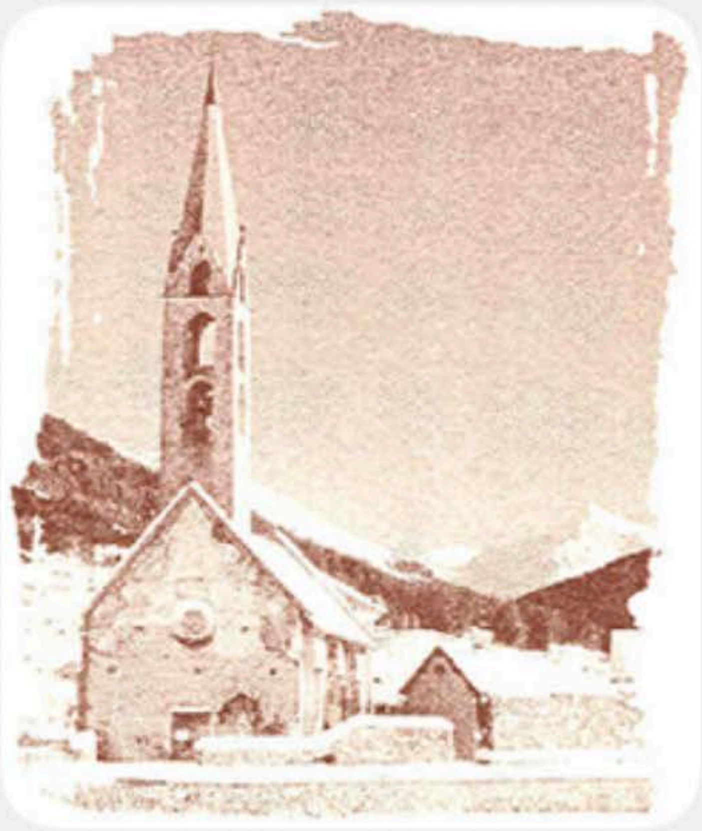
JG|U Concettina Sfienti
Johannes Gutenberg-Universität - Institut für Kernphysik, Mainz

Commercial

61th International Winter Meeting on Nuclear Physics

January 27 to 31, 2025 Bormio, Italy

HOME GENERAL INFORMATION NEWS



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.

2025 Edition

The 60th edition of the Bormio conference will be held from January 27 to 31 2025 in Bormio (Italy).

As for previous edition, we are foreseeing two **special** initiatives for **young students**

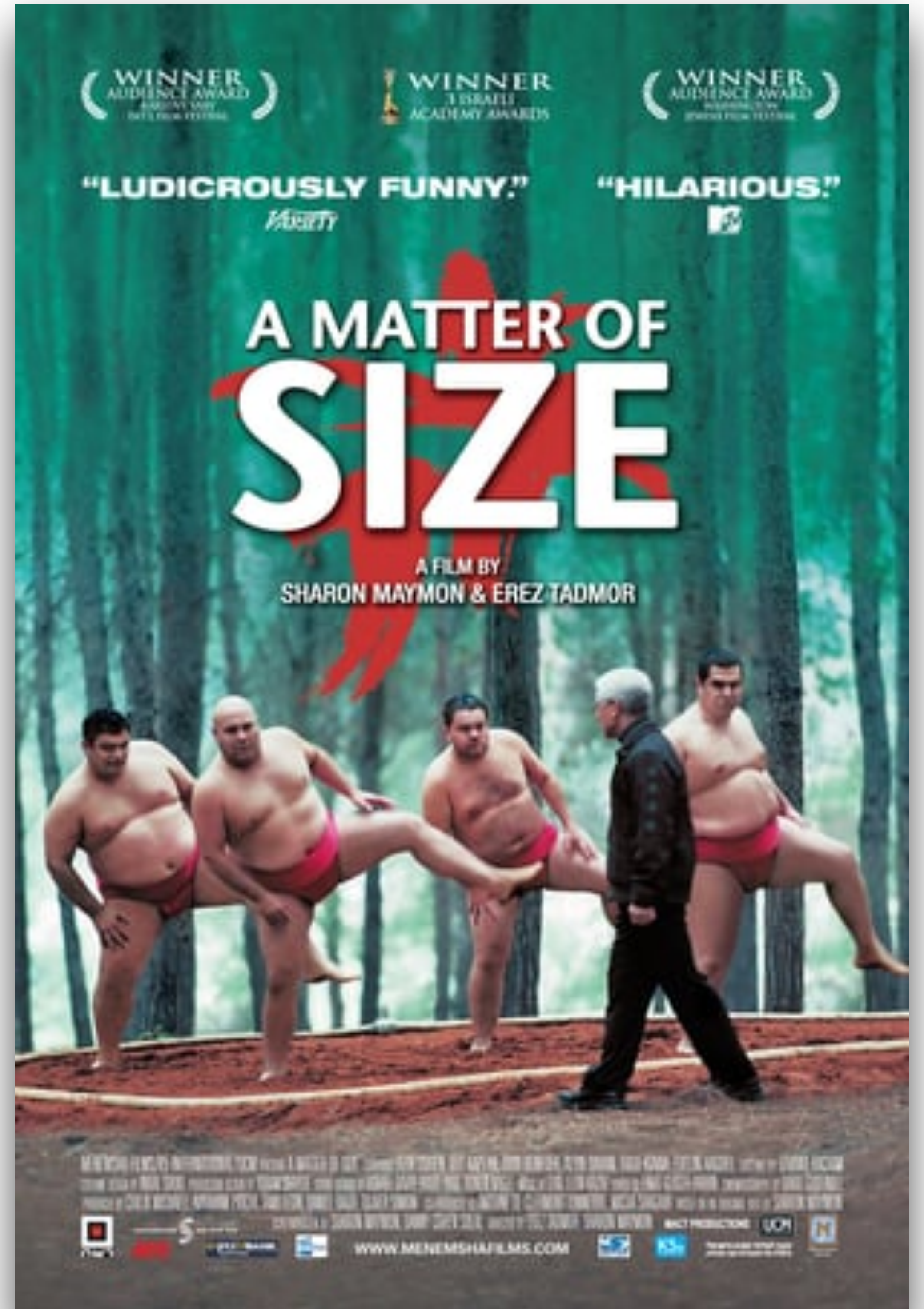
- **PRE-CONFERENCE SCHOOL**

To improve the participation of students and young researchers at the conference a pre-conference school is taking place on **SUNDAY 26 January 2025**: four topical lectures will be held covering the basis of the main physics topics dealt within the conference. Students are asked to select the proper field in the registration form, if they intend to participate.

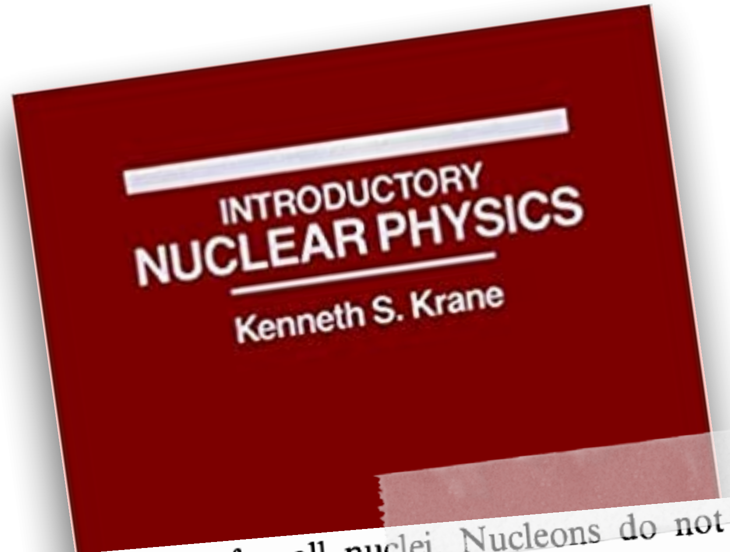
- **STUDENTS FELLOWSHIPS**

A limited number of fellowships will be awarded to brilliant students to cover their accommodation and conference fee. Students who intend to apply for the fellowships are asked to send their application (**cover letter, CV and abstract**) in one single pdf file to organizers@bormioconf.org by **OCTOBER 13th**.
Participation to the pre-conference school for students awarded our student fellowships is mandatory.

Nuclear Sizes…



Nuclear Charge Radius

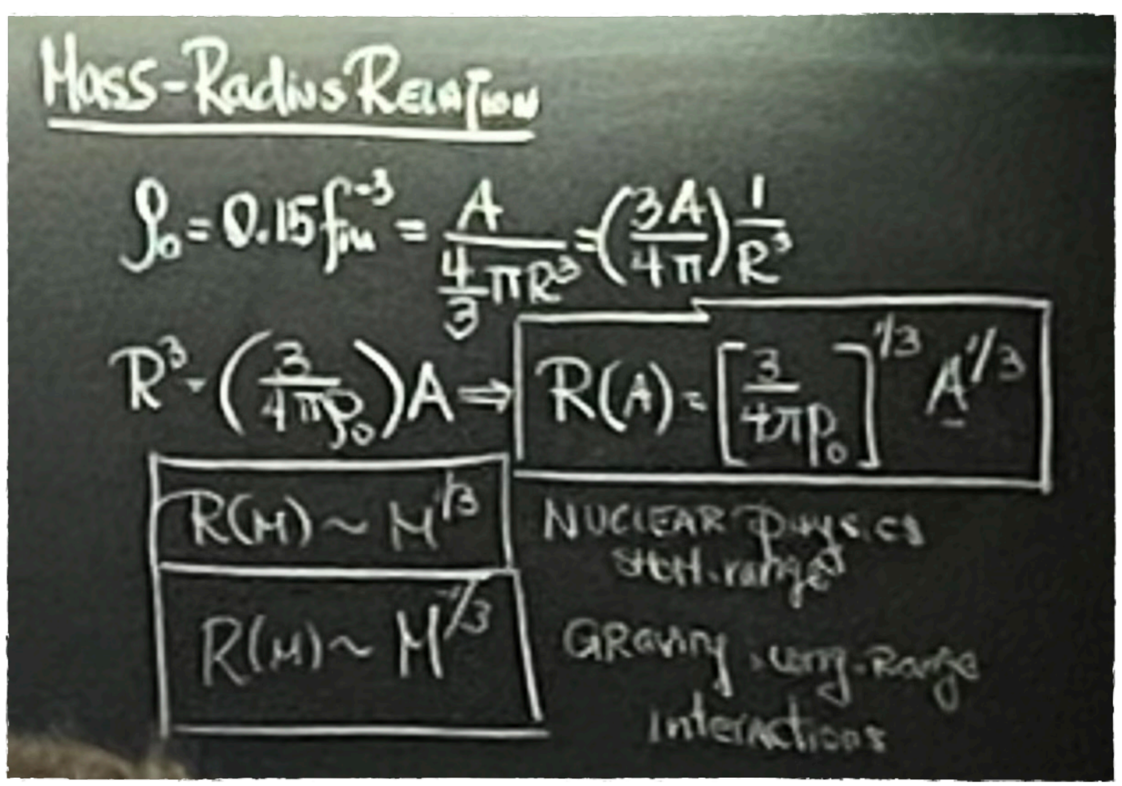


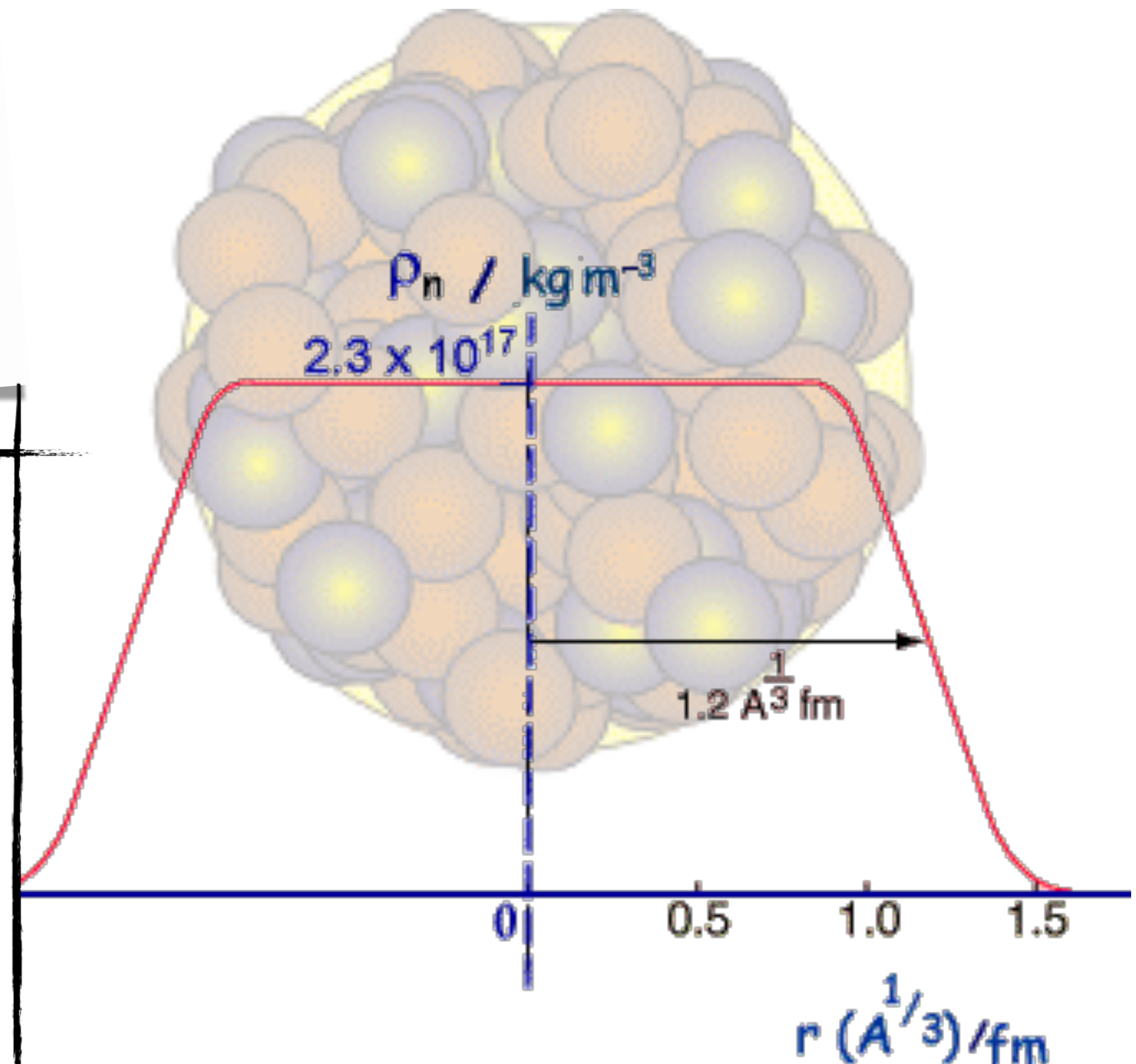
nearly the same for all nuclei. Nucleons do not seem to congregate near the center of the nucleus, but instead have a fairly constant distribution out to the surface. (The conclusion from measurements of the nuclear matter distribution is the same.) Thus *the number of nucleons per unit volume is roughly constant*:

$$\frac{A}{\frac{4}{3}\pi R^3} \sim \text{constant} \qquad (3.7)$$

where R is the mean nuclear radius. Thus $R \propto A^{1/3}$, and defining the proportionality constant R_0 gives

$$R = R_0 A^{1/3} \qquad (3.8)$$





“ Diamonds are *for ever* …

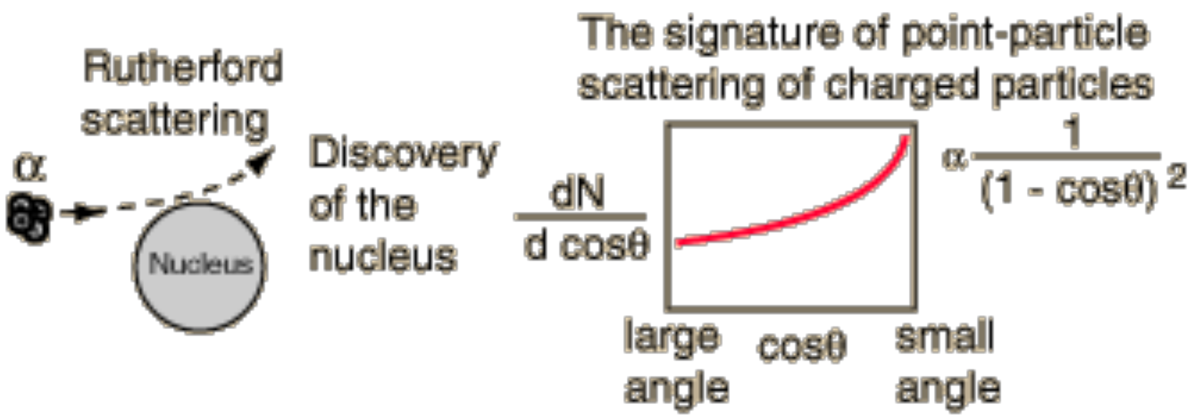
“ Diamonds are *for ever* …

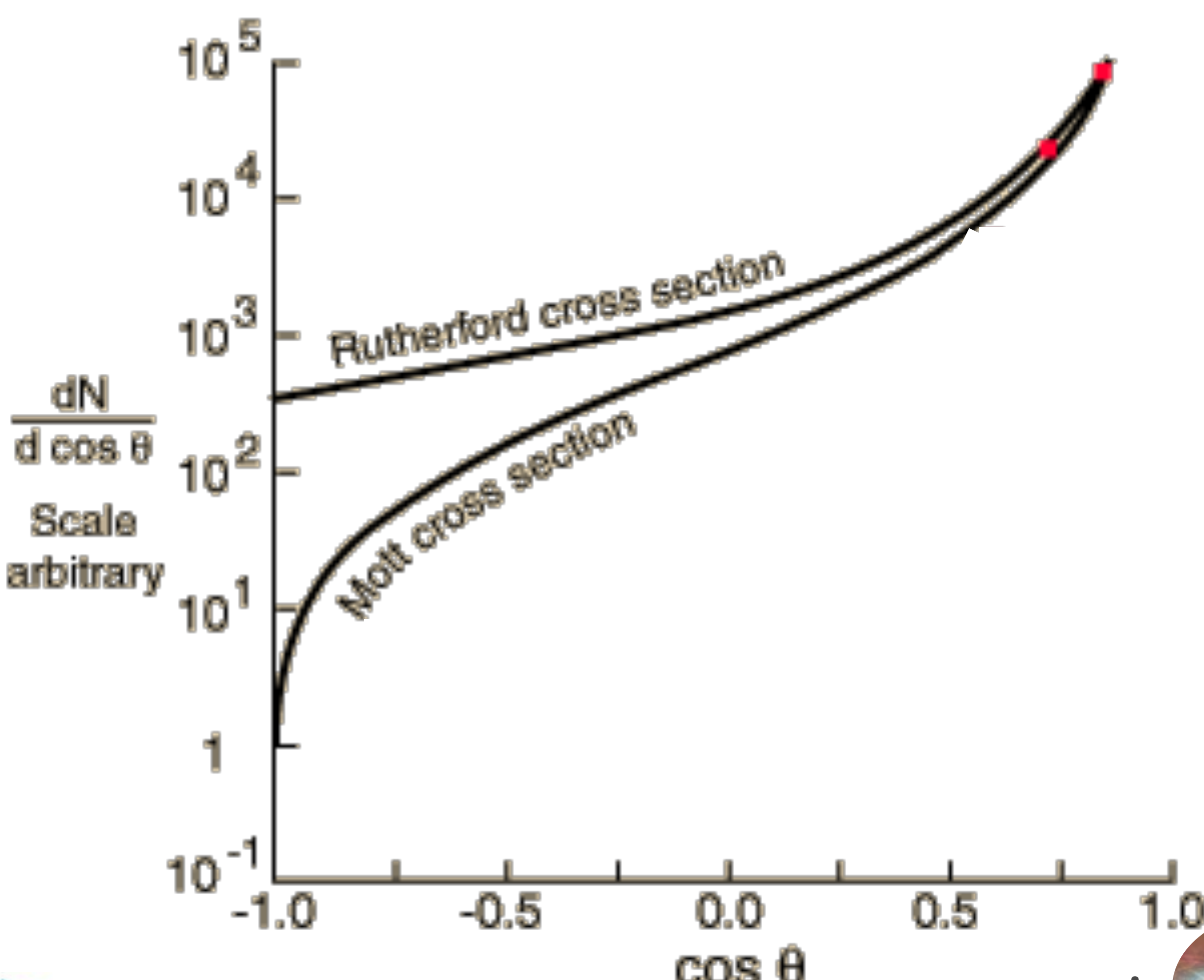
Form Factors are *ethernal*”

http://hyperphysics.phy-astr.gsu.edu/

Rutherford Scattering

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





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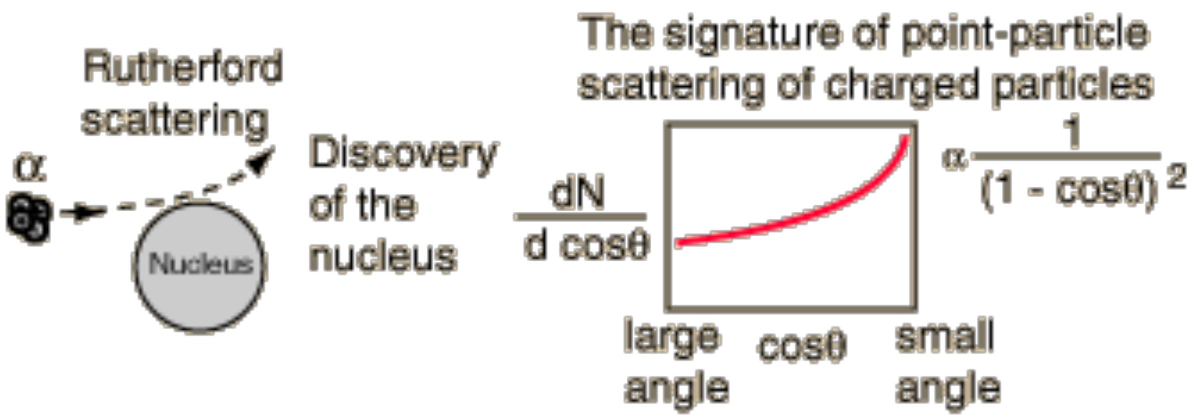
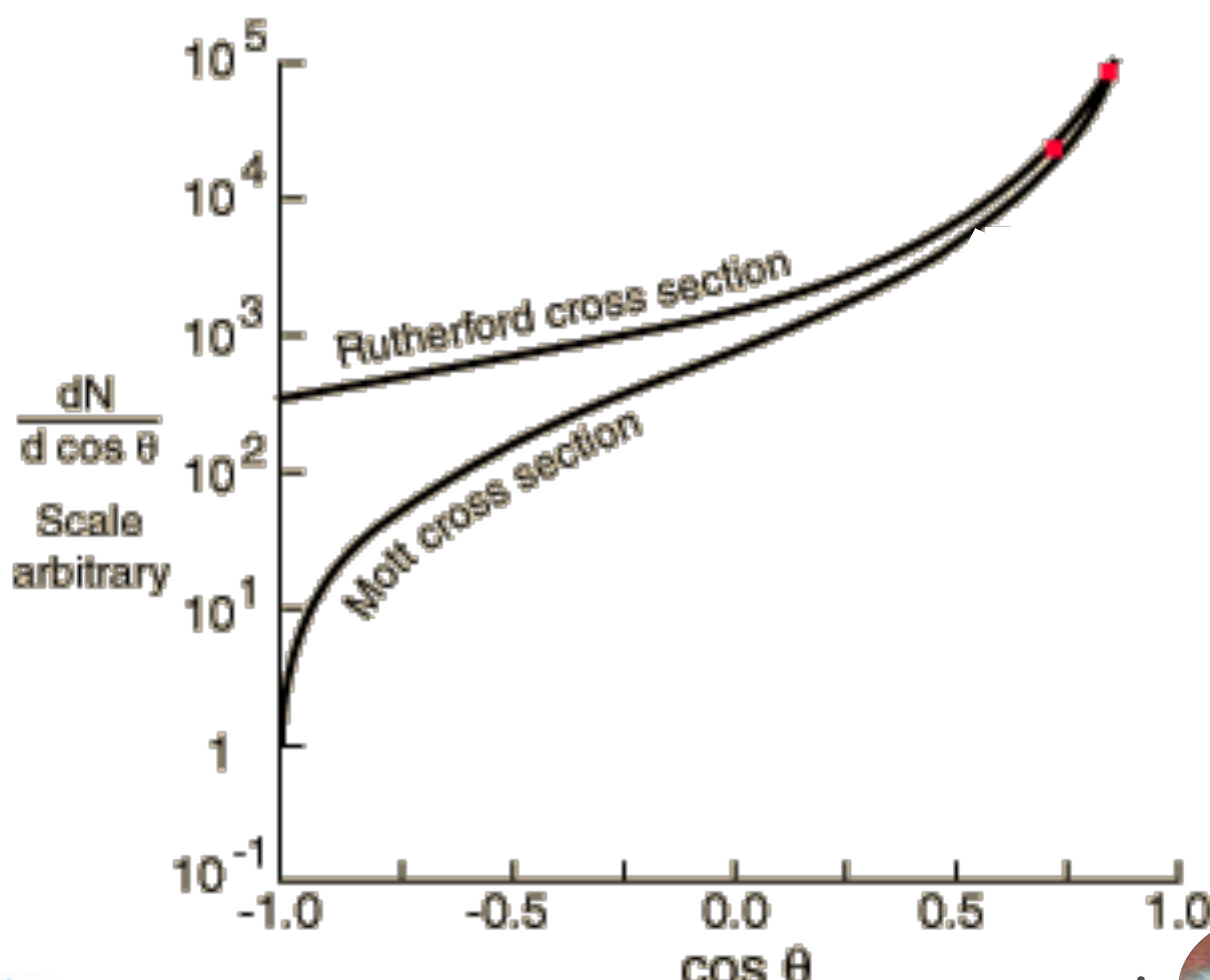




Rutherford Scattering

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

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

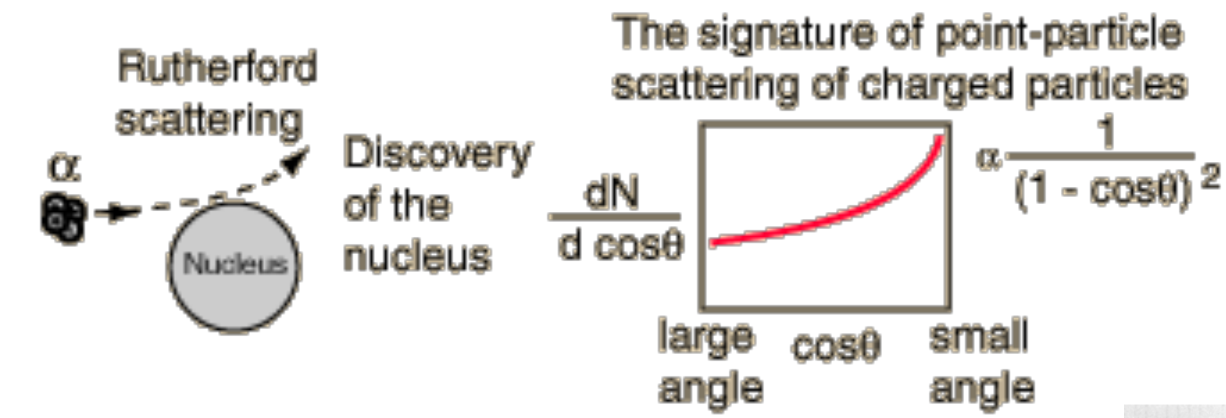
$$\frac{d\sigma}{d\Omega} = \underbrace{\frac{\alpha^2}{4E_1^2 \sin^4\theta/2}}_{\text{Rutherford}} \underbrace{\frac{E_3}{E_1}}_{\text{Proton recoil}} \left(\underbrace{\cos^2\frac{\theta}{2}}_{\text{Electric/Magnetic scattering}} - \underbrace{\frac{q^2}{2M^2}\sin^2\frac{\theta}{2}}_{\text{Magnetic term due to spin}} \right)$$

Pointlike Dirac proton!

“Diamonds are *for ever*…

Form Factors are *ethernal*”

http://hyperphysics.phy-astr.gsu.edu/



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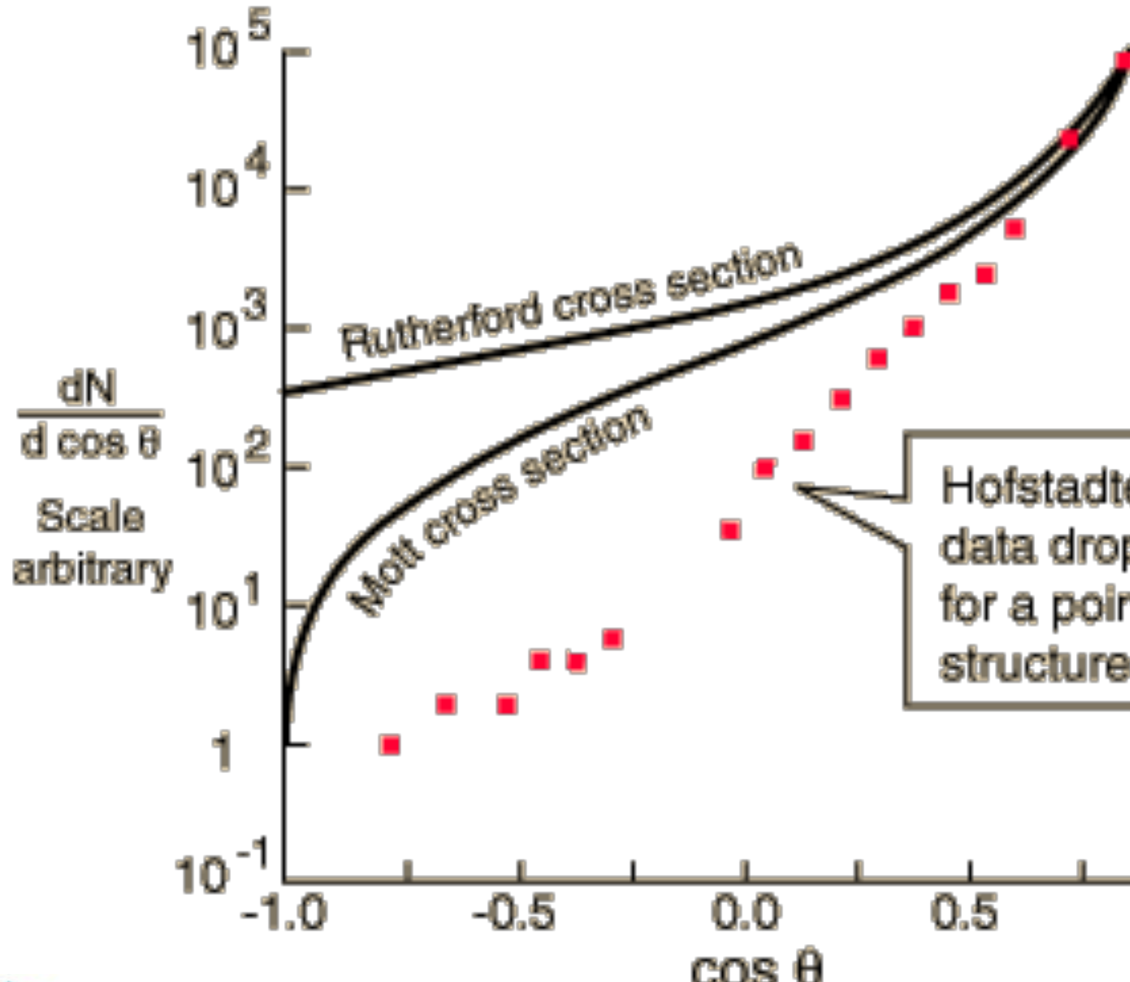


Hofstadter, R., et al., Phys. Rev. 92, 978 (1953).

$$\left(\frac{d\sigma}{d\Omega}\right)_{exp} = \left(\frac{d\sigma}{d\Omega}\right)^*_{Mott} |F(\vec{q}^{\,2})|^2$$

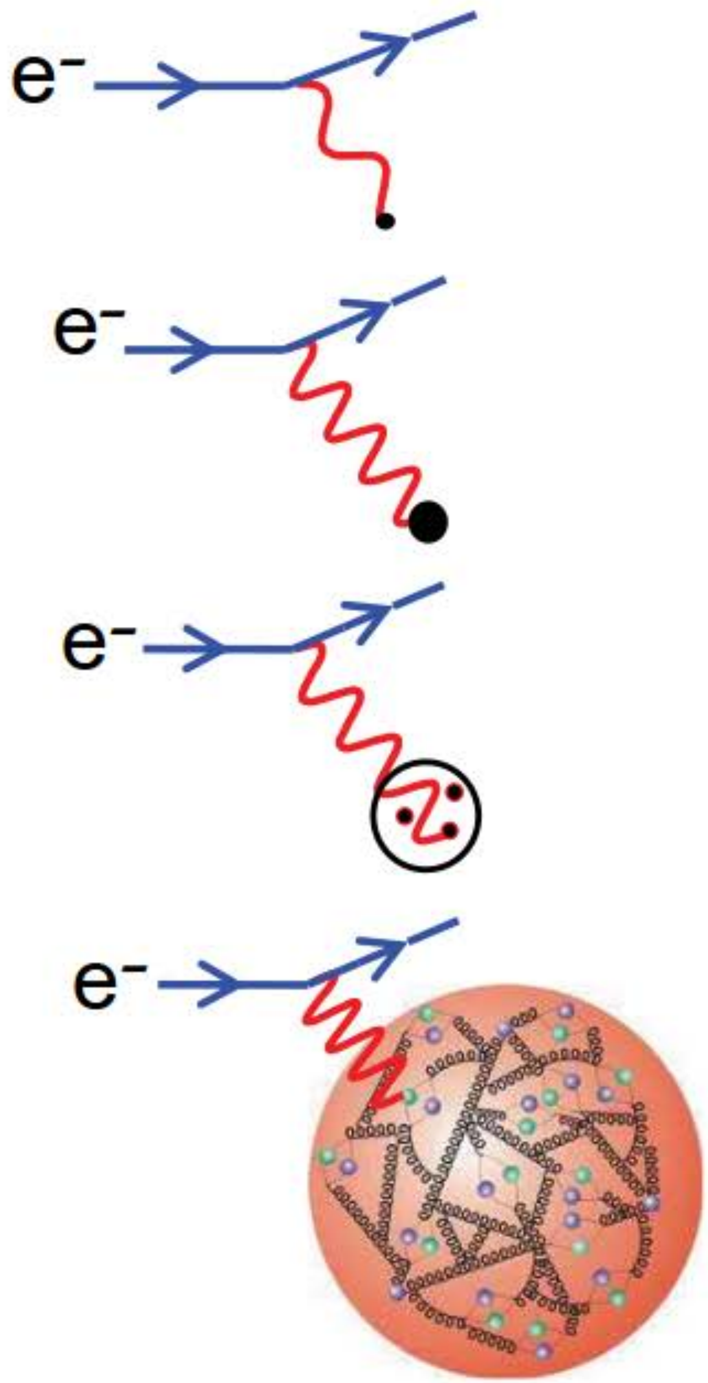
… *per aspera ad astra* …

CONCETTINASFIENTI

#MakeHumansSmartAgain

Form Factors

Qualitatively, FF accounts for the phase differences between contributions to the scattered wave from different points of the charge distribution

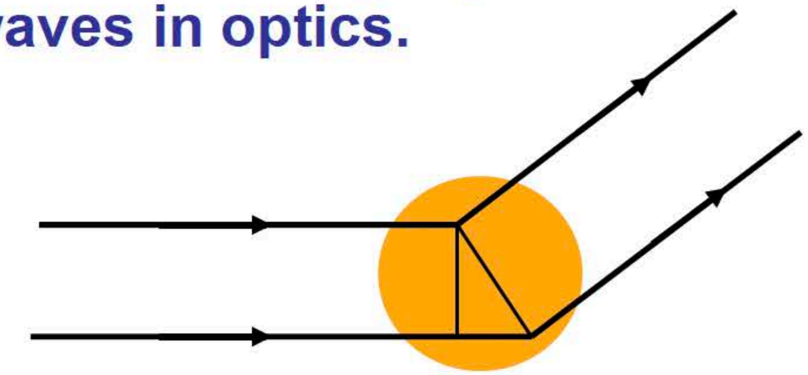


- At very low electron energies $\lambda \gg r_p$:
  the scattering is equivalent to that from a "point-like" spin-less object
- At low electron energies $\lambda \sim r_p$:
  the scattering is equivalent to that from a extended charged object
- At high electron energies $\lambda < r_p$:
  the wavelength is sufficiently short to resolve sub-structure. Scattering from constituent quarks
  (for a nucleus, from the constituent protons and neutrons)
- At very high electron energies $\lambda \ll r_p$:
  the proton appears to be a sea of quarks and gluons.

Form Factors

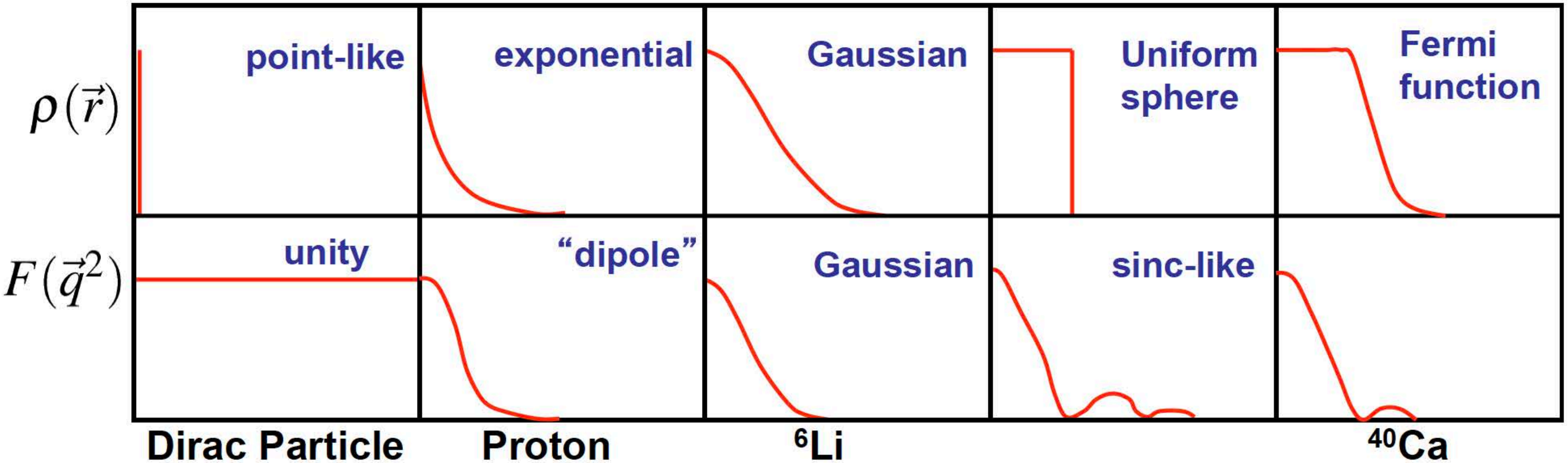
Qualitatively, FF accounts for the phase differences between contributions to the scattered wave from different points of the charge distribution

- **There is nothing mysterious about form factors – similar to diffraction of plane waves in optics.**



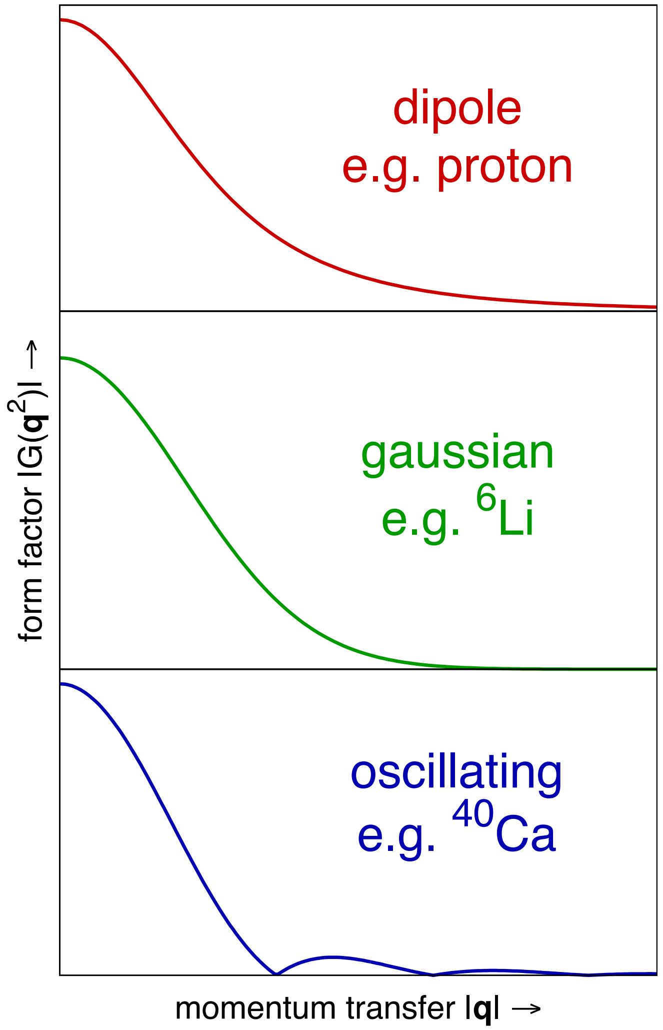
- **The finite size of the scattering centre introduces a phase difference between plane waves "scattered from different points in space". If wavelength is long compared to size all waves in phase and** $F(\vec{q}^2) = 1$

For example:



Form Factors from Elastic eN scattering

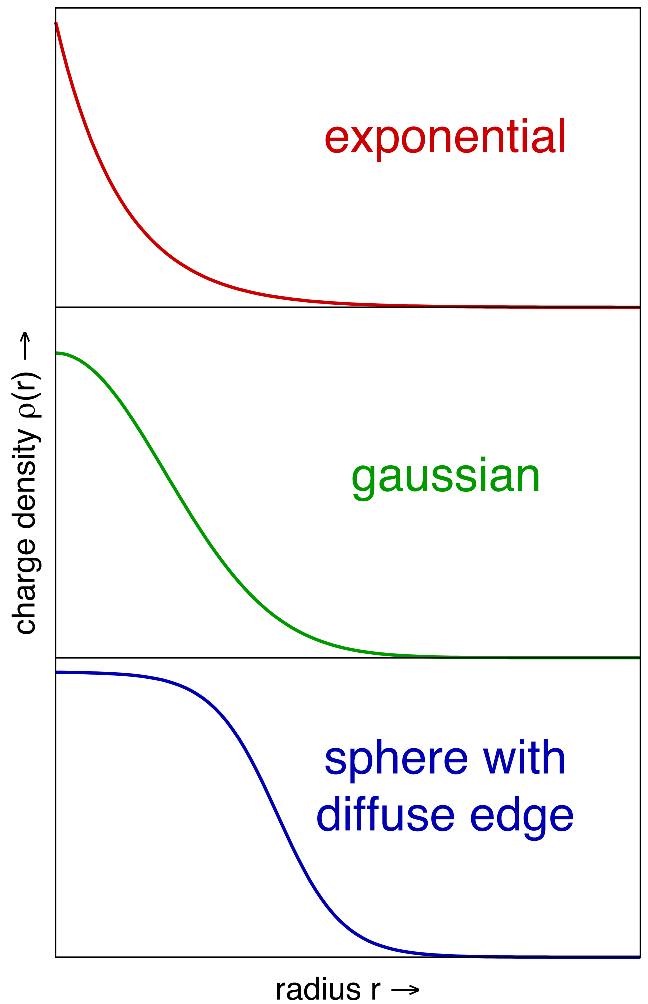
form factor: $F(q^2) = \frac{1}{e}\int_0^\infty \rho(r)\,\frac{\sin qr}{qr}\,4\pi r^2\,dr$



Fourier

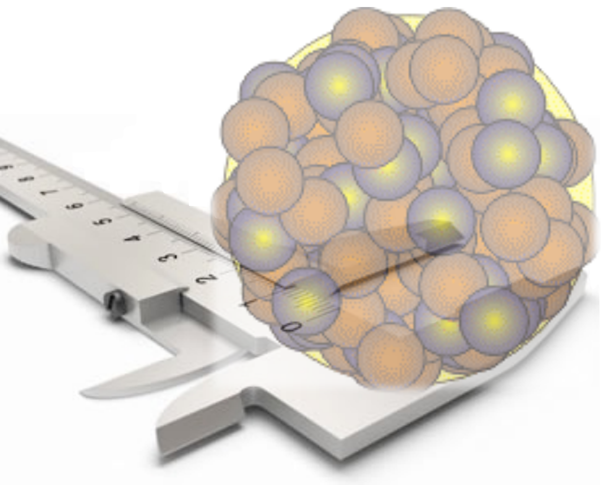
⇔

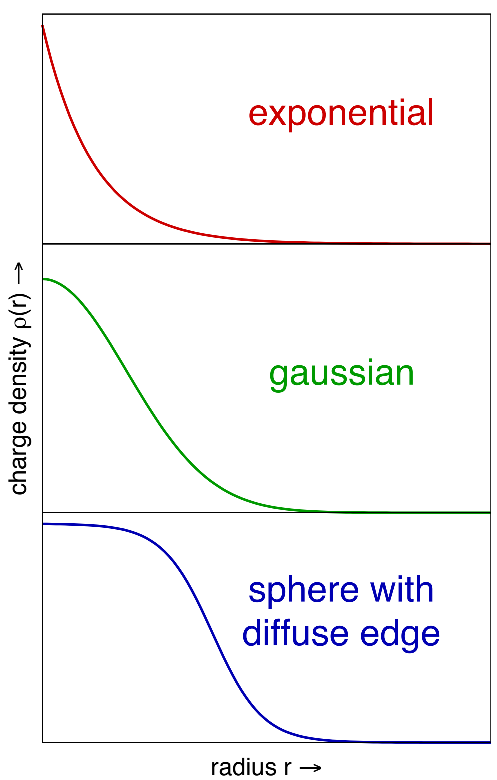
Transform



charge distribution: $\rho(r) = \frac{e}{(2\pi)^3}\int_0^\infty F(q^2)\,\frac{\sin qr}{qr}\,4\pi q^2\,dq$

Nuclear Charge Radius





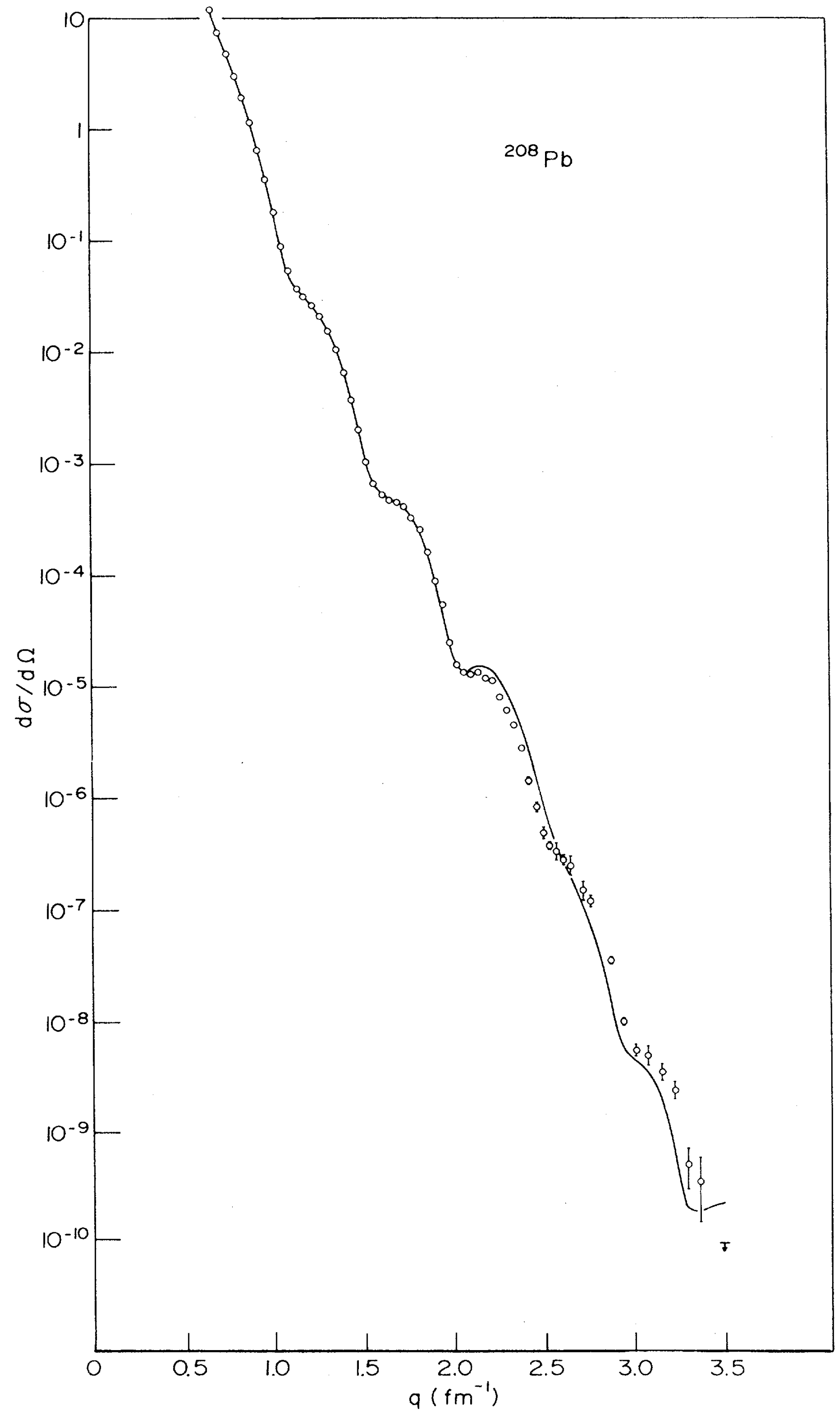


FIG. 10. Cross sections for elastic electron scattering from ^{208}Pb at 502 MeV compared with DME mean-field theory prediction (solid line).

- Cross section over **12 orders of magnitude**!
- **THIS** is our picture of the atomic nucleus!

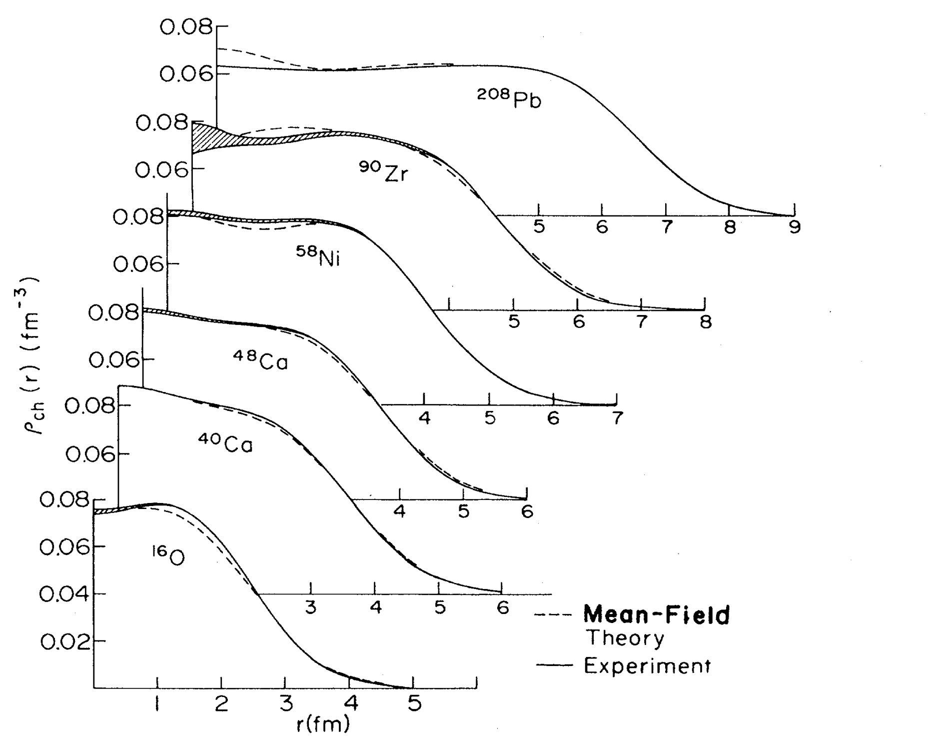
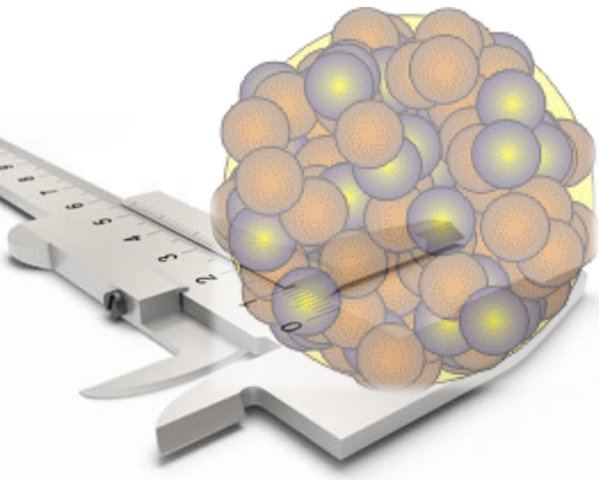
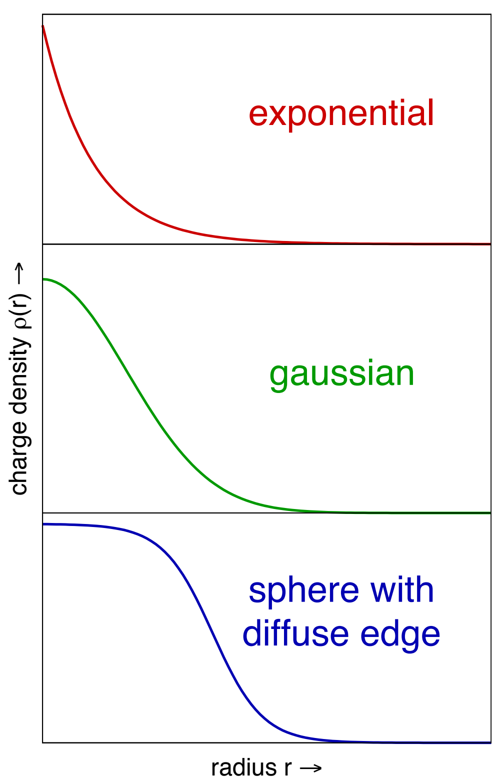


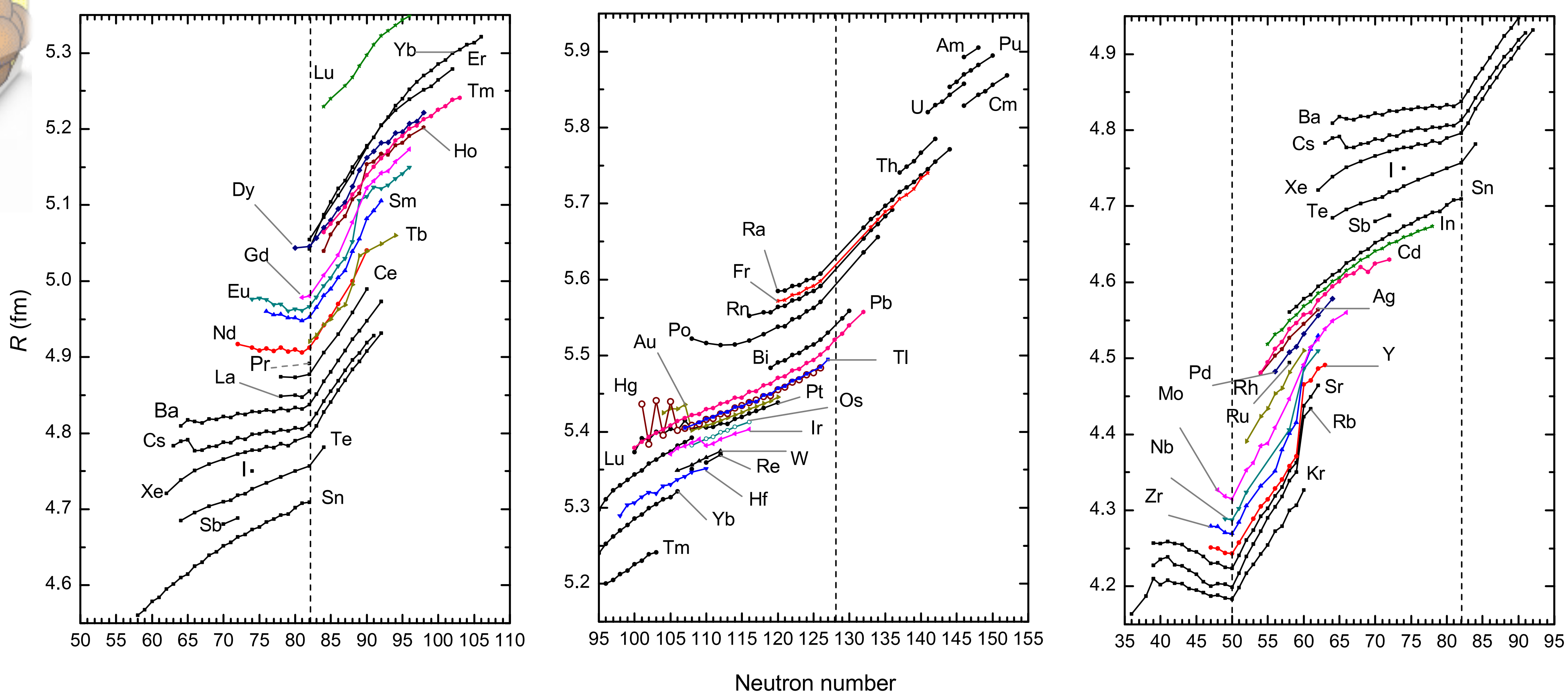
FIG. 11. Comparison of DME mean-field theory charge distributions in spherical nuclei (dashed lines) with empirical charge densities. The solid curves and shaded regions represent the error envelope of densities consistent with the measured cross sections and their experimental uncertainties.

Nuclear Charge Radius





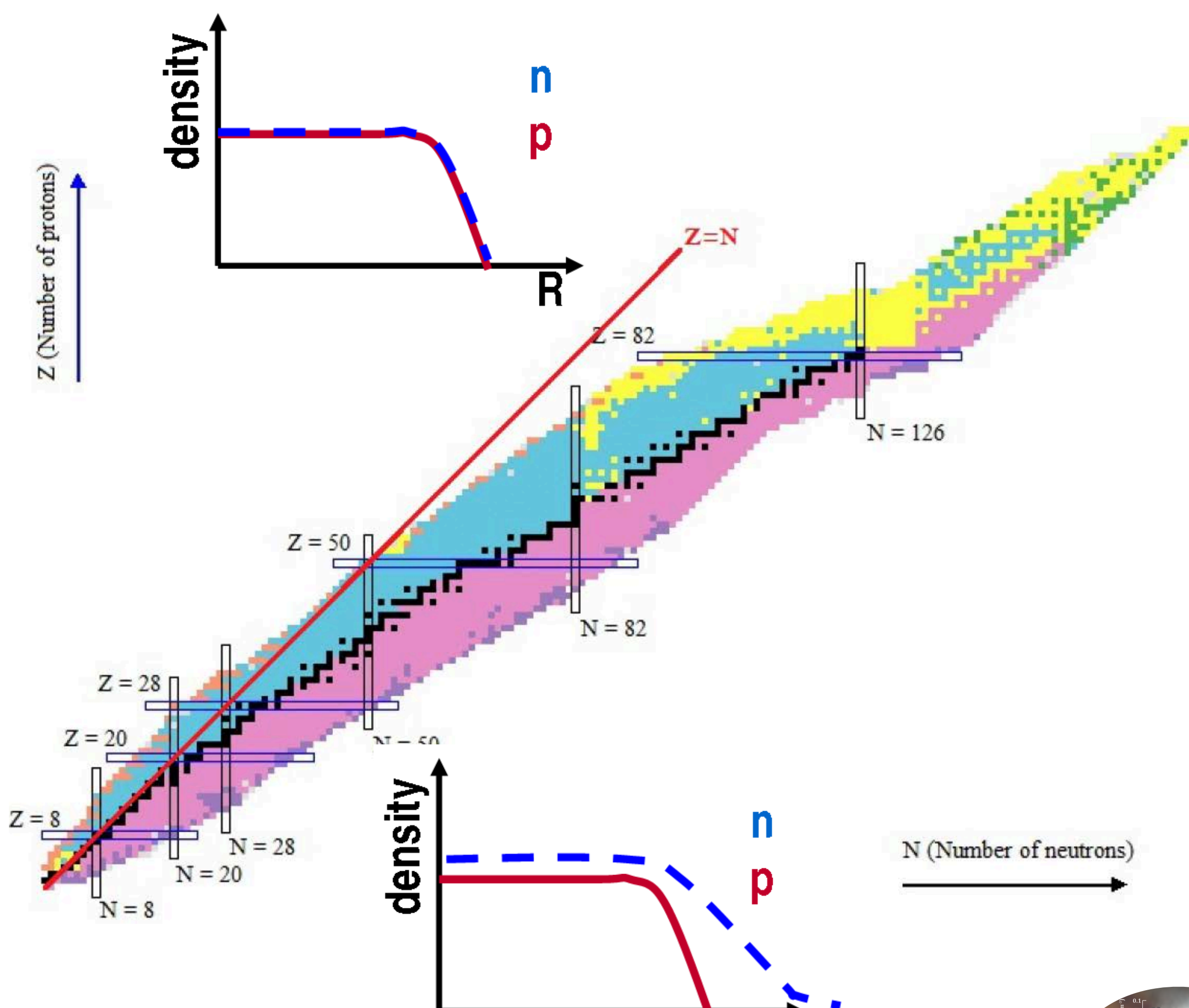
I. Angeli, K.P. Marinova / Atomic Data and Nuclear Data Tables 99 (2013) 69–95



- Kinks at closed neutron shells
- Regular odd-even staggering
- Obvious shape effects
- **Radii of isotopes increase at ~half rate of $1.2A^{1/3}$!!!**

...did somebody already mentioned neutron-skin to you?

The neutron skin measures how much neutrons stick out past protons



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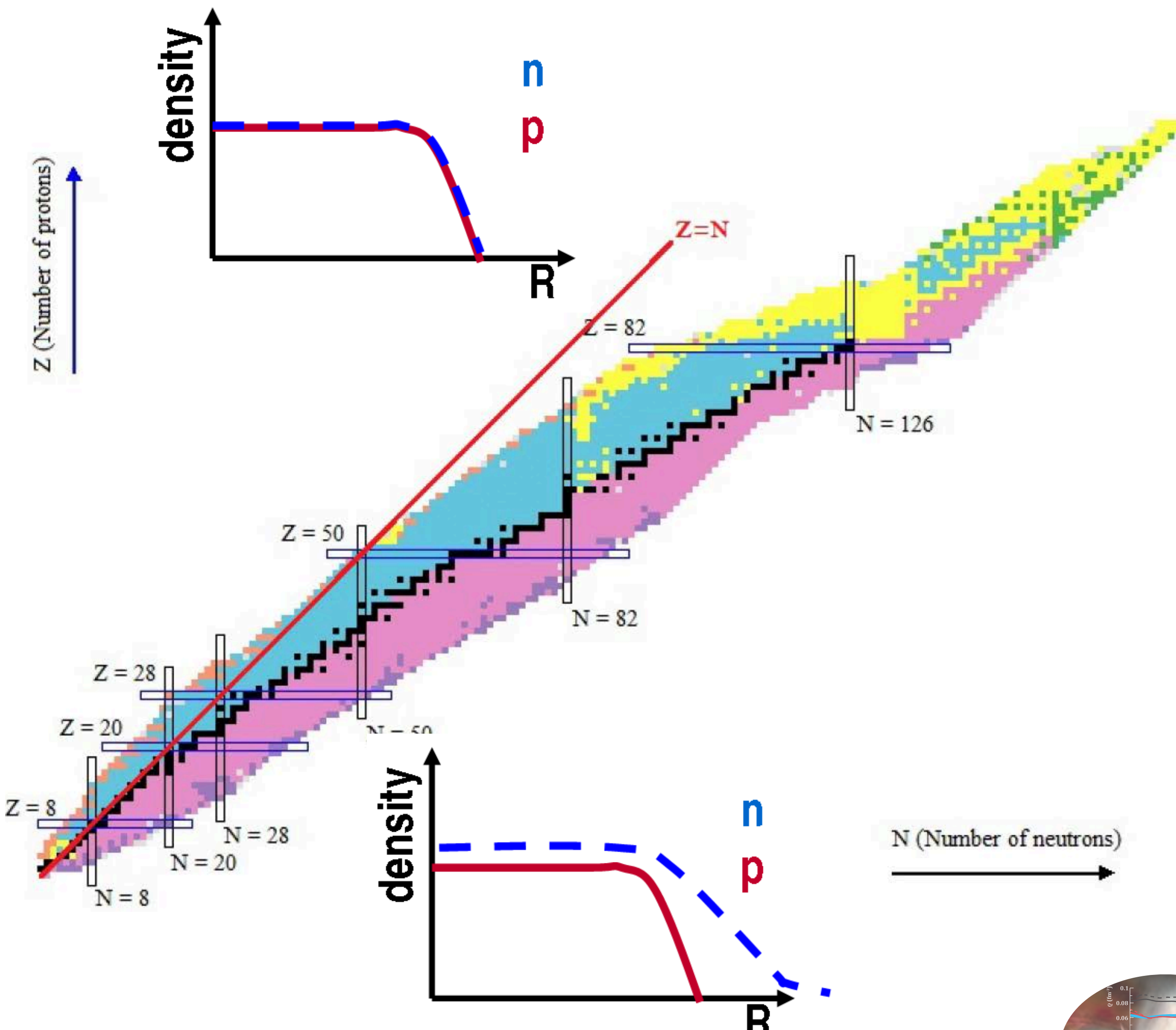
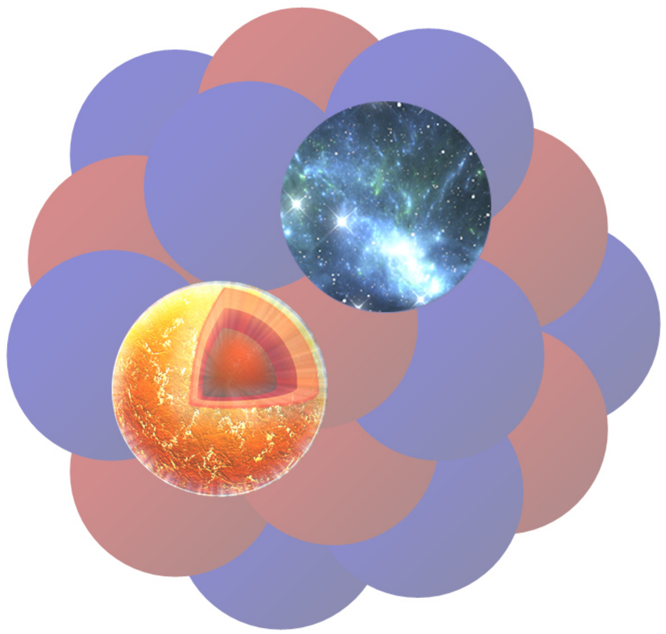
Symmetry energy favours moving them to the surface



Surface tension favours spherical drop of uniform equilibrium density

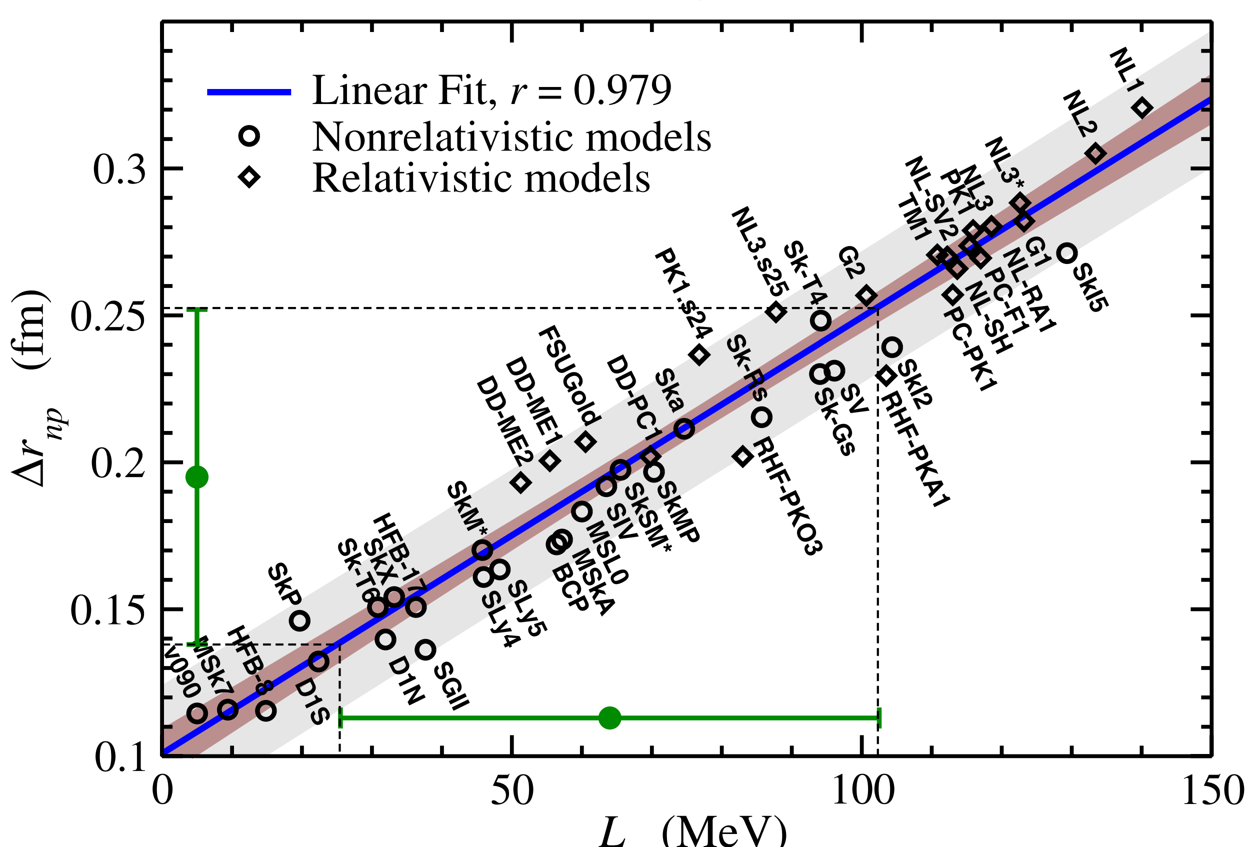
The spoiler: reality!



$$\mathcal{E}(\rho,\alpha)=\mathcal{E}(\rho,\alpha=0)+S(\rho)\,\alpha^2+\dots$$

$$S(\rho)=J+L\left(\frac{\rho-\rho_0}{3\rho_0}\right)+\frac{1}{2}K_{\text{sym}}\left(\frac{\rho-\rho_0}{3\rho_0}\right)^2+\dots$$

X. Roca-Maza, at al. Phys. Rev. Lett. 106, 252501 (2011)

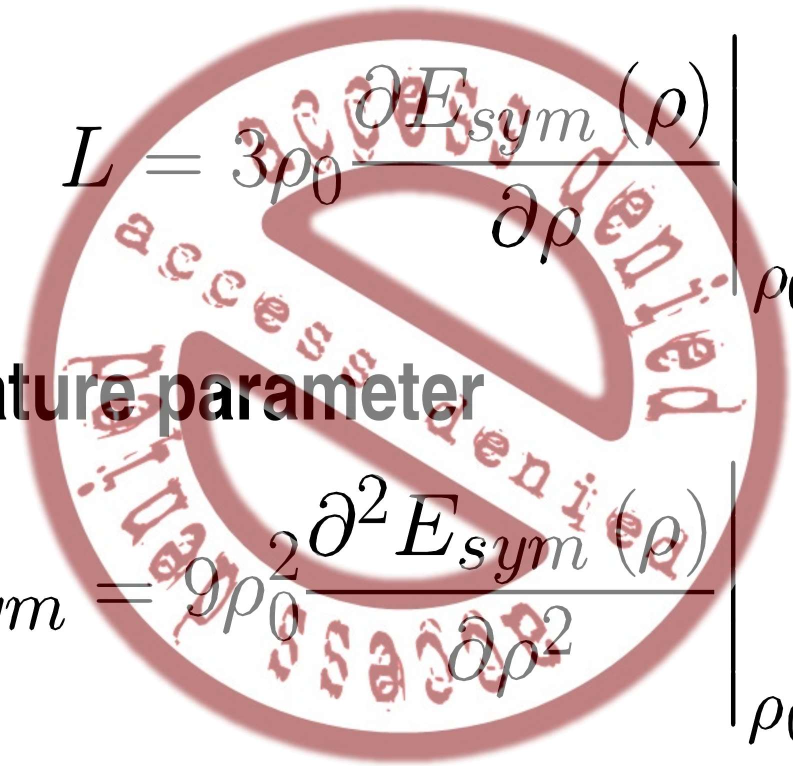


slope parameter

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

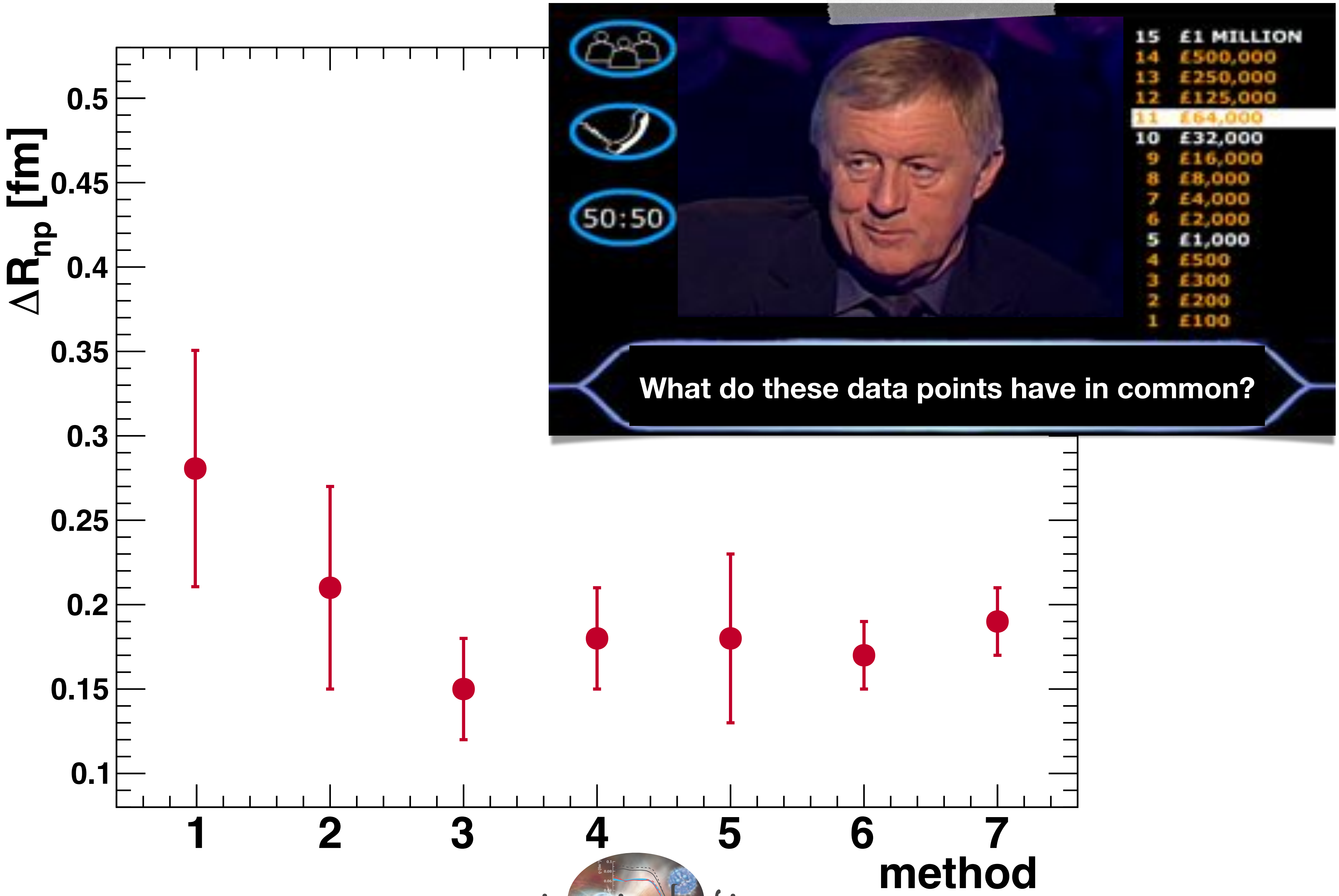
curvature parameter

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



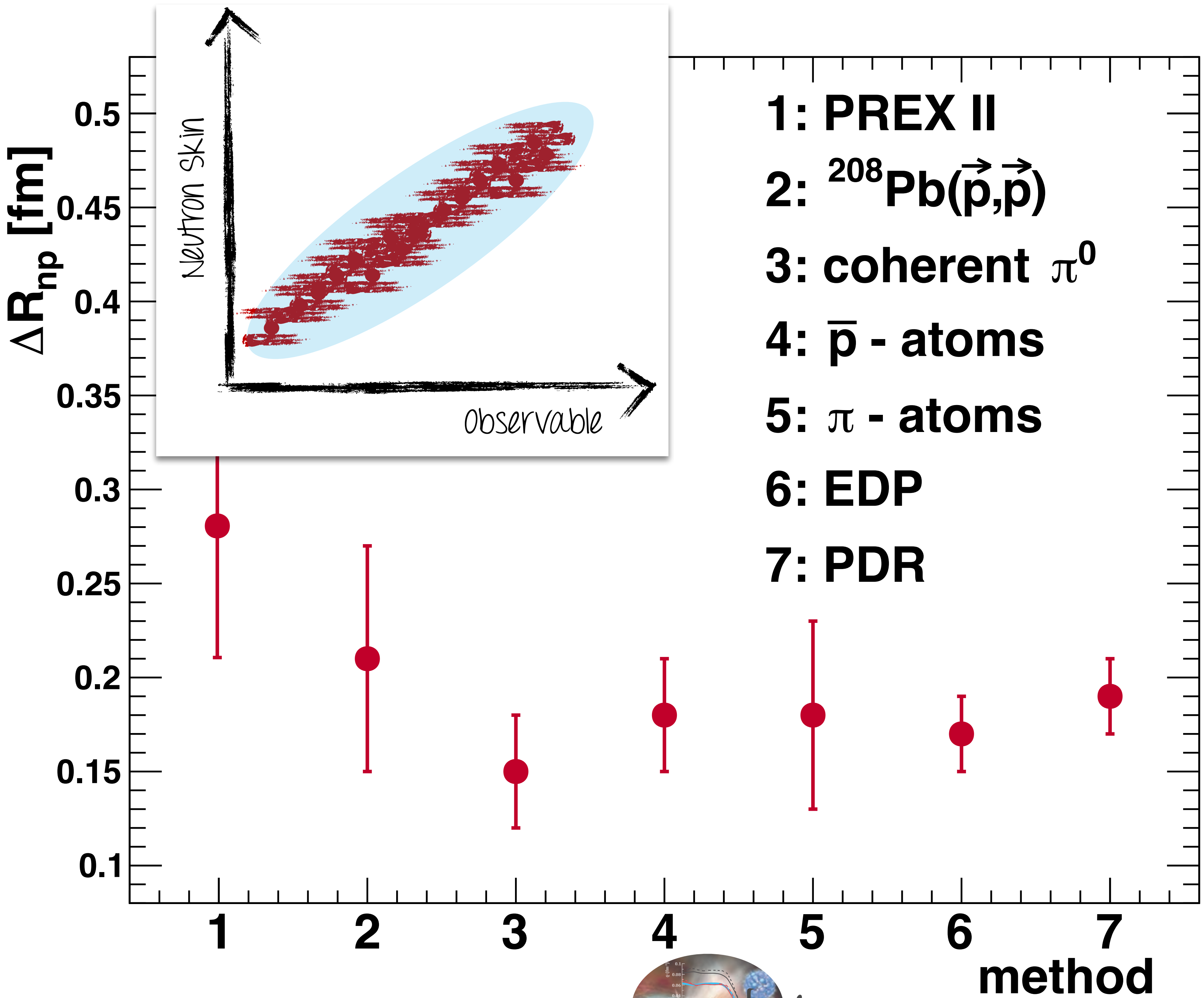
The stairway to heaven

The answer to the ultimate question



The stairway to heaven

NONE is an actual MEASUREMENT of neutron skin!



... per aspera ad astra ...

The stairway to heaven

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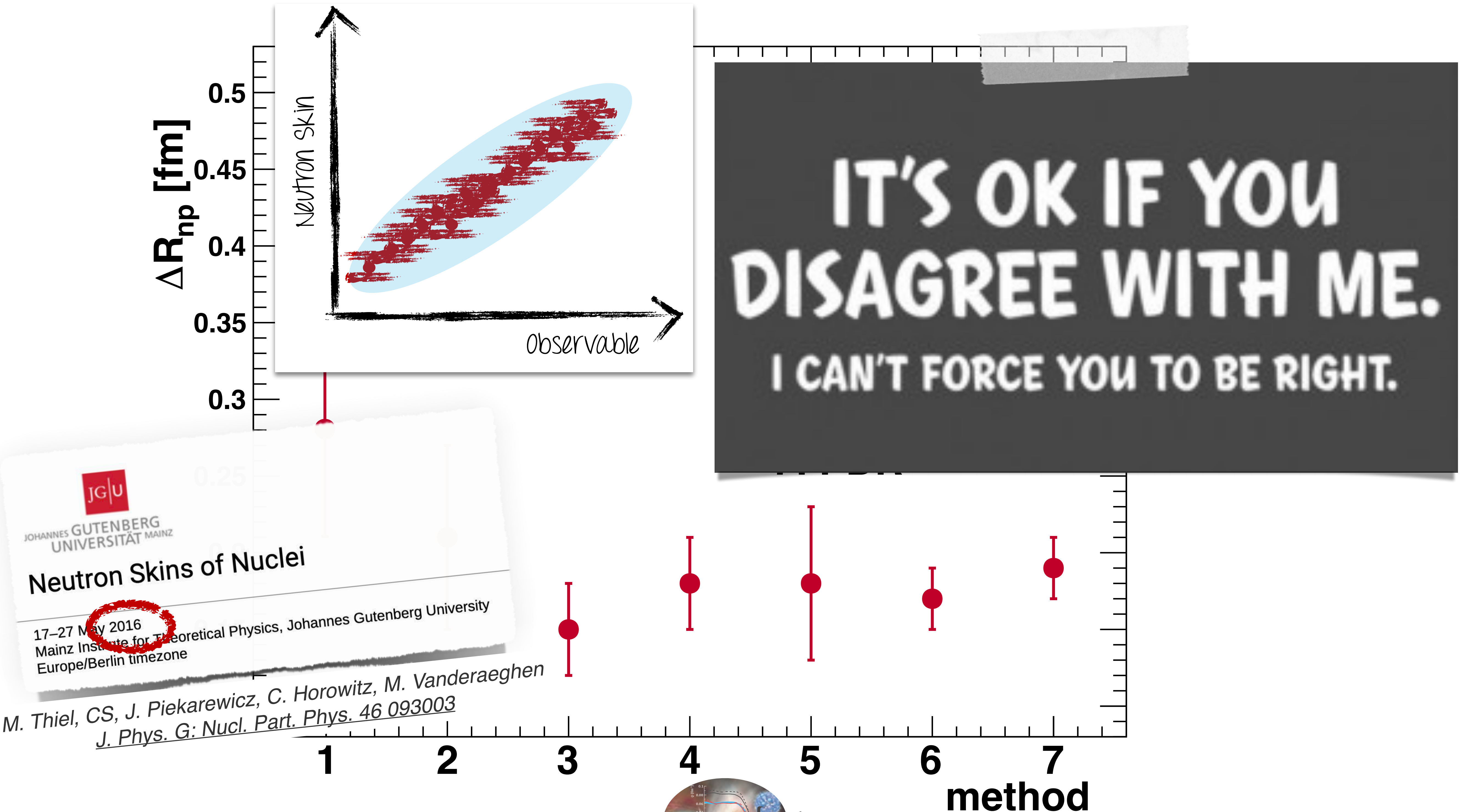
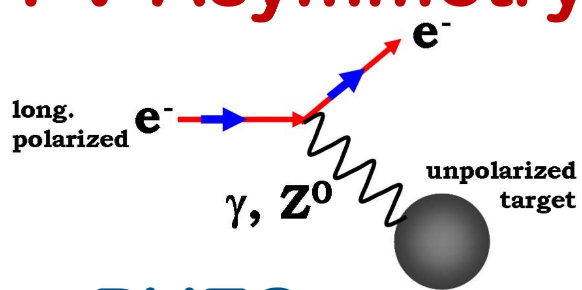


The stairway to heaven
(or the highway to hell, depending on your level of optimism)

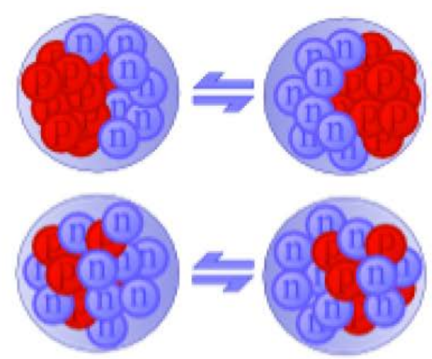
(Personal selection)

PV-Asymmetry



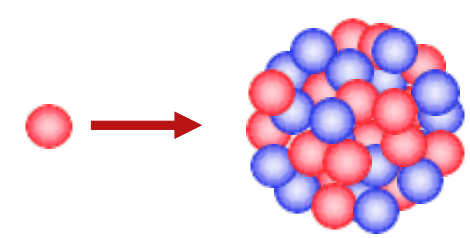
PVES

Resonance Strength

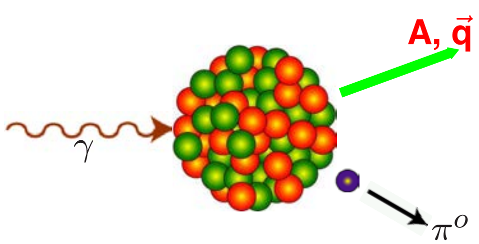


Collective Excitation

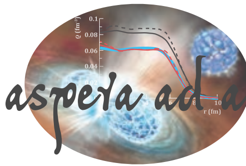
Cross-section



Hadronic Probes



EM Probes



... per aspera ad astra ...

The stairway to heaven
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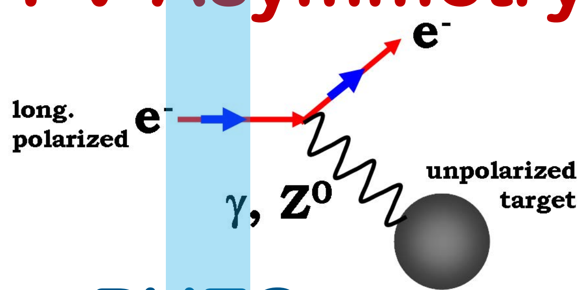
PV-Asymmetry



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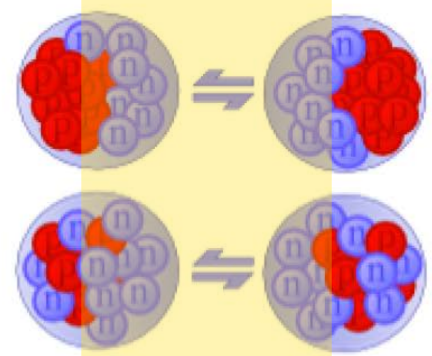
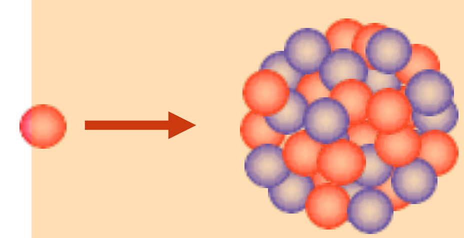


Collective Excitation

????...

Cross-section



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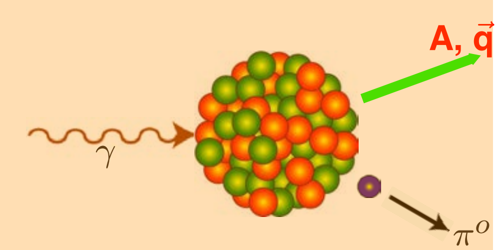

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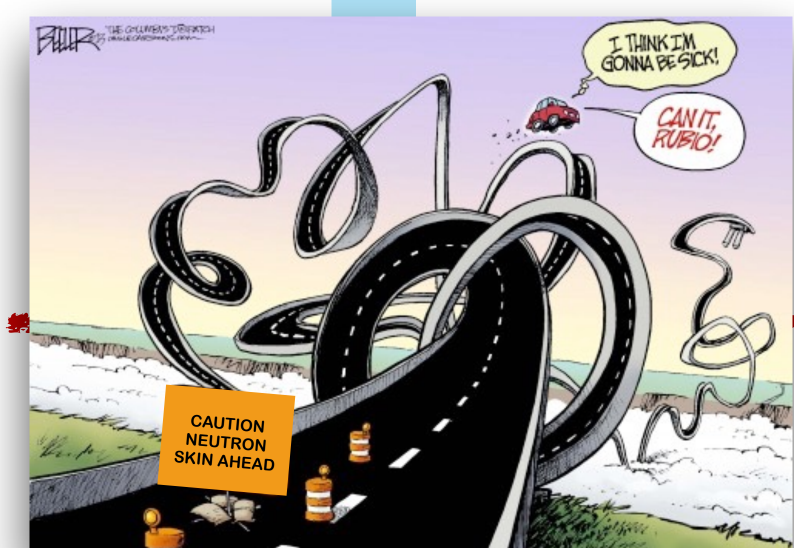


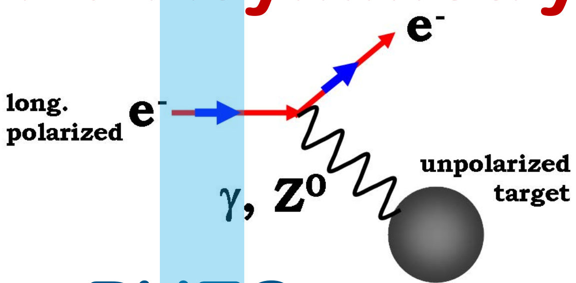
Theo. uncertainties (a.u)

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

(Personal selection)

Experimental Challenges (in unit of frustration)

PV-Asymmetry



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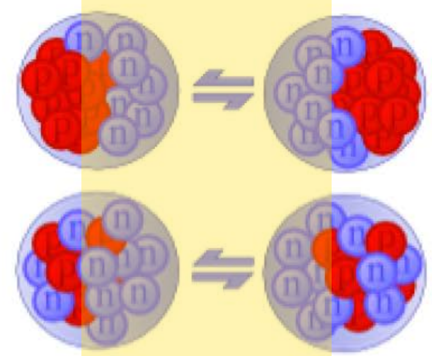
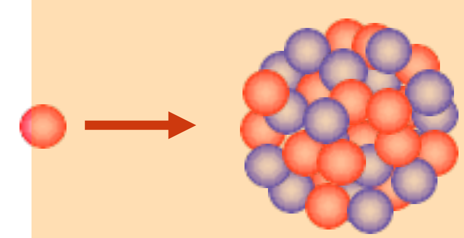


Collective Excitation

????...

Cross-section



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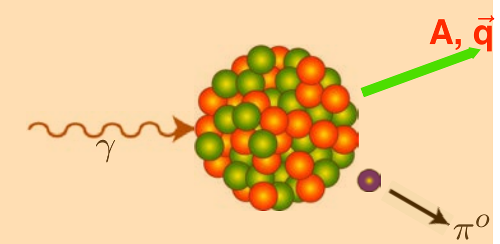

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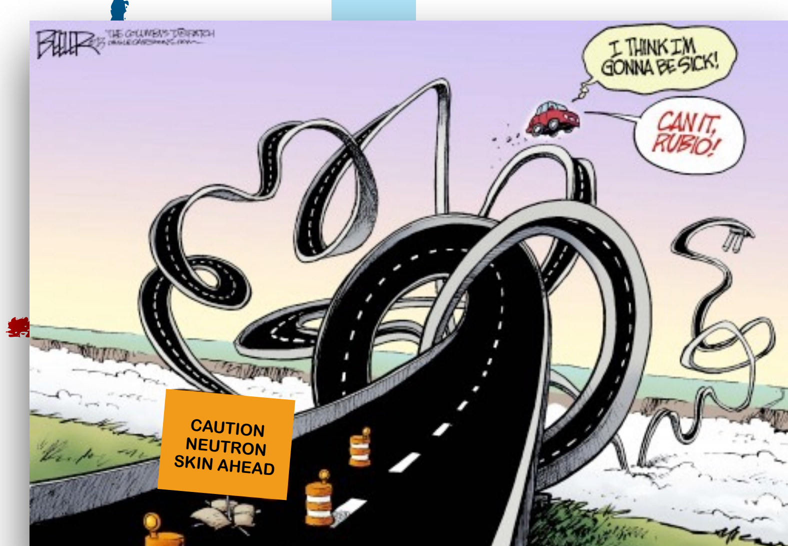


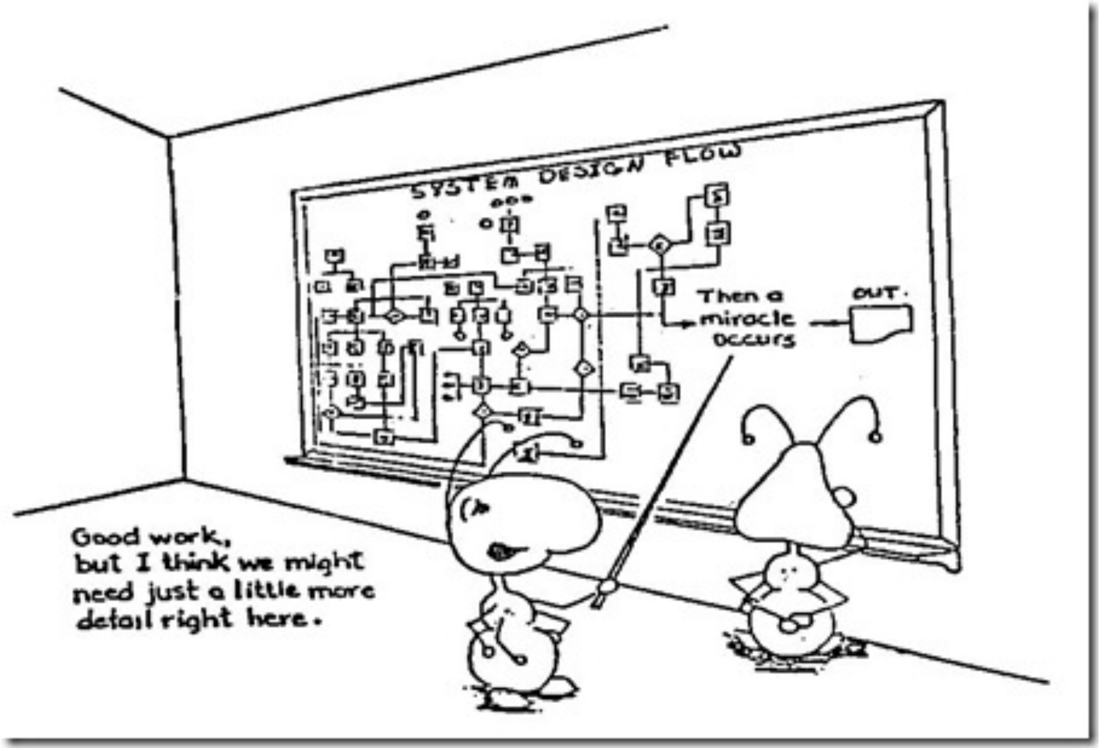
Theo. uncertainties (a.u)

... per aspera ad astra ...

Exercise nr. 1
(let's walk down the highway to hell)

- Proton scattering J. Zenihiro et al. Phys. Rev. C **82**, 044611
- Dipole polarisability A. Tamii et al., Phys. Rev. Lett. **107**, 062502
- Coherent pi0 C.M.Tabert et al. Phys. Rev. Lett. **112**, 242502
- Antiprotonic atoms: A. Trzcinska et al. Phys. Rev. Lett. **87**, 082501
- Heavy Ion collisions G. Giancalone et al. Phys. Rev. Lett. **131**, 202302

- **Step 1: Create a Flow Diagram: Create a flow diagram of the analysis procedure.**



(*) this is not an acceptable flow diagram!

Exercise nr. 1
(let’s walk down the highway to hell)

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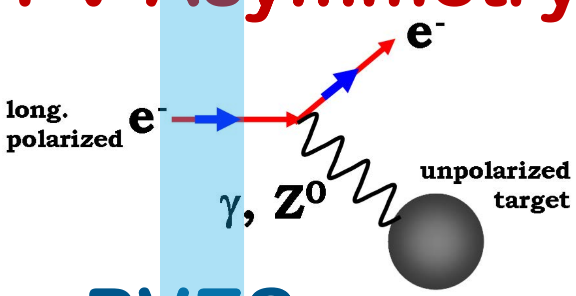
- **Step 1: Create a Flow Diagram: Create a flow diagram of the analysis procedure.**
- **Step 2: Identify Error Sources: For each step, identify potential sources of uncertainty.**
- **Step 3: Quantify Uncertainties: Assign (when possible) numerical values to each source of uncertainty.**

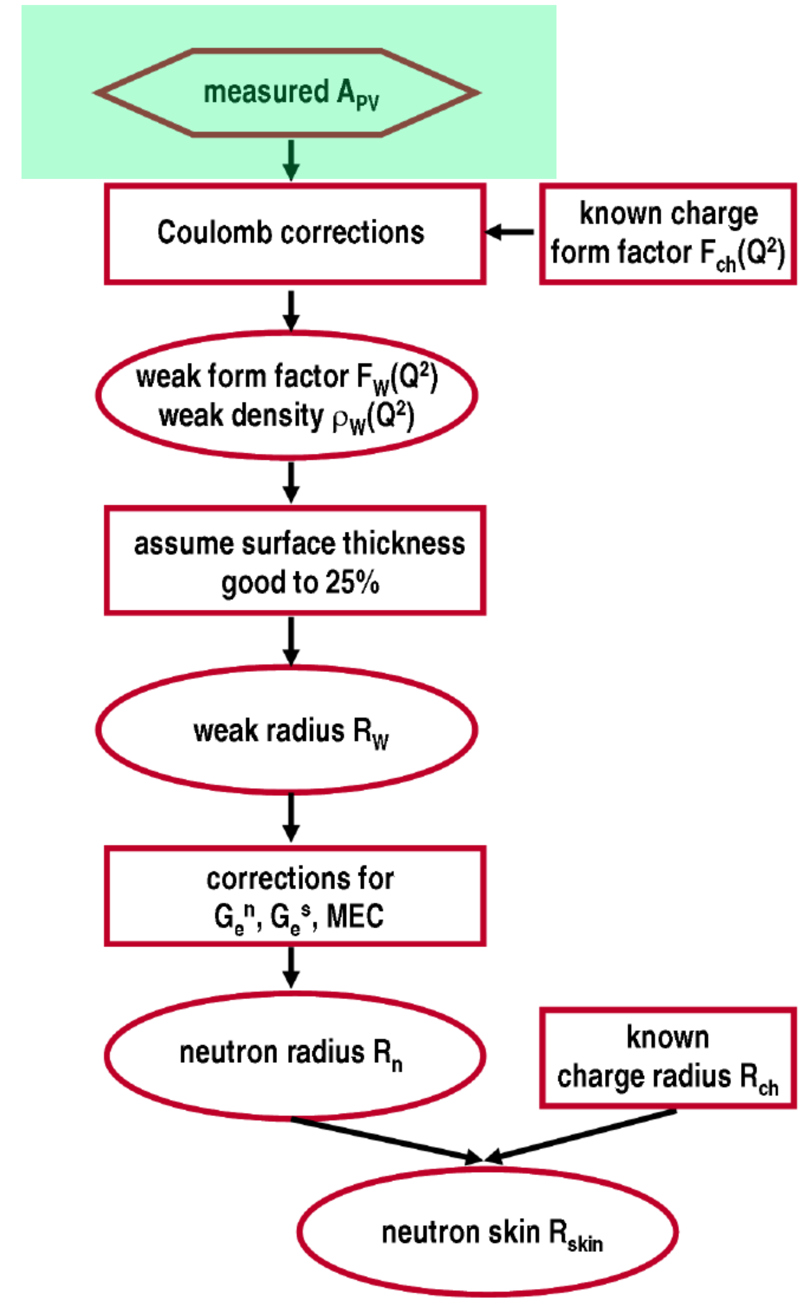
The shortest road …

Experimental Challenges
(in unit of frustration)

PV-Asymmetry



PVES



Theo. uncertainties (a.u)

The weak interaction in a nutshell

- Mediated by 3 massive gauge bosons: $W^{\pm}$, Z^0
- $W^{\pm}$ and Z^0 can interact with each other
- $W^{\pm}$ and γ can interact
- two types of weak interaction: charge (CC) and neutral (NC) currents
- $W^{\pm}$ and Z^0 also couple to the weak charges of the fermions:

Fermion	electric charge	weak charge
ν_e, ν_μ, ν_τ	0	
e, μ, τ,	−1	
u, c, t	2/3	
d, s, b	1/3	
p (uud)	+1	
n (udd)	0	

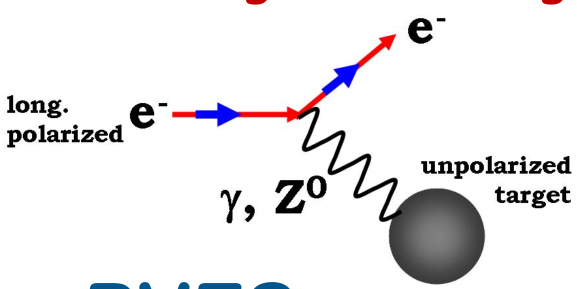
The weak interaction in a nutshell

- Mediated by 3 massive gauge bosons: $W^\pm$, Z^0
- $W^\pm$ and Z^0 can interact with each other
- $W^\pm$ and γ can interact
- two types of weak interaction: charge (CC) and neutral (NC) currents
- $W^\pm$ and Z^0 also couple to the weak charges of the fermions:

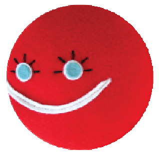
Fermion	electric charge	weak charge
ν_e, ν_μ, ν_τ	0	1
e,μ,τ,	−1	$-1+4\sin^2\Theta_w \approx 0$
u, c, t	2/3	$1-8/3\sin^2\Theta_w$
d, s, b	1/3	$-1+4/3\sin^2\Theta_w$
p (uud)	+1	≈ 0
n (udd)	0	≈ 1

The weak interaction in a nutshell

PV-Asymmetry



PVES

		
electric charge	1	0
weak charge	≈0.07	1

Non-PV e-scattering

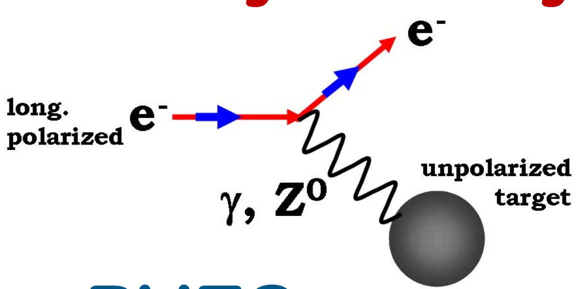
Electron scattering γ exchange provides R_p through nucleus FFs

PV e-scattering

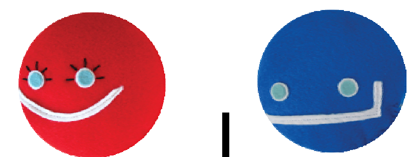
Electron also exchange Z, which is parity violating and primarily couples to neutron

The weak interaction in a nutshell

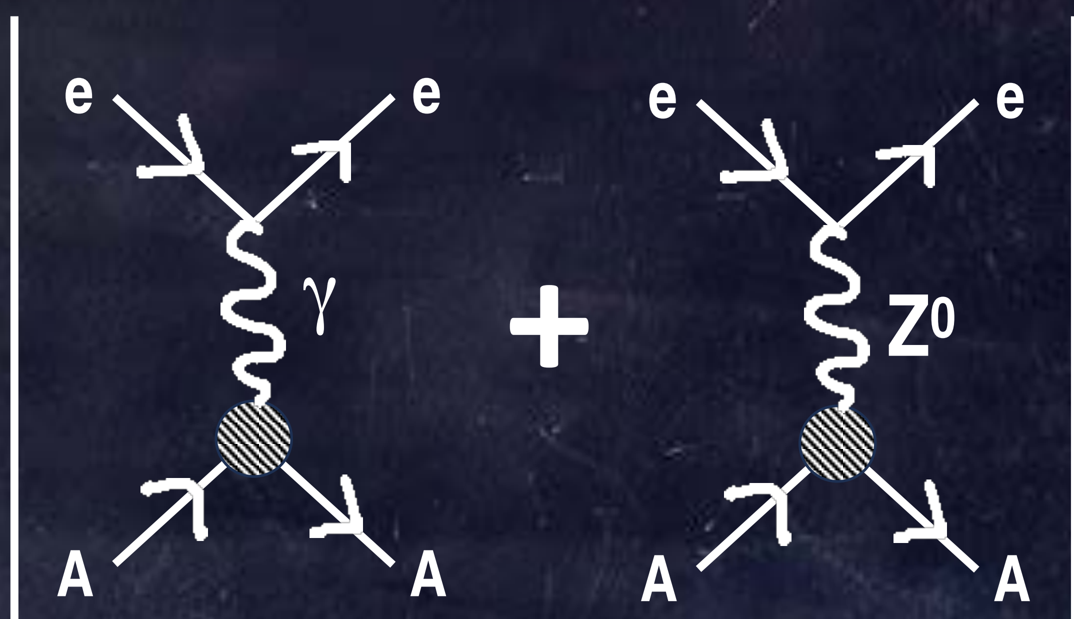
PV-Asymmetry



PVES

		
electric charge	1	0
weak charge	≈0.07	1

$\sigma \propto$



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

① ② ③

normalized to ①: $\sigma \propto \; 1 \; + \; 10^{-5} \; + \; 10^{-10}$

① pure EM interaction
② interference term
③ pure weak interaction

Parity violation in electron scattering

LETTERS TO THE EDITOR

PARITY NONCONSERVATION IN THE FIRST ORDER IN THE WEAK-INTERACTION CONSTANT IN ELECTRON SCATTERING AND OTHER EFFECTS

Ya. B. ZEL' DOVICH

Submitted to JETP editor December 25, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **36**, 964-966 (March, 1959)

WE assume that besides the weak interaction that causes beta decay,

$$g(\bar{P}ON)(\bar{e}^{-}O\nu) + \text{Herm. conj.}, \qquad (1)$$

there exists an interaction

$$g(\bar{P}OP)(\bar{e}^{-}Oe^{-}) \qquad (2)$$

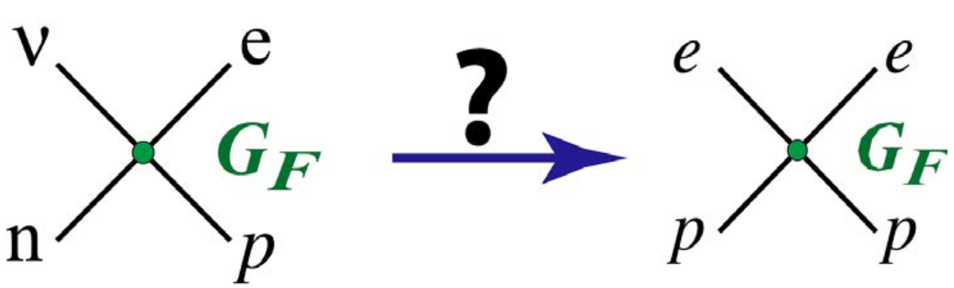
with $g \approx 10^{-49}$ and the operator $O = \gamma_\mu(1 + i\gamma_5)$ characteristic[1] of processes in which parity is not conserved.*

Then in the scattering of electrons by protons the interaction (2) will interfere with the Coulomb scattering, and the nonconservation of parity will appear in terms of the first order in the small quantity g. Owing to this it becomes possible to test the hypothesis used here experimentally and to determine the sign of g.

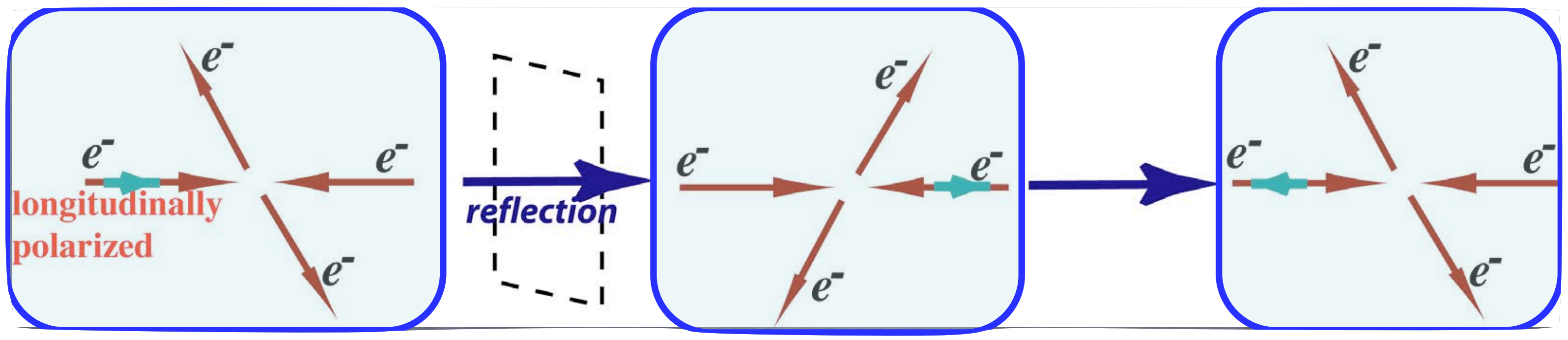
In the scattering of fast ($\sim 10^9$ ev) longitudinally polarized electrons through large angles by unpolarized target nuclei it can be expected that the cross-sections for right-hand and left-hand electrons (i.e., for electrons with $\sigma \cdot p > 0$ and $\sigma \cdot p < 0$) can differ by 0.1 to 0.01 percent. Such an effect is a specific test for an interaction not conserving parity.

Neutron β Decay

Electron-proton Weak Scattering



PVeS: How to ....



- One of the incident beams longitudinally polarised
- Change sign of longitudinal polarisation
- Measure fractional rate difference

The matrix element of the Coulomb scattering is of the order of magnitude e^2/k^2, where k is the momentum transferred ($\hbar = c = 1$). Consequently, the ratio of the interference term to the Coulomb term is of the order of gk^2/e^2. Substituting $g = 10^{-5}/M^2$, where M is the mass of the nucleon, we find that for $k \sim M$ the parity non-conservation effects can be of the order of 0.1 to 0.01 percent.

$$\sigma \;\alpha\; \left|A_{EM} + A_{weak}\right|^2$$

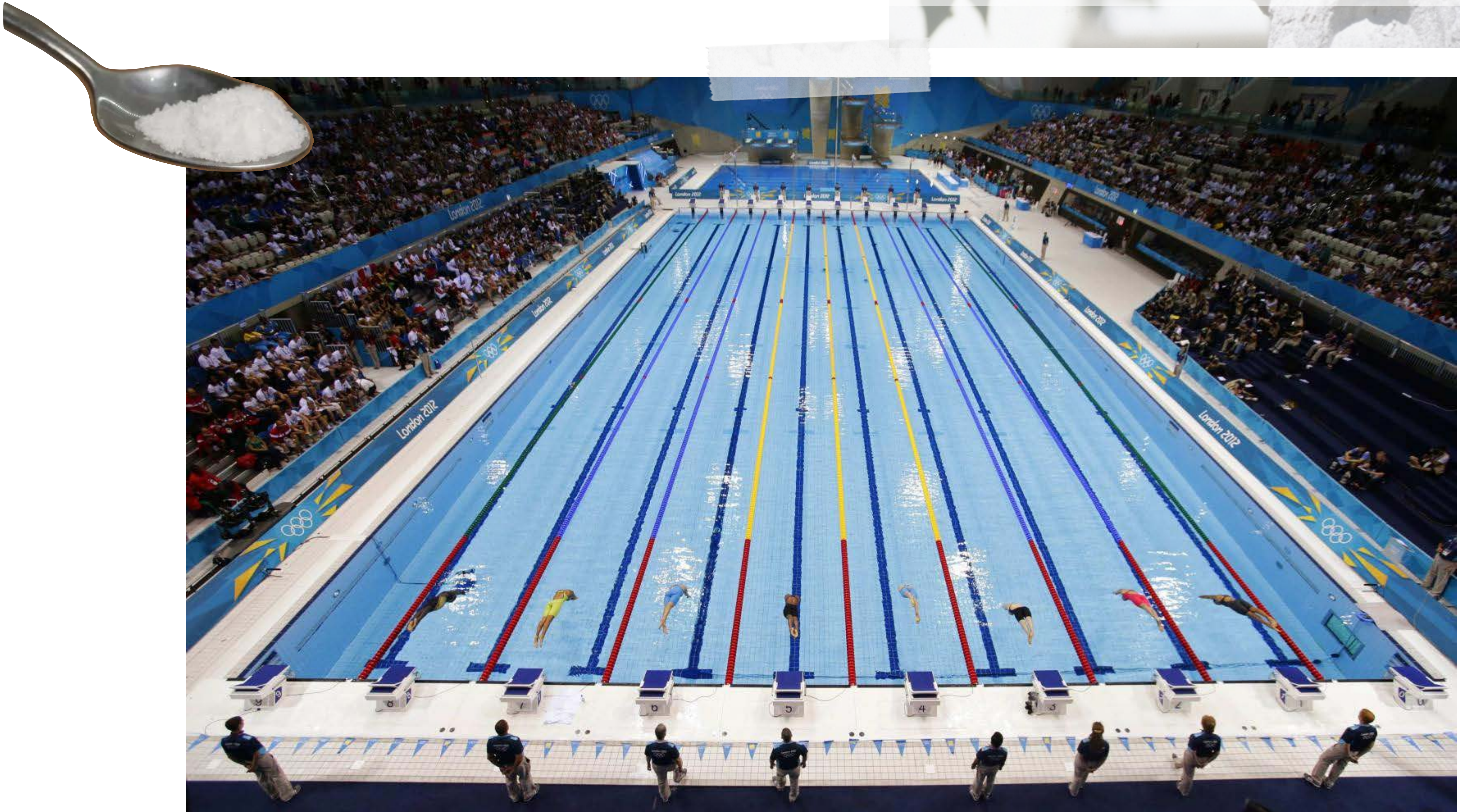
$$\sim \left|A_{EM}\right|^2 + \boxed{2A_{EM}A^*_{weak}} + \dots$$

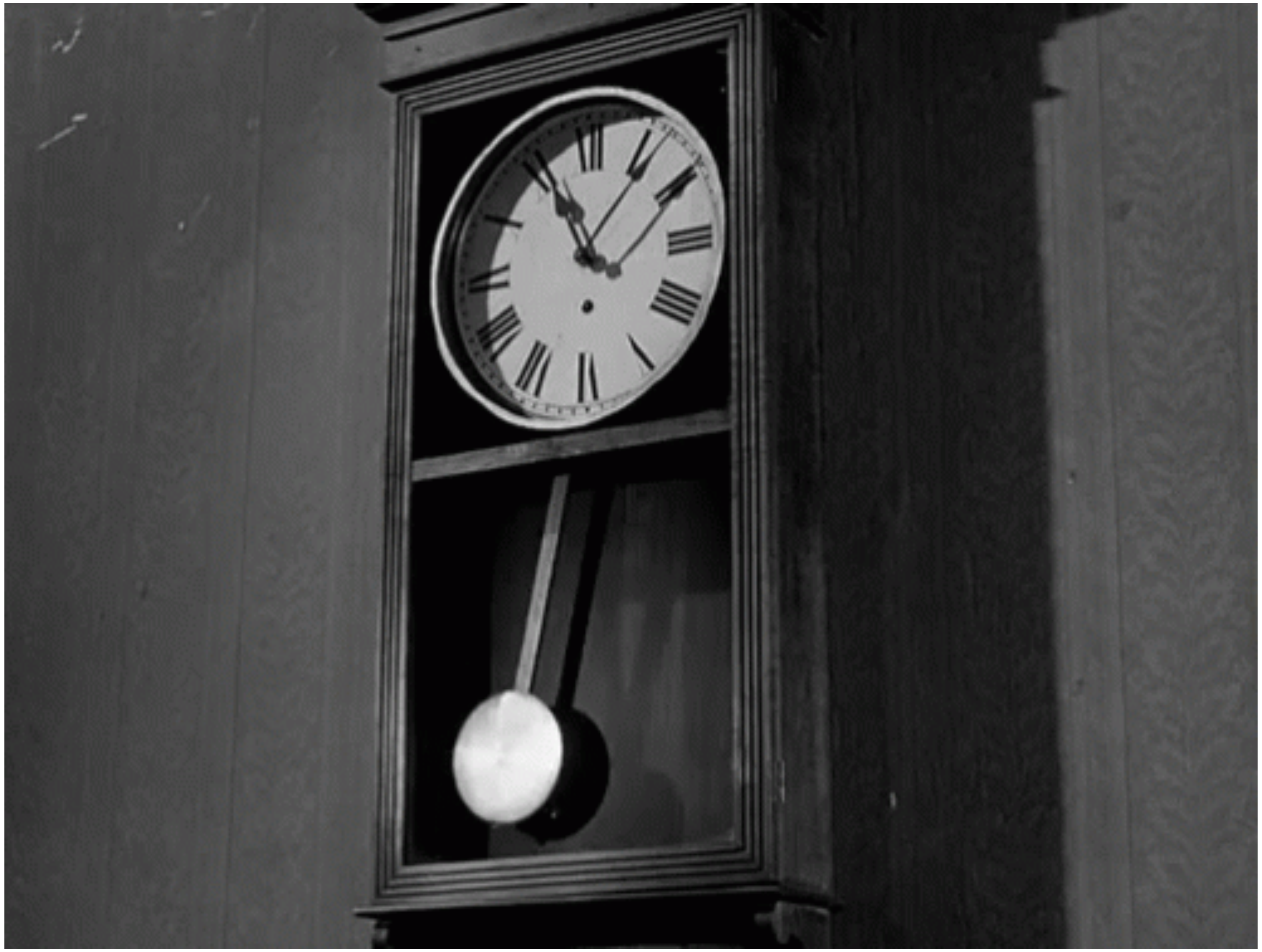
Parity-violating

$$A_{PV} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} \sim \frac{A_{weak}}{A_{EM}} \sim \frac{G_F Q^2}{4\pi\alpha}$$

$Q^2 \approx 0.1$ -1 $GeV^2 \rightarrow A_{PV} \leq 10^{-6} - 10^{-4}$

ppm

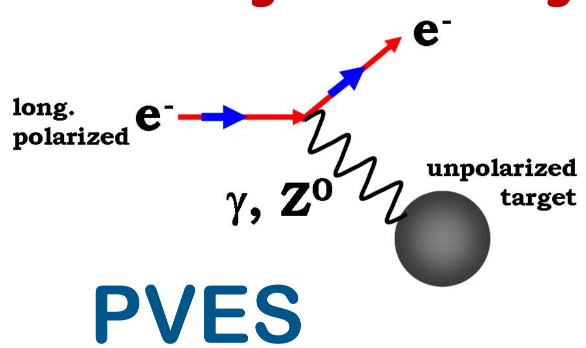




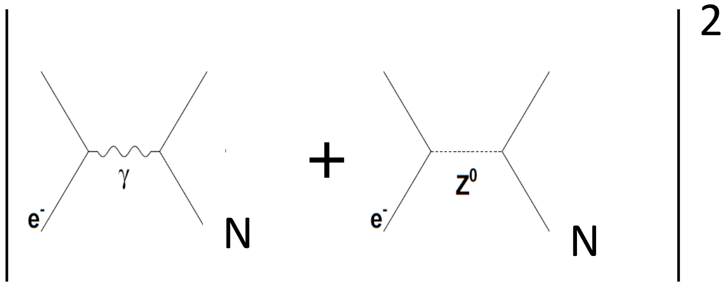
1 sec in 32 years!

PVeS: How to ....

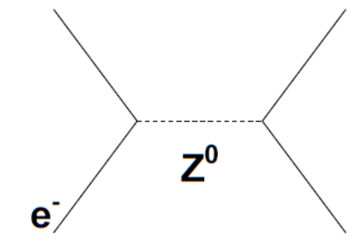
PV-Asymmetry



$\sigma \propto$

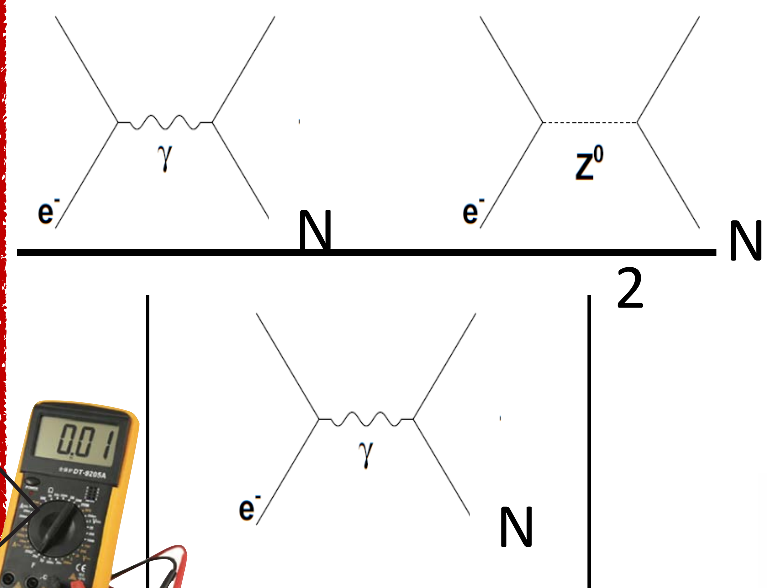


...to measure ...



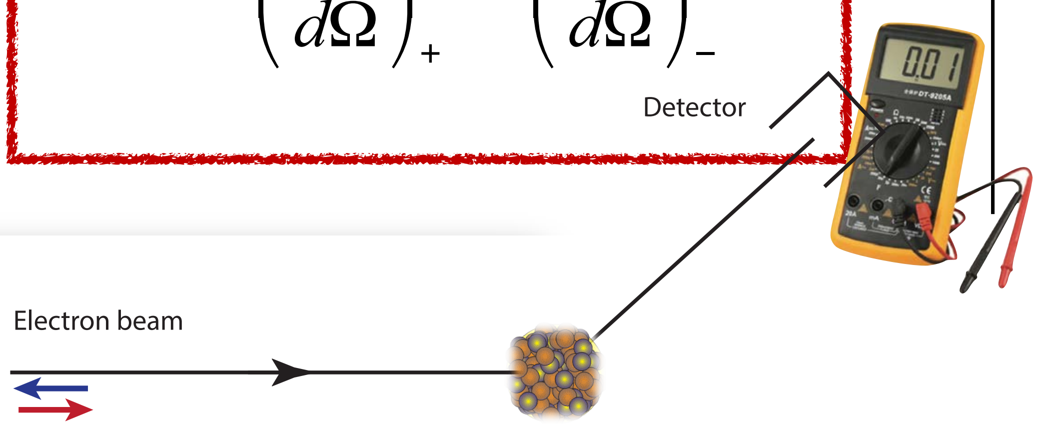
....construct ....

$$A_{PV} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_+ - \left(\frac{d\sigma}{d\Omega}\right)_-}{\left(\frac{d\sigma}{d\Omega}\right)_+ + \left(\frac{d\sigma}{d\Omega}\right)_-} \approx$$

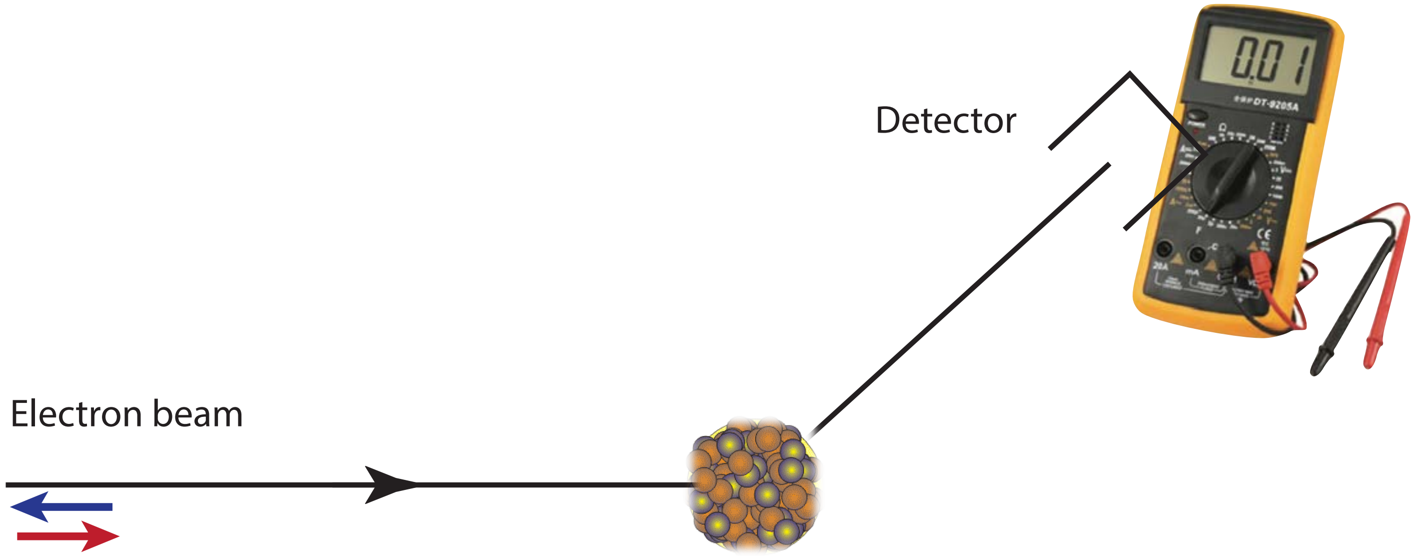


$$= \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{Q_W}{A} \cdot \frac{F_W(Q^2)}{F_{ch}(Q^2)}$$

$$F_W(Q^2) = \int d^3r \frac{\sin(Qr)}{Qr} \rho_W(r)$$

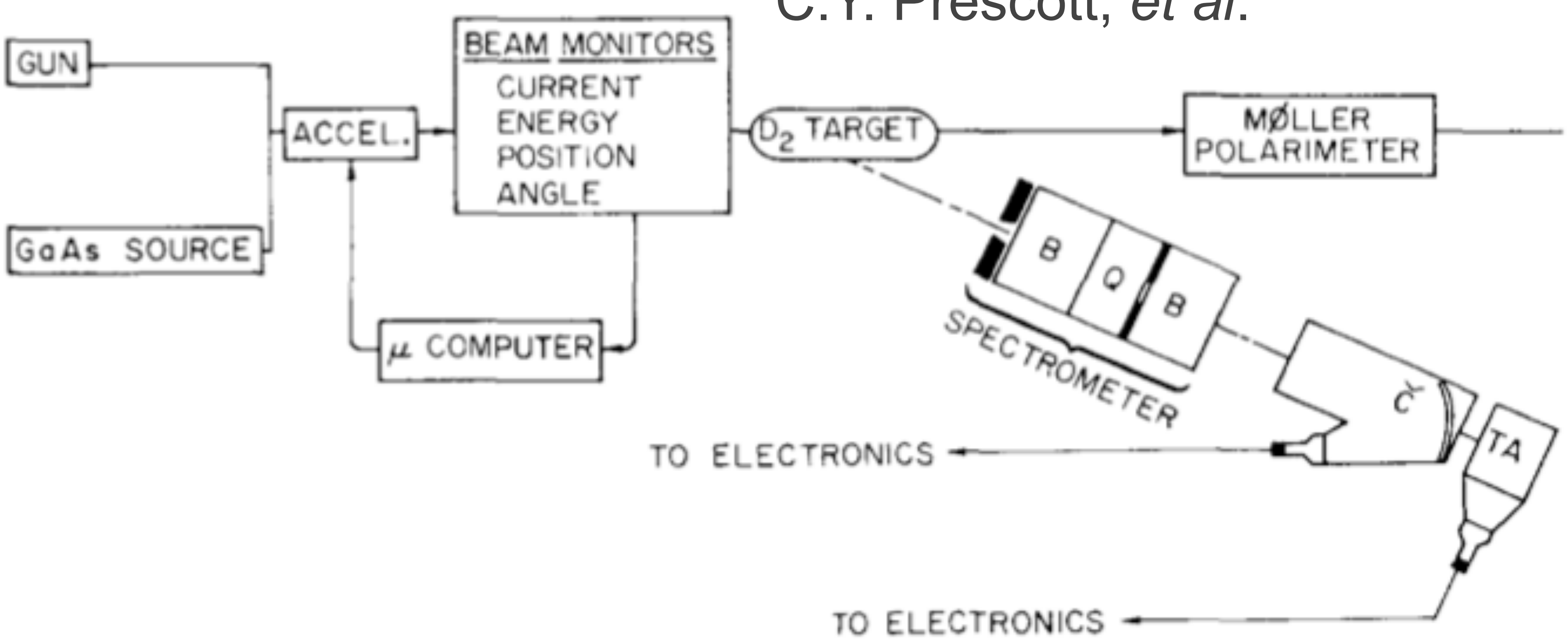


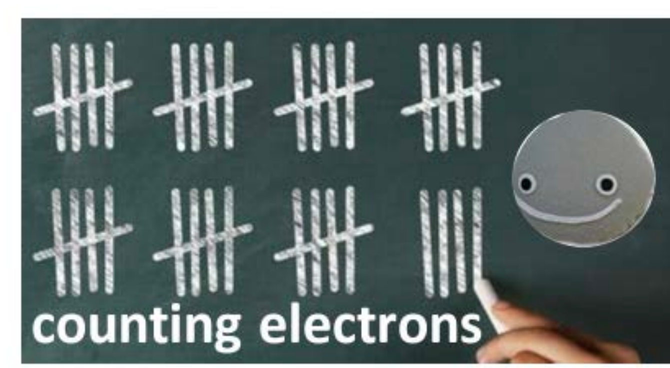
..so where is hell?



$$A_{PV} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_+ - \left(\frac{d\sigma}{d\Omega}\right)_-}{\left(\frac{d\sigma}{d\Omega}\right)_+ + \left(\frac{d\sigma}{d\Omega}\right)_-}$$

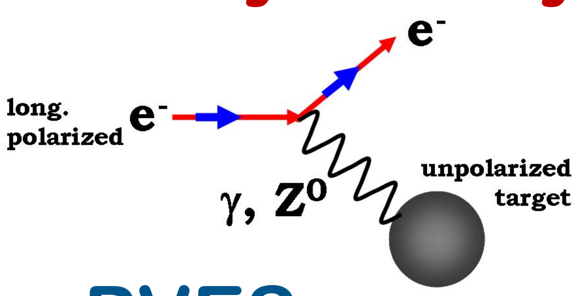
C.Y. Prescott, *et al.*





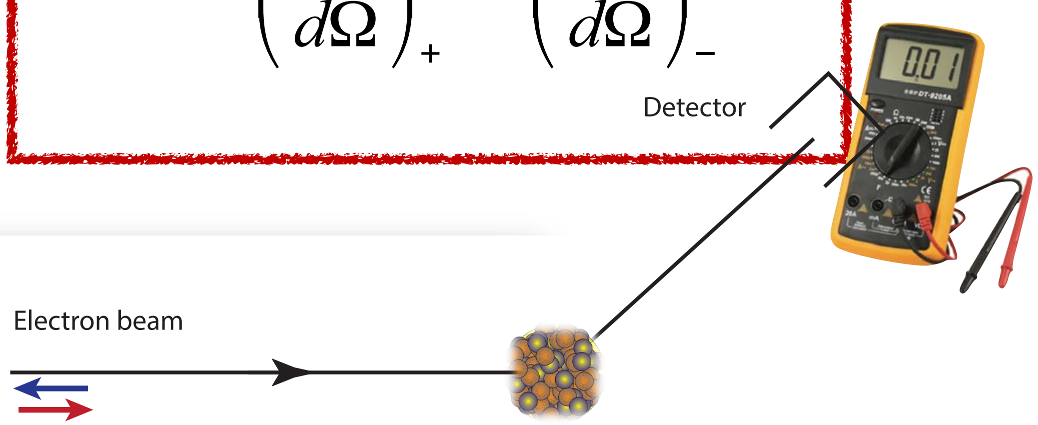
Welcome to Hell!

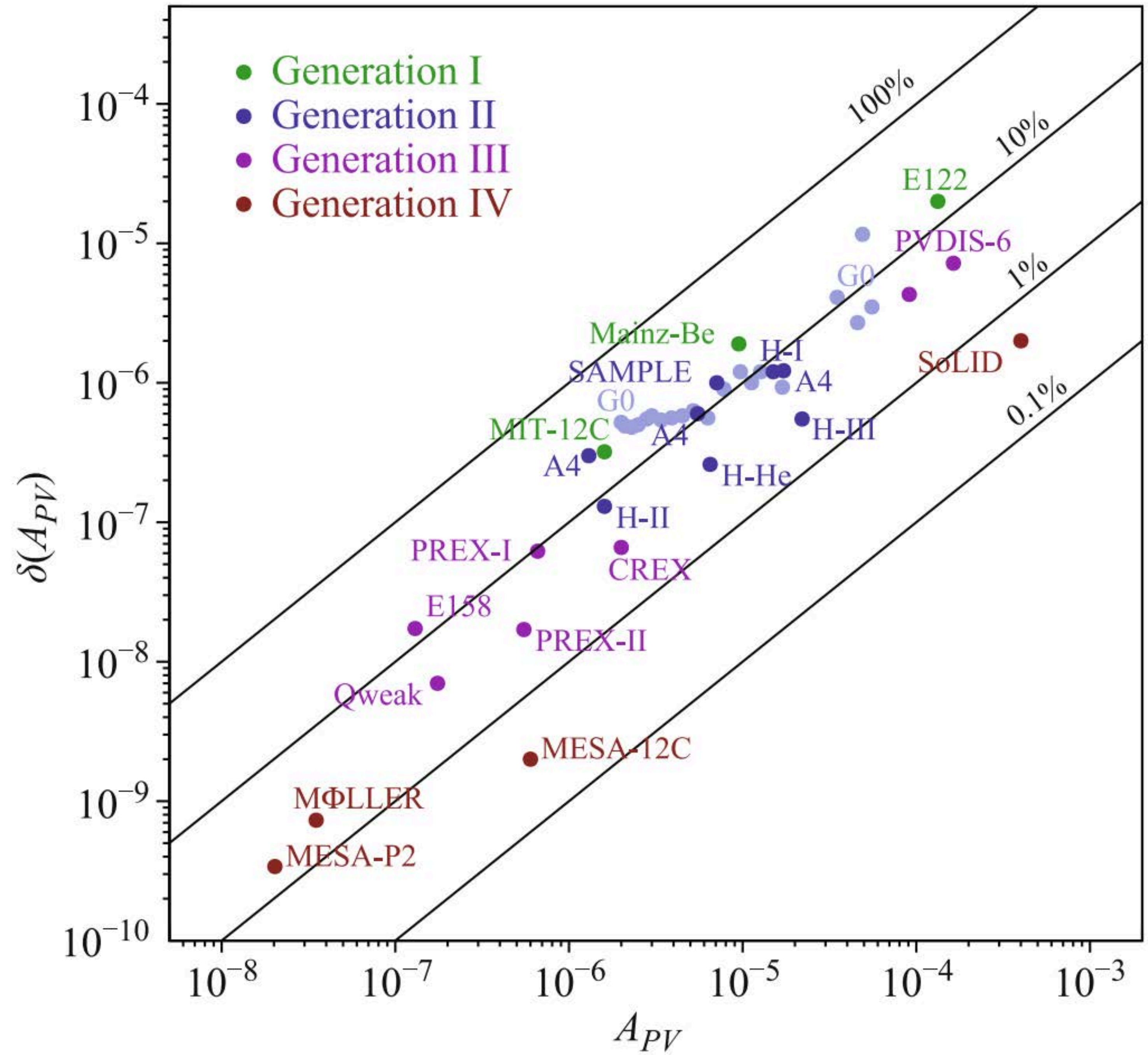
PV-Asymmetry



PVES

$$A_{PV} = \frac{\left(\frac{d\sigma}{d\Omega}\right)_+ - \left(\frac{d\sigma}{d\Omega}\right)_-}{\left(\frac{d\sigma}{d\Omega}\right)_+ + \left(\frac{d\sigma}{d\Omega}\right)_-} \approx$$

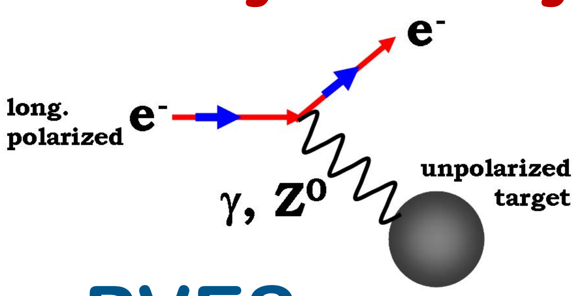




P. Souder and K. Paschke, Front. Phys. 11(1), 111301 (2016)

Welcome to Hell!

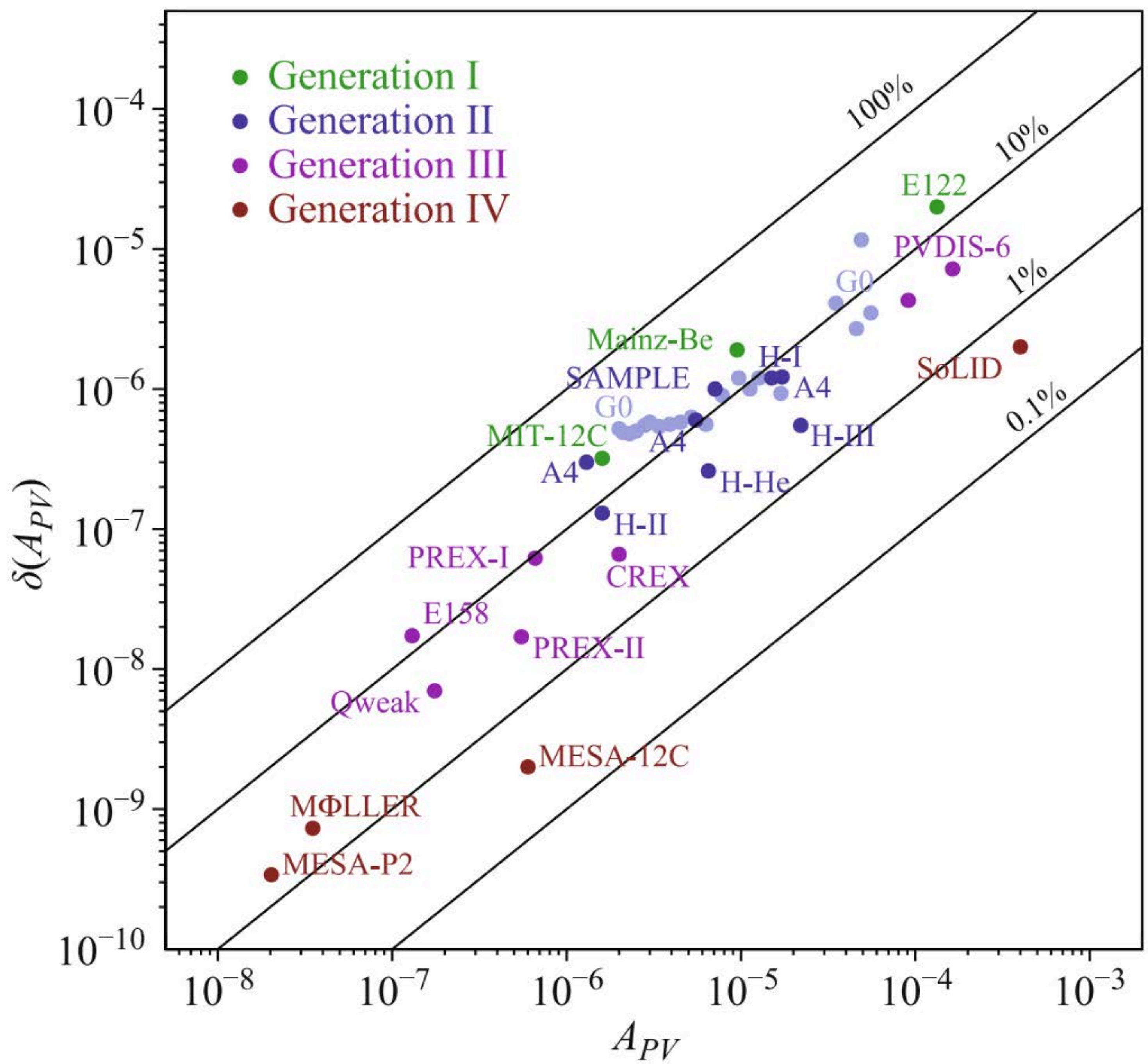
PV-Asymmetry



PVES

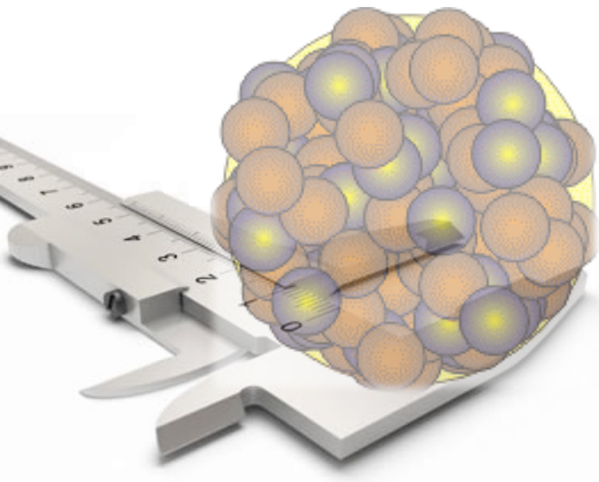
- Essentially means 1.5% on A_{PV}
- A_{PV} is 40 parts per billion
- $\delta(A_{PV})$ is 0.6 parts per billion

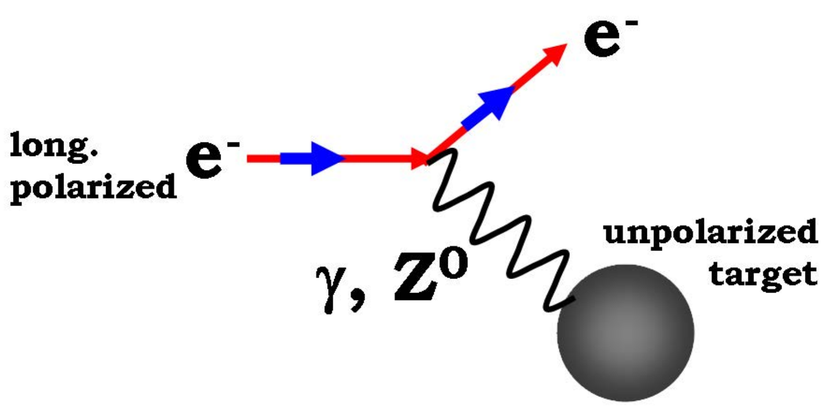
$$\delta(A_{PV}) \propto \frac{1}{\sqrt{N}}$$



P. Souder and K. Paschke, Front. Phys. 11(1), 111301 (2016)

Welcome to Hell!



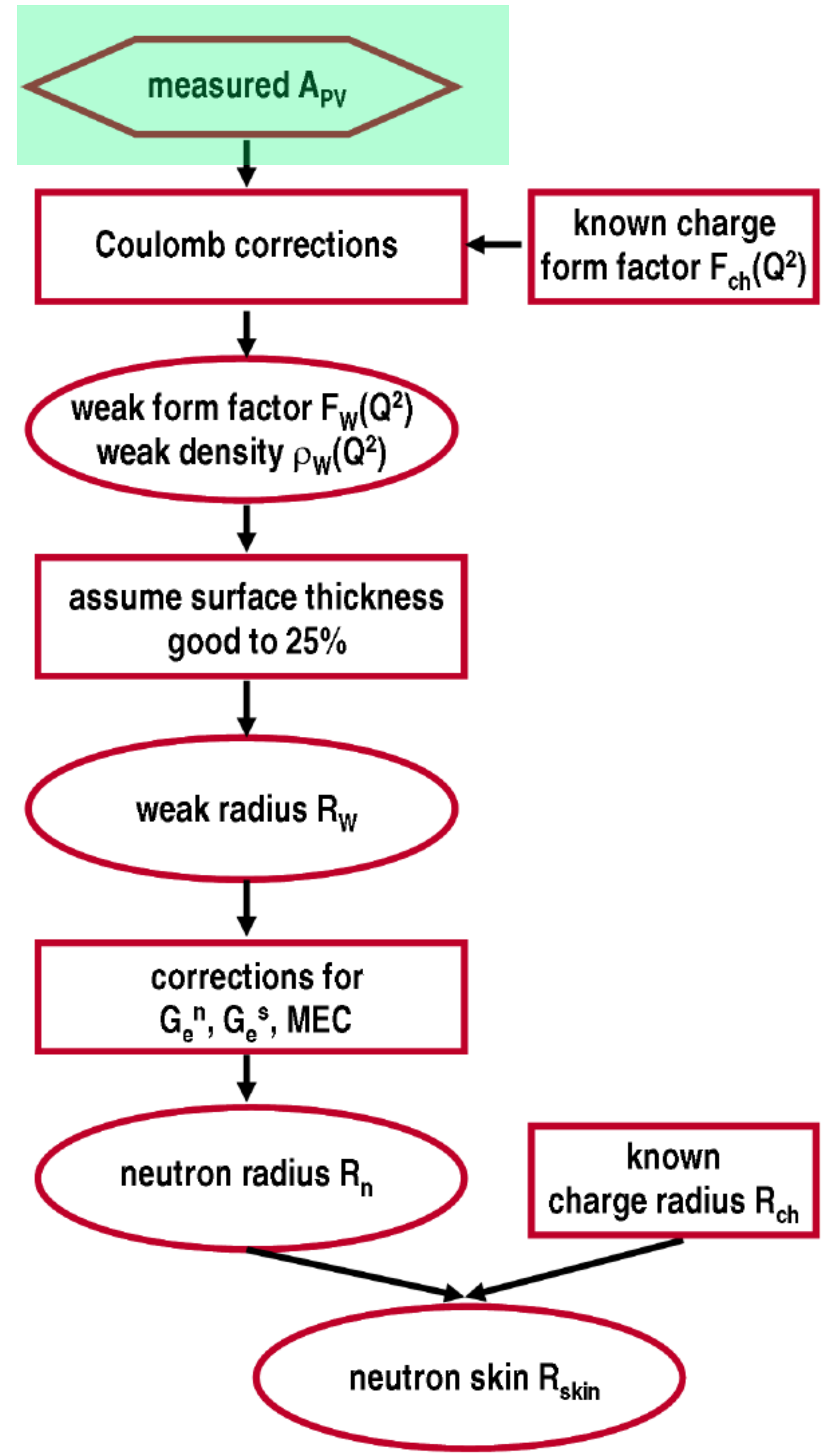


$$\delta(A_{PV}) \propto \frac{1}{\sqrt{N}}$$

…. need a few $N=10^{18}$ e^-

… close to 10^{11} electrons/s

…but statistics is not everything! 😱



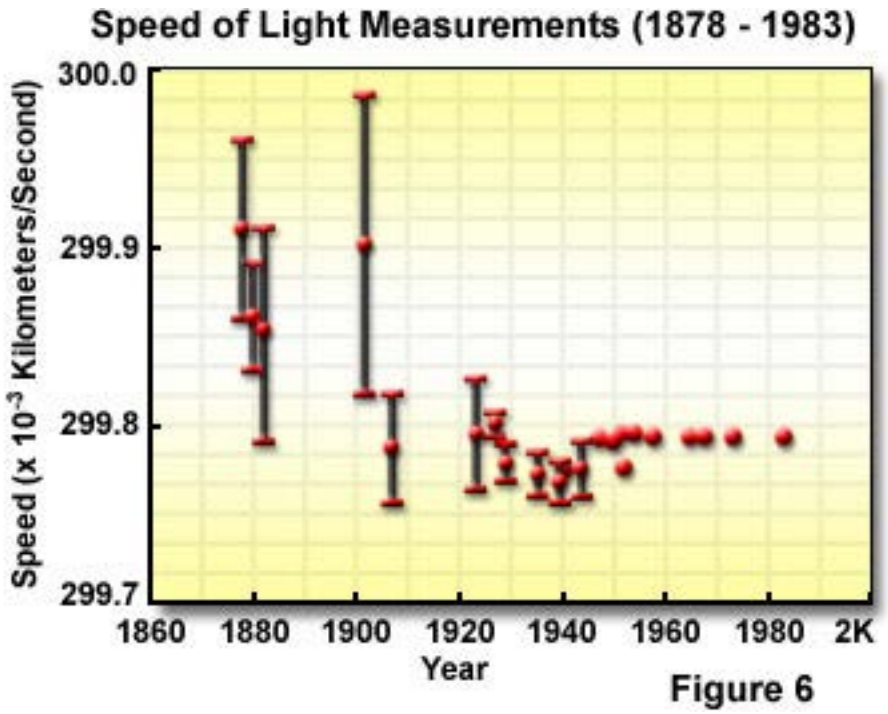
…if you are going through hell keep going!

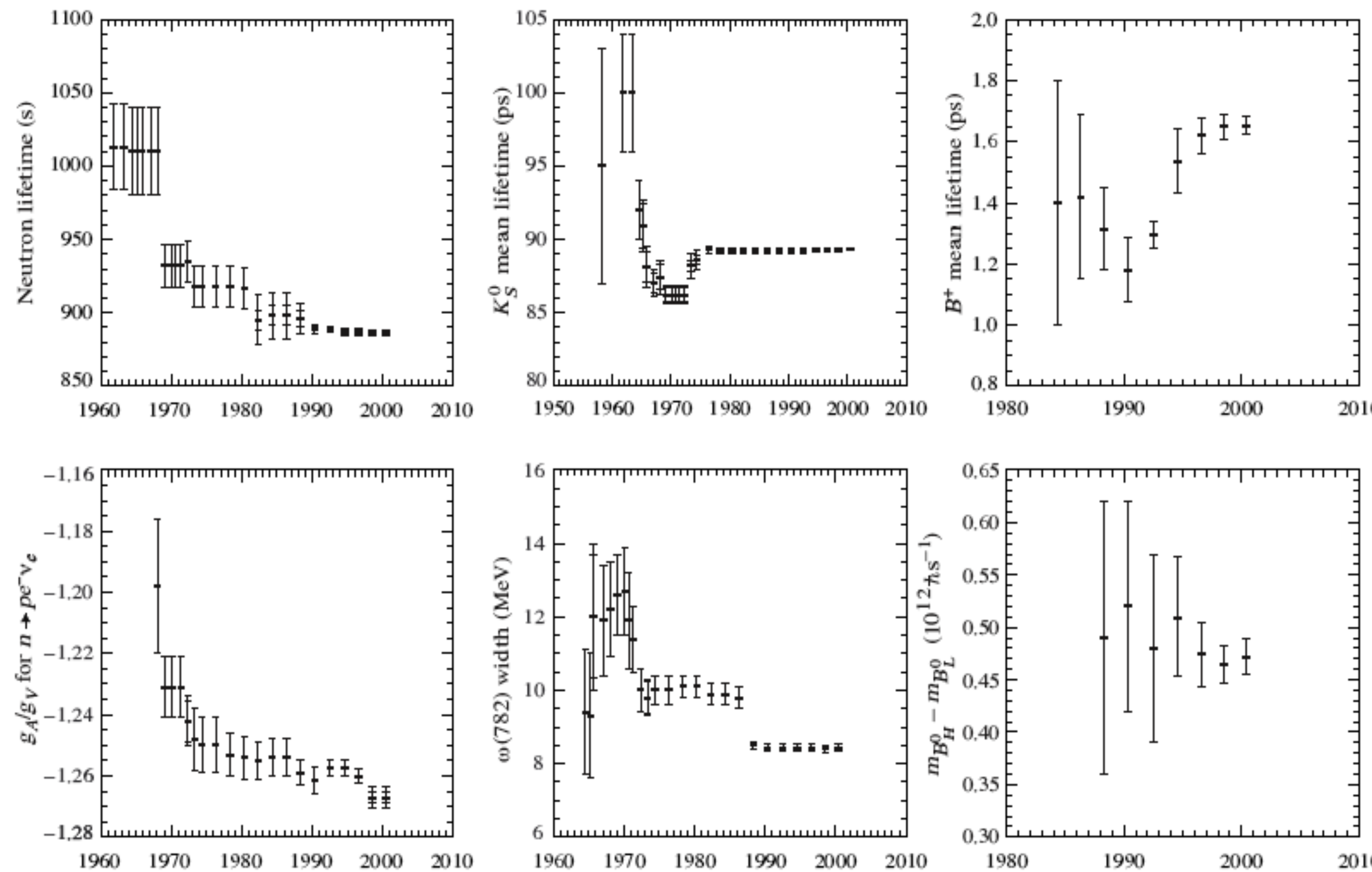
Blinding factors

↓

Raw Asymmetries (A_{meas})

Have you blinded your analyst?





Just a coincidence that there are several measurements in a row that have close to the same central values? Even with such large uncertainties?

Credit: D. Armstrong

Armstrongs' criterion: when to blind

Blinding is a good idea* for any analysis in which:

a) there is judgment involved -eg.setting cuts, choosing data sets, deciding on background subtraction techniques, which polarimeter to trust, linear regression vs. beam modulation, Q_2ambiguities, GEANT 3 vs GEANT 4 radiative corrections, *etc.*

and

b) there is an "expected" answer, eg.from precise previous experiments or theoretical prediction –eg.....ALWAYS!

*translation: *absolutely flipping essential*

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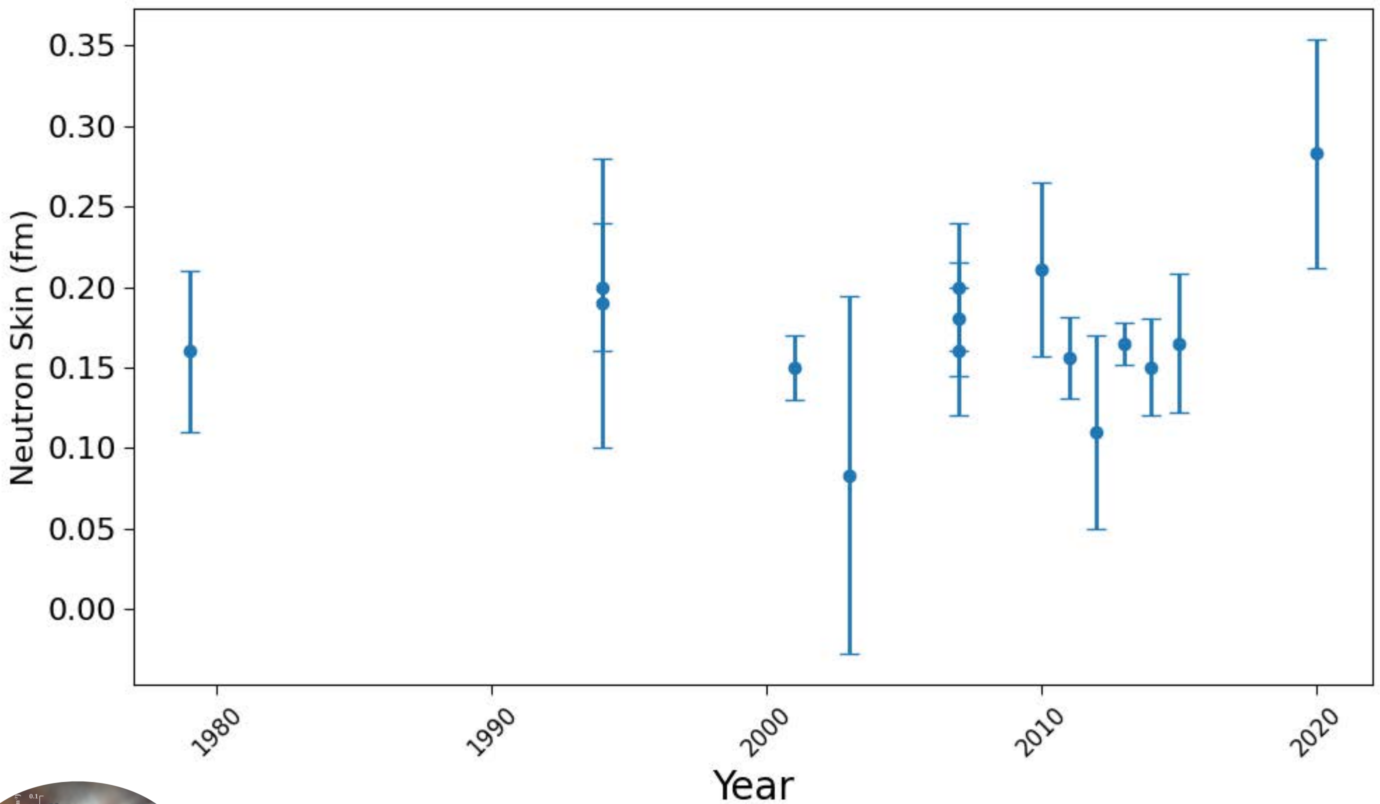
and

b) there is an "expected" answer, eg.from precise previous experiments or theoretical prediction –eg…..ALWAYS!

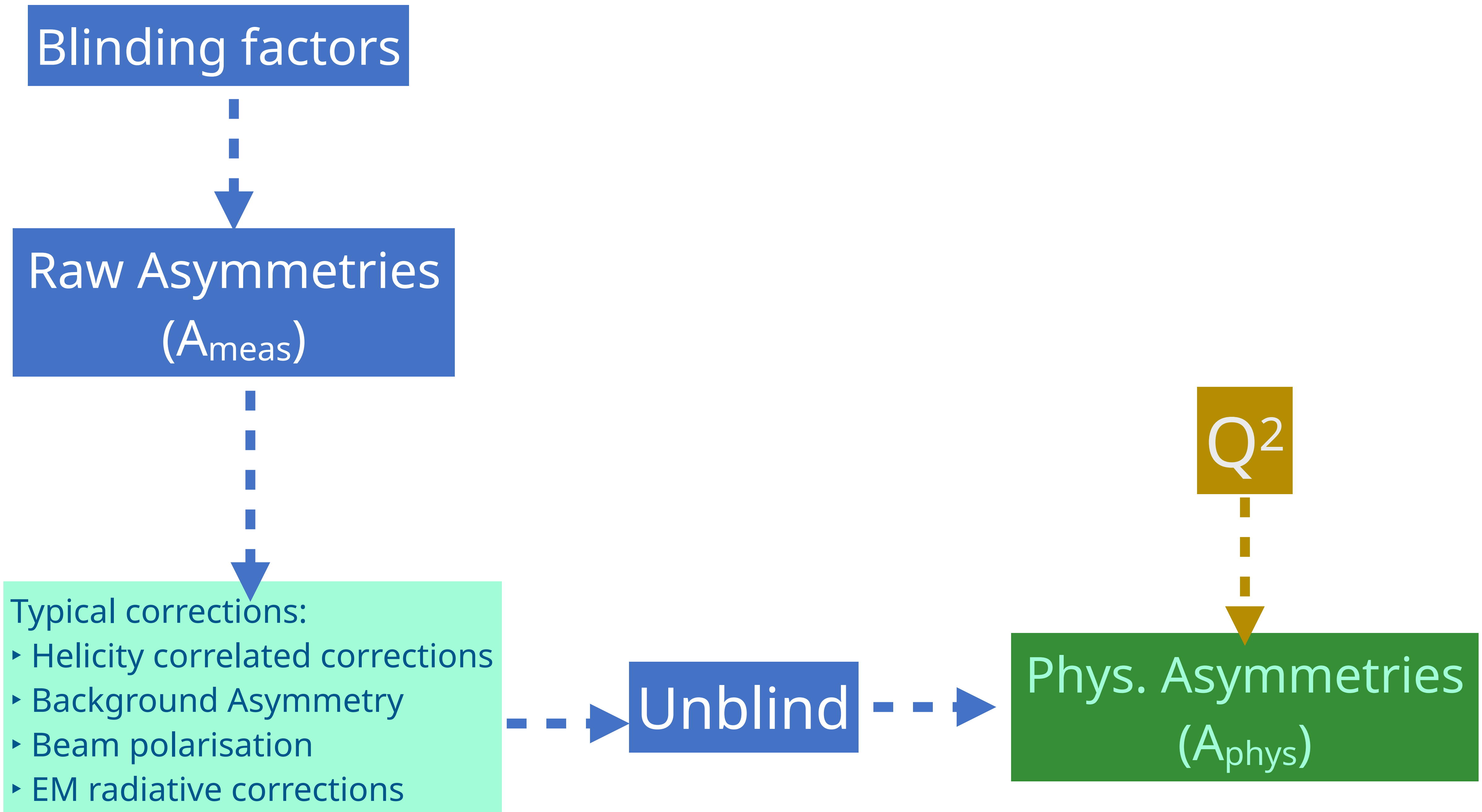
*translation: *absolutely flipping essential*

F. Sammarucca Symmetry 2024, 16(1), 34

Type of Measurement	Extracted Neutron Skin in ^{208}Pb
Proton-nucleus scattering [4]	0.083 − 0.111
Proton-nucleus scattering [5]	$0.211^{+0.054}_{-0.063}$
Proton-nucleus scattering [6]	0.20 ± 0.04
Proton-nucleus scattering [7]	
Polarized proton-nucleus scattering [8]	0.16 ± 0.05
Polarized proton-nucleus scattering [9]	
Polarized proton-nucleus scattering [5]	$0.211^{+0.054}_{-0.063}$
Pionic probes [10]	0.11 ± 0.06
Pionic probes [11]	
Coherent π photoproduction [12]	$0.15 \pm 0.03^{+0.01}_{-0.03}$
Coherent π photoproduction [13]	$0.20^{+0.01}_{-0.03}$
Antiprotonic atoms [14]	0.20 (±0.04) (±0.05)
Antiprotonic atoms [15]	0.16 (± 0.02) (±0.04)
Antiprotonic atoms [16]	0.15 ± 0.02
Electric dipole polarizability [17]	0.13 − 0.19
Electric dipole polarizability [18]	0.165 (±0.09) (±0.013) (±0.021)
Electric dipole polarizability *via* polarized scattering at forward angle [19]	$0.156^{+0.025}_{-0.021}$
Electric dipole polarizability [20]	
Pygmy dipole resonances [21]	0.18 ± 0.035
Interaction cross sections [22]	
(α, α') GDR 120 MeV [23]	0.19 ± 0.09
α-particle scattering [24]	



…if you are going through hell keep going!



…if you are going through hell keep going!

Blinding factors

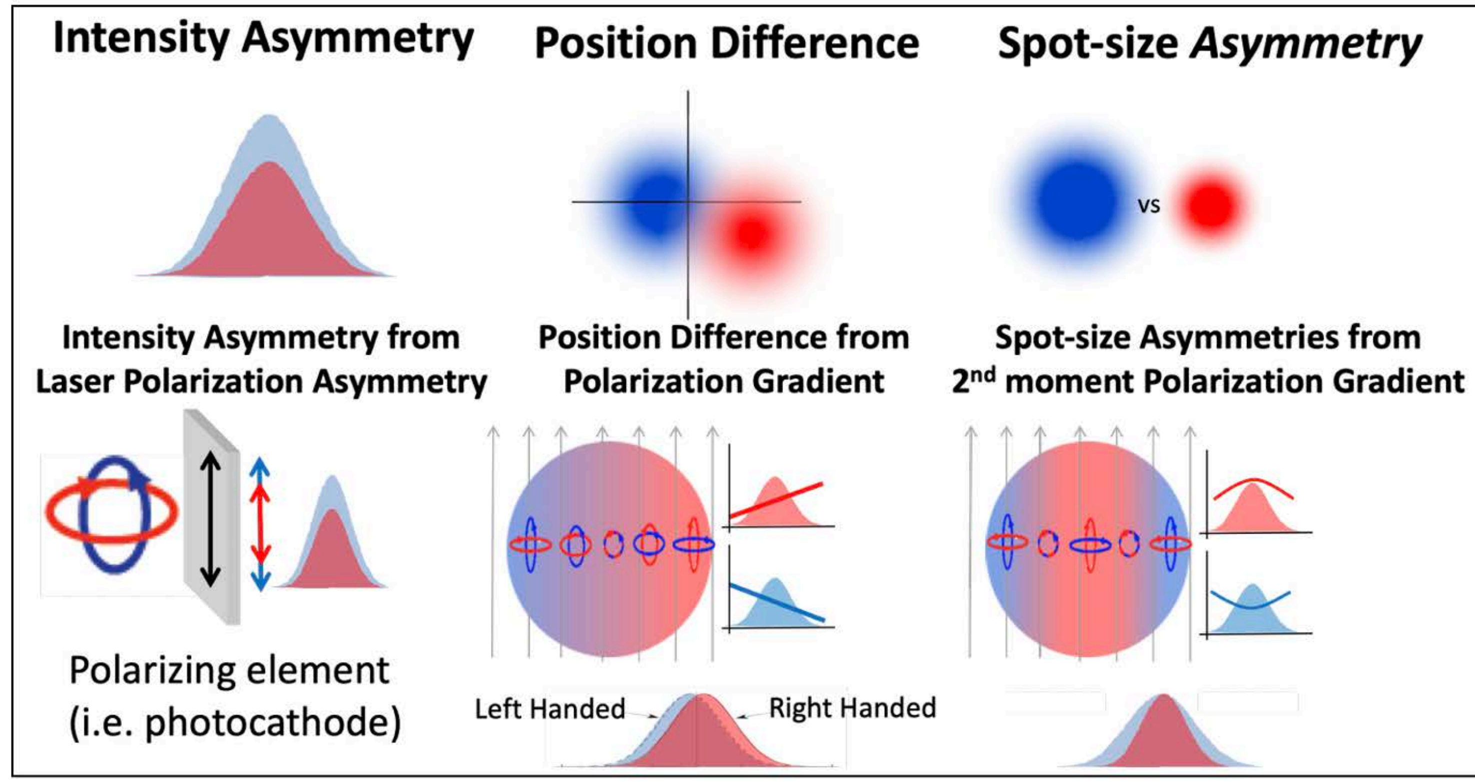
Raw Asymmetries (A_{meas})

Typical corrections:
- **Helicity correlated corrections**
- Background Asymmetry
- Beam polarisation
- EM radiative corrections

Unblind

Phys. Asymmetries (A_{phys})

Electron Beam Asymmetries arise from Laser Beam Asymmetries



Data analysis

Blinding factors

Raw Asymmetries
(A_{meas})

$$A_{corr} = A_{det} - A_{beam} - A_{trans} - A_{nonlin} - A_{blind}$$

$$A_{phys} = R_{radcorr}\, R_{accept}\, R_{Q^2} \frac{A_{corr} - P_L \sum_i f_i A_i}{P_L(1 - \sum_i f_i)}$$

Q^2

Typical corrections:

- Helicity correlated corrections
- Background Asymmetry
- Beam polarisation
- EM radiative corrections

Unblind

Phys. Asymmetries
(A_{phys})

The art of being consistently wrong

$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{Q_W}{A} \cdot \frac{F_W(Q^2)}{F_{ch}(Q^2)}$$

→

$$\frac{\Delta F_W}{F_W} = \sqrt{\left(\frac{\Delta A_{PV}}{A_{PV}}\right)^2 + \left(\frac{\Delta Q^2}{Q^2}\right)^2 + \left(\frac{\Delta Q_W}{Q_W}\right)^2 + \left(\frac{\Delta F_{ch}}{F_{ch}}\right)^2}$$

The art of being consistently wrong

$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{Q_W}{A} \cdot \frac{F_W(Q^2)}{F_{ch}(Q^2)} \longrightarrow \frac{\Delta F_W}{F_W} = \sqrt{\left(\frac{\Delta A_{PV}}{A_{PV}}\right)^2 + \left(\frac{\Delta Q^2}{Q^2}\right)^2 + \left(\frac{\Delta Q_W}{Q_W}\right)^2 + \left(\frac{\Delta F_{ch}}{F_{ch}}\right)^2}$$

$$A_{corr} = A_{det} - A_{beam} - A_{trans} - A_{nonlin} - A_{blind}$$

$$A_{phys} = R_{radcorr}\, R_{accept}\, R_{Q^2} \frac{A_{corr} - P_L \sum_i f_i A_i}{P_L (1 - \sum_i f_i)}$$

Systematic Error	Absolute (ppm)	Relative (%)
Polarization	0.0083	1.3
Detector Linearity	0.0076	1.2
Beam current normalization	0.0015	0.2
Rescattering	0.0001	0
Transverse Polarization	0.0012	0.2
Q^2	0.0028	0.4
Target Backing	0.0026	0.4
Inelastic States	0	0
TOTAL	0.0140	2.1

The art of being consistently wrong

$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{Q_W}{A} \cdot \frac{F_W(Q^2)}{F_{ch}(Q^2)} \longrightarrow \frac{\Delta F_W}{F_W} = \sqrt{\left(\frac{\Delta A_{PV}}{A_{PV}}\right)^2 + \left(\frac{\Delta Q^2}{Q^2}\right)^2 + \left(\frac{\Delta Q_W}{Q_W}\right)^2 + \left(\frac{\Delta F_{ch}}{F_{ch}}\right)^2}$$

$$A_{corr} = A_{det} - A_{beam} - A_{trans} - A_{nonlin} - A_{blind}$$

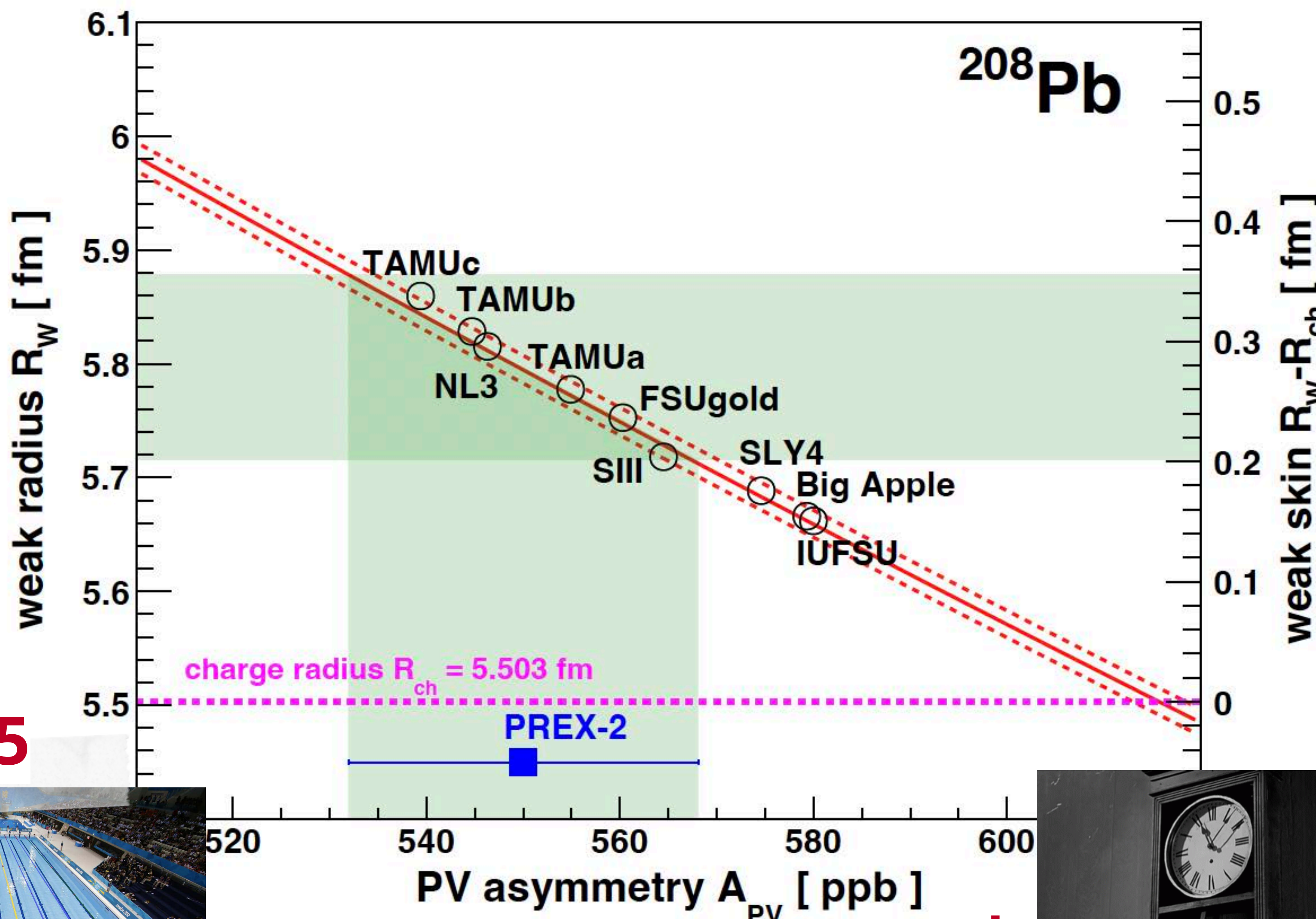
$$A_{phys} = R_{radcorr}\, R_{accept}\, R_{Q^2} \frac{A_{corr} - P_L \sum_i f_i A_i}{P_L (1 - \sum_i f_i)}$$

$$-q^2 = Q^2 = 4EE'\sin^2\left(\frac{\theta_e}{2}\right) = \frac{4E^2 \sin^2 \frac{\theta_e}{2}}{1 + \frac{2E}{M_N}\sin^2\frac{\theta_e}{2}}$$

Systematic Error	Absolute (ppm)	Relative (%)
Polarization	0.0083	1.3
Detector Linearity	0.0076	1.2
Beam current normalization	0.0015	0.2
Rescattering	0.0001	0
Transverse Polarization	0.0012	0.2
Q^2	0.0028	0.4
Target Backing	0.0026	0.4
Inelastic States	0	0
TOTAL	0.0140	2.1

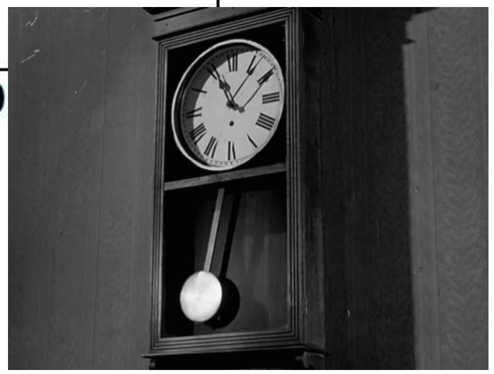
The shortest road …

$$A_{PV} = \frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \cdot \frac{Q_W}{A} \cdot \frac{F_W(Q^2)}{F_{ch}(Q^2)} \longrightarrow \frac{\Delta F_W}{F_W} = \sqrt{\left(\frac{\Delta A_{PV}}{A_{PV}}\right)^2 + \left(\frac{\Delta Q^2}{Q^2}\right)^2 + \left(\frac{\Delta Q_W}{Q_W}\right)^2 + \left(\frac{\Delta F_{ch}}{F_{ch}}\right)^2}$$

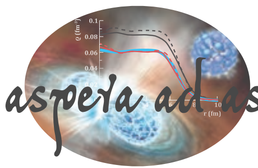


0.5

± 20

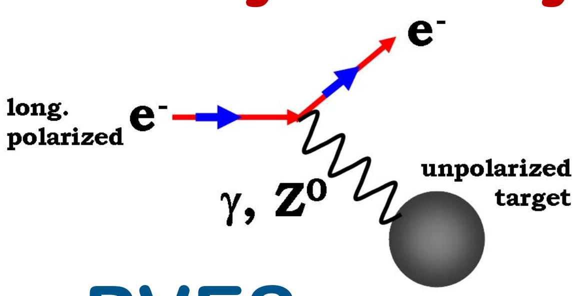


… per aspera ad astra …



Welcome to Hell!

PV-Asymmetry

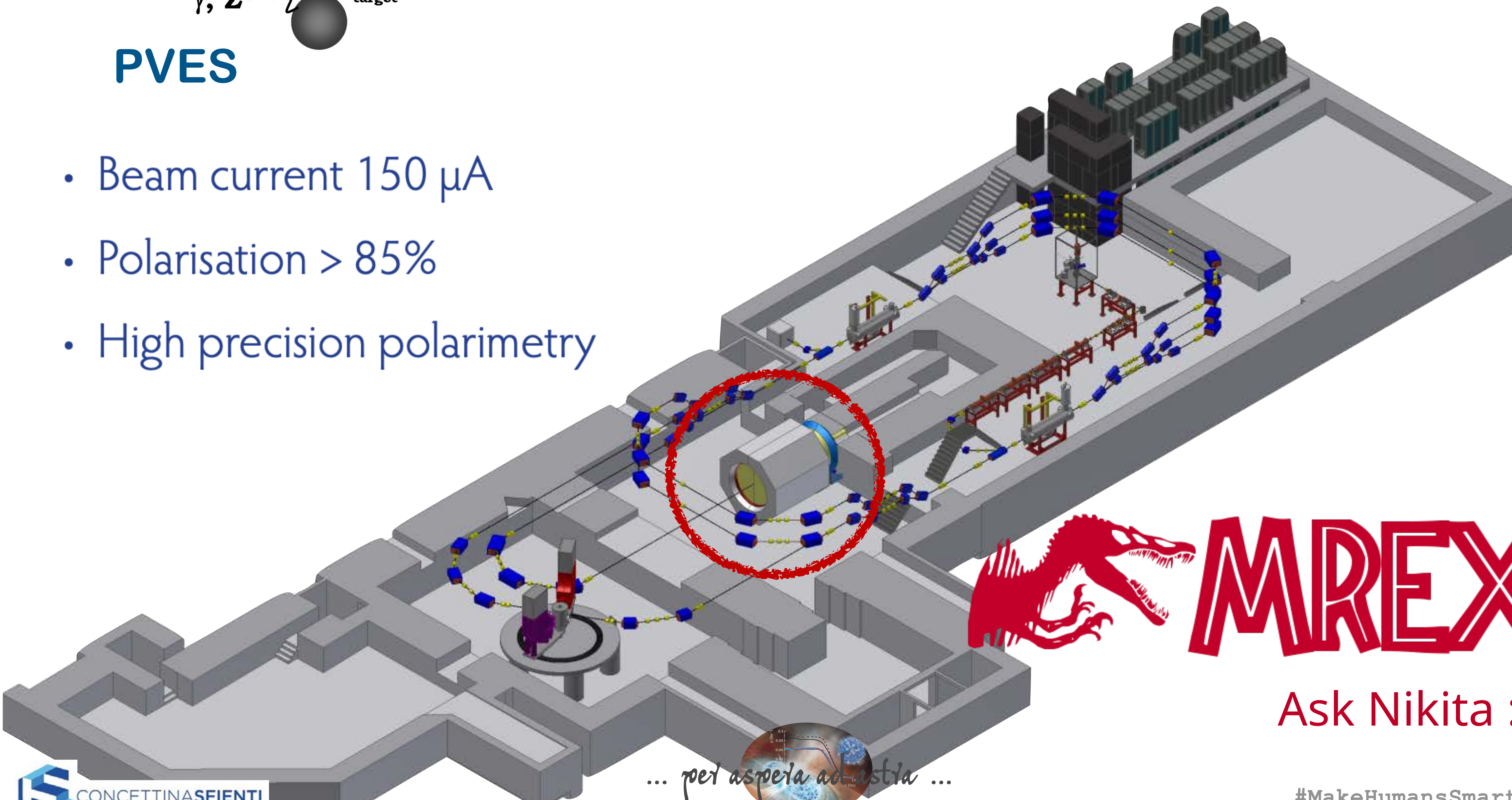


PVES

.... need a few $N=10^{18}$ electrons!

... close to 10^{11} electrons/s

- Beam current 150 μA
- Polarisation > 85%
- High precision polarimetry



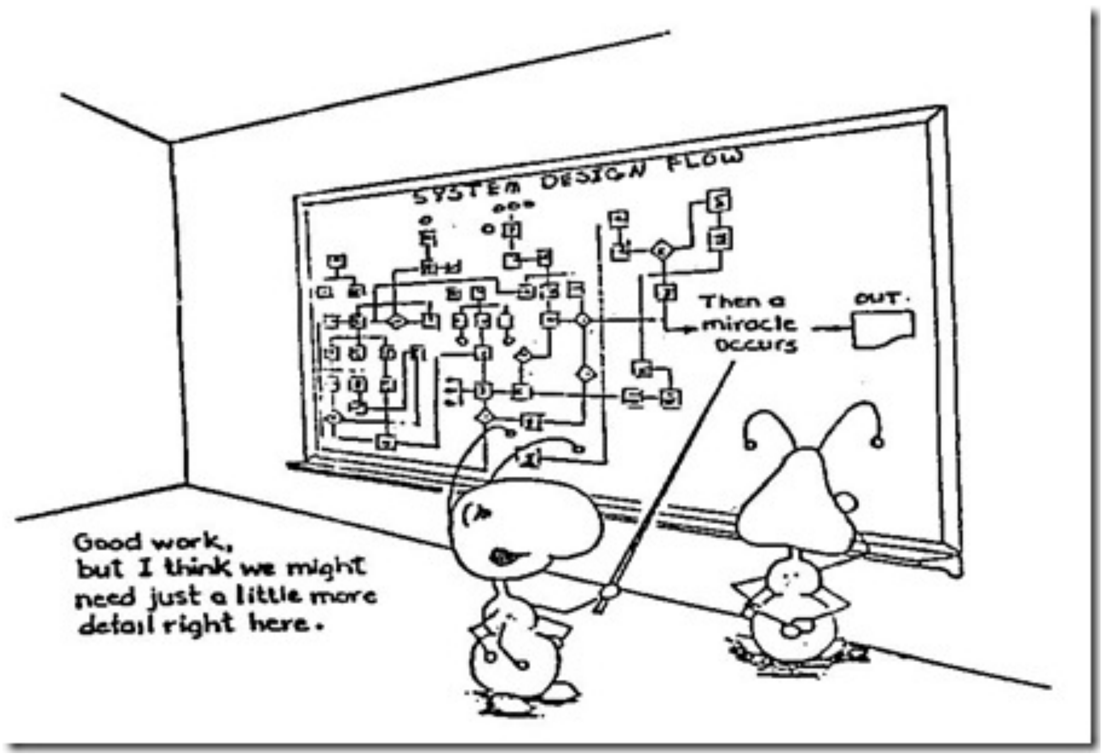
MREX

Ask Nikita :-)

Exercise nr. 1
(let's walk down the highway to hell)

- Proton scattering J. Zenihiro et al. Phys. Rev. C **82**, 044611
- Dipole polarisability A. Tamii et al., Phys. Rev. Lett. **107**, 062502
- Coherent pi0 C.M.Tabert et al. Phys. Rev. Lett. **112**, 242502
- Antiprotonic atoms: A. Trzcinska et al. Phys. Rev. Lett. **87**, 082501
- Heavy Ion collisions G. Giancalone et al. Phys. Rev. Lett. **131**, 202302

- **Step 1: Create a Flow Diagram: Create a flow diagram of the analysis procedure.**



(*) this is not an acceptable flow diagram!

Exercise nr. 1
(let's walk down the highway to hell)

- Proton scattering J. Zenihiro et al. Phys. Rev. C **82**, 044611
- Dipole polarisability A. Tamii et al., Phys. Rev. Lett. **107**, 062502
- Coherent pi0 C.M.Tabert et al. Phys. Rev. Lett. **112**, 242502
- Antiprotonic atoms: A. Trzcinska et al. Phys. Rev. Lett. **87**, 082501
- Heavy Ion collisions G. Giancalone et al. Phys. Rev. Lett. **131**, 202302

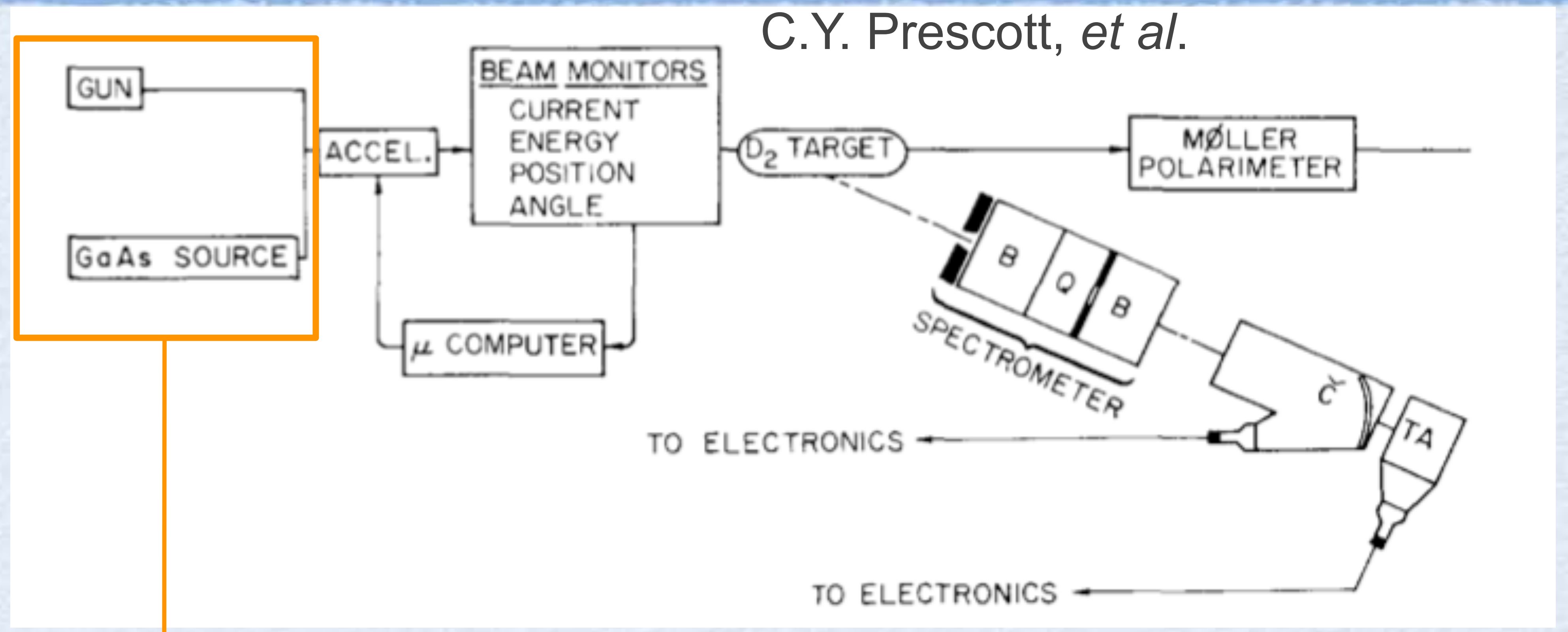
- **Step 1: Create a Flow Diagram: Create a flow diagram of the analysis procedure.**
- **Step 2: Identify Error Sources: For each step, identify potential sources of uncertainty.**
- **Step 3: Quantify Uncertainties: Assign (when possible) numerical values to each source of uncertainty.**

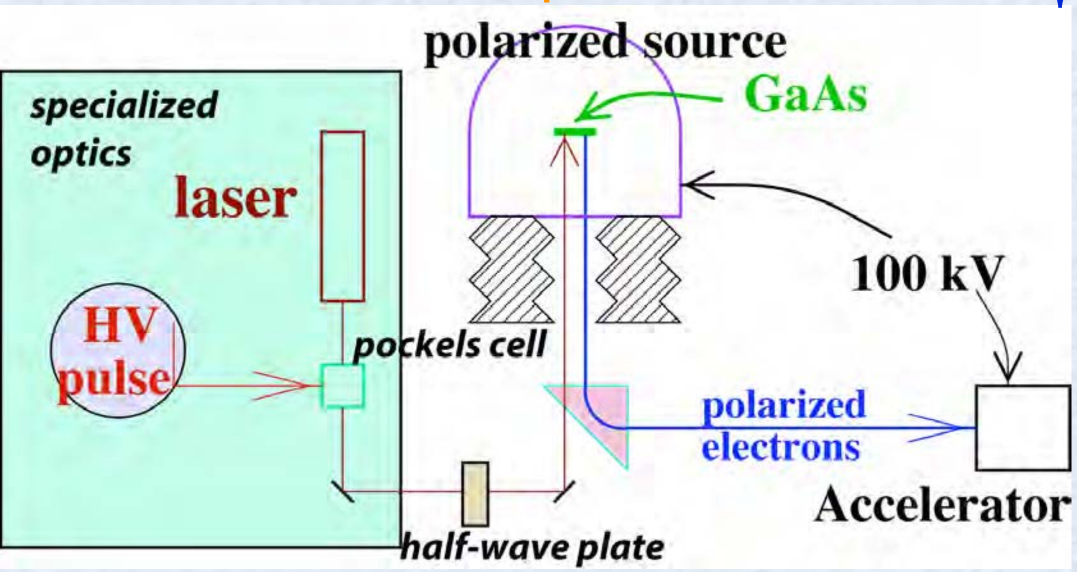
Discussion
(let's walk down the highway to hell)

Anatomy of a Parity Experiment

The E122 Experiment at the Stanford Linear Accelerator Center

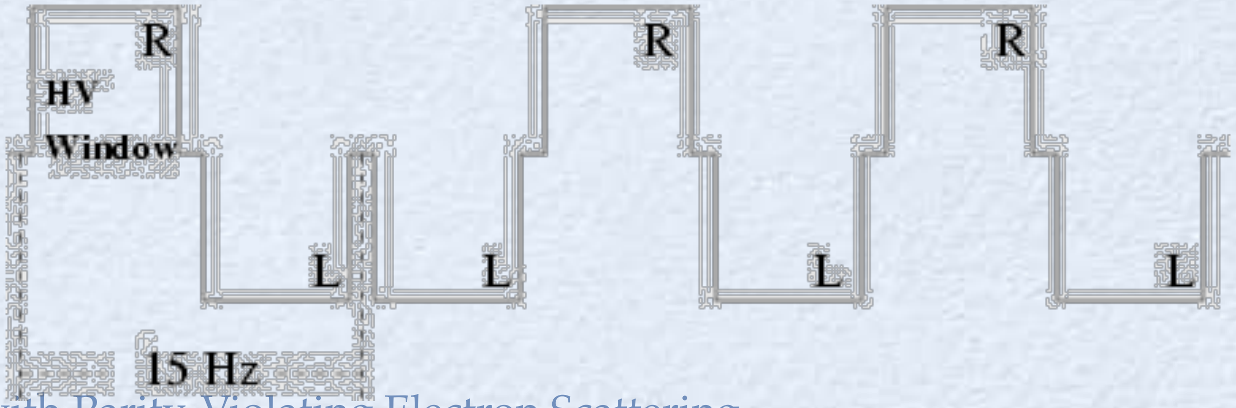
C.Y. Prescott, *et al.*





✧ **Beam helicity sequence is chosen pseudo-randomly**

- Helicity state, followed by its complement
- Data analyzed as "pulse-pairs"



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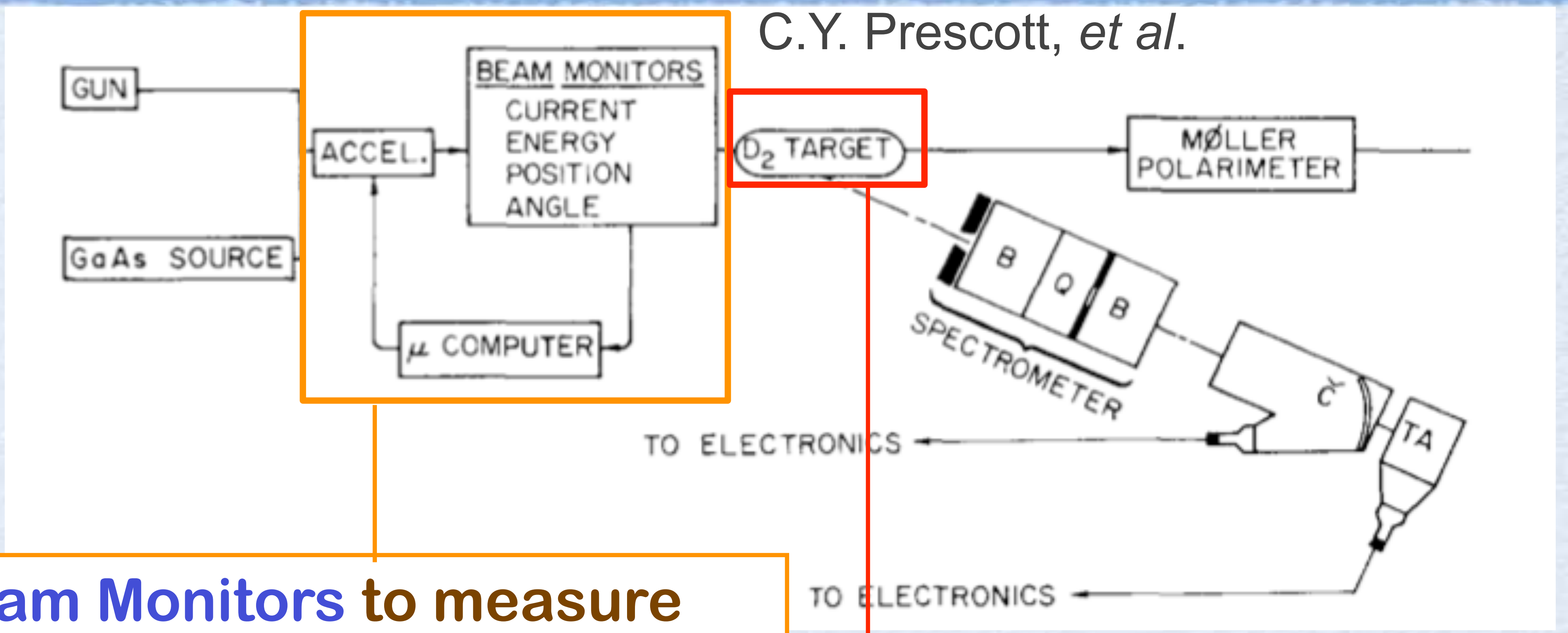

- **Beam Monitors** to measure helicity-correlated changes in beam parameters

- **High-power cryotarget** 30 cm long for high luminosity

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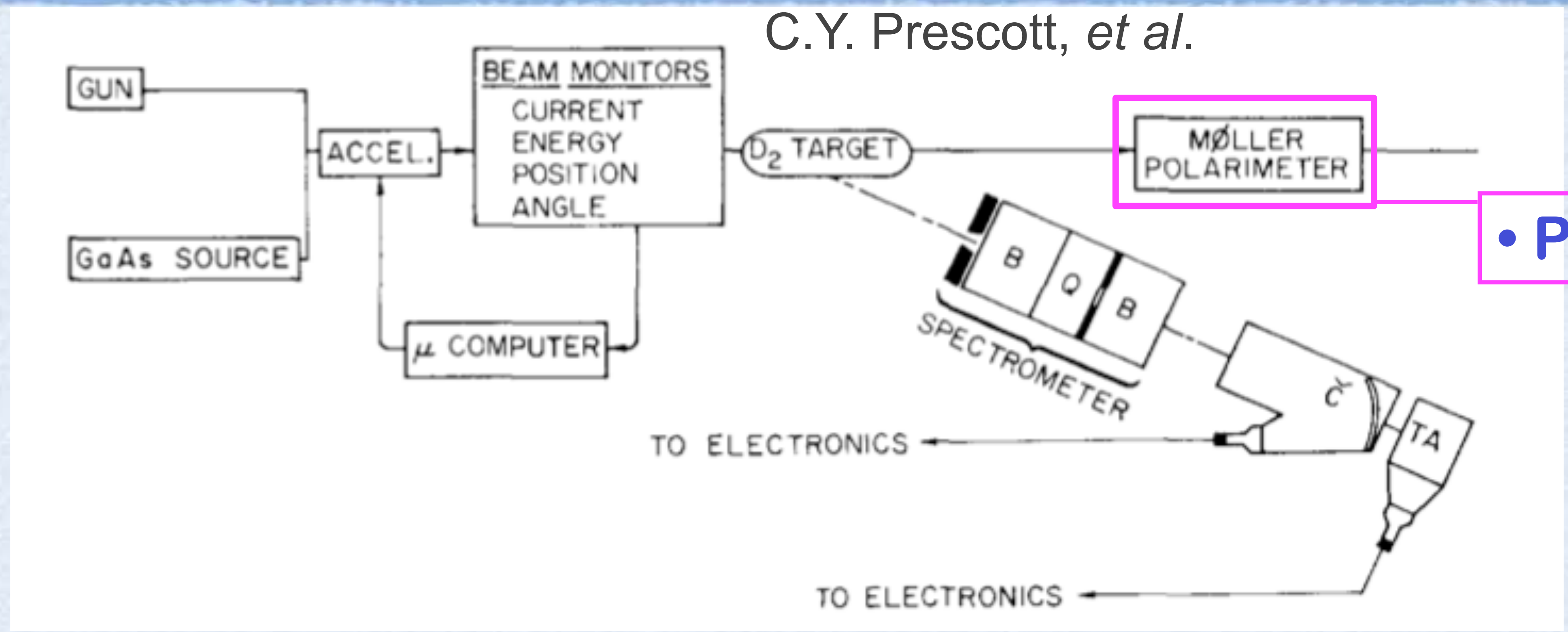

- **Polarimetry**

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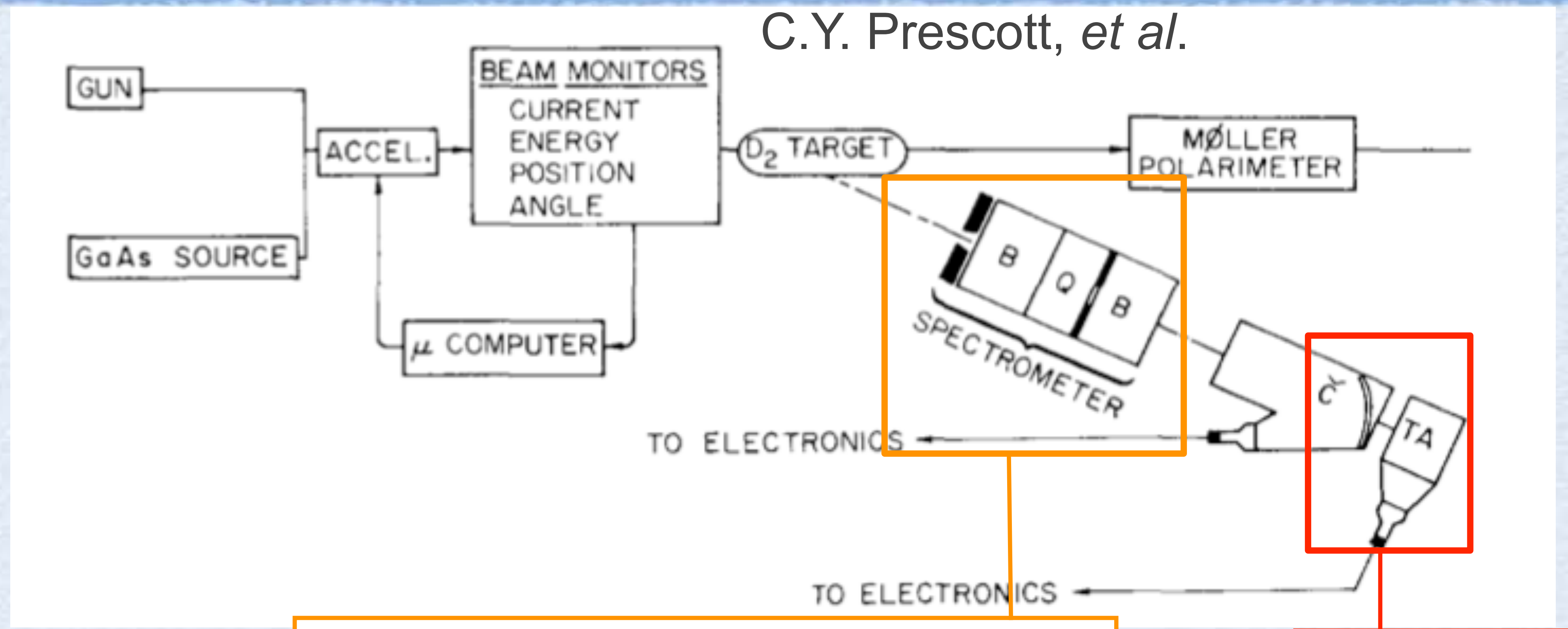

- **Magnetic spectrometer** directs flux to background-free region

- **Flux Integration** measures high rate without deadtime