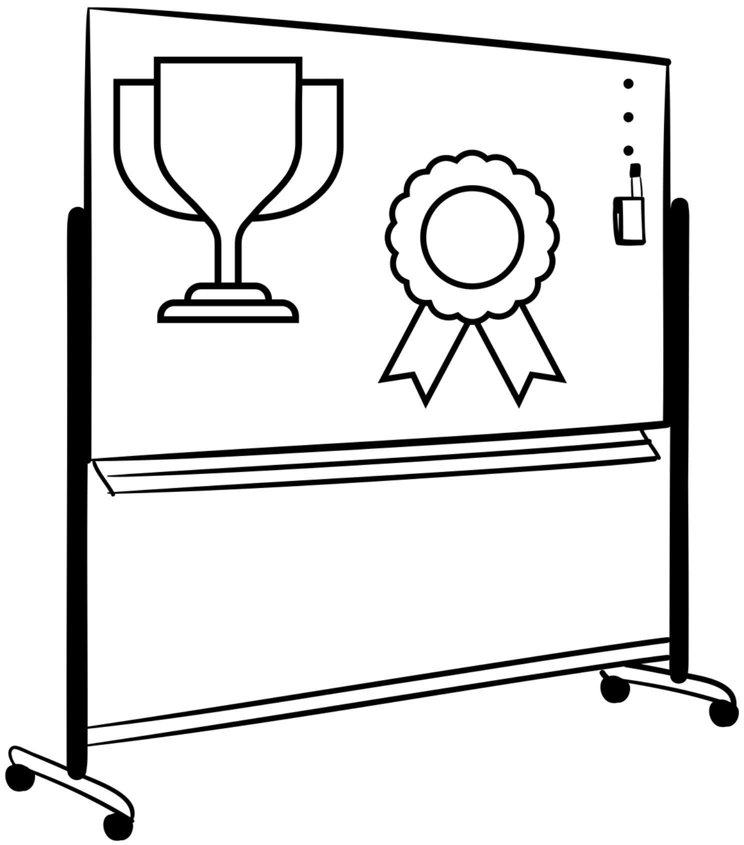
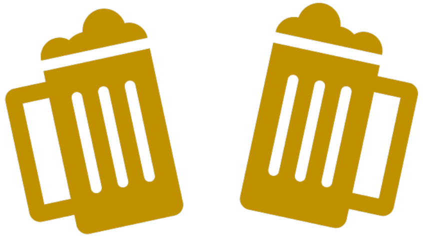
Poster Jamboree session

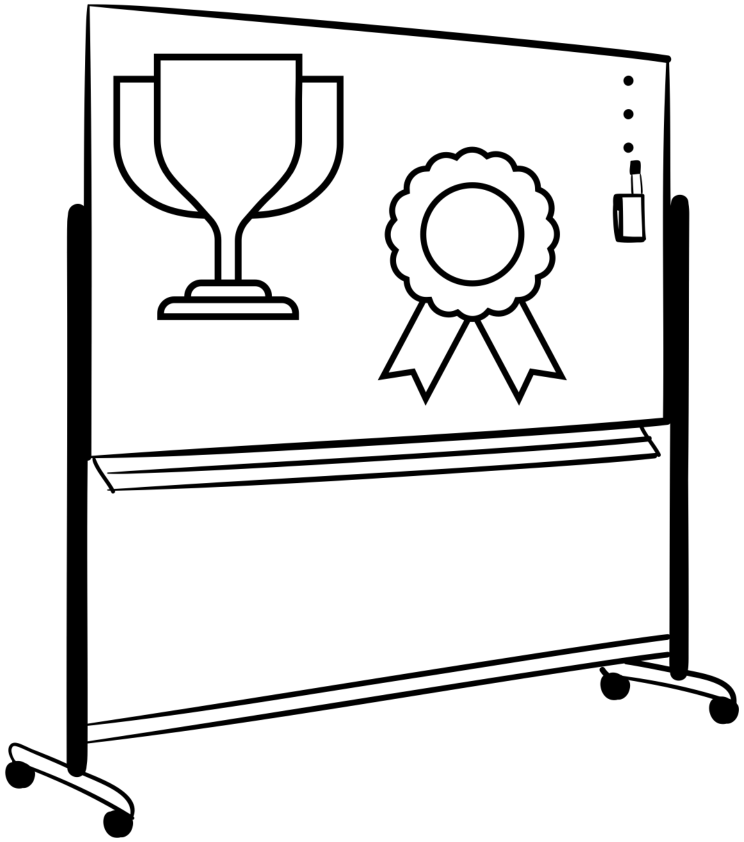
Poster Jamboree session



- We have 20 contributions on many different topics!
- Each student will deliver a 3 minutes "elevator pitch" talk.
- After we will move to the poster session with **beer, appetizers and lots of time to discuss!**



Poster Jamboree session

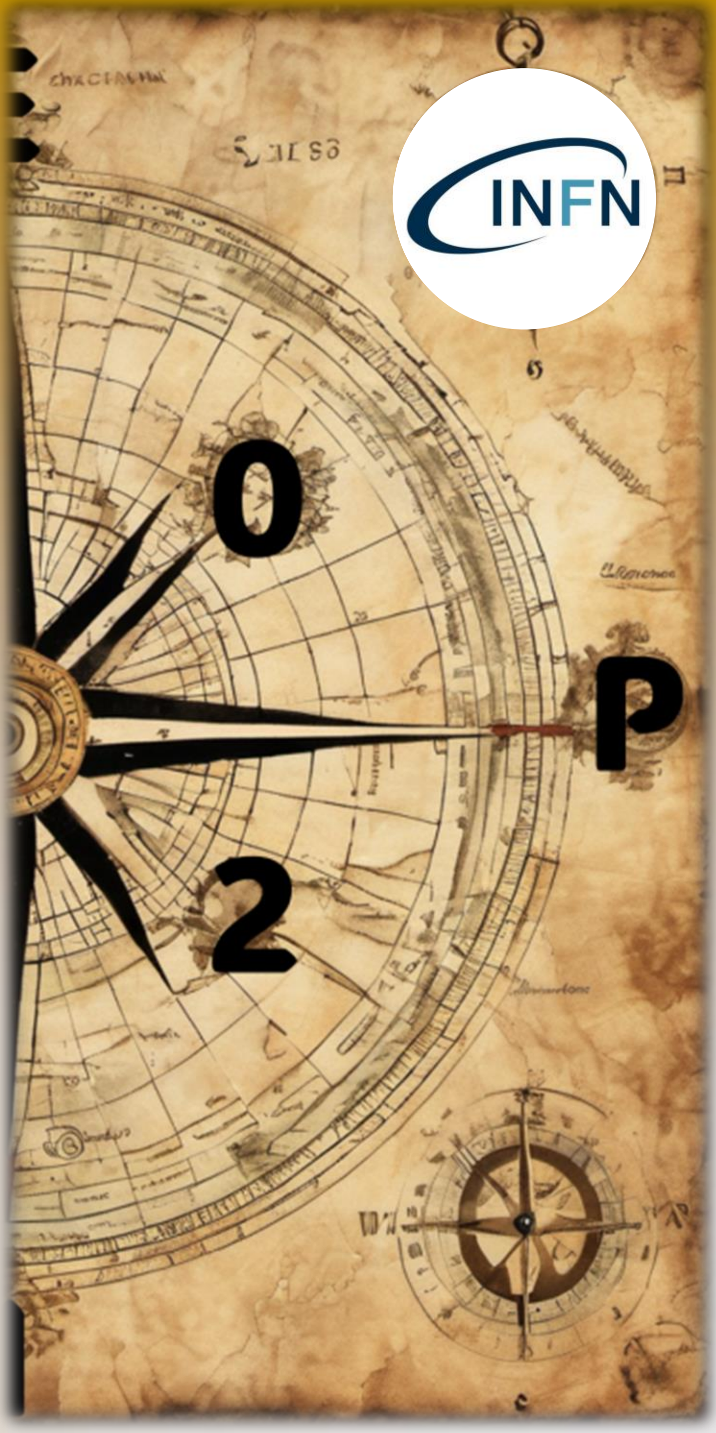


We will reward the **best teaser** and **best poster** contributions.

Express your preference using the google form at the following QR code

SCAN ME

LOW-ENERGY GLOBAL ANALYSIS FOR ELECTROWEAK AND NUCLEAR PHYSICS



In collaboration with

M. Cadeddu, N. Cargioli, F. Dordei & C. Giunti

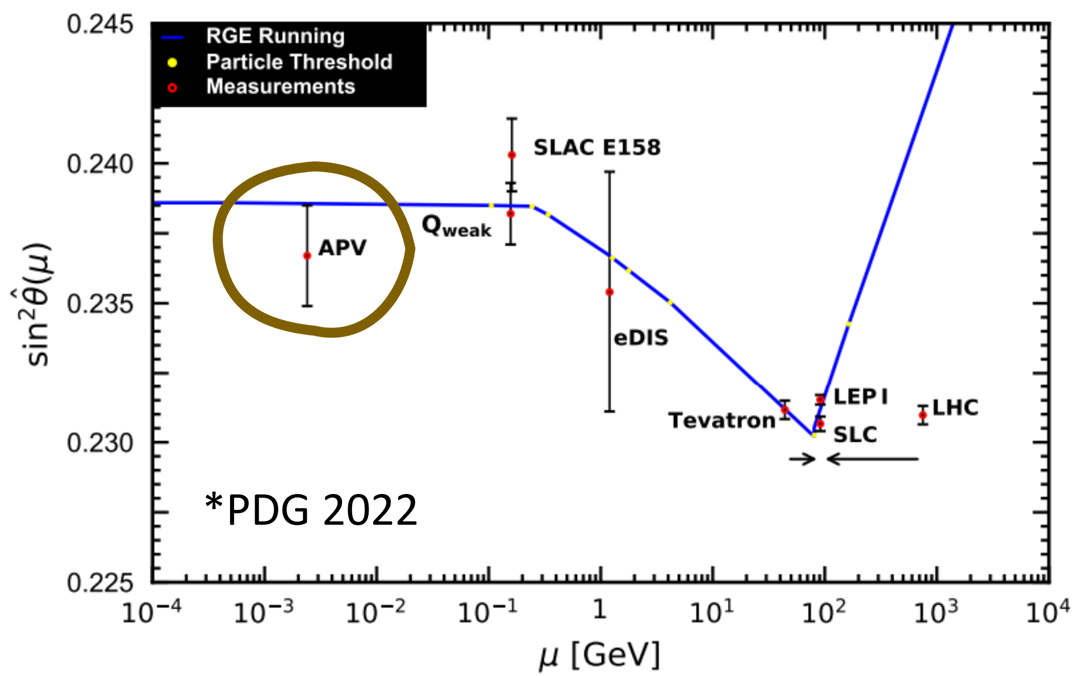
Mattia Atzori Corona
(mattia.atzori.corona@ca.infn.it)
PhD, University Of Cagliari & INFN Cagliari

Electroweak Framework

The Standard Model Picture

$$SU(2)_L \otimes U(1)_Y \otimes SU(3)_c$$

Electroweak interactions — **Strong Interactions**



Weak Mixing Angle

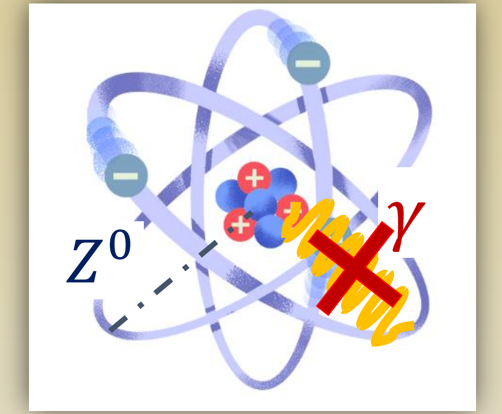
Key parameter of the electroweak unification

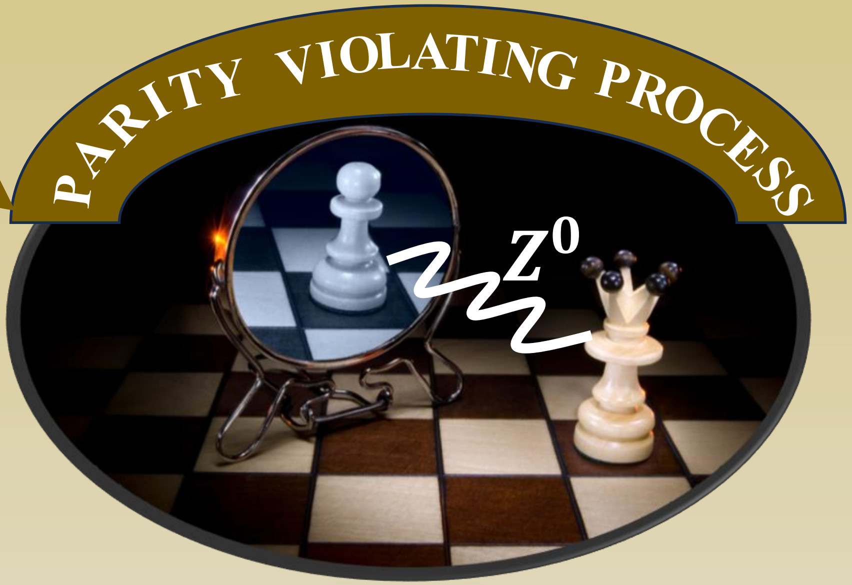
$$\begin{pmatrix} A_\mu \\ Z_\mu \end{pmatrix} = \begin{pmatrix} \cos\theta_W & \sin\theta_W \\ -\sin\theta_W & \cos\theta_W \end{pmatrix} \begin{pmatrix} B_\mu \\ W_\mu^{(3)} \end{pmatrix}$$

- To what extent can we consider this measurement **reliable**?
- Are there **other probes** to investigate this **low-energy** regime?

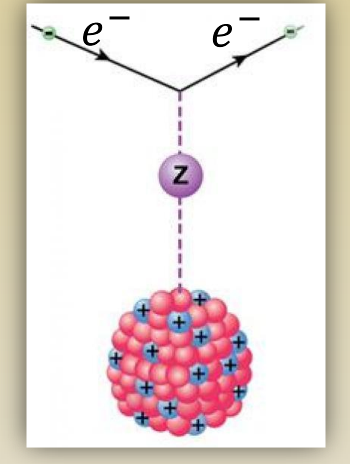
Low-Energy Electroweak Processes

APV
Atomic Parity Violation

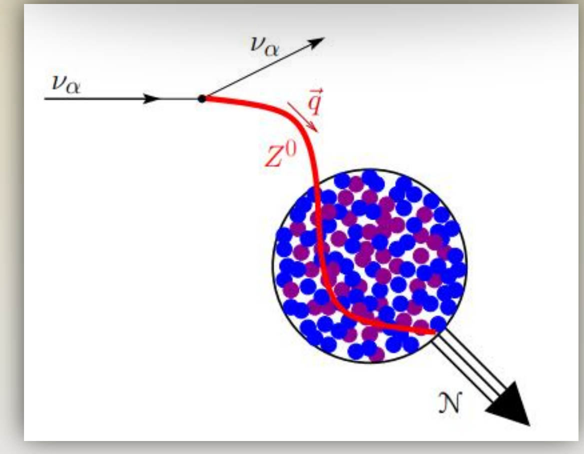




PVES
Parity Violating Electron Scattering



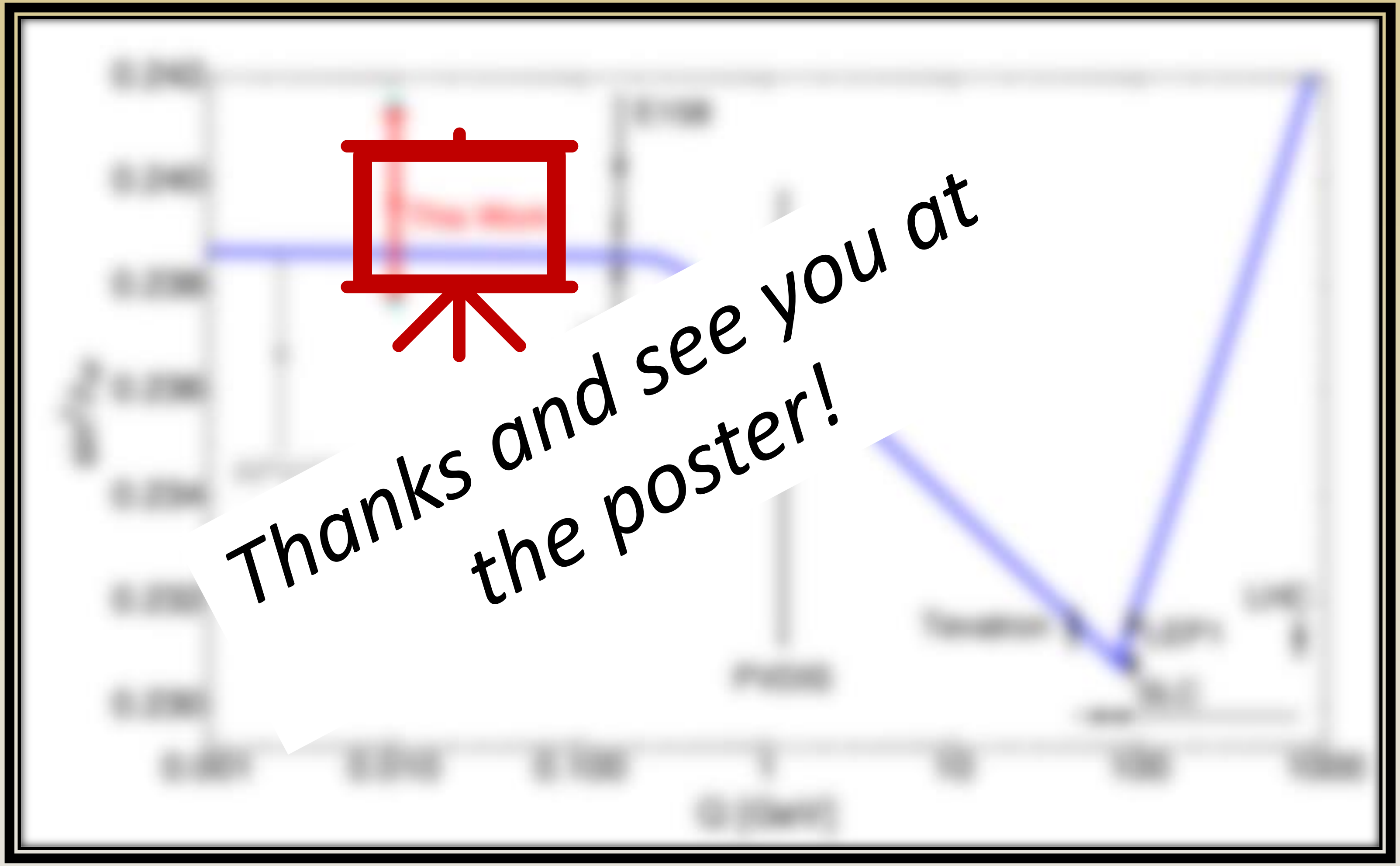
CEvNS
Coherent Elastic ν Nucleus Scattering



WARNING

The measurements from these probes depend on the nuclear structure!

Global Electroweak Fit



But if you cannot wait…
have a look at

MAC et al.
PRD 110 (2024) 3, 033005

DFG Deutsche Forschungsgemeinschaft
FOR5327

JG|U
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

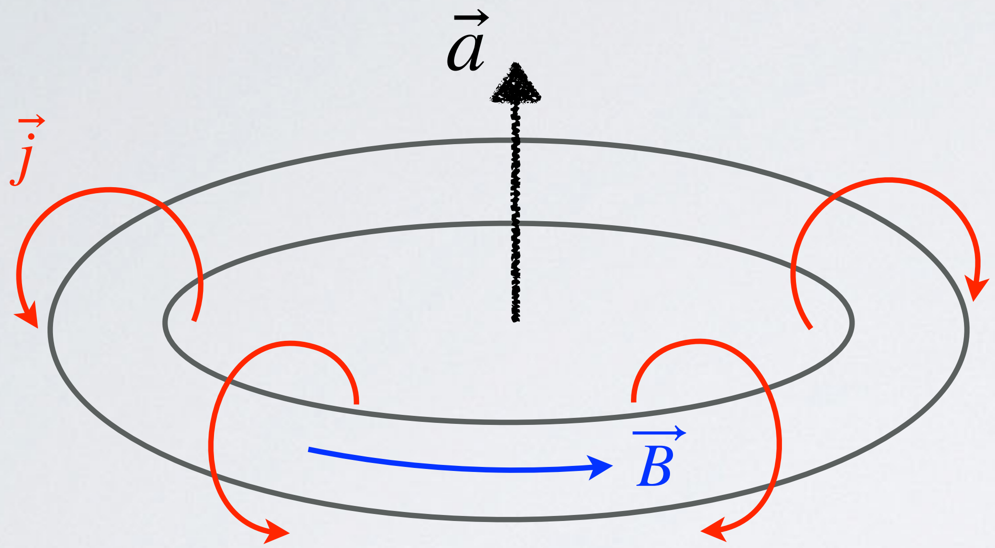
NEW SUM RULES FOR THE ANAPOLE AND ELECTRIC-DIPOLE MOMENTS

Volodymyr Biloshytskyi
in collaboration with M. Gorchtein and V. Pascalutsa

EPIC 2024, Geremeas, Sardinia, Italy, September, 22-27, 2024

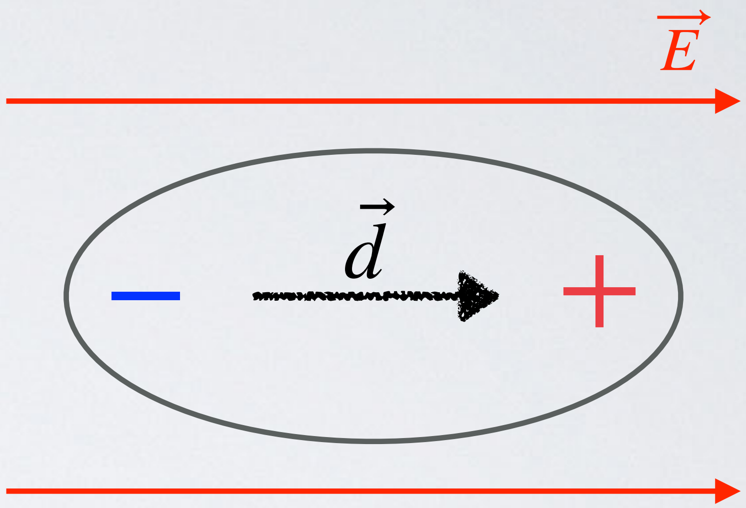
$\hat{P}$ and $\hat{P}\hat{T}$ violation for spin-1/2 particles

~~$\hat{P}$~~: anapole moment

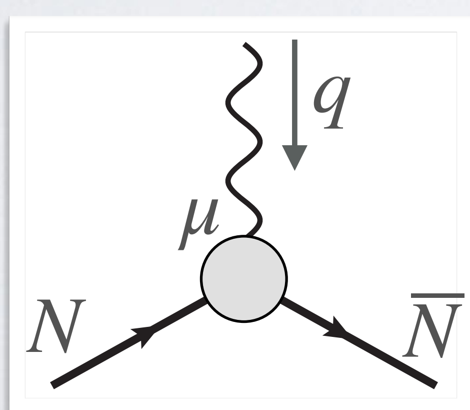


$$\mathcal{H}_{\rm int}^{\rm anapole} = -\,a\,\vec{\sigma}\cdot\left[\vec{\nabla}\times\vec{B}-\frac{\partial\vec{E}}{\partial t}\right]$$

~~$\hat{P}\hat{T}$~~: electric dipole moment

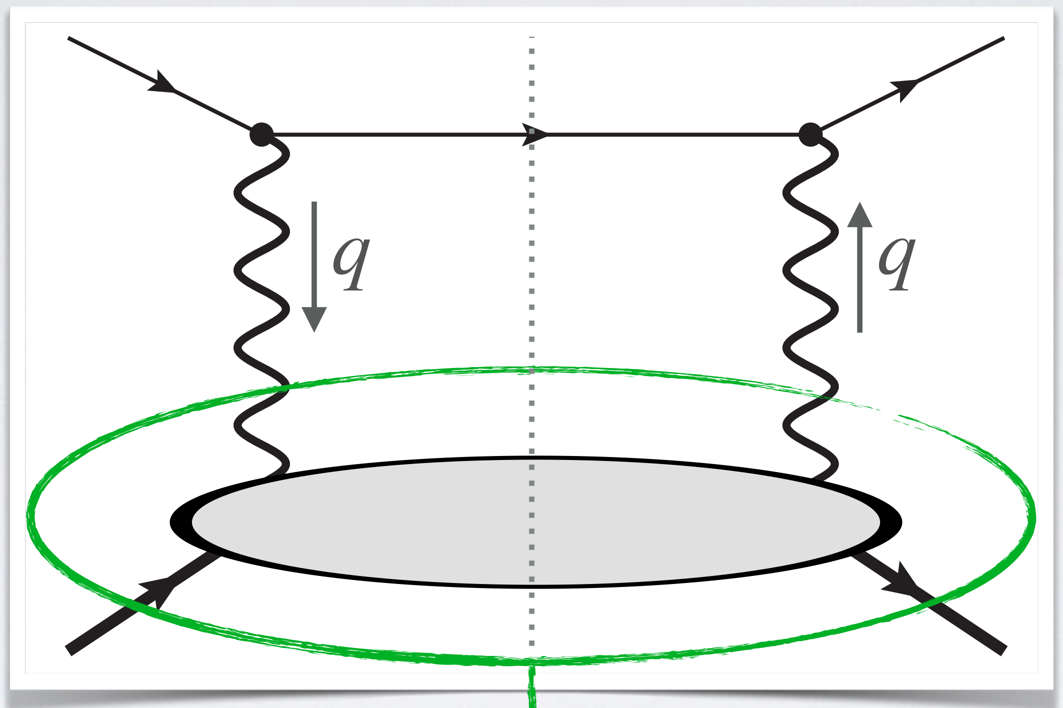


$$\mathcal{H}_{\rm int}^{\rm EDM} = -\frac{d}{2M}\vec{\sigma}\cdot\vec{E}$$



$$= \overline{N}\left[\gamma^\mu F_1(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}F_2(q^2) + \frac{q^2\gamma^\mu - \not{q}\,q^\mu}{M^2}\gamma_5\,a(q^2) + \frac{i\sigma^{\mu\nu}q_\nu}{2M}\gamma_5\,d(q^2)\right]N$$

eN scattering and forward Compton sum rules



Doubly-virtual forward Compton scattering

γN polarized cross sections

$\int$

Sum rules

model-independent!

Low-energy observables

e.g. dipole moments, polarizabilities etc.

Sum rules for electromagnetic moments

- Sum rules for anomalous magnetic moment $\varkappa$ - known

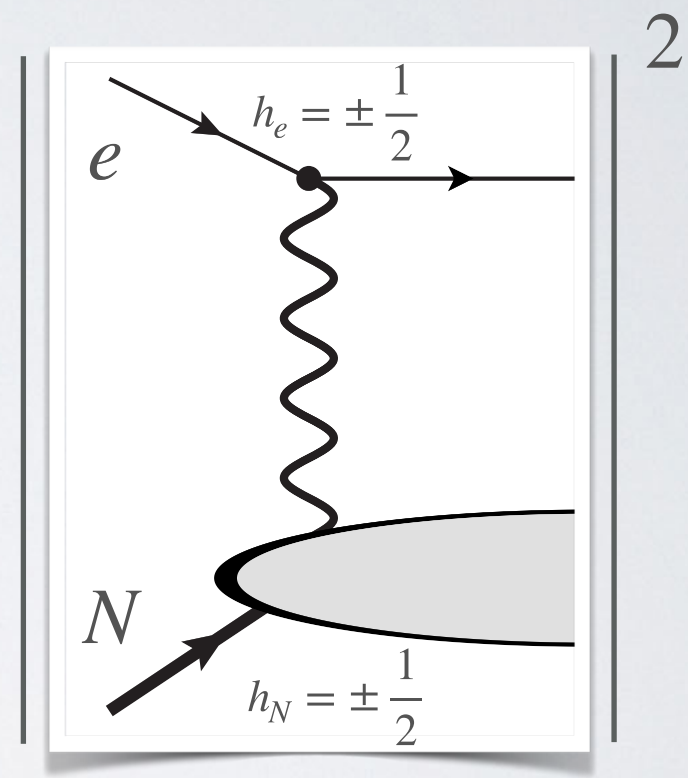
1966 - Gerasimov-Drell-Hearn sum rule   1970 - Burkhard-Cottingham sum rule   1975 - Schwinger sum rule $\propto \varkappa$

NEW !

- Sum rule for anapole moment a ~~$\hat{P}$~~

$$(q_N/e + \varkappa)\, a = \frac{M^3}{8\pi^2 \alpha_{\text{em}}} \lim_{Q^2 \to 0} \int d\nu \frac{\partial}{\partial Q^2} \left[\sigma^{-}_{TT} - \sigma^{+}_{TT}\right](\nu, Q^2)$$

observables:



- Sum rule for electric dipole moment d ~~$\hat{P}\hat{T}$~~

$$(q_N/e + \varkappa)\, d = \frac{M^2}{4\sqrt{2}\pi^2 \alpha_{\text{em}}} \lim_{Q \to 0} \int \frac{d\nu}{Q} \left[\sigma^{-}_{LT} - \sigma^{+}_{LT} + \sigma^{+}_{TL} - \sigma^{-}_{TL}\right](\nu, Q^2)$$

☑ Perturbative verification in simple models

Thank you for attention!

I look forward to seeing you at my poster!

Three-nucleon neutrinoless double beta decay potentials with chiral EFT

EPIC 2024 Workshop
Calaserena, Geremeas, Sardinia
Sept 22-27th, 2024

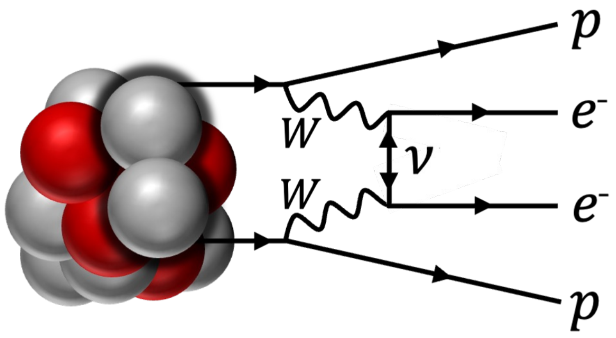
Graham Chambers-Wall
Washington University in St. Louis

Advisors: Saori Pastore & Maria Piarulli

in collaboration with Lustin Lieffers & Emanuele Mereghetti

Neutrinoless double beta decay $(0\nu\beta\beta)$

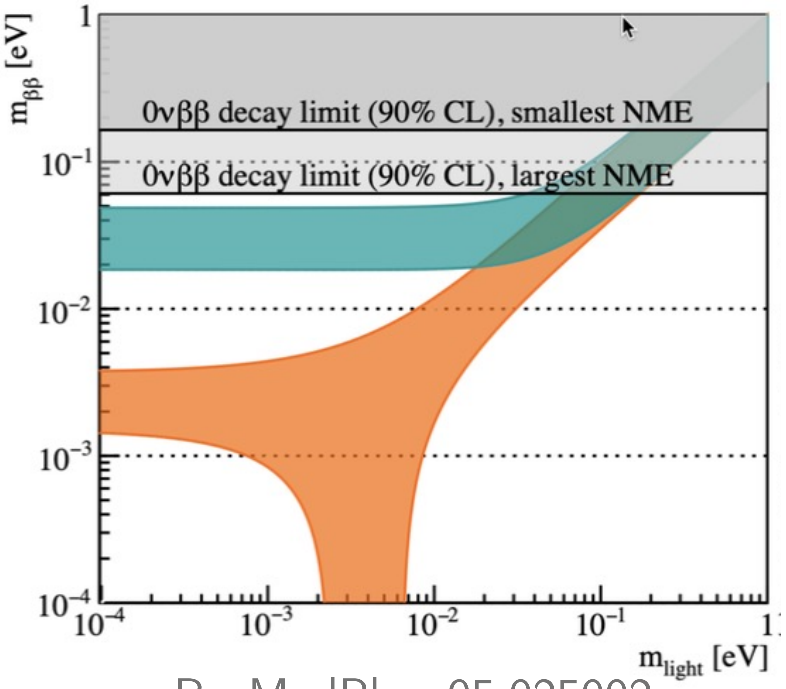
- Observation clear signal of BSM physics
- Next generation tonne-scale experiments improve bound by order of magnitude and rule out inverted ordering (in minimal scenario)



$$\left[T^{0\nu}_{1/2}\right]^{-1} = G^{0\nu}\left|M^{0\nu}\right|^2\left|f(m_i, U_{ei})\right|^2$$

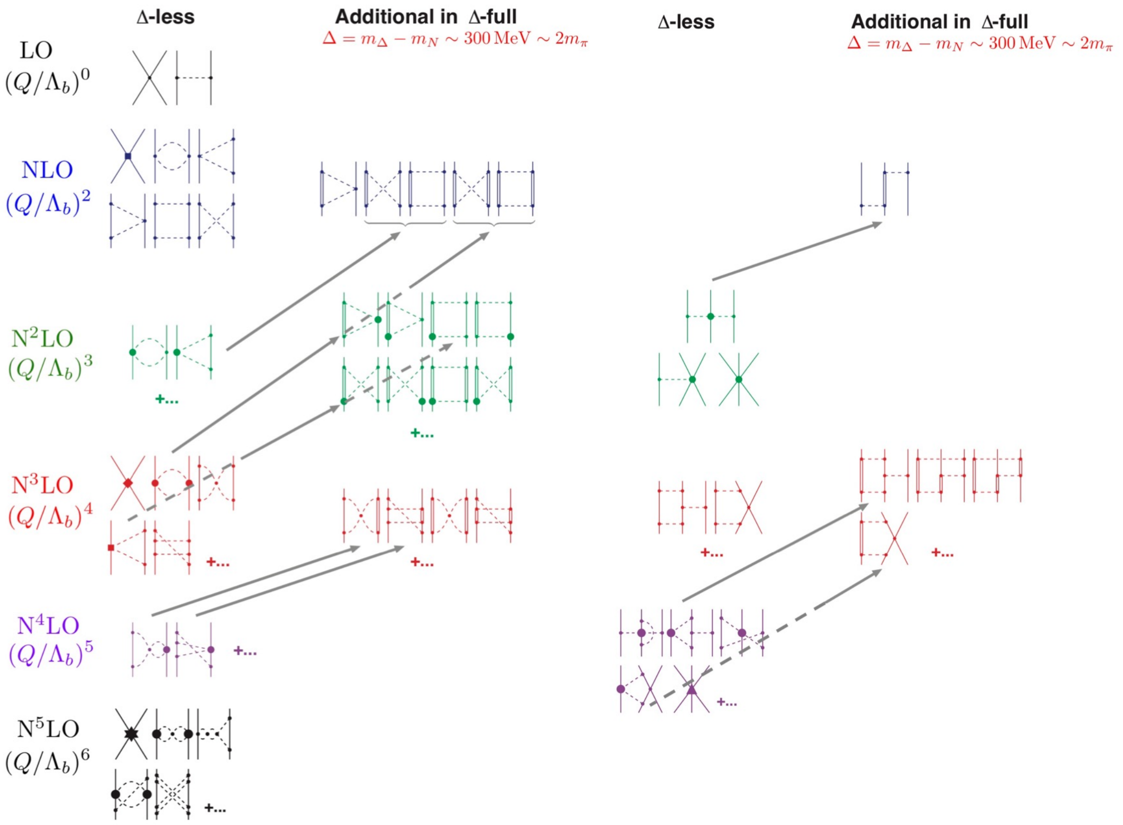
- In standard mechanism, rate is proportional to nuclear matrix element times effective Majorana neutrino mass

  ⇒ Need input from nuclear theory to extract neutrino mass



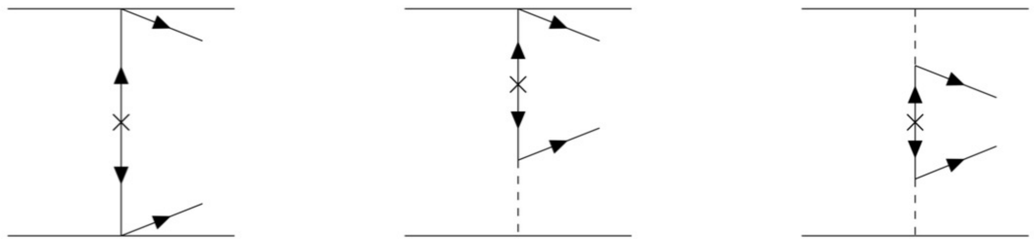
RevModPhys.95.025002

Chiral effective field theory (χEFT)

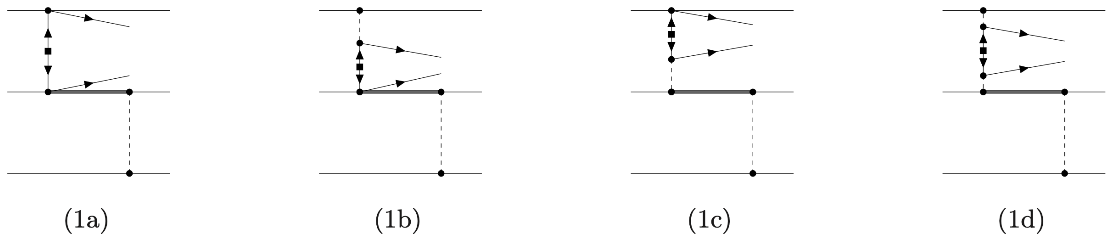


Piarulli and Tews, *Front. Phys.* 30 (2020)
Entem and Machleidt, *J. Phys. Rep* 503(1) (2011)

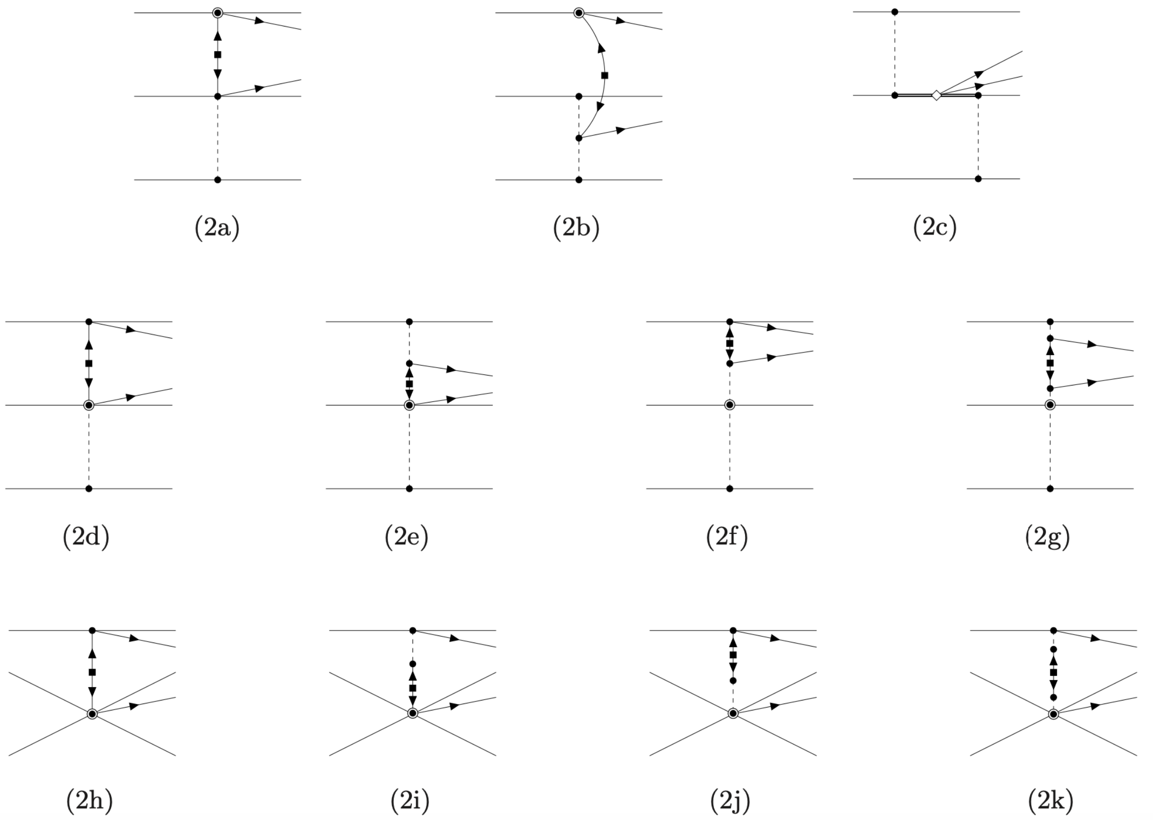
- Based on approximate chiral symmetry of QCD
- Pions, nucleons, deltas as fundamental degrees of freedom
- Provides hierarchy of many-nucleon forces and currents
- Derive $0\nu\beta\beta$ transition operator, dubbed "**neutrino potential**," within χEFT
  ⇒ input for nuclear matrix elements



Three-nucleon potentials



NLO



N2LO

Outlook

- Derived three-nucleon potentials within χEFT
- Can be input into many-body computations to calculate nuclear matrix elements
- Currently implementing into quantum Monte Carlo

Thank you!

PSI ETH zürich

n2EDM

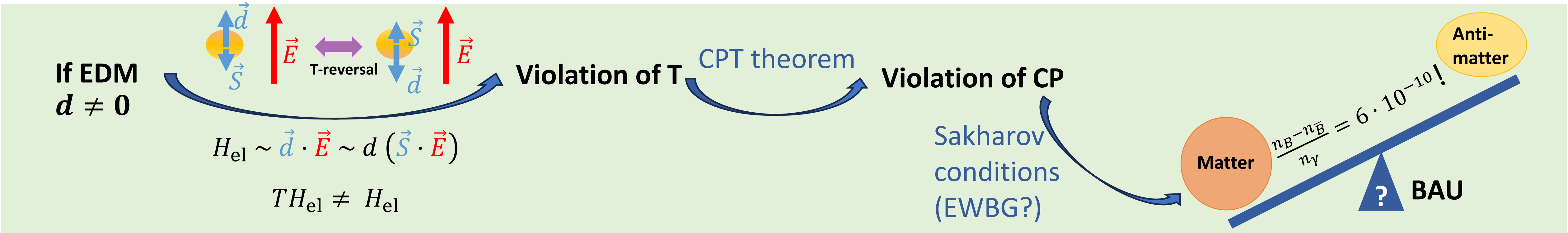
The n2EDM experiment at PSI

A precise measurement searching for the neutron electric dipole moment

Wenting Chen, on behalf of the nEDM collaboration

Cagliari, EPIC 2024 - Electroweak Physics InterseCtions, 24.09.2024

EDM as a probe of New Physics



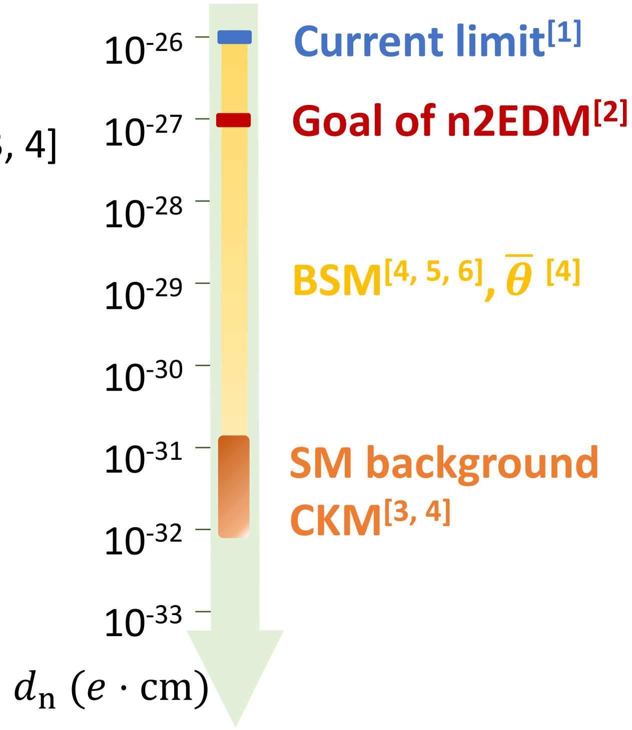
within Standard Model:

- Small background from CKM mechanism→ $d_{n,\mathrm{CKM}} \sim 10^{-32}\ e \cdot \mathrm{cm}$ [3, 4]
- Tuning of QCD $\overline{\theta}$ - term, associated with the "strong CP problem" [4].

Beyond Standard Model:

- EDMs as powerful constraints on new physics models at or above electroweak scale.

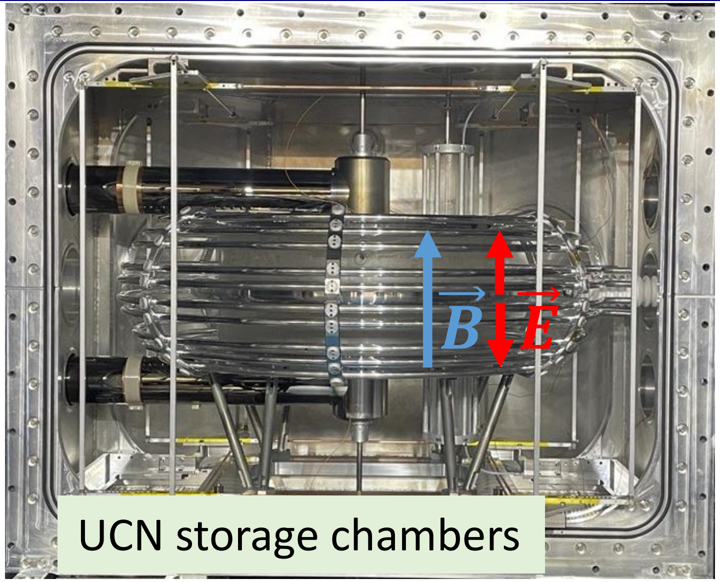
  Example: SUSY (MSSM)[4, 5], g2HDM[6] ...



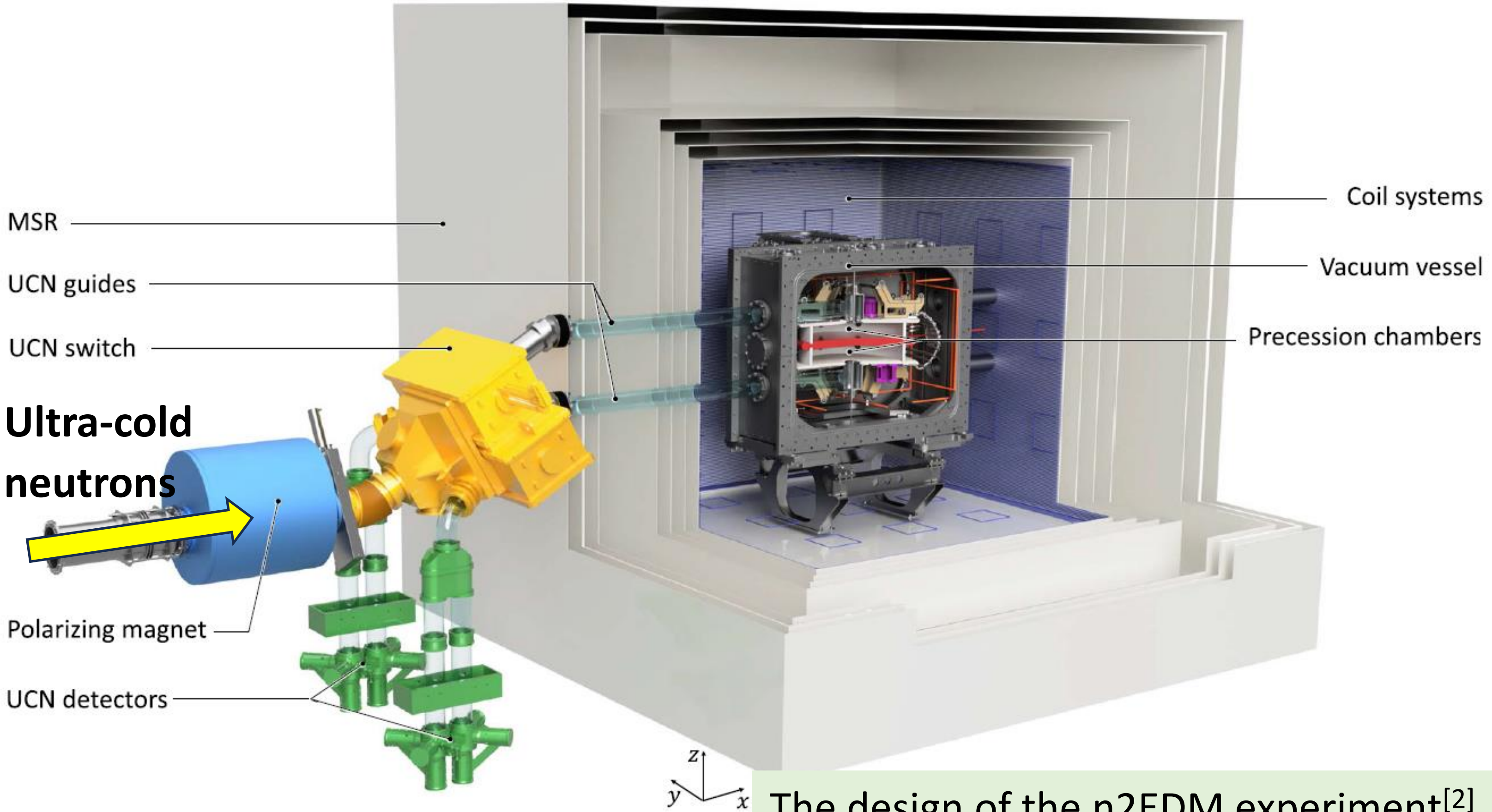
n2EDM experiment @ PSI

Measuring the neutron precession frequency $f_{\rm n} = \frac{\mu_{\rm n}}{\pi\hbar} B \pm \frac{d_{\rm n}}{\pi\hbar} E$ in a double-chamber setup.

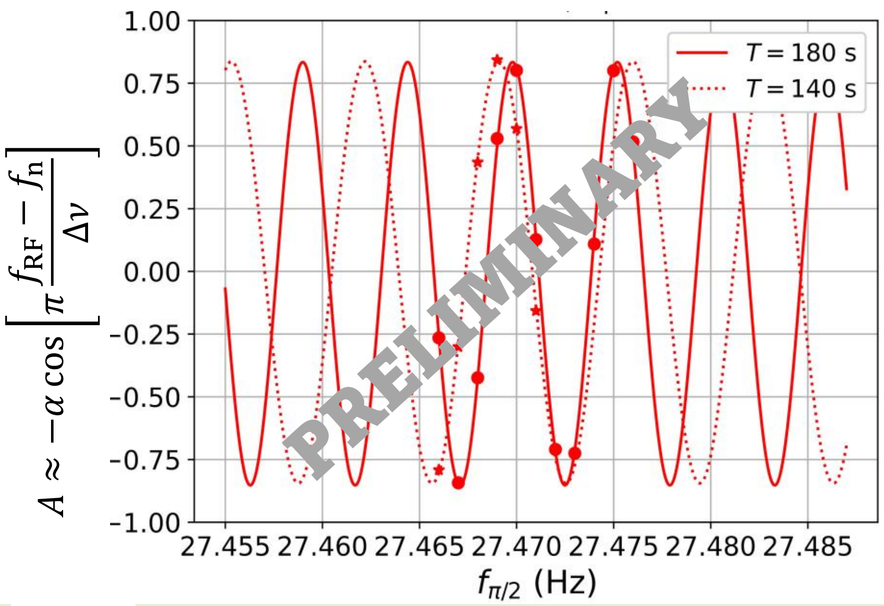
Using the Ramsey method and counting spin-up/down neutrons.



UCN storage chambers



The design of the n2EDM experiment[2]



New result: Ramsey asymmetry plot

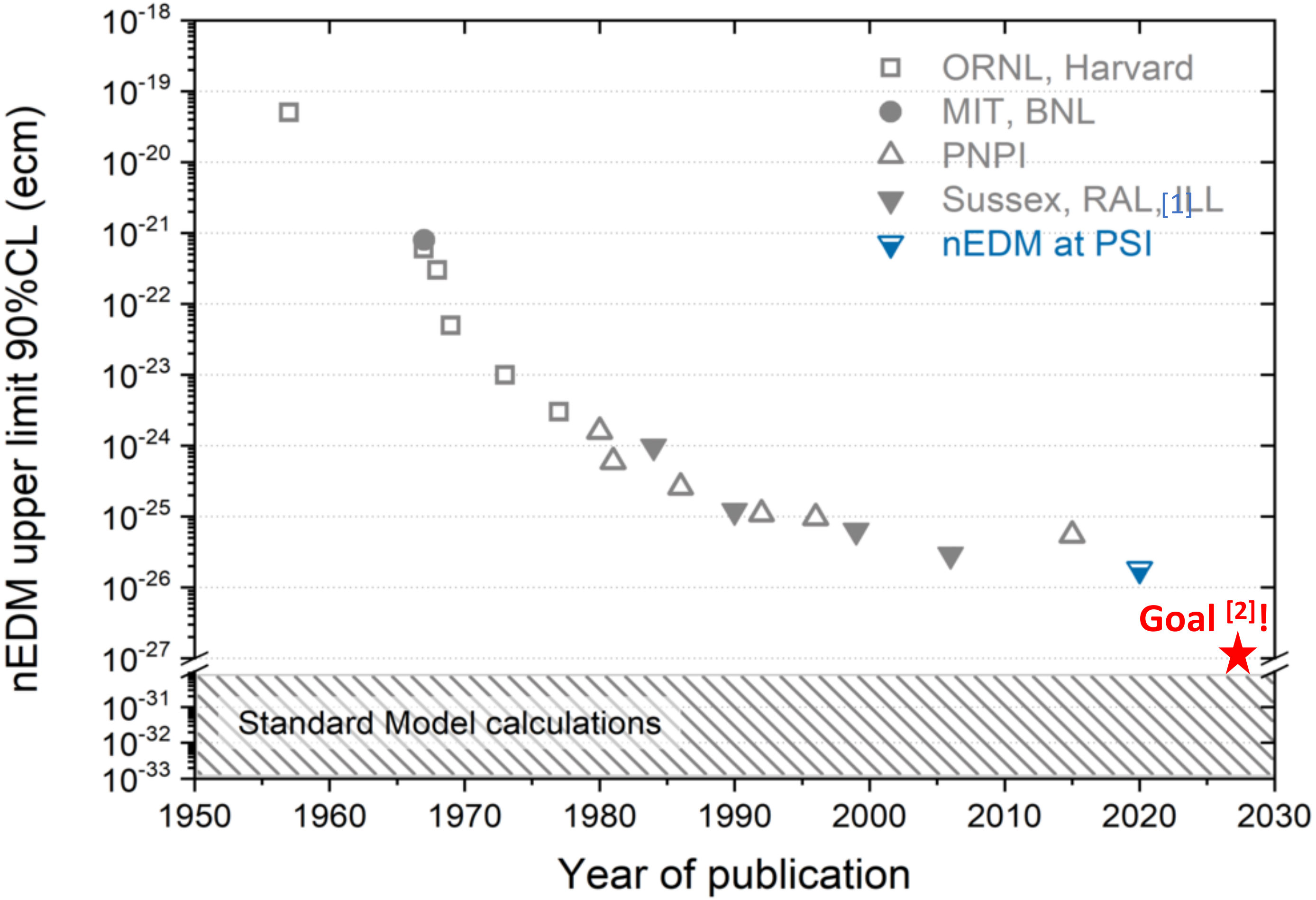
Thank you for your attention!

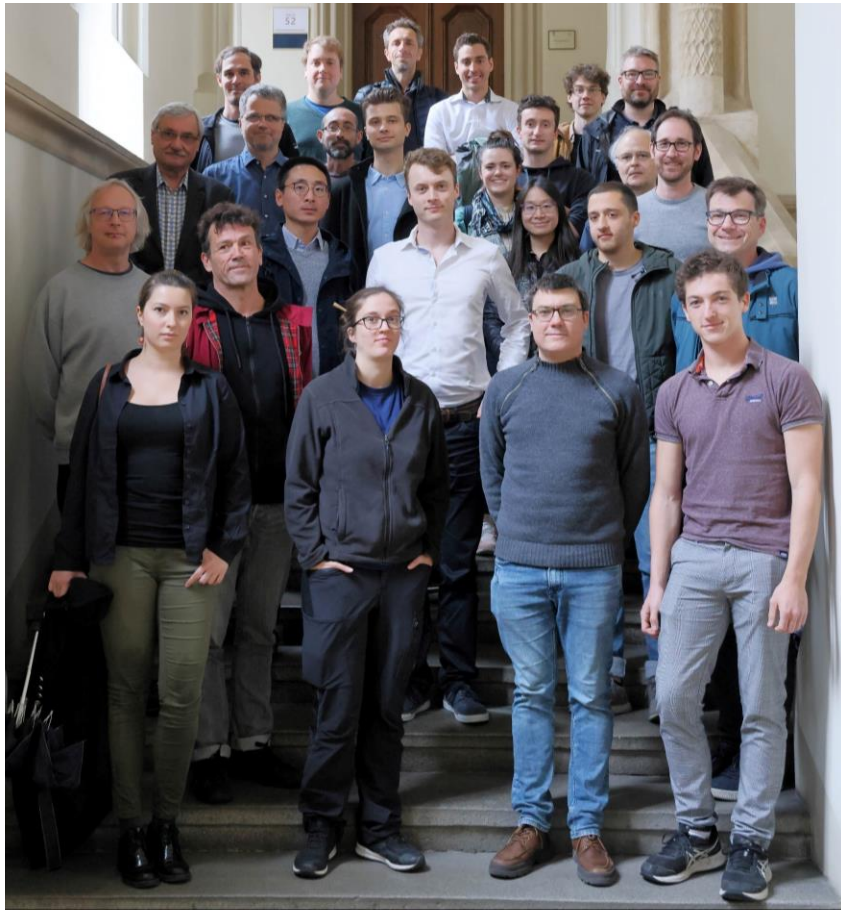
References:

[1] C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020)
[2] N.J. Ayres et al., Eur. Phys. J. C 81, 512 (2021)
[3] C-Y. Seng, Phys. Rev. C 91, 025502 (2015)
[4] M. Pospelov and A. Ritz, Ann. Phys. 318, 119-169 (2005)
[5] S A. Abel and O. Lebedev, JHEP 01, 133 (2006)
[6] K. Fuyuto et al., Phys. Lett. B 755, 491-497 (2016)

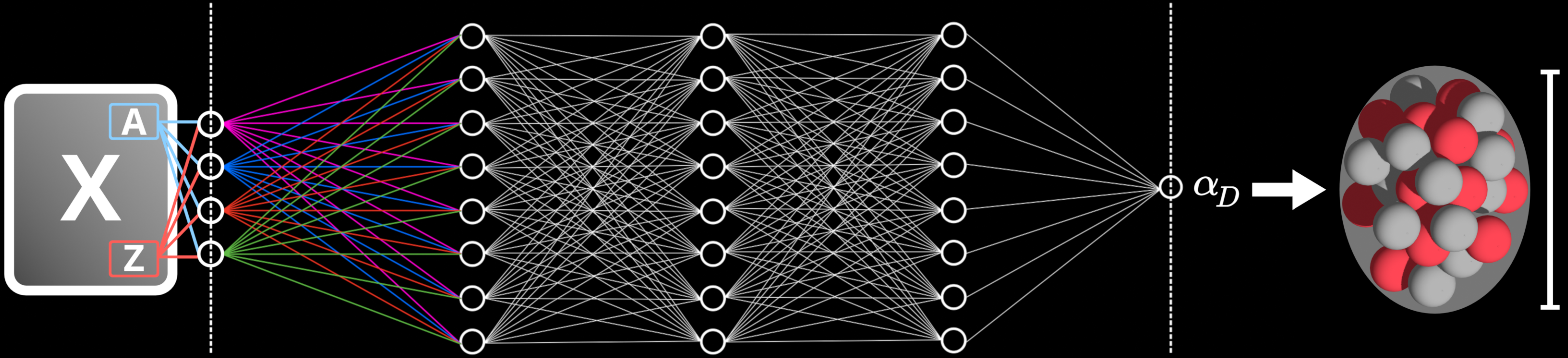
n2EDM

Swiss National Science Foundation





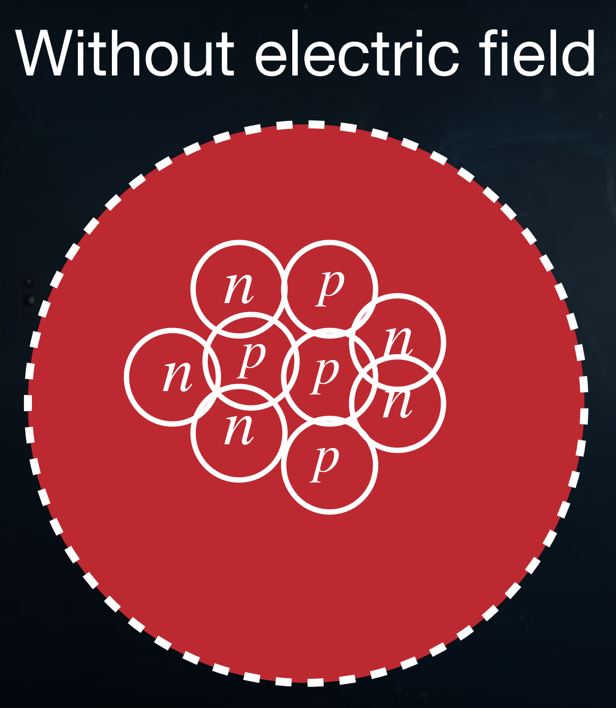
α_D - Harnessing the Power of Neural Networks



Tim Egert - EPIC 24.9.2024, Johannes Gutenberg Universität

Motivation - Why α_D and Neural Networks

- α_D is closely related to the symmetry energy → nuclear EoS → neutron stars

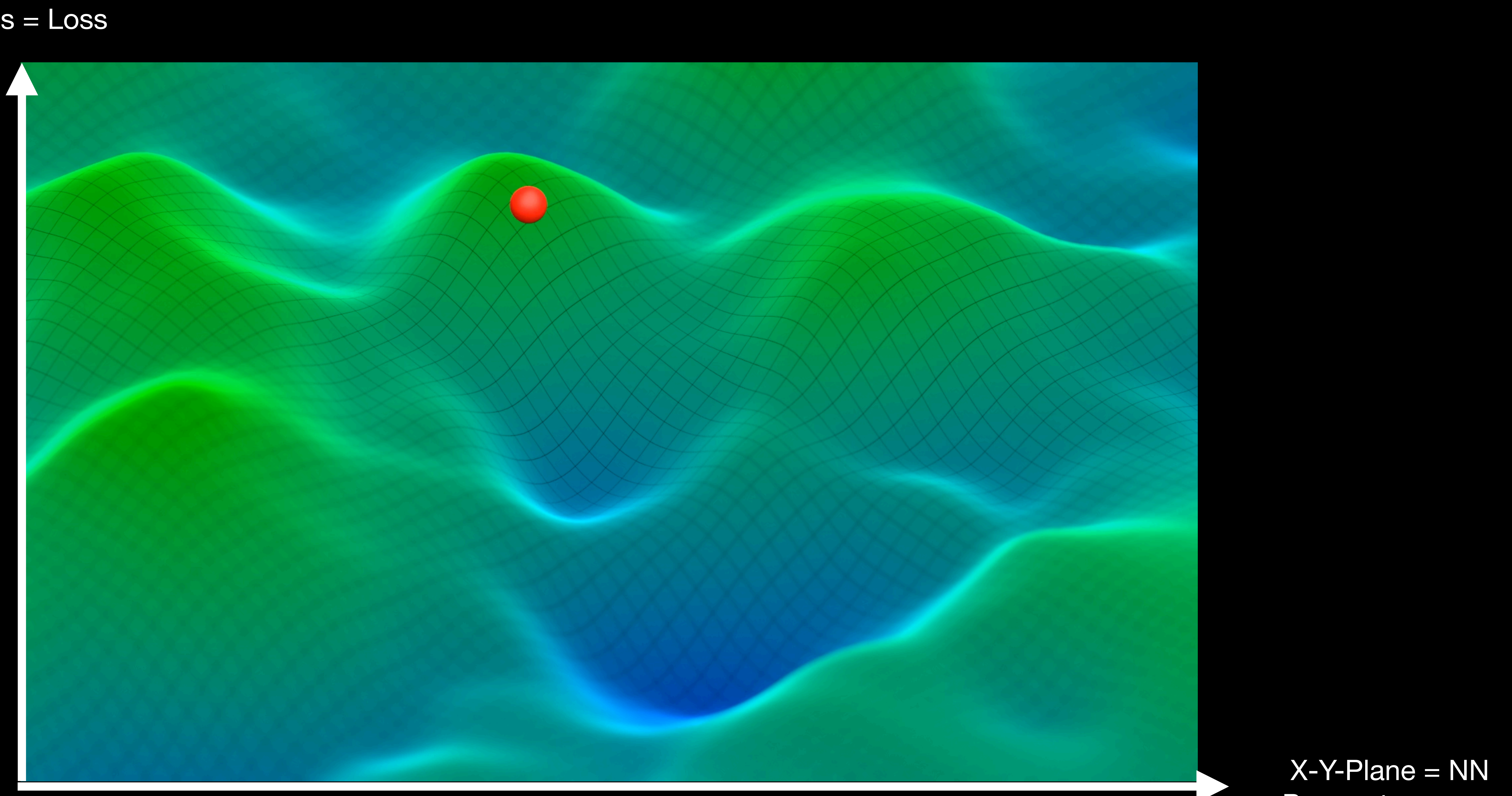


- Scarce experimental dataset
- Theoretical calculations are challenging

  → Require validation

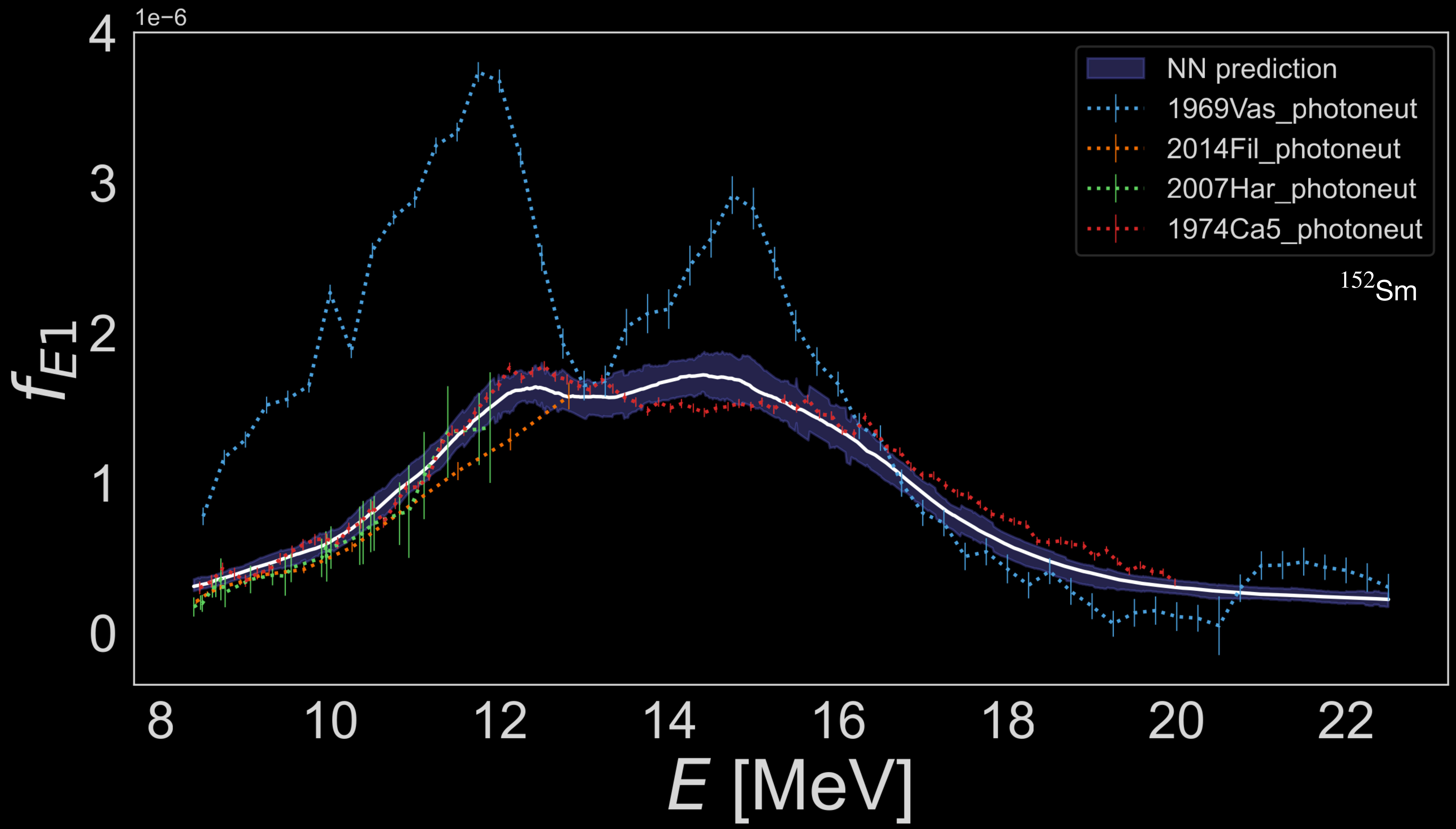
- Testing: AI applied to small datasets in nuclear physics

The Solution - Neural Networks



Gradient descent on a loss surface in parameter space

Results

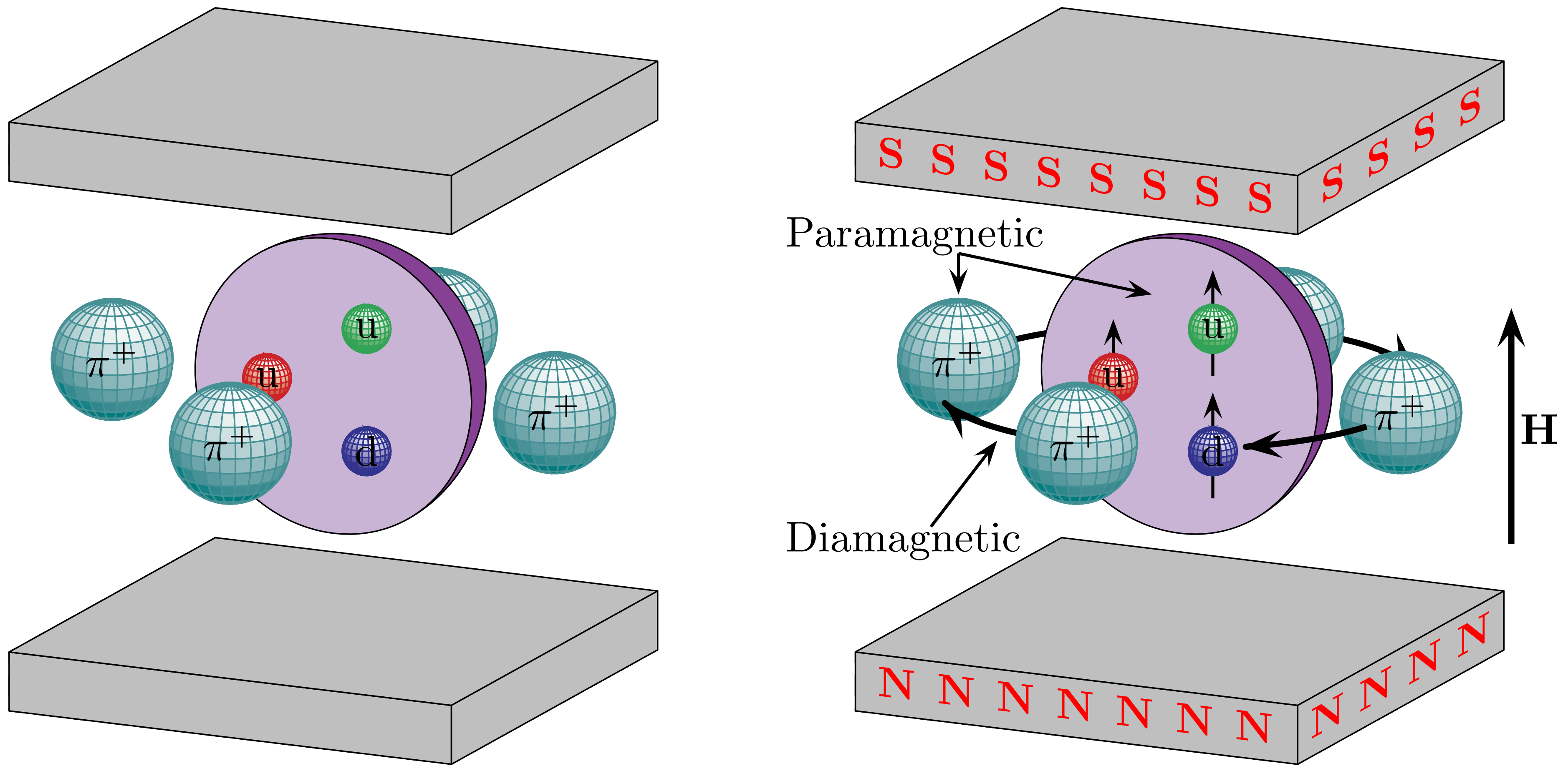


1e−6
4
3
2
1
0
f_{E1}
8
10
12
14
16
18
20
22
E [MeV]
NN prediction
1969Vas_photoneut
2014Fil_photoneut
2007Har_photoneut
1974Ca5_photoneut
^{152}Sm

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data



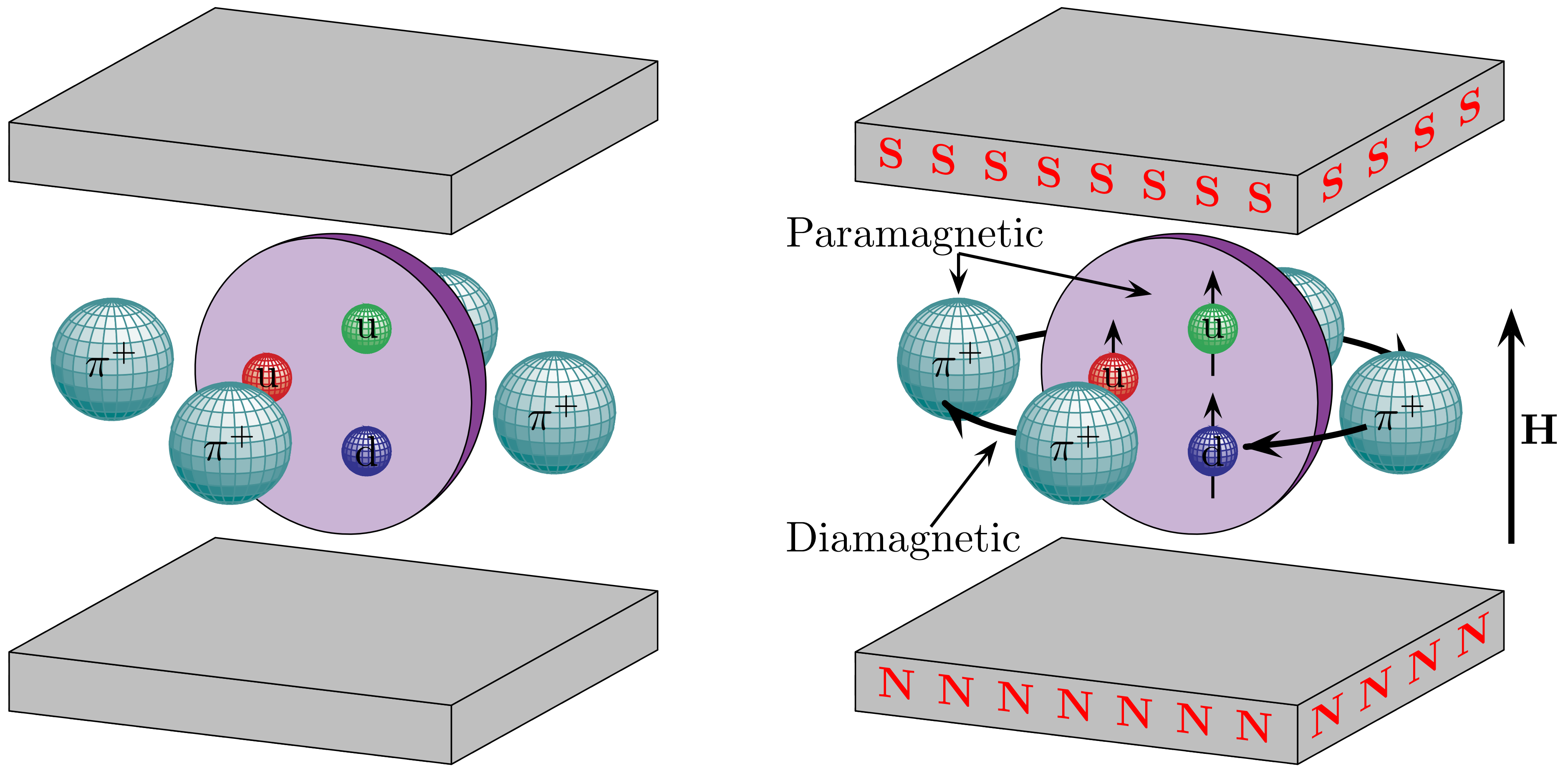
Magnetic dipole polarizability:

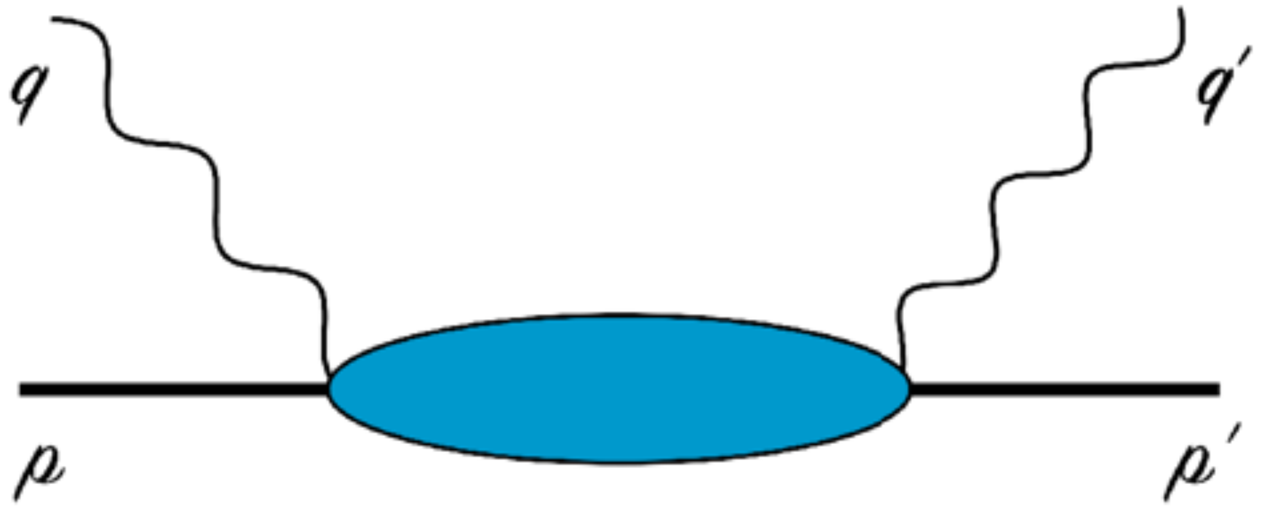
$$\vec{P} = \beta_{M1} \vec{H}$$

for polarization induced by magnetic field

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data





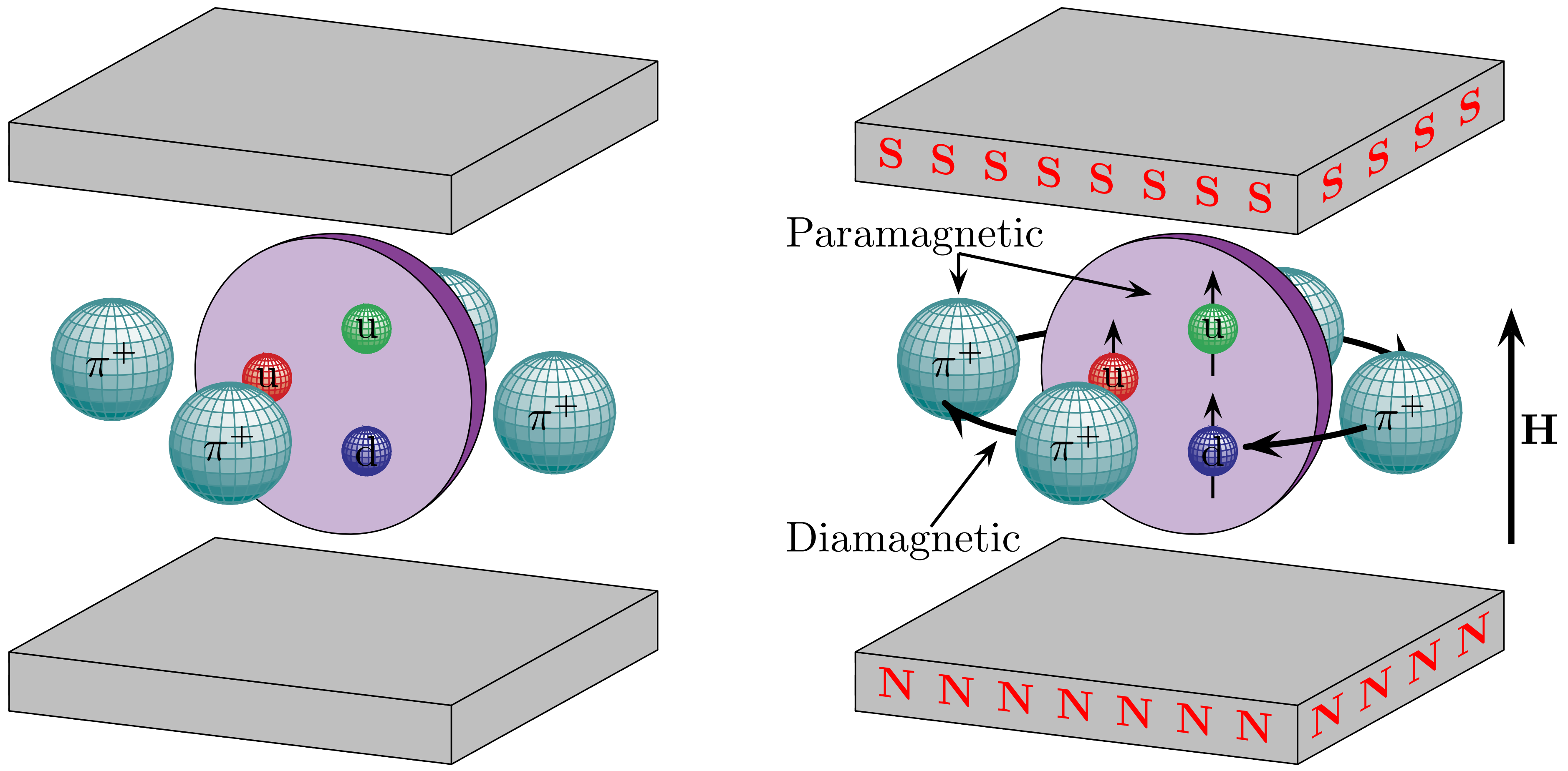
Magnetic dipole polarizability:

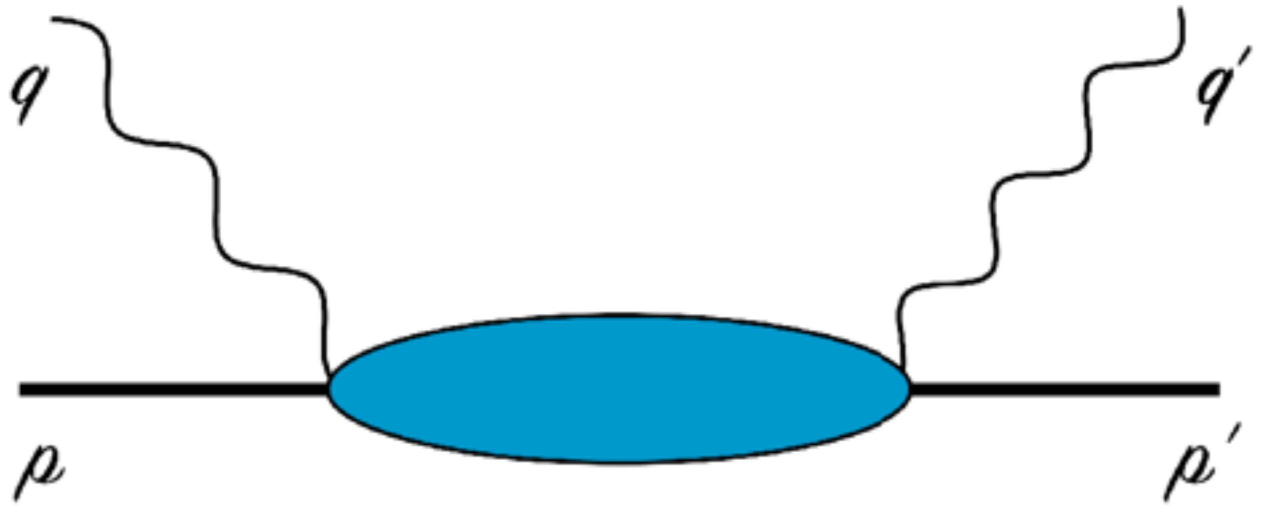
$$\vec{P} = \beta_{M1} \vec{H}$$

for polarization induced by magnetic field

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

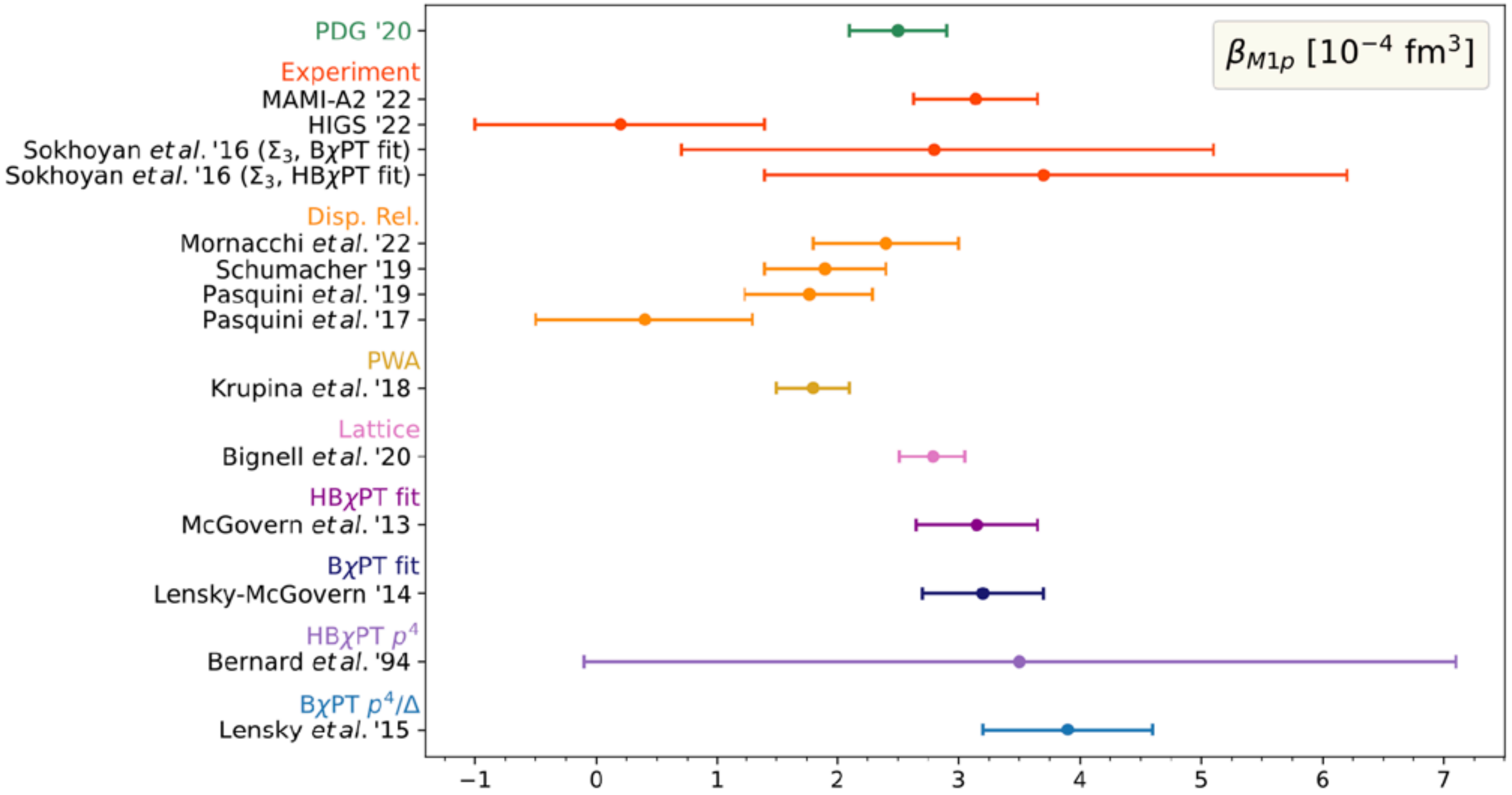




Magnetic dipole polarizability:

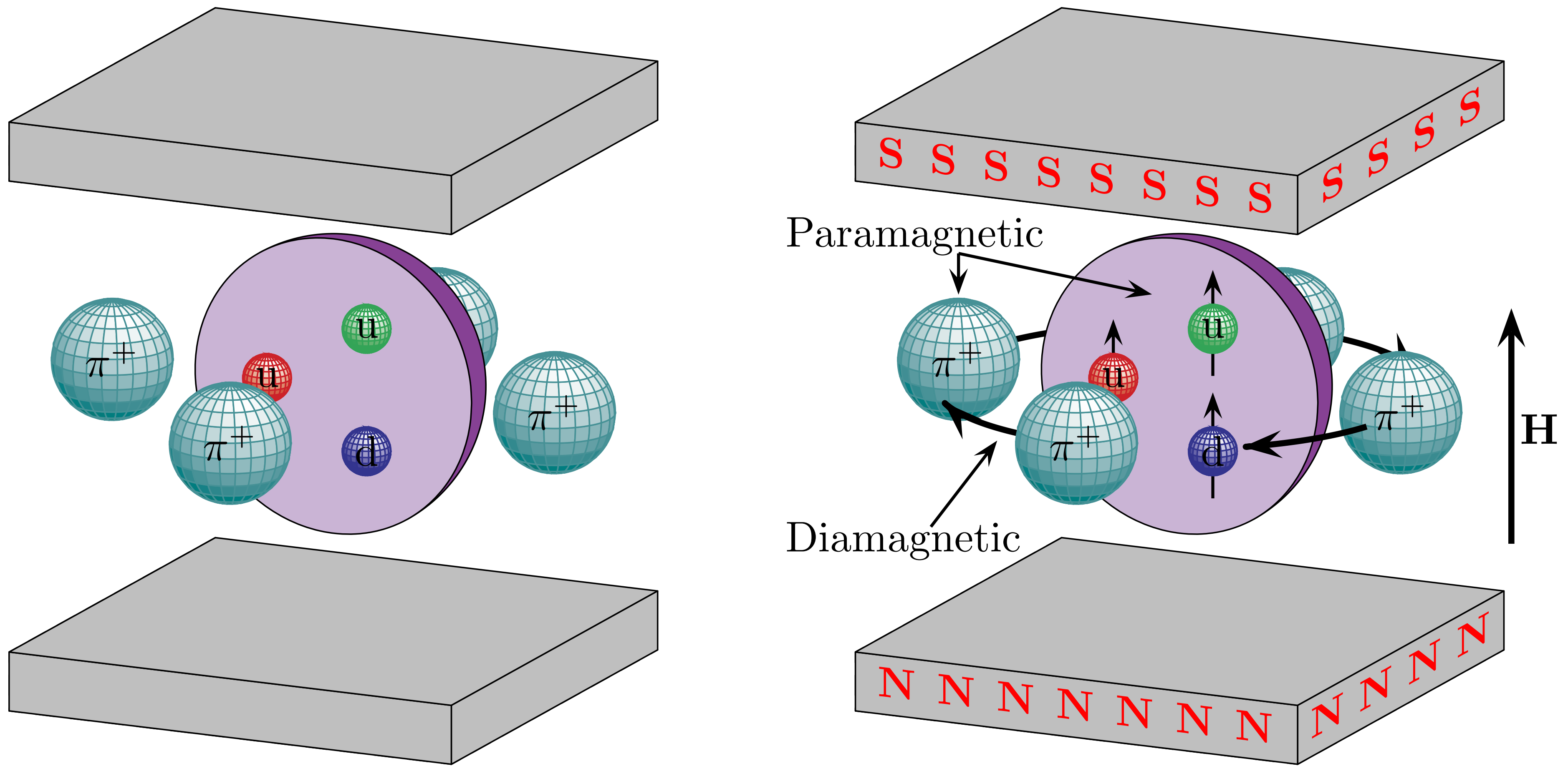
$$\vec{P} = \beta_{M1} \vec{H}$$

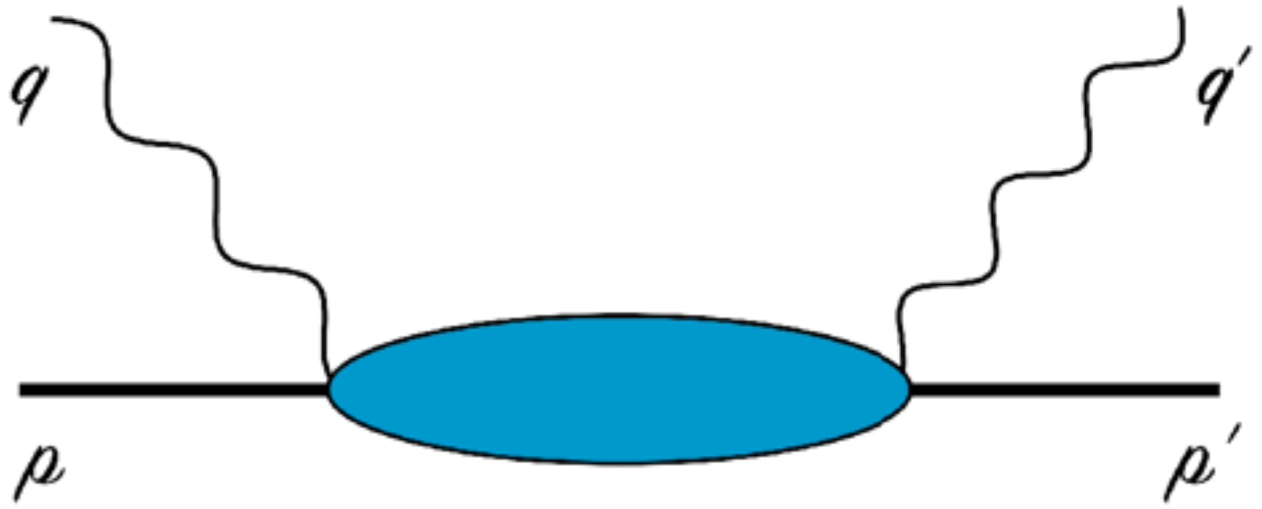
for polarization induced by magnetic field

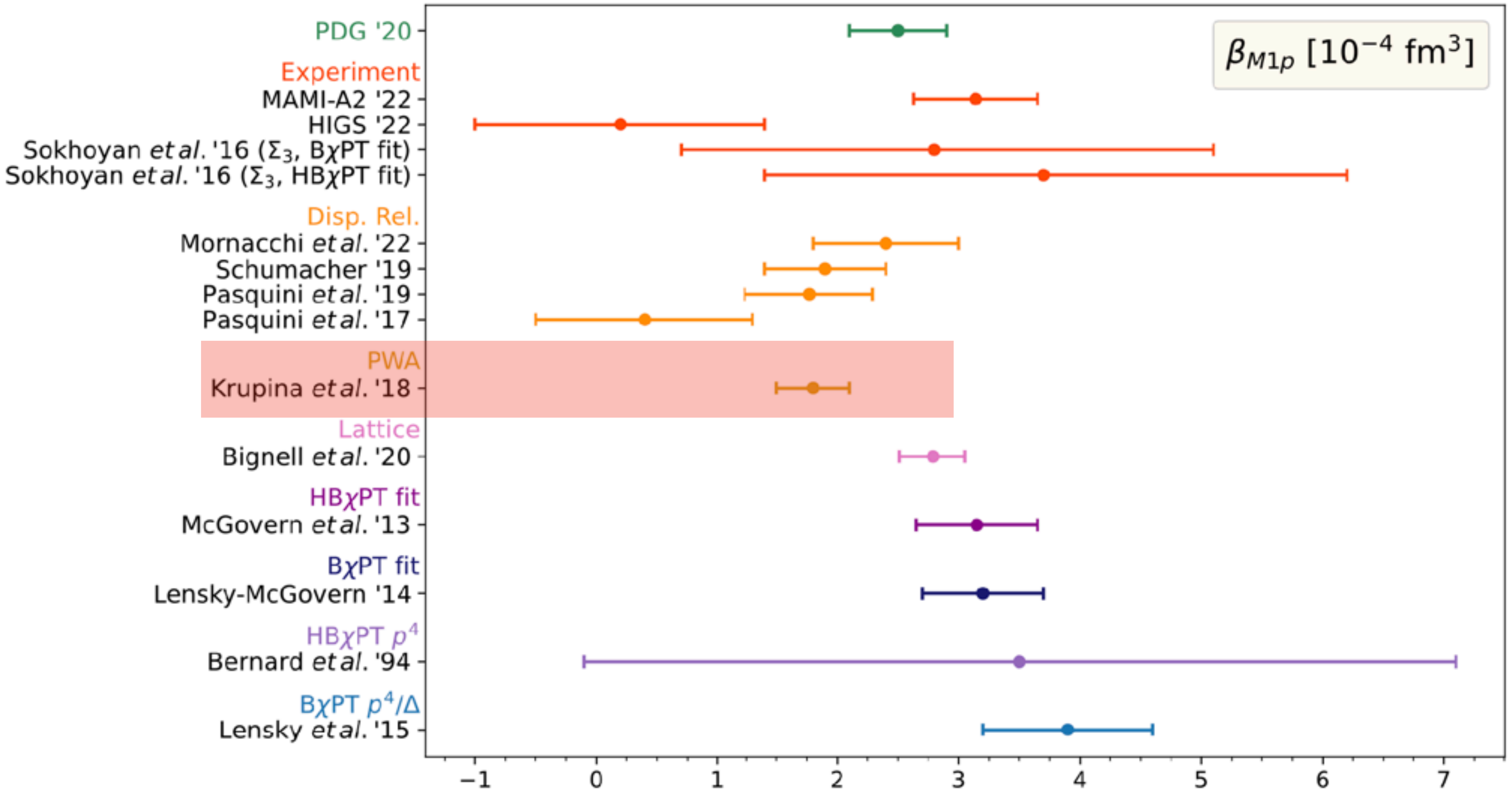


Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data







Magnetic dipole polarizability:

$$\vec{P} = \beta_{M1}\vec{H}$$

for polarization induced by magnetic field

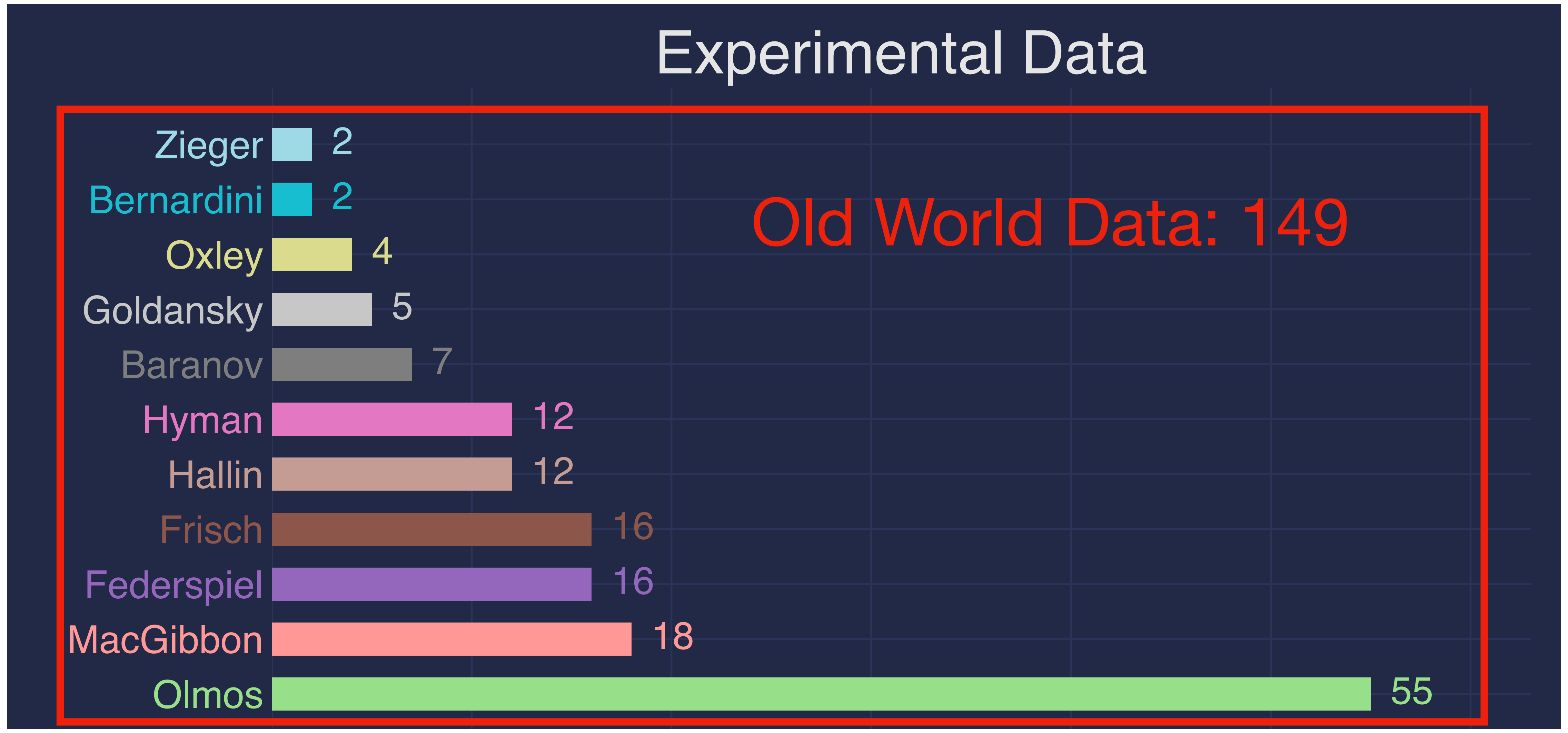
JG|U

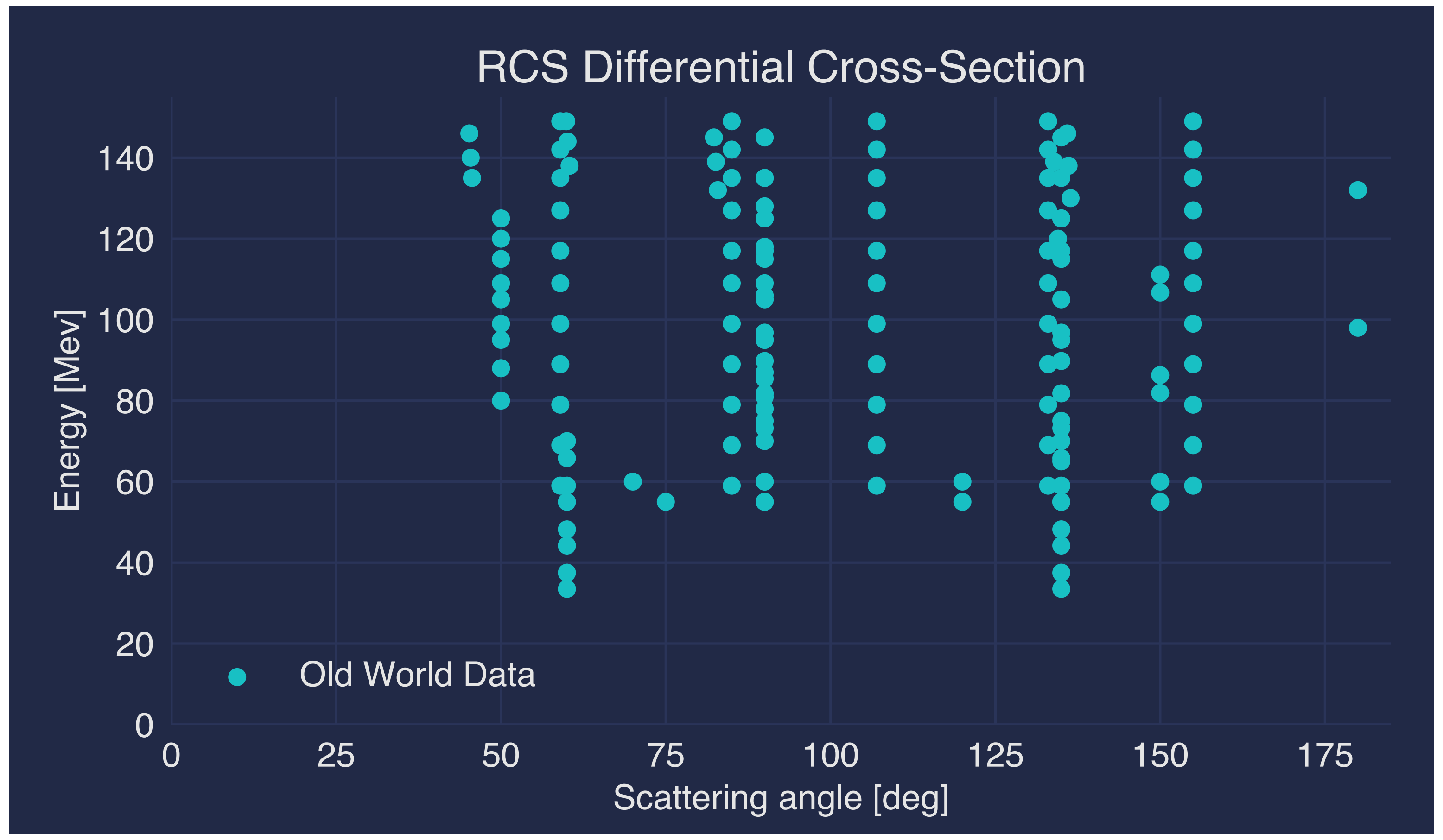
Timon Esser

Institut für Kernphysik

Johannes Gutenberg-Universität Mainz

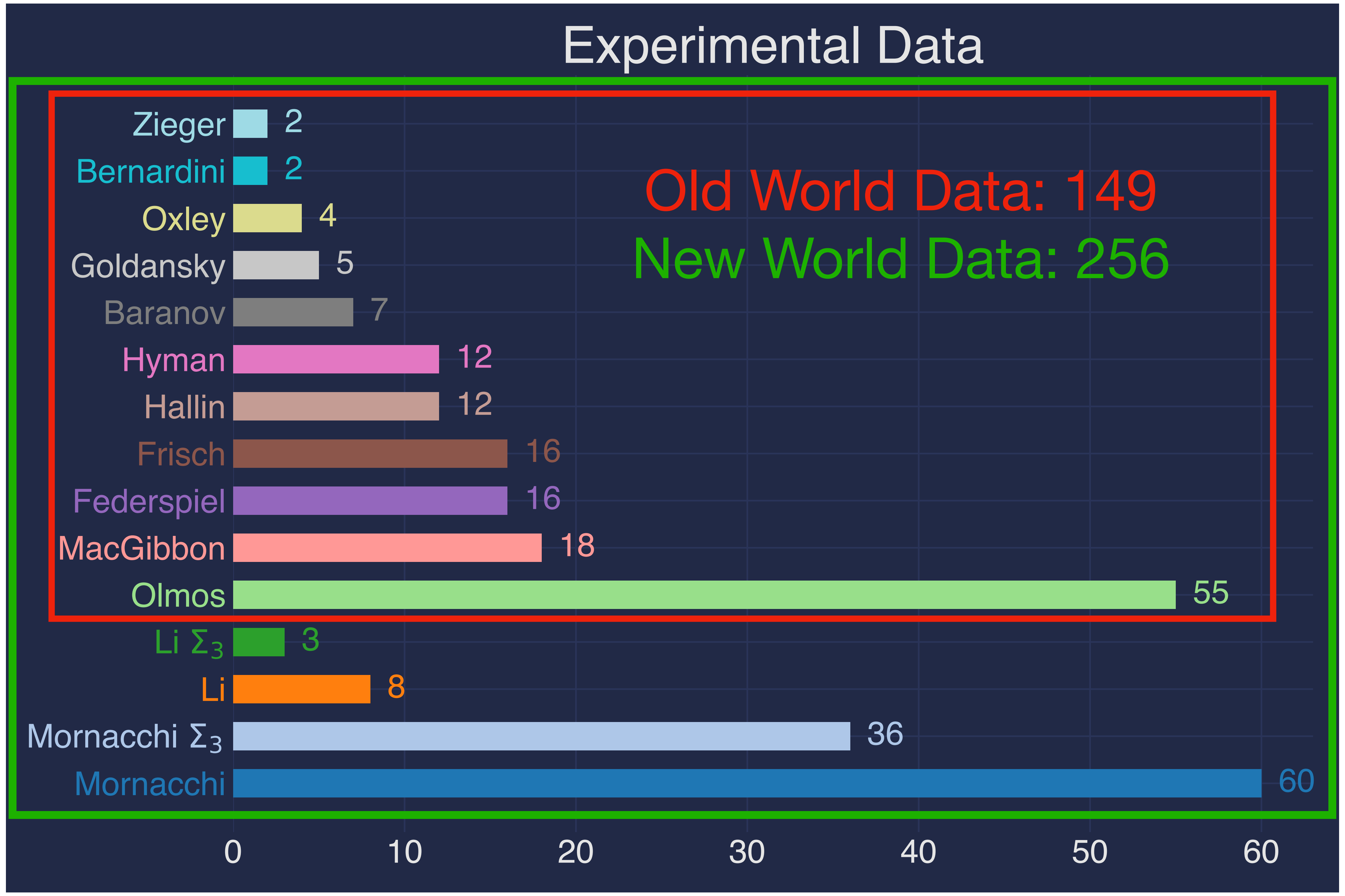
Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

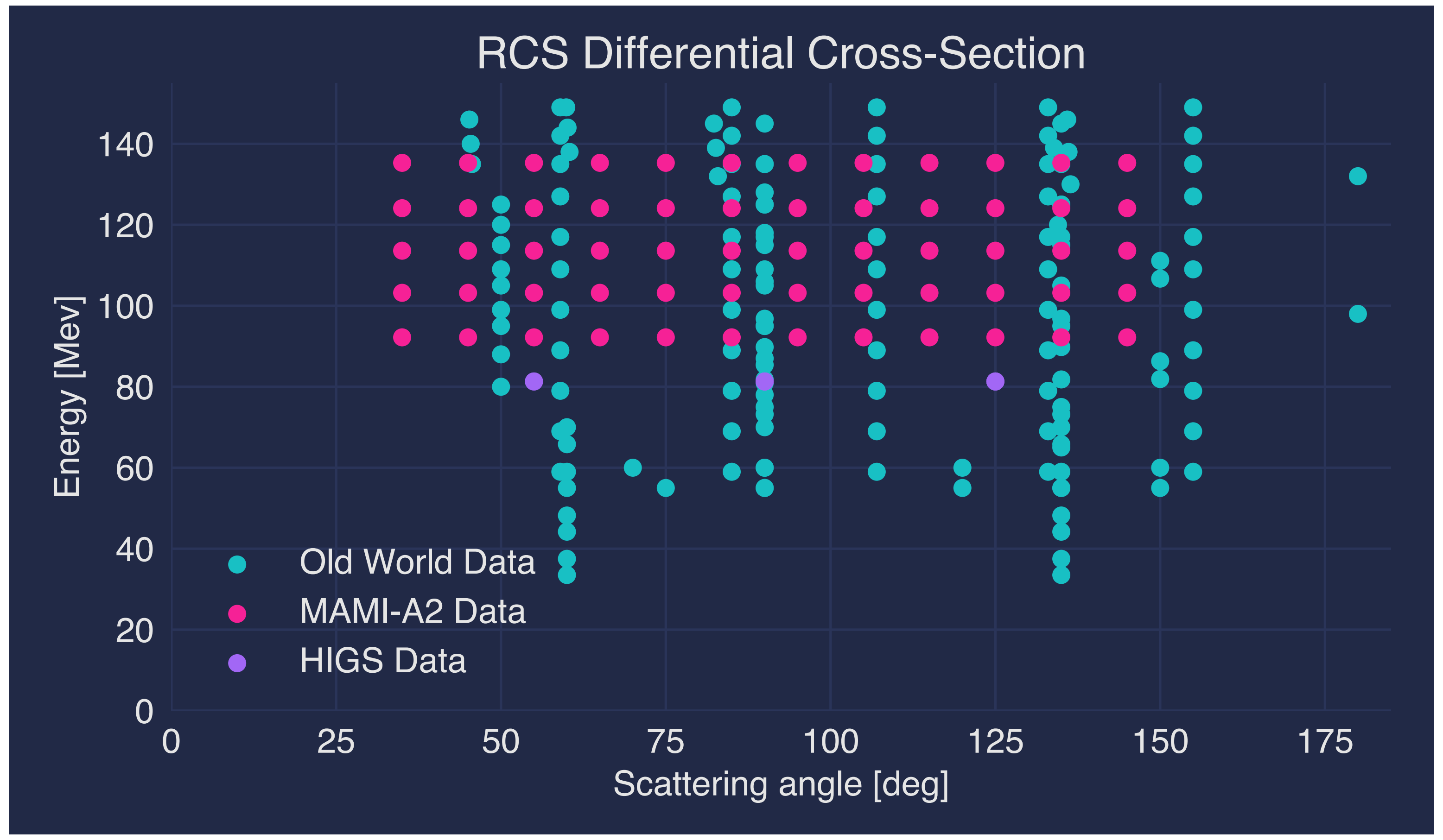




Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

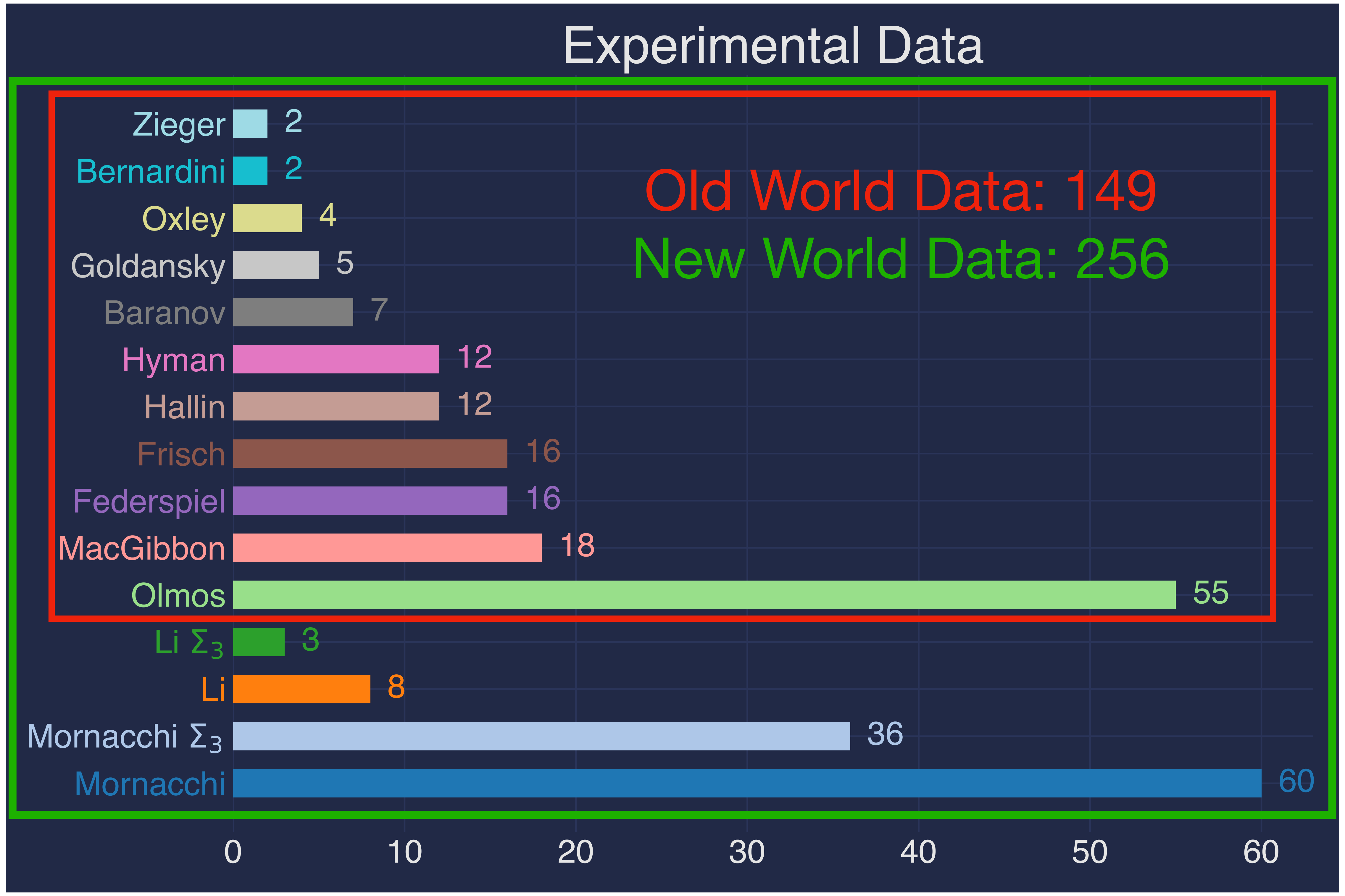
Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

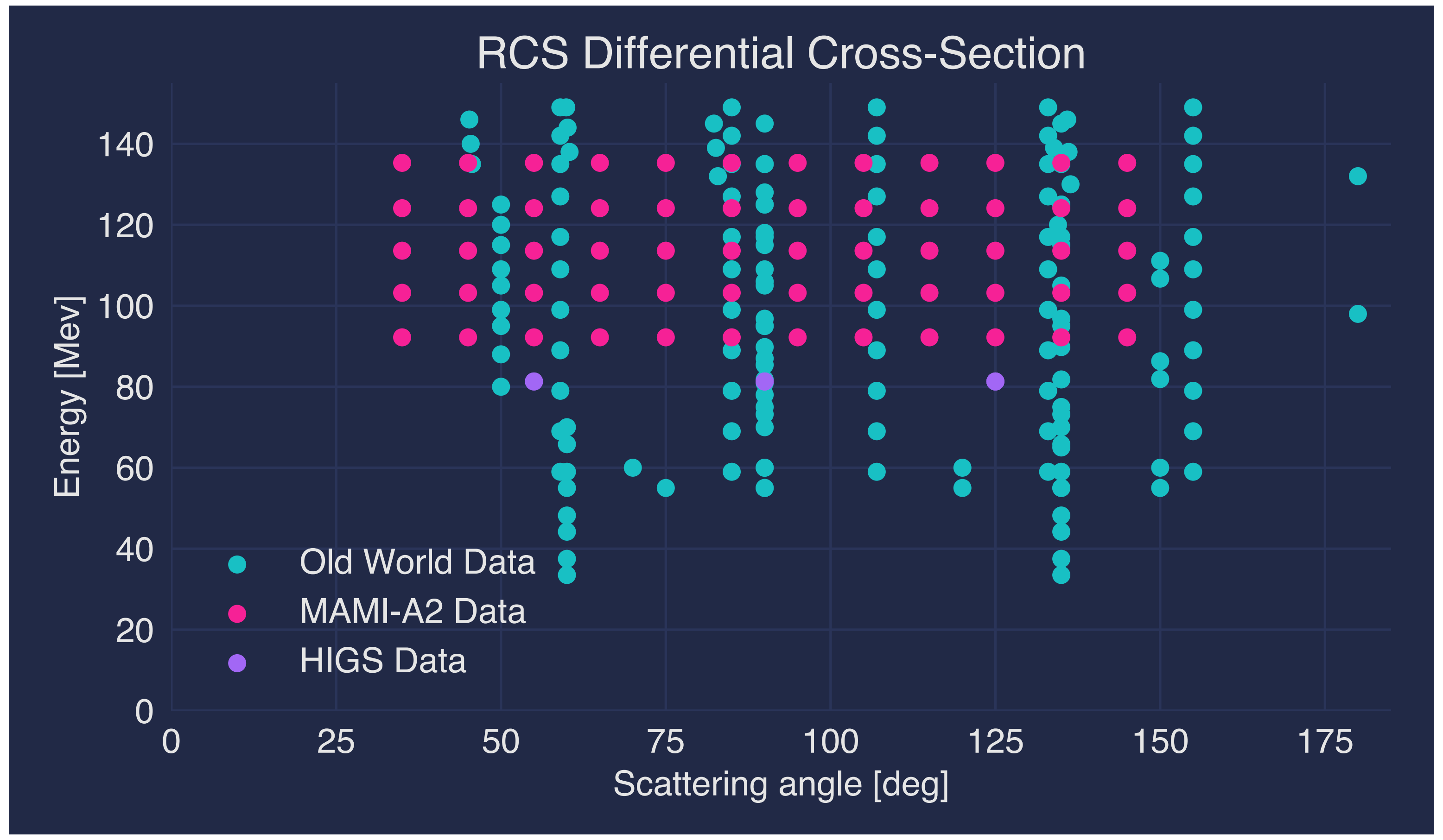


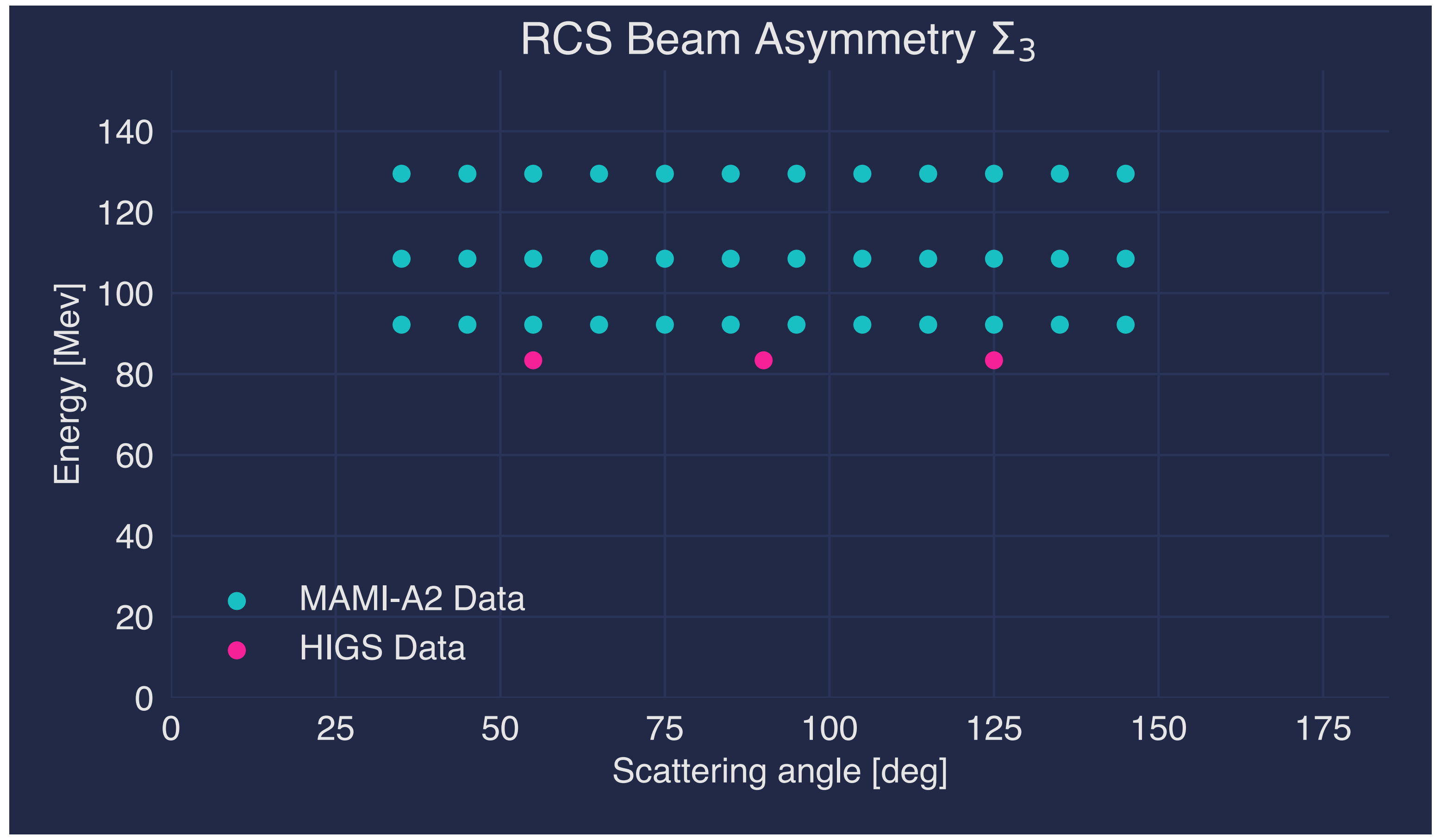


Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data







Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

- 70% more data

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

- 70% more data
- Reduced model dependence

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

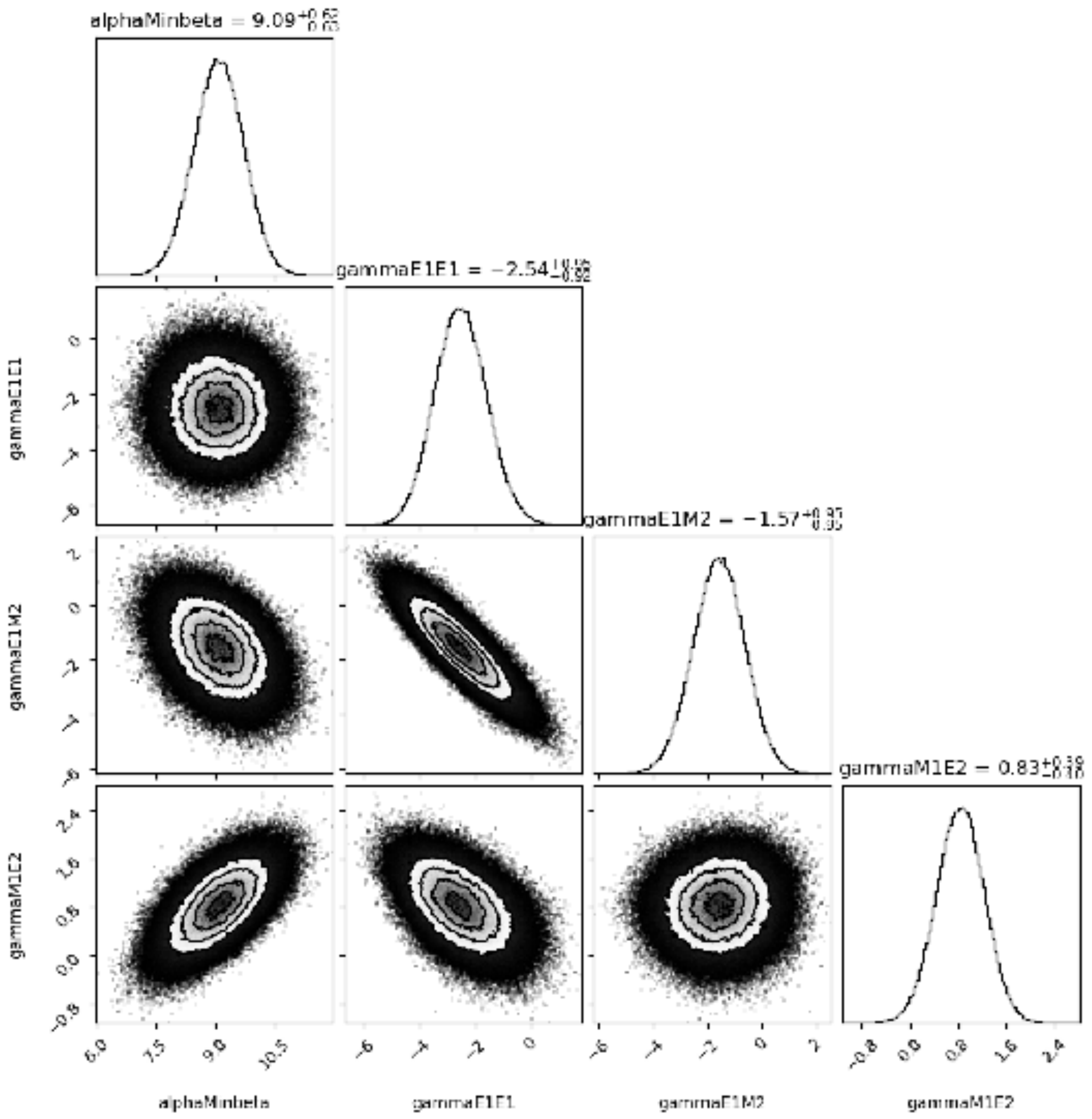
- 70% more data
- Reduced model dependence
- Accounting for normalisation uncertainties

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

- 70% more data
- Reduced model dependence
- Accounting for normalisation uncertainties
- Refined fitting method

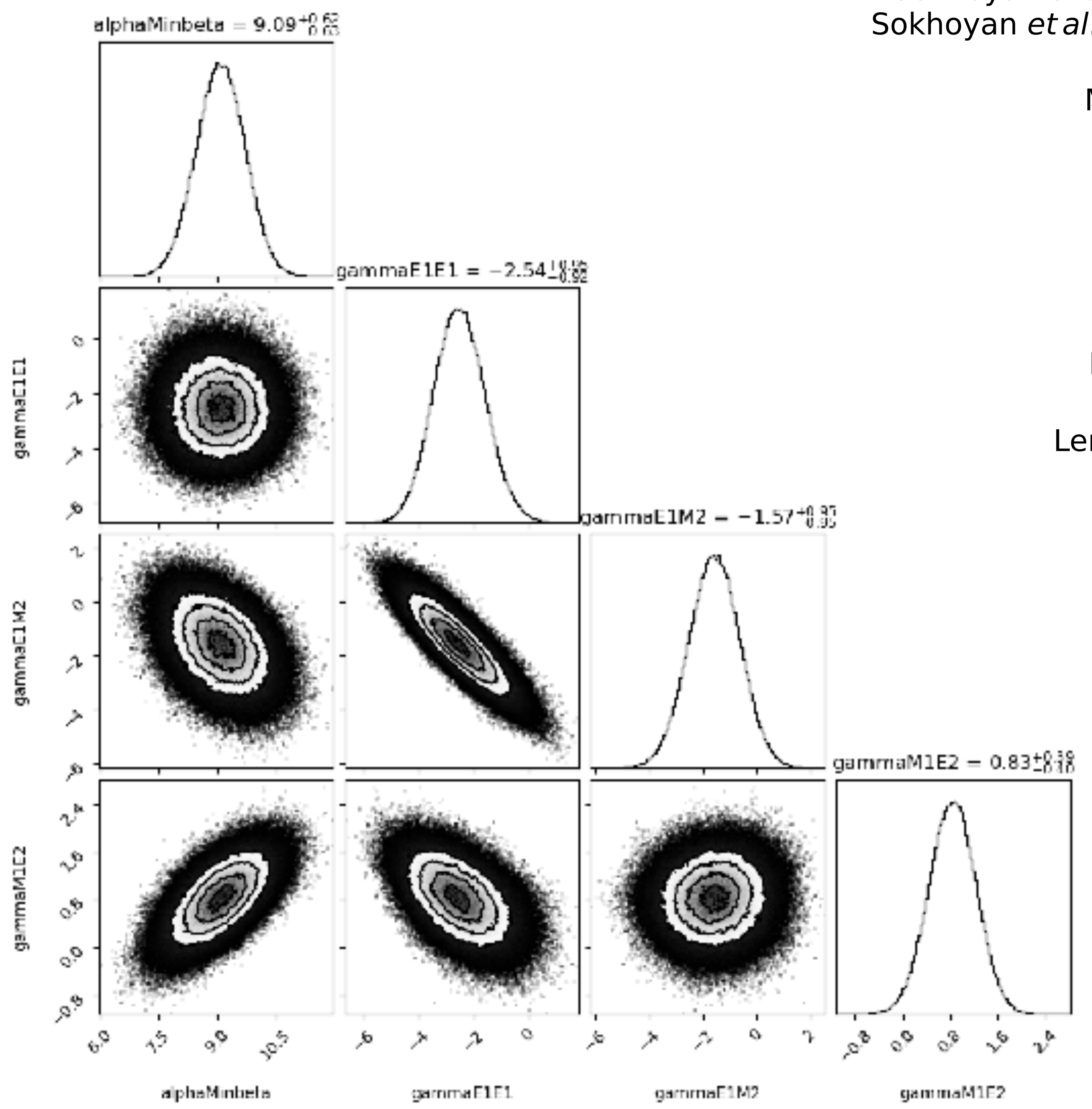


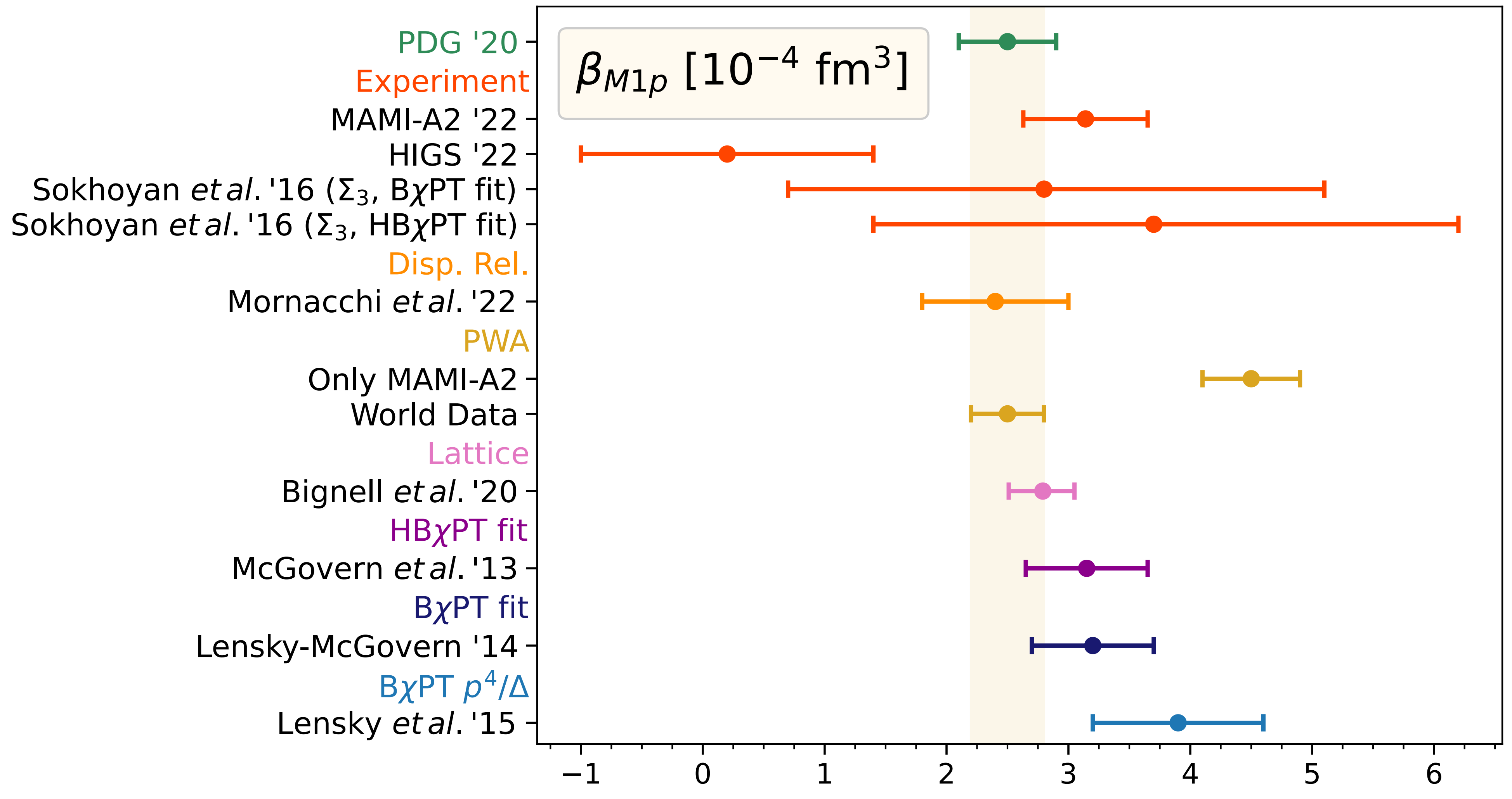
Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

- 70% more data
- Reduced model dependence
- Accounting for normalisation uncertainties
- Refined fitting method



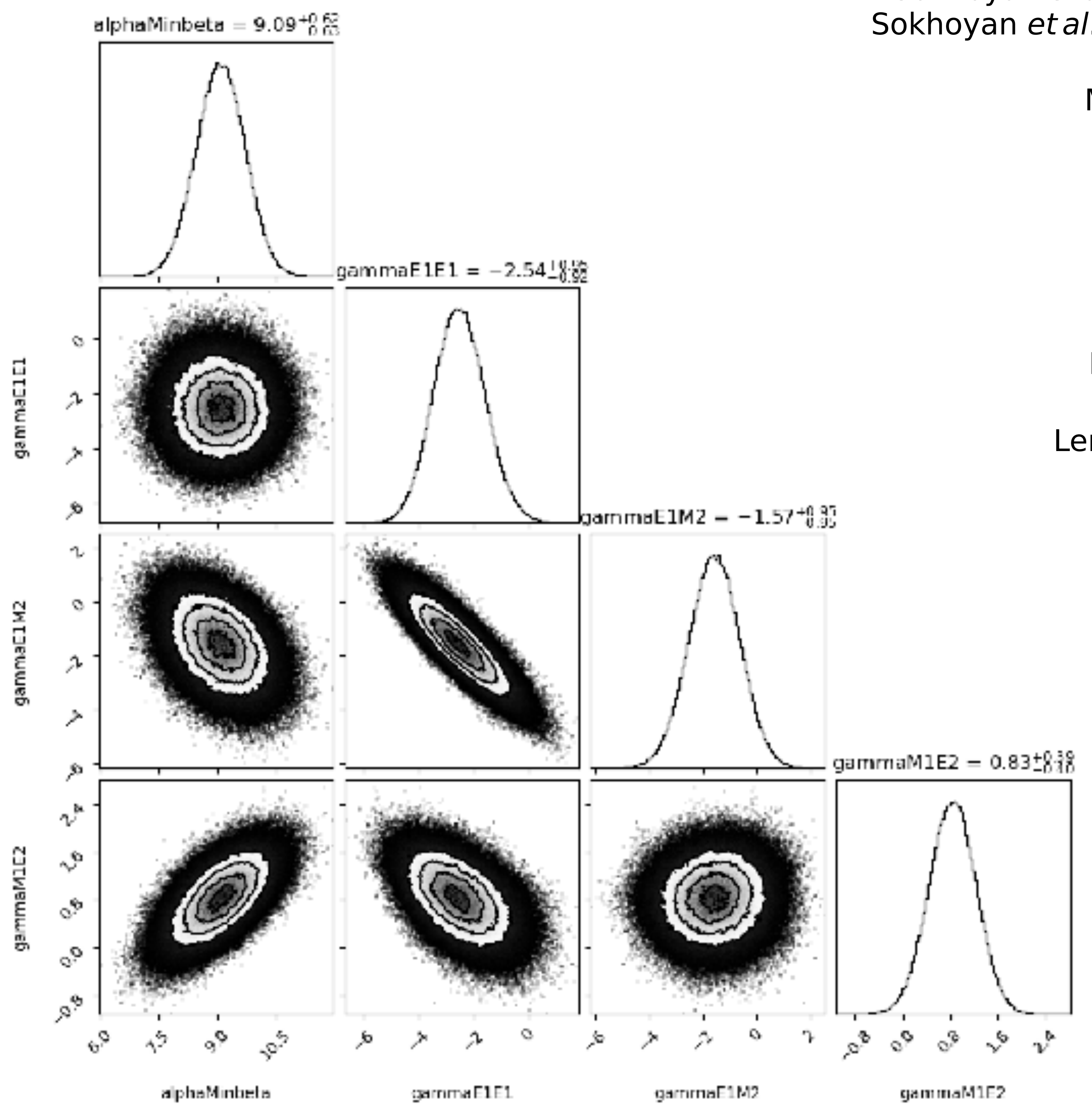


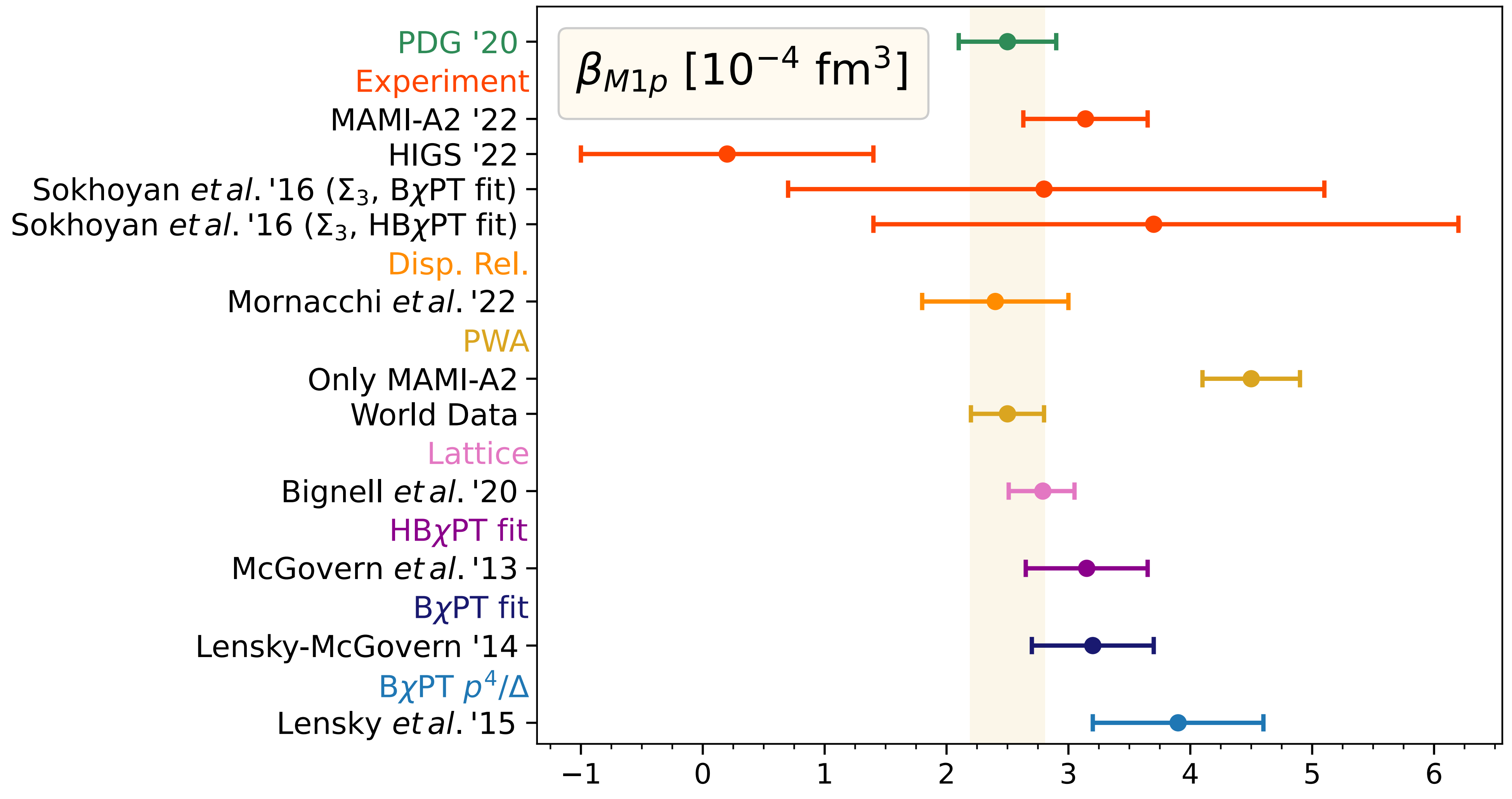
Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Proton scalar and spin polarisabilities from partial wave analysis of Compton scattering data

Improvements

- 70% more data
- Reduced model dependence
- Accounting for normalisation uncertainties
- Refined fitting method





Do you want to take a closer look?

Then come and visit me at my poster.

Timon Esser
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

TRIUMF

Electroweak corrections to V_{ud} via nuclear theory

Michael Gennari

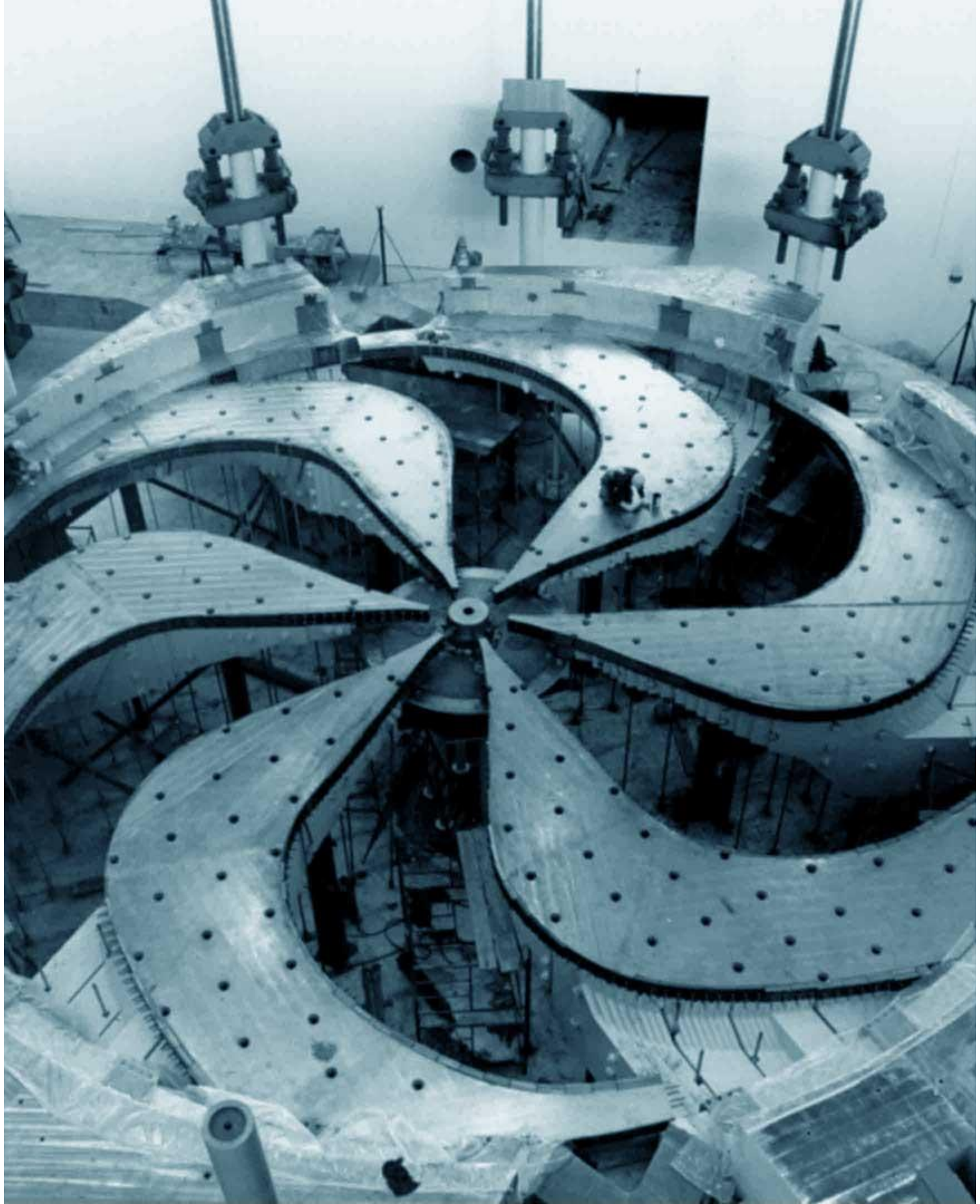
TRIUMF and University of Victoria

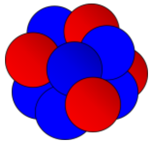
Collaborators: Mehdi Drissi, Mack Atkinson, Chien-Yeah Seng, Misha Gorchtein, Petr Navrátil

University of Victoria

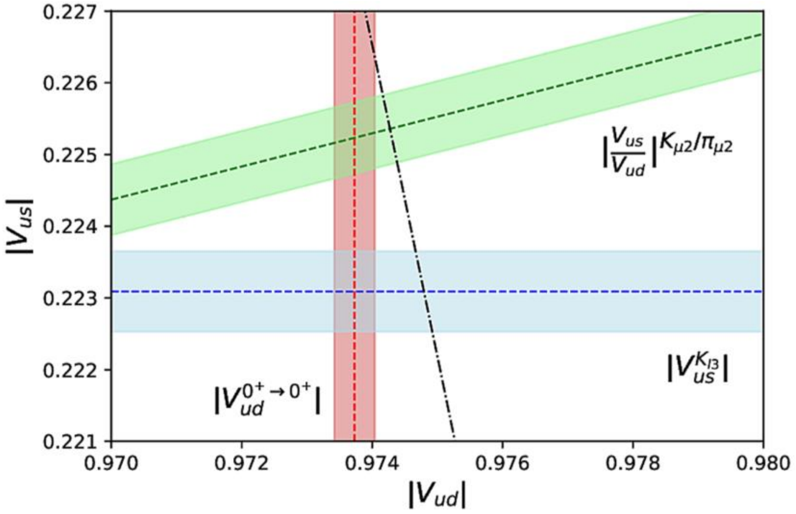
FRIB

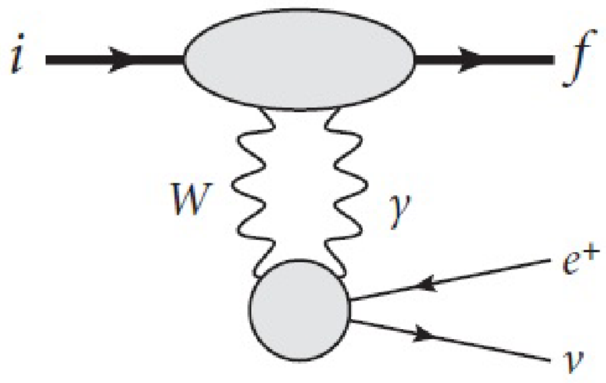
JOHANNES GUTENBERG UNIVERSITÄT MAINZ





$SU(3)_C$ ← Standard Model → $SU(2)_L \times U(1)_Y$

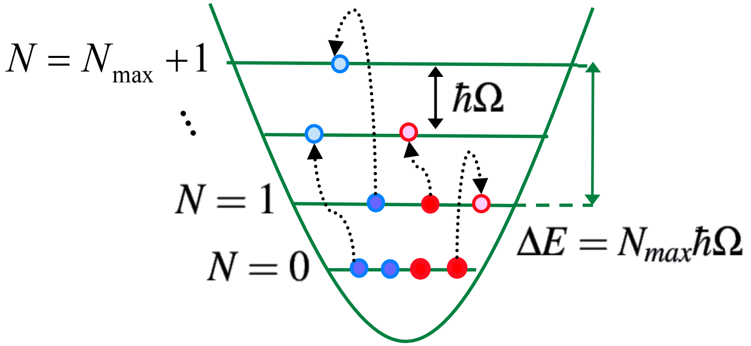


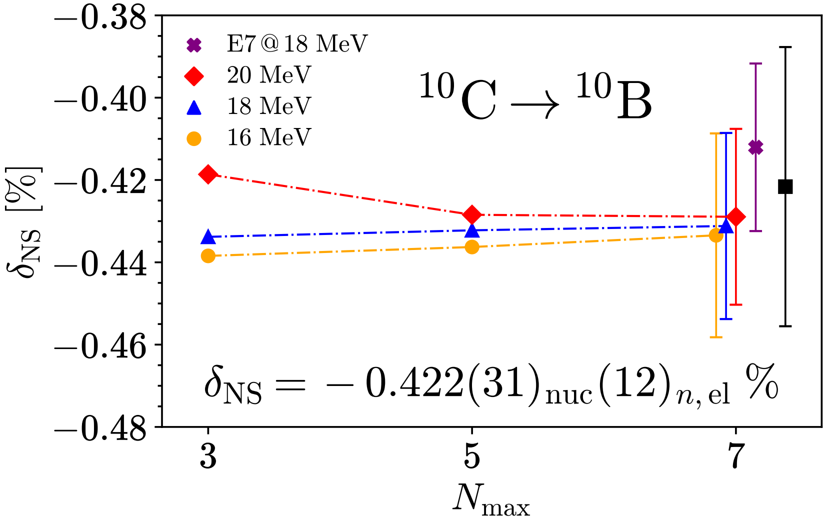


Haxton et al. (2007)
Seng et al. (2023)

$$\mathcal{F}t = ft(1+\delta_R')(1-\delta_C+\delta_{NS})$$

Barrett et al. (2013)
Haydock (1974)



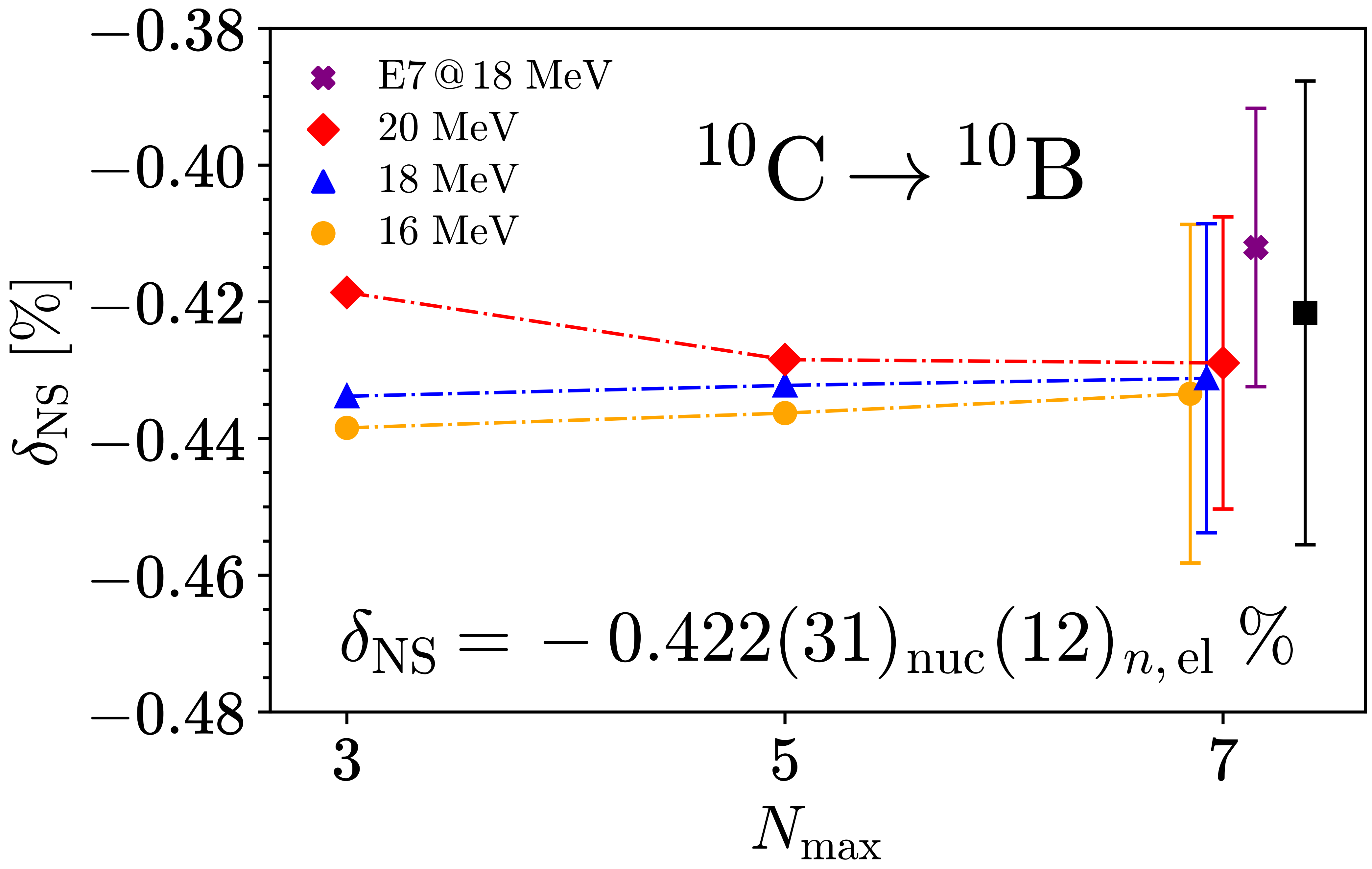


Chiral Effective Field Theory

Entem et al. (2017)
Somà et al. (2020)

Weinberg (1991)
Epelbaum (2009)

$$H\left|\Psi_A^{J^\pi T}\right\rangle = E^{J^\pi T}\left|\Psi_A^{J^\pi T}\right\rangle$$



E7@18 MeV
20 MeV
18 MeV
16 MeV
$^{10}\mathrm{C} \to {}^{10}\mathrm{B}$
$\delta_{\mathrm{NS}} = -0.422(31)_{\mathrm{nuc}}(12)_{n,\mathrm{el}}\,\%$
−0.38
−0.40
−0.42
−0.44
−0.46
−0.48
δ_{NS} [%]
3
5
7
N_{max}

3

TRIUMF

Thank you
Merci

www.triumf.ca

Follow us **@TRIUMFLab**

Discovery, accelerated

NUCLEUS: recent results and prospects

Marco Giammei

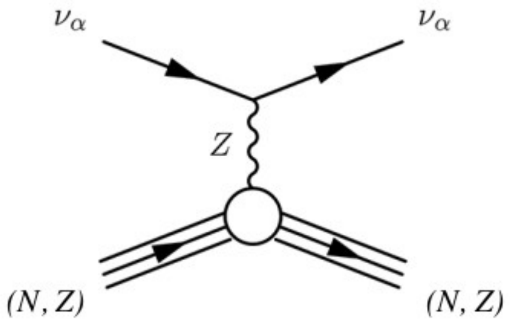
INFN

TOR VERGATA
UNIVERSITÀ DEGLI STUDI DI ROMA

EXPERIMENT
nu cleus

CEνNS

- The **Coherent Elastic Neutrino-Nucleus Scattering** (CEνNS) was predicted by Freedman in 1973 within **the Standard Model**
- It was **firstly seen only in 2017** by the COHERENT collaboration
- The **CEνNS cross section is several orders of magnitude bigger** compared to that of other low-energy process involving neutrinos, **but the nuclear recoil produced (the observable) is very small**

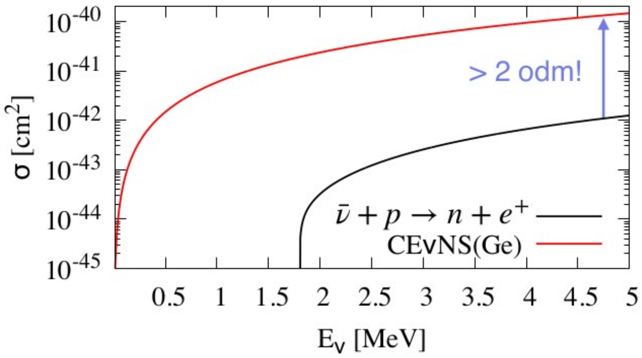


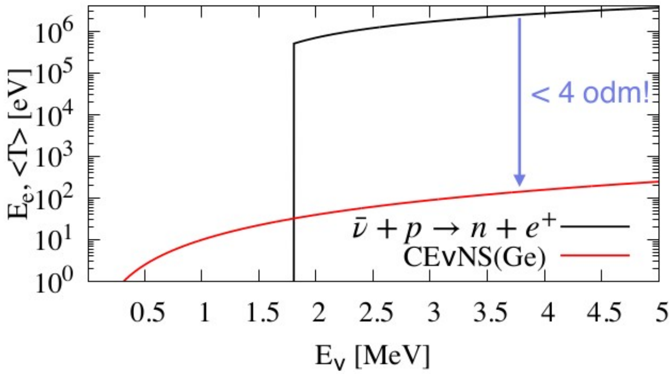
$$\sigma_{\mathrm{CE}\nu\mathrm{NS}} = \frac{G_F^2}{4\pi} F^2(q^2) Q_W^2 E_\nu^2$$

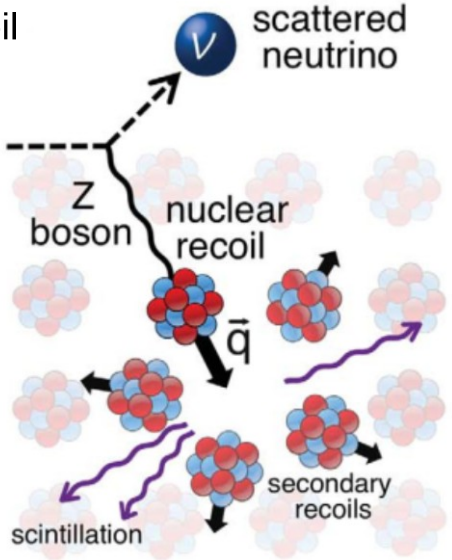
$$Q_W = N - Z(1 - 4\sin^2\theta_W) \sim N$$

Observable: kinetic energy of nuclear recoil

$$< T >= \frac{2}{3} \frac{E_\nu^2}{M_A}$$

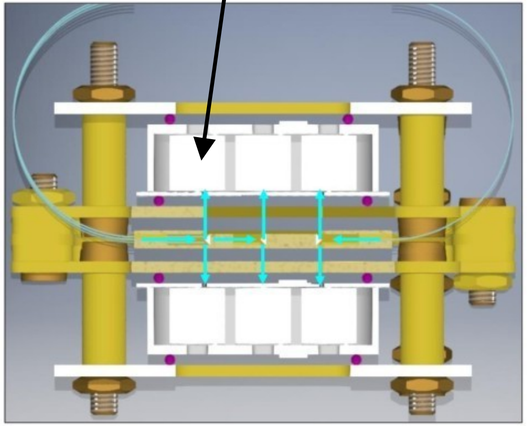


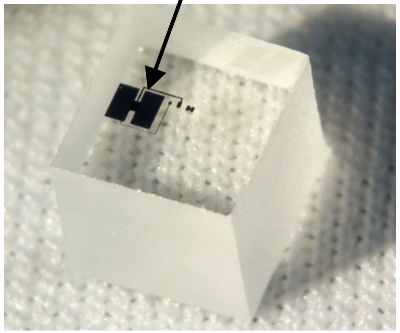


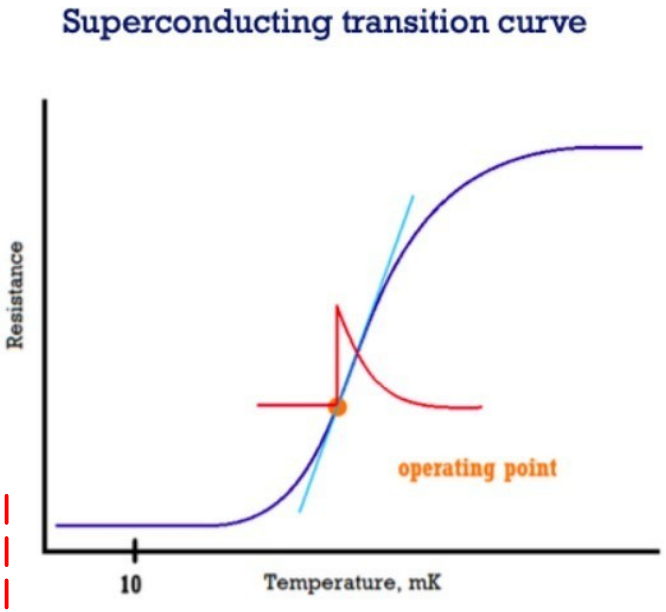


NUCLEUS Cryogenic Target Detector

Absorber crystals + Transition Edge Sensors (TES)







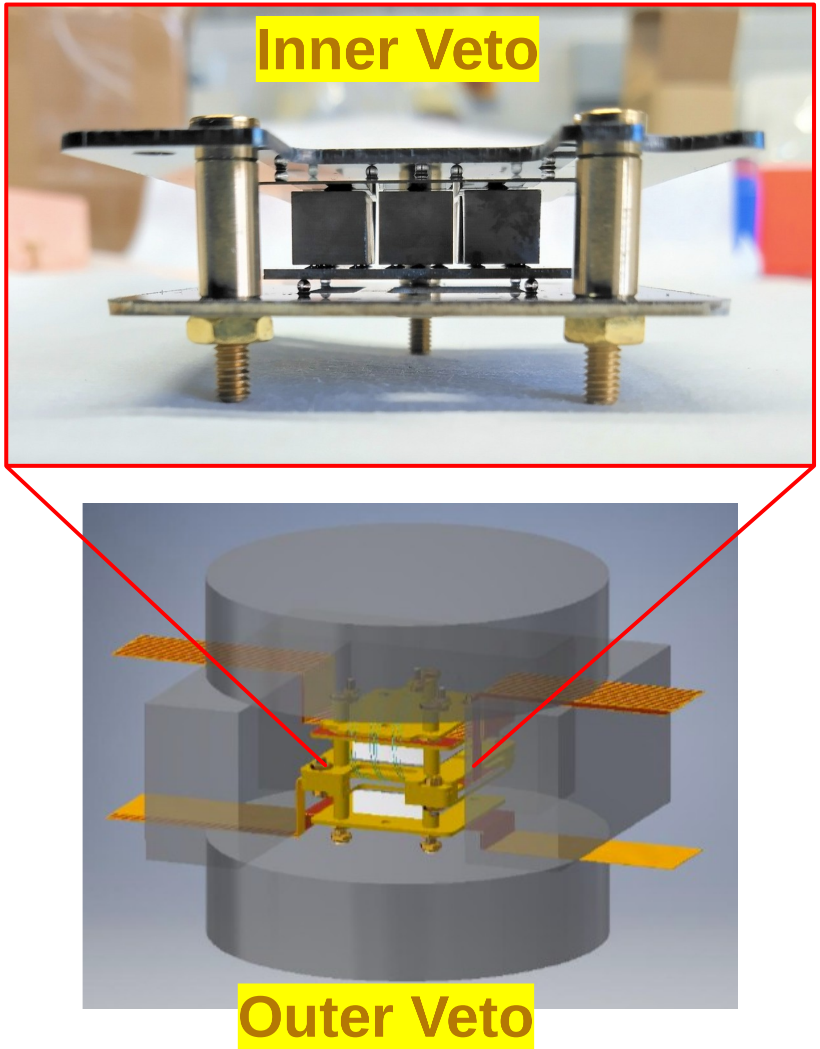
NUCLEUS-10g Cryogenic Detector: two 3x3 matrices of target detectors made of Al_2O_3 and $CaWO_4$

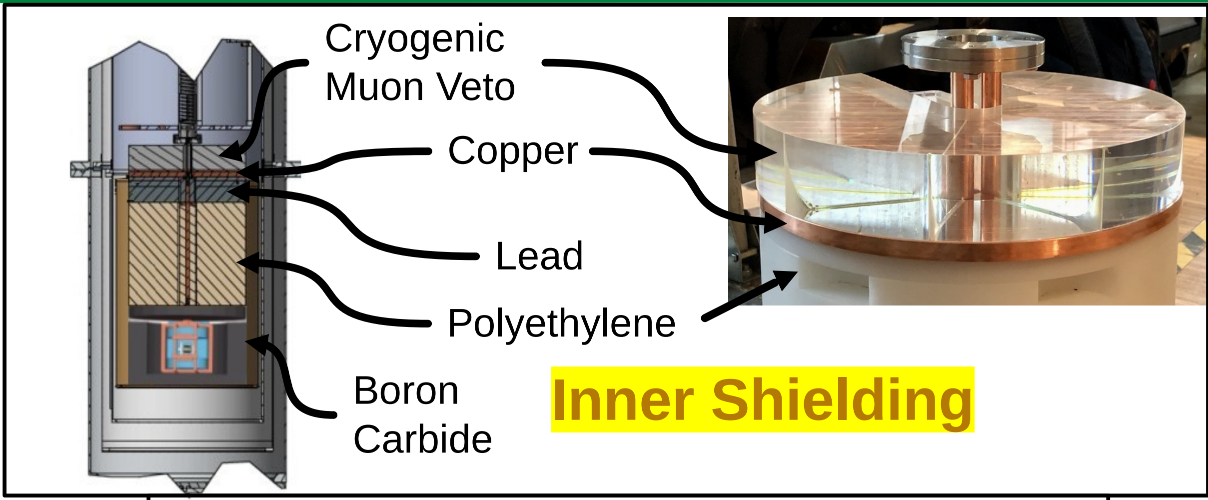
- Baseline resolution well under 10 eV
- Rise Time ~ 0.5 ms
- Decay Time ~ 15 ms

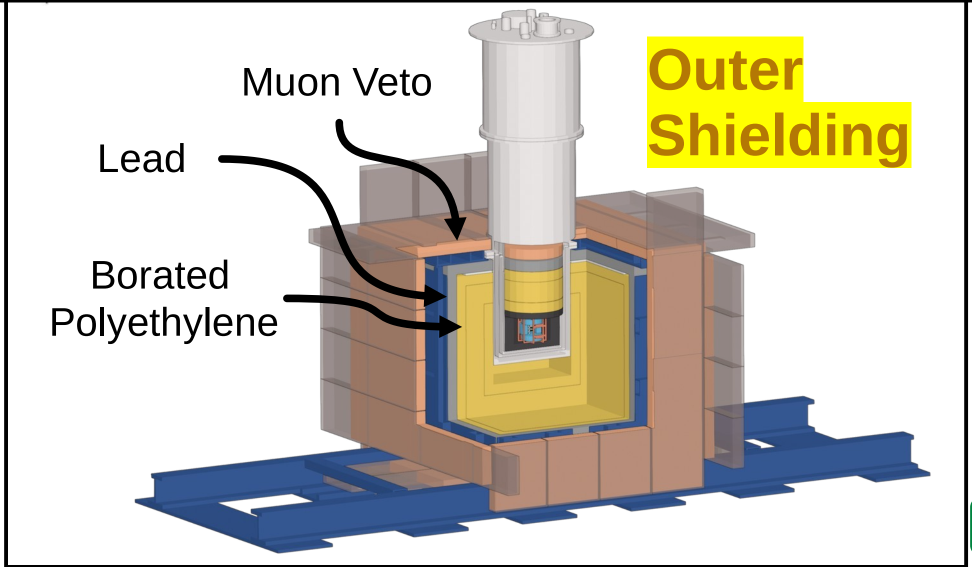
CEvNS produced upon scattering on $CaWO_4$

Particle Interaction → Phonon Production → TES heating → Resistance Change

Active Vetoes and Passive Shielding







Boosting of the Generalized Contact Formalism

Nitzan Goldberg
Prof. Nir Barnea

The Racah Institute of Physics
The Hebrew University of Jerusalem

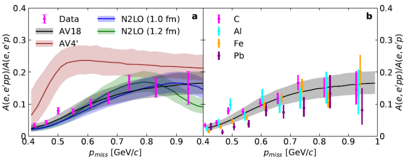
EPIC,
Sepetember 2024

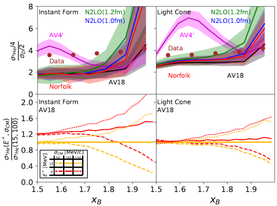
GCF and Lab calculations

- Nuclear Short Range Correlations (**SRCs**) are pair of nucleons that are **close together** in the nucleus.
- The General Contact Formalism (**GCF**) describes SRC using the Ansatz

$$\Psi\left(\boldsymbol{k}_1, \boldsymbol{k}_2, \ldots, \boldsymbol{k}_A\right) \underset{k_{ij} \to \infty}{\longrightarrow} \varphi_{ij}\left(\boldsymbol{k}_{ij}\right) A_{ij}\left(\boldsymbol{K}_{ij}, \{\boldsymbol{k}_n\}_{n \neq i,j}\right)$$

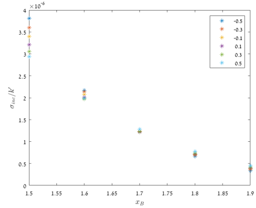
- Lab frame calculations show **good results** for the **exclusive cross section**. However, for the **inclusive case**, there is a **disagreement with the data**.

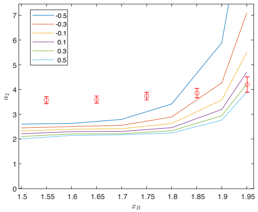




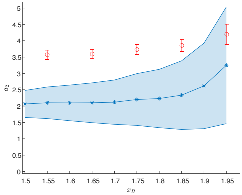
Boosted frames calculations

We have calculated **invariant quantities** such as $\frac{\sigma_{inc}}{k'}$ and $\frac{\sigma_{inc}^{^4He}}{\sigma_{inc}^{d}}$ in **boosted** frames.





We also defined the **semi-Breit** frame for each value of x_B to find the optimal frame.



Thank you!

MREX: The Mainz Radius EXperiment

Nikita Kozyrev

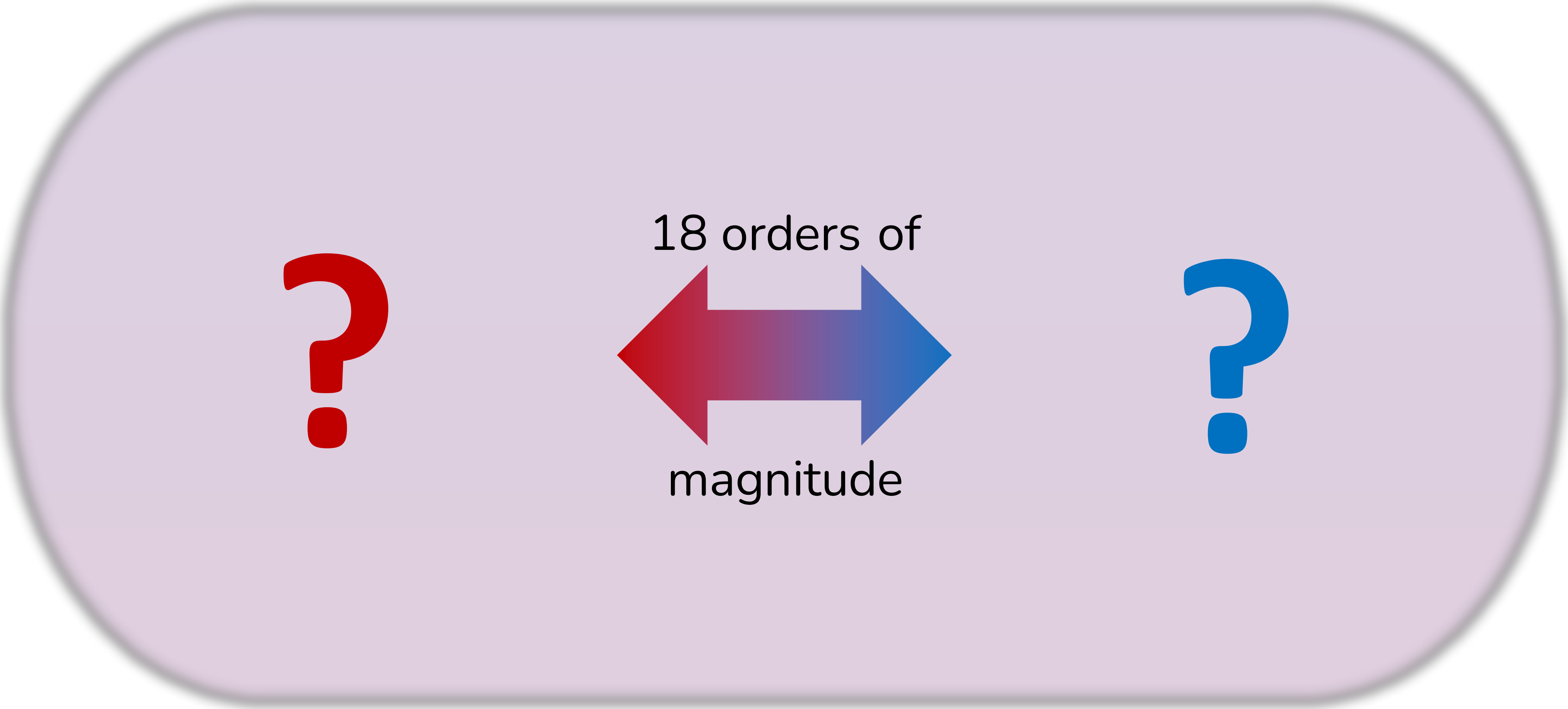
Institute for Nuclear Physics, Johannes Gutenberg-University Mainz

Cluster of Excellence PRISMA+ Precision Physics, Fundamental Interactions and Structure of Matter

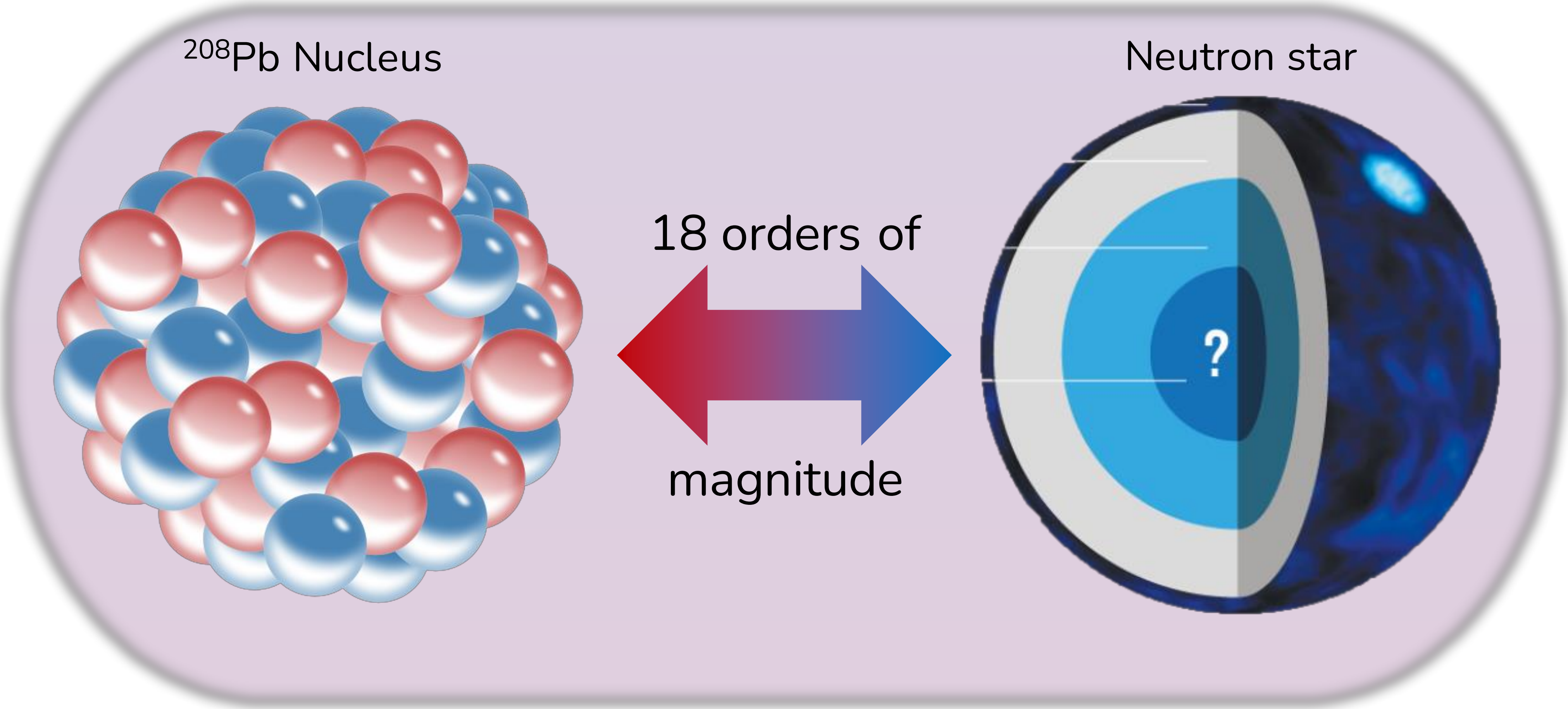
Electroweak Physics InterseCtions 2024

JG|U JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Connecting different scales



Connecting different scales



Neutron Skin and PREX-II

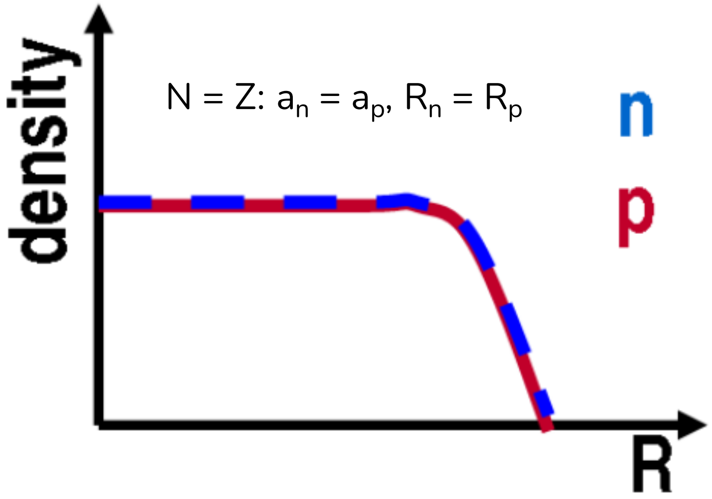
Nucleus

$$R_{skin} = R_n - R_p$$
$$R_n = \sqrt{\langle r_n^2 \rangle}$$
$$R_p = \sqrt{\langle r_p^2 \rangle}$$

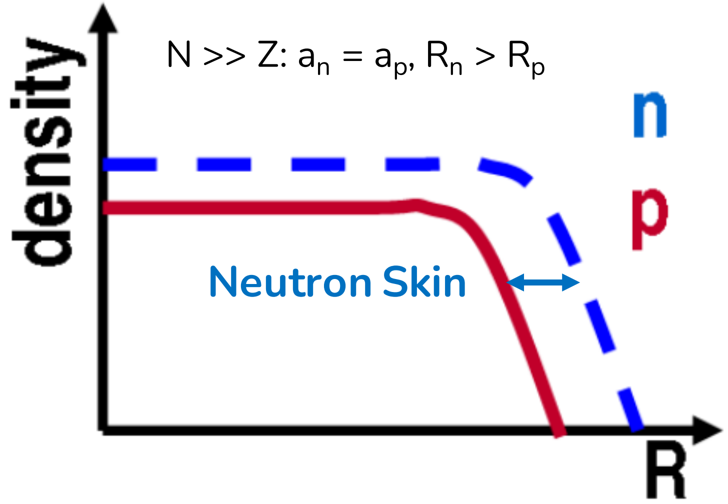
Neutron star

$\Lambda_\star$(LIGO)
$R_\star$(NICER)

$$\mathcal{E}(\rho,\alpha) = \mathcal{E}_{\rm SNM}(\rho) + \alpha^2 \mathcal{S}(\rho) + \mathcal{O}(\alpha^4)$$
$$\alpha \equiv (\rho_n - \rho_p)/(\rho_n + \rho_p)$$
$$L \equiv 3\rho_0 \left(\frac{\partial S}{\partial \rho}\right)\Big|_{\rho_0}$$



J. Phys. G, **46** (2019), 093003



Neutron Skin and PREX-II

Nucleus

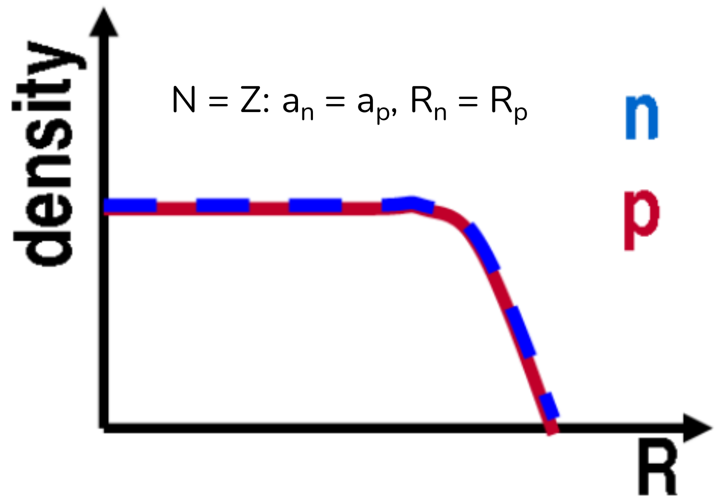
$$R_{skin} = R_n - R_p$$
$$R_n = \sqrt{\langle r_n^2 \rangle}$$
$$R_p = \sqrt{\langle r_p^2 \rangle}$$

Neutron star

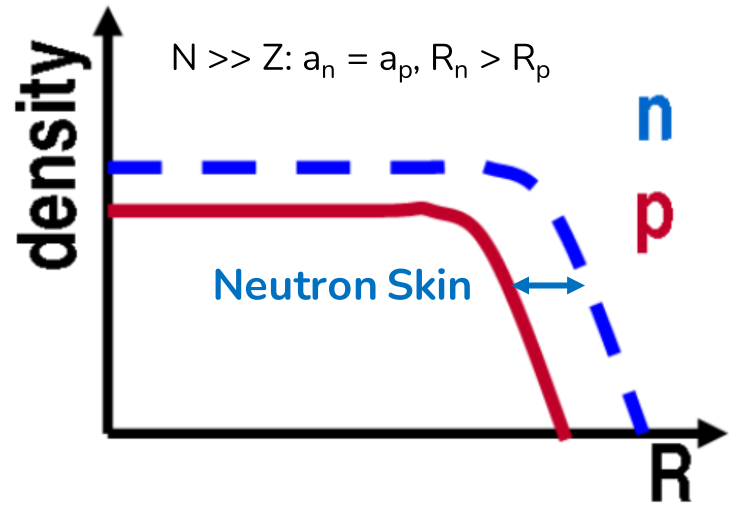
$\Lambda_\star$(LIGO)
$R_\star$(NICER)

$$\mathcal{E}(\rho,\alpha) = \mathcal{E}_{\rm SNM}(\rho) + \alpha^2 \mathcal{S}(\rho) + \mathcal{O}(\alpha^4)$$
$$\alpha \equiv (\rho_n - \rho_p)/(\rho_n + \rho_p)$$
$$L \equiv 3\rho_0 \left(\frac{\partial S}{\partial \rho}\right)\Bigg|_{\rho_0}$$

PREX-II: PVES determination of R_{skin} in ^{208}Pb
But: low statistics and tension with **astrophysics**



J. Phys. G, **46** (2019), 093003



Neutron Skin and PREX-II

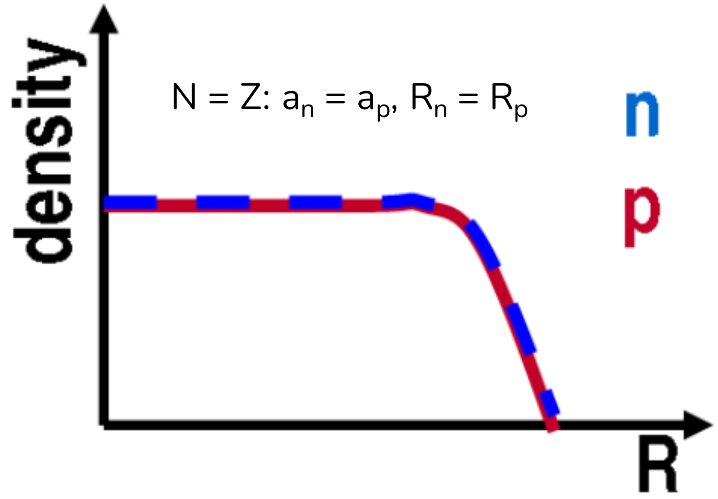
Nucleus

$$R_{skin} = R_n - R_p$$
$$R_n = \sqrt{\langle r_n^2 \rangle}$$
$$R_p = \sqrt{\langle r_p^2 \rangle}$$

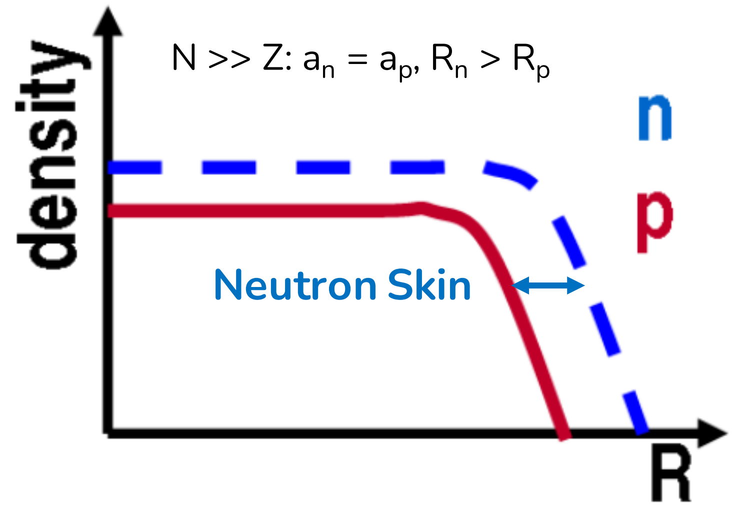
Neutron star

$\Lambda_\star$(LIGO)
$R_\star$(NICER)

$$\mathcal{E}(\rho,\alpha) = \mathcal{E}_{\text{SNM}}(\rho) + \alpha^2 \mathcal{S}(\rho) + \mathcal{O}(\alpha^4)$$
$$\alpha \equiv (\rho_n - \rho_p)/(\rho_n + \rho_p)$$
$$L \equiv 3\rho_0 \left(\frac{\partial S}{\partial \rho}\right)\Big|_{\rho_0}$$



J. Phys. G, **46** (2019), 093003

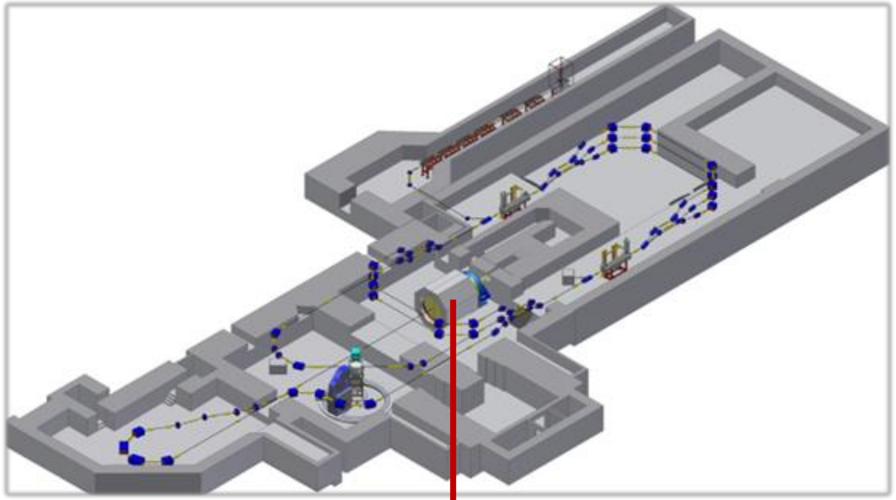


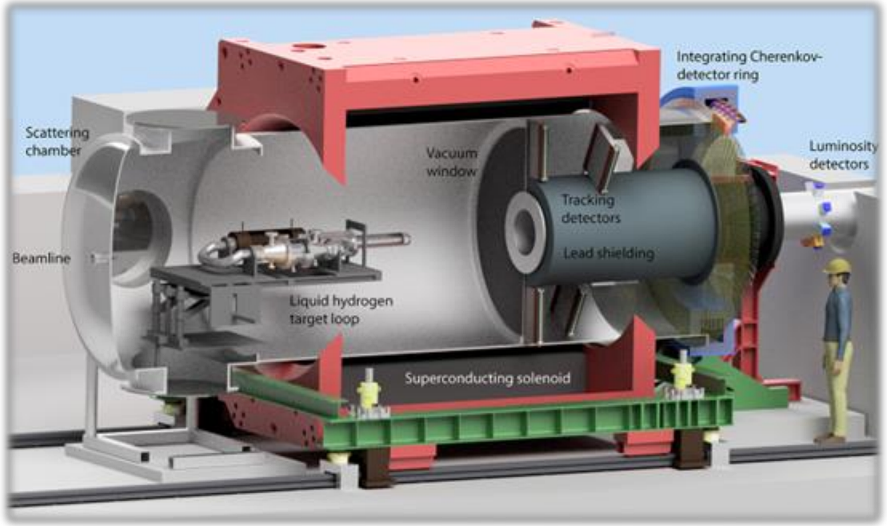
PREX-II: PVES determination of R_{skin} in ^{208}Pb
But: low statistics and tension with **astrophysics**

MREX

Outline

- Want to use Mainz Energy-recovering Superconducting Accelerator (**MESA**) and the **P2** experiment detector setup



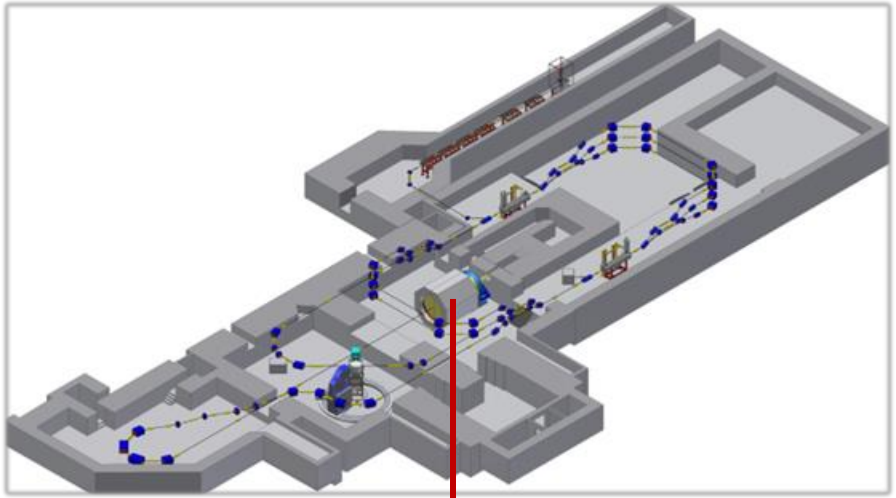


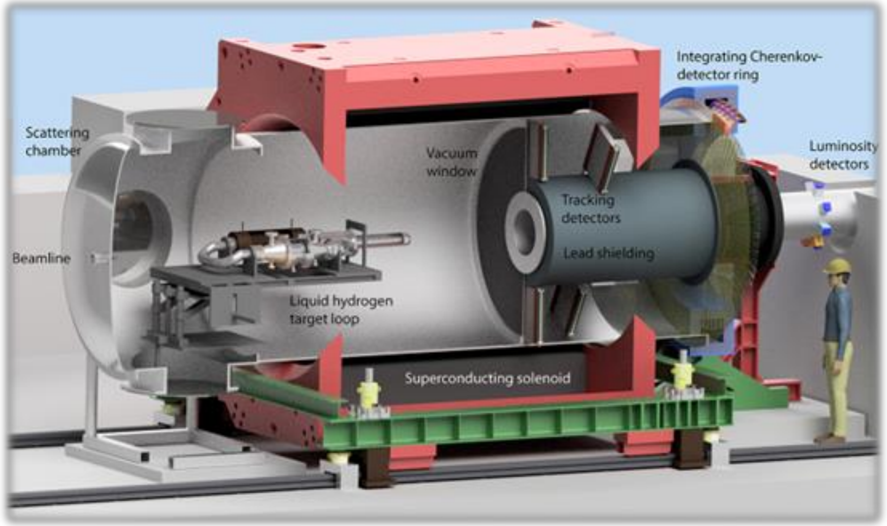
Outline

- Want to use Mainz Energy-recovering Superconducting Accelerator (**MESA**) and the **P2** experiment detector setup

- Need to match **<Q^2>** = 0.0062 (GeV/c)^2 of PREX-II

$$Q^2 = -q^2 = -(p - p')^2 = \frac{4EE'}{c^2} \cdot \sin^2\left(\frac{\theta}{2}\right)$$





Outline

- Want to use Mainz Energy-recovering Superconducting Accelerator (**MESA**) and the **P2** experiment detector setup

- Need to match **<Q²>** = 0.0062 $(\mathrm{GeV}/c)^2$ of PREX-II

$$Q^2 = -q^2 = -(p-p')^2 = \frac{4EE'}{c^2} \cdot \sin^2\left(\frac{\theta}{2}\right)$$

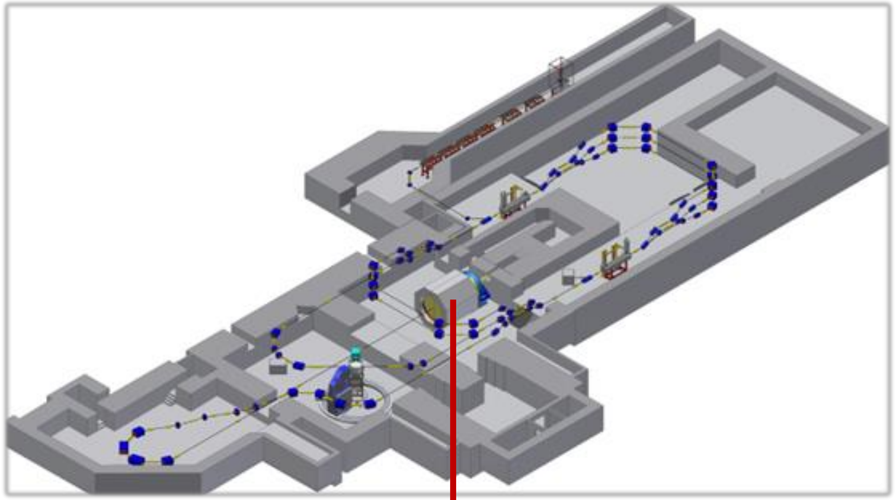
- Must account for and minimize **non-elastic contributions**

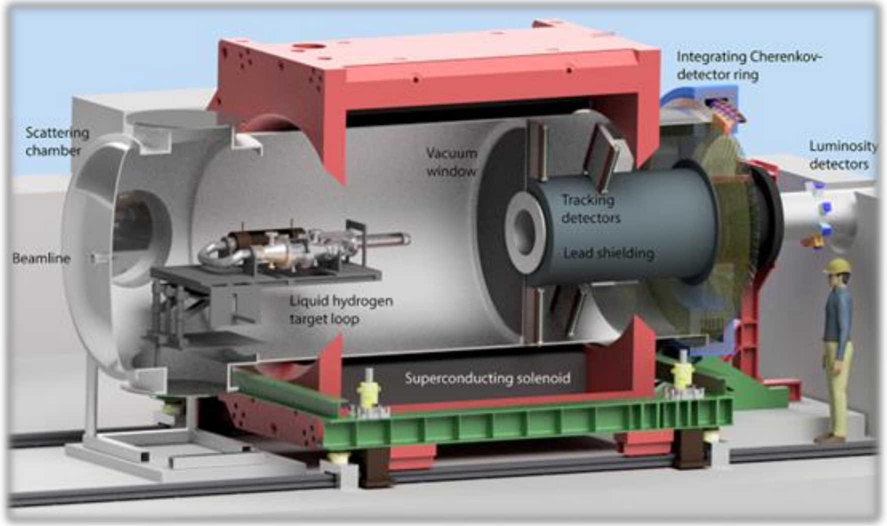
$$A^{meas} = (1 - \sum f_i)A^{el} + \sum f_i A_i, \text{ or}$$

$$A^{el} = \frac{A^{meas} - \sum f_i A_i}{(1 - \sum f_i)}.$$

$$\Delta A_i^f = \frac{A^{meas} - A_i}{(1 - \sum f_i)^2} \Delta f_i,$$

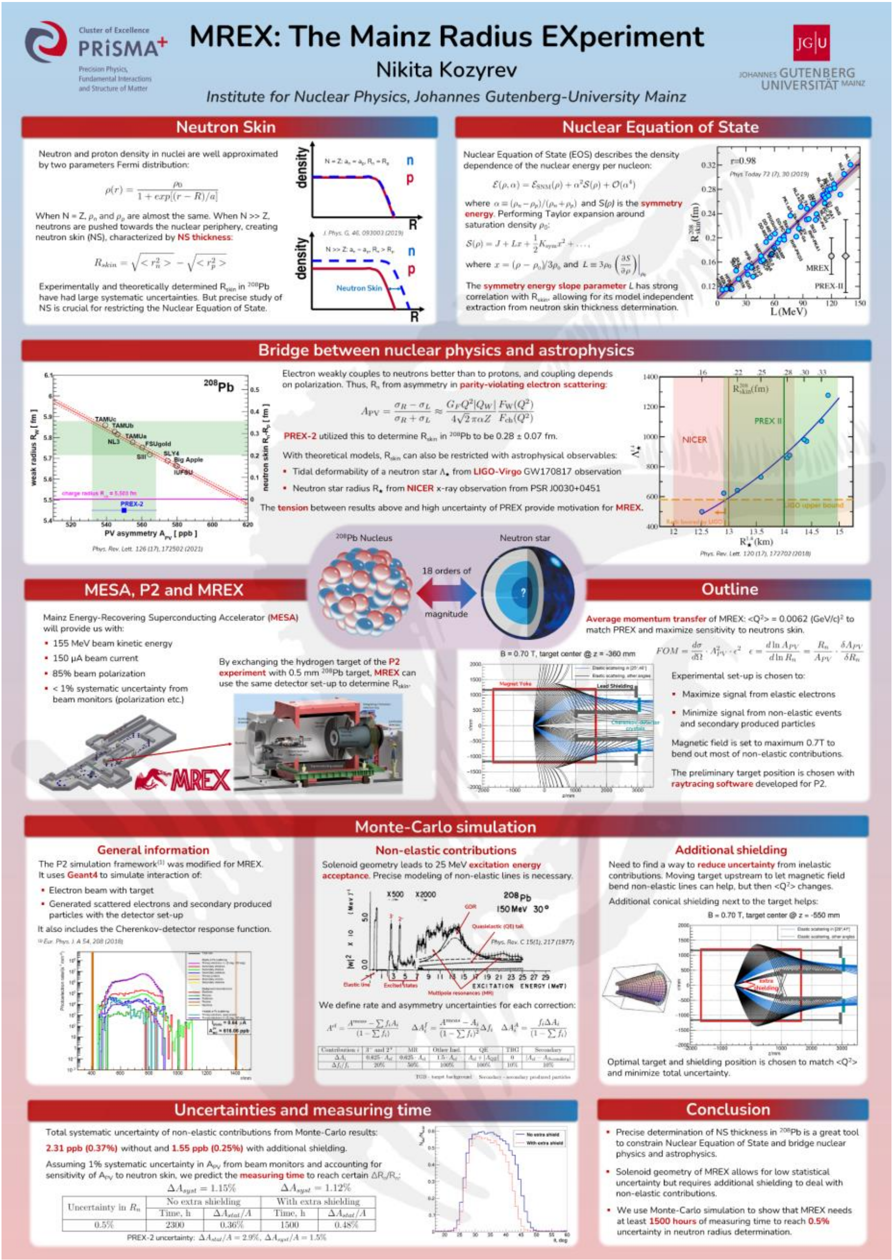
$$\Delta A_i^A = \frac{f_i \Delta A_i}{(1 - \sum f_i)}.$$





Come by to learn:

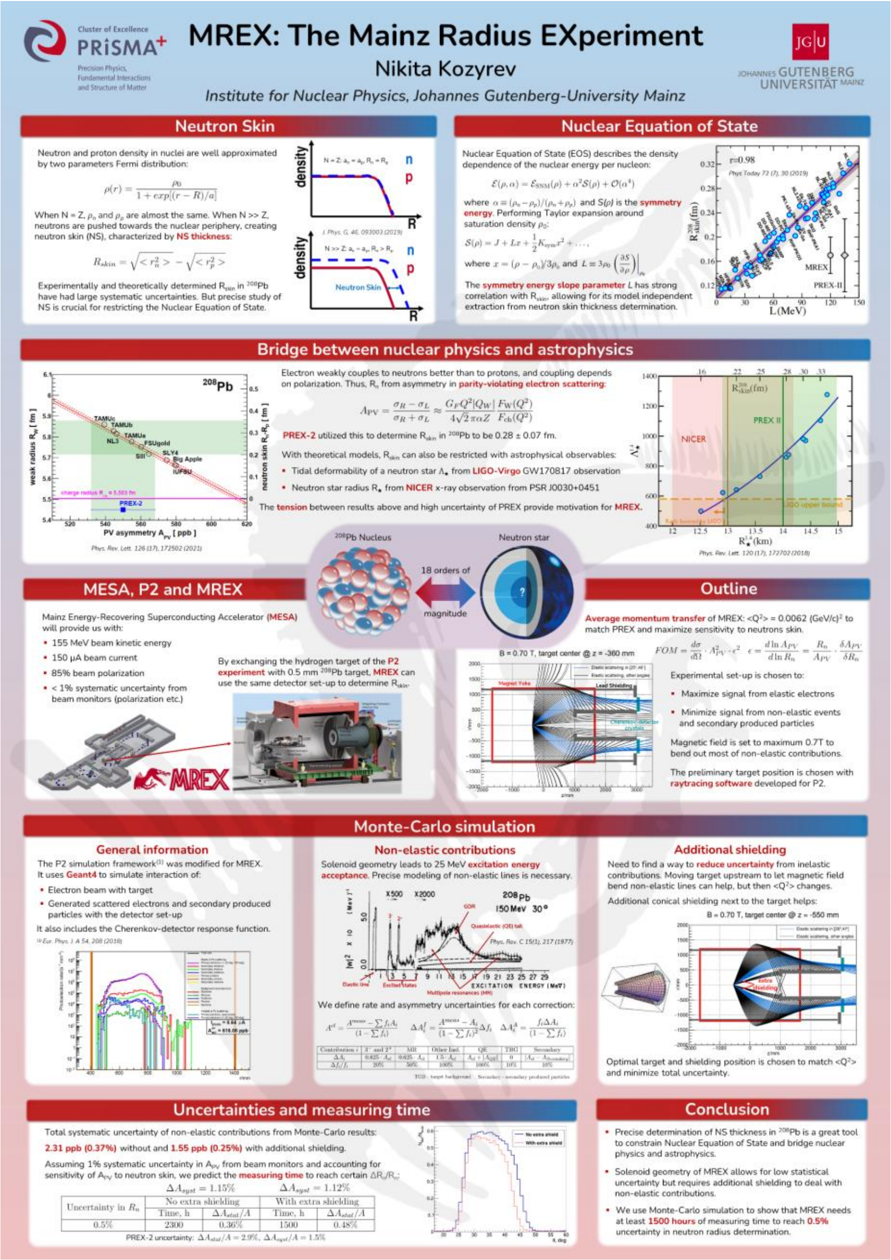
- How the simulation framework is built
- How to reduce uncertainty from non-elastics
- Which uncertainty in R_n can we reach
- How much measuring time we need



Come by to learn:

- How the simulation framework is built
- How to reduce uncertainty from non-elastics
- Which uncertainty in R_n can we reach
- How much measuring time we need

Thank you for your attention!



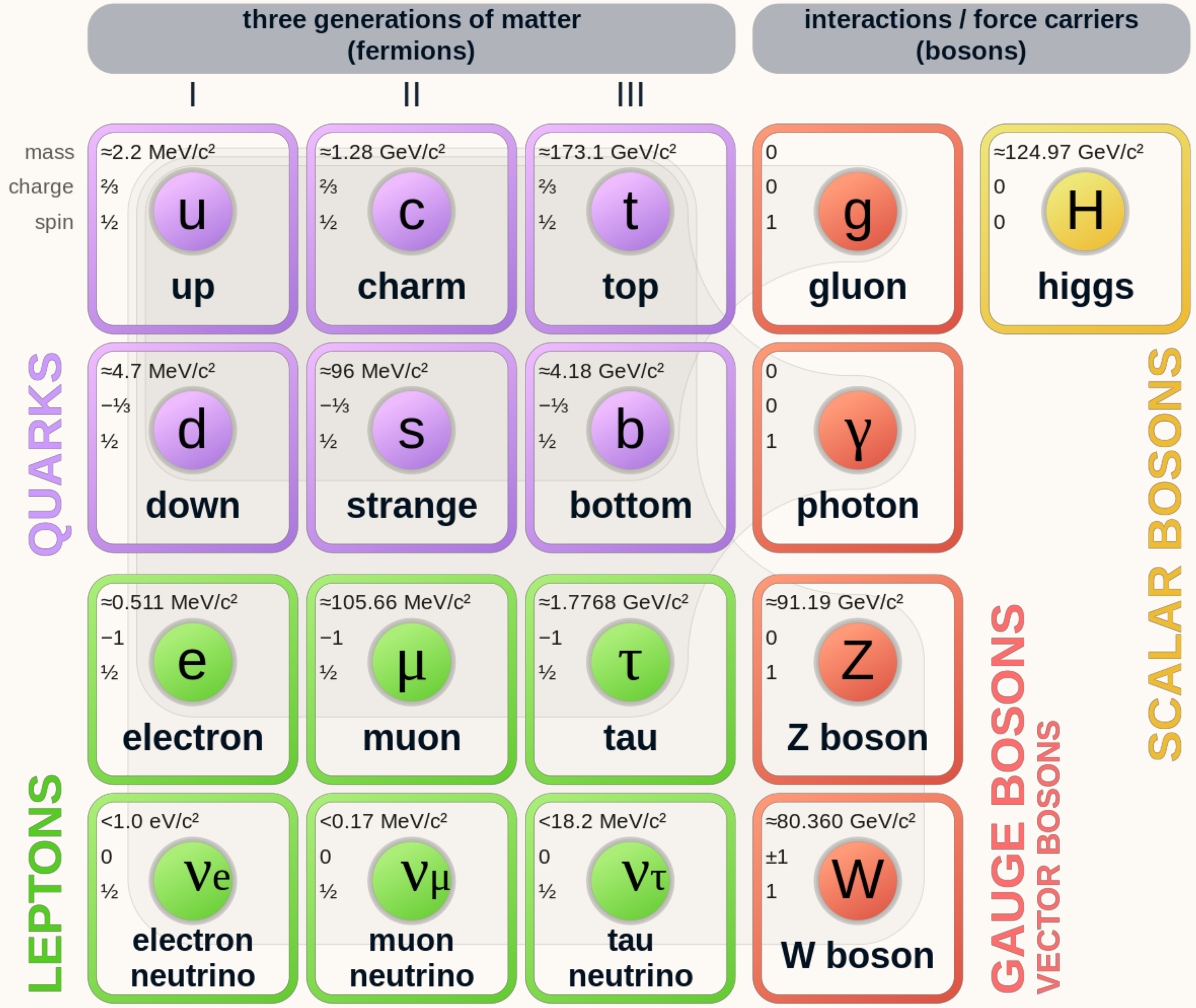
MANIFESTATION OF PHYSICS BEYOND THE STANDARD MODEL IN ATOMIC AND MOLECULAR PHENOMENA

Andrew Mansour

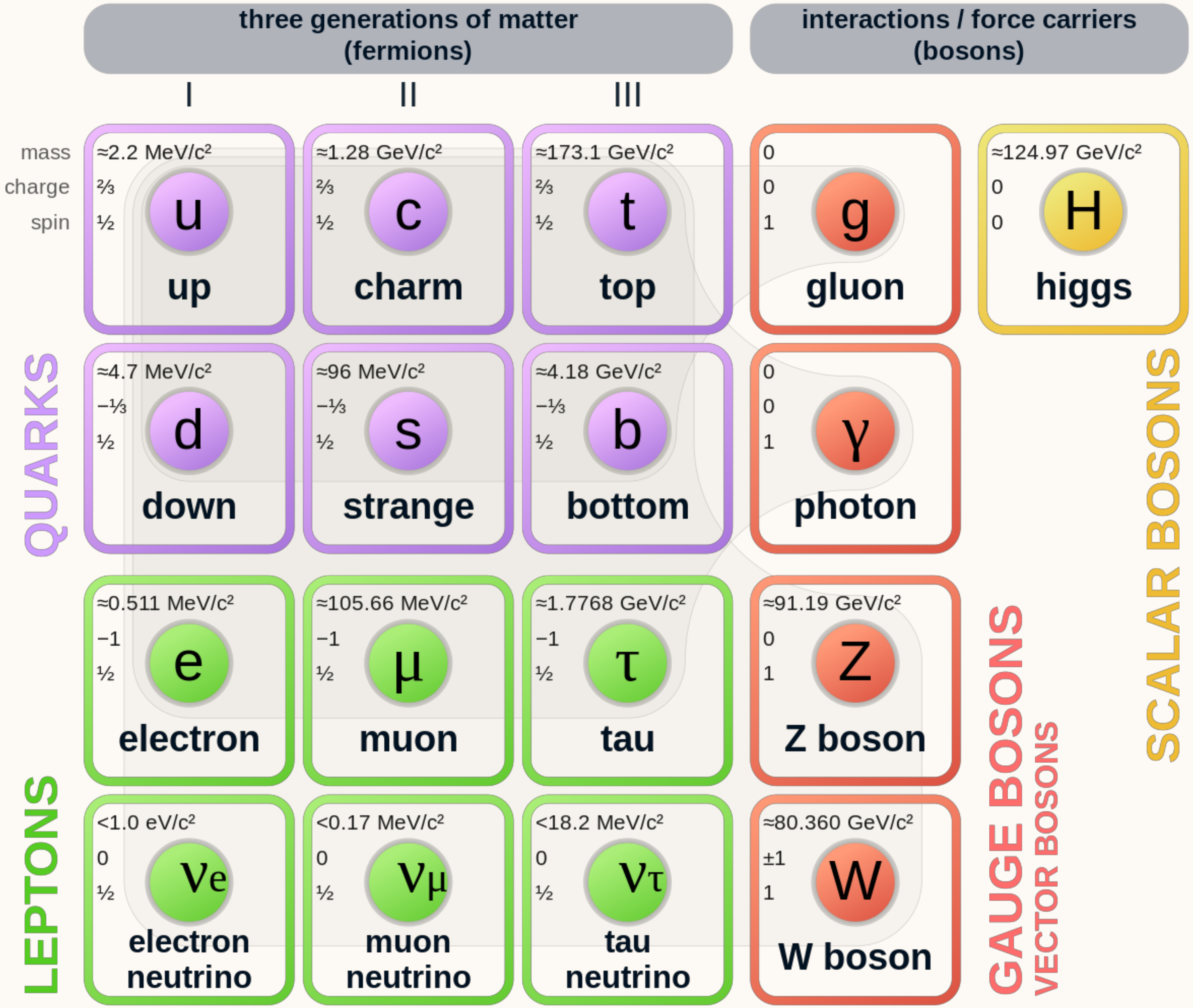
Supervisor: Prof. Victor Flambaum

UNSW SYDNEY

Standard Model of Elementary Particles



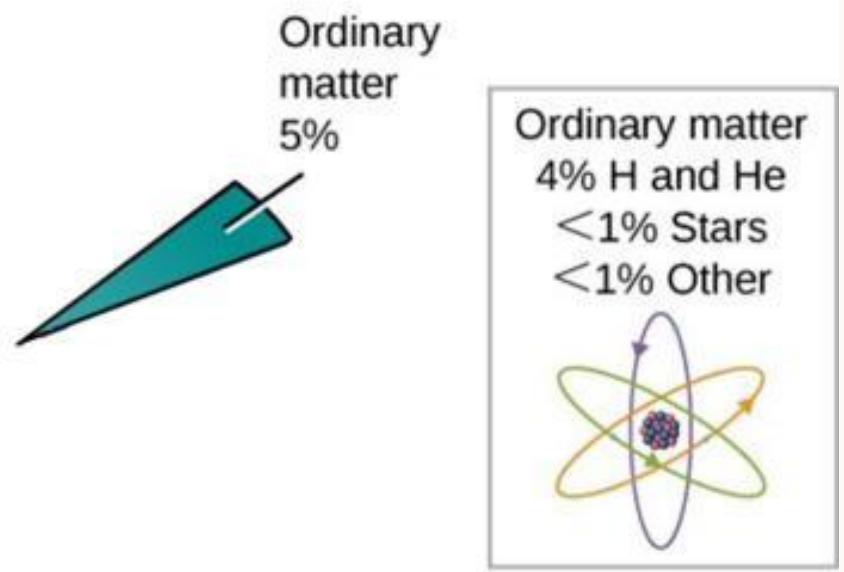
Standard Model of Elementary Particles

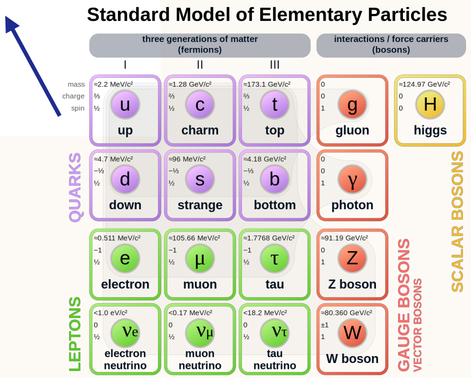


We would not exist!

COMPOSITION OF THE UNIVERSE

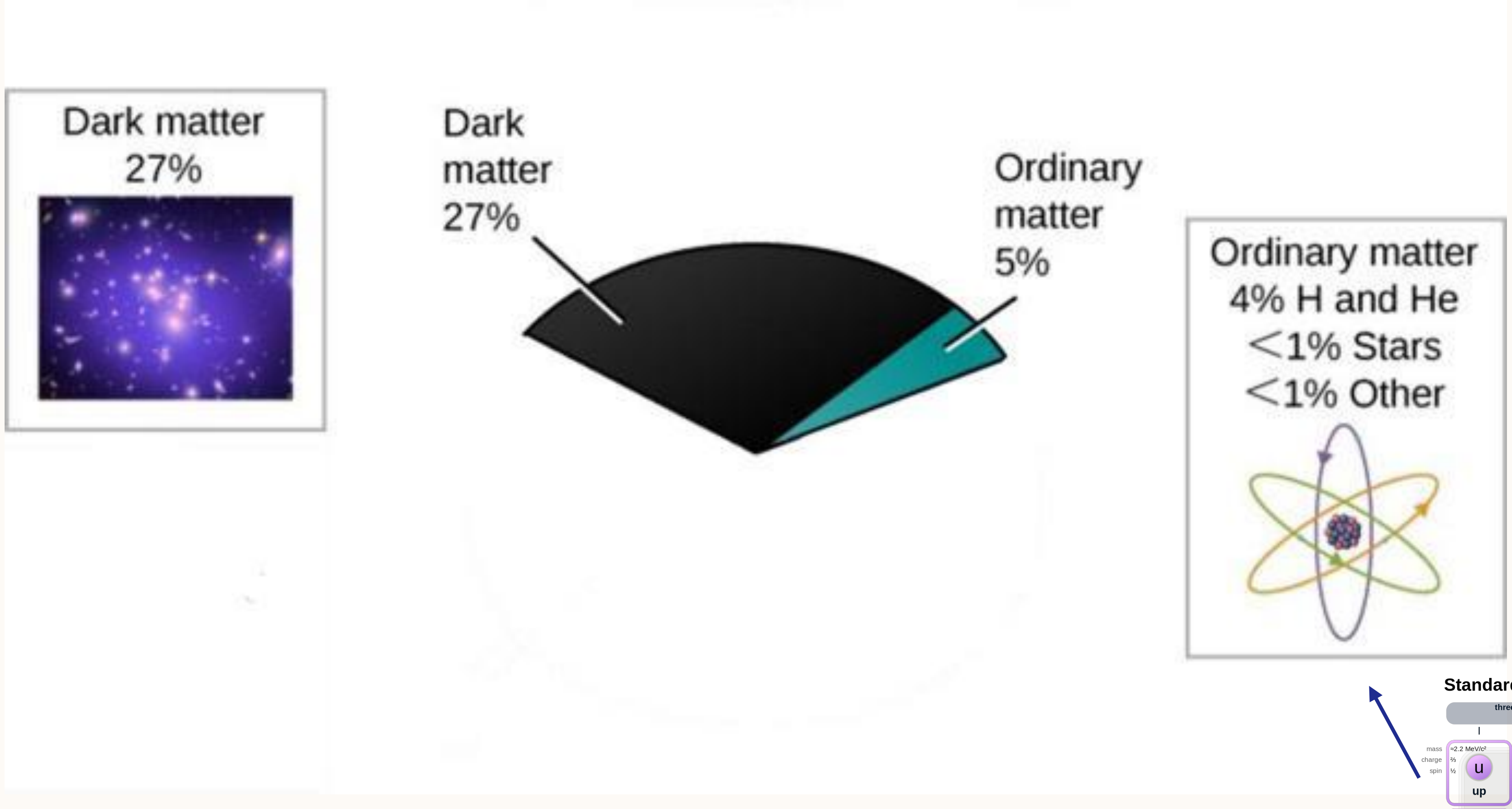
We would not exist!

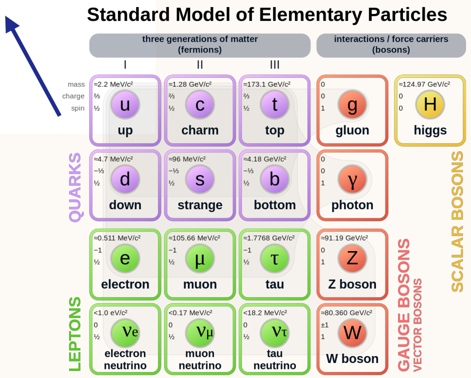




COMPOSITION OF THE UNIVERSE

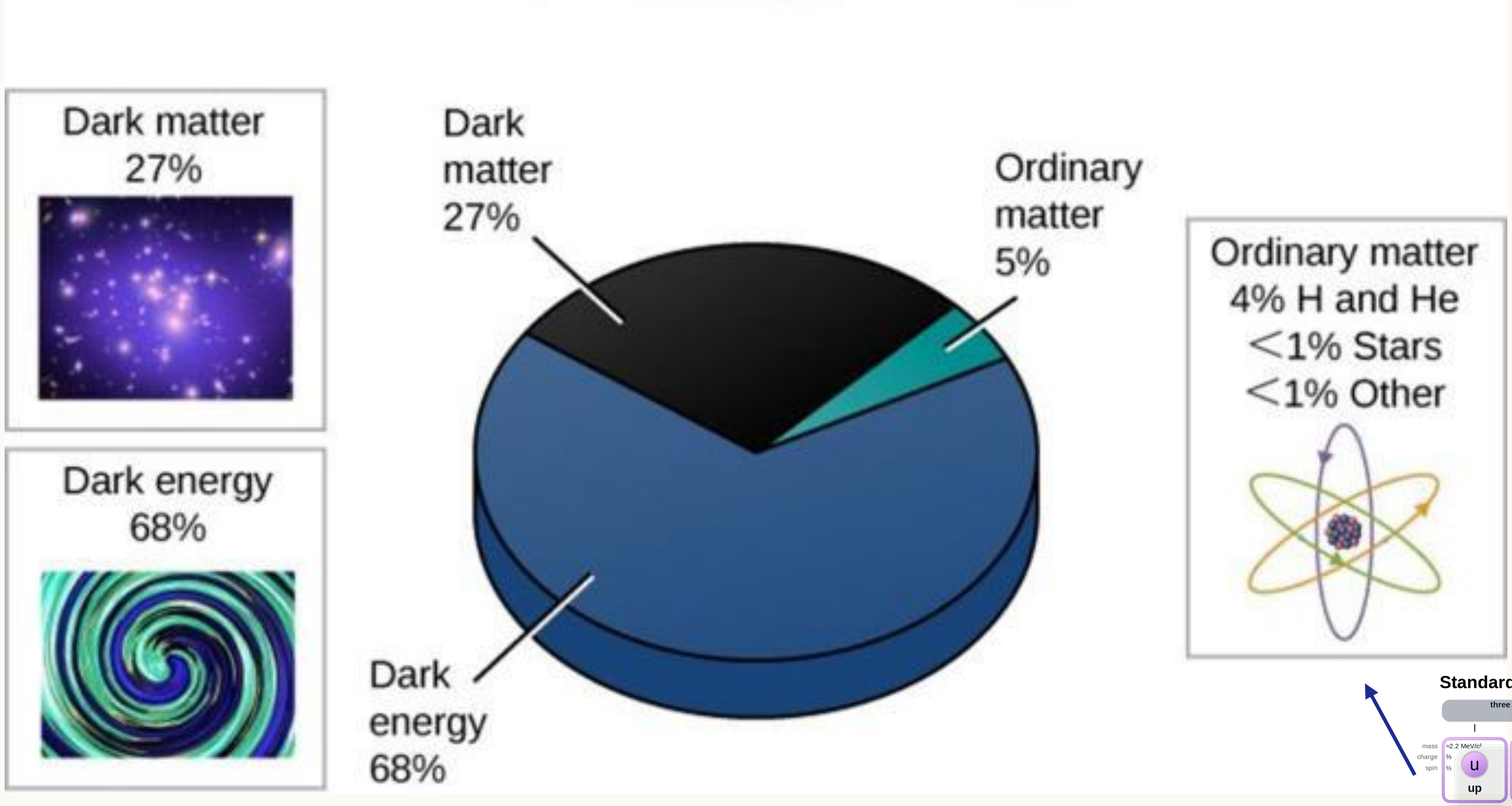
We would not exist!

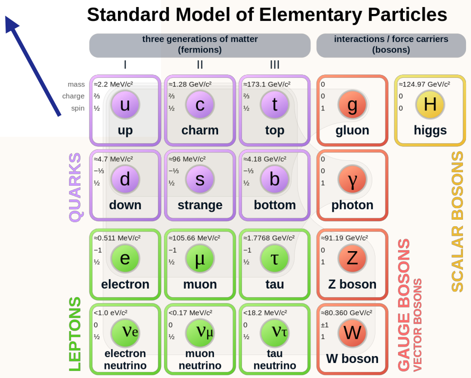




COMPOSITION OF THE UNIVERSE

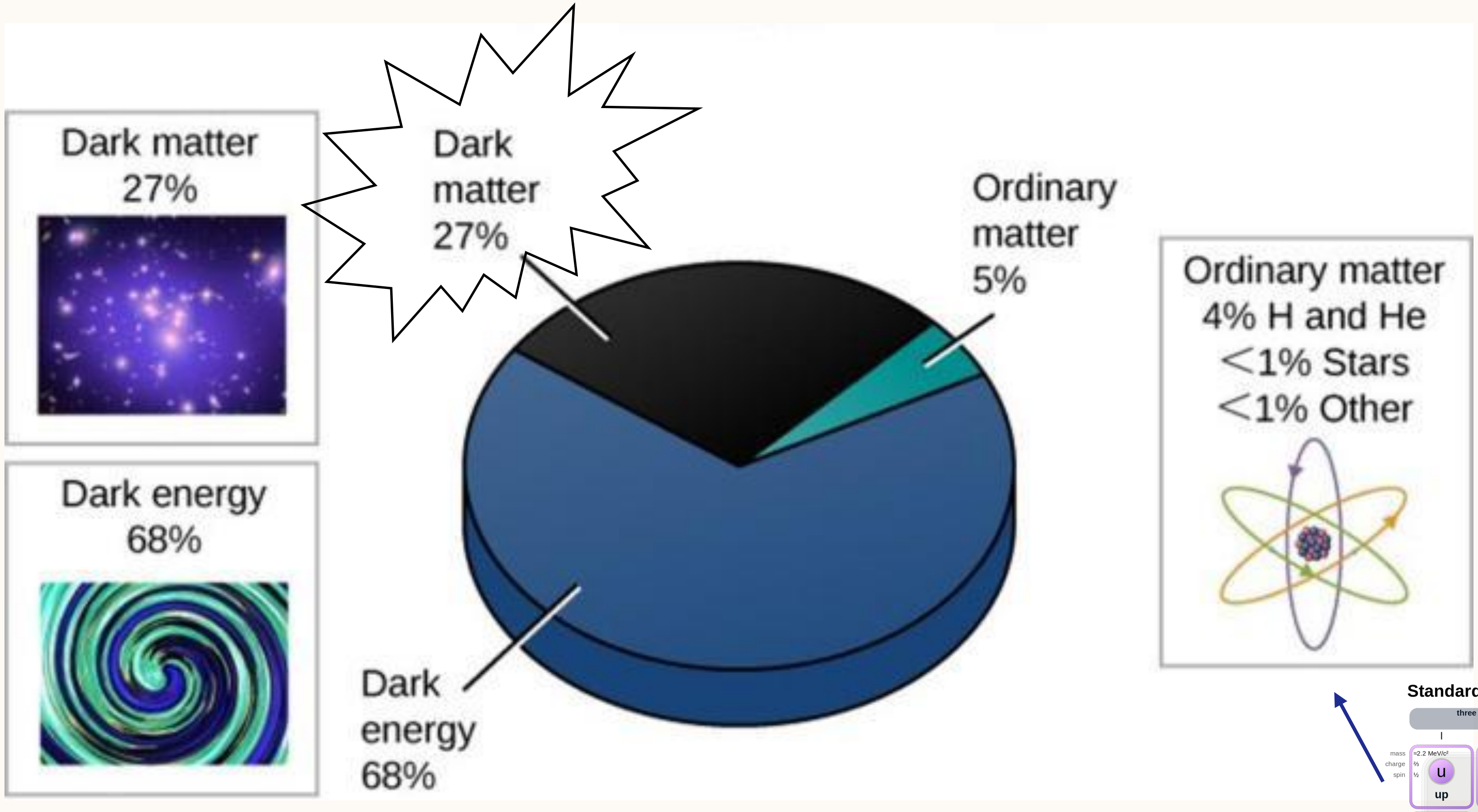
We would not exist!

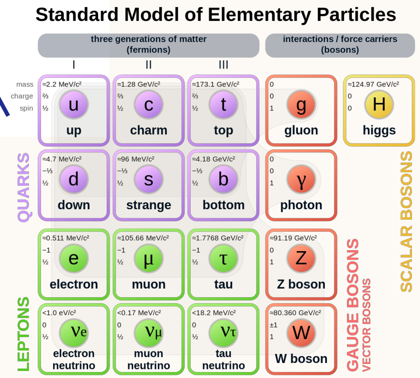




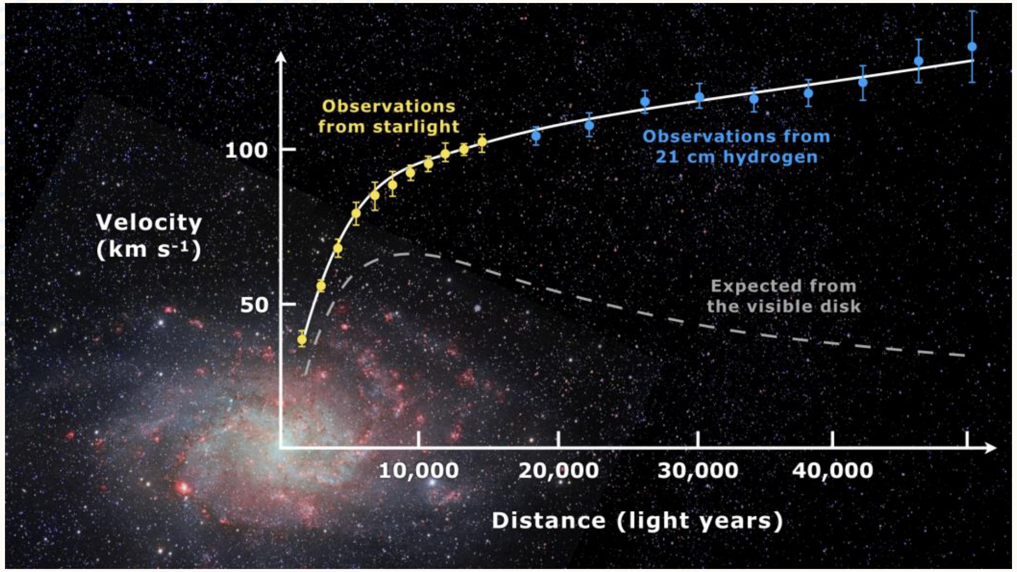
COMPOSITION OF THE UNIVERSE

We would not exist!

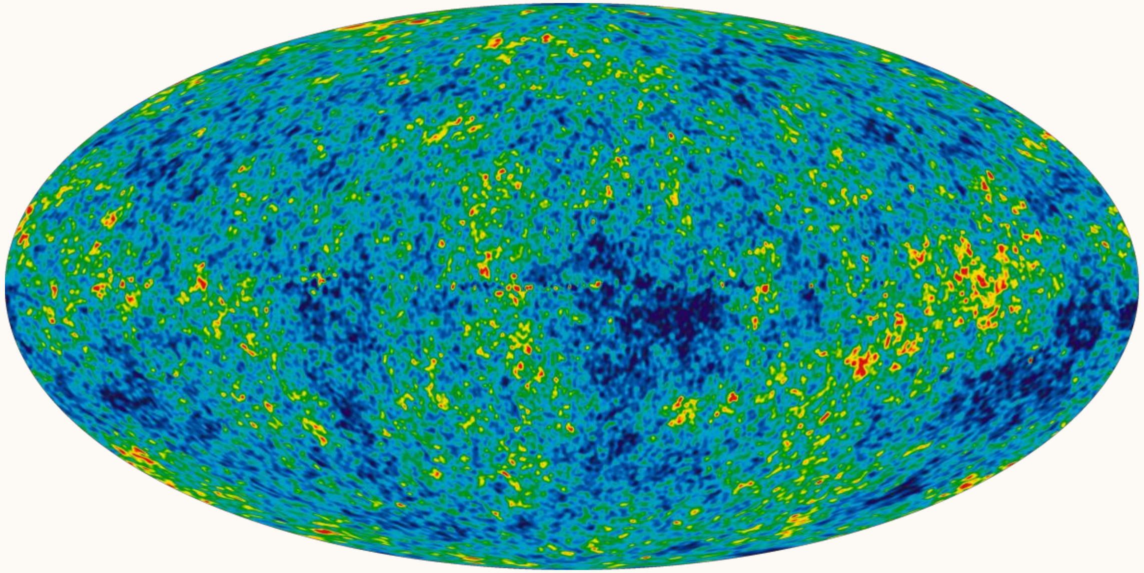




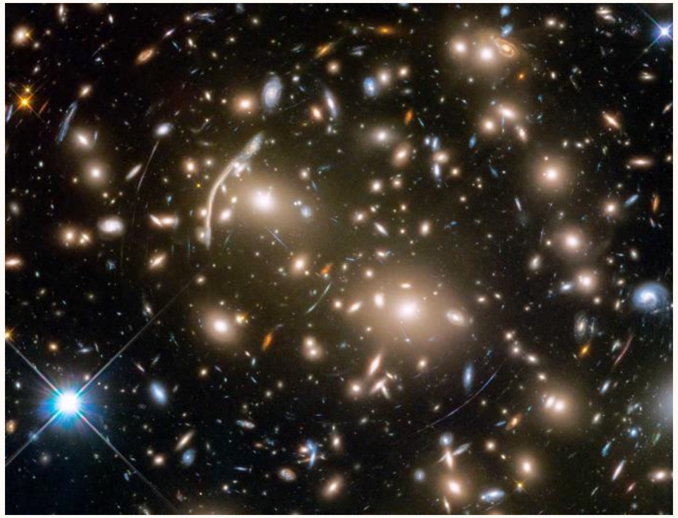
EVIDENCE FOR DARK MATTER



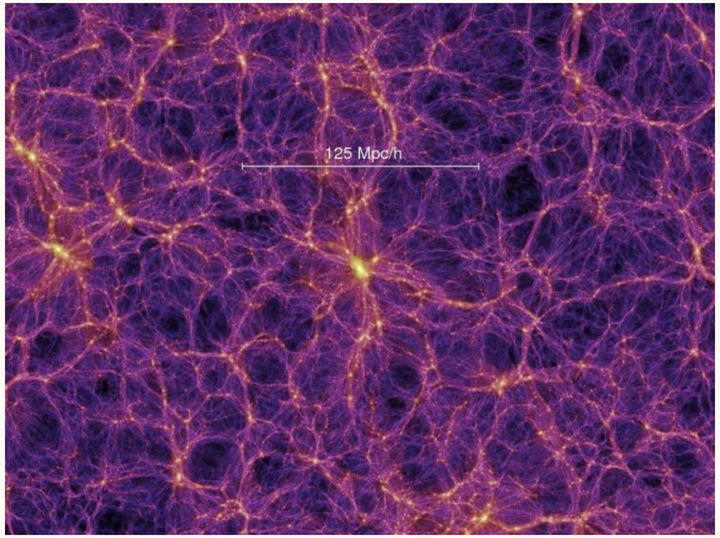
Rotation curves



Cosmic Microwave Background

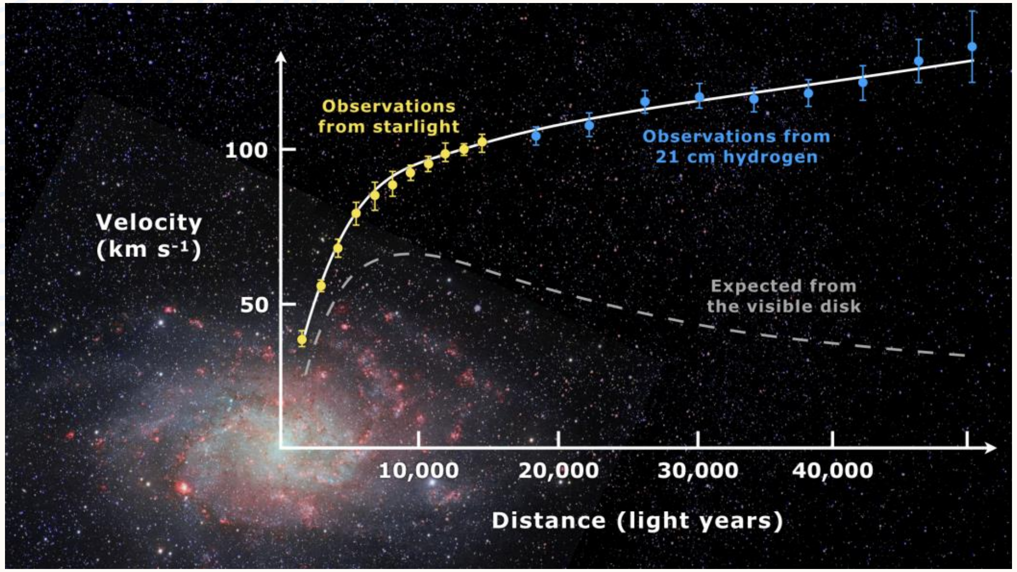


Gravitational lensing
[NASA, ESA, and J. Lotz and the HFF Team (STScI)]

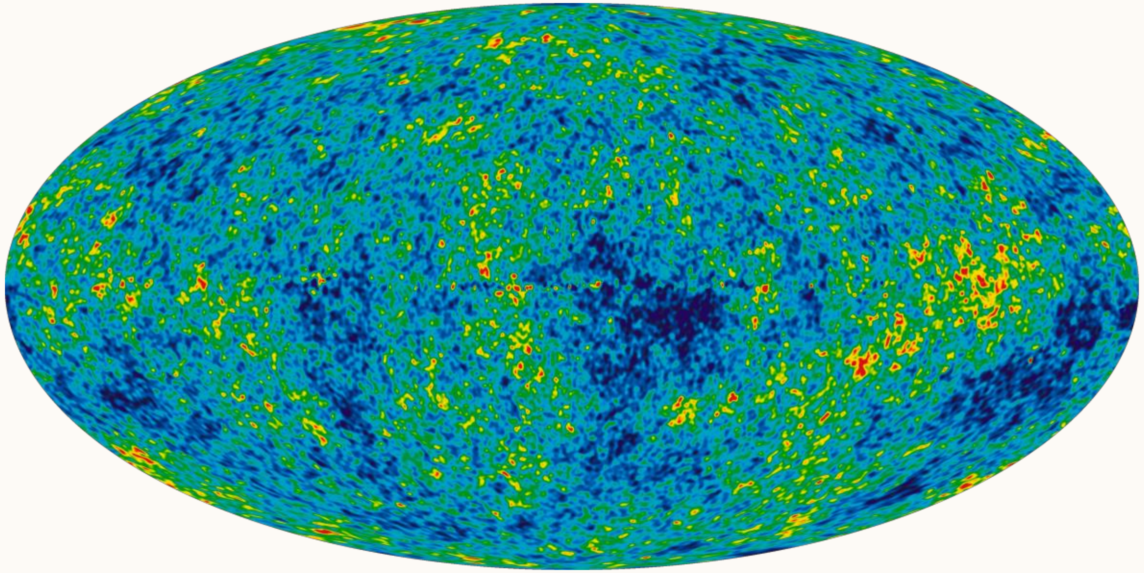


Large Scale Structures
[Millennium Simulation Project]

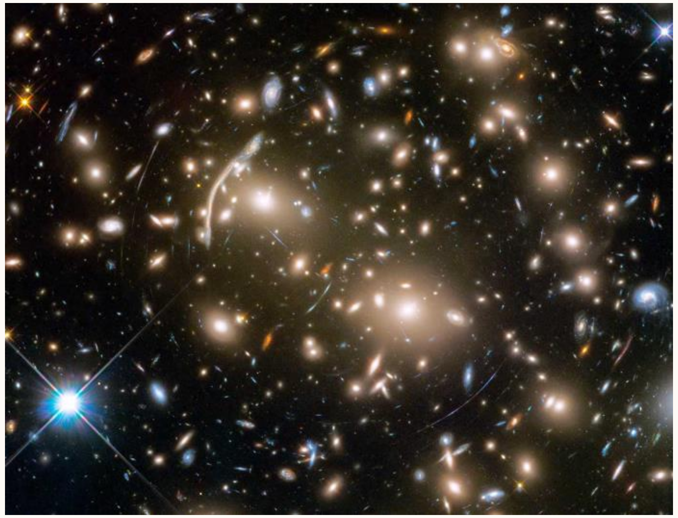
EVIDENCE FOR DARK MATTER



Rotation curves



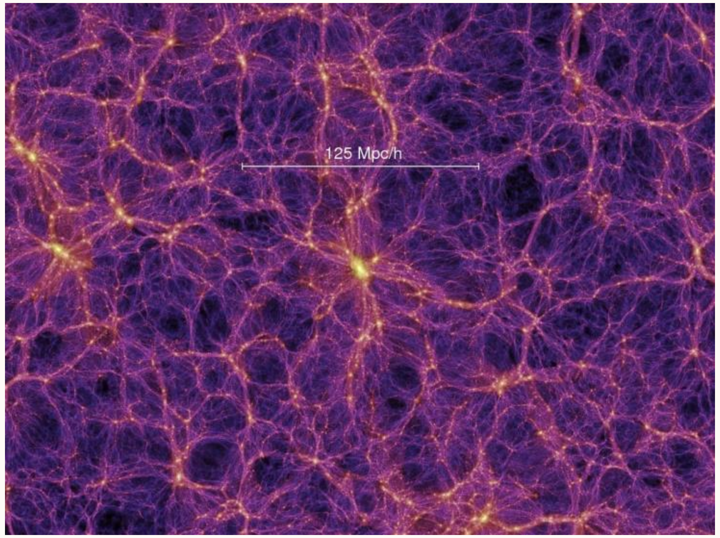
Cosmic Microwave Background



Gravitational lensing
[NASA, ESA, and J. Lotz and the HFF Team (STScI)]

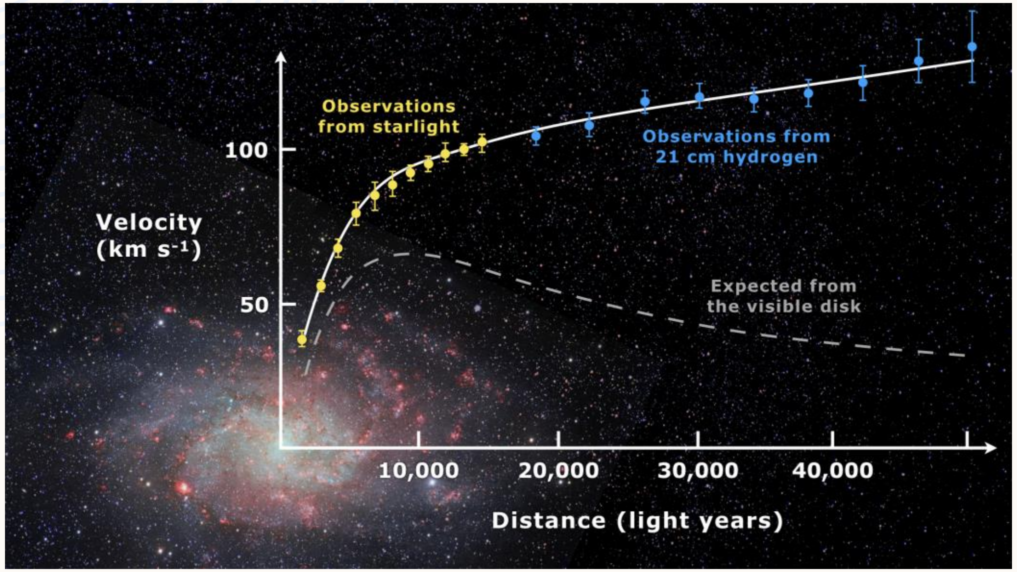
HOW DO WE SEARCH FOR (ULTRALIGHT) DARK MATTER?

- Atomic Clocks
- Highly-charged ions
- Molecules
- Nuclear Clocks
- Laser interferometers
- Atomic magnetometry
- Ultracold neutrons
- Solid-state magnetometry
- Electric dipole moments

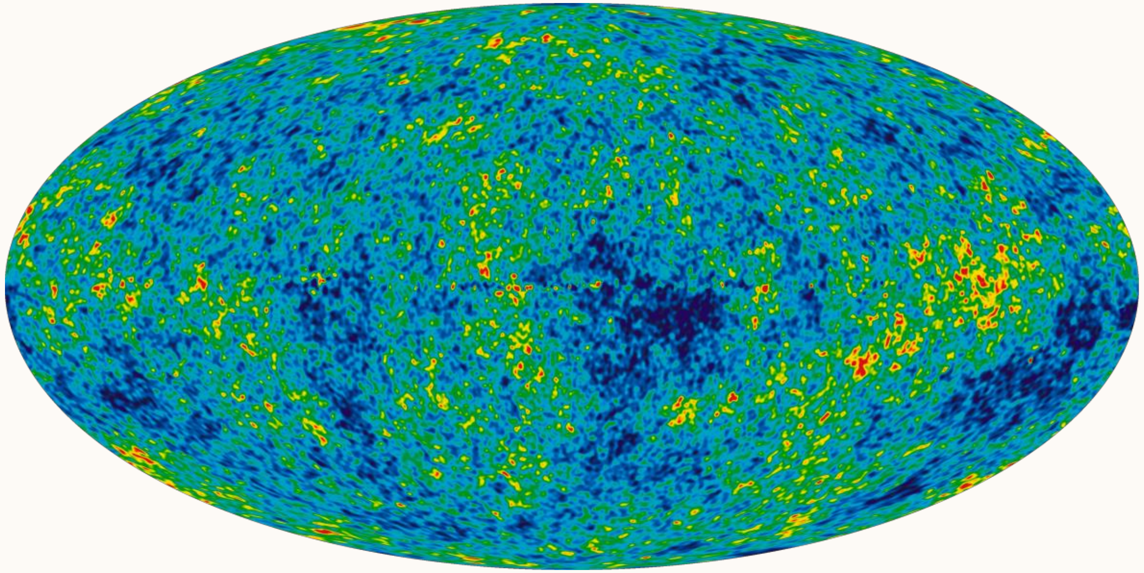


Large Scale Structures
[Millennium Simulation Project]

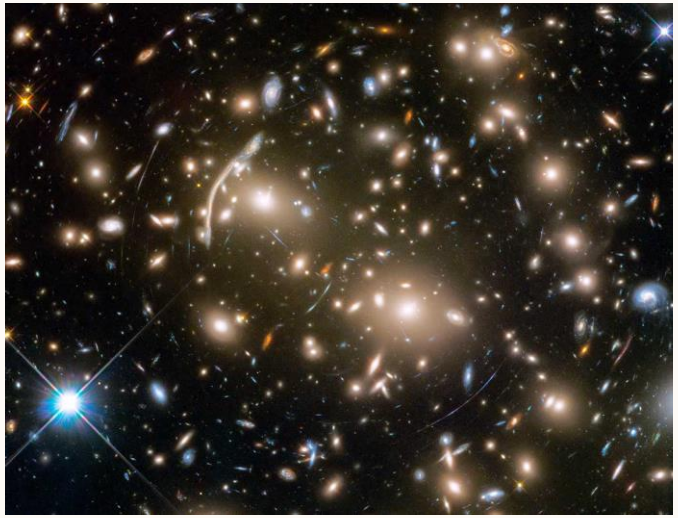
EVIDENCE FOR DARK MATTER



Rotation curves



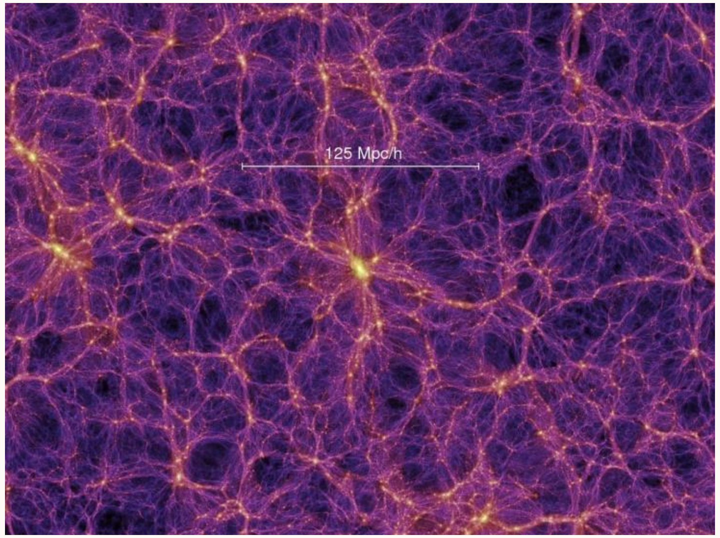
Cosmic Microwave Background



Gravitational lensing
[NASA, ESA, and J. Lotz and the HFF Team (STScI)]

HOW DO WE SEARCH FOR (ULTRALIGHT) DARK MATTER?

- Atomic Clocks
- Highly-charged ions
- Molecules
- Nuclear Clocks
- Laser interferometers
- Atomic magnetometry
- Ultracold neutrons
- Solid-state magnetometry
- Electric dipole moments



Large Scale Structures
[Millennium Simulation Project]

Towards Form Factor Effects in the P2 Experiment

Rolando Martinez-Ramirez

Institute for Nuclear Physics, JGU

Supervisor: Prof. Jens Erler

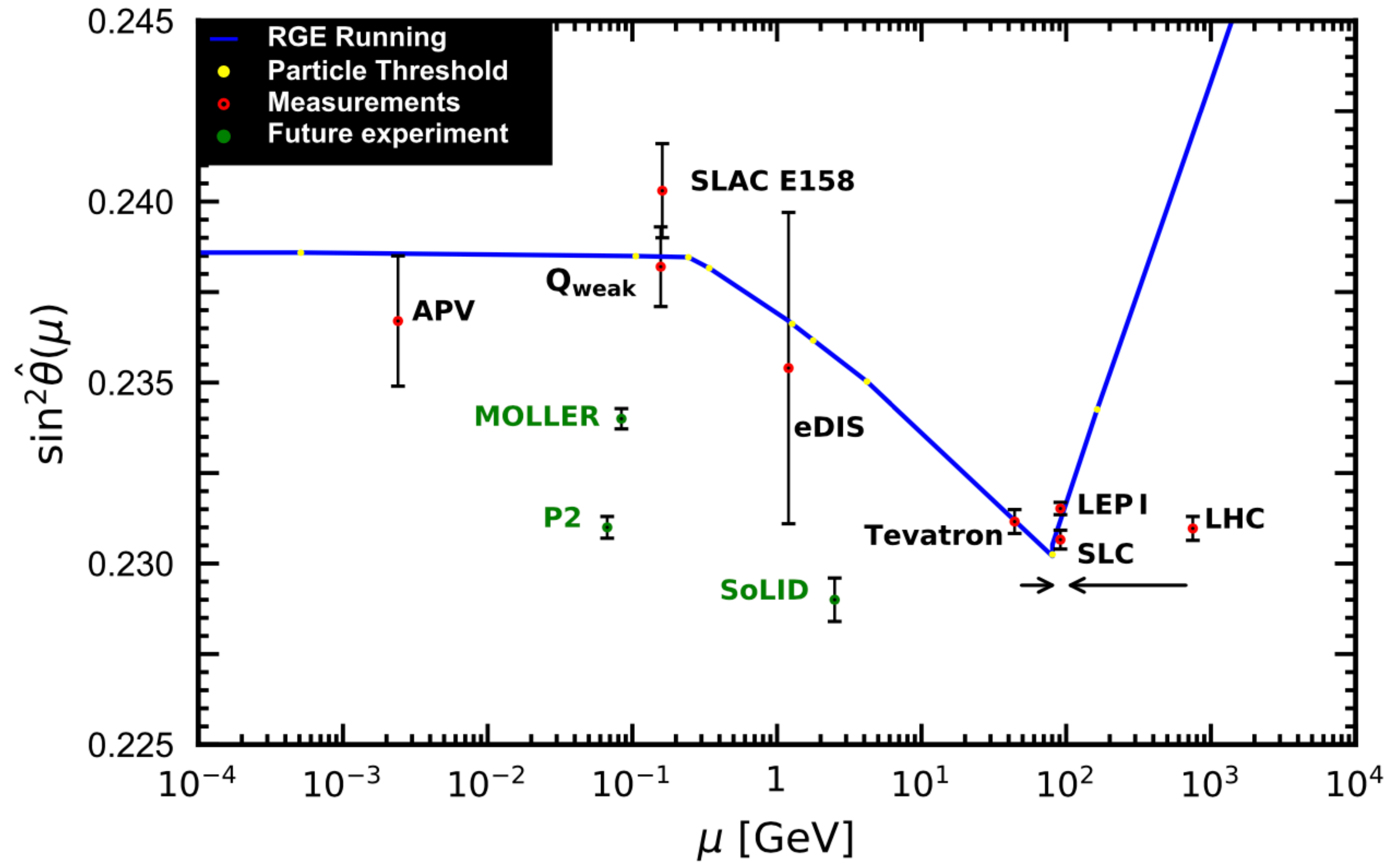
P2 Experiment in MESA Accelerator at Mainz

- **The goal:** Clear determination of $\sin^2\theta_W$ at low-energies ⟶ SM precision test

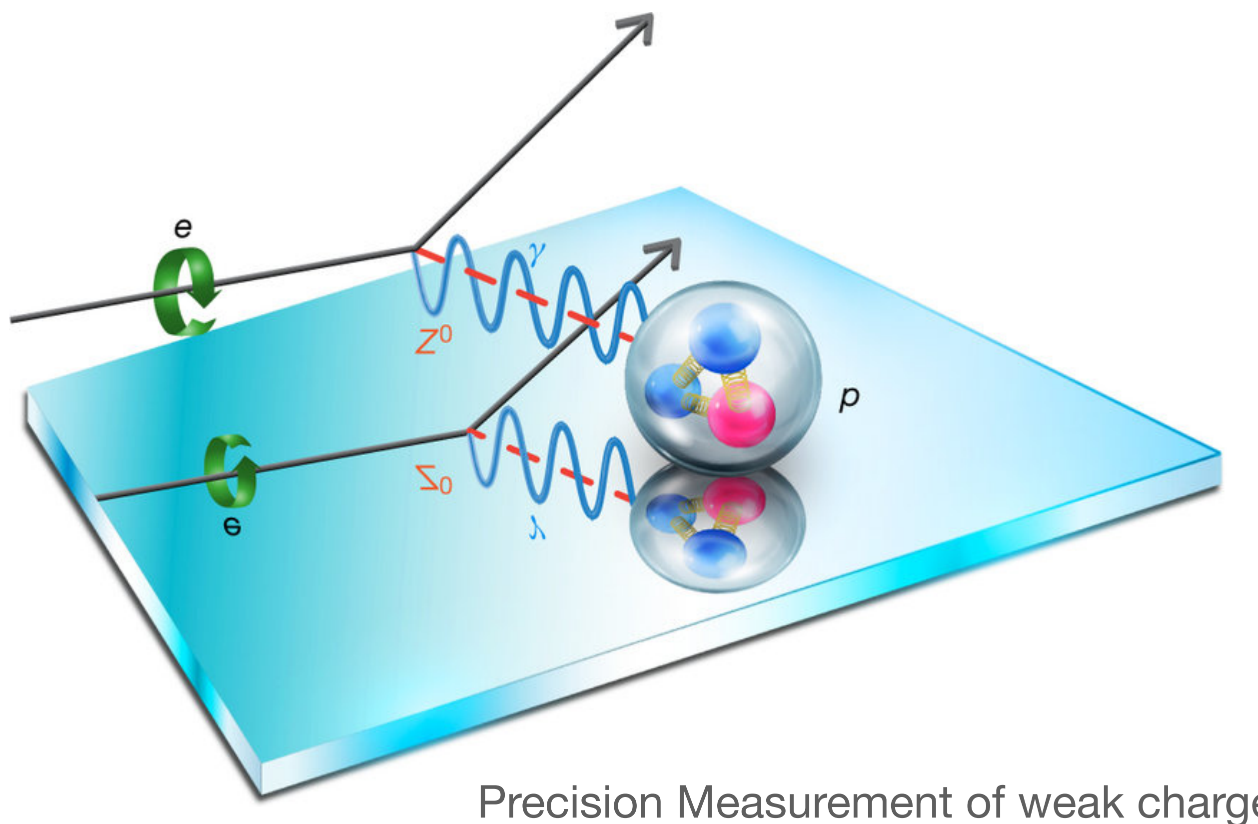
- **The way:** Precise measurement of proton's weak charge Q_W^p

$$Q_W^p = (1 - 4\sin^2\theta_W)$$

↳ Extraction of weak mixing angle

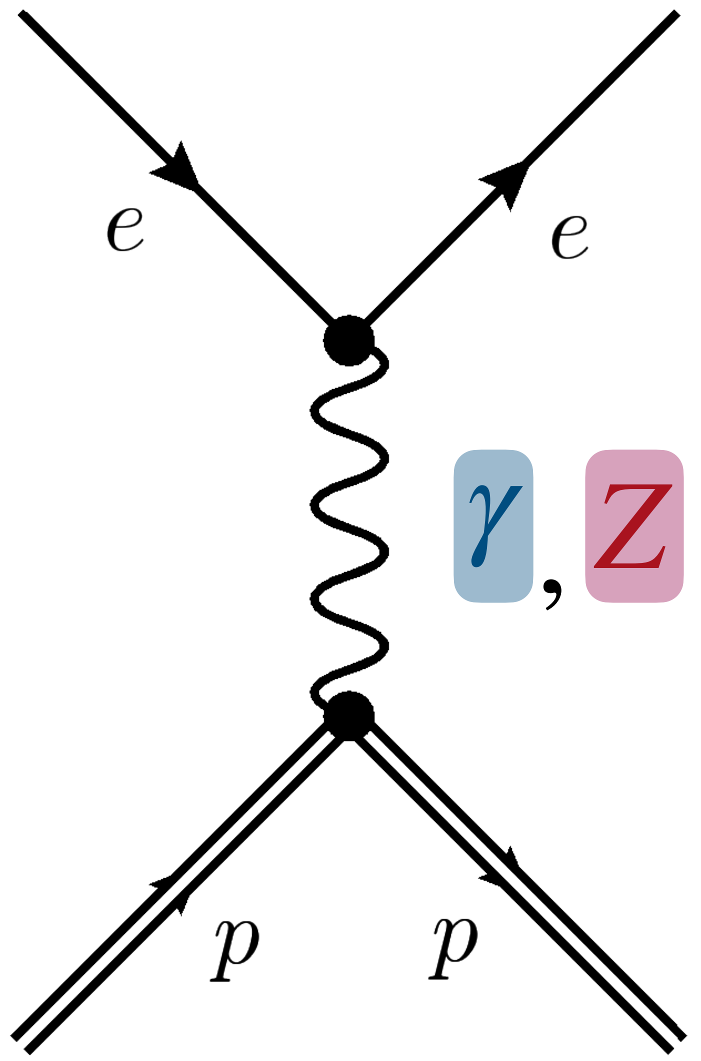


- **The observable:** Parity Violation asymmetry in elastic electron-proton scattering



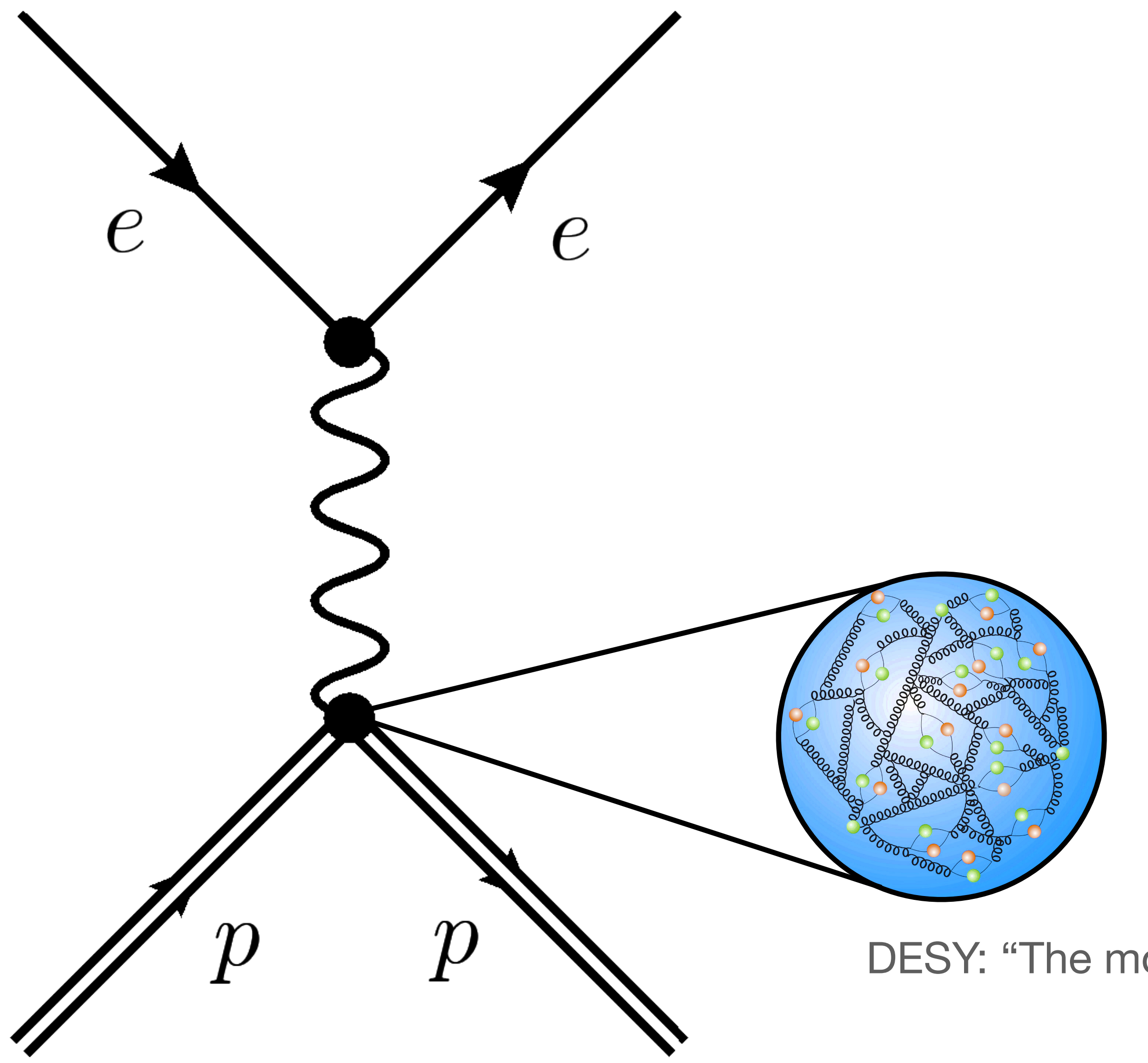
Precision Measurement of weak charge of the proton, The Jefferson Lab Qweak Collaboration

$e\,p \to e\,p$:



$$A^{PV}(Q^2) \equiv \frac{\sigma_+ - \sigma_-}{\sigma_+ + \sigma_-}$$ ⟶ Parity-violating asymmetry

Form Factors in Parity Violation Asymmetry



DESY: “The most precise picture of the proton”

- The proton inner structure plays a role in the asymmetry:

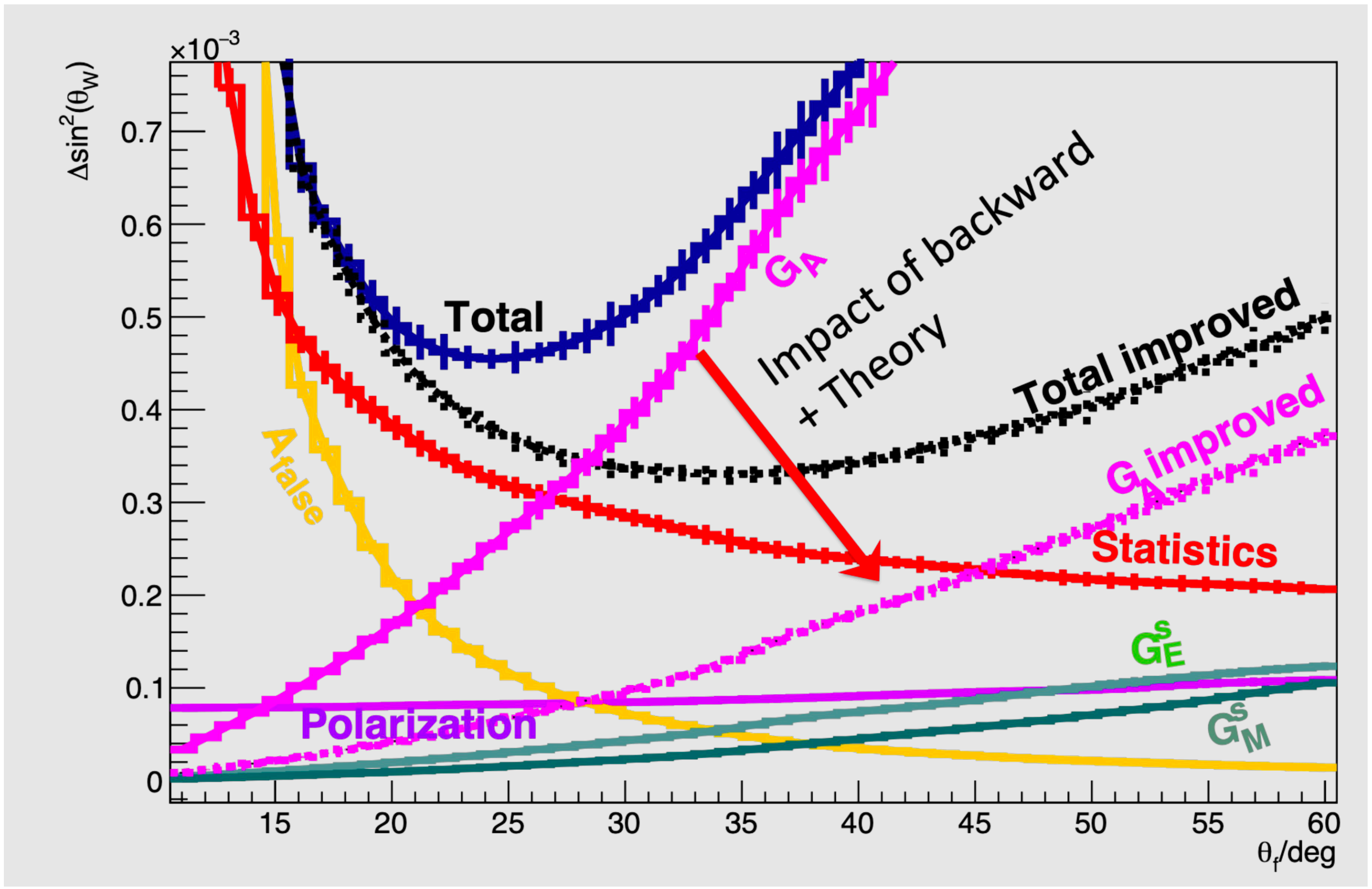
$$A_p^{PV} = -\frac{G_F}{2\sqrt{2}\pi\alpha} Q^2 \left[Q_W^p - F\left(Q^2\right) \right]$$

Form Factors: Encode contributions from the hadronic structure of the nucleon

- At low momentum transfer, A_p^{PV} is dominated by Q_W^p

$$F(Q^2 \to 0) \to 0$$

- …but Form Factor effects have to be considered to achieve the desirable precision:



D. Becker et. al., *Eur. Phys. J. A* 54 (2018) 11, 208

How the Form Factor contributions affect the Q_W^p measurement?

How can we quantify and minimize uncertainties?

See you at the poster session!

An improved description of neutrino emission from SN1987A

Riccardo Maria Bozza[1,2], Vigilante di Risi[1,3], Veronica Oliviero[1,2], Giuseppe Matteucci[1,2], Giulia Ricciardi[1,2], Francesco Vissani[4]

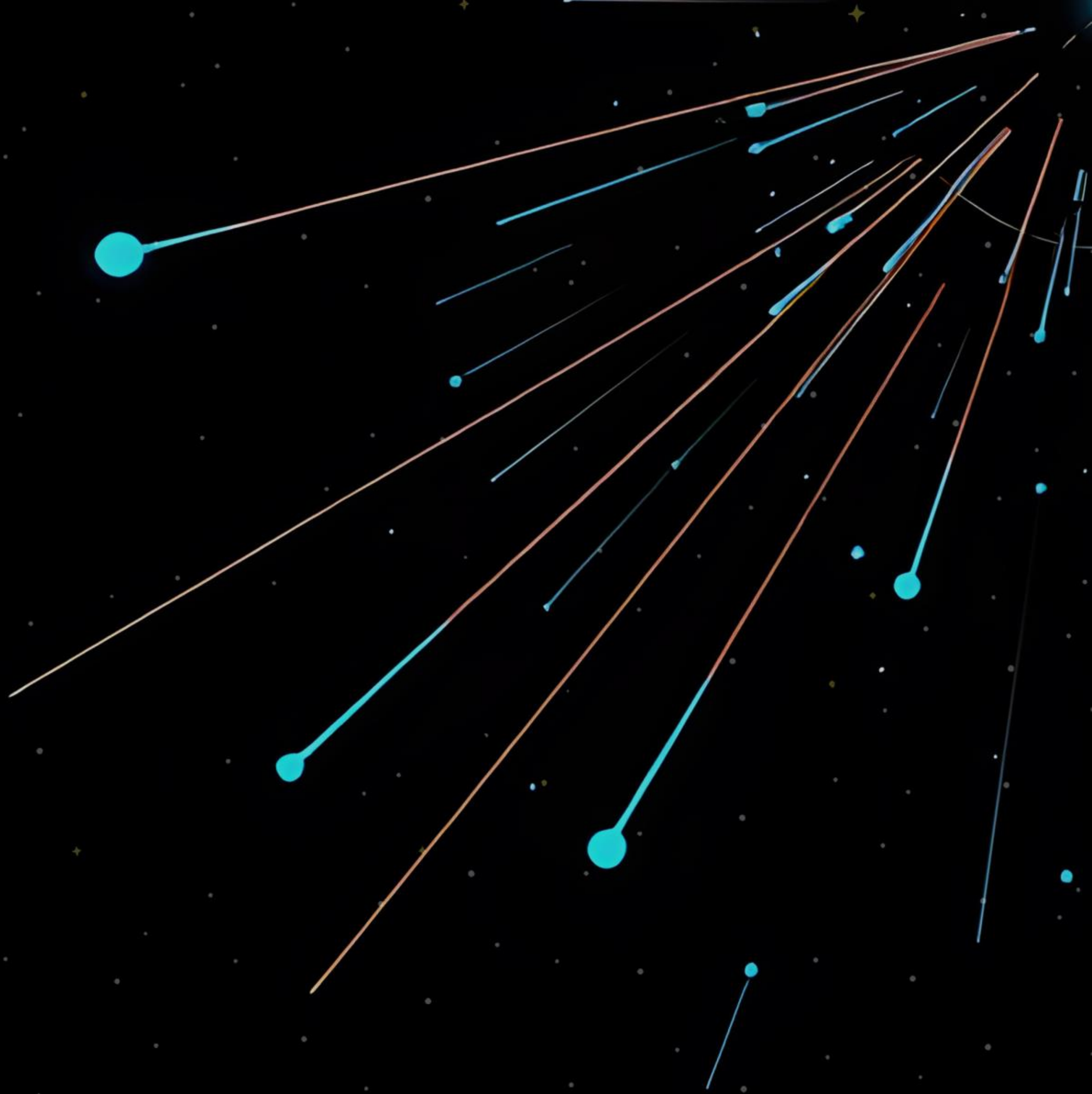
[1]*Department of Physics 'Ettore Pancini', University of Naples Federico II, Naples, Italy*
[2]*Istituto Nazionale di Fisica Nucleare, Sezione di Napoli, Naples, Italy*
[3]*Quantum Theory Center (ħQTC), Danish-IAS, IMADA, Southern Denmark Univ., Denmark*
[4]*Laboratori Nazionali del Gran Sasso (INFN), Assergi, Italy*

In 1987 a type II supernova (SN1987A) exploded in the Large Magellanic Cloud, 51.4 kpc far from Earth.

Over 30 seconds, 29 neutrinos were detected, supporting the prediction that neutrinos are the primary energetic emission from such stellar events.

The neutrinos were observed by three experiments: Kamiokande-II (Japan), Baksan Neutrino Observatory (Russia), and the Irvine-Michigan-Brookhaven detector (USA).

To this day, SN1987A is the only supernova we've caught through neutrinos, making it a one-of-a-kind event worth examining further.



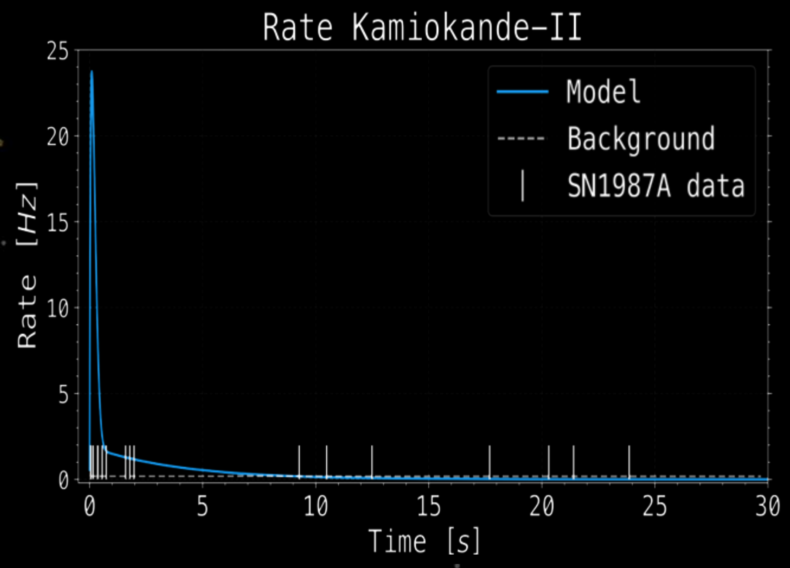
We analyzed SN1987A data with a new and state-of-the-art model of the neutrino flux based on physical parameters.

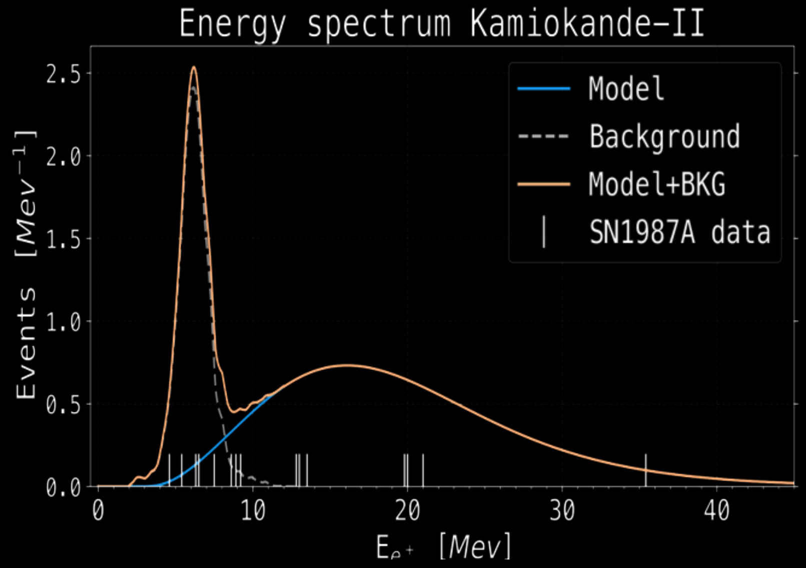
The strengths of our analysis:

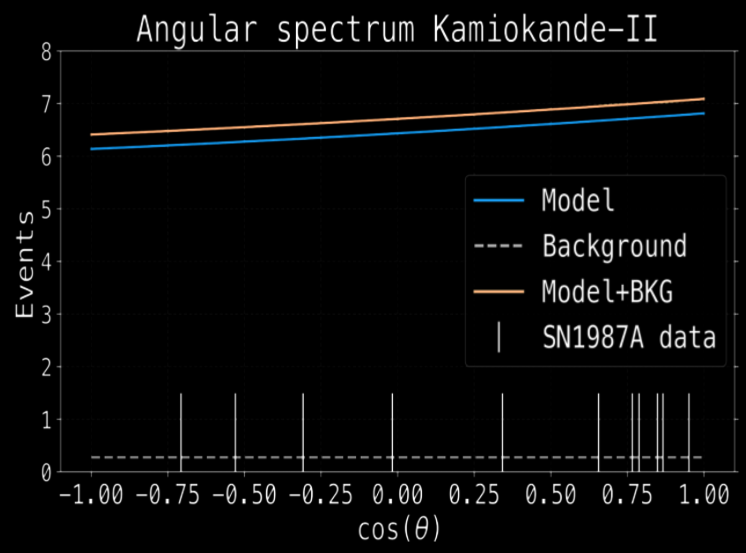
- Energy and temporal distributions based on supernova models
- Accurate temporal description of both emission and cooling phases
- Rigorous handling of experimental responses specific to each detector
- Incorporates all available data for robust analysis
- Utilizes the latest estimates of IBD cross-sections
- Two independent Python and Mathematica codes to ensure reliability

The parameters of our model:

- Temperature scale
- Radius of the resulting neutron star
- Accretion and cooling times
- Emission peak time (new!)
- Sync time for each detector







We can't wait to observe a new supernova!
What if today's the day?

Give a look to our poster to be prepared!

Thank you

pictures generated with FLUX.1, an open-source image generation model

Testing Non-Commutative Quantum Gravity Models with VIP Experiment at Gran Sasso National Laboratories

Federico Nola

University of Campania Luigi Vanvitelli

24 09 2024

Istituto Nazionale di Fisica Nucleare
Laboratori Nazionali di Frascati

Università degli Studi della Campania *Luigi Vanvitelli*

Pauli Exclusion Principle (PEP):

- Fundamental principle in Quantum Mechanics: two electrons in an atom **cannot** share the same set of **quantum numbers**.
- Quantum Gravity models suggest possible **violations** of PEP due to **non-commutative spacetime** [1].

Goal of the experiment

Look for possible PEP violations using the VIP experiment to test different non-commutative quantum gravity models.

Motivation:

- Quantum Gravity as **unification theory** of Quantum Mechanics and General Relativity.
- VIP Experiment explore several classes of **Non-Commutative Quantum Gravity** models.

The VIP Experiment:

- Conducted at **Gran Sasso National Laboratories (LNGS)**.
- Searches for forbidden **X-ray transitions** in atomic electrons.
- Focus on **copper** (VIP-2) and **lead** (VIP Lead) atoms.

PEP Violations:

- Indicated by shifted X-ray emissions.
- Non-commutative spacetime can generate **deformed symmetries**, leading to PEP violations.

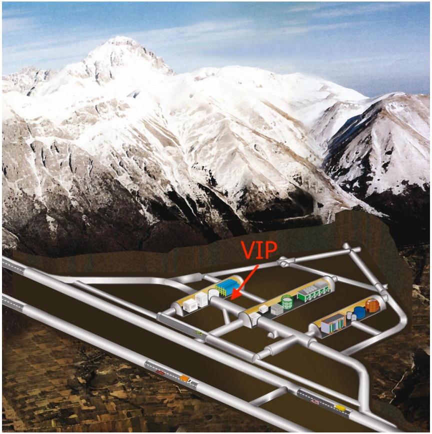


Figure: VIP location at LNGS

Results and Future Prospects

Current Findings:

- Constraints on the scale of **spacetime non-commutativity**.
- Limits on Quantum Gravity models.

Future Plans:

- Upgrade to **VIP-3** [2] in 2025 to study elements with higher atomic numbers.
- New insights into **Quantum Gravity** and PEP violations.

A_i, M_k	Lower limit on Λ in Planck scale unit
A_1, $k = 1$	$3.1 \cdot 10^{21}$
A_1, $k = 2$	$1.4 \cdot 10^{-1}$
A_1, $k = 3$	$4.9 \cdot 10^{-9}$
A_2, $k = 1$	$2.8 \cdot 10^{21}$
A_2, $k = 2$	$1.4 \cdot 10^{-1}$
A_2, $k = 3$	$5.1 \cdot 10^{-9}$
A_3, $k = 1$	$4.2 \cdot 10^{21}$
A_3, $k = 2$	$1.5 \cdot 10^{-1}$
A_3, $k = 3$	$5.6 \cdot 10^{-9}$

Table: Lower limits Λ obtained for the scale of non-commutativity for each analyses performed [1].

Thank you for the attention!

References: [1]Piscicchia et al. Universe 9.7 (2023): 321., [2]Manti et al. Entropy 26.9 (2024): 752.

Constraints on new physics in SMEFT Framework

Vigneshwaran Palaniappan
Advisor: Prof. Dr. Jens Erler

Electroweak **P**hysics **I**nterse**C**tions
September, 22nd-27th, 2024
Calaserena Resort, Geremeas, Sardinia (Italy)

PRiSMA+

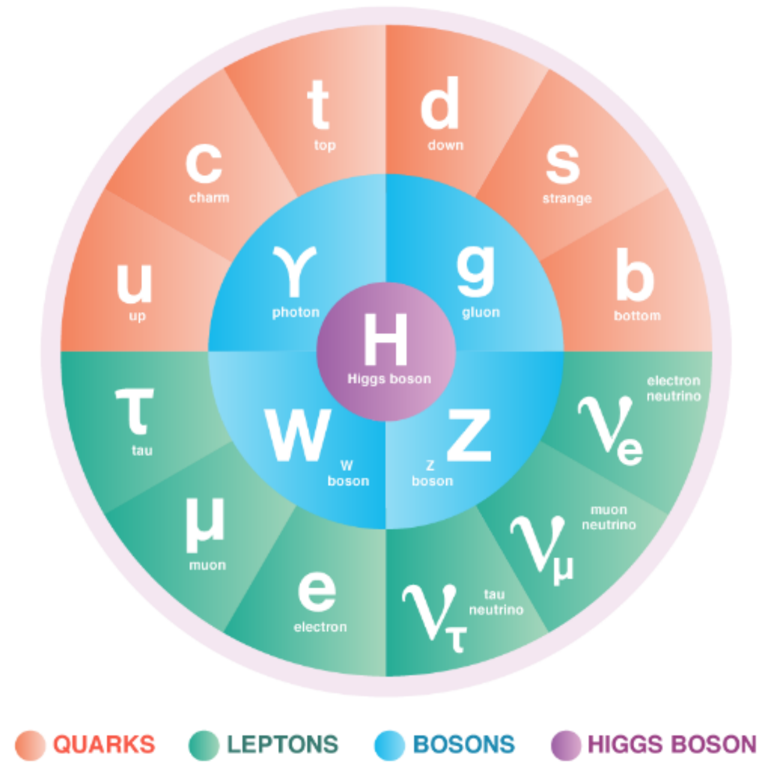
JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Motivation

<u>Standard Model(SM)</u>

- Describes elementary particles and their interactions
- Tested to good precision

SM contents



Symmetry magazine, a joint Fermilab/SLAC publication.

Motivation

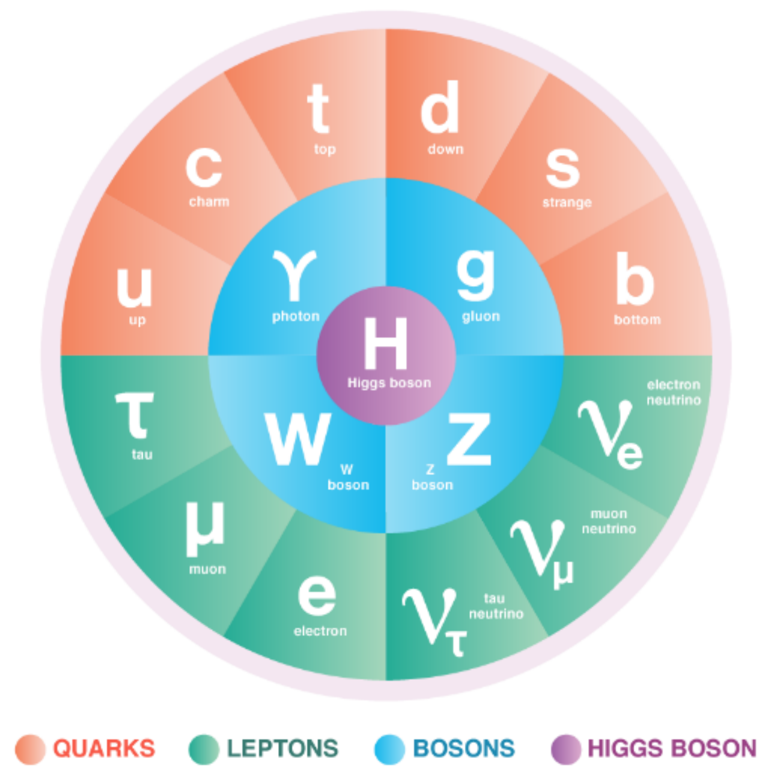
Standard Model(SM)

- Describes elementary particles and their interactions
- Tested to good precision

Limitations of SM

- Experimental tensions:muon g−2, W mass, CKM unitarity)
- Unexplained phenomena: Neutrino masses, Dark matter,...
- Theoretical incomplete(Higgs/ flavour hierarchy, Strong CP, Quantum gravity,...)

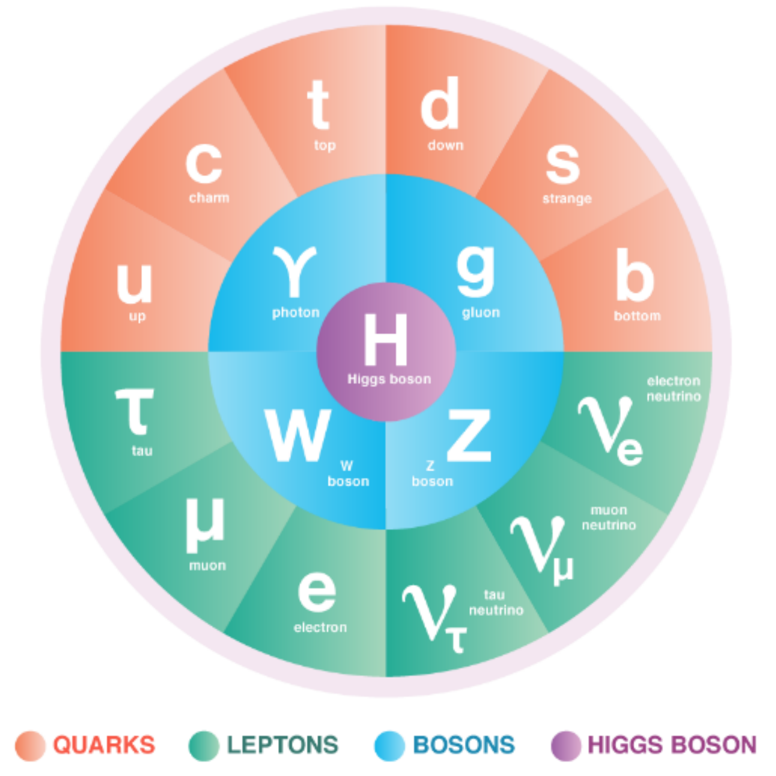
SM contents



Symmetry magazine, a joint Fermilab/SLAC publication.

Motivation

SM contents



Symmetry magazine, a joint Fermilab/SLAC publication.

Standard Model(SM)

- Describes elementary particles and their interactions
- Tested to good precision

↓

Limitations of SM

- Experimental tensions:muon g−2, W mass, CKM unitarity)
- Unexplained phenomena: Neutrino masses, Dark matter,...
- Theoretical incomplete(Higgs/ flavour hierarchy, Strong CP, Quantum gravity,...)

↓

Standard Model Effective Field Theory(SMEFT)

- Framework to interpret deviation from SM predictions
- Model-independent approach to explore new physics

"All things EFT" lecture series: How well do we know the SMEFT by Veronica Sanz

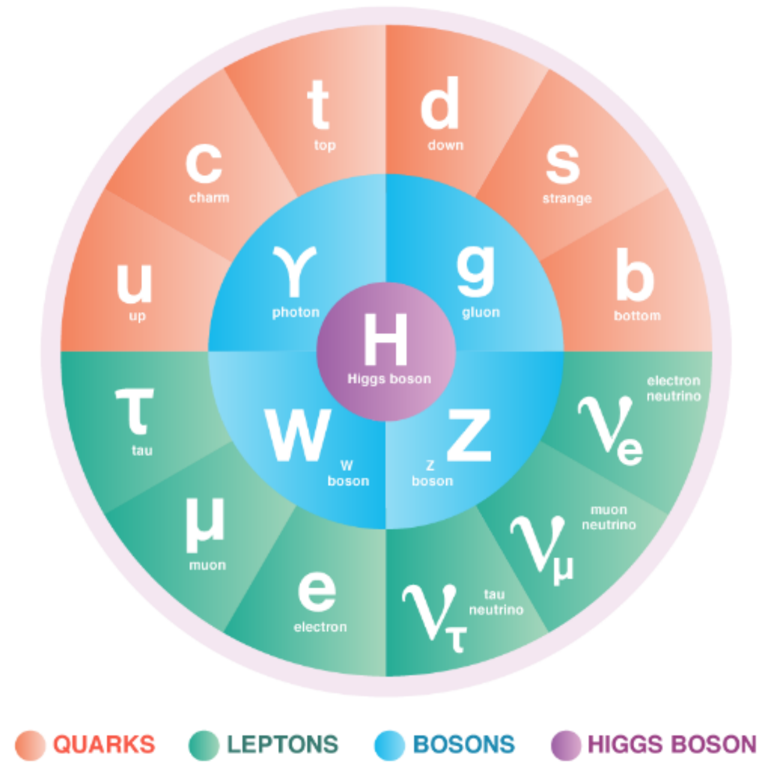
Motivation

Standard Model(SM)
- Describes elementary particles and their interactions
- Tested to good precision

Limitations of SM
- Experimental tensions:muon g—2, W mass, CKM unitarity)
- Unexplained phenomena: Neutrino masses, Dark matter,...
- Theoretical incomplete(Higgs/ flavour hierarchy, Strong CP, Quantum gravity,...)

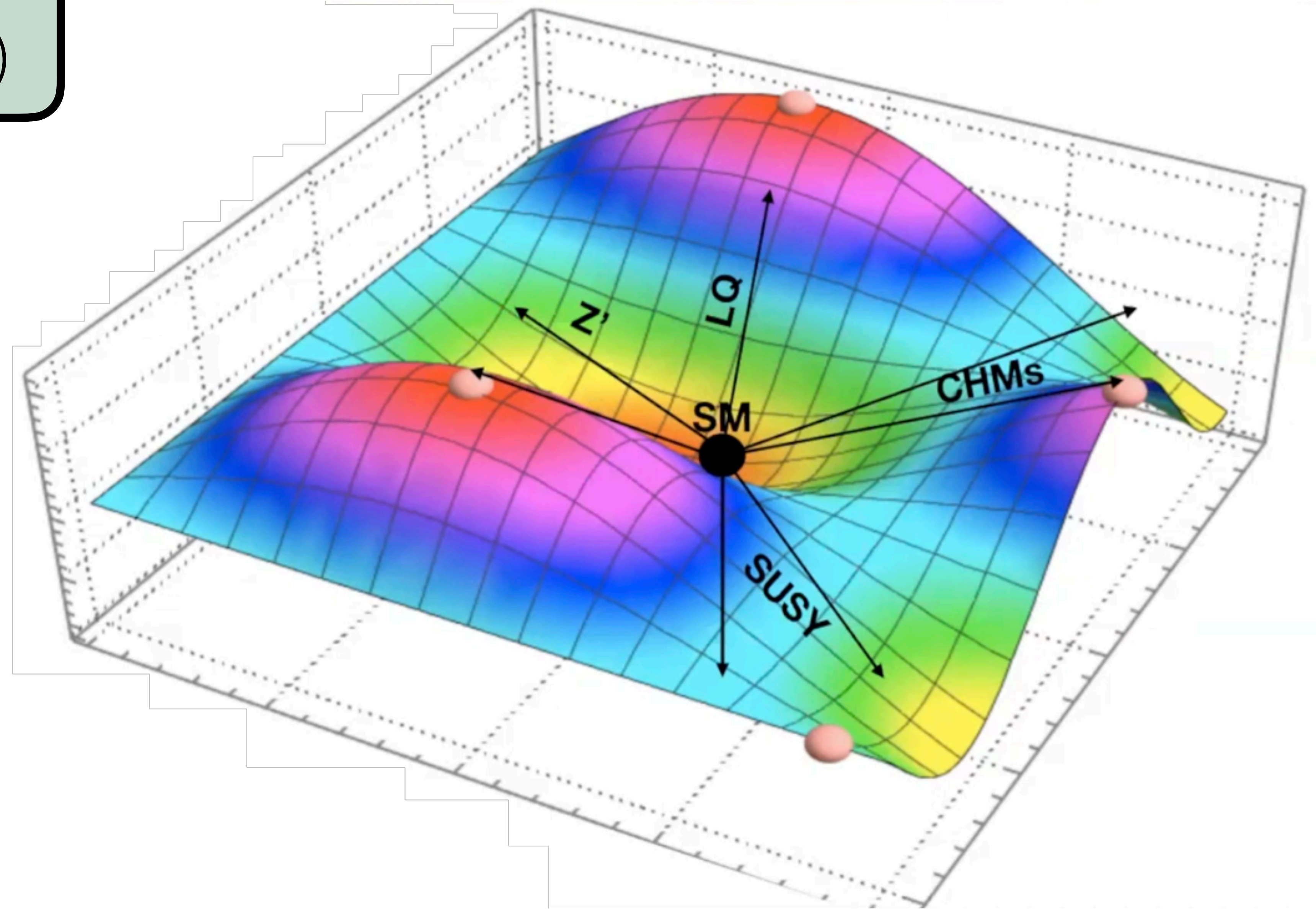
Standard Model Effective Field Theory(SMEFT)
- Framework to interpret deviation from SM predictions
- Model-independent approach to explore new physics

SM contents



Symmetry magazine, a joint Fermilab/SLAC publication.

EFT parameter space



“All things EFT” lecture series: How well do we know the SMEFT by Veronica Sanz

SMEFT

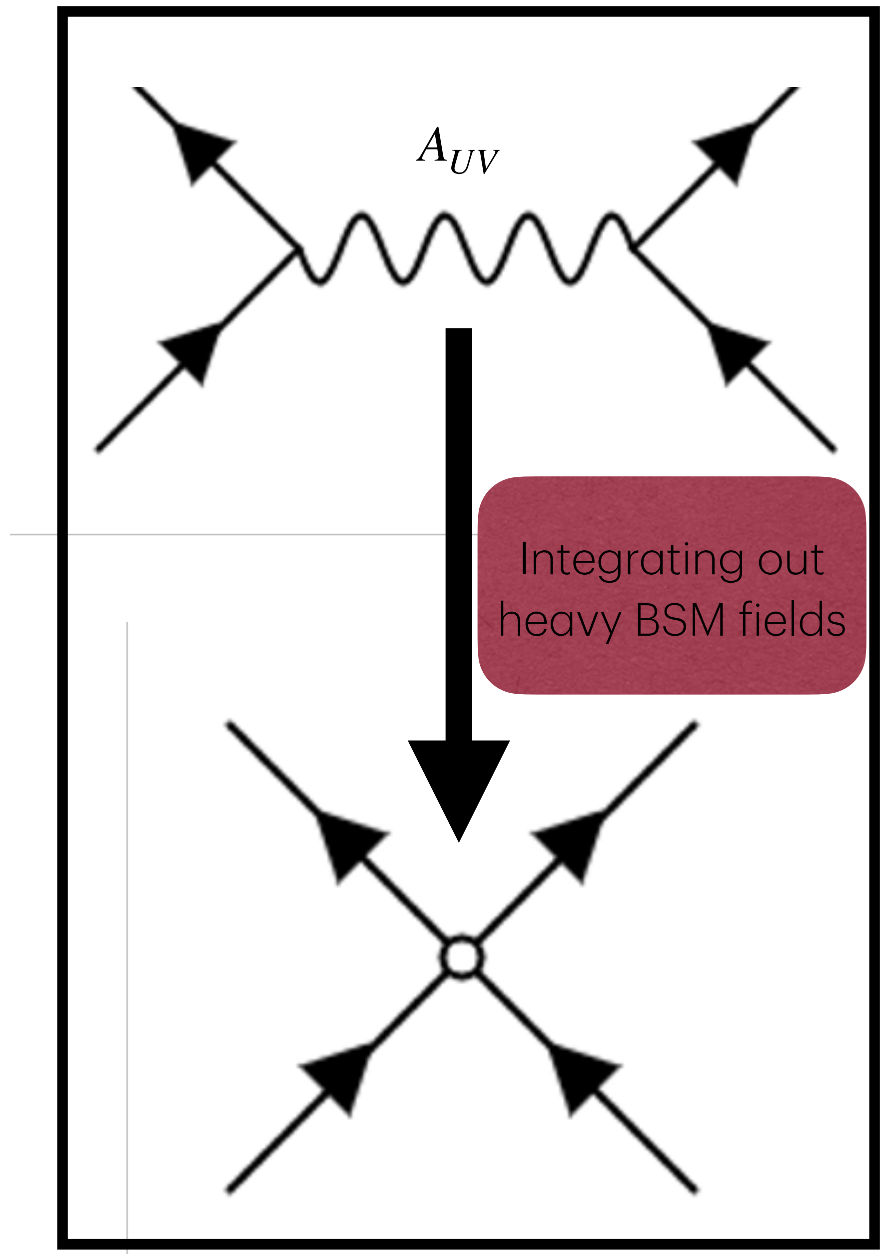
Bottom-up EFT: Captures new physics effects by systematically adding higher dimension operators(d>4) to the SM

SMEFT

Bottom-up EFT: Captures new physics effects by systematically adding higher dimension operators(d>4) to the SM

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}^{(4)}_{\text{SM}} + \underbrace{\frac{1}{\Lambda}\sum_k C_k^{(5)}\mathcal{O}_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)}\mathcal{O}_k^{(6)} + \frac{1}{\Lambda^3}\sum_k C_k^{(7)}\mathcal{O}_k^{(7)} \ldots}$$

Effects of BSM physics are encoded in the higher dim. Operators

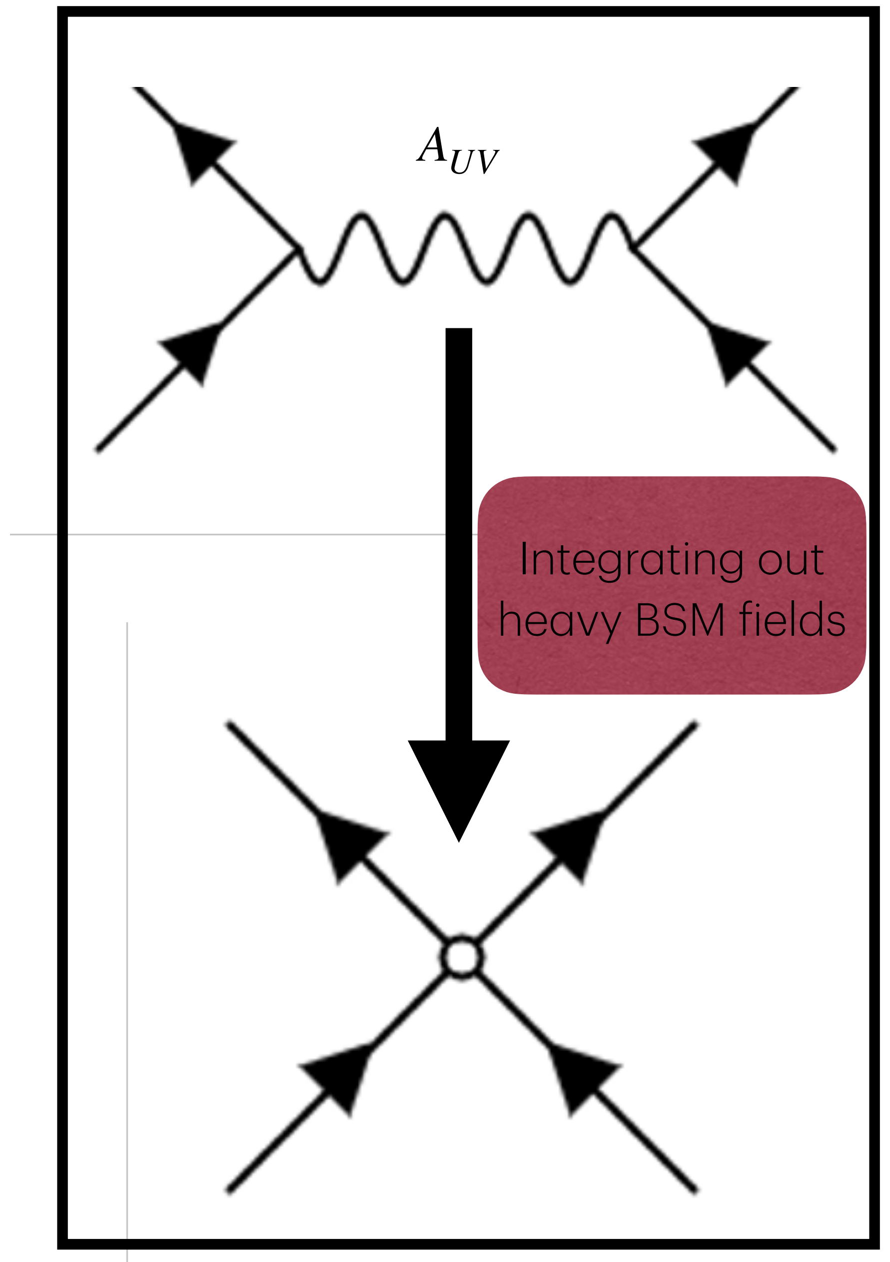


SMEFT

Bottom-up EFT: Captures new physics effects by systematically adding higher dimension operators(d>4) to the SM

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}^{(4)}_{\text{SM}} + \frac{1}{\Lambda}\sum_k C_k^{(5)}\mathcal{O}_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)}\mathcal{O}_k^{(6)} + \frac{1}{\Lambda^3}\sum_k C_k^{(7)}\mathcal{O}_k^{(7)}\ldots$$

Effects of BSM physics are encoded in the higher dim. Operators



Assumptions:

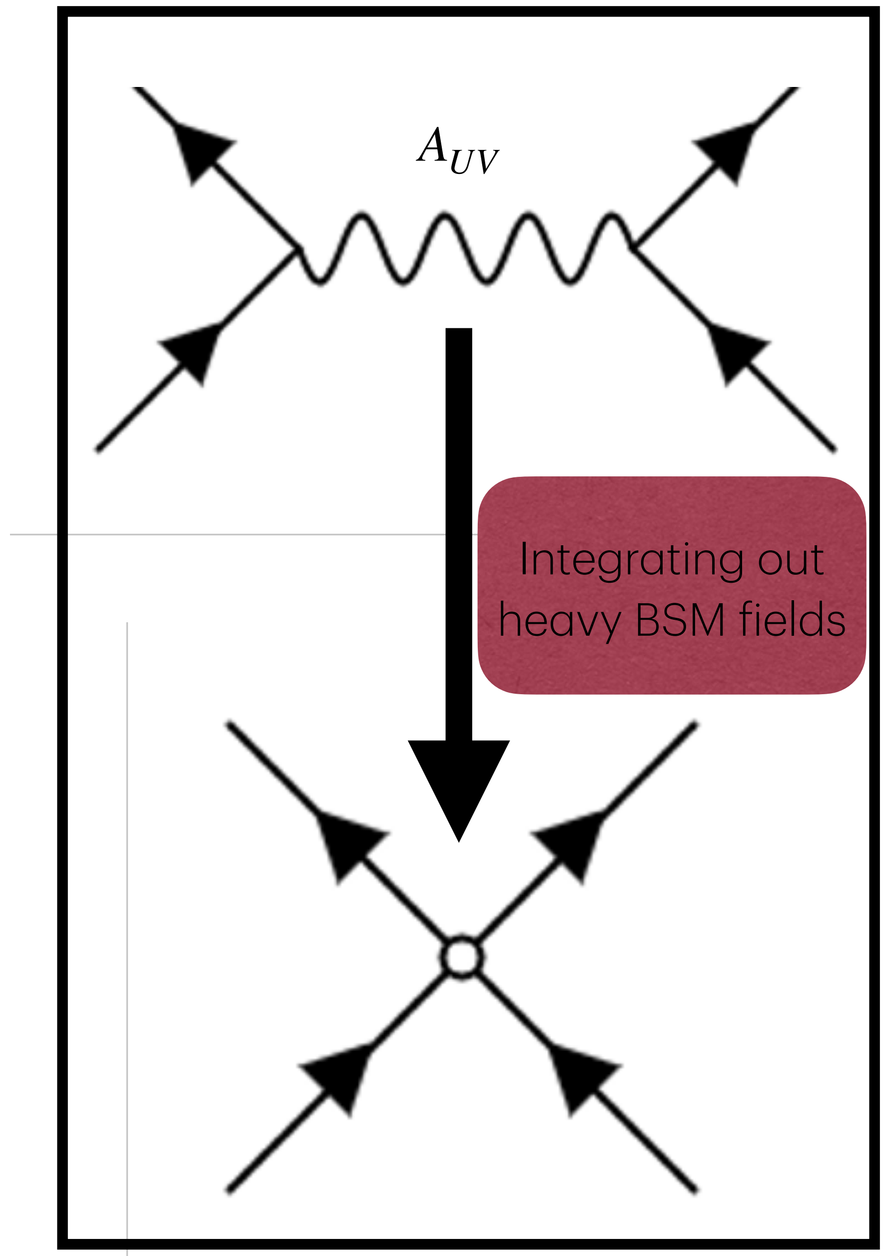
- New physics scale $(\Lambda) \gg$ EW scale (v)
- No new light d.o.f
- Operators are invariant under SM gauge group

SMEFT

Bottom-up EFT: Captures new physics effects by systematically adding higher dimension operators(d>4) to the SM

$$\mathscr{L}_{\text{SMEFT}} = \mathscr{L}_{\text{SM}}^{(4)} + \frac{1}{\Lambda}\sum_k C_k^{(5)}\mathcal{O}_k^{(5)} + \frac{1}{\Lambda^2}\sum_k C_k^{(6)}\mathcal{O}_k^{(6)} + \frac{1}{\Lambda^3}\sum_k C_k^{(7)}\mathcal{O}_k^{(7)} \dots$$

Effects of BSM physics are encoded in the higher dim. Operators



Assumptions:

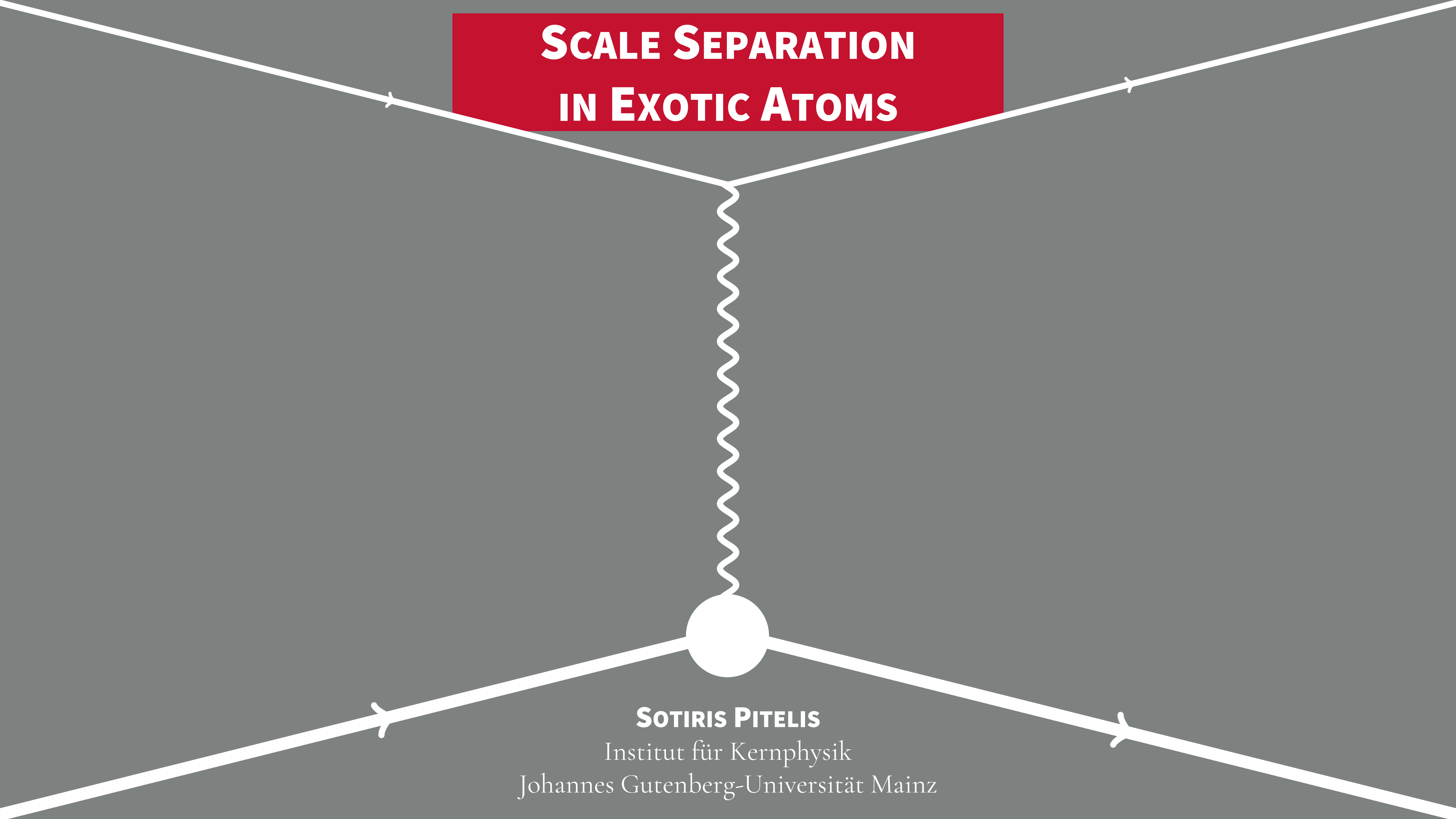
- New physics scale $(\Lambda) \gg$ EW scale (v)
- No new light d.o.f
- Operators are invariant under SM gauge group

My work:

- Study the effects of dim.6 operators on the electroweak observables
- Explore the complementarity between low and high energy experiments to constrain new physics.

Thank you

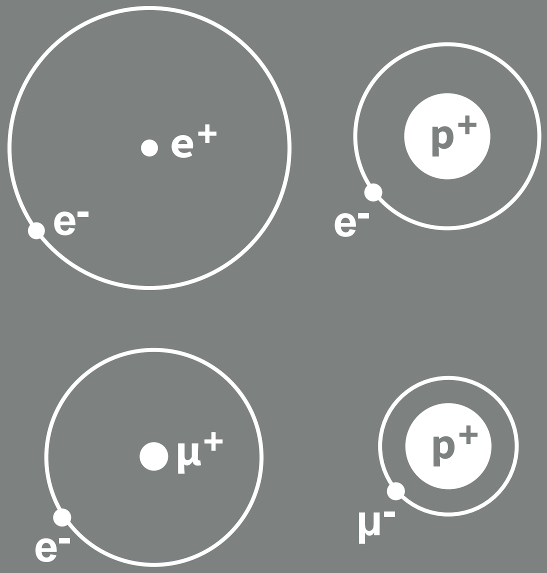
SCALE SEPARATION IN EXOTIC ATOMS



SOTIRIS PITELIS
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

SCALE SEPARATION IN EXOTIC ATOMS

PRECISION SPECTROSCOPY OF (EXOTIC) ATOMS



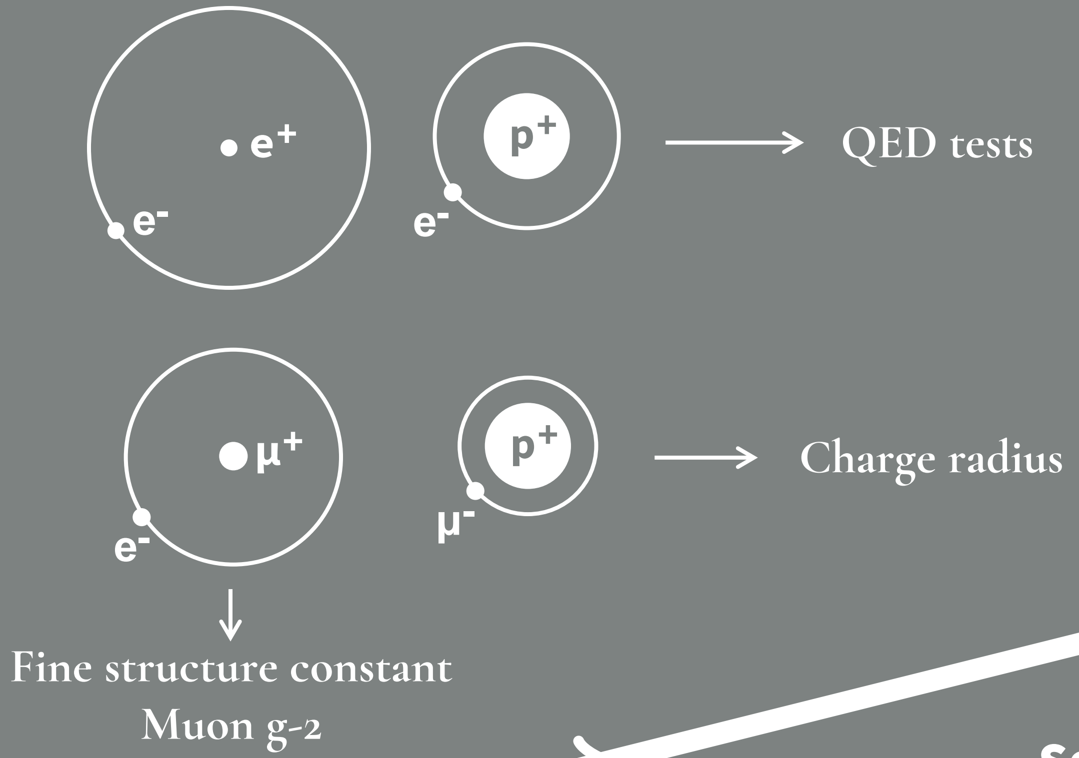
SOTIRIS PITELIS

Institut für Kernphysik

Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

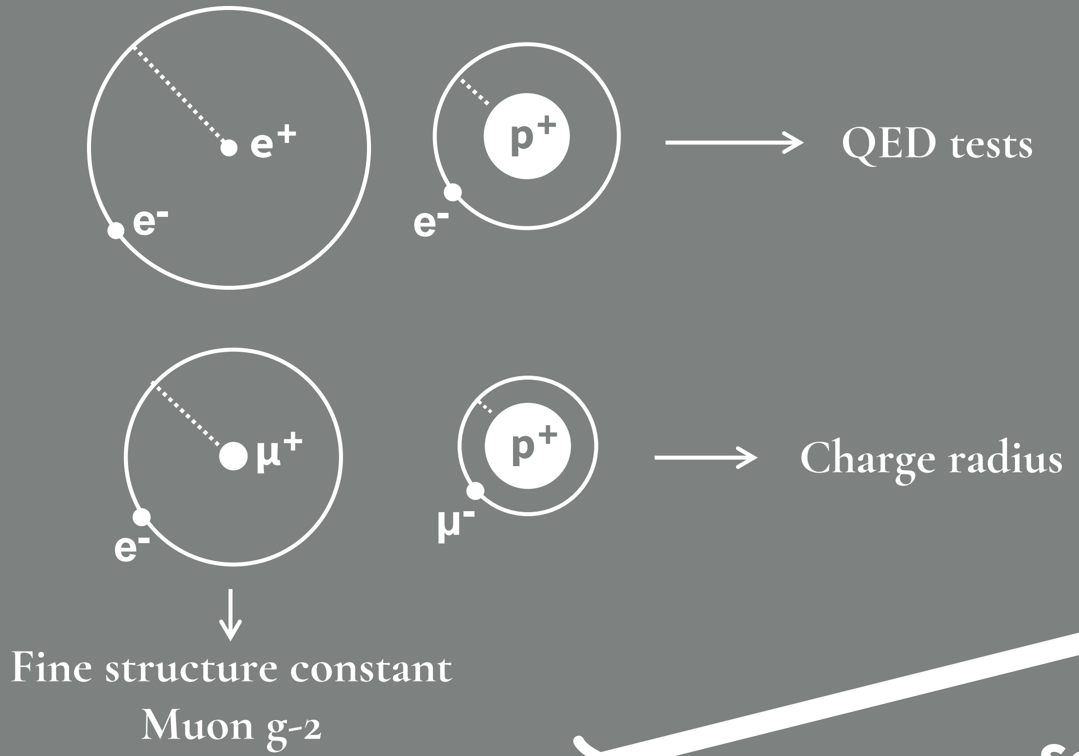
Precision Spectroscopy of (Exotic) Atoms



Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

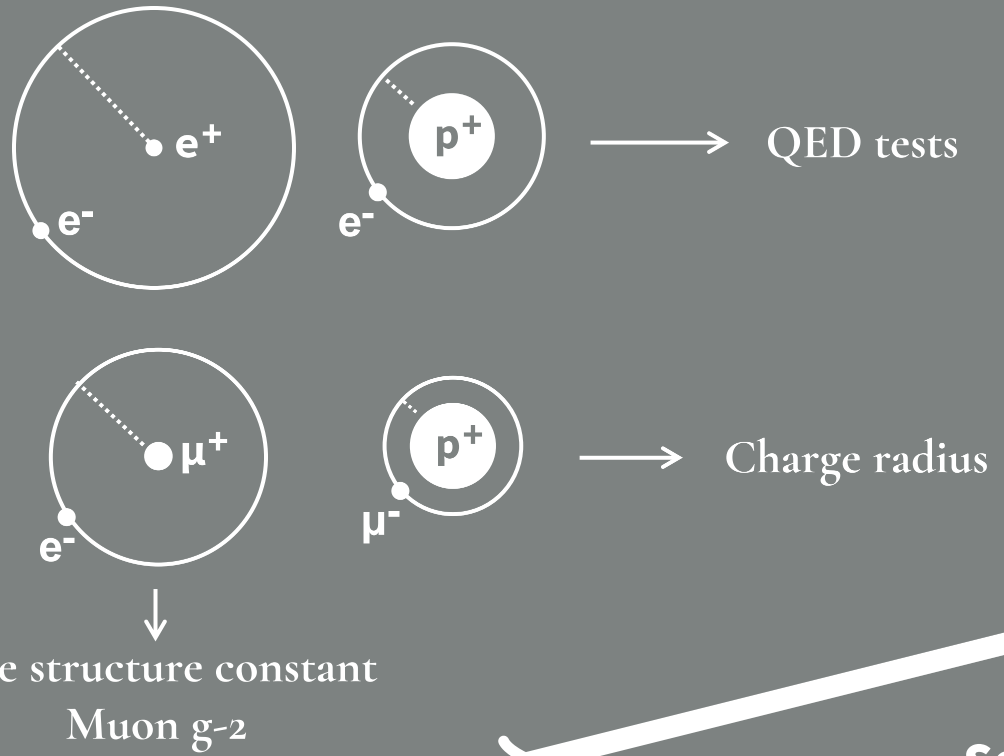
Precision spectroscopy of (exotic) atoms

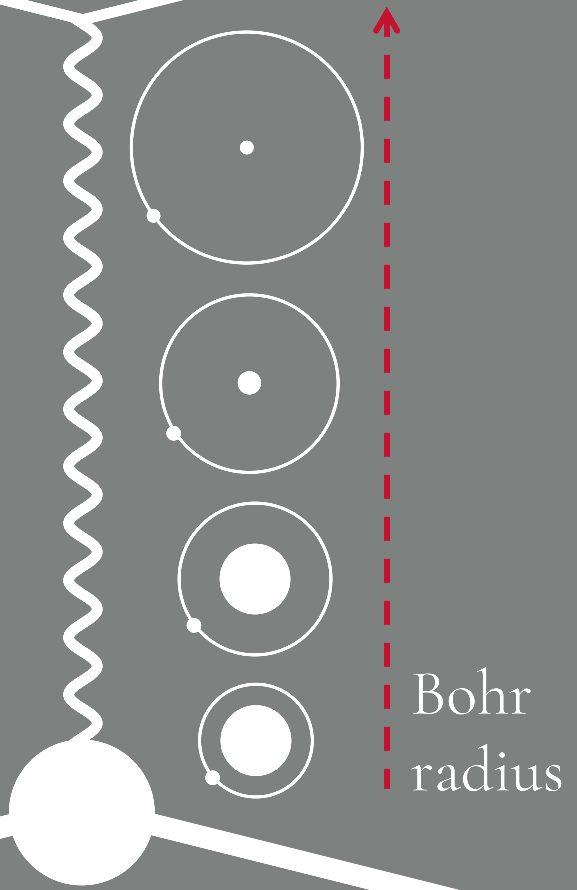


Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

Precision Spectroscopy of (Exotic) Atoms

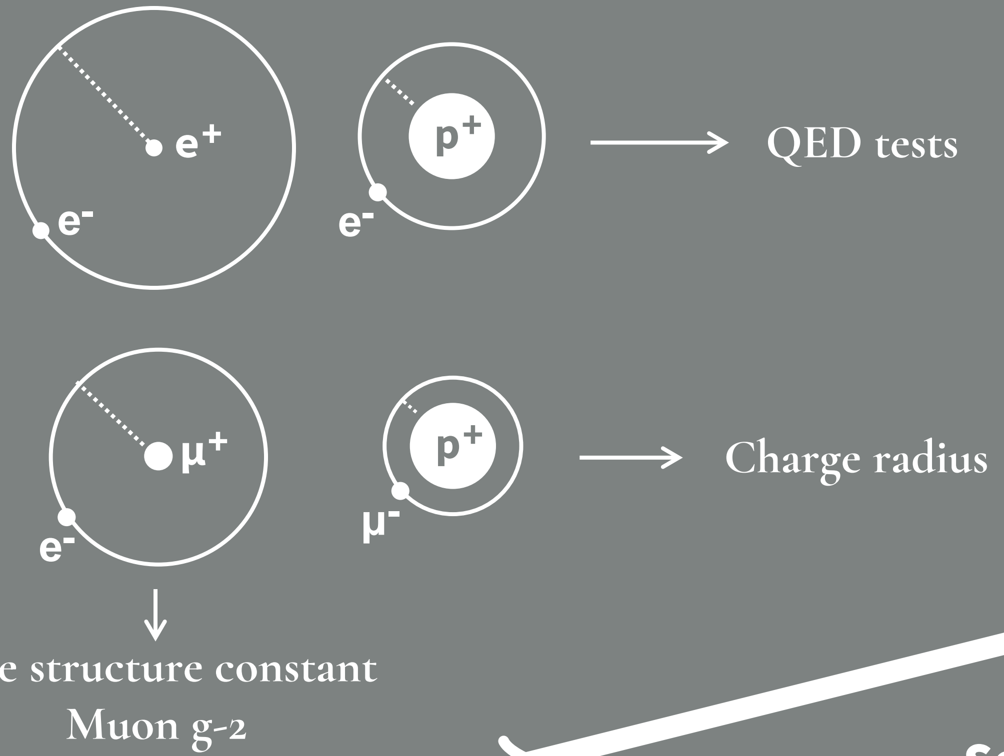




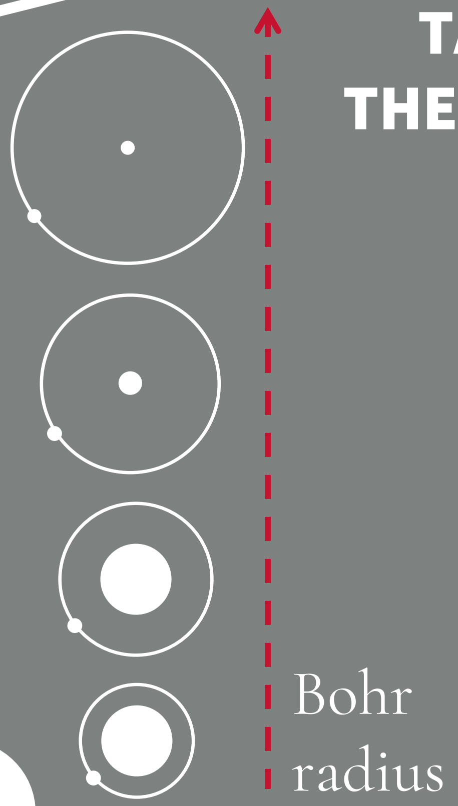
Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

PRECISION SPECTROSCOPY OF (EXOTIC) ATOMS



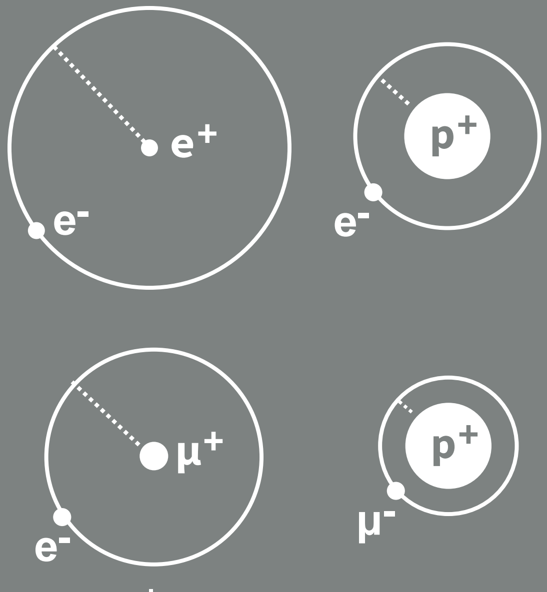
TAKING ADVANTAGE OF THE SEPARATION OF SCALES



Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

PRECISION SPECTROSCOPY OF (EXOTIC) ATOMS



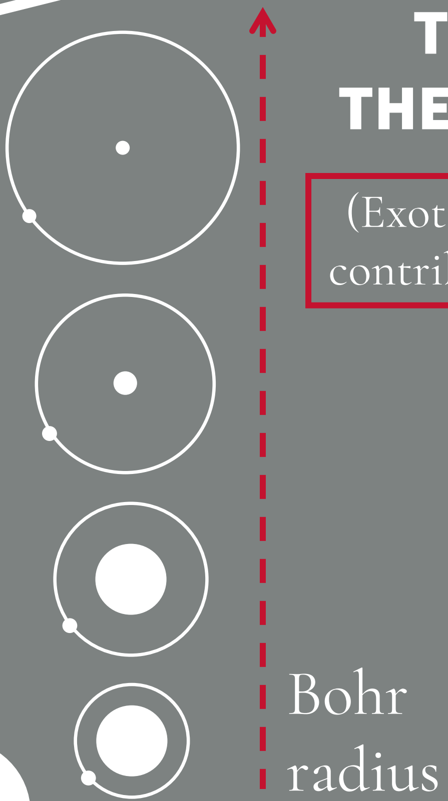
→ QED tests

→ Charge radius

↓ Fine structure constant
Muon g-2

TAKING ADVANTAGE OF THE SEPARATION OF SCALES

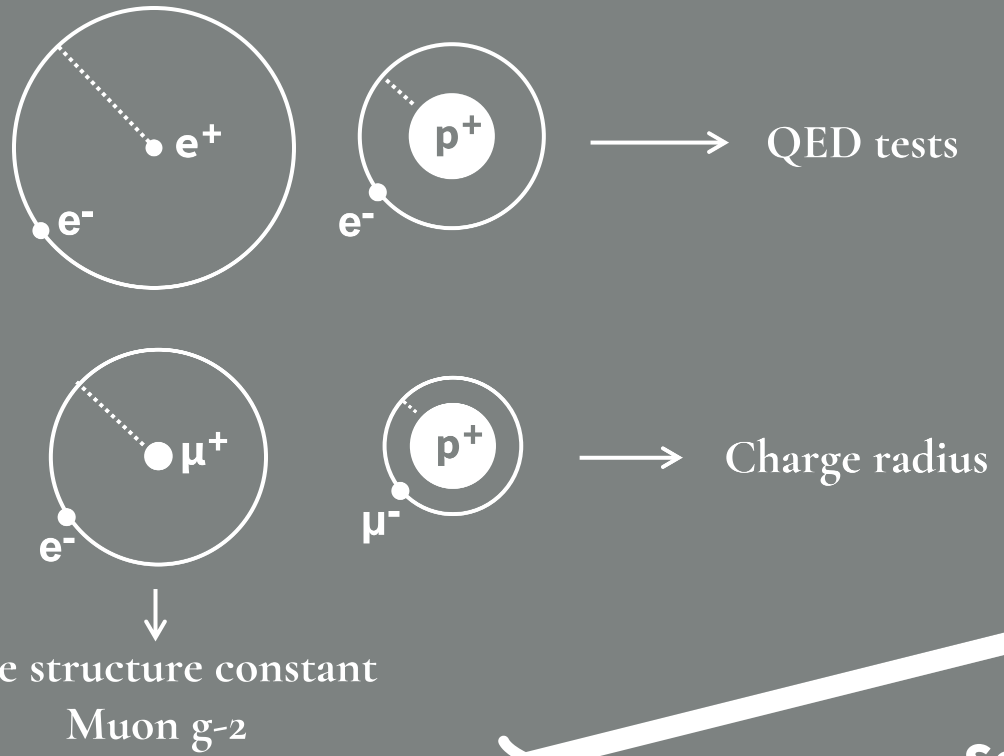
(Exotic) atoms are sensitive to different soft contributions depending on their Bohr radius



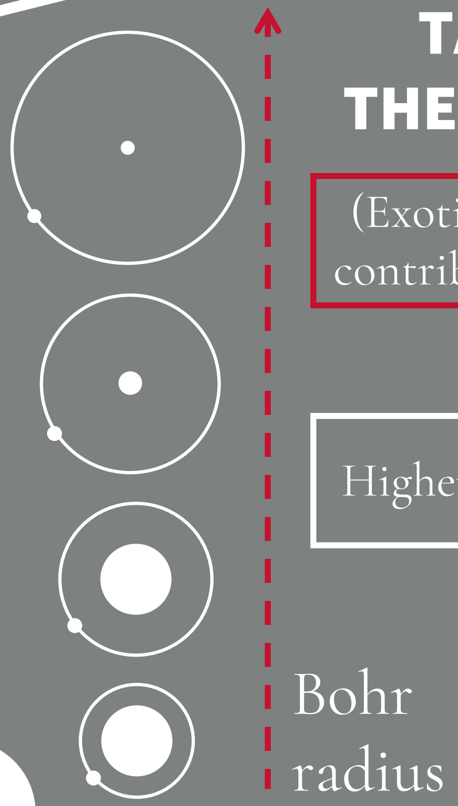
Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

Precision spectroscopy of (exotic) atoms



Taking advantage of the separation of scales



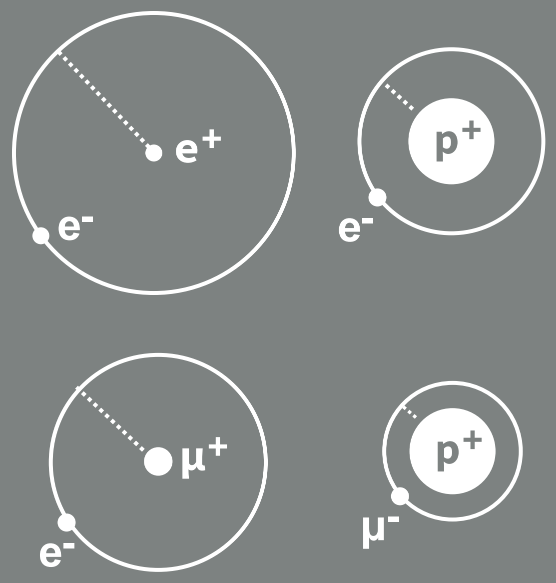
(Exotic) atoms are sensitive to different soft contributions depending on their Bohr radius

Higher-order corrections might be enhanced

Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

Scale Separation in Exotic Atoms

Precision spectroscopy of (exotic) atoms

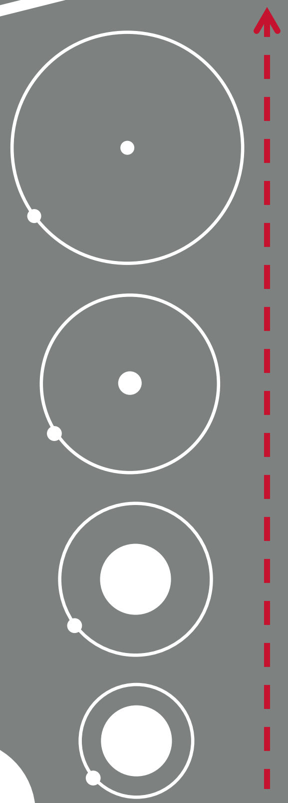


→ QED tests

→ Charge radius

↓ Fine structure constant
Muon g-2

Taking advantage of the separation of scales

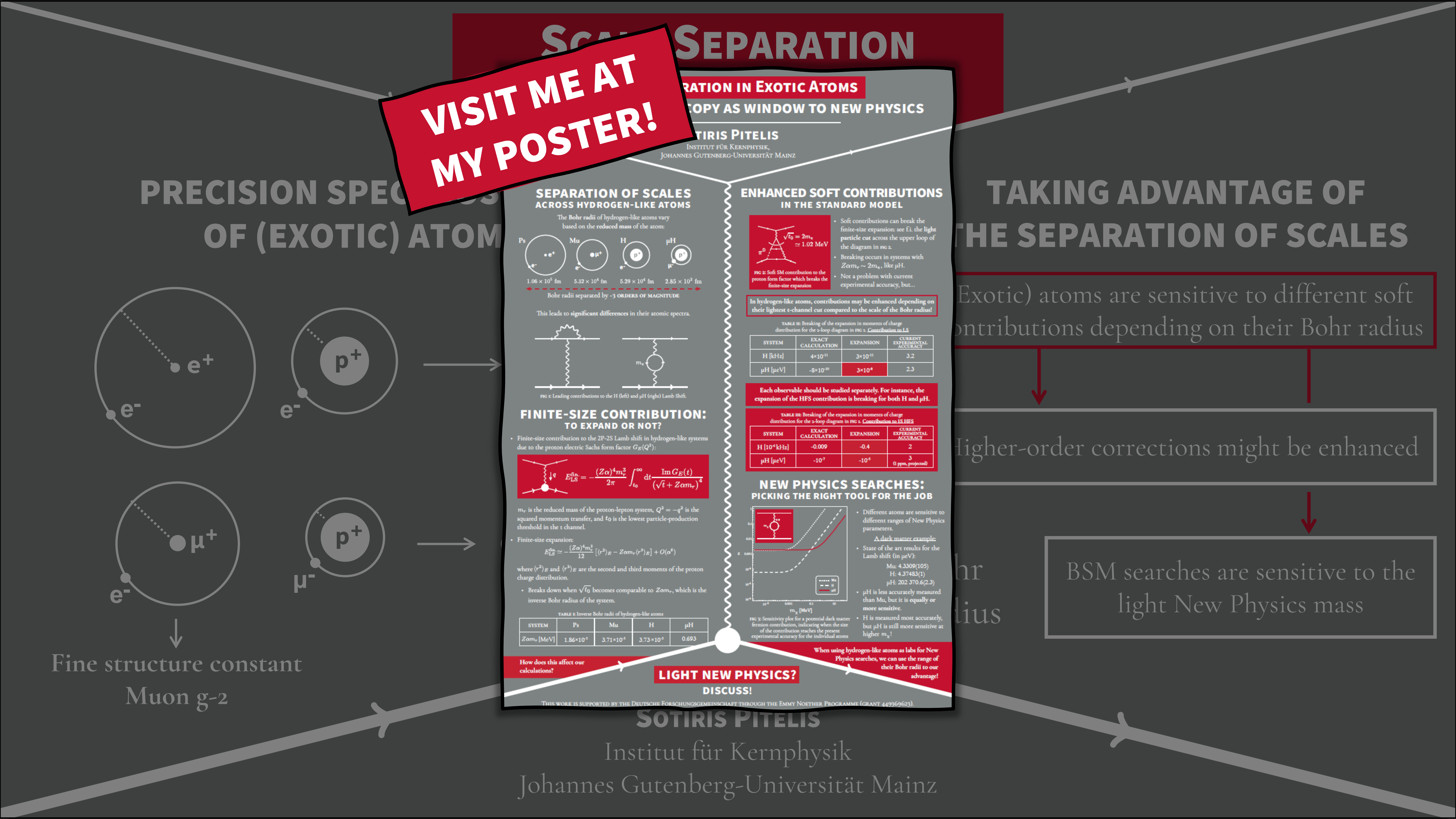


(Exotic) atoms are sensitive to different soft contributions depending on their Bohr radius

Higher-order corrections might be enhanced

BSM searches are sensitive to the light New Physics mass

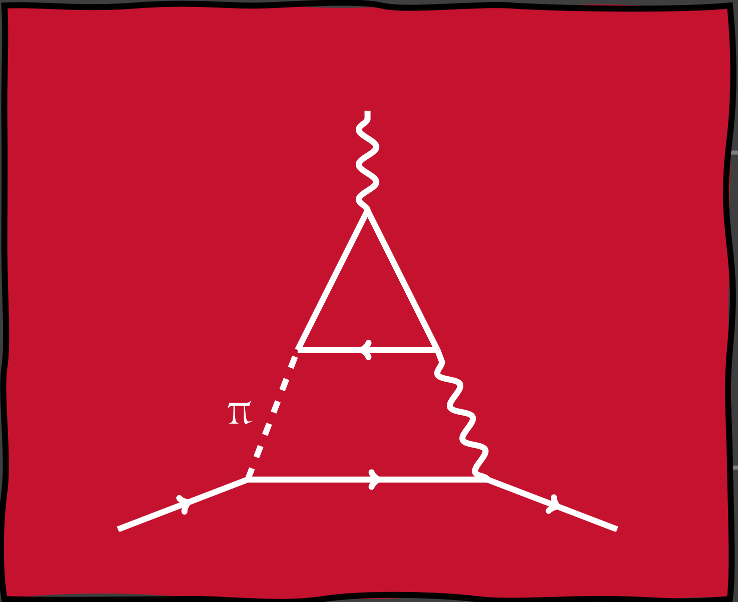
Sotiris Pitelis
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz



VISIT ME AT MY POSTER!
SEPARATION
PRECISION SPEC
OF (EXOTIC) ATOM
e+
e-
p+
e-
μ+
e-
p+
μ-
Fine structure constant
Muon g-2
TAKING ADVANTAGE OF
THE SEPARATION OF SCALES
Exotic) atoms are sensitive to different soft
ontributions depending on their Bohr radius
Higher-order corrections might be enhanced
BSM searches are sensitive to the
light New Physics mass
hr
lius
SOTIRIS PITELIS
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz
RATION IN EXOTIC ATOMS
COPY AS WINDOW TO NEW PHYSICS
TIRIS PITELIS
INSTITUT FÜR KERNPHYSIK,
JOHANNES GUTENBERG-UNIVERSITÄT MAINZ
SEPARATION OF SCALES
ACROSS HYDROGEN-LIKE ATOMS
The Bohr radii of hydrogen-like atoms vary
based on the reduced mass of the atom:
Ps
Mu
H
μH
1.06 × 10⁵ fm
5.32 × 10⁴ fm
5.29 × 10⁴ fm
2.85 × 10² fm
Bohr radii separated by ~3 ORDERS OF MAGNITUDE
This leads to significant differences in their atomic spectra.
FIG 1: Leading contributions to the H (left) and μH (right) Lamb Shift.
FINITE-SIZE CONTRIBUTION:
TO EXPAND OR NOT?
Finite-size contribution to the 2P-2S Lamb shift in hydrogen-like systems due to the proton electric Sachs form factor G_E(Q²):
Finite-size expansion:
Breaks down when √t₀ becomes comparable to Zαm_r, which is the inverse Bohr radius of the system.
TABLE I: Inverse Bohr radii of hydrogen-like atoms
SYSTEM
Ps
Mu
H
μH
Zαm_r [MeV]
1.86×10⁻³
3.71×10⁻³
3.73×10⁻³
0.693
How does this affect our calculations?
ENHANCED SOFT CONTRIBUTIONS
IN THE STANDARD MODEL
√t₀ = 2m_e ≃ 1.02 MeV
FIG 2: Soft SM contribution to the proton form factor which breaks the finite-size expansion
Soft contributions can break the finite-size expansion: see f.i. the light particle cut across the upper loop of the diagram in FIG 2.
Breaking occurs in systems with Zαm_r ~ 2m_e, like μH.
Not a problem with current experimental accuracy, but...
In hydrogen-like atoms, contributions may be enhanced depending on their lightest t-channel cut compared to the scale of the Bohr radius!
SYSTEM
EXACT CALCULATION
EXPANSION
CURRENT EXPERIMENTAL ACCURACY
H [kHz]
4×10⁻¹¹
3×10⁻¹¹
3.2
μH [μeV]
-8×10⁻¹⁰
3×10⁻⁶
2.3
Each observable should be studied separately. For instance, the expansion of the HFS contribution is breaking for both H and μH.
SYSTEM
EXACT CALCULATION
EXPANSION
CURRENT EXPERIMENTAL ACCURACY
H [10⁻⁶kHz]
-0.009
-0.4
2
μH [μeV]
-10⁻⁷
-10⁻⁵
3
NEW PHYSICS SEARCHES:
PICKING THE RIGHT TOOL FOR THE JOB
Different atoms are sensitive to different ranges of New Physics parameters.
A dark matter example:
State of the art results for the Lamb shift (in μeV):
Mu: 4.3309(105)
H: 4.37483(1)
μH: 202 370.6(2.3)
μH is less accurately measured than Mu, but it is equally or more sensitive.
H is measured most accurately, but μH is still more sensitive at higher m_χ!
When using hydrogen-like atoms as labs for New Physics searches, we can use the range of their Bohr radii to our advantage!
LIGHT NEW PHYSICS?
DISCUSS!

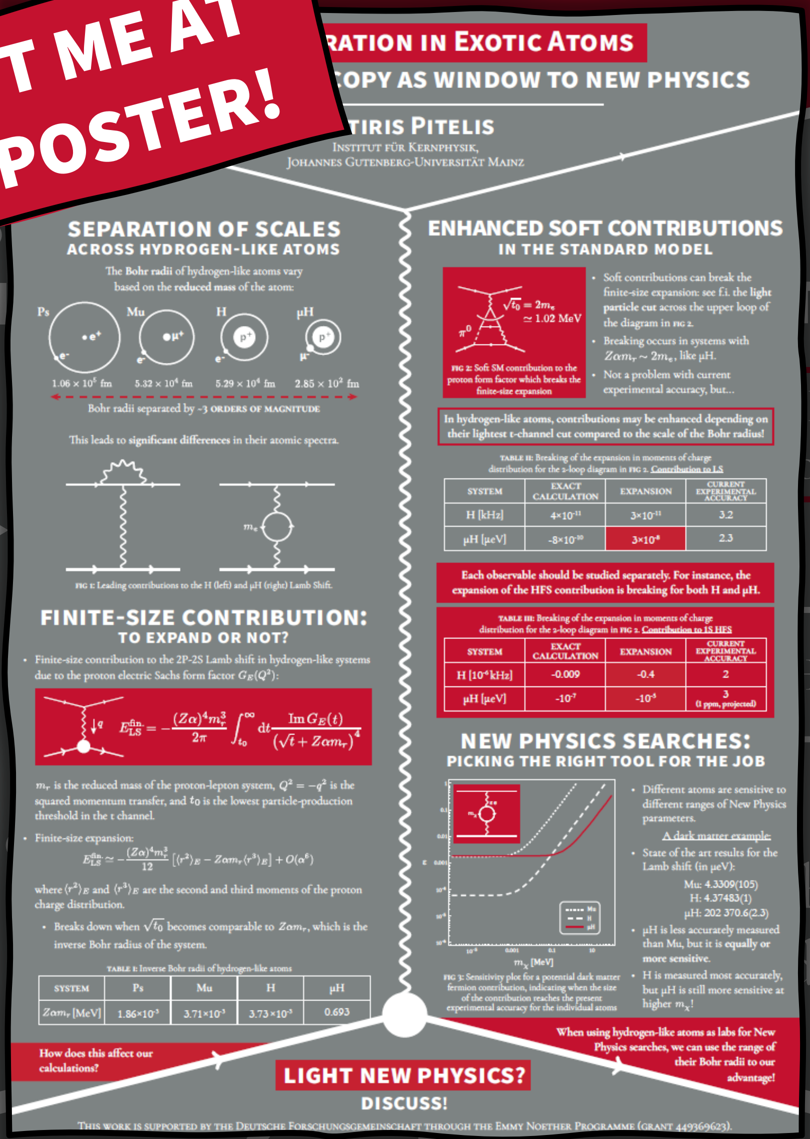
SC… SEPARATION

PRECISION SPEC… OF (EXOTIC) ATOM…



Fine structure constant
Muon g-2

VISIT ME AT MY POSTER!



TAKING ADVANTAGE OF THE SEPARATION OF SCALES

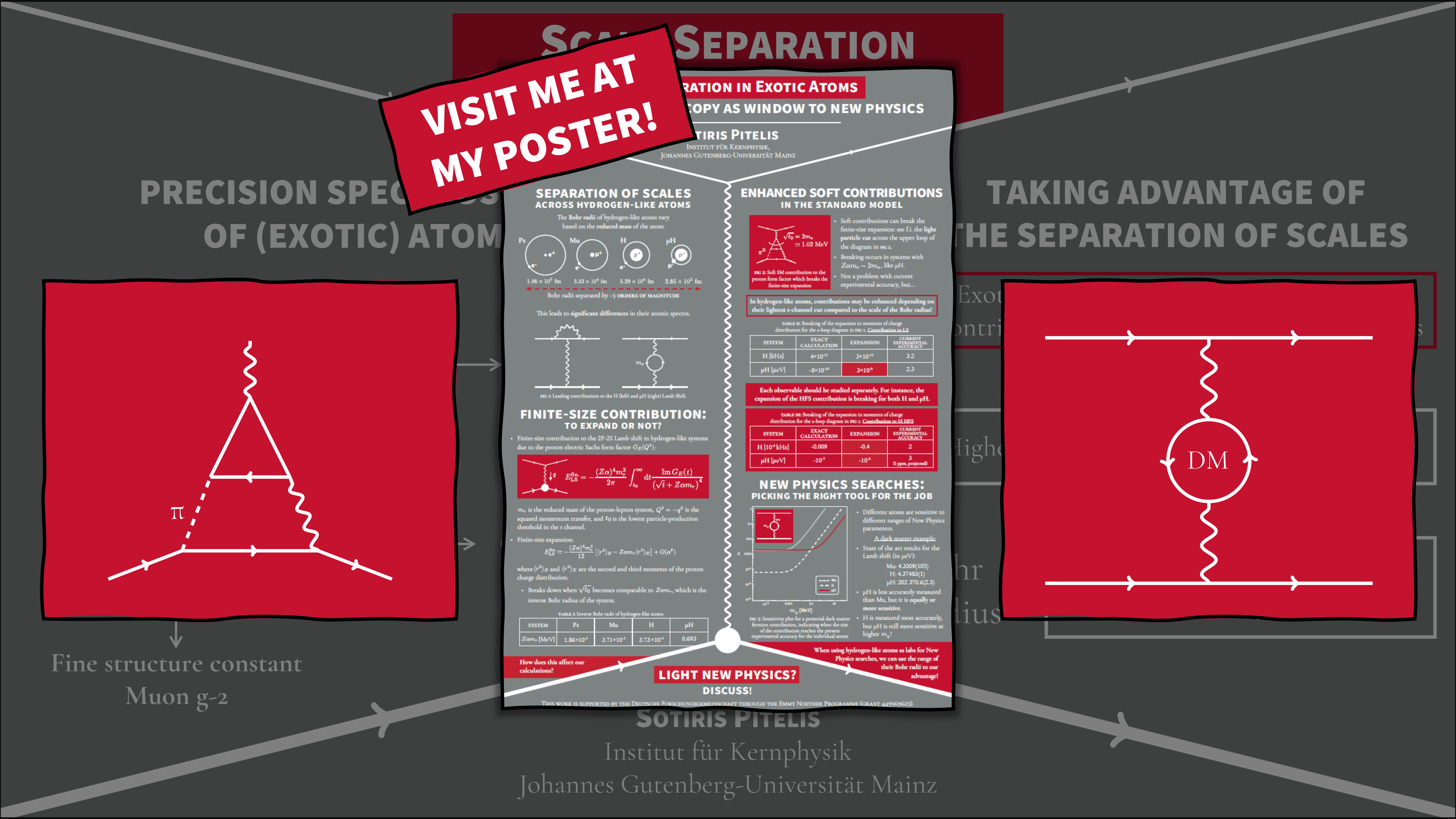
…Exotic) atoms are sensitive to different soft …ontributions depending on their Bohr radius

…igher-order corrections might be enhanced

…hr
…dius

BSM searches are sensitive to the light New Physics mass

SOTIRIS PITELIS
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz



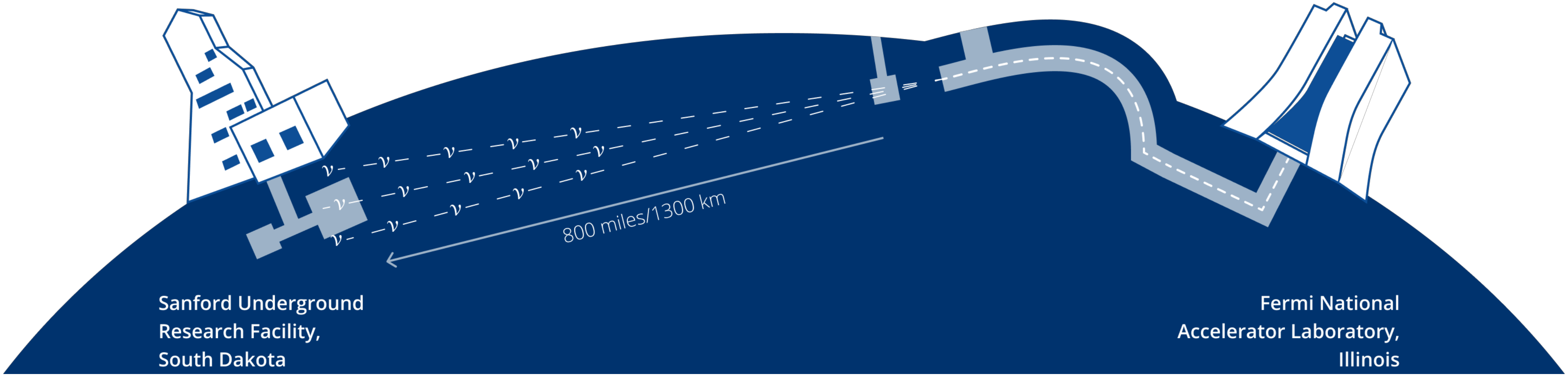
SCALE SEPARATION
VISIT ME AT MY POSTER!
PRECISION SPECTROSCOPY OF (EXOTIC) ATOMS
TAKING ADVANTAGE OF THE SEPARATION OF SCALES
π
DM
Fine structure constant
Muon g-2
SCALE SEPARATION IN EXOTIC ATOMS
SPECTROSCOPY AS WINDOW TO NEW PHYSICS
SOTIRIS PITELIS
Institut für Kernphysik, Johannes Gutenberg-Universität Mainz
SEPARATION OF SCALES ACROSS HYDROGEN-LIKE ATOMS
The Bohr radii of hydrogen-like atoms vary based on the reduced mass of the atom:
Ps Mu H μH
1.06 × 10⁵ fm 5.32 × 10⁴ fm 5.29 × 10⁴ fm 2.85 × 10² fm
Bohr radii separated by ~3 orders of magnitude
This leads to significant differences in their atomic spectra.
FIG 1: Leading contributions to the H (left) and μH (right) Lamb Shift.
FINITE-SIZE CONTRIBUTION: TO EXPAND OR NOT?
Finite-size contribution to the 2P-2S Lamb shift in hydrogen-like systems due to the proton electric Sachs form factor G_E(Q²):
m_r is the reduced mass of the proton-lepton system, Q² = −q² is the squared momentum transfer, and t₀ is the lowest particle-production threshold in the t channel.
Finite-size expansion:
where ⟨r²⟩_E and ⟨r³⟩_E are the second and third moments of the proton charge distribution.
Breaks down when √t₀ becomes comparable to Zαm_r, which is the inverse Bohr radius of the system.
TABLE I: Inverse Bohr radii of hydrogen-like atoms
SYSTEM Ps Mu H μH
Zαm_r [MeV] 1.86×10⁻³ 3.71×10⁻³ 3.73×10⁻³ 0.693
ENHANCED SOFT CONTRIBUTIONS IN THE STANDARD MODEL
√t₀ = 2m_e ≃ 1.02 MeV
FIG 2: Soft SM contribution to the proton form factor which breaks the finite-size expansion
Soft contributions can break the finite-size expansion: see f.i. the light particle cut across the upper loop of the diagram in FIG 2.
Breaking occurs in systems with Zαm_r ~ 2m_e, like μH.
Not a problem with current experimental accuracy, but...
In hydrogen-like atoms, contributions may be enhanced depending on their lightest t-channel cut compared to the scale of the Bohr radius!
TABLE II: Breaking of the expansion in moments of charge distribution for the 2-loop diagram in FIG 2. Contribution to LS
SYSTEM EXACT CALCULATION EXPANSION CURRENT EXPERIMENTAL ACCURACY
H [kHz] 4×10⁻¹¹ 3×10⁻¹¹ 3.2
μH [μeV] -5×10⁻¹⁰ 3×10⁻⁸ 2.3
Each observable should be studied separately. For instance, the expansion of the HFS contribution is breaking for both H and μH.
TABLE III: Breaking of the expansion in moments of charge distribution for the 2-loop diagram in FIG 2. Contribution to 1S HFS
SYSTEM EXACT CALCULATION EXPANSION CURRENT EXPERIMENTAL ACCURACY
H [10⁻⁶ kHz] -0.009 -0.4 2
μH [μeV] -10⁻⁷ -10⁻⁵ 3 (1 ppm, projected)
NEW PHYSICS SEARCHES: PICKING THE RIGHT TOOL FOR THE JOB
FIG 3: Sensitivity plot for a potential dark matter fermionic contribution, indicating when the size of the contribution reaches the present experimental accuracy for the individual atoms
Different atoms are sensitive to different ranges of New Physics parameters.
A dark matter example:
State of the art results for the Lamb shift (in μeV):
Mu: 4.3309(105)
H: 4.37483(1)
μH: 202 370.6(2.3)
μH is less accurately measured than Mu, but it is equally or more sensitive.
H is measured most accurately, but μH is still more sensitive at higher m_χ!
How does this affect our calculations?
When using hydrogen-like atoms as labs for New Physics searches, we can use the range of their Bohr radii to our advantage!
LIGHT NEW PHYSICS?
DISCUSS!
This work is supported by the Deutsche Forschungsgemeinschaft through the Emmy Noether Programme (grant 449369623).
SOTIRIS PITELIS
Institut für Kernphysik
Johannes Gutenberg-Universität Mainz

TOWARDS AB INITIO CALCULATIONS OF NEUTRINO-NUCLEUS SCATTERING

Immo Reis, JGU Mainz
In collaboration with: Joanna Sobczyk, Sonia Bacca

EPIC 2024, 24/09/2024

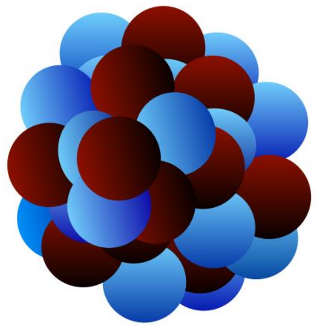
NEUTRINO-OSCILLATION EXPERIMENTS

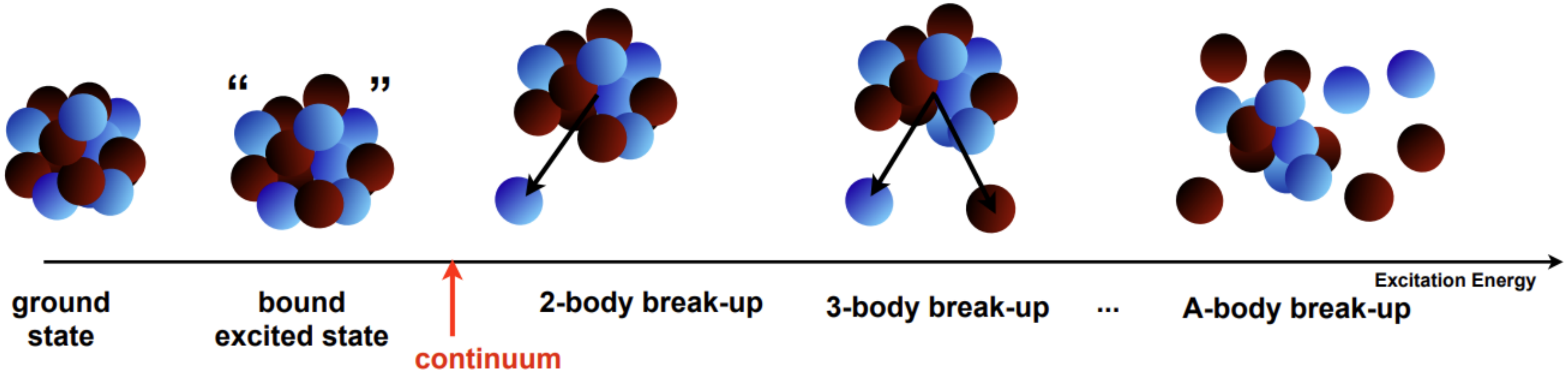


https://lbnf-dune.fnal.gov/about/overview/

THE AB INITIO APPROACH

$$R(\omega) = \sum_{\mu} \langle \Psi_0 | \Theta^\dagger | \Psi_\mu \rangle \langle \Psi_\mu | \Theta | \Psi_0 \rangle \, \delta(\omega - E_\mu + E_0)$$





$$\Phi(\sigma) = \int K(\sigma,\omega) R(\omega) d\omega \;\; = \langle \Psi_0 | \Theta^\dagger \hat{K}(\sigma, H - E_0) \Theta | \Psi_0 \rangle$$

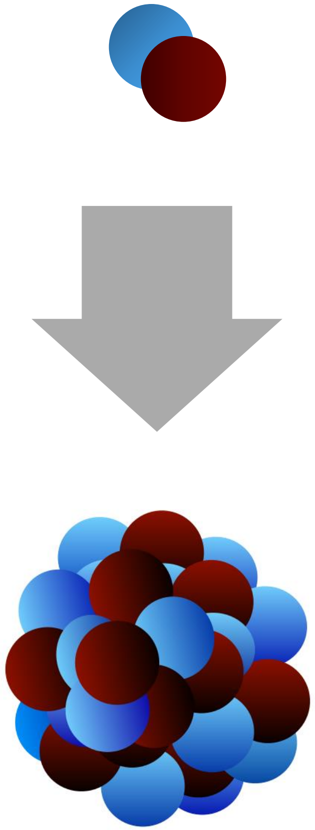
Efros, Leidemann, and Orlandini Phys. Lett. B 338, 130 – 133 (1994).

THE DEUTERON AS A SANDBOX

$$R(\omega) = \sum_{\mu} \langle \Psi_0 | \Theta^\dagger | \Psi_\mu \rangle \langle \Psi_\mu | \Theta | \Psi_0 \rangle \, \delta(\omega - E_\mu + E_0)$$

$$\Phi(\sigma) = \int K(\sigma, \omega) R(\omega) d\omega \qquad K(\sigma, \omega) = \sum_{k=0}^{\infty} c_k(\sigma) T_k(\omega)$$

Sobczyk and Roggero, Phys. Rev. E **105**, 055310



Weinberg Angle Detection
-
Developing New Methods via simulated Z-Boson Events

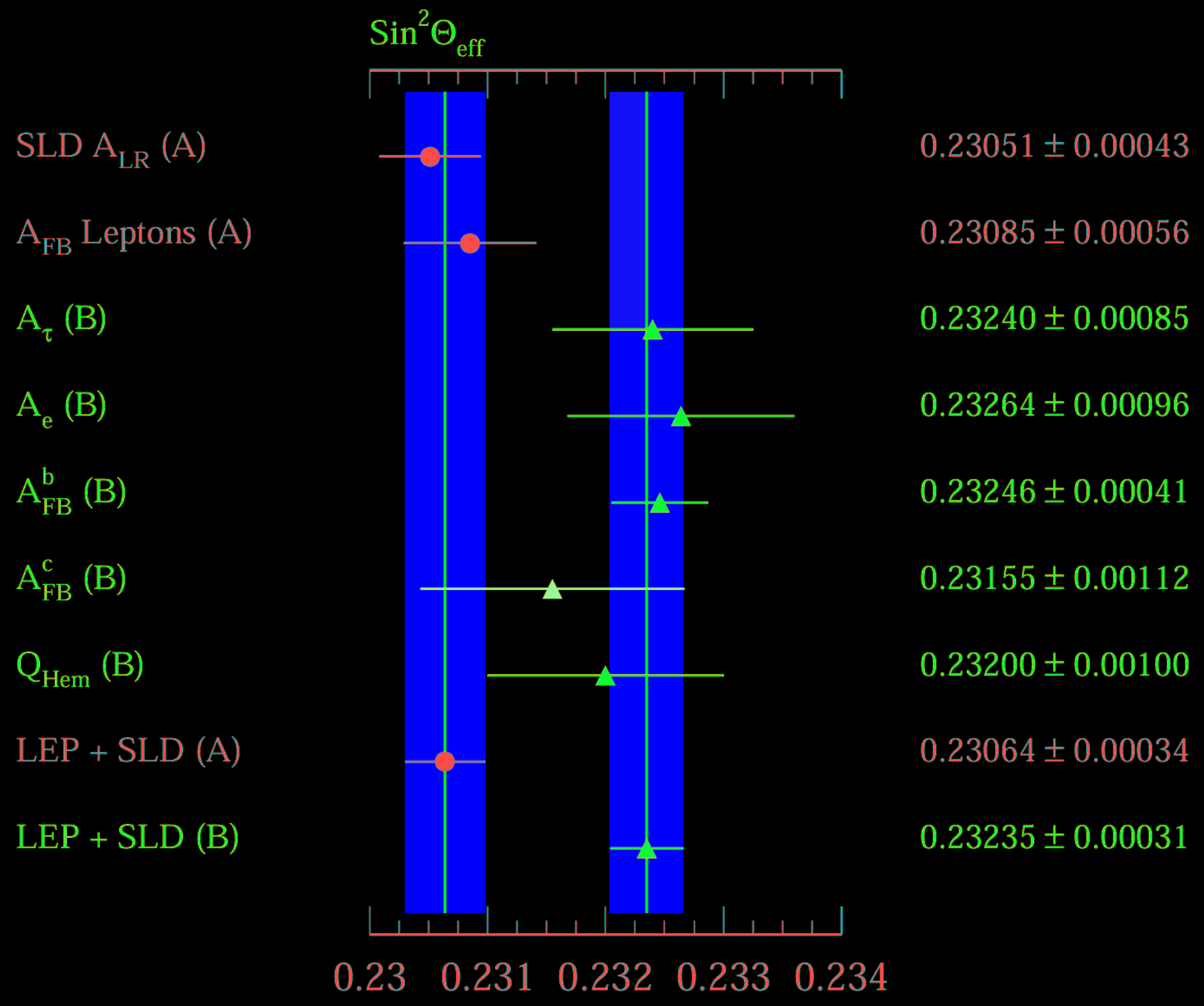
Sabrina Saul

Johannes-Gutenberg University Mainz

EPIC Sardinia 2024

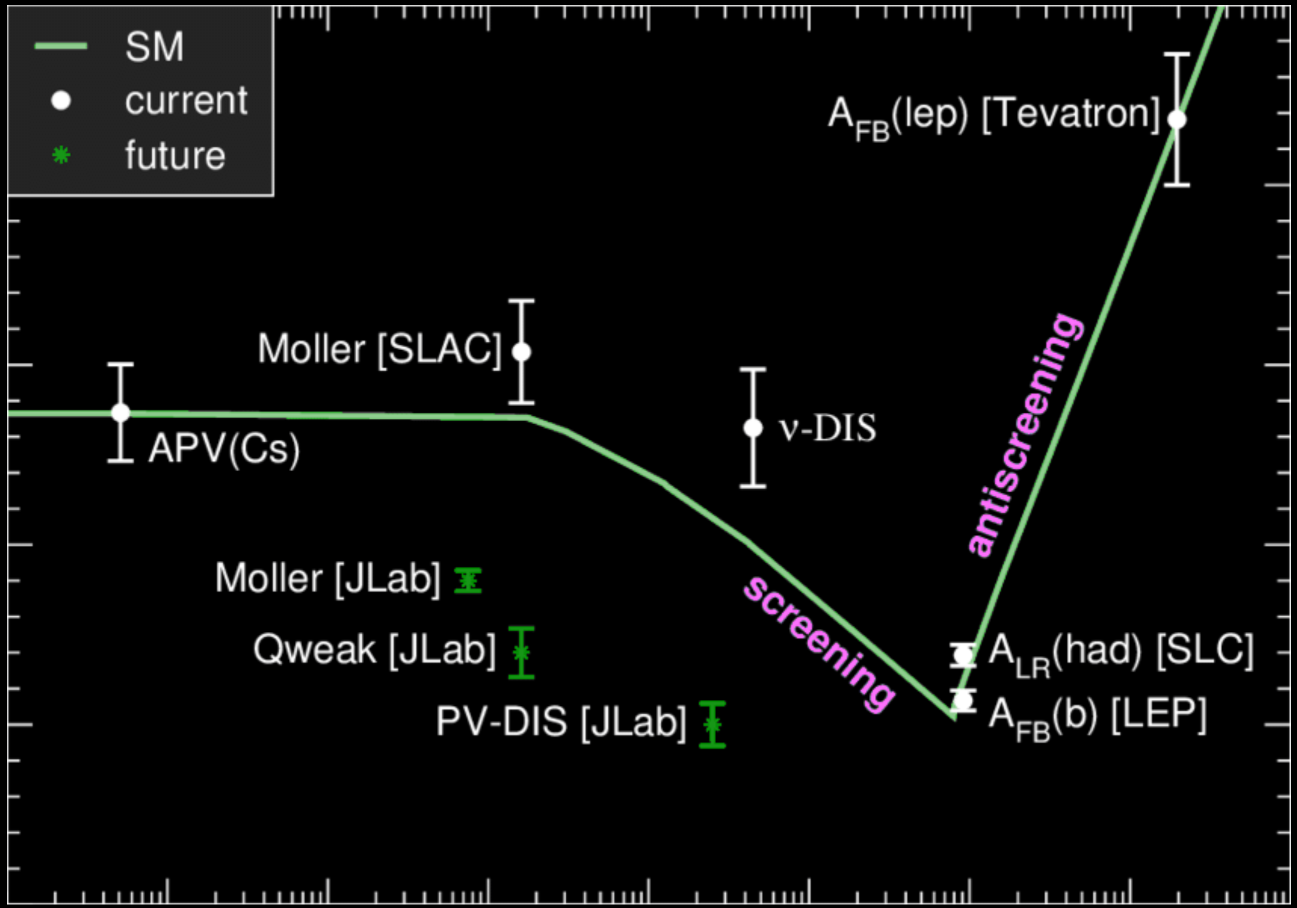
The struggle with measuring the Weinberg angle

- SLD at SLAC with 80% polarized beam
  - → A_{LR} with electron beam
- L3, ALEPH, DELPHI, OPAL at LEP with unpolarized beam
  - → A_{FB} with electron/positron beam
- Two measurement methods lead to deviations of 3.7σ



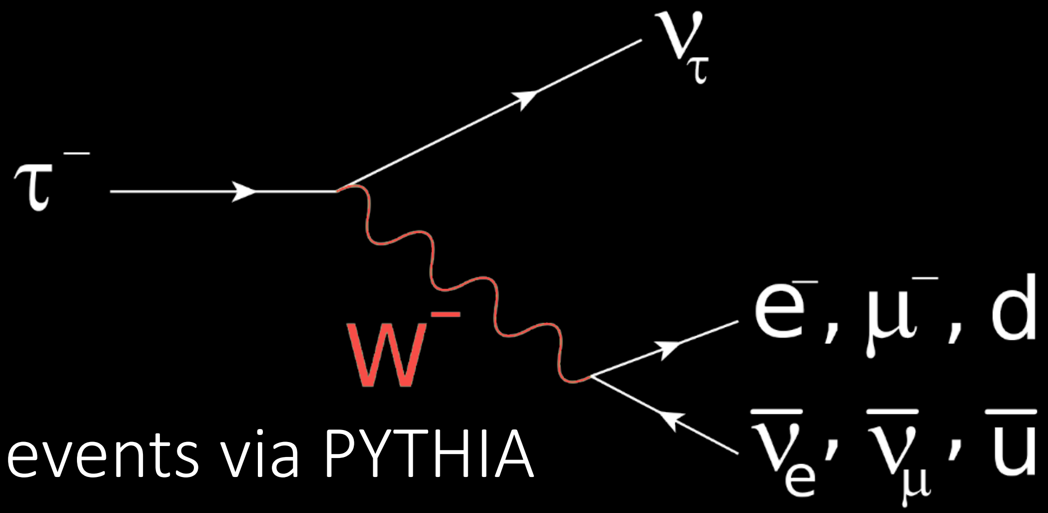
From Aziz, T. (1997). Asymmetry measurements at LEP/SLC revisited. Modern Physics Letters A, 12(33), 2535-2541.

Now (almost) everyone is measuring θ_W …



From Erler, J. (2011). Radiative corrections and Z'. Hyperfine Interactions, 200, 57-62.

Another try: ATLAS @ LHC



- Simulation of 1 Million Z production events via PYTHIA

→ Include detector simulation

- Use decay products to gain information about parent particle helicity
- Test different cuts and selection methods to obtain polarization of decay products

Neutrino Experiments

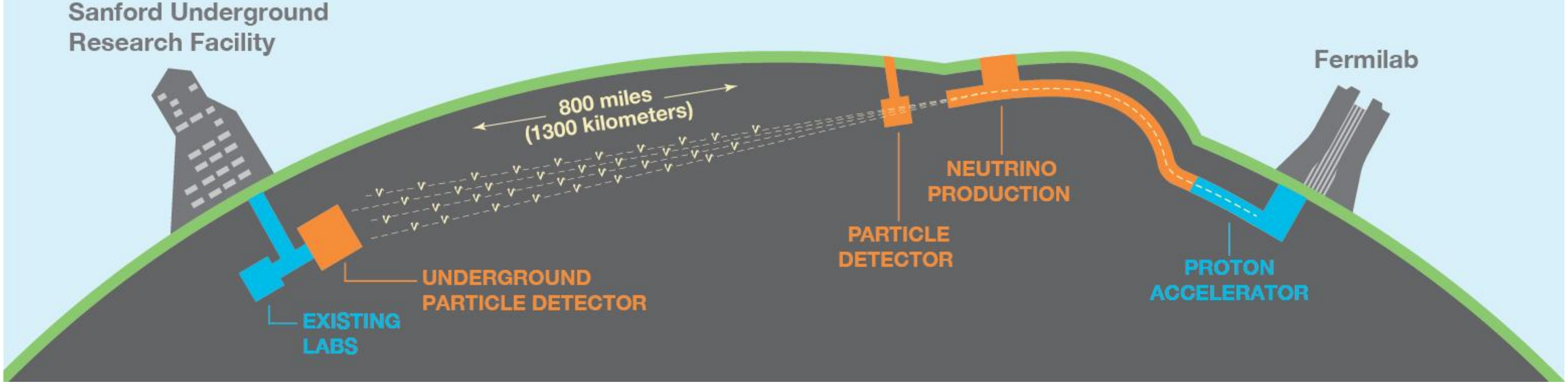
$$\begin{pmatrix} |\nu_e\rangle \\ |\nu_\mu\rangle \\ |\nu_\tau\rangle \end{pmatrix} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix} \begin{pmatrix} |\nu_1\rangle \\ |\nu_2\rangle \\ |\nu_3\rangle \end{pmatrix}$$

Long-baseline (LBL) neutrino experiments: e.g., DUNE (US), HyperK (Japan)

- observe and detect neutrino oscillations, near & far detector
- nuclear effects are main component of the systematic error

[DUNE, Fermilab]

$$P(E_\nu, L)_{\nu_\alpha \to \nu_\beta} \approx \sin^2(2\theta_e)\sin^2\left(\frac{\Delta m^2 L}{4E_\nu}\right)$$



Why using electrons for neutrino physics?

- Similar properties:

$$\left(\frac{d^2\sigma}{d\Omega d\omega}\right)_e = \sigma_M \left[A_L R_L + A_T R_T \right]$$

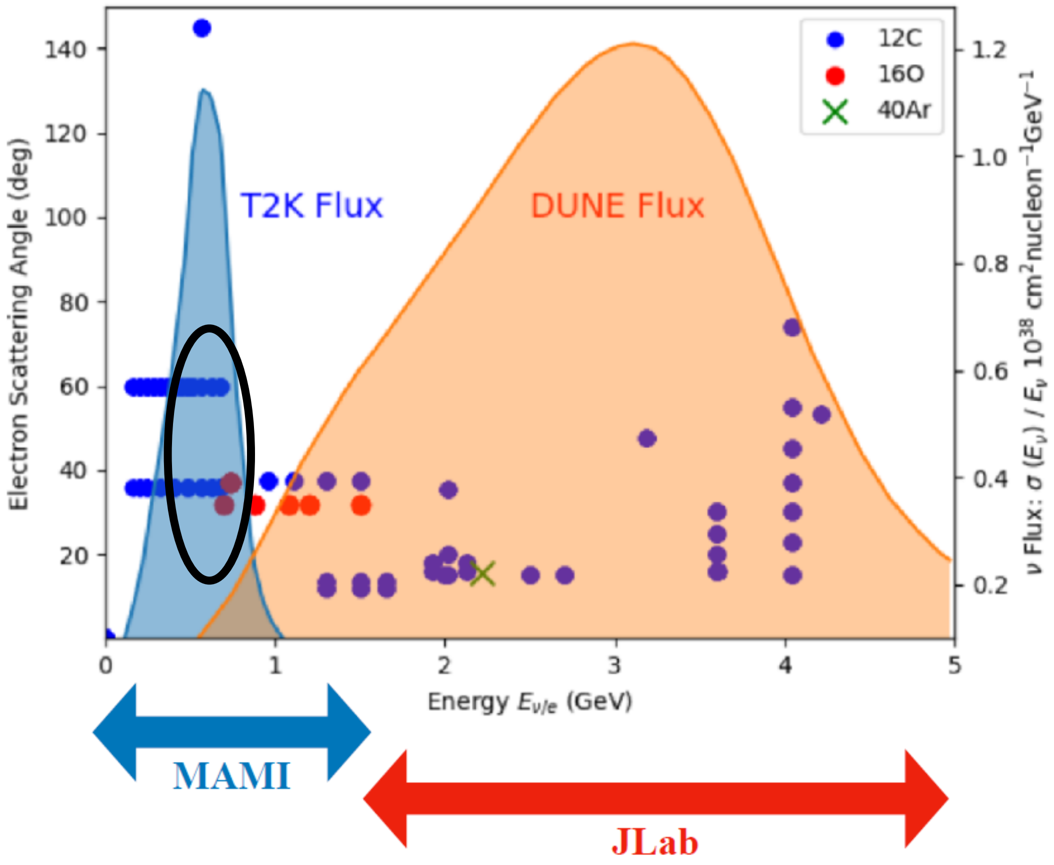
$$\left(\frac{d^2\sigma}{d\Omega d\omega}\right)_{\nu/\bar{\nu}} = \sigma_0 \left[A_{CC} R_{CC} + A_{CL} R_{CL} + A_{LL} R_{LL} + A_T R_T \pm A_{T'} R_{T'} \right]$$

- Useful to constrain model uncertainties
- Electrons have precisely known energies
  → Test incoming energy reconstruction methods

Target nuclei used in LBL experiments:

- ^{12}C, ^{16}O and ^{40}Ar

Existing inclusive data for relevant 'electrons for neutrinos' - target nuclei



Experiments in Mainz @ A1

A1 setup is an unique tool for electron for neutrino experiments:

- covers a broad range of scattering angles
- beam energies from 50 MeV to 1.6 GeV

→ possible to investigate different nuclear effects

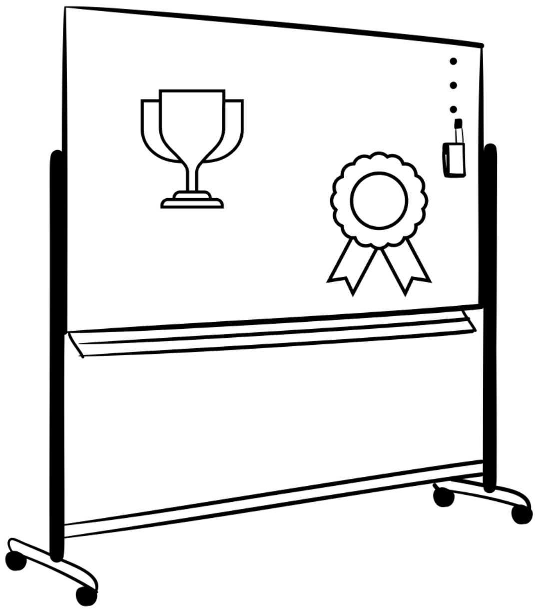
- We have data for different kinematics of carbon and argon
- And measured oxygen (not analyzed yet)

If you want to see the results, come to my poster!!

Thank you to all the speakers!

And Please, remember to Vote!

We will reward the **best teaser** and **best poster** contributions.
Up to 3 preferences allowed!



Express your preference using the google form at the following QR code

SCAN ME