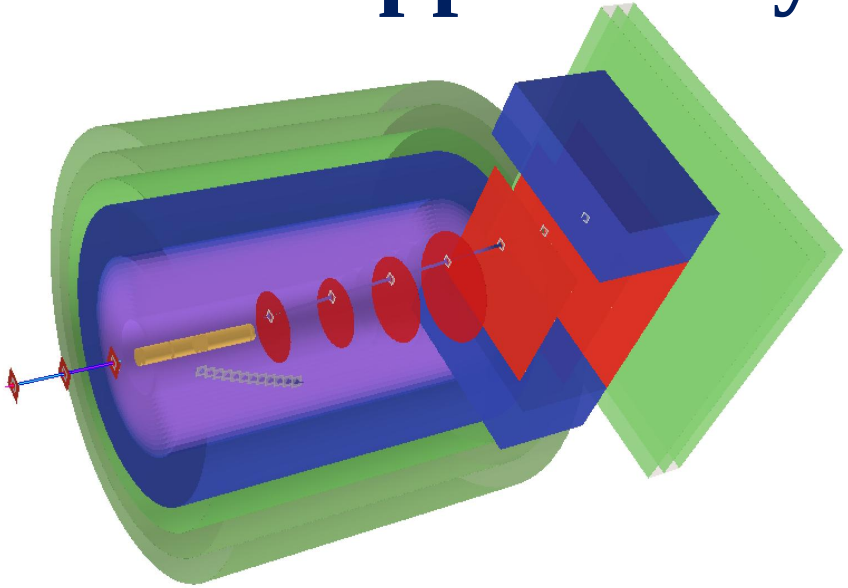
The LUNE experiment

-- A new scientific opportunity @ HIAF



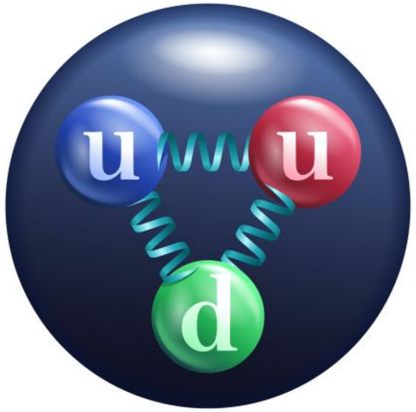
尹航（华中师范大学）

On behalf of LUNE collaboration

第七届粒子物理天问论坛

September 19th, 2025

Proton: basic questions



- The origin of its mass?
  - Make up nearly 90% of the normal matter in the universe
  - Elementary valence quarks: 1% level contribution
- The origin of confinement?
  - Quarks hadronized and form protons as the universe cooled below Hagedorn temperature
- Distribution of strong force?
  - Keep quarks confined
  - Make protons stable particles

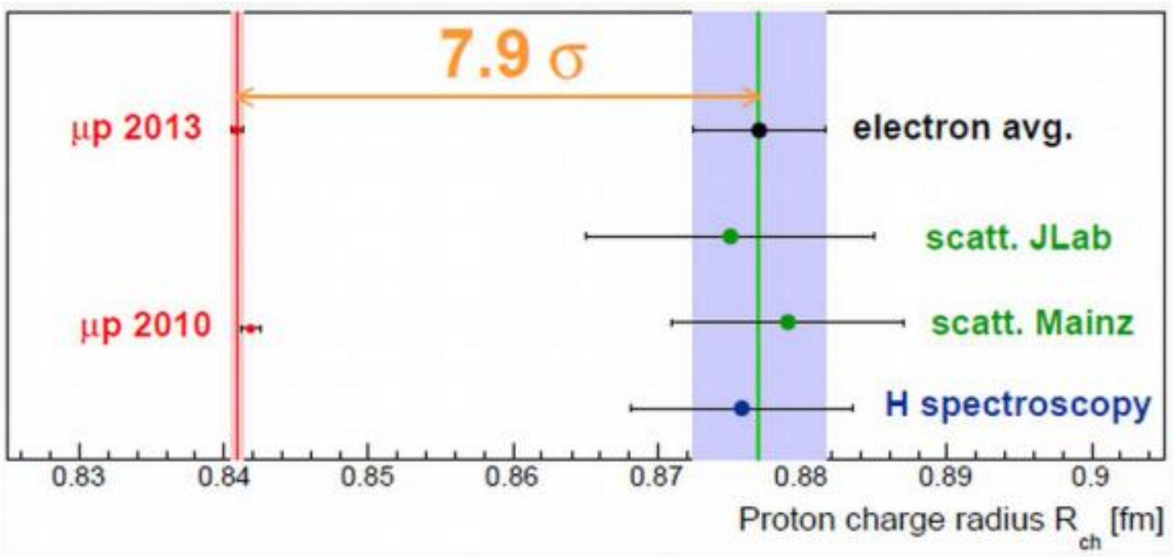
Fundamental global properties of proton

- The structure of strongly interacting particles can be probed using other fundamental forces
  - Electromagnetic, weak, gravity (in principle)

em: Vector	$\partial_\mu J^\mu_{\rm em} = 0$	$\langle N' \vert J^\mu_{\bf em} \vert N\rangle$	$\longrightarrow$	$Q_{\rm prot}$	$=$	$1.602176487(40)\times 10^{-19}{\rm C}$
				$\mu_{\rm prot}$	$=$	$2.792847356(23)\mu_N$
weak: Axial	PCAC	$\langle N' \vert J^\mu_{\bf weak} \vert N\rangle$	$\longrightarrow$	g_A	$=$	$1.2694(28)$
				g_p	$=$	$8.06(0.55)$
gravity: Tensor	$\partial_\mu T^{\mu\nu}_{\bf grav} = 0$	$\langle N' \vert T^{\mu\nu}_{\bf grav} \vert N\rangle$	$\longrightarrow$	$M_{\rm prot}$	$=$	$938.272013(23)\,{\rm MeV}/c^2$
				J	$=$	$\frac{1}{2}$
				D	$=$	**?**

Proton charge radius

- Back to 2013, a lot of interest on the proton charge radius
- The Proton Radius Puzzle
  - Test theoretical understanding of proton
  - Related to the QCD



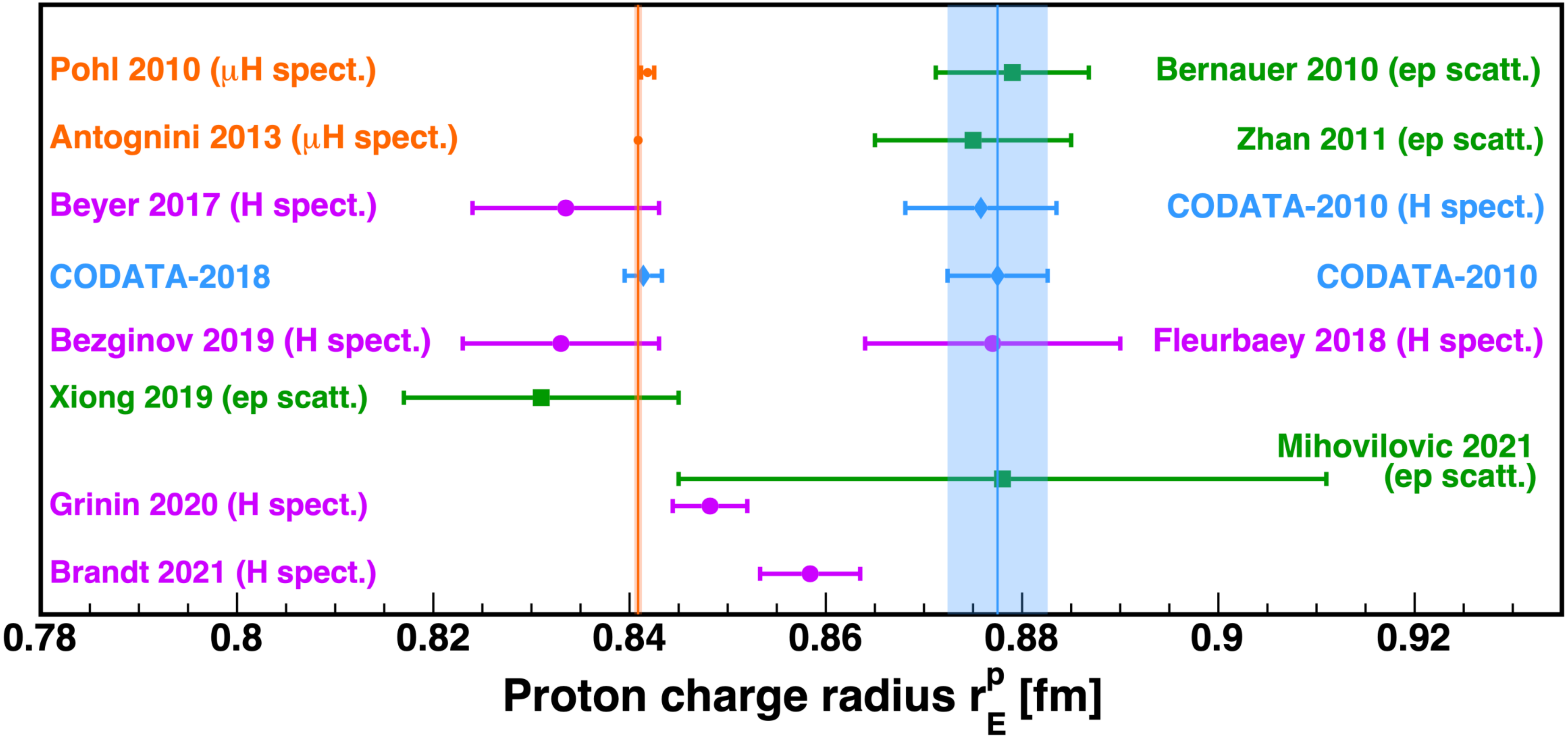
μp 2013: Antognini *et al.*, Science **339**, 417 (2013)

JLab: Zhan *et al.*, PLB **705**, 59-64 (2011)

Mainz: Bernauer *et al.*, PRL **105**, 242001 (2010)

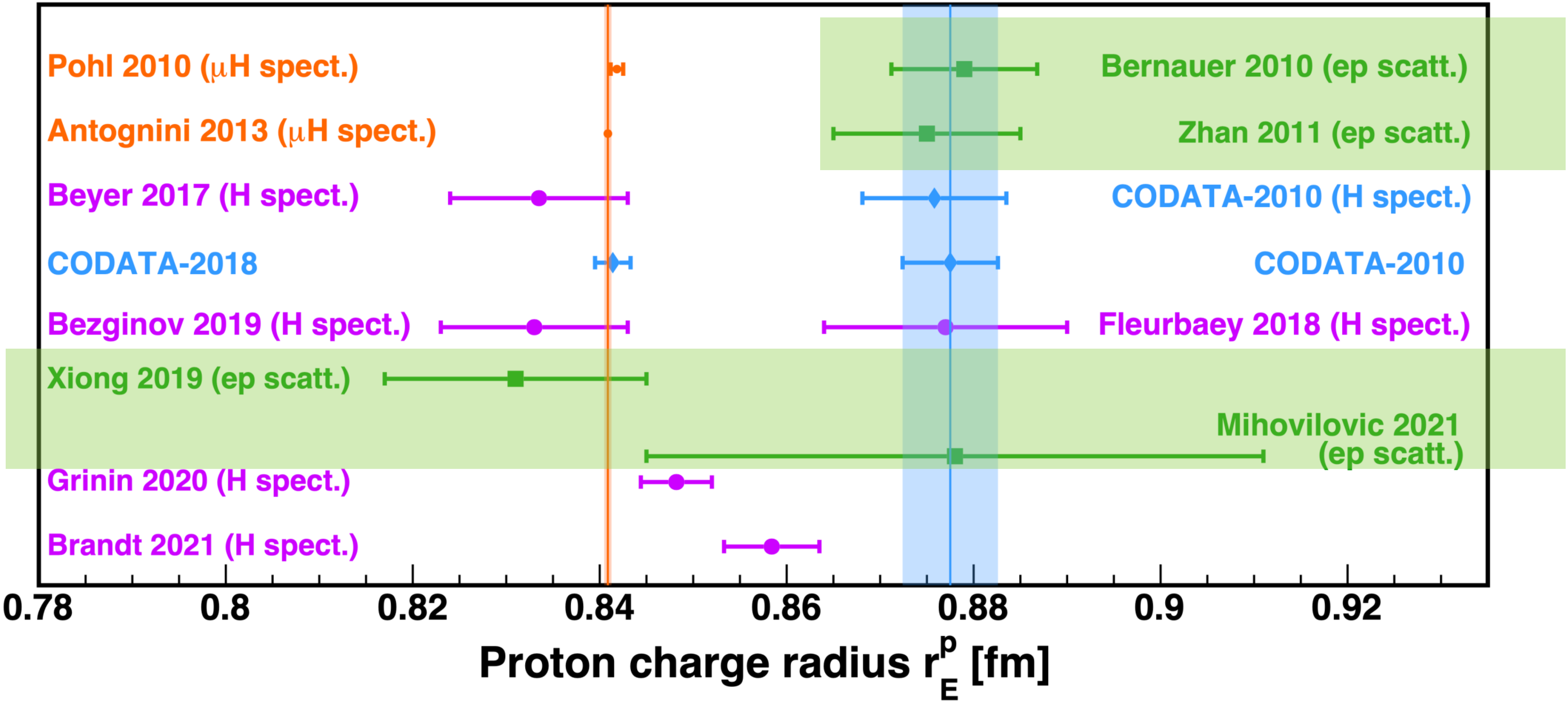
μp 2010: Pohl *et al.*, Nature **466**, 213 (2010)

Proton charge radius

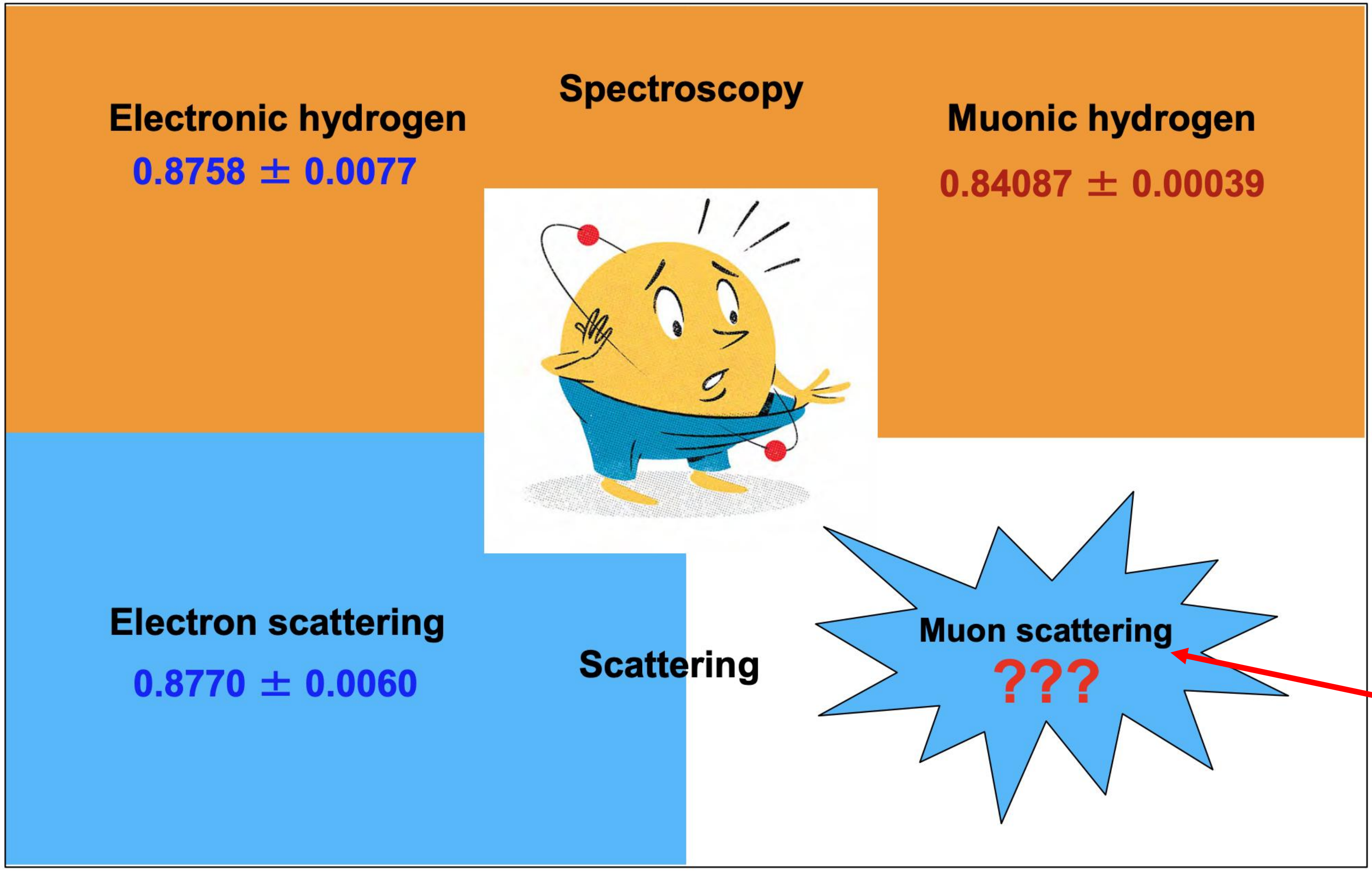


Proton charge radius

Results from electron-scattering experiments



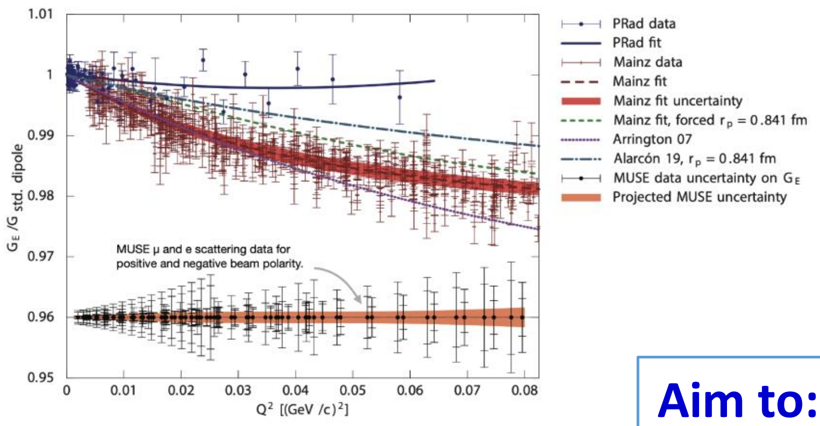
μp scattering



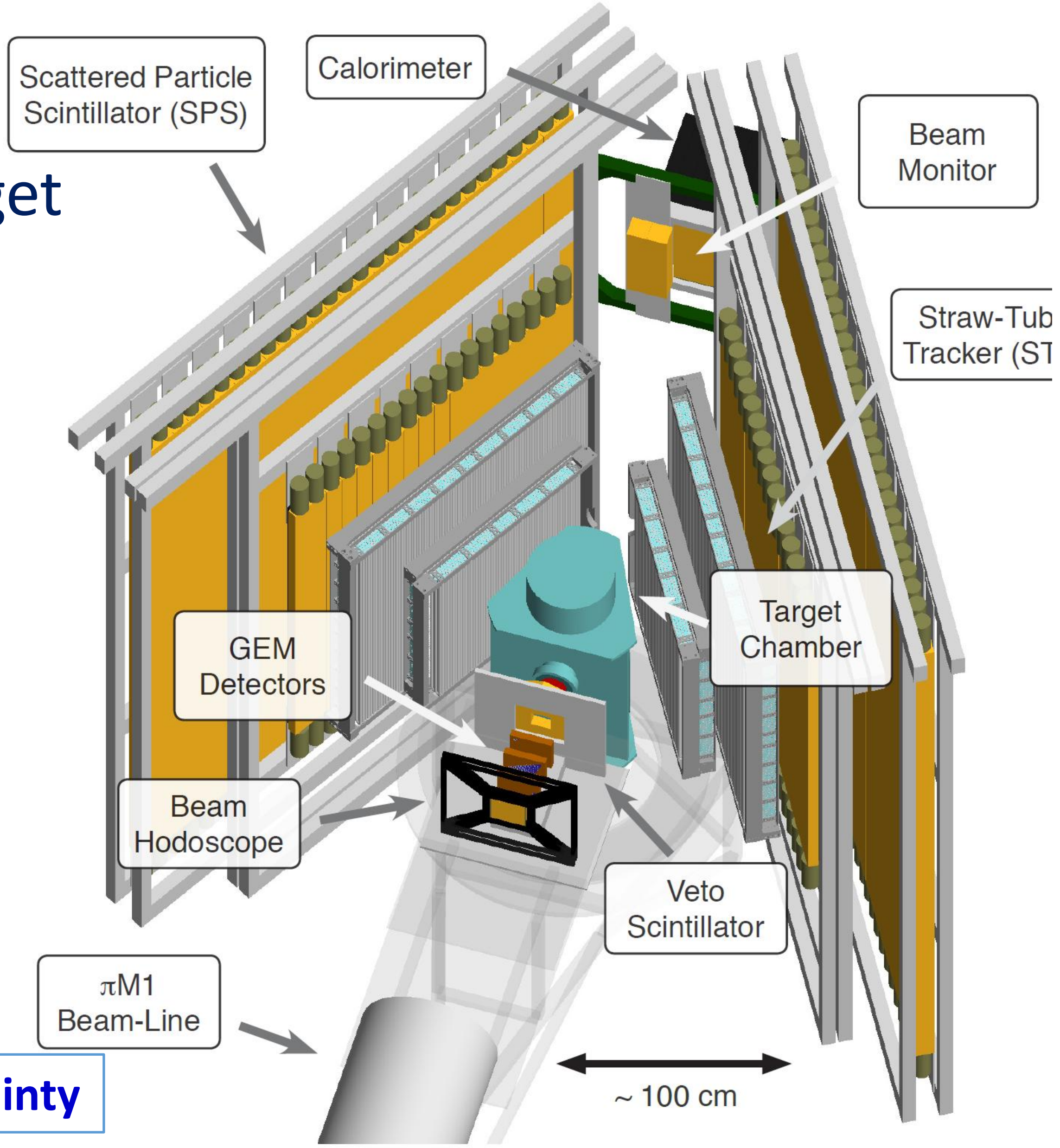
PSI: MUSE experiment
CERN: Amber experiment

MUSE @ PSI

- Beams of $e^{\pm}, \pi^{\pm}, \mu^{\pm}$ on liquid H_2 target
  - Separate particles by TOF
  - Start to taking data: ~2023
- Muon beam:
  - $115 - 210\ MeV/c$
  - $\theta: 20^o - 100^o$

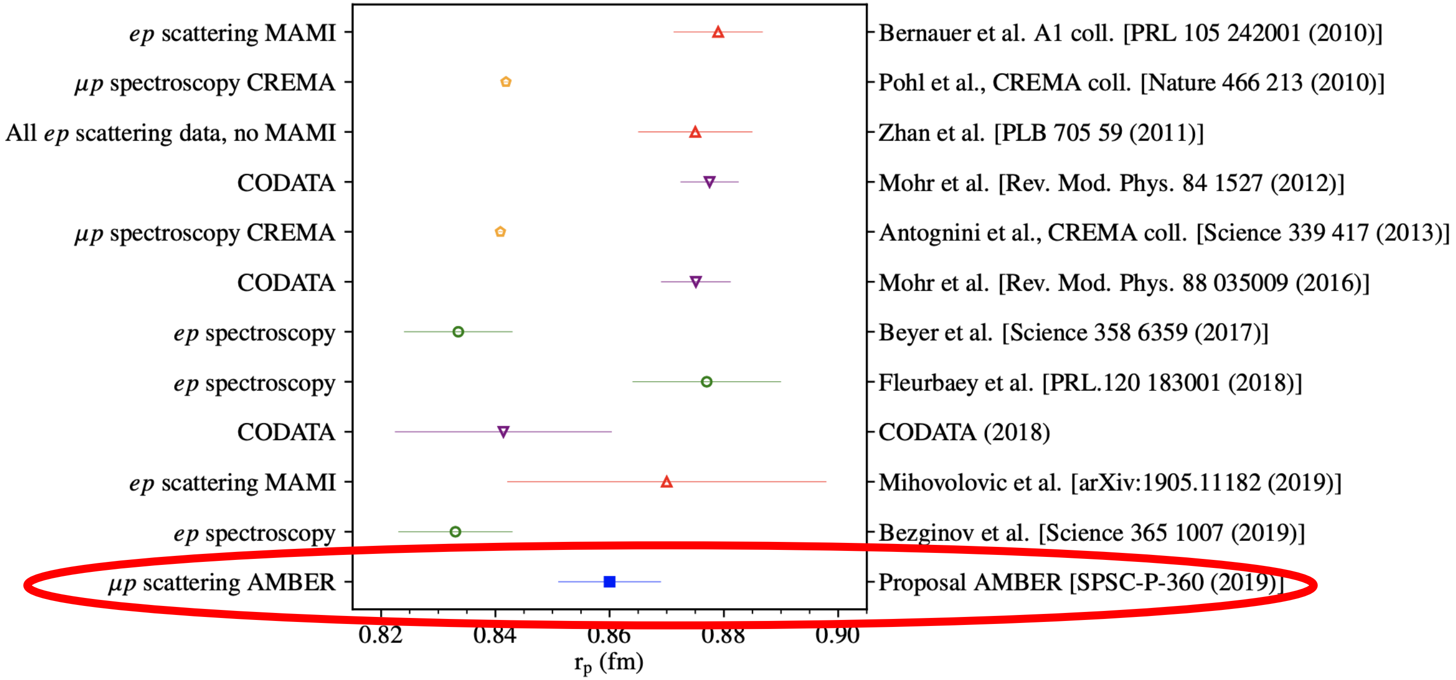


Aim to: 0.5% uncertainty



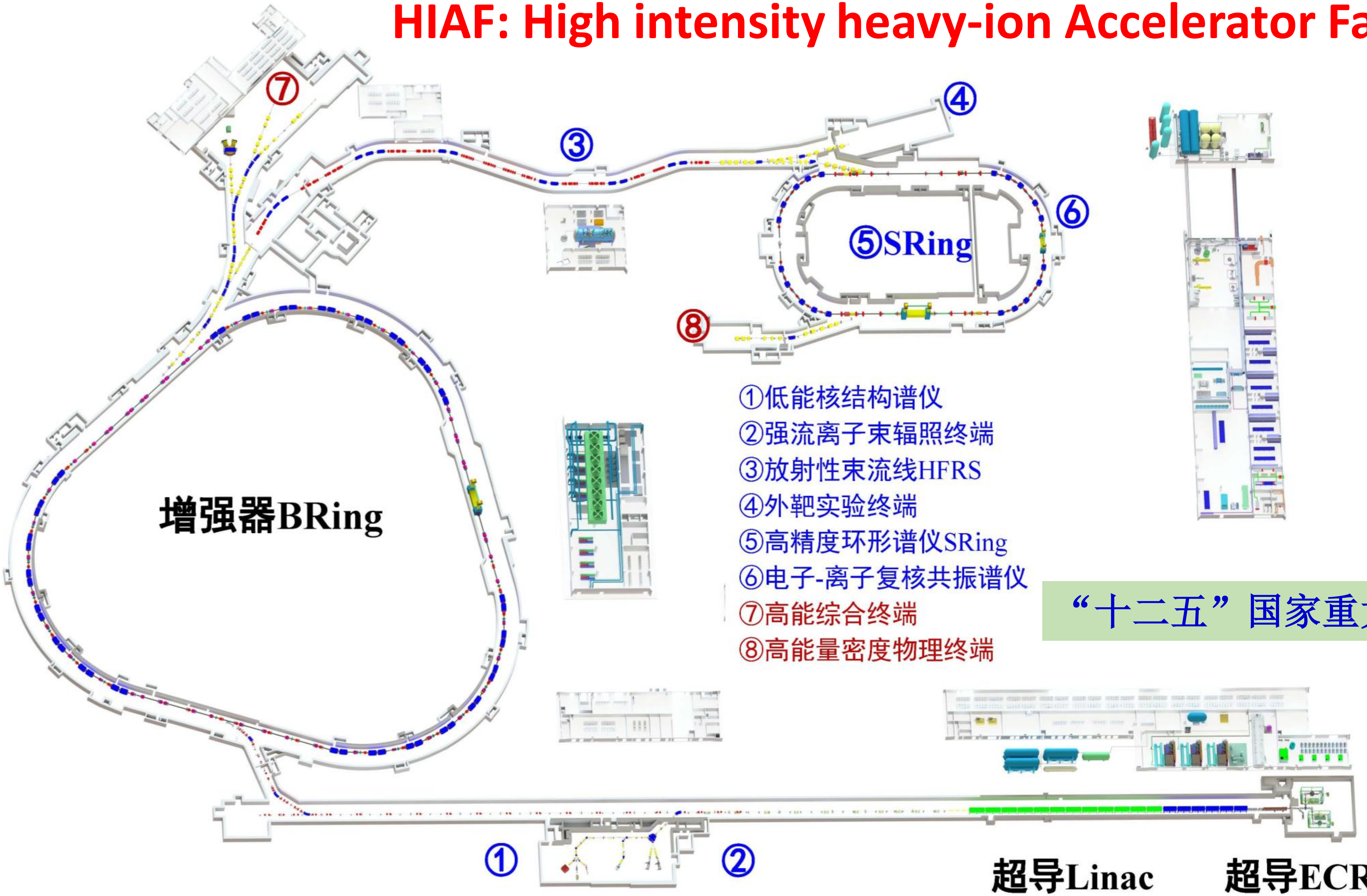
Amber @ CERN

- Compass -> Amber (NA66): Apparatus for Meson and Baryon Experimental Research
  - A fixed target experiment at M2 beam line
  - Beam: muon, proton, pion, kaon from 50 GeV to 280 GeV



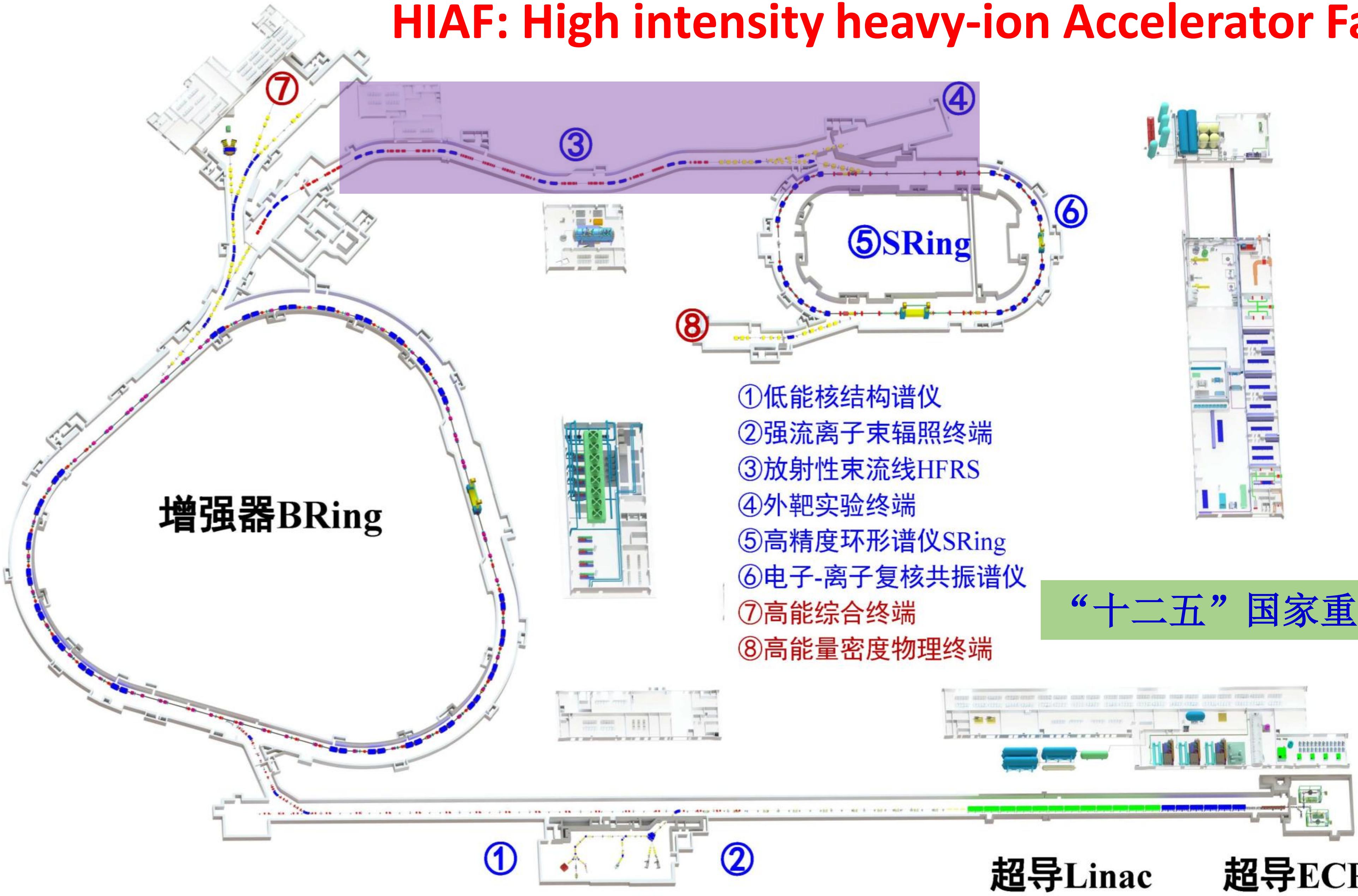
Aim to: 1% uncertainty

HIAF: High intensity heavy-ion Accelerator Facility



“十二五”国家重大科技基础设施

HIAF: High intensity heavy-ion Accelerator Facility



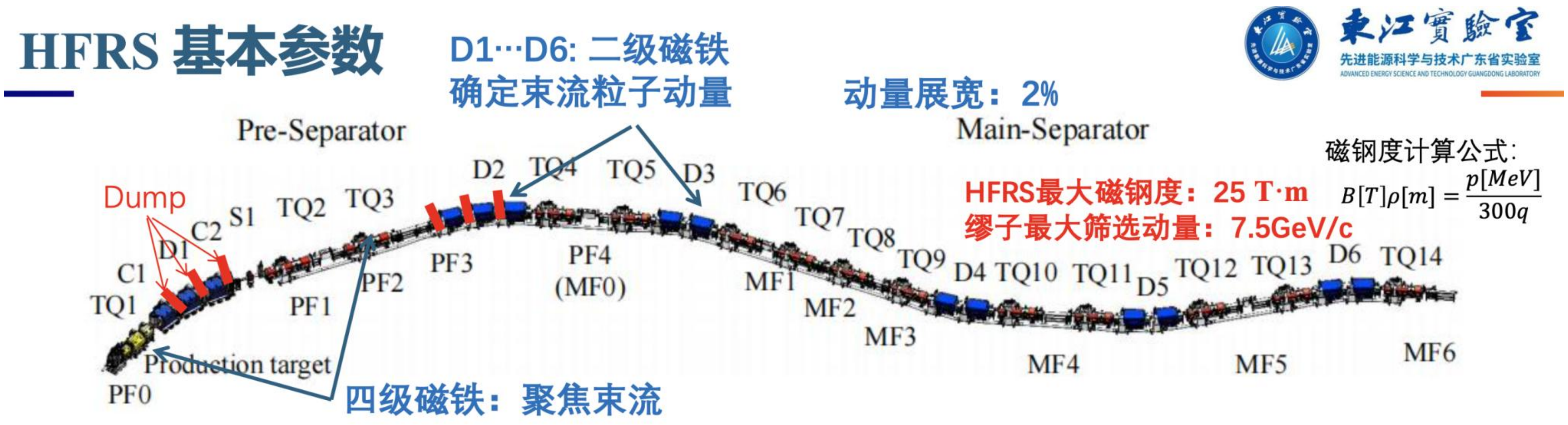
①低能核结构谱仪
②强流离子束辐照终端
③放射性束流线HFRS
④外靶实验终端
⑤高精度环形谱仪SRing
⑥电子-离子复核共振谱仪
⑦高能综合终端
⑧高能量密度物理终端

“十二五”国家重大科技基础设施

HIAF muon source

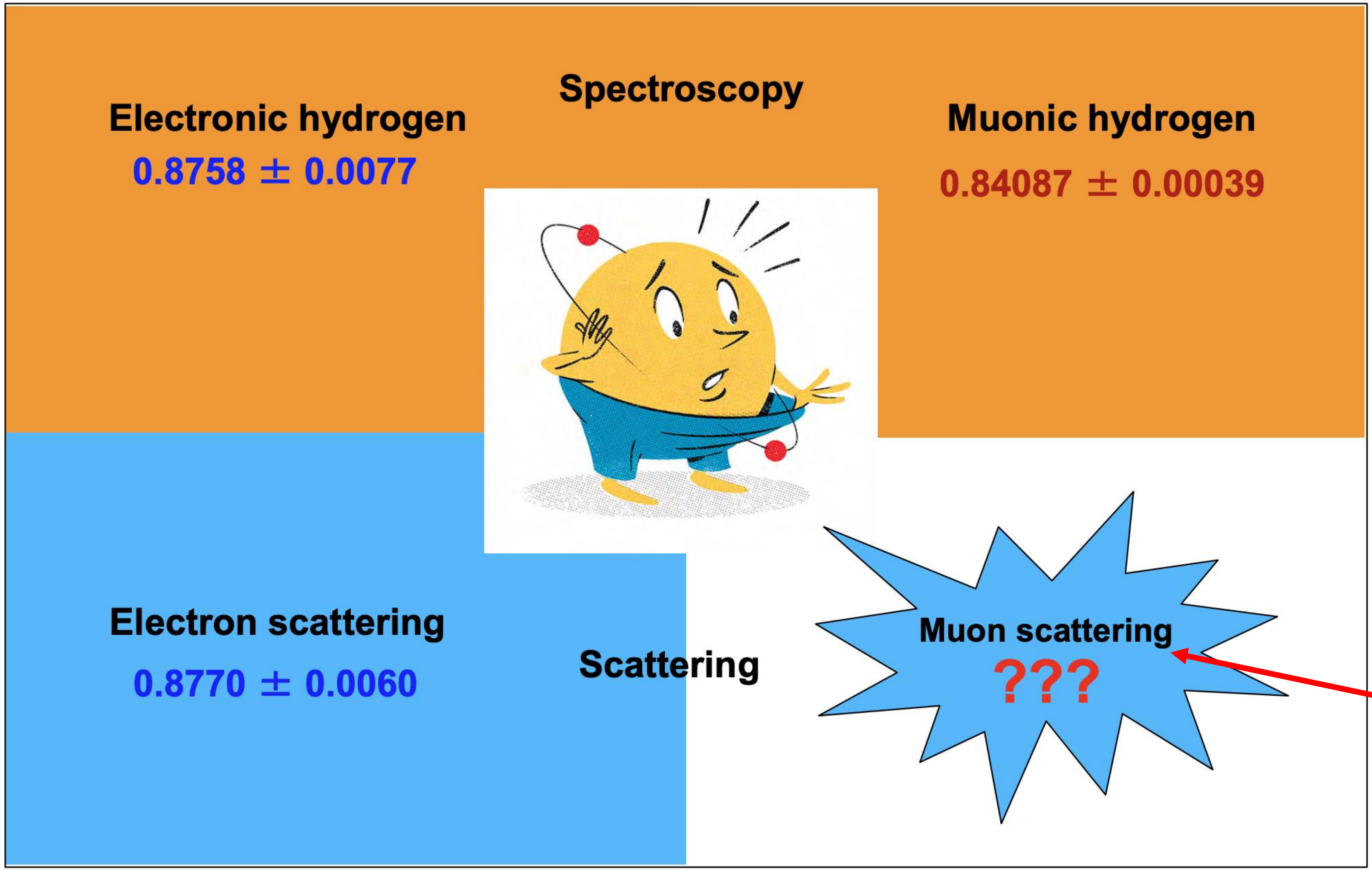
From 徐宇's talk

- HIAF可以利用~~HFRS~~ HIRIBL 束线产生缪子束流
  - 动量：500MeV/c – 7.5GeV/c
  - 产额：$10^6 - 10^7\ \mu/s$
  - 束斑大小：10cm*10cm
  - 经过特殊设置，纯度可以达到100%



μp scattering

Scientific opportunities with a few-GeV muon beam at HIAF?



PSI: MUSE experiment
CERN: Amber experiment
HIAF: LUNE experiment

LUNE Collaboration

- **L**ow-energy m**U**on-**N**ucleon scattering **E**xperiment
- 目前参与单位及成员:

蓝色为学生

  - 华中师范大学: 陈凯、胡辉港、计晨、宋晓程、孙向明、汪虎林、王翔鹏、王亚平、谢跃红、尹航、张冬亮、周晓康 等
  - 山东大学: 李远、熊伟志
  - 近代物理所: 陈良文、窦彦昕、徐宇 、张瑞田、章学恒等
  - 中国科学技术大学: 韩良、潘子文、王宇、杨思奇、赵梓含
  - 合肥工业大学：王泽人、张宇
  - 上海交通大学: 陈翔、李亮、卢泽嘉
  - 北京大学：李奇特
  - 河海大学：柏栋
  - 武汉大学：王纪科
  - 深圳技术大学：李迪开
  - 汕头大学：刘浪天
  - 帕多瓦大学：韩群东

中国科学院近代物理研究所

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Nu Xu

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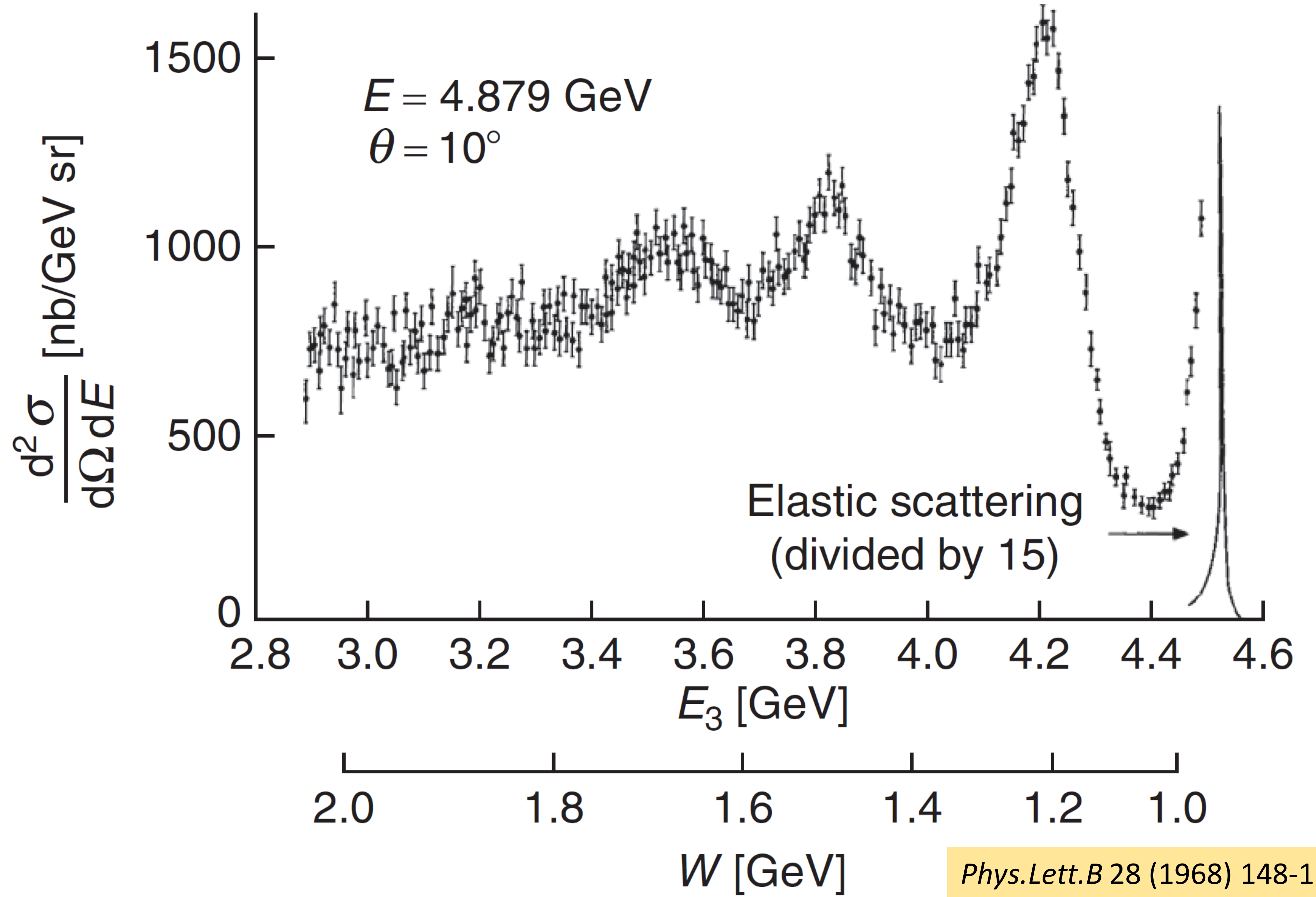
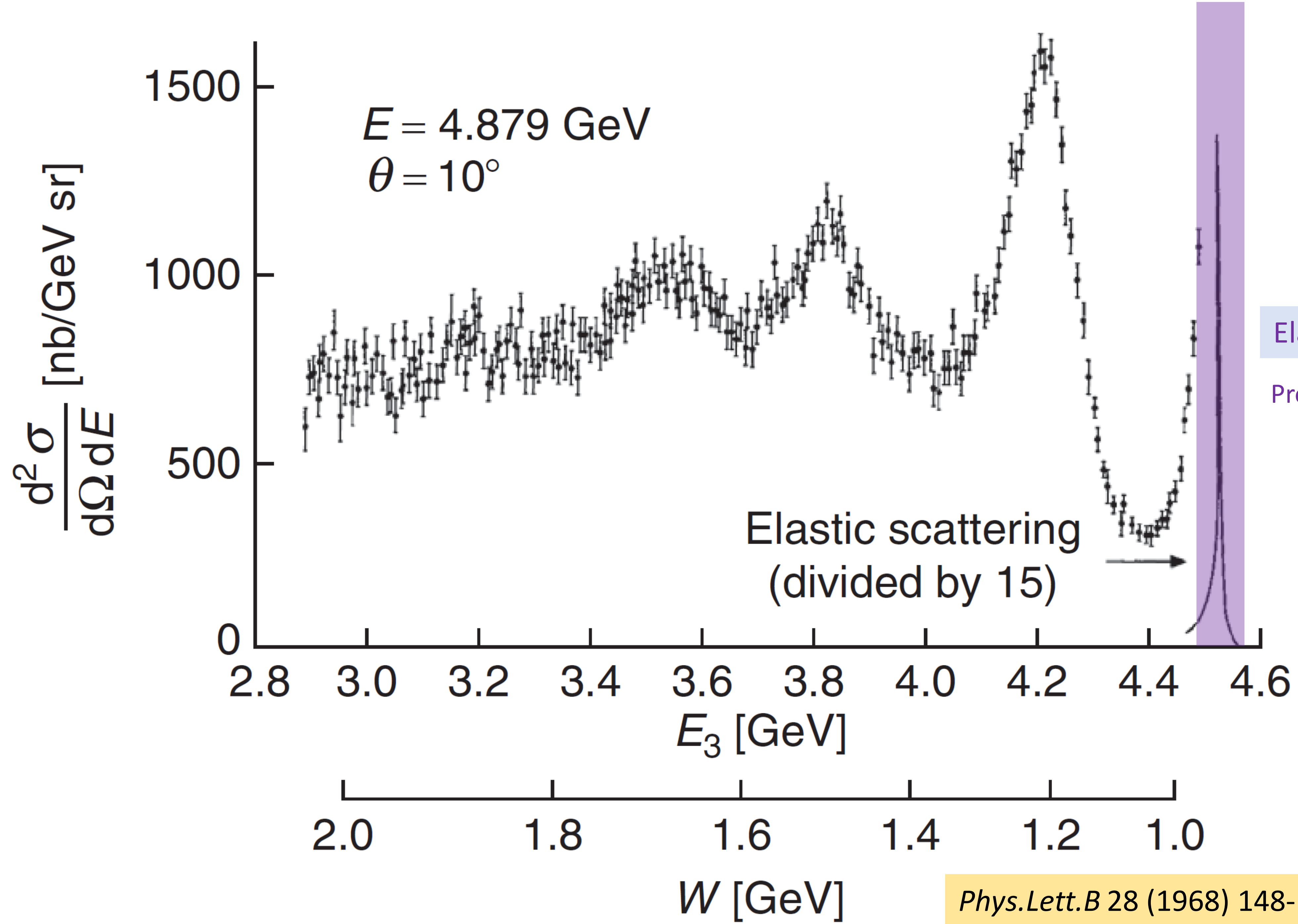


Phys.Lett.B 28 (1968) 148-151



Elastic scattering

Proton charge radius

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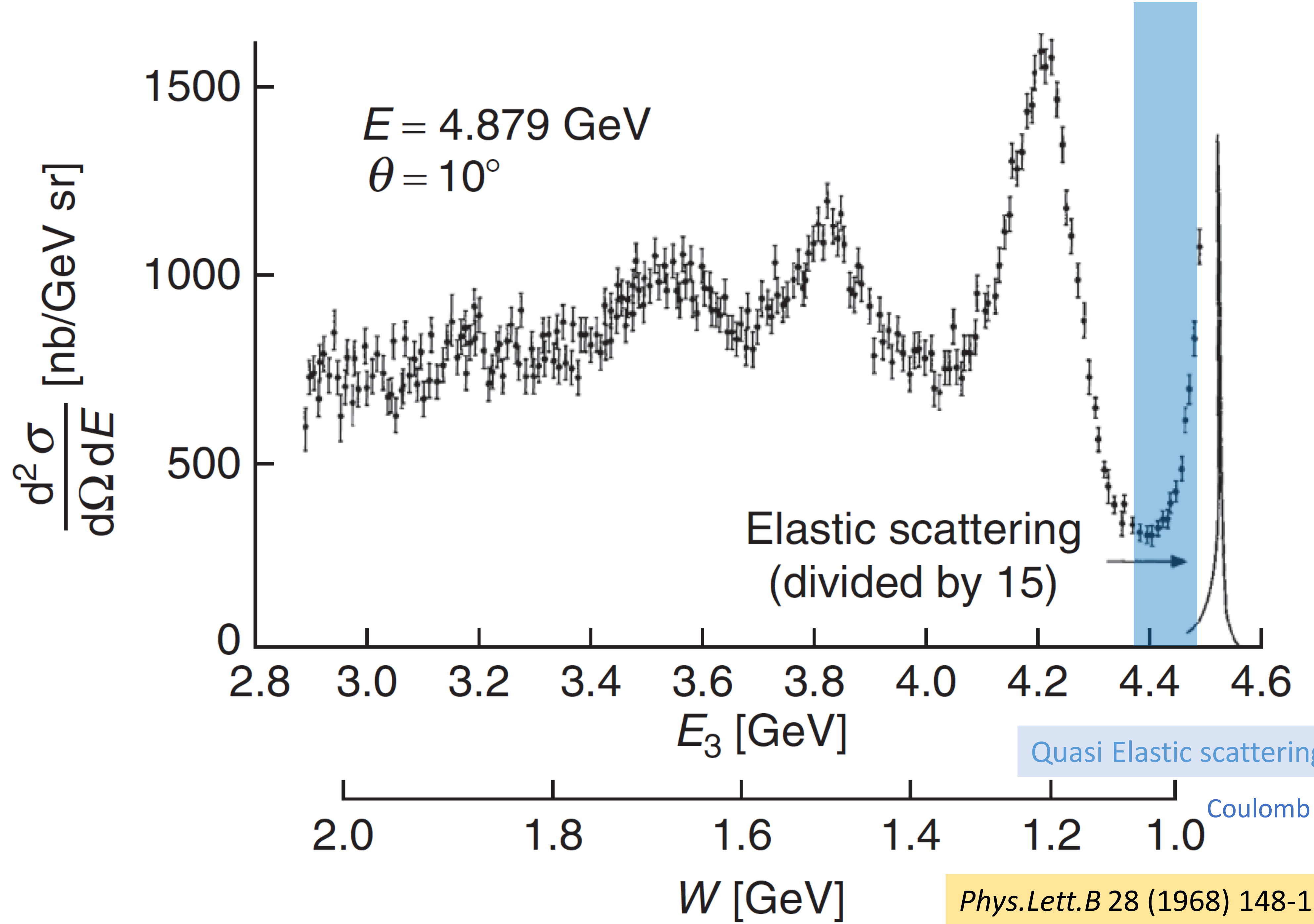

Quasi Elastic scattering

Coulomb Distortion

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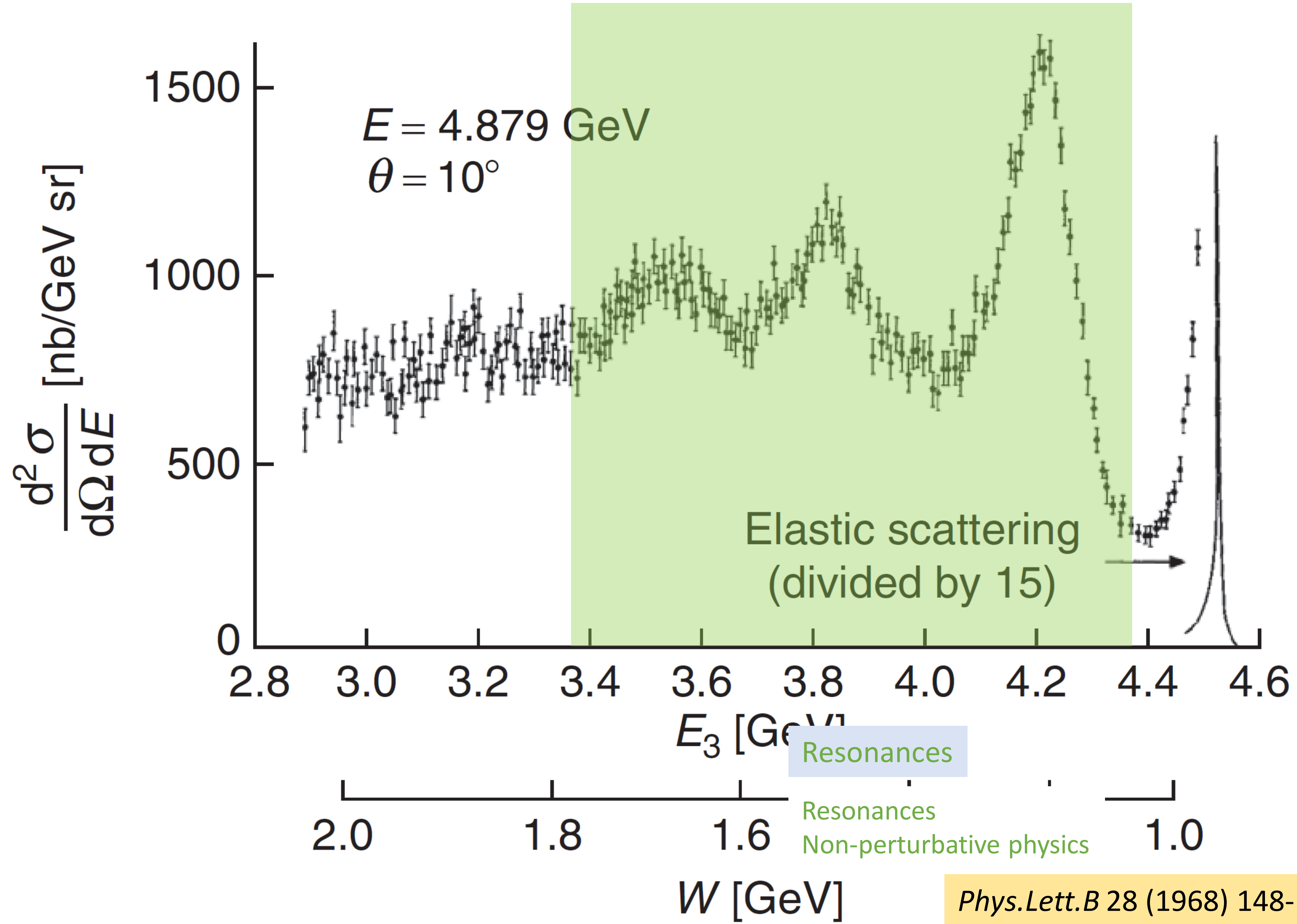

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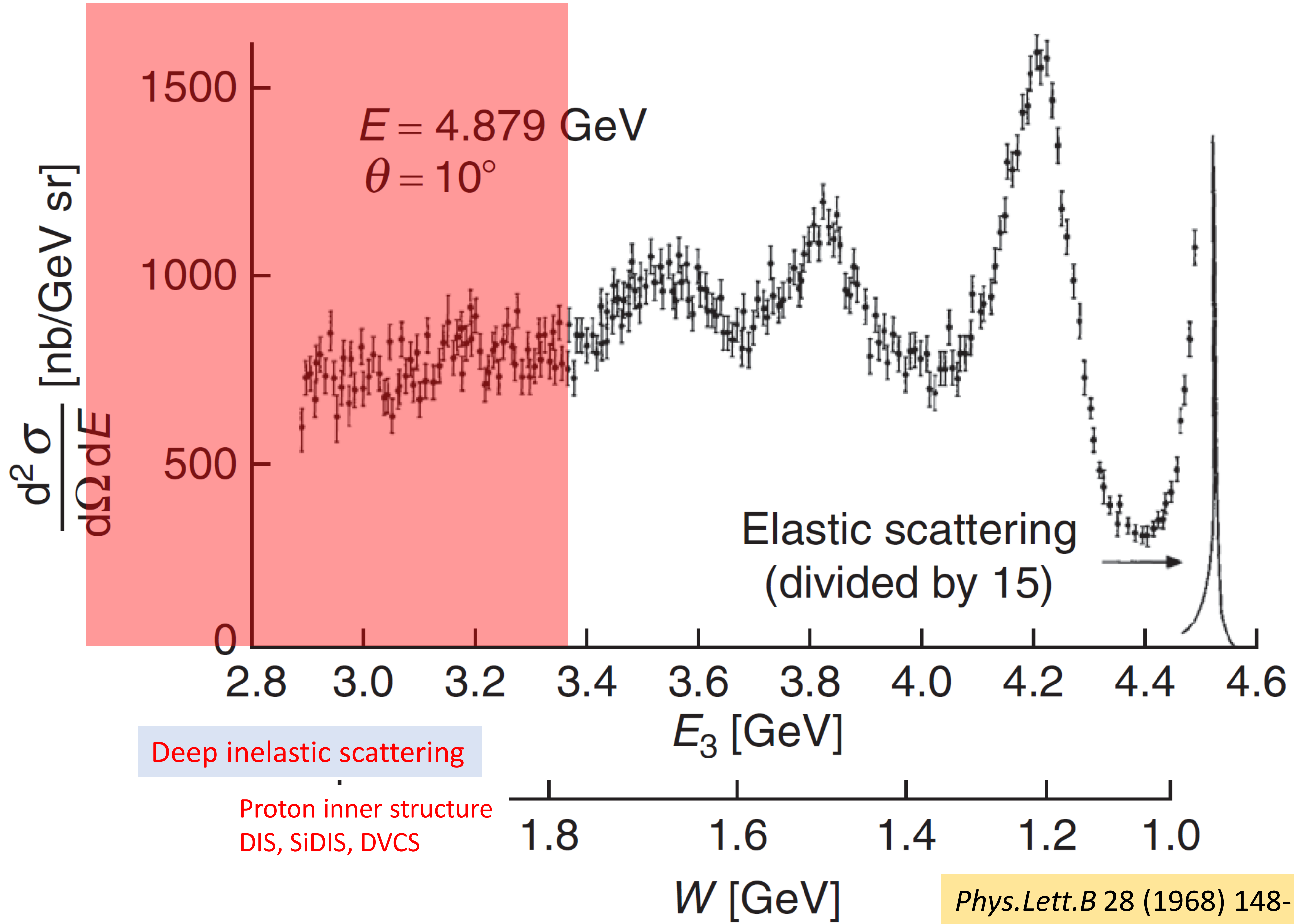
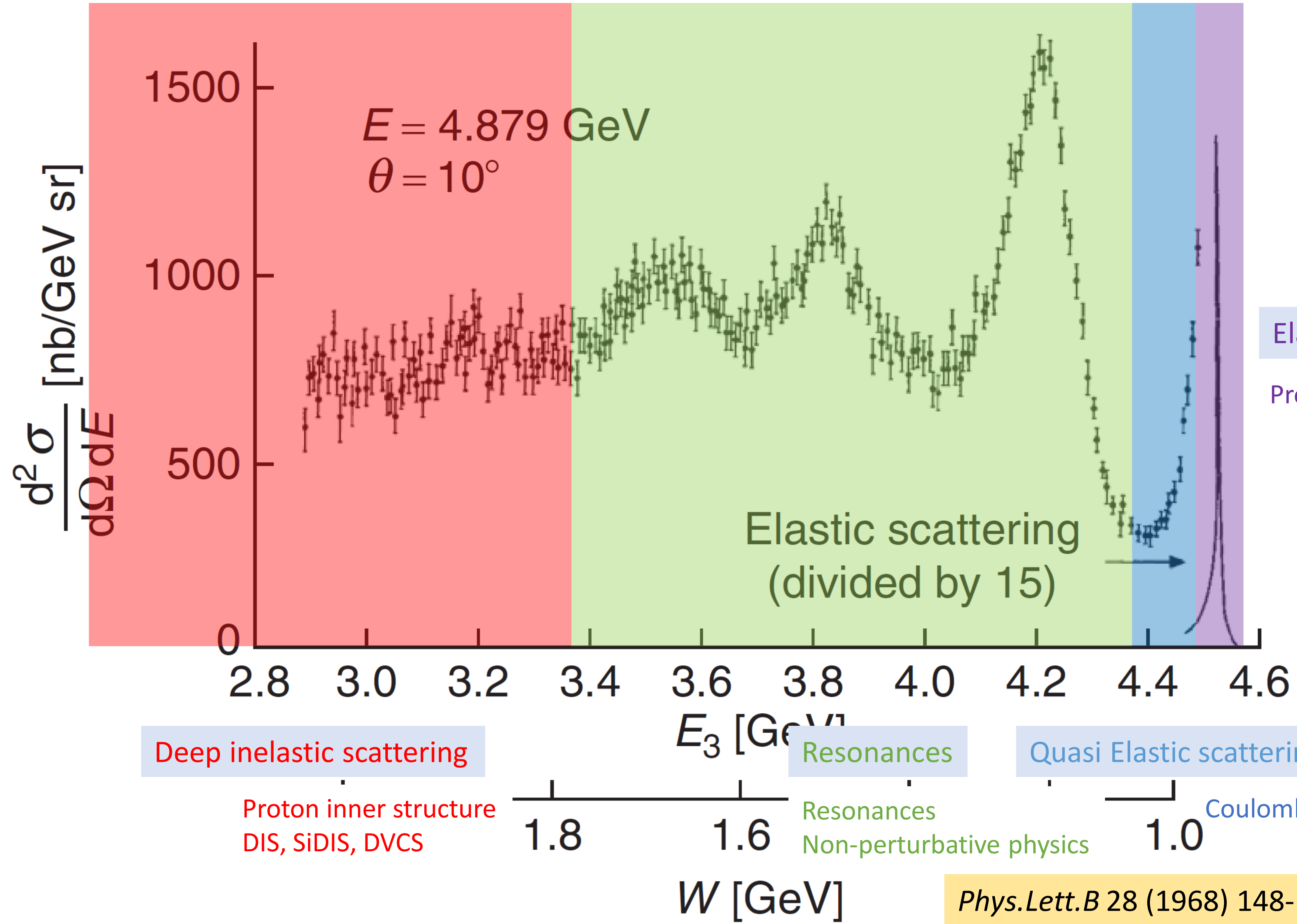


Deep inelastic scattering

Proton inner structure
DIS, SiDIS, DVCS

Phys.Lett.B 28 (1968) 148-151



Elastic scattering

Proton charge radius

Deep inelastic scattering

Proton inner structure
DIS, SiDIS, DVCS

Resonances

Resonances
Non-perturbative physics

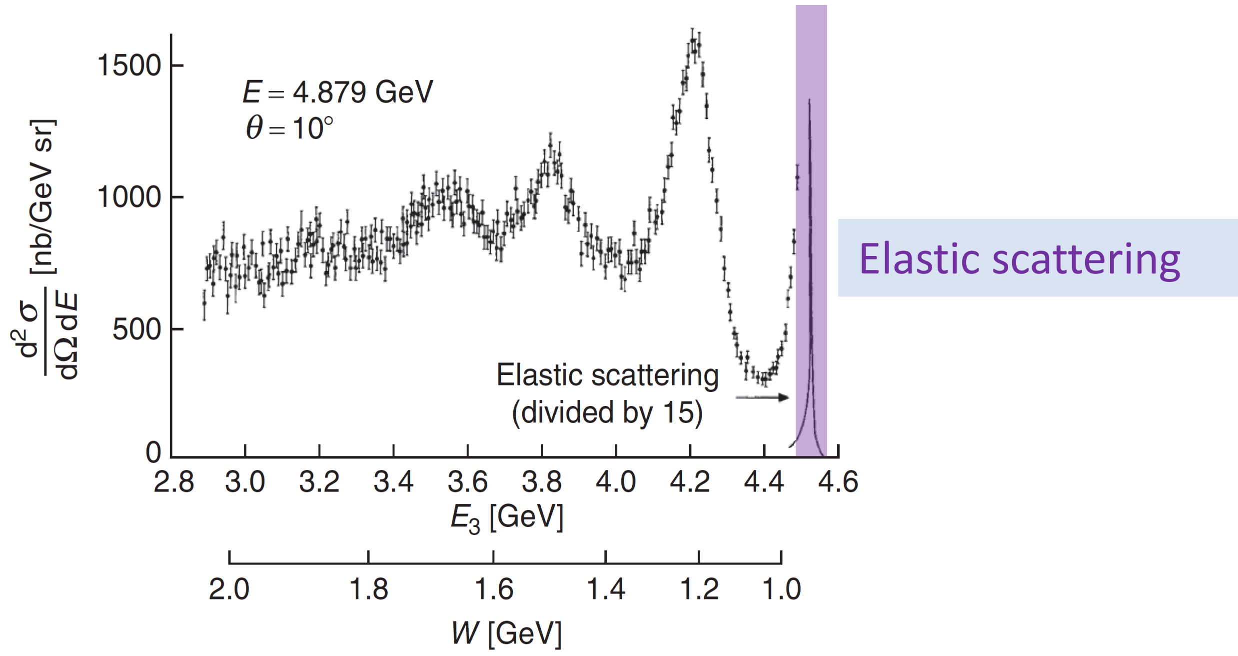
Quasi Elastic scattering

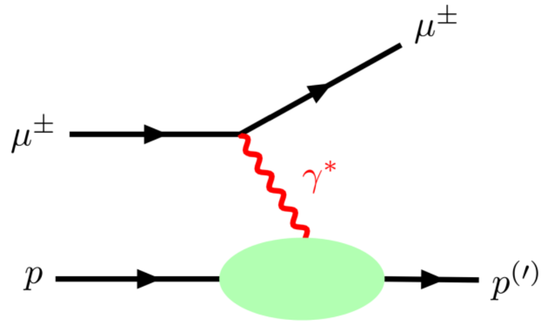
Coulomb Distortion

Phys.Lett.B 28 (1968) 148-151

Physics Motivation (liquid hydrogen)

- **Elastic scattering:**
  - **Proton charge radius**
  - Two photon exchange: μ^+ and μ^-
  - Proton charge form factors: (LFU)
- Advantages:
  - Large cross-section: mb
  - small scattering angle (1-10^o)
  - momentum measurement of incoming/scattered muon
- Detector requirements:
  - Dipole magnetic field: a few GeV muons
  - Precision measurement of particle direction





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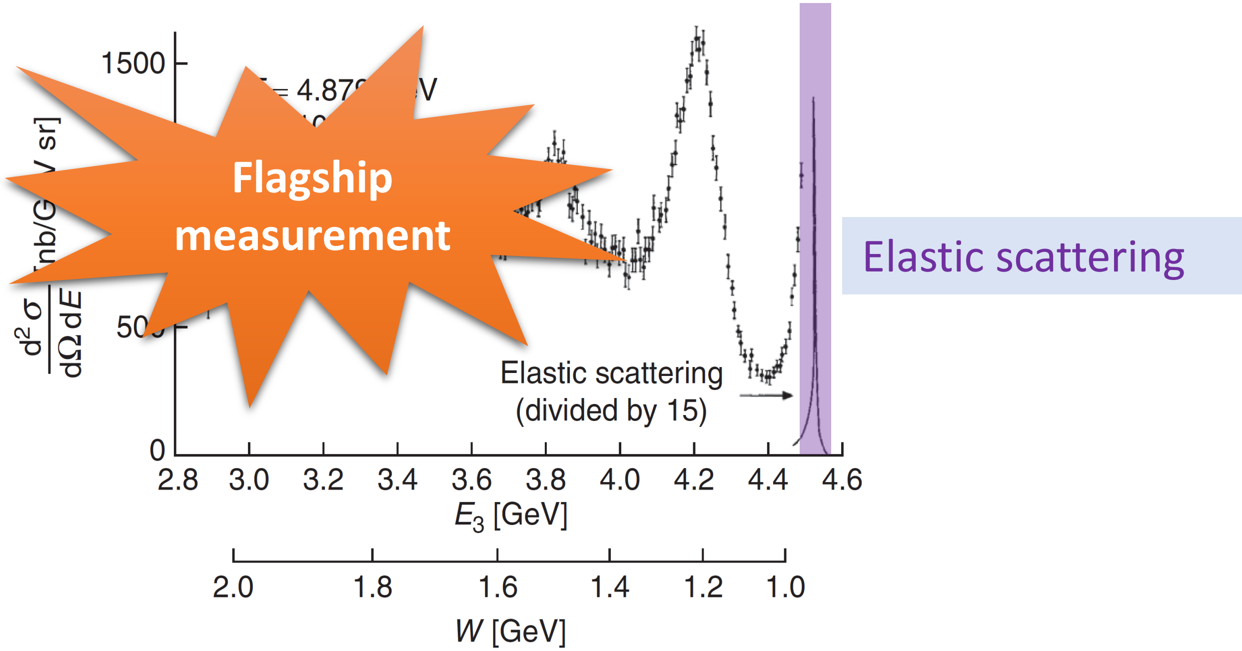

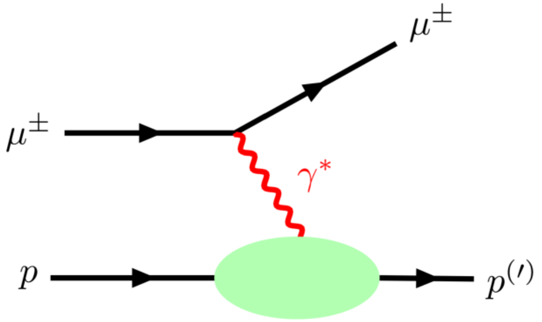

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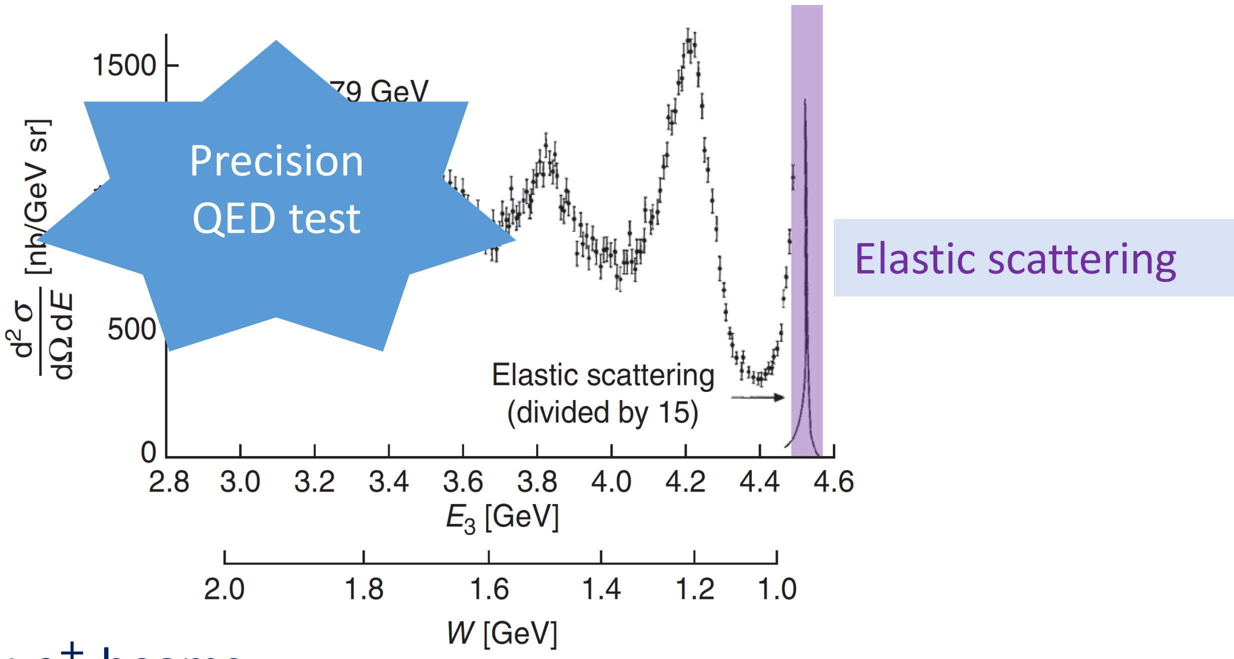
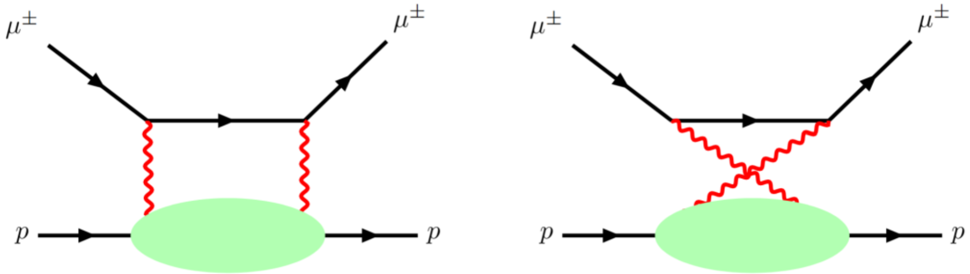
  - **Two photon exchange: μ^+ and μ^-**
  - Proton charge form factors: (LFU)
- Advantages:
  - Large cross-section: mb
  - Electron-scattering experiments:
    - → the difficulty of producing high-intensity e^+ beams
- Detector requirements:
  - Dipole magnetic field: a few GeV muons
  - Precision measurement of particle angle

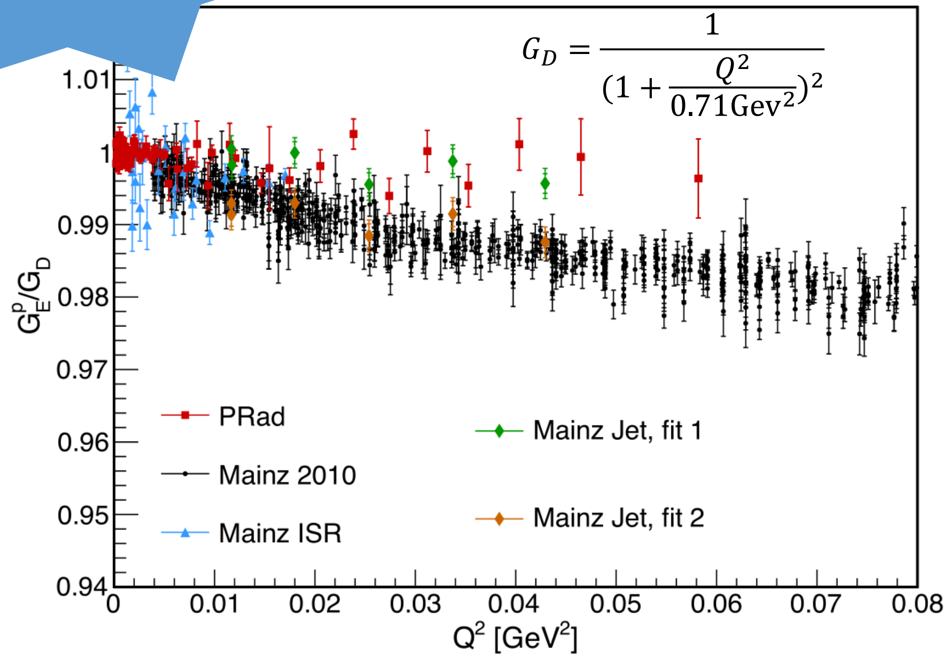




Physics Motivation (liquid hydrogen)

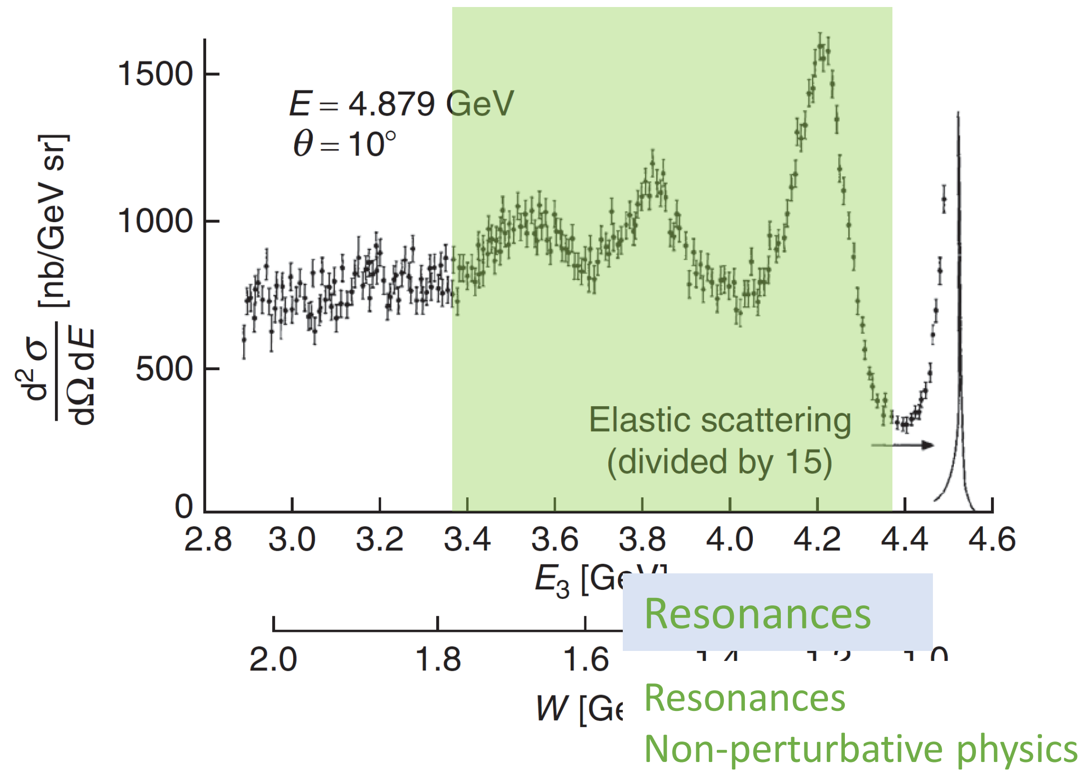
- **Elastic scattering:**
  - Proton charge radius
  - Two photon exchange: $\boldsymbol{\mu^+}$ and $\boldsymbol{\mu^-}$
  - **Proton charge form factors: (LFU)**
- Advantages:
  - Large cross-section: mb
  - Resolve tension between PRad and Mainz
- Detector requirements:
  - Dipole magnetic field: a few GeV muons
  - Precision measurement of particle angle

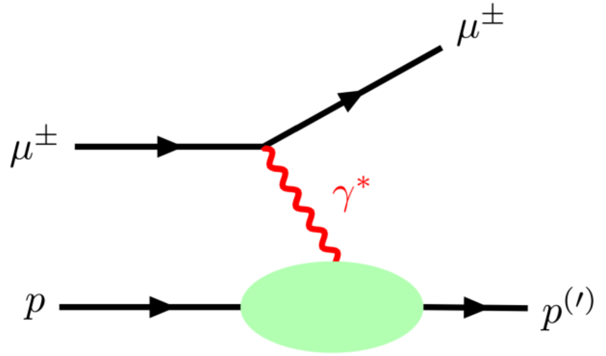
LFU



Physics Motivation (inelastic)

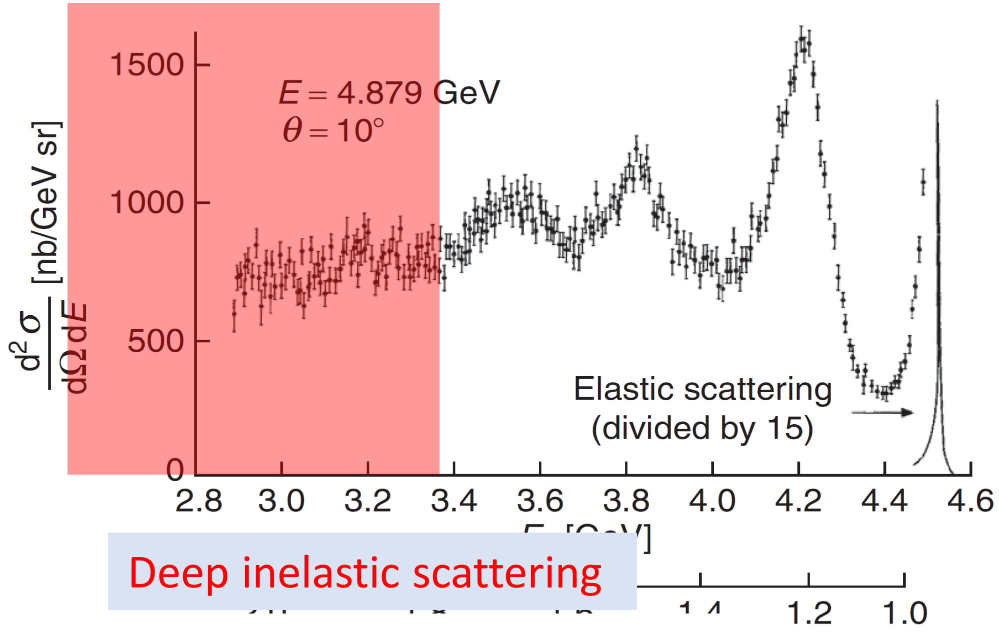
- **Inelastic scattering (resonances):**
  - Resonance studies
  - A clean probe of non-perturbative QCD
- Reasonable cross-section:
  - μb
  - momentum measurement of incoming/scattered muon



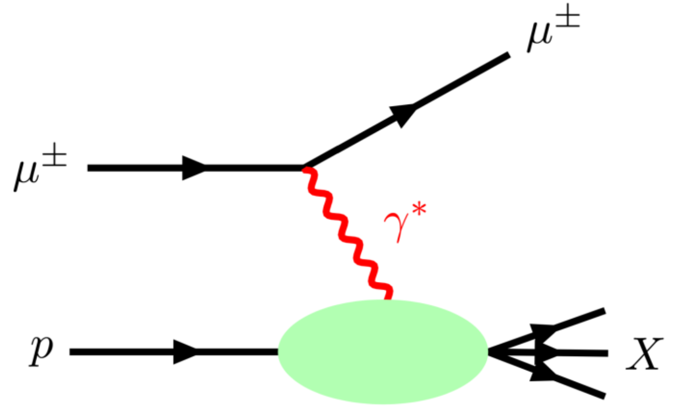


Physics Motivation (DIS)

- **Deep-Inelastic scattering (DIS):**
  - PDFs related studies
  - Proton structure
  - New physics
- Reasonable cross-section:
  - μb - nb
  - momentum measurement of scattered muon
  - Multiple final states: $\pi^0, \pi^\pm, \gamma, K$
- Detector requirements:
  - Particle-ID: PID



Proton inner structure
DIS, SiDIS, DVCS



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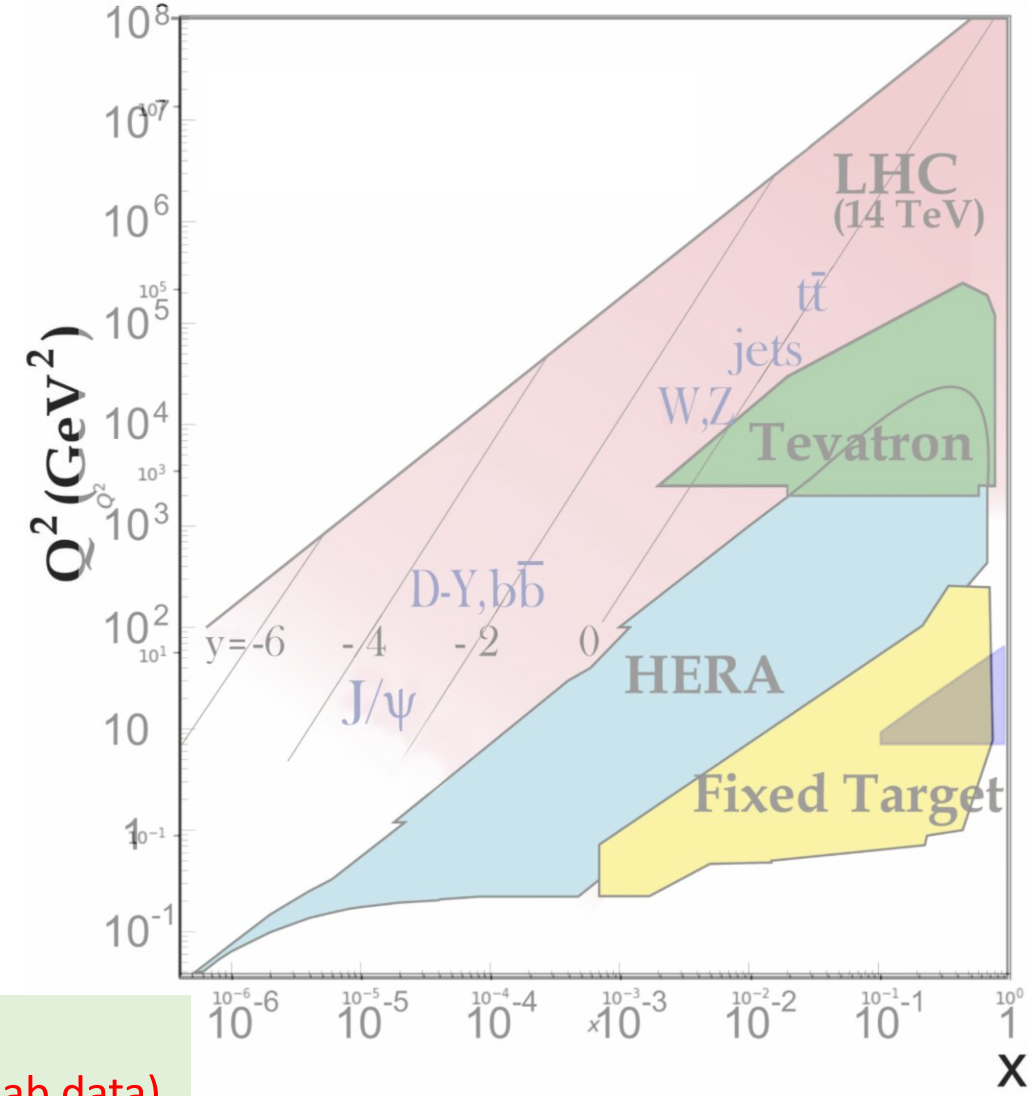

Too close to the non-perturbative region, excluded in the PDFs global fit (also true for JLab data)

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- **Deep-Inelastic scattering (DIS):**
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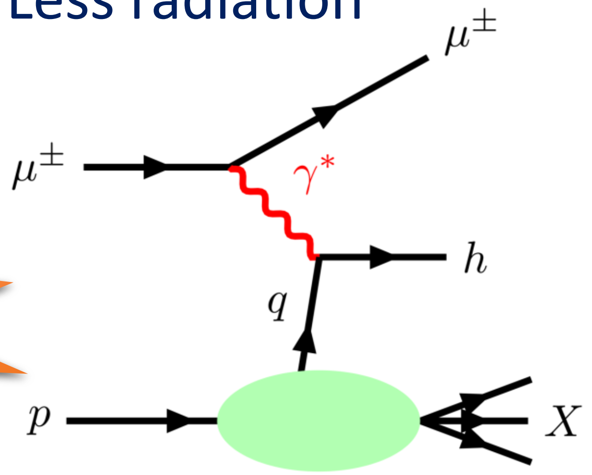
- Detector requirements:
  - Particle-ID: PID

- Semi-inclusive Deep-Inelastic scattering (SIDIS):
  - TMD
- Small cross-section:
  - 100-900 nb
  - Clean environment
  - Less radiation

Flagship measurement



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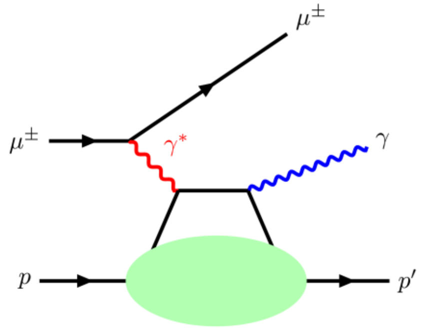
- Detector requirements:
  - Particle-ID: PID

- Deeply Virtual Compton Scattering (DVCS):
  - Proton inner structure
  - Gravitational form factor
- Small cross-section:
  - nb
  - polarized muon beam
  - motivation for upgrade of HIAF muon source

High impact measurement, but with limited statistics



Physics Motivation (DIS)

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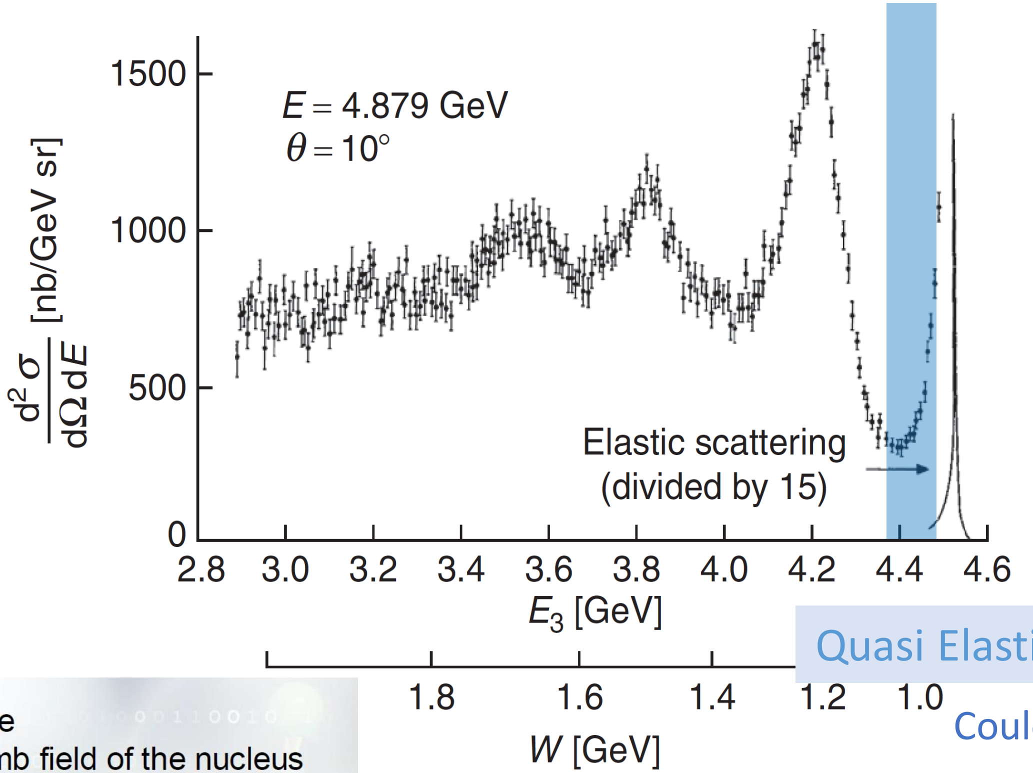
  - momentum measurement of scattered muon
  - Multiple final states: $\pi^0, \pi^\pm, \gamma, K$
- Detector requirements:
  - Particle-ID: PID

- New physics:
- With Pb as target
  - $\mu N \to \mu N + MET$
  - $\mu N \to \mu\mu\mu N$
  - $\mu N \to \gamma\gamma\mu N$
  - $\mu N \to \mu N' + MET$

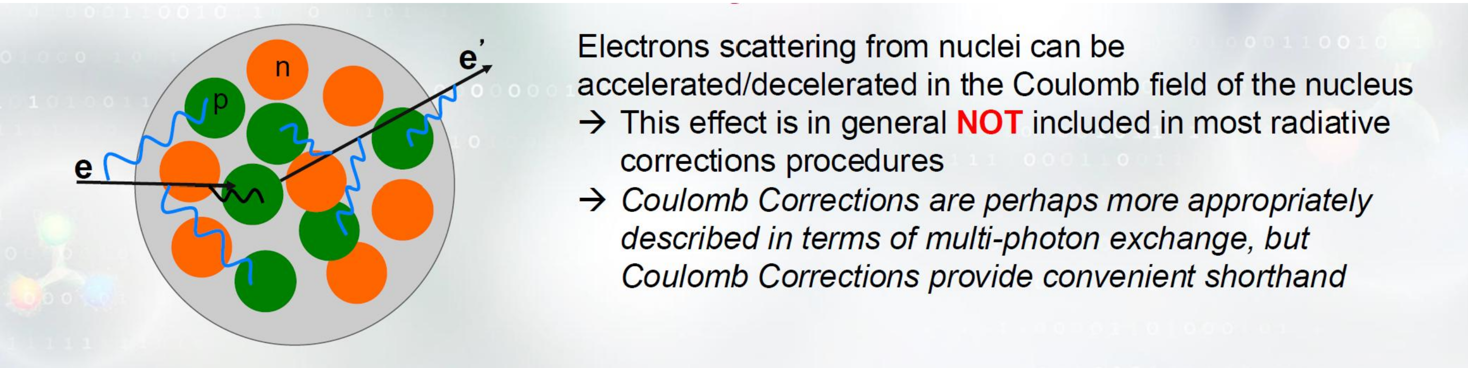
Physics Motivation (Quasi-elastic)

- **Quasi-Elastic scattering:**
  - Coulomb Distortion
- Target: Copper/Carbon
  - Study this from QE to DIS
  - Muon has less radiations



Quasi Elastic scattering

Coulomb Distortion



Physics Motivation (Other targets)

- Liquid Deuterium ($\mathrm{LD_2}$)

- Helium (^3He)

- Motivations:
  - Neutron charge distribution
  - EMC
  - SRC: Short range correlation
  - Form factors

Physics @ LUNE

Analyses	Impacts	Target	Comments
Proton charge radius	★★★★★	Liquid hydrogen	With low momentum muon beam
Two photon exchange	★★★★	Liquid hydrogen	Measured in both elastic/DIS regions
Proton Form factors	★★★★	Liquid hydrogen	Probe LFU
Resonances	★★★	Liquid hydrogen	Limited statistics compared with JLab experiments
DIS	★★★★★	Liquid hydrogen	Probe proton inner structure: TMD
Semi inclusive DIS	★★★★★	Liquid hydrogen	Probe proton inner structure: TMD, 3D
DVCS	★★★★	Liquid hydrogen	Need polarized beam, higher flux (HIAF upgrade)
NP (Dark matter)	★★★★	Pb	Need find more physics channels
Neutron charge distri.	★★★★★	LD_2 / ^{3}He (gas)	Polarized beam, polarized target
Short range corr./EMC	★★★★★	LD_2, ^{3}He,C,Fe,Pb	Better have Neutron detector
Coulomb Distortion	★★★★★	C, Cu	Important for precision prediction

Physics @ LUNE

Analyses	Impacts	Target	Comments
Proton charge radius	★★★★★	Liquid hydrogen	With low momentum muon beam
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Physics @ LUNE

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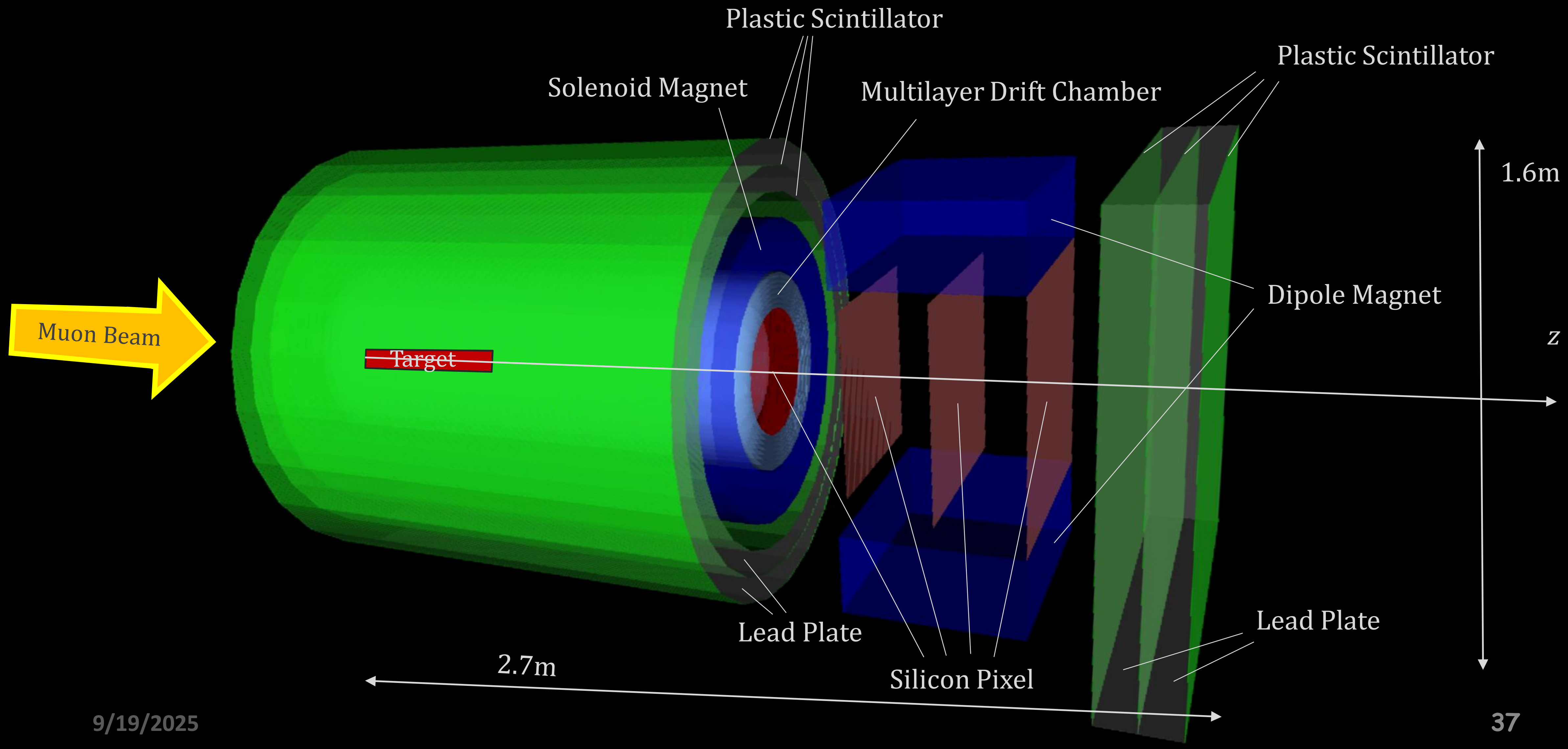
Short range corr./EMC	★★★★★	LD_2, ^3He,C,Fe,Pb	Better have Neutron detector
Coulomb Distortion	★★★★★	C, Cu	Important for precision prediction

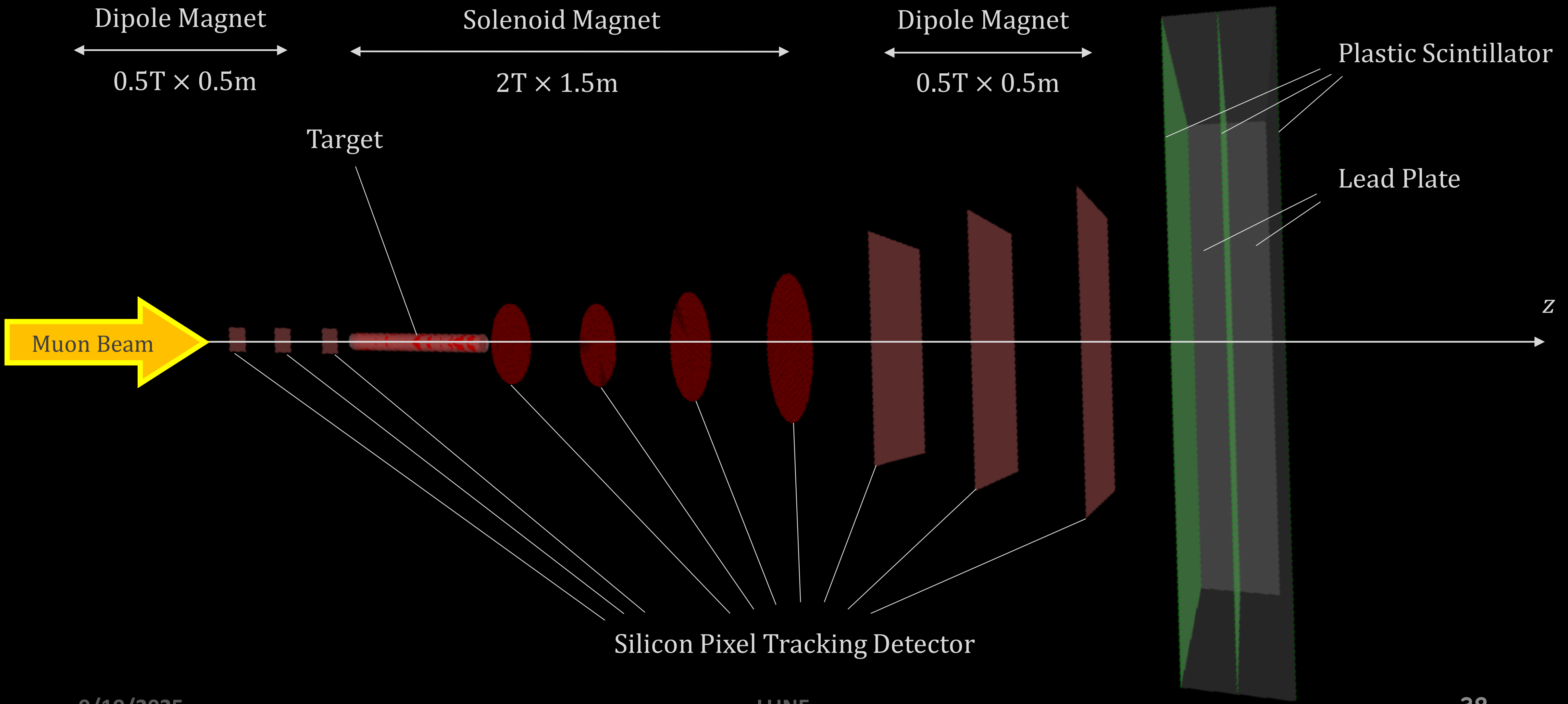
Detector requirements

- Momentum measurement for scattering particles
  - A few GeV charged tracks: cannot use TOF
  - Magnetic fields: solenoid in center region, dipole in the forward region
- Position + angle measurement for incoming/scattering muons
  - silicon pixel detector
- Large detector acceptance, special for small scattering muon
  - Proton charge radius need go down to small Q^2 region: small angle event
- Particle identification
  - Kaon, pion, proton, muon, electron, gamma identifications

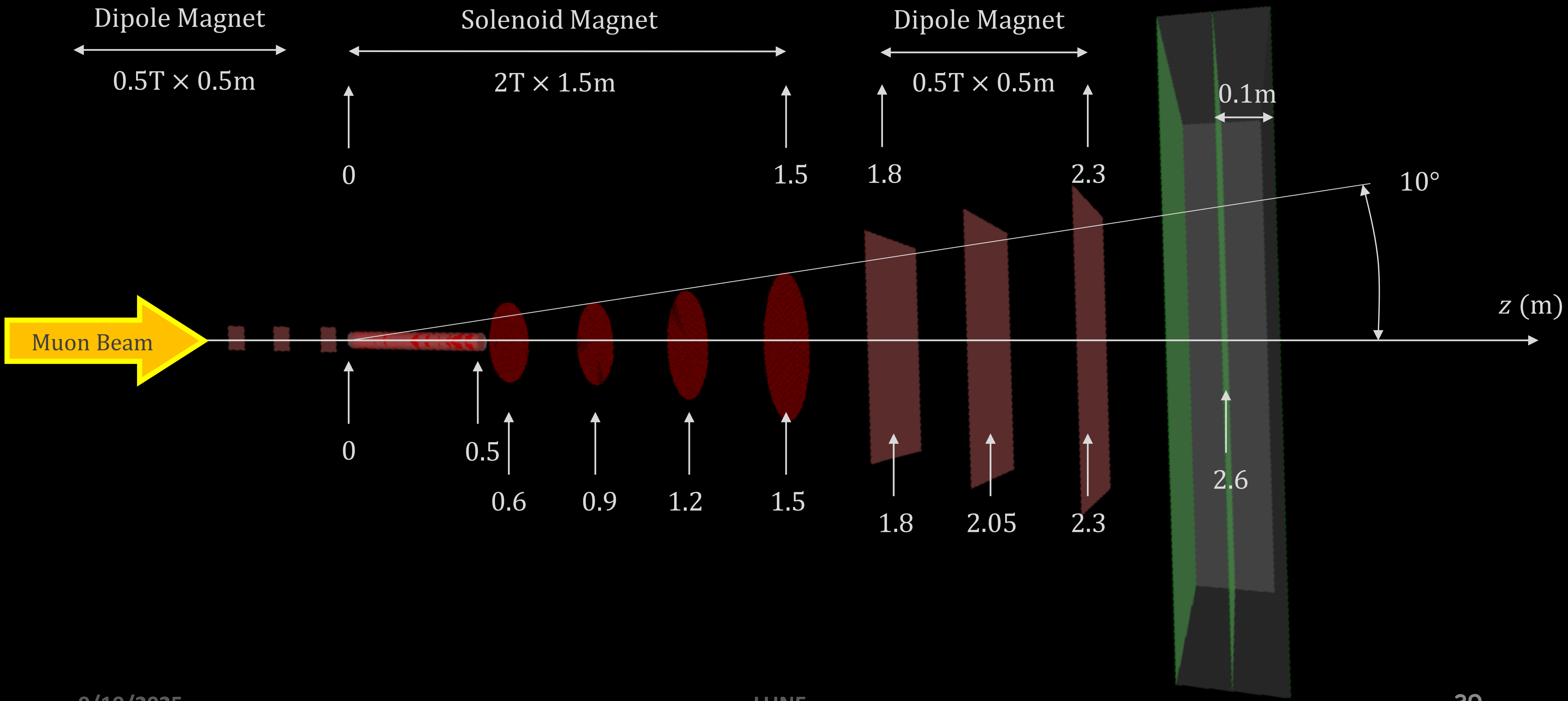
First version of Lune Detector



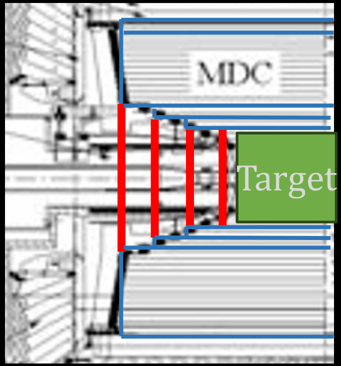
Beam monitoring + forward tracking

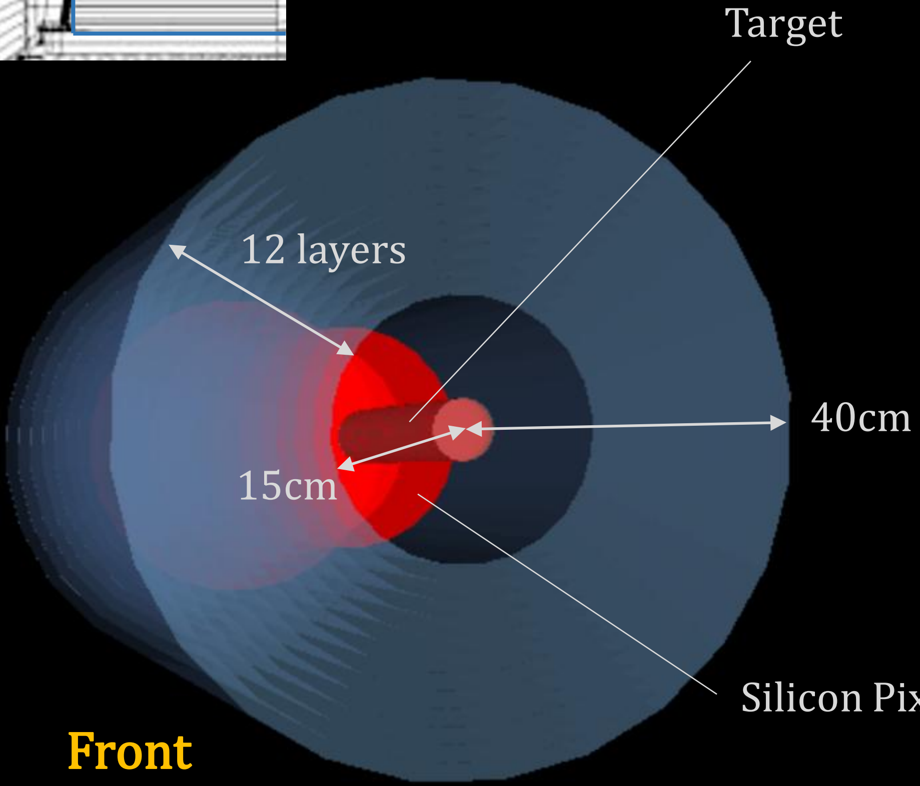


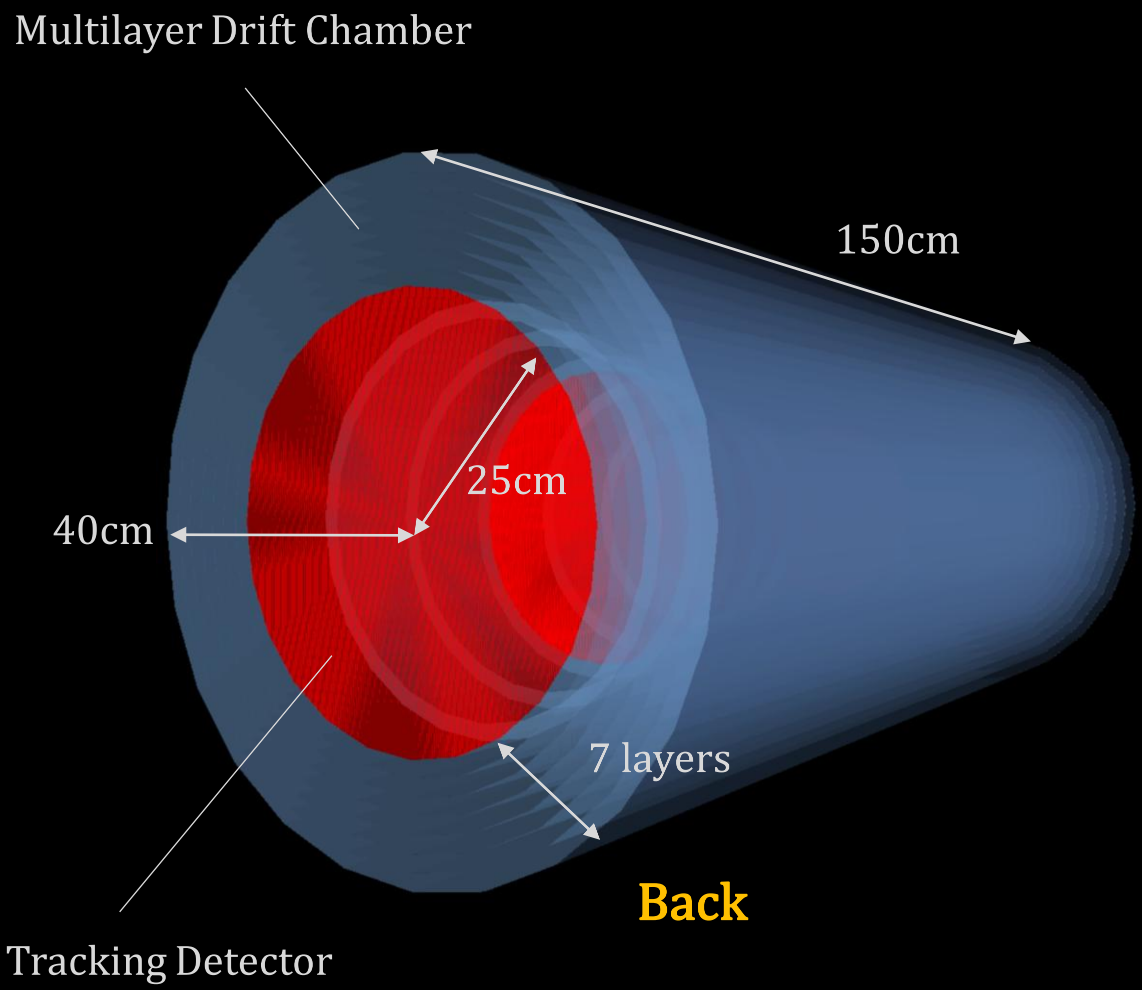
Beam monitoring + forward tracking



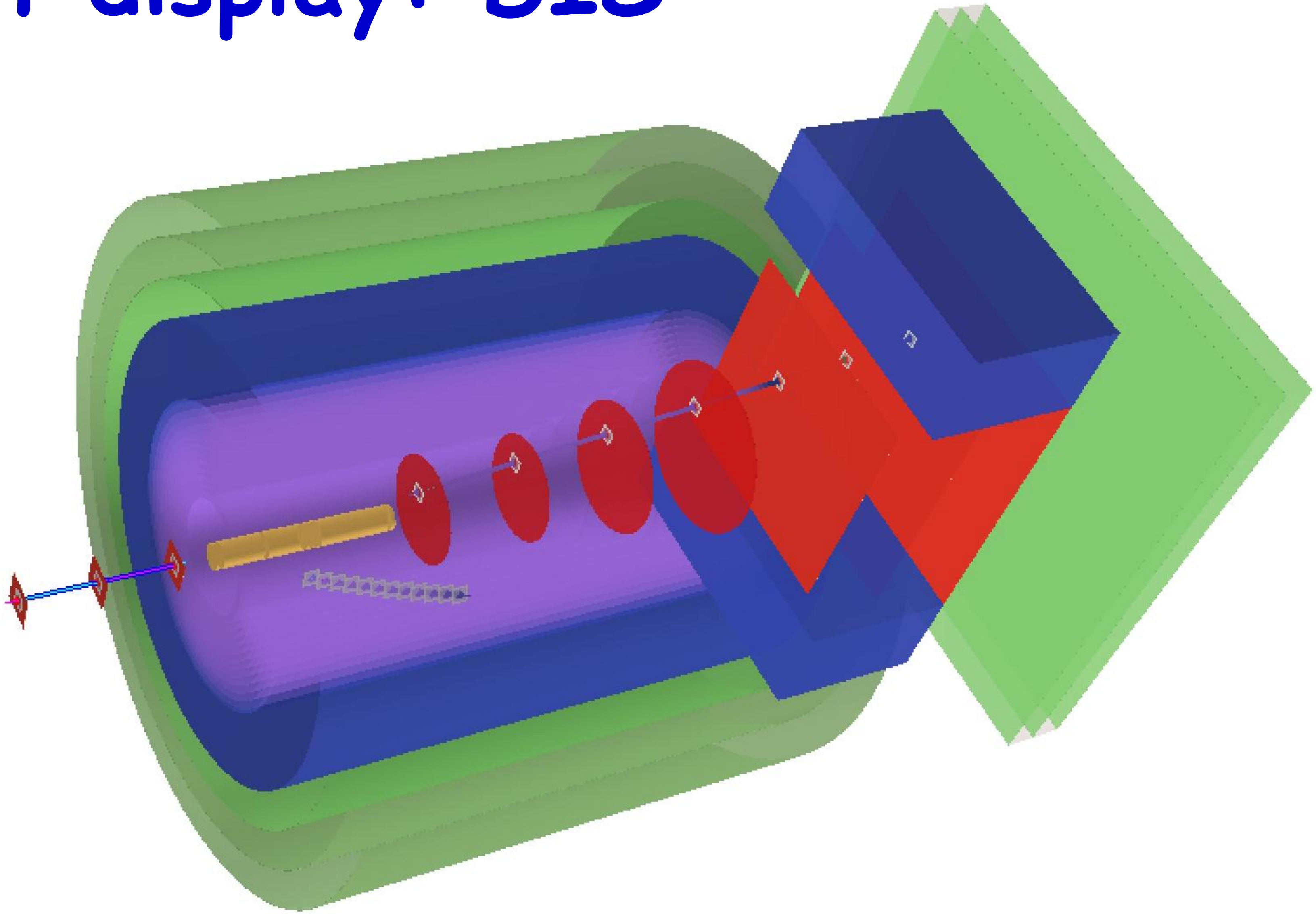
Multilayer Drift Chamber



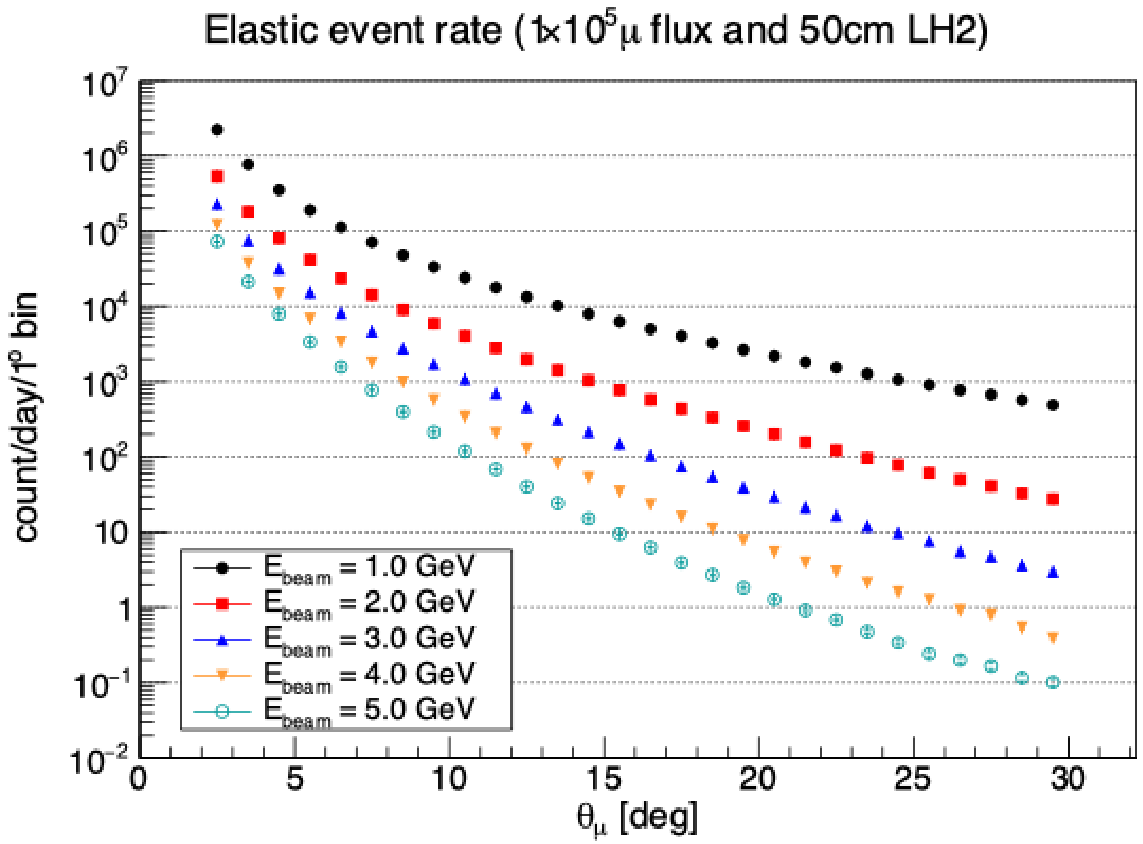


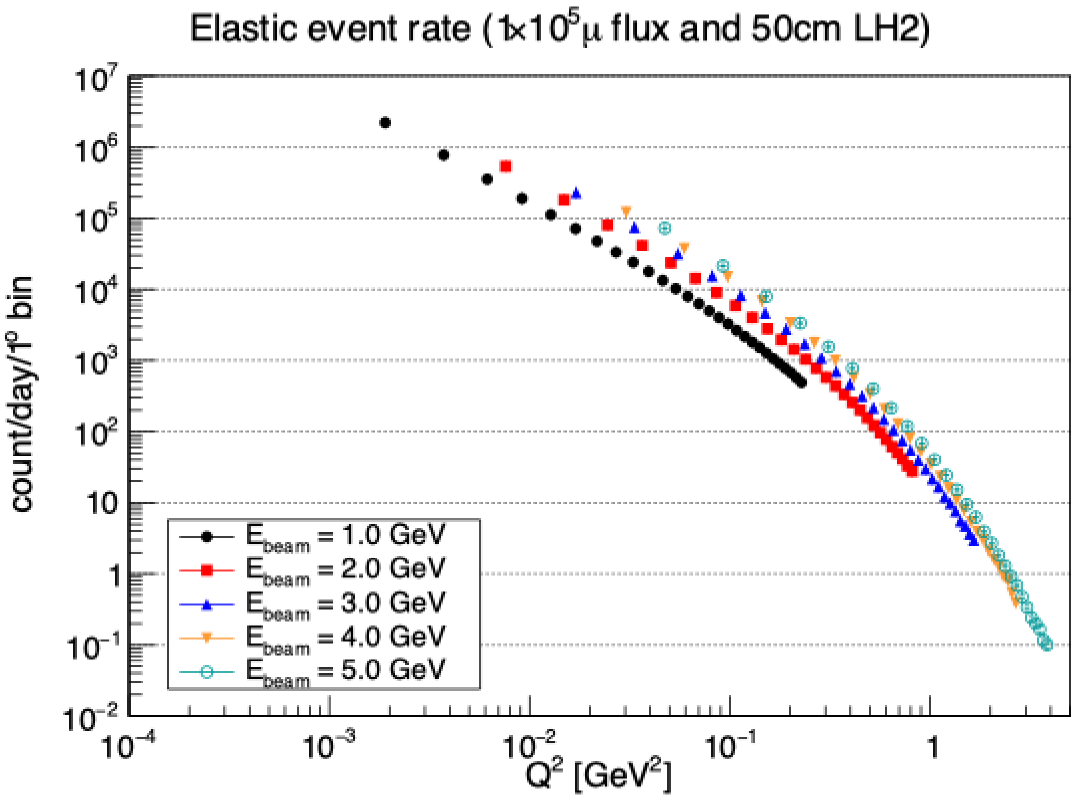


Event display: DIS



Elastic scattering: event rate



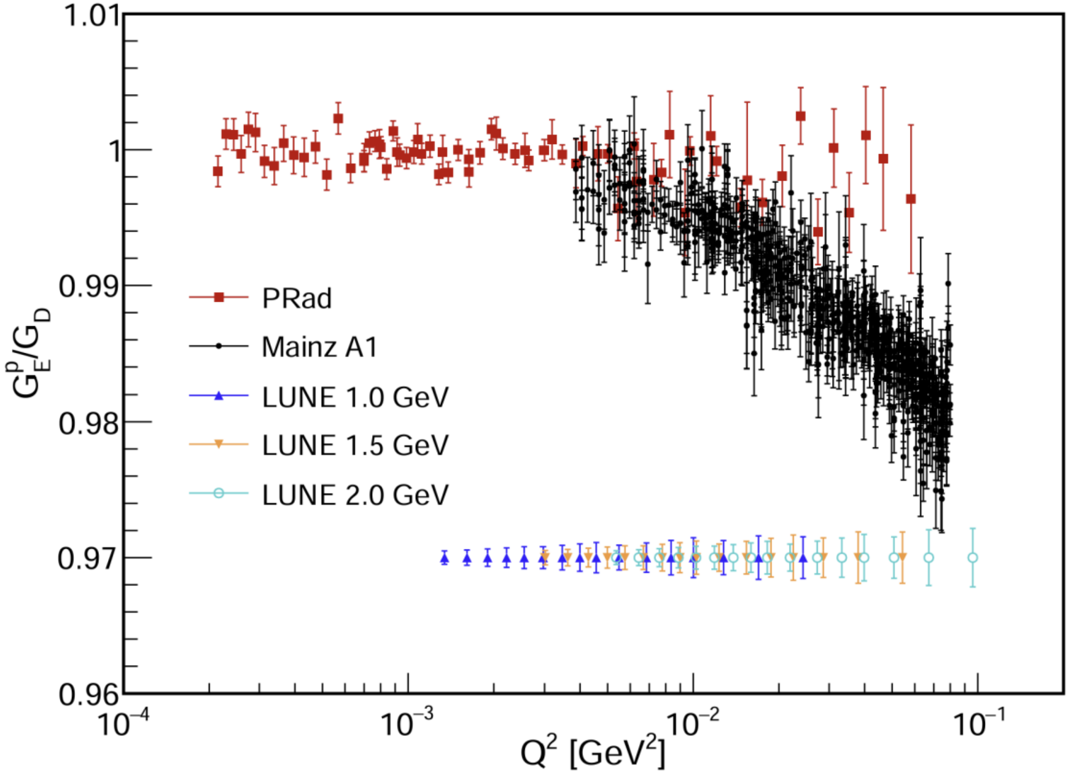


Projection

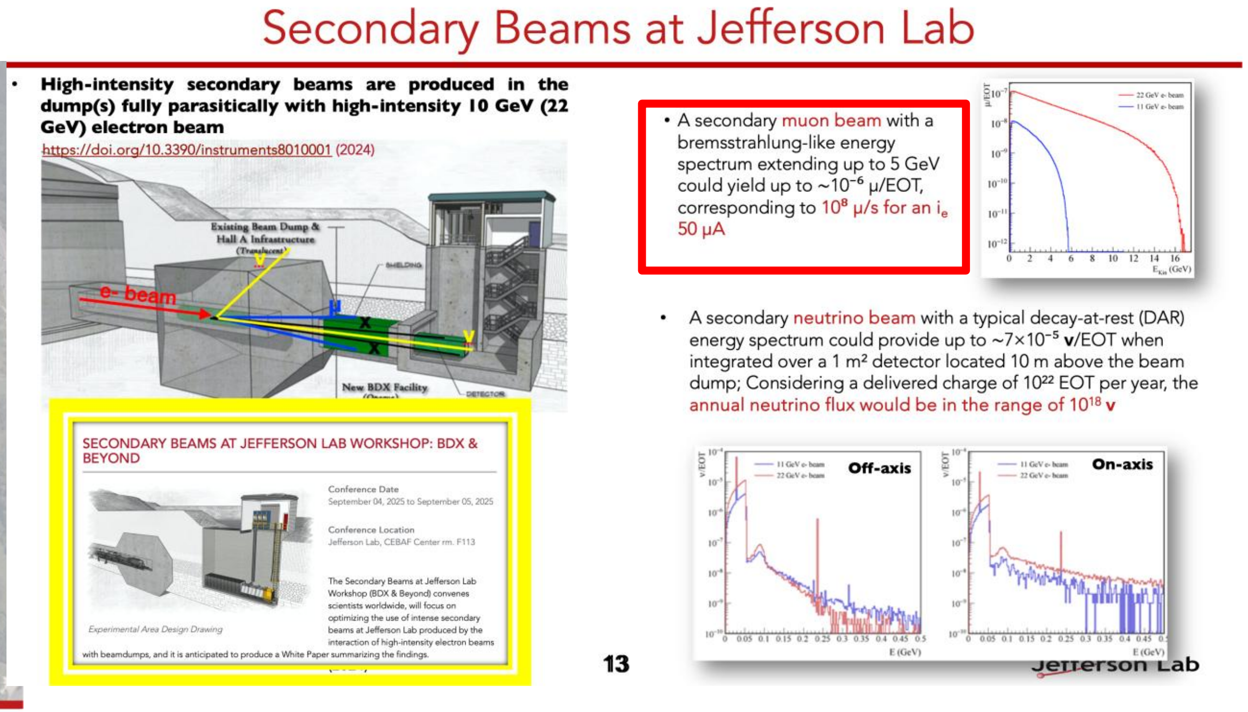
- Proton radius measurement needs low momentum muon beam

- Assuming 20 cm LH2 target
  - 15 days @ 1.0 GeV
  - 30 days @ 1.5 GeV
  - 60 days @ 2.0 GeV

- Stat. uncertainty on proton radius:
  - ~ 0.0022 fm (~0.3%)
  - Compared to 1% (Amber), 0.5% (MUSE)



JLab muon facility



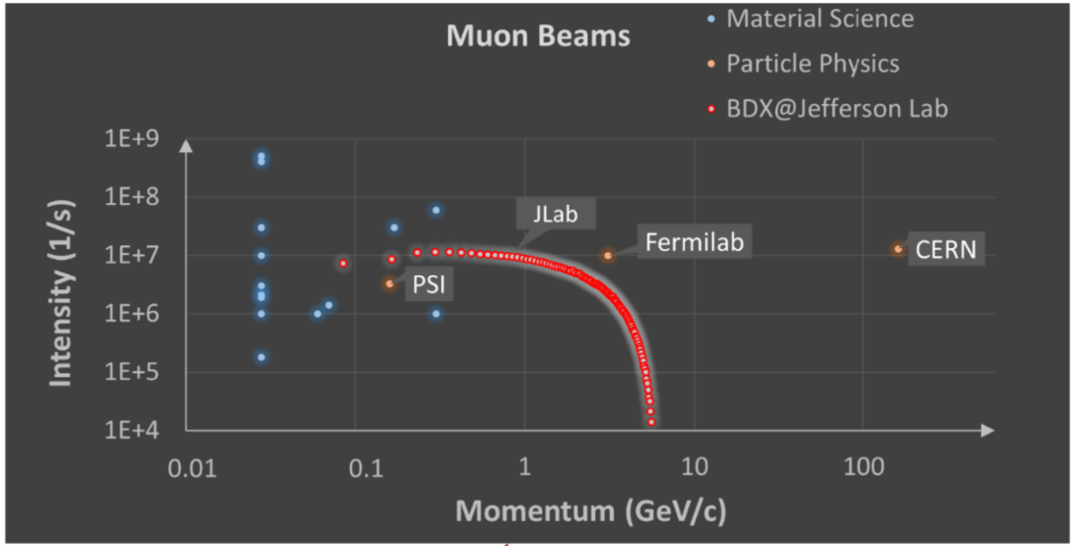
https://indico.jlab.org/event/960/

JLab muon facility

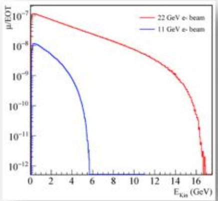
Secondarv Beams at Jefferson Lab

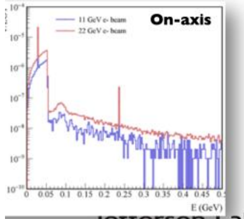
TJNAF is managed by Jefferson Science Associates for the US Department of Energy

Secondary Beams at Jefferson Lab



log scale!





n a typical decay-at-rest (DAR) up to ~7×10^{-5} **ν**/EOT when located 10 m above the beam charge of 10^{22} EOT per year, the n the range of 10^{18} **ν**

Only 3 muon beamlines in use today: SPS/M2 at CERN for COMPASS, the muon storage ring for (g-2)μ at Fermilab, and PiM1 for MUSE at PSI.

There are more planned beams, e.g. at J-PARC for a (g-2)μ, not included in the graph.

The potential JLab facility would *uniquely* provide muons in a large range of momenta, while other muon beams have a small momentum bite. Fermilab, for example, is fixed to 3.1 GeV/c momentum.

The surface muon beams for material science are low momentum.

14

https://indico.jlab.org/event/960/

JLab muon facility

Secondary Beams at Jefferson Lab

TJNAF is managed by Jefferson Science Associates for the US Department of Energy

Secondary Beams at Jefferson Lab

Only 3 muon beamlines in use today:

Conclusions and Outlook

- Jefferson Lab offers an exceptional environment for exploring QCD in the non-perturbative regime, combining high luminosity with state-of-the-art experimental facilities. *(Upgrades here, too – see e.g. Keith, Paremuzyan talks Thursday afternoon)*
- Strategic upgrades, like the 22 GeV energy enhancement will expand our reach into uncharted regimes of hadronic physics.
- The development of positron beams is essential to isolating and quantifying two-photon exchange effects, while also enabling symmetry tests and rare process searches that deepen our exploration of the Standard Model and beyond.
- Innovative experiments such as MOLLER, SoLID, BDX, Hall C Hypernuclear and studies at the K-Long Facility will deepen our understanding of nucleon structure, dark sectors, and the role of strangeness in QCD.
- A new facility for muons and neutrinos is attracting new scientific communities to partner with the JLab community and nuclear physics.
- Advanced technology development, such as made possible by the proposed MPGD center, fuels new experiments broadly by allowing for enhanced measurement capabilities with improved resolution and high rate.
- Together, these opportunities signal a dynamic future, one that bridges precision measurements with bold exploration, and keeps Jefferson Lab at the forefront of discovery.

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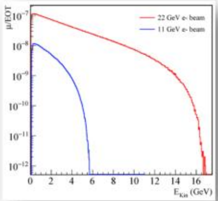

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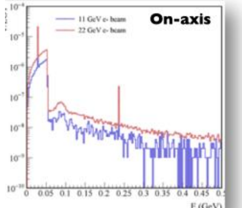

Jefferson Lab

Conclusion

- The HIAF muon source offers a unique opportunity to explore new frontiers in nuclear and particle physics
  - **Proton charge radius**: critical cross-check from muon scattering
  - **Proton inner structure**: DIS, SIDIS, DVCS
  - **Neutron charge distribution**
  - **Nuclear effects**: SRC/EMC, Coulomb Distortion
  - **New physics**: Dark matter searches
- JLab is also planning a muon facility in the coming years
- Outlook: an unexplored research domain @ HIAF muon facility
  - LUNE collaboration would like to contribute to it

Conclusion

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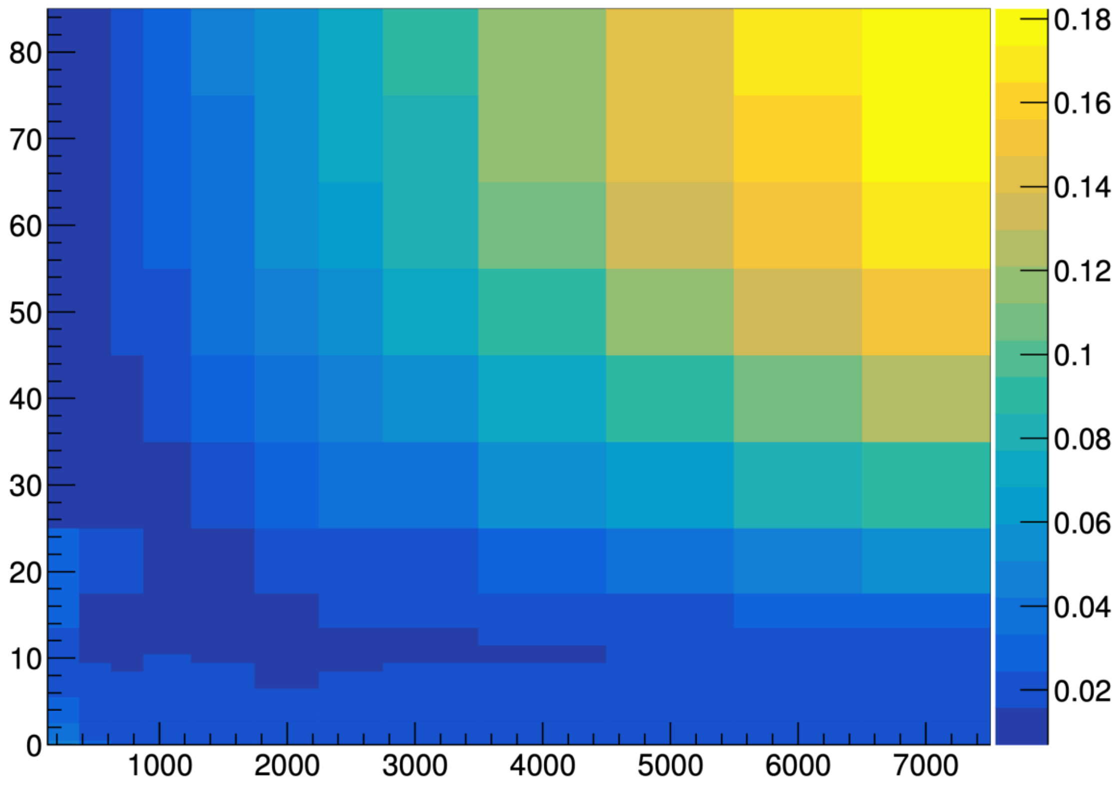
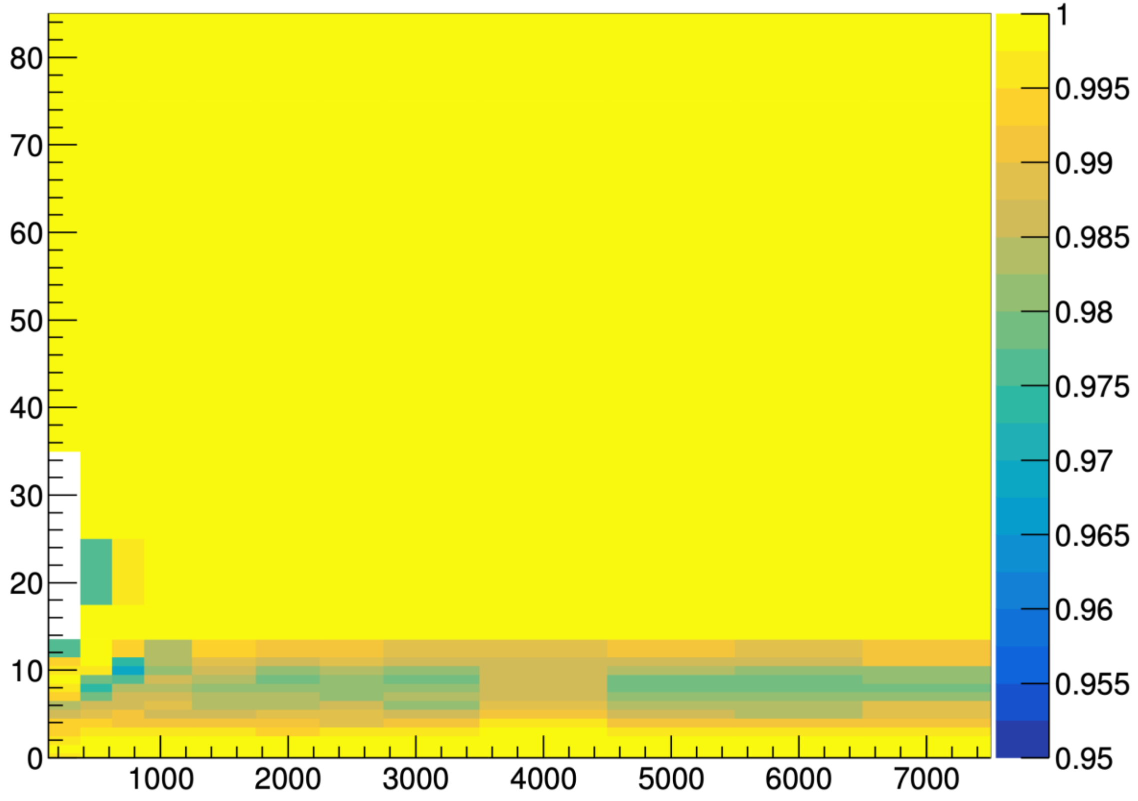
LUNE is an open collaboration: we warmly invite you to join

and help shape the future of muon-nucleon physics!!!

Backup

Track resolution and reco efficiency





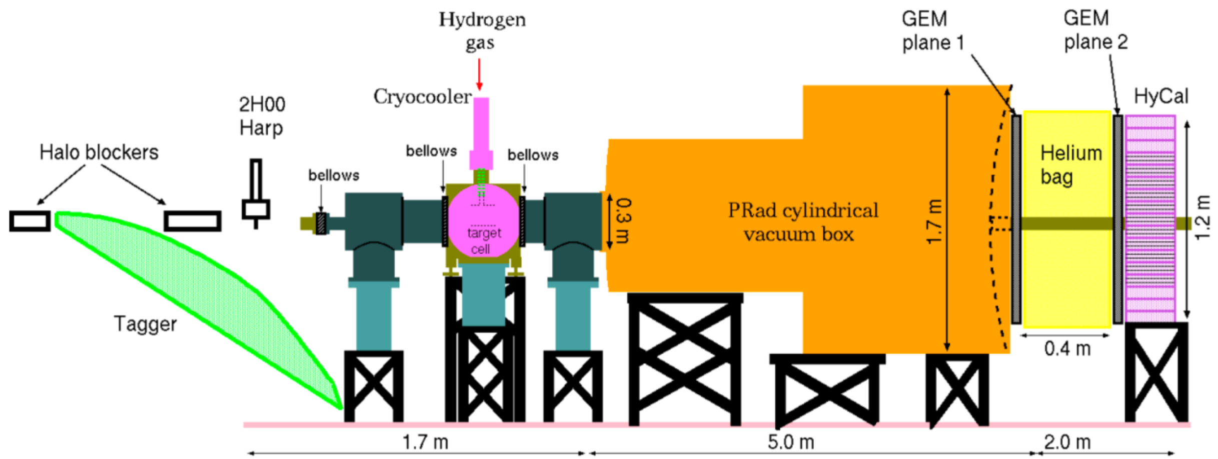
Reconstruction/Generators

- GenFit: for track reconstruction
  - Experiment independent framework for track reconstruction
  - Also used in PANDA @FAIR, Belle II
- Rave: vertex finding and reconstruction
  - A toolkit for vertex reconstruction
  - Developed from CMS
- K4reco: cluster reconstruction + PID
  - Marlin algorithms ported to Gaudi, included in Key4hep
- Generators:
  - esepp (elastic), djangoh (DIS), epic (DVCS), HEPGen++ (DVCS)

PRad-II @ JLab

- Forward acceptance, high resolution EM calorimetry and coordinate detector for tracking
  - Data taking: 2026
- Large angular acceptance:
  - θ_e: $0.5^o - 7^o$
  - Q^2: 2×10^{-5} to 6×10^{-2} GeV/c^2

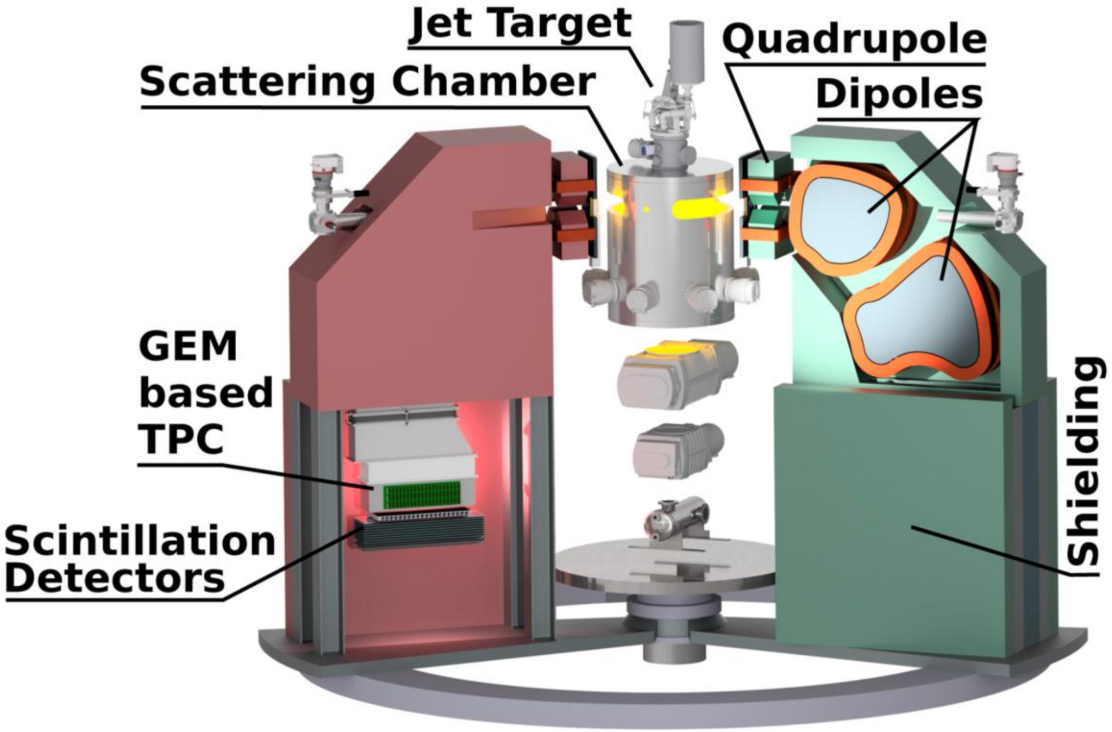
PRad-II Experimental Setup (Side View)



Source	PRad Δr_p (fm)	PRad-II Δr_p (fm)
Stat. uncertainty	0.0075	0.0015
Event selection	0.0070	0.0030
Radiative correction	0.0069	0.0004
Detector efficiency	0.0042	0.0025
Beam background	0.0039	0.0014
HyCal response	0.0029	0.0001
Acceptance	0.0026	0.0001
Beam energy	0.0022	0.0001
Inelastic ep	0.0009	0.0001
G_M^p model	0.0006	0.0005
Total syst.	0.0115	0.0043
Total uncertainty	0.0137	0.0046

MAGIX @ Mainz

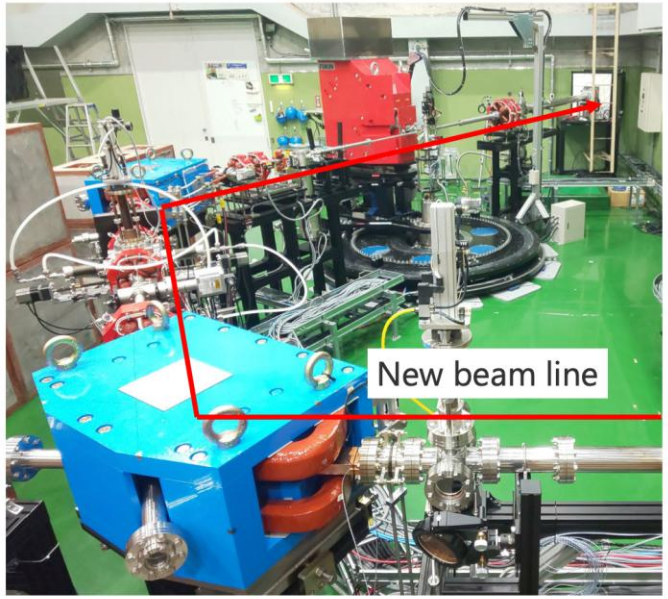
- Accelerator: 1 mA electron beam, energy up to 105 MeV
- Target: cryogenic supersonic gas jet
  - Effectively point-like target
- Expected precision: < 0.1%

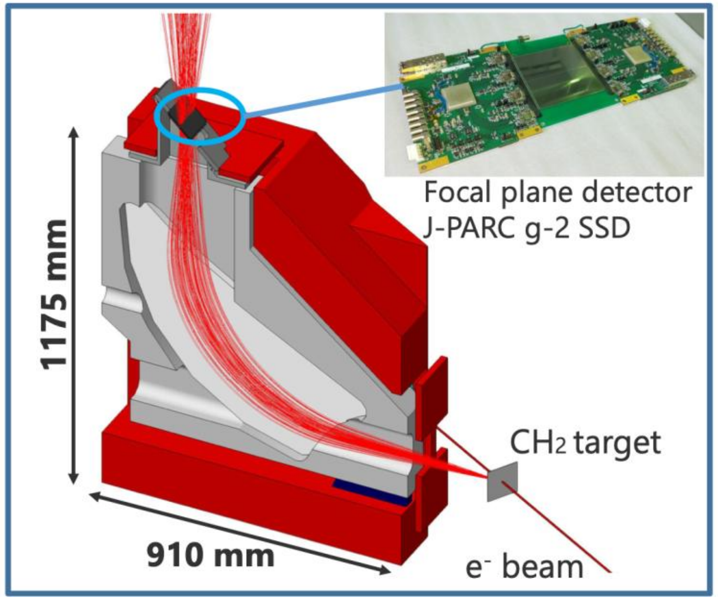


ULQ2 experiment

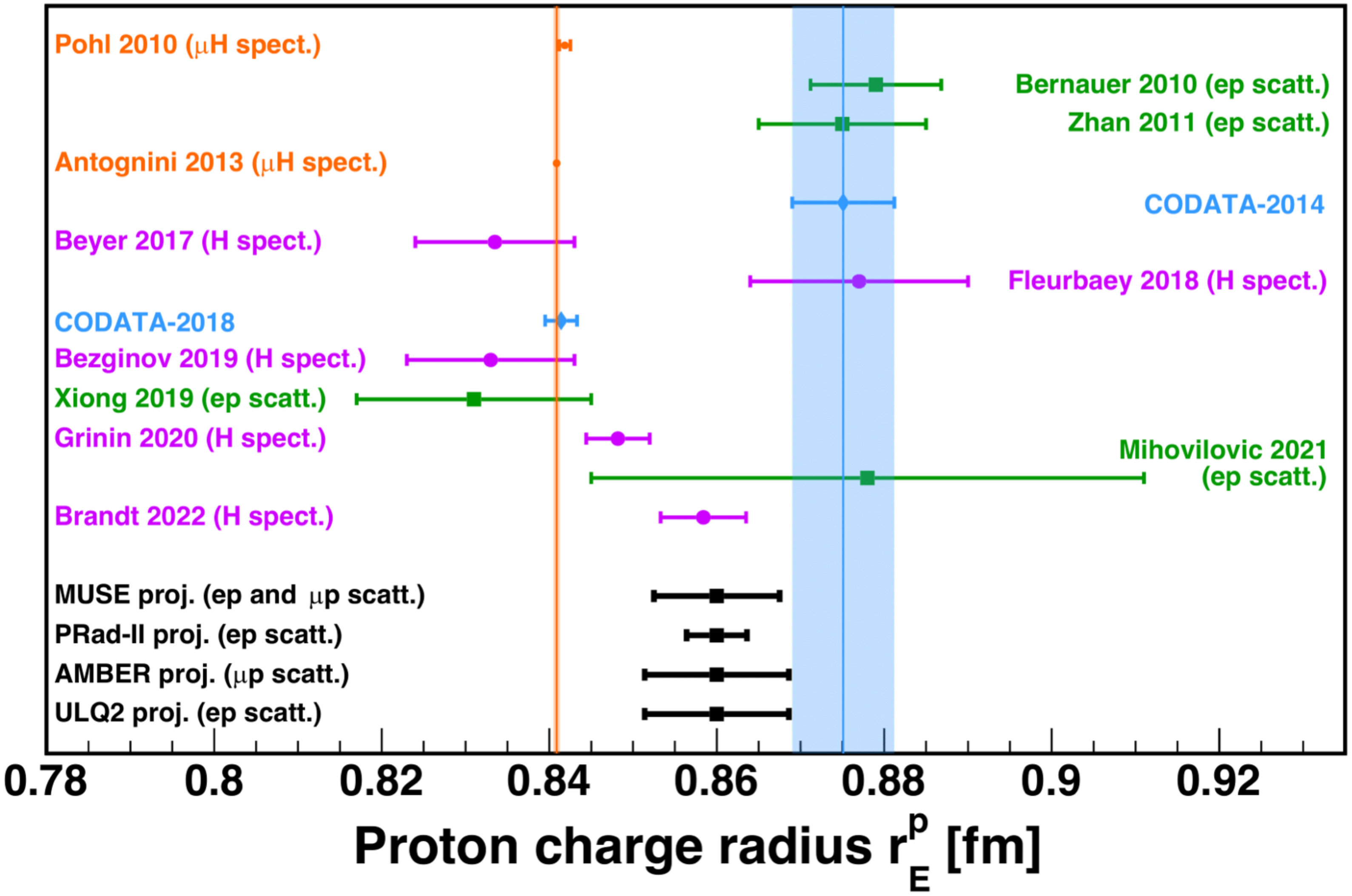
- Tohoku University: ELPH (Electron photon Science)
- Electron beam energy: from 20 to 60 MeV
- Q^2: 3×10^{-4} to 8×10^{-3} GeV/c^2
- Target: CH2
- Precision: 0.1%

First beam	Sep. 11, 2020
Commissioning	Sep., Oct., Nov. 2020, May, June, July 2021





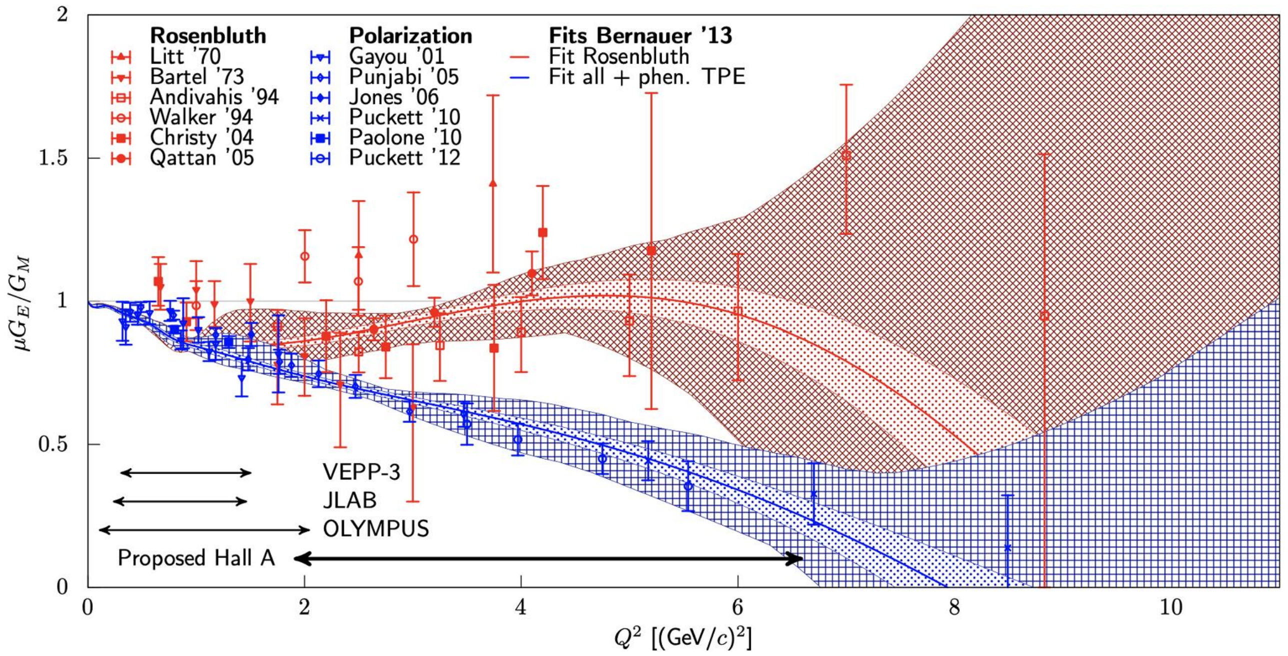
Projection

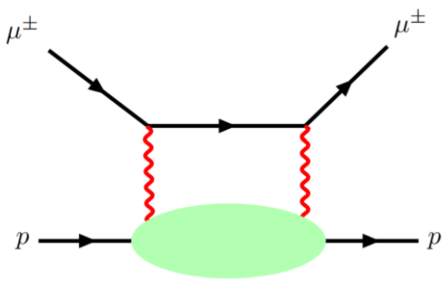


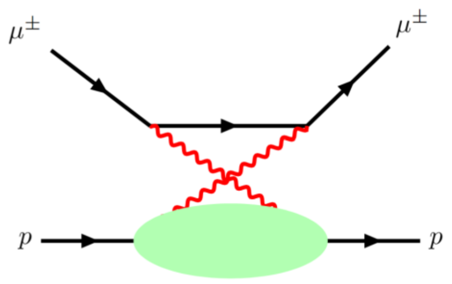
Pohl 2010 (μH spect.)
Bernauer 2010 (ep scatt.)
Zhan 2011 (ep scatt.)
Antognini 2013 (μH spect.)
CODATA-2014
Beyer 2017 (H spect.)
Fleurbaey 2018 (H spect.)
CODATA-2018
Bezginov 2019 (H spect.)
Xiong 2019 (ep scatt.)
Grinin 2020 (H spect.)
Mihovilovic 2021 (ep scatt.)
Brandt 2022 (H spect.)
MUSE proj. (ep and μp scatt.)
PRad-II proj. (ep scatt.)
AMBER proj. (μp scatt.)
ULQ2 proj. (ep scatt.)
0.78
0.8
0.82
0.84
0.86
0.88
0.9
0.92
Proton charge radius r_E^p [fm]

Two photon exchange (TPE)

- Interference between one photon and two photon diagrams: $\ell^{\pm}$
- Key to resolving the proton form factor discrepancy
  - Rosenbluth vs. polarization transfer methods
- Muon-proton scattering: unique test of lepton universality

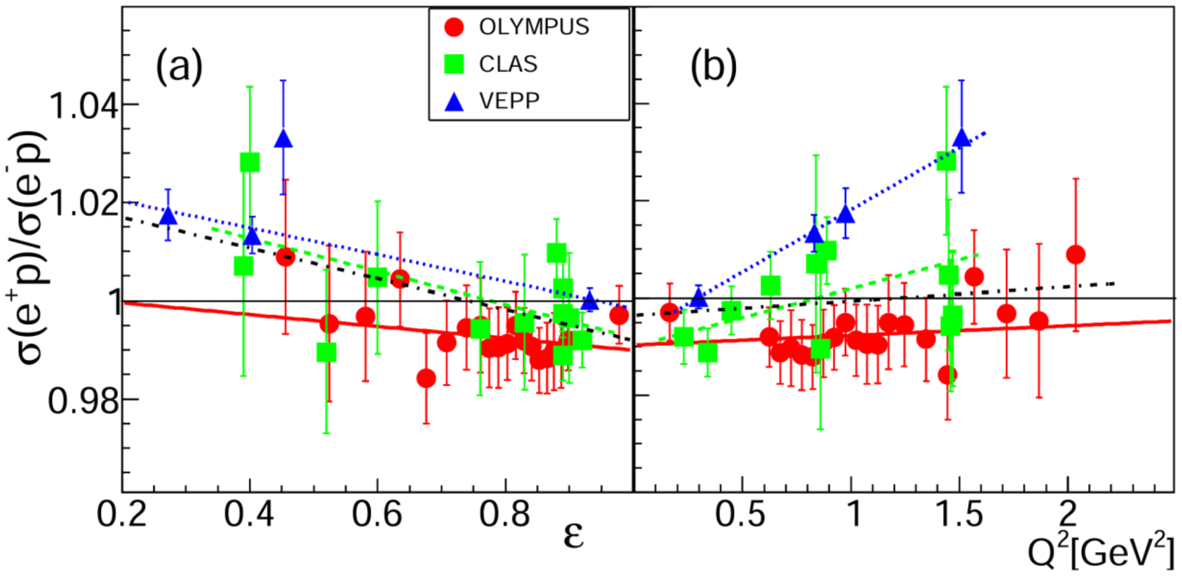






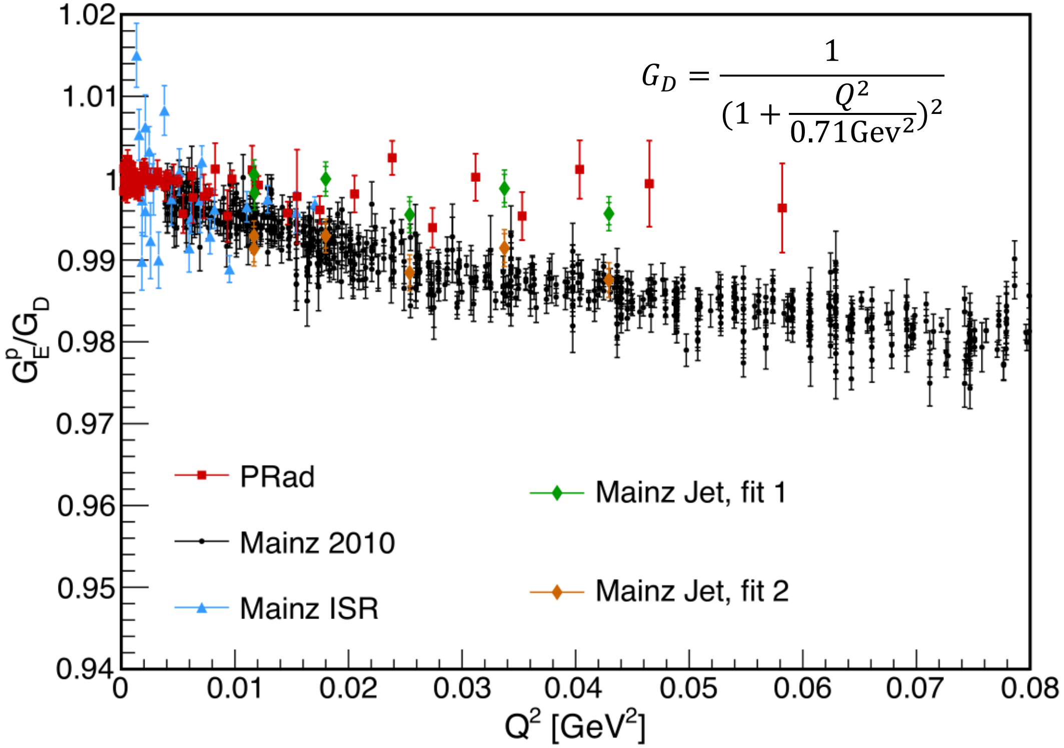
Two photon exchange (TPE)

- Electron scattering:
  - JLab, OLYMPUS@DESY, VEPP-3@Novosibirsk
  - Compared e^+p with e^-p elastic scattering
  - TPE at few-% level: explain part of form factor discrepancy
- Muon scattering:
  - Heavier mass: sensitivity to TPE at low Q^2
  - Direct test of TPE universality
- Essential correction for proton charge radius measurement

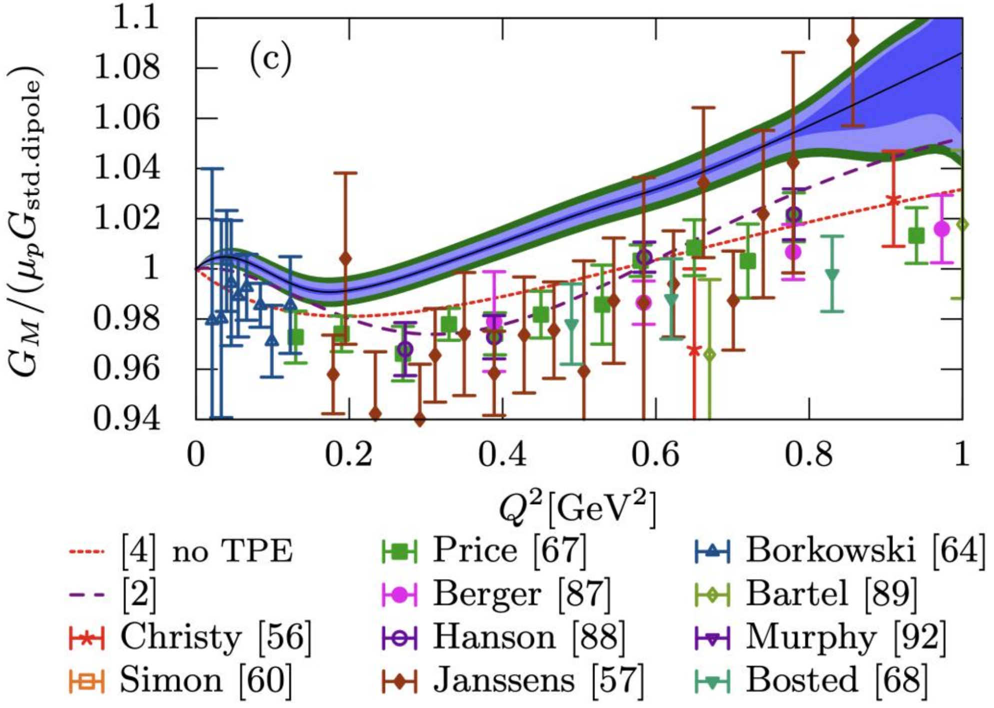


Proton form factor puzzle

- Over 1% difference for G_E between the PRad data and the Mainz data
  - Possible reasons: radiative correction? Unknown systematics? Fitting procedure?...
- Large discrepancy also exist for magnetic radius and G_M
  - 0.776(38) fm for Mainz data , 0.914 (35) fm for world data excluding Mainz (G. Lee et al. PRD 92 013013)



WX and Chao Peng (彭潮) *Universe* 9 (2023) 4, 182

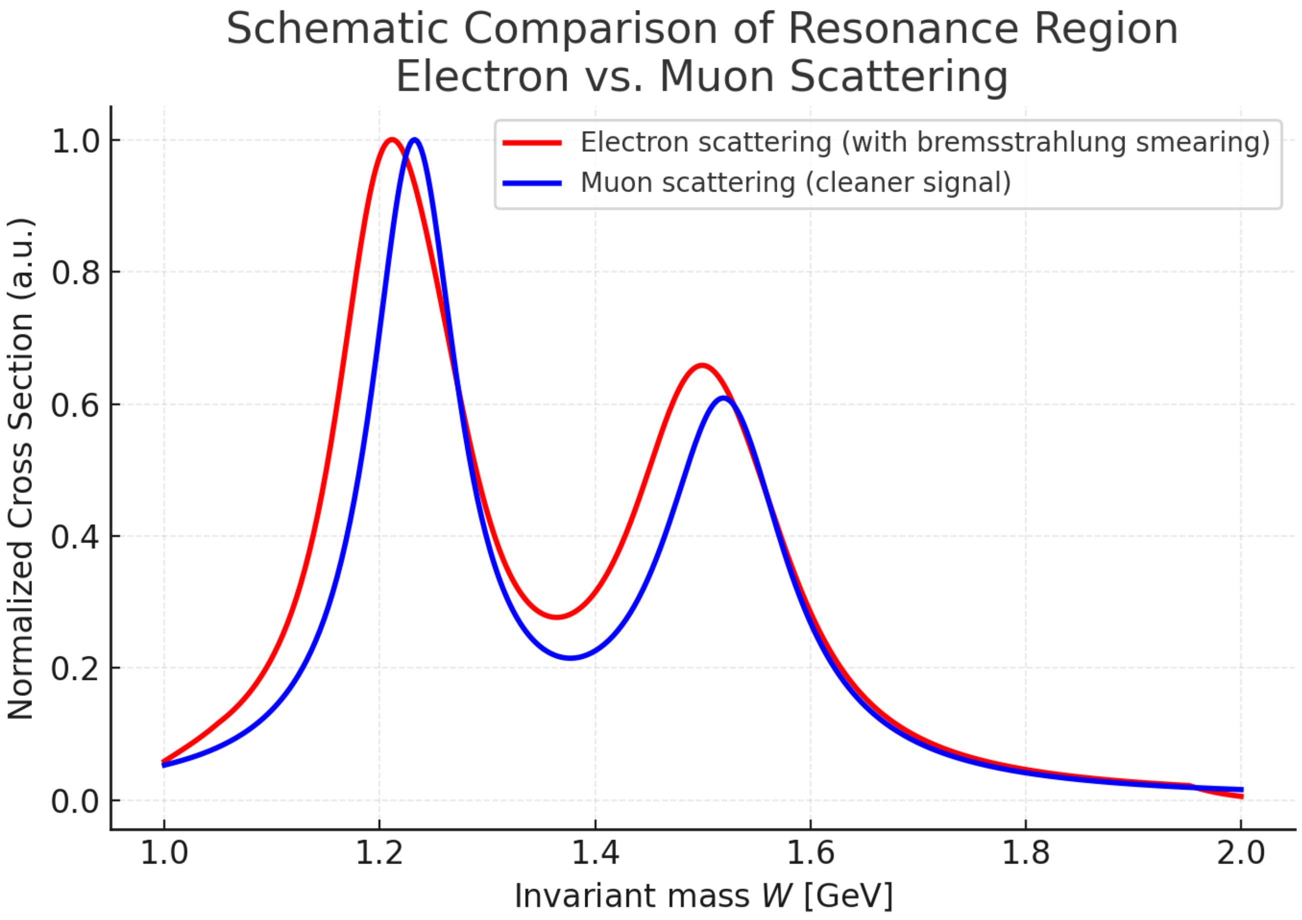


J. Bernauer et al. *PRC* 90 (2014) 1, 015206

Resonance studies

Aspect	ep	μp	Advantage of μp
Beam intensity	$10^{11} - 10^{12}/s$	$10^{6}/s$	Limited statistics
Radiative correction	Large bremsstrahlung, strong radiative tails that smear resonance peaks	Suppressed bremsstrahlung ($m_\mu \gg m_e$): cleaner resonance signals	Clearer extraction of resonance cross sections
Q^2 Coverage	Wide, but low-Q^2 dominated by radiative effects	Access to lower "effective Q^2" region without huge radiative backgrounds	Complementary kinematics
Form Factor/Transition Studies	Extensive measurements at JLab & SLAC	Sparse — essentially unexplored	Opportunity for new data
New Physics Sensitivity	Limited — well tested with electrons	Tests lepton universality, motivated by proton radius puzzle & g−2	Unique physics reach

Resonance studies

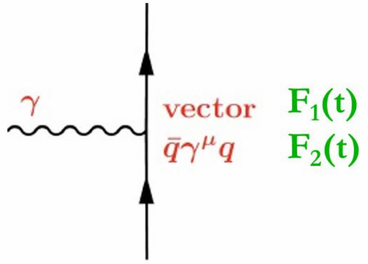


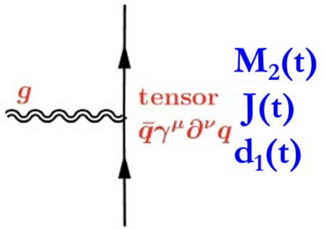
Proton properties

The structure of strongly interacting particles can be probed by means of the other fundamental forces: *electromagnetic*, *weak*, and (in principle) *gravity*.

em:	$\partial_\mu J^\mu_{\text{em}} = 0$	$\langle N' \| J^\mu_{\text{em}} \| N \rangle$	$\longrightarrow$	Q_{prot}	$=$	$1.602176487(40) \times 10^{-19}\text{C}$
	vector			μ_{prot}	$=$	$2.792847356(23)\mu_N$
weak:	PCAC	$\langle N' \| J^\mu_{\text{weak}} \| N \rangle$	$\longrightarrow$	g_A	$=$	$1.2694(28)$
	axial			g_p	$=$	$8.06(0.55)$
gravity:	$\partial_\mu T^{\mu\nu}_{\text{grav}} = 0$	$\langle N' \| T^{\mu\nu}_{\text{grav}} \| N \rangle$	$\longrightarrow$	M_{prot}	$=$	$938.272013(23)\,\text{MeV}/c^2$
				J	$=$	$\frac{1}{2}$
	tensor			D	$=$	**?**

P. Schweitzer et al., arXiv:1612.0672, 2016.





extreme weakness of the gravitational interaction

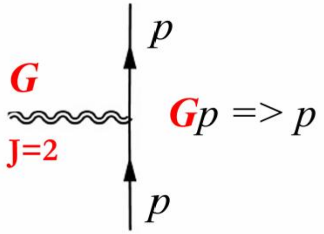
The D-term is the "last unknown global property" of the nucleon

Gravitational form factor (GFFs)

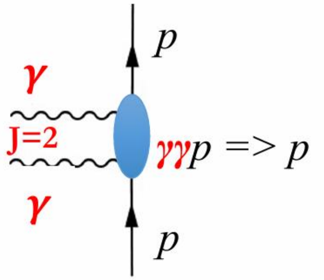
- Nucleon matrix element of Energy-Momentum Tensor (EMT) has three scalar form factors

$$\left\langle p_2 \middle| \hat{T}^q_{\mu\nu} \middle| p_1 \right\rangle = \bar{U}(p_2)\left[M_2^q(t)\frac{P_\mu P_\nu}{M} + J^q(t)\frac{\iota\left(P_\mu \sigma_{\nu\rho} + P_\nu \sigma_{\mu\rho}\right)\Delta^\rho}{2M} + d_1^q(t)\frac{\Delta_\mu \Delta_\nu - g_{\mu\nu}\Delta^2}{5M}\right] U(p_1)$$

- $M_2^q(t)$: Mass/energy distribution inside the nucleon
- $J^q(t)$: Angular momentum distribution
- $d_1^q(t)$: Forces and pressure distribution

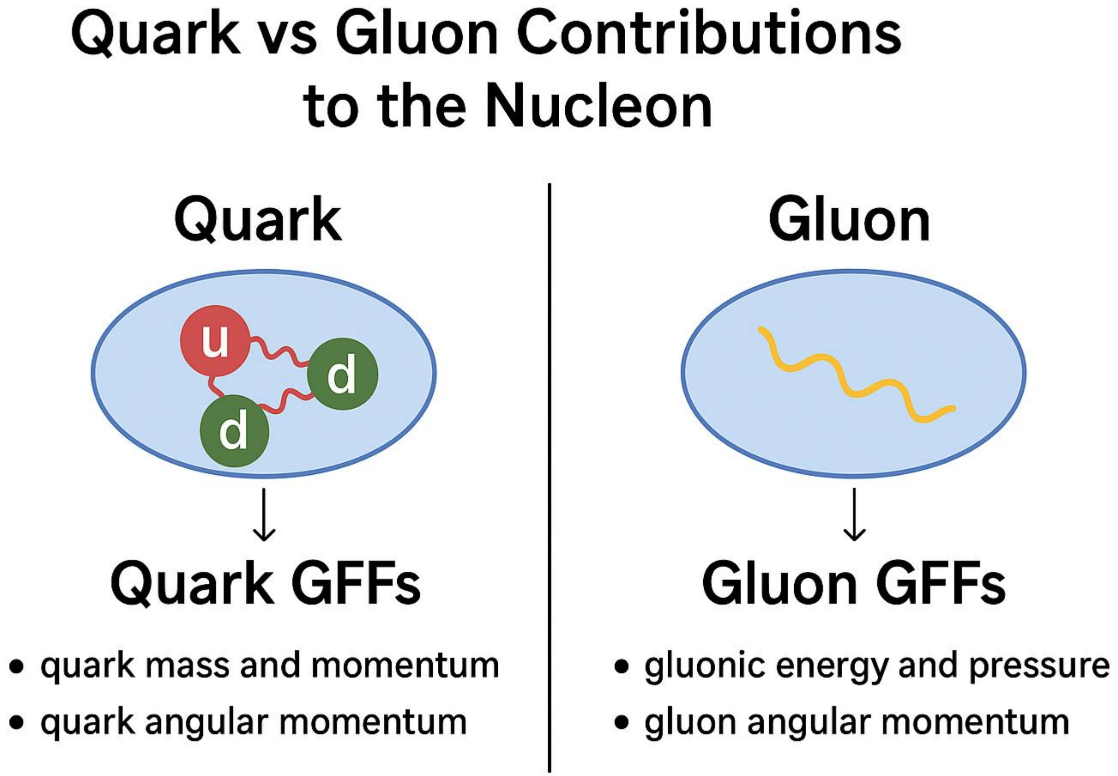


DVCS



GPDs ←→ GFFs

GFFs: quark vs. gluon



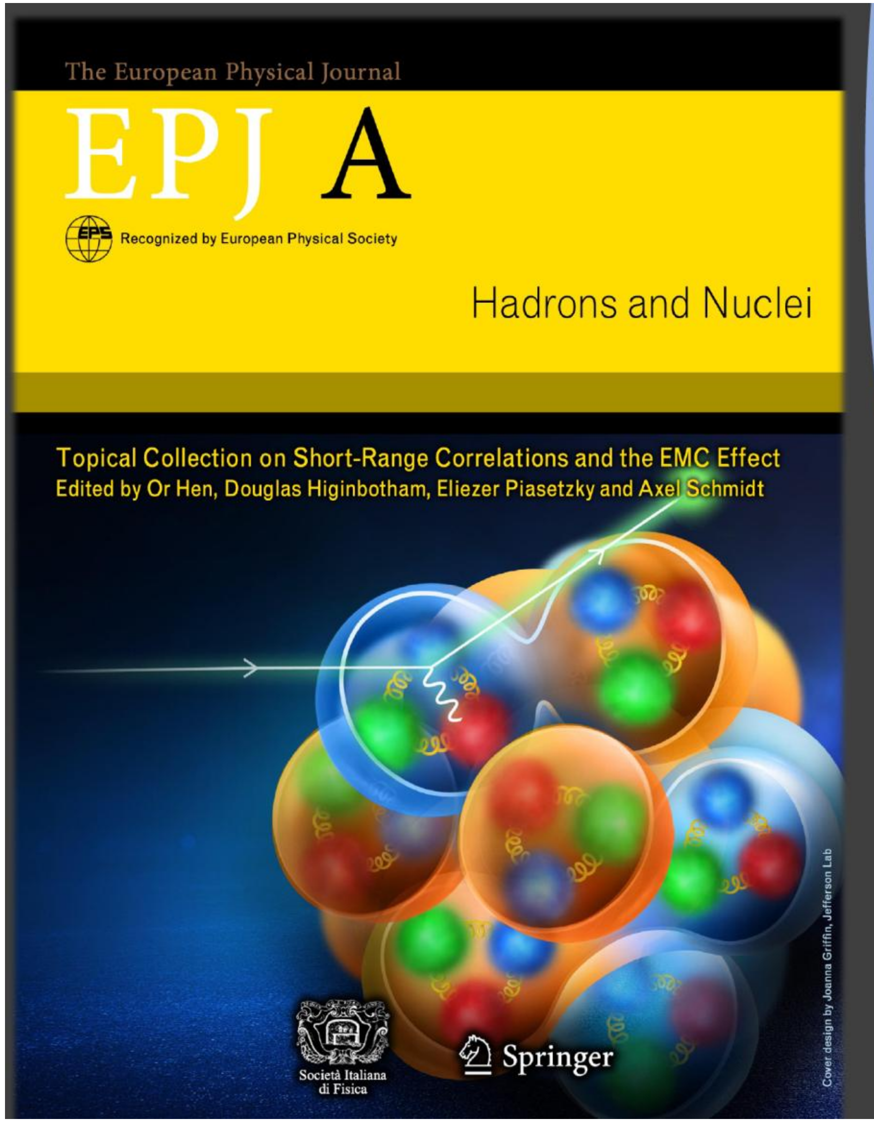
	Quark GFFs	Gluon GFFs
Partons	u, d, s, …	gluon
Probe	DVCS, SIDIS, …	J/ψ , Υ production
Status	JLab, COMPASS, HERA	only recently probed, still with large uncertainties
Structure	Quark “skeleton”	Gluon “binding glue”, nucleon mass
Muon energy	HIAF	HIAF upgrade (photon energy of 8.2 GeV for J/ψ production)

JLab: Nature **615**, 813–816 (2023)

Short range correlation

- **Nuclear structure**: How nucleons are arranged in nuclei at short distances
- **Tensor forces**: How the nucleon–nucleon interaction works at high relative momentum
- **EMC–SRC connection**: Whether nucleon structure modifications (parton distributions in nuclei) originate from short-range nucleon-nucleon dynamics
- **Dense matter physics**: How nucleons behave in environments like neutron stars (where nucleons are packed closer than in normal nuclei)

Short range correlation



Isospin Structure:
Phys. Rev. Lett. 122, 172502 (2019)
Nature 560, 617 (2018)
Science 346, 614 (2014)
Phys. Rev. Lett. 113, 022501 (2014)

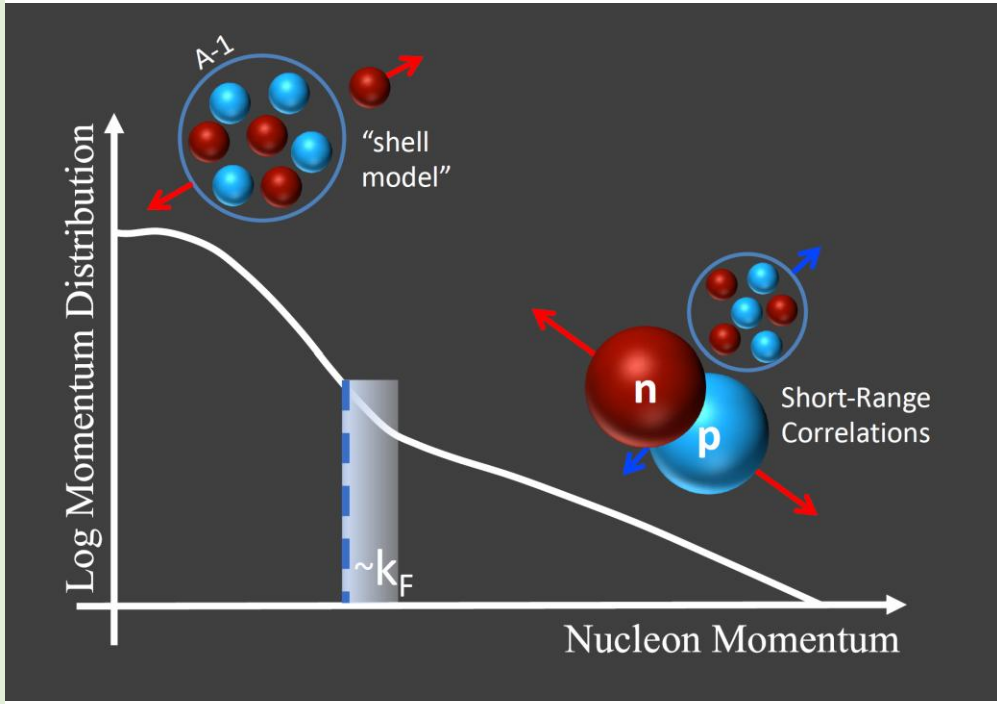
C.M. Motion:
Phys. Rev. Lett. 121, 092501 (2018)

Hard-Reaction Dynamics:
Nature Physics 17, 693 (2021)
Phys. Lett. B 797, 134792 (2019)
Phys. Lett. B 722, 63 (2013)

Nuclei / Nuclear Matter Properties:
Phys. Lett. B 800, 135110 (2020)
Phys. Lett. B 793, 360 (2019)
Phys. Lett. B 785, 304 (2018)
Phys. Rev. C 91, 025803 (2015)

Effective Theory:
Nature Physics 17, 306 (2021)
Phys. Lett. B 805, 135429 (2020)
Phys. Lett. B 791, 242 (2019)

Quantum Numbers, Mass, Asymmetry Dependence:
Phys. Rev. C 103, L031301 (2023)
Phys. Lett. B 780, 211 (2018)
PRC 92, 024604 (2015)
PRC 92, 045205 (2015)



Luminosity

- Instantaneous Luminosity:
  - Target: 50 cm liquid hydrogen (LH)
  - Muon flux: 1×10^5
  - $2 \times 10^{29} cm^{-2} s^{-1} = 2 \times 10^{-7}\ pb^{-1} s^{-1}$
- Integrated Luminosity:
  - 6 months: 24 hours per day
  - $\mathbf{3.1\ pb^{-1}}$