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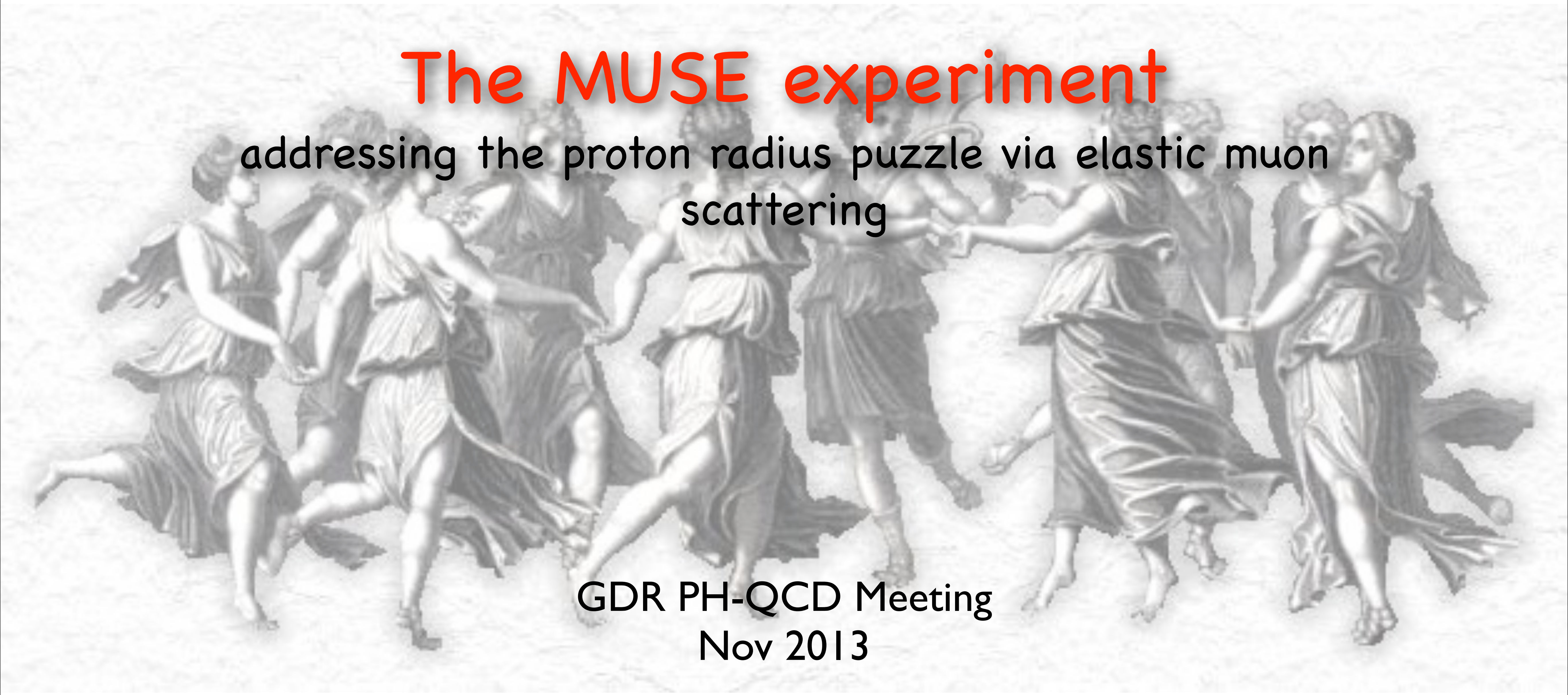
The MUSE experiment

addressing the proton radius puzzle via elastic muon scattering



GDR PH-QCD Meeting
Nov 2013

Guy Ron
Hebrew University of Jerusalem

http://www.phys.huji.ac.il/~gron

Form Factor Moments

$$\int e^{-i\vec{k}\cdot\vec{r}}\rho(\vec{r})d^3r \propto \int r^2\rho(r)j_0(kr)dr$$

3d Fourier Transform for isotropic density

$$G_{E,M}(Q^2) = 1 - \frac{1}{6}\left\langle r^2_{E,M}\right\rangle Q^2 + \frac{1}{120}\left\langle r^4_{E,M}\right\rangle Q^4 - \frac{1}{5040}\left\langle r^6_{E,M}\right\rangle Q^6 + \cdots$$

Non-relativistic assumption (only) = k=Q; G is F.T. of density

$$-6\frac{dG_{E,M}}{dQ^2}\bigg|_{Q^2=0} = \left\langle r^2_{E,M}\right\rangle \equiv r^2_{E,M}$$

Slope of $G_{E,M}$ at Q^2=0 defines the radii. This is what FF experiments quote.

Notes

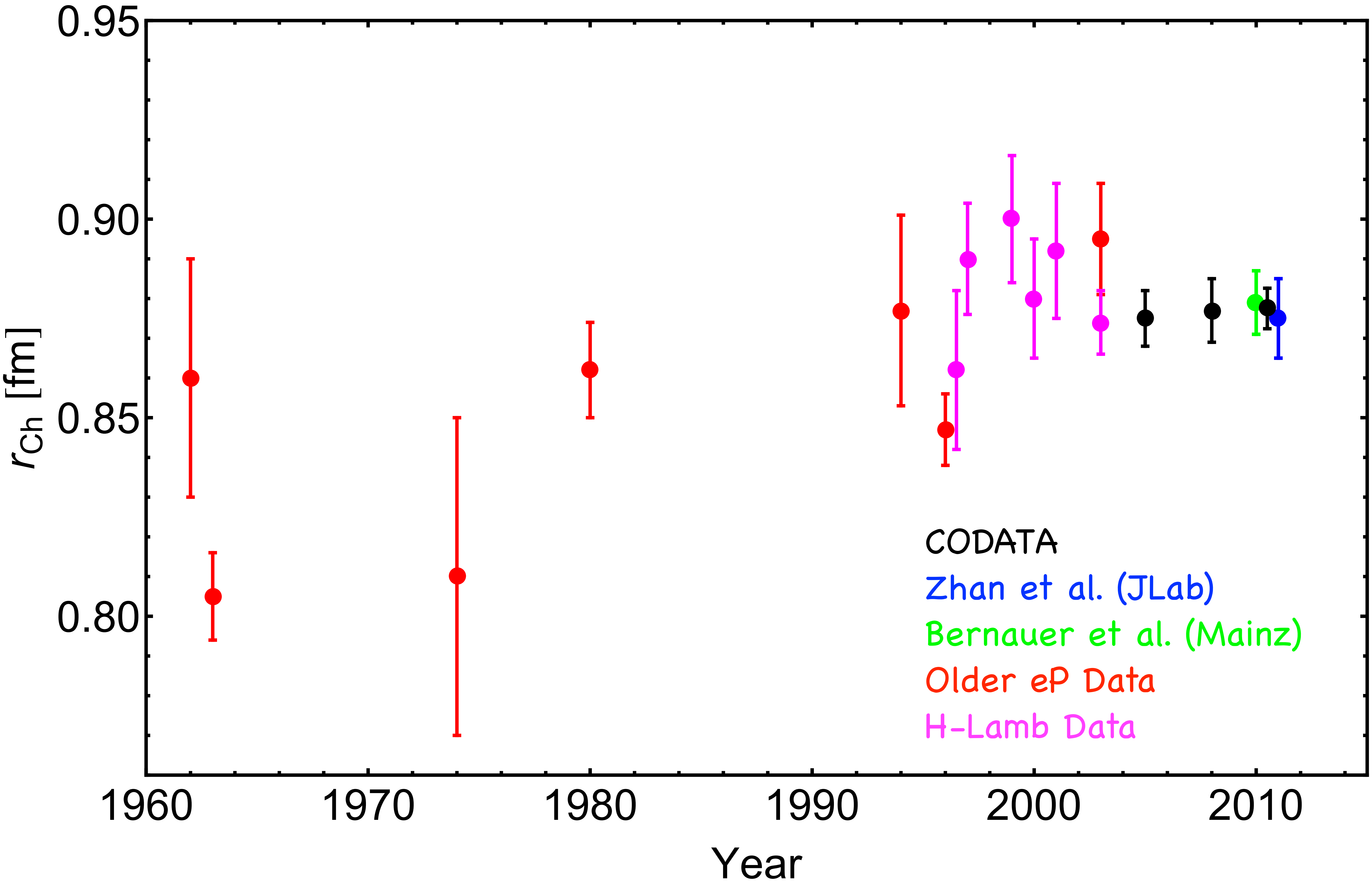
- In NRQM, the FF is the 3d Fourier transform (FT) of the Breit frame spatial distribution, but the Breit frame is not the rest frame, and doing this confuses people who do not know better. The low Q^2 expansion remains.

Boost effects in relativistic theories destroy our ability to determine 3D rest frame spatial distributions. The FF is the 2d FT of the transverse spatial distribution.

The slope of the FF at $Q^2 = 0$ continues to be called the radius for reasons of history / simplicity / NRQM, but it is not the radius.

Nucleon magnetic FFs crudely follow the dipole formula, $G_D = (1+Q^2/0.71\ \mathrm{GeV}^2)^{-2}$, which a) has the expected high Q^2 pQCD behavior, and b) is amusingly the 3d FT of an exponential, but c) has no theoretical significance

Time evolution of the Radius from H Lamb Shift + eP



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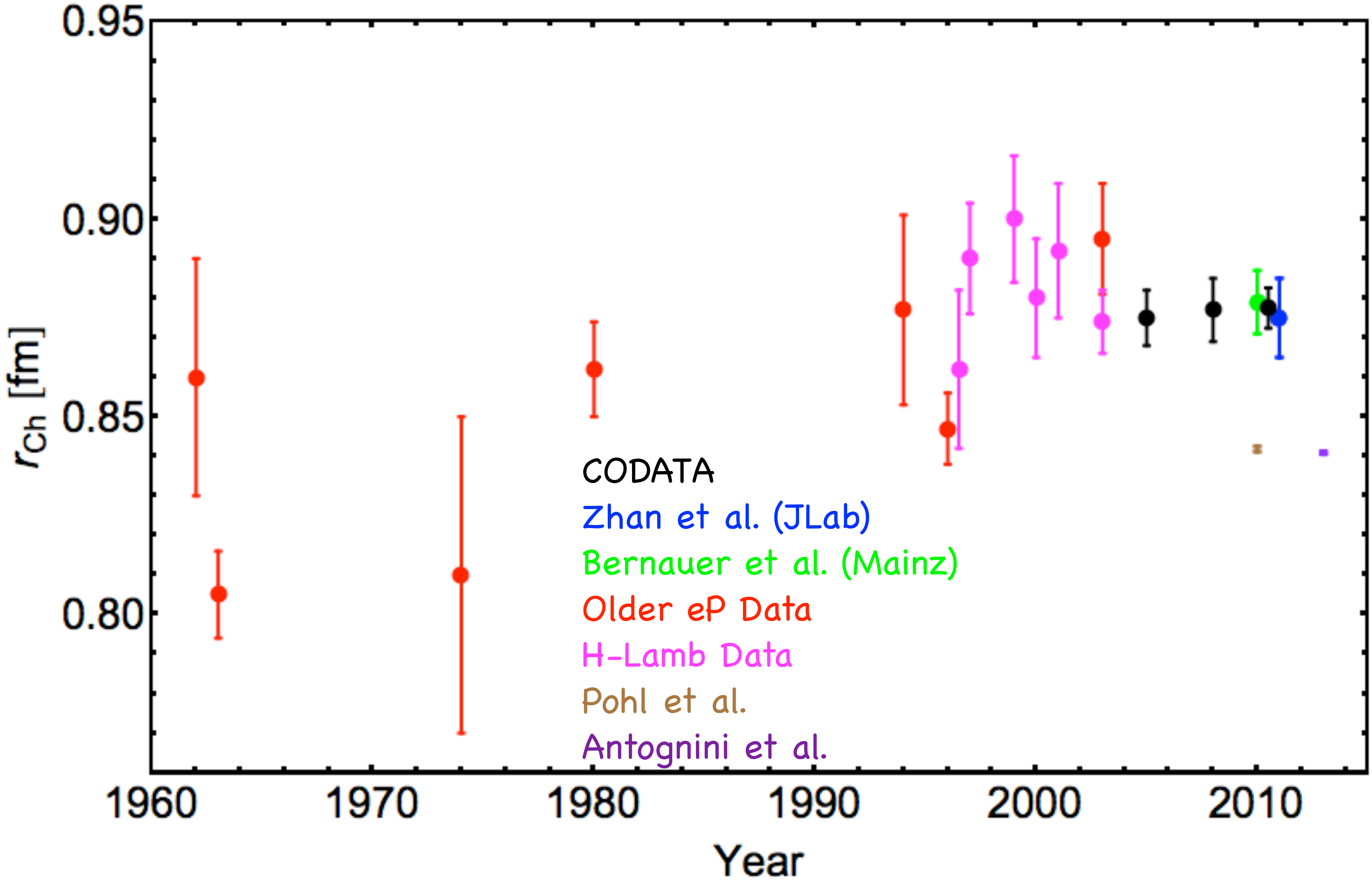

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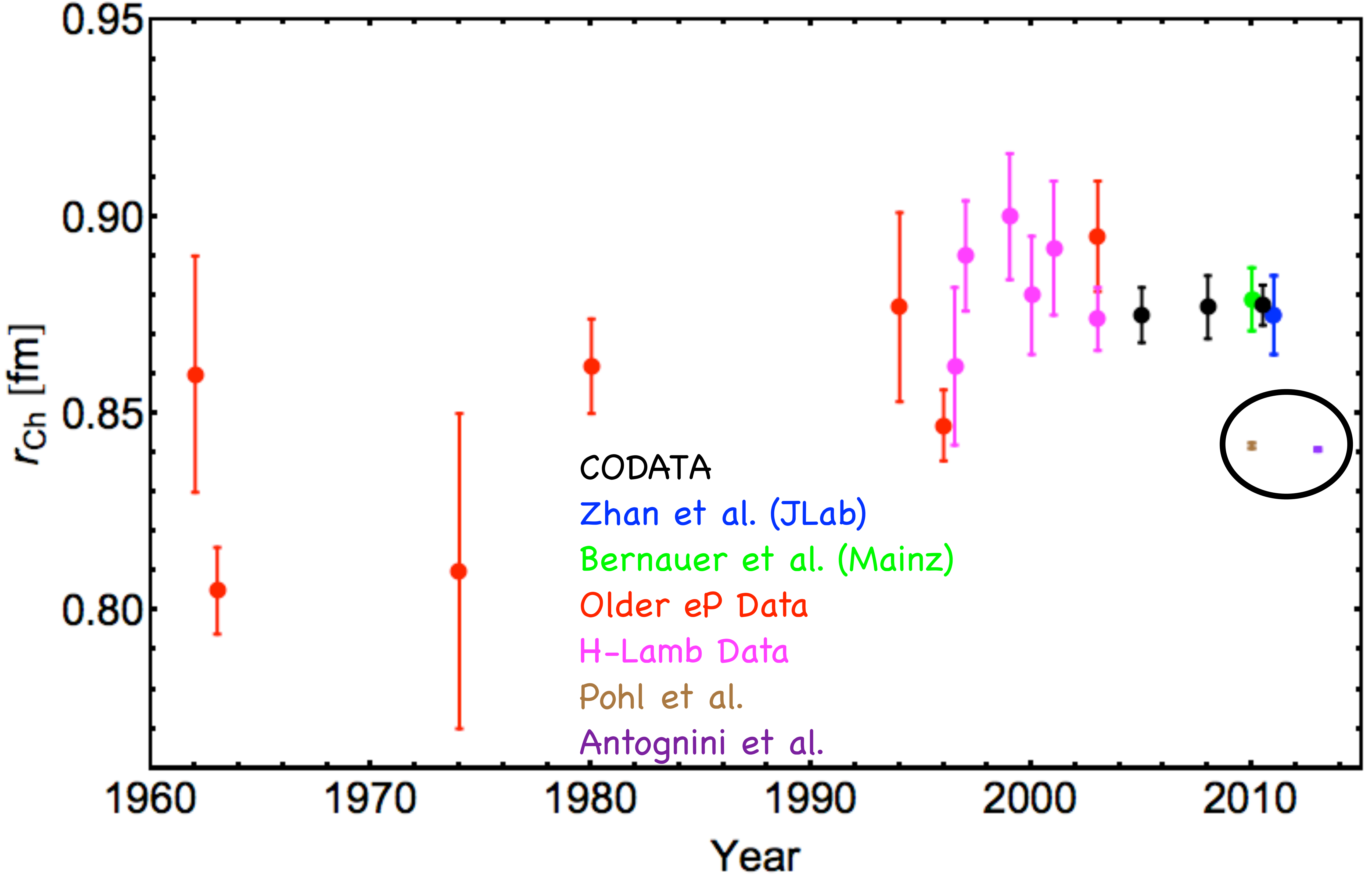

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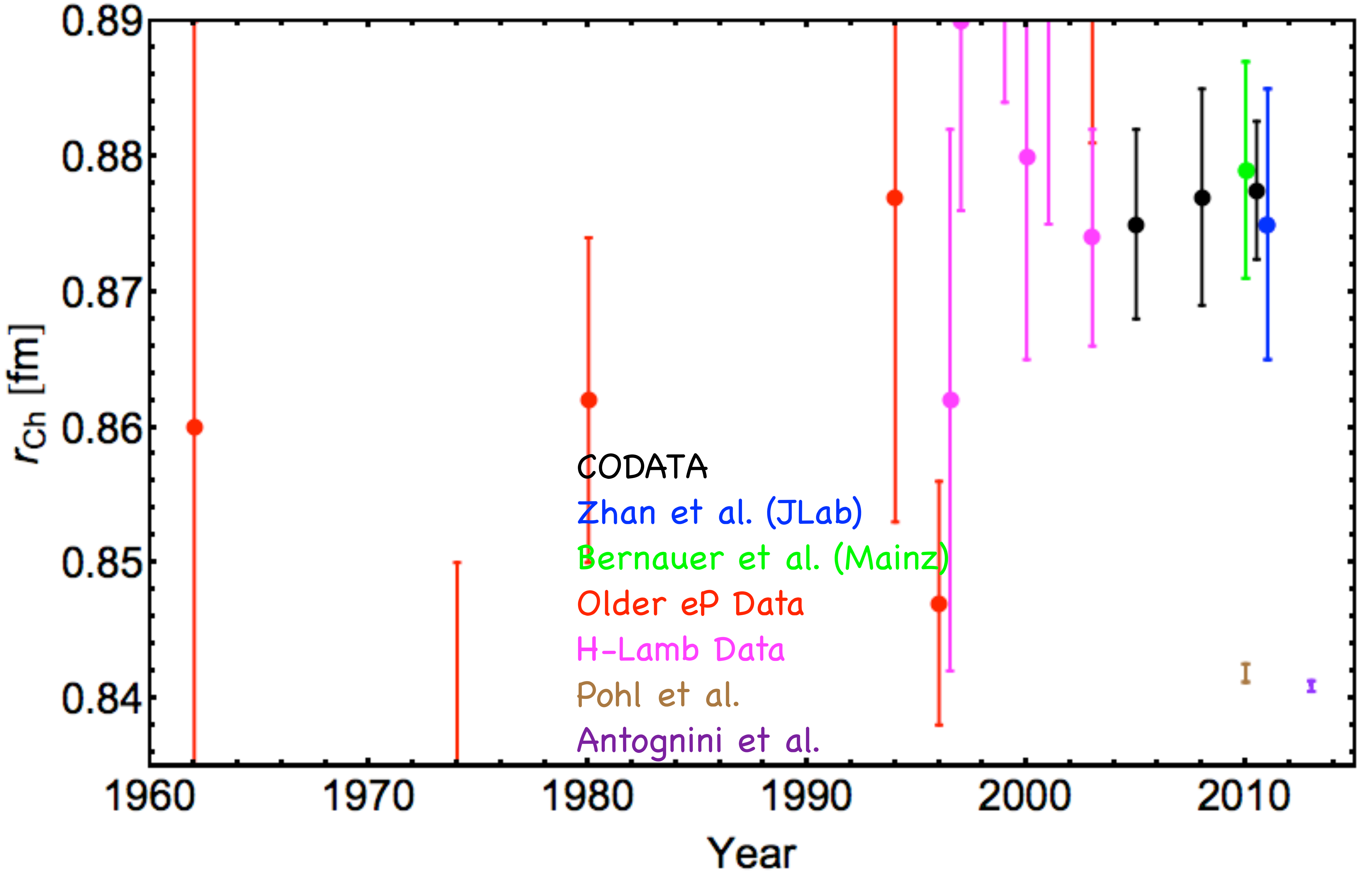
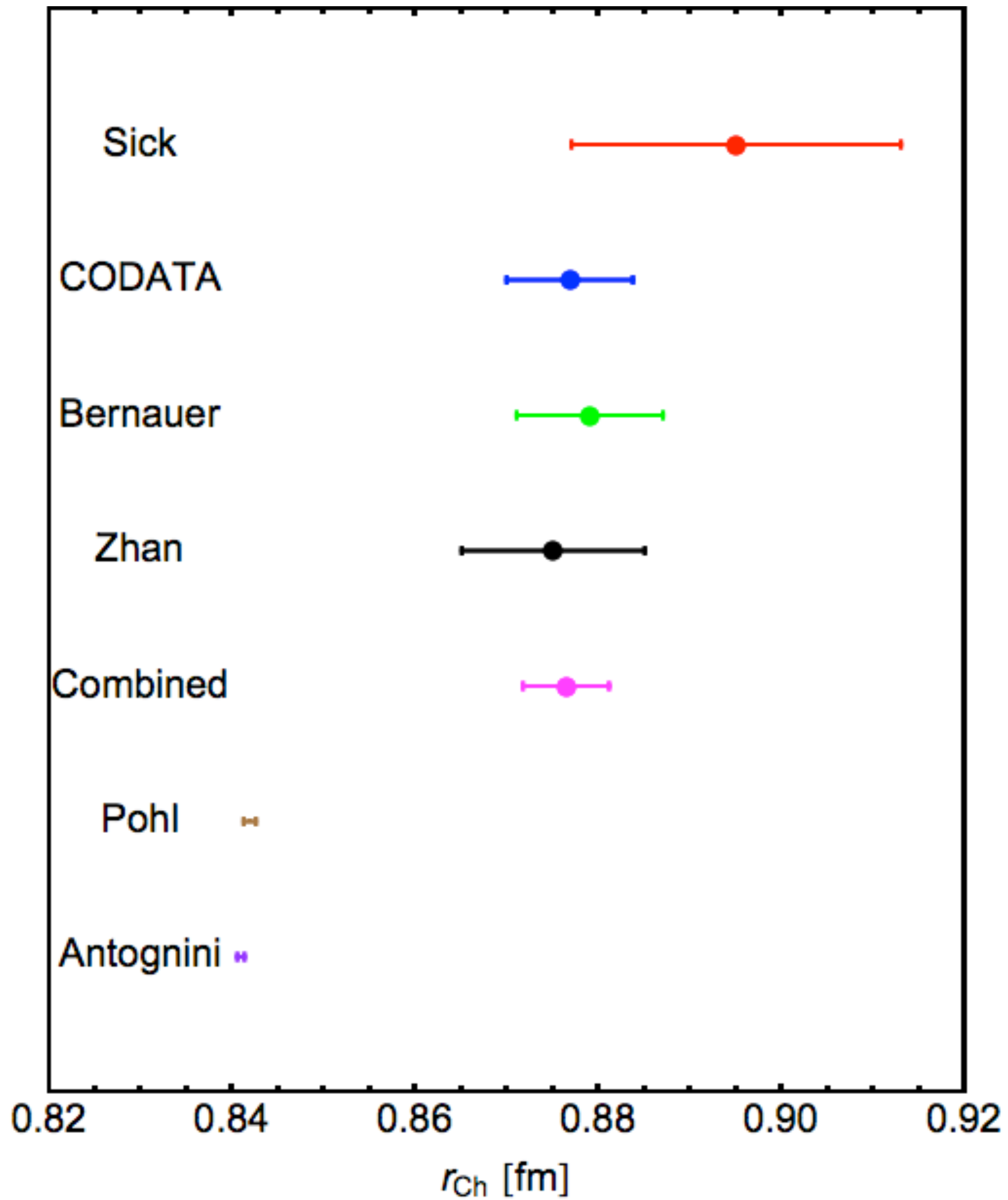


Proton Radius Puzzle

Muonic hydrogen disagrees with atomic physics and electron scattering determinations of slope of FF at $Q^2 = 0$

#	Extraction	$\langle r_E \rangle^2$ [fm]
1	Sick	0.895±0.018
2	CODATA	0.8768±0.0069
3	Mainz	0.879±0.008
4	This Work	0.875±0.010
5	Combined 2-4	0.8764±0.0047
6	Pohl	0.84184 ± 0.00067
7	Antognini	0.84087 ± 0.00039



Proton R

Muonic hydrog ctron
scattering dete

#	Extraction
1	Sick
2	CODATA
3	Mainz
4	This Work
5	Combined 2-4
6	Pohl
7	Antognini

Huh?

Muonic Hydrogen: Radius 4% below previous best value

Proton 11-12% smaller (volume), 11-12% denser than previously believed

Particle Data Group:

"Most measurements of the radius of the proton involve electron-proton interactions, and most of the more recent values agree with one another... However, a measurement using muonic hydrogen finds **r**p = 0.84184(67) fm, which is eight times more precise and seven standard deviations (using the CODATA 10 error) from the electronic results... Until the difference between the **ep** and μ**p** values is understood, it does not make much sense to average all the values together. For the present, we stick with the less precise (and provisionally suspect) CODATA 2010 value. **It is up to workers in this field to solve this puzzle.**"

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Directly related to the strength of QCD in the non perturbative region.

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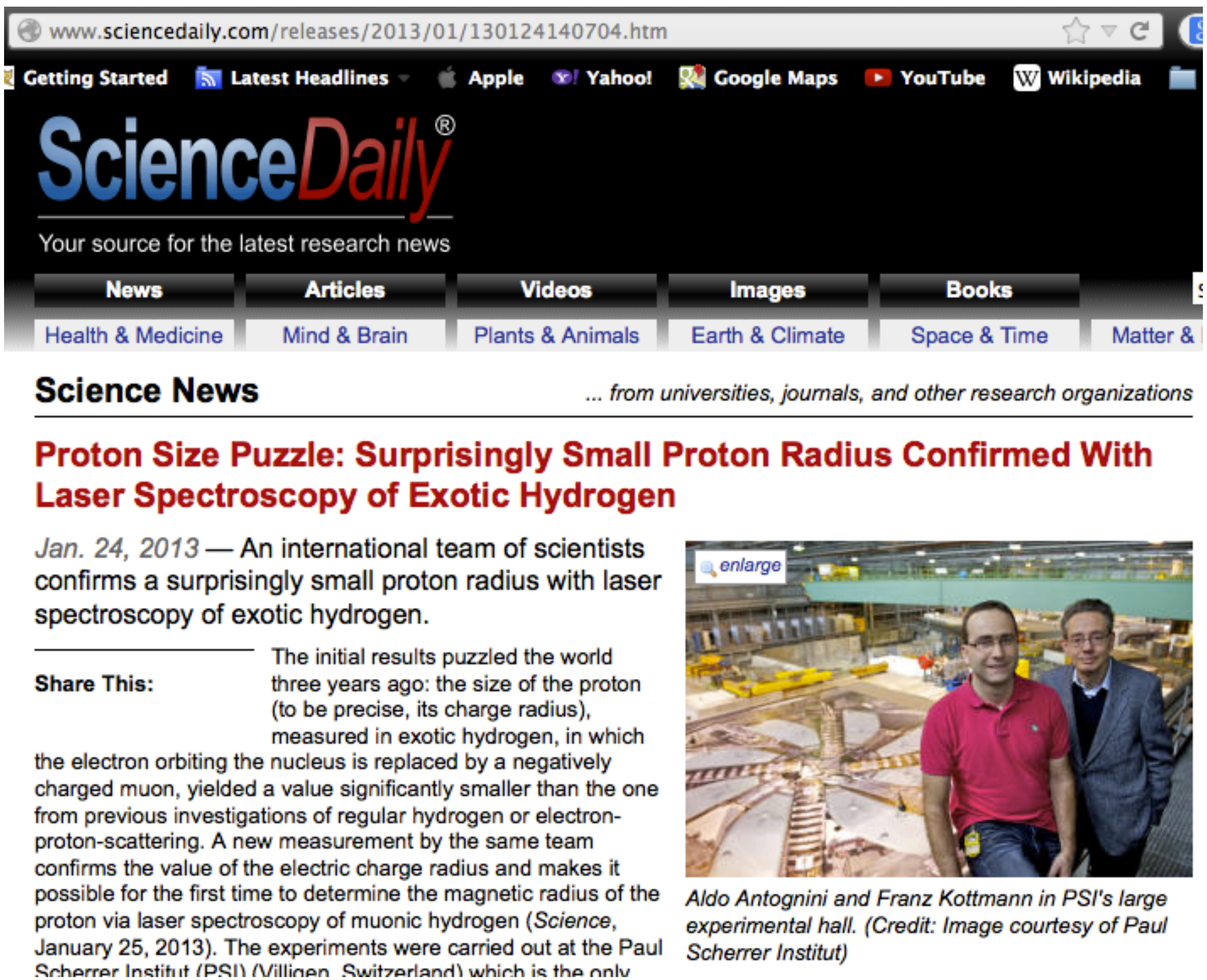
Directly related to the strength of QCD in the non perturbative region.

Which would be really important if we actually knew how to extract "strength of QCD" in the non perturbative region.

Executive Summary

- The size of the proton determined with muons is different from the size determined with electrons.
- We don't know why.
- The Puzzle is attracting a lot of attention.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Proton Size Puzzle: Surprisingly Small Proton Radius Confirmed With Laser Spectroscopy of Exotic Hydrogen

Jan. 24, 2013 — An international team of scientists confirms a surprisingly small proton radius with laser spectroscopy of exotic hydrogen.

Share This:

The initial results puzzled the world three years ago: the size of the proton (to be precise, its charge radius), measured in exotic hydrogen, in which the electron orbiting the nucleus is replaced by a negatively charged muon, yielded a value significantly smaller than the one from previous investigations of regular hydrogen or electron-proton-scattering. A new measurement by the same team confirms the value of the electric charge radius and makes it possible for the first time to determine the magnetic radius of the proton via laser spectroscopy of muonic hydrogen (*Science*, January 25, 2013). The experiments were carried out at the Paul Scherrer Institut (PSI) (Villigen, Switzerland) which is the only

enlarge

Aldo Antognini and Franz Kottmann in PSI's large experimental hall. (Credit: Image courtesy of Paul Scherrer Institut)

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Shrinking proton puzzle persists in new measurement

19:00 24 January 2013 by Lisa Gro

A puzzle at the heart of the atom refu
measurement yet of the proton's radiu
smaller than the laws of physics dema
debated for two years.

The latest finding deepens the need f
explanation, to account for the incons
hole is deeper now," says Gerald Mill
Seattle, who was not involved in the r

The saga of the proton radius began i
Pohl at the Max Planck Institute of Qu
determined the width of the fuzzy ball
smaller than had been assumed.

Previous teams had inferred the proto
measure directly, by studying how ele
uses the simplest atom, hydrogen, wh
proton. A quirk of quantum mechanics

www.sciencenews.org/view/generic/id/347775/description/Protons_radius_revised_downward

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Proton's radius revised downward

Surprise measurement may point to new physics

By Andrew Grant
Web edition: January 24, 2013
Print edition: February 23, 2013; Vol.183 #4 (p. 8)

A+ A-

Only in physics can a few quintillionths of a meter be cause for uneasy
excitement. A new measurement finds that the proton is about 4 percent
smaller than previous experiments suggest. The study, published in the
25 issue of *Science*, has physicists cautiously optimistic that the discrepa
between experiments will lead to the discovery of new particles or forces

ww.redorbit.com/news/science/1112770740/physics-conundrum-due-to-conflicting-proton-meas

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Does Size Matter? Protons May Be Smaller Than Previously Thought

January 25, 2013

arstechnica.com/science/2013/01/hydrogen-made-with-muons-reveals-proton-size-conundrum/

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ars technica

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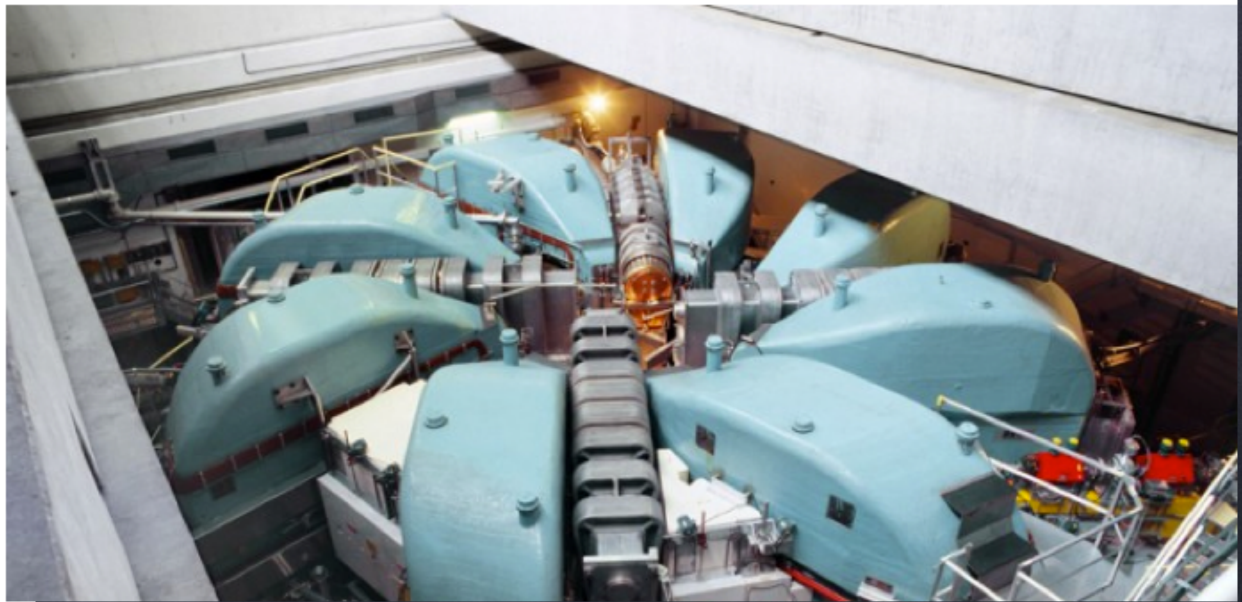
SCIENTIFIC METHOD / SCIENCE & EXPLORATI

Hydrogen made with muons reveals proton size conundrum

A measurement that's off by 7 standard deviations may hint at new physics.

by **John Timmer** - Jan 24 2013, 2:01pm EST

PHYSICAL SCIENCES



phys.org/news/2013-01-physicists-surprisingly-small-proton-radius.html

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Physicists confirm surprisingly s

Jan 24, 2013

International team of physicists confirms surprisingly small proton
spectroscopy of exotic hydrogen. The initial results puzzled the w
the size of the proton (to be precise, its charge radius), measured
which the electron orbiting the nucleus is replaced by a negatively
yielded a value significantly smaller than the one from previous in
hydrogen or electron-proton-scattering. A new measurement by th
the value of the electric charge radius and makes it possible for th
determine the magnetic radius of the proton via laser spectroscop

The experiments were carried out at the Paul Scherrer Institut (PS
Switzerland) which is the only research institute in the world provi
amount of muons. The international collaboration included the Ma
Quantum Optics (MPQ) in Garching near Munich, the Swiss Fede
Technology ETH Zurich, the University of Fribourg, the Institut für

www.huffingtonpost.com/2013/01/25/proton-radius-smaller-physicists-new-research_n_2549576.h

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Proton Radius Is Smaller Than Physicists Had Thought, New Research Shows

Posted: 01/25/2013 8:20 am EST

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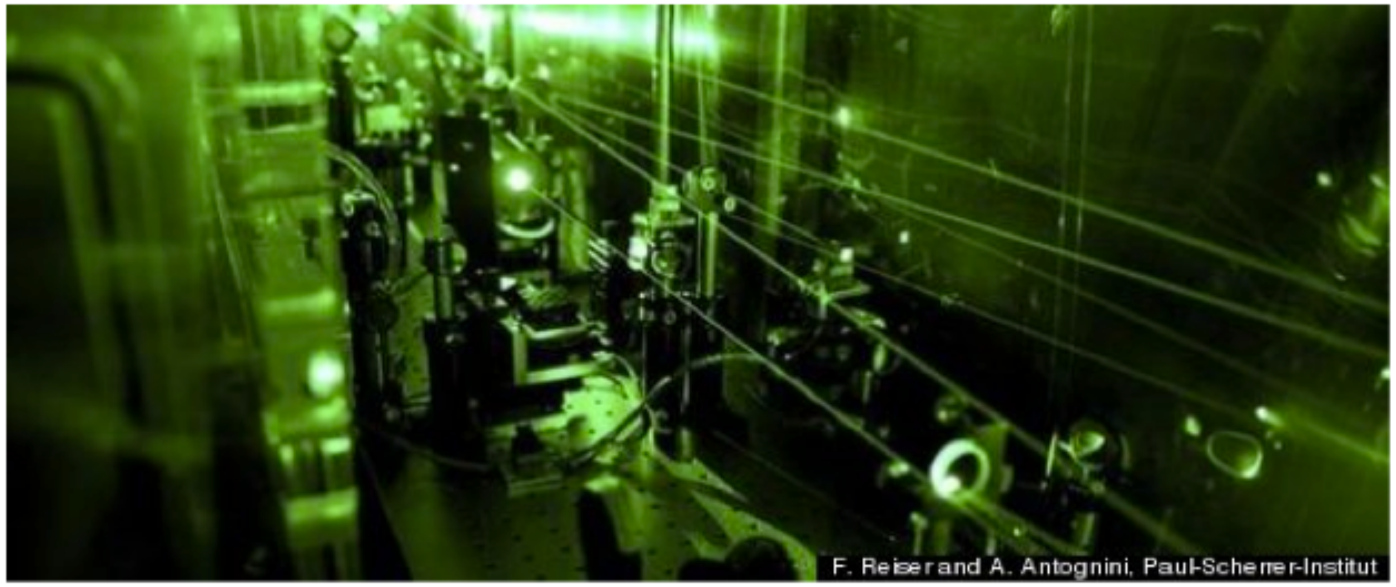
F. Reiser and A. Antognini, Paul-Scherrer-Institut

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By: Jesse Emspak, LiveScience Contributor
Published: 01/24/2013 03:02 PM EST on LiveScience

How many protons can dance on the head of a pin? The answer is nowhere near as straightforward as one may think — and it might offer new insights into one of the most well-tested theories in physics.

www.nature.com/news/shrunken-proton-baffles-scientists-1.12289

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NATURE | NEWS

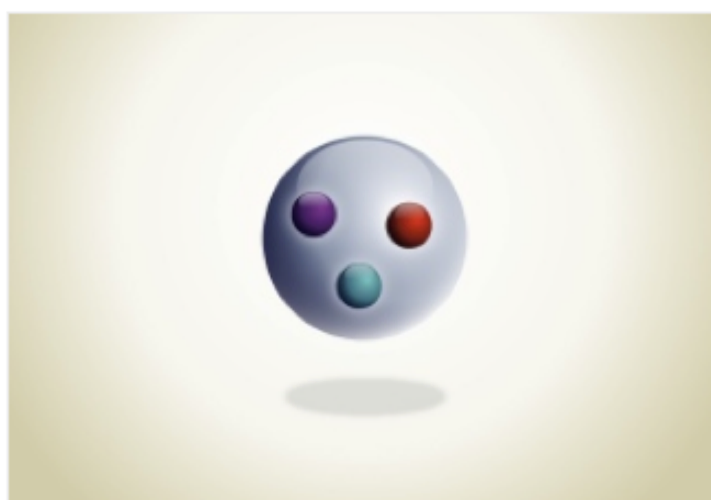
Shrunken proton baffles scientists

Researchers perplexed by conflicting measurements.

Geoff Brumfiel

24 January 2013

One of the Universe's most common particles has left physicists completely stumped. The proton, a fundamental constituent of the atomic nucleus, seems to be smaller than thought. And despite three years of careful analysis and reanalysis of numerous experiments, nobody can figure out why.



The proton's three quarks are (mostly) confined within a region 0.87 femtometres in radius — or is it 0.84?

WESLEY FERNANDES

An experiment published today in *Science*[1] only deepens the mystery, says Ingo Sick, a physicist at the University of Basel in Switzerland. "Many people have tried, but none has been successful at elucidating the discrepancy."

www.scientificamerican.com/article.cfm?id=shrunken-proton-baffles-scientists

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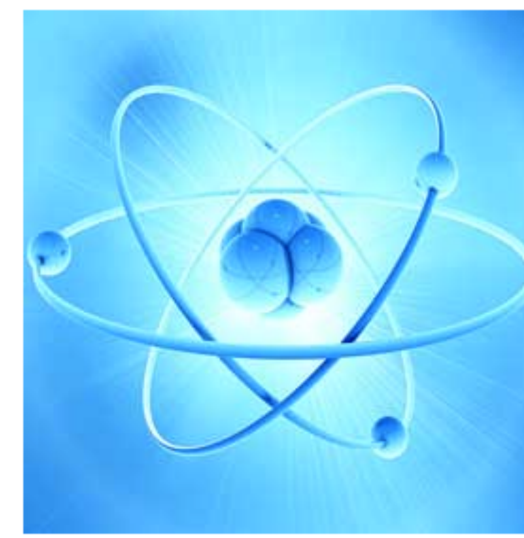
Shrunken Proton Baffles Scientists

Researchers are perplexed by conflicting measurements for one of the universe's most common particles

By Geoff Brumfiel and Nature magazine

One of the Universe's most common particles has left physicists completely stumped. The proton, a fundamental constituent of the atomic nucleus, seems to be smaller than thought. And despite three years of careful analysis and reanalysis of numerous experiments, nobody can figure out why.



Pin it

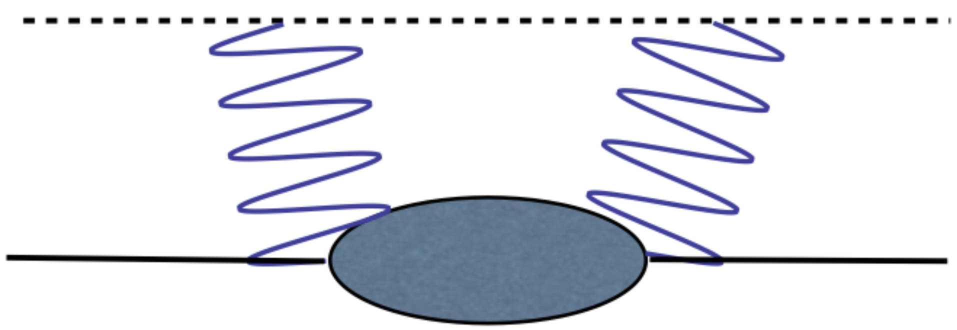
The proton's three quarks are (mostly) confined within a region 0.87 femtometers wide — or is it 0.84?

Image: Flickr/Argonne National Laboratory

An experiment published today in *Science* only deepens the mystery, says Ingo Sick, a physicist at the University of Basel in Switzerland. "Many people have tried, but none has been successful at elucidating the discrepancy."

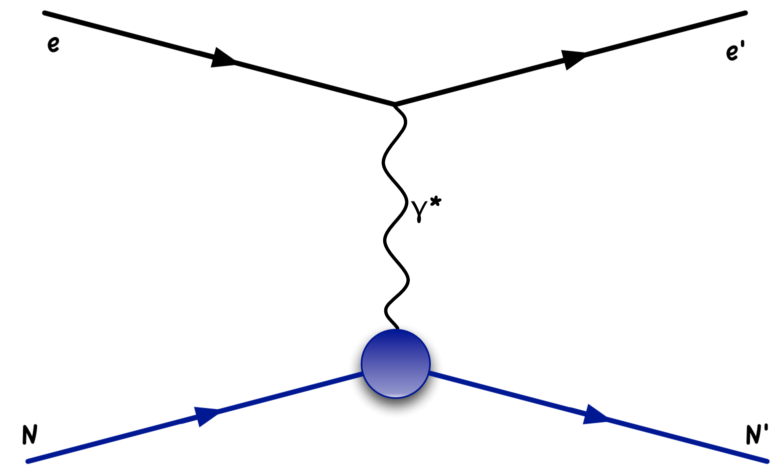
The (surviving) Theory Explanations

- Novel Hadronic Physics



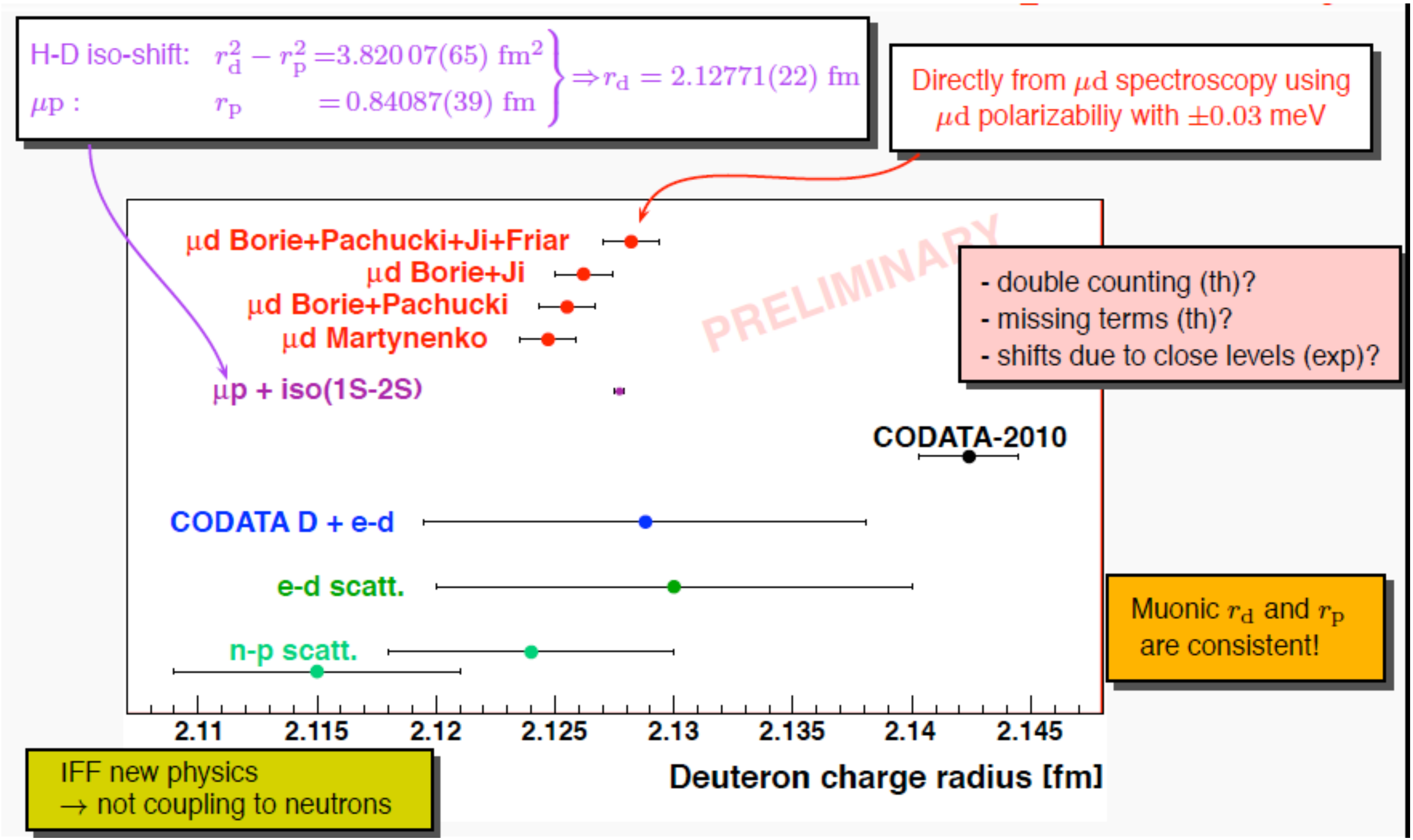
- There is a polarizibility correction that depends on m_l^4, affecting muons but not electrons
- Part of the correction is not (strongly) constrained by data or theory; it might resolve puzzle.

- Novel Beyond Standard Model Physics



- There could be unknown particles that couple μp but not ep, in addition to γ
- Evading impacts on known physics requires 2 new particles for cancellations

μD Lamb Shift



Slide Courtesy A. Antognini

The Scattering Experiments

The scattering knowledge is dominated by the recent Bernauer et al Mainz experiment, plus (our) JLab polarization data and older cross section experiments.

Extracting a radius from the scattering data has been a challenge.

Until recently, all analyses ignored most of the following issues:

- Coulomb corrections
- Two-photon exchange
- Truncation offsets
- World data fits vs radius fits
- Model dependence
- Treatment of systematic uncertainties
- Fits with unphysical poles
- Including time-like data to ``improve'' radius

The good modern analyses tend to have fewer issues.

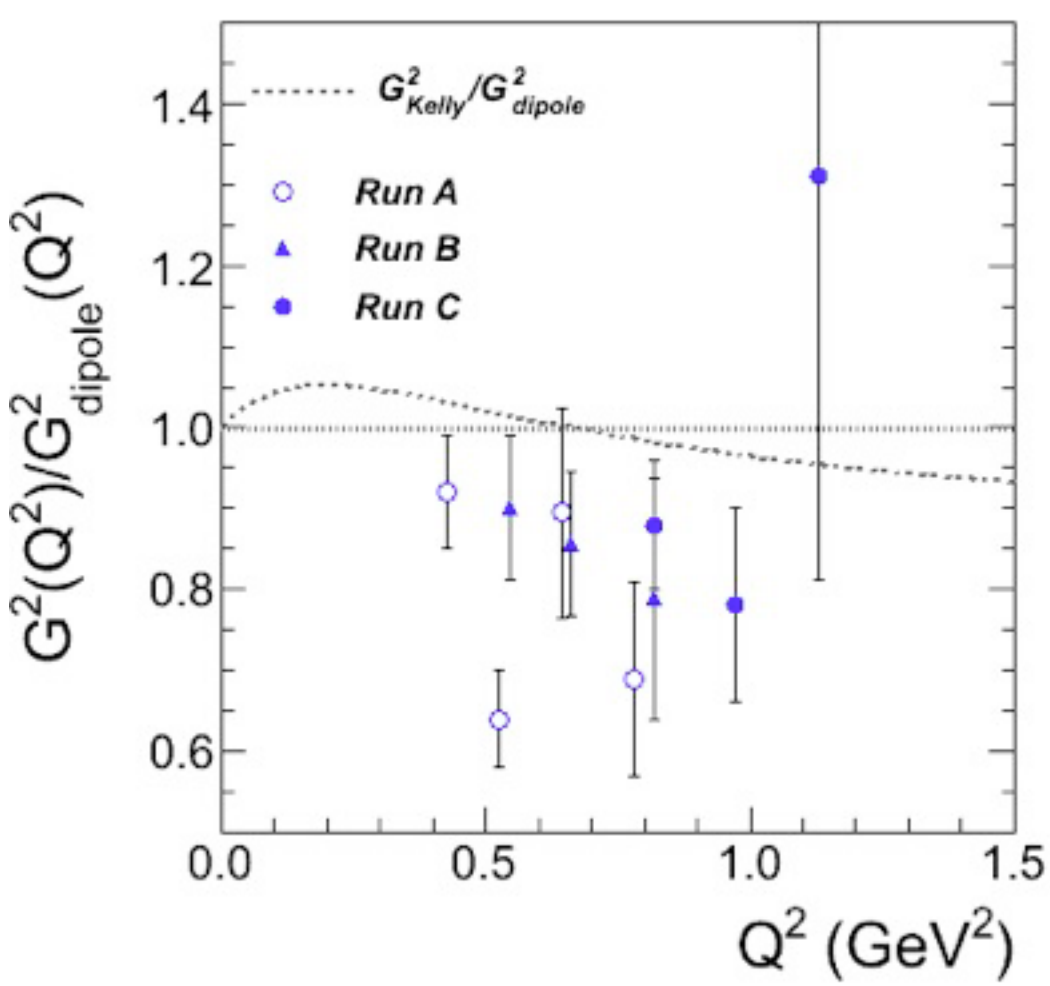
Where to now?

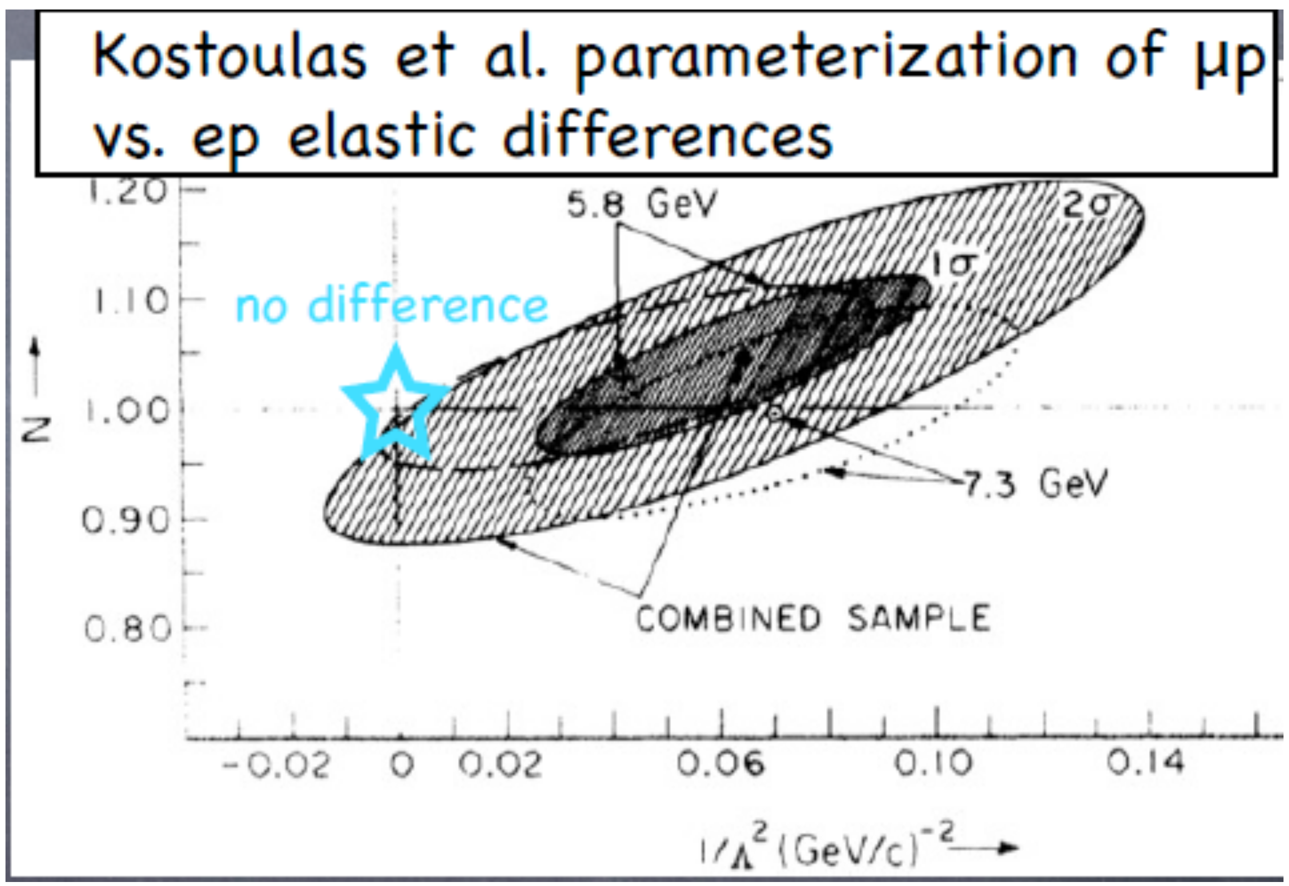
μP Scattering

- Why μp scattering?
- It should be relatively easy to determine if the μp and ep scattering are consistent or different, and, if different, if the difference is from novel physics or 2γ mechanisms:
  - If the μp and ep radii really differ by 4%, then the form factor slopes differ by 8% and cross section slopes differ by 16% - this should be relatively easy to measure.
  - 2γ affects e^+ and e^-, or μ^+ and μ^-, with opposite sign - the cross section difference is twice the 2γ correction, the average is the cross section without a 2γ effect. It is hard to get e^+ at electron machines, but relatively easy to get μ^+ and μ^- at PSI.

e-μ Universality

In the 1970s / 1980s, there were several experiments that tested whether the ep and μp interactions are equal. They found no convincing differences, once the μp data are renormalized up about 10%. In light of the proton ``radius'' puzzle, the experiments are not as good as one would like.





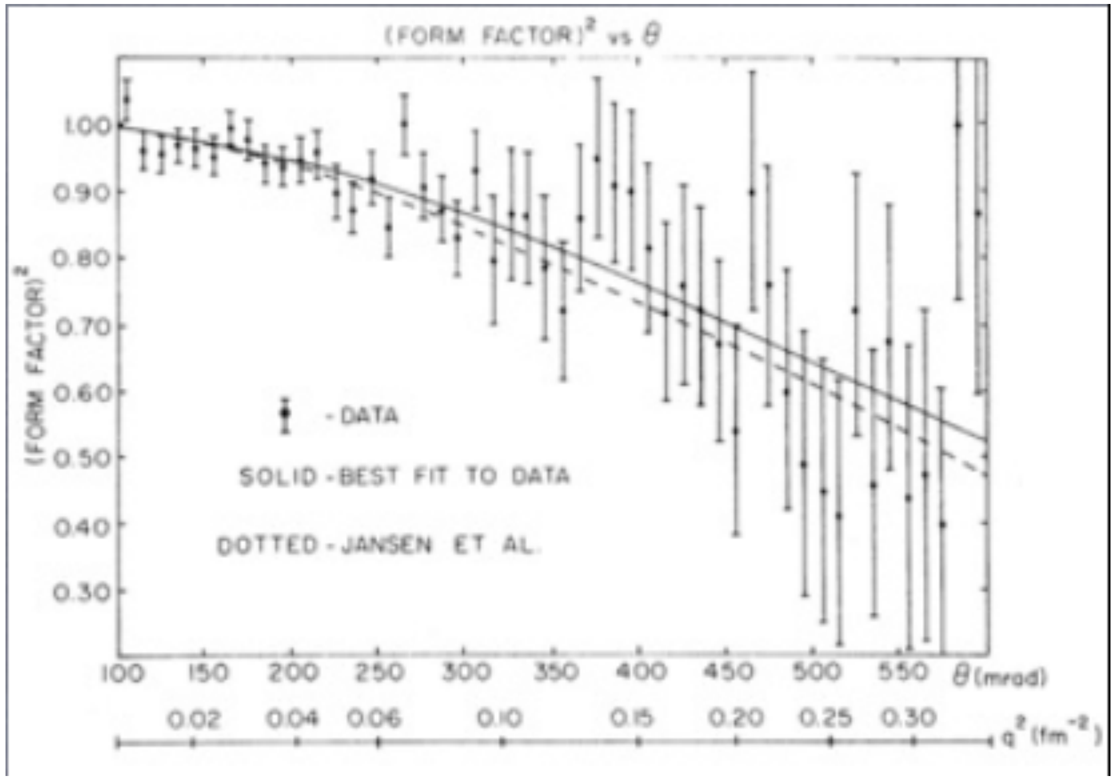
e-μ Universality

The 12C radius was determined with ep scattering and μC atoms.

The results agree:
Cardman et al. eC: 2.472 ± 0.015 fm
Offermann et al. eC: 2.478 ± 0.009 fm
Schaller et al. μC X rays: 2.4715 ± 0.016 fm

Ruckstuhl et al. μC X rays: 2.483 ± 0.002 fm

Sanford et al. μC elastic: 2.32 ± 0.13 fm



Perhaps carbon is right, e's and μ's are the same.

Perhaps hydrogen is right, e's and μ's are different.

Perhaps both are right - opposite effects for proton and neutron cancel with carbon.
But perhaps the carbon radius is insensitive to the nucleon radius, and μd or μHe would be a better choice.

MUSE - PSI R12-01.1 Technique

r_p (fm)	ep	μp
atom	0.877±0.007	0.841±0.0004
scattering	0.875±0.006	?

$d\sigma/d\Omega(Q^2)$ = counts / ($\Delta\Omega$ N_{beam} $N_{target/area}$ x corrections x efficiencies)

$$\left[\frac{d\sigma}{d\Omega}\right] = \left[\frac{d\sigma}{d\Omega}\right]_{ns} \times \left[\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + \left(2\tau - \frac{m^2}{M^2}\right) G_M^2(Q^2) \frac{\eta}{1-\eta}\right]$$

$$\left[\frac{d\sigma}{d\Omega}\right]_{ns} = \frac{\alpha^2}{4E^2} \frac{1-\eta}{\eta^2} \frac{1/d}{\left[1 + \frac{2Ed}{M} \sin^2\frac{\theta}{2} + \frac{E}{M}(1-d)\right]} \qquad d = \frac{\left[1 - \frac{m^2}{E^2}\right]^{1/2}}{\left[1 - \frac{m^2}{E'^2}\right]^{1/2}}$$

$$\eta = Q^2/4EE'$$

following Preedom & Tegen, PRC36, 2466 (1987)

The MUon proton Scattering Experiment collaboration (MUSE):

R. Gilman (Contact person),[1] E.J. Downie (Spokesperson),[2] G. Ron (Spokesperson),[3] A. Afanasev,[2] J. Arrington,[4] O. Ates,[5] F. Benmokhtar,[6] J. Bernauer,[7] E. Brash,[8] W. J. Briscoe,[2] K. Deiters,[9] J. Diefenbach,[5] C. Djalali,[10] B. Dongwi,[5] L. El Fassi,[1] S. Gilad,[7] K. Gnanvo,[11] R. Gothe,[12] K. Hafidi,[4] D. Higinbotham,[13] R. Holt,[4] Y. Ilieva,[12] H. Jiang,[12] M. Kohl,[5] G. Kumbartzki,[1] J. Lichtenstadt,[14] A. Liyanage,[5] N. Liyanage,[11] M. Meziane,[15] Z.-E. Meziani,[16] D. Middleton,[17] P. Monaghan,[5] K. E. Myers,[1] C. Perdrisat,[18] E. Piasetzsky,[14] V. Punjabi,[19] R. Ransome,[1] D. Reggiani,[9] P. Reimer,[4] A. Richter,[20] A. Sarty,[21] E. Schulte,[16] Y. Shamai,[22] N. Sparveris,[16] S. Strauch,[12] V. Sulkosky,[7] A.S. Tadepalli,[1] M. Taragin,[23] and L. Weinstein[24]

How do we Resolve the Radius Puzzle

- New data needed to test that the e and μ are really different, and the implications of novel BSM and hadronic physics
  - BSM: scattering modified for Q^2 up to m^2_{BSM} , enhanced parity violation
  - Hadronic: enhanced 2γ exchange effects
- Experiments include:
  - Redoing atomic hydrogen
  - Light muonic atoms for radius comparison in heavier systems
  - Redoing electron scattering at lower Q^2
  - Muon scattering on nuclei.
  - **Muon scattering!**

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MUSE tests these

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Possible next Gen.

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MUSE tests these

Possible next Gen.

Other planned Experiments

Experiment Overview

PSI πM1 channel

≈115, 153, 210 MeV/c mixed beams of $e^\pm$, $\mu^\pm$ and $\pi^\pm$

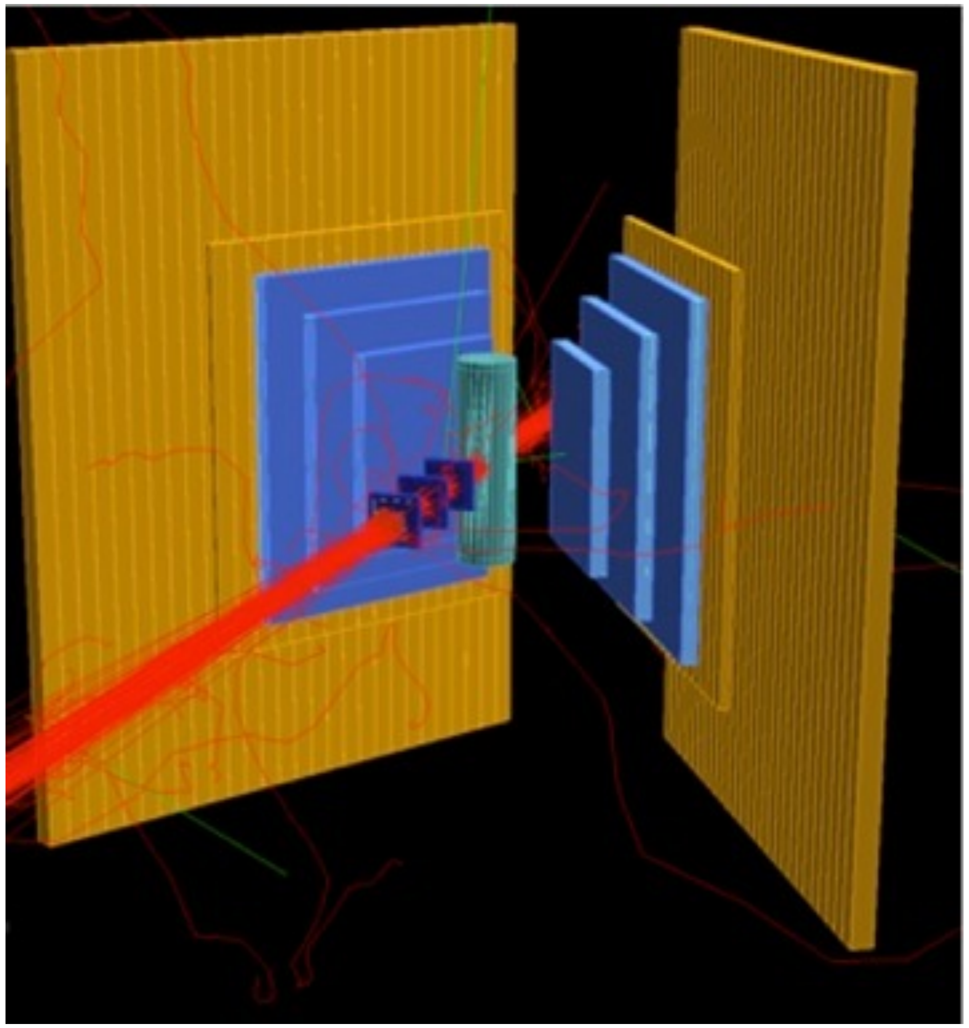
$\theta \approx 20^o - 100^o$

$Q^2 \approx 0.002 - 0.07\ \mathrm{GeV}^2$

About 5 MHz total beam flux, ≈2-15% μ's, 10-98% e's, 0-80% π's

Beam monitored with SciFi, ``quartz'' Cerenkov, GEMs

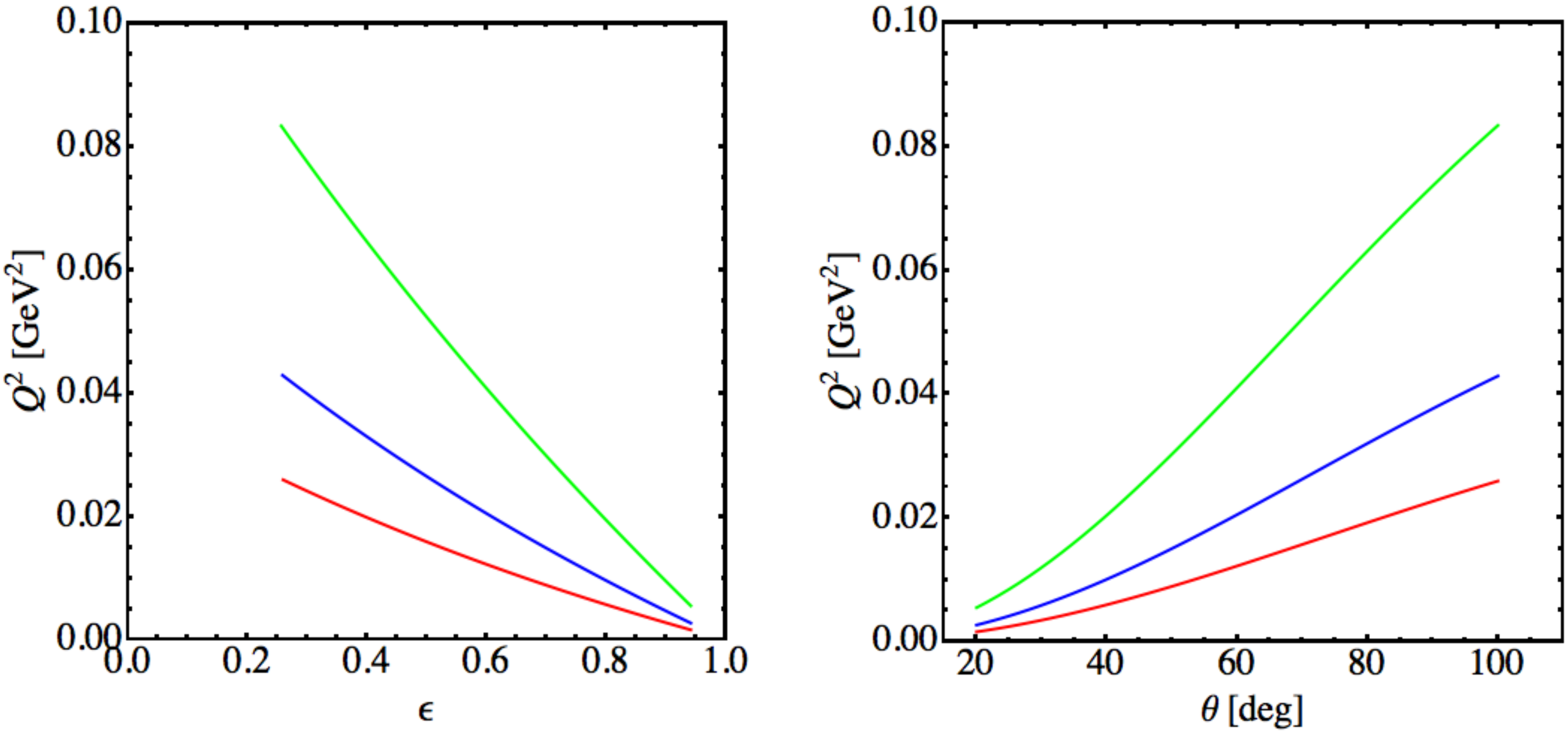
Scattered particles detected with wire chambers and scintillators



Not run like a normal cross section experiment - 7-8 orders of magnitude lower luminosity.

But there are some benefits: count every beam particle, no beam heating of target, low rates in detectors, ...

Experiment Overview



$\theta \approx 20^o - 100^o$

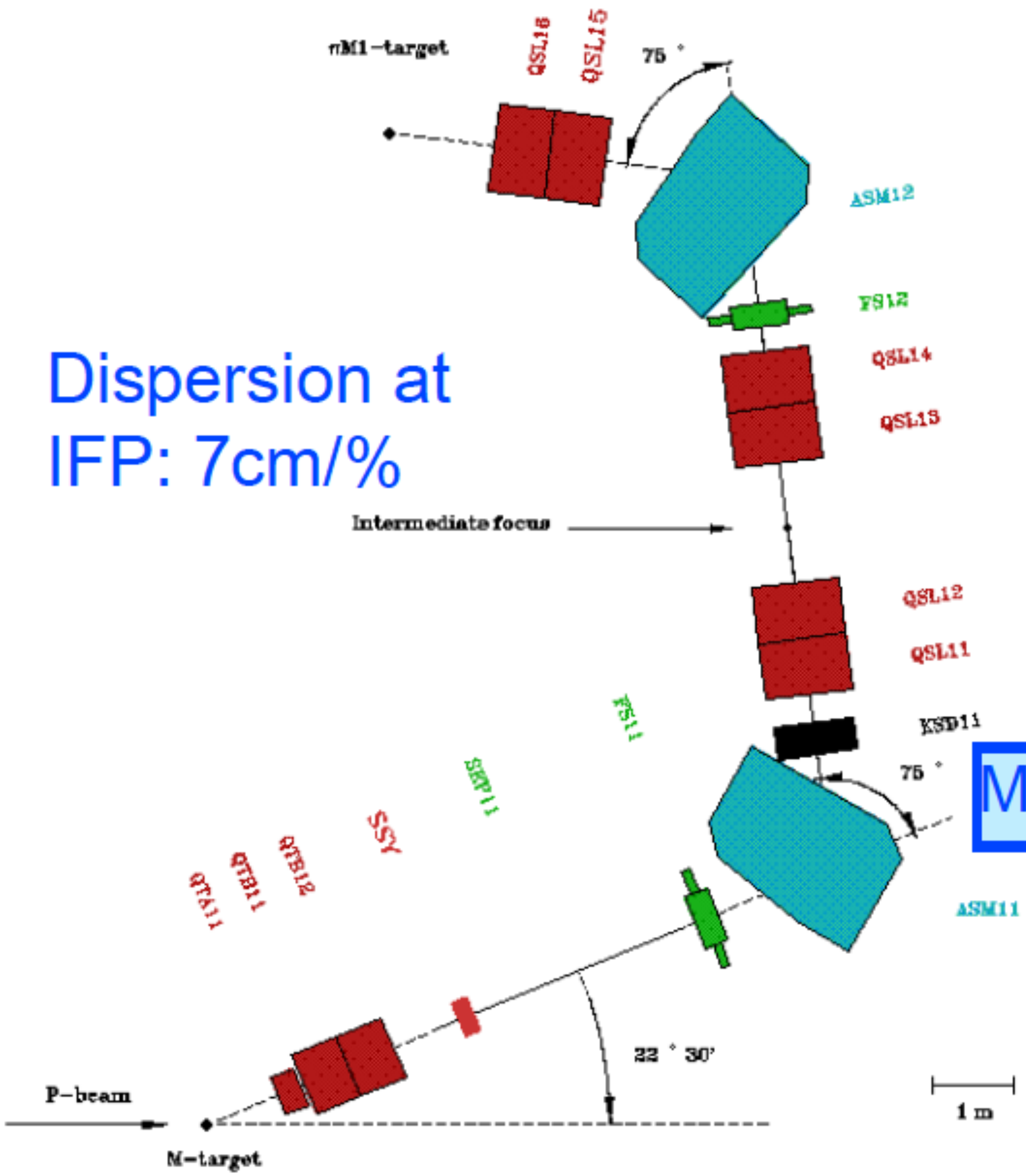
$Q^2 \approx 0.0015 - 0.08$ GeV^2

$\varepsilon \approx 0.256 - 0.94$

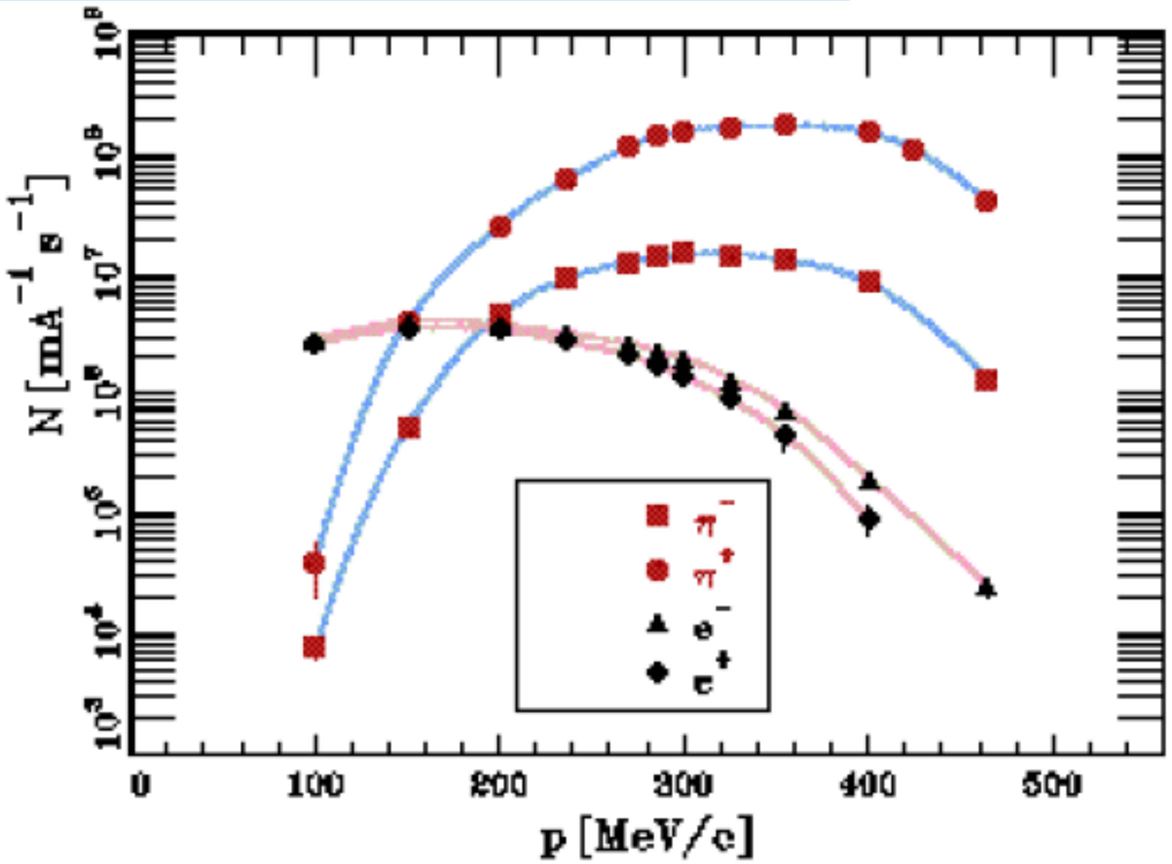
Essentially same coverage for all beam particles.

PSI πM1 Channel Characteristics

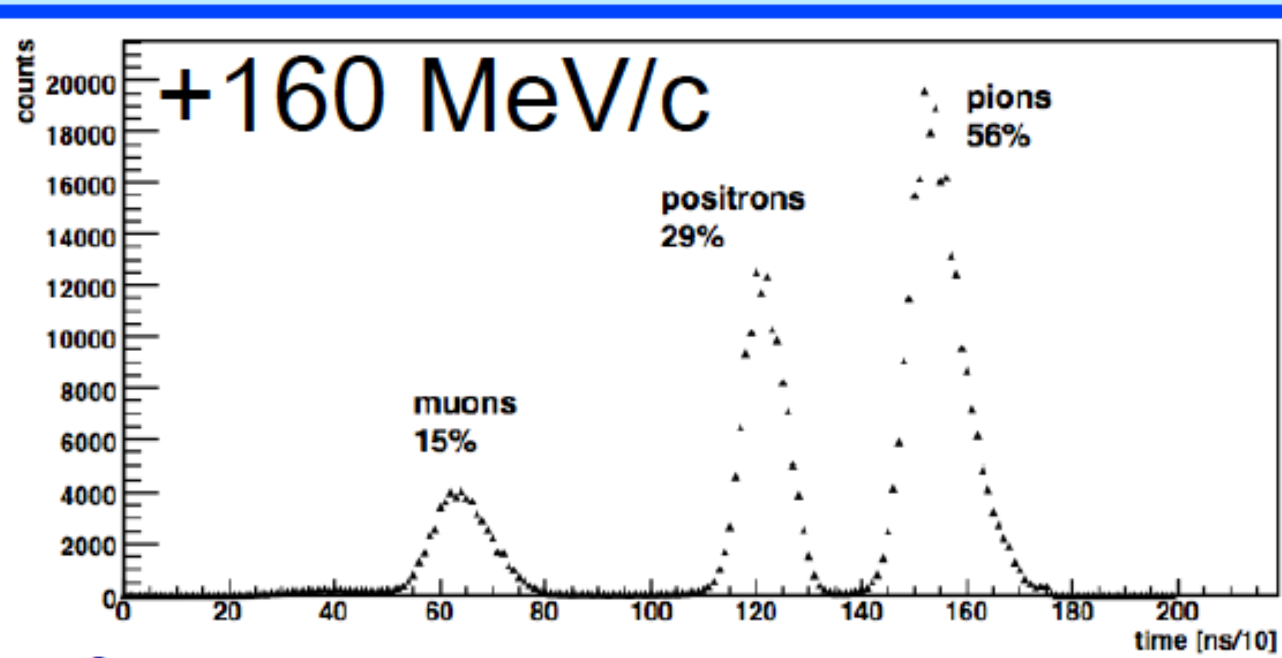
≈100 - 500 MeV/c mixed beam of μ's + e's + π's



Dispersion at IFP: 7cm/%

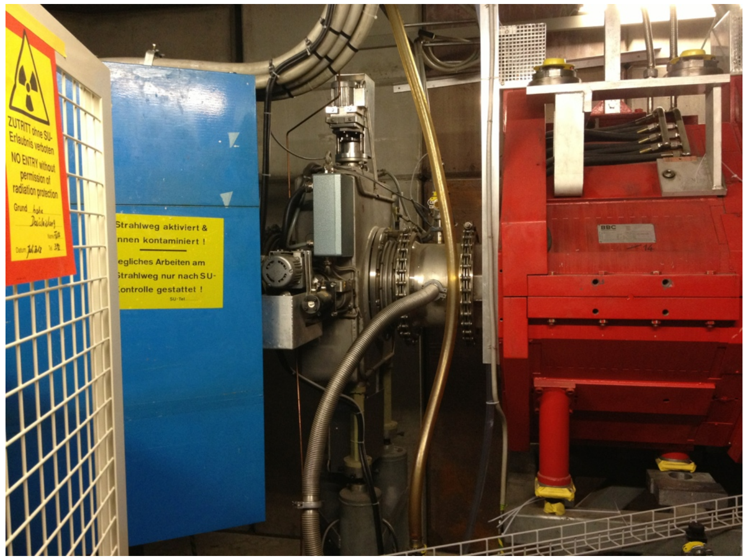


Momentum acceptance: 3% resolution: 0.1%

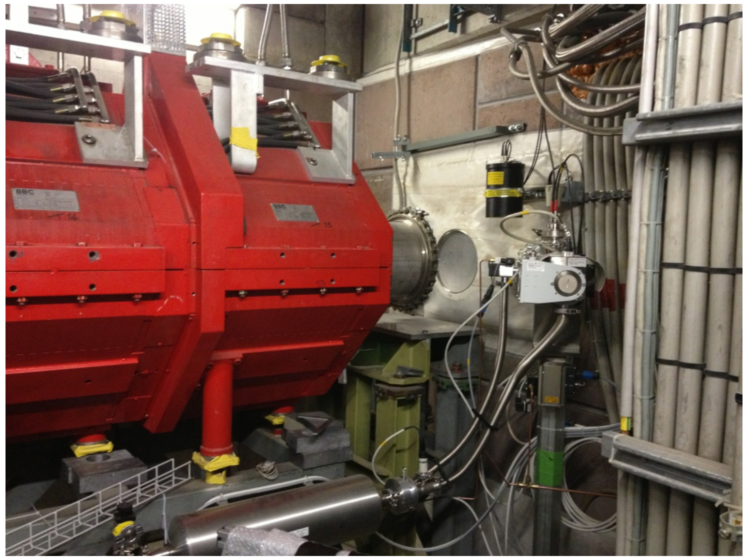


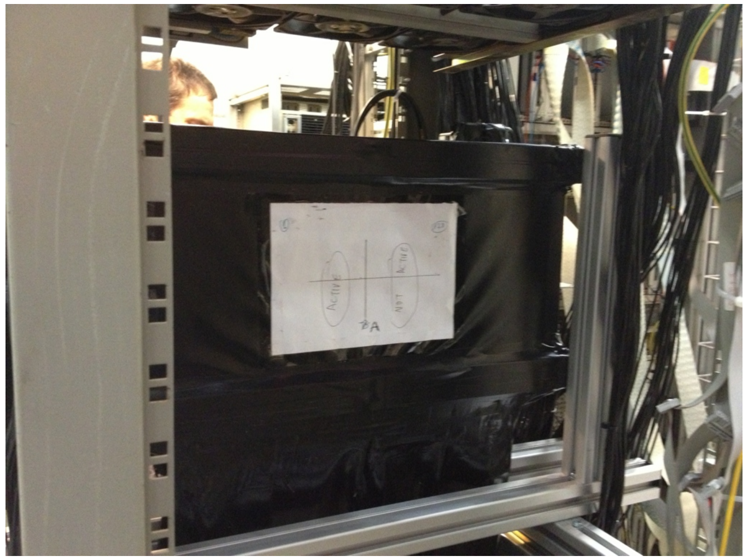
Beam spot (nominal): 1.5 cm X x 1 cm Y, 35 mr X' x 75 mr Y'

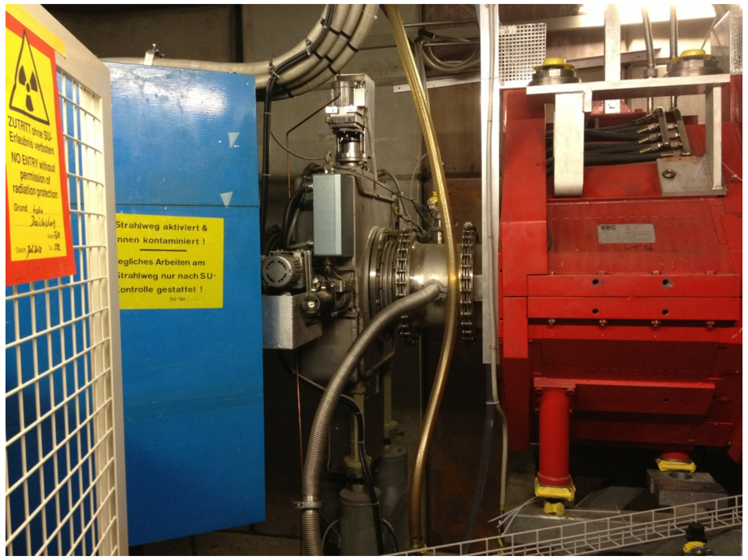
Spots from 0.7x0.9 cm^2 up to 16x10 cm^2, $\Delta p/p$ from 0.1-3.0%, used previously.

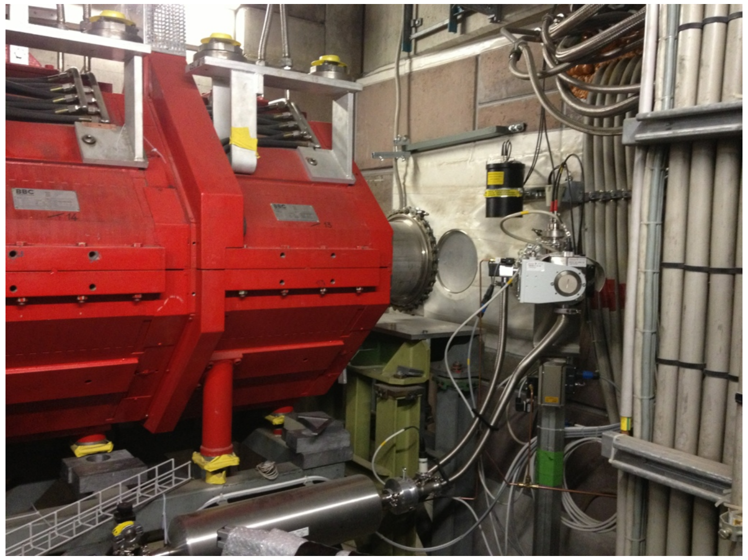


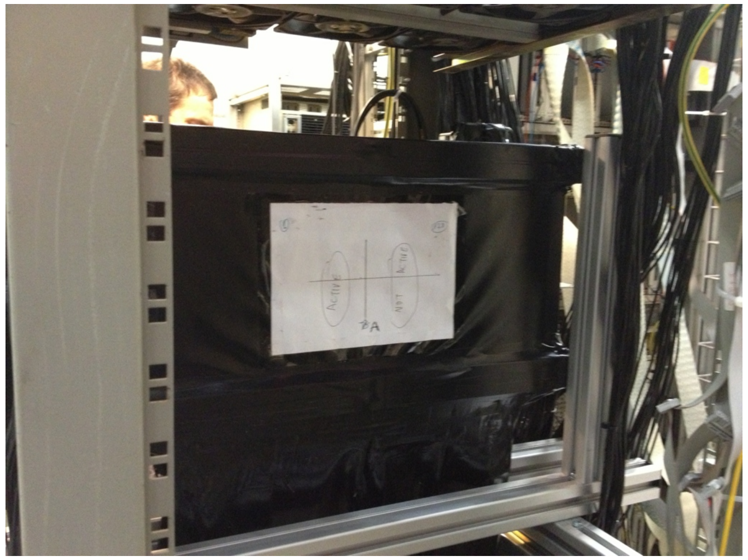
ZUTRITT ohne SU-Erlaubnis verboten
NO ENTRY without permission of radiation protection
Grund
Strahlweg aktiviert &
nnen kontaminiert !
egliches Arbeiten am
Strahlweg nur nach SU-
Kontrolle gestattet !
SU-Tel

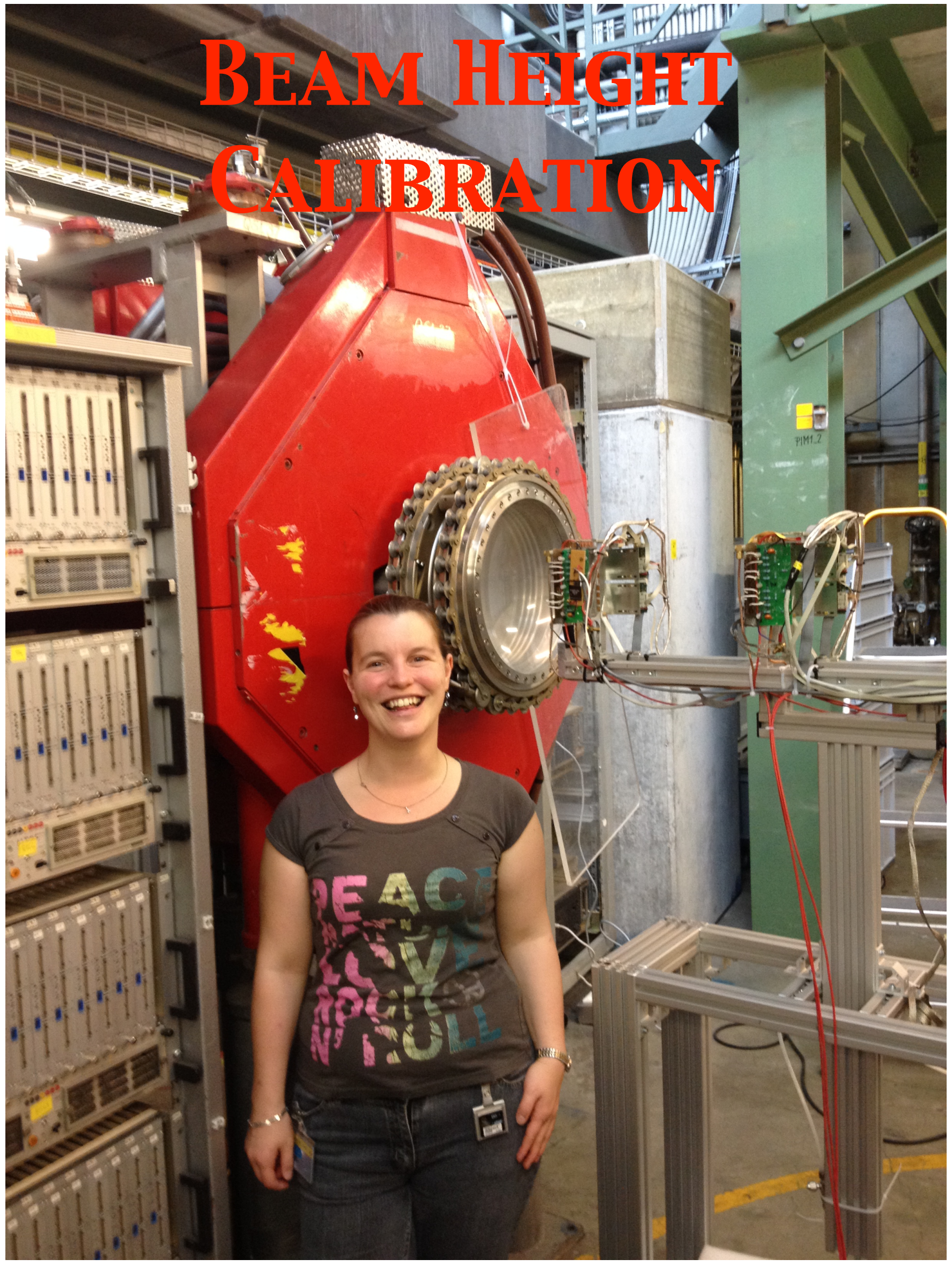




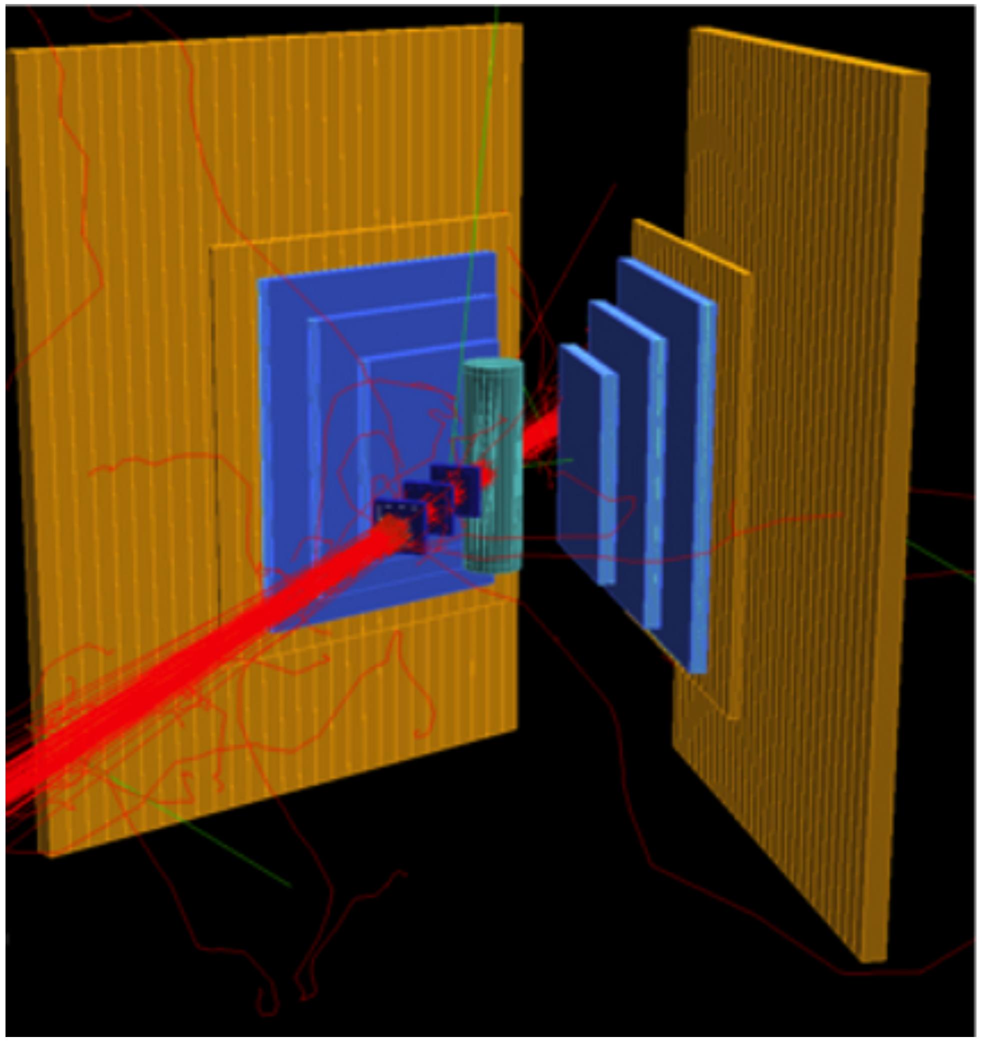


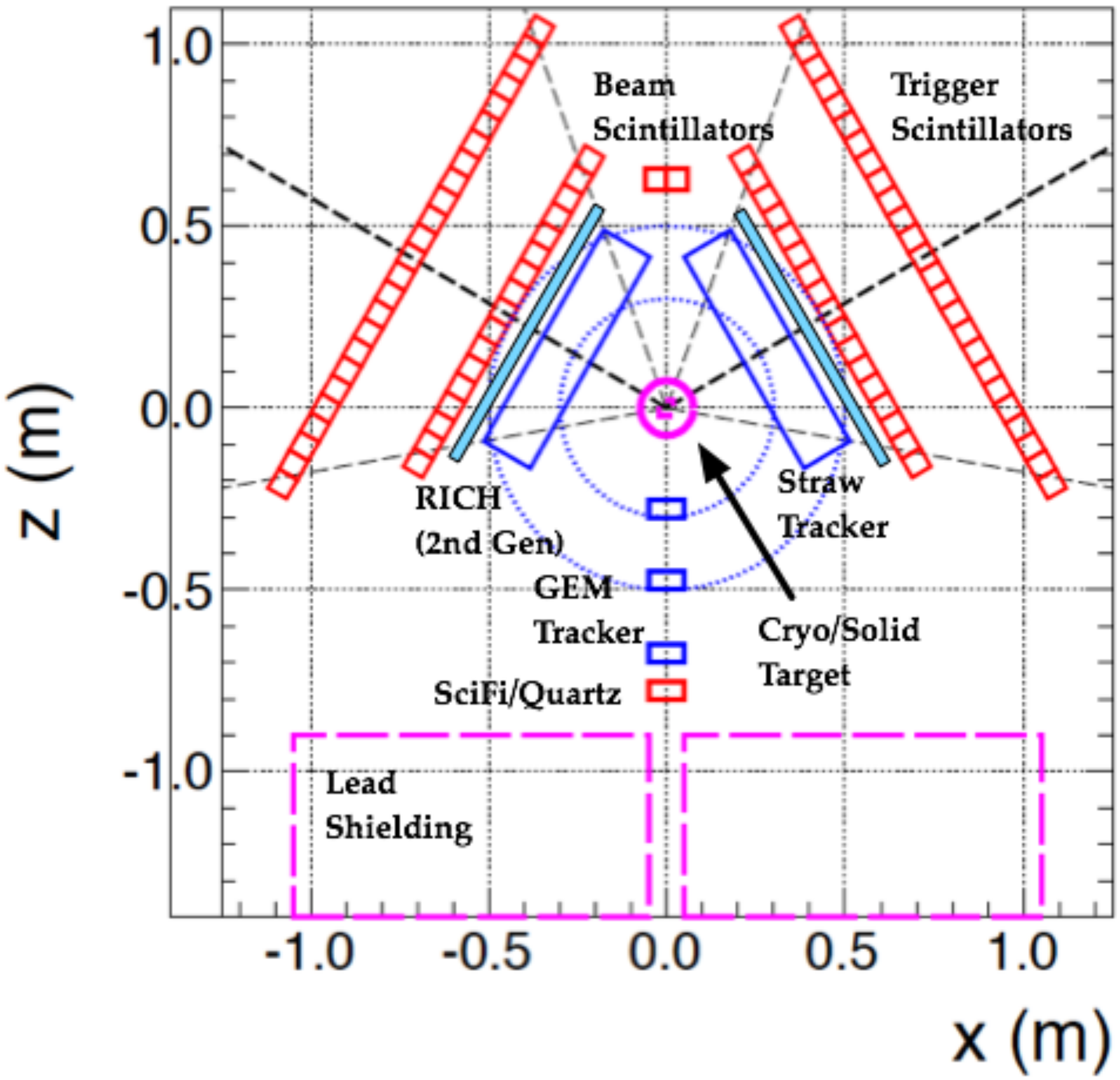





Beam Height
Calibration

Not your garden variety experiment





Low beam flux. → Large angle, non-magnetic detectors.

Secondary beam. → Tracking of beam particles to target.

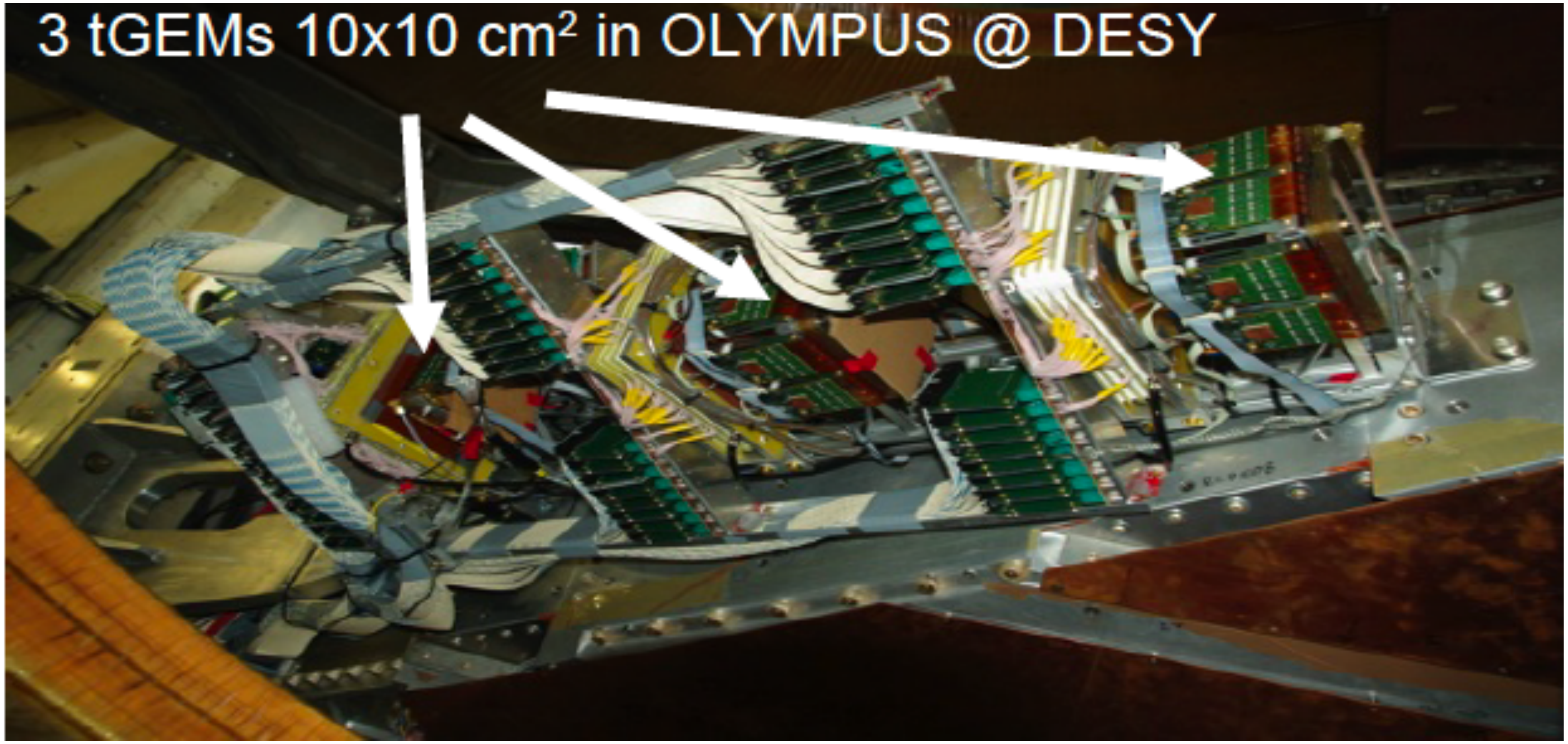
Mixed beam. → Identification of beam particle in trigger.

Detectors - SciFi

- Target
  - 1ns Timing for PID with Beam RF.
  - Beam flux normalization.
  - Position and Time correlation with GEMs.
- IFP
  - PID for triggering and position to determine momentum
- Design
  - 2mm fibers, double ended maPMT readout.

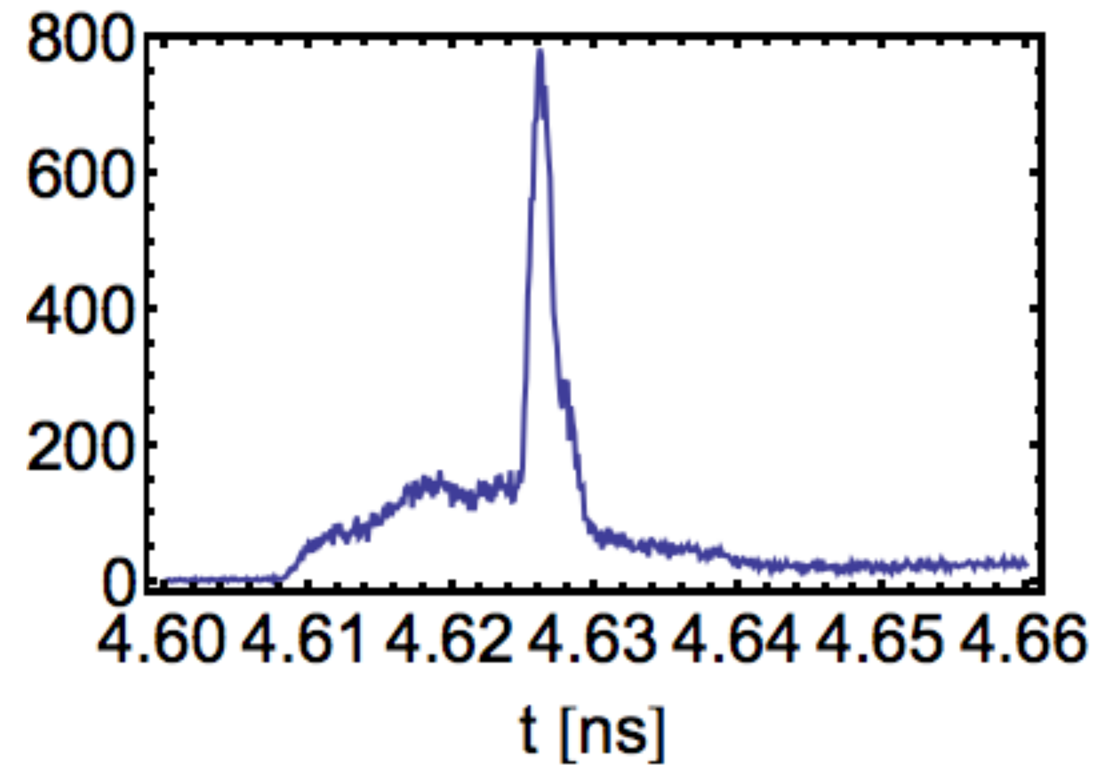
Detectors - GEMs

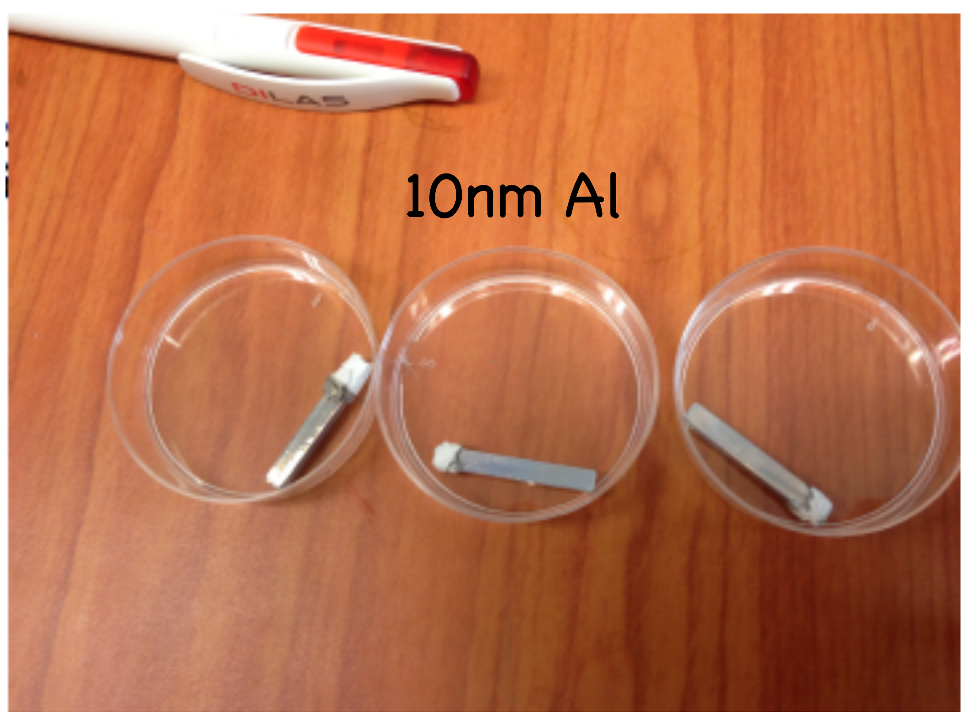
- Determine trajectory for scattering angle and Q^2.
- Third GEM rejects ghost tracks.
- Existing detector repurposed from OLYMPUS experiment @ DESY.



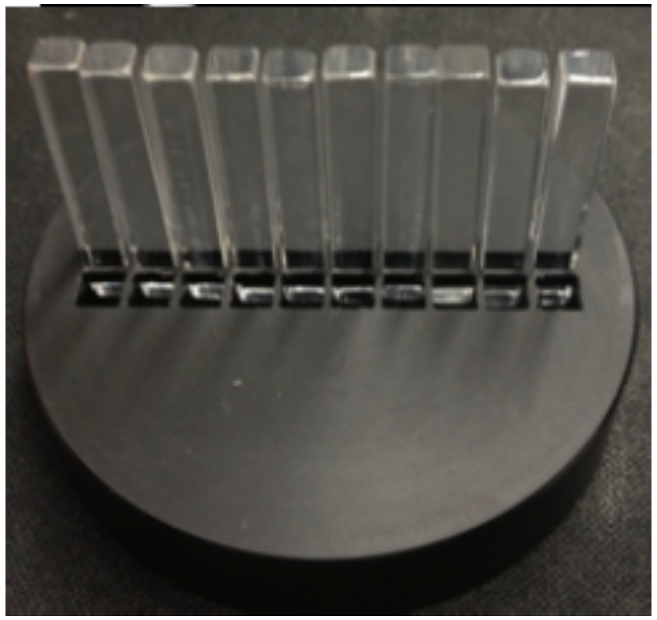
Detectors - "Quartz" Cerenkov

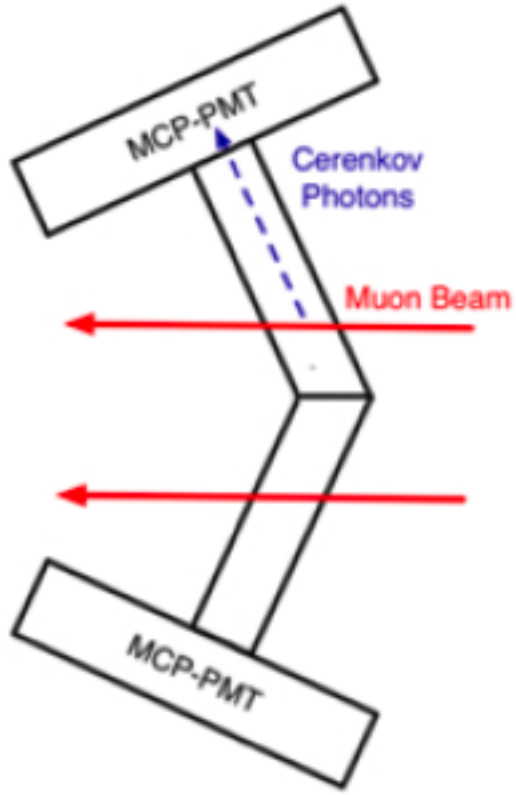
- Improve timing at target.
- Muon decay event rejection.
- Estimate 25-50ps resolution.
- Quartz bars angled at Cernekov angle -> better timing from prompt photons.
- Fast MCP-PMT photon detection.
- Likely to use Sapphire instead of Quartz (diamond is even better, but costly).





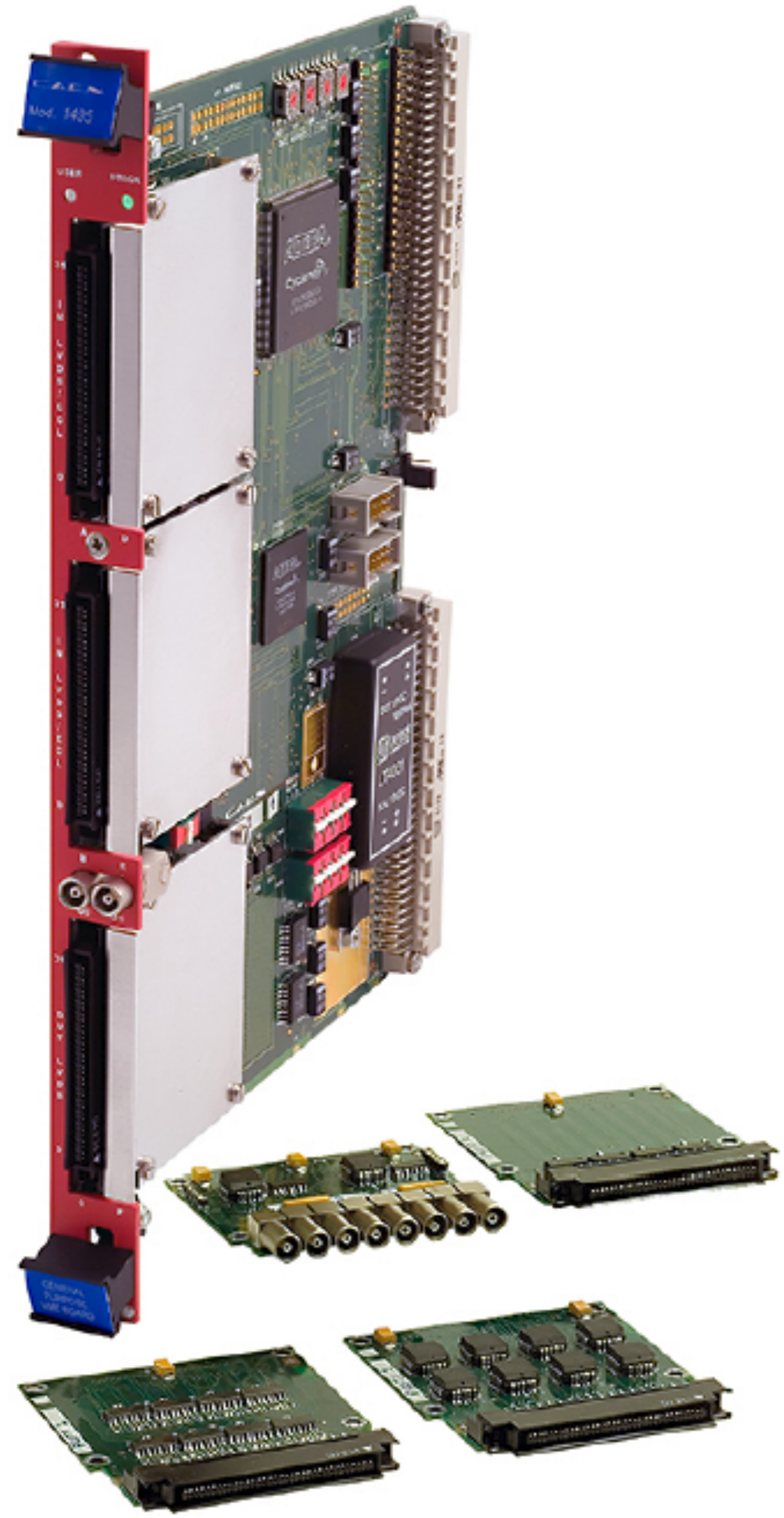
Quartz Bars





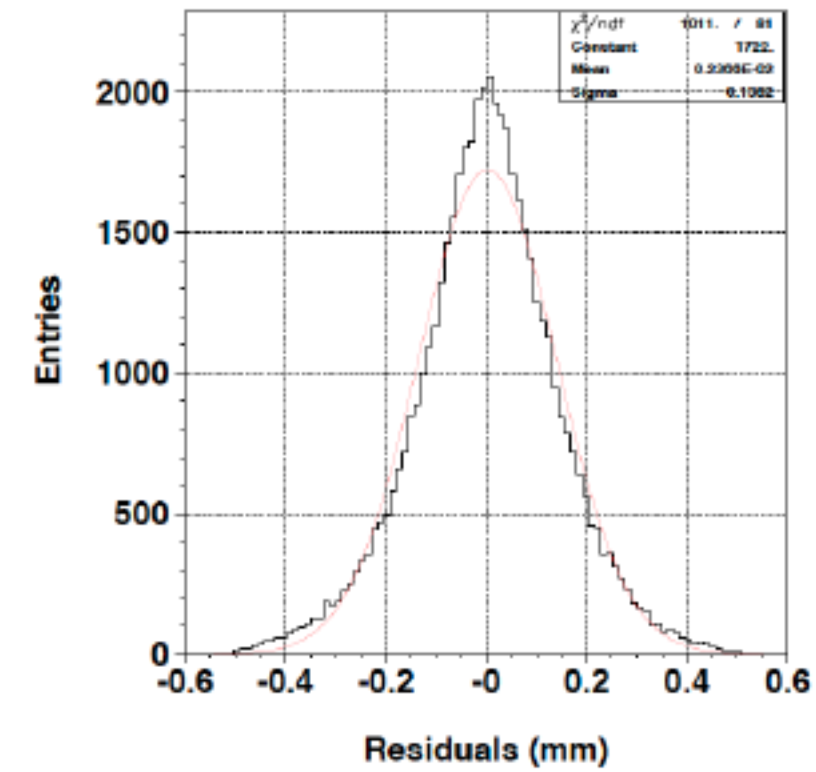
Trigger - Custom FPGA Design

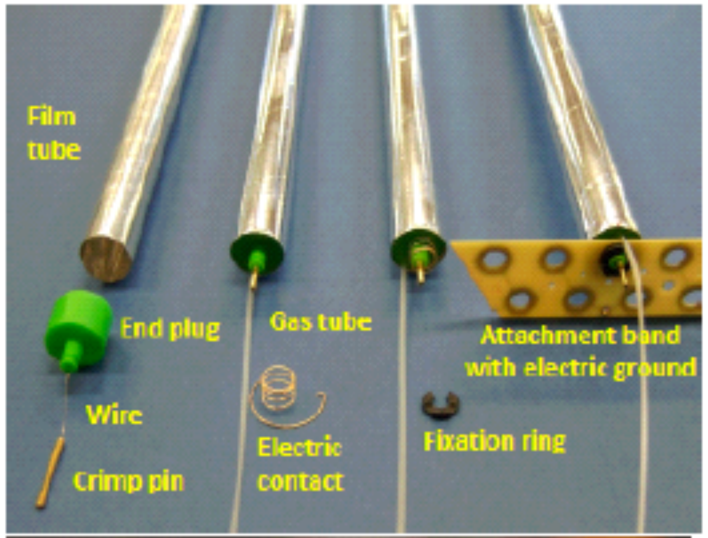
- Custom FPGA design for beam PID.
- SciFi + Beam RF + Cerenkov -> Beam PID
- Count particles and reject pions.
- Need 99.9% pion rejection efficiency.

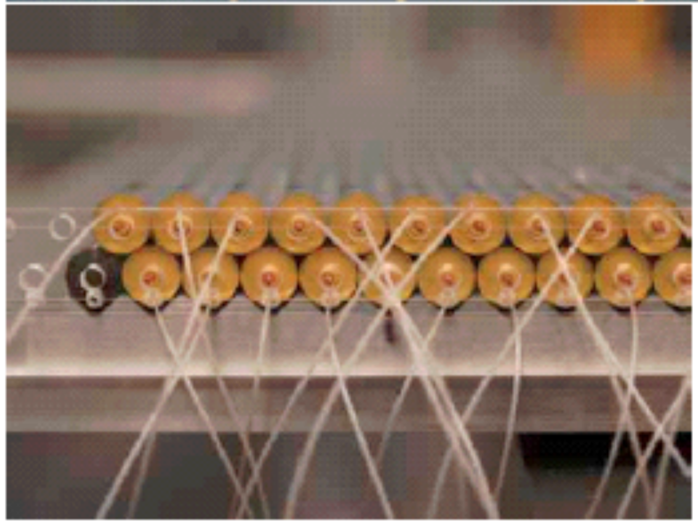


Detectors - Straw Tube Tracker

- Determine scattered particle trajectory with high efficiency and resolution.
- Design based on exiting PANDA design - 140um resolution expected.
- Thin walled (25um) over pressured (2 bar) straws.
- Directly coupled to fast readout boards.
- Calibrated relative to GEMs by rotating mount into beamline.
- ~3000 straws total.

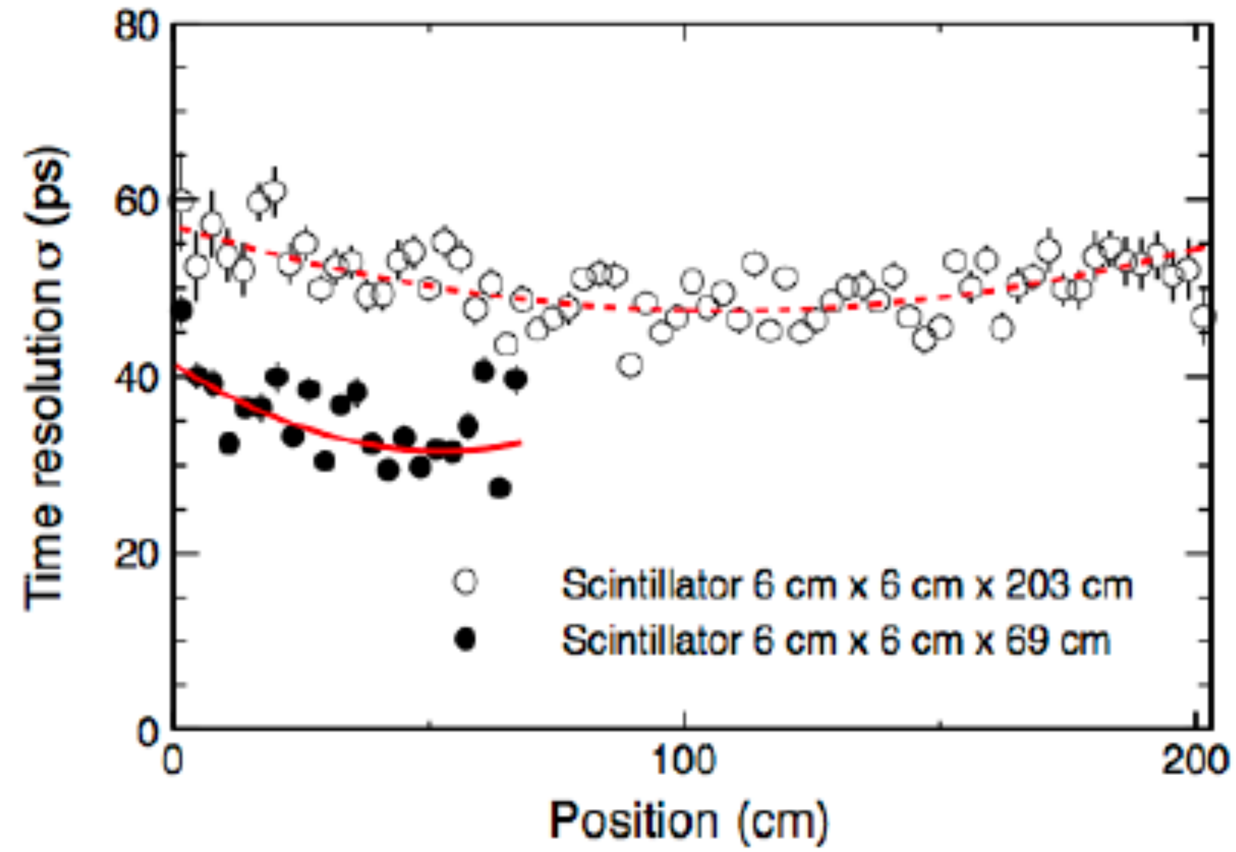






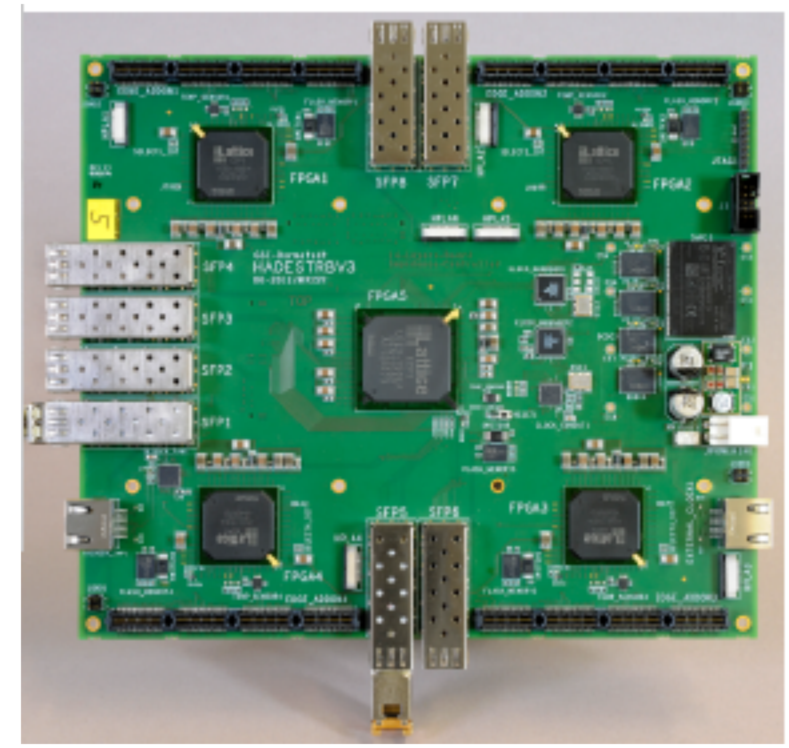
Detectors - Trigger Scintillators

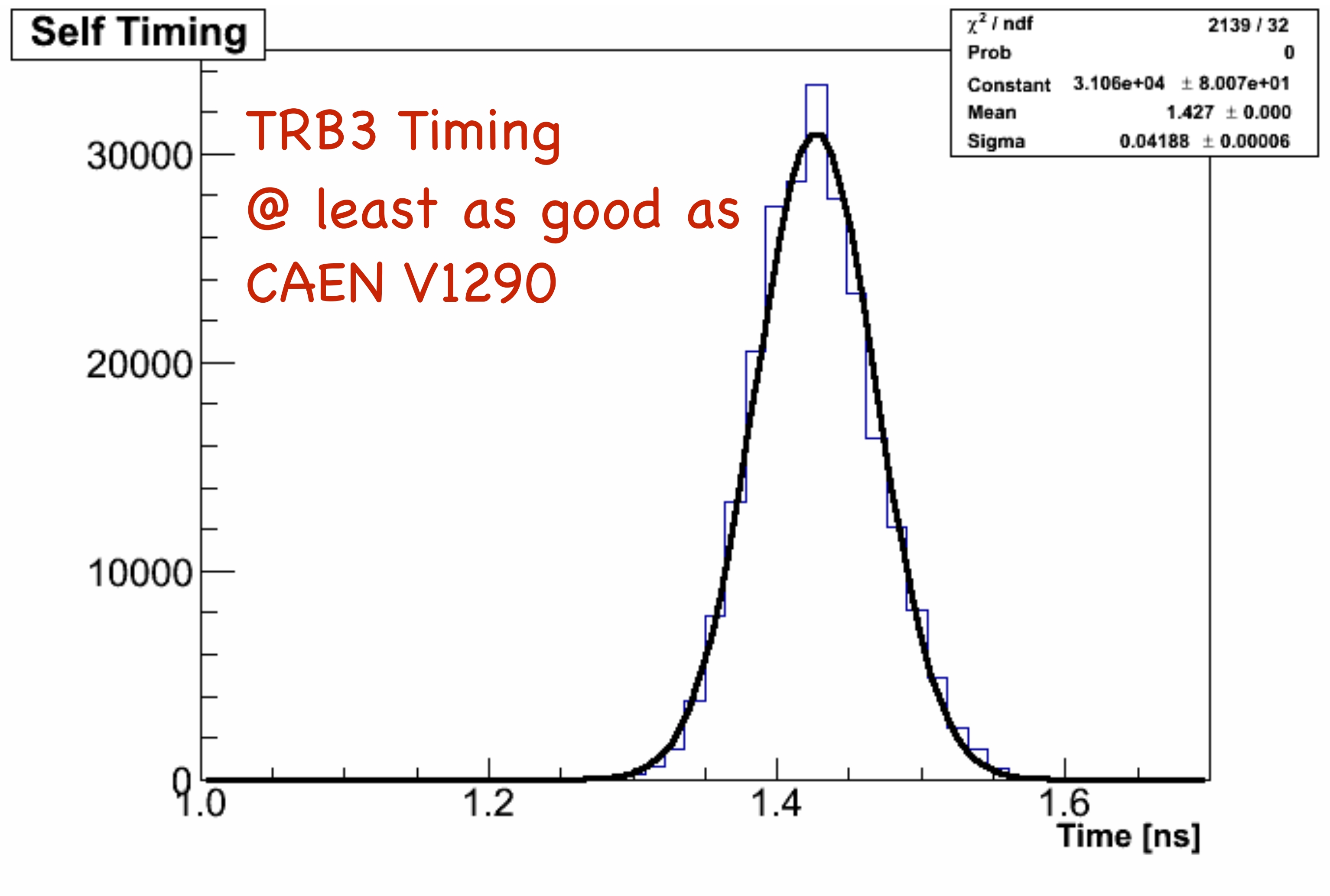
- Detect scattered particles with 2 planes of scintillators.
- High precision (40-50ps) timing and electron rejection.
- Total 94 bars (2 sides + beam).

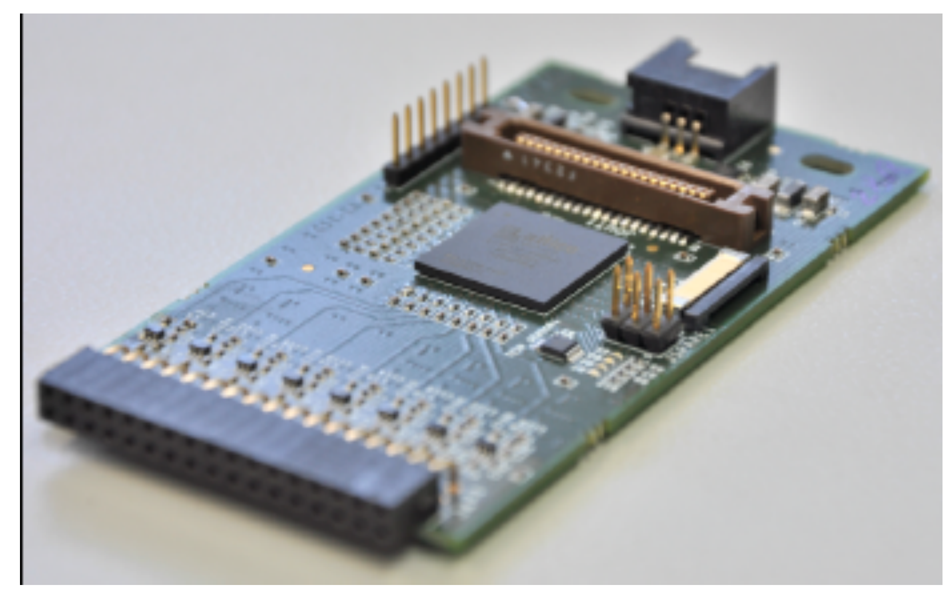


Data Acquisition

- Custom designed Time-to-Digital converters (25ps resolution). 2000€ / 256Ch !
- FPGAs as front end discriminator/amplifier.
- High channel density (256ch/board).
- ADC signals into standard CAEN architecture.
- Custom designed signal splitters.







Also used @ Mainz.
Collaboration being set up.

Fall 2012
Test Run

MUSE Test Run Report

The MUon proton Scattering Experiment collaboration (MUSE):

W.J. Briscoe,[1] K. Deiters,[2] E. Downie,[1] R. Gilman,[3] K.E. Myers,[3] E. Piasetzsky,[4] D. Reggiani,[2] P. Reimer,[5] G. Ron,[6] V. Sulkosky,[7] and M. Taragin[8]

Recycled (3 mm) SciFi + prototype SC scintillators (5 cm x 5 cm)

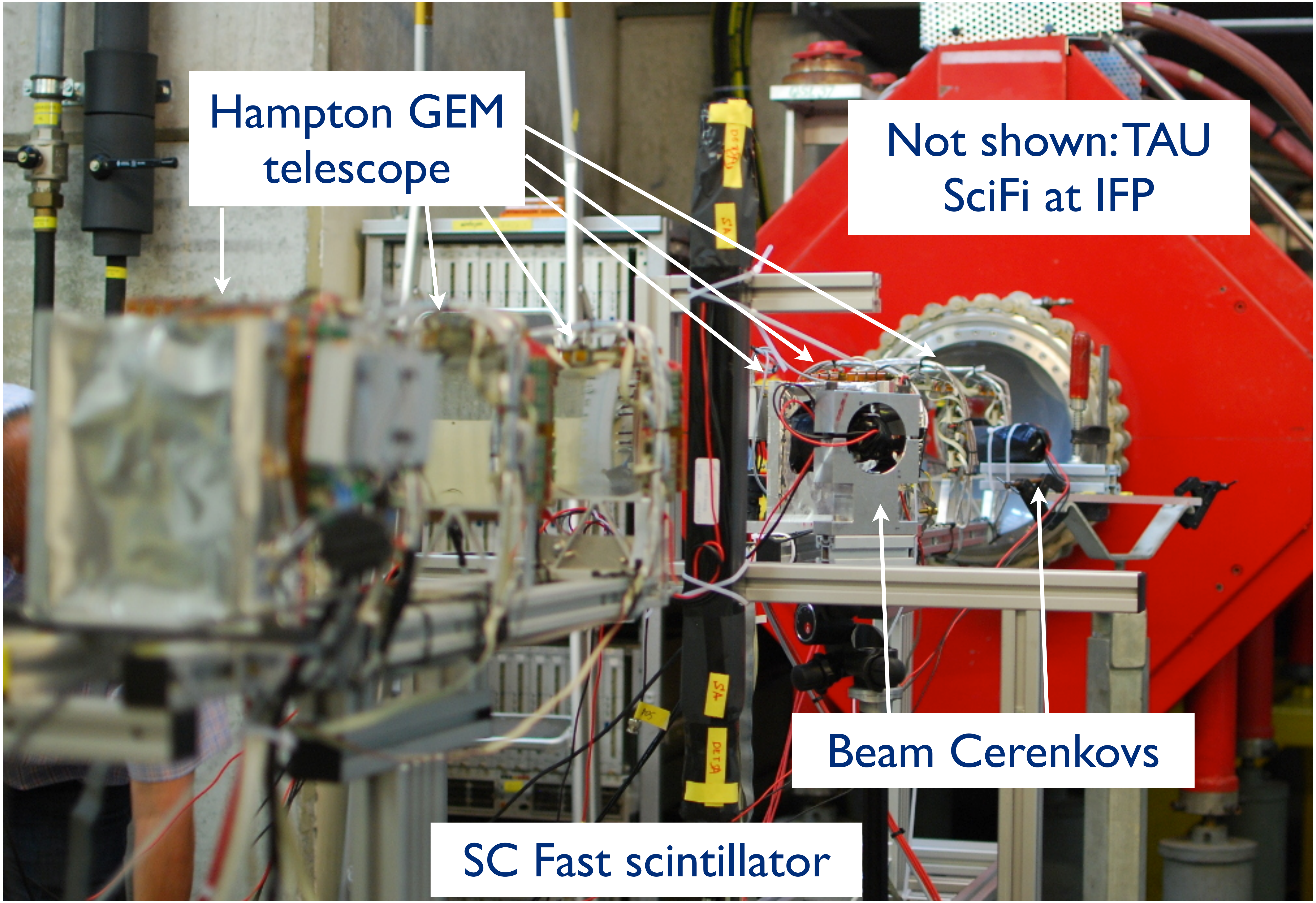
NIM trigger

VME read out

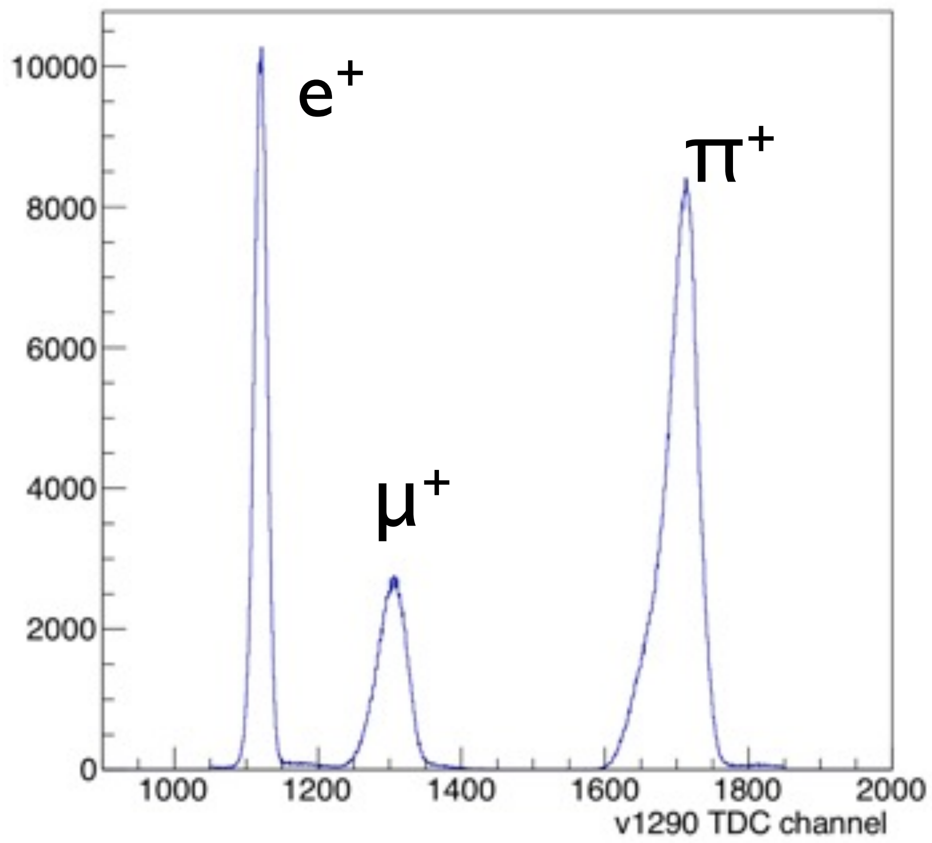
working physicists

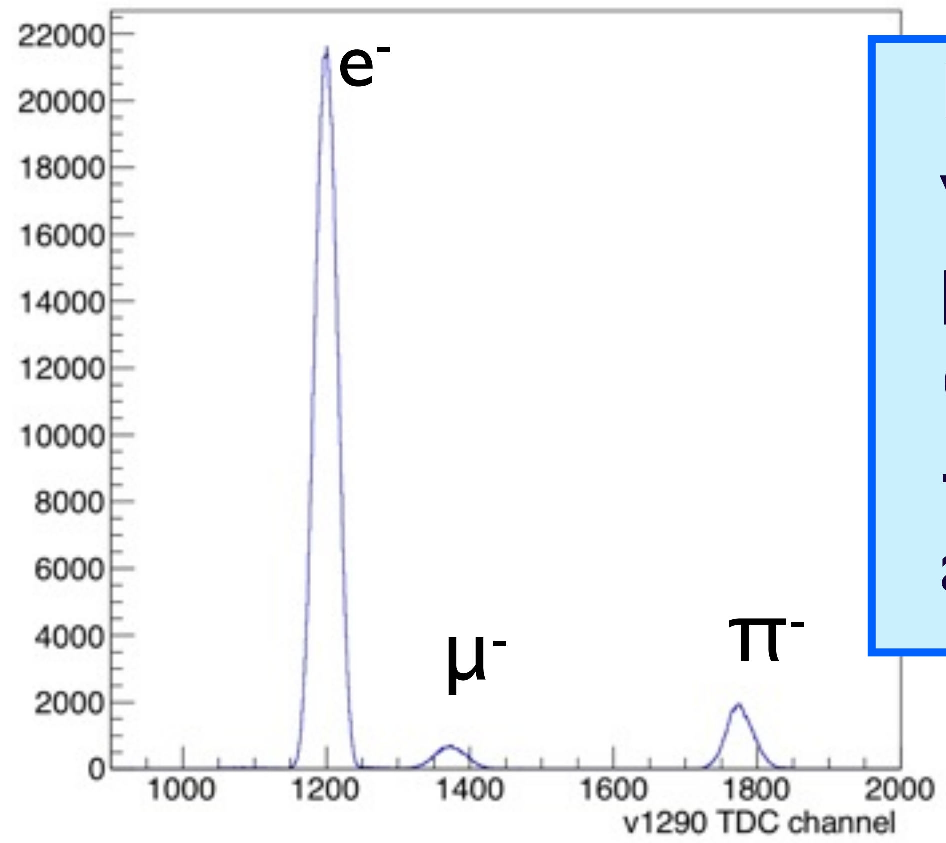
test run report on website:
http://www.physics.rutgers.edu/~rgilman/elasticmup

Summer 2013 Test Run



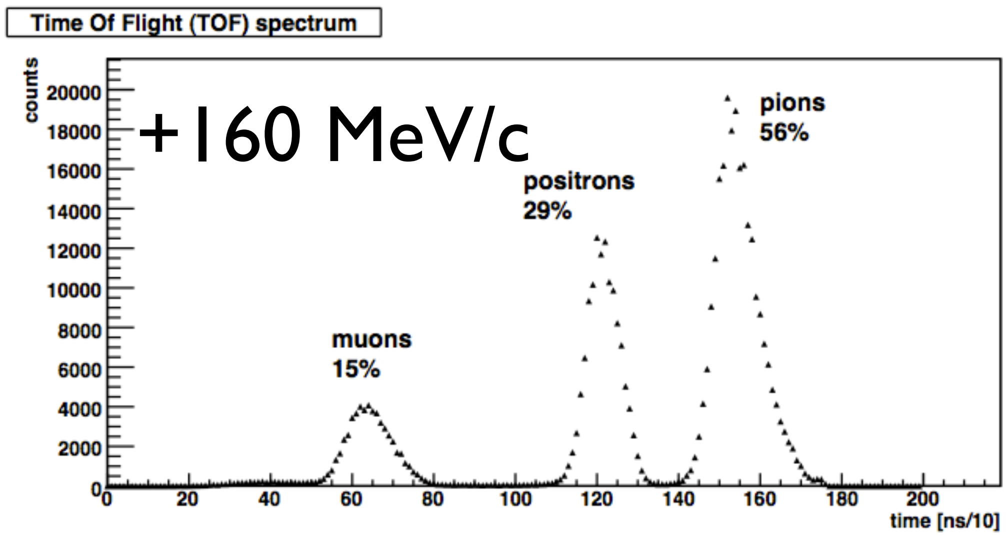
πM1 Channel - RF time in target region





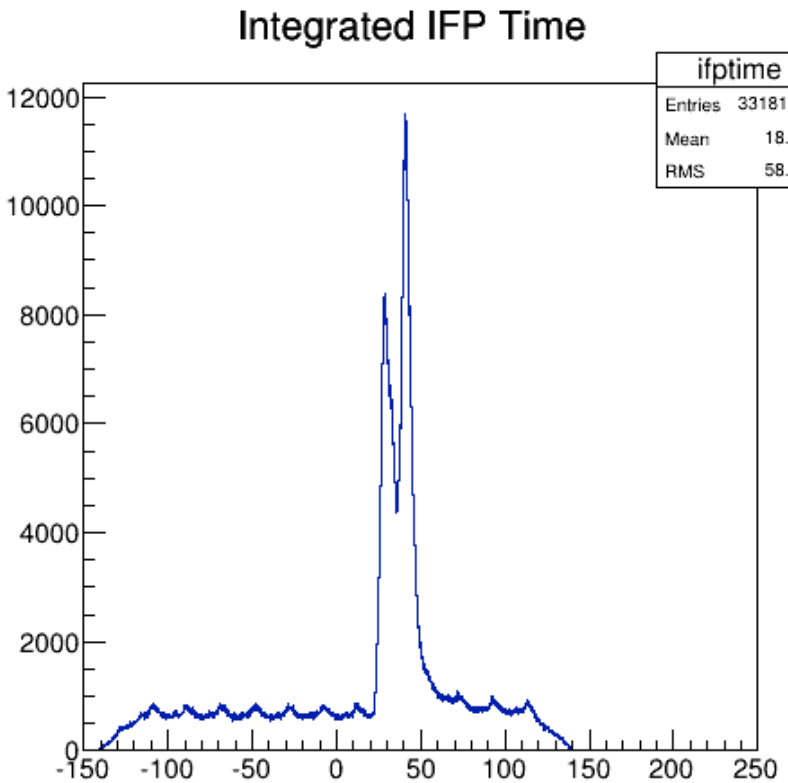
RF peaks broader with 2.2 mA protons, ≈350 ps (σ) for e's and 400 - 500 ps (σ) for μ's and π's

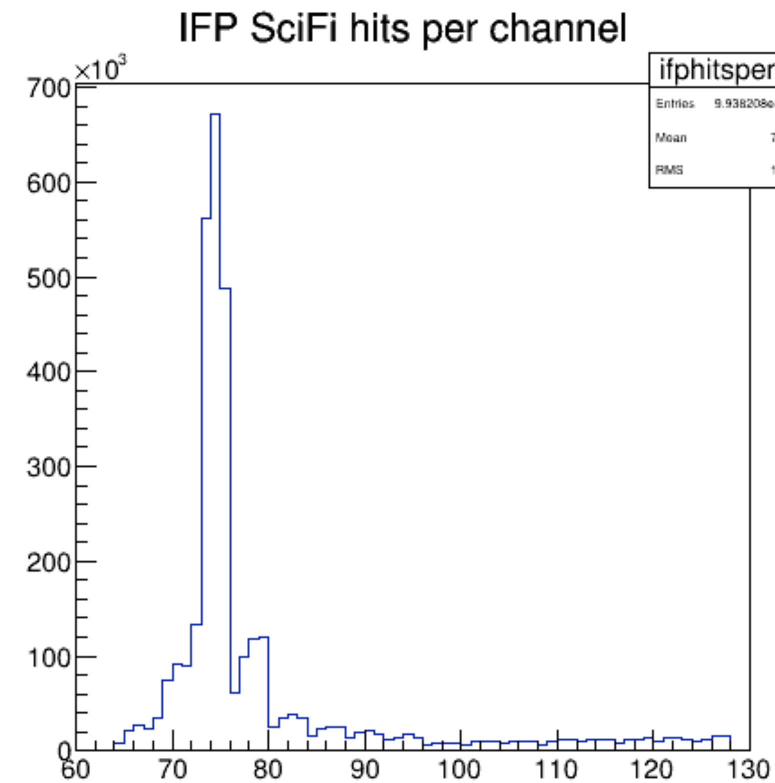
Obtained RF time spectra for several momenta from ≈110 to 225 MeV/c, and used these to determine relative particle fluxes

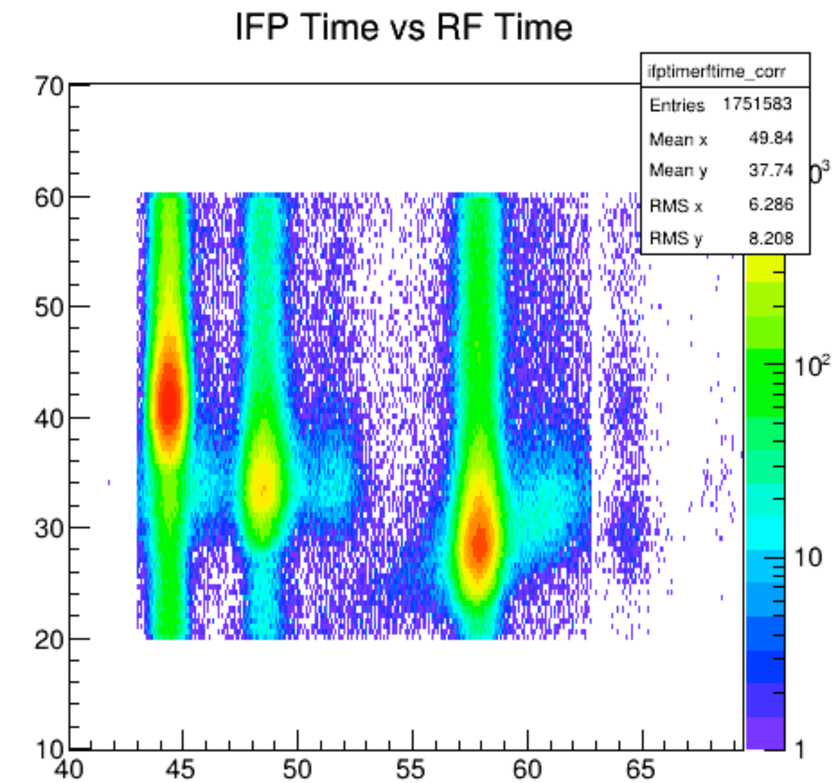


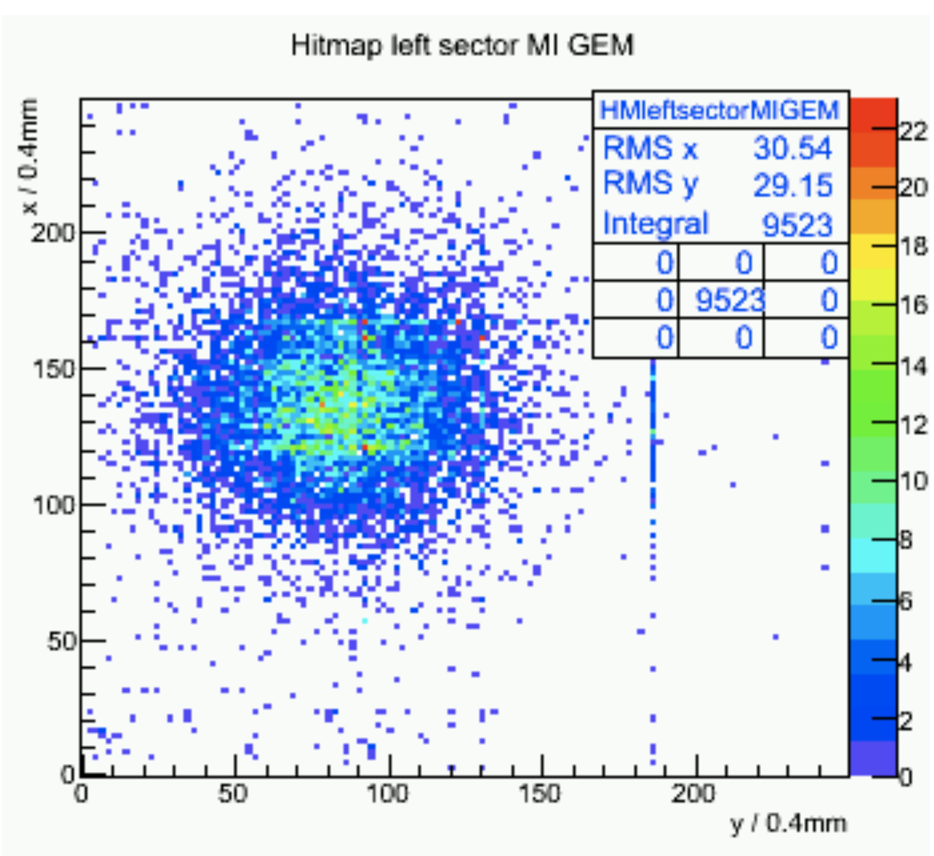
Old spectra, for comparison

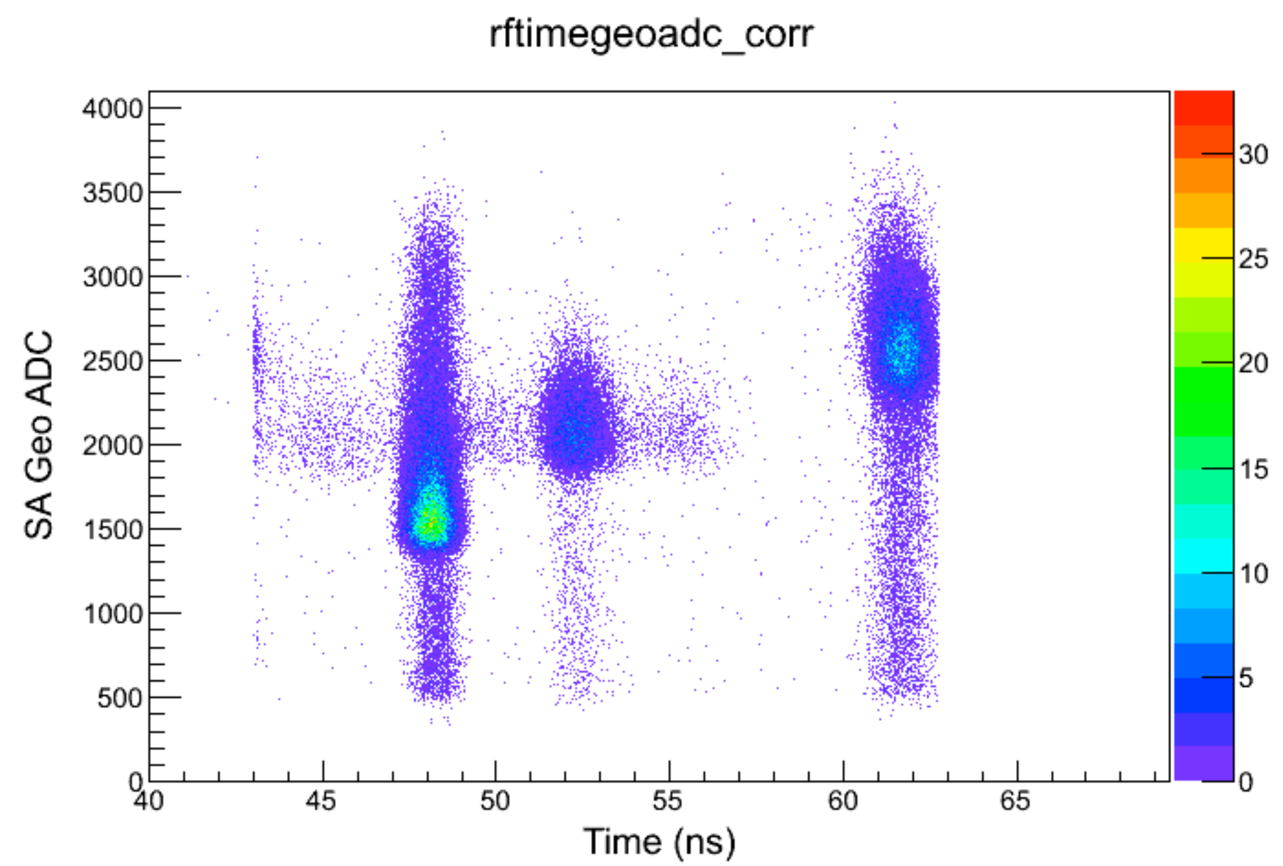
Summer 2013 Test Run





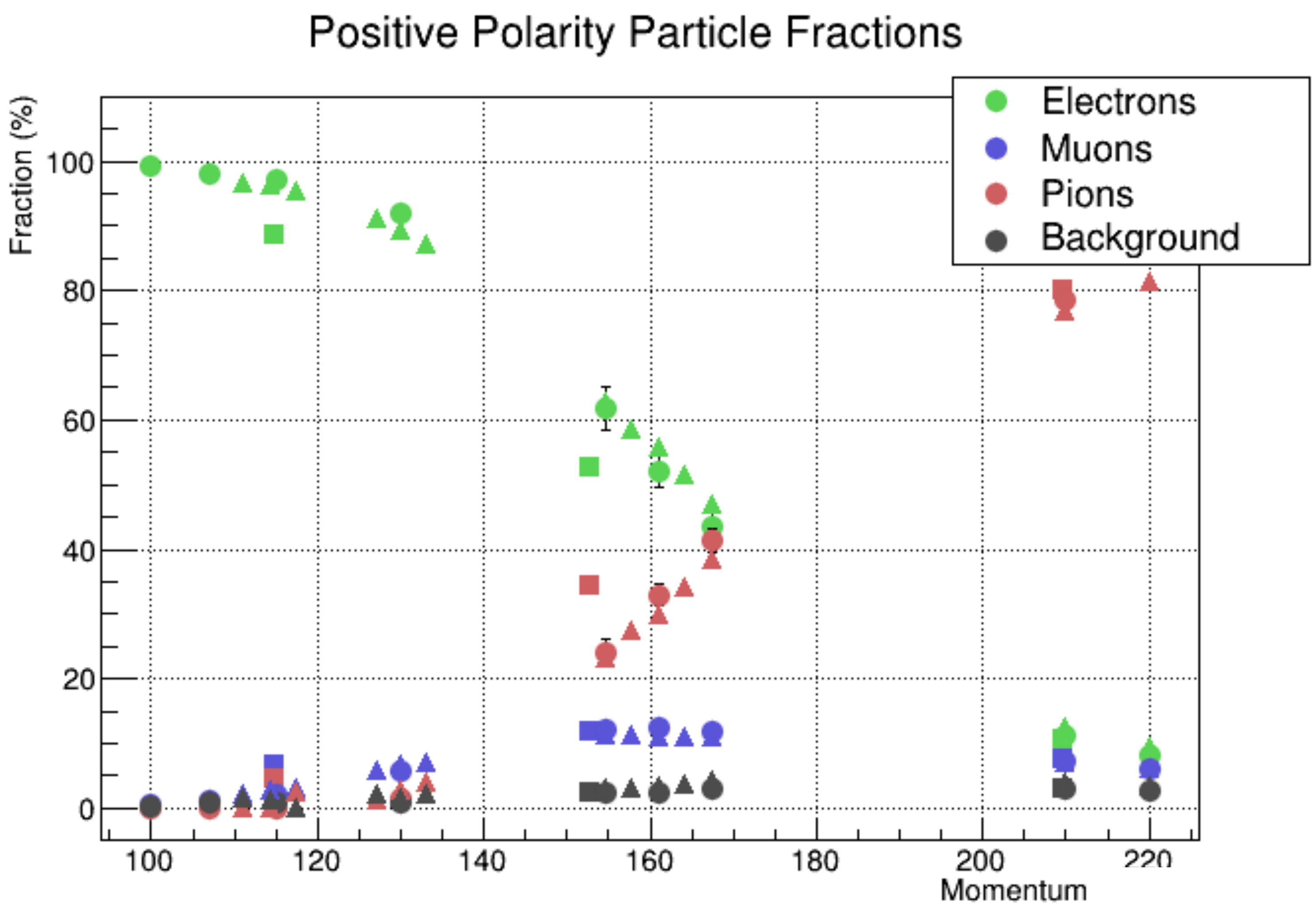


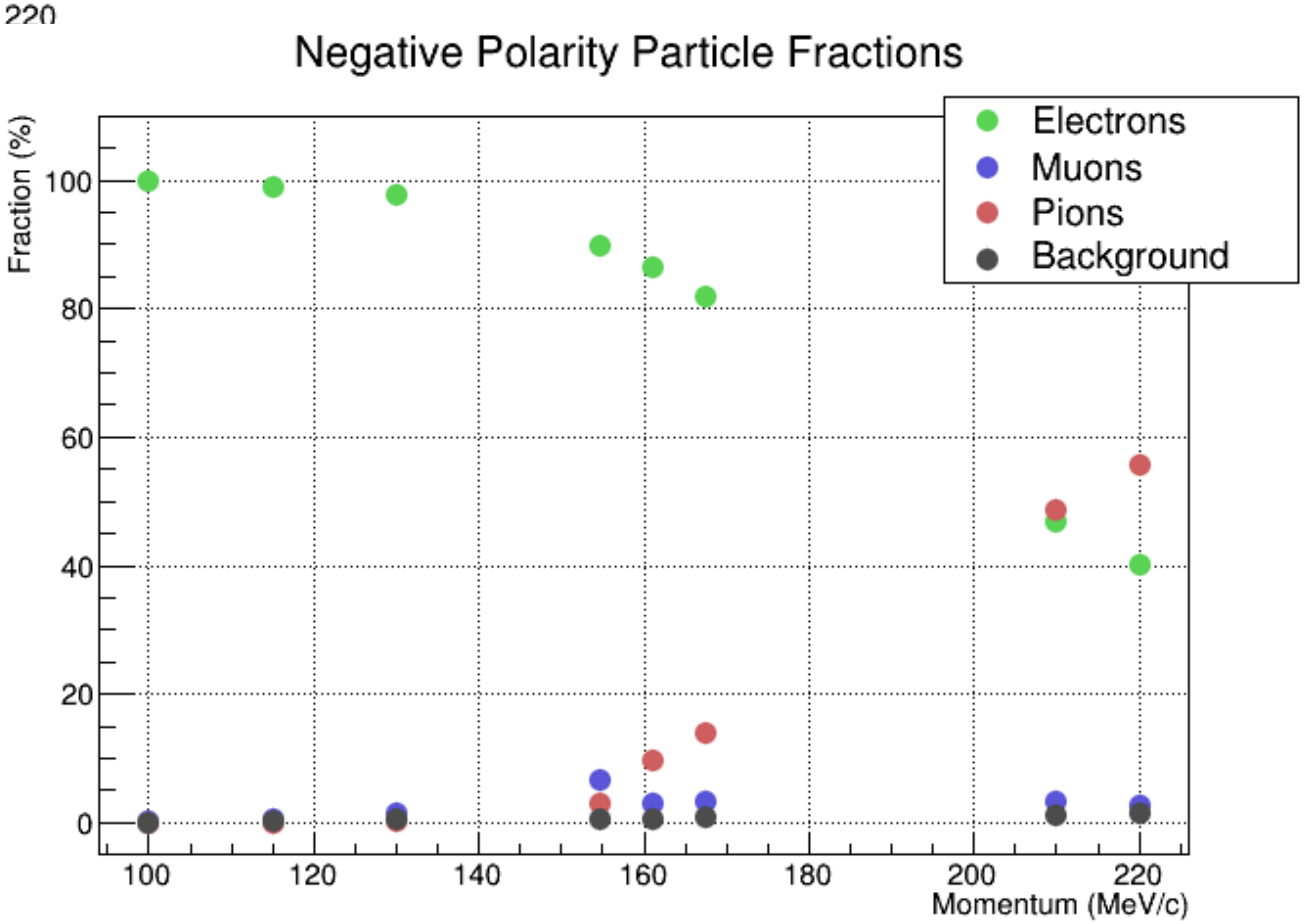




Particle fractions in beam

First measurement in piM1





Dec 2013 Tests

- More beam tests starting in a week.
- Basic measurements at each beam momentum:
  - Determine RF time / particle type distributions
  - Determine beam size at target for each particle type and divergence.
  - Determine beam distributions, dispersion and resolutions at Intermediate Focal Point (IFP) for each particle type.
- Other measurements for constraints on simulations:
  - Look for protons in + polarity at IFP and see what we need to range them out.
  - Look at beam halo.
  - Put target at beam and scintillators to mimic experimental conditions.
- Equipment tests:
  - Test MCP-PMT timing with Quartz/Sapphire.
  - Test TRB3 timing with time-walk corrections.

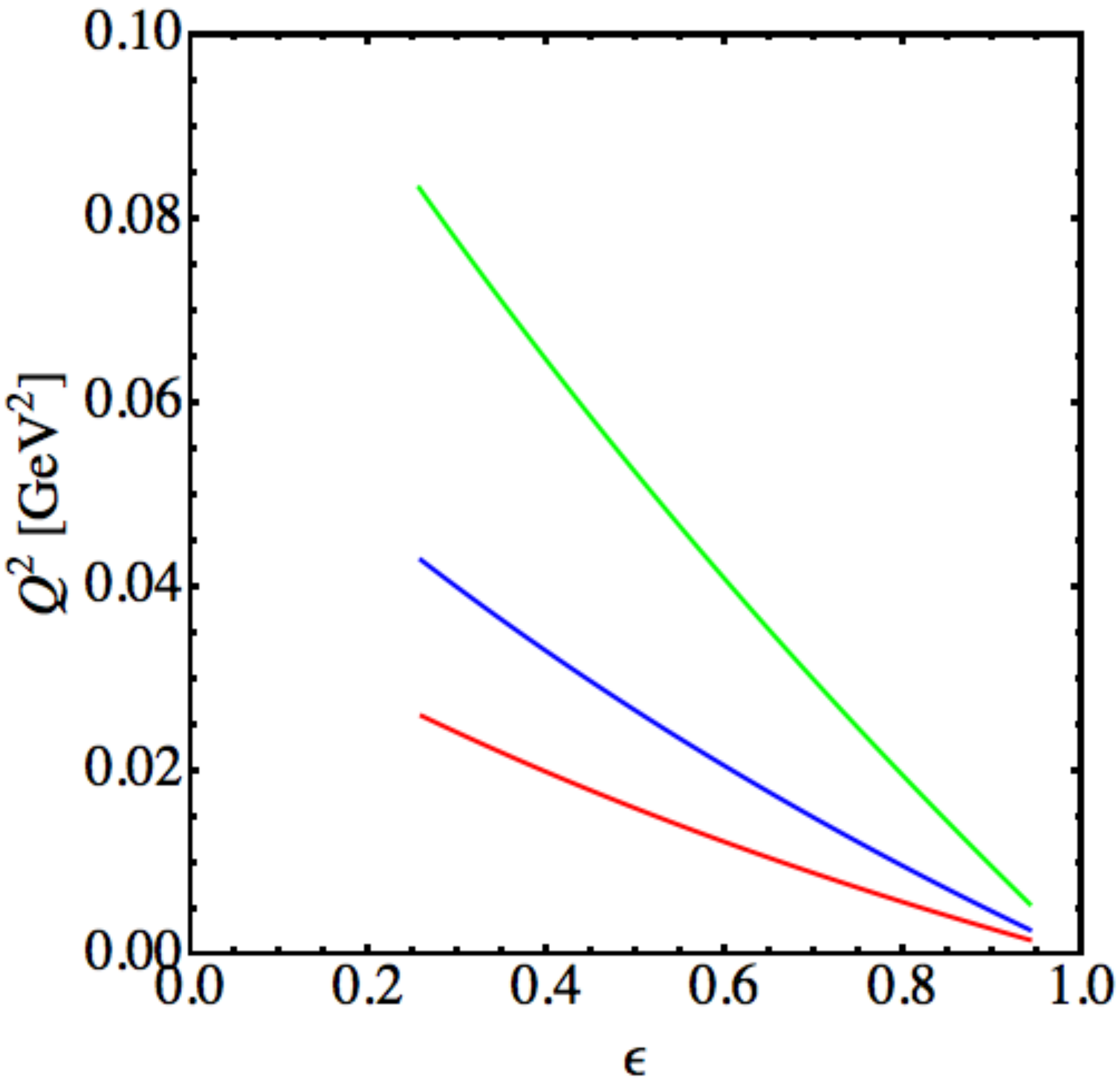
Next Few Years for MUSE

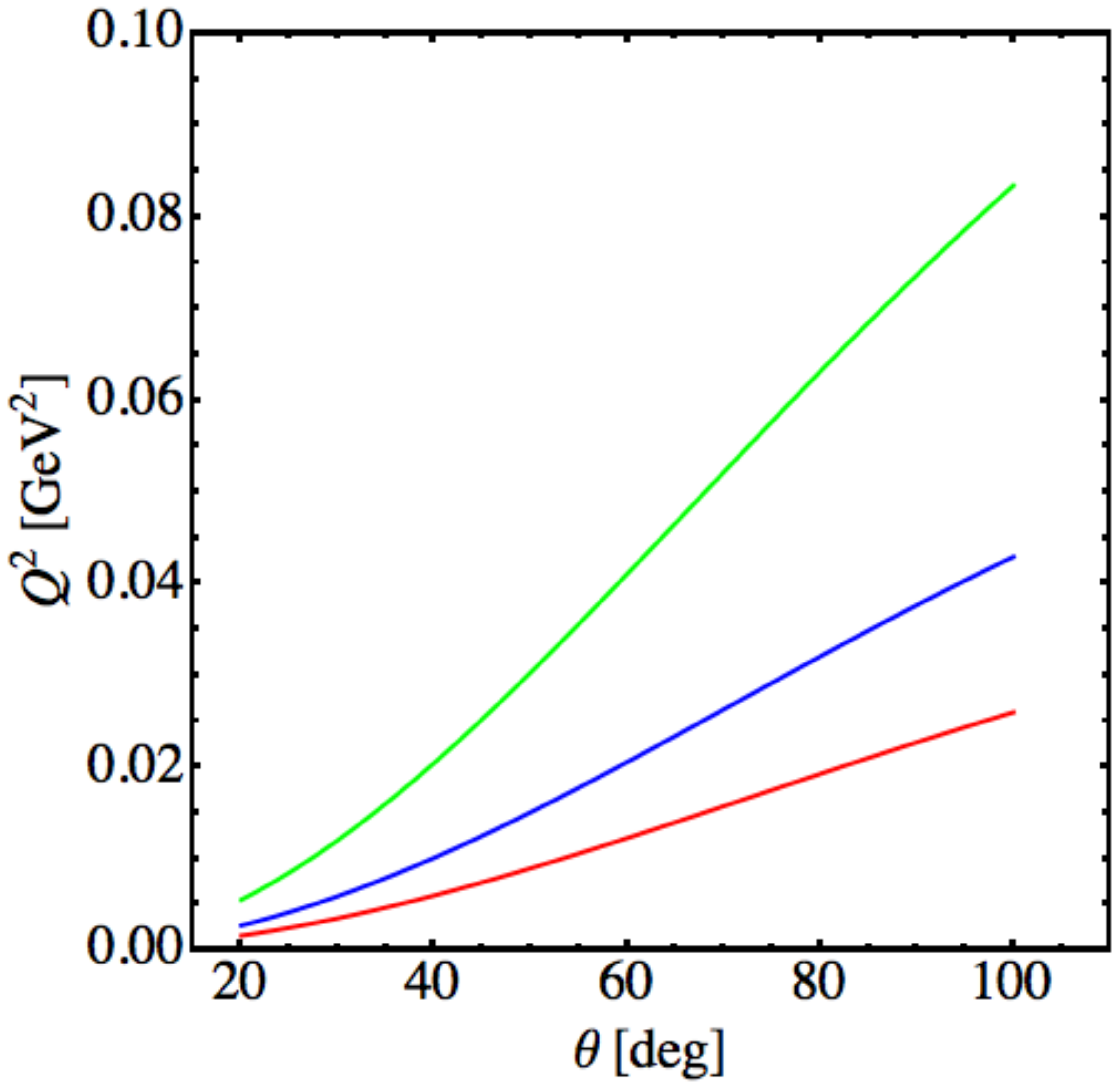
Feb 2012	First PAC presentation
July 2012	PAC/PSI Technical Review
fall 2012	1st test run in πM1 beamline
Jan 2013	PAC approval
summer 2013	2nd test run in πM1 beamline
fall 2013	funding requests + beam test
summer 2014	money arrives? - start construction
summer 2015	start assembling equipment at PSI
late 2015	set up and have dress rehearsal
2016-2017	2 6-month experiment production runs

New Equipment Summary

Detector	Who	Technology
Beam SciFi	Tel Aviv	conventional
GEMs	Hampton	detector exists
Sapphire Cerenkov	Rutgers	prototyped (Albrow et al)
FPGAs	Rutgers	conventional
Target	George Washington	conventional - very low power
Straw Tube Tracker	Hebrew U	copy existing system (PANDA)
scintillators	South Carolina	copy existing system
DAQ	George Washington	conventional, except TRB3

Experiment Overview





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Essentially same coverage for all beam particles.

Systematics

We are mainly concerned with relative systematic uncertainties as we plan to normalize data. Renormalization consistent with estimated absolute systematic uncertainties adds confidence to the relative systematic uncertainty estimates and to the results.

For relative systematics, used when the data are normalized to the $Q^2 = 0$ point, most effects are at the 0.1% level: detector efficiencies, solid angle, ...

The larger systematics are ≈0.3% for angle determination, and multiple scattering, and 0.5% for radiative corrections.

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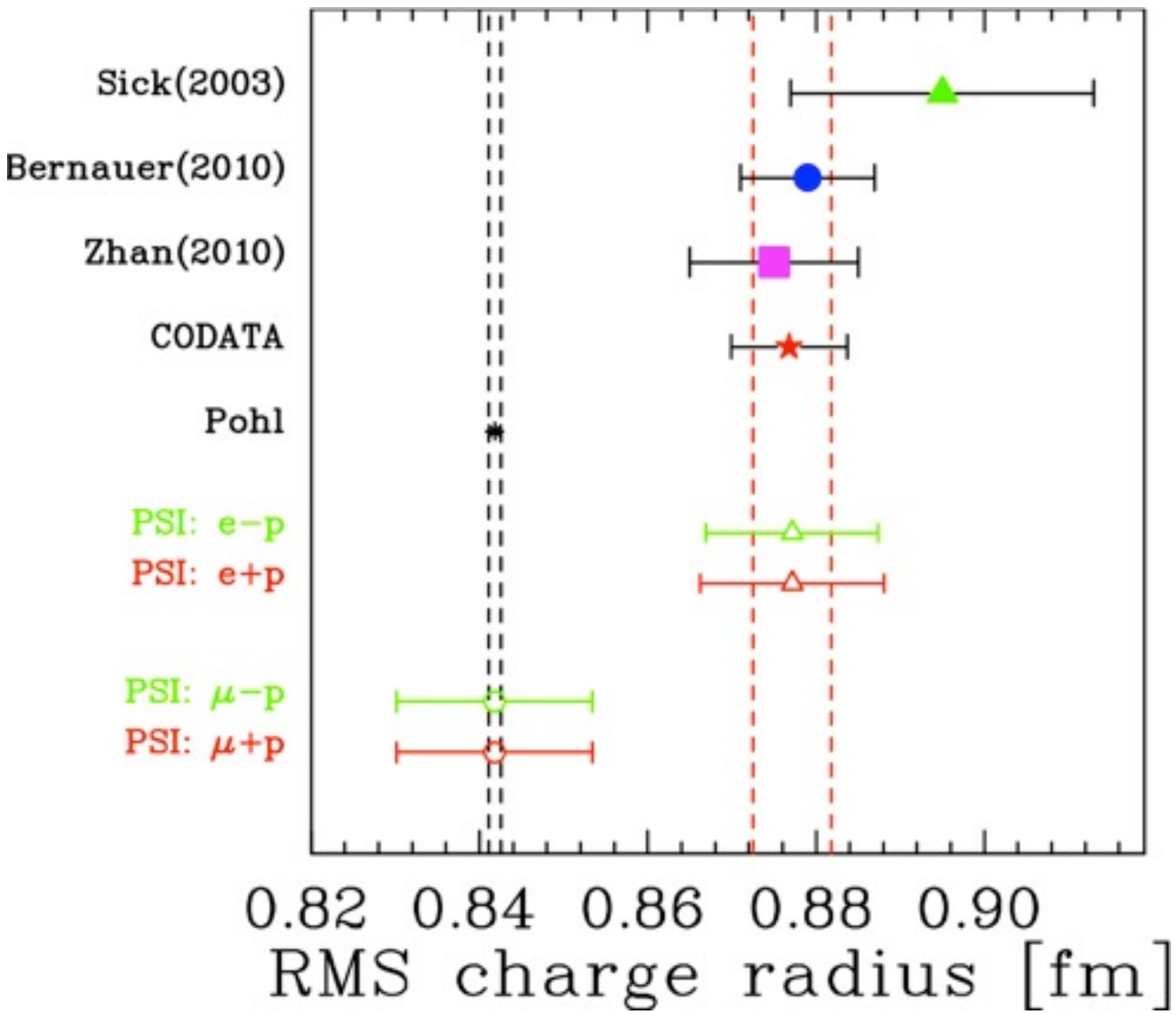
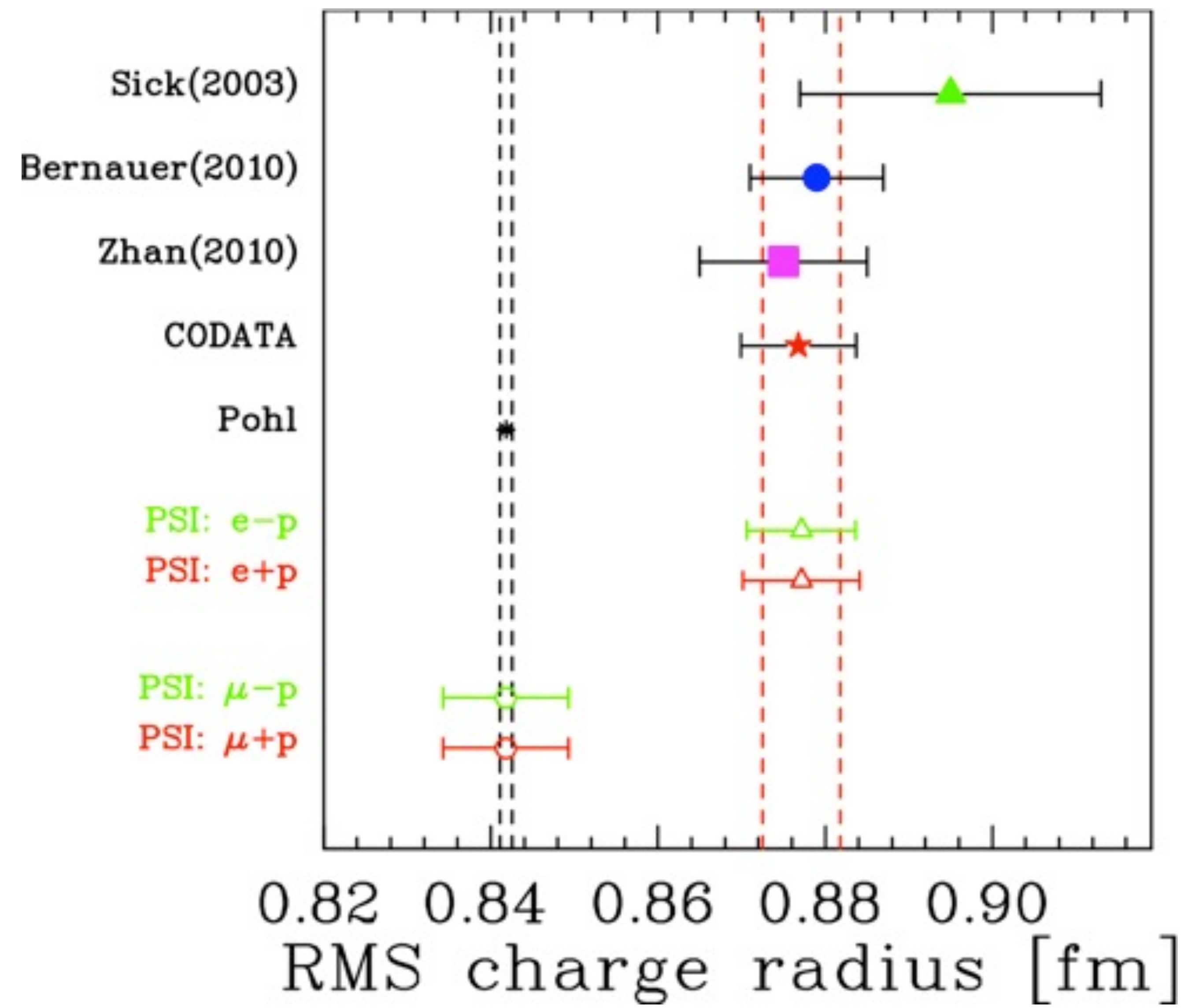
The larger systematics are ≈0.3% for angle determination, and multiple scattering, and 0.5% for radiative corrections.

- Material budget reduction.
- New radiative correction calculations.

Physics





Radius extraction from J Arrington.

Left: independent absolute extraction.

Right: extraction with only relative uncertainties.

The Real Bottom Line

Charge radius extraction limited by systematics, fit uncertainties

Comparable to existing e-p extractions, but not better

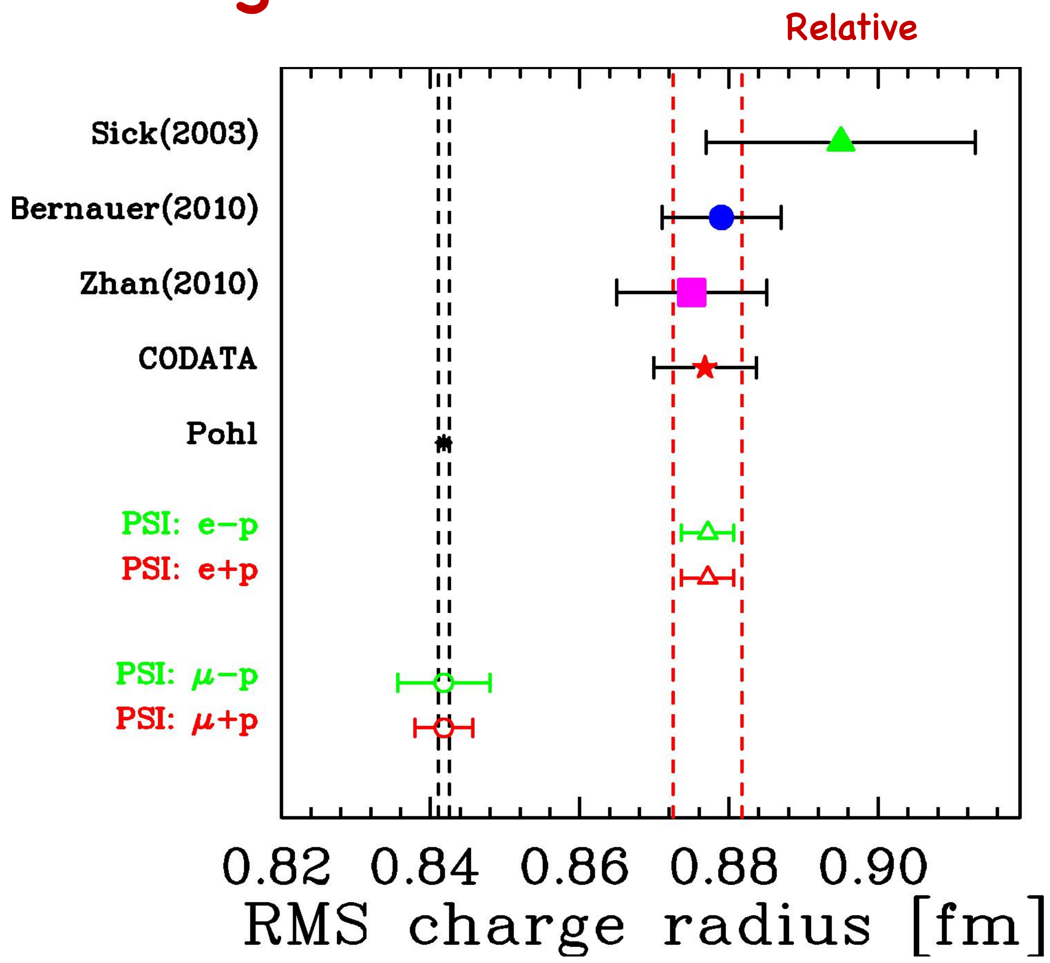
Many uncertainties are common to all extractions in the experiments: Cancel in e+/e-, m+/m-, and m/e comparisons

Precise tests of TPE in e-p and m-p or other differences for electron, muon scattering

Comparing e/mu gets rid of most of the systematic uncertainties as well as the truncation error.

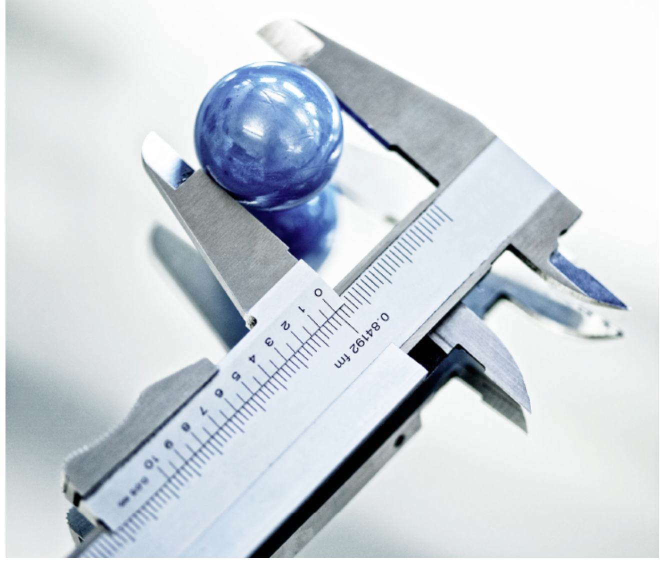
Projected uncertainty on the difference of radii measured with e/mu is 0.0045.

Test radii difference to the level of 7.7σ (the same level as the current discrepancy)!



Summary

- High profile issue for Nuclear Physics.
- But explanation unclear:
  - Two competing physics explanations (BSM, 2γ).
  - But also experimental/analysis explanations exist.
- MUSE tests both hypothesis.
- In 3-4 years we should have results from electron scattering experiments and start seeing results from muon scattering ➛ New physics coming ?
- Collaborators welcome!



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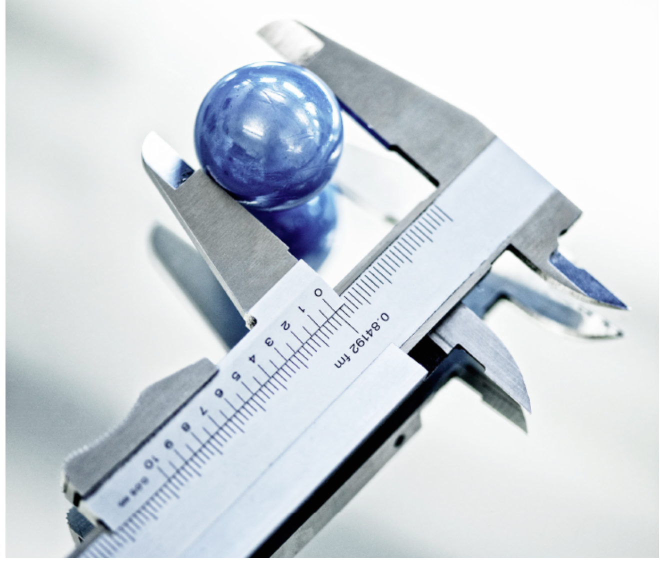

"The spectrum of hydrogen atom has proved to be the Rosetta stone of modern physics." - T.W. Hänsch