Studying the Proton ``Radius" Puzzle with μp Elastic Scattering

MUon proton Scattering Experiment (MUSE) collaboration

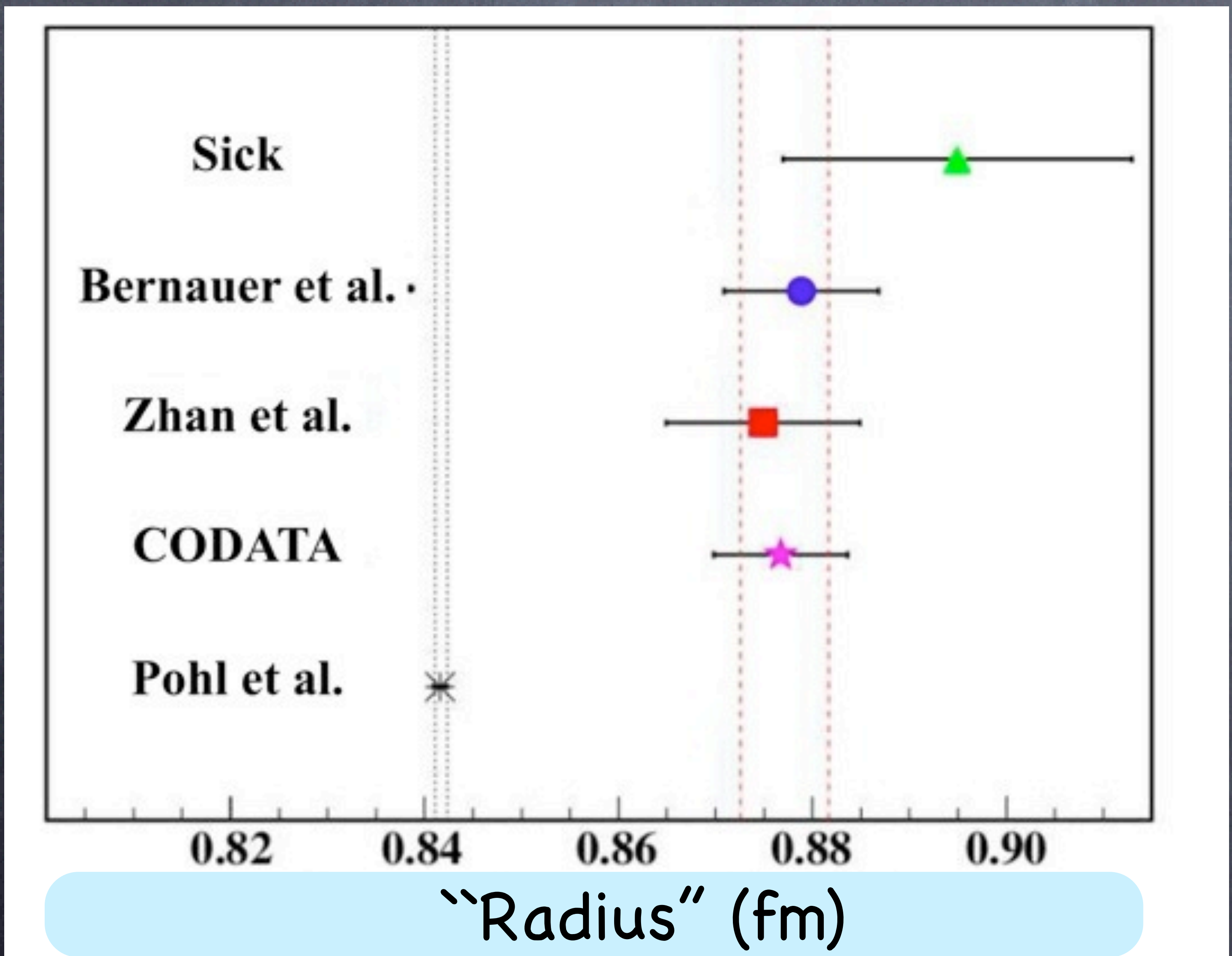
E Downie (GWU)
R Gilman (RU)
G Ron (HU)
with 46 collaborators
from 21 institutions

- Brief physics motivation.
  - The disagreement between ep and μp measurements of the radius remains, and is more puzzling than ever.
- The proposed MUSE measurement.
  - Beam & test run
  - Detector plans
  - Expected Results

The Proton ``Radius" Puzzle

Muonic hydrogen disagrees with ep atomic physics and scattering determinations of the slope of FF at $Q^2 = 0$. The difference (#5 vs #6) is 7σ. This is a high-profile issue - Nature paper, APS plenary & many invited talks, PSAS2012 Symposium, Trento ECT* Workshop Nov 2012

What could explain the difference?



#	Extraction	r_p (fm)
1	Sick	0.895±0.018
2	Bernauer Mainz	0.879±0.008
3	Zhan JLab	0.870±0.010
4	CODATA	0.877±0.007
5	Combined 2-4	0.876±0.005
6	Muonic Hydrogen	0.842±0.001

Possible Resolutions to the Puzzle

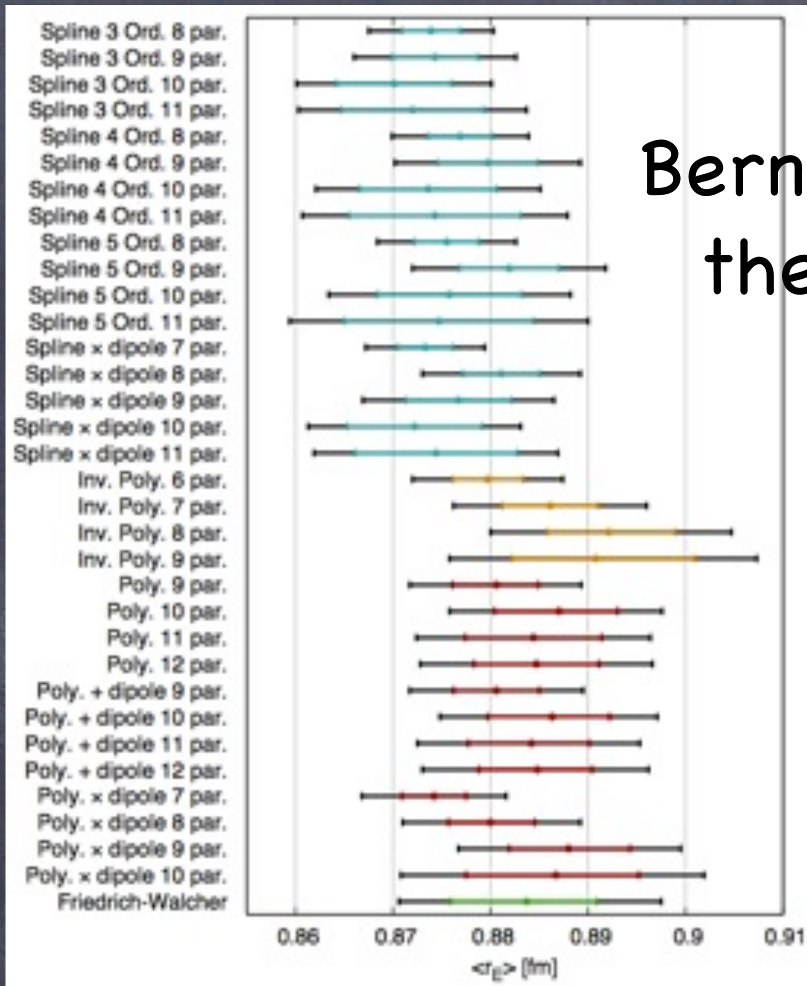
- The μp result is wrong. No doubts about experiment or atomic theory, but various suggestions about aspects of proton structure for extracting the proton radius - all ruled out or not widely believed.
- The ep (scattering) results are wrong. Uncertainties bigger than claimed? The fit procedures are not good enough? The data do not go to low enough Q^2? Structures or slope changes at low Q^2?
- Novel beyond-Standard-Model Physics differentiates μ and e. Can explain PRP and muon g-2 with several existing models, although parameters constrained, also by other existing data.

Some Developments since January 2012

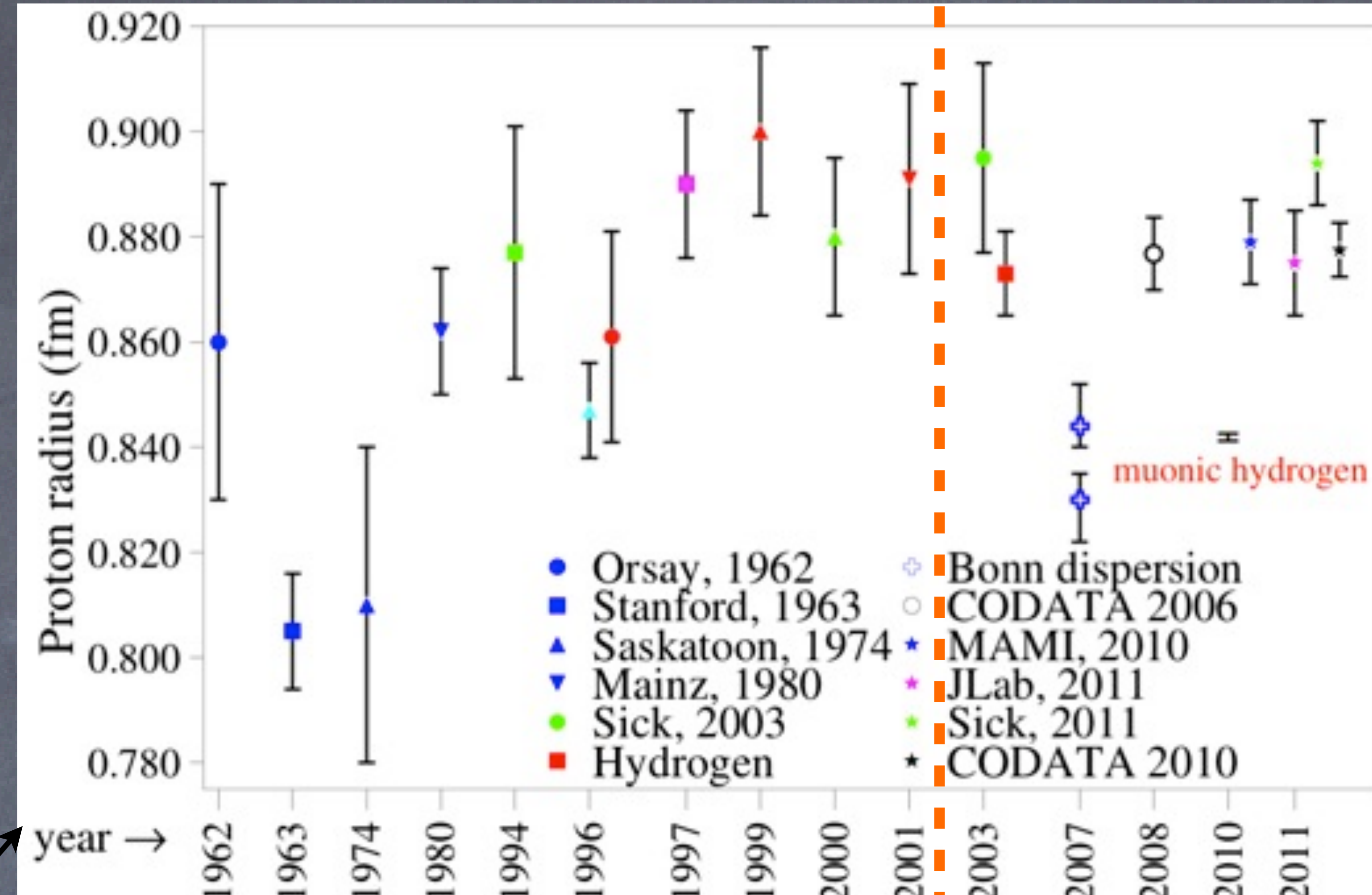
(and our opinions in some cases)

- July 2012 technical review: Major issues: beam tests, simulations
- Fall 2012 beam tests. πM1 beam is adequate for experiment.
- Trento Workshop on Proton Radius Puzzle: 47 experts in atomic, nuclear, and beyond-standard-model physics theory and experiment: Favored solutions to radius puzzle: BSM physics or incorrect radius from electron experiments. Hadronic physics explanation not favored. New data needed. The puzzle is even more puzzling.
  - JLab low Q^2 ep → ep approved and likely to run 2014-2015.
  - Long term atomic physics efforts underway - more muonic hydrogen (Science), heavier muonic atoms, new & improved ep experiments
- Review papers in preparation: Pohl, Gilman, Miller, Pachucki, arXix:1301.0905, Ann Rev Nucl Part Sci; Carlson

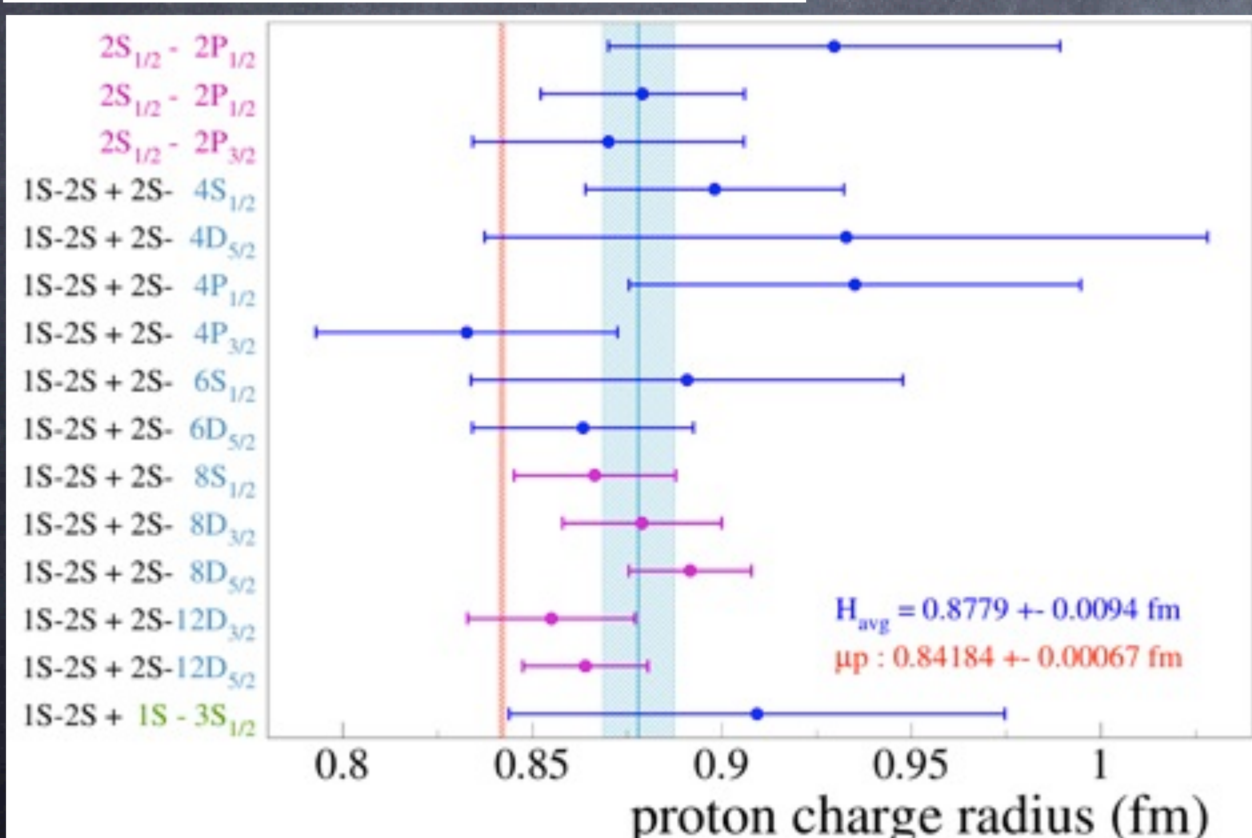
Proton Radius



Bernauer thesis



Pohl et al review



Recent Scattering Results Analyses

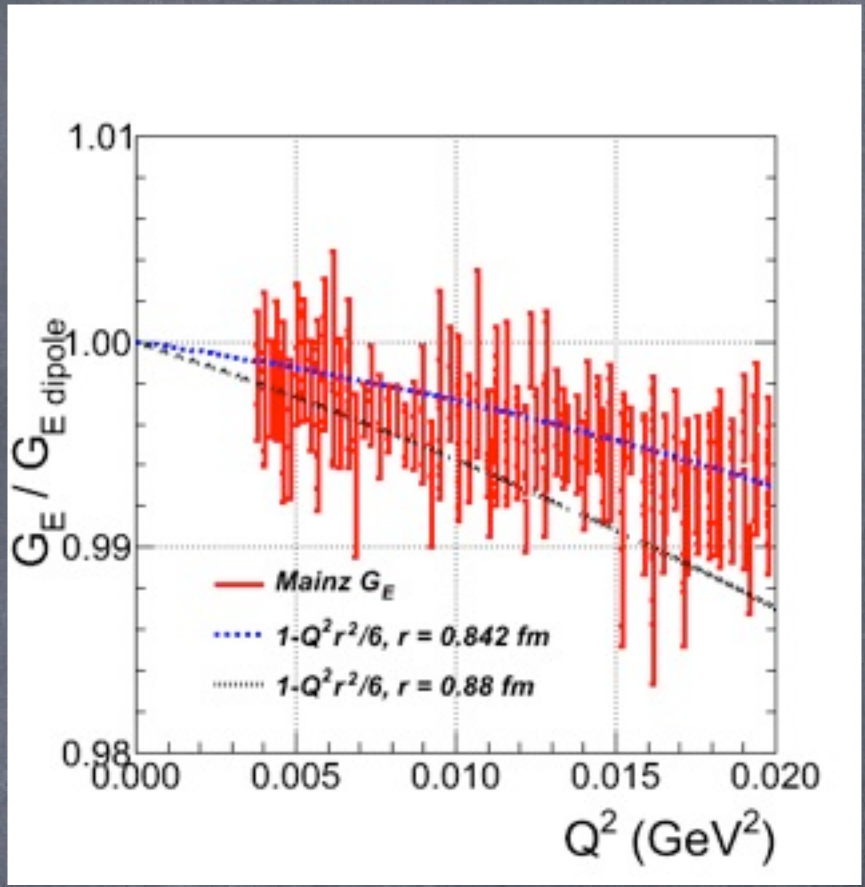
- Sick: sum of Gaussians: 0.886 ± 0.008 fm
- Hill+Paz: z expansion: 0.871 ± 0.009 ± 0.002 ± 0.002 fm
- Lorenz: dispersion relations / VMD: 0.84-0.85 fm
- Griffioen+Carlson: only low Q^2 data: ≈0.84 fm

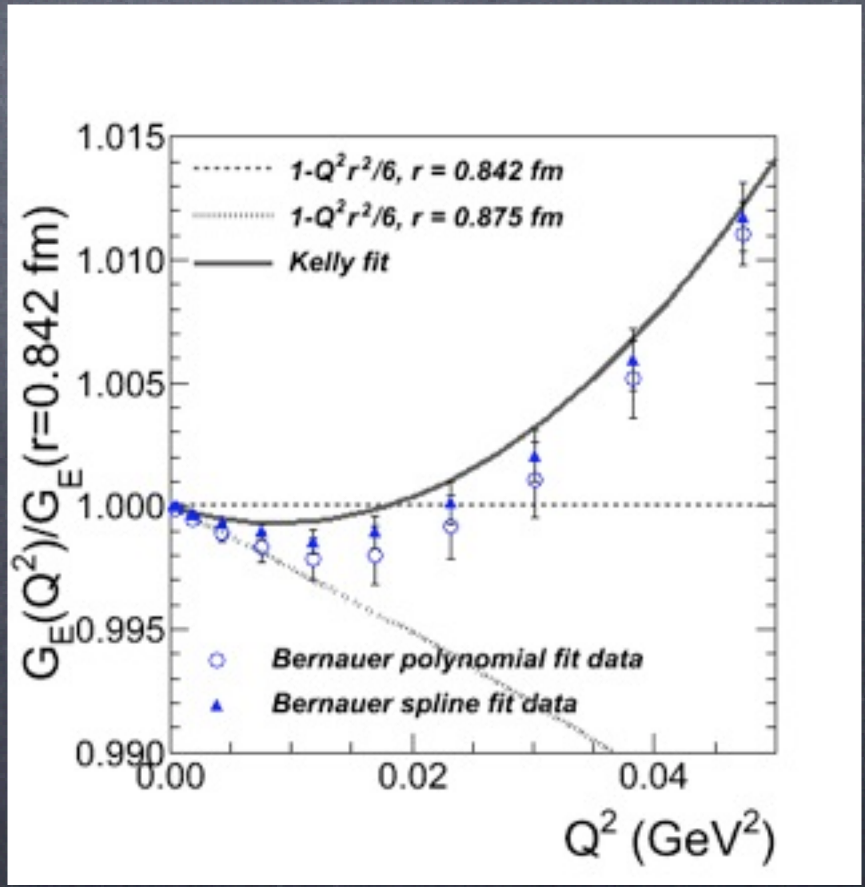
Why is extracting a radius from scattering experiments so hard?

Mainz A1 Data

$$G_E(Q^2) = 1 - Q^2r^2/6 + Q^4r^4/120 \ldots$$

- Low Q^2 Mainz data: top - raw data, bottom - rebinned G_E
- Points to understand:
  1. High precision experiment needed
  2. Normalization of data to Q^2 = 0 basically unavoidable
  3. Higher order terms come in early
  4. Truncation a potential issue
  5. (I. Sick: radius mainly sensitive to Q^2 region from 0.01 - 0.06 GeV^2)

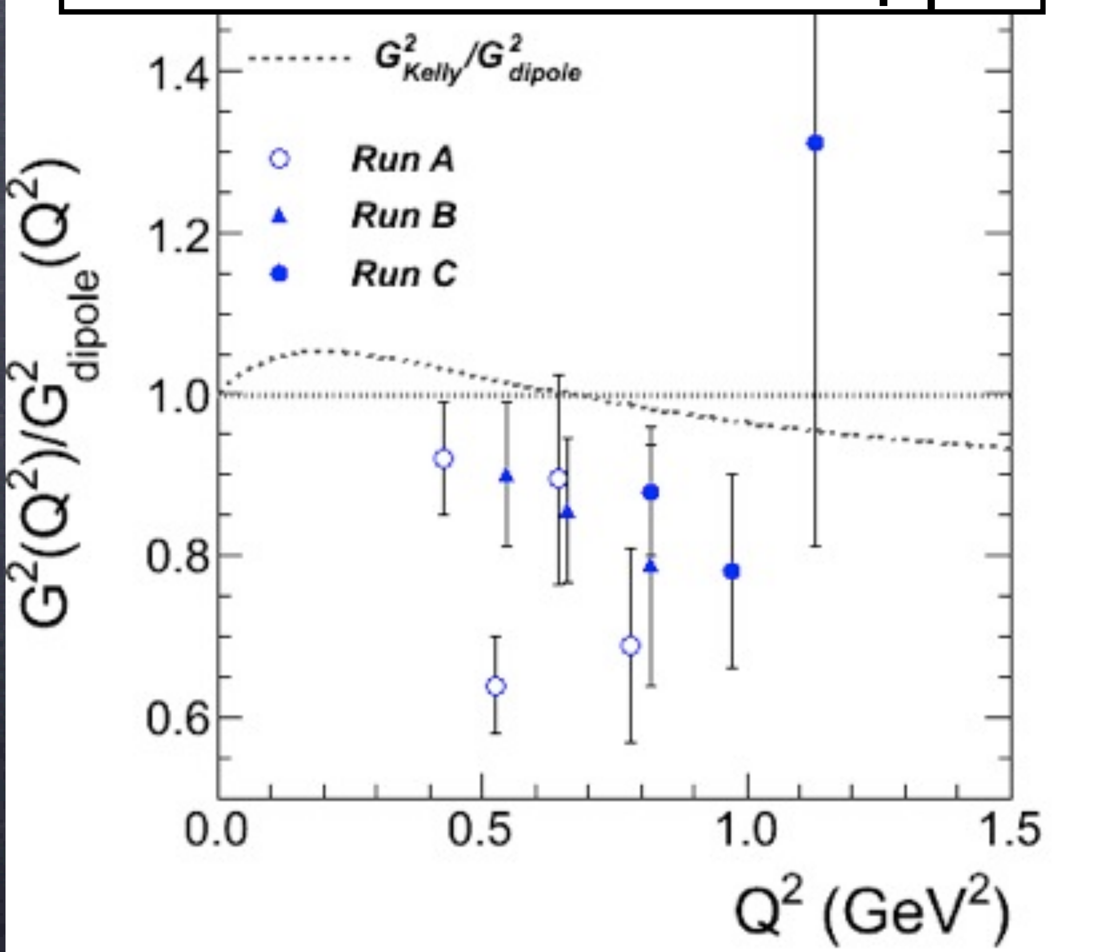




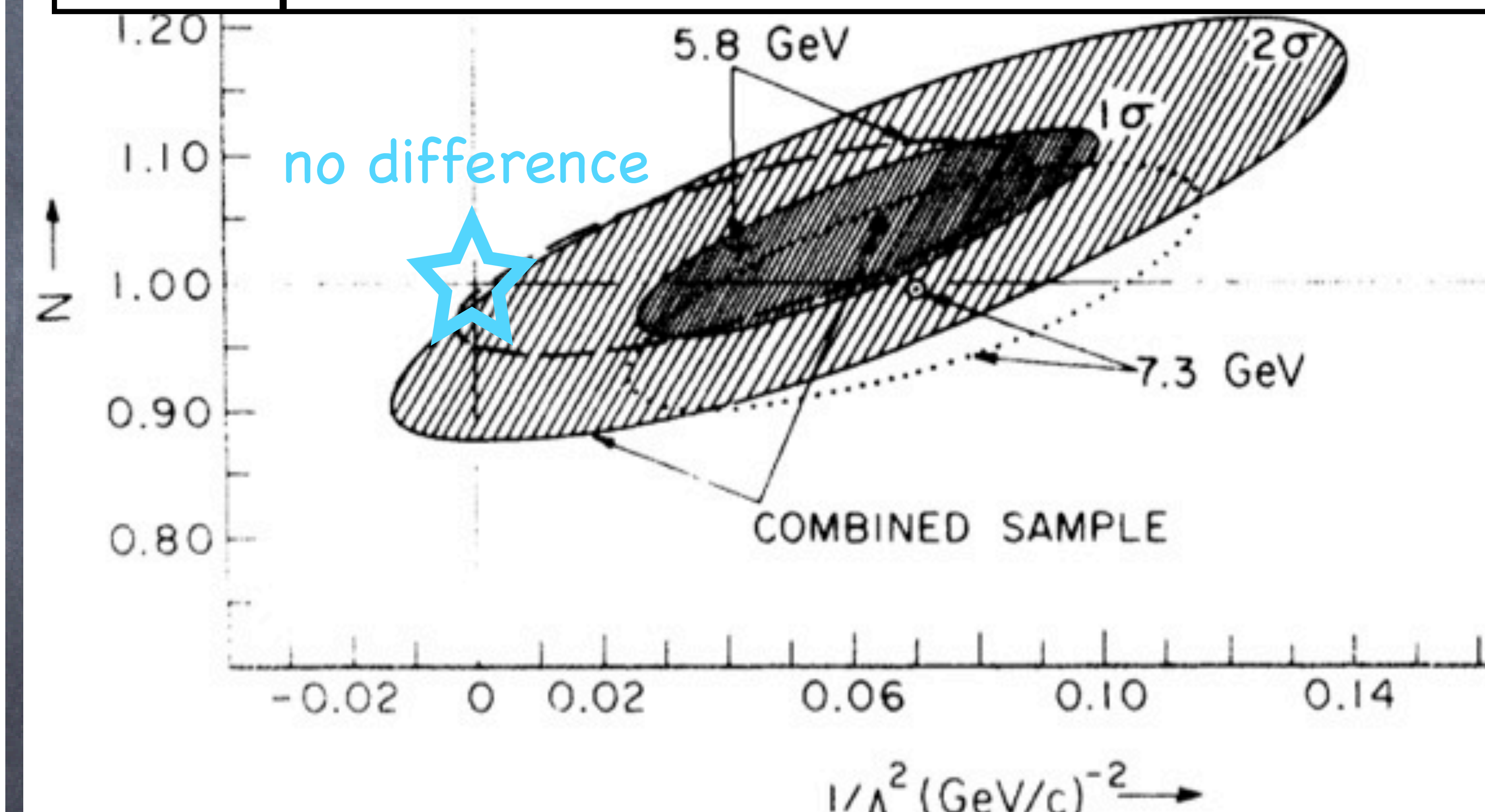
e-μ Universality

In the 1970s / 1980s, several scattering experiments tested whether ep and μp interactions are equal, to within the 10% precision of the experiments. In light of the proton ``radius" puzzle, the 10% experiments are not as good as one would like.

Ellsworth et al.: form factors from elastic μp



Kostoulas et al. parameterization of μp vs. ep elastic differences



Entenberg et al DIS: $\sigma_{\mu p}/\sigma_{ep} \approx 1.0 \pm 0.04$ (±8.6% systematics)

e-μ Universality

The ^{12}C radius was determined with eC scattering and μC atoms. The results agree:

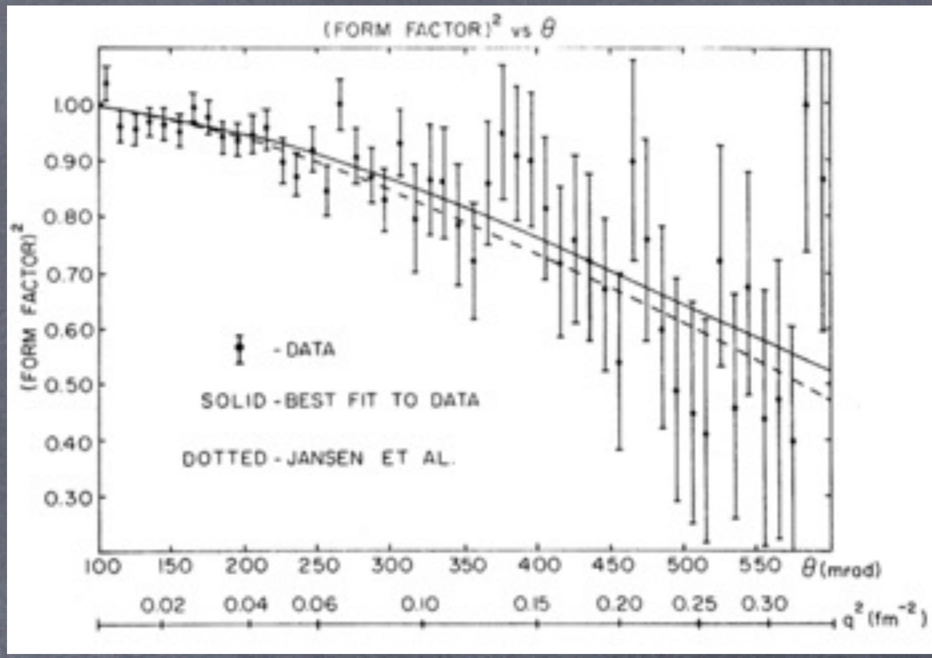
Cardman et al. eC: 2.472 ± 0.015 fm

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 $^{+0.13}_{-0.18}$ 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: μp Scattering at PSI

- Directly test the most interesting possibility, that μp and ep interactions are different, in a scattering experiment:
    - to higher precision than previously,
    - in the low Q^2 region (same as Mainz and JLab experiments) for sensitivity to radius
    - with $\mu^\pm$ to study possible 2γ mechanisms, but with improved sensitivity from low energy and large angle
    - measuring both $\mu^\pm p$ and $e^\pm p$ to have direct comparison and a robust, convincing result.
- Depending on the results, 2nd generation experiments (lower Q^2, $\mu^\pm n$, higher Q^2, ...) might be desirable or unneeded.

Our Approach in PSI R12-01.1

r_p (fm)	ep	μp
atom	0.877±0.007	0.842±0.001
scattering	0.875±0.006	?

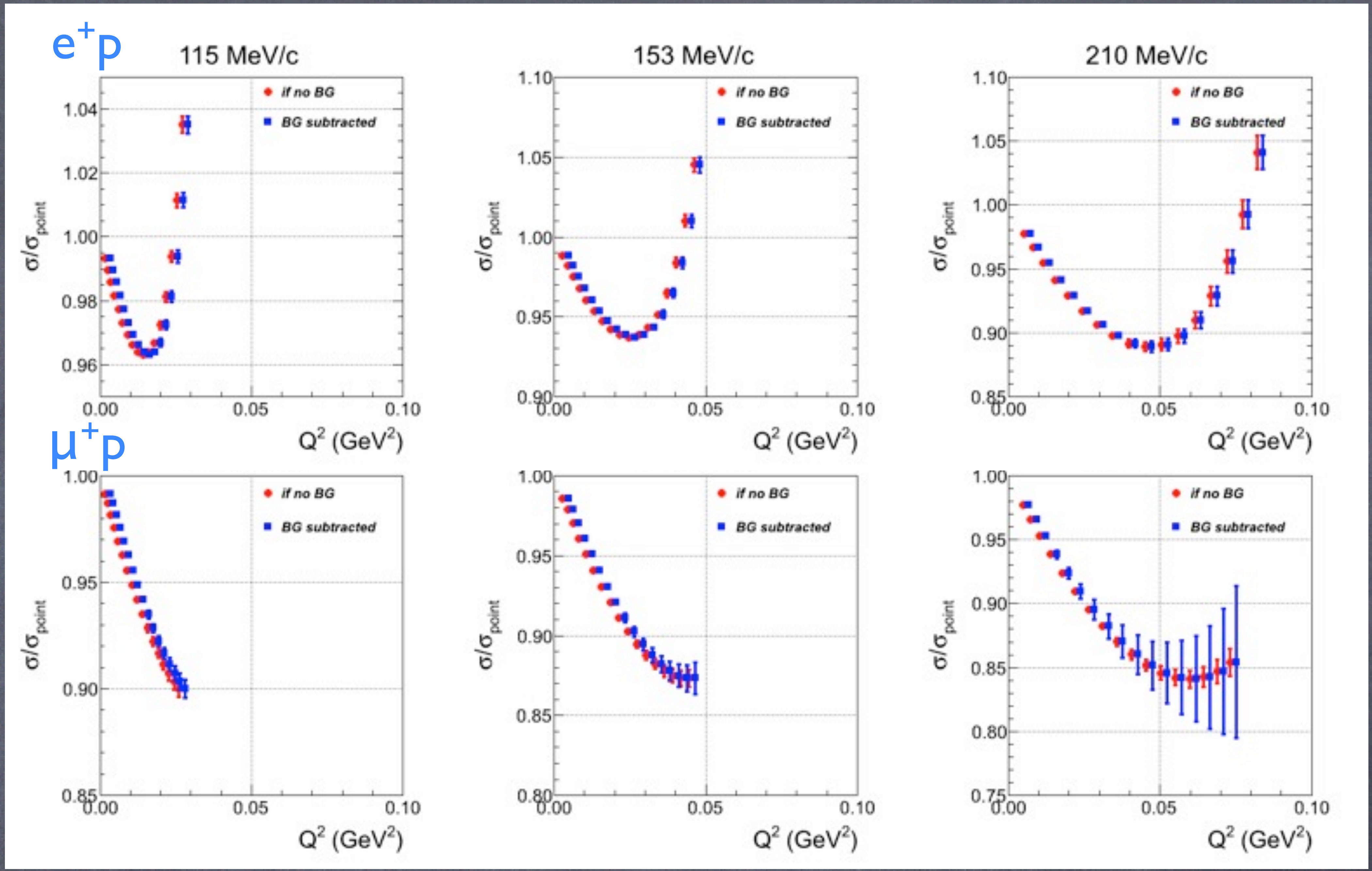
$$\left[\frac{d\sigma}{d\Omega}\right] = \left[\frac{d\sigma}{d\Omega}\right]_{ns} \times \left[\frac{G_E^2(Q^2) + \tau G_M^2(Q^2)}{1+\tau} + \left(2\tau - \frac{m^2}{M^2}\right) G_M^2(Q^2) \frac{\eta}{1-\eta}\right]$$

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

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

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

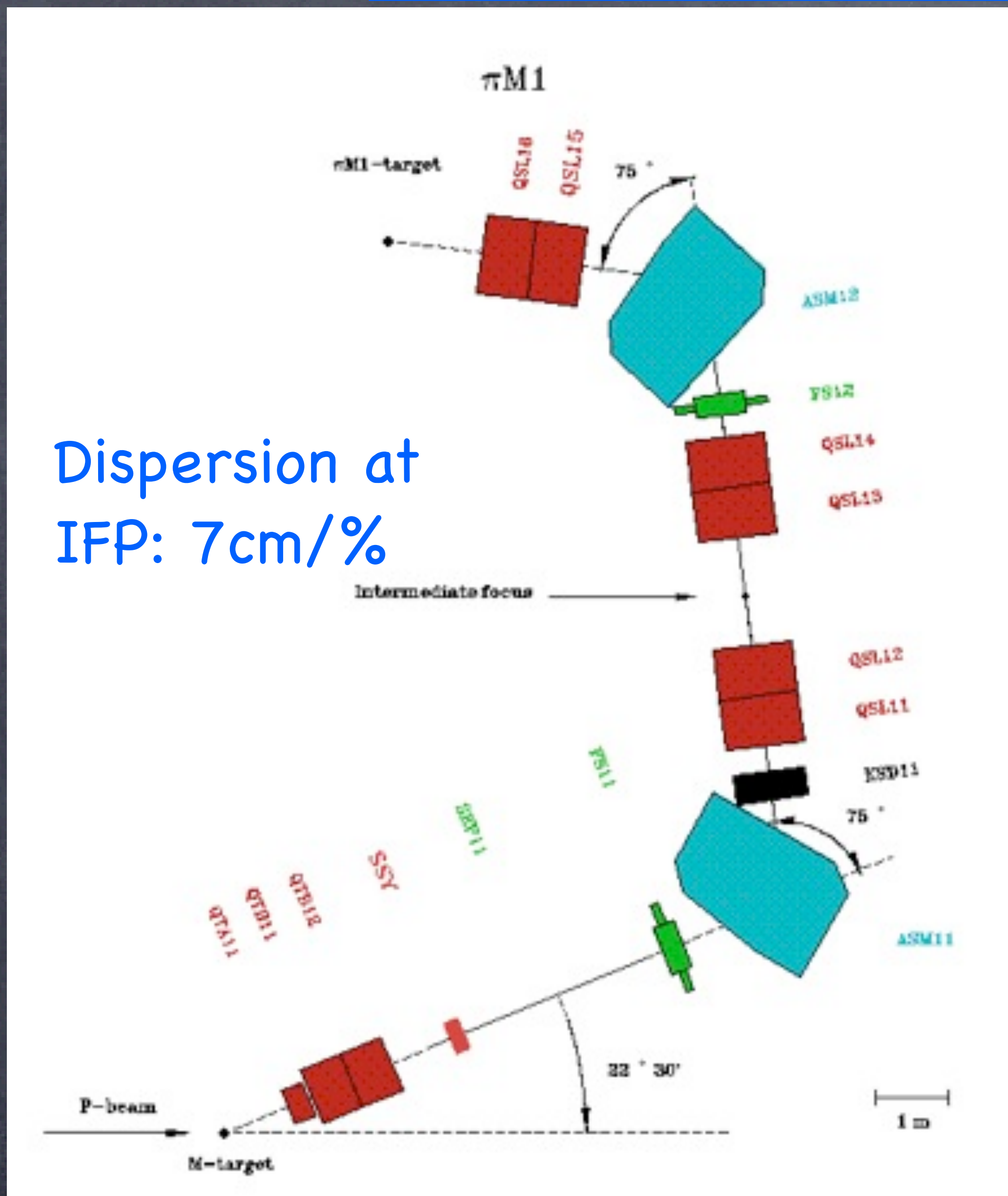
Estimated Results!



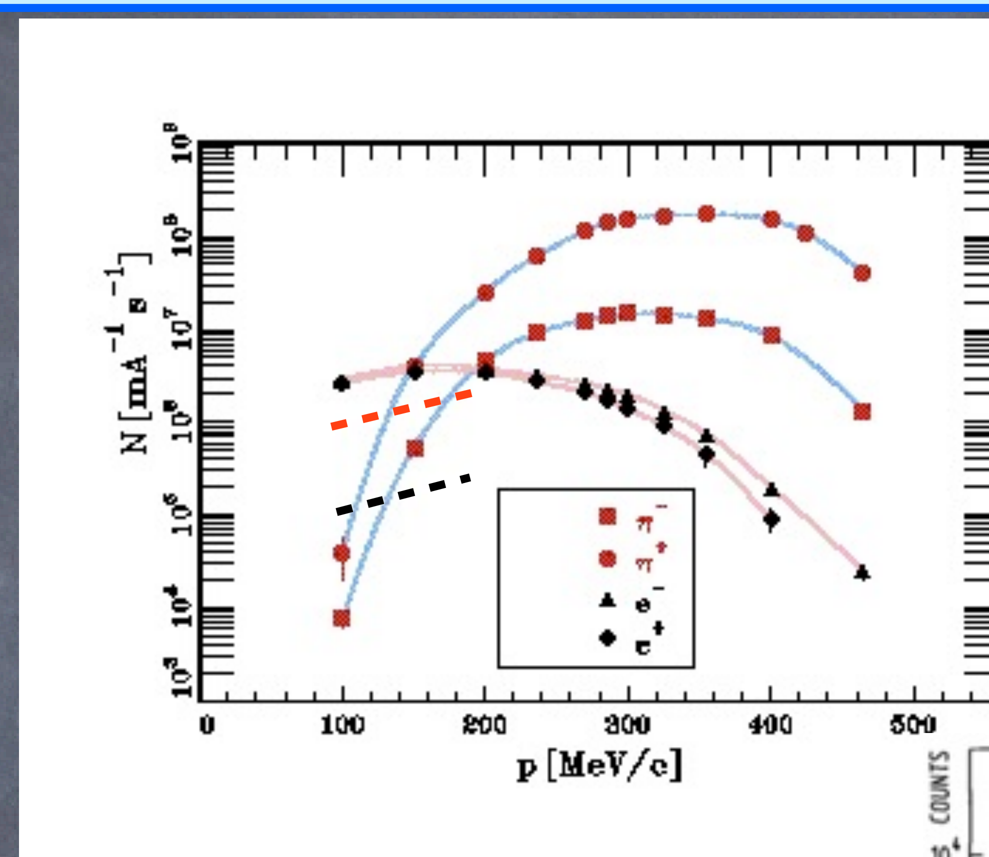
- statistical uncertainties only
- similar results for e⁻p and μ⁻p
- πM1 channel, with p_{in} = 115, 153, and 210 MeV/c: PID reasons.
- Measured rates scaled to 5 MHz, 1 month signal + 1 month bg
- Choose $\theta_{scatter}$ = 20 - 100°: rates, backgrounds, systematics.
- Statistical uncertainties include end cap subtractions and μ decay subtractions (for μ's) - the issue for 210 MeV/c at larger Q^2

πM1 Channel - Nominal Characteristics

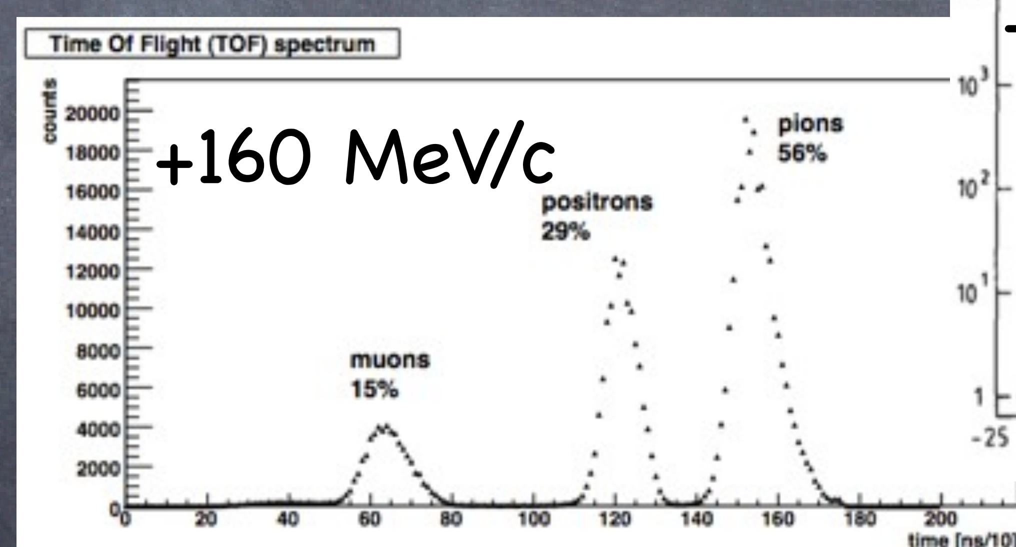
≈100 - 500 MeV/c mixed beam of μ's + e's + π's

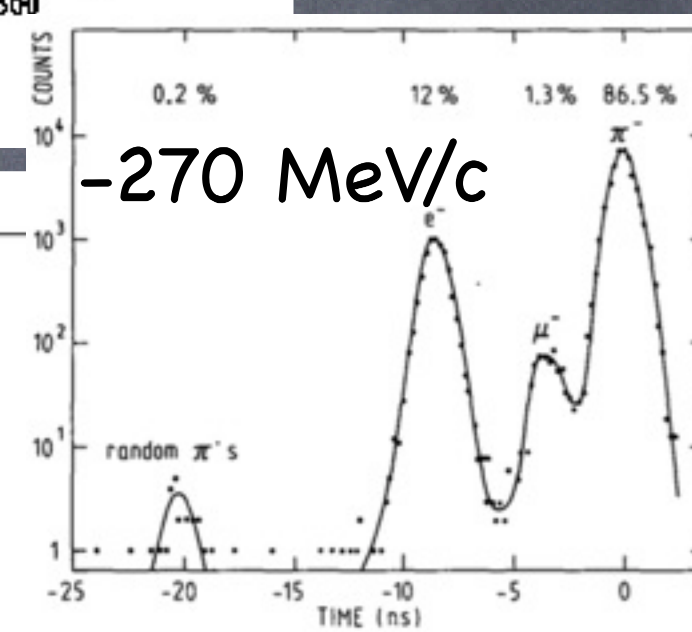


Dispersion at IFP: 7cm/%



January 2012: standard parameters + muon speculation





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

Momentum acceptance: 3% resolution: 0.1%

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

Fall 2012 Test Run

MUSE Test Run Report

The MUon proton Scattering Experiment collaboration (MUSE):

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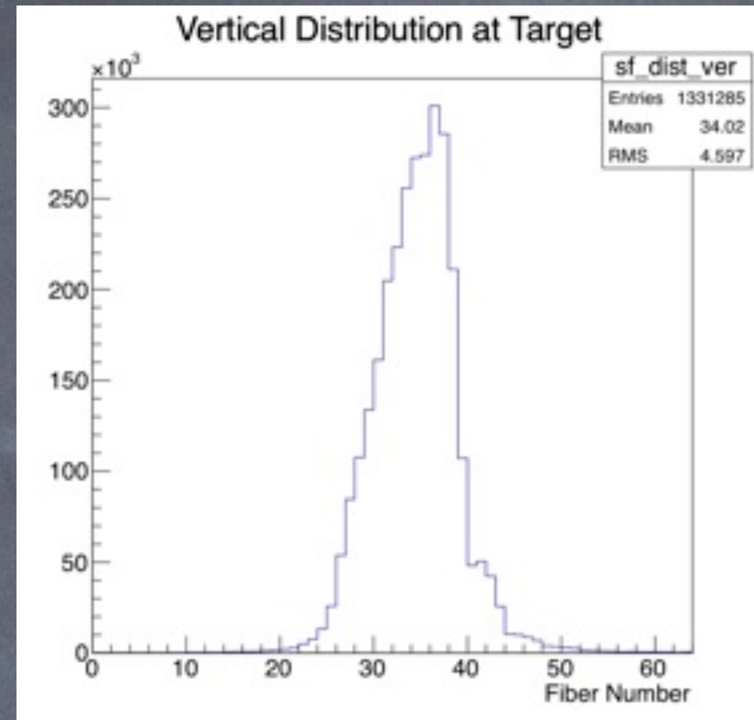
Recycled (3 mm) SciFi + prototype SC scintillators (5 cm x 5 cm)

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

NIM trigger, VME read out, working physicists

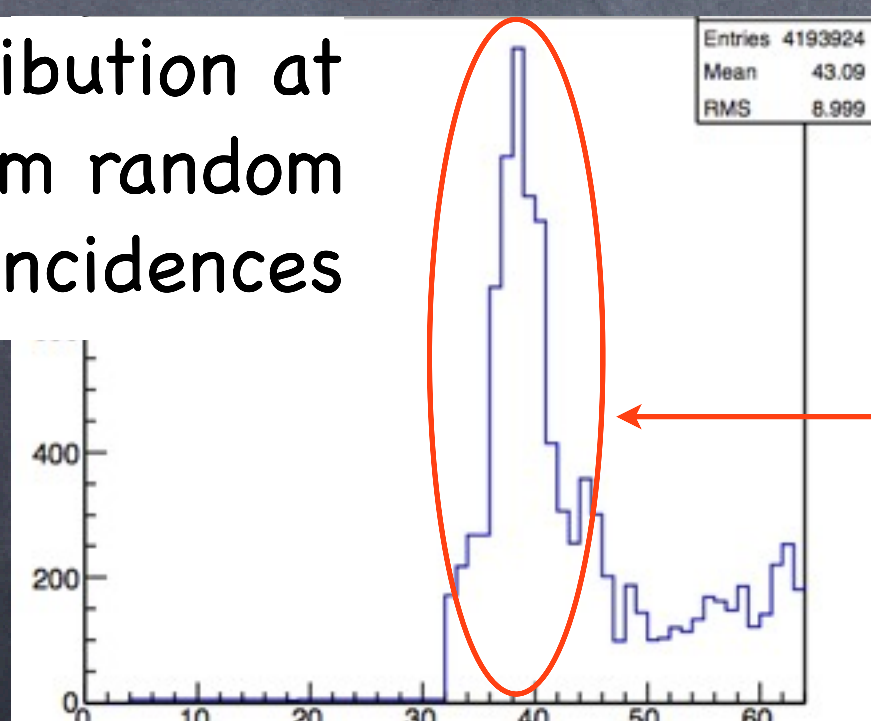
πM1 Channel - Beam Envelope

Pre-optimal tune: measured beam spot with SciFi array and found no significant dependence on particle type - also at IFP



target distributions visually the same for all particle types, but RMS always slightly larger for π's

vertical distribution at IFP from random coincidences

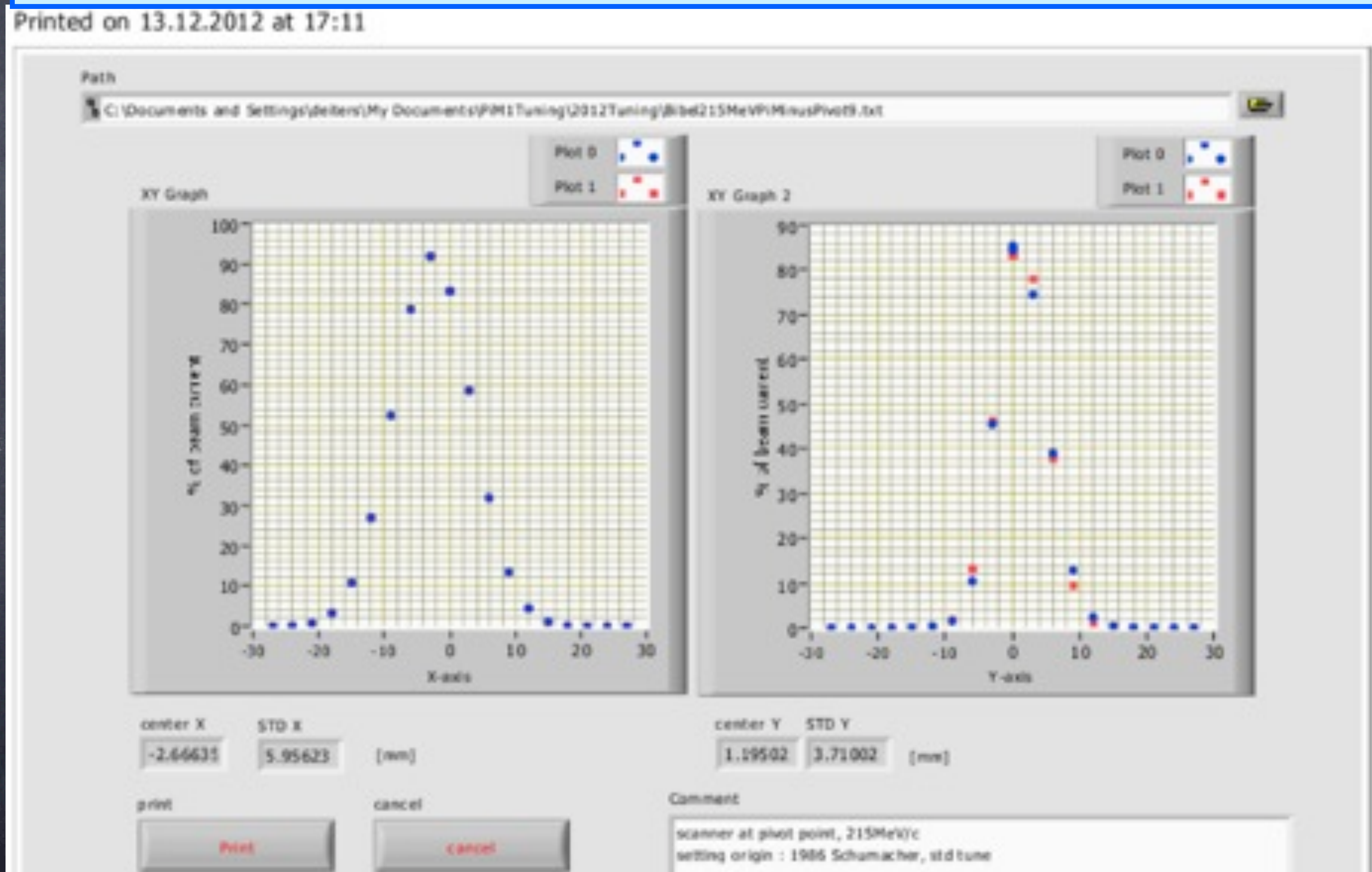


background: ≈99.9% of particles reaching target within 5 cm (15 fiber) vertical region at IFP

πM1 Channel - Beam Envelope

Beam spot measured by small moving scintillator, with no detector at IFP, after debugging + tuning:

$\sigma_{X(Y)}$ = 6(4) mm $FW_{X,Y}$ = 4.0(2.5) cm



Background at IFP

- Large background rate at IFP - up to 200 MHz!
  - Neutrals - we detected ≈30 MHz in a ≈6x oversized detector
  - ≈1/3 of pions at IFP decay before reaching target
  - Charged particles transported to IFP outside acceptance to reach target
  - Possibly some protons, but it seemed not to be the case.
- To keep IFP detector rates low...
  - Use collimator at IFP to reduce beam flux, not FS11 jaws
  - Cut on momentum acceptance
  - Build detector to appropriate size
  - Reduce planned beam flux from 10 MHz to 5 MHz

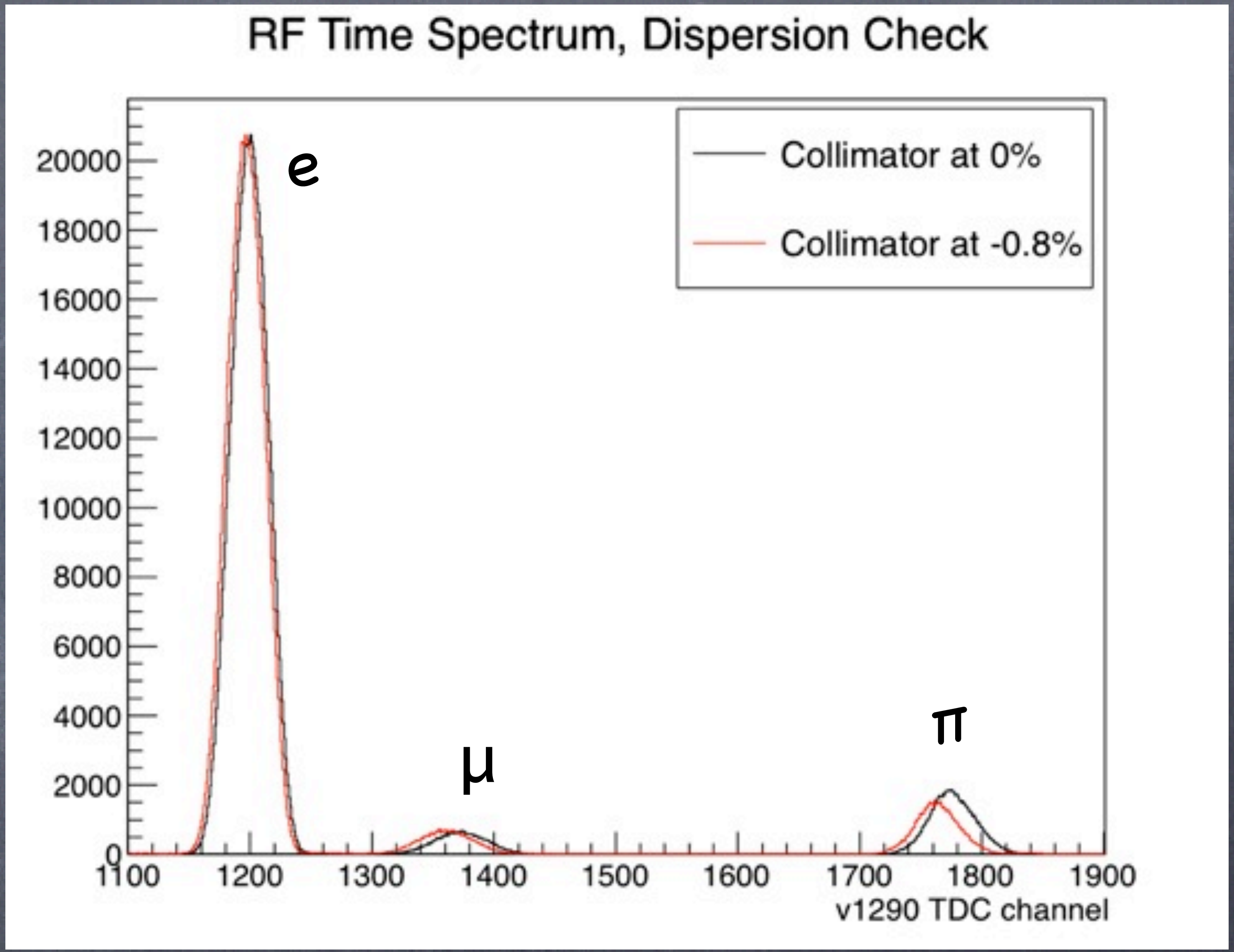
πM1 Channel - Dispersion at IFP

Before final tune developed, checked dispersion at IFP.

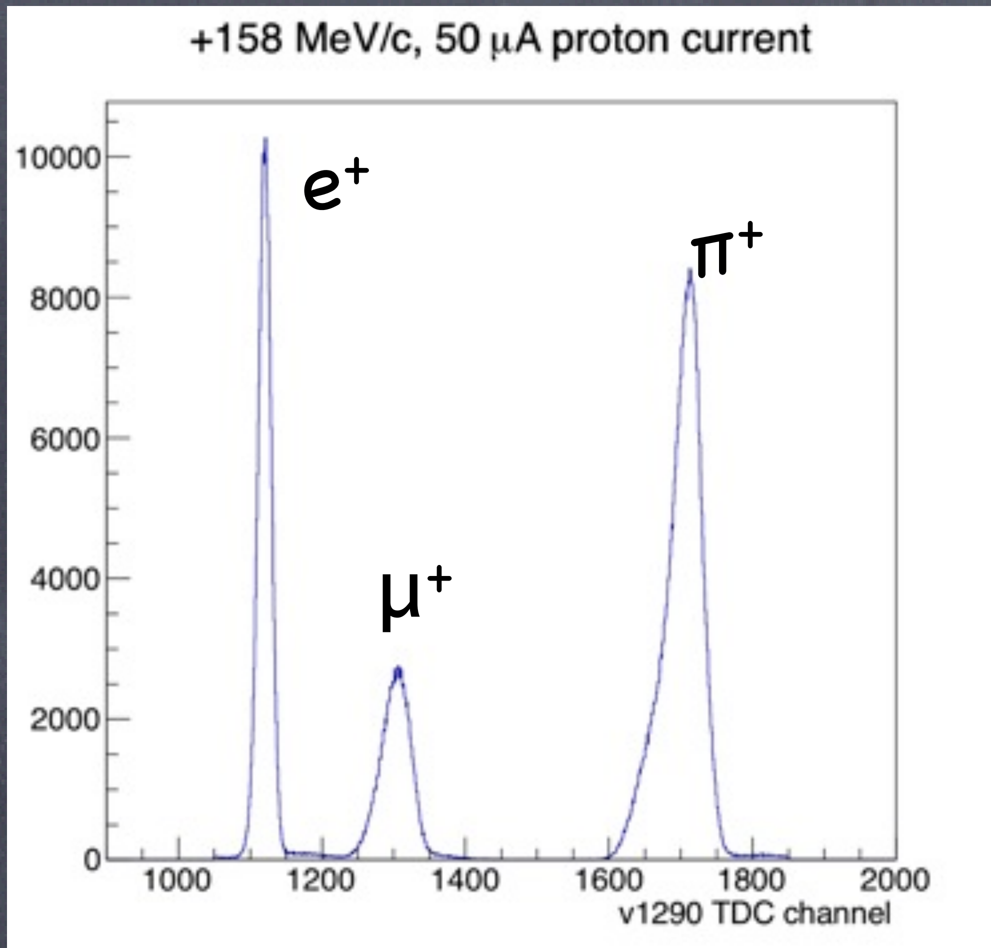
Moved 0.14% wide collimator about 0.8% to look for shift in peak times.

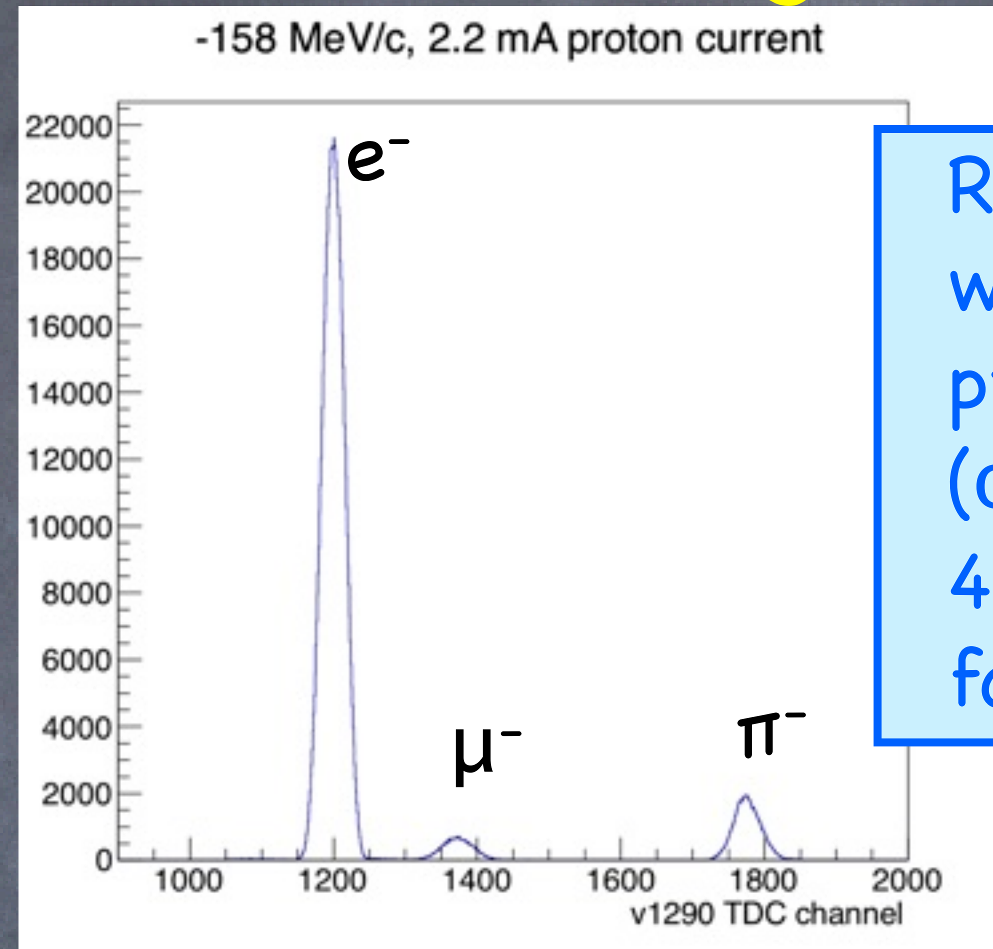
e peak stable to 25 ps.

μ and π peaks shift consistently with each other and with 0.6% momentum change.

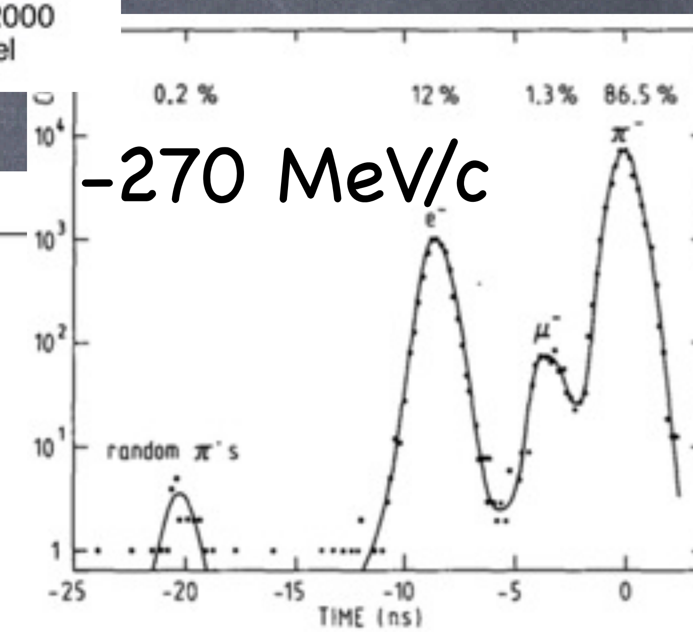


πM1 Channel - RF time in target region

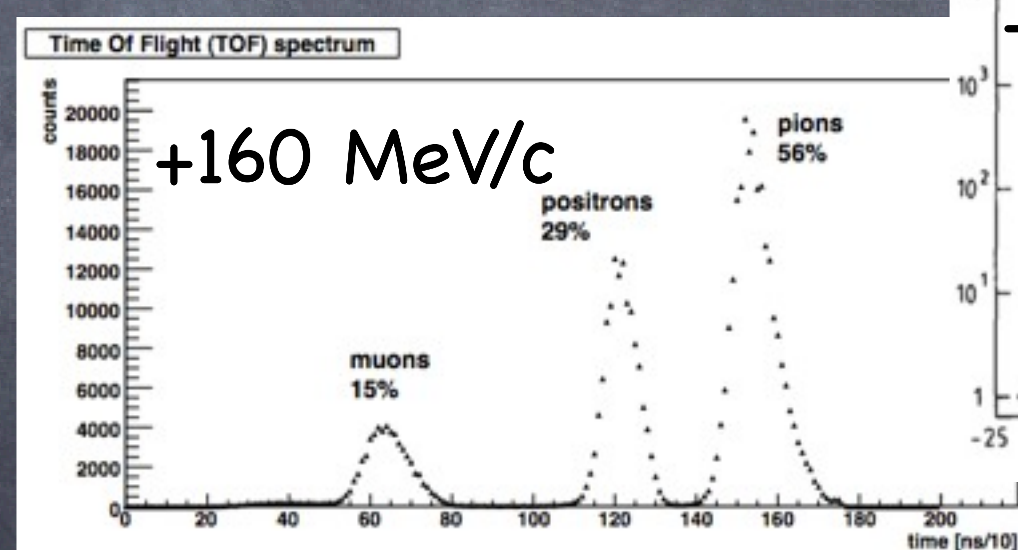




RF peaks broader with 2.2 mA protons, ≈350 ps (σ) for e's and 400 - 500 ps (σ) for μ's and π's



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 - 160 reversed from our 158

πM1 Channel - particle fluxes

for full channel acceptance with 2.2 mA primary proton beam
(Our measurements of relative flux + earlier πM1 data for absolute e and π flux.)

p (MeV/c)	π (MHz)	μ (MHZ)	e (MHz)	Σ (MHz)
+115	0.72	0.72	6.7	8.3
+153	7.1	2.0	7.8	17
+210	65	6.1	8.5	79
-115	0.02	0.2	7.2	7.4
-153	1.3	0.4	10.2	12
-210	10.7	3.7	9.6	24

πM1 Channel - particle fluxes

limiting flux to 5 MHz total, by cutting the 3% momentum bite

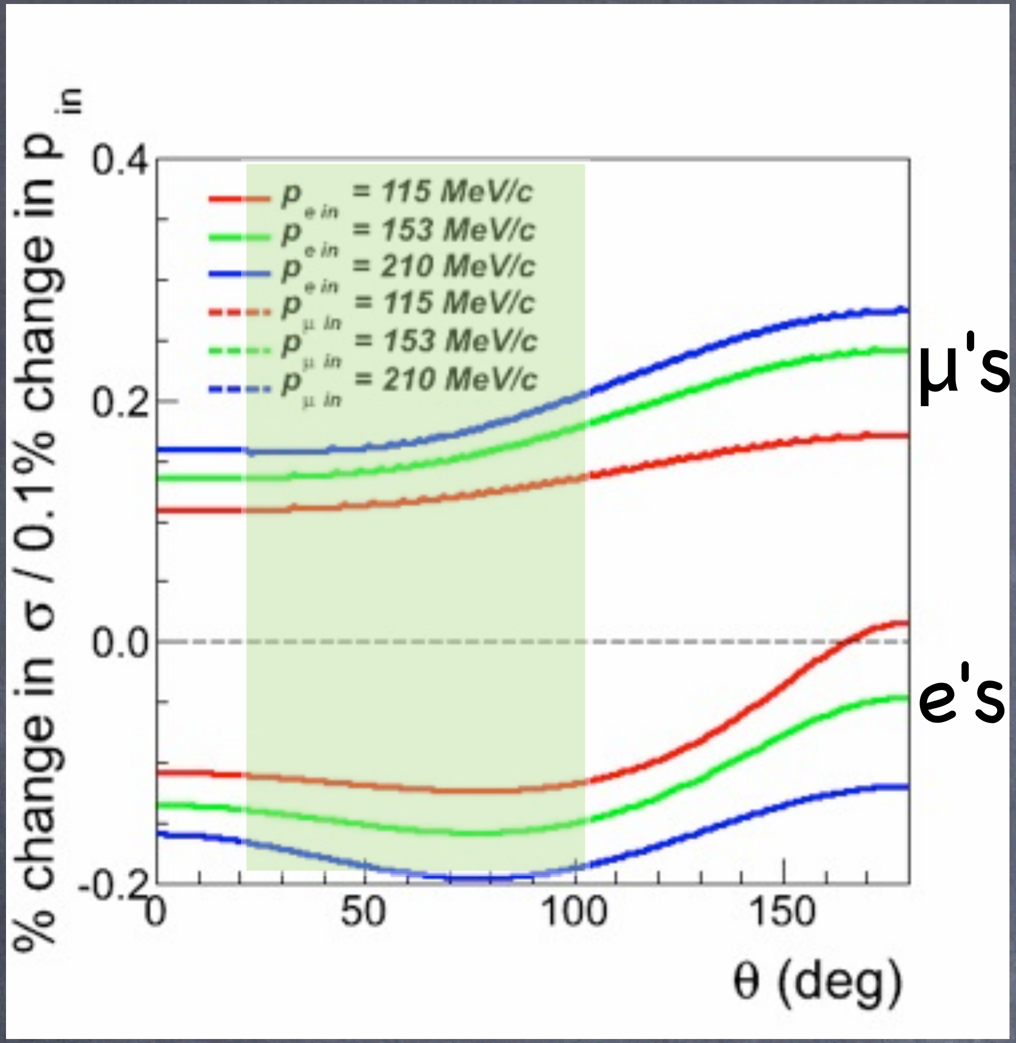
p (MeV/c)	π (MHz)	μ (MHZ)	e (MHz)	momentum bite (%)
+115	0.43	0.43	4.0	1.8
+153	2.10	0.59	2.3	0.9
+210	4.1	0.39	0.54	0.2
-115	0.01	0.14	4.9	2.0
-153	0.55	0.17	4.3	1.3
-210	2.23	0.77	2.0	0.6

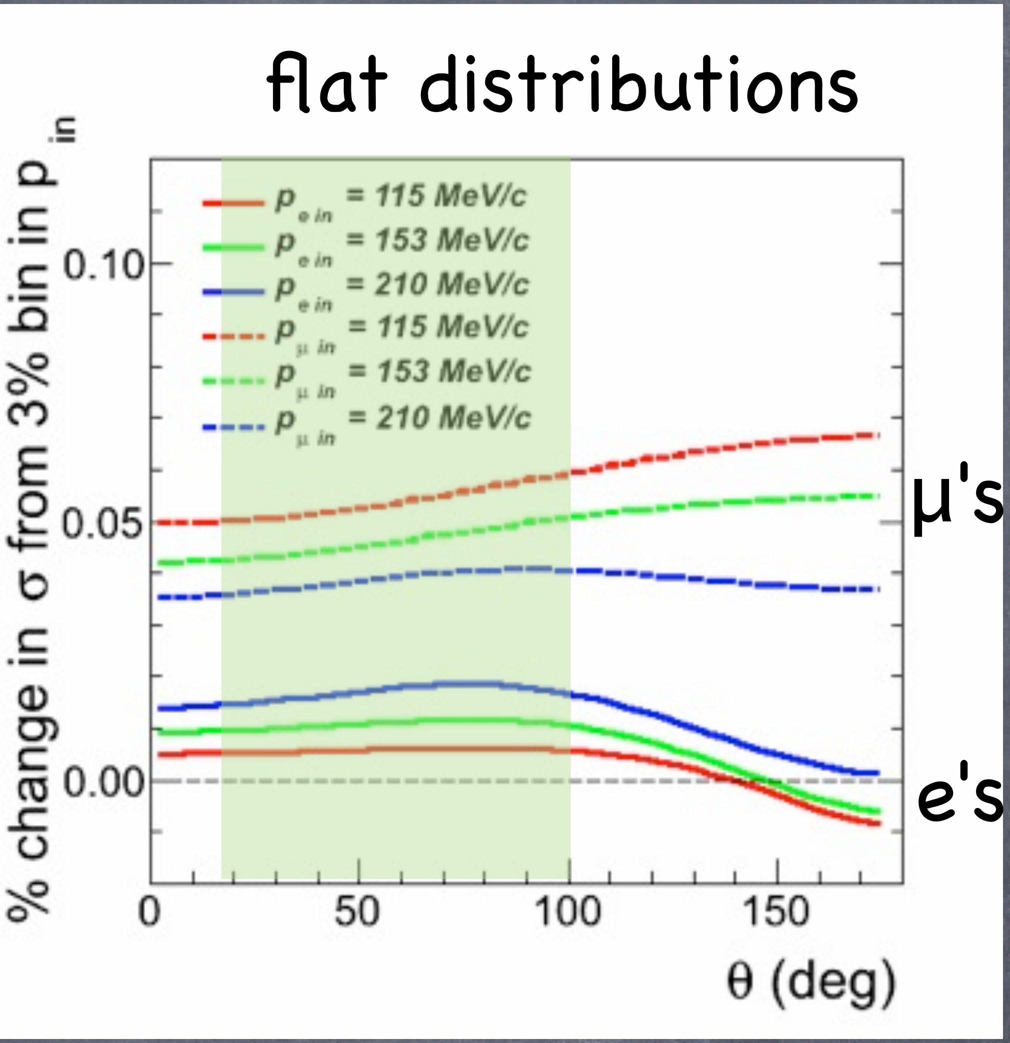
Flux of e's 1.4 - 35 times larger than flux of μ's

Beam Line Summary

- Good flux of μ's at target, much better flux of e's
- Beam properties independent of particle type
- Time width of particles assumed to be 500 ps (σ) - will indicate later this is not a problem - although electrons appear to be ≈350 ps
- Protons not an issue at our momenta
- Reduced planned beam flux from 10 MHz to 5 MHz to ease background rate issues, mainly at IFP, but also accidental coincidences at target

Beam Momentum Systematics to Control





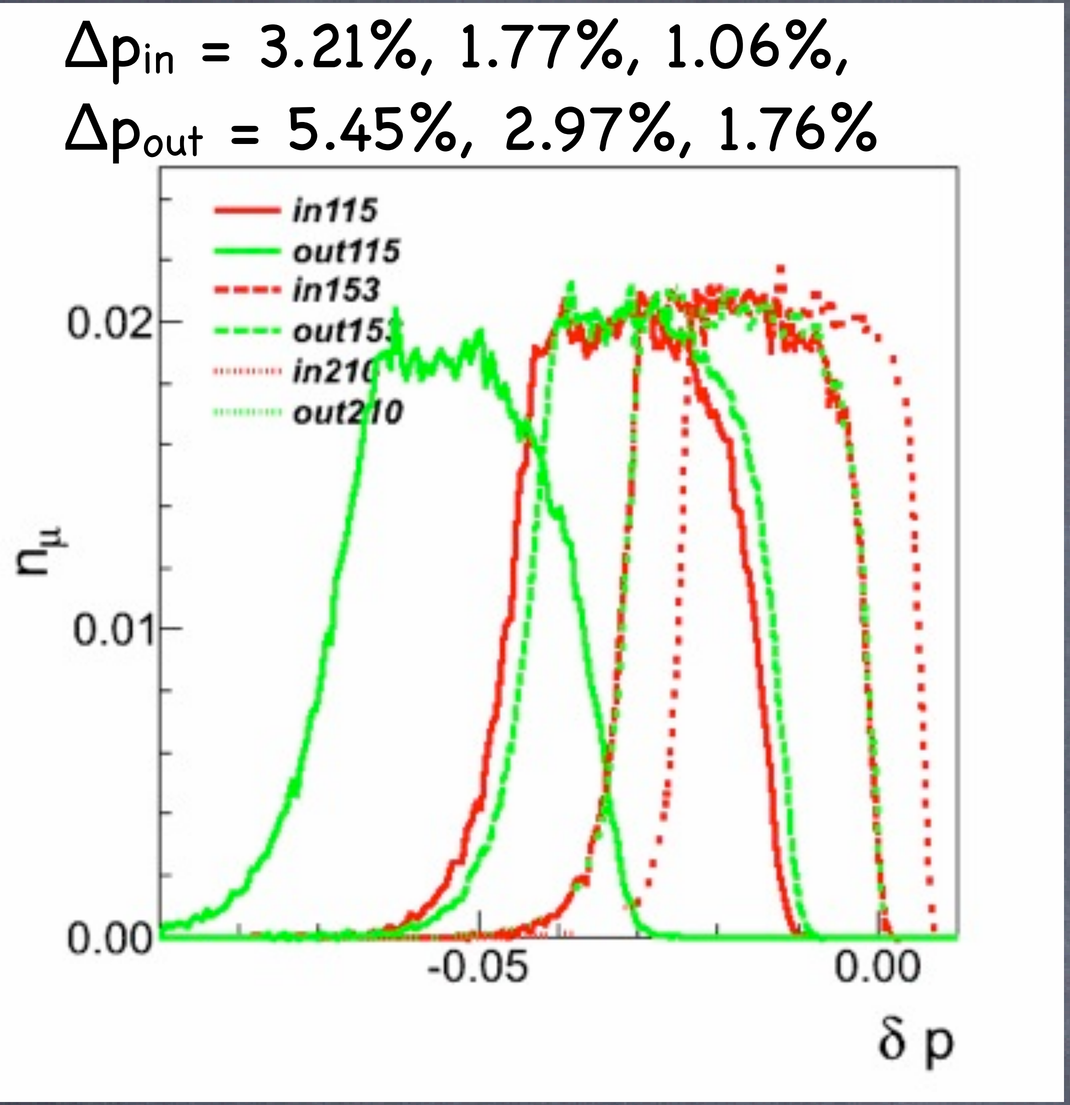
Left: momentum offsets and averaging act like a small normalization change. Effect slightly different for e's and μ's.

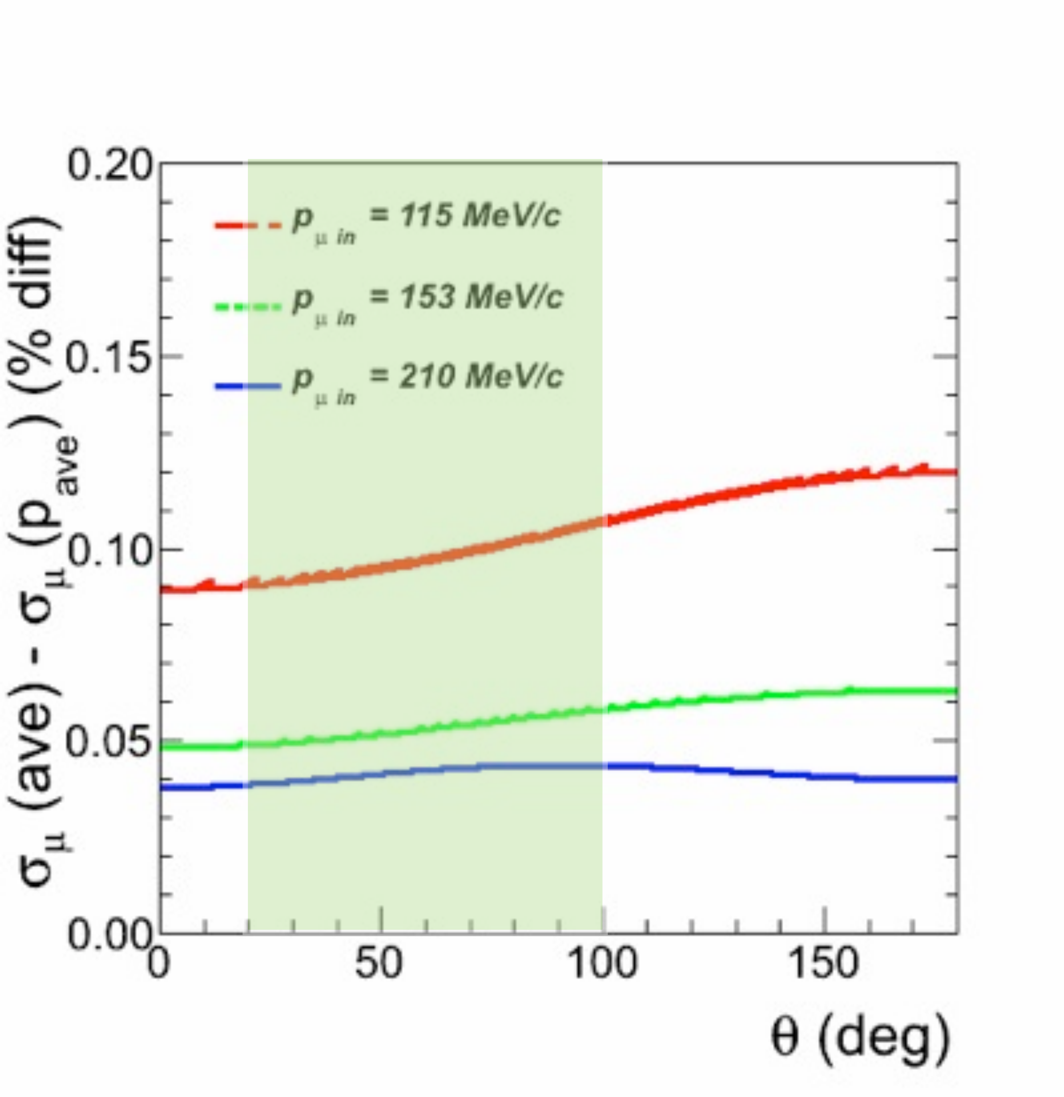
Right: averaging over momentum range vs assuming at central momentum acts like even smaller momentum change.

Plan to measure central momentum to 0.1% - 0.2% through TOF.

Directly calculated from cross section formula, Kelly form factors.

What Happens with a Realistic Muon Spectrum?

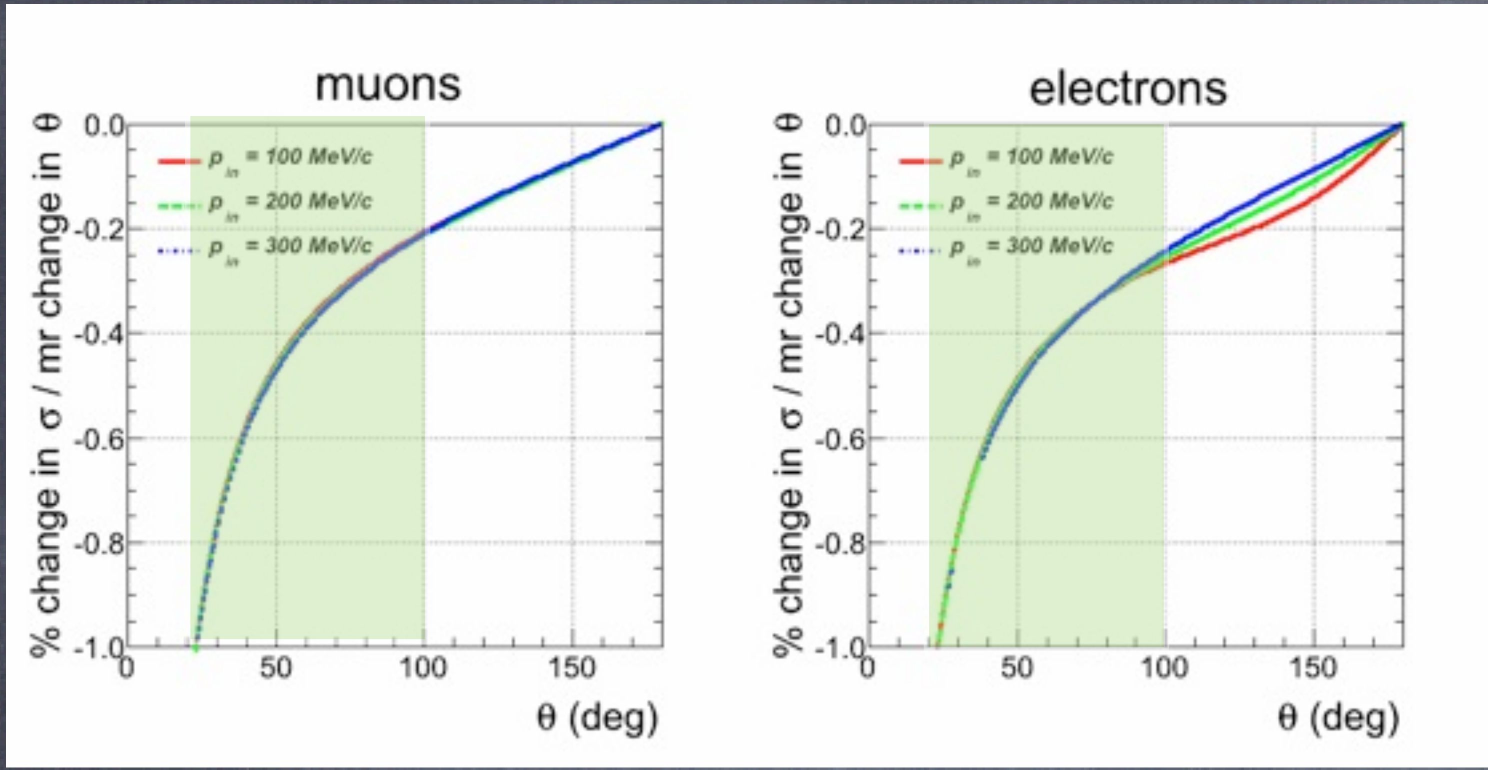


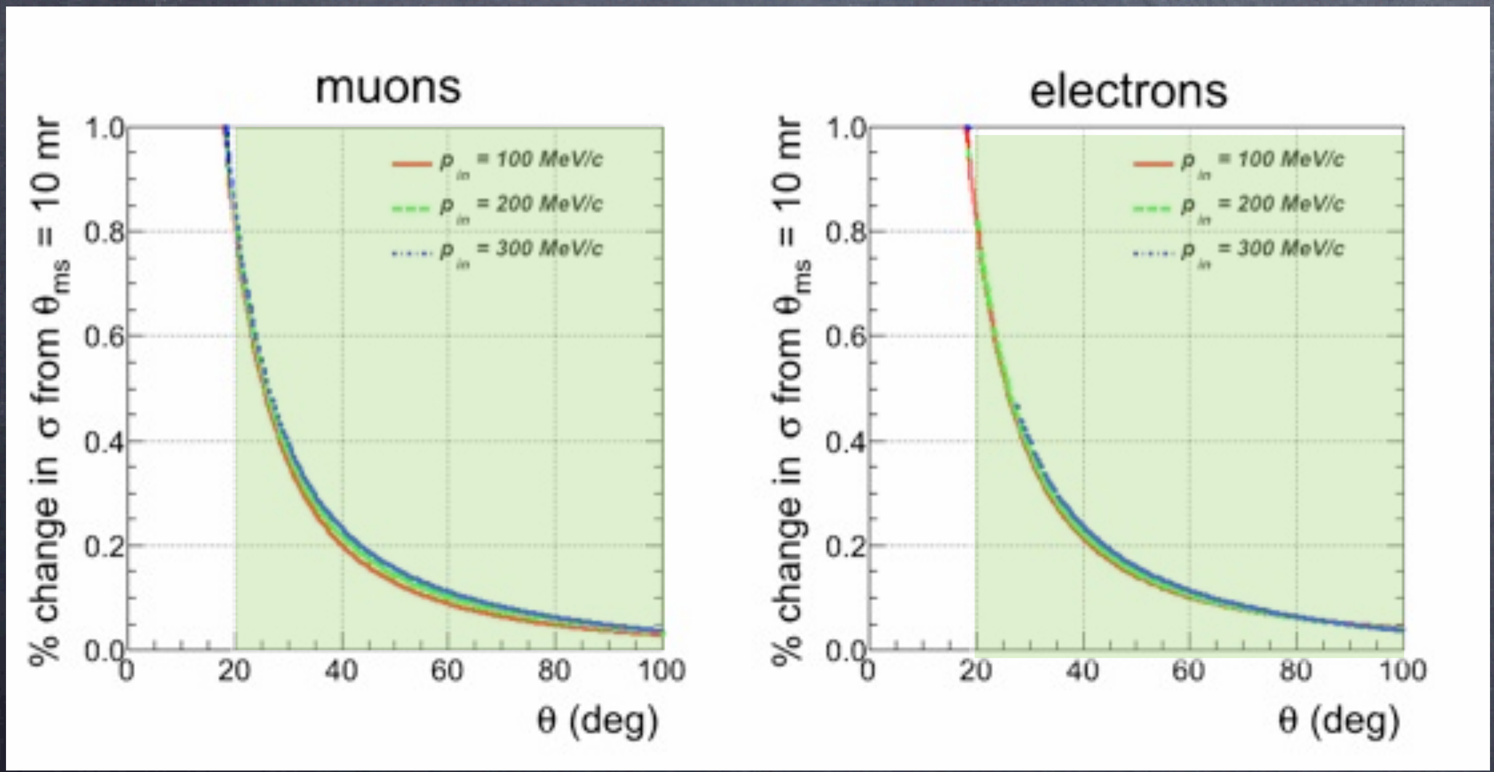


Left: Used Geant4 starting with flat spectrum 3% wide centered at δp = 0, generated spectrum shape into and out of the cryogenic hydrogen target (after passing through SciFi's + GEMs).

Right: redid averaging procedure, comparing to central momentum predicted by Geant4. The effect remains small, can be corrected out with the simulation, and does not matter for normalized data.

Beam Angle Systematics to Control



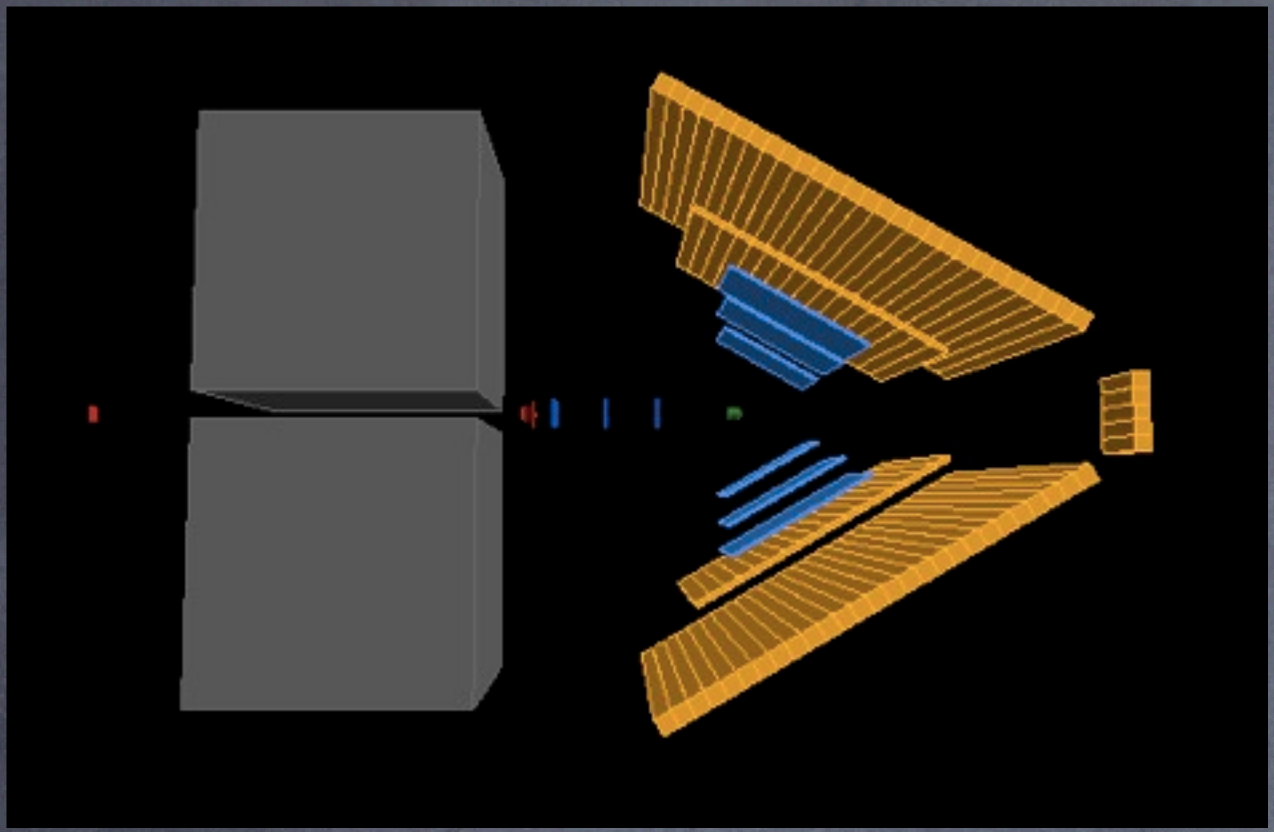


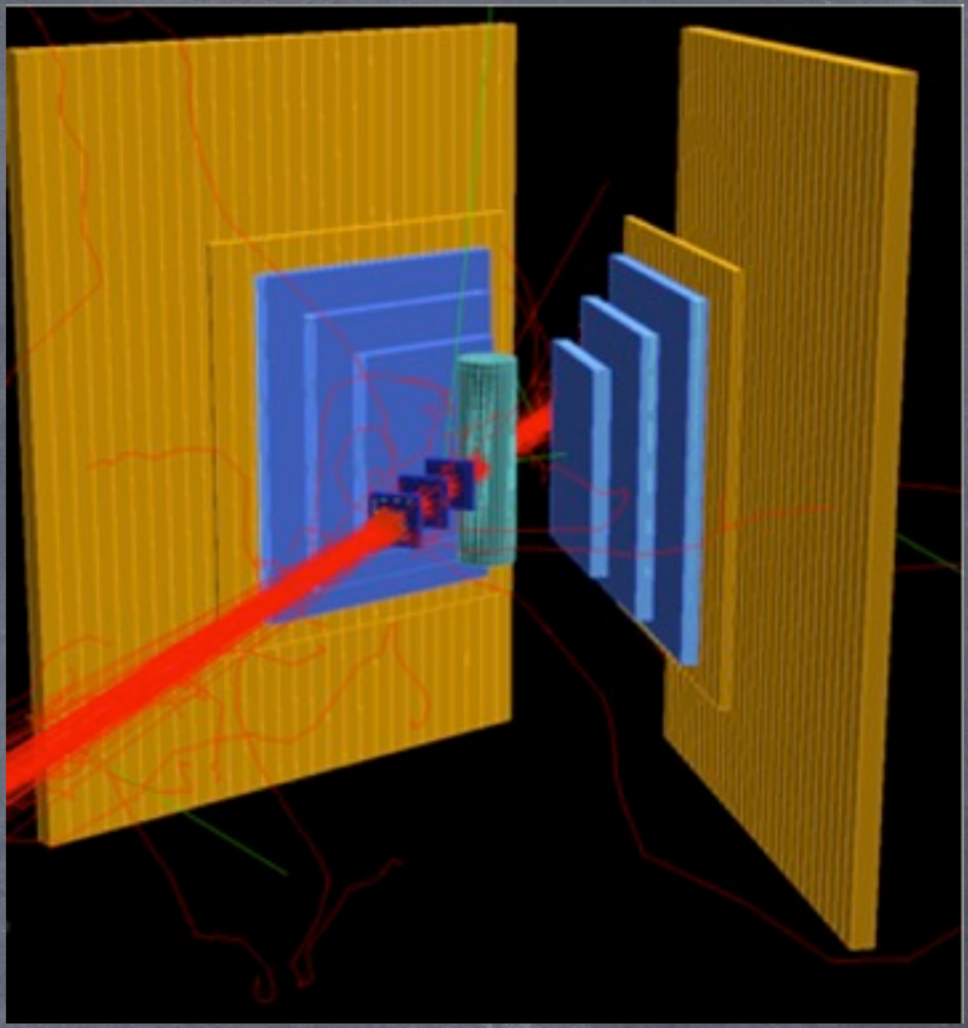
Should know central angle to mr level, but can average over several mr. We are near the 10-mr limit with 115 MeV/c μ's.

Effects essentially the same for e's and μ's, and for all beam momenta.

Will determine central angle in dedicated calibration run to < 1 mr.

``How do we do this?'' Detector Cartoon





One of many Geant4 simulations we have done.

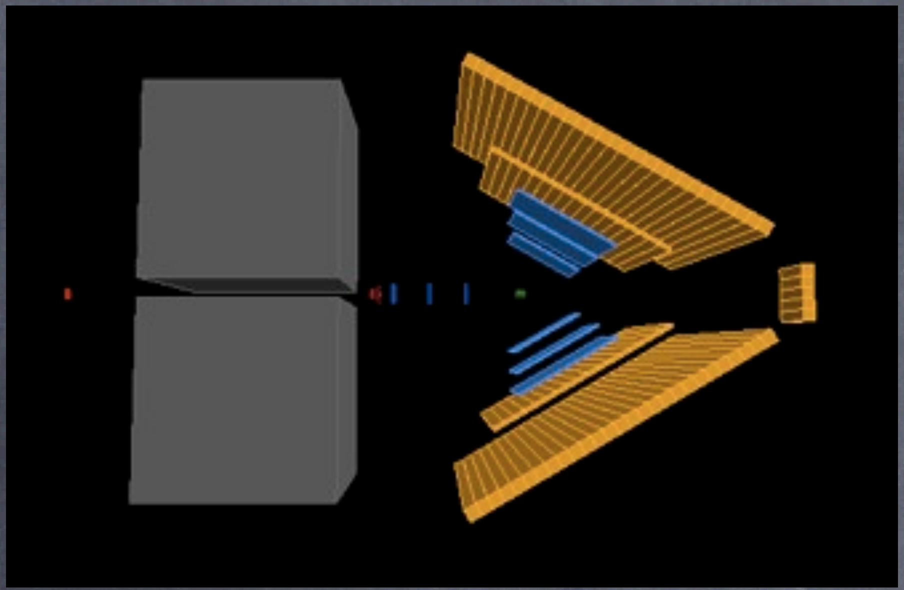
Beam passes though IFP SciFi array, shielding wall, target SciFi array, beam quartz Cerenkov, GEM chambers, target, and beam scintillators.

Wire chambers and scintillator walls detect scattered particles.

Geant4 to estimate background ginles and trigger rates. Target / collimator backgrounds are very sensitive to beam distributions; we do not yet have detailed enough beam information for simulation and design - a goal for mid 2013 test run with GEMs.

New Equipment Summary

Detector	**Who**	**Technology**
Beam SciFi	Tel Aviv, St. Mary's	conventional
GEMs	Hampton	detector exists
Quartz Cerenkov	Hebrew	prototyped
FPGAs	Rutgers	conventional
target	Hebrew	conventional
wire chambers	MIT	copy existing system
scintillators	SC	copy existing system
DAQ	GWU	conventional, except TRB3 prototyped

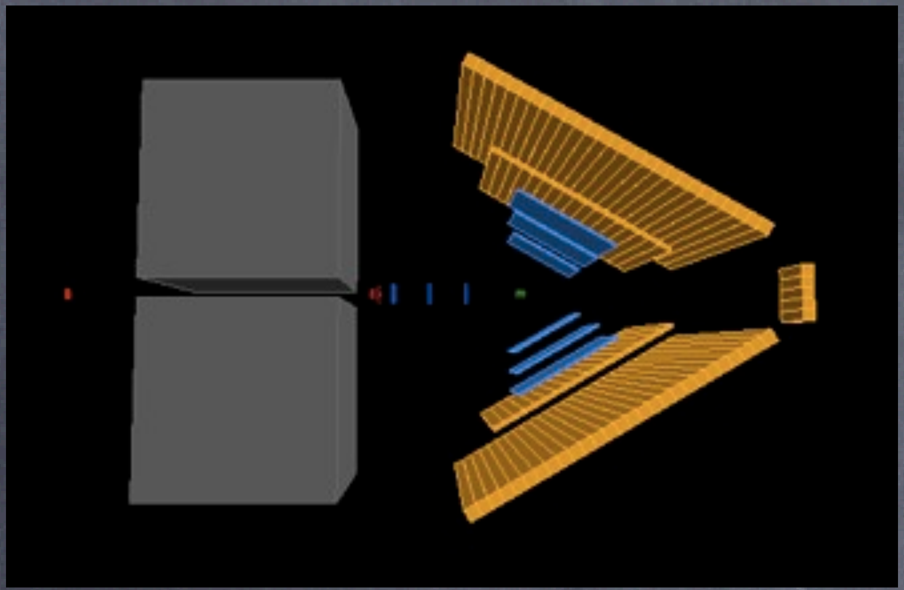


Beam SciFi's

Tel Aviv U, St. Mary's U

- At target, PID with RF time for beam flux normalization for absolute cross sections + triggering, position and time for correlations with GEMs to determine trigger vs random tracks
- At IFP, PID for triggering and position for determining momentum
- TOF between two counters for PID

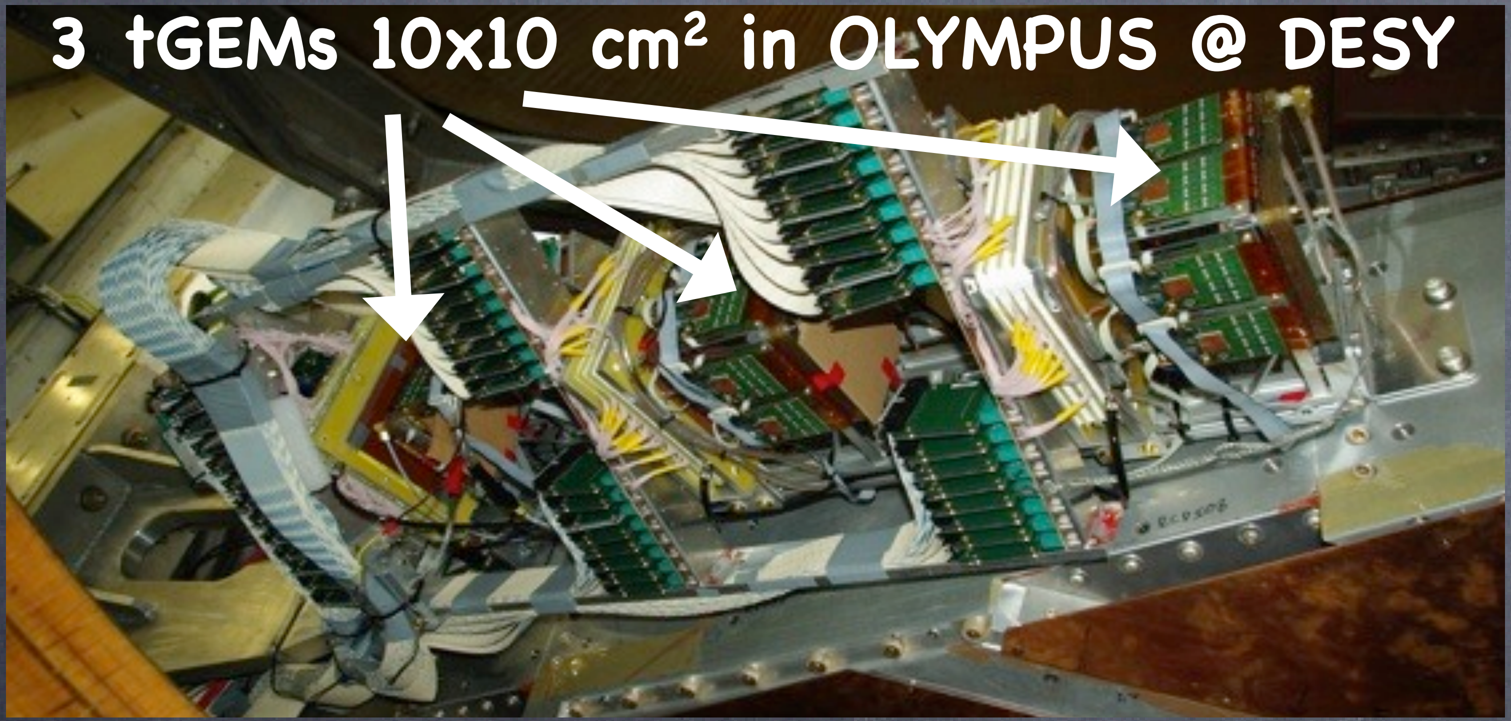
Plan to use well-established conventional technology - 2 mm fibers with double-ended maPMT read out. Resolution of about 1 ns (σ) demonstrated with prototype. XX' (XYU) orientations for SciFi (target) detector, with ≈120 (100) fibers about 8 cm maximum active area.



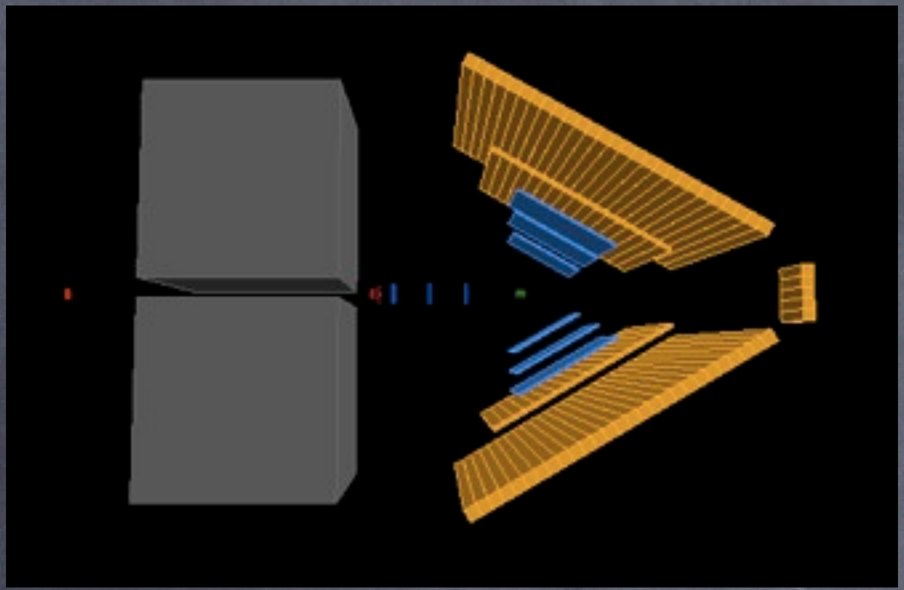
GEM Chambers

Hampton U.

- Determine trajectory into target for scattering angle and Q^2
- Third GEM to reject ghosts



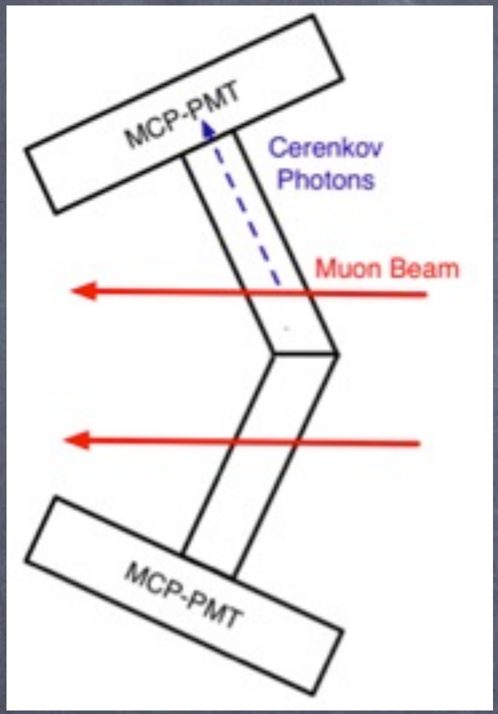
Existing GEMs built for and used in the DESY OLYMPUS experiment. The GEMs are basically all set to be used as is, but need a small amount of work to speed up the read out algorithm.

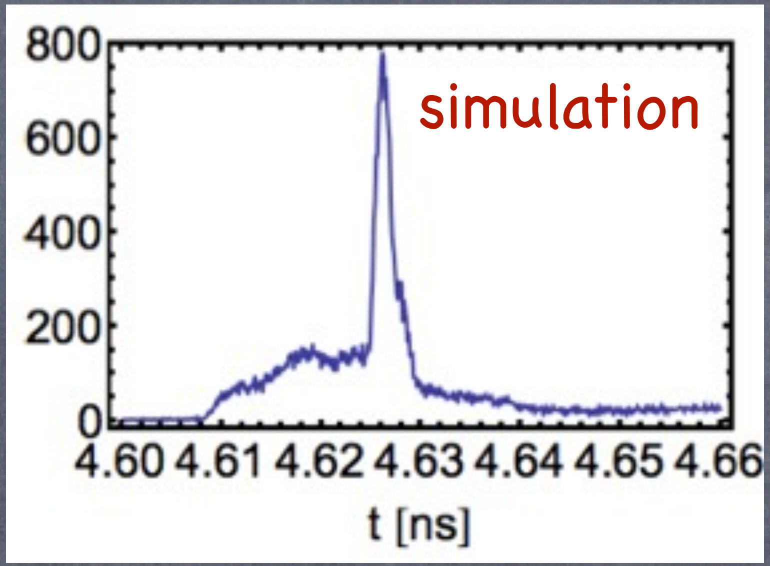


Quartz Cerenkov

Hebrew U.

- Improved timing at target region for
  - better RF time PID in analysis stage
  - Muon decay event rejection

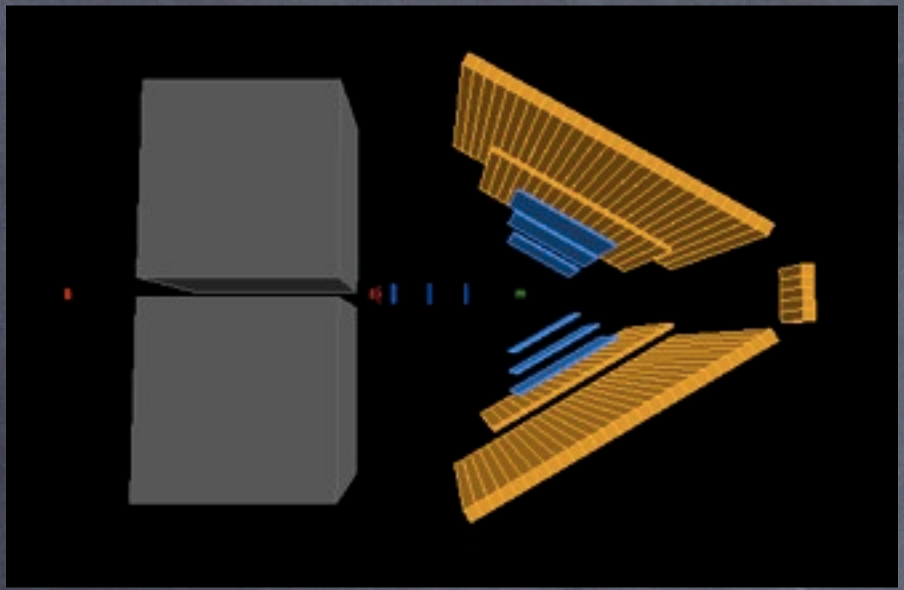




Quatz Cerenkovs by Albrow et al (FNAL) achieved 10 ps resolution.

Key feature to good timing is orienting quartz at the Cerenkov angle.

In our case, we have 10x fewer photons, and a larger beam spot, so resolution will be ≈100 ps (assumed in muon decay event rejection), but ≈50 ps after hit position corrections are done.



FPGAs

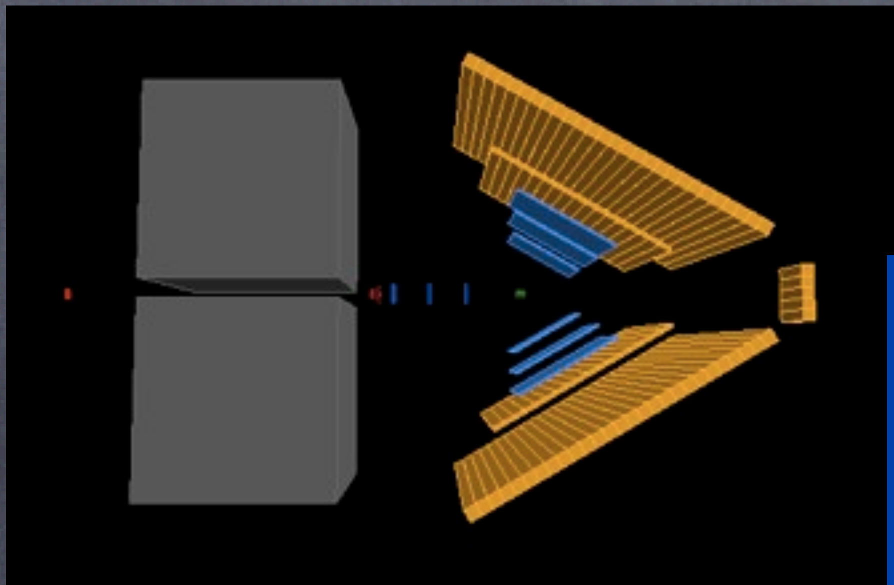
Rutgers U.

- Custom beam PID FPGA
  - Input SciFi and RF signals to determine particle type, counting all types and rejecting pions
  - Can use IFP+target SciFi, or target SciFi alone with some loss of e efficiency at 115 MeV/c
- Trigger FPGA - CAEN v1495: beam PID + scattered particle = trigger

See proposal / TDR for discussion.

With any 1-plane to ID target π, ≈99.9% efficient to reject π's or ID e's and μ's for 153 and 210 MeV/c.

At 115 MeV/c, need to adjust windows and/or 2/3 planes for e's, or will over-reject e's by IDing them as π's.

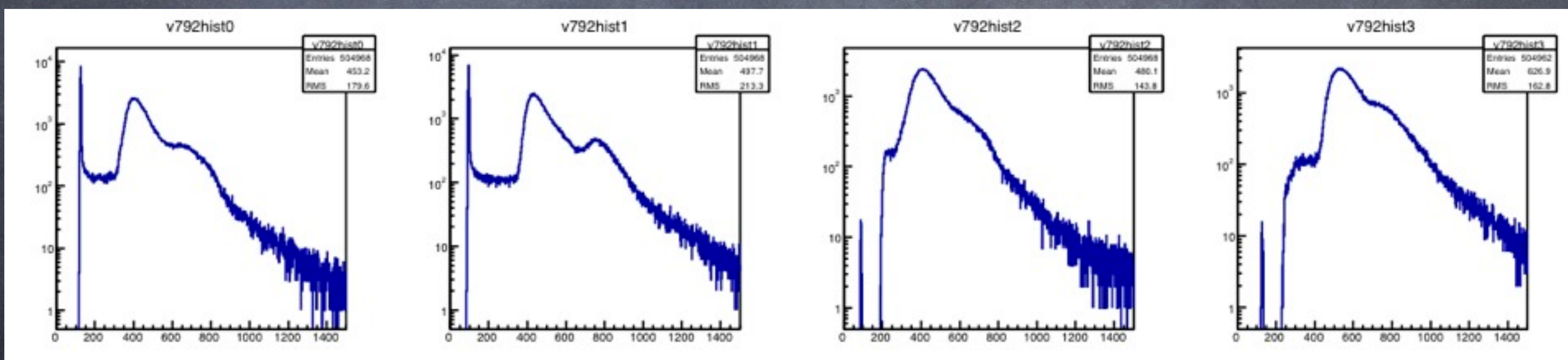


Beam Scintillators

U. So. Carolina

- ``Parasitic'' monitor on random non-triggering beam particles, downstream of target

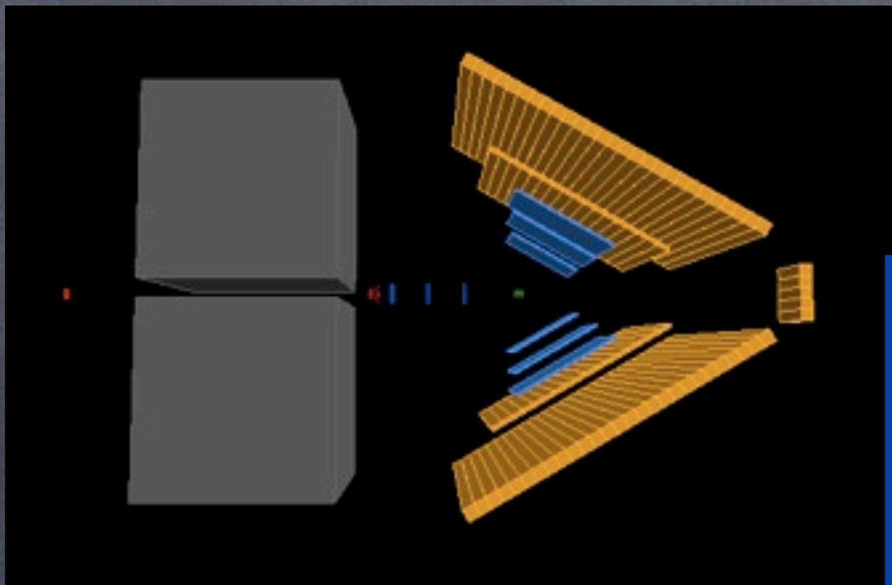
Same So. Carolina design built for JLab CLAS12 as is being used to detect scattered particles - discussed later in talk



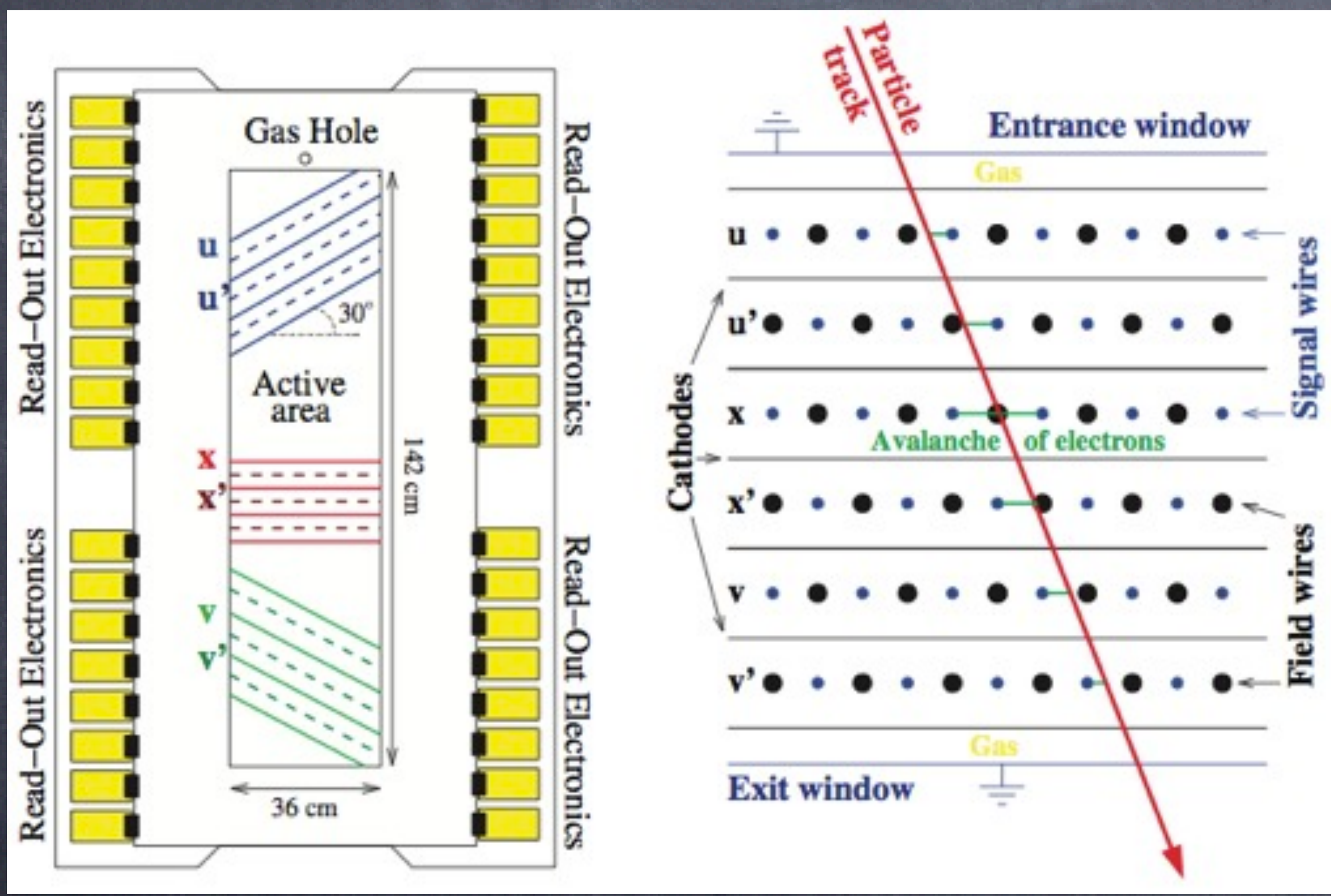
Some test run data - such as these So Carolina scintillator QDC spectra - were taken to verify simulations. The major features of these spectra were predicted by the sulations.

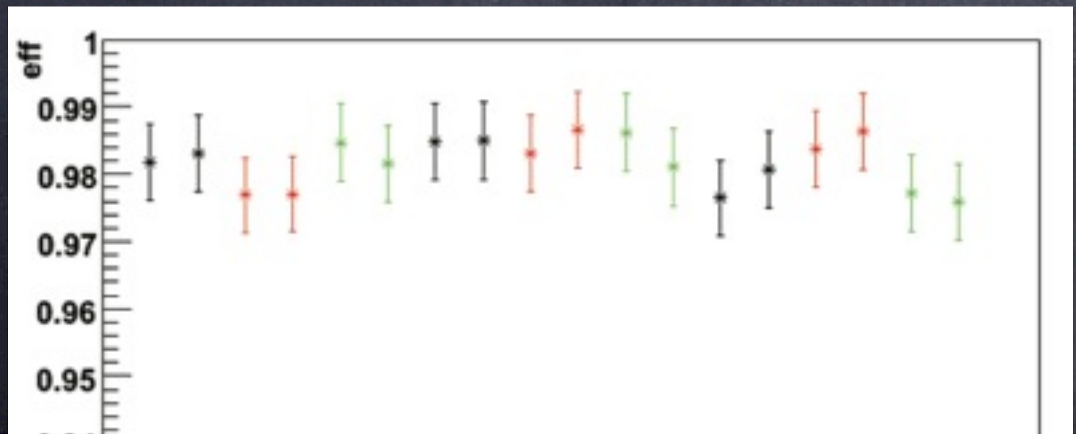
Wire Chambers

MIT



- Determine scattered particle trajectories with high efficiency and resolution.



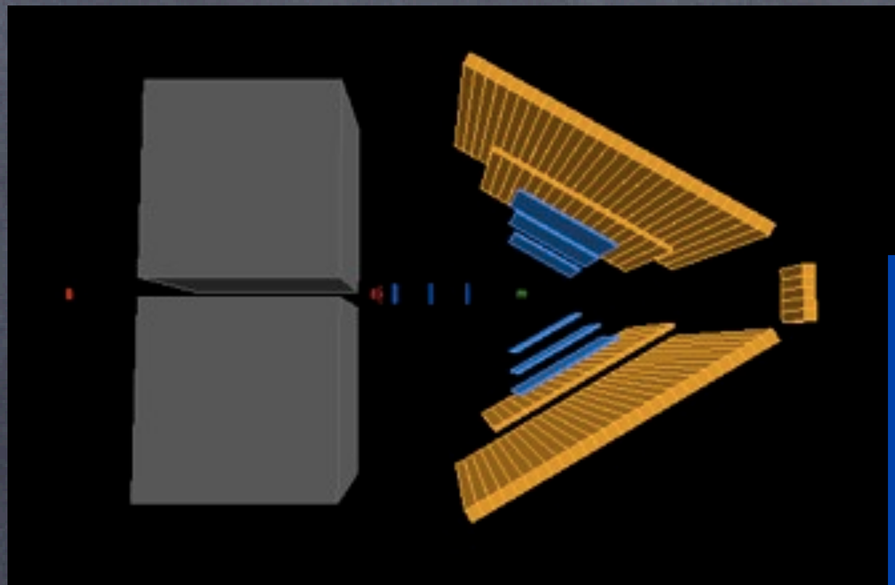


Copying the Hall A / UVa Bigbite design, which gave 98% plane efficiency and 98% tracking efficiency in harsh conditions.

3 UU'VV'XX' chambers

Wire position to 35 μm, particle position resolution to 100 μm

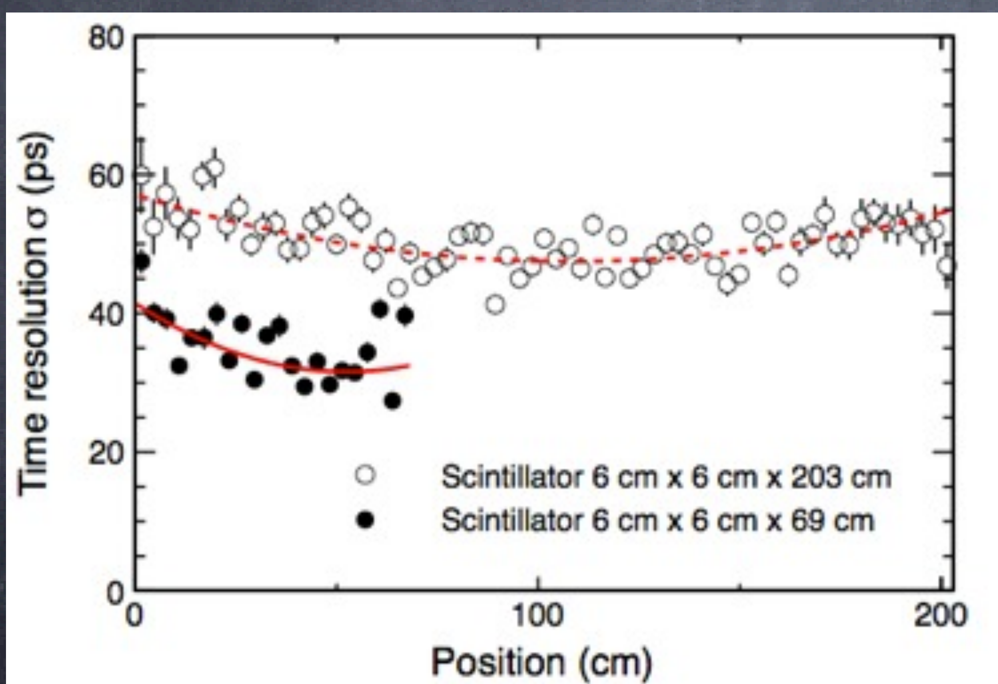
Calibrated relative to GEMs by rotating chambers into beam



Scintillators

U. So. Carolina

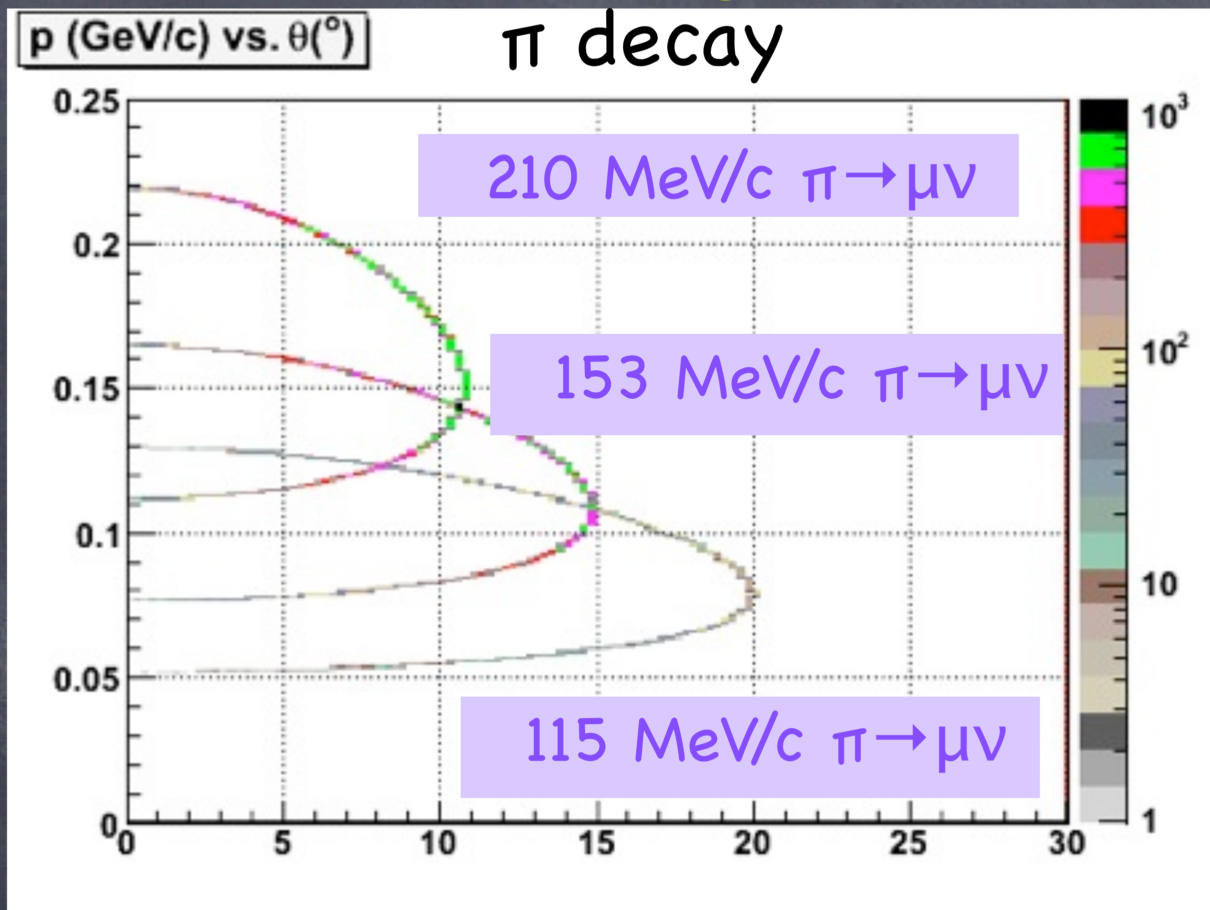
- Detect scattering particles depositing few MeV in each of two planes
- High precision timing for PID and rejection of electrons from muon decay.



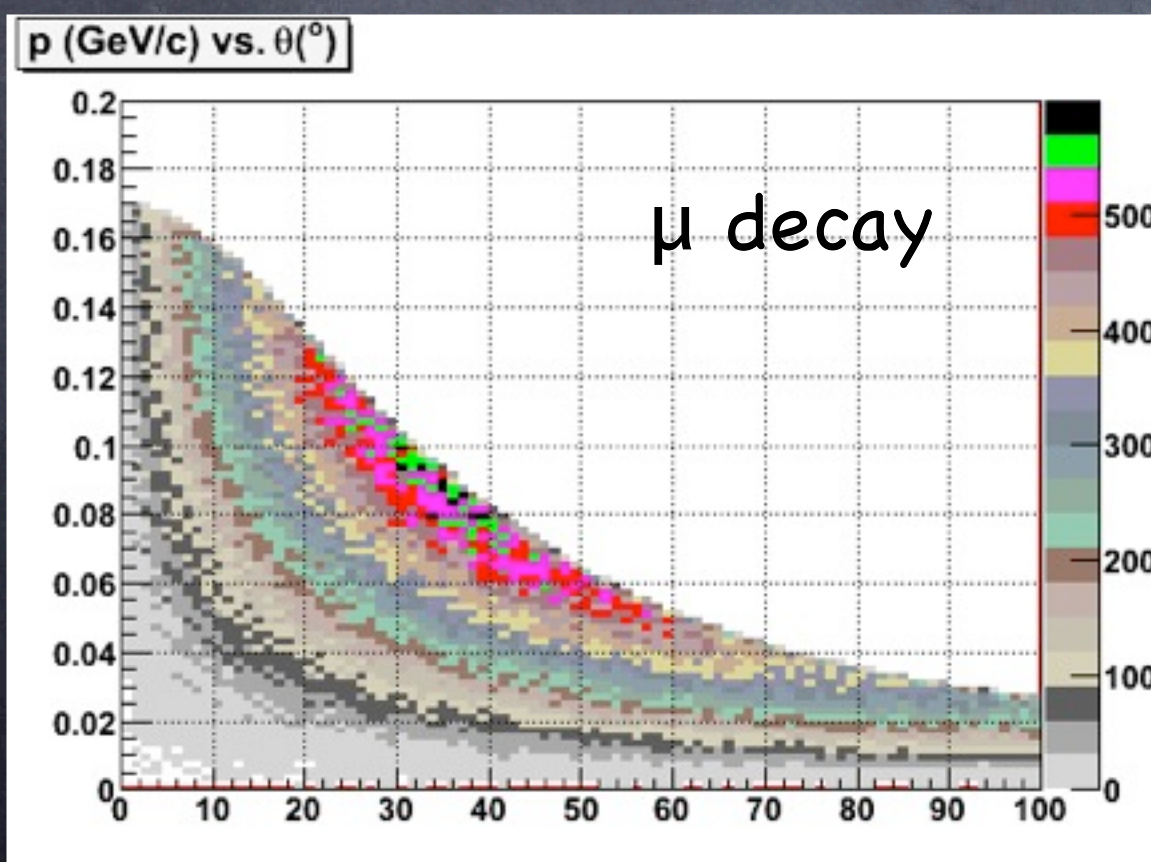
Adopting So. Carolina design built for JLab CLAS12, with front (rear) plane having 17 (27) scintillator paddles of 6 cm wide x 2 (6) cm thick x 103 (163) cm long, about 50 (73) cm from target

Expect ≈40 (50) ps resolution for front (rear) paddles

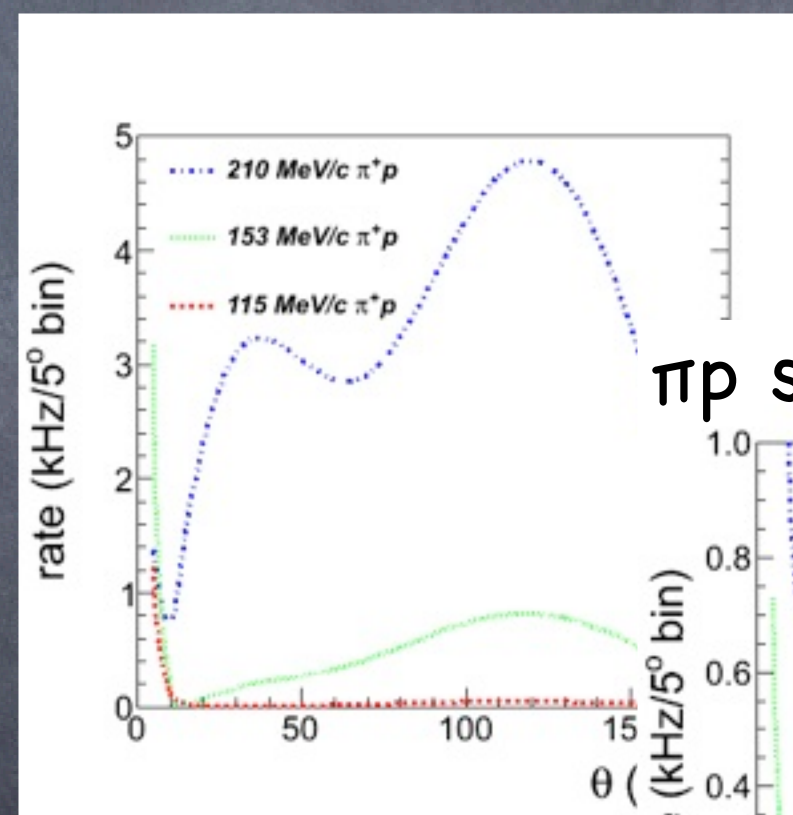
Backgrounds

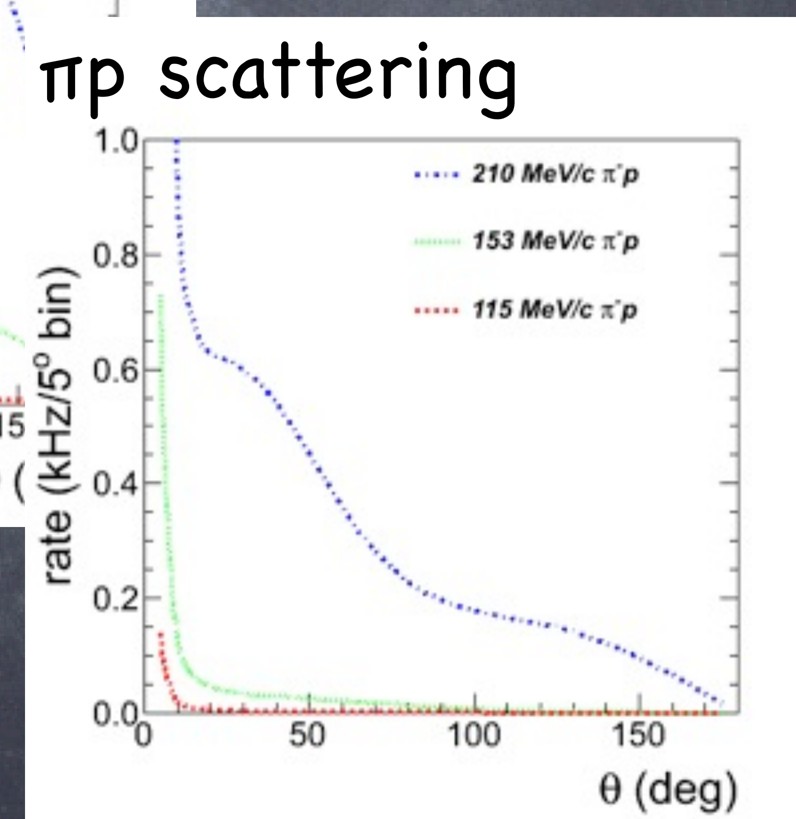


Used Geant4 to simulate many backgrounds. Most lead to rates in detectors but not many triggers, and can be rejected in analysis. The main issues are μ decays and end cap scattering, which cannot be removed at the trigger level.

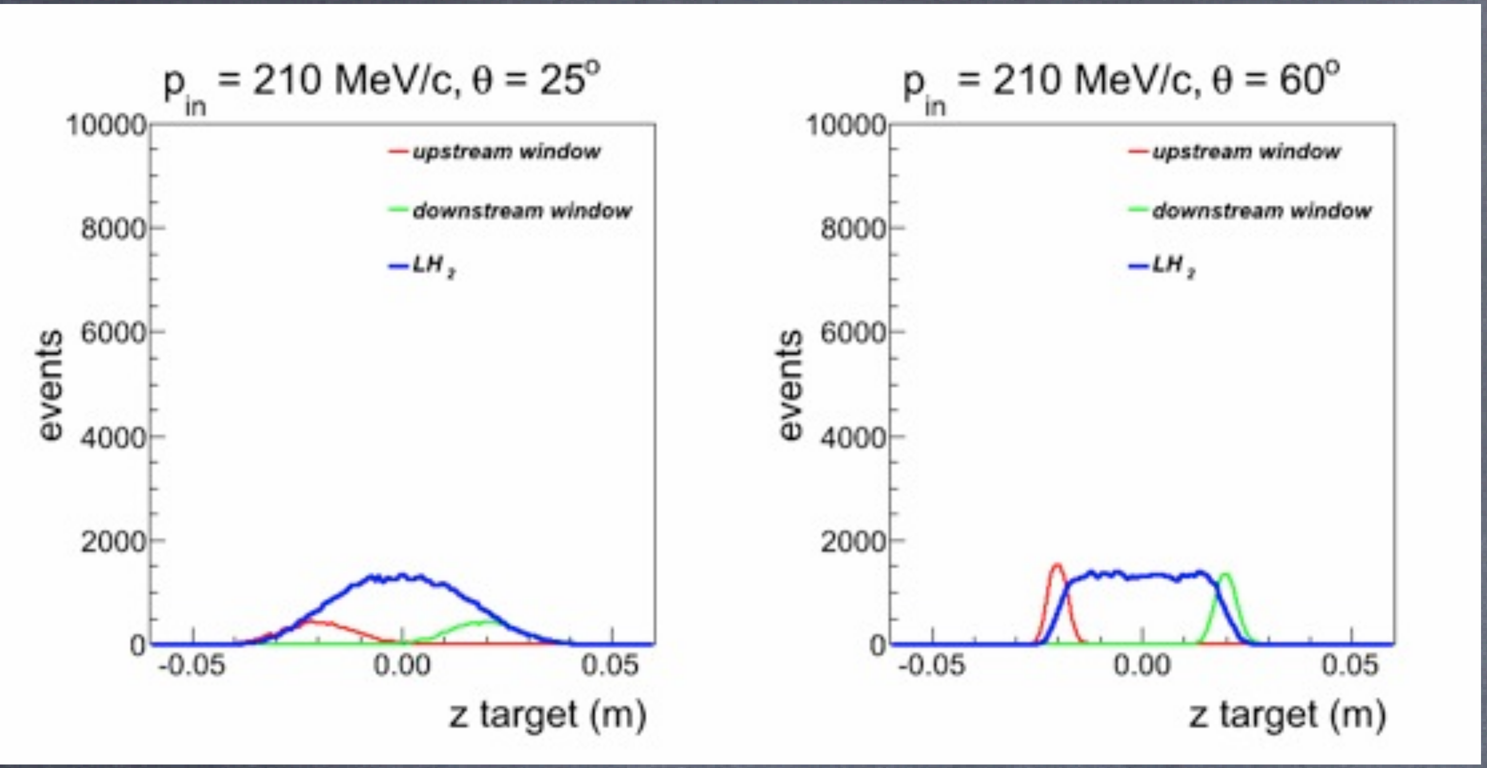


Not shown: Moller, Bhabha, & δ electrons





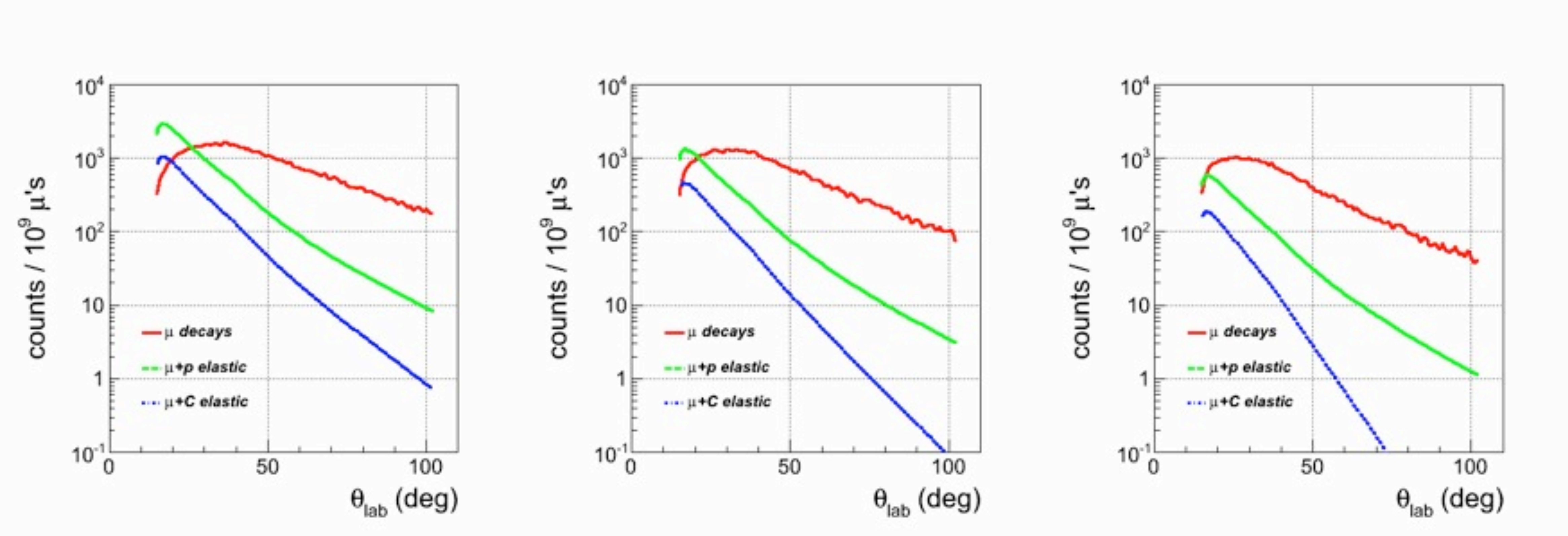
Backgrounds II



The main issues are μ decays and end cap scattering, which cannot be removed at the trigger level.

End cap scattering can only be removed by subtractions.

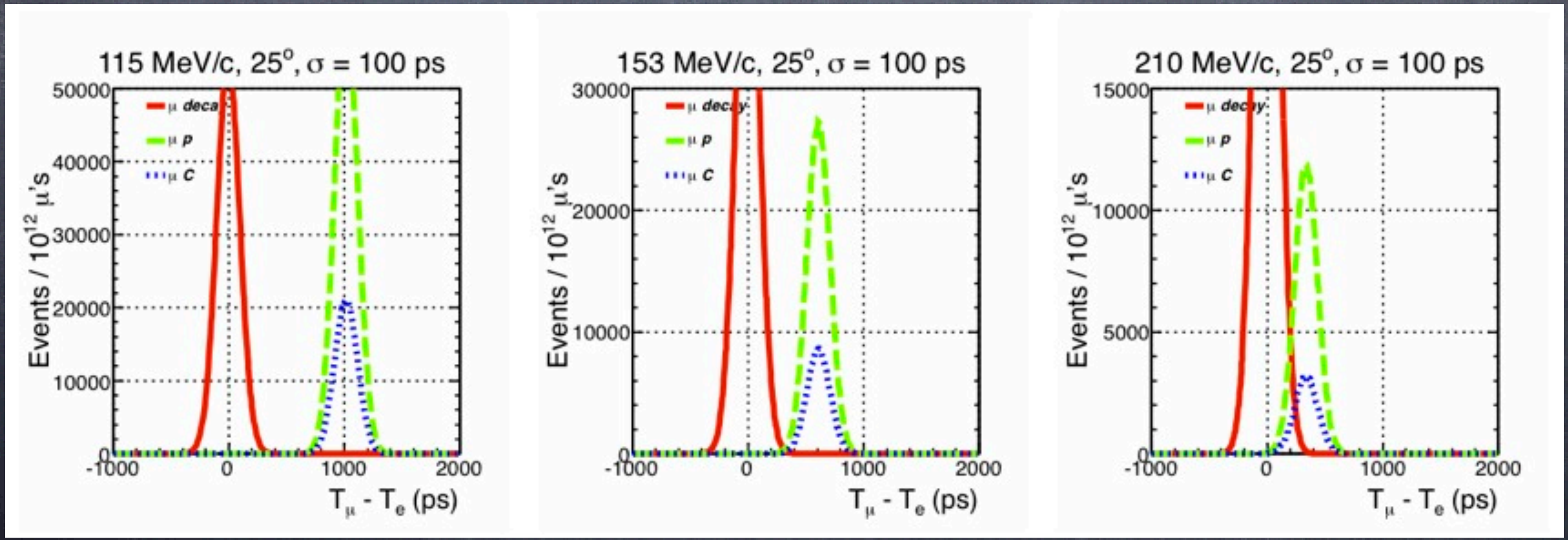
This leaves the relative rates shown below.



Backgrounds III

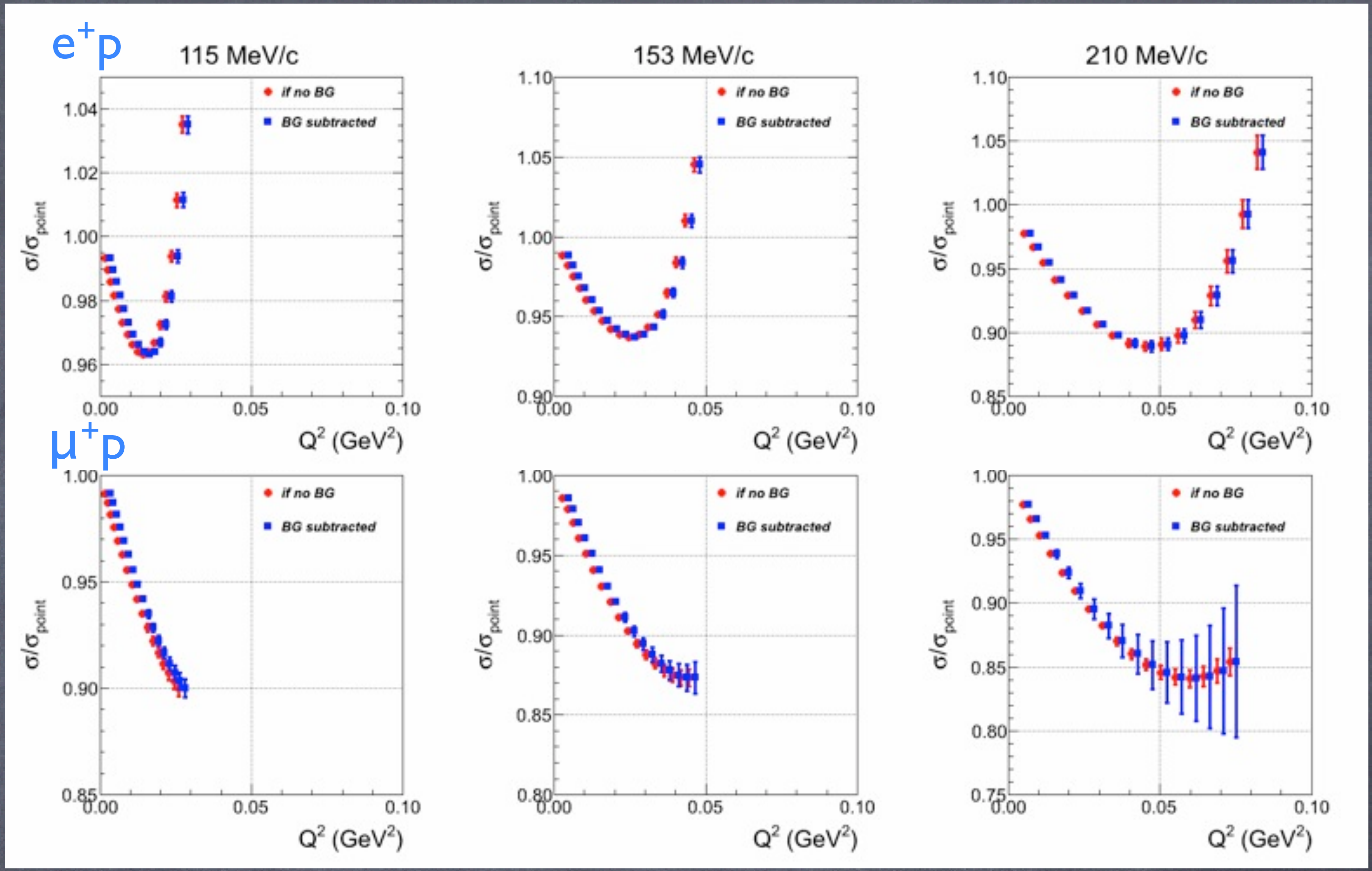
The main issues are μ decays and end cap scattering, which cannot be removed at the trigger level.

Muon decays are largely removed by TOF from quartz Cerenkov to scintillators - 100% / 96% / 34% removed at 115 / 153 / 210 MeV/c



Estimated Results!

- statistical uncertainties only
- similar results for e^-p and μ^-p



- πM1 channel, with p_{in} = 115, 153, and 210 MeV/c: PID reasons.
- Measured rates scaled to 5 MHz, 1 month signal + 1 month bg
- Choose $\theta_{scatter}$ = 20 - 100°: rates, backgrounds, systematics.
- Statistical uncertainties include end cap subtractions and μ decay subtractions (for μ's) - the issue for 210 MeV/c at larger Q^2

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 (shown earlier), and 0.5% for radiative corrections.

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

Radiative Corrections

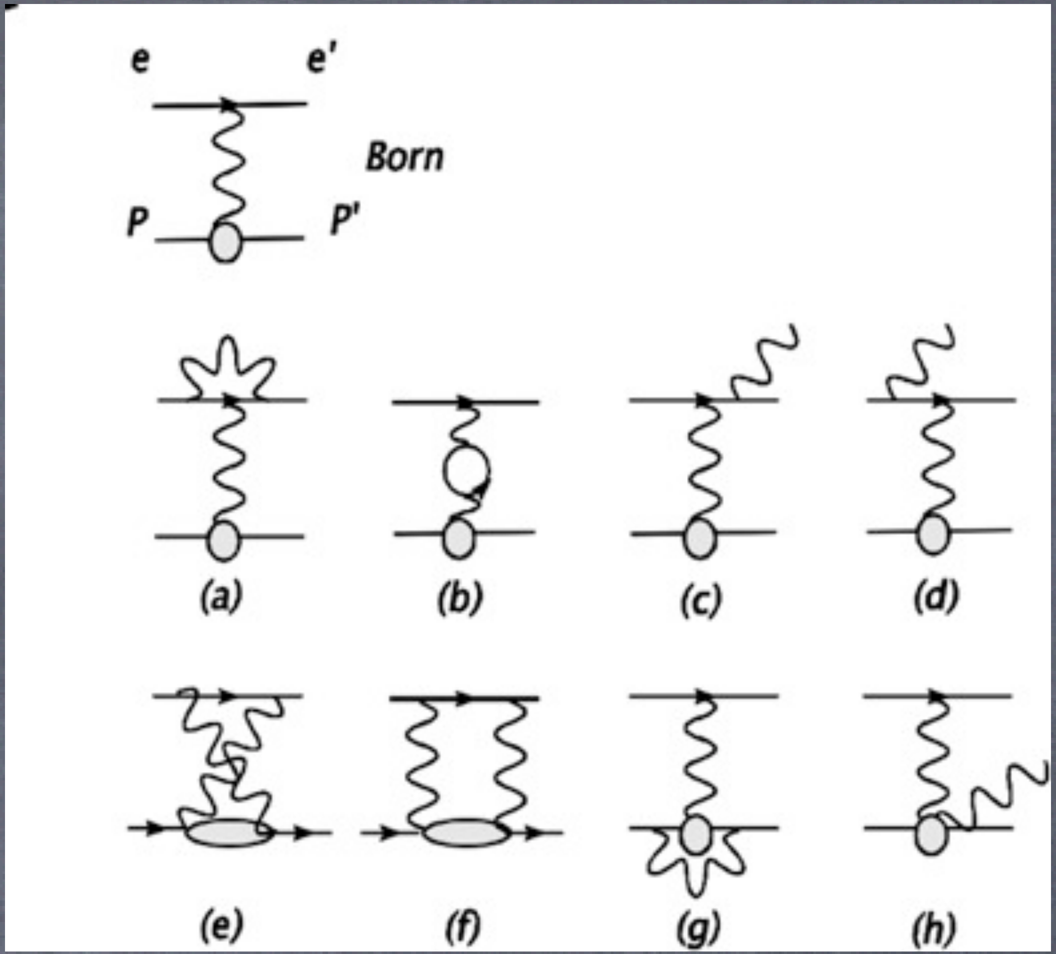
The larger systematics are ≈0.3% for angle determination, and multiple scattering (shown earlier), and 0.5% for radiative corrections.

For muons, external bremmstrahlung is small - see Geant4 simulated muon spectrum.

Vacuum polarization comes from an e^+e^- loop and is the same as for electron scattering.

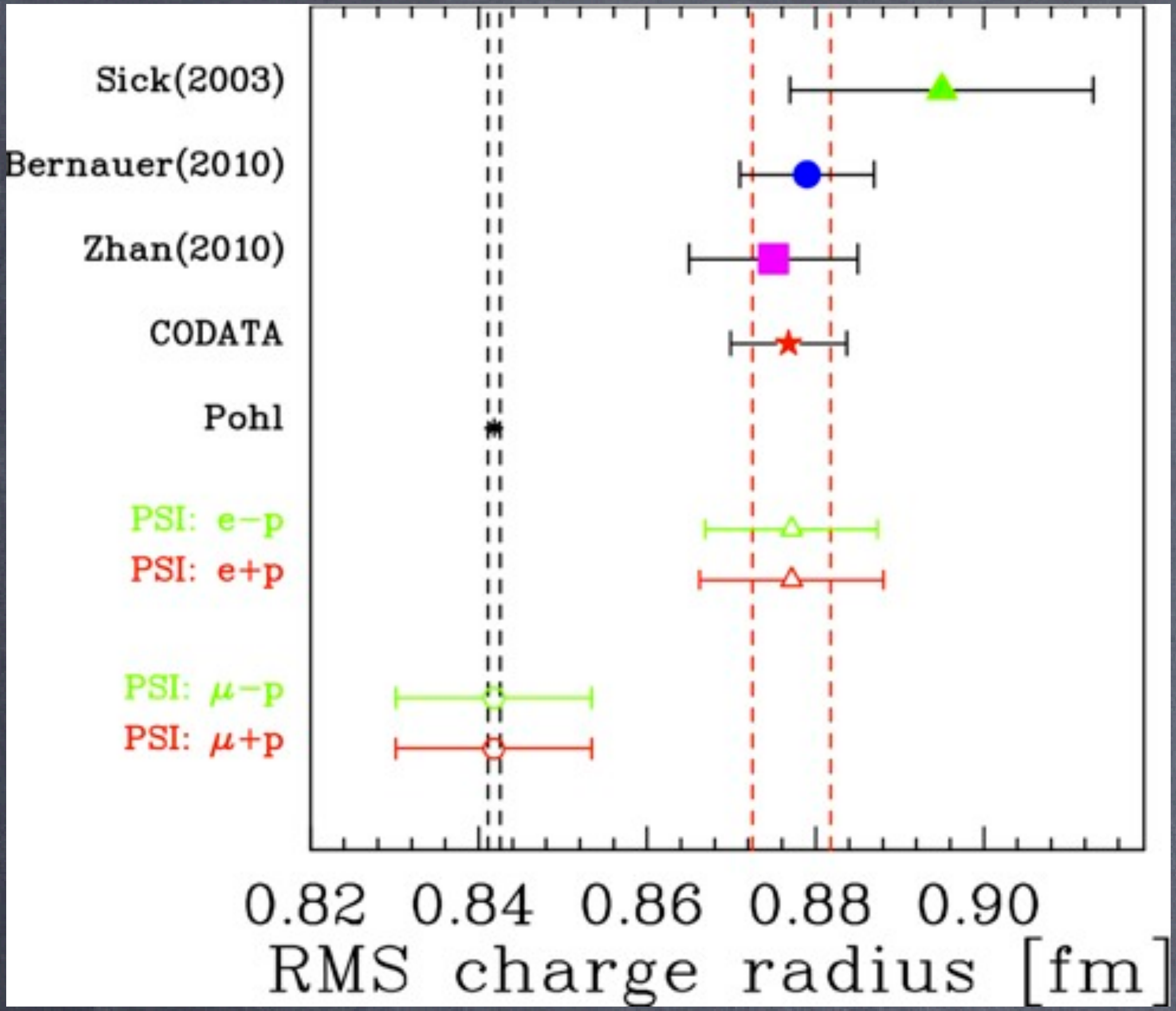
Vertex corrections are reduced due the the muon mass, compared to electron scattering, but less than the naive estimate since there is an additional helicity nonconserving term.

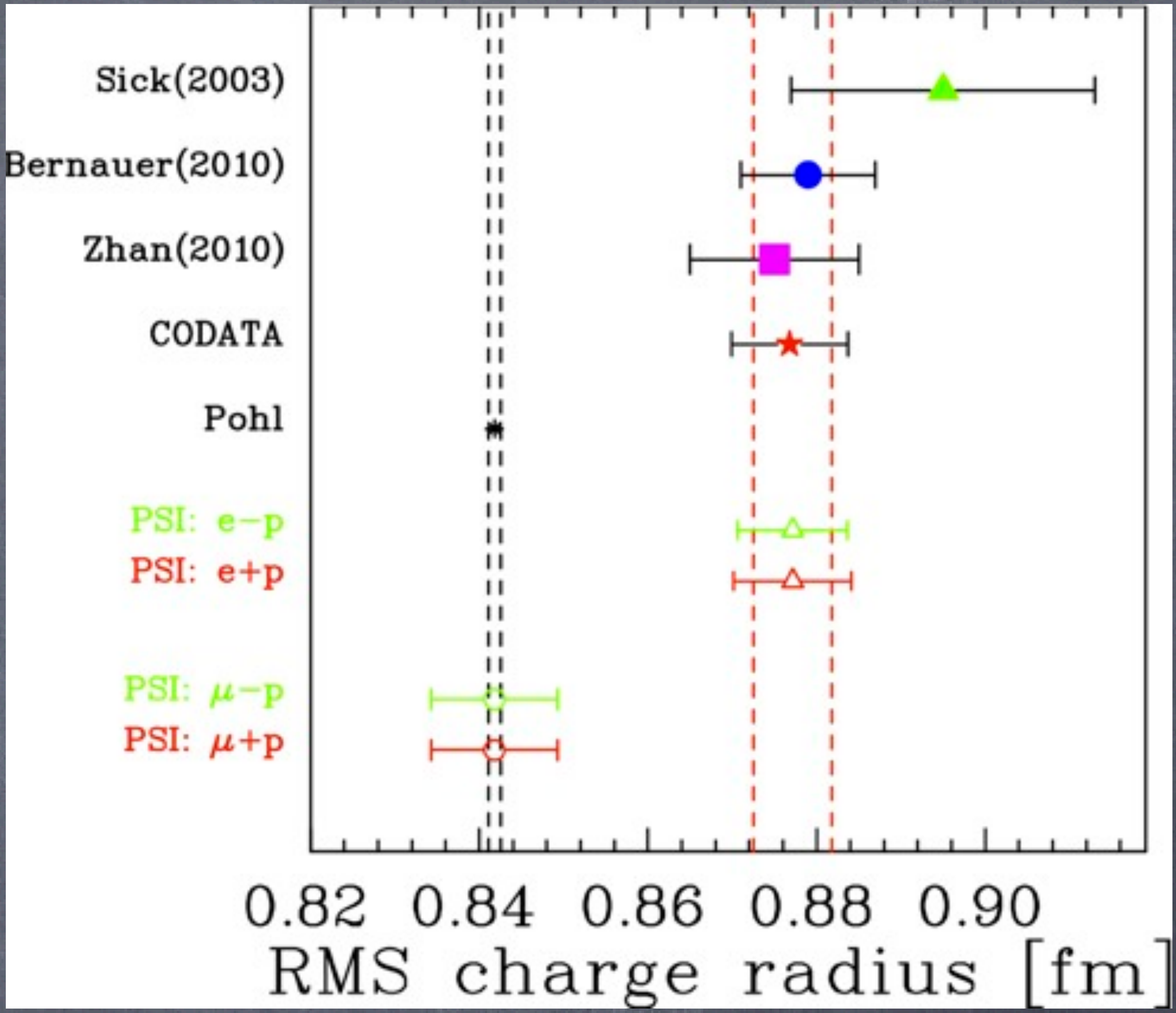
TPE is measured in the experiment. Difference between + and - scattering.



Being studied by A Afanasev and E Borie

Physics





Radius extraction from J Arrington.

TPE, cross section comparison not shown

Time Line

Feb 2012	First PAC presentation
July 2012	PAC/PSI Technical Review
fall 2012	1st test run in πM1 beamline
Jan 2013	PAC approval?
≈June 2013	2nd test run in πM1 beamline
fall 2013	funding requests
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

Summary

- The proton radius puzzle is a high-profile issue - APS plenary talk & invited sessions, PSAS2012 Symposium, Trento ECT* Workshop Nov 2012, review papers
  - Explanation unclear
  - PSI μp scattering directly tests interesting possibilities: Are μp and ep interactions different? If so, does it arise from 2γ exchange effects ($\mu^+ \neq \mu^-$) or BSM physics ($\mu^+ \approx \mu^- \neq e^-$)
- Request:
  - physics approval.
  - Test time in summer 2013 - should expect annual few week tests afterward until run
  - 3-year experiment cycle - year "1" set up and dress rehearsal, year "2" and "3" 6-month production runs

Collaboration

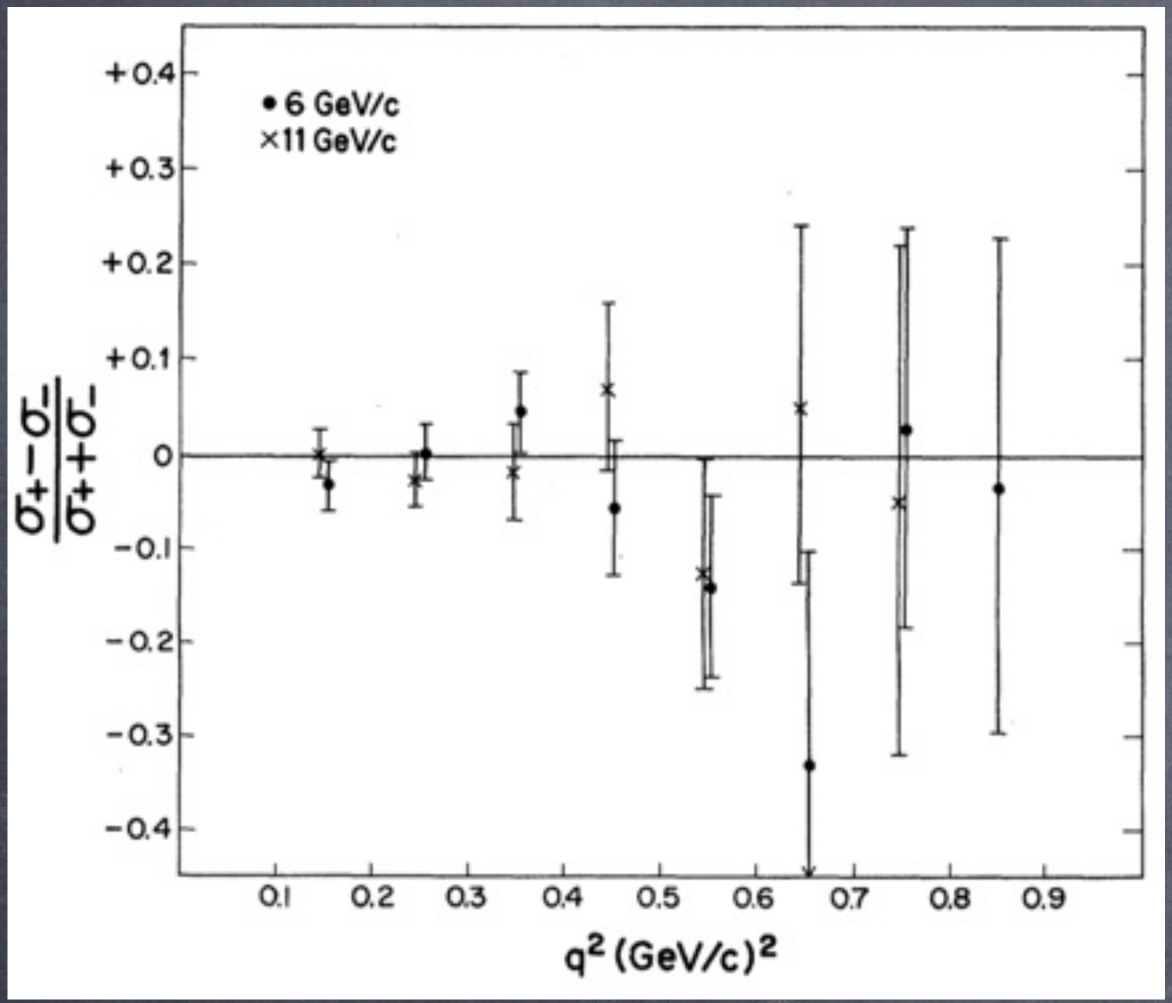
The MUon proton Scattering Experiment collaboration (MUSE):

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]

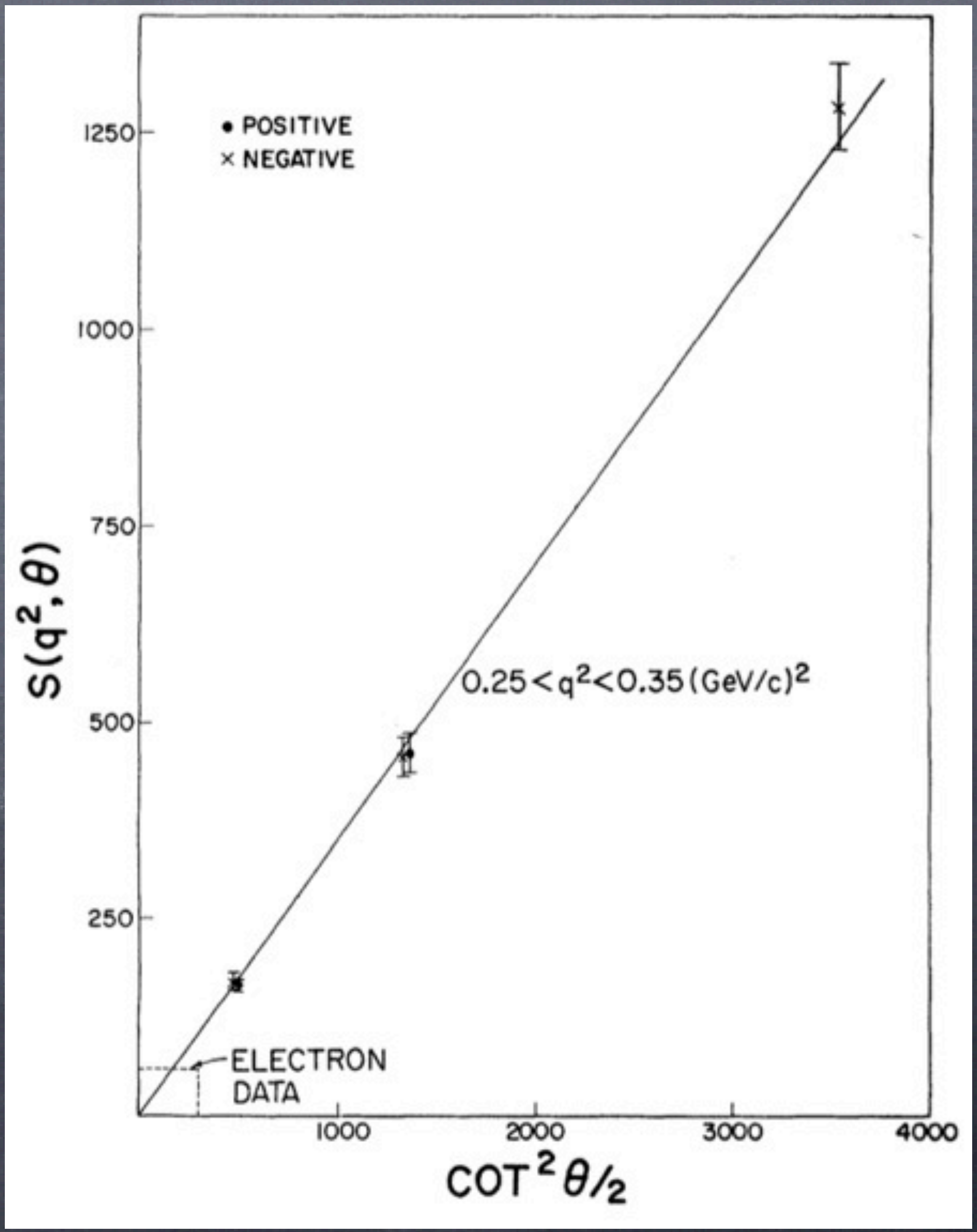
Backup Slides Follow

Two-photon exchange tests in μp elastics

Camilleri et al. PRL 23: No evidence for two-photon exchange effects, but very poor constraints by modern standards.



No difference between μ^+p and μ^-p elastic scattering



Rosenbluth plot is linear.

Determining Flux - Muon Decays

The flux determined by the Sci-Fi at the IFP has to be corrected for μ decays between the counter and the target, and for trajectories that do not make it to the target, so a 2^{nd} Sci-Fi will be used near the target.

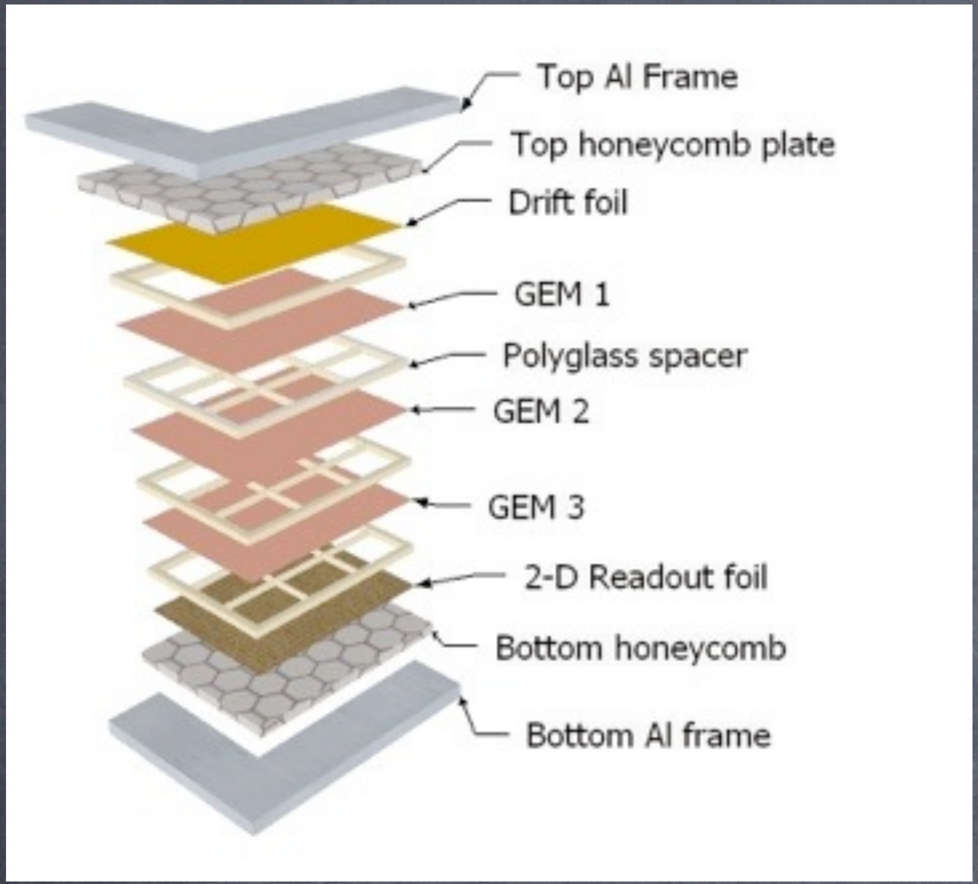
The decay correction is:

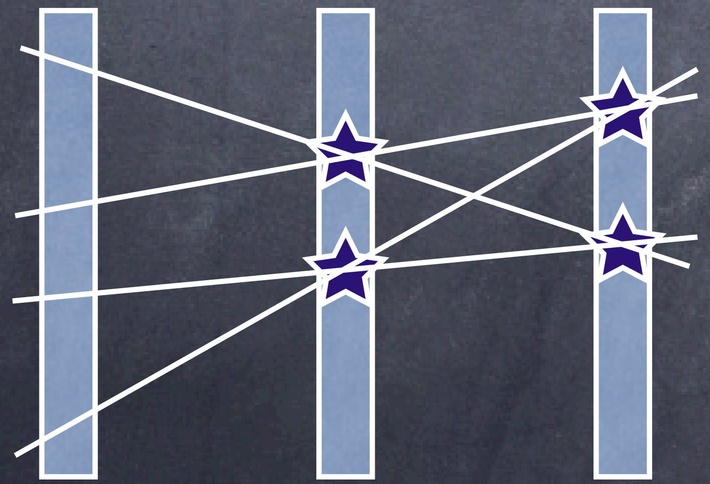
$N_{target} = N_{counter}\, e^{-t/\gamma\tau} = N_{counter}\, e^{-d/\beta\gamma c\tau} = N_{counter}\, e^{-dm/pc\tau}$.

About 10^{-5} of the muons decay per cm of flight path, or about 1% decay from the IFP array to the target. The decaying fraction can be calculated to ≈0.1%, the survival fraction much more precisely to ≈0.001%.

GEM Chambers

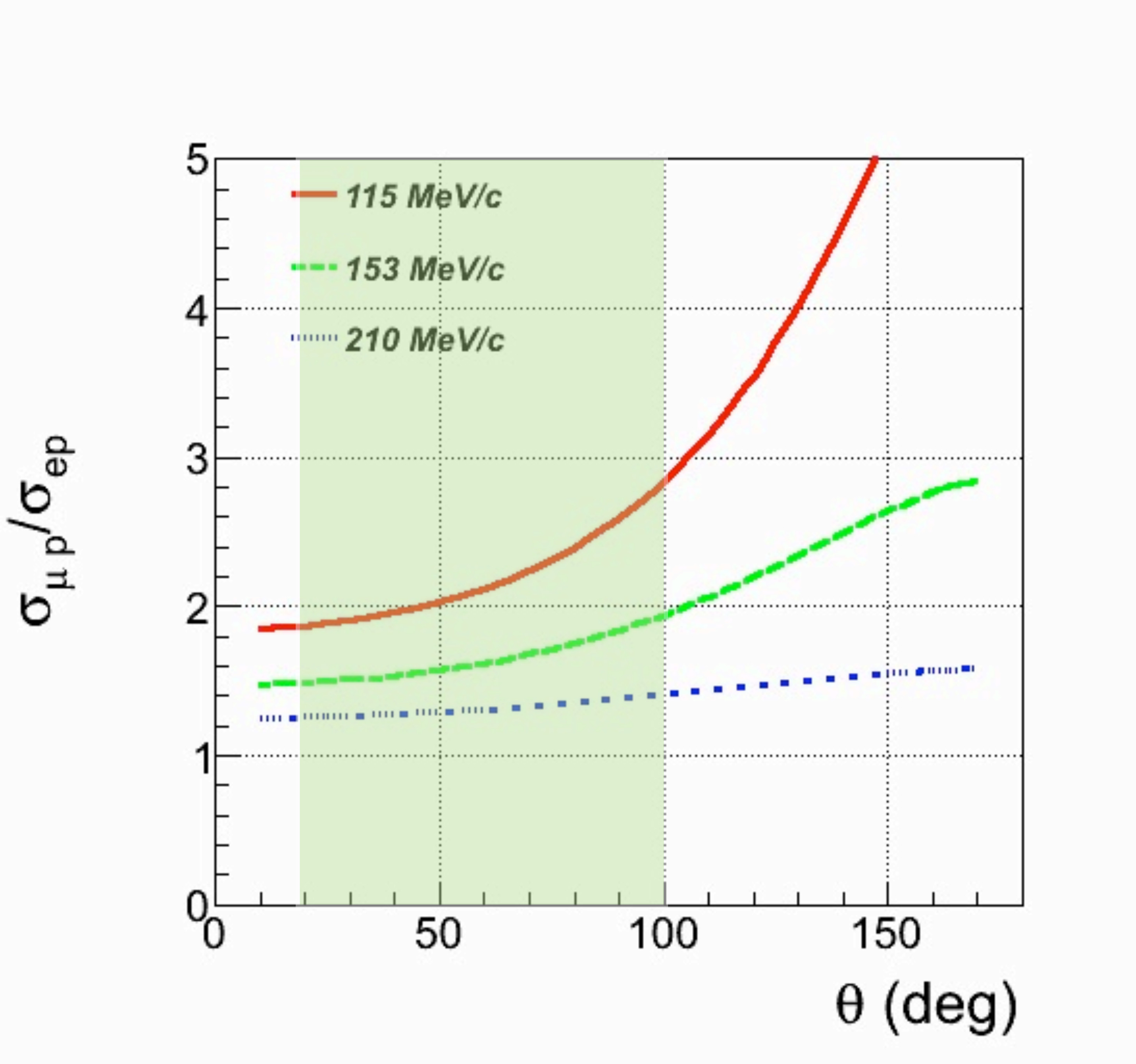
Hampton, UVa

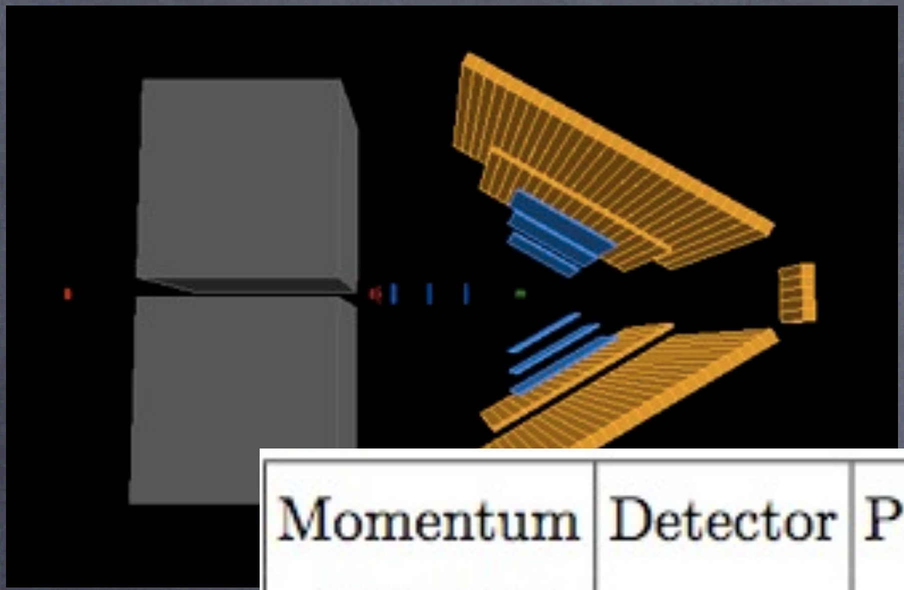




- COMPASS GEMs routinely operated to ≈2.5 MHz/cm^2.
- Tests by various groups have gone up to several 10s of MHz/cm^2.
- We are assuming 10 MHz/1.5 cm^2 = 6.7 MHz/cm^2 (average) rate.
- Gas avalanche is in a ≈ 100 μm wide – the 1.5 cm^2 πM1 beam spot is "100 x 150 pixels" in size, so the 2-3 random coincidence trajectories have negligible probability of overlap.
- Angle divergence of beam leads to ghosts, which can be removed by a 3rd chamber. (Rotation not needed.)
- Electronics might allow removal of particles from other RF buckets.

πM1 Channel - relative e/μ cross sections





Beam PID FPGA

Rutgers U.

Momentum (MeV/c)	Detector	Particle Type	Fraction e ID	Fraction μ ID	Fraction π ID
115	target	e	0.9950	0.0000	0.6582
115	target	μ	0.0000	0.9934	0.0367
115	target	π	0.6309	0.0423	0.9896
153	target	e	0.9950	0.0357	0.0000
153	target	μ	0.0421	0.9954	0.0000
153	target	π	0.0000	0.0000	0.9960
210	target	e	0.9904	0.0000	0.0007
210	target	μ	0.0000	0.9914	0.0000
210	target	π	0.0013	0.0000	0.9918