Answers to Reviewers Questions

MUSE Funding Review

1) Detailed Error Budget

- **Note on preparing for systematics & run plan**

Design for survey.

Machining at 10 - 25 um level.

Calibration runs for energy determination (RF and TOFs), simulation verification (walls in beam, ...), angle offsets (rotated table & high energy), trigger verification (low to high incident flux), ... and calibration information from random beam particle coincidences in data.

Run at 6 primary settings (3 momenta x 2 polarities), with L/R spectrometers, and at 2 special settings (small momentum and angle offsets) for multiple overlaps as check of systematics and means to extend Q^2 range.

1) Detailed Error Budget

- On statistical uncertainties: these range from ~0.1% up to about 7% for muons at the largest energy & angle.

- For electrons, systematic uncertainties are larger except for angles > 60^o at 210 MeV/c, where statistics grow to ~1.5%.

- For muons, there is a trade off in the analysis for decay subtractions: tighter cuts lead to improved statistics after subtraction but increased systematics. Plots are done assuming wide cuts giving minimal systematic and maximal statistical uncertainty. Will be optimized in analysis.

- Currently systematics dominate for the forward about 3/4, 1/2 and 1/4 of the angular distributions at 115, 153, and 210 MeV/c, respectively.

- The radius extraction is systematics dominated.

1) Detailed Error Budget

- **Point-to-point systematics on cross sections in one data-taking setting**

Verified by comparing up to 2x5 measurements at same Q^2 for each particle

Systematic	Magnitude	Notes
$\Delta\Omega$	0.14%	partial bin-to-bin correlations
N_{beam}	-	absolute, in scaler & trigger
$x\rho_{target}$	-	$\geq$1% absolute
ρ_{target}	-	higher order, in simulation
ε_scintillator	0.1%	θ-dependent difference from sim
ε_STT_tracking	-	map out ε with 99.7% of events
ε_beamline_dets	-	no significant angle dependence
ε_trigger	-	avoid θ-dependence
ε_DAQ	0.01%	all triggers counted to 0.01%
p_incident	0.1%	mainly absolute effect
p_averaging	0.01%	mainly absolute effect
angle determination	0.1%	machining, calibrations, L/R arms
multiple scattering	0.3%	rms of corr., but difference from sim

1) Detailed Error Budget

- **Point-to-point systematics on cross sections in one data-taking setting**

Verified by comparing up to 2x5 measurements at same Q^2 for each particle

Systematic	Magnitude	Notes
radiative corr - e	0.5%	Brem - 2 gamma small for G_E
radiative corr - μ	0.1%	Brem suppressed
radiative corr - 2γ	-	Measure, average out
Magnetic corr.	0.1%	1% difference in 30% corr/√12
cuts - GEM fiducials	-	beam line detector cuts
cuts - end cap sub	-	study in data if results vary with sub cut
cuts - μ decay sub	-	study in data if results vary with sub cut
cuts - vertex cut	-	study in data if results vary with sub cut
detector stablity	-	study in data
normalization unc.	*0.2%*	*normalization unc. in pseudodata fit*
TOTAL	0.4%/0.63%	for μ/e in one setting

1) Detailed Error Budget

- Recap: estimated "significant" systematics in cross section in one bin vs another in a single kinematic setting

Systematic	Magnitude	Notes
$\Delta\Omega$	0.14%	partial bin-to-bin correlations
ϵ_scintillator	0.1%	θ-dependent difference from sim
p_incident	0.1%	mainly absolute effect
angle determination	0.1%	machining, calibrations, L/R arms
multiple scattering	0.3%	rms of corr., but difference from sim
radiative corr - μ/e	0.1% / 0.5%	Brem
Magnetic corr.	0.1%	1% difference in 30% corr/$\sqrt{12}$
normalization unc.	*0.2%*	*normalization unc. in pseudodata fit*
TOTAL	0.4%/0.63%	for μ/e in one setting

1) Detailed Error Budget

- Now we compare + to - at the "same momentum. What cancels?

Systematic	Magnitude	For +/-	Notes
$\Delta\Omega$	0.14%	-	
ε_scintillator	0.1%	0.1%	partially cancels
p_incident	0.1%	0.1%	
angle determination	0.1%	-	
multiple scattering	0.3%	-	beam energy ≈ same
radiative corr - μ/e	0.1% / 0.5%	-	beam energy ≈ same
Magnetic corr.	0.1%	-	beam energy ≈ same
normalization unc.	*0.2%*	0.2% x $\sqrt{2}$	
TOTAL	0.4%/0.63%	0.3%	

1) Detailed Error Budget

- Now we compare e to μ at the same angle. Q^2 is a few percent different for the two reactions.

Systematic	Magnitude	For e/μ	Notes
ΔΩ	0.14%	-	
ε_scintillator	0.1%	-	assumes time variation small
p_incident	0.1%	-	separately normalize data sets
angle determination	0.1%	-	
multiple scattering	0.3%	0.15%	same shape but different magnitude
radiative corr - μ/e	0.1% / 0.5%	0.5%	same shape but different magnitude
Magnetic corr.	0.1%	0.05%	typical, not max
normalization unc.	*0.2%*	0.2% x √2	
TOTAL	0.4%/0.63%	0.6%	dominated by radiative correction

1) Detailed Error Budget

- Now we compare e to μ at the same Q^2. The angles are slightly different for the two reactions.

Systematic	Magnitude	For e/μ	Notes
ΔΩ	0.14%	0.14%	overlapping bins partially cancel
ε_scintillator	0.1%	0.1%	overlapping bins partially cancel
p_incident	0.1%	-	separately normalize data sets
angle determination	0.1%	0.1%	overlapping bins partially cancel
multiple scattering	0.3%	0.15%	same shape but different magnitude
radiative corr - μ/e	0.1% / 0.5%	0.5%	same shape but different magnitude
Magnetic corr.	0.1%	0.05%	typical, not max
normalization unc.	*0.2%*	0.2% x √2	
TOTAL	0.4%/0.63%	0.6%	

2) Beamtime to be statistics dominated

- Have not been able to definitively answer this - has not been able to confer with John Arrington about his fits.
- Cannot cut beam time:

  Electron uncertainties appear to increase 20% from statistics.

  Muon uncertainties appear to increase 40% from statistics.

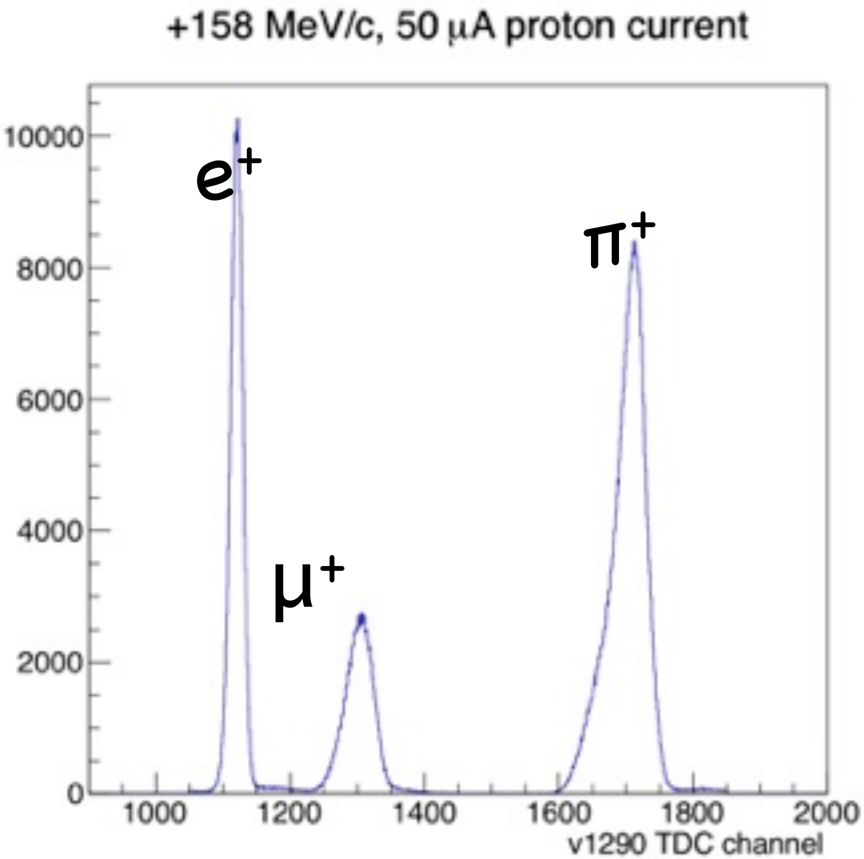
  High statistics are essential for thoroughly understanding systematics.

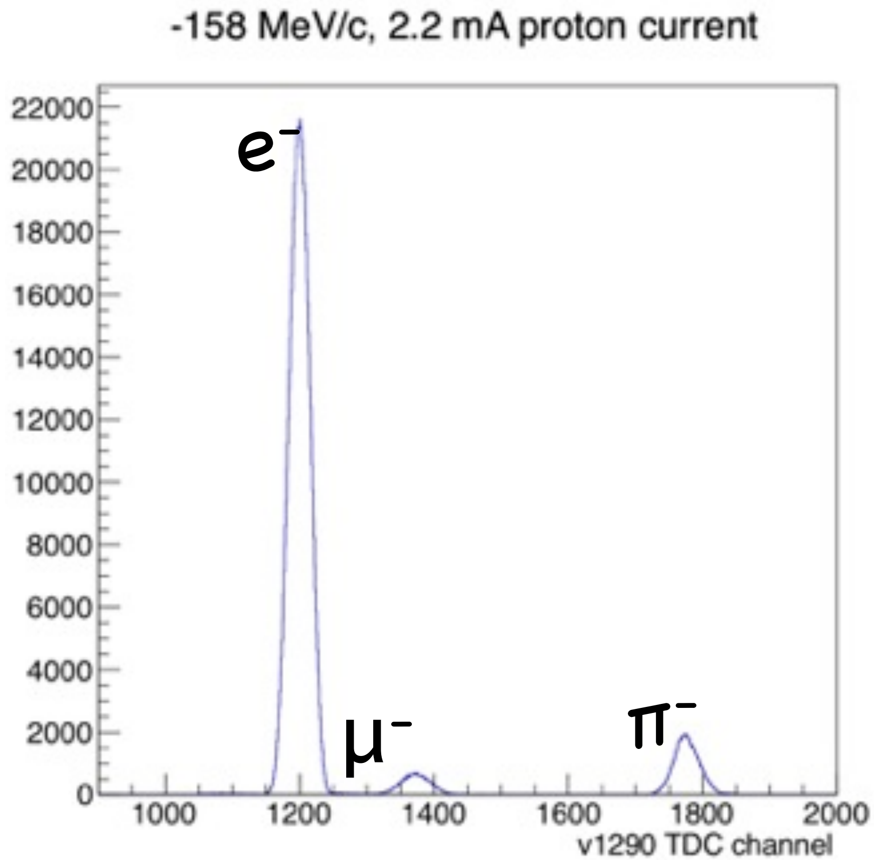
3) Lessons from Beamtimes

- Test runs in fall 2012, June, October, December 2013 studied
- ➔ Beam properties
- ➔ Detectors & DAQ
  - Not intending to give a review talk here,
  - Just indicating variety of studies undertaken.

3a) Beam Properties

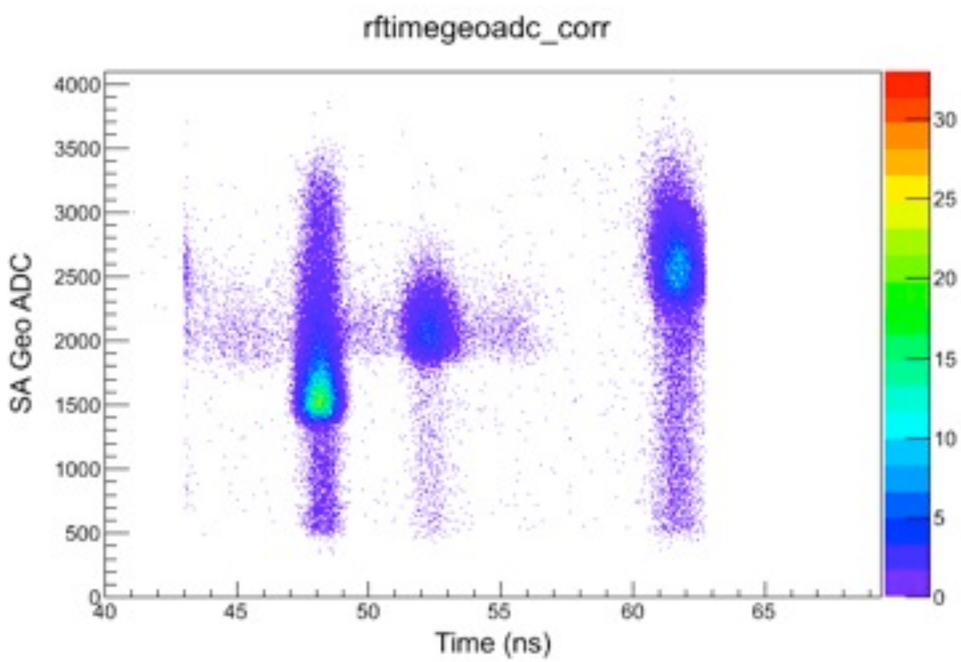
- Clean RF time peaks, with small - percent level - backgrounds

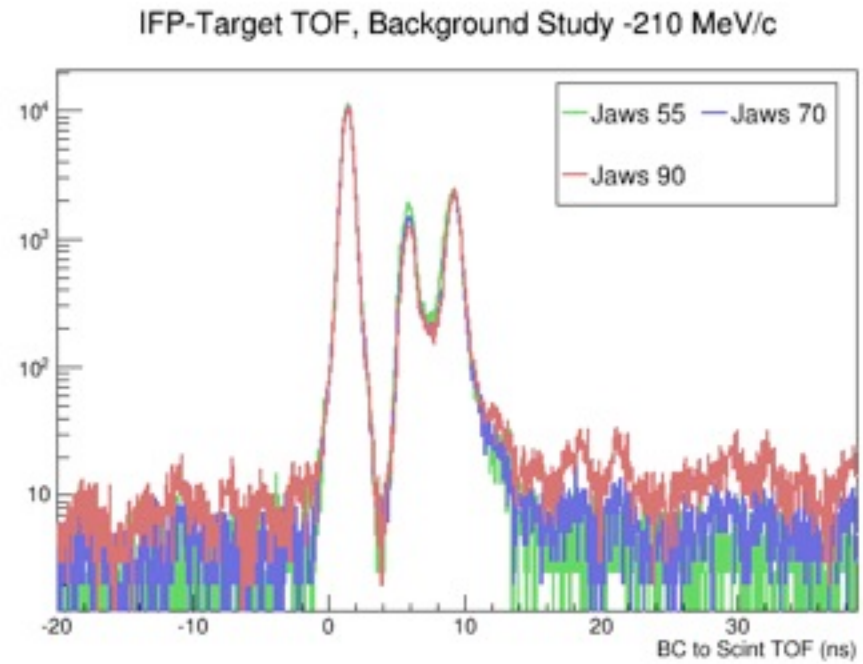


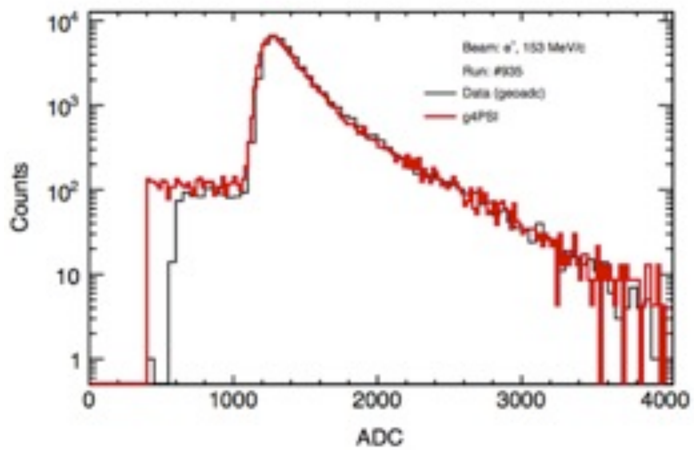


3a) Beam Properties

- Particle IDs confirmed by pulse height vs RF time and by TOF over 12 m vs RF time - only 1D TOF shown







3a) Beam Properties

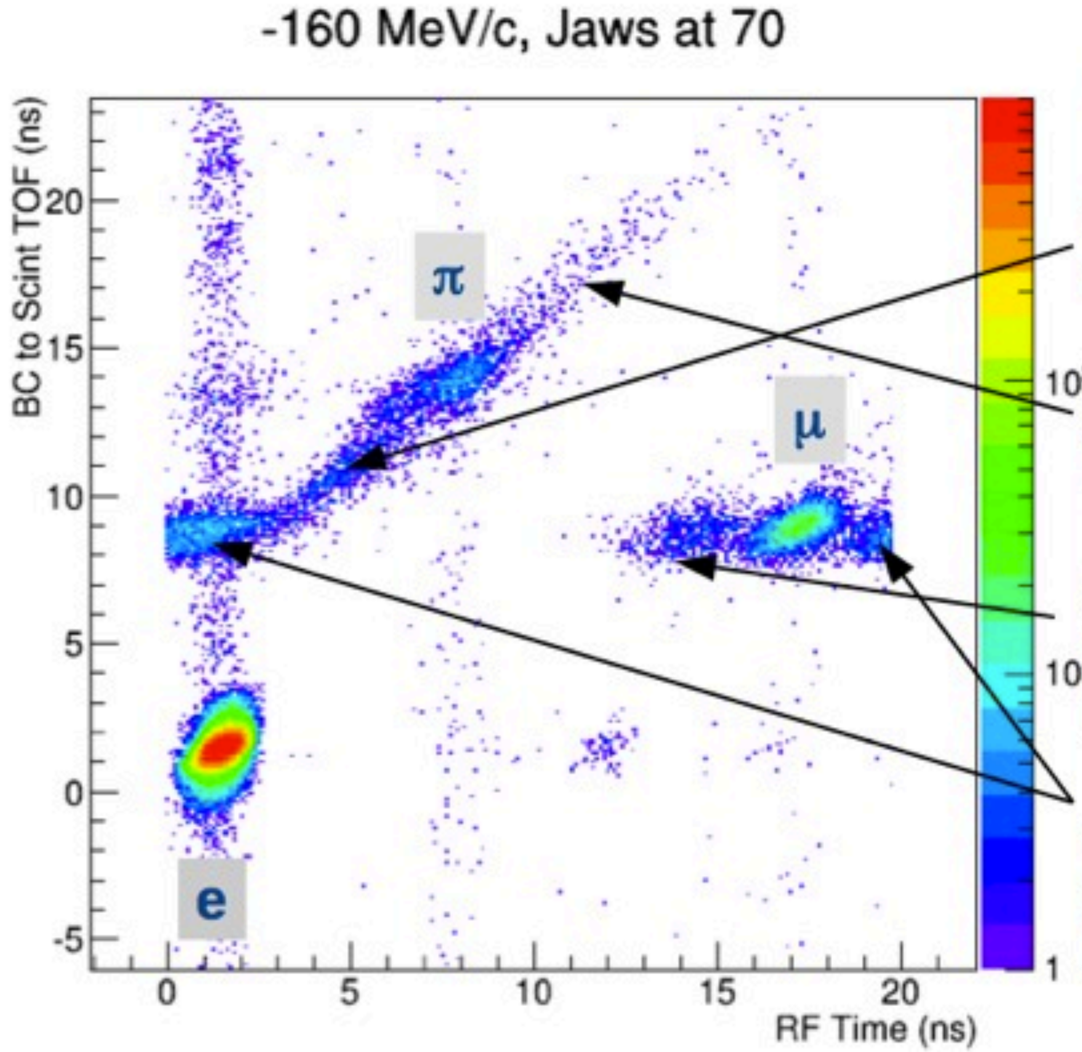
- If you look in detail you can see and identify backgrounds

log scale

-160 MeV/c

Jaws 55
~ closed

IFP-Targ
TOF
vs.
RF Time



Ron Simulation:

π-μ decays after IFP w/ forward μ

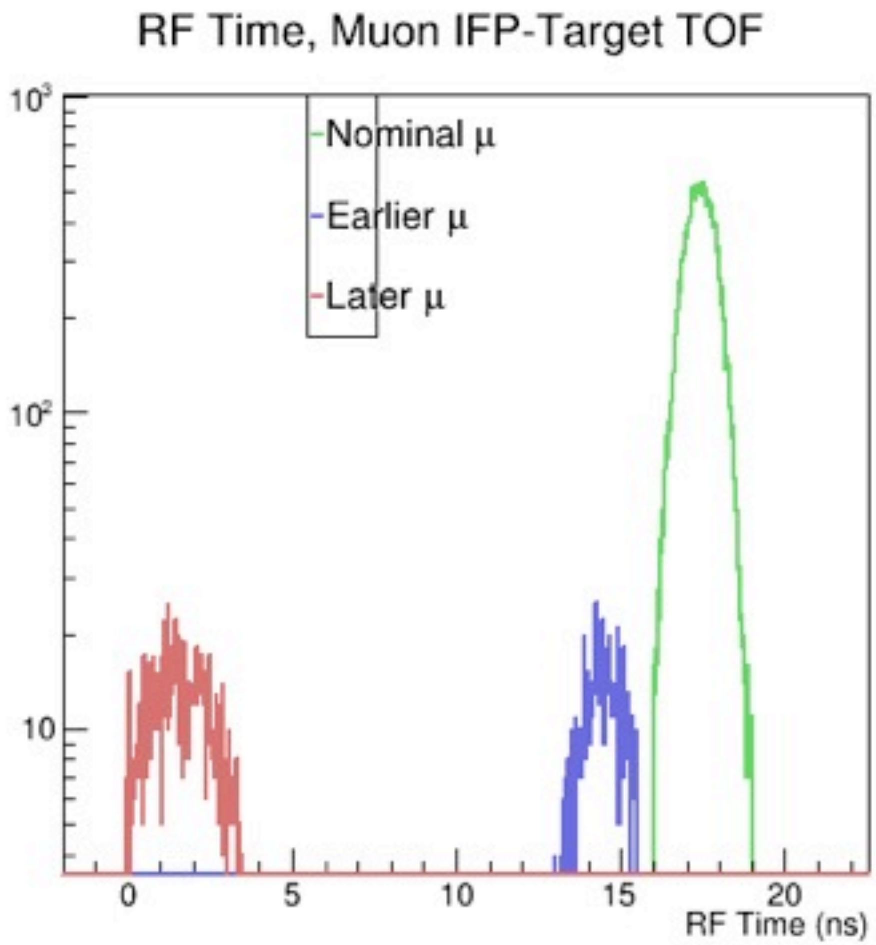
π-μ decays after IFP w/ backward going μ

π-μ decays before IFP w/ backward μ, higher momentum π's

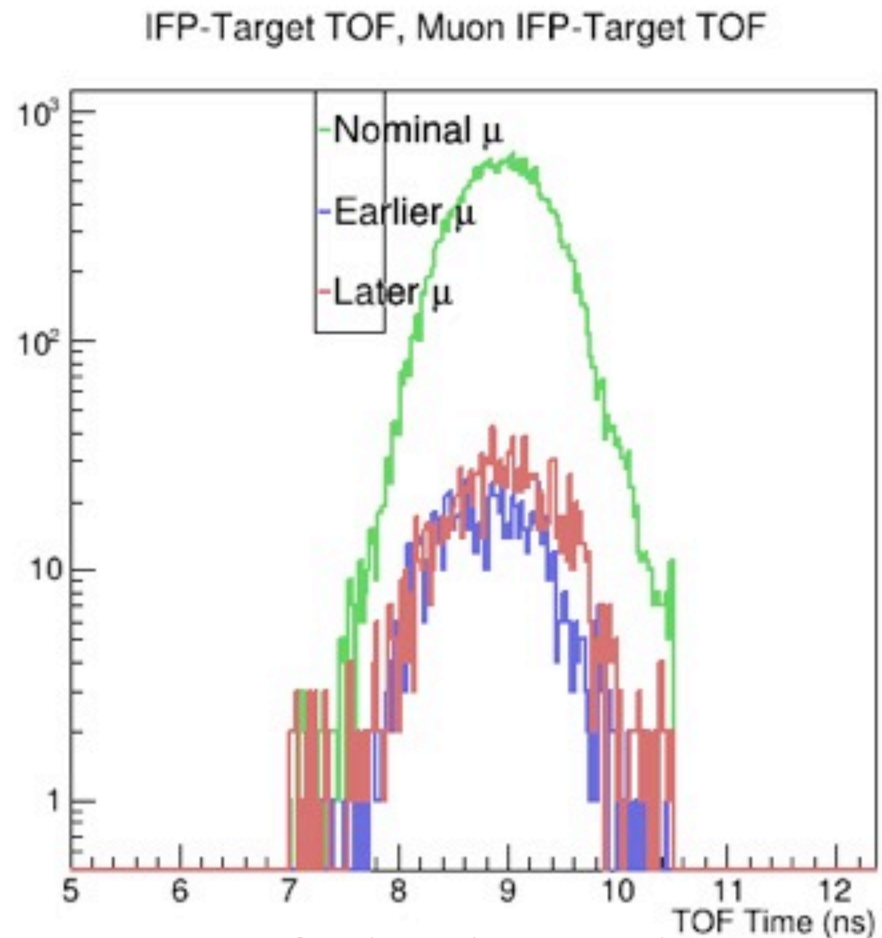
π-μ decays before IFP w/ forward going μ, lower momentum π's

3a) Beam Properties

- Mapped out particle type vs momentum



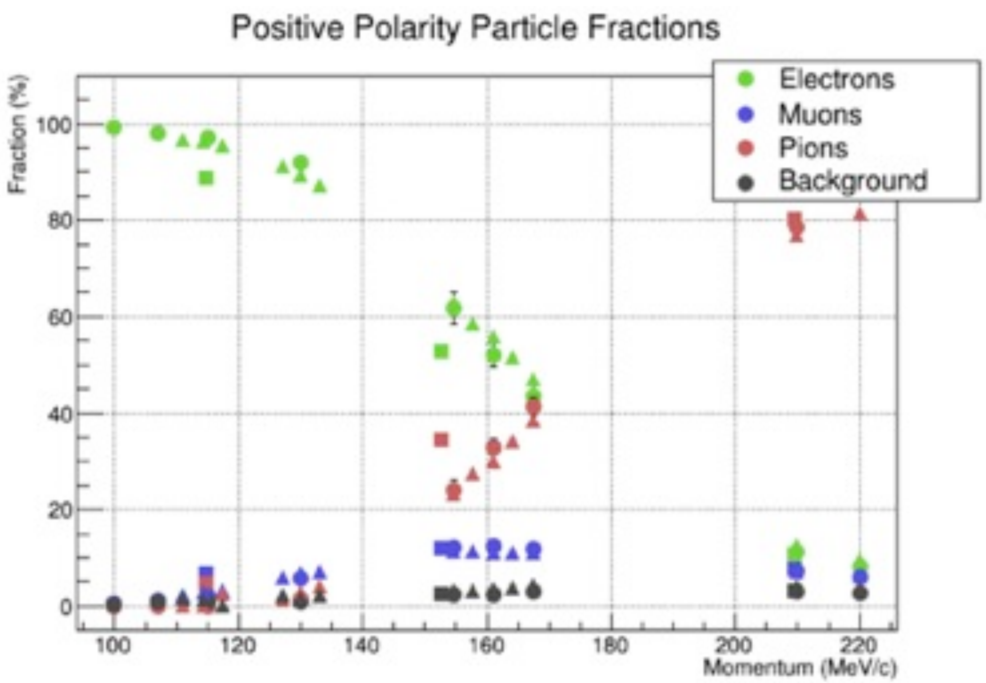
3 regions in RF time for muon TOF from IFP to target

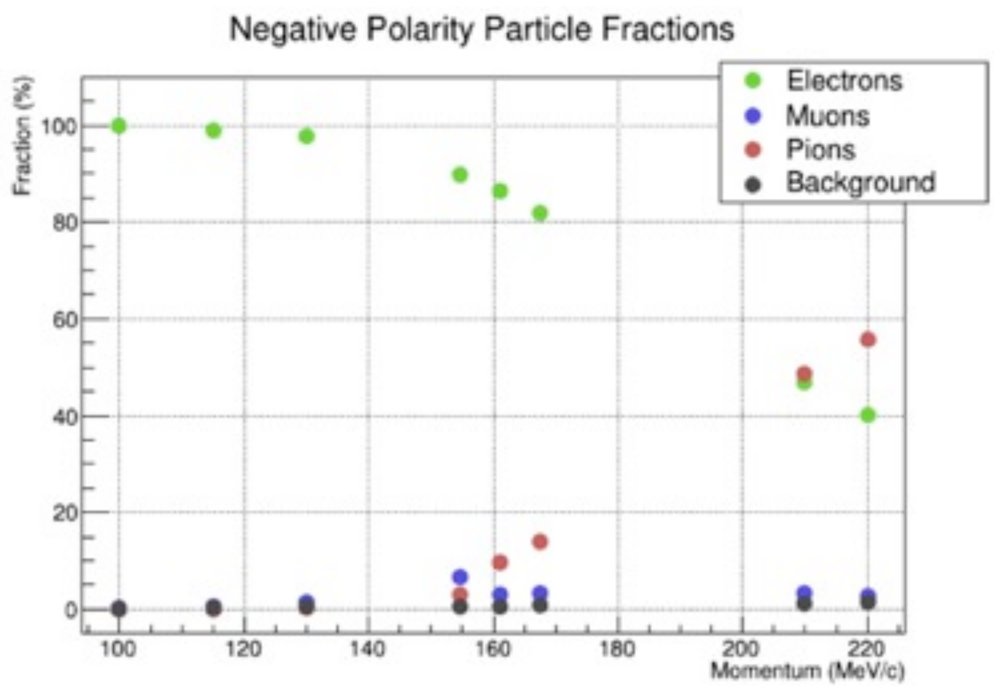


IFP to target TOF for 3 muon RF time regions

3a) Beam Properties

- Mapped out particle type vs momentum



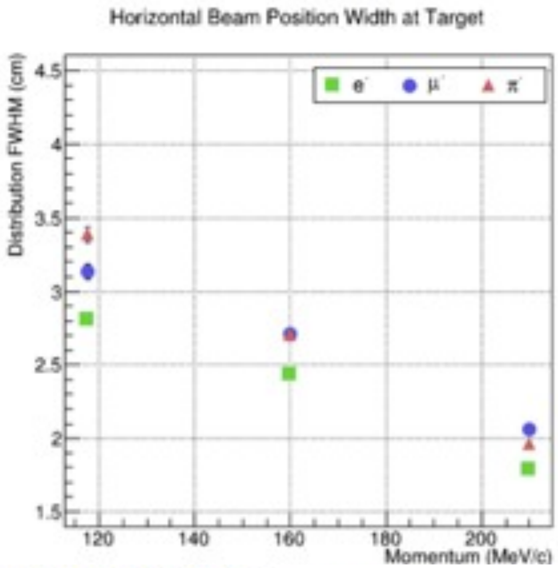


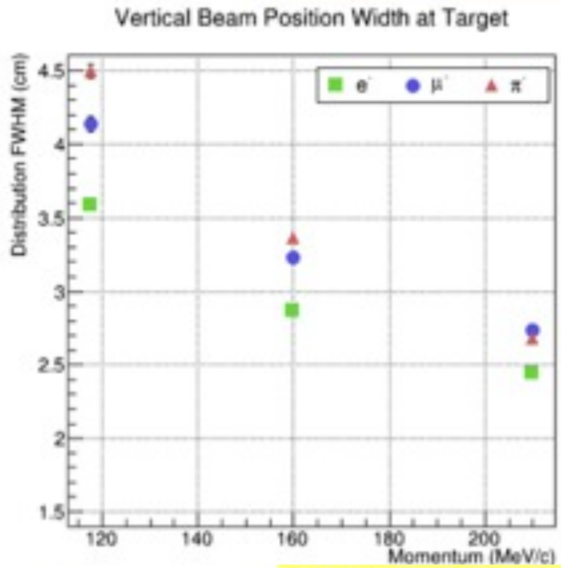
3a) Beam Properties

- Beam spot mapped with GEMs basically independent of particle type - this data not for well tuned spot.

Beam Position Width projected at Target:

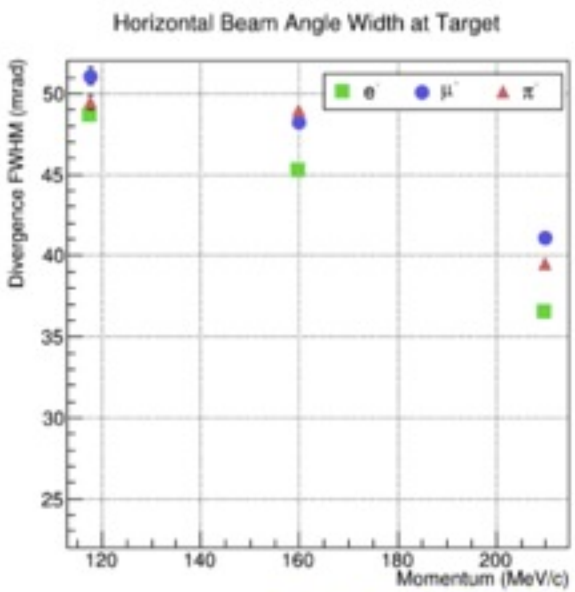
Note: No detector at IFP

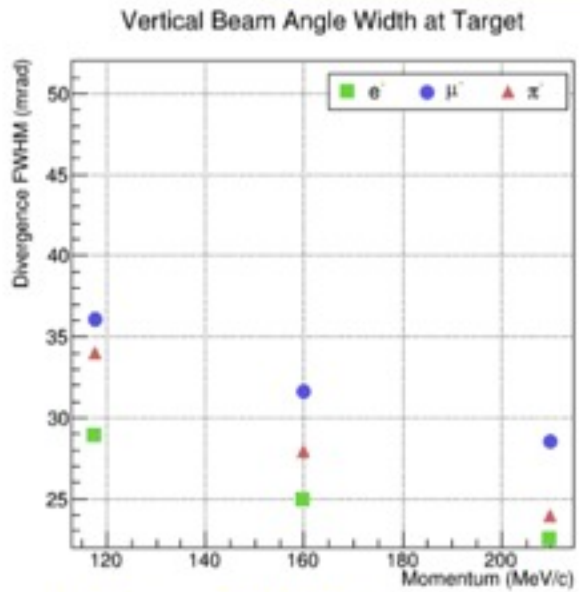




Beam Divergence:

Note: No detector at IFP

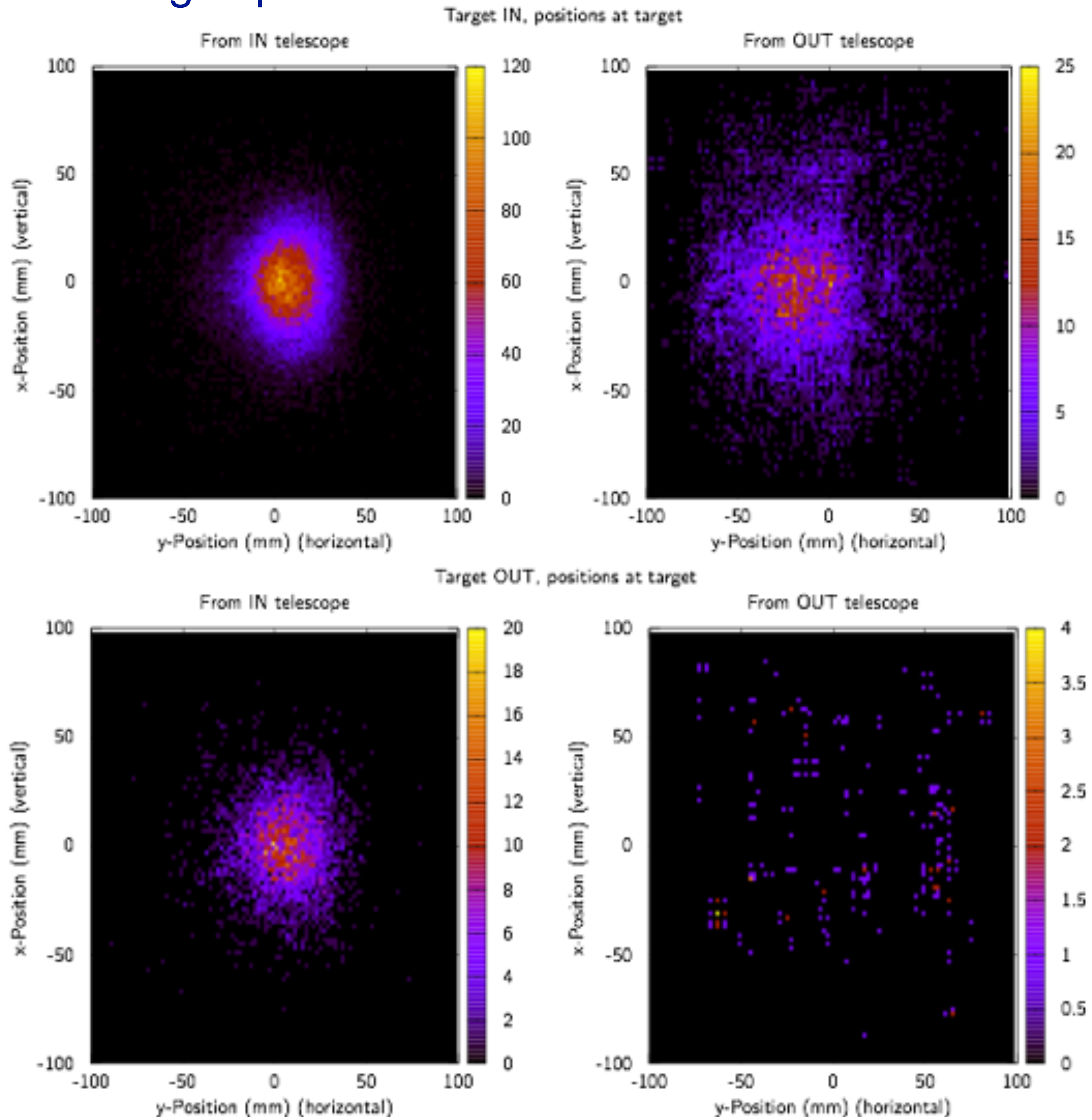




At ~117.5 MeV/c: 50 mrad x 35 mrad FWHM

3a) Beam Properties

- Mini-scattering experiment for GEM reconstructions



3a) Beam Properties Lessons Learned

- Sufficient flux of muons for experiment.
- RF time generally sufficient to separate particles for triggering.
- Beam properties independent of particle type.
- Managed to reproduce about 1 x 1.5 cm spot at some times, but...
- Need to work on channel tuning, reproducibility, understanding hysteresis.
- Backgrounds small, but cannot be ignored.
- Not shown: cleaner to collimate at IFP rather than with jaws
- Large neutral backgrounds at IFP require beam Cerenkov rather than SciFi.
- Need faster turnaround on analysis for tuning.
- **Confirmed that beam properties are sufficient for experiment.**

3b) Detectors & DAQ studied

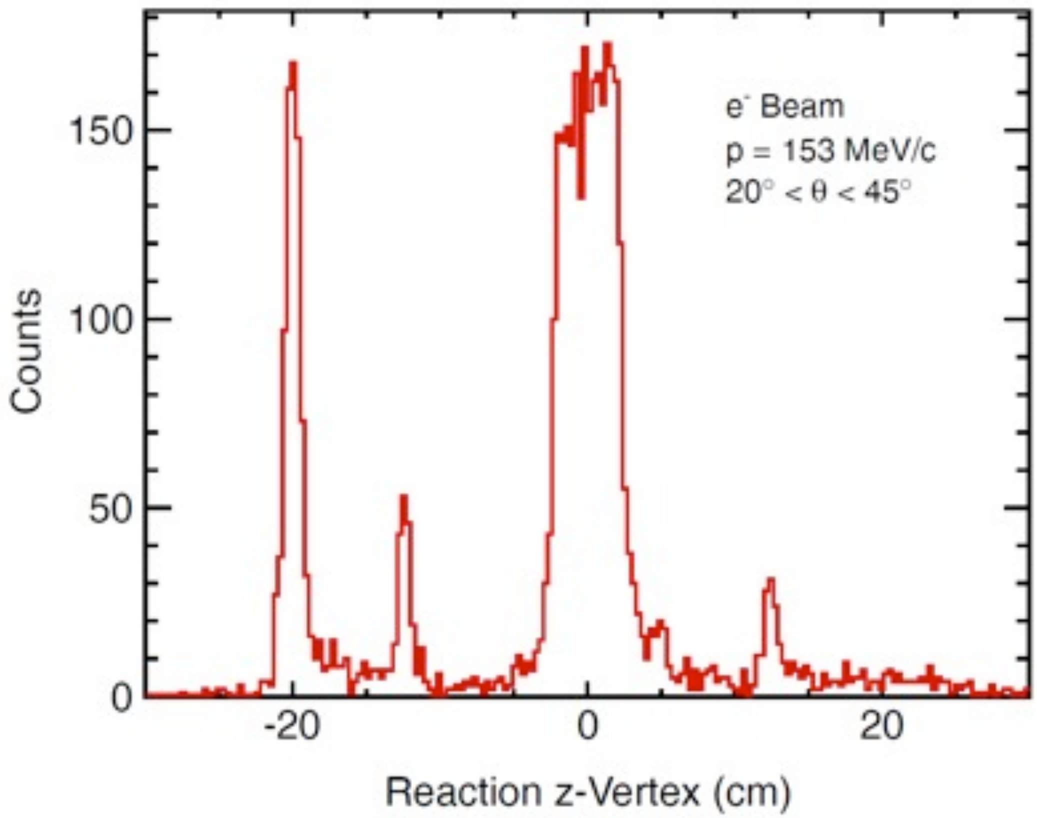
- South Carolina scintillator response compared to simulation.
- GEMs operated at PSI
- Beam Cerenkov technique studied with beam, with quartz and sapphire radiators on Hamamatsu 9779, and cosmics on both radiators on MCP

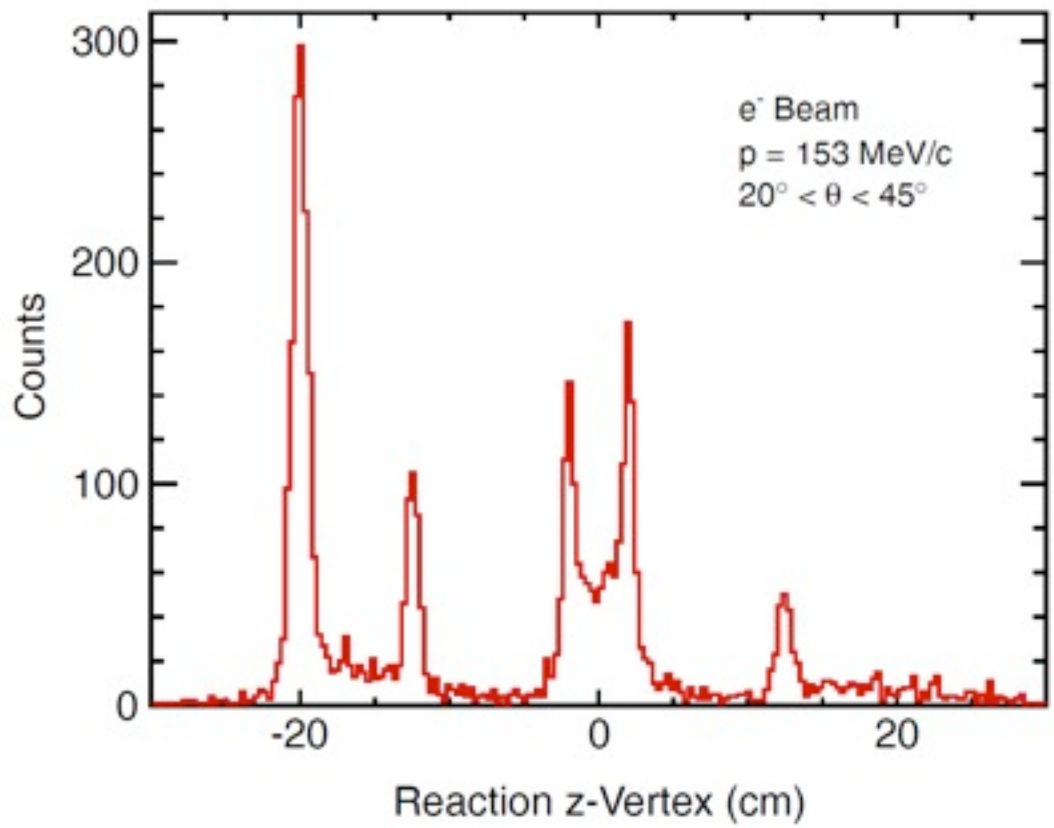
- Read out v262 I/O register, v767, v1190, v1290 TDCs, v792 QDC, GEMs, and TRB3 with MIDAS
- Four new MIDAS drivers developed, others upgraded
- Tests done largely with old NIM electronics, with various consequent issues

4) Empty Target Plots

Full

Empty (H_2 gas)

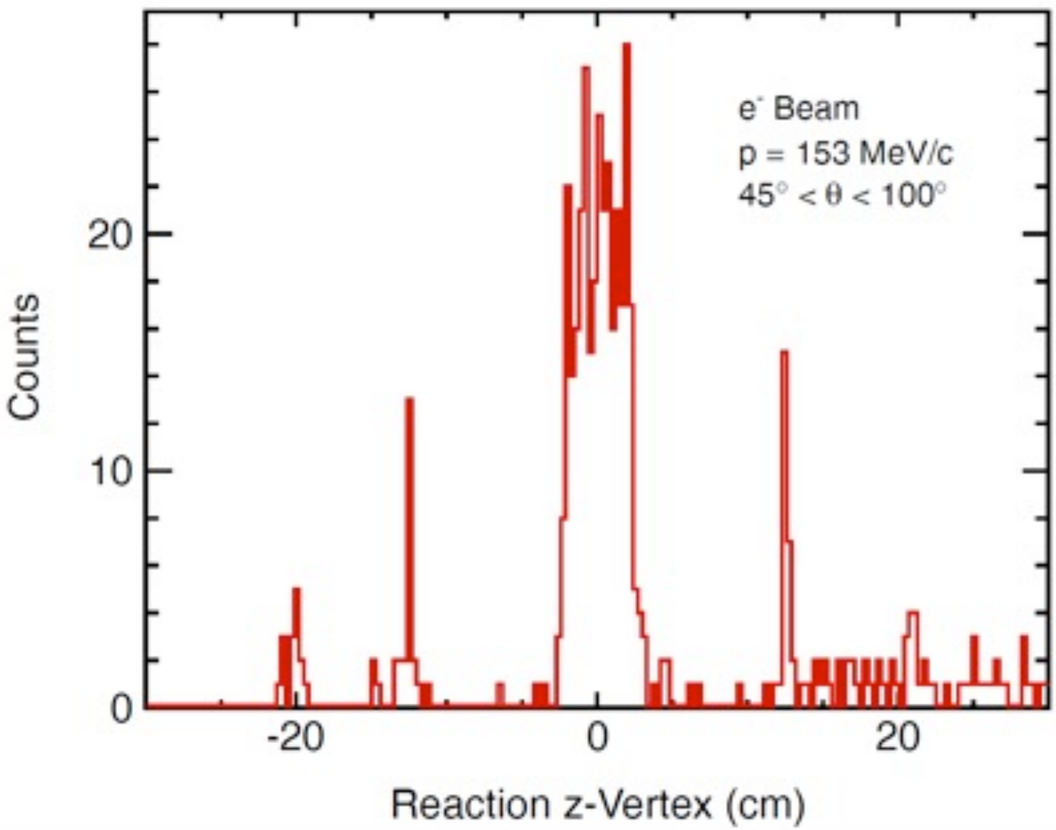




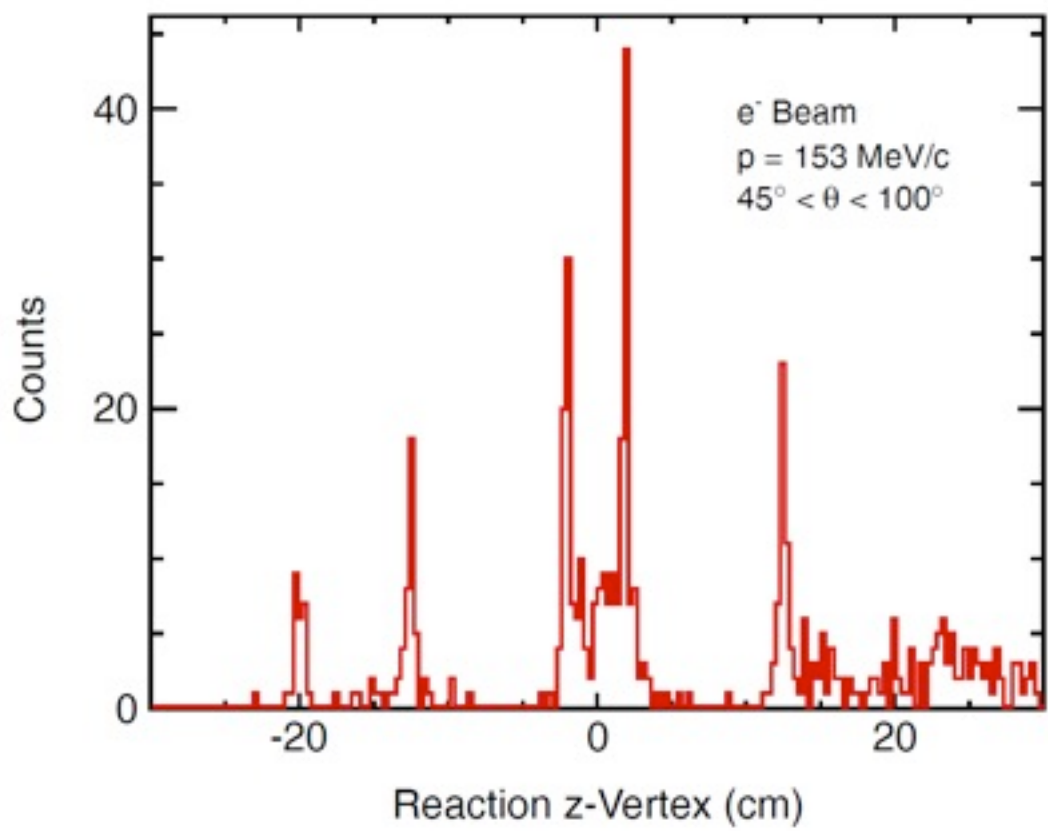
- Particle species: e-, 153 MeV, 20°<θ<45°

4) Empty Target Plots

Full



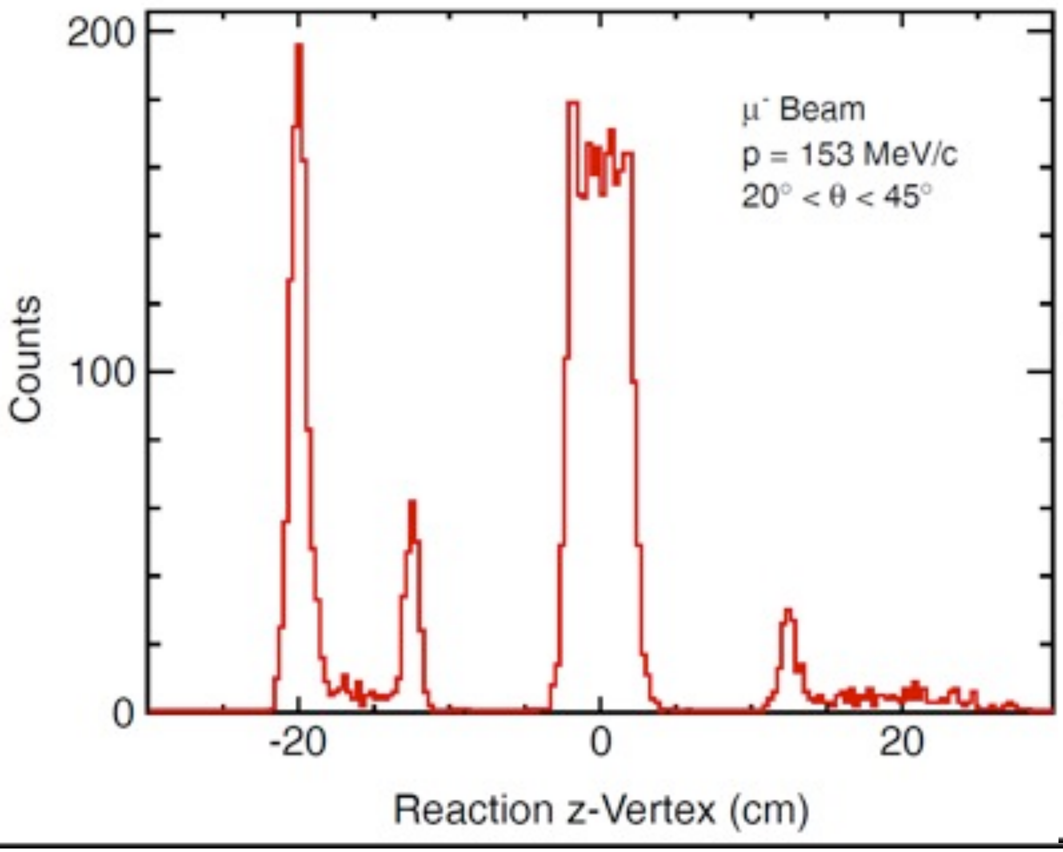
Empty (H_2 gas)



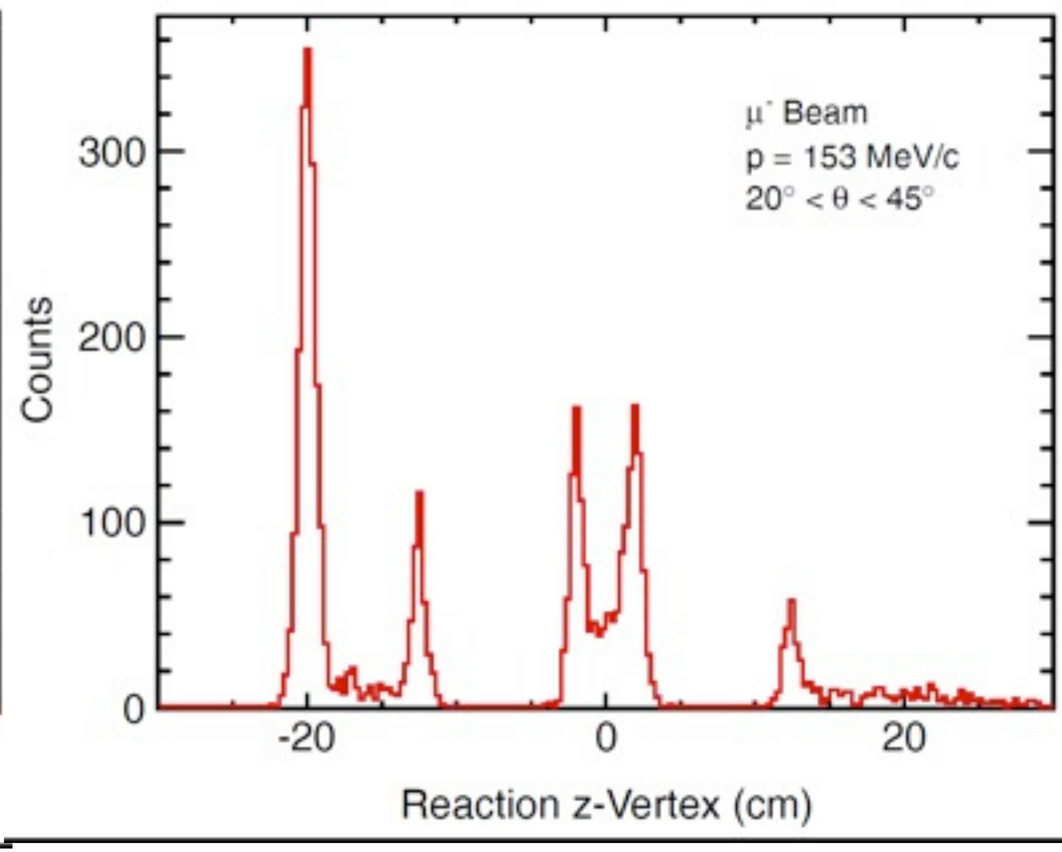
- Particle species: e-, 153 MeV, 45°<θ<100°

4) Empty Target Plots

Full



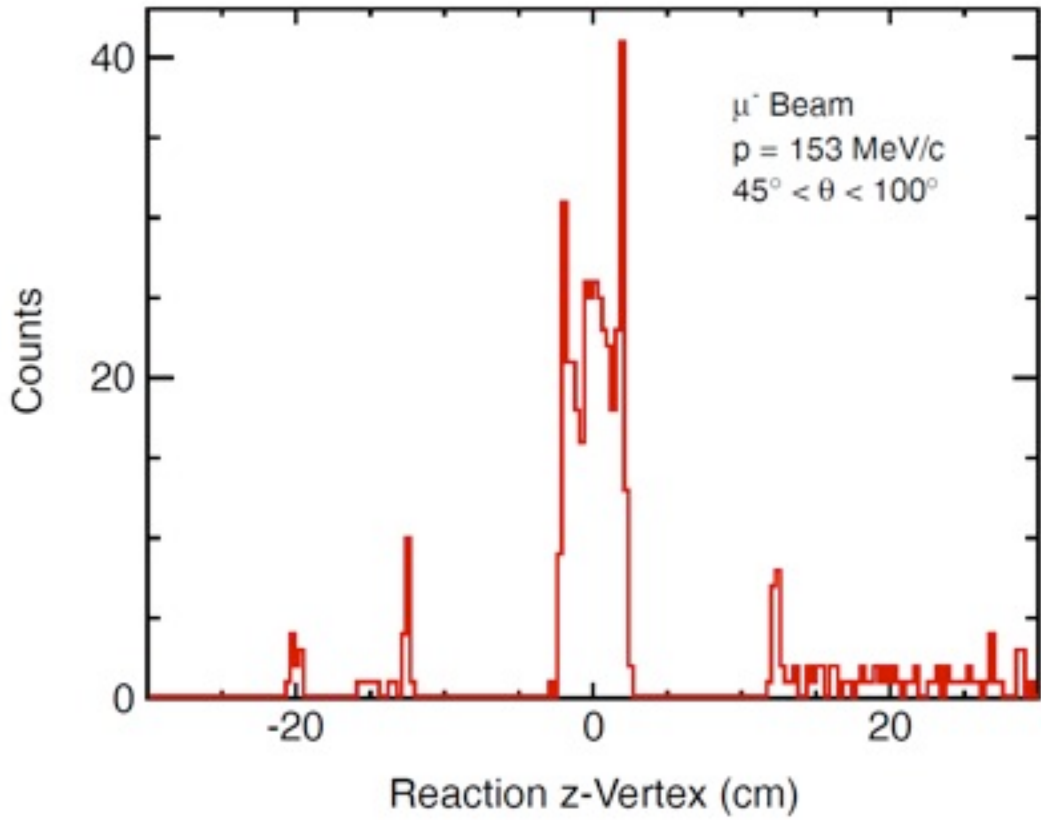
Empty (H_2 gas)



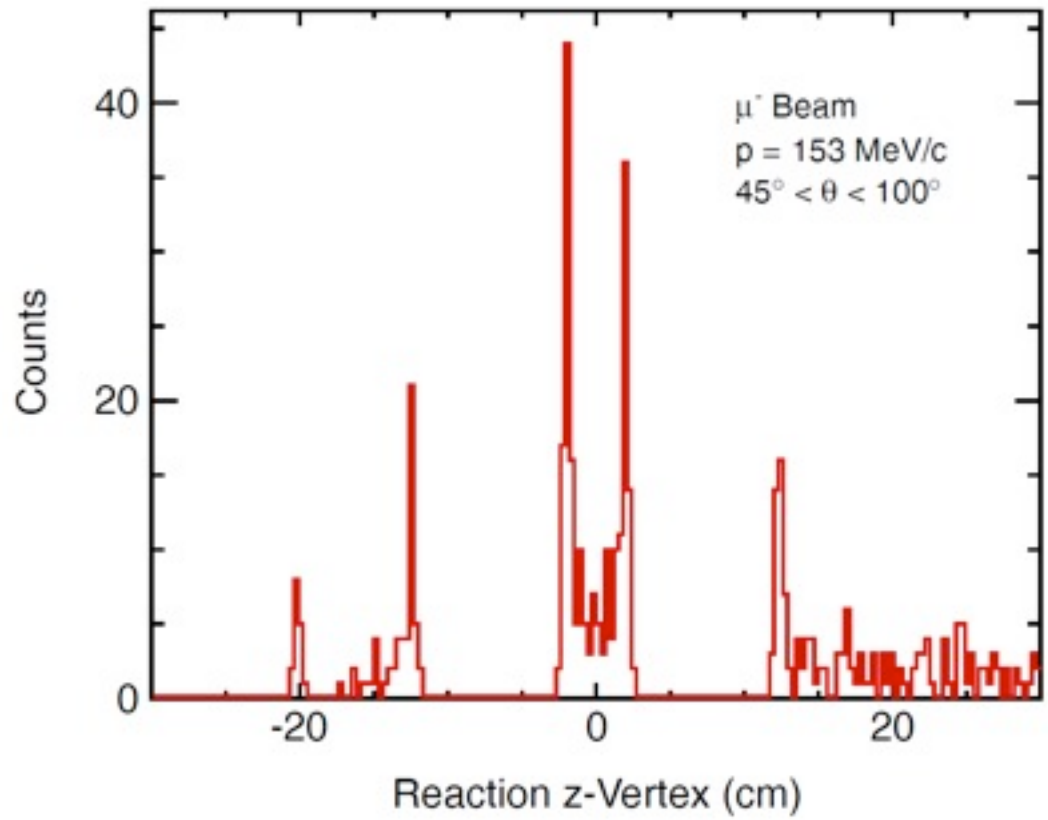
- Particle species: μ-, 153 MeV, 20°<θ<45°

4) Empty Target Plots

Full



Empty (H_2 gas)



- Particle species: μ-, 153 MeV, 45°<θ<100°

5) Plans for June test run & impact on TDR

- Beam studies:
  - How to tune, hysteresis etc.

- GEM studies:
  - Speeding up readout → to check readout speed / DAQ rate possible

- Faster readout of v792s → verify DAQ rate capabilities
- SciFi prototype test → to ensure that our plans are valid
- Beam Cerenkov with MCP beam test → finalise B.C. design options
- Better test channel-to-channel TRB3 resolution → proof of principle
- Test TRB3 Scaler readout → verify DAQ capability
- TOF measurement for μ's, and side tails of μ's to check if tails have same p

6) Implications of BV45

- **The experiment is approved by the PSI PAC**
- **Test beam allocated without problem** whenever we need it
- **Significant (measurement-scale) beam time will be allocated when:**
    - ➔ PSI Research Committee reviews completed TDR
        - TDR revision was not completed in time for BV45
    - ➔ PSI RC does detailed review of feasibility / uncertainties
        - Not presented to BV45
    - ➔ A single reviewer wants to see a G4 Beamline simulation

- Progress since BV45
    - ➔ TDR is already substantially updated along the lines of PSI request

- No impact on schedule when Jan 2015 PSI review successful

7) a) Scope of the Israeli part of the funding?

SciFi

➔ Unchanged from the proposal.

◆**Straw Tubes Tracker:**

➔ One GS will now be funded at Temple University.

➔ Hebrew University manpower is now one GS only.

➔ Additional HUJI manpower (guaranteed - funded by HUJI): 50% tech, 24 h/week Undergraduate (2 students * 1.5 day/week), 2 d/week grad student labor (4 grad students * 0.5 d/week). E-shop design for distribution card.

◆ Additional funding applied for by Israeli institutes: 1 GS each for TAU and HUJI (decision in July 2014, funding to start Oct 2014).

◆ Note: The funding to Israeli institutes is only for the construction phase of the experiments. Graduate students and travel for the running phase of the experiment will be funded by Israeli grants.

7) b) Potential American replacement?

- No US groups with necessary capacity currently available to replace the Israeli part of the construction grant
- No Israeli funding structure available for this type of equipment construction outside of Israel
- Running and analysis participation will be funded from Israeli sources
- HUJI / TAU very valuable collaborators with extensive technical / cryogenics / university infrastructure, assisting in many areas
- We have replaced some Israeli funding with US funding by replacing HUJI grad. student with Temple grad. student

8) Design work and who is doing it for each WBS?

- **1 Table & supports:** Argonne designer Tom O'Conner
- **2 SciFi:** support structure designed by D. Horrowitz (HUJI external contractor)
- **3 Cerenkov:** tgt Cv. support Argonne; IFP Cv. support Manuel Schwartz (GSI)
- **4 Straw Chambers:**
  - ➔STT frames D. Horrowitz (HUJI external contractor)
  - ➔PCB electronics design HUJI shop (Gabi Zini)
- **5 Target:**
  - ➔ Cryogenic systems: Danny Horowitz + PSI Engineer
  - ➔ Other Components: Bill Rotkowski + Bill Briscoe
- **6 Electronics:** Electronics mounting & hall layout EJD & Conrad
- **7 Scintillators:**
  - ➔Supports for scattered particle scints., beam scints. Argonne (TO'C)
  - ➔Scattered & beam scint. structures coordinated with SC (mounting)
  - ➔Supports for veto scint. Argonne (TO'C) coordinated closely with Target
- **8 GEM:**
  - ➔Support between GEM & table by Argonne (TO'C) (coordinated with HU)

9) Manpower

- See website! (Excel not pretty on a slide...)

10) Fall-back plan (no construction money 2014)

- As long as we know the experiment will be funded in 2015:
- Construction will be put off – **NO DESIGN WORK!!!**
- Continue test measurements
- Head towards full review @PSI in 2015
- Put off dress rehearsal & experiment running by one year respectively
- This time could be used **MUCH more** productively if a small pot of money could be made available for design work
- Problems resulting from this senario:
    - ➔ Lose some of existing students
    - ➔ Possible cost increases
- Without funding commitment: real issues for people submitting / with current proposals under review

10) b) demonstrate readiness to PSI PAC?

- Partially answered in Q6
  - ➔TDR already substantially updated / improved, more to follow from beam tests
  - ➔ G4 beamline being invesigated by D. Reggiani
  - ➔ Systematics & simulations further developed
- NB Experiment is approved but for the lifetime of the experiment, PSI will continue to do an annual review of progress!
- All of the issues from BV45 under construction / resolved

Backup Slides

- Shift taking / test run participation to date: Morty Taragin (Weizmann Institute), Paul Reimer (Argonne), Jan Bernaeur (MIT), Vince Sulkosky (Longwood / MIT), Juergen Diefenach (MIT / Mainz), Cristina Colicott (Dalhouse U.), *Guy Ron (HUJI), Eli Piazetsky (TAU), Jechiel Lichtenstadt (TAU)*

<u>Future / current:</u>

- **PSI:** Beamline improvements (extra quadrupoles, NMR, etc); HV supplies; LV supplies; splitters; CFD; gas; **beam!**

- **GWU:** cryolab outfitting,

- **HUJI & TAU:** 50% tech, 24 h/week, **u**ndergraduate (2 students * 1.5 day/week), 2 d/week grad student labor (4 grad students * 0.5 d/week). E-shop design for distribution card, more if grant successful...

- **BSF TAU / Rutgers:** Prototyping of SciFi

11) Examples of In-kind contributions

◆ Shift taking / test run participation to date: Morty Taragin (Weizmann Institute), Paul Reimer (Argonne), Jan Bernaeur (MIT), Vince Sulkosky (Longwood / MIT), Juergen Diefenach (MIT / Mainz), Cristina Colicott (Dalhouse U.), *Guy Ron (HUJI), Eli Piazetsky (TAU), Jechiel Lichtenstadt (TAU)*

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