Status of the Quasi-Isochronous Helical Channel

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Outline

- Motivation
- Overall layout
- Some results
- Summary and Future

Motivation

- A Quasi-Isochronous HCC aims to take advantage of a larger RF bucket size when operating near transition for purpose of capture and bunching after the tapered solenoid.

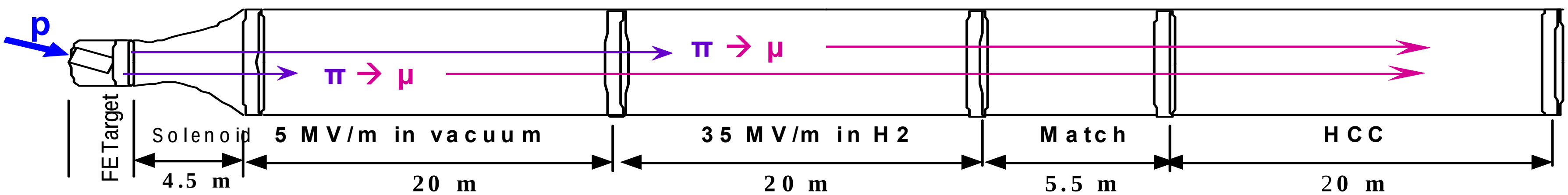
$$A_{bucket} = \frac{16\beta}{w_{rf}}\sqrt{\frac{eV_{\max} E_{synch}}{2\pi h|\eta|}}\,\frac{1-\sin(\varphi_s)}{1+\sin(\phi_s)}$$

- We expect cooled particles with initial energy above separatrices to fall into buckets. Particles in buckets migrate toward center.
- Having control over both γ_T and energy of synchronous particle should enlarge phase space available for particles to be captured.
- The Quasi-Isochronous HCC should match naturally into an HCC maximized for cooling (equal cooling decrements).

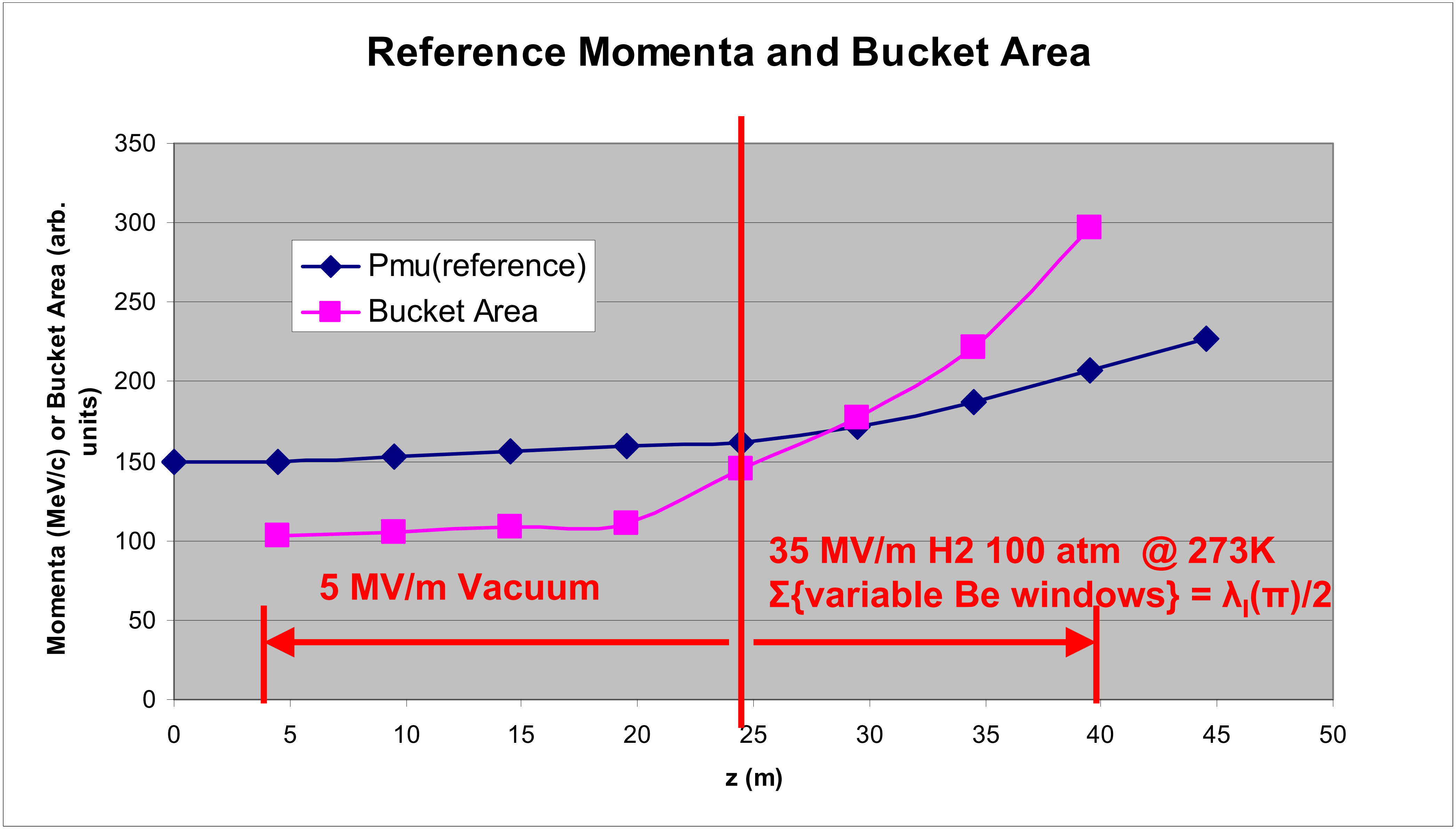
Overall Layout

- We start the design with an existing HCC configuration that is optimized for cooling for now.
- HCC acceptance is approximately 150 MeV/c < p < 300 MeV/c.
- Bsol(HCC) ~ 4.2T.
- Therefore, we modify the front end as follows:
  1. Tapered solenoid is modified from Bz with 20 T → ~2 T to 20 T → 4.2 T. This shortens tapered solenoid length from 12.9 m to 4.5 m .
  2. In desire to maximize number of muons that fall into the HCC acceptance, we implement 2 sequential straight sections:
     a. 20 m of RF in vacuum @ 5MV/m to capture mu's & pi's and allow lower momenta pions to decay into muons.
     b. 20 m of RF in material (Be & 100 atm GH2) @ 35 MV/m to enlarge RF bucket size and promote otherwise useless higher energy pions to interact with material, producing lower energy pions that decay into muons in useful momenta range.
  3. Incorporate existing match section and HCC. RF, GH2, and Be windows are added into match. Those already exist in the HCC portion (diff values).

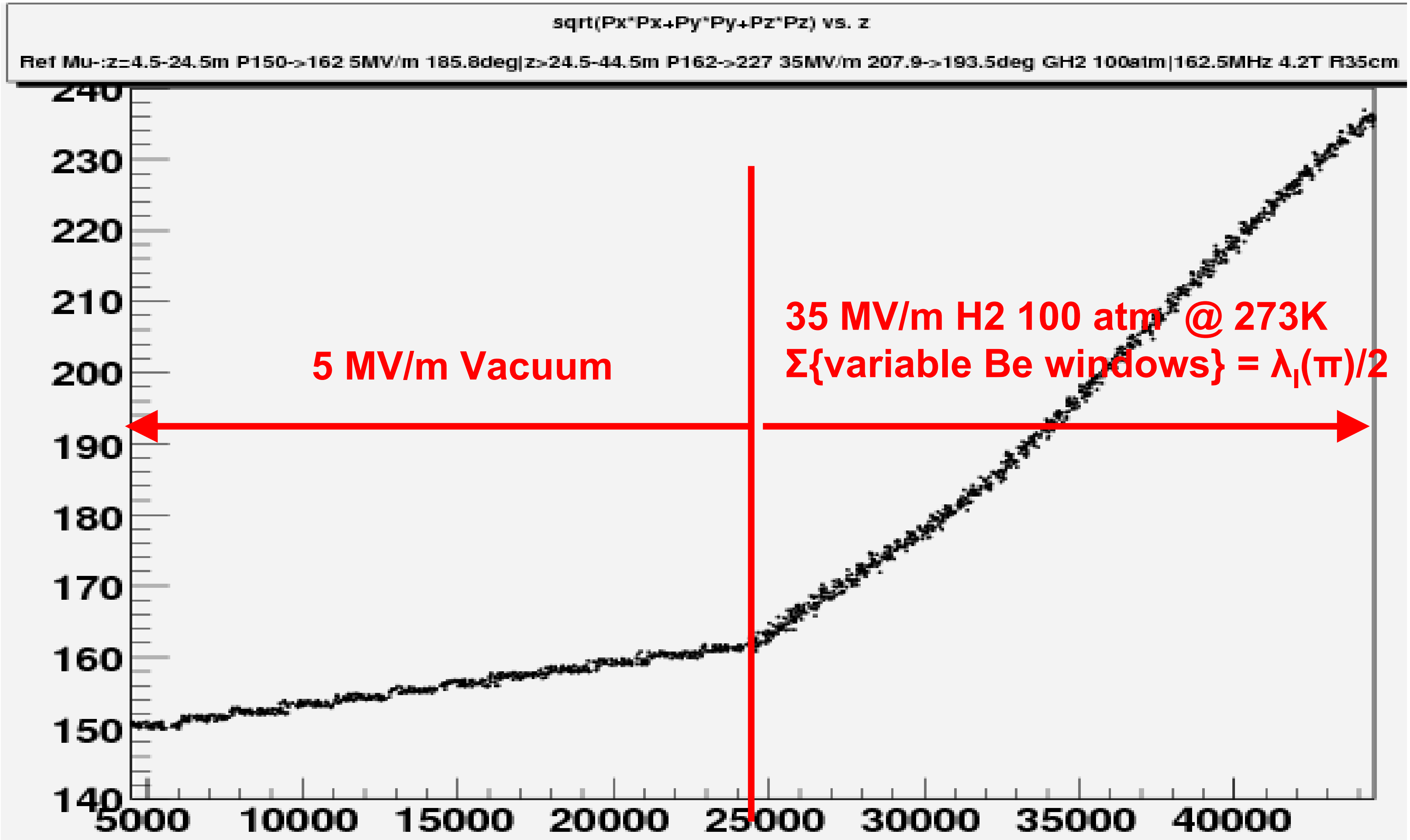
Overall Layout



z(m)	Subsystem	Purpose	Physical Dimensions	Fields
0.0 to 4.5	Capture/Tapered Solenoid	Enhance pion/muon capture	L = 4.5 m R = 7.5 cm → 35 cm	Bsol = 20 T → 4.2 T
4.5 to 24.5	Straight RF Buncher in vacuum	1. Initial capture of pi's & mu's into RF buckets. 2. Allow lower momenta pi's to decay into mu's.	L = 20 m R = 35 cm	Bsol = 4.2 T 160 RF Cavities: Ez,max = 5 MV/m, f= 162.5 MHz φs=186°: P(μ−)=150→162 MeV/c
24.5 to 44.5	Straight RF Buncher in 100 atm H2 w/ variably thick Be windows.	1. H2 gas allows higher RF gradient for enlarged buckets. 2. Be promotes useless higher momenta pi's to degrade energy, enhancing decay into useful mu's.	L = 20 m R = 35 cm	Bsol = 4.2 T 160 RF Cavities: Ez,max = 35 MV/m, f= 162.5 MHz φs=208→194°, P(μ−)=162→237 MeV/c
44.5 to 50.0	Match into HCC	1. To match between straight solenoid into HCC. 2. Enhance mu capture due to transition occurring in match.	L = 5.5 m (5.5 λ's) R = 35 cm	Bsol = variable 44 RF Cavities: Ez,max = 35 MV/m, f= 162.5 MHz φs varied to maintain P(μ−)=237 MeV/c
50.0 to 70.0	HCC	• To cool muons.	L = 20 m (20 λ's) R = 35 cm	Bsol = variable 160 RF Cavities: Ez,max = 35 MV/m, f= 162.5 MHz φs=-12.6° to maintain P(μ−)=237 MeV/c



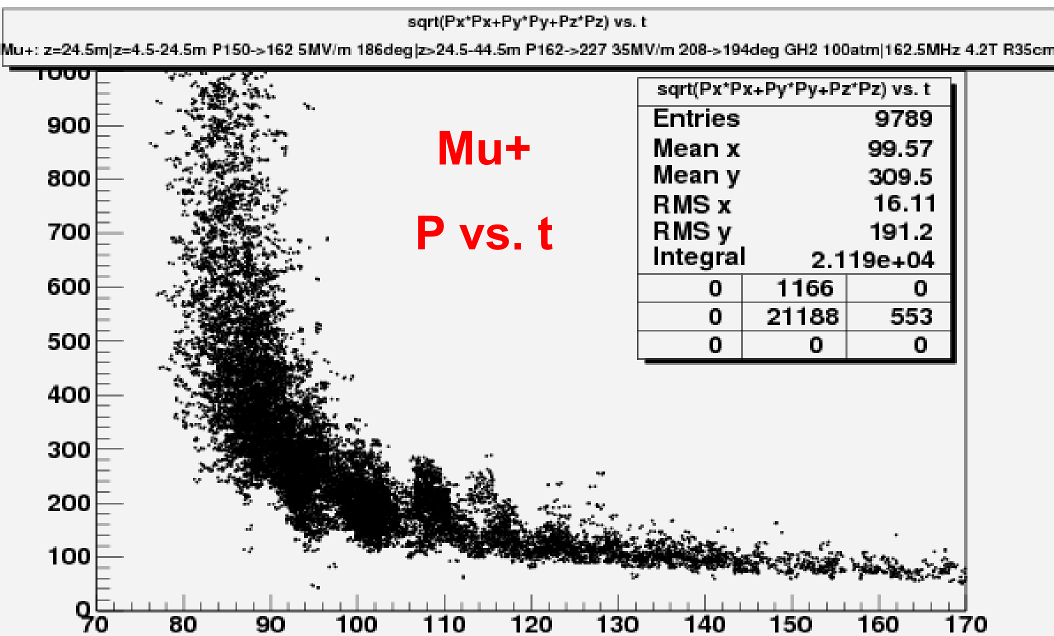
Reference Momenta and Bucket Area
Momenta (MeV/c) or Bucket Area (arb. units)
z (m)
Pmu(reference)
Bucket Area
5 MV/m Vacuum
35 MV/m H2 100 atm @ 273K
Σ{variable Be windows} = λI(π)/2
0
50
100
150
200
250
300
350
0
5
10
15
20
25
30
35
40
45
50

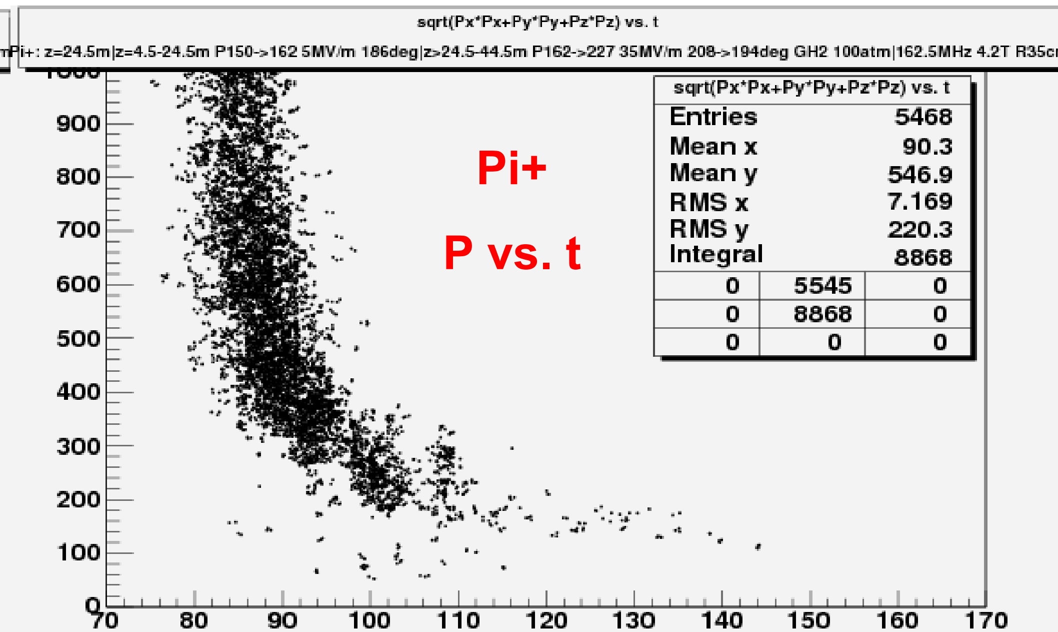


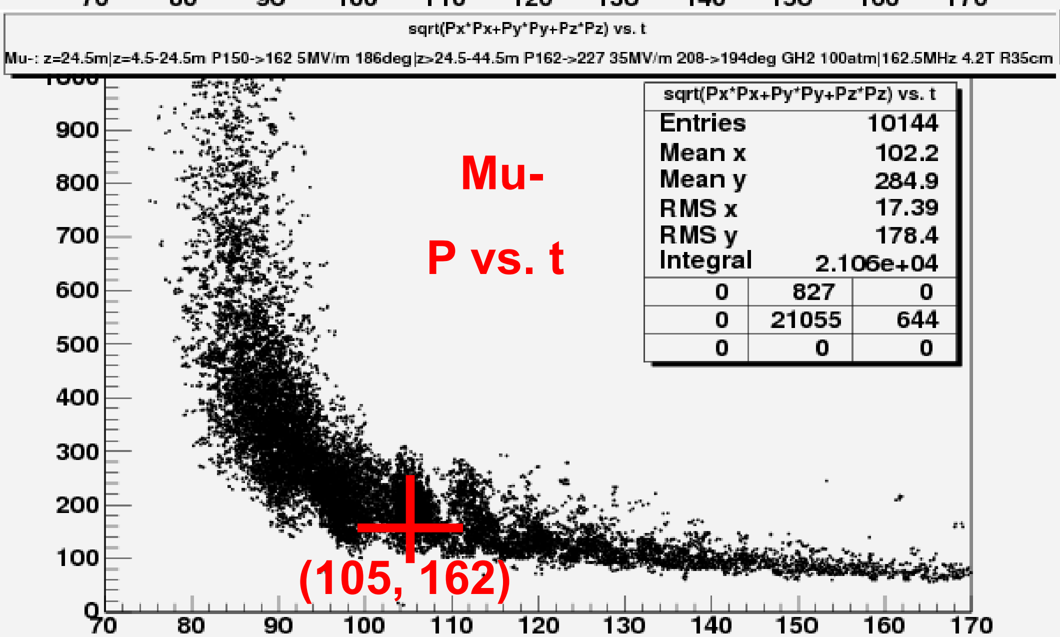
Muons, Inc.

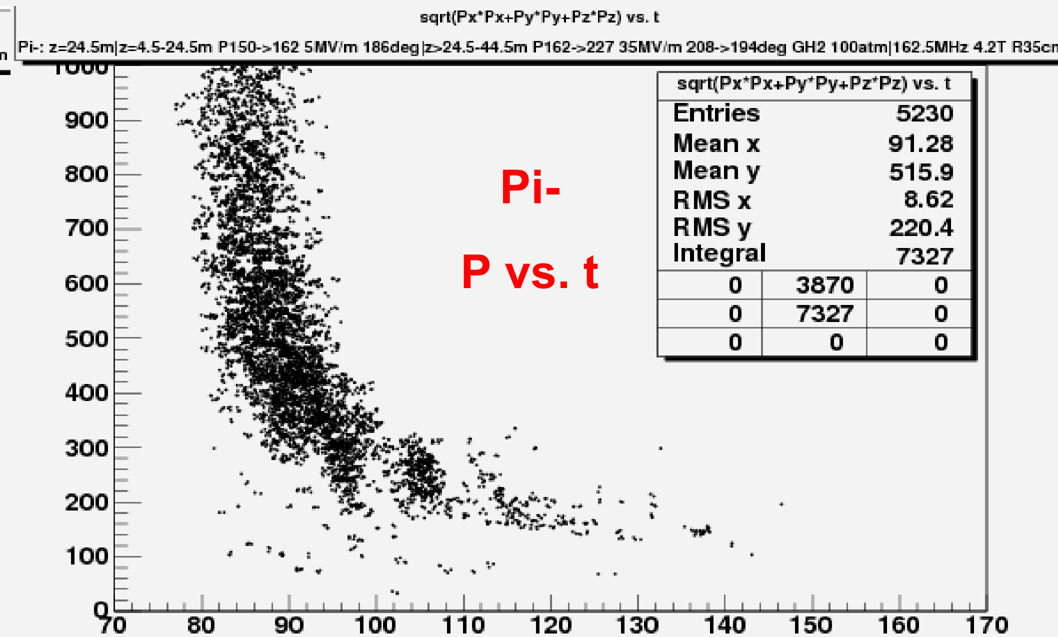
Fermilab

At end of 5 MV/m Vacuum (z=24.5m)

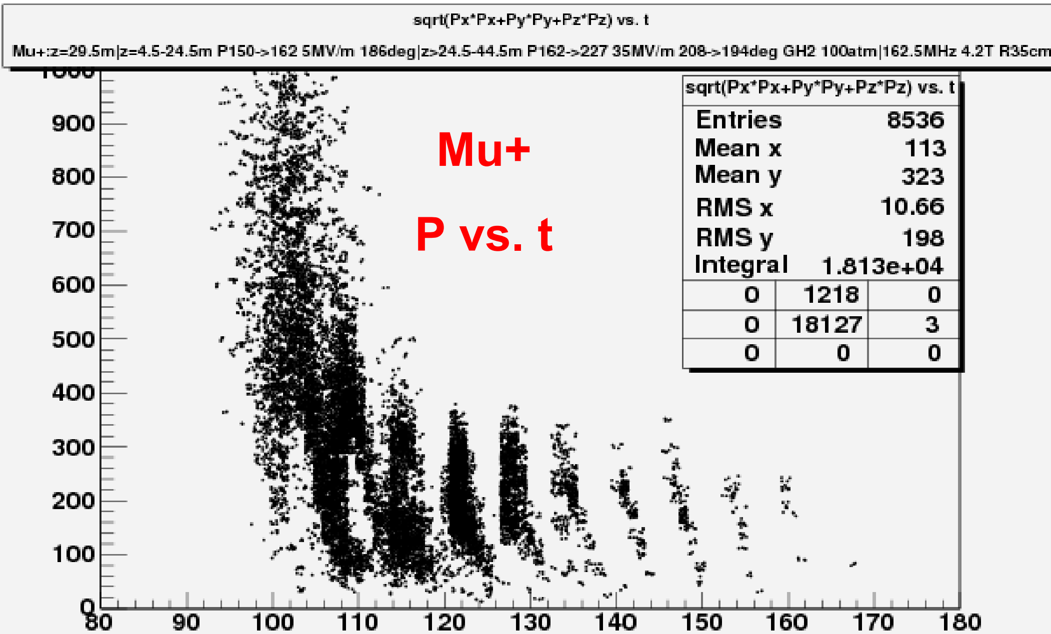


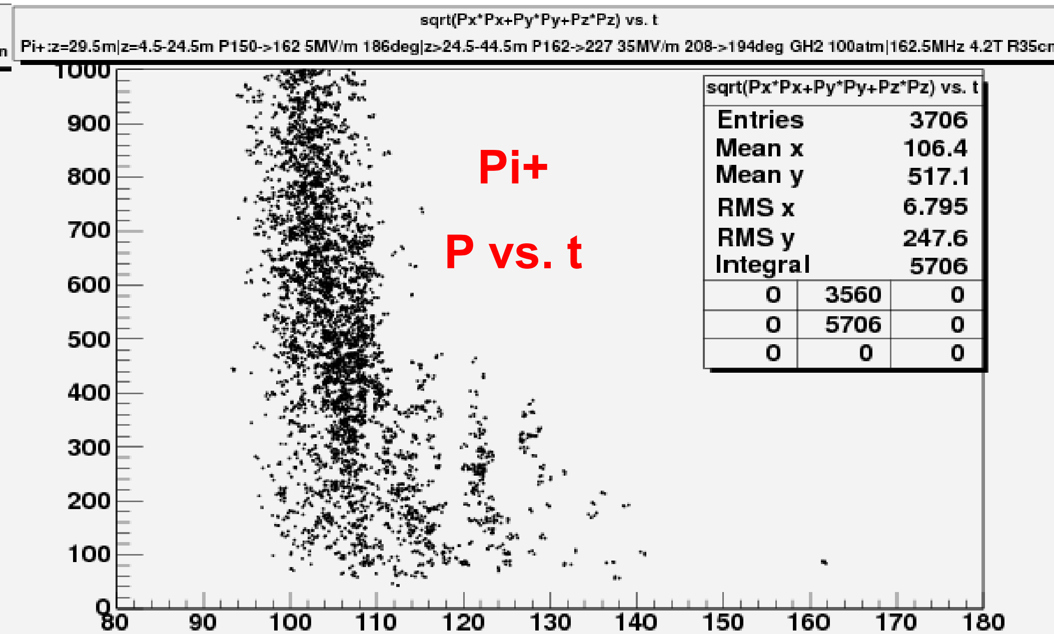


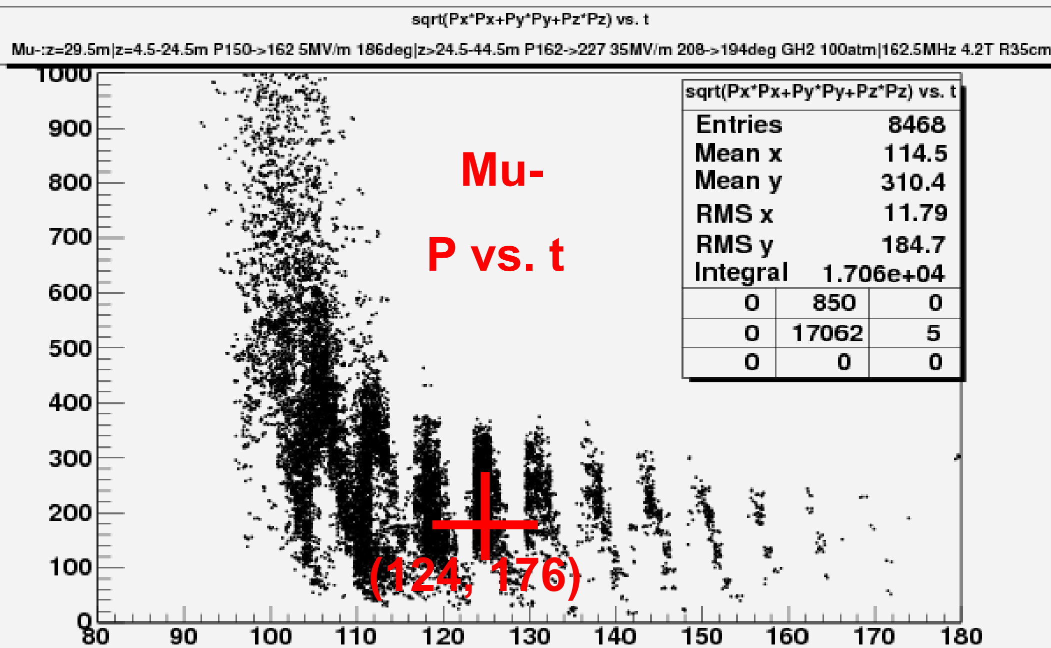


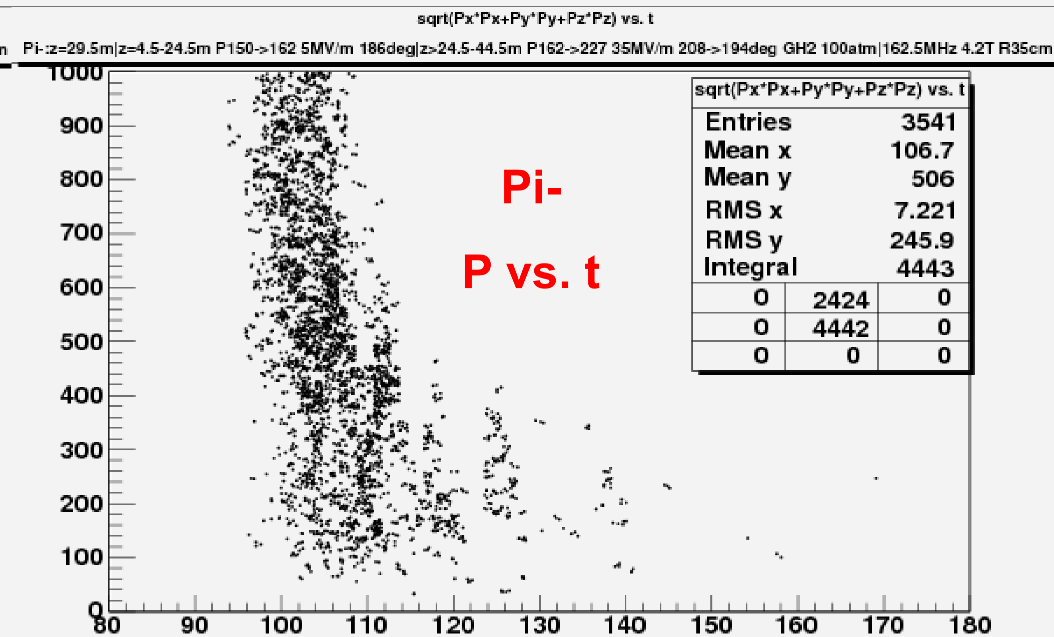


5 m into 35 MV/m w/ H2 @ 100 atm 273K (z=29.5m)

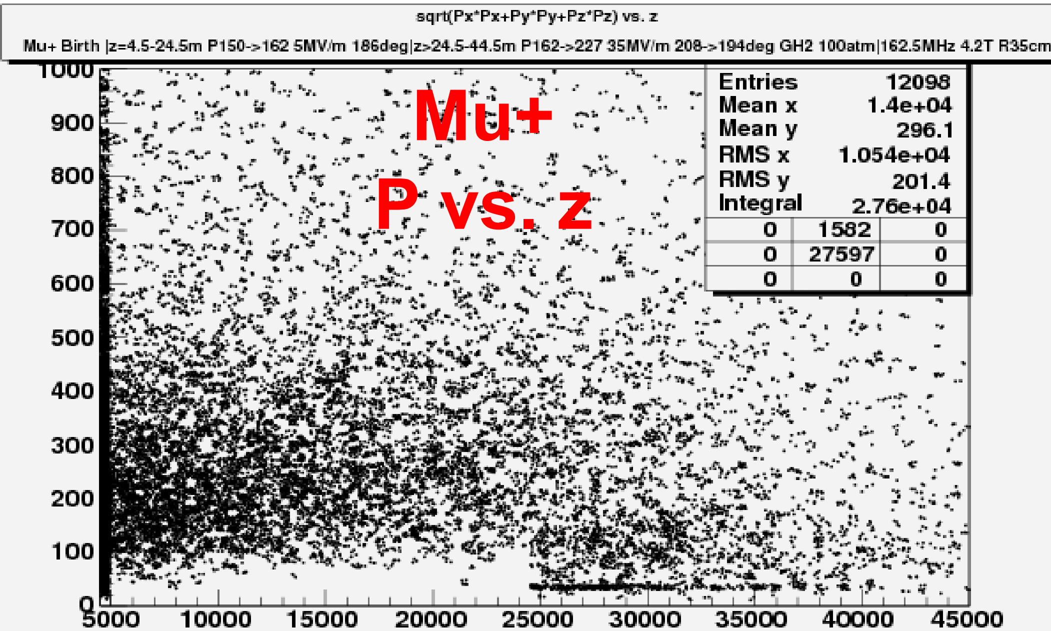


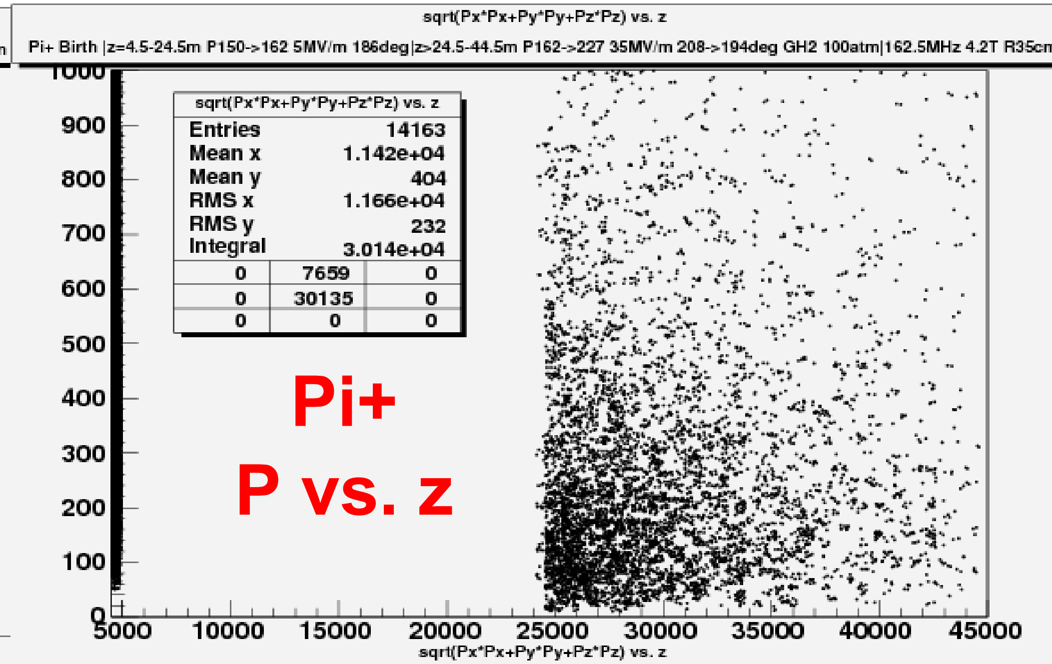


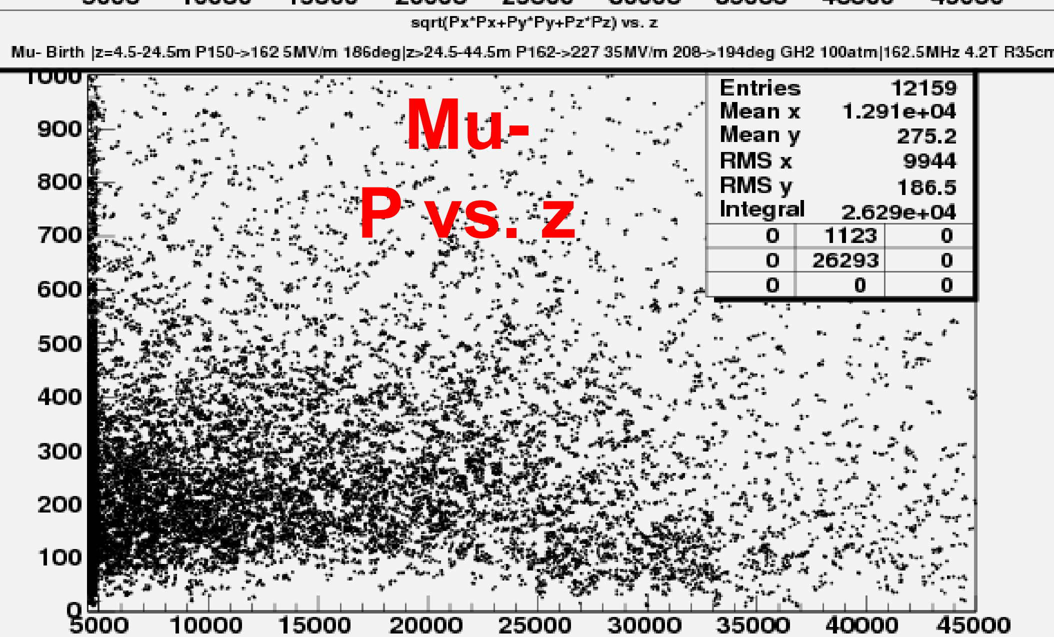


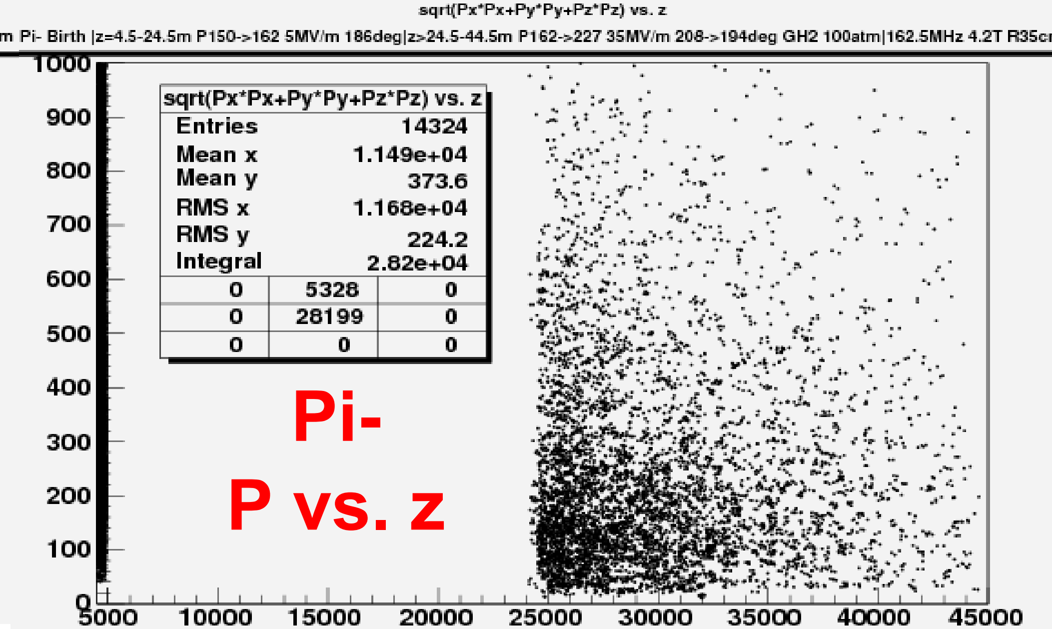


Birth of Particles

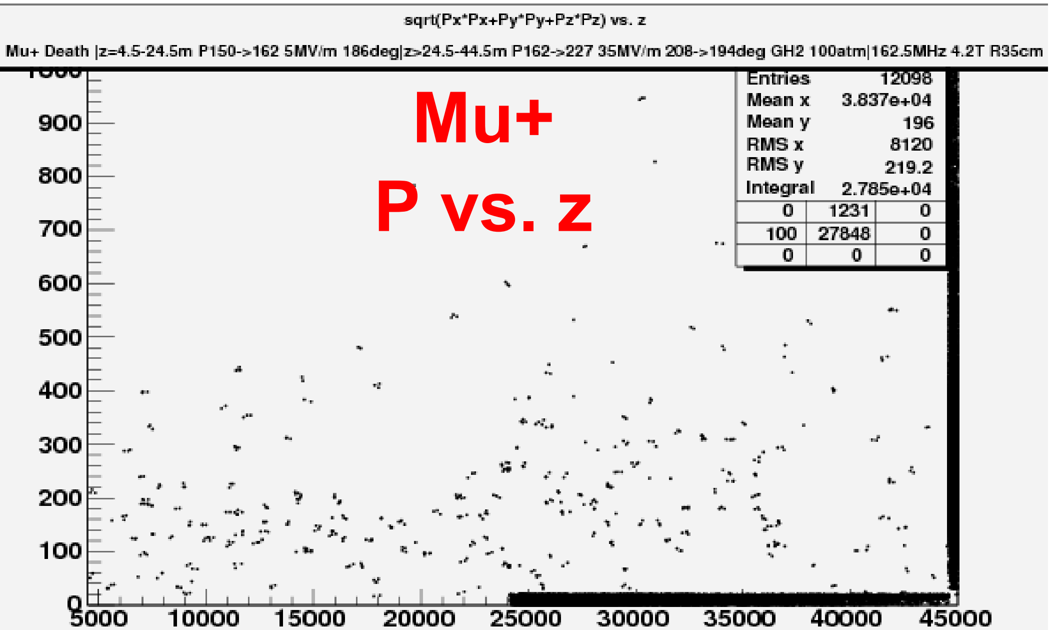


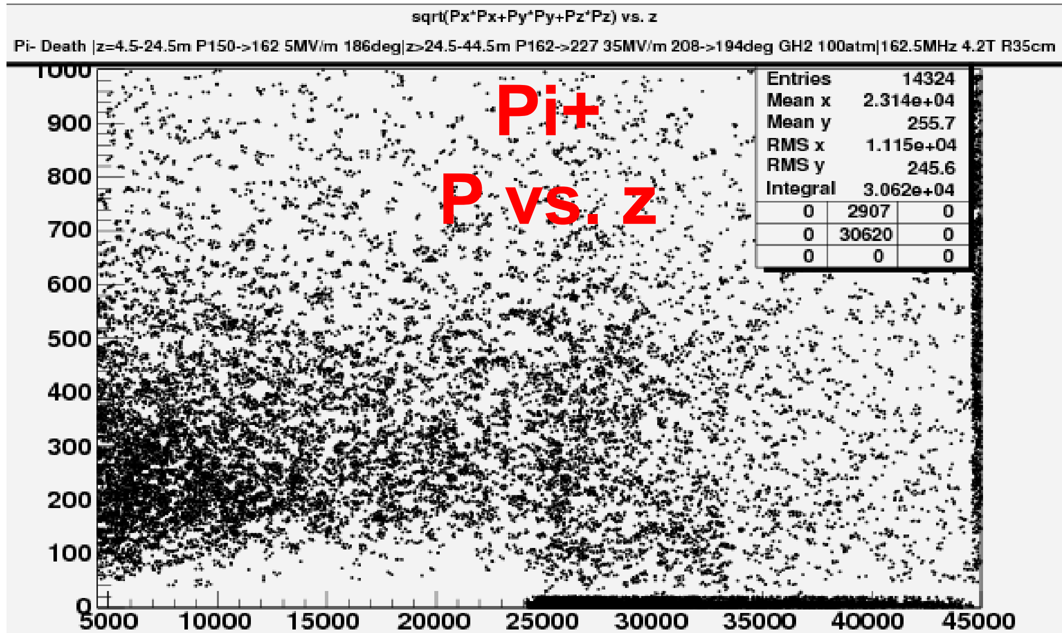


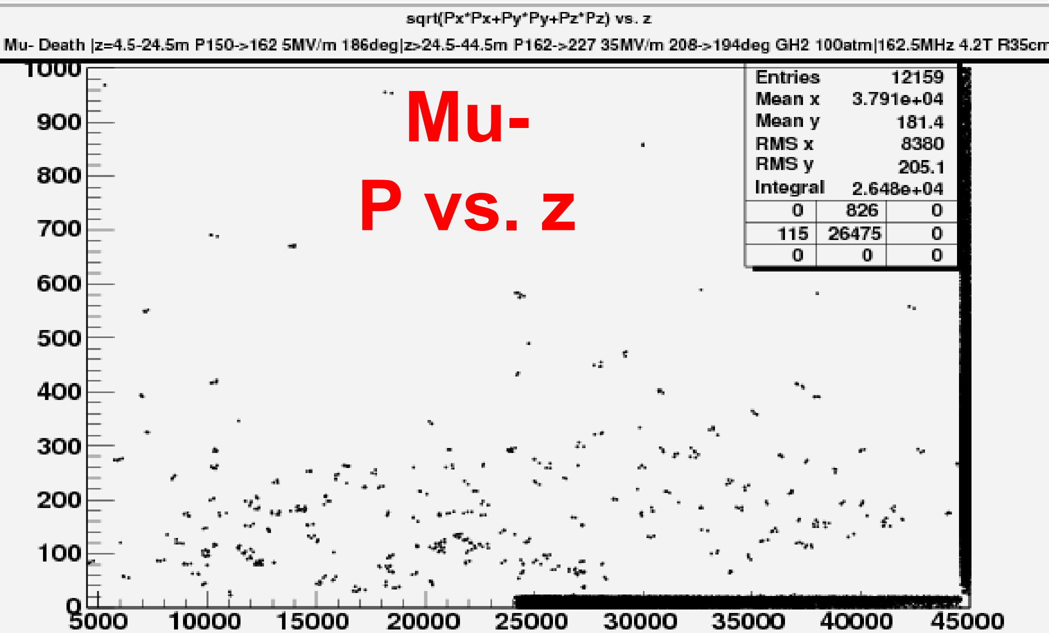


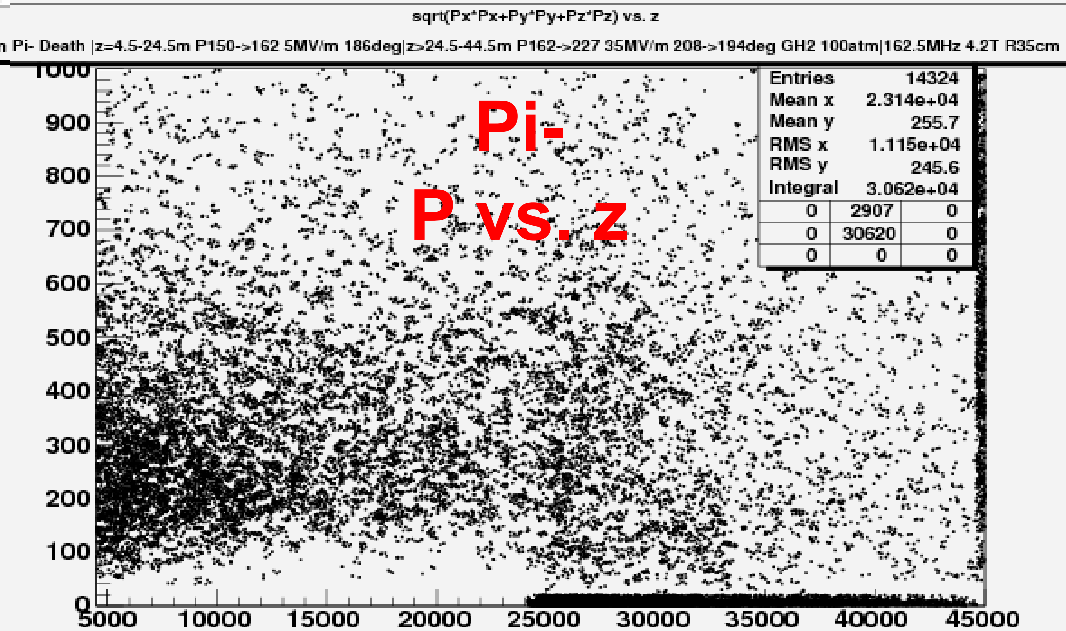


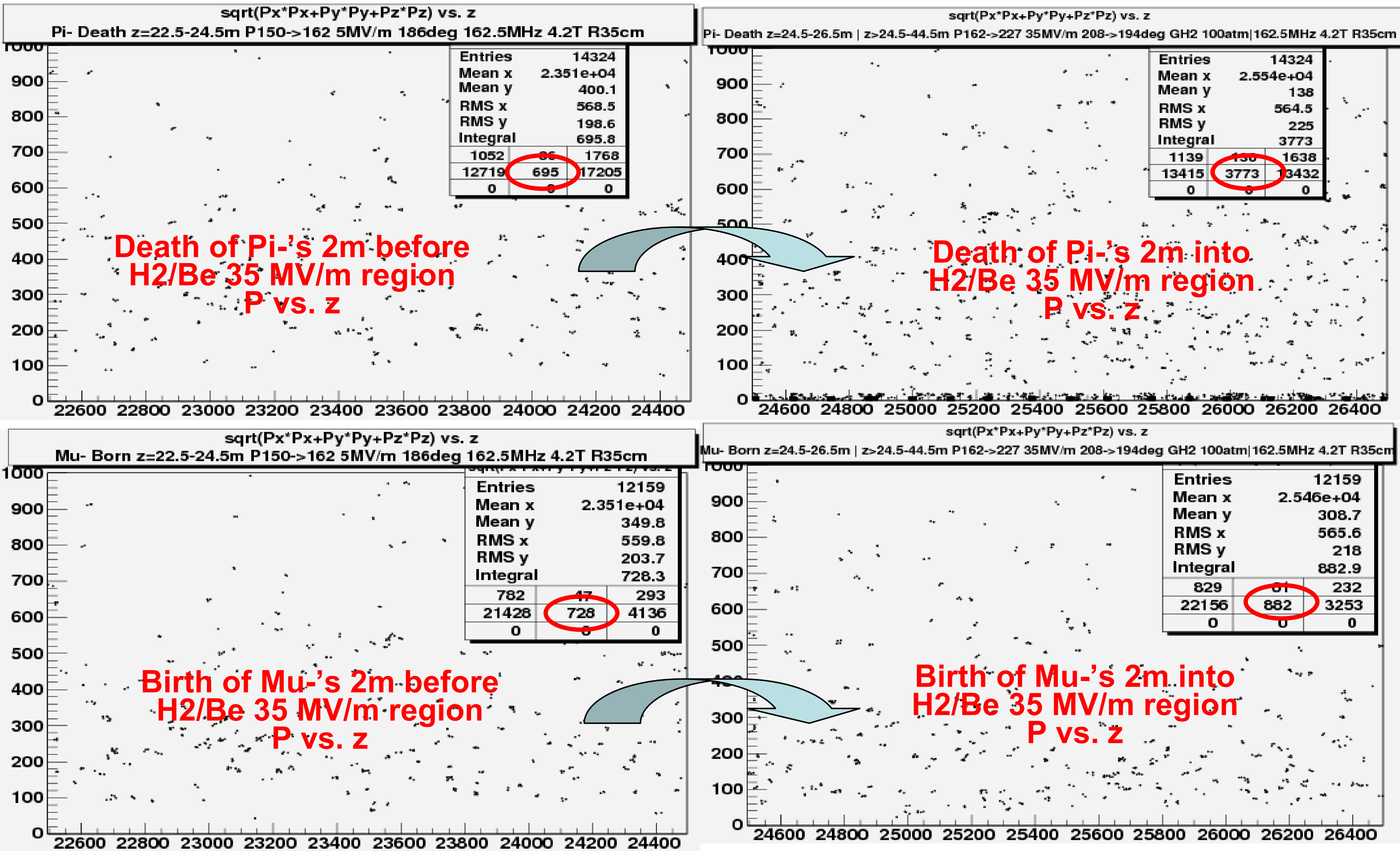
Death of Particles







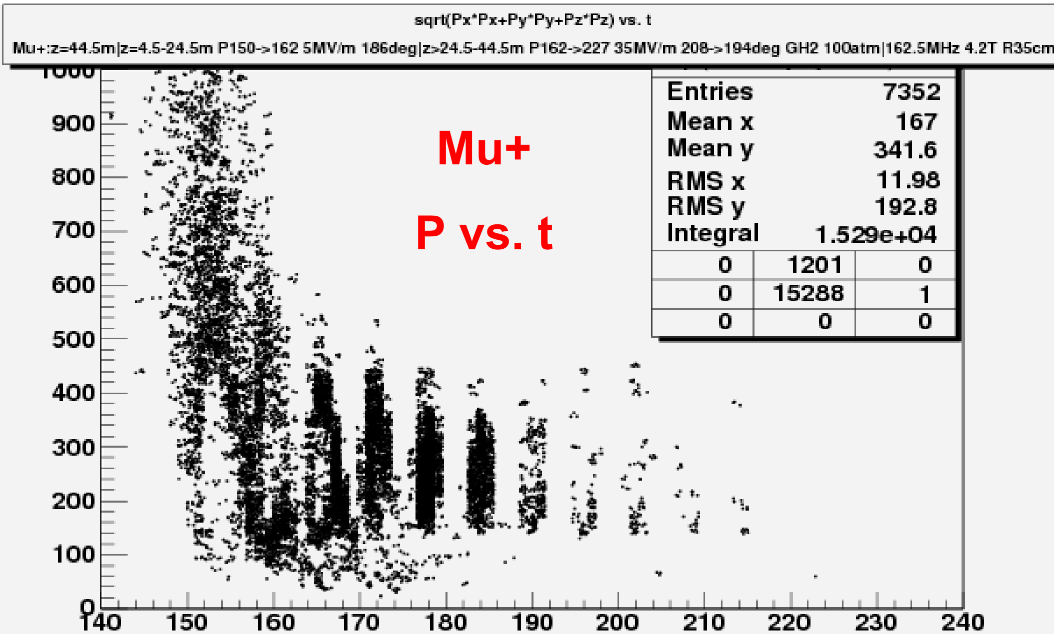


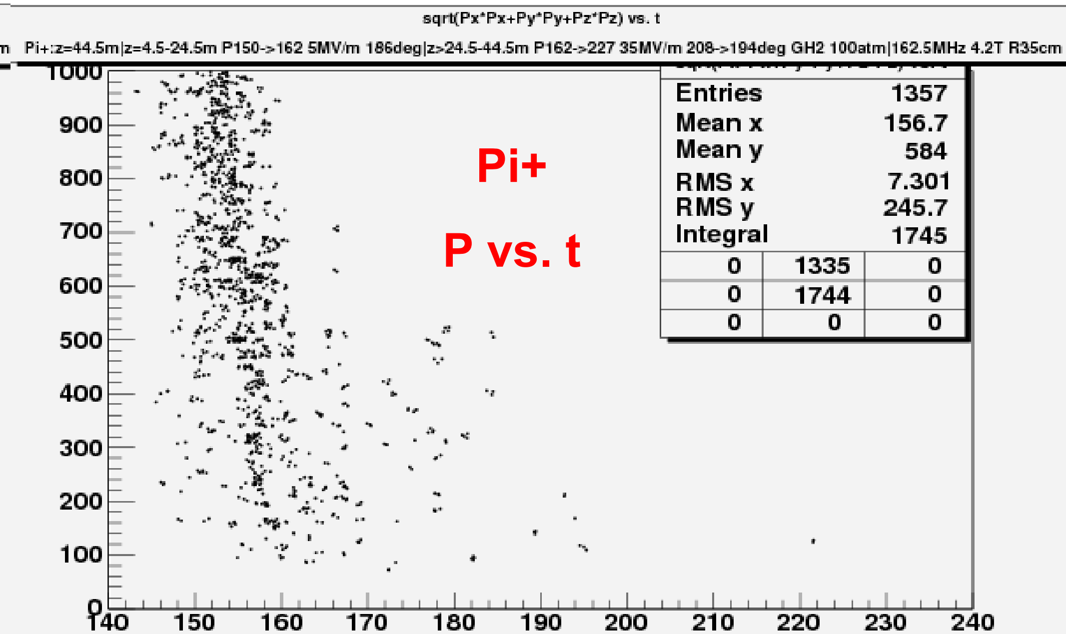

sqrt(Px*Px+Py*Py+Pz*Pz) vs. z
Pi- Death z=22.5-24.5m P150->162 5MV/m 186deg 162.5MHz 4.2T R35cm
Entries 14324
Mean x 2.351e+04
Mean y 400.1
RMS x 568.5
RMS y 198.6
Integral 695.8
1052 1768
12719 695 17205
0 0
Death of Pi-'s 2m before
H2/Be 35 MV/m region
P vs. z
sqrt(Px*Px+Py*Py+Pz*Pz) vs. z
Pi- Death z=24.5-26.5m | z>24.5-44.5m P162->227 35MV/m 208->194deg GH2 100atm|162.5MHz 4.2T R35cm
Entries 14324
Mean x 2.554e+04
Mean y 138
RMS x 564.5
RMS y 225
Integral 3773
1139 1638
13415 3773 13432
0 0
Death of Pi-'s 2m into
H2/Be 35 MV/m region
P vs. z
sqrt(Px*Px+Py*Py+Pz*Pz) vs. z
Mu- Born z=22.5-24.5m P150->162 5MV/m 186deg 162.5MHz 4.2T R35cm
Entries 12159
Mean x 2.351e+04
Mean y 349.8
RMS x 559.8
RMS y 203.7
Integral 728.3
782 293
21428 728 4136
0 0
Birth of Mu-'s 2m before
H2/Be 35 MV/m region
P vs. z
sqrt(Px*Px+Py*Py+Pz*Pz) vs. z
Mu- Born z=24.5-26.5m | z>24.5-44.5m P162->227 35MV/m 208->194deg GH2 100atm|162.5MHz 4.2T R35cm
Entries 12159
Mean x 2.546e+04
Mean y 308.7
RMS x 565.6
RMS y 218
Integral 882.9
829 232
22156 882 3253
0 0
Birth of Mu-'s 2m into
H2/Be 35 MV/m region
P vs. z

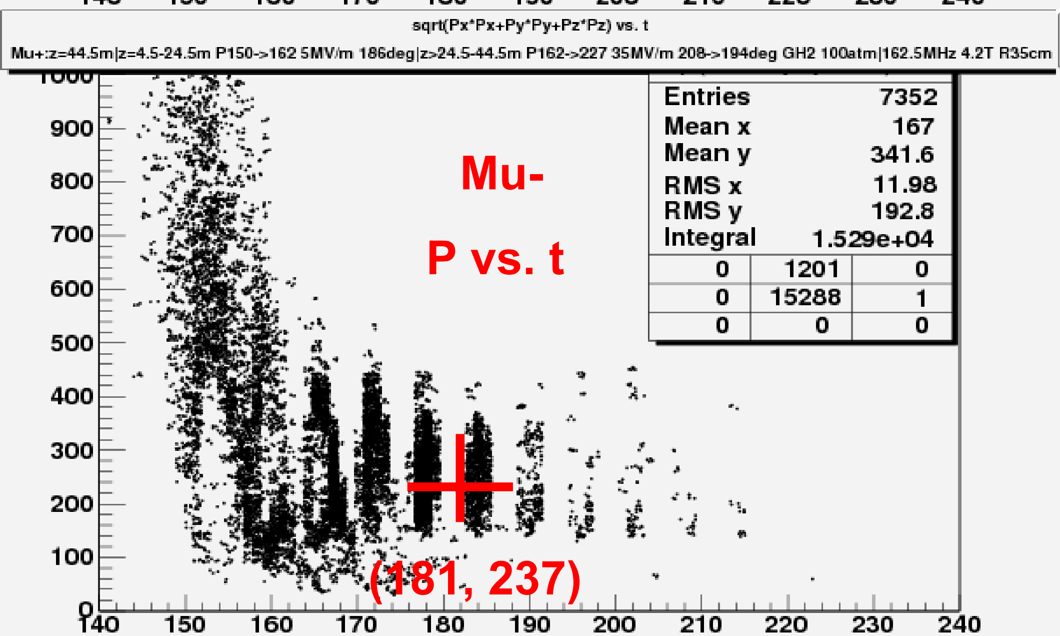
The rate of muons created across the transition from vacuum into the Be/H2 has increased by:

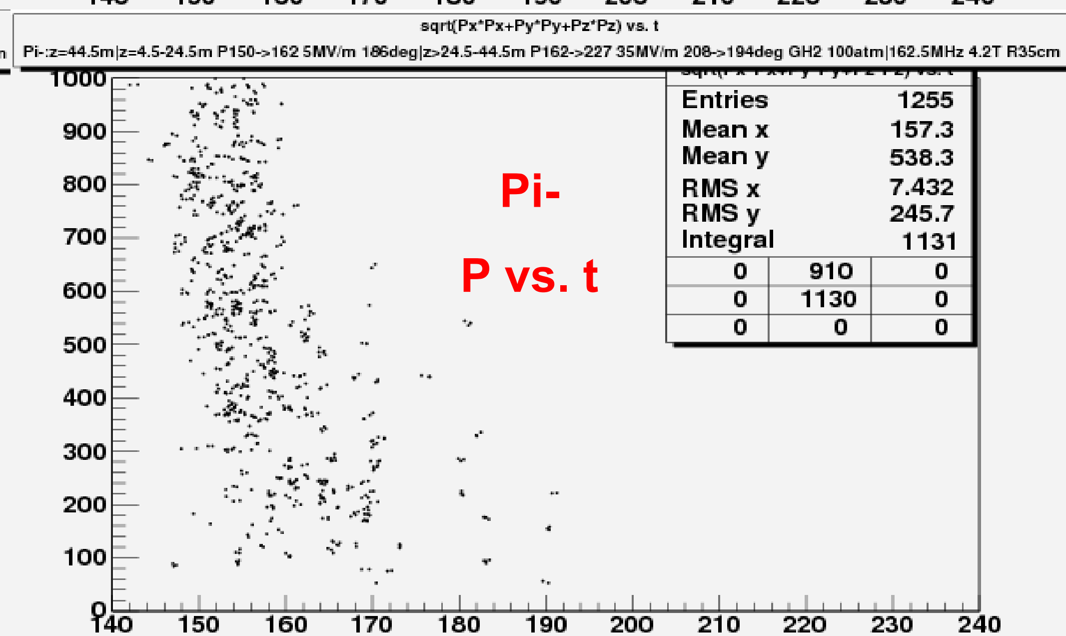
~21% (728→882)

20 m into 35 MV/m w/ H2 @ 100 atm 273K (z=44.5m)







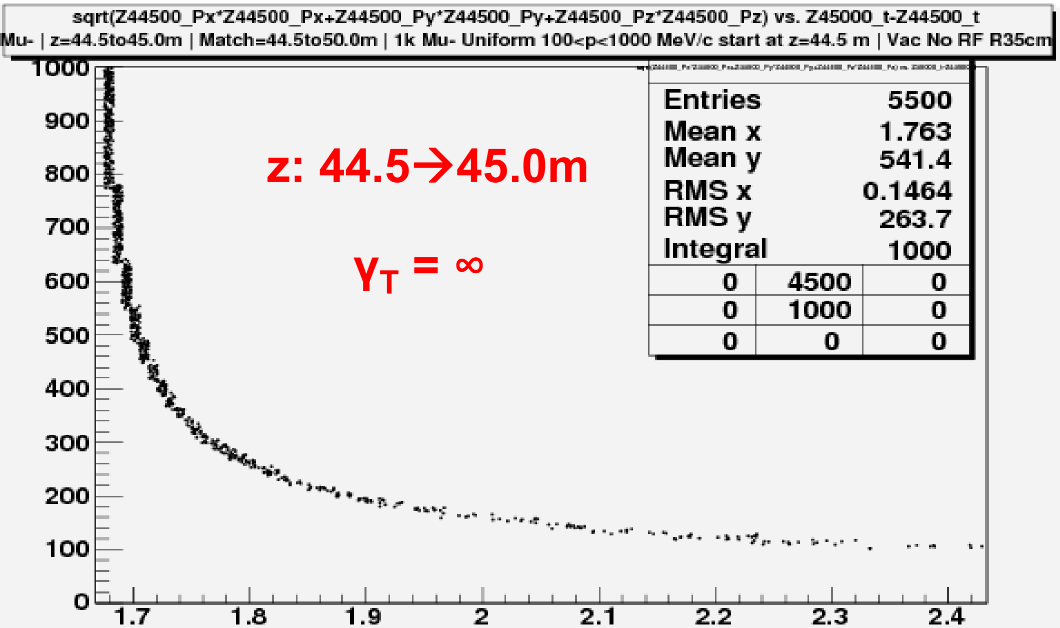


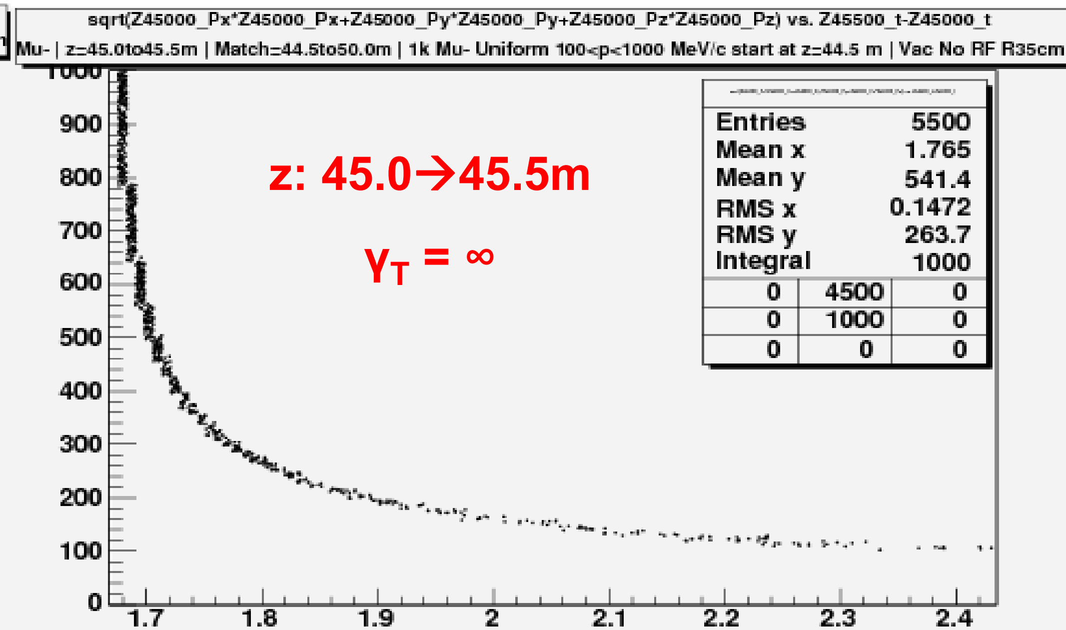
Design of RF in Matching Section

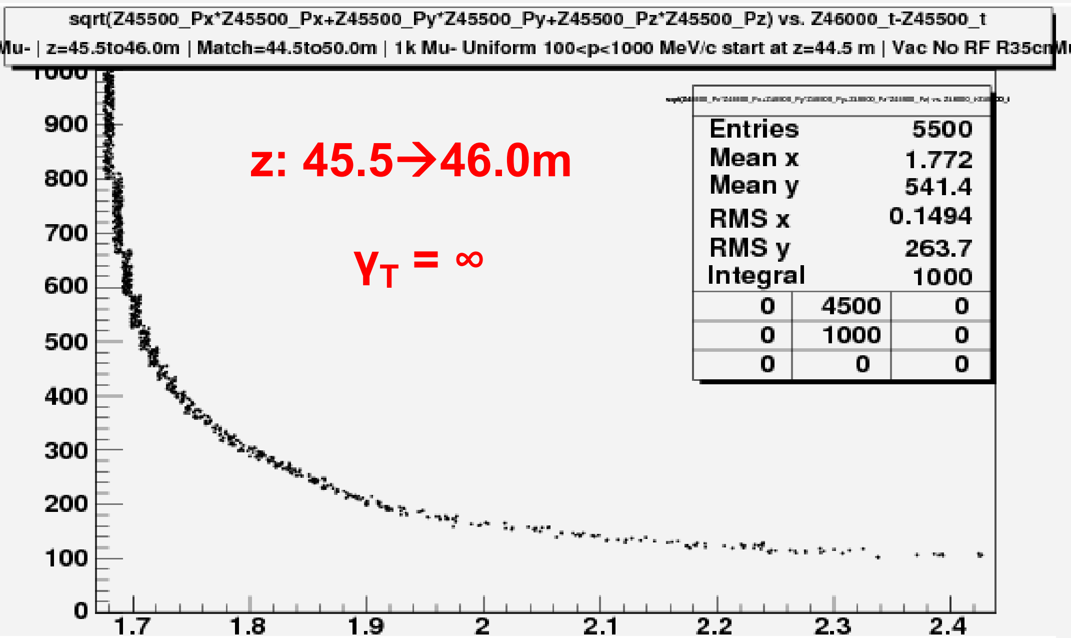
1. In the current design, we simply adjusted φ_s to compensate the increased energy loss due to the longer path muons must travel as κ grows from 0 to 1 (1.13) across the match and maintain Pref = 237 MeV/c. Unfortunately, this causes the RF bucket area to shrink after passing through transision.
2. Ideas for the future to enable RF bucket growth across the match:
    a. Allow φ_s to change across match in order to maintain RF bucket growth.
    b. Increase max gradient across match (sub-optimal at start of match).

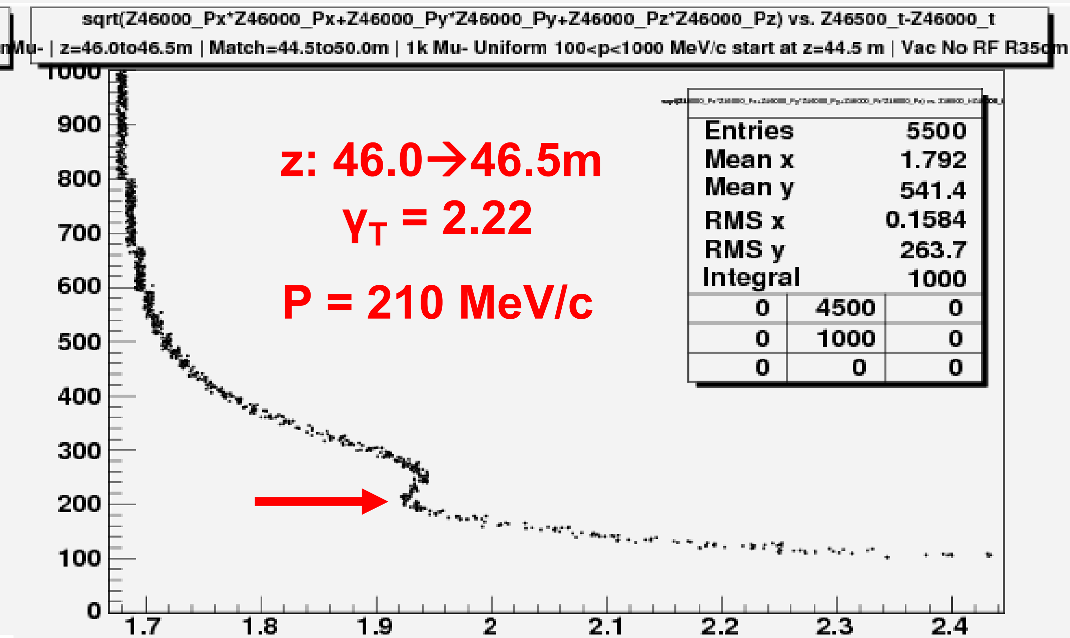
$$A_{bucket} = \frac{16\beta}{w_{rf}} \sqrt{\frac{eV_{\max} E_{synch}}{2\pi h|\eta|}} \frac{1-\sin(\varphi_s)}{1+\sin(\phi_s)}$$

1: Strictly Earliest Arrival Method









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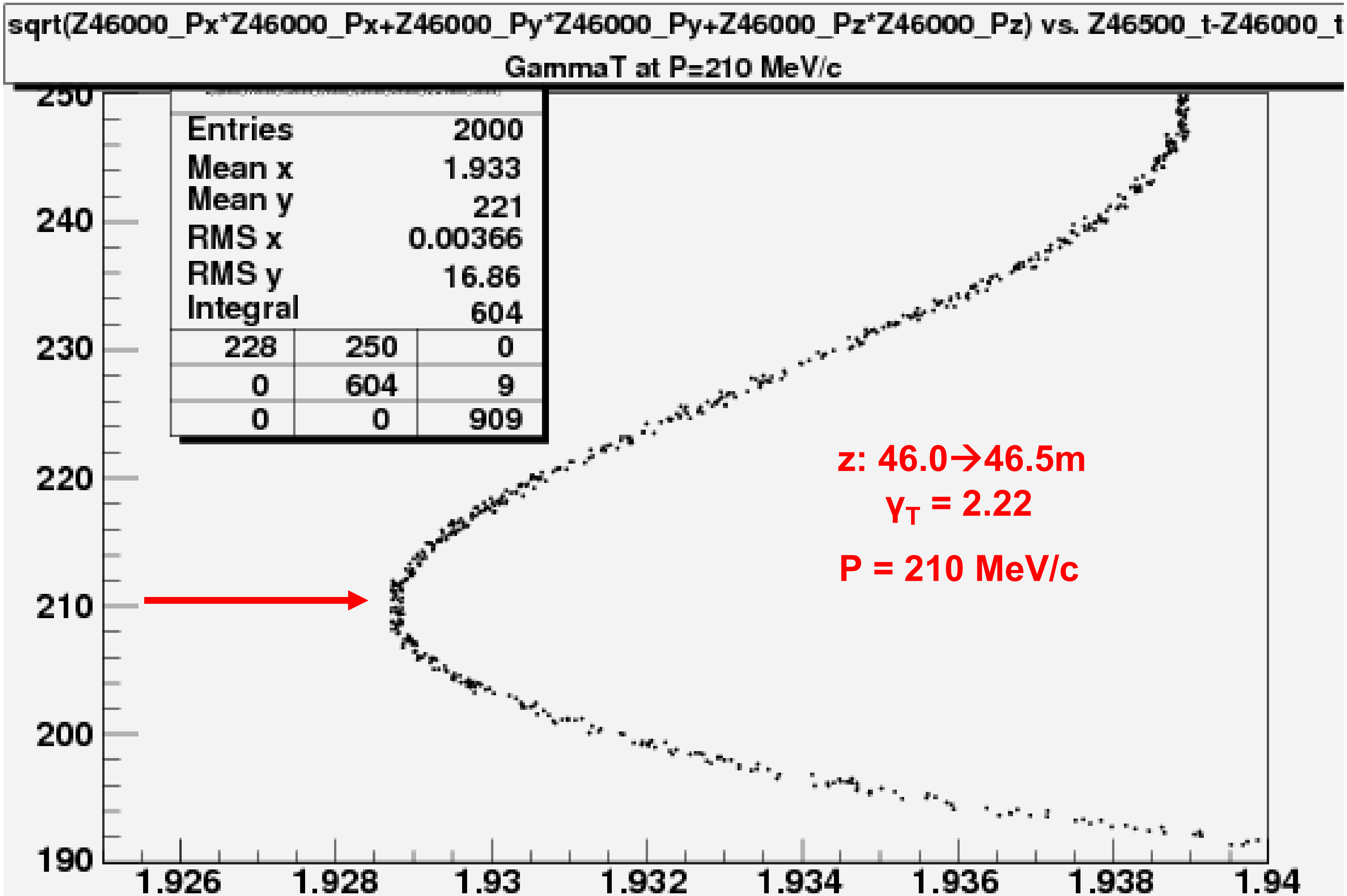
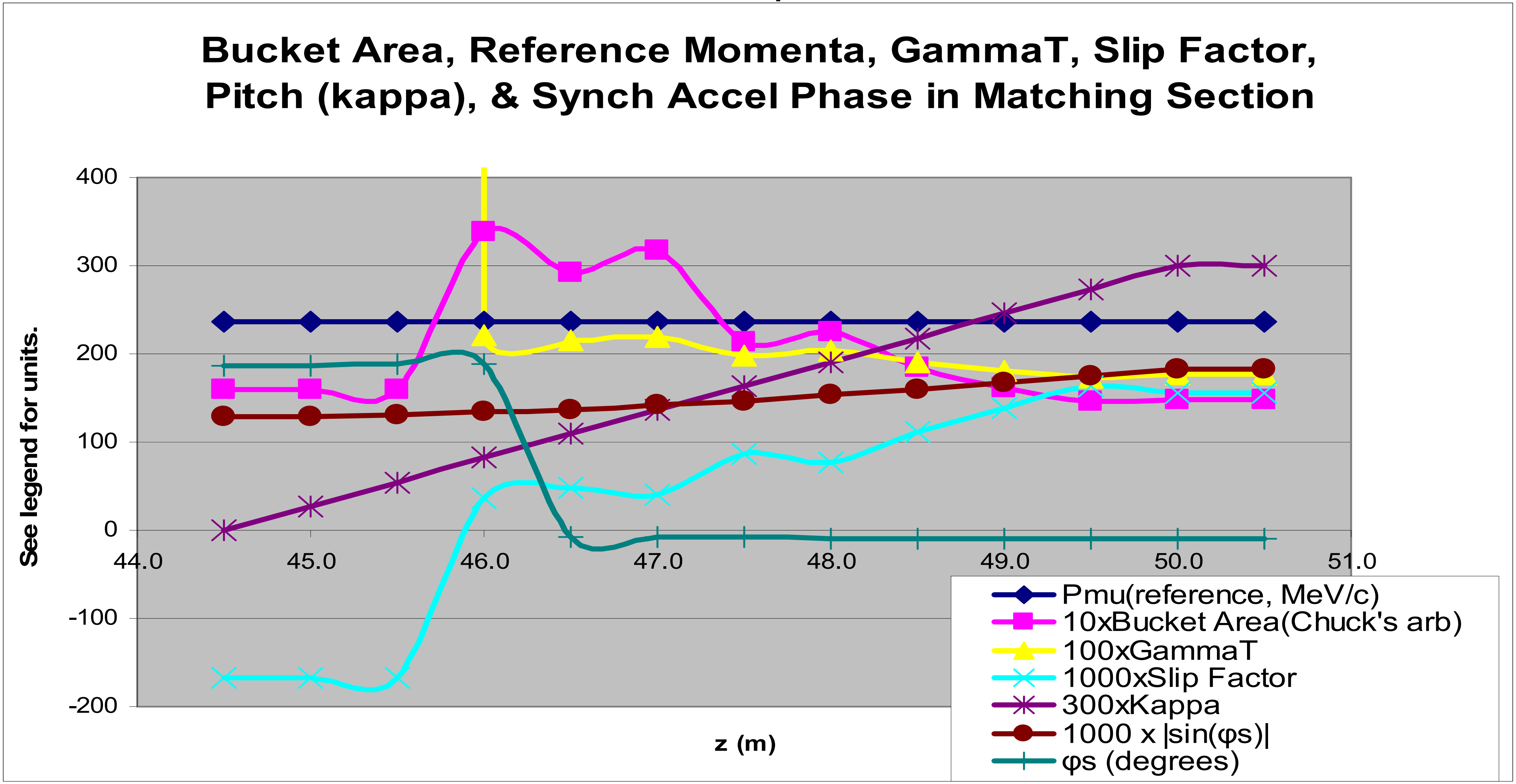


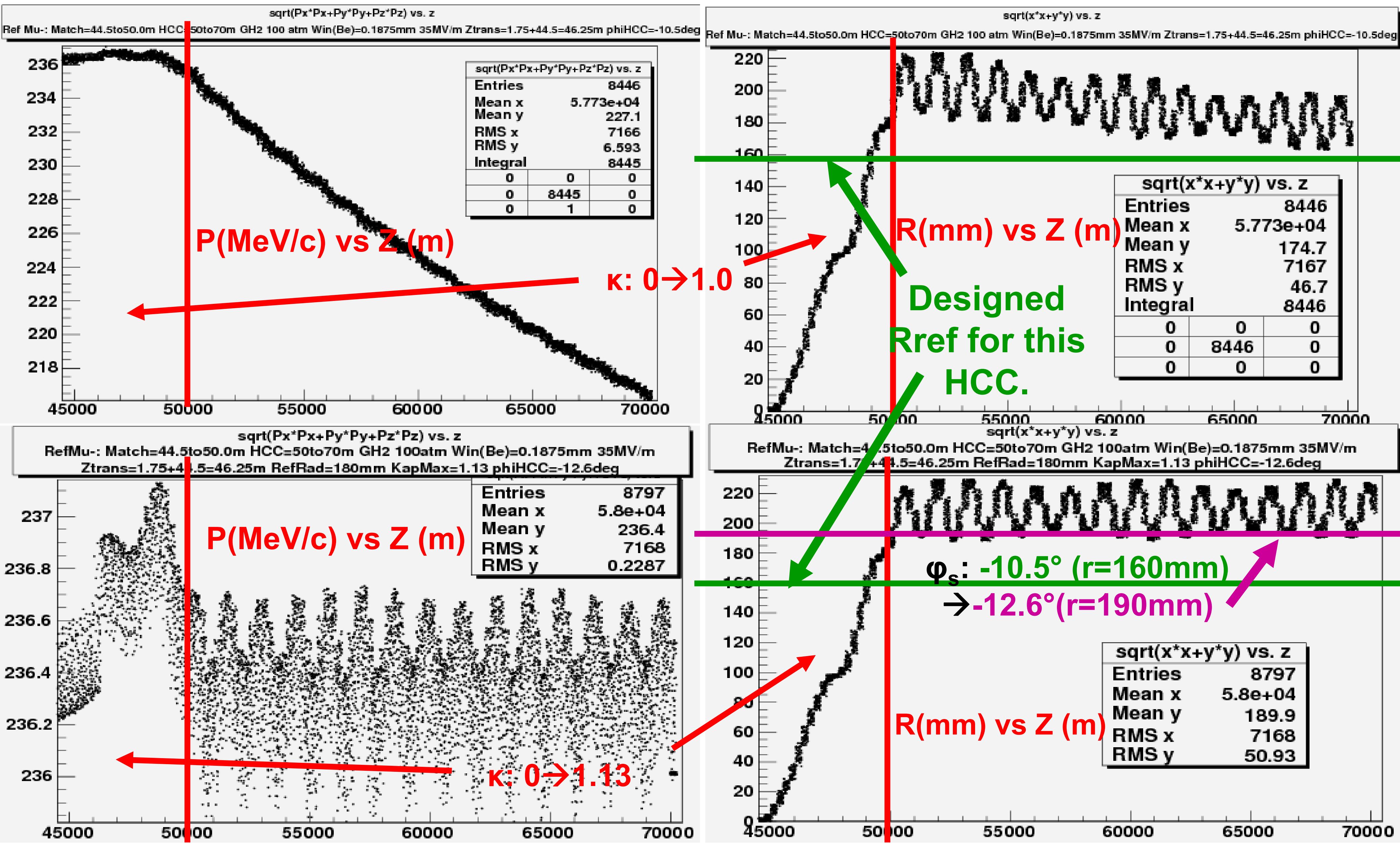
Design of φ_s based on constant reference momentum (237 MeV/c) and previously extracted γ_T in matching section



Note that because κ goes from 0 to 1 (or 1.13), the reference sees more material as it traverses the matching section and thus |sin(φs)| must increase to compensate energy loss, forcing the bucket area to decrease along z.

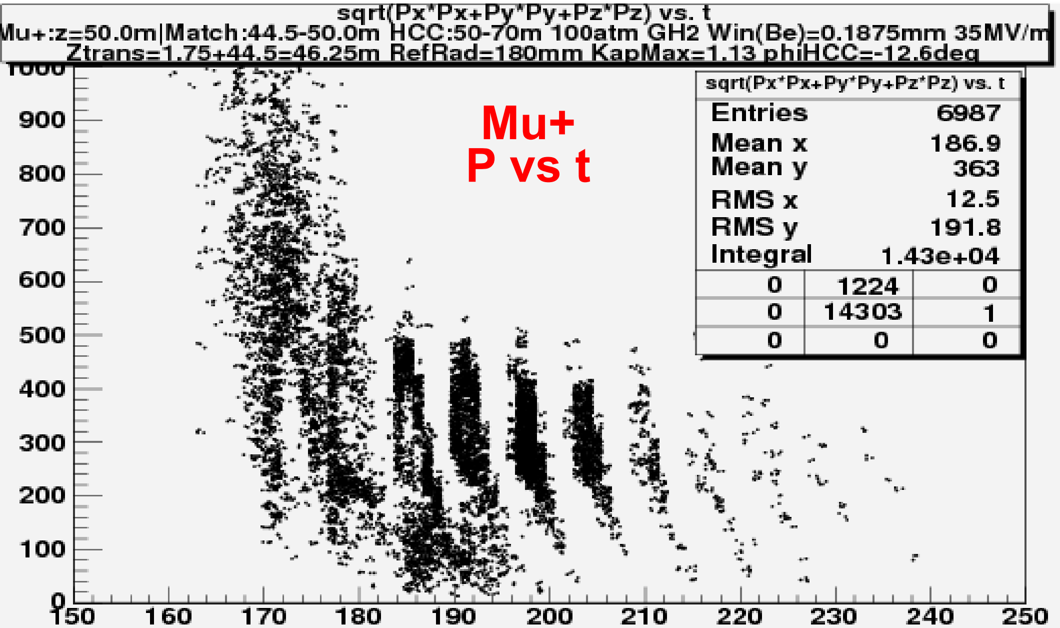
$$A_{bucket} = \frac{16\beta}{w_{rf}}\sqrt{\frac{eV_{\max}E_{synch}}{2\pi h|\eta|}}\frac{1-\sin(\varphi_s)}{1+\sin(\phi_s)}$$

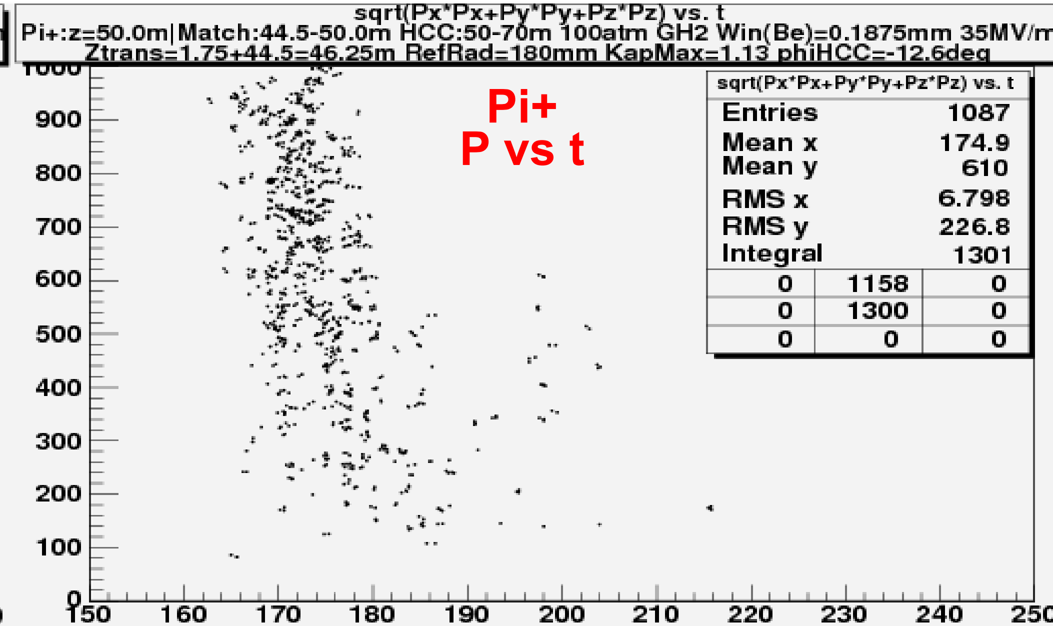
Modification of design to accommodate different reference radius (159mm to ~190mm).

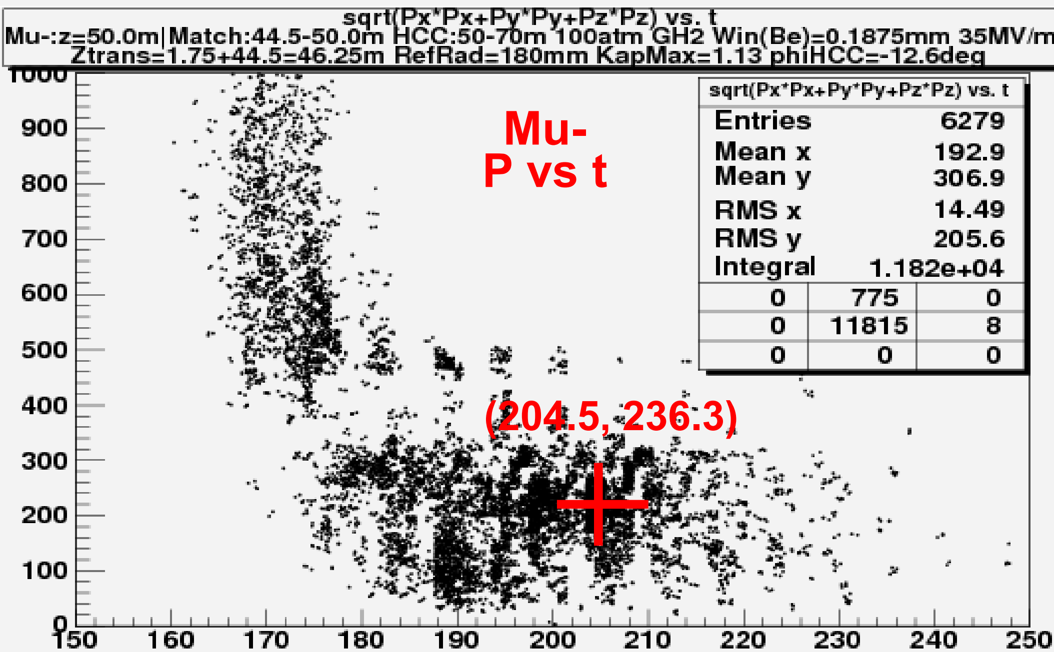


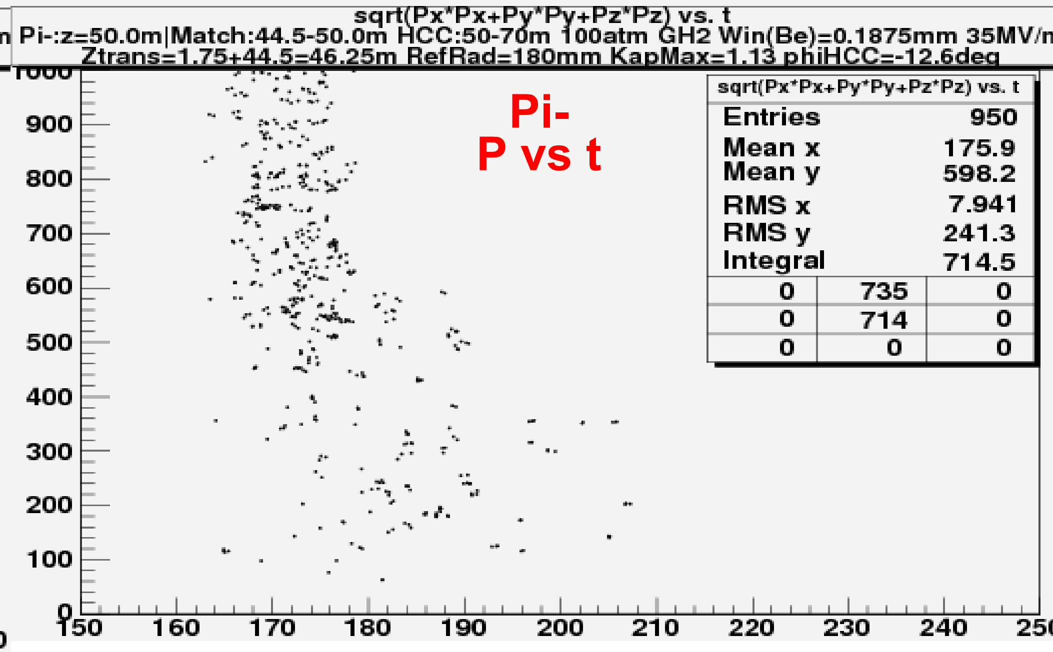
Results of Pi's and Mu's from MERIT-like targetry

z = 50.0 m (End of Match)









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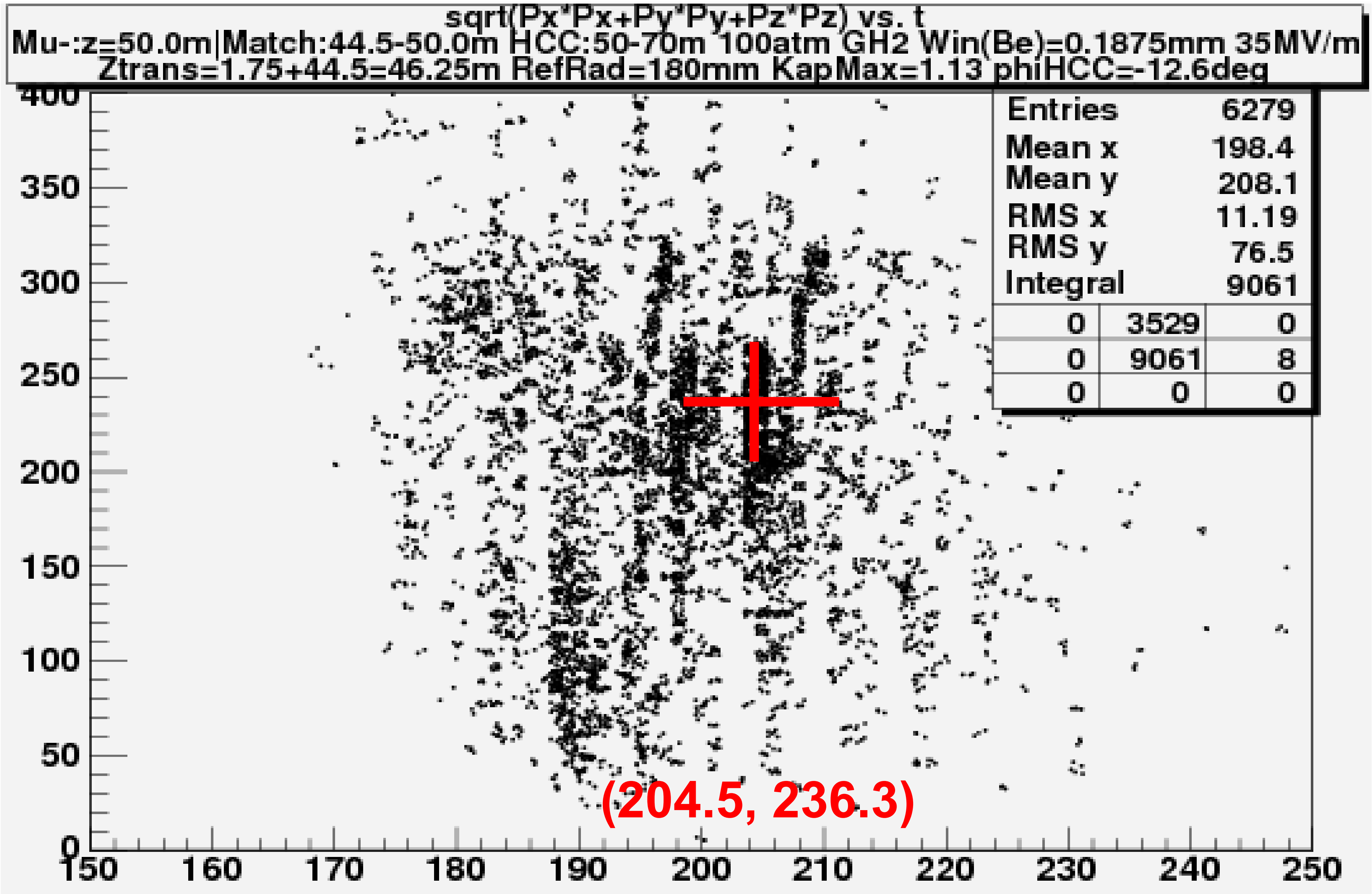

Summary & Future

- We have made a preliminary design of a system upstream of the HCC to enhance the number of muons in the HCC acceptance.
- We have demonstrated the increase of muons by introducing material to create more pions.
  - Observe 21% increase in muon creation rate at interface.
- We have introduced RF with H2 gas into the match and performed a preliminary study that involves crossing transition.
- We have ideas on how to enhance the capture rate and transport of muons across the matching section:
  1. Allow φs to change across match in order to maintain RF bucket growth.
  2. Increase max gradient across match (sub-optimal at start of match).