Front End – gas-filled cavities

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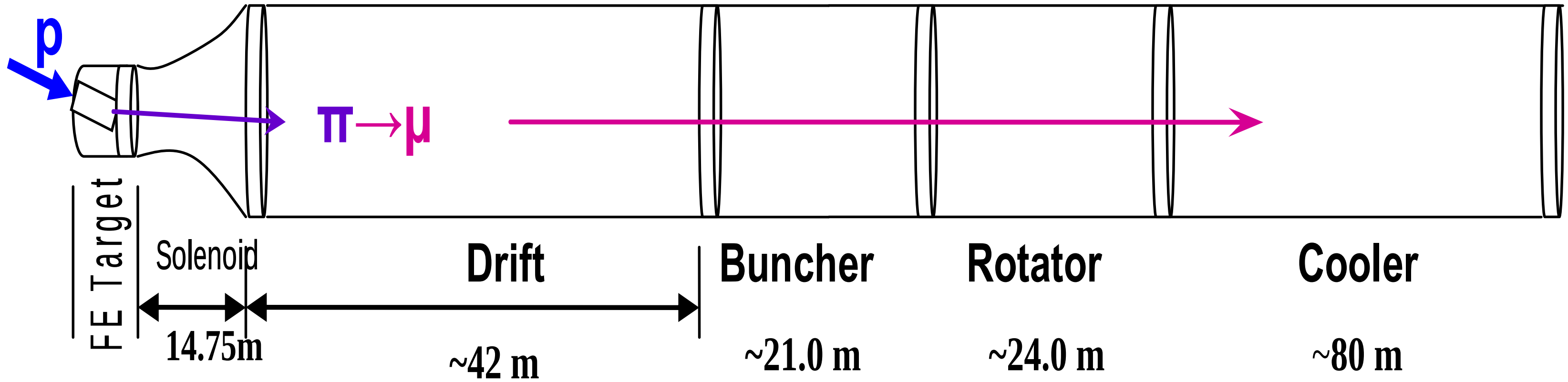
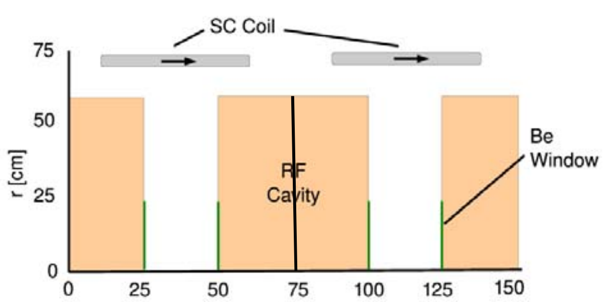
Outline

- **Front End for Muon Collider/ Neutrino Factory**
  - Baseline for MAP
    - 8 GeV proton beam on Hg target
  - 325 MHz
    - With Chicane/Absorber
- **Current status**
  - New targetry
    - 6.75 GeV on C target
  - New Mars generated beams
    - Mars ouput much different from previous version
  - Buncher rotator with H_2 gas
    - rematches OK except for loss at beginning of buncher
    - can cool and rottoe simultaneously
  - beam for Low-energy muons
    - 150 MeV/c buncher/rotator

325MHz “Collider” front end



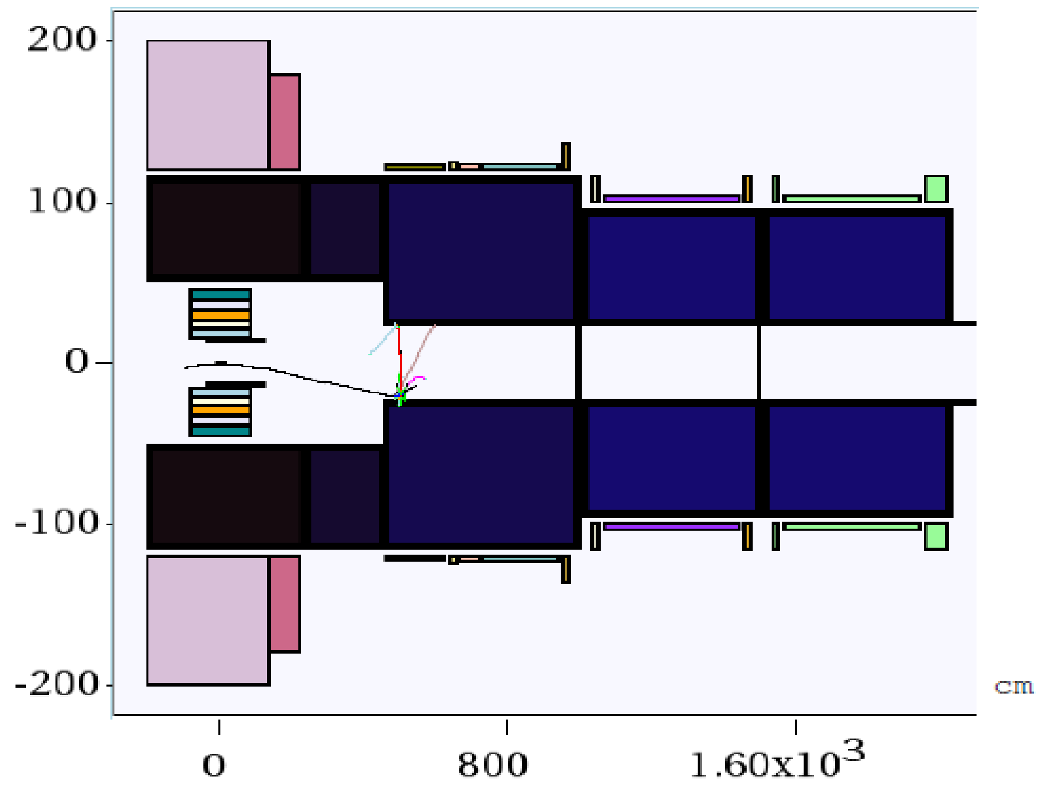
- **Drift**
  - 20 T → 2 T
- **Buncher**
  - P_o = 250MeV/c
  - P_N = 154 MeV/c; N = 10
  - V_{rf} : 0 → 15 MV/m
    - (2/3 occupied)
  - f_{RF} : 490 → 365 MHz

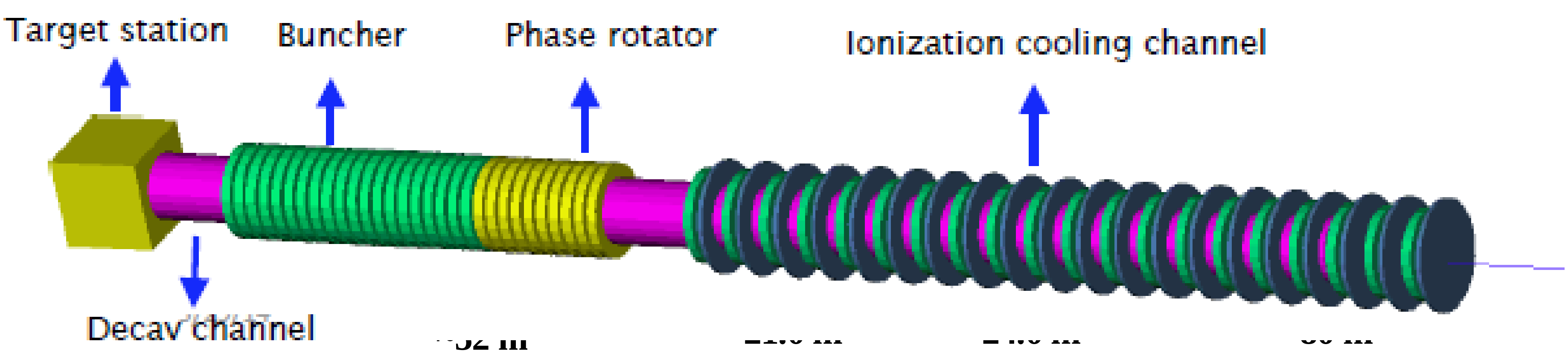


- **Rotator**
  - V_{rf} : 20MV/m
    - (2/3 occupied)
  - f_{RF} : 364→ 326 MHz
  - N = 12.045
  - $P_{0,}$ P_N → 245 MeV/c
- **Cooler**
  - 245 MeV/c
  - 325 MHz
  - 25 MV/m
  - 2 1.5 cm LiH absorbers /0.75m

New Proton Driver parameters

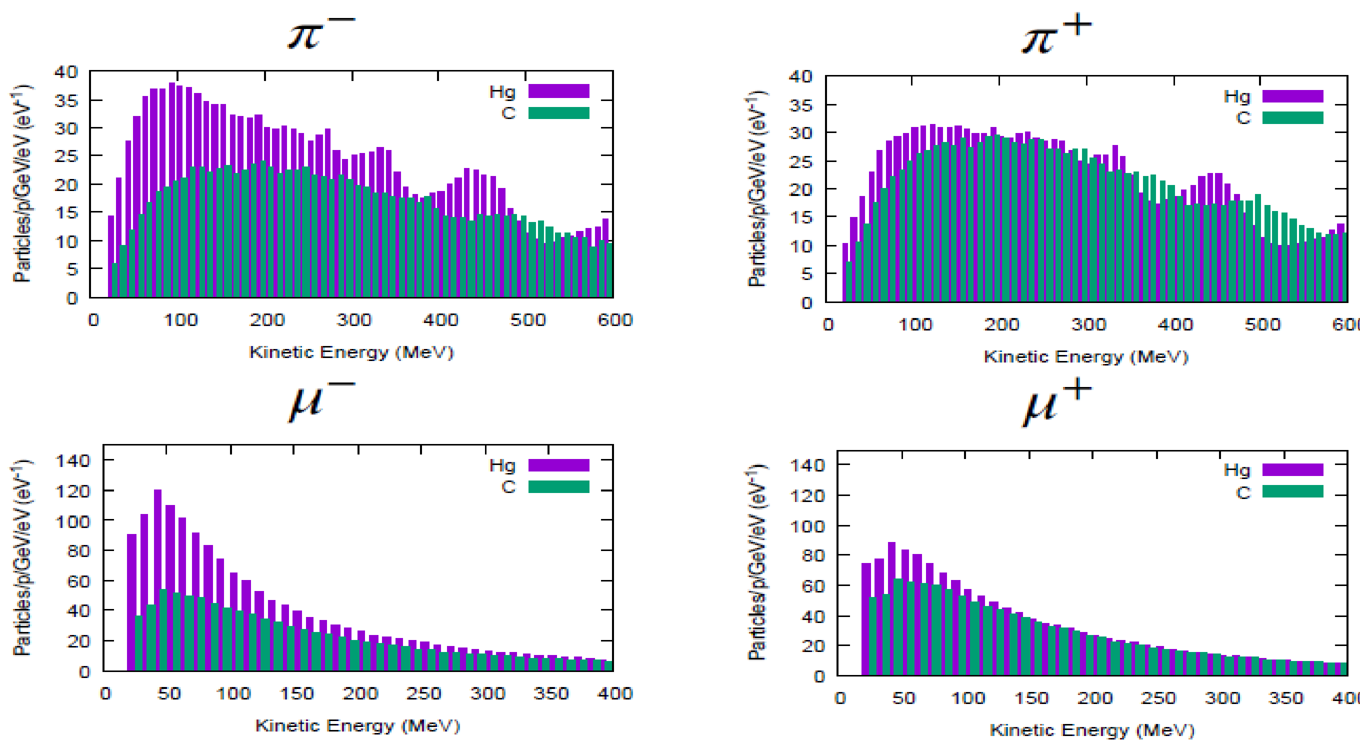
- **6.75 GeV p, C target**
  - 20 → 2 T short taper
    - ~5 m (previously 15)
  - X. Ding produced particles at $z = 2 \rightarrow 10$ m using Mars
  - short initial beam
- **Redo ICOOL data sets to match initial beam**
  - ref particles redefined
    - in for003.dat
    - and for001.dat





Following Scott's review of front end

- Use initial distributions (obtained by X. Ding)
  - 8 GeV protons on Hg target
    - + and - particles
  - 6.75 GeV protons on C target
  - Start beam from *z* = 10 m
    - must retranslate into ICOOL reference particles
  - Early losses on apertures have already occurred
    - 23 cm apertures



ICOOL translation tips

- **start at "z = 10 m"**
  - (particle time zero is at -1 m)
- **reference particles**
  - **250** MeV/c ; **154** MeV/c μ^+
    - 165.75 MeV ; 81.1 MeV μ^+
  - time set by 1 m as 6,75 GeV proton + 10 m as μ^+
  - reference particles set in for003.dat, not for001.dat

for003.dat

```
01-Feb-2015 X. Ding C 10 m -
0.0 0.250 3.95709E-08 0.0 0.154 4.381345E-08 2
    1   1 -3 0  4.354479e-008  1.000000e+000    0.03737
0.03656 0  7.861861e-004  2.558375e-002  2.189235e-001 0 0 0
    3   1 -3 0  3.712592e-008  1.000000e+000   -0.03459   -
0.11247 0  1.617131e-001  3.506310e-002  4.670452e-001 0 0 0
    6   1 -3 0  3.748837e-008  1.000000e+000    0.00304   -
0.04460 0 -1.827203e-002 -5.931789e-002  7.809555e-001 0 0
0
   10   1 -3 0  3.738523e-008  1.000000e+000    0.07979
0.13944 0 -4.890422e-002  3.733585e-001  1.515145e+000 0 0
0
```

In ICOOL for001.dat

```
REFP
2 0 0 0 3
REF2
2 0 0 0
```

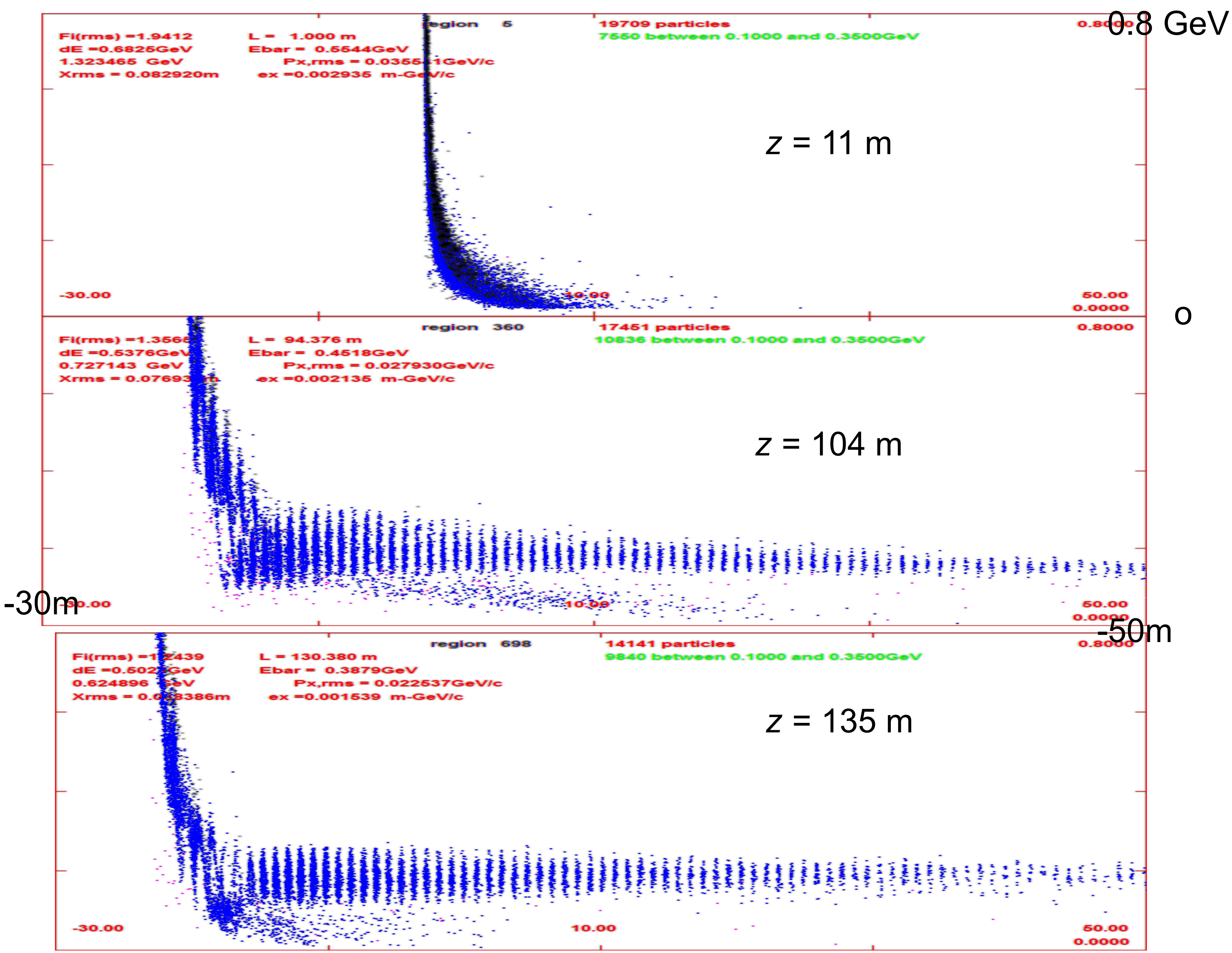
Simulation results

- **Simulation results**
  - Hg target 8 GeV –end of cooling
  - **~0.0756 μ^+/p; ~0.0880 μ-/p;**

  - C target 6.75 GeV p
  - **~0.0613 μ^+/p; ~0.0481 μ^-/p;**
    - 0.0726 μ^+/p; ~0.0570 μ^-/p when multiplied by 8/6.75

- **Previous front ends had ~0.1 to ~0.125 μ/p**
  - Redo with old initial beams
    - 2010 Hg 8GeV p
      - **0.114μ^+/p**
    - 2014 Hg 8GeV p
      - **0.112μ^+/p**

Progression of beam through system



6.75 GeV p/ C target – 8GeV Hg

- Simulations capture typically somewhat less than before
  - Big difference in MARS production model
    - Mars Inclusive → LAQGSM=1
  - Drop in production for ~8 GeV
    - *Are previous MARS simulations that showed an advantage in production for ~8 GeV still true ?*

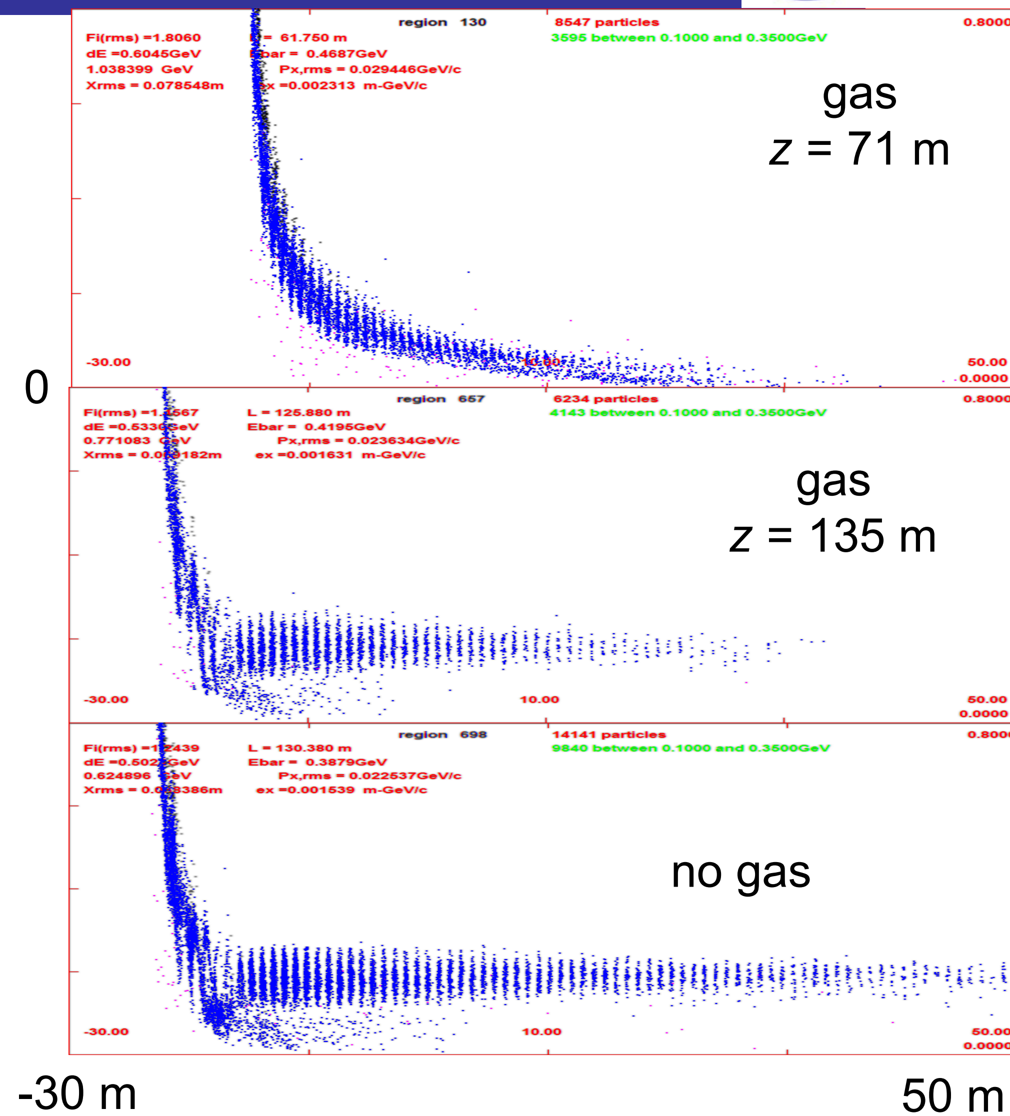
- IQGSM=0: exclusive CEM (cascade exciton model?) for $E < 3$ GeV, MARS inclusive for $E > 5$ GeV, LAQGSM for some special cases. Old MARS default.
- IQGSM=1: CEM for $E < 0.3$ GeV, LAQGSM for $0.5 \text{ GeV} < E < 8$ GeV, MARS inclusive for $E > 10$ GeV. New MARS default.

Studies on gas-filled rf for buncher/rotator

- **Stratakis et al. have done cooling channel with gas-filled rf**
  - ~34 atm H_2 to stop breakdown
- **Extrapolate back to include buncher/rotator**
  - use gas to suppress breakdown in buncher/rotator
  - rf in ~2 T solenoids

Add gas-filled rf in buncher/rotator

- 34 – 100 atm equivalent
  - 1.14 MeV/m
    - 34 atm
  - 3.45 MeV/m
    - 100atm
  - for 34 atm
    - add ~2 MV/m to rf
- First tries with ICOOL
  - GH in buncher 1 atm
    - no change in capture
  - Change to 34 atm by
    - DENS GH 34.0
  - Runs OK but
    - reduces capture by 20%
    - mostly from low-E muons
      - shorter bunch train



Updated gas-filled front end

- **added gas in rotator**
  - 34 atm
    - *dE/dx*
- **Increased rf a bit**
  - Buncher 15z → 2+20(z/24) MV/m
  - Rotator 20 → 25
    - ref particles decelerate to 230Mev/c
  - Cooler 25 → 28 MV/m
- **Results are not so bad**
  - 8GeV Hg + → 0.0718 μ/p
  - 8GeV Hg - → 0.0773 μ/p
  - 6.75 geV C + → 0.0539 μ^+/p
  - 6.75 geV C -→ 0.0430μ^-/p

  ~10% worse than baseline

- **Tweak of reference particle to fit ICOOL features** (for 100atm)

  REFP

  2 0.250 0. 1.55 4

  REF2

  2 0.154 0. 6.9

  - **use phase model 4**
    - **tracks reference particles energy loss in drft/absorber but not in rf**
    - **fixed energy gain.loss in rf**
  - **ref particle acceleration fitted to end at ~245 MeV/c**

FrontEnd variations

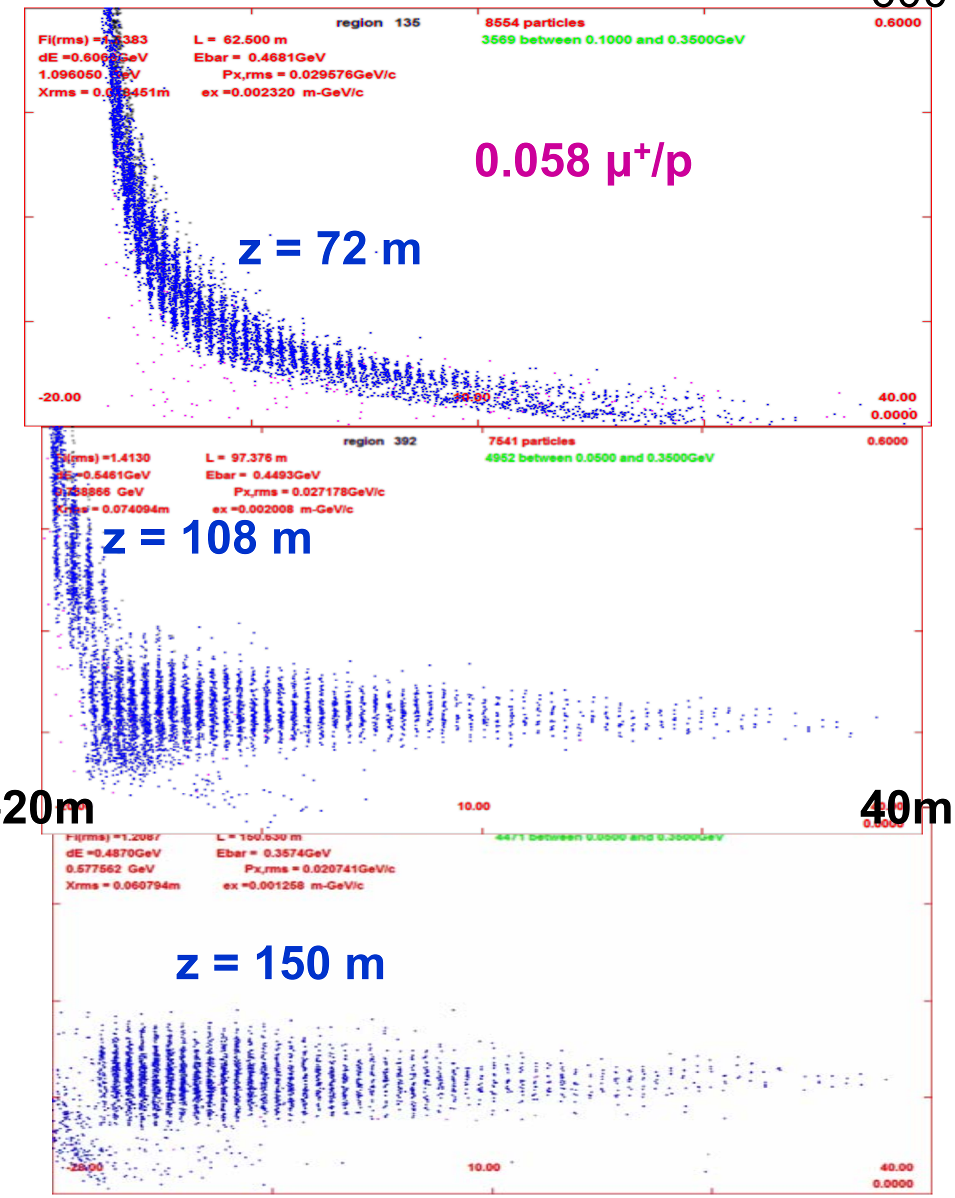
- Reduce buncher gas to 17 atm
  - ~ 10% better
  - back to ~ baseline
  - ~0.062 μ^+/p
- decelerating rotator or constant energy rotator?
  - C → ~0.063 μ^+/p
  - about the same
  - no real advantage/disadvantage in deceleration
- Note initial beam is "cooled", but only in one dimension
  - B = 2 T – no field flip
  - Angular momentum increases

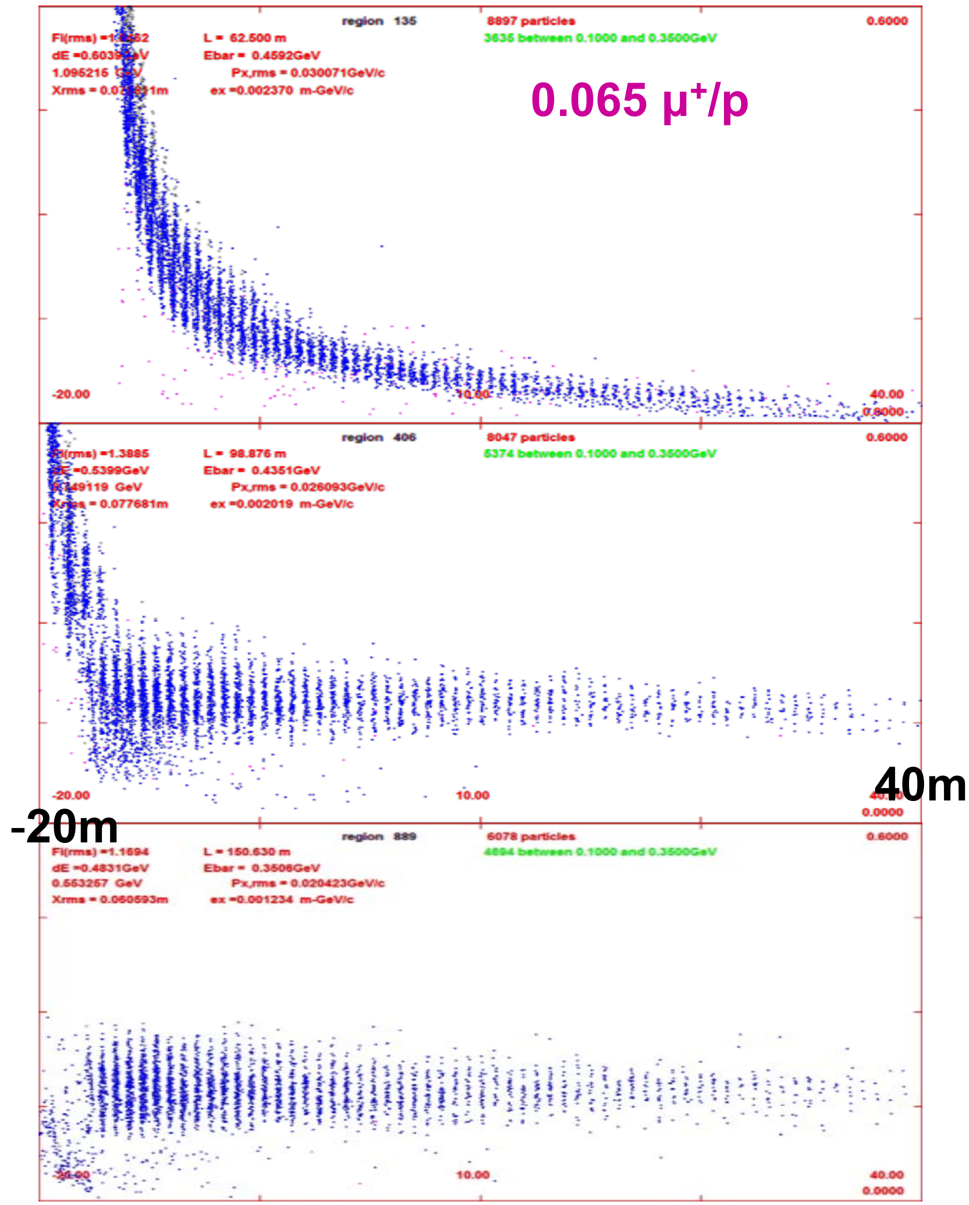
z	ε_t	ℓ=L/2	ε_+	ε_-
59	0.0184	0.0054	0.0246	0.0138
78	0,0173	0.0059	0.0243	0.0124
102	0.0151	0.0074	0.0242	0.0095

Compare 17/34

34 --- 34 atm | **17 --- 34 atm**

600 MeV/c





Increase rotator to 100atm

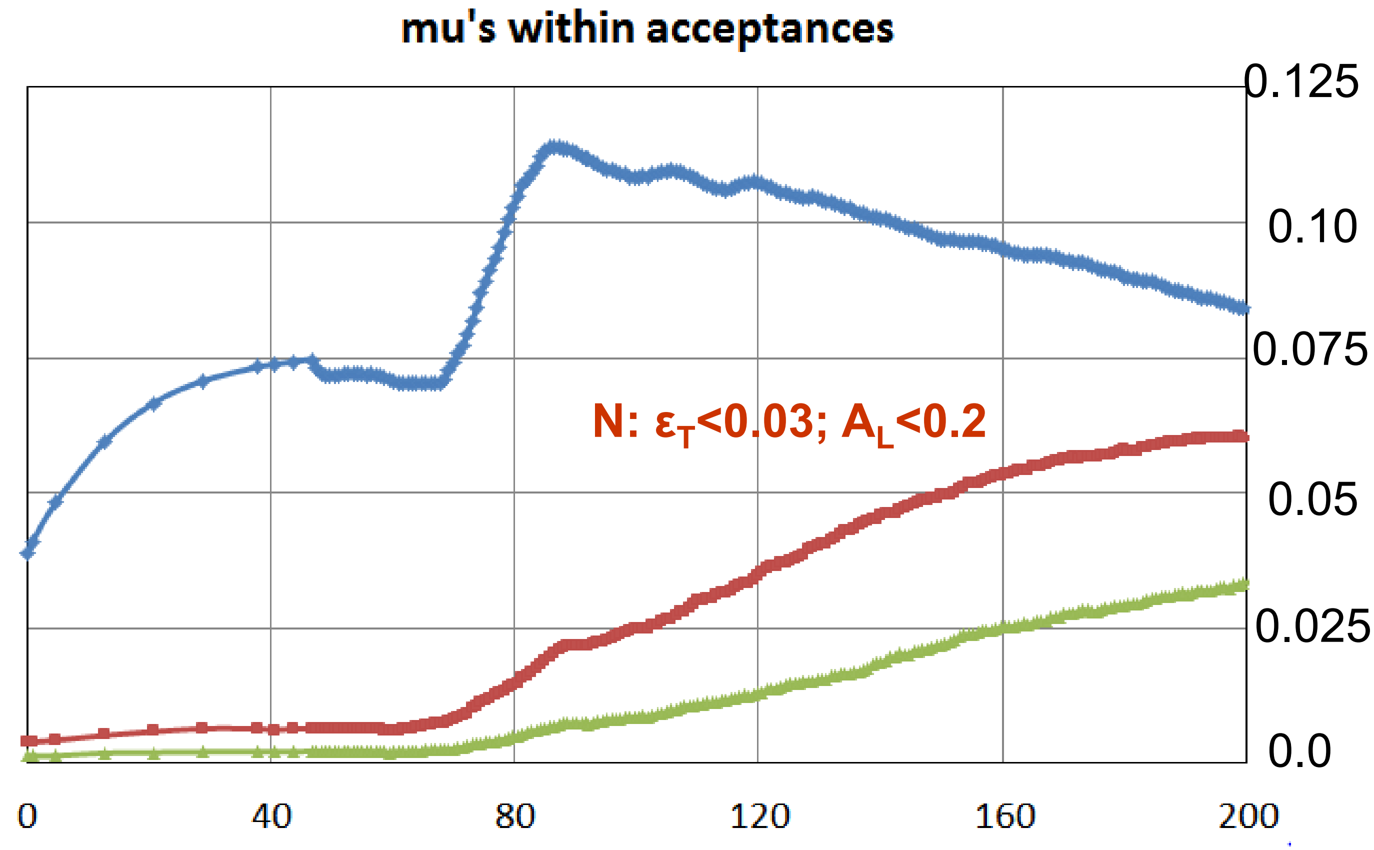
- **Buncher at 17atm**
  - LESS INITIAL LOSS
- **With V = 20/25/28**
  - ~0.059 μ/p (C 6.75)
  - ~10% less than 17/34
- **Increase Rotator gradient to 28 MV/m**
  - to compensate energy loss
- **Fairly good performance**
  - ~0.063 μ/p (C 6.75)
- **Buncher at 34 atm**
  - ~0.058 μ/p (C 6.75)
  - V = 22/28/30 MV/m
  - worse than 17/100 case
- **More cooling in Rotator**
  - 1-D cooling (2T solenoid)
  - one mode highly damped
- **Significant initiation of cooling**
  - (integrating rotator/cooler)
  - shortens following cooler

z	ε_t	ℓ=L/2	ε_+	ε_-
77	0.0176	0.0061	0.0248	0.0124
89	0,0144	0.0077	0.0241	0.0087
102	0.0128	0.0088	0.0242	0.0066

Beam difference notes

- **Most of loss in intrinsic performance is from gas in buncher**
  - Beam enters completely unbunched
  - Initial rf is weak; and slowly increases

- **After some initial loss, SIMILAR TO GAS-FREE BASELINE**



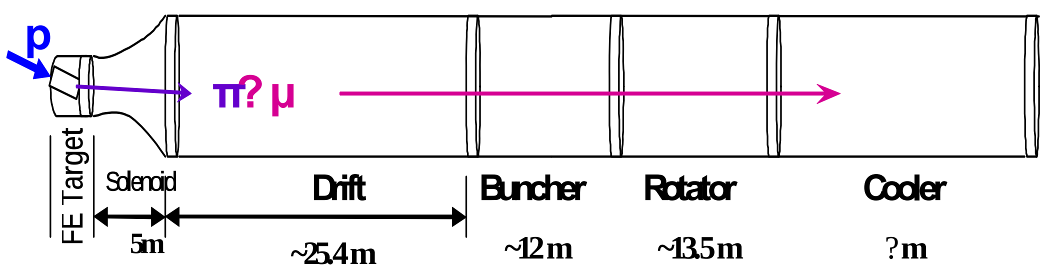
Continue Cooling with H2 Gas

- Previous cases used baseline front end cooling
  - 2 LiH 1.5 cm absorbers per cell
- 240 atm of H_2
  - ~8.3 MV/m loss from gas

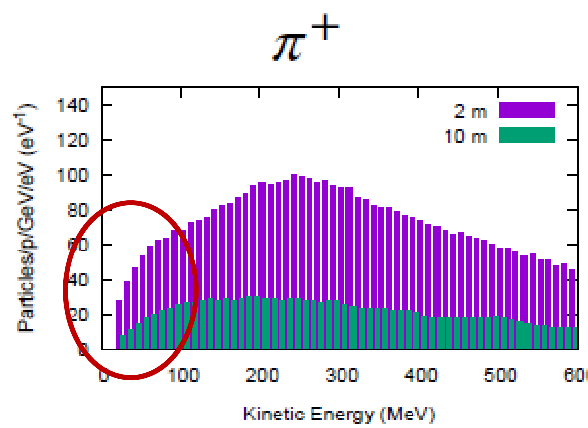
- Preliminary results
  - Throughput improved to ~0.068 μ^+/6.75 GeV proton C target

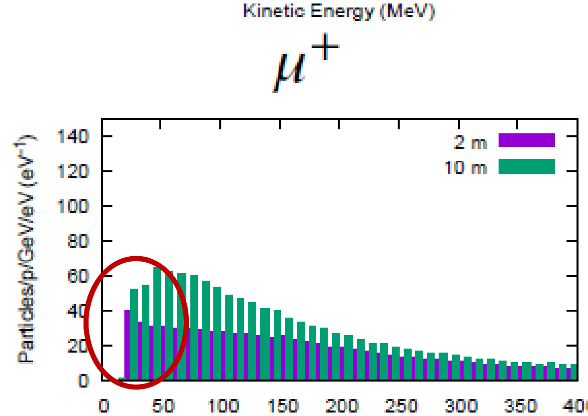
Low-E capture

- **Capture at low momentum**
  - prepare beam for low-E μ experiment
- **Somewhat scaled back version of front end**
  - 30.4m drift
  - shorter buncher /rotator
    - 12 m / 13.5 m
    - 0 → 15 MV/m, 15 MV/m
      - vacuum rf
  - B=2T



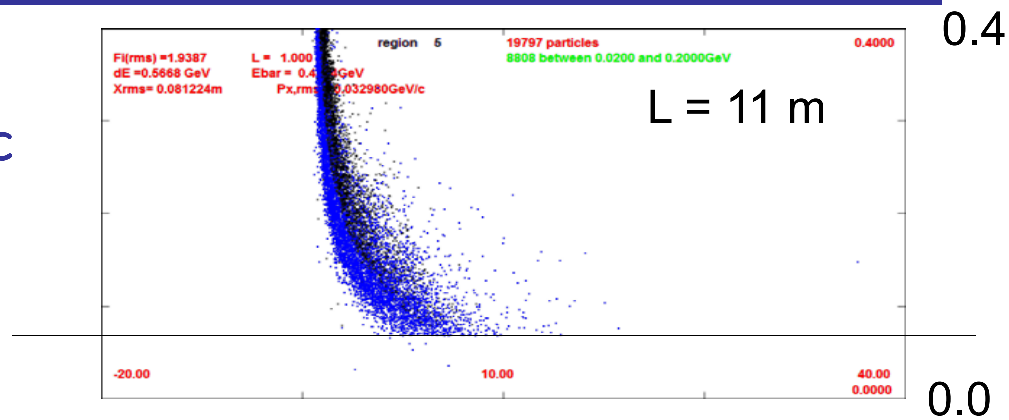
- **Parameters**
  - 150 MeV/c … 100 MeV/c reference particles
  - 77.8 // 39.8 MeV
- **Bunch to 150 MeV/c**
- **Cooling at 2 T**



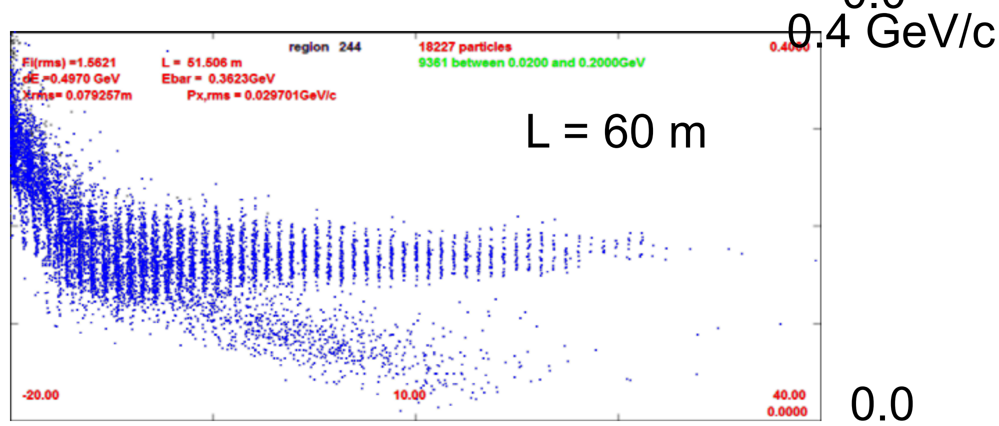


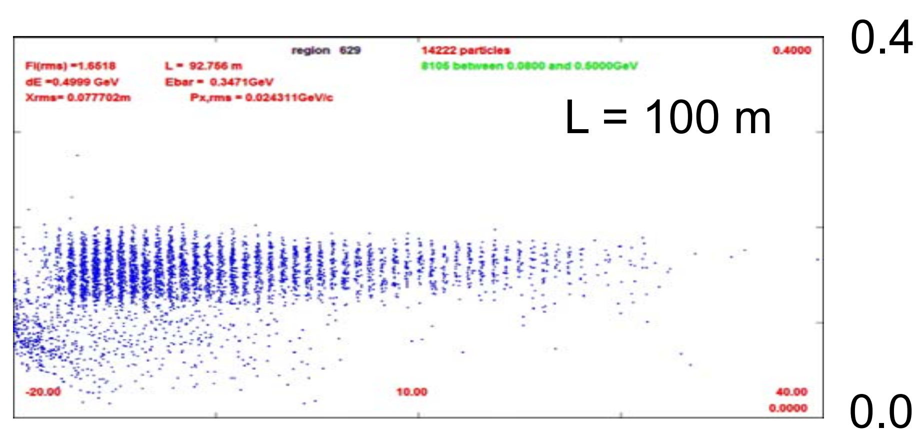
simulation of low-E buncher

- **Used Ding initial beam**
  - initial beam cut off at ~70 MeV/c
    - 21 MeV kinetic energy
  - bunch train formed



- **Cooling from 60m ➔ 100m**
  - longitudinal antidamping
    - g_L = ~ -0.5
  - B=2T , 2cm
  - more used to separate captured from uncaptured beam
  - ~0.05 μ/p within acceptance ??
    - not sure what acceptance criteria to use





LHC discoveries motivate future research…

Simulation Results

- **Simulation obtains**
  - ~0.125 μ/p within acceptances
  - with ~60m Cooler
  - 325 MHz – less power
  - shorter than baseline NF
- **But**
  - uses higher gradient
  - higher frequency rf → smaller cavities
  - shorter than baseline NF
  - more bunches in bunch train