Measuring momentum using TOF0 and TOF1

How well can we do using a simple method?

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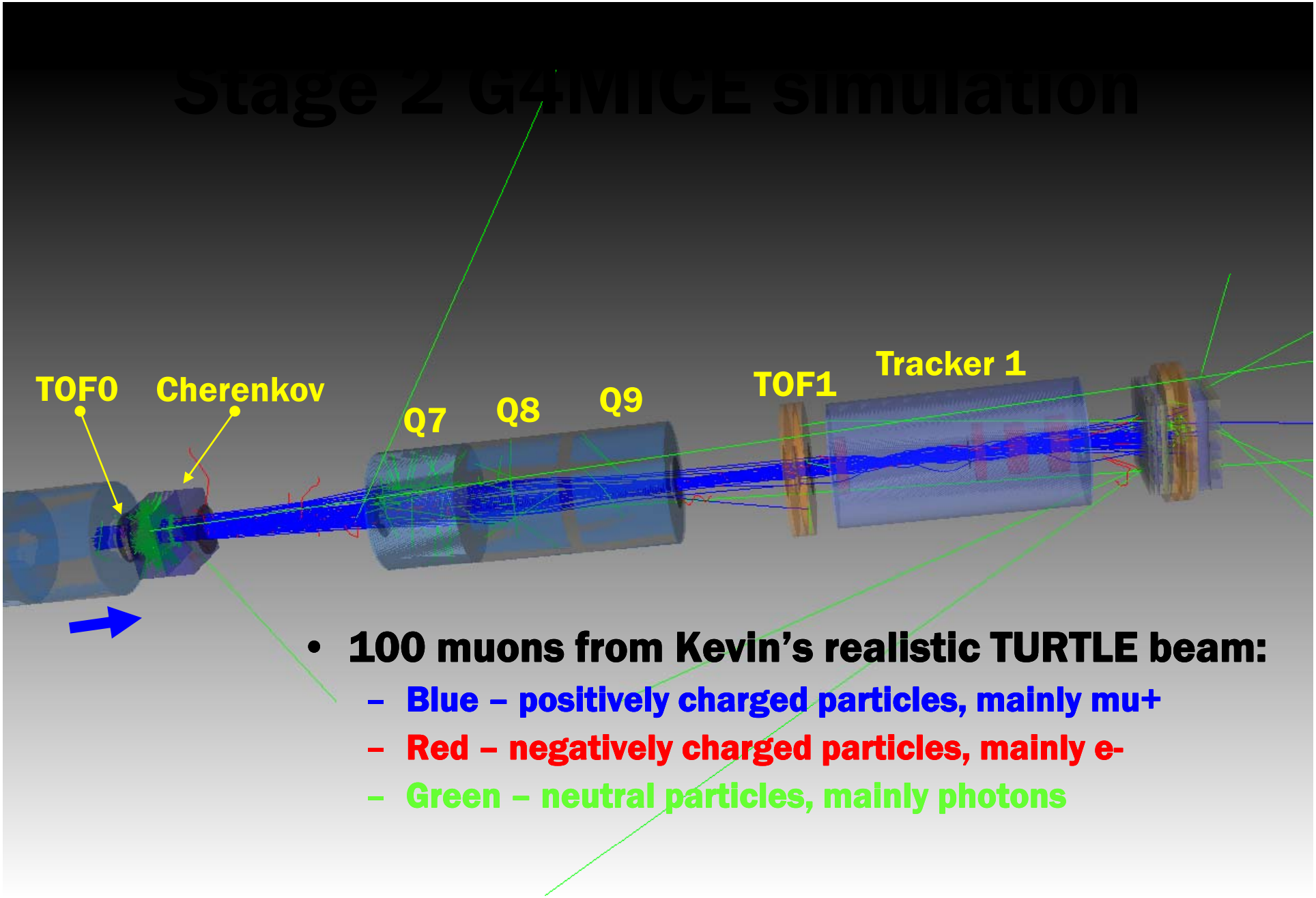
CM20 analysis session 12th February 2008

Back of an envelope prediction

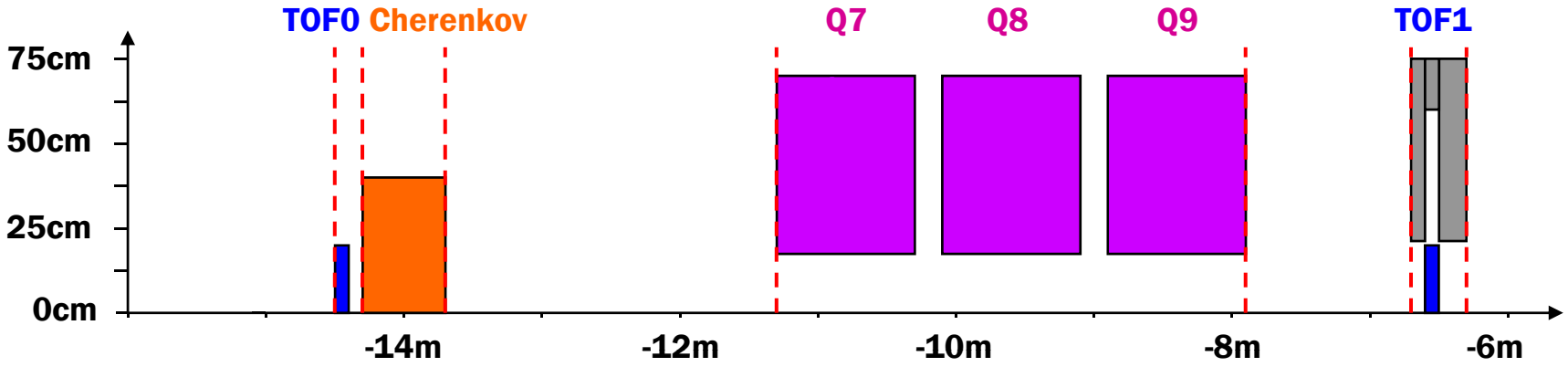
- **Expected p resolution performance:**
  - Each TOF has a timing resolution of 50ps
  - Time of flight has a resolution ~70ps
  - Assume (for now) this is the dominant error
  - Resolution of 2–3 MeV/c for 200 MeV/c muons
- **Are there other effects which increase σ_p?**
  1. Look at the beam line from TOF0 to TOF1
  2. Simple scheme for momentum reconstruction
  3. Try to understand what the important contributions to the error are

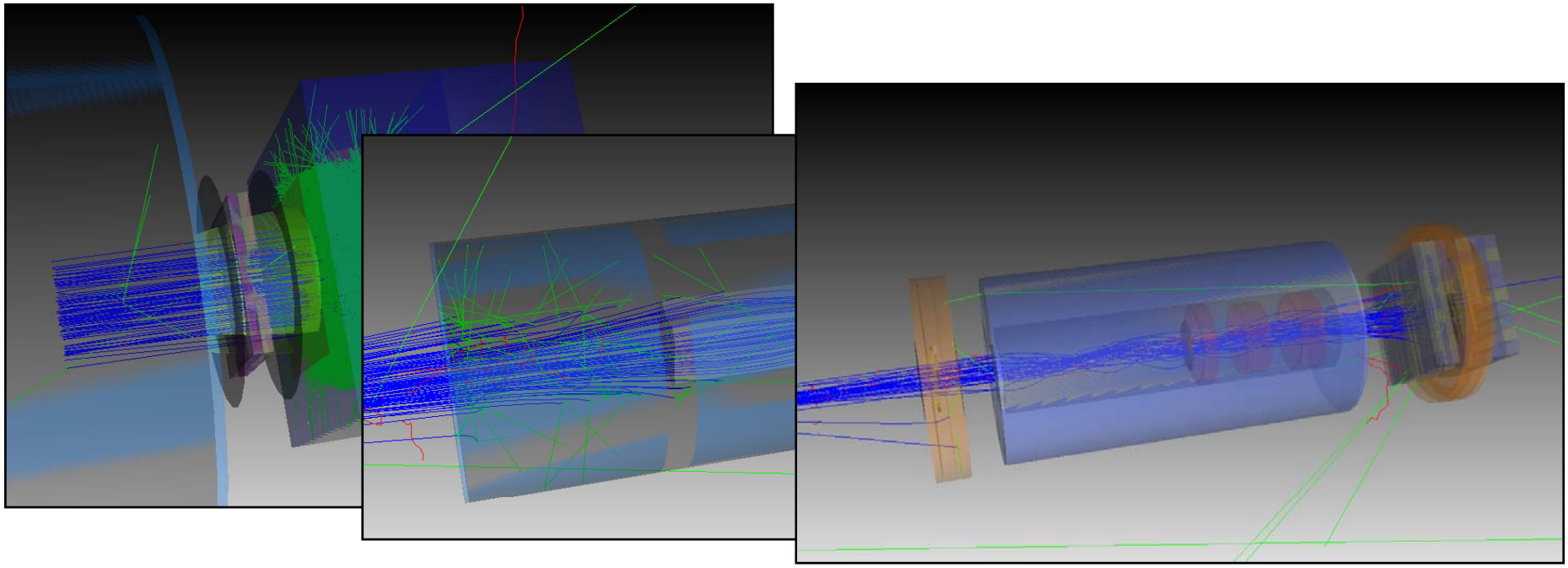
Stage 2 G4MICE simulation

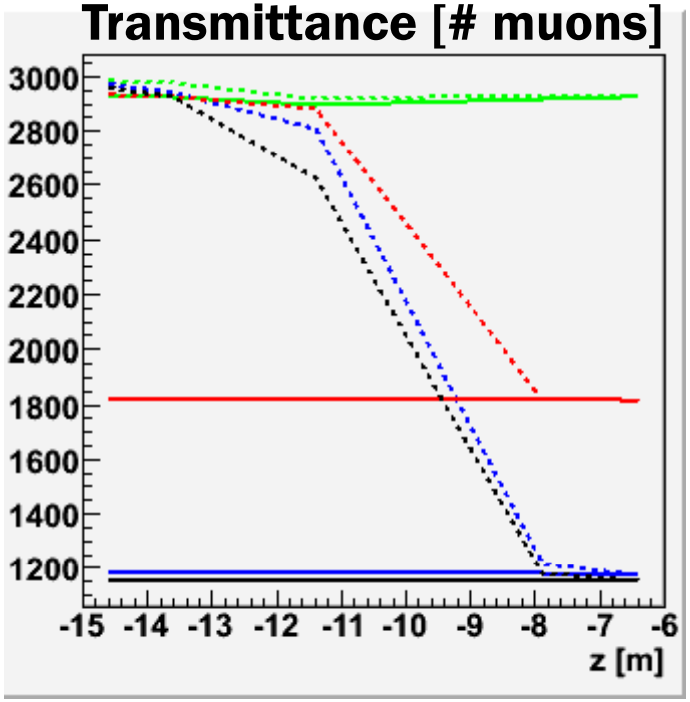


- **100 muons from Kevin's realistic TURTLE beam:**
  - **Blue – positively charged particles, mainly mu+**
  - **Red – negatively charged particles, mainly e-**
  - **Green – neutral particles, mainly photons**

Overview of the beam line

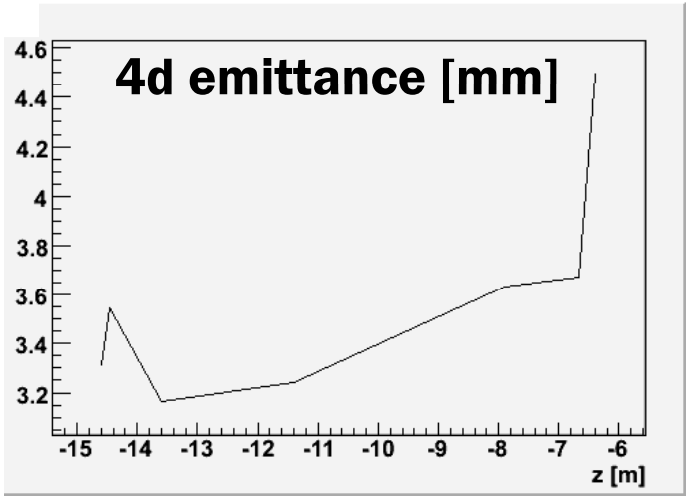


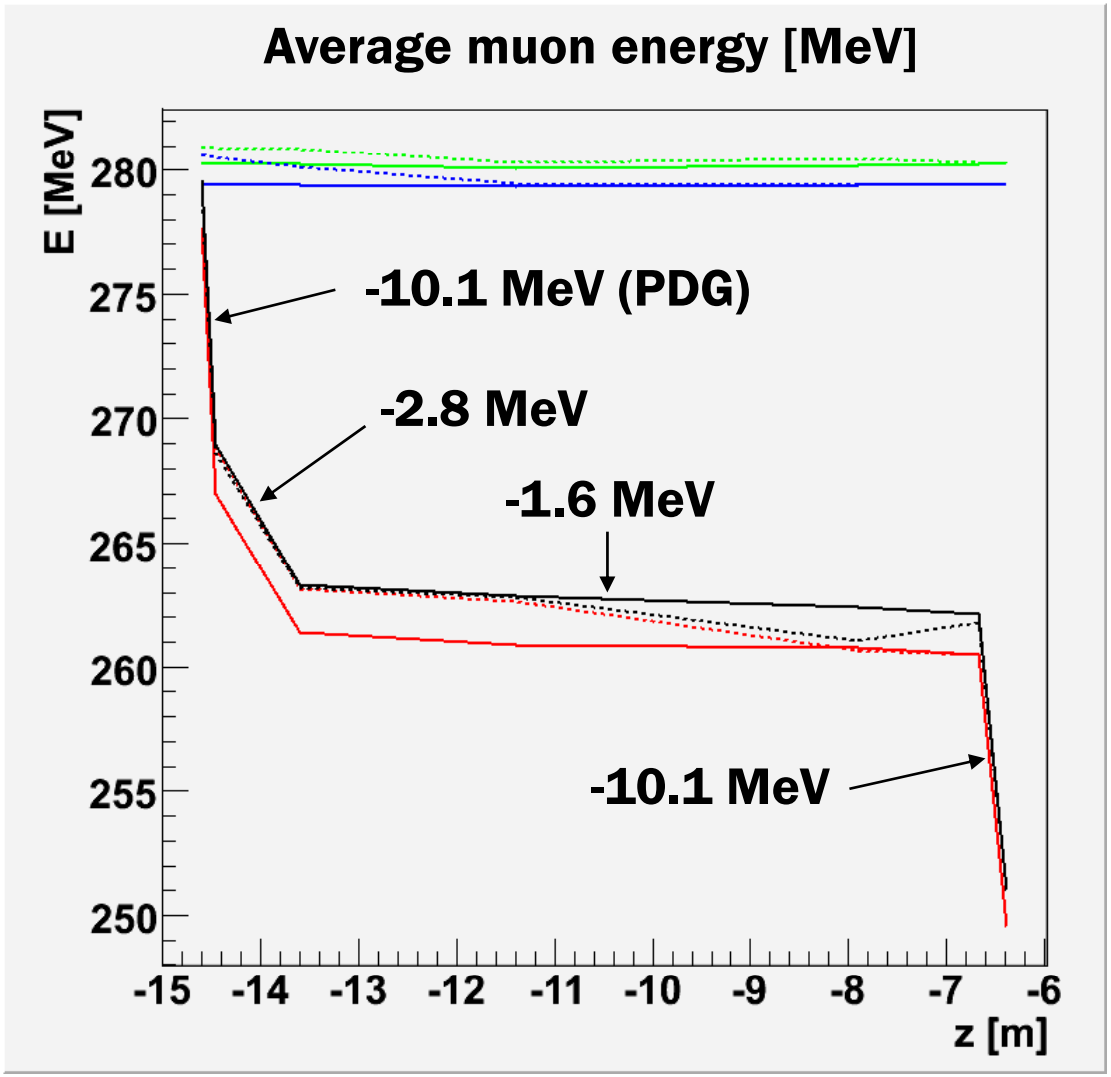




Only muons which get through TOF1

All muons





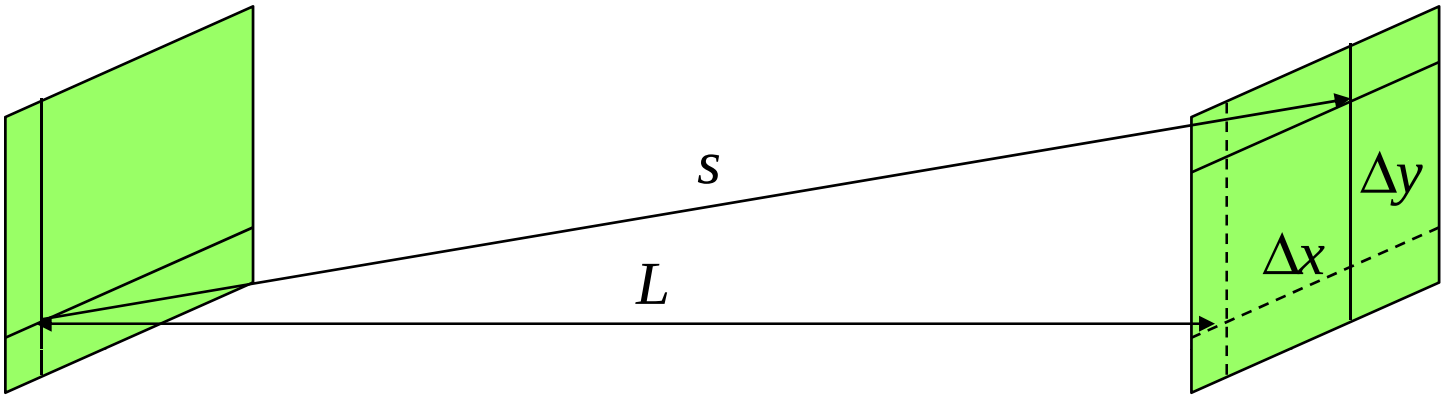
Scattering: ON, energy loss: ON	Scattering: OFF, energy loss: ON
Scattering: ON, energy loss: OFF	Scattering: OFF, energy loss: OFF

PDG estimates

detector	material	details	thickness	density	dE/dx (min I)	dE	mass	p	E
			cm	g cm-3	MeV g-1 cm2	MeV	MeV c-2	MeV c-1	MeV
TOF0	scintillator	polyvinyltoluene	5.00	1.03	1.97	10.12	105.00	250.00	271.15
Cherenkov	aerogel	silica aerogel	8.00	0.20	1.74	2.78	105.00	238.99	261.04
Air	air	dry, 1 atm	730.00	0.00	1.82	1.60	105.00	235.94	258.25
TOF1	scintillator	polyvinyltoluene	5.00	1.03	1.97	10.12	105.00	234.19	256.65

beta	**dt**	gamma	E - dE = Enew	pnew	**dp**	X0	X0	**98% dθ**
	ns		MeV	MeV c-1	**MeV c-1**	g cm-2	cm	**degrees**
0.92	**18.08**	2.58	261.04	238.99	**11.01**	43.90	42.62	**1.06**
0.92	**29.13**	2.49	258.25	235.94	**3.04**	27.25	136.25	**0.77**
0.91	**2663.41**	2.46	256.65	234.19	**1.75**	36.62	30390.04	**0.48**
0.91	**18.27**	2.44	246.53	223.06	**11.14**	43.90	42.62	**1.15**

Simple momentum reconstruction



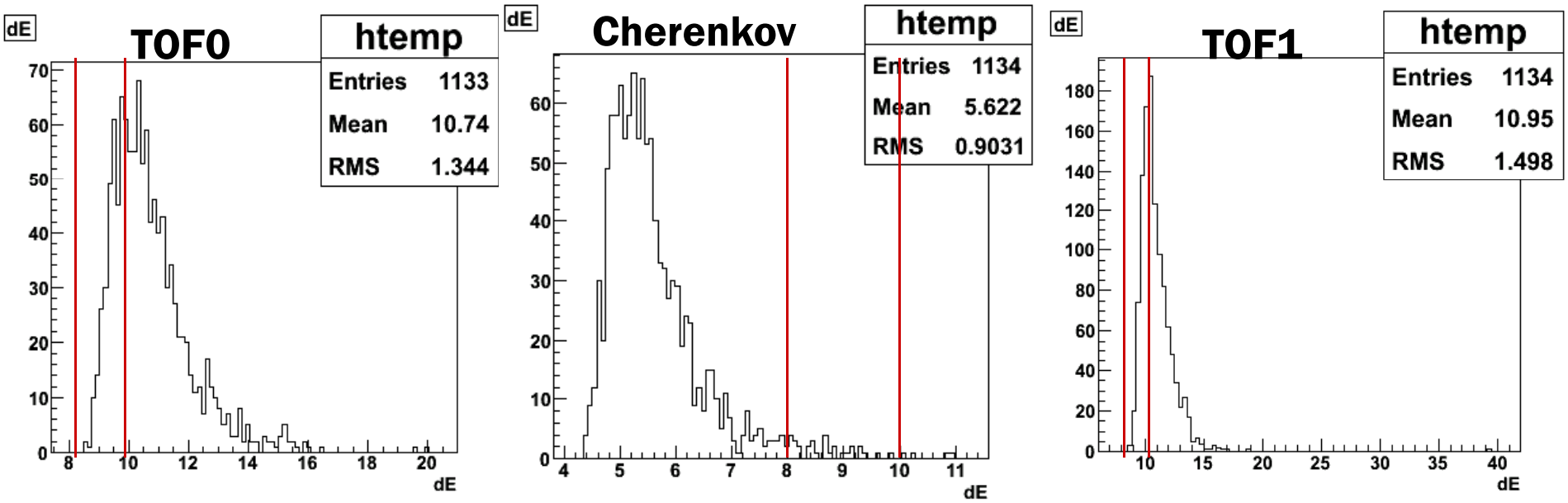
- **For each individual muon:**
  - **Estimate p in the air between TOF0 and TOF1** $p_{AIR} = \frac{sm}{\sqrt{t^2c^2 - s^2}}$
    - **Time of flight** $t = t_1 - t_0$
    - **Straight line distance TOF0 hit to TOF1 hit** $s = \sqrt{L^2 + \Delta x^2 + \Delta y^2}$
  - **Estimate p before TOF0** $p_{TOF\,0} = p_{AIR} + \Delta p_{AIR} + \Delta p_{CKOV} + \Delta p_{TOF\,0}$
    - **Momentum losses from PDG dE/dx for minimum ionizing particles**
  - **Estimate p after TOF1** $p_{TOF1} = p_{AIR} - \Delta p_{TOF1}$

Possible factors affecting p resolution

- **Properties of the TOF0 → TOF1 beam line**
  - **Width of the Landau distribution of energy loss**
  - **Scattering**
  - **Focusing in quadrupole magnets**
  - **Scraping**
- **Properties of the TOF stations**
  - **Timing resolution**
  - **Spatial resolution**
  - **Dealing with 'corner clippers'**

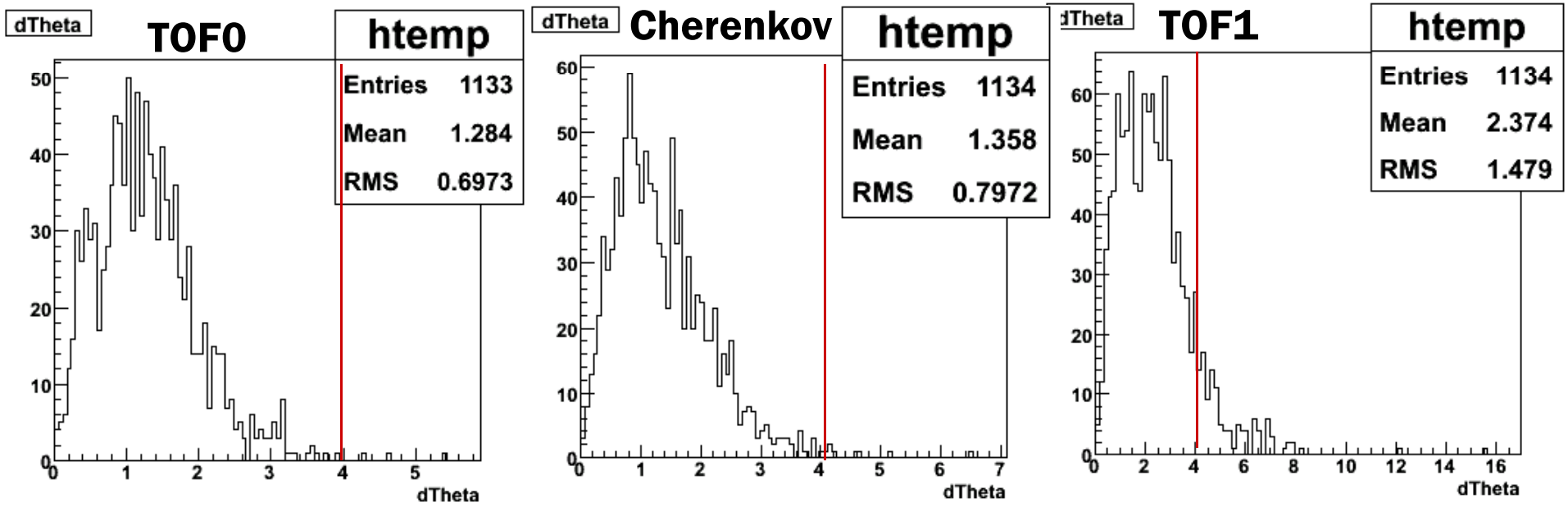
‘Landau’ distribution of energy loss

- **Width of the energy loss distribution**
  - **Lowers our momentum resolution up/downstream of the TOFs**
  - **2 – 3 MeV, 1% overall broadening**
- **Histograms of energy loss / MeV**



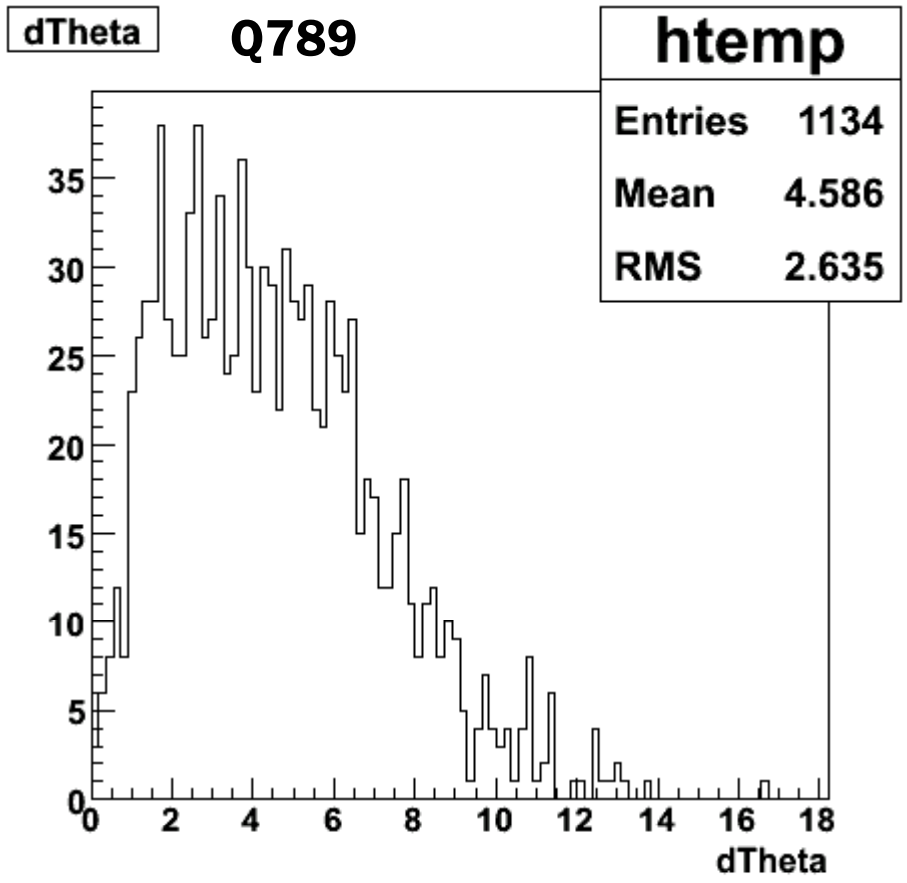
Scattering

- Causes muons to deviate from a straight line between TOF0 and TOF1
  - Increased path length
  - Underestimate momentum
  - 1 – 2 degrees overall
- Histograms of scattering angle / degrees

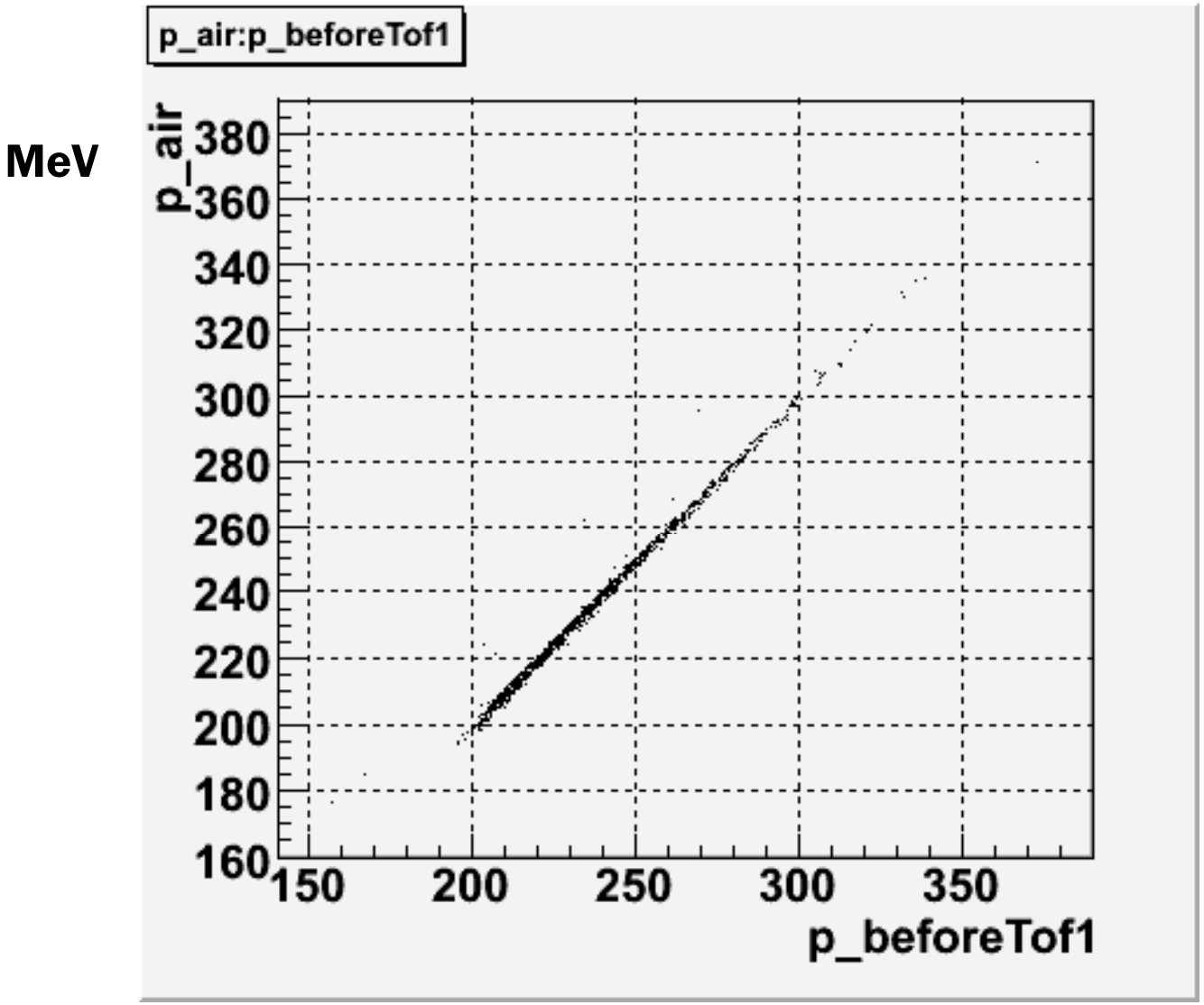


Focusing in quadrupole magnets

- Also causes muons to deviate from a straight line between TOF0 and 1
  - ~5 degrees over Q7-9
  - More significant than scattering
- Histogram / degrees
- 3000 incident muons
  - 1133 transmitted with quads
  - Only 659 without

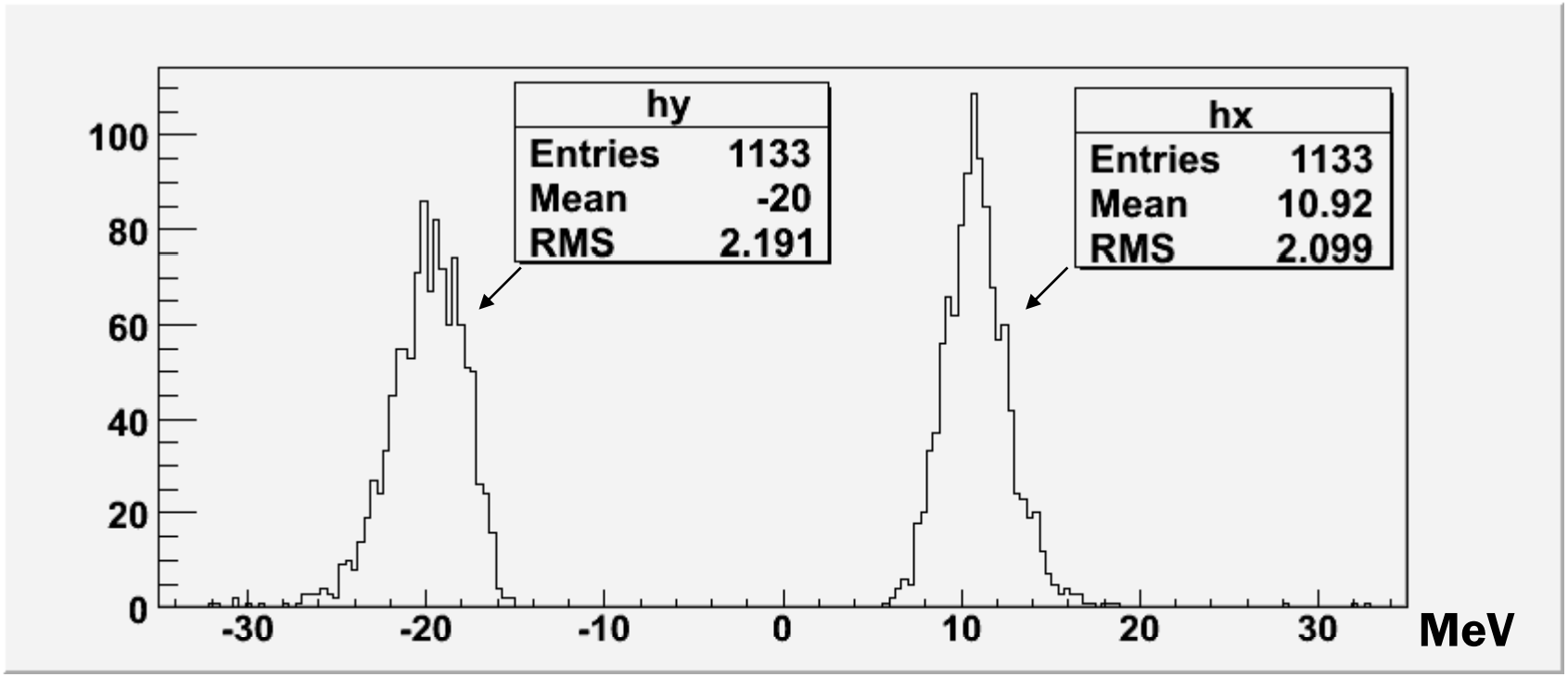


p_{air} estimate from s and T.O.F.



Pure MC p reconstruction

$p_{air} - p_{TOF0}$ $p_{air} - p_{TOF1}$

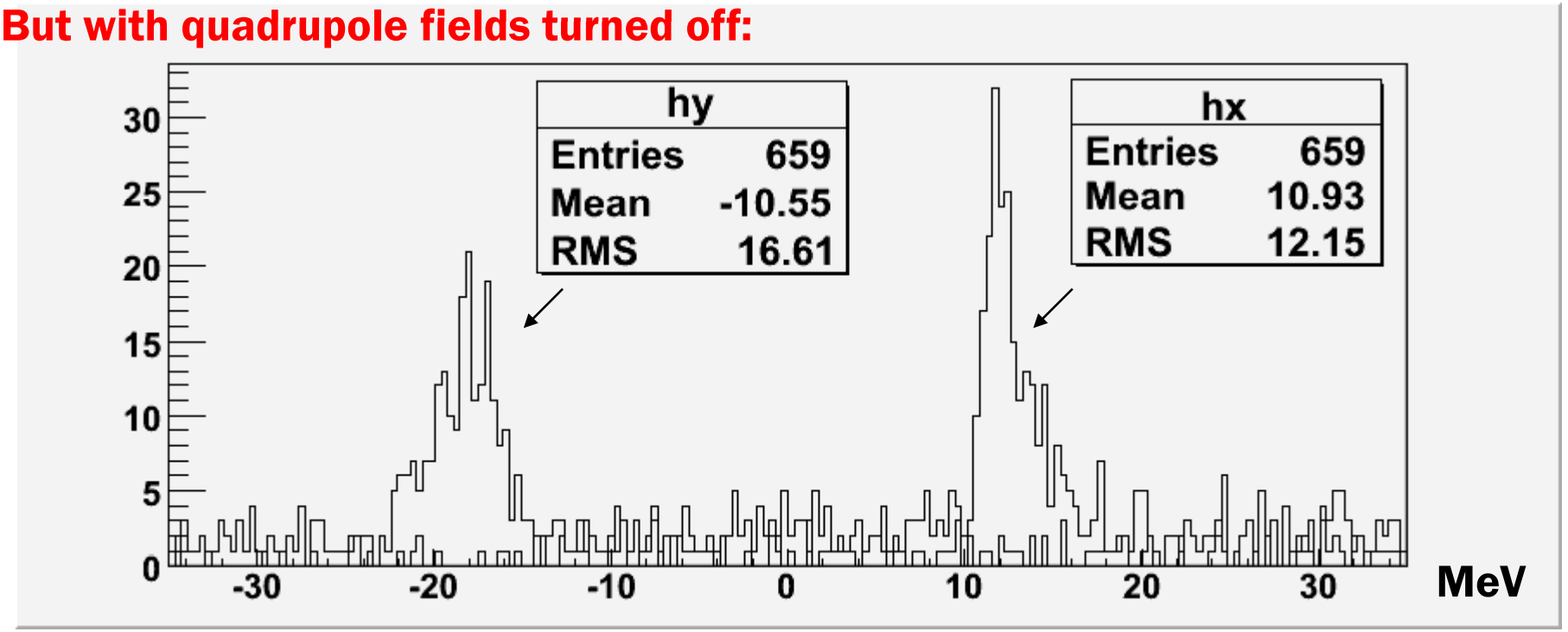


- **The intrinsically attainable momentum resolution is comparable to that resulting from the timing resolution of the TOFs**

Pure MC p reconstruction

$p_{air} - p_{TOF0}$ $p_{air} - p_{TOF1}$

But with quadrupole fields turned off:

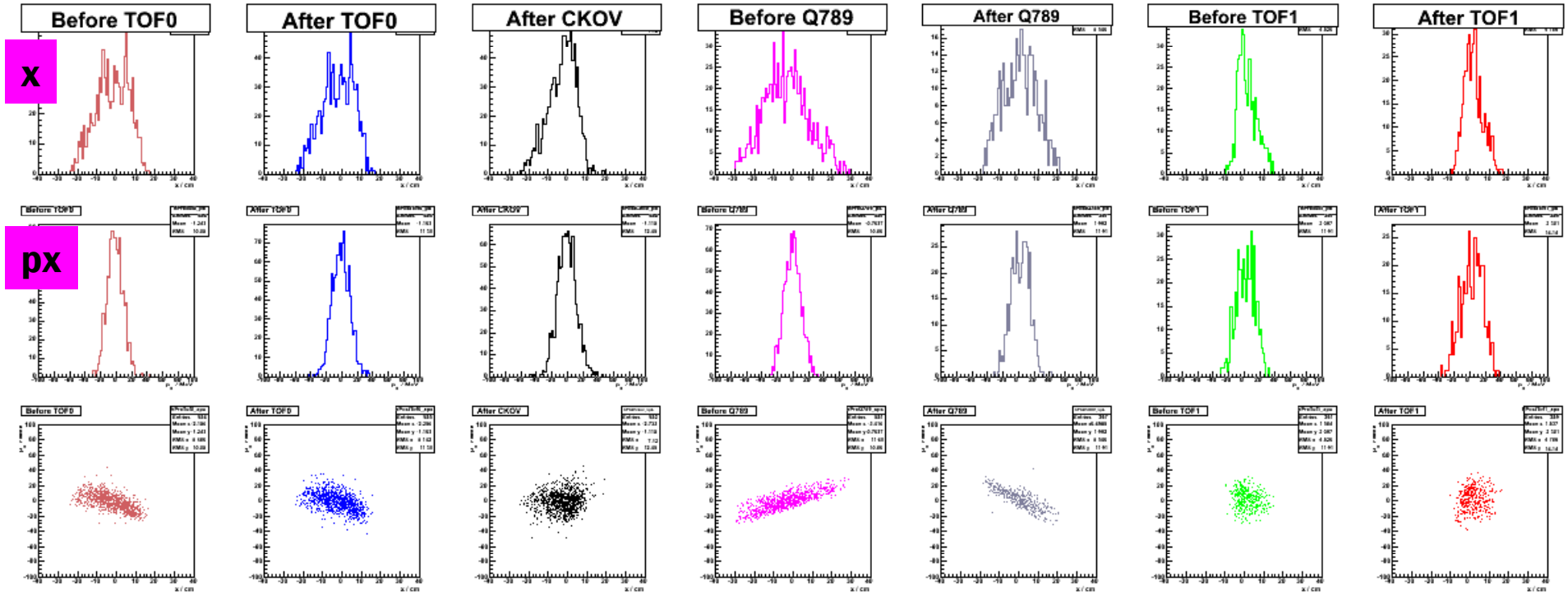


Simple p reconstruction conclusions

- 'Intrinsic' momentum resolution is ~2 MeV/c
- This is comparable to that resulting from the predicted TOF timing resolution
  - 70ps → 2 – 3 MeV/c
- Average x' is <1 degree
  - p_z is equivalent to p at this precision
- Quadrupoles improve momentum resolution
  - 10 – 20 MeV/c with zero quadrupole fields

Extra slides

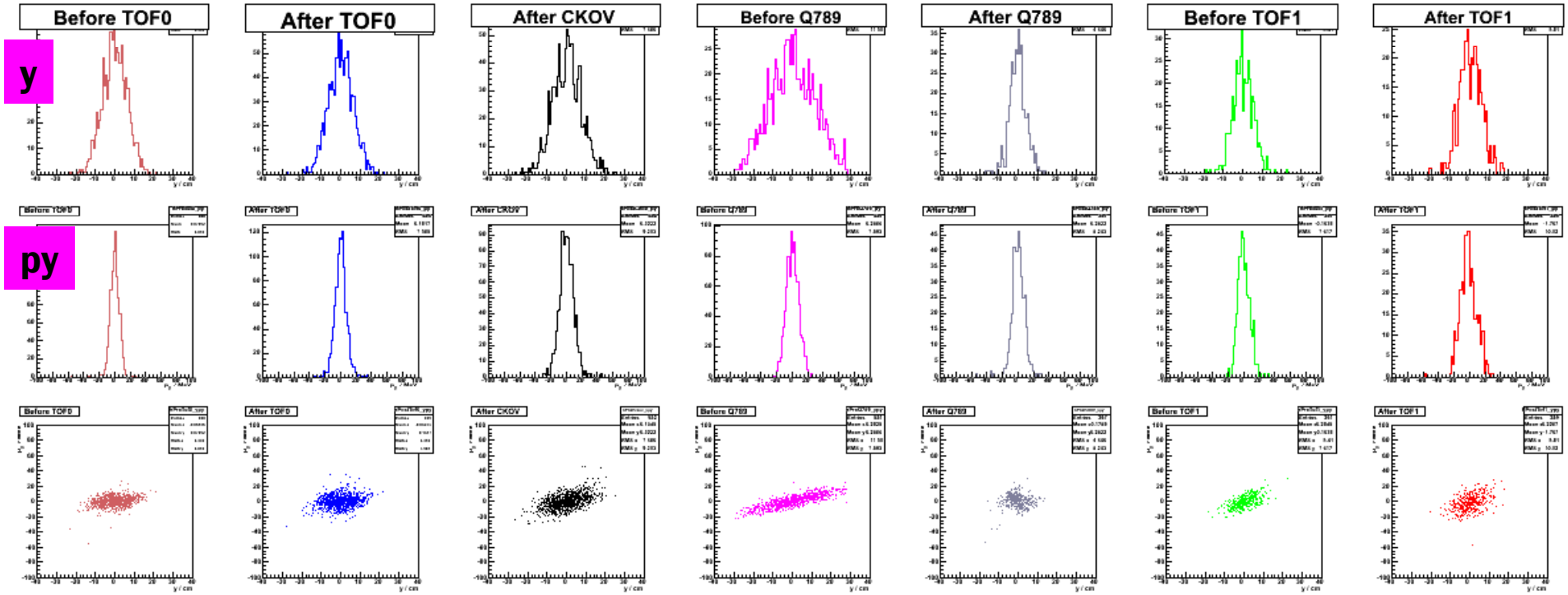
Transverse phase space: horizontal



-100 MeV – 100 MeV px / MeV

x / cm -40 cm – 40 cm

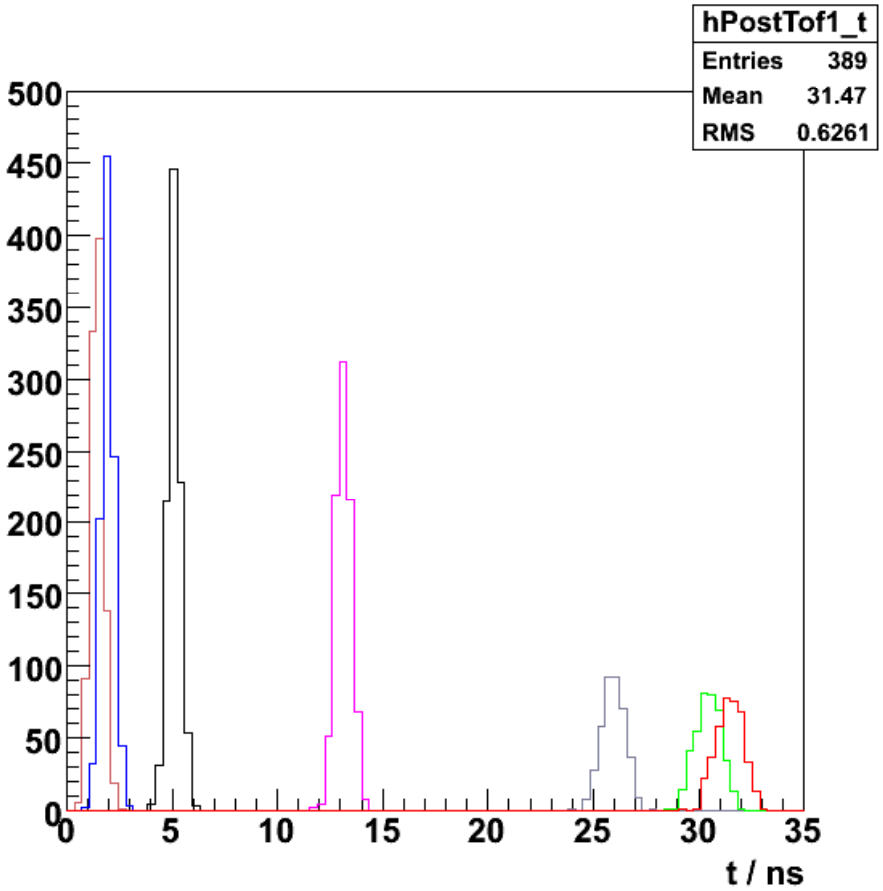
Transverse phase space: vertical

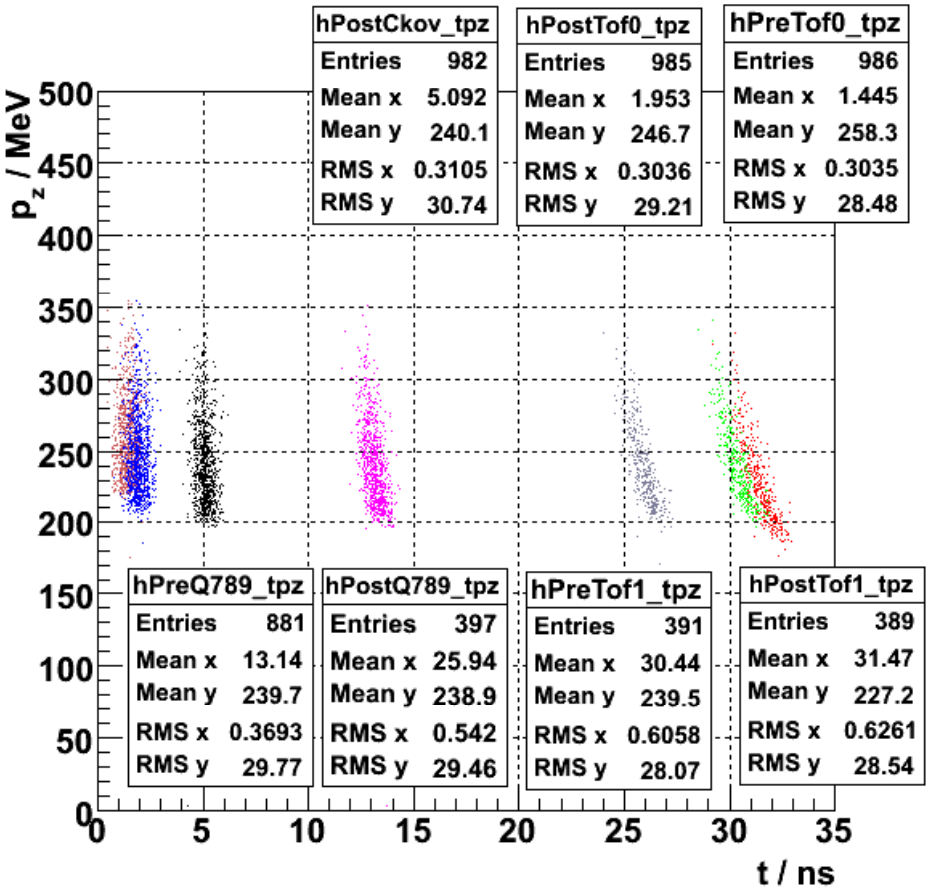


-100 MeV – 100 MeV py / MeV

y / cm -40 cm – 40 cm

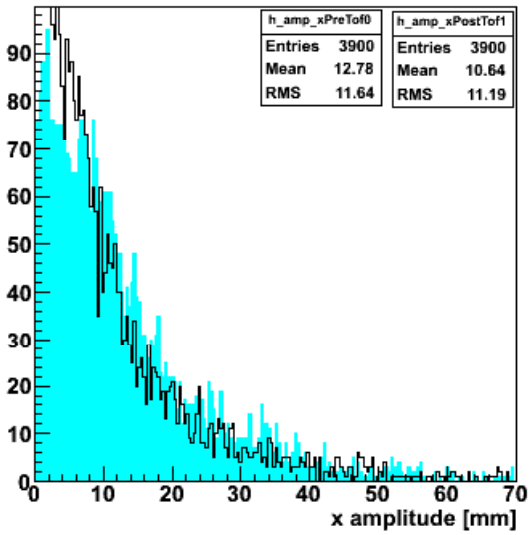
Longitudinal phase space



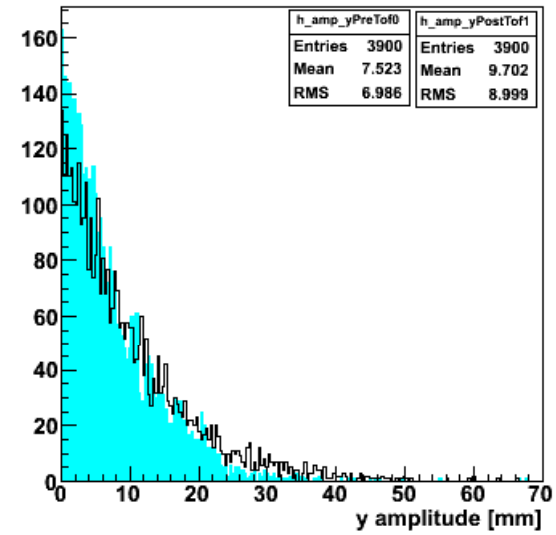


Amplitude analysis of muons surviving to TOF1

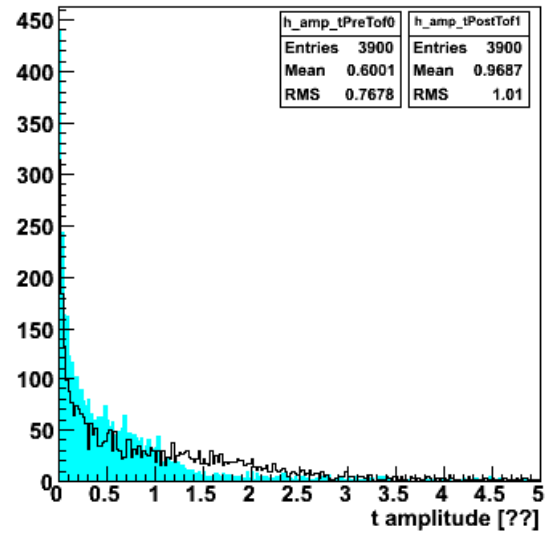
Before TOF0



Before TOF0



Before TOF0

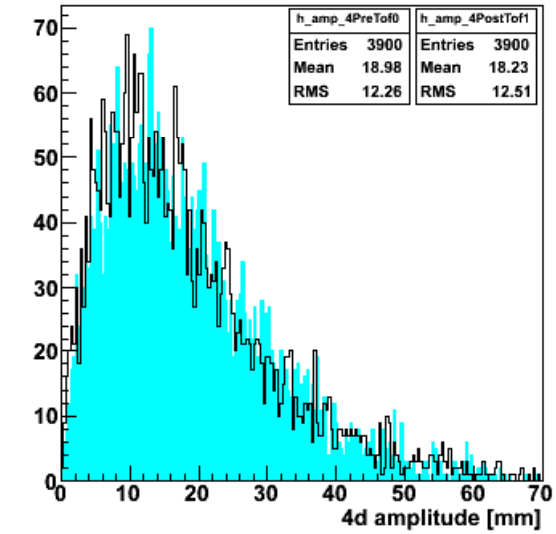


MC amplitude of survivors

Just before TOF0

Just after TOF1

Before TOF0



Before TOF0