Technical Design Review
Studying the Proton ``Radius" Puzzle with μp Elastic Scattering
Beam Line

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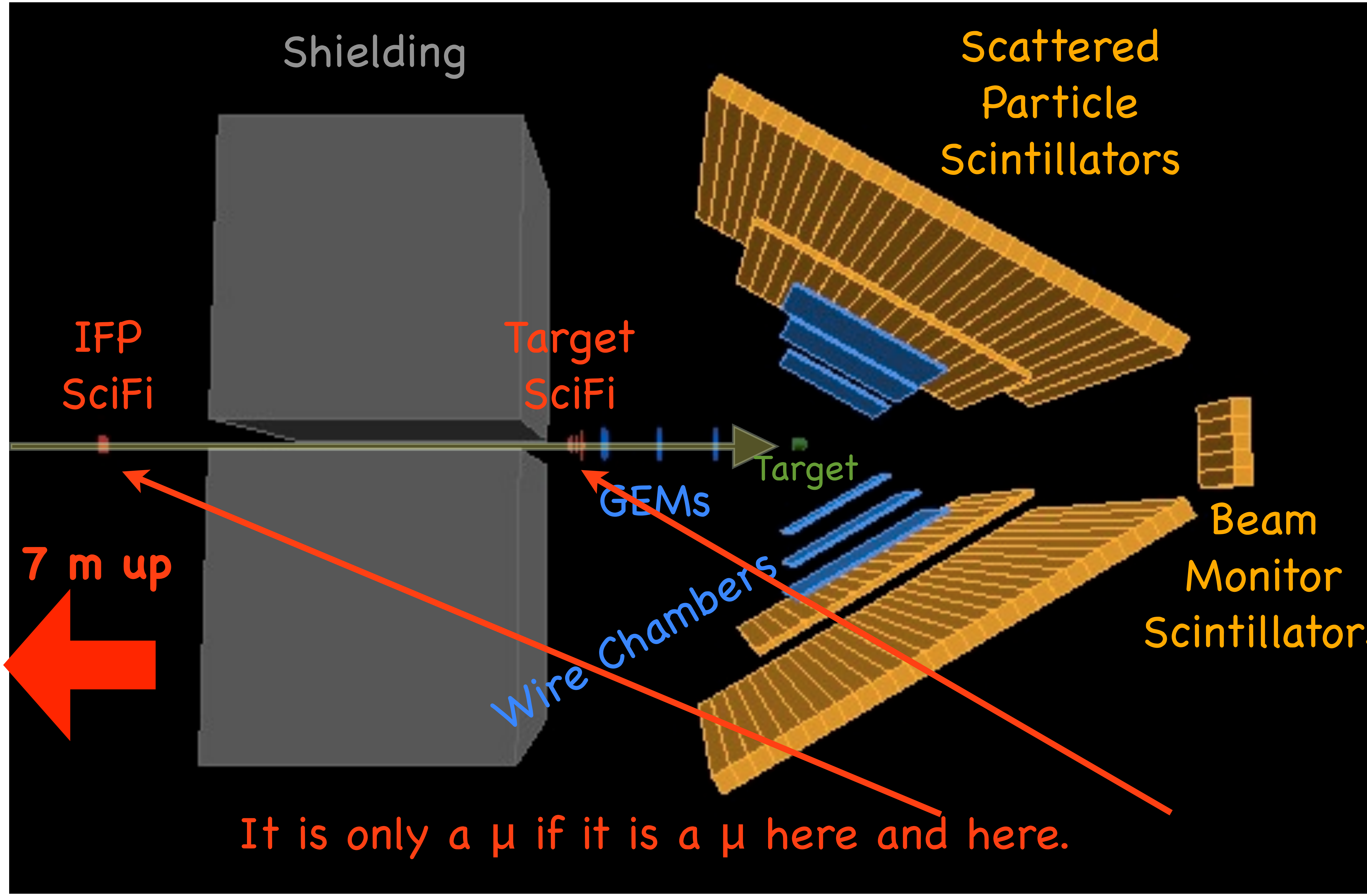
The πM1 beam line has largely been used for π scattering, not μ scattering. What properties should we expect for the μ beam?

Flux? Spot Size? Divergence?
Momentum Resolution?

Are the μ beam properties similar to those for the π beam?

Of course not - there is a μ halo from π decays in flight. But...



The beam μ halo is largely suppressed because it must be a μ from near the production target. More on this later in the trigger discussion.

Simulations with TURTLE

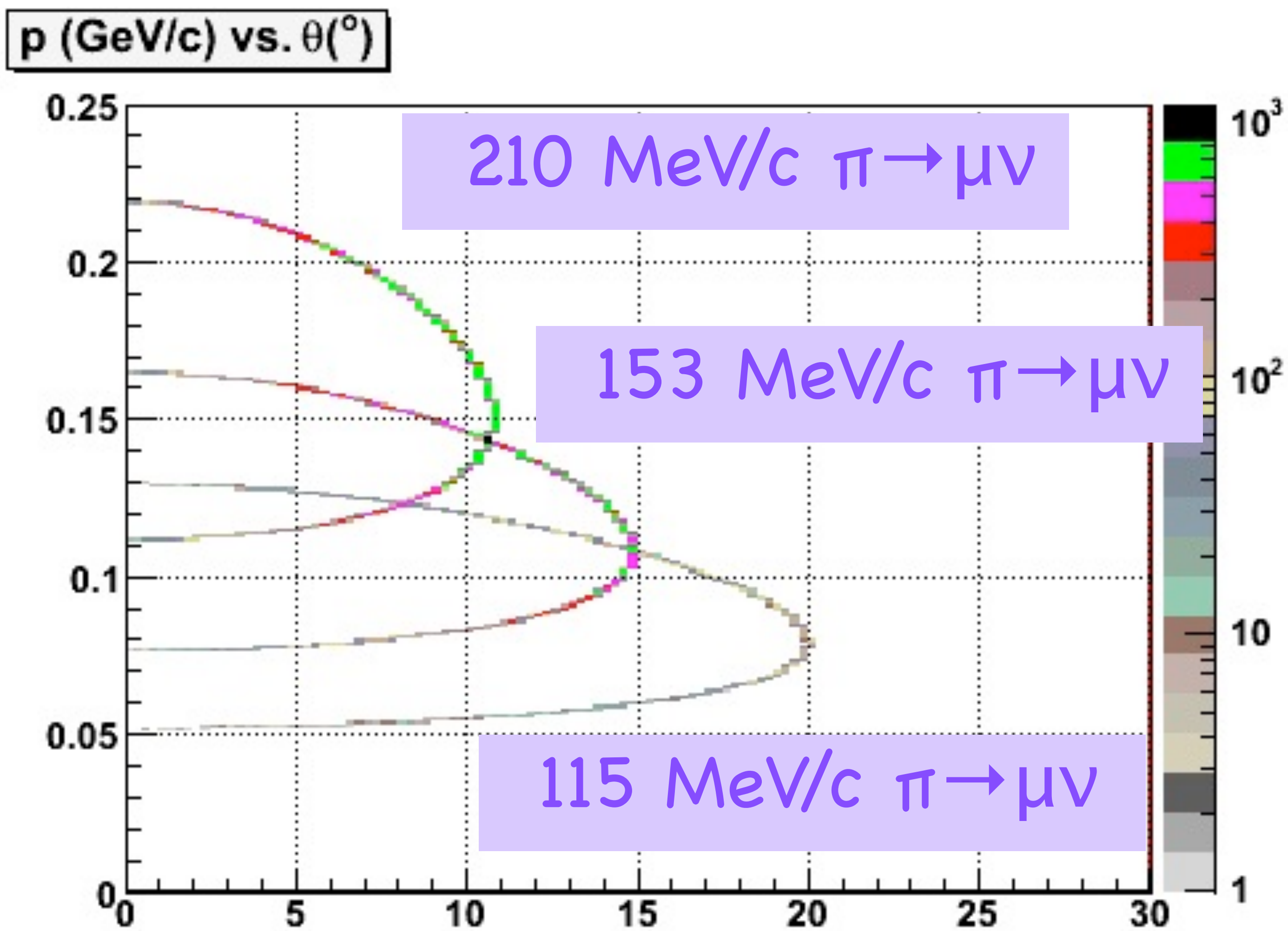
The beam line was simulated using TURTLE.

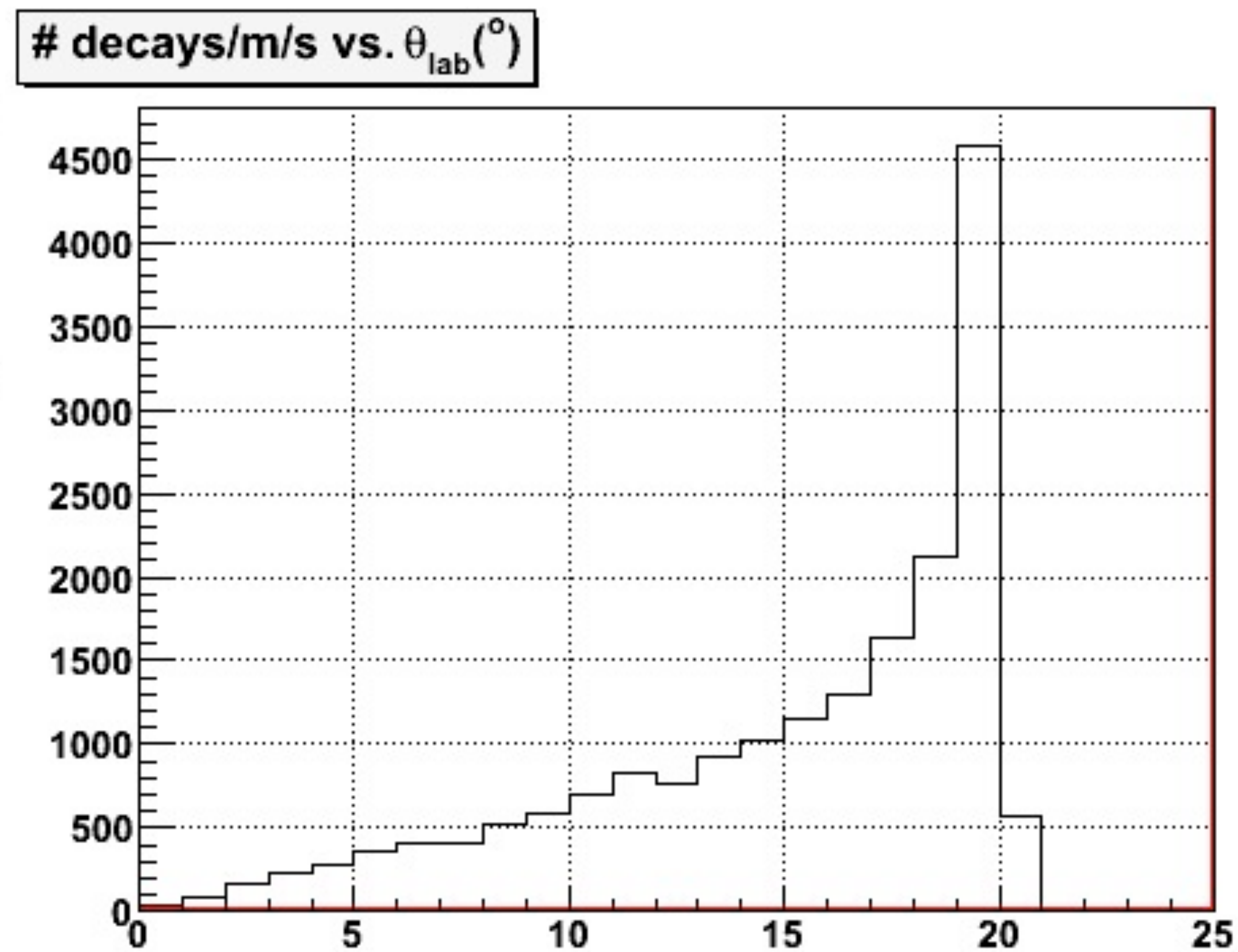
A uniform distribution of π's was thrown in the general direction of the πM1 channel, and transported through the channel to the target.

The μ distribution was created from the decay of the initial uniform π distribution. It was possible to tag the μ's and distinguish between μ's produced in the region of the production target (which will be shown), and those produced by decay of π's within the channel (which will not be shown).

Decays in flight of π's & μ's lead to beam halos of μ's & e's, generally at significant angles to the beam with poorly defined momenta.

Distribution of μ's from π Decay

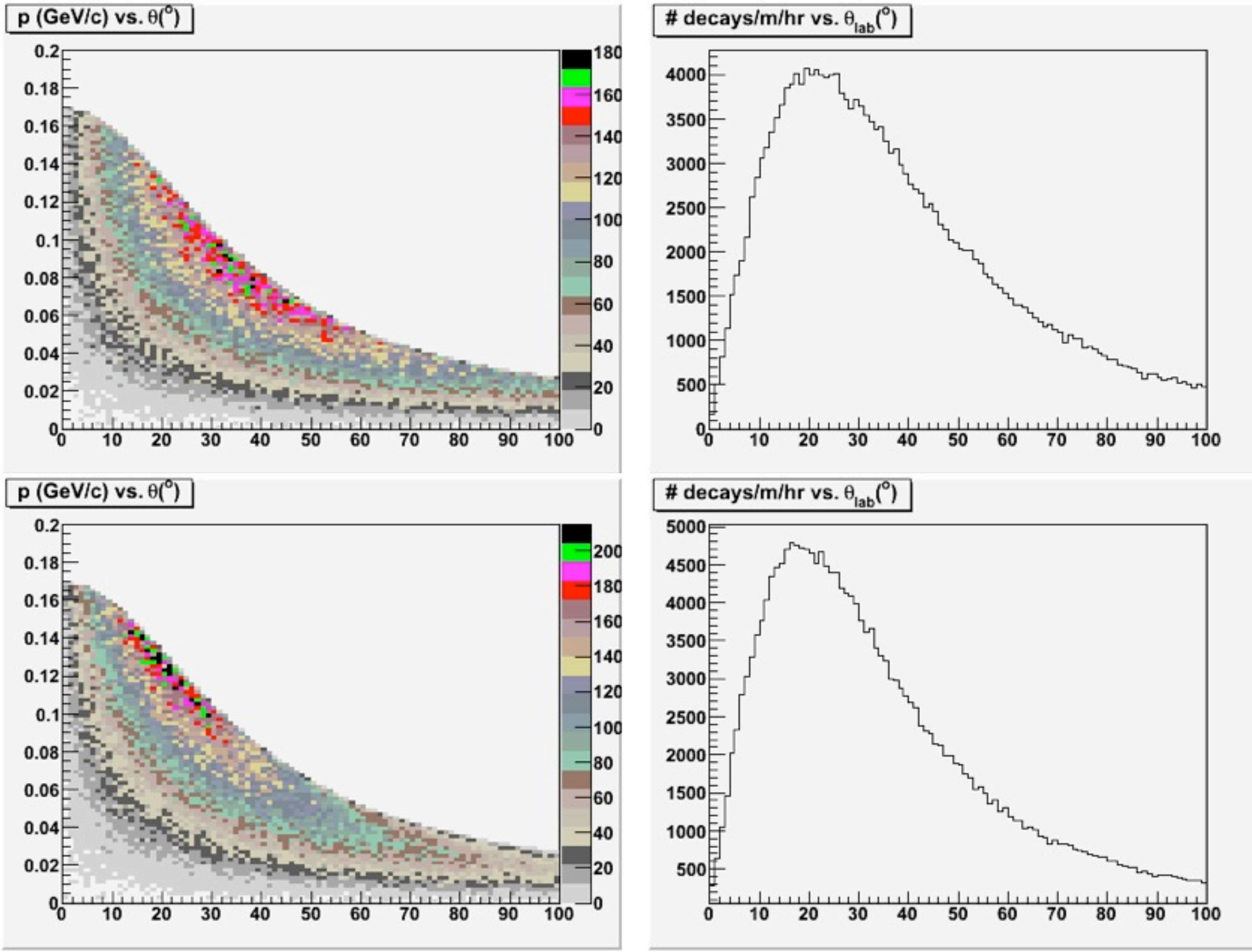




Distribution of e's from μ Decay

Distribution of electrons from 153 MeV/c μ decay.

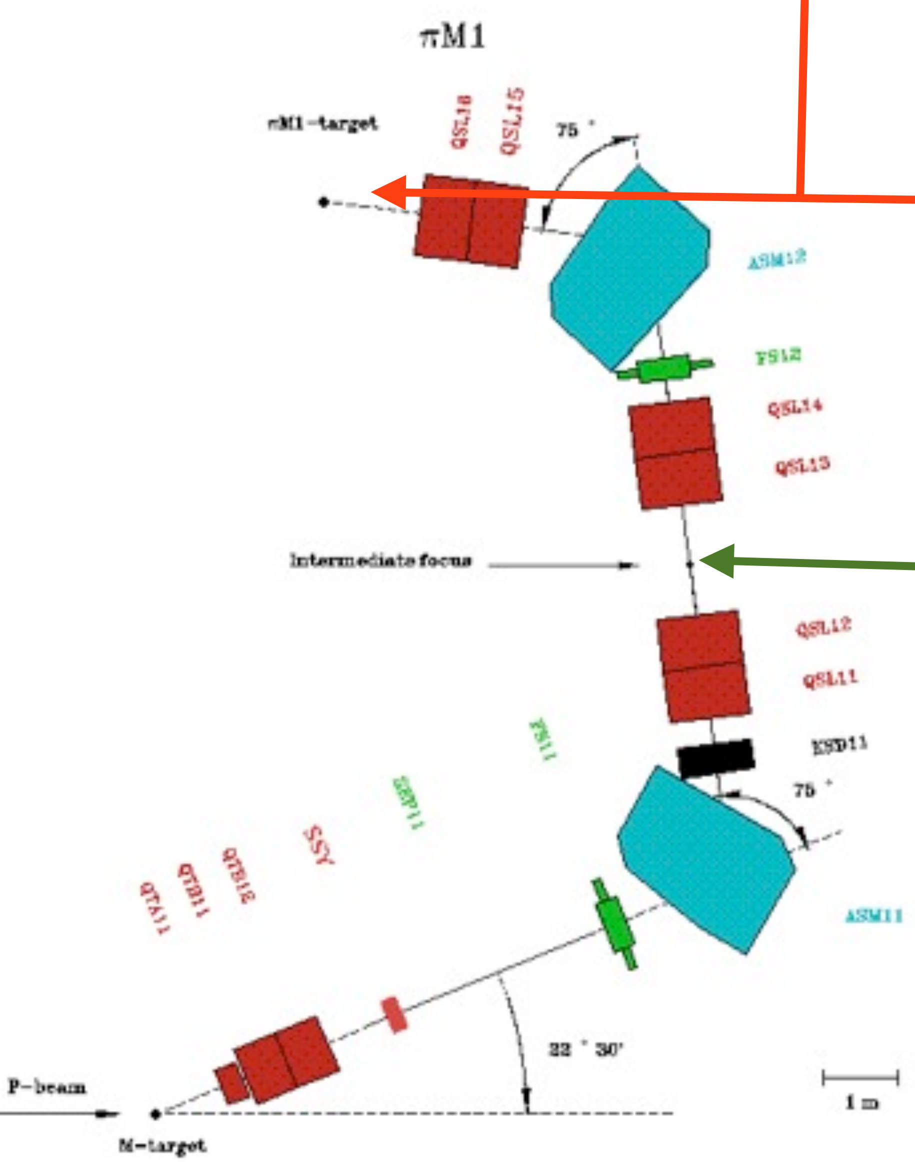
Distribution modified if μ polarized - here for S || p.

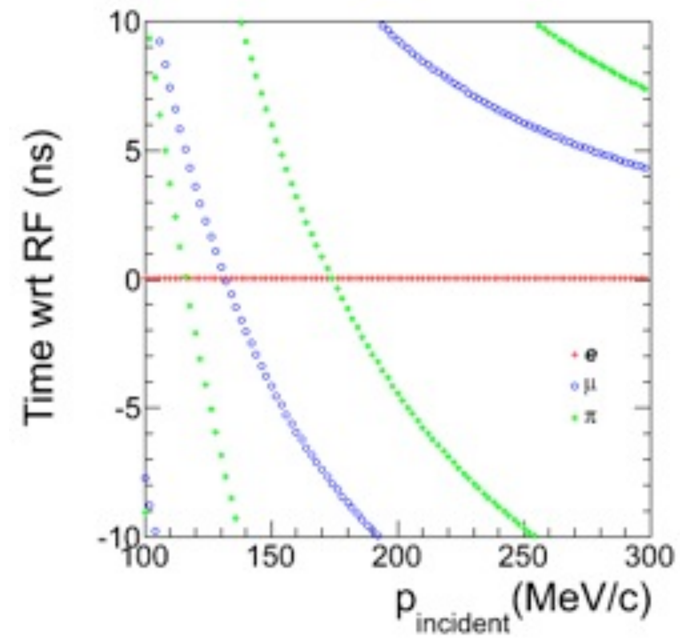


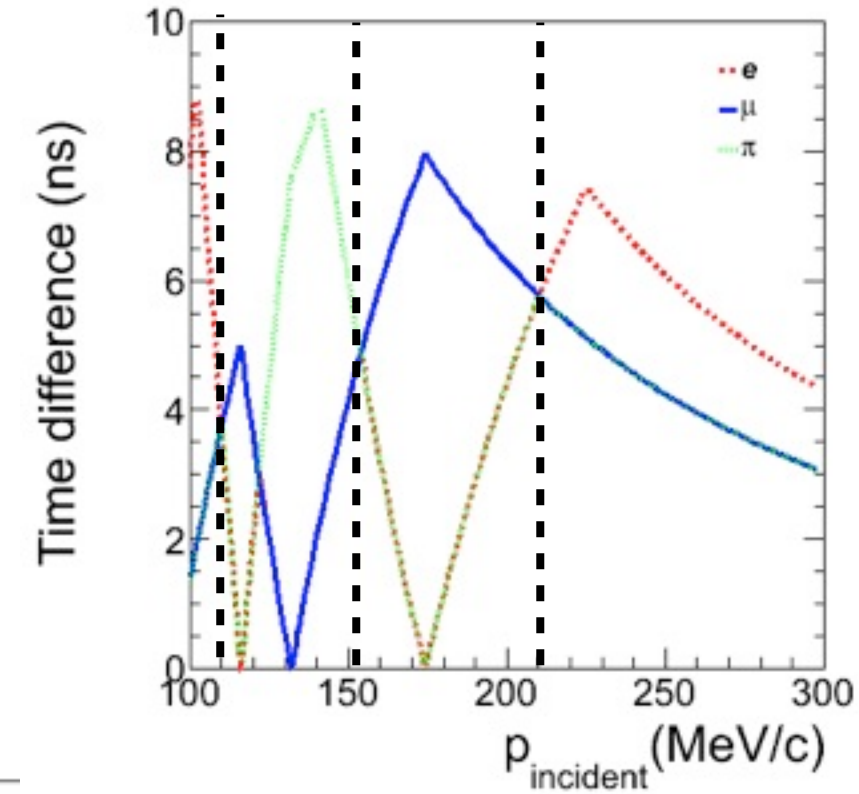
Lab angles, relative to μ momentum.

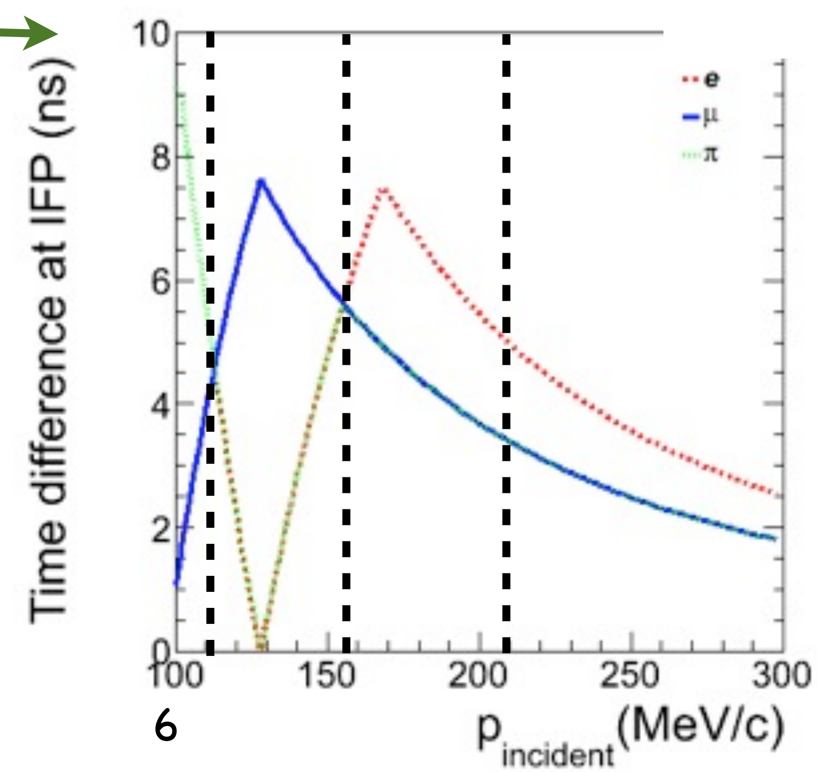
Determining Particle Type with RF Time

Measure RF time
here & here







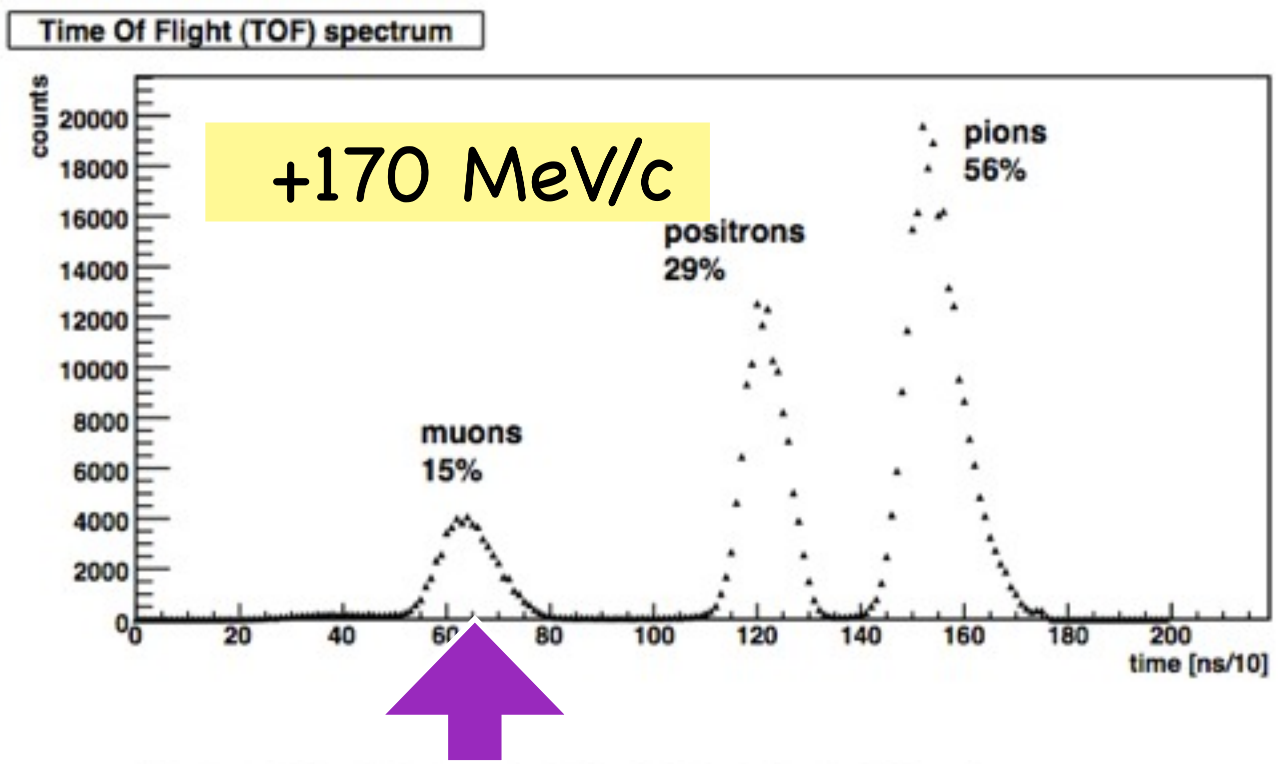


π, μ, and e can all be separated

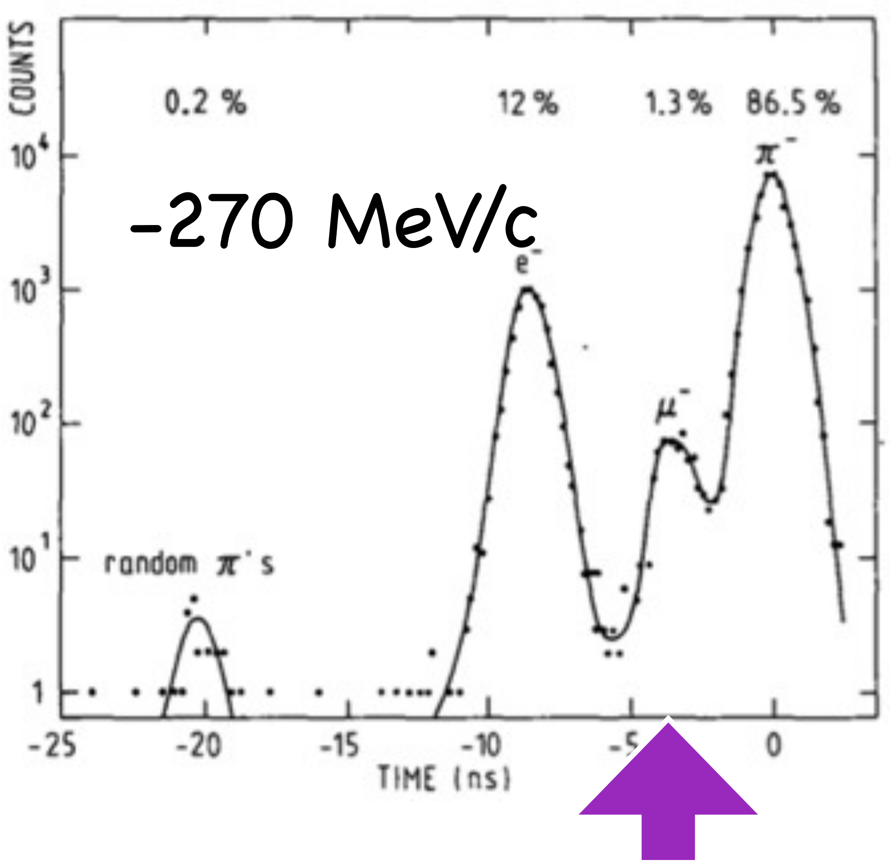
Flux

Flux has been measured using small scintillators in the beam.

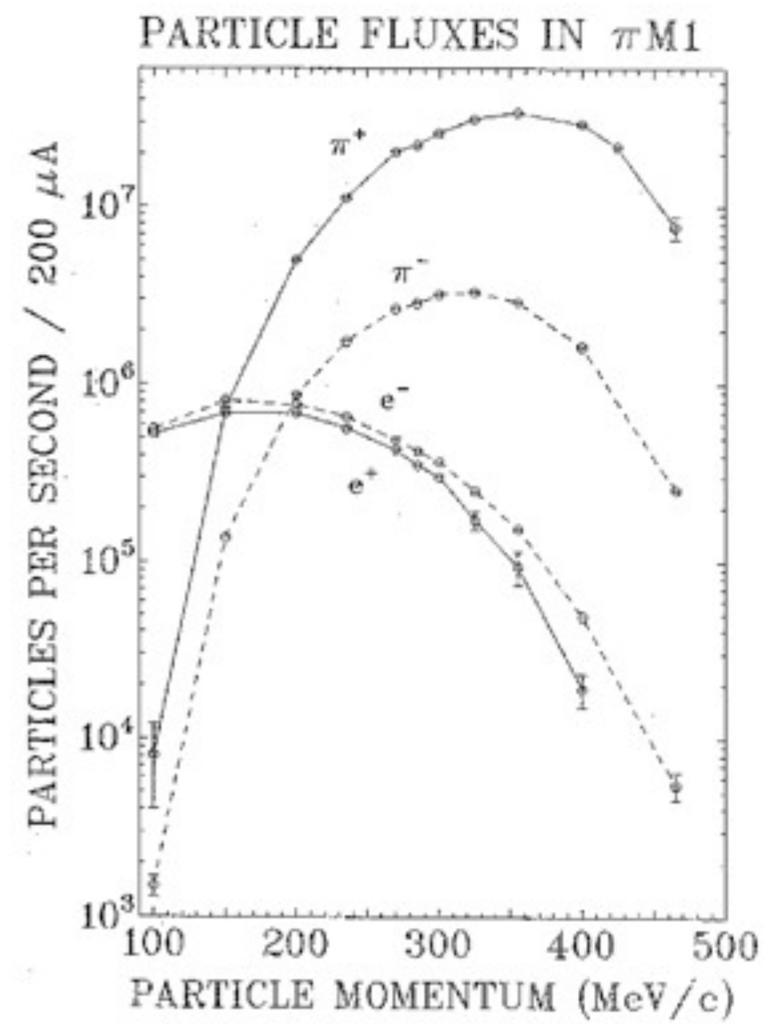
The flux is not well established for muons.



These are μ's from the production target region. They have the right μ RF time. If they were μ's from π decays in flight, they would have a π RF time. If they were "0°" μ's from π decays in the channel, there would not be so many of them.

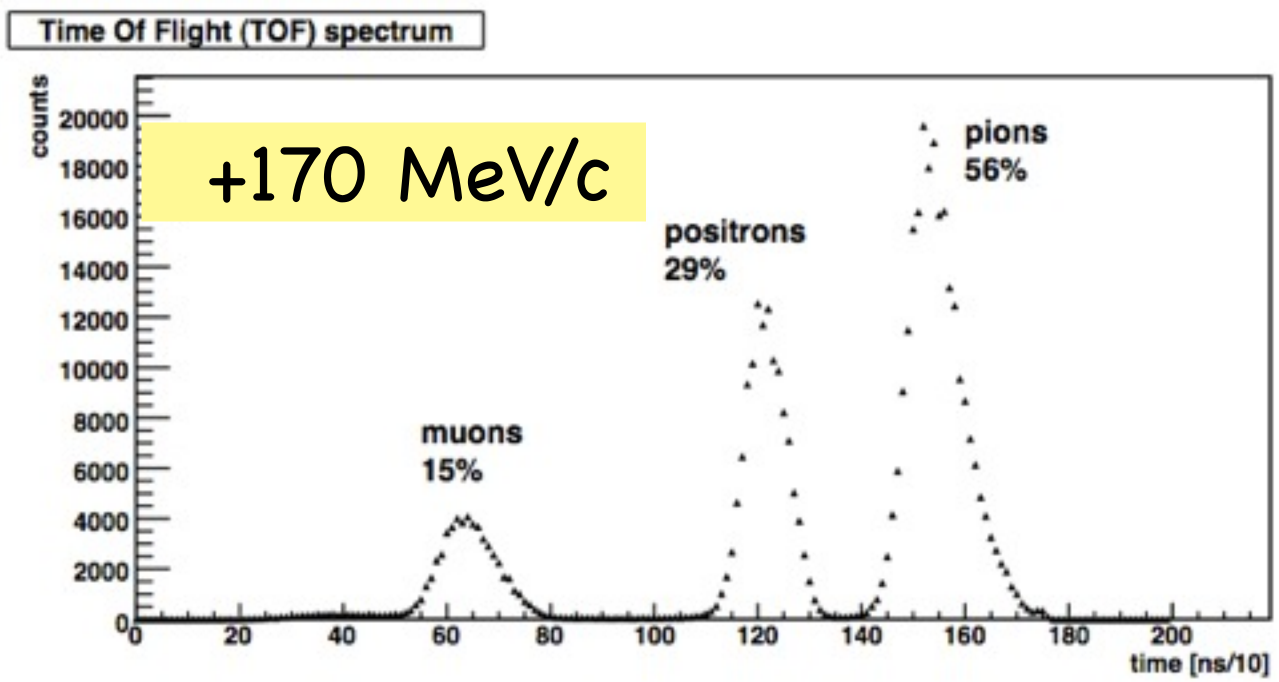


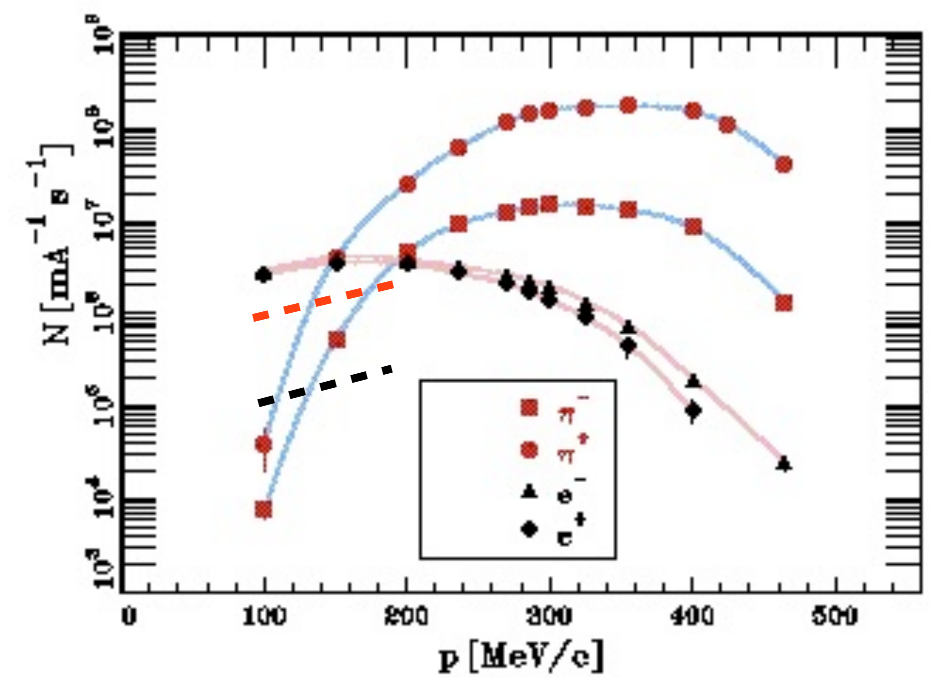
From Schumacher and Sennhauser report, 1987

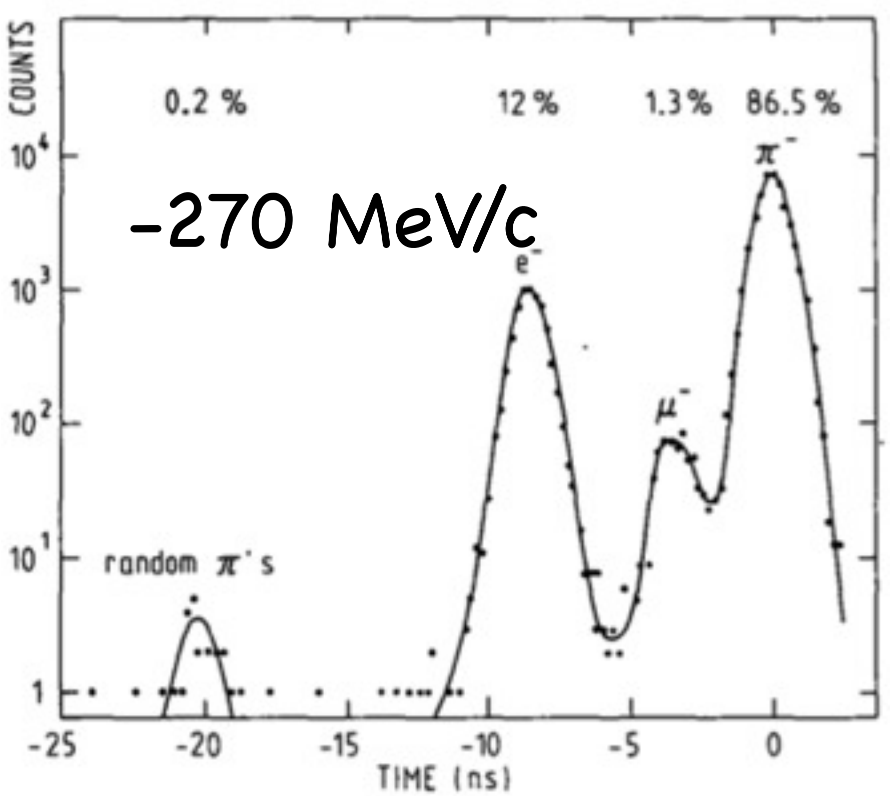


Flux

Not well established for muons







Muon flux roughly estimated using spectra shown, and assuming the same μ/π ratio for both polarities, and the ratio increases as momentum decreases. ➪ 8 at 115 MeV/c, 36% at 153 MeV/c, 7% at 210 MeV/c.

Our simulations are not good enough to tell us the actual muon flux - it will have to be determined by measurements.

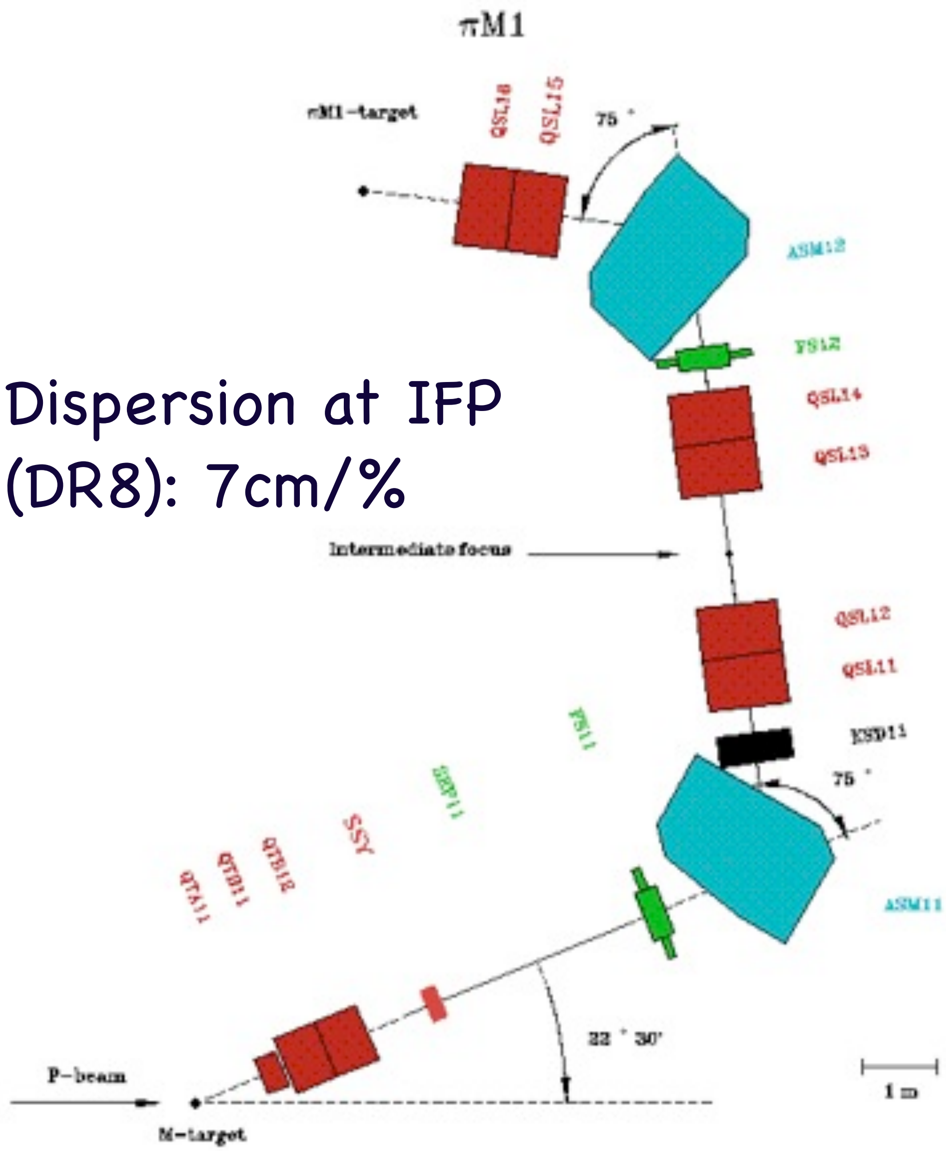
Estimated Beam Flux

p (MeV/c)	+/-	π (MHz)	μ (MHz)	e (MHz)	Σ (MHz)
115	+	0.12	1	6	9
153	+	7	2.5	7	18
210	+	70	5	6	70
115	-	0.023	0.2	6	6
153	-	1.4	0.5	8	9
210	-	12	1	7	12

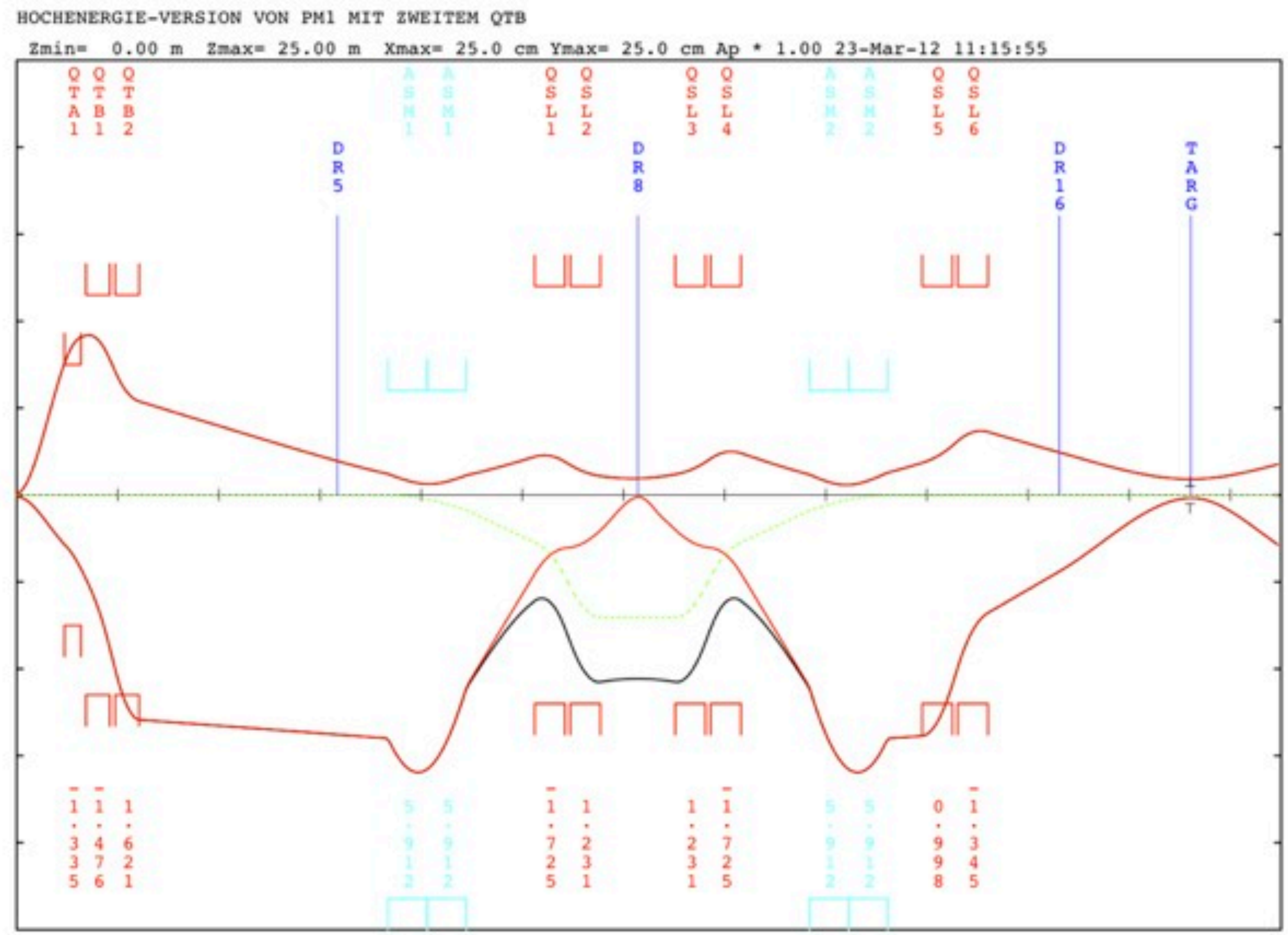
Fluxes for 2 mA protons. For detector / analysis reasons, we will close FS11 jaws to limit the total flux to 10 MHz. This is not believed to affect any beam properties other than flux.

πM1 Channel – Nominal Characteristics

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



Dispersion at IFP (DR8): 7cm/%

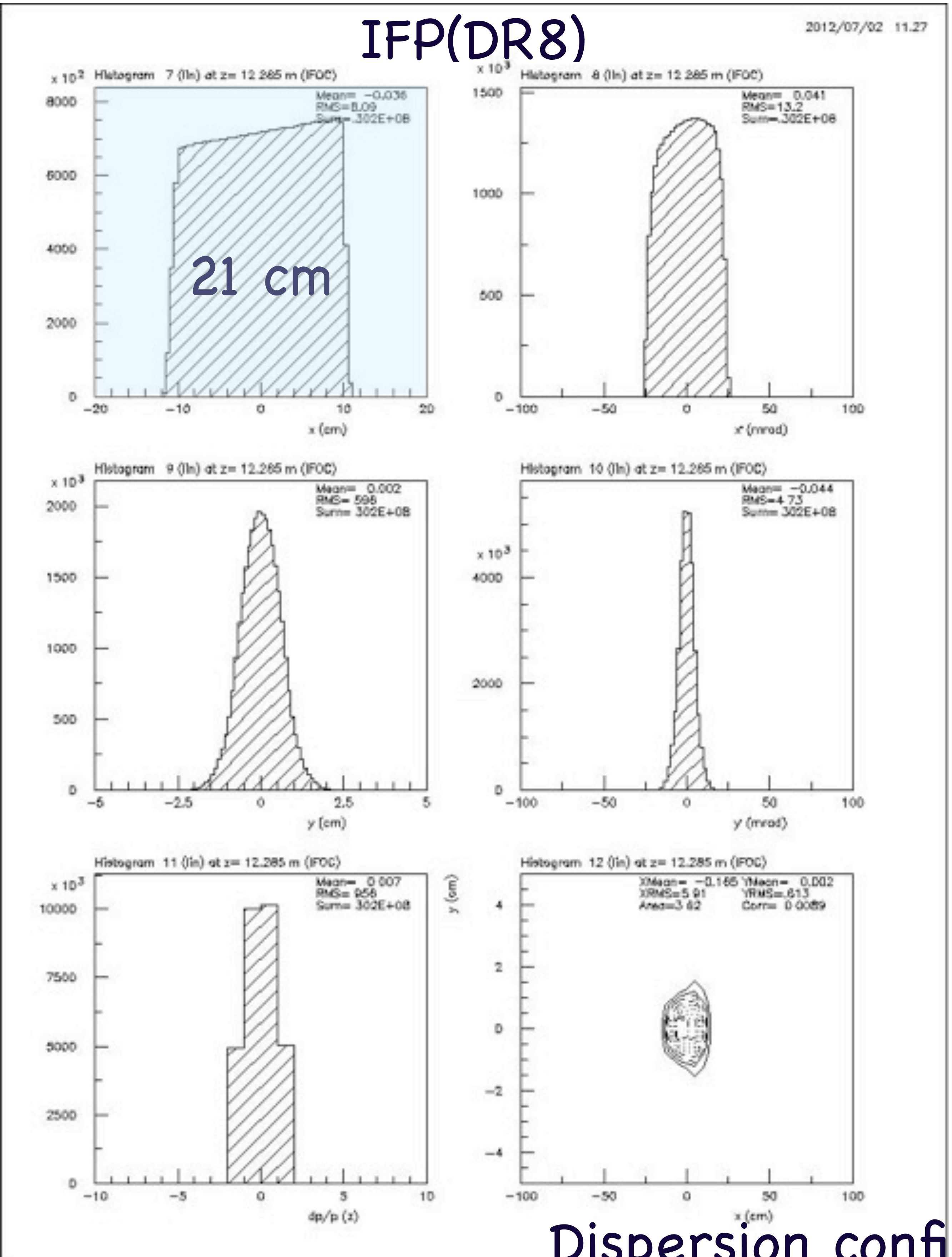


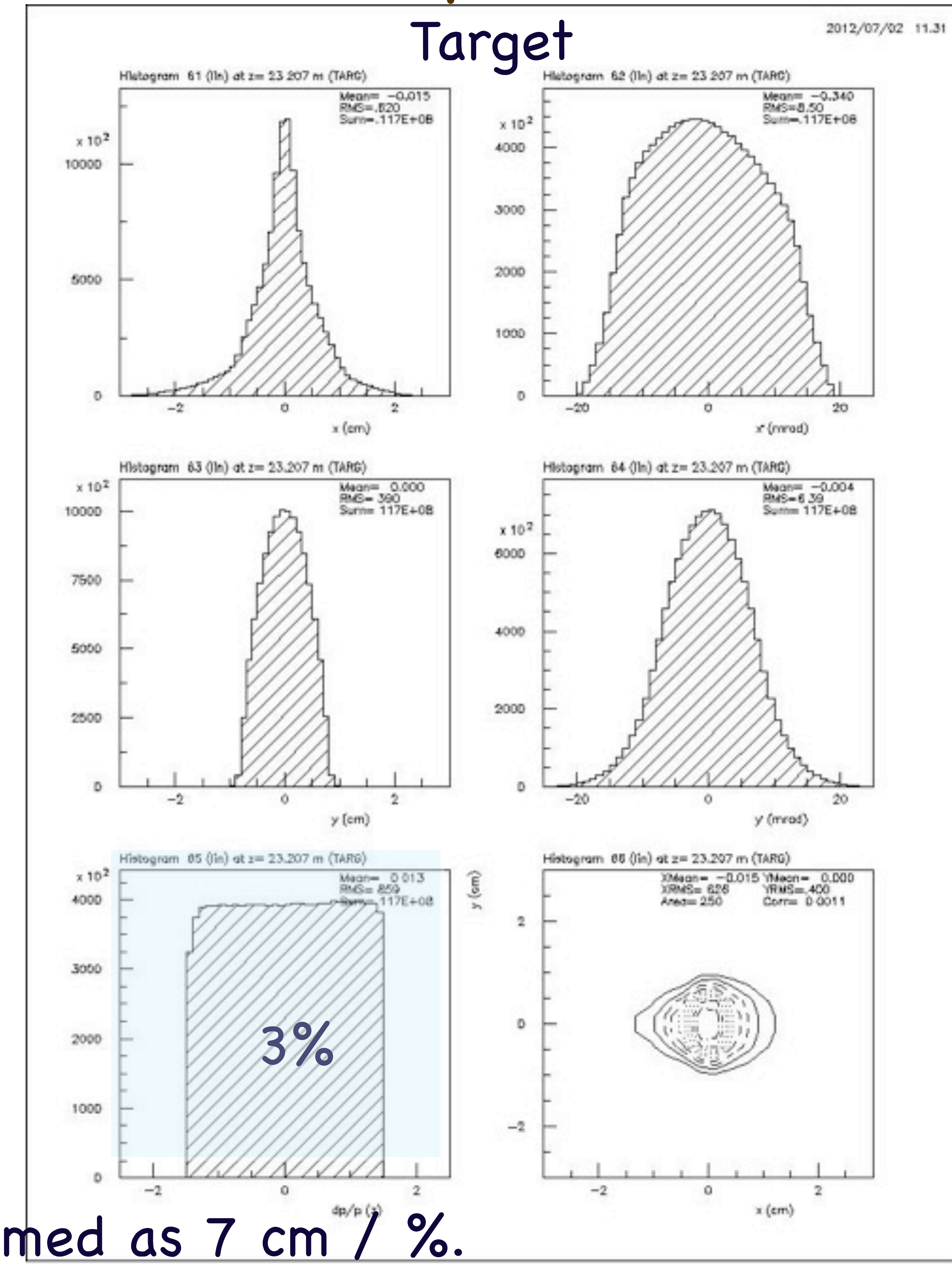
Beam spot (nominal):
1.5 cm X x 1 cm Y,
35 mr X' x 75 mr Y'

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.

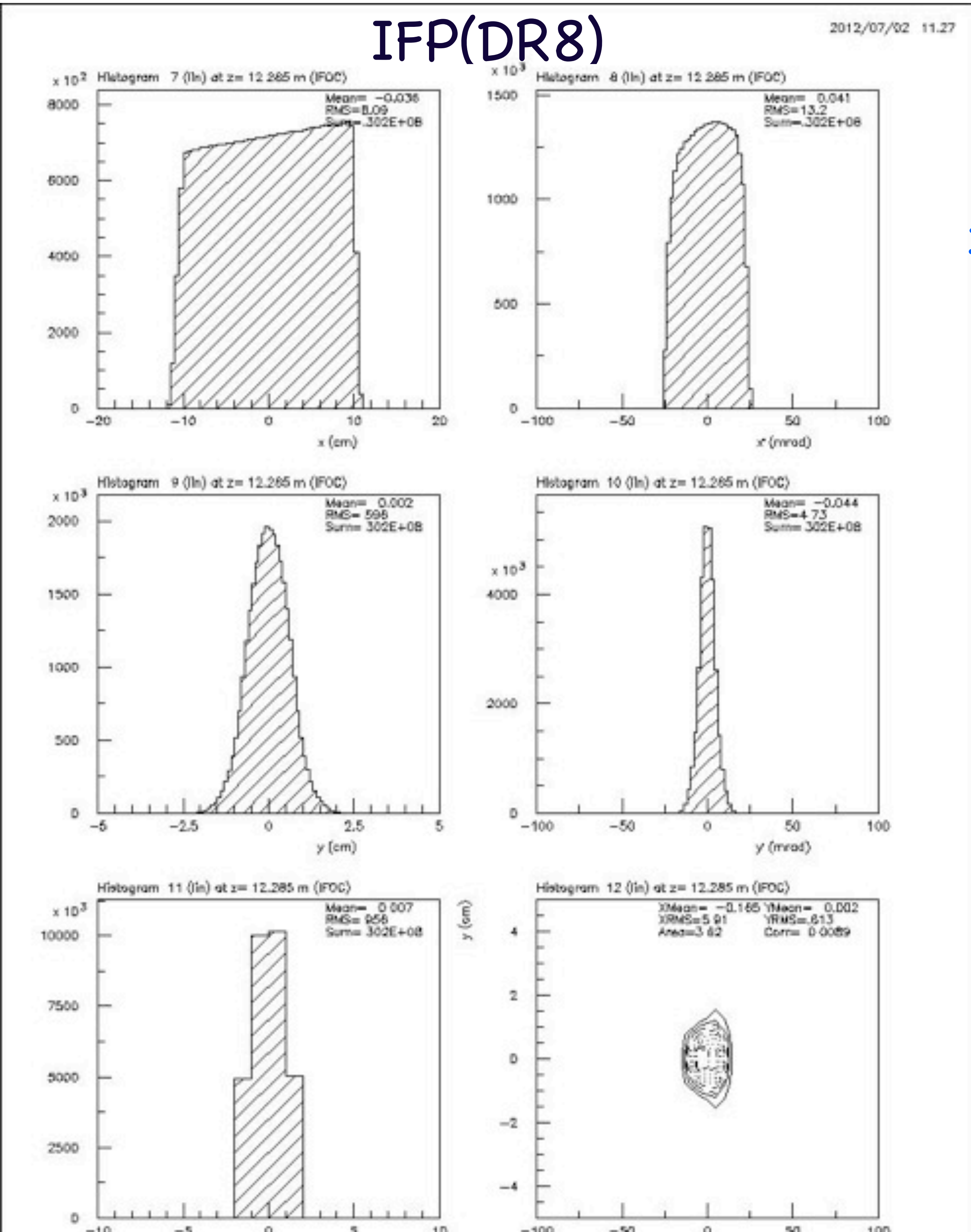
π Simulation with TURTLE - dispersion

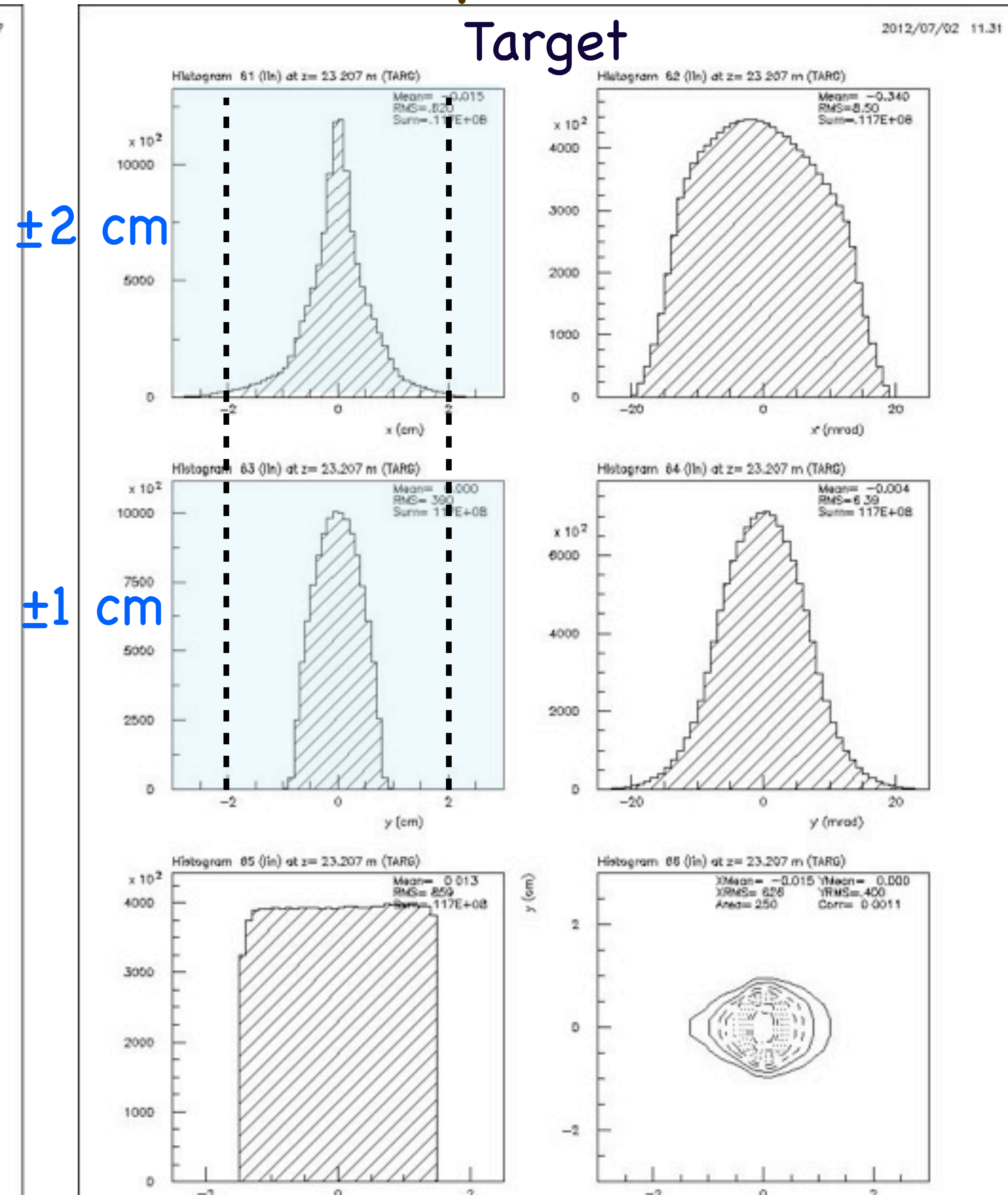




Dispersion confirmed as 7 cm / %.

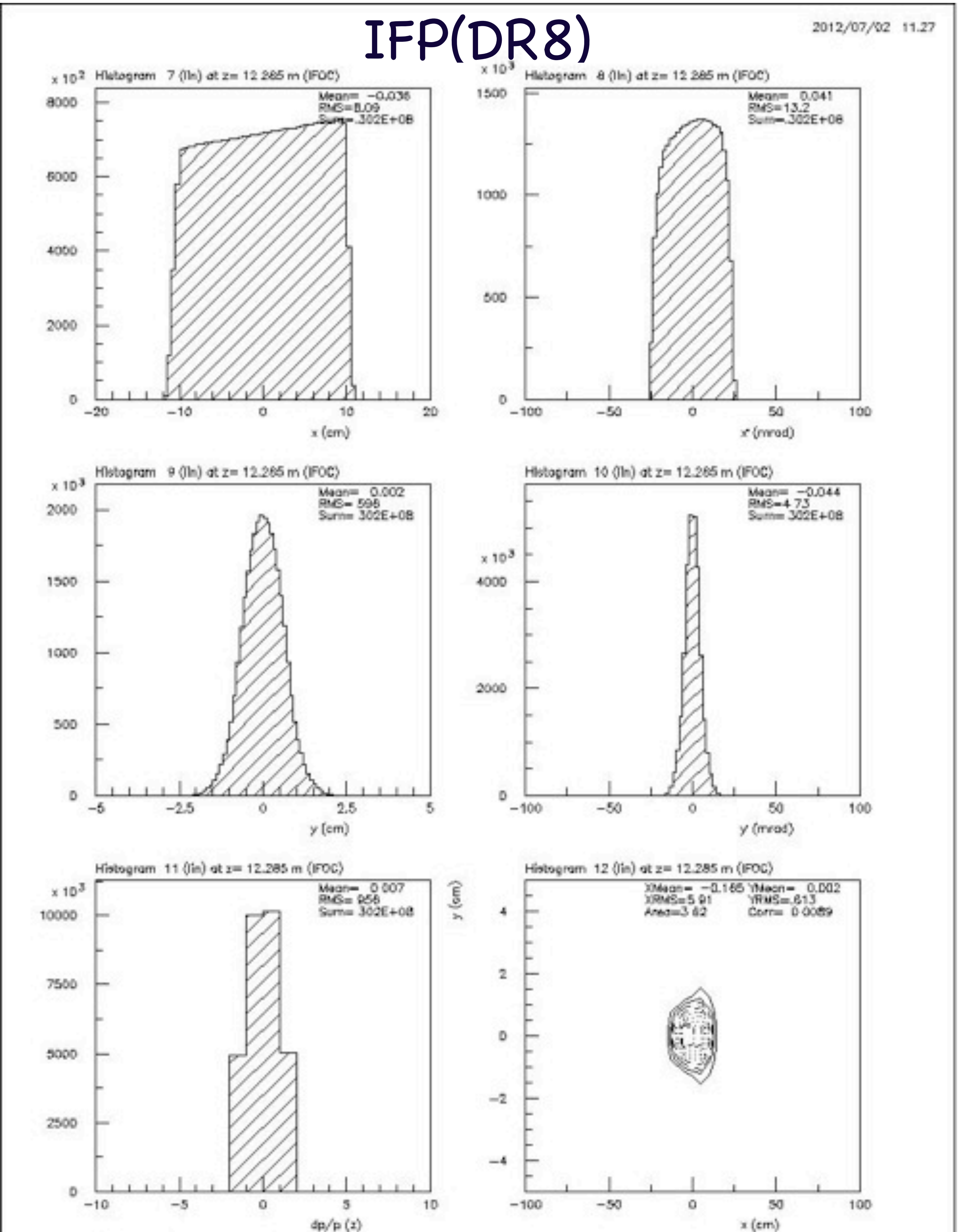
π Simulation with TURTLE - spot size

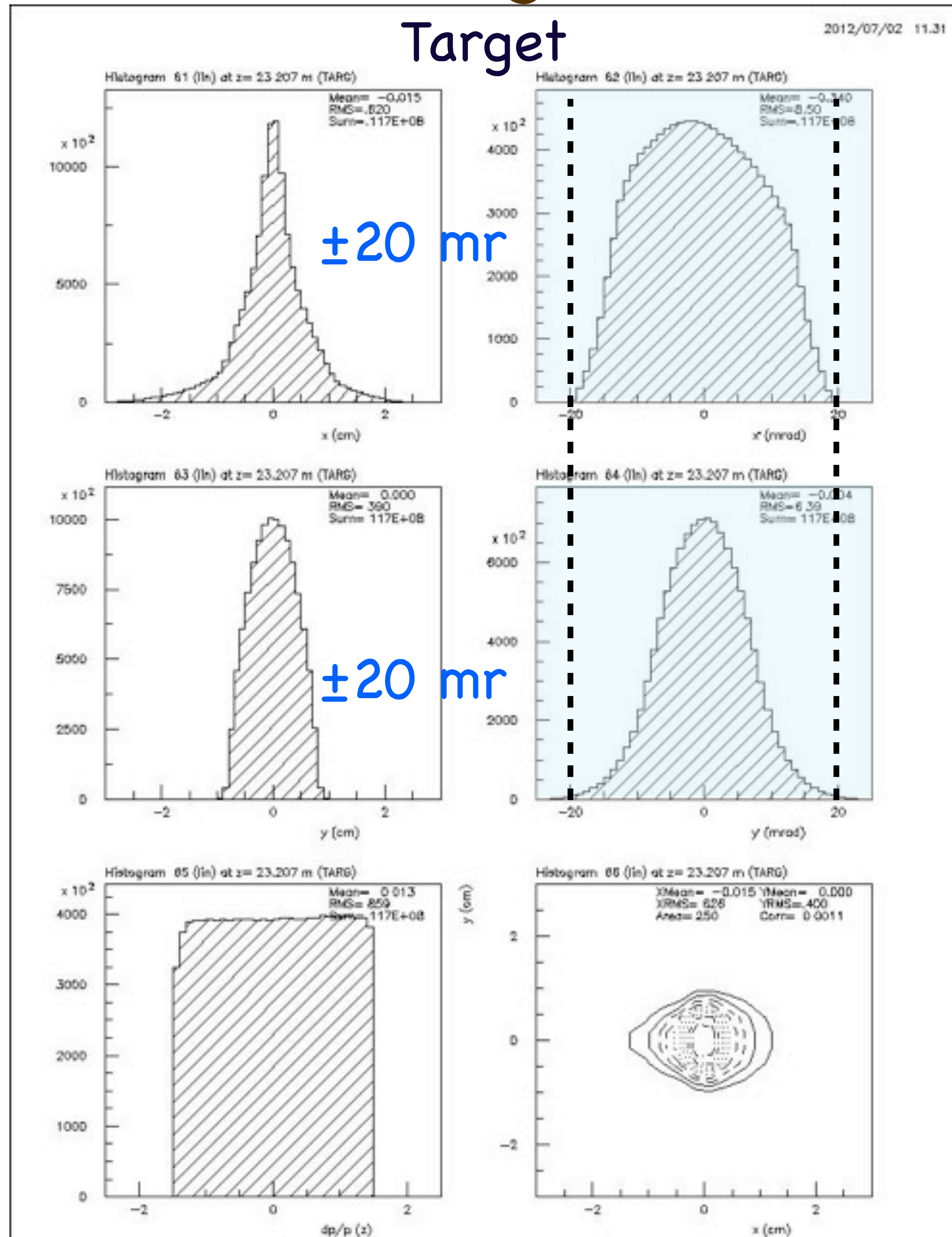




Not too different from 1.5 cm in X by 1 cm in Y

π Simulation with TURTLE - divergence





Consistent with nominal 35 mr in X', but Y' narrower than 75 mr

π Simulation with TURTLE - summary

Acceptence: 3%

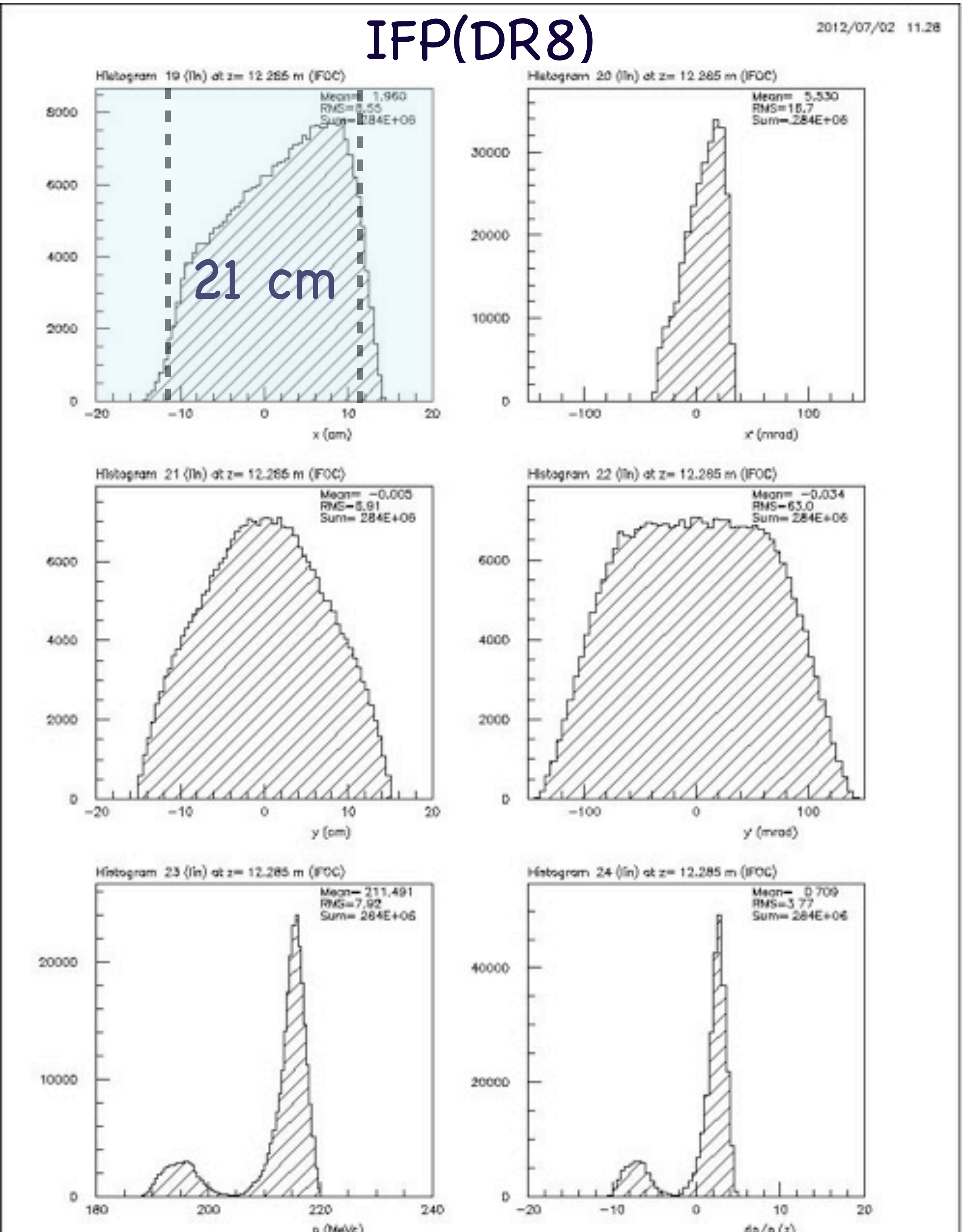
Dispersion at IFP(DR8): 7 cm/%

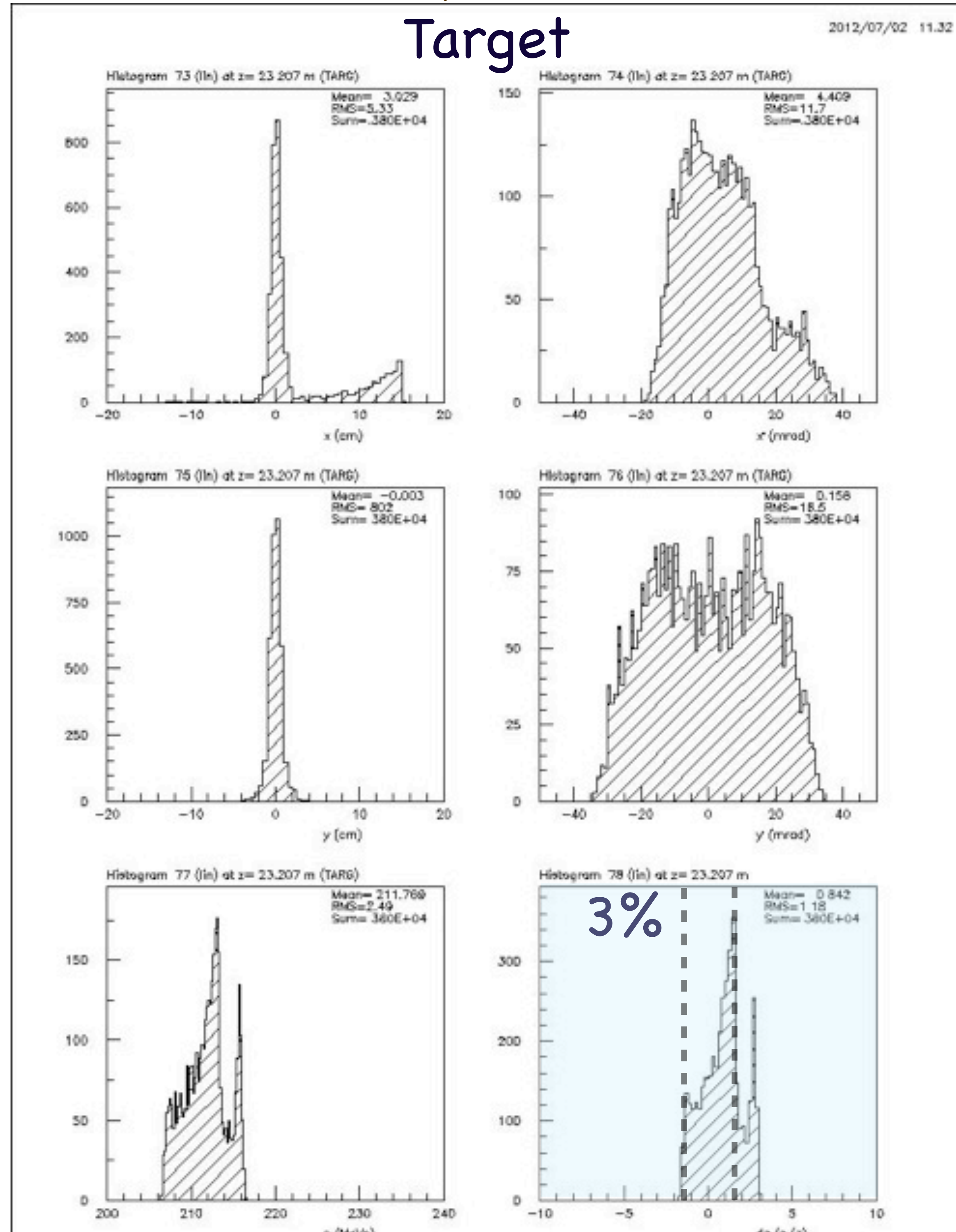
Spot size: ±2 cm in x (+ a small tail), ±1 cm in y

Divergence: ±20 mr in x and y

Simulation more or less consistent with nominal beam parameters.

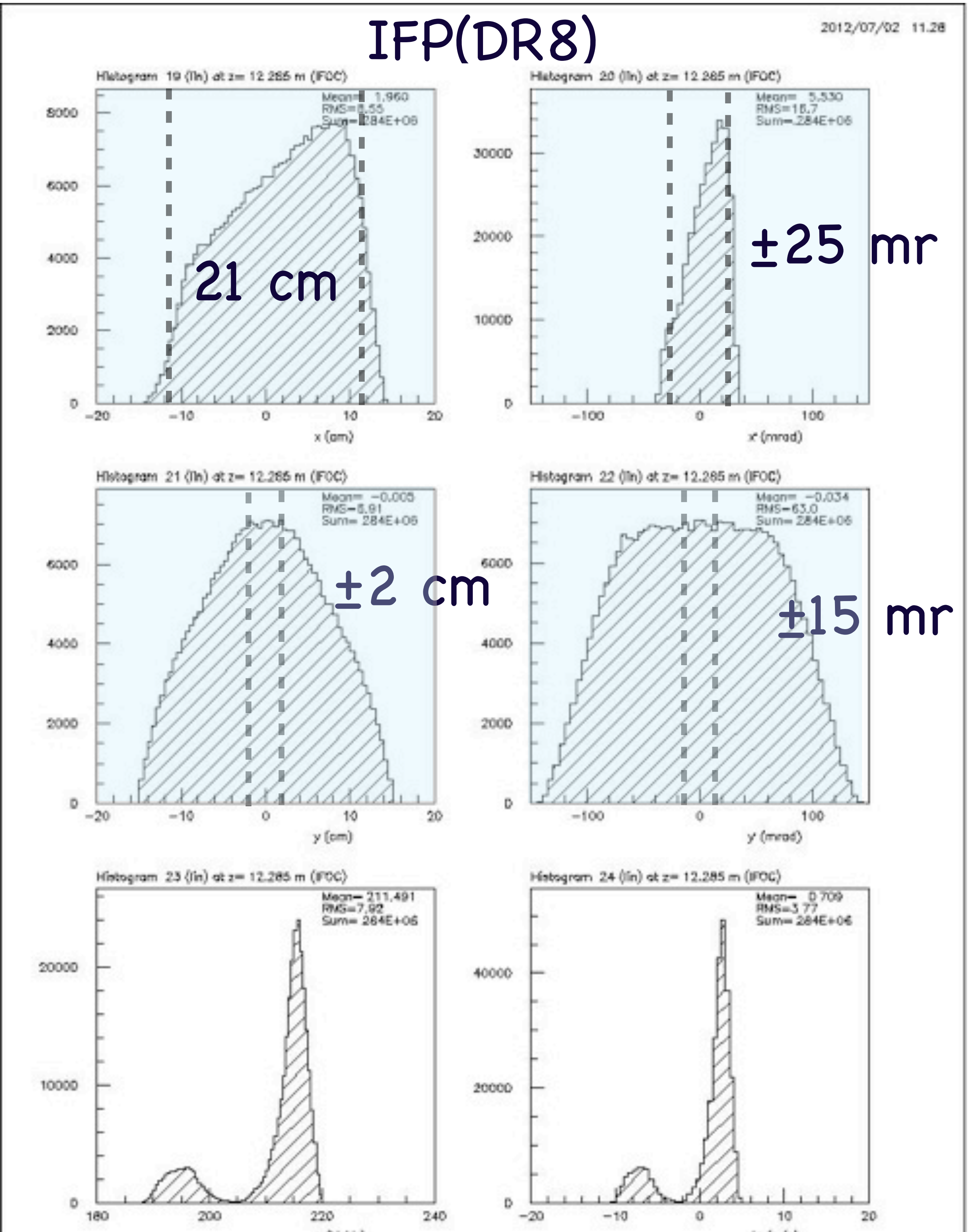
μ Simulation with TURTLE - dispersion

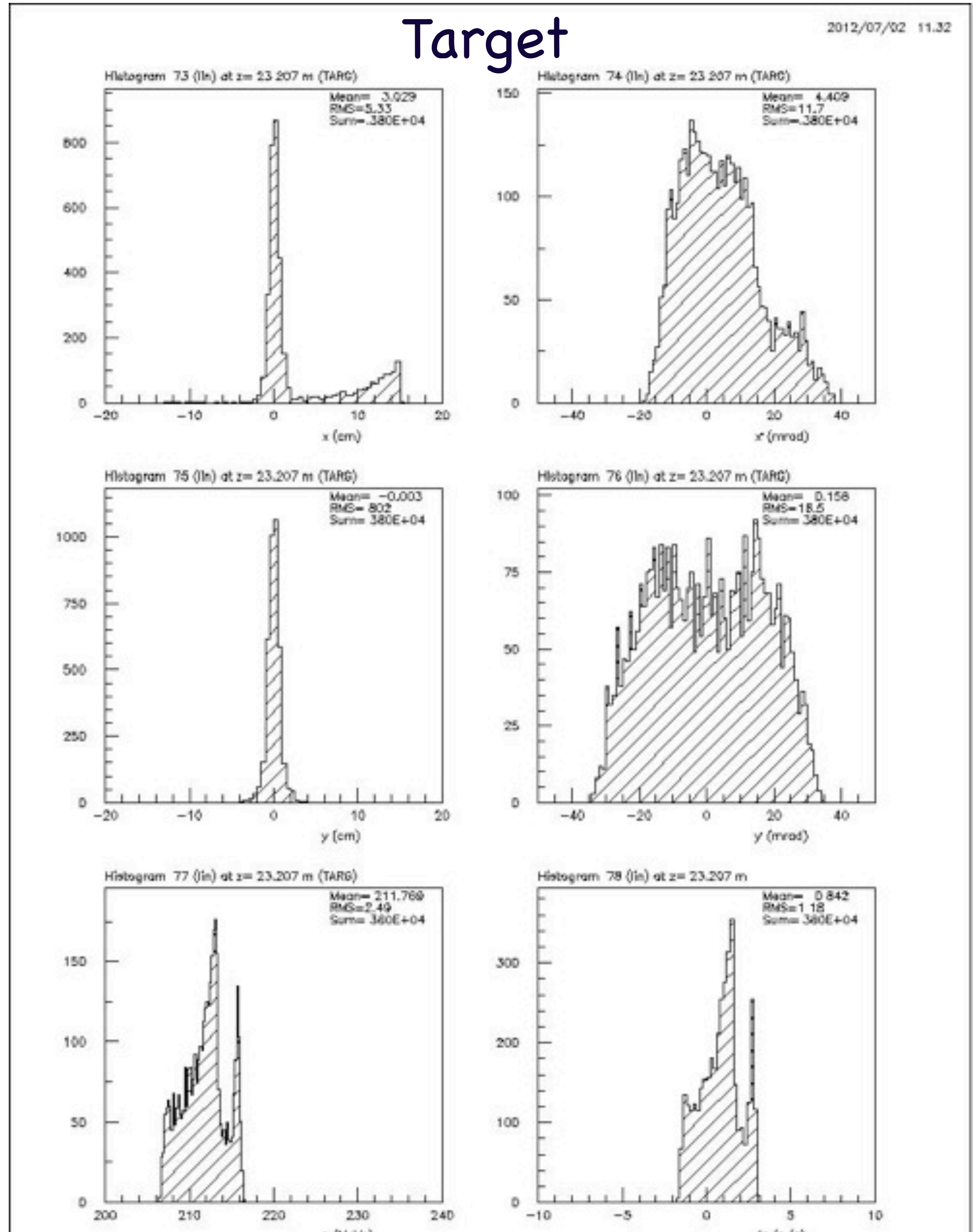




Width at IFP 2-3 cm wider. Side peak in momentum nonphysical?

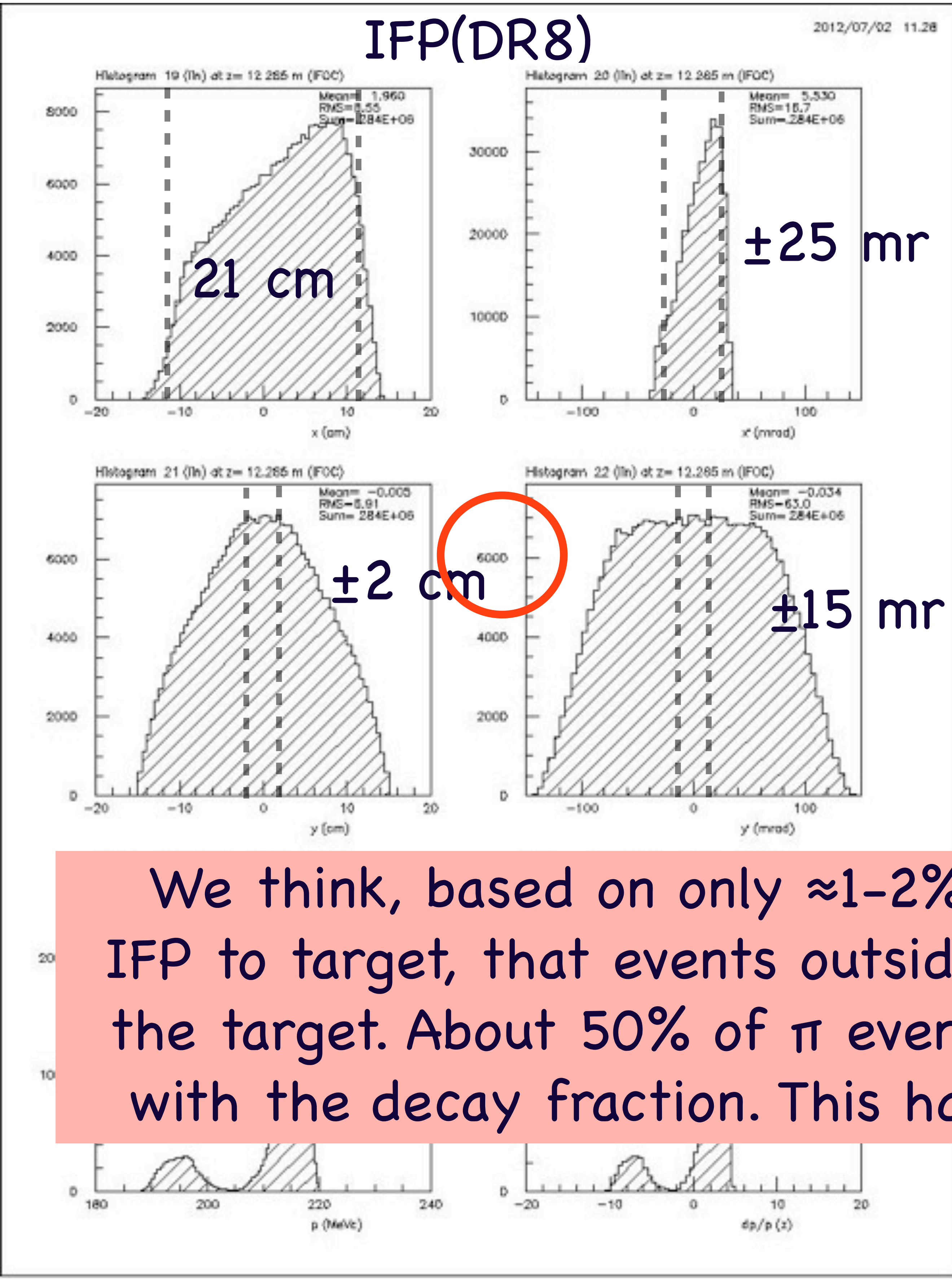
μ Simulation with TURTLE - IFP vs π

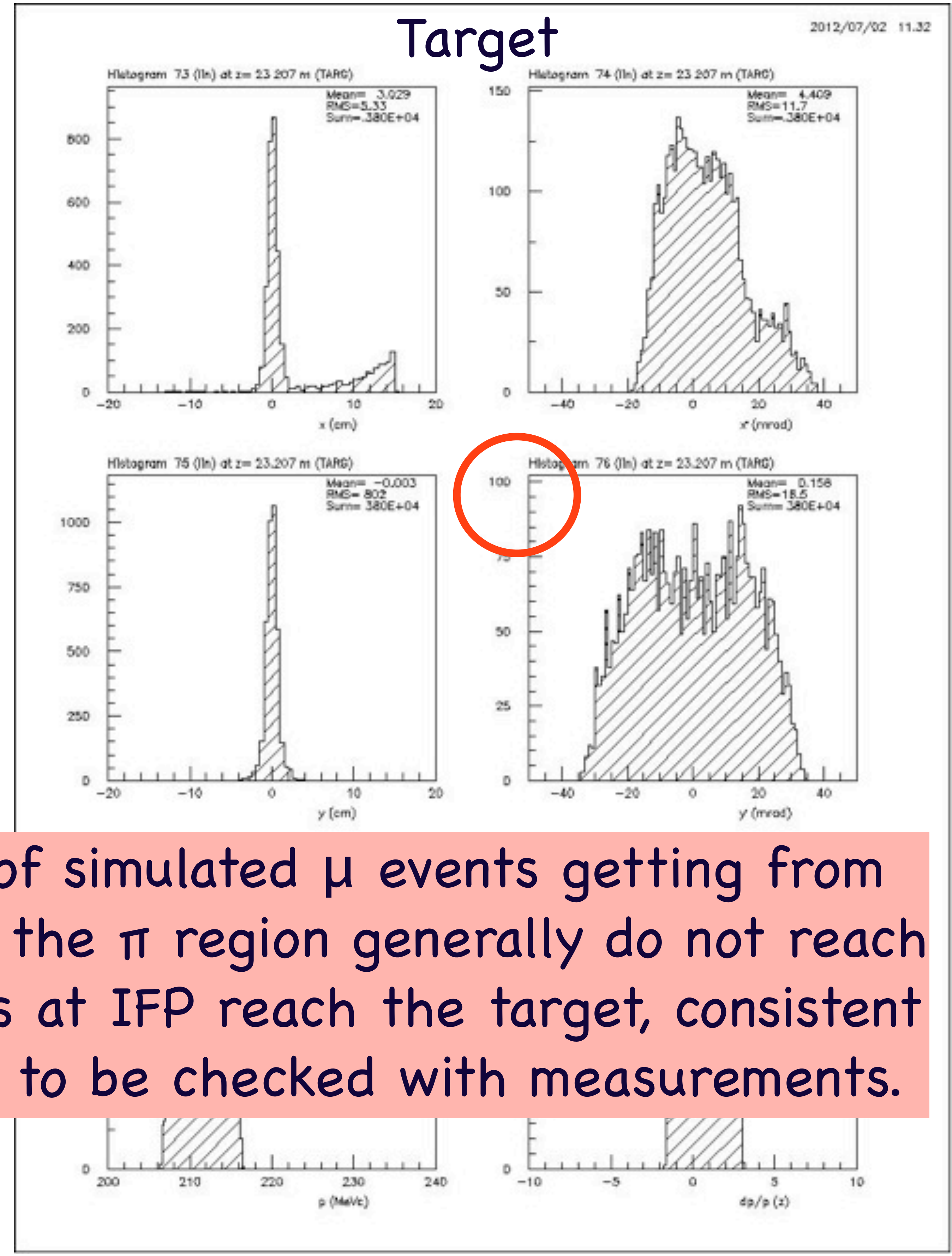




Spot at IFP slightly wider in x. Enormously wider in y!?

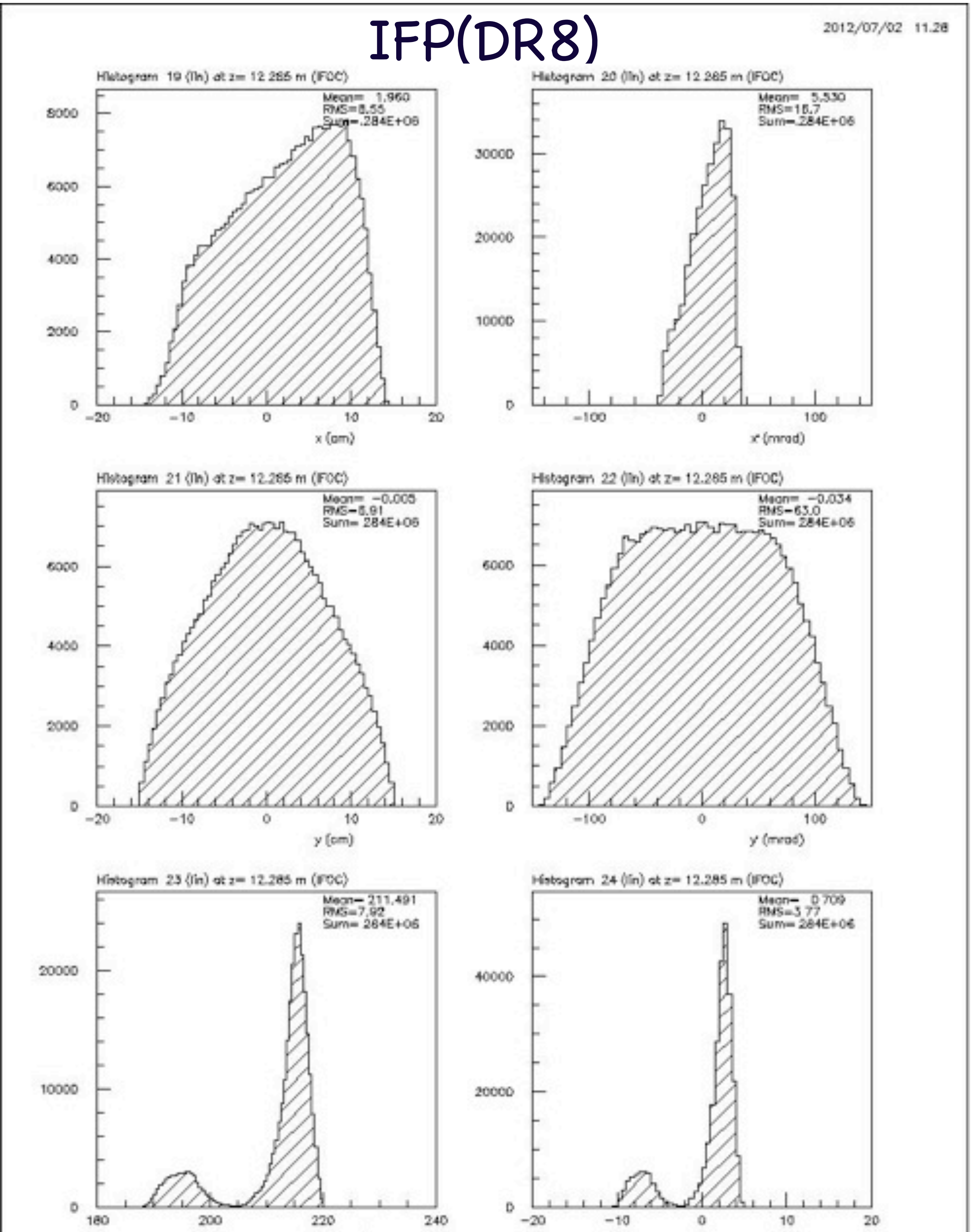
μ Simulation with TURTLE - IFP vs π

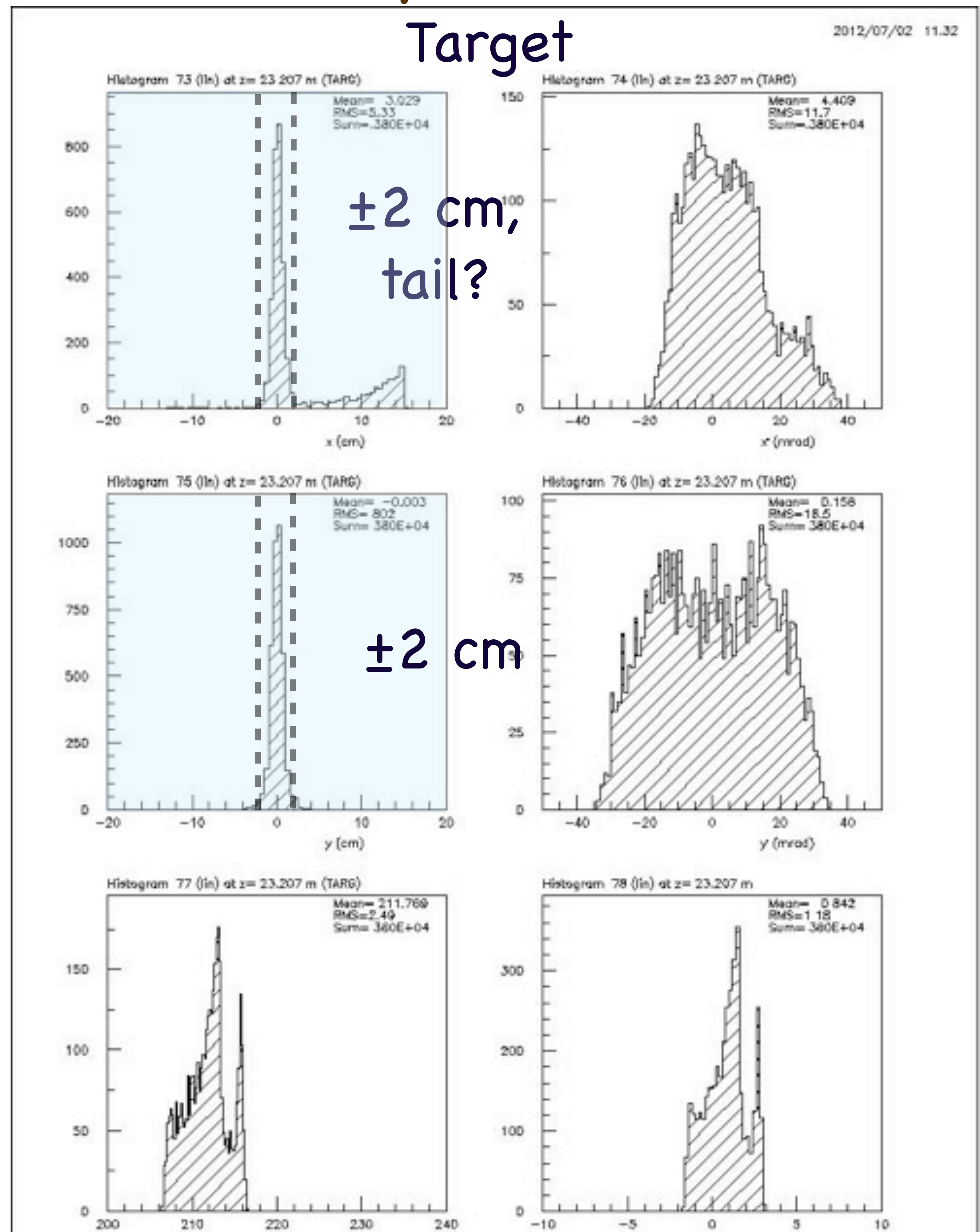




We think, based on only ≈1-2% of simulated μ events getting from IFP to target, that events outside the π region generally do not reach the target. About 50% of π events at IFP reach the target, consistent with the decay fraction. This has to be checked with measurements.

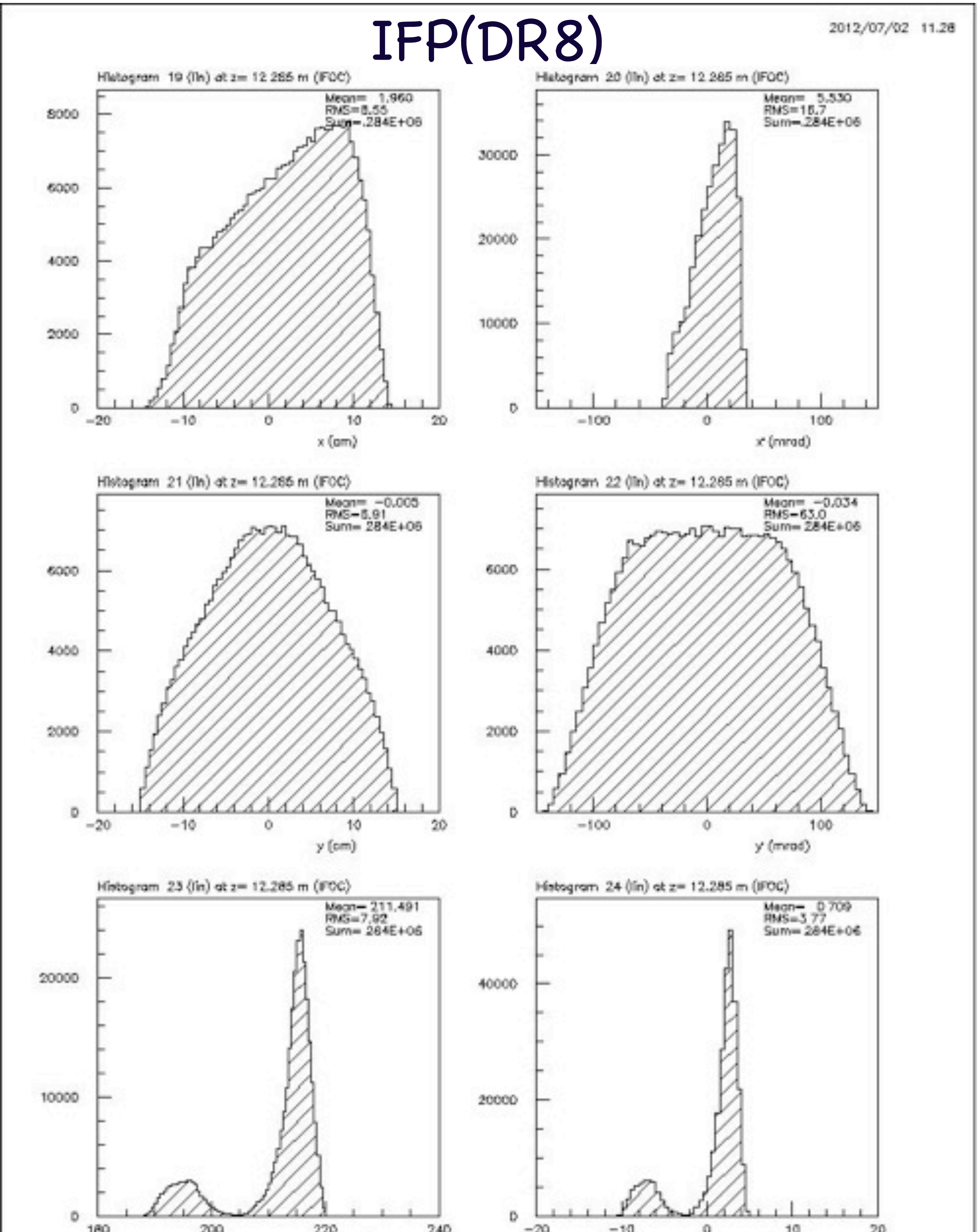
μ Simulation with TURTLE - spot size

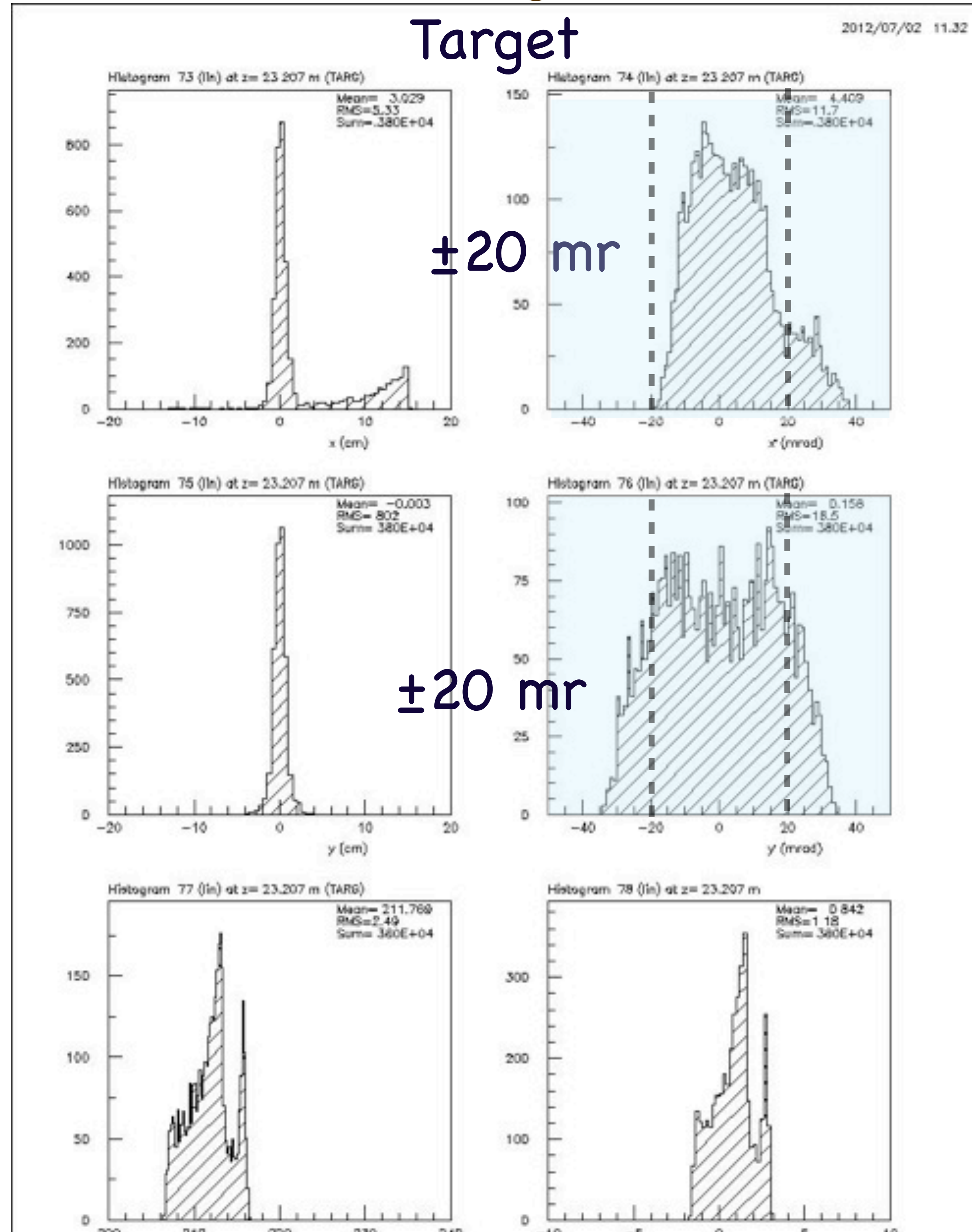




The μ distribution is 2x wider in y. In x, there is a nonphysical tail?

μ Simulation with TURTLE - divergence





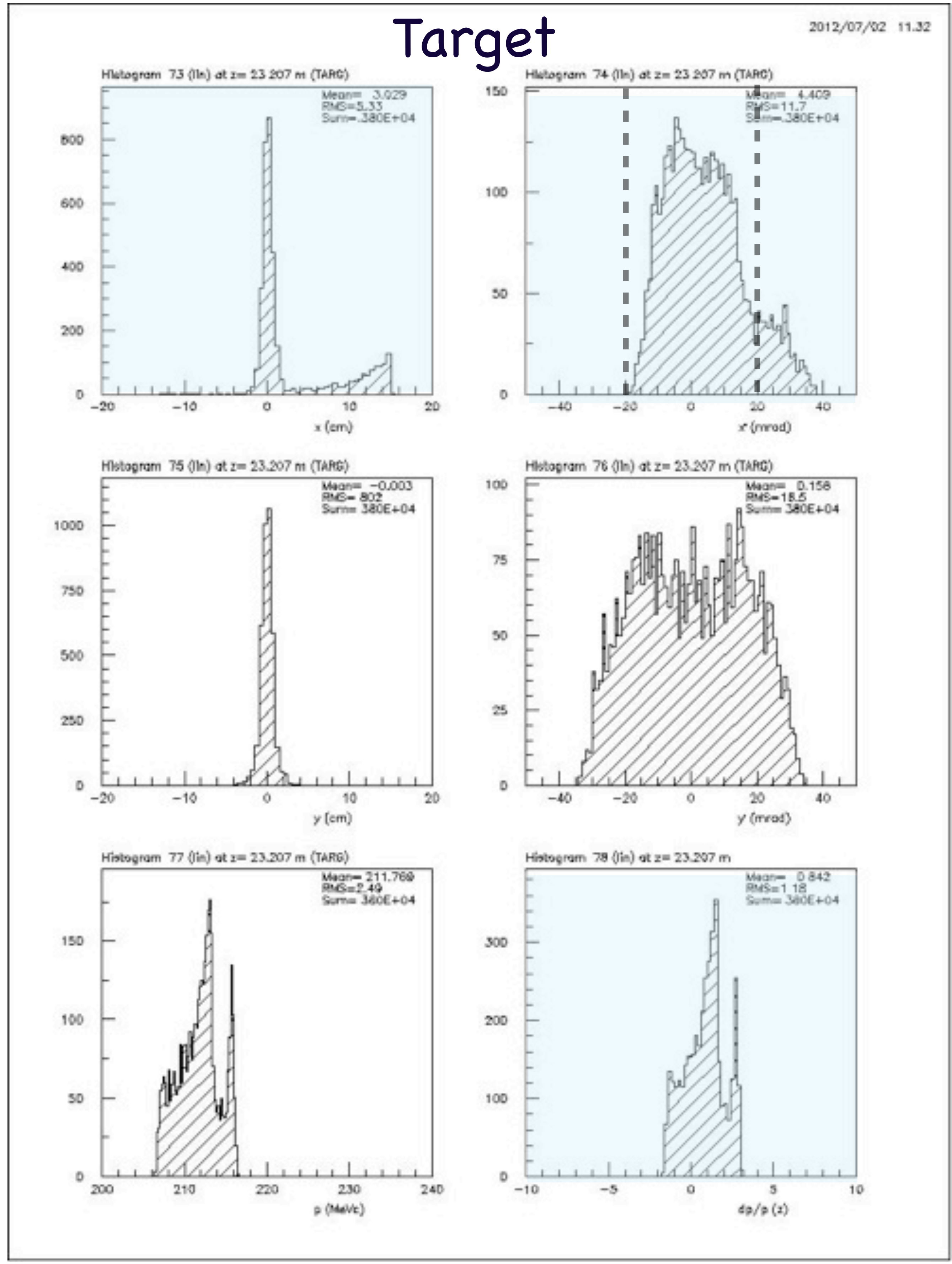
Correlated with the +x tail is a +x' tail. y' is ±30 mr, vs ±20 mr for π's.

μ Simulation with TURTLE - tail

We have suspected that the tails in x, x', and p are correlated.

We believe that a forward angle π decay just before the channel follows trajectories that in practice get eliminated by beam pipes, etc., that are not in the simulation.

The +x tail, if real, should be largely eliminated by shielding, and if not by detector cuts. This will be checked during test runs this fall.



μ Simulation with TURTLE - summary

The muon distributions at the IFP are slightly wider in x, x', but much wider in y, y'. We think that the broader y, y' IFP distributions arise largely from μ's that do not get to the target. We should be able to confirm this with test measurements this fall.

With a nominal dispersion of 7cm/%, and the distribution a few cm wider, we expect that the momentum resolution will be within a few x 0.1%. We should be able to confirm this with test measurements this fall.

The μ target distributions in x, x' are similar to the π distributions, except for tails that we think are non-physical. The μ target distributions in y, y' are 1.5-2 x wider than the π distributions, which largely does not matter. We should be able to confirm this with test measurements this fall.

The tests are important to ensure we design detectors and the cryotarget to be the right sizes.