Update of the frictional cooling studies at Nevis Labs/Columbia University

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for the Nevis group:
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and the Columbia summer students
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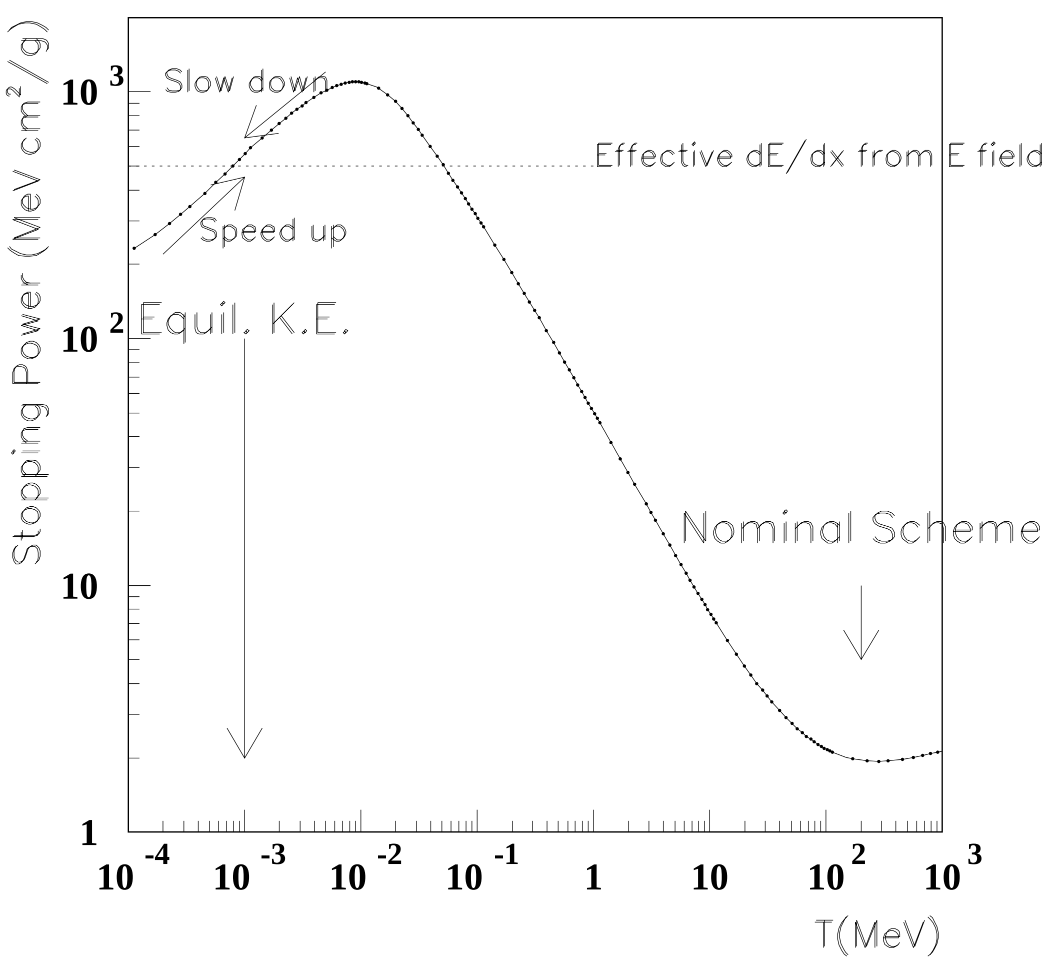
- Frictional cooling
- Simulation and optimization
  - Target and magnet
  - Phase rotation
  - Cooling
- The experimental set-up

Frictional cooling: The idea

Helium



cool μ's where $\frac{dE}{dx} \propto \beta$

and compensate the energy loss by an E–field: **cooling**

Below the ionization peak dE/dx is dominated by

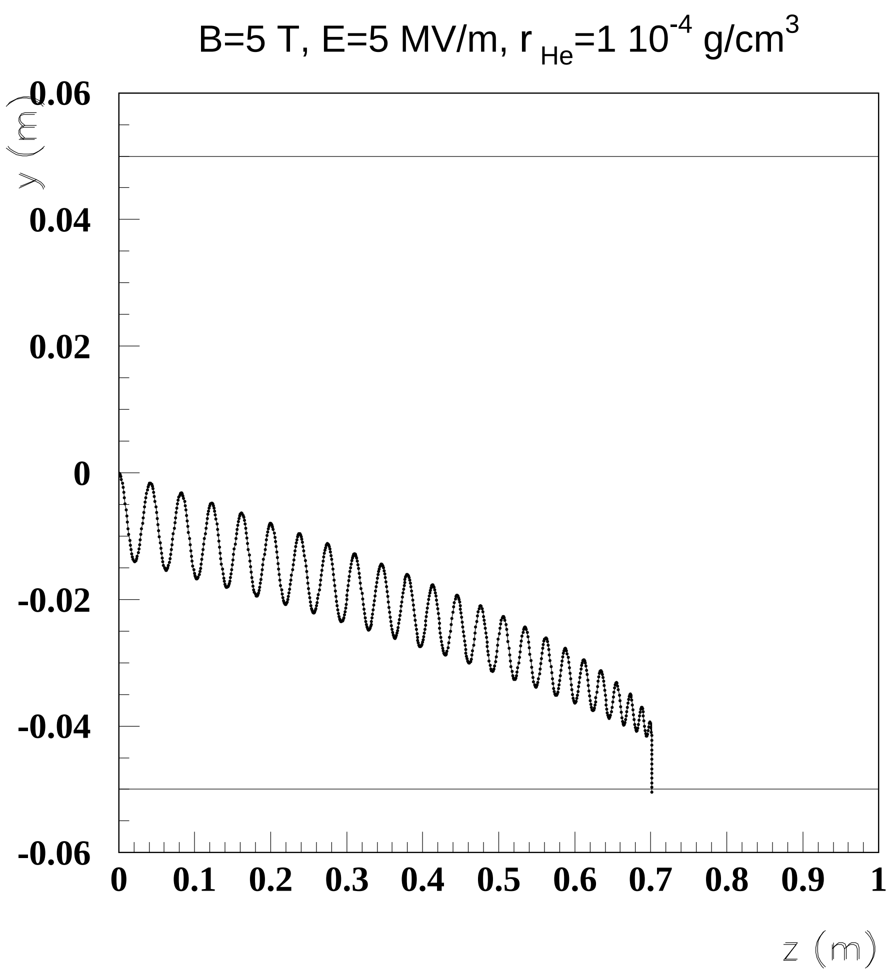
- nuclear recoil
- excitation
- charge exchange (muonium) for μ^+ and capture for μ^-

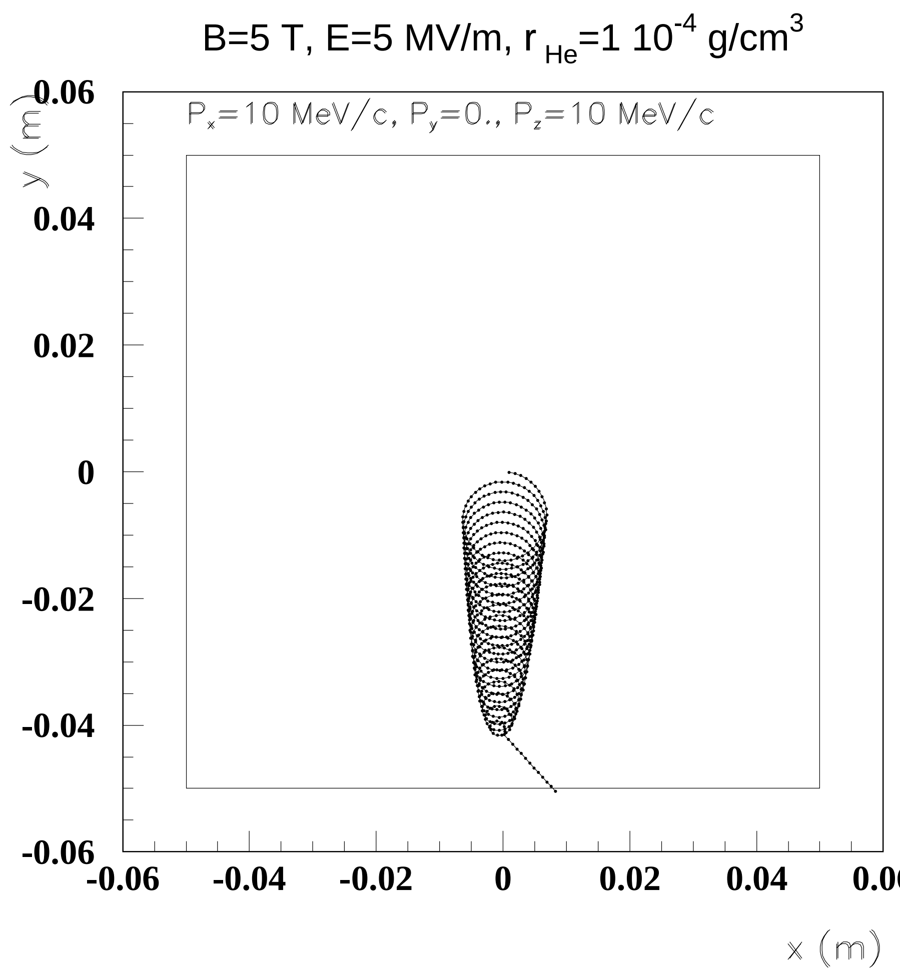
Issues/ consequences/ comments:

- large dE/dx $\Rightarrow$ work with a gas
- with $\vec{E} \parallel \vec{B}$ we never get below the peak $\Rightarrow$ apply $\vec{E} \perp \vec{B}$

work with very low energy muons in Helium at low density

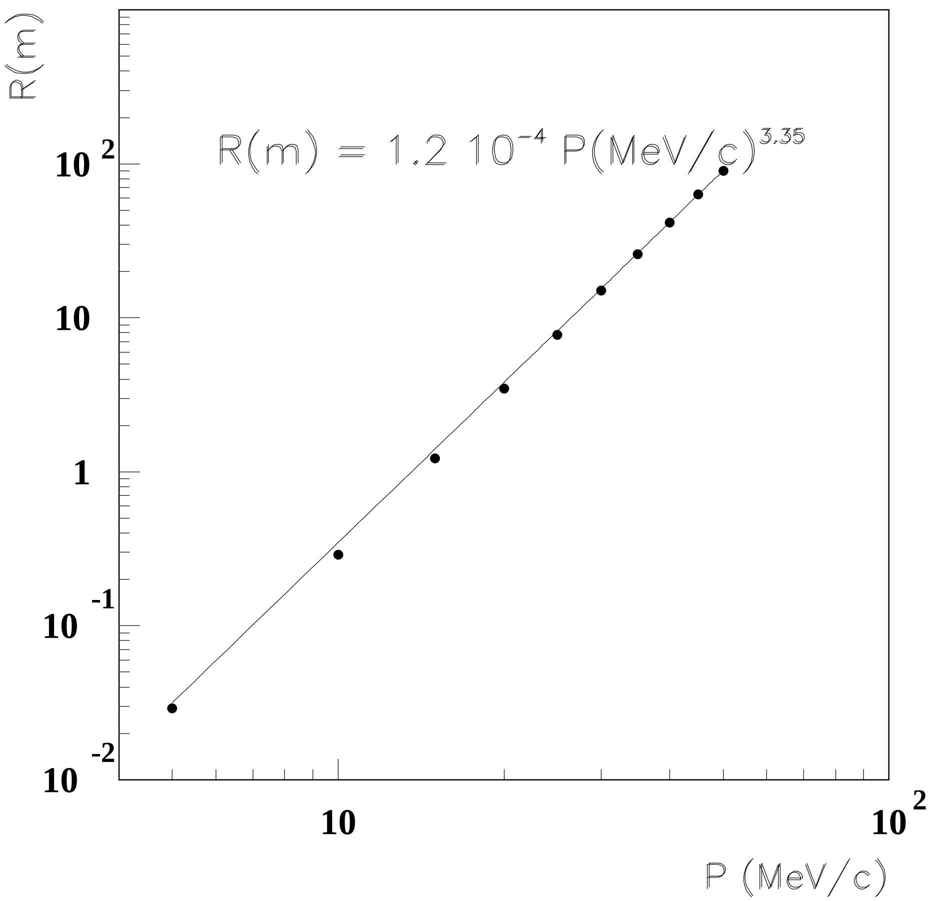
Frictional cooling: particle trajectory

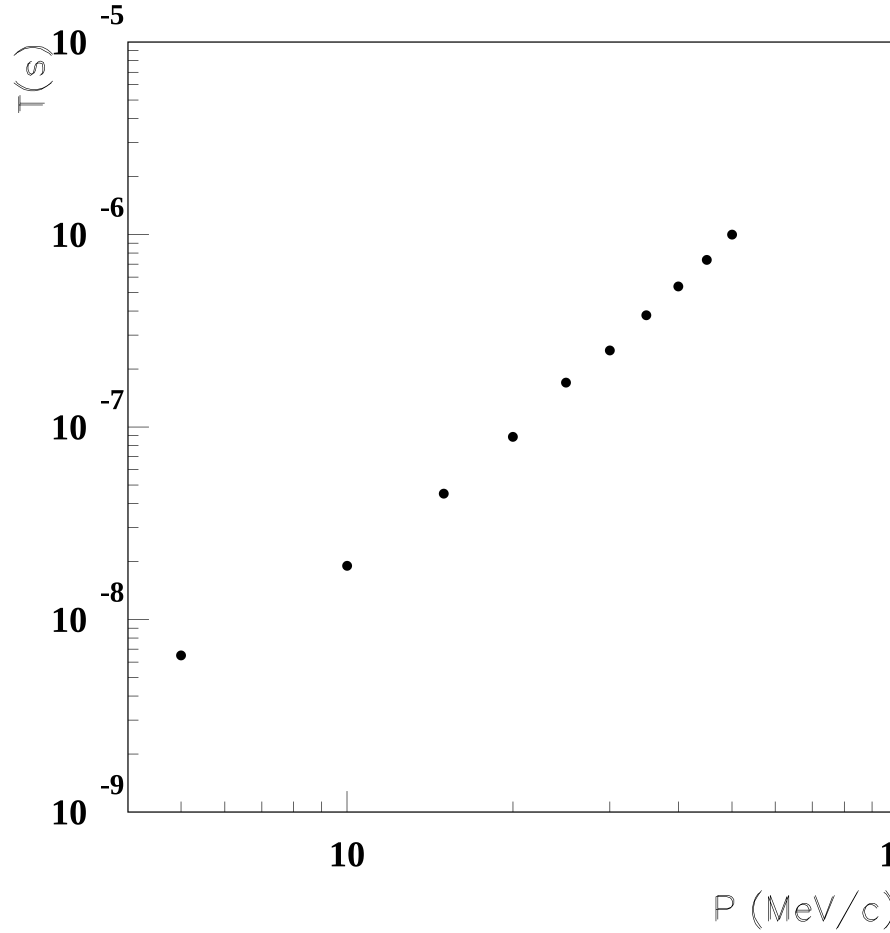




calculated with continuous energy loss

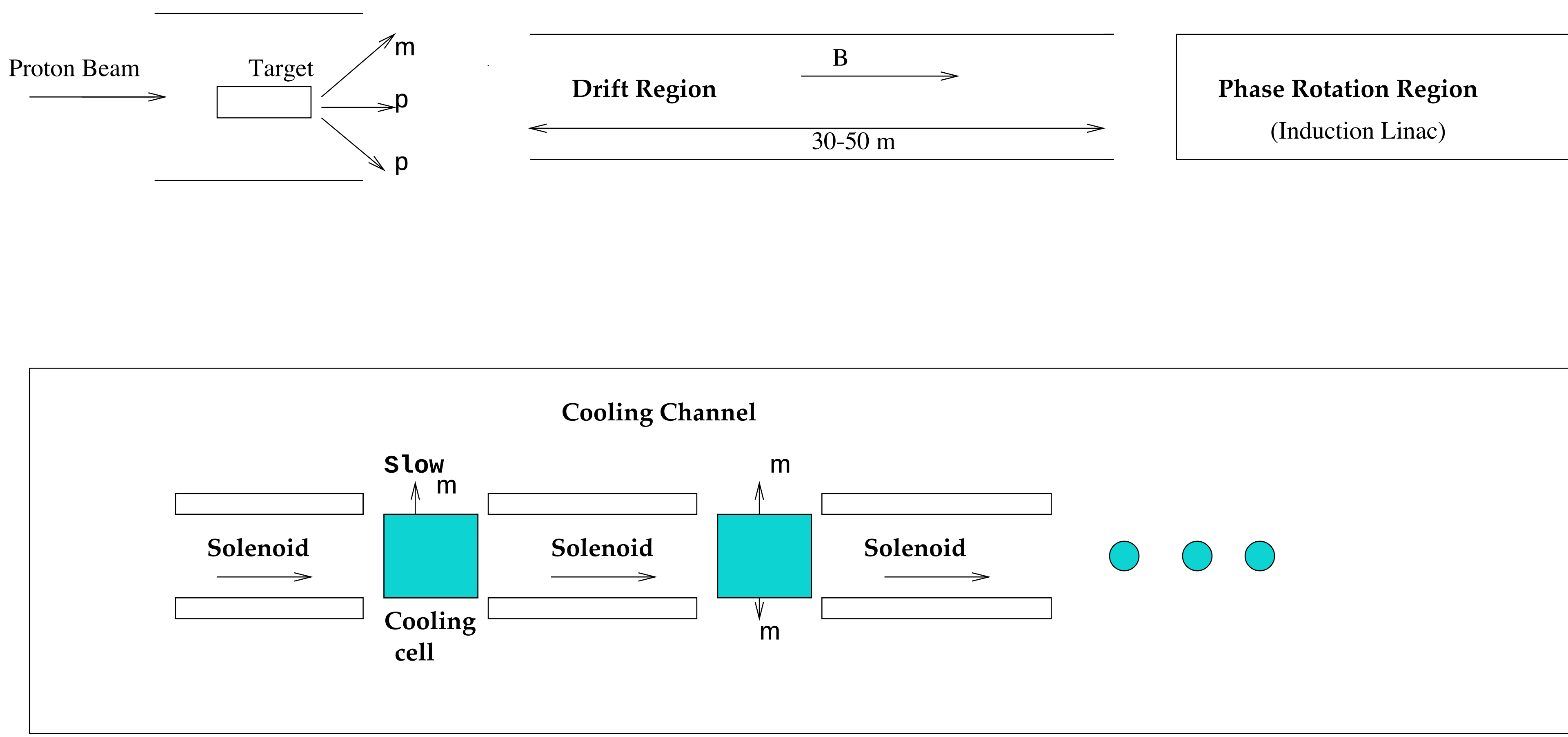
Frictional cooling: stop the μ





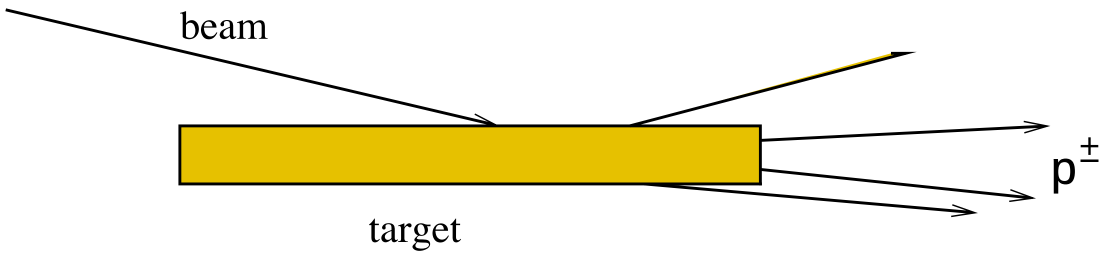
$\Rightarrow$ need low initial muon momenta

Frictional cooling scheme

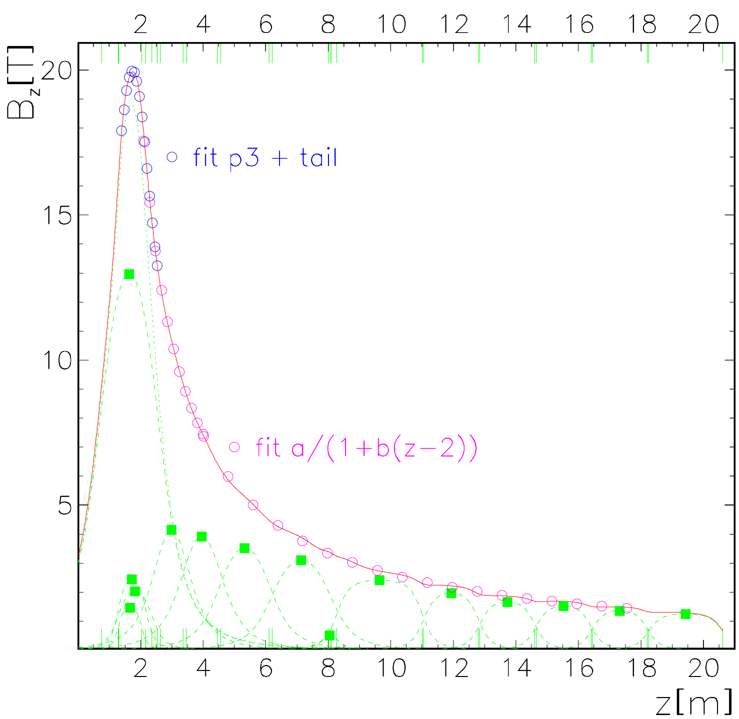


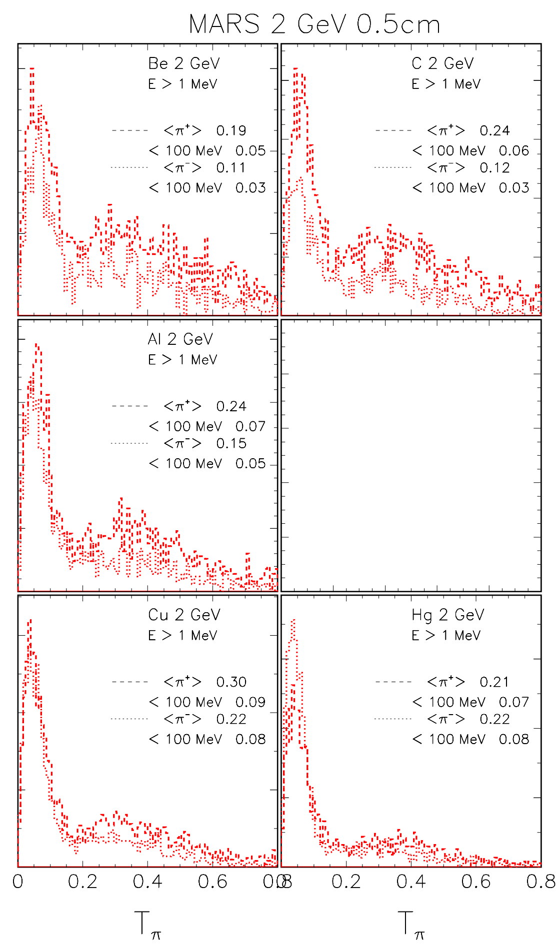
Optimize: target, phase rotation and cooling channel (in a toroid)

Target system: study II



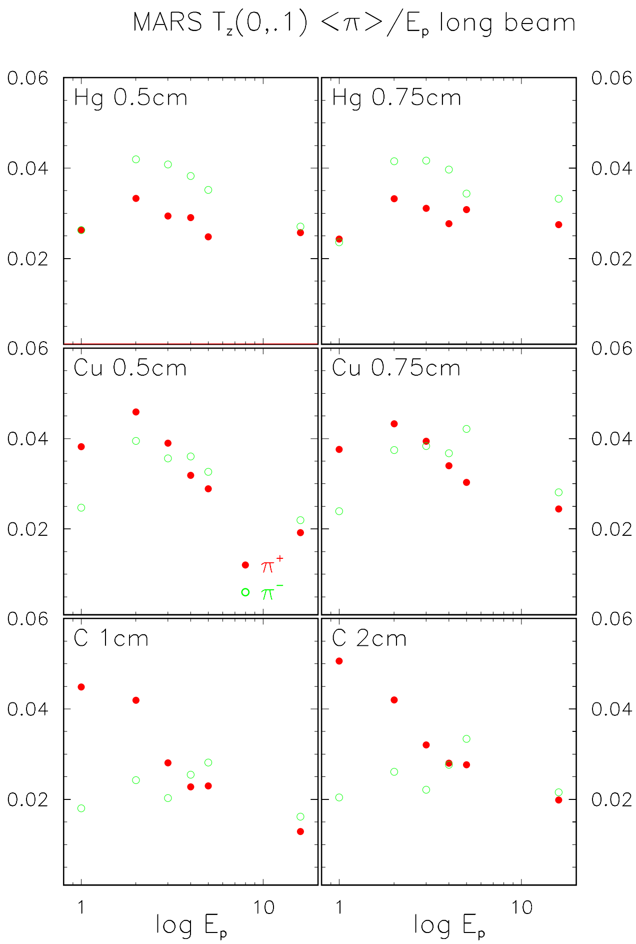
Longitudinal (StudyII) scheme

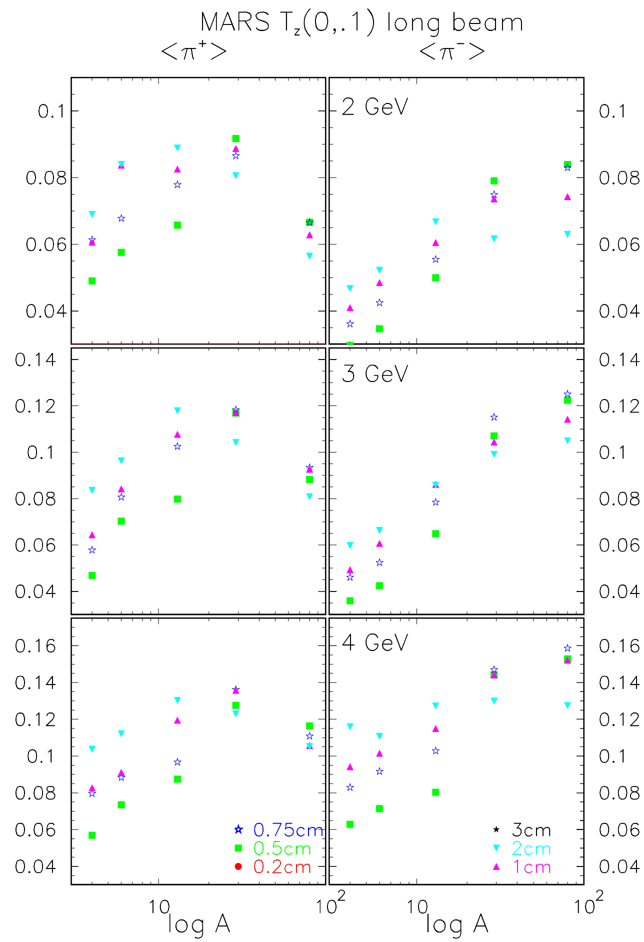


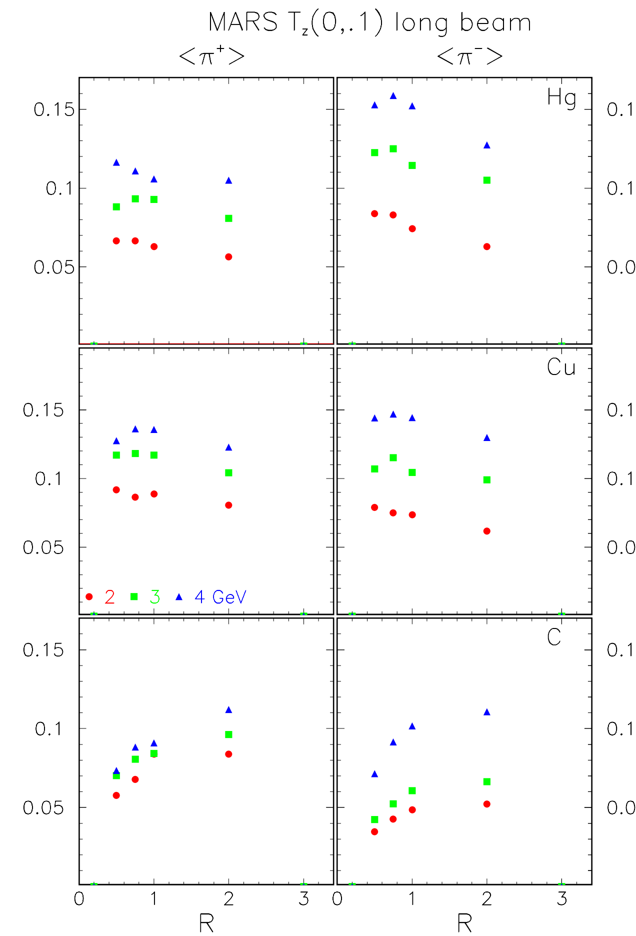


Target (study II): MARS scan

Optimize E_p, target A, radius, length

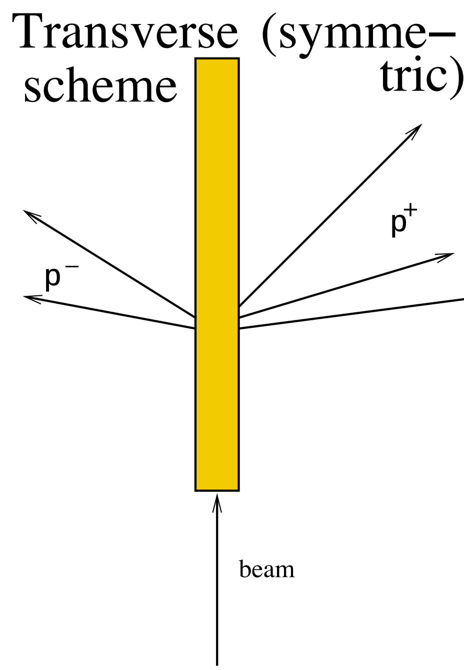


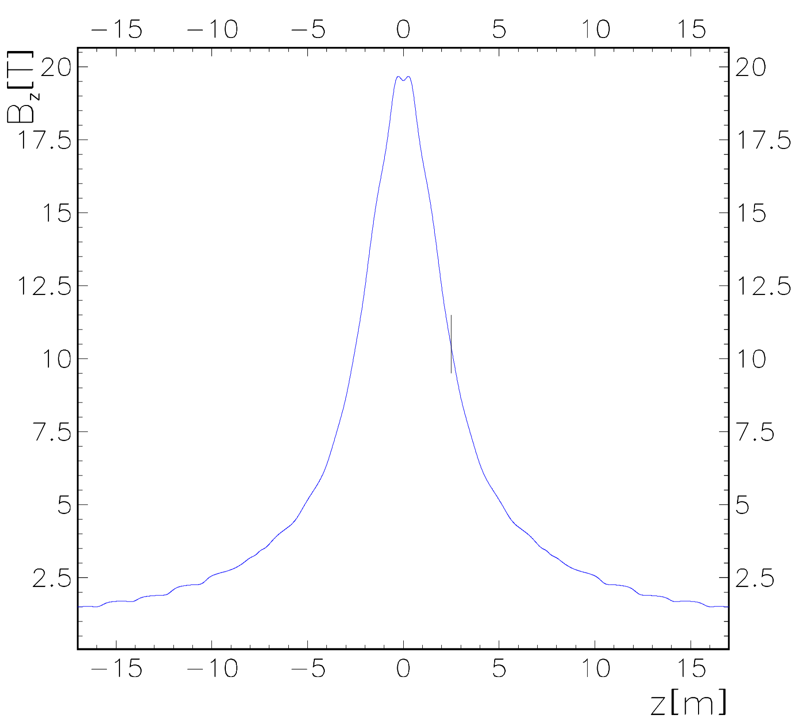


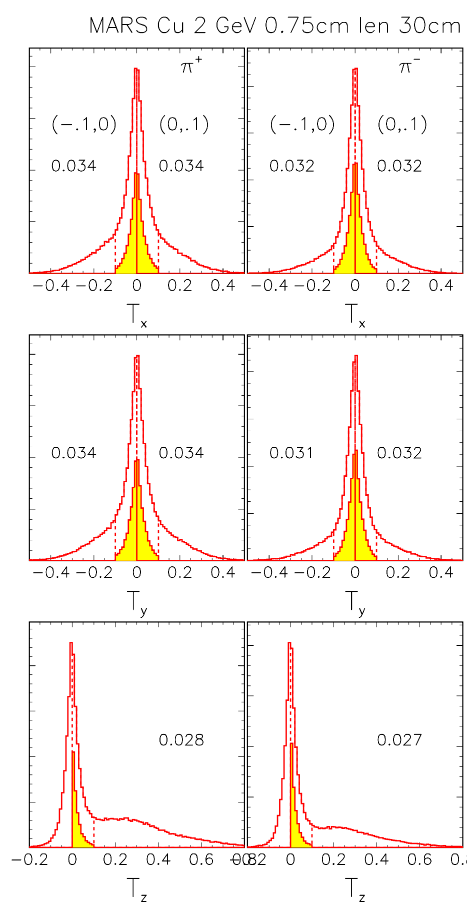


Target system: transverse target

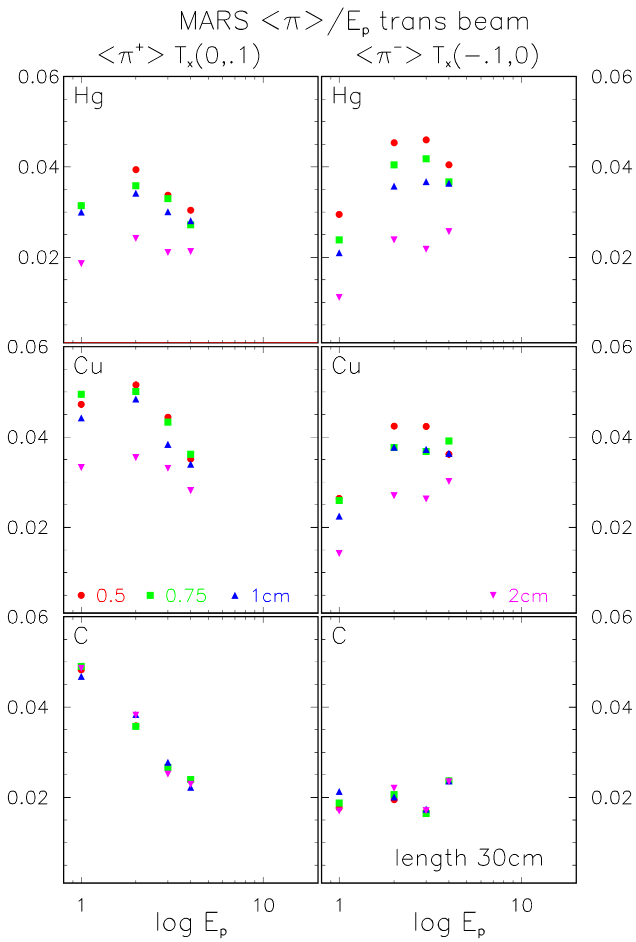
- cool μ^+ and μ^- in the same time
- exploit the non-leading behaviour of the low energy π
- calculated a new, symmetric magnet with a gap

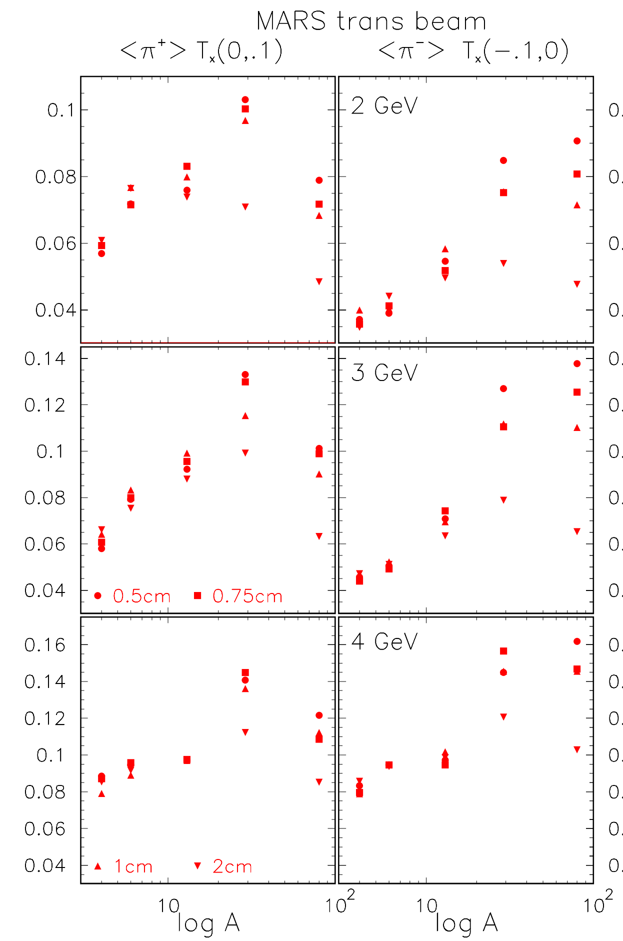


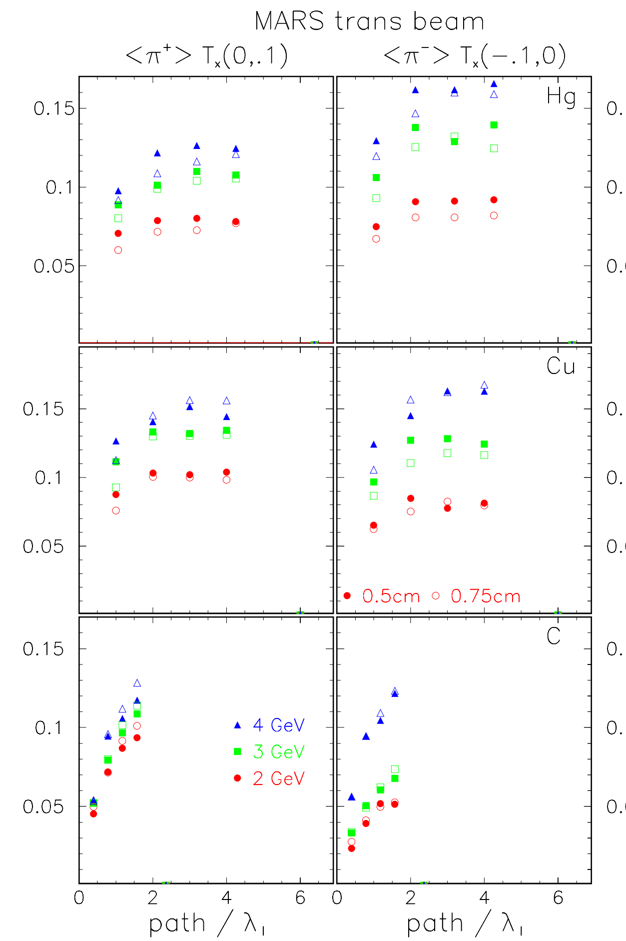




Target (transverse): MARS scan



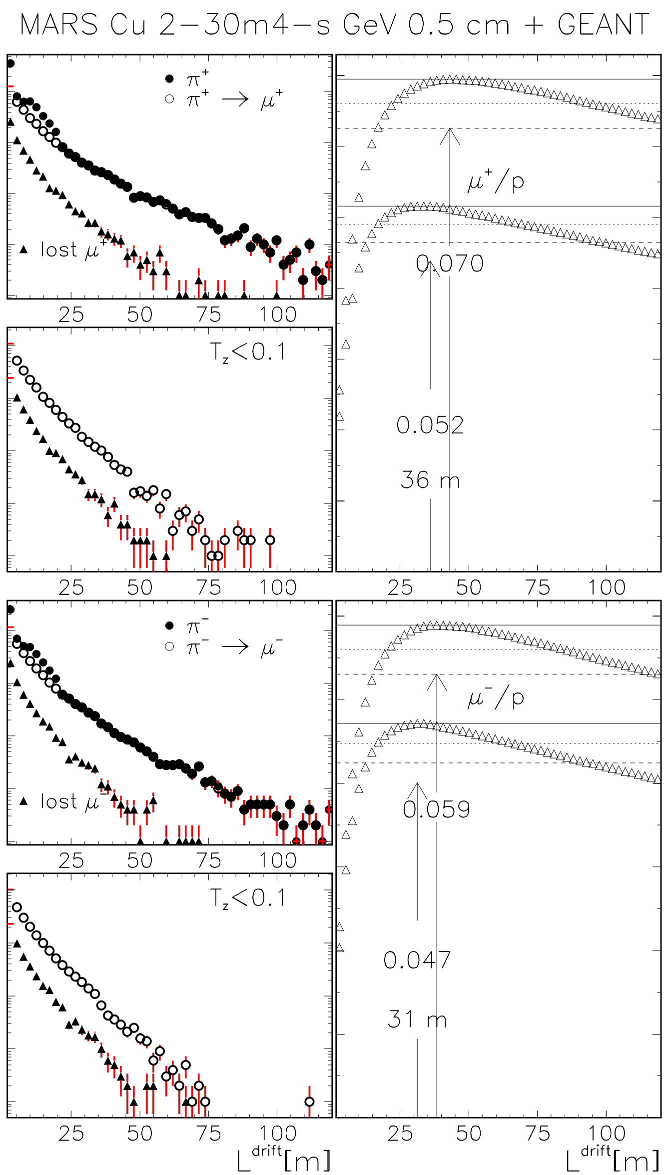


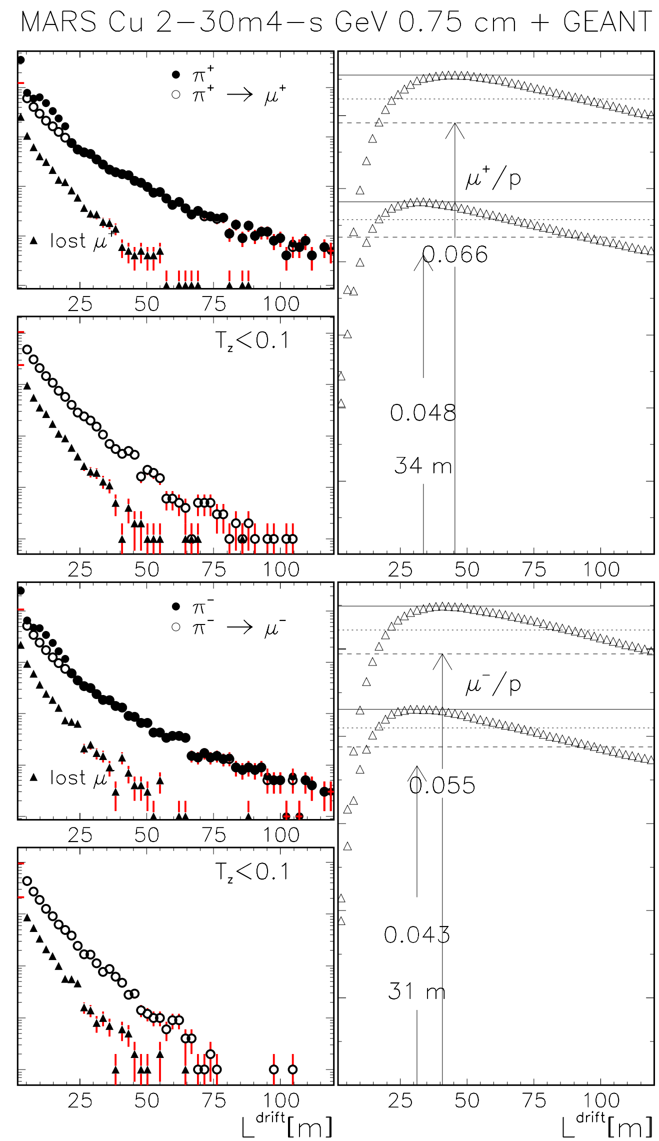


further GEANT investigation of best configuration

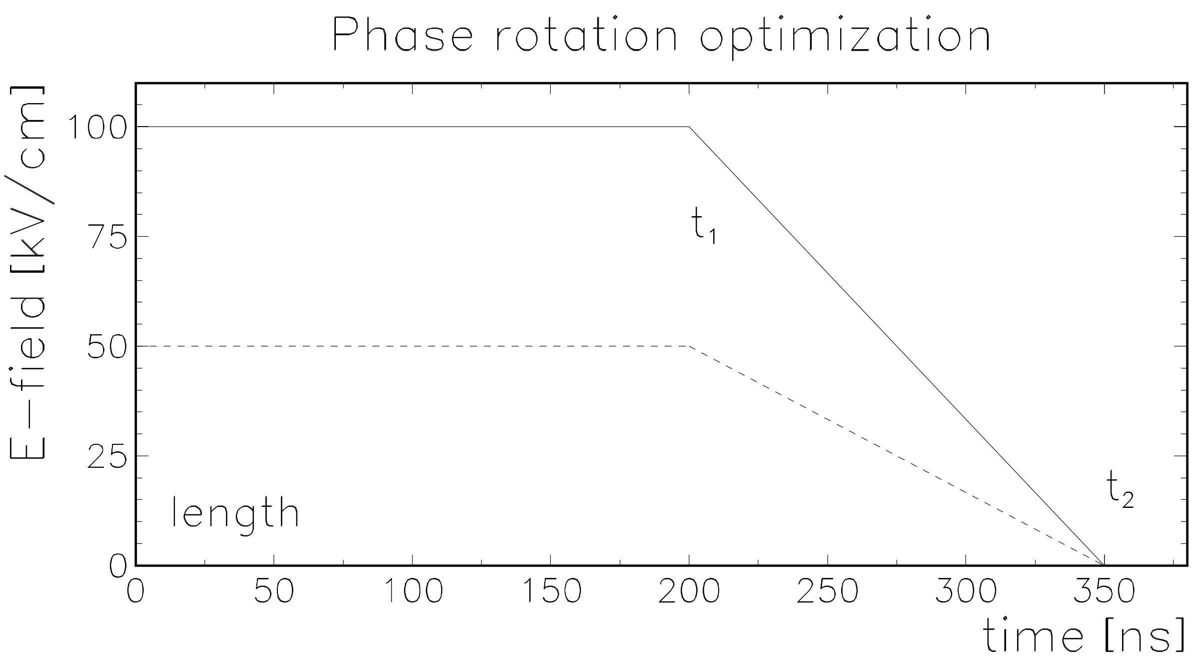
Cu, E_p = 2 GeV, target 0.5 or 0.75 cm thick

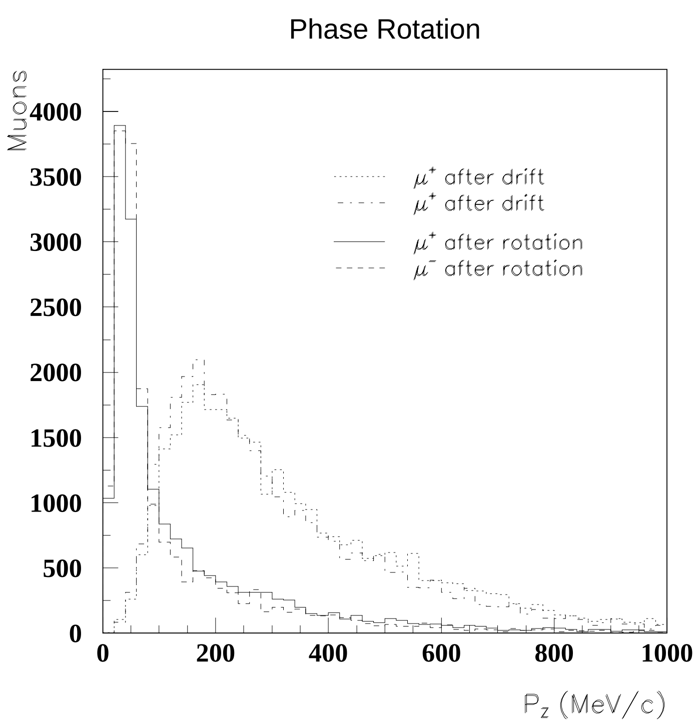
Target (transverse): GEANT

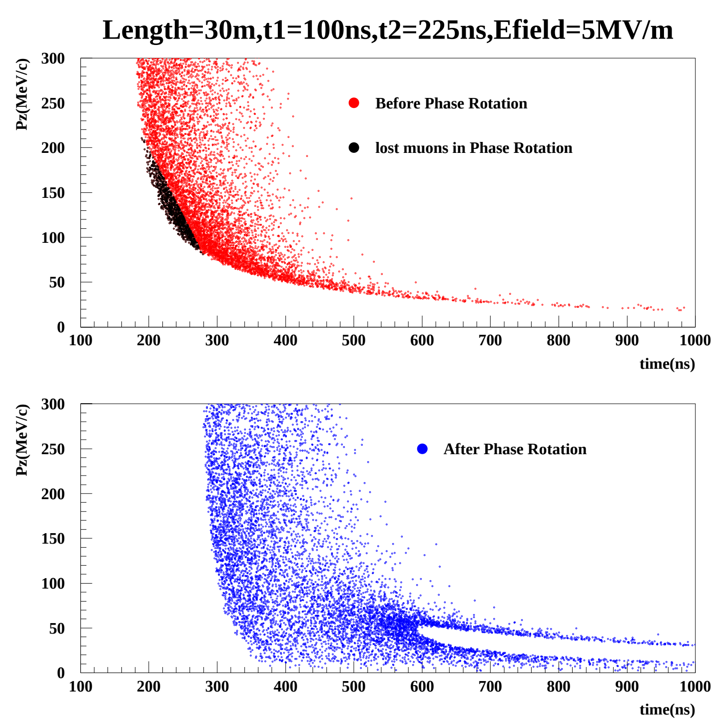




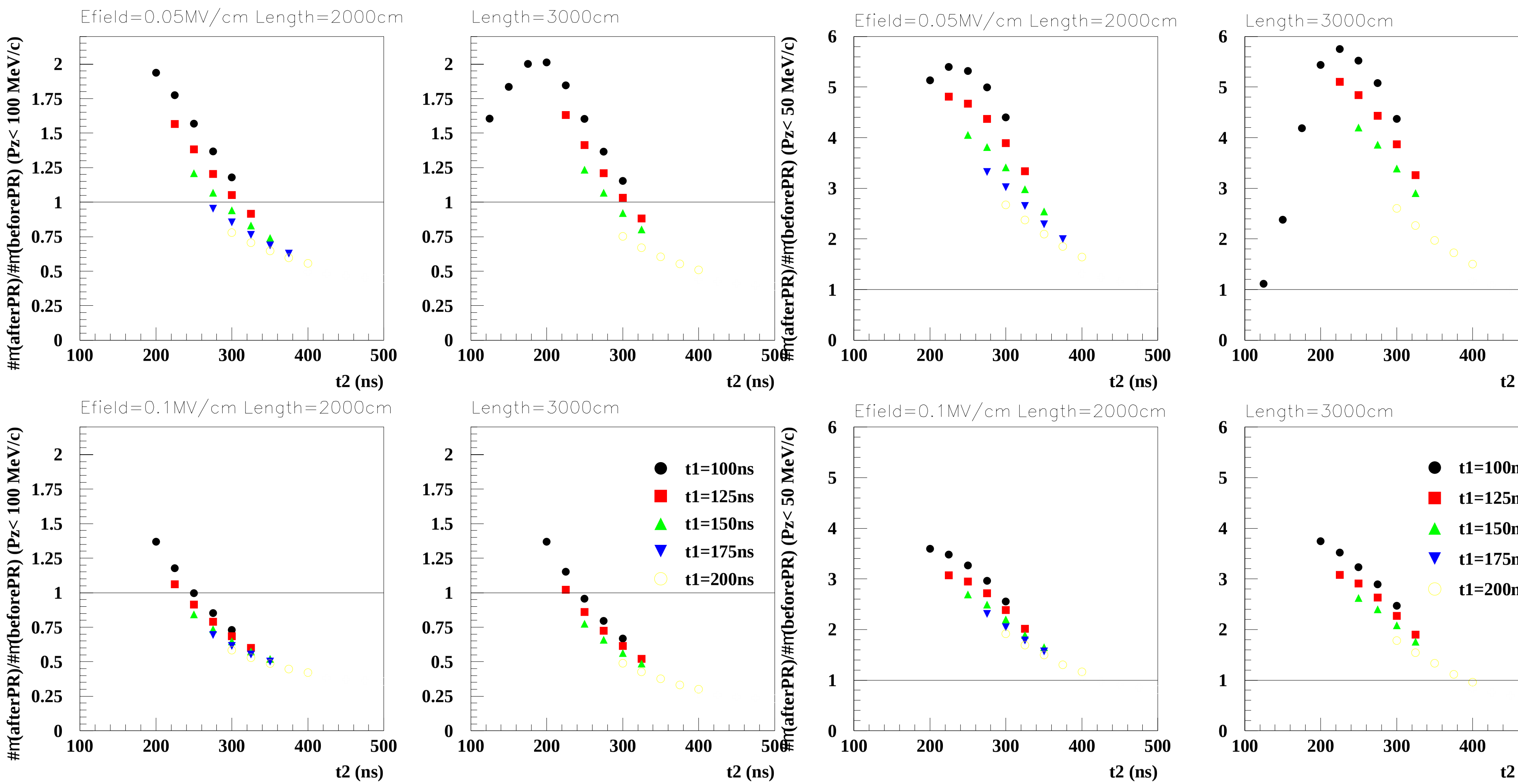
Phase rotation: scheme







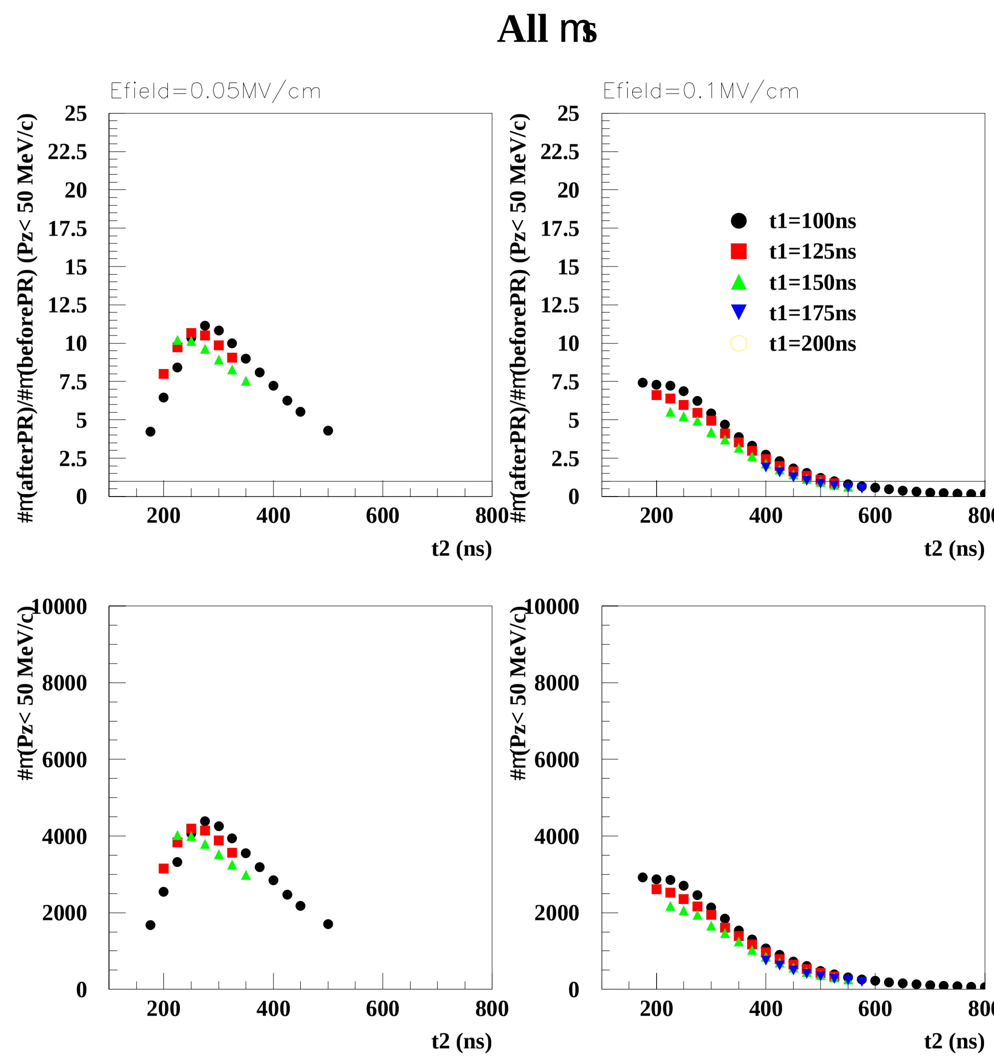
Phase rotation: results



$p_z < 100$ MeV $p_z < 50$ MeV

Phase rotation: RING results

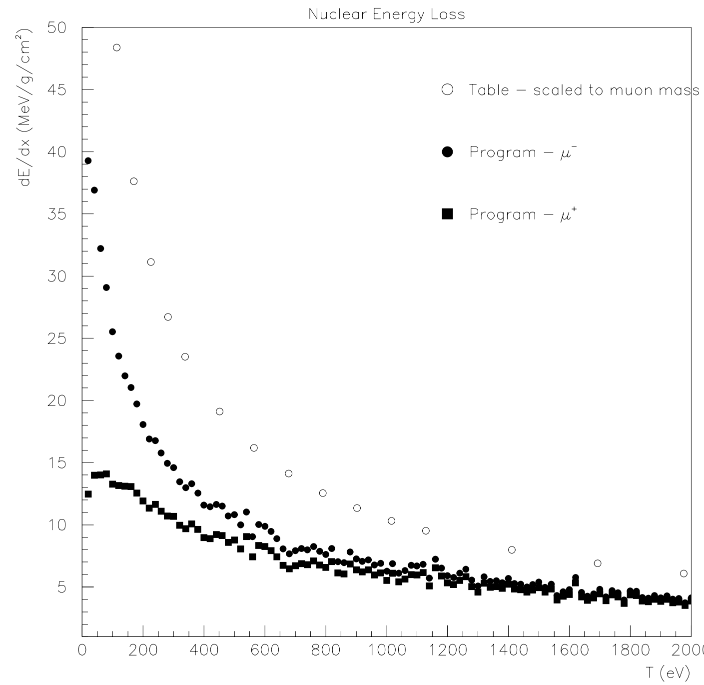
- Include phase rotation inside cooling channel $|p_z| < 50$ MeV

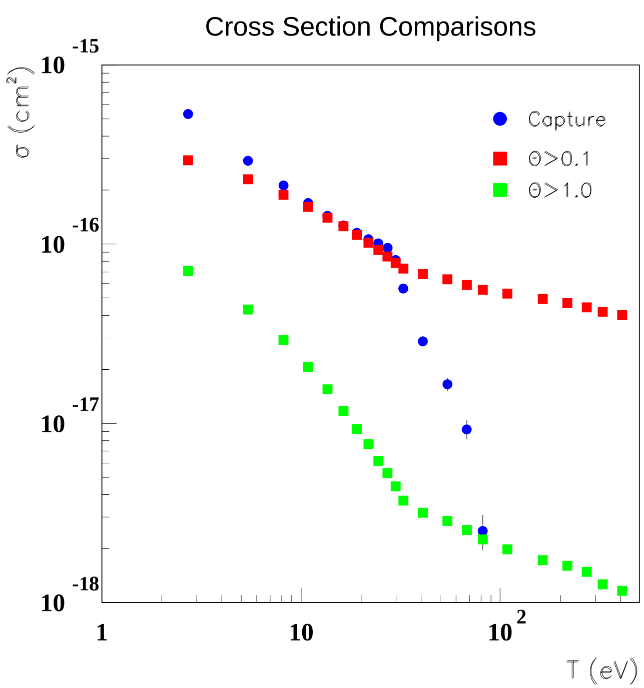


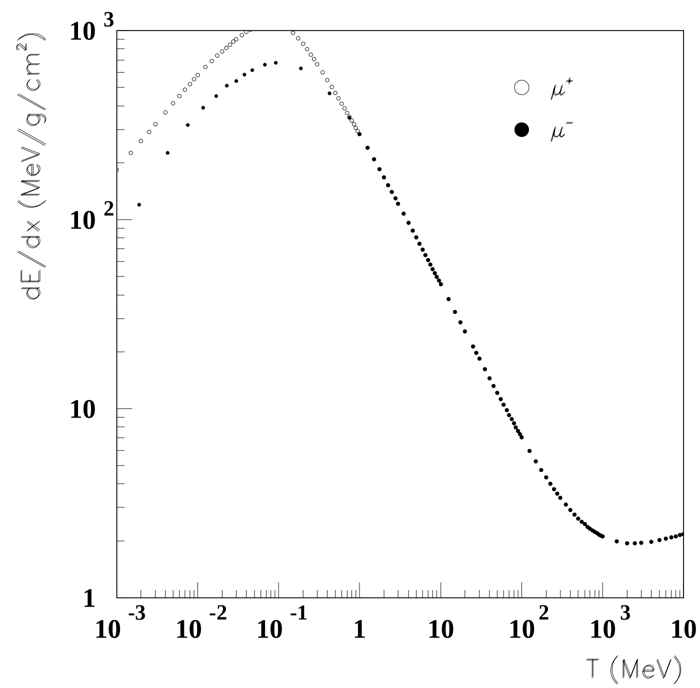
$|p_z| < 50$ MeV

Cooling: realistic simulation

- Electronic energy loss continuous (NIST table)
- Nuclear energy loss (multiple scattering) discrete
- Include Barkas effect and μ^- capture
- Incorporate scattering cross section into the cooling program: $T_\mu > 2$ keV Born approx, else classical $\theta(b)$ $\rightarrow d\sigma/d\theta \rightarrow$ mean free path







Frictional cooling: particle trajectory

He w density 1. 10^{-4} gm/cm^3

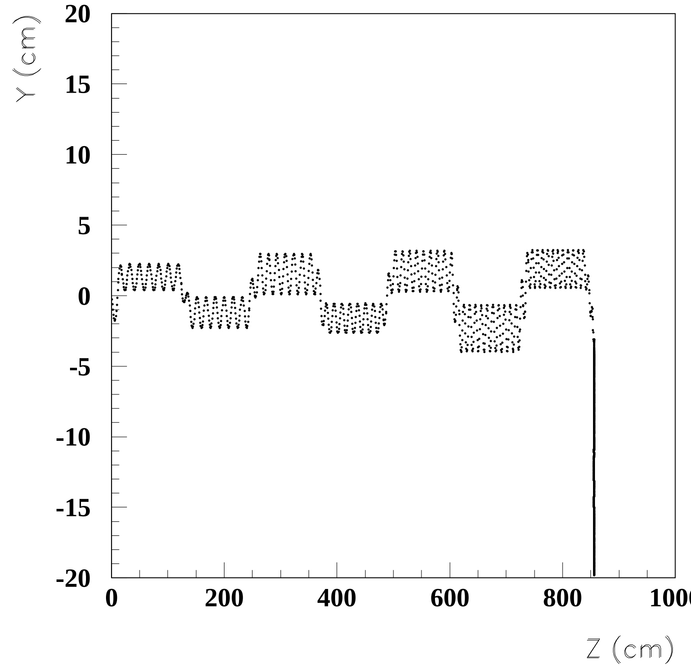
B = 5T uniform for now

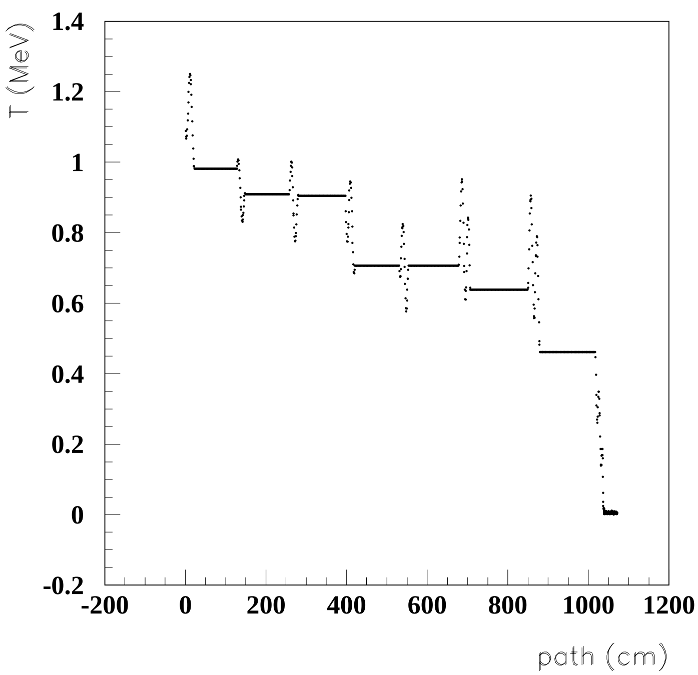
E = 8 MV/m (increased from 5 to avoid μ^- capture)

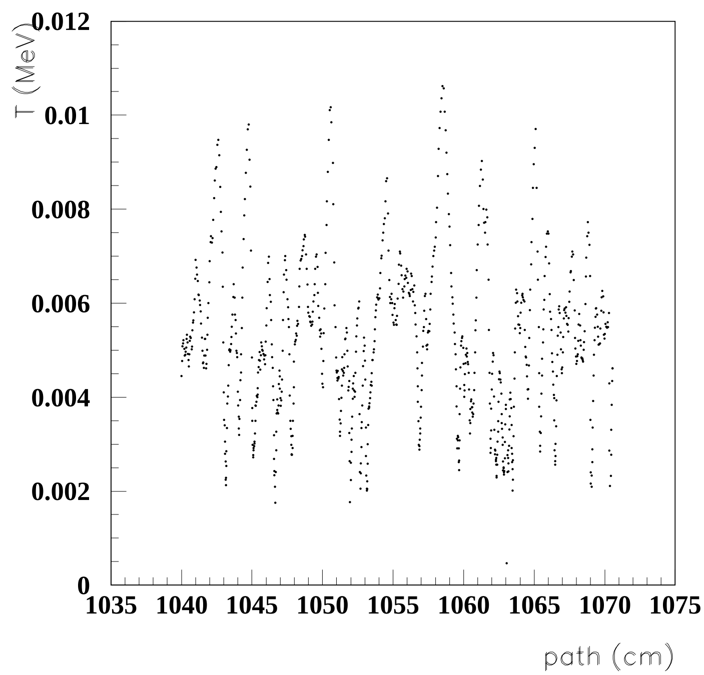
cooling cell - 42x42x20 cm^3

the cells are placed between 1m solenoids, with radius 42 cm

No E field in solenoids

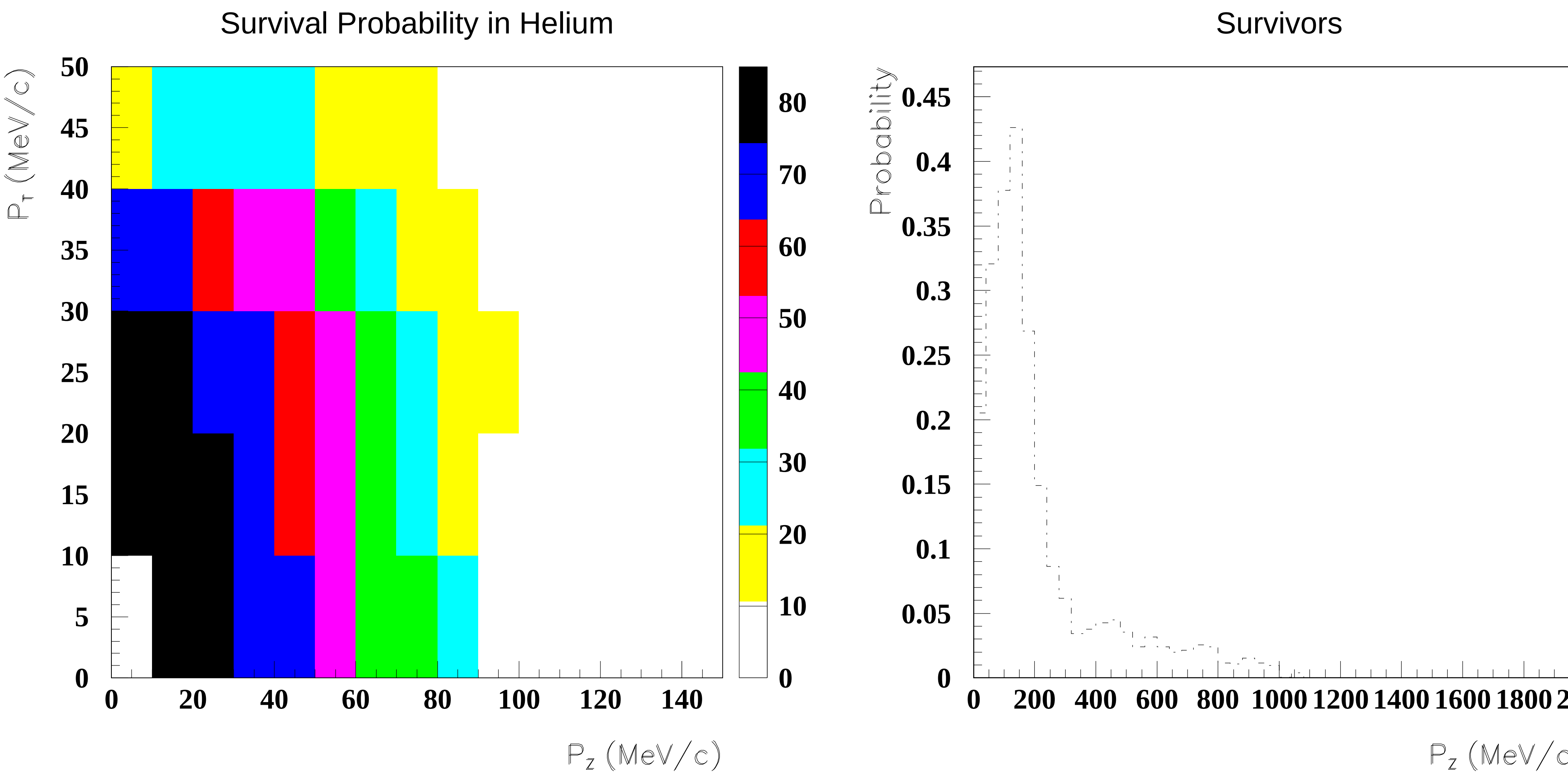






calculated with realistic energy loss

Frictional cooling: survival probability



Frictional cooling: what did we achieve

First and preliminary result (based on ≈ 80 μ's with $p_{x,y,z} < 50$ MeV)

	μ^+		μ^-	
After	cooling	drift	cooling	drift
μ/proton	0.005	0.057†	0.004	0.058†
rms(p_x) (MeV)	0.07	9.4	0.17	7.7
rms(p_y) (MeV)	0.08	10.3	0.23	9.9
rms(p_z) (MeV)	0.07	53	0.10	64
rms(tran) (cm^2)	40×60	25	40×60	25
rms(long) (cm)	250	1200	190	930
phase space reduction*	$6\ 10^5$		$6\ 10^4$	

† for $T_z < 100$ MeV

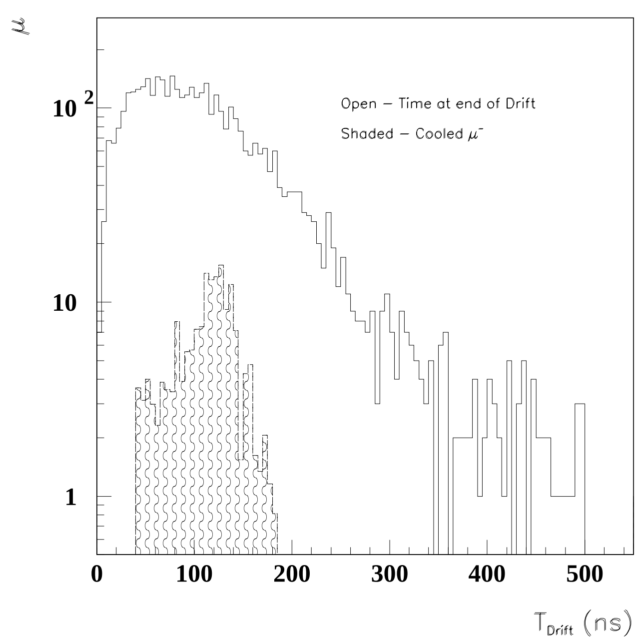
* phase space factor for the μ's which are cooled

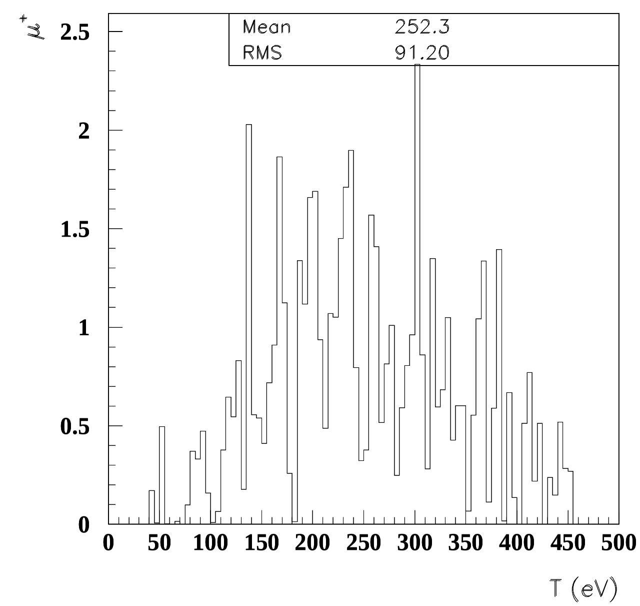
We continue to work on:

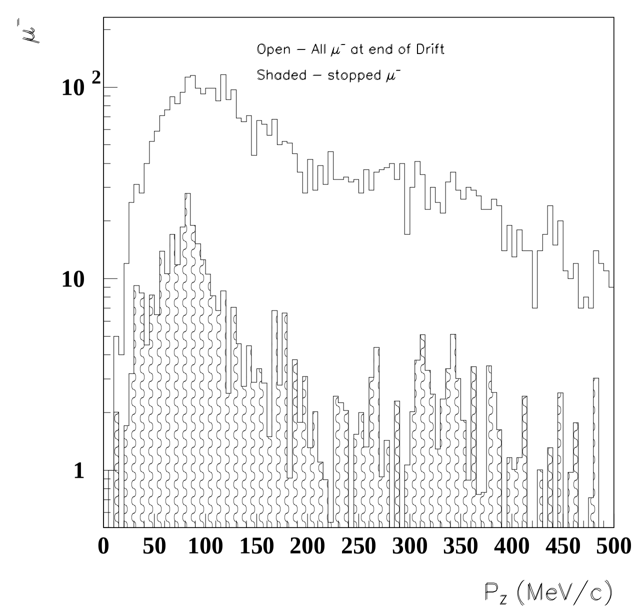
- finalizing MARS and GEANT studies
- the phase rotation optimization
- incorporate fringe fields into cooling
- matching B-fields between target (drift) region, phase rotation and cooling ring
- extraction of μ from the cooling ring, and first re-acceleration

Cooling: RING simulation

- 1m long solenoid
- 0.2m long cooling cell
- 60m ring







Frictional cooling: what did we achieve

First and preliminary RING result

(based on $\approx$ 10000 μ's with $40 < T_{arrival} < 200$ ns)

	μ^+ ($t_2 = 225$ns)		μ^- ($t_2 = 275$ns)	
After	cooling	drift	cooling	drift
μ/proton	0.008	0.057†	0.005	0.058†
rms(p_x) (MeV)	0.07	16	0.10	14
rms(p_y) (MeV)	0.07	16	0.10	15
rms(p_z) (MeV)	0.09	37	0.13	32
rms(tran) (cm^2)	60×50	50	60×50	50
rms(long) (cm)	121	387	276	387
phase space reduction*	1.4×10^6		1.3×10^5	

† for $T_z < 100$ MeV

∗ phase space factor for the μ's which are cooled

We continue to work on:

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Gas Breakdown

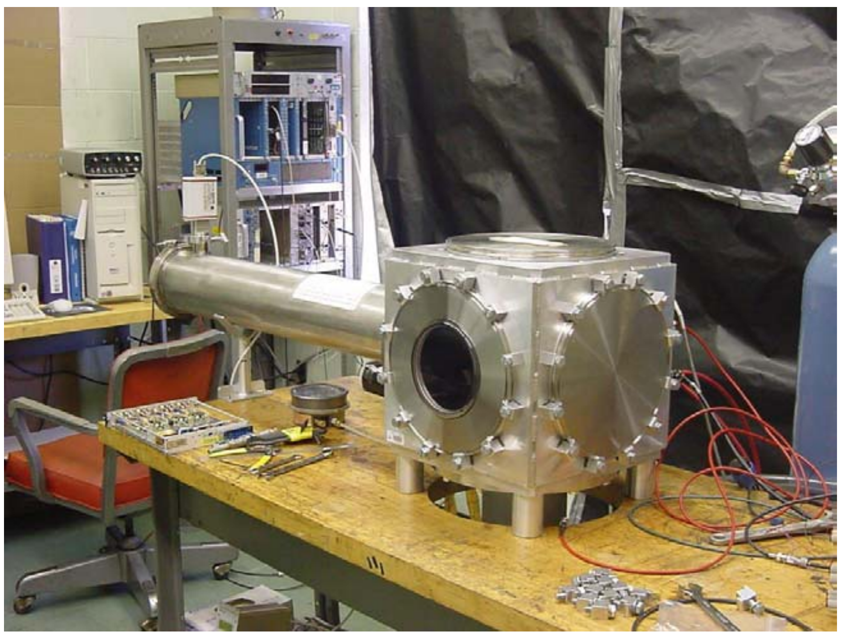
Can we apply high E-fields in gas without causing avalanche?

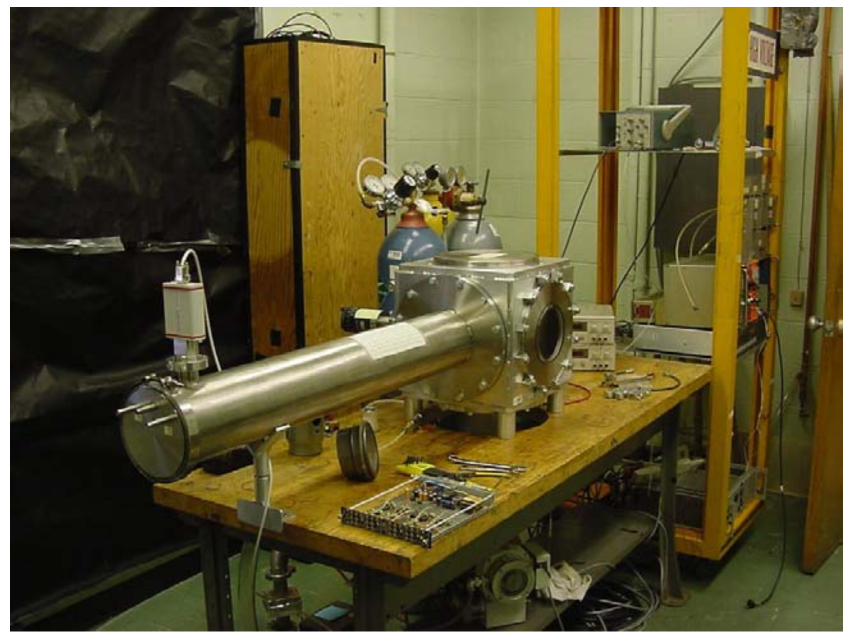
- High Magnetic field will help
- An Electron starting from rest in crossed E & B fields:
  Max. Kinetic Energy=$2m(e/B)^2$
  For $E = 5$ MV/m, $B = 5$ T $(KE)_{max} = 16$ eV
- A muon from rest in crossed E & B fields:
  For $E = 5$ MV/m, $B = 5$ T $(KE)_{max} = 3.3$ keV

$E_{ion}(H_2) = 13.6$ eV, $E_{ion}(He) = 24.6$ eV

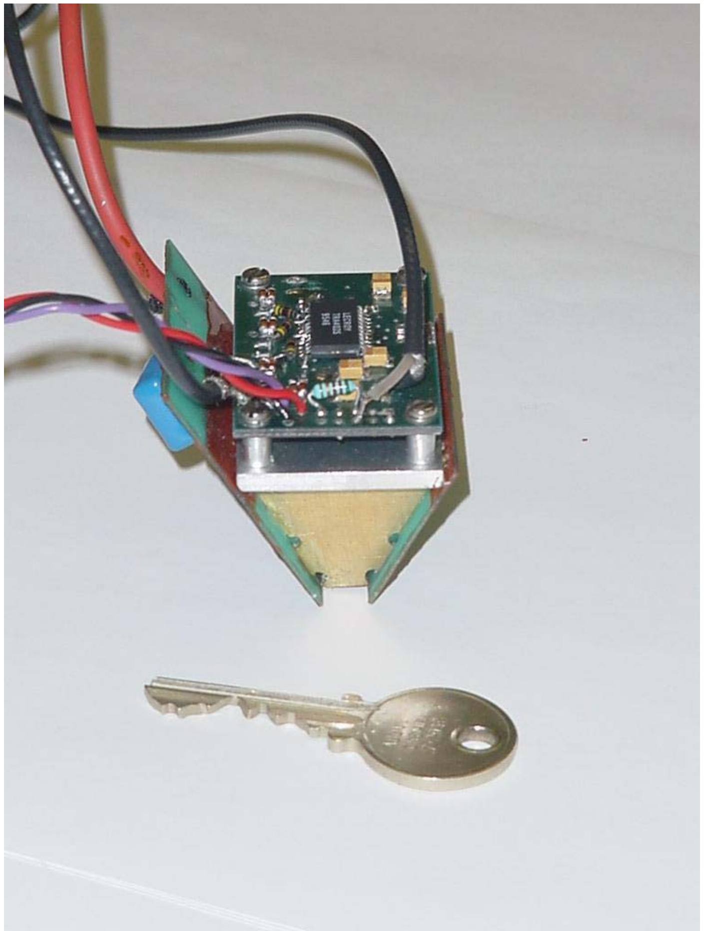
Experimental Work at Nevis

- We want to measure the energy loss, the m $s_{capture}$, test cooling principle

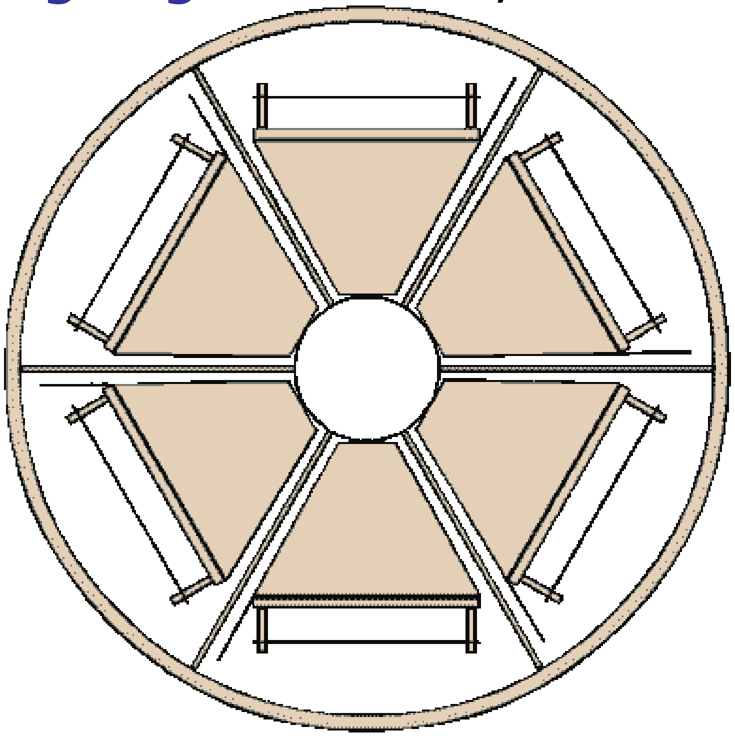




MultiWire Proportional Chamber



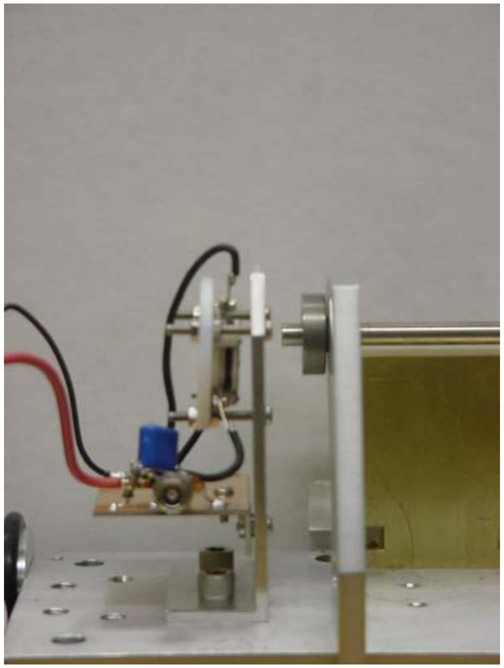
- Single Wire prototype constructed, tested with P10
- Ongoing: Multiwire, use Xe gas.



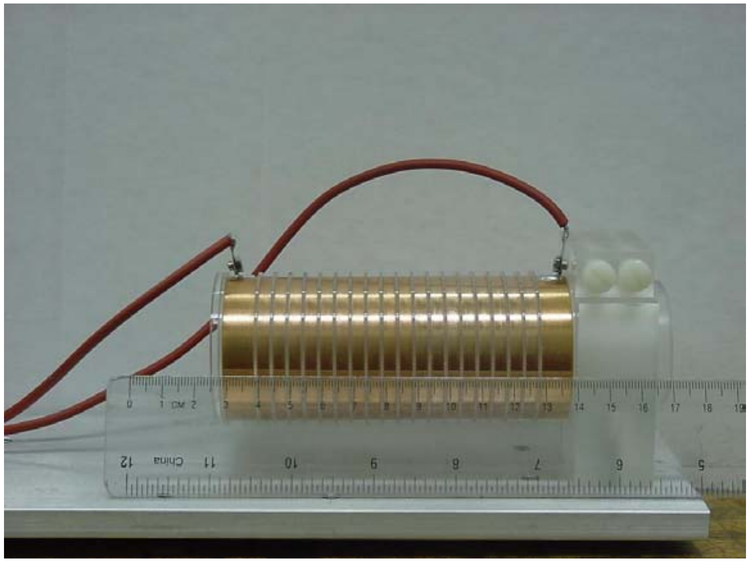
MicroChannelPlate

- MCP used to measure ms & e
- Use a,b,g sources in 4 MeV p beam at Nevis & 10-40 KeV mbeam at PSI

MCP: front



side



Accelerating grid