GEANT4 Simulation of a Helical Channel

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Fermilab
Discovering the Nature of Nature

Physics Motivation

Helical channel* is a new concept which promised large 6D cooling factor towards ν-source/muon collider design

* Proposed by Y. Derbenev

The Trick ⟵ use a solenoid + rotating dipole to produce a large P dispersion in the T plane, and cool with wedge absorbers (T + L cooling)

Need full simulation (GEANT style), eventually:

- Promising (worth studying)
- Not mainstream (time for new software development)

Helical Channel : "venture enterprise" (S.Geer)

Why GEANT4?

- **GEOMETRY:** GEANT3 limited to pre-defined basic shapes
  GEANT4 allows to define new shapes (CAD interface)
- **TRACKING:** double precision built-in, and tracking in EM fields improved in GEANT4
- **PHYSICS:** more complete set of EM processes and better hadronic physics (GEANT4)

Other facts:

- GEANT4 written in OO C++ (easier for the user to implement a simulation, students do not write in Fortran anymore)
- GEANT3 will not be supported anymore by CERN. Will GEANT3 run in the computers and platforms we use a few short years from now?

VMS/fortran/GEANT3/PAW → UNIX/C++/GEANT4/ROOT

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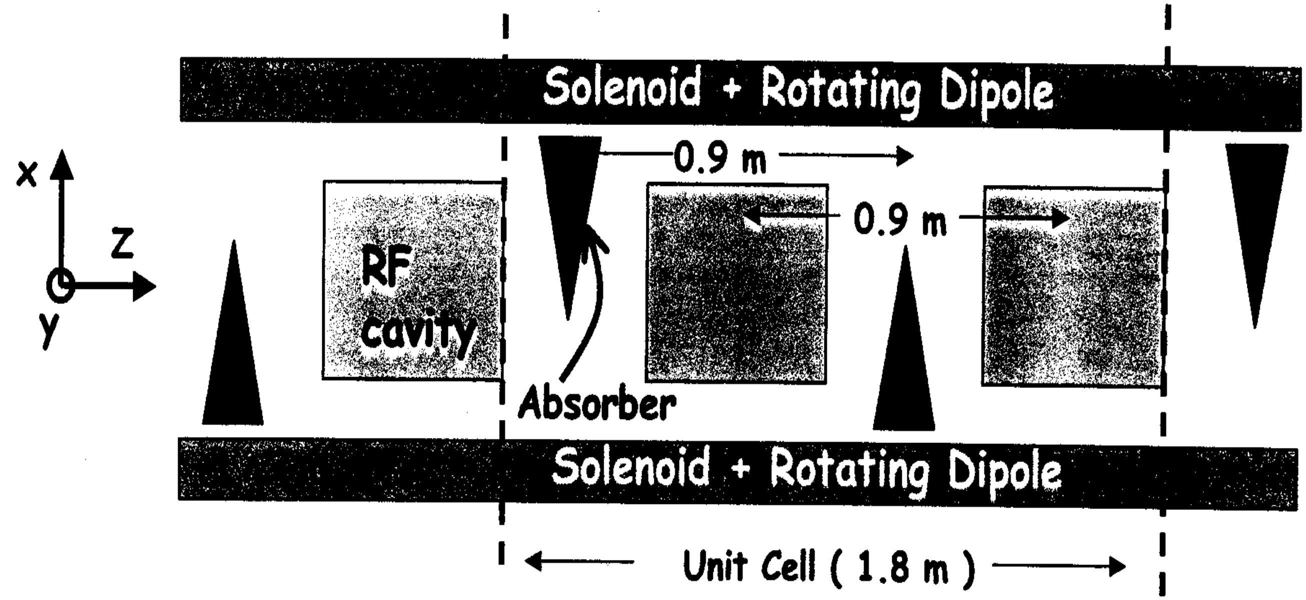
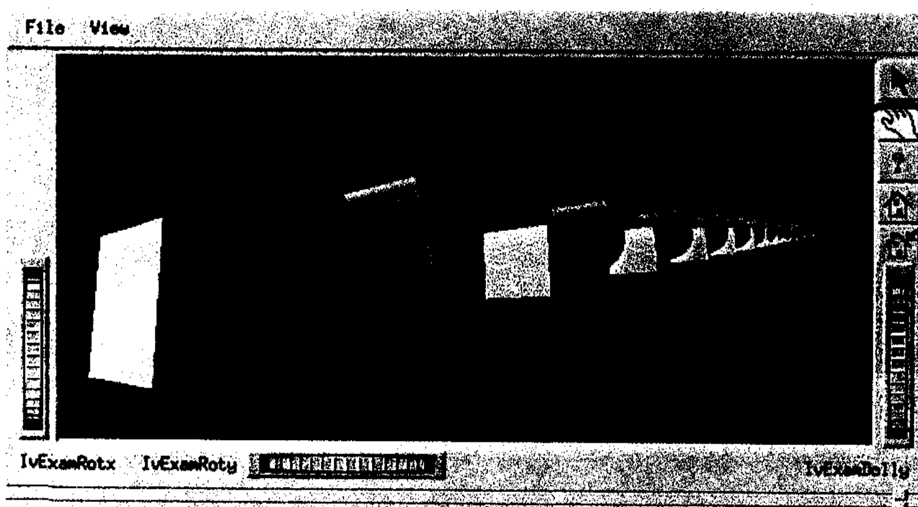
Geometry of the Helical Channel*

* mostly based on V.Balbekov's design (Aug 7th 2000)





GEANT4 visualization
(Open Inventor)

(the purple disks are idealized RF cavities)

40 cells long

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The Magnetic Field

Solenoid	Rotating Dipole
$B_z = f(r,z)$	$B_x = A\cos\left(\frac{2\pi}{\lambda}z\right)$
$B_r = g(r,z)$	
↑ Constructed from current distributions	$B_y = A\sin\left(\frac{2\pi}{\lambda}z\right)$
	$B_z = 0$

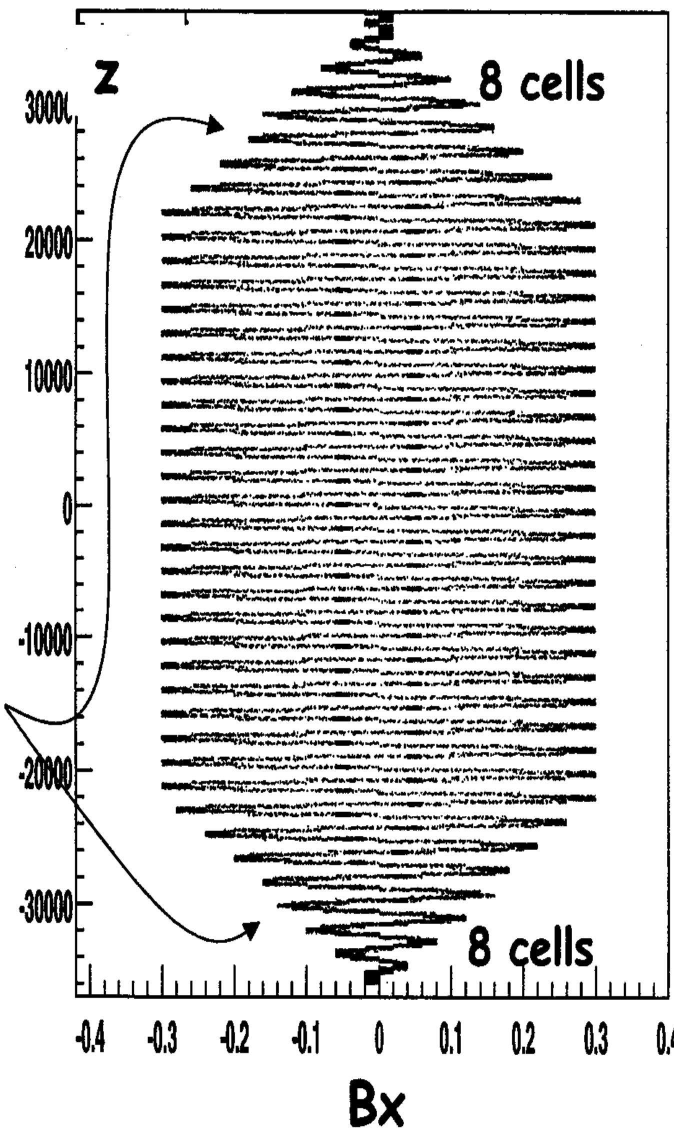
A = 0.3 Tesla adiabatic turn on/off

λ=1.8 m (dipole)

B_z^{max} = 5 Tesla (solenoid)

Parameters chosen for

Eref=260 MeV



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Magnetic Field Tool

Object oriented *C++* code to interface *GEAN4* with ascii files containing coil/sheet description.

Solenoid tool reads...

x	y	z	$r$min	$r$max	φmin	φmax	$z$min	$z$max	*nsheets*
idsheet	*typesheet*	*zsheet*	*thicksheet*	*radsheet*	*lensheet*	*cursheet*			
2	...	...	...	...	...	...			
...	...	...	...	...	...	...			
n	...	...	...	...	...	...			

Constructs an object solenoid field with all this info plus a field map grid (spline fit), makes it available to *GEANT4*, and writes a binary file.

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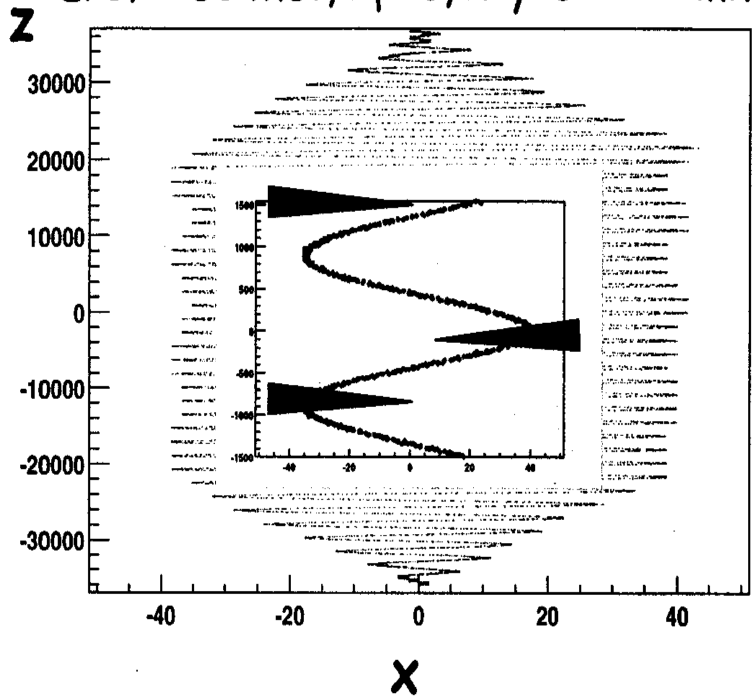
The Absorber

Ideal particle's trajectory

Eref=260 Mev, P_T =0, x=y=0 ⟵ initial parameters



Choice of absorber material and thickness driven by RF and beam parameters

Material: LiH

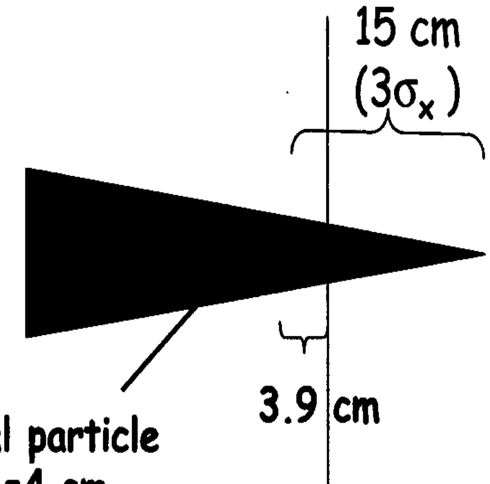
dE/dx = 1.70 Mev/cm
(Eref=260 MeV)

Oscillatory motion with $A=3.9$ cm and $\lambda=1.8$m

Maximum dp/dx at z=A

⬇

place absorbers



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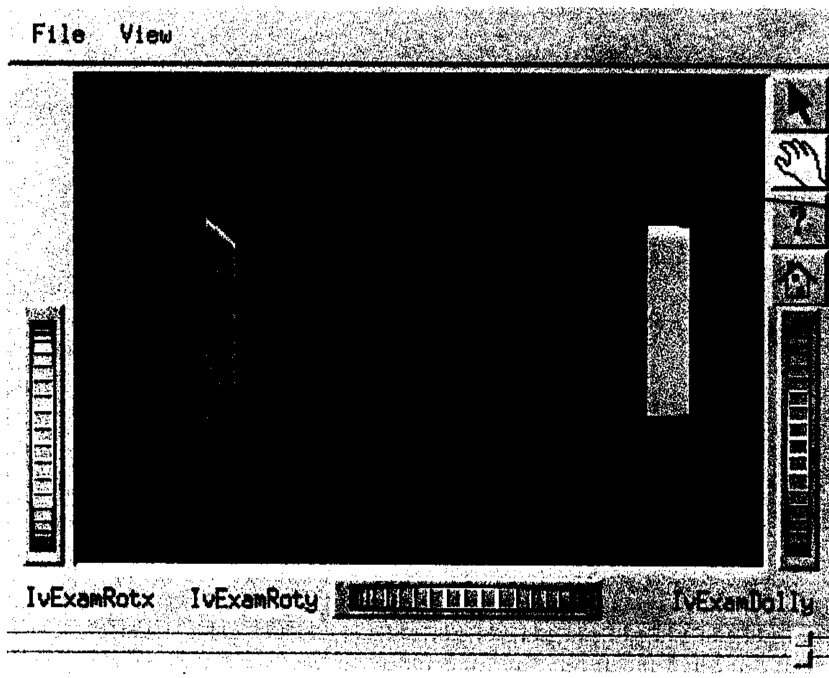
The RF System

Ideal (very unrealistic) model to facilitate tuning:

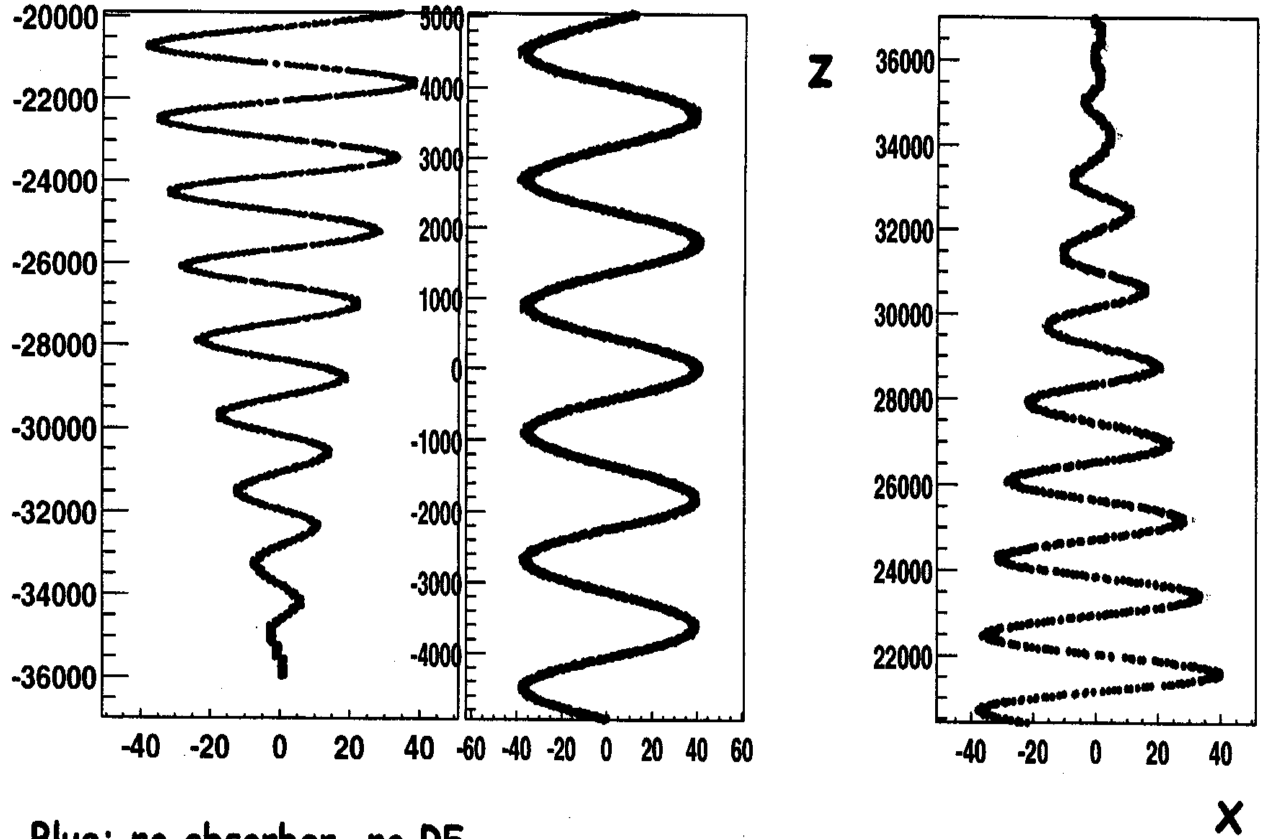
f=201 MHz, 1 cm long, peak voltage 1360 Mev/m to provide 6.8 MeV at sync phase of 30°



RF cavity placed inmediatelly the absorber

Tuning the System for the Ideal Particle

Phase of RF cavities adjusted to provide a sync phase of 30° at arrival of ideal particle (dE/dx fluctuations and multiple scattering turned off)



Blue: no absorber, no RF

Red: absorber, RF included

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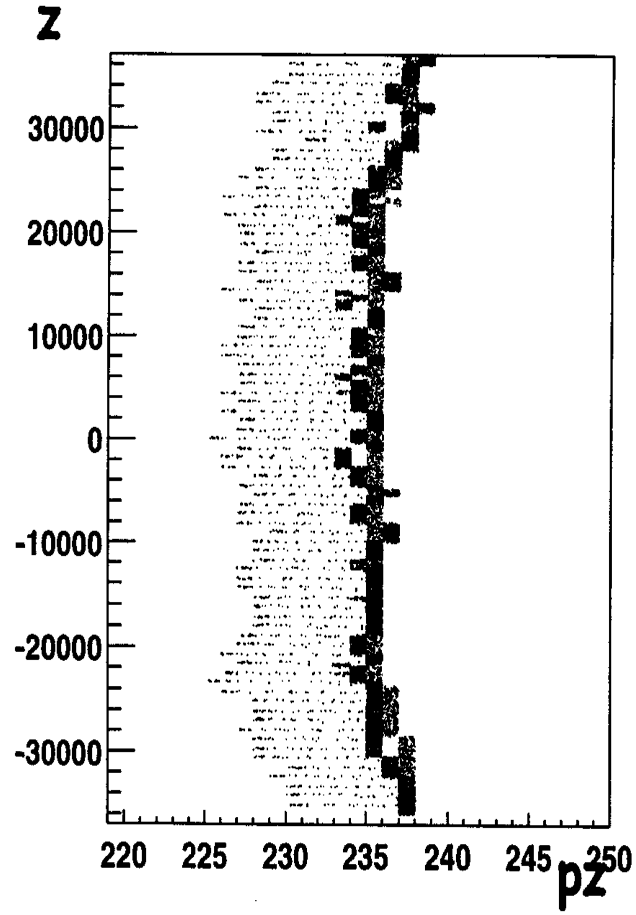
Ideal particle, Eref=260 MeV



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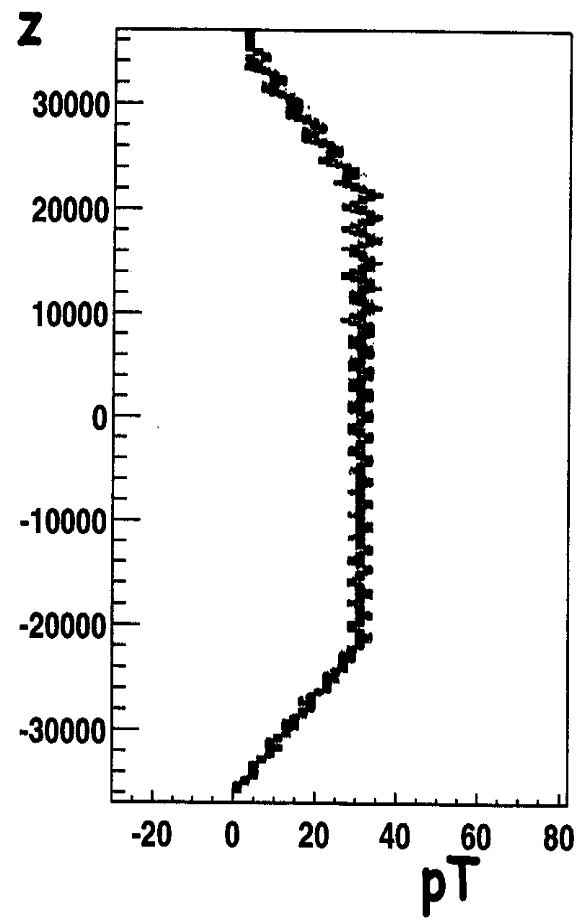

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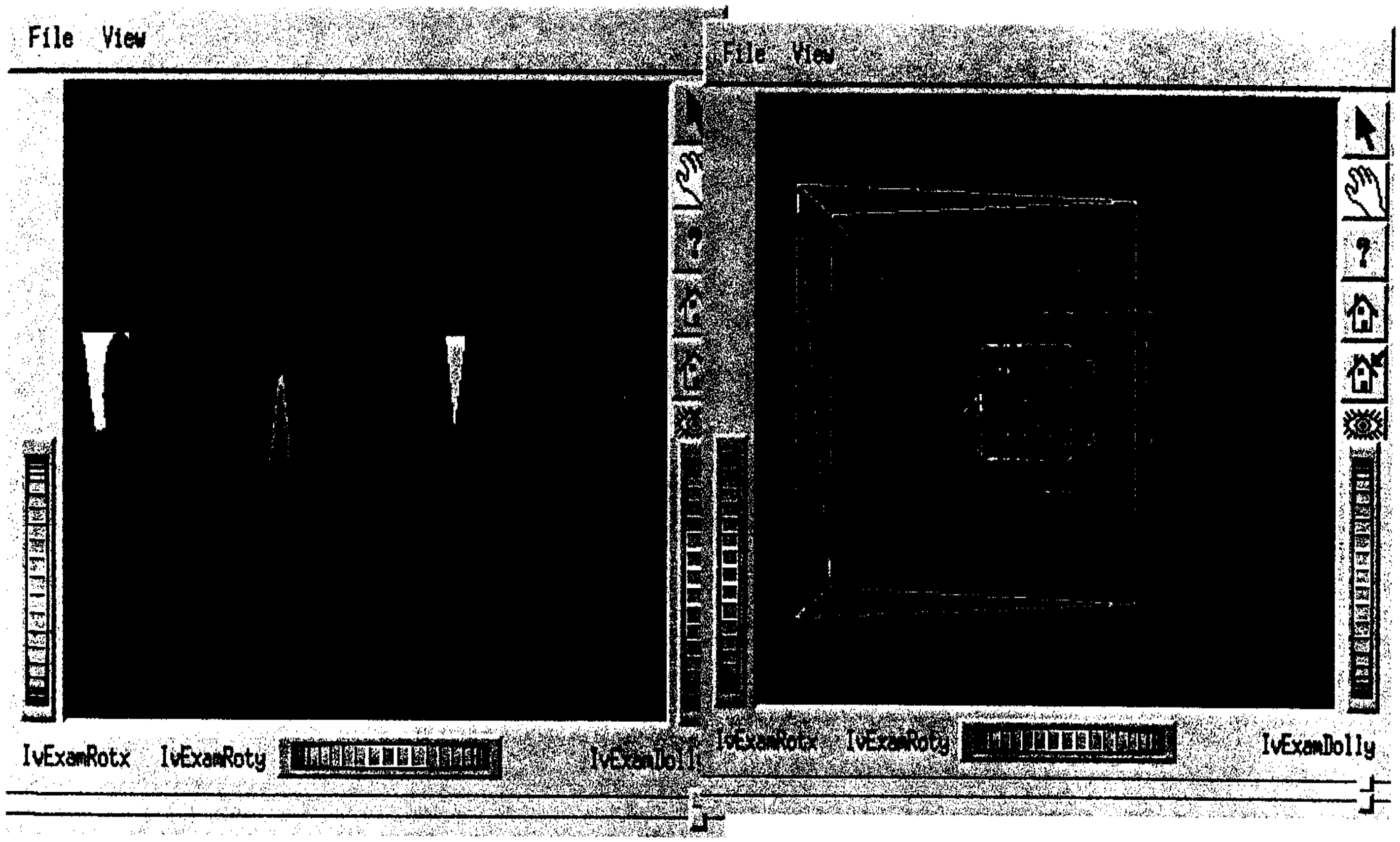
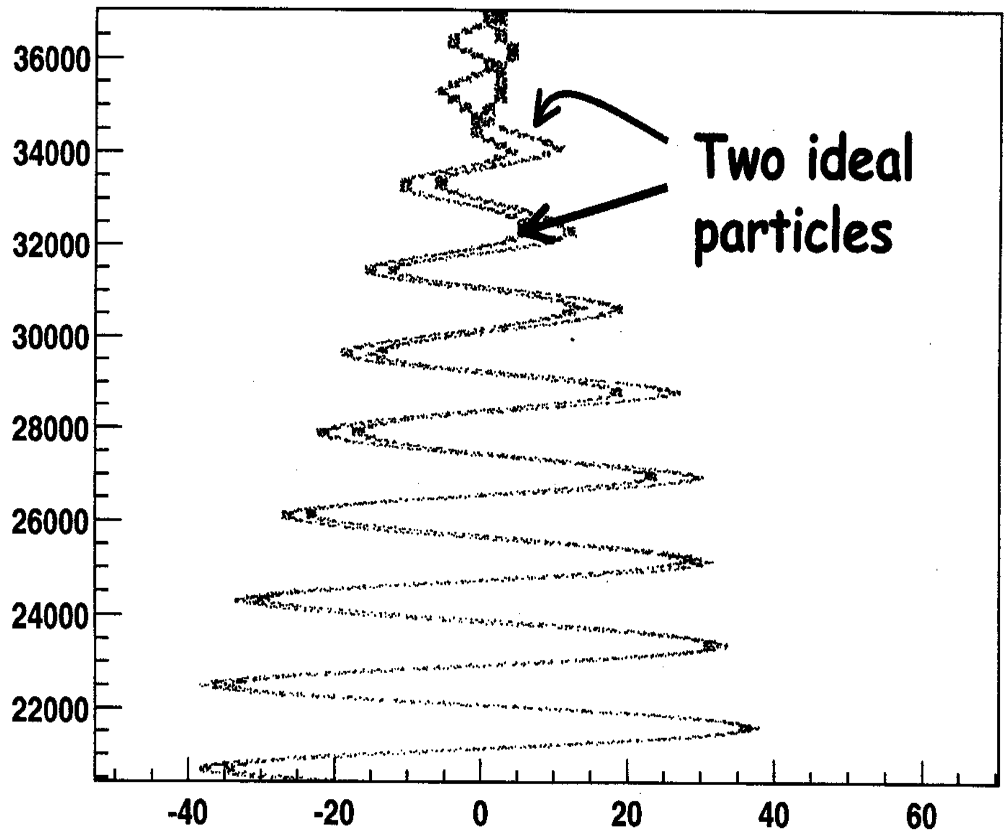
Ideal particle, Eref=260 MeV



If I turn on dE/dx fluctuations....



The Initial Beam

$\langle x_{Li} \rangle = 0 \quad \sigma_{xLi} = 3.25\,\mathrm{cm}$

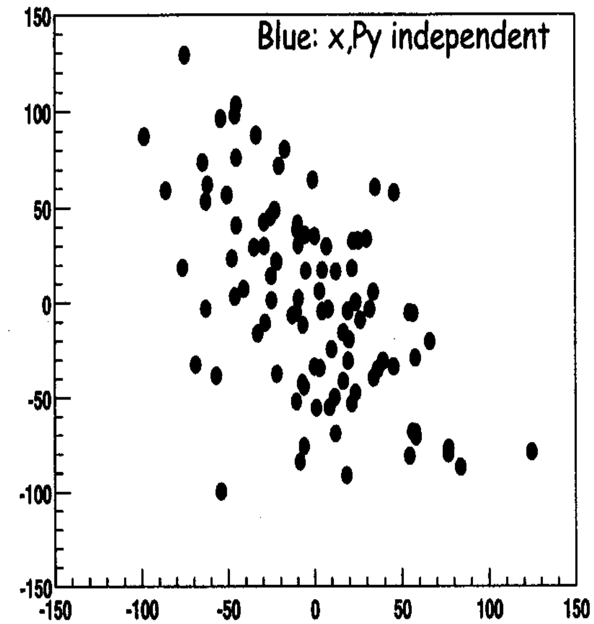
$\langle p_{xi} \rangle = 0 \quad \sigma_{pxi} = 48.7\,\mathrm{MeV}$ Larmor centers

$\langle y_{Li} \rangle = 0 \quad \sigma_{yLi} = 3.25\,\mathrm{cm}$

$\langle p_{yi} \rangle = 0 \quad \sigma_{pyi} = 47.7\,\mathrm{MeV}$

$\langle ct \rangle = 0 \quad \sigma_{ct} = 10\,\mathrm{cm}$

$\langle E \rangle = 260\,\mathrm{MeV} \quad \sigma_E = 25\,\mathrm{MeV}$



$$x = x_L + \frac{P_y}{B_z^{max}}$$

$$y = y_L + \frac{P_x}{B_z^{max}}$$

x-y correlations simulate the beam entering the solenoid

6D Emittance Of blue and red are the same

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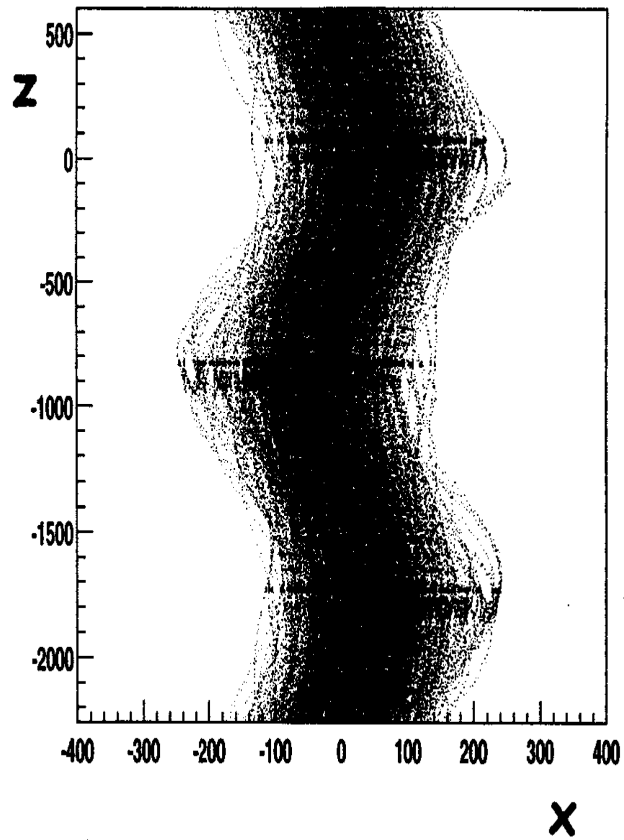
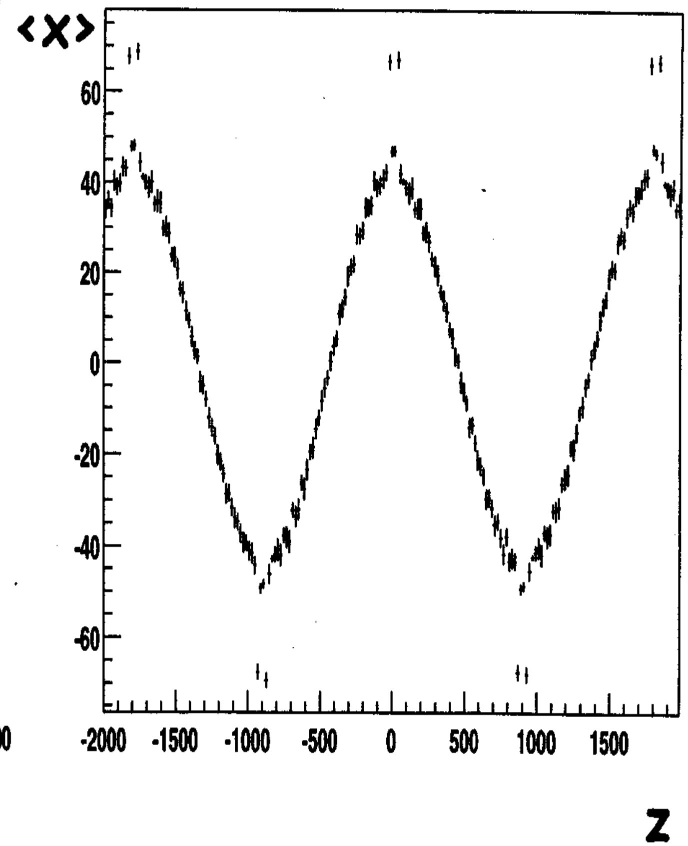
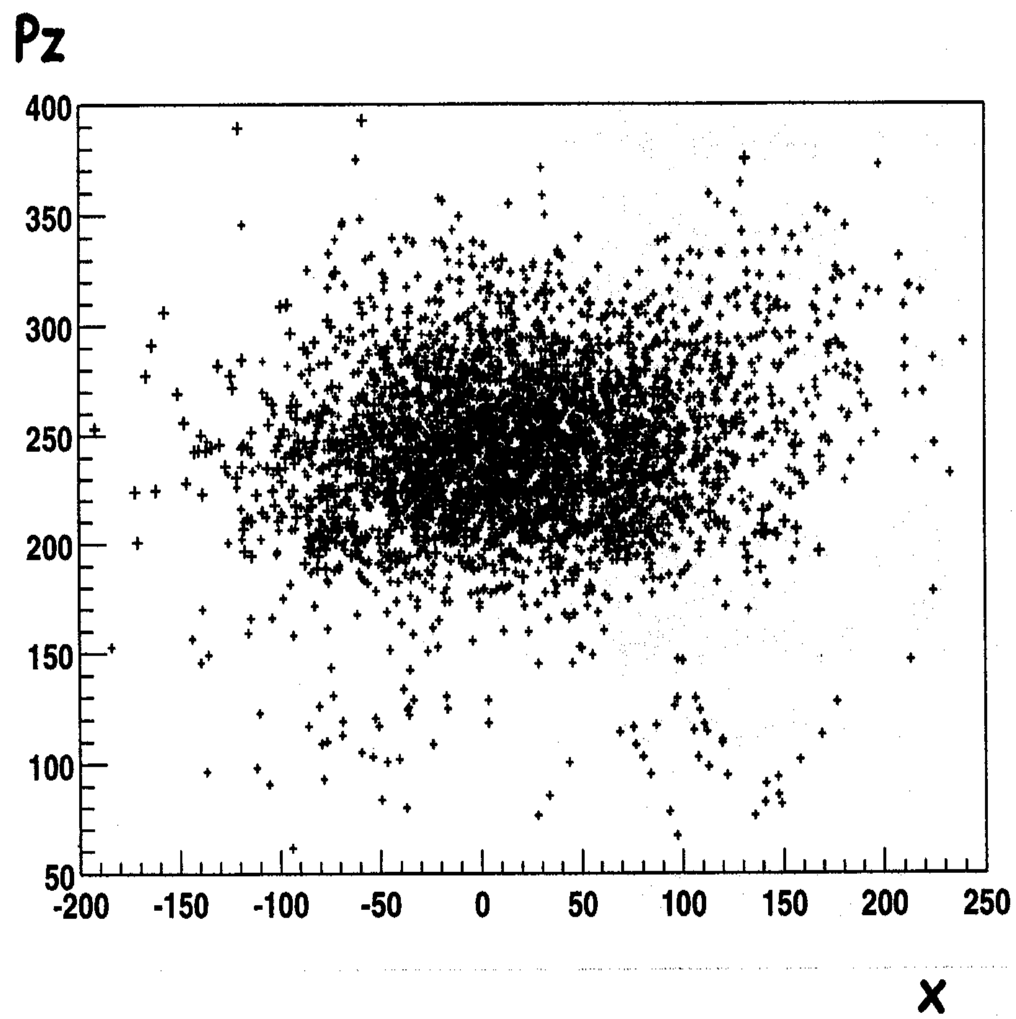
X vs Z for the Beam

All the physics processes except multiple scattering are modeled (1000 particles)





x-Pz Correlation



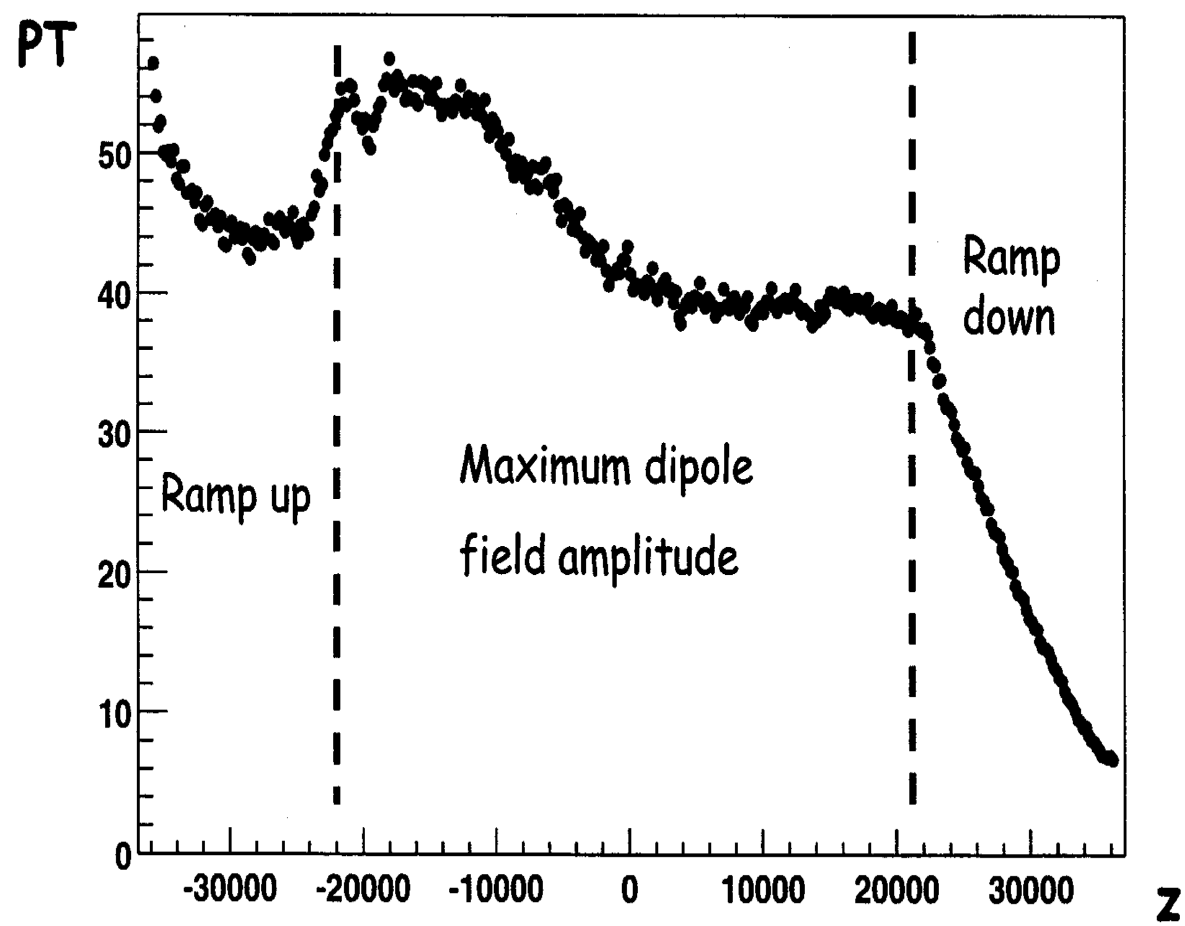
B: initial

B: cell 9

G: cell 29

R: final

<PT> versus Z



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Emittance vs Channel Length

Before entering the magnetic field ($\langle \delta x \delta py \rangle = 0$):

$$\boxed{E_{N6D} = \sigma_x \, \sigma_{px} \, \sigma_y \, \sigma_{py} \, \sigma_{ct} \, \sigma_E \, / \, m_\mu^3}$$

Same as inmediatelly after entering the magnetic field ($\langle \delta x \delta py \rangle \neq 0$)

$$\boxed{E_{N6D}^{init} = 5.3762 \text{ cm}^3}$$

$E_{N6D}(z)$ = sqrt(det M)/m_μ^3 given the correlations introduced by the combined effect fo magnetic field, absorbers, RF cavities

Not yet done! (numerical problems)

Conclusions

- A Helicoidal Cooling Channel (parameters proposed by V.Balbekov) was simulated using GEANT4
- Inpection of significant plots express the channel has a reasonable behavior.
- To do: include multiple scattering, play with parameters, calculate Emittance (for quantitative statements)

Learning exercise - use and developed new tools (C++,GEANT4, magnetic field constructors, Root), become familiar with beam physics

Future: wrap this up and move to whatever shows to be interesting during this workshop (related to the feasibility II and MUCOOL efforts)