Muon Phase Rotation and Cooling: Simulation Work at CERN

Work done at CERN and INFN since Nufact01

- new 88 MHz front-end
- update on cooling experiment simulations
- figure of merit for cooling performance
- simulation software (PATH)

contributions from:
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New 88 MHz Front-End

idea: eliminate the 44 MHz section and start directly with 88 MHz

- 44 MHz cavities are bulky and difficult objects
- longitudinal acceptance of 0.1 eVs is compatible with 88 MHz
- solenoid field in the reference scenario was too conservative
- start phase rotation closer to the target, i.e. limit longitudinal emittance growth due to semi-relativistic effects
- depends on achievable gradient (will not work below 4 MV/m)

New 88 MHz Front-End

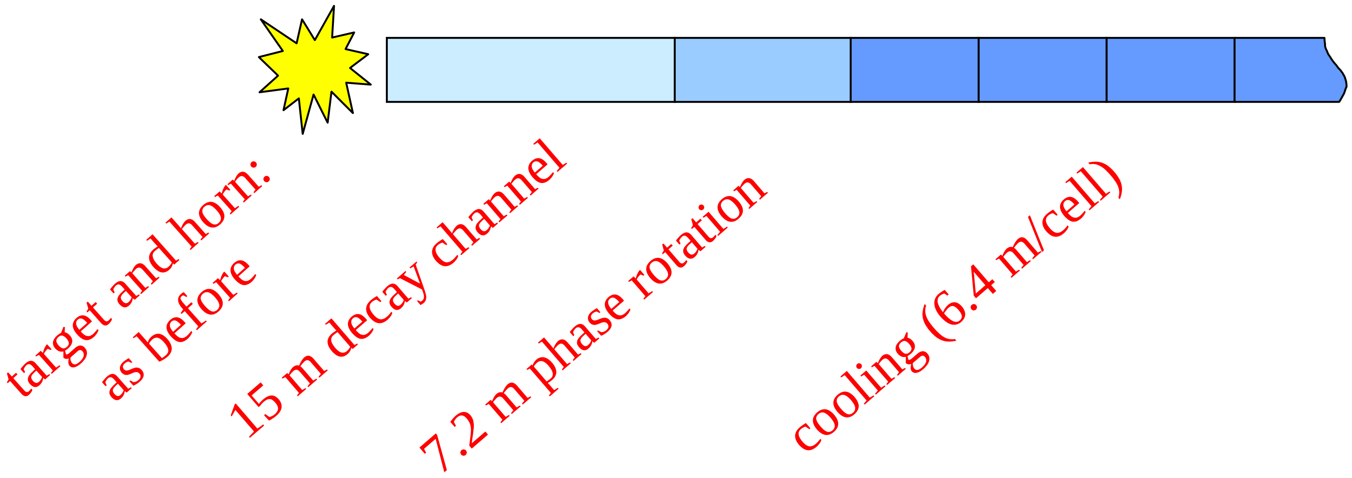
what made the new front-end possible
- solenoid gradients can be higher than we thought
this is a result of the solenoid design done for the MICE study

quench limit for *NbTi* at 4.5 K: 9 T
maximum B_z on axis: 4.5 T if at 60% on load line
6.0 T if at 80% on load line

- solenoid strength of 4 T appears possible
- bore radius of 88 MHz cavities can be increased from 15 cm to 20 cm

this allows to employ 88 MHz cavities from the beginning without loosing too much transverse acceptance

New 88 MHz Front-End: Lay-Out



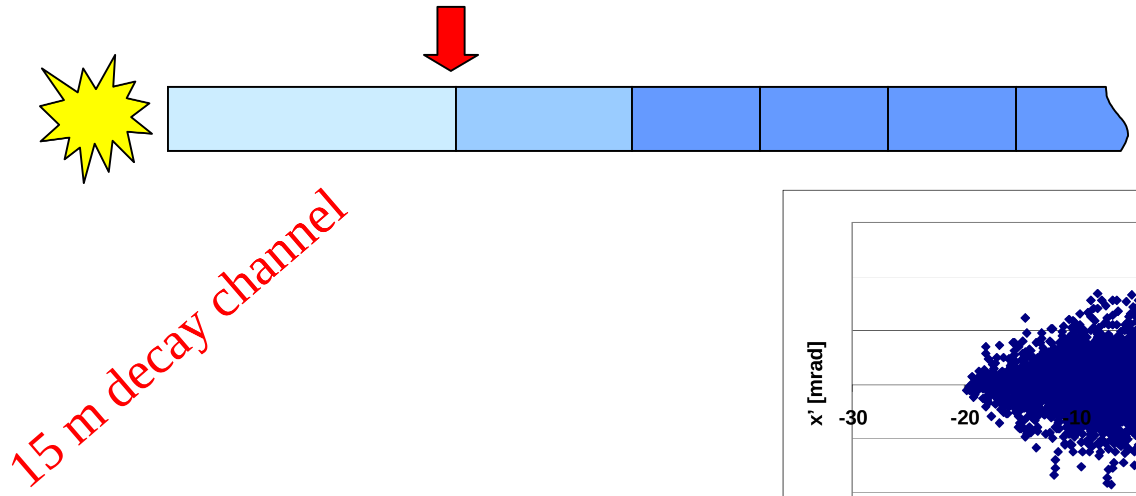
- distribution from target as before
- 15 m solenoid decay channel at 4 T
- 7.2 m phase rotation, 8 3 88 MHz cavities (l = 0.9 m, ΔE =3.6 MV/cavity, Φ = -90^{o}) with 4 T solenoids
- cooling modules (10 – 20)
  1 module: 6 cavities (88 MHz, Φ = 0^{o}), 0.5 m LH absorber, 0.5 m matching solenoid
- optional: second stage cooling channel with quadrupoles

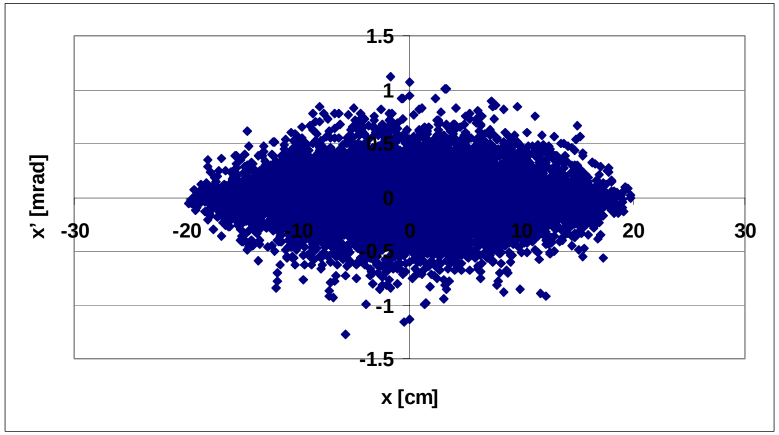
New 88 MHz Front-End: Lay-Out

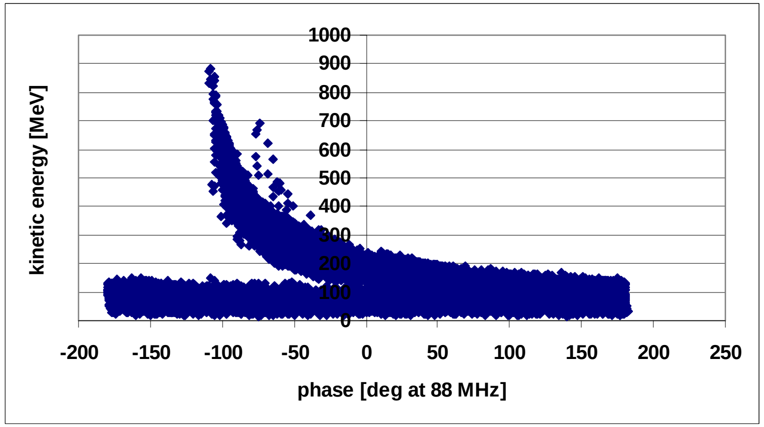
80 MHz	Decay	Rotation	Cooling I	Acceleration I	Acceleration II
Length [m]	15	8	90	≈ 10	≈ 450
Diameter [cm]	40	40	40	30	20
B-field [T]	4	4	4	4	quads
Frequency [MHz]		80	80	80	80-200
Gradient [MV/m]		4	4	4	4-10
Kin Energy [MeV]		200	200	300	2000

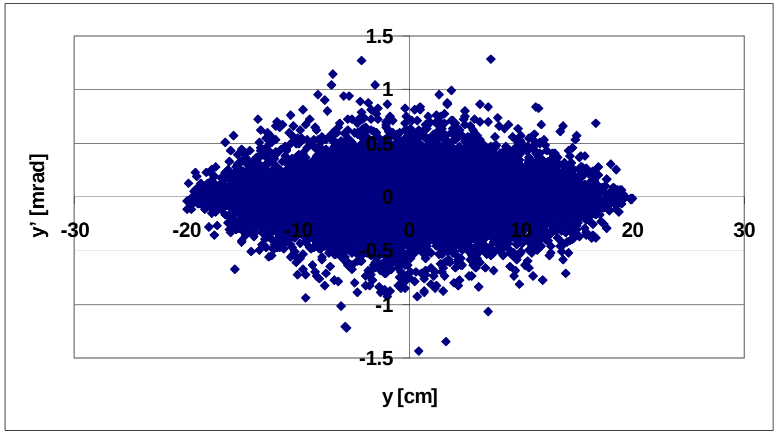
fields: hard-edge equivalent; gradient: average
options: have r = 20 cm in first part of cooling channel, then r = 15 cm
quadrupole channel: no coupling, but acceptance is only twice RLA acceptance (presently: 5 times RLA acceptance!)

New 88 MHz Front-End: Decay Channel

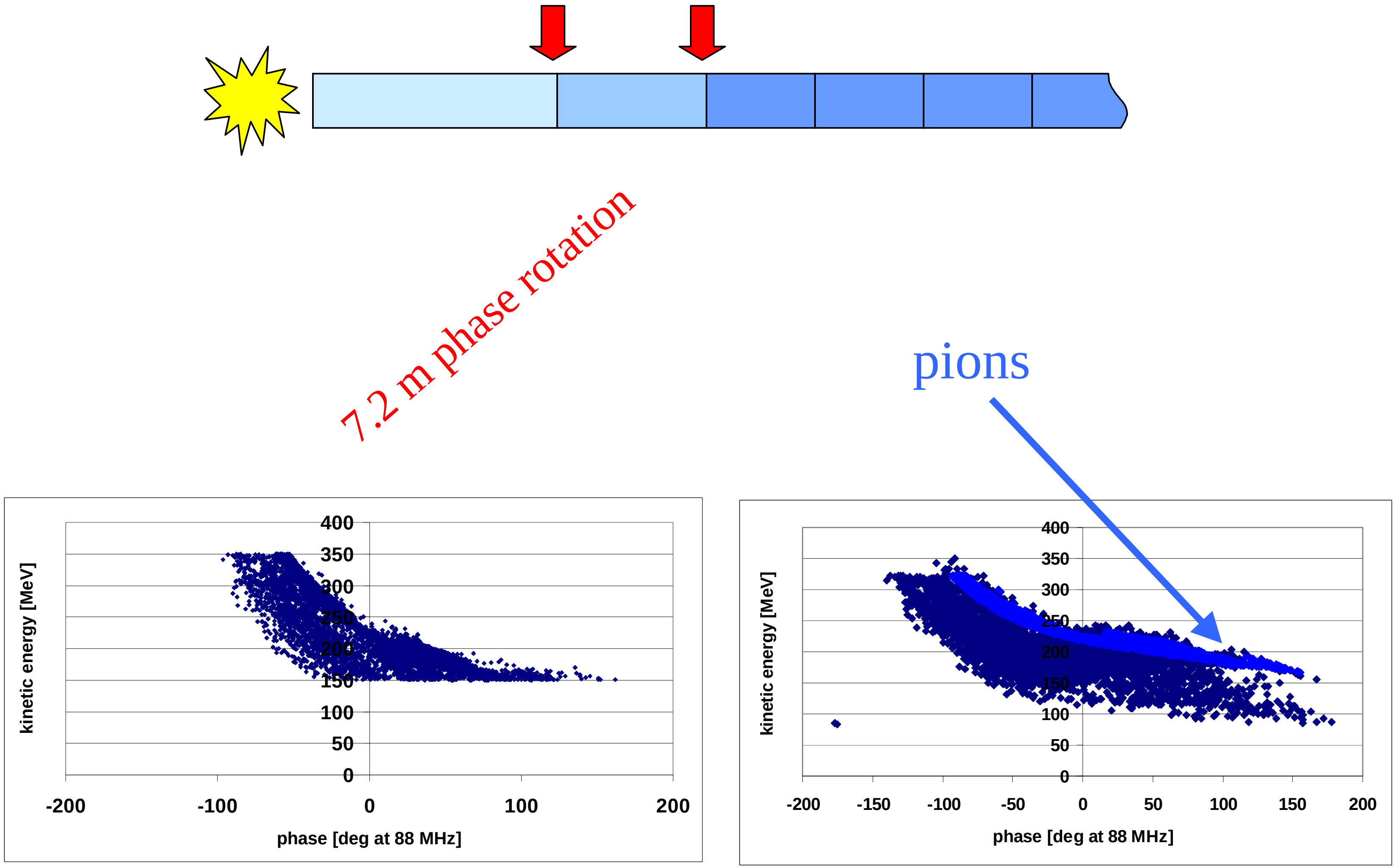




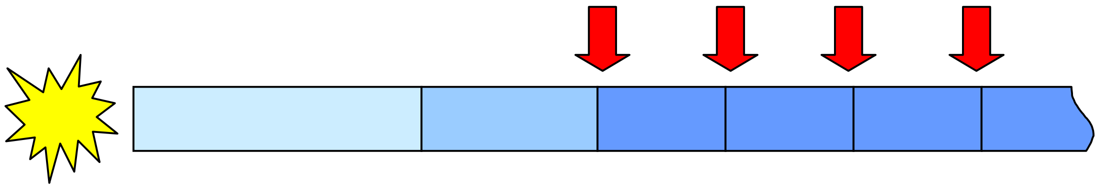


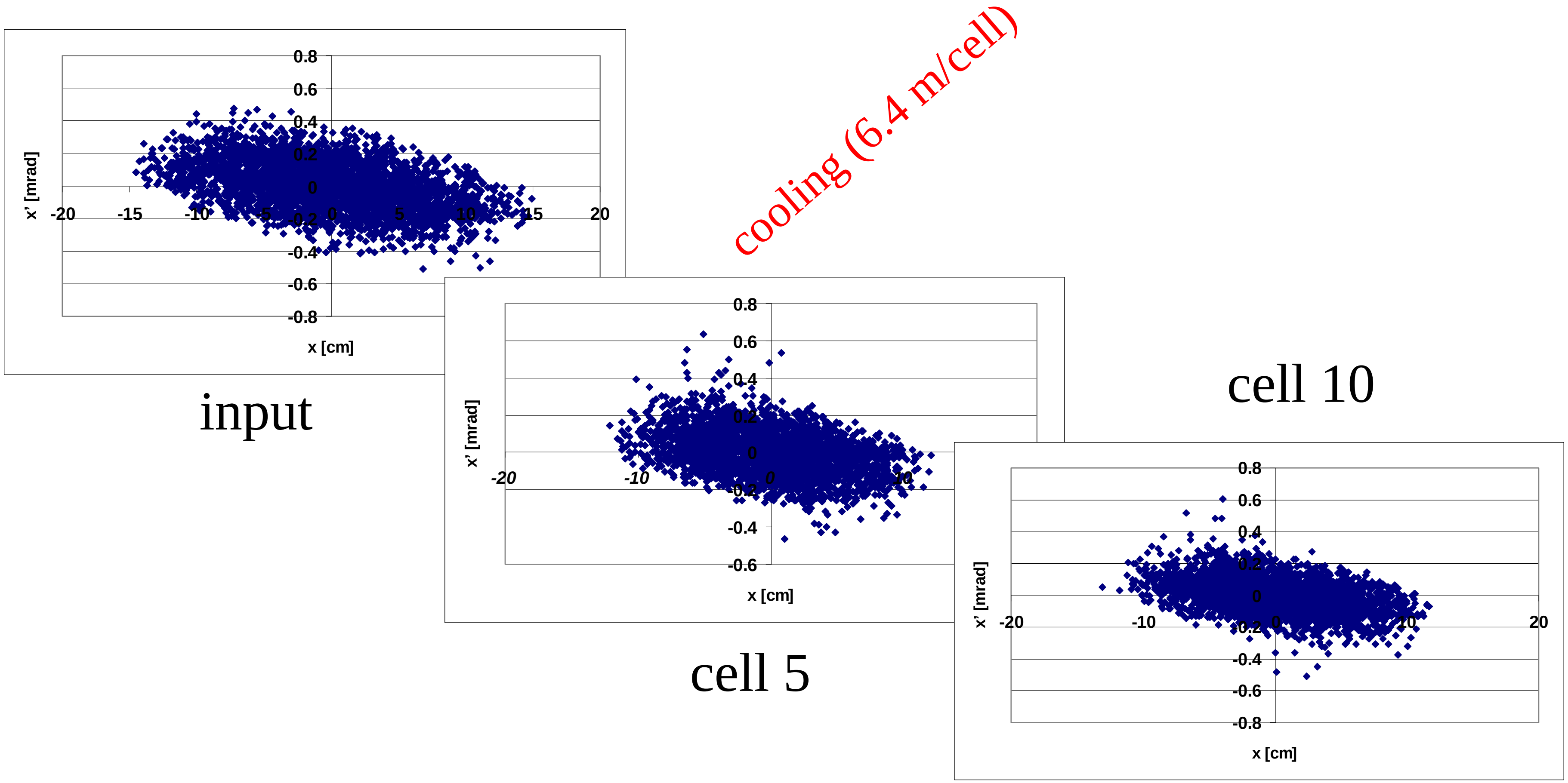


New 88 MHz Front-End: Phase Rotation

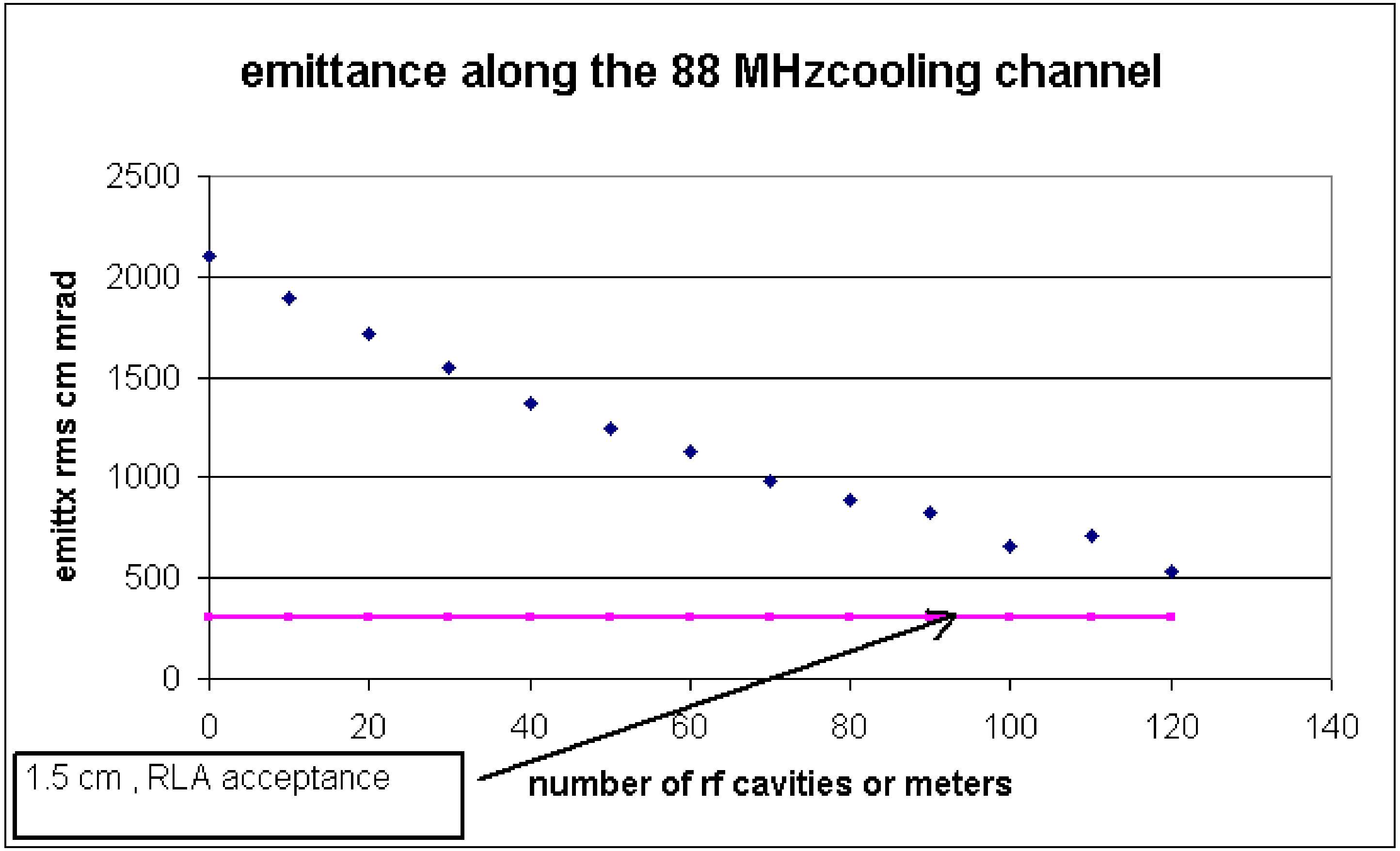


New 88 MHz Front-End: Cooling

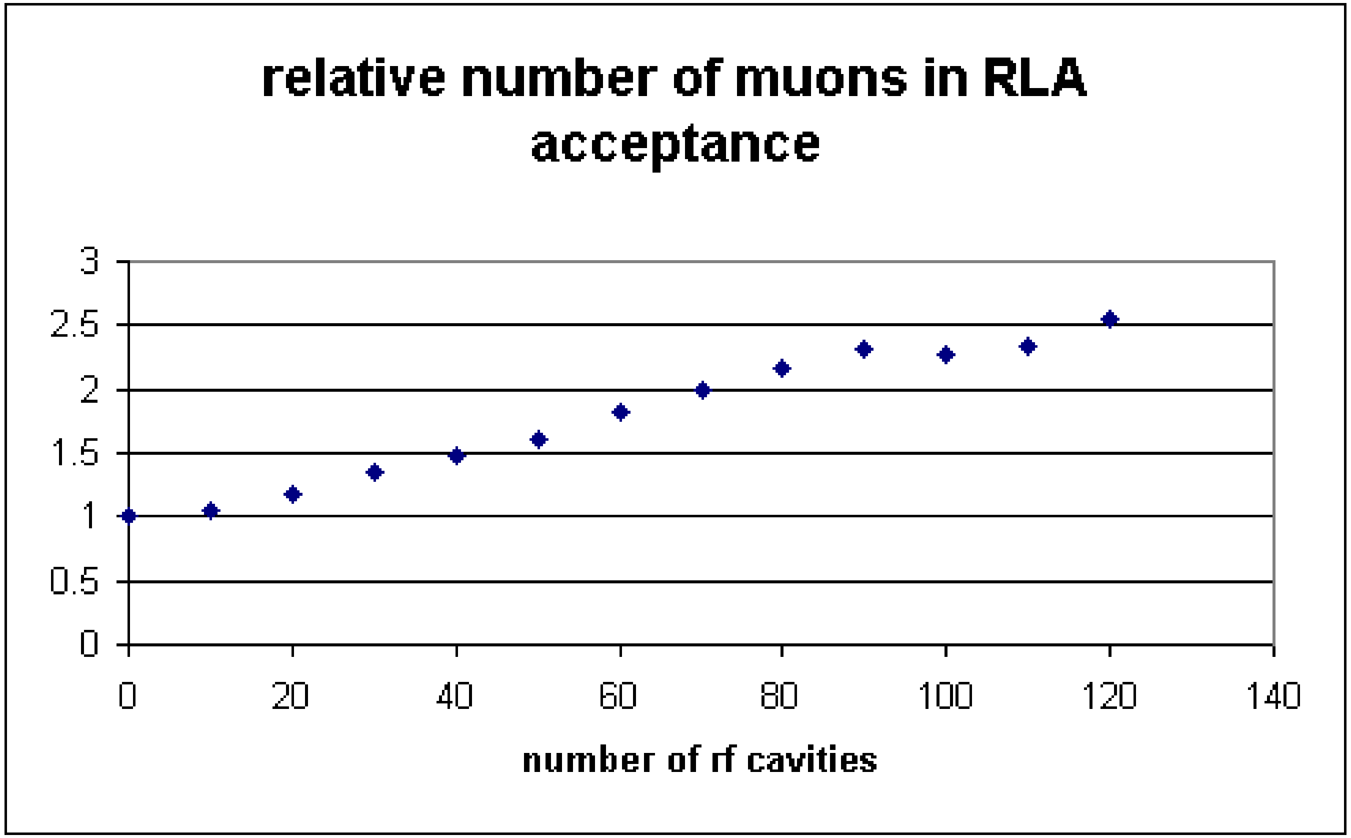




New 88 MHz Front-End: Cooling Performance



New 88 MHz Front-End: Cooling Performance



cooling efficiency is comparable to present 44/88 MHz channel

Cooling Experiment Simulations

<u>two options studied:</u>

a) 88 MHz (4 cavities and 8 cavities, 4 MV/m)

work done at CERN: optimisation, tracking through field maps (note the equivalence of hard-edge and field map model), parameter scan

b) 200 MHz (4 cells at 7.6 MV/m)

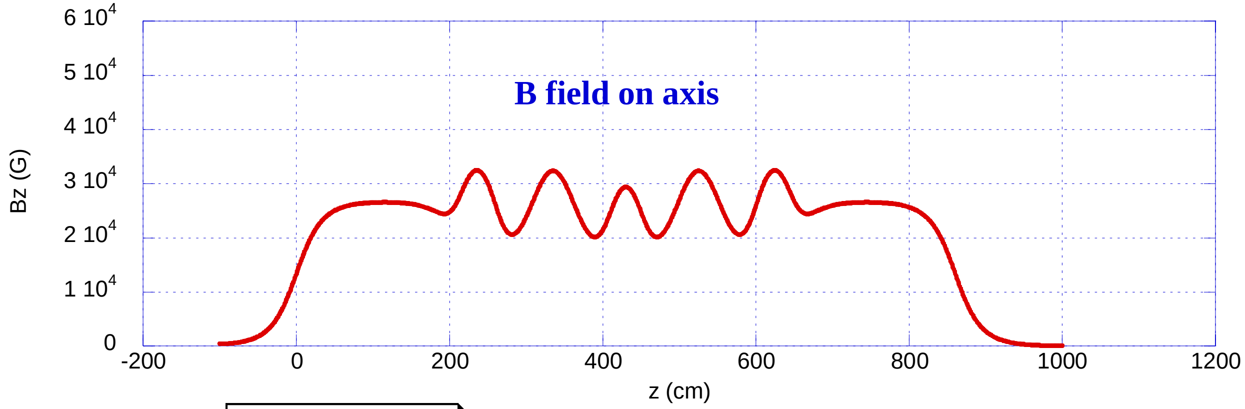
work done at INFN Frascati in collaboration with CERN

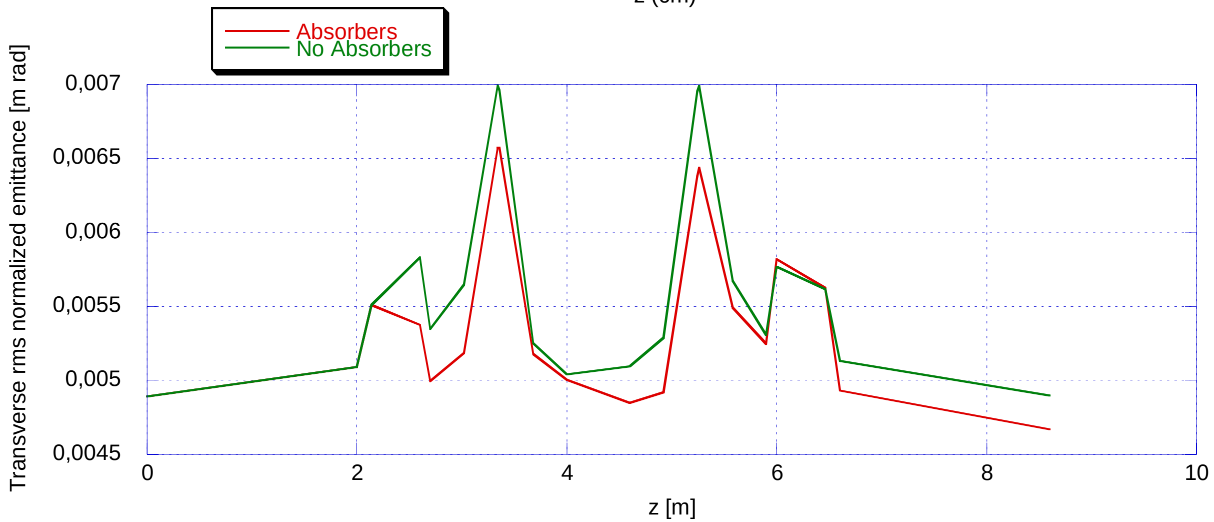
cooling efficiency comparable – solenoid arrangement very different! (88 MHz option shows less coupling than 200 MHz option)

see CERN NUFACT Notes 90, 108 and EPAC 2002

200 MHz Option: PATH Simulation

M.Migliorati, C.Vaccarezza, F.Tazzioli (INFN Frascati)





particle gain in acceptance: + 9% as in 88 MHz case

PATH simulation of 2 × 2 cell 200 MHz cavity with 2 × 46 cm LH absorber

Cooling Experiment: Figure of Merit

• Cooling channel: increase the number of muons in the acceptance of the following accelerators and the decay ring (3 planes independently).

• Solenoidal optics: inter-plane coupling depending on lattice and z-position.

• To measure cooling performance in the presence of coupling (i.e. along the cooling experiment):

➔ Algorithm to count particles in 4D/6D acceptance hyperellipsoids. Measure 4D/6D cooling rather than 2D projections.

Orientation of the ellipsoid adapted to muon distribution to maximize counts.

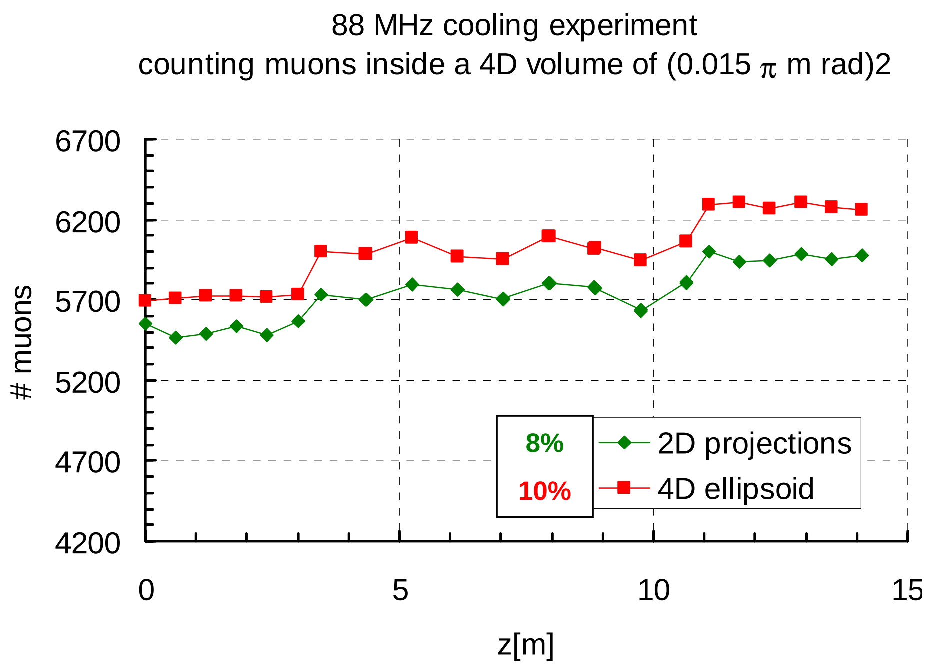
Condition for counting particles in *k* dimensional hyperellipsoids:

$$X_0^T \Sigma^{-1} X_0 \leq \left(\frac{\varepsilon_{\text{acceptance}}}{\varepsilon_{\text{rms}}} \right)^{2/k}$$

X_0 … coordinate vector of the particle

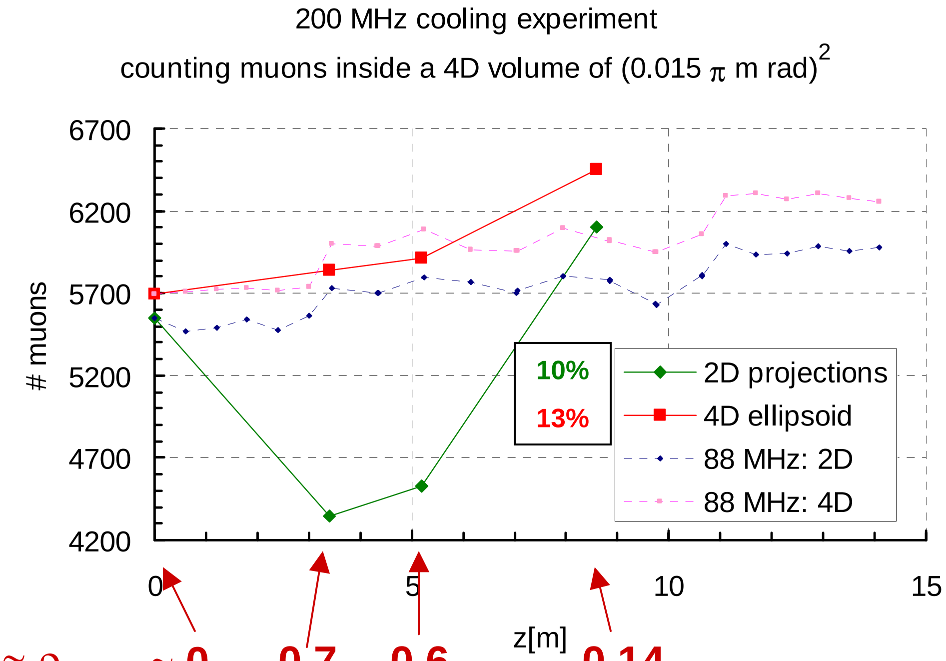
Σ … beam sigma matrix

Cooling Experiment: Figure of Merit



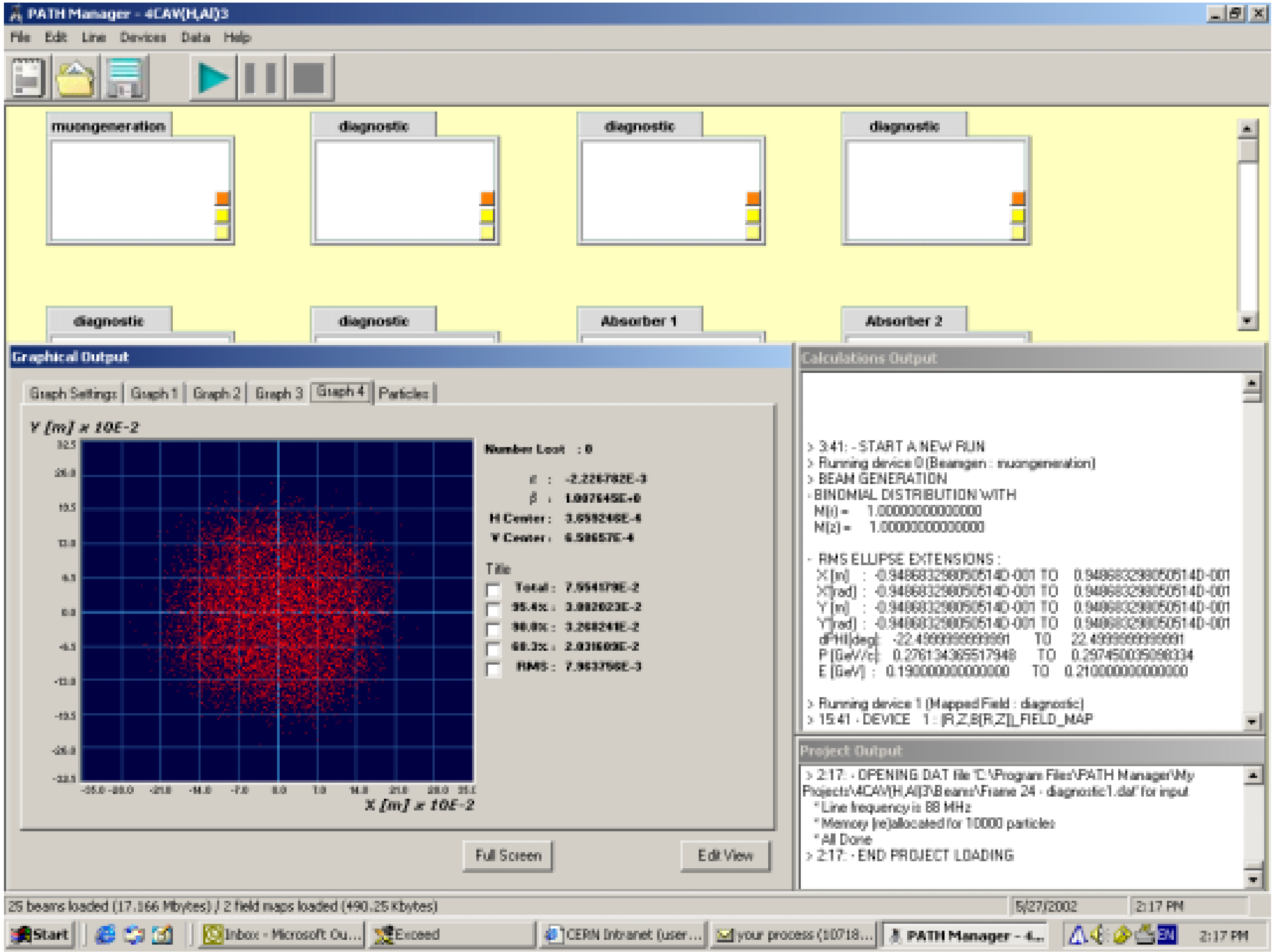
Correlation: $\rho_{x,py} \approx \rho_{y,px} \leq$ **0.08**

Follow the cooling performance along the z-position in the presence of correlations

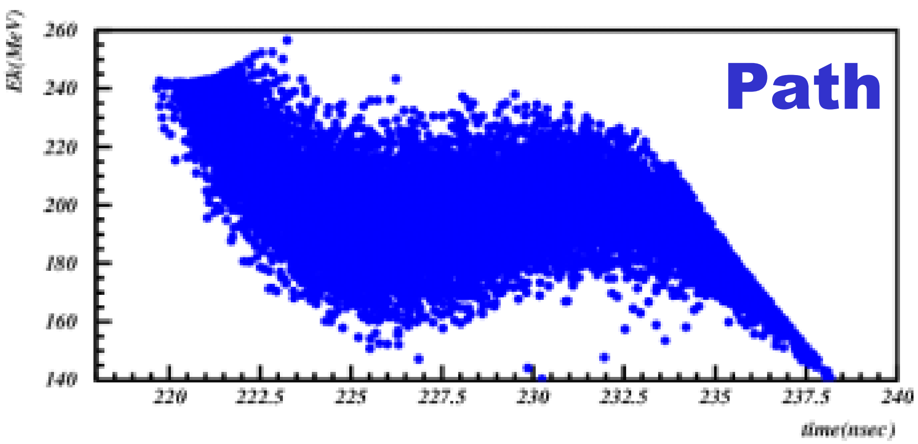


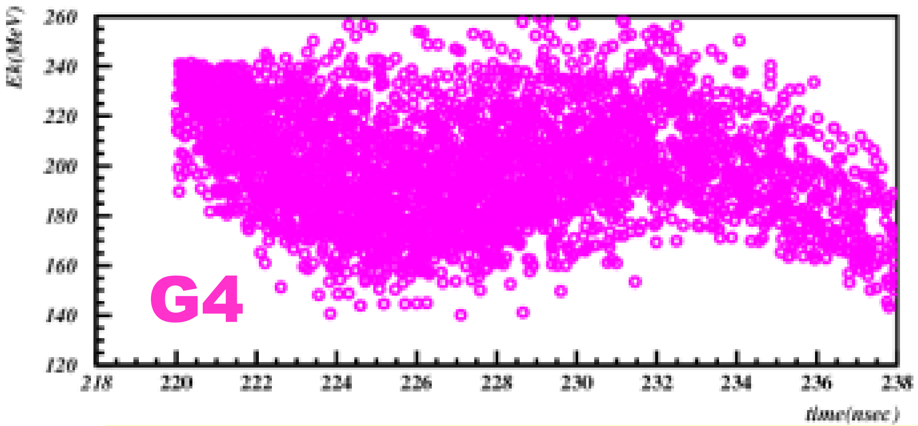
Correlation: $\rho_{x,py} \approx \rho_{y,px}$ $\approx$ **0** **0.7** **0.6** **0.14**

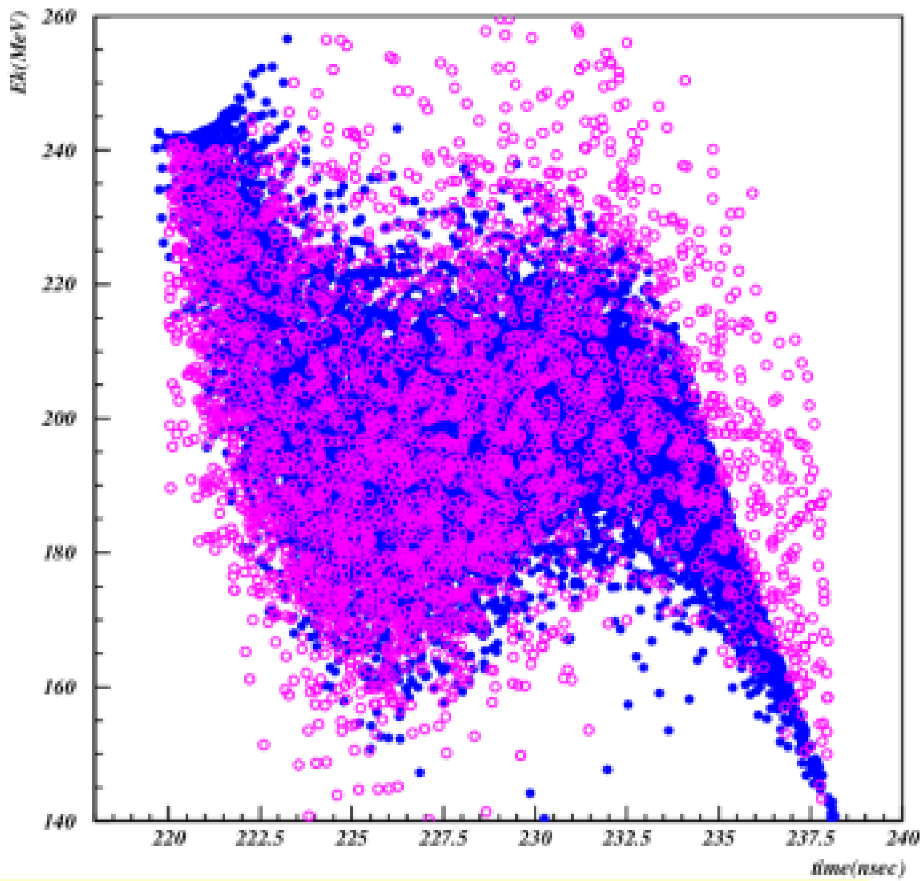
Simulation Code PATH: User Interface



Simulation Code PATH: Cross Check vs GEANT4



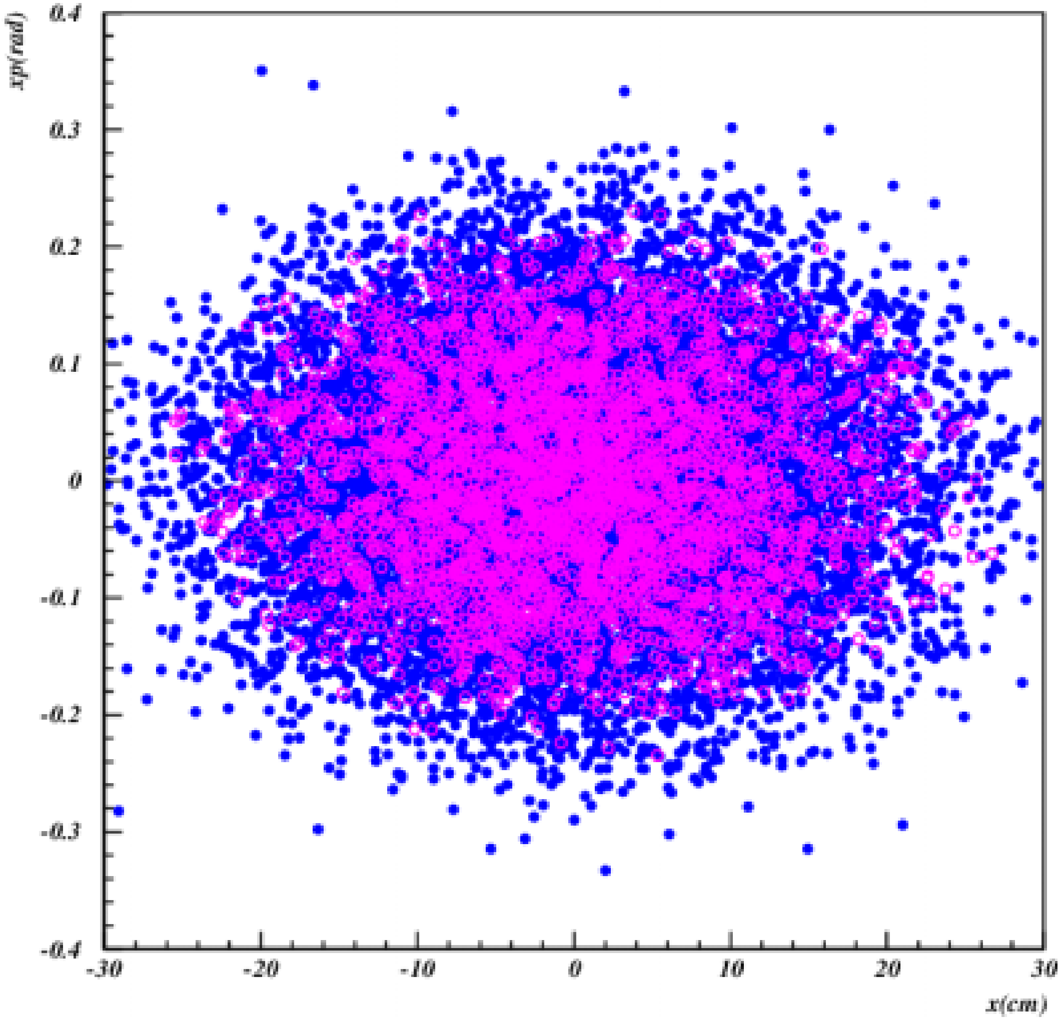




simulation of the phase rotation in the CERN cooling channel with PATH and GEANT4

remaining discrepancies: rf tuning, not exactly the same channel

Simulation Code PATH: Cross Check vs GEANT4



<u>transverse plane:</u>
small discrepancy due to particle dynamics in solenoid channel

<u>overall comparison result:</u>

- muons at input: PATH 15222
  G4 4560
- transmission: PATH 100%
  G4 94%

see CERN NF Note 102

Summary

- new 88 MHz front-end designed
- cooling experiment at 88 MHz: study finished and documented (NF Note 108)
- cooling experiment at 200 MHz: study finished and documented (NF Note 108 and EPAC2002)
- figure of merit for cooling experiment and cooling channel studied
- PATH/GEANT comparison: very good agreement