Precooling with Gas in the "Front-End"

Kevin Paul

Muons, Inc.

In collaboration with:

- Roland Johnson (*Muons, Inc.*)
- David Neuffer (*FNAL*)

kpaul@muonsinc.com

Introduction

- Muons, Inc.:
  - High-Pressure Gas-Filled RF Cavities
  - Helical 6D Cooling Channel (HCC)
- Challenges:
  - Breakdown suppression
  - High Gradients within high magnetic fields
  - *High Gradients at low frequency*
  - *Radiation limits*

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Motivation

- What else can we do?
  - Capture beam into RF early
  - Capture large fraction of beam with RF
  - RF phase rotation over short distance
  - Simultaneous precooling
- What problems can we face?
  - Pion interaction with gas
  - Pion decay within RF buckets

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Plan

- Simple comparison:
  - Neutrino Factory-like baseline (No RF or Gas)
  - Neutrino Factory-like baseline w/ HP Gas (100 atm)

    $\lambda_I = 59.4\ \mathrm{m}$
  - 201.25 MHz RF w/ HP Gas
  - "Back-of-the-envelop" Phase Rotation

    (i.e., "Phase Rotation by Dummies")

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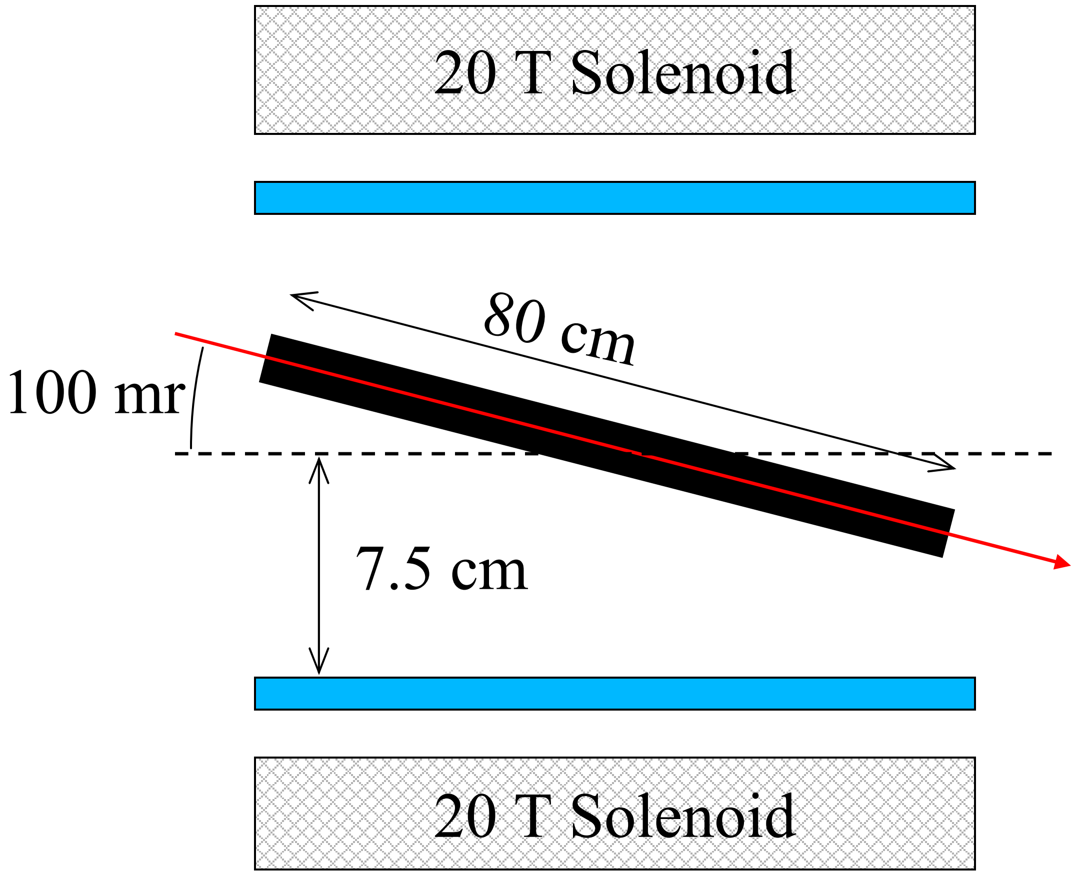
Production



- 80cm long, 1cm radius Carbon Target
- 1 MW / 8 GeV protons
- 20 T capture solenoid
- 100 mrad tilt angle
- 7.5 cm radius beam pipe

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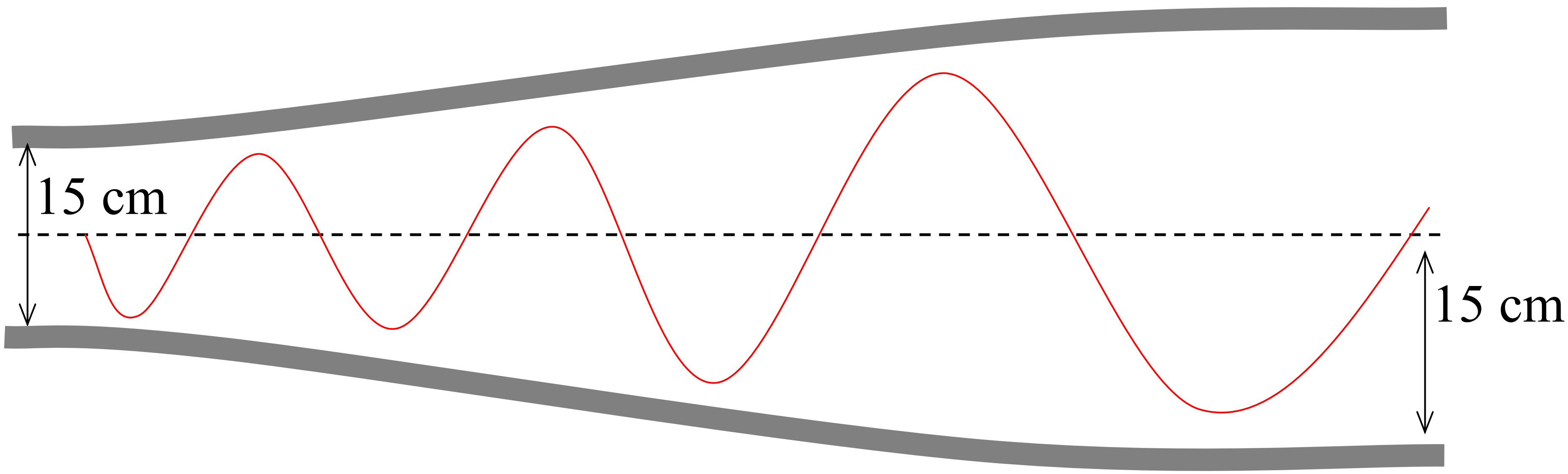
Adiabatic Matching



- Adiabatically decrease field strength to 5 T
- Increase beam pipe radius to 15 cm (*matches HCC*)
- Short matching section (5 m)

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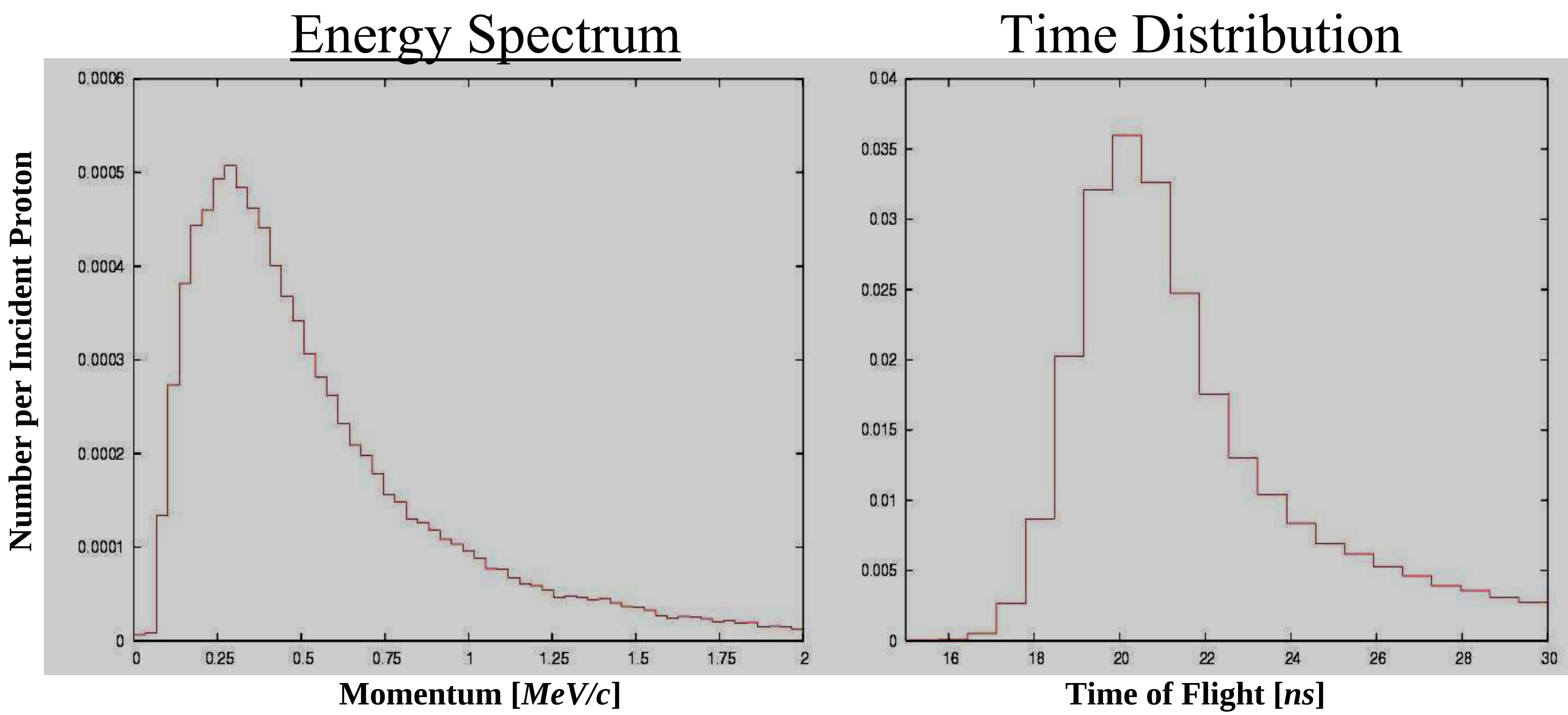
Initial Distribution



- 74% Pions / 26% Muons
- 0.14 π / 0.05 μ per POT

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Baseline Examples

- Neutrino Factory-like Decay Channel:
  - 50 m of 5 T solenoid
  - *No RF cavities*
  - *No HP gas*
- Immediate Capture into RF cavities:
  - 50 m of 5 T solenoid
  - 201.25 MHz / 50 MV/m / 20 cm RF cavities
  - *No HP gas*

HP Gas Examples

- Neutrino Factory-like Decay Channel with gas:
  - 50 m of 5 T solenoid
  - *No RF cavities*
  - 100 atm / Room Temp. GH_2
- Immediate Capture into RF cavities with gas:
  - 50 m of 5 T solenoid
  - 201.25 MHz / 50 MV/m / 20 cm RF cavities
  - 100 atm / Room Temp GH_2

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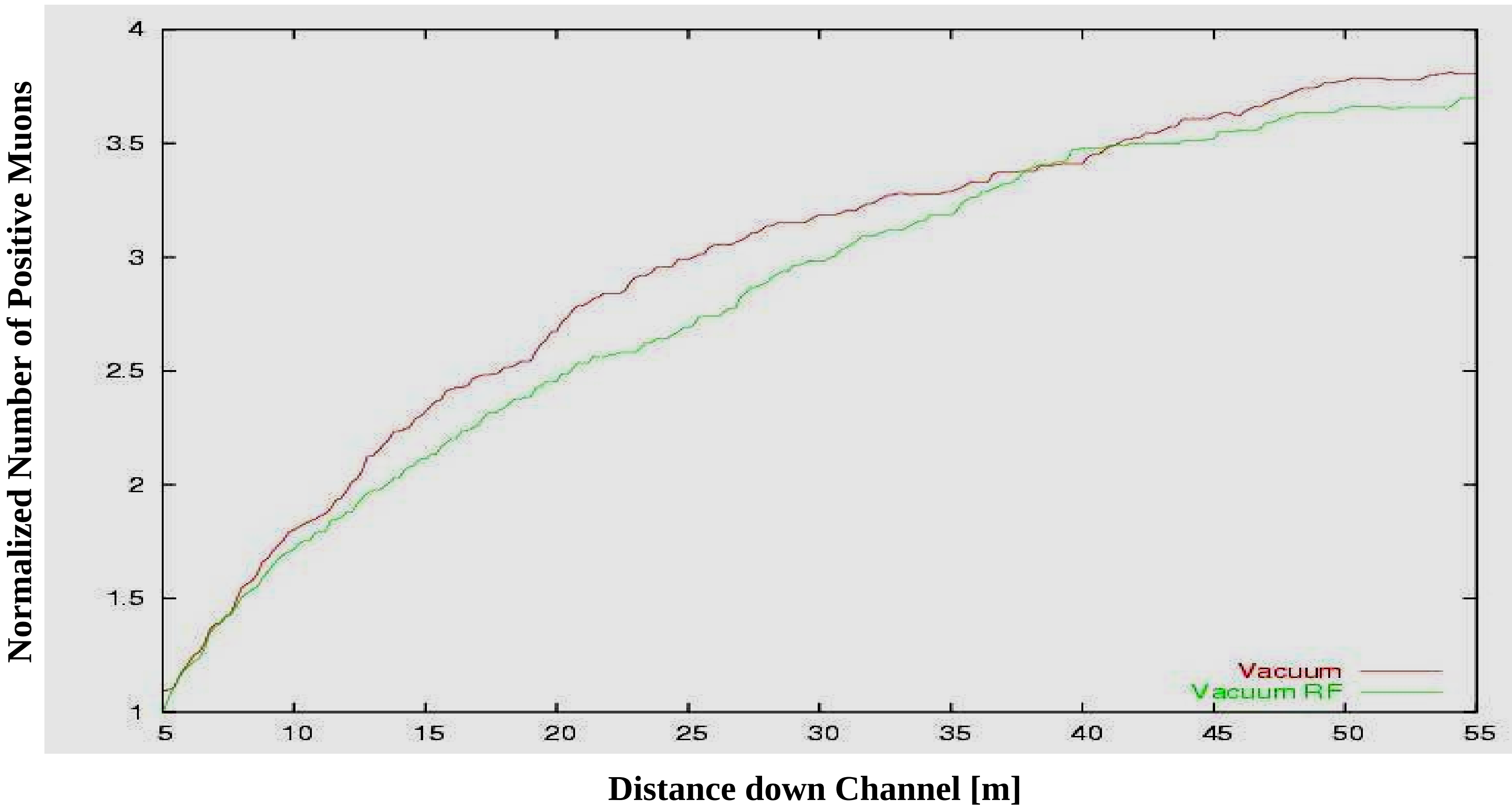
What are the losses due to RF?

Muon Transmission



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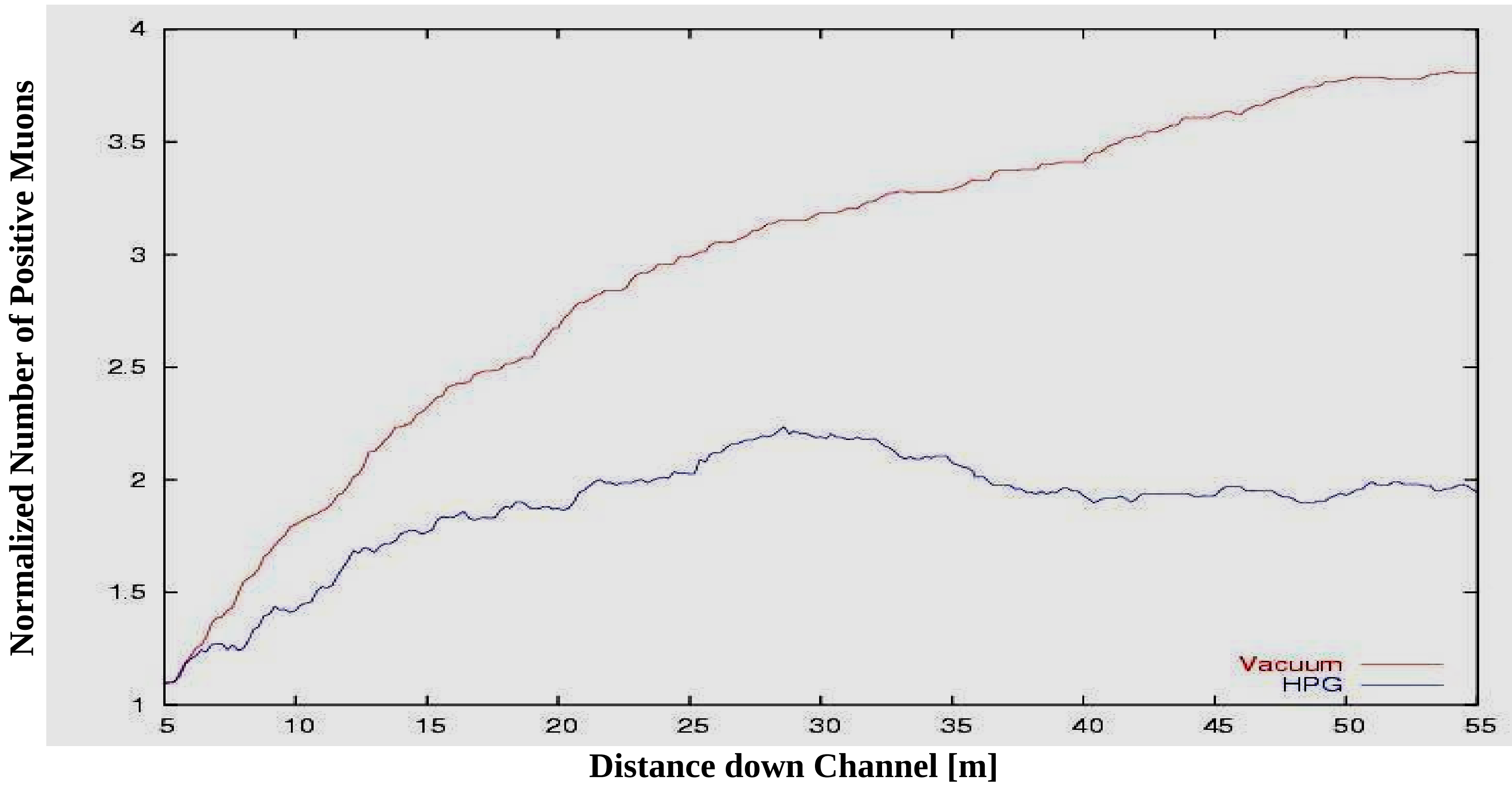
What are the losses due to gas?

Muon Transmission



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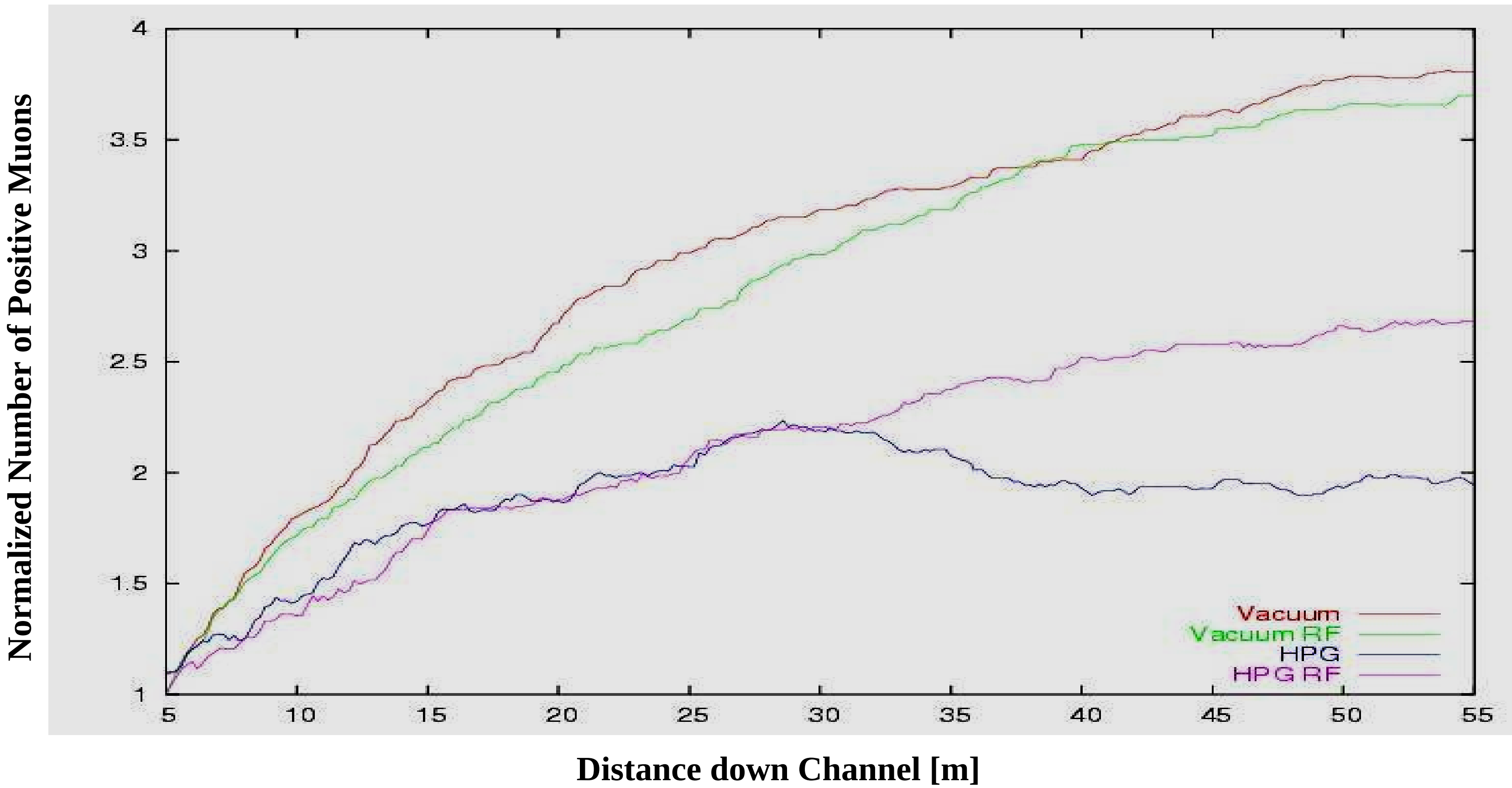
And if we do everything at once?

Muon Transmission



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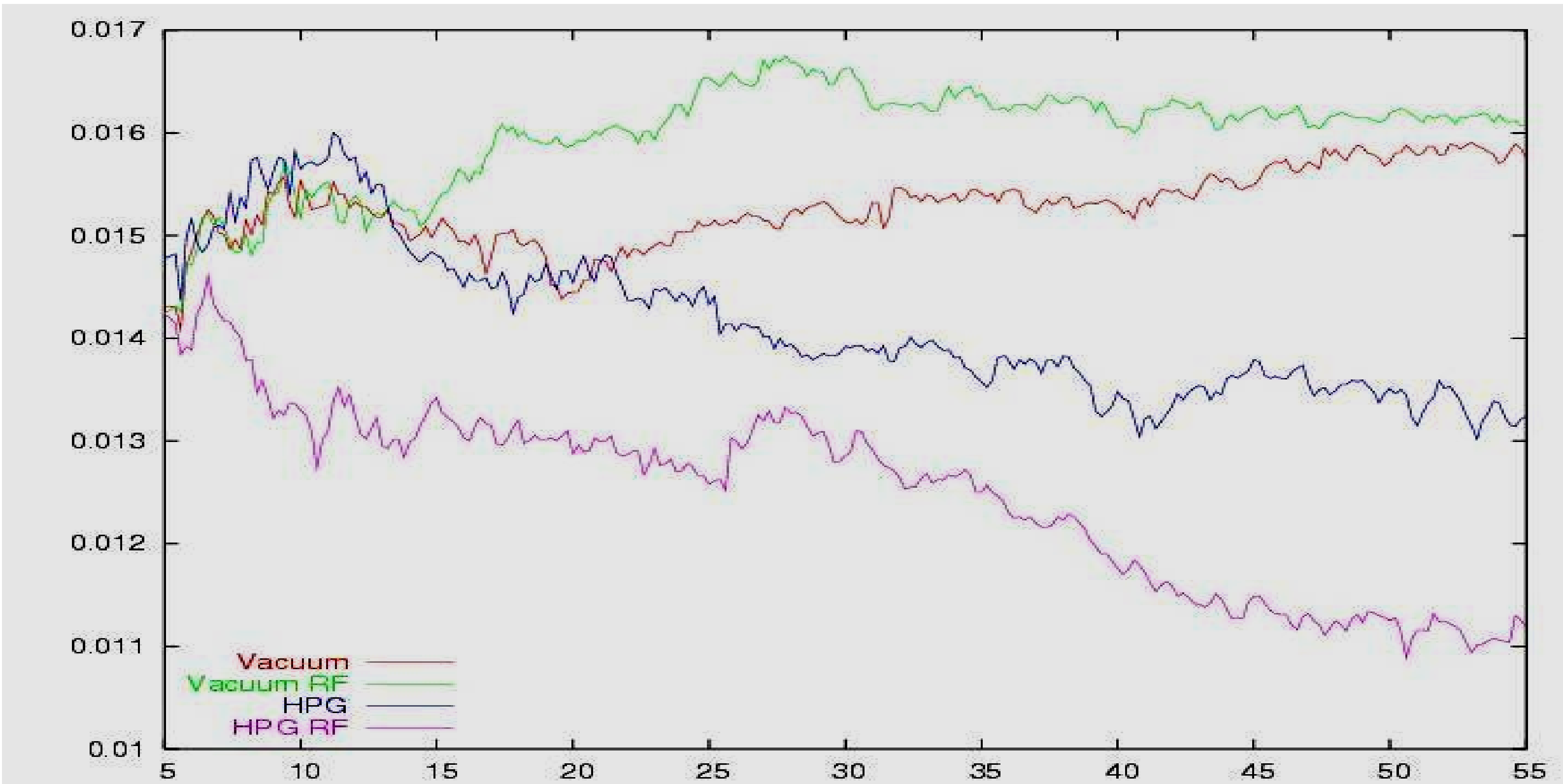
Do we see any cooling?

<u>Muon Transverse Emittance</u>

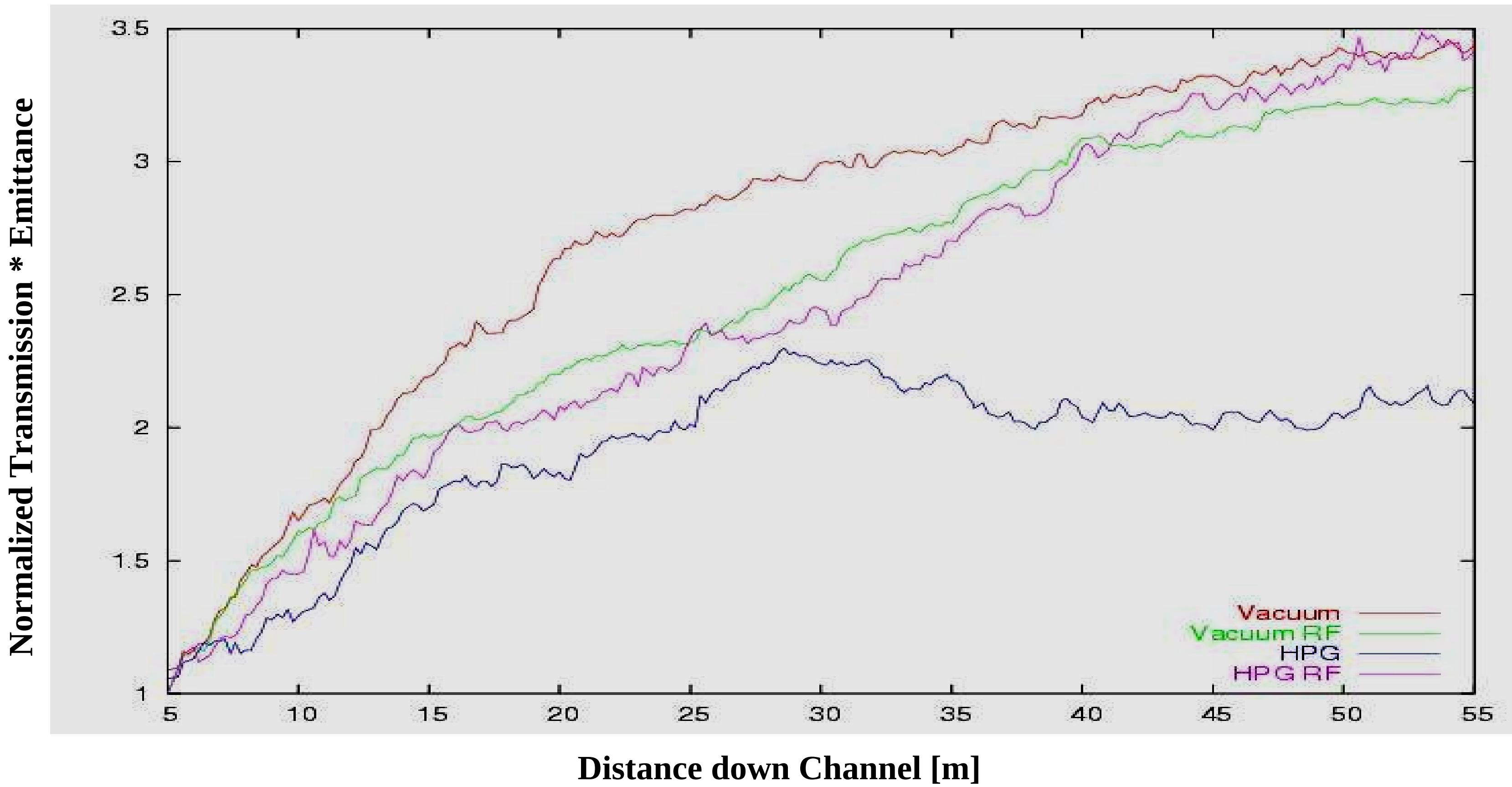


Transverse Emittance [m radian]

Distance down Channel [m]

Is it worth writing home about?

Transverse "Merit Factors"



Phase Rotation

- What do we need to phase rotate initial beam?
  - Large gradient (50 MV/m)
  - Low frequency (50 MHz)
  - *HPG* (100 atm / Room Temp.)
- New problems:
  - Large gradient → Large energy spread
  - Large energy spread → *Large tune spread?*

$$Q_s \sim V^{1/2} E^{-1/2}$$

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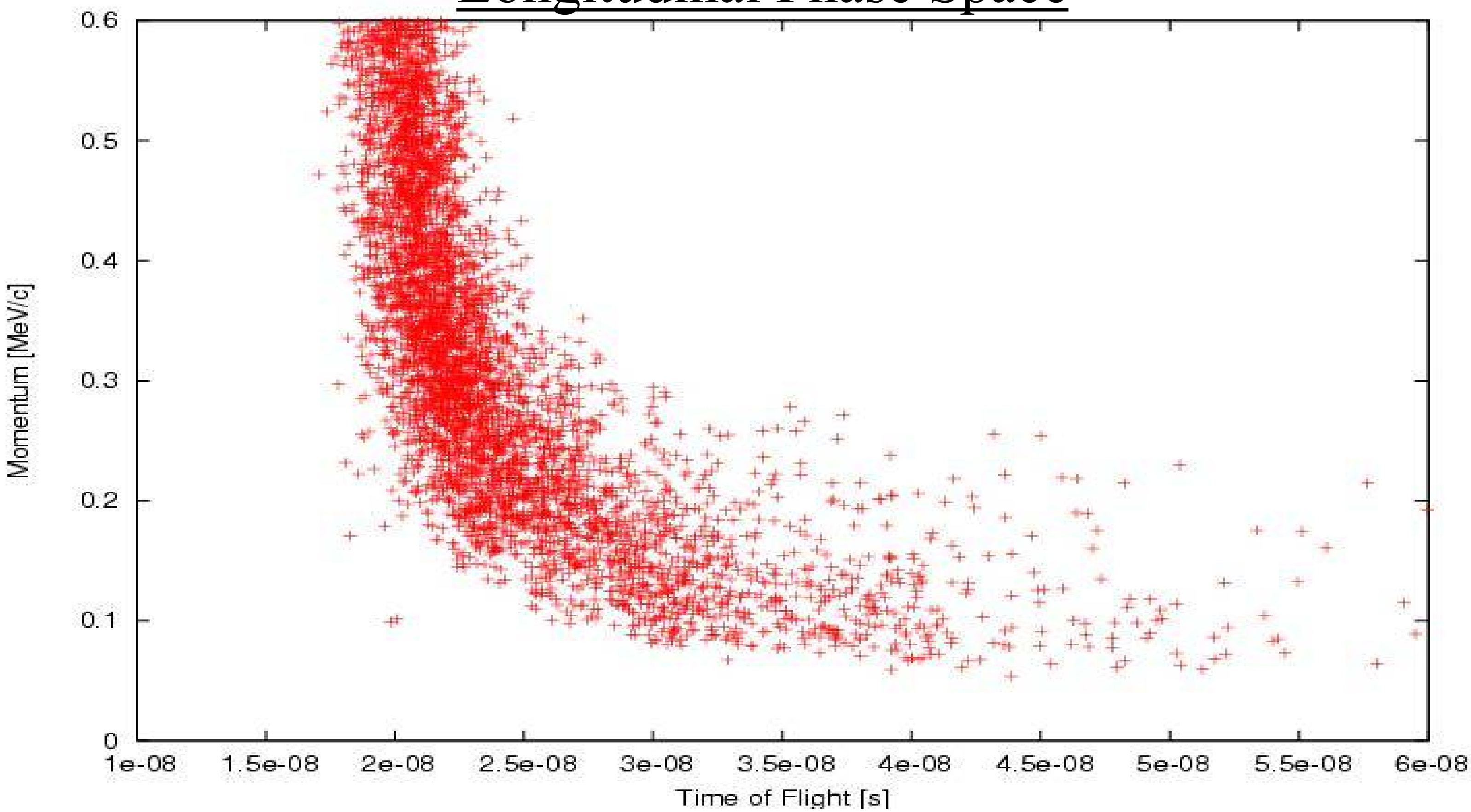
Initial Beam

<u>Longitudinal Phase Space</u>



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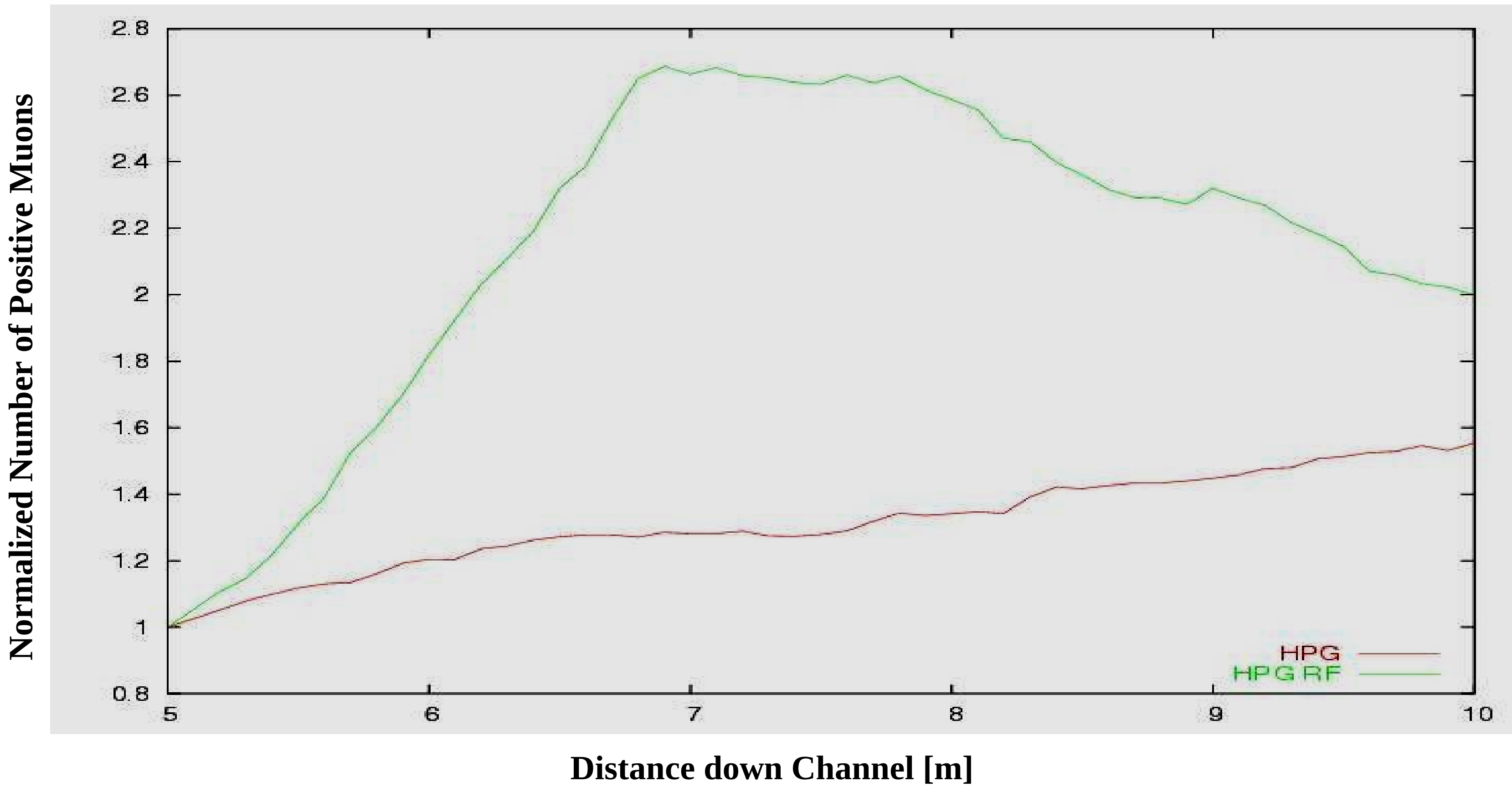
This should to be fun…

- The beam is not ideal for rotation…
  - Enormous energy spread
  - Still a fairly long time spread
  - Strong correlation between energy and time
- But wait…
  - Use the gas to lower the energy via dE/dx loss
  - Move low energy particles up with RF
  - Use reference momentum lower than peak

Well, that's something!

Muon Transmission in the 200-300 MeV/c Momentum Range



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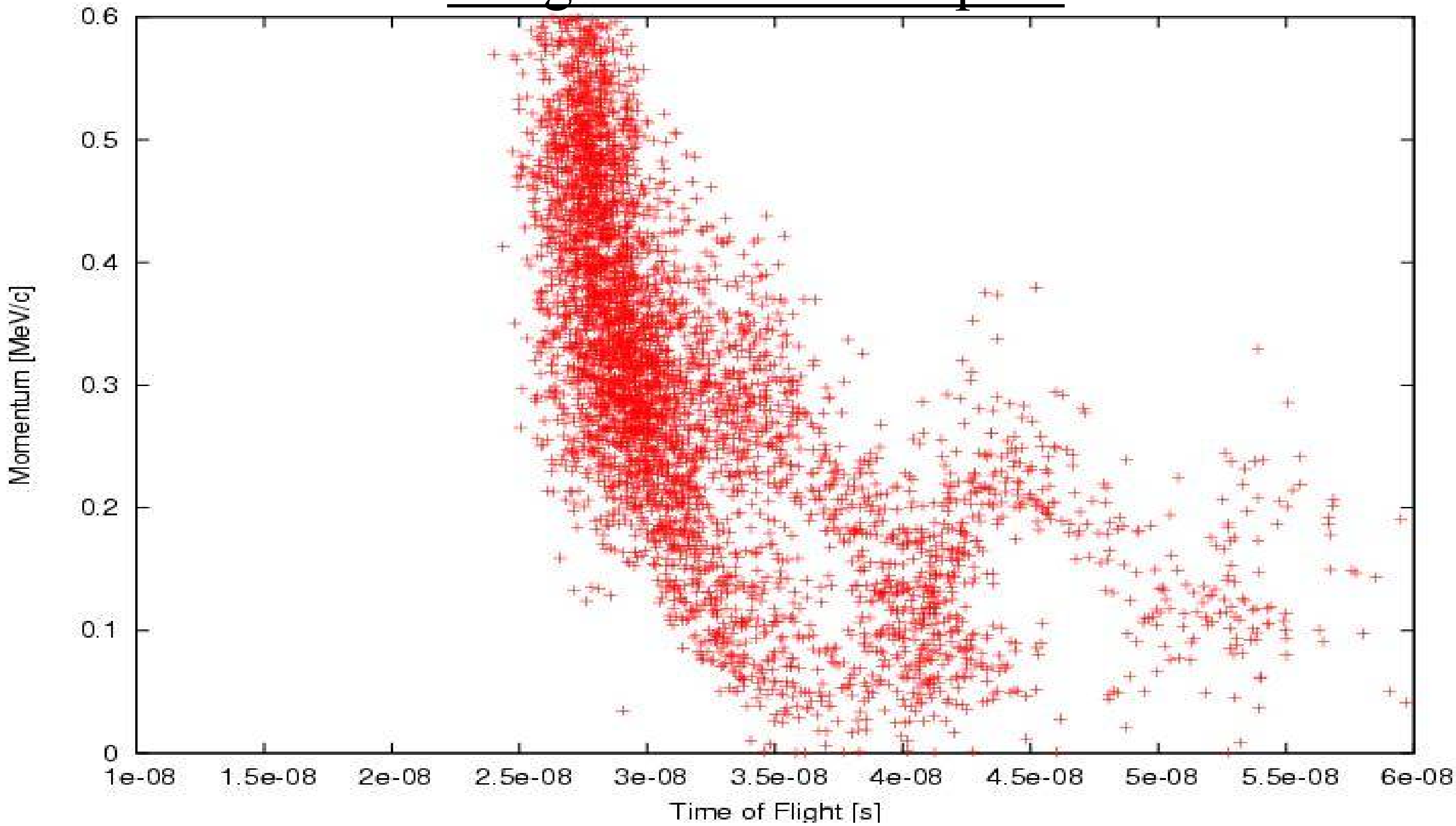
Final Beam (after 2 m)

Longitudinal Phase Space



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Put it all together

- Phase rotation:
  - 50 MHz / 50 MV/m / 0.2 m RF cavities
  - 2 m of transport
- Dump it into RF:
  - 201.25 MHz / 50 MV/m / 0.2 m RF cavities
  - 48 m of transport

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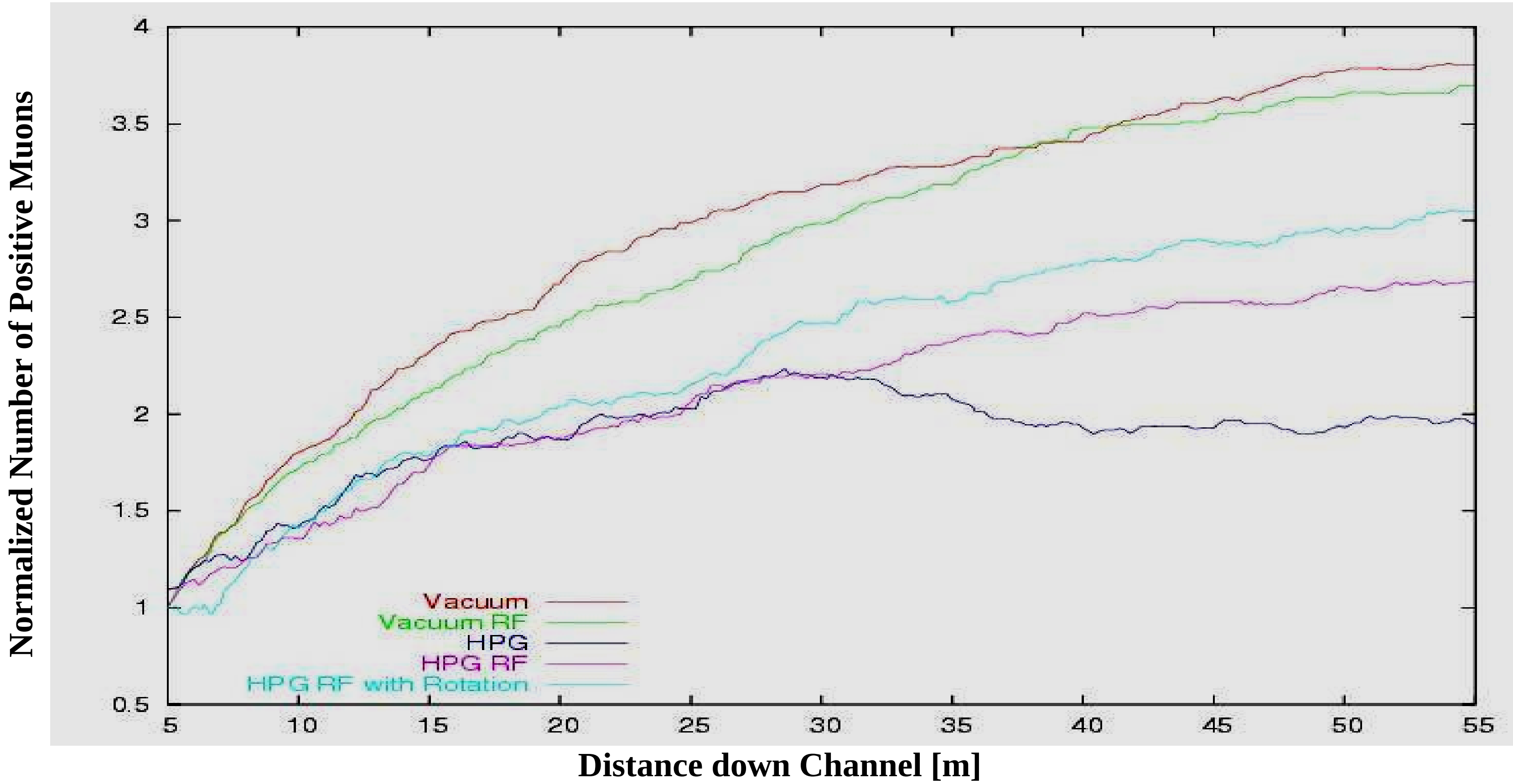
Transmission…

Muon Transmission



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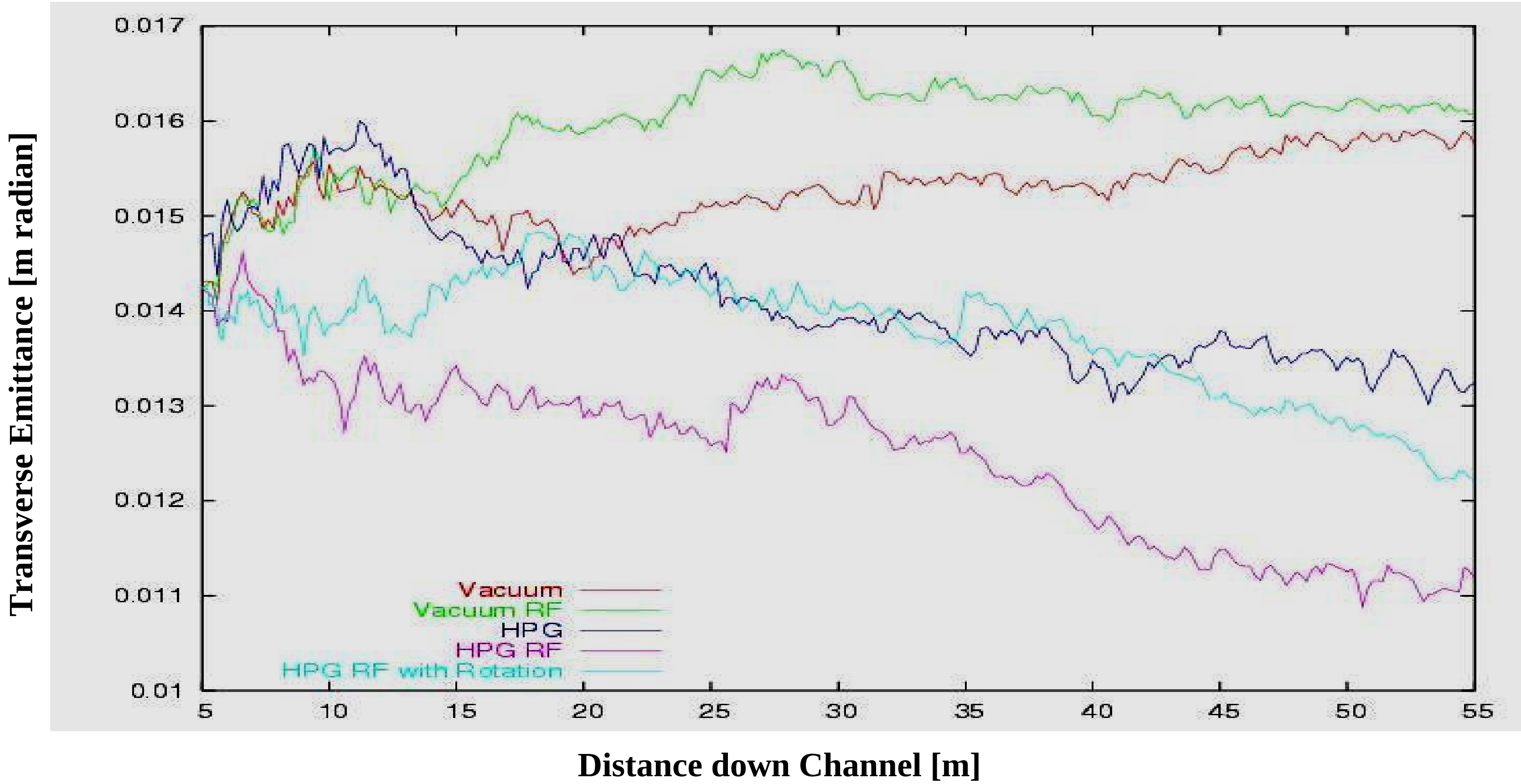
Cooling…

Muon Transverse Emittance



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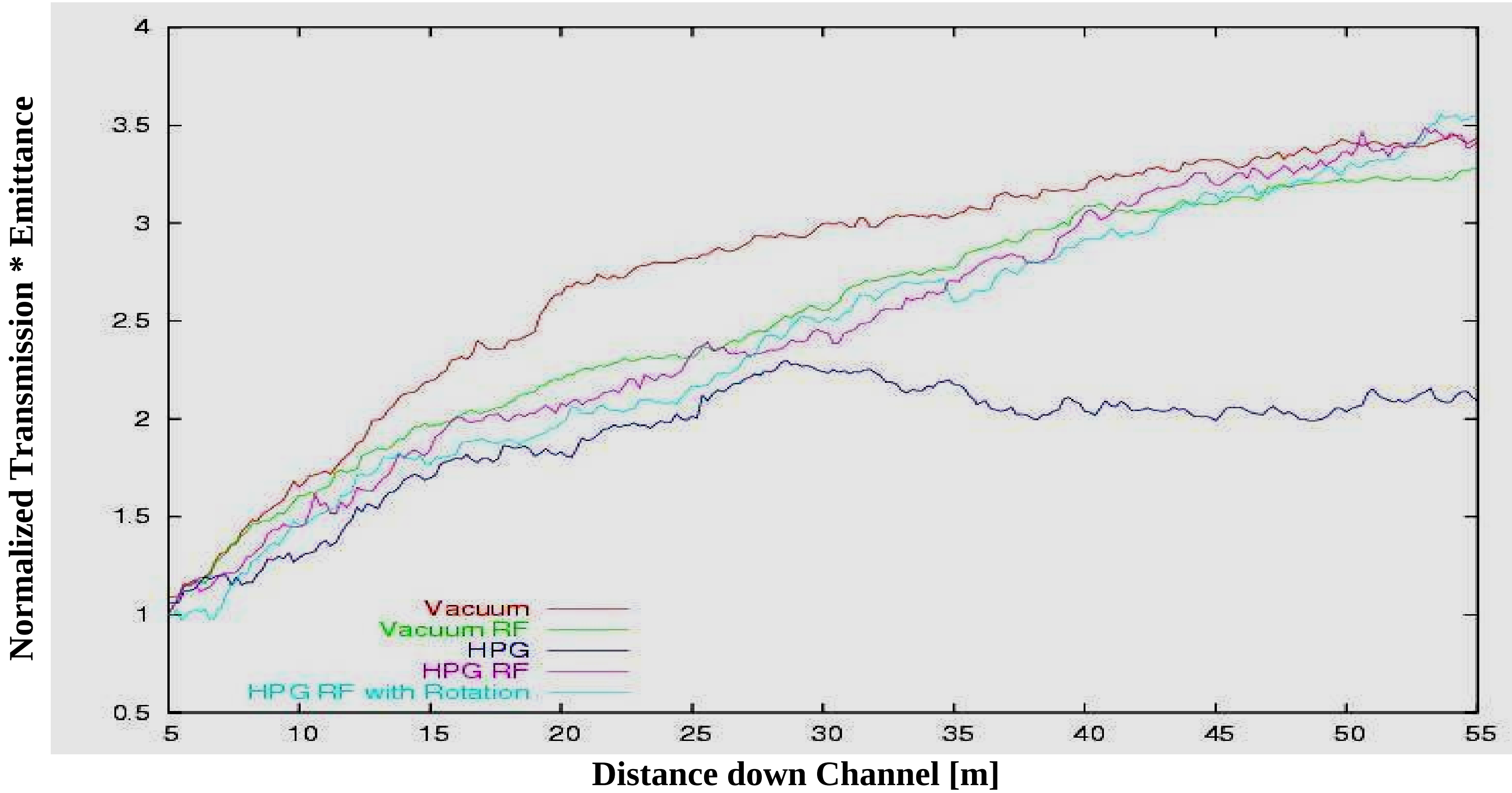
Merit…

Transverse "Merit Factors"



Summary

- HP Gas:
  - Losses are significant, but…
  - Losses may be manageable
- Phase rotation:
  - Difficult, but…
  - Interesting / Useful / Possible?
- Lot's of room for improvement!

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