# Frontend Optimization, Development & Application

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*From work in collaboration with:*

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**Overview:**

- Pion Production, Capture and Decay...

  ...Solenoid-based design

  ...Realistic optimization for Study 2A

  ...Full simulation with MARS and G4Beamline

- Bunching and Phase Rotation: (*ongoing*)

  ...Quadrupole-based design

  ...Designed for the quad-based cooling channel

  ...Full simulation with G4Beamline

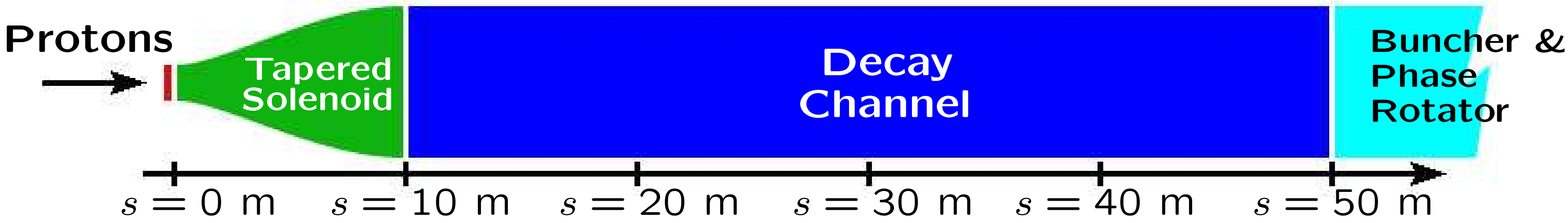
- Fermilab Proton Driver Upgrade...

  ...Applications for neutrino factory technology

  ...Intense decay-in-flight neutrino beams

  ...Combined simulation with MARS and ICOOL

## Pion Production, Capture & Decay:




- Primary beam...

  ...24 GeV protons with a total of 1 MW power

  ...Incident at 67 mrad with respect to the channel axis

- Target region...

  ...1 cm diameter Hg jet at 100 mrad (33 mrad crossing angle)

  ...20 T solenoid around target for pion capture

- Tapered solenoid matching section...

  ...Adiabatic transport into ∼1 T field in decay channel

- Uniform solenoid decay channel...

  ...1.25 T - 2.00 T field for muon capture over ∼50 m

## **Pion Production, Capture & Decay:** *continued*

- Objective...

  ...Optimize muon yields at end of decay channel

  ...Make design as realistic as possible

  ...Drive the cost down as far as possible

- MARS Studies...

  ...Examine Study 2 target design parameters
  (jet-beam crossing angle and jet thickness)

  ...Improve tapered solenoid design
  (functional form and length)

  ...Optimize field strength at target and in decay channel

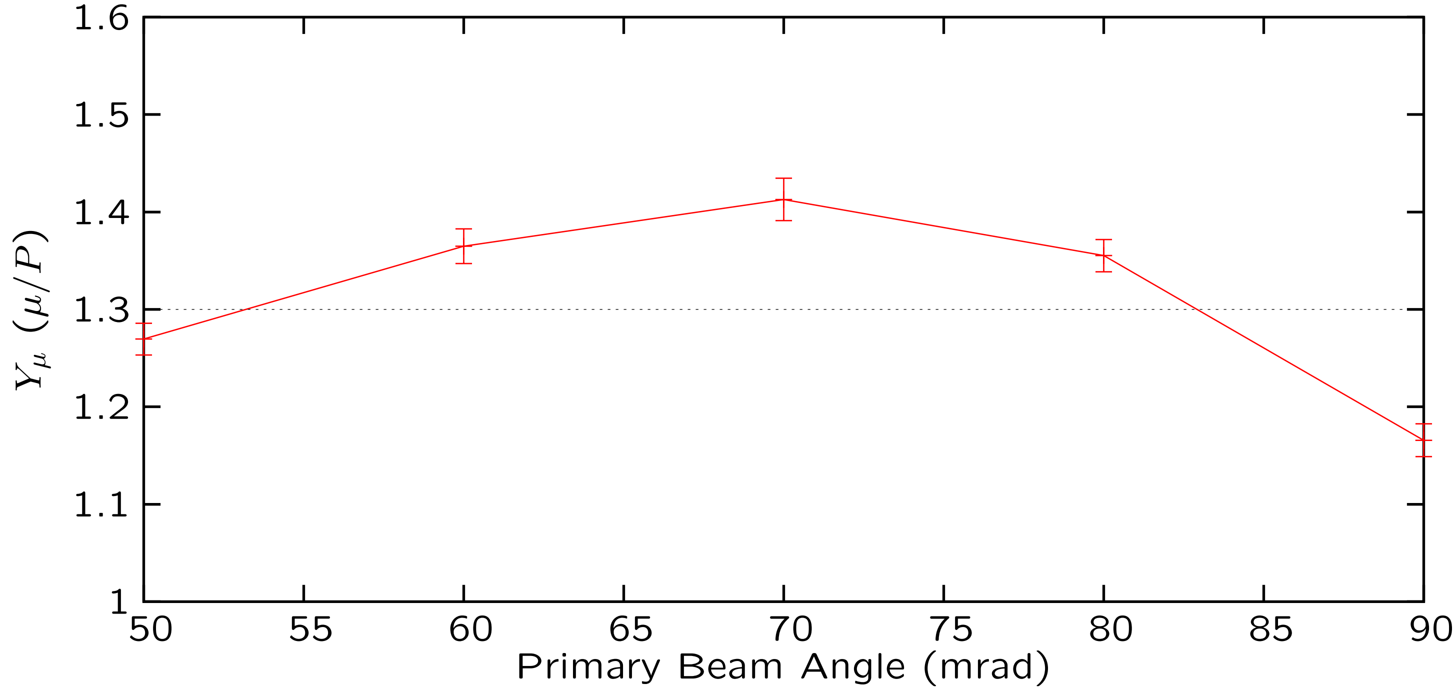
## **Pion Production, Capture & Decay:** *continued*

- Jet-beam crossing angle...

  ...Assume 20 T field at target & 1.75 T in decay channel

  ...100 mrad jet angle and *1.5 cm jet thickness*

  ...Vary primary beam angle



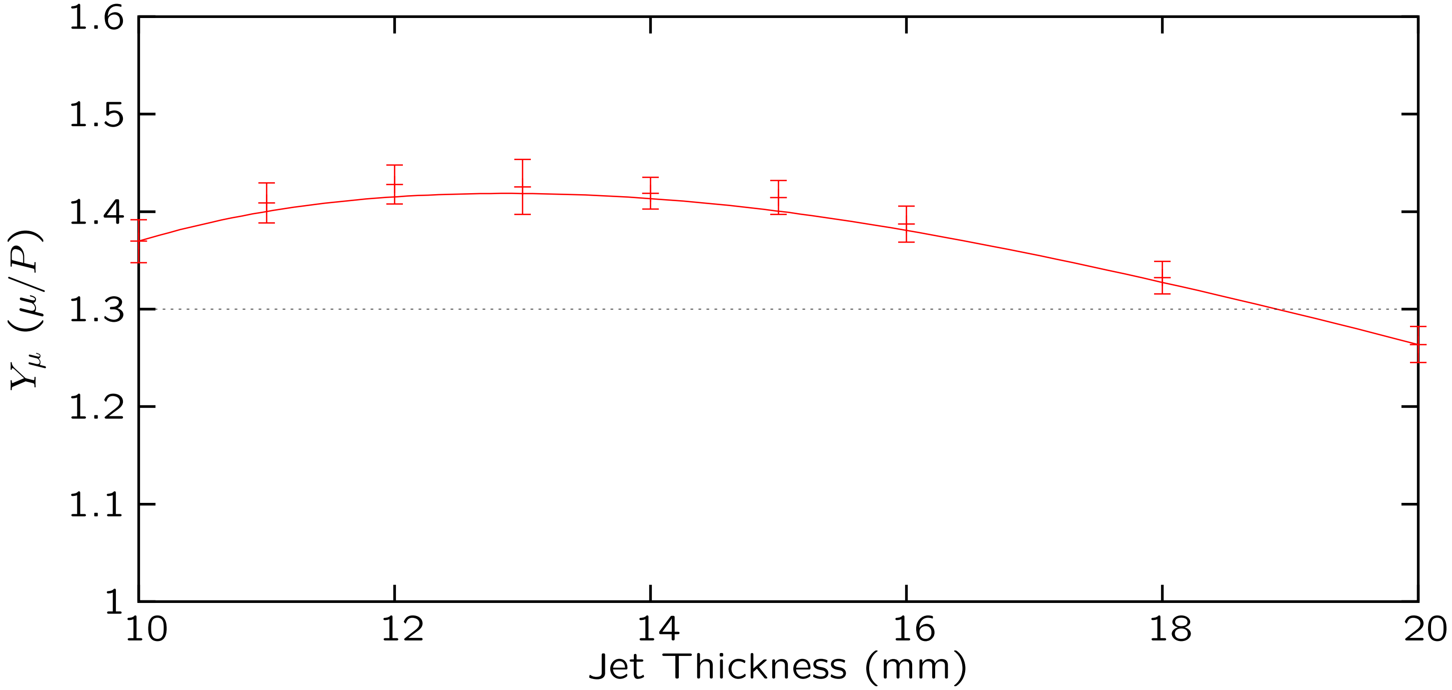
## **Pion Production, Capture & Decay:** *continued*

- Jet thickness...

  ...Assume 20 T field at target & 1.75 T in decay channel

  ...100 mrad jet angle and 67 mrad primary beam angle

  ...Vary the jet thickness



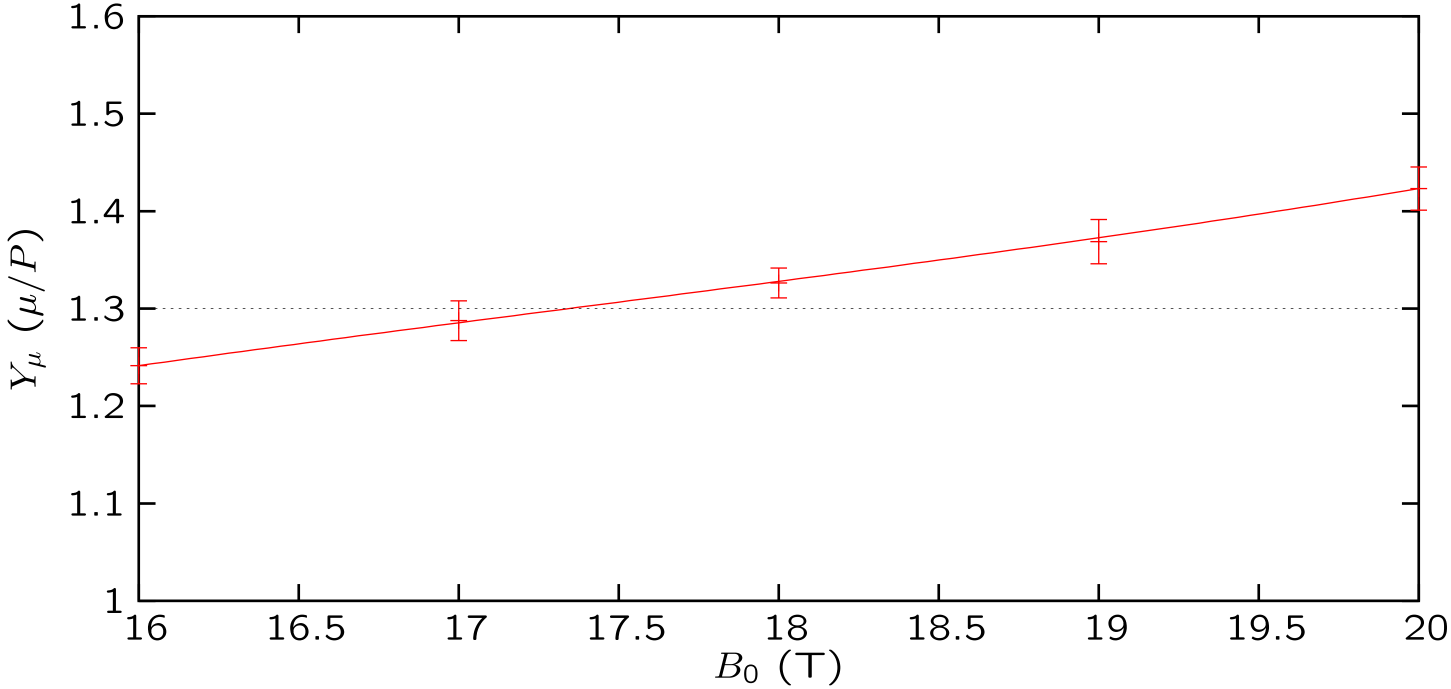
## **Pion Production, Capture & Decay:** *continued*

- Capture solenoid field strength...

  ...100 mrad jet angle and 67 mrad primary beam angle

  ...1.75 T in decay channel and 1.5 cm jet thickness

  ...Vary the field strength at target (constant flux)



**Pion Production, Capture & Decay:** *continued*

- New tapered solenoid design...

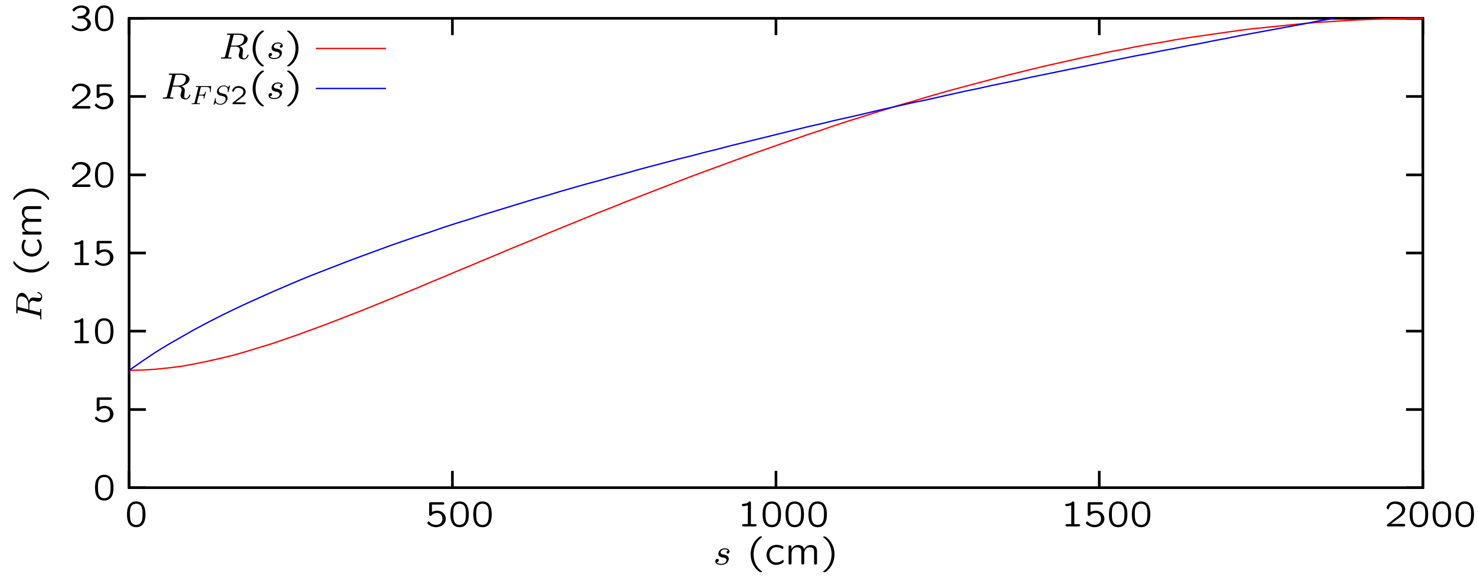
$$R(s) = \sqrt{\alpha_0 + \alpha_1 s + \alpha_2 s^2 + \alpha_3 s^3}$$

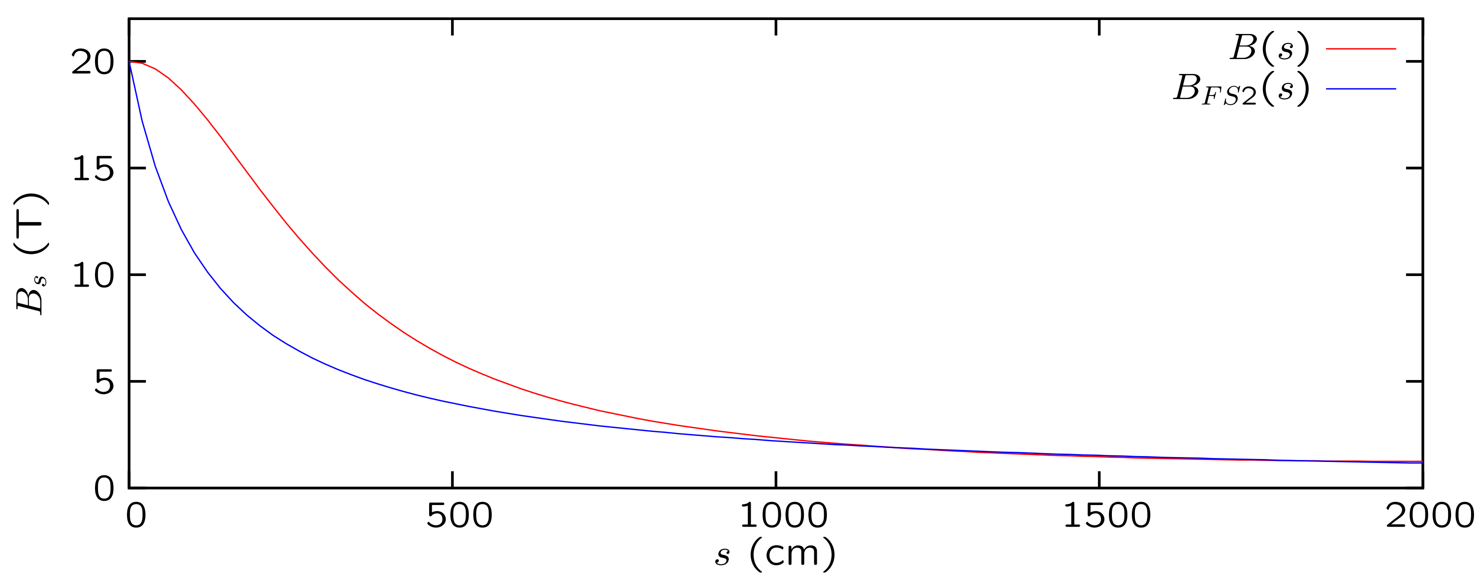
$$B(s) = \frac{\Phi_0}{\pi} \left( \frac{1}{\alpha_0 + \alpha_1 s + \alpha_2 s^2 + \alpha_3 s^3} \right)$$

where:

$$R(s_1) = R_1 \qquad R(s_2) = R_2$$

$$\frac{\partial R}{\partial s}(s_1) = 0 \qquad \frac{\partial R}{\partial s}(s_2) = 0$$


R(s)
R_FS2(s)
R (cm)
s (cm)
0
5
10
15
20
25
30
0
500
1000
1500
2000


B(s)
B_FS2(s)
B_s (T)
s (cm)
0
5
10
15
20
0
500
1000
1500
2000

## **Pion Production, Capture & Decay:** *continued*

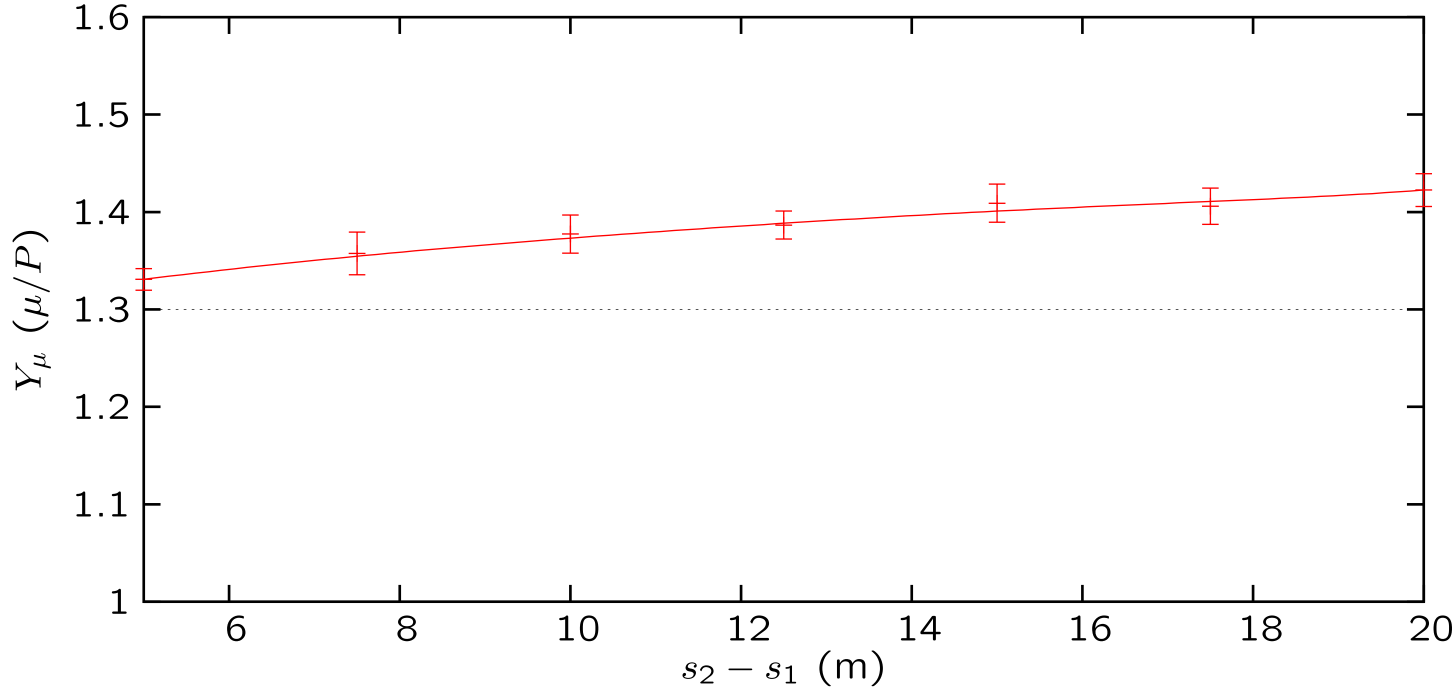
- Tapered solenoid length...

  ...100 mrad jet angle and 67 mrad primary beam angle

  ...20 T at target & 1.75 T in decay channel

  ...1.5 cm jet thickness

  ...Vary the length of the tapered solenoid



**Pion Production, Capture & Decay:** *continued*

- Results...

  ...Jet/Beam angles are optimum in FS2

  *Jet Angle: 100 mrad*
  *Beam Angle: 67 mrad*

  ...Thicker jet will increase yield and (*unfortunately*) instantaneous temperature rise in mercury

  *Jet Thickness: 1-1.5 cm*

  ...Field strength at target can decrease without significant loss in yield

  *Capture Solenoid: 19-20 T*

  ...Improved taper design allows us to decrease the length of the taper without significant loss in yield

  *Taper Length: 12.2 m*

  ...Increased decay channel field strength (PRIOR STUDY):

  *Decay Channel Field Strength: 1.75 T*

## Pion Production, Capture & Decay: *continued*

- Ongoing...

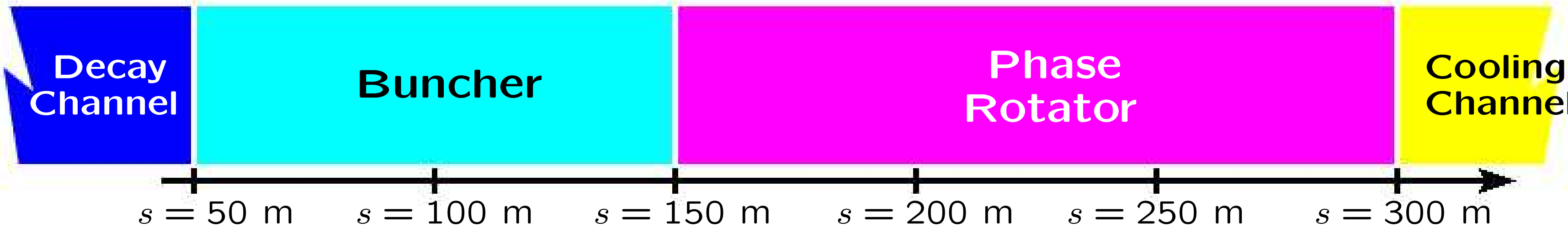
  ...Continued optimization of target

  ...Improved coil configurations for better fits

  ...Downstream simulation in ICOOL (*BNL*)

  ...*Full* simulation in G4Beamline

# Bunching & Phase Rotation:




- Matching Section...

  ...Required to match solenoids into quads

- Buncher & Phase Rotator...

  ...FODO lattice design to match quad cooling channel:

  *Quad Magnet Length: 60 cm*

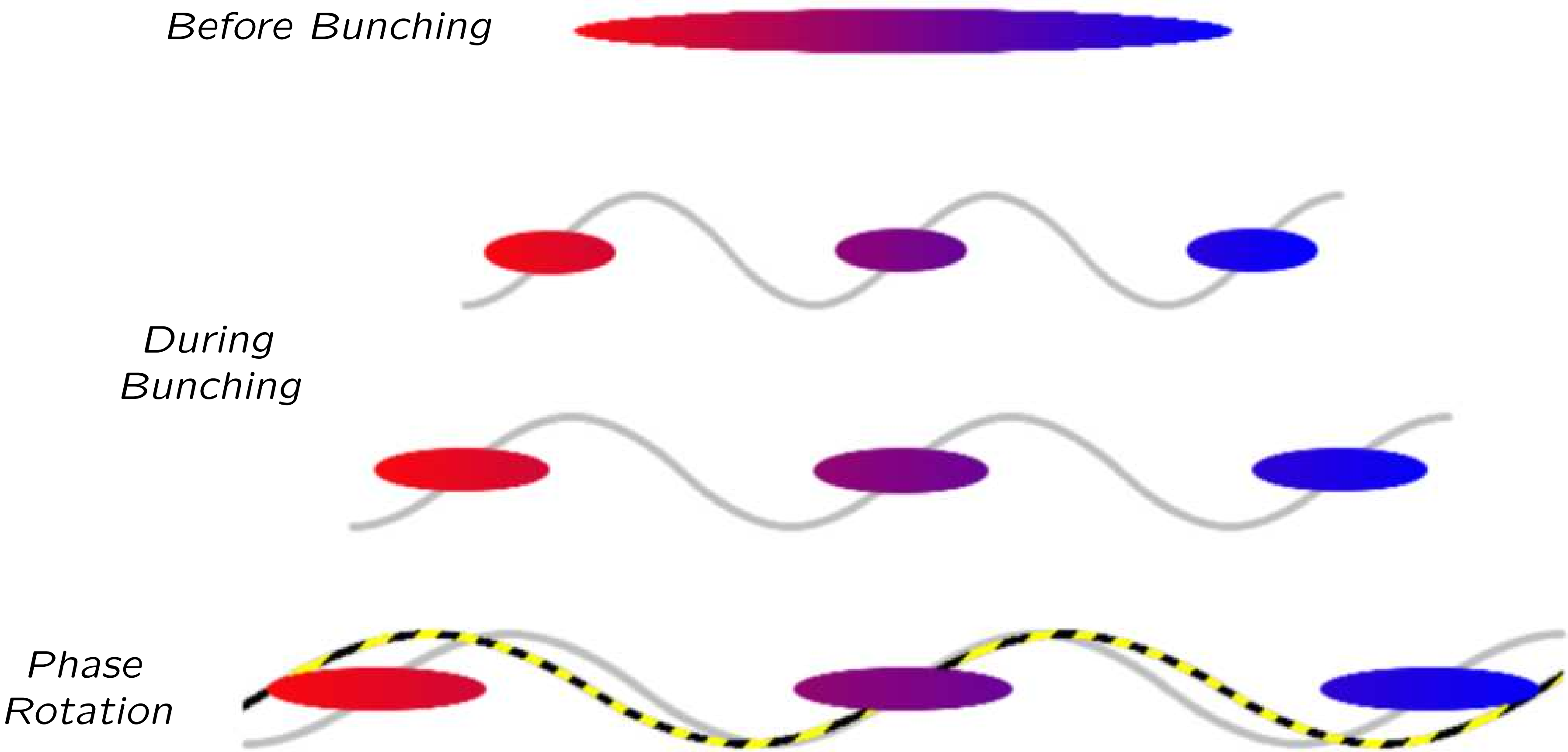
  *Quad Magnet Bore: 60 cm*

  *Quad Magnet Spacing: 40 cm*

  ...Cavity frequencies must decrease as "early" bunches outrun the "late" bunches (pulse lengthens)

  ...Decrease frequency even more so early/late bunches are decelerated/accelerated

## **Bunching & Phase Rotation:** *continued*



## **Bunching & Phase Rotation:** *continued*

- Work is ongoing...

  ...Simple cavity design is complete

  ...Needs to be implimented in G4Beamline

- Collaboration...

  ...Will naturally match into the quad cooling channel
  (Already simulated in COSY by K. Makino)

  ...Buncher & Phase Rotator will be simulated in COSY

  ...Cooling channel will be added to G4Beamline

**Fermilab Proton Driver Upgrade:**

- Objective...

  ...Explore possible low-energy neutrino beam options for a 2 MW proton driver upgrade at FNAL

  ...Uses the large remaining fraction of 8 GeV protons that are not injected in the Main Injector

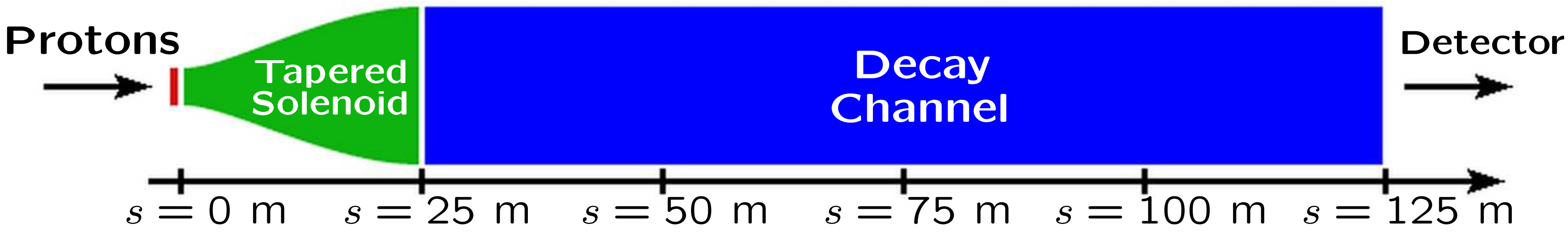
- Explored possibilities...

  ...High-intensity MiniBooNE

  ...Pion/Muon decay-at-rest (DAR) neutrino beams using a large target/beam dump

  ...Pion/Muon decay-in-flight (DIF) neutrino beams using neutrino factory technology

## **Fermilab Proton Driver Upgrade:** *continued*




- Primary beam...

  ...8 GeV protons with a total of 2 MW power

  ...Incident at 67 mrad with respect to the channel axis

- Target region...

  ...1.5 cm diameter C rod at 100 mrad (33 mrad crossing angle)

  ...20 T solenoid around target for pion capture

- Tapered solenoid matching section...

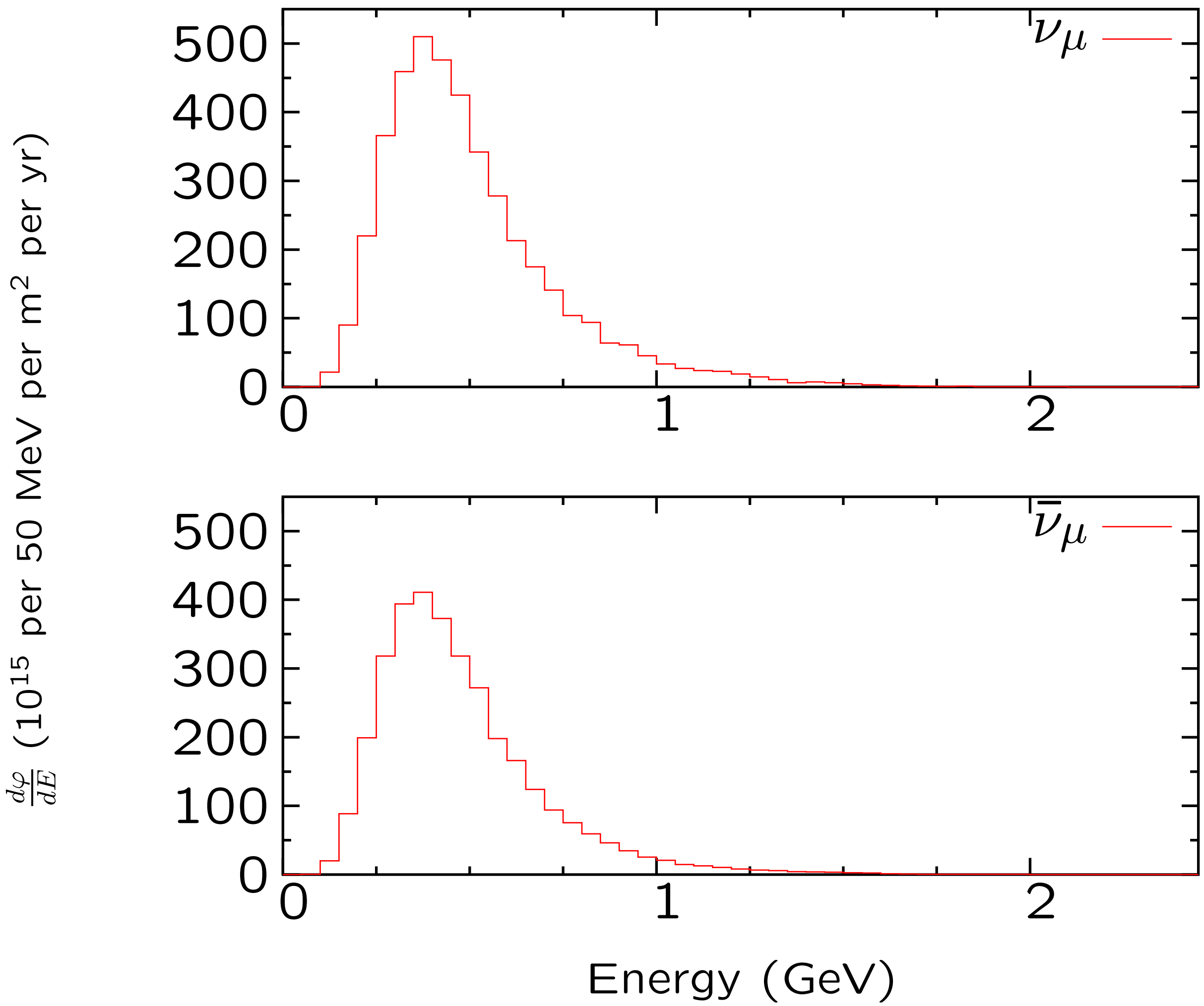
  ...Adiabatic transport into 1.25 T field in decay channel

- Uniform solenoid decay channel...

  ...1.25 T field for muon capture over 100 m

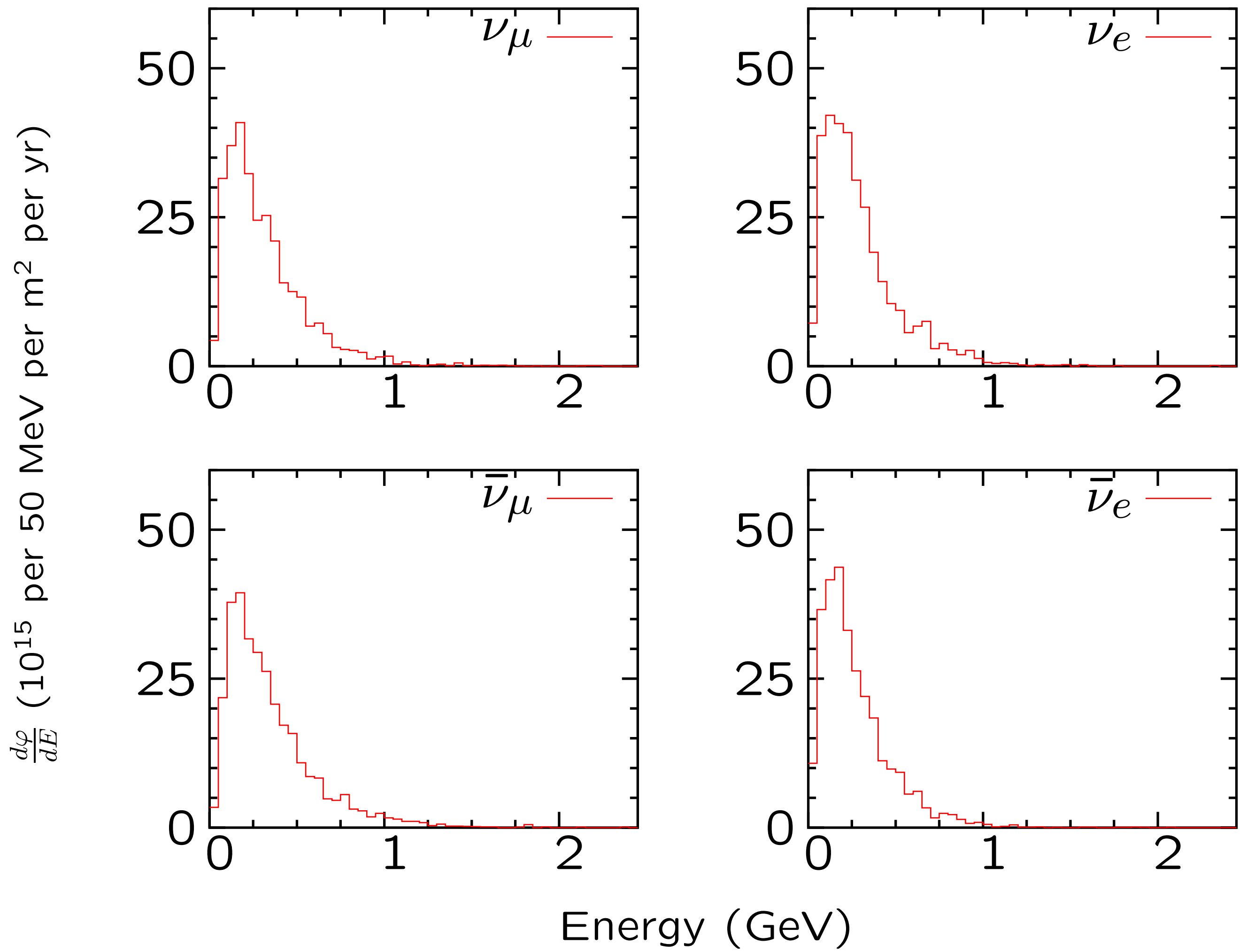
## **Fermilab Proton Driver Upgrade:** *continued*

Neutrino Fluxes from $\pi^{\pm}$ Decays at the Detector with $1.6 \times 10^{22}$ POT at 8 GeV



# Fermilab Proton Driver Upgrade: *continued*

Neutrino Fluxes from $\mu^{\pm}$ Decays at the Detector with $1.6 \times 10^{22}$ POT at 8 GeV



**Fermilab Proton Driver Upgrade:** *continued*

- Work ongoing...

  ...Fluxes have been generated with MARS and ICOOL

  ...Rates will be generated with Nuance for a
  Large-scale MiniBooNE-like detector

  ...Work to be published shortly
  (with S. Brice, S. Geer, and R. Tayloe)