# Neutrino Factory

## Draft #2 Notes For Presentation at St Croix

5/2/99

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In collaboration with E. Keil & C. Johnsen (CERN)

## Contents

# 1 Physics Introduction

NEUTRINO OSCILLATIONS

If Super K is right:

$$\Delta m^2 \approx 3\ 10^{-3}\ (eV^2) \qquad \eta \approx 1$$

K2K and/or NUMI will:

- Confirm
- But will not see "appearance"
- Not know if "sterile"
- Not observe if $\nu_e \ \rightarrow \ \nu_\tau$

SPS May:

- Observe 5-10 $\nu_\tau$'s /year
- Not know if "sterile"
- Not observe if $\nu_e \ \rightarrow \ \nu_\tau$

## NEED PRECISION EXPERIMENT

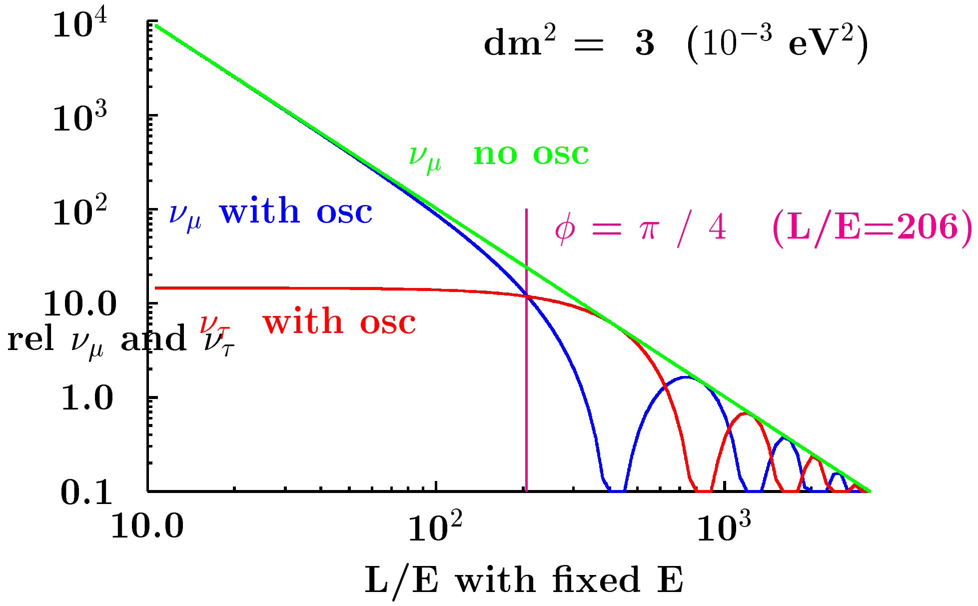
### Determine Maiani Matrix
### (c.f. CKM Matrix & B Factories)

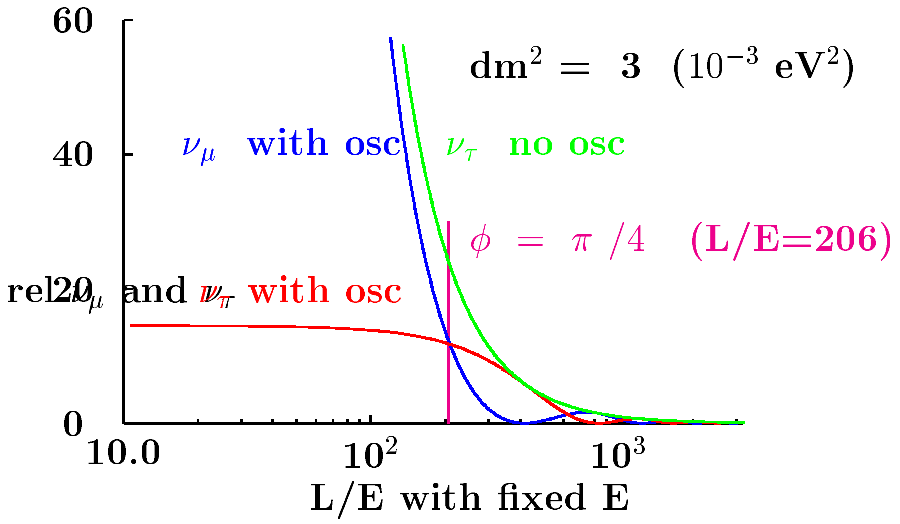
### Muon Storage ring $\nu$ Beam

- AGS is most intense p source
- $\nu$'s 30 $\times$ SPS
- $\nu_\mu$ and $\mu_e$
- Exactly known
- Beam to Gran Sasso and/or Soudan
- Narrower energy spread

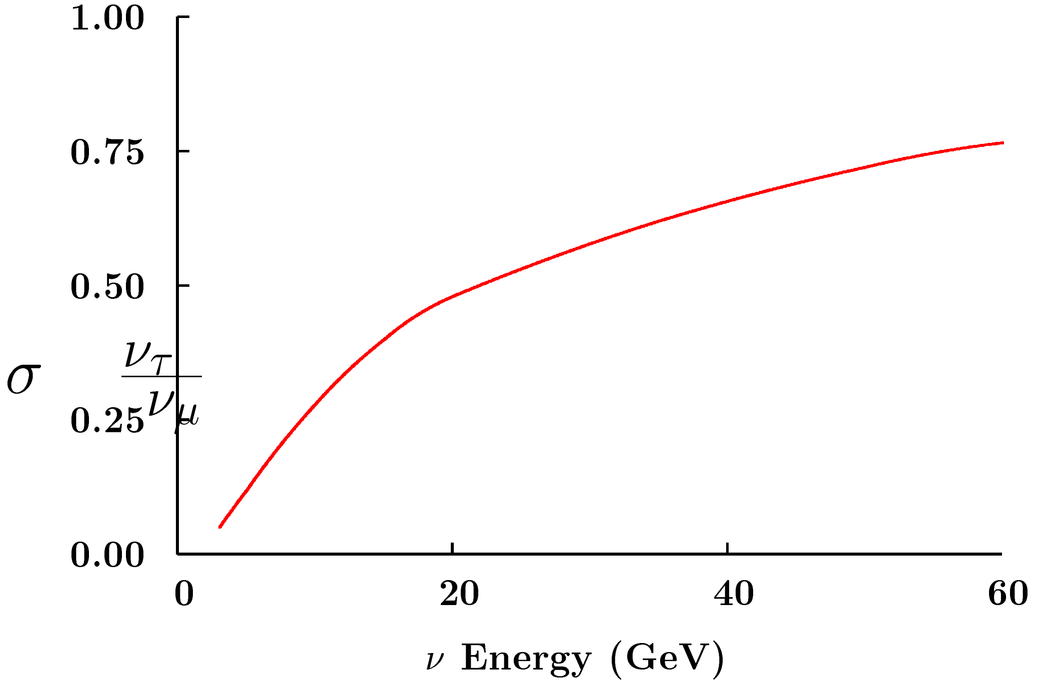
**Event Energy Distributions**

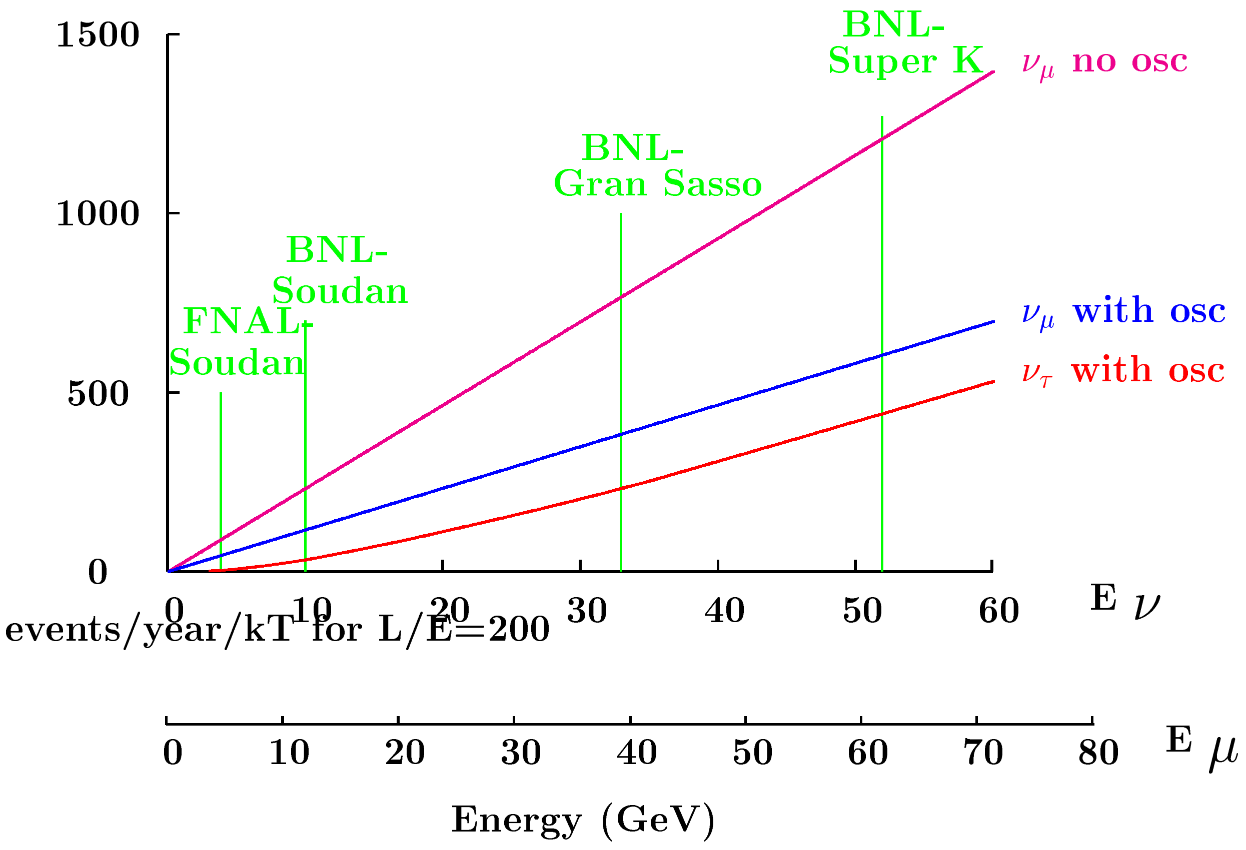
## 2 Choice of Parameters L & E



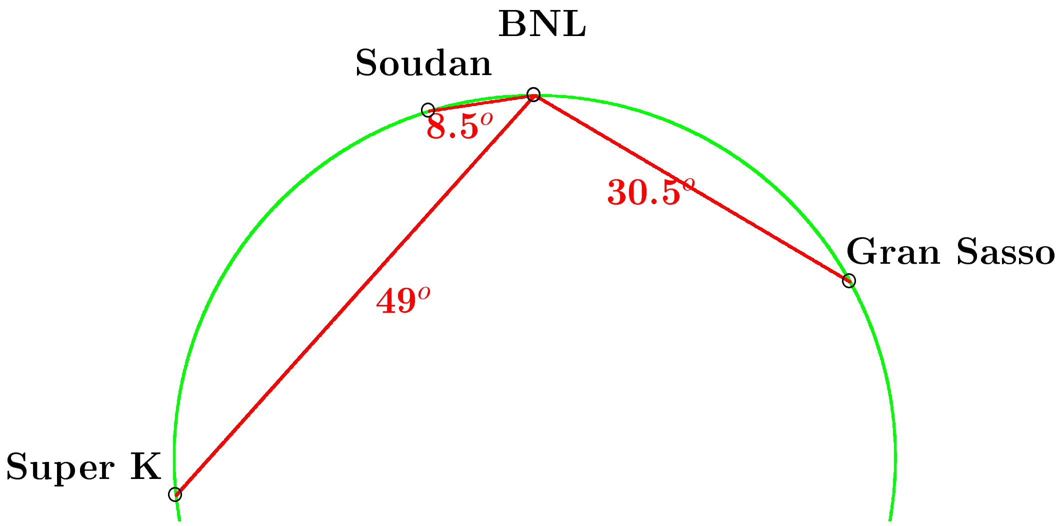
# ENERGY & LENGTH



**Map**

**Angles**



# Events

$$N_{cc\mu} \ \propto \ N_p \ E_p^3 \ L^{-2} \ m$$

**For AGS/PS**
**E=24 GeV**
**Rep=2 Hz**
**N=$10^{14}$ ppp**
**P=0.8 MW**
**$N_\mu/N_p$ = 0.1**
**Year=$10^7$ sec**
**$\mu$'s/year=2 $10^{21}$**

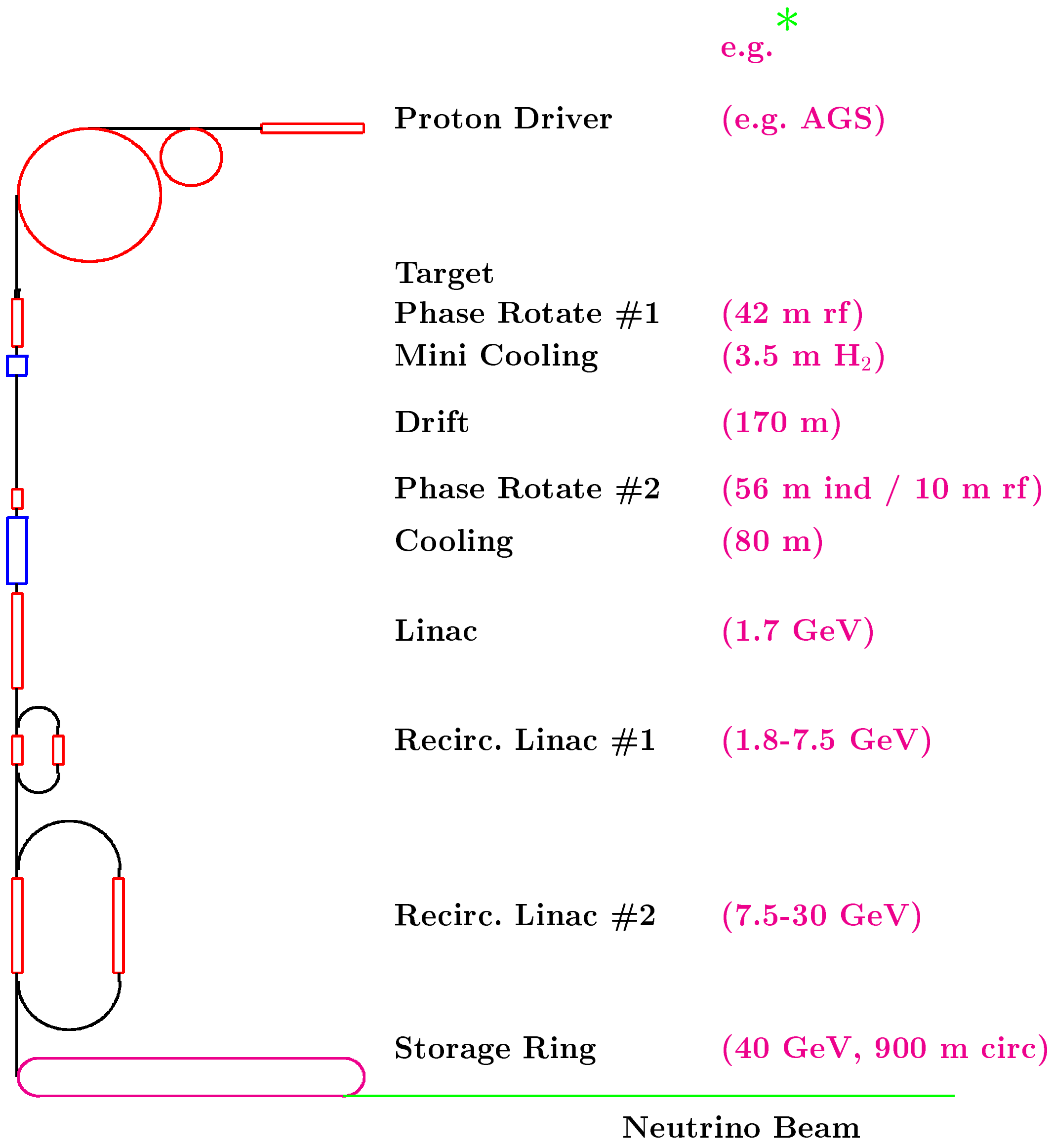
**Scale From Andre Rubbia:**

**Events (BNL-Gran Sasso) per kT year with no oscillations, no polarization.**

$$CC_\mu = 6000 \quad \left(\frac{2}{15}\right)\left(\frac{40}{5.5}\right)^3\left(\frac{730}{6480}\right)^2\left(\frac{1}{4.8}\right) \quad = \quad 800$$

| <E> | GeV | | $\mu$ Ring 32 | | SPS Exp 26 |
|---|---|---|---|---|---|
| | Osc. | BNL-GS $\approx$ FNAL-GS | BNL-S | CERN-GS FNAL-S | CERN-GS |
| km | | 6480 | 1980 | 730 | 730 |
| L/E | | 200 | 62 | 23 | 28 |
| CC $\nu_\mu$ | no | 800 | 8600 | 63k | 1.5k |
| CC $\nu_\mu$ | yes | 400 | 8200 | 63k | 1.5k |
| CC $\nu_\tau$ | yes | 260 | 320 | 320 | 8 |
| CC $\bar{\nu}_e$ | no | 330 | 3500 | 26k | 600 |

## 3 Design of Neutrino Factory




* Very Preliminary Design in Collaboration with Keil & Johnsen (CERN)

# Phase Rotation

| | len<br>m | rad | B<br>T | f<br>MHz | grad<br>MV/m | n/n | $\sigma_{ct}$<br>m | dE/E<br>% | emit<br>$\pi$ mm |
|---|---|---|---|---|---|---|---|---|---|
| target | .45 | .075 | 20 | | | .66 | .3 | 100 | - |
| match | 3 | .2 | 2 | | | | | | |
| rf | 3 | .3 | 1.25 | 60 | 8 | | | | |
| rf | 33 | .3 | 1.25 | 30 | 5 | | | | |
| rf | 7.5 | .3 | 1.25 | 45 | 7 | .35 | 1.8 | 15 | 20 |
| cool 1 | 3.5 | .3 | 1.25 | | | .33 | 1.8 | 15 | 11 |
| drift | 170 | .37 | .6 | | | .28 | | | |
| Ind Lin | 56 | .25 | 1.25 | | 1 | .28 | 20 | 5 | 10 |
| Selected | | | | | | .2 | 13 | 3 | 9 |

Average Polarization = .37 (peak value of .65 for 10% )
dp/p 2 %

# Bunching (not Simulated)

| | |
|---|---|
| freq | 175 MHz |
| $\lambda$ | 1.7 m |
| bunches | 40 |
| $\sigma_z$ | 17 cm |
| rms dp/p | 6 % |
| emit | 9 $\pi$ mm |

# Cooling

| | |
|---|---|
| freq | 175 MHz |
| $\lambda$ | 1.7 m |
| B | 2 T |
| Grad | 15 MV/m |
| Cell | 5 m |
| H2 | .8m |
| cells | 16 |
| length | 80 m |
| $\sigma_z$ | 17 cm |
| rms dp/p | 6$\rightarrow$12 % |
| emit | 9 $\rightarrow$3 $\pi$ mm |

# Acceleration

min E for full sc cells 7.5 GeV
min E for 1/4 sc cells 1.8 GeV

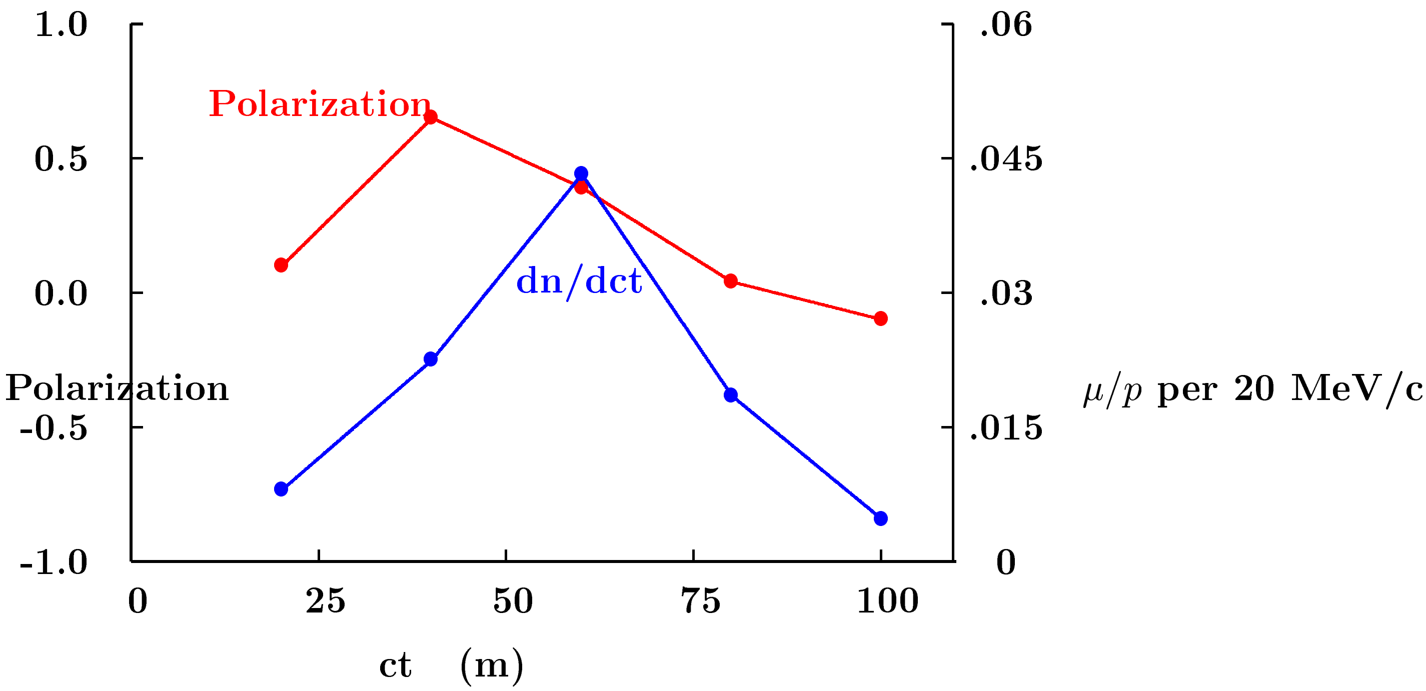
| | | Lin 1 | Lin 2 | Recirc 1 | Recirc 2 |
|---|---|---|---|---|---|
| E | GeV | .1-.6 | .6-1.8 | 1.8-7.5 | 7.5-40 |
| freq | MHz | 175 | 350 | 350 | 350 |
| Grad | MV/m | 15 | 10 | 10 | 10 |
| $\Delta$ E | GeV | .5 | 1.3 | 1.1 | 3.2 |
| n | | 1 | 1 | 4 | 10 |

# Muon Budget

| | Factor | $\mu$/p |
|---|---|---|
| Pions after Match (< 1 GeV, forward) | | 0.66 |
| After Phase Rotation #1 (selected) | 0.45 | 0.3 |
| After Phase Rotation #2 (selected) | 0.7 | 0.21 |
| After RF Capture | 0.7 | 0.15 |
| After Cooling | 0.9 | 0.13 |
| After Acceleration | 0.7 | 0.92 |

Polarization vs. position along the bunch train

File nu5: $\mu/p$=.21 P=.37



## Efforts relative to Collider

| | |
|---|---|
| p Source | Minor Upgrade |
| Target | 1/5 Power of Col |
| Capture | Same as Col |
| Phase Rot #1 | Same as Col |
| Phase Rot #2 | Same ? |
| Cooling | 1/25 vs 1/1000000 |
| Acceleration | $\approx 1/2$ |
| Storage Ring | Angled Down |

- $\approx$ half cost of Higgs Collider
- Demonstrates all components of Collider
- Upgradeable to Collider

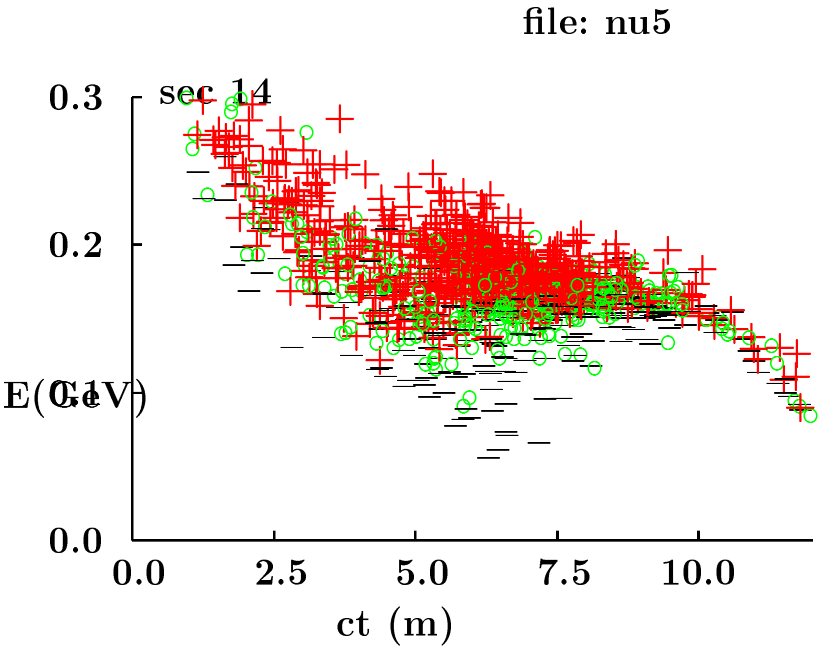
# 4 Appendix: Simulations of Capture and Phase Rotations

## Using Program MCM

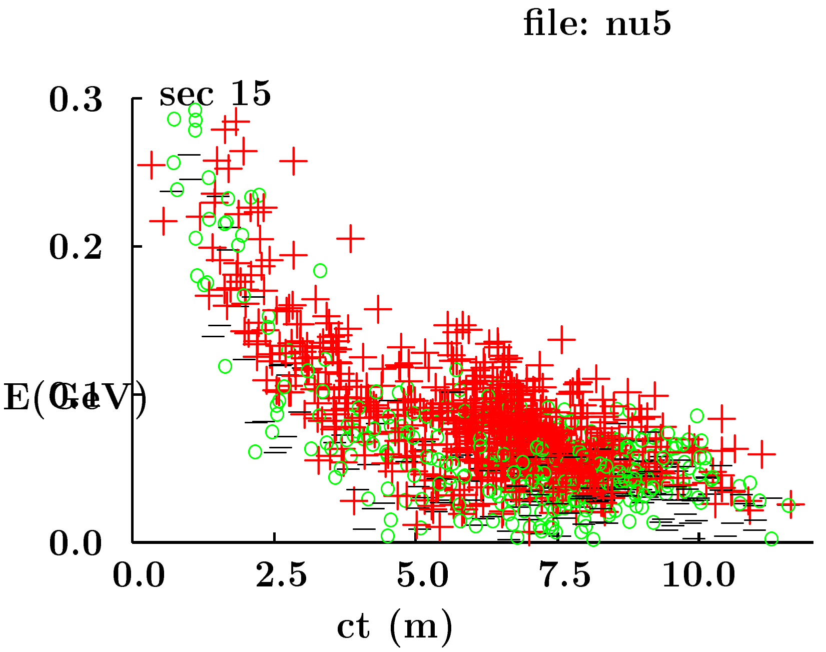
Color and symbols indicate Polarization:

| | |
|---|---|
| red + | P > .3 |
| green o | .3 > P > -.3 |
| black − | -.3 < P |

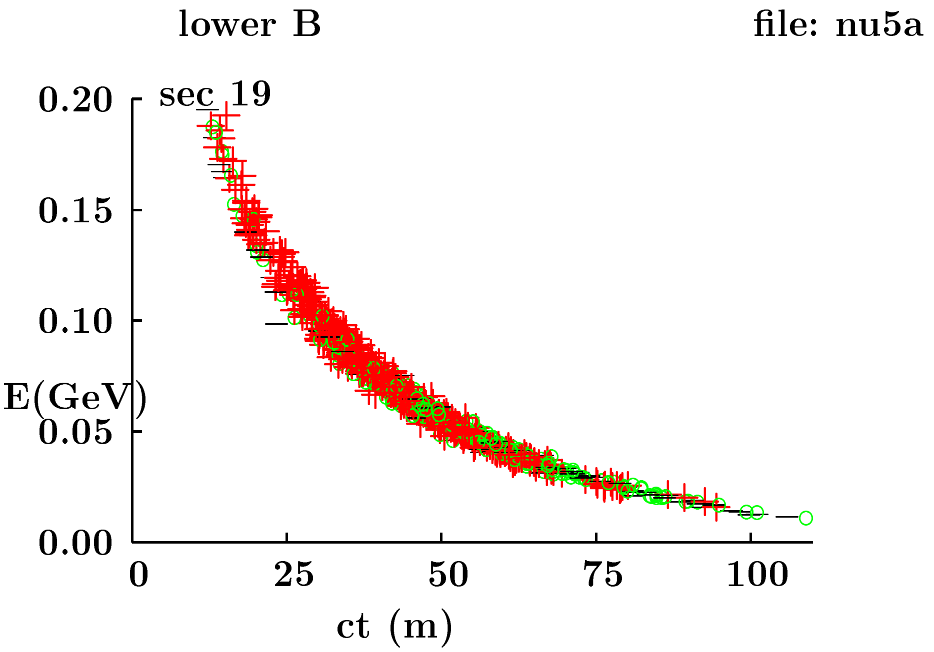
After First Phase Rotation:



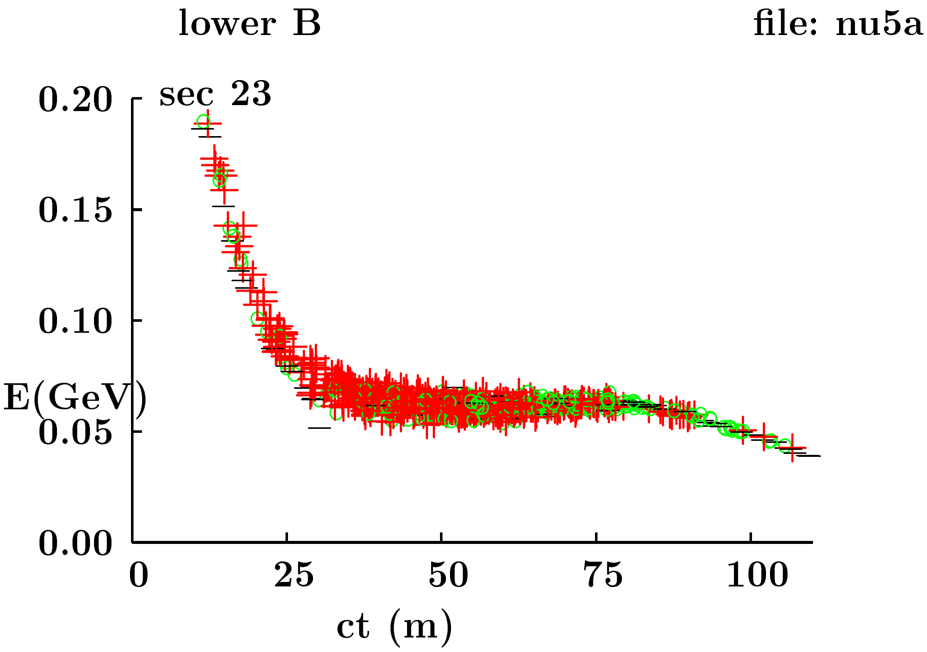

After 3.5 m of Hydrogen:



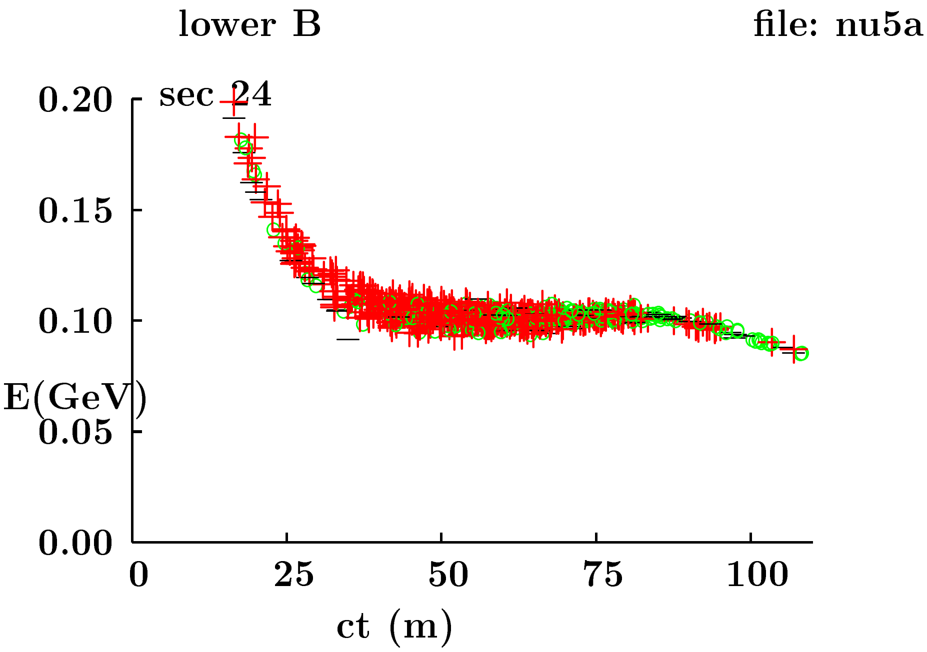

After 160 m Drift:



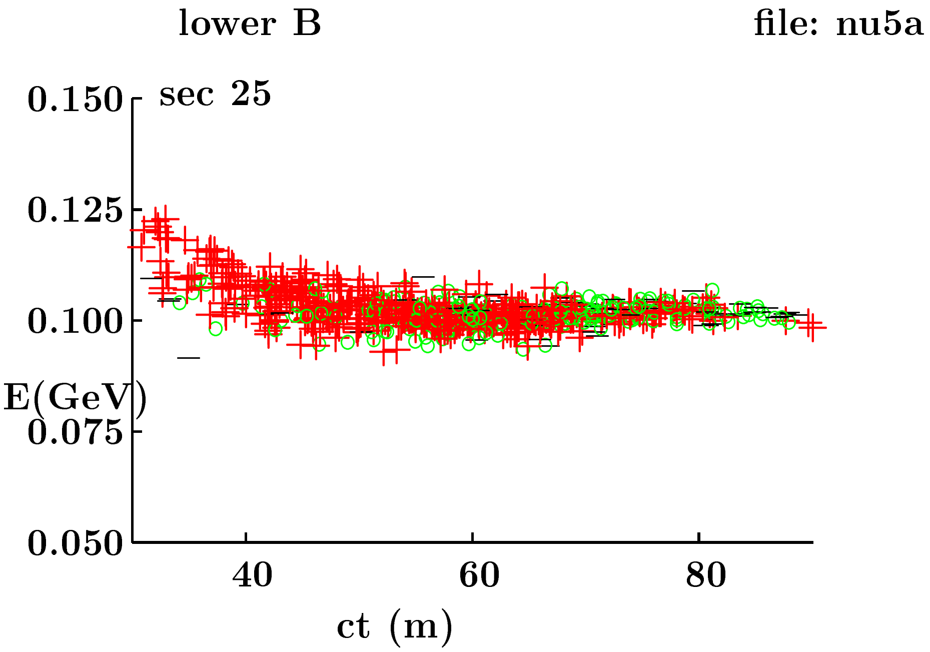

After rf to correct energy:




After Acc to 100 MeV




Selected region of ct:



lower B
file: nu5a
sec 25
0.150
0.125
0.100
E(GeV)
0.075
0.050
40
60
80
ct (m)