Measuring Neutrino Cross–Sections and Neutrino Detector R&D at the Fermilab Antiproton Debuncher

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Summary

Motivation

The Fermilab Antiproton Debuncher is a 8.9 GeV/c storage ring with three long straight sections.

In normal operation, the Debuncher has muons (as well as antiprotons) circulating.

We should consider using the Debuncher as a "poor mans" Neutrino Factory to:

1. Measure electron−antineutrino cross−sections
2. Investigate the performance of candidate detector technologies for Superbeams and Neutrino Factories
3. Study the backgrounds that are important for long baseline ν_e appearance searches

Acknowledgments

Mario Campanelli's talk at NUFACT01 on building a dedicated low energy muon ring for neutrino cross−section measurements at the CERN SPL.

The Fermilab P−860 proposal to use the Debuncher to provide a beam for a neutrino oscillation search. Insufficient intensity for this, but the P−860 work provides a database for a quantitative assessment of the neutrino flux at the Debuncher.

Debuncher Characteristics

Momentum:	8.9 GeV/c
Momentum acceptance:	+– 2%
Transverse acceptance:	25π mm–mrad
Circumference:	~500 m
Straight Section Length:	~65 m
N_μ / $N_{antiproton}$	1.0 +– 0.2
Antiproton rate	~4 x 10^{11} / hour
$\gamma\tau_\pi$	~ 1 turn
$\gamma\tau_\mu$	~ 117 turns
T_P (μ–spin precession period)	~20 turns

With 4–years of data taking there would be
6 x 10^{14} muon decays in a given straight–section

Fluxes and Event Rates

Consider a 0.1 kt detector placed 15m downstream of the end of a Debuncher straight section.

Beam contained within a fiducial area with a radius of ~1m.

For a first estimate scale event rates in P−860 proposal:

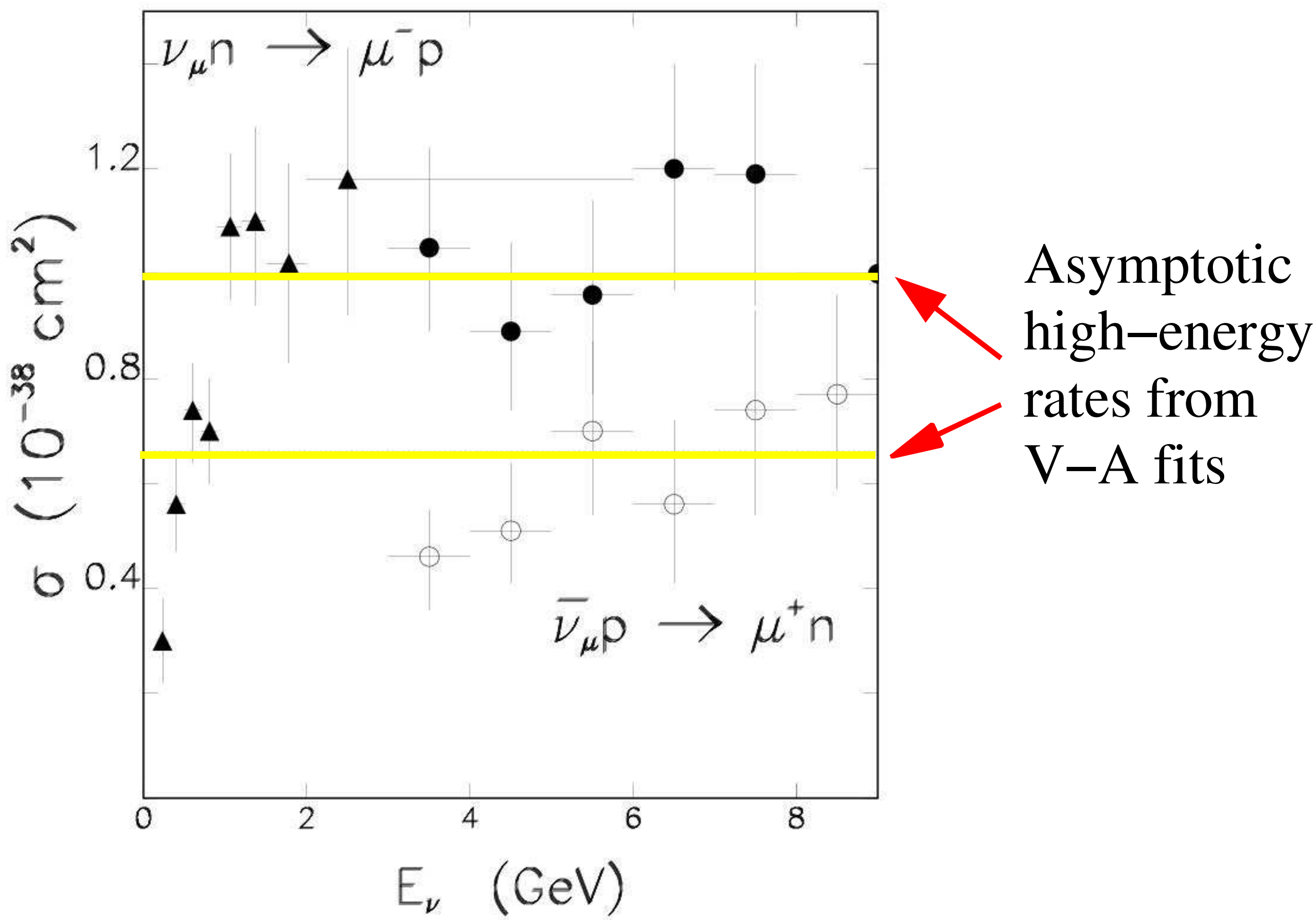
Process	Events / 0.4 kt−years
$\bar{\nu}_e$ (all)	6330
$\bar{\nu}_e$ (QE, SP only)	1440
ν_μ (all)	14500
ν_μ (QE, SP, DEEP)	4370
$\bar{\nu}_\mu$ (p decay)(all)	181000
$\bar{\nu}_\mu$ (QE, SP)	54600

Notes: (i) assumes $\sigma(\bar{\nu}) / \sigma(\nu) = 0.5$ for all rates ... not quite right
(ii) includes detector efficiency factor = 0.75

Quasi–Elastic Scattering

Existing measurements are sparse & have low statistical precision:

S. Barish et al, PRD 16 (1977) 3103
J. Brunner et al., Z. Phys. C45, 551 (1990)



The antineutrino QE cross–sections are known with a precision of ~30% in each 1 GeV bins ... based on a sample of 159 events.

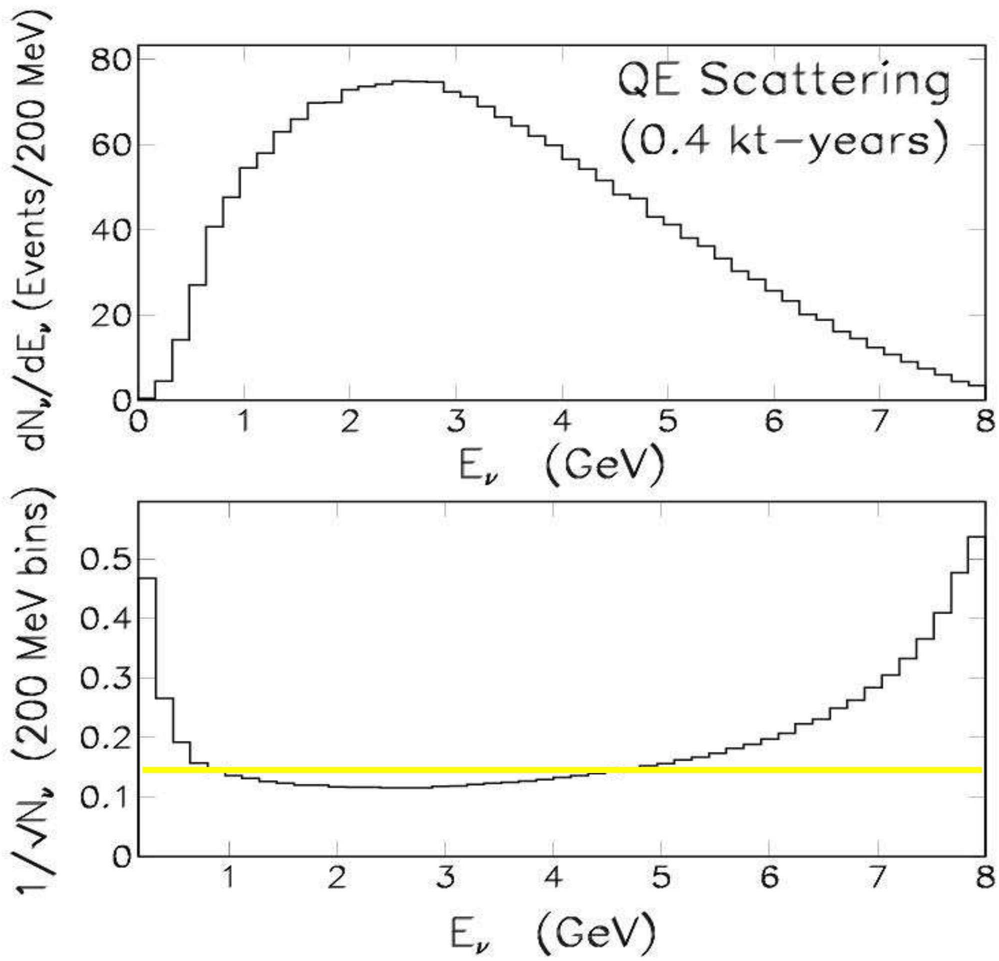
Quasi–Elastic Scattering Rates at the Debuncher

To calculate $\bar{\nu}_e$ QE rates at the Debuncher:

1. Simulate an experiment 15m downstream of a straight section
2. Assume unpolarized muons
3. Use QE cross–sections based on existing measurements ... with high energy rates from V–A fits –> $\sigma(\bar{\nu}) / \sigma(\nu) = 0.67$
4. Include 10% muon momentum spread.
5. Take 0.1 kt fiducial mass, 4 years of data–taking –> 0.4 kt–years.

–> 2100 QE events

Quasi–Elastic Scattering Rates at the Debuncher



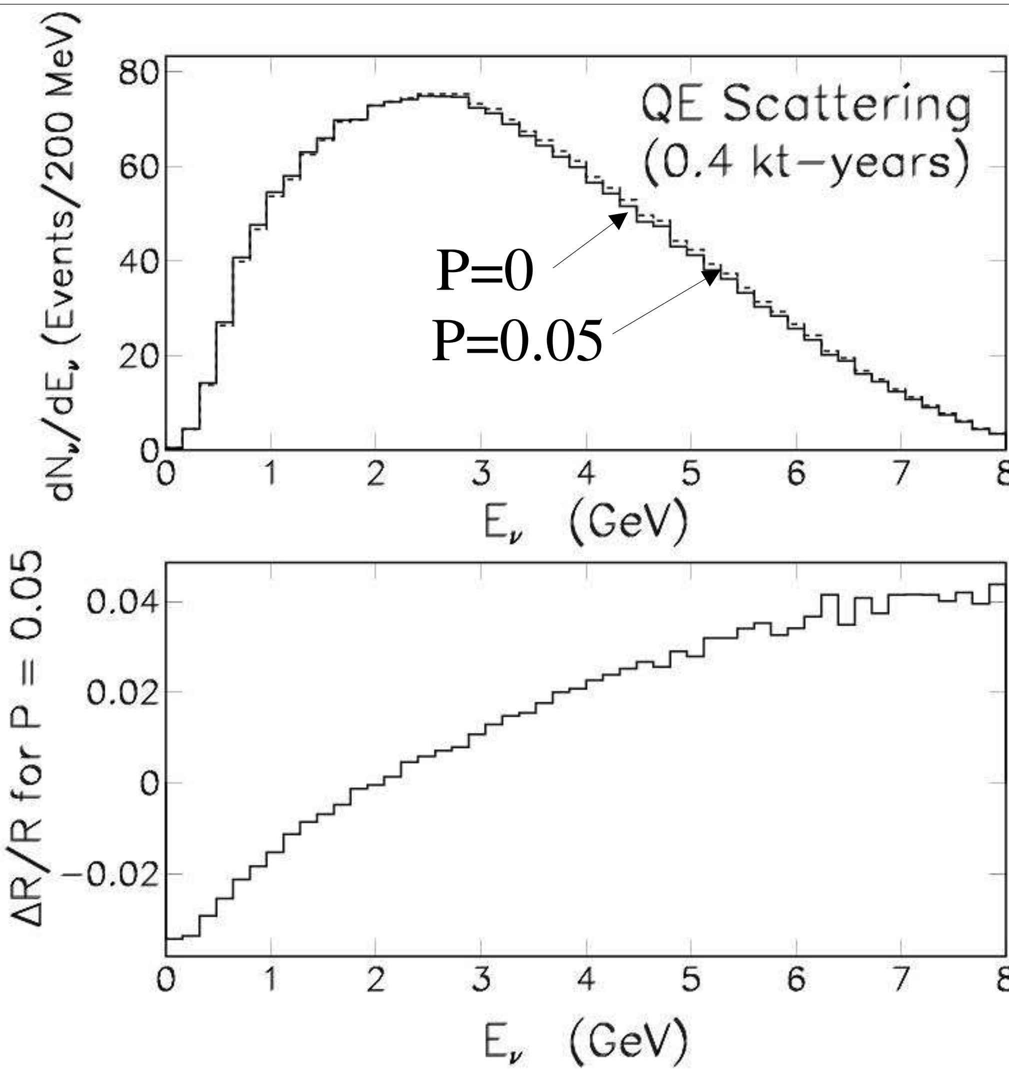
Statistical precision: better than 15% for each 200 MeV bin in the range $1 < E_\nu < 5$ GeV

Muon Polarization

Muons produced with polarization P = +1, spins precess every ~20 turns. Since $\gamma\tau_\mu$ ~ 117 turns >> 20 turns, the time averaged polarization is 0 (to a good approximation).

The muon polarization is important, since it controls the neutrino and antineutrino energy distributions.

Knowledge of the time−dependent polarization can be exploited ... use of time−dependent energy distributions.



Consider a 5% uncertainty on the time−averaged P

Change in rates less than 4% in each energy bin.

$\Delta R/R$ = [rate(P=0.05) − rate(P=0)] / rate(P=0)

Open Questions

1. How precisely can the absolute fluxes (number of muons in the ring) be determined ?

2. What will the total systematic uncertainty on the cross–sections be ?

3. Is the statistical precision sufficient to motivate the measurements ?

4. Would it be better to exploit higher statistics with ν_e (rather than $\bar{\nu}_e$) at the MINOS beam, or are the antineutrino measurements well motivated anyway ?

5. Are the other advantages of a Debuncher beam (cf the MINOS beam) motivation enough to propose an experimental area (cheaper, faster, better (or at least different) systematics and backgrounds, ...) ?

Summary

The Fermilab Antiproton Debuncher exists, and will be operating for the next few years.

If we build an experimental area downstream of one of the straight sections we will have an R&D facility for detector development and cross–section measurements.

Strawman proposal:

Build a 0.1 kt Liquid Argon detector in a solenoid.
Measure the ν_e cross–sections.
Study electron charge–sign measurements.
Study backgrounds to ν_e appearance searches.

Is there a better strawman scenario ?

If you are interested in exploring the possibility of a proposal for a Debuncher experiment ... lets talk !

If you are interested in an R&D experiment using the MINOS beam ... we should pursue this too, and see which option is best.