Tevatron Fixed Target Redux and the NuSOnG Proposal

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AD/TD Accelerator Seminar

6 May 2008

- *Short history of Fermilab Fixed Target*
- *Two Options for after Run II*
  - *120/150 GeV Fixed Target*
  - *800 GeV Fixed Target*
- *NuSOnG proposal @ 800 GeV*

Why this talk?

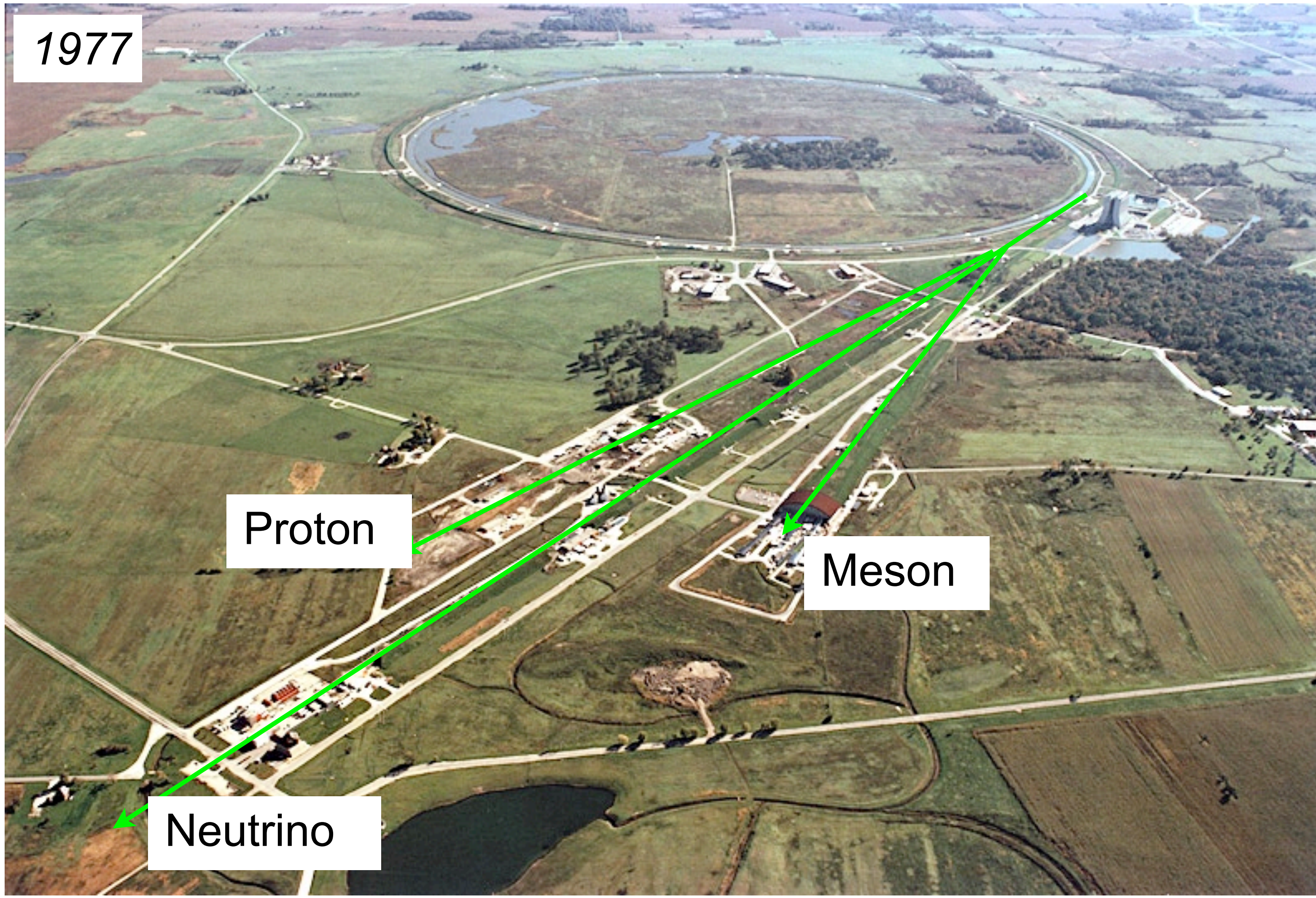
- Is the Tevatron really about "finished"?
- The Tevatron is the only facility that can provide high-energy (TeV) fixed target beams at high rates
- NuSOnG requires neutrino beam energies well in excess of 30 GeV (like 300 GeV)

- From this talk, we want to spur ideas for experiments, and identify issues with high intensity fixed target operation

- PAC will discuss this program option at their June mtg

Fixed Target History

- Main Ring ran fixed target program until 1982
- Tevatron ran FT 1983-2000
  - shared time as Collider, ~50/50



Fixed Target History

- Main Ring:
  - 200-400 GeV
  - 10-20 sec cycle
  - >~3×10^{13} ppp (30 Tp)
- Tevatron:
  - 400-800 GeV
  - 40-120 sec cycle
  - 20-28 Tp
- Resonant Extraction:
  - slow spill.
  - pings

30 Tp in 1981

FERMINEWS

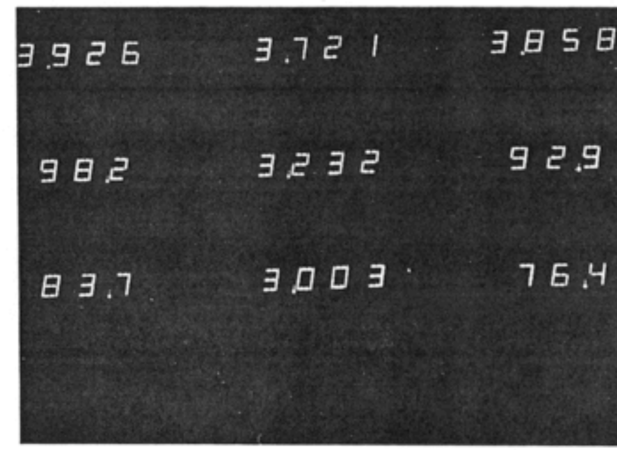
Fermi National Accelerator Laboratory

Operated by Universities Research Association Inc.
Under Contract with the United States Department of Energy

Vol. 4, No. 12 March 19, 1981

3.003×10^{13} PROTONS PER PULSE AT 4:25 p.m. ON SUNDAY, MARCH 15

Robert R. Wilson (center, foreground), Fermilab director emeritus, and Leon Lederman (right, foreground) join the celebration in the Main Control Room



The bottom, center number tells the story in four digits of the magnificent accomplishment. This Polaroid shot was taken in the Control Room and shows the panel that displayed the readouts from beam intensity monitors.

SPECIAL BULLETIN

The Accelerator Division set an all-time world intensity record of 3.003×10^{13} protons per pulse at 400 GeV at 4:25 p.m. on March 15.

ACCELERATOR DIVISION REJOICES

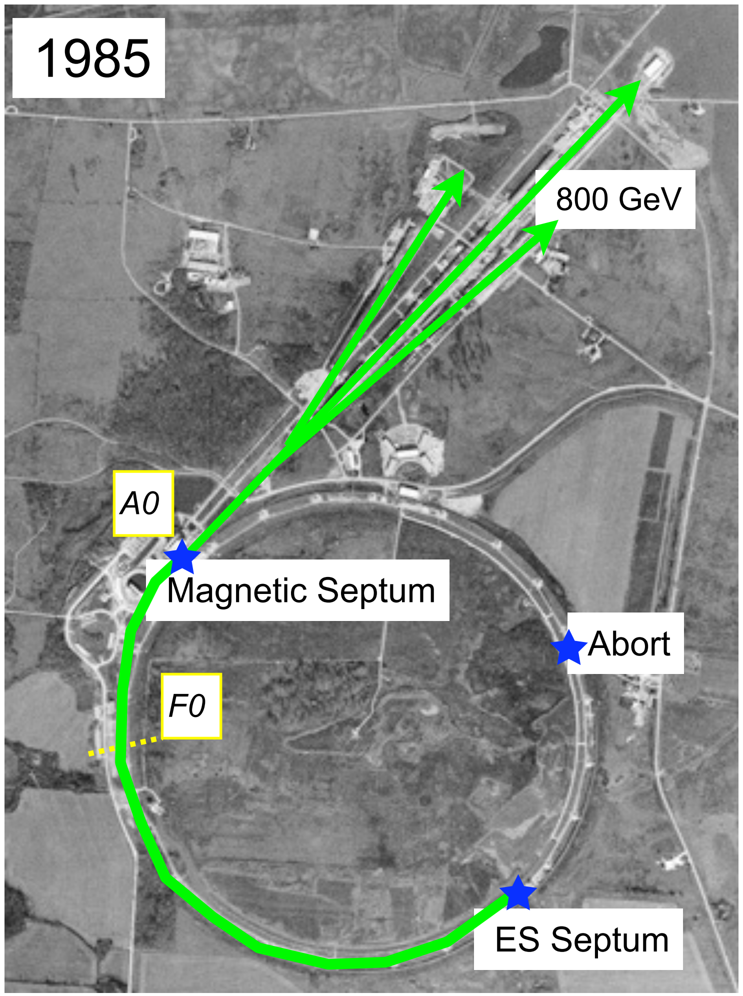
Throughout the Accelerator Division, signs proclaimed the division's recent

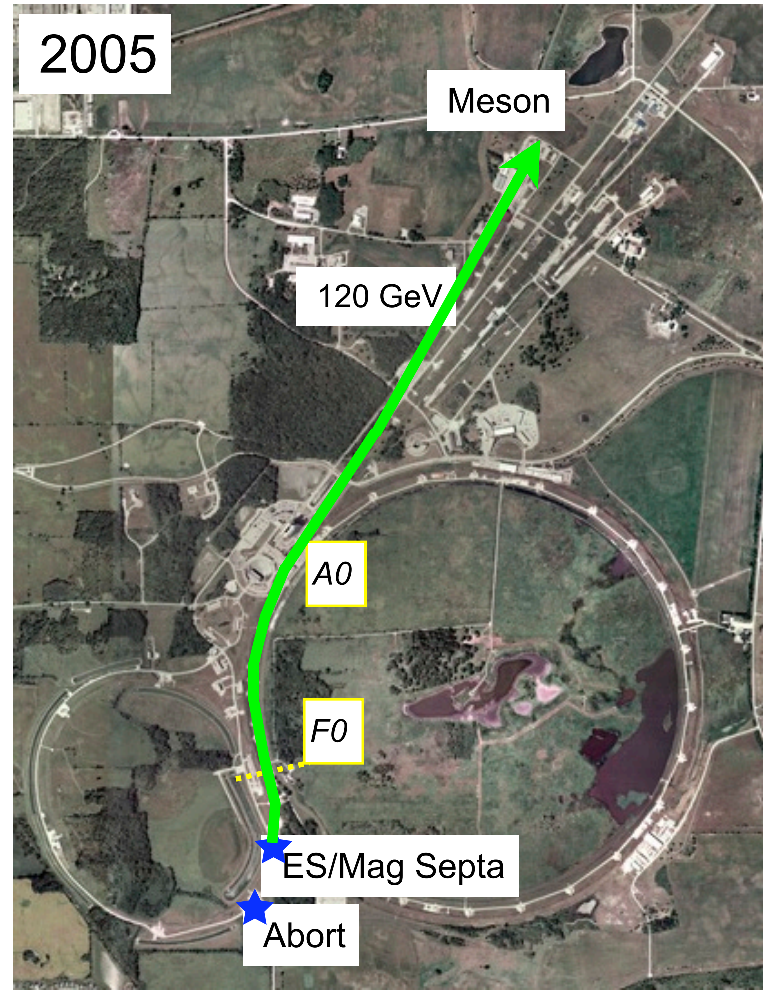
Enter Main Injector…

- With the commissioning of the Main Injector, and the full push of the collider physics program, fixed target physics was relegated to 120 GeV from the new synchrotron.

- This program, dubbed Switchyard 120 (SY120), began operation in 2004.

pre-MI and post-MI FT Configurations





- MR/Tev: beam extracted from A0 straight section
  - MI: transport to F0, thru MR remnant, to A0 and out...

Tevatron Configurations

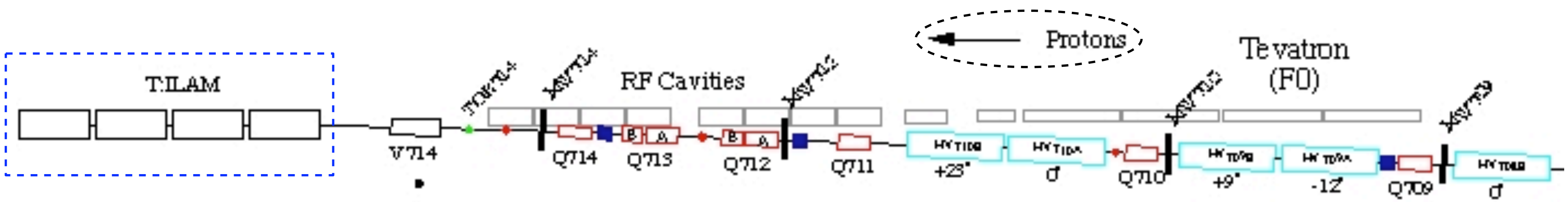
- pre-Y2K (2000, not Young-Kee...), would push/pull Fixed Target equipment with D0 detector, A0 abort
- C0 abort was proton-only; rated for high rate, high intensity fixed target operation.

	pre-MI FT	Run II Collider	
A0	Extr. Channel	Abort	<-- hi-β
B0	---	"CDF"	<-- low-β
C0	Abort	--- (BTeV)	
D0	ES septa	"D0"	<-- hi/low-β
E0	injection	instrumentation	
F0	RF	RF / injection	

F0 Straight Section w/ Main Injector

- The Main Injector ties into the Tevatron tunnel at F0, where Tevatron RF cavities are also located

Lambertson Magnet:
if ON, then stays in Tevatron
if OFF, then to pbar/Switchyard



looking from center of Main Injector

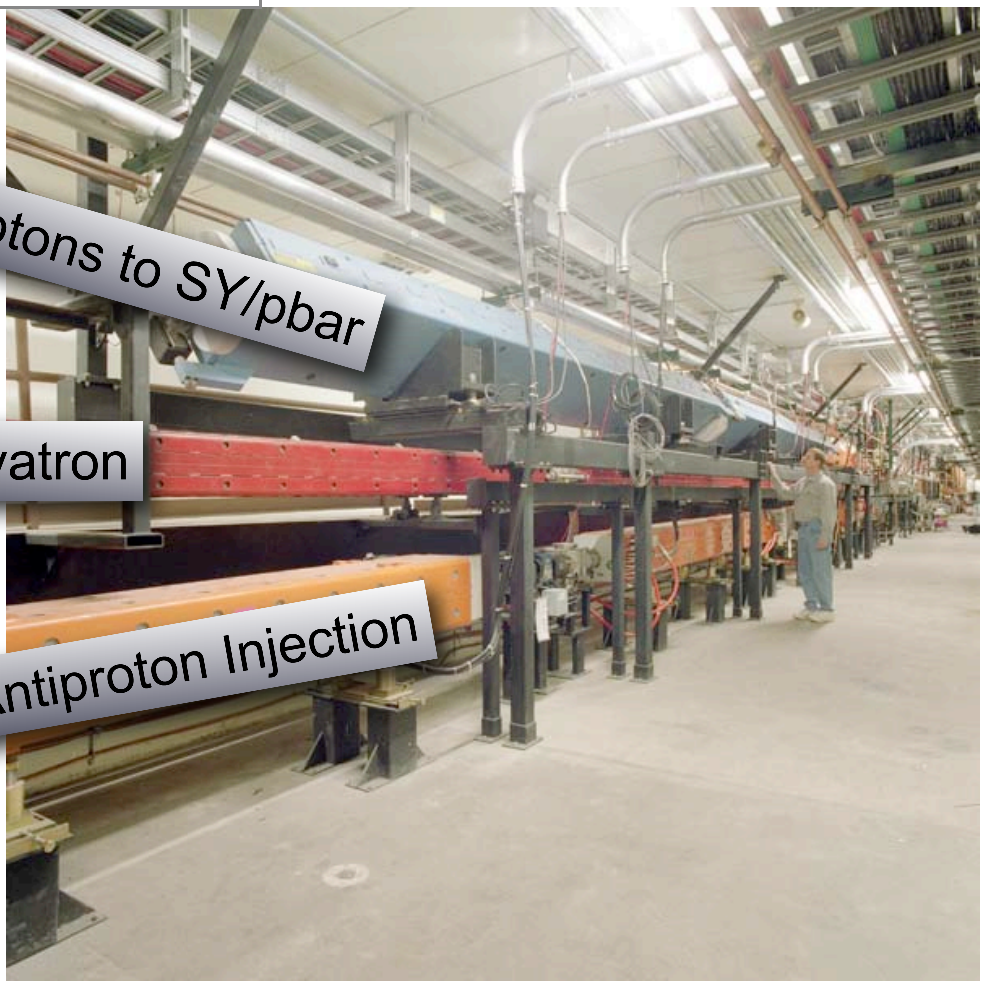
from MI

Beam approaches injection magnetic septa from below; if septa are on, beam is deflected vertically and eventually kicked onto the Tevatron closed orbit; if septa are off, beam passes through and on toward either pbar source or to the SY120 beam line

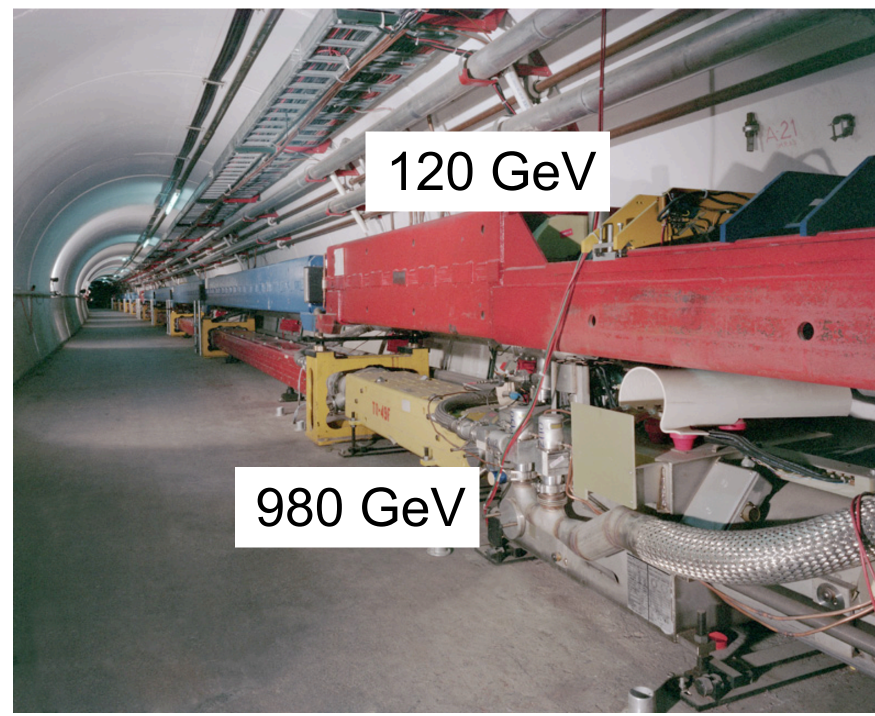
Main Ring "Remnant"

Remaining Main Ring elements are used to transport beam through Tevatron:

F0 Region:



Final Destinations:
F17 --> pbar production
A0 --> to Switchyard



Switchyard 120

- "Main Ring Remnant" is used to transport beam from F0 to F17 (for pbar production) and/or on toward A0 and the Switchyard/Meson Test Facility.
- SY120 beam line runs at 120 GeV, but with Power Supply upgrades could probably reach 150 GeV.
- Typical Operation:
  - When running, typically pulse one 120 GeV ramp ~ every 2 mins.
  - $\sim 1\text{x}10^{12}$ (1 Tp) spilled (slow resonant extraction) over a 4 sec flat-top
    - i.e., 250 Gp/s (peak), 8 Gp/s (ave), 3.3% d.f.

List of SY120 Users since MI

List of Test Beam Memoranda of Understanding (MOU):

T979: Ultra-fast timing, Under review
T978: CALICE Experiment, Approved
T976: CsI Timing Experiment, Experiment completed
T972: Radiation Shielding Experiment, Taking data
T971: LHCb Silicon Detector Upgrade, Approved
T970: DHCAL Detector Research, Experiment completed
T969: GammeV, Experiment completed (IB)
T968: T2K Muon Monitor Prototype Taking data
T967: Muon g-2 Calorimeter Test, Experiment completed
T966: Monolithic pixel detector for ILC, Taking data
T965: PSiP Photosensors, Experiment completed
T964: ILC GEM Chamber Characteristics, Taking data
T963: STAR Muon Telescope Detector, Completed
T962: Mini Liquid Argon TPC, Approved (MINOS hall)
T959: Microparticle Shielding Assessment, Completed
T958: FP420 Fast Timing Test, Experiment completed
T957: NIU Tail Catcher/Muon Test, Experiment completed
T956: ILC Muon Detector Tests, Experiment completed
T955: RPC Detector Tests, Experiment completed
T953: U. Iowa Cerenkov Light Tests, Taking data
T951: ALICE EMCAL Prototype Test, Experiment completed
T950: Vacuum Straw Tracker, Experiment completed
T945-Add. 1: Muon Veto Detector for COUPP, Taking data
T945: COUPP Bubble Chamber, Taking data (MINOS hall)
T943: U. Hawaii Monolithic Active Pixel Det., Experiment completed
T941: UIowa PPAC Test, Experiment completed
T936: US/CMS Forward Pixel, Experiment completed
T935: BTeV RICH, Experiment completed
T933: BTeV ECAL, Experiment completed
T932: Diamond Detector, Approved
T931: BTeV Muon, Experiment completed
T930: BTeV Straw, Experiment completed
T927: BTeV Pixel, Experiment completed
T926: RICE, Experiment completed

see... http://www-ppd.fnal.gov/MTBF-w/

What's Next for the Tevatron?

Program Impact

- SY120 reflects small impact on other operations
  - very infrequent time line interruptions for 120 GeV ramps
    - one MI pulse (2.4 sec, say) in standard two minute time line: 2% hit on remaining program demanding beam from the Main Injector
- On other hand, may say that SY120 program is limited due to the fact that it interrupts other higher-priority programs that demand beam from the Main Injector --
  - antiproton production, NuMI
- This is the cost of doing several projects/experiments with intellectual connections...

can we remove this "limit"?

A Unique Facility

- As the world's first superconducting synchrotron the Tevatron was able to deliver fixed target beams at nearly twice the particle energy of any other facility.
- While other SC synchrotrons have been built since, none have the ability to ramp rapidly to full field and thus support a viable fixed target program at particle energies near 1 TeV
- With the end of Collider Run II program approaching, some are considering fixed target options again...
  - high statistics ν_μ scattering experiment (NuSOnG)
  - Kaon physics
  - More demand for detector (e.g., ILC) test beams
  - ??

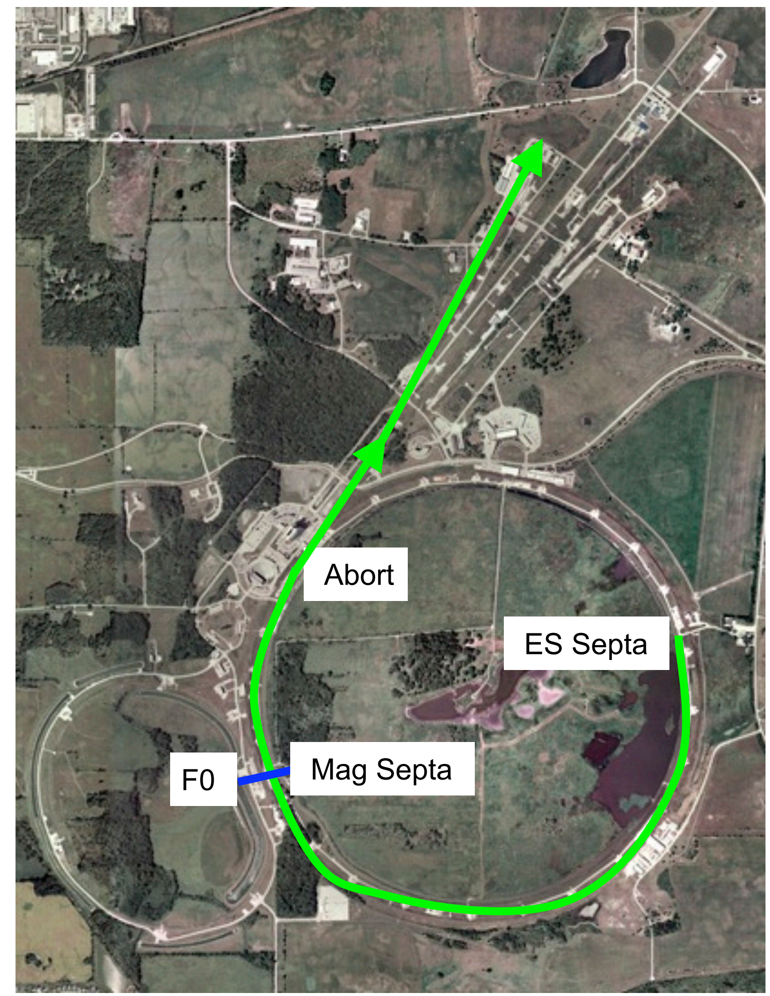
see: http://www.fnal.gov/directorate/Longrange/ Steering_Public/documents.html

Two Fixed Target Options to Consider

- **Option One --**
  - Operate Tevatron as a "stretcher ring" to store and provide beam to the existing test beam facility, or to future experiments that can tie to the extracted beam line.
    - operate at injection energy of 150 GeV (and upgrade the beam line to SY150), or operate Tevatron at 120 GeV
    - "easy" to implement, almost immediately
- **Option Two --**
  - Resurrect high-energy (800 GeV) fixed target capability
    - though components still exist, would require more down time than Option One to implement
- **Issues for both:**
  - demands of experimental programs, and operating costs

TEV120-150

- Can use the F0 injection septum as an extraction septum (needs a polarity switch)
- Install electrostatic septum near F0, or perhaps C0
  - C0 presently "unused"; ideal for 1/2-integer extraction
- resurrect slow-spill feedback system ("QXR")
  - fast air-core quadrupole magnets
  - may wish to upgrade electronics
- Then, "ready to go"



Performance Issues at 120/150 GeV

- Intensity limitations
  - Tevatron Fixed Target program ran at 20-28 Tp per pulse
  - limited by intensity dependent instabilities at higher energy (typ. ~ 600 GeV) as momentum spread adiabatically reduced
  - Transverse impedance of Tevatron improved during Run II
    - Lambertson Magnets identified as major sources, and beam tube liners introduced; greatly stabilized transverse motion
- However, 30 Tp was also about limit of injector
  - Today, the MI can deliver 40-45 Tp per pulse, and two pulses can be used to fill the Tevatron --> 80 Tp!
    - (same as AGS record intensities at Brookhaven, 28 GeV)

Performance Issues at 120/150 GeV

- Abort at A0 can handle it…
  - to extent that we equate 80 Tp @ 120 GeV with 10 Tp @ 980 GeV (today's Run II operation)
  - Naturally, fault conditions, etc., would need verification
- Tevatron would be run DC at 120/150: no snap-back, tune drift, etc.; more quench margin
- Beam can be stored in Tev, and spilled "on demand" at different rates at different times
- Many/most fixed target users want smooth beam spill; could consider use of barrier buckets to get rid of 53 MHz component; or, pre-condition in the MI ahead of time. Many variants could be explored.

Tev120 -- beam on demand

- ❖ **Examples of possible particle rates, for comparison**

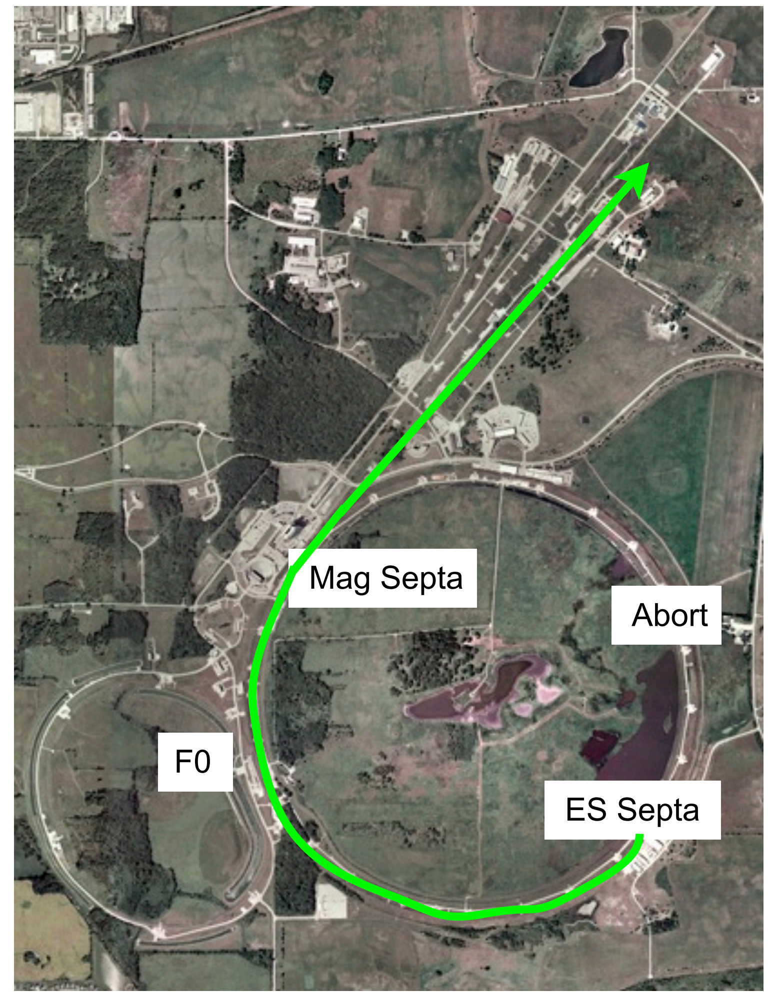
Present Operation (1 Tp row)

N_{max}	Cycle (sec)	dN/dt (Gp/sec, ave)	dN/dt (Gp/sec, max)	POT/yr (10^{18}/yr)	duty factor	hit on MI pgm
1 Tp (1 pulse)	120	8	250	0.17	3.3%	2.5%
30 Tp (15+15)	3600	8	8	0.17	99.9%	0.08%
30 Tp (15+15)	120	250	260	5	97.5%	2.5%
40 Tp (20+20)	60	660	700	14	95%	5%
50 Tp (1 pulse)	15	3300	4200	70	80%	10%

Scenarios assume 1.5 sec MI cycle, 3 sec in Tev for debunching and/or other “preps”; 66% of year operation

TEV800

- While running 120/150 GeV, prep for 800 Gev operation…
  - Proposed neutrino expt, NuSOnG, needs high enegy
- RF at F0 precludes extraction there at 800 GeV; thus, A0
- Re-install electrostatic septum at D0, as previous FT running
- Extraction:
  - if fast res. extr., need "QXR"
  - perhaps form few, long bunches and use kickers? would work out exact scenario with experiment



Performance Issues at 800 GeV

- We know that 800 GeV slow extraction works by design; however, intensity limitations at high energy were always an issue
  - today's high intensity limit at high energy unknown, following septum magnet beam tube upgrades, etc.; but should be improved over FT runs of past
  - also, beam damper systems much improved these days
    - But note: neutrino expt. proposal -- 2.5x Tev record intensity (later)
- Abort at C0 -- decommissioned with BTeV in sight
  - would need to re-commission extraction kickers (may need new pulse forming network) and extraction magnets
  - 28 Tp @ 800 GeV = 3.5 MJ;   75 Tp --> 10 MJ
  - need to re-examine instantaneous rates onto abort block, etc.

Performance Issues at 800 GeV

- Ramp-rate & magnet issues
  - Power Supplies and RF capable of delivering 55 GeV/s (used previously in FT mode); may be desirable to update/upgrade some dump switch equipment in PS system
  - Magnets appear capable of higher rates
    - would need more RF; suggest stick with standard rate
  - Neutrino program wants lots of beam in short amount of time -- i.e., pulses (or, "pings") rather than slow spill
  - Thus, use above ramp rate to make a 36-40 sec cycle, with a ~1 sec (or less) flat-top for extracting many (5-50) pulses

Performance Issues at 800 GeV

- Early FT running in 1980's resulted in many magnet failures
  - bus lead restraints within cryostat identified and fixed
  - since then, ~250,000 cycles between magnet failures
    - (this rate includes failures of non-standard Tev magnets)
  - Note: neutrino exp wants $2x10^{20}$ POT w/ 75 TP/cycle
    - --> ~2.6 million cycles ---> ~10 failures likely
  - need to either have enough spares to last through the experimental program, or re-ignite capabilities of repairing
- If 10-12 failures of main magnets is the right scale, then enough spares and repair capabilities exist for the NuSOnG experiment (spool pieces will be the issue)

Performance Issues at 800 GeV

- Particle Extraction
  - Previous FT running, typically 60 sec cycle w/ ~25-28 Tp/pulse, spilled over 20-23 sec flat-top, roughly a 33-40% duty factor
  - During slow resonant extraction, beam was "pinged" ("fast" resonant extraction) to the neutrino experiments
  - It may be that few, long bunches could be formed in Tev (or prepped in MI) and then could be kicked out with kicker magnets (kick out 8 bunches of 10 Tp each, say)
    - Single-turn extraction was cleanly performed (test conditions) in Tevatron w/ 10 Tp.
  - If only 1-2 neutrino experiments in Switchyard, then would deliberate the extraction method depending upon the needs of the users -- both approaches seem feasible

Summary (Accelerator)

- A first look at two possible Fixed Target Options:
  - 120/150 GeV “stretcher ring”
  - 800 GeV FT redux, for neutrino program
- Stretcher -- “straightforward” to implement; fast turn-around time; SY120 program/beam line exists
  - higher intensities for various programs -- yet to be demonstrated, but looks very feasible
- 800 GeV Beam -- much to re-install, but mostly still exists; hi-intensity an issue, needs addressing
  - we know Z/n is better, but good enough? dampers? beam loading? abort system adequate?

up next...

Tevatron-based Neutrino Beams

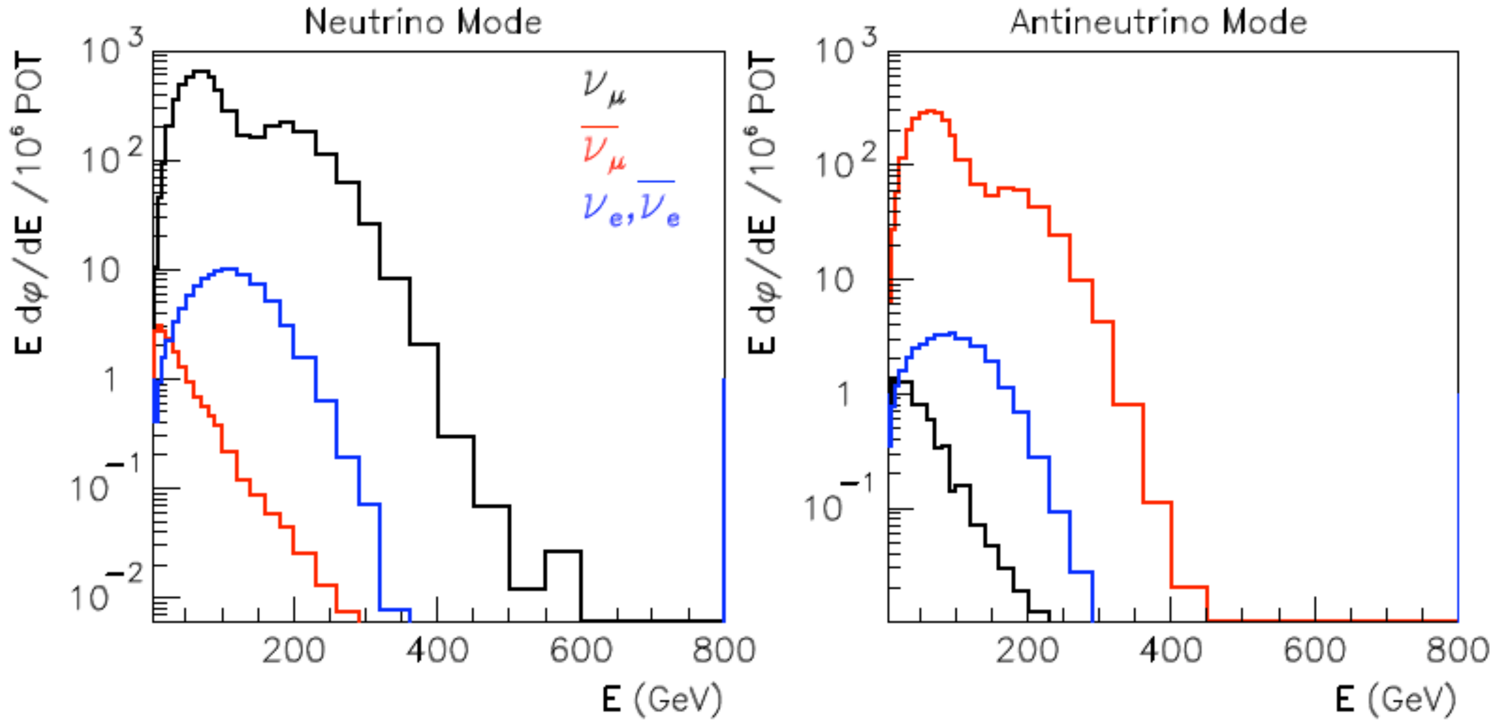
1. Tev-based neutrino beams
2. 5 reasons this program is unique
3. A history of this idea
4. How much does it cost?

Tevatron-based Neutrino Beams

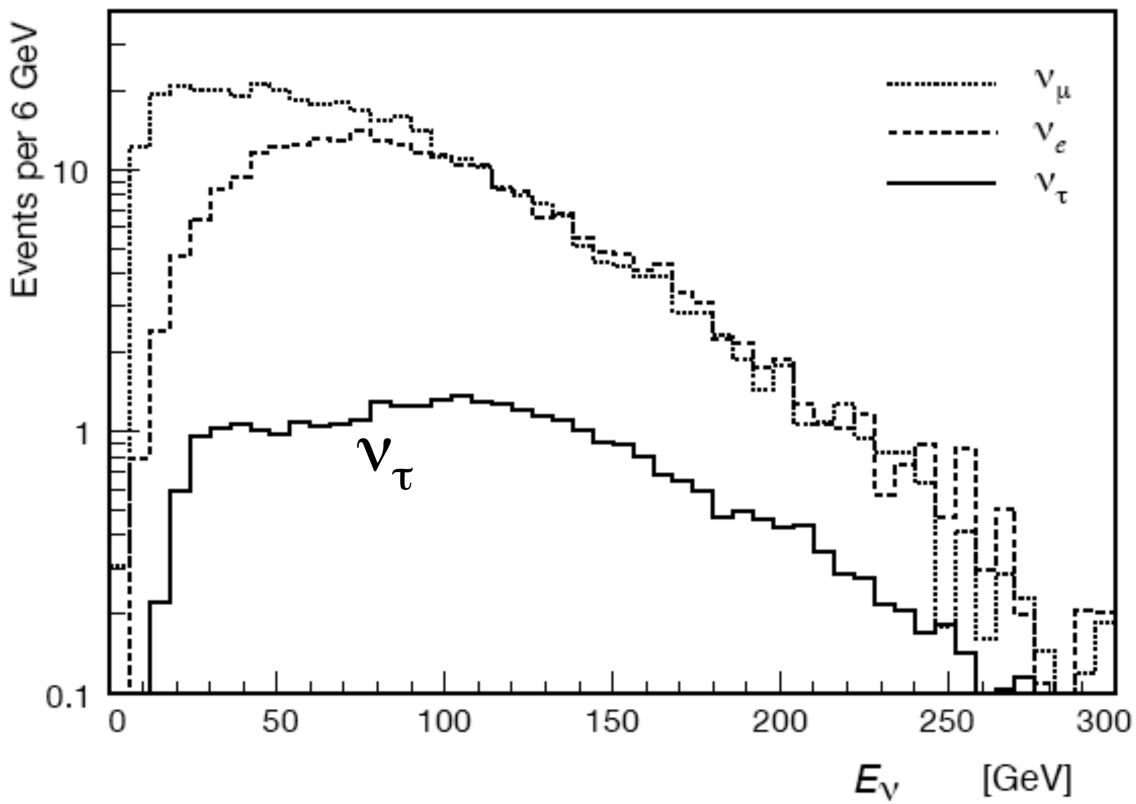
A Tevatron-based beam offers the highest energy neutrino beams in the world.

Example 1: The NuTeV Flux

Uniquely high energy, and low background, produced using a sign-selected quad-train



Example 2: The DoNuT (Discovery of the Nu Tau) Flux



Uniquely enriched in ν_τ's which are above threshold for CCQE

It's all about flavor & energy!

A Tev-based program is the only source of

High purity ν_μ beams at high energies

Enriched ν_τ beams at high energies

Our idea:

Build a combined-beam facility,
providing both a sign-selected beam and a beam dump flux,

with ×20 times the NuTeV POT/year
with ×150 times the total DoNuT POT

5×10^{19} POT/year

This a small cost to the planned neutrino programs
(cost is mainly in ramp time)

It does not require substantial proton source upgrades

The Experiments I will discuss also need calibration beams

Other slow-spill experiments
might happen at the same time…

The Neutrino Physics at a Tev-based Program

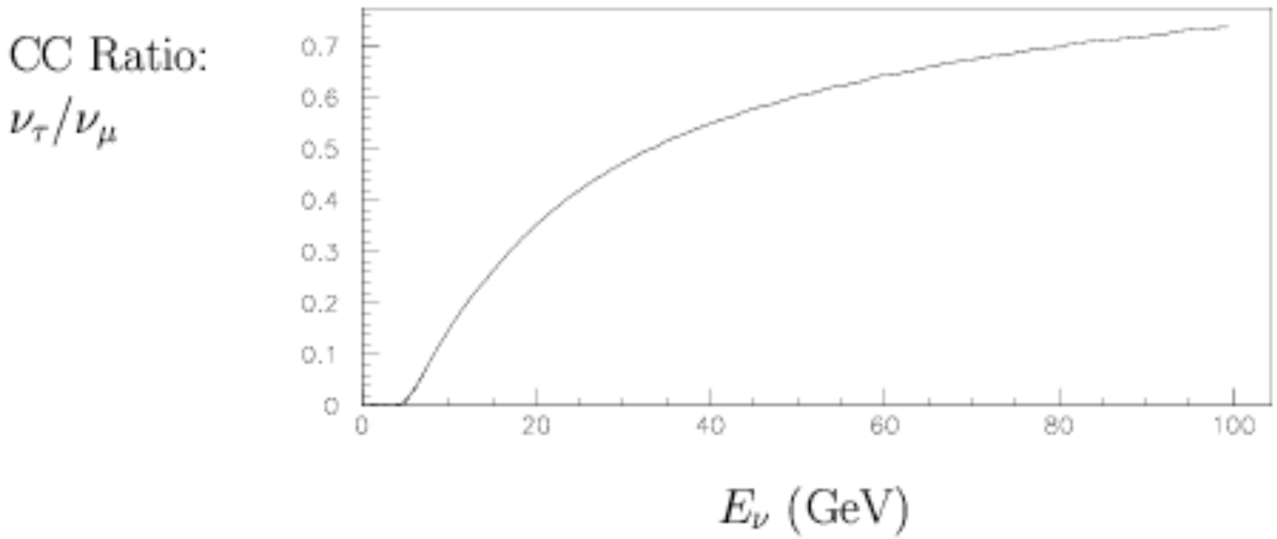
5 reasons this program is unique

Why this program is unique? #1: Rate!

	Total detected at any energy, all detectors	Total that will be seen in the Tev-based neutrino program
ν_e	~500k	**> 6M** (in NuSOnG)
ν_μ	<10M	**> 600M** (in NuSOnG)
ν_τ	10	**~1000-1M** (small expt -- a 5 kton LAr)

Why this program is unique?

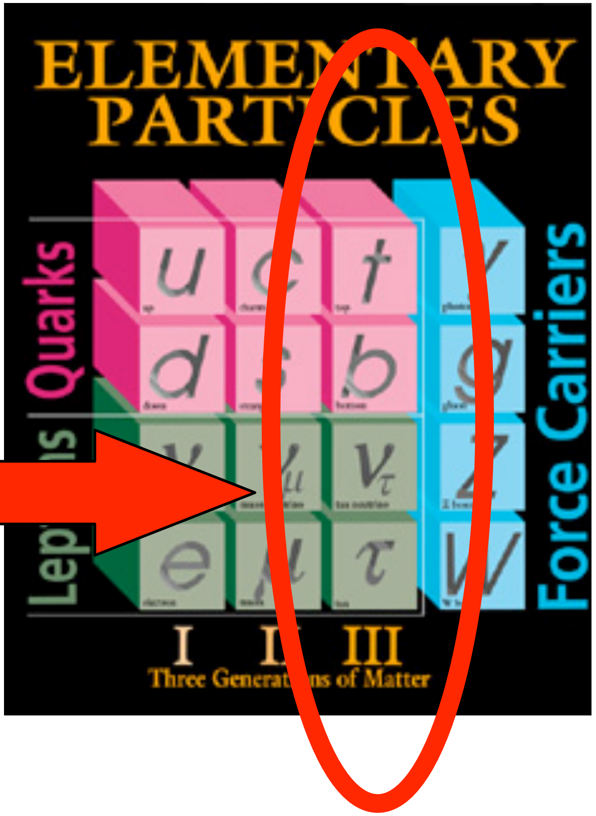
#2 It is above threshold for ν_τ production



$\nu_\mu \rightarrow \nu_\tau$ experiments like MINOS produce a lot of ν_τ
but they are all below threshold

The only practical way to make a ν_τ beam above threshold is
via 800 GeV p on target producing D_s which decays

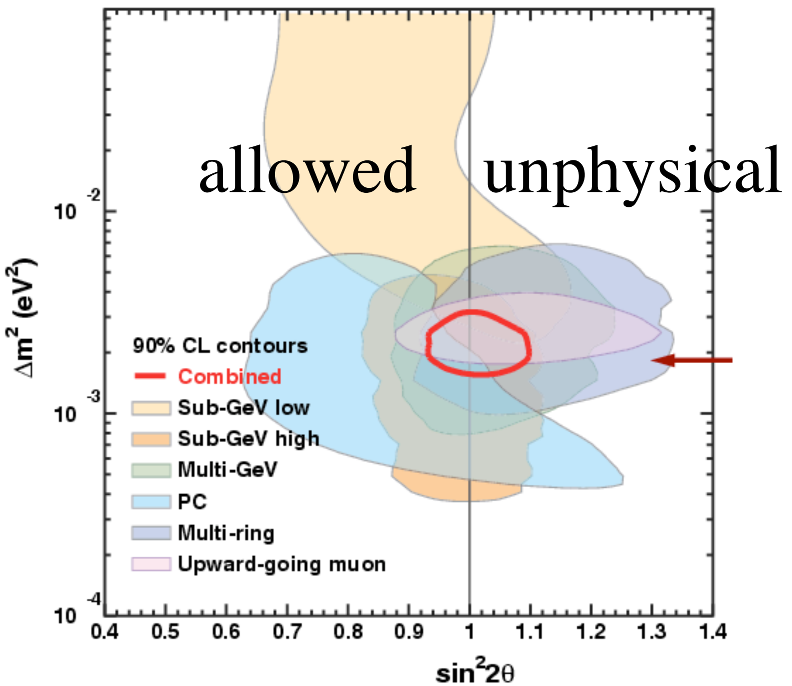
Why are ν_τ's interesting?



They are the least-studied fermion

Many models favor new physics signatures in the 3rd generation

The maximal $\nu_\mu \rightarrow \nu_\tau$ mixing may be telling us something about the ν_τ!



Expt.	best fit	ref.
Minos	1.01	hep-ex/0607088
SK:	1.02	hep-ex/050106
K2K:	1.2	hep-ex/0606031

To see ~1 M ν_τ events you need a 5 kton LAr detector

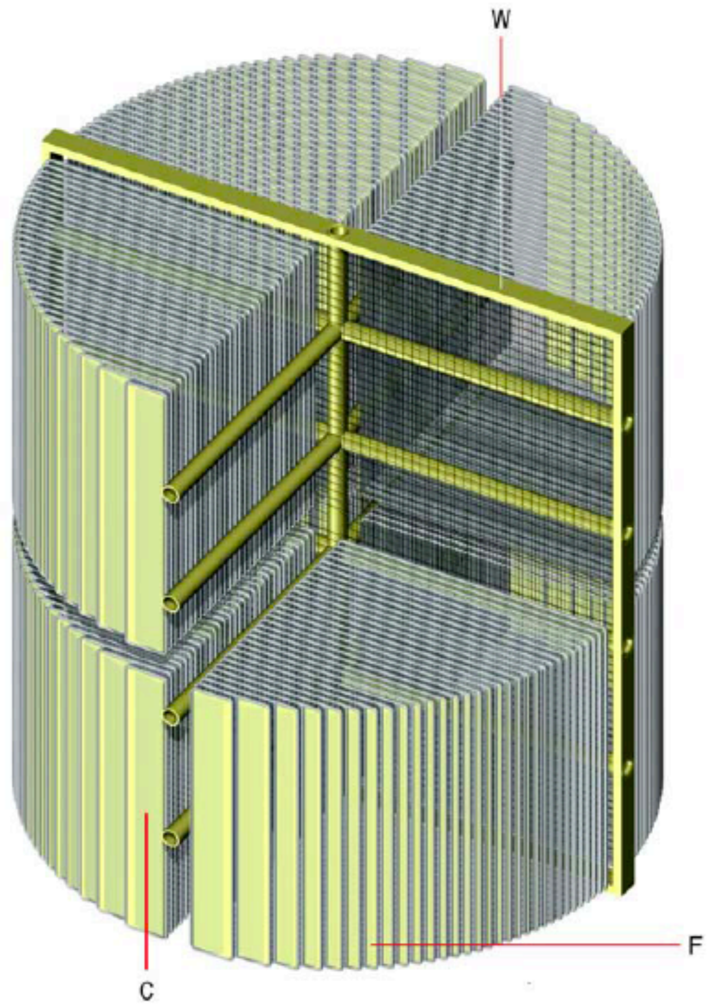


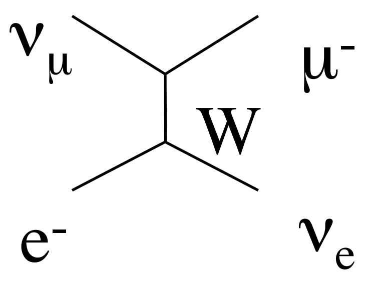
Figure 4 – The inside detector, with one of the top quarters not shown. W: wire chambers; F: field-shaping electrodes; C: cathodes. The inner reinforcing cross is also indicated.

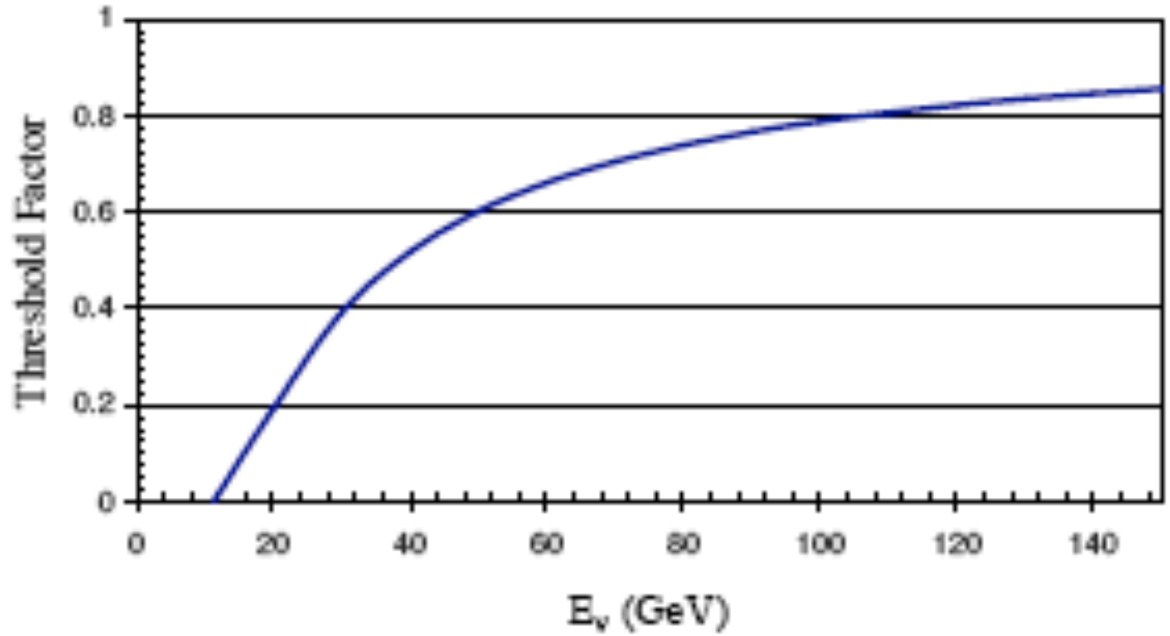
Which at the same time could provide valuable R&D for a 100 kton LAr detector at DUSEL for the neutrino factory

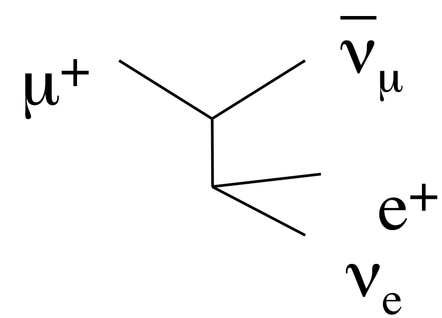
You would probably begin with a smaller emulsion, LAr TPC hybrid to get ~1000 events

Why this program is unique?

#3 It is above threshold for "inverse muon decay"





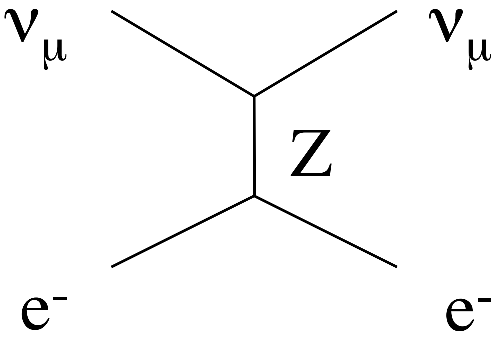


This cross section is very precisely known because it is directly related to muon decay,

so you can use this process to measure the flux to high precision

Why this program is unique?

#4 A large sample of neutrino-electron scattering events

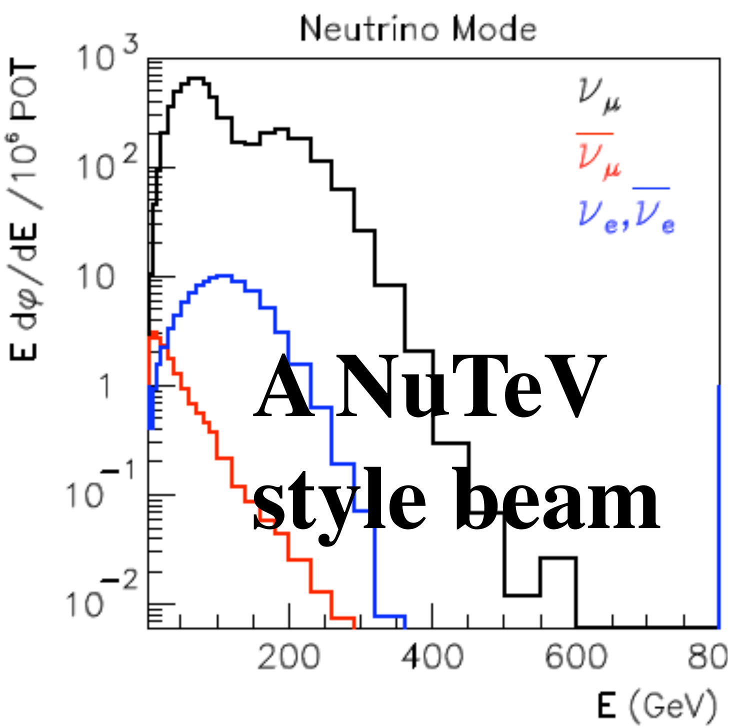


75,000 events

30× the existing sample

Measured in the NuSOnG Experiment…

NuSOnG: Neutrino Scattering On Glass



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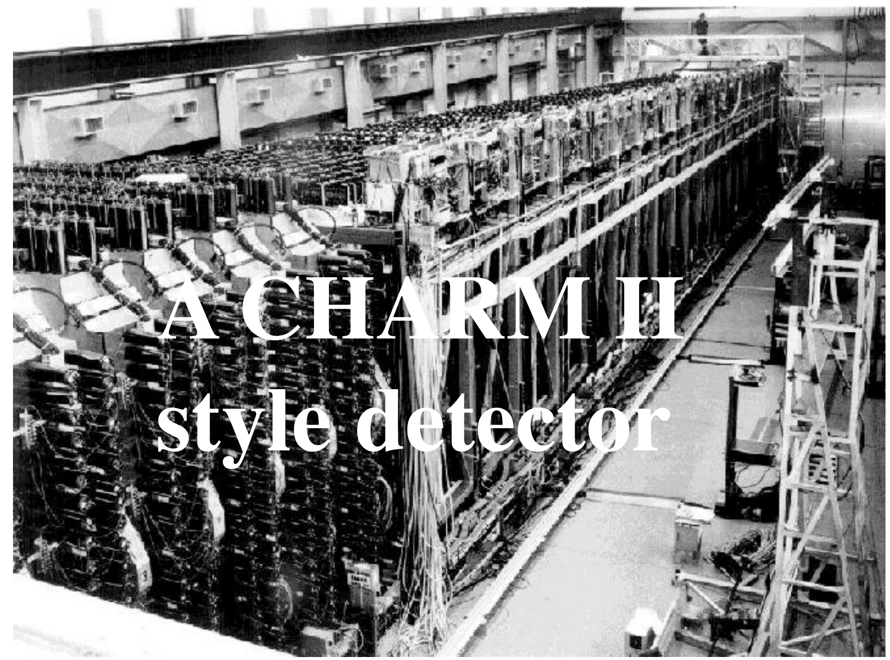


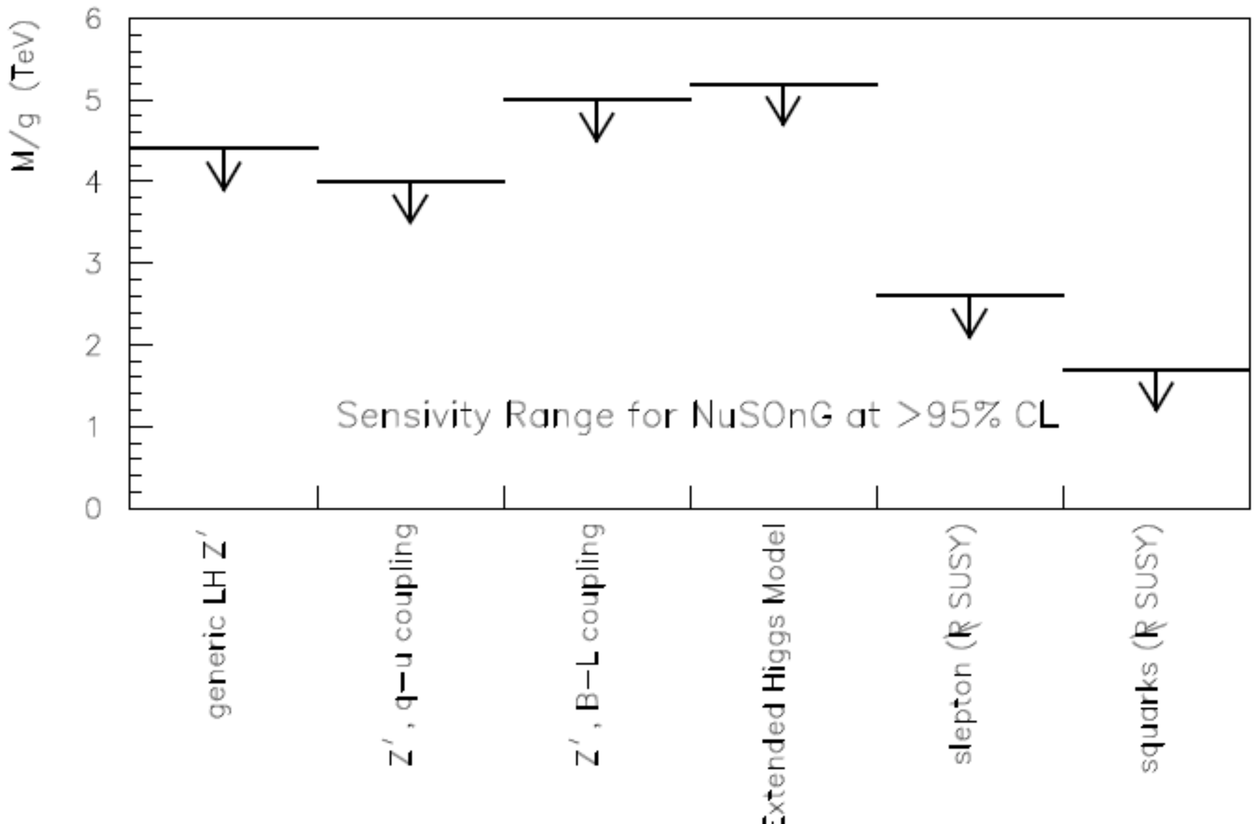
High energy,
very pure beam
(×20 POT)

Fine-grained,
massive detector
(×6 mass)

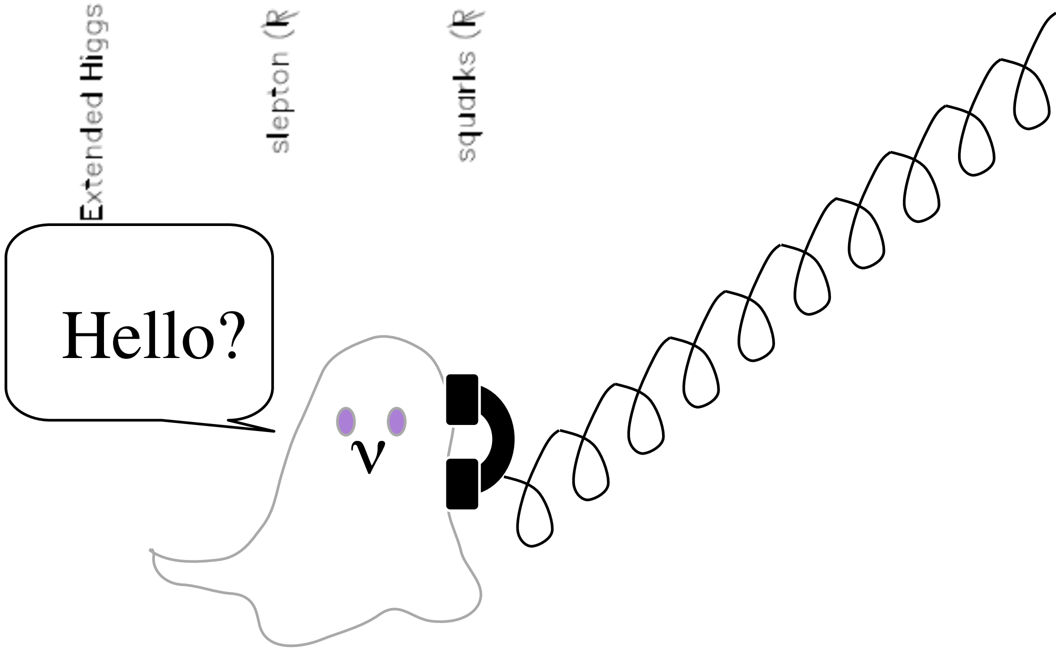
Initial 5-year run-plan 1.5E20 POT in ν , 0.5E20 POT in $\bar{\nu}$

Could be followed by a phase II $\bar{\nu}$ extended run

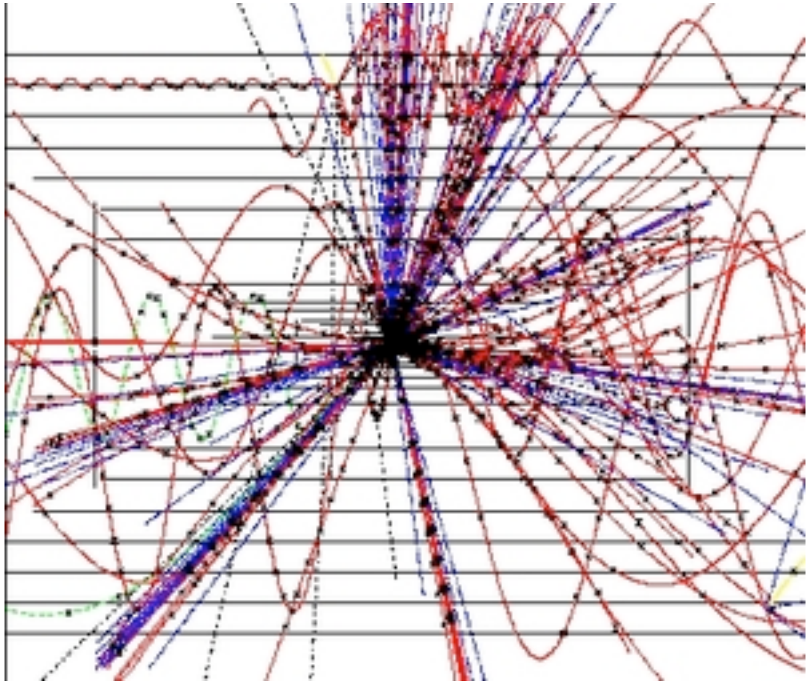
Why is measuring neutrino-electron scattering exciting?
We think that neutrinos talk to high-energy scale particles…



The mass reach is the same as the LHC direct searches…



When LHC turns on…

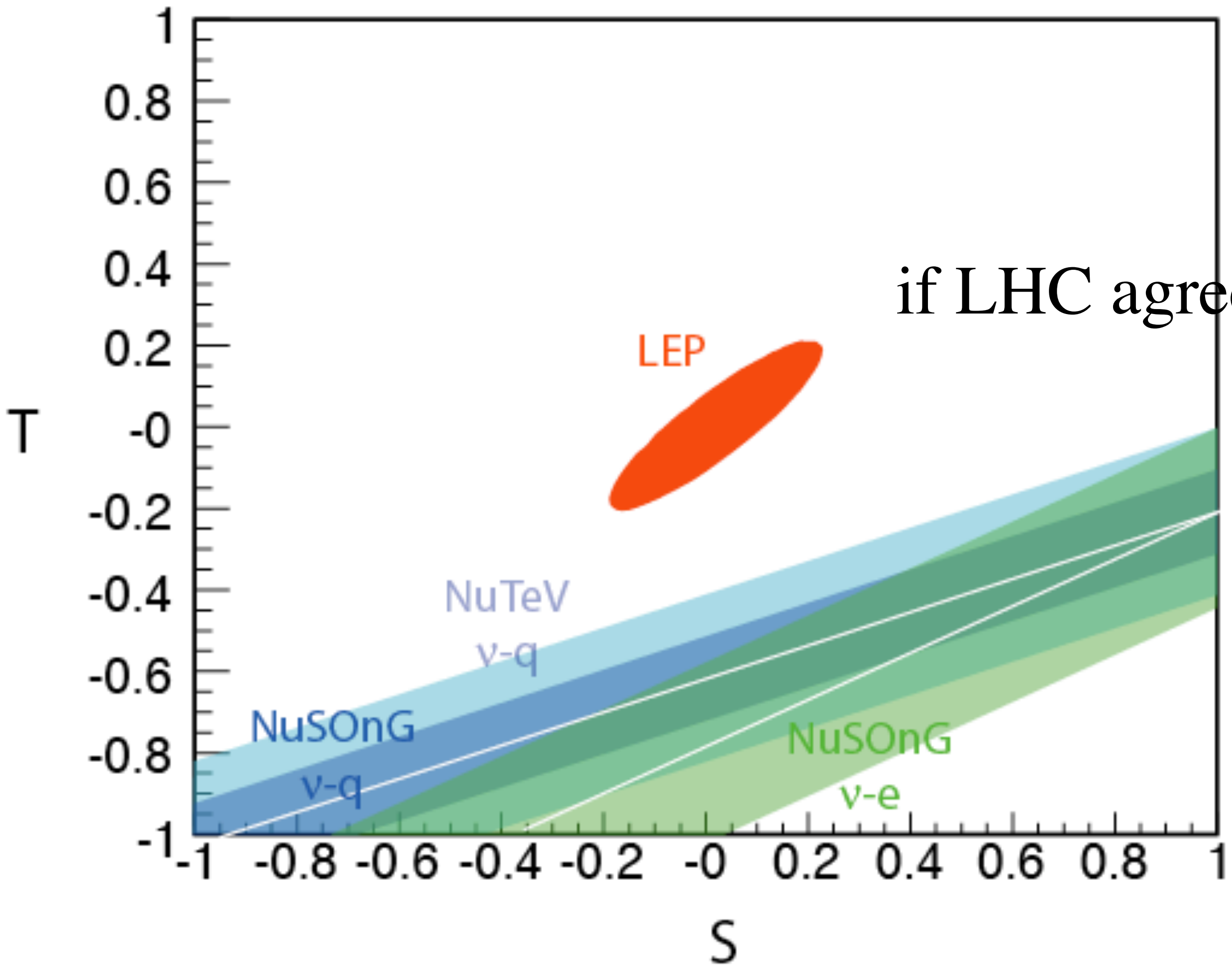


It will be exciting, but very messy!

NuSOnG makes 4 measurements which help untangle the mess:

- neutrino-electron scattering
- antineutrino-electron scattering
- neutrino-quark scattering
- antineutrino-quark scattering

Even if LHC sees nothing but the Standard Model Higgs, NuSOnG might see something…



if LHC agrees with LEP

But NuSOnG agrees with the NuTeV anomaly

There is new physics in the neutrino sector!

Learn more about NuSOnG:

Andre de Gouvea will be giving the
Wine & Cheese Seminar
this Friday, 4:00
on NuSOnG

also at http://www-nusong.fnal.gov

Why this program is unique?
#5 Neutrissimo Searches!

massive partners to
the known neutrinos

ν_1 ν_2 ν_3 **N**

A nice, small, inexpensive, dedicated neutrissimo decay search

Tev
target
area

would be a first -- past experiments have been add-ons

Accelerator limits are based on mixing to light ν

Their mass is limited by the parent particle

$\pi \Rightarrow e\ N$	$m(N) < 130$ MeV
$\pi \Rightarrow \mu\ N$	$m(N) < 20$ MeV
$K \Rightarrow e\ N$	$m(N) < 450$ MeV
$K \Rightarrow \mu\ N$	$m(N) < 350$ MeV

Only a Tev-based beam allows you to search in B-decay
you to reach up to ~5 GeV!

The REAL reason this program is unique…

The protons have to be ~800 GeV for this physics!

NuSOnG needs a beam with flux >30 GeV, peaking at ~100 GeV, almost none below (achieved by energy-angle correlation)

The ν_τ experiments need a high rate of D_S production for flux, and neutrinos above tau CC threshold.

The Neutrissimo search needs fixed-target B-production

The reason no one else can do this program is that no one else has a Tevatron!

But wait! There's more!

Other possible neutrino experiments …

- A study of neutrino-production of charm (HiResMuNu)
- A tagged neutrino experiment

Other Physics… Slow Spill

- $D^0 \overline{D^0}$ mixing (already under consideration)
  this experiment can also measure D_S production,
  important to a high precision ν_τ experiment
- Followup to HyperCP? (just an idea..)
  Watch for final results from HyperCP
  later this year…

The History of this Idea…

A Brief History…

The idea has been around for some time,

The call from the Steering Committee for "near term experiments that can be supported by an evolution of the Fermilab accelerator complex" caused the idea to gel.

The concept was endorsed by the Steering Committee:

[An] experiment with an 800 GeV proton beam would impose approximately a five percent tax on NuMI for both Project X and SNuMI. Proton-source upgrades, particularly Project X, make possible a stronger neutrino-science program.

FNAL Steering Group seeks input from HEP community

Director Pier Oddone has charged Deputy Director Young-Kee Kim to lead a Steering Group to develop a strategic roadmap for the accelerator-based HEP physics program at Fermilab (see Director's Corner, Fermilab Today, April 17, 2007). The roadmap will outline discovery opportunities during the period before ILC construction can begin, while supporting the international R&D and engineering design for as early a start of the ILC as possible. The Steering Group, consisting of members of the US HEP community and Laboratory staff, will report to Director Oddone by August 1.

The Steering Group would like to solicit input from the HEP community as widely as possible. As part of this effort, Kim has been meeting with collaborations of experiments at Fermilab, will give a report on the Steering group's work at the Fermilab and SLAC Users Meetings on June 6 and June 7, respectively, and will conduct Town Hall meetings on the same days. To provide input, please email Kim a note or a letter with your thoughts.

The Steering Group would also like to hear ideas from the community on near-term experiments that can be supported by an evolution of the Fermilab accelerator complex. If you have suggestions, please write up a single-page sketch consisting of the physics case, back-of-envelope discussion of accelerator requirements, and a brief detector description. Please send your input by Monday, June 11.

You can find the charge, membership and activities of the Steering Group here.

History with the PAC:

Presentation of an EOI in Nov, 2007
PRD article on Terascale reach,
as follow-up to questions, Mar, 2008

And planned future with the PAC

Summary of a Tev-based program (in answer to
PAC questions), June 2008
PRD article on QCD as follow-up to questions,
autumn, 2008
LOI with more details of NuSOnG design,
autumn, 2008

from a letter to the collaboration from Pier Oddone, Dec 2007

It is too early to consider a full proposal, but I encourage the plan to submit an LOI to be considered by the PAC. Many things are uncertain in the future HEP program and I can think of circumstances that would make NuSOnG a very attractive option

from a letter to the collaboration from Pier Oddone, May 2008

NuSOnG will be among the possibilities considered when the Committee discusses the experiments for the long-range strategic plan of the Laboratory at its June meeting. The Committee notes that a discovery at the LHC whose nature could be explored through neutrino scattering (e.g., a Z′) could make an experiment like NuSOnG compelling.

… at first I thought, “rats! wait ‘til LHC???”
then I realized… that’s next year!

… rumor is that P5 says something similar.

How much does it cost?

From the costs turned into P5 by the Directorate…
all have EDIA, G&A, no escallation

Upgrades to the Tevatron	$0.5M
Running the Tevatron (incremental cost)	$15M/year
Building the two Neutrino Beams, inc. building	$22.5 M
NuSOnG detector & building	$118.5M

A program of: $322M

- Neutrino beams (including running)
- NuSOnG
- 2 small neutrino experiments
- A D-mixing expt w/ beam

i.e.
30M year/10 years

Final Thoughts..

- As stated before, Tevatron is a unique facility for providing high energy fixed target beams
- Before dismantling the Tevatron and its infrastructure, should be sure that it truly has lived out its useful life
  - Tev120 -- quick set-up; Tev800 -- longer shutdown required, but has all been done before
- NuSOnG...
  - This program can involve 500-750 physicists, putting out excellent physics in the interim while we build the next accelerator.
  - It has unique and interesting physics goals
  - It can be staged
  - It uses our resources well...

Further Reading…

- Beams Documents Database:
  - http://beamdocs.fnal.gov/AD-public/DocDB/DocumentDatabase
    - #'s 2178, 2222, 2849
- Fermilab Steering Group Presentation (McGinnis):
  - http://www.fnal.gov/directorate/Longrange/Steering_Public/meeting-2007-04-16.html
- NuSOnG information:
  - http://www-nusong.fnal.gov/
  - http://lanl.arxiv.org/abs/0803.0354