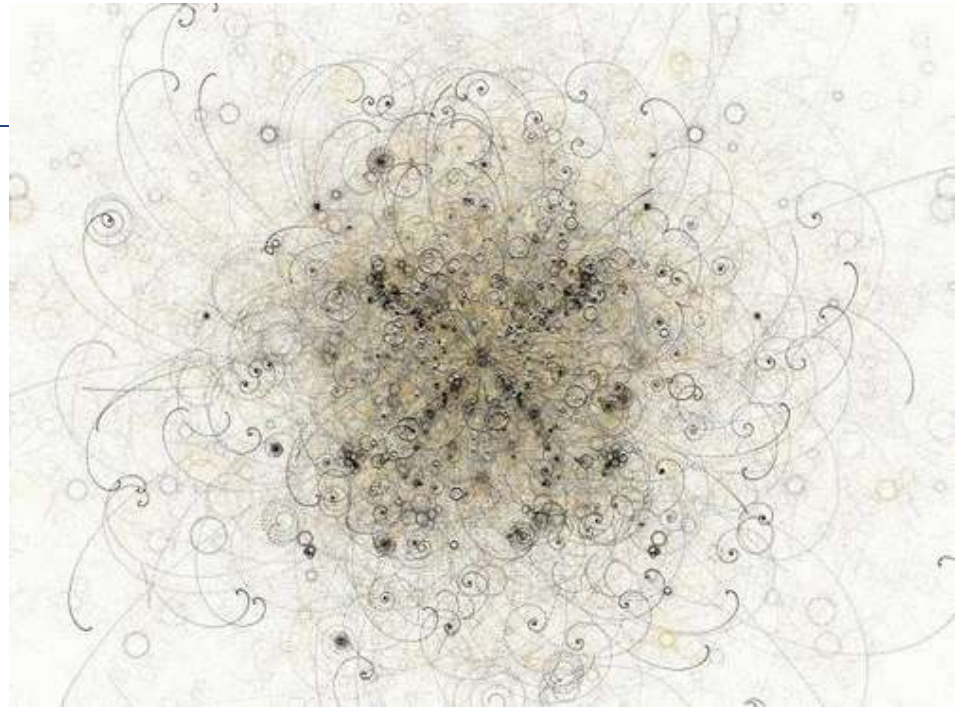
Announcements

Quiz:
- Next quiz on Friday

Homework:
Third HW due **Friday** before class on gradescope

Office hours: back to Fridays from 4-5pm



Outline Guidelines: Due February 28th on gradescope

1. Title
2. Abstract
3. Logical structure of the paper
4. One sentence for each section

See previous slides for details

Synchrotron Radiation

"Electromagnetic radiation emitted when charged particles travel in curved paths" - NIST

ie. Accelerated perpendicular to their velocity

Magnetic field necessary to keep particles on synchrotron orbit:

$$\frac{mv^2}{r} = qvB$$

$$p = mv = qBr$$

transformation from SI units ,

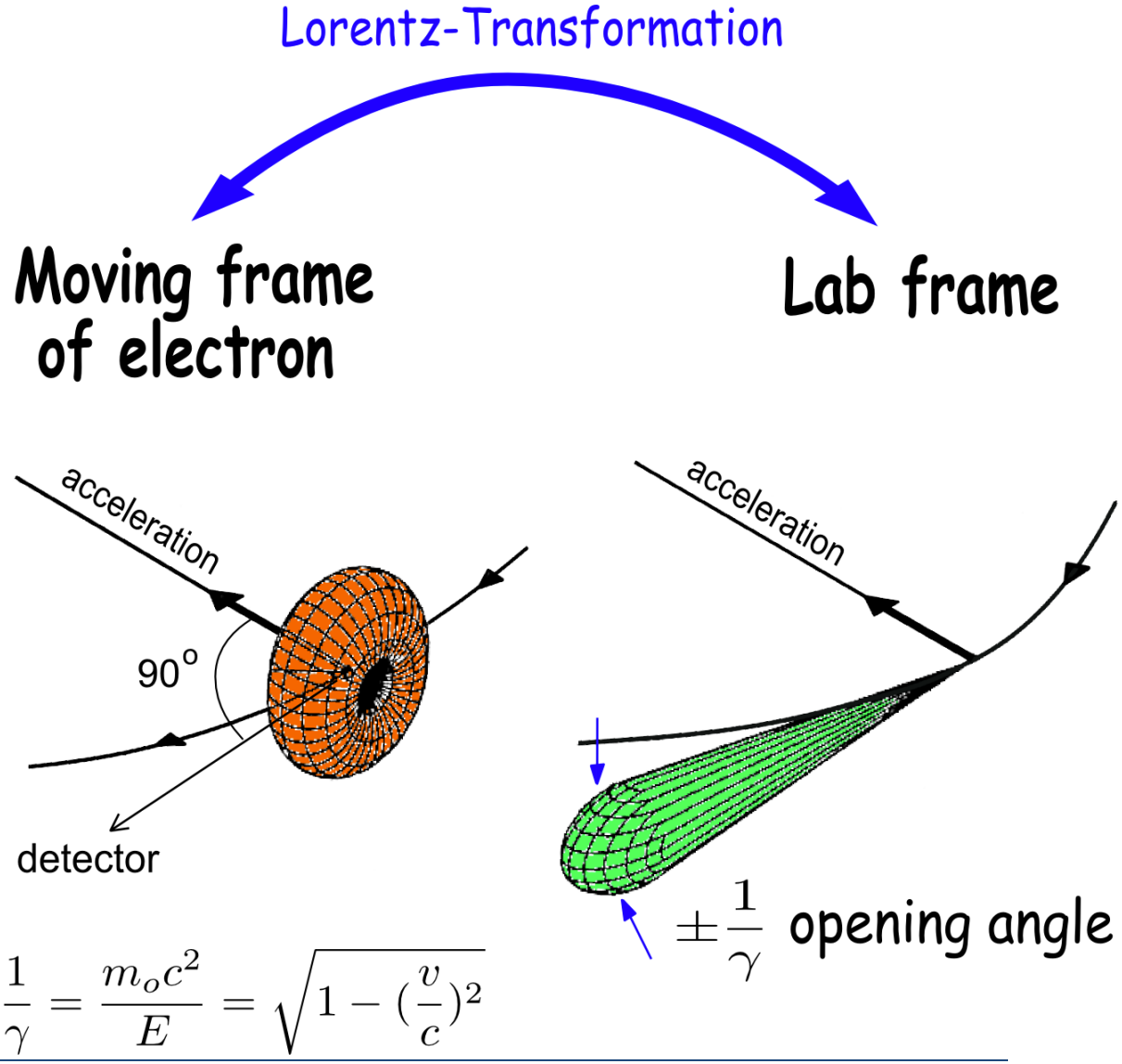
$$p\,[\mathrm{GeV}] = 0.3\, q\, B\,[\mathrm{T}]\, r\,[\mathrm{m}]$$

q = charge of particle accelerating
B = magnetic field
r = radius of accelerator

When designing an accelerator maximize B, set r, for maximum momentum

Synchrotron Radiation

In the moving particle's rest frame, the particle experiences an acceleration
→ it emits radiation
Boosted to the lab frame, the radiation is in a narrow cone tangential to the particle trajectory



$$\frac{1}{\gamma} = \frac{m_o c^2}{E} = \sqrt{1 - (\frac{v}{c})^2}$$

Synchrotron radiation

- The radiated power is given by

$$P = \frac{q^2 c \gamma^4}{6\pi\epsilon_0 r^2}$$

where $\gamma = \frac{E}{mc^2}$

- Therefore, the radiation power scales as $1/m^4$

Given this: use electrons or protons in circular accelerators?

Synchrotron radiation

- The radiated power is given by $$P = \frac{q^2 c \gamma^4}{6\pi\epsilon_0 r^2}$$

- And $$\gamma = \frac{E}{mc^2}$$

- Therefore, the radiation power scales as $1/m^4$

Given this: use electrons or protons in circular accelerators?

Protons will give off less synchrotron radiation
Electrons are easy to accelerate but lose lots of energy

Synchrotrons as colliders

- Synchrotrons are often used as colliders
- Two beams circulate

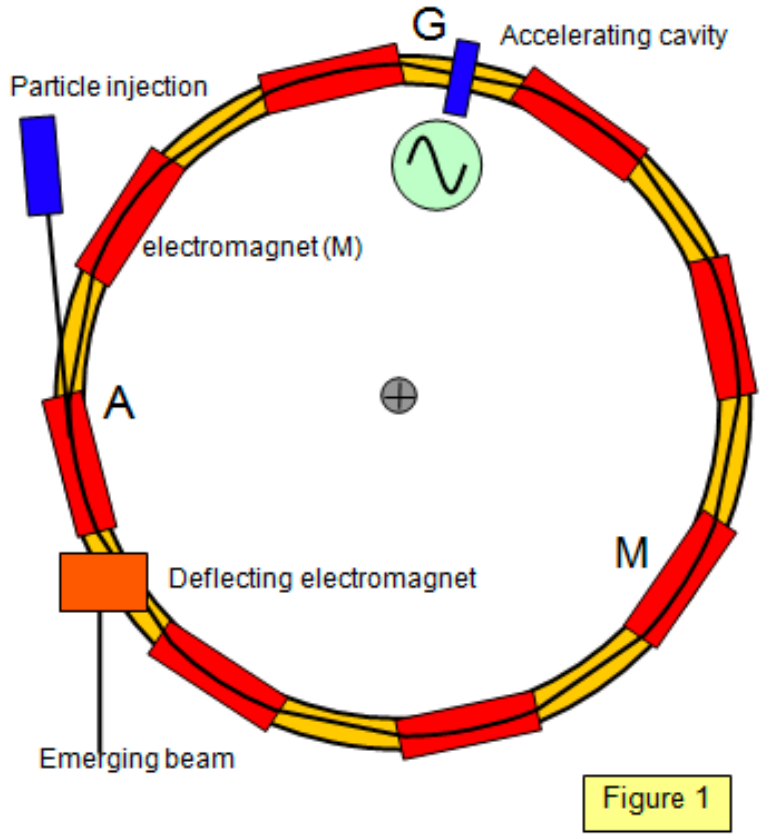
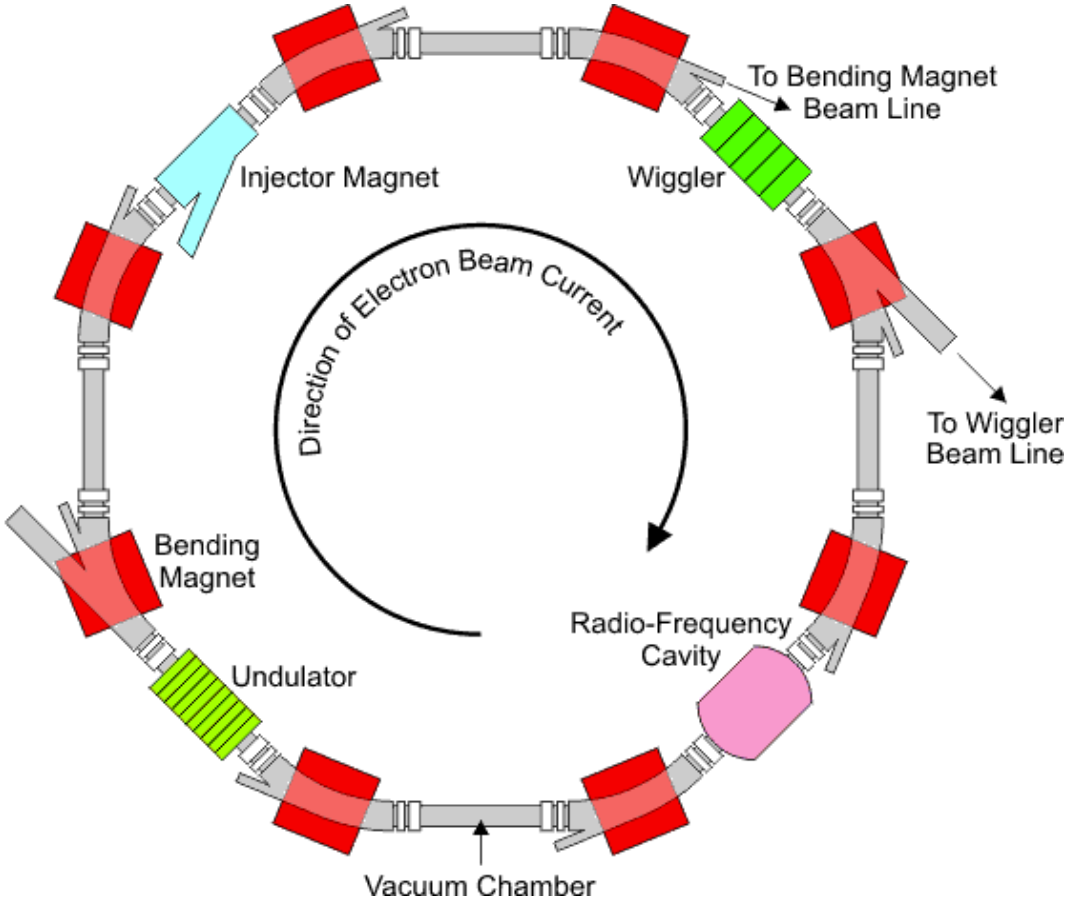


Figure 1

- Requires lots of dipole magnets
- But only one acceleration gap
- Requires fast injector magnet
- Producing user beams requires fast extractor magnet

Intense x-ray sources from synchrotrons

- Circulate electron beam, synchrotron radiation for experimental areas tangential to beam line



- Undulator and wiggler are series of short dipoles to produce synchrotron radiation
- Control wavelength and intensity better than from bending in dipole

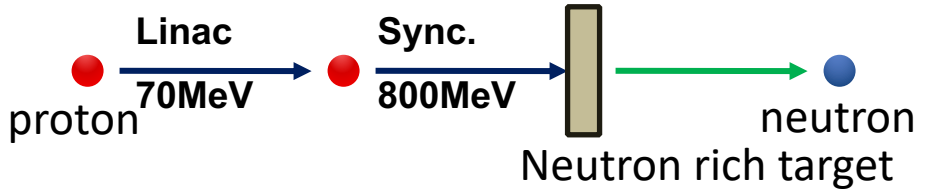
Neutral and Unstable Beams

The particles used in accelerators must be stable and charged, but ,there are a number of ways to produce beams of neutral (neutron, photons,…) or unstable (exotic nuclei, $\pi^{\pm}$,…) particles.

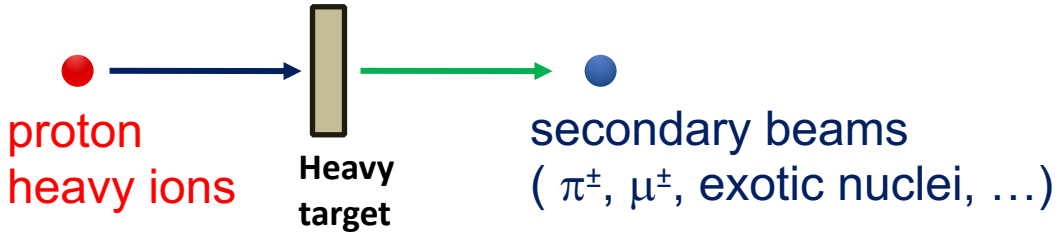
neutrons

nuclear reactor : low energies of 1-2MeV
ILL reactor, Institute Laue-Langevin, in France

spallation : ISIS, Rutherford Appleton Laboratory, in UK



unstable particles

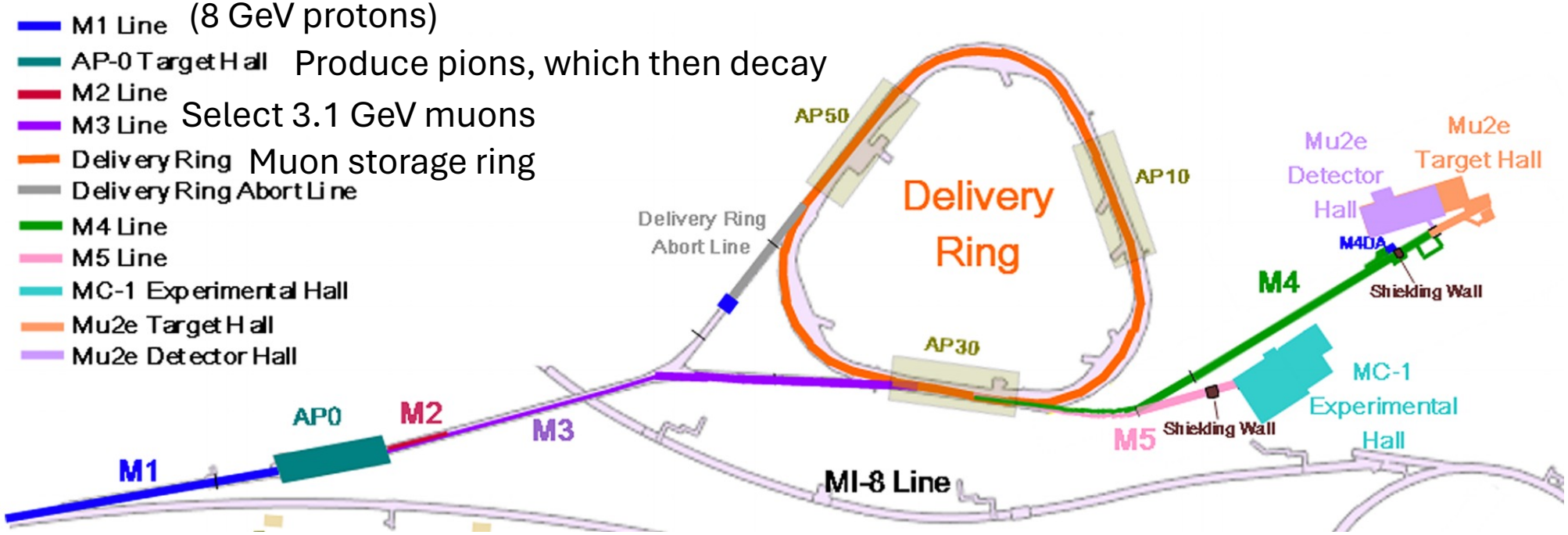


Muon beam at Fermilab

- Very pure muon beam for precision muon experiments (g-2)

  Accelerate muons so much that their lifetime is very long

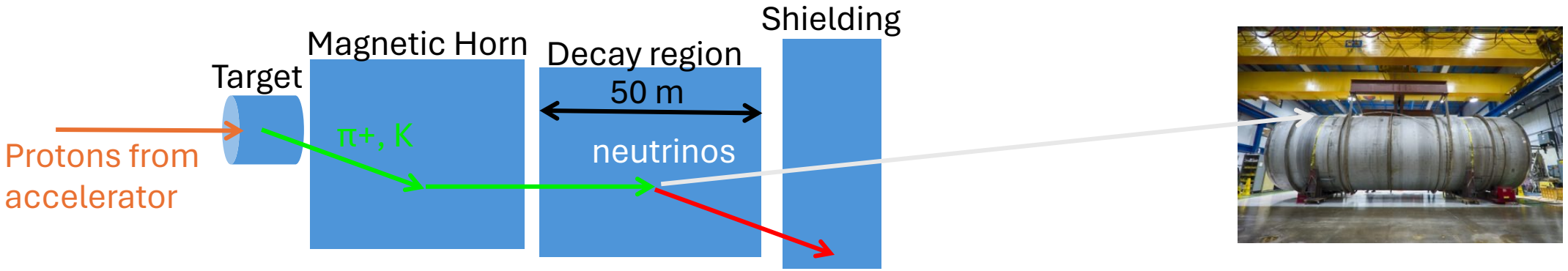
  Measure magnetic moment of the muon



Neutrino beams

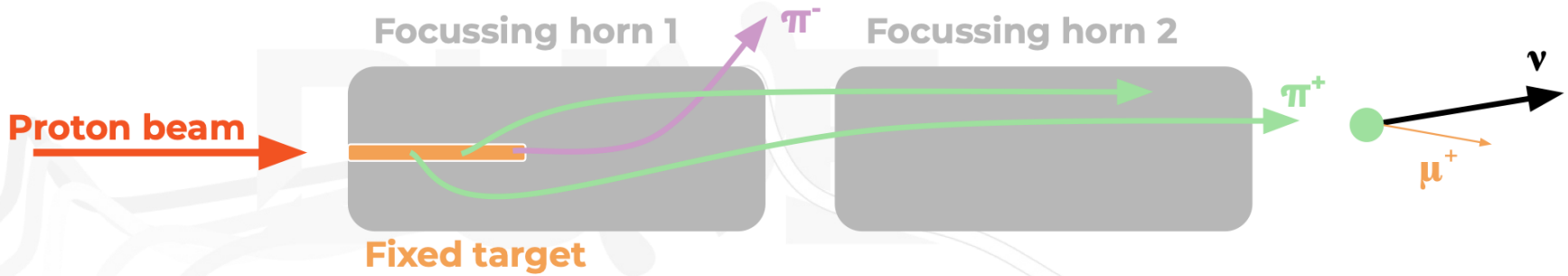
Can't focus neutrinos since they are electrically neutral
Instead, focus particles that decay into neutrinos!

Making a neutrino beam:

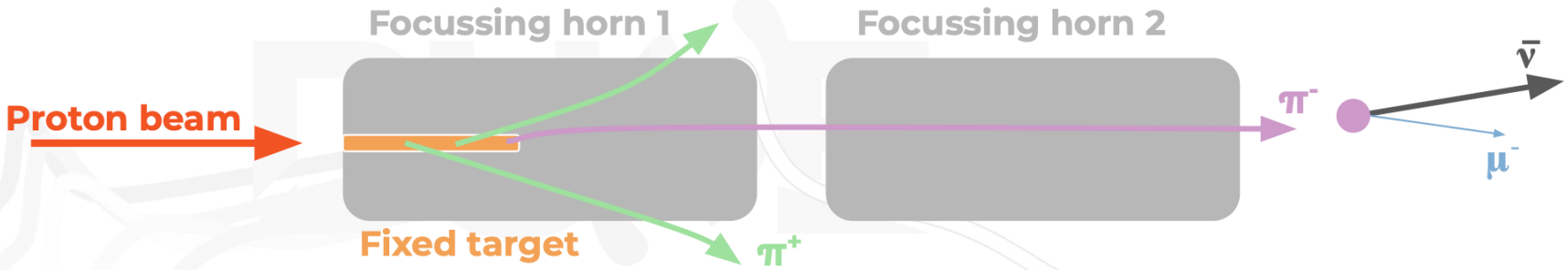


Neutrinos vs. Anti-Neutrinos

Flip the horn current to focus positive or negatively charged particles



Neutrino mode, focussing positive particles



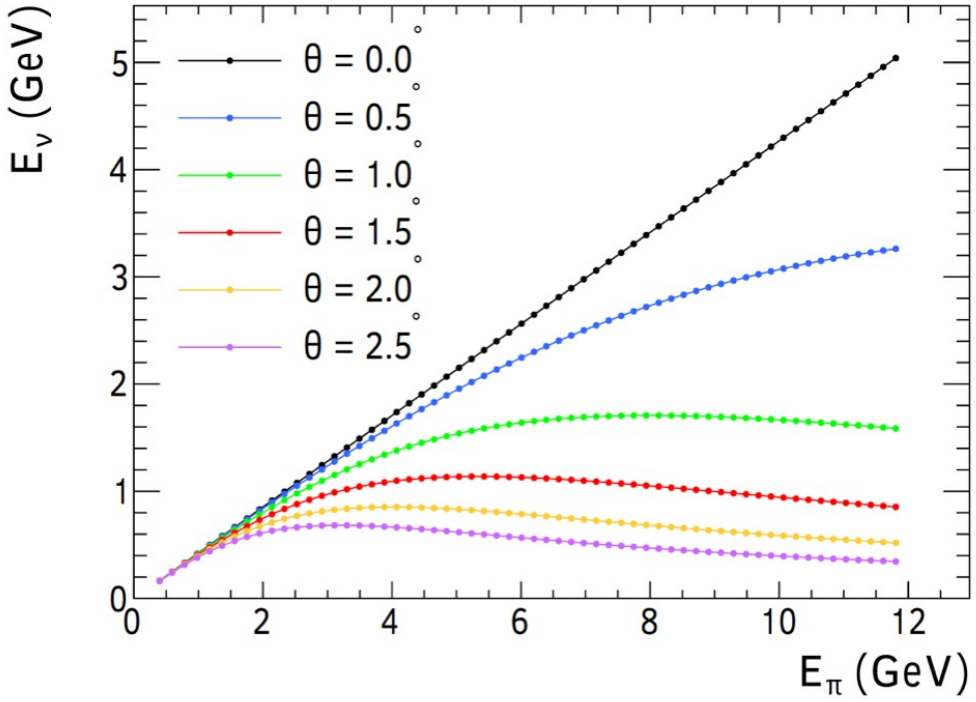
Anti-neutrino mode, focussing negative particles

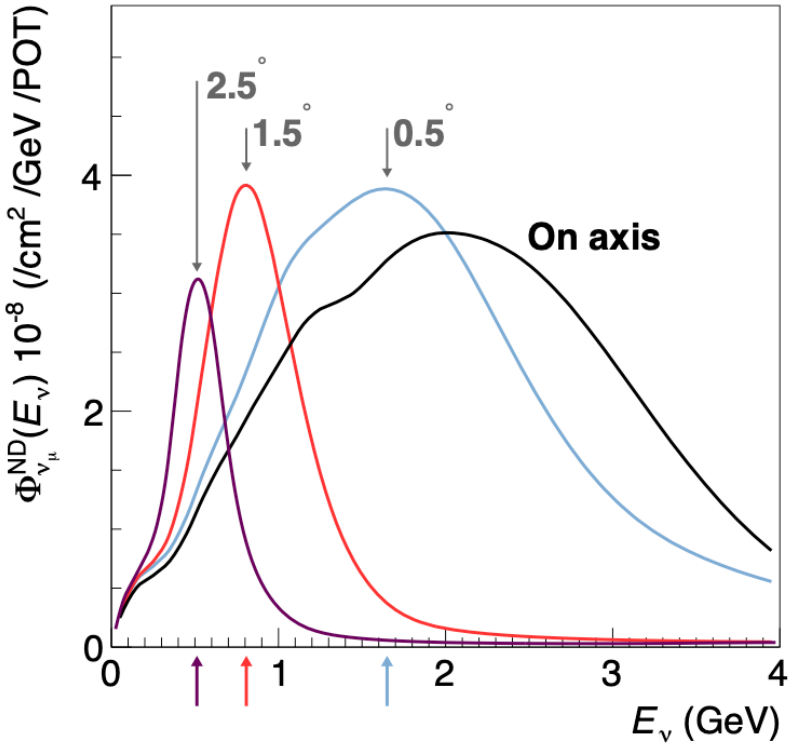
Neutrino Energy?

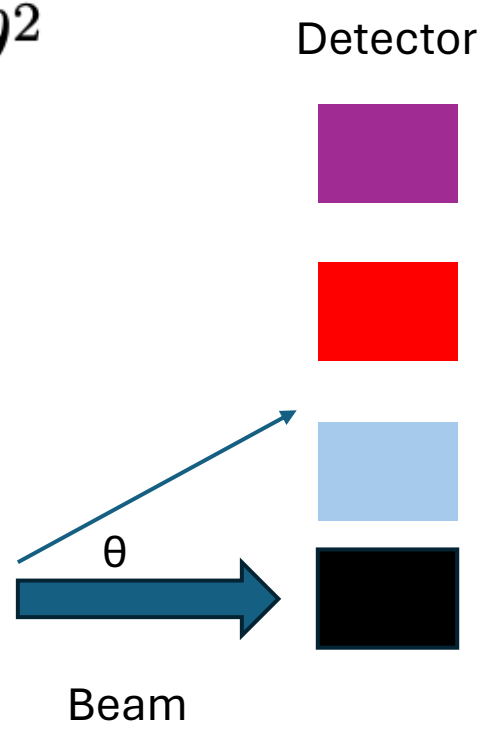
- Because neutrinos are neutral we cannot focus them

Most neutrinos come from two body pion decay:

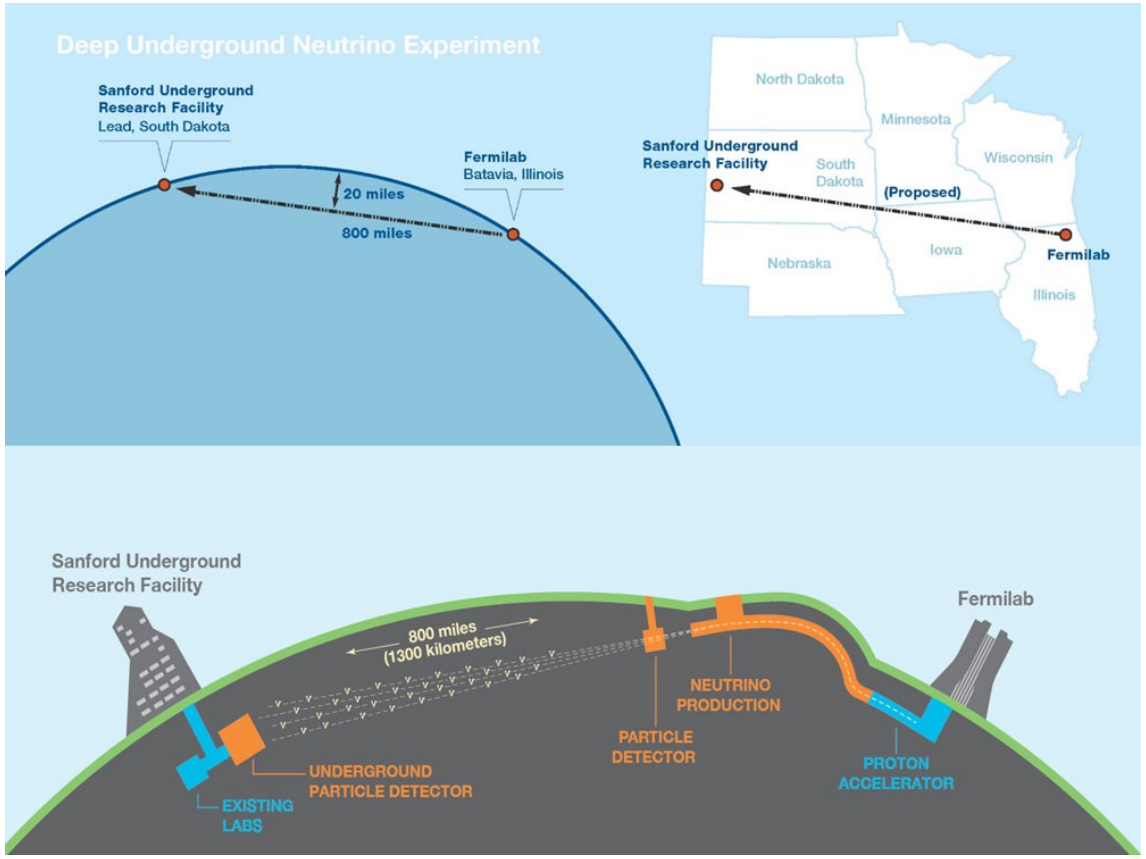
$$E_\nu = \frac{[1-(m_\mu/m_\pi)^2]E_\pi}{1+\gamma^2\theta^2}$$

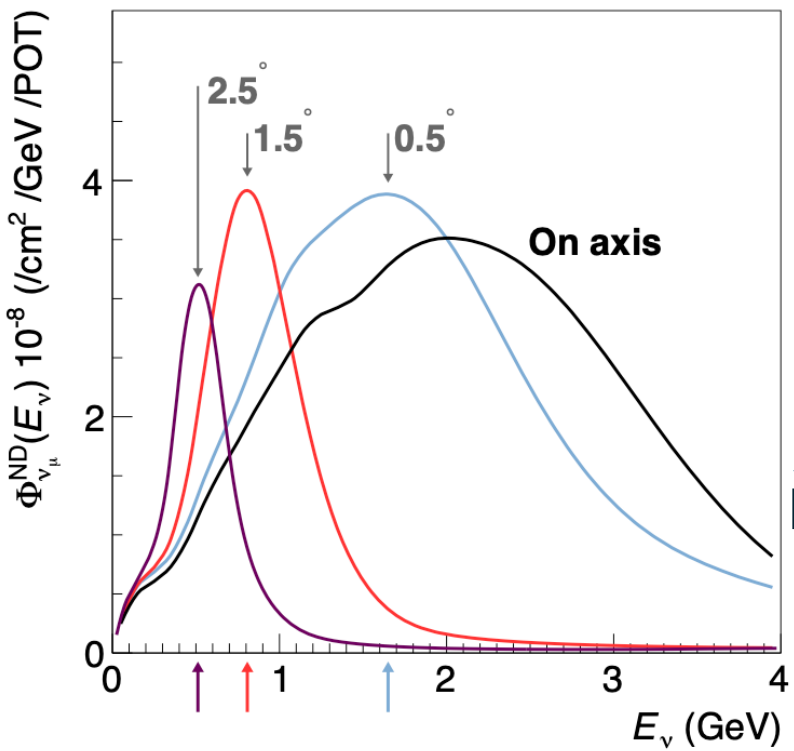


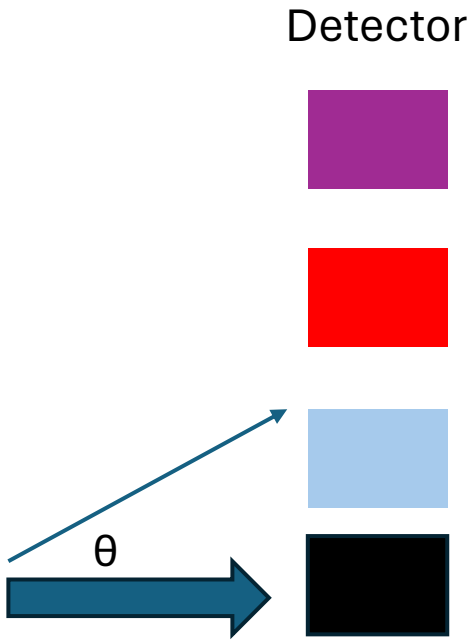




DUNE

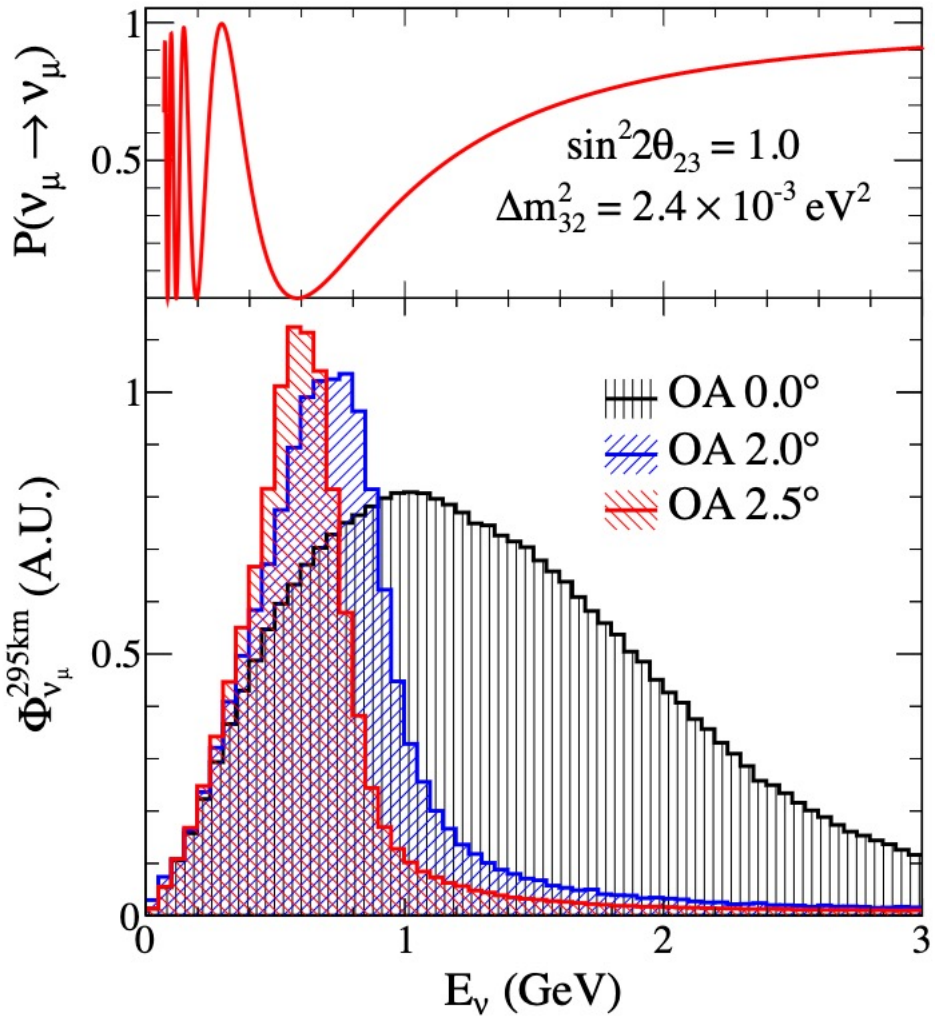

Deep Underground Neutrino Experiment
Sanford Underground Research Facility
Lead, South Dakota
Fermilab
Batavia, Illinois
20 miles
800 miles
North Dakota
Minnesota
Wisconsin
South Dakota
(Proposed)
Nebraska
Iowa
Illinois
Sanford Underground Research Facility
Fermilab
800 miles (1300 kilometers)
NEUTRINO PRODUCTION
PARTICLE DETECTOR
PROTON ACCELERATOR
UNDERGROUND PARTICLE DETECTOR
EXISTING LABS

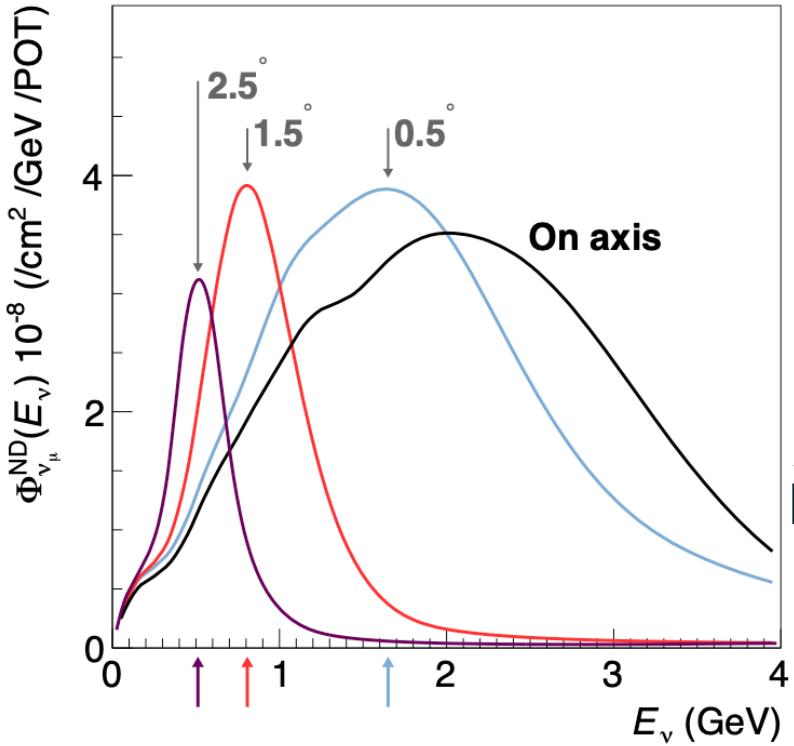

2.5°
1.5°
0.5°
On axis
$\Phi^{ND}_{\nu_\mu}(E_\nu)$ 10^{-8} (/cm^2 /GeV /POT)
E_ν (GeV)
0
1
2
3
4

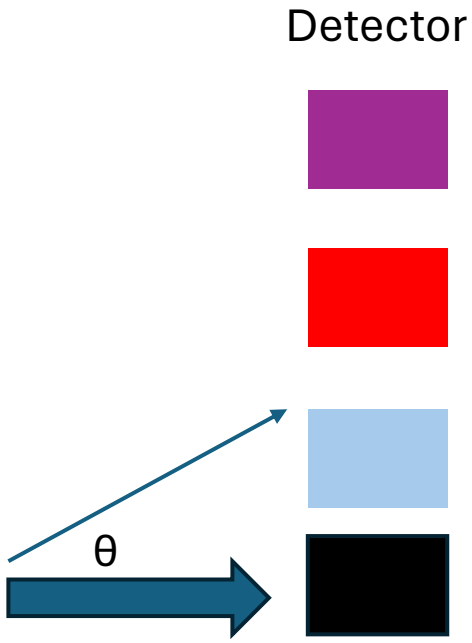

Detector
θ
Beam

Detector Location Optimized for Physics

T2K Experiment







arxiv: 1211.0469