Neutrinos from a PIon beamLine (nuPIL)

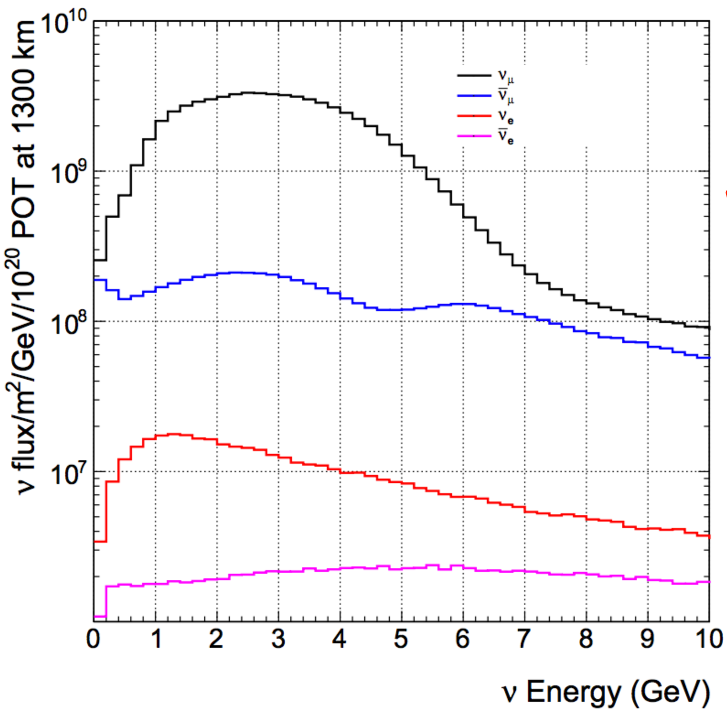
Ao Liu

Outline

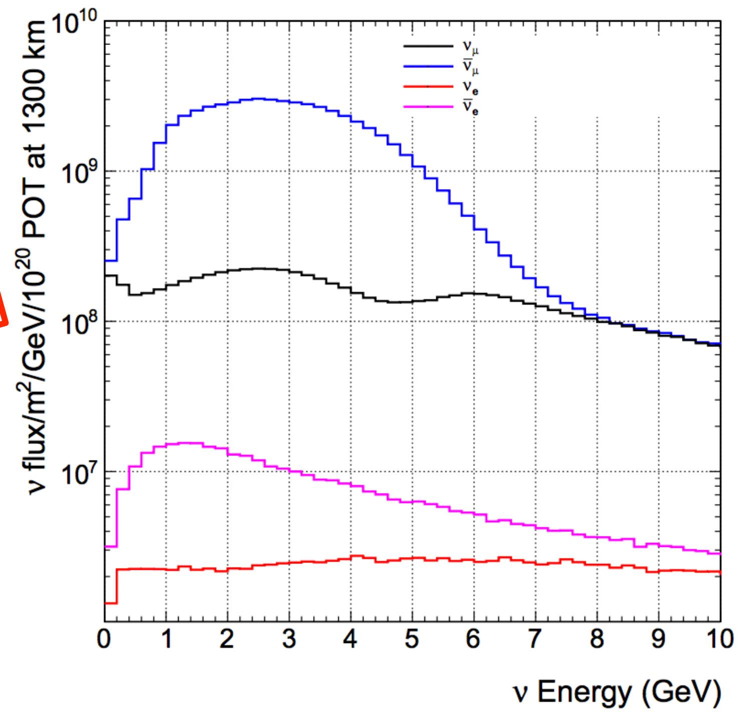
- Motivation
  - Neutrino flux and background at LBNF/DUNE
  - More physics topics from a beamline than from a concrete pipe, even the concrete would agree.
- Methodology
  - Provide sign selection on the secondary particle beam after horn focusing
  - Control (rather than release) the beam with betatron oscillation → more useful decays
- Results

Motivation – a better ν_μ beam

- Neutrino flux at DUNE



CDR-Physics Volume



- Inevitably collects decays from wrong-sign particles after they leave the horns (the only sign-selection devices).

Motivation – a better ν_μ beam (Cont'd)

- The signal for ν_e appearance is an excess of CC ν_e and ν_e-bar interactions over the expected background in the far detector, which is composed of
  - CC interactions of ν_e and ν_e-bar intrinsic to the beam;
  - misidentified ν_μ and ν_μ-bar CC events;
  - NC events and ν_τ (bar) CC events
- DUNE detector not magnetized: relying on the high-resolution imaging to *statistically* discriminate neutrinos from anti-neutrinos.

Motivation – a better ν_μ beam (Cont'd)

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  - misidentified ν_μ and ν_μ-bar CC events;
  - NC events and ν_τ (bar) CC events
- What if anti-neutrinos don't exist at all? The appearance signal will be much cleaner, the detector DOES NOT NEED to be magnetized!

Motivation – a better ν_μ beam (Cont'd)

- The signal for ν_e appearance is an excess of CC ν_e and ν_e-bar interactions over the expected background in the far detector, which is composed of
  - CC interactions of ν_e and ν_e-bar intrinsic to the beam;
  - misidentified ν_μ and ν_μ-bar CC events;
  - NC events and ν_τ (bar) CC events
- Moreover, due to the optics feature of the beamline, the intrinsic ν_e from μ decays is greatly reduced (almost eliminated)

Motivation – a better ν_μ beam (Cont'd)

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  - CC interactions of ν_e and ν_e-bar intrinsic to the beam;
  - misidentified ν_μ and ν_μ-bar CC events;
  - NC events and ν_τ (bar) CC events
- Moreover, due … beamline, the … greatly reduce… (…)

Remember, in nuSTORM, the production straight was designed with an exactly opposite purpose: to KEEP muons in the straight. The nuPIL straight is a good example of a badly designed nuSTORM straight.

Motivation – a better ν_μ beam (Cont'd)

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  - CC interactions of ν_e and ν_e-bar intrinsic to the beam;
  - misidentified ν_μ and ν_μ-bar CC events;
  - NC events and ν_τ (bar) CC events
- Moreover[2], the flux of the neutrino beam can be precisely known by measuring the pion beam in the beamline, which can't be done at DUNE.

Motivation – more opportunities (more than a neutrino program)

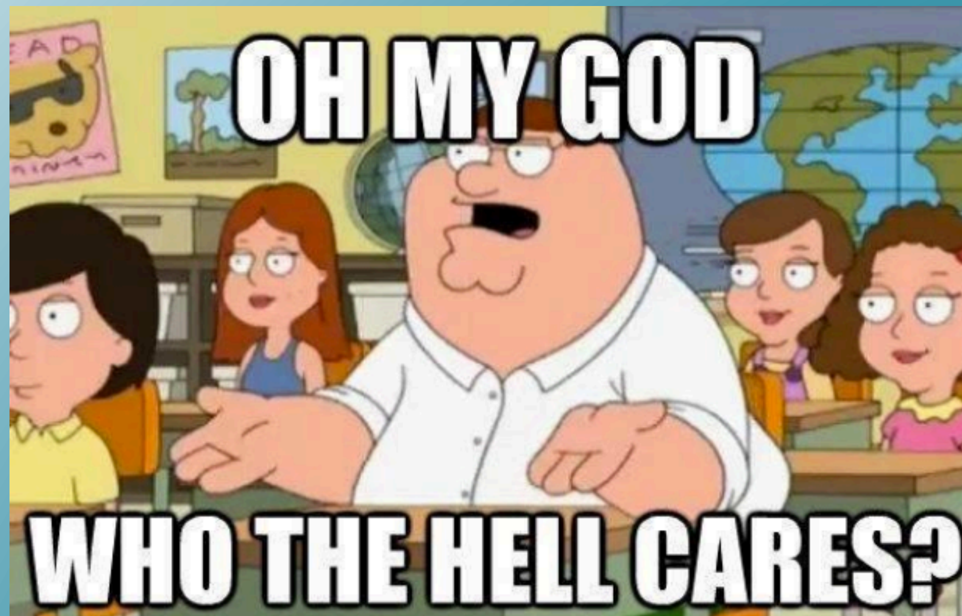
- What is left for us is a ν_μ beam which is
  - almost pure (ν_e from π decays still unavoidable, but they ~= super rare)
  - precisely known/monitored.

Are you sure it's because MICE got into our concrete pipe?

- **and** research opportunities on measuring π+μ mixed beam, PID identification techniques, magnet engineering, etc., a test bed for future muon facilities! An accelerator project, an accelerator lab!
- **plus a** reusable non-interacted primary proton beam (see later slides)

Methodology

How we make this work



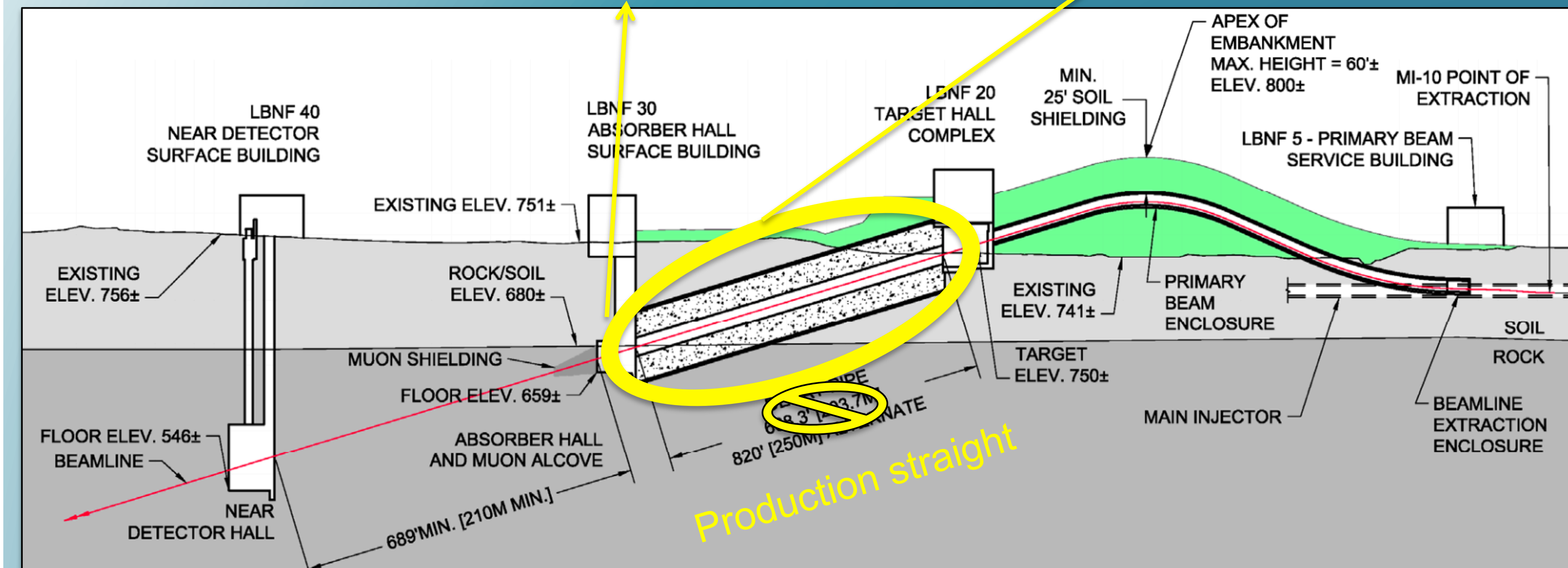
Methodology

How we make this work

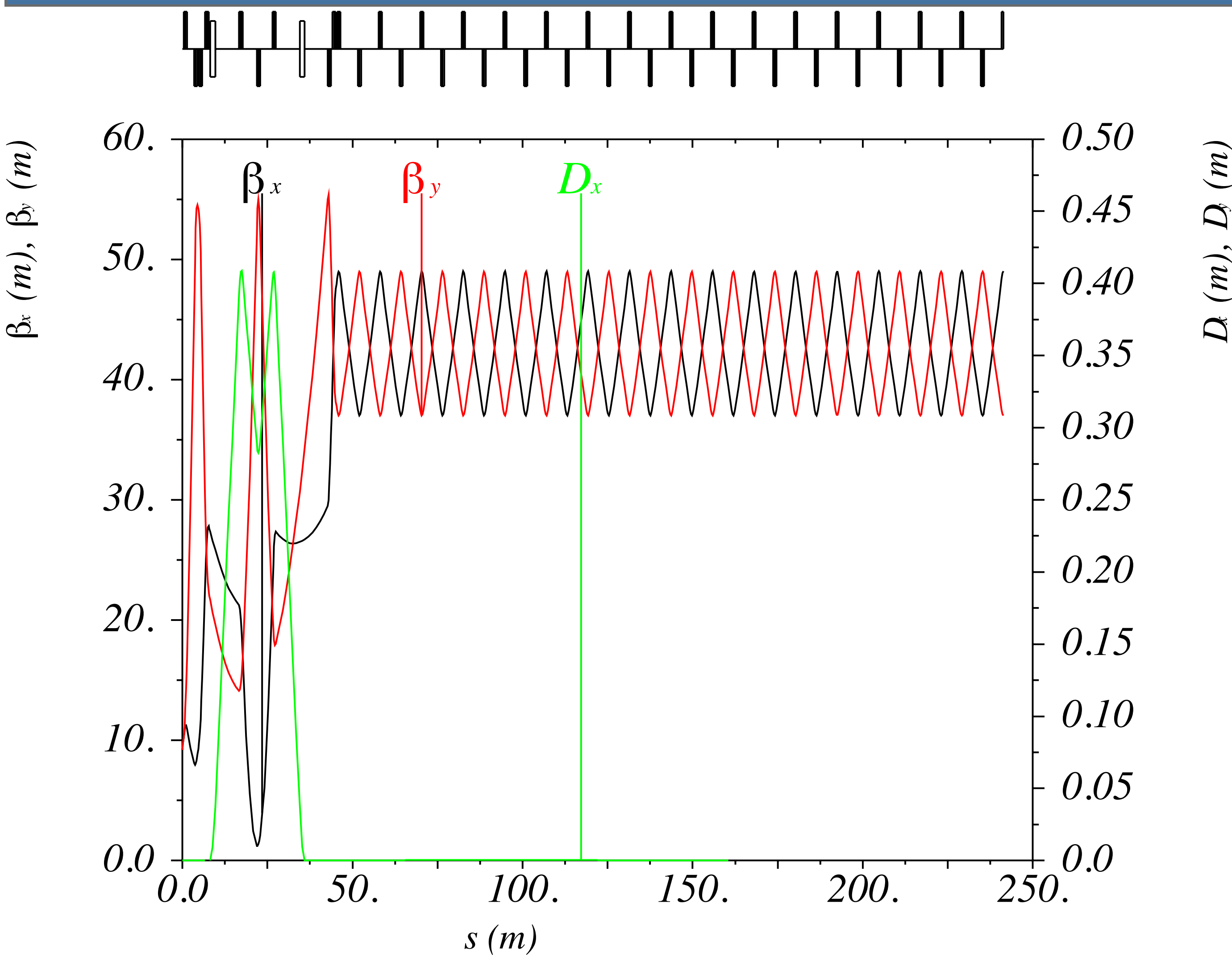
Methodology - layout

LBNF's absorber is here. Collects π, μ, p, UCO, etc.

Make magnets, not concrete.



Methodology – beamline optics



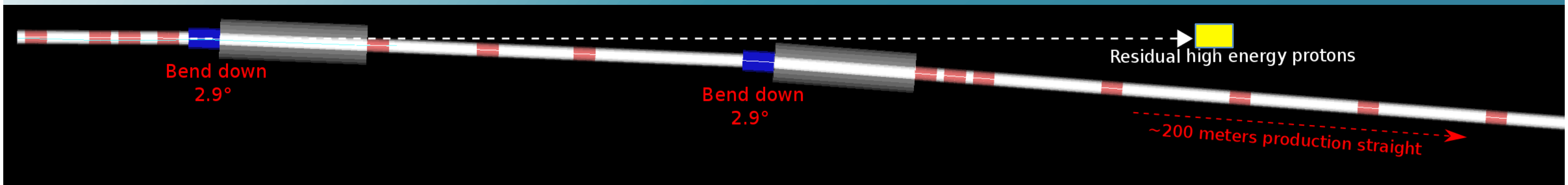
Two bending dipoles (both downwards) provides wonderful sign selection;

The net pitch angle is 5.8 degrees, as in the DUNE beamline setting;

Total length of the beamline ~ 240 meters, production straight section ~ 200 meters

Methodology – beamline appearance

Our absorber is here.
Collects mostly, protons.



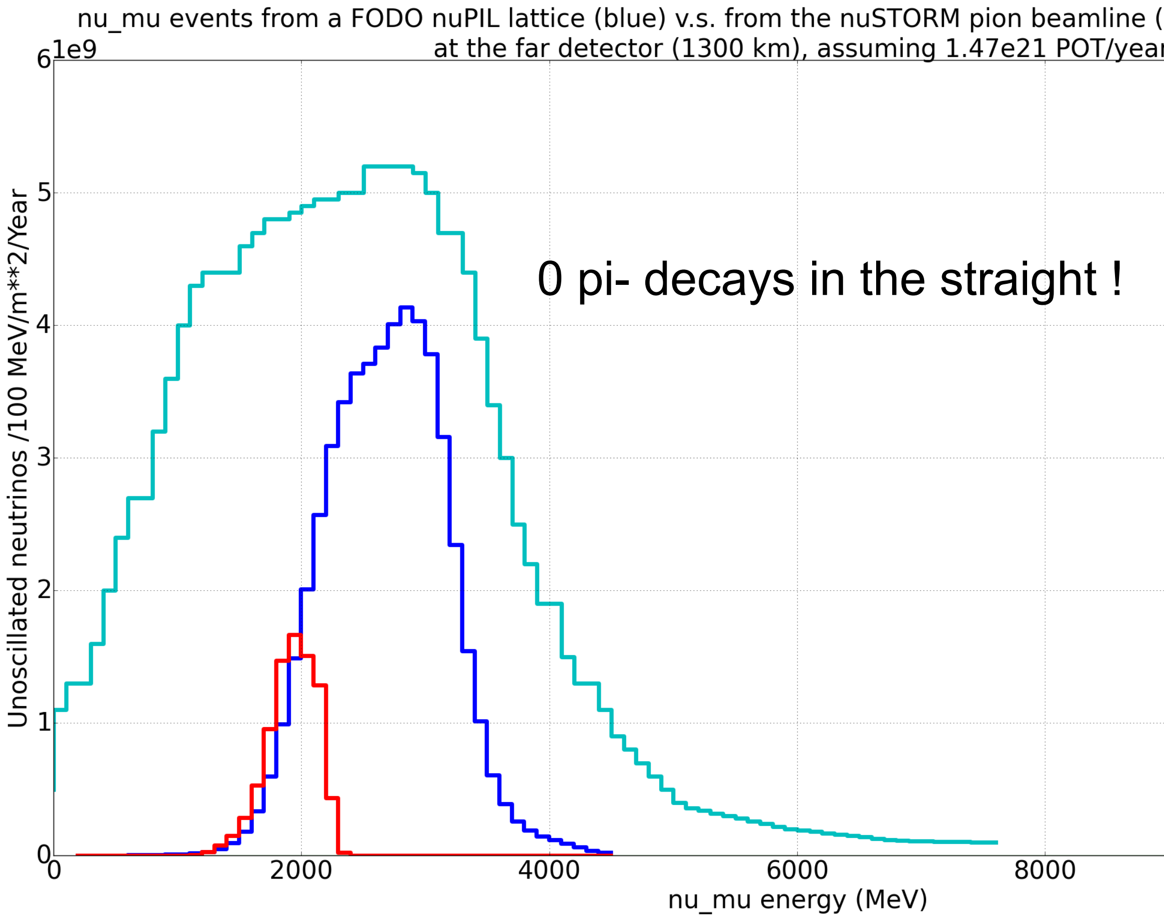
How to get the neutrino flux at the FD starting from a lattice design:

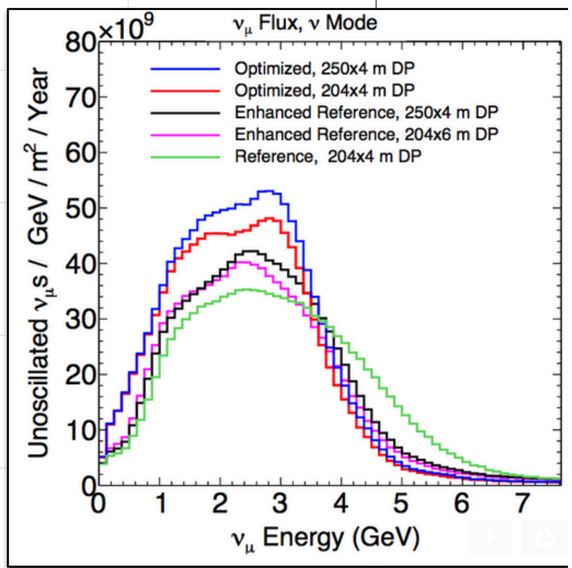
1. Track particles in G4Beamline, record the ones that decayed, and their children.
2. Based on the G4BL loss file, particles that are killed by the aperture can be filtered out.
3. Using the particle decay information, most importantly their directions of motion, we can calculate the nu flux at a detector using the kinematics.

Results

without optimization yet

Flux


nu_mu events from a FODO nuPIL lattice (blue) v.s. from the nuSTORM pion beamline (red), and DUNE (light green)
at the far detector (1300 km), assuming 1.47e21 POT/year
1e9
Unoscillated neutrinos /100 MeV/m**2/Year
nu_mu energy (MeV)
0 pi- decays in the straight !

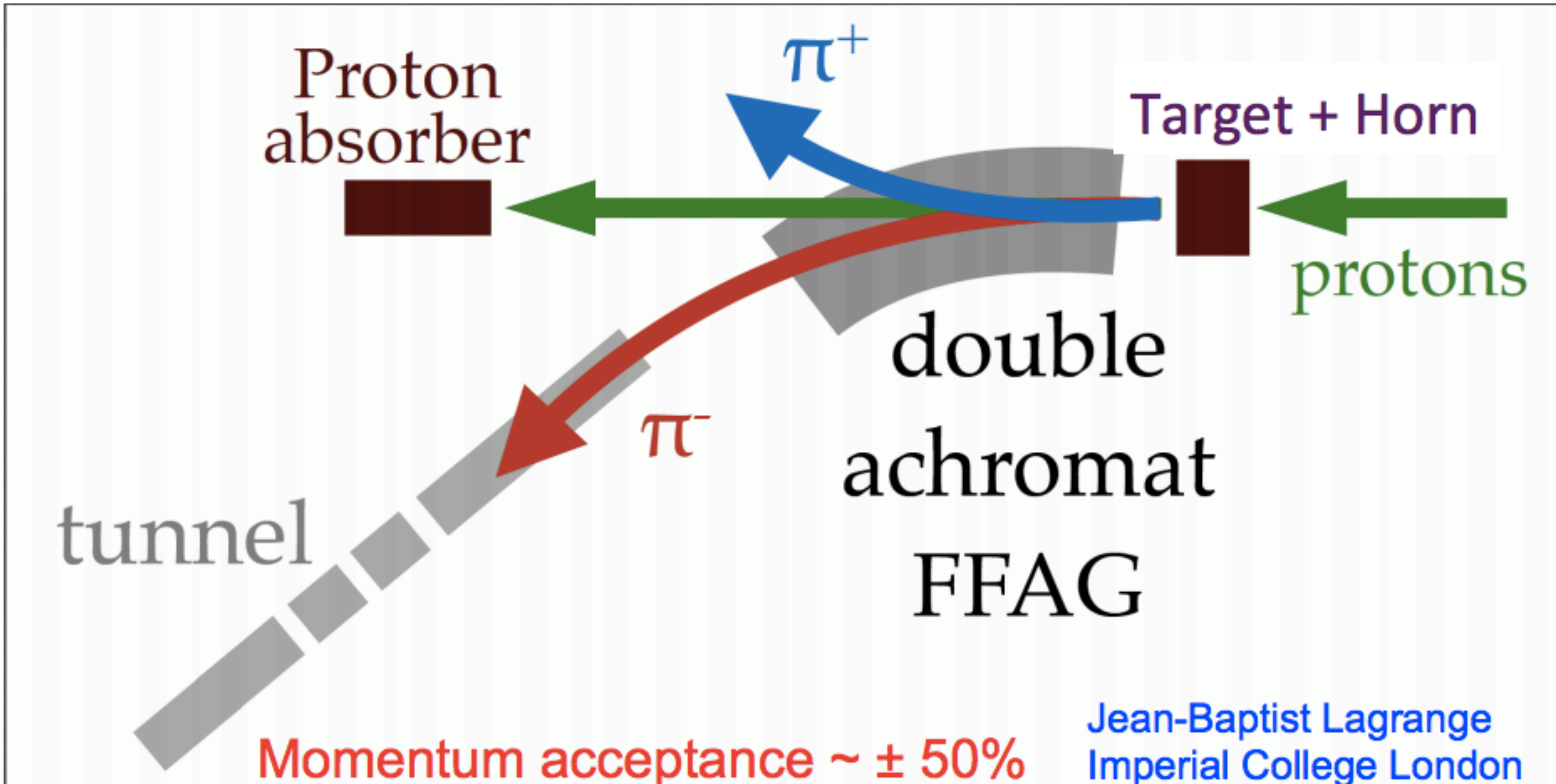

ν_μ Flux, ν Mode
$\times10^9$
Optimized, 250x4 m DP
Optimized, 204x4 m DP
Enhanced Reference, 250x4 m DP
Enhanced Reference, 204x6 m DP
Reference, 204x4 m DP
Unoscillated ν_μs / GeV / m^2 / Year
ν_μ Energy (GeV)

Flux (cont'd)

- As shown, the flux at ~ 3 GeV is comparable with the original DUNE flux, but our flux drops sharply with energy going off-peak
- A possible solution is to use an FFAG lattice with very large momentum acceptance and phase space acceptance, but there may be trade-offs (under investigation by JB Lagrange).

FFAG Design Concept

ν from a pion injection line



Momentum acceptance ~ ± 50%

Jean-Baptist Lagrange
Imperial College London

Conclusion & Future work

Conclusion

- The neutrino beam from the pion beamline is pure, and can be precisely known;
- The neutrino flux from a purely FODO pion beamline is able to provide a "nearly comparable" flux with DUNE's beam at the far detector, but only within a narrow neutrino energy band.
- The FFAG pion beamline is under design and is promising.

Future Work for FODO Design

- Add sextupoles in the lattice and compensate some of the nonlinear effects;
- Perform a preliminary optimization using the Genetic Algorithm / Simulated Annealing algorithm on the transmission efficiency;
- Using a full tracking in the FFAG lattice, calculate the nu flux at the FD, and compare.