MOMENT Synergies with Other Projects

Jingyu Tang
Institute of High Energy Physics, CAS

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Main Topics

- MOMENT concept
- Proton driver technology synergy with other projects
- Target technology synergy with other projects
- Neutrino beamline technology synergy with other projects
- Detector technology synergy with other projects
- Summary

MOMENT Concept

MOMENT Concept

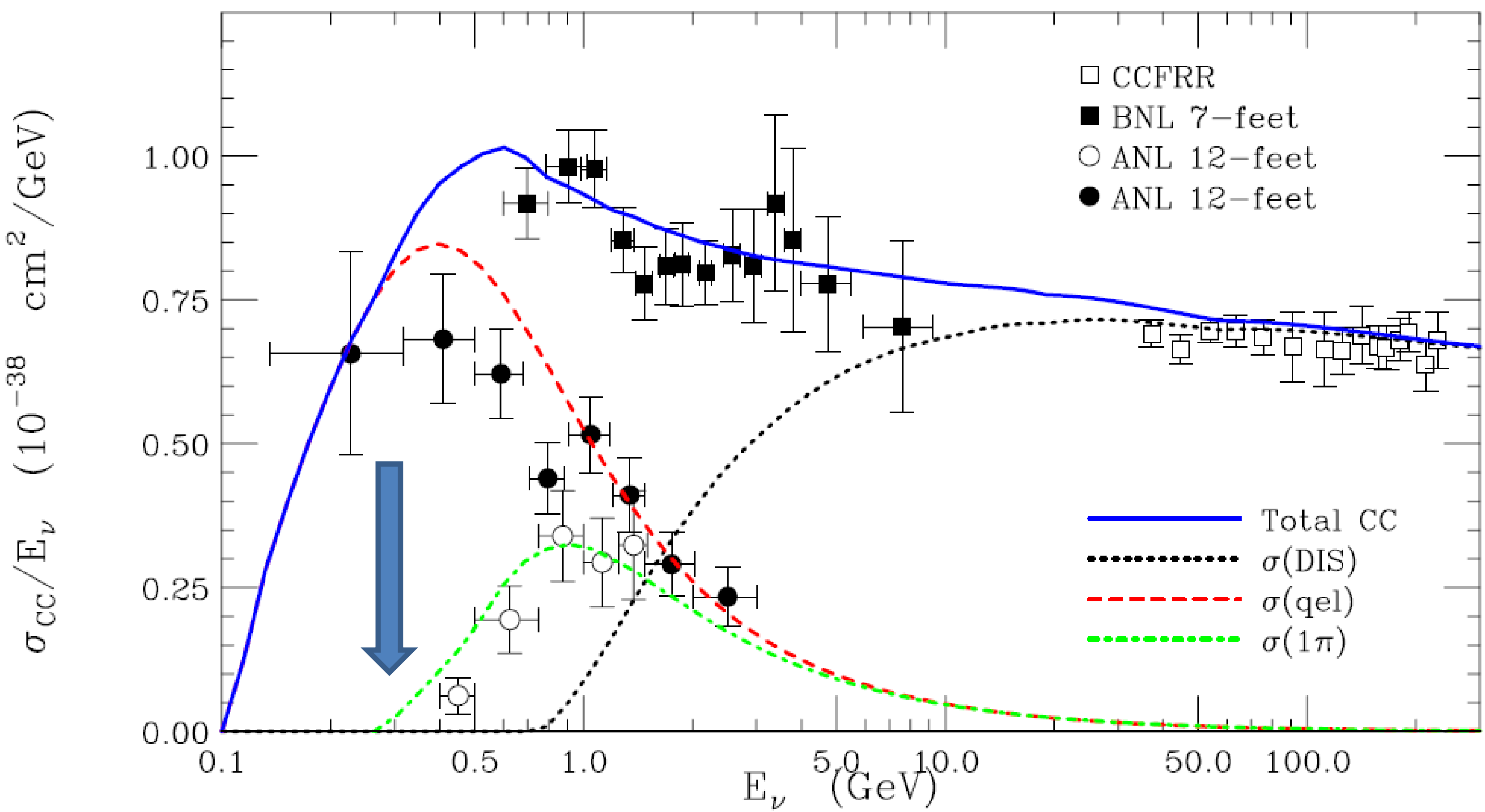
- MOMENT: A muon-decay medium baseline neutrino beam facility
- MOMENT was launched in 2013 as the third phase of neutrino experiments in China
  - Neutrino experiments at Daya Bay continues data-taking
  - Jiangmen (JUNO, or DYB-II) has started civil construction
- A dedicated machine to measure CP phase, if other experiments (such as LBNF/DUNE, HyperK) will have not completed the task
- As a driving force to attract researchers from China as well international collaborators to work on neutrino experiments based on accelerators

A concept to exploit high-flux medium-energy muon-decay neutrinos

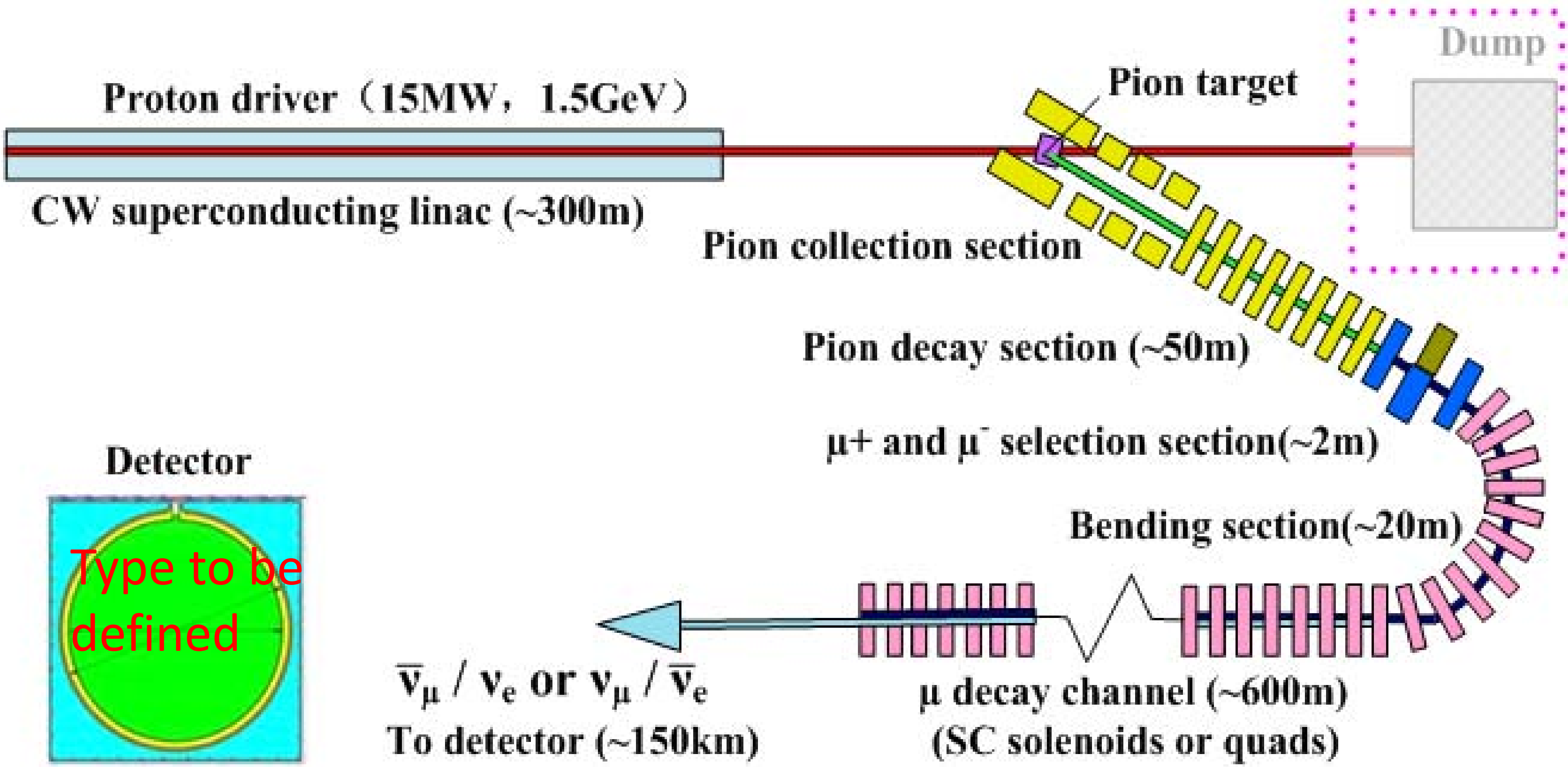
- Using a CW proton linac as the proton driver
  - Based on the China-ADS linac
  - 15 MW in beam power
- Fluidized target in high-field SC solenoid
  - Granular tungsten or mercury jet
  - Collection of pions and muons of both charges
- Neutrino beam from pure μ+ or μ- decays
  - Medium energy (250 MeV) for medium-baseline experiment
  - From long decay channel instead of decay rings for NF and nuSTORM

μ Decay channel - a π^0-free neutrino beam line

- Neutrino energy: **~ 300 MeV ➔ baseline = 150 km**
- Although we loose some statistics due to lower cross section, but we gain by being background free from π^0



Schematic for MOMENT

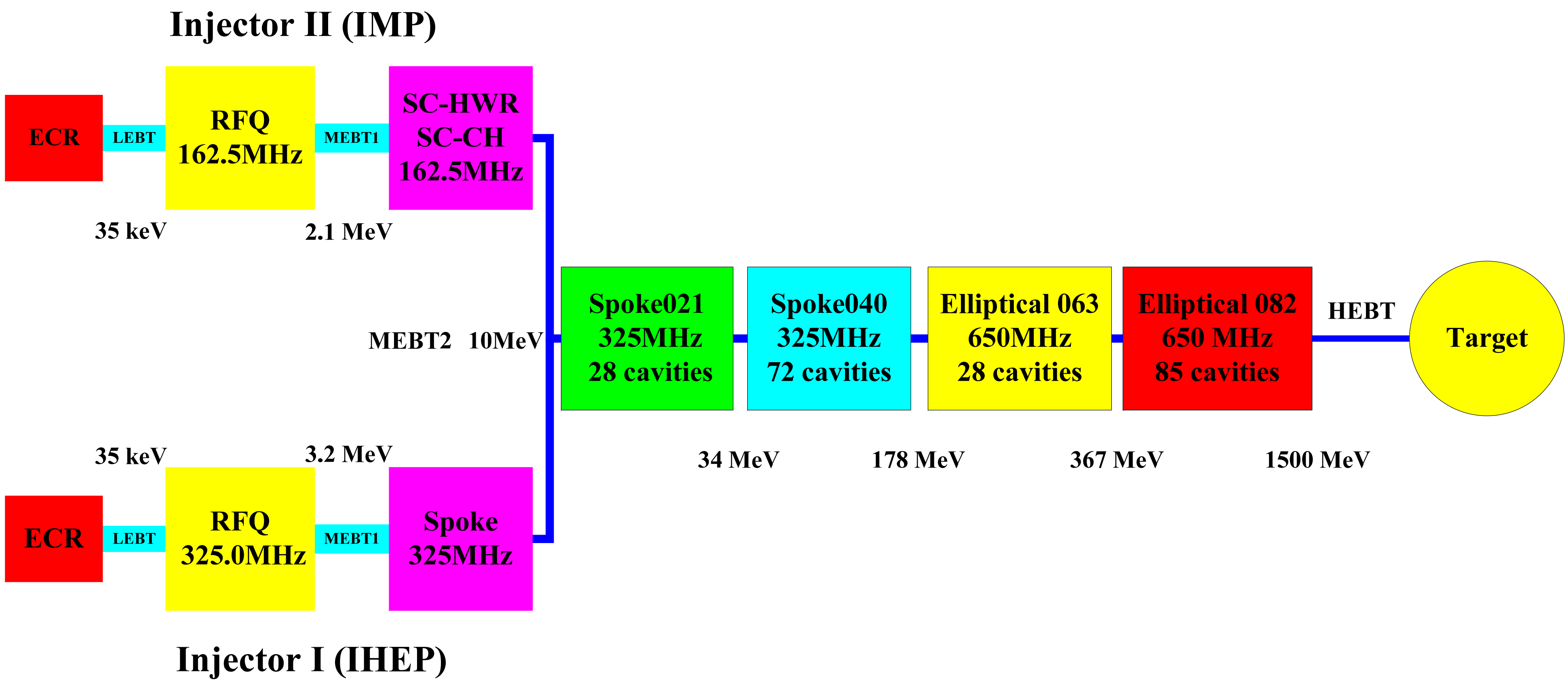


Proton driver technology synergy with other projects

MOMENT proton driver: a CW superconducting linac

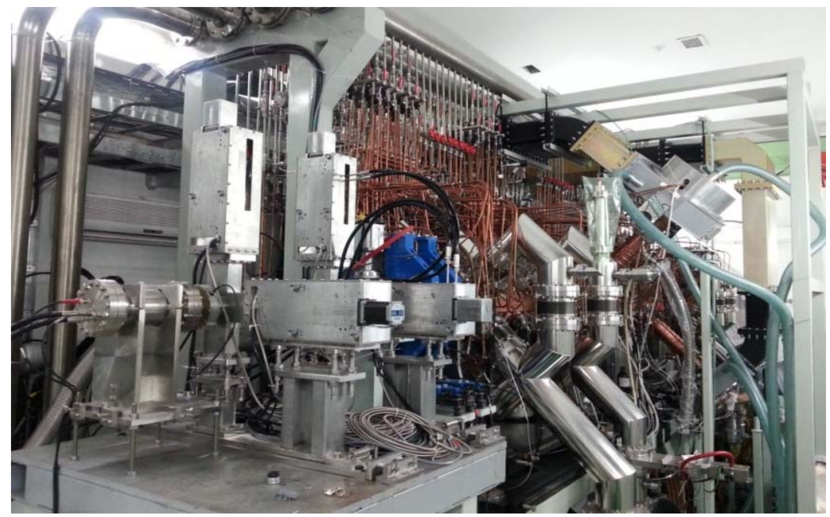
- A CW proton SC linac can provide the highest beam power, and selected as the proton driver for MOMENT
- China-ADS project and MYRRHA are developing such a CW proton linac. PIP-II (PIXE) is developing CW RF linac but with lower beam duty.
- If China-ADS program goes well, the linac could be also used as the proton driver for MOMENT in 2030's.
  - Proton beam: 1.5 GeV, 10 mA (15 MW)
  - Alternate: extending energy to 2.0 GeV

Design scheme for the C-ADS linac

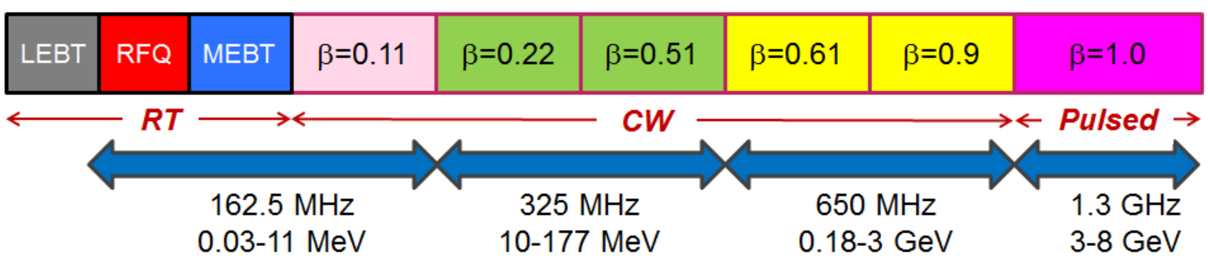


R&D efforts on ADS linac at IHEP and IMP

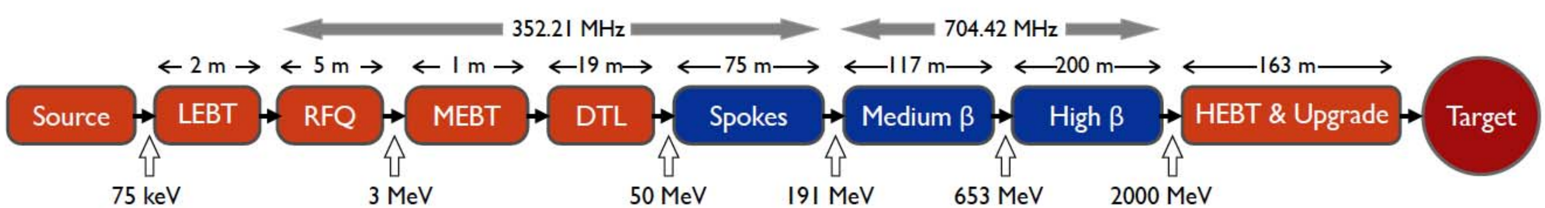
- IMP completed the commissioning test of a 5 MeV front-end (10 mA, 162.5 MHz, 2.1 MeV RFQ in CW mode, a cryomodule HWR in pulsed mode)
- IHEP is testing another scheme (3.2 MeV RFQ, a cryomodule Spoke, 10 mA, 325 MHz)
- Prototyping on both low-β and medium-β cavities



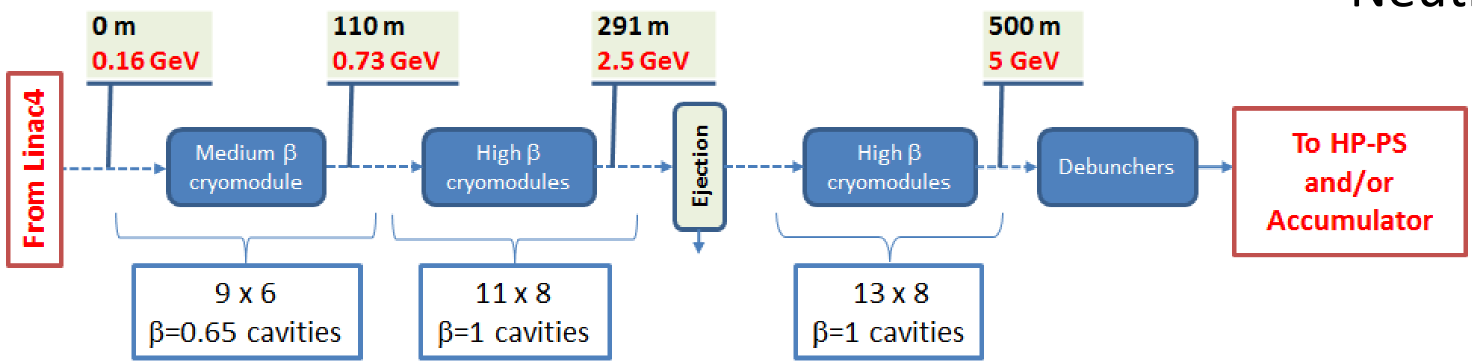
- High power proton accelerators are mandatory to neutrino beam facilities
- MOMENT proton driver shares technologies with the other proposed neutrino beams, such as Neutrino Factory, Project-X (now PIP-II) and ESSnuSB
  - Development of superconducting cavities (low-β, medium-β, high-β) and the high duty factor RF equipment
  - Beam loss control in high power proton linacs
  - Interface with target station



Project-X (Upper)
ESSnuSB (Lower)



Neutrino Factory (SPL)



Comparison of proton drivers

	Beam power (MW)	Linac Energy (GeV)	RF duty factor (%)	Peak current (mA)	SC cavity types
MOMENT	15	1.5 (~2.5)	100	10	5
Neutrino Factory	4	5 (SPL)	4	20	2
Project-X (PIP-II)	3 (0.2)	3 (0.8)	100 (10)	5 (2)	6(5)
ESSnuSB	5	2	4	62.5	3

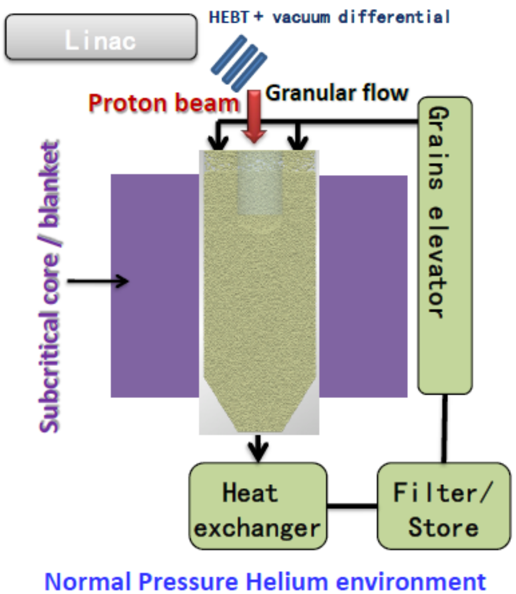
(Project-X has also a pulsed linac section of 3-8 GeV)

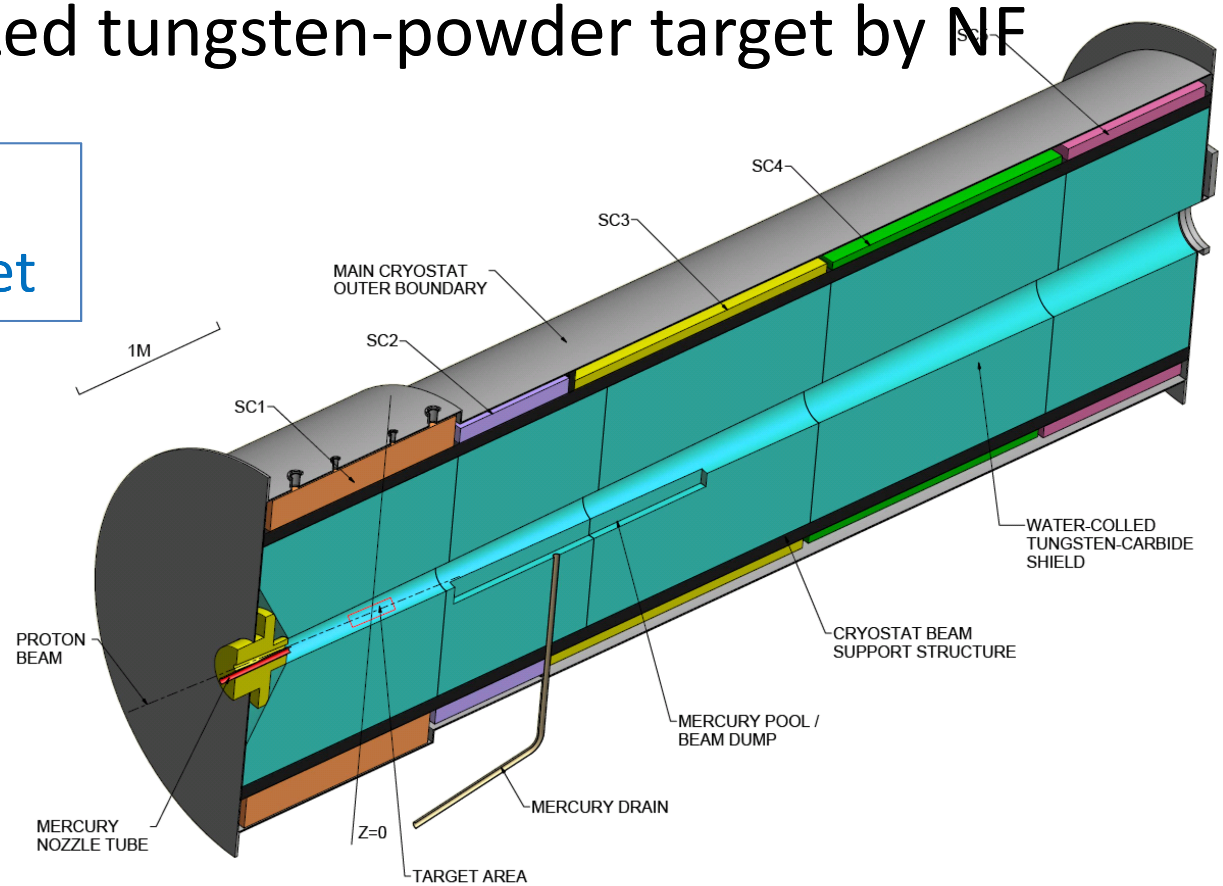
Target technology synergy with other projects

MOMENT Target Station

- Baseline design: Mercury jet target (similar to NF design, MERIT) and high-field superconducting solenoids
  - Higher beam power: heat load, radioactivity
  - On the other hand, easier to some extent due to CW proton beam (no shock-wave problem)
- More interests in developing fluidized granular target in collaborating with C-ADS target team, and also waiting for study result with fluidized tungsten-powder target by NF collaboration

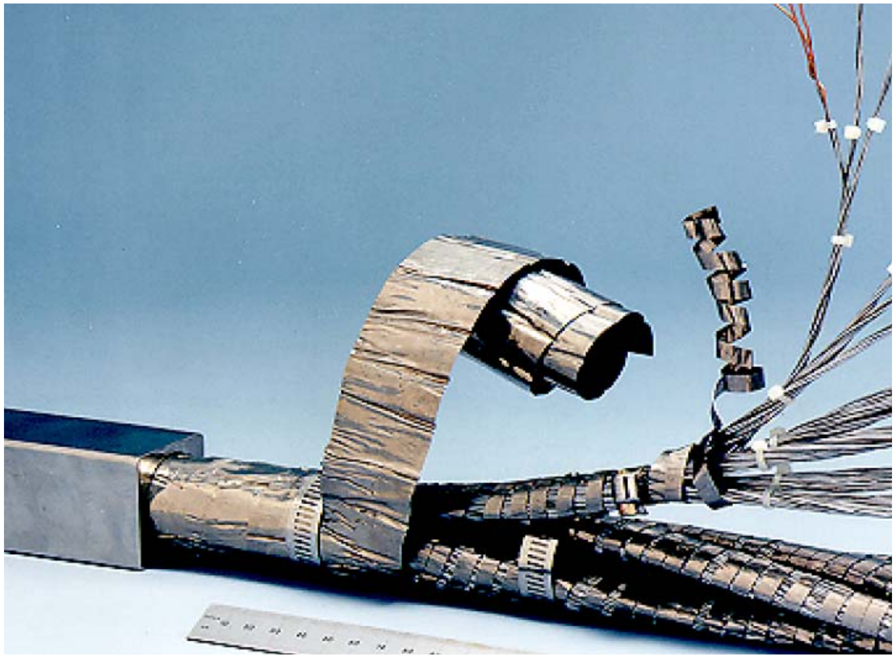
Trying to work out a feasible concept based on granular target

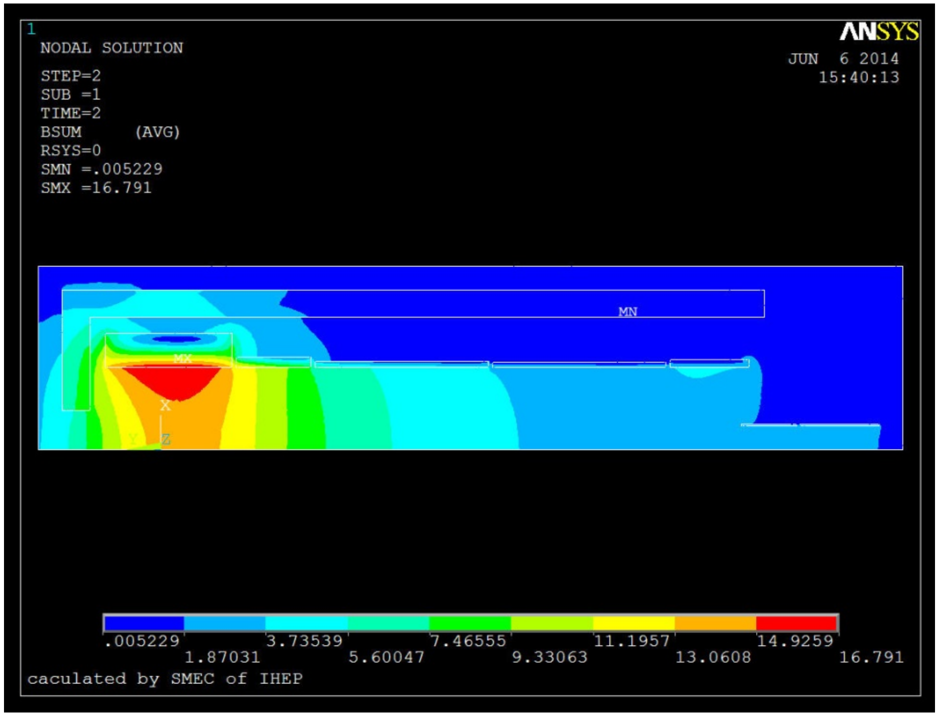




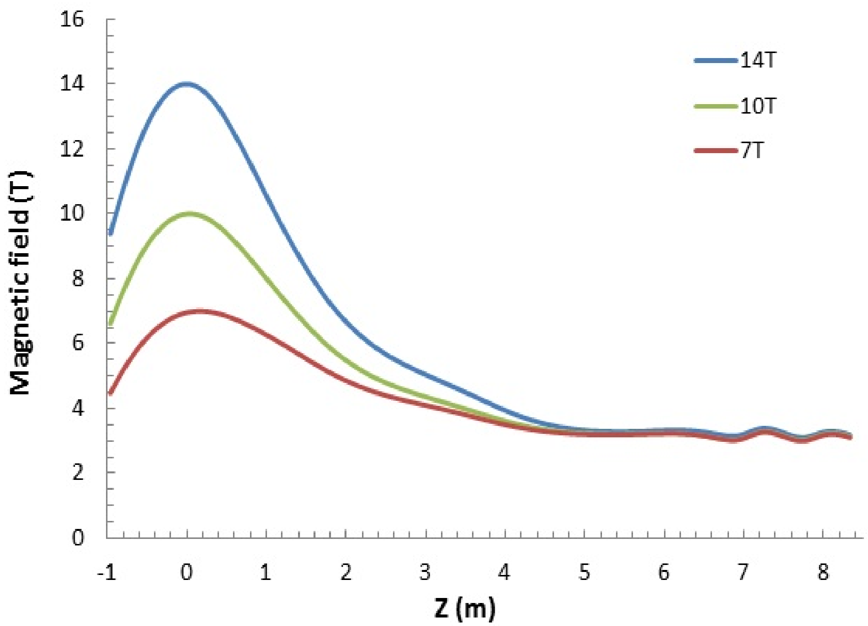
High-field superconducting solenoids

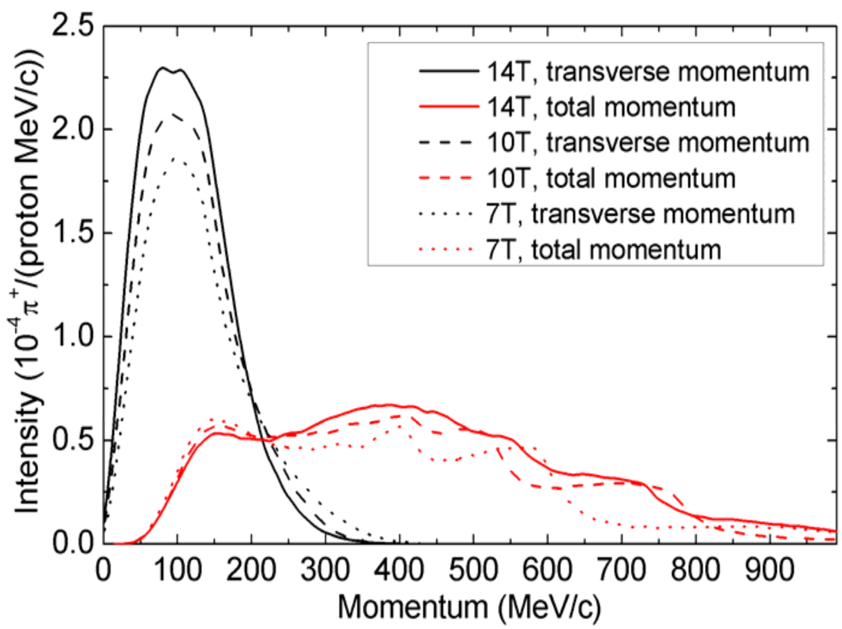
- Very large apertures due to collection of secondary /tertiary beams and space for inner shielding
  - Based on Nb_3Sn superconducting conductors, CICC (Cable-in-Conduit Conductor) coil (ITER)
  - HTS coils are also under consideration
  - High-field magnet R&D efforts at IHEP (incorporated with SPPC)





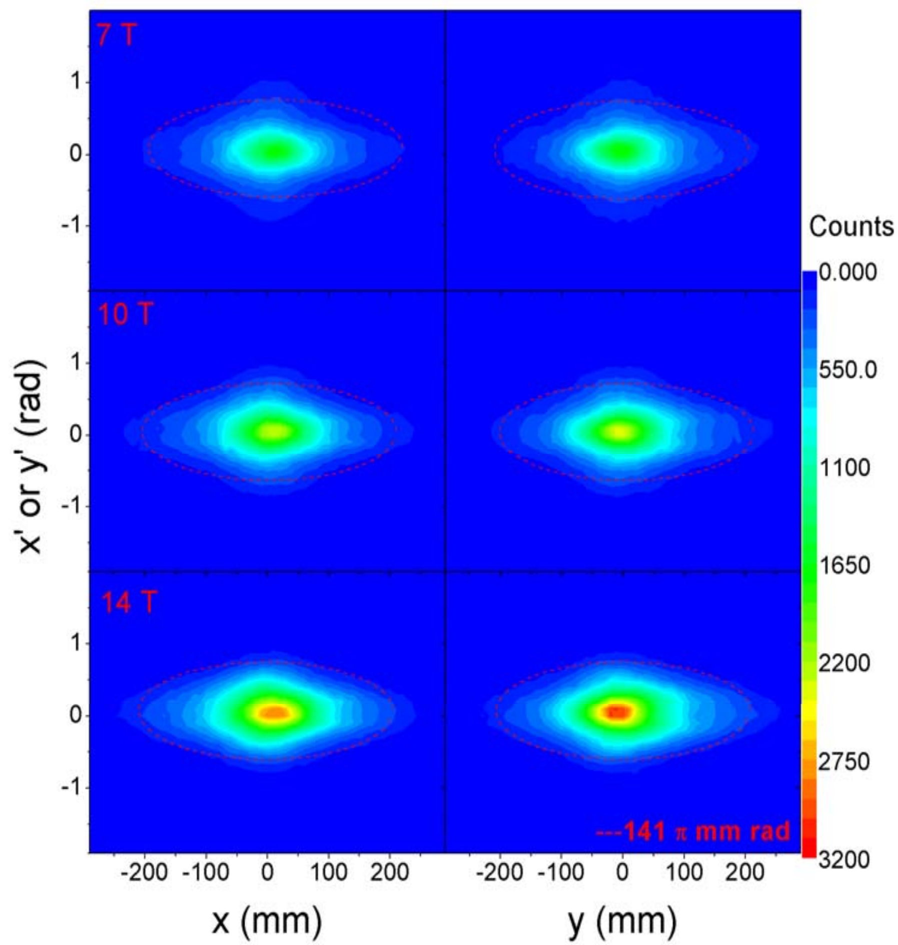
- Different field levels have been studied: 7/10/14 T
  - Evident advantage on pion collection with higher field
- Relatively short tapering section: <5 m (Vassilopoulos' talk)
- High radiation dose level is considered not a big issue here (compared with ITER case)(both Nb_3Sn and HTS conductors are radiation resistant, problems are with electrical insulation)





Pion production and collection

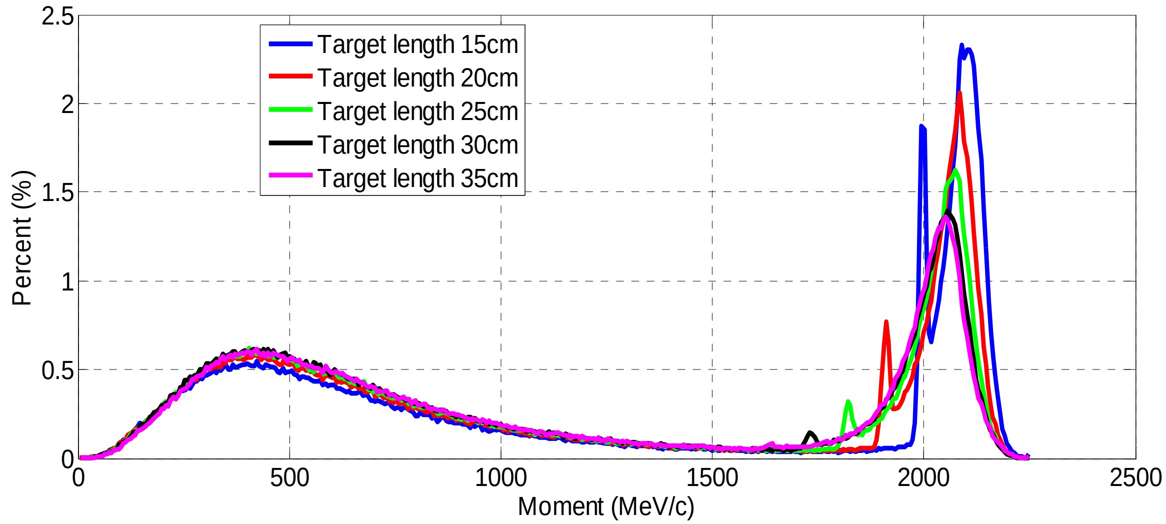
- Pion production rate: 0.10 pion/proton (1.5 GeV, 300 mm Hg)
- Collection efficiencies of forward/total pions: 82% / 58% (@14 T)



- Distributions in (X-X')/(Y-Y') at end of pion decay channel (from upper down: 7/10/14T)
- Higher field increases the core density significantly (favorable)

Spent protons

See Cai's talk



- There are two parts in the spent protons:
  - Scattered protons from the side of the thin mercury jet and the pass-thru protons from the jet which have higher energy (4.7 MW with 30 cm target)
  - From nuclear reactions, lower energy (1.8 MW with 30 cm target)
- We must find ways to deal with the spent protons, either collimated or separating from the π/μ beam or transporting to the final dump.
  - Very difficult due to high beam power and large moment range and emittance

- High power target station is a technically challenging issue, and even more challenging when high magnetic-field is required.
  - Huge heat deposit in target (cooling, shocking wave)
  - Very high irradiation level (protection, material lifetime, electrical insulation)
  - Very high electromagnetic force, space limitation
  - Interface with primary and secondary beamlines
- Conventionally, carbon target inside a magnetic horn is used (very short pulse, up to 2 MW, low repetition rate)
- New type of neutrino beams (NF and MOMENT) uses high-repetition or CW proton beams, and higher power
  - Mercury jet target (now preferable fluidized tungsten target)
  - Superconducting solenoids for π capture and focusing
  - Extremely challenging

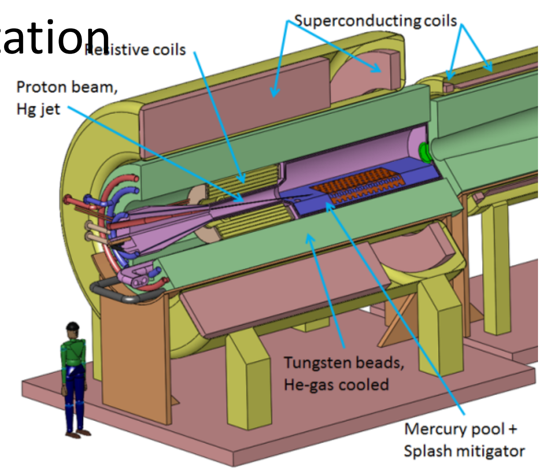
Synergy efforts

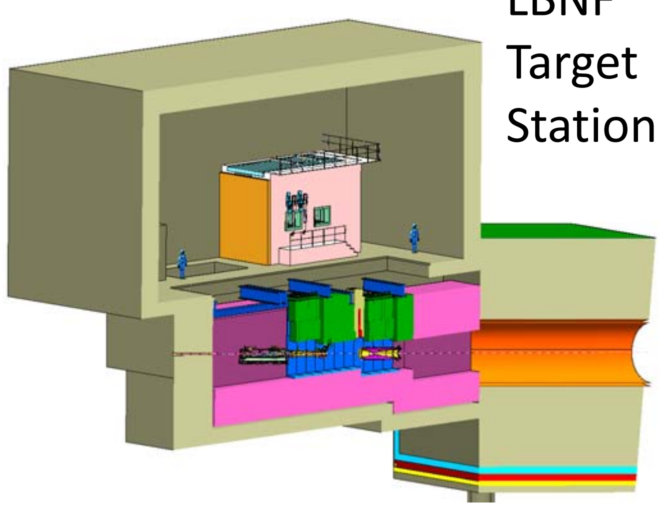
- Precise simulations on π production yield, material and proton energy
  - MARS, GEANT4, MCNP, FLUKA: not consistent
- Study on magnetic field taper
- Design and R&D on fluidized tungsten target (NF and MOMENT)
- Design and R&D on high-field superconducting solenoids (NF and MOMENT)
- Study on cooling and shielding methods in MW targets
- Interface issues with primary and secondary beamlines (windows, shielding, dump)
- Spent protons

Comparison of target stations

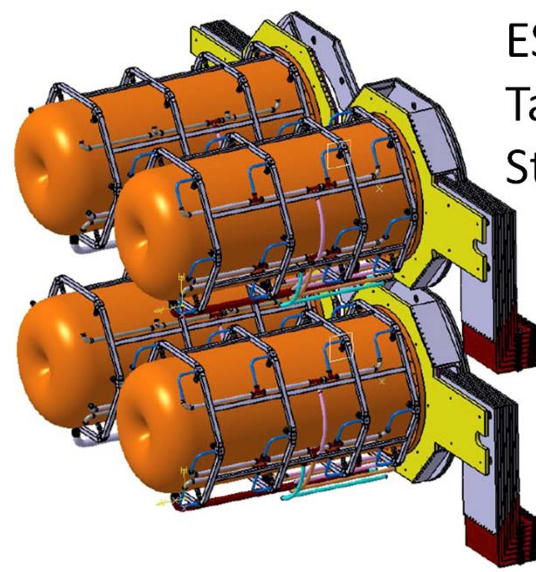
	Beam power (MW)	Proton energy (GeV)	Target	Magnetic field
MOMENT	15	1.5 (~2.5)	Granular W or Hg jet	SC solenoids
Neutrino Factory	4	5 (SPL)	Fluidized W or Hg jet	SC solenoids + RT insert
LBNF	2	120	Carbon	Horns
ESSnuSB	5	2	4 * Carbon	Horns

NF Target Station





LBNF Target Station

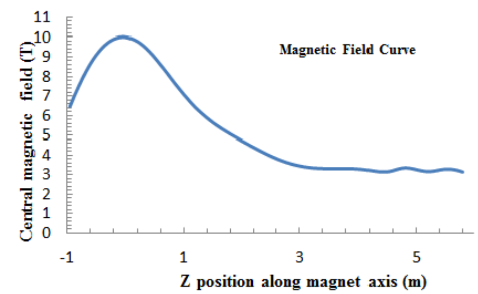


ESSnuSB Target Station

Neutrino beamline technology synergy with other projects

MOMENT Secondary beamline

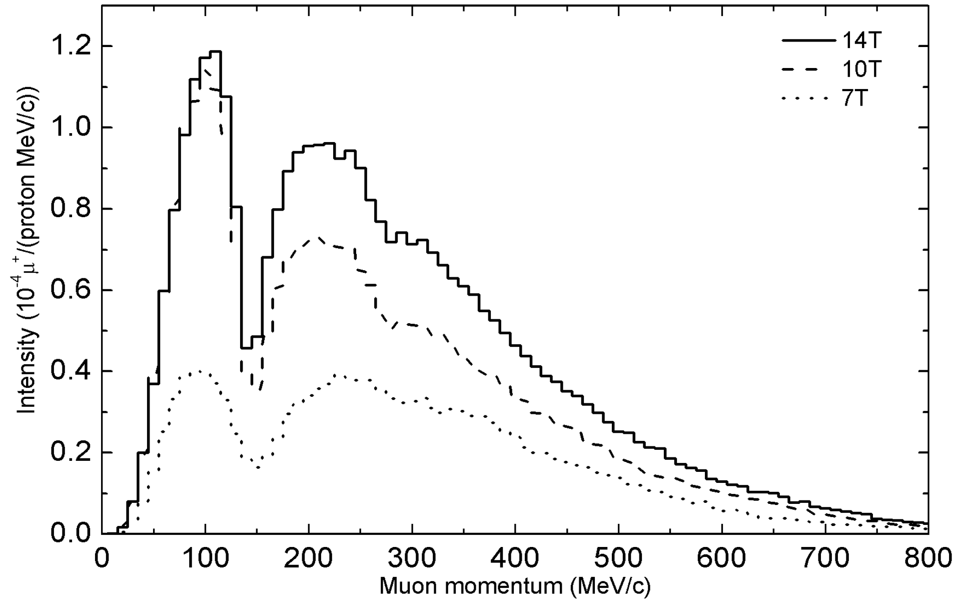
- Transporting both pions and muons
- A straight section in SC solenoids of about 100 m to match the SC solenoids at the target, and for the pions to decay into muons
  - Adiabatic field transition (tapering section)
  - Extraction of scattered protons
  - Very large emittance and momentum spread
  - Longer section for energetic pions to decay



- Similar beam rigidity assures that pions and muons can be transported in the same focusing channel
  - Momentum and emittance of pions most preserved in muons

More about the pion decay channel

- SC solenoids form FOFO lattice (stop-band at certain energy)
- Very large acceptance for channels
- About 0.0052 μ+/proton for about 50 πmm-rad at entrance of muon decay channel

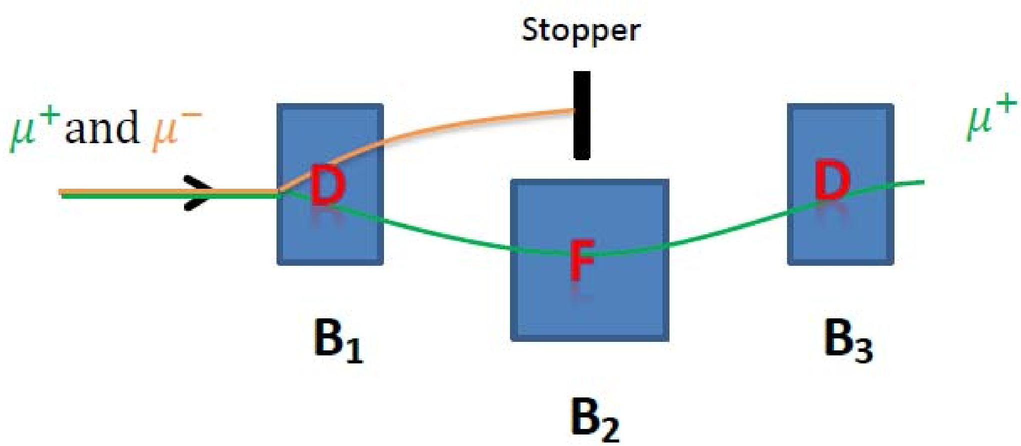


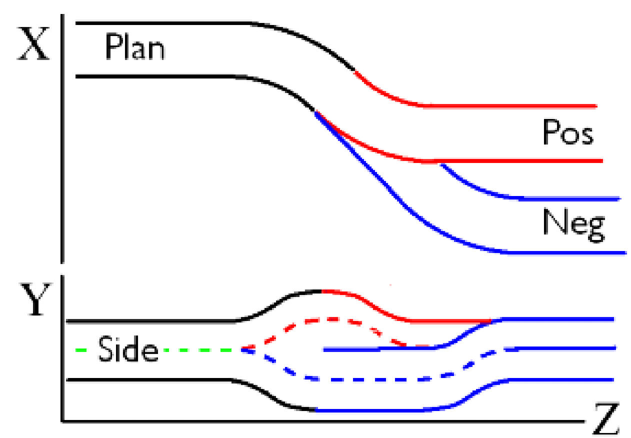
	muon/proton	Portion（%）
No limit on emittance	9.48E-03	100
Emittance: 100 πmm-rad	8.04E-03	85
Emittance: 80 πmm-rad	7.31E-03	77
Emittance: 50 πmm-rad	5.22E-03	55

Emittance limit in both (X-X') and (Y-Y')

Charge selection

- A selection section to select π+/μ+ from π-/μ-, as either μ+ beam or μ- beam is used for producing the required neutrinos
  - Reverse the fields when changing from μ+ to μ-
  - Also for removing very energetic pions who still survive
  - Very difficult due to extremely large beam emittance (T/L)
- Two schemes: based on 3 SC dipoles with strong gradient (or FFAG), and bent SC solenoids





Muon transport and decay
- Muon decay channel

- A long decay channel of about 600 m is designed for production of neutrinos
  - About 35% (centered momentum: ~300 MeV/c)
- Important to have smaller divergent angle
  - Neutrino energy spectrum at detector related to the angle
  - Modest beam emittance and large aperture
  - Adiabatic matching from 3.7 T in the bending section to 1.0 T in the decay section

Aperture/Field	Acceptance (πmm-rad) X: in mm; X': in mrad
ϕ600, 3.7 T	100 (x: 280, x': 357)
ϕ800, 1.0 T	65 (x: 380, x': 171)

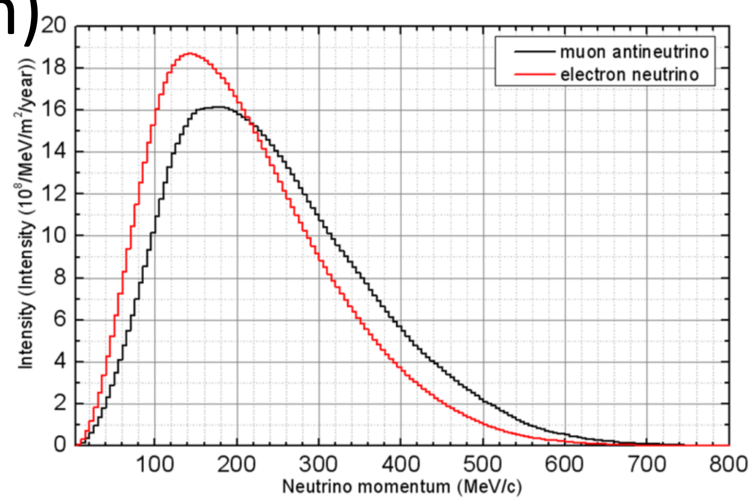
Estimate of neutrino flux

- POT (5000 h): 1.125×10^{24} proton/year
- Muon yield: 1.62×10^{-2} μ/proton
- Total neutrino yield: 4.8×10^{-3} ν/proton (in pair)

  5.4×10^{21} ν/year (in pair)

  (NF: 1.1×10^{21} ν/year)
- Neutrino flux at detector: dependent on the distance

  4.7×10^{11} ν/m^2/year (@150 km)



Challenges and synergy efforts in neutrino beamlines

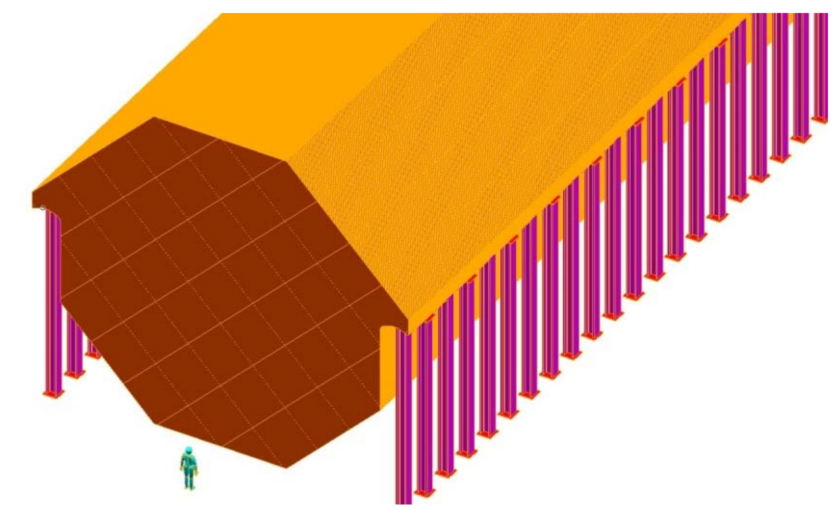
- Charge selection of $\pi+/\pi-$ and $\mu+/\mu-$ [NF]
  - Very large emittance/momentum range
- Dumping both protons and secondary particles [All]
  - Mixed beam, high power
- Manipulation in phase space [NF, nuSTORM]
  - Adiabatic conversion of transverse momentum into longitudinal
  - Bunching rotation
  - Emittance cooling

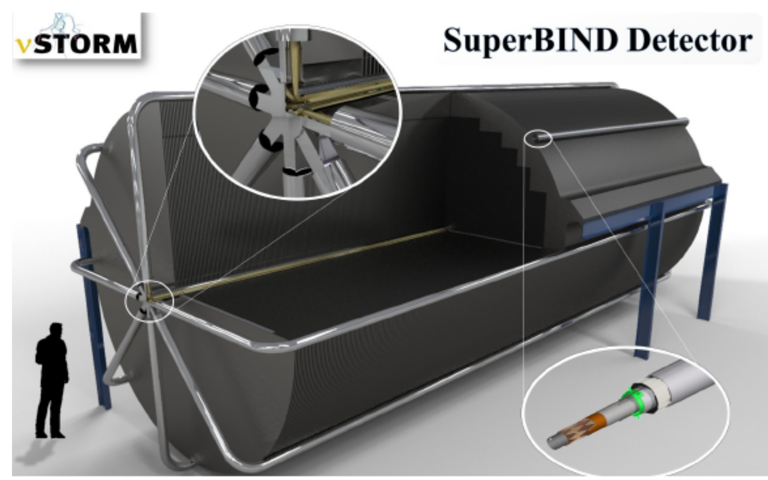
Detector technology synergy with other projects

- Suitable detectors for MOMENT are still under study
  - Flavor sensitive: e/μ identification
    Water Cherenkov, liquid Ar, liquid scin.
  - Charge sensitive: ν and anti-ν
    Magnetized, liquid scin., Gd-doped water (IBD)
  - NC/CC sensitive: NC background rejection
  - Very large target mass required

$$\mu^+ \to e^+ + \nu_e + \bar{\nu}_\mu$$
$$\nu_e \searrow \nu_\mu \qquad \bar{\nu}_\mu \searrow \bar{\nu}_e$$
$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$$
$$\bar{\nu}_e \searrow \bar{\nu}_\mu \qquad \nu_\mu \searrow \nu_e$$

- Detector synergy
  - Magnetized detector, e.g. MIND by NF and SuperBIND by nuSTORM
  - Water Cherenkov detector (or doped), MEMPHIS by ESSnuSB/LBNO and HyperK detector
  - Liquid scintillator detector such as JUNO





Summary

- As an interesting study, MOMENT attracts Chinese researchers to collaborate on neutrino beams
  - on MOMENT itself
  - on other international projects
- MOMENT shares many physical and technical aspects with other neutrino beams
  - Proton driver, target, secondary beam line, detector etc.
  - International collaborations will benefit the community: with the ongoing projects LBNF and Hyper-K, and with the studies Neutrino Factory, ESSnuSB and nuSTORM

Thank you for attention!