MOMENT的初步模拟

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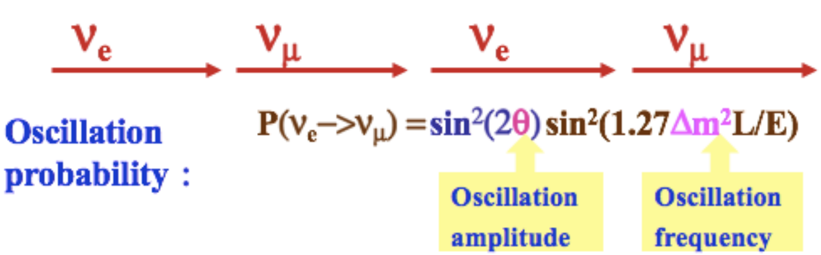
主要内容

- **MOMENT简介**
- **模拟工作**
  - 靶区的模拟（FLUKA）
  - Muon衰变通道的模拟（G4beamline）
  - 中微子通量的计算
- **小结**

Introduction

- **MOMENT was launched in 2013 (IPAC13/Nufact2013) as the third phase of neutrino experiments in China**
  - Neutrino experiments at Daya Bay continues data-taking
  - Jiangmen (JUNO, or DYB-II) will start civil construction end year

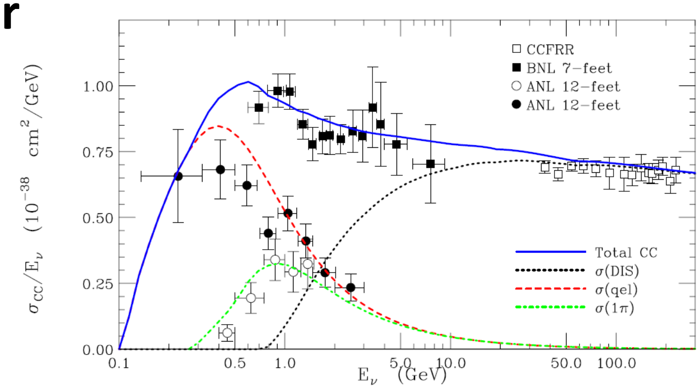
- **A dedicated machine to measure CP phase, if other experiments (such as LBNF, HyperK) will have not completed the task in 10 years**



- **Known parameters : θ_{23}, θ_{12}, $|\Delta M^2_{23}|$, ΔM^2_{12},**
- **Recent progress: θ_{13}**
- **Unknown parameters: mass hierarchy(ΔM^2_{23}), CP phase δ**

A medium baseline superbeam facility

- **Medium baseline with neutrino energy of about 300 MeV**
  - Eliminate pi0 background
- **Muon-decay neutrinos instead of pion-decay ones**
- **Using a CW proton linac as the proton driver**
  - Simplified design from the China-ADS linac
  - 1.5 GeV, 10 mA ➔ 15 MW in beam power
- **Mercury jet target in high-field SC solenoid**
  - Collection of pions and muons
- **Muon transport and decay channel**
  - Pure μ+ or μ- decay
- **High neutrino flux at a detector of >50 km**

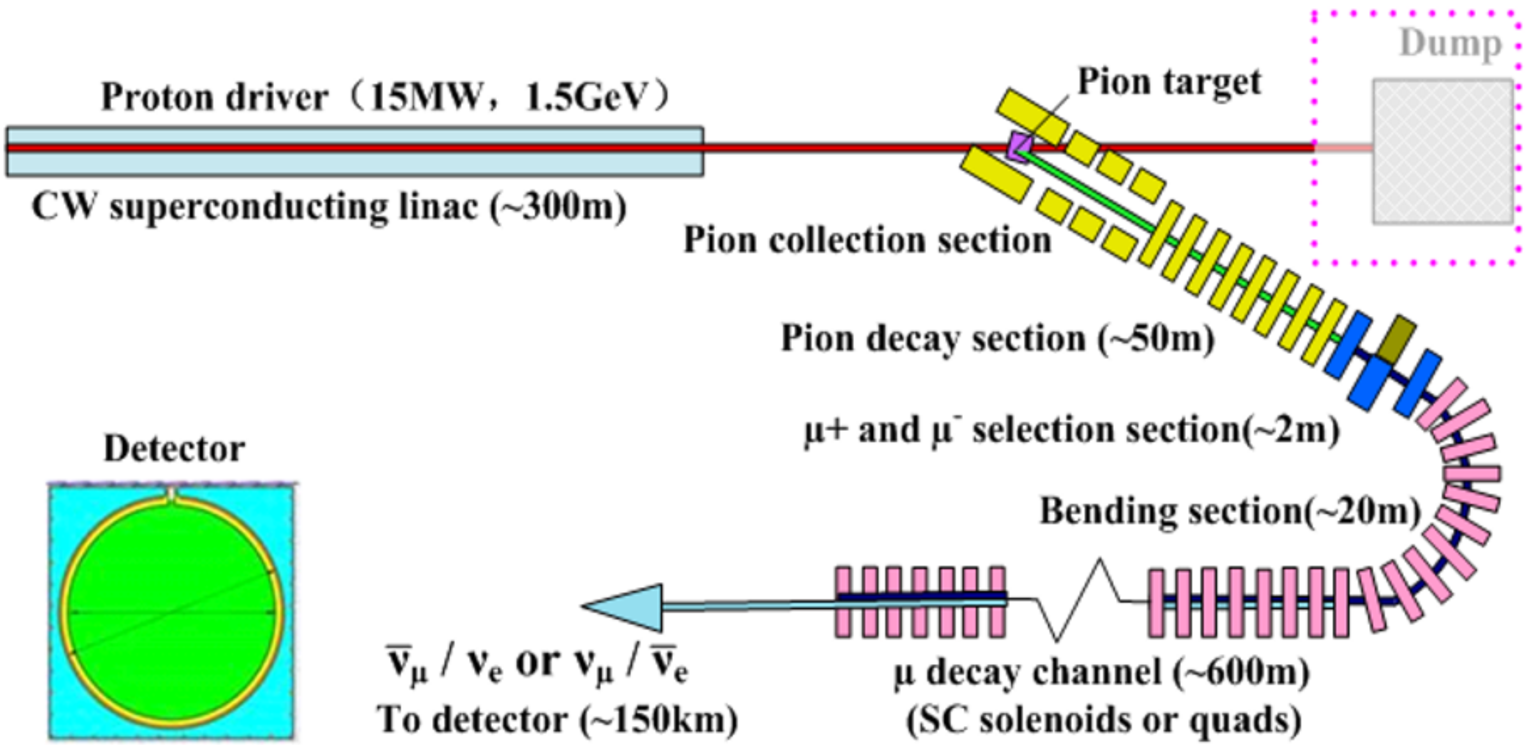


$$\pi^\pm \rightarrow \mu^\pm + \nu_\mu(\bar{\nu}_\mu)$$

$$\mu^- \rightarrow e^- + \nu_\mu + \bar{\nu}_e$$

$$\mu^+ \rightarrow e^+ + \bar{\nu}_\mu + \nu_e$$

Schematic for MOMENT



模拟在实验物理中的应用

- 实验设计阶段：物理目标的模拟，探测器性能的模拟，辅助实验设计。通常采用快速近似的模拟方法（fast simulation）。

- 完整模拟（full simulation）阶段：根据探测器的设计方案开发模拟软件。相应的模拟用来调试离线重建（reconstruction）和分析软件。

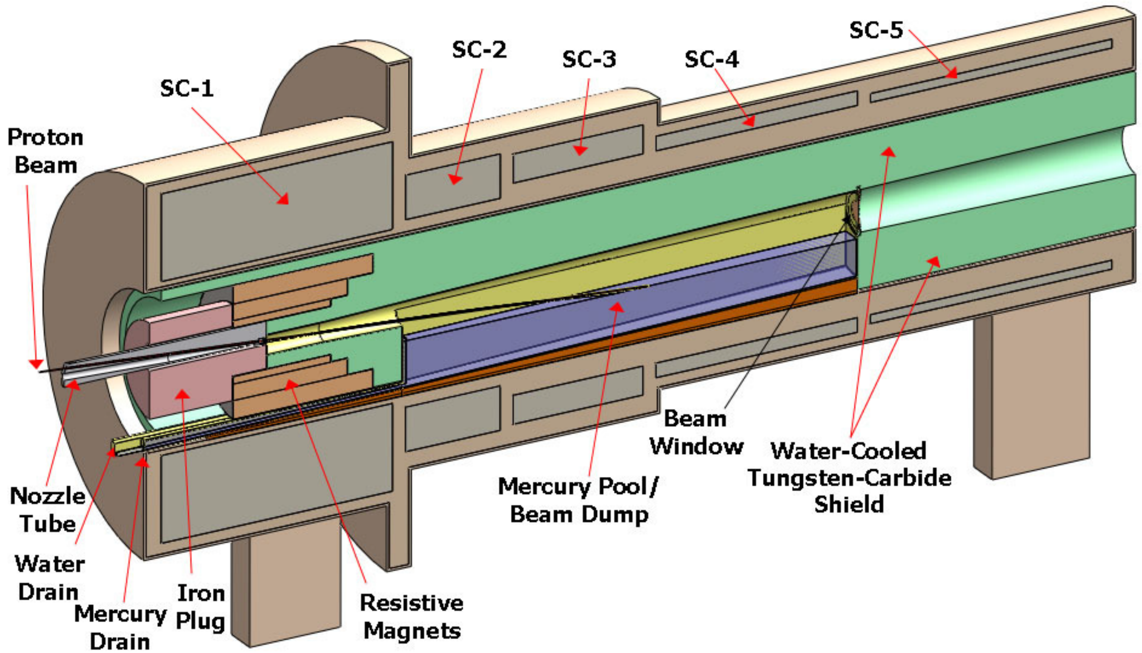
- 调试（validation）阶段：与实验数据相比较，调整相互作用模型参数，检查各种分布。

Proton Driver

- **A CW proton SC linac can provide the highest beam power, and selected as the proton driver for MOMENT**
  - Beam power: 15 MW
  - Beam energy: 1.5 GeV
  - Beam current: 10 mA
- **China-ADS project has been launched in beginning 2011, with a long-term goal to drive a subcritical reactor with 12-15 MW proton beam**
- **One of the main goals in the China-ADS R&D phase is to solve the technical problems with the SC proton linac working in CW mode**
- **If R&D successful in CW linac, e.g. 250 MeV in 2020, the accumulated experience will allow us to build a proton driver based on the similar CW linac in GeV but with much lower requirement on reliability**

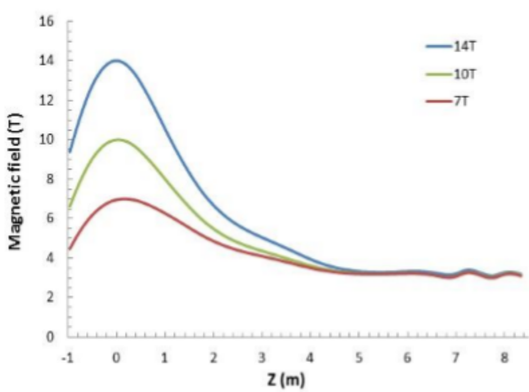
Target and pion/muon collection

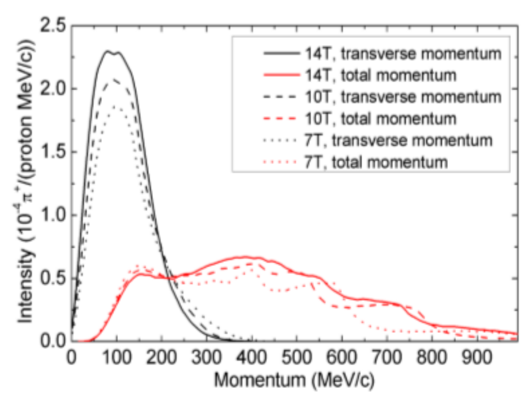
- **Mercury jet target (similar to NF design, MERIT)**
  - Higher beam power: heat load, radioactivity
  - On the other hand, easier to some extent due to CW proton beam



Magnetic field

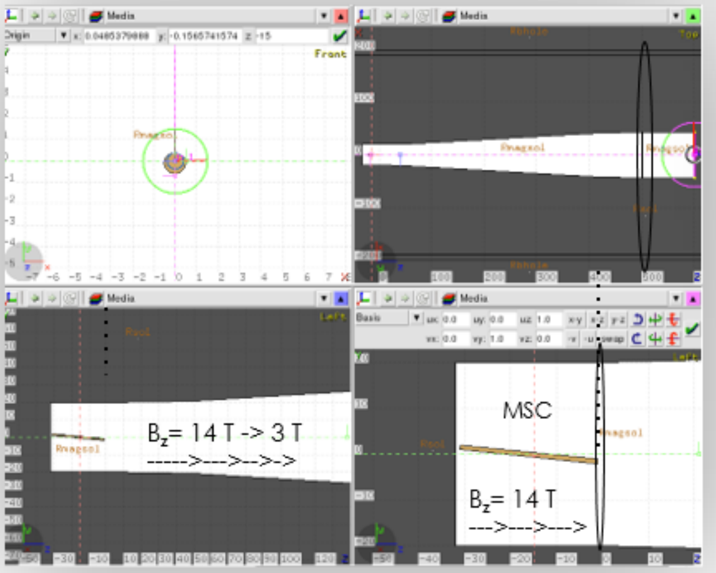
- Different field levels have been studied: 7/10/14 T
  - Evident advantage on pion collection with higher field
- Relatively short tapering section: <5 m
- High radiation dose level is considered not a big issue here (compared with ITER case)(both Nb_3Sn and HTS conductors are radiation resistant, problems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





Target optimization

figure of merit:
π, μ, p^+ yields, distributions downstream of:
- the Main Capture Solenoid (MSC)
- Adiabatic Transport Solenoid

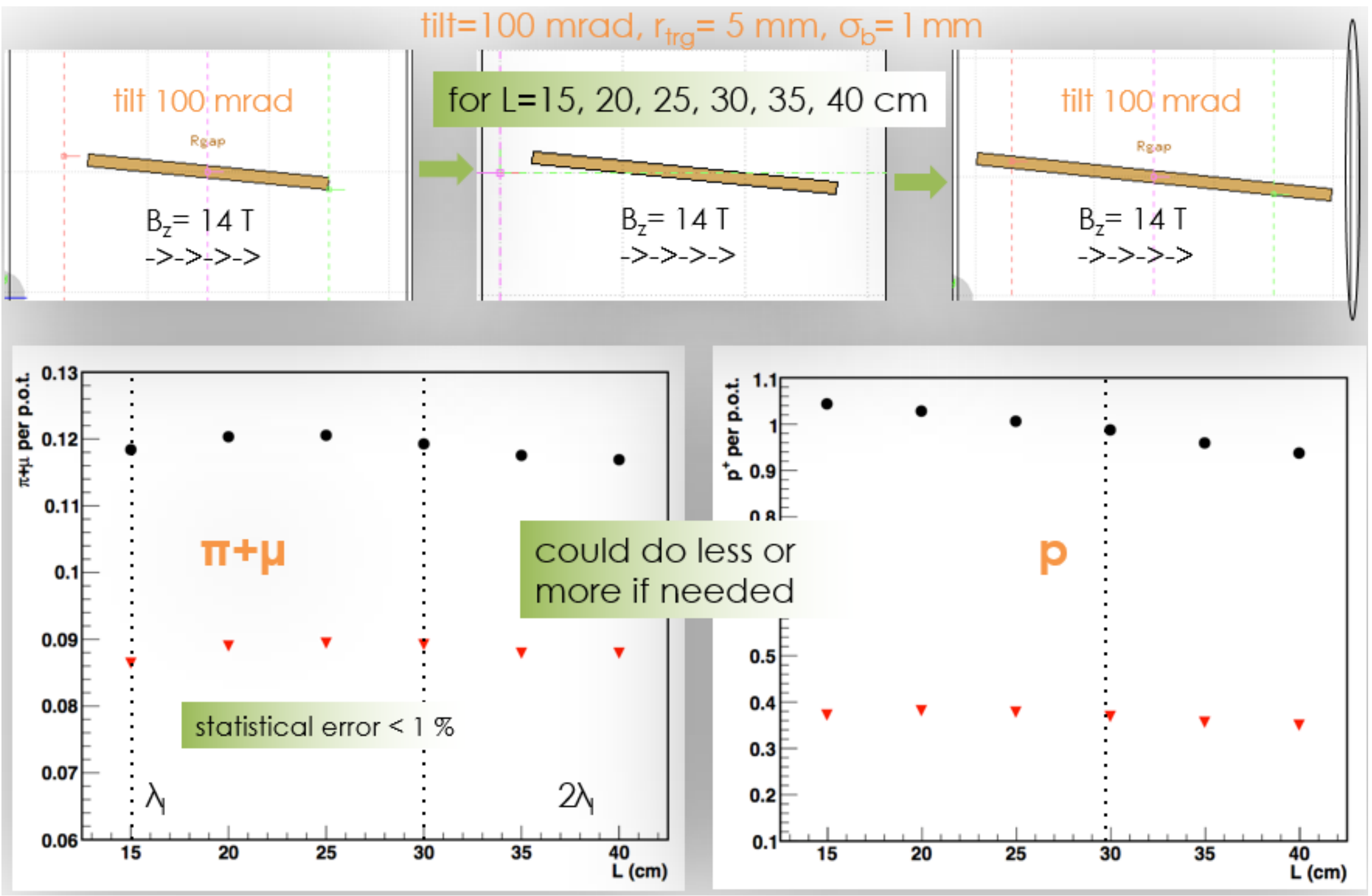


Main Capture Solenoid "idealized" field constant
B = 14 T, L_{MCS}= 32 cm, r_{MCS}= 20 cm

study tilts, lengths, radii, beam-sizes

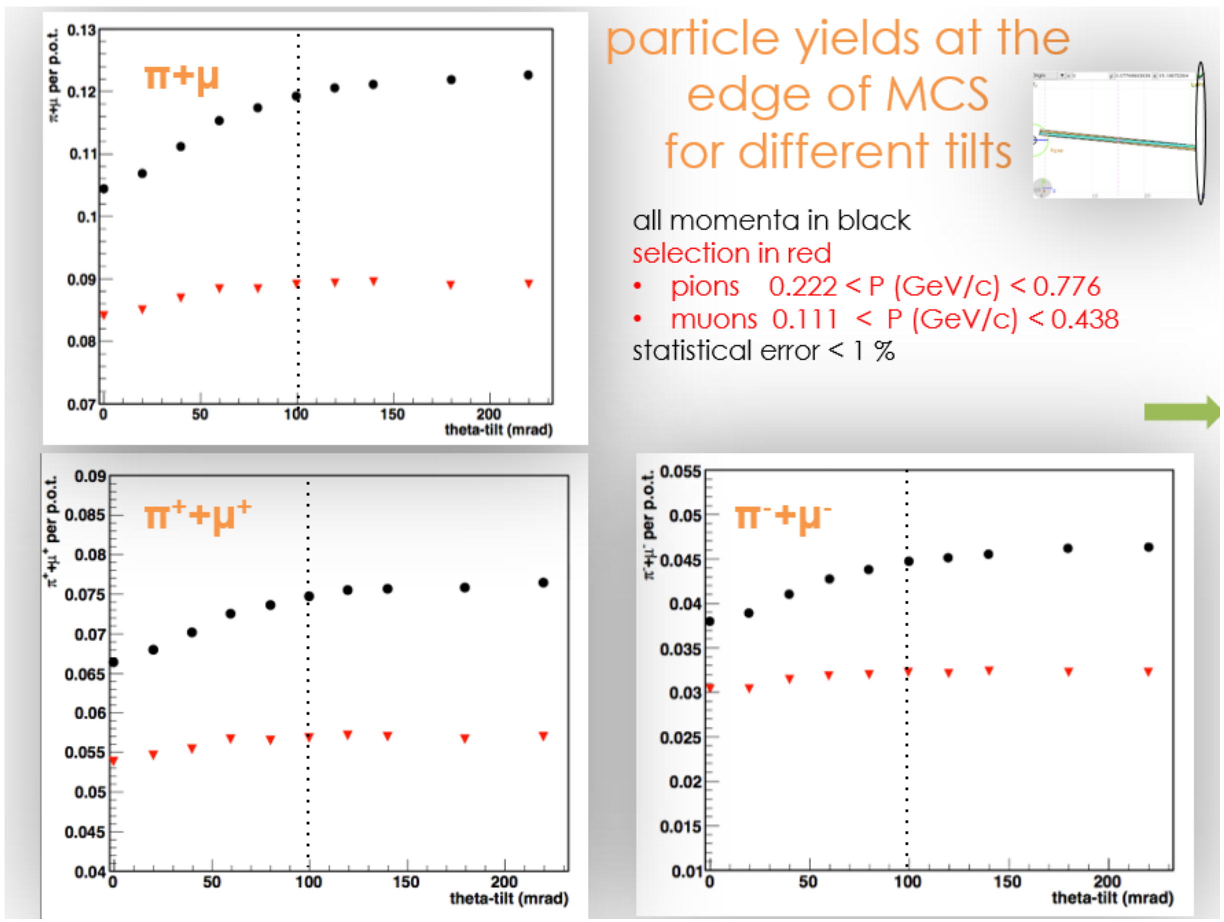
Adiabatic Transport Solenoid
L = 5, 10, 15, 20, 50 m
r = 20 cm - > 43.2 cm
B = 14 T -> 3 T

Target length



yield is maximal at 2 interaction lengths or slightly less

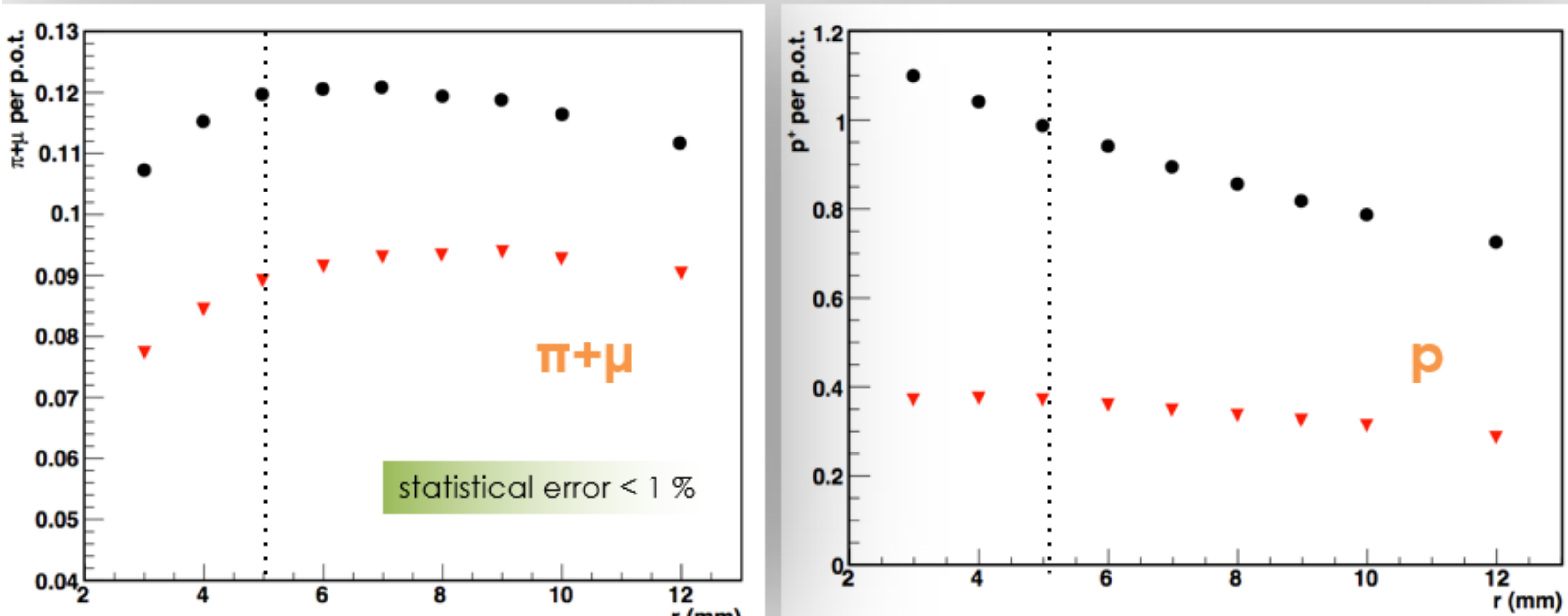
Target tilt



more with = or > 100 mrad target-tilt

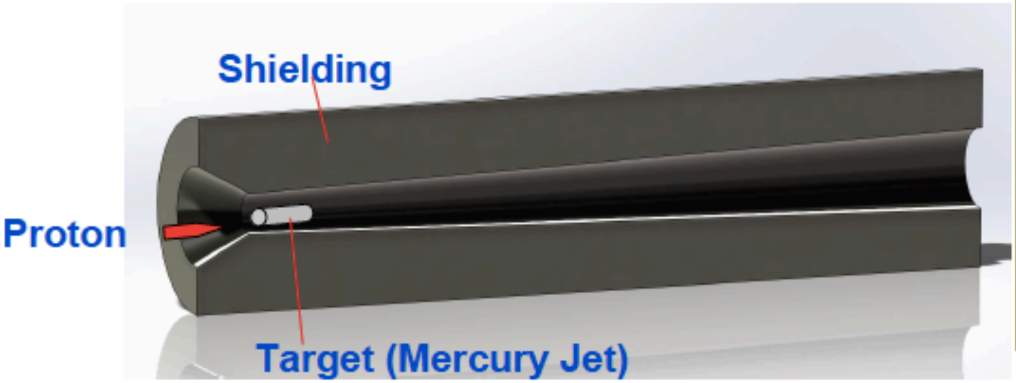
Target radius

tilt=100 mrad, L_{trg}=30 cm, σ_b= 1 mm



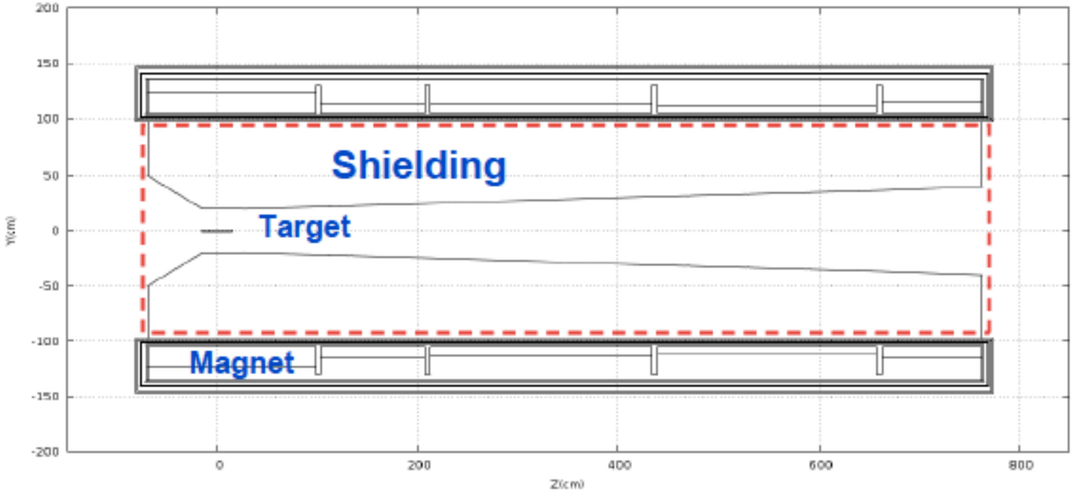
could do more in radius if needed

Shielding



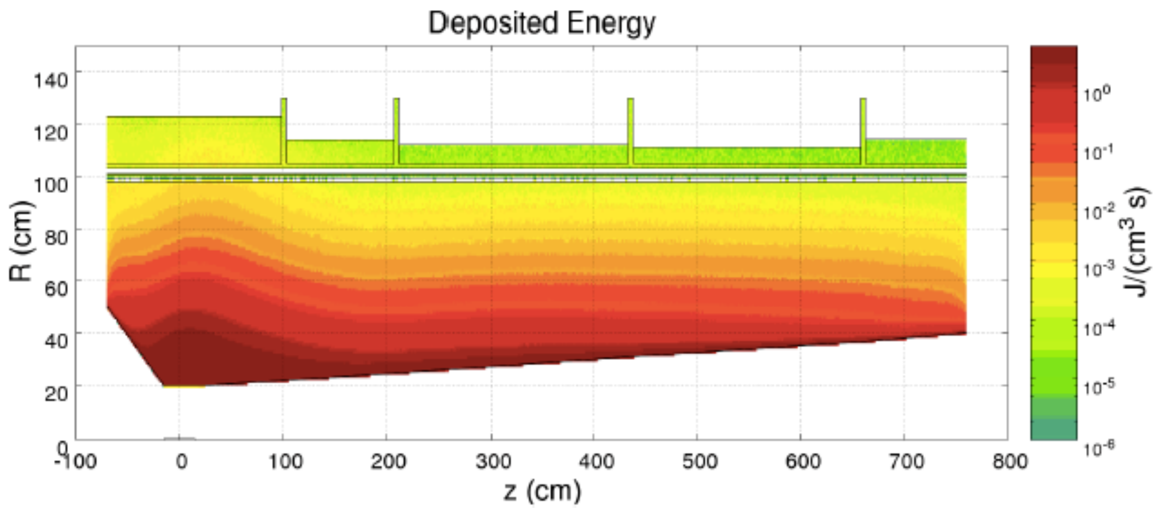
Function of Shielding:

1. Protect equipments from high radiation
2. Absorb most of heat load from beam power
3. Minimize the heat load on magnets



Material: Tungsten
Length=8.33 m
Diameter=2 m
Density=19 g/cc
Volume=22.5 m^3
Mass=428 t

Heat deposition



Heat deposition for Proton beam power = 15 MW

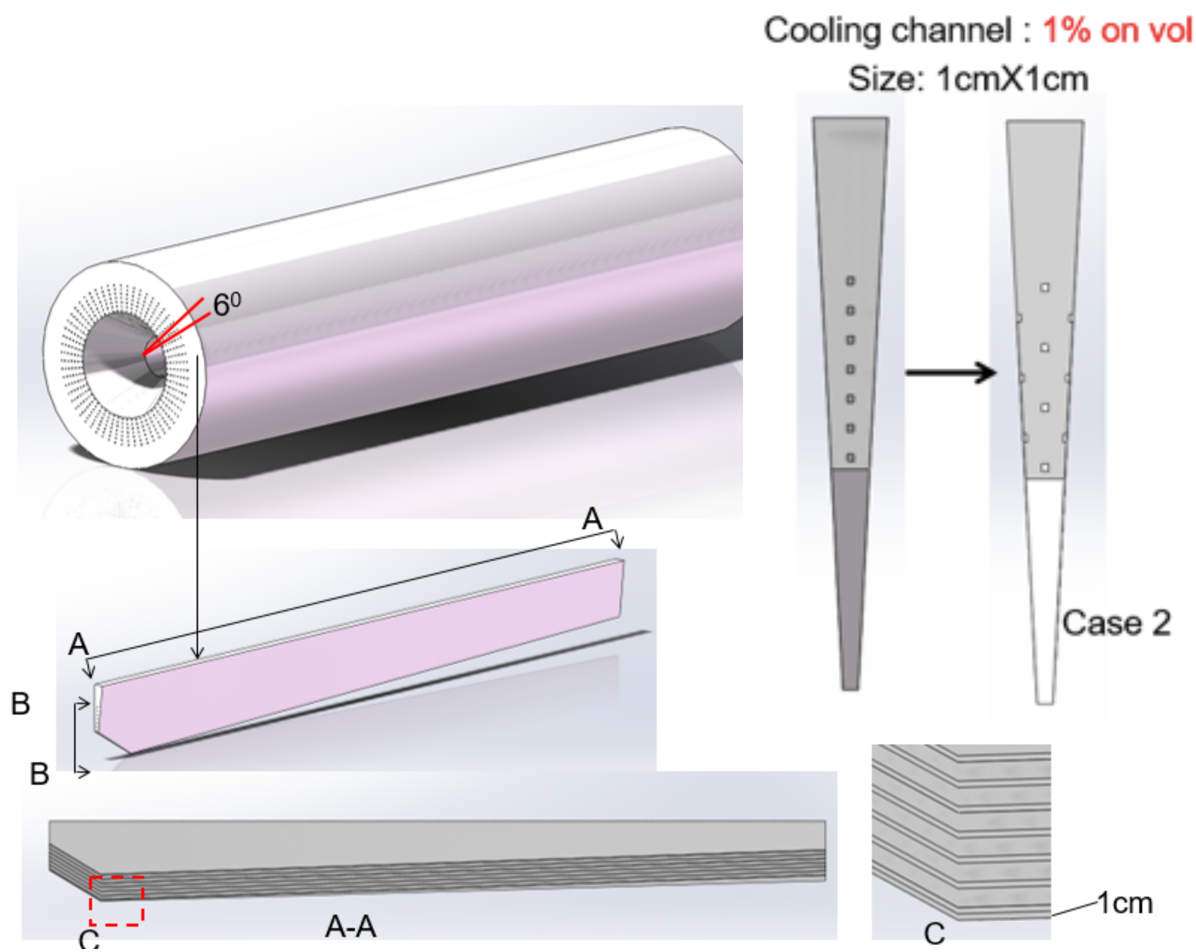
Proton: 1.5 GeV, 10 mA

Target: Hg Length=300 mm, R=5 mm

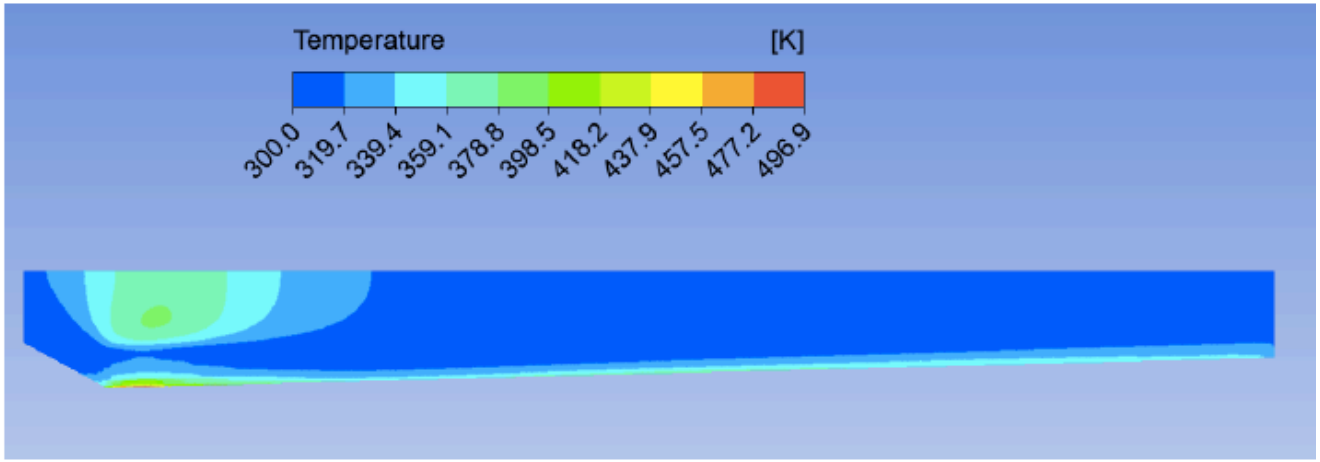
Shielding: Tungsten

Heat load on Shielding: 9.9 MW
Max volumetric heat source=2.2x10^8[W m^-3]

Cooling structure design



Heat load (water)

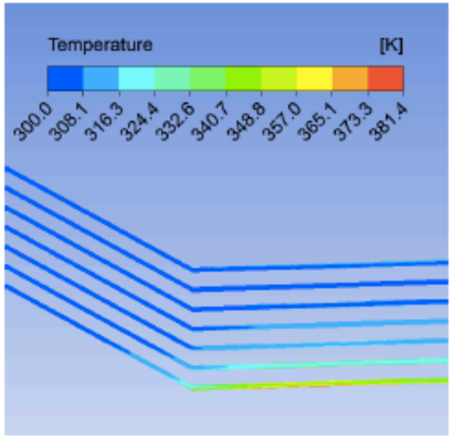


Pressure Drop= 0.8 MPa

Outlet T=311.7 K ΔT=11.7 K

Mass flow rate=7X997 kg/m^3*5 m/s*0.0001 cm^2=3.49kg/s

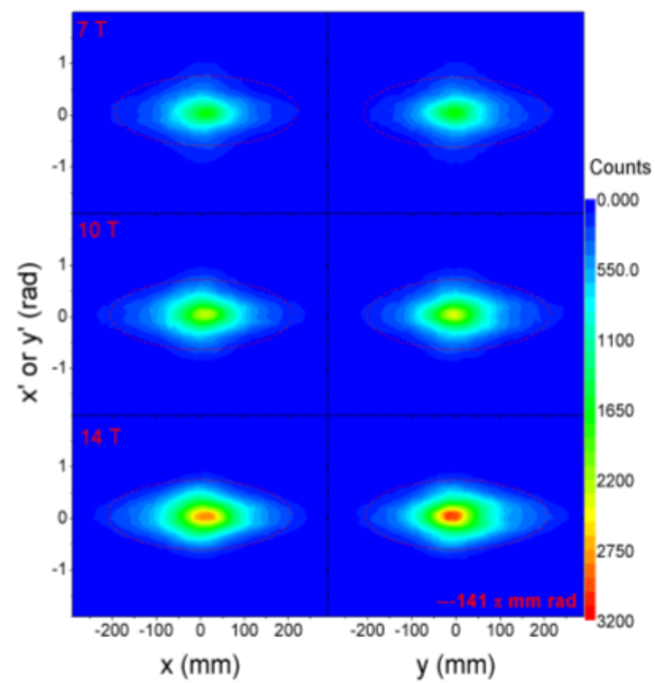
Total mass flow rate @ Shielding=206kg/s=744 m^3/h



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



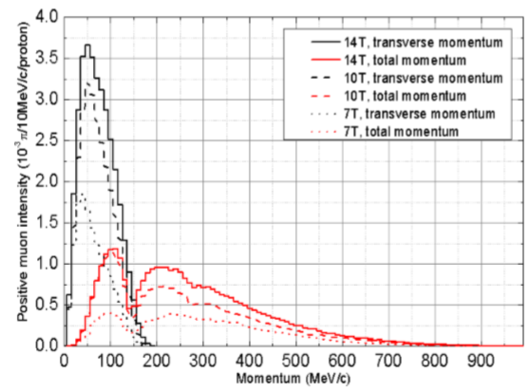
Pion decay section

- 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
- Similar beam rigidity assures that pions and muons can be transported in the same focusing channel
- About 0.0052 mu+/proton for about 50 pi mm-rad at entrance of muon decay channel

Expected: >±50% centered at 300 MeV/c

	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')

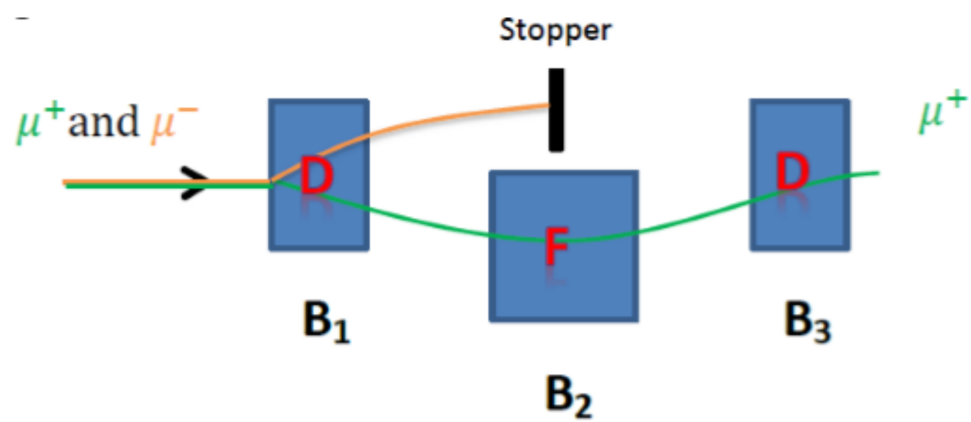


Muon momentum spectrum at the entrance of the bending section

Charge Selection

- **A selection section to select pi+/mu+ from pi-/mu-, as either mu+ beam or mu- beam is used for producing the required neutrinos**
  - Reverse the fields when changing from mu+ to mu-
  - Also for removing very energetic pions who still survive
  - Very difficult due to extremely large beam emittance (T/L)

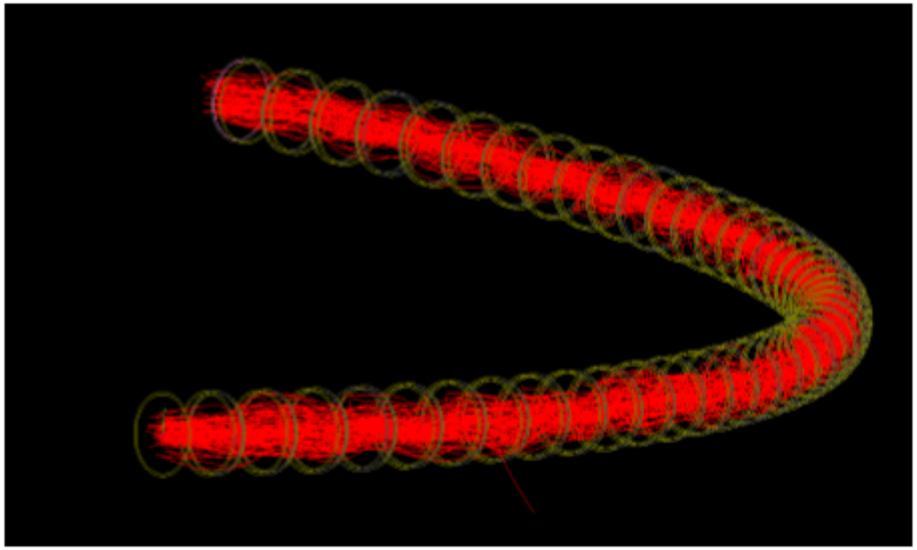
- **based on 3 SC dipoles with strong gradient (DFD triplet focusing, a few meters). For very large emittance, large bending angles (40 deg /-80 deg /40 deg)**



Muon bending section

- A bending section is required before the muon decay channel, to suppress the background of pion-decayed neutrinos at the detector by limiting the momentum acceptance when needed

- Bending section by slanted solenoids (39*2 deg = 78 deg) has very good momentum acceptance, dp/p>+/-50%



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)

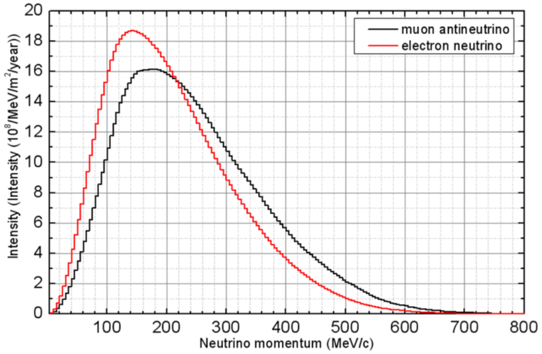
Estimate of neutrino flux

- Proton on target (operation 5000 h): 1.125×10^{24} proton/year
- Muon yield: 1.62×10^{-2} μ/proton
- Muon decay probability: 0.35
- 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)



Summary

- **Give a brief introduction to MOMENT**
  - Muon-decayed neutrinos (CW protons→ DC neutrinos)
  - High neutrino flux with neutrino energy: 100-300 MeV
  - Preliminary studies show MOMENT a competitive facility

- **Future plan for target/beam simulation**
  - Optimization of magnetic field
  - Test the particle yields with a different simulation code (Geant4/MARS15)
  - Other possible target candidate (e.g. fluidized granular target)

Thanks!

Backup

Energy Deposition

- Very high heat load from beam-target interaction (neutrons, gammas) , strong shielding needed to reduce heat load in cryostat and radiation level in coils
  - Shielding block thickness: 800 mm (~10 MW, also tough)
  - Heat load in cryostat: ≤1 kW
  - Dose rate in coils: 6×10^{13} /(m^2 s), which means a fluence of 6×10^{21} /m^2 for 10 years (10^7 s per year)