Horn and Solenoid Options in Neutrino Factory

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NuFact08, Valencia

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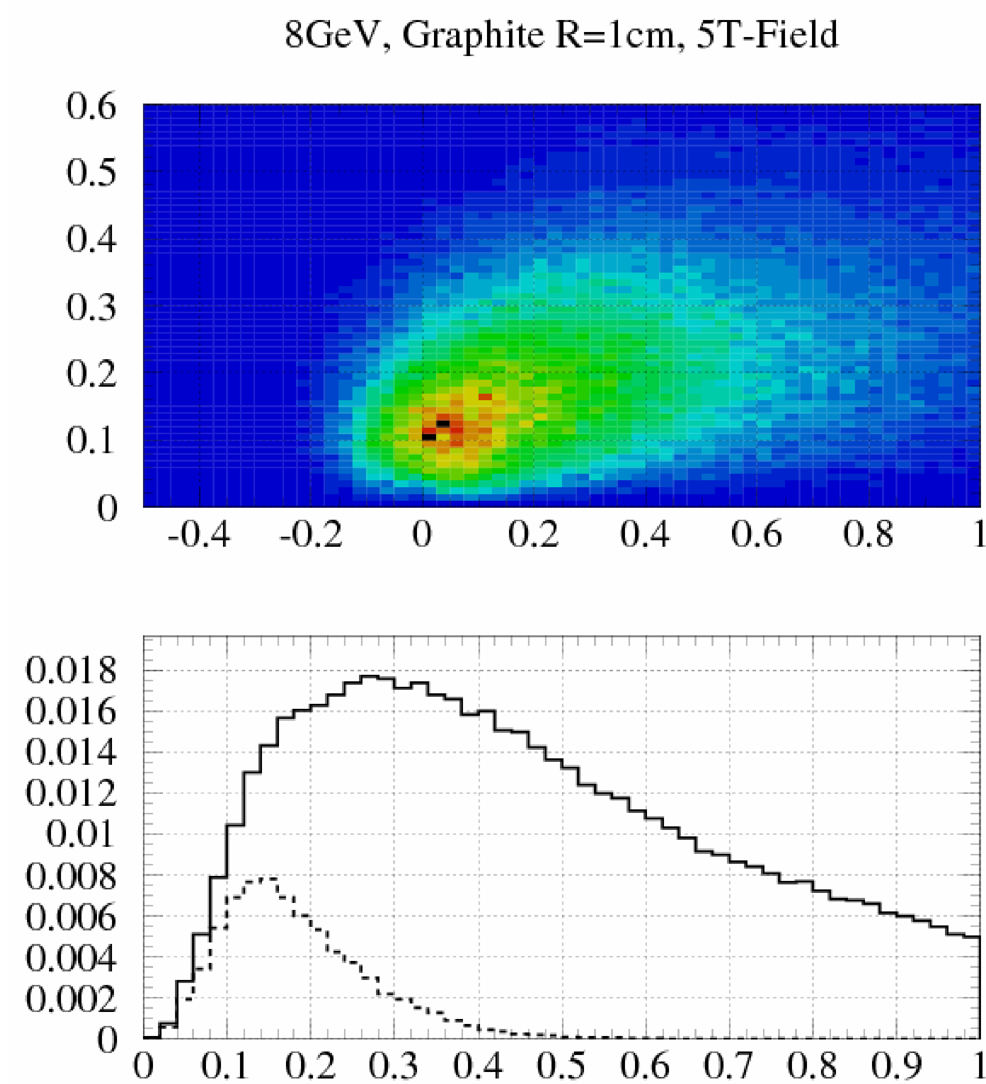
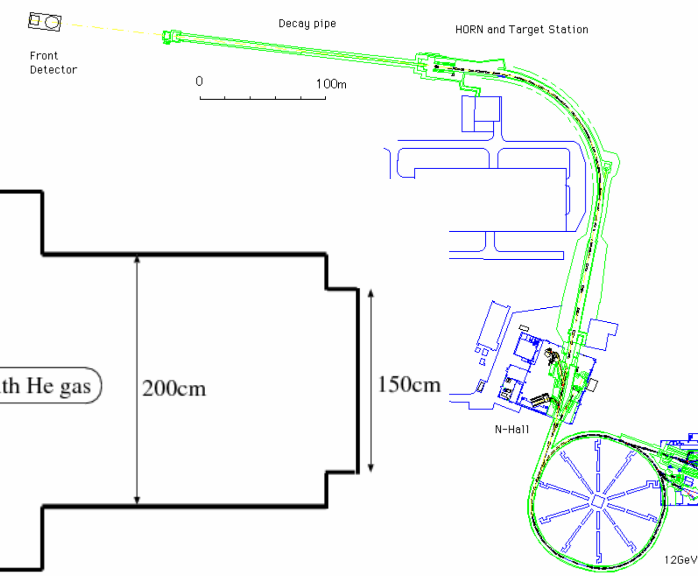
-- A brief review of pion capture scheme
in NuFact, SuperBeam and mu-e conversion

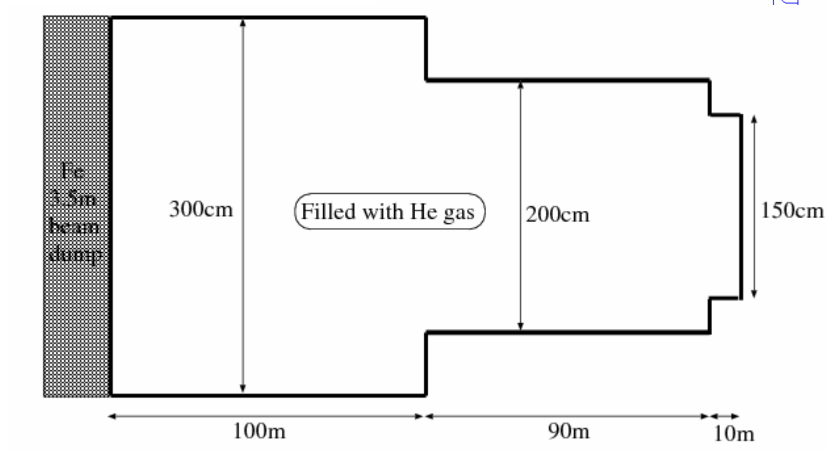
Mission of pion capture system

- In neutrino factory
  - use accelerated muons
  - need muons in small radius and small divergence for accelerating
  - utilize pions less than 1GeV
    - muons around 0.2 GeV/c for cooling
- In SuperBeam
  - use forward-focused pions
    - point to parallel
  - need pions with small divergence to achieve neutrinos at long distance
  - utilize higher energy pions
    - Off-axis configuration provides narrow band neutrino beam
- In mu-e conversion experiment
  - use stopped muons with negative charge
  - need muons less than 0.1 GeV/c
  - utilize negative pions around 0.1 GeV/c
    - prefer to avoid high energy pions for less background

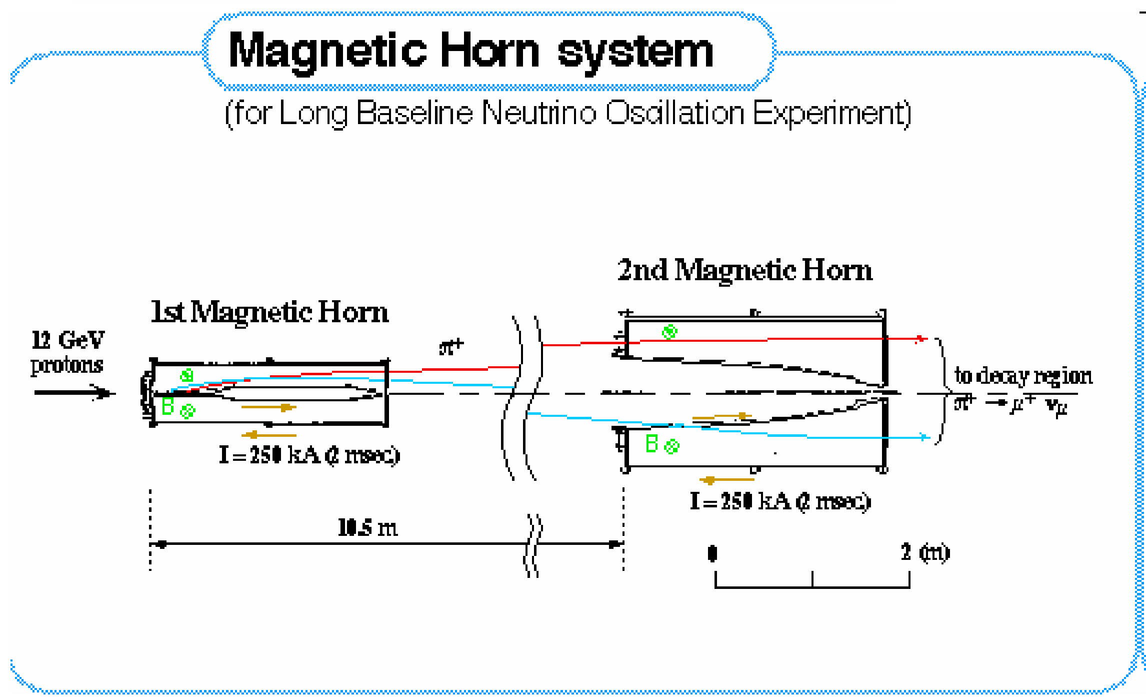


Horn in K2K



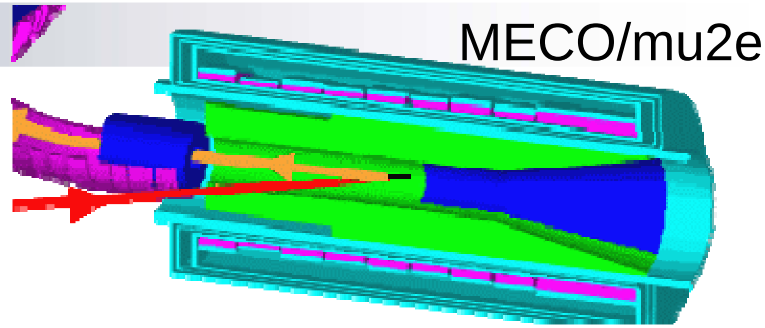


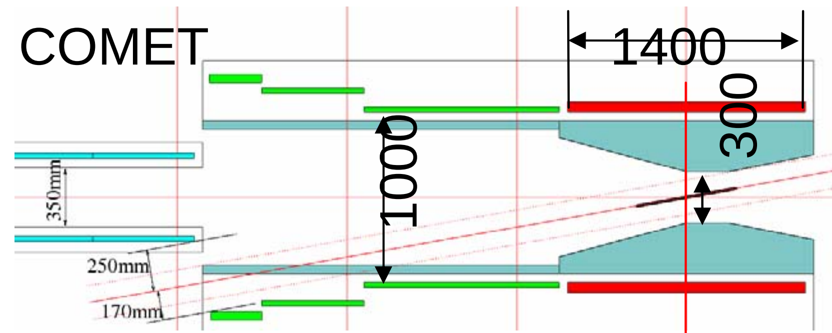
- 250 kA in 2.5 msec, 2.2 sec cycle
- Aluminum alloy conductor
  - ϕ30mm Al target embedded
- Thermal load
  - 14.4 kJ/pulse (Joule heat 12 kJ/pulse) on 1st horn
- Successful operation over 1 year (>10^7 pulses)

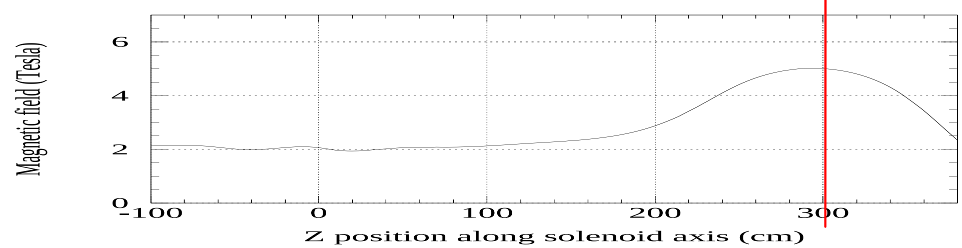


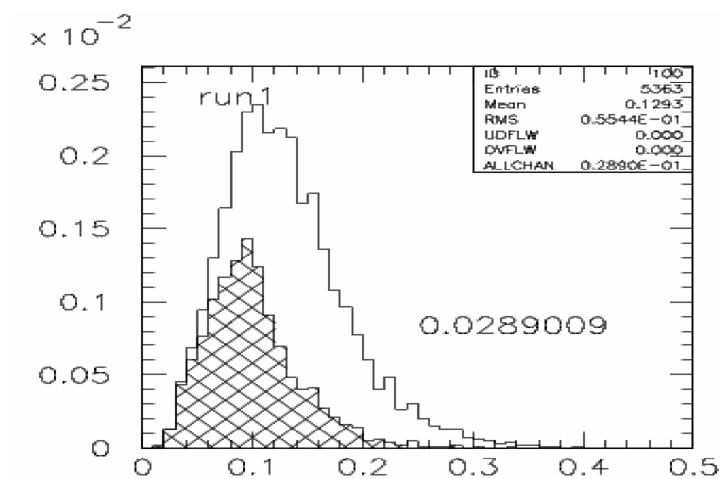
Solenoid in mu-e conversion exp.

- collect backward soft pions
- 5T at solid target
- Proton beam dump located forward
- Solenoid for NF could be used with low energy proton beam.



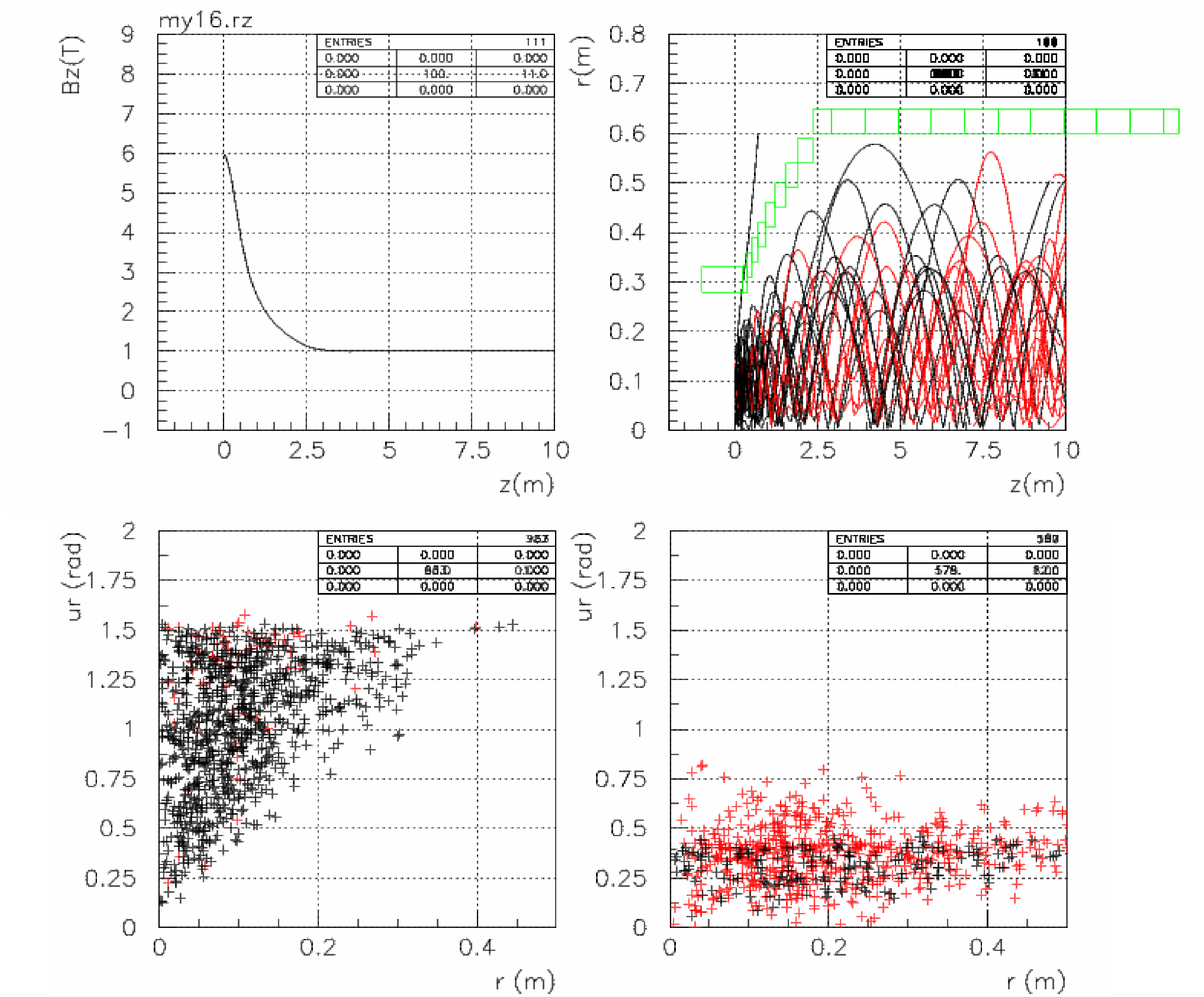




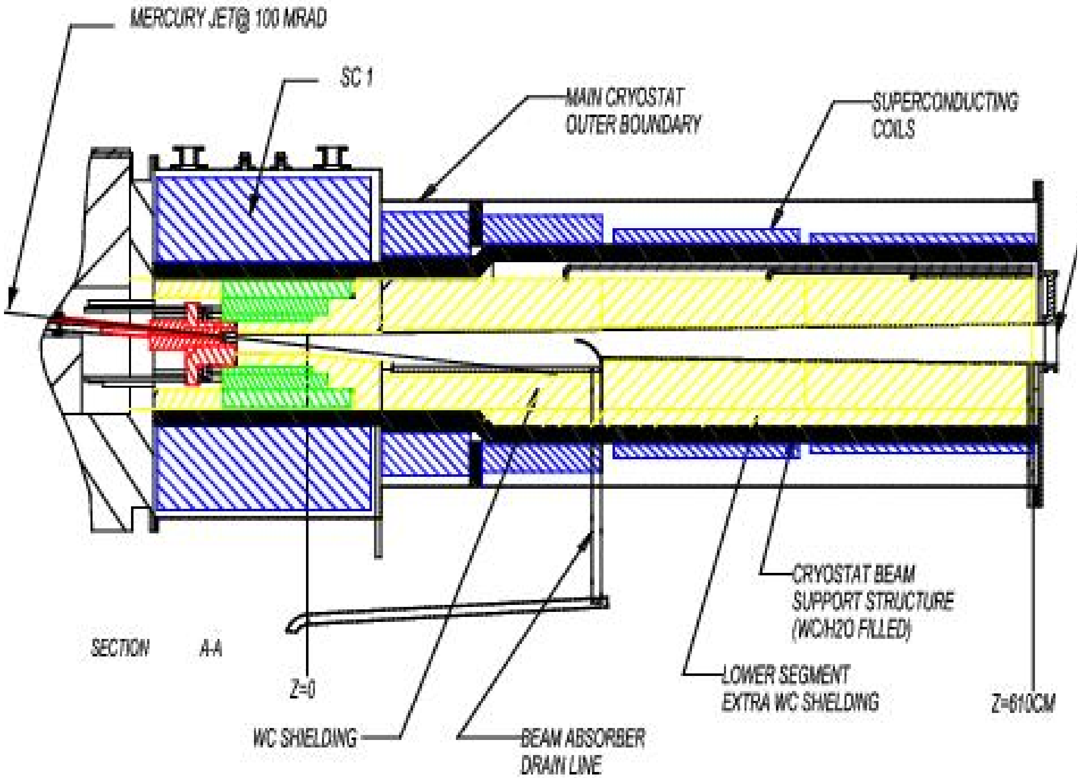


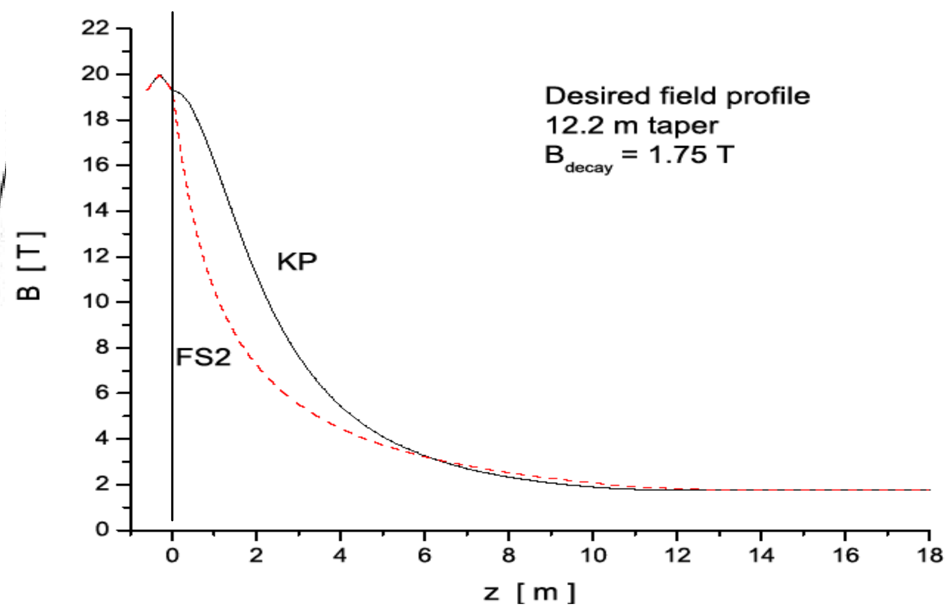
Tracks in Solenoid

- Backward pions collected
- 6T→1T in 2.5m
- 50 % of pions decay at 5 meter



Solenoid in Neutrino Factory

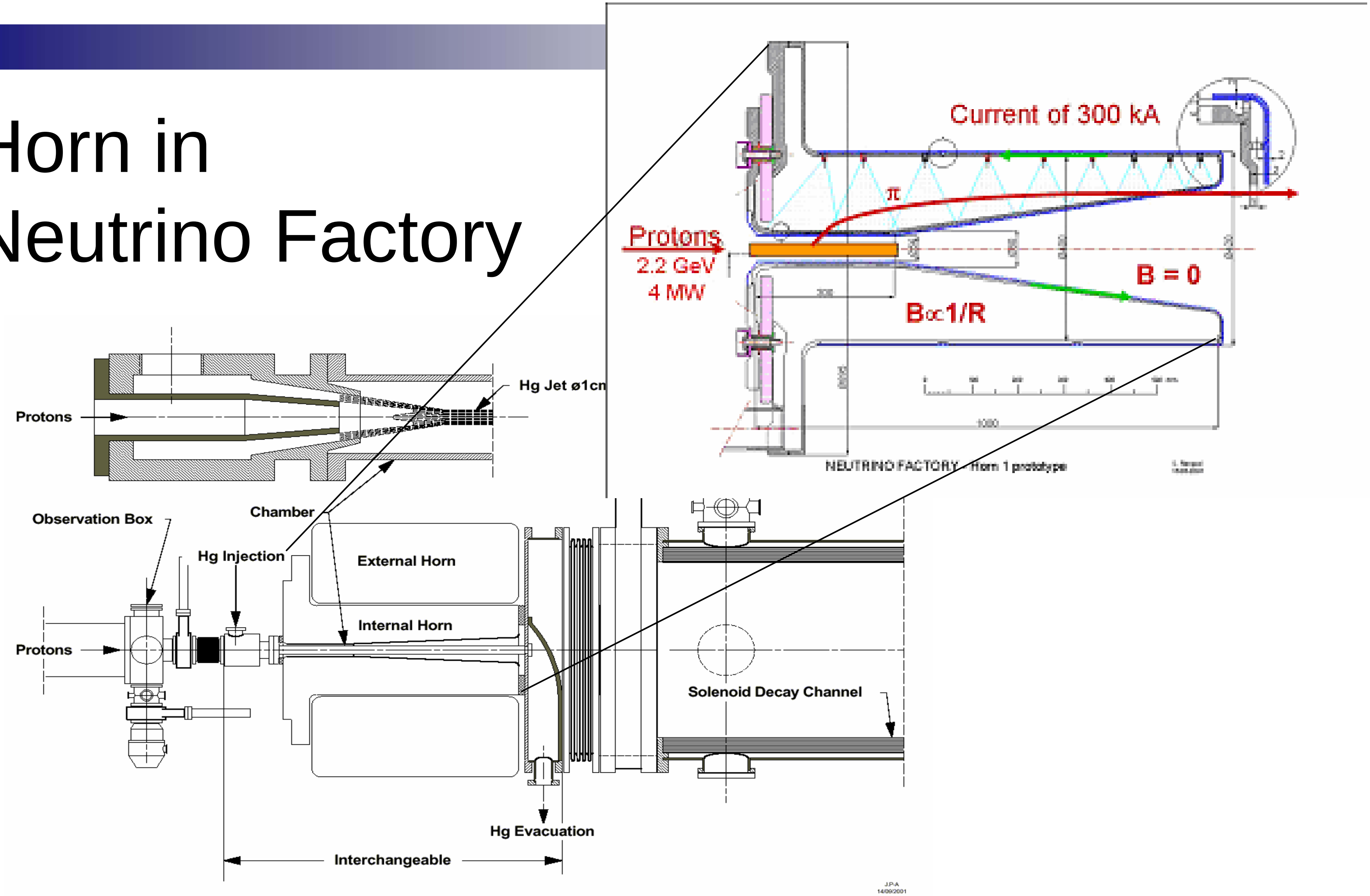




$$Const. = p_t \times r \propto p_t^2 / B \propto Br^2$$

- 20T at target, bore = 15 cm
- $P^t_{max}=0.3BR/2$
- matching to decay solenoid with 1.75T, bore = 60 cm
- tapered in 6 meter

Horn in Neutrino Factory



- 50 Hz
- pulsed current of 300kA (internal horn), 600kA (external horn)
- inner bore = 8 cm

Yield estimate

ISS report

Table 8. Pion and muon production estimates in different cases.

Case	Reference	Program	E_p (GeV)	p Range (GeV/c	μ/π	μ/π per GeV
FFAG Solenoid	[31]	MARS	50		1.2	0.024
FFAG Solenoid	[31][a)]	MARS	50	0–1000	2.0	0.040
CERN Solenoid	[32]	FLUKA	2.2	50–800	0.18	0.082
CERN 300kA Horn (?)	[34]	MARS	2.2	50–800		0.010
CERN 400kA Horn (?)	[34]	MARS	2.2	50–800		0.014
CERN Solenoid (?)	[34]	MARS	2.2	50–800		0.017
CERN Solenoid	[34]	MARS	16	50–800		0.025
Study 2a	[21, 41]	MARS	25	0–1000	0.8	0.033

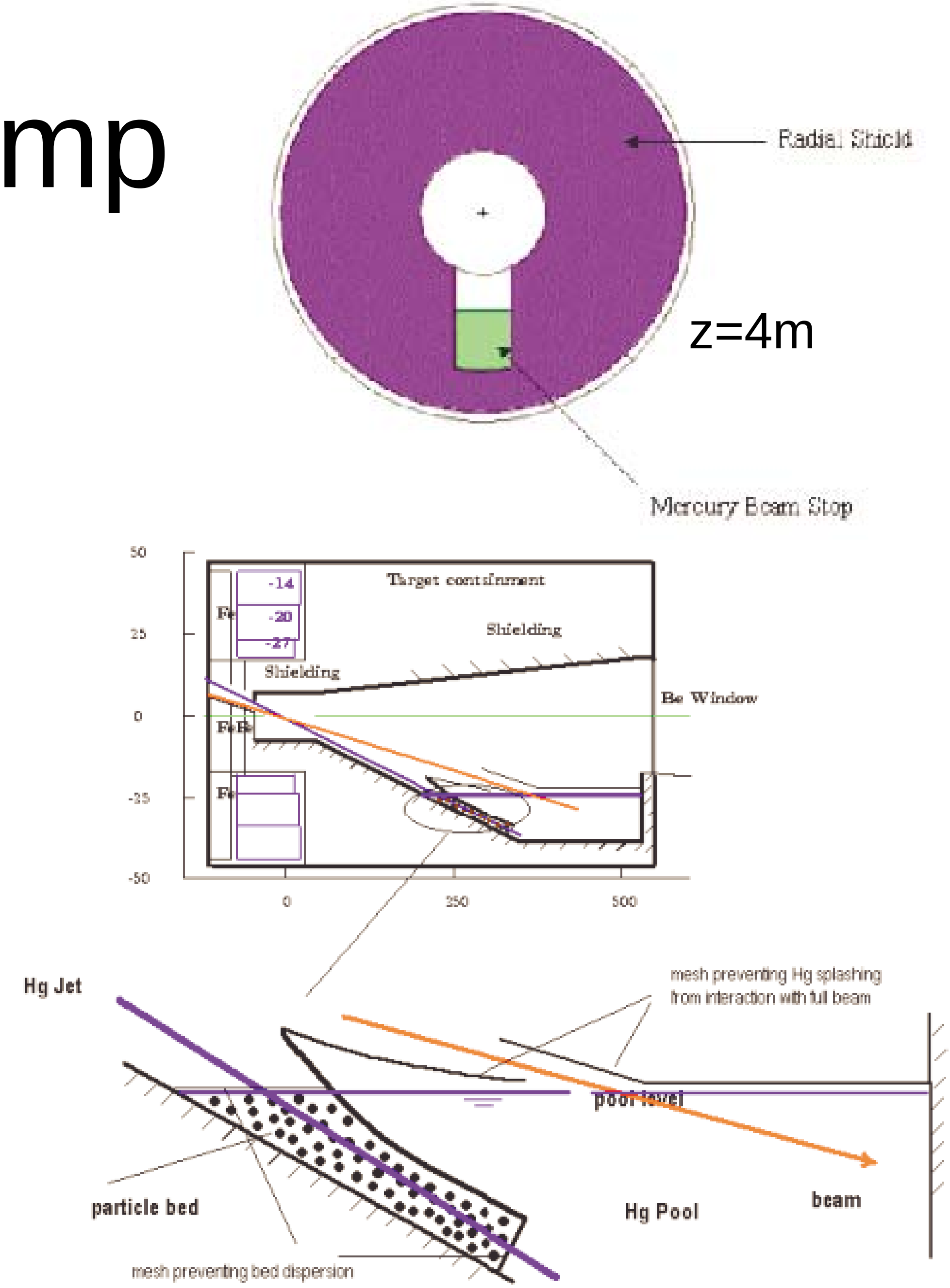
CERN NF note 42

Horn	π^+/POT/GeV	
300 kA	0.021	no material absorption
after 1 m	0.014	
300 kA	**0.016**	with material absorption
after 1 m	0.010	
400 kA	0.020	with material absorption
after 1 m	0.014	

Thinner conductor is better → strength?

Proton beam dump

- No way to extract protons off solenoid
- All the beam energy should be dumped in Solenoid
- Circulated mercury pool, provided from jet target
- Radiation in solenoid should be an issue

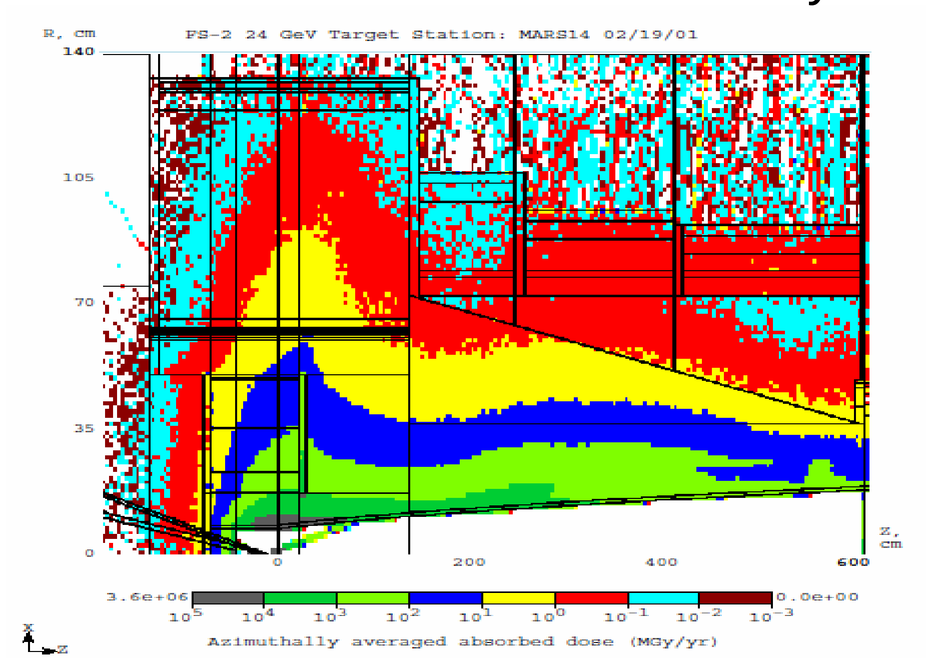


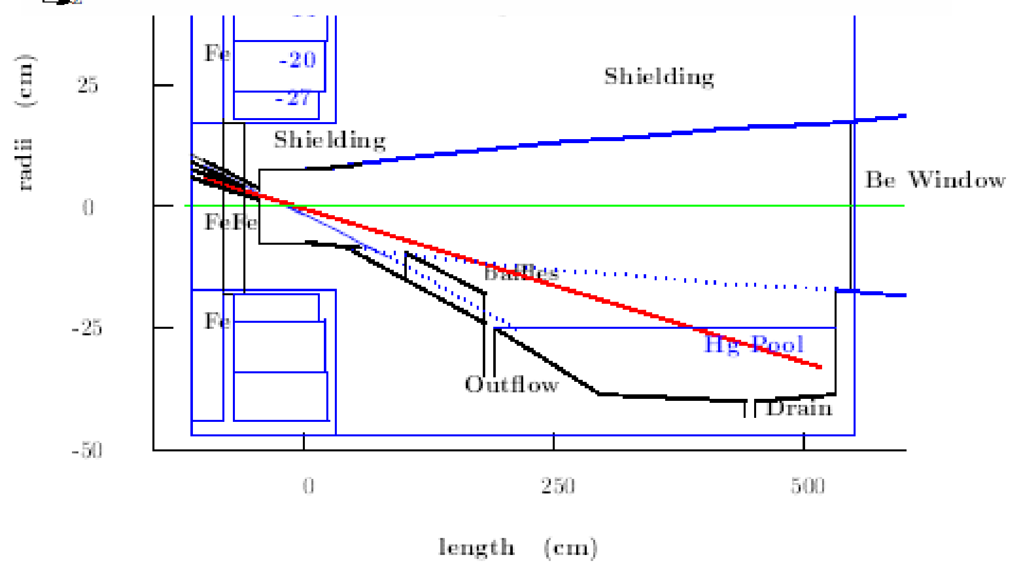
US Study-II

Radiation dose

US Study-II

- 70% of beam power is deposited in target cell
- 40kW in Coaxial shield around target
  - peak ~ 10 W/g → 10^{11} Gy/yr
- 589kW in Surrounding Shield





Lifetime

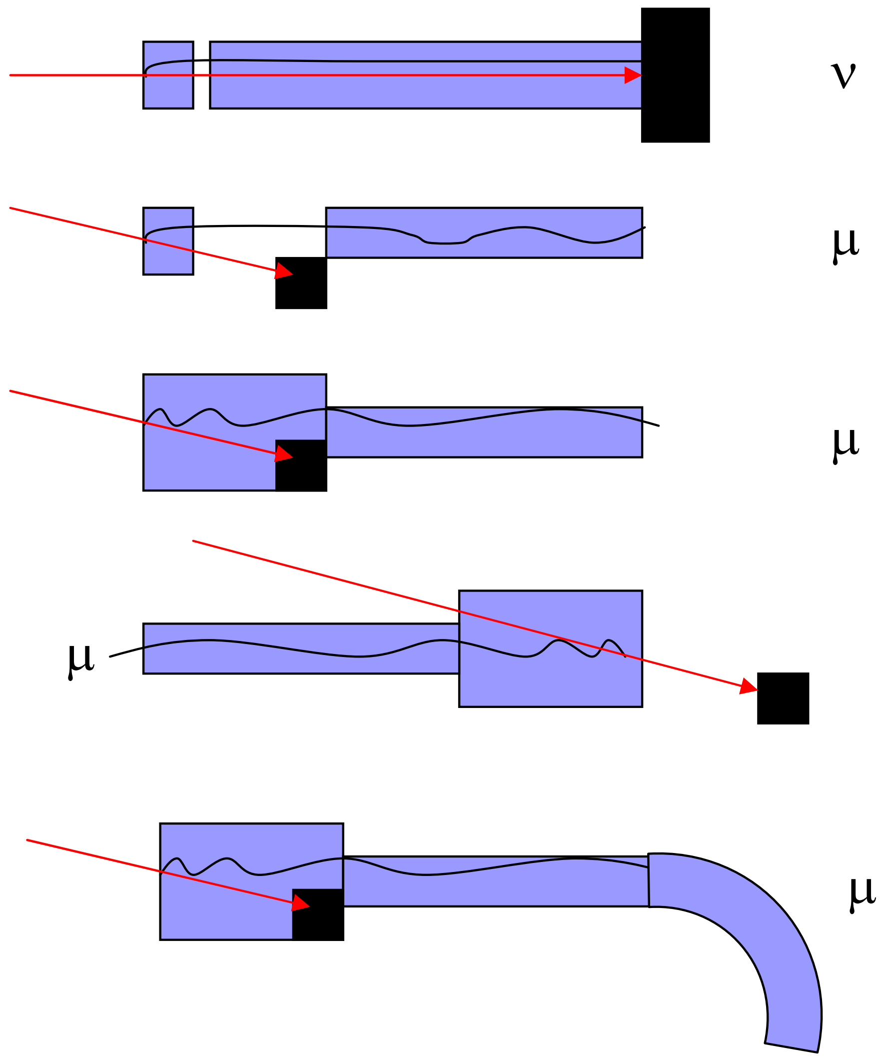
- Solenoid
  - DC operation
  - Radiation dose on superconducting coil
    - should be < 100MGy
    - insert heavy material shield into solenoid bore
- Horn
  - vibration by pulsed current
    - 10^9 pulses/yr at 50 Hz
    - MiniBOONE horn: 170 kA, 5 Hz for 8 GeV
    - T2K horn: 320 kA, <0.6Hz, for 30-50GeV
  - Radiation
    - No shield around target

US study-II

Component	Radius (cm)	Dose/yr (Grays/2×10^7 s)	Max allowed Dose (Grays)	1 MW Life (years)	4 MW life (years)
Inner shielding	7.5	2×10^{11}	10^{12}	5	1.25
Hg containment	18	2×10^9	10^{11}	50	12
Hollow conductor	18	1×10^9	10^{11}	100	25
Superconducting coil	65	6×10^6	10^8	16	4

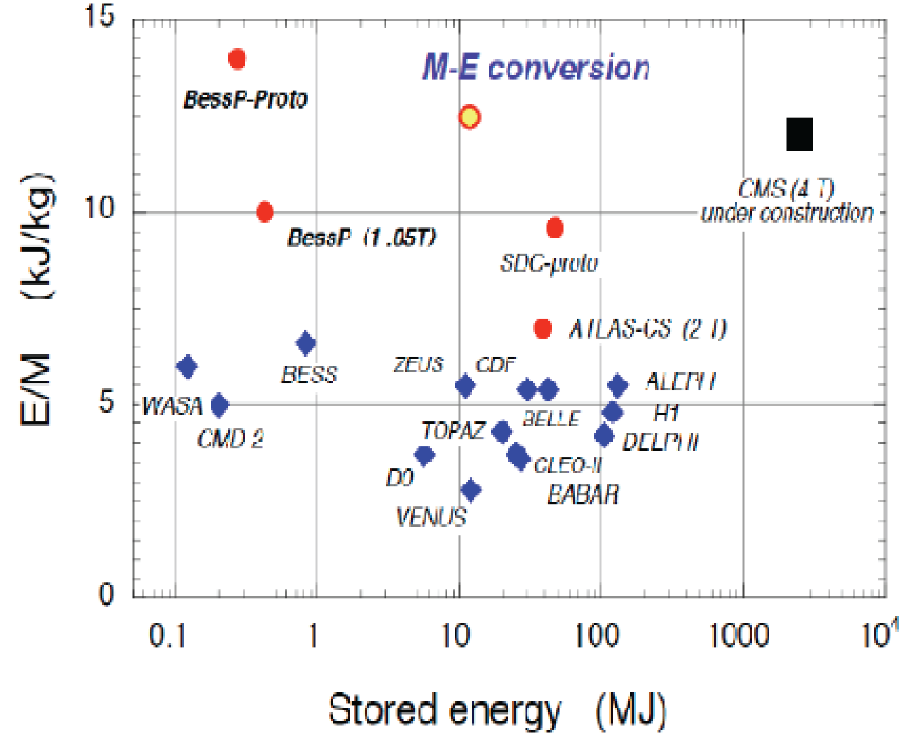
Possible staged approach

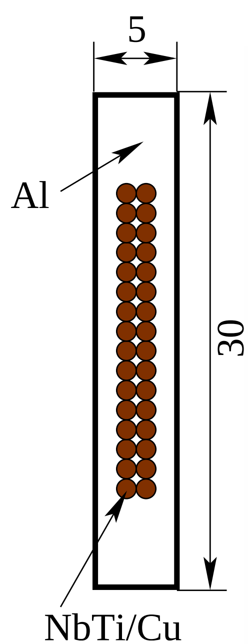
- Upgrade scenario from Super Beam to Neutrino Factory
  - Horn + DecayVolume
    - low freqency
    - off axis
  - Horn + DecaySolenoid
    - Low frequency
  - Solenoid + DecayVolume
    - High frequency
    - on axis
  - Solenoid + DecaySolenoid
    - High frequency
- Upgrade scenario from muon exp. to Neutrino Factory
  - Solenoid + DecaySolenoid (+bent solenoid)
    - backward capture
    - momentum selection
    - Low energy + SolidTarget
  - Solenoid + DecaySolenoid
    - forward
    - High energy + MercuryJet

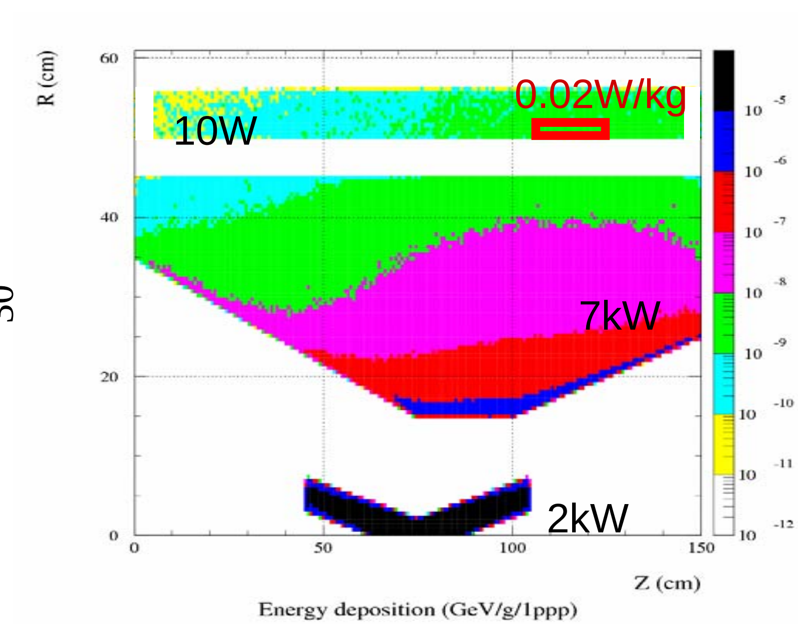


Superconducting Coil

- COMET case
  - 5T
  - 1m bore
  - 10W (peak: 0.02W/kg)
  - 0.4 MGy/yr for 0.1MW beam
  - Detector thin solenoid technique
  - Indirect cooling
  - Al-stabilized cable (NbTi)
  - Well-established technology
    - ATLAS, BESS, CMS, …
  - 6cm thick
  - 80A/mm2 (566A/mm2 in NbTi)
  - 1ton coil mass
  - 12MJ

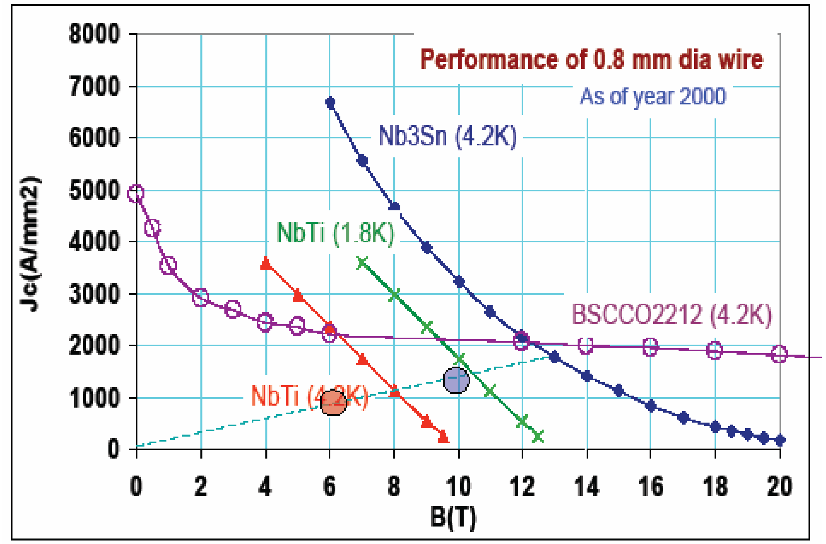


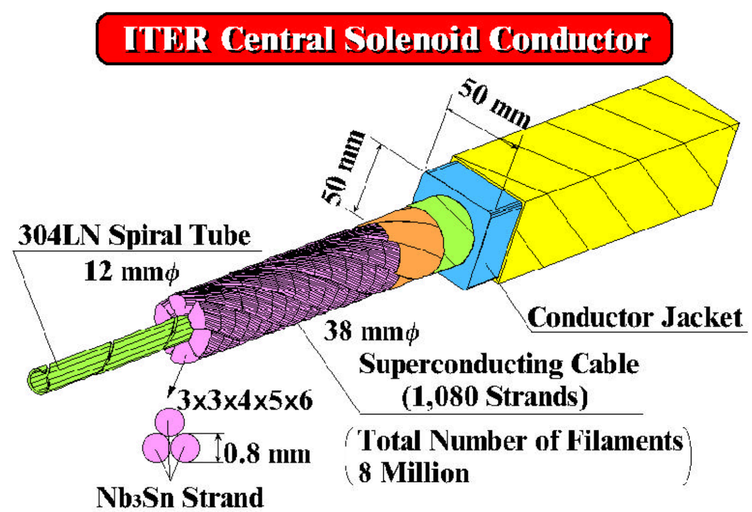




Superconducting Coil

- US Study-II case
  - 14T
  - 1.3 m bore
  - ~0.3W/kg
  - 3MGy/10^7s for 1MW beam
  - Fusion reactor technique
  - Direct cooling
  - Cable in Conduit
  - 64cm thick
  - 20A/mm2 (234A/mm2)
- R&D
  - Radiation
    - insulation with organic material up to 10 MGy
    - change Jc, resistivity





Summary

- Solenoid option is straightforward to collect soft pions and then obtain muons in decay solenoid
  - R&D on radiation damage of insulator up to 10 MGy
- Horn can capture, focus pions to parallel
  - Need to match to decay solenoid in Neutrino Factory scheme to obtain muons
  - Need to overcome ~10^9 pulses/yr at 50 Hz
- Beam dump and radiation dose in target station is an issue
  - Maintenance scenario