Neutrino experiment at J-PARC

Yoshikazu Yamada
(KEK-IPNS)
for T2K collaboration and J-PARC
Neutrino facility construction group

Talk at “NP04” Tokai, Aug. 2, 2004

Contents (summary for ν part of NP04)

- Introduction of T2K experiment
- Proton beam line
- Target & neutrino beam
- Neutrino Detectors
- Schedule

T2K collaboration

- Formed in May 2003
- **12 countries**, 53 institutions
  ~150 collaborators
- Spokesperson: K.Nishikawa

Canada: **TRIUMF, U. Alberta, York U., U. Toronto,U. Victoria, U. Regina**
China: **IHEP(Inst. Of High Energy Phys.)**
France: **CEA Saclay**
Italy: **U. Roma, U. Bari, U. Napoli, U. Padova**
Japan: **ICRR, U. Tokyo, KEK, Tohoku U., Hiroshima U., Kyoto U., Kobe U., Osaka City U., U. Tokyo, Miyagi U. of Education**
Korea: **Seoul National U., Chonnam National U., Dongshin U., Kangwon U., Kyungpook National U., KyungSang National U.,SungKyunKwan U., Yonsei U.**
Poland: **Warsaw U.**
Russia: **INR**
Spain: **U. Barcelona, U. Valencia**
Switzerland: **U. Geneva**
UK: **RAL, Imperial College London, Queen Mary Westfield College London, U. Liverpool**
USA: **UCI, SUNY-SB, U. Rochester, U. Pennsylvania, Boston U., CSU, Duke, Dominguez Hills, BNL, UCB/LBL, U. Hawaii, ANL, MIT, LSU, LANL, U. Washington**

T2K experiment

Long baseline neutrino oscillation experiment from Tokai to Kamioka.

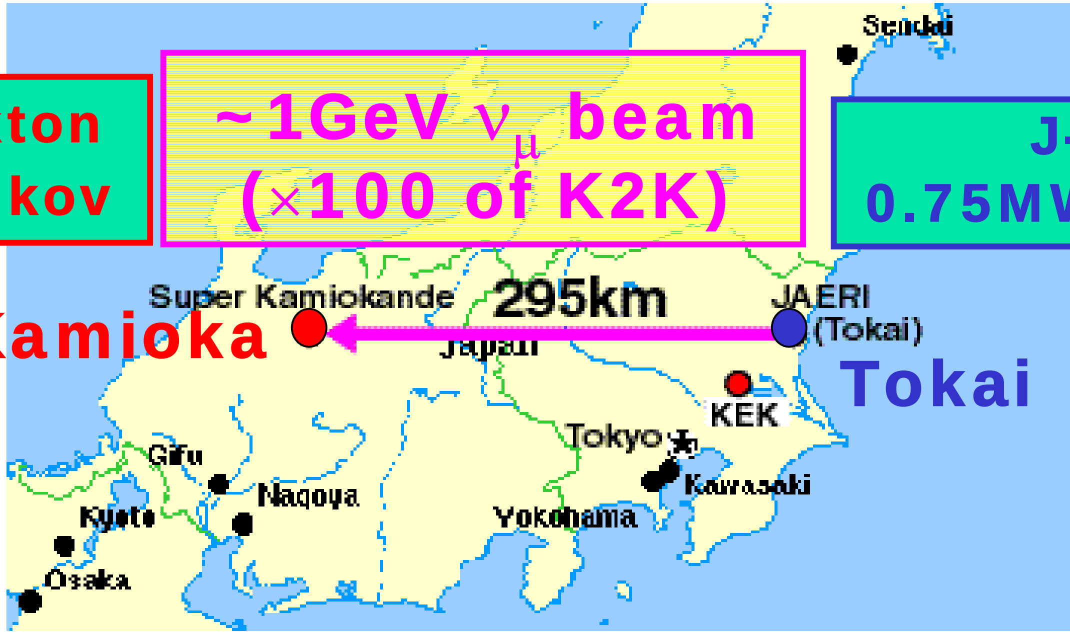
Super-K: 50 kton Water Cherenkov

~1GeV ν_μ beam ($\times$100 of K2K)

J-PARC 0.75MW 50GeV PS

Kamioka

Tokai



Phase2: Hyper-K?

Phase2: 4 MW ?

Physics motivations

- **Discovery of $\nu_\mu \rightarrow \nu_e$ appearance**
- **Precise meas. of disappearance $\nu_\mu \rightarrow \nu_x$**
- **Discovery of CP violation (Phase2)**

Neutrino oscillation

If neutrinos are massive,

Weak eigenstates

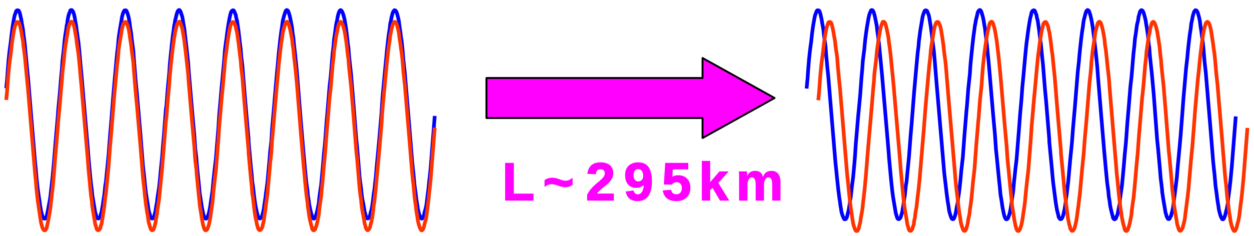
$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = \mathrm{U_{MNS}}\,\mathrm{V_M^{CP}}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mass eigenstates: m_1, m_2, m_3

$$\mathrm{U_{MNS}} = \begin{pmatrix}1 & 0 & 0\\ 0 & +c_{23} & +s_{23}\\ 0 & -s_{23} & +c_{23}\end{pmatrix}\begin{pmatrix}+c_{13} & 0 & +s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & +c_{13}\end{pmatrix}\begin{pmatrix}+c_{12} & +s_{12} & 0\\ -s_{12} & +c_{12} & 0\\ 0 & 0 & 1\end{pmatrix}$$

$c_{ij} = \cos(\theta_{ij})$, $s_{ij} = \sin(\theta_{ij})$

$$\mathrm{V_M^{CP}} = \begin{bmatrix}e^{i\alpha_1} & 0 & 0\\ 0 & e^{i\alpha_2} & 0\\ 0 & 0 & 1\end{bmatrix}$$



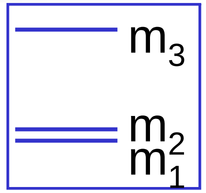
$\nu_\mu \rightarrow \nu_\tau$, ν_e
Oscillation

$$|\nu_\alpha\rangle = |\nu_1\rangle\cos\theta + |\nu_2\rangle\sin\theta \Rightarrow |\nu_1\rangle\, e^{-i\frac{m_1^2}{2E}L}\cos\theta + |\nu_2\rangle\, e^{-i\frac{m_2^2}{2E}L}\sin\theta$$

$$= |\nu_\alpha\rangle\left(1-\sin^2 2\theta\sin^2\left(\Delta m^2\frac{L}{4E}\right)\right) + |\nu_\beta\rangle\sin^2 2\theta\sin^2\left(\Delta m^2\frac{L}{4E}\right)$$

$\alpha = e, \mu, \tau$ $\quad m_1 < m_2$

ν_μ disappearance

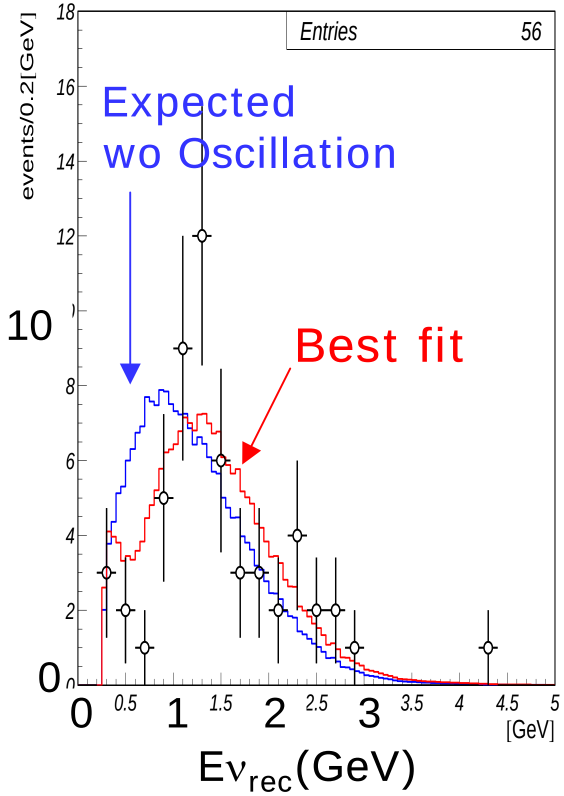


Precise measurement of θ_{23},Δm_{23}
: ν_μ disappearance

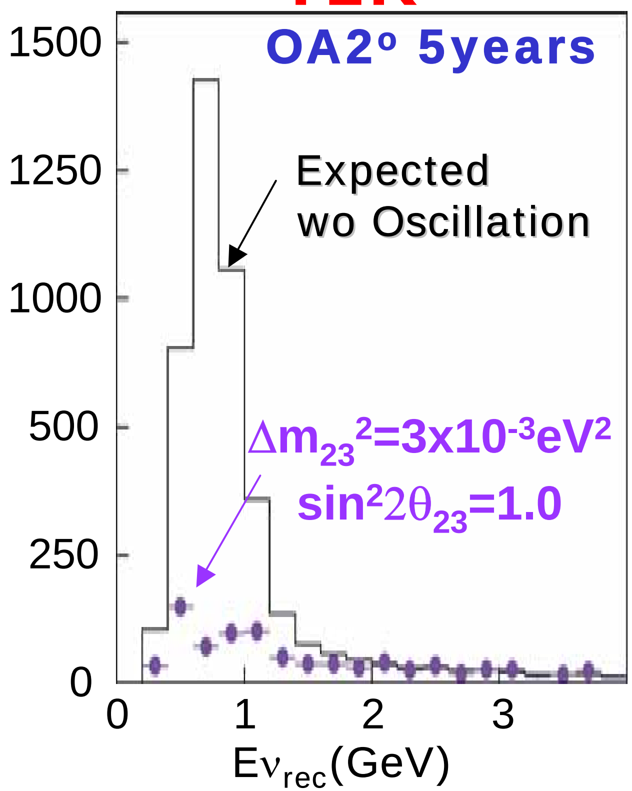
$$\Delta m^2_{12} << \Delta m^2_{23} \approx \Delta m^2_{13}$$

$$P_{\mu \to x} \approx 1 - \cos^4 \theta_{13} \cdot \sin^2 2\theta_{23} \cdot \sin^2 \left(1.27 \Delta m^2_{23} L / E_\nu\right)$$

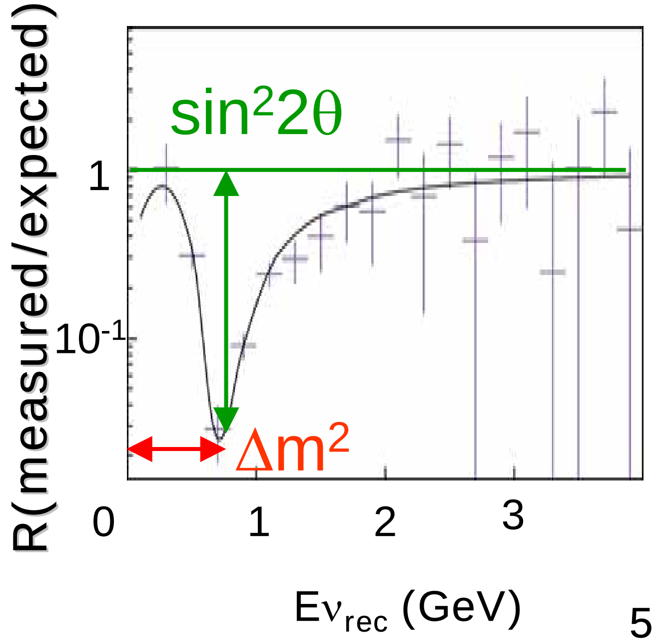
K2K



T2K

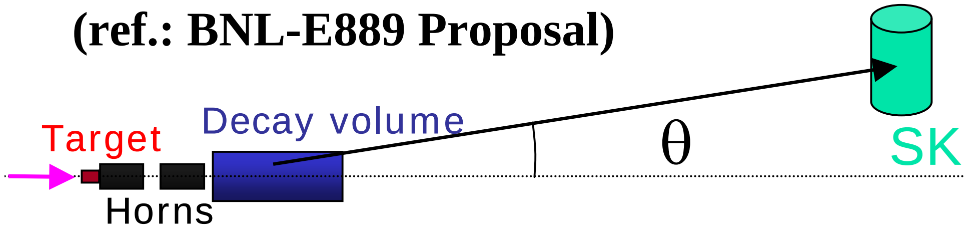


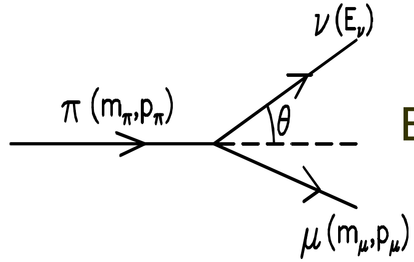
$\delta(\sin^2 2\theta_{23}) \sim 0.01$
$\delta(\Delta m_{23}^2) \sim < 1 \times 10^{-4}$



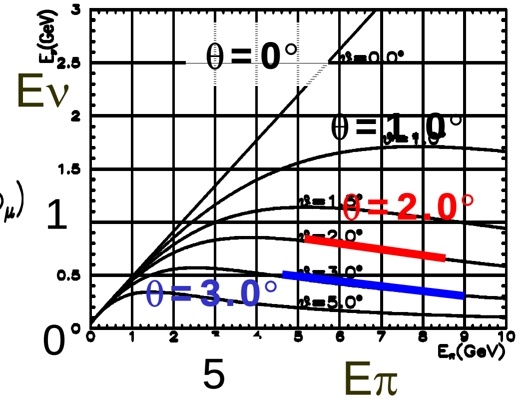
Off Axis Beam

(ref.: BNL-E889 Proposal)

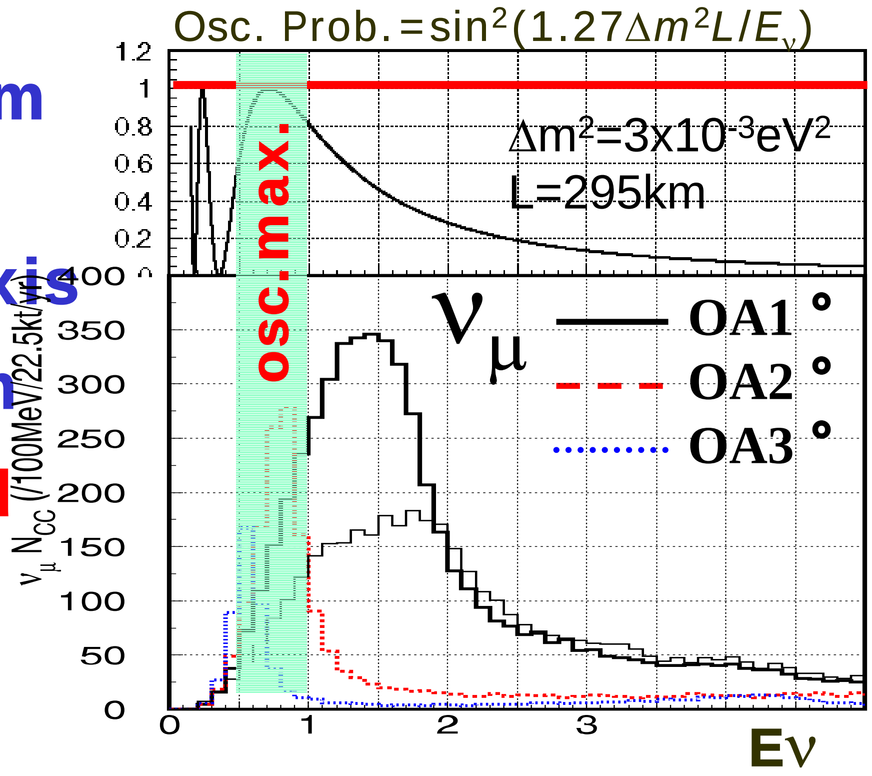




$$E_\nu = \frac{m_\pi^{\ 2} - m_\mu^{\ 2}}{2(E_\pi - p_\pi \cos\theta)}$$



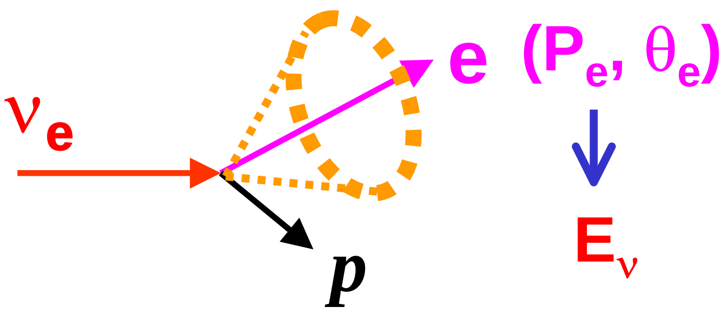
- Pions produced at target decay in Decay Volume
  ⇒ Wide Band neutrino Beam
- WBB is intentionally misaligned from detector axis
- Quasi monochromatic beam
- **Off axis angle: 2°~3° tuned for oscillation maximum**

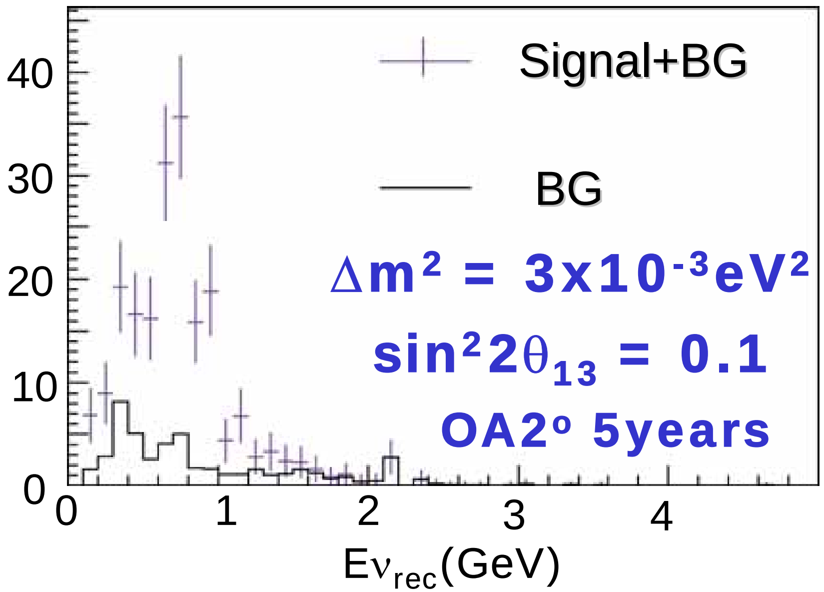


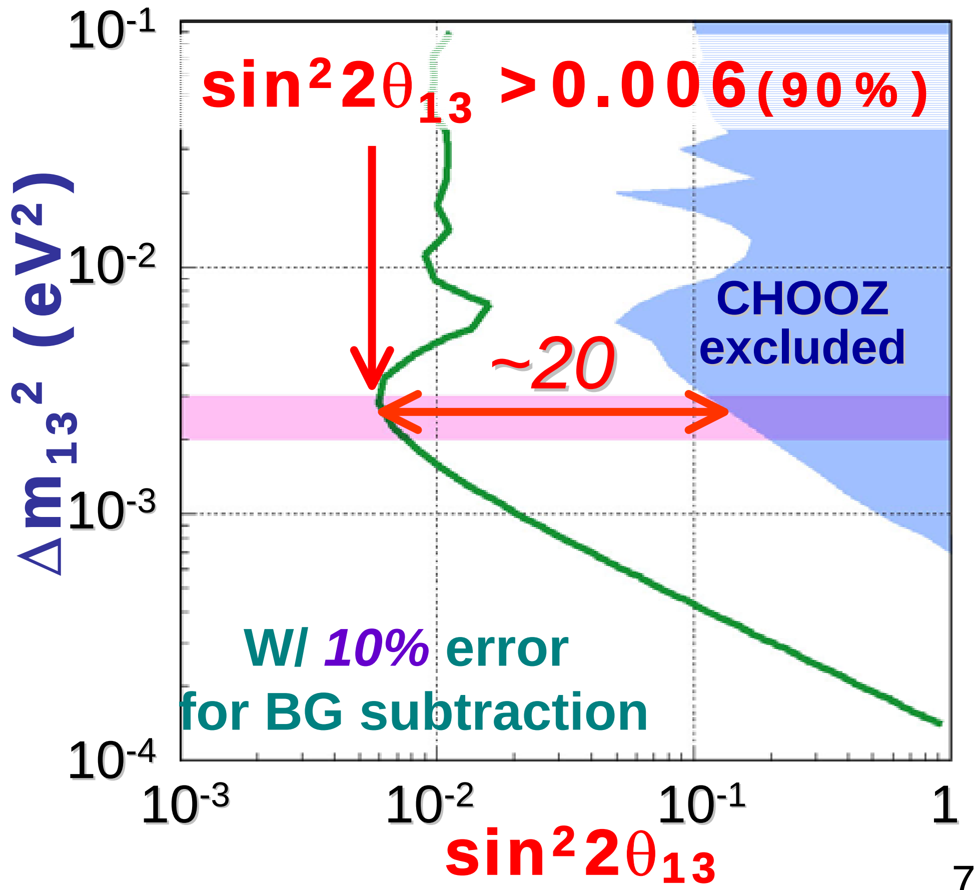
ν_e appearance

Discovery of ν_e appearance (θ_{13},Δm_{13})

$$P_{\mu \to e} \approx \sin^2 \theta_{23} \cdot \sin^2 2\theta_{13} \cdot \sin^2 \left(1.27 \Delta m^2_{13} L / E_\nu\right)$$





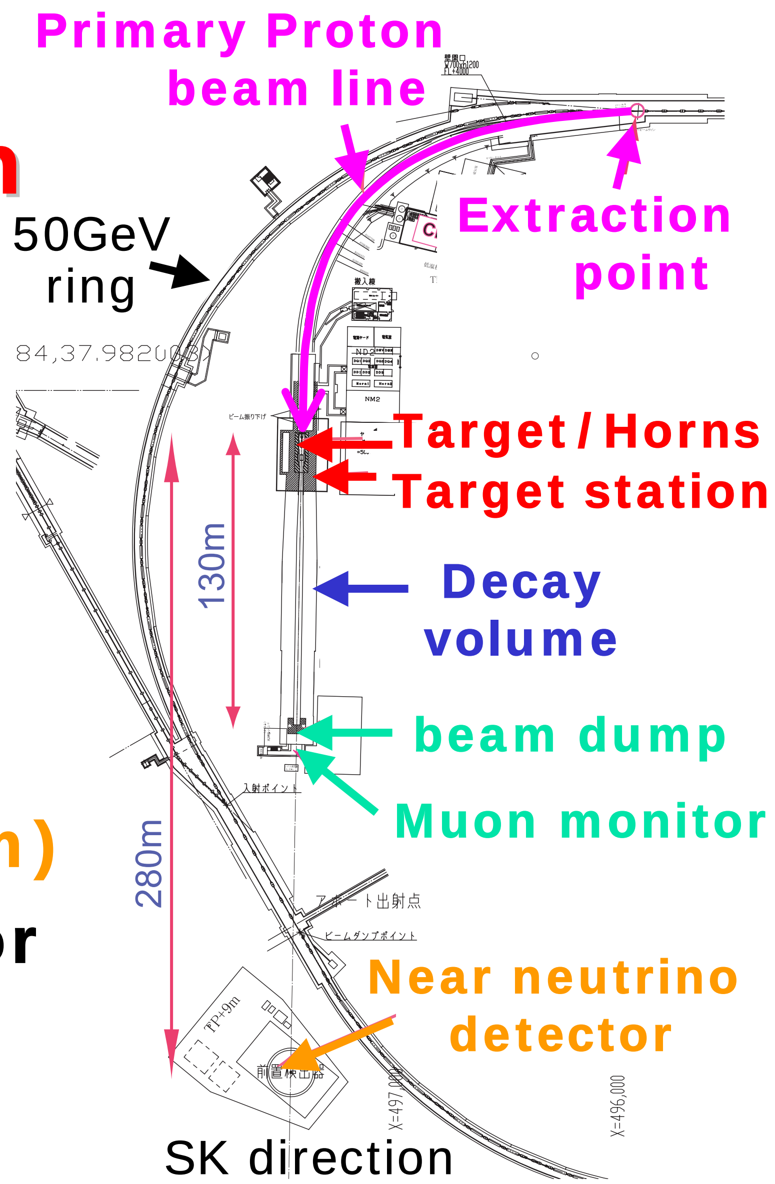


Neutrino facility

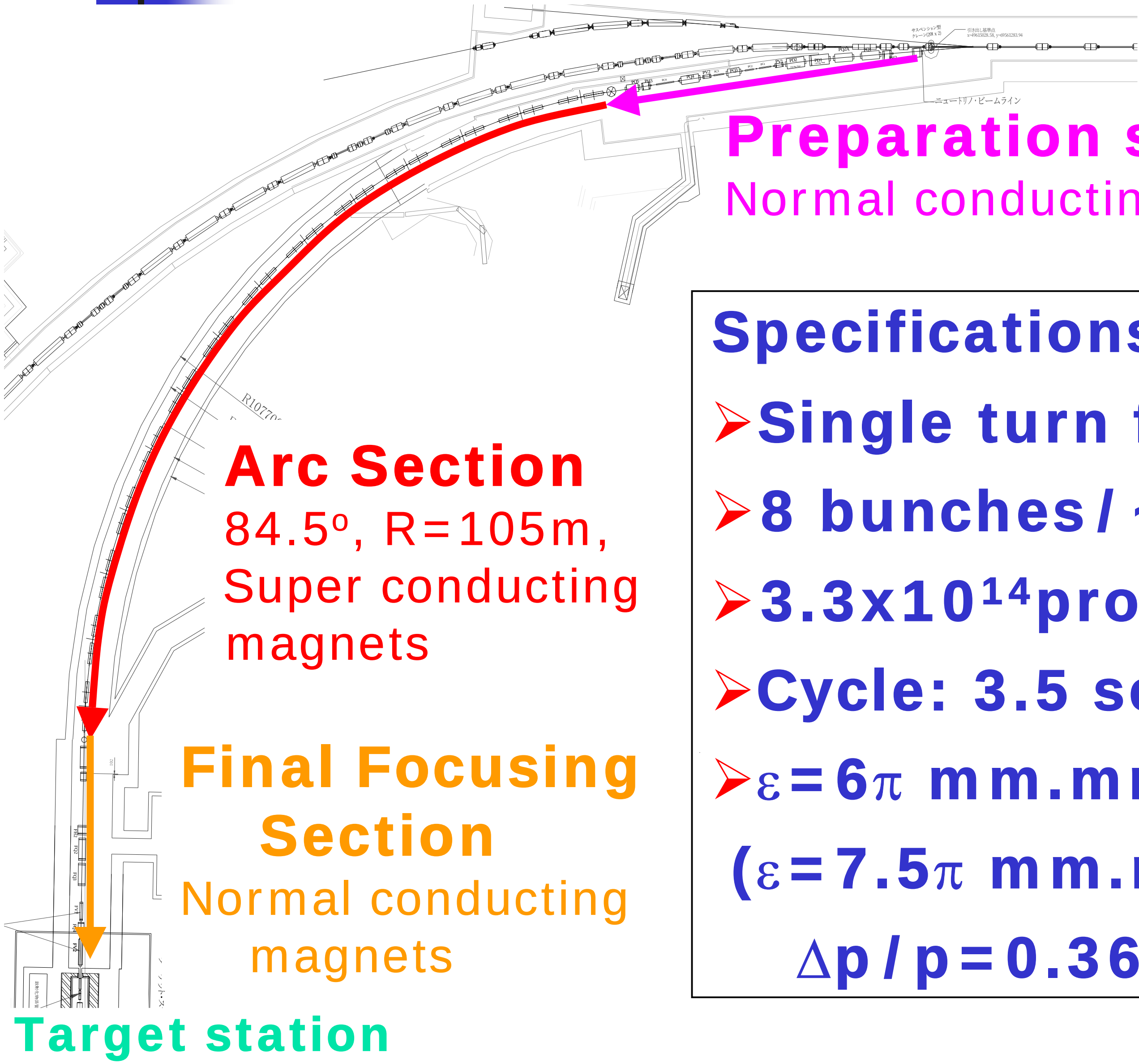
Approved in Dec. 2003
for 5 years construction

Components

- Primary proton beam line
- Target / Horn system
- Decay volume (130m)
- Beam dump
- Muon monitor
- Near neutrino detector (280m)
- Second near neutrino detector (~2km): not approved yet



Proton beam line

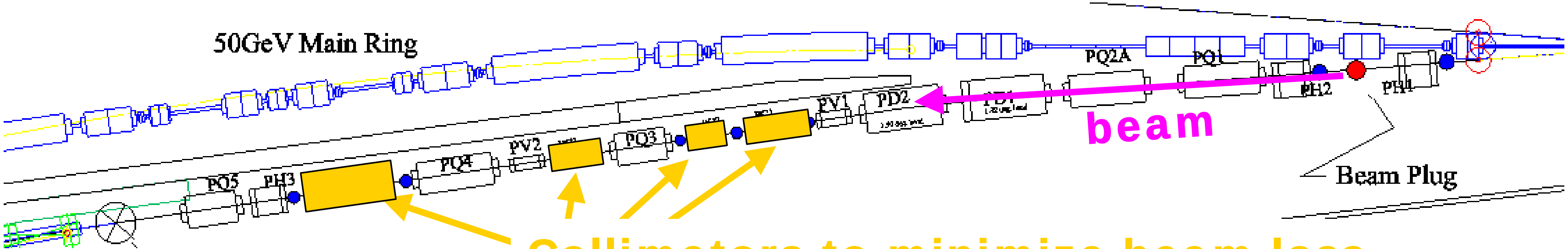


Specifications (50GeV)

- Single turn fast extraction
- 8 bunches/~5μs
- 3.3×10^{14}protons/spill
- Cycle: 3.5 second
- $\varepsilon=6\pi$ mm.mr, $\Delta p/p=0.31\%$
  ($\varepsilon=7.5\pi$ mm.mr, $\Delta p/p=0.36\%$ @40GeV)

Preparation Section

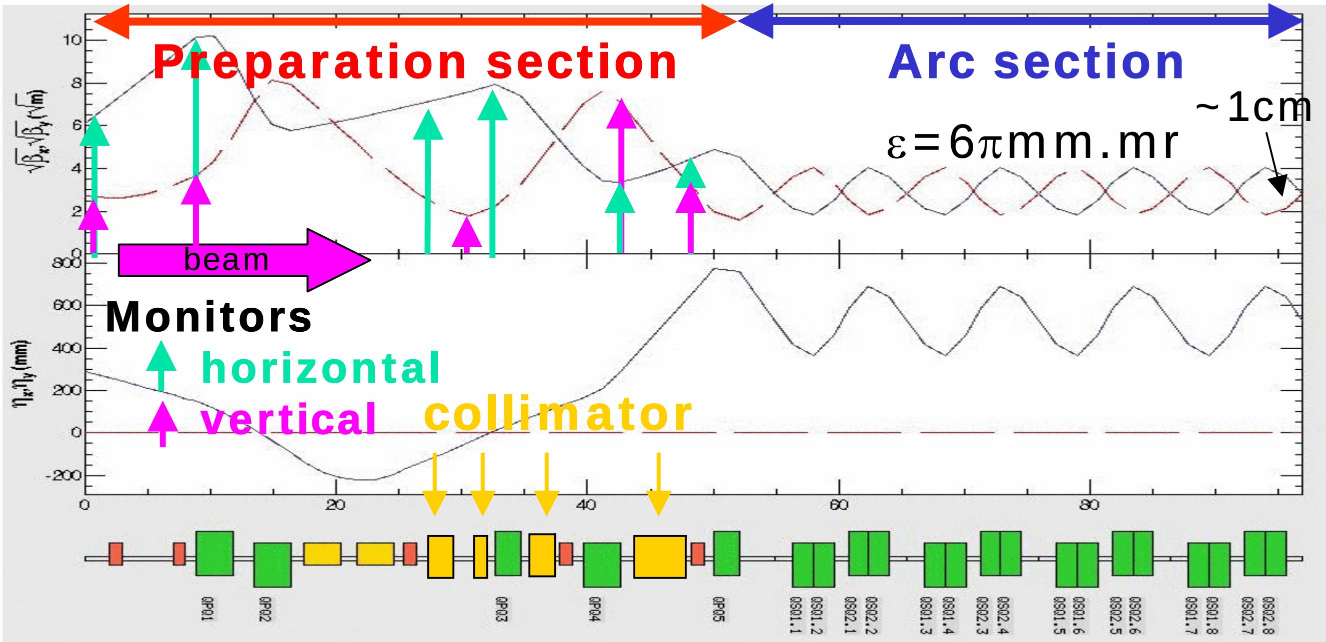
- Matching beam from PS to ARC section



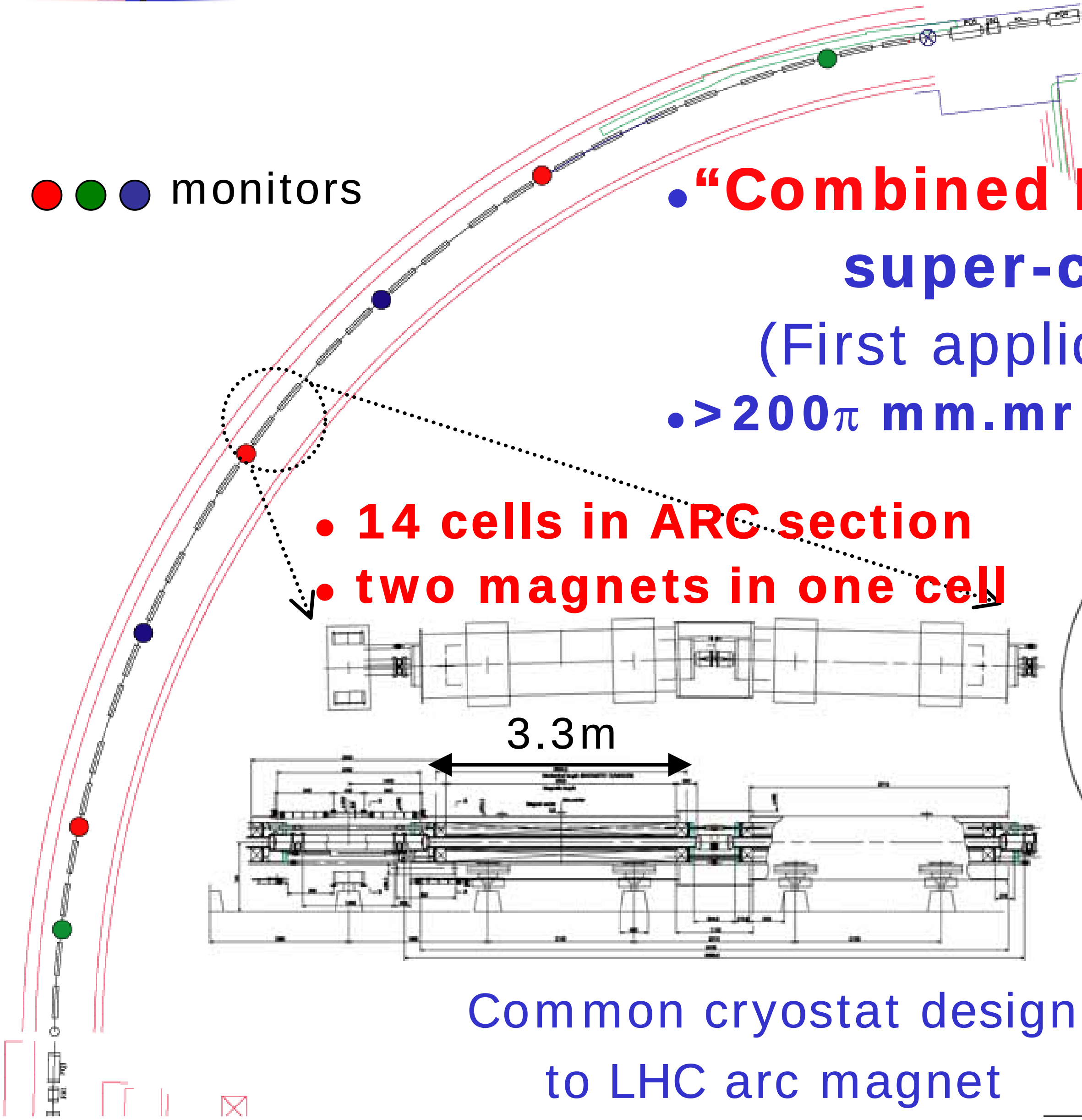
Collimators to minimize beam loss
& heat load at super-conducting magnets

Top view

- Dipole(H):2
- Quadrupole:5
- Steering:5
- 5 with MIC



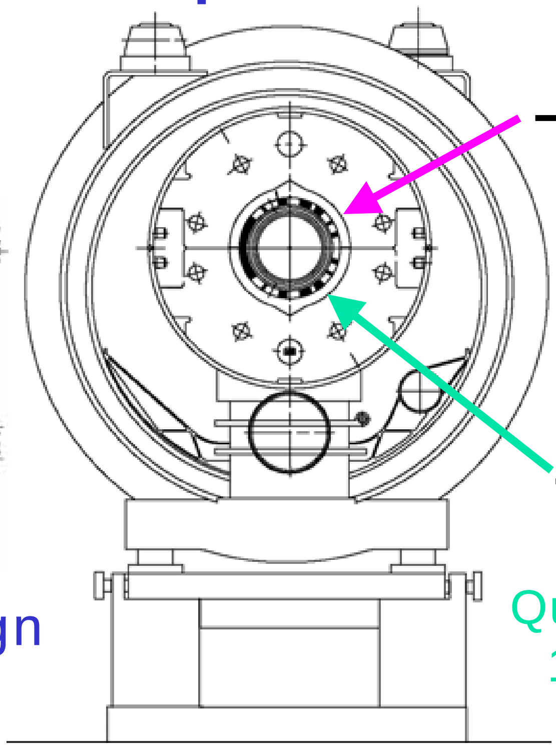
Arc section

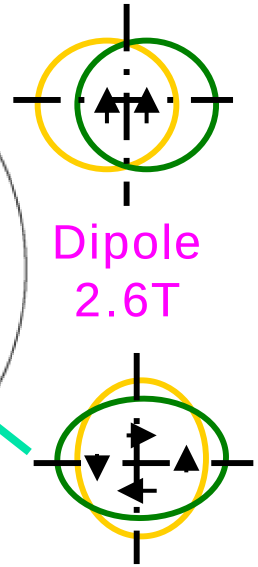


- “Combined Function” super-conducting magnets (First application in the world)
- >200π mm.mr acceptance

- 14 cells in ARC section
- two magnets in one cell

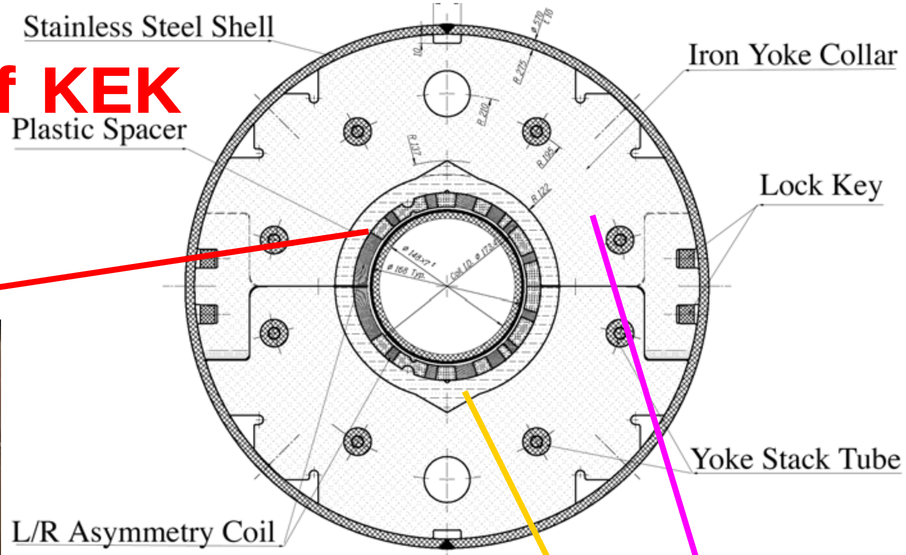
Common cryostat design to LHC arc magnet





R&D for S.C. magnet

Cryogenic Science Center of KEK

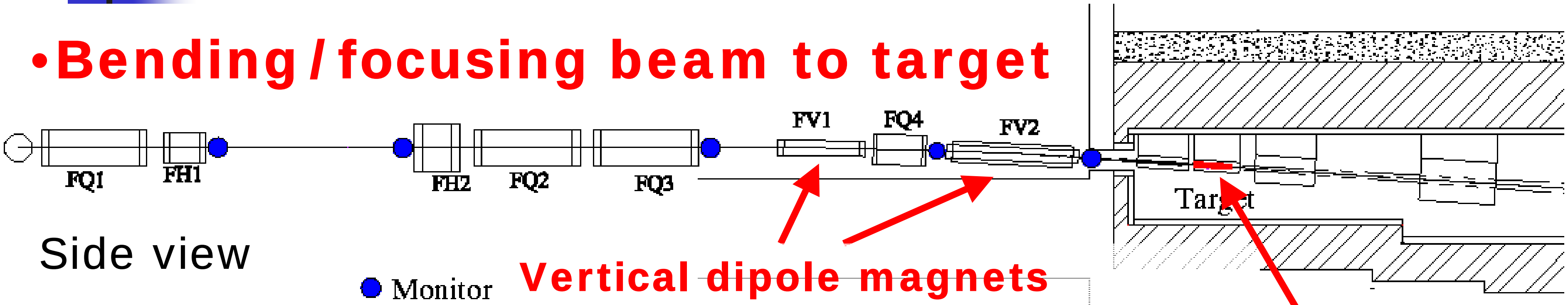


winding coil for prototype magnet at KEK (7/28/2004)

Trial Iron Yoke & Plastic Collar

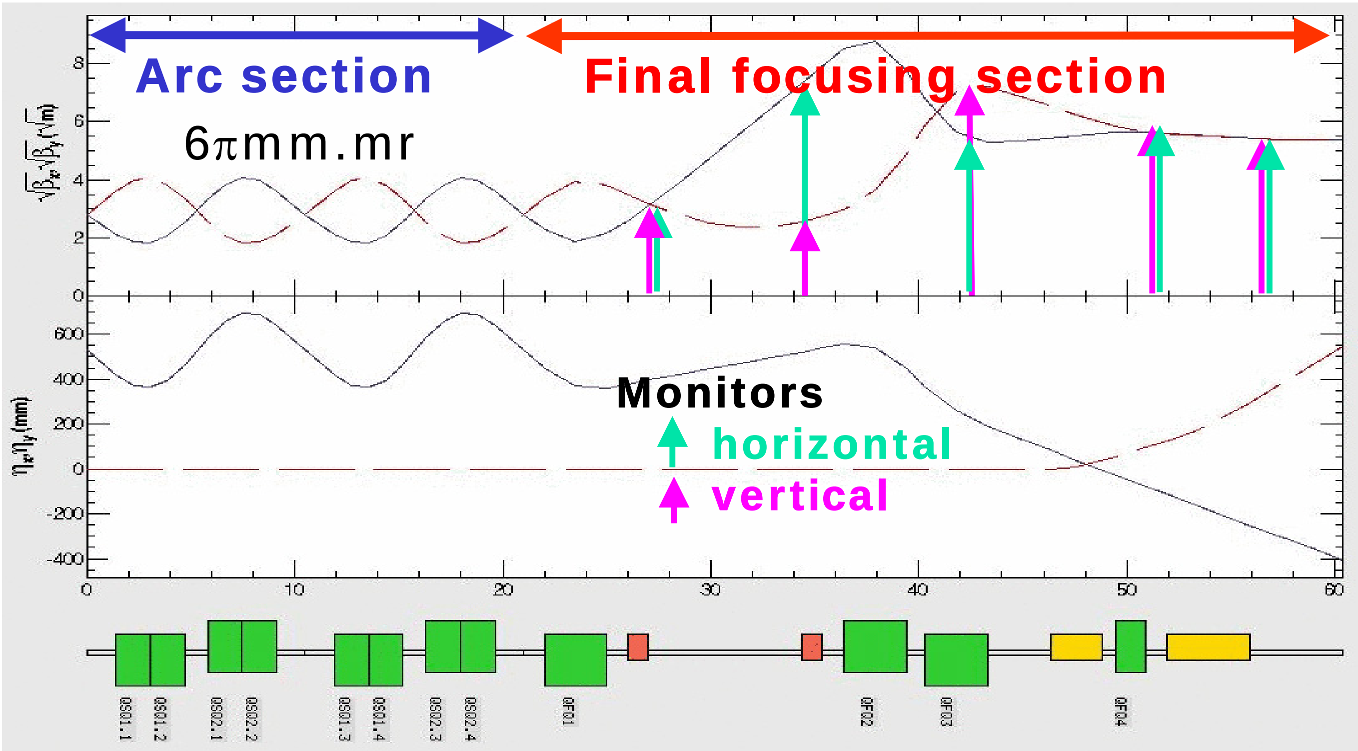
Final Focusing section

- Bending/focusing beam to target



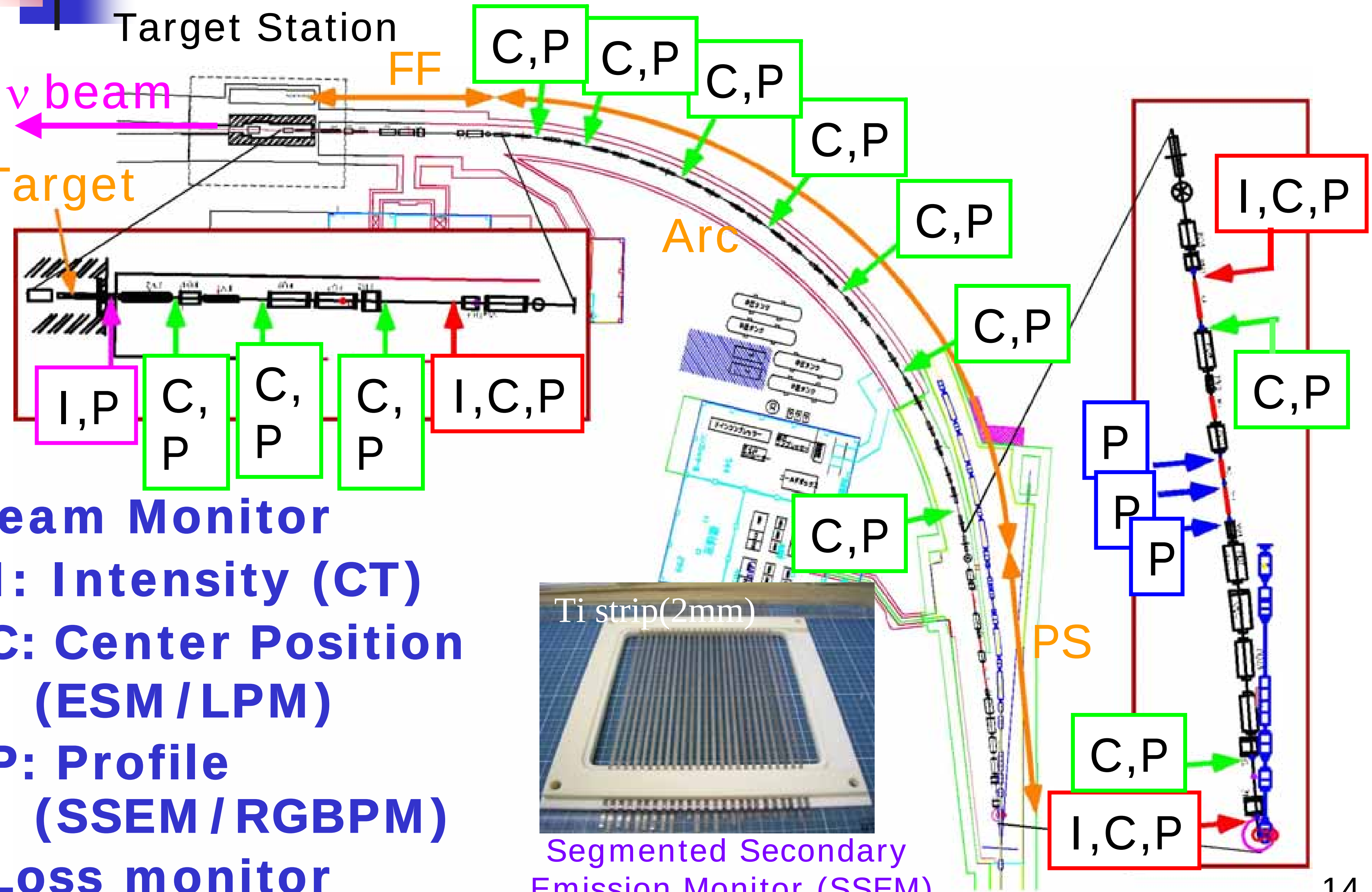
Vertical dipole magnets to change off-axis angle (2°~3°)

σ_r~6mm at target



- Dipole(V):2
- Quadrupole:4
- Steering:2

Beam monitors

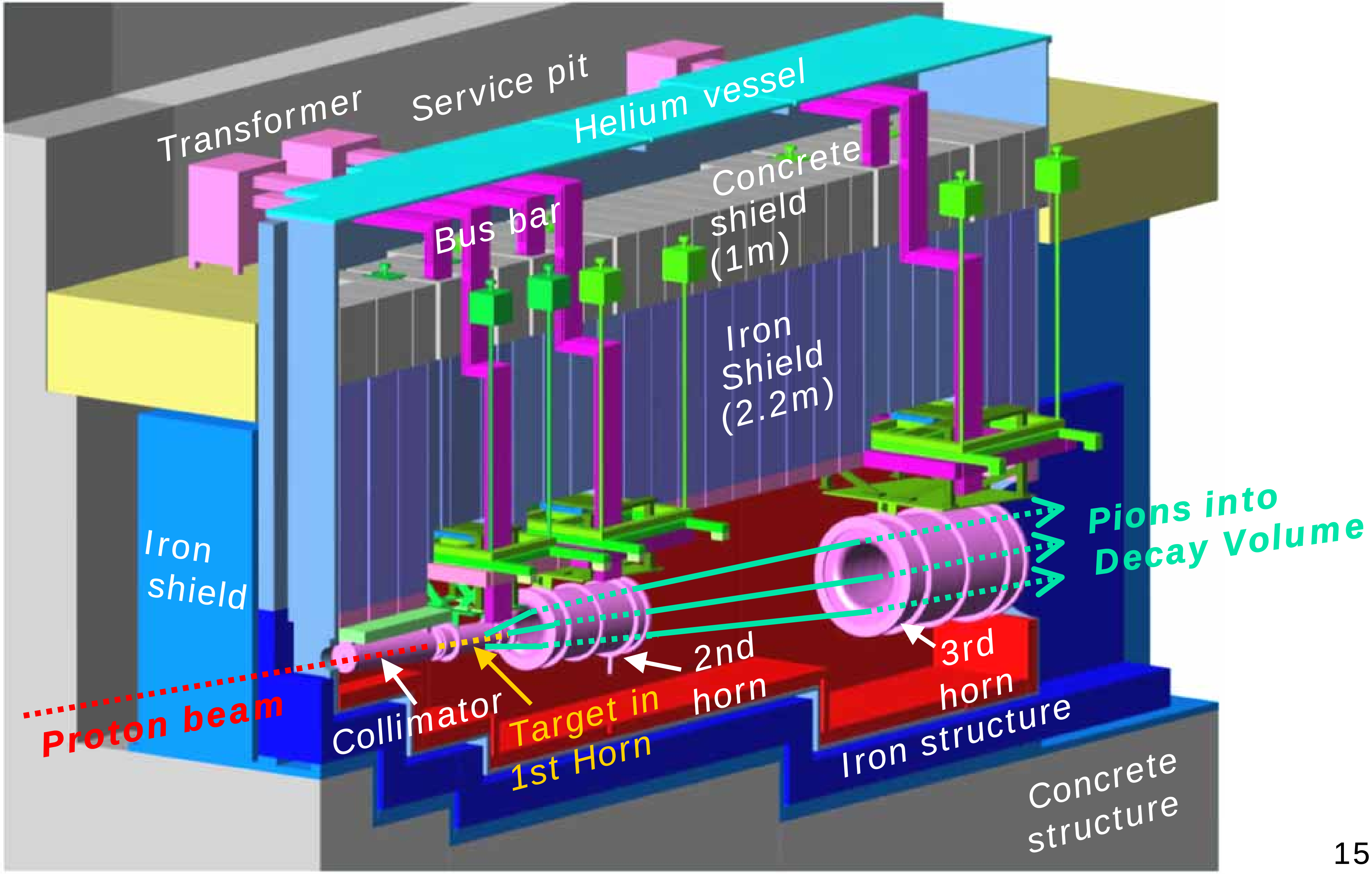


Beam Monitor

- **I: Intensity (CT)**
- **C: Center Position (ESM / LPM)**
- **P: Profile (SSEM / RGBPM)**
- **Loss monitor**

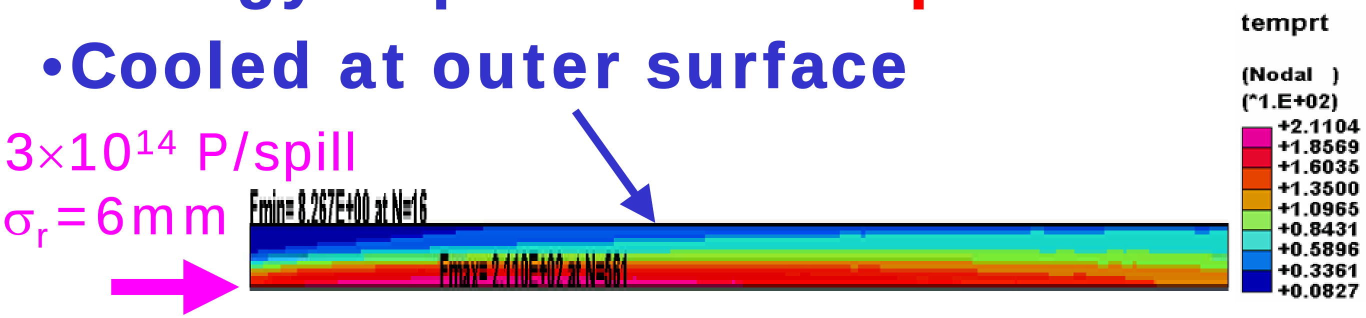
Segmented Secondary Emission Monitor (SSEM)

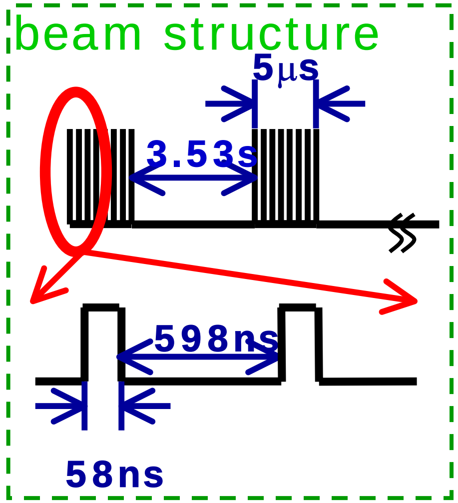
Target Station

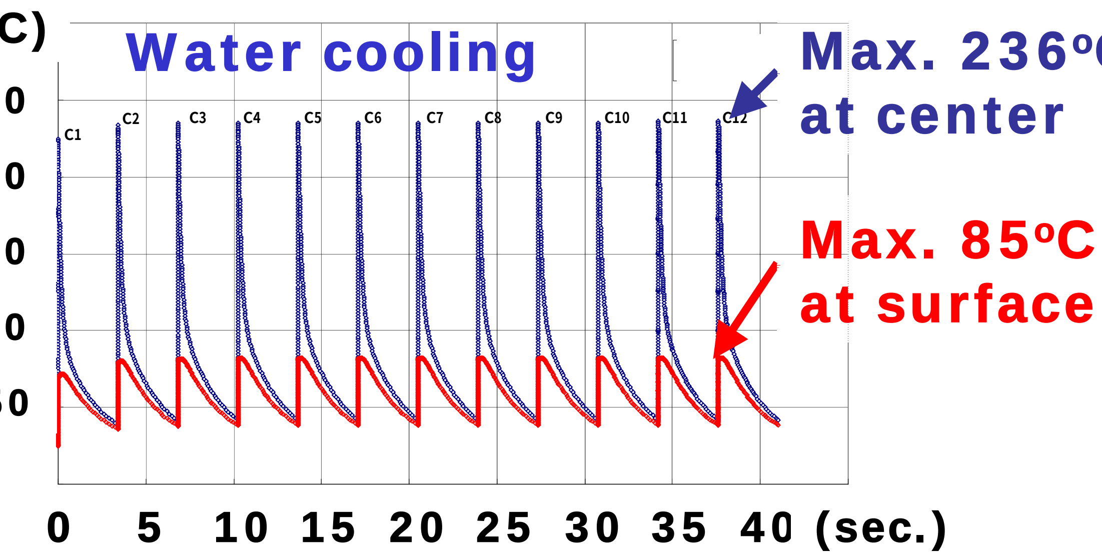


Target

- **Carbon Graphite target: 30mm(D)x900mm(L)**
- **2 interaction length (70% int.)**
- **Energy deposit: 58kJ/spill**
- **Cooled at outer surface**



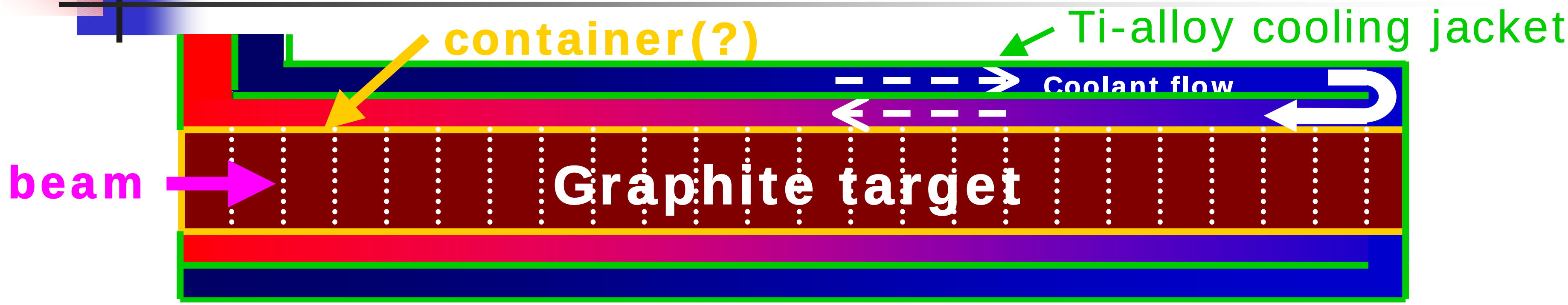




Equivalent stress due to ΔT~200K ~ 7MPa

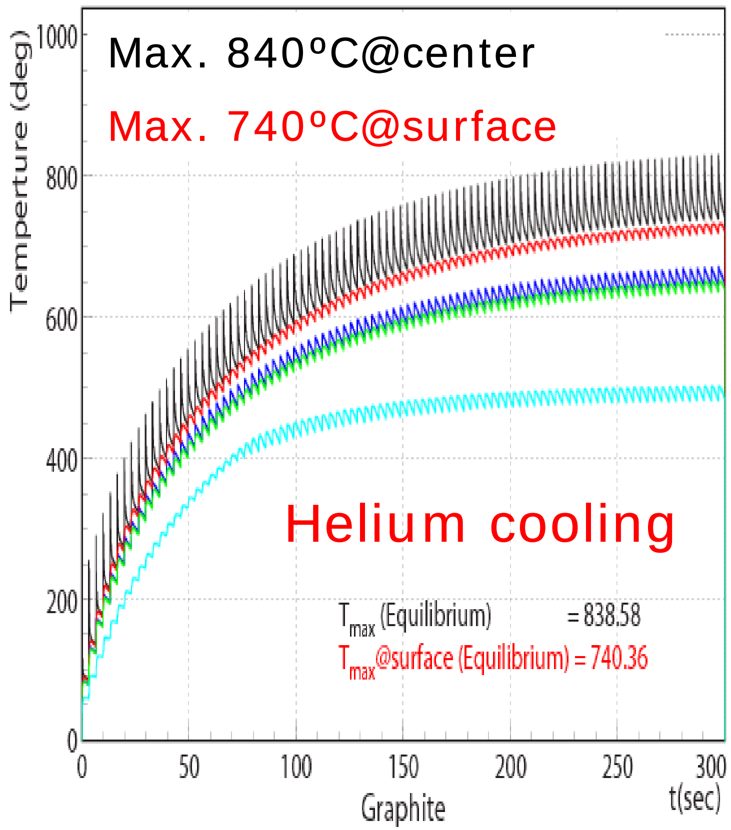
< Tensile strength of Graphite: 37MPa

Cooling of target

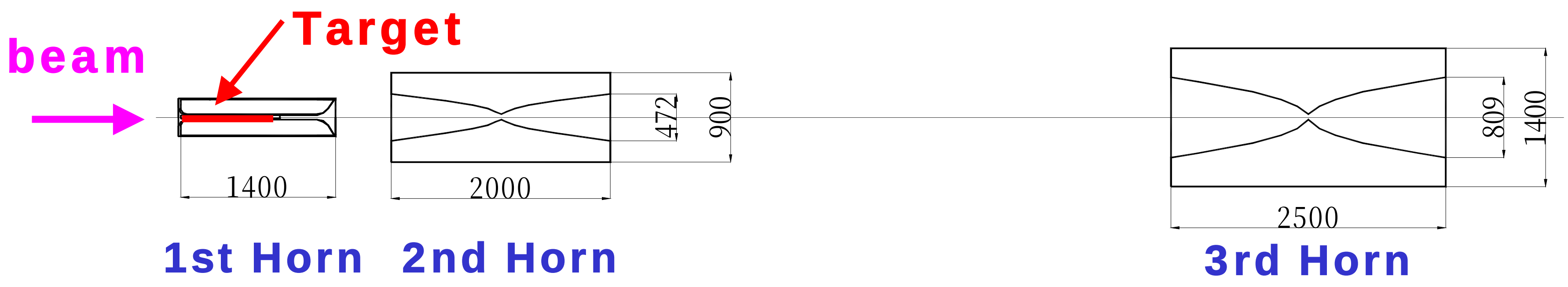


Two scenarios

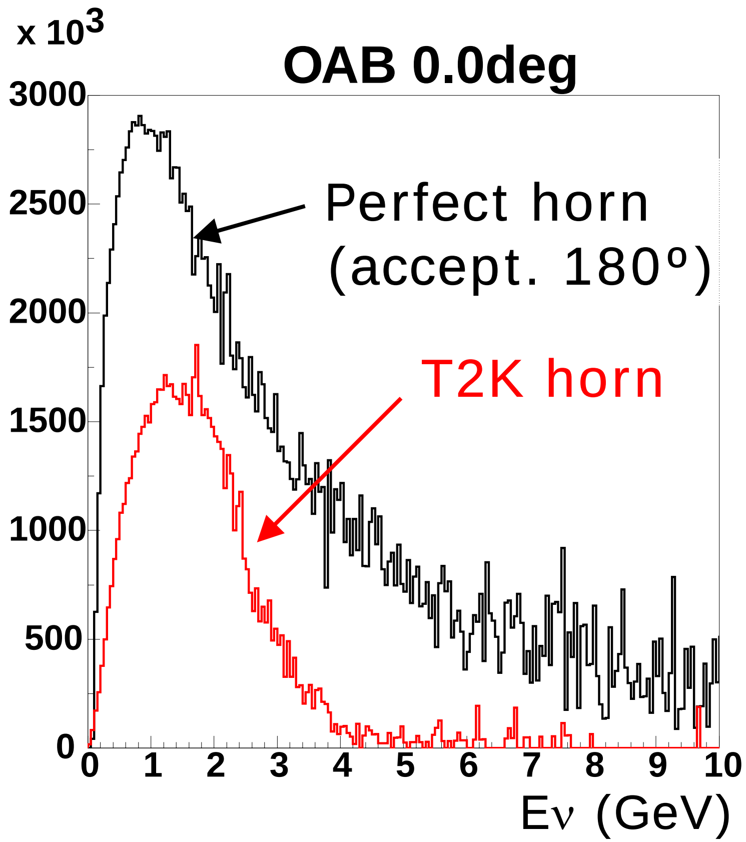
- **Water cooling**
  - Required thermal transfer (6kW/m^{2}K) was achieved in test setup.
  - Shrink of graphite due to radiation damage may be a problem.
    $\Rightarrow$ irradiation test at BNL
- **Helium gas cooling**
  - No container for graphite
  - 500W/m^{2}K expected with 50m/s at 5 atm
  - He temperature 380ºC at max.
  - He cooling test in next Sep.



Horn system

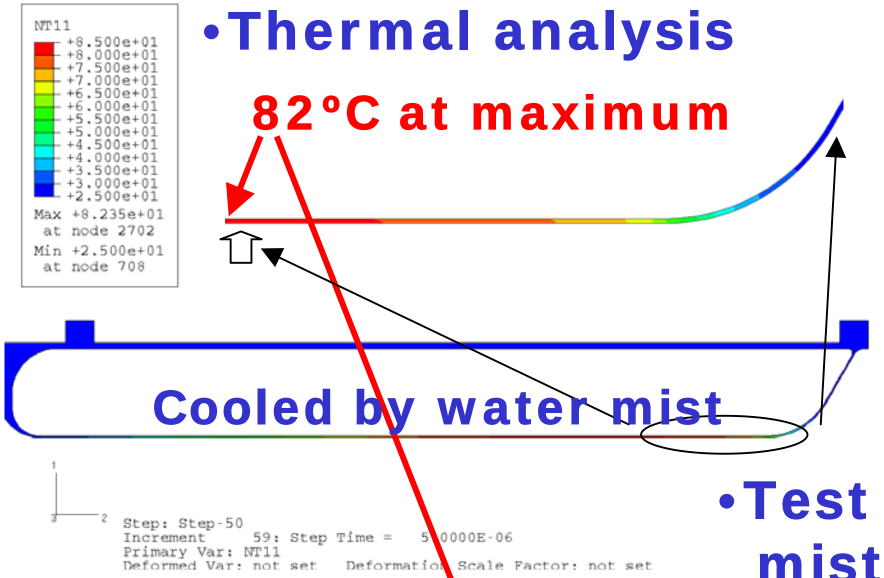


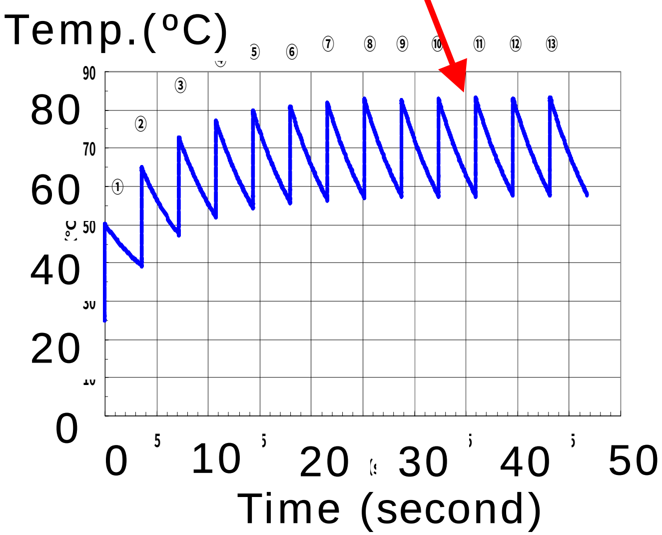
- Converge secondary pions into decay volume
- 3 horn system
- Carbon target in 1st horn
- Made with Aluminum
- 320kA pulse current
- Under design and R&D



R&D for horn

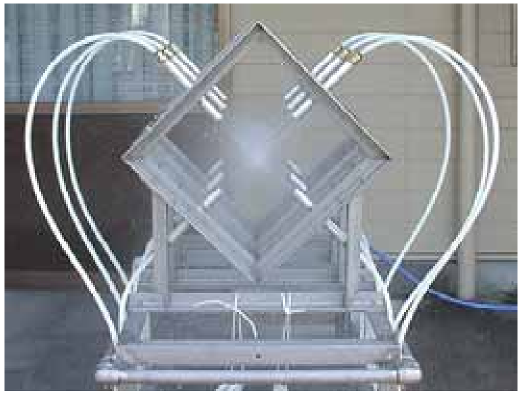
• Thermal analysis





• Prototype inner conductor

• Test of water mist cooling

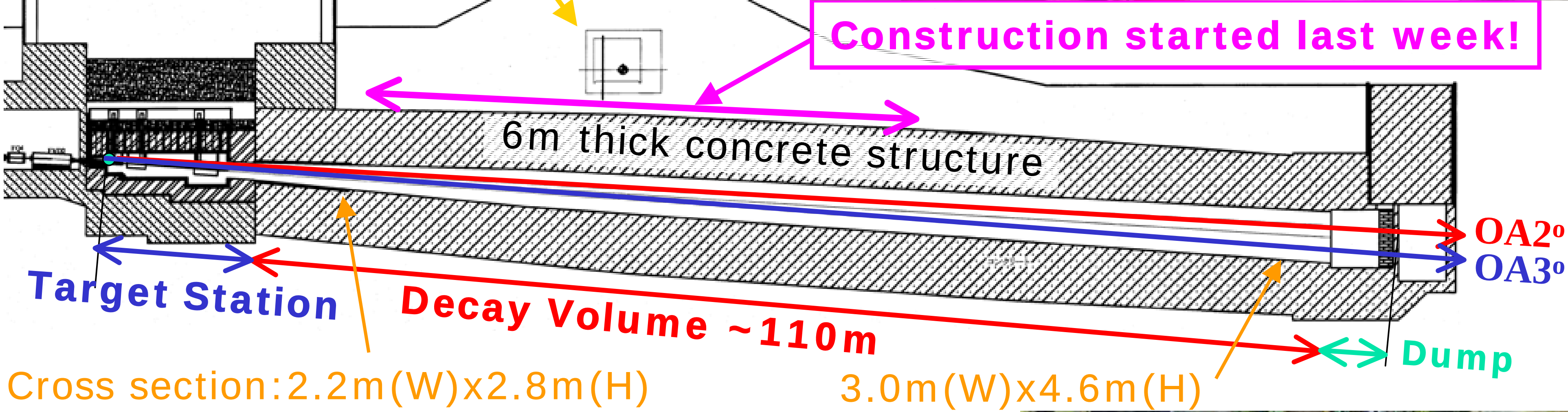


6kW/m^{2}K achieved

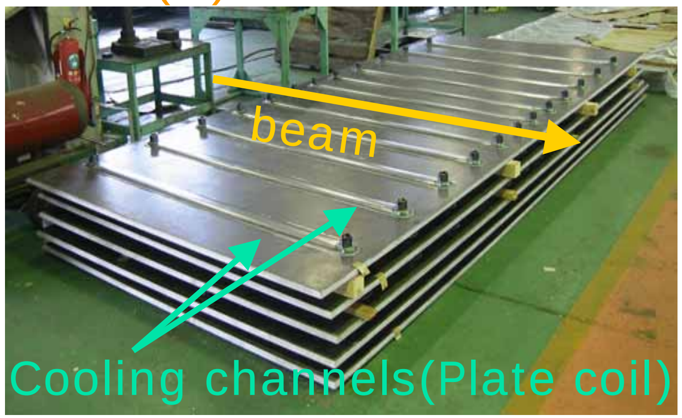
• Test of Friction Stir Welding

No damage by repetition fatigue after 1.1×10^7 pulse load

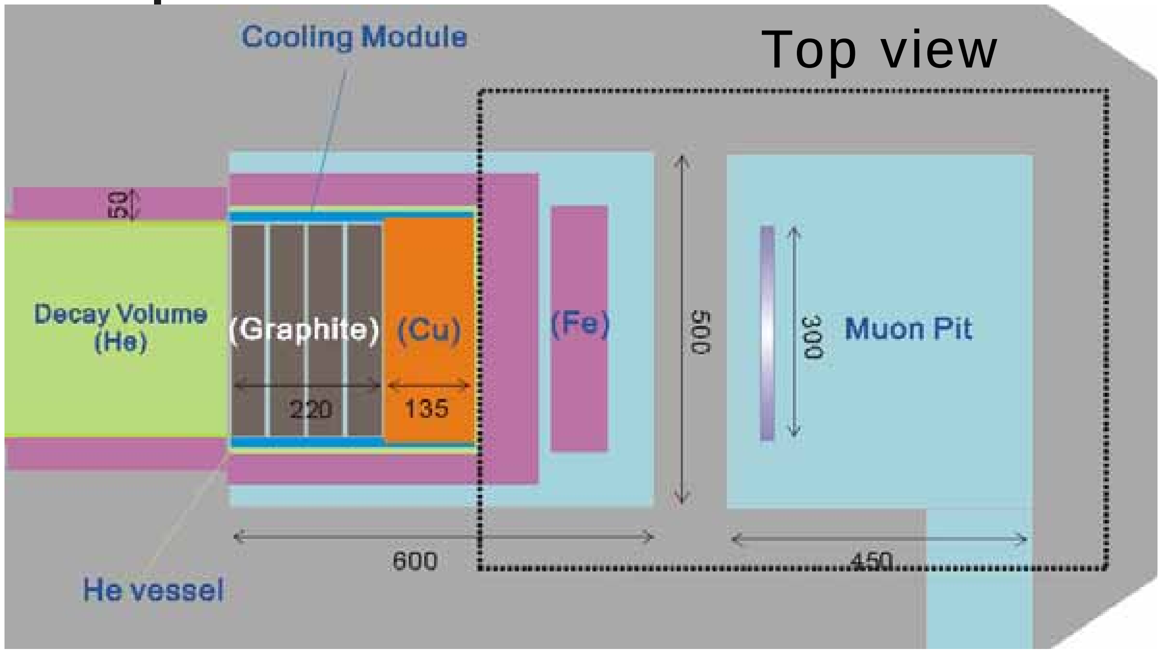
Decay Volume

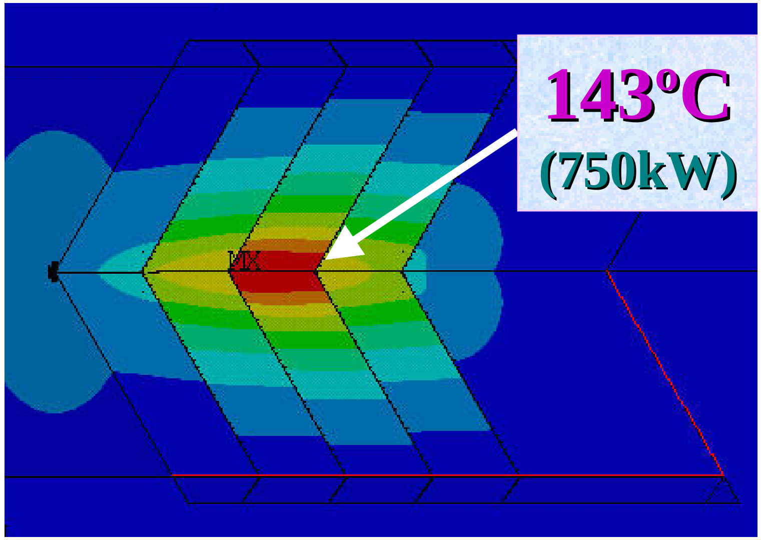


- Cover Off Axis angle : 2°~3°
- Square box shape made with water cooled iron plates (T<60°C at 4MW)
- Filled by 1atm Helium gas



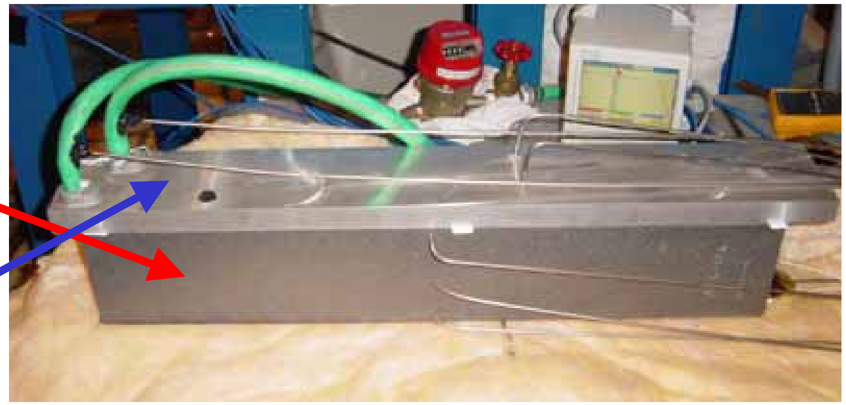
Beam Dump



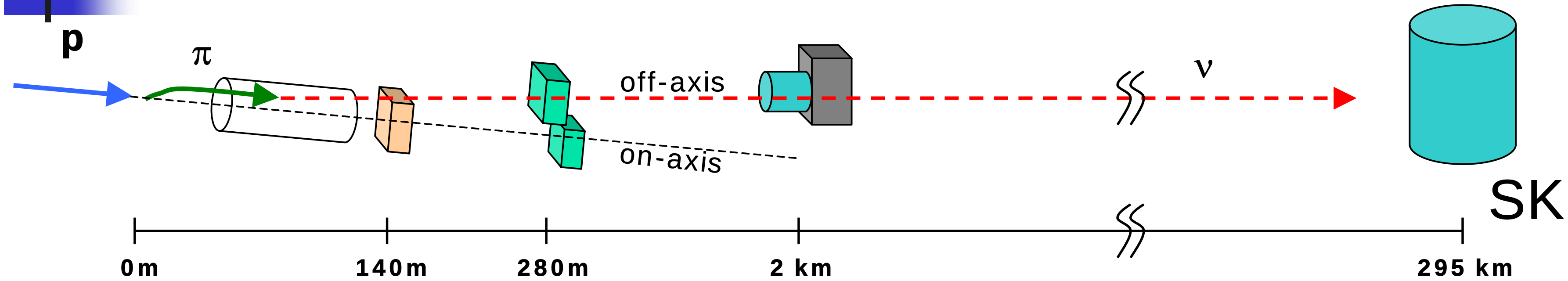


CNGS/LHC-type design

- Core:Graphite Blocks
- Cooling Module(CM):
  Water circuit cast Al alloy
- More optimization for 4MW

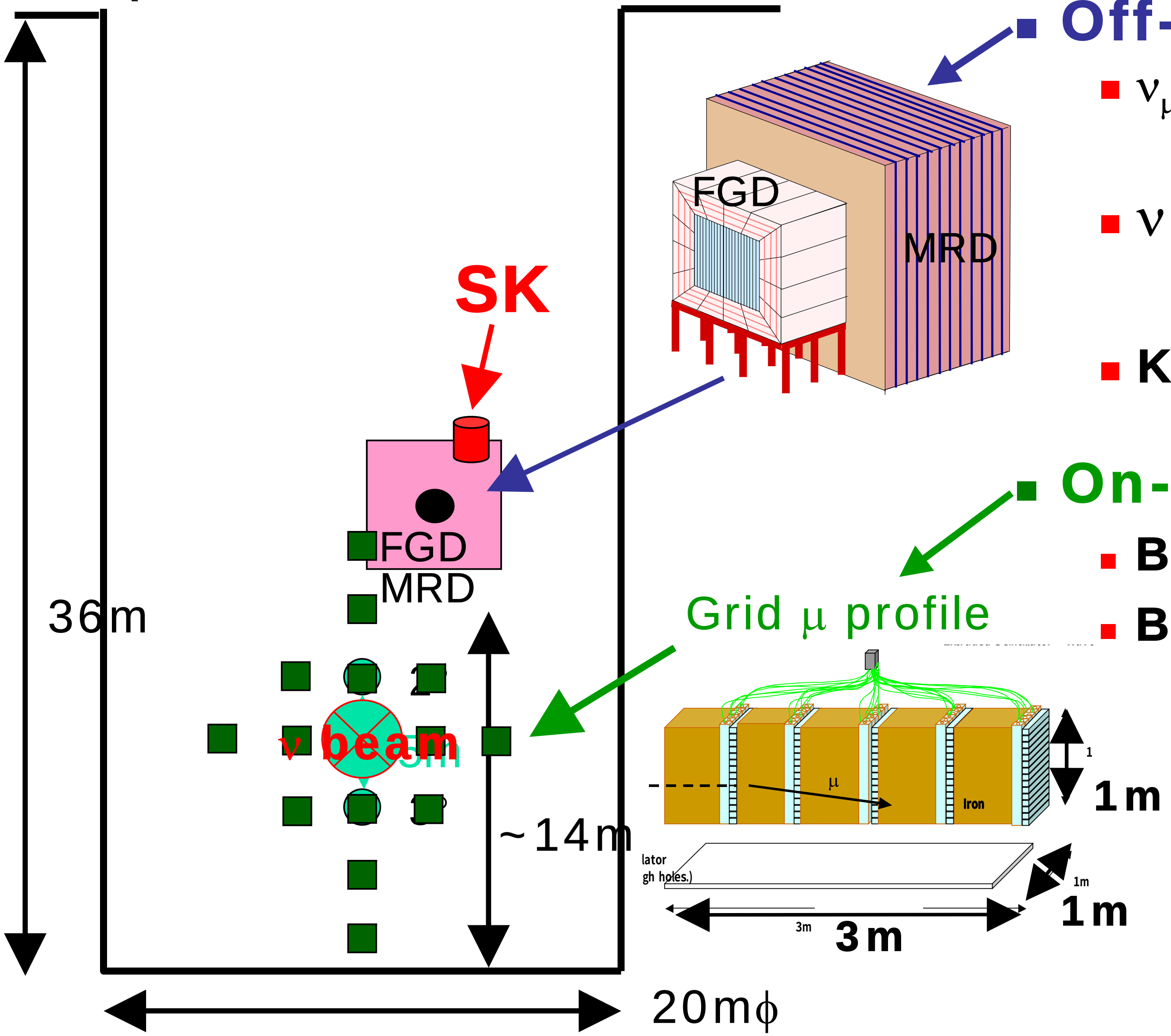


Detectors



- **Muon monitors @140m (dump)**
  - Fast (spill-by-spill) monitoring of beam direction / intensity
- **Near detector @280m**
  - Neutrino intensity/spectrum/direction
  - Two detector systems for on and off axis.
- **Second Near Detector @2km**
  - ν_μ energy spectrum and ν_e background study with almost same condition as for SK
  - Not approved yet
- **Far Detector @295km: Super Kamiokand**

Near Detector @280m

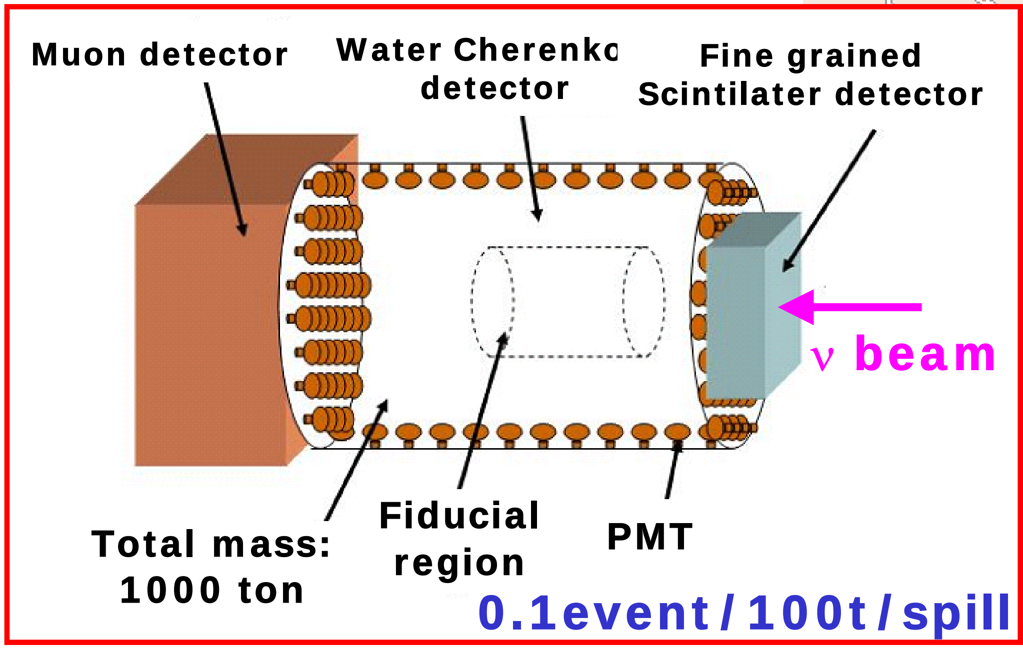


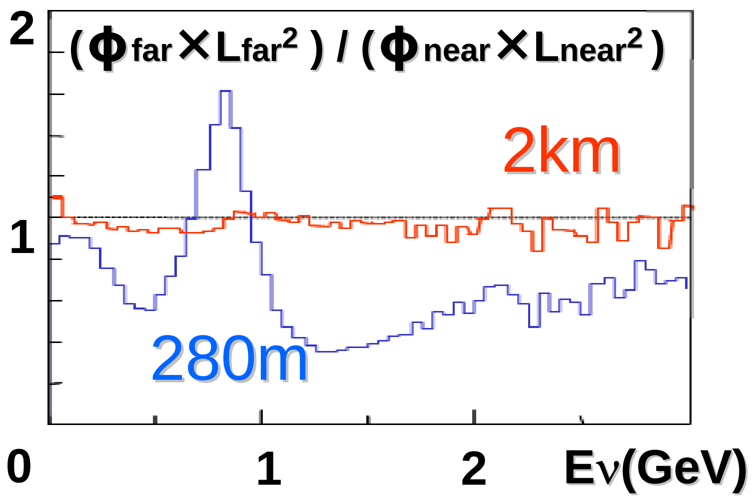
- **Off-axis (~2°)**
  - ν_μ **and** ν_e **fluxes and spectra**
  - **ν interaction study (CC-QE,non-QE,π^0,)**
  - **Kaon contributions**
- **On-axis (0°)**
  - **Beam direction**
  - **Beam stability**

Design work just started

Near Detector @2km

- ν_μ energy spectrum for ν_μ disappearance
- ν_e background study for ν_e appearance

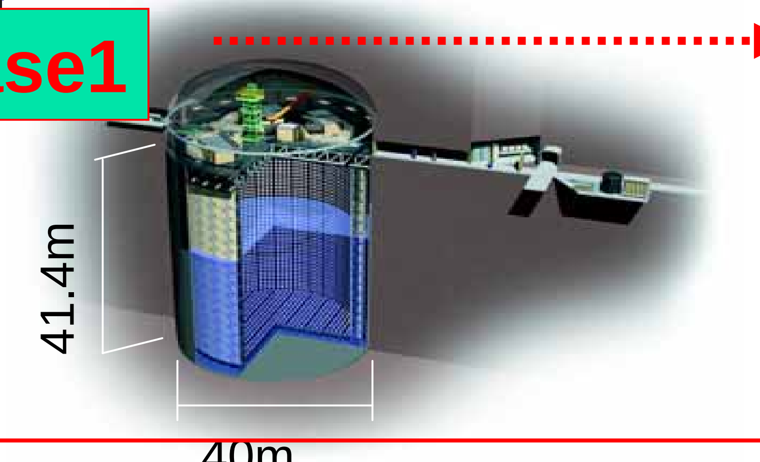


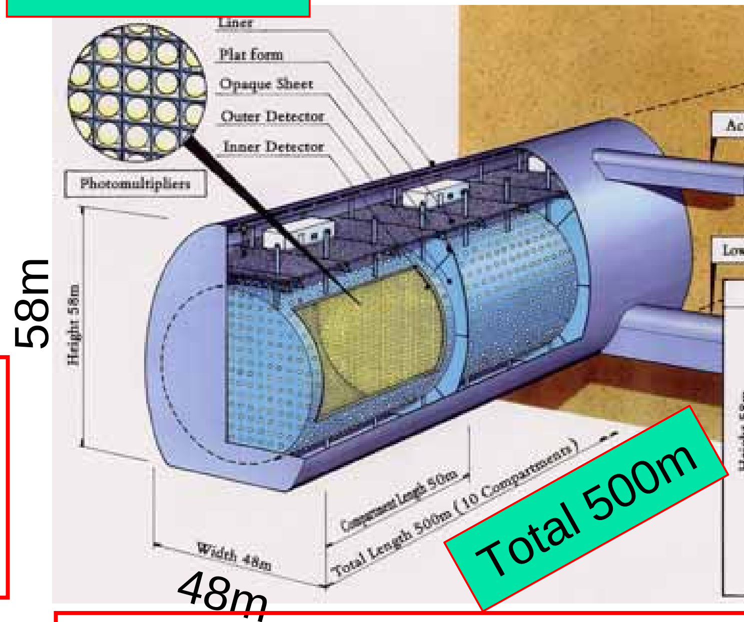


- Under discussion
- Not approved yet

Far Detector

Phase1 → Phase2



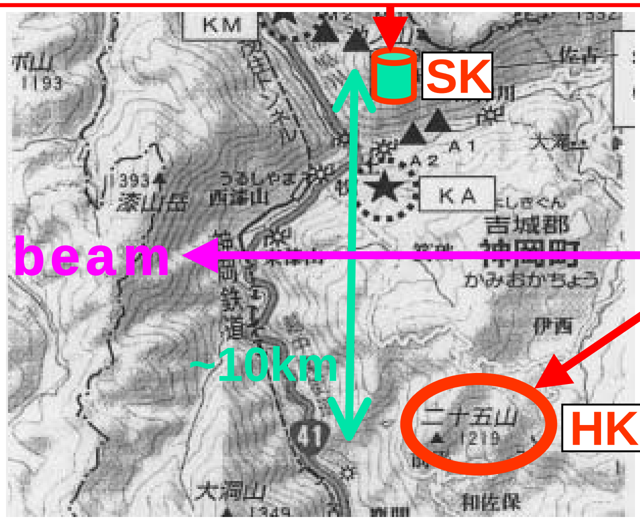


Super-Kamiokande

- 50kt water Cherenkov
- 11,000 20inch PMT's(2006)

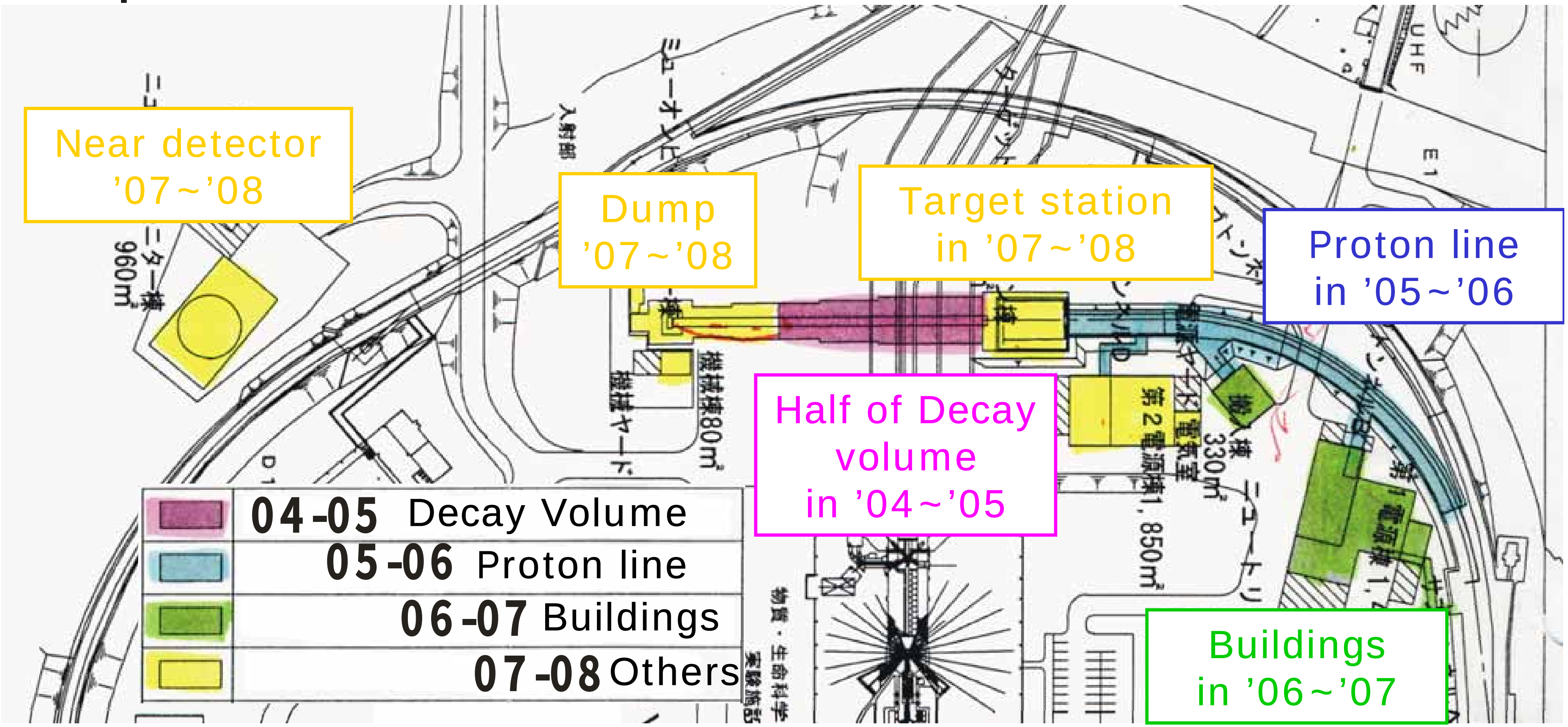
Hyper-Kamiokande

- ~1Mt water Cherenkov
- ~200,000 photo-sensors



Same Off axis angle for SK and HK

Construction schedule



- **Five years construction in 2004~2008**
- **Detailed design for construction in this year**
- **Most heavy construction in last 2 years**

Summary

- T2K collaboration started in 2003.
  - Discovery of $\nu_\mu \rightarrow \nu_e$ appearance
  - 100 times larger intensity than K2K
  - Off axis(2~3°) configuration with SK
- Neutrino beam facility was approved for five years construction in 2004~2008.
  - Design and R&D are on going.
  - Construction of decay volume started.
- Start experiment in 2009