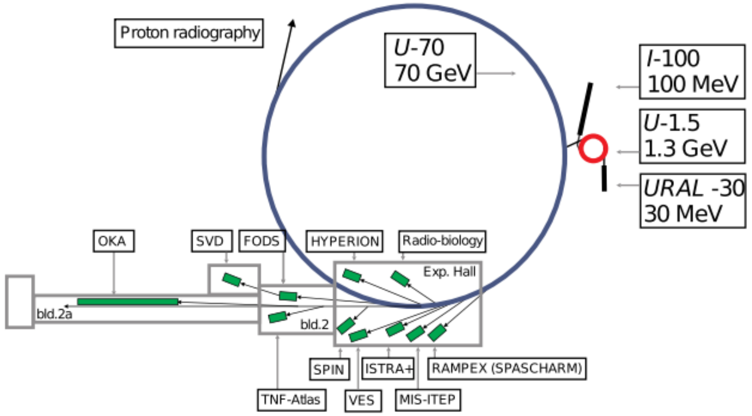
The 6th International Conference on Particle Physics and Astrophysics (ICPPA-2022)

Designing a tagged neutrino beam at the U-70 accelerator complex

Roman Sinyukov
NRC "Kurchatov Institute" – IHEP, Protvino

P2O: Protvino to ORCA

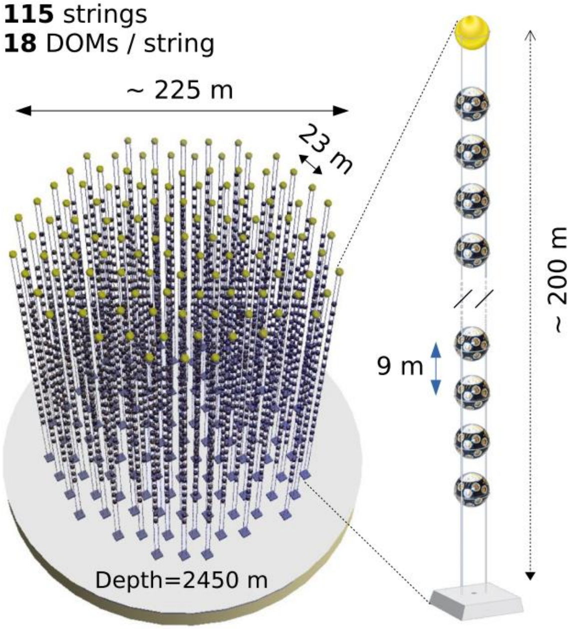


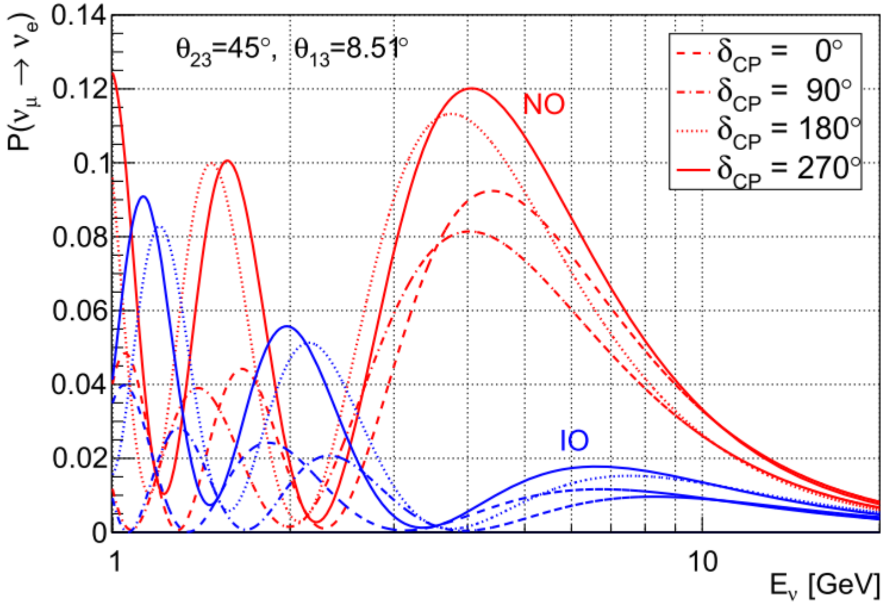
Current operation:

- **Protons up to 70 GeV (60 GeV)**
- **10^{13} protons/cycle**
- **5 μs spill every 9 s**

Upgradable up to 90 – 450 kW

Vacuum oscillation maximum at E ≈ 5 GeV

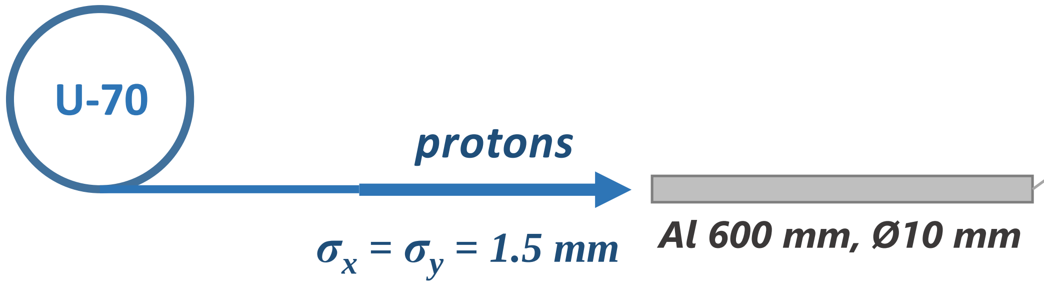


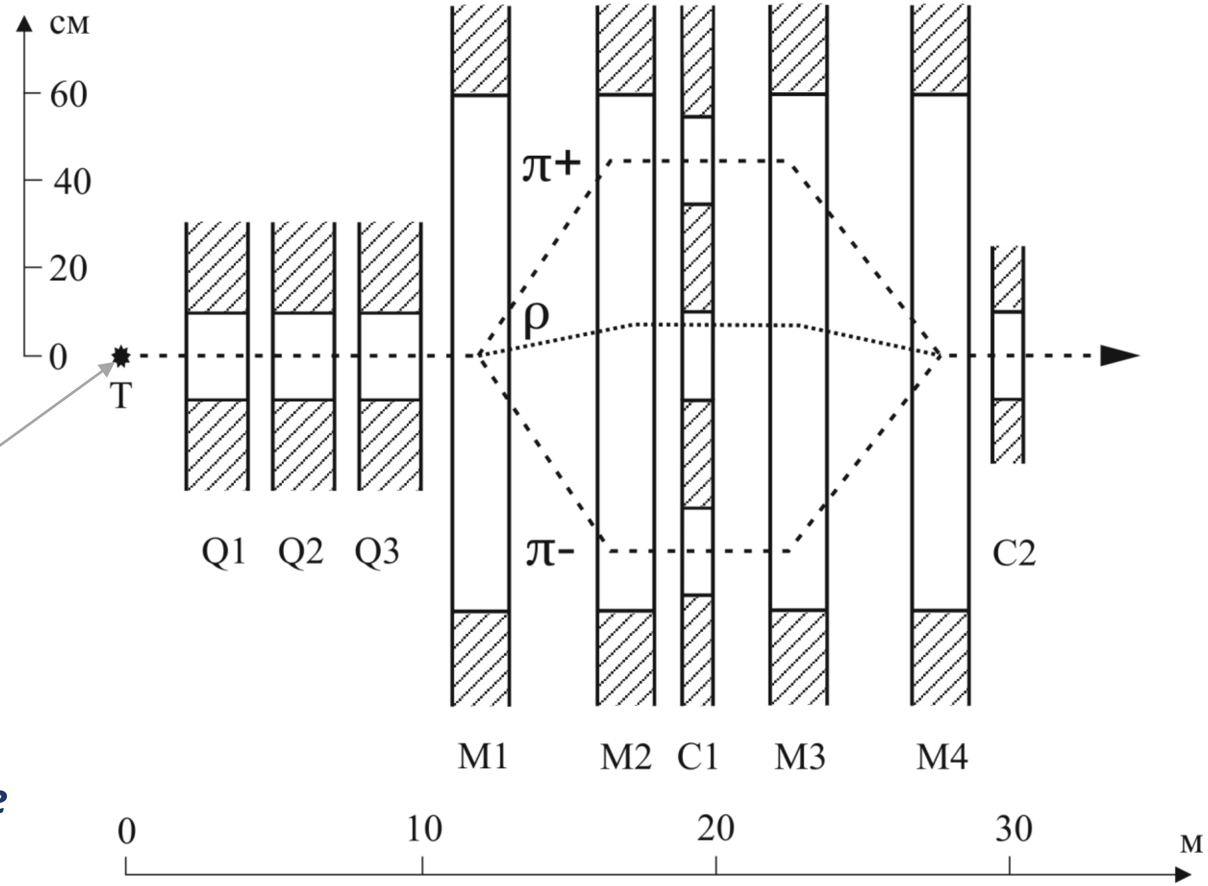


Objective:
produce a neutrino beam with an energy peak at about 5 GeV

Conceptual design of beamline

$$\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\widetilde{\nu}_{\mu})$$





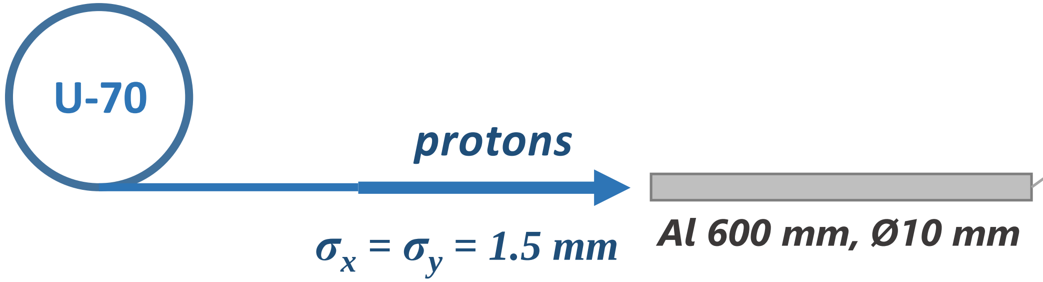
Assumptions:

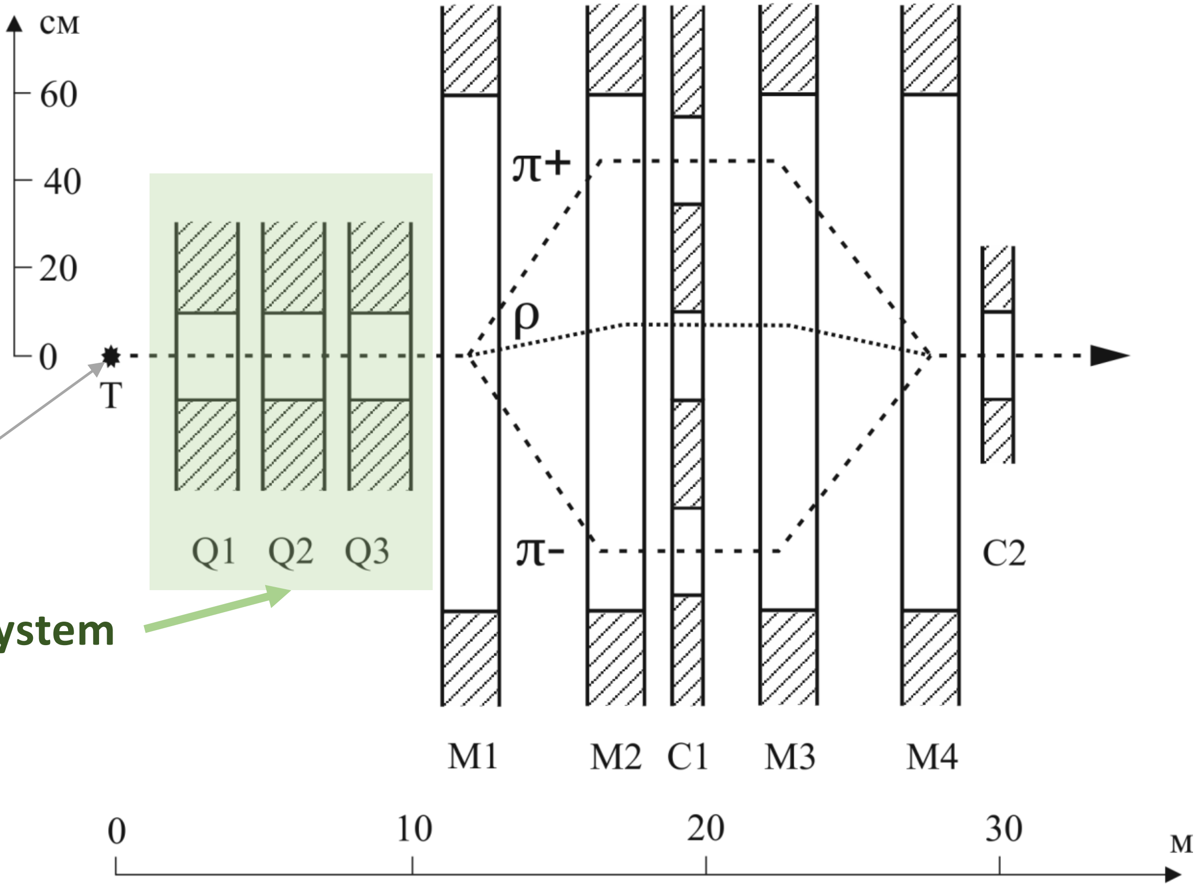
- *only $\pi^{\pm}$ are considered as a source of neutrinos*
- *pions that get into the matter during transport are excluded from consideration*

Configuration of the optical system and collimator parameters were chosen based on the requirements of the neutrino spectrum

Conceptual design of beamline

$$\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\widetilde{\nu}_{\mu})$$





Focusing system

Assumptions:

- ***only $\pi^{\pm}$ are considered as a source of neutrinos***
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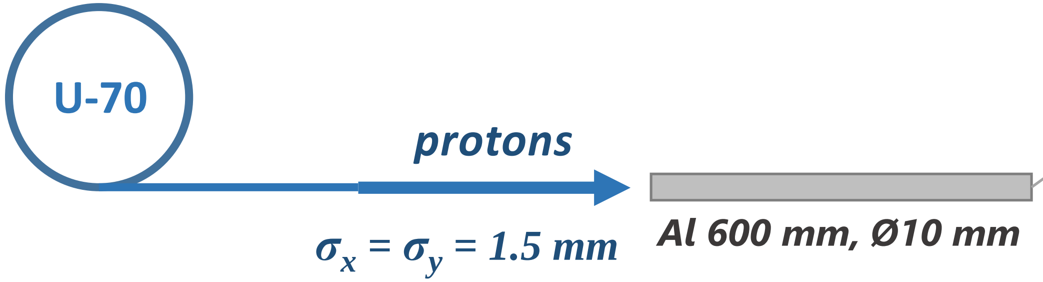
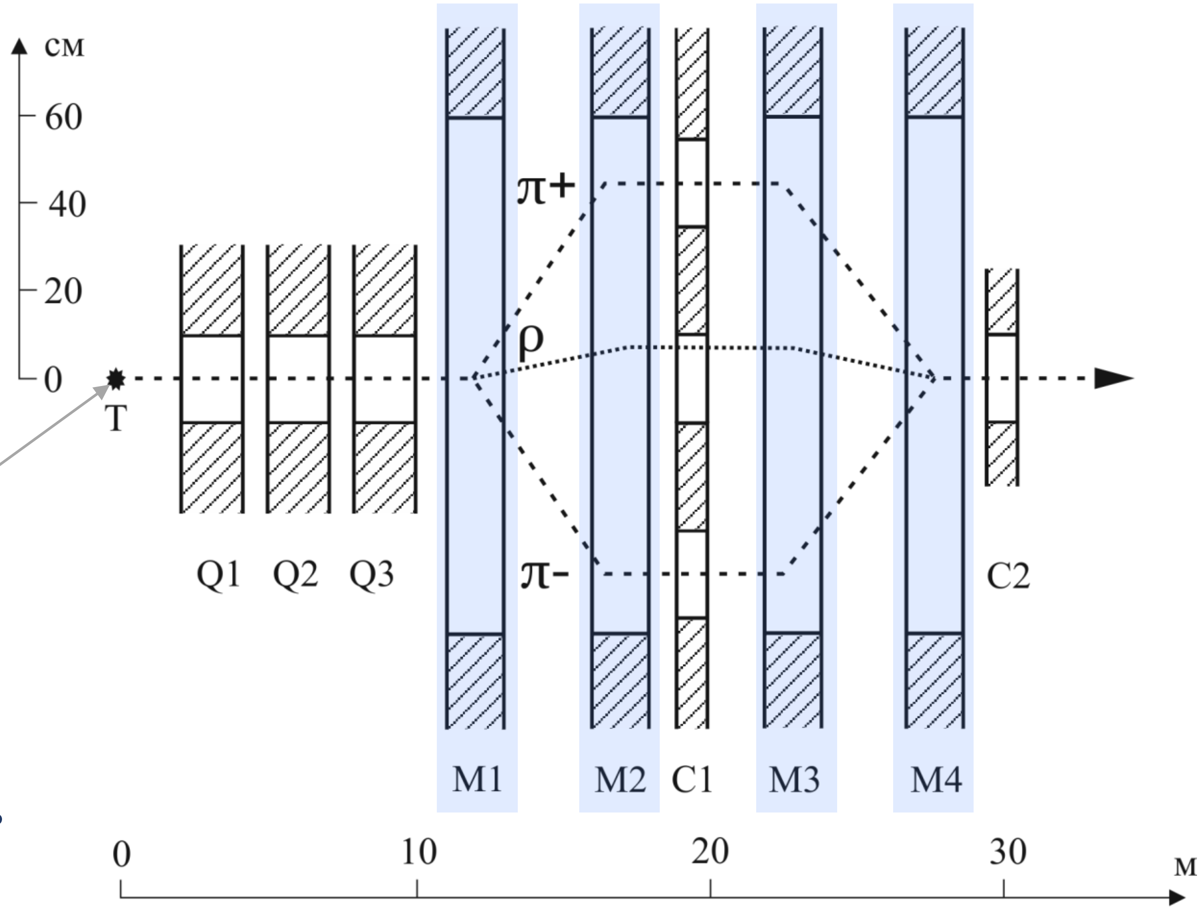
Q1-Q3 quadrupoles 2m long, aperture: Ø200 mm

Conceptual design of beamline

$$\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\widetilde{\nu}_{\mu})$$



Zero-dispersion magnetic system



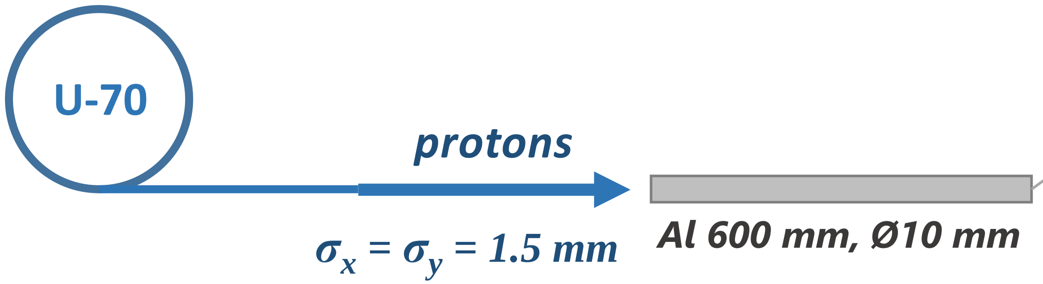
Assumptions:

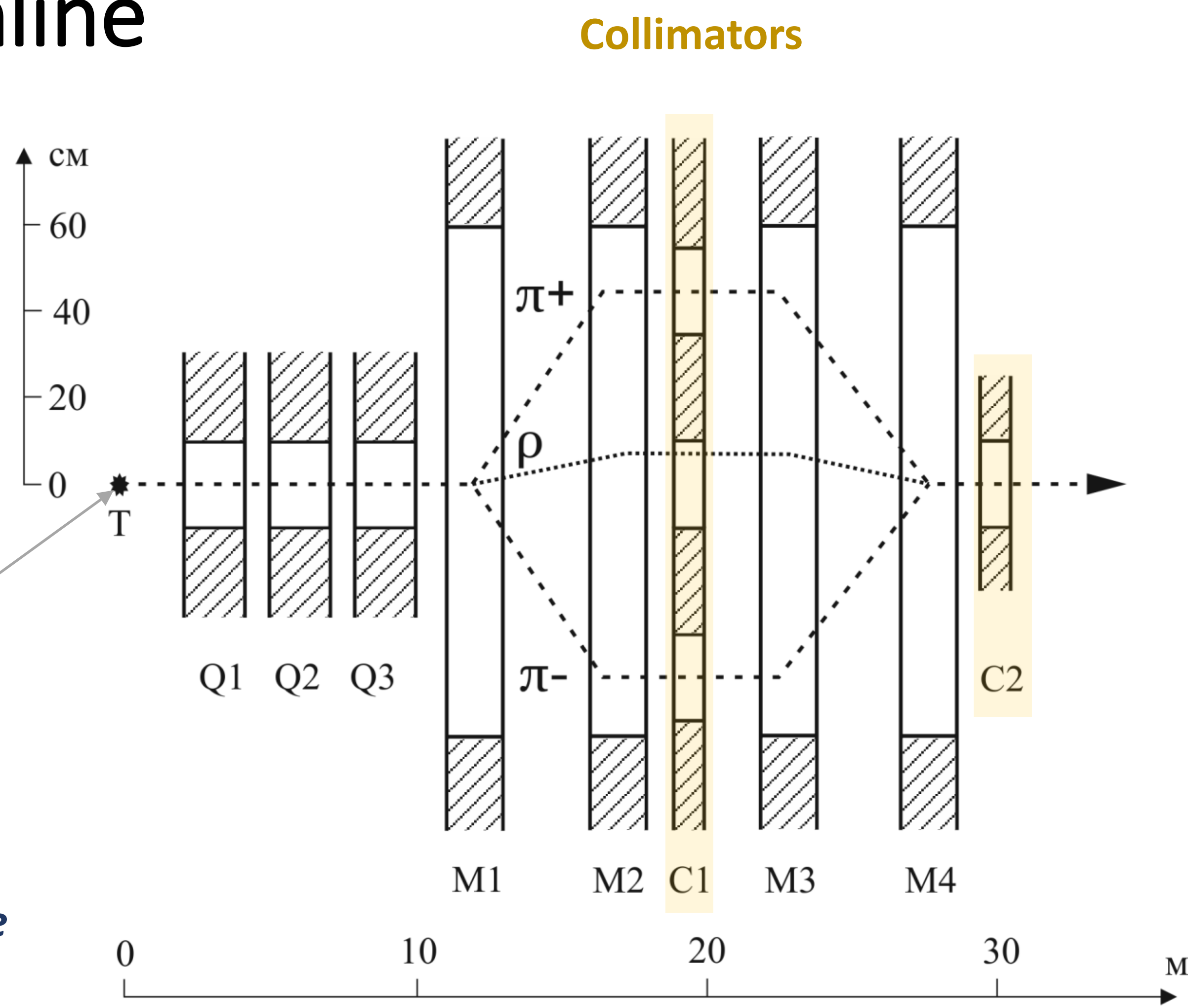
- ***only $\pi^{\pm}$ are considered as a source of neutrinos***
- ***pions that get into the matter during transport are excluded from consideration***

M1-M4 bending magnets 2m long, H x V = 1200 x 200 mm

Conceptual design of beamline

$$\pi^{\pm}, K^{\pm} \rightarrow \mu^{\pm} + \nu_{\mu}(\widetilde{\nu}_{\mu})$$





Assumptions:

- ***only $\pi^{\pm}$ are considered as a source of neutrinos***
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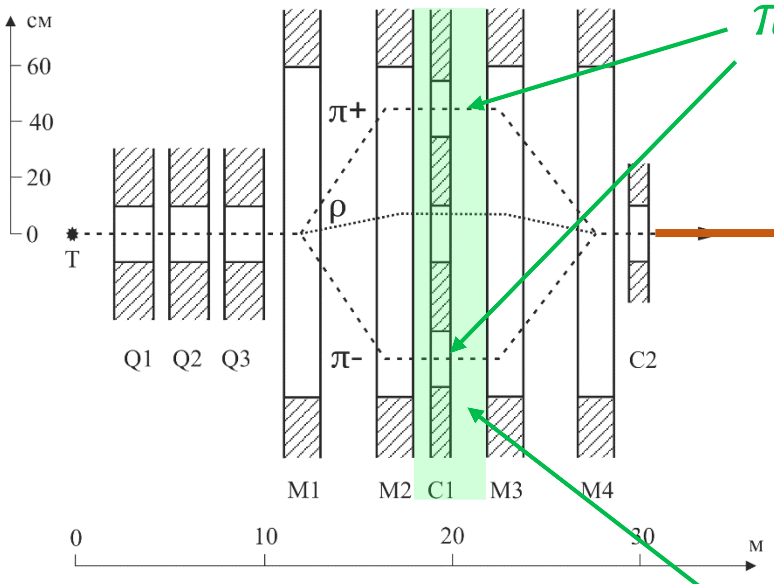
C1 (3 x Ø200 mm), C2 200 x 200 mm² aperture

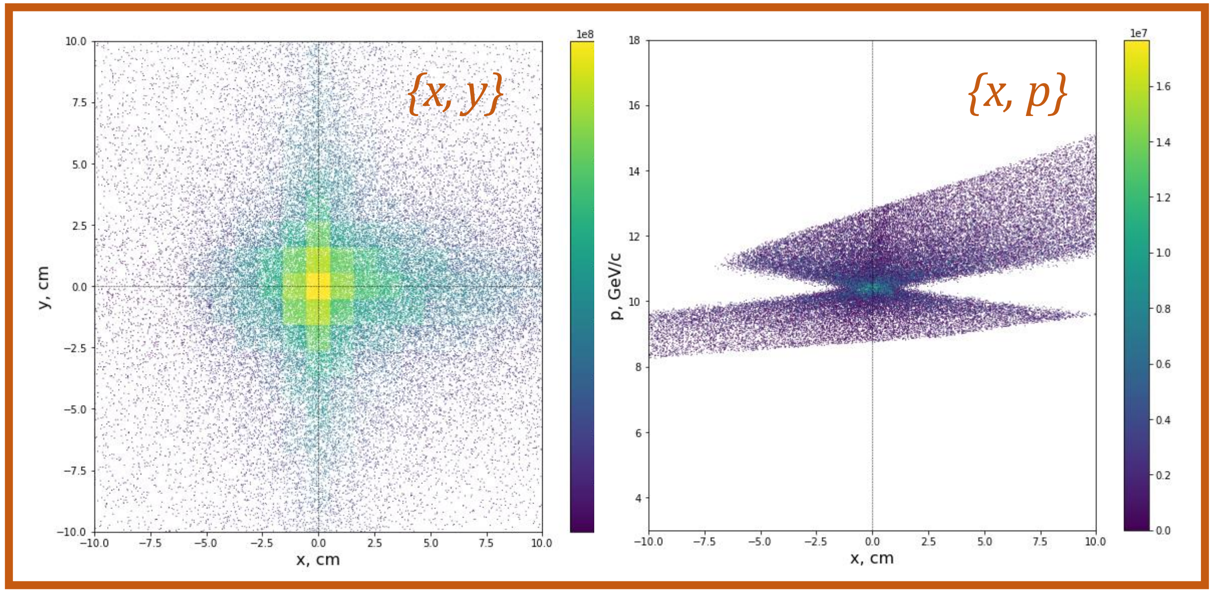
Conceptual design of beamline

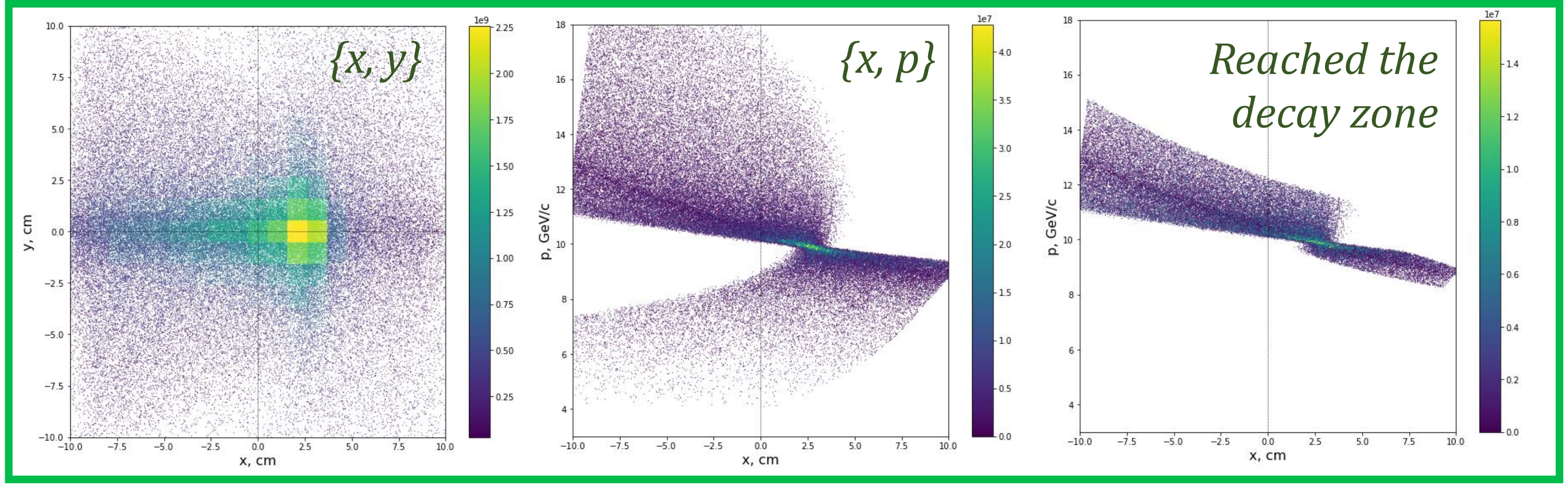


$\pi^{\pm}$ tagging zone

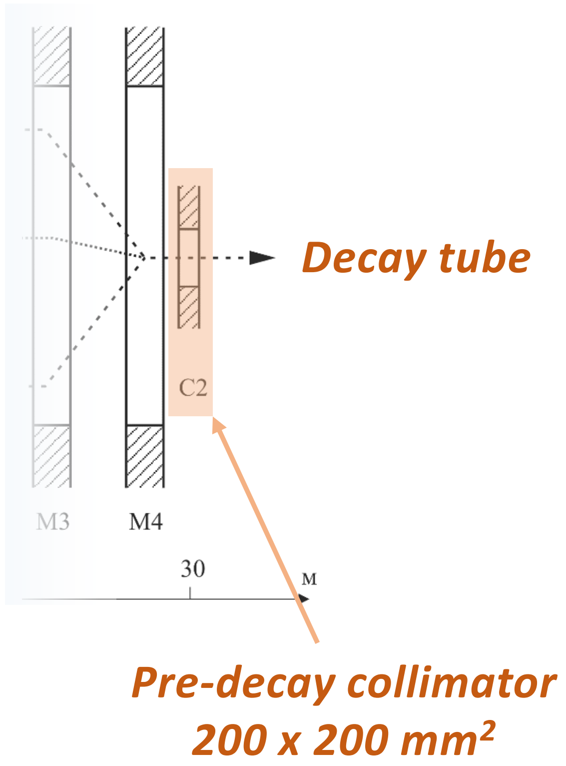
Decay tube

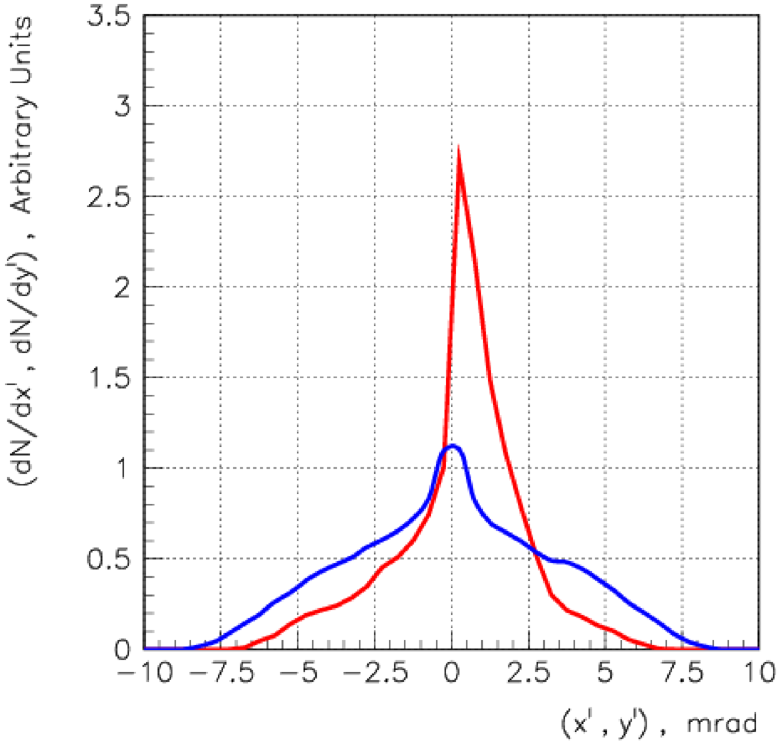
150 m long
Ø 1.5 m

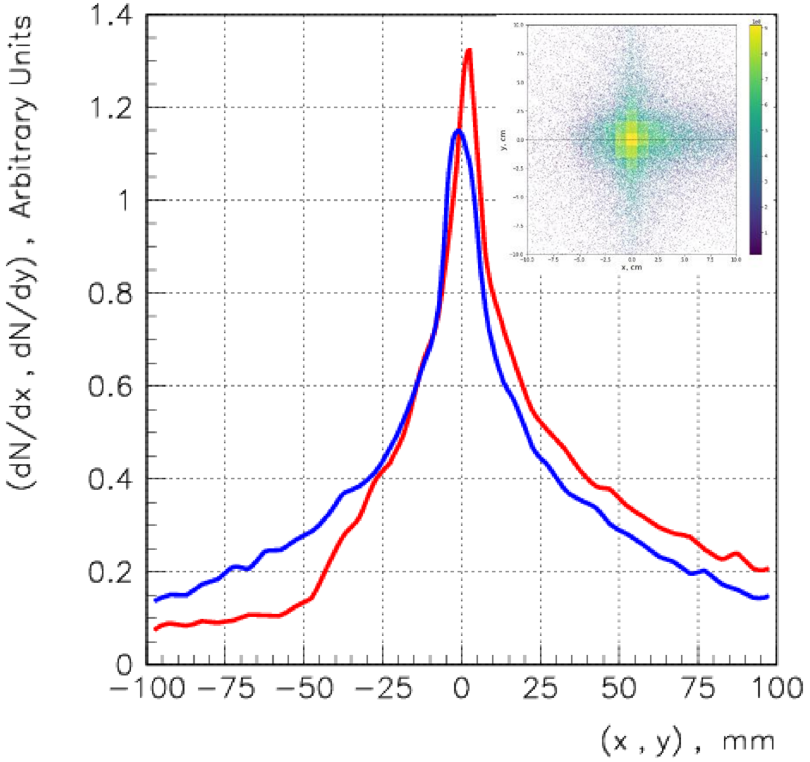




Spatial distributions of pions at the beginning of the decay tube







$\sigma[x'] = 1.75\ mrad$ $\quad x' = p_x/p_z$

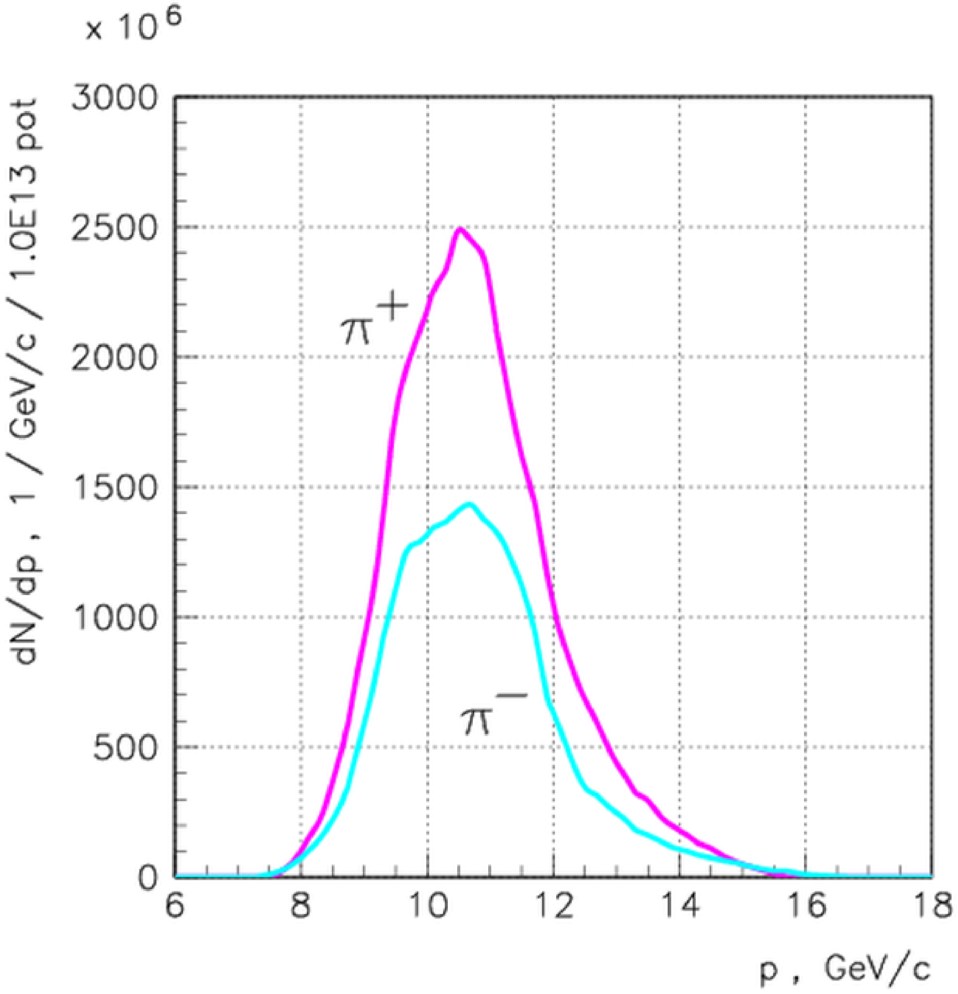
$\sigma[y'] = 3.05\ mrad$ $\quad y' = p_y/p_z$

$\sigma[x] = 39.7\ mm$

$\sigma[y] = 43.6\ mm$

$$\theta_\pi \approx \sqrt{x'^2 + y'^2} \qquad \sigma[\theta_\pi] \cong 3.9\ mrad$$

The spectrum of pions at the beginning of the decay tube



RMS = 10.5 GeV

Relativistic case

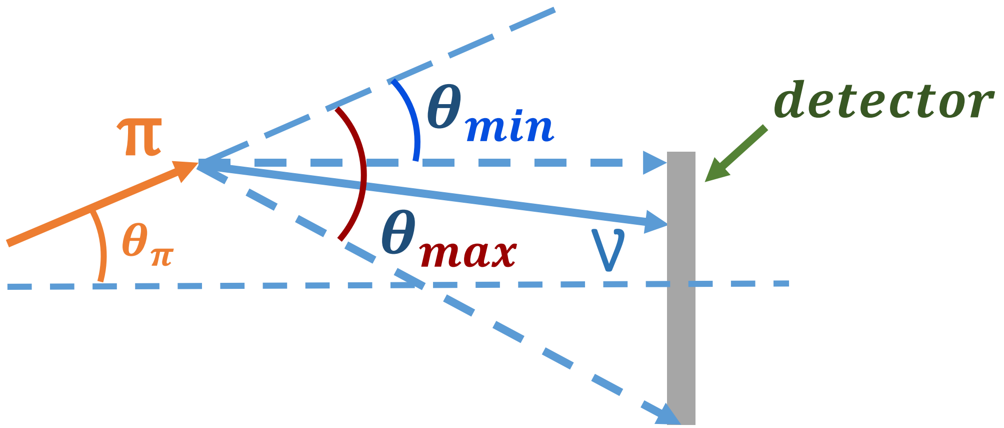
$$E_{\upsilon_{max}} = \left(1 - m_\mu^2/m_\pi^2\right) \cdot p_\pi = 0.43 \cdot p_\pi$$

RMS_{E_π} = 10.5 GeV $\longrightarrow$ $E_{\upsilon_{max}} \sim 4.5\ GeV$

$7.31 \cdot 10^9$ *π^+ per cycle*

$4.46 \cdot 10^9$ *π^- per cycle*

Neutrino radial distribution at the far detector

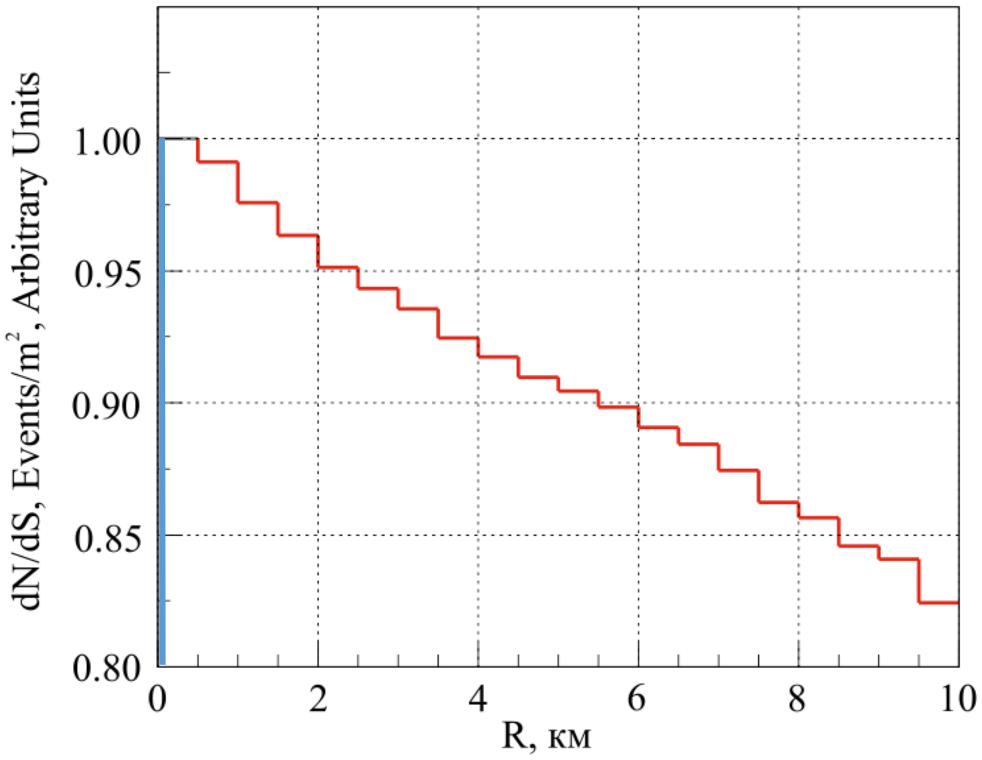


Neutrino angle at center of mass

$$\cos\theta^* = \frac{\cos\theta - \beta}{1 - \beta\cos\theta}$$

$$\boxed{\theta \equiv \theta_{\pi\nu}}$$

$$E = \frac{E^*}{\gamma(1 - \beta\cos\theta)}$$



Generating the uniform distribution of $\cos\theta^*$ in the center-of-mass within the limits corresponding to the capture angles θ_{min}, θ_{max} of the detector in the lab frame (same logic for φ)

Neutrino spectrum at the far detector

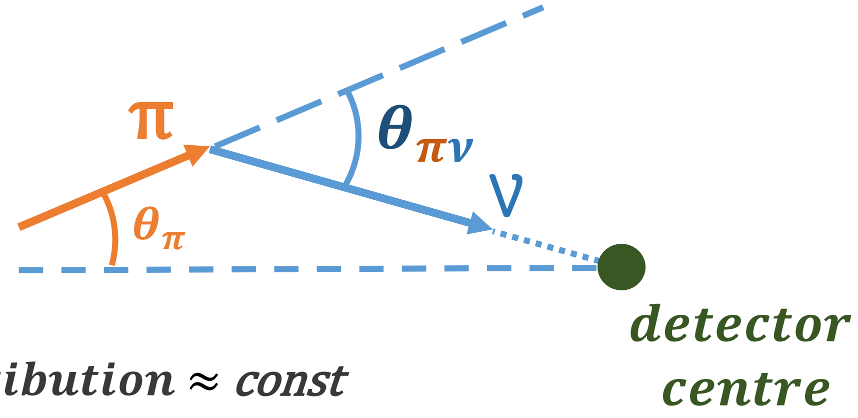
Fast calculation algorithm $\theta_d \ll \sigma[\theta_\pi]$

$L_d \approx 2595\ km$

$\theta_d \approx 0.04\ mrad$

$\theta_\pi \approx \sqrt{x'^2 + y'^2}$

$\sigma[\theta_\pi] \cong 3.9\ mrad$

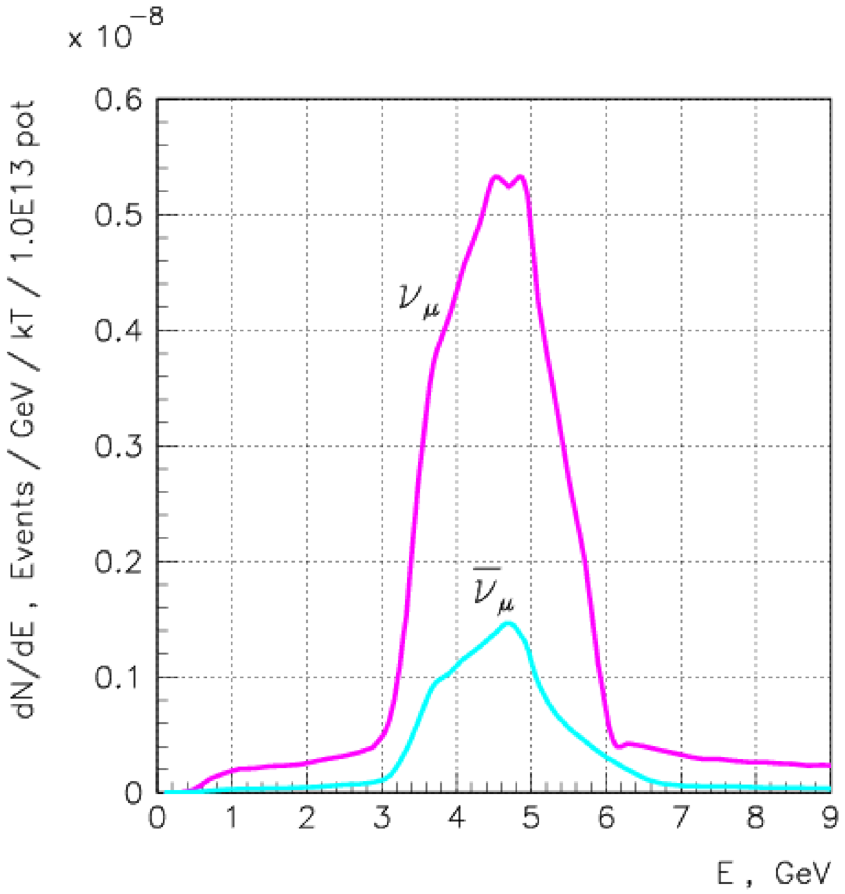


$Neutrino\ angle\ distribution \approx const$

$$\frac{dN}{d\Omega} = \frac{1}{4\pi\gamma^2(1-\beta cos\theta_{\pi\nu})^2}$$

We assume that all neutrinos always fall in the center of the detector, which allows us to clearly determine their energies

$$E = \frac{E^*}{\gamma(1-\beta\ cos\theta_{\pi\nu})}$$



$Events_\nu \sim \Phi_\nu, E_\nu\ and\ m_{det}$

Summary

- The conceptual design of the beamline is presented
- Fast calculation algorithm was applied to adjust and optimize the channel
- The optics of the beamline are designed to produce pi mesons in the pulse range of 8-14 GeV/c, which provides the required range of neutrino energies corresponding to the first oscillation maximum