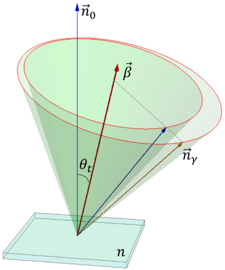

FARICH simulation

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FARICH standalone simulation

- Geant-4 (version 10) and Root packages are used
- The geometry consists from photon detector, cherenkov radiator and generator of primary particles

- All necessary data to describe optical parameters of materials, quantum efficiency of PMT, number of PMT's chips (aka pixel), size of the chip and etc are located in text files
- Global parameters such as spacing between PMTs, their number along x and y axes for specifying detector matrix, type and momentum primary particle and etc are transferred to simulation using Geant–4 macros

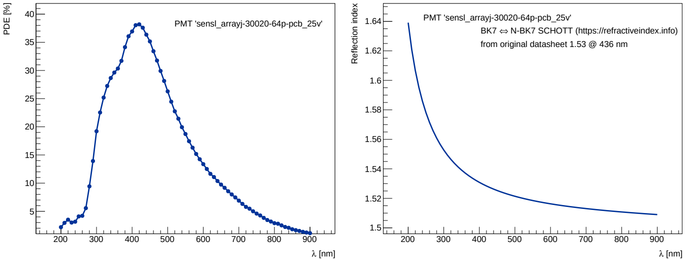
✓ These data are not part of program code and can be changed at the right time in any text editor. The technique does not require rebuilding the program code every time, which data were changed, and provides a convenient and flexible interface for calculations

FARICH standalone simulation: PMT

- Currently description of two types of silicon PMTs has been prepared

Type PMT	Number of chips	Chip size [mm]	Chip pith [mm]	Outer size [mm]	Noise [kHz/chip_area]
S14161-3050HS (Hamamatsu)	64	3.0	0.2	25.8	130.0
ARRAYJ-30020-64P-PCB (SensL)	64	3.16	0.2	26.68	499.3

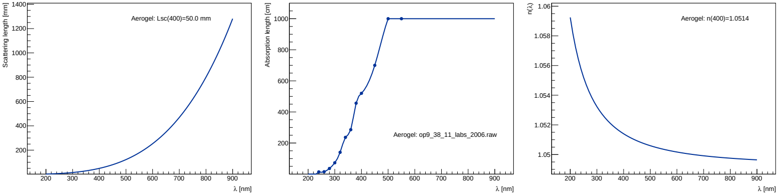
- Each chip represents an independent sensitivity detector with unique identifier. As a result, the photon detector consists of large set of such chips with the same parameters
- The optical properties of chips are described in wavelength range from 200 nm to 900 nm



- Every hit (aka photoelectron) in event has data: `x` and `y` coordinates (chip center) in common coordinate system of the photon detector and time. According to noise level of chip noise hits are generated also

FARICH standalone simulation: cherenkov radiator

- Single or multi-layer (up to 4 layers) aerogel blocks can be specified as radiator (other materials are possibility)
- Optical parameters such $L_{sc}(\lambda)$, $L_{abs}(\lambda)$ and $n(\lambda)$ are determined for each layer separately
  - the calculate L_{sc} is performed according to $L_{sc}(\lambda) = L_{sc}(400)(\lambda/400)^4$, where $L_{sc}(400)$ are measured experimentally for our aerogels
  - using dispersion law of silica aerogel* calculations of $n(\lambda)$ were performed
  - for all types aerogel we use one set of data points for $L_{abs}(\lambda)$, that were obtained in our group

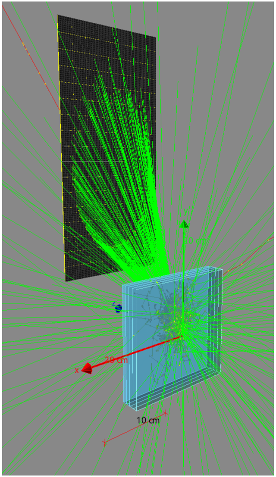


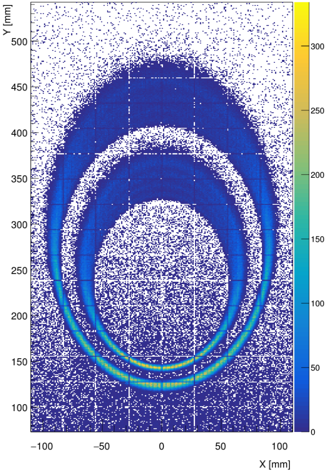
Radiator type	layer #1		layer #2		layer #3		layer #4	
	$n(400)$	t [mm]	$n(400)$	t [mm]	$n(400)$	t [mm]	$n(400)$	t [mm]
ideal	1.0410	9.32	1.0438	8.93	1.0468	8.55	1.0500	8.20
single_40mm	1.0514	40.0	–	–	–	–	–	–
arich	1.0450	20.0	1.0550	20.0	–	–	–	–
op447-1	1.0294	3.0	1.0333	8.0	1.0374	7.0	1.0405	9.0
op447-3	1.0433	6.0	1.0465	8.0	1.0526	7.0	1.0536	6.0

* *T.Bellunato et al., "Refractive index dispersion law of silica aerogel", European Physics Journal C 52 (2007)*

FARICH standalone simulation: generator

- The primary particle generator allows to set parameters such as:
  - primary particle type, for example $\mathtt{e}^-$, μ, π or $\mathtt{K}$
  - the particle momentum
  - direction of the particle (aka track) relative to plane of cherenkov radiator in units polar $\theta_{\mathtt{t}}$ and azimuth $\varphi_{\mathtt{t}}$ angles





FARICH reconstruction

- Three technique of reconstruction were developed and tested: reconstruction by radius, reconstruction by PDF, reconstruction by dependence θ_c vs φ_c

Simulation conditions

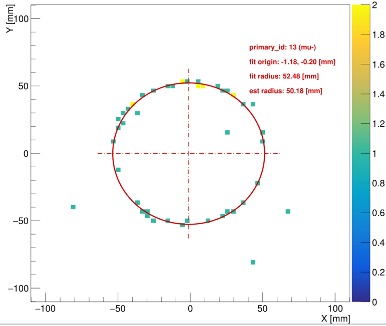
- `ARRAYJ-30020-64P-PCB` was used as PMT
- Five types of aerogel radiator were considered: ideal, single_40mm, arich, op447-1 and op447-3
- μ and π were selected as primary particles
- Momentum of the particles was in range from 500 MeV/c to 1600 MeV/c
- The angles of the particles (tracks) were fixed at only one set: $\theta_t = 0$ deg and $\varphi_t = 90$ deg
- The number of starts of the generator of the particles (events) varied in the range $(30 \div 50) \times 10^3$

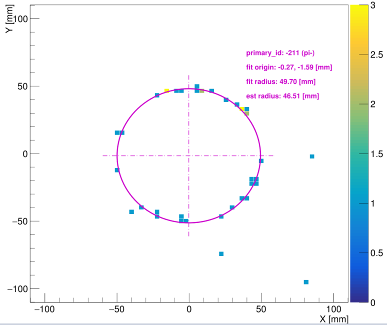
FARICH reconstruction: by radius

- For the reconstruction two-dimensional distribution coordinates of hits $\mathtt{x_{chip}}$ and $\mathtt{y_{chip}}$ per event was used
- Distribution of time of hits was also taken into account
- Gaussian function was used as fitting function:

$$\mathtt{G}(\mathtt{r},\mathtt{t},\mathtt{x_0},\mathtt{y_0}|\sigma_\mathtt{t},\sigma_\mathtt{r}) = \frac{1}{2\pi\sigma_\mathtt{t}\sigma_\mathtt{r}}\exp\left(-\frac{(\mathtt{d_{hit}}-\mathtt{r})^2}{2\sigma_\mathtt{r}^2} - \frac{(\mathtt{t_{hit}}-\mathtt{t})^2}{2\sigma_\mathtt{t}^2}\right), \text{where}$$

  - $\mathtt{r}$ and $\mathtt{t}$ reconstructed parameters of the ring radius and time in event
  - $\sigma_\mathtt{r}$ and $\sigma_\mathtt{t}$ errors of radius and time, respectively
  - $\mathtt{x_0}$ и $\mathtt{y_0}$ reconstructed parameters of the ring center position in event
  - $\mathtt{d_{hit}} = \sqrt{(\mathtt{x_{chip}}-\mathtt{x_0})^2 + (\mathtt{y_{chip}}-\mathtt{y_0})^2}$ distance (radius) for each hit



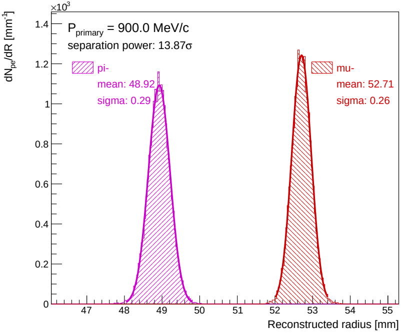


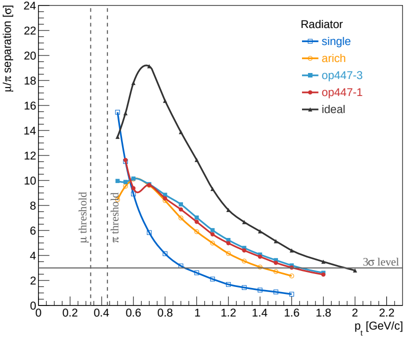
FARICH reconstruction: by radius

- The quality of identification (separation power) was determined as

$$\mathtt{sep} = \frac{2|\mathtt{m}_\pi - \mathtt{m}_\mu|}{\sigma_\pi + \sigma_\mu}, \text{ where}$$

  - $\mathtt{m}_\pi$, $\mathtt{m}_\mu$, σ_π and σ_μ are obtained from fitting distribution of radii (left picture)
- Examples of quality identification for five types of radiators are presented at right picture



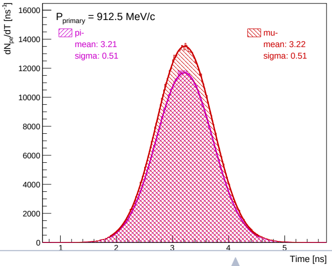


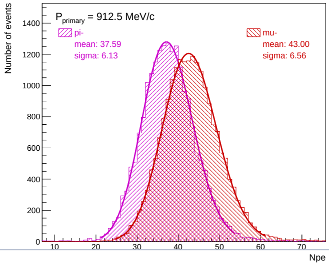
FARICH reconstruction: by PDF

- Reconstruction using probability density functions (PDFs) is based on an estimate of probability that each hit belongs to certain momentum (radius, time and number of hits per event)
- The probabilities are further used to determine the exact value of velocity (aka β) in event

$$\mathcal{L}(\beta,\theta_\mathtt{t}) = \sum_{\mathtt{i}=1}^{\mathtt{N_{hits}}} \ln\Big(\mathtt{F_{rad}}(\mathtt{r_i}|\beta,\theta_\mathtt{t})\mathtt{G_{time}}(\mathtt{t_i}|\beta,\theta_\mathtt{t})\Big) + \ln\Big(\mathtt{P_{npe}}(\mathtt{N_{pe}}|\beta,\theta_\mathtt{t})\Big),\text{ where}$$

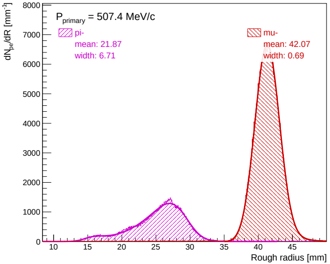
  - β and $\theta_\mathtt{t}$ velocity and polar angle of primary particle
  - $\mathtt{F_{rad}}(\mathtt{r_i}|\beta,\theta_\mathtt{t})$ normalized radius PDF of hit with radius $\mathtt{r_i}$
  - $\mathtt{G_{time}}(\mathtt{t_i}|\beta,\theta_\mathtt{t})$ normalized time PDF of hit with time $\mathtt{t_i}$
  - $\mathtt{P_{npe}}(\mathtt{N_{pe}}|\beta,\theta_\mathtt{t})$ normalized PDF of event with number of hits $\mathtt{N_{pe}}$
- Functions $\mathtt{G_{time}}(\mathtt{t_i}|\beta,\theta_\mathtt{t})$ and $\mathtt{P_{npe}}(\mathtt{N_{pe}}|\beta,\theta_\mathtt{t})$ are gaussian and poisson functions, respectively

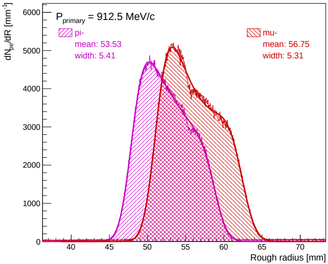




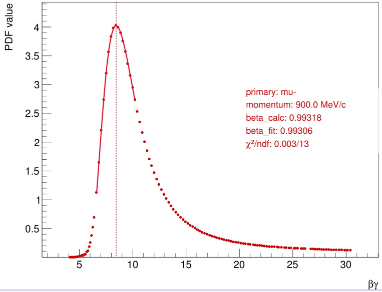
FARICH reconstruction: by PDF

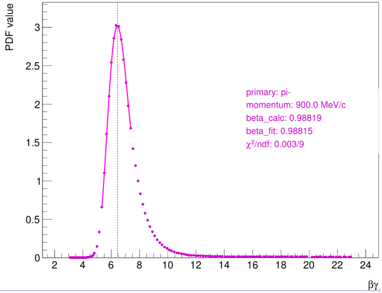
- $F_{rad}(r_i|\beta,\theta_t)$ is more complex especially for low momentums





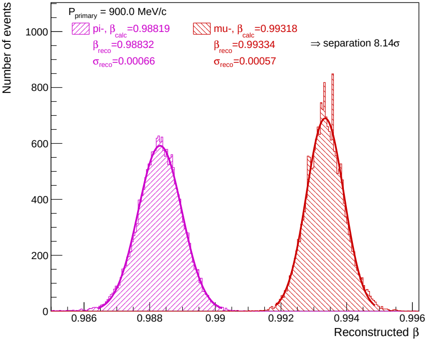
- Examples of PDF values for single event and velocity fitting result

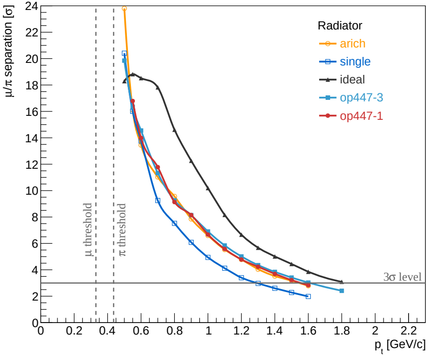




FARICH reconstruction: by PDF

- Examples of quality of identification (left) and separation power for various types of radiators (right)



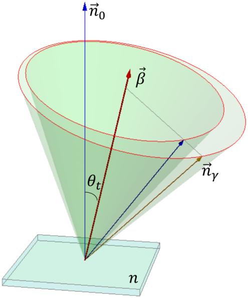


FARICH reconstruction: by dependence θ_c vs φ_c

- The dependence of polar angle of cherenkov photons θ_c from azimuth angle φ_c are used in this reconstruction
- The values θ_c and φ_c are defined in primary particle coordinate system and, therefore, to define them, it is necessary to translate them into laboratory coordinate system in which the primary particle moves (position of primary particle in laboratory coordinate system is determined by its initial position and angles θ_t and φ_t)
- The dependence of θ_c on φ_c can be expressed as

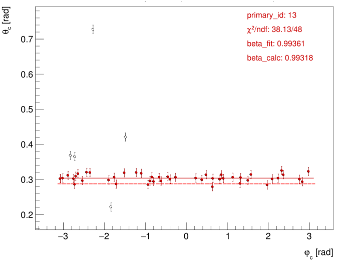
$$\theta_c(\varphi_c|\beta, n, \theta_t) = \arccos\left(\frac{1}{n\beta}\right) + \arccos\left(n\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right) + (\vec{n}_0\vec{n}_\gamma)\sqrt{1-n^2\left(1-(\vec{n}_0\vec{n}_\gamma)^2\right)}\right), \text{where}$$

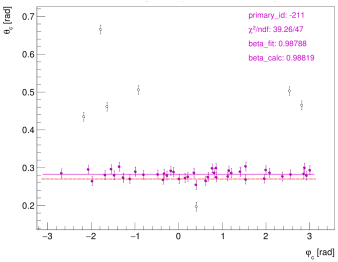
- n average value refraction index of radiator
- $(\vec{n}_0\vec{n}_\gamma) = \cos\theta_t/(n\beta) + \cos\varphi_c \sin\theta_t \sqrt{1-1/(n\beta)^2}$
- $\vec{n}_0$ and $\vec{n}_\gamma$ vectors of the radiator and Cherenkov cone normal, respectively



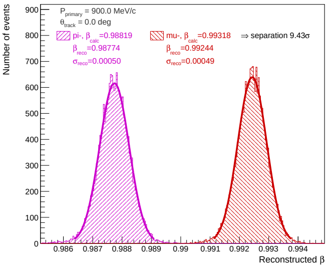
FARICH reconstruction: by dependence θ_c vs φ_c

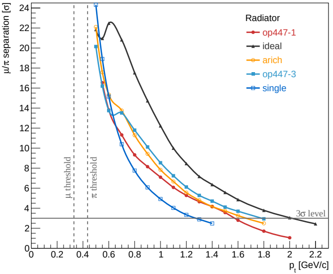
- Examples of using function $\theta_c(\varphi_c|\beta, n, \theta_t)$ to fit data



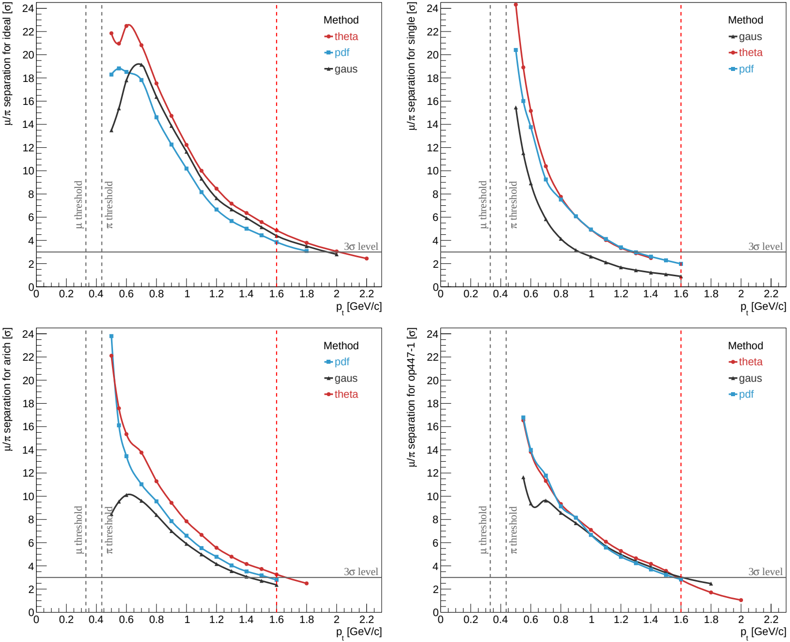


- Examples of obtaining quality of identification (left) and separation power for various types of radiators (right)



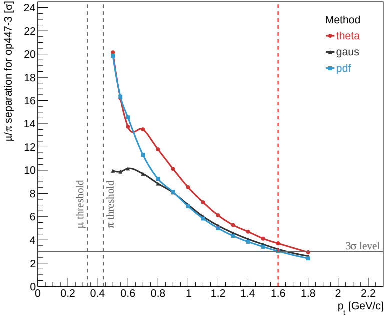


FARICH reconstruction: method comparison



FARICH reconstruction: method comparison

- Values of power separation obtained by three methods for op447-3 aerogel radiator

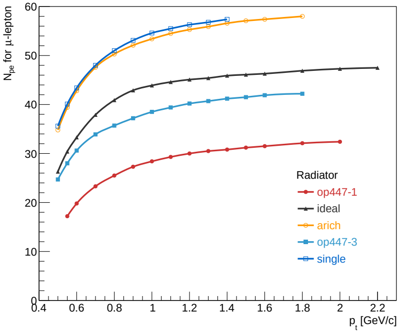


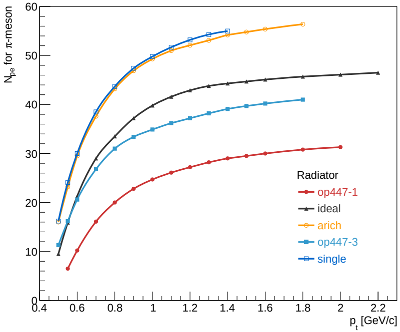
Summary

- The best result is provided reconstruction by angles (θ_c vs φ_c)
- In case of single–layer (single_40mm) and double–layer (arich) radiators, reconstruction by radius shows worst result at small momentums. This can be explained by the fact that there is no focusing in these radiators at low momentums
- At the same time, with sufficient focusing in case of large momentums, reconstruction by radius gives comparable results to reconstruction by PDF. Reconstruction by radius is more simple than other methods and can be used for fast test in case particles with $\beta \simeq 1$ and $\theta_t = 0$ deg

FARICH reconstruction: Npe

- The number of photoelectrons for the μ–lepton (left) and π–meson (right)





Summary

- We tested the simulation on real data, which were taken at our test beam facility ($\beta \simeq 1$ and $\theta_t = 0$ deg), and it is in good agreement

Standalone simulation package

- The package is 80% ready
- To do list
  - magnetic fields: longitudinal (barrel part) and transverse (endcap part)
  - physical background from interaction point and detector materials

Reconstruction package

- The package is about 60% ready
- To do list
  - developing reconstruction for various angles of primary particles (θ_t up to 45 deg)
  - obtaining likelihood of identifications for set of primary particles ($\mathtt{e}^-$, μ, π and $\mathtt{K}$) and implementing these values into Aurora framework to represent PID FARICH

✓ So, we will have hard working but very interesting way duiring year :)

Thanks for your attention !

Coordinate system in standalone simulation

- Axes x and y are perpendicular to the direction of primary track
- The z–axis is longitudinal to the direction of primary track
- The polar angle θ is in the plane zy
- The azimuth angle φ is in the plane xy