

R&D on SiPM-based ASHIPH counters for the Super Tau-Charm facility

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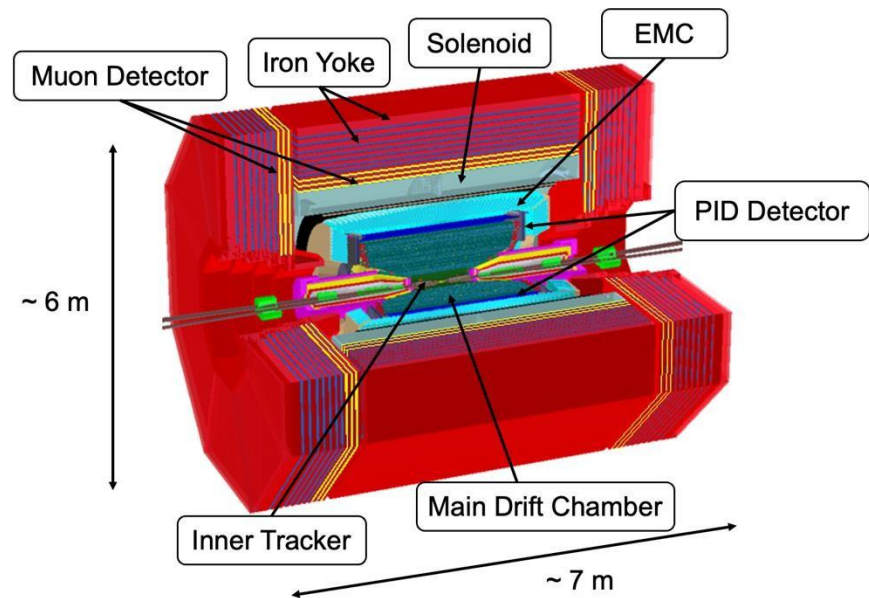
INSTR 2026, Hefei, China

Oct. 12-16, 2026

STCF PID system requirements

❖ Highly efficient and precise reconstruction of exclusive final states produced in 2-7 GeV e^+e^- collisions

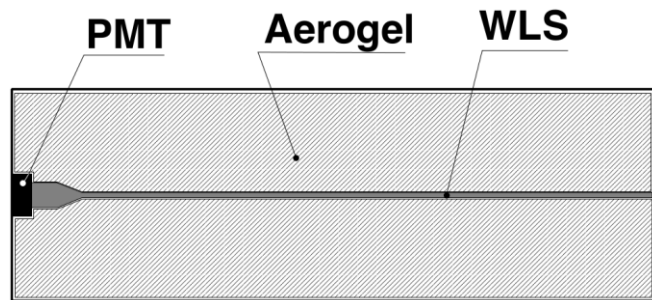
- High tracking efficiency ($>90\%$ @ $0.1 \text{ GeV}/c$) and high momentum resolution for low- p ($<1\text{GeV}/c$) charged particles, precise measurement of low-energy ($<1\text{GeV}$) photons.
→ low mass tracking and PID detectors
- Excellent PID: π/K and μ/π separation in full momentum range (up to 3.5 GeV)



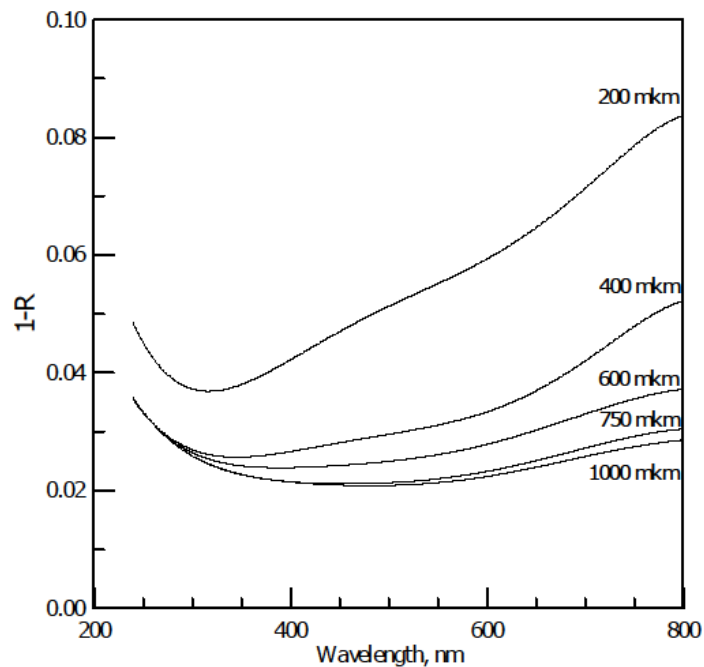
Process	Physics Interest	Optimized Subdetector	Requirements
$\tau \rightarrow K_s \pi \nu_\tau$, $J/\psi \rightarrow \Lambda \bar{\Lambda}$, $D_{(s)}$ tag	CPV in the τ sector, CPV in the hyperon sector, Charm physics	ITK+MDC	acceptance: 93% of 4π ; trk. eff.: $> 99\%$ at $p_T > 0.3 \text{ GeV}/c$; $> 90\%$ at $p_T = 0.1 \text{ GeV}/c$ $\sigma_p/p = 0.5\%$, $\sigma_{\gamma\phi} = 130 \mu\text{m}$ at $1 \text{ GeV}/c$
$e^+e^- \rightarrow KK + X$, $D_{(s)}$ decays	Fragmentation function, CKM matrix, LQCD etc.	PID	π/K and K/π misidentification rate $< 2\%$ PID efficiency of hadrons $> 97\%$ at $p < 2 \text{ GeV}/c$
$\tau \rightarrow \mu\mu\mu$, $\tau \rightarrow \gamma\mu$, $D_s \rightarrow \mu\nu$	cLFV decay of τ , CKM matrix, LQCD etc.	PID+MUD	μ/π suppression power over 30 at $p < 2 \text{ GeV}/c$, μ efficiency over 95% at $p = 1 \text{ GeV}/c$
$\tau \rightarrow \gamma\mu$, $\psi(3686) \rightarrow \gamma\eta(2S)$	cLFV decay of τ , Charmonium transition	EMC	$\sigma_E/E \approx 2.5\%$ at $E = 1 \text{ GeV}$ $\sigma_{\text{pos}} \approx 5 \text{ mm}$ at $E = 1 \text{ GeV}$
$e^+e^- \rightarrow n\bar{n}$, $D_0 \rightarrow K_L \pi^+ \pi^-$	Nucleon structure Unity of CKM triangle	EMC+MUD	$\sigma_T = \frac{300}{\sqrt{p^3(\text{GeV}^3)}} \text{ ps}$

Jianbei Liu “STCF Detector and Performance”, FTCTF2025

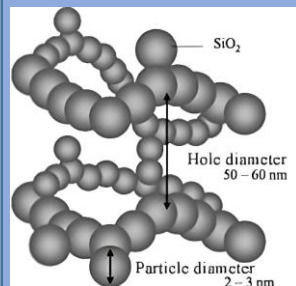
ASHIPH technique for STCF



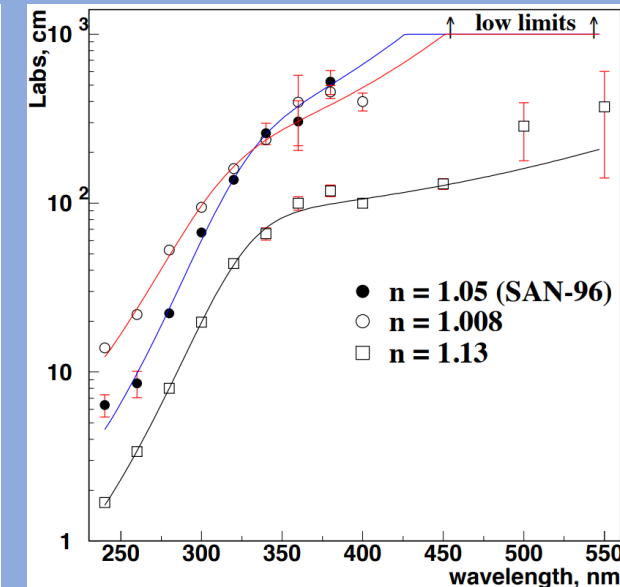
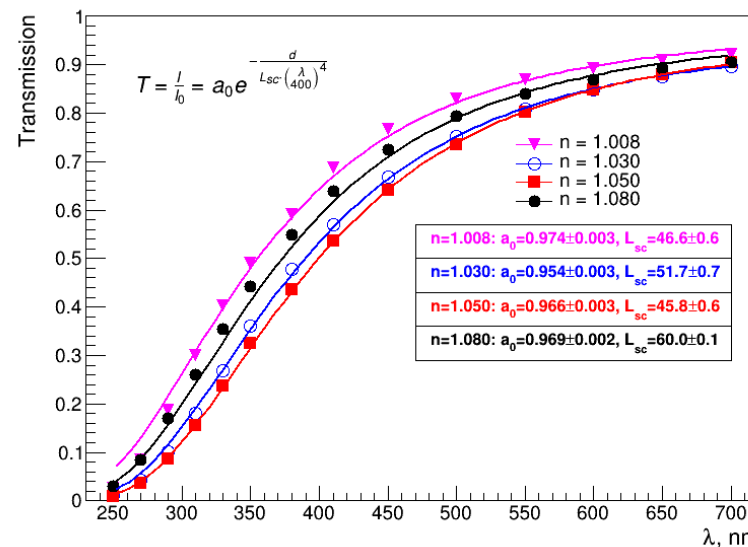
Aerogel – SHifter – PHotomultiplier



Aerogel radiator is wrapped in highly reflective PTFE film

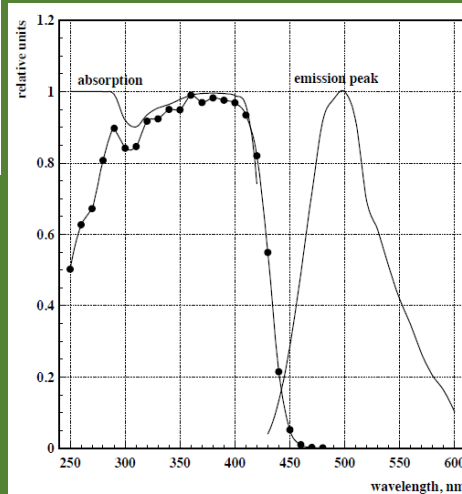


Aerogel spectral characteristics

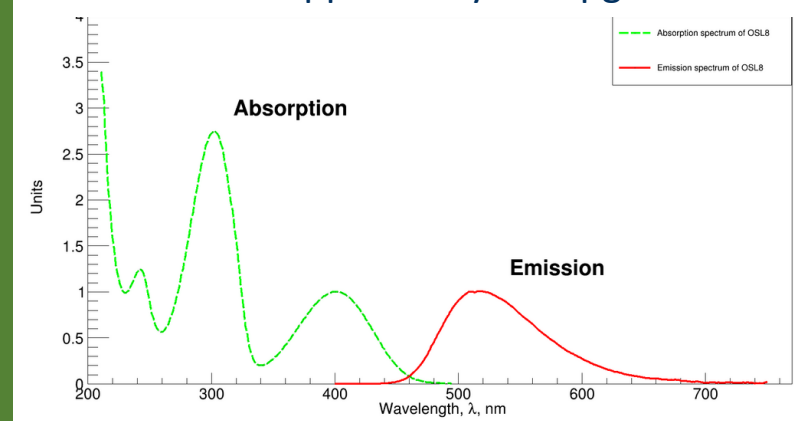


Wavelength shifters spectral characteristics

BBQ is used in operational systems

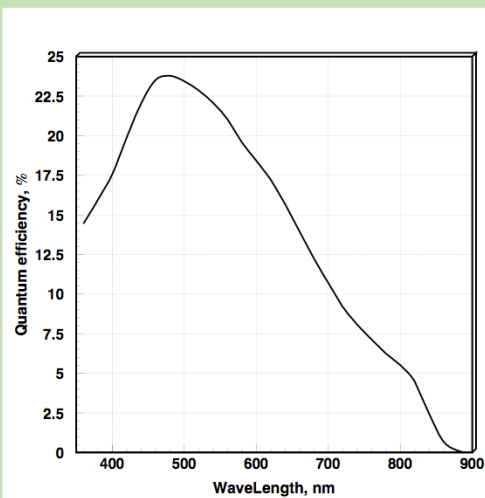
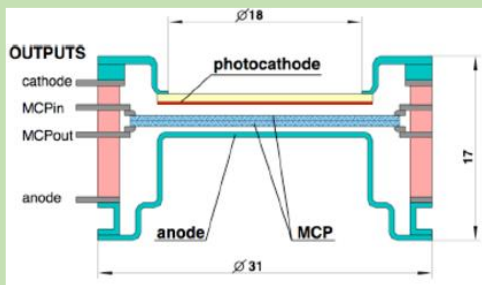
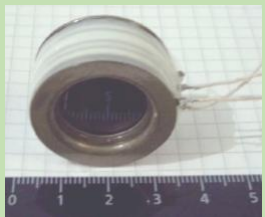


OSL8 – opportunity for upgrade



PMT as option for ASHIPH upgrade

MCP PMT

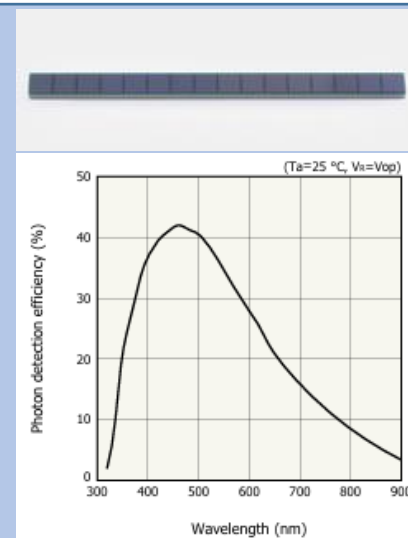


- Manufacturer: “Ekran FEP” (Novosibirsk)
- Borosilicate glass window
- Multialkali (Sb-Na-k-Cs) photocathode
- MCP’s channel diameter is of 7 μm
- Maximum QE=23% at 500 nm
- Photoelectron collection coefficient ~ 0.6
- $\text{PDE} = \text{QE} \times \text{CE} \approx 14\%$
- Axial magnetic field
- Power supply 3-4 kV

SiPM

Hamamatsu S13363-3050NE-16

- Effective photosensitive area 3×3 mm
- Number of pixels 3584
- PDE=40% at 500 nm
- Any direction magnetic field
- Power supply < 100 V ($V_{\text{BR}}=53$ V typ.)
- DCR 60 kHz/mm² ($V_{\text{R}}=V_{\text{OP}}$)
- Gain 1.7×10^6



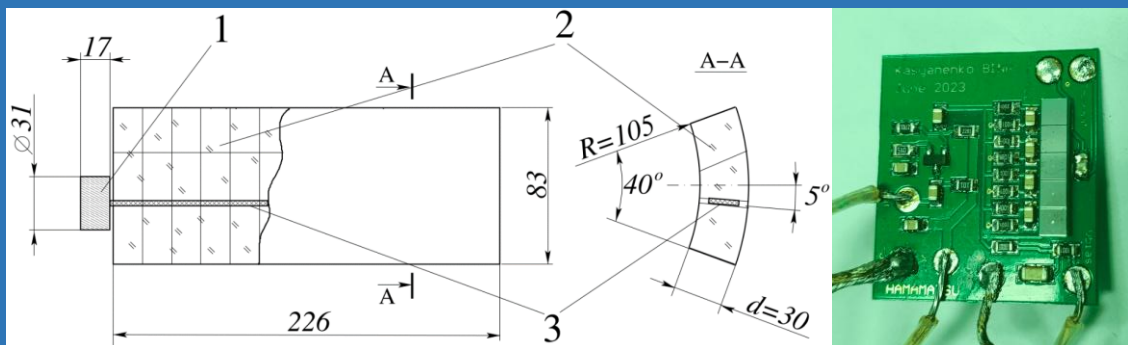
NDL EQR20 11-3030D-S

- Effective photosensitive area 3×3 mm
- Number of pixels 2500
- PDE=46% at 420 nm
- Any direction magnetic field
- Power supply < 100 V ($V_{\text{BR}}=27.5$ V typ.)
- DCR 150 kHz/mm² ($V_{\text{R}}=V_{\text{OP}}$)
- Gain 8.2×10^5

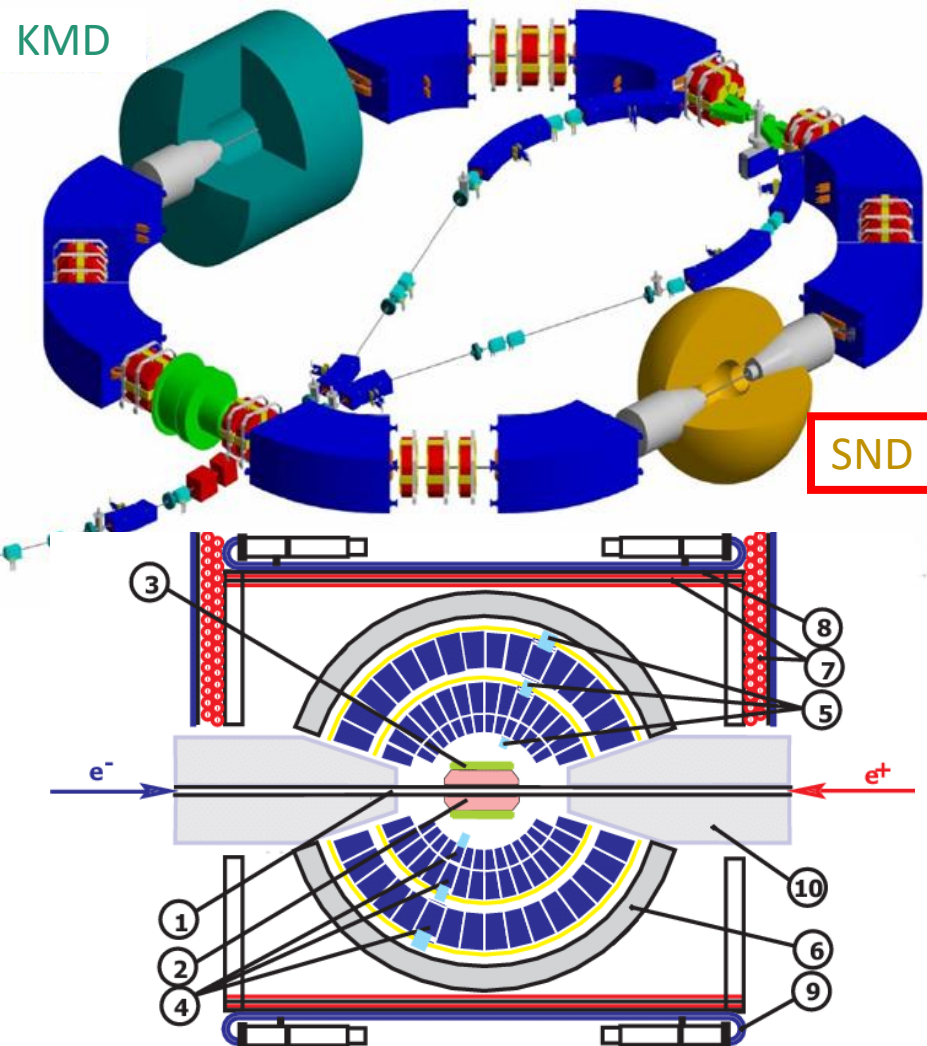
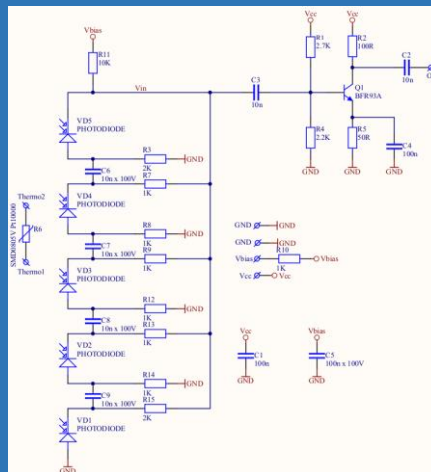
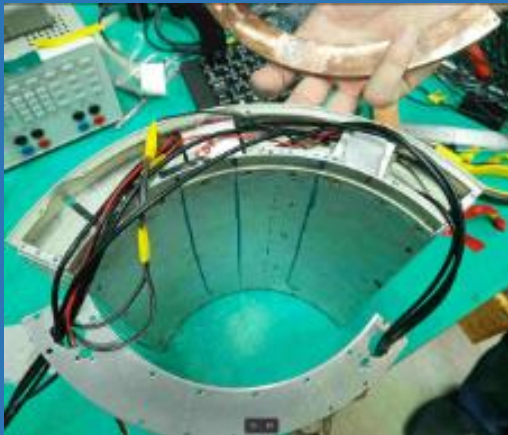


ASHIPH-SiPM prototype for the SND detector

SND ASHIPH prototype

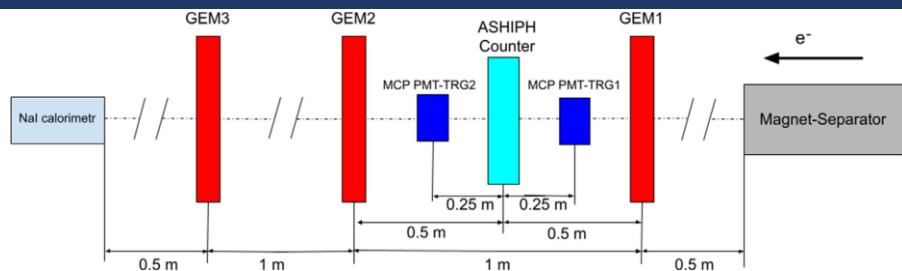


- WLS with cross-section 17×3 mm²
- Array of 5 SiPMs made from S16365-3050NE-16 (Hamamatsu) with BINP FEE
- Aerogel $n=1.05$ and $n=1.12$



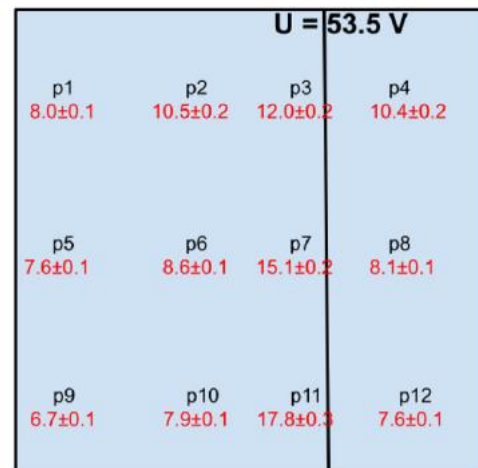
Schematic view of the VEPP-2000 acceleration complex and the SND detector. 3 – SND ASHIPH system

Results of electron testbeam at the BINP VEPP4-M complex



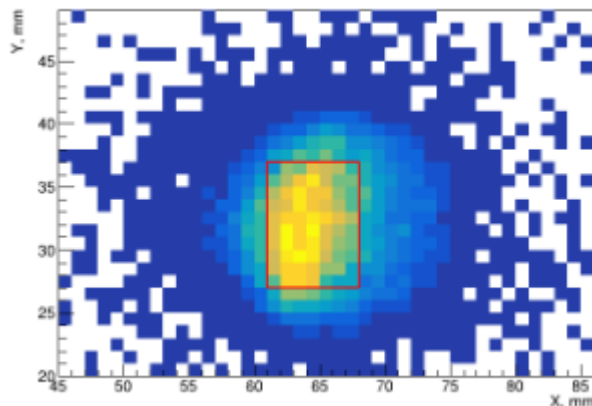
Schematic diagram of experimental setup:

- Tracking – GEM (red);
- 2 MCP PMT TRG – CC (blue);
- Magnet-separator (grey) ($E_e=2.5$ GeV);
- Nal calorimeter (100×100×300 mm³) (light grey);
- ASHIPH SND prototype (cyan).

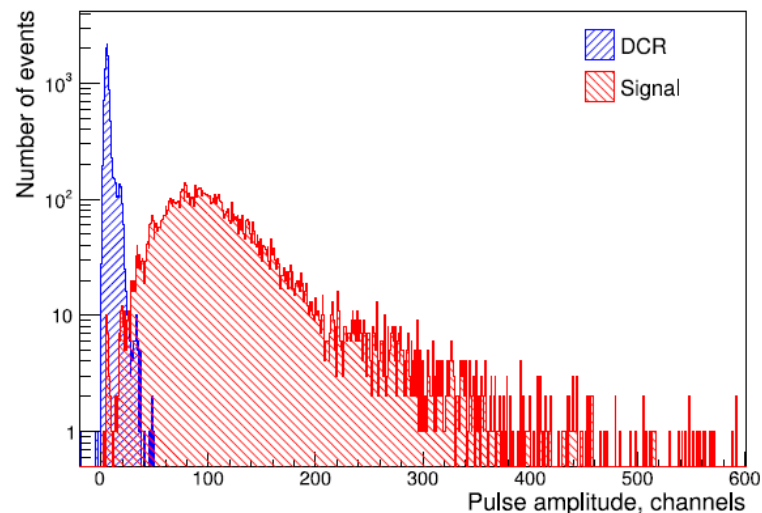


Map of the $N_{ph.e.}$ yield at various points for the $n=1.05$ aerogel

- $\langle N_{ph.e.} \rangle_{1.05} = 9.2 \pm 0.6$
- Non-uniformity $\sim 30\%$ (max-min)

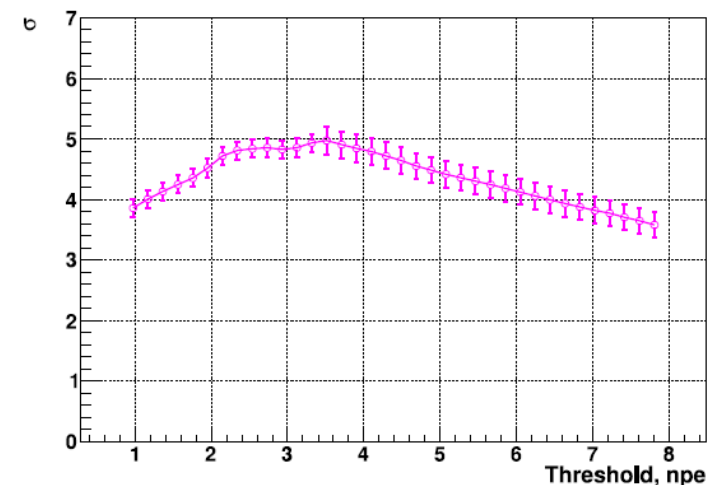
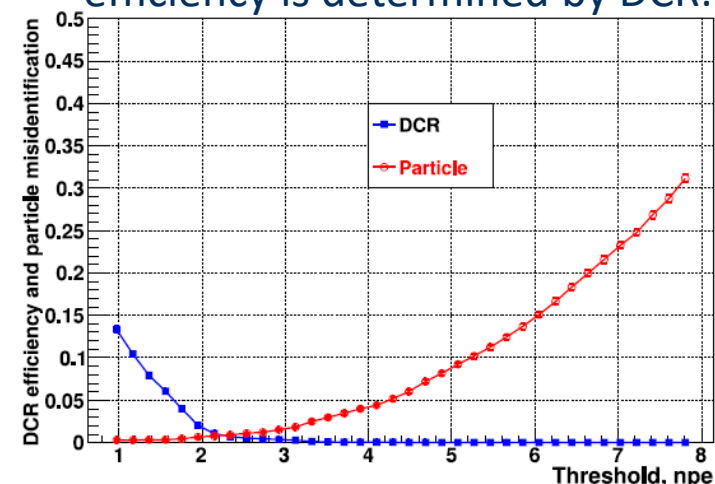


Event selection with GEM detector coordinates



Signal and DCR amplitude spectra

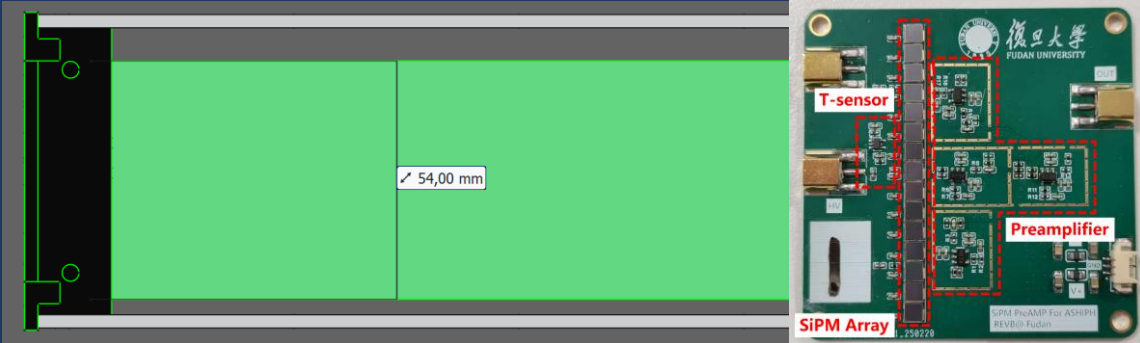
Assuming that all subthreshold efficiency is determined by DCR:



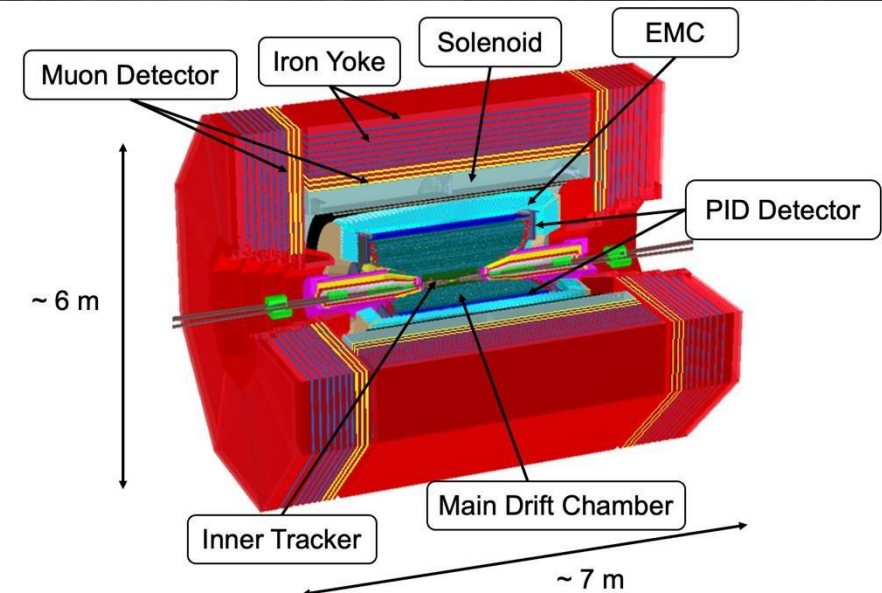
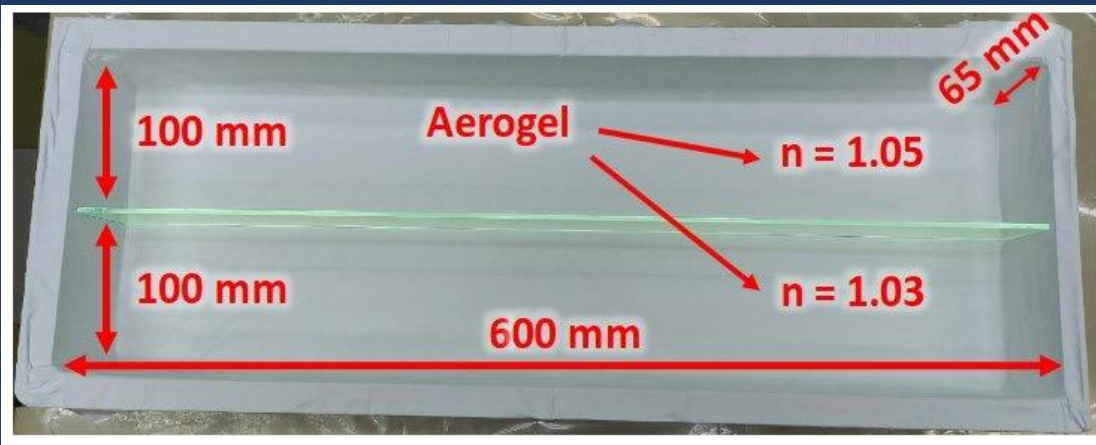
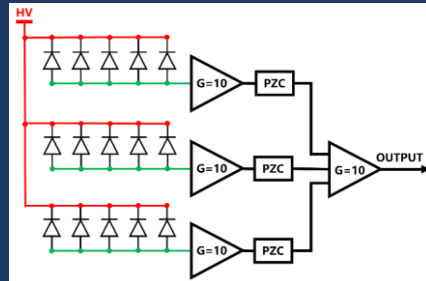
<https://doi.org/10.1016/j.nima.2026.171799>

ASHIPH-SiPM prototype for the Super Tau-Charm facility

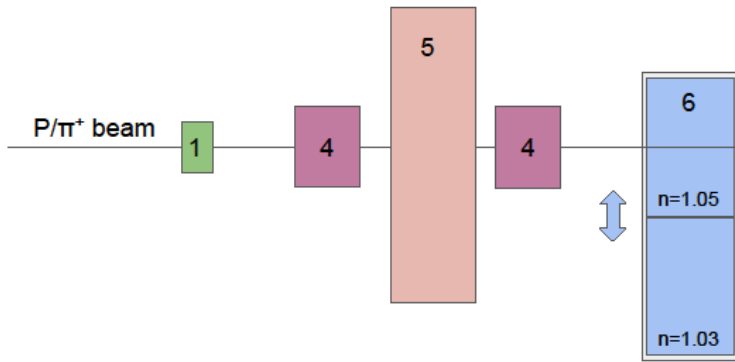
STCF ASHIPH prototype



- WLS with cross-section $54 \times 3 \text{ mm}^2$
- Array of 15 SiPMs NDL EQR20 11-3030D-S with FDU FEE
- Aerogel $n=1.03$ and $n=1.05$



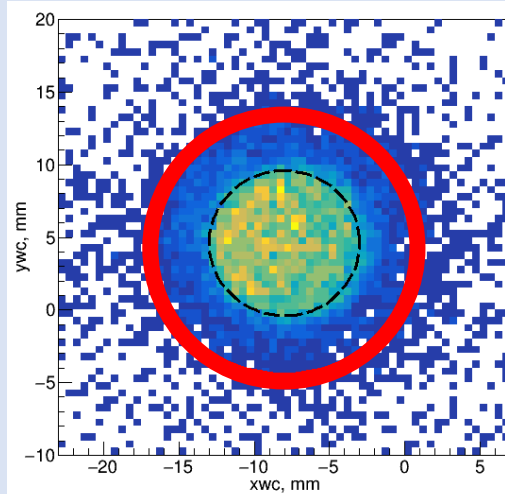
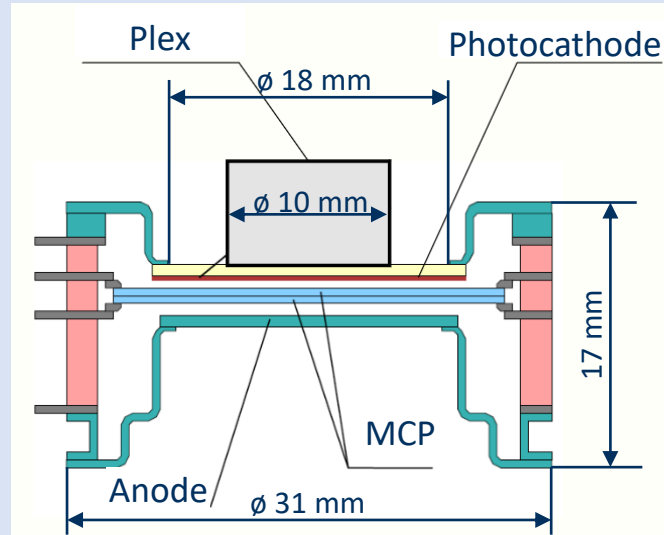
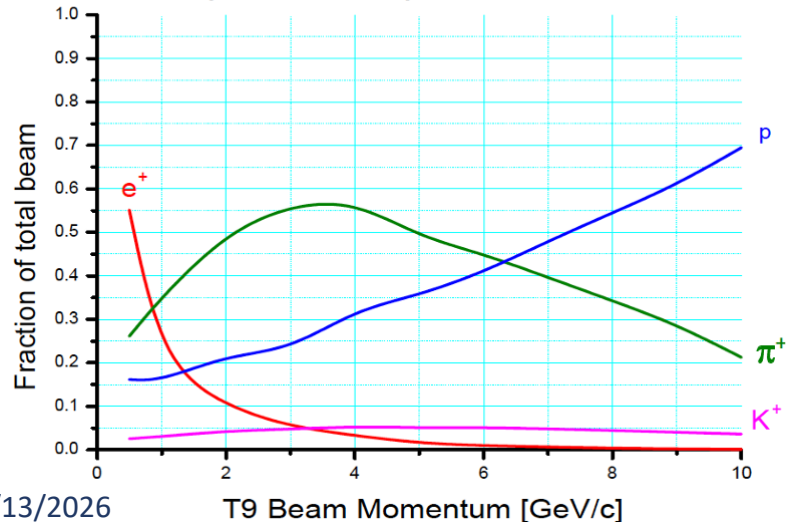
Results of hadron testbeam at PS-T9, CERN



Schematic diagram of experimental setup:

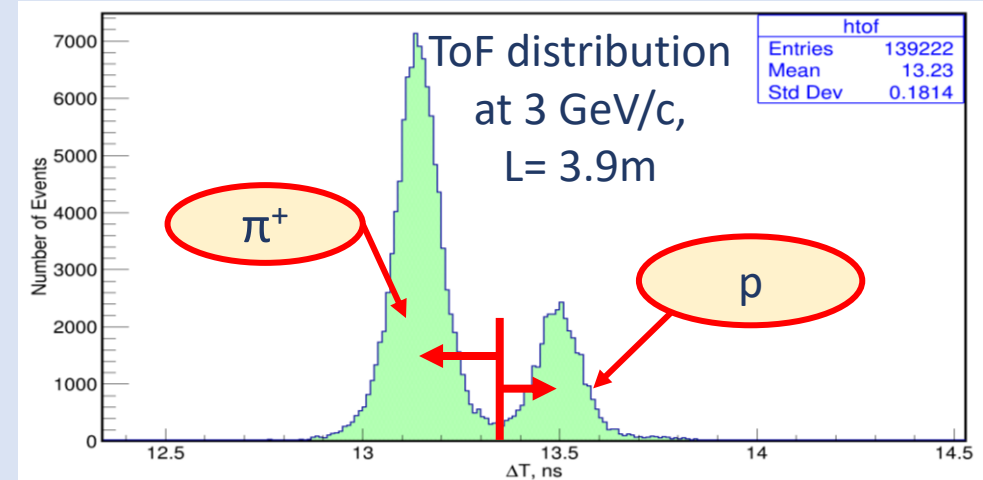
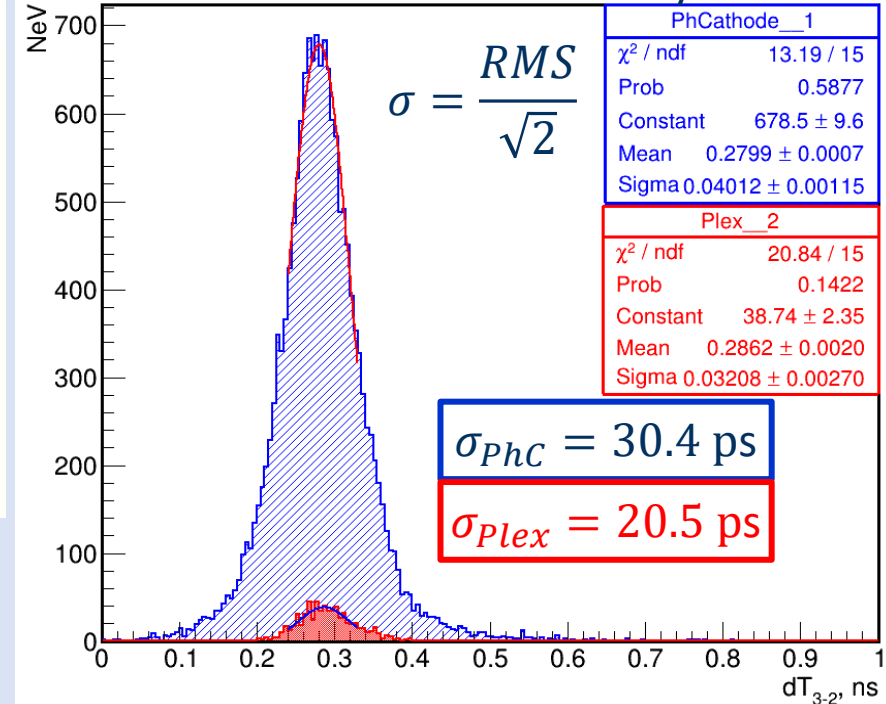
- 1-3 – MCP PMTs – ToF (3.9 m);
- 4 – scintillation counters – CC(+2);
- 5 – DWC – coordinate detector;
- 6 – ASHIPH STCF prototype.

Composition of positive beam

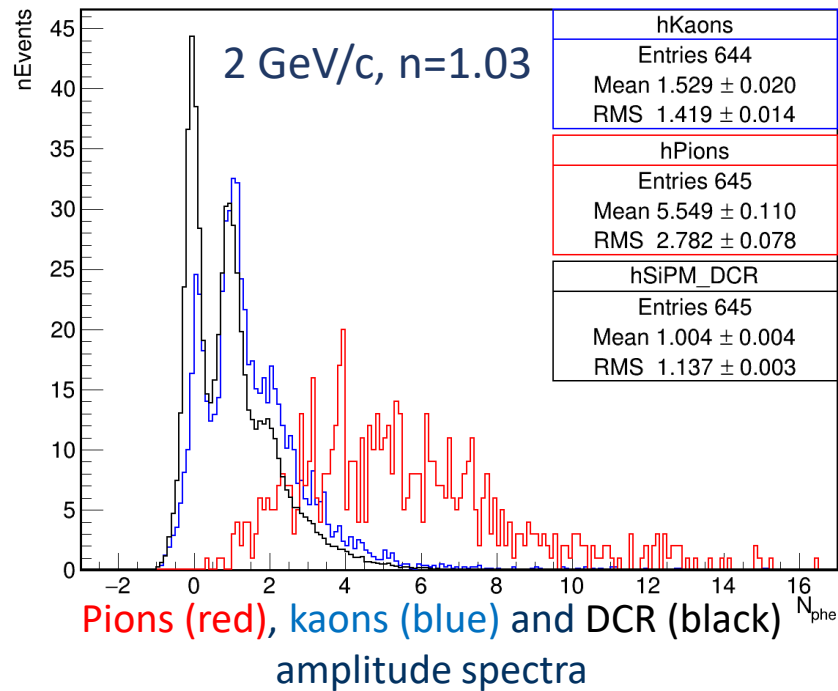


Event selection with DWC coordinates – “soft” cuts

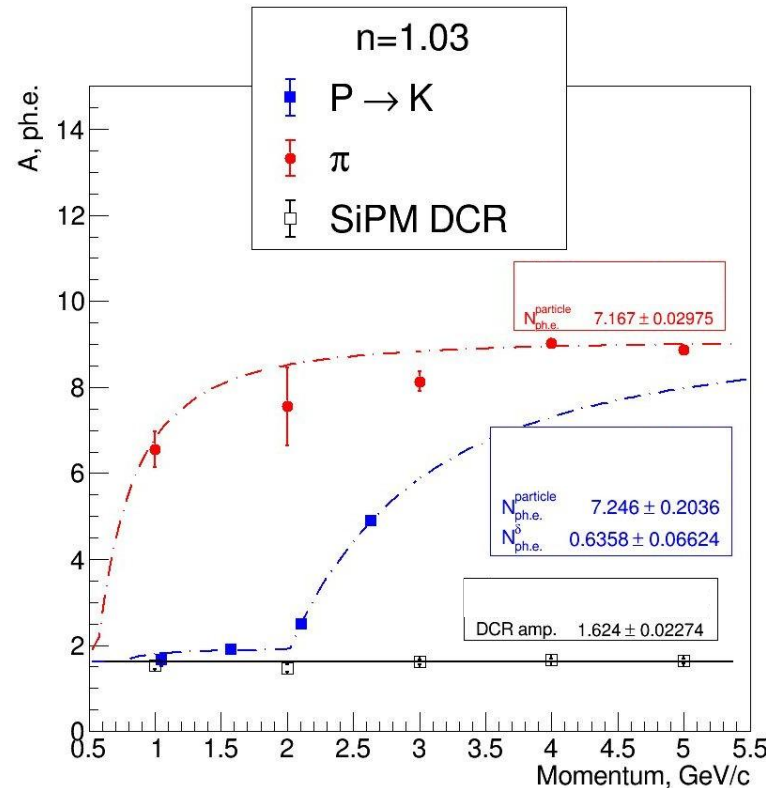
Time resolution of ToF system



Results of hadron testbeam at PS-T9, CERN



$$p_K = p_p \cdot \frac{m_K}{m_p}$$



Dependence of counter's amplitude on momentum

$$\mu = \mu_0 + \mu_{max} \cdot \frac{p^2 - p_{thr}^2}{p^2}$$

$$N_{phe.} \pi_{5GeV} = 7.2 \pm 0.2$$

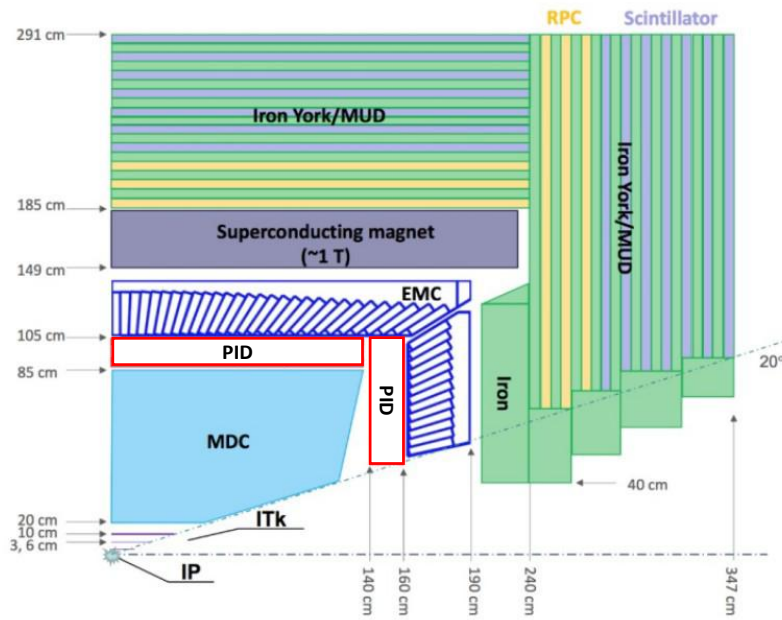
Subthreshold amplitude ~ 2 ph.e.:

- 0.6 δ -electrons
- 1.6 DCR

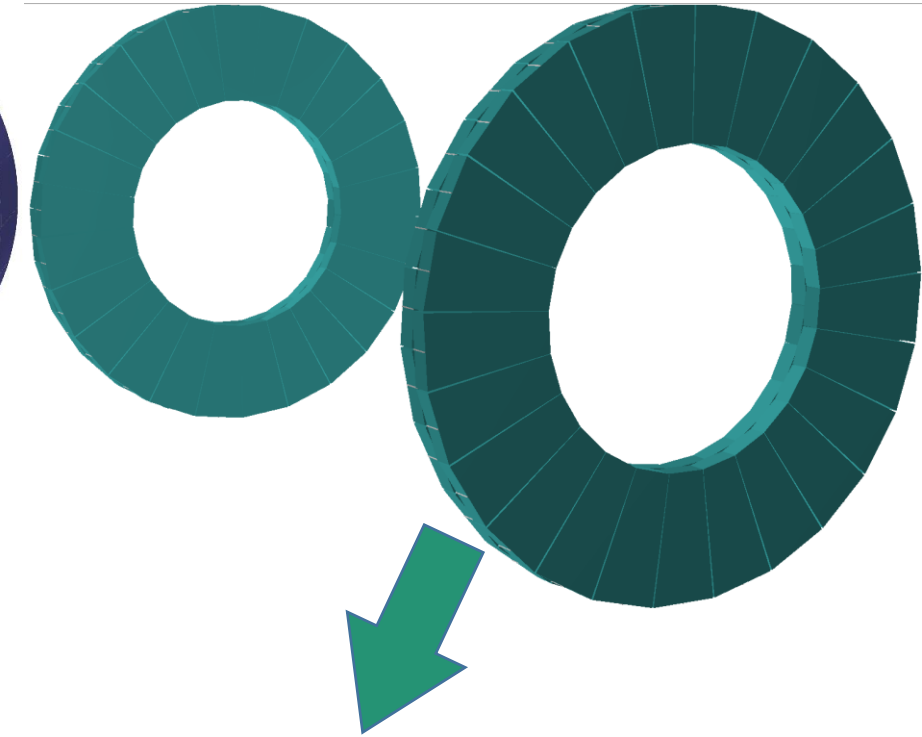
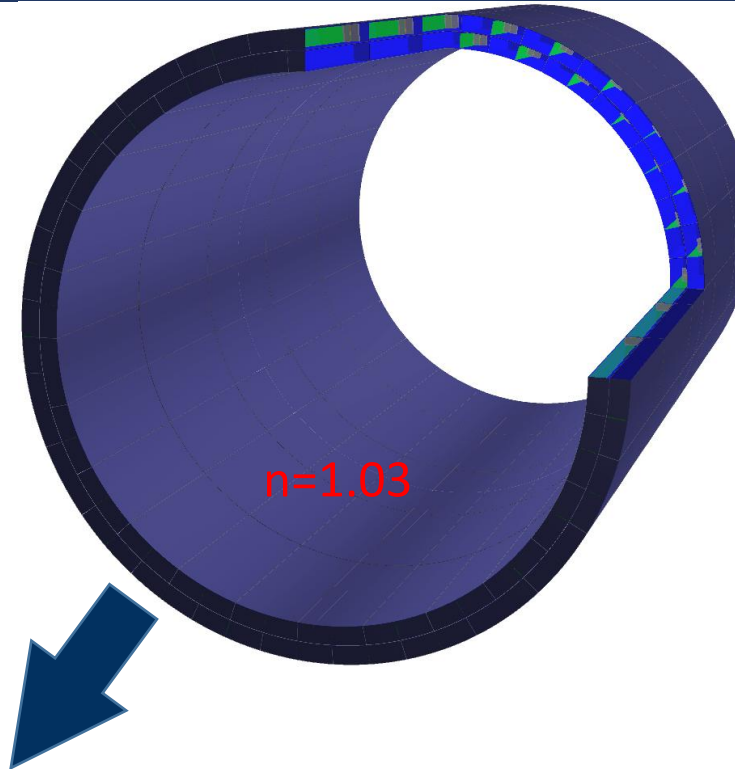
$$DCR \approx 30 \text{ Mcps/ch} = 200 \text{ kcps/mm}^2$$

$$\text{Time resolution } (4,70 \pm 0,14) \text{ ns}$$

ASHIPH simulation in the OSCAR framework



Solid Angle Coverage : $94\% \bullet 4\pi$ ($\theta \sim 20^\circ$)



- Total number of counters: 250 (~ 1740 L of aerogel)
- **2 layers** (125 counters on layer): are shifted relative to each other by half of a period
- Thickness of the system: 12.5 cm ($0.11X_0$, aluminum walls)
- 5 segments: 1 segments content of 25 counters
- Length of the system: 280 cm (counter length: 56 cm)

- Total number of counters: 200 (100 in each end-cap)
- **2 layers** (50 counters per layer): are shifted relative to each other by half of a period (7.2° of the φ -angle)
- Thickness of the system: 14 cm ($0.14X_0$, aluminum walls)
- Inner radius 450 mm, outer radius 820 mm
- Geometric efficiency is about 95%

Simulated physical processes

❖ Aerogel optics

- Refractive index
- Absorption length
- Scattering length

❖ WLS optics

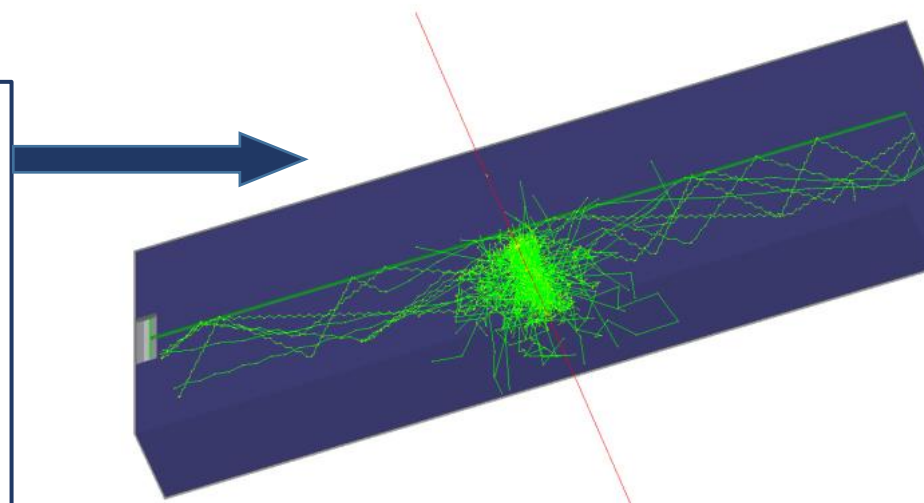
- Refractive index of the PLEX
- Absorption length of the PLEX
- Emission of the BBQ

❖ Teflon reflection

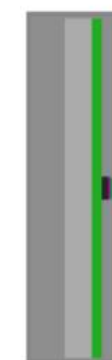
- Reflectivity

❖ SiPM simulation

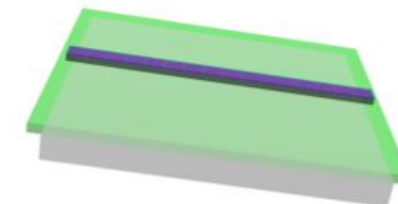
- Photon detection



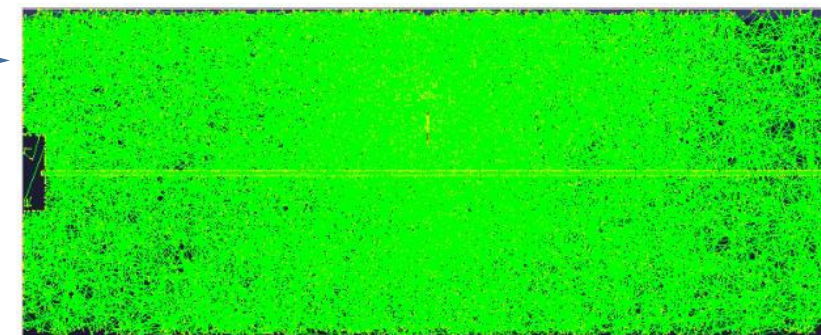
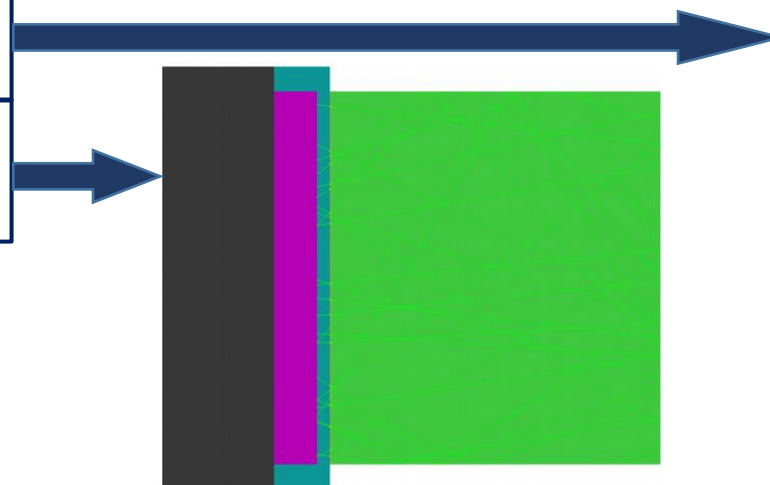
Counter



Electronic box



SiPMs + PCB(5x5.4 cm) +
Peltier(5x5 cm)



Signal shape simulation in the OSCAR framework

Parametrization of single photoelectron signal model:

$$v(t) = V_0(Ae^{-t/\tau_D} + Be^{-t/\tau_R} + Ce^{-t/\tau_H})\sigma(t)$$

$$A = -\frac{\tau_H}{\tau_H - \tau_D}$$

$$B = \frac{\tau_H}{\tau_H - \tau_R}$$

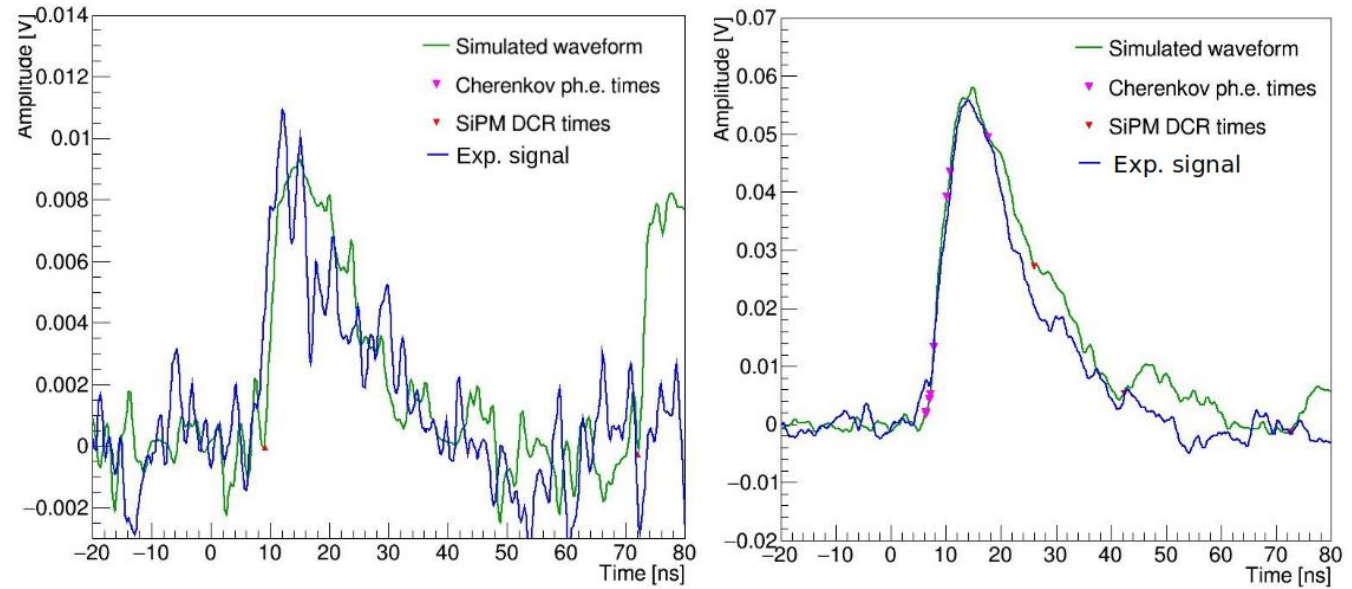
$$C = \frac{\tau_H(\tau_R - \tau_D)}{(\tau_H - \tau_D)(\tau_H - \tau_R)}$$

where

τ_R – pulse rise time;

τ_D – pulse decay time;

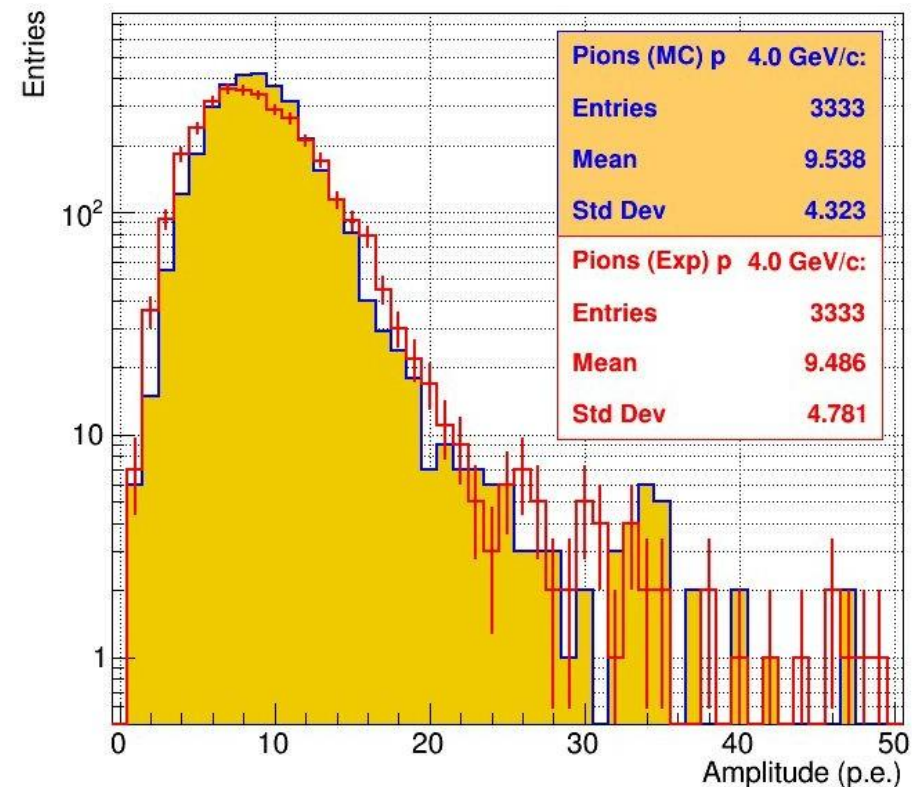
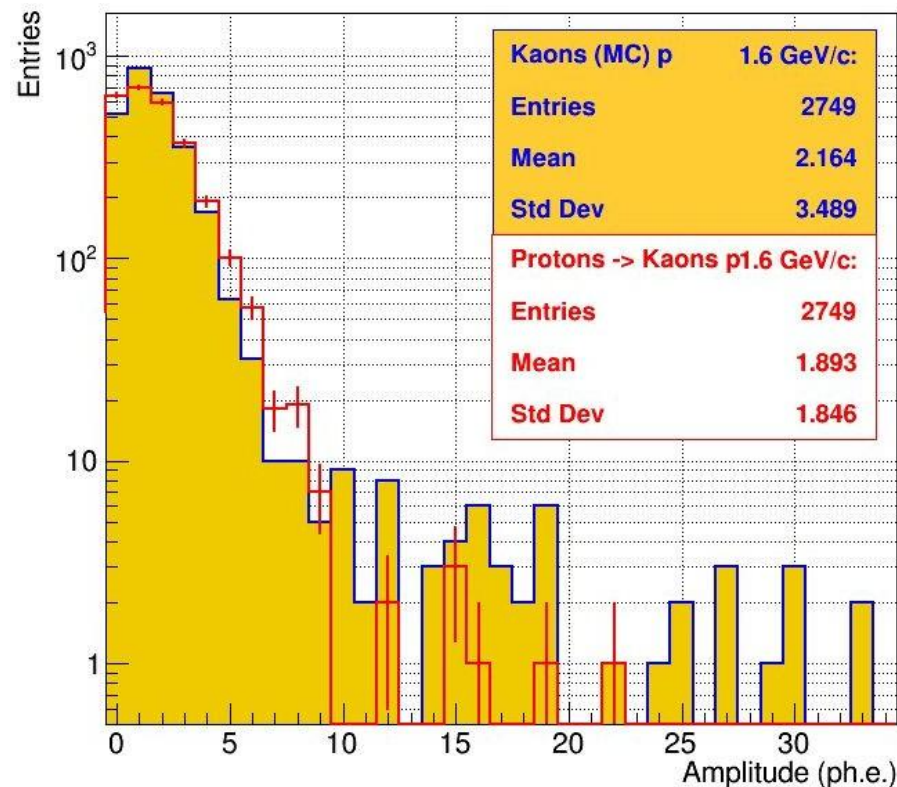
τ_H – return to baseline time.



Experimental and simulated SiPM waveforms for different $N_{\text{ph.e.}}$

Comparison of experiment and simulation

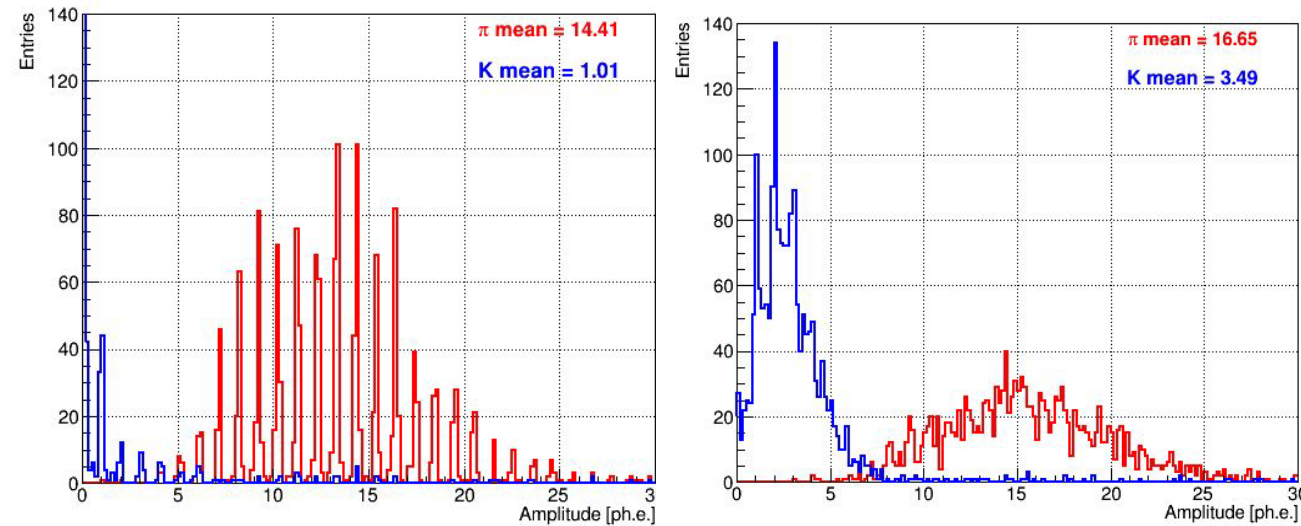
DCR ≈ 30 Mcps/ch = 200 kcps/mm²



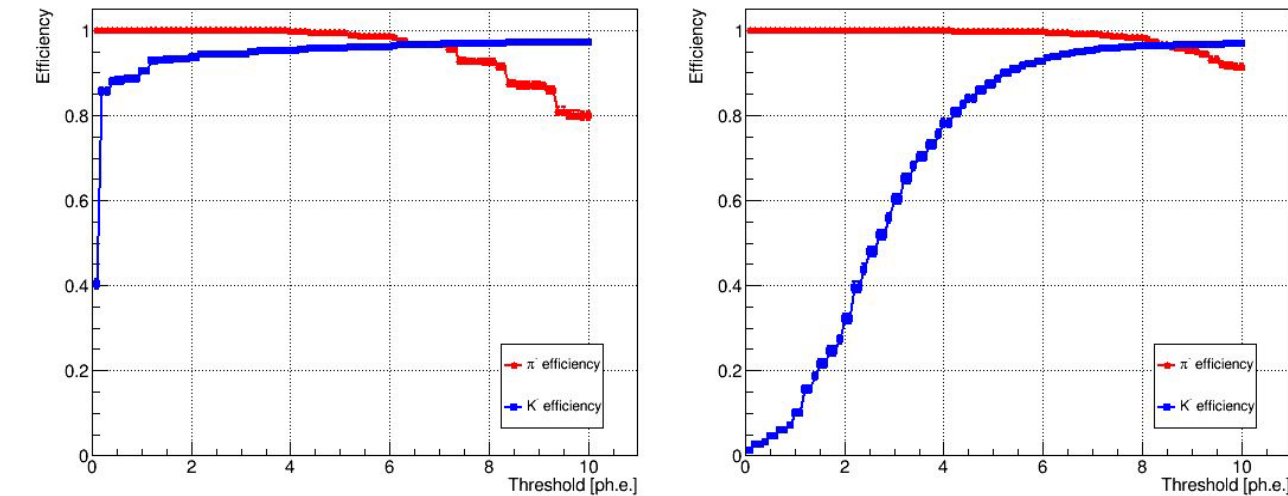
Yellow - simulation, red – experimental data.

Material budget before ASHIPH counter: in simulation $< 0,06X_0$, in experiment $\sim 1X_0$.

BASHIPH simulation in the OSCAR framework



Reconstructed **pions** and kaons amplitude distributions for DCR of 1 kHz/mm² (left) and of 200 kHz/mm² (right)



Dependence of **pions** and kaons detection efficiency on threshold amplitude for DCR of 1 kHz/mm² (left) and of 200 kHz/mm² (right)

Sum of two layers!!

$$N_{\sigma} = \sqrt{2}[\text{erf}^{-1}(1 - 2\varepsilon_K) + \text{erf}^{-1}(1 - 2\varepsilon_{\pi})]$$

$$\varepsilon_{\pi} = \frac{N_{\pi}(A_{\text{sum}} > A_{\text{thr}})}{N_{\pi}^{\text{tot}}}$$

$$\varepsilon_K = \frac{N_K(A_{\text{sum}} < A_{\text{thr}})}{N_K^{\text{tot}}}$$

- DCR = 200 kHz/mm²
- $A_{\text{thr}} = 5.0$ ph.e.
- π/K -separation better than **3 σ** in the range from 0.7 to 2 GeV/c

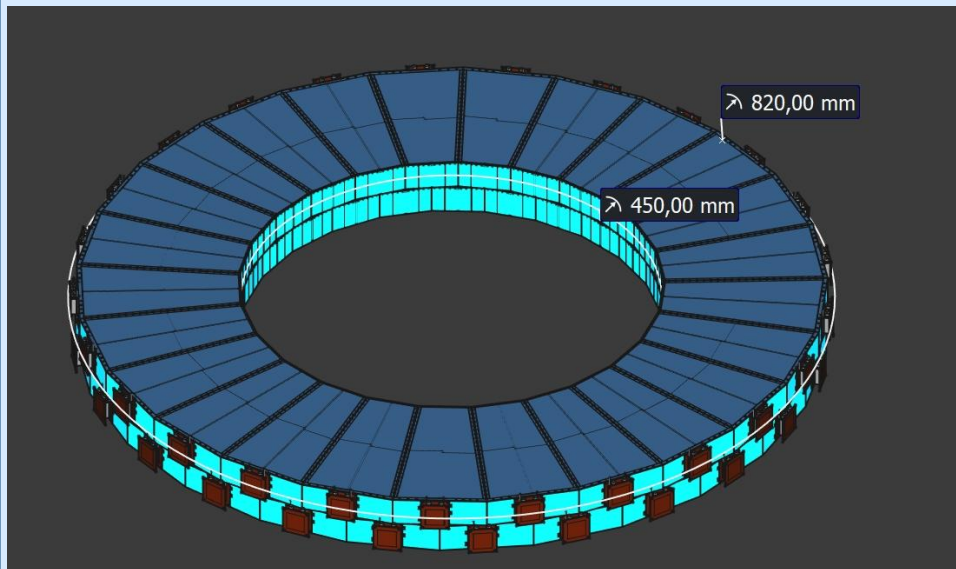
- DCR = 1 kHz/mm²
- $A_{\text{thr}} = 0.9$ ph.e.
- π/K -separation better than **4 σ** in the range from 0.7 to 2 GeV/c

EASHIPH (End-cap ASHIPH) system

$$N_{\sigma} = \sqrt{2}[\text{erf}^{-1}(1 - 2\varepsilon_K) + \text{erf}^{-1}(1 - 2\varepsilon_{\pi})]$$

π/K from 0.7 to 2.0 GeV/c: $N_{\sigma} > 3$

- Aerogel with $n=1.03$
- Material budget is about 6.9% X_0 per layer.

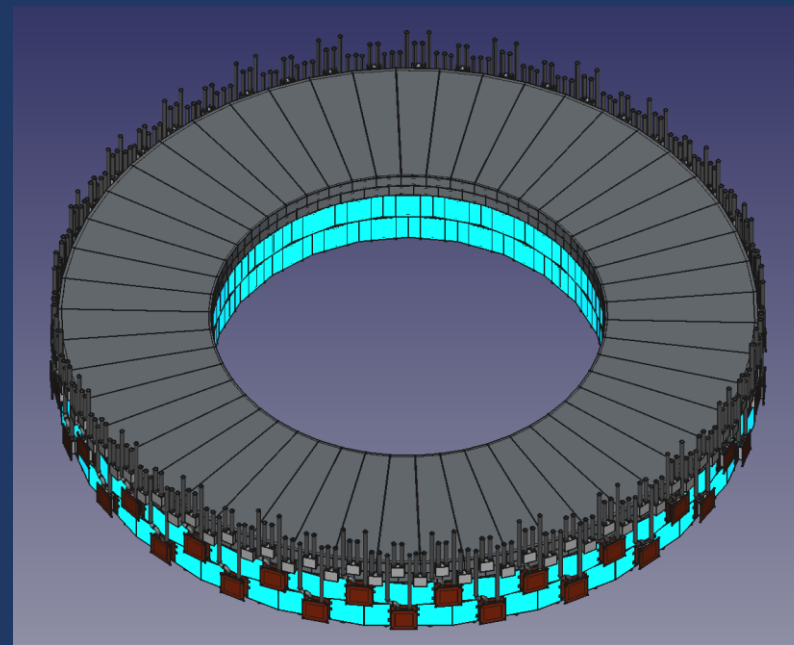


Sketch of the 2-layer EASHIPH system

π/K from 0.7 to 2.5 GeV/c: $N_{\sigma} > 3$

K/p from 1.6 to 3 GeV/c: $N_{\sigma} > 3$

- Aerogel with $n=1.02$ and $n=1.07$
- For future upgrades



Sketch of the 4-layer EASHIPH system

Summary

- ❖ Two ASHIPH-SiPM prototypes were developed and tested with electron and hadron beams:
 - Small prototype 226x89x30 with $n=1.05$ for the SND upgrade gives $N_{\text{ph.e.}}(\text{beta}=1)=9.2\pm0.6$
 - Big prototype 600x203x65 with $n=1.03$ for STCF project gives $N_{\text{ph.e.}}(\text{beta}=1)=7.2\pm0.2$
- ❖ Dependencies of DCR efficiency, particle misidentification and separation power on threshold in $N_{\text{ph.e.}}$ were obtained with electron beam.
- ❖ Results from testing STCF ASHIPH prototype with hadron beams are shown:
 - Average amplitude from pions with $P=4$ GeV/c is equal to 7.2 ± 0.2 ph.e.;
 - subthreshold amplitude components (0.6 ph.e. δ -electrons and 1.6 ph.e. DCR);
 - time resolution of 4.70 ± 0.14 ns.
- ❖ Results obtained were used to tune the simulation in the OSCAR framework:
 - π/K separation better than 3σ in the range from 0.7 to 2 GeV/c was demonstrated in two layers system based on aerogel with $n=1.03$.
- ❖ 4-layer option of ASHIPH system for end-cap region of the STCF project proposed and implemented in simulation:
 - reliable π/K separation from 0.7 to 2.5 GeV/c and K/p separation from 1.6 to 3 GeV/c is demonstrated.

Thank you for your attention!

Backups

Material budget

- Material scan was performed with the help of the DD4HEP tools within the OSCAR framework.
- One layer of ASHIPH counters provide 6.9% of X_0 in total including 1.6% X_0 from additional materials from non-active area.
- Real system consists of at least 2 layers.
- Change of aluminum to carbon fiber reinforced plastic (CFRP) for counter housing can decrease total layer thickness by 2% of X_0 .

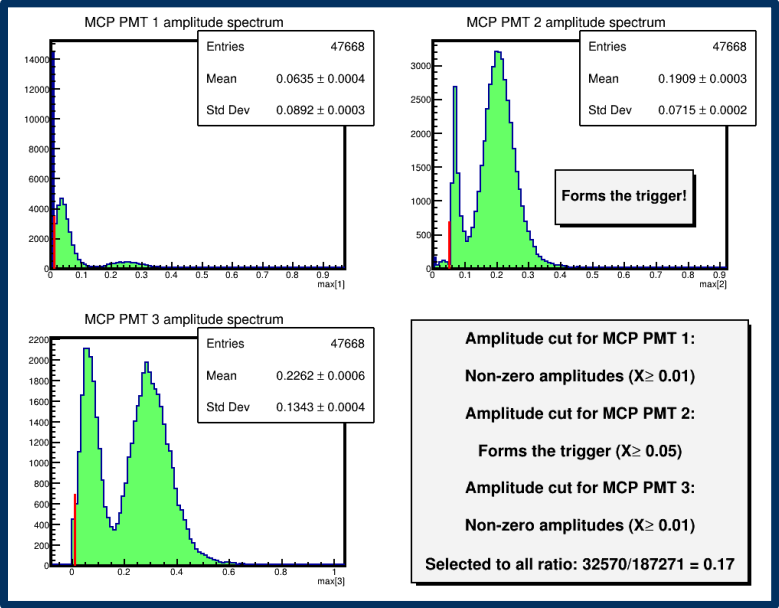
Counter's active area

No layer	Material's name	Z_0	Atomic mass (A), [g/mol]	Density, g/cm ³	X_0 , [cm]	Thickness, cm	X/X_0 , integrated
1	G4 _{Al}	13	26.982	2.699	8.896	0.1	0.0113
2	TEFLON	8	17.32	0.267	130.5	0.0025	0.0115
3	Aerogel _{n=1.03}	11	21.65	0.139	194.57	6.0	0.0423
4	TEFLON	8	17.32	0.267	130.5	0.0025	0.0115
5	G4 _{Al}	13	26.982	2.699	8.896	0.1	0.0113

Additional materials

No layer	Material's name	Z_0	Atomic mass (A), [g/mol]	Density, g/cm ³	X_0 , [cm]	Thickness, cm	X/X_0 , integrated
1	Edge border(Al)	13	26.982	2.699	8.896	0.07	0.0083
2	Edge border (TEFLON)	8	17.32	0.267	130.5	0.0018	$1.41 \cdot 10^{-5}$
3	WLS (PMMA)	15	~29	1.19	34.07	0.11	0.00324
4	SiPMs (Si)	14	28	2.329	9.37	$4.48 \cdot 10^{-5}$	$4.78 \cdot 10^{-6}$
5	PCBs (G10)	8	16	1.8	17.87	0.01	$5.57 \cdot 10^{-4}$
6	Peltier (Ceramic)	10.7	21.82	3.97	7.038	0.0166	0.00235
7	Cooling sys. (Al)	13	26.982	2.699	8.896	0.017	0.00186

Additional information from PS-T9 testbeam



Amplitude spectra of MCP PMTs

Obtained statistics

Aerogel Momentum	n = 1.03	n = 1.05
	18k	19k
1 GeV/c	9k	8k
2 GeV/c	598k	139k
3 GeV/c	500k	390k
4 GeV/c	73k	36k
5 GeV/c		

Barrel ASHIPH simulation in the OSCAR framework

$$\varepsilon_{\pi} = \frac{N_{\pi}(A_{sum} > A_{thr})}{N_{\pi}^{tot}}$$

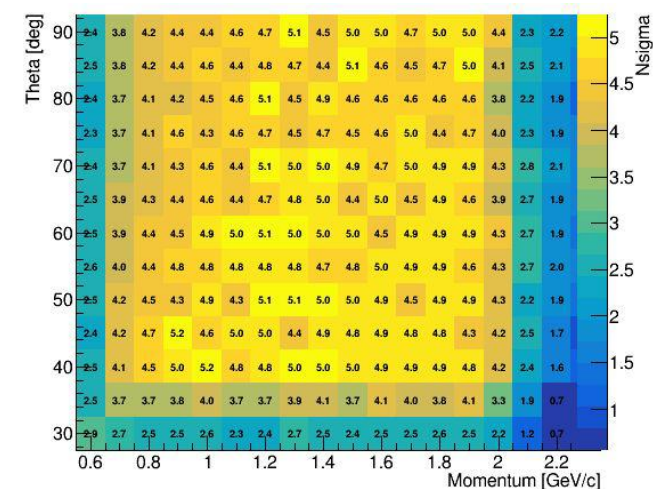
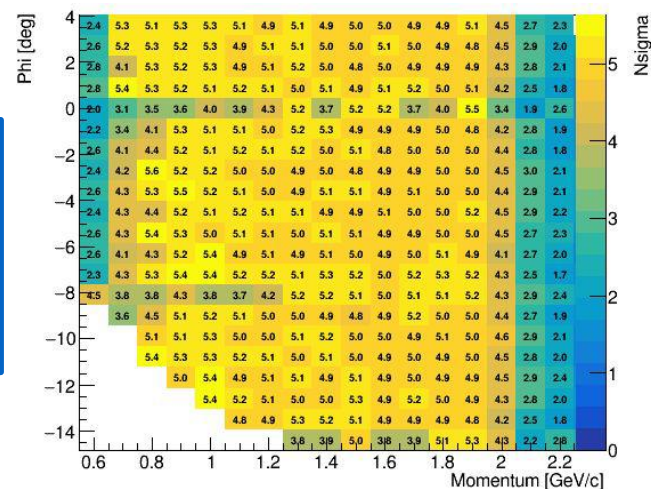
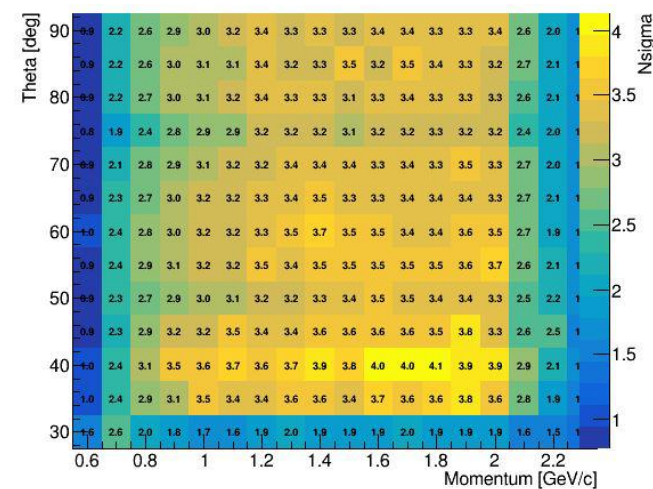
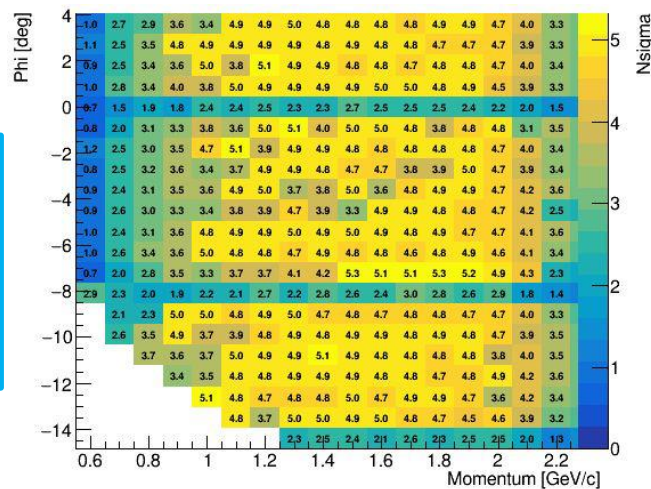
$$\varepsilon_K = \frac{N_K(A_{sum} < A_{thr})}{N_K^{tot}}$$

$$N_{\sigma} = \sqrt{2}[\text{erf}^{-1}(1 - 2\varepsilon_K) + \text{erf}^{-1}(1 - 2\varepsilon_{\pi})]$$

- DCR = 200 kHz/mm²
- $A_{thr} = 5.0$ ph.e.
- π/K -separation better than **3 σ** in the range from 0.7 to 2 GeV/c

- Drop regions correspond to the WLS and borders between counters

- DCR = 1 kHz/mm²
- $A_{thr} = 0.9$ ph.e.
- π/K -separation better than **4 σ** in the range from 0.7 to 2 GeV/c

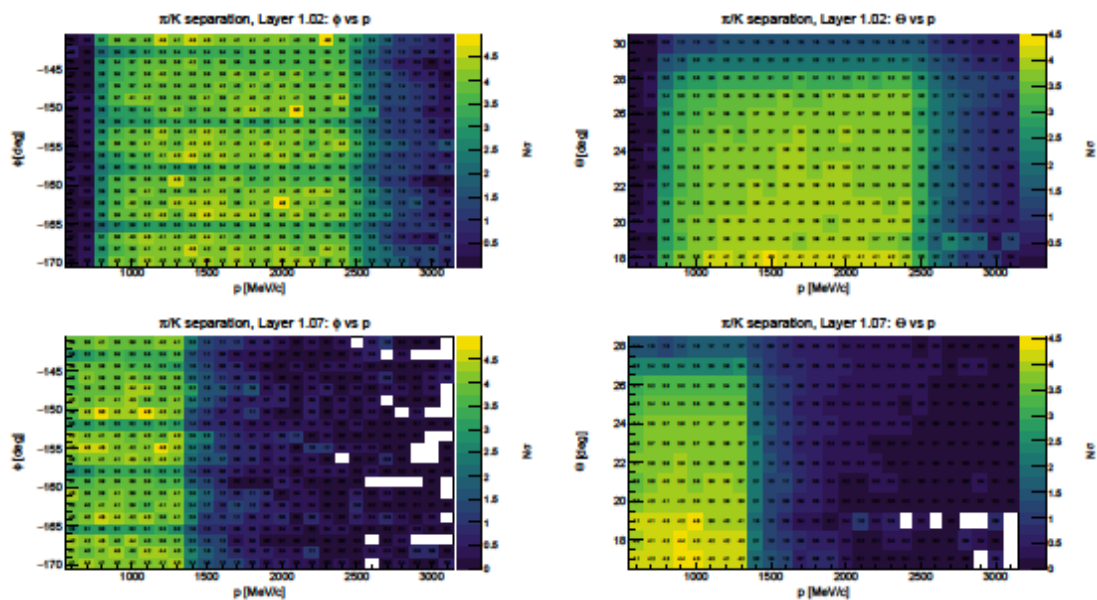


Separation power as a function of momentum and ϕ (left) and θ (right)

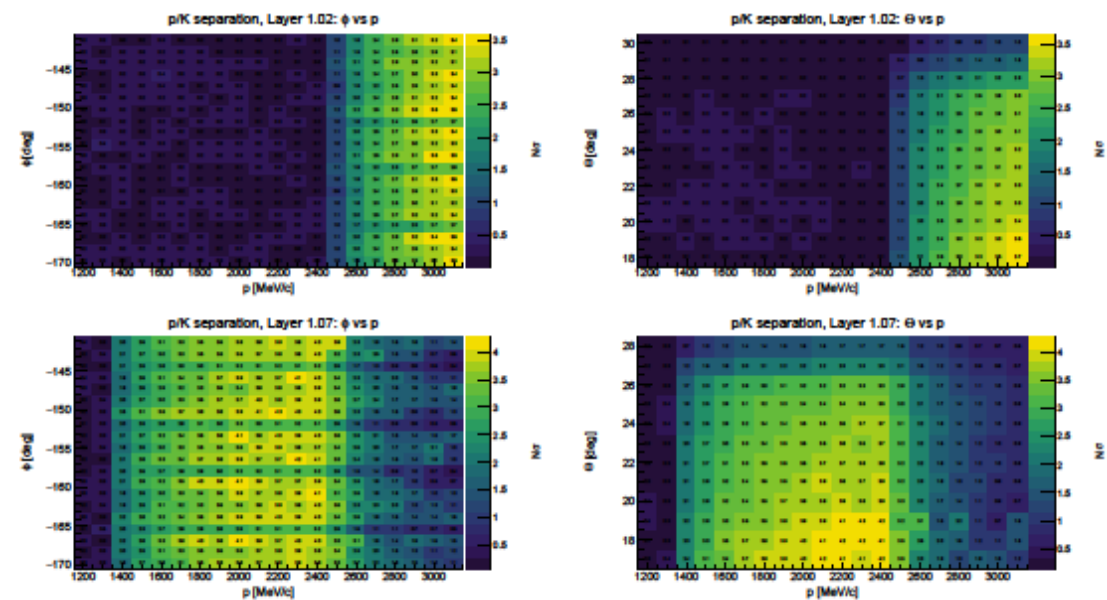
4-layer EASHIPH simulation

$$N_{\sigma} = \sqrt{2}[\text{erf}^{-1}(1 - 2\varepsilon_K) + \text{erf}^{-1}(1 - 2\varepsilon_{\pi})]$$

π/K from 0.7 to 2.5 GeV/c: $N_{\sigma} > 3$



K/p from 1.4 to 3 GeV/c: $N_{\sigma} > 2.5$



π/K separation provided by 2-layer sub-systems based on aerogels with refractive indices $n=1.02$ (top) and $n=1.07$ (bottom). π/K separation power N_{σ} as a function of momentum and ϕ (left) and θ (right) for DCR 1 kHz/mm² with threshold values $A_{\text{thr}} = 0.5$ ph.e.

K/p separation provided by 2-layer sub-systems based on aerogels with refractive indices $n=1.02$ (top) and $n=1.07$ (bottom). K/p separation power N_{σ} as a function of momentum and ϕ (left) and θ (right) for DCR 1 kHz/mm² with threshold values $A_{\text{thr}} = 0.5$ ph.e.