PID detectors for K/π separation of particles with momenta p>1.5 GeV

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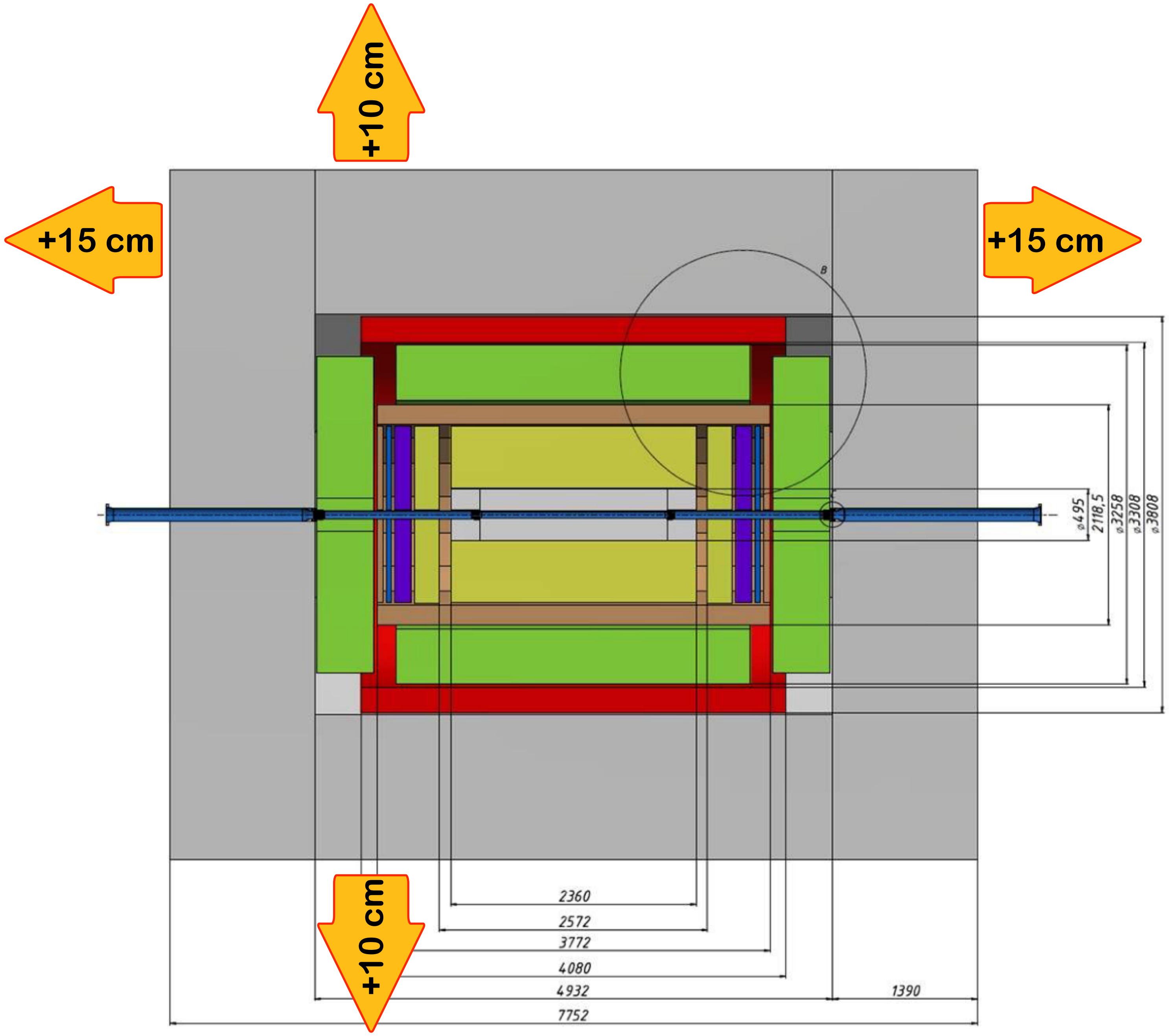
Outline

- Motivation for PID above 1.5 - 2 GeV (Cherenkov detector)
  - D meson production and asymmetries
  - Light hadron (π, K, p) production and asymmetries
- Detectors of Cherenkov light
  - Threshold detectors
  - RICH (Ring Imaging CHerenkov) detectors
  - DIRC (Detection of Internally Reflected Cherenkov light) detectors
- Position of Cherenkov detector in SPD (discussion)

Possibility for a new PID detector in SPD

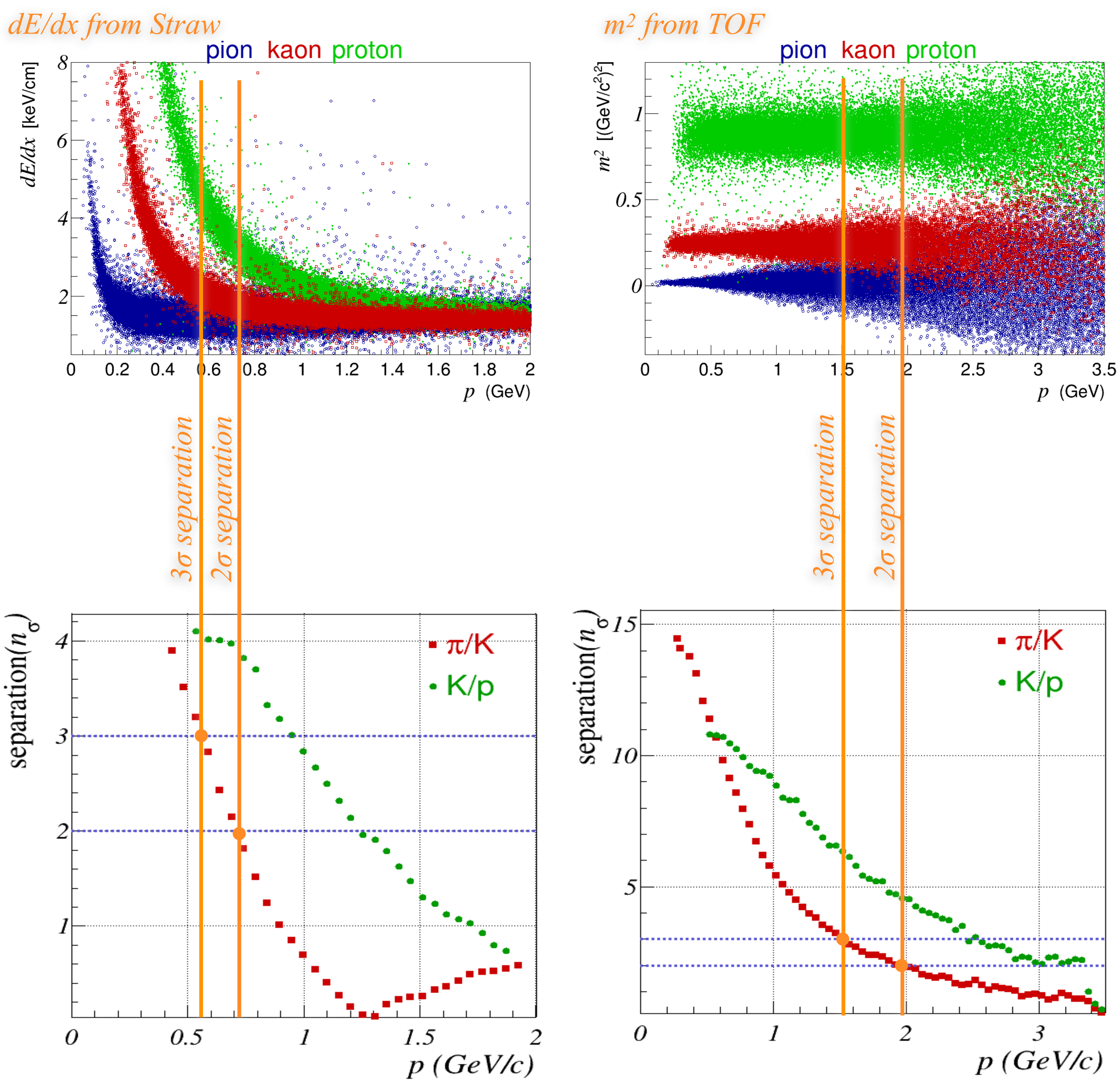


- After discussions with KOMETA late last year, the upper weight limit of the SPD detector (without electronic platform) has been increased from 1100 tons to 1500 tons, t.e. we have +400 tons.

- 1-2 years ago, the option of installing a Cherenkov detector in the SPD barrel was initially discussed, but it was abandoned due to lack of space.

- So far, we have left only 16 cm of space on both sides of the detector for the Cherenkov threshold detector, which may be too small.

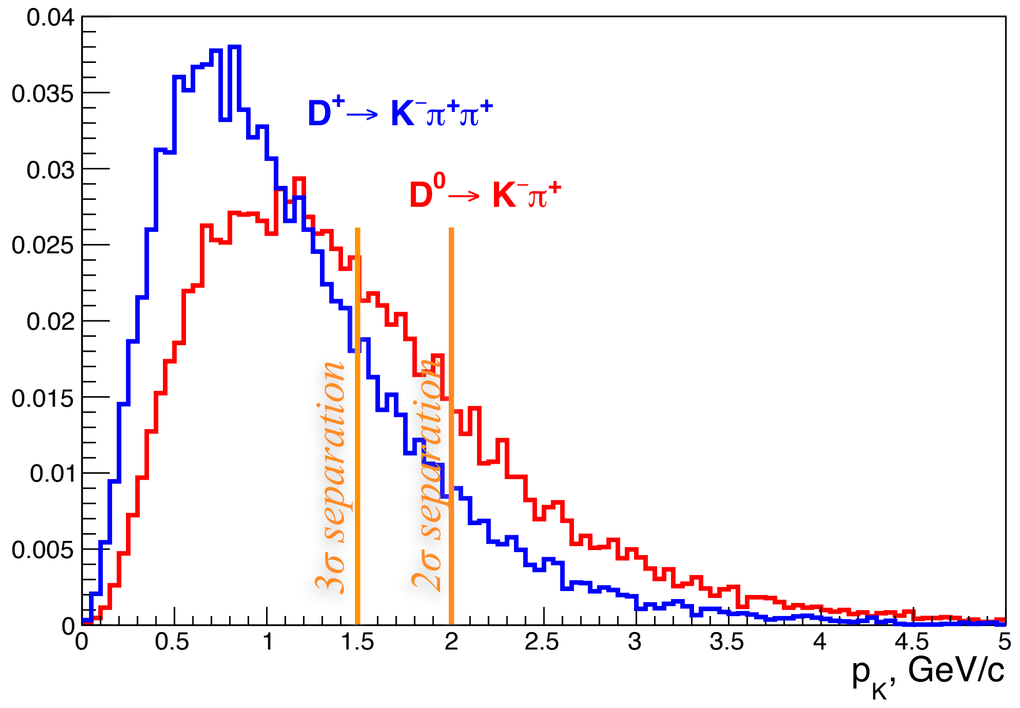
TOF vs dE/dx for π/K separation in SPD

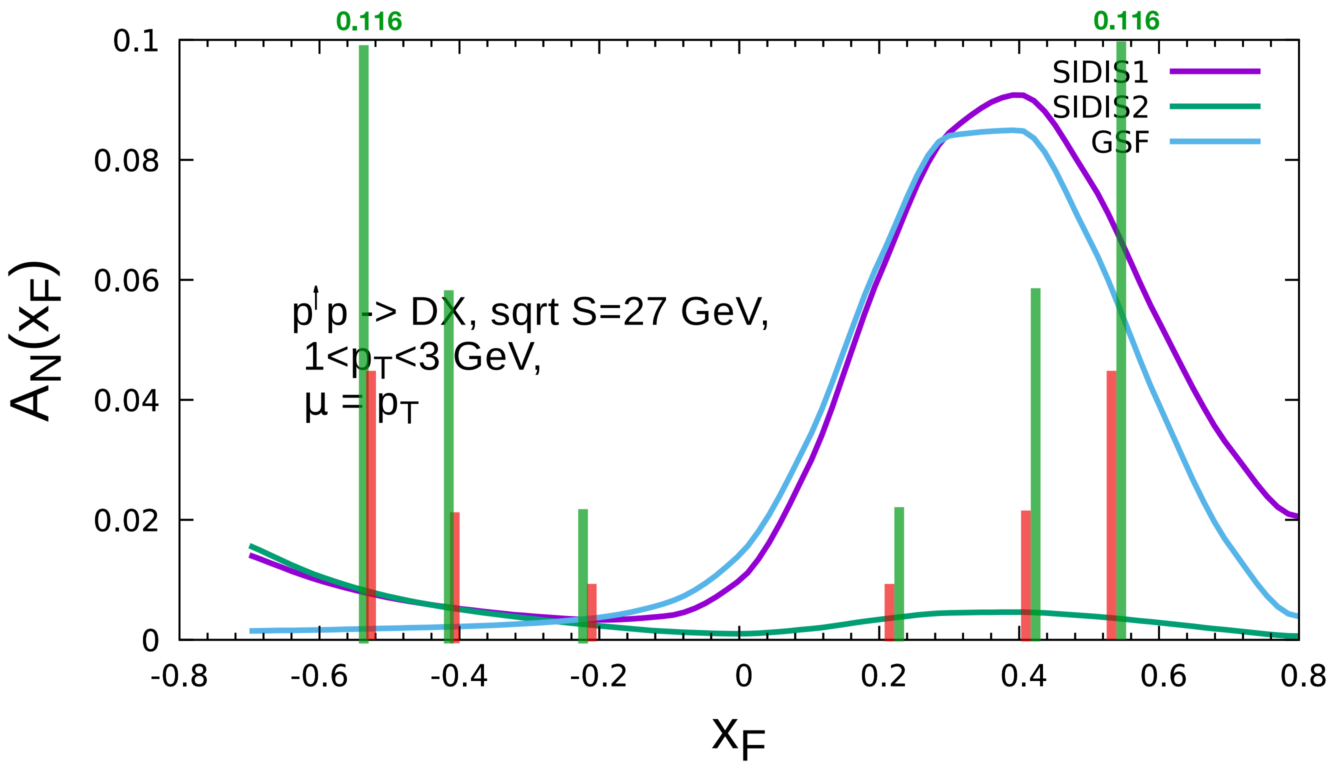


A.Ivanov, SPD CM in Oct 2022

- According to present state of simulation, a 3σ separation of π and K can be achieved for momenta
  - p < 0.55 GeV (ST)
  - p < 1.5 GeV (TOF)
- ST is useful only for short tracks which do not cross TOF (or 1-st phase setup without TOF)
- Many physics applications will require a PID for momenta p > 1.5 GeV

Production of D mesons in SPD

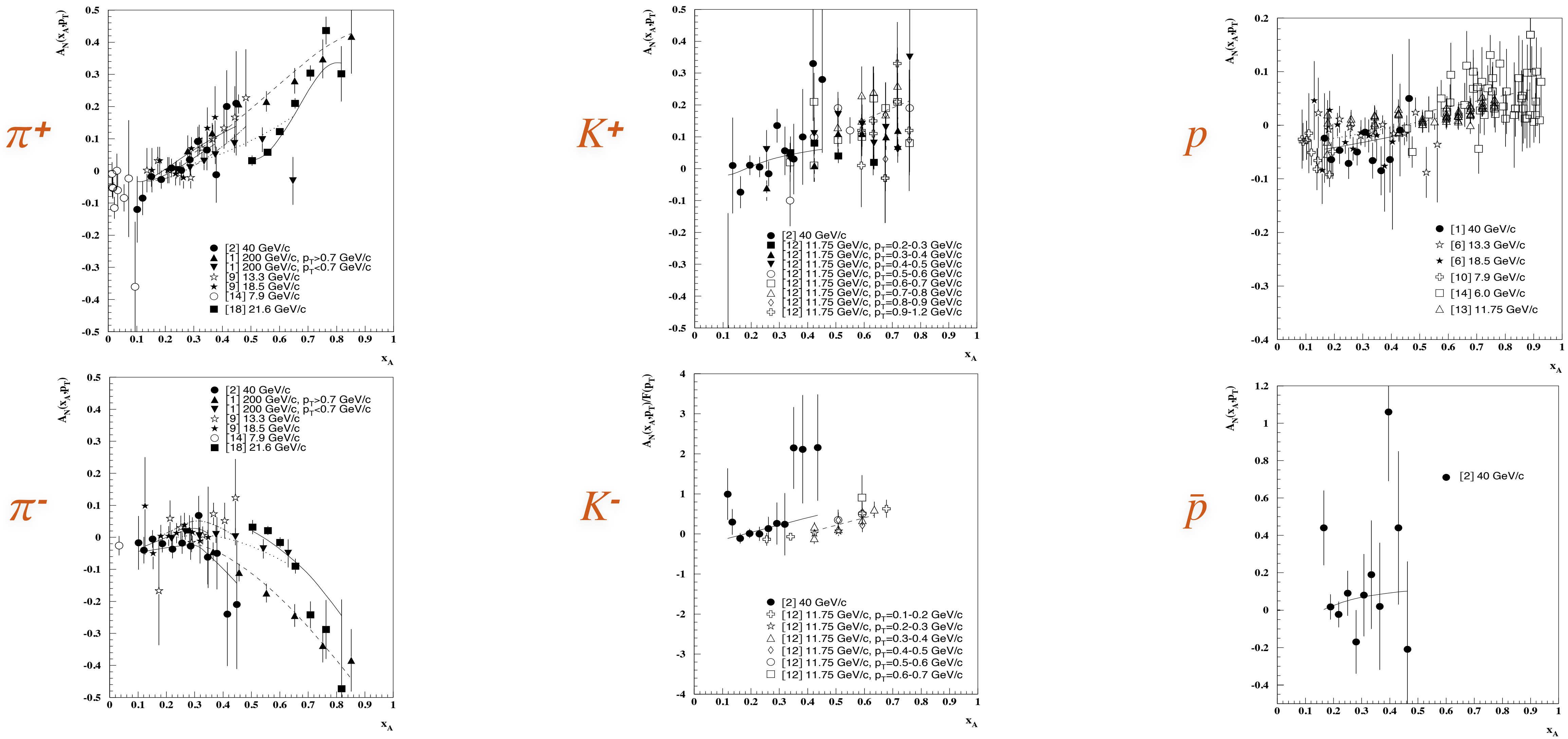




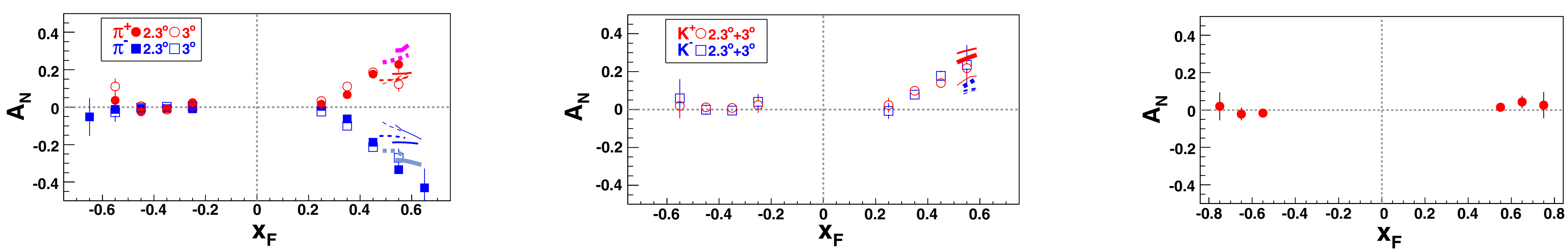
- The region of p<1.5 GeV (3σ separation) covers only ~50% of kaons produced in D decays.
- The largest effect for A_N is expected for x_F=0.4, i.e. high momentum mesons.

Light hadron (π, K, p) asymmetries

Fixed target experiments (Eur.Phys.J.C14(2000)427)



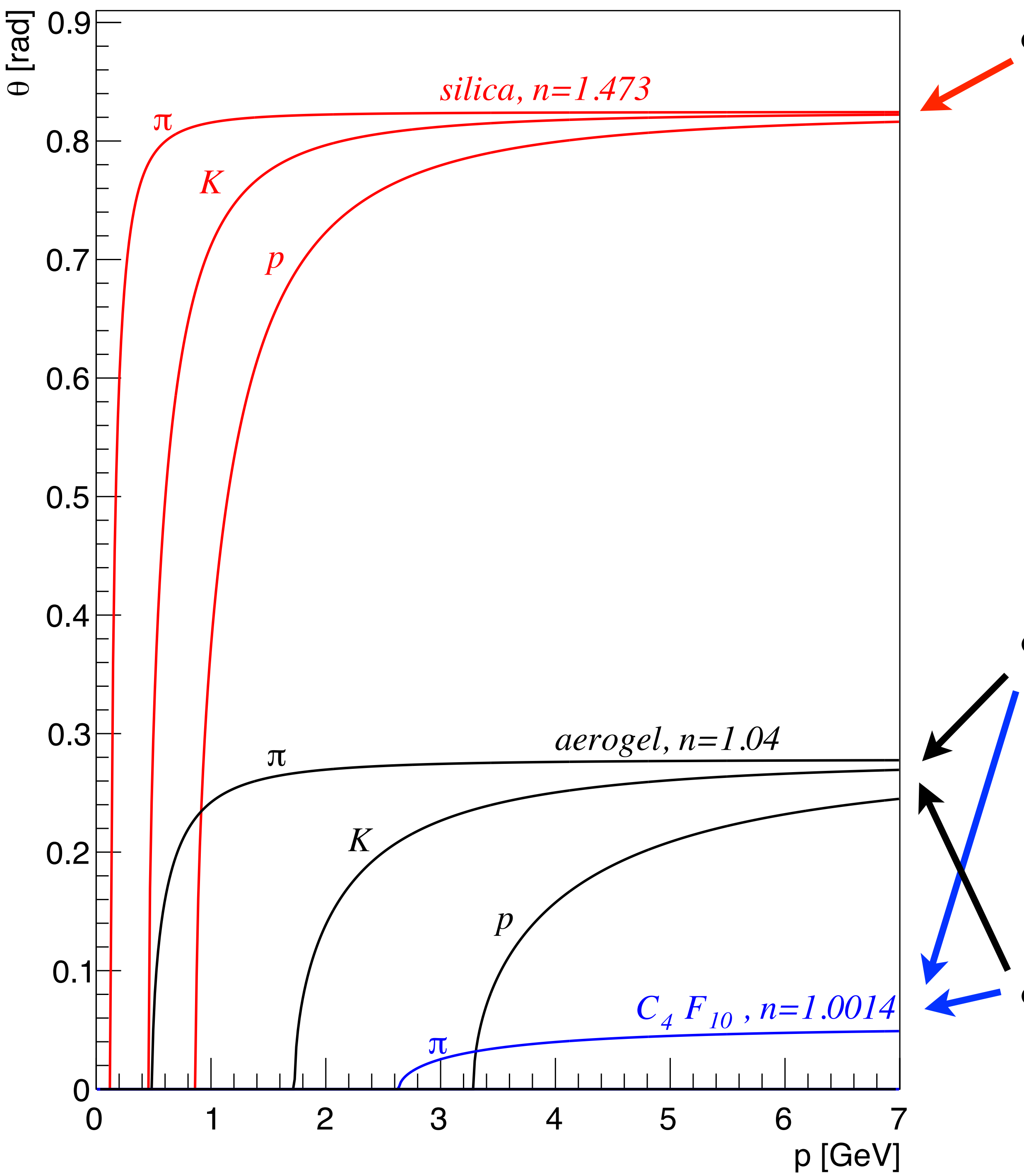
Collider experiment BRAHMS (Phys.Rev.Lett.101(2008)042001)



For E_{CM}=27GeV: p=4GeV → x_F=0.3, p=6GeV → x_F=0.45

$$m = p\sqrt{n^2 cos^2\theta - 1}$$

Cherenkov detectors (high momentum PID)



- **DIRC (Detection of Internally Reflected Cherenkov light) detectors**
  - First use of DIRC in BaBar in 1990s
  - TOP (Time of Propagation) counter in Belle-II
  - TORCH (Time Of internally Reflected Cherenkov light) in LHCb
  - FDIRC (Focusing DIRC) for GLUEX
  - FDIRC for the PANDA barrel and endcap
  - FDIRC is proposed for EIC
- **RICH (Ring Imaging CHerenkov) detectors**
  - Used in high-energy experiments since 1982 (E605)
  - RICH1 of LHCb (Aerogel+gas)
  - RICH of HERMES (Aerogel+gas)
  - ARICH (Aerogel RICH) endcap detector in Belle II
- **Threshold detectors**
  - Extensively used since 1950s in many experiments
  - ASHIPH (Aerogel SHifer PHotomultplier) in KEDR

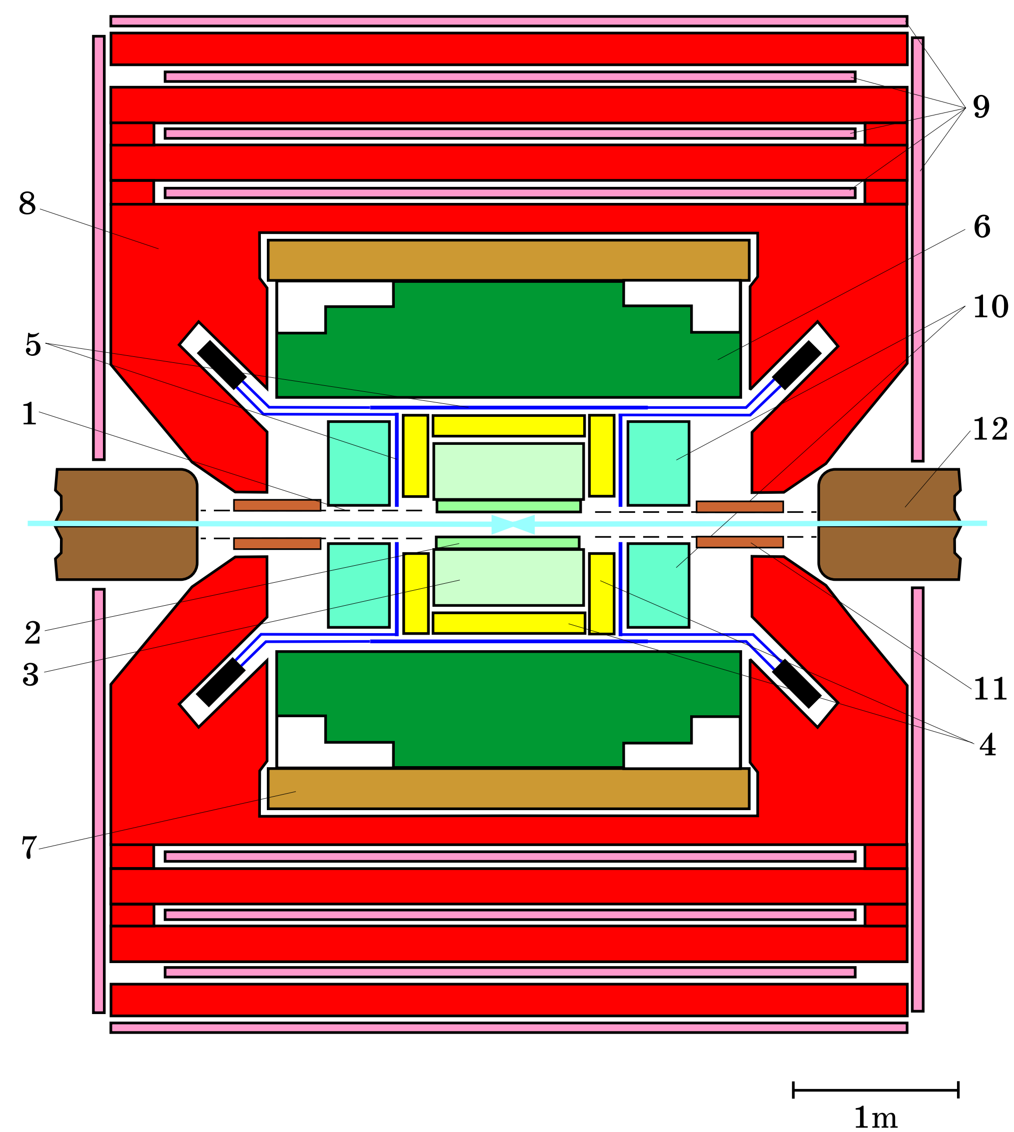
Cherenkov threshold detector

- ASHIPH (Aerogel SHifer PHotomultplier) in KEDR
- TDR of SPD

ASHIPH Cherenkov threshold counter in KEDR

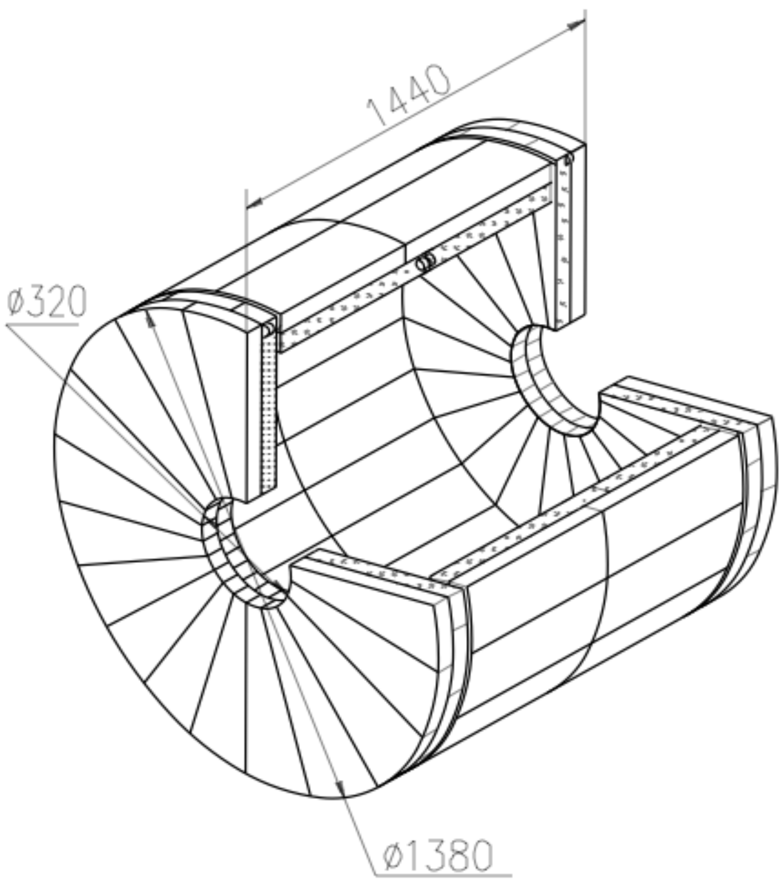
Барельная часть АЧС КЕДР перед установкой в детектор.

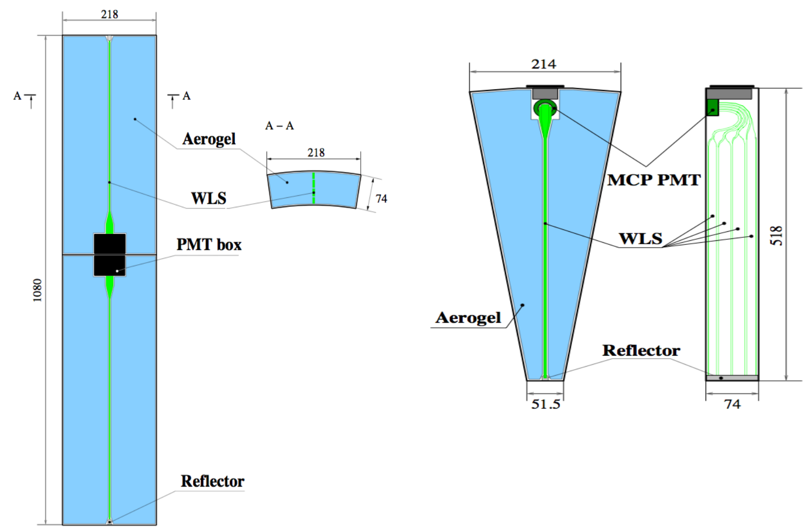
Detector KEDR



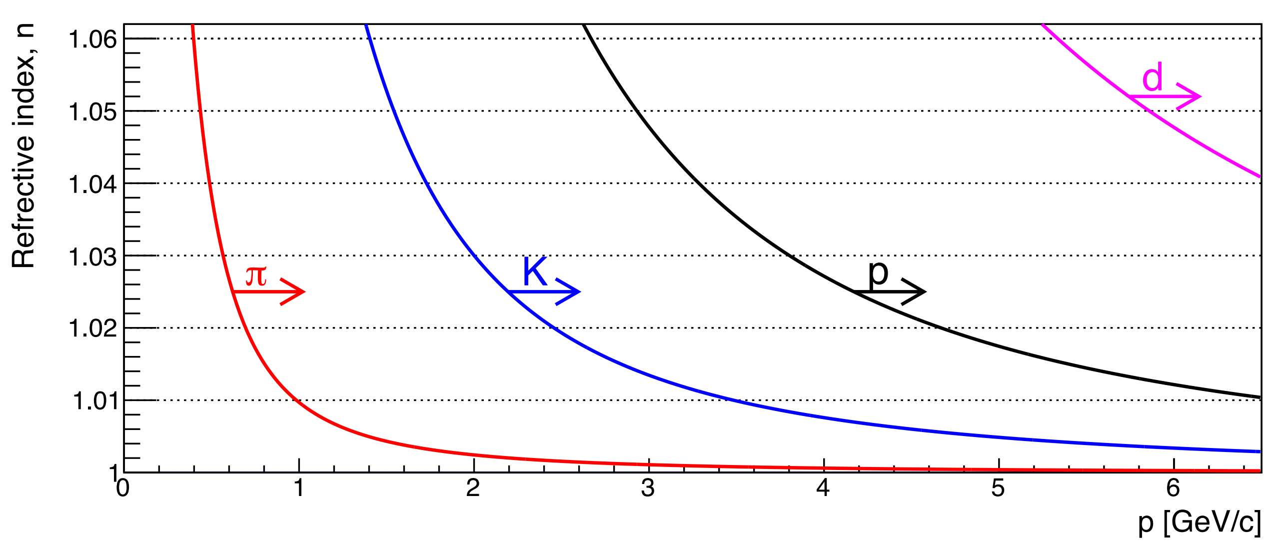
1 - Beam pipe
2 - Vertex detector
3 - Drift chamber
4 - Aerogel threshold counters
5 - ToF counters
6 - Lkr calorimeter
7 - Superconducting coil
8 - Yoke
9 - Muon chambers
10 - CsI calorimeter
11 - Compensating solenoid
12 - Quadrupole

ASHIPH Cherenkov threshold counter in KEDR





- 160 counters arranged in 2 layers
- 96% of solid angel
- 1000 liters of aerogel with n=1.05
- π/K- separation in momentum range 0.6-1.5GeV/c
- Light collection with help of WLS
- 160 MCP PMTs with photocathode ø18mm able to work in magnetic field up to 2T
- Thickness of the material is 12%X_0



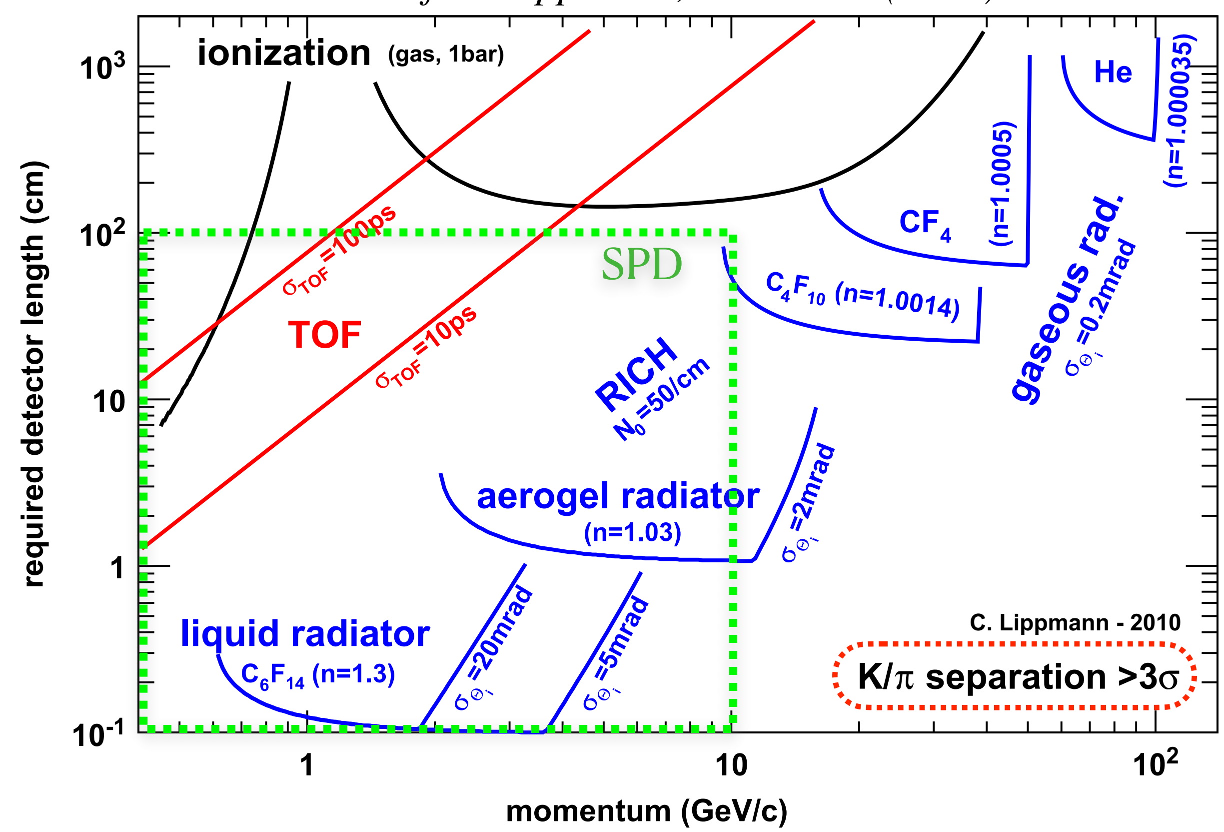
RICH (Ring Imaging CHerenkov) detector

- RICH1 of LHCb (Aerogel+gas)
- RICH of HERMES (Aerogel+gas)
- ARICH (Aerogel RICH) endcap detector in Belle II

RICH detector for SPD

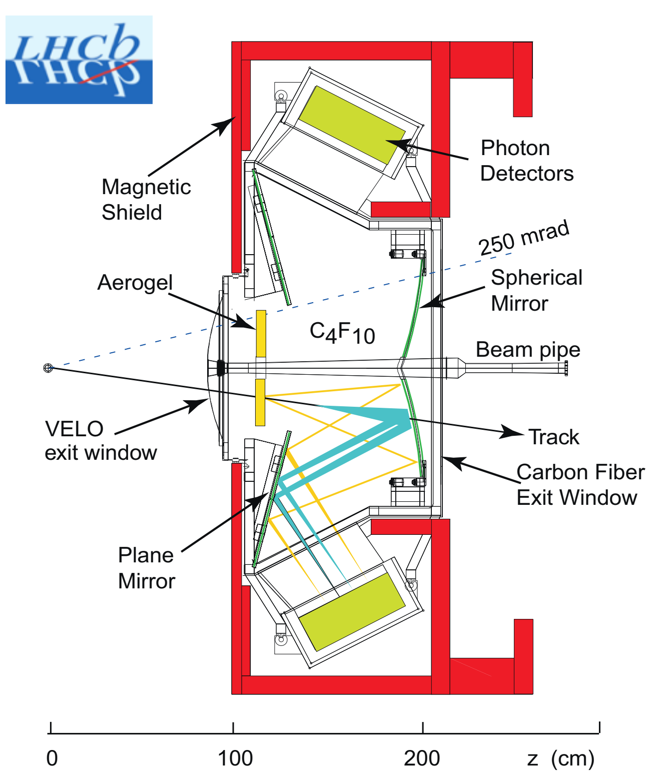
- In region of SPD (*l~1* m, *p<10* GeV) aerogel is the most efficient radiator
- Dual radiator (Aerogel+C_4F_{10}) can improve the efficiency for larger momenta
- Example of a dual RICH is
  - RICH1 of LHCb. It was used in Run I for identification in the 2<p<40 GeV range

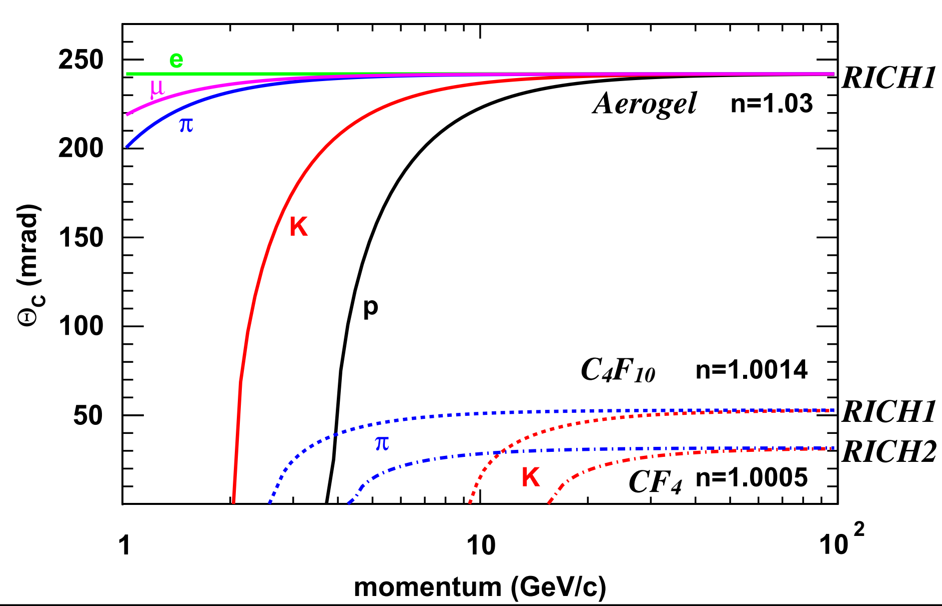
Ref: C.Lippmann, NIMA 666 (2012) 148

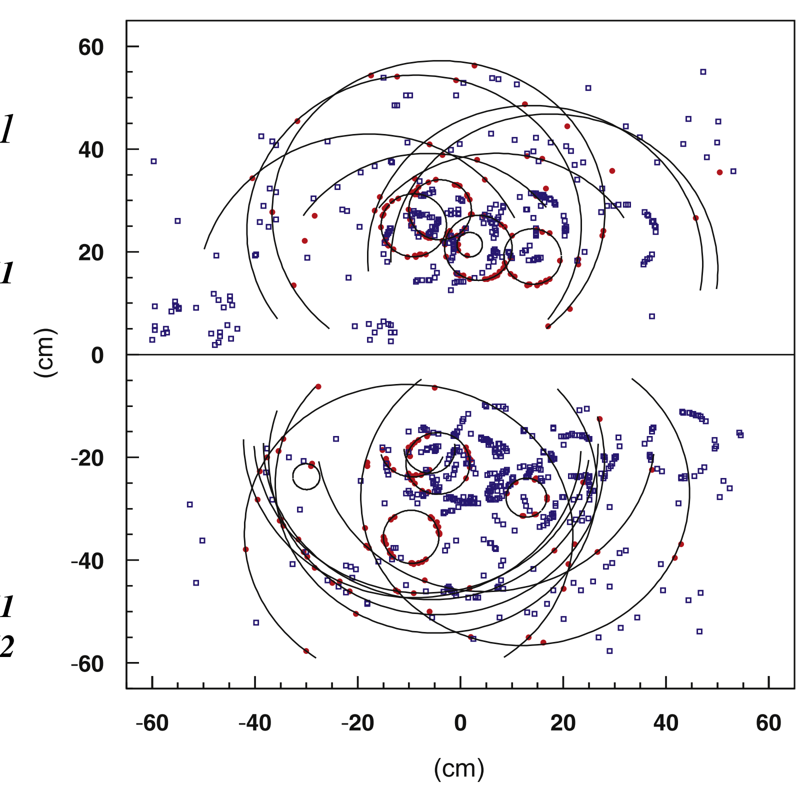


LHCb RICH1, Run I

Ref: M.Adinolfi et al, Eur.Phys.J.C 73 (2013) 2431



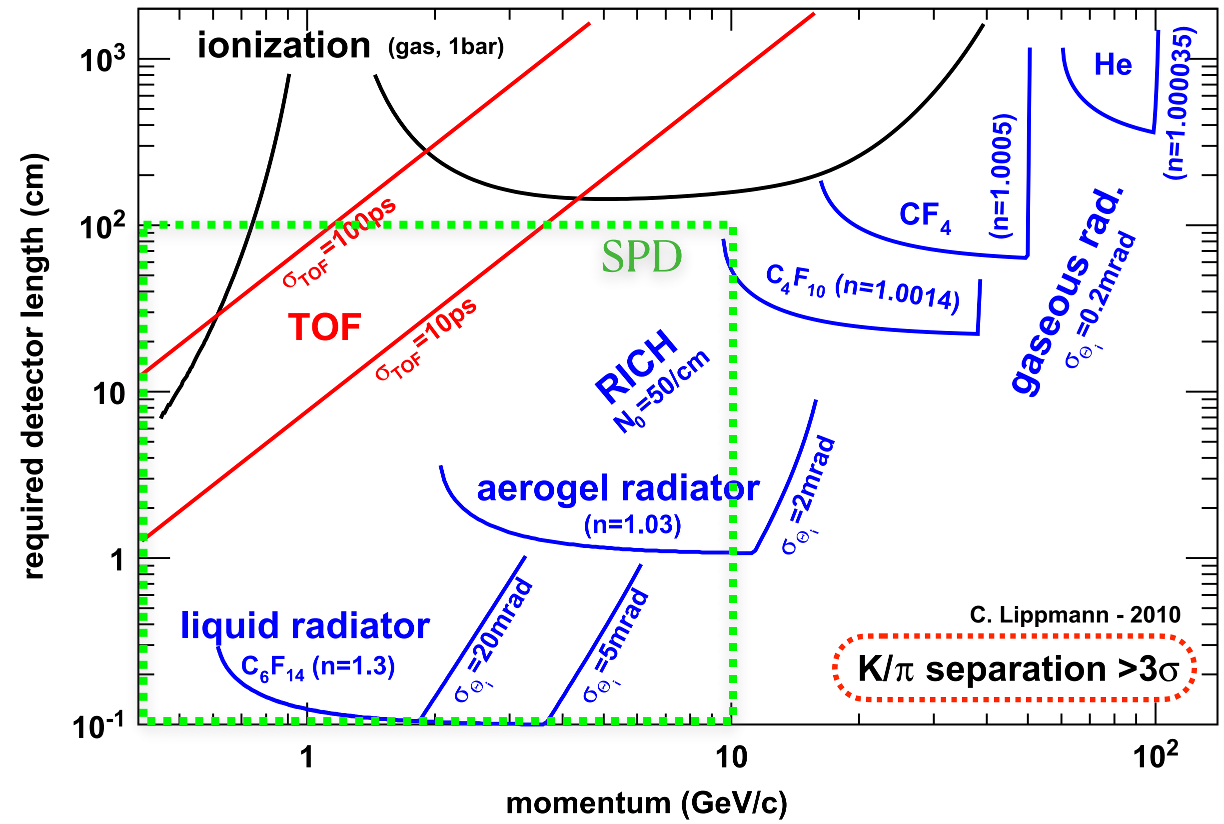


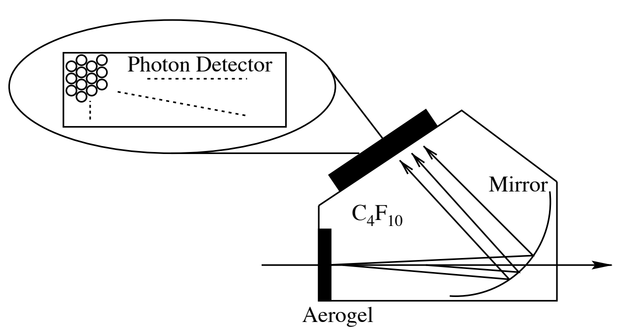


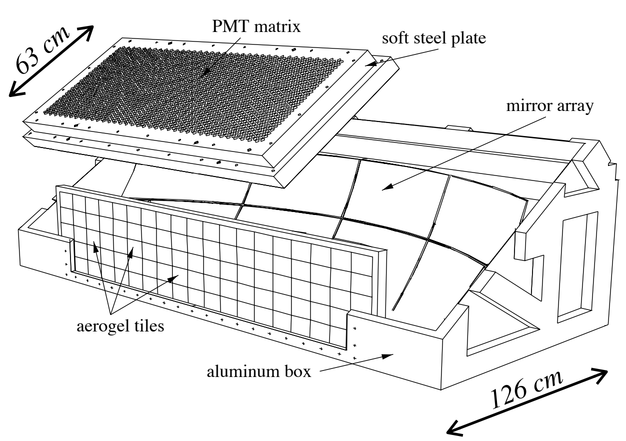
RICH detector for SPD

- In region of SPD (*l~1* m, *p<10* GeV) aerogel is the most efficient radiator
- Dual radiator (Aerogel+C_4F_{10}) can improve the efficiency for larger momenta
- Example of a dual RICH is
    - RICH1 of LHCb. It was used in Run I for identification in the *2<p<40* GeV range
    - RICH of HERMES (DESY). It was used in the range of *2<p<15* GeV

Ref: C.Lippmann, NIMA 666 (2012) 148

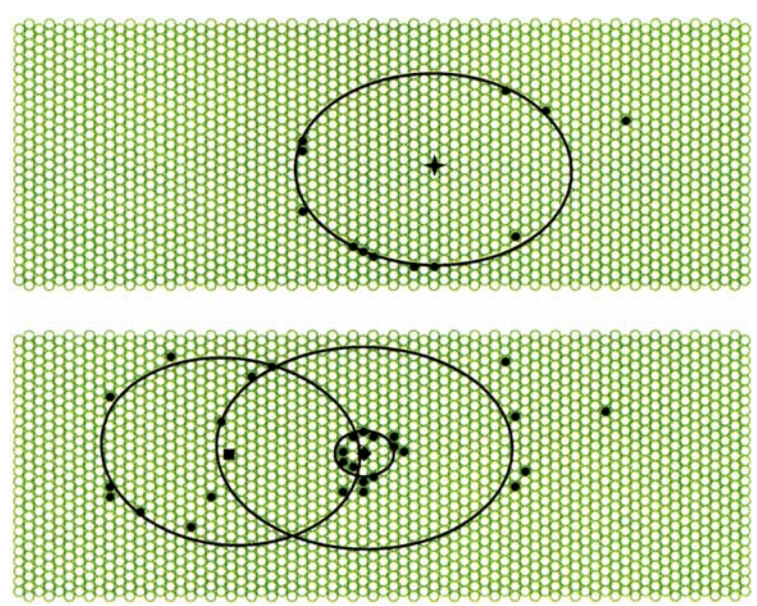


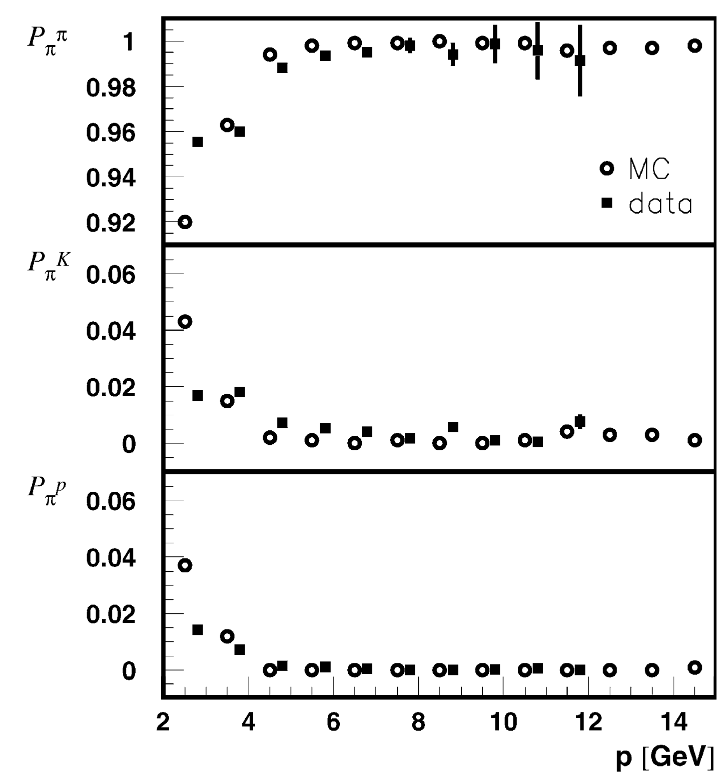




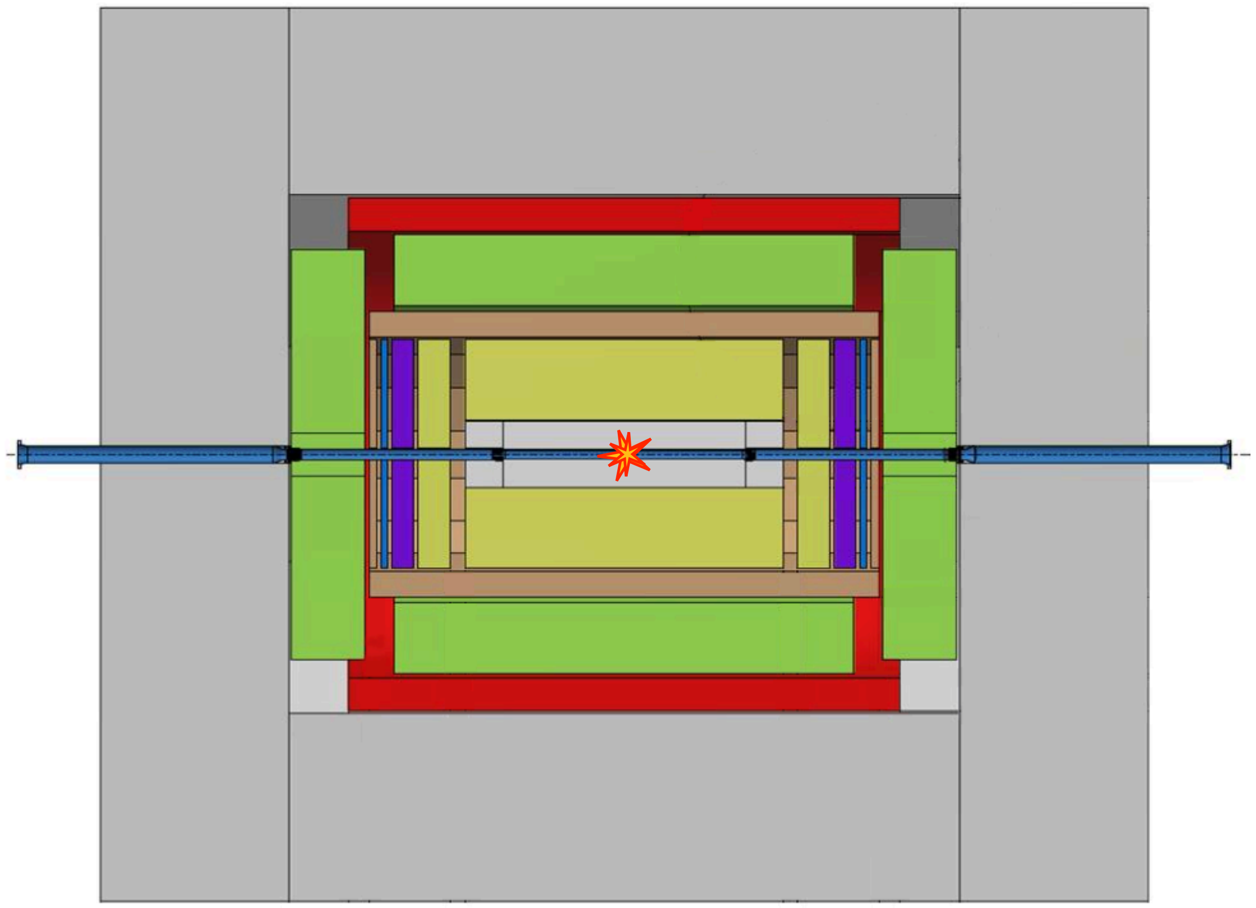
HERMES (DESY) RICH

Ref: N.Akopov et al, NIMA 479 (2002) 511



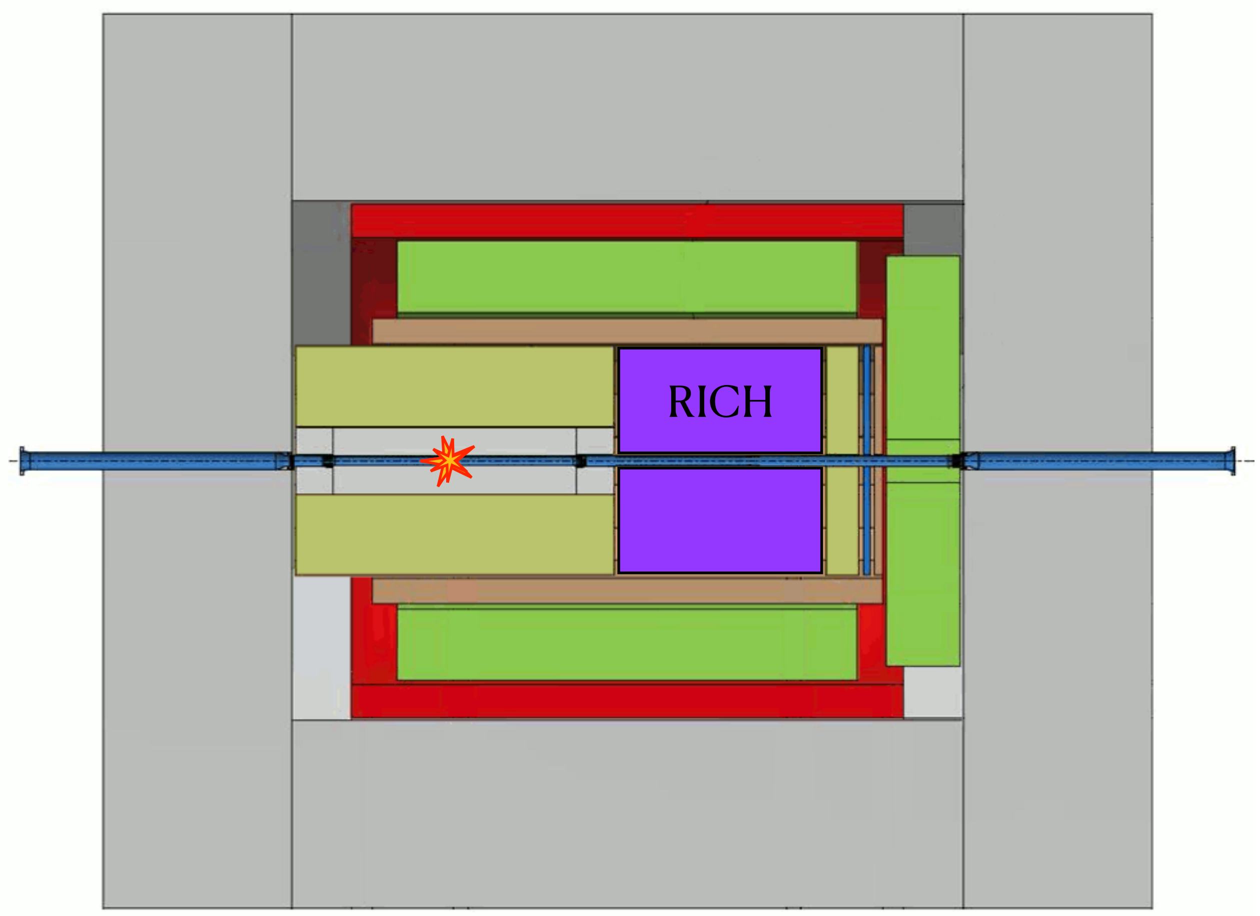


RICH detector for SPD

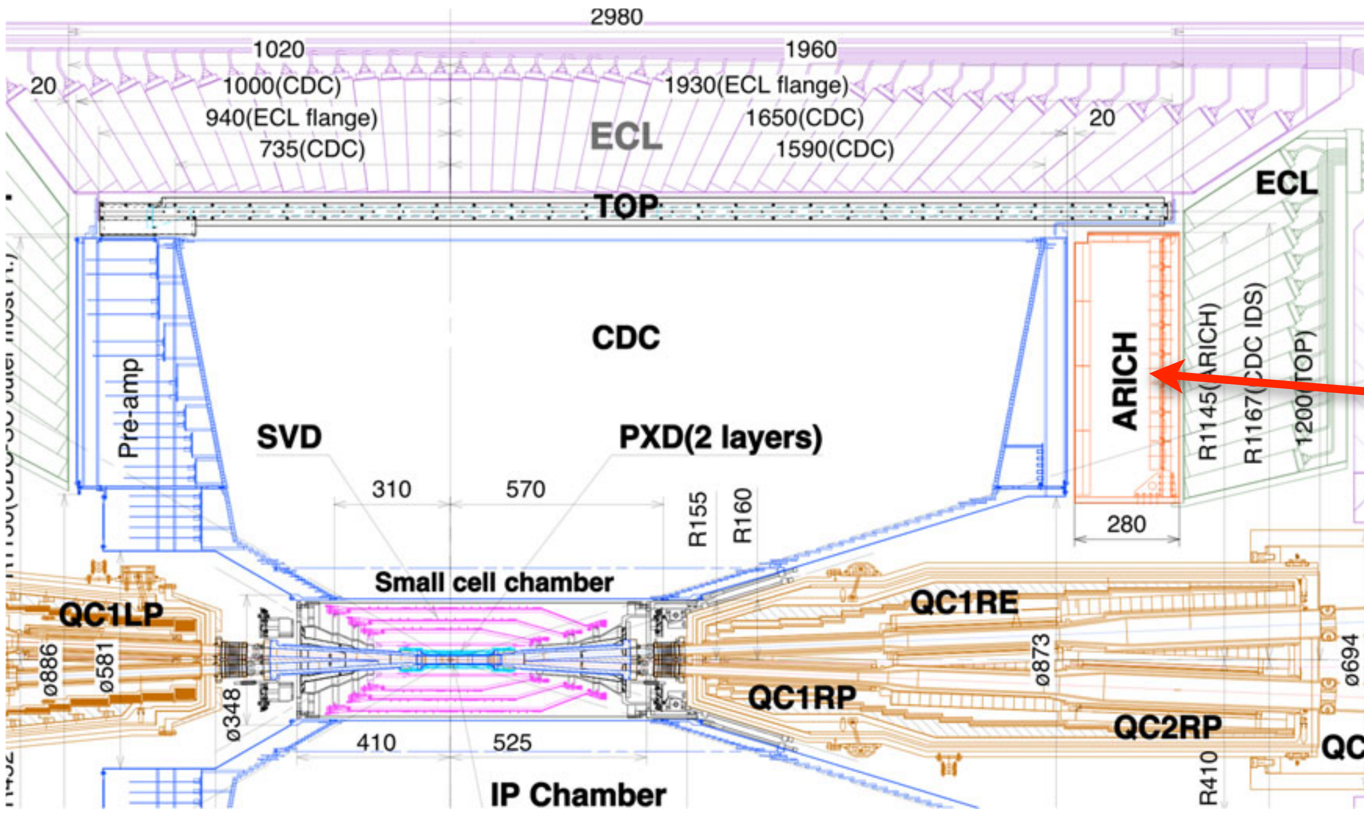


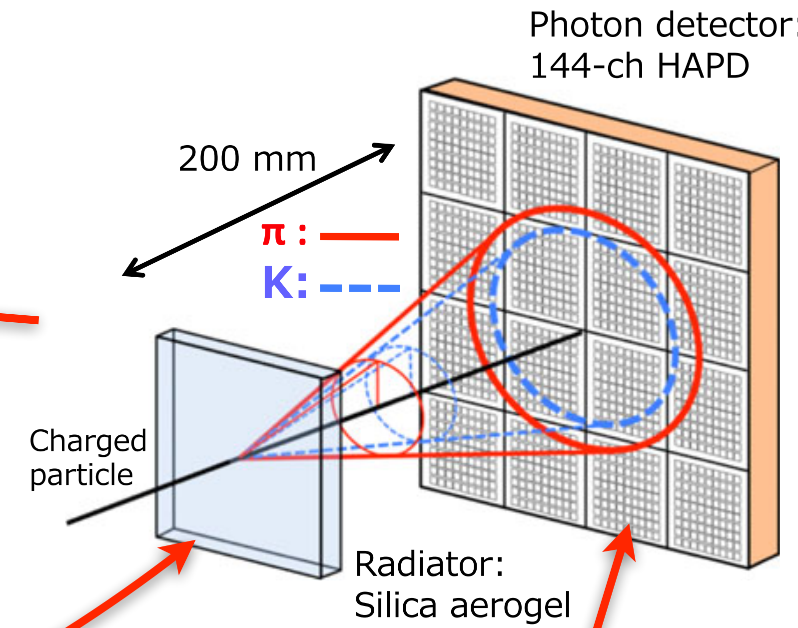
- Up - down stream symmetric layout in present configuration (TDR)
- So far, only Δz=16 cm is dedicated to each of two Cherenkov detectors (disks) in endcaps

- IP is displaced by ~120 cm from center (asymmetric layout)
- Imitation of a fixed target experiment
- Volume for RICH: R=87cm, L=130 cm
- ST-barrel must be a self-supporting structure



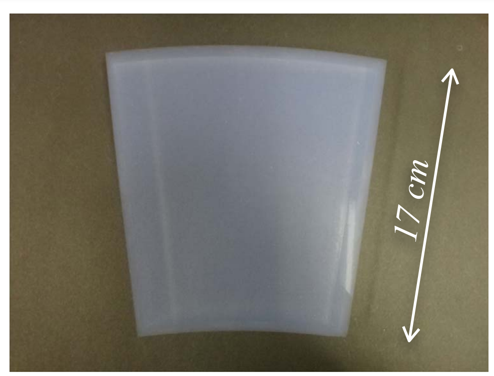
ARICH (in endcap) of the Belle II experiment

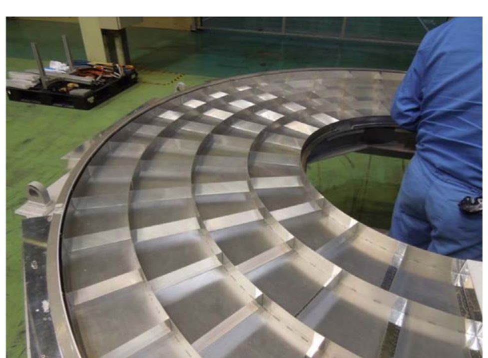


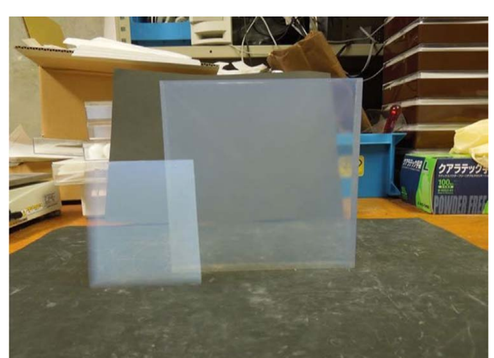


Dual-Aerogel radiator

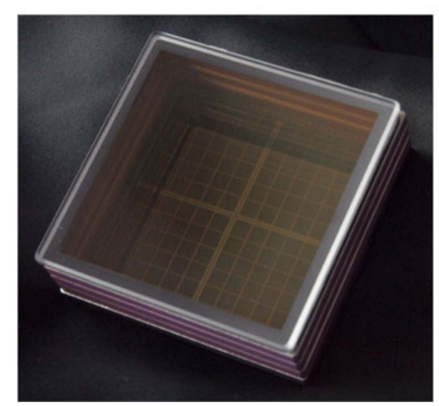
- Focusing effect using n_1=1.045 and n_2=1.055
- Mass production in 2014
- Ref: *NIMA 876 (2017) 129*

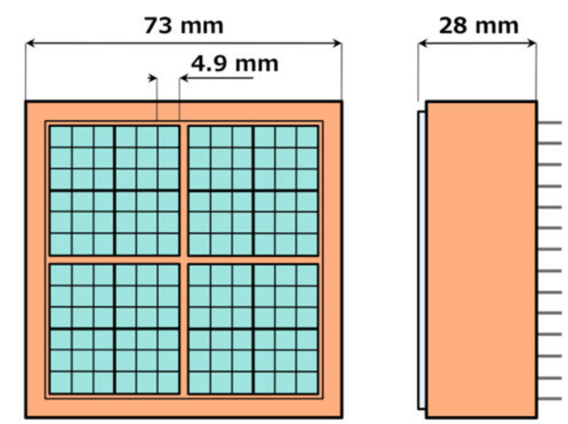






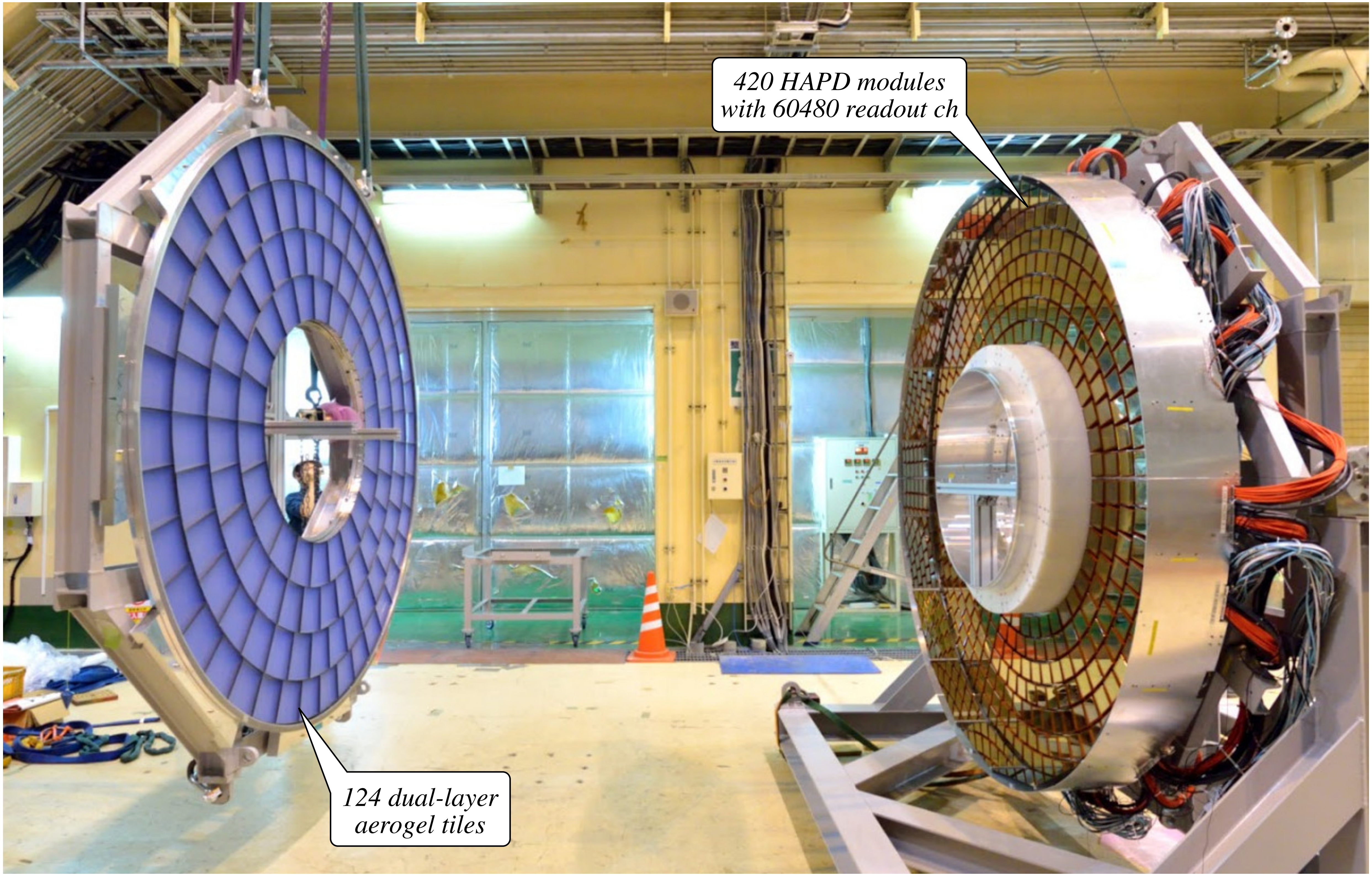
HAPD (Hybrid Avalanche Photo Detector)





- R_π -R_K = 5 mm for p = 4 GeV → pixel size is 5 mm
- Ref: *PTEP 2016 (2016) 3, 033H01 [1603.02503]*

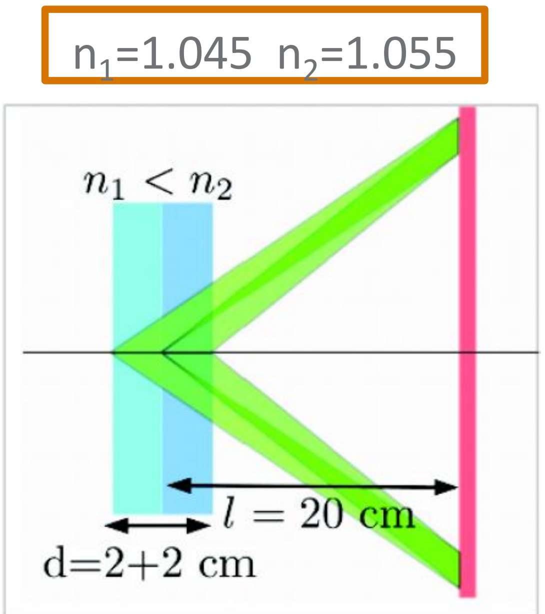
ARICH (in endcap) of the Belle II experiment

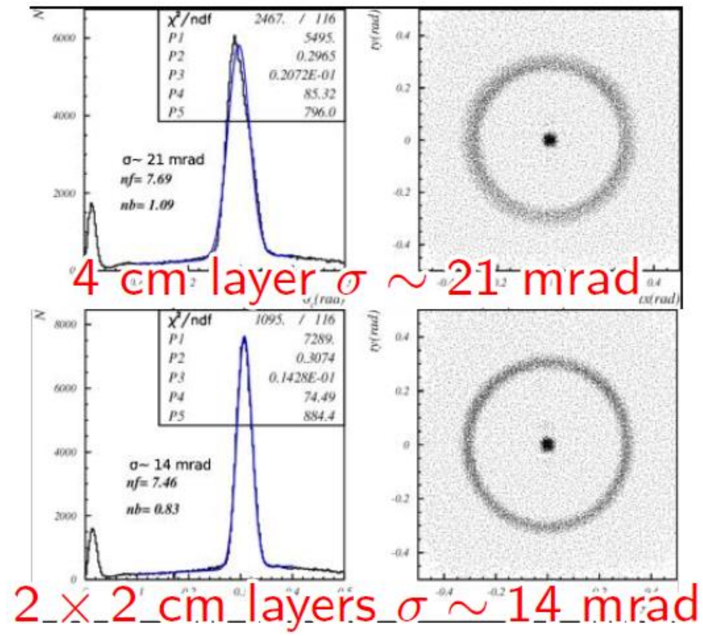


Installed in Oct 2017

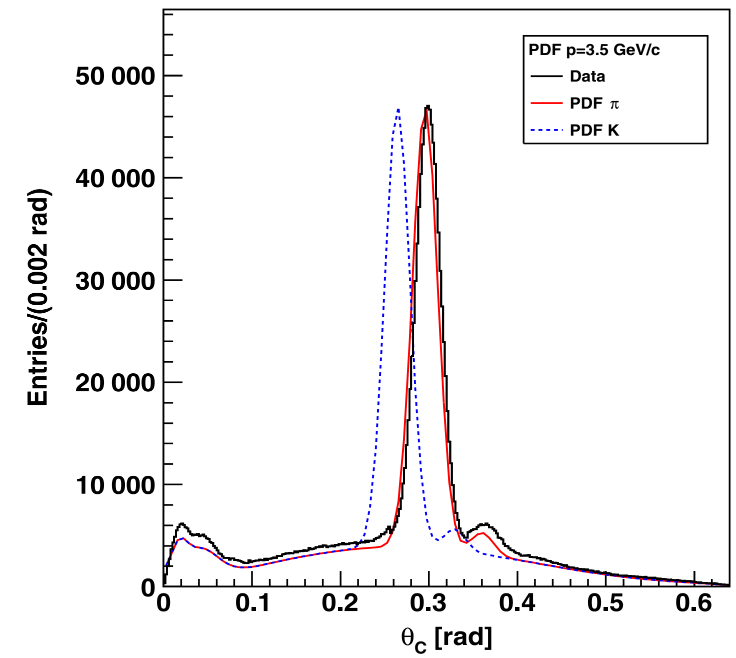
ARICH (in endcap) of the Belle II experiment

Focusing principle

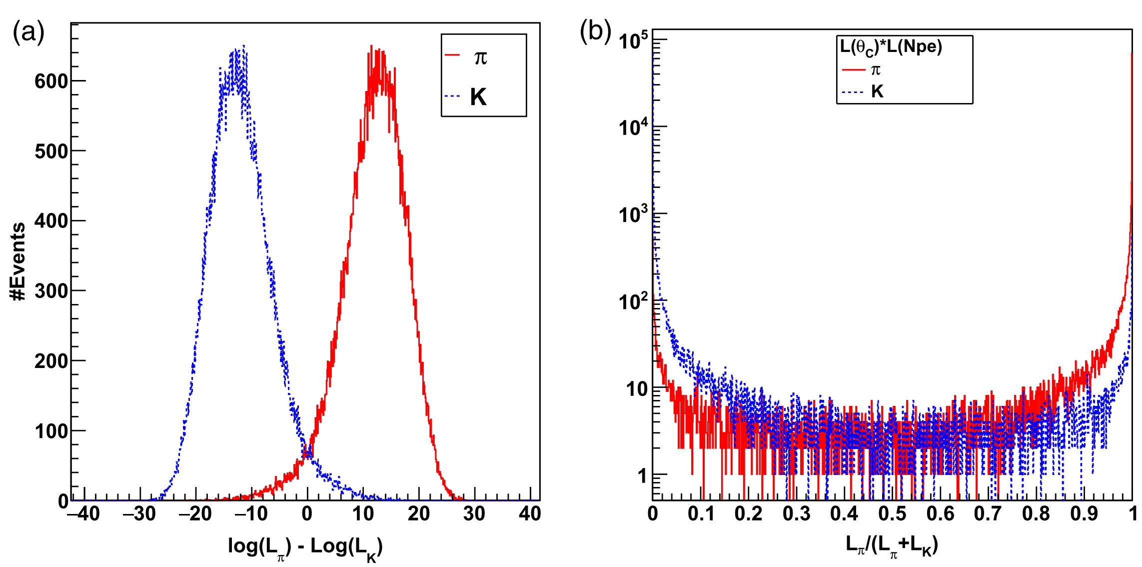




Cherenkov angle for π and K



π and K likelihoods



The difference between the likelihoods

Likelihood ratio distribution

Fig. 15. (a) Distribution of the likelihood difference between the pion (solid line) and kaon (dashed line) at 3.5 GeV/c. (b) Likelihood ratio distribution for pions and kaons at 3.5 GeV/c.

Efficiency of π and K identification

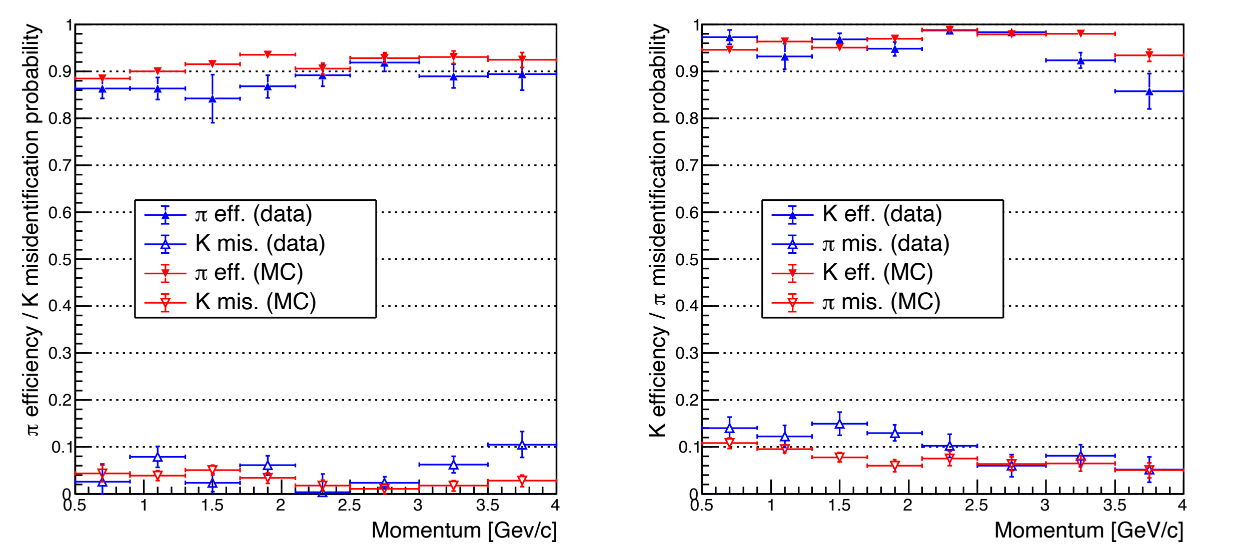


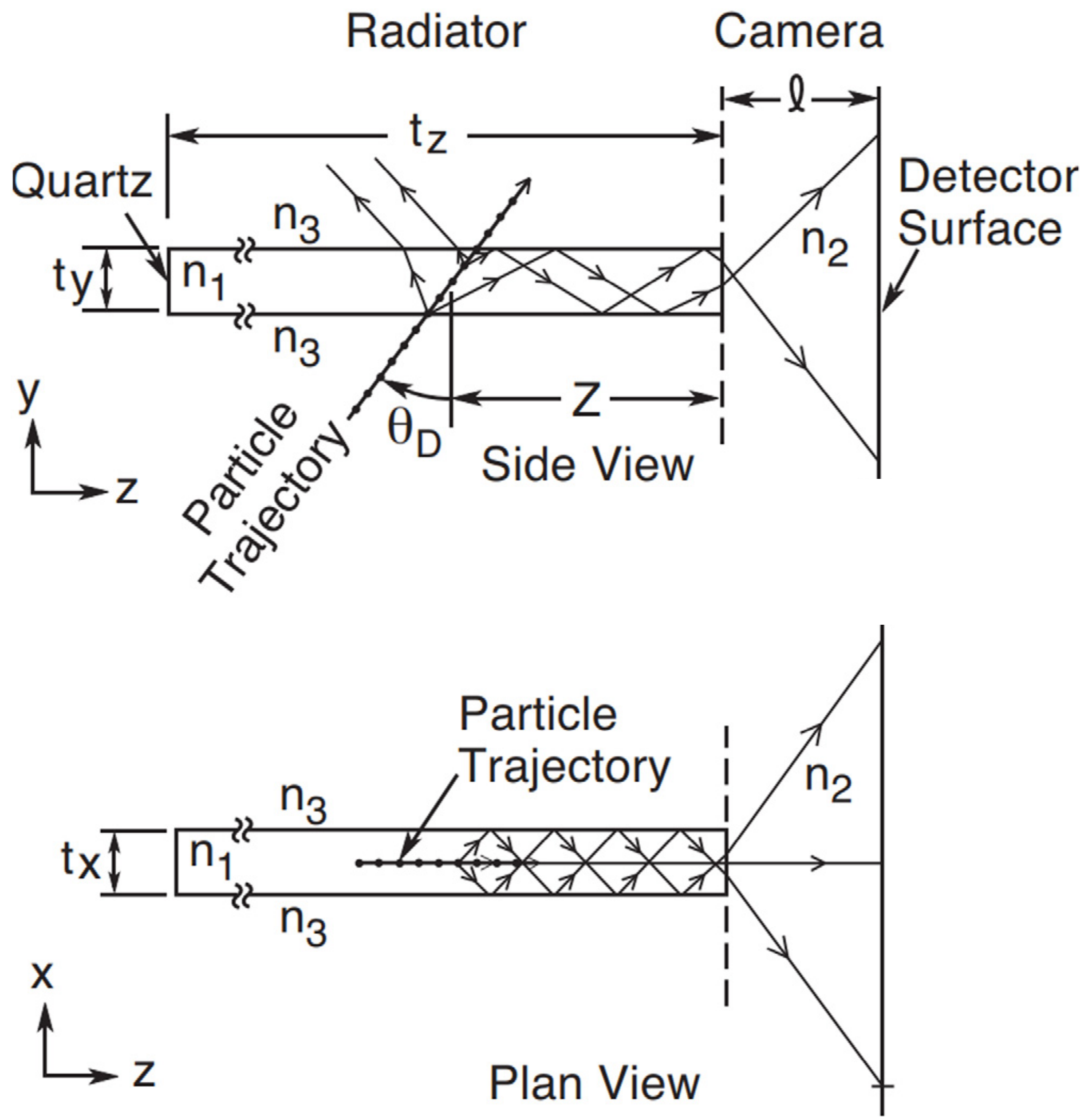
Figure 14: Efficiency and misidentification probability as a function of the momentum: π efficiency and K misidentification probability (left), and K efficiency and π misidentification probability (right).

DIRC (Detection of Internally Reflected Cherenkov light) detector

Ref: B.Ratcliff and J.Va'vra, NIMA 970 (2020) 163442

- First use of DIRC in BaBar in 1990s
- Pattern recognition based DIRC
  - FDIRC (Focusing DIRC) for GLUEX
  - FDIRC for the PANDA barrel and endcap
- Time-based DIRC
  - TOP (Time of Propagation) counter in Belle-II
  - TORCH (Time Of internally Reflected Cherenkov light) in LHCb
- DIRC-type detector is proposed for EIC

DIRC concept



- Charged particle traversing radiator with refractive index n and $\beta = v/c > 1/n$ emits Cherenkov photons on cone with half opening angle

$$\cos \theta_c = 1/\beta n(\lambda)$$

- For tracks with $\beta \approx 1$ and $n > \sqrt{2}$ some photons are always totally internally reflected
- Bar, plate or disk is made of Fused Silica ("Quartz") and serve as a radiator and a light guide
- Photons exit radiator via optional focusing optics into expansion region, detected on photon detector array
- DIRC is intrinsically a 3-D device, measuring: x, y, and time of Cherenkov photons, defining θ_c, ϕ_c, $t_{propagation}$

DIRC of the BaBar experiment

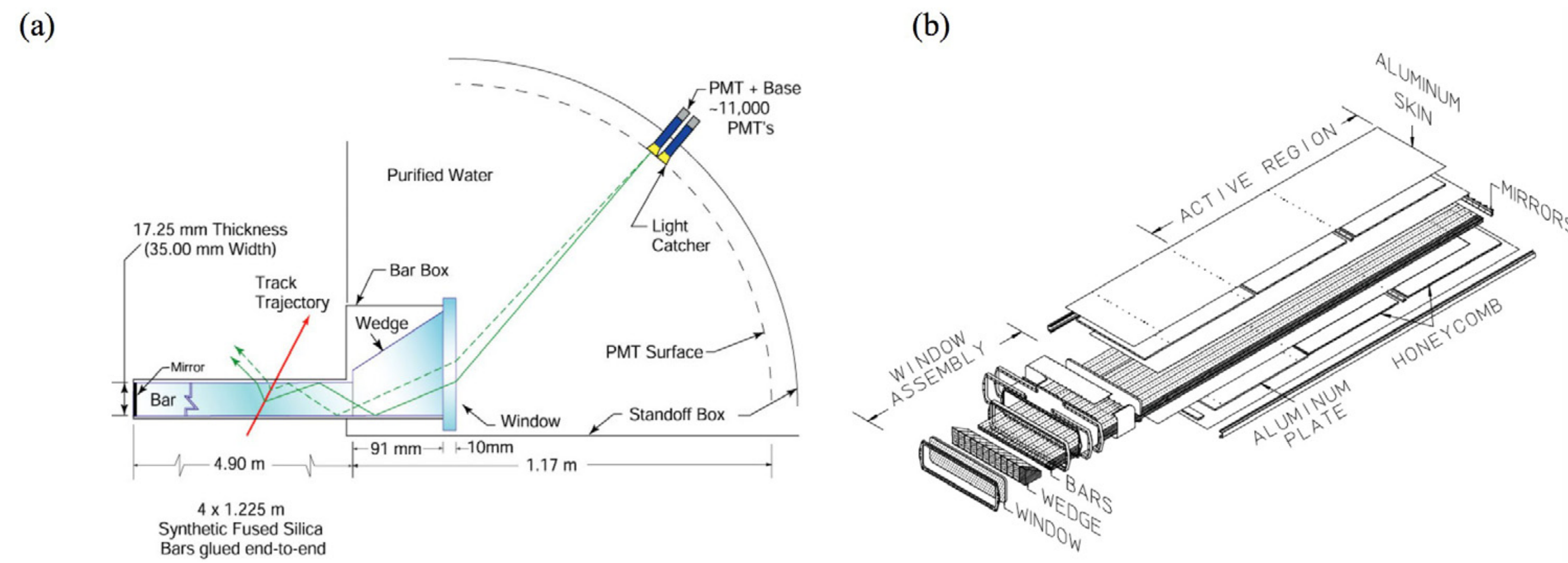


Fig. 2.1. (a) Schematic of the DIRC fused silica radiator bar and imaging region. End bar cross-section acts as a pin hole in imaging camera. (b) BaBar DIRC bar box housing fused silica radiator. Each bar box had 12 bars, each one was 1.7 cm × 3.5 cm × 4.90 m.

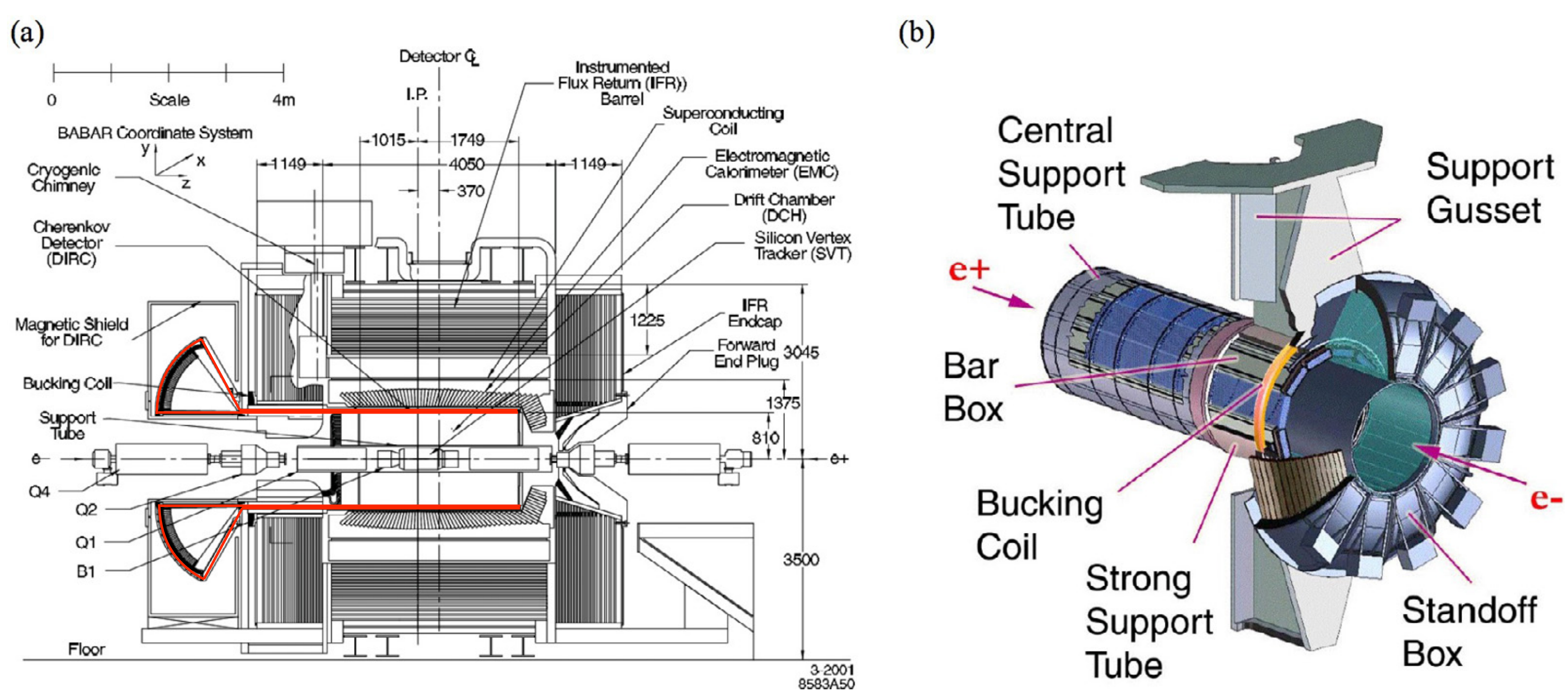
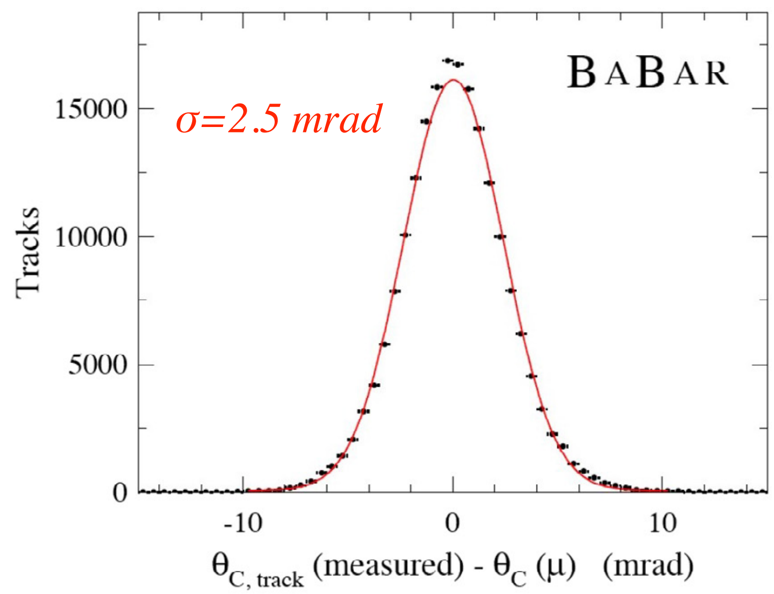


Fig. 2.2. (a) Overall BaBar experiment. The DIRC photon camera is located outside of magnet which meant that the DIRC bars had to penetrate the iron endcap structure. All dimensions are given in millimeters. (b) Schematic view of the principal components of the DIRC mechanical support structure. The magnetic shield is not shown in this view.

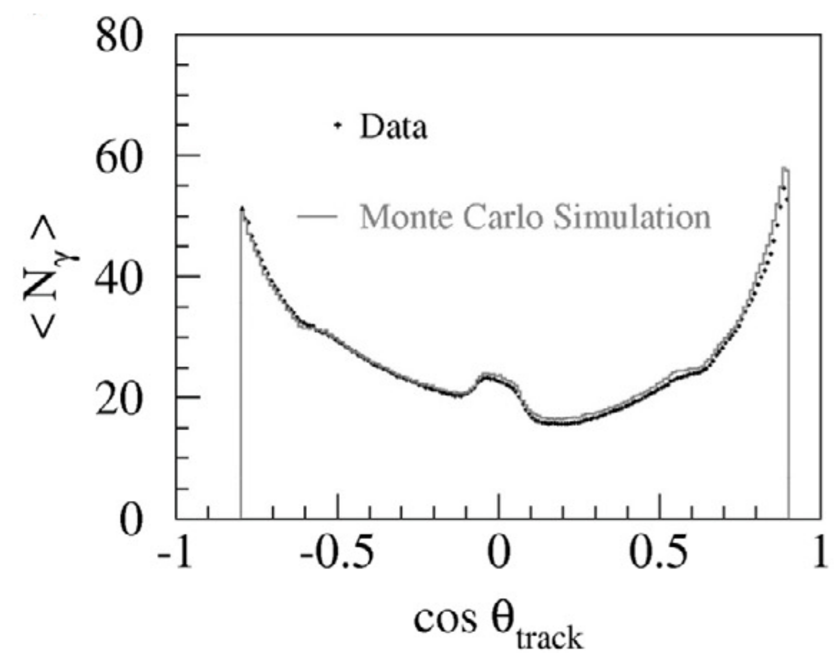
DIRC of the BaBar experiment

DIRC of the BaBar experiment

Resolution for Cherenkov angle



Average number of detected photons



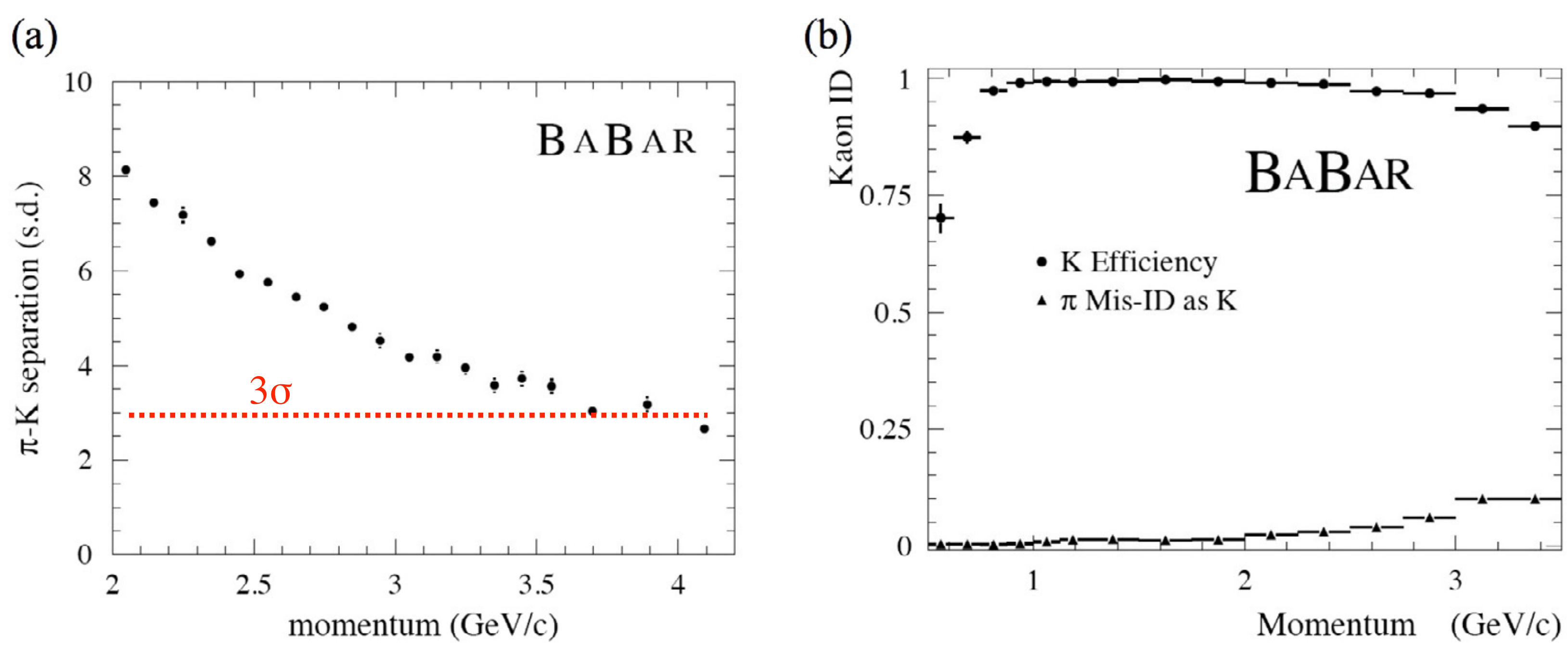
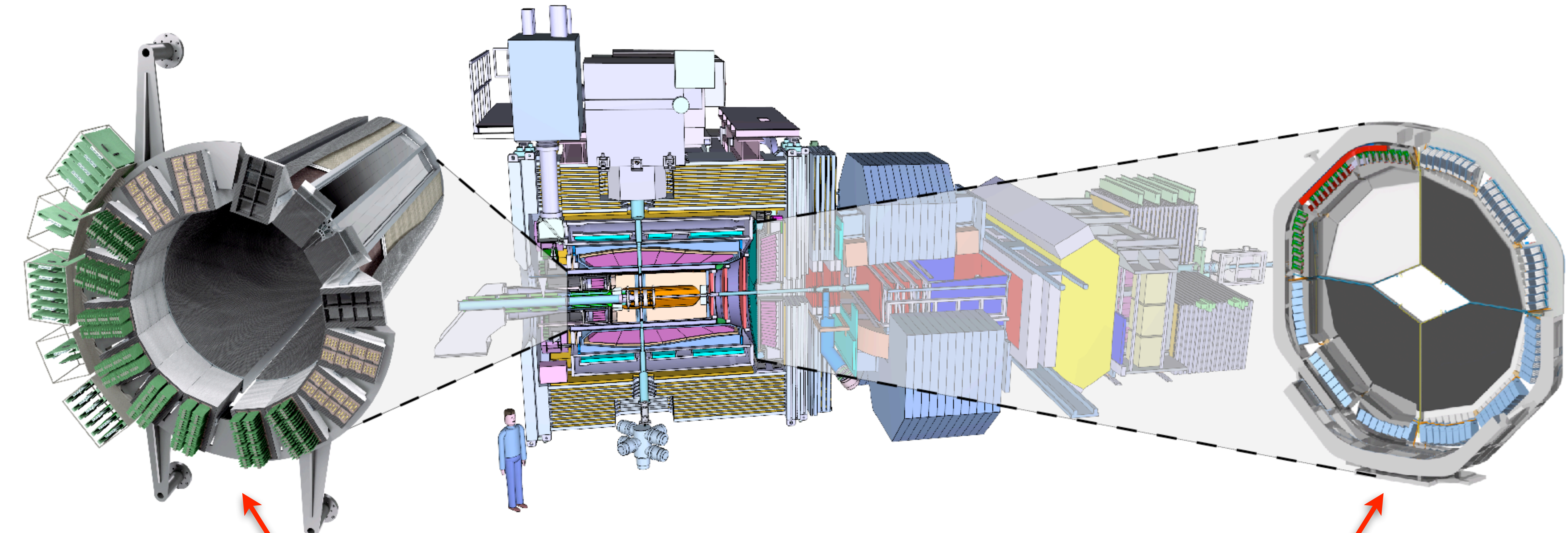


Fig. 2.5. (a) DIRC π-K separation versus track momentum measured in $D0 \to K^- \pi^+$ decays selected kinematically from inclusive D^* production. (b) DIRC Kaon efficiency vs. pion miss-ID as Kaon.

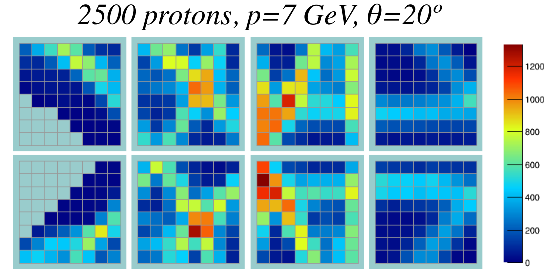
Focusing DIRC of the PANDA experiment

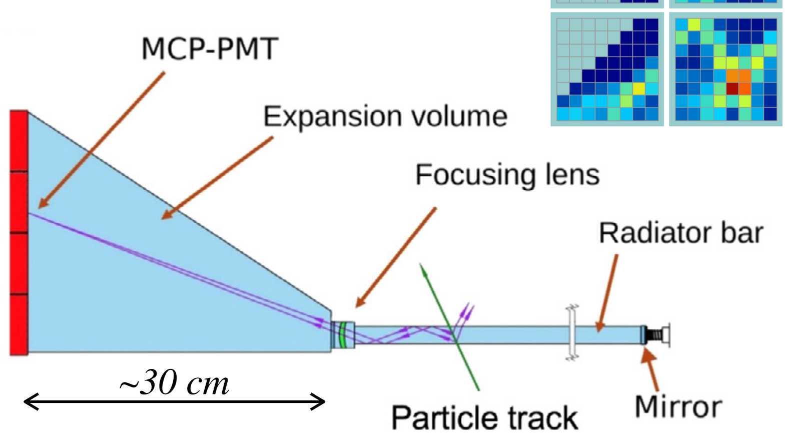


Barrel DIRC

Bar: 2.4 m × 5.3 cm × 1.7 cm

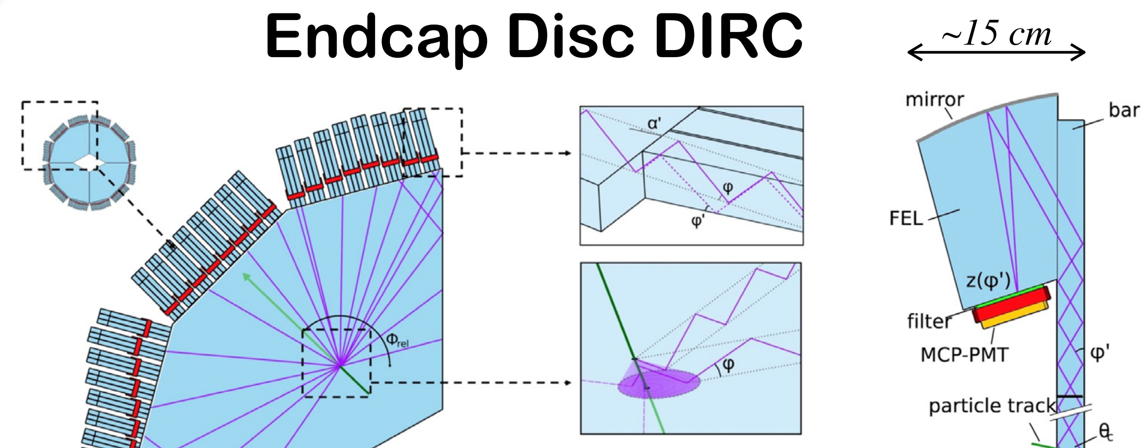
2500 protons, p=7 GeV, θ=20º





π/K separation better than 3σ for 0.5<p<3.5 GeV

Endcap Disc DIRC

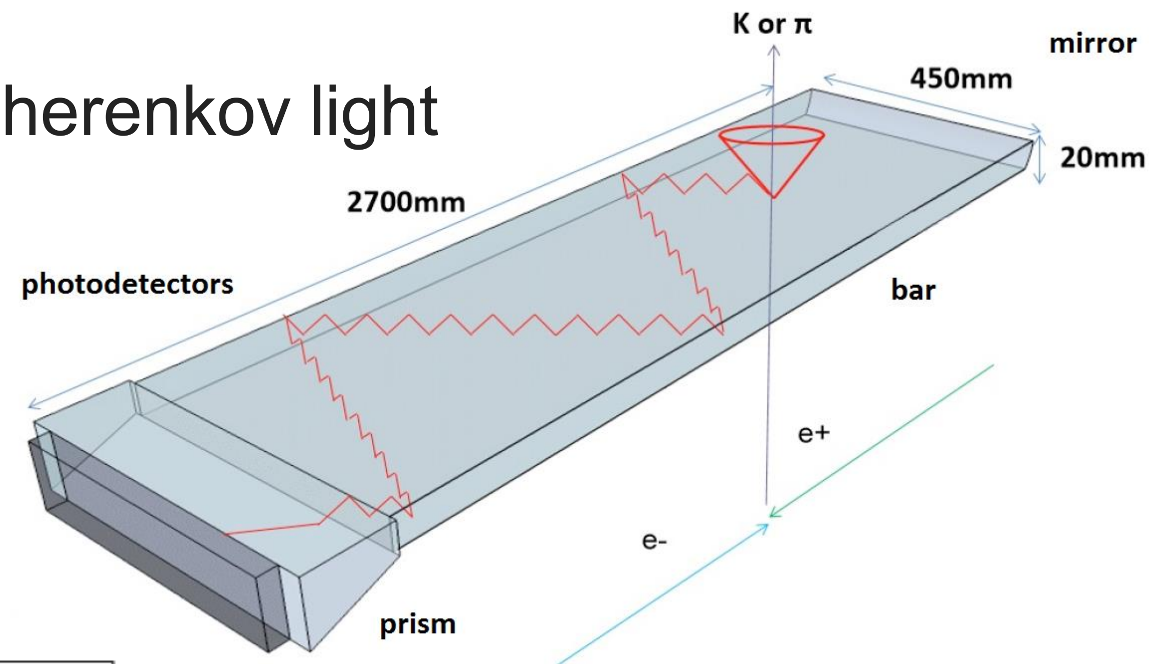


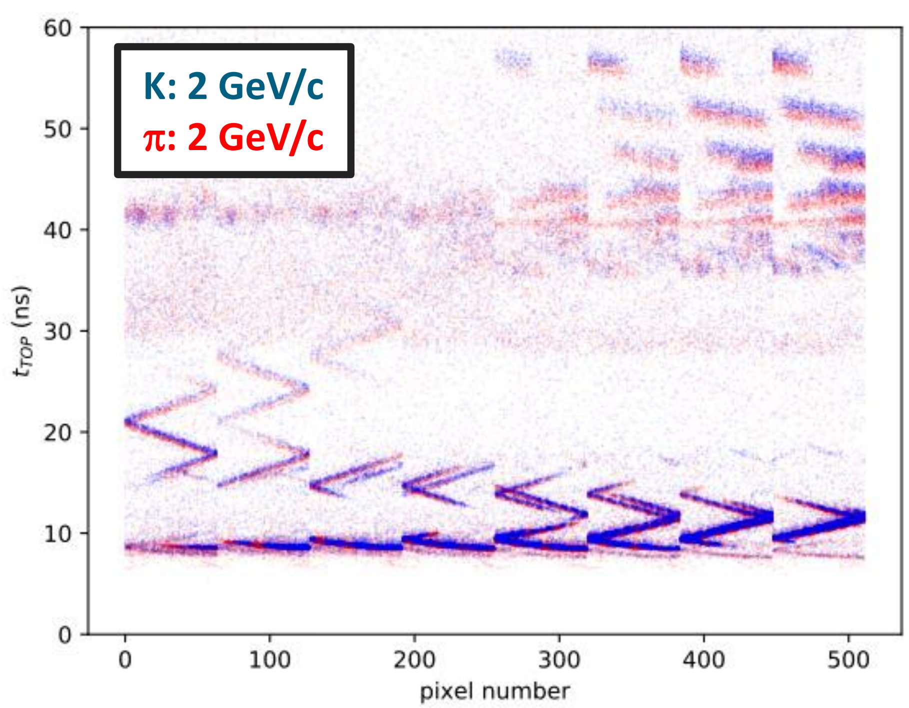
$$\theta_c = \arccos\left(\sin\theta_p \cos\phi_{rel} \cos\varphi + \cos\theta_p \sin\varphi\right)$$

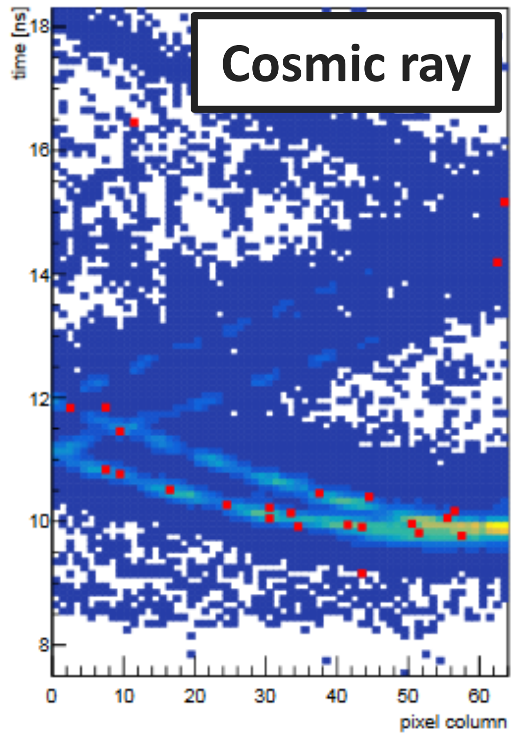
π/K separation better than 3σ for 0.7<p<4 GeV

DIRC-type TOP (in barrel) of the Belle II experiment

- Measurement of internally-reflected Cherenkov light
- Time-Of-Propagation detector
  - 16 quartz bar coverage of barrel in ϕ
  - Custom MC-PMTs (32/module)
  - FPGA feature extraction
- Used for π/K separation in barrel

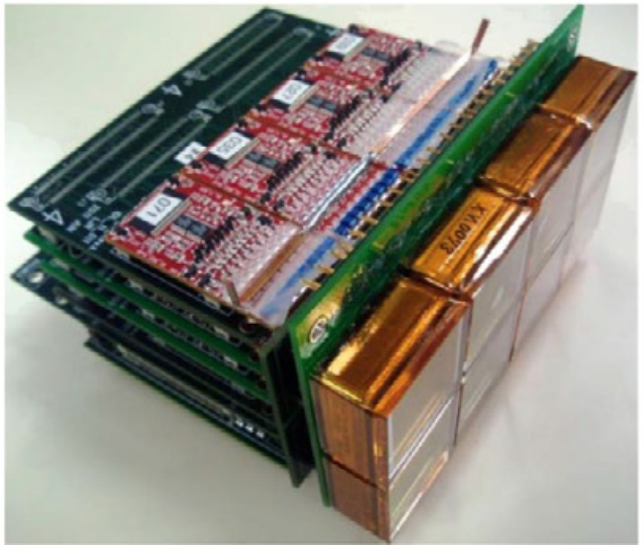


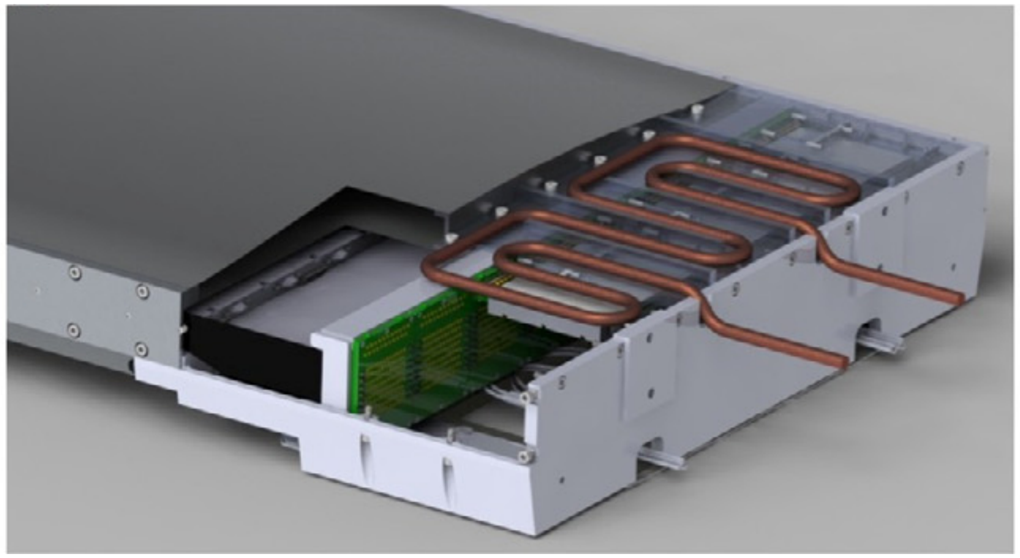




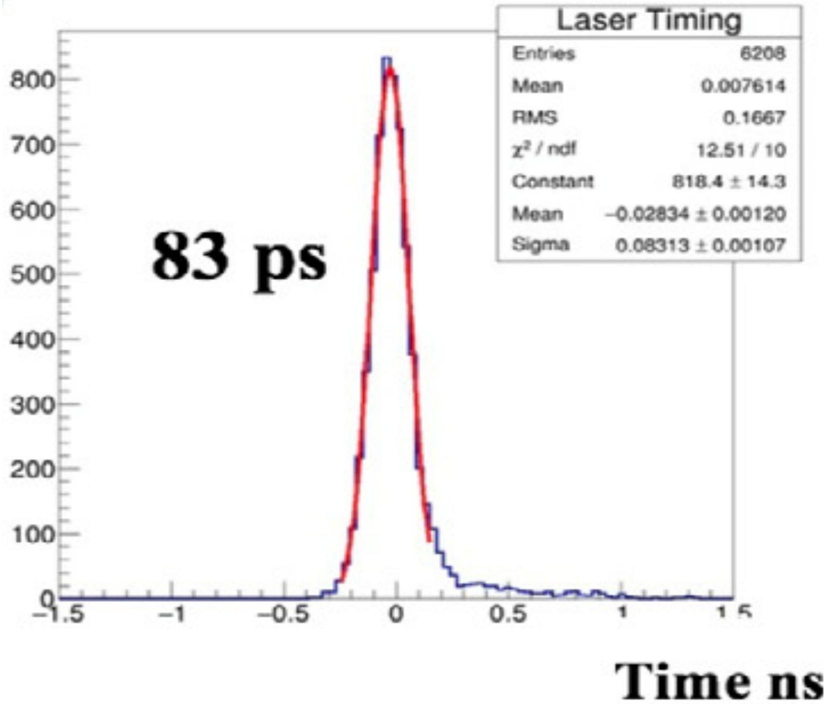
DIRC-type TOP (in barrel) of the Belle II experiment

Hamamatsu 16-pixel MCPs are coupled to a package with amplifiers and IRSX waveform digitizers

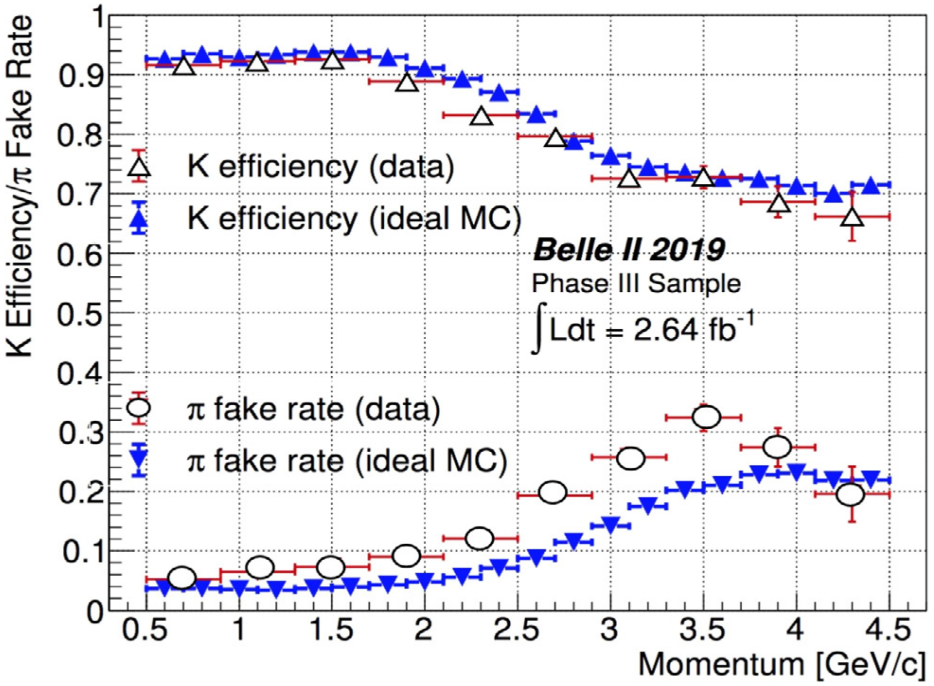




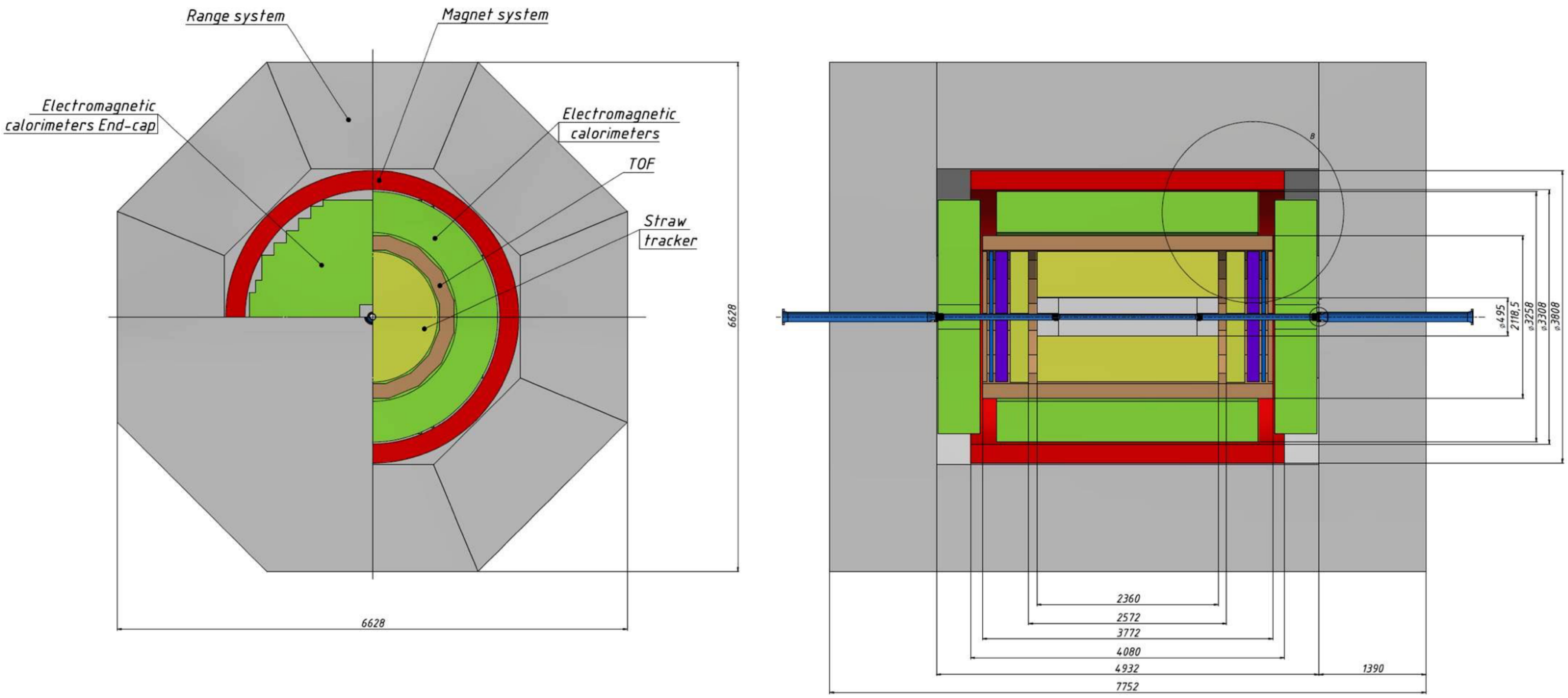
Single photon timing resolution (TTS)



Kaon identification efficiency with $R_{K/\pi}$>0.5



Where we can place DIRC and/or ARICH in SPD?



- **Barrel:** The region dedicated to TOF can be enlarged by ~10 cm in the radial direction. DIRC can be placed between TOF and Straw Tracker
  - If size of one ECal-endcap is decreased radially, we can place the imaging part of DIRC on top of it
- **Endcap:** The thickness of the aerogel detector is now 16 cm. To be enlarged up to 30 cm.
- No need to discuss now whether we can afford DIRC (phase 2 or 3 of SPD) but **the volume must be reserved** before the beginning of the 1-st phase construction.

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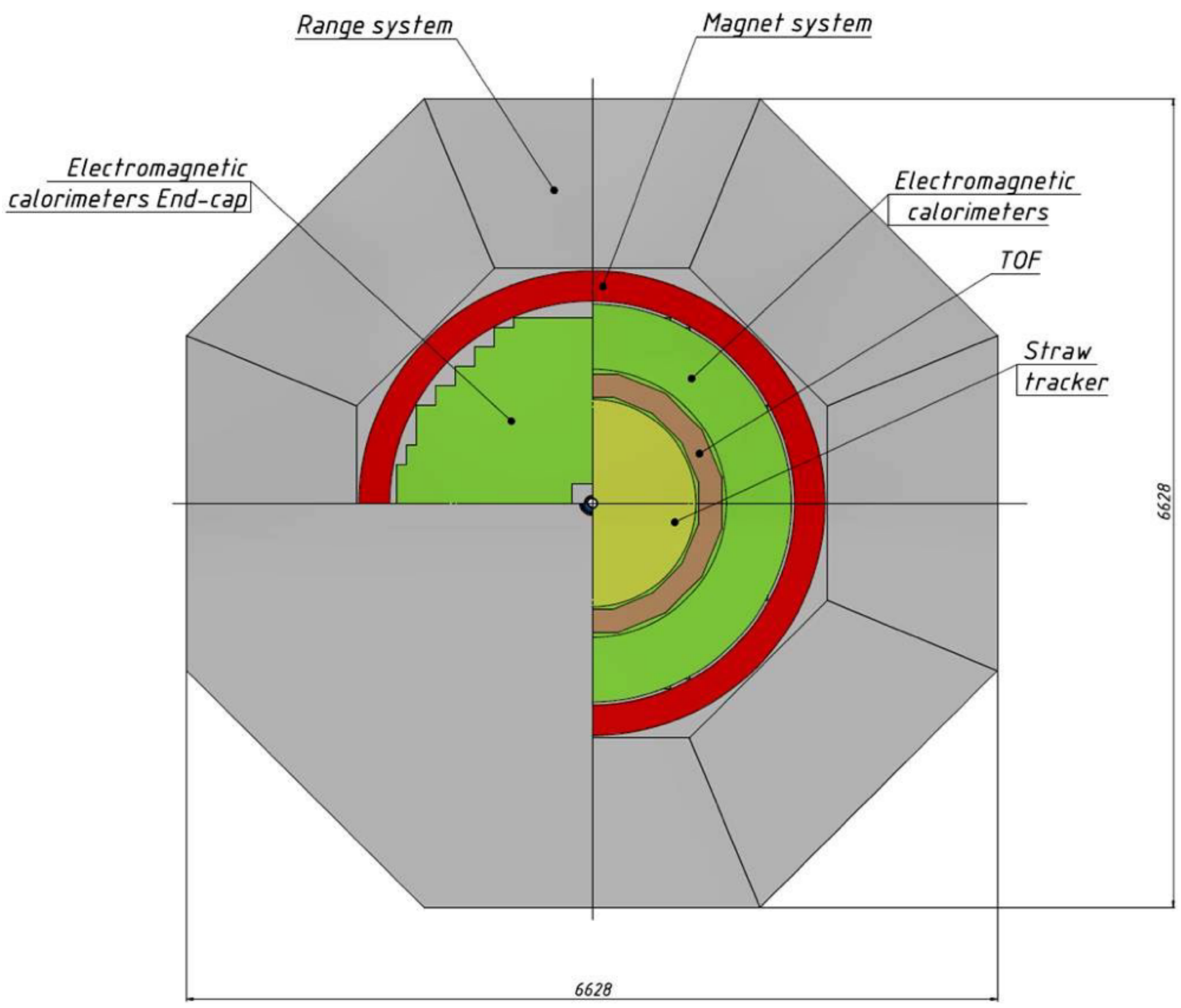

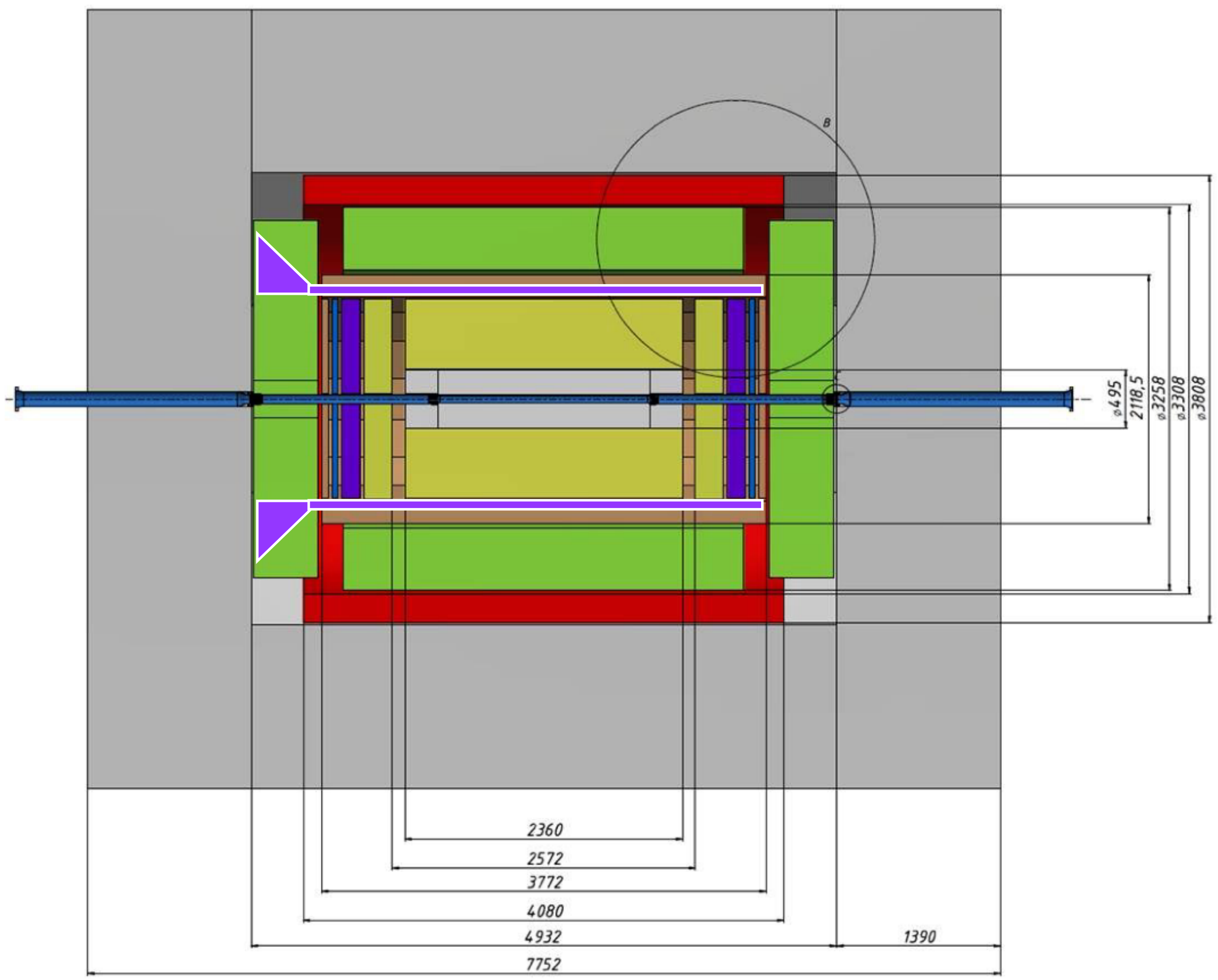

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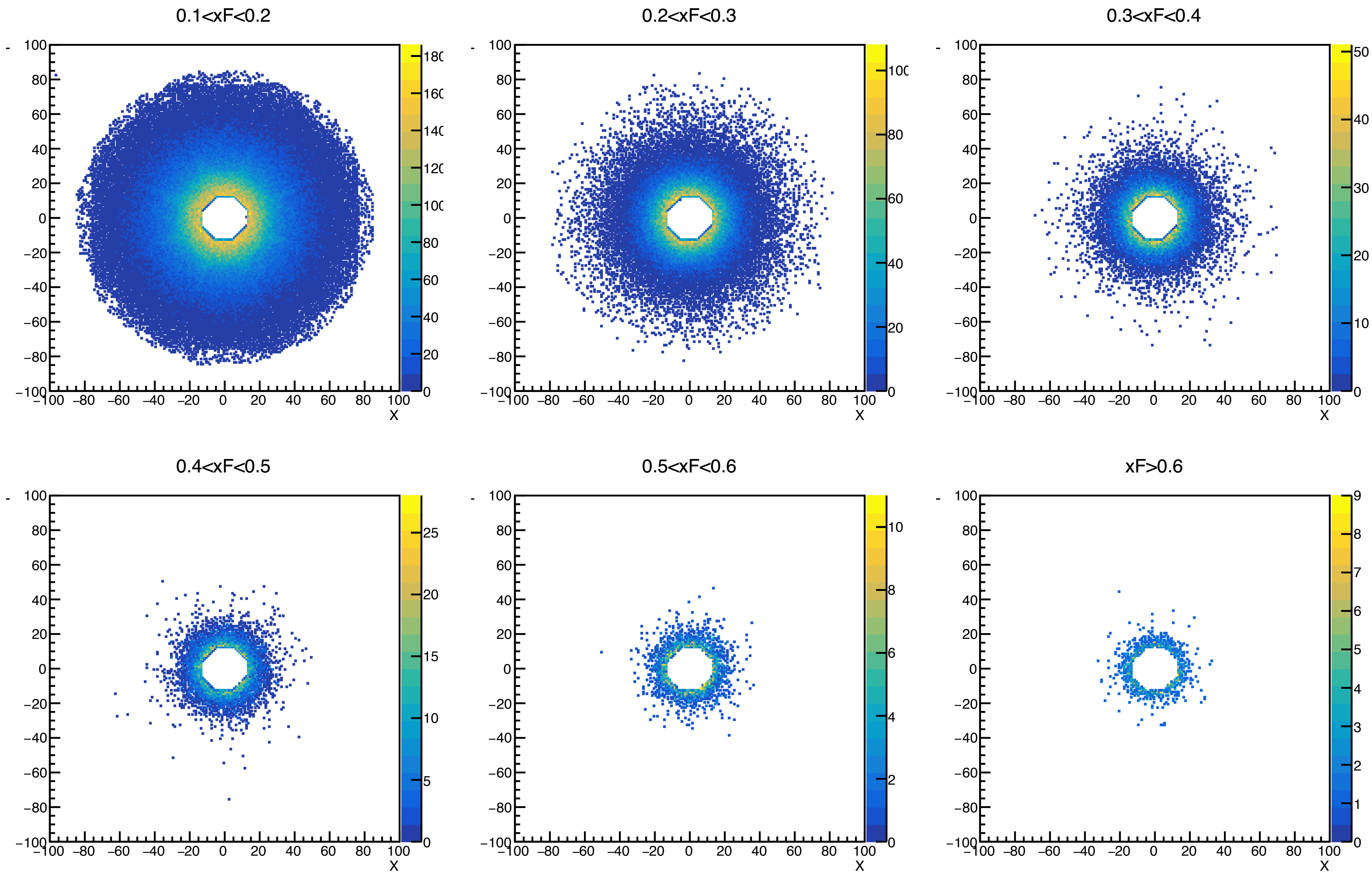
Summary: possible options for SPD

- **Now in SPD CDR and TDR**
  - Threshold detector (a la ASHIPH/KEDR)
- **Option for the barrel**
  - DIRC-based detector (a la Panda or Belle II)
- **Options for the endcap(s)**
  - Asymmetric layout, gas+aerogel radiator (a la LHCb or HERMES)
  - ARICH, aerogel exclusively as a radiator (a la Belle II)
  - DIRC-based detector (a la Panda)
- **Now we don't need to make a strict decision about the type of detector. However, a place for this detector should be allocated now.**

spare slides


0.1<xF<0.2
0.2<xF<0.3
0.3<xF<0.4
0.4<xF<0.5
0.5<xF<0.6
xF>0.6
X

TOF vs dE/dx in SPD

- According to present state of simulation, a 3σ separation of π and K can be achieved for momenta
  - p < 0.55 GeV (ST)
  - p < 1.5 GeV (TOF)
- ST is useful only for short tracks which do not cross TOF (or 1-st phase setup without TOF)