Status Report of DIRAC

DIRAC Addendum

LIFETIME MEASUREMENT OF $\pi^+\pi^-$ AND $\pi^\pm K^\mp$ ATOMS TO TEST LOW-ENERGY *QCD*

DIRAC collaboration

75 Physicists from 19 Institutes

CERN
Geneva, Switzerland

Czech Technical University
Prague, Czech Republic

Institute of Physics ASCR
Prague, Czech Republic

Nuclear Physics Institute ASCR
Rez, Czech Republic

Ioannina University
Ioannina, Greece

INFN-Laboratori Nazionali di Frascati
Frascati, Italy

Trieste University and INFN-Trieste
Trieste, Italy

University of Messina
Messina, Italy

KEK
Tsukuba, Japan

Kyoto Sangyou University
Kyoto, Japan

Tokyo Metropolitan University
Tokyo, Japan

IFIN-HH
Bucharest, Romania

JINR
Dubna, Russia

SINP of Moscow State University
Moscow, Russia

IHEP
Protvino, Russia

Santiago de Compostela University
Santiago de Compostela, Spain

Basel University
Basel, Switzerland

Bern University
Bern, Switzerland

Zurich University
Zurich, Switzerland

Outline

Physics motivation

DIRAC addendum

- Modified DIRAC setup
- Vacuum Channel and Shielding
- Detectors
- Readout system
- Trigger
- DAQ

Main goals of the run 2007

Conclusions

Main goals of DIRAC Addendum

- *Lifetime measurement of $A_{2\pi}$ atoms in a model-independent way with precision better than 6%,which gives a precision for $|a_0 - a_2|$ better than 3%; this will provide a sensitive check for understanding the chiral symmetry breaking in QCD, giving an indication about the value of the quark condensate.*

- *Observation of $A_{\pi K}$ and $A_{K\pi}$ atoms.*
  The measurement of their lifetime with precision of 20% and difference of πK scattering lengths $|a_{1/2} - a_{3/2}|$ with accuracy about 10%.

- *Observation of the long-lived (metastable) states of $A_{2\pi}$, with prospect to measure the energy difference between ns and np states, and of determining the value of $2a_0 + a_2$ in a model-independent way.*

All these steps are important for a crucial check of the predictions of the low-energy QCD and for an understanding of the nature of the QCD vacuum

πK scattering

What new will be known if πK scattering length will be measured?

The measurement of the s-wave πK scattering lengths would test our understanding of the chiral $SU(3)_L \times SU(3)_R$ symmetry breaking of QCD (u, d and s quarks), while the measurement of $\pi\pi$ scattering lengths checks only the $SU(2)_L \times SU(2)_R$ symmetry breaking (u, d quarks).

This is the main difference between $\pi\pi$ and πK scattering!

Time scale for the $A_{2\pi}$ and $A_{\pi K}$ experiment

The following schedule was approved by RB CERN in December 2004

2006

Manufacture and installation of new detectors and electronics: 6 months

Test of the Upgraded setup and calibration: 3 months

2007 and 2008

Measurement of $A_{2\pi}$ lifetime: 12 months

In this time 86000 $\pi\pi$ atomic pairs will be collected to measure $A_{2\pi}$ lifetime with precision of:

$$\frac{\sigma_\tau}{\tau} = 6\%, \quad \frac{\sigma(a_0 - a_2)}{a_0 - a_2} = 3\%$$

At the same time we also plan to observe $A_{\pi K}$ and $A_{\pi K}$ and to detect 5000 πK atomic pairs for estimation of $A_{\pi K}$ lifetime with precision of:

$$\frac{\sigma_\tau}{\tau} = 20\%, \quad \frac{\sigma(a_{1/2} - a_{3/2})}{a_{1/2} - a_{3/2}} = 10\%$$

This estimation of the beam time is based on the $A_{2\pi}$ statistics collected in 2001 and on the assumption of having 2.5 spills per supercycle during 20 hours per day.

Experimental results

Present low-energy QCD predictions for ππ scattering lengths:

ChPT predicts s-wave scattering lengths:

$$a_0 = 0.220 \pm 0.005\ (2.3\%)$$

$$a_2 = -0.0444 \pm 0.0010\ (2.3\%)$$

$$a_0 - a_2 = 0.265 \pm 0.004\ (1.5\%)$$

First result: L. Rosselet *et al.*, Phys. Rev. D15 (1977) 574

$$a_0 = 0.28 \pm 0.05\ (18\%)$$

using Roy eqs.

DIRAC published results, 2001 data:

$$a_0 - a_2 = 0.264 \pm 7.5\%(stat)^{+3\%}_{-8\%}(syst)$$

expected statistical accuracy ≤5%:

Results from E865/BNL experiment:

$K \to \pi^+\pi^- e^+\nu_e (K_{e4})$

S. Pislak *et al.*, Phys. Rev. Lett. 87 (2001) 221801

$$a_0 = 0.203 \pm 0.033\ (16\%) \quad a_2 = -0.055 \pm 0.023\ (42\%)$$

using Roy eqs.

$$a_0 = 0.216 \pm 0.013\ (stat) \pm 0.004\ (syst) \pm 0.002\ (theor)$$

$$\delta a_0 = \pm 6\%\ (stat) \pm 2\%\ (syst) \pm 1\%\ (theor)$$

using Roy eqs. and chiral symmetry constraints $a_2 = f_{ChPT}(a_0)$

Results from NA48/2: $K^+ \to \pi^0\pi^0\pi^+$

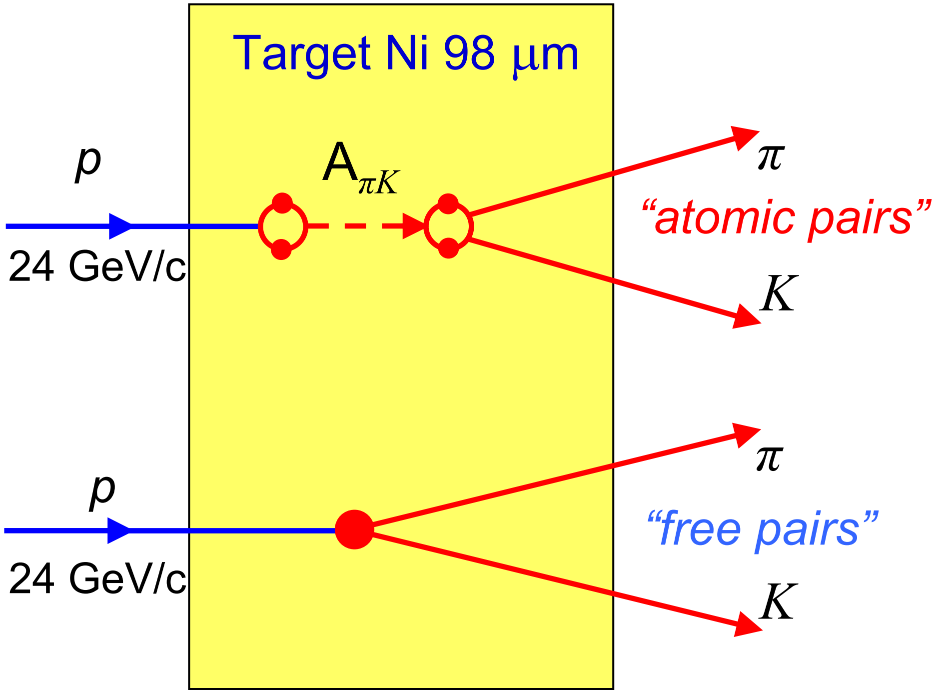
NA48/2 Collaboration Phys. Lett. B 633, 2006

$$a_0 - a_2 = 0.268 \pm 3.7\%(stat) \pm 1.5\%(syst) \pm 4.8\%(ext)$$

Expected results of DIRAC (upgraded) at PS CERN:

$$\tau(A_{2\pi}) \to \delta(a_0 - a_2) = \pm 2\%(stat) \pm 1\%(syst) \pm 1\%(theor)$$

Method of $A_{\pi K}$ and $A_{K\pi}$ observation and lifetime measurement



$\tau(A_{\pi K})$ is too small to be measured directly

e. m. interaction of $A_{\pi K}$ in the target

$$A_{\pi K} \rightarrow \pi^+ K^-$$

$$A_{K\pi} \rightarrow K^+ \pi^-$$

$$Q < 3 MeV/c,\ p_K = \frac{m_K}{m_\pi} p_\pi, \Theta_{lab} < 3\ mrad$$

- *Coulomb from short-lived sources*
- *non-Coulomb from long-lived sources*

<u>Main features of the DIRAC set-up</u>

Thin targets: ~ 7×10^{-3} X_0, Nuclear efficiency: 3×10^{-4}

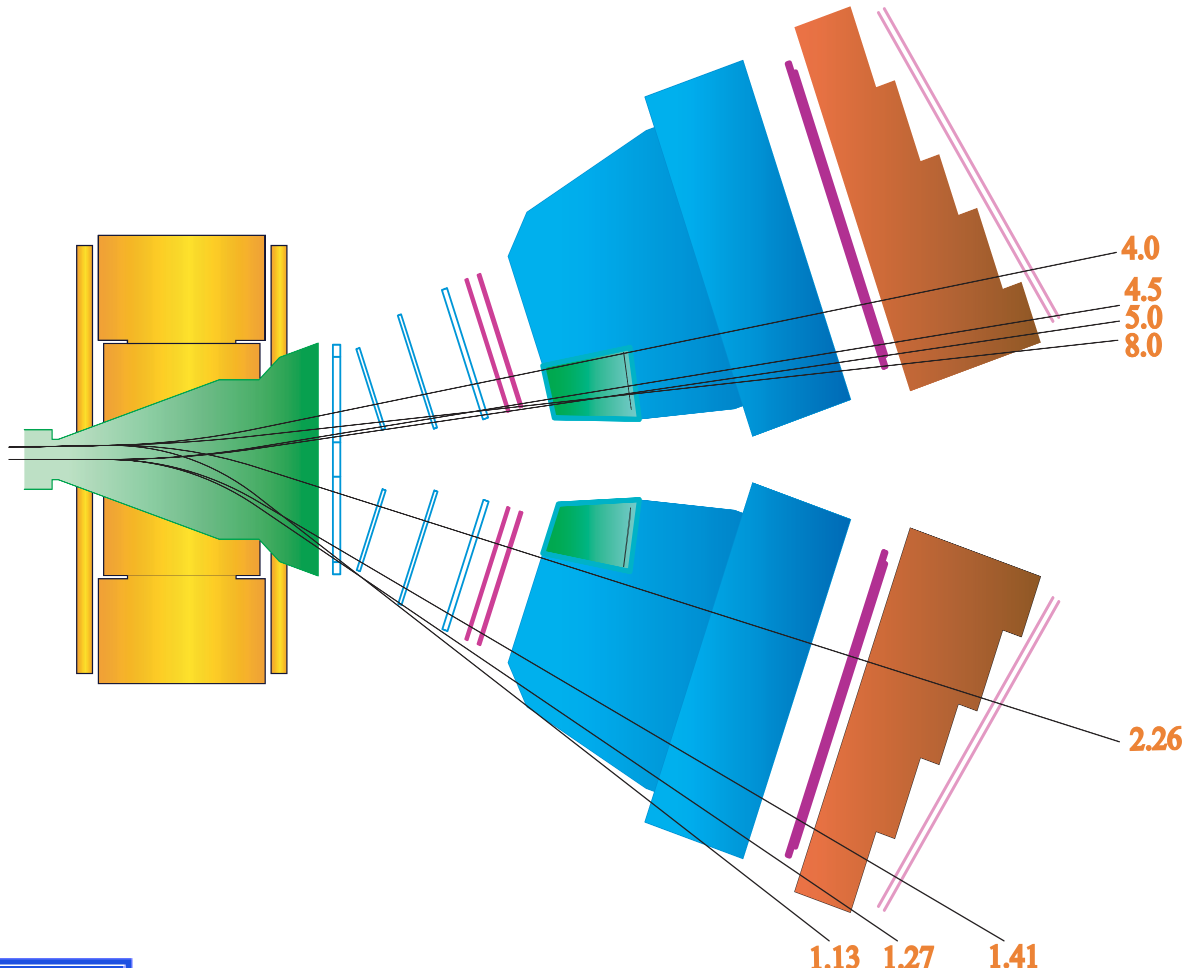
Magnetic spectrometer

Proton beam ~ 10^{11} proton/spill

Resolution on Q: $Q_x \approx Q_y \approx Q_L \approx 0.5$ MeV/c

Trajectories of π^- and K^+ from the $A_{\pi K}$ break-up

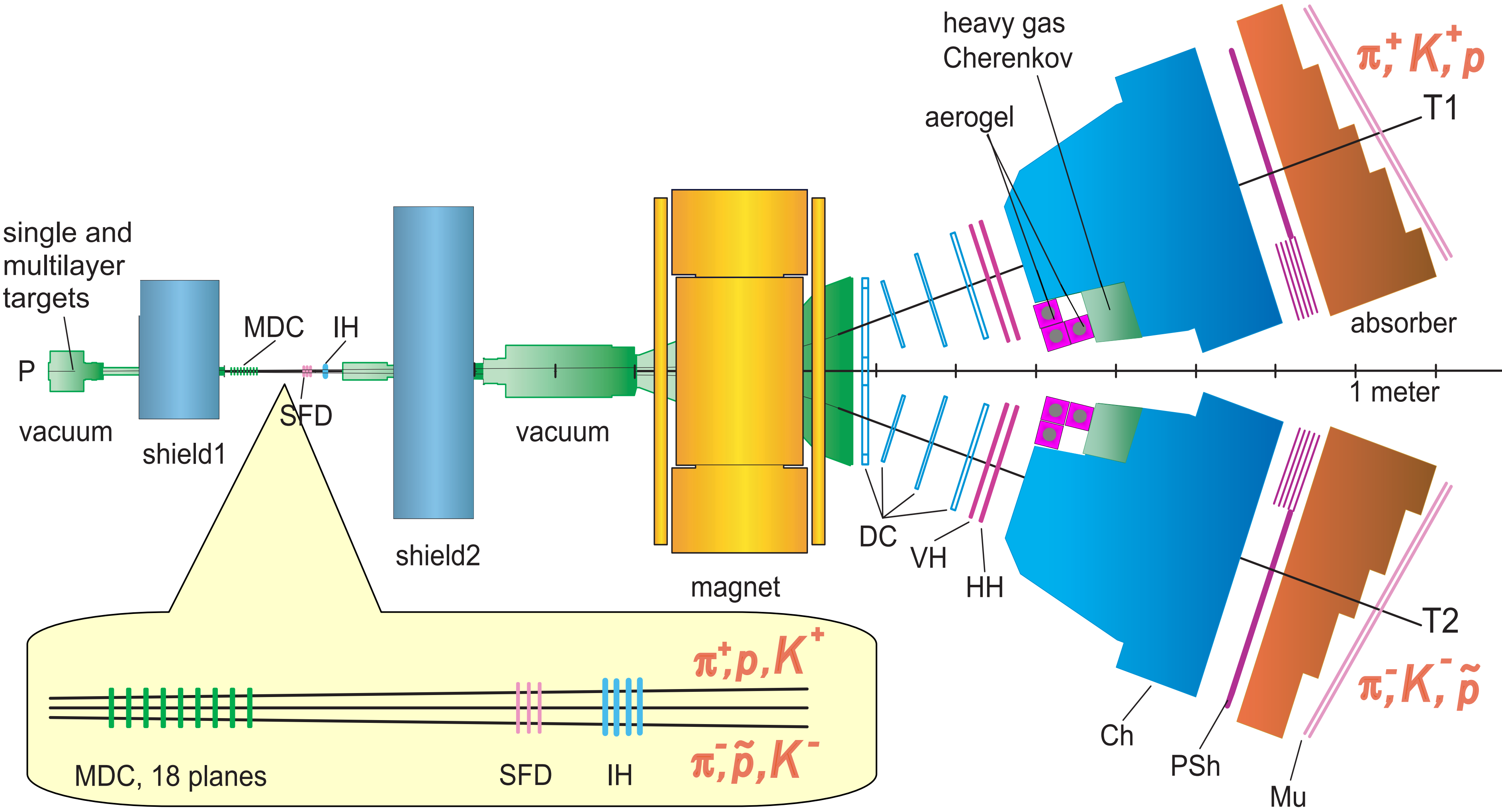
The numbers to the right of the tracks lines are the π^- and K^+ momenta in GeV/c



The $A_{\pi K}$, π^- and K^+ momenta are shown in the following table:

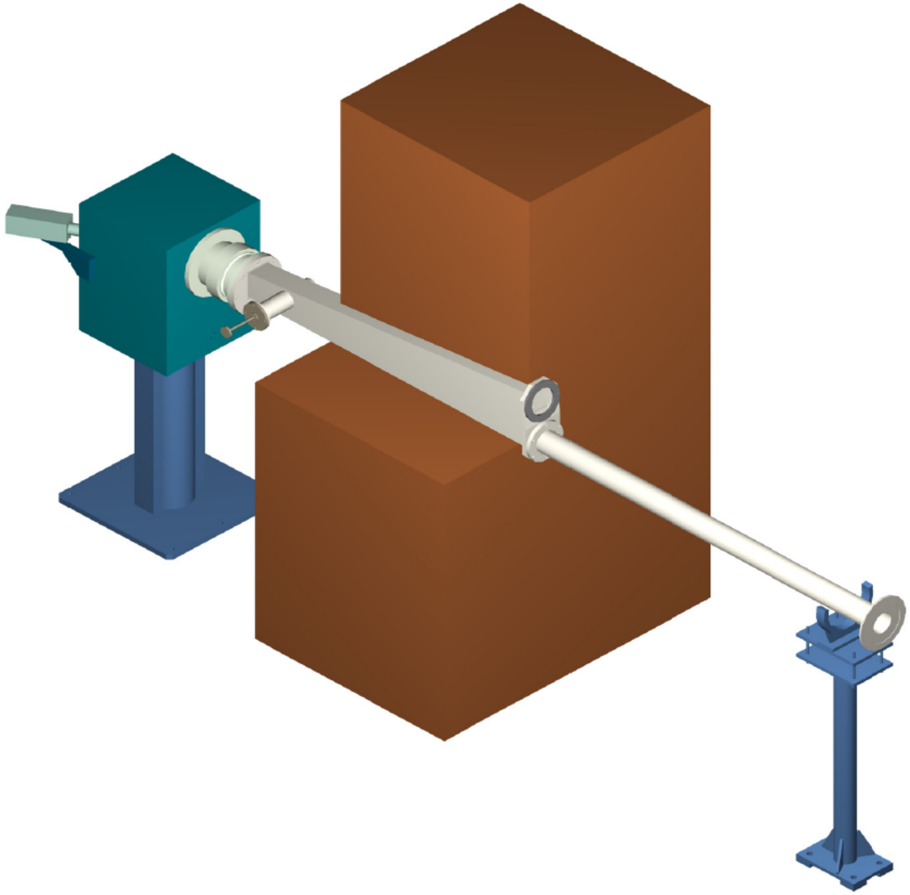
P_{atom} (GeV/c)	P_{π} (GeV/c)	P_{K} (GeV/c)
5.13	1.13	4.0
5.77	1.27	4.5
6.41	1.41	5.0
10.26	2.26	8.0

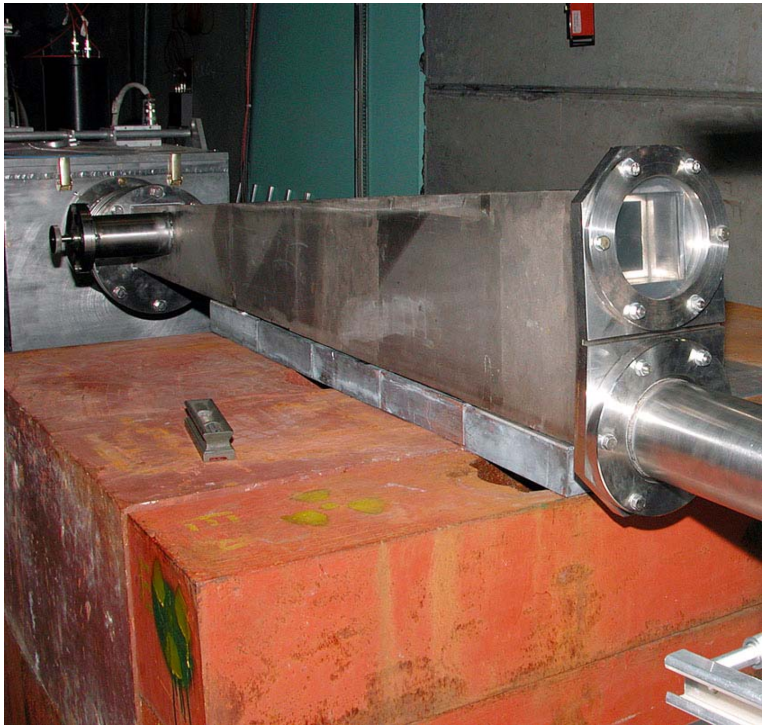
Upgraded DIRAC experimental set-up description



Vacuum Channel and Shielding

Responsibility: **JINR (*Dubna*, Russia)**

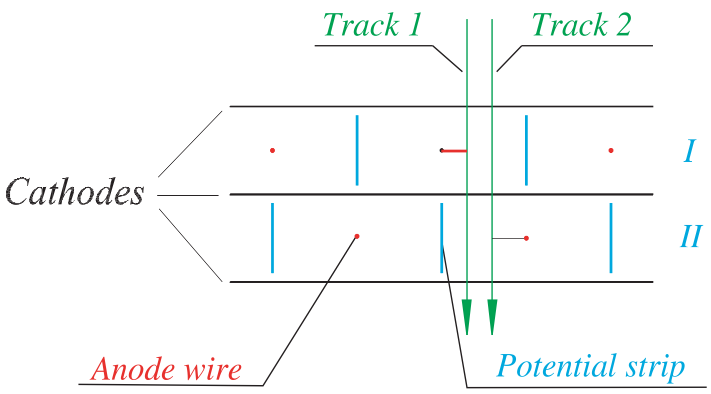




Status:
Installed in March 2006,
vacuum tests finished.
Completed.

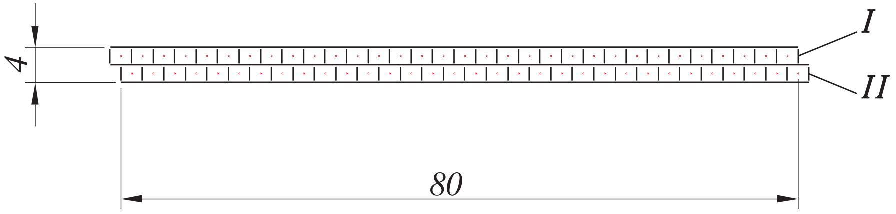
Microdrift Chambers (I)

Responsibility: **JINR (*Dubna*, Russia) with participation of Basel University (*Basel*, Switzerland)**



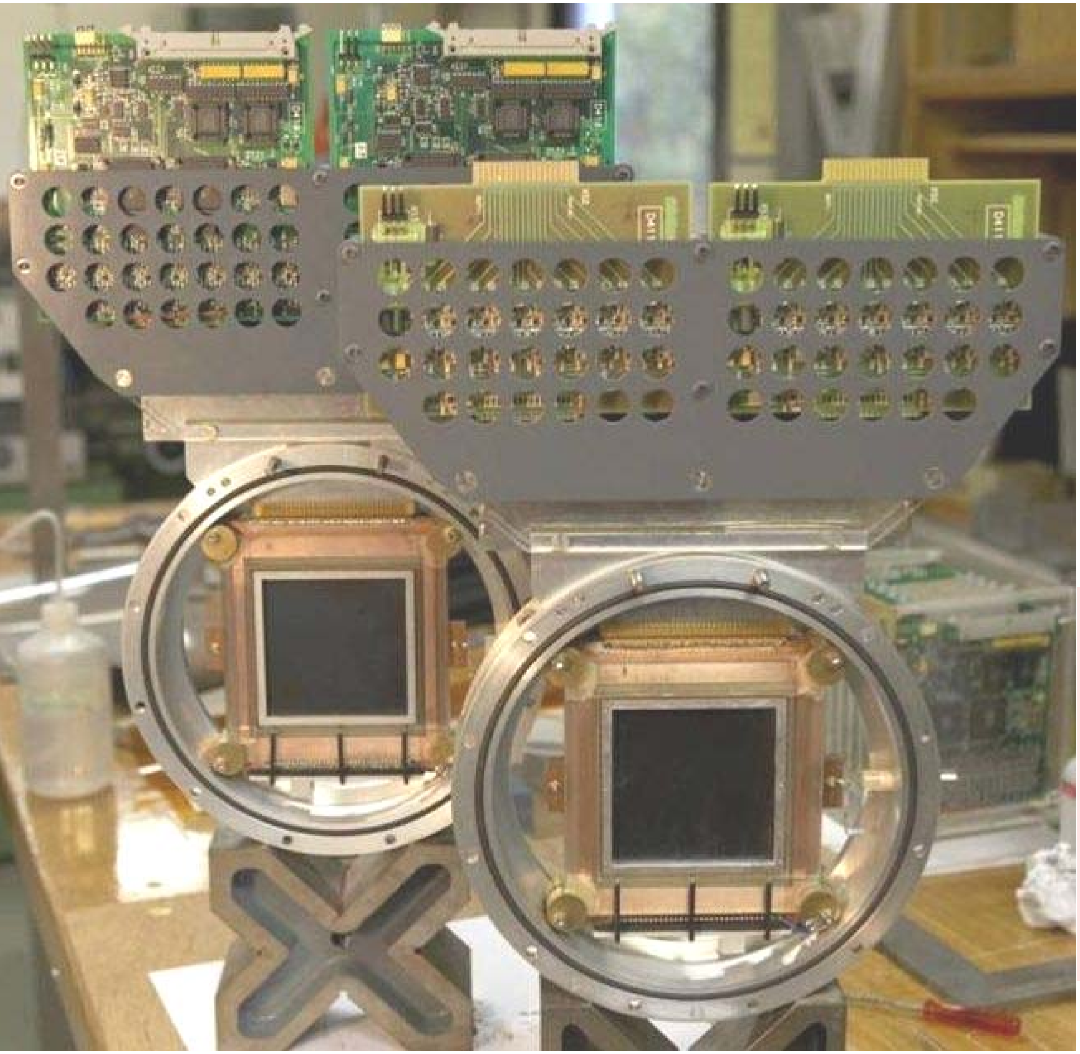
Characteristics:

- spatial accuracy $< 22\ \mu m$ from the beam test;
- double track resolution $< 200\ \mu m$;
- one plane efficiency at the beam intensity $I = 2\times10^{11}$ protons per spill $> 98\%$;
- total detector thickness $<5\times10^{-3}\ X_0$;
- drift time $< 30\ ns$;
- time resolution $< 1\ ns$;
- readout time $< 3\ \mu s$.



According to the results of MDC tests in 2003-2004, the detector stability was improved for the heavy radiation conditions at DIRAC. This improvement is achieved by modification of MDC electrodes and installation of preamplifiers (640 channels)

Microdrift Chambers

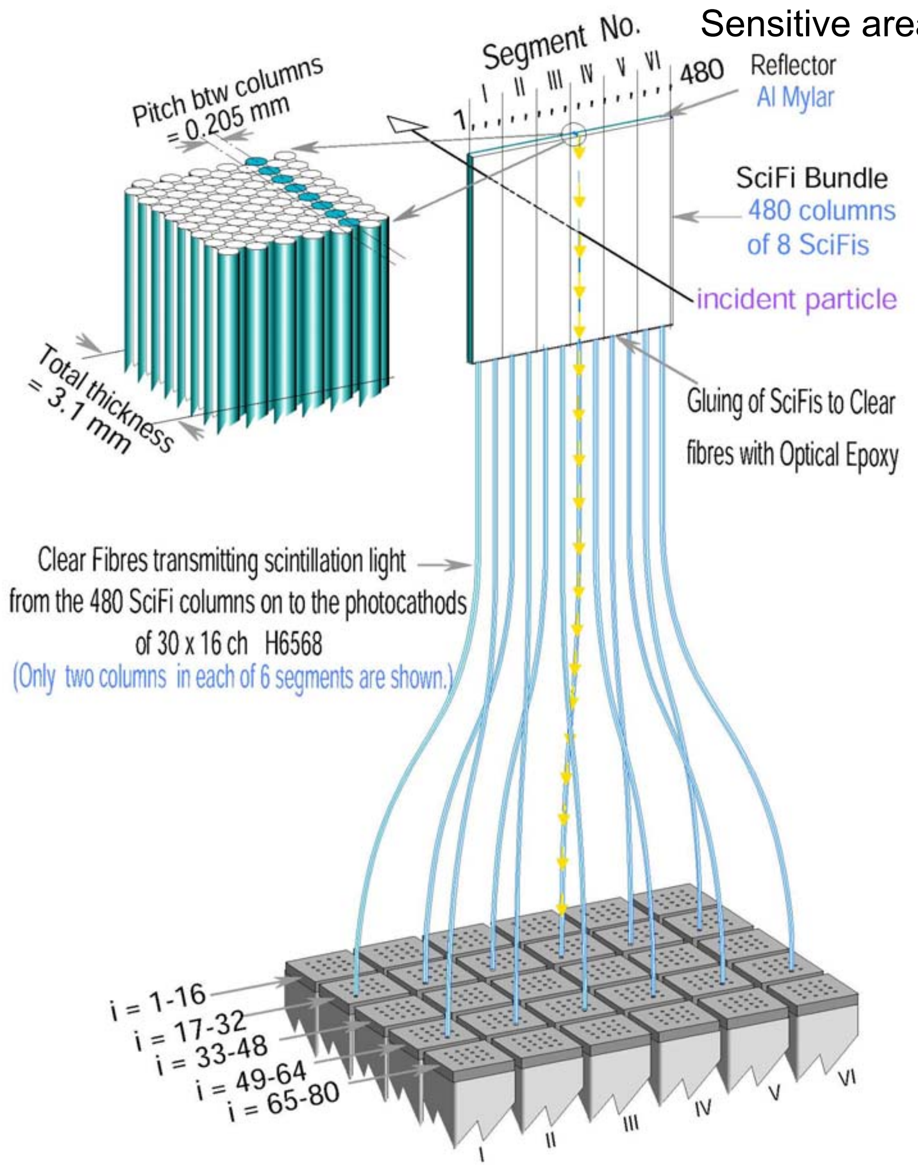


Status

Chambers with the new electrodes and all electronics were installed at CERN and the high voltage test was performed in 2006. The first version of the tracking code has been developed.

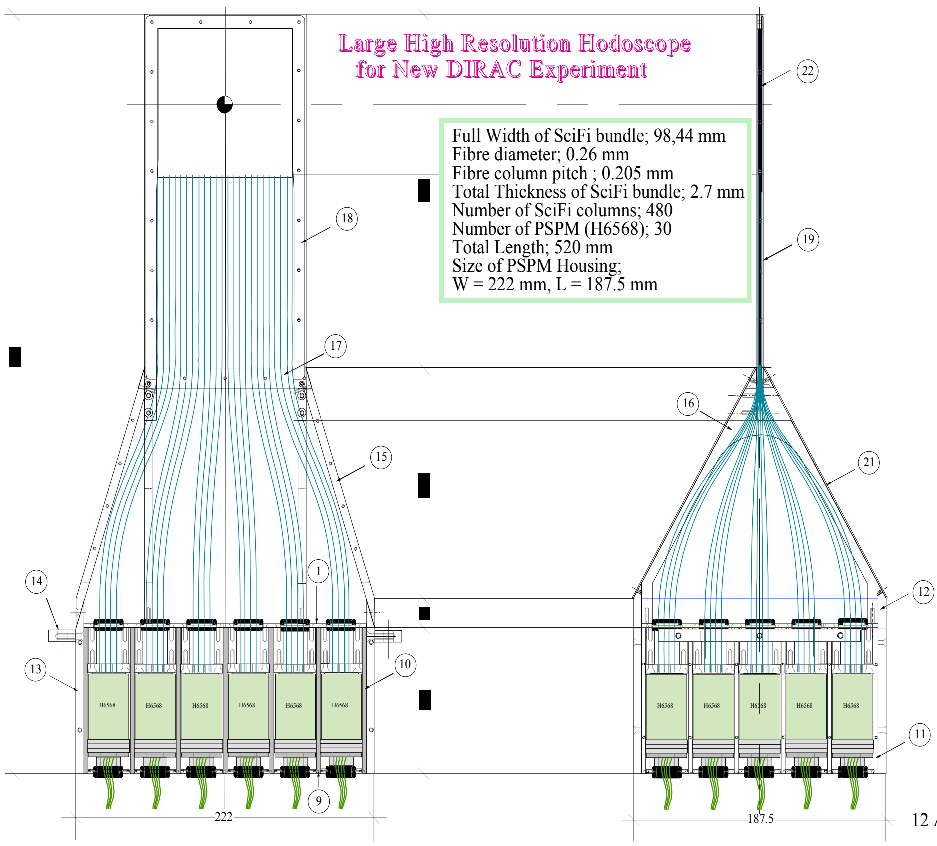
Scintillation Fiber Detector (I)

Sensitive area = 98.5 x 107 mm^2



Scintillation Fiber Detector (II)

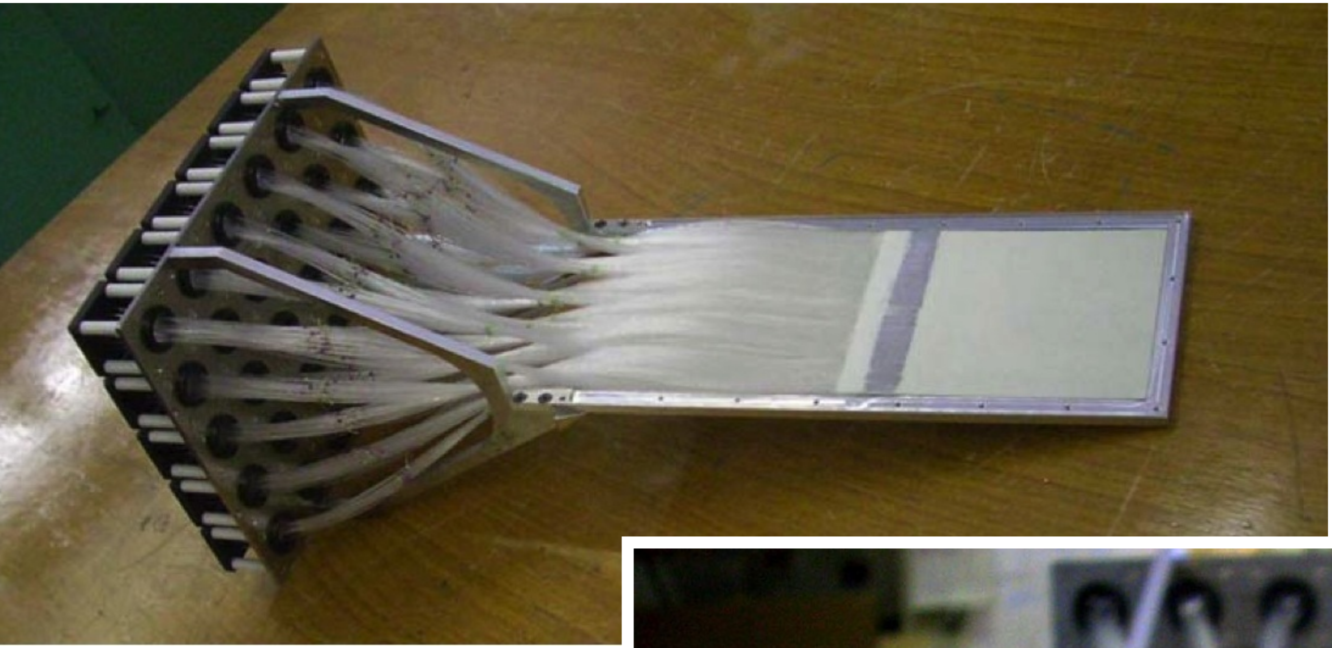
Responsibility: **Japan Universities (Japan); IHEP (*Protvino*, Russia); JINR (*Dubna*, Russia); INFN-Trieste (*Trieste*, Italy); University of Messina (*Messina*, Italy)**



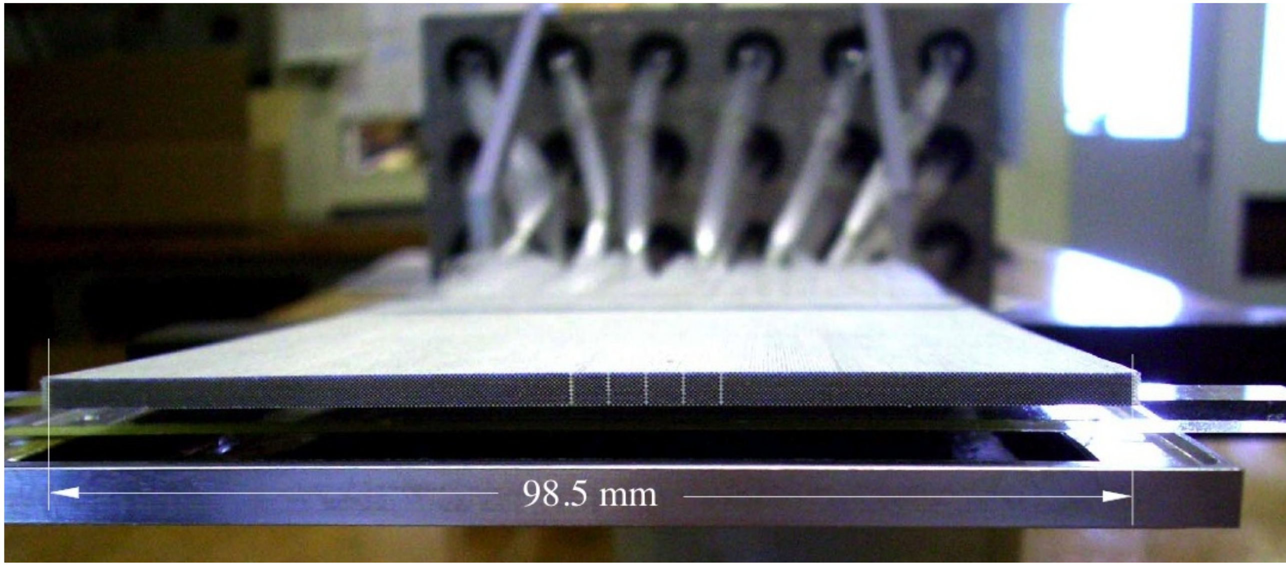
Characteristics:

- Size of the plane — $100\times100\ mm^2$
- Thickness of the material for one plane — $3\ mm$ (1% X_0)
- Mean light output: — $\approx 11\ p.e.$
- Mean Detector Efficiency: — $\approx 98\ \%$
- Time Resolution without coordinate and amplitude corrections — $\approx 0.46\ ns$
- Space resolution — $\sigma \approx 60\ \mu m$
- New electronics (*ADC-TDC for each channel*) — *960 channels*

Scintillation Fiber Detector (III)

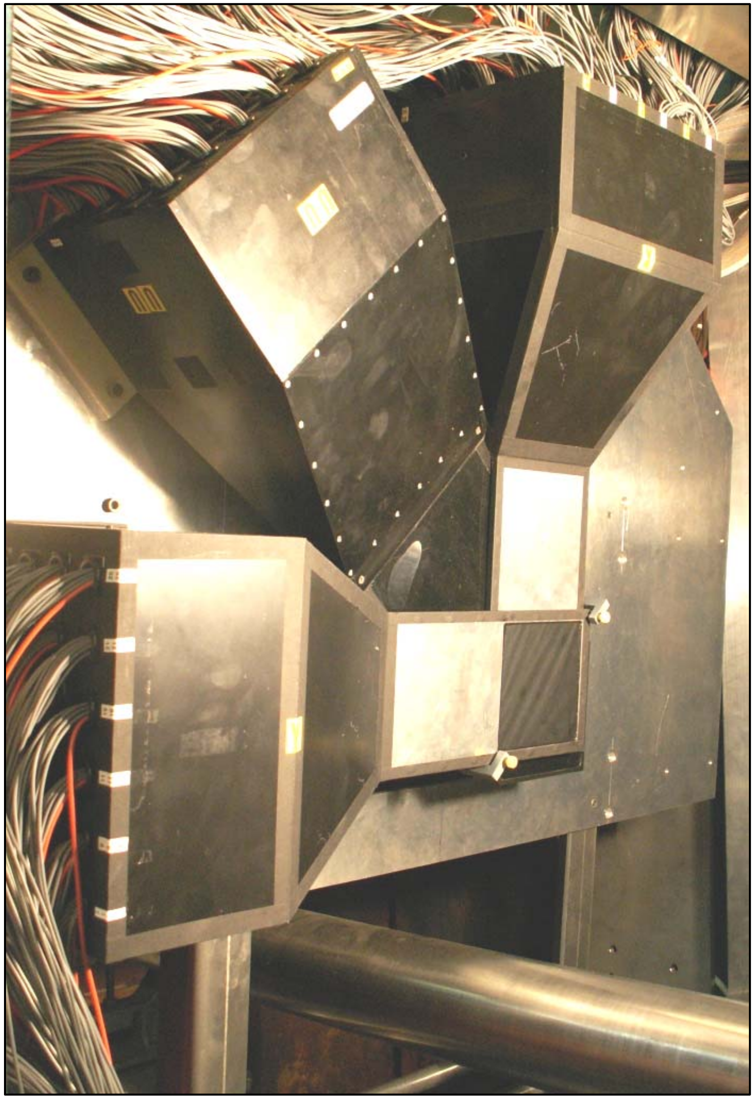


Sensitive area
98.5 x 107 mm²
consists of 480 columns of 8 Scintillating Fiber of 0.26 mm in diameter



5 columns illuminated are distant by
0.205 mm x 16 = 3.28 mm

Scintillation Fiber Detector



Status:
Two new SFD detectors were tuned on the test beam T11 during August-September 2006, installed at the DIRAC setup and checked.

Ionisation Hodoscope

Responsibility: IHEP (*Protvino*, Russia)
Basel University (*Basel,* Switzerland)

In 2007 the detector will be used with amplifiers !

Drift Chambers (I)

Responsibility: **JINR (*Dubna*, Russia)**

Drift Chamber (DC) System.

The DC system consists of four chamber modules per arm including 6 sensitive planes in X and Y projection.

The first module (DC1) has a frame common to both arms; it has two active regions of 80×40 cm^2 housing 6 planes of signal wires (*X, Y, W, X',Y',W'*).

Three modules are then place on each spectrometer arm:

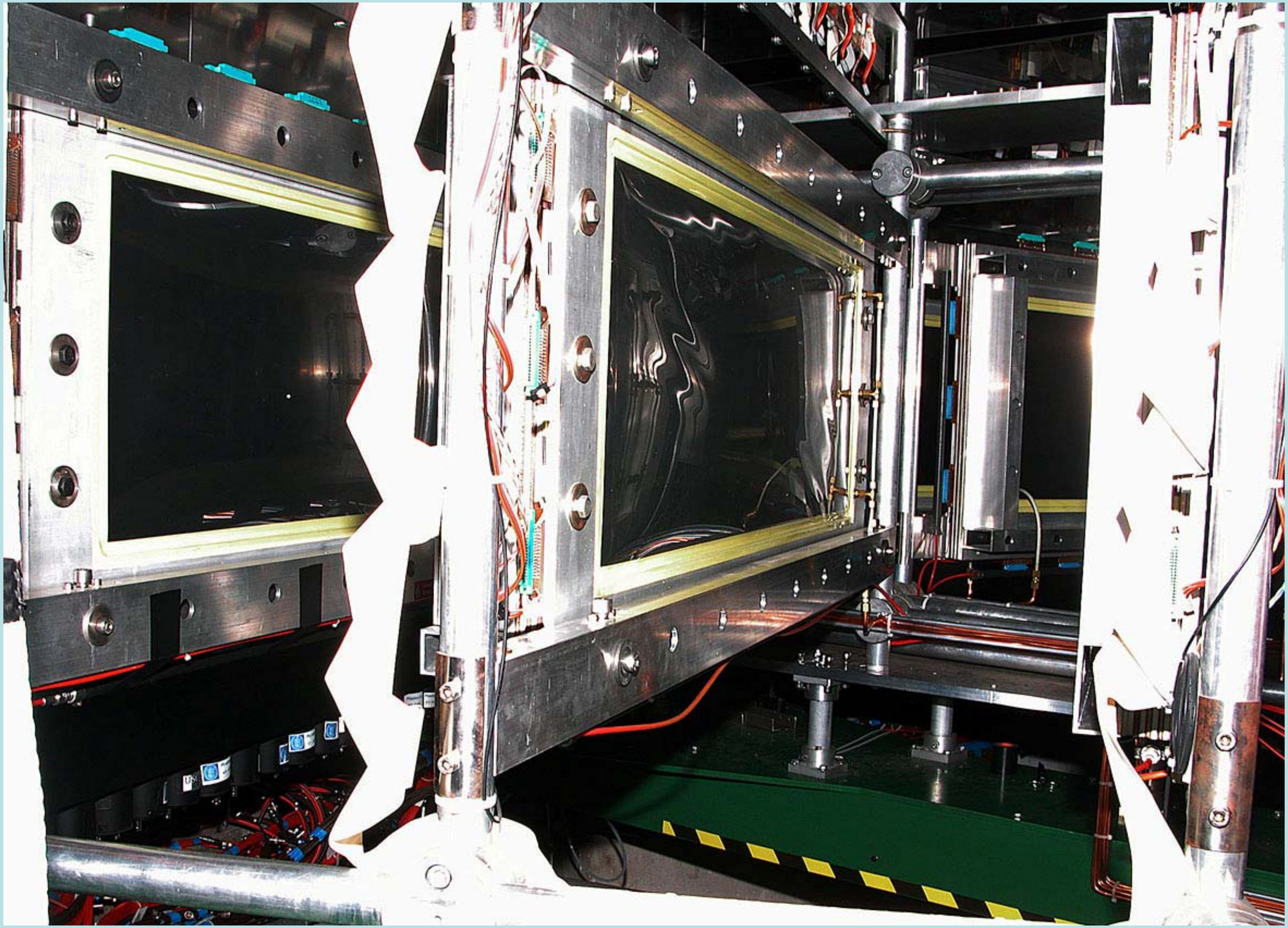
- ✓ DC2 with an active area of 80×40 cm^2 and 2 wire planes (*X, Y*);
- ✓ DC3 with an active area of 112×40 cm^2 and 2 wire planes (*X, Y*);
- ✓ DC4 with an active area of 128×40 cm^2 and 4 wire planes (*X, Y, X',Y'*).

After successful and long drift chamber operation at the first stage of the experiment, it was decided to perform full revision of all drift chambers.

Status:

All modules of DC were repaired (spares also), tested under high voltage and installed in the DIRAC setup.

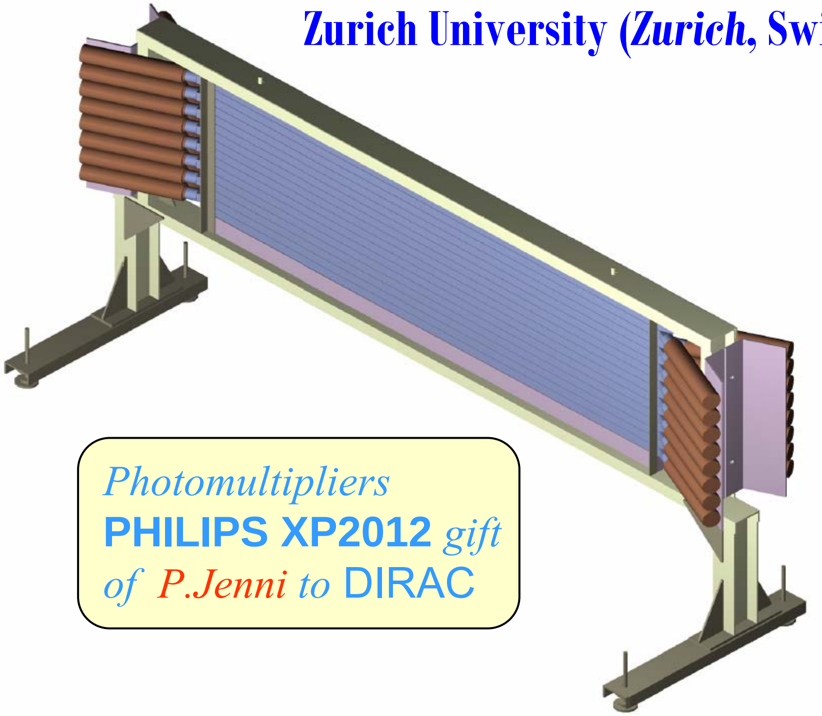
Drift Chambers (II)



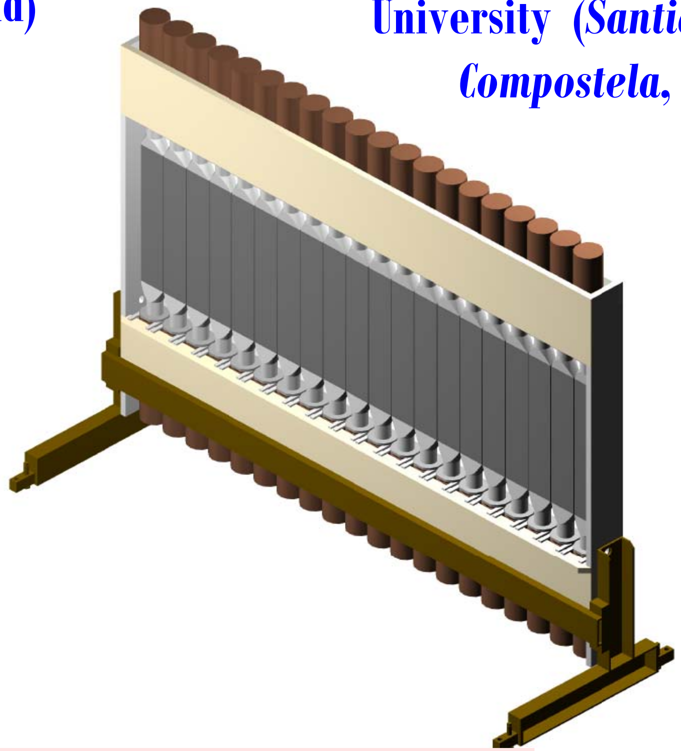
Vertical and Horizontal Hodoscopes

Responsibility: **IHEP (*Protvino*, Russia); Czech Technical University (*Prague*, Czech Republic); Zurich University (*Zurich*, Switzerland)**

Santiago de Compostela University (*Santiago de Compostela*, Spain)



Photomultipliers **PHILIPS XP2012** *gift of P.Jenni to* DIRAC



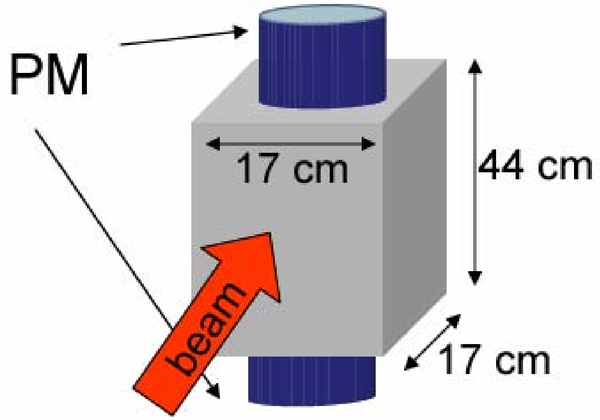
Status:

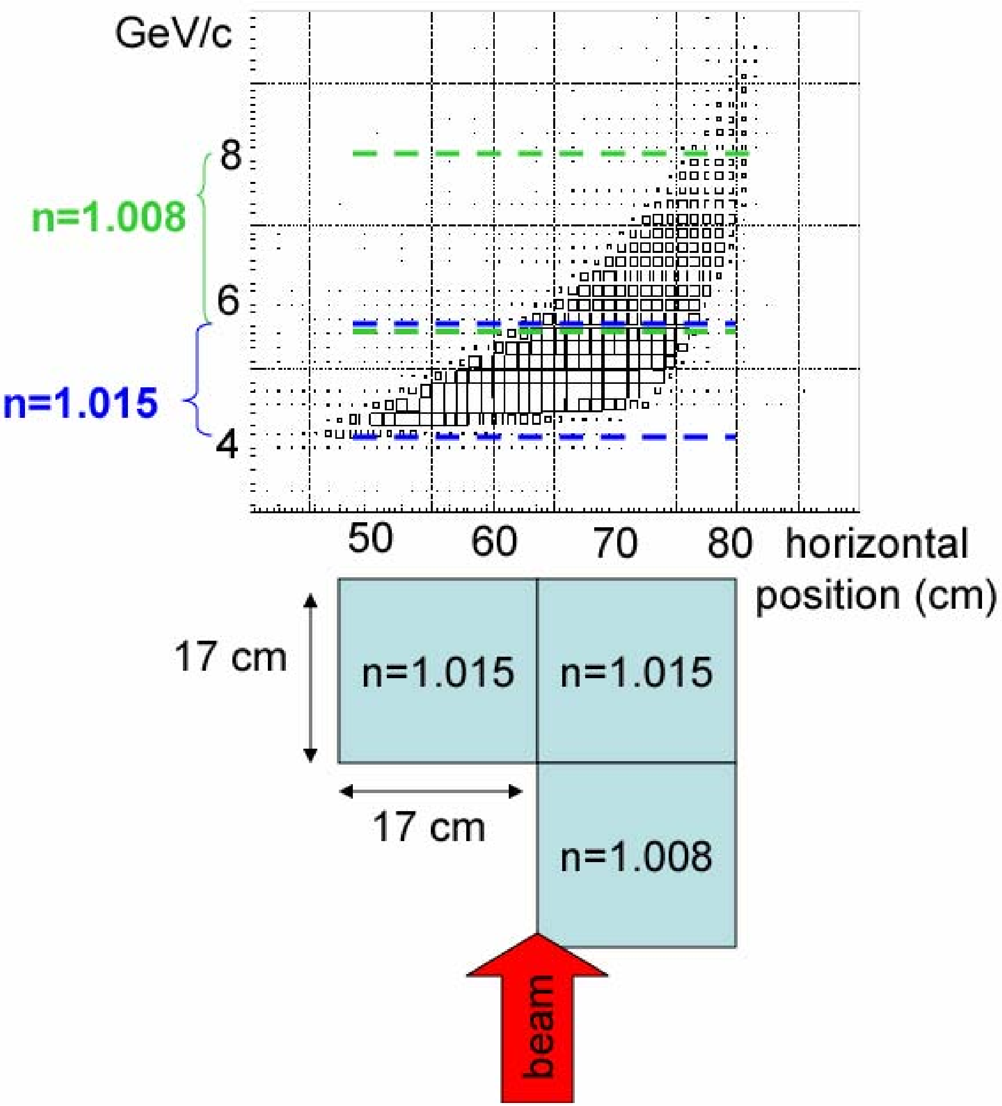
VH and HH were installed and tuned with the e^+e^- pairs in 2006.

Aerogel Cherenkov detector (I)

Responsibility:

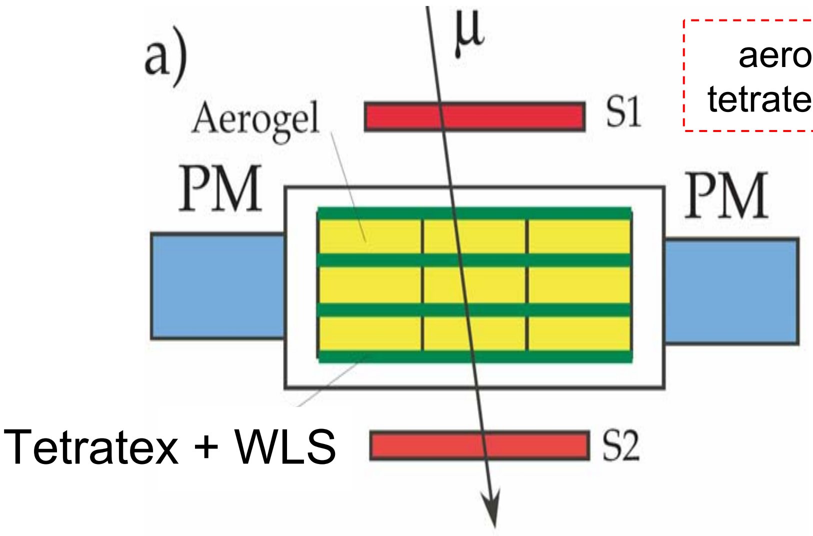
Zurich University (*Zurich*, Switzerland)

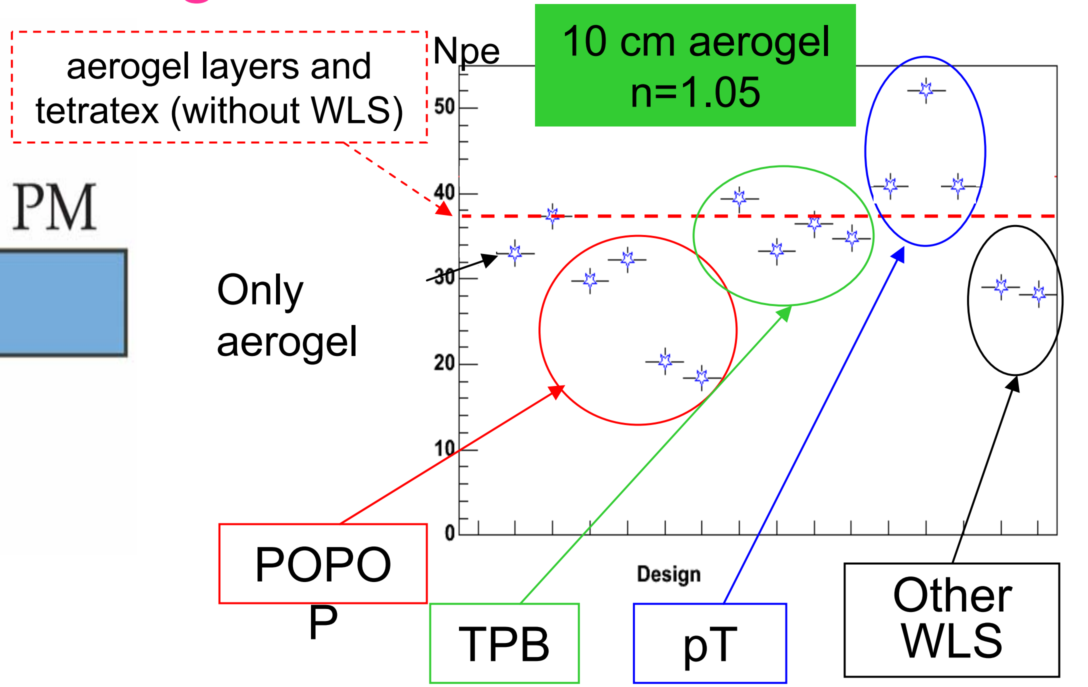


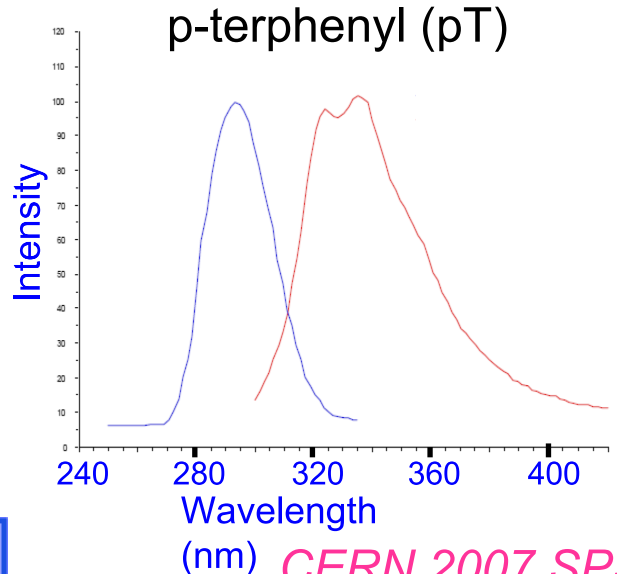


Aerogel Cherenkov detector

Design of an aerogel Čerenkov counter







Estimated N_{pe} for 15 cm aerogel (n=1.008) as a function of K-momentum

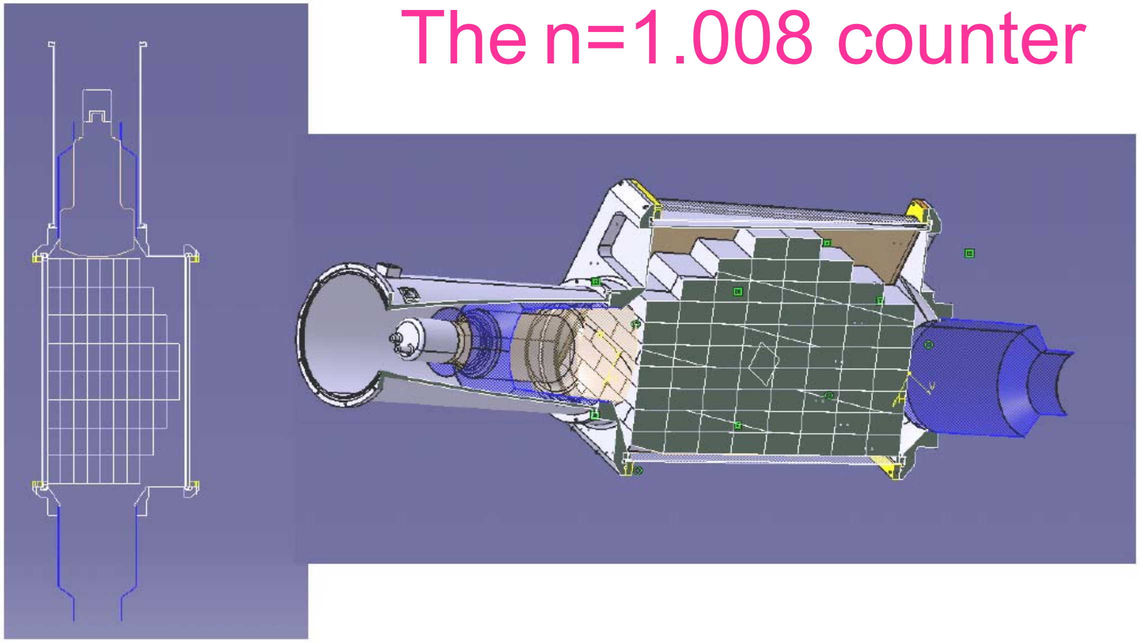
p [GeV/c]	N_{pe}	p [GeV/c]	N_{pe}
4.5	4.3	5	6.8
6	10.4	7	12.3
8	13.7	9	14.6

Aerogel Cherenkov detector

Responsibility:

Zurich University (*Zurich*, Switzerland)

The n=1.008 counter

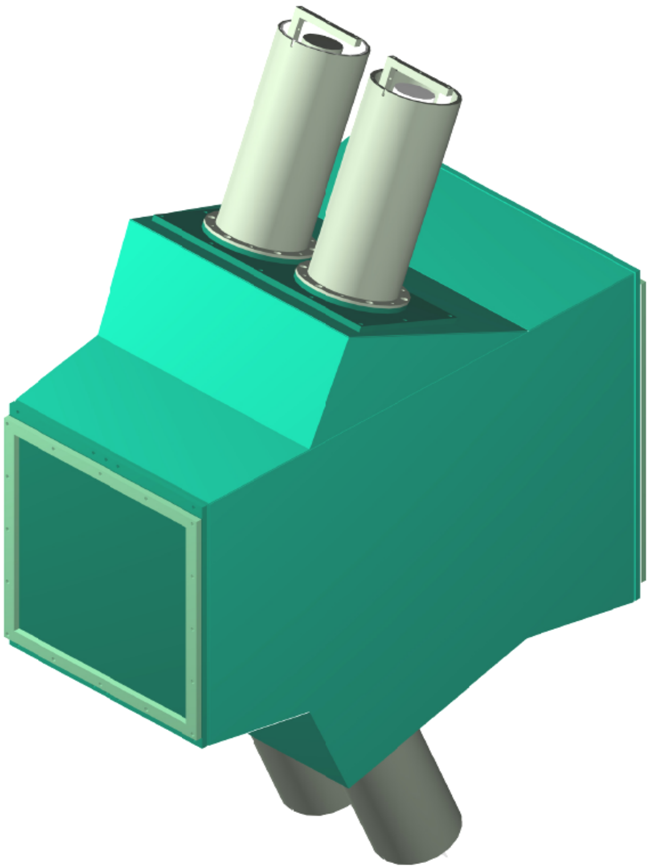


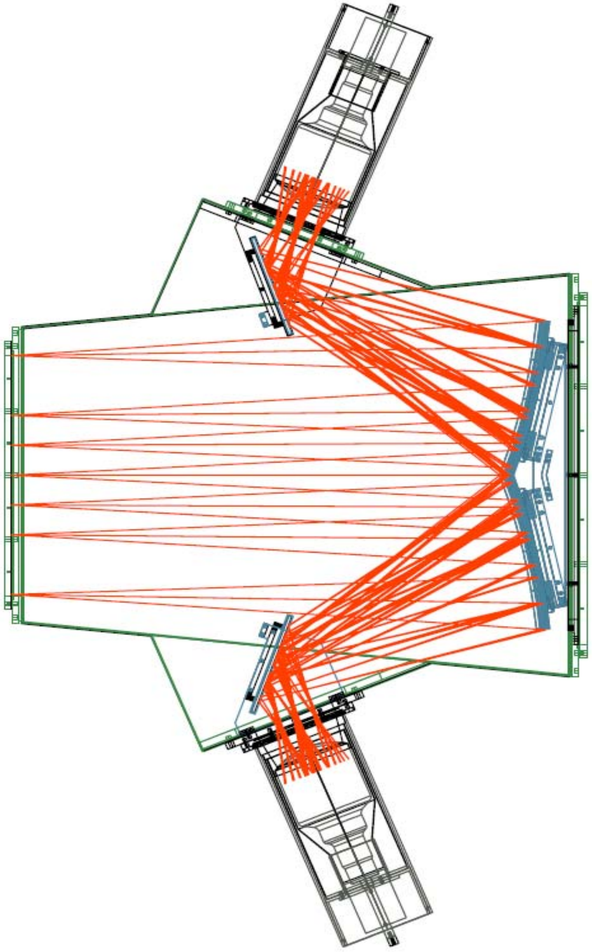
Status:

Aerogel detectors were installed on the setup

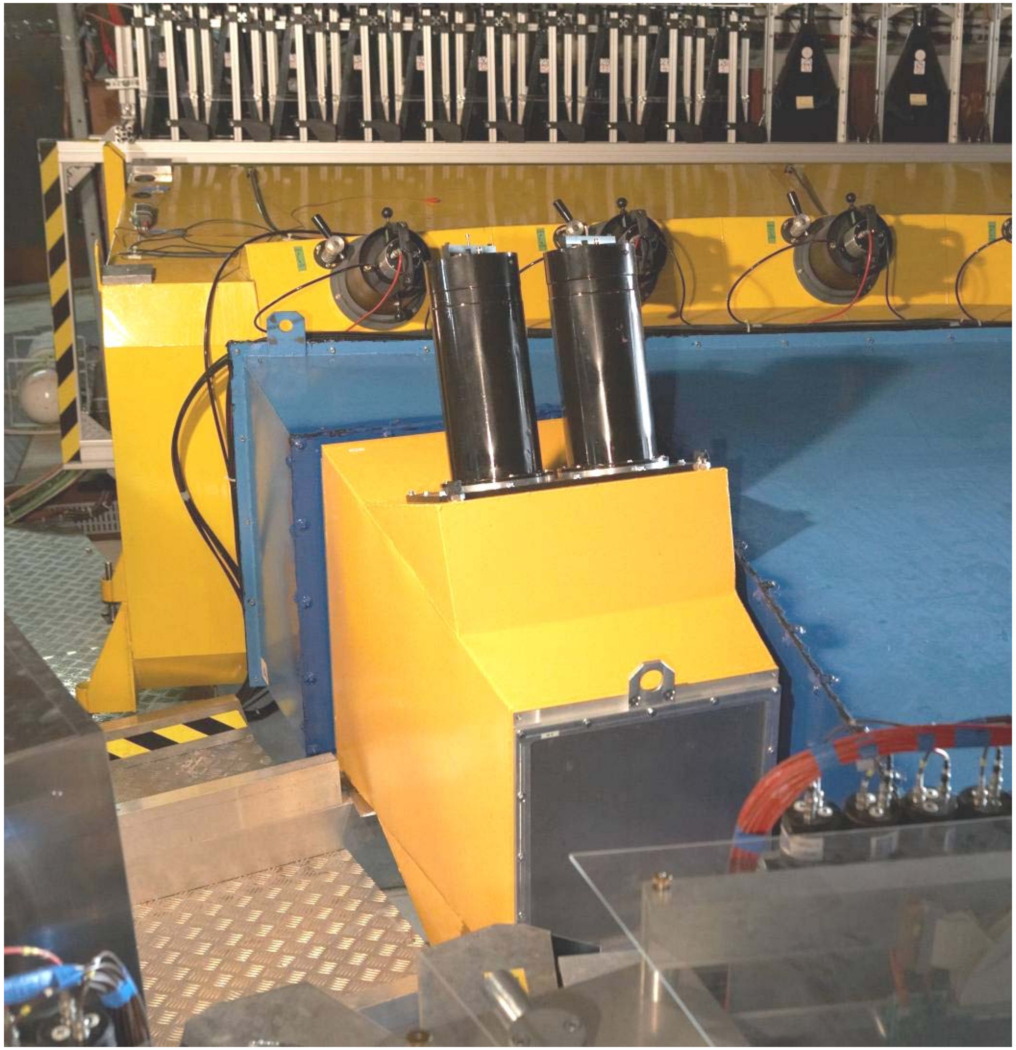
Cherenkov detector (C_4F_{10}) - I

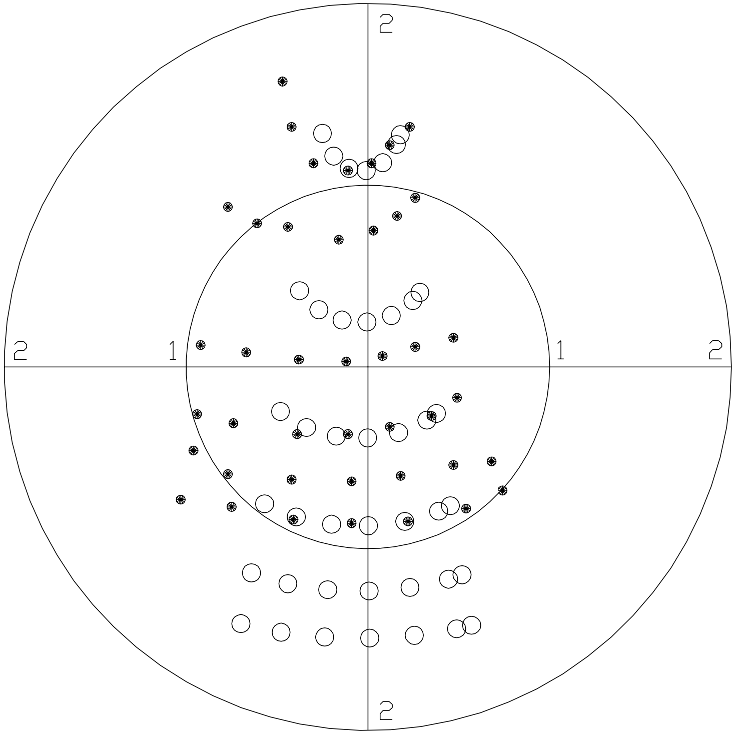
Responsibility: **JINR (*Dubna*, Russia) with participation of INFN (*Frascati* National Lab, Italy); IFIN-HH (*Bucharest*, Romania); Zurich University (*Zurich*, Switzerland); Adviser: O. Ullaland (CERN)**





Cherenkov detector (C_4F_{10}) - II





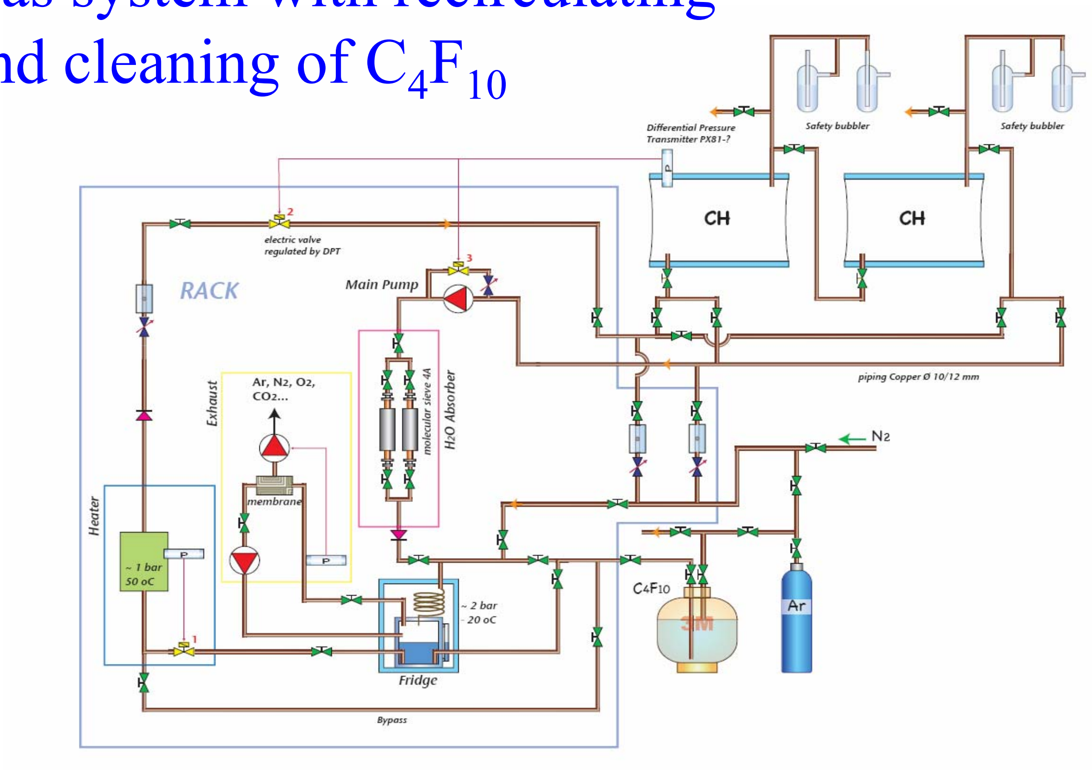
Laser test:

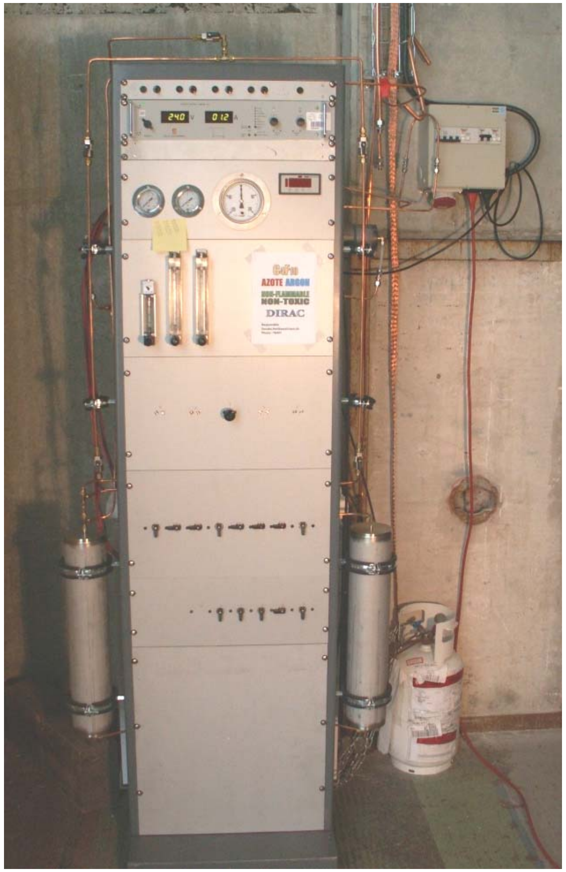
Left top PM (left arm).

Cherenkov detector (C_4F_{10}) - III

Responsibility: **Zurich University (*Zurich*, Switzerland); Adviser: O. Ullaland (CERN)**

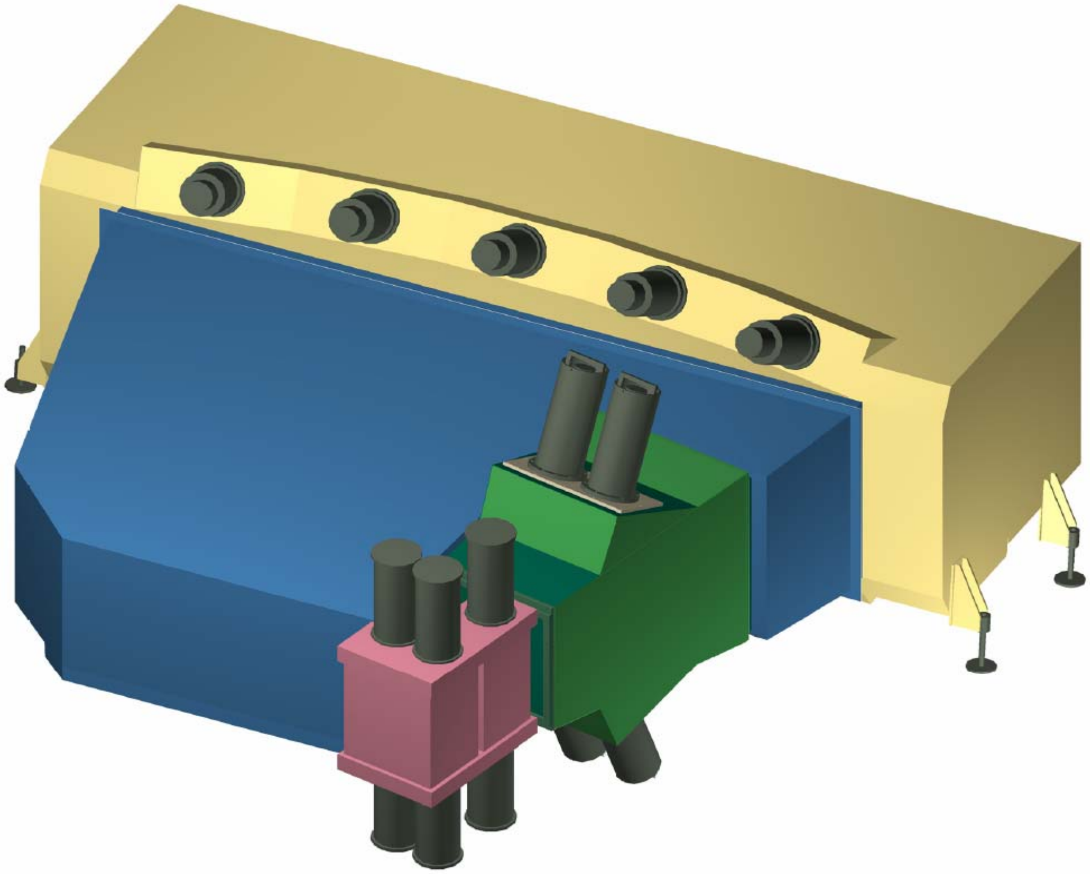
Gas system with recirculating and cleaning of C_4F_{10}





Status: It is assembled

All Cherenkov detectors

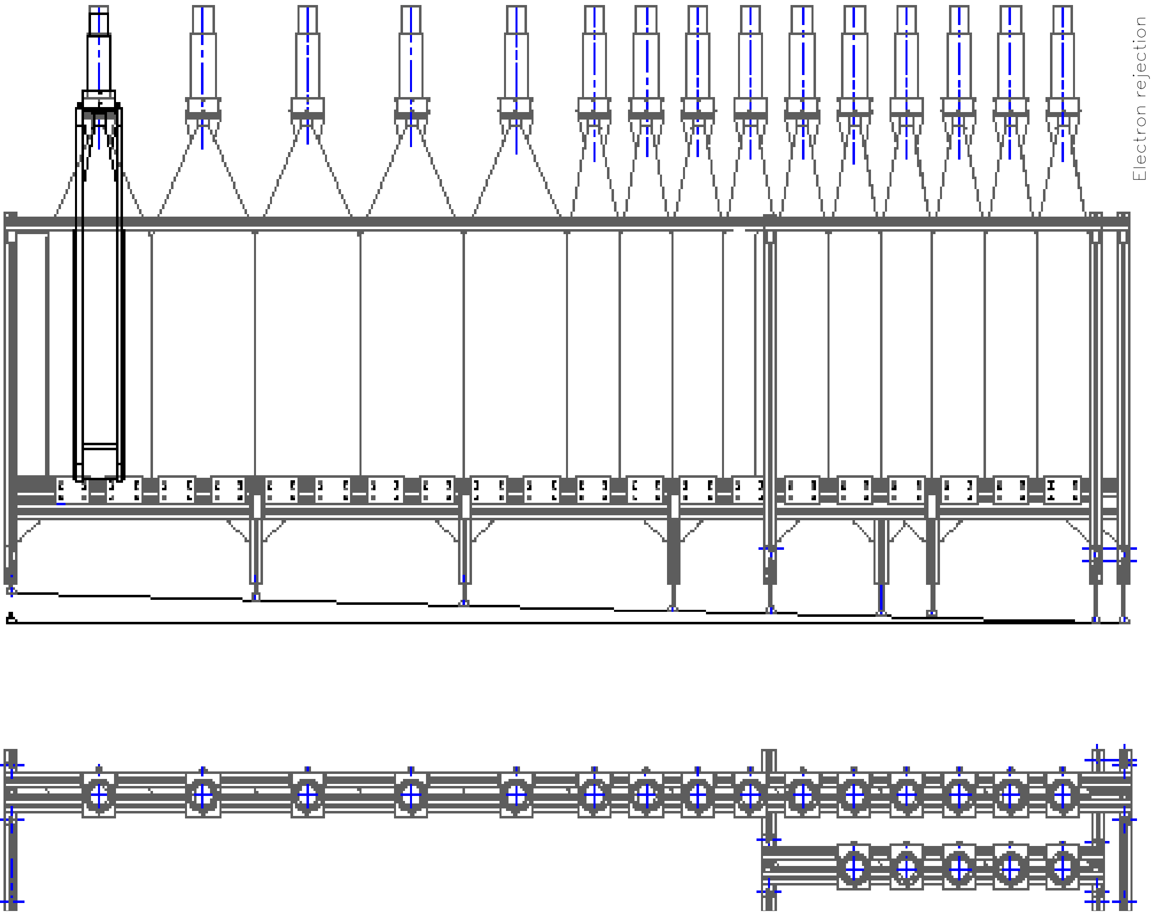


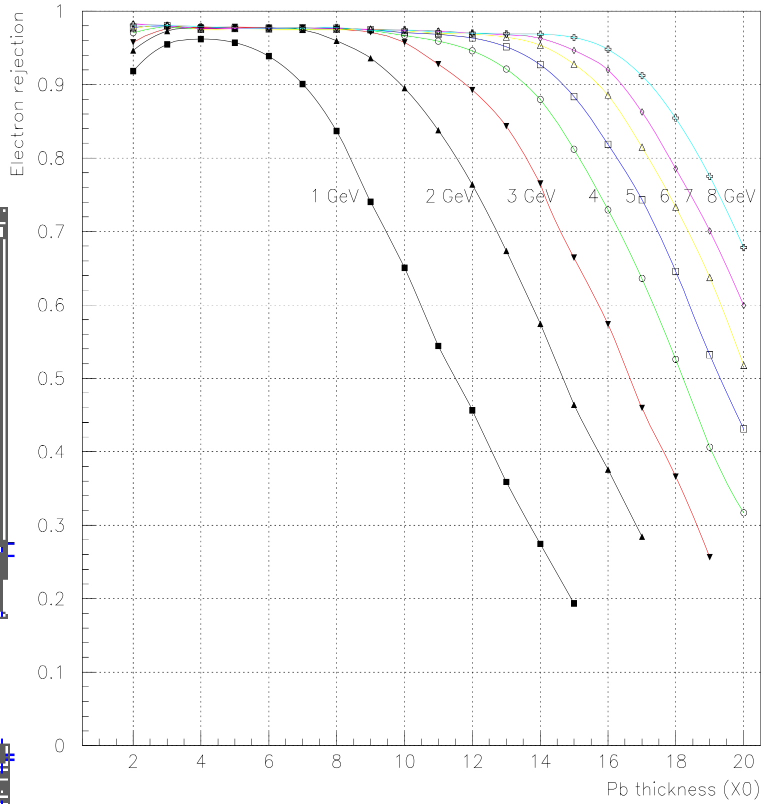
Status:

Cherenkov detector (N_2) was cut, aerogel counters and Cherenkov detector (C_4F_{10}) have been installed.

Preshower detector (I)

Responsibility: **IFIN-HH (*Bucharest*, Romania)**



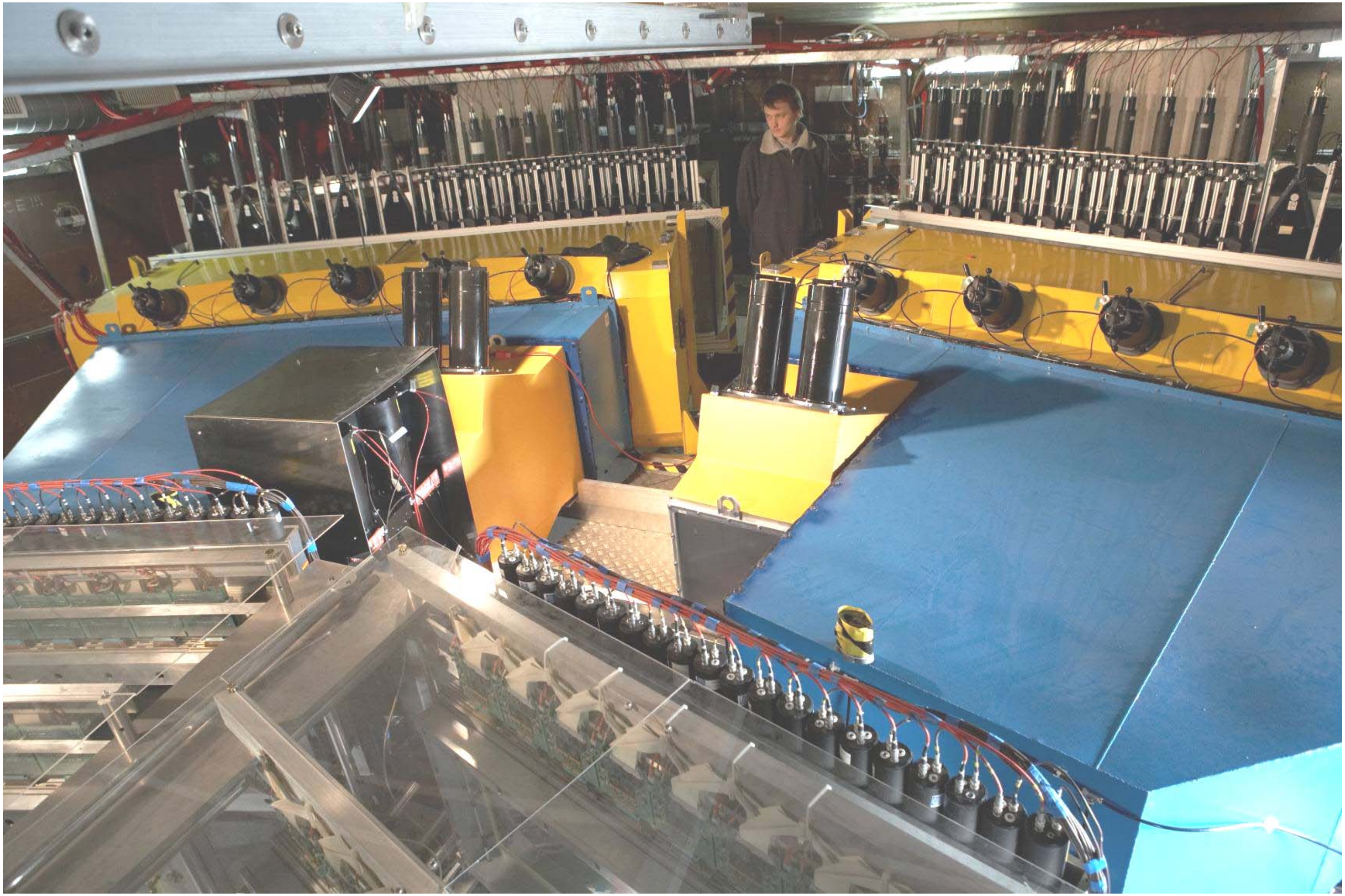


Preshower detector (II)

Status:

Installed at the setup and calibrated with $\pi^+\pi^-$ mesons and e^+e^- pairs in 2006.

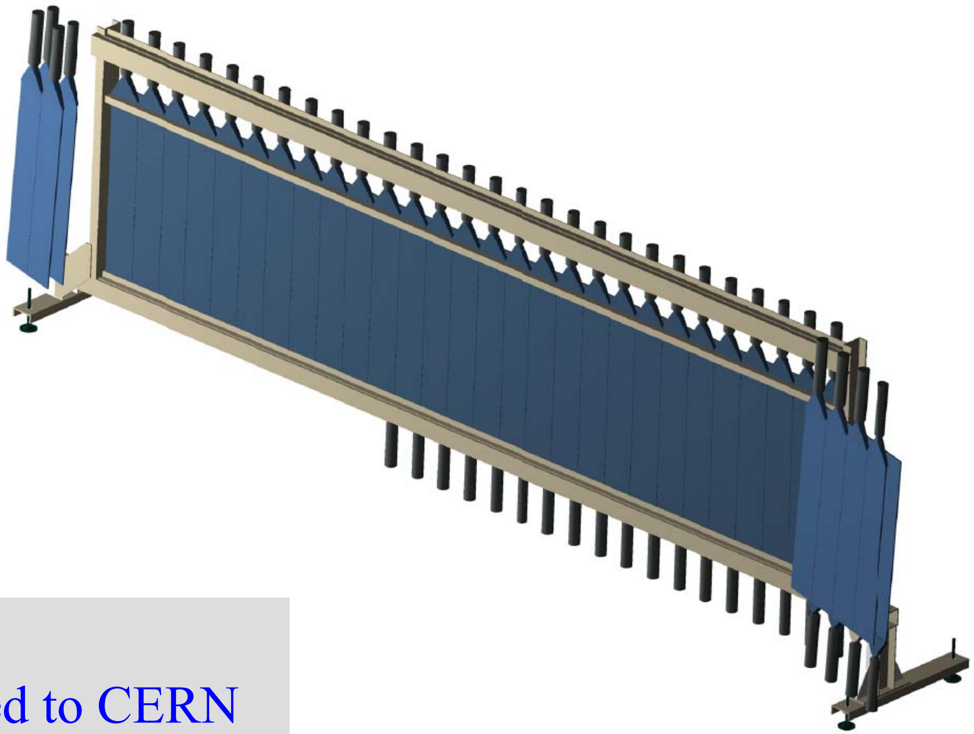
All Cherenkov detectors



Muon detector

Responsibility: **IHEP (*Protvino*, Russia)**

24 slabs (12 slabs per arm) will be added to the existing muon scintillation hodoscopes in order to increase their acceptance.



Status:
The tested counters will be delivered to CERN at the beginning of June 2007.

The goal of the 2006 RUN

I. To tune all detectors with current trigger electronics and DAQ and to collect data for $\pi^+\pi^-$, π^-K^+ and π^+K^- pairs. Analysis of this data will give a possibility to calculate the number of $A_{2\pi}$, $A_{K\pi}$ and $A_{\pi K}$.

II. To install and to test new electronics with Scintillating Fiber Detector and Ionization Hodoscope of DIRAC setup.

Trigger

Responsibility: **JINR (*Dubna*, Russia)**

The List of Triggers:

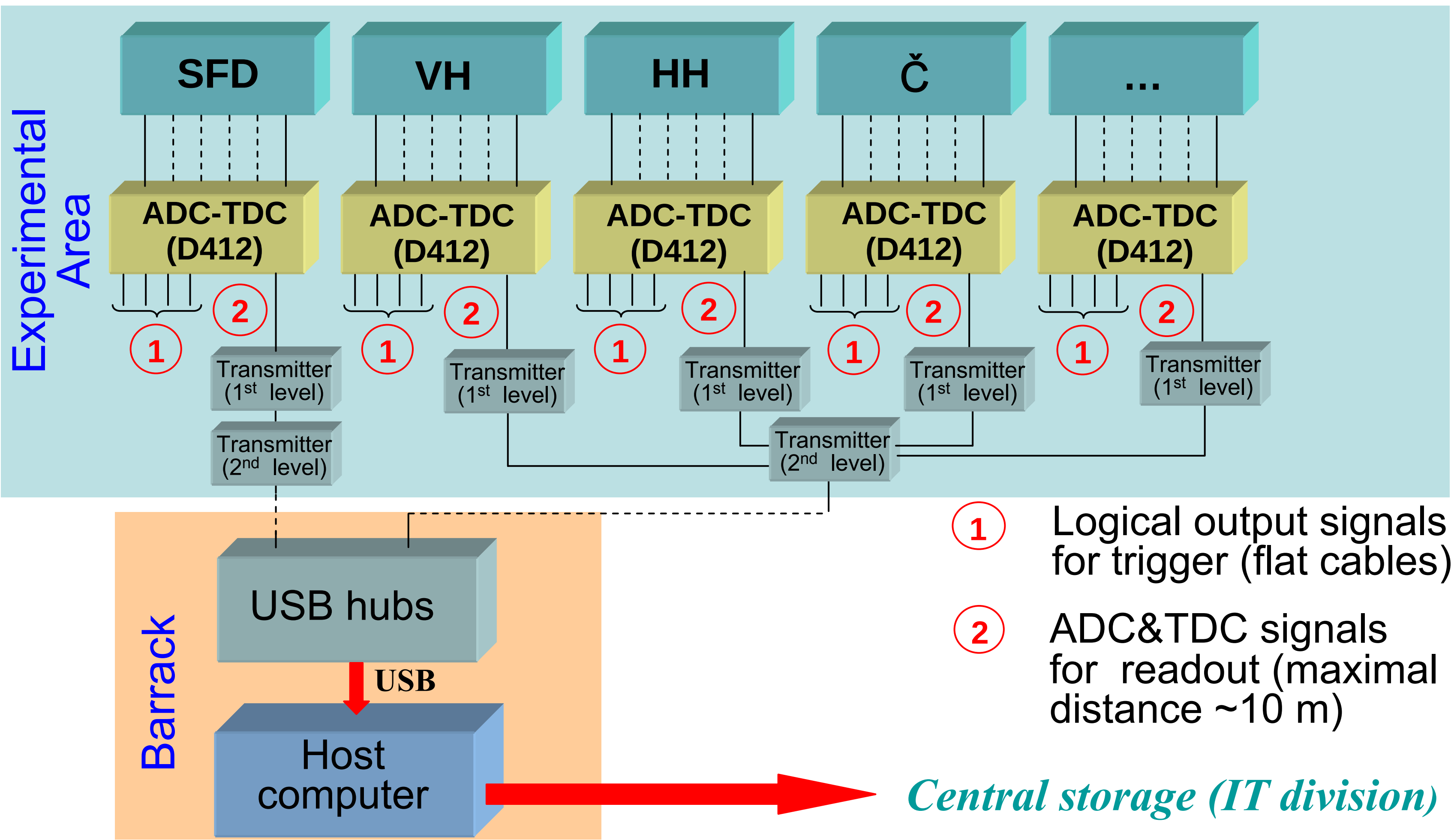
1. $A_{\pi\pi}$ $A_{\pi K}$ $A_{K\pi}$
2. $\pi^+\pi^-$ π^+K^- $K^+\pi^-$
3. $\pi^-\pi^-$, $\pi^+\pi^+$, pp
4. K^+K^- and $p\tilde{p}$
5. e^+e^- and $(e^+e^-e^+e^-)$
6. $(\pi^-\pi^-)$ $(\pi^+ \text{ or } p)$, $(\pi^+\pi^+)$ (π^-)
7. $(\pi^-\pi^-)$ $(\pi^+\pi^+)$

Status:
Trigger System with the specified performances will be tuned at the beginning of the DIRAC 2007 run.

Expected number of triggers per spill ~ 4000, event volume 4 *Kbytes*
Expected volume of data per spill ~ 16 *Mbytes* (~50 *Mbytes/supercycle*)
(current transmitting capacity of the line with IT-division (~50 *Mbytes/supercycle*)

Readout System

Responsibility: **JINR (*Dubna*, Russia) with participation of IFIN-HH (*Bucharest*, Romania); Zurich University (*Zurich*, Switzerland)**



Status of the new electronics

Readout System

ADC-TDC	53 modules	
Transmitter 1st level	10 modules	All electronics modules have been produced
Transmitter 2nd level	4 modules	
Auxiliary module	3 modules	

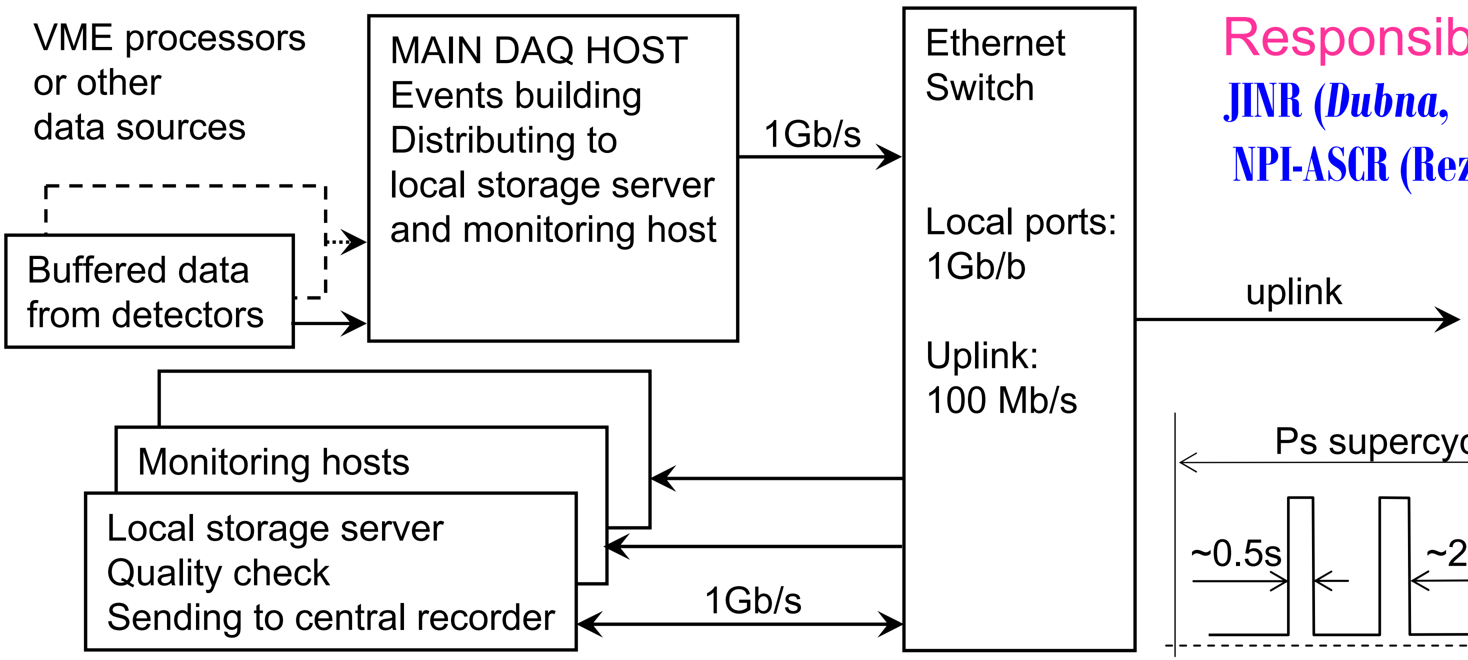
Trigger System

Shaper K436	20 modules	All trigger modules have been produced
Level translator	21 modules	

Time schedule:

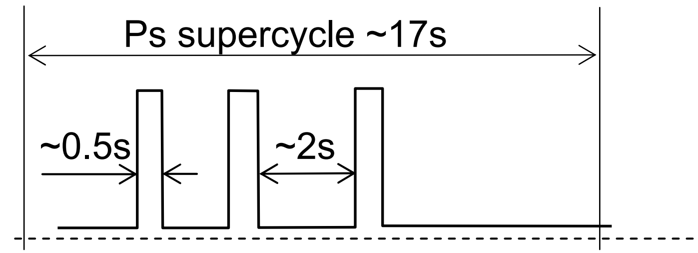
Trigger modules, Chain ADC-TDC – TRANSMITTER I – TRANSMITTER II and the dedicated software are being tuned at JINR and will be delivered to CERN in May 2007

Data Acquisition System



Central storage (IT division)

Responsibility:
JINR (*Dubna*, Russia),
NPI-ASCR (Rez, Czech Republic);



Status:

Software for automatic and interactive on-line monitoring of data done in 2006

Some tests and tuning will be required at the beginning of beam time 2007.

Upgrading and tuning hardware and operating systems for computers which are critical for data acquisition system done in July-August 2006.

Software for handling with new electronic modules was written in April-November 2006. Some tests and tuning will be required after assembling new front-end electronics in May-June 2007.

Observation of $A_{\pi K}$ and $A_{K\pi}$ atoms

Ni(2001) $n_{A2\pi}$=6530 (4 months of data-taking)

per month: $n_{A2\pi}$=1600

$$\frac{N(A_{2\pi})}{N(A_{\pi K})} \propto \frac{P_B^3(\pi\pi)}{P_B^3(\pi K)} \frac{\Delta\sigma_\pi}{\Delta\sigma_K}$$

$$\frac{N(A_{2\pi})}{N(A_{\pi K} + A_{K\pi})} \approx 12$$

Expected efficiency of DIRAC-II is improved by more than a factor of 2

πK atom: W_{ion}(Ni)=0.31 W_{ion}(Pt)=0.55

For Ni target (per month): $n_{A2\pi}$=3200 $n_{A\pi K} + n_{AK\pi}$ =190

For Pt target (per month): $n_{A\pi K} + n_{AK\pi}$ =340

First observation of $A_{\pi K}$ and $A_{K\pi}$ atoms:

expected significance after 2 months: 5σ or more

Plan for the run 2007

I. Tuning of all detectors with the new front-end, readout and trigger electronics June-July 2007.

II. Data-taking with the upgraded setup August-October 2007.

Conclusions

I. All detectors with the new front-end, readout and trigger electronics will be operational in 2007.

II. Aim of the upgraded setup is

the first observation of $K^+\pi^-$ and π^+K^- atoms

in 2007.