Status Report of DIRAC

LIFETIME MEASUREMENT OF $\pi^+\pi^-$ ATOMS TO TEST LOW-ENERGY *QCD* PREDICTIONS

and

DIRAC Addendum

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

L. Nemenov

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

I. DIRAC Addendum

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

II. Status of DIRAC Analysis

Main goal 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

DIRAC Addendum

Present low-energy QCD predictions for $\pi\pi$ 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 current results, 2001 data:

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

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:

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

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

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:

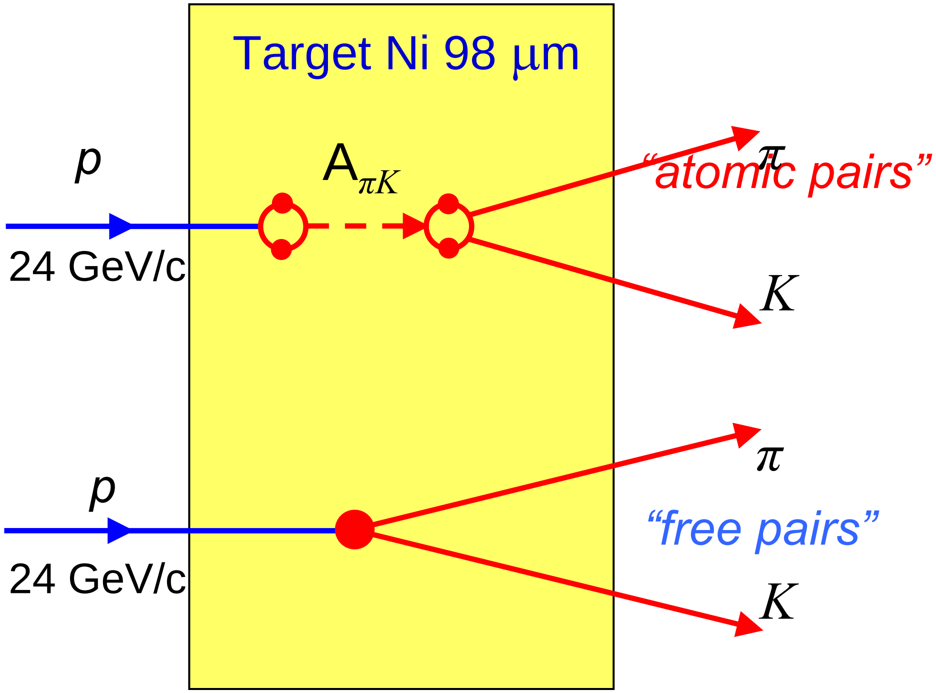
$$\frac{\sigma_\tau}{\tau} = 6\%, \qquad \frac{\sigma(a_0 - a_2)}{a_0 - a_2} = 3\%$$

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:

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

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.

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

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

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

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

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

Main features of the DIRAC set-up

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

Magnetic spectrometer

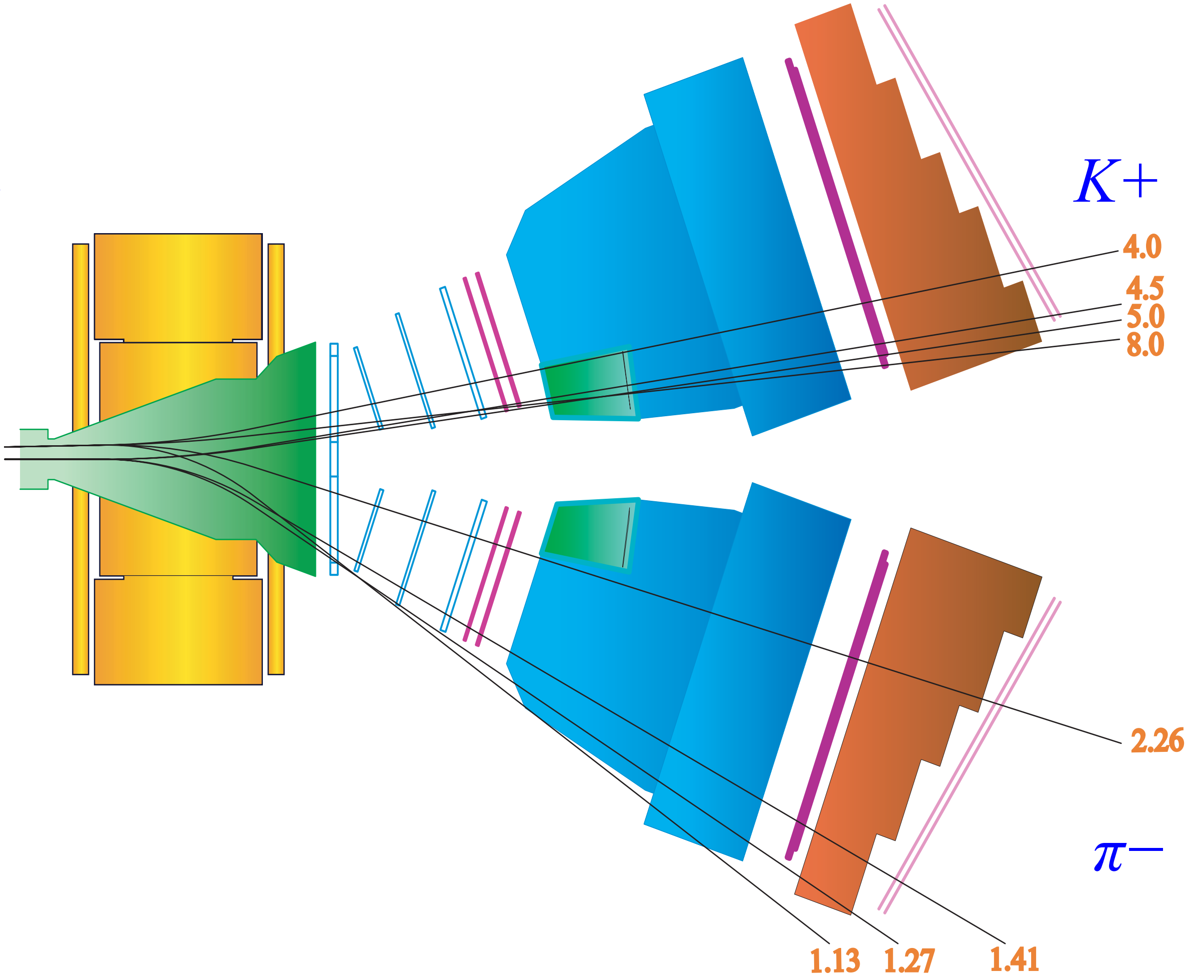
Proton beam ~ 10^{11} proton/spill

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

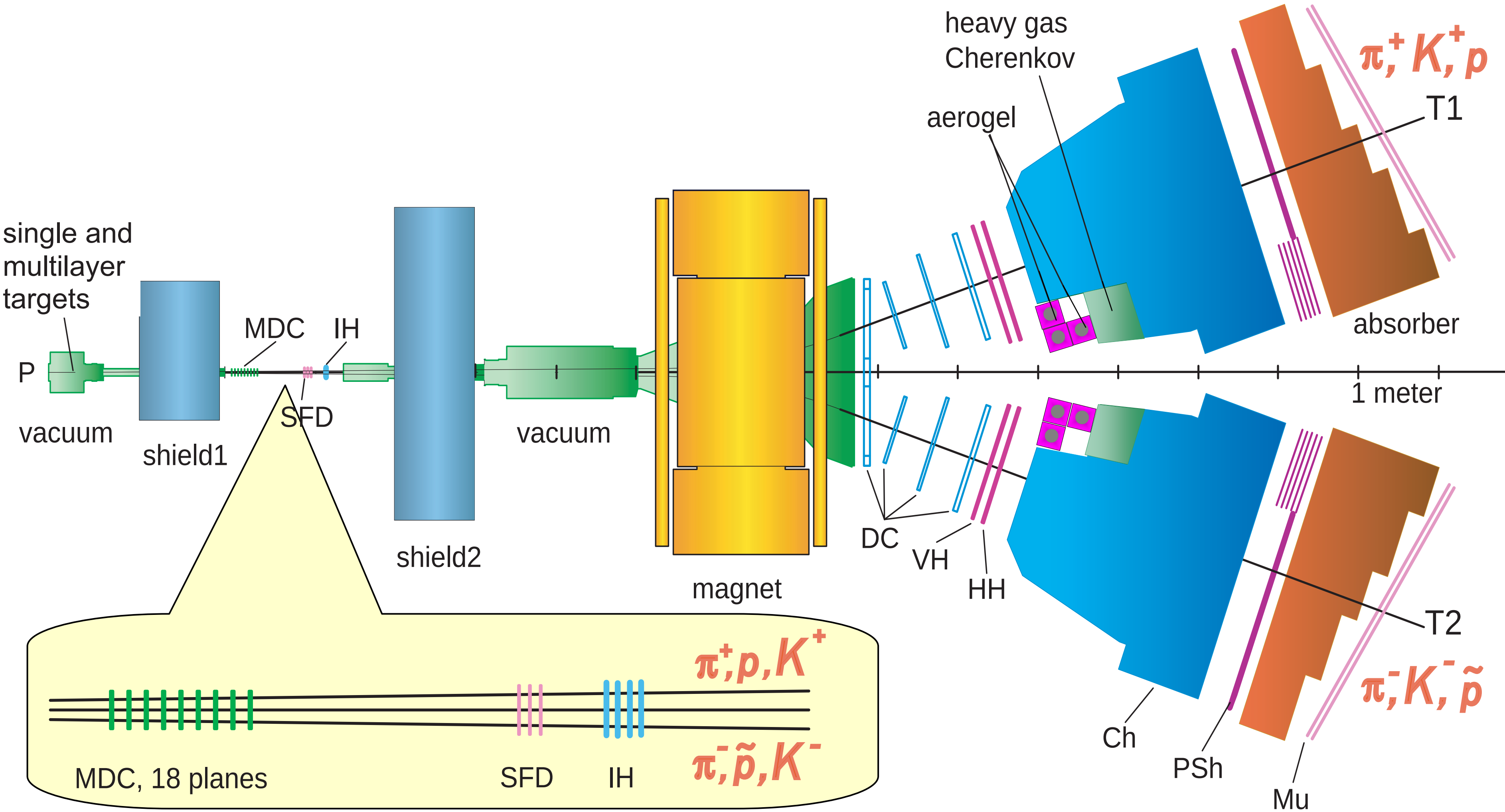
The $A_{\pi K}$ breaks up to π^- and K^+ with the unequal momenta

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



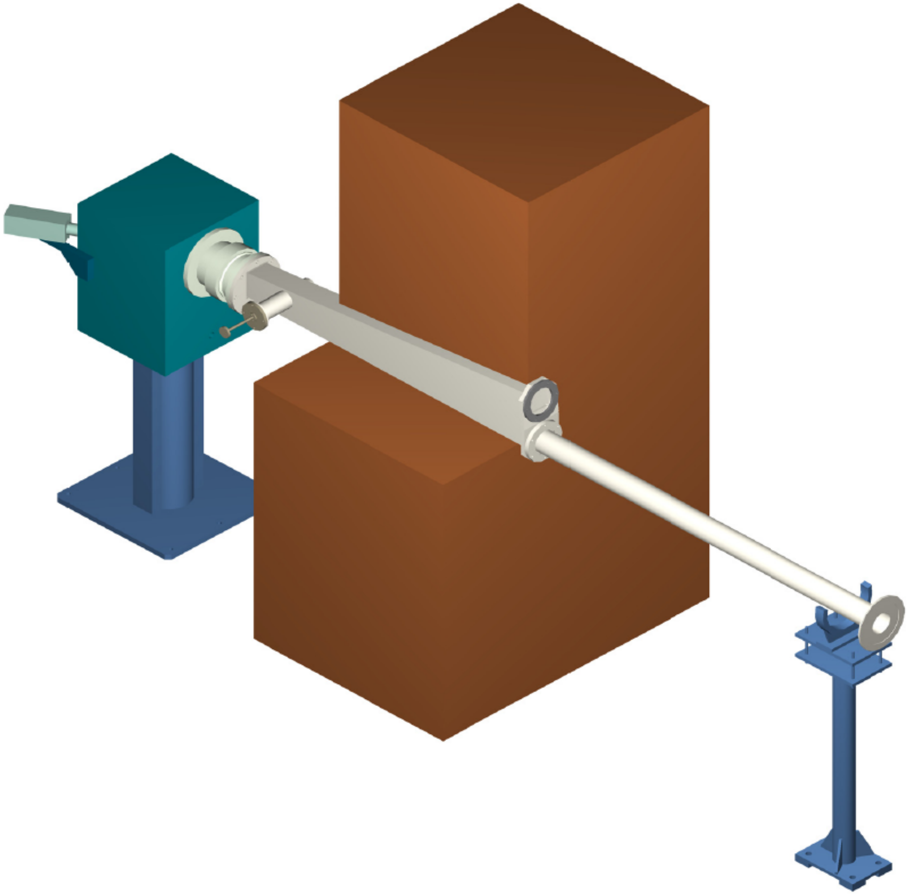
Numbers are the π^- and K^+ momenta in GeV/c

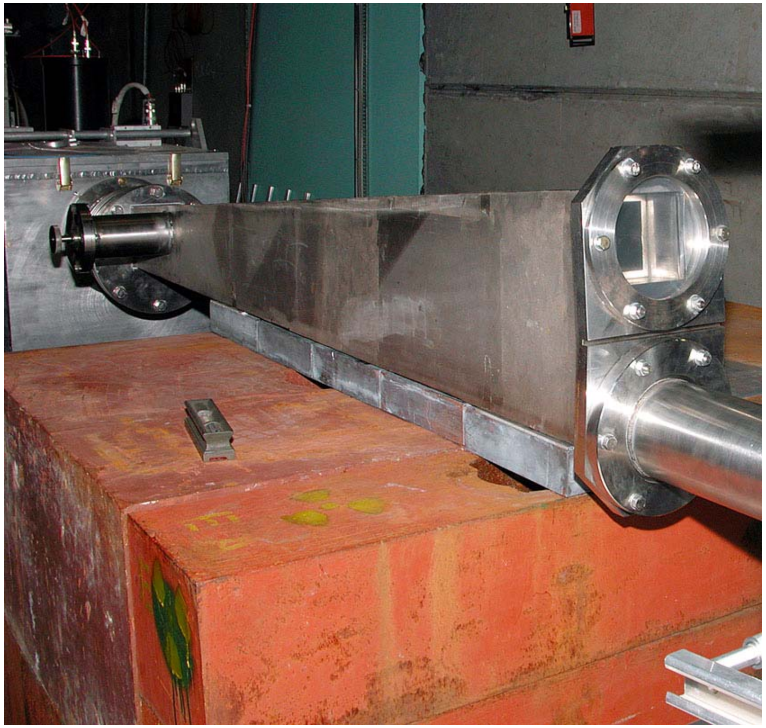
Upgraded DIRAC experimental set-up description



Vacuum Channel and Shielding (I)

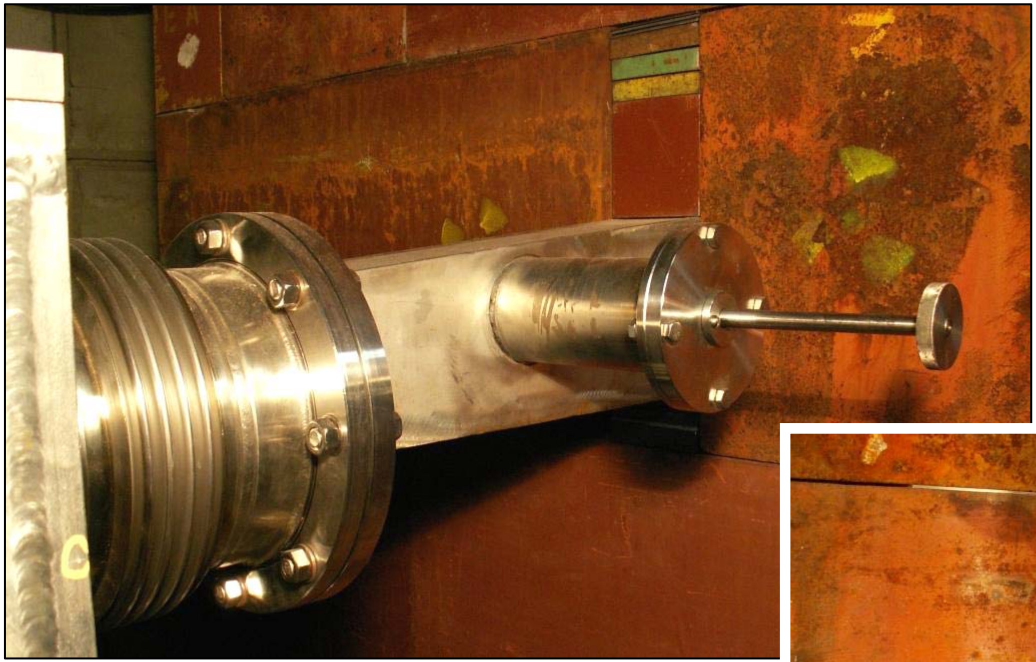
Responsibility: **JINR (*Dubna*, Russia)**





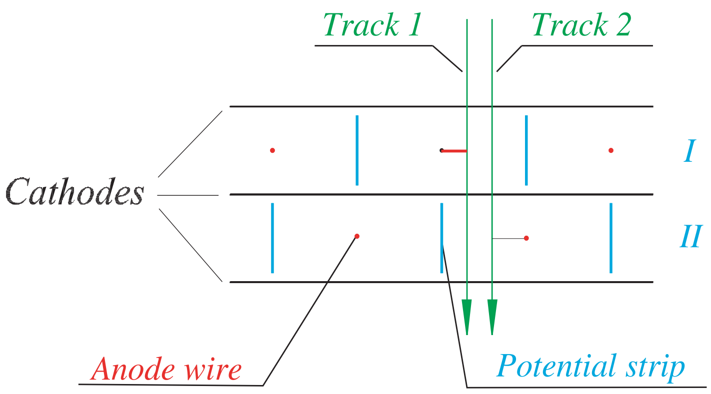
Status:
Installed in March 2006,
vacuum tests are done.
Completed.

Vacuum Channel and Shielding (II)



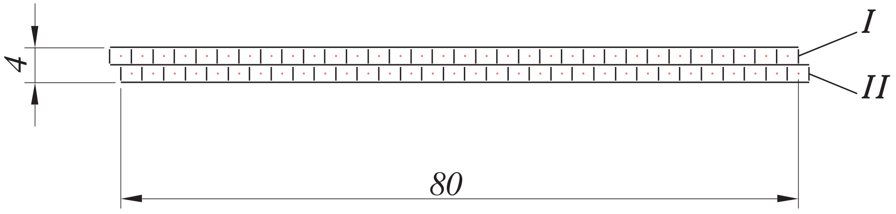
Microdrift Chambers (I)

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



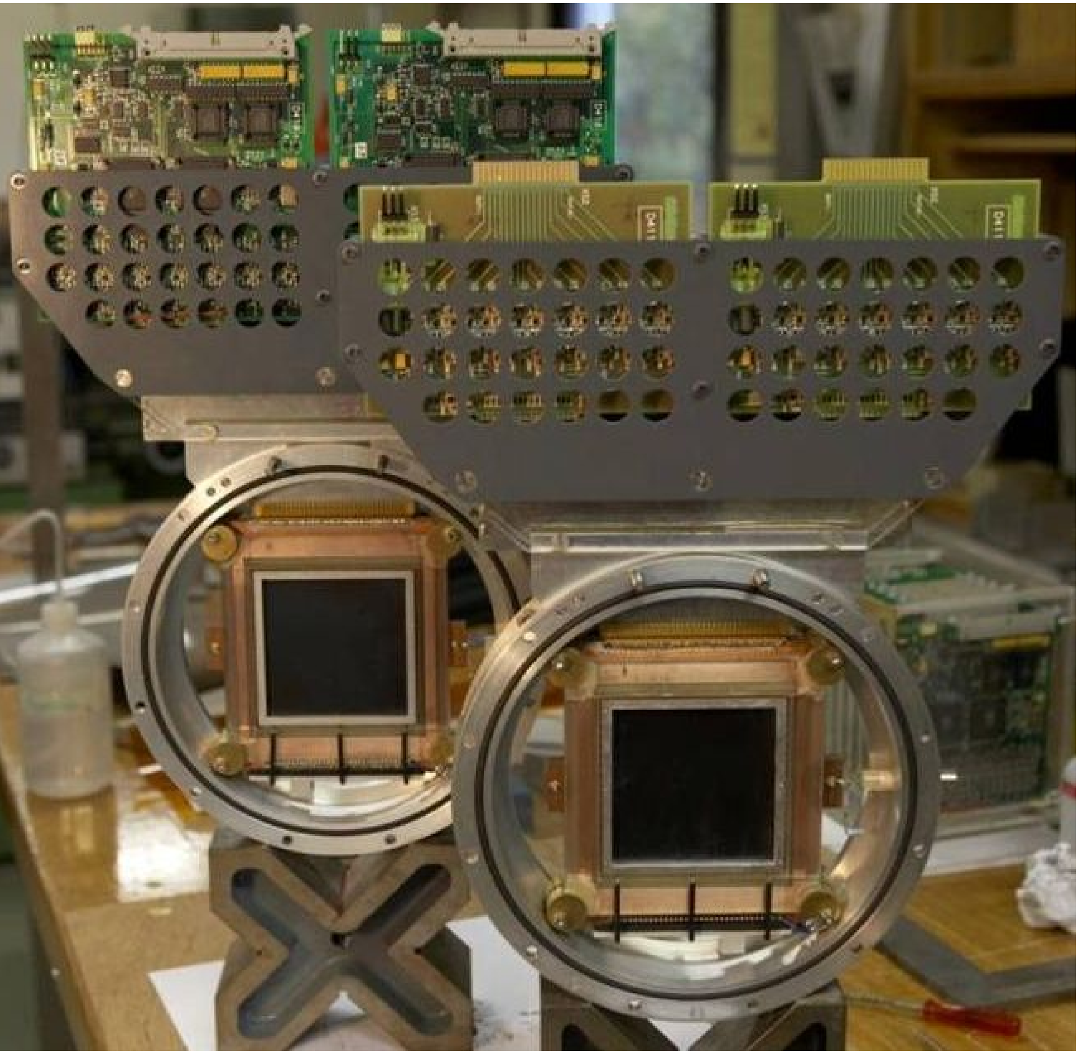
Characteristics:

- 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 (II)

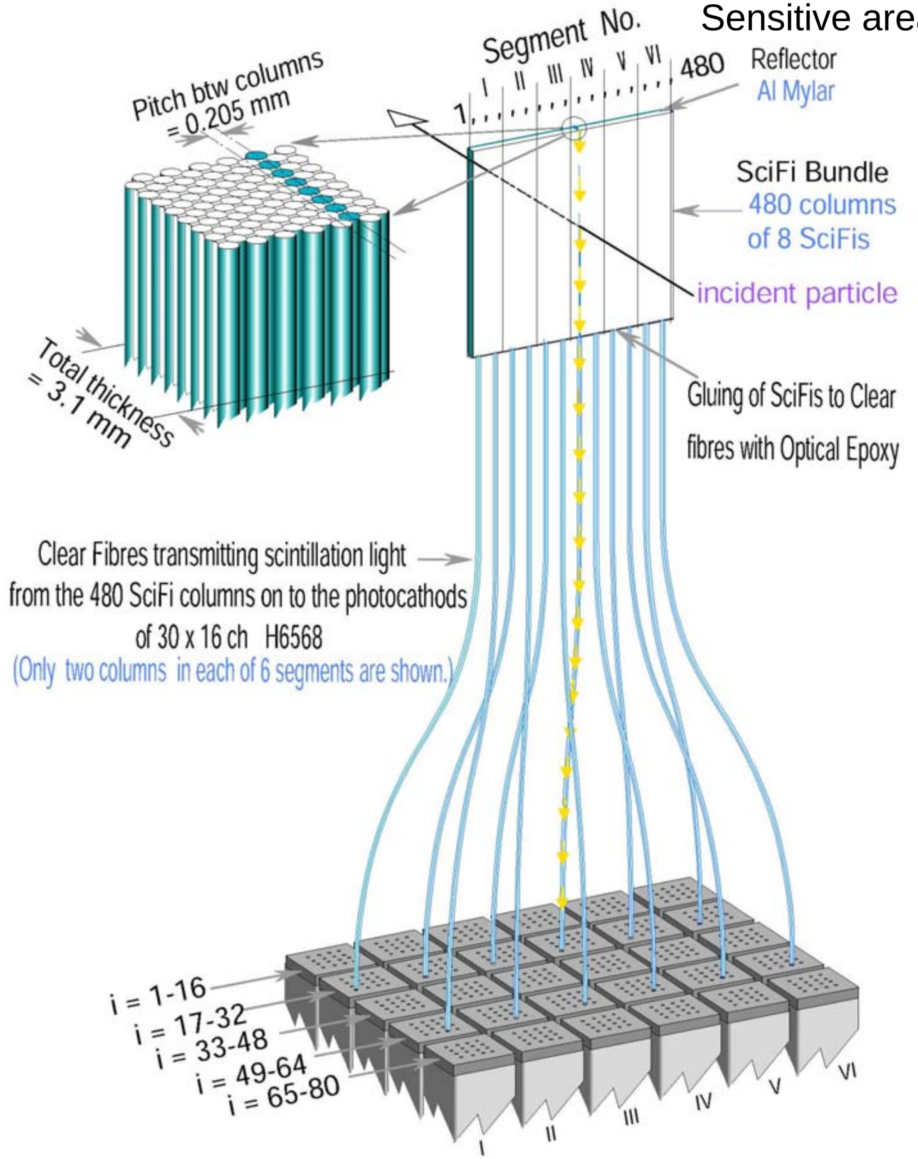


Status

Chambers with the new electrodes and all electronics have been delivered to CERN. The high voltage test has been performed. The first version of the tracking code has been developed.

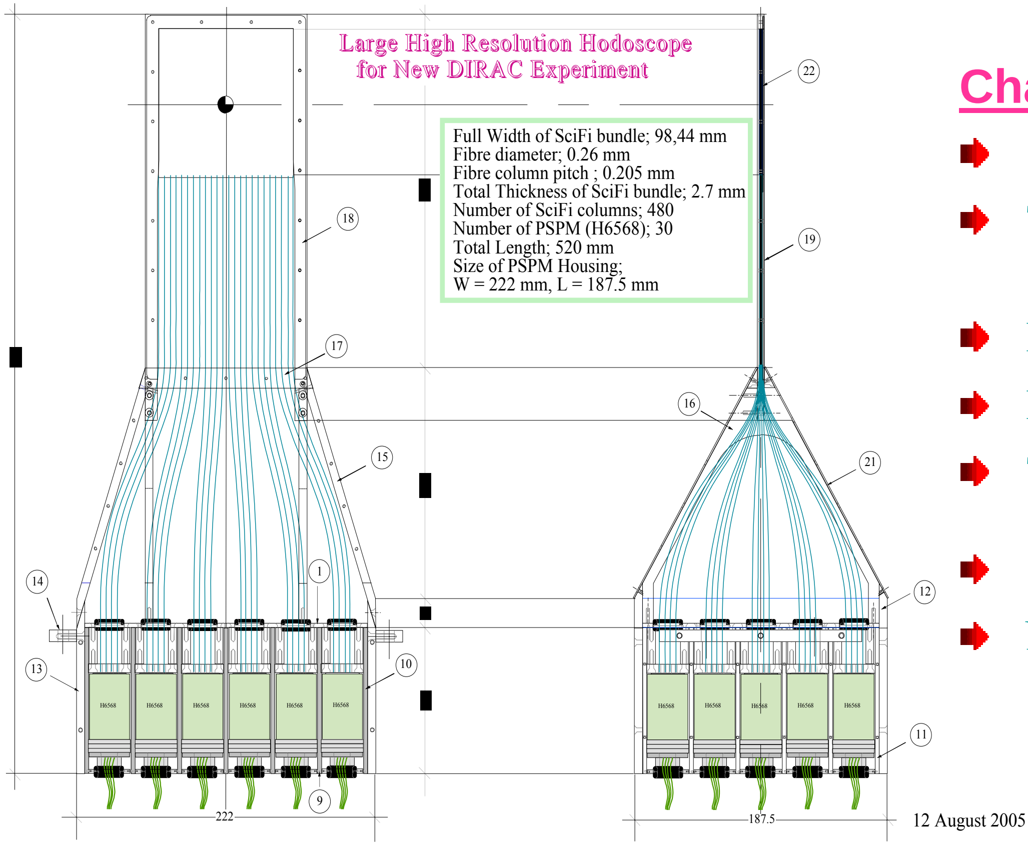
Scintillation Fiber Detector (I)

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)**

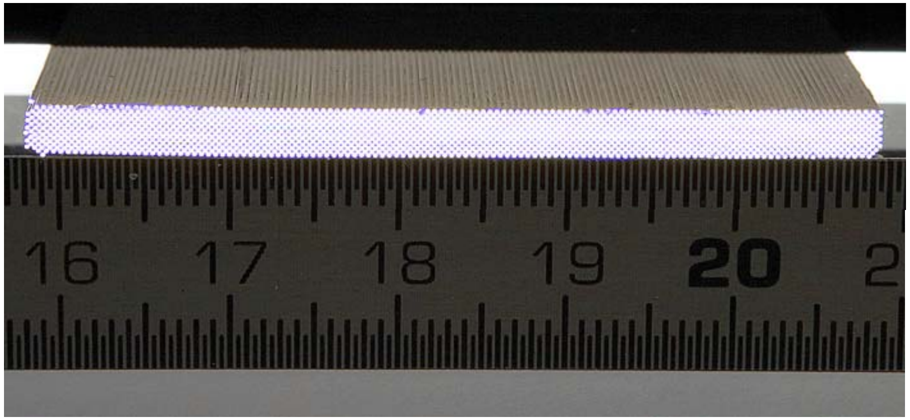


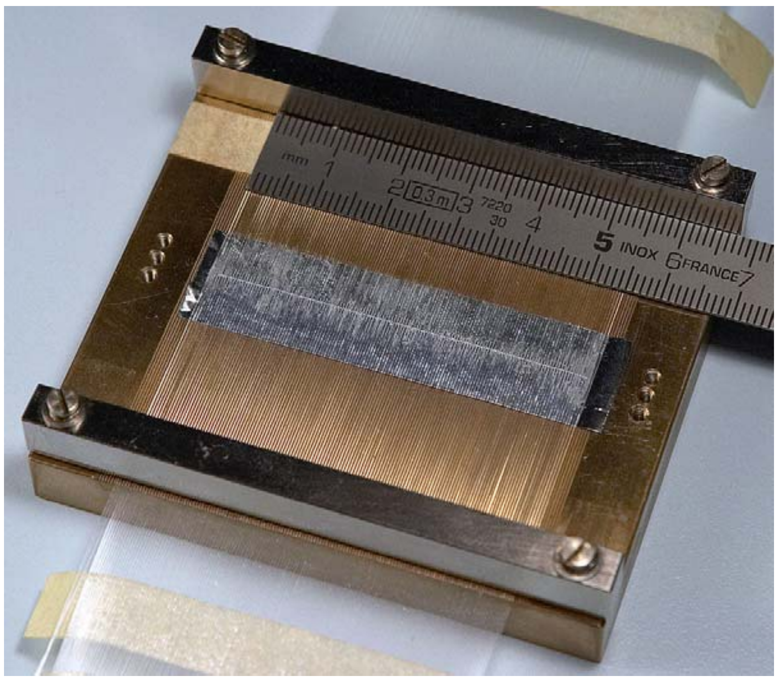
Characteristics:

- 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 — $60\ \mu m$
- New electronics (*ADC-TDC for each channel*) — 960 *channels*

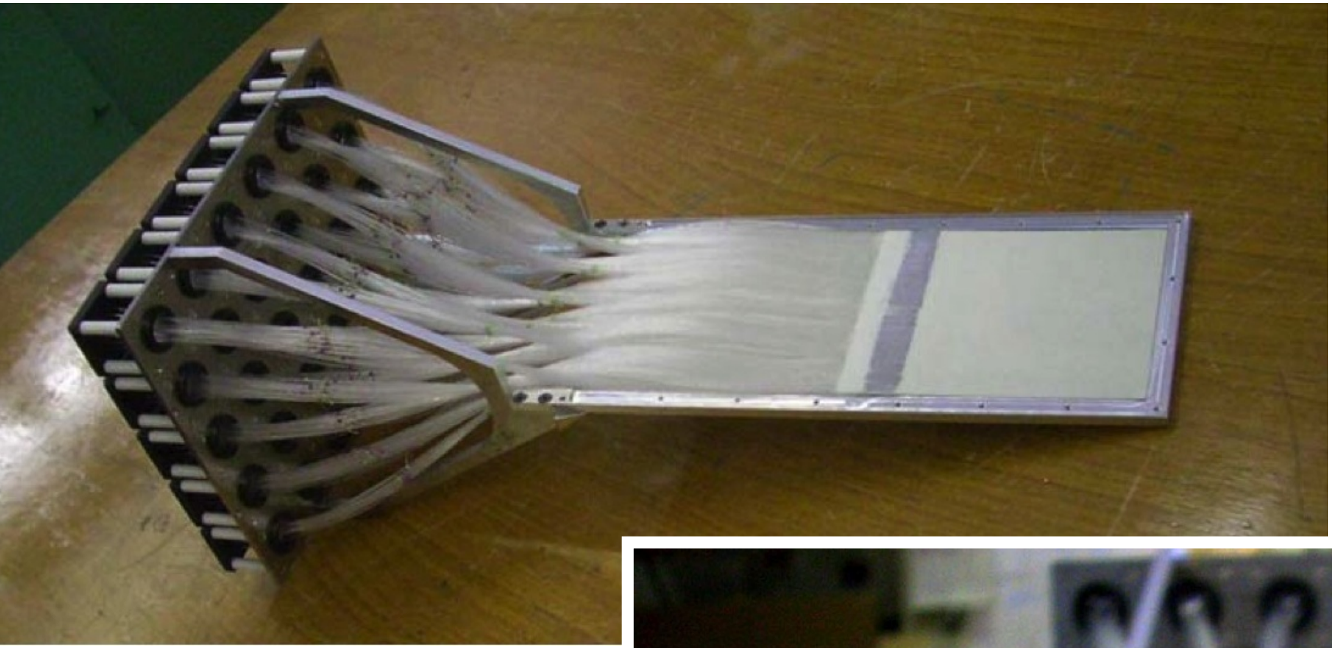
Two new SFD detectors were tuned on the test beam T11 during August-September 2006, installed at the DIRAC setup and checked.

Scintillation Fiber Detector (III)

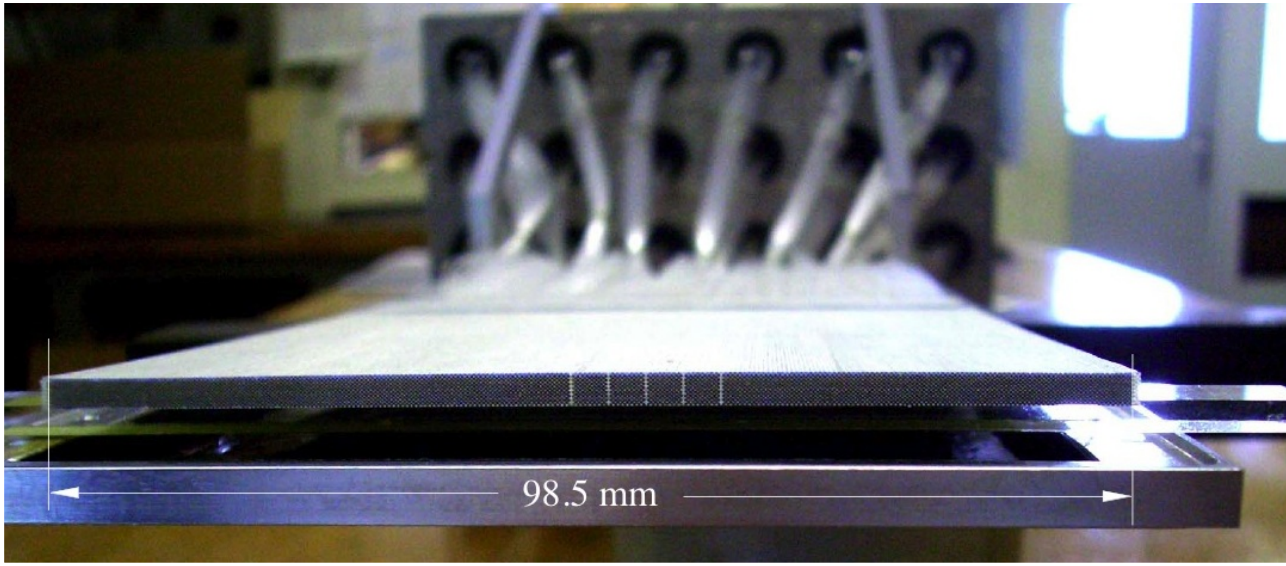




Scintillation Fiber Detector (IV)

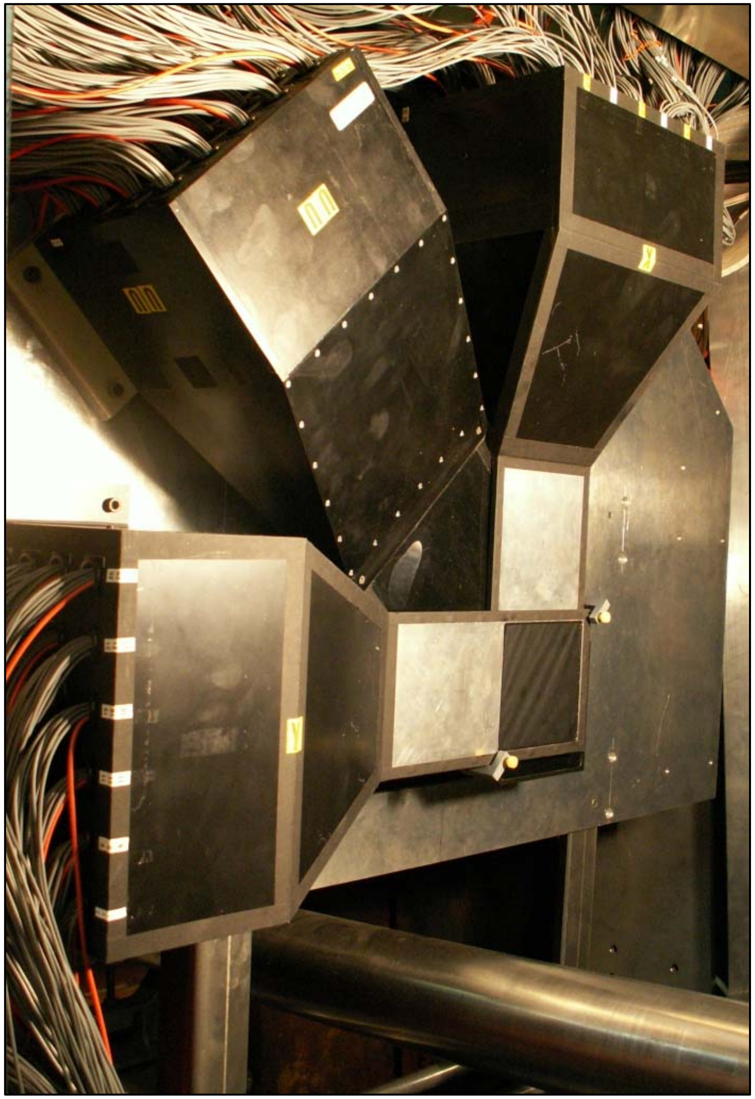


Sensitive area
98.5 x 107 mm²
consists of 480 columns
of 8 Scintillating Fiber of
0.26 mm in diameter



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

Scintillation Fiber Detector (V)



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:

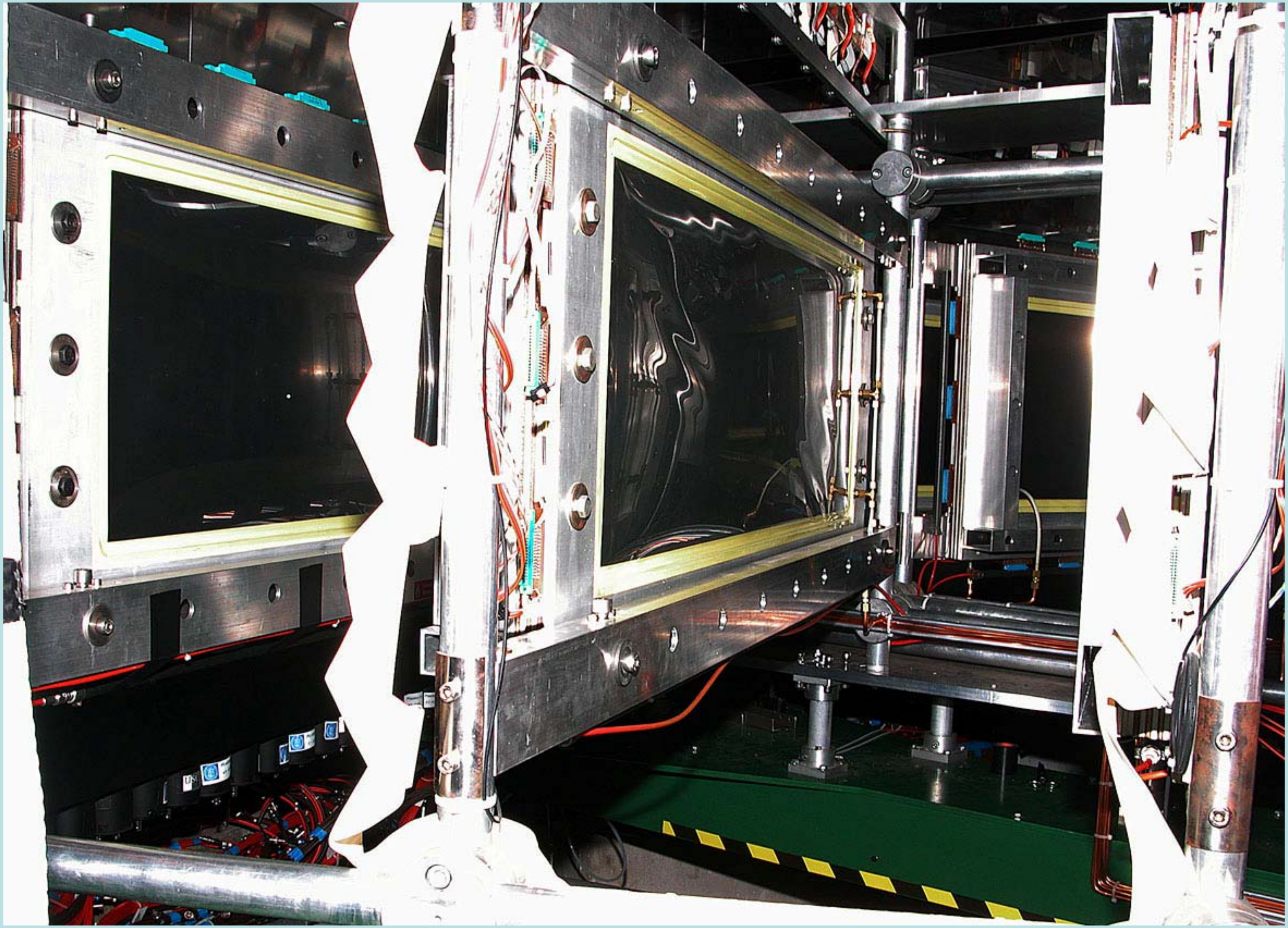
- ✓ DC2 with an active area of 80×40 cm^2 and 2 wire planes (*X, Y*);
- ✓ DC3 with an active area of 112×40 cm^2 and 2 wire planes (*X, Y*);
- ✓ DC4 with an active area of 128×40 cm^2 and 4 wire planes (*X, Y, X',Y'*).

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)

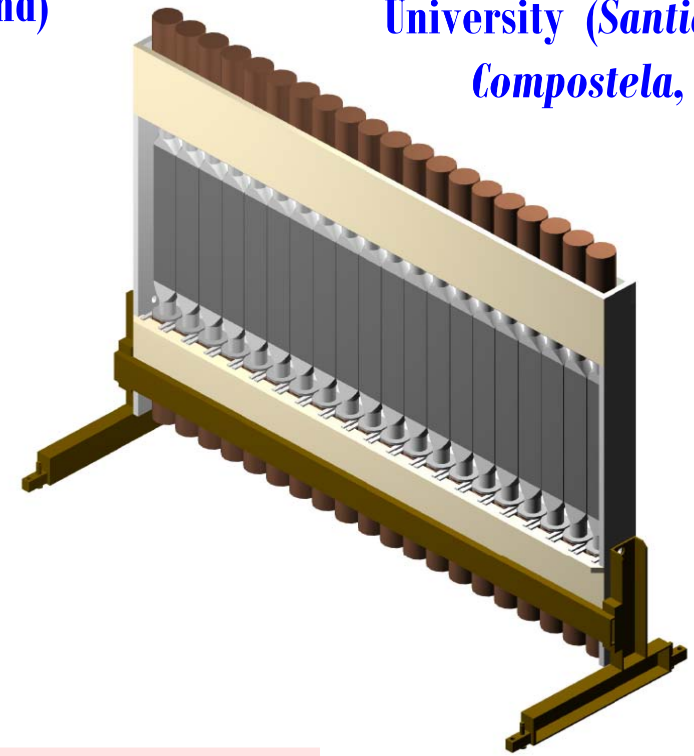


Vertical and Horizontal Hodoscopes (I)

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

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

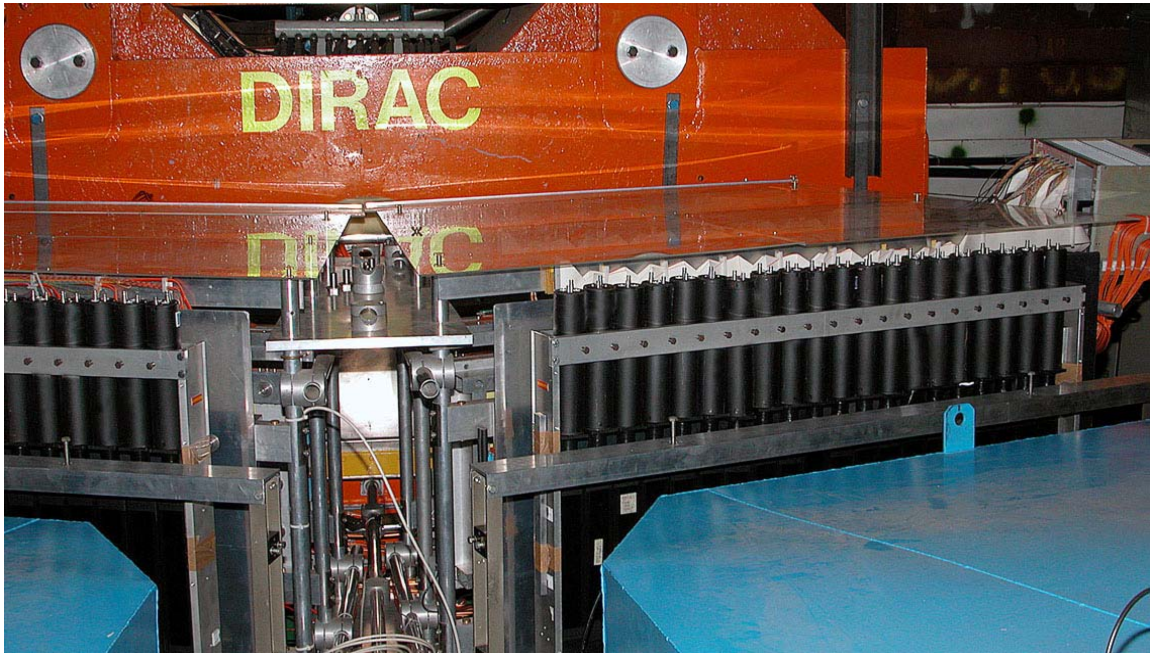
Photomultipliers **PHILIPS XP2012** *gift of P. Jenni to* DIRAC

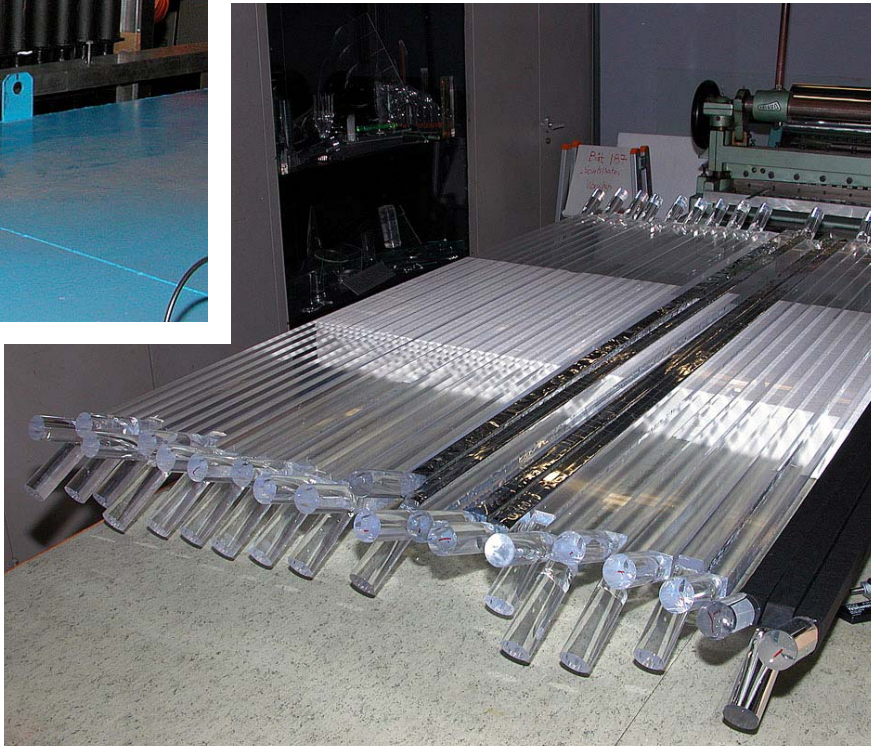


Status:

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

Vertical and Horizontal Hodoscopes (II)

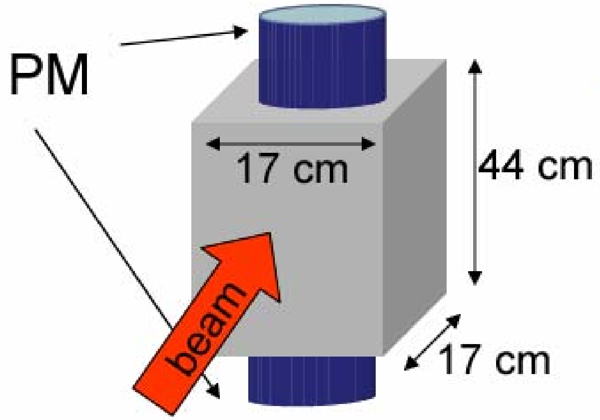


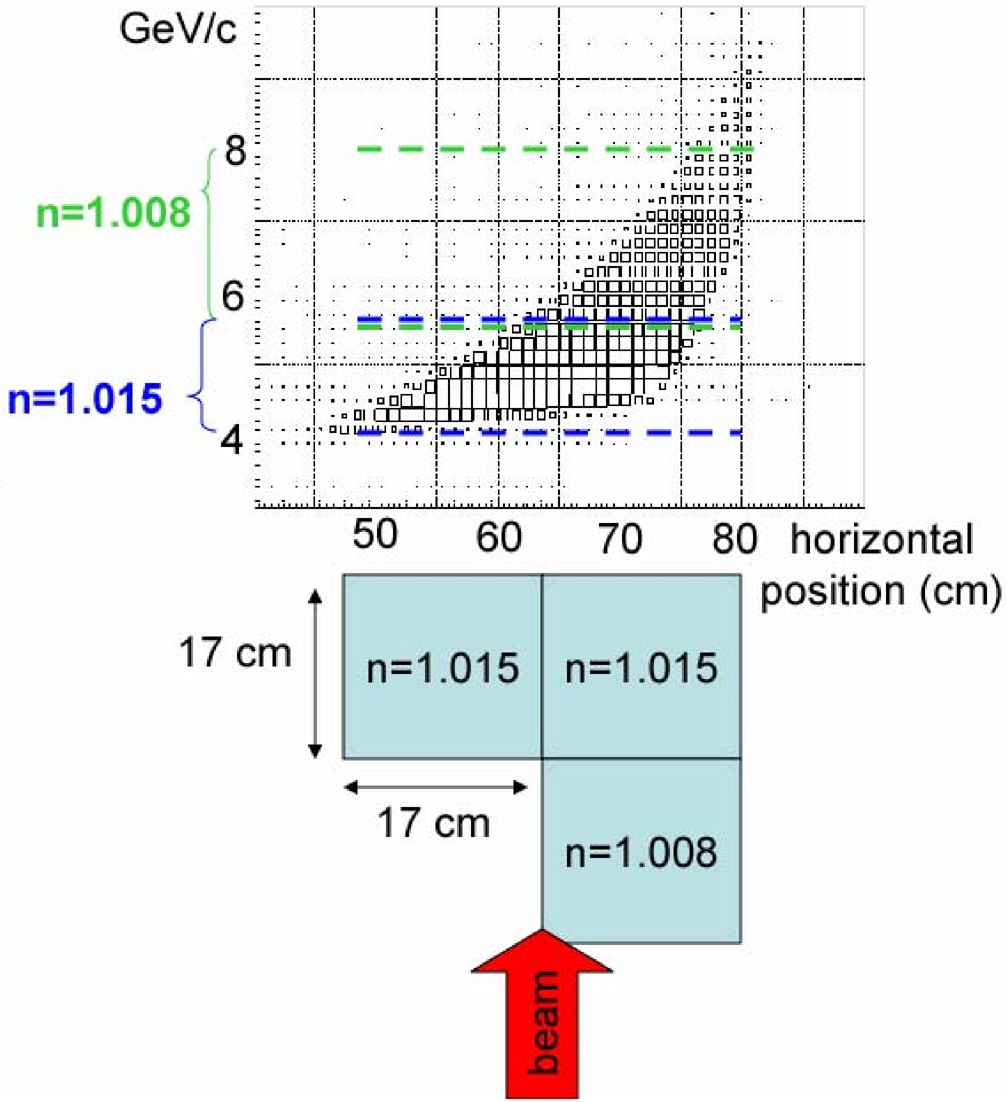


Aerogel Cherenkov detector (I)

Responsibility:

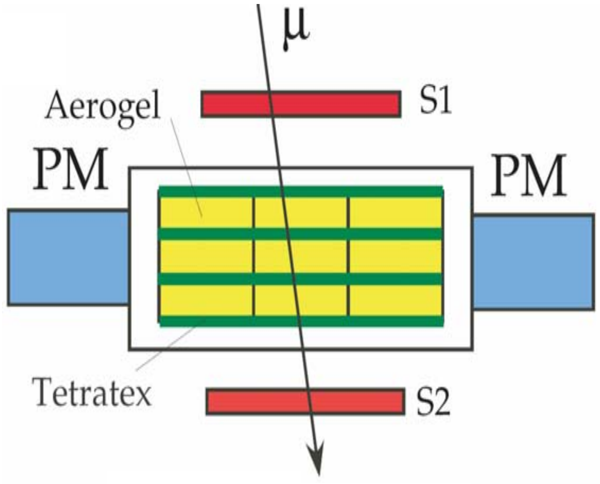
Zurich University (*Zurich*, Switzerland)

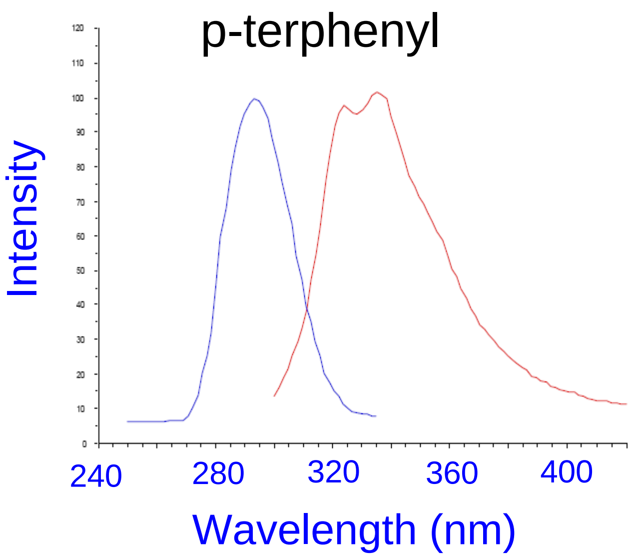


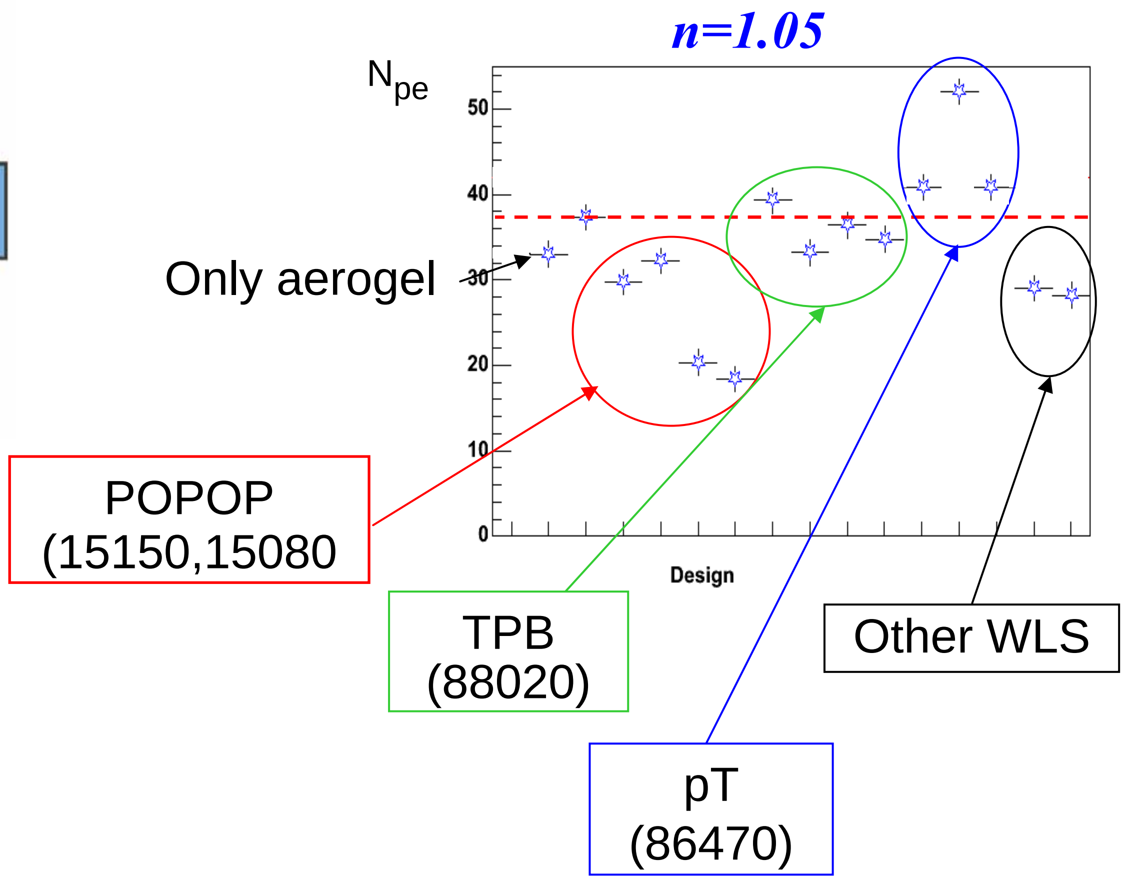


Aerogel Cherenkov detector (II)

The sandwich design

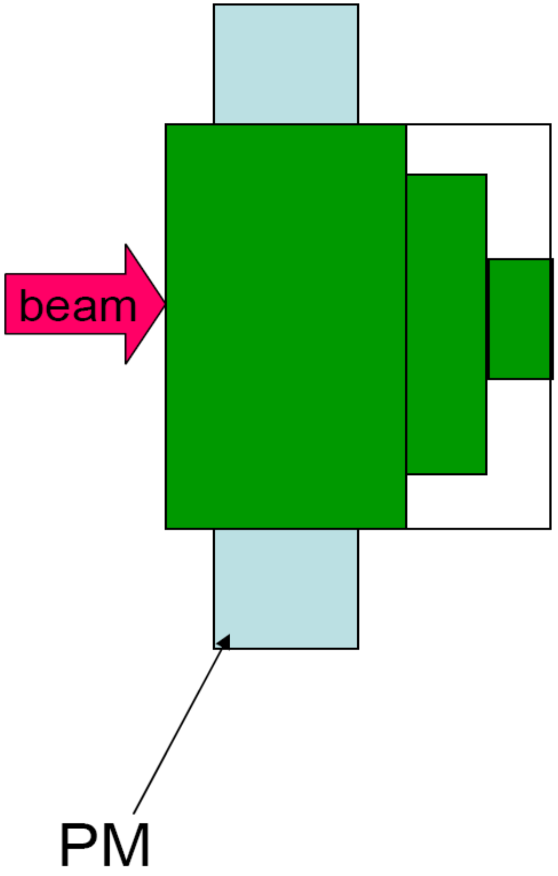


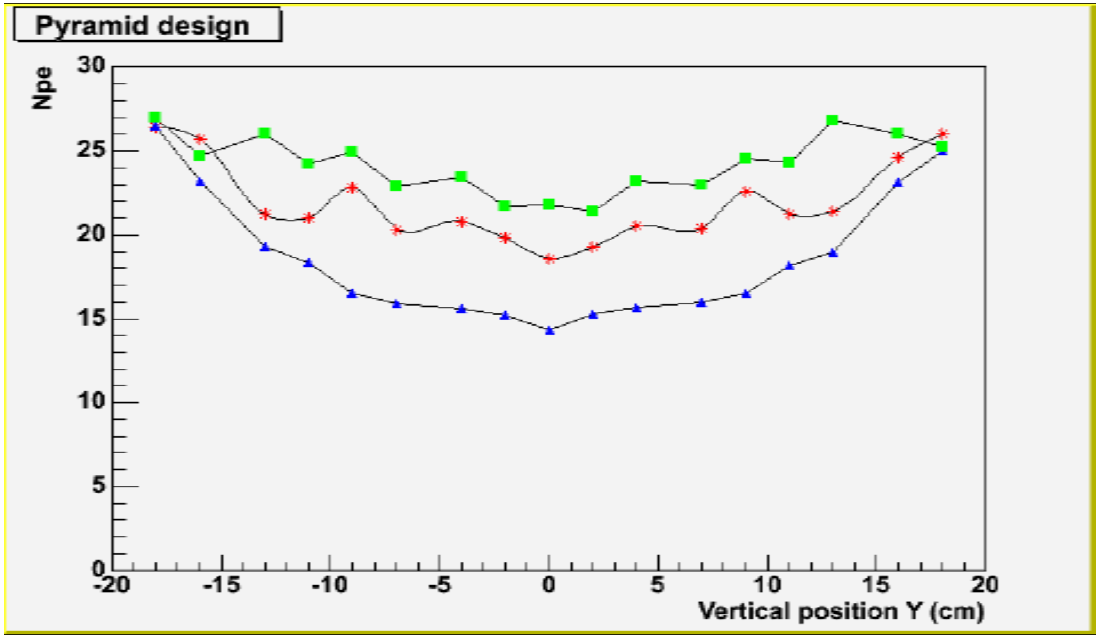




Aerogel Cherenkov detector (III)

The pyramid design

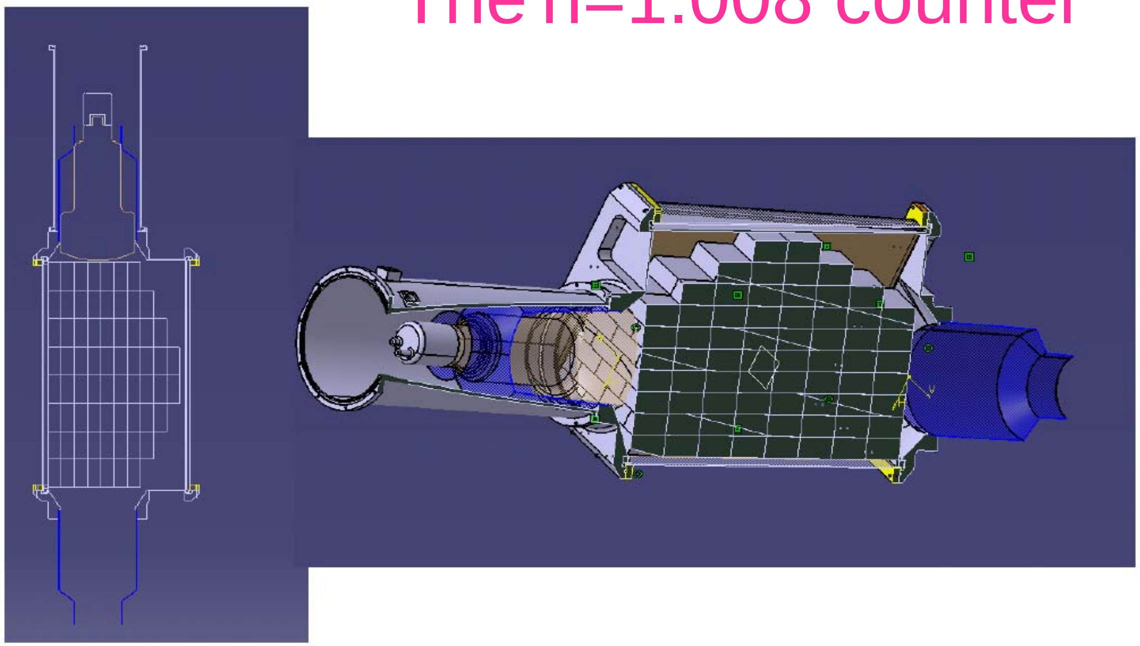




- In blue : box design.
- In red : Pyramid design with 2 layers of thickness 2 cm.
- In green : Pyramid design with 2 layers of thickness 4 cm.

Aerogel Cherenkov detector (IV)

The n=1.008 counter

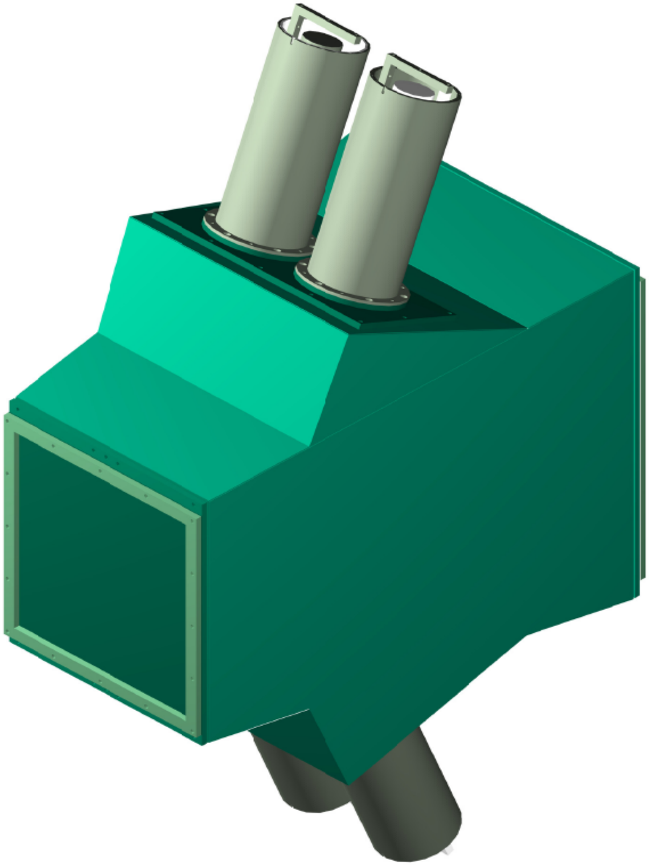


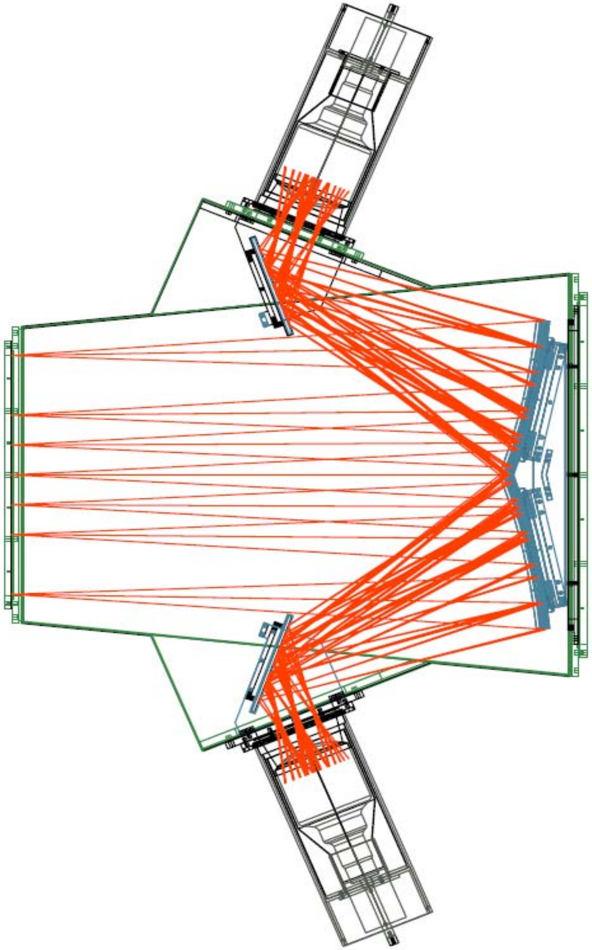
Status:

Aerogel detectors were installed on the setup

Cherenkov detector (C_4F_{10}) - I

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

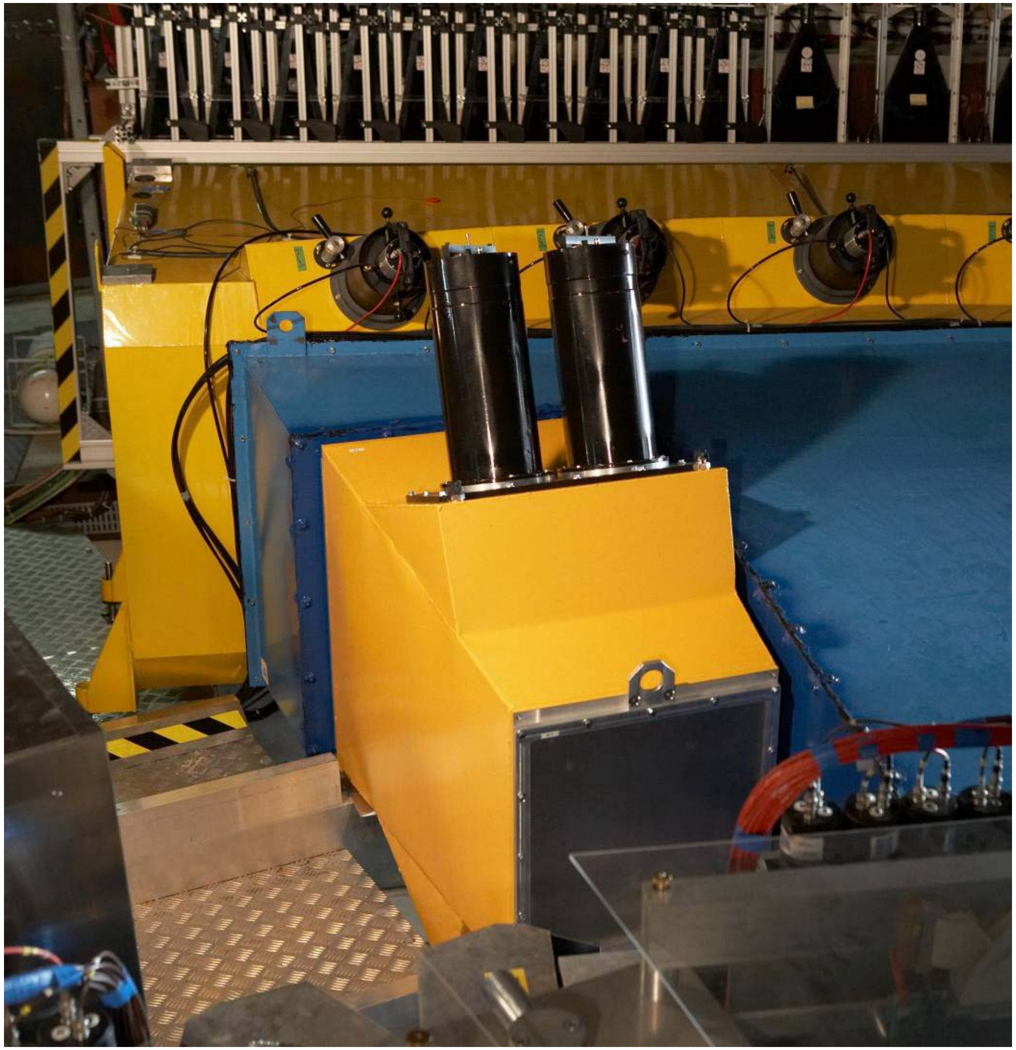


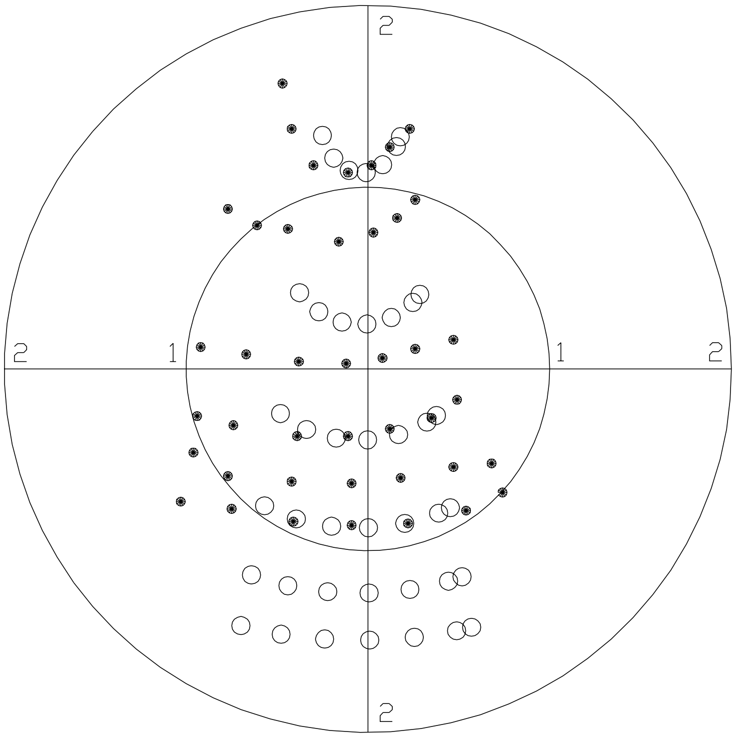


Cherenkov detector (C_4F_{10}) - II

Cherenkov detector (C_4F_{10}) - III

Cherenkov detector (C_4F_{10}) - IV





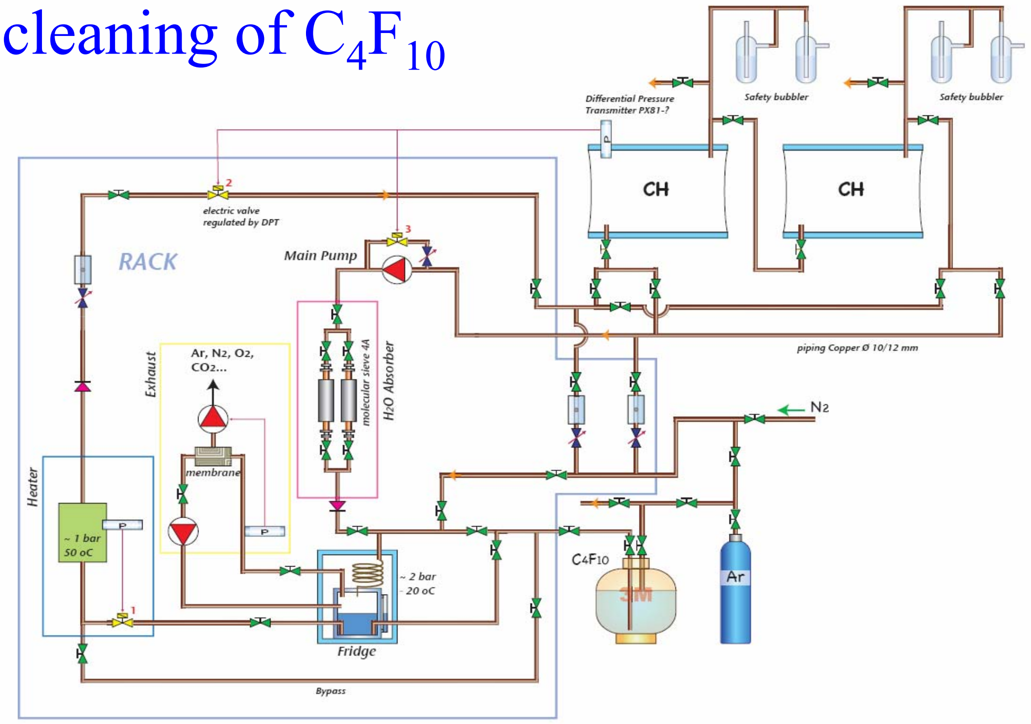
<u>Laser test:</u>

Left top PM (left arm).

Cherenkov detector (C_4F_{10}) - V

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

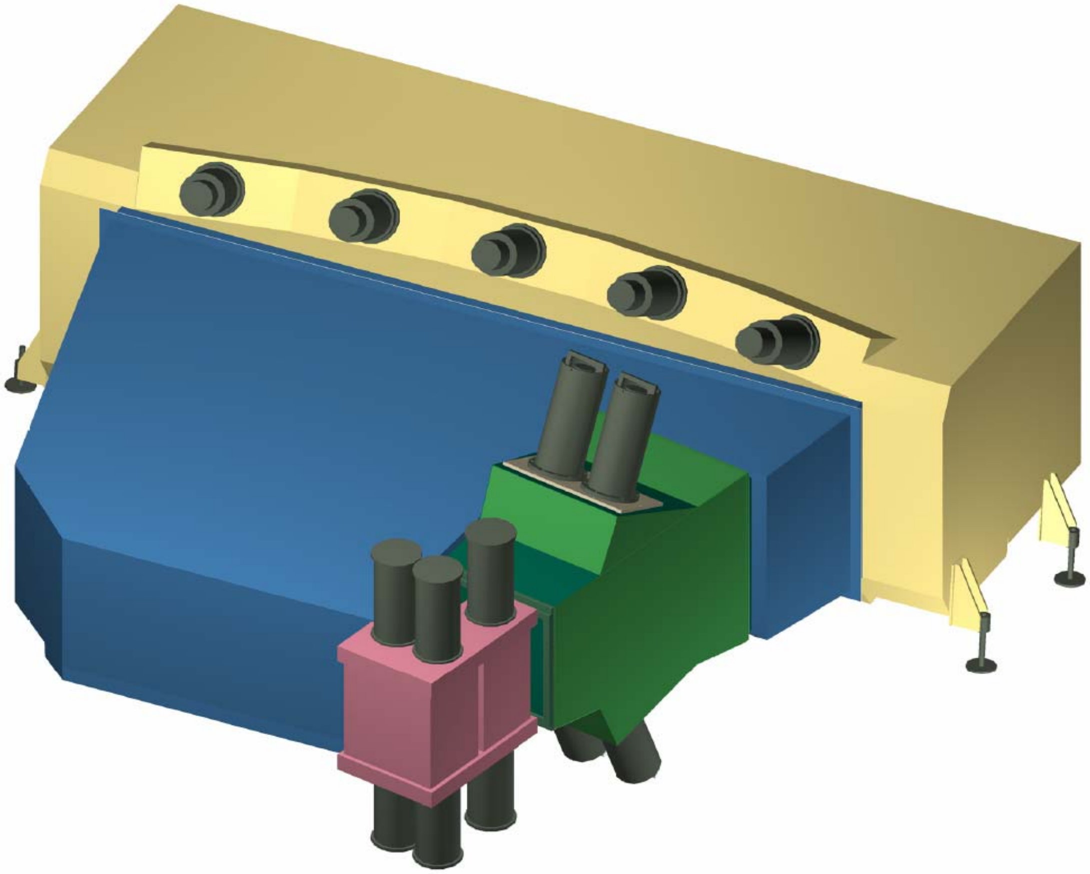
Gas system with recirculating and cleaning of C_4F_{10}



Status:

It is assembled and will be tuned before the end of November 2006.

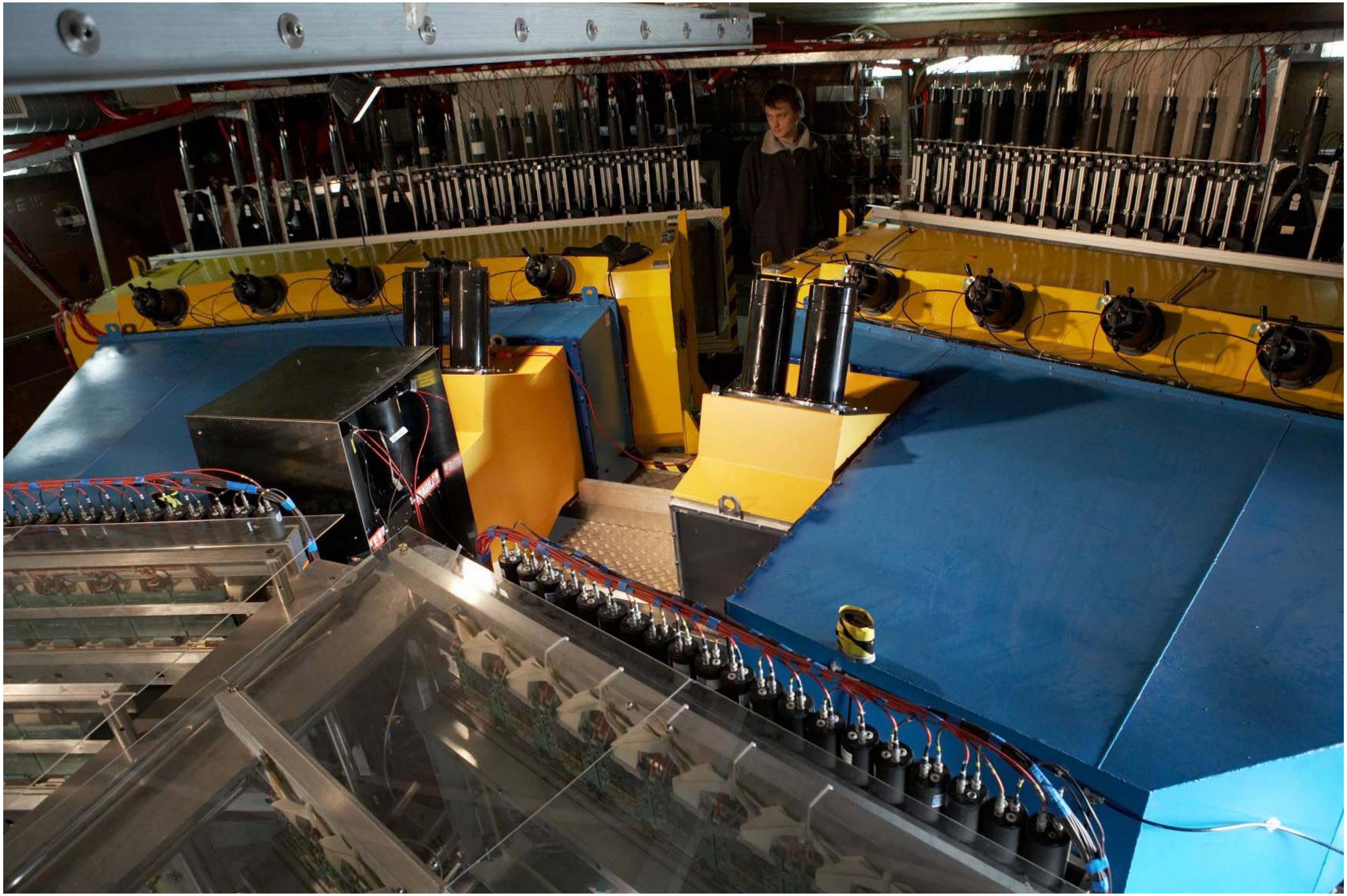
All Cherenkov detectors



Status:

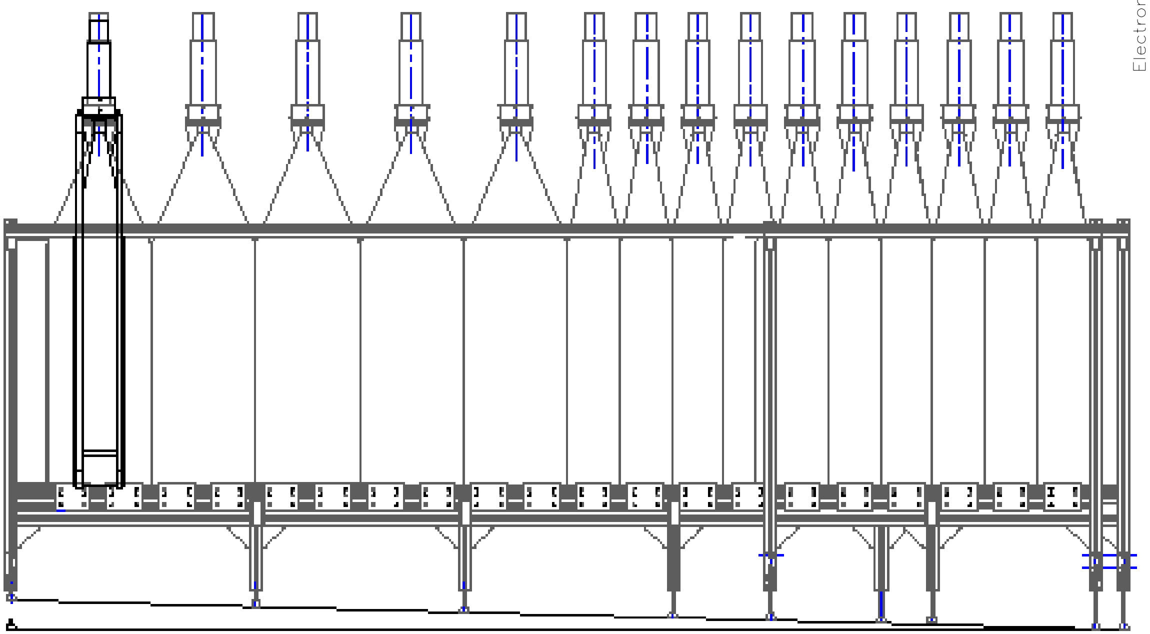
Cherenkov detector (N_2) was cutted, aerogel counters and Cherenkov detector (C_4F_{10}) have been installed by the end of October 2006

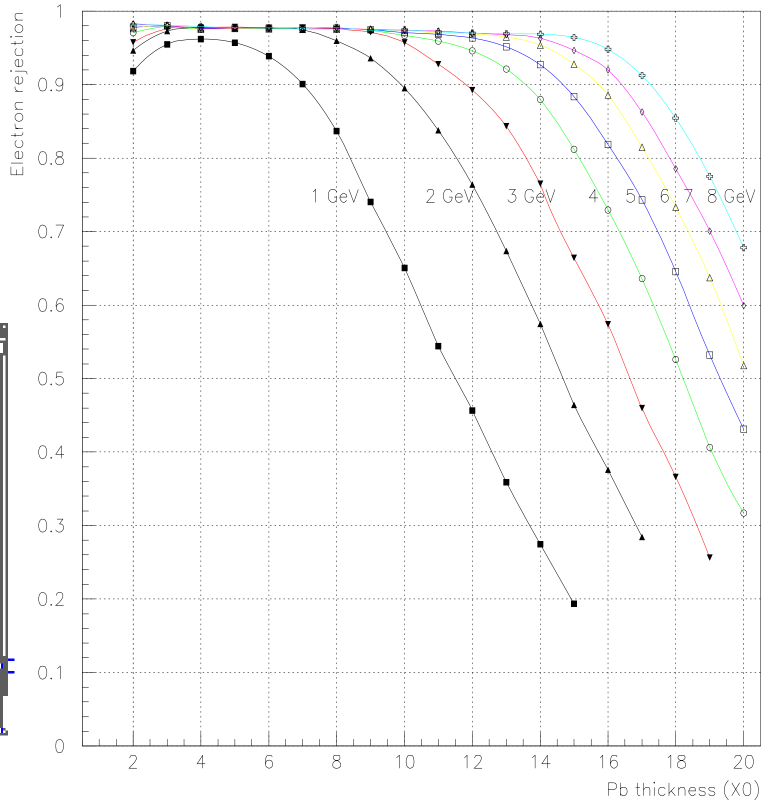
All Cherenkov detectors

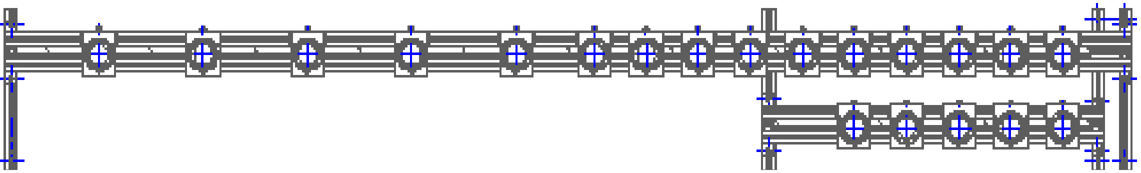


Preshower detector (I)

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





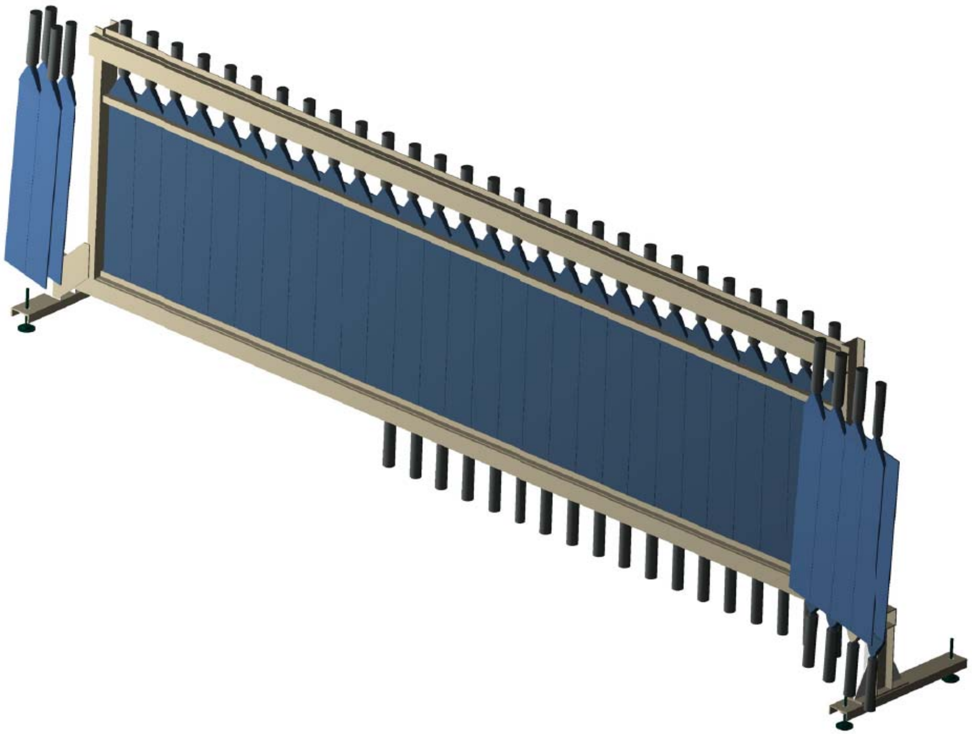


Status:
Installed at the setup and calibrated with $\pi^+\pi^-$ mesons and e^+e^- pairs.

Preshower detector (II)

Muon detector

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



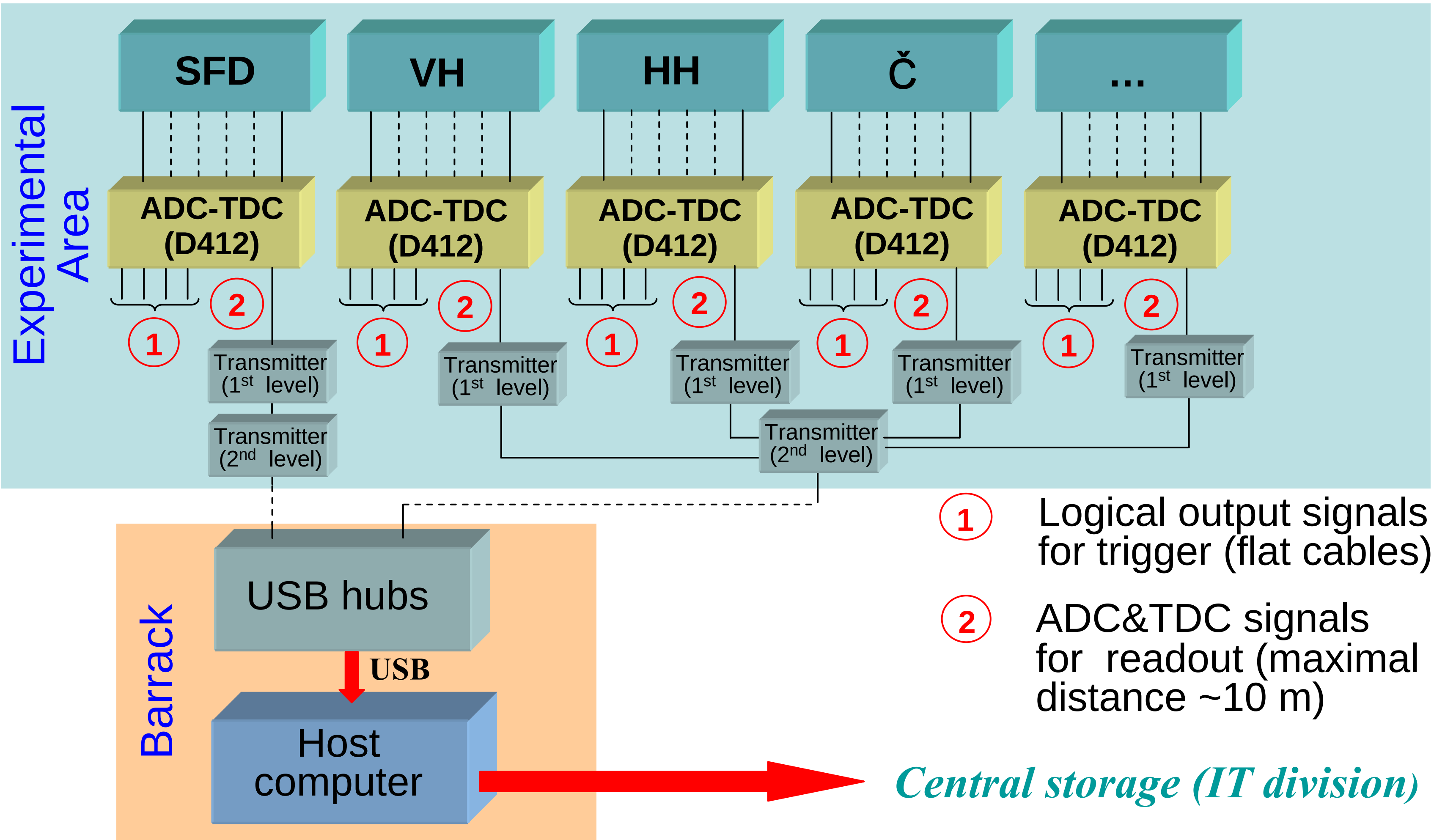
24 slabs (12 slabs per arm) will be added to the existing muon scintillation hodoscopes in order to increase their acceptance.

Without these slabs the background of non-identified muons from pion decays will increase by few percent.

Status:
The new slabs will be installed in 2007.

Readout System (I)

Responsibility: ***JINR** (**Dubna**, Russia); Basel University (**Basel**, Switzerland); **IFIN-HH (Bucharest, Romania)**; **Santiago** de Compostela University (**Santiago de Compostela**, Spain); Zurich University (**Zurich**, Switzerland)*



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*)

Status of the new electronics

Readout System

ADC-TDC	57 modules	18 are existing, 39 will be ready before the end of December 2006
Transmitter 1st level	10 modules	Test will be finished at November 2006 Will be ready before March 2007
Transmitter 2nd level	4 modules	
Auxiliary module	3 modules	

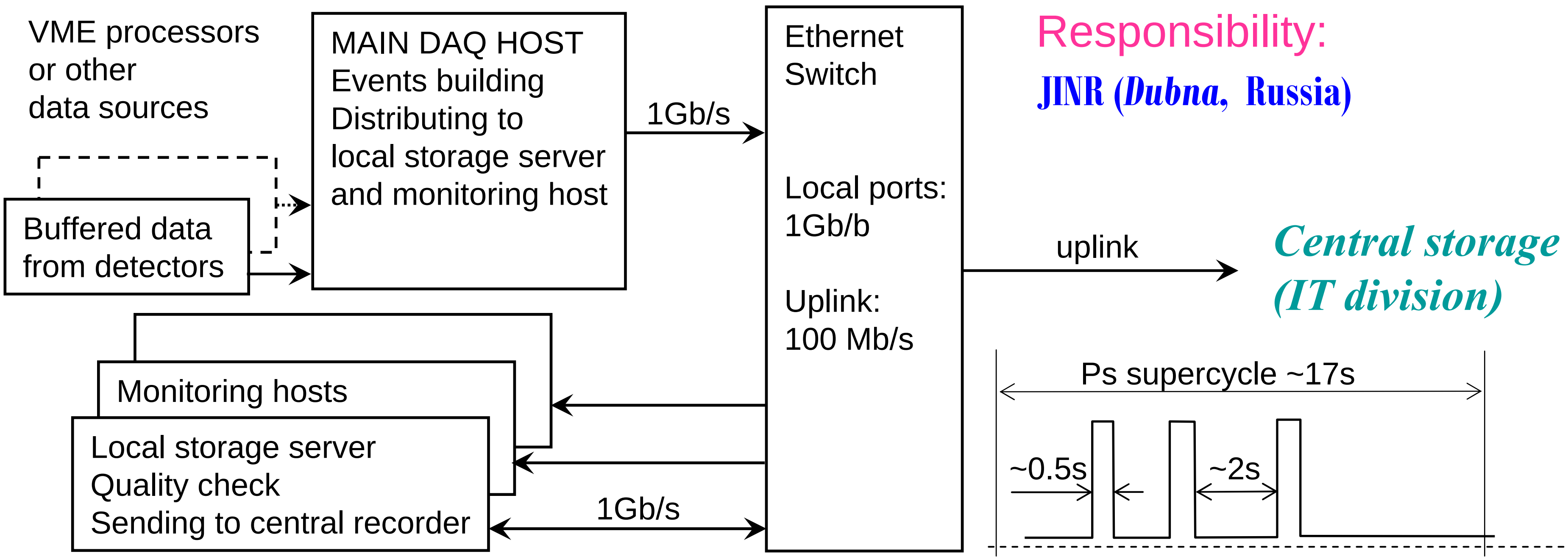
Time schedule:

Chain ADC-TDC – TRANSMITTER I – TRANSMITTER II and the dedicated software will be tuned in March – April 2007 in JINR and delivered to CERN in May 2007

Trigger System

Shaper K436	20 modules	Will be ready before March 2007
Level translator	21 modules	Will be ready before March 2007

Data Acquisition System



Responsibility:

JINR (*Dubna*, Russia)

Status:

Revising software for automatic and interactive on-line monitoring of data. This work was done mainly during this year. Some tests and tuning will be required at the beginning of year 2007 beam time.

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-May 2006. Some tests and tuning will be required after assembling new front-end electronics in 2007.

Conclusion

I. Before the end of November 2006 all detectors will be installed on the setup.

II. Before the March 2007 all new front-end electronics, all readout electronics, and trigger electronics will be ready.

III. Before the end of May 2007 upgrade setup will be ready for the tuning on T8 beam and data taking

IV. Before the end of 2006 the value of $A_{2\pi}$ lifetime will be obtained basing on $\sim 13000\ \pi^+\pi^-$ atomic pairs.

DIRAC analysis

Improvements on systematics in P_{Br}

CC background	no improvement	$\pm$ 0.007
signal shape	no improvement	$\pm$ 0.002
Multiple scattering	measured to ±1% **(DONE)**	+ 0.002 /−0.002
$K^+K^- / p\tilde{p}$ admixtures	to be measured*	+ 0.000 /−0.023
Finite size effects	to be measured**	+ 0.000 /−0.017
Total		**+ 0.008 /−0.030**

* To be measured in 2007/2008 with new PID

** To be measured in 2006/2008 with new trigger for identical particles at low Q

Improvements on data quality by fine tuning

- Adjustments of the drift characteristics almost run-by-run
- B-field adjustment and alignment tuning with Λ-mass

$\Rightarrow$ New pre-selection for all runs **(DONE)**

Comments on analysis strategies

Using only downstream detectors and investigating only Q_L causes less sensitivity to multiple scattering and to the signal shape. Studies are under way and very promising.