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

2 May 2006

DIRAC collaboration

75 Physicists from 18 Institutes

CERN
Geneva, Switzerland

Czech Technical University
Prague, Czech Republic

Institute of Physics ASCR
Prague, 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. The goal of the 2006 RUN

III. Status of DIRAC Analysis

Main goal of DIRAC Addendum

- *Lifetime measurement, in a model-independent way, of $A_{2\pi}$ atoms 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 the possibility of measuring 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 low energy QCD and for understanding the nature of the QCD vacuum

DIRAC Addendum

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 current results, 2001 data:

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

Results from E865/BNL experiment: $K \rightarrow \pi^+\pi^- e^+\nu_e (K_{e4})$

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

using Roy eqs.

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

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

$$a_0 = 0.216 \pm 0.013\,(stat) \pm 0.004(syst) \pm 0.002\,(theor)$$
$$\delta a_0 = \pm 6\%\,(stat) \pm 2\%(syst) \pm 1\%\,(theor)$$

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

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:

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

πK scattering

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

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

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:

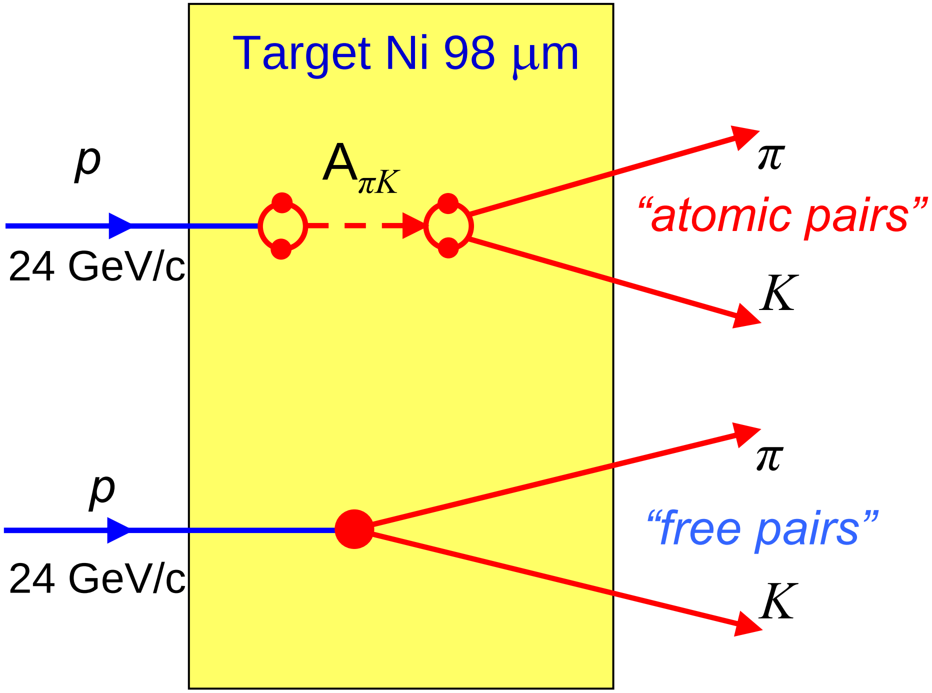
$$\frac{\sigma_\tau}{\tau} = 6\%, \qquad \frac{\sigma(a_0 - a_2)}{a_0 - a_2} = 3\%$$

At the same time we also plan to observe $A_{\pi K}$ and $A_{K\pi}$; to detect 5000 πK atomic pairs to estimate $A_{\pi K}$ 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



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

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

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

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

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

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

Main features of the DIRAC set-up

Thin targets: $\sim 7 \times 10^{-3} X_0$, Nuclear efficiency: 3×10^{-4}

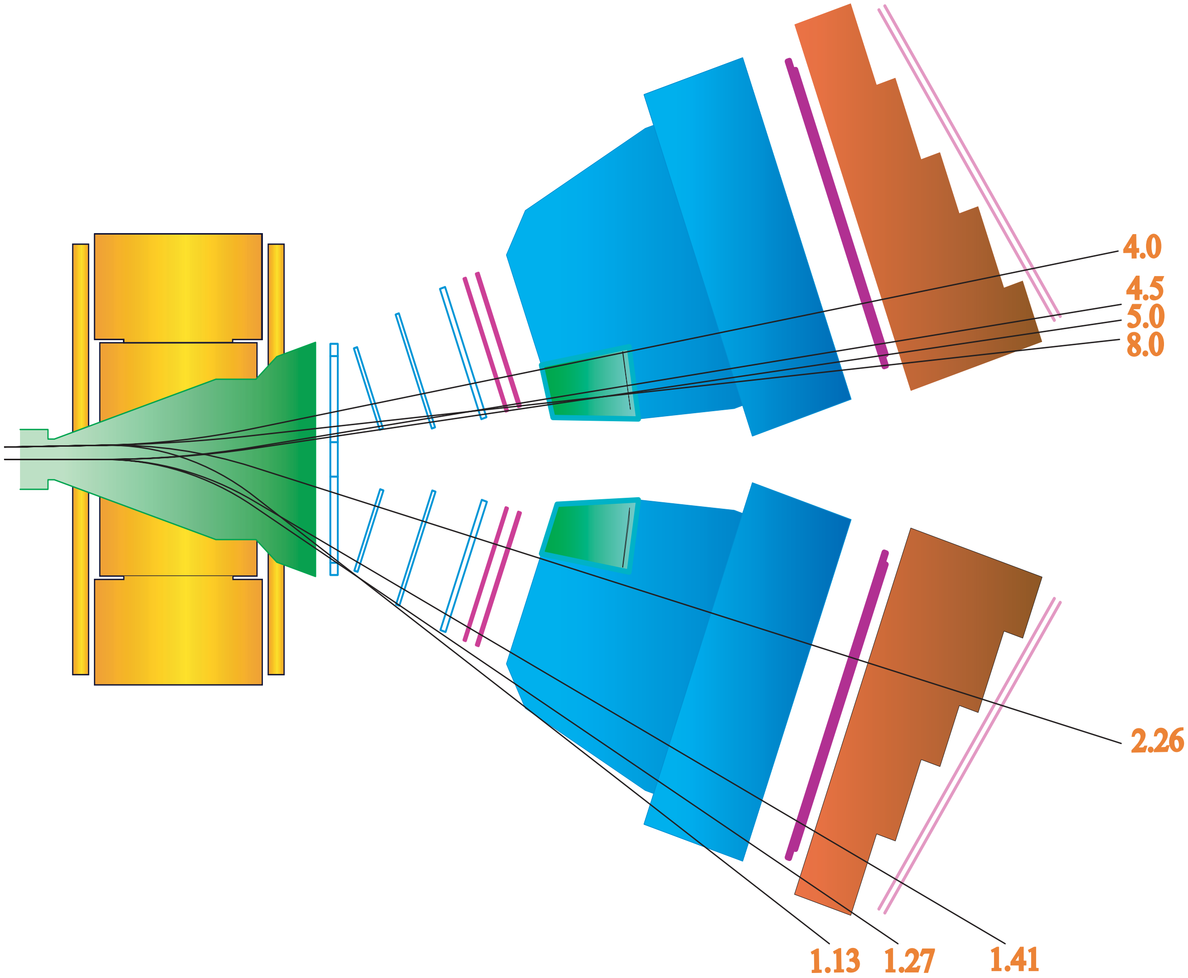
Magnetic spectrometer

Proton beam $\sim 10^{11}$ 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

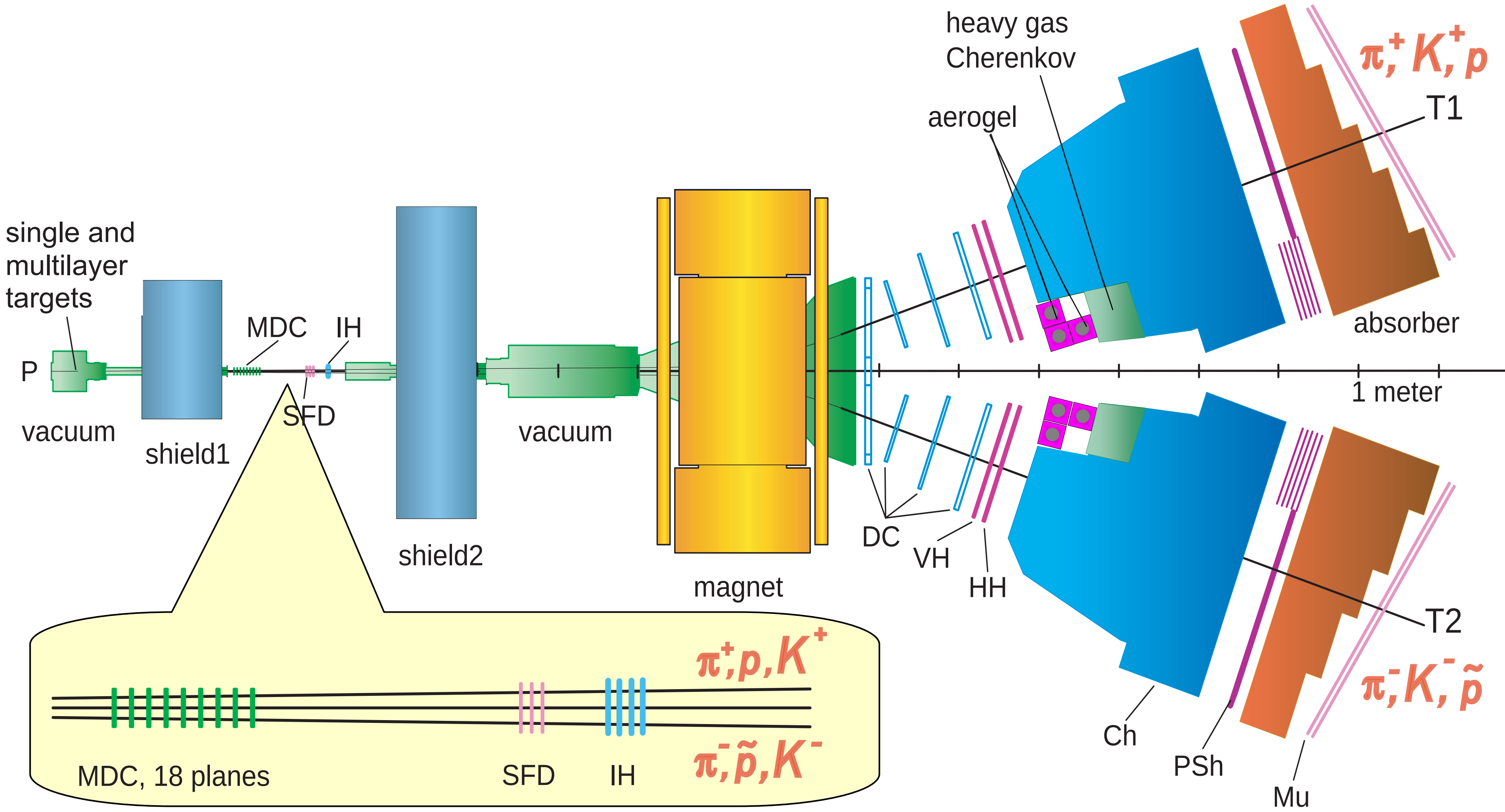
Numbers are the π^- and K^+ momenta in GeV/c



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

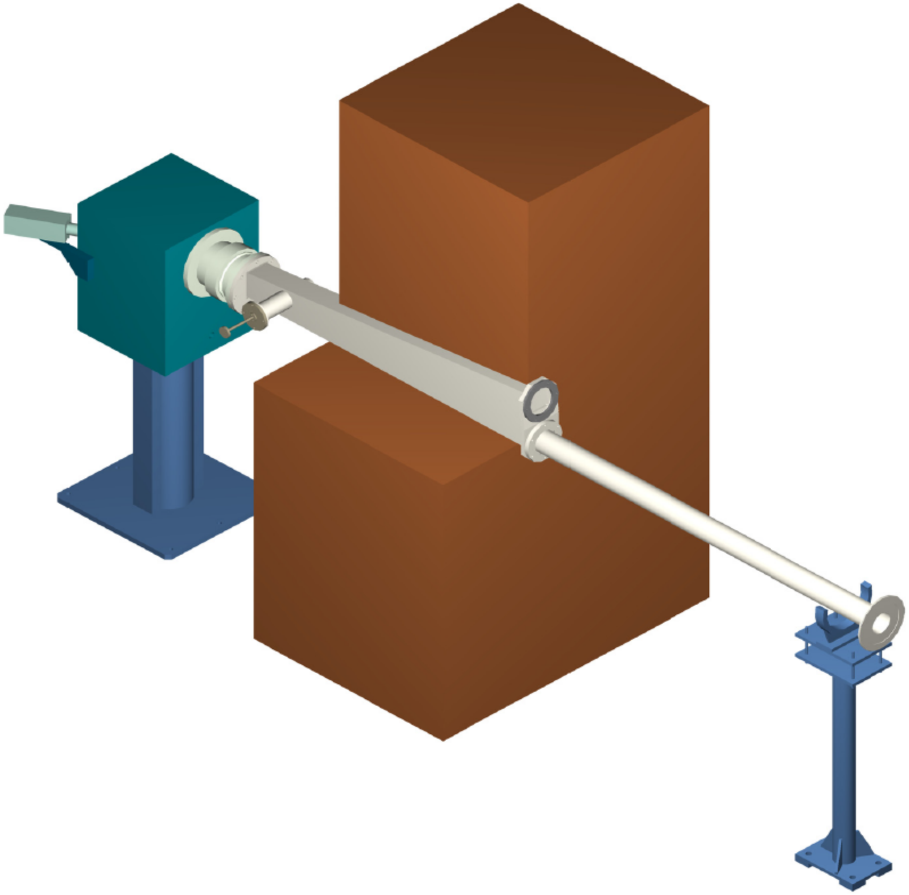
P_{atom} (GeV/c)	P_{π} (GeV/c)	P_K (GeV/c)
5.13	1.13	4.0
5.77	1.27	4.5
6.41	1.41	5.0
10.26	2.26	8.0

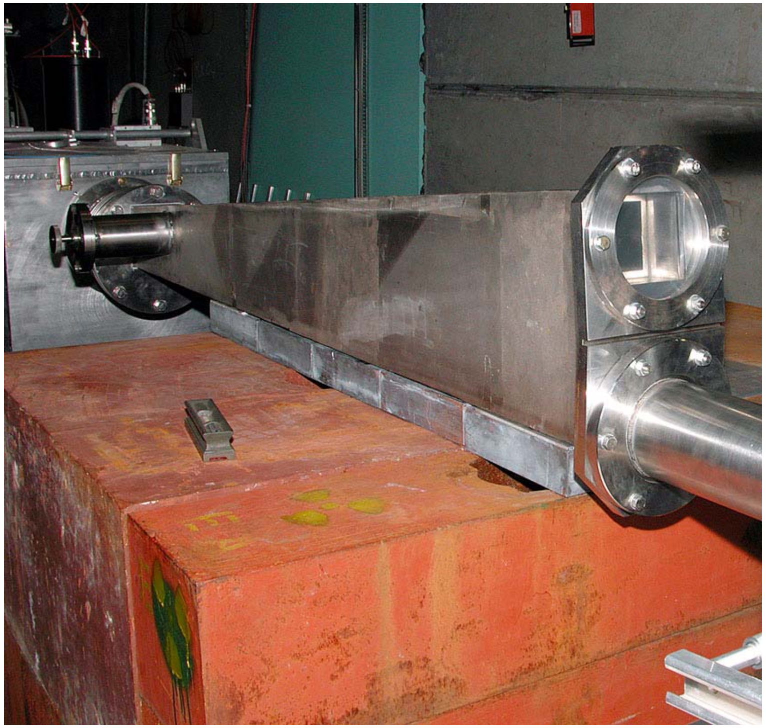
Upgraded DIRAC experimental set-up description



Vacuum Channel and Shielding

Responsibility: JINR (*Dubna*, Russia)

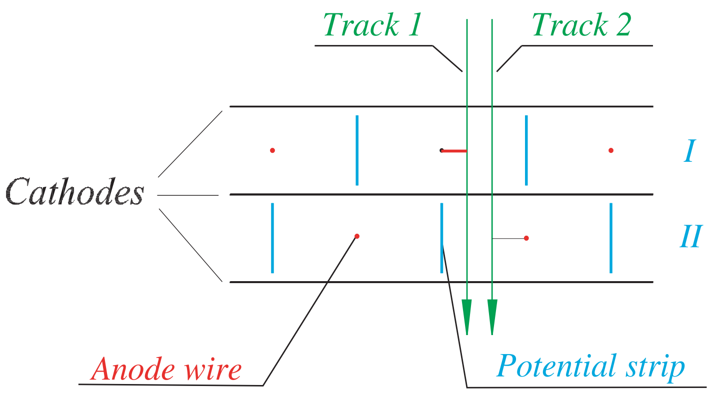


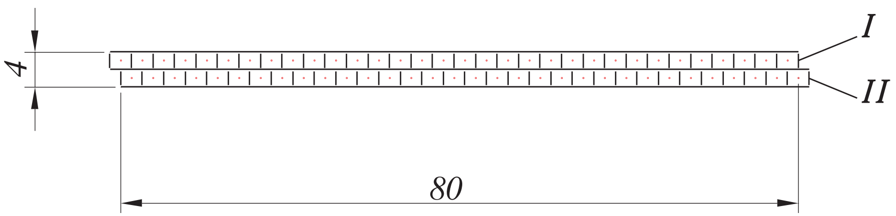


Time Schedule:
Installed in March 2006, vacuum tests are done. Completed.

Microdrift Chambers (I)

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



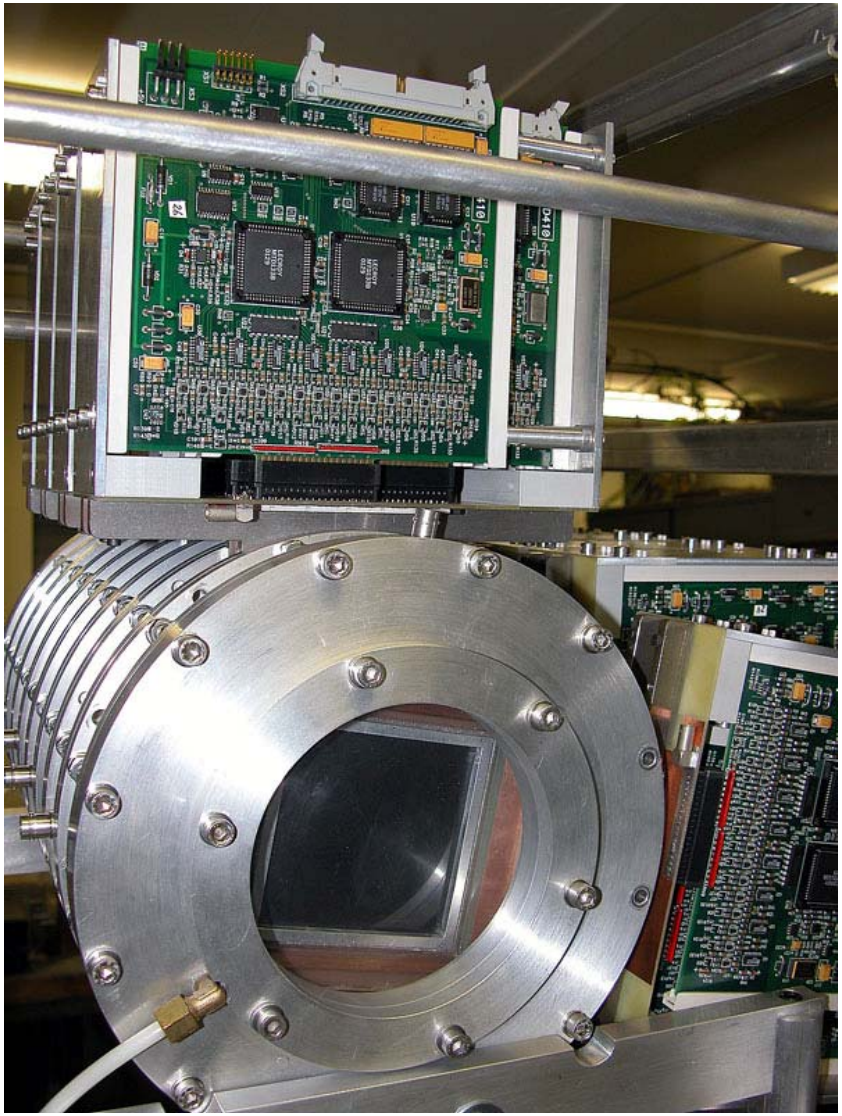


Characteristics:

- spatial accuracy $< 22 \pm 4\ \mu m$ 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 has to be improved for the DIRAC heavy radiation conditions. This improvement will be achieved by some modification of MDC electrodes.

Microdrift Chambers (II)



Time Schedule:

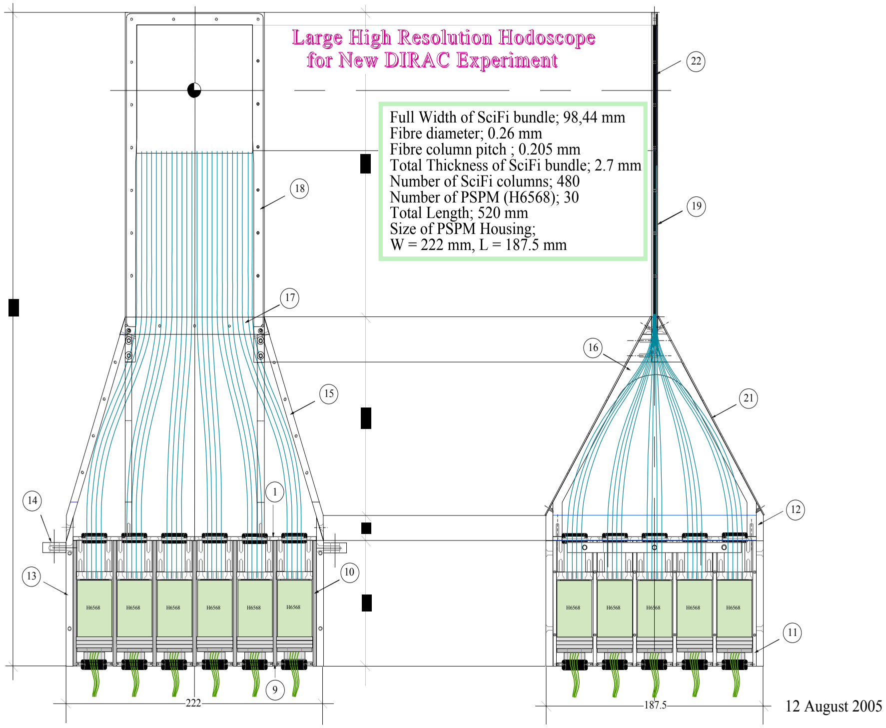
February-April 2006:
preparation of new electrodes at JINR.

May-June 2006:
tests of the modified MDC detector with a radioactive source for high voltage.

July 2006:
the MDC detector will be mounted in the DIRAC setup at CERN.

Scintillation Fiber Detector (I)

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



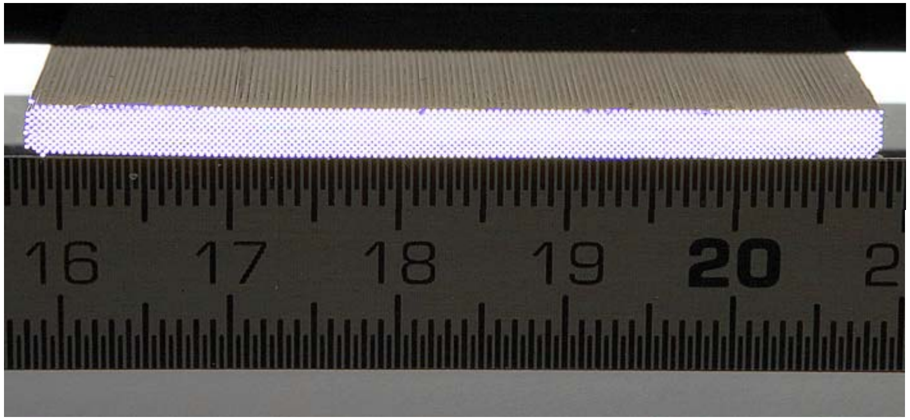
Characteristics:

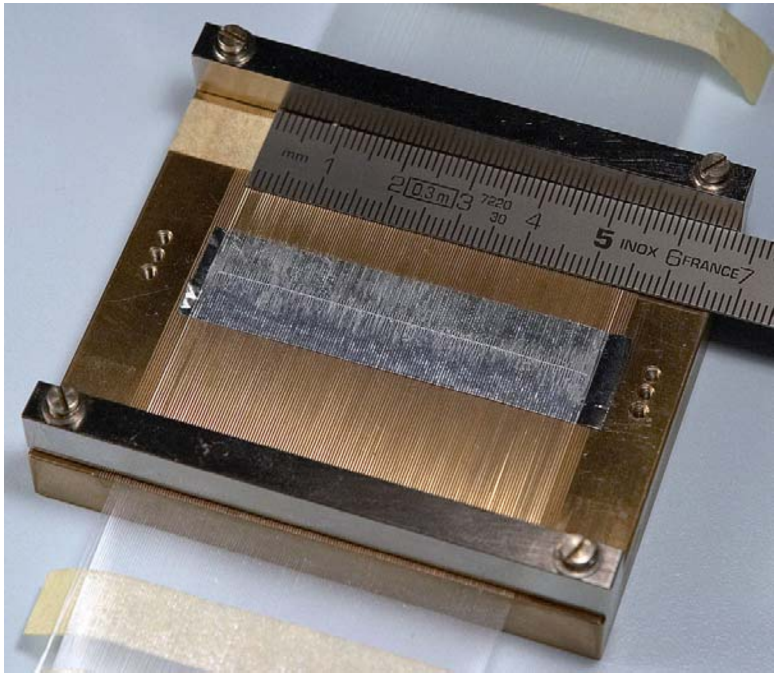
- Size of the plane — $100 \times 100\ mm^2$
- Thickness of the material for one plane — $3\ mm$ (1% X_0)
- Mean light output: — $\approx 11\ p.e.$
- Mean Detector Efficiency: — $\approx 98\ \%$
- Time Resolution without coordinate and amplitude corrections — $\approx 0.46\ ns$
- Space resolution — $60\ \mu m$
- New electronics (*ADC-TDC for each channel*) — 920 *channels*

Time Schedule:

Production of fiber layers is finished. Housings are ready. Two detectors will be assembled in the middle of July and will be installed on the setup in August after beam tests on T11

Scintillation Fiber Detector (II)





Drift Chambers (I)

Responsibility: JINR (*Dubna*, Russia)

Present status of the 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'*).

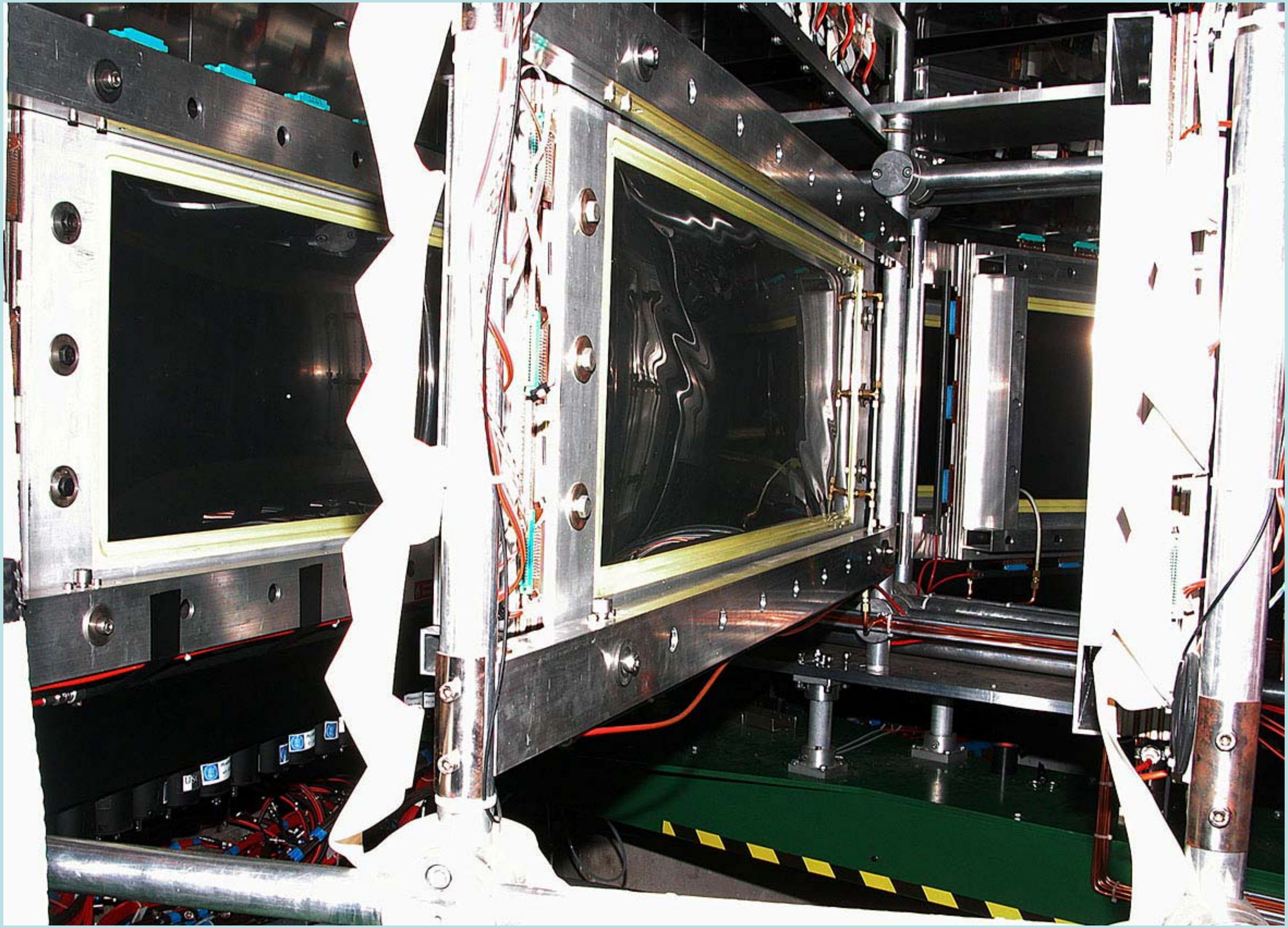
After successful and long drift chamber operation at the first stage of the experiment, it was decided to perform full revision of all drift chambers.

Time Schedule:

Both DC1 modules were repaired. High Voltage tests for this modules will be fulfilled in July, installation in the DIRAC setup is planning at the begin of August.

DC2, DC3 and DC4 modules were repaired (spares also), tested under High Voltage and installed in the DIRAC setup.

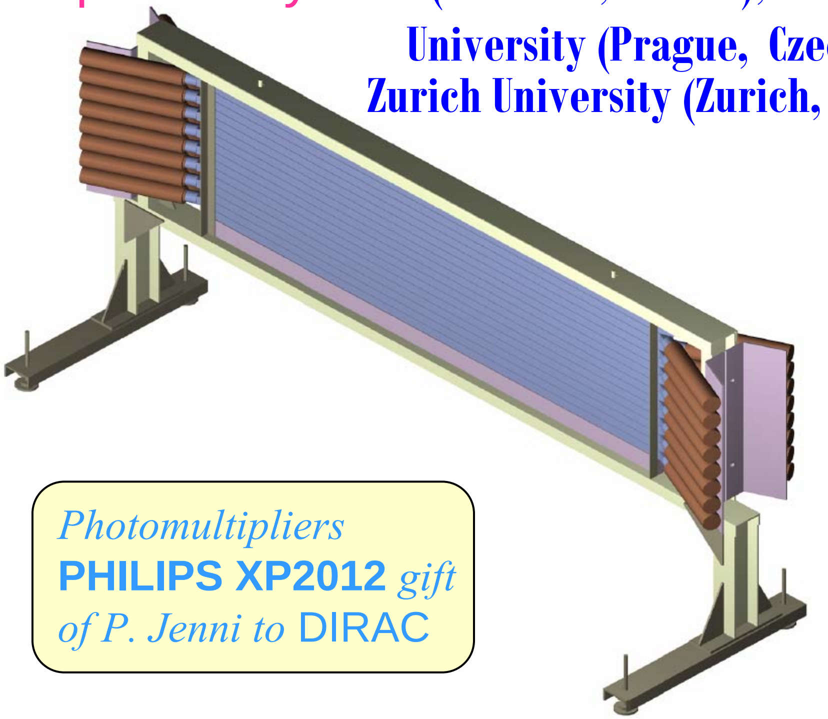
Drift Chambers (II)

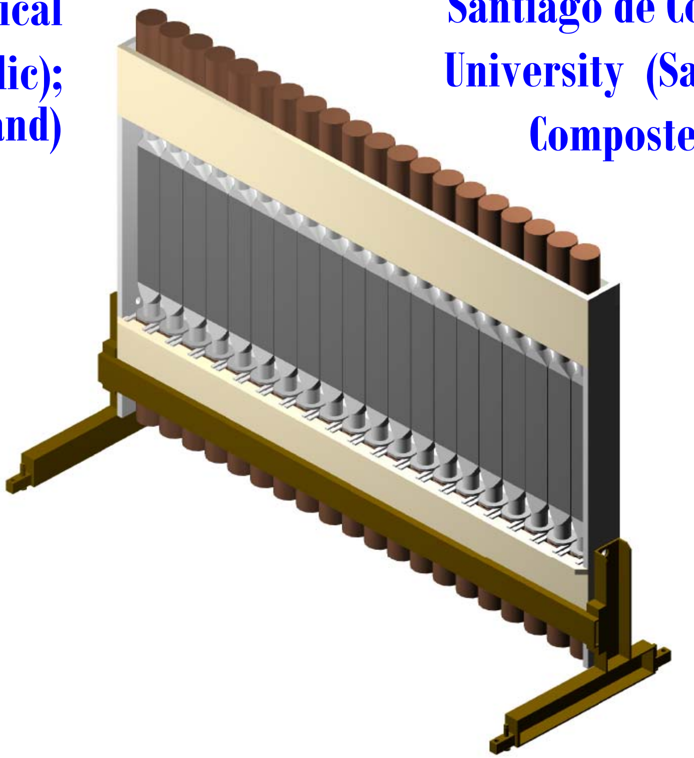


Vertical and Horizontal Hodoscopes (I)

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

Santiago de Compostela University (Santiago de Compostela, Spain)





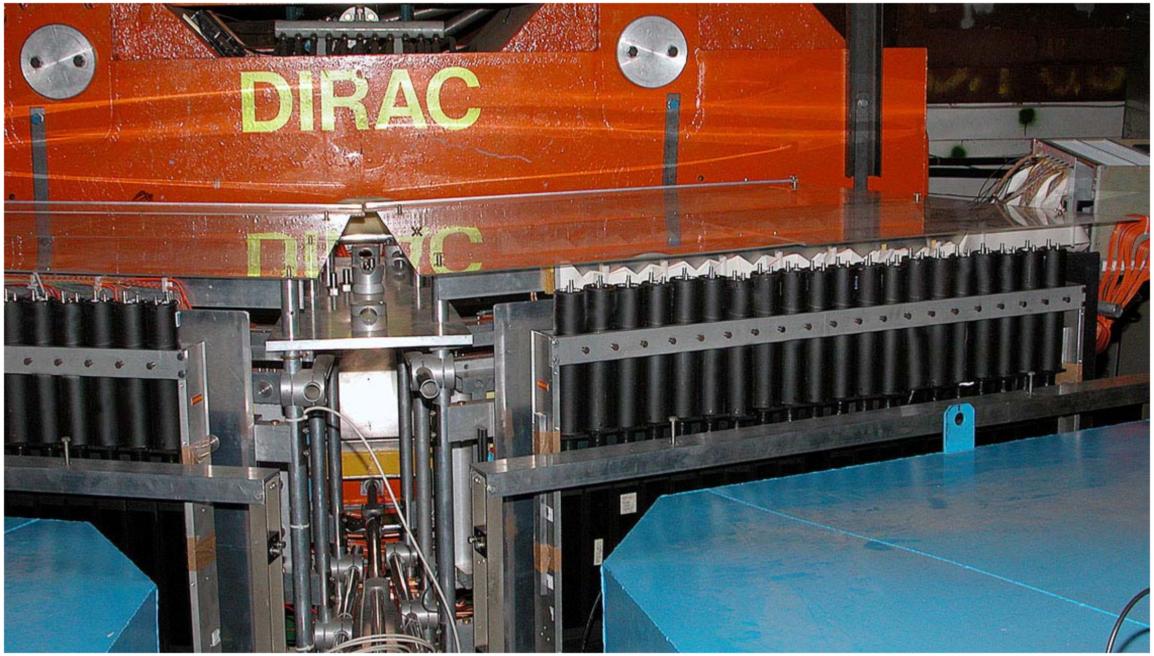
Photomultipliers **PHILIPS XP2012** *gift of P. Jenni to* DIRAC

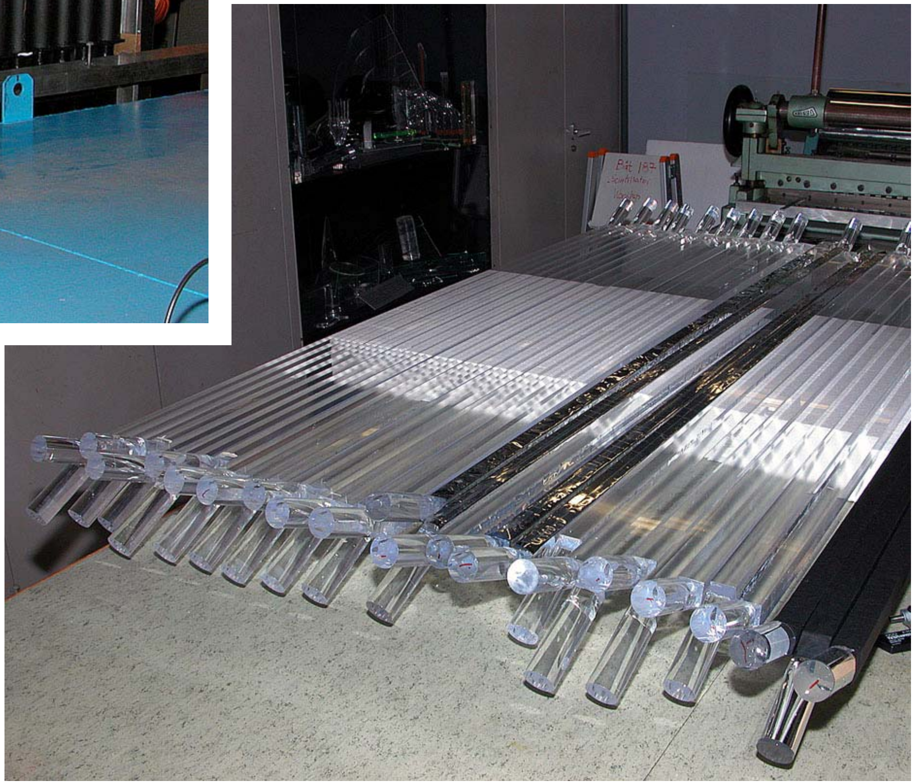
Time Schedule:

VH: All slabs of the Vertical Hodoscopes were refreshed and together with new support installed back. Four additional scintillation slabs will be added to the existing Vertical Hodoscopes at the end of July.

HH: New longer Horizontal Hodoscopes will be installed before the end of May. There will be 32 slabs (16 slabs per arm) by **1500×25×25** mm^3.

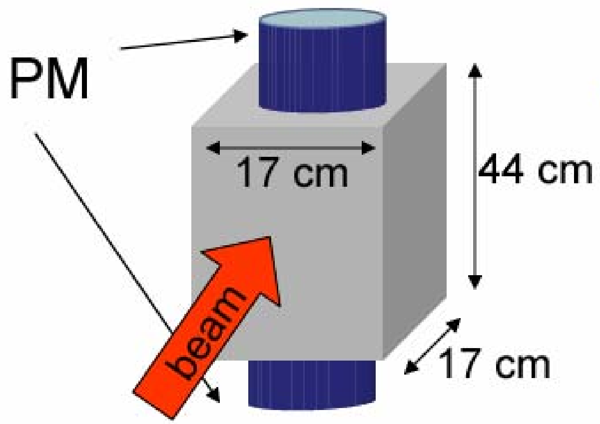
Vertical and Horizontal Hodoscopes (II)

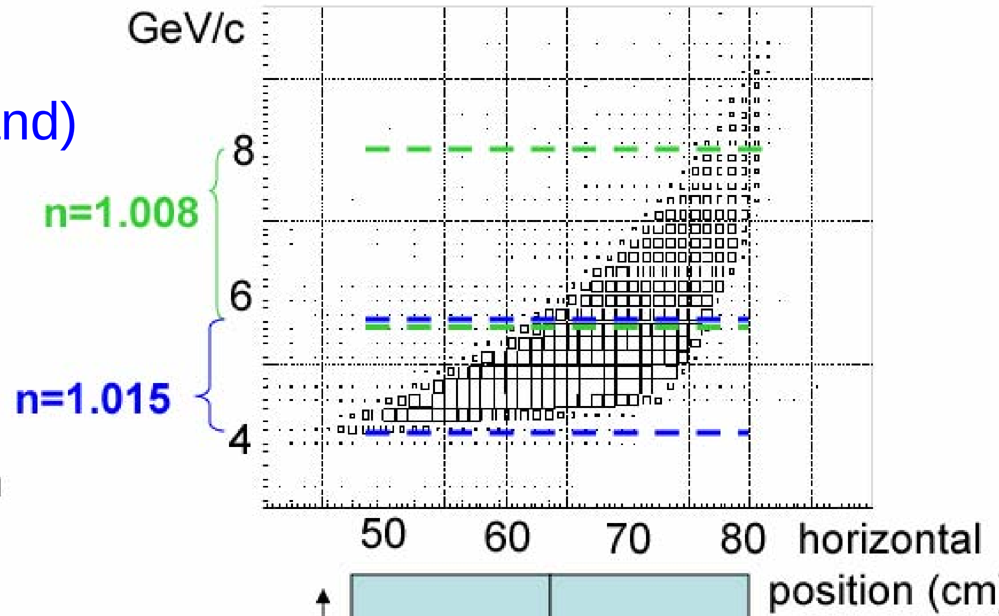


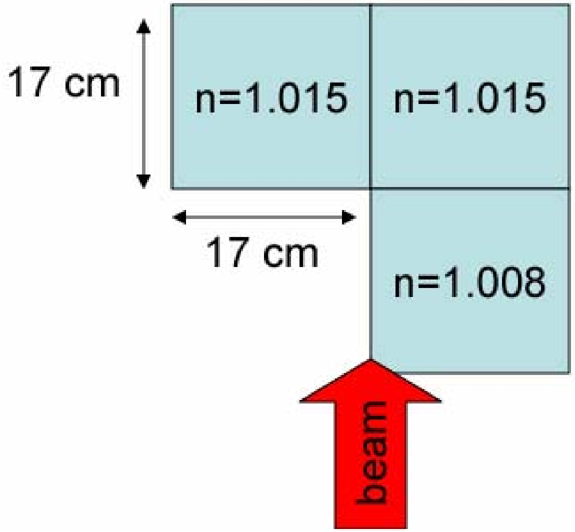


Aerogel Cherenkov detector (I)

Responsibility:
Zurich University (*Zurich,* Switzerland)

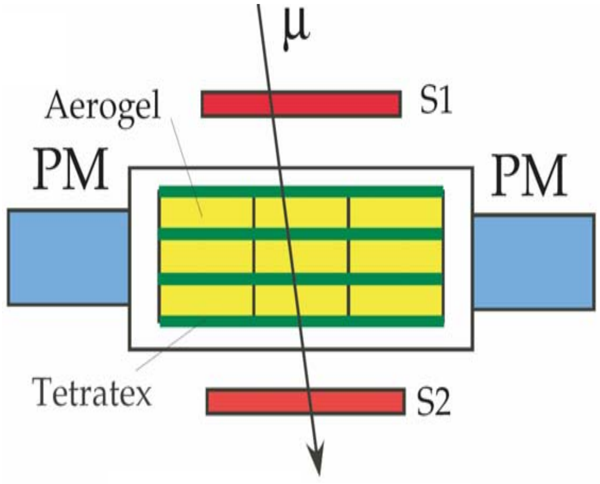


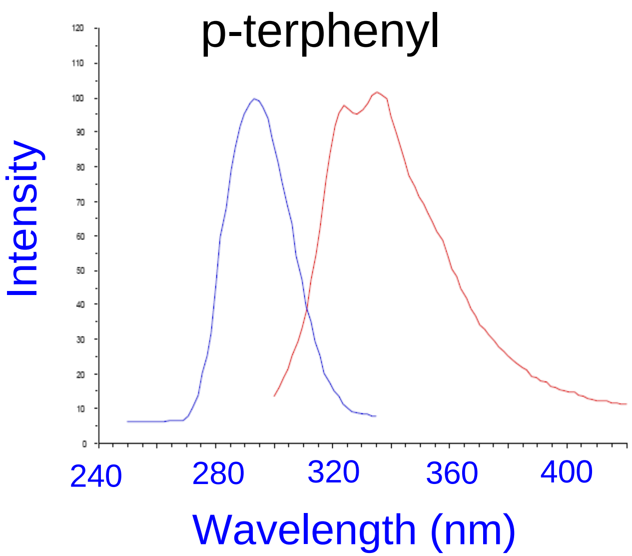


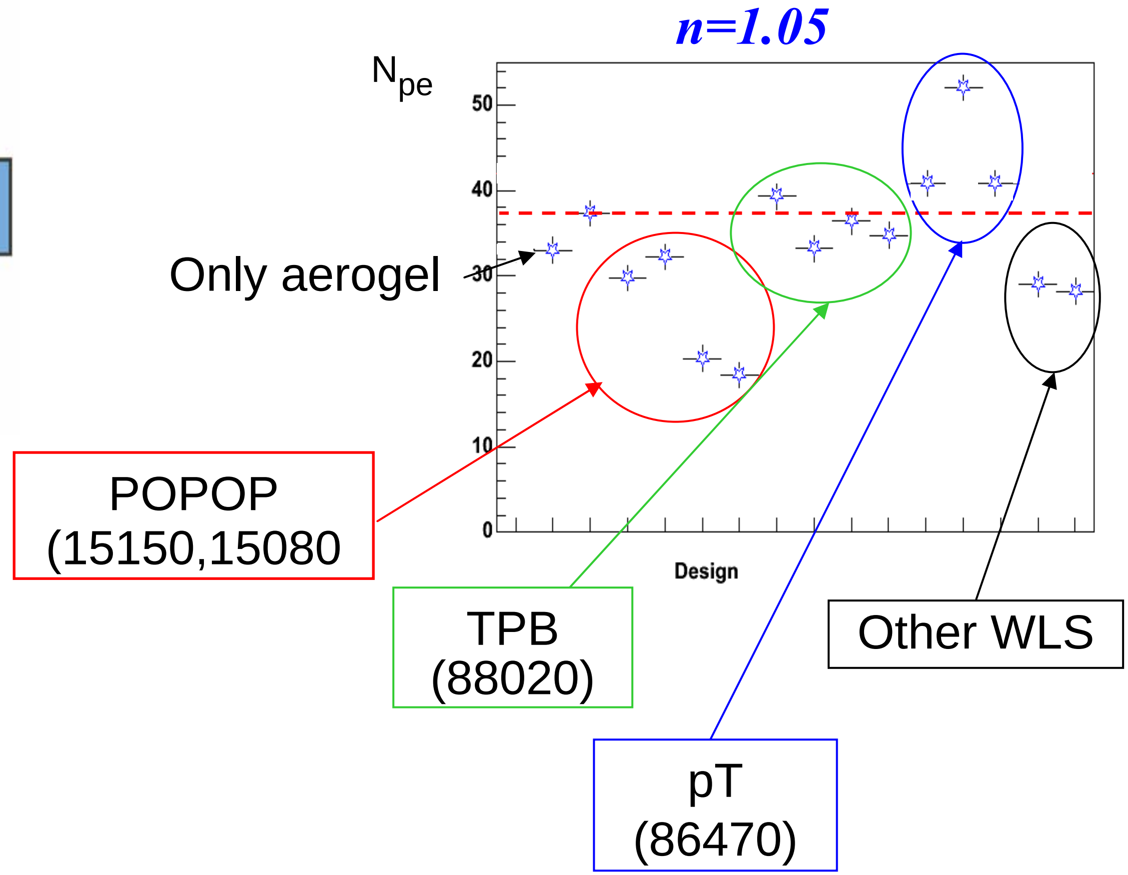


Aerogel Cherenkov detector (II)

The sandwich design

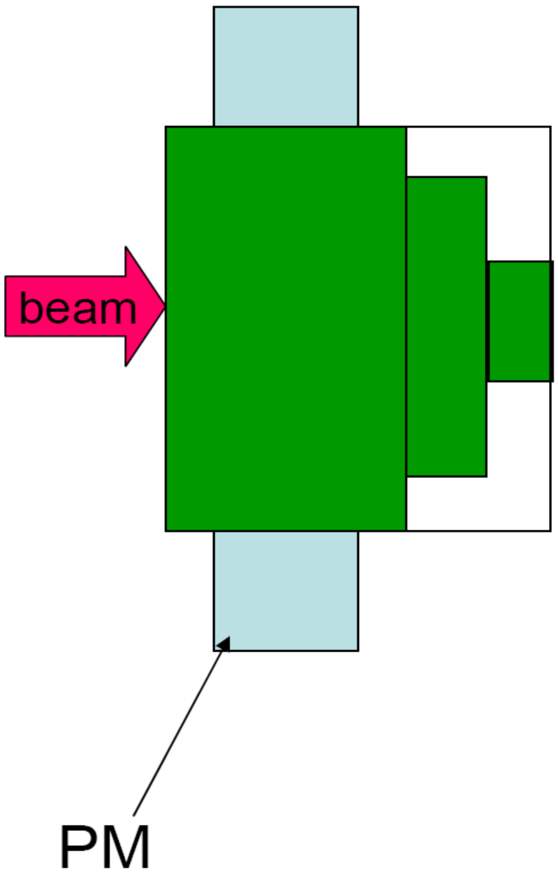


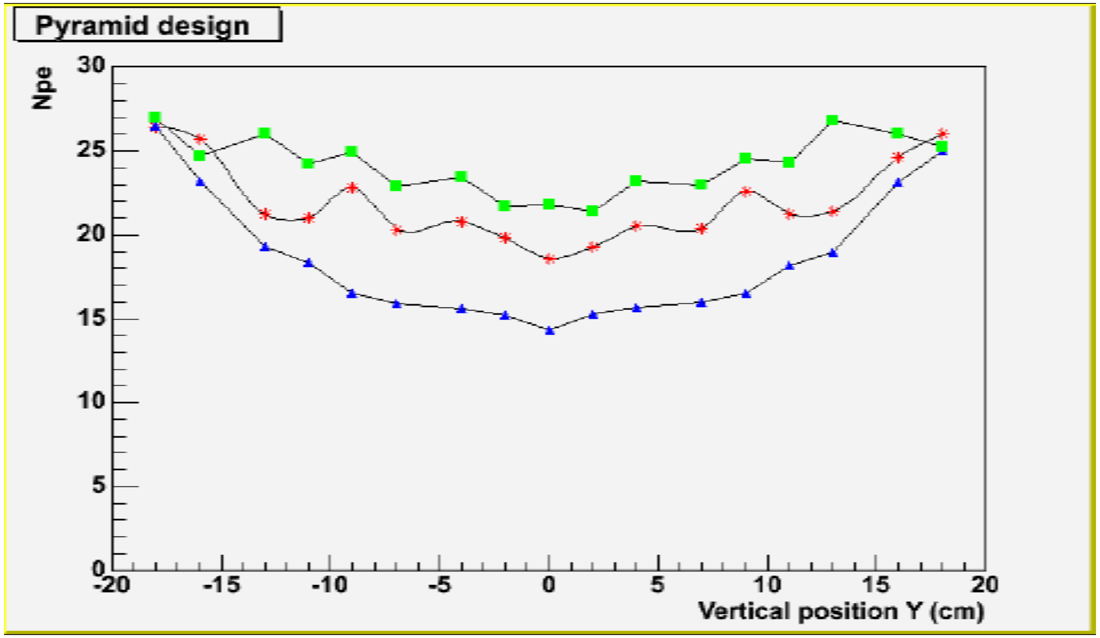




Aerogel Cherenkov detector (III)

The pyramid design

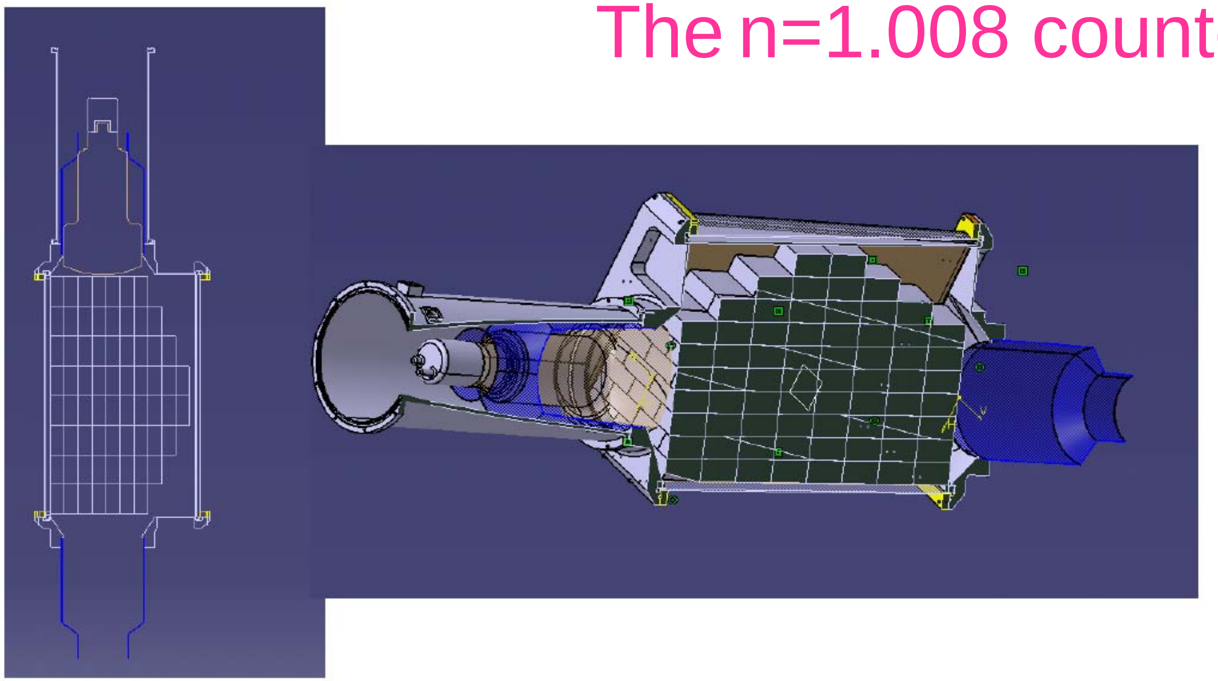




- In blue : box design.
- In red : Pyramid design with 2 layers of thickness 2 cm.
- In green : Pyramid design with 2 layers of thickness 4 cm.

Aerogel Cherenkov detector (IV)

The n=1.008 counter

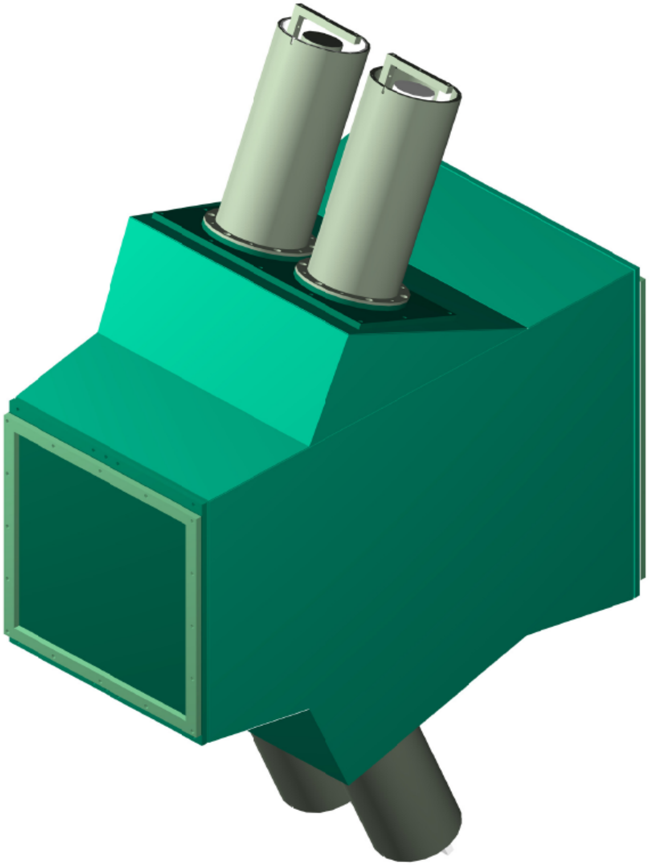


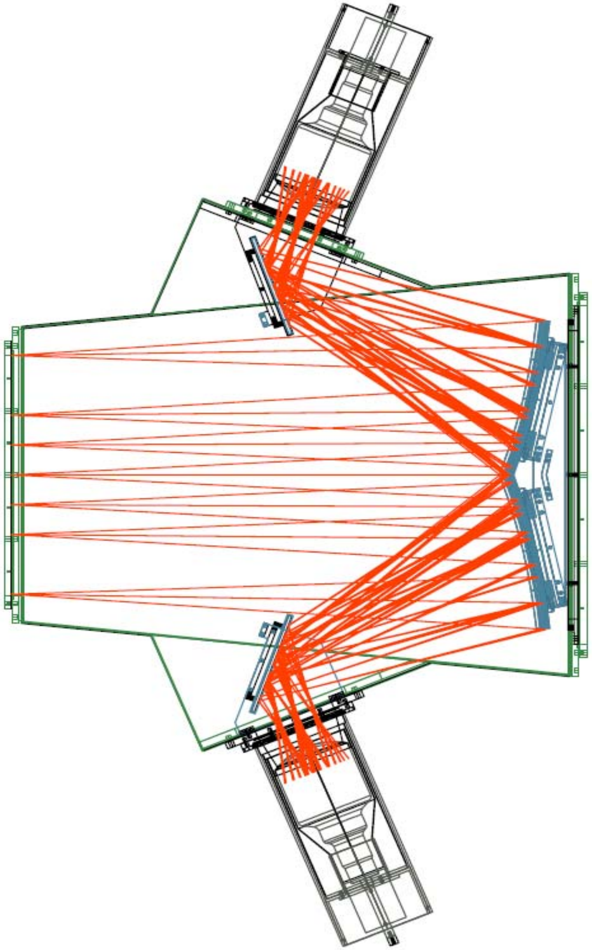
Time schedule:

- PMs already arrived and calibrated
- Aerogel from Novosibirsk (n=1.008) and Panasonic (n=1.015) already arrived
- The mechanics are in production and should be ready beginning May
- Quick test using cosmic rays during May-June
- Installation in DIRAC experiment in July

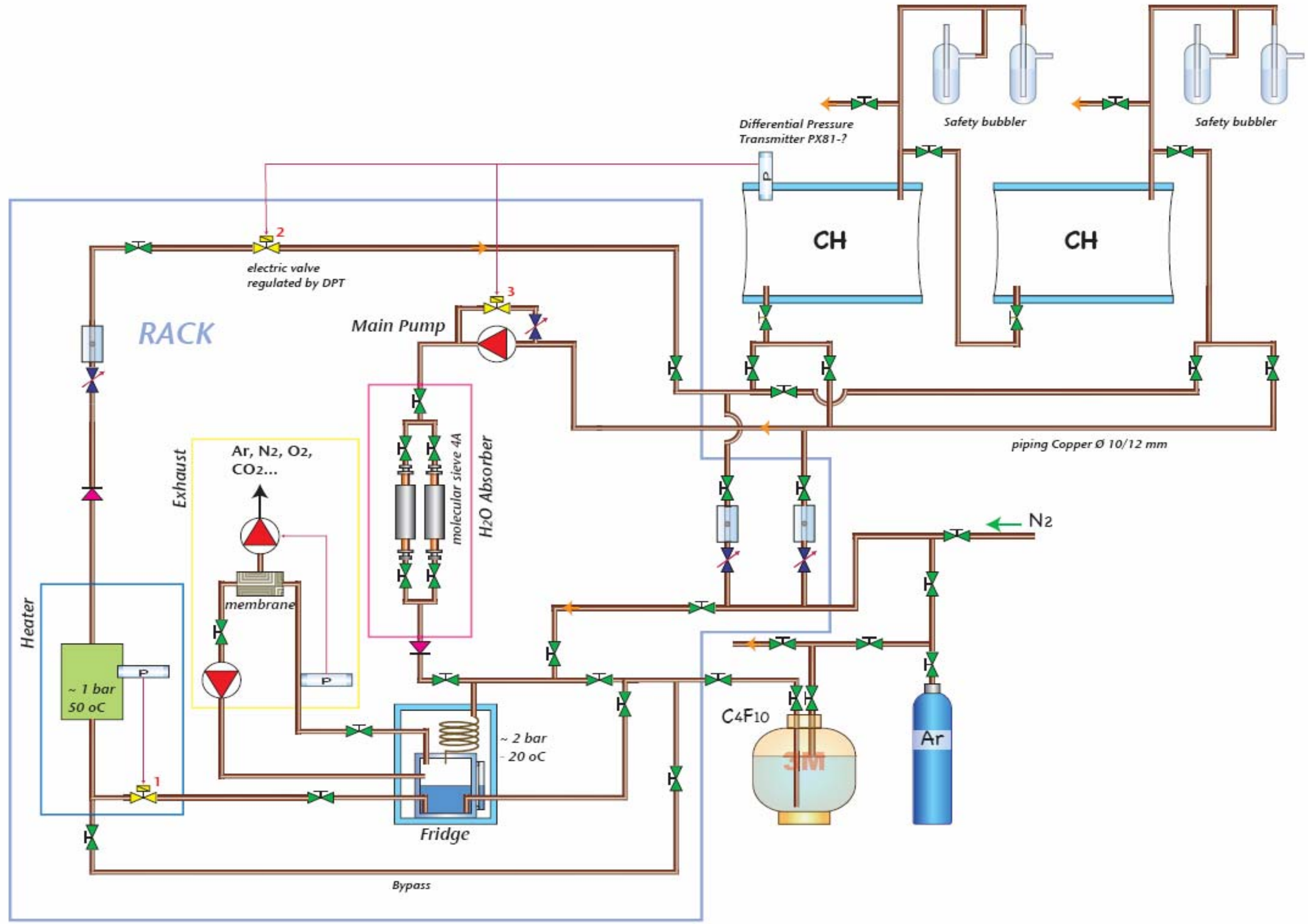
Cherenkov detector (C_4F_{10}) - I

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

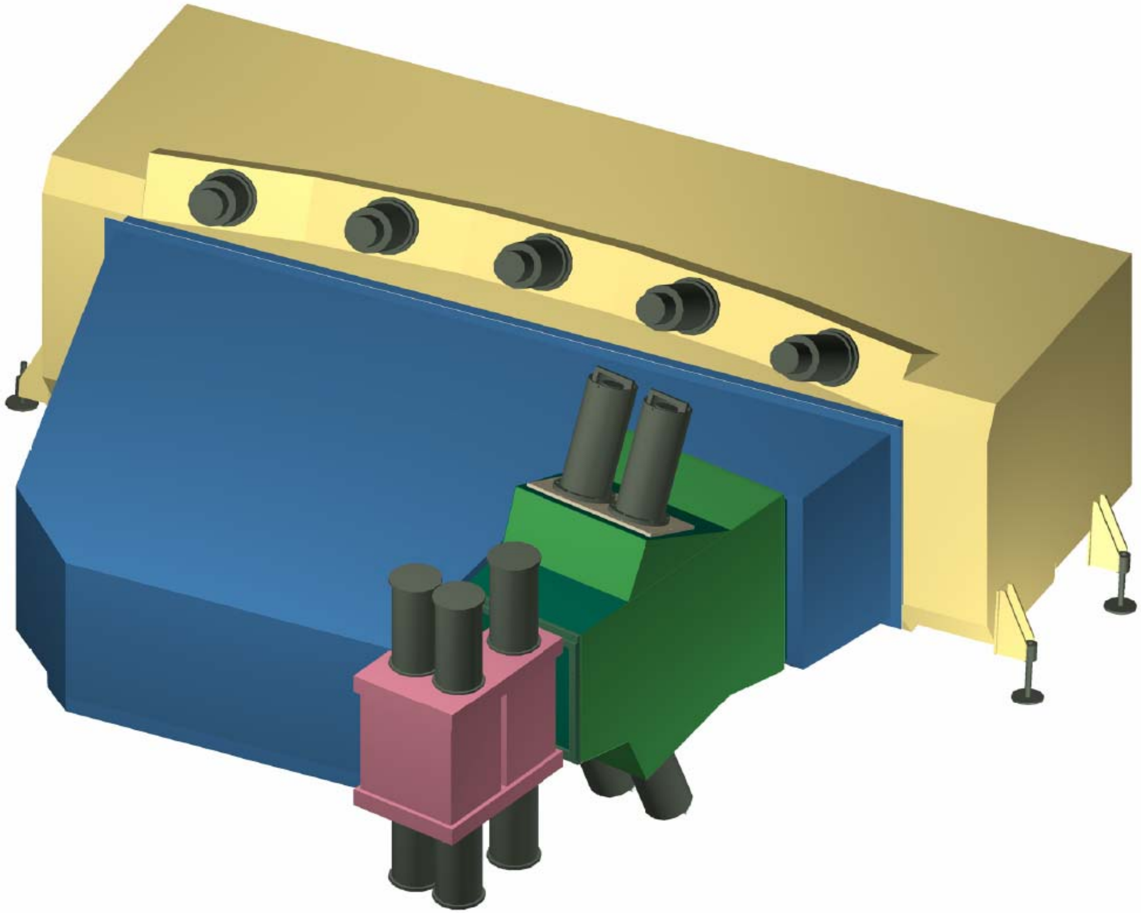




Cherenkov detector (C_4F_{10}) - II



Cherenkov detector (C_4F_{10}) - III



Time Schedule:

Box with flat and spherical mirrors supports and PM housings will be finished and tested for leakproofness in **May**.

Flat mirrors are **ready**. Spherical mirrors will be ready before end of **June**.

Mirror evaporation – **July**

Photomultipliers will be delivered in **July**.

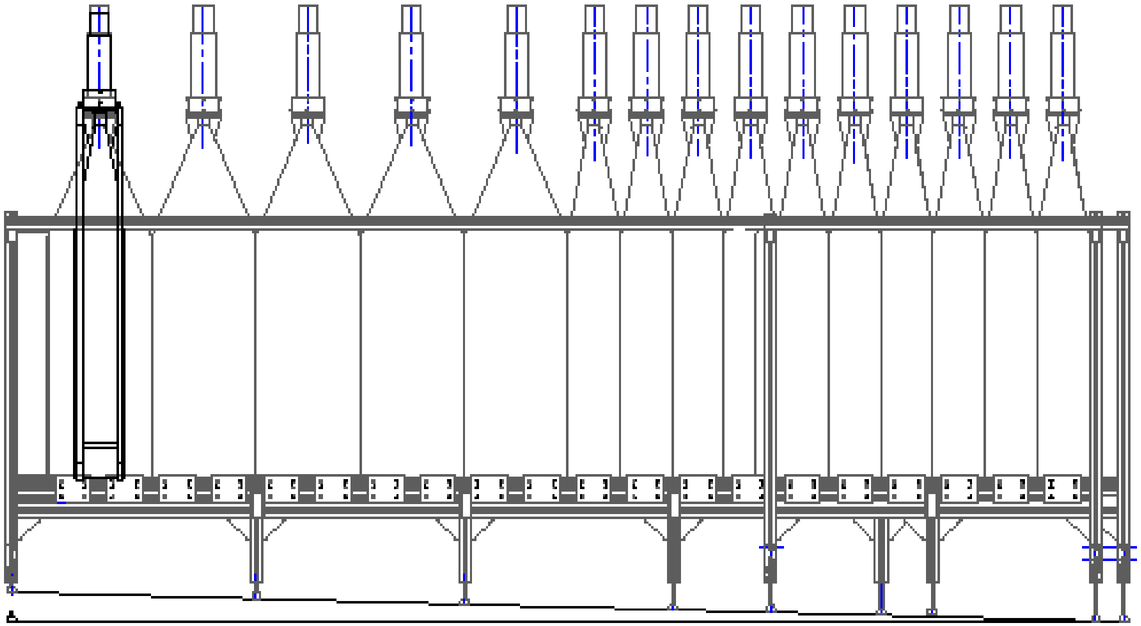
Assembling – **July-August**.

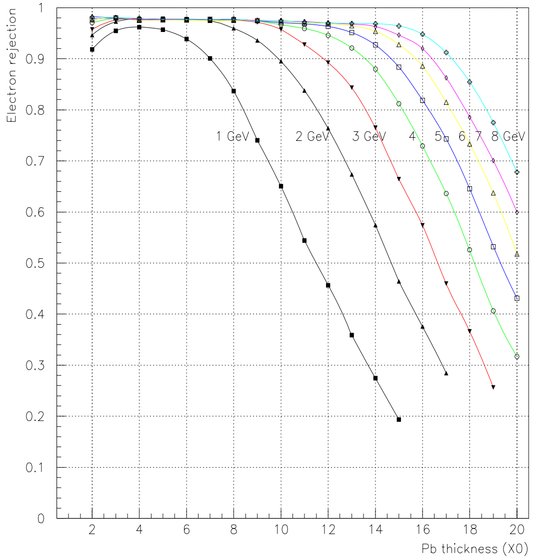
Setting up in DIRAC – before middle of **August**.

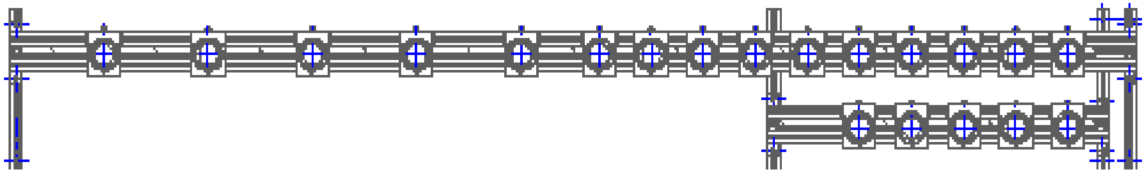
Gas system – **July-August**.

Preshower detector (I)

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







Time Schedule:

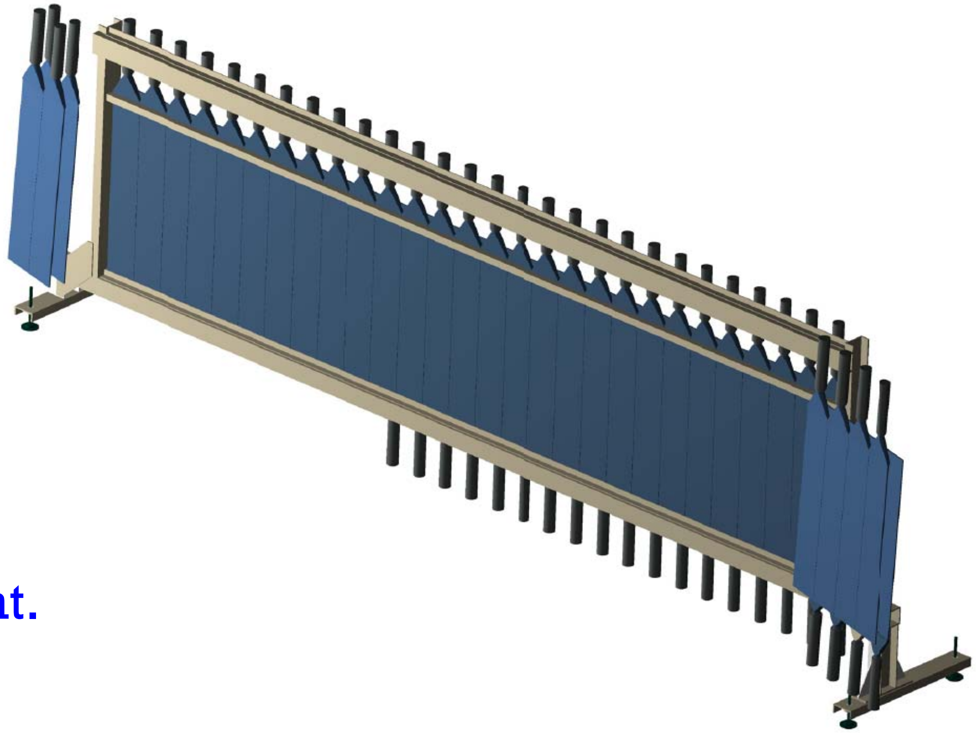
New preshower was installed in April 2006.

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.



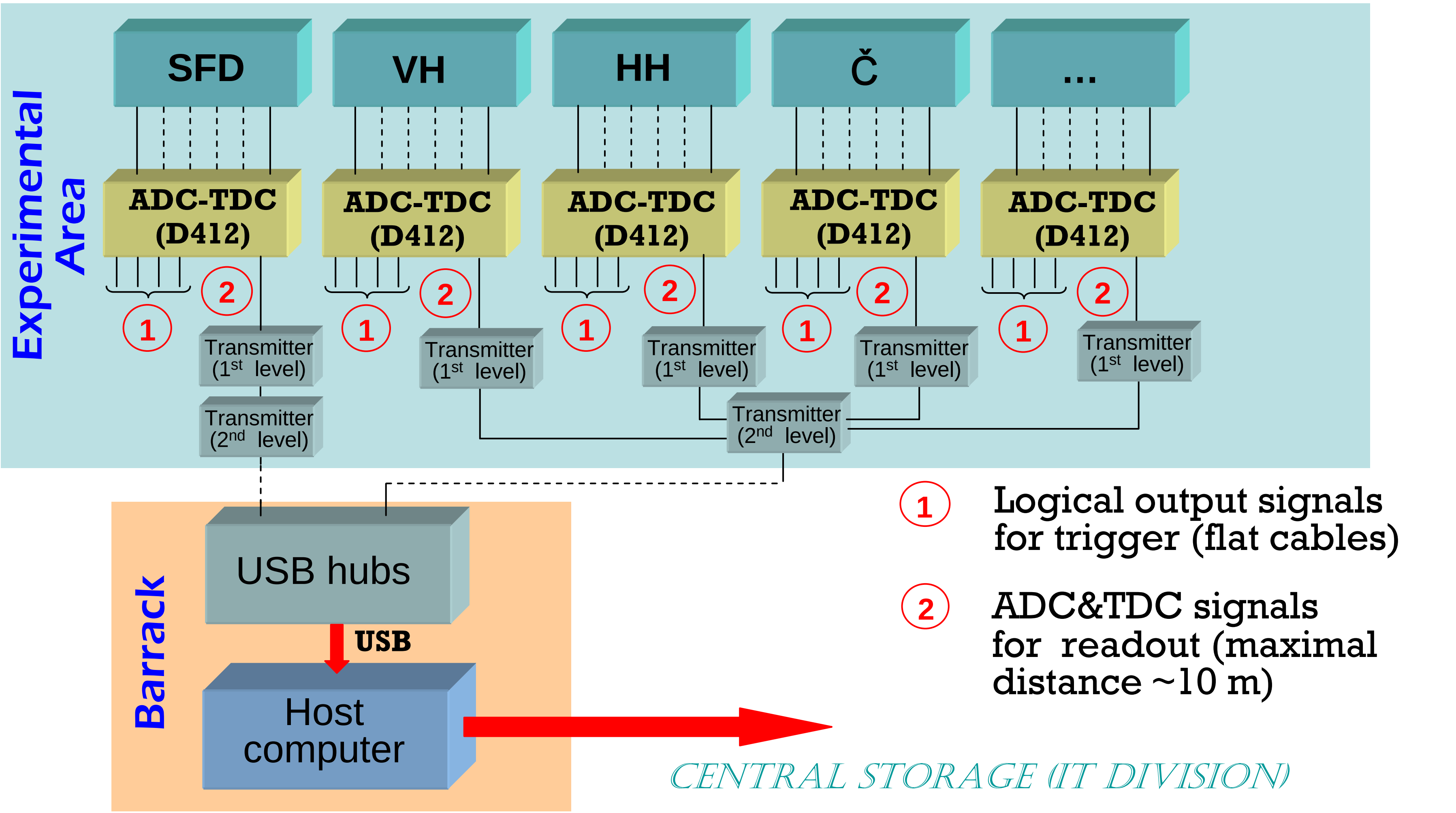
Without these slabs background of non-identified muons from pion decays will increase by few percent.

Time Schedule:

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

Time Schedule:
Tuning of the Trigger System with the specified performances will be begun at the end of the DIRAC 2006 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	51 modules	Three prototypes were made and tested.
Transmitter 1st level	9 modules	Prototype was made and tested.
Transmitter 2nd level	4 modules	Design was finished, no prototype.
Auxiliary module	3 modules	Design was finished, no prototype.

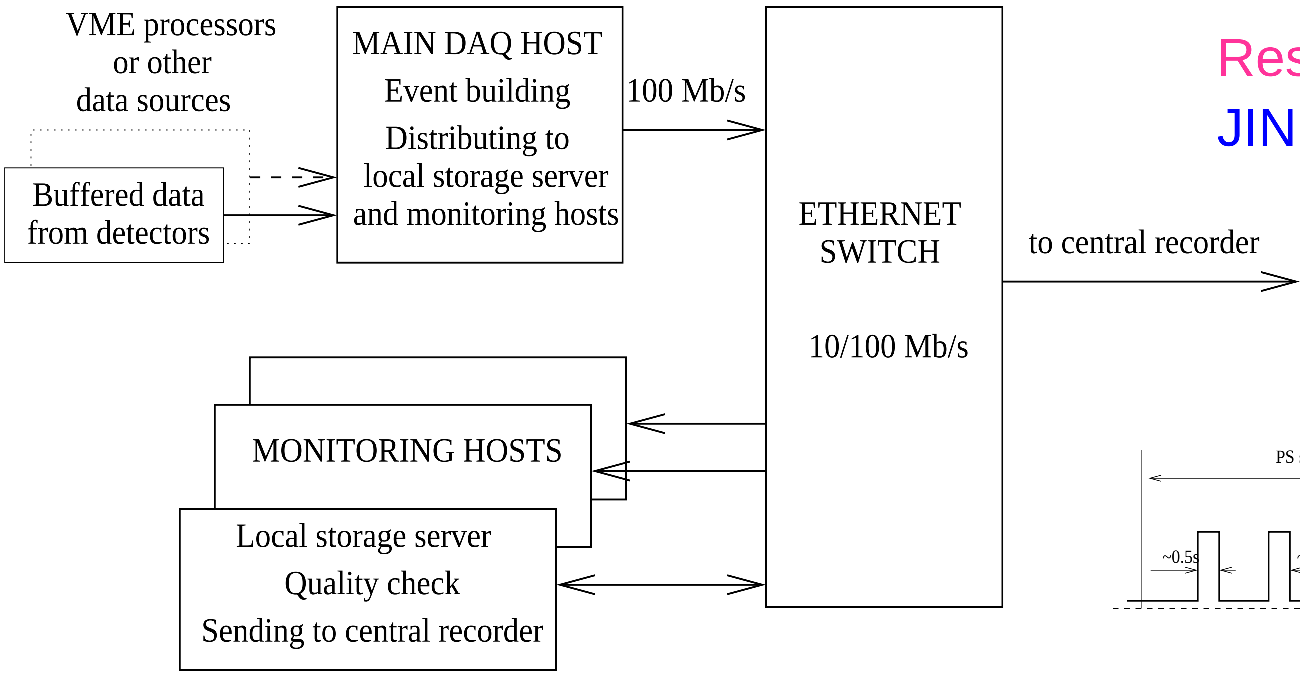
Time Schedule:

All modules will be ready in July and will be checked before the end of August, including chain ADC-TDC – TRANSMITTER I – TRANSMITTER II and the dedicated software. Electronics starts to work with SFD and IH. These detectors are not in the trigger.

Trigger System

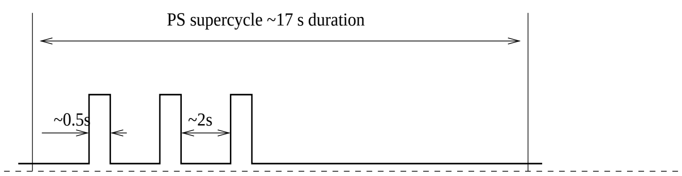
Shaper K436	20 modules	Prototypes were made and tested
Level translator	21 modules	Prototypes were made and tested

Data Acquisition System



Responsibility:

JINR (*Dubna*, Russia)



Time Schedule:

Revising software for automatic and interactive on-line monitoring of data. This work was done partly in March 2006, and will be finished during test runs in August-September 2006.

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

Software for handling with new electronic modules was written in April-May 2006.

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.

DIRAC analysis

Improvements on systematics in P_{Br}

CC background	no improvement	± 0.007
signal shape	no improvement	± 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 drift characteristics almost run-by-run
- B-field adjustment and alignment tuning with Λ-mass

⇒ New pre-selection for all runs **(DONE)**

Comments on analysis strategies

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