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

CERN 2005 SPS and PS Experiments Committee

L. Nemenov

27 September 2005

DIRAC PS212

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

Status of DIRAC

- Life time measurement
- Increasing of the statistics
- Decreasing of the systematic error

DIRAC Addendum

- Modified DIRAC setup
- Channel and shielding
- Detectors
- Readout system
- Trigger
- DAQ

DIRAC analysis (I)

Results from the analysis of data taken on a Ni target in 2001 were published in
J. Phys. G30 (2004) 1929
Phys. Letters B619 (2005) 50

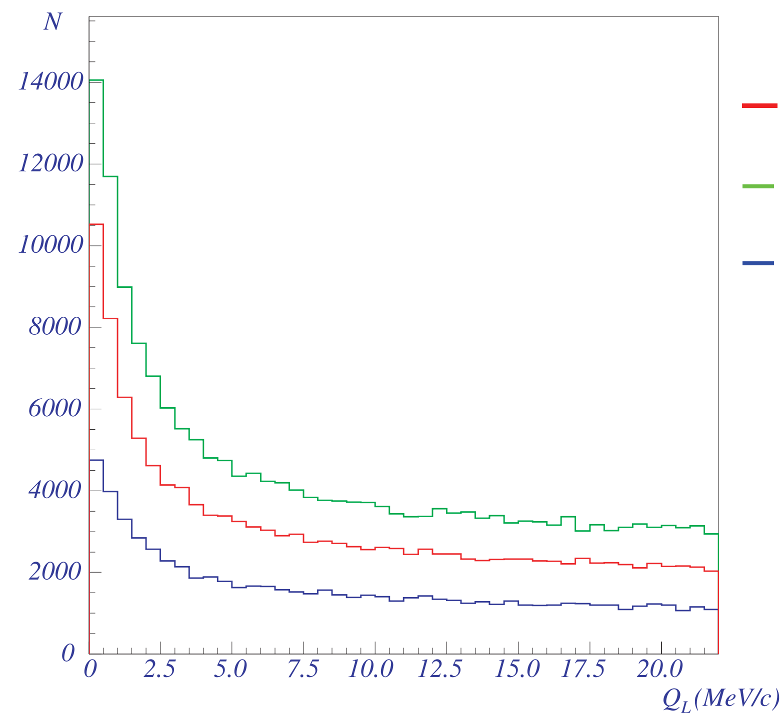
Signal:	6530±294	events
CC background:	374022±3969	events

The break-up probability was found to be:

$$P_{br} = 0.452 \pm 0.023_{stat} \left.\begin{matrix} +0.009 \\ -0.032 \end{matrix}\right\}_{syst} = 0.452 \begin{matrix} +0.025 \\ -0.039 \end{matrix}$$

The main systematic errors are due to:

Quantitative determination of CC background	±0.007
Details of the signal shape	±0.002
Multiple scattering	+0.006/–0.013
K^+K^- and pp_{bar} admixtures	+0.000/–0.023
Finite size effects in CC background	+0.000/–0.017
Total	**+0.009/–0.032**



DIRAC analysis (II)

Results for the lifetime: $\tau_{1S} = 2.91 \left.{}^{+0.45}_{-0.38}\right\}_{stat} \left.{}^{+0.19}_{-0.49}\right\}_{syst} = 2.91 {}^{+0.49}_{-0.62}\ [fs]$ $\tau_{1S}^{ChPT} = 2.9 \pm 0.1\ [fs]$

Result for scattering lengths: $|a_0 - a_2| = 0.264 {}^{+0.033}_{-0.020}\ [m_\pi^{-1}]$ $|a_0 - a_2|_{ChPT} = 0.265 \pm 0.004\ [m_\pi^{-1}]$

Improvements with full statistics

Number of Atomic pairs (approx.)									
	Pt1999 24 GeV	Ni2000 24 GeV	Ti2000 24 GeV	Ti2001 24 GeV	Ni2001 24 GeV	Ni2002 20 GeV	Ni2002 24 GeV	Ni2003 20 GeV	Sum
Sharp selection	280	1300	900	1500	**6500**	3000	4500	1400	**19400**
Downstream only									27000

$$\left.\frac{\sigma_{P_{br}}}{P_{br}}\right|_{stat}^{now} = 0.051 \Rightarrow \left.\frac{\sigma_{P_{br}}}{P_{br}}\right|_{stat}^{full\ statistics} = 0.03 \Rightarrow \left.\frac{\delta |a_0 - a_2|}{a_0 - a_2}\right|_{stat} = 5\%$$

as in the project

DIRAC analysis (III)

Improvements on systematic

CC background	no improvement	± 0.007
signal shape	no improvement	± 0.002
Multiple scattering	measured to ±1%	+ 0.002 /-0.002
K^+K^-/pp_{bar} admixtures	to be measured*	+ 0.000 /-0.023
Finite size effects	to be measured** /improved calculations	+ 0.000 /-0.017
Total		**+ 0.008 /-0.030**

* To be measured in 2006/2008 with new PID

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

Improvements on data quality by fine tunings

Adjustments of drift characteristics almost run-by-run

B-field adjustment and alignment tuning with Λ-mass

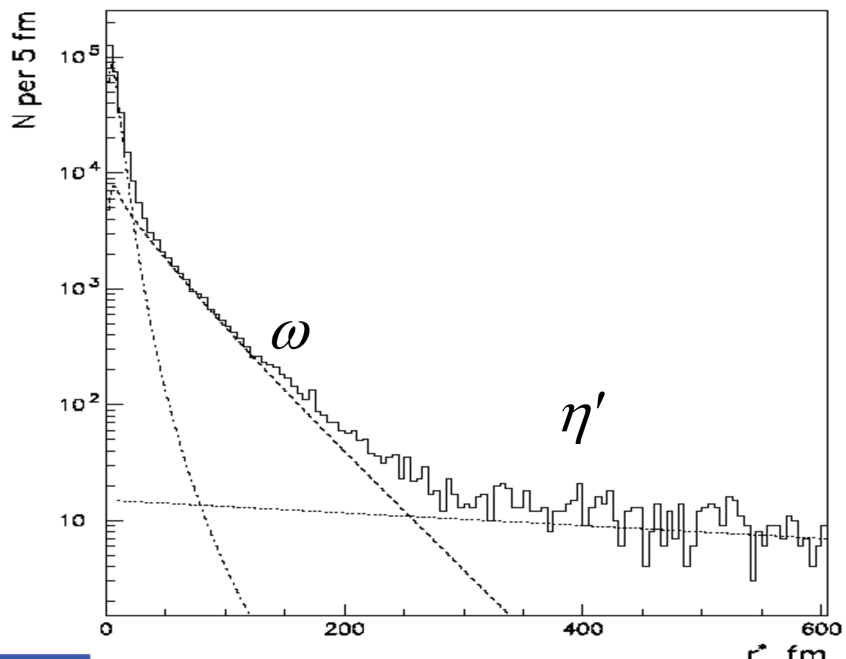
⇒ New preselection for all runs

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.

Finite-size effects (I)

- characteristic scale $|a| = 387\ fm$ (Bohr radius of $\pi\pi$ system)
- average value of $r^* \sim 10\ fm$
- range of $\omega \sim 30\ fm$
- range of $\eta' \sim 900\ fm$
- critical region of $r^* \sim |a|$ is formed by ω and η' pairs



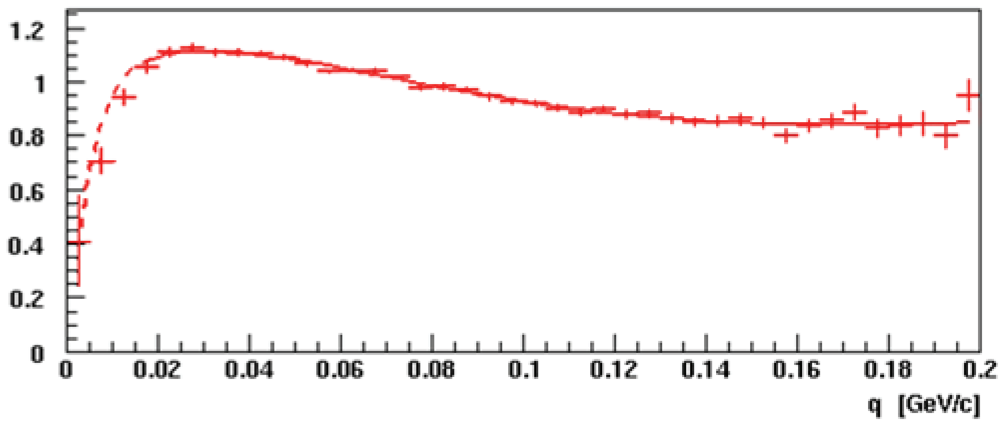
UrQMD simulation pNi 24 GeV:

- ~15% ω pairs
- < 1% η' pairs

$\Rightarrow$ shift in P_{br} mainly due to ω pairs

Finite-size effects (II)

CF($\pi^-\pi^-$) arbitrary normalization



Simulation vs fit of DIRAC $\pi^-\pi^-$ CF

- simulation $N_\omega(\pi^-\pi^-) = 19.2\%$
- fit result $N_\omega(\pi^-\pi^-) = 21\pm7\%$

$\Rightarrow$ good description of ω pairs by UrQMD

In $\pi^+\pi^-$ system finite-size effect induces shift in P_{br}

✓ UrQMD simulation $N_\omega(\pi^+\pi^-) = 15\% \Rightarrow \delta P_{br} \sim 2\% \Rightarrow \delta\tau \sim 5\%$

✓ upper limit at 1σ of $\pi^-\pi^-$ fit $N_\omega(\pi^+\pi^-) = 20\% \Rightarrow \delta P_{br} \sim 3\% \Rightarrow \delta\tau \sim 7.5\%$

$\Rightarrow$

Systematic shift in τ measurement from finite-size effect < 10%

i.e. less then present DIRAC statistical error in τ.

Expected shift with multi-layer target in future DIRAC 5 times less

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 length $|a_{1/2}-a_{3/2}|$ 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

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

Manufacture of all new detectors and electronics:	18 months
Installation of new detectors:	3 months

2006

Test of the Upgraded setup and calibration:	4 months

Observation $A_{2\pi}$ in the long-lived states.

2007 and 2008

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

In this time 86000 $\pi\pi$ atomic pairs will be collected to estimate $A_{2\pi}$ 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 $A_{K\pi}$;
to detect 5000 πK atomic pairs to estimate $A_{\pi K}$ 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.

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.

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.

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

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: $K^+ \rightarrow \pi^0\pi^0\pi^+$

$$(a_0 - a_2)m_\pi = 0.281 \pm 0.007\,(stat) \pm 0.014\,(syst)$$

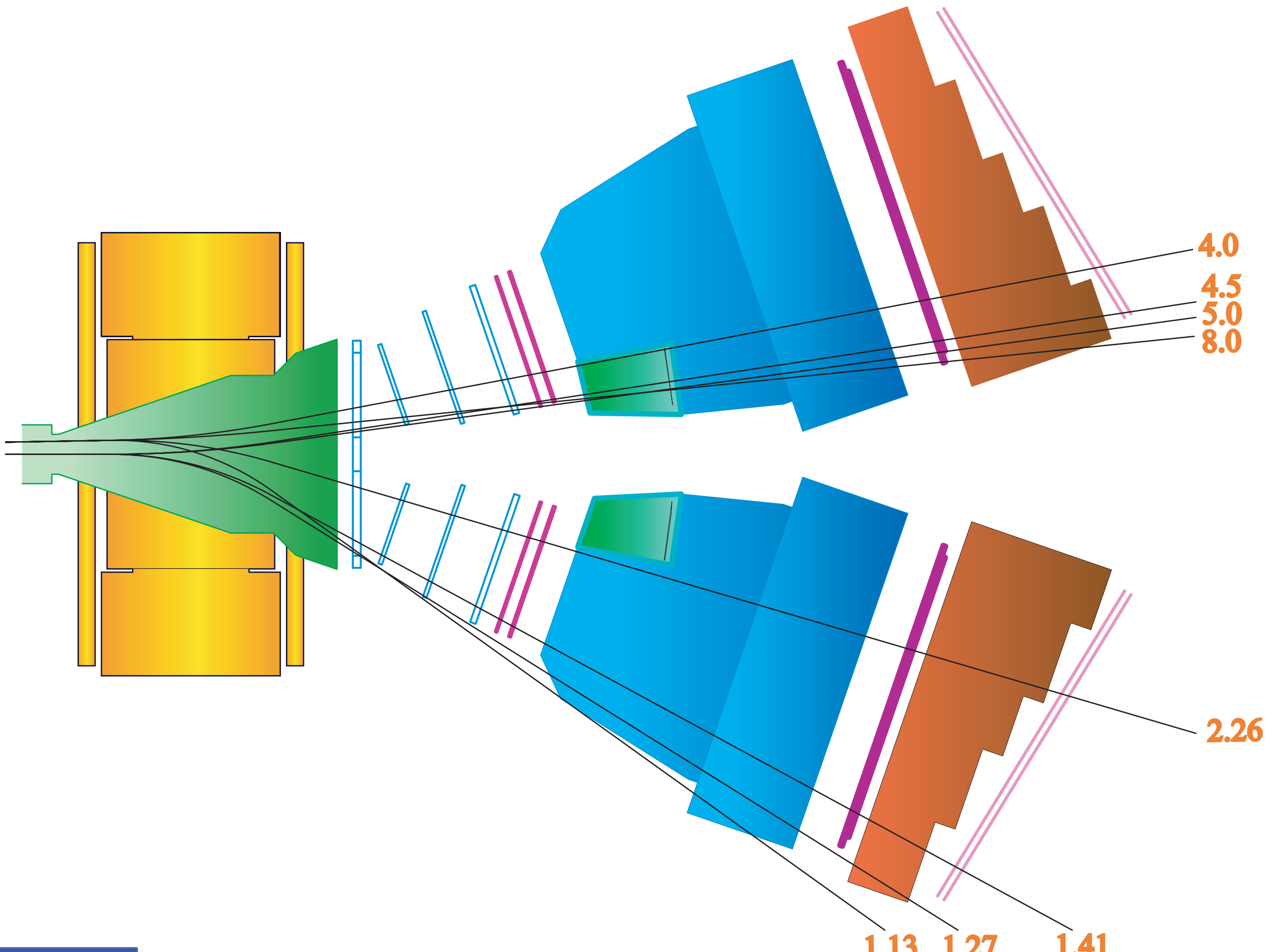
not including theoretical uncertainties

Expected results of DIRAC (upgraded) at PS CERN:

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

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

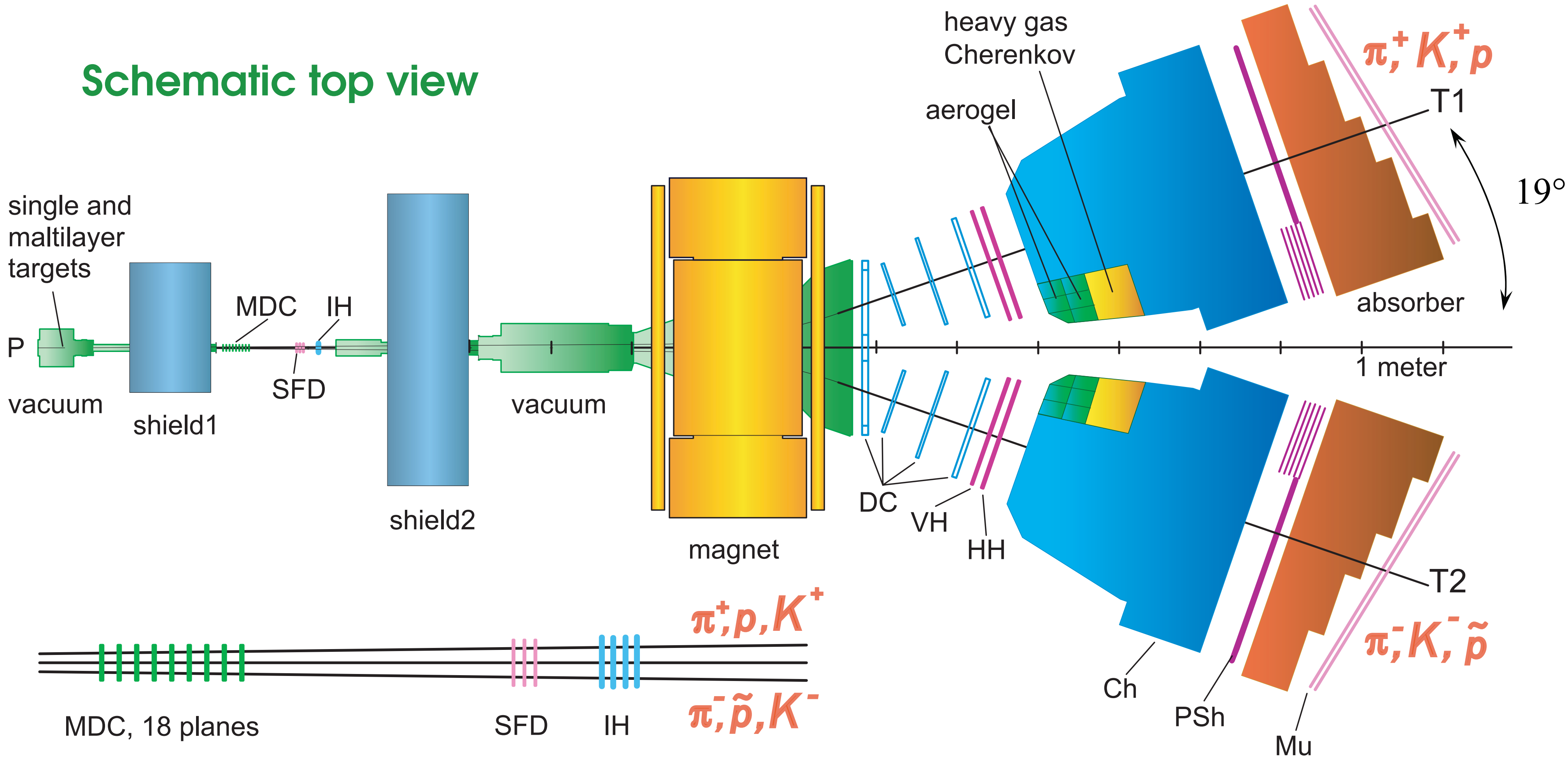


The $A_{\pi K}$, π^- and K^+ momenta are shown in the following table:

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

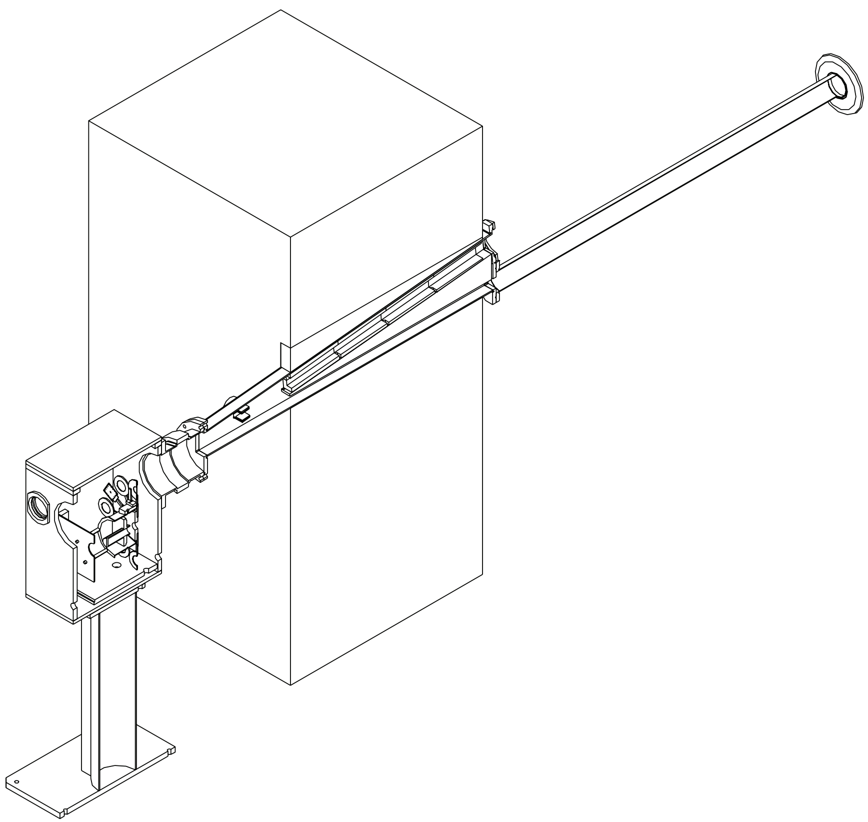
Upgrade DIRAC experimental set-up description

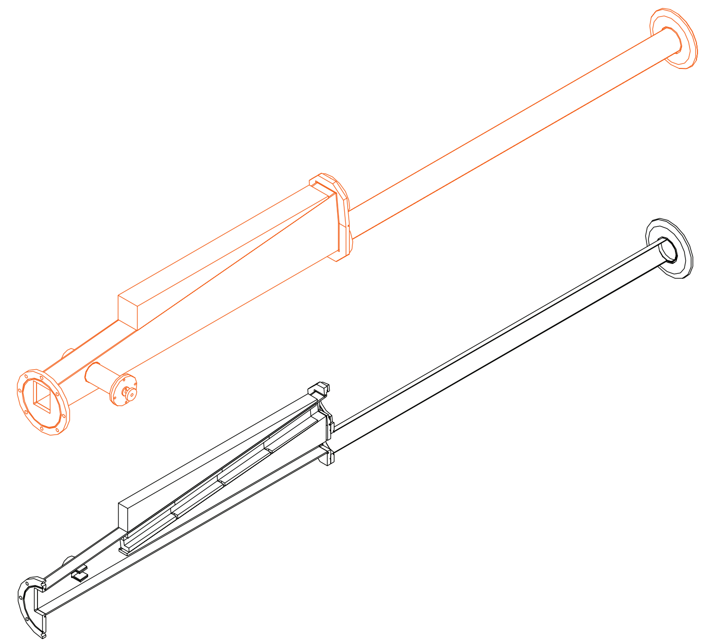
Schematic top view



Channel and shielding

Responsibility: JINR (*Dubna*, Russia)



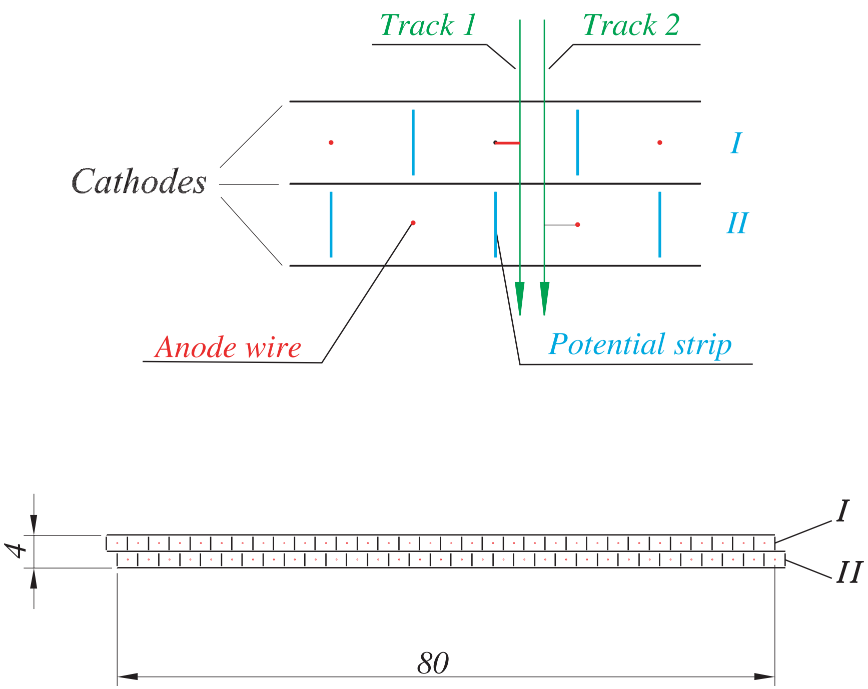


<u>Time Schedule:</u>

New vacuum section with collimators for the primary and secondary beams will be manufactured by the middle of October 2005, transported from Dubna to CERN by the end of this year and installed together with iron shielding into the DIRAC setup in the first quarter of the next year.

Microdrift Chambers

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



Characteristics:

✓spatial accuracy $< 22\pm4\ \mu m$ 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 $< 3\ \mu s$.

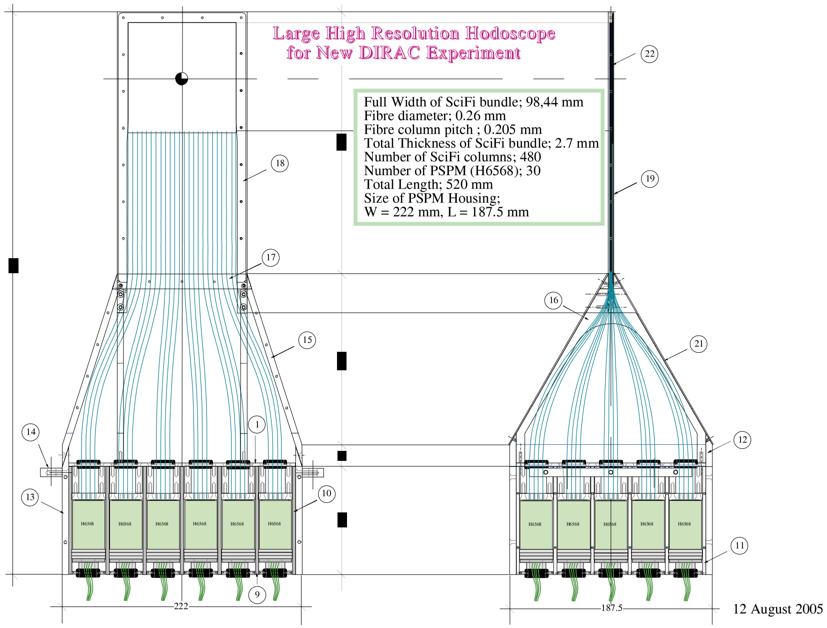
According to the results of MDC tests in 2003-2004, the detector stability has to be improved for the DIRAC heavy radiation conditions. This improvement will be achieved by some modification of MDC electrodes.

Time Schedule:

February-April 2006: new electrodes making at JINR. April-May 2006: tests of the modified MDC detector with a radioactive source for high voltage. June 2006: the MDC detector will be mounted in the DIRAC setup at CERN.

Scintillation Fiber Detector

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% RL)
- ✓ Mean light output: — $\approx 11\ p.e.$
- ✓ Mean Det. 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*) — 1200 *channels*

Time Schedule:

Additional tests of the F1 Prototype with a radioactive source are scheduled for October 2005. Production of fiber layers and detector housing will be finished in December 2005. Components for FE electronics will be delivered in two steps: 480 channels before the end of 2005 and 480 channels before March 2006. All electronics boards will be finished by May 2006. The full detector will be assembled before the beam test at T8 scheduled for June 2006.

Ionisation Hodoscope

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

In 2006 the detector will be used without changes

Drift Chambers

Responsibility: JINR (*Dubna*, Russia)

<u>Present status of the Drift Chamber (DC) System.</u>

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 $80\times40cm^2$ housing 6 planes of signal wires (*X, F, W, X', Y', W'*).

Three modules are then place on each spectrometer arm:

- ✓ DC2 with an active area of $80\times40\ cm^2$ and 2 wire planes (*X, Y*);
- ✓ DC3 with an active area of $112\times40cm^2$ and 2 wire planes (*X, Y*);
- ✓ DC4 with an active area of $128\times40cm^2$ and 4 wire planes (*X, Y, X', Y'*).

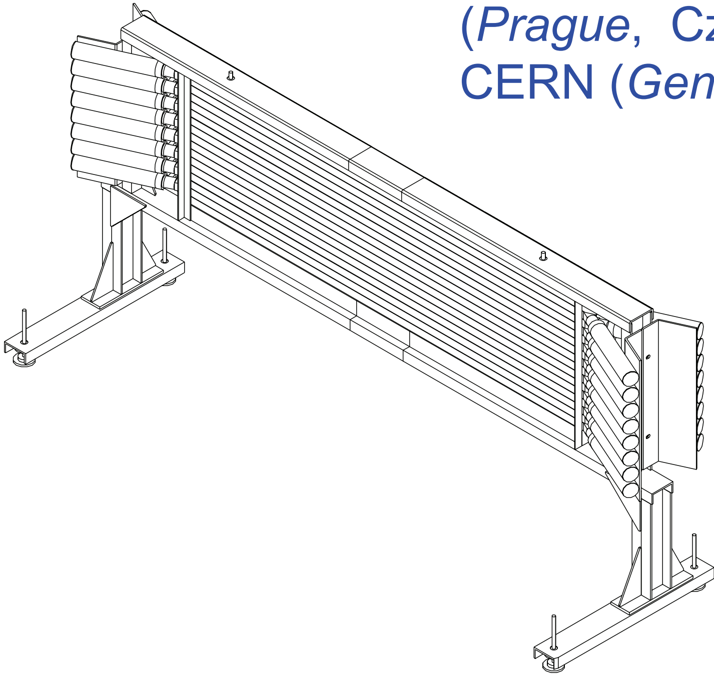
After successful and long drift chamber operation at the first stage of the experiment, it was decided to perform full revision of all drift chambers.

<u>Time Schedule:</u>

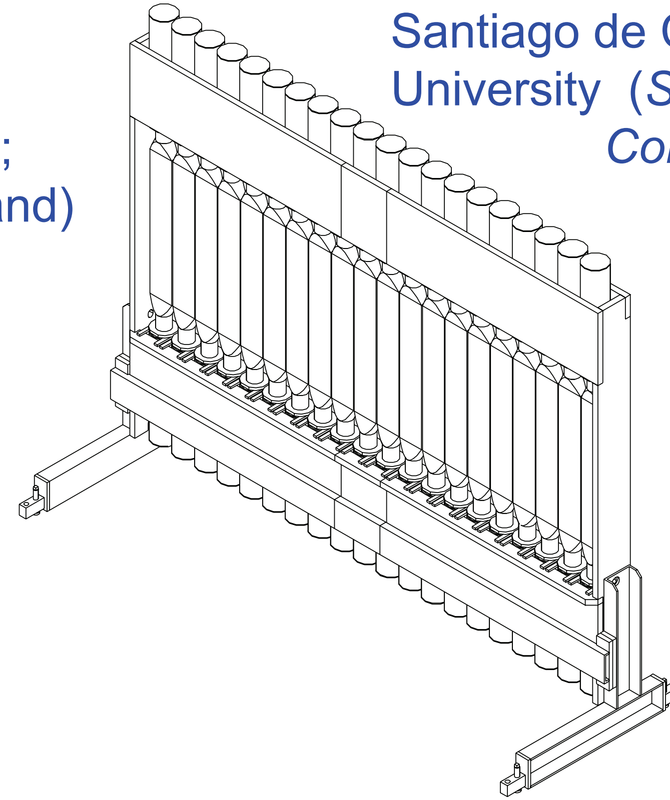
In the first half of the year one DC1, three DC2, two DC3 and one DC4 modules were repaired. In October – November one more DC4 module will be repaired. In the same time all these modules will be tested with radioactive source. All DC modules, which must be installed in the DIRAC setup, will be ready for the experiment in 2005. In the first half of 2006 all spare DC modules will be repaired.

Vertical and Horizontal Hodoscopes

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



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



Time Schedule:

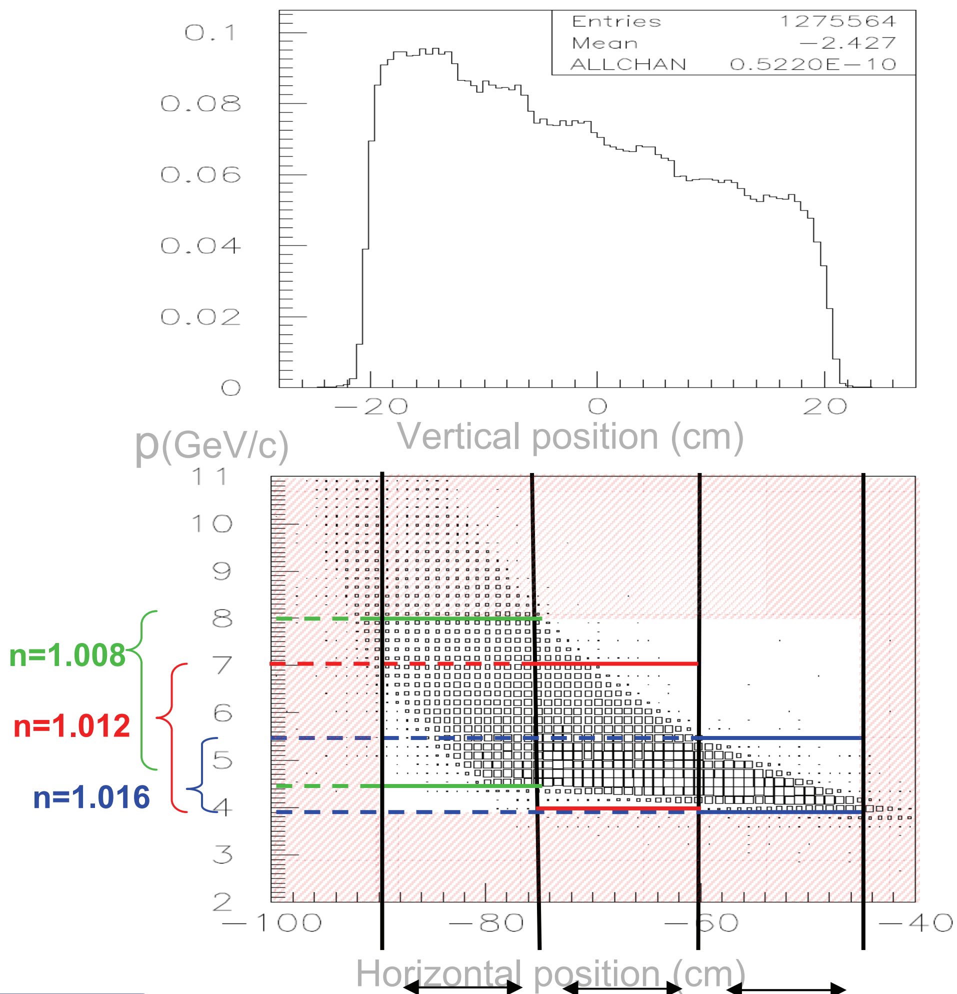
VH: Four additional slabs will be added to the existing vertical scintillation hodoscopes. These slabs will be manufactured in the first quarter 2006.

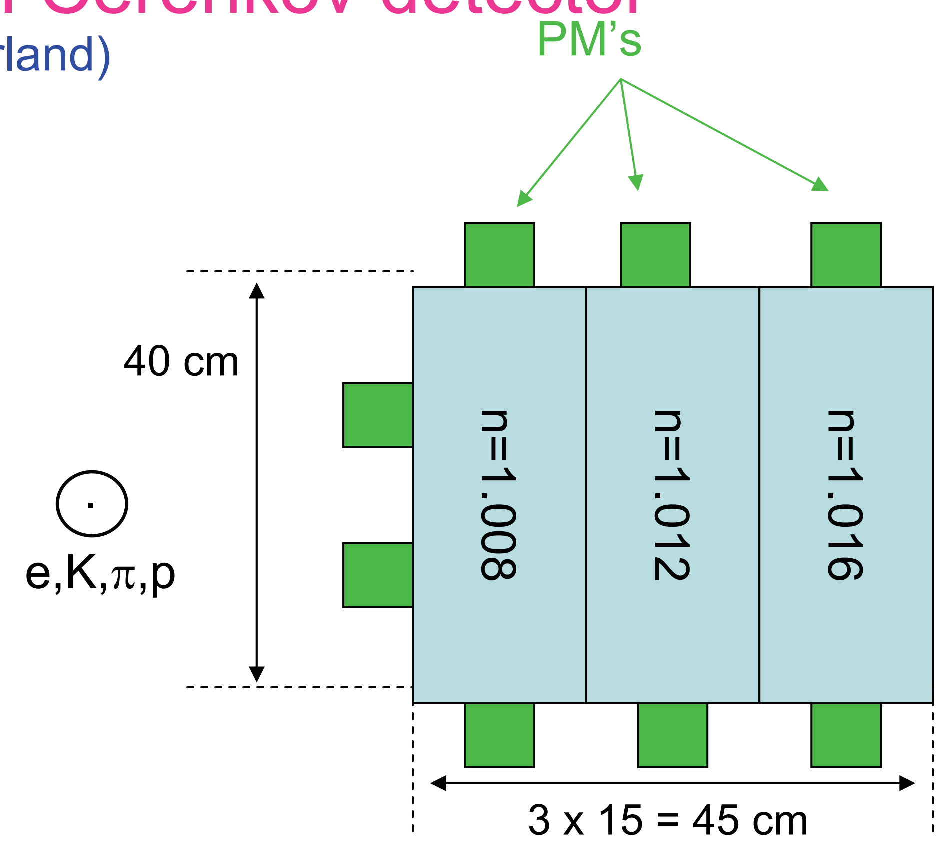
HH: New longer horizontal hodoscopes will be installed. There will be 32 slabs (16 slabs per arm) by $1500 \times 25 \times 25\ mm^3$. Photomultipliers are already at CERN. Scintillators will be transported to CERN at the end of September 2005. The hodoscopes will be assembled at the end of November 2005.

Aerogel Cherenkov detector (I)

Design of the aerogel Čerenkov detector

Responsibility: Zurich University (*Zurich*, Switzerland)

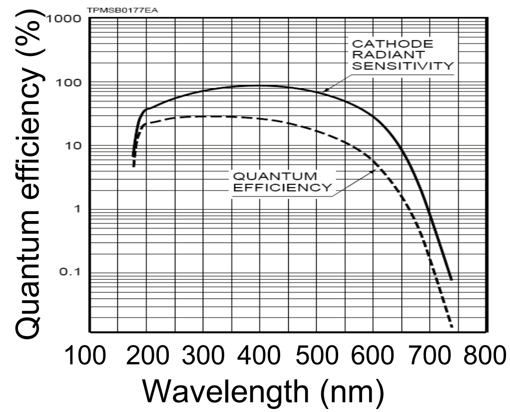


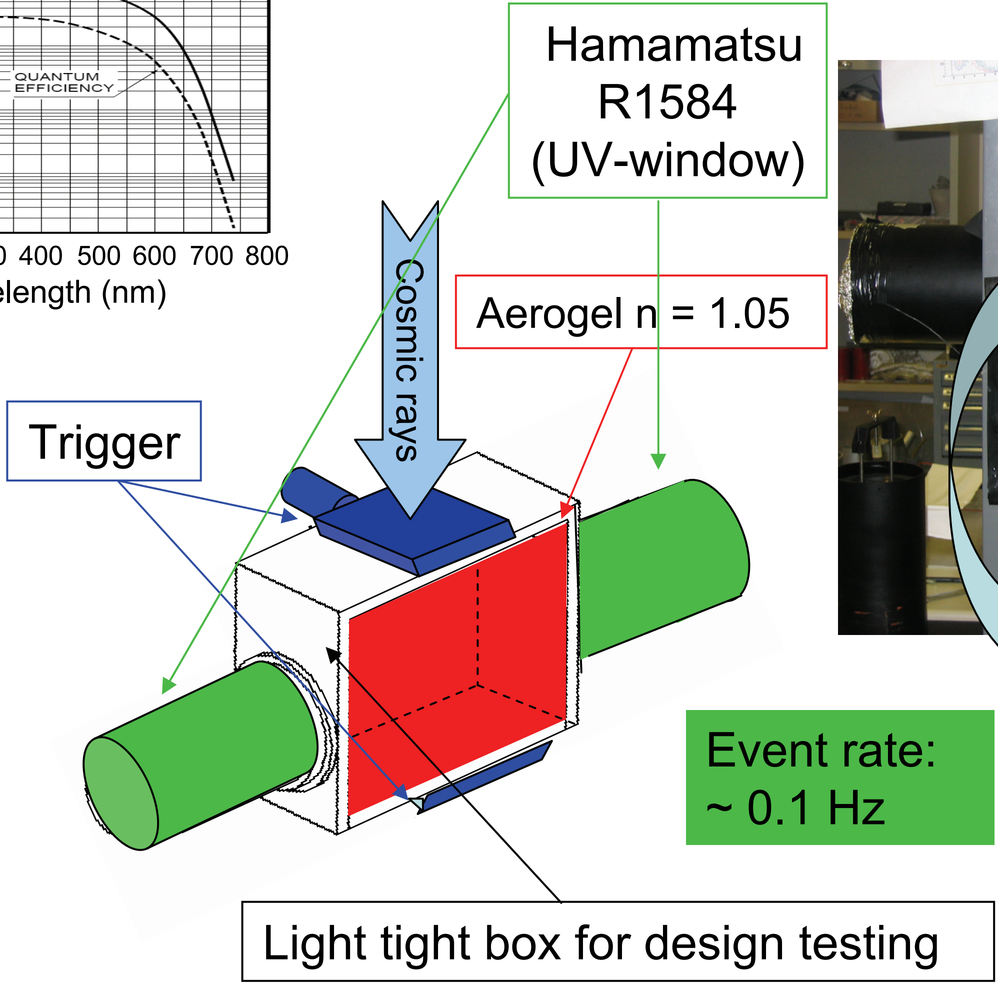


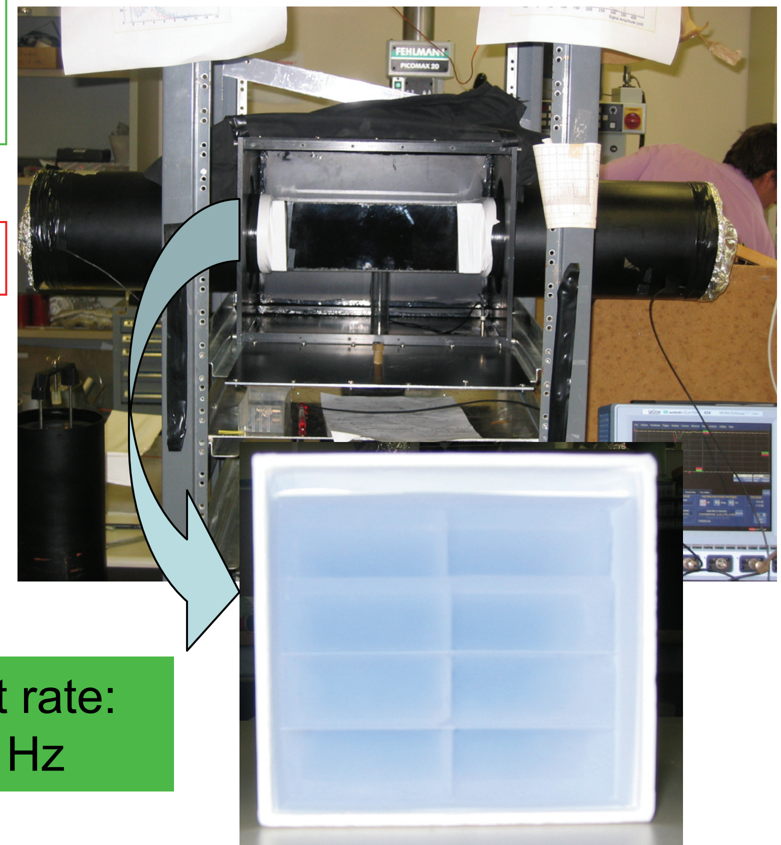
3 independent detectors are needed in each spectrometer arm

Aerogel Cherenkov detector (II)

Cosmic ray test setup



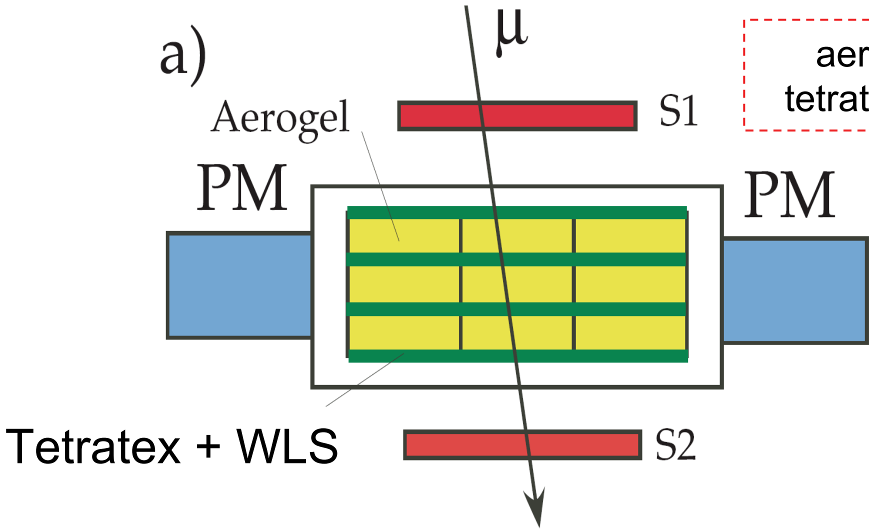


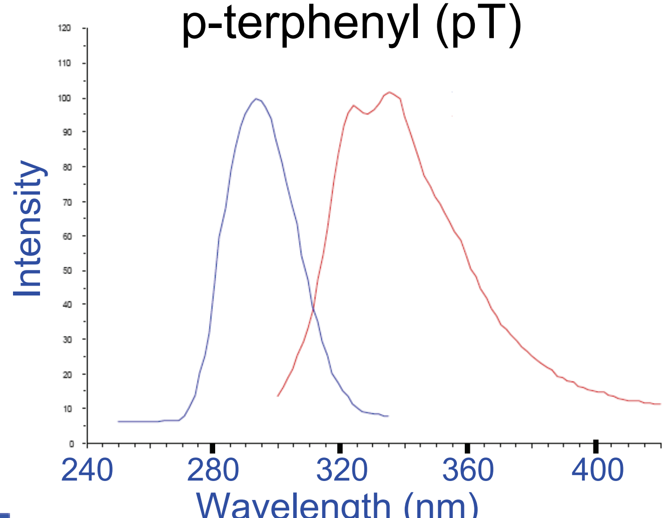


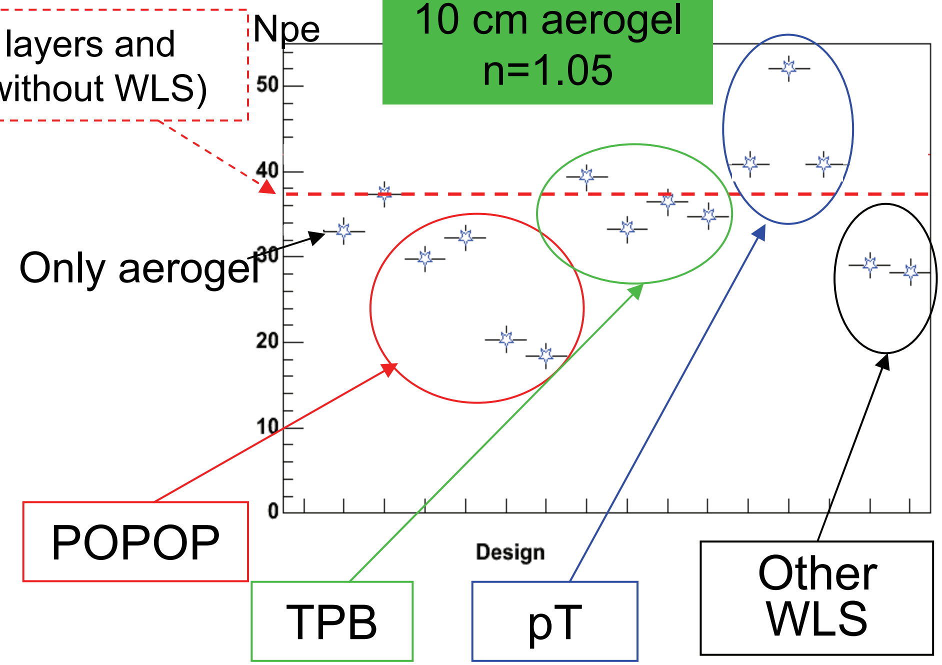
Event rate:
~ 0.1 Hz

Aerogel Cherenkov detector (III)

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

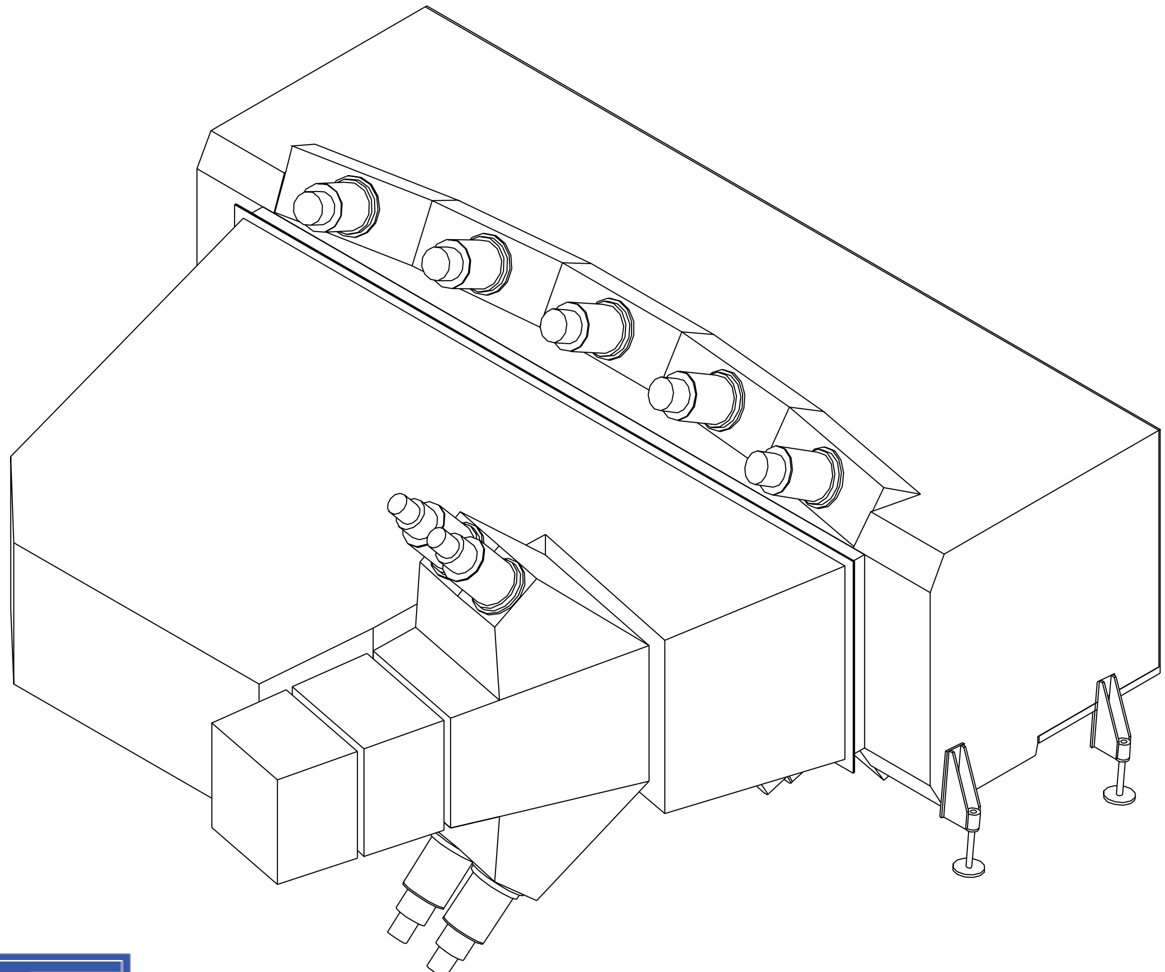
Aerogel Cherenkov detector (IV)

Time Schedule

- End of the year : Construction of the mechanical structure for the final design
- January – March 2006 : aerogel with index n=1.008 will be produced for 1 arm
  - ✓ first test of the final design with cosmic rays
  - ✓ and possibly e -test beam
- March – May 2006 : aerogel for first arm will be produced
  - ✓ installation in beam
- May – July 2006 : aerogel for second arm will be produced

Cherenkov detector (C_4F_{10}) - I

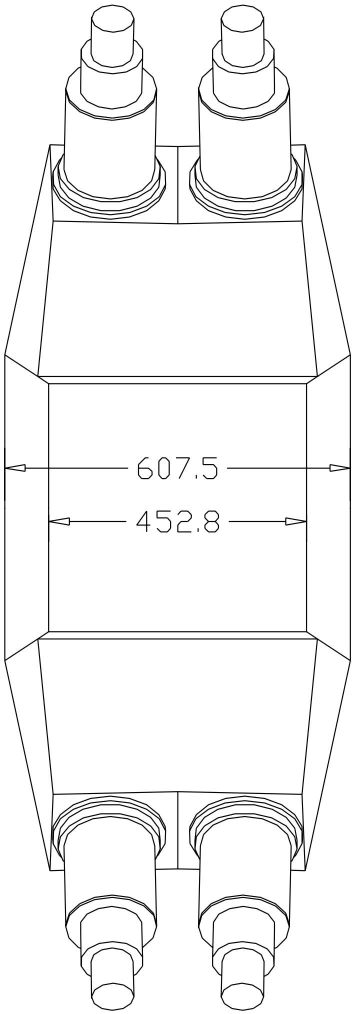
Responsibility: JINR (*Dubna*, Russia); IFIN-HH (*Bucharest*, Romania); Zurich University (*Zurich,* Switzerland)
Adviser: O. Ullaland (*CERN*)

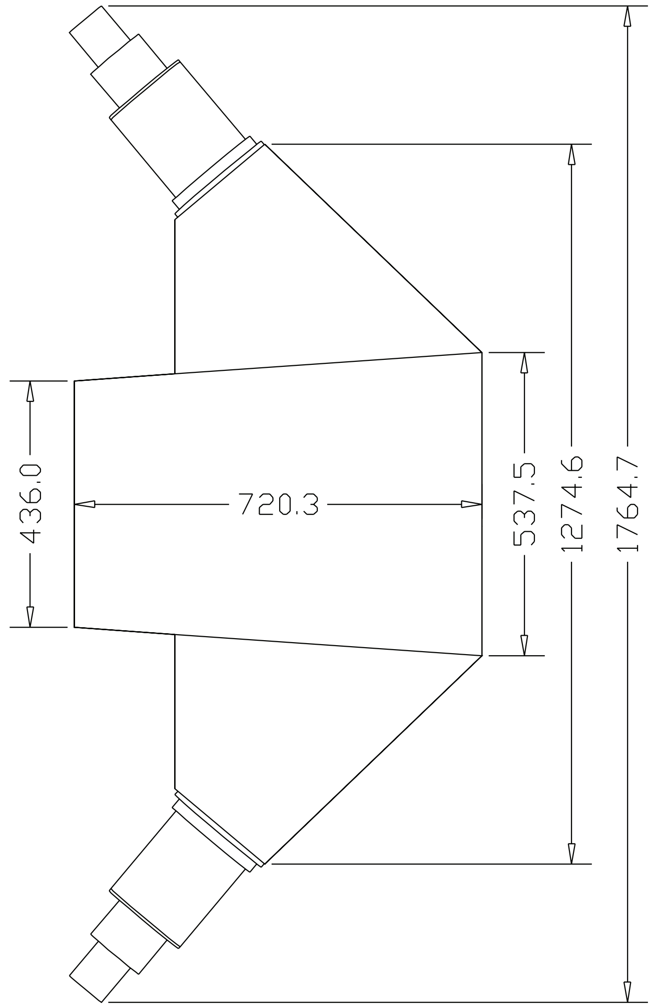


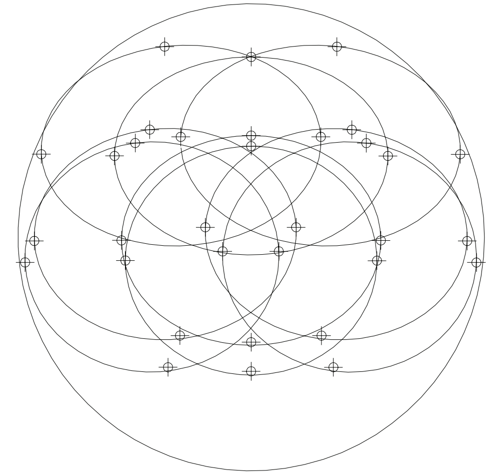
Time Schedule:

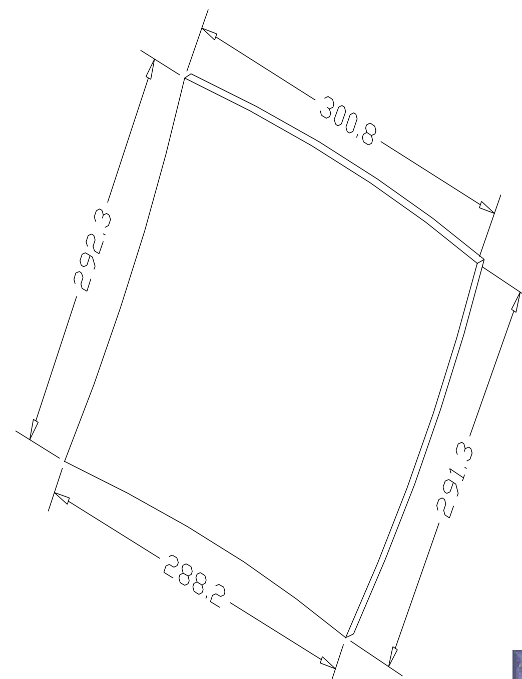
Design of the detector will be ready by November 2005. In October 2005 request for mirrors production will be prepared. Final drawings of the detector support and housing will be ready in January 2006. Production will take 3 months and will be finished by May 2006. Detector with mirrors and gas system will be assembled in May-June 2006.

Cherenkov detector (C_4F_{10}) - II









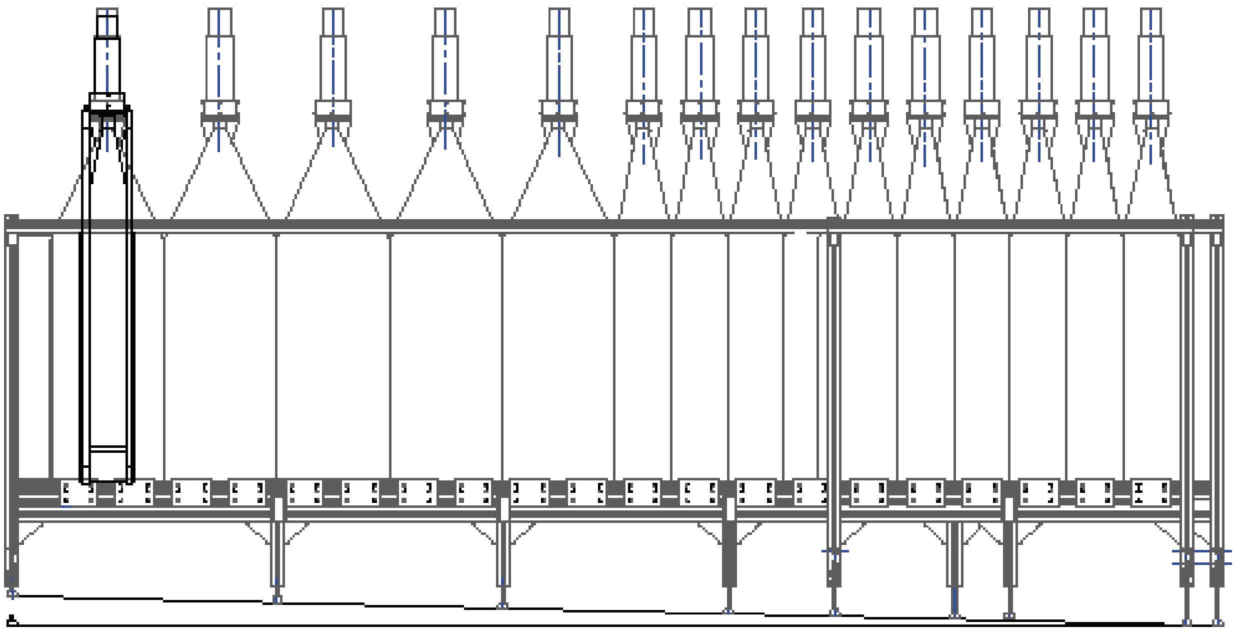
CERN 2005 SPS and PS Experiments Committee

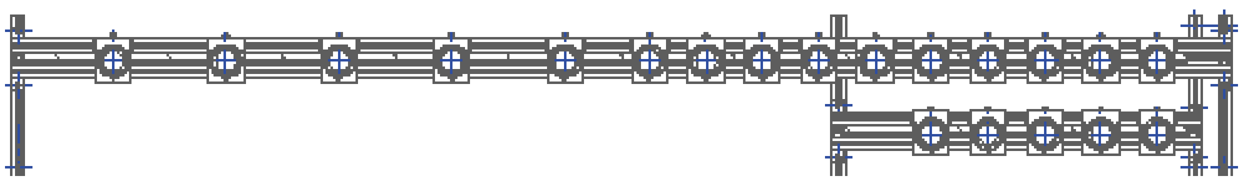
L. Nemenov

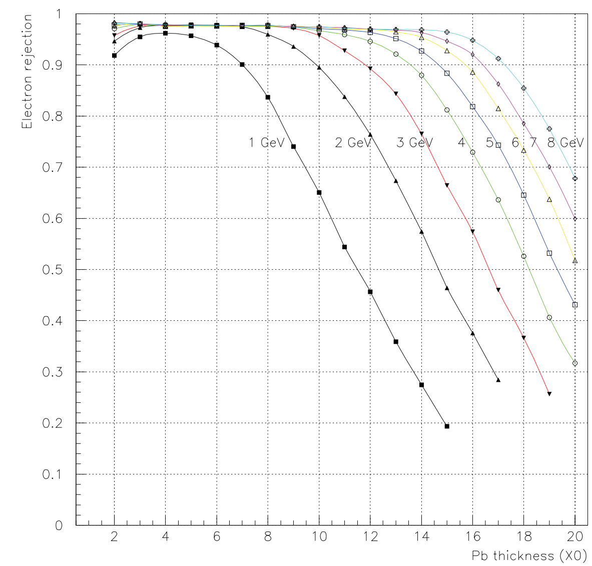
27 September 2005

Preshower detector

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





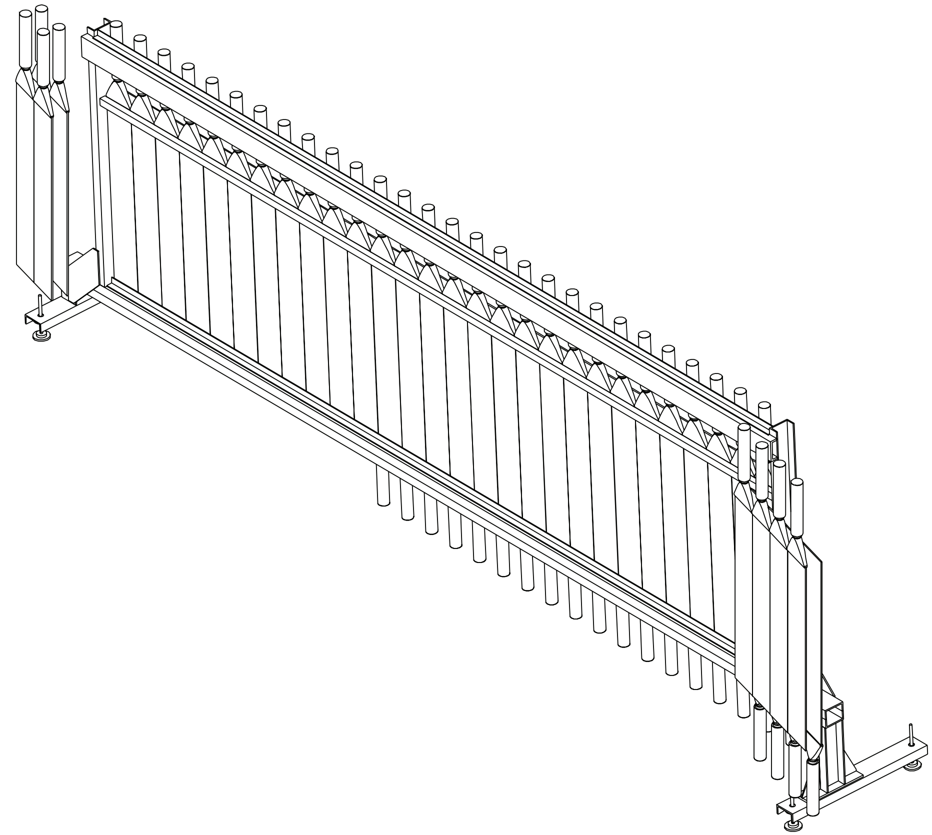


Time Schedule:

New preshower will be installed in October-November 2005.

Muon detector

Responsibility: IHEP (*Protvino*, Russia)



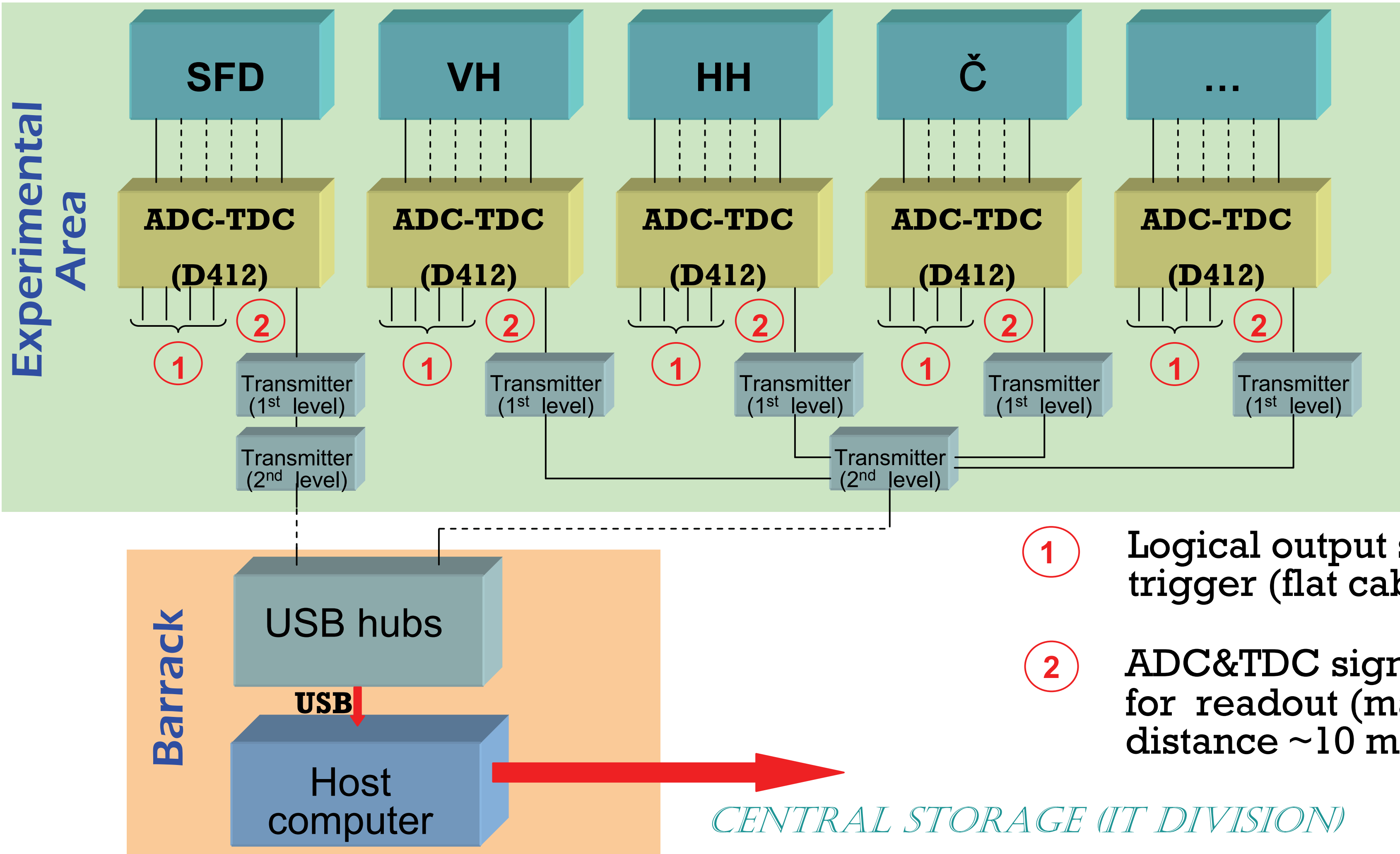
24 slabs (12 slabs per arm) will be added to the existing muon scintillation hodoscopes in order to increase its acceptance.

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 2006 or in 2007.

Readout System (I)

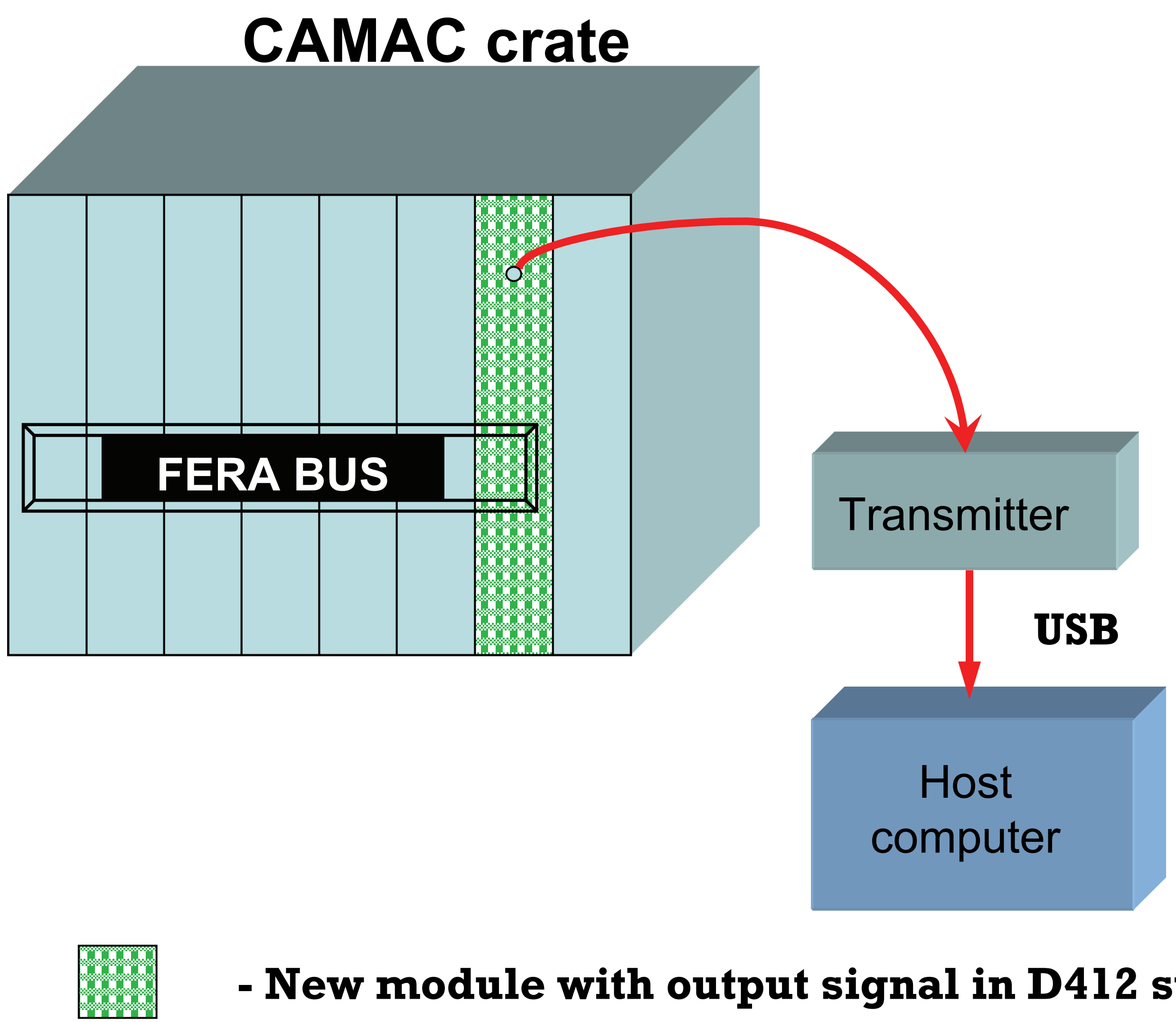
Responsibility: JINR (*Dubna*, Russia); Basel University (*Basel,* Switzerland); Santiago de Compostela University (*Santiago de Compostela,* Spain); Zurich University (*Zurich,* Switzerland)



1 Logical output signals for trigger (flat cables)

2 ADC&TDC signals for readout (maximal distance ~10 m)

Readout system (II)



Time Schedule:

In 2006 new electronics will be used with SciFi detector. This electronics will use a high-speed USB bus for data transfer.

In 2004 a prototype D412 (ADC+TDC) was successfully tested with 32 channels of SFD.

The level translator to LVDS and pulse width shaper modules have been developed. Transmitter prototype is scheduled to be ready before March 2006. For production of full set of transmitters it's needed one month.

Trigger

Responsibility: JINR (*Dubna*, Russia)

The List of Triggers:

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

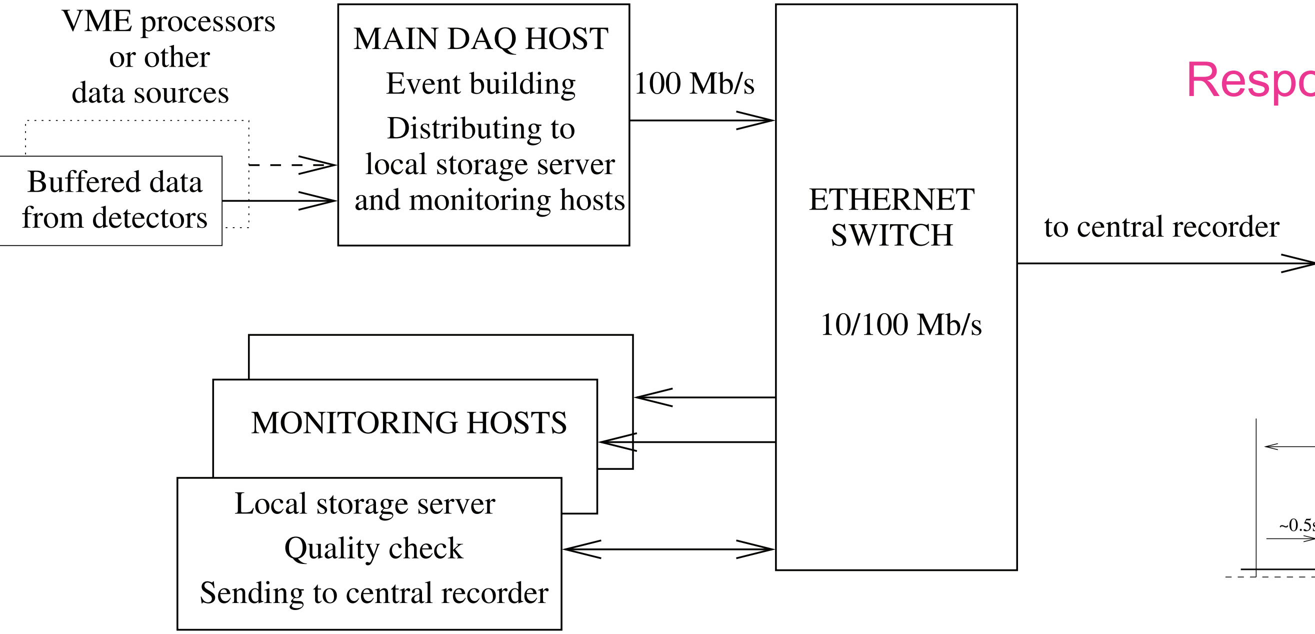
What we need:

1. For $A_{\pi K}$ and $A_{K\pi}$ two more track analysers (cost estimation 3700 CHF for unit).
2. New T1 will be without meantimers, so it's necessary to organize coincidence for photomultipliers of one slab for VH and HH.
3. Trigger for identical particles (track analyser modification).

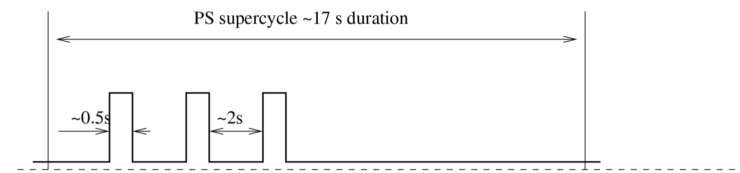
Time Schedule:
The trigger system with the above features will be ready when beam starts and tuned in the initial part of the DIRAC 2006 run.

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

Data Acquisition System



Responsibility: JINR (*Dubna*, Russia)



Time Schedule:

Revising of DAQ software for finding and eliminating possible limitations.
This work will be finished during year 2005.

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

Upgrading and tuning hardware and operating systems for computers which are critical for data acquisition system spring-summer of year 2006.

Writing software for handling new electronic modules April-May of 2006.

DIRAC Setup Modifications (Cost estimation)

✓ New Vacuum Channel and Shielding	20 kCHF	(JINR)
✓ Micro Drift Chambers	18 kCHF	(JINR)
✓ New Scintillating Fiber Detector with Electronics	135 kCHF	(Japanese University, JINR, INFN-Trieste)
✓ Vertical Hodoscope (4 additional slabs)	16 kCHF	(Santiago de Compostela)
✓ Horizontal Hodoscope	12 kCHF	(Prague)
✓ Aerogel detectors	180 kCHF	(Zurich)
✓ Upgrade of the existing Cherenkov counter	10 kCHF	(Common Fund)
✓ Heavy Gas Cherenkov Counter	80 kCHF	(Bucharest, Common Fund)
✓ Preshower detector	20 kCHF	(Bucharest)
✓ Muon detector	12 kCHF	(Protvino)
✓ Trigger and Readout system	120 kCHF	(Common Fund, Santiago de Compostela)
✓ Data Acquisition System (new hardware)	20 kCHF	(Common Fund)
Overall cost of the setup upgrading:	**643 kCHF**	