THE FAST PHOTON DETECTION SYSTEM OF COMPASS RICH-1

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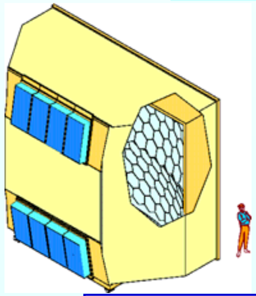
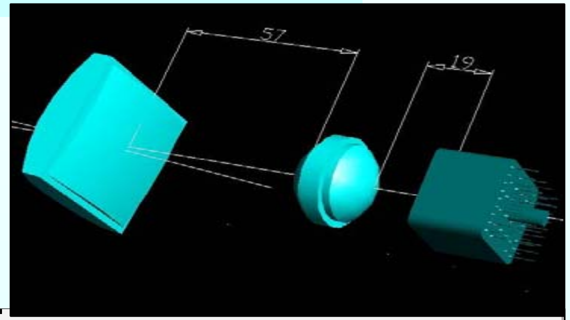


Fulvio Tessarotto

on behalf of the *COMPASS RICH Upgrade Group*

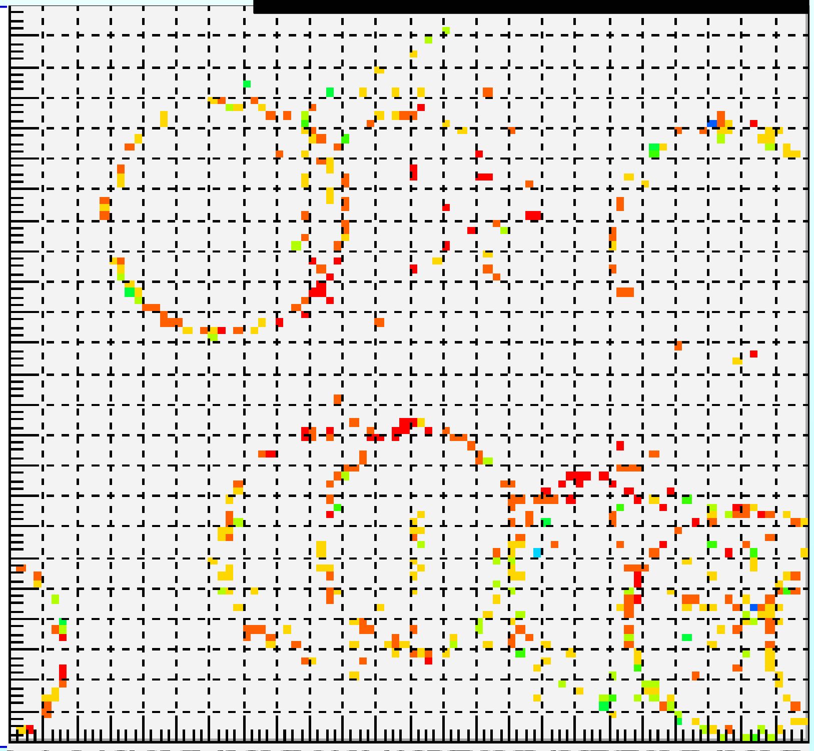


COMPASS RICH-1

The motivations for the upgrade

The project and the construction

The preliminary performances during 2006 run



THE COMPASS SPECTROMETER

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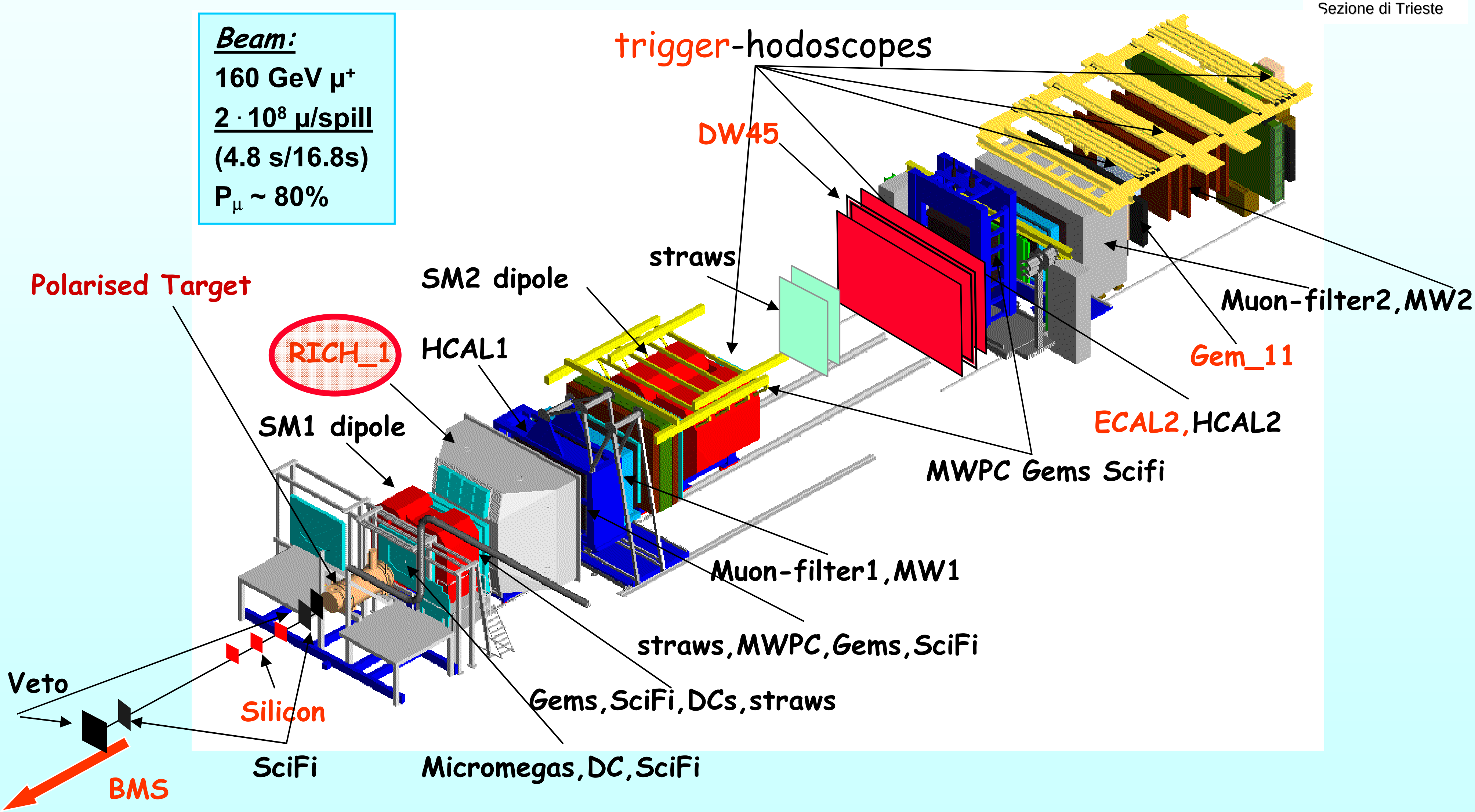
Beam:
160 GeV μ^+
$2 \cdot 10^8$ μ/spill
(4.8 s/16.8s)
$P_\mu \sim 80\%$



COMPASS RICH-1

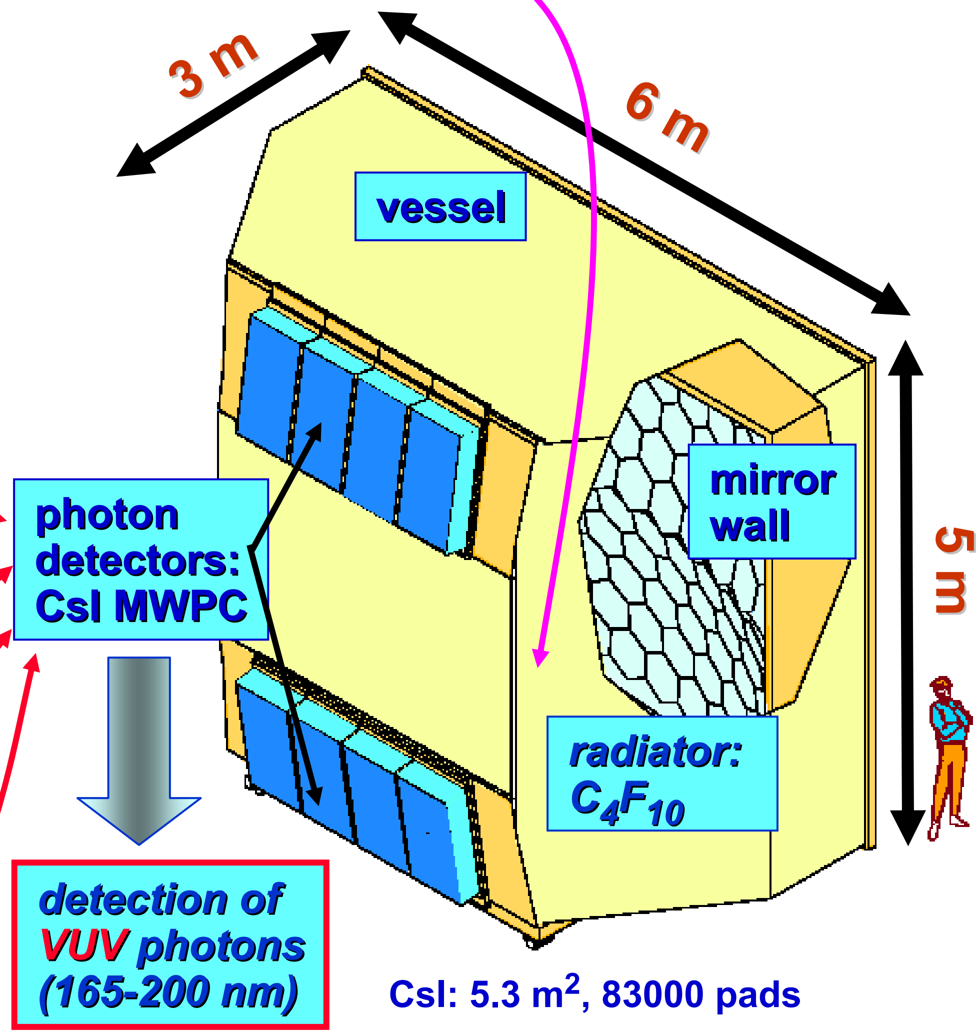
Trieste: INFN, Univ. & ICTP,
Turin: INFN and University,
Bielefeld University,
CERN technical support

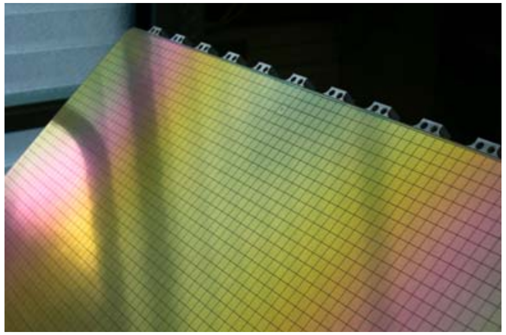
requirements:

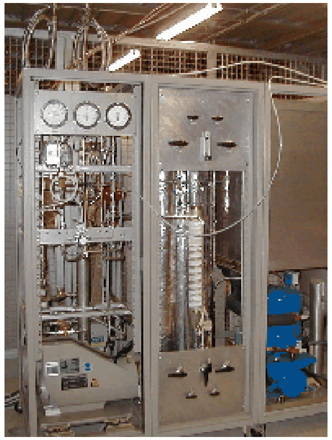
- hadron PID up to ~45 GeV/c
- LARGE acceptance (large size):
  H: 500 mrad
  V: 400 mrad
- able to stand trigger rates up to 20 KHz
- beam rates up to $4 \cdot 10^7$ Hz
- minimize material in the acceptance

detector designed in 1996

- PROJECT COST : ~ 3 M €





COMPASS RICH-1 performances

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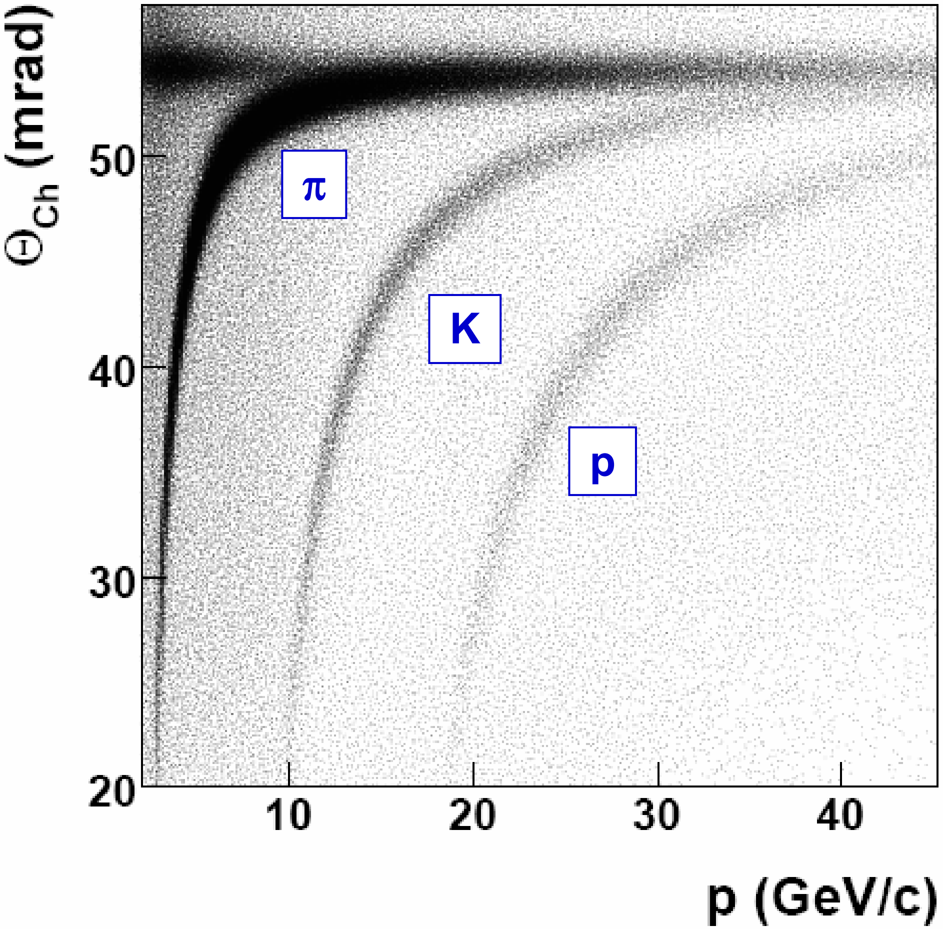

RICH-1 is in operation at COMPASS since 2001

- *photons / ring ($\beta \approx 1$, complete ring in acceptance) : **14***
- $\sigma_{\theta\text{-ph}}$ ($\beta \approx 1$) : ***1.2 mrad***
- σ_{ring} ($\beta \approx 1$) : ***0.6 mrad***
- *2σ π-K separation @ **43 GeV/c***
- *PID efficiency **> 95%*** (θ_{Ch} > 30 mrad) *except for the very forward region*

- E. Albrecht et al, NIM A 33 (2003) 127
- E. Albrecht et al, NIM A 553 (2005) 215

RICH-1: experimental challenges

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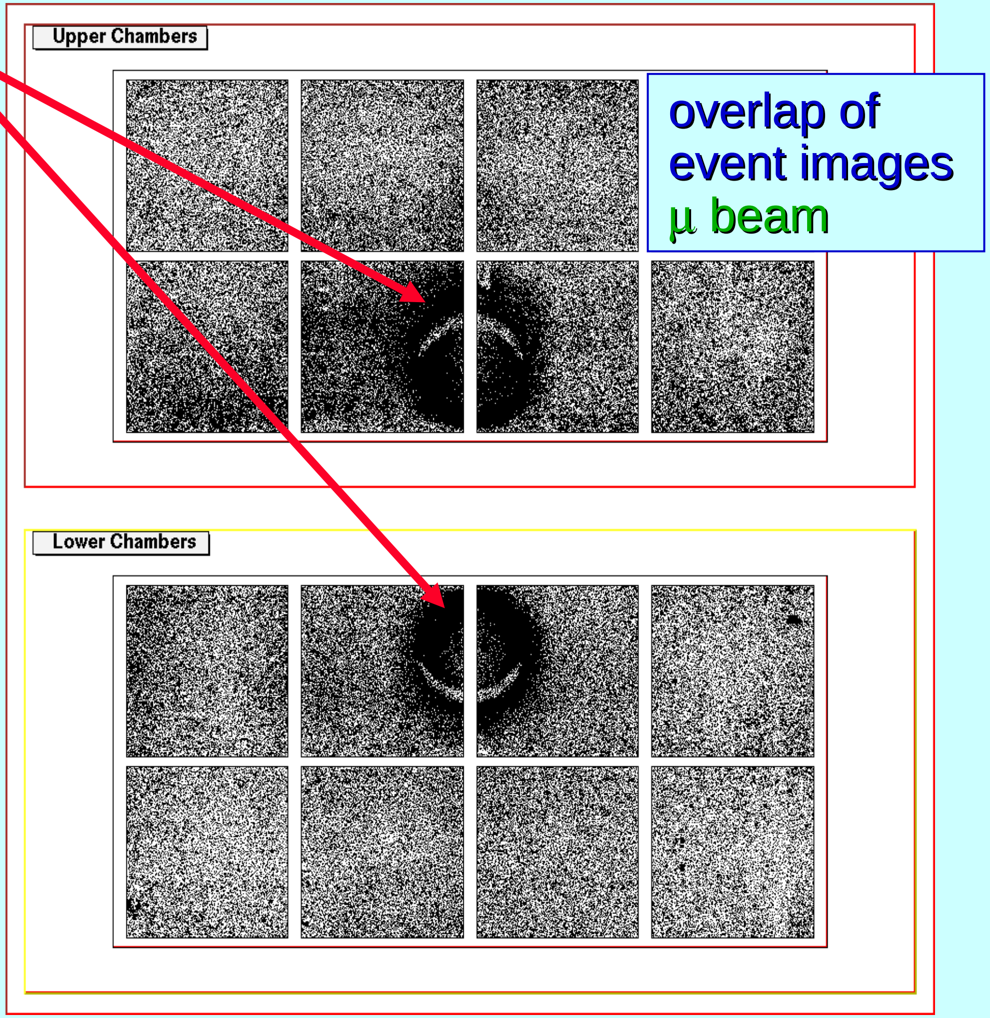
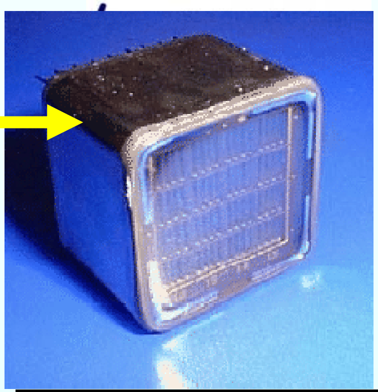
- **THE EXPERIMENTAL ENVIRONMENT**
  - **huge uncorrelated background related to the memory of the MWPCs + read-out**
- **THE HIGH RATE OPERATION**
  - **Increased beam intensity:**
    - **ultimate goal 100 MHz**
    - **presently: 40 MHz**
  - **Increased trigger rates**
    - **up to 100 KHz**
    - **presently: 20kHz**
  - **No dead time (Luminosity)**



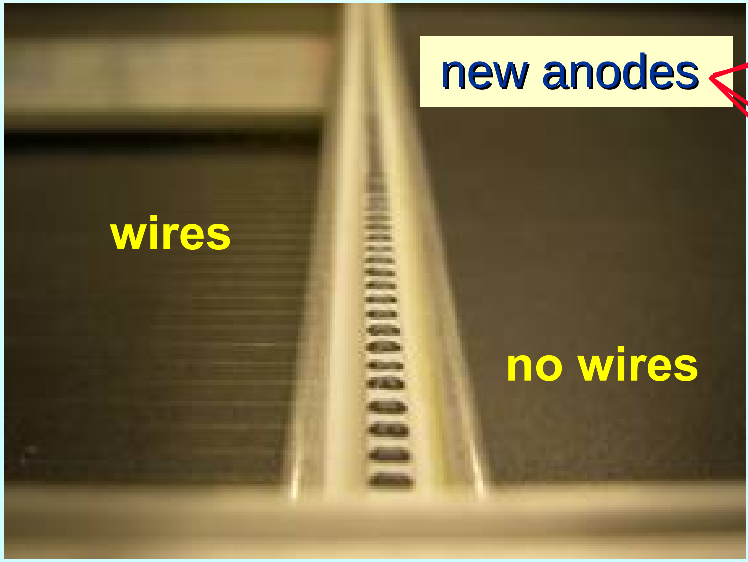
RICH-1: the upgrade using MAPMTs

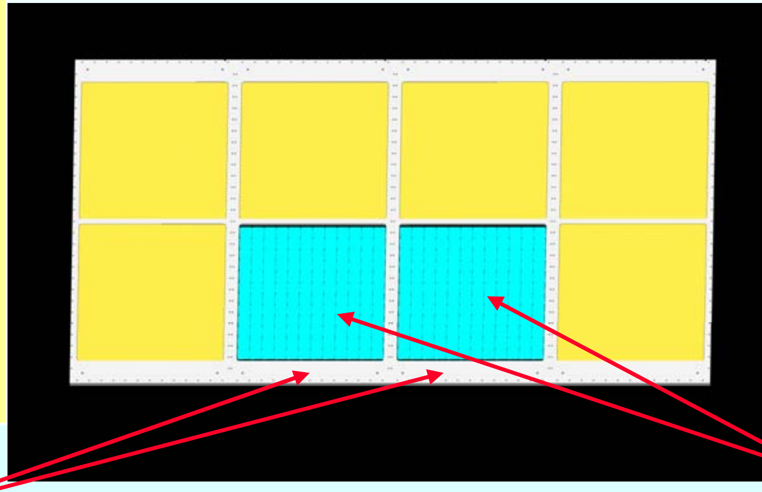


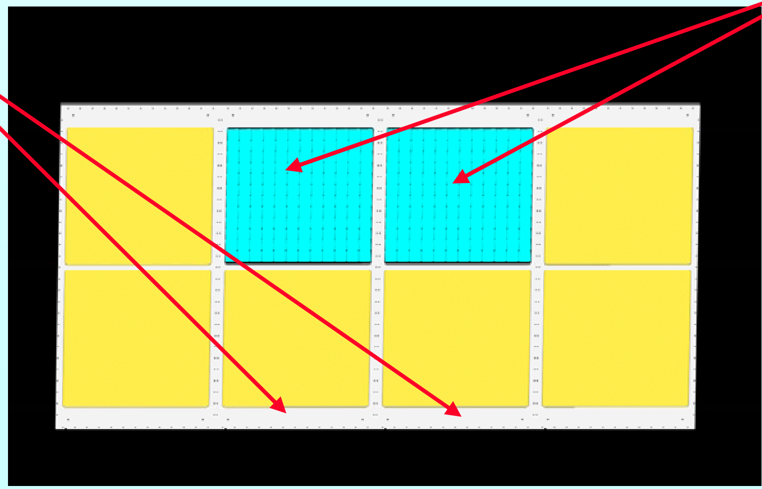
12 outer CsI cathodes: change electronics, use APV25-S1 chip

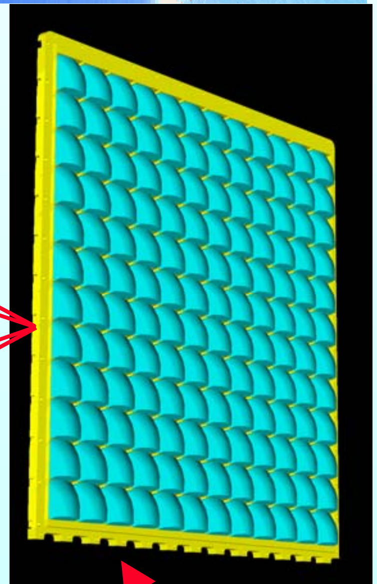
4 central CsI cathodes: remove and insert frames with MAPMTs and lense telescopes

keep mechanical compatibility, build (and test) 4 new anodes with "half-wires"









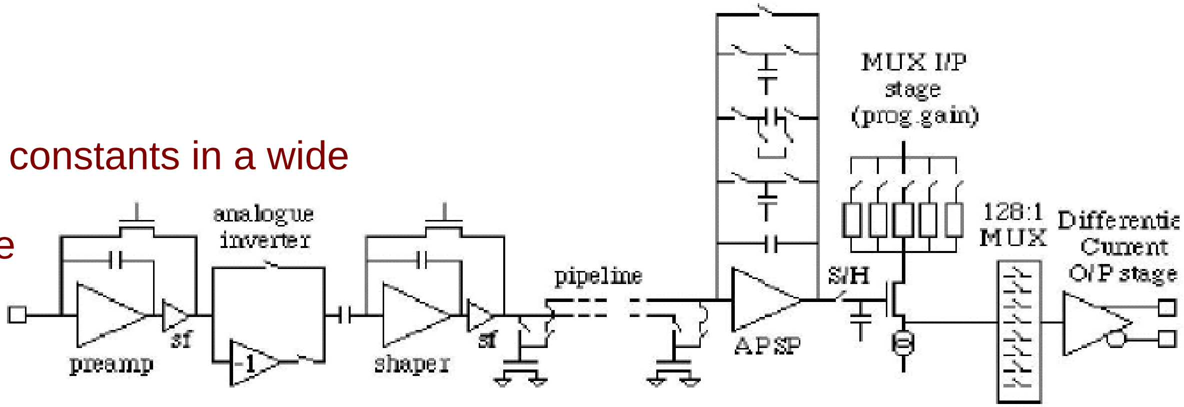
Same mechanics as CsI photo-cathode frame

Outer region: the APV25-S1 r/o electronics

APV25S1 developed for CMS u-strip silicon detectors

Main characteristics of the APV25-S1:

- 128 channels / chip
- pre-amplifier and shaper with adjustable time constants in a wide range 50-300 ns
- 40 MHz sampling on 192 cells analog pipeline

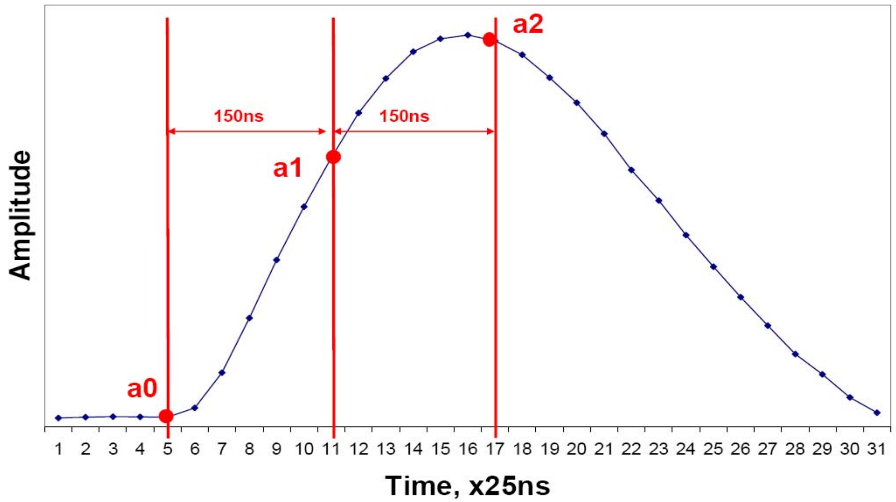


peaking time: ~ 300 ns

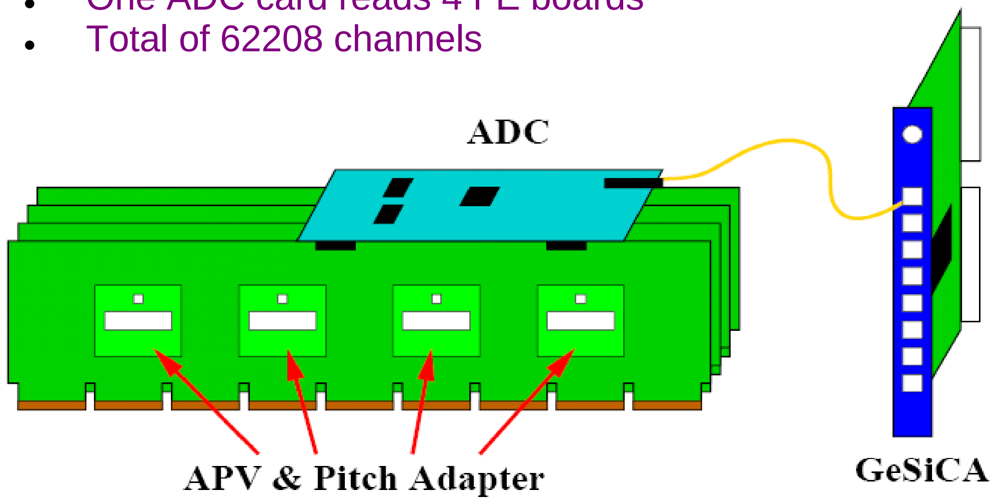
No dead time up to 80 kHz trigger rate

3 samples read for each hit to get signal timing

Signal time : T = a1/a2 * 156.25 - TCS_phase



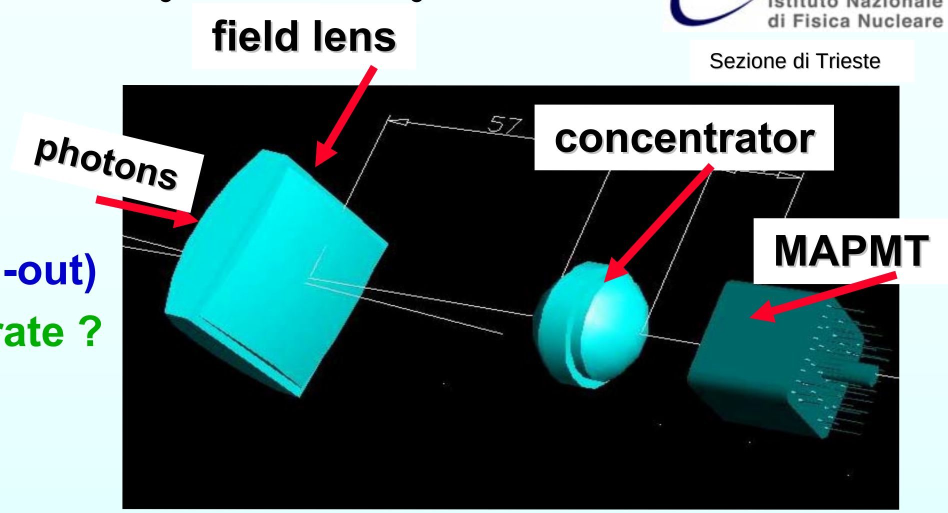
- Each APV chip is glued and bonded onto a small PCB (module)
- Each front-end board read 432 channels (4 APV modules)
- One ADC card reads 4 FE boards
- Total of 62208 channels

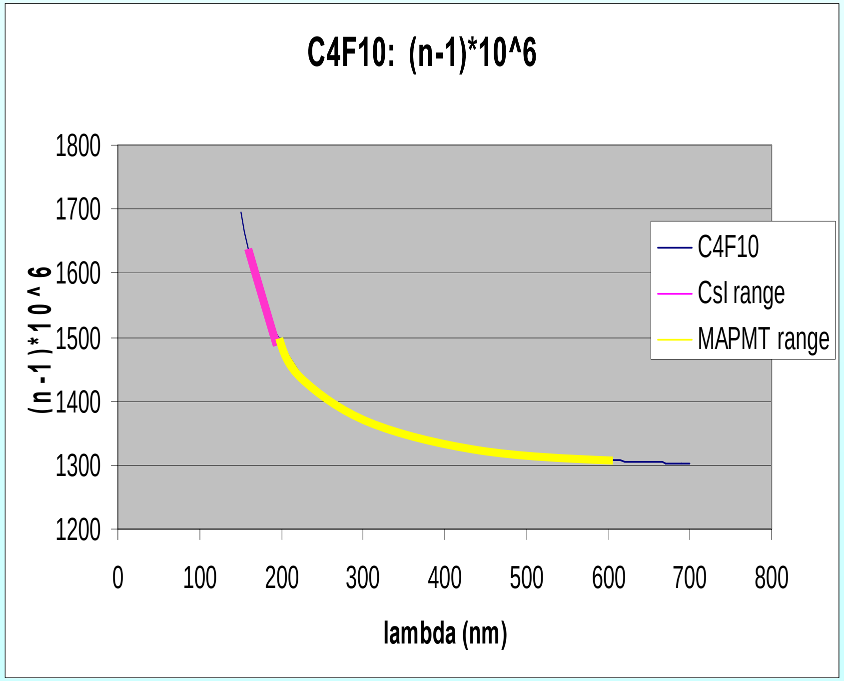


Central region: the principle

Photon detectors : MAPMT

- wide wavelength range
- time resolution < 1 nsec
- short detection system memory (MAPMT + read-out)
- adequate for high rate operation – up to which rate ?
- robust
- efficiency for single photon detection ?





challenges:

<u>large ratio</u> of the collection and photocathode areas with minimal image distortion

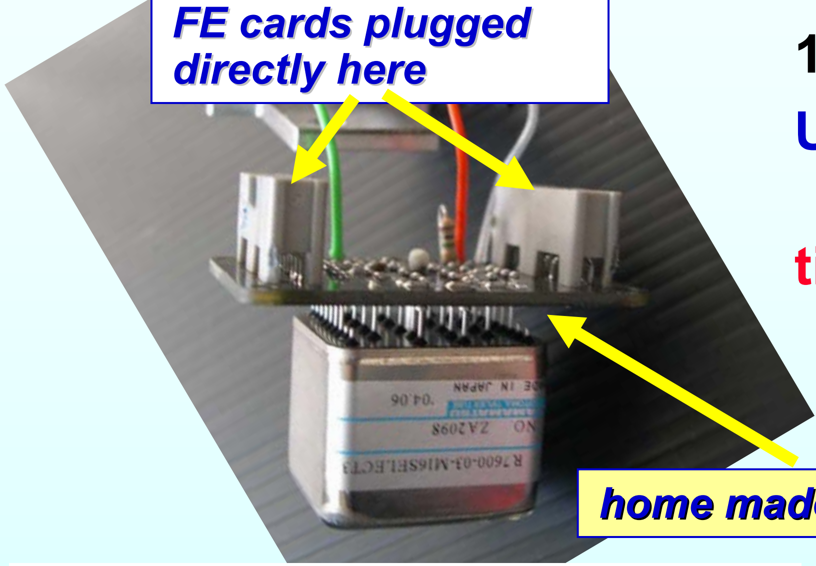
→ ratio = <u>7.3</u> ←→ critical LENS SYSTEM design

<u>UV range</u> ←→ fused silica LENSES

couple to a <u>read-out system</u> able to guarantee efficiency, high rate operation and to preserve time resolution

MAPMT: HAMAMATSU R7600-03-M16

FE cards plugged directly here



home made voltage divider

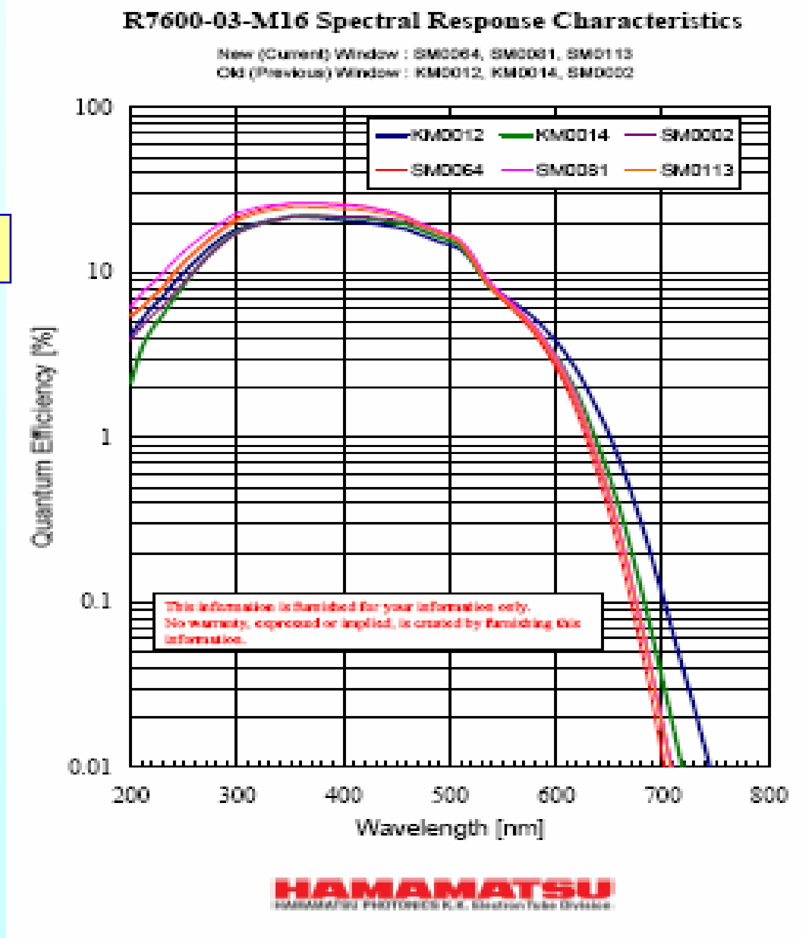
16 anodes

UV extended glass

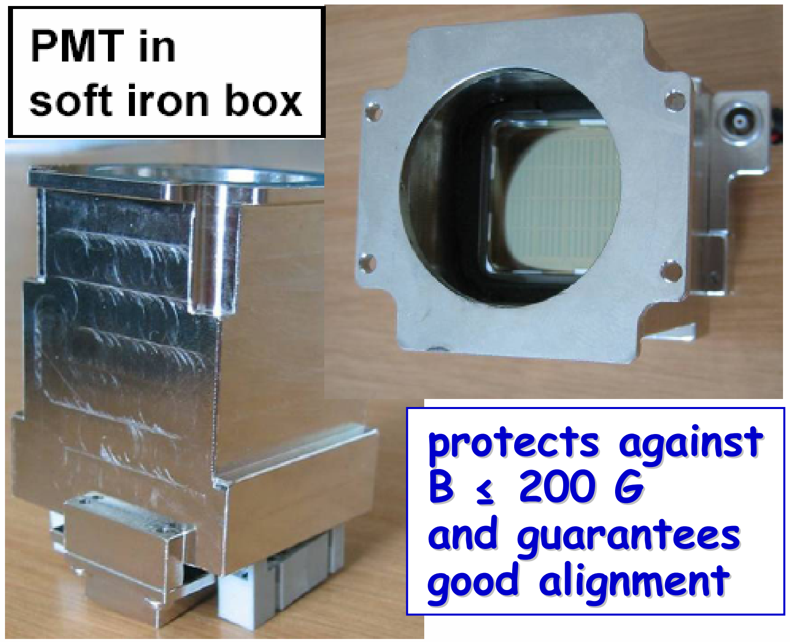
time resolution ~ 0.3 nsec

recall:
effective QE including window losses

(collection efficiency not included)



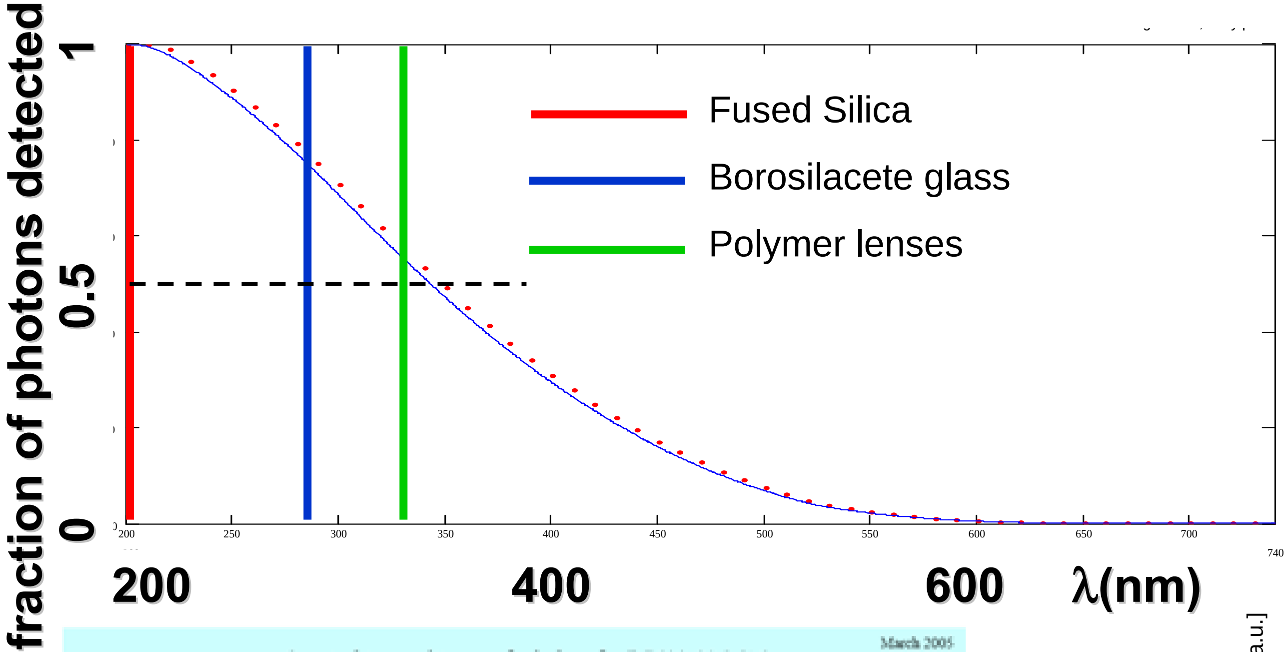
PMT in soft iron box

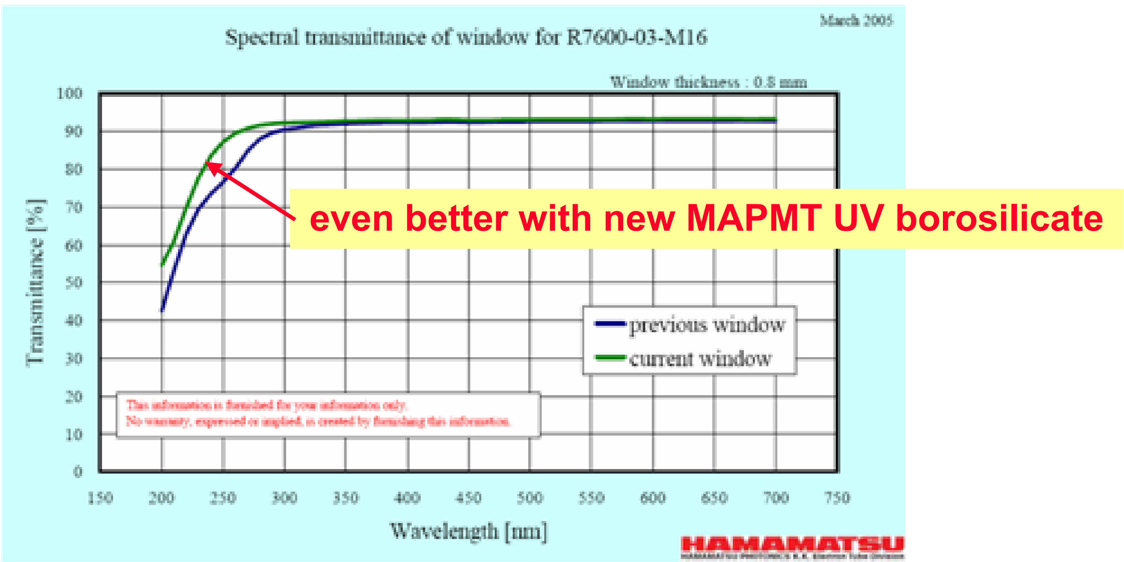


protects against B ≤ 200 G and guarantees good alignment

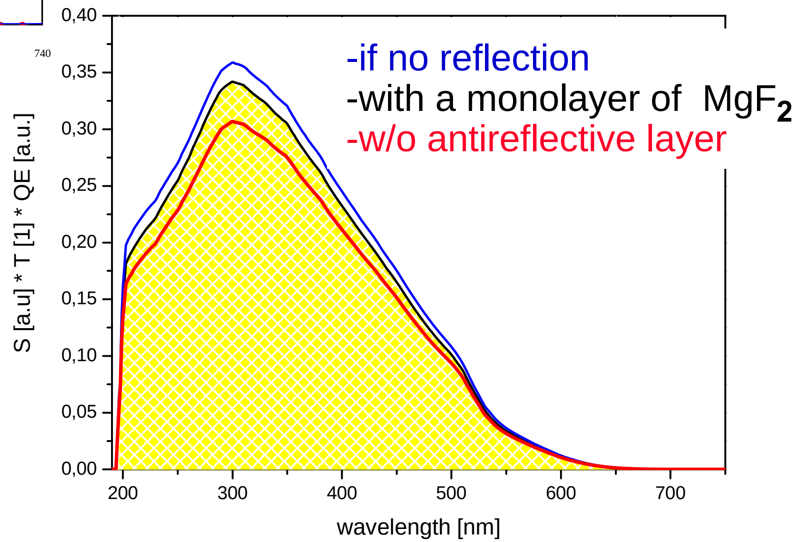
$$\int_{\lambda}^{800} QE\ (\lambda)\cdot S(\lambda)\cdot d\lambda \Big/ \int_{200}^{800} QE\ (\lambda)\cdot S(\lambda)d\lambda$$

UV EXTENTED IS BETTER





and even better with antireflective coating: 8.4% more photons



Convolution of Cherenkov light and effective QE

THE FUSED SILICA LENS TELESCOPE

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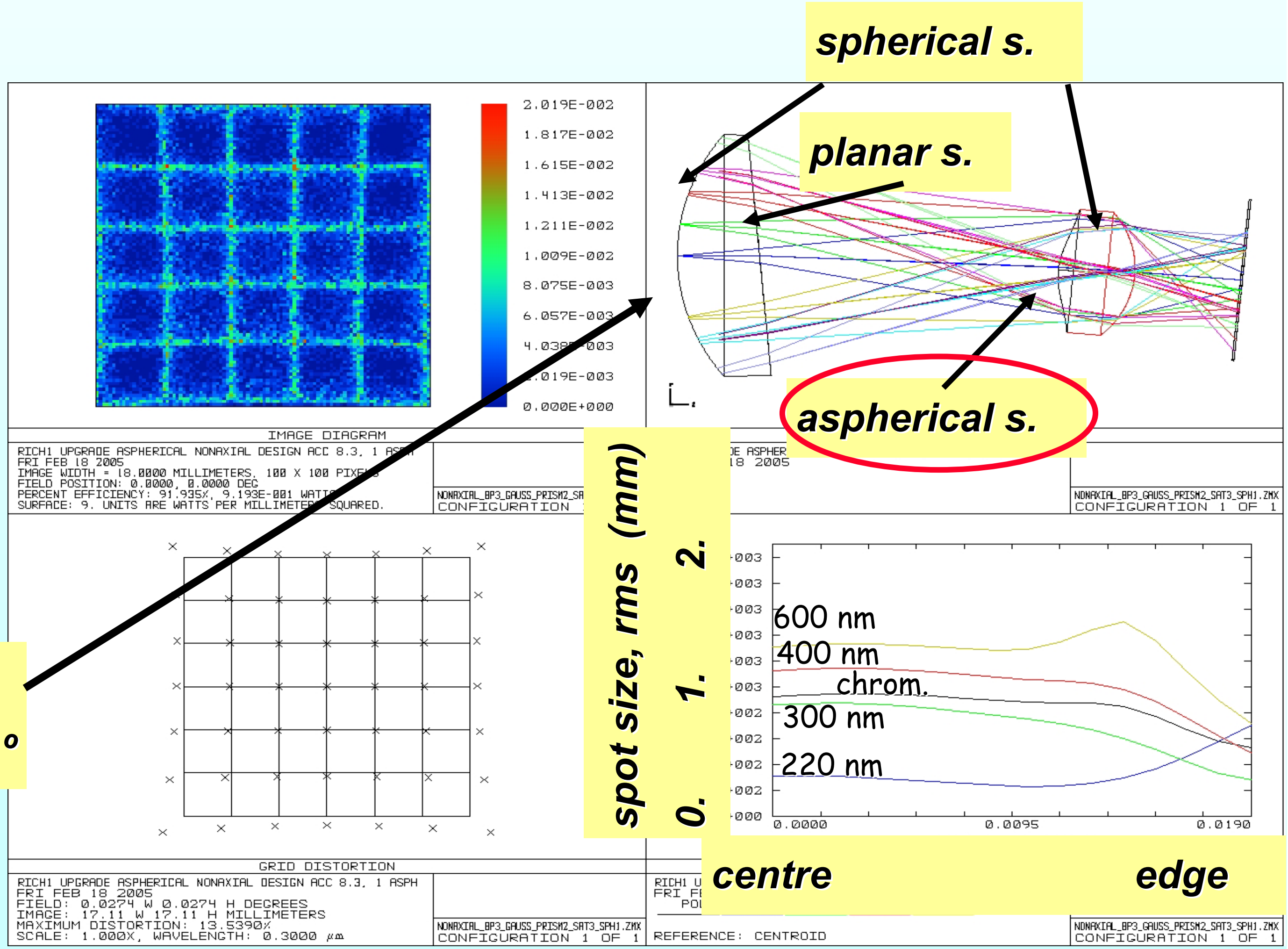
OPTIMISATION CRITERIA

- limited image distortions
  → RICH resolution
  (chromaticity is taken into account)
- angular acceptance of the telescope
- mechanical constrains
- manifacturing parameters (feasibility, cost!!!)

AXIS TILT: 5 º

ANGULAR ACCEPTANCE: ± 9.5 º



FUSED SILICA LENSES

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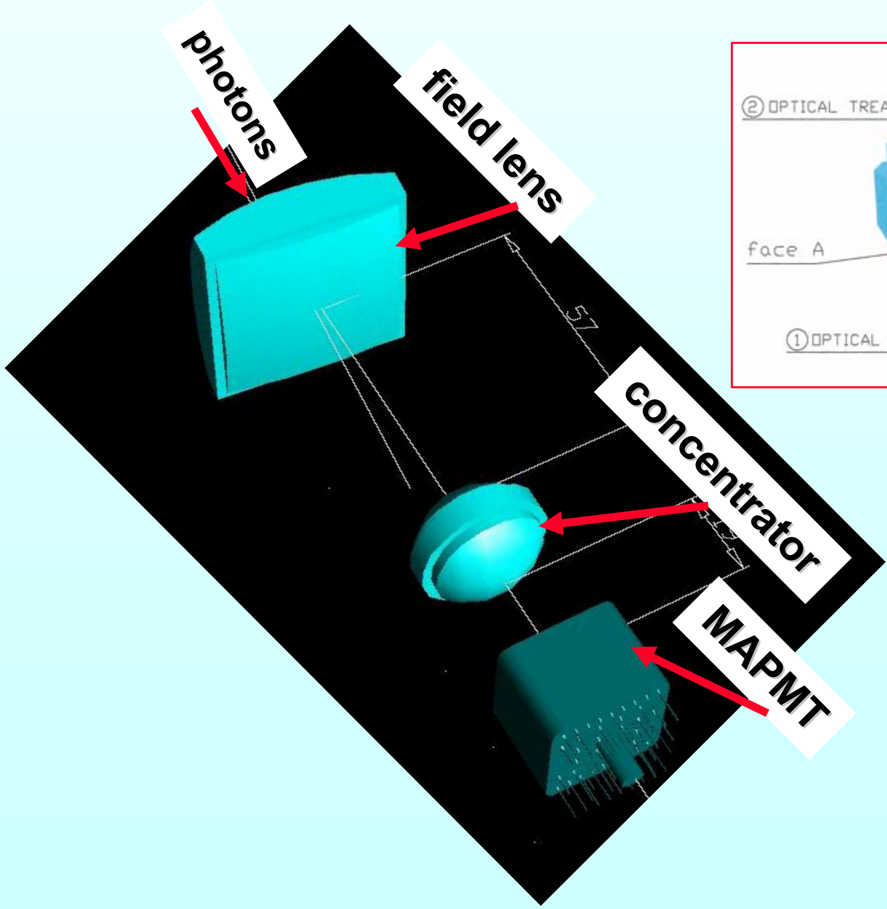
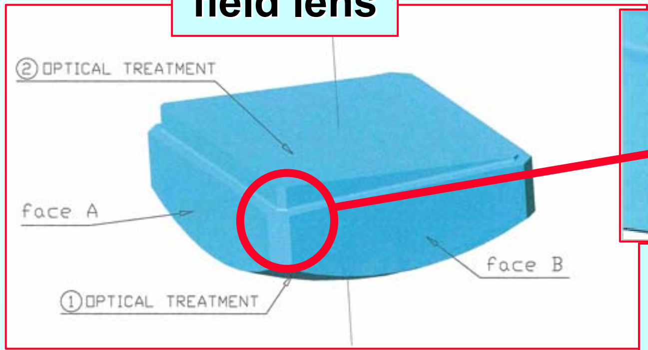
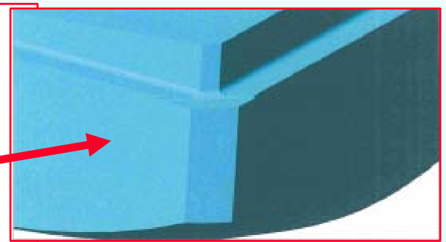
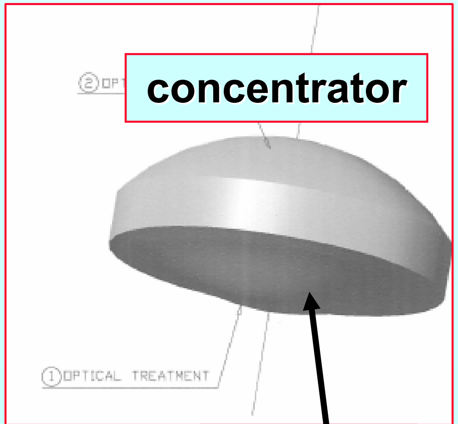
material: fused silica, Corning 7980, standard grade F5







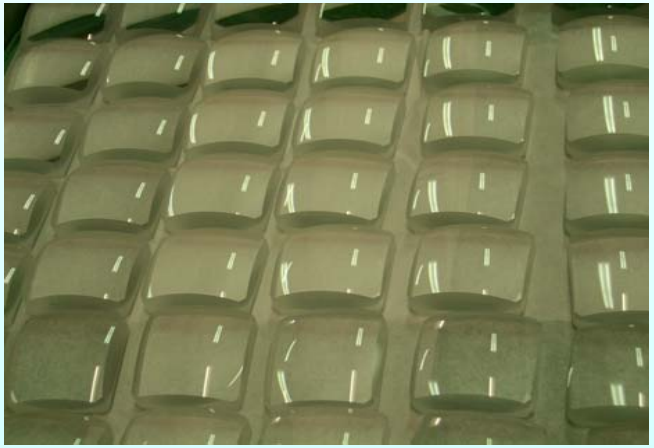
complex and delicate mechanical machining

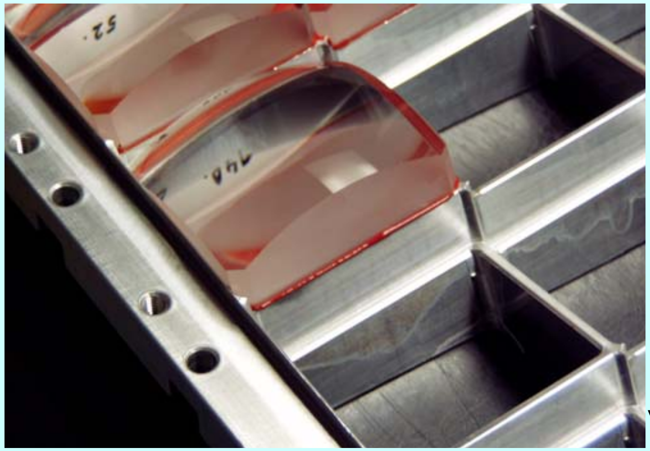


aspheric surface

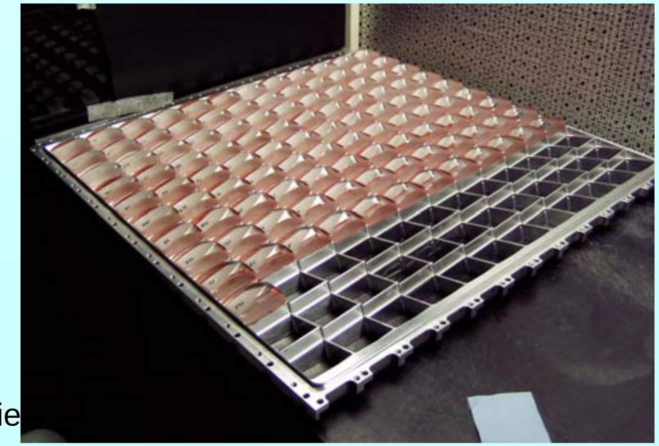
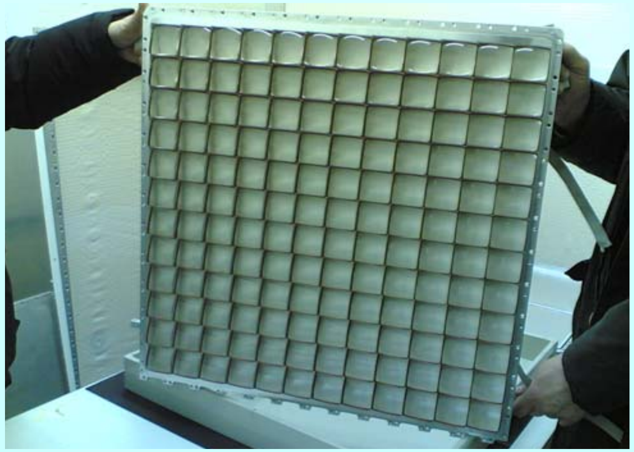








Vie

OPTICS QUALITY CONTROL
THE HARTMANN METHOD

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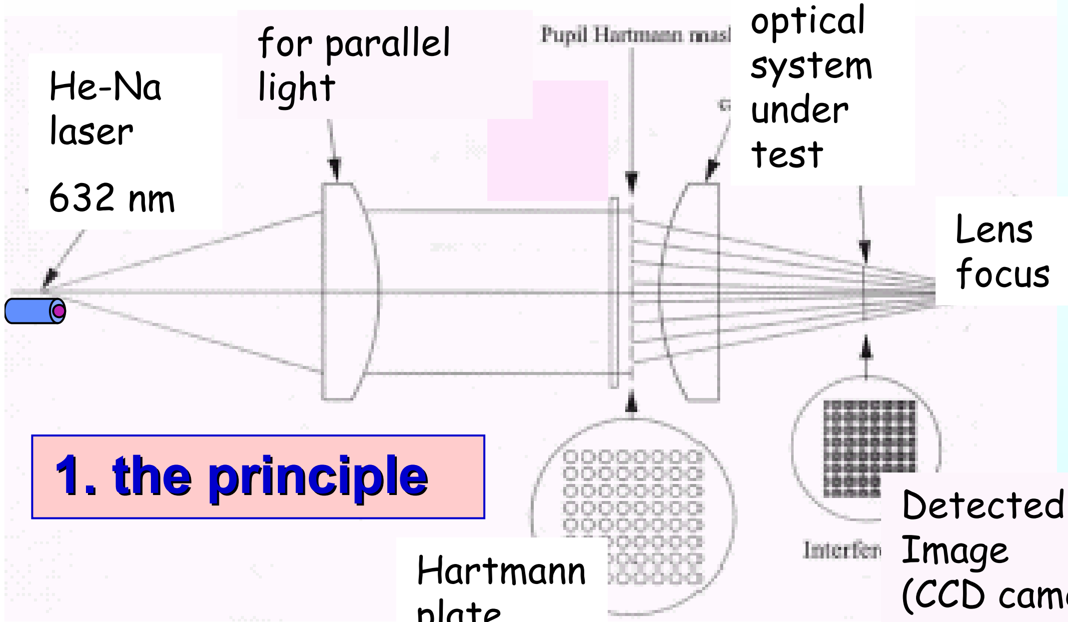
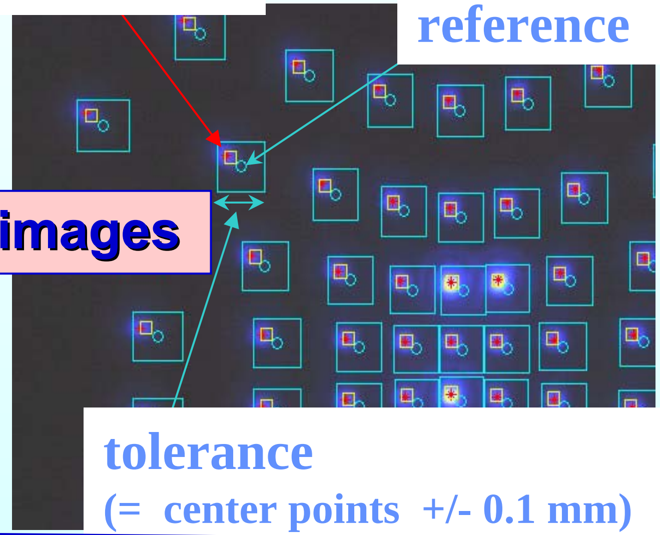
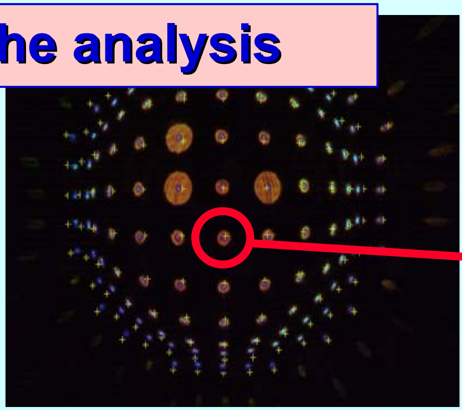
1. the principle

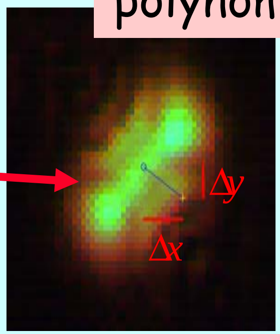


2. the images

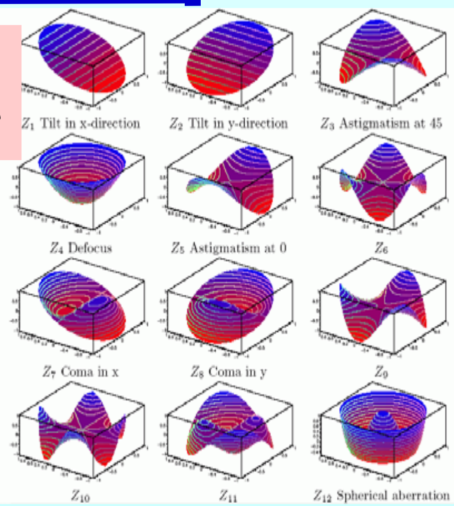


3. the analysis

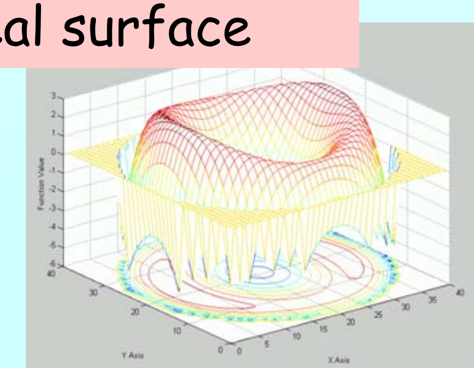




Zernike polynomials



Deviations from ideal surface



OPTICS, THE ACHIEVEMENTS

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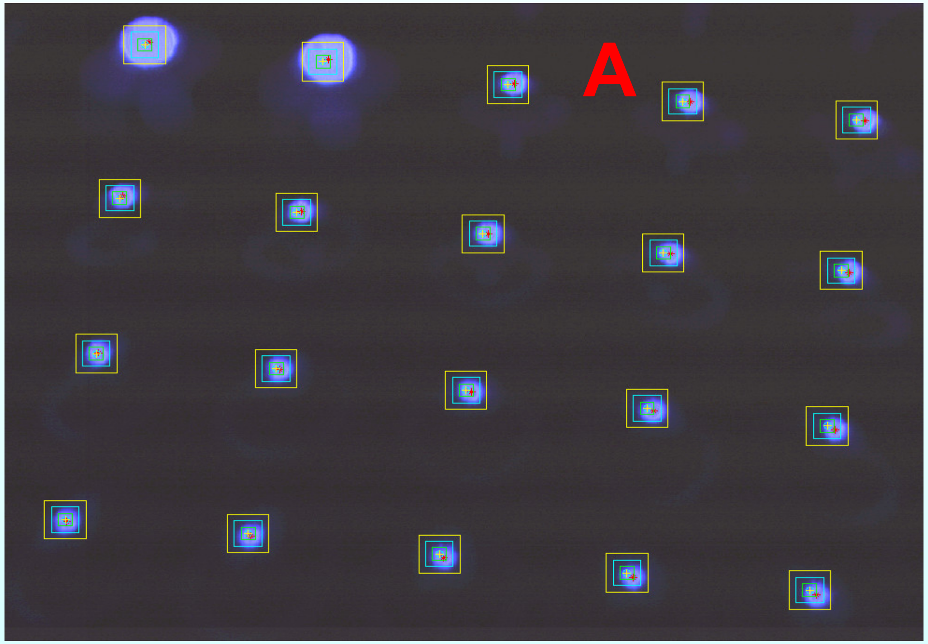

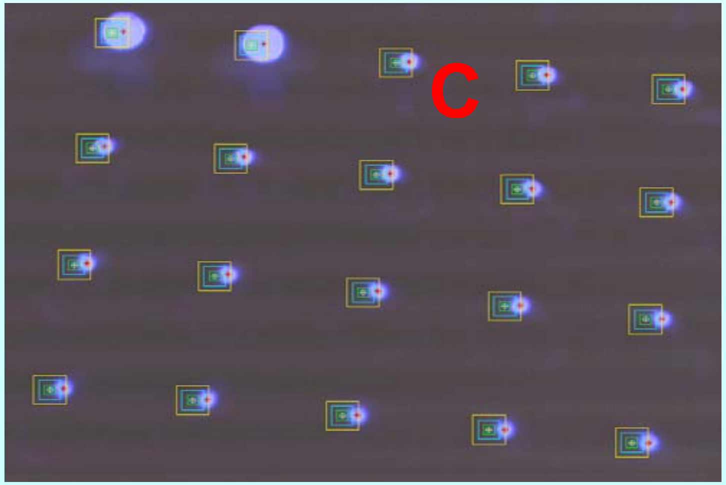

576 TELESCOPES:

A) ~70% within 50 μm tolerance
B) ~20% within 100 μm tolerance
C) ~10% within 150 μm tolerances

MAPMT Quality Control

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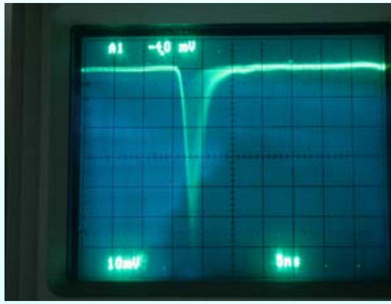
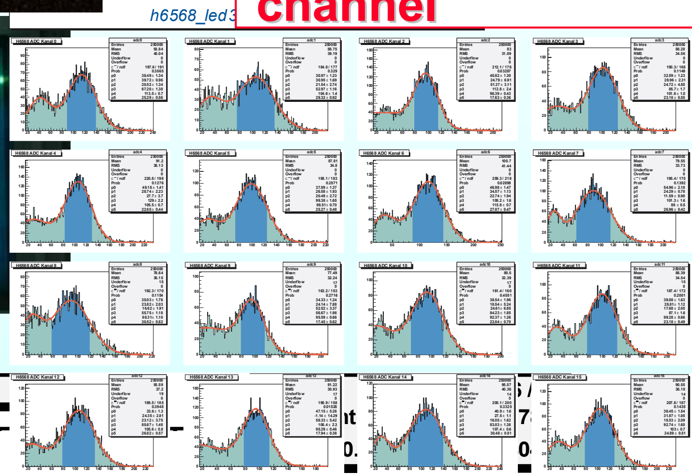
- 620 MAPMTs
- less than 10 MAPMT not fully satisfactory (mainly: too high dark current – we require:

  I_{dark} < 2 nA/ch after ½ h in dark environment)

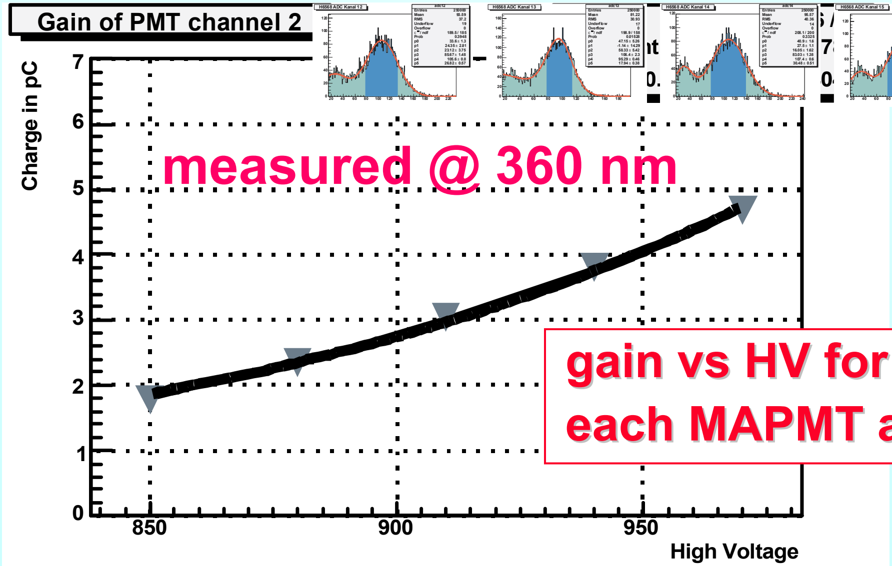


Individual ADC spectra for each channel



PROTOCOL – 2 h / MAPMT

- Visual Inspection (Pixel grid o.k.)
- Noise rates and dark current
- Scope Image stored
- Signal shape, uniformity, gain
  - measuring ADC distribution @ several Voltages
- Quantum efficiency
  - measurement with blue LED and UV LED



measured @ 360 nm

gain vs HV for each each MAPMT anode

MAPMT GAIN AT HIGH RATE

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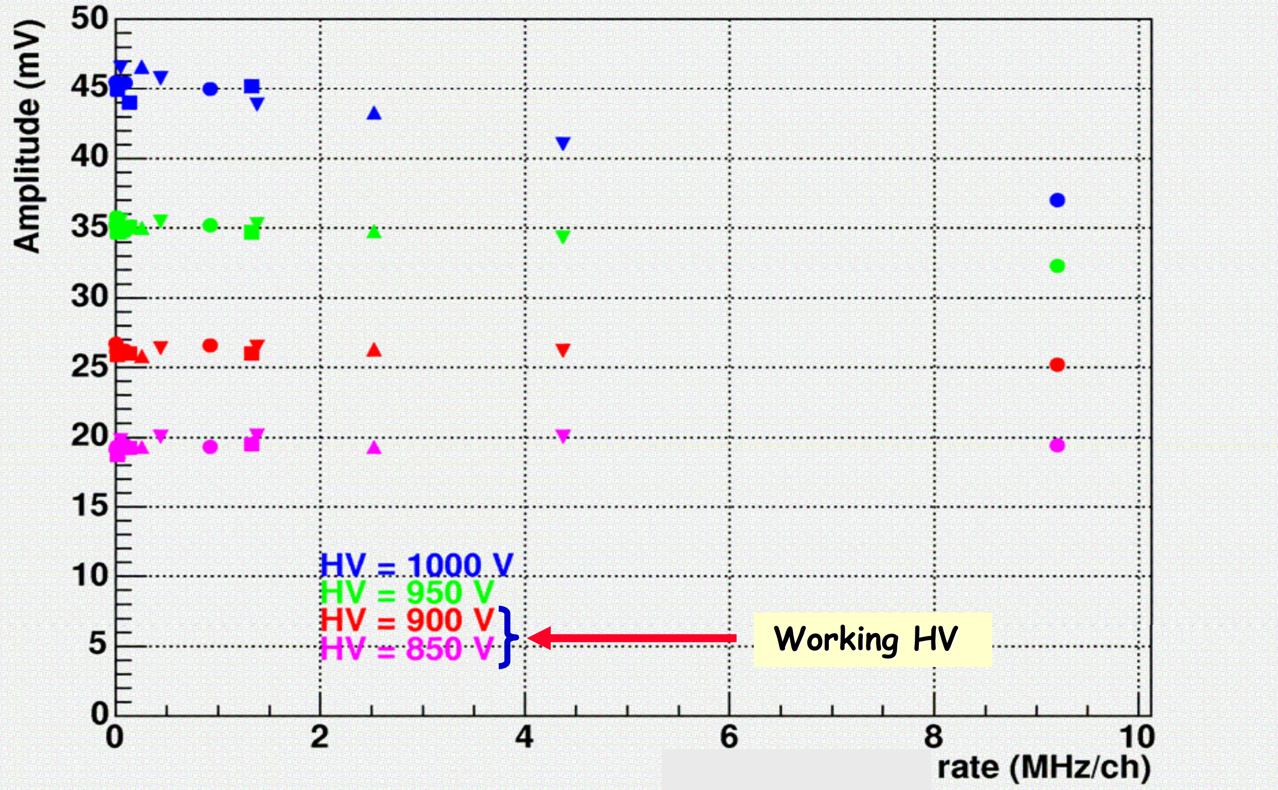
mean signal amplitude versus rate/pixel

pulsed light source synchronus to trigger + random background from lamp

measured for single photoelectron

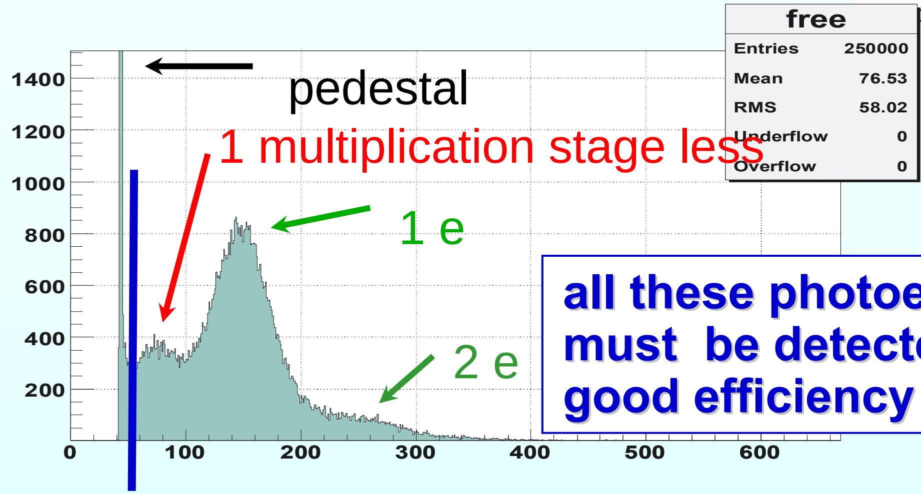


Goal
(for the future needs of COMPASS):
<u>operate up to 5MHz/pixel single photoelectron rates</u>

<u>no rate limitation from MAPMT</u>

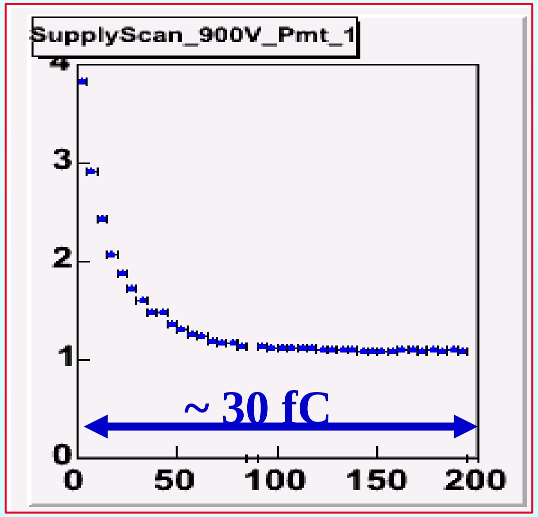
SINGLE PHOTOELECTRON DETECTION

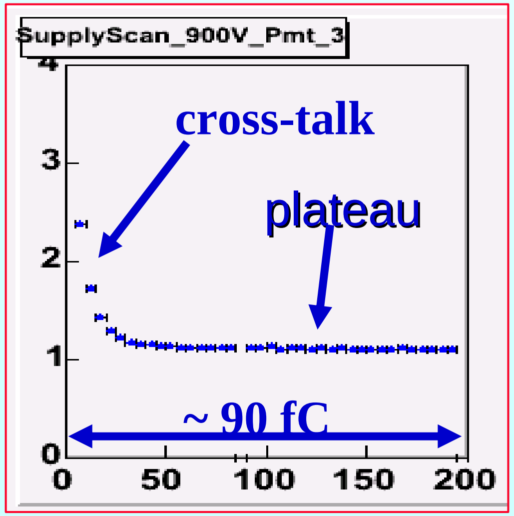
Single photoelectron : wide dynamic range

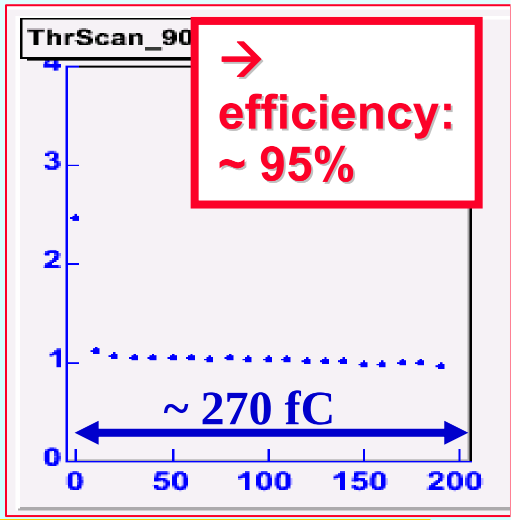


all these photoelectrons must be detected for good efficiency

Plots:
hits /event vs threshold setting





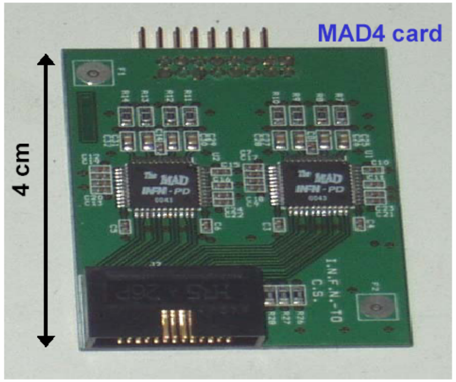


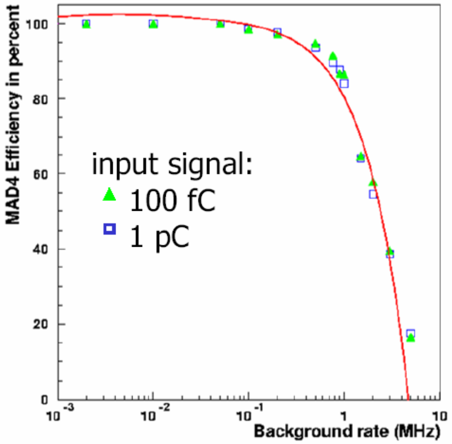
a flat region (no photon loss), good for safe threshold setting, is clearly identified between the cross-talk region and the region where detection loss starts (third plot)

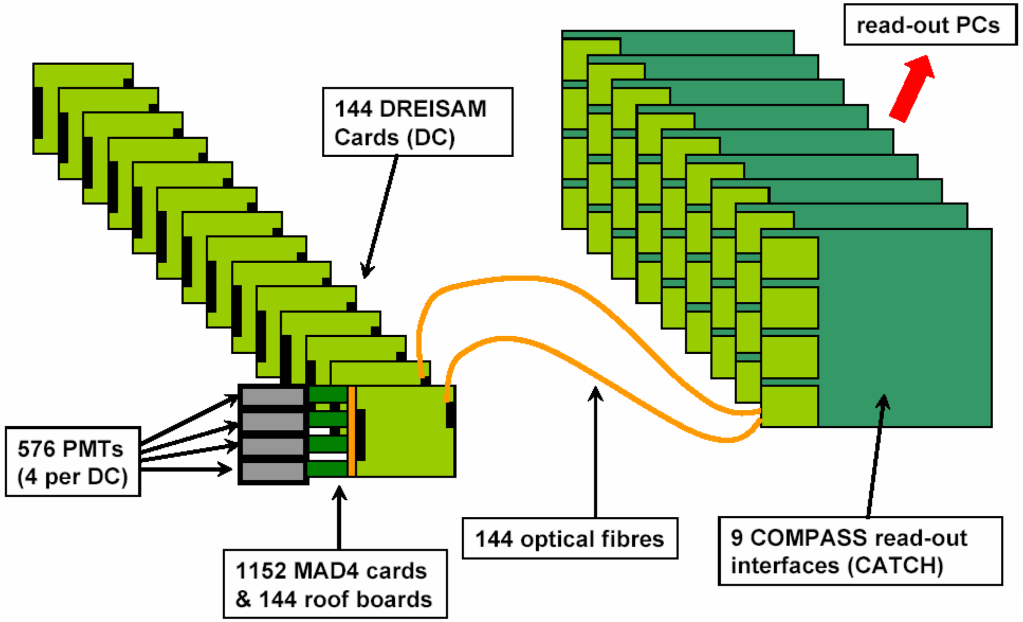
Analogue read-out electronics: MAD4 preamplifier

- up to ≈ 1 MHz / channel
- low noise ≈ 5-7 fC
- single photon PMT signal ≈ 1 pC (at 900 V)
- clear separation signal / noise

further development by INFN TORINO: CMAD in 2007 up to 5 MHz / channel



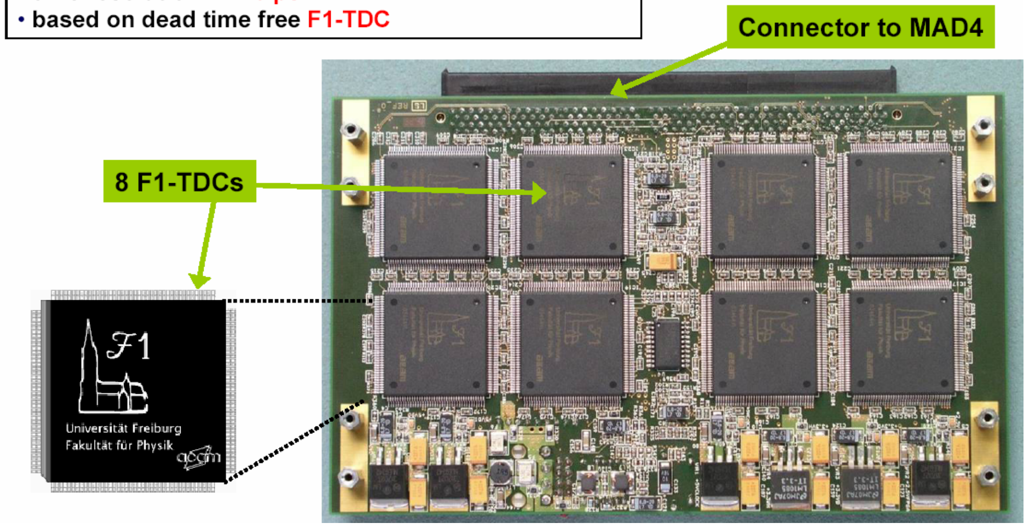


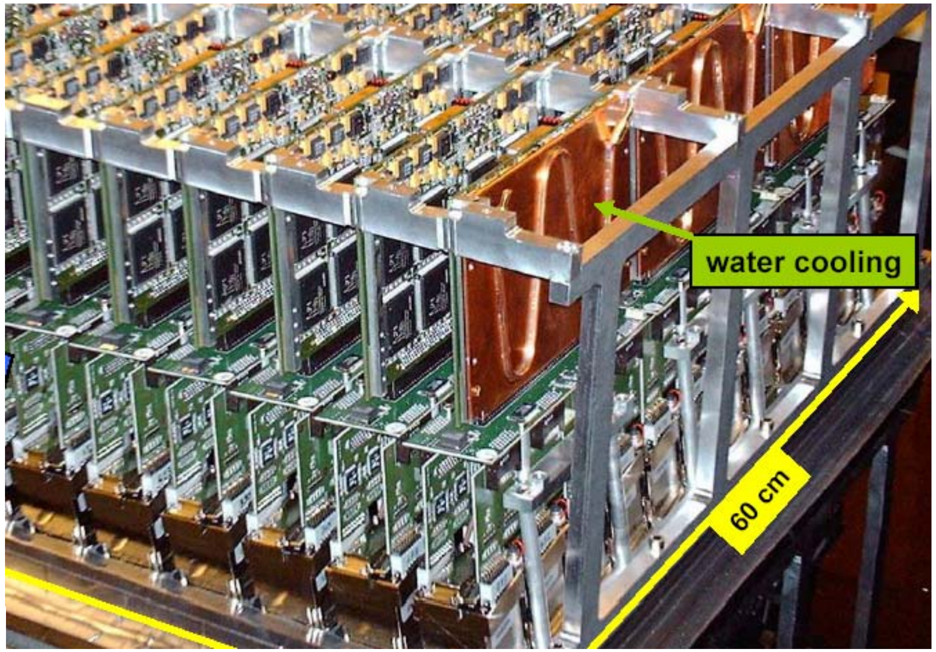


Digital read-out electronics: DREISAM card

- 64 channels per card, compact solution
- optical data transfer (40 MByte/s)
- high rates per channel 10 MHz @ 100 kHz trigger rate
- time resolution < 120 ps
- based on dead time free F1-TDC

complete digitalisation on the detector





SCHEDULE OF ASSEMBLING

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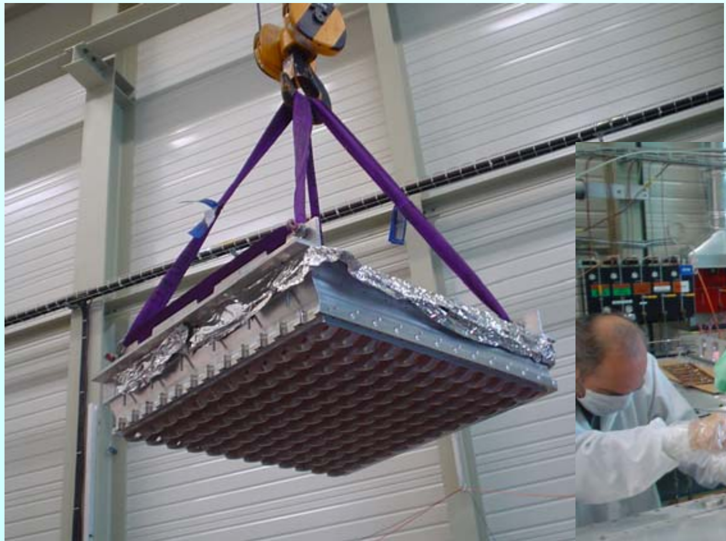
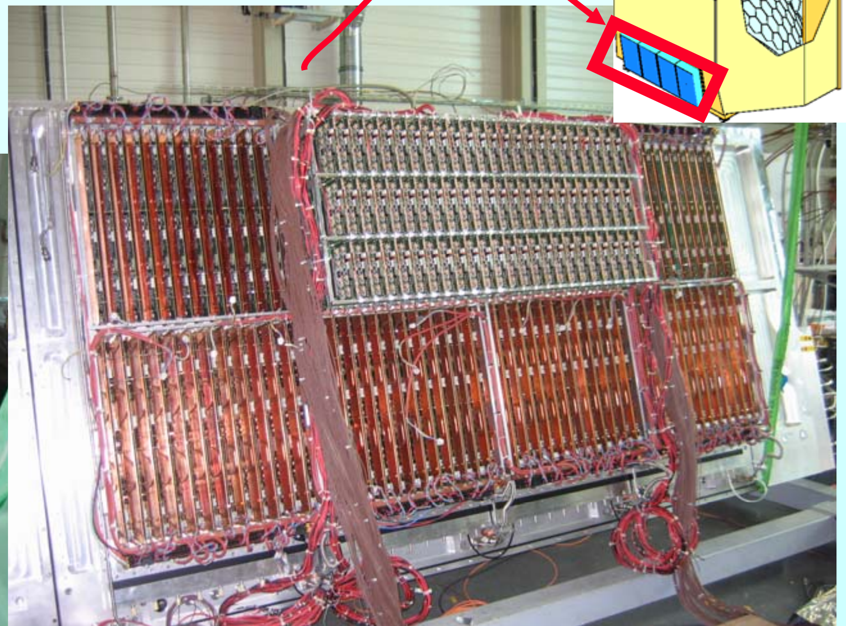
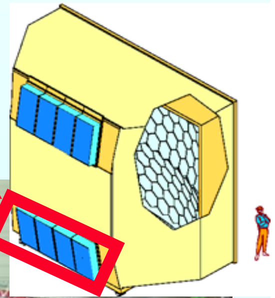
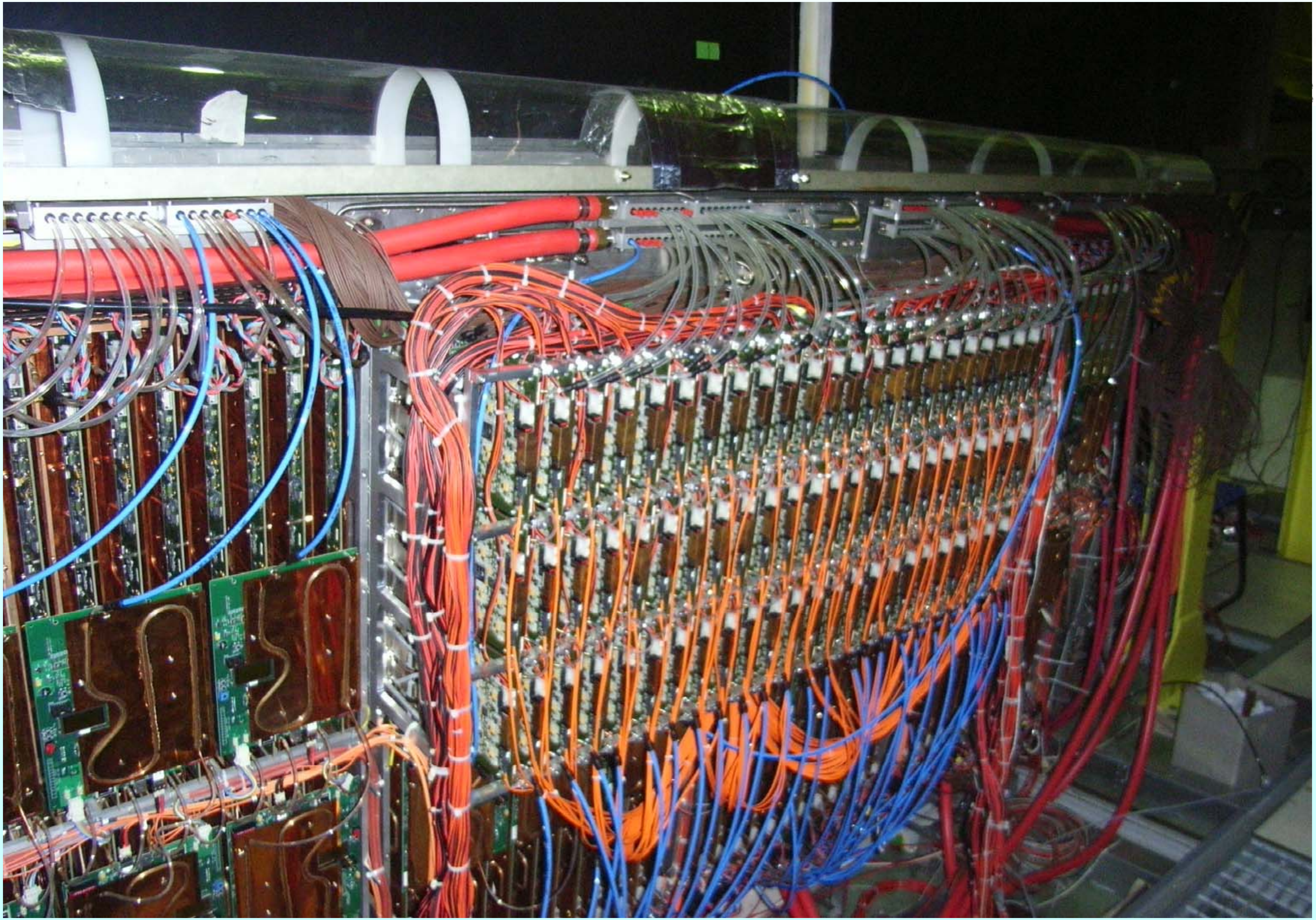
- **Preliminary studies up to October 2004**
- **Project design November 2004 – March 2005**
- **Material procurement and constructions April 2005 - March 2006**
- **Assembly April-May 2006**
- **Ready for beam , June 2006**









The Upper Detector from inside

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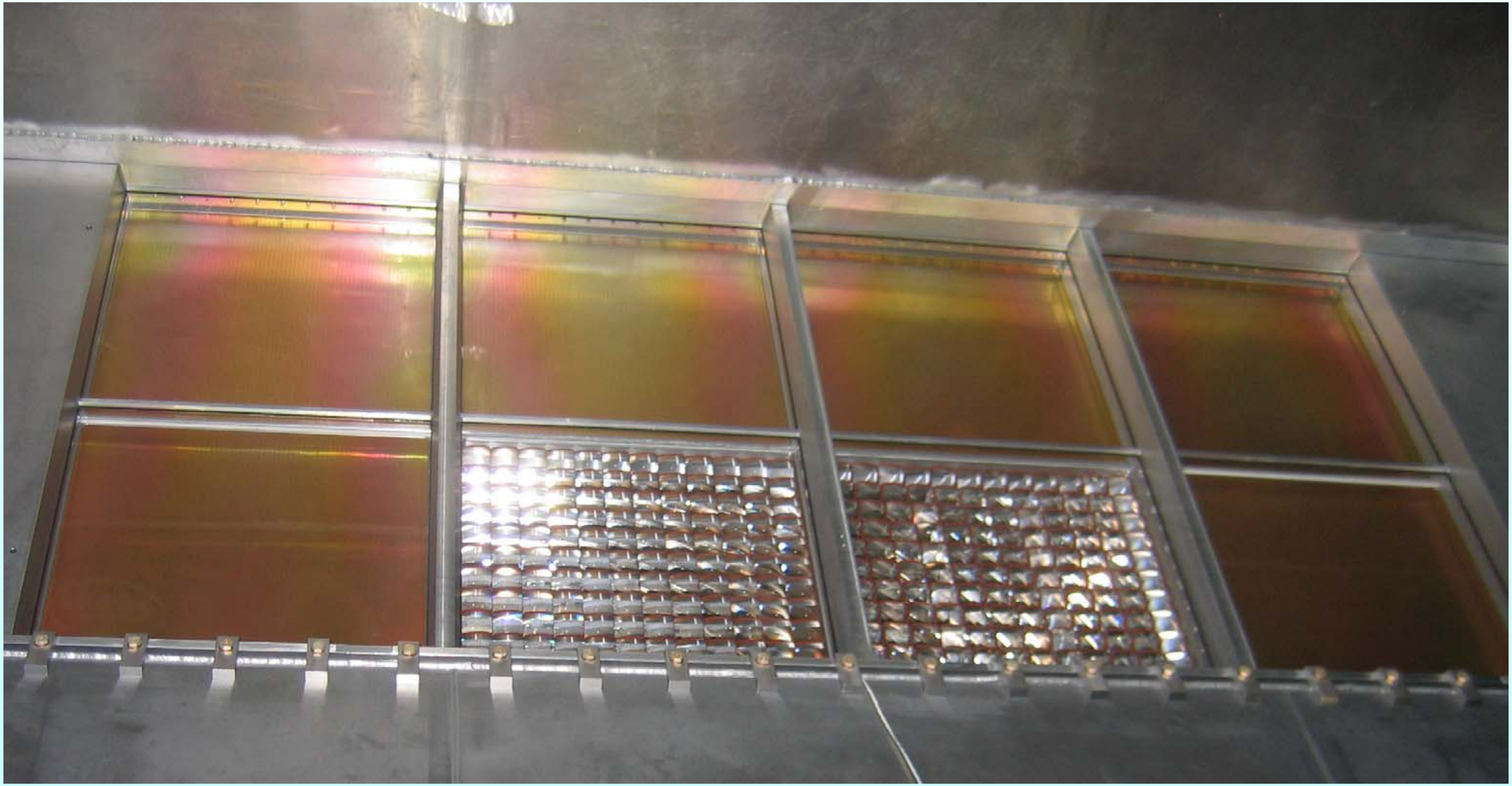

The central part of the lower detector

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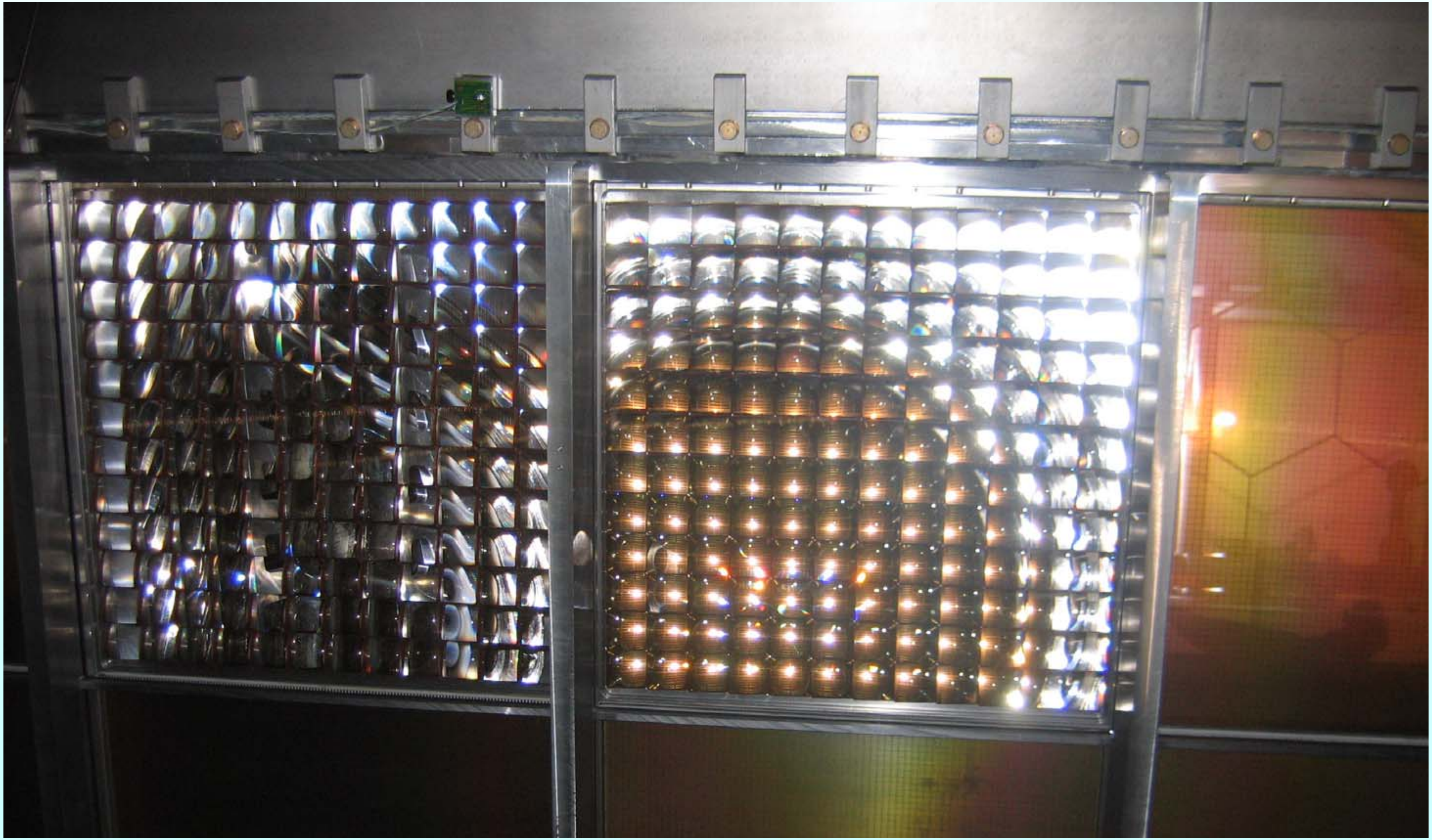
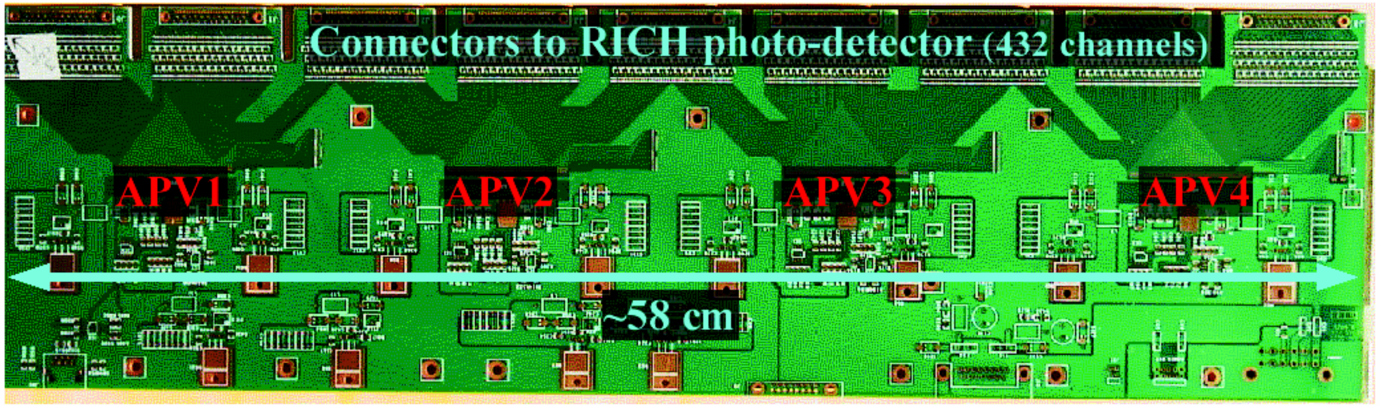
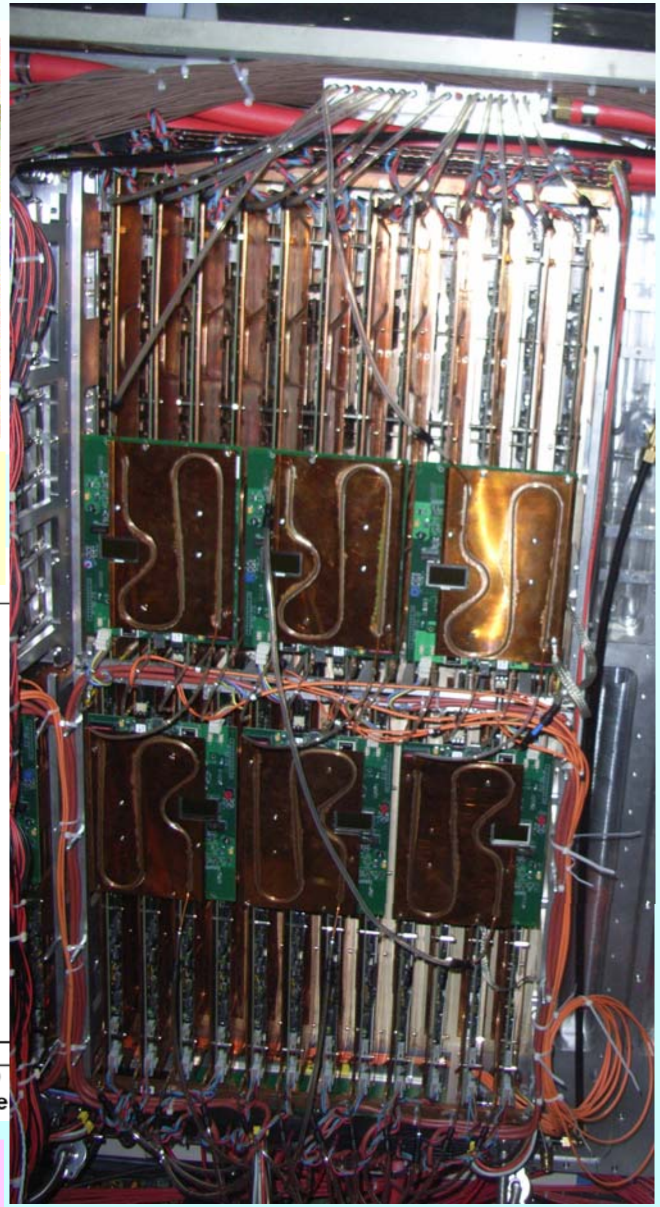


Performances of RICH APV electronics

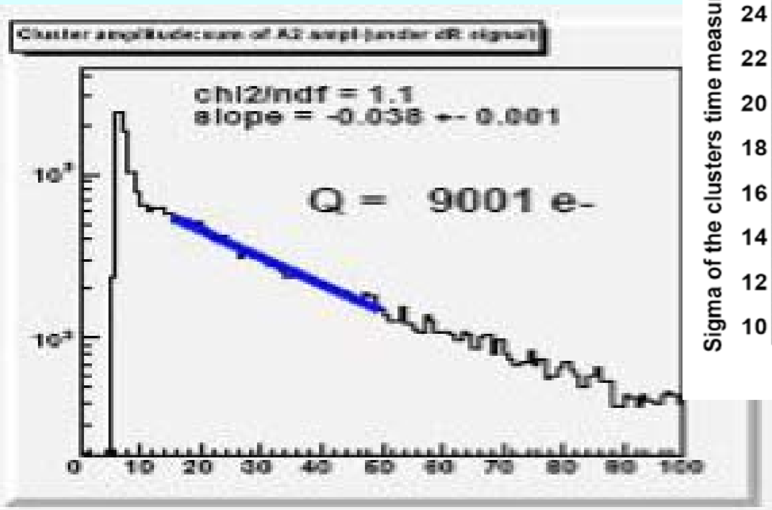




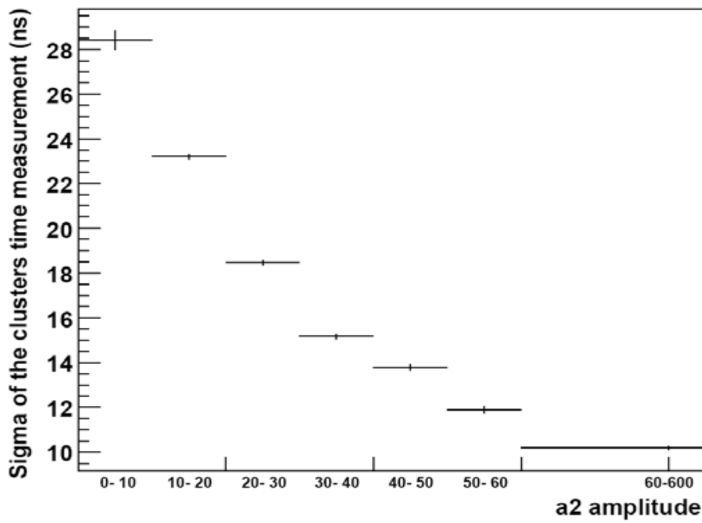
Amplitude spectrum for clusters associated with tracks

the average collected charge is ~9000 e^- @ 2000V

(noise level: ~680 e^-)

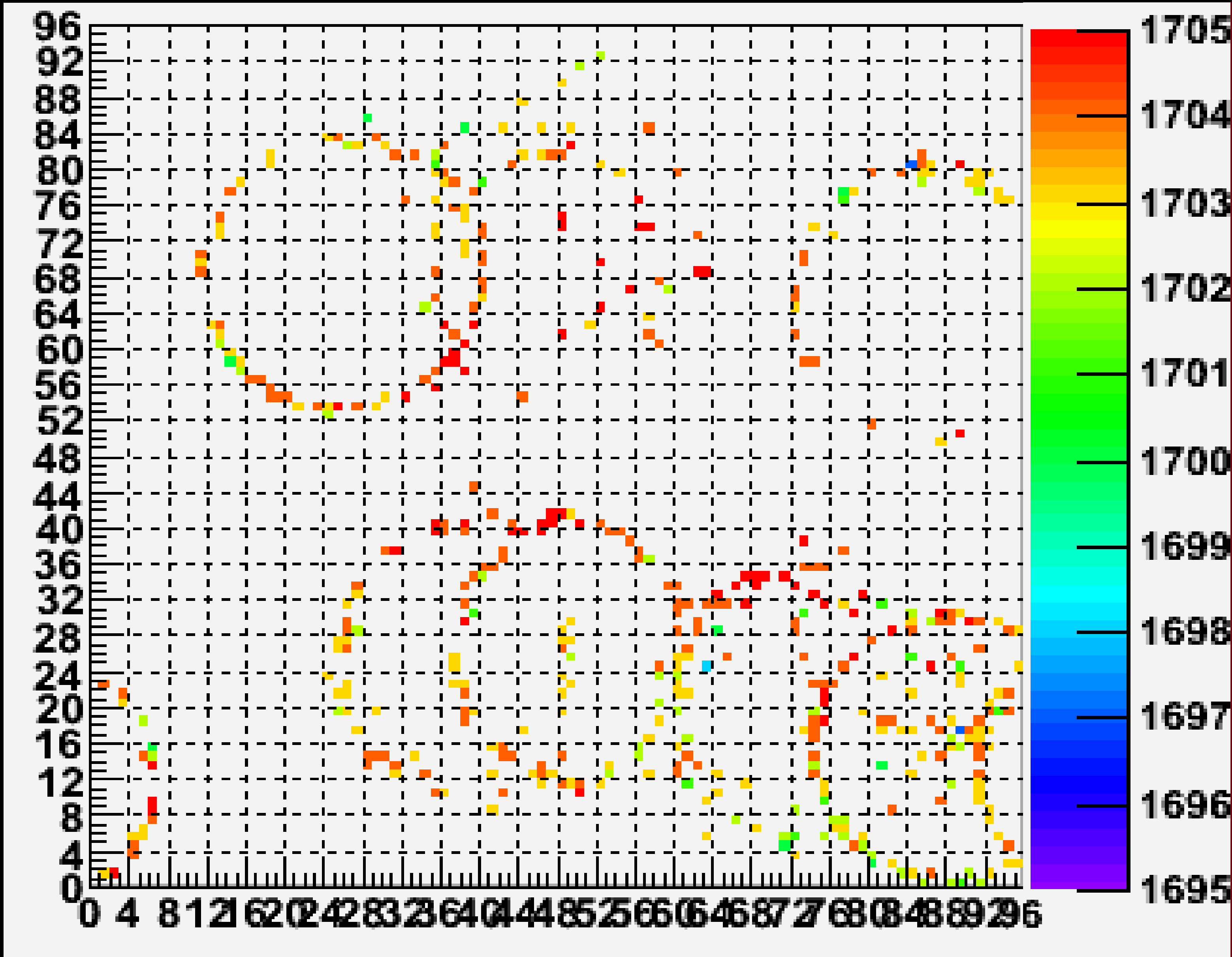


time resolution (ns) versus amplitude:



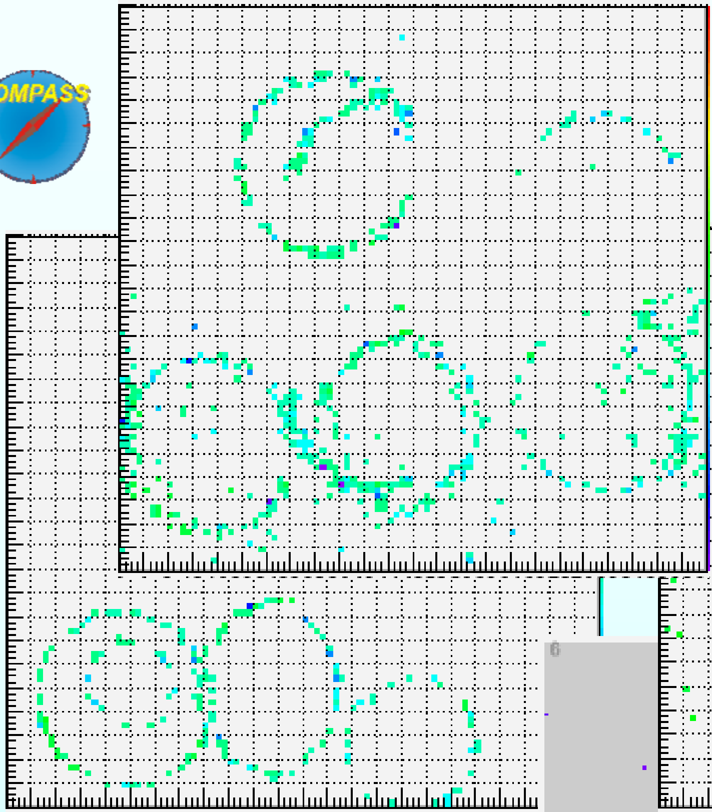
almost dead-time free

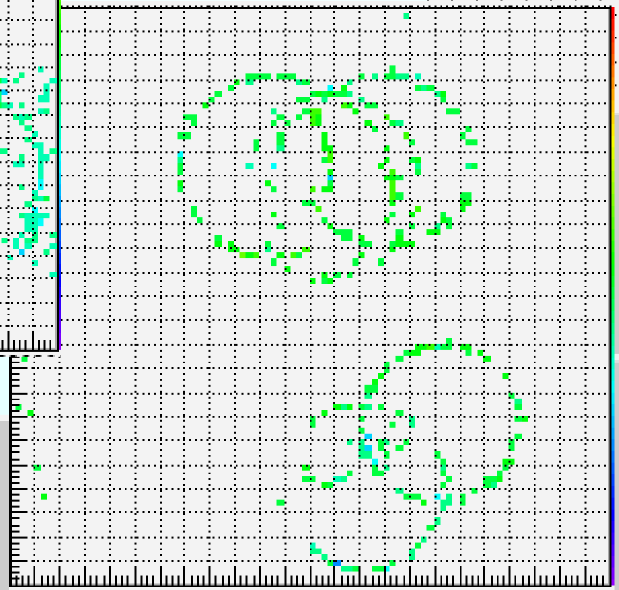
ON LINE EVENT DISPLAY FOR THE CENTRAL AREA

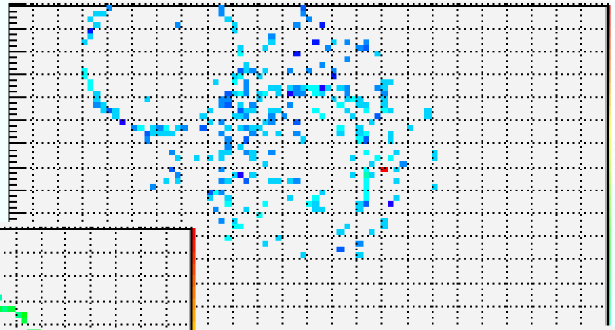


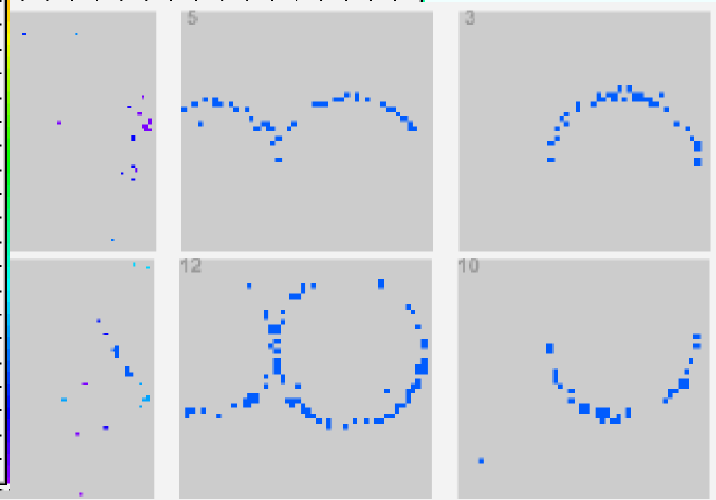
10 ns time window

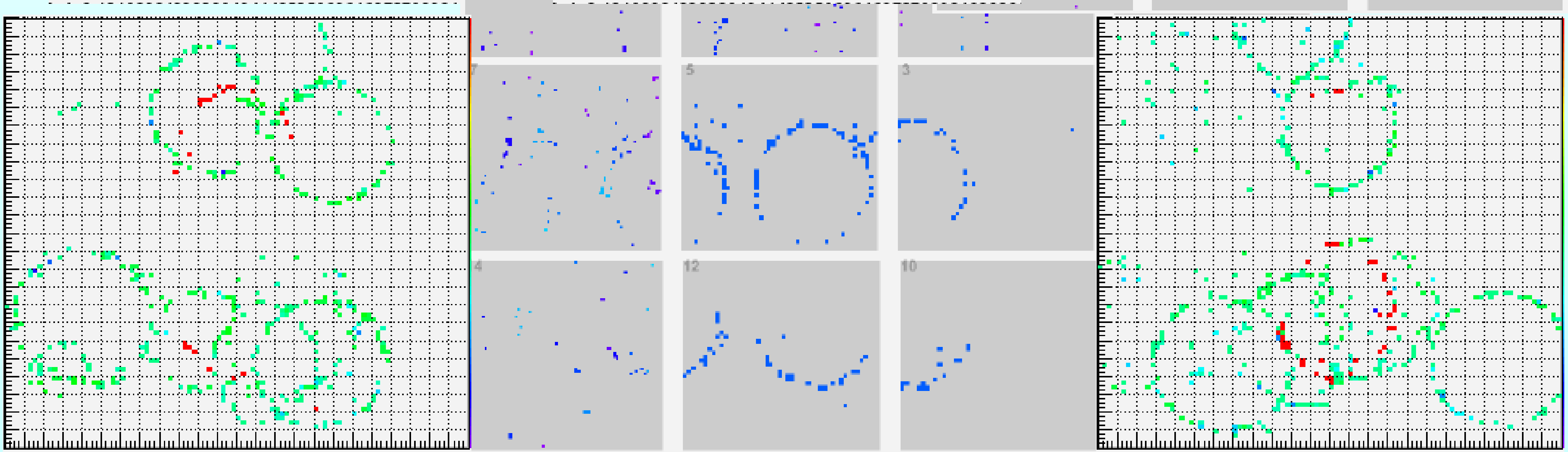
RINGS











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photon time peak

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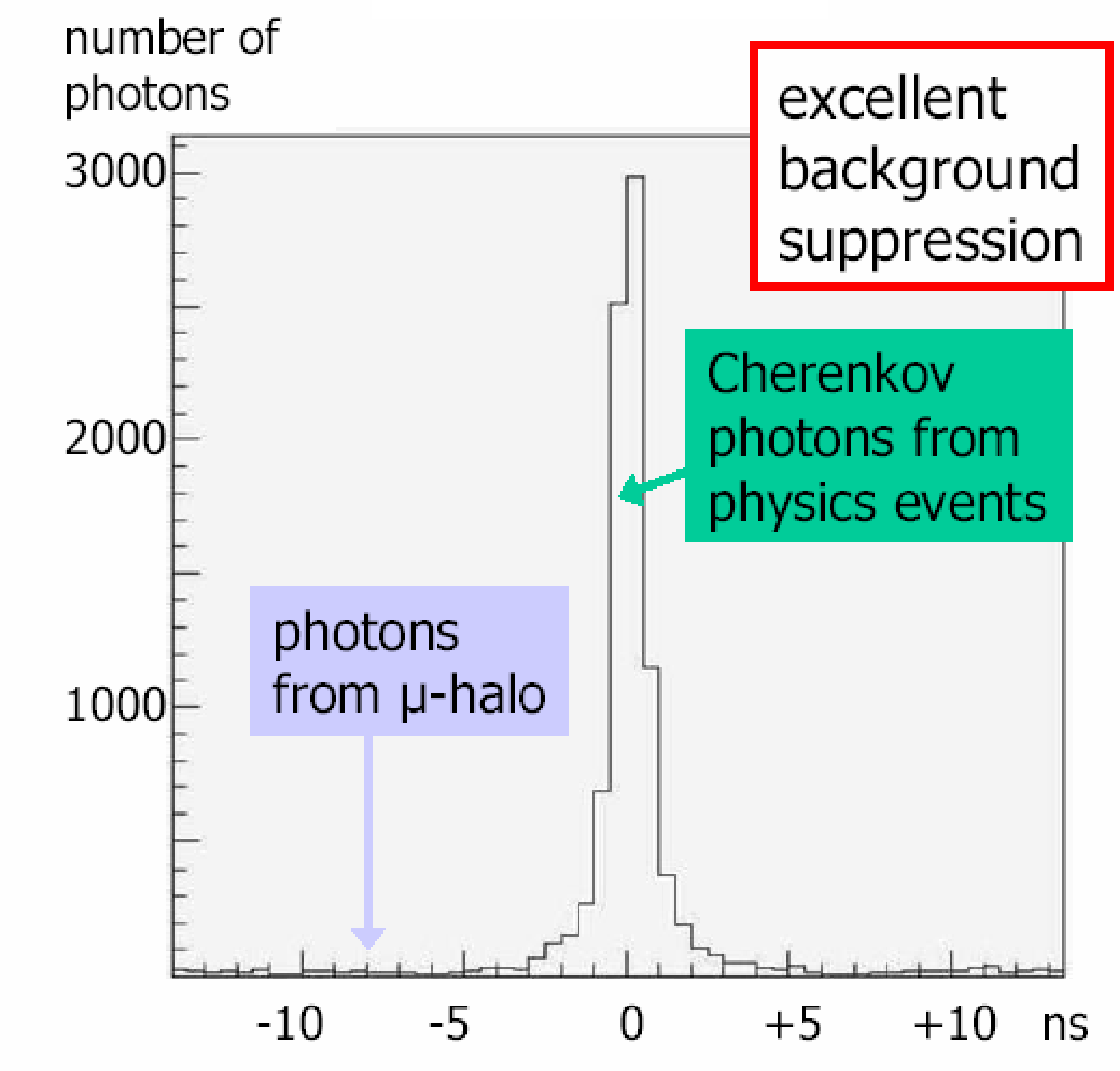
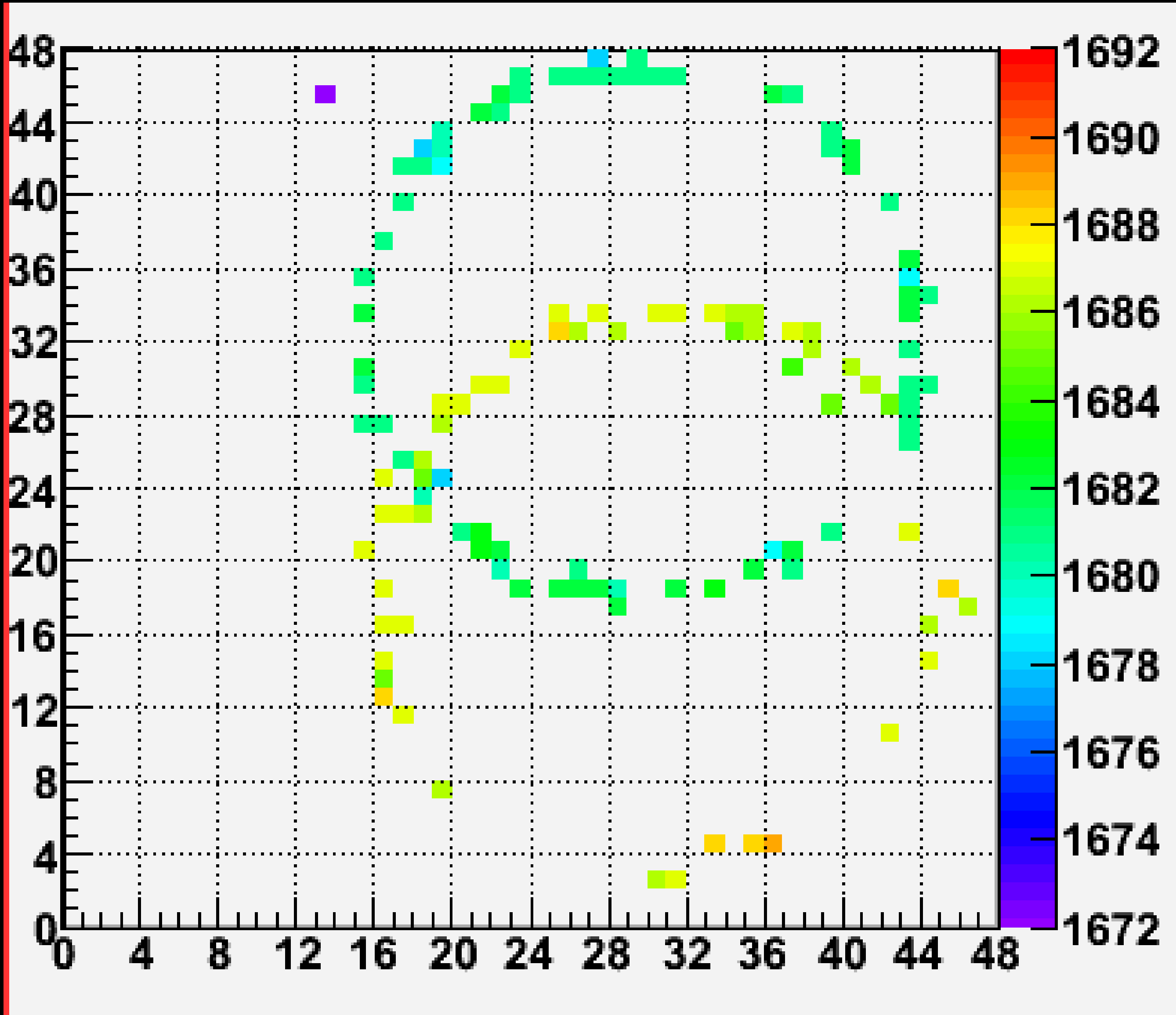
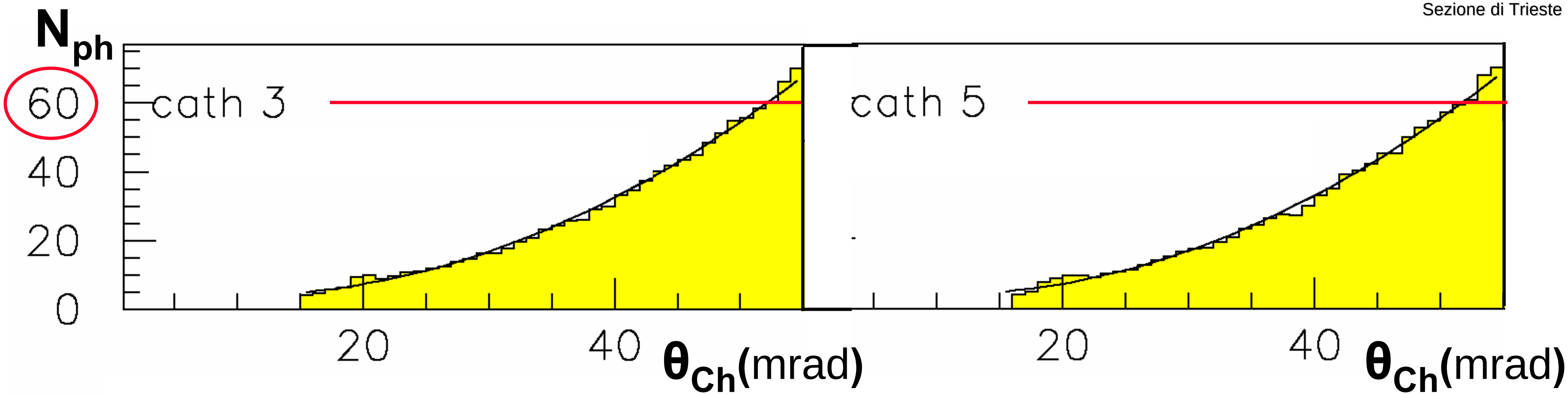


M (GeV/c²)

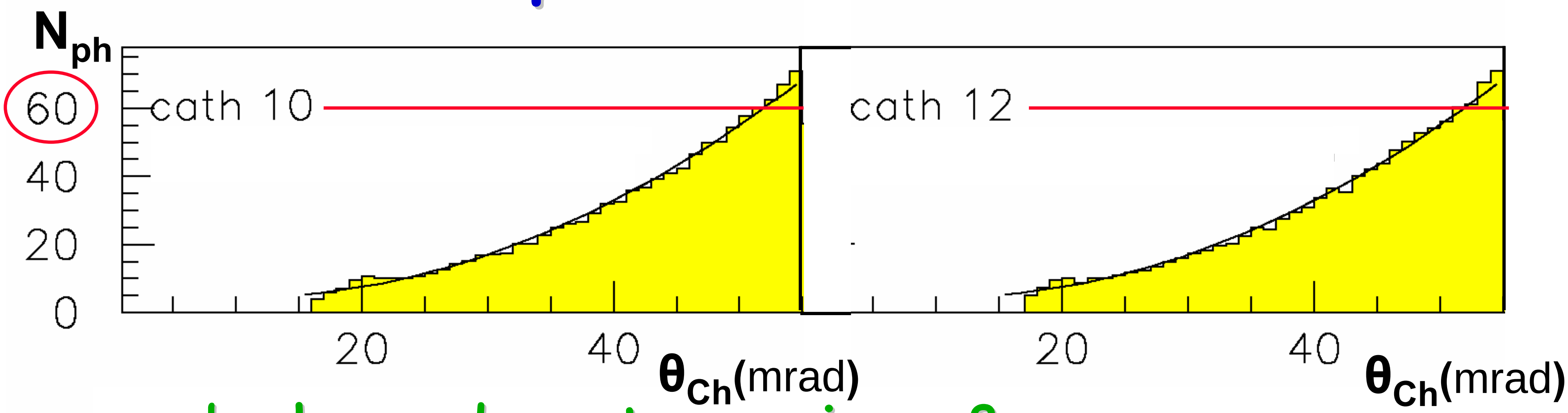
time resolution is useful for correctly assigning hits to rings



Number of detected photons



in the four quarters of the central area



mean background counts per ring ~ 8

UPGRADED RICH PERFORMANCES

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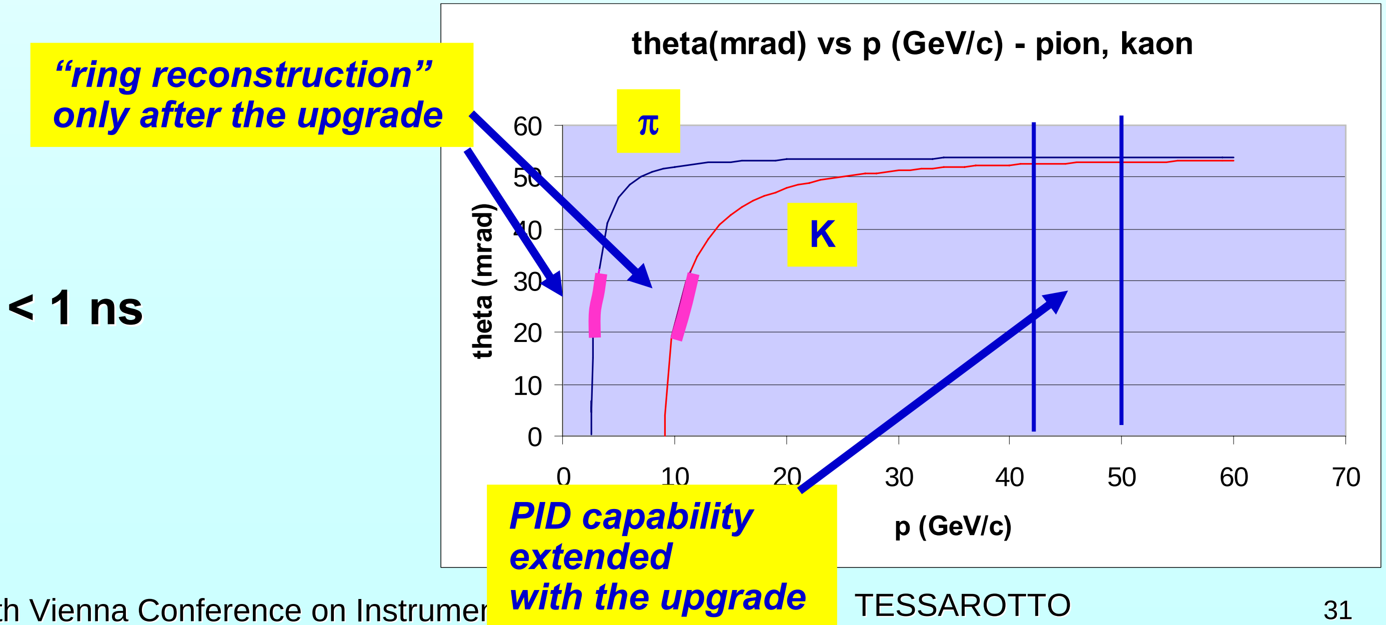
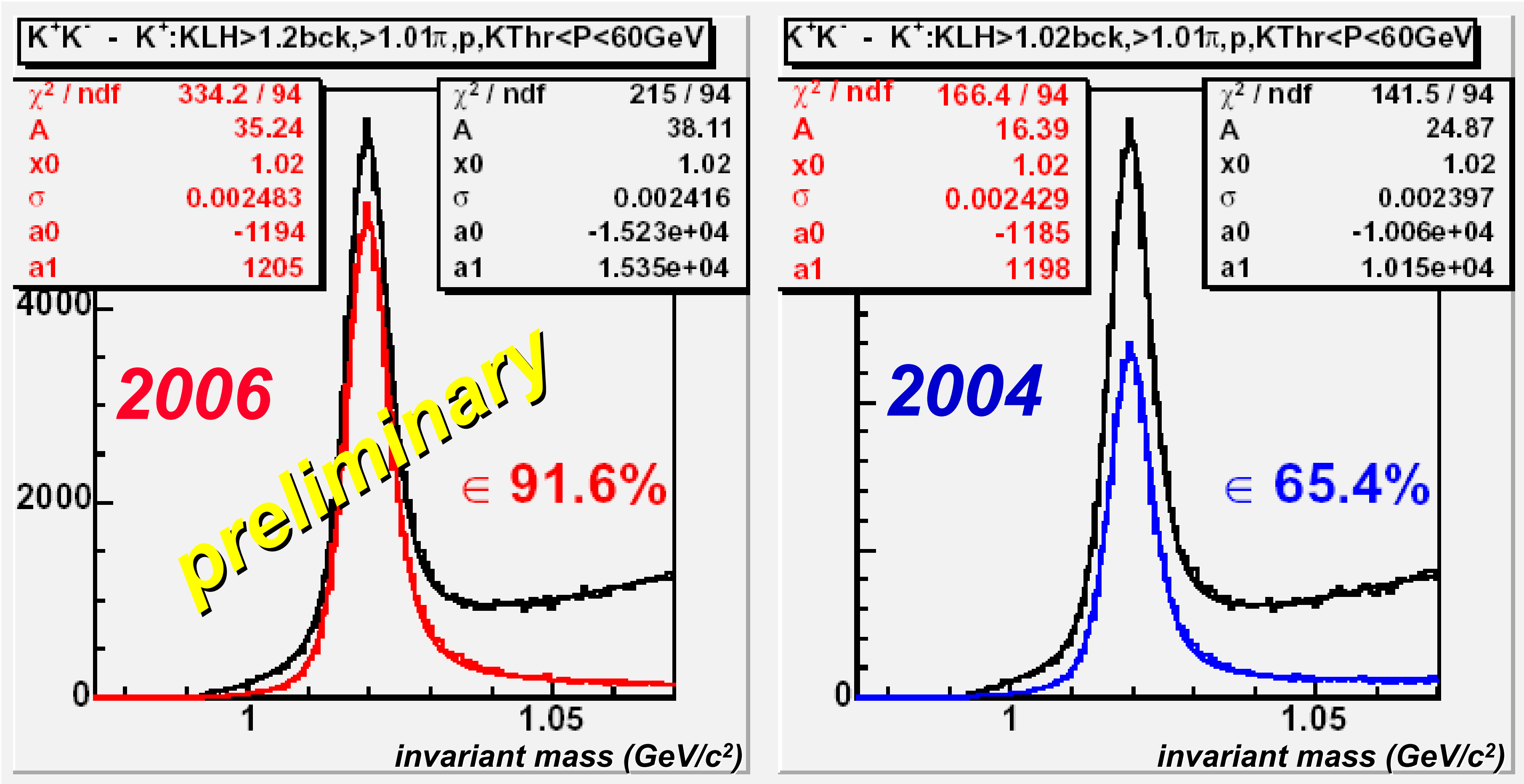
- **N_{ph} / ring ~ 60** *($\beta \approx 1$)* *IN THE CENTRAL REGION*
- **σ_{ring} ~ 0.3 mrad** *($\beta \approx 1$)* (2004: **σ_{ring} = 0.6 mrad**)
- **2 σ π/K separation up to p > 55 GeV/c** (2004: **2 σ π/K p=43 GeV/c**)
- **effective Cherenkov threshold:** see plot
- **Time resolution < 1 ns**

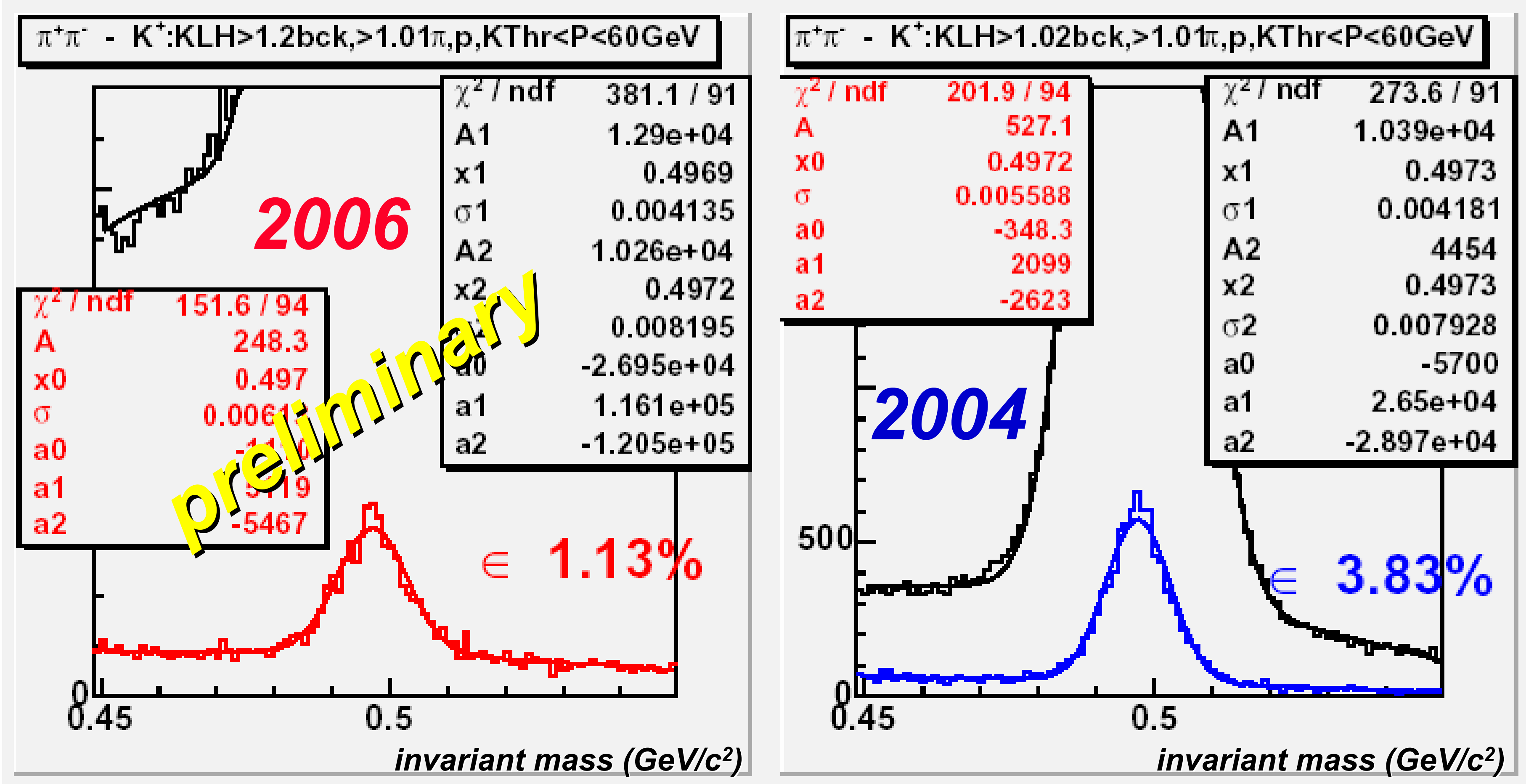


Improved efficiency



Probability of correclty identify a kaon in the most delicate kinematic region is estimated using kaons from decay of exclusively produced φ(1020) mesons

Improved purity



Probability of misidentification of a true pion as a kaon in the most delicate kinematic region is estimated using pions from decay of exclusively produced K_s

Improved PID performances

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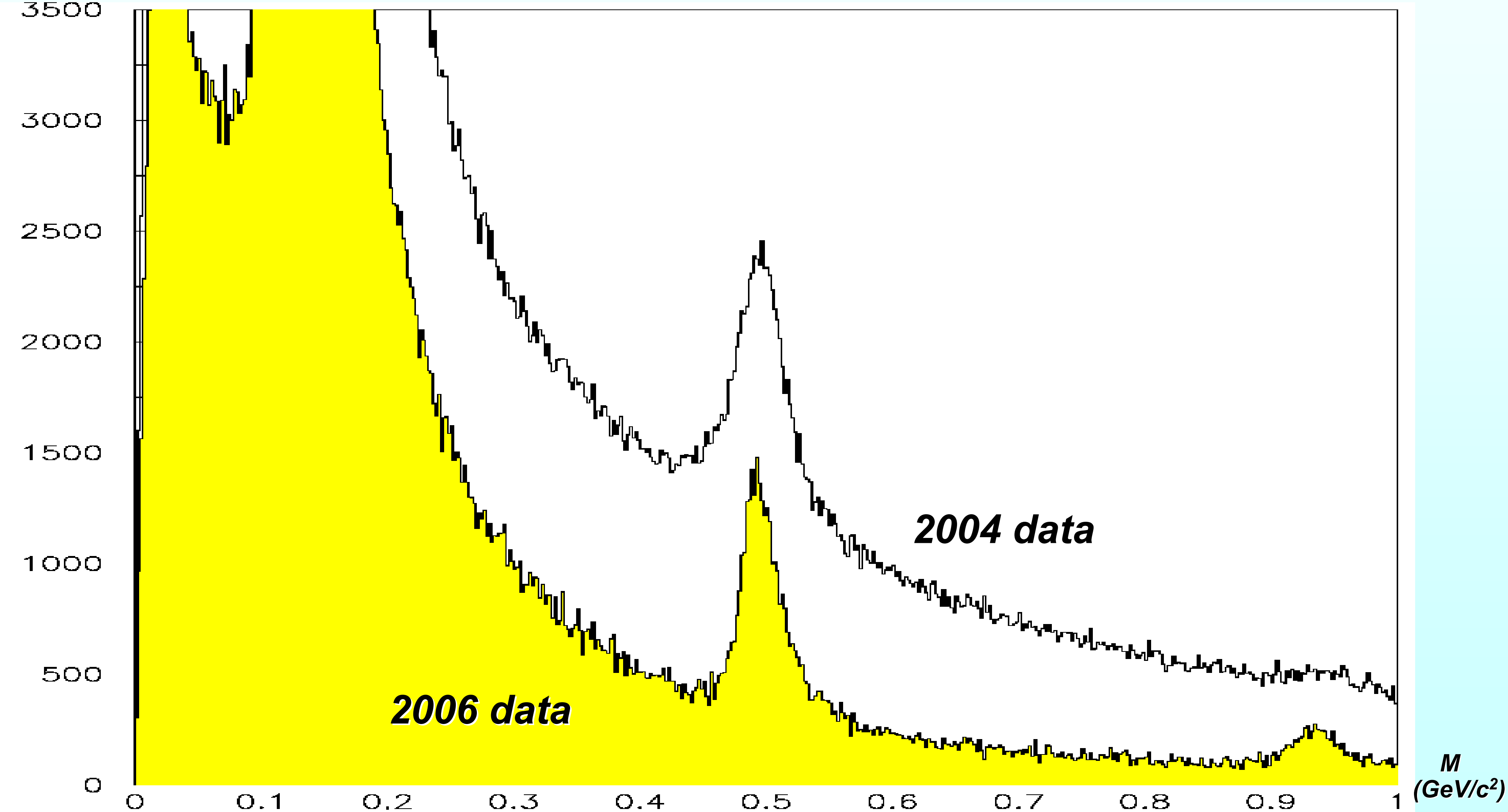

Conclusions

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**COMPASS RICH-1 has undergone a major upgrade,
changing r/o electronics for CsI MWPC and implementing a
fast photon detection system based on MAPMTs in the central area.**

The design and construction took 1.5 y: November 2004 – May 2006

**During the COMPASS run in 2006 the upgraded RICH-1 showed:
~60 detected photons, $N_0 \sim 70$, $\sigma_{\theta_C} \sim 0.3$ mrad, $\sigma_t < 1$ ns.**

**It can stand ~ 100 kHz trigger rate, it has high efficiency
and purity and 2σ π-K separation at > 55 GeV/c**

COMPASS RICH-1 has really outstanding performances

THE TEAM

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… that made this project a reality so effectively and so quickly

P.Abbon(11), M.Alekseev(12), H.Angerer(9), M. Apollonio(13), R.Birsa(13), P.Bordalo(7), F.Bradamante(13), A.Bressan(13), L.Busso(12), M.Chiosso(12), P.Ciliberti(13), M.L.Colantoni(1), S.Costa(12), T.Dafni(11), S.Dalla Torre(13), E.Delagnes(11), H.Deschamps(11), V.Diaz(13), N.Dibiase(12), V.Duic(13), W.Eyrich(4), D.Faso(12), A.Ferrero(12), M.Finger(10), M.Finger Jr(10), H.Fischer(5), S.Gerassimov(9), M.Giorgi(13), B.Gobbo(13), D.von Harrach(8), F.H.Heinsius(5), R. Joosten(2), B.Ketzer(9), V.N. Kolosov(3)*, K.Königsmann(5), I.Konorov(9), D.Kramer(6), F.Kunne(11), A.Lehmann(4), S. Levorato(13), A.Maggiora(12), A.Magnon(11), A.Mann(9), A.Martin(13), G.Menon(13), A.Mutter(5), O. Nähle(2), F.Nerling(5), D.Neyret(11), P.Pagano(13), S.Panebianco(11), D.Panzieri(1), S.Paul(9), G.Pesaro(13),C. Pizzolotto(4), J. Polak(6), P.Rebourgeard(11), E. Rocco(13), F.Robinet(11), P.Schiavon(13), C.Schill(5), P.Schoenmeier(4), W.Schröder(4), L.Silva(7), M.Slunecka(10), F.Sozzi(13), L.Steiger(10), M.Sulc(6), M.Svec(6), F.Tessarotto(13), A.Teufel(4), H. Wollny(5)

- (1) INFN, Sezione di Torino and Universita' del East Piemonte, Alessandria, Italy
- (2) Universität Bonn, Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany
- (3) CERN, European Organization for Nuclear Research, Geneva, Switzerland
- (4) Universität Erlangen–Nürnberg, Physikalisches Institut, Erlangen, Germany
- (5) Universität Freiburg, Physikalisches Institut, Freiburg, Germany
- (6) Technical University of Liberec, Liberec, Czech Republic
- (7) LIP, Lisbon, Portugal
- (8) Universität Mainz, Institut für Kernphysik, Mainz, Germany
- (9) Technische Universität München, Physik Department, Garching, Germany
- (10) Charles University, Praga, Czech Republic and JINR, Dubna, Russia
- (11) CEA Saclay, DSM/DAPNIA, Gif-sur-Yvette, France
- (12) INFN, Sezione di Torino and Universita' di Torino, Torino, Italy
- (13) INFN, Sezione di Trieste and Universita' di Trieste, Trieste, Italy

Alessandria	Bonn
CERN (Geneve)	Erlangen
Freiburg	TUM (Munich)
Liberec	LIP (Lisbon)
Mainz	Prague
Saclay	Torino
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