Astroparticles and Atmosphere Workshop, 26-28 May 2003, Paris

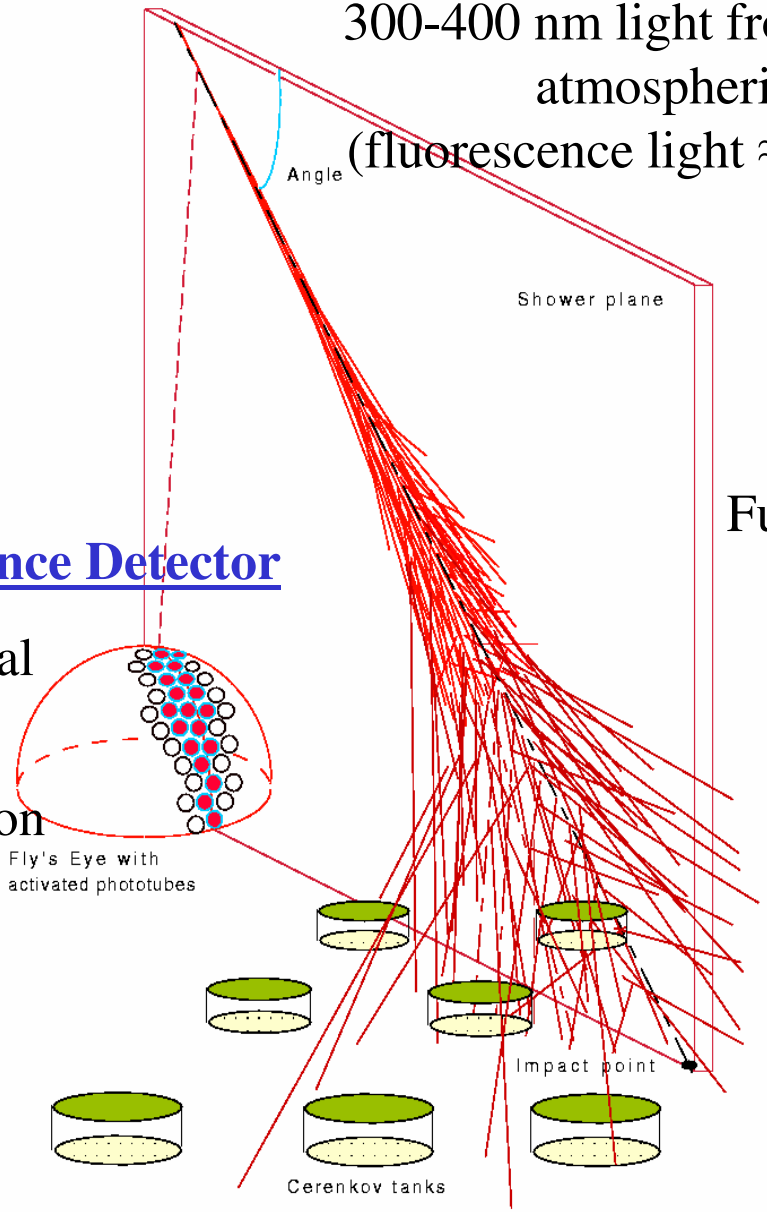
The AUGER Fluorescence Detector

Air fluorescence yield for high energy cosmic ray detection

P. Privitera
Universita' di Roma Tor Vergata and
INFN Sezione di Roma II

The Auger hybrid concept

300-400 nm light from de-excitation of atmospheric nitrogen (fluorescence light ≈ 4 photons / m / e)



Fully efficient for cosmic rays of $E > 10^{19}$ eV

Fluorescence Detector

- E + longitudinal development
- Time ≈ direction

Surface Detector

- Shower size ≈ E
- Time ≈ direction

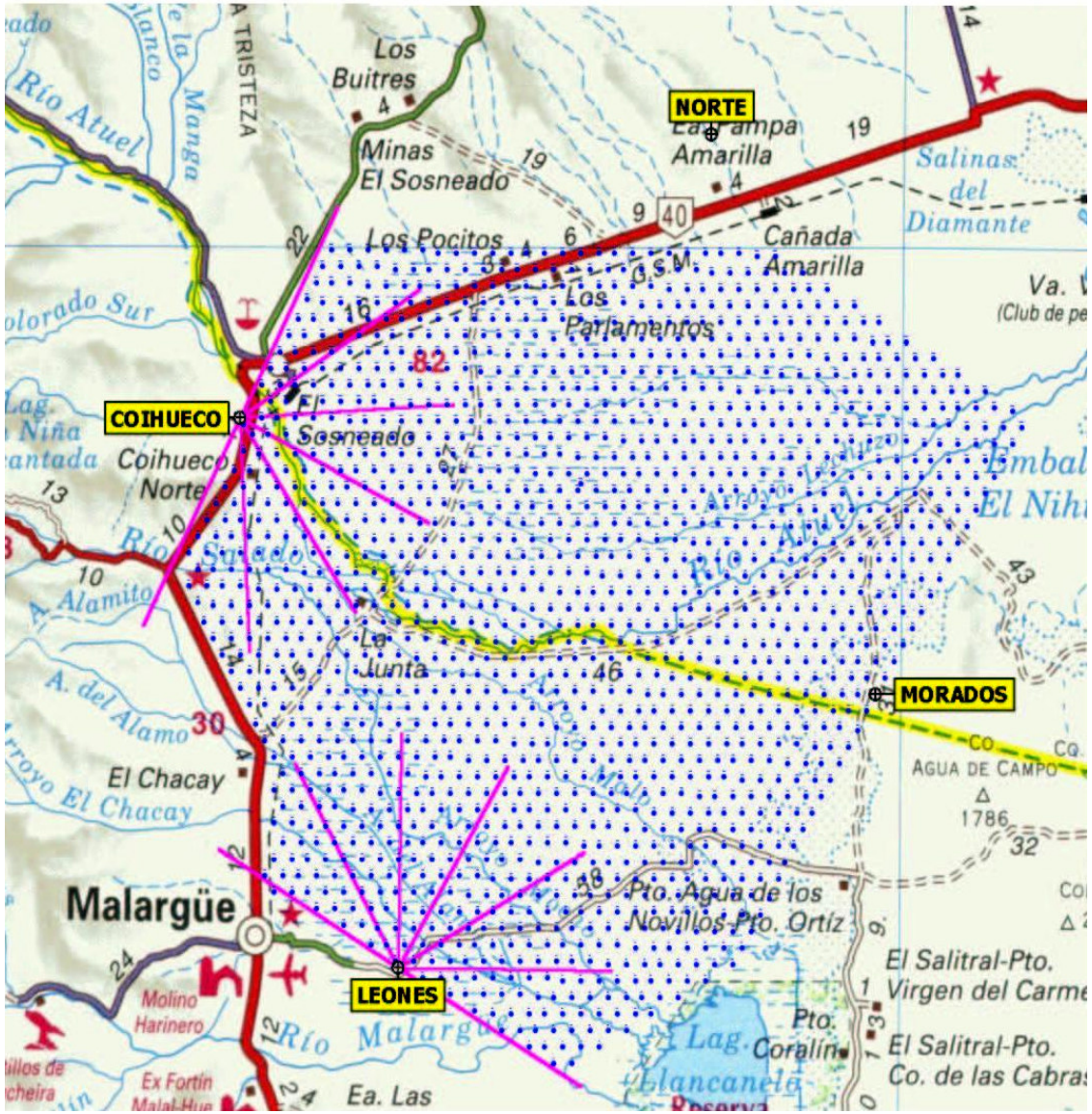
The Auger Observatory

- 3000 km^2 covered

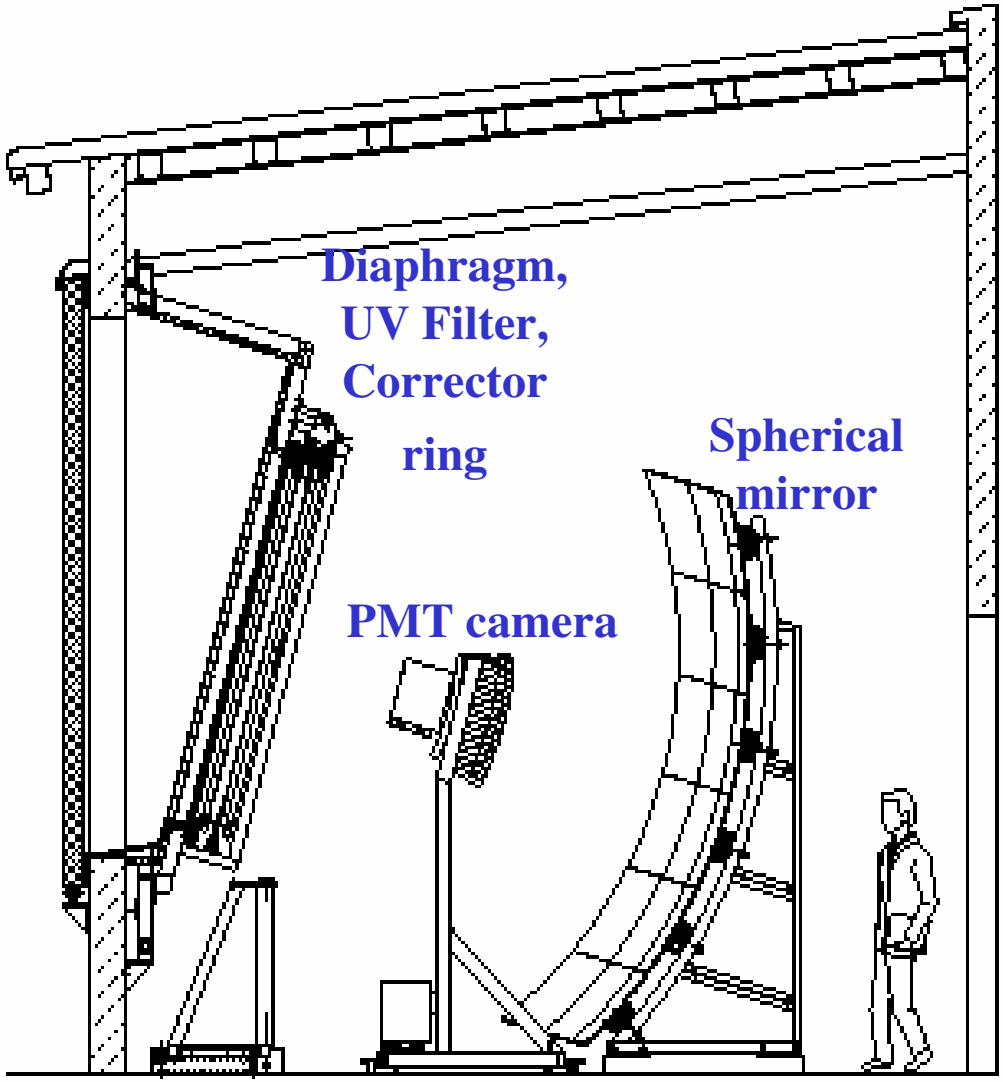
aperture 7400 km^2 sr

- **FD eye (4 peripheral eyes, 6 telescopes each) 11000 PMTs**

- 1600 **SD Cerenkov tanks (spacing 1.5 Km) 4800 PMTs**



The Auger FD telescope

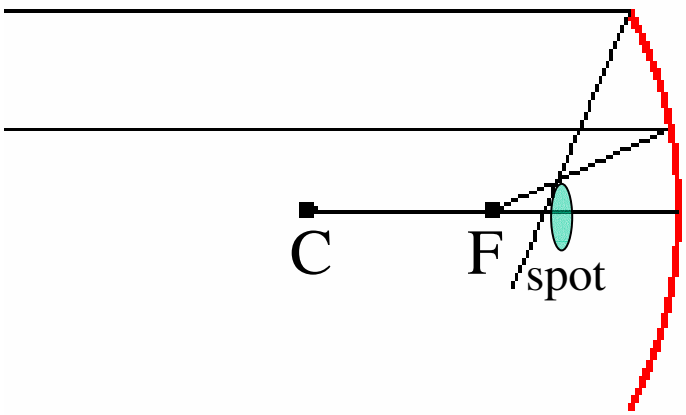


✓ Schmidt optics: (eliminates coma aberration) Spherical mirror R_{curv} = 3.4 m, 2.2 m diameter diaphragm, corrector ring, 30^ox30^o FOV, 15 mm diameter spot

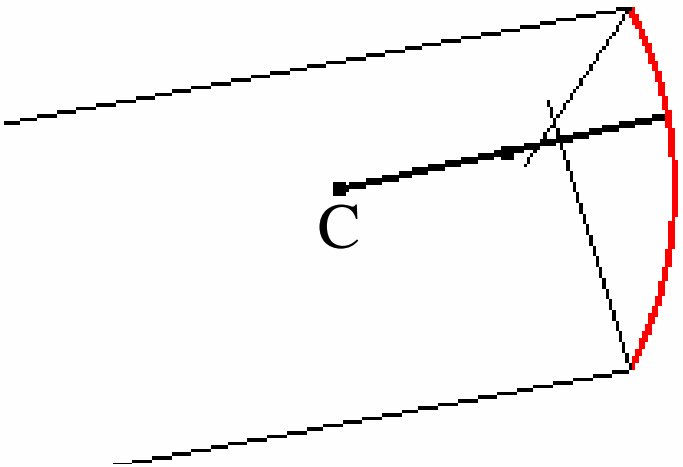
✓ Spherical focal surface: 20x22 hexagonal PMT (Photonis XP3062); light collectors to recover cracks; pixel size = 45 mm

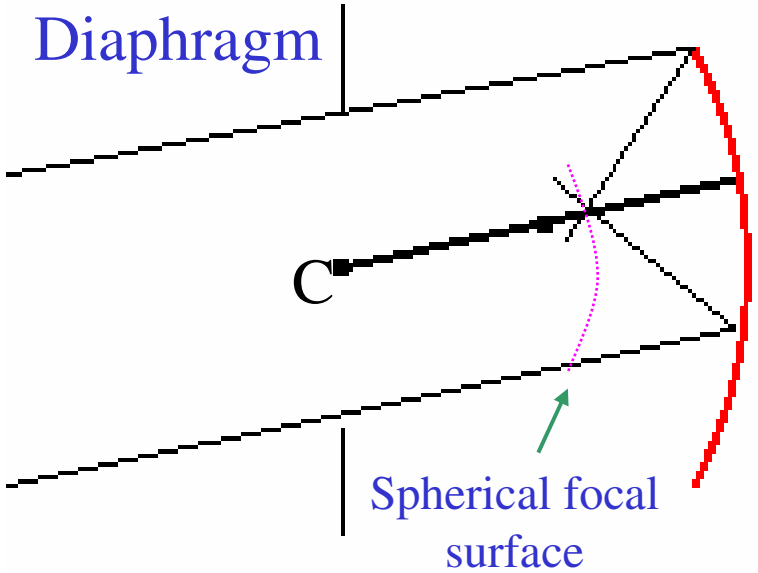
The Schmidt optics

Spherical aberration



Coma aberration

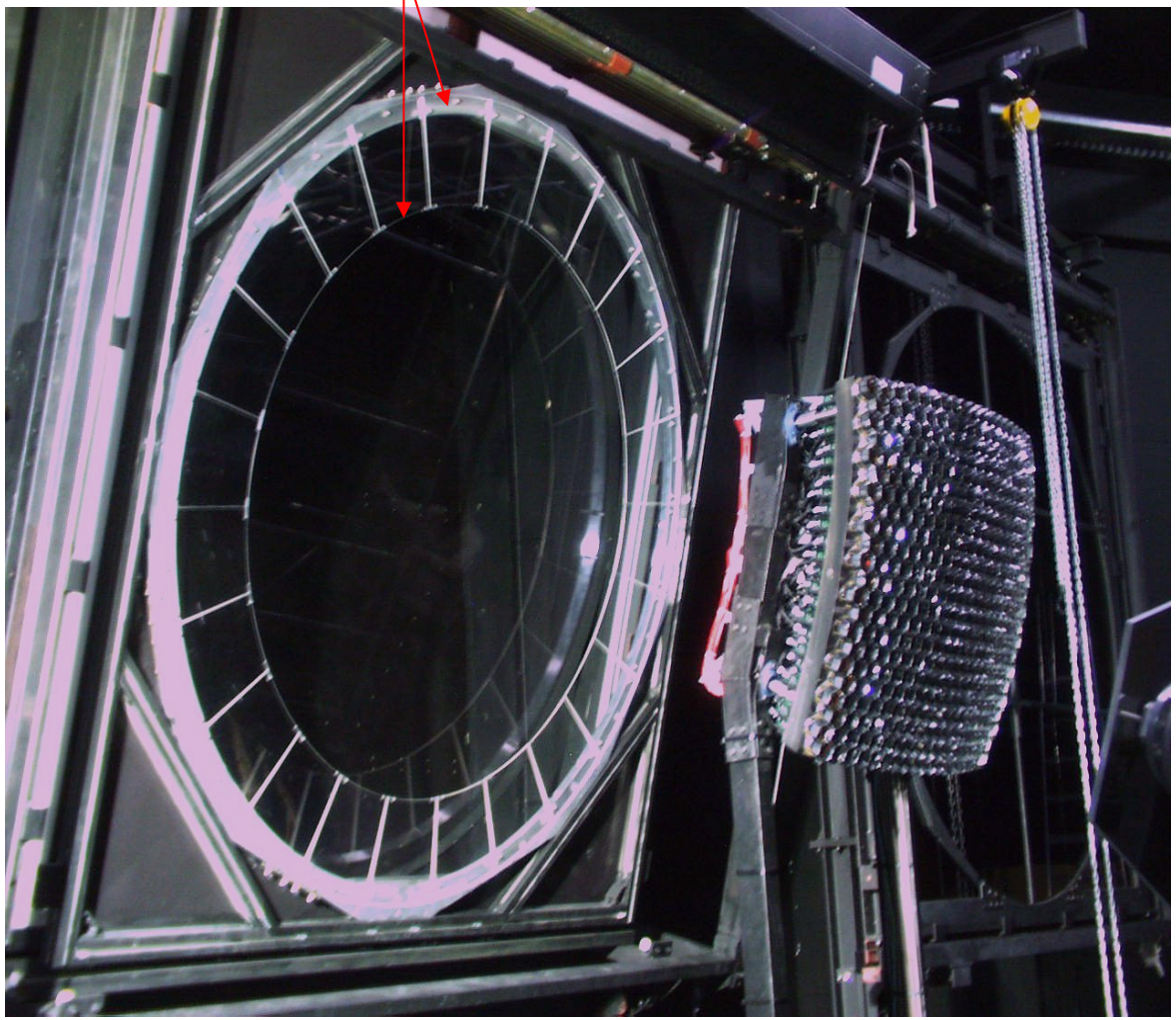




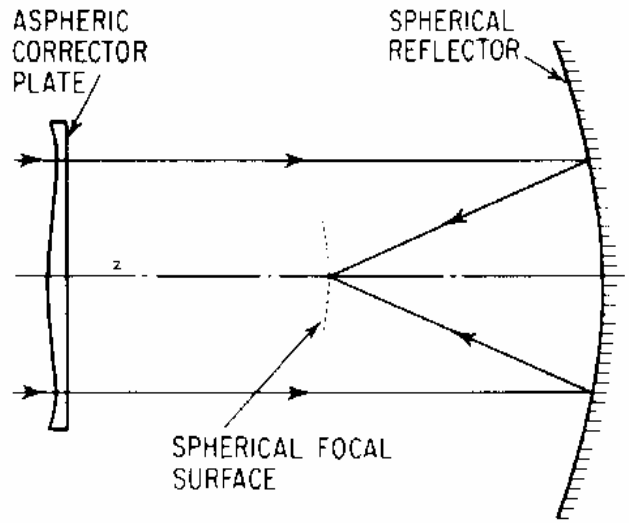
Coma eliminated

The corrector ring

gain a factor 2 in light collection



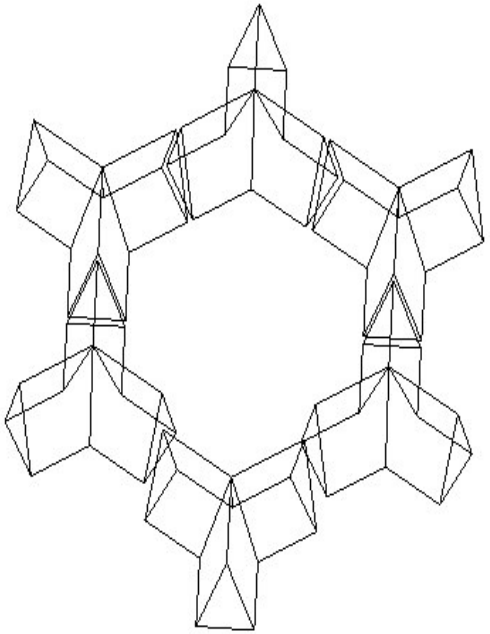
The ring lenses correct the additional spherical aberration, keeping the spot size within the nominal 15 mm diameter



The FD camera

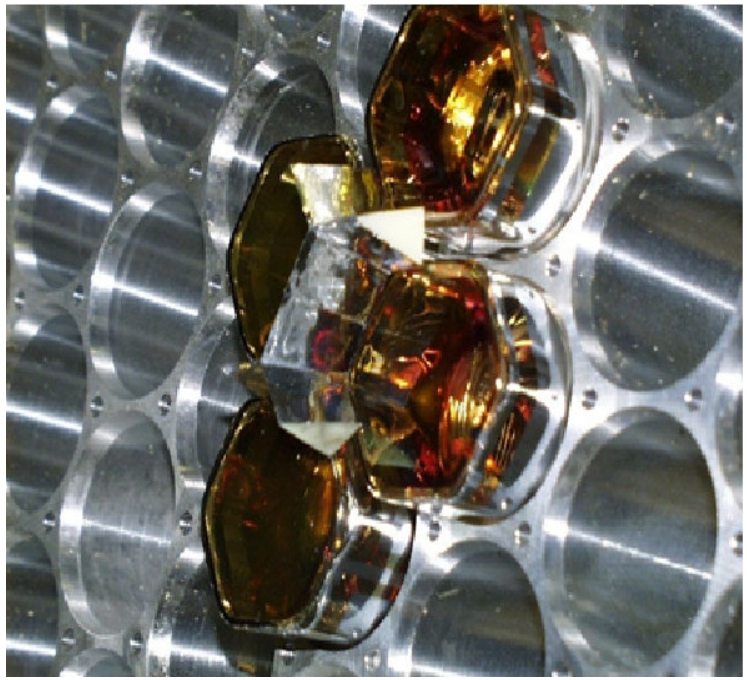
440 PMTs on a
spherical surface

90 cm



Light collectors to recover border inefficiencies

"mercedes star" with aluminized mylar reflecting walls

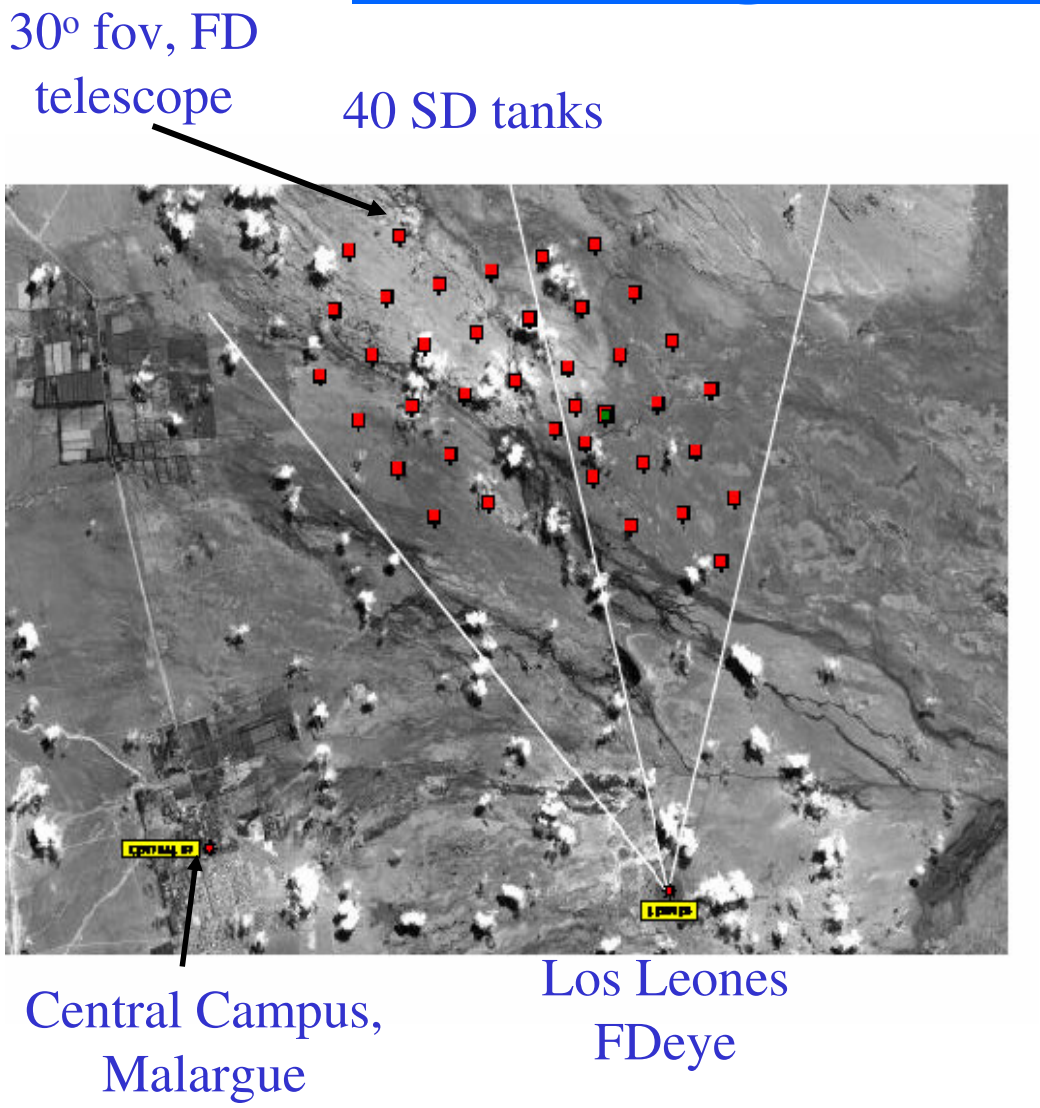


FD buildings

Los Leones

Coihueco

The Engineering Array

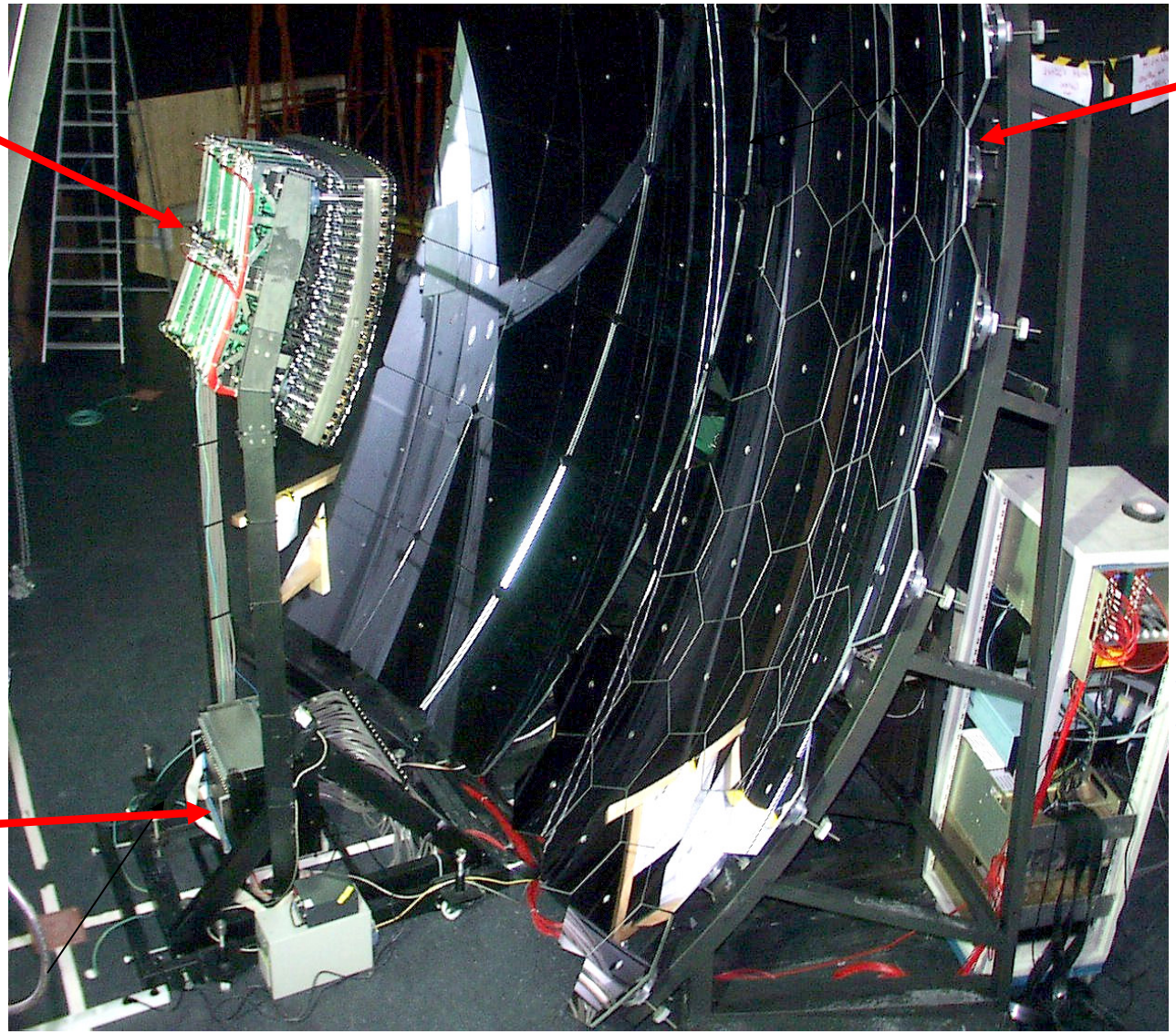


Aims :

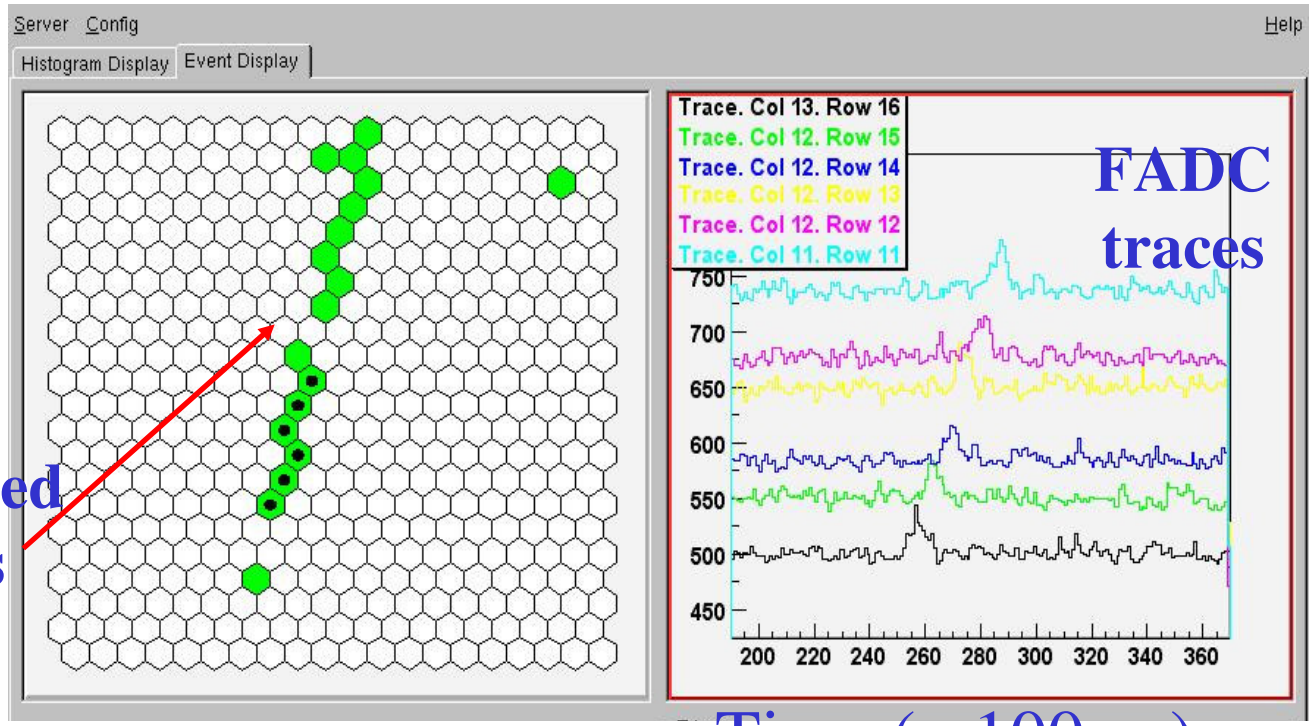
- **Tank deployment and commissioning, comms, FD telescopes installation**
- **Hybrid trigger and timing, CDAS**
- **Internet connection with data mirroring in US and Europe, data analysis**
- **First showers observed May 2001**

- **December 2001–March 2002 stable data taking ≈80 hybrid triggers**

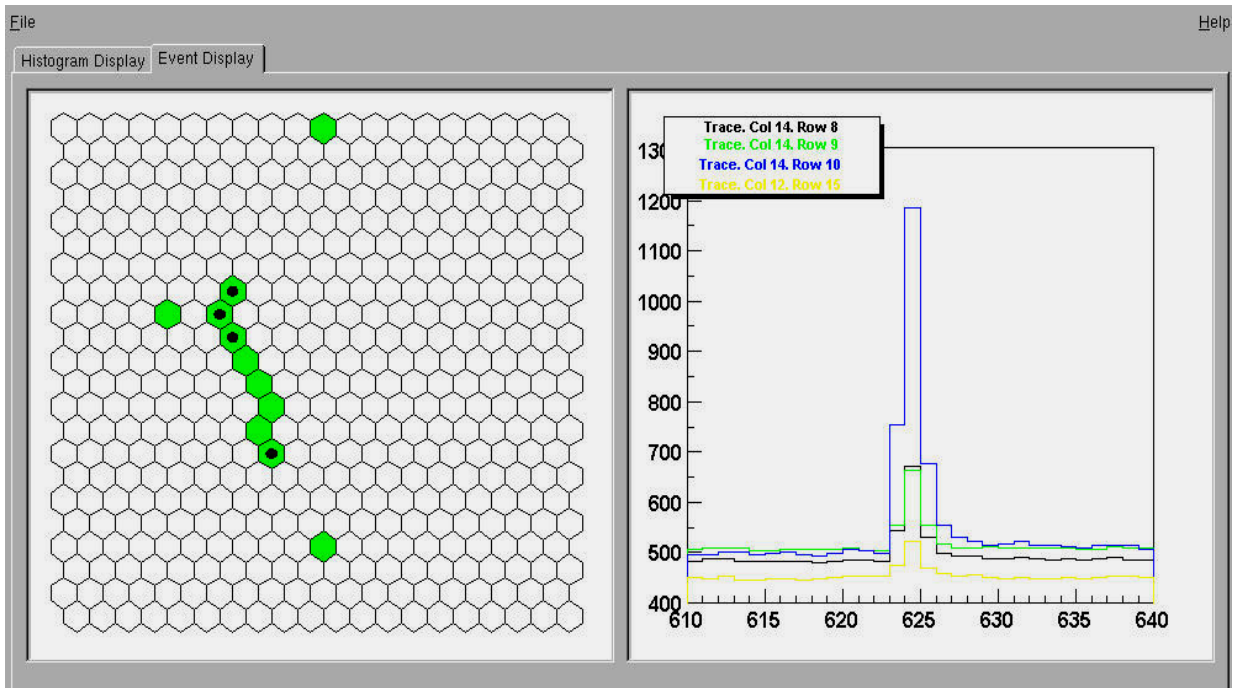
The FD telescope at Los Leones



FD shower candidate



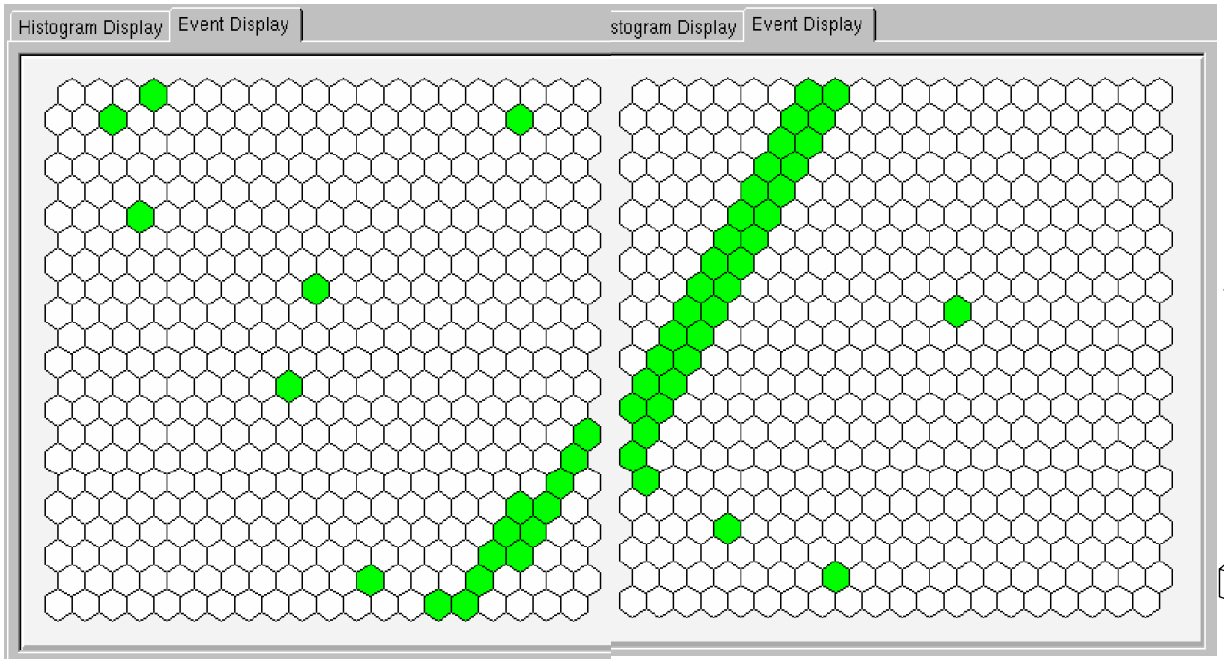
Triggered pixels

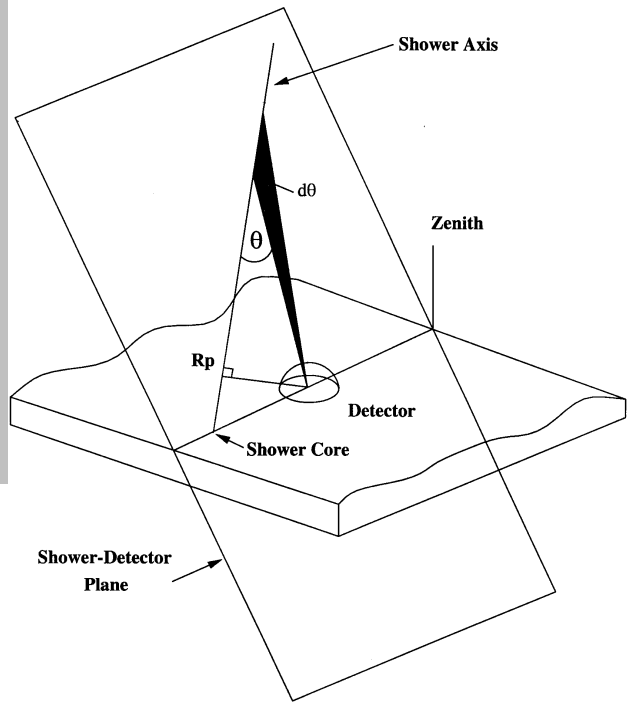


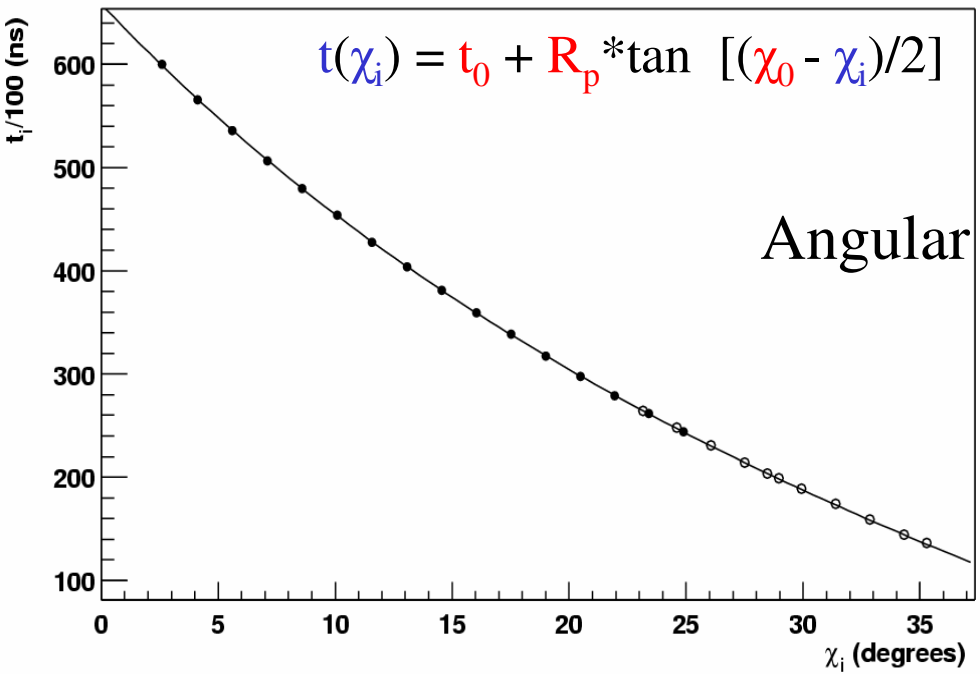
Background event

Cosmic passing through PMTs

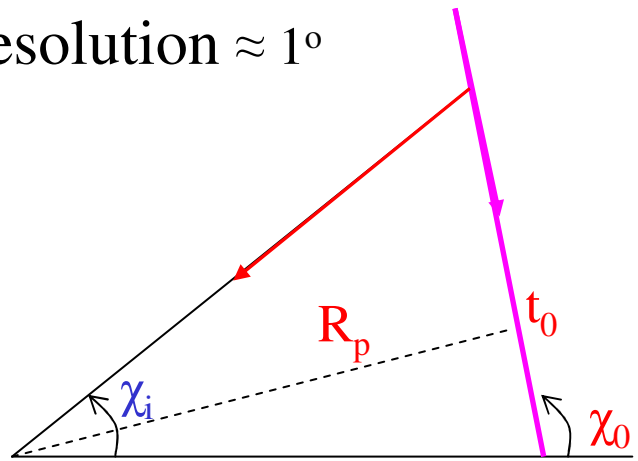
FD shower



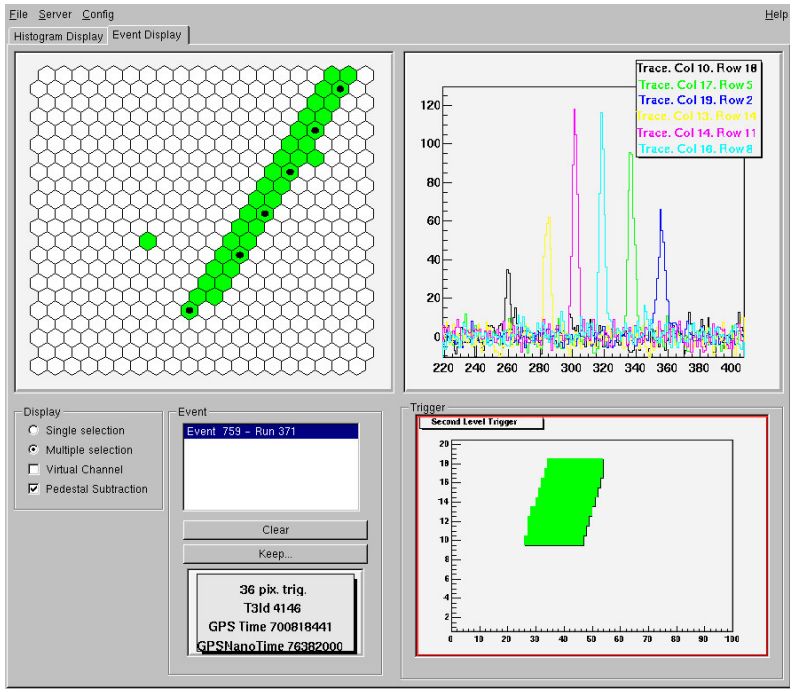


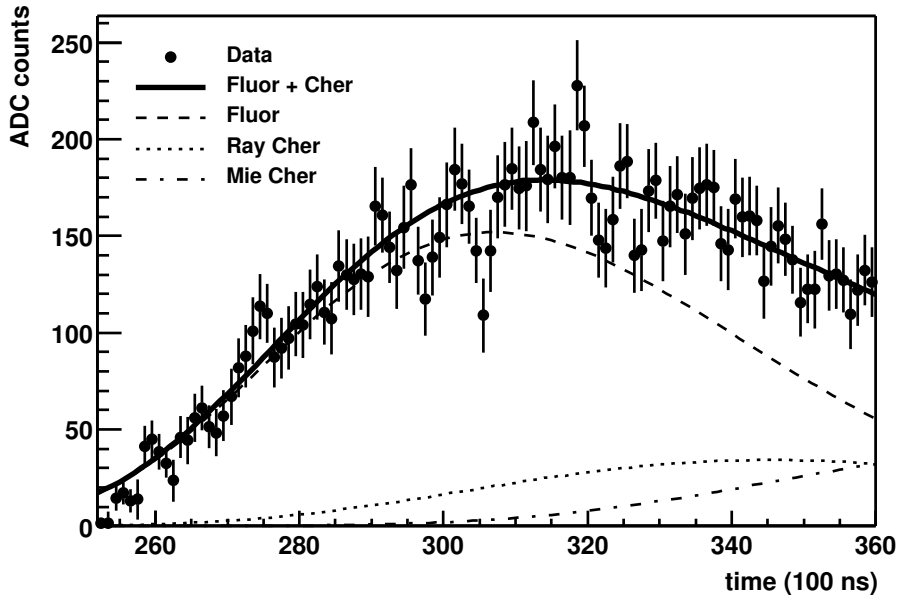


Angular resolution ≈ 1°



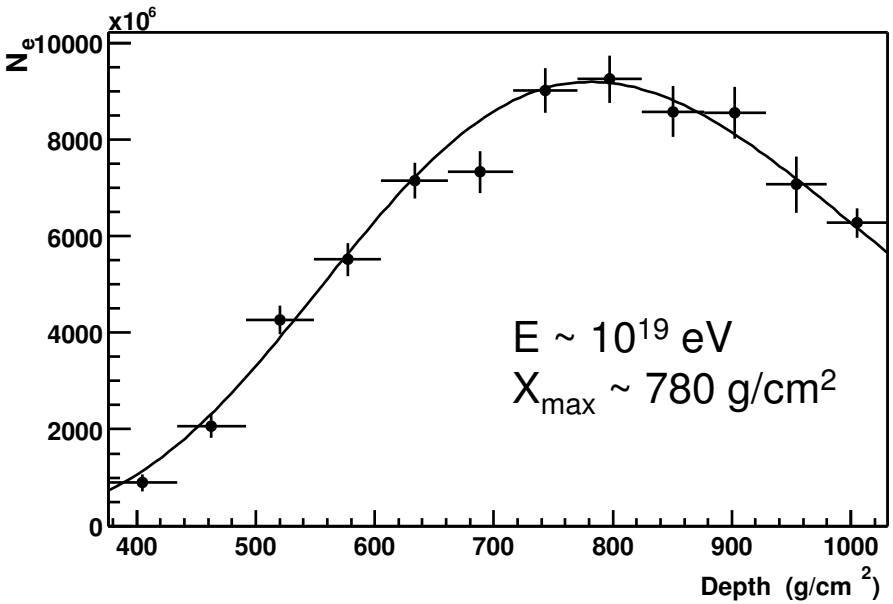
Shower energy



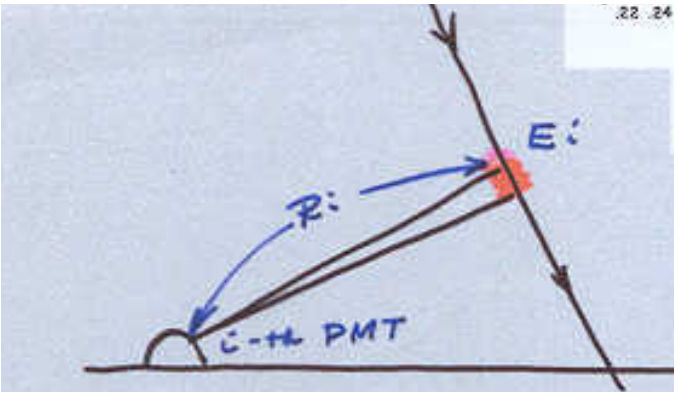


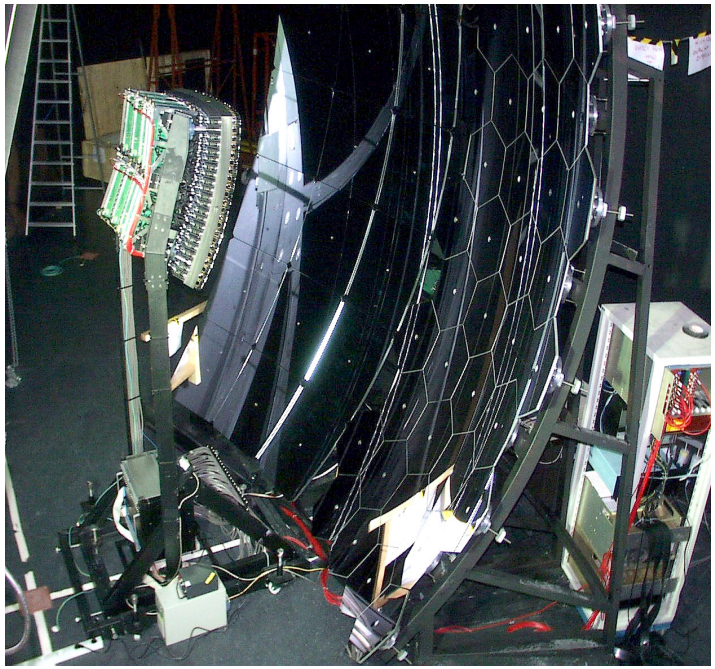
Fluorescence yield, atmosphere attenuation, pixel calibration, Gaisser-Hillas fit…

$$E_{em} \simeq \frac{E_c}{X_0} \int dX N_e(X)$$



Fluorescence yield





$$N^{p.e.} = \sum_{\lambda} N_{\gamma}(\lambda) \frac{A'}{R_i^2} \varepsilon(\lambda)\, T(\lambda)$$

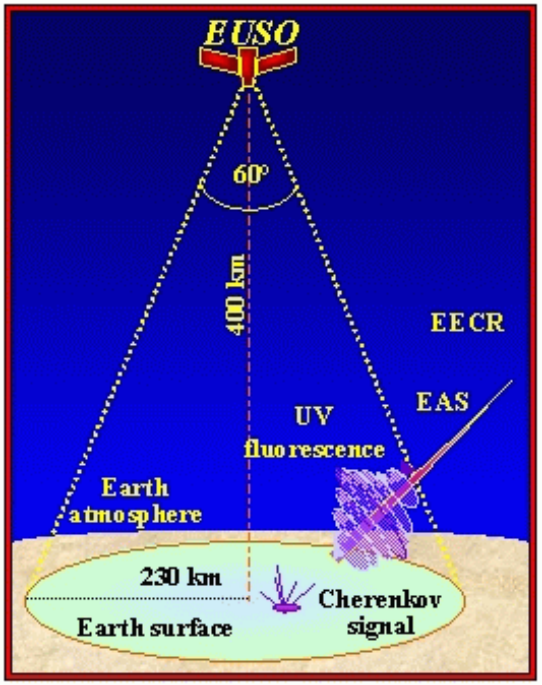
Emitted Photons

Geometry

Detector

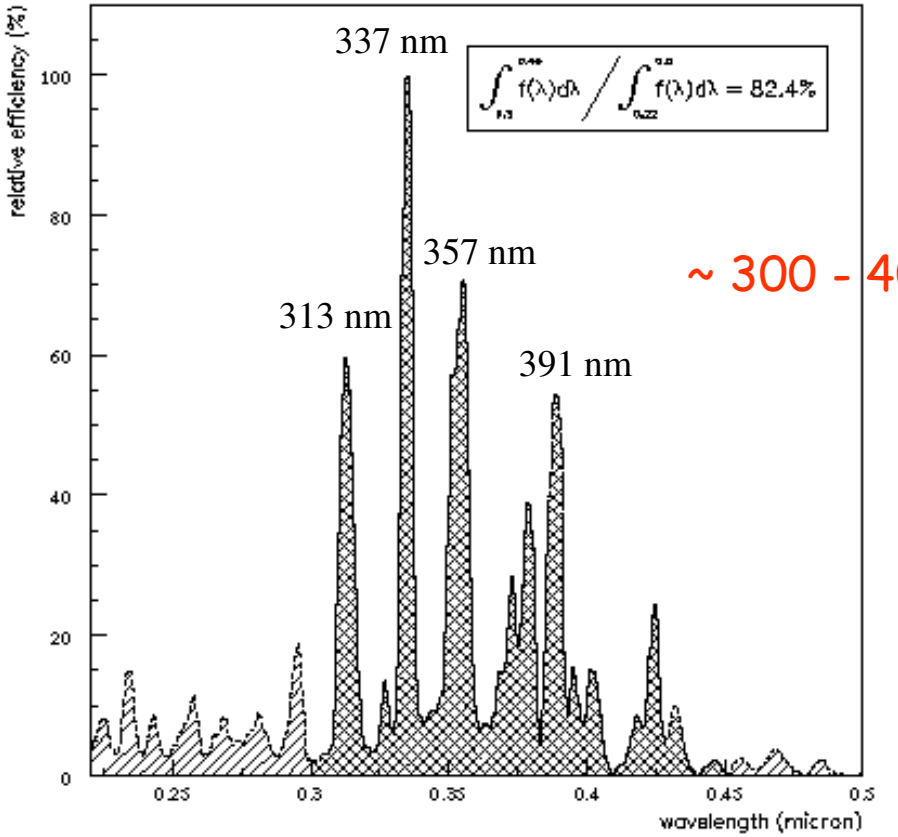
Atmosphere

Common systematics



Fluorescence yield in air

Excitation of the nitrogen molecules and their radiative dexcitation . Collisional quenching



~ 300 - 400 nm

Bunner, Ph.D Thesis
Cornell Univ. 1967

Measurements with α and 50 keV electrons totally absorbed in air

We must measure:

- **Electron energy dependence**

  ~dE/dx

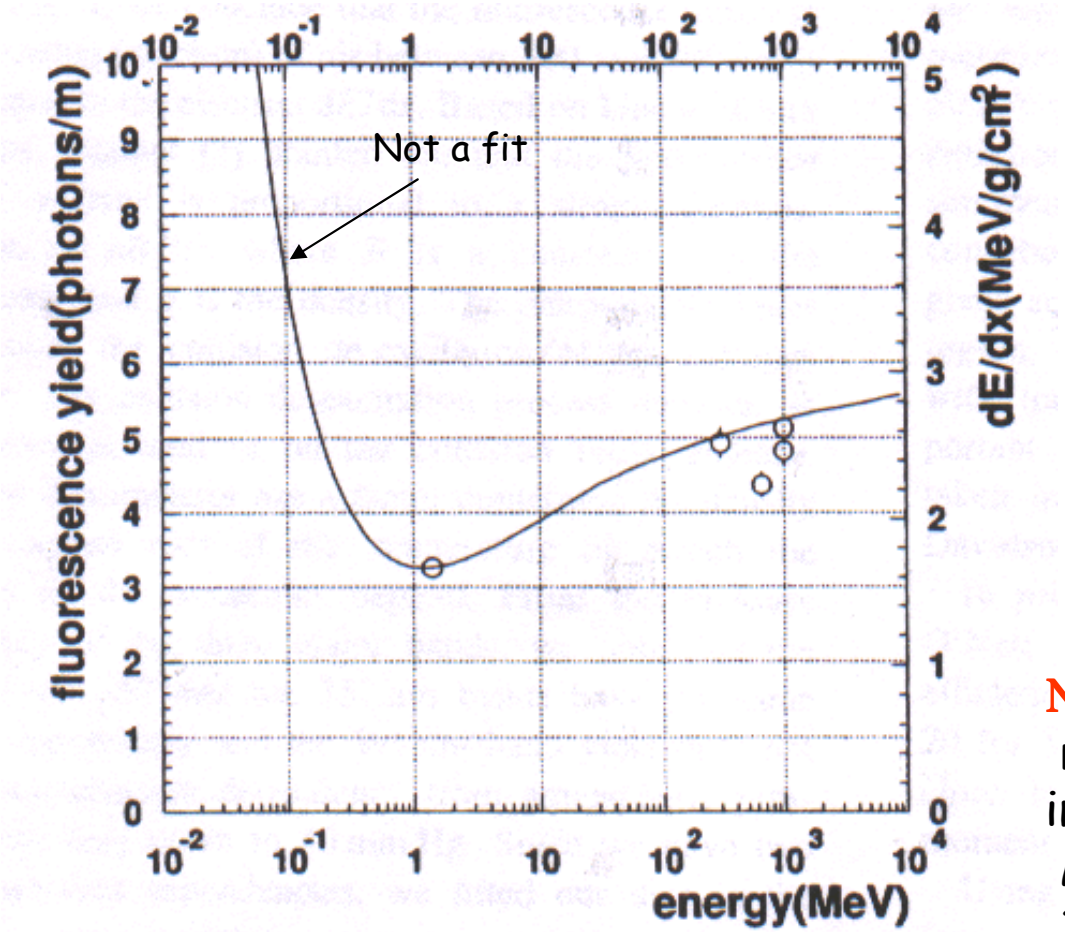
- **p and T, gas dependence**

  Yield vs altitudine
  Argon, O_2 quenching,
  water vapour over the ocean

- **λ dependence**

  Atmospheric transmission,
  Raleigh scattering ~$1/\lambda^4$

Electron energy dependence

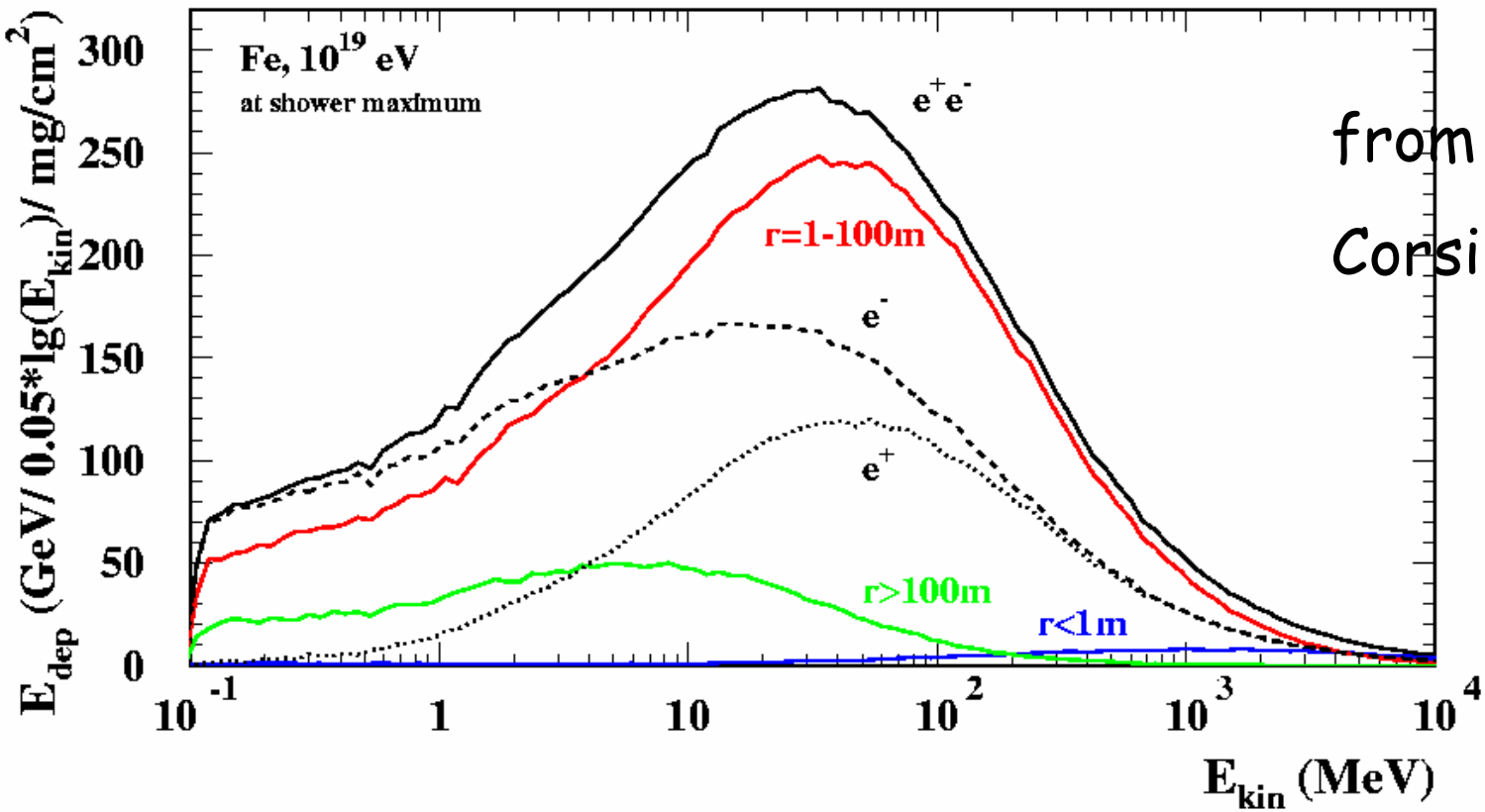


Kakimoto et al.,
NIM (1996)

~ 2 experimental points:
- 1.4 MeV ^{90}Sr
- around 1 GeV e-beam

NOTE: no measurements exist in the range of critical energy of electrons in air (80 MeV)
Most of energy deposited by 1-few hundreds MeV electrons/ positrons (see H. Klages contribution)

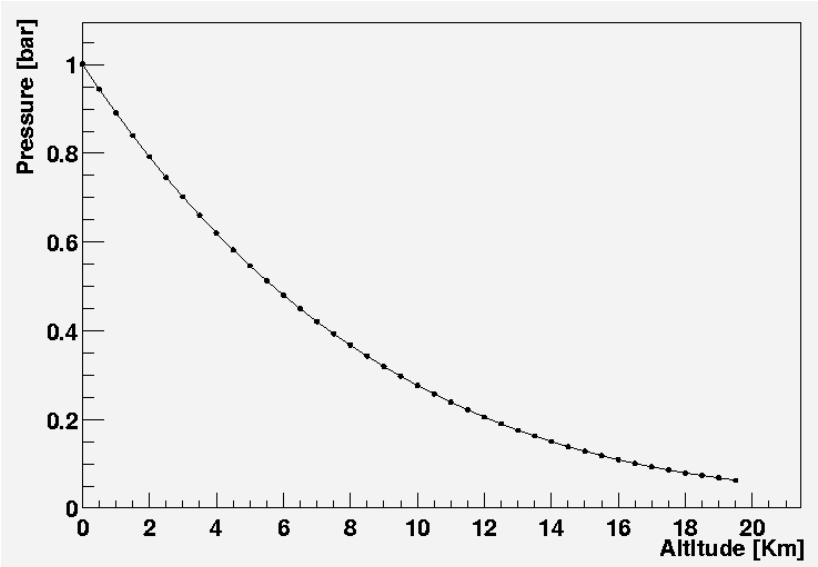
Most of the energy deposited by 1 – few hundreds MeV electrons/positrons

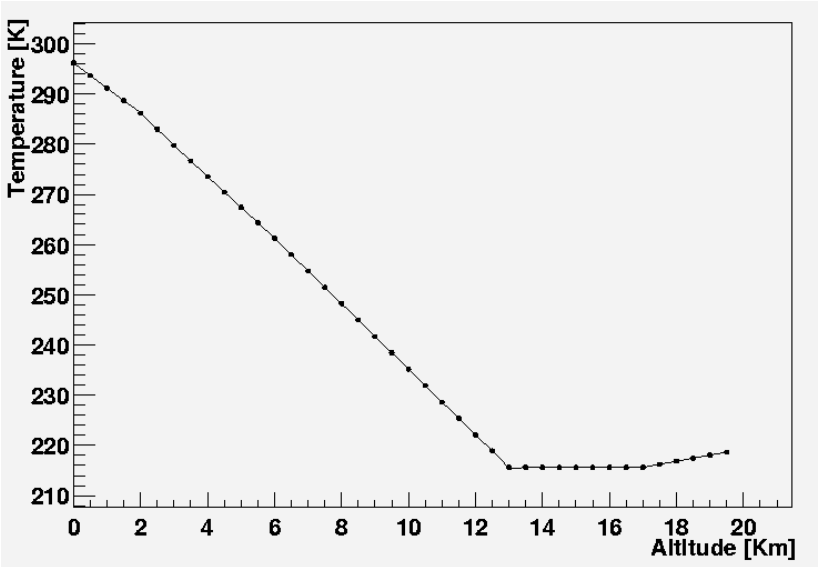


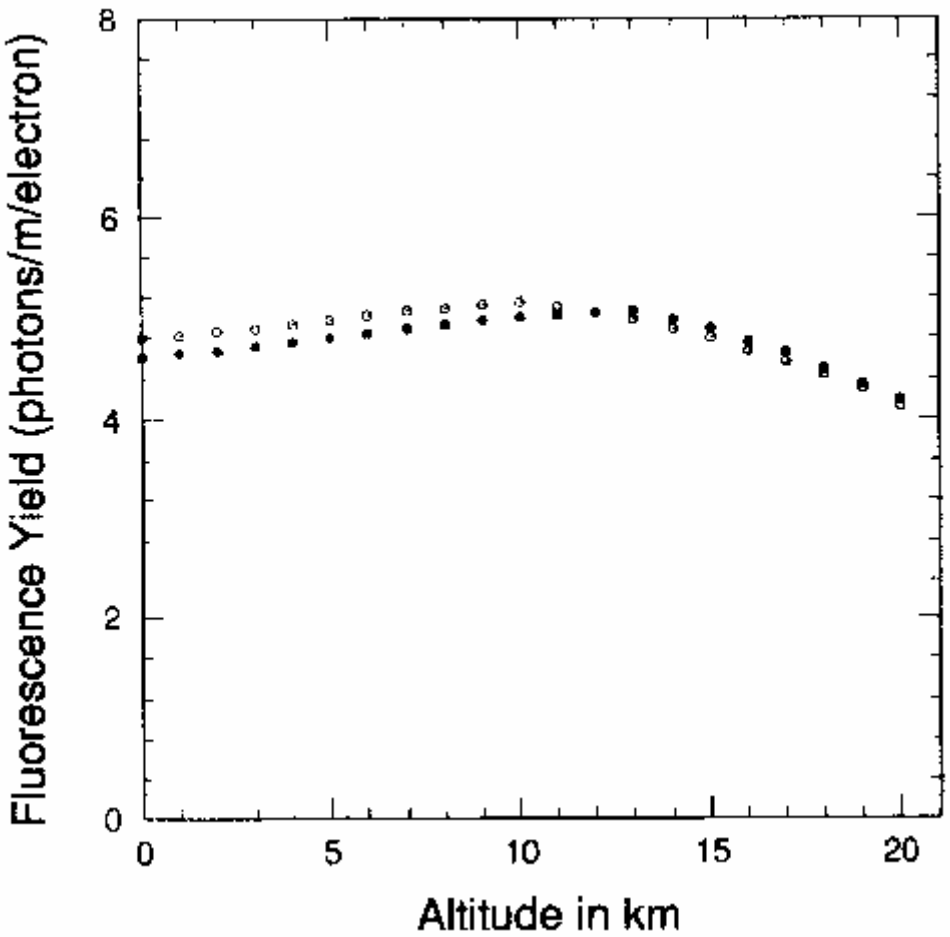
from H. Klages

Corsika study

Fluorescence yield vs altitude



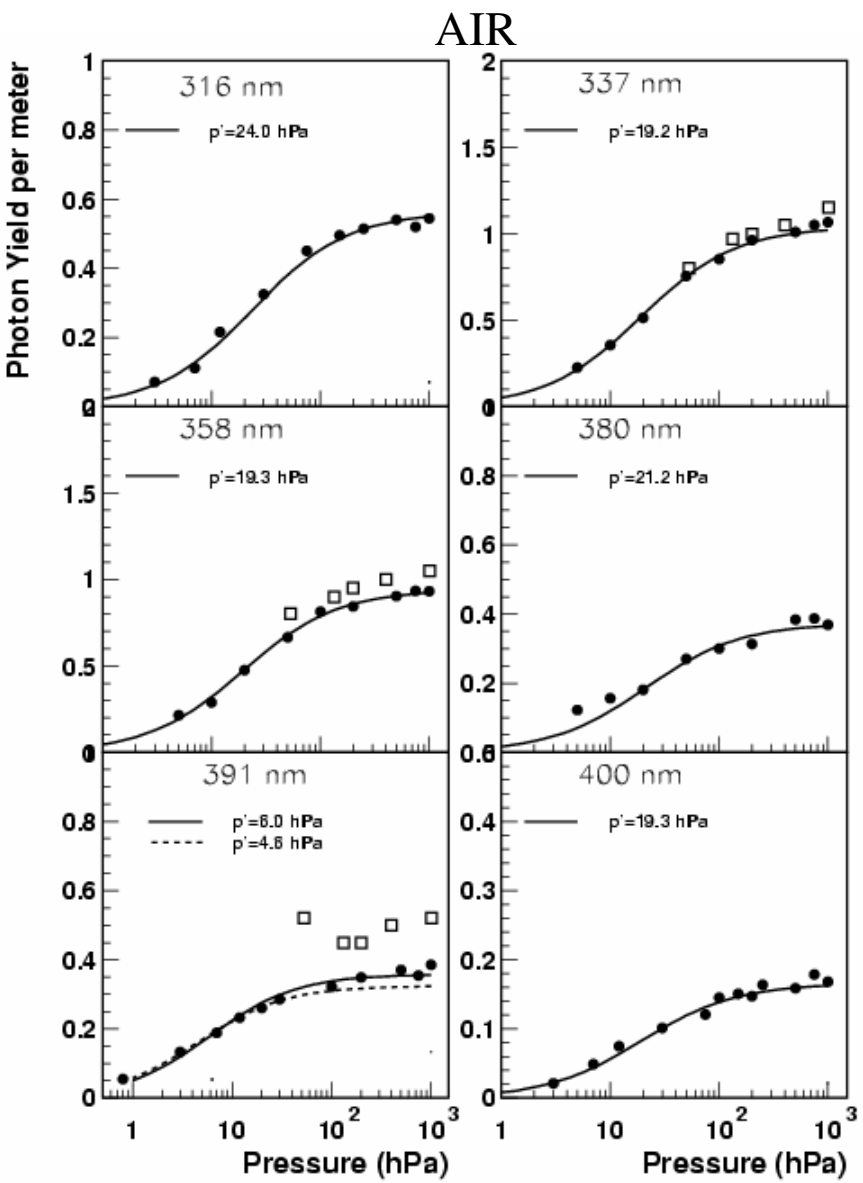


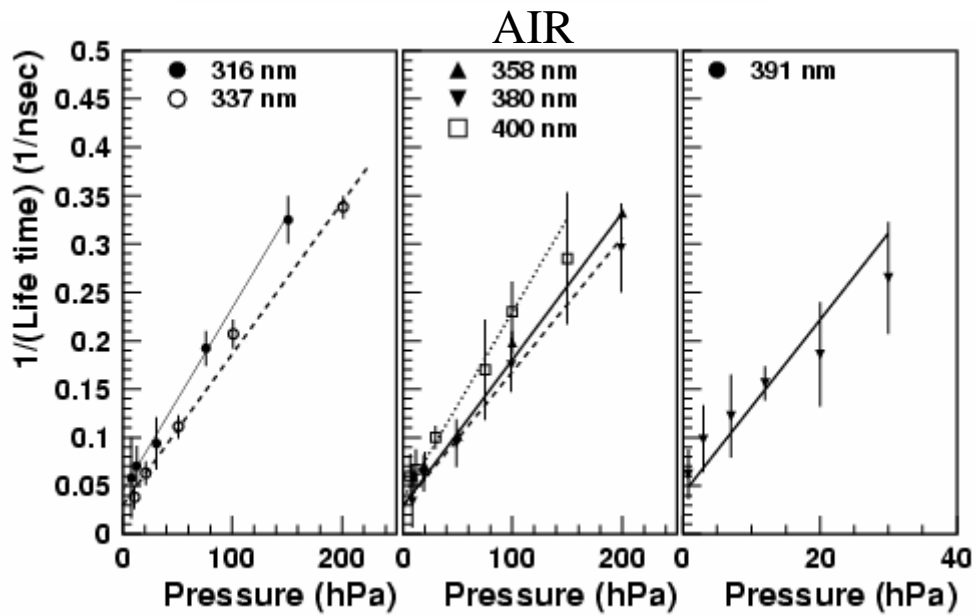


Pressure dependence

$$Fl.\ Yield \propto \frac{p}{1+p/p'}.$$

$$\tau = \frac{\tau_0}{1+p/p'}.$$





$$p' \propto 1/(\sigma_{coll}\bar{v}),$$

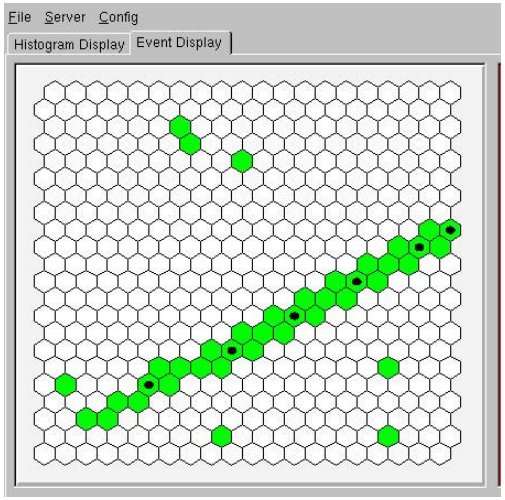
$(\propto \sqrt{kT})$

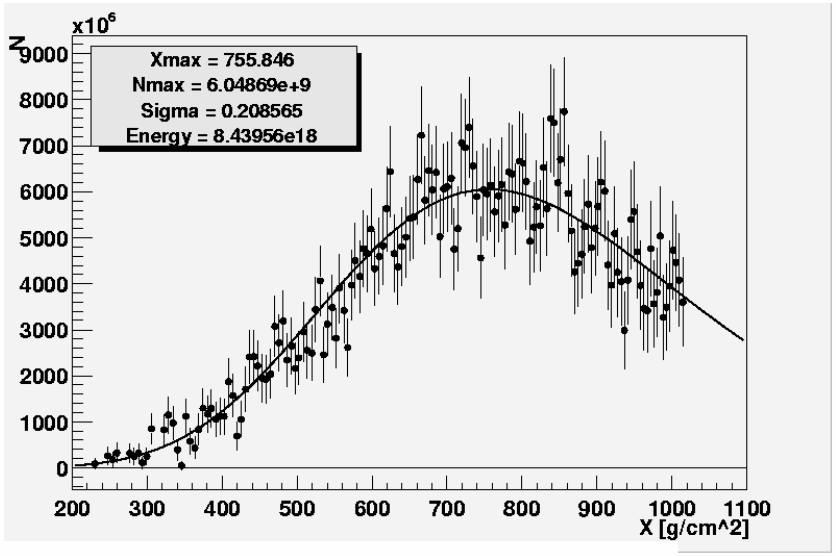
~ T independent

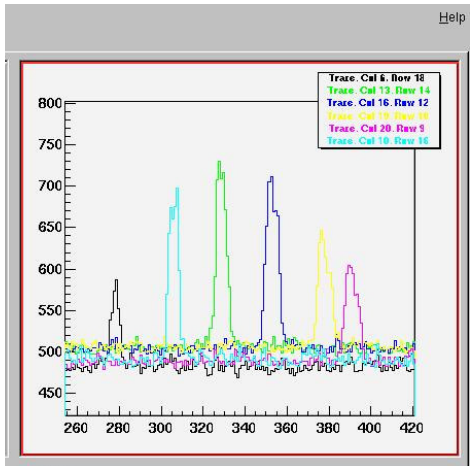
Nagano et al.,
astro-ph/0303193
β source

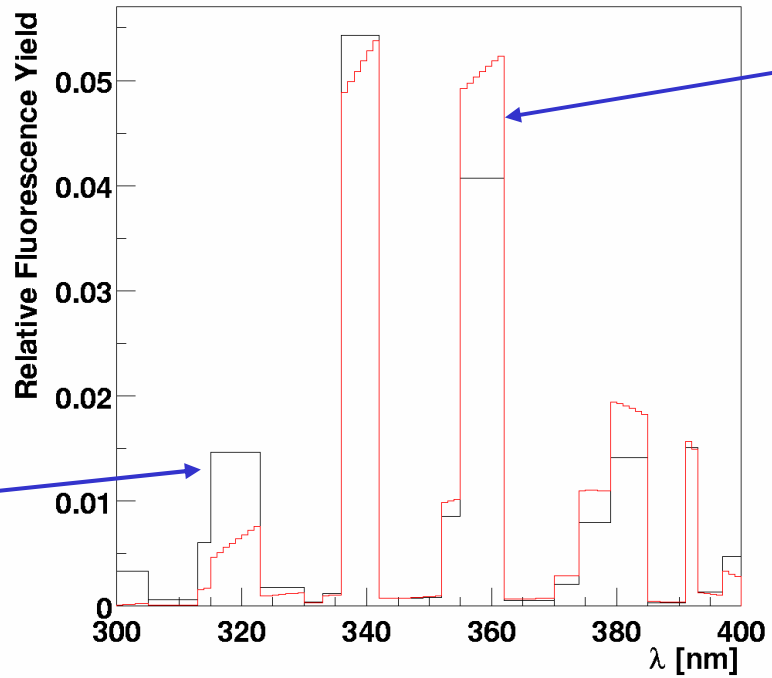
NOTE: T dependence has never been measured

Fluorescence yield spectrum







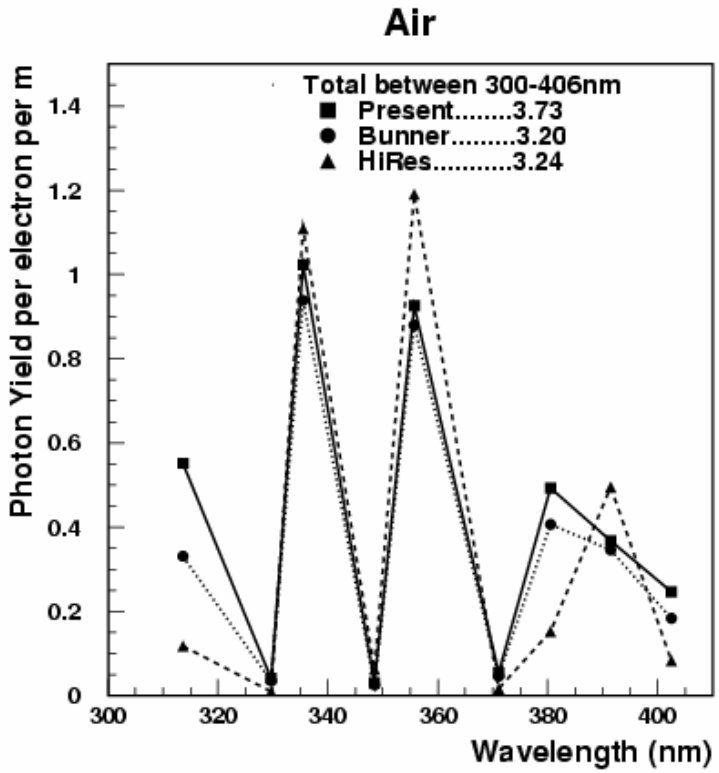


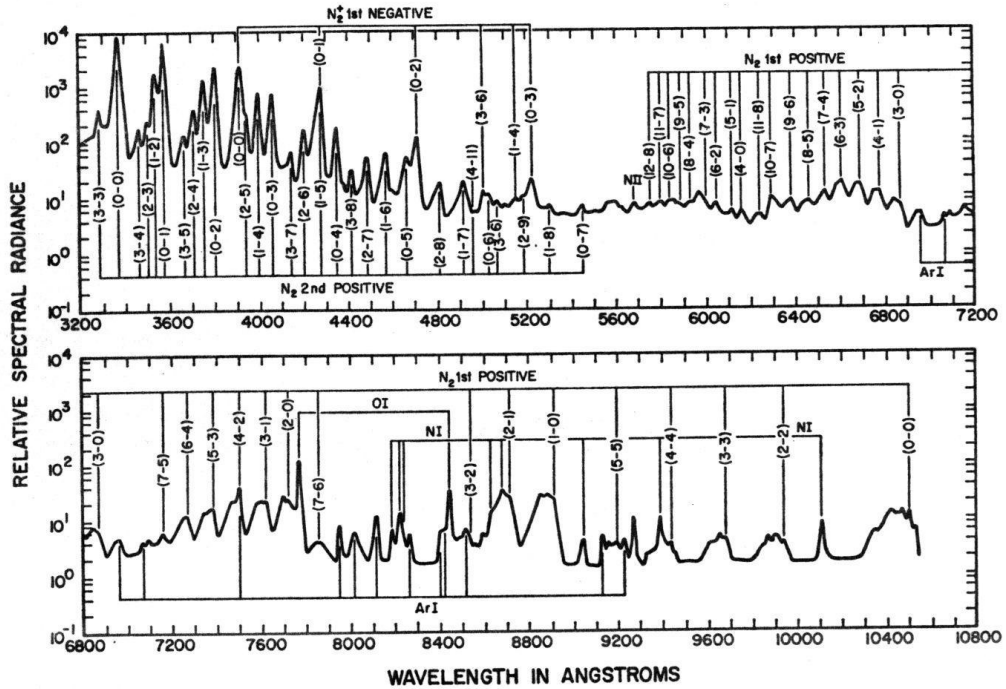
atmosphere and detector

At the shower maximum

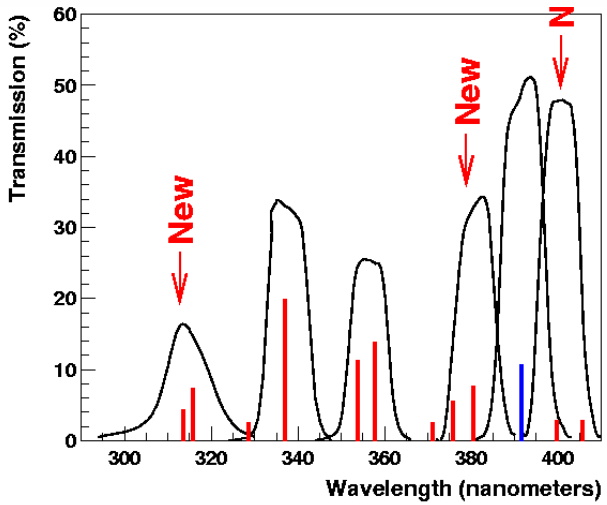
at emission point

Fluorescence yield spectrum





Davidson and O'Neil (1964)

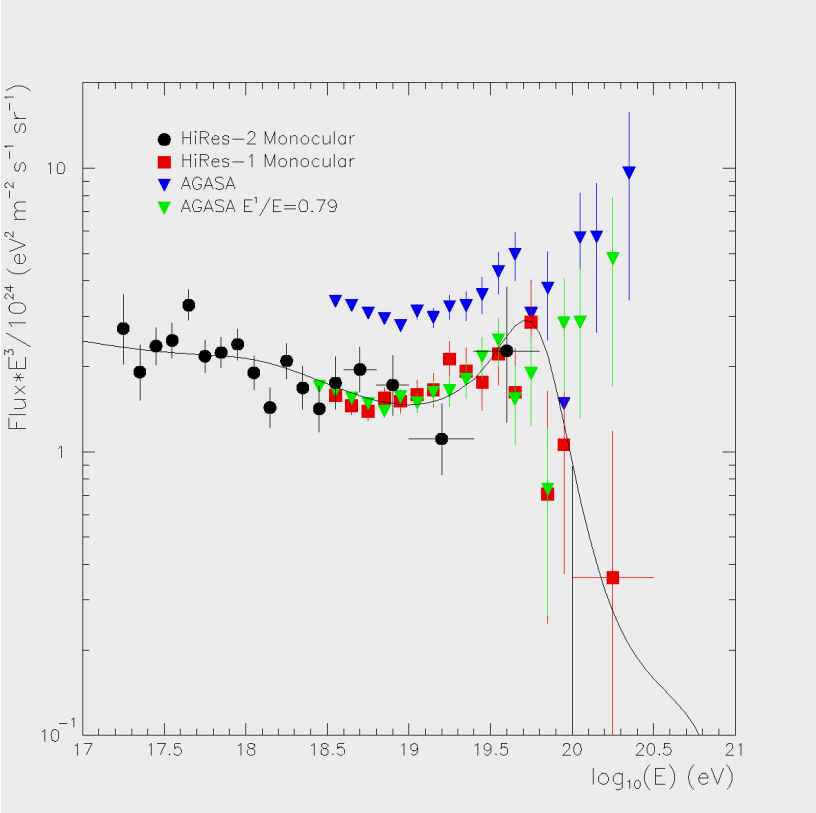


Nagano et al., astro-ph/0303193
β source

~ 10 nm filters

NOTE: the only existing detailed spectrum (50 keV electrons stopping in air at 600 torr, 1.8 nm resolution)

Absolute energy scale



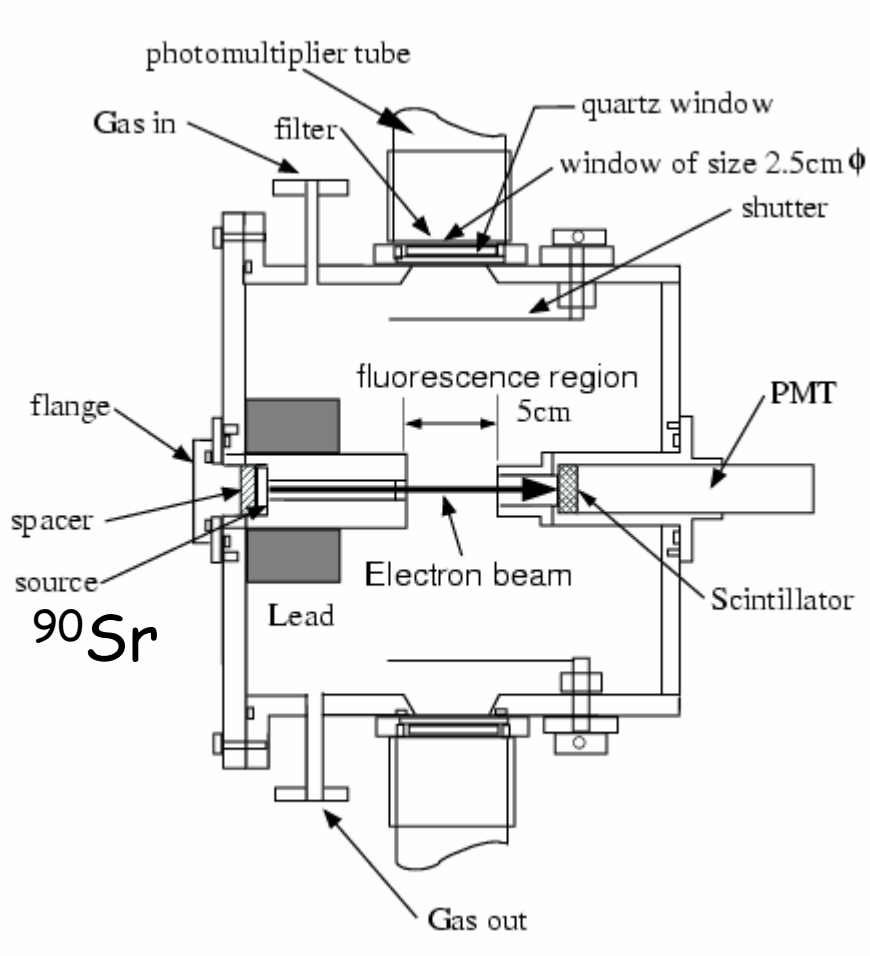
AGASA vs HIRES

Bergman (HIRES)
ICHEP 2002

We need to measure the fluorescence yield to better than 5 % (even 10% difficult....)

Nagano, Kobayakawa, Sakaki, Ando

astro-ph/0303193



i	λ	transition	ε	Φ°	A	B
	nm	state	m^{-1}	$\times 10^{-3}$	m^2kg^{-1}	$m^3kg^{-1}K^{-\frac{1}{2}}$
1	311.7	2P(3,2)				
2	313.6	2P(2,1)	0.552±0.033	0.463±0.029	19.6 ±1.2	2.04±0.17
3	315.9	2P(1,0)				
4	328.5	2P(3,3)				
5	330.9	2P(2,2)	(0.041±0.012)[a]			
6	333.9	2P(1,1)				
7	337.1	2P(0,0)	1.024±0.028	1.006±0.027	45.4 ±1.2	2.56±0.09
8	346.9	2P(3,4)				
9	350.0	2P(2,3)	(0.030±0.009)[a]			
10	353.7	2P(1,2)				
11	357.7	2P(0,1)	0.926±0.051	0.850±0.047	40.7 ±2.3	2.54±0.18
12	367.2	2P(3,5)				
13	371.1	2P(2,4)	(0.054±0.016)[a]			
14	375.6	2P(1,3)	(0.493±0.074)[b]	(0.388±0.058)[b]	(19.8 ±3.0)[b]	
15	380.5	2P(0,2)	0.367±0.038	0.289±0.029	14.7 ±1.5	2.31±0.25
17	391.4	1N(0,0)	0.204±0.079	1.33 ±0.23	69.8 ±12.	20.1 ±6.9
16	389.4	2P(3,6)				
18	394.3	2P(2,5)	0.163±0.071	0.121±0.052	6.4 ±2.8	2.25±0.09
19	399.8	2P(1,4)	0.163±0.011	0.134±0.009	7.2 ±0.5	2.54±0.24
20	405.9	2P(0,3)	(0.247±0.043)[b]	(0.205±0.035)[b]	(10.9 ±1.9)[b]	
Sum(measured)			3.40 ±0.13			
Sum(corrected)			3.73 ±0.15			

14% relative error on fluorescence yield

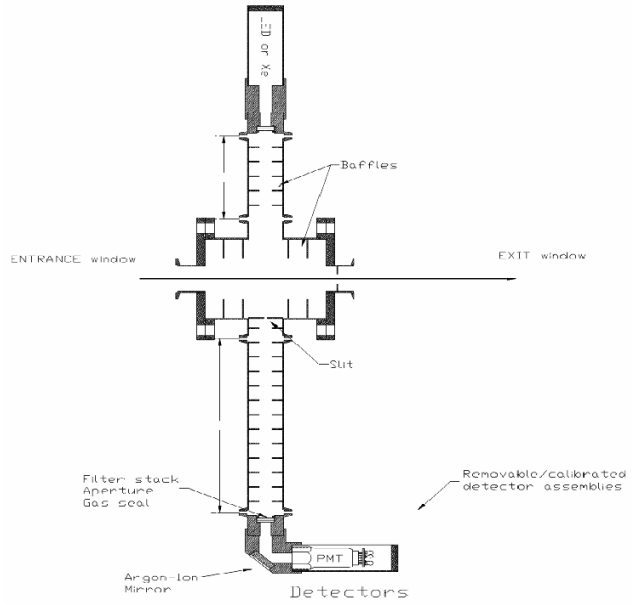
A Proposal for an Experiment (E-165):

FLUORESCENCE IN AIR FROM SHOWERS

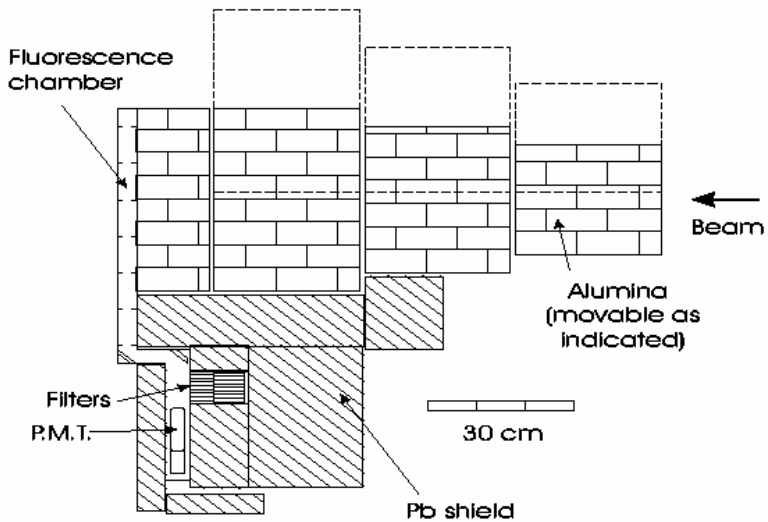
(FLASH)

August 27, 2002

J. Belz[1], Z. Cao[2], P. Chen[3*], C. Field[3], P. Hüntemeyer[2], W-Y. P. Hwang[4], R. Iverson[3], C.C.H. Jui[2], T. Kamae[3], G.-L. Lin[4], E.C. Loh[2], K. Martens[2], J.N. Matthews[2], W.R. Nelson[3], J.S.T. Ng[3], A. Odian[3], K. Reil[3], J.D. Smith[2], P. Sokolsky[2*], R.W. Springer[2], S.B. Thomas[2], G.B. Thomson[5], D. Walz[3]



SLAC 28.5 GeV e-beam



Measure fluorescence emission vs shower depth

AIRFLY

AIRFLY: Air Fluorescence Induced by Electrons in a Wide Energy Range

F. Arciprete[1], M. Bohacova[2], J. Bluemer[3], E. Bollmann[4], R. Caruso[5], P. Di Carlo[5], C. Escobar[6], A. Esposito[7], P. Facal[1], A. C. Fauth[6], C. Goletti[1], M. Hrabovsky[8], E. Kemp[6], H.O. Klages[4], M. Kleifges[4], S. Klepser[3], M. Iarlori[5], G. Matthiae[1], G. Mazzitelli[7], H. Nogima[6], M. Palatka[8], S. Petrera[5], P. Privitera[1], P. Prosposito[1], J. Ridky[2], V. Rizi[5], G. Salina[1], L. Santos[6], P. Schovanek[8], V. Vacek[9], P. Valente[7], V. Verzi[1], V. Vins[9], M. Vlcek[8], T. Waldenmaier[4]

(1) University of Rome Tor Vergata and Sezione INFN di Roma II, Italy
(2) Inst. of Physics, Czech Academy of Science, Czech Republic
(3) University of Karlsruhe, Germany
(4) Forschungszentrum Karlsruhe, Germany
(5) INFN and Physics Department, L'Aquila University, Italy
(6) Universidade Estadual de Campinas, Brasil
(7) Laboratori Nazionali di Frascati dell'INFN, Italy
(8) Joint Laboratory of Optics of PU and Inst. of Physics AS CR, Czech Republic
(9) Czech Technical University, Czech Republic

AIRFLY

- **Electron energy dependence**

  - ^{90}Sr (2.3 MeV) and ^{106}Ru (3.5 MeV) 10 mCi sources, electron and positron beam at the BTF of the L.N.F. in the range 50-750 MeV (in particular @80MeV E_{crit} air)

- **p and T, gas dependence**

  - Cylindrical chamber with p (1 mb – 1 b) and T (220-300 K) control, gas system with N_2 , O_2 and Ar mixing, artificial dry "air", water vapor control

- **Wavelength dependence**

  - low noise PMT + interference filters, calibrated light source, spectrophotometer

- **Application as monitor of the beam intensity**

  - The absolute calibration of the fluorescence yield allows a non-destructive measurement of the beam intensity (particularly interesting at low intensity $\leq 10^7$ part./bunch)

The DAΦNE Beam Test Facility

Electrons production scheme

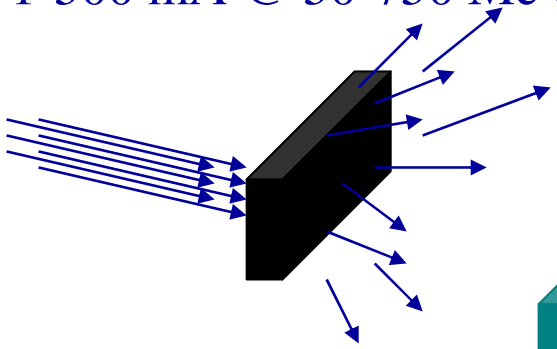
Pulse Duration 1-10 ns

Max. repetition rate 50 Hz

LINAC Beam

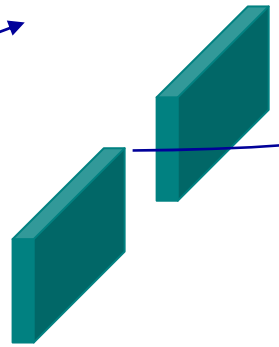
(Max. 10^{10} particles/bunch)

1-500 mA @ 50-750 MeV

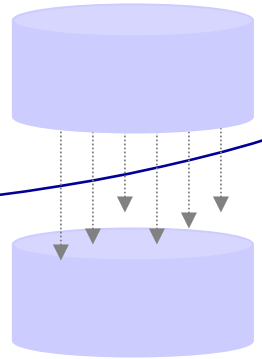


tunable Cu target:

1.7, 2.0, 2.3 X_0



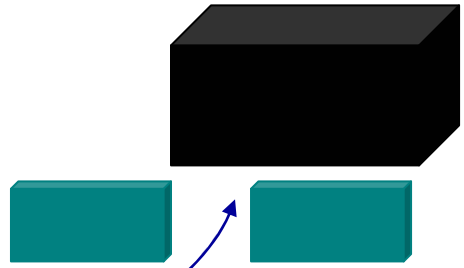
collimators



45^0 magnet

BTF HALL

calorimeter

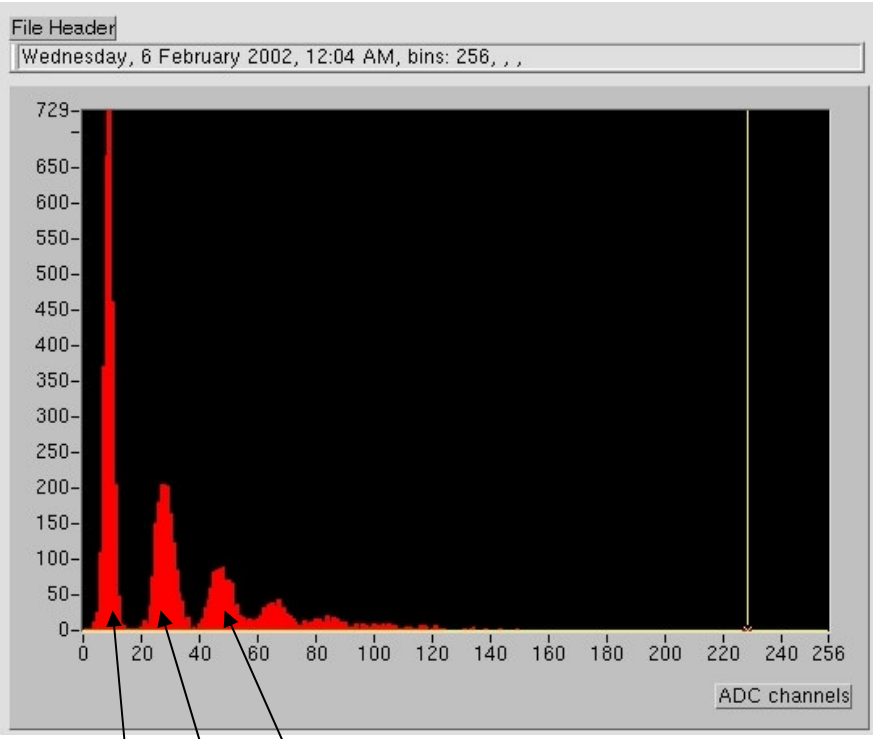


50-750 MeV beam

1% energy spread

The Beam Test Facility at DAΦNE

~ single electron/bunch

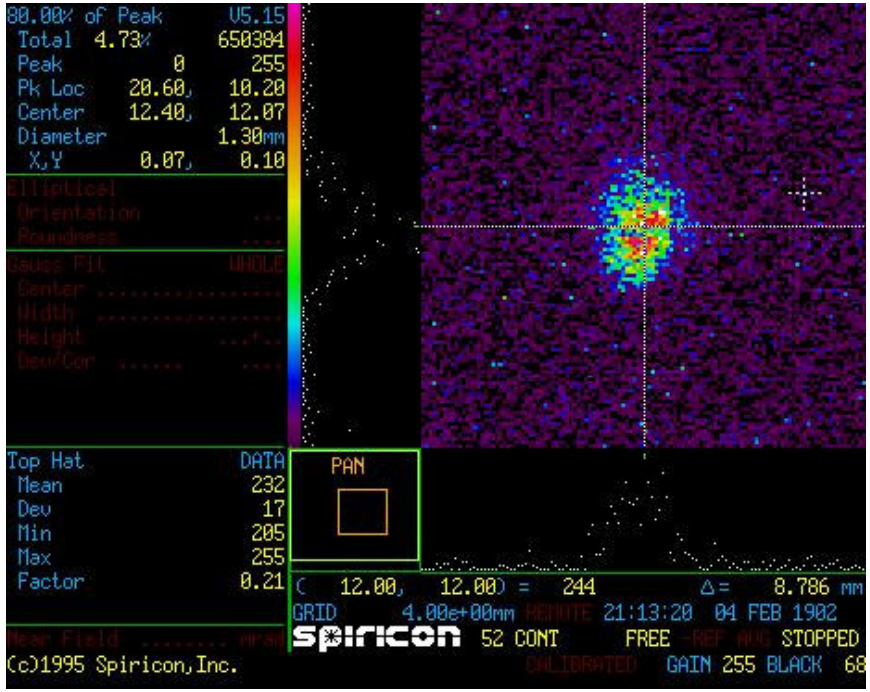


1 2 3

energy measured

at the BTF calorimeter

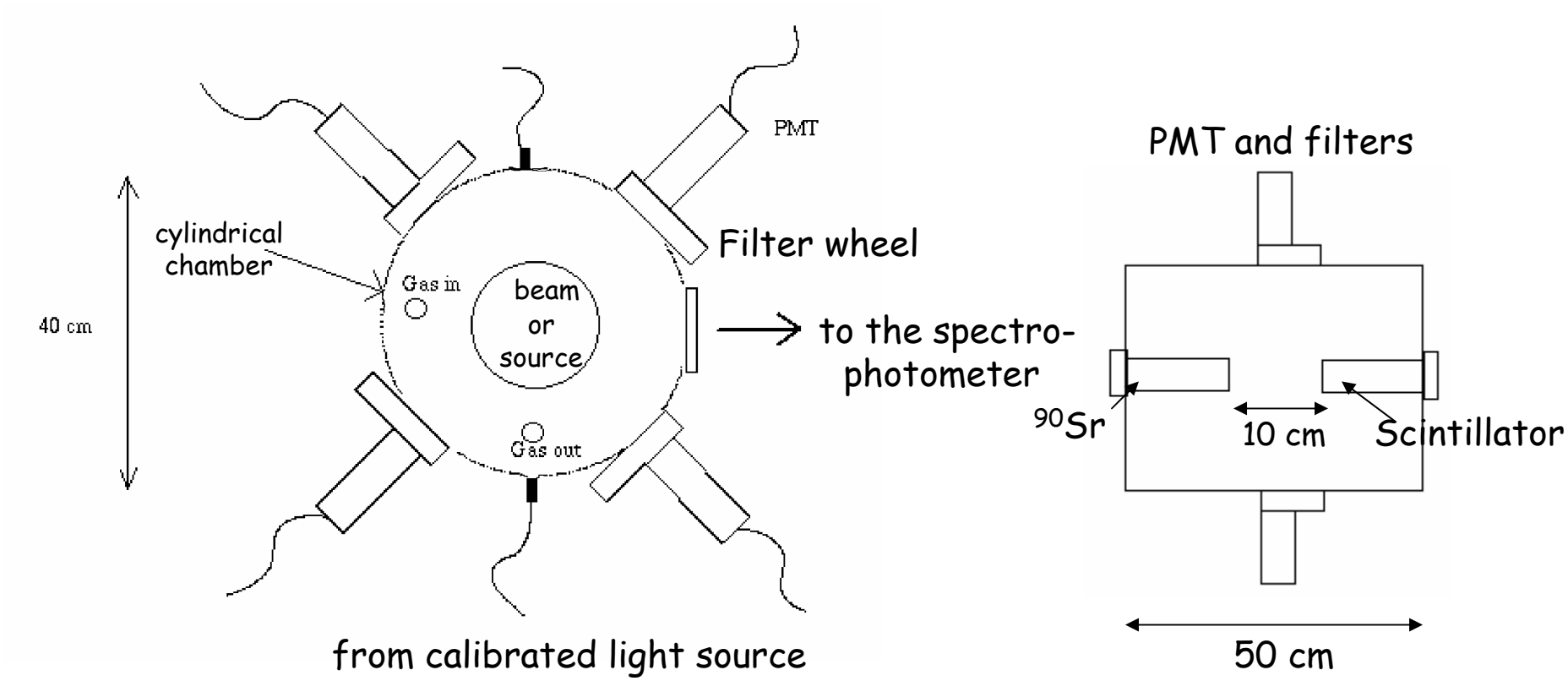
Beam spot ~ 1 mm diameter



Possible to defocus beam to

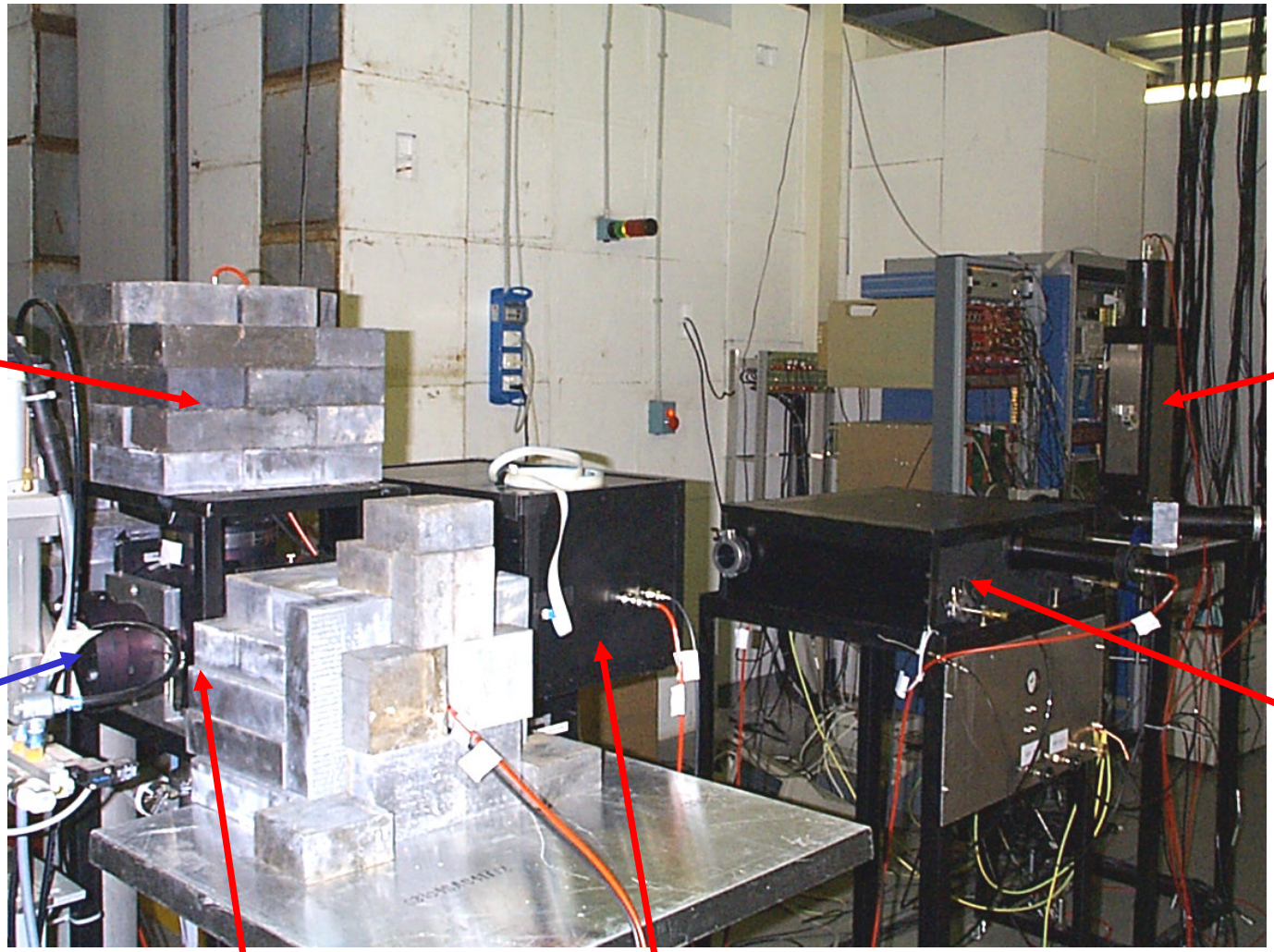
test density effect

The chamber

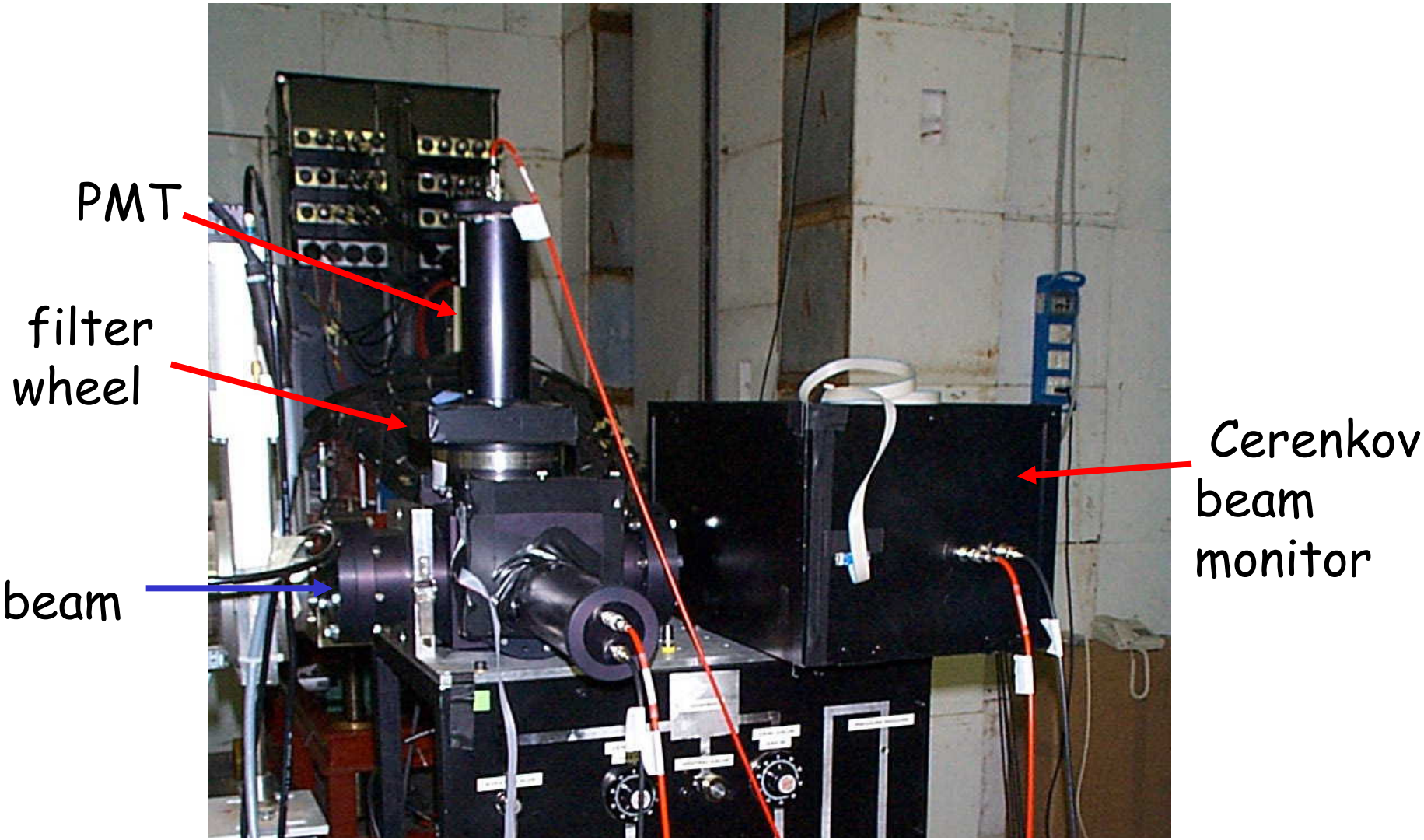


A smaller chamber (20 cm diam. e 20 cm height) will be used as beam intensity monitor

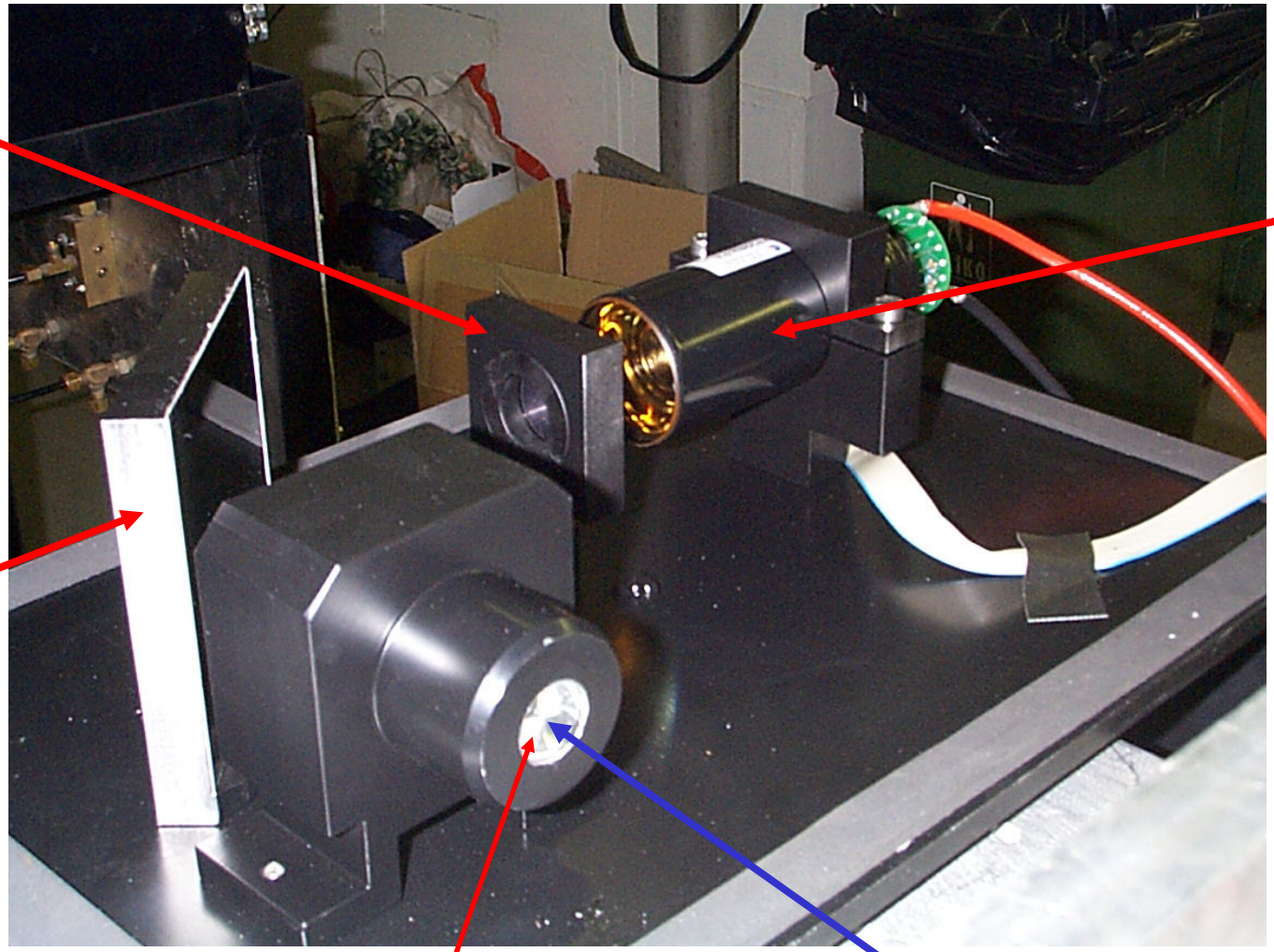
AIRFLY at the BTF

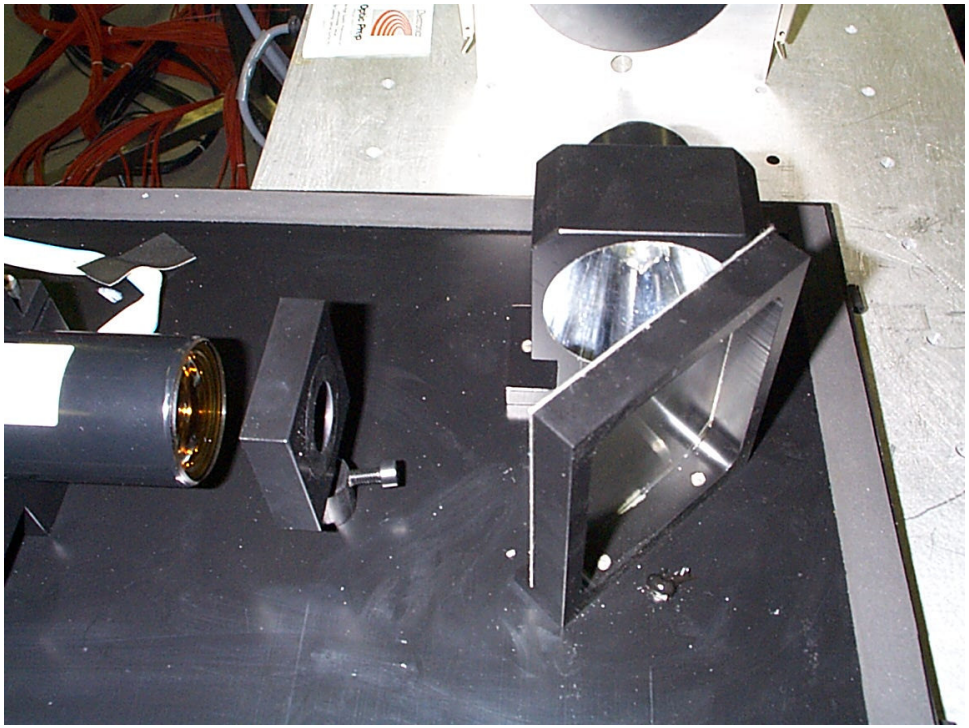


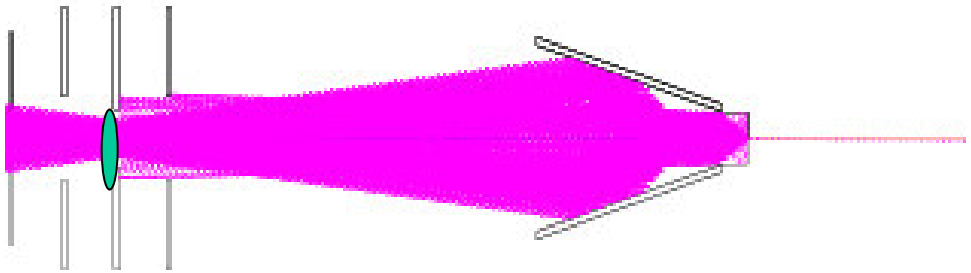
The fluorescence chamber at the BTF



The Cerenkov beam monitor







The Cerenkov beam monitor

The Cerenkov light is extracted from the plexiglass radiator by appropriate shaping of the end part without optical connection to the PMT.

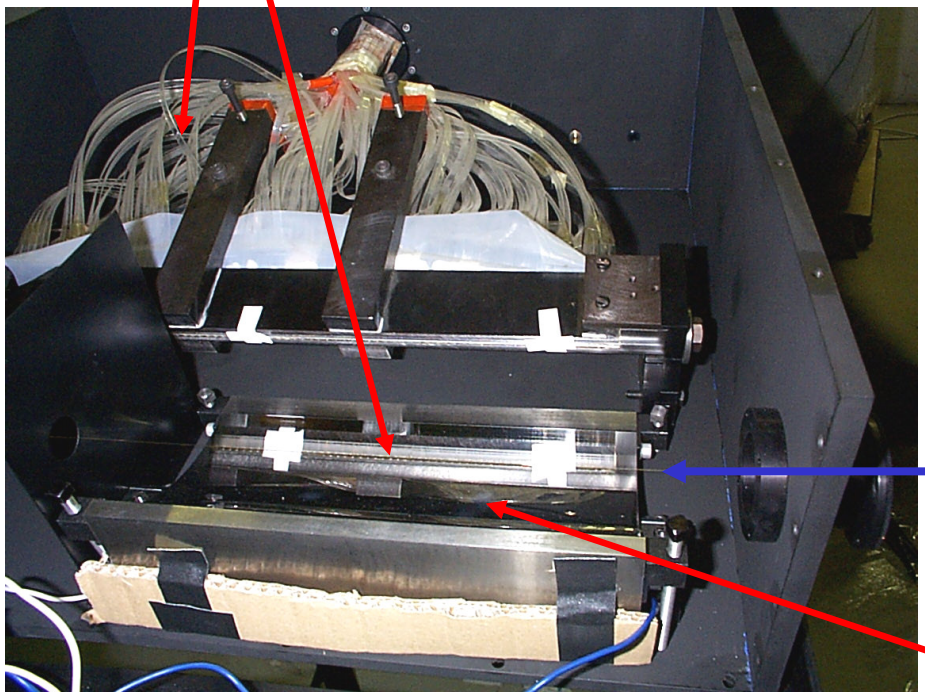
Calibrated attenuating filters allow the measurement of the beam intensity over several order of magnitudes.

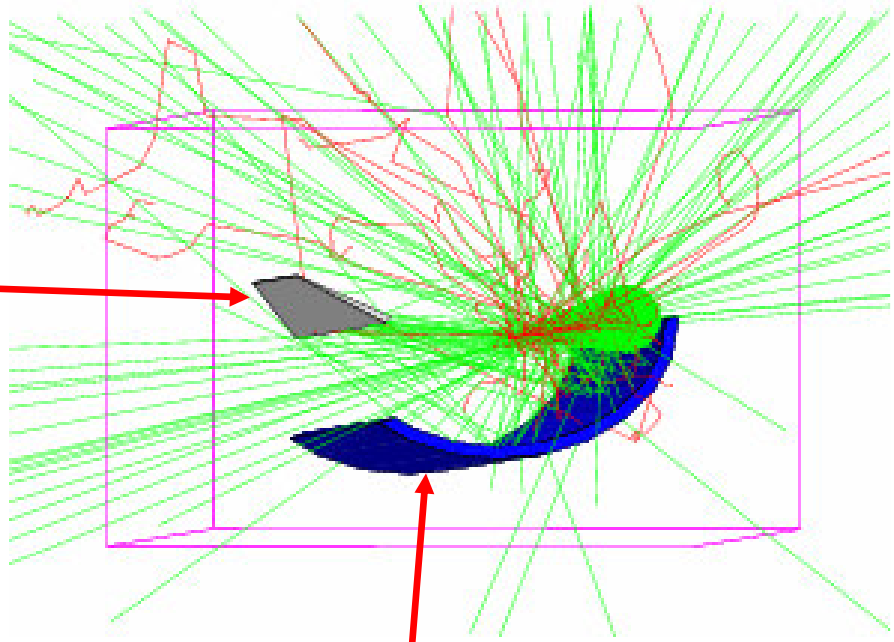
Inter-calibration with the calorimeter

The elliptical mirror chamber

Light collecting fibers

To PMT





beam

Elliptical mirror

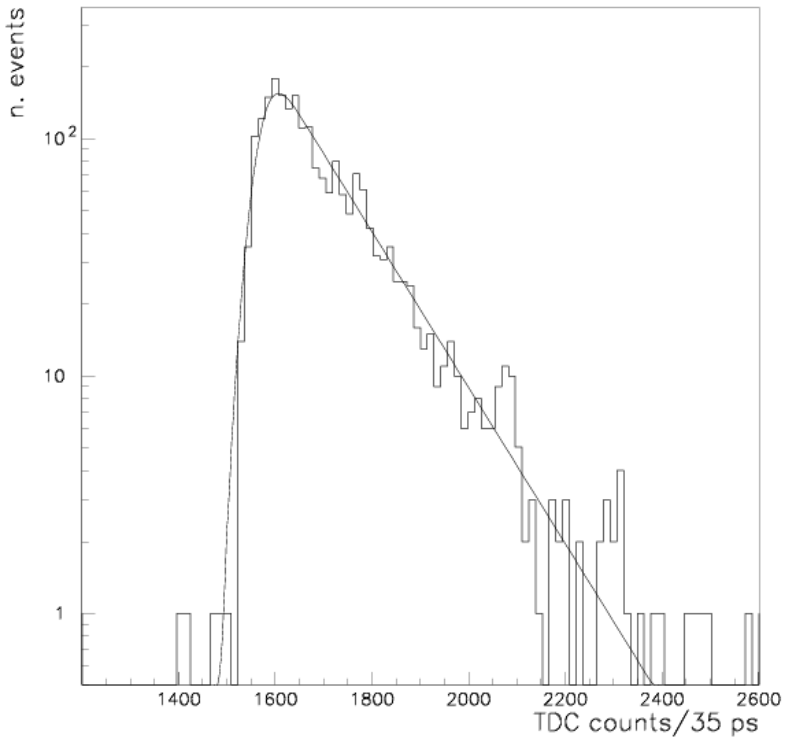
Significantly increased acceptance

Measurements at the first test beam

- Understanding and optimization of beam associated background. Improved shielding along the BTF line and around PMTs.
- Successful BTF commissioning of 1 ns bunch for fluorescence lifetime measurement
- Operation of fluorescence chamber with nitrogen and dry air. Remote control of gas and pressure. First measurements with interference filters. First energy scan.
- Successful test of elliptical mirror concept (factor 10 higher light collection)
- Inter-calibration of calorimeter and Cerenkov beam monitor.

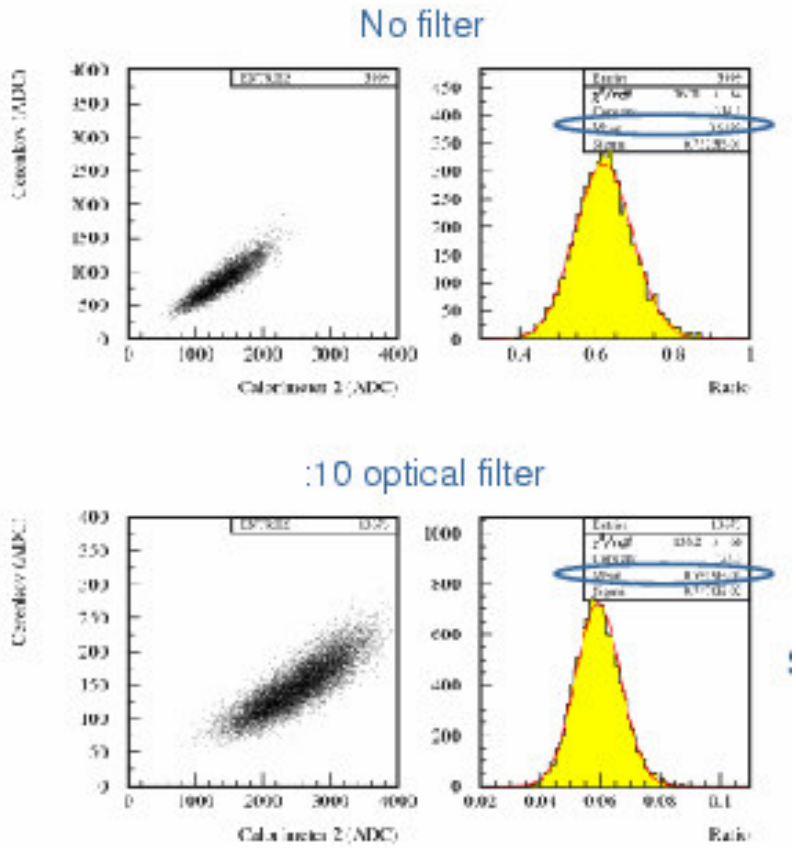
First measurements at the test beam

Fluorescence Lifetime
≈5 ns at 340 mbar N_2



Calorimeter – Cerenkov

Inter calibration



Outlook

- The community has recognized the importance of different approaches to the measurement and interpretation of the fluorescence yield (First International Workshop on Air Fluorescence, Utah Oct. 5-8 2002).
- Several independent experiments are being planned/performed. Goal: absolute measurement of the fluorescence yield at better than 10%.
- AIRLIGHT 03, Burg Liebenzell, 11-14 Dec. 2003
- Fluorescence yield and atmosphere:
  p,T vs altitude, gas composition
  wavelength attenuation