

# ***L' ESPERIMENTO***



# Gli obiettivi di fisica

## Nucleon spin structure

- Gluon polarization  $\Delta G(x)$
- Flavour-dependent helicity functions  $\Delta q(x)$
- Transverse-spin distribution functions  $\Delta_T q(x)$
- Spin-dependent fragmentation ( $\Delta D^{\Lambda_n}$ )

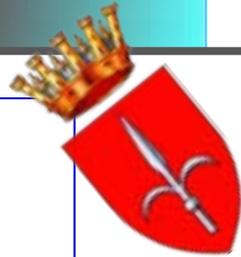
*Studio della struttura di spin dei nucleoni, cioè dei componenti dei nuclei atomici: p, n*

## Spectroscopy

- Primakoff reactions
  - Polarizability of  $\pi$  and K
- Glueballs and hybrids
- Charmed mesons and baryons
  - Semileptonic decays
  - Double-charmed baryons

*Studio della zoologia delle particelle di tipo adronico (fra le quali vi sono i nucleoni)*

# COMPASS & TRIESTE



Un gruppo di fisici di Trieste e' stato fra i proponenti di COMPASS e il loro interesse di fisica e' centrato sullo studio della struttura di **spin** dei nucleoni

Hanno contribuito all'esperimento anche progettando e realizzando un rivelatore che e' una delle maggiori sfide realizzative di COMPASS: il **RICH-1**

# LO SPIN: una proprietà fondamentale

- lo *spin* : il "momento angolare innato" delle particelle intuitivamente (ma impropriamente) immaginato come il movimento di una **trottola**
- *puo' avere solo valori interi o seminteri del cosiddetto **quanto di azione di Plank***
- **$e, p, n$  hanno spin  $1/2$**
- lo spin dell'elettrone **determina la distribuzione degli elettroni negli orbitali atomici** e quindi gioca una funzione preminente nei processi chimici; lo spin del protone e del neutrone svolge **un ruolo essenziale nella struttura dei nuclei** → il mondo intorno a noi e' fatto così come lo vediamo perché  $e, p, n$  hanno spin  $\frac{1}{2}$  !



# p, n - sono ELEMENTARI ?

- p, n : **NUCLEONI**
- dalla teoria di DIRAC  
per una particella *elementare* con spin  $\frac{1}{2}$  e carica elettrica  $\rightarrow$  momento magnetico, direttamente proporzionale alla carica ed inversamente proporzionale alla massa
- questo non e' verificato per i nucleoni
- p ha momento magnetico  $\sim 3$  volte maggiore
- n ha momento magnetico  $\sim -2/3$  quello di p

# L'evoluzione della conoscenza del protone

- Negli anni '50 a Stanford, in California si misura la dimensione finita (= non e' puntiforme !!!) del protone ( $\sim 1\text{fm}$ )
- Negli anni '60, sempre a Stanford, si scopre con sorpresa che il protone ha una struttura interna, fatta di partoni
- Classificazione degli adroni: si introducono i quark
- Identificazione partoni

1919

anni 60

anni 70

anni 90



*particella elementare*

*partoni*

*quark e gluoni*

*quark del mare*

# Il contesto

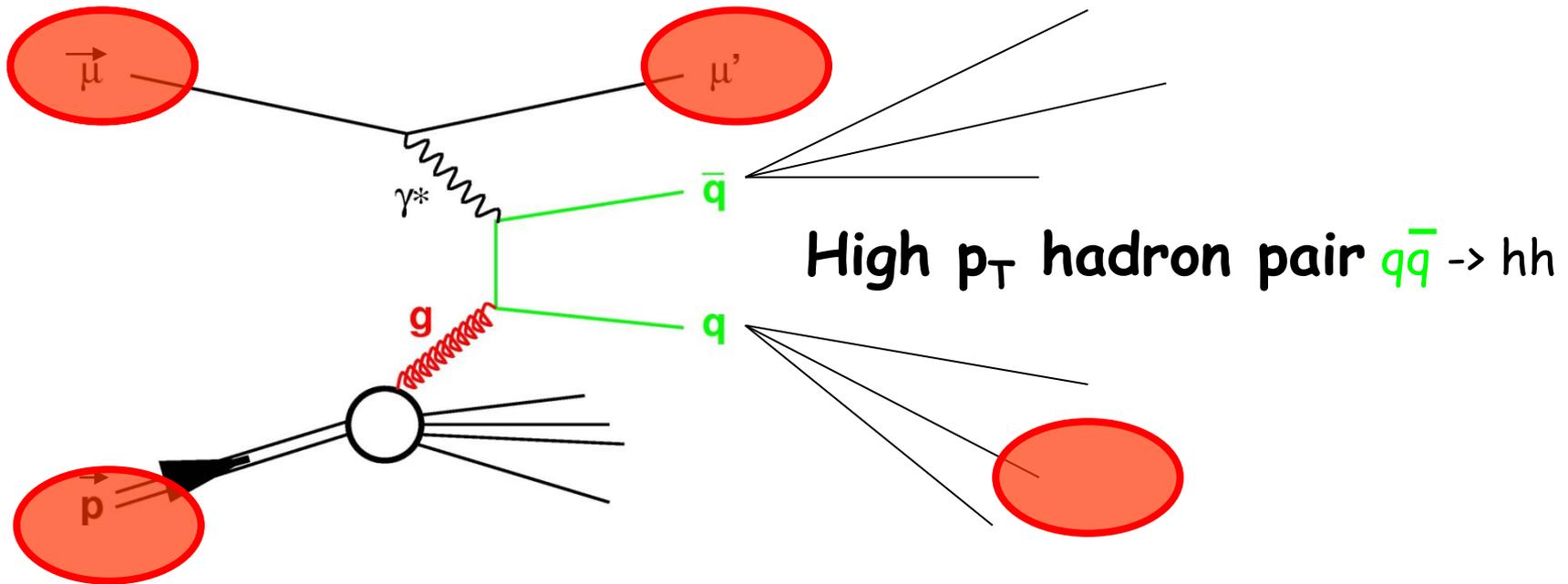
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- Negli anni '60, sempre a Stanford, si scopre con sorpresa che il protone ha una struttura interna, fatta di partoni
- I partoni risultano avere spin  $\frac{1}{2}$ , come gli elettroni
- Negli anni '70 la disponibilità di bersagli polarizzati consente di studiare l'urto profondamente inelastico polarizzato e nell'83 la prima misura (SLAC-Yale) è in accordo con le aspettative basate sul modello a quark
- Nel 1988 dalla EMC del CERN esce un risultato incredibile: solo una frazione molto piccola (forse 0) dello spin del protone è dovuta allo spin dei quark

# Il contesto

- Più di mille articoli teorici vengono scritti, con le più svariate interpretazioni di questa "crisi dello spin"
- Una nuova generazione di esperimenti, in Europa e negli Stati Uniti, inizia uno studio sistematico di questo fenomeno, confermando il risultato di EMC
- I risultati presentano un quadro sempre più ricco, ma lasciano intatto il quesito iniziale: dove sta lo spin del protone?
- Nel 1994 risulta chiaro che solo un nuovo approccio, con un apparato sperimentale diverso, capace di analizzare le particelle uscenti dall'interazione principale può consentire di rispondere a una domanda chiave: qual'è l'apporto dei gluoni allo spin del protone?

# $\Delta G/G$ from $c\bar{c}$ and high $p_T$ hadron pairs

Photon Gluon Fusion:  $\gamma g \rightarrow q\bar{q}$



# La Collaborazione

- **1996: *COMPASS Proposal***
- **1997: *CERN approval of the Experiment***
- **2000: *Technical run***
- **2001: *Commissioning + 2 weeks of data***
- **2002: *Physics run***

**30 Istituti da 10 Stati**

**250 fisici**

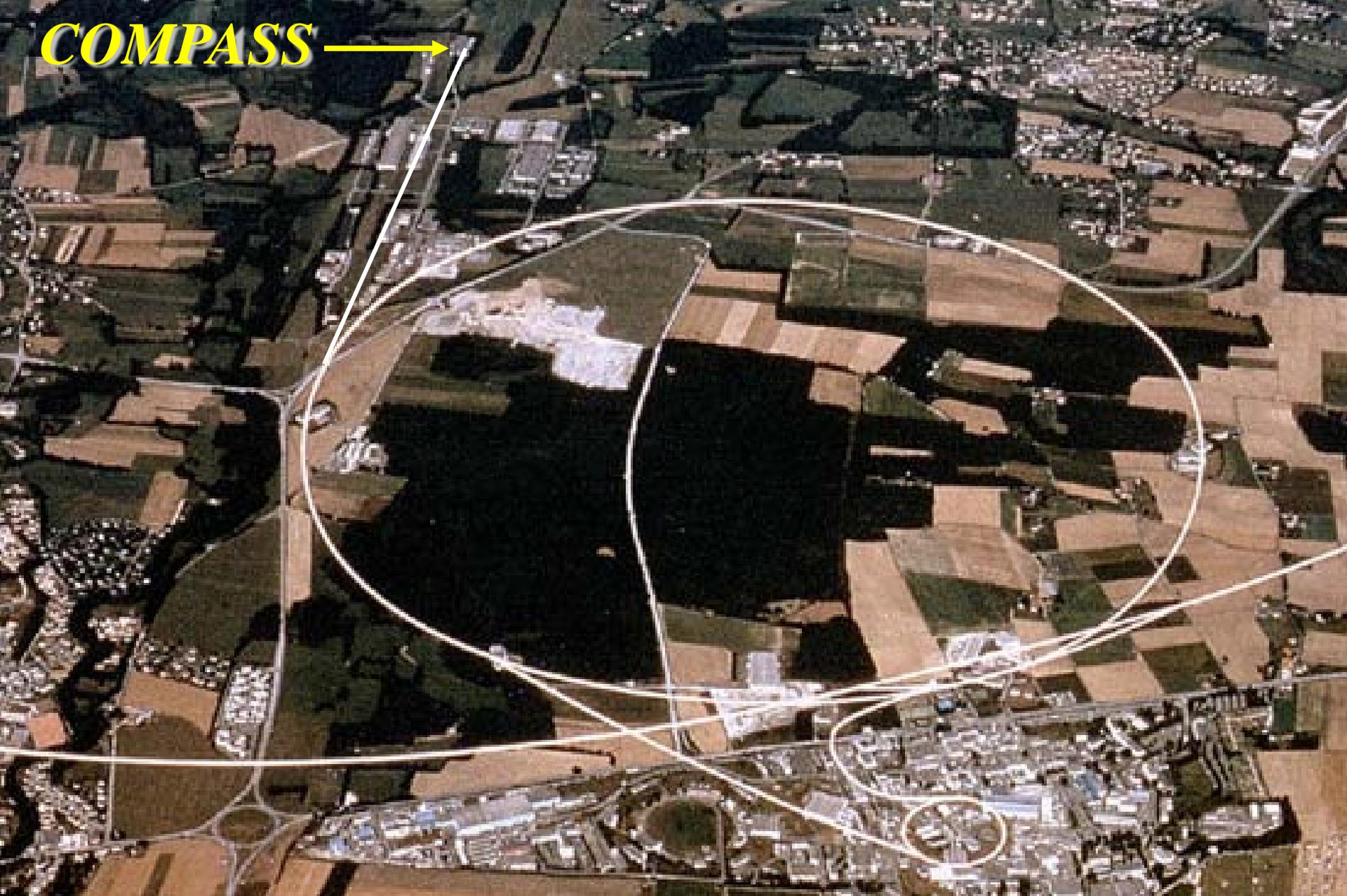
*Jura*

*Geneva Lake*

*COMPASS*

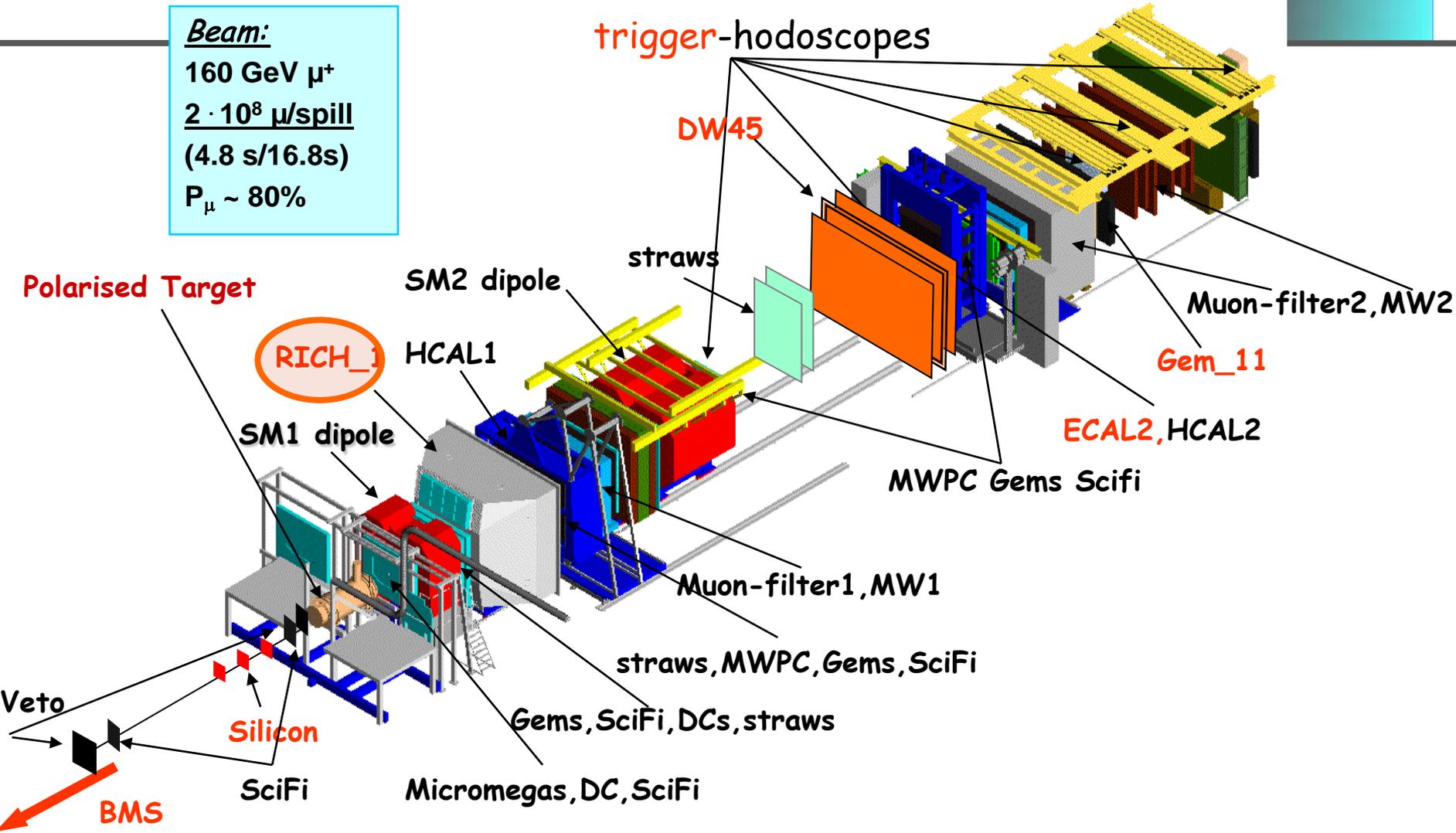


**COMPASS** →



# THE COMPASS SPECTROMETER

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

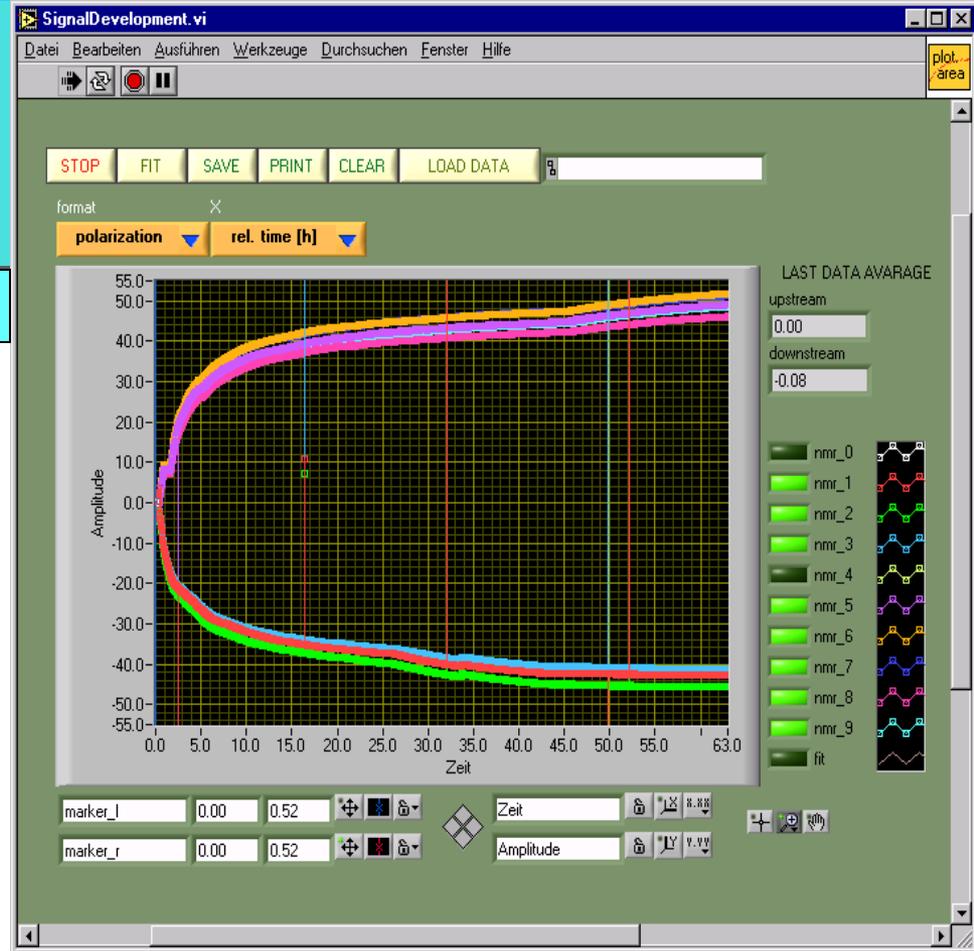
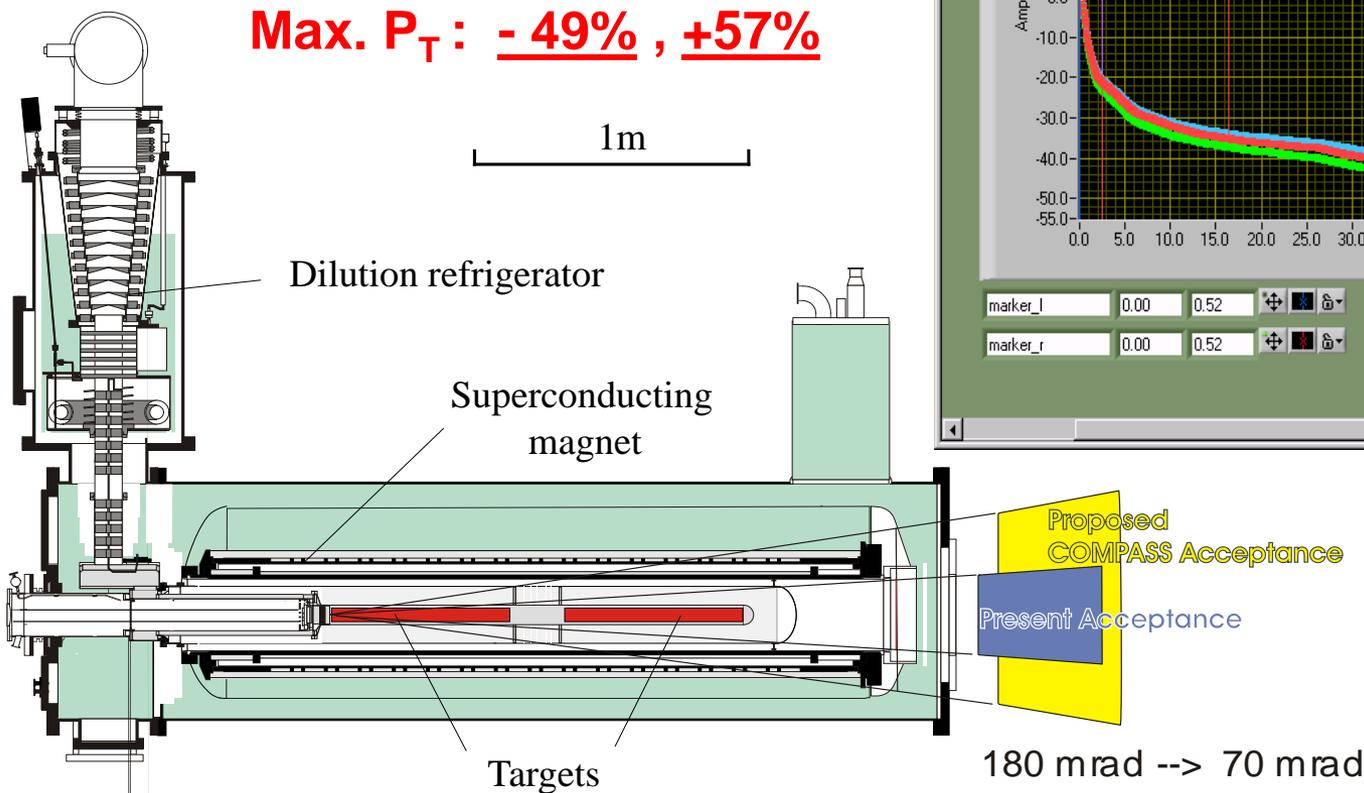


# <sup>6</sup>LiD Target

2 halves polarised in opposite directions

Dynamic Nuclear Polarization  
Frequency Modulation

Max.  $P_T$  : -49% , +57%



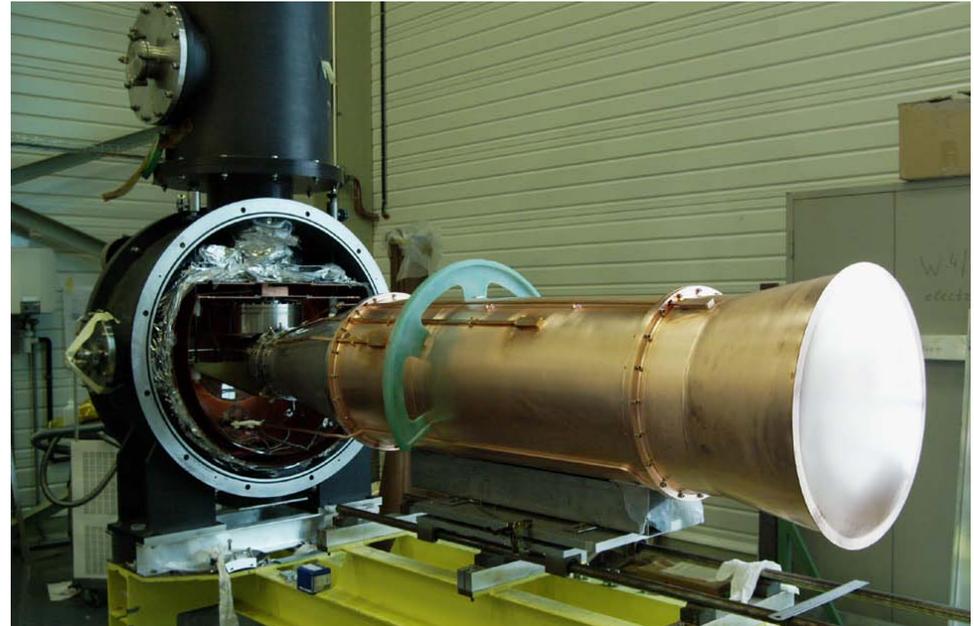
Dilution factor ~50%

Solenoid: 2.5 T

Dipole: 0.5 T

Relaxation time:  
>1000 h for 0.5 T

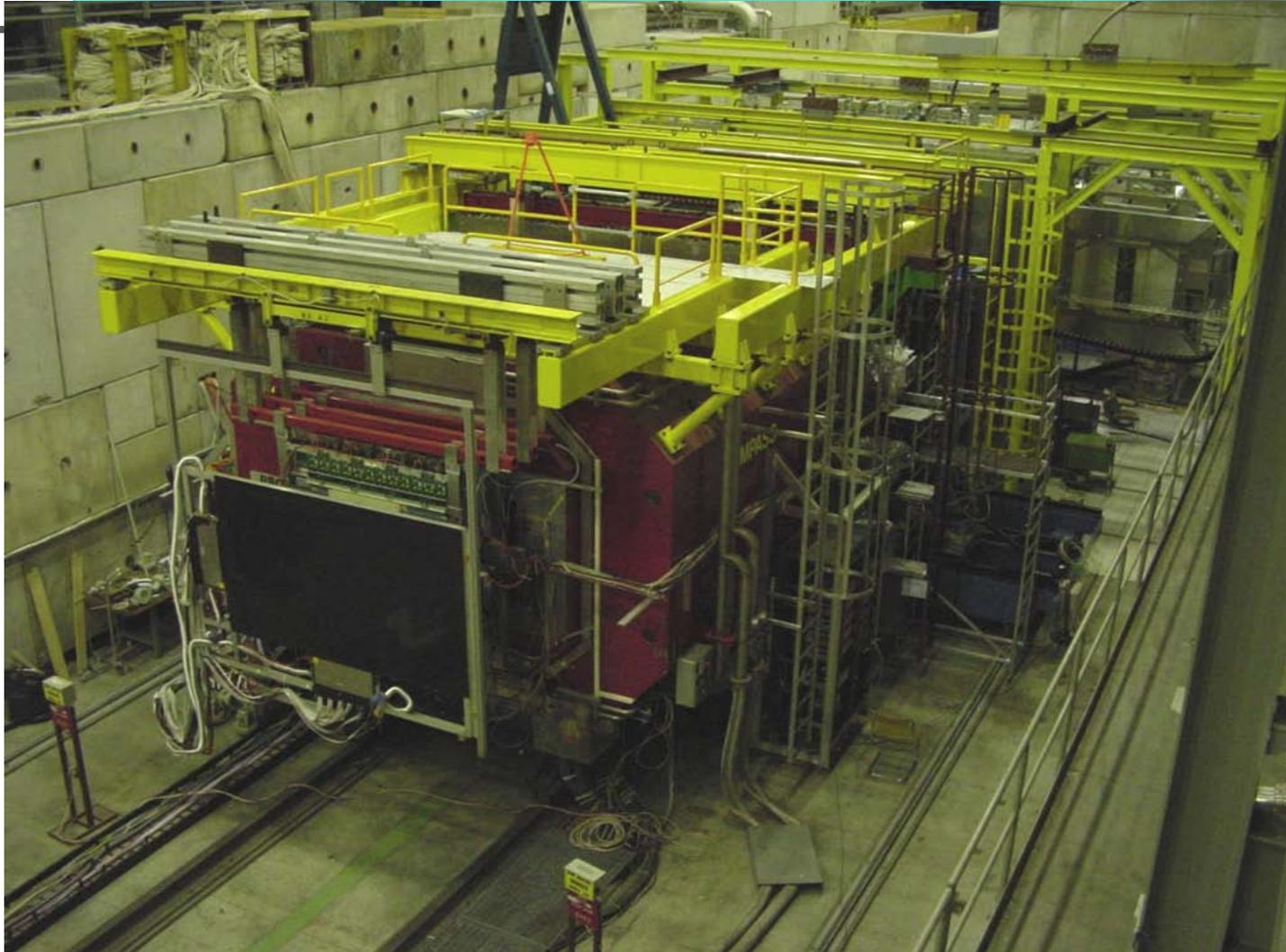
# Polarized target upgrade, in 2006



New 3-cell system & microwave cavity  
matched for larger acceptance,  
reduces false asymmetries

- New COMPASS target magnet
- → 180 mrad

# SM2 and the LAS region



# Scintillating Fibers Hodoscopes

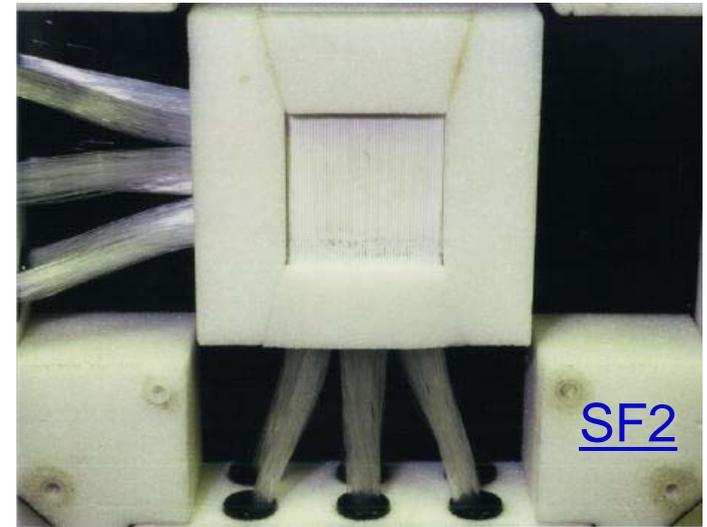
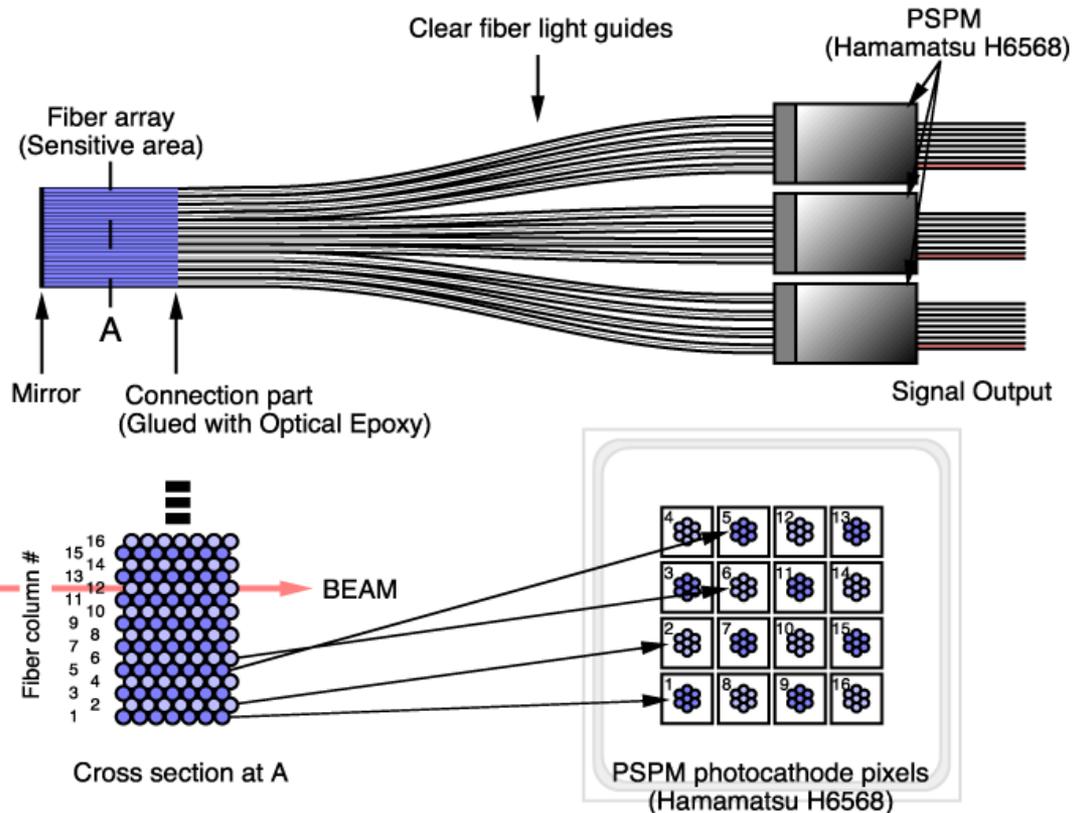
**9 stations: 21 coordinates**

*Rate capability > 5 MHz  
per channel*

*Efficiency: 99%*

*Space resol. 130 – 250  $\mu\text{m}$*

*Time resol. < 400 ps*



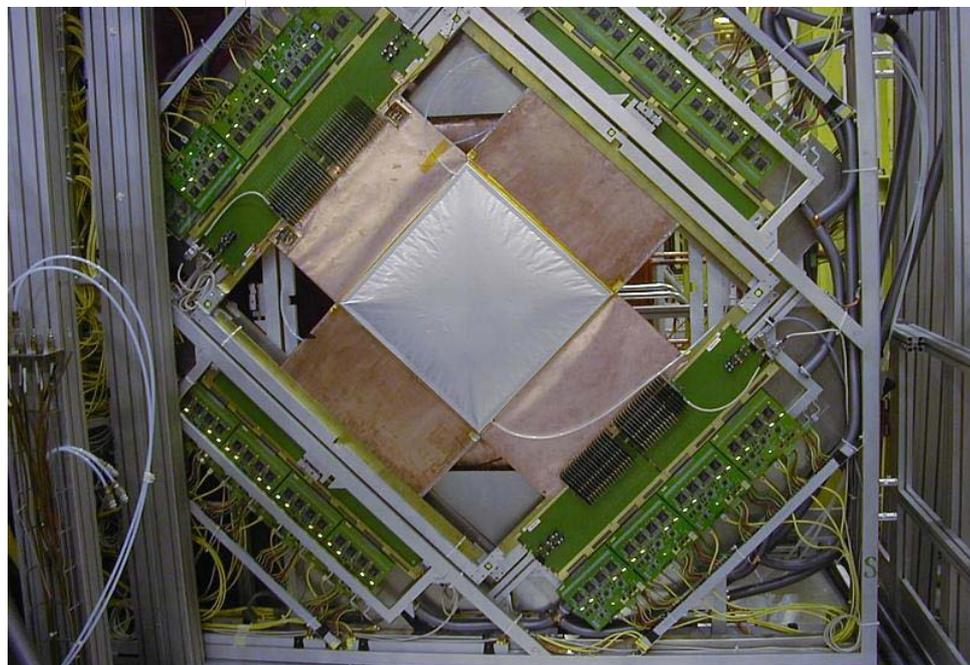
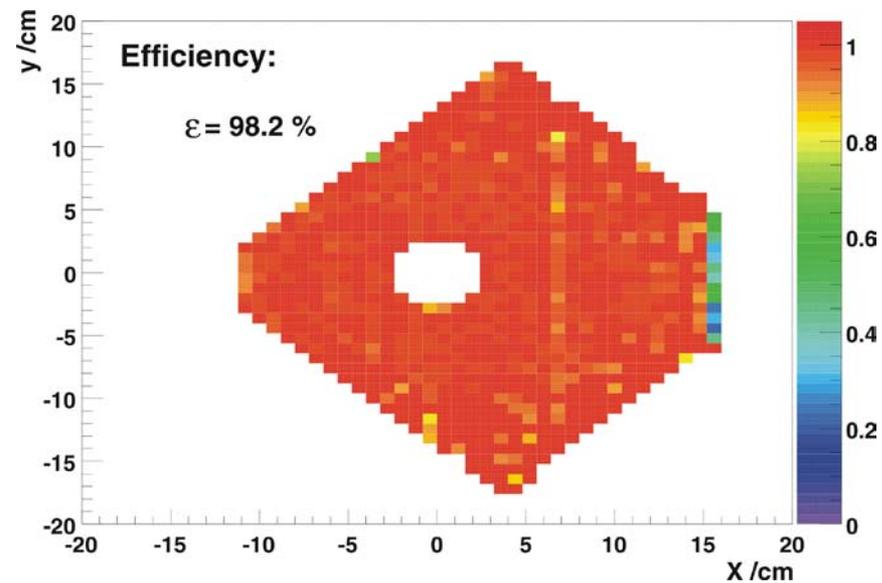
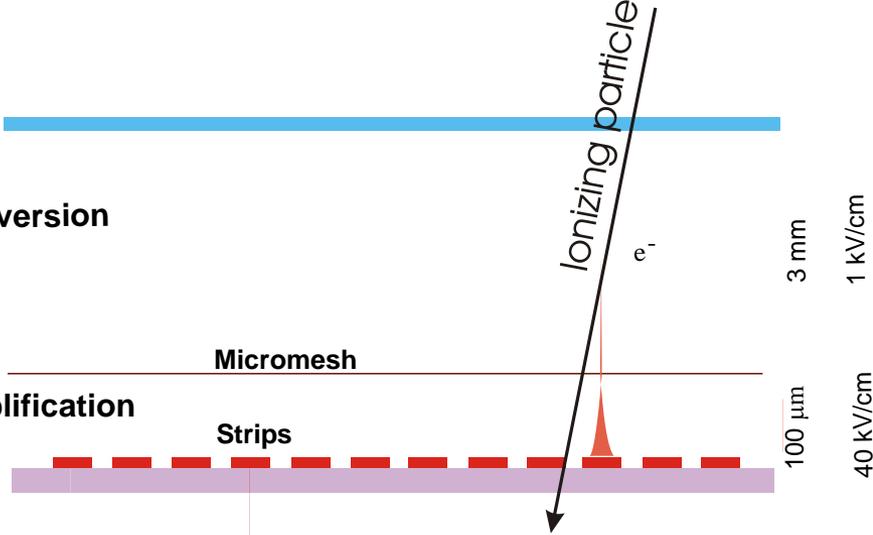
**Sensitive area:**  
**7-layers of Kuraray SCSF-78MJ 0.5 mm  $\varnothing$**

$\mu\Omega$

12 planes  $40 \times 40 \text{ cm}^2$   
Space resolution:  $70 \mu\text{m}$   
Time resolution:  $8 \text{ ns}$

Conversion

Amplification

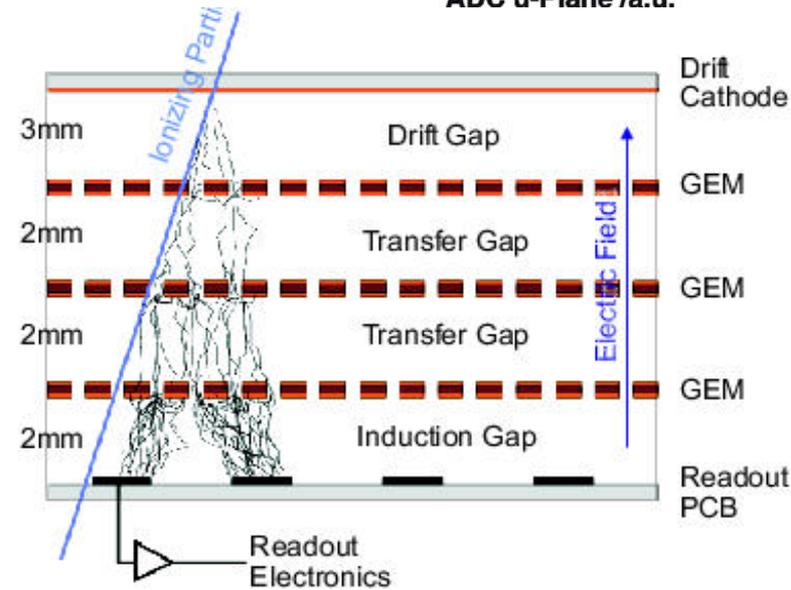
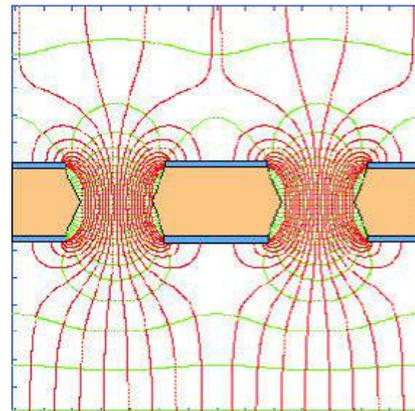
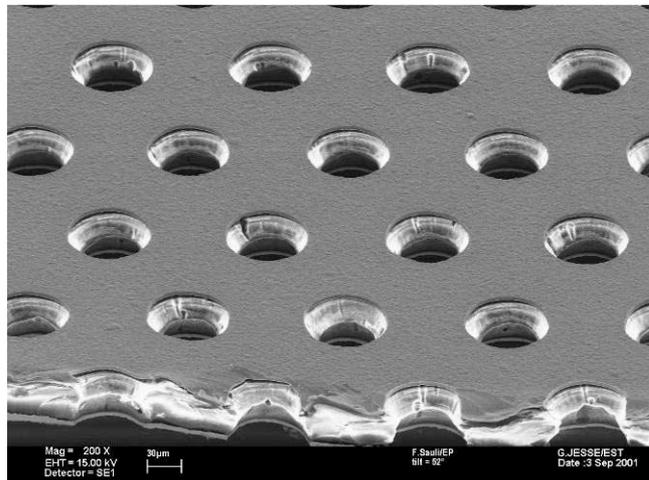
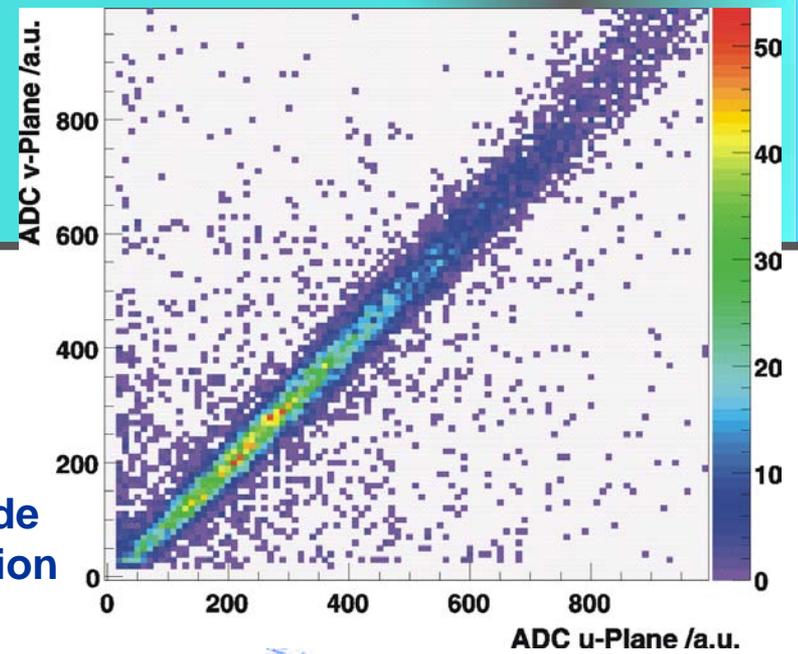


# GEM

## 20 triple GEM detectors with 2 dimensional r/o

- Space resolution: 70  $\mu\text{m}$
- Efficiency  $\sim 96 - 97\%$
- Time resolution: 15 ns

amplitude  
correlation

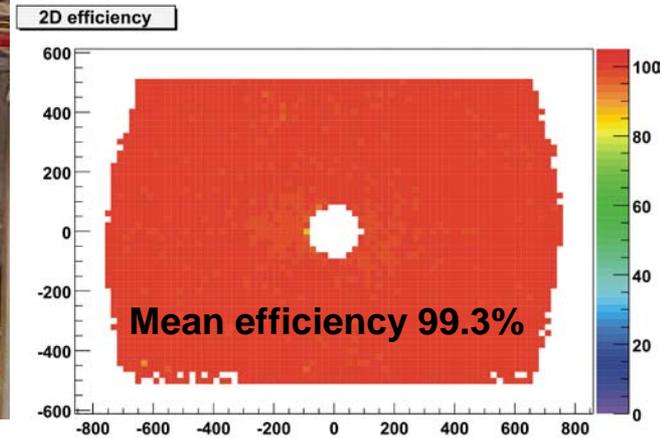
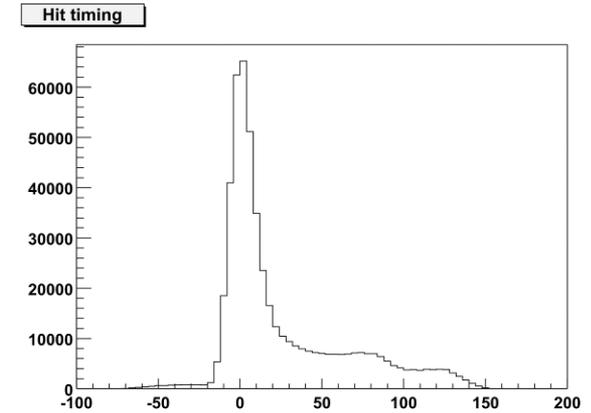
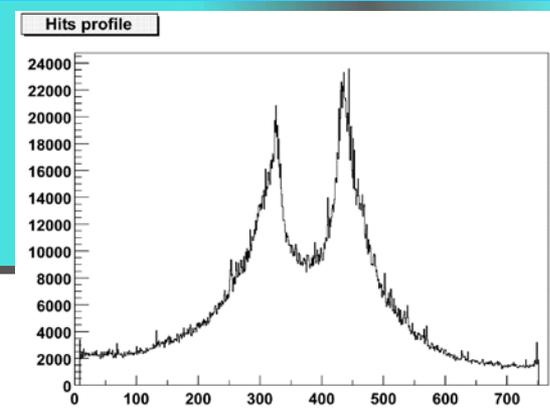
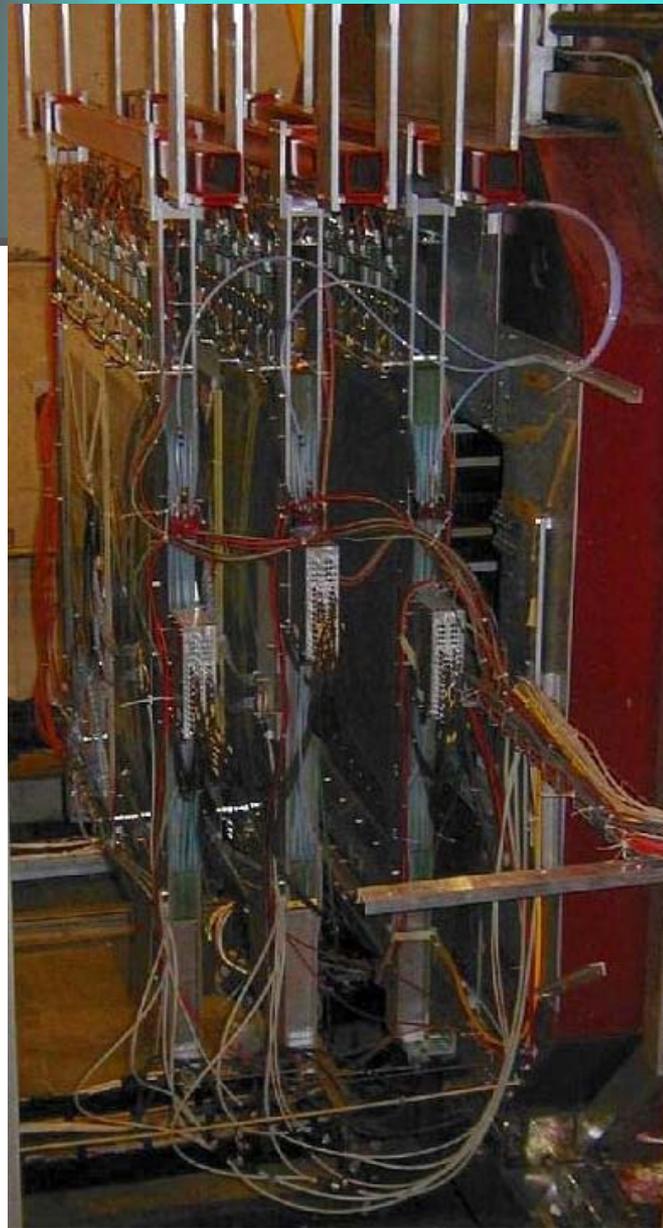


# MWPCs

Total of 34 planes

*SAS Tracking*

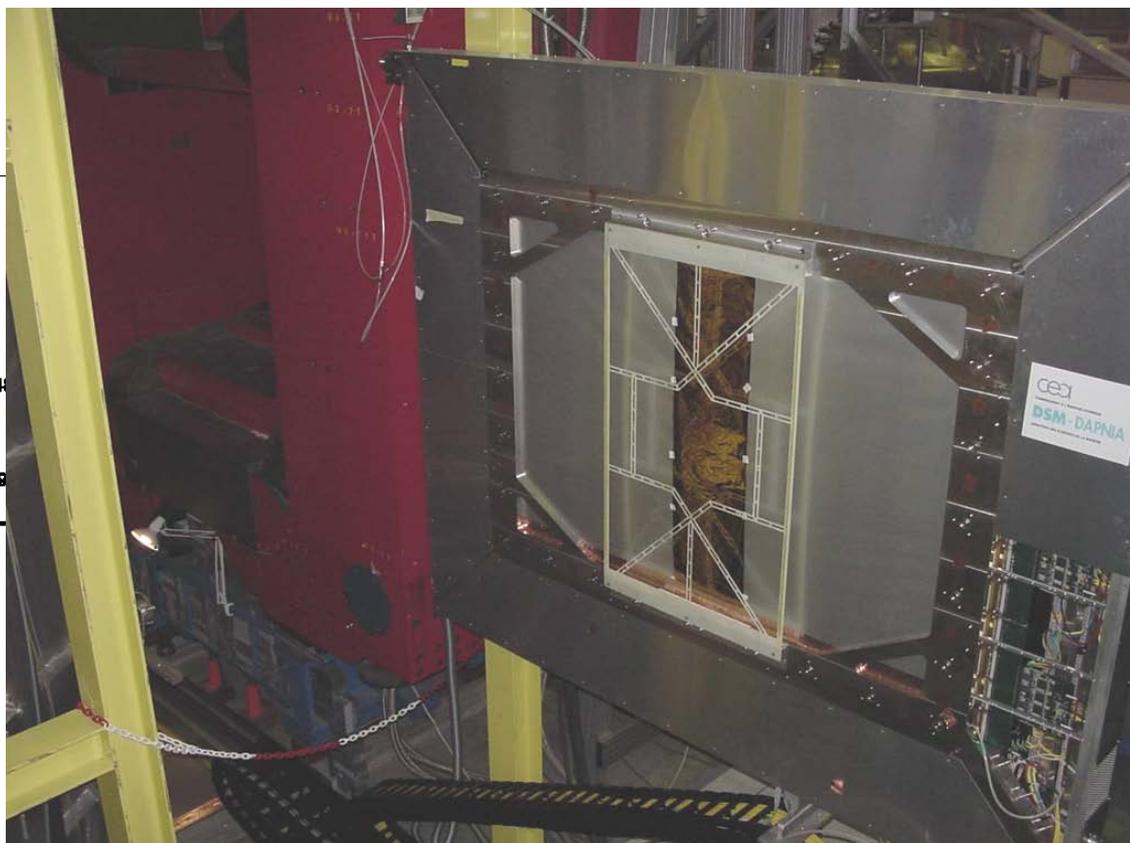
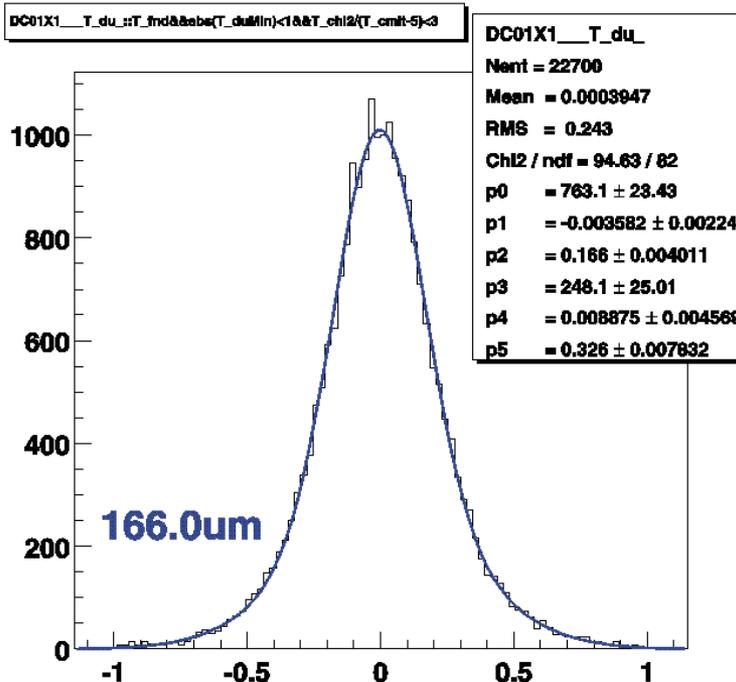
- Gas mixture:  
70% Ar, 20% CF<sub>4</sub>, 10% CO<sub>2</sub>
- High voltage: 4.25 kV
- Discr. threshold: 4fC



# Drift Chambers for LAS

3 chambers with 8 coordinates each

Efficiency: 95 - 99.8 %



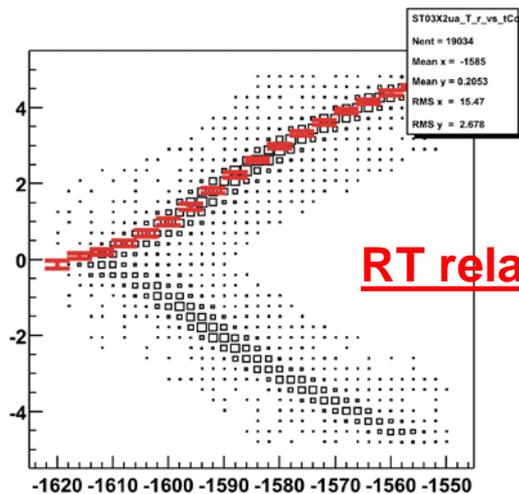
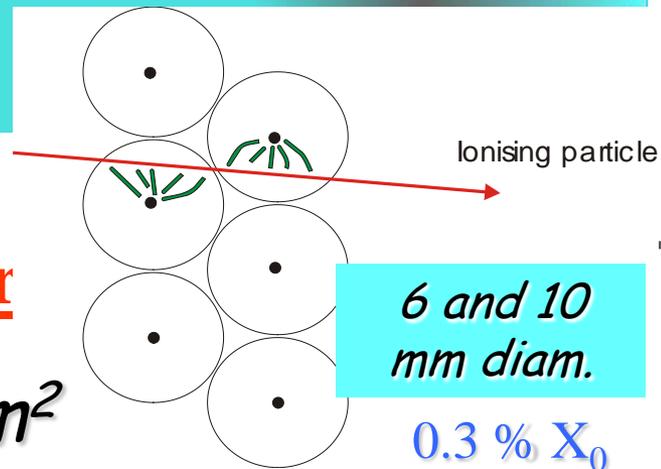
# Drift Chambers for SAS



# STRAWs

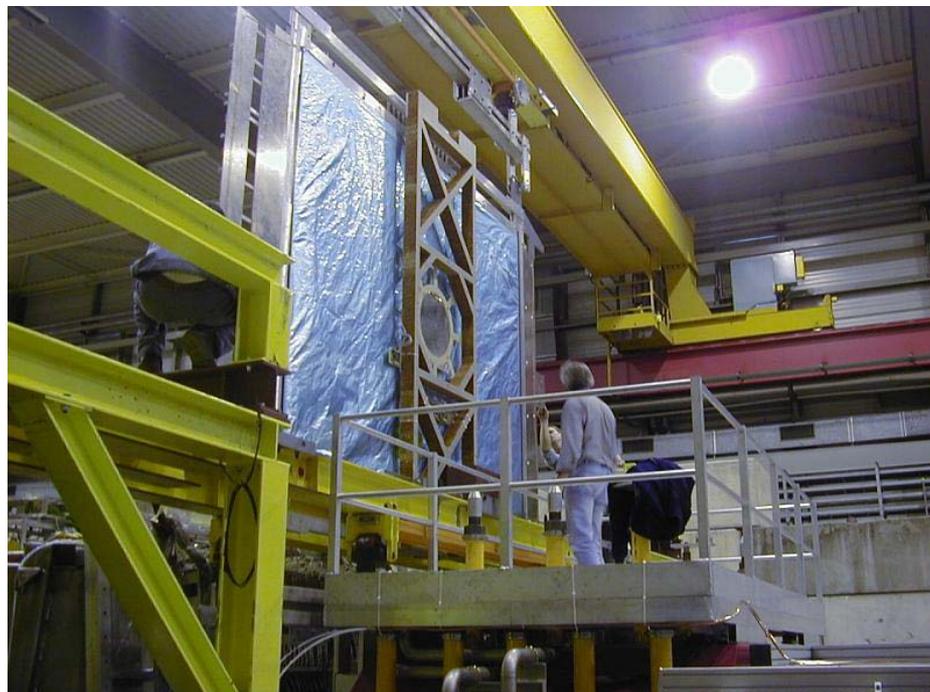
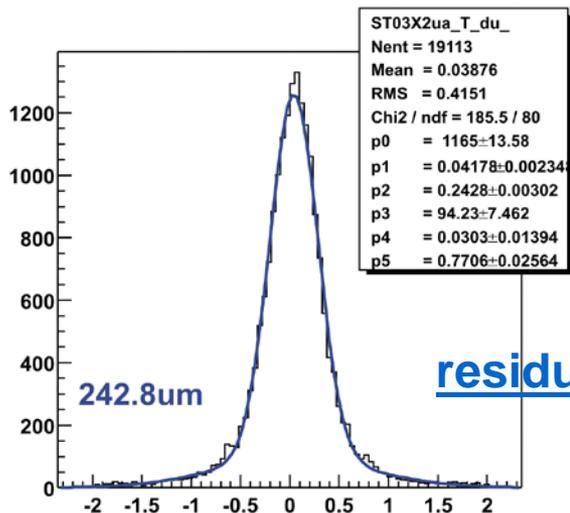
**1 Module =**  
**6 double layer**

$3.2 \times 2.4 \text{ m}^2$



**RT relation**

Installation of a double layer



# HCAL 1



*Muon Wall 2*

*Muon Wall 1*



# RICH

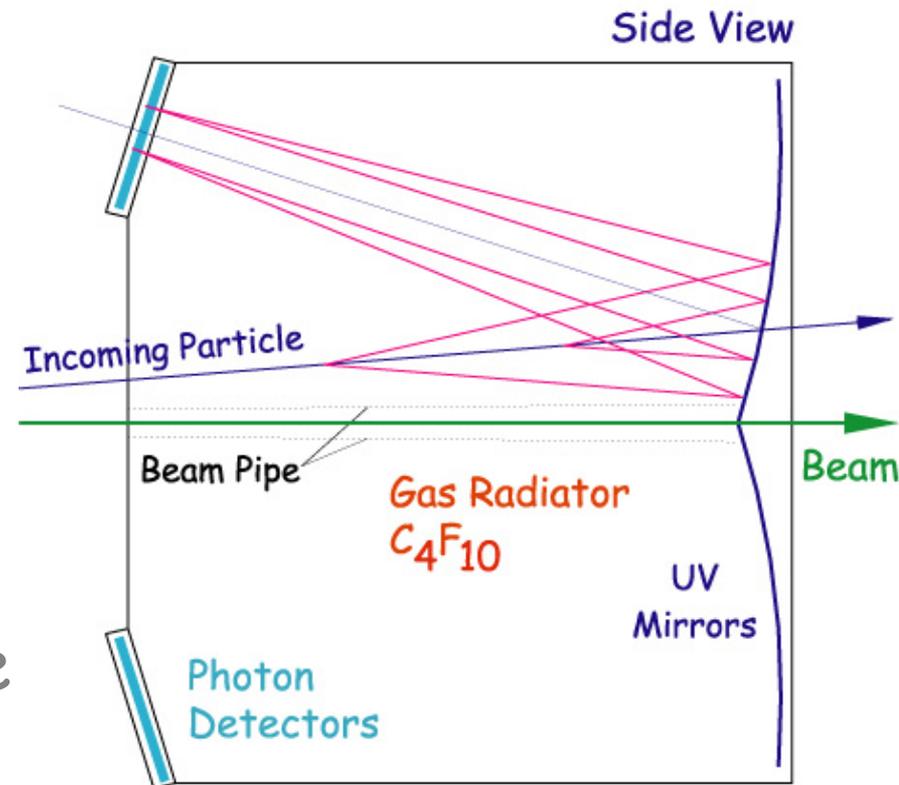
RICH =

Ring

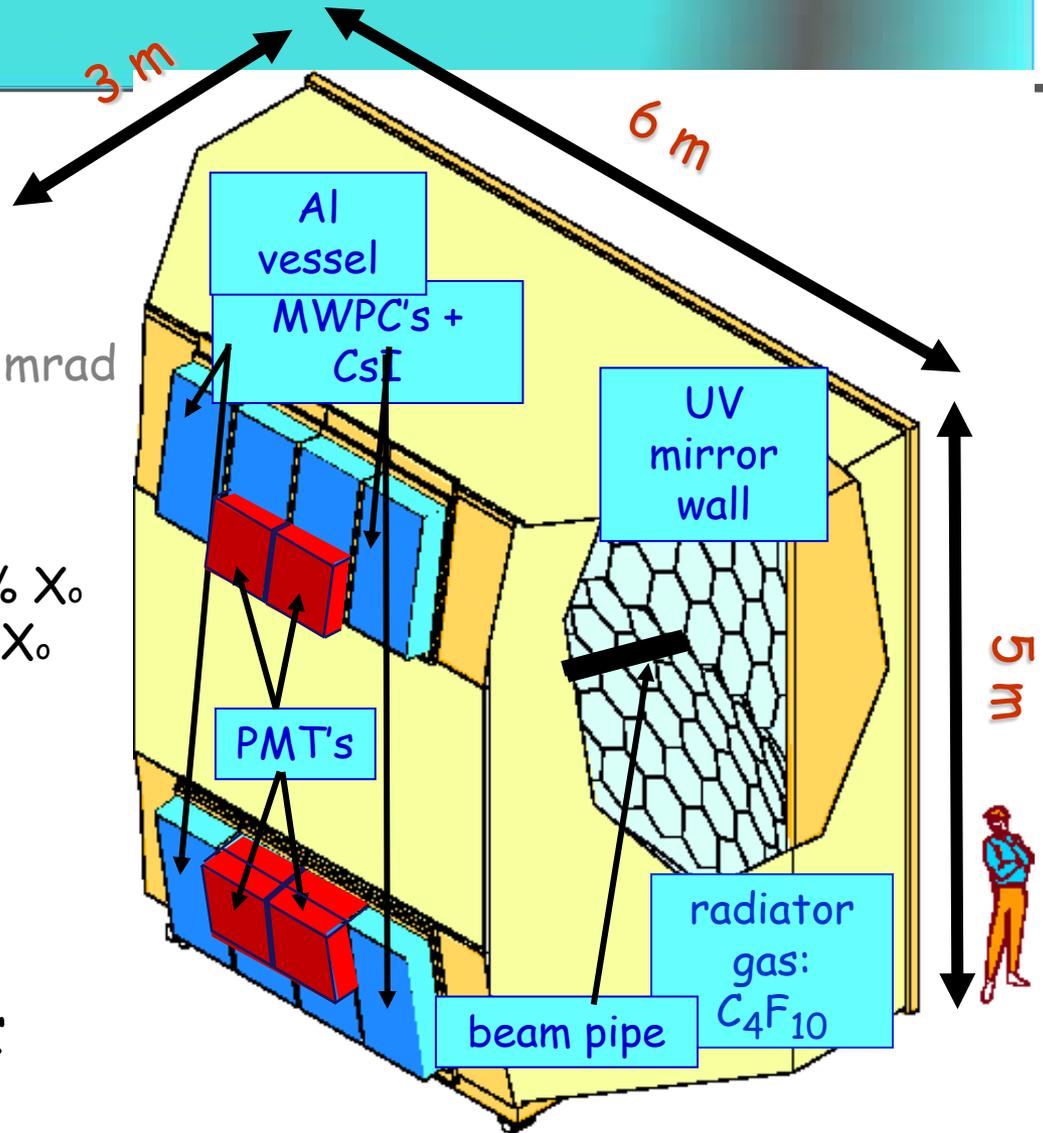
Imaging

Cherenkov (detector)

Uso un effetto  
elettromagnetico per  
misurare la velocità di  
particelle ultrarelativistiche  
fino a  $(c-\beta)/c \sim 10^{-7}$



# COMPASS RICH-1



hadron PID from 3 to 60 GeV/c

acceptance: H: 500 mrad V: 400 mrad

trigger rates: up to ~100 KHz

beam rates up to  $\sim 10^8$  Hz

material in the beam region: 2.4%  $X_0$

material in the acceptance: 22%  $X_0$

detector designed in 1996

in operation since 2002

upgraded in 2006

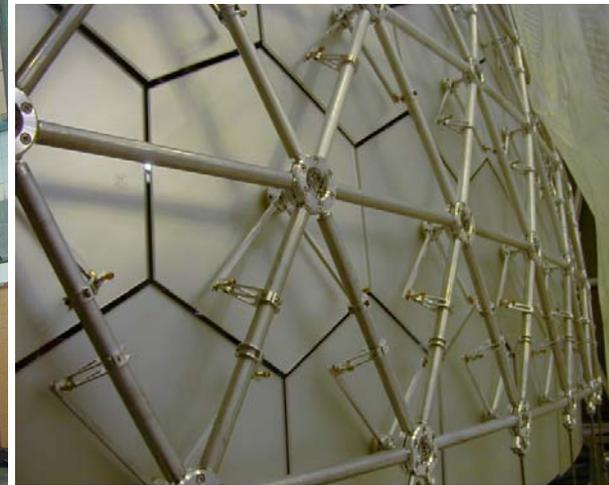
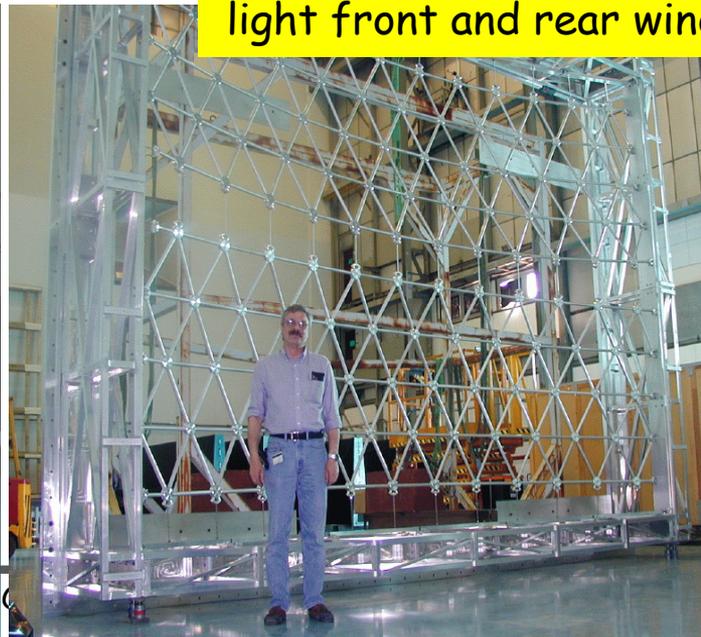
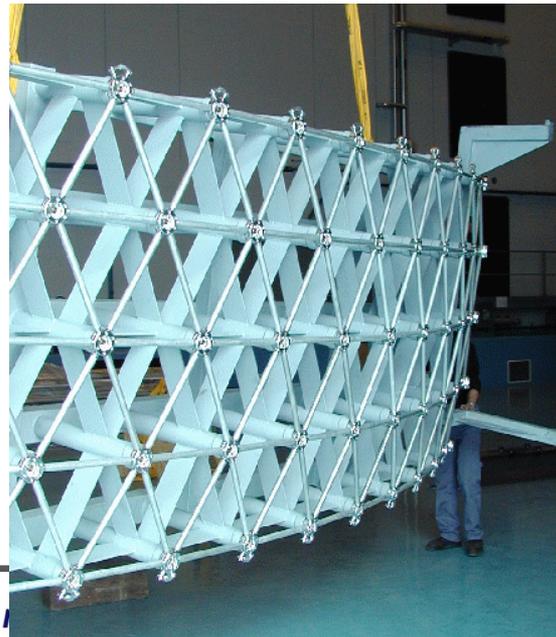
total investment:  $\sim 4$  M €

# the vessel and the mirror

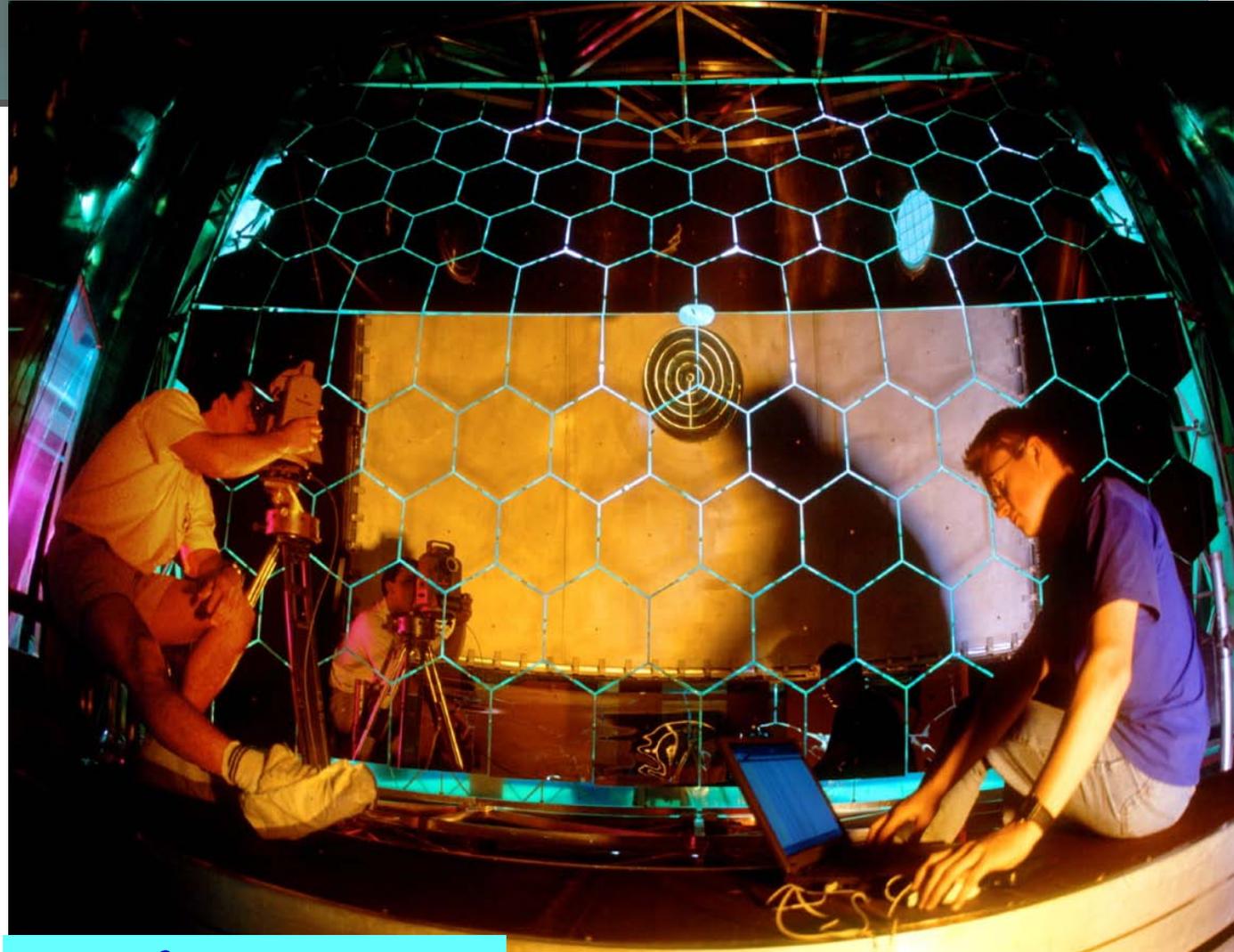


Large and accurate  
mechanics

light front and rear windows



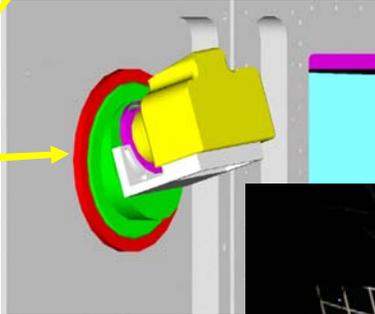
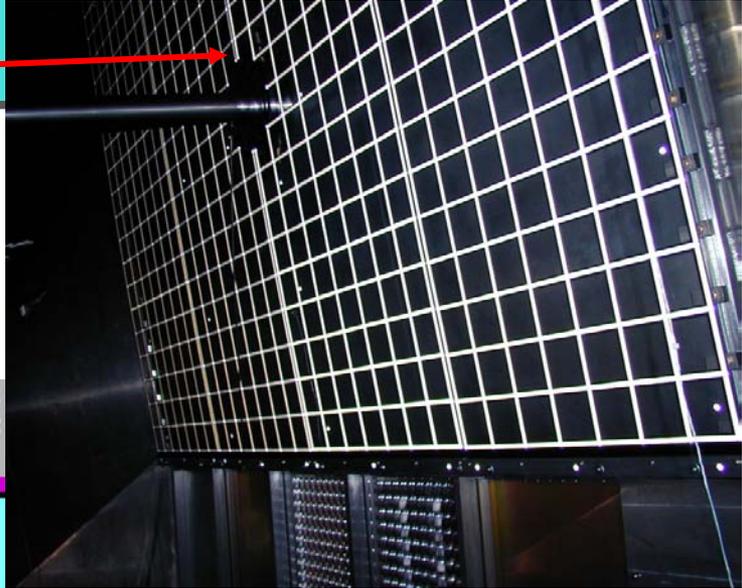
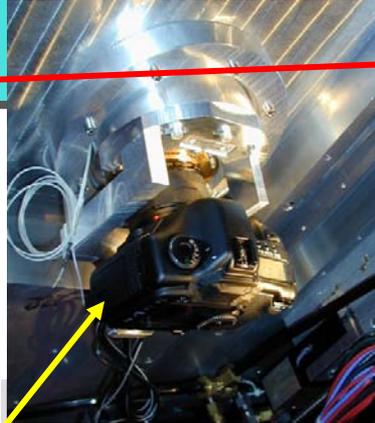
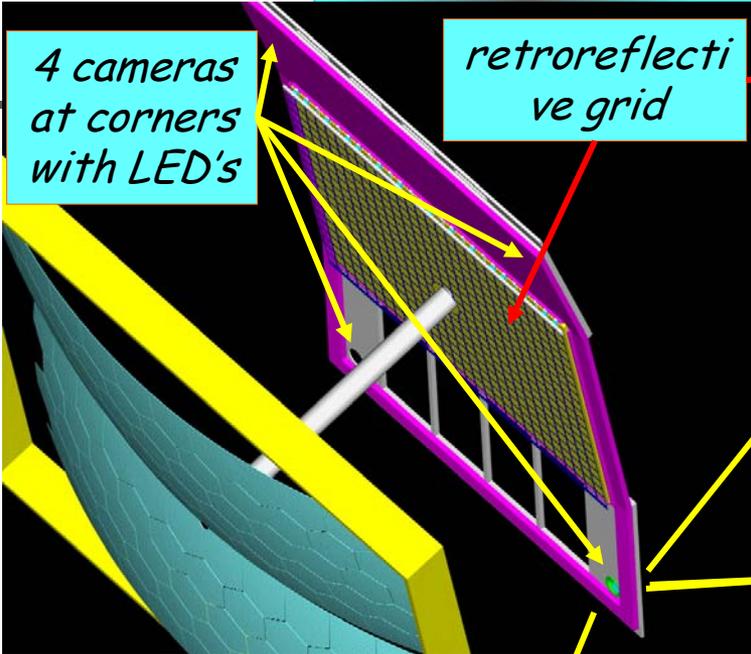
# mirrors and alignment



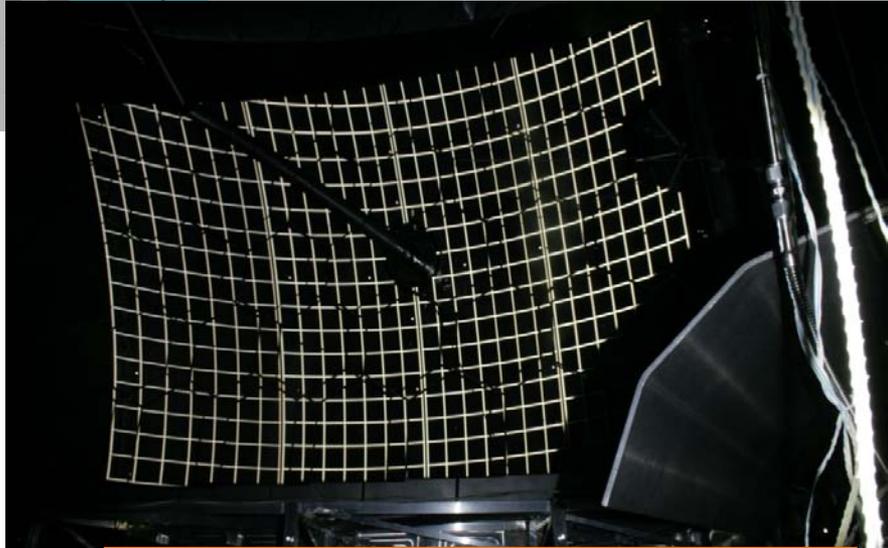
*21 m<sup>2</sup>, 116 mirrors  
radius: 6.6 m*

angular regulation screws

# CLAM: mirror alignment monitoring

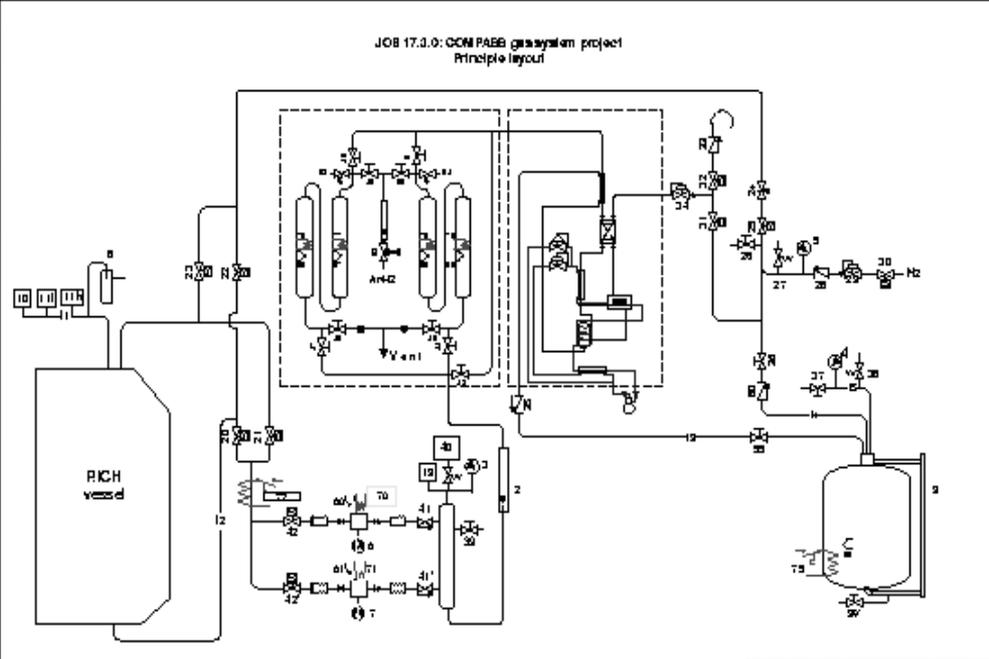


CLAM system in operation since  
accuracy: 30  $\mu$ rad  
photogrammetric calibration of cameras  $\rightarrow$  measurement of absolute mirror tilt



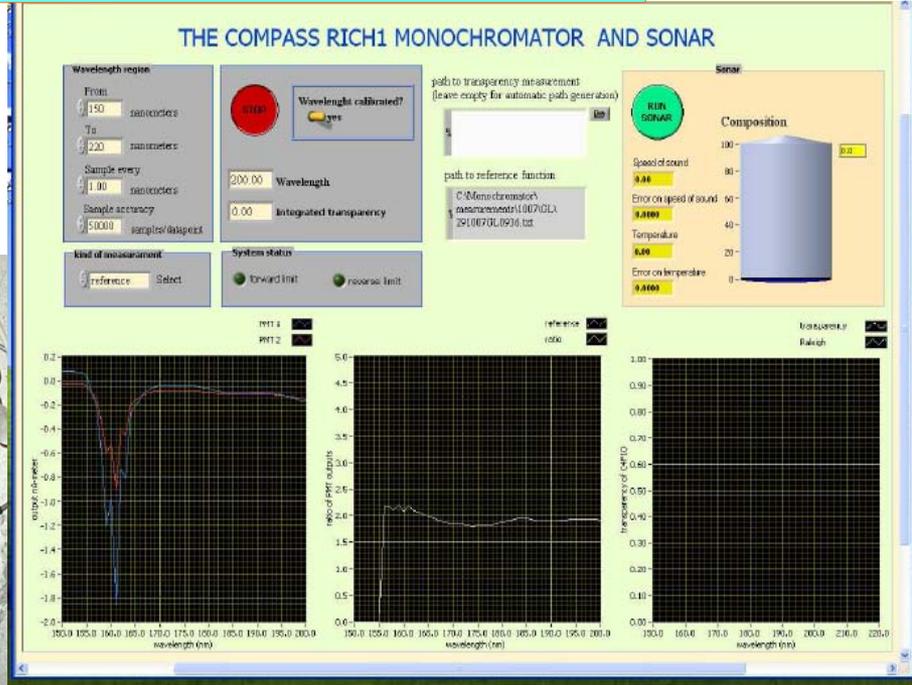
"CLAM" picture for mirror monitoring

# The radiator gas system



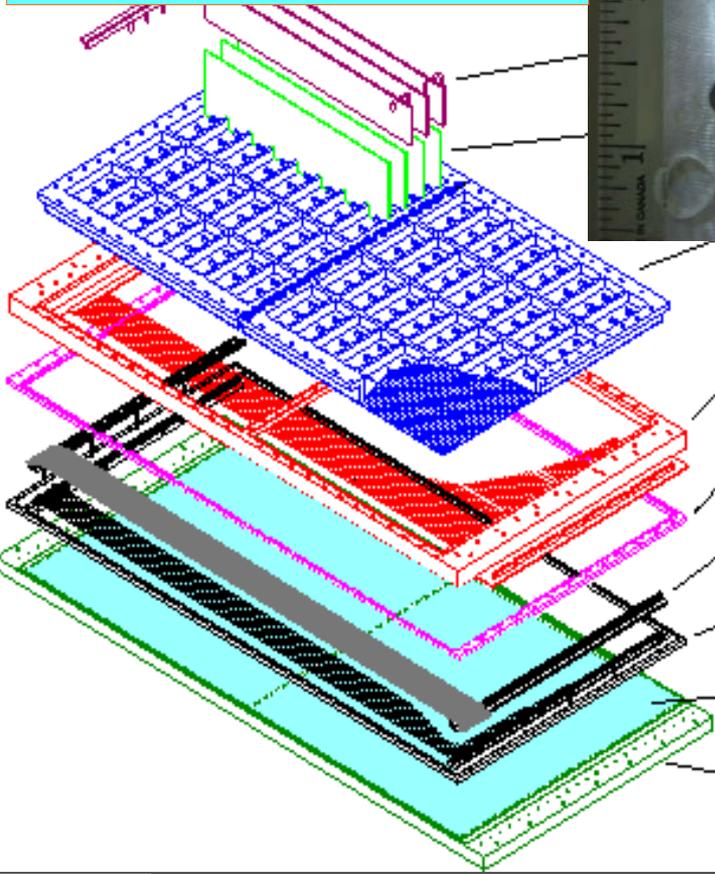
*has excellent performances*

COMPASS RICH1 gas system	Basile M...
Principle layout	SCALE ..
CERN/ES/MS/PSF	2.1/3.00
	17.3.0



# The 8 MWPC's with CsI photocathodes

*built in 1999 - 2000,  
after prototypes  
tests  
(RD26 development)*

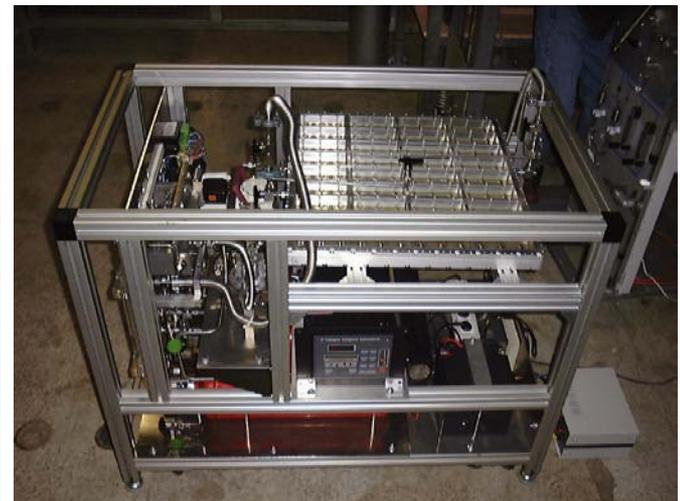
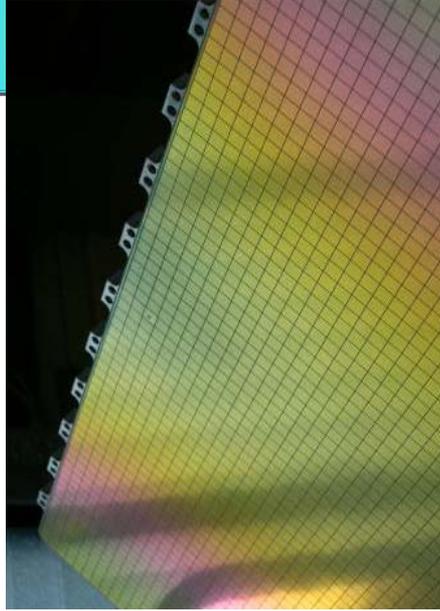


24-26 febbraio 2012

Silvia DALLA TORRE (INFN Trieste)

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# The CsI photocathodes



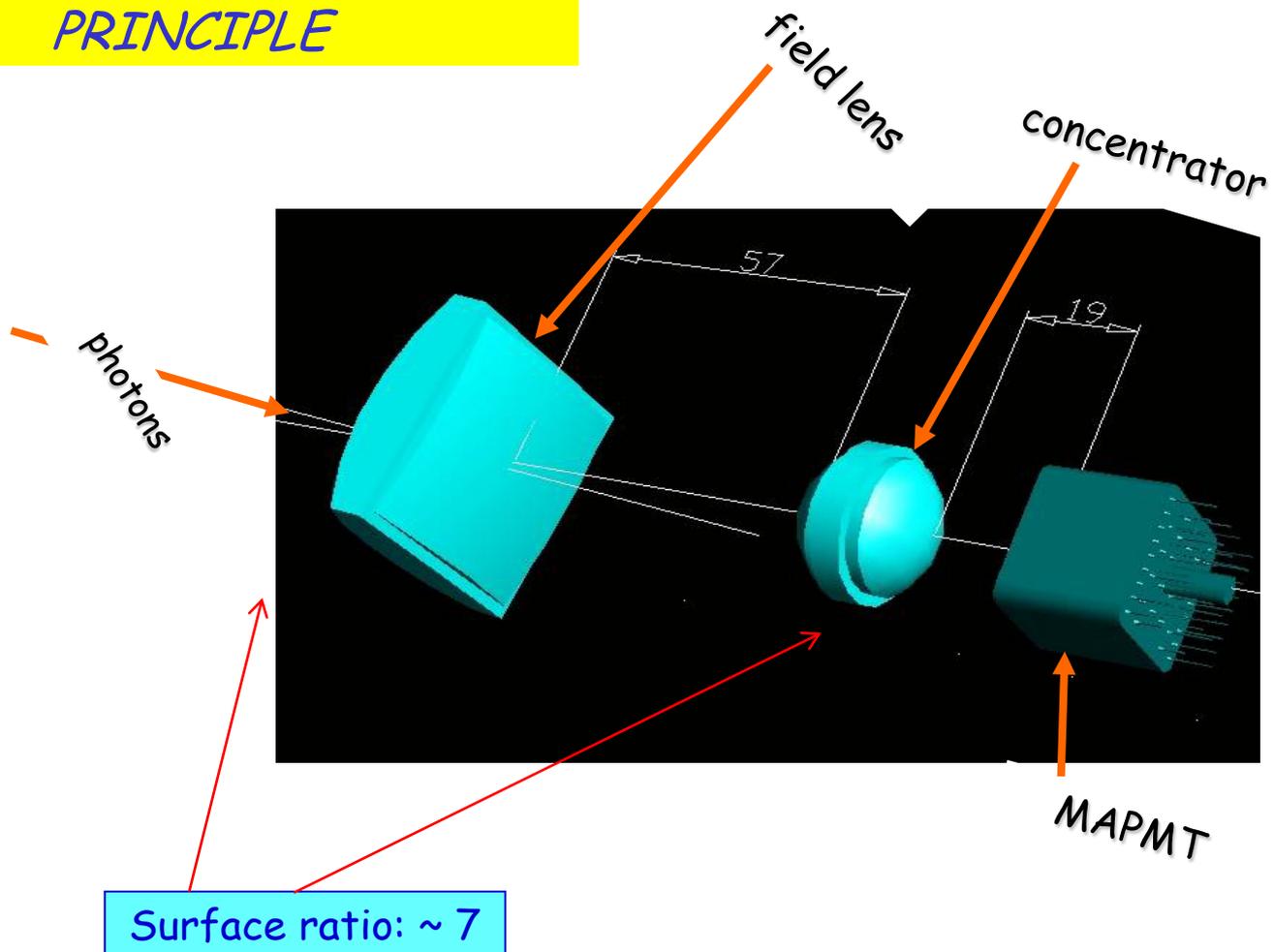
24-26 febbraio 2012

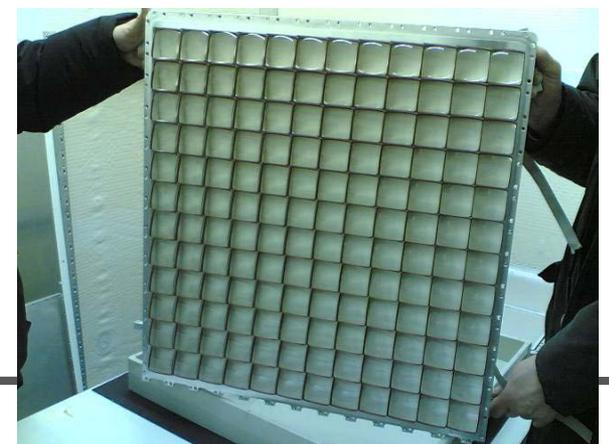
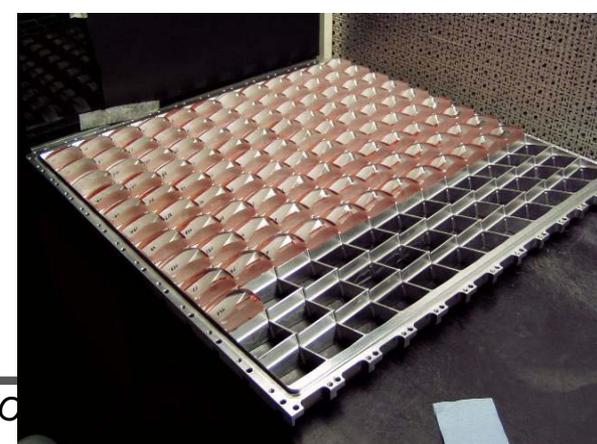
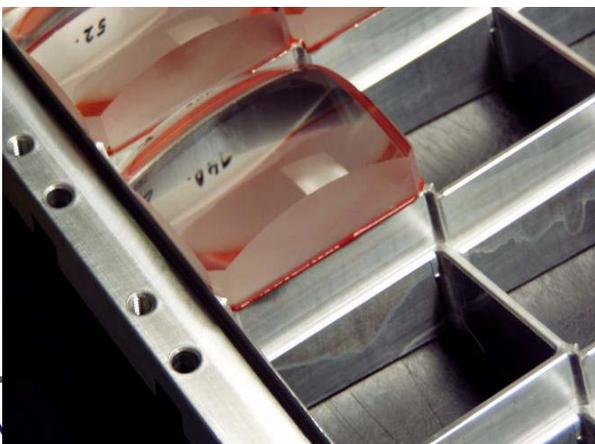
Silvia DALLA TORRE (INFN Trieste)

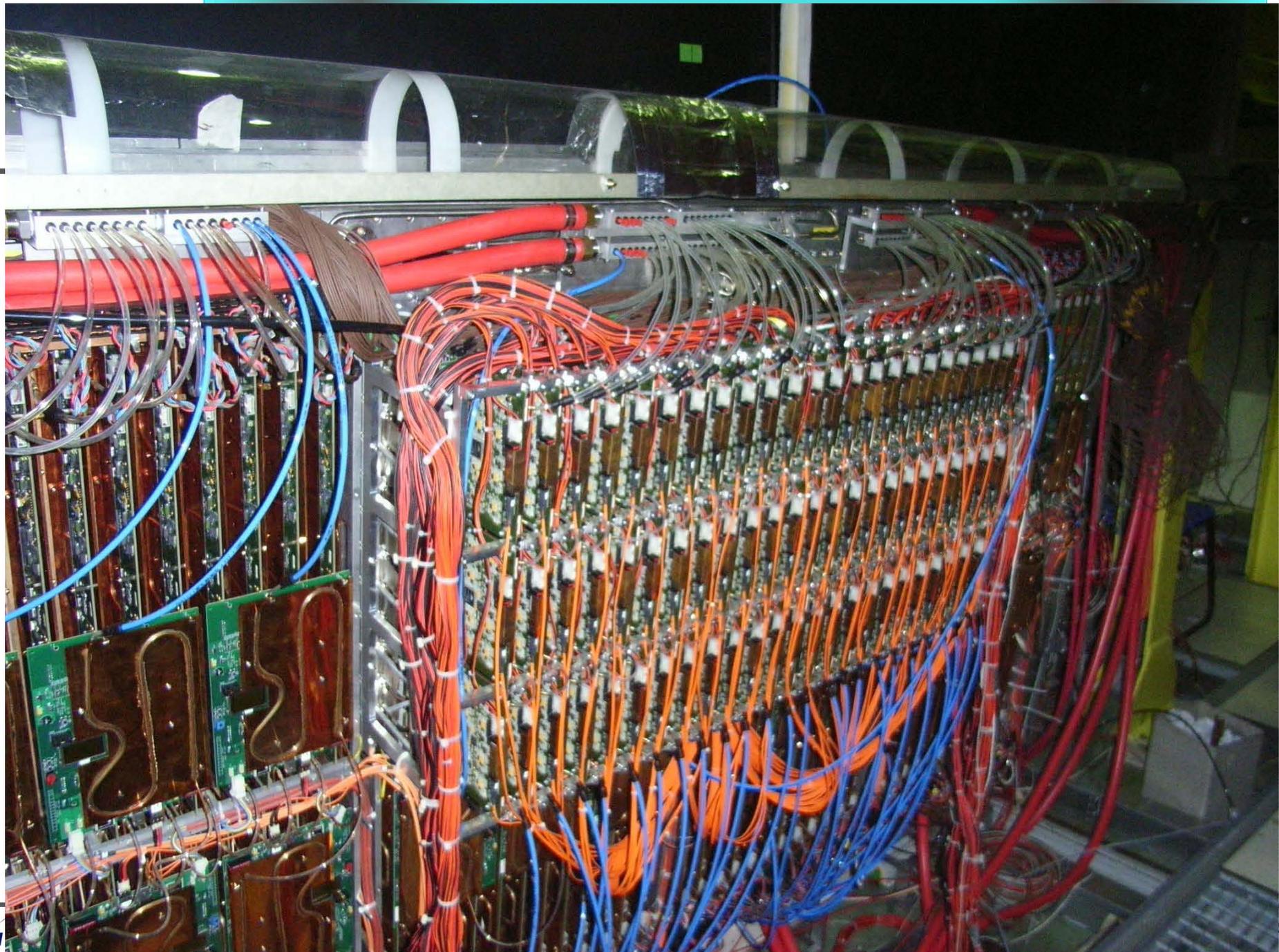
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# UPGRADE WITH MAPMT

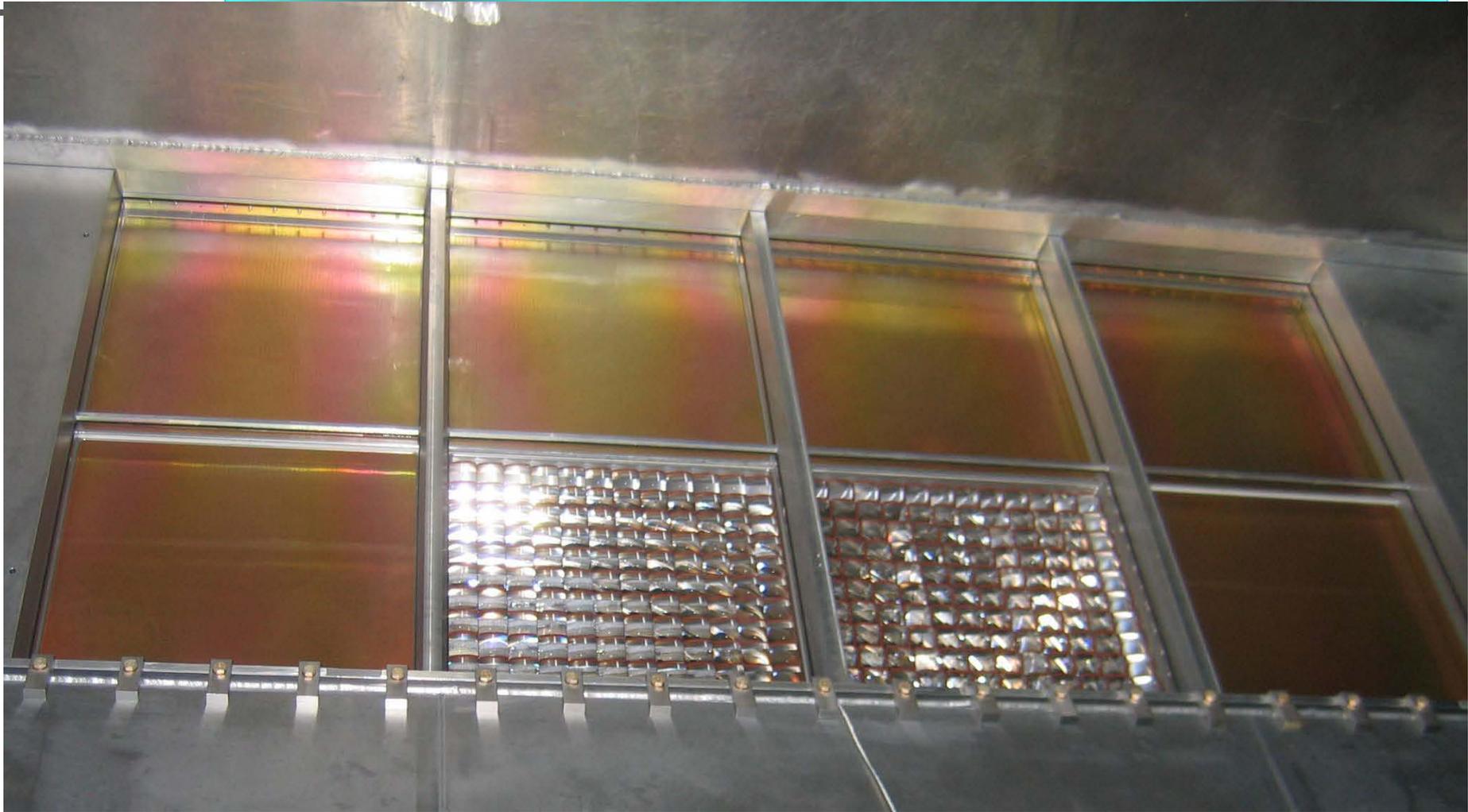
## PRINCIPLE



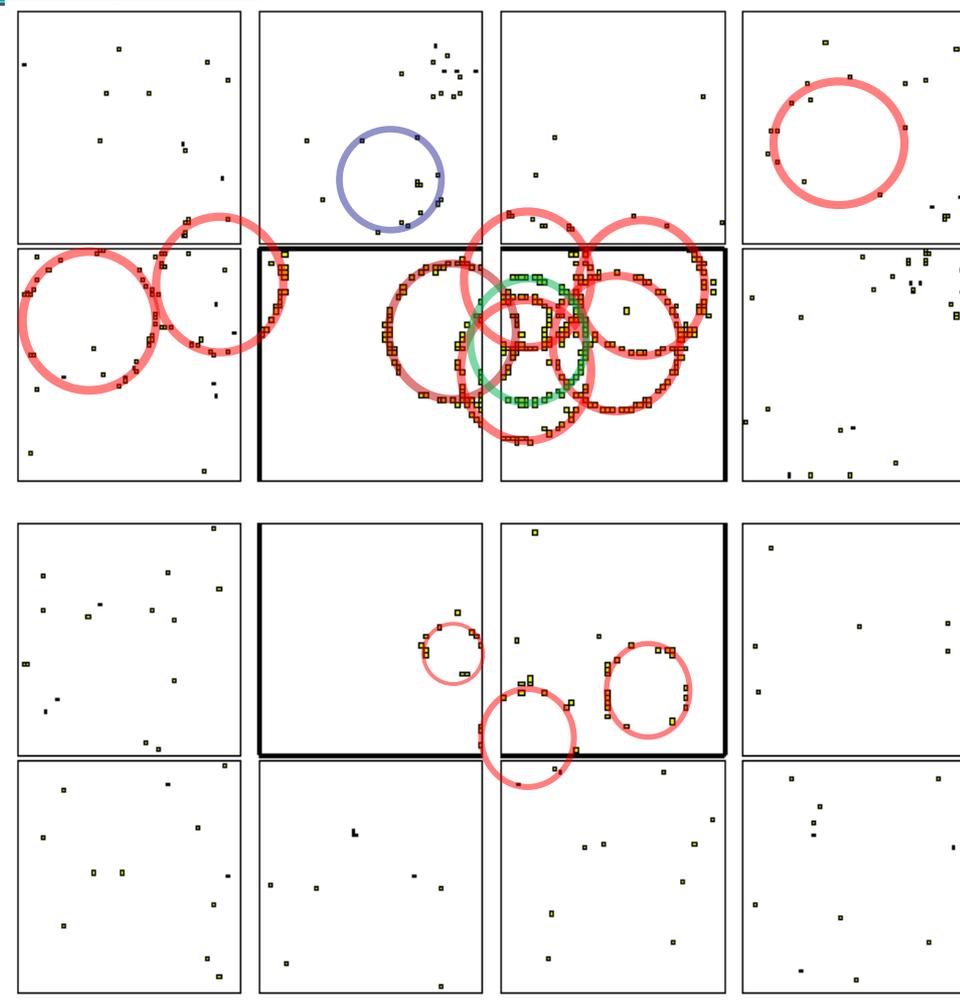




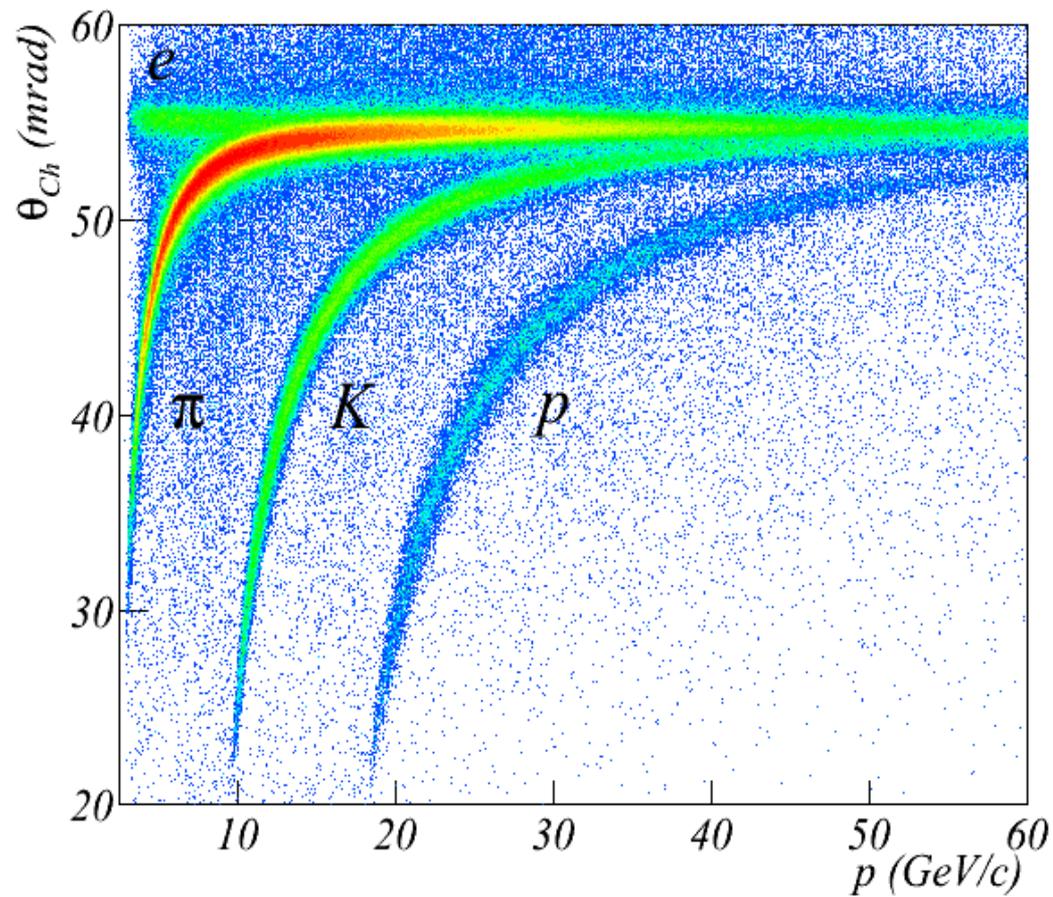
# The Upper Detector from inside



# A typical event

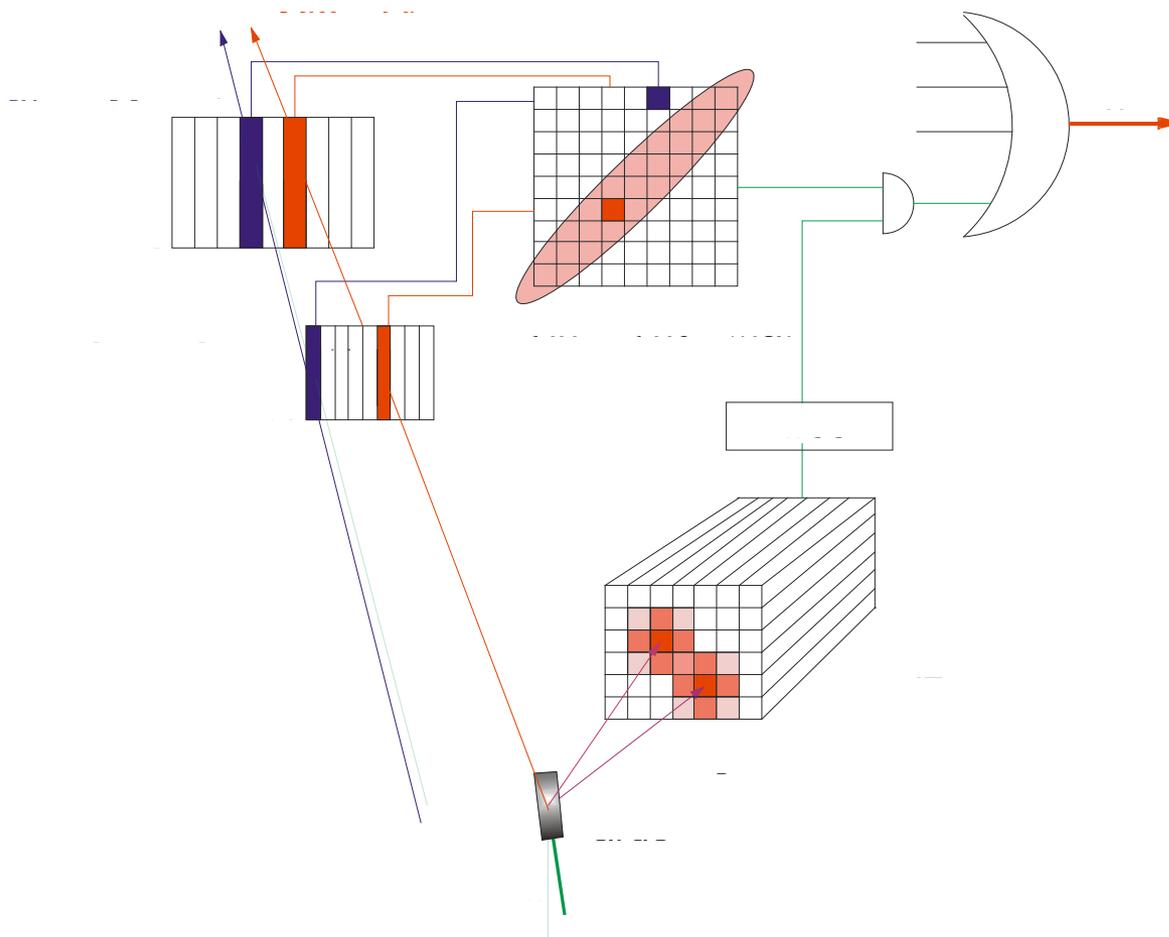


# RESULTS



# Trigger concept

Trigger:  $(H4 * H5) * (HCAL1 \vee HCAL2)$



# COMPASS Computing Farm

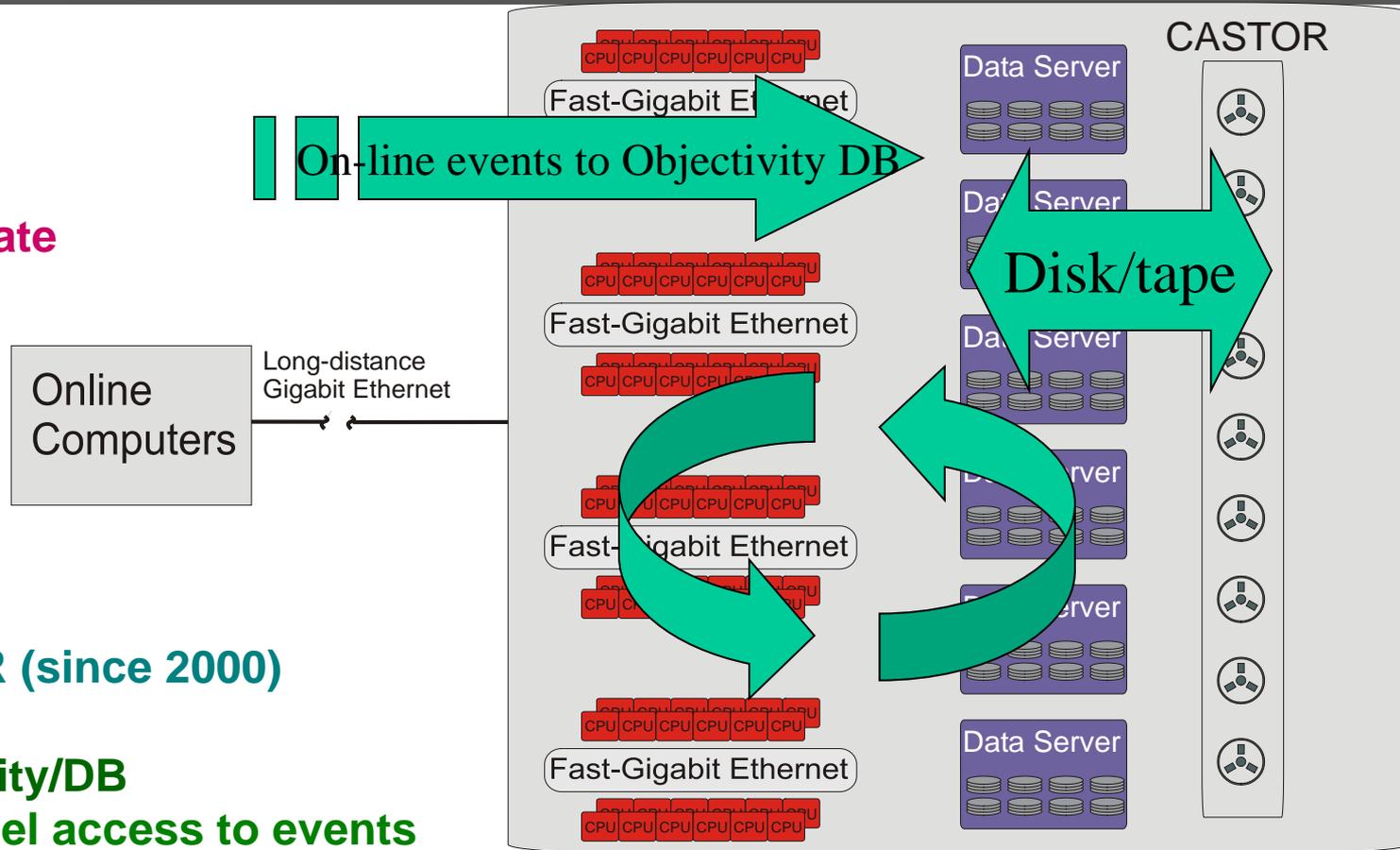
200 CPUs

35 MB/s input rate  
300 TB/year

Use of CASTOR (since 2000)

Use of Objectivity/DB

- Farm parallel access to events
- DST production
- RAW-DST connection without data duplication



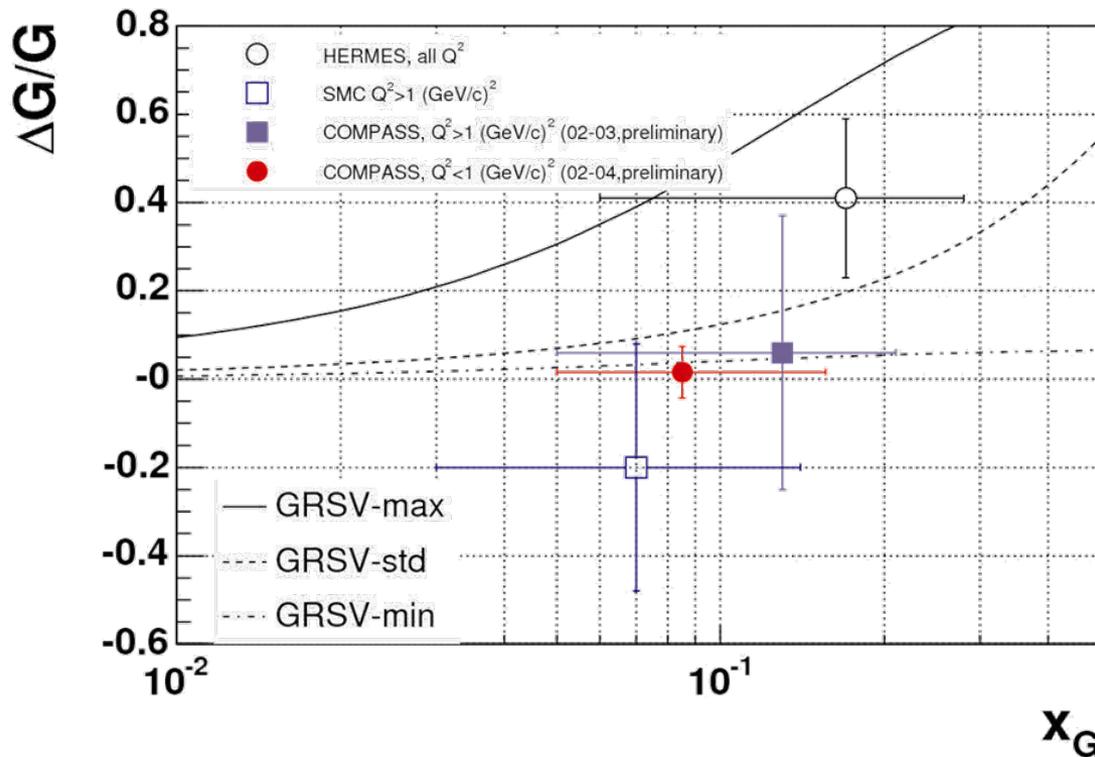
# 2002 - 2012

- 2002 160 GeV  $\mu$  beam &  ${}^6\text{LiD}$  Long/Transv ( $\sim 80/20$ )
- 2003 idem
- 2004 idem
- 2004 hadron beam
- 2005 NO SPS beam (Several upgrades)
- 2006 160 GeV  $\mu$  beam &  ${}^6\text{LiD}$  Long
- 2007 160 GeV  $\mu$  beam &  $\text{NH}_3$  Long/Transv
- 2008 hadron beam
- 2009 hadron beam
- 2010 160 GeV  $\mu$  beam &  $\text{NH}_3$  Transv
- 2011 160 GeV  $\mu$  beam &  $\text{NH}_3$  Long
- 2012 hadron beam /  $\mu$  beam

*Beam for COMPASS in 2014,  
2015, 2016  
Detailed calendar being  
defined  
(2013: CERN shut-down)*

# RISULTATI, SOLO UN PAIO DI ESEMPI

# $\Delta G/G$ from high- $p_T$ pairs



LO SPIN DEI NUCLEONI NON E' DOVUTO NEPPURE AI GLUONI ... UNA DELLE MOTIVAZIONI PER **COMPASS II**

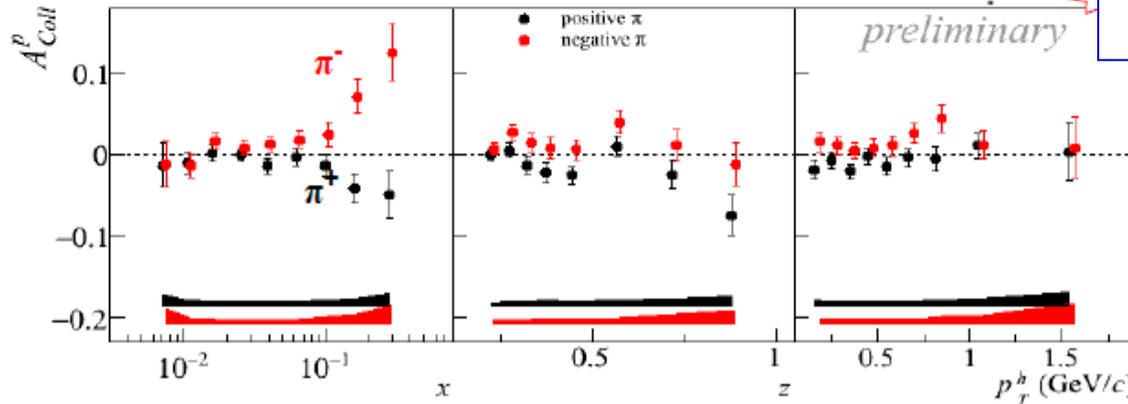
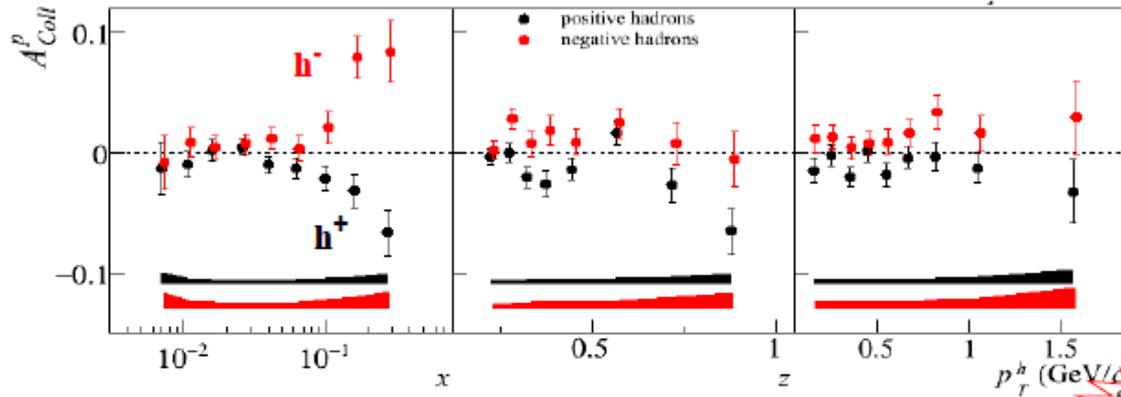
# Systematic exploration of the N transverse spin structure

## Collins asymmetry - proton

final COMPASS results from 2007 data



PLB 692 (2010) 240



LA COMPRENSIONE DELLA NATURA DI SPIN DEI NUCLEONI PUO' VENIRE SOLO DA UNO STUDIO DETTAGLIATO... ANCORA UNA MOTIVAZIONE PER **COMPASS II**

# COMPASS II

## Physics programme:

- Hard exclusive photon and meson production
- Measurements of unpolarised PDFs and TMD effects in SIDIS
- Pion-induced Drell-Yan muon pair production
- Transverse-momentum-dependent effects in SIDIS
- Experimental studies of chiral perturbation theory

**5 year of data taking starting in 2012 !!!**

**COMPASS-II Proposal approved by CERN  
Research Board on 1<sup>st</sup> December 2010**