



# *L'ESPERIMENTO*



*Fulvio Tessarotto*



# Sommario

- ***La nascita di COMPASS***
  - *Il contesto ed il problema di fisica*
  - *La Collaborazione e la presentazione della proposta di esperimento*
- ***L'apparato sperimentale***
  - *Il disegno dell'apparato*
  - *La scelta delle migliori tecnologie*
  - *La costruzione dei rivelatori*
    - *Il bersaglio polarizzato*
    - *I rivelatori per il tracciamento*
    - *Il RICH e i calorimetri*
    - *Il sistema di trigger e l'acquisizione*
- ***Commissioning and data taking***
  - *Far funzionare tutto assieme: il primo run*
  - *I turni di presa dati, i controlli e le decisioni*
- ***L'analisi e la proclamazione dei risultati***
  - *La polarizzazione del gluone*
  - *La trasversità*



# Il contesto

- Negli anni '50 a Stanford, in California si misura la dimensione finita 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
- 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



# La “spin crisis”

20 anni fa, un gruppo di fisici sperimentali guidati da Vernon Hughes fece una notevole scoperta:

**Solo una piccola frazione dello spin del protone è fornita dallo spin dei quark!**

- Rimise in discussione il semplice modello a quark che aveva grandissimo successo ed era universalmente accettato
- Uno degli articoli più citati della fisica sperimentale nucleare e particellare
- Diede origine ad uno dei più ampi programmi di ricerca in fisica delle particelle



# 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 tutte le particelle uscenti dall'interazione principale puo` consentire di rispondere a una domanda chiave: qual'e` l'apporto dei gluoni allo spin del protone?



# La Collaborazione

- *1995: HMC and CHEOPS L.o.I. at CERN*
- *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 Physicists**

*Programma iniziale: 8 anni di presa dati*



# 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 ( $\Delta D^{\Lambda_q}$ )

## Spectroscopy

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



# Cos'e` lo spin?

- E` un concetto quantistico di difficile visualizzazione
- E` legato al momento angolare:
  - Simmetria angolare: ISOTROPIA
  - Invarianza per cambiamento di angolo
  - Quantità che si conserva: MOMENTO ANGOLARE ( $J$ )
  - Lo stato di un sistema e` determinato dal valore di  $J$
  - La quantizzazione agisce su  $J$ : multipli dell'unità  $\hbar$

Gli spinori sono oggetti "piu` elementari" dei vettori in  $\mathbb{C}^3$

- $X = (x_1, x_2, x_3)$ ;  $X \cdot X = 0$  (vettore isotropo)
- Superficie bidimensionale, si puo` descrivere con 2 coord.
- $Z = (z_1, z_2) \leftrightarrow X = (x_1, x_2, x_3)$  ( $x_1 = z_0^2 - z_1^2$ ,  $x_2 = i(z_0^2 + z_1^2)$ ,  $x_3 = -z_0 z_1$ )
- Una rotazione di  $\theta$ :  $X \rightarrow e^{-i\theta}X$  ma  $Z \rightarrow e^{-i(\theta/2)}Z$



# Cos'e` lo spin?

Nel 1927 P.A.M. Dirac scrisse un'equazione che descrive correttamente le proprietà osservabili degli elettroni attribuendo loro la natura di spinori, con  $\text{spin} = \frac{1}{2} \hbar$ .

Lo spin o momento angolare intrinseco forma, con la massa e la carica elettrica le caratteristiche fondamentali dell'elettrone.

Lo spin è anche legato al momento magnetico delle particelle: per decidere se una particella è elementare basta misurarne il momento magnetico e confrontarlo con quello predetto dalla teoria.



# Spin: a history full of surprises

- Stern & Gerlach (1921) Space quantization associated with direction
- Goudschmidt & Uhlenbeck (1926): Atomic fine structure & electron spin magnetic moment
- Stern (1933) Proton anomalous magnetic moment  $2.79 \mu_N$
- Kusch(1947) Electron anomalous magnetic moment  $1.00119\mu_0$
- Prescott & Yale-SLAC Collaboration (1978)  
EW interference in polarized e-d DIS, parity non-conservation
- European Muon Collaboration (1988): Spin Puzzle
- Transverse single spin asymmetries: E704, AGS pp scattering,  
...

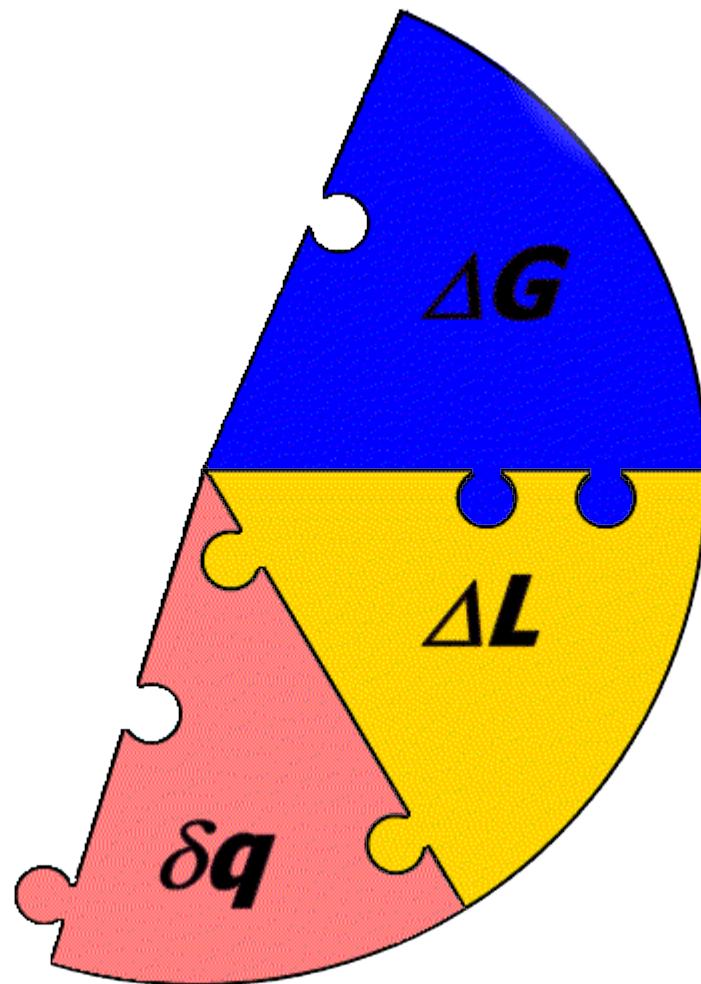


# What are we after?

- When the nucleon is polarized, how do quarks and gluons make up and/or respond to this polarization?
  - Where does the spin of the nucleon come from? (spin decomposition)
    - Gluon and quark helicity
    - Orbital angular momentum
  - Interesting polarization-dependent observables
    - Transversity (figure this in a spin sum rule?)
    - Sivers functions



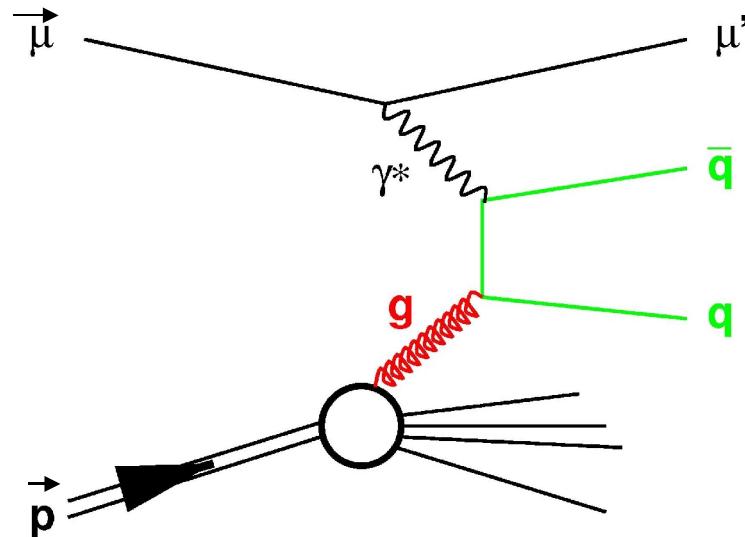
# (spin) structure of the nucleon





# $\Delta G/G$ from $\alpha^-$ and high $p_T$ hadron pairs

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



High  $p_T$  hadron pair  $q\bar{q} \rightarrow hh$

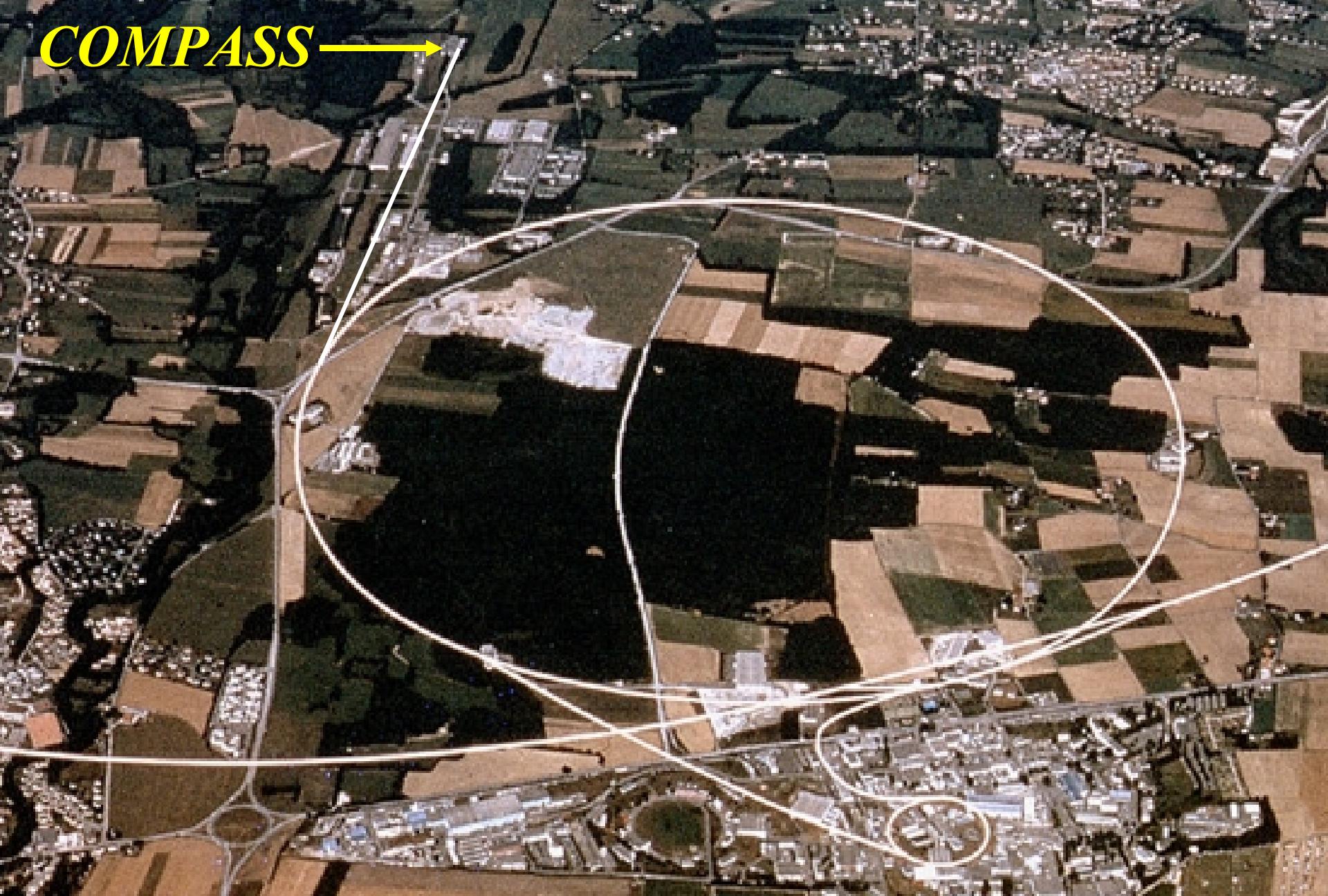
*Jura*

*Geneva Lake*

*COMPASS*



**COMPASS**





# COMPASS luminosity

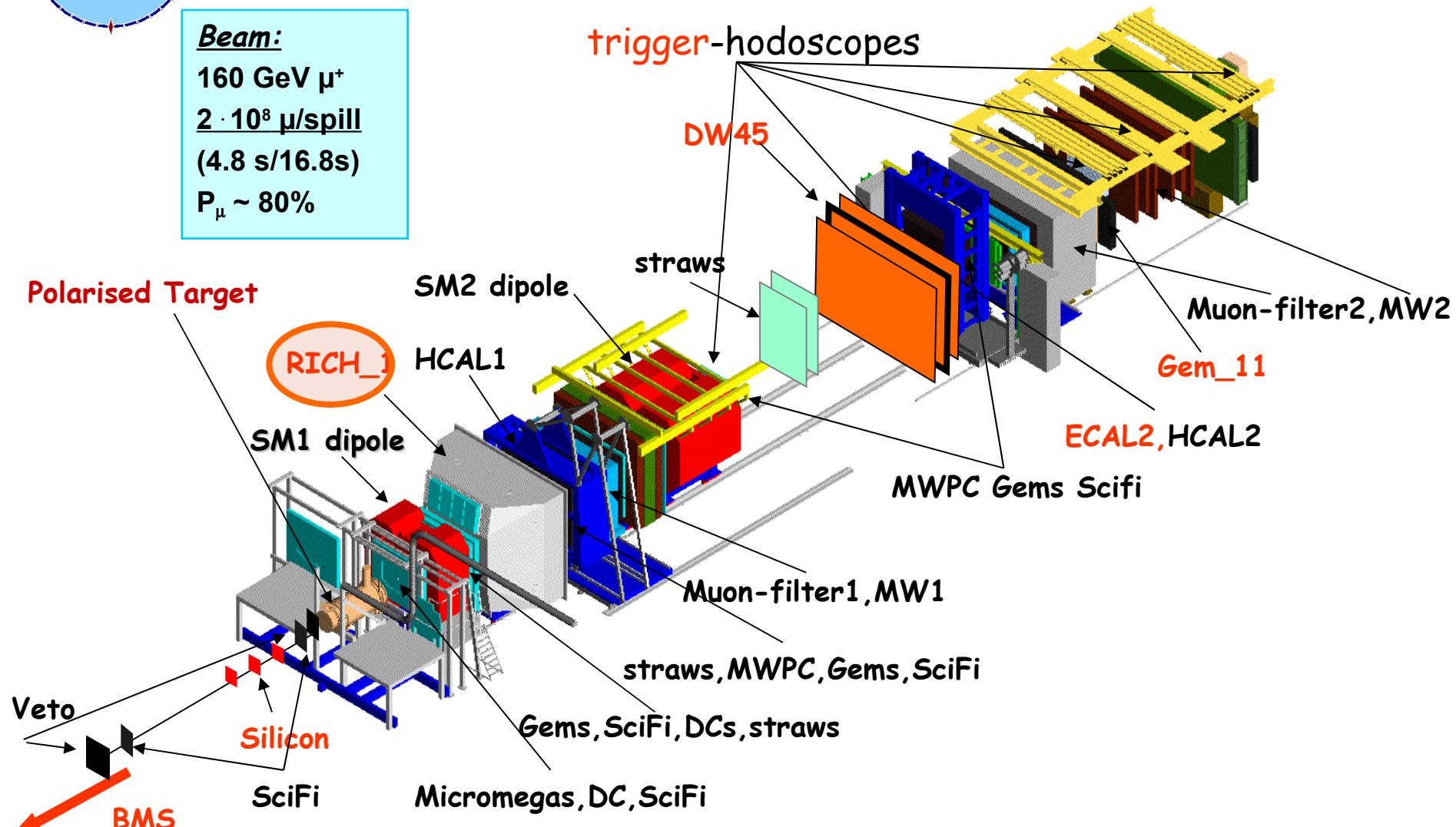
- CERN SPS  $\mu^+$  beam:
  - $E_\mu = 160 \text{ GeV}$ ,  $P_B = -0.80$
  - Intensity:  $2 \times 10^8 / \text{spill}$ ,  $T = 16.8 \text{ s}$
- ${}^6\text{LiD}$  solid target:
  - $2 \times 60 \text{ cm}$  long,  $f \approx 0.50$ ,  $P_T \approx 0.5$
- 2 outstanding spectrometers:
  - LAS:  $1.0 \text{ Tm}$ ,  $\pm 70 \text{ mrad}$
  - SAS:  $4.0 \text{ Tm}$ ,  $\pm 40 \text{ mrad}$

$$L \approx 5 \times 10^{32} \text{ s}^{-1} \text{ cm}^{-2}$$



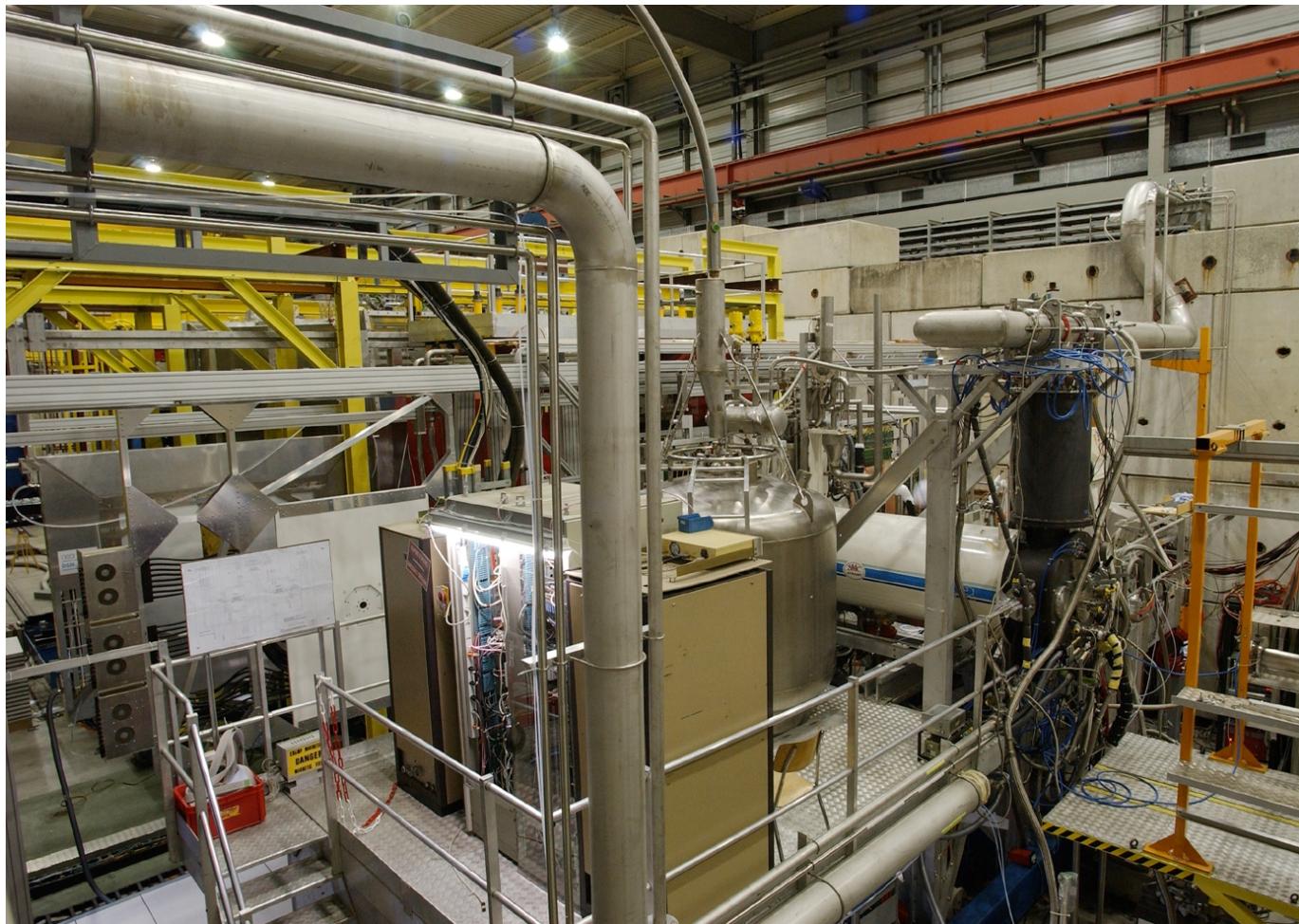
# THE COMPASS SPECTROMETER

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





# The target region in the hall



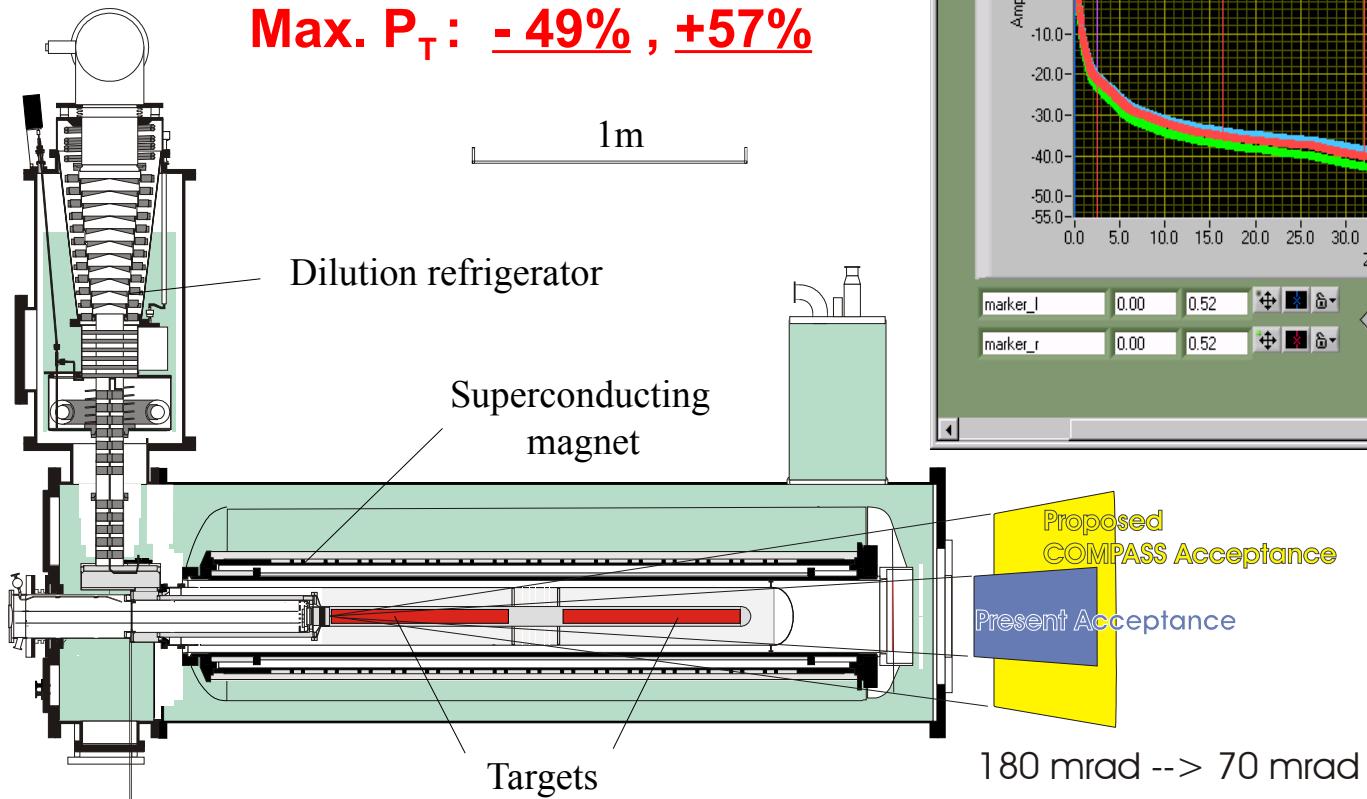


# $^6\text{LiD}$ Target

2 halves polarised in opposite directions

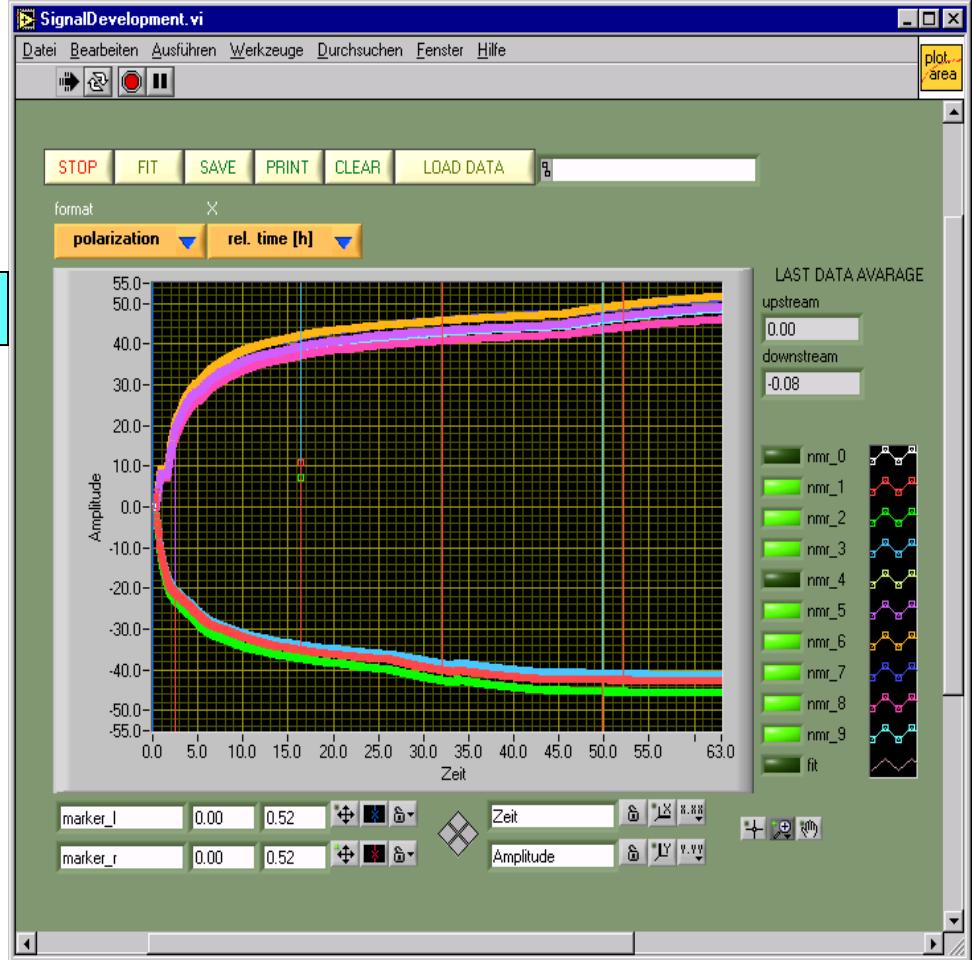
Dynamic Nuclear Polarization  
Frequency Modulation

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



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Dilution factor ~50%

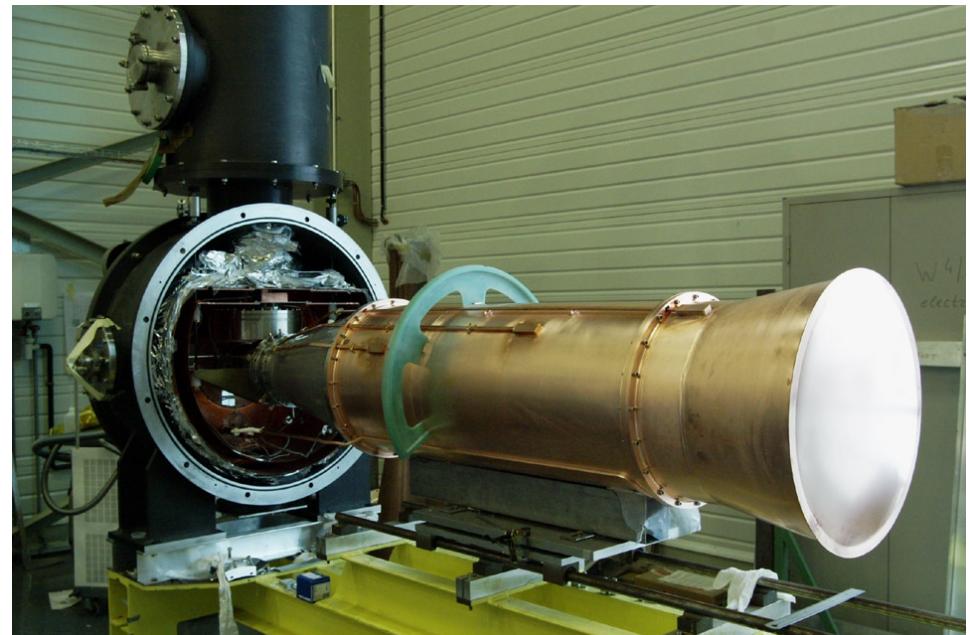
Solenoid: 2.5 T

Dipole: 0.5 T

Relaxation time:  
>1000 h for 0.5 T



# Polarized target upgrade, in 2006

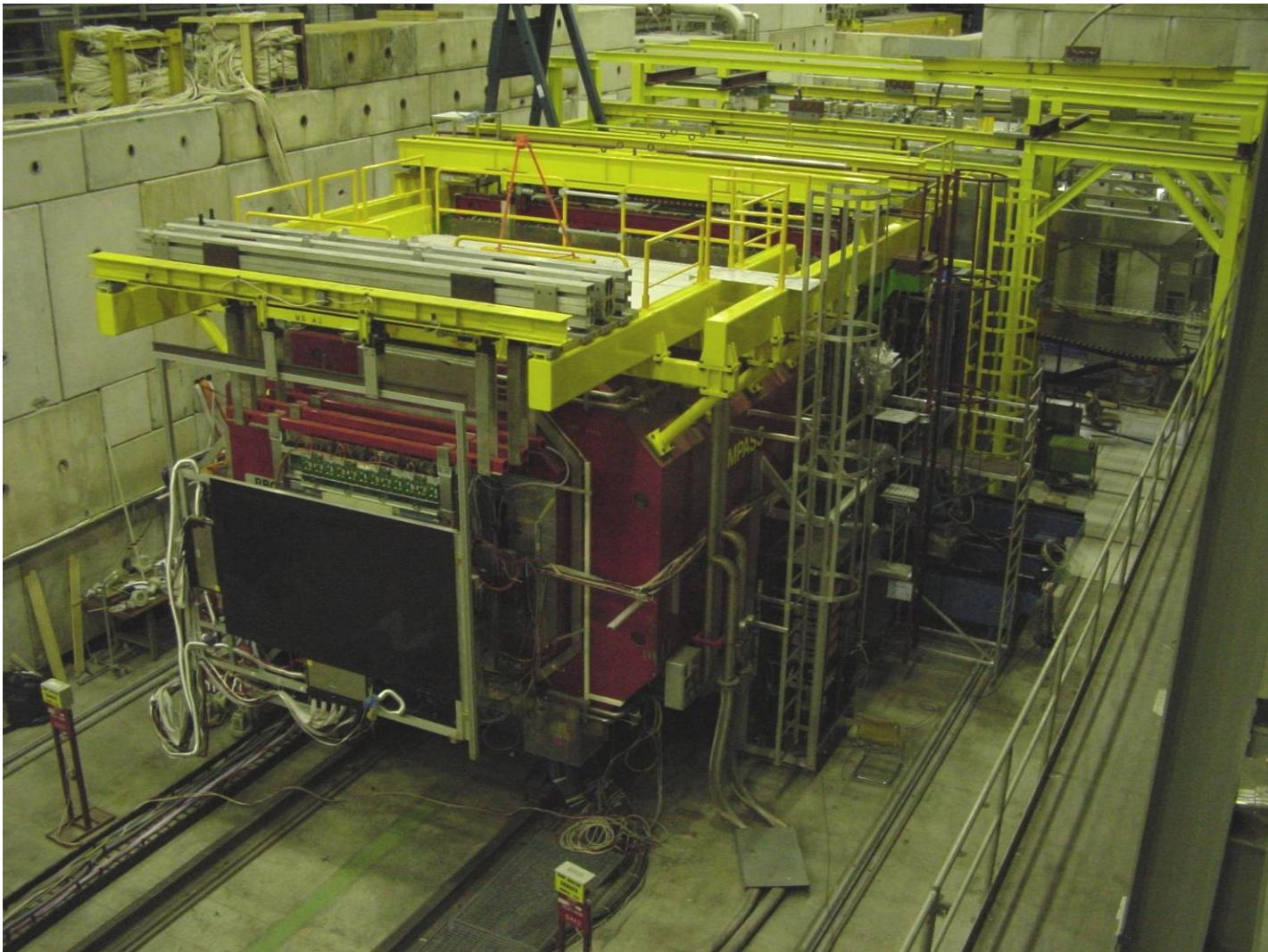


- New COMPASS target magnet  
→ 180 mrad

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



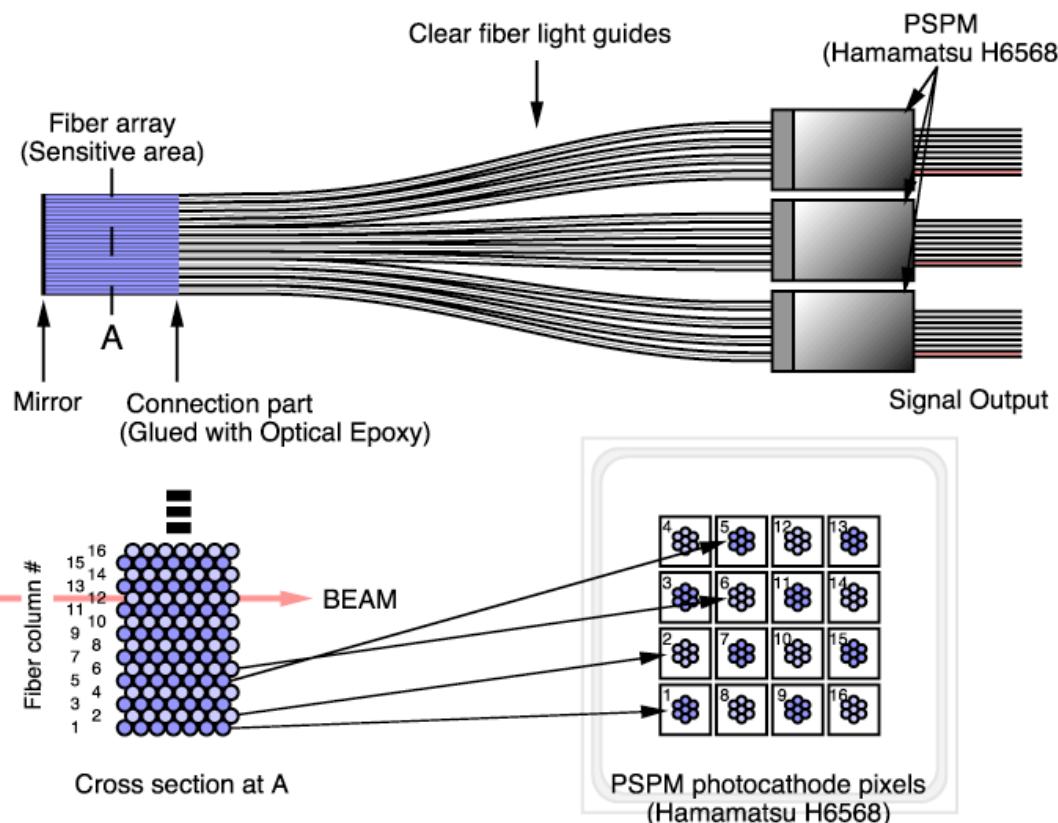
# SM2 and the LAS region





# Scintillating Fibers Hodoscopes

**9 stations: 21 coordinates**

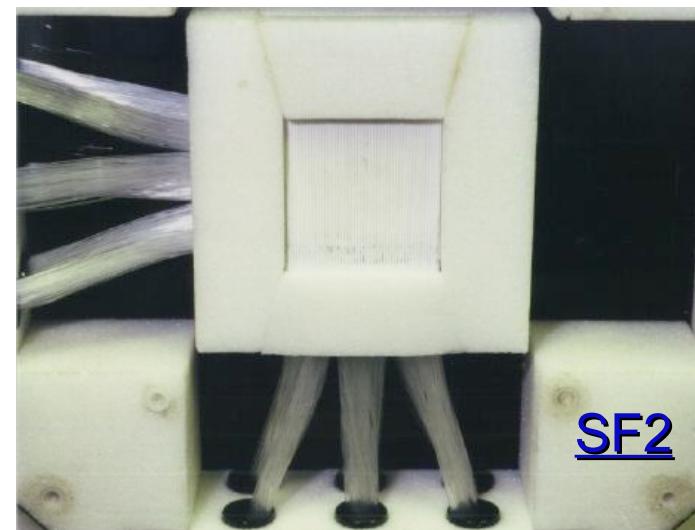


*Rate capability > 5 MHz per channel*

*Efficiency: 99%*

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

*Time resol. < 400 ps*



**Sensitive area:**

**7-layers of Kuraray SCSF-78MJ 0.5 mm Ø**

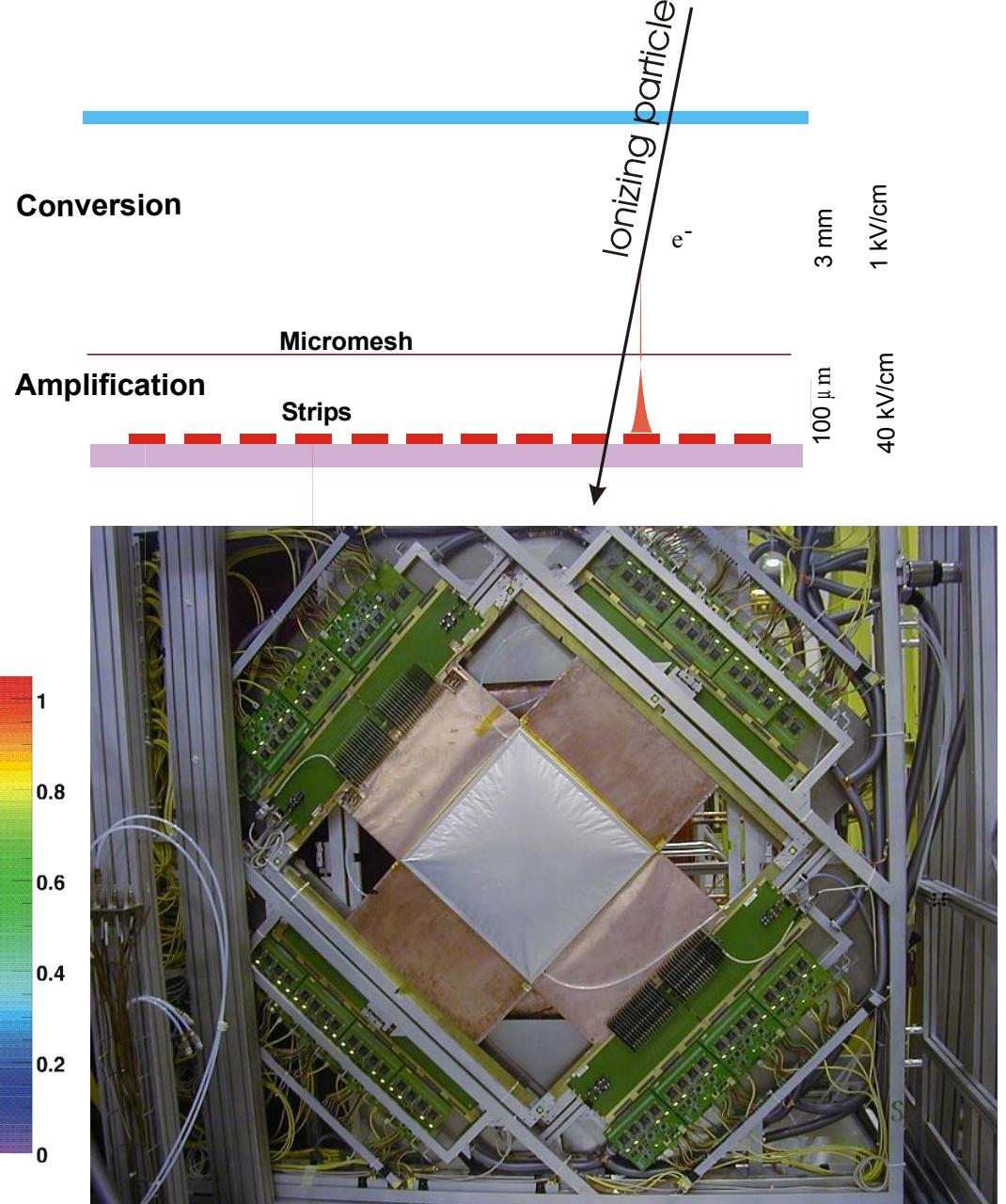
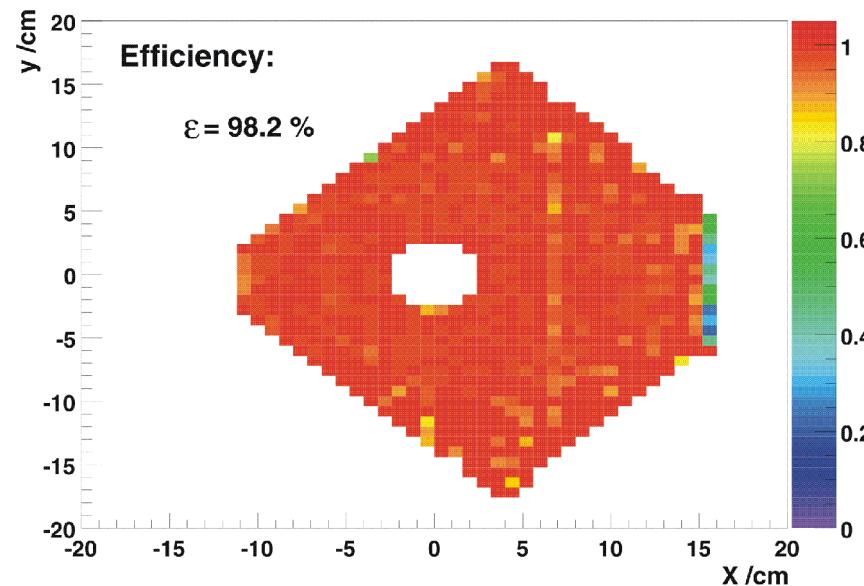


$$\mu \Omega$$

**12 planes     $40 \times 40 \text{ cm}^2$**

**Space resolution:  $70 \mu\text{m}$**

**Time resolution: 8 ns**



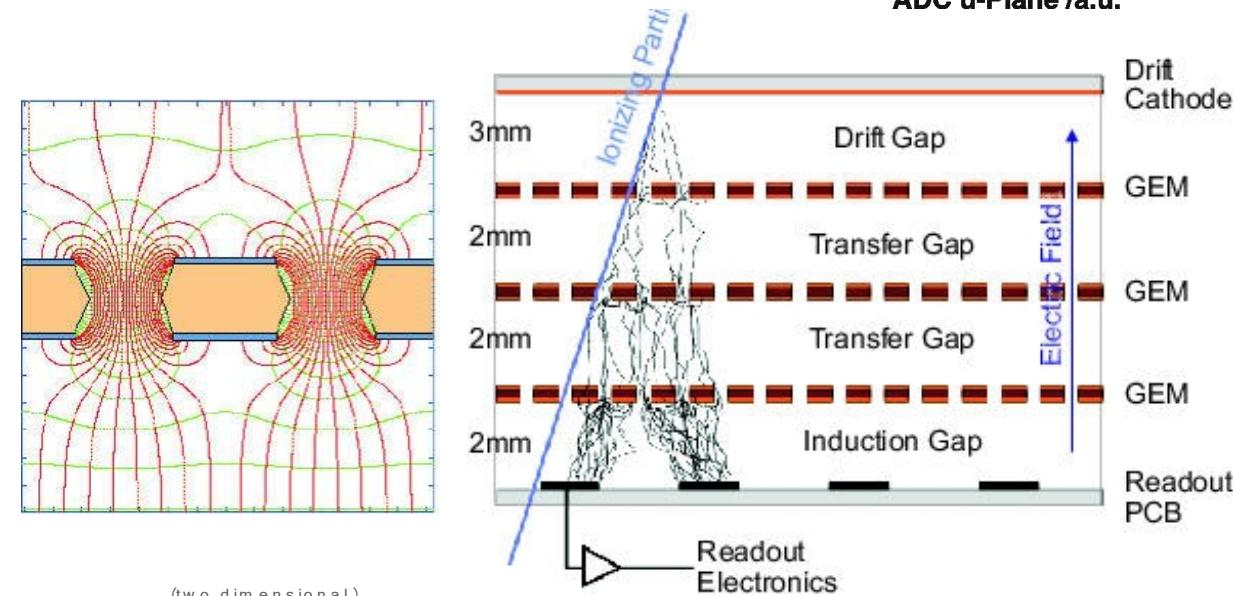
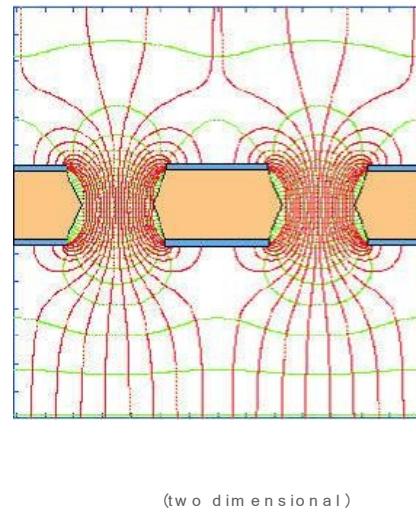
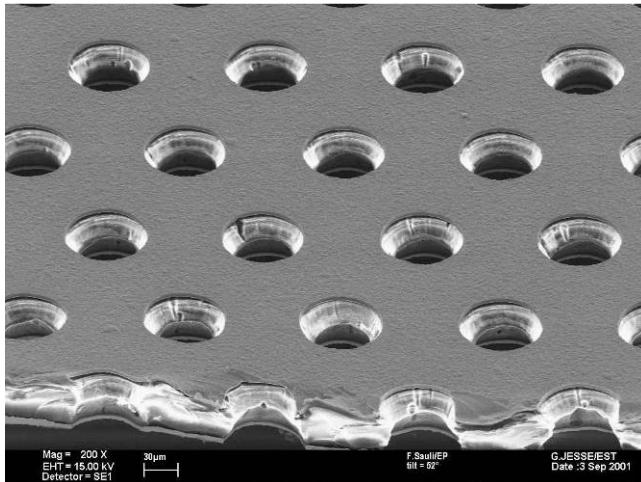
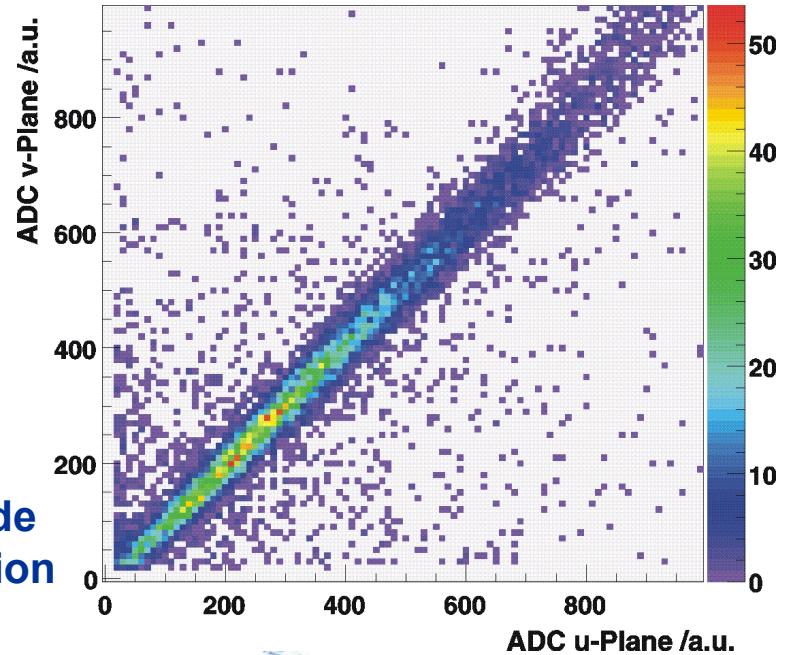


# GEM

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



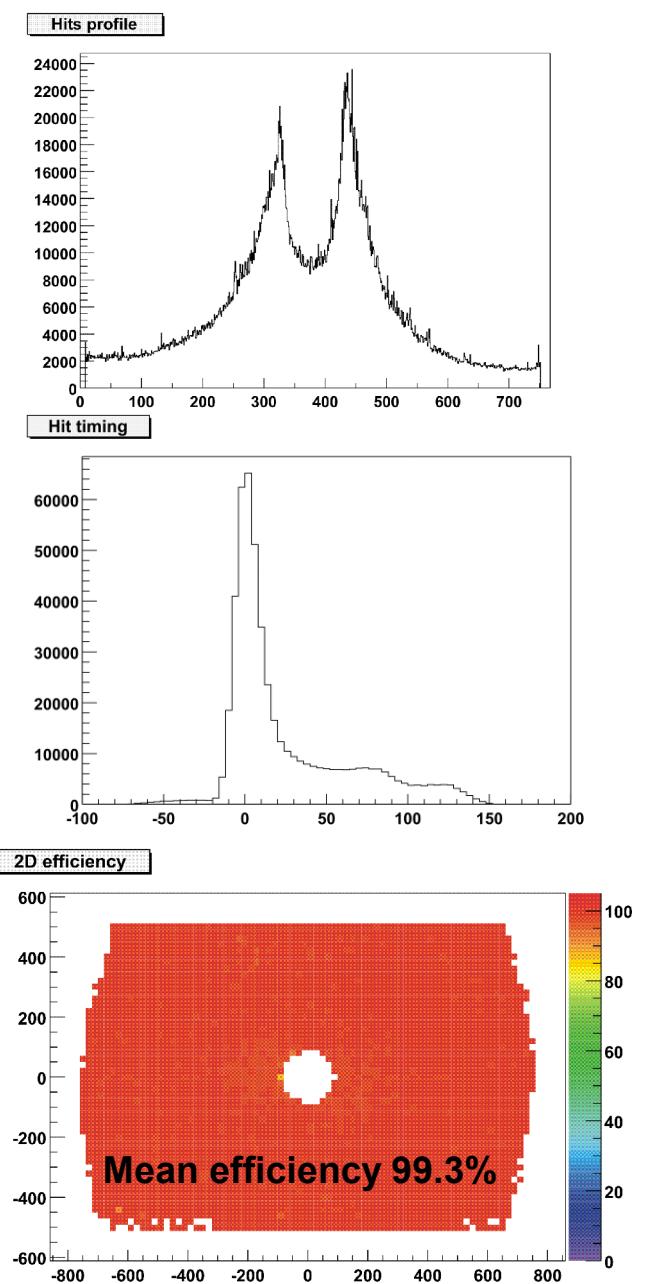
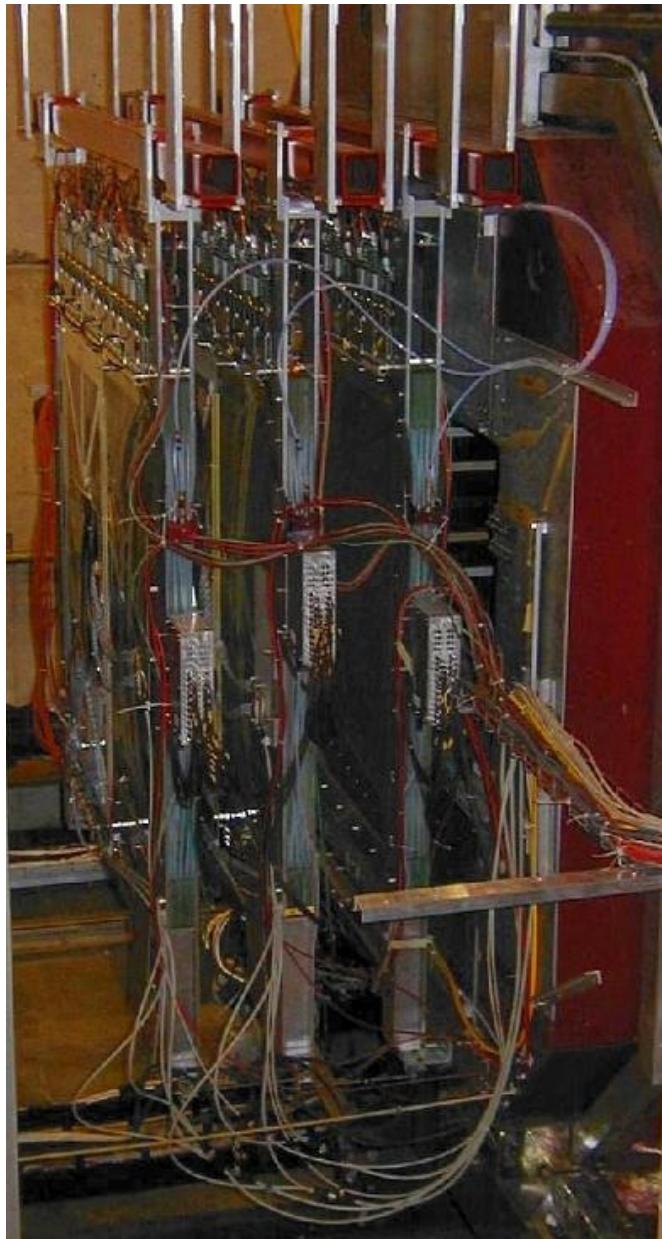


# MWPCs

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



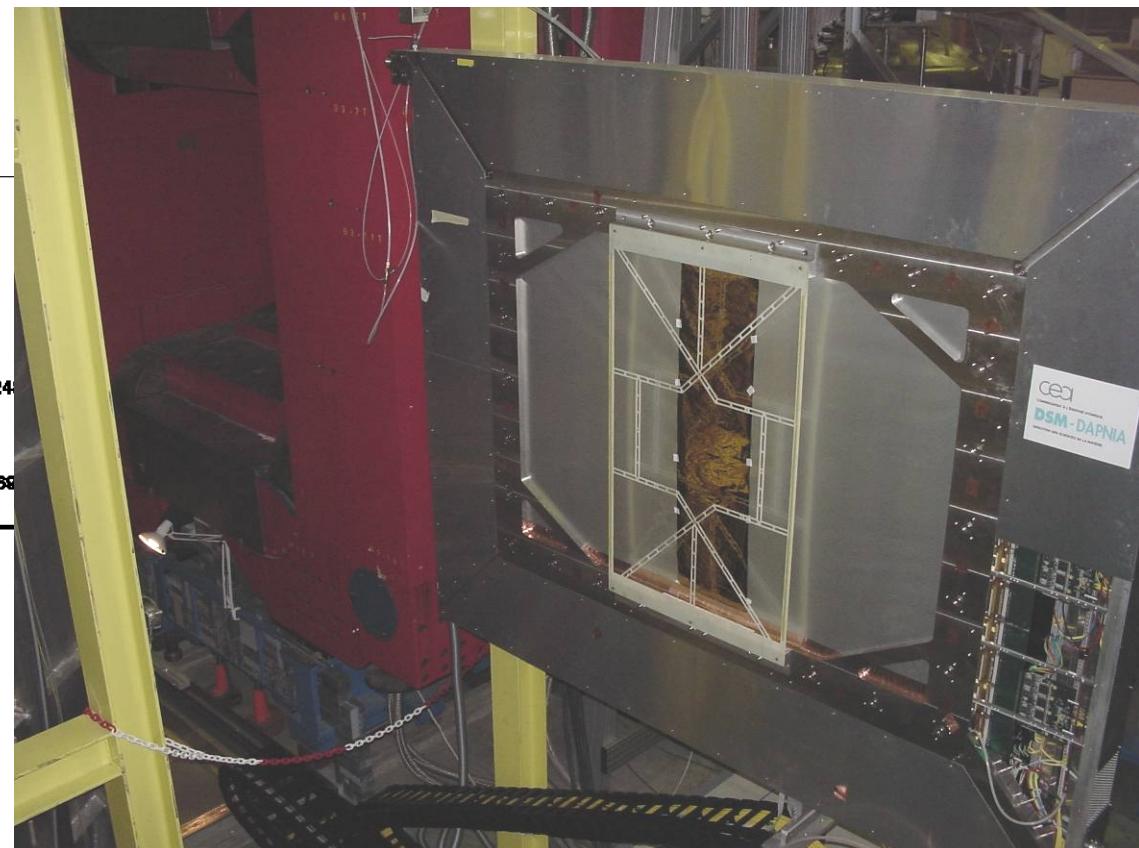
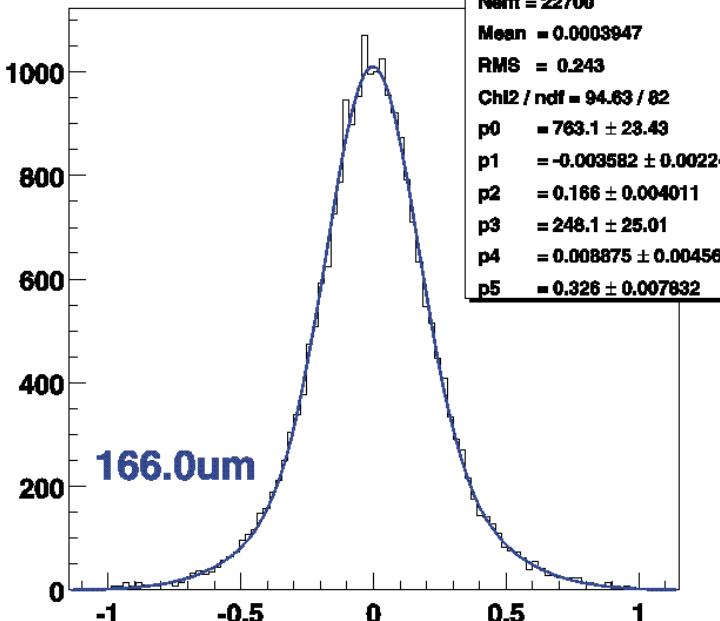


# Drift Chambers for LAS

3 chambers with 8 coordinates each

Efficiency: 95 - 99.8 %

DC01X1\_\_T\_du\_>T\_fnd&&abs(T\_duMin)<1&&T\_ch12/T\_cmit<3



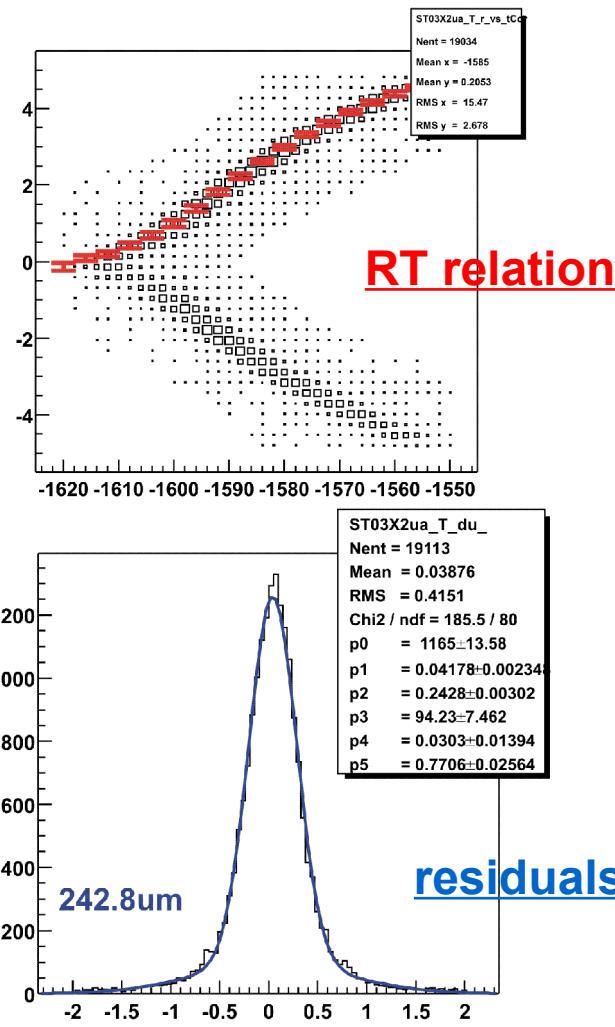


# Drift Chambers for SAS



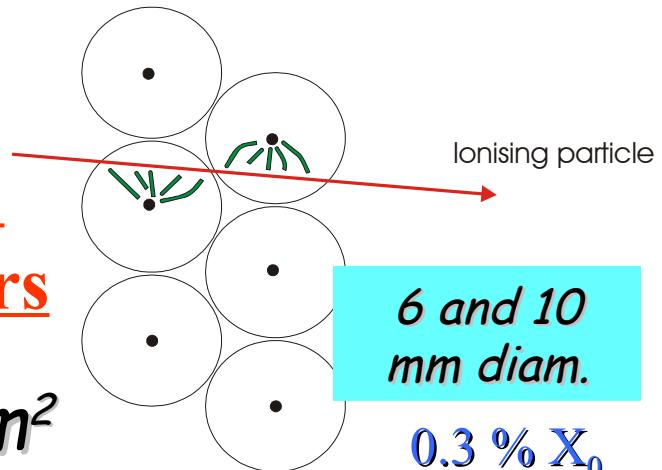


# STRAWs

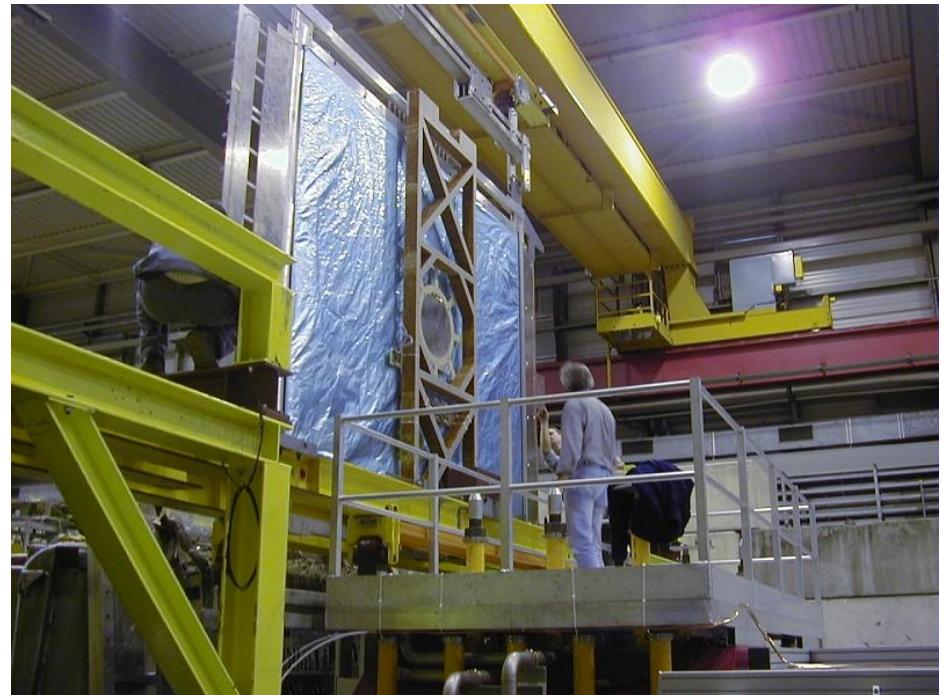


1 Module =  
6 double layers

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



Installation of a double layer





# HCAL 1





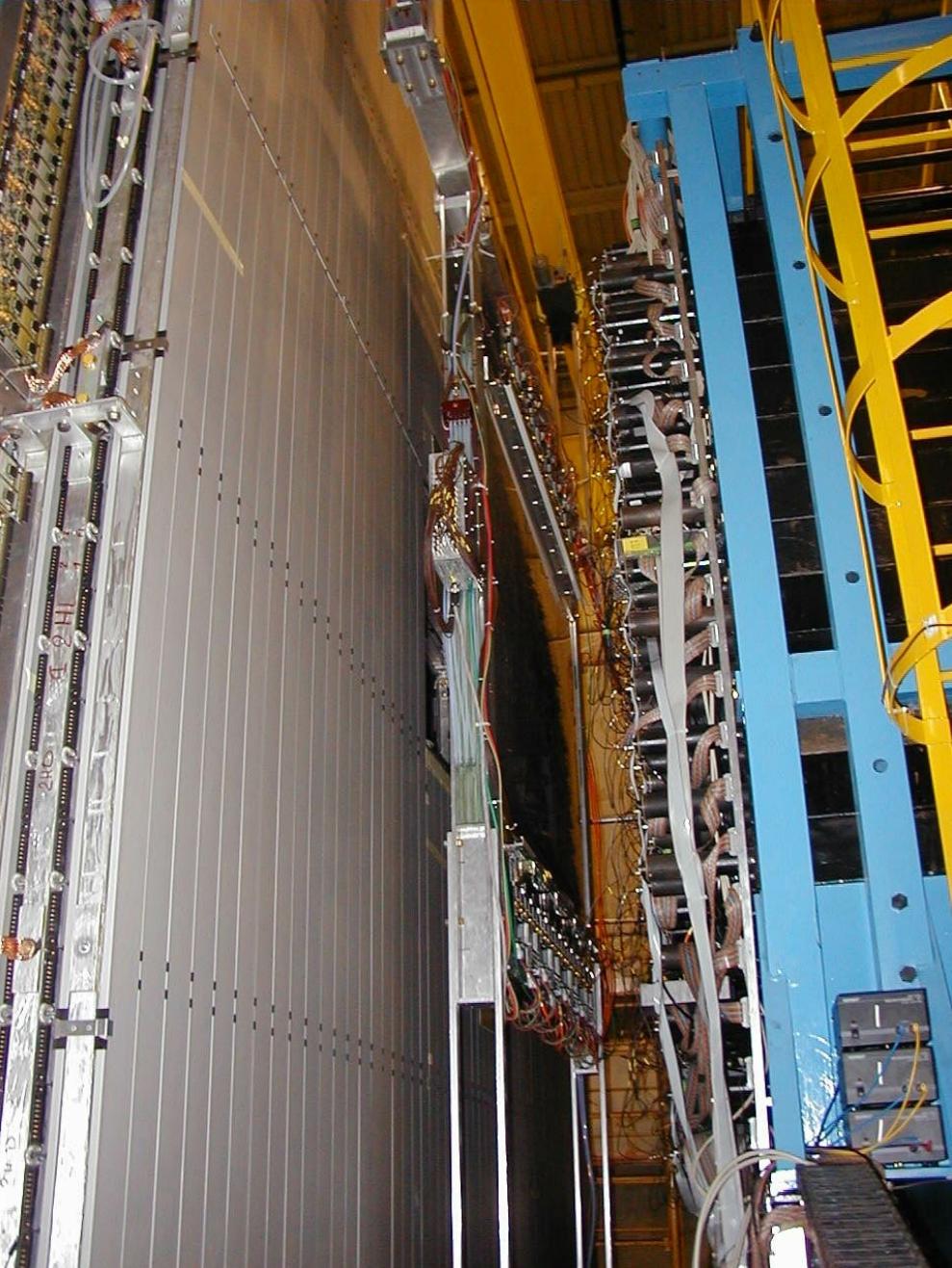
# Muon Wall 1

and

# Muon Wall 2



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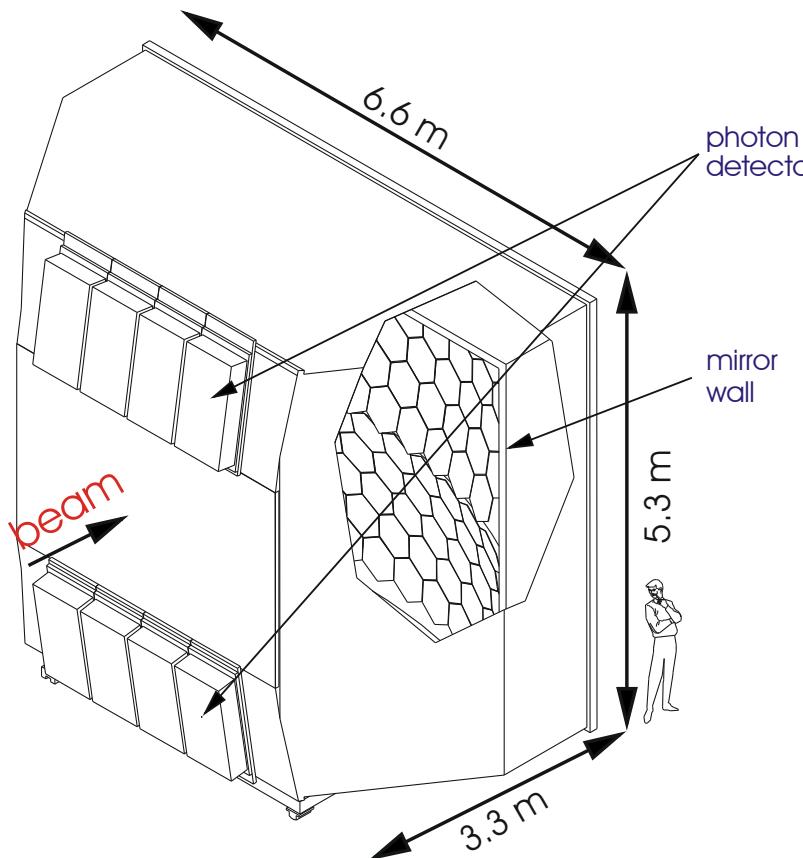
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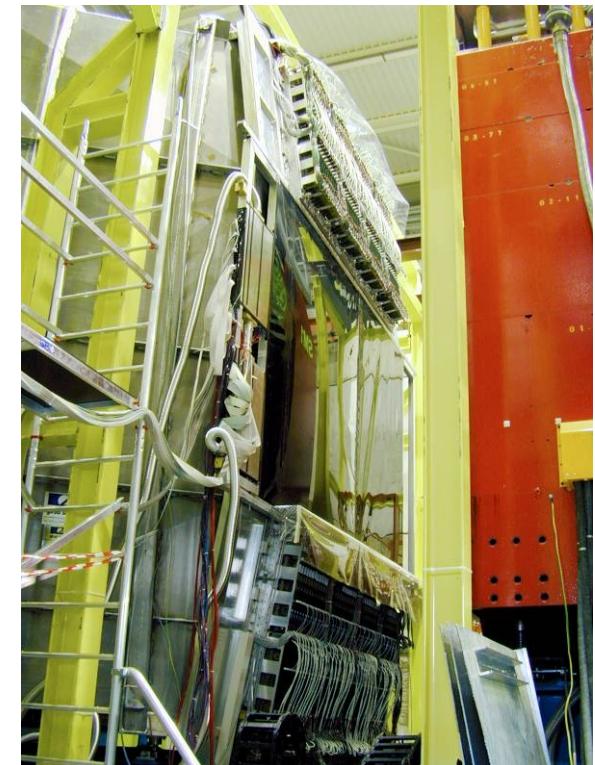
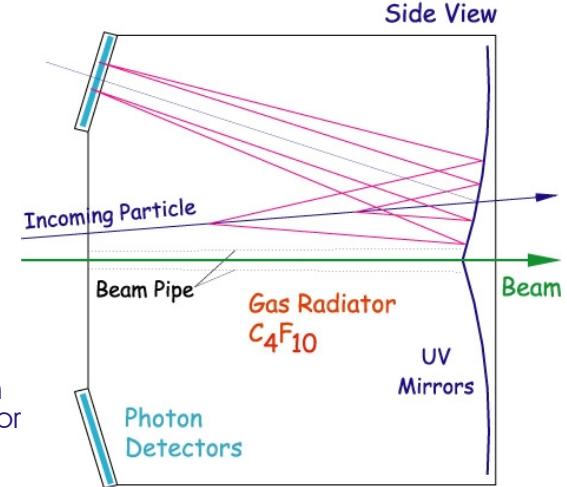


# RICH 1

- Radiator: 3 m  $C_4F_{10}$
- Vessel volume: 90  $m^3$
- 116 mirrors
- Focal length = 3 m
- 5.3  $m^2$  UV detectors:
  - MWPC with CsI photo-sensitive cathodes
  - 8x8  $mm^2$  pads
- 84k channels
- 10 bits ADC r/o
- Local thr. comparison and 0 suppression



$6 \text{ eV} < E_\gamma < 7.5 \text{ eV} \Rightarrow \text{high gas purity}$





# COMPASS RICH-1

requirements:

- hadron PID up to  $\sim 45 \text{ GeV}/c$
- LARGE acceptance (large size):

H: 500 mrad

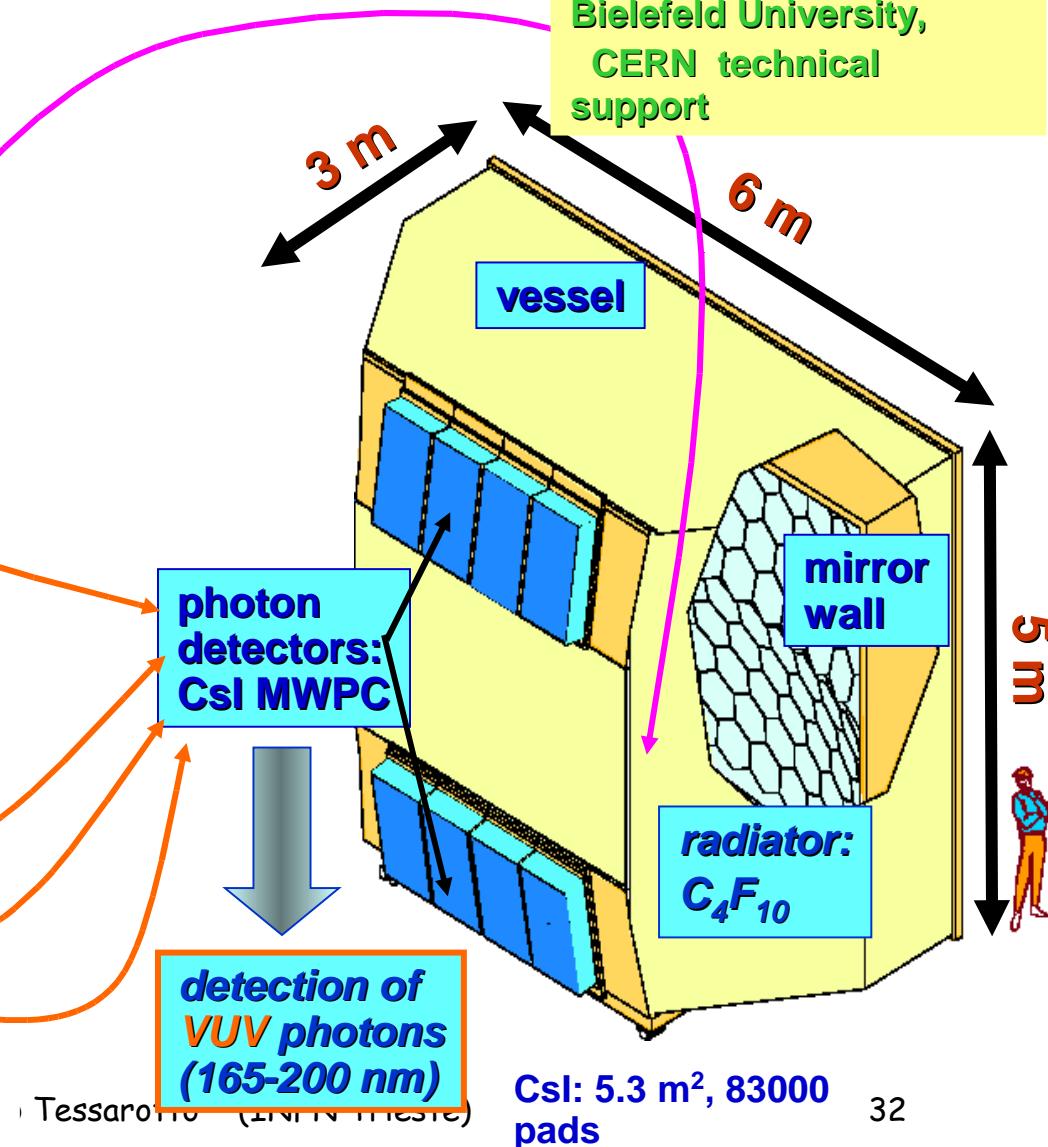
V: 400 mrad

- able to stand trigger rates up to 20 KHz
- beam rates up to  $4 \cdot 10^7 \text{ Hz}$
- minimize material in the acceptance

detector designed in 1996

- PROJECT COST :  $\sim 3 \text{ M } \text{\euro}$

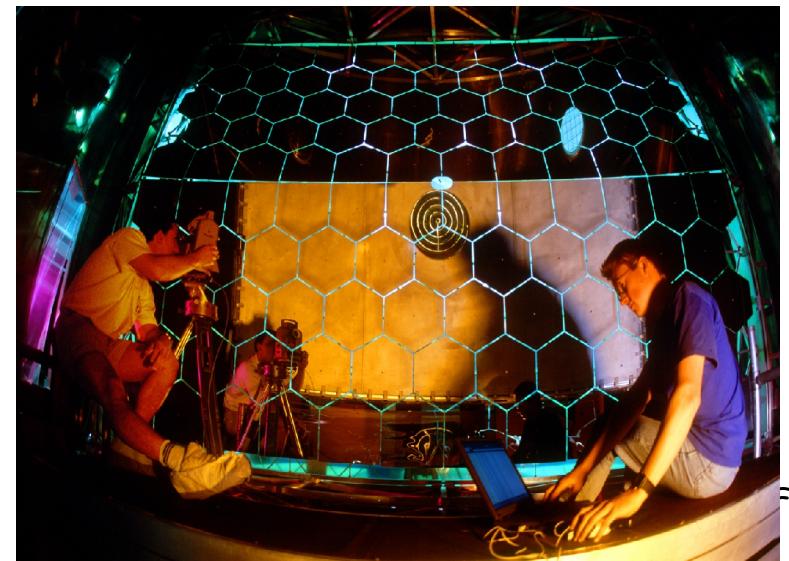
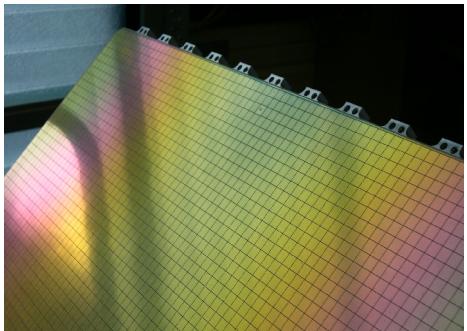
Trieste: INFN, Univ. & ICTP,  
Turin: INFN and University,  
Bielefeld University,  
CERN technical support



Tessarollo (INFN Trieste)

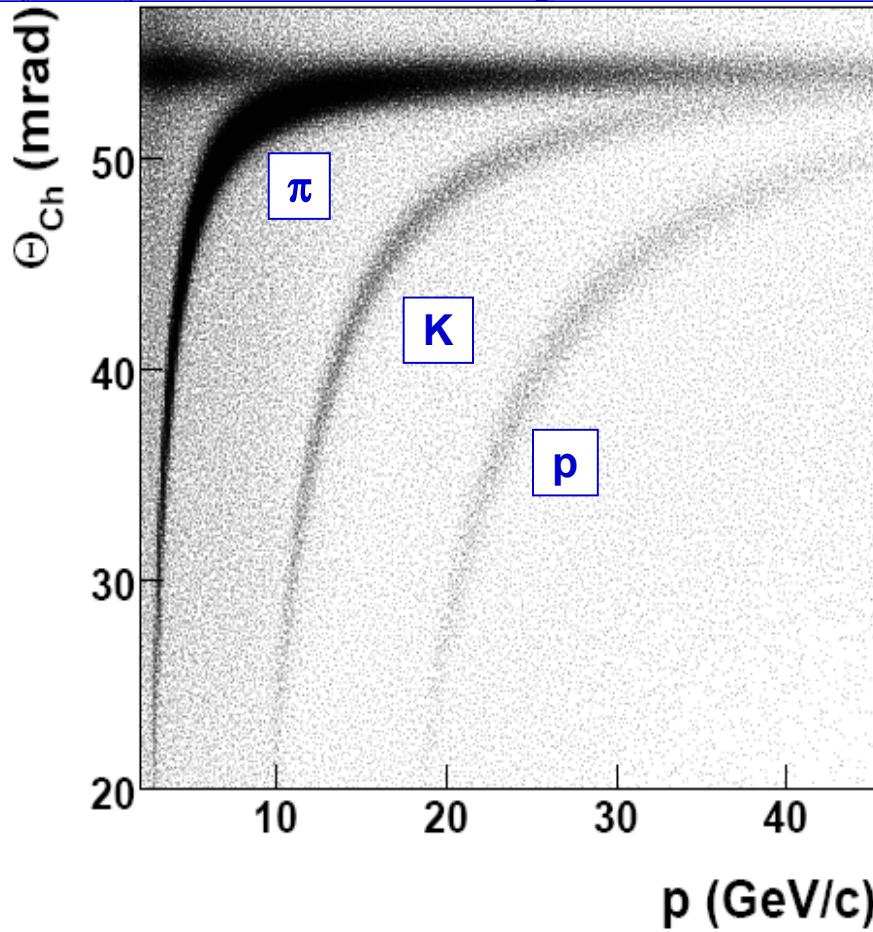
CsI:  $5.3 \text{ m}^2$ , 83000 pads

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# COMPASS RICH-1 performances



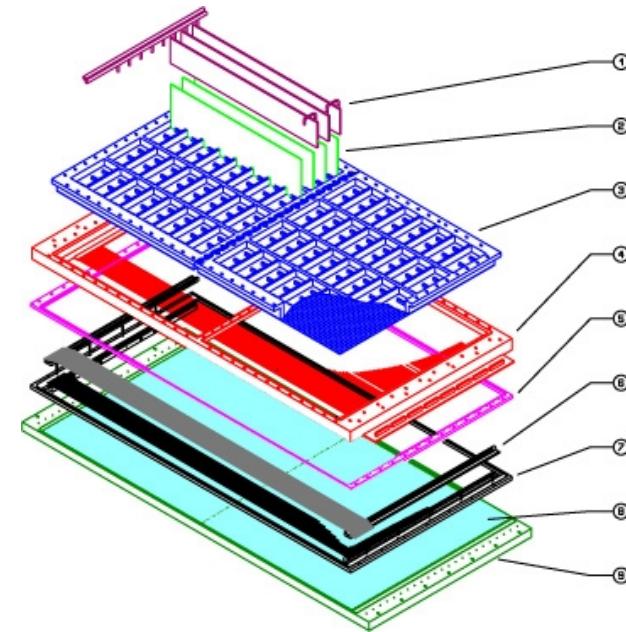
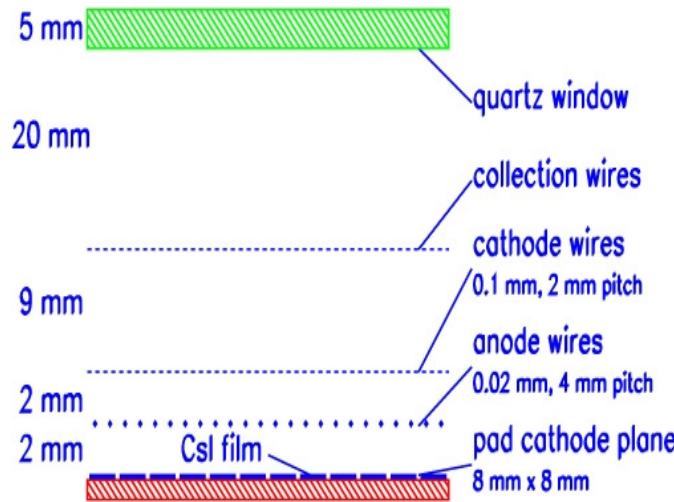
- RICH-1 is in operation  
at COMPASS  
since 2001**
- photons / ring ( $\beta \approx 1$ , complete ring in acceptance) : **14**
  - $\sigma_{\theta-ph}$  ( $\beta \approx 1$ ) : **1.2 mrad**
  - $\sigma_{ring}$  ( $\beta \approx 1$ ) : **0.6 mrad**
  - $2\sigma$   $\pi$ - $K$  separation @ **43 GeV/c**
  - **PID efficiency > 95%**  
 $(\theta_{ch} > 30$  mrad)  
except for the very forward region

- E. Albrecht et al, NIM A 33 (2003) 15

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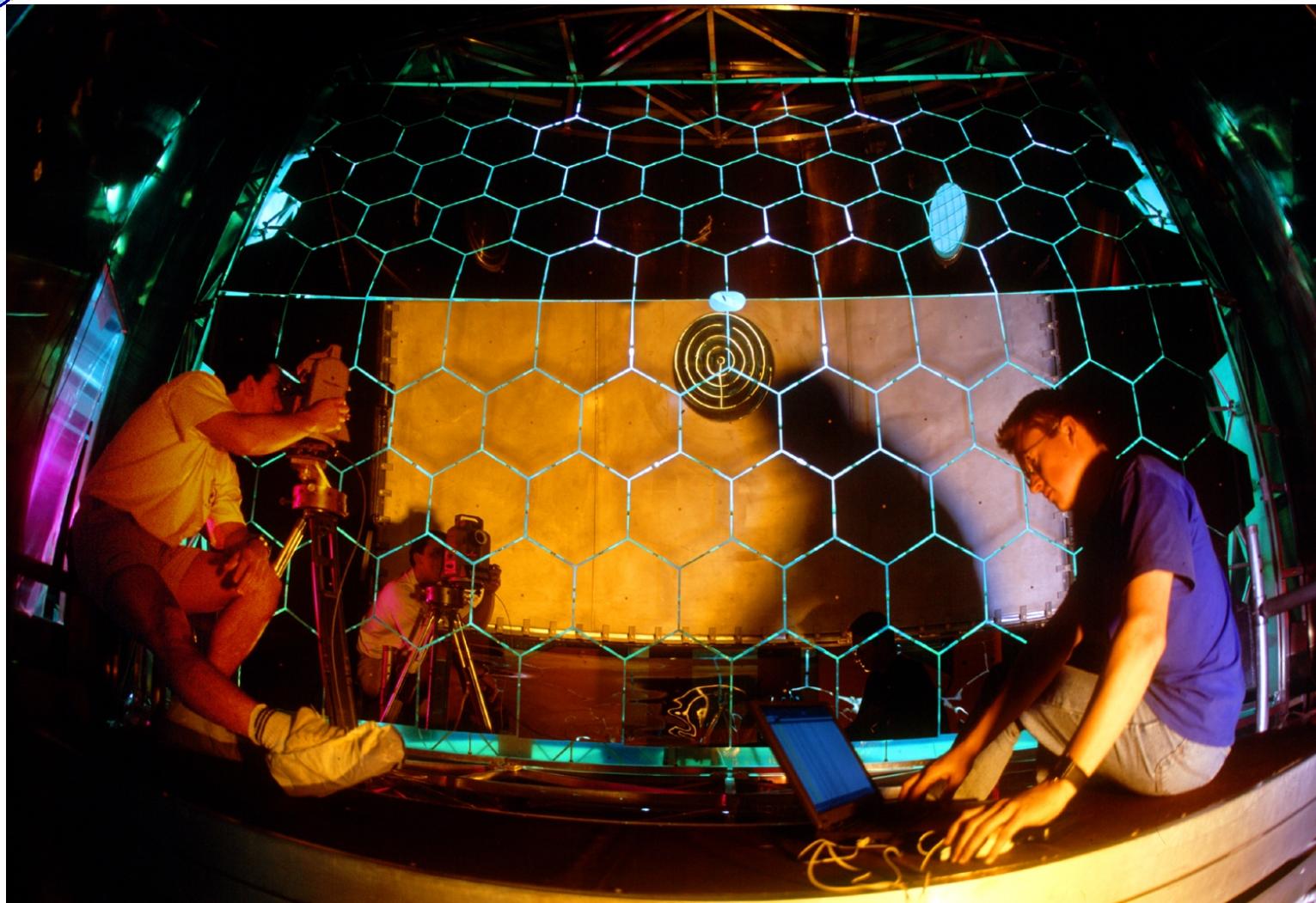


# Photon Detectors



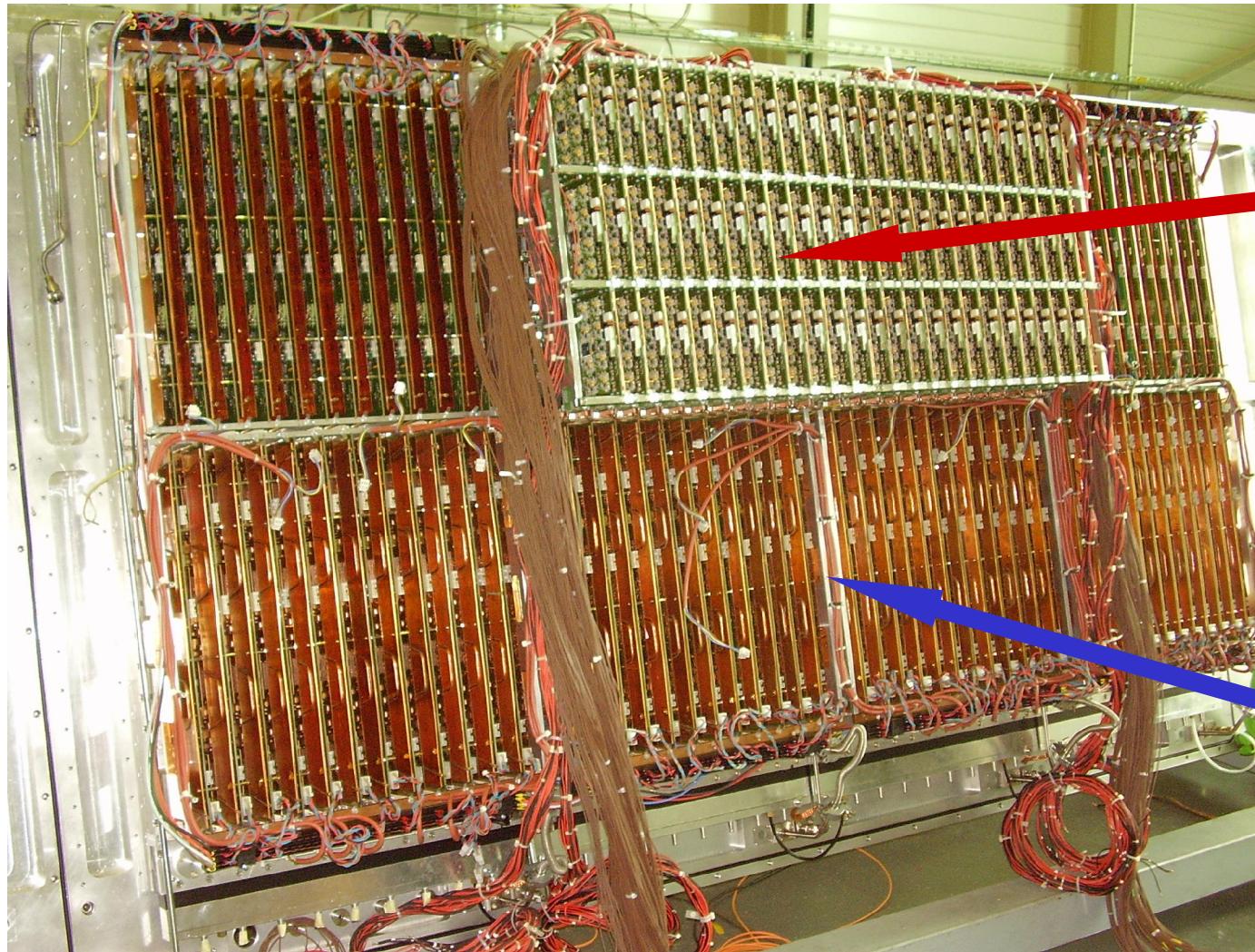


# RICH Mirrors





# RICH-1 upgrade, in 2006



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**Lens system**

+ MAPMTs

+ MAD4

+ F1

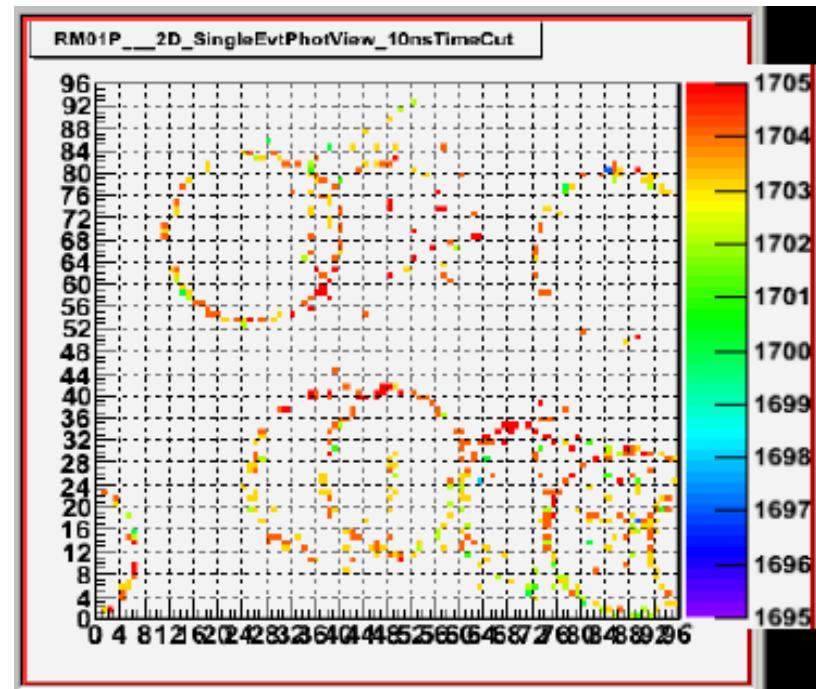
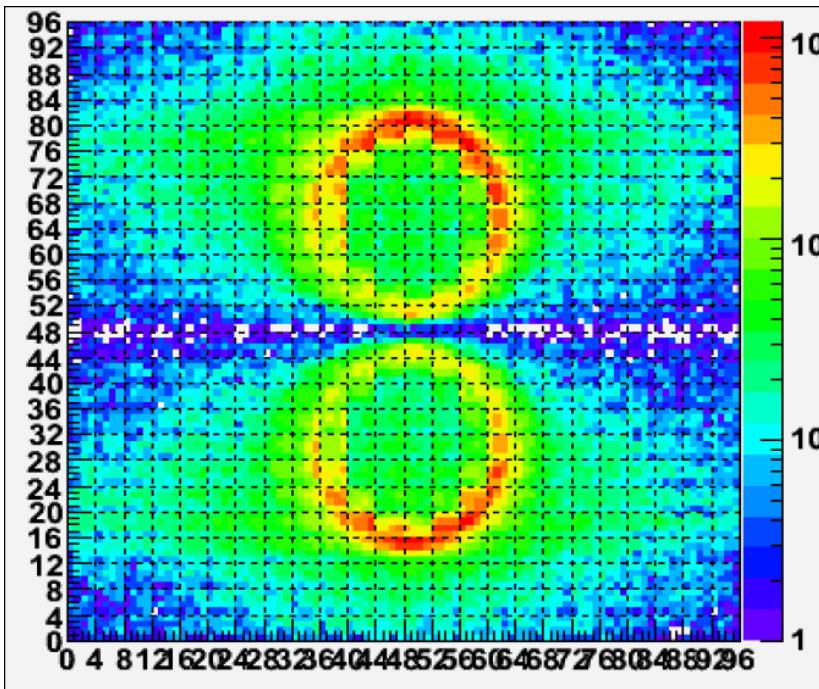
**CsI MWPC**

+ APV25S1

+ ADC

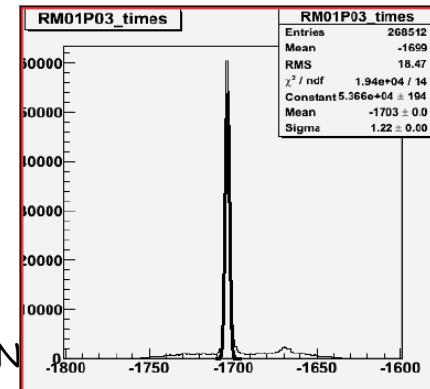


# RICH-1 upgrade, MAPMTs "on-line"



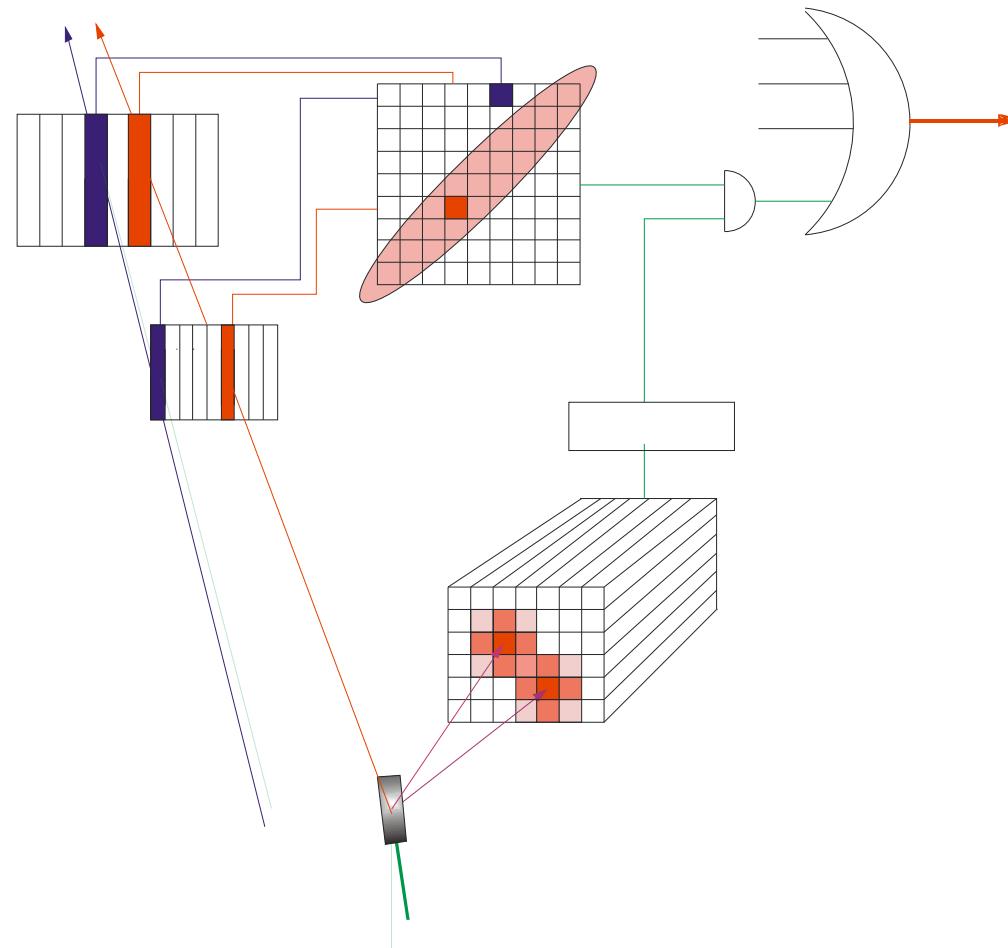
Very promising results !

- Precise timing
- High photon statistics

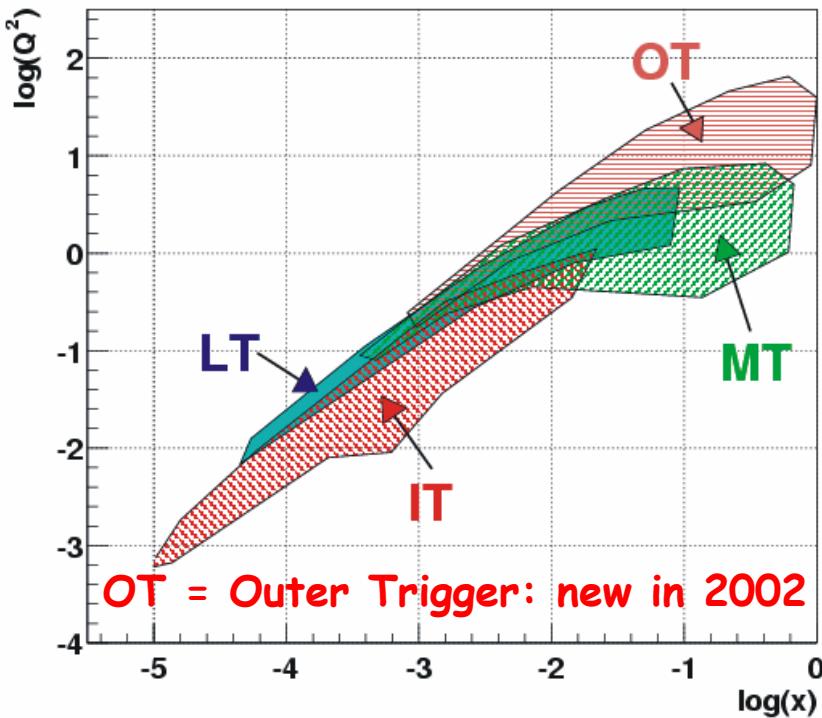




# Trigger concept

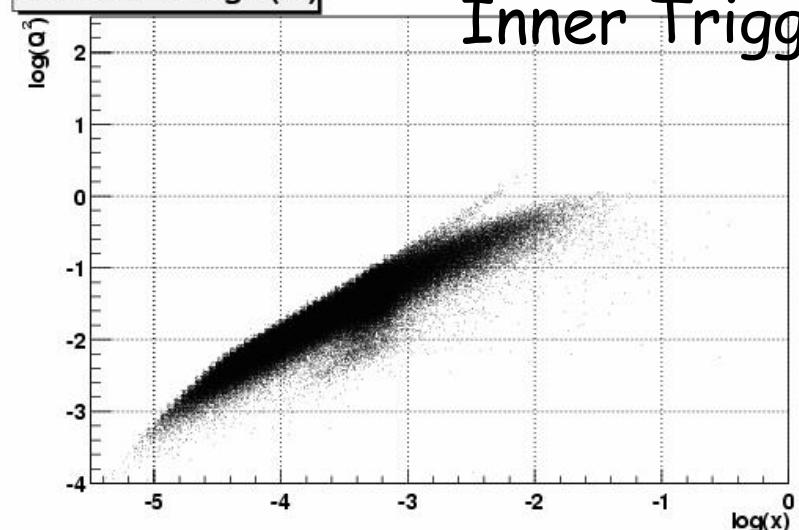


## Kinematic ranges for IT, LT, MT, OT

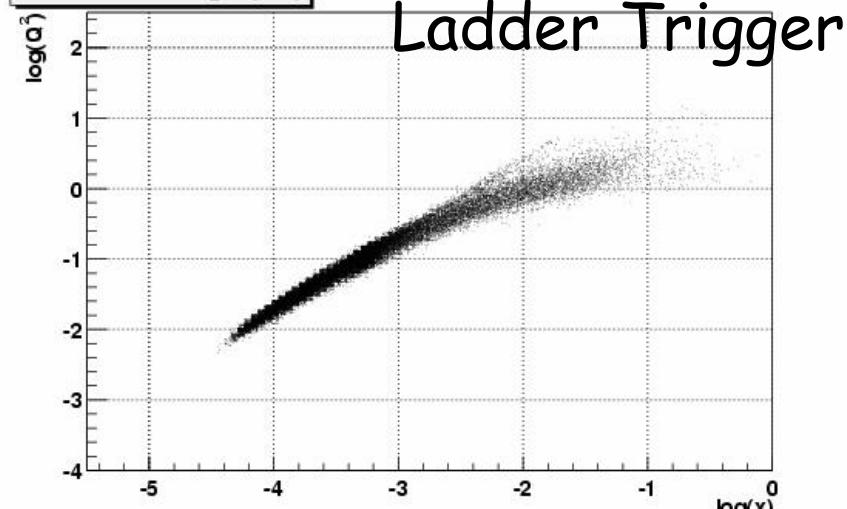


# Trigger coverage

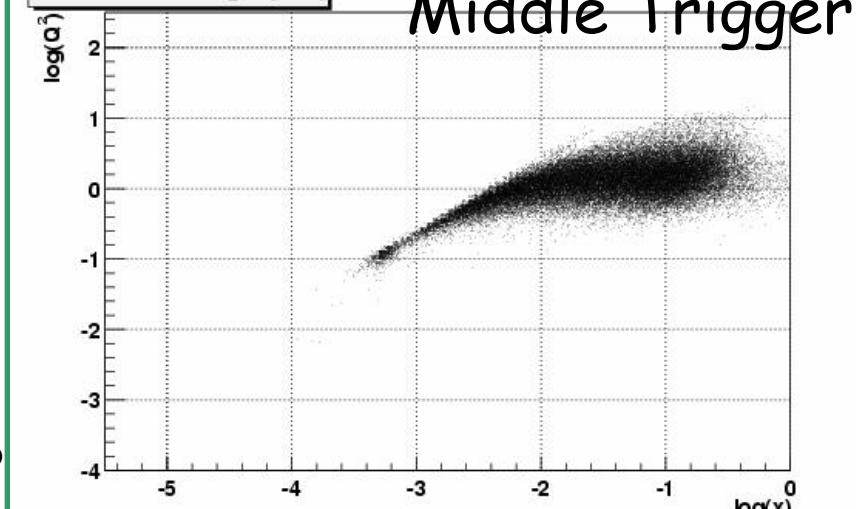
## Kinematic range (IT)



## Kinematic range (LT)



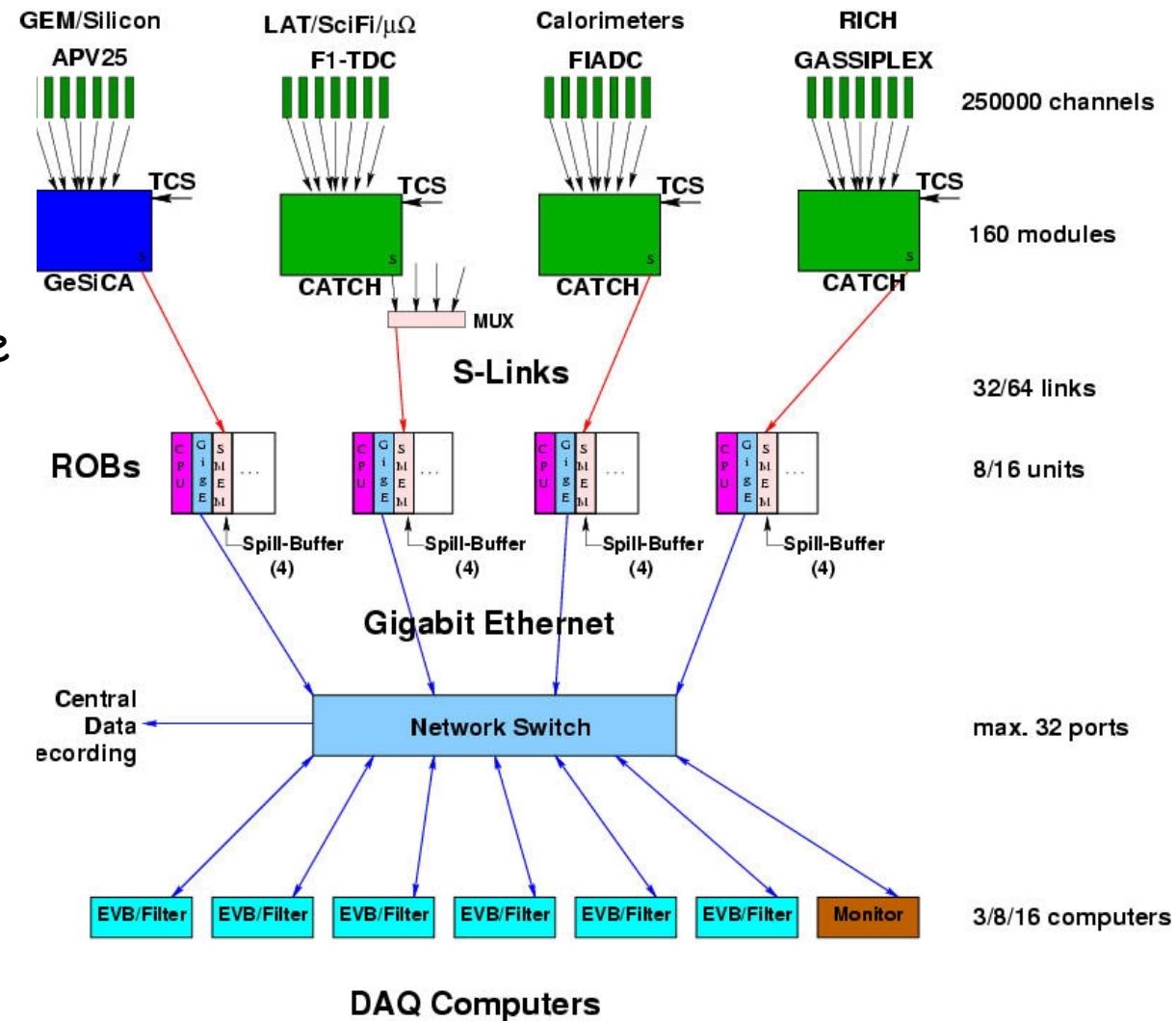
## Kinematic range (MT)





# ONLINE and DAQ

## Detector Frontends



## Layered architecture

- Front end
- Read-out buffers
- Event building stage
- Recording

## Hardware:

- Custom COMPASS solutions
- Mainstream PC and networking

## Software

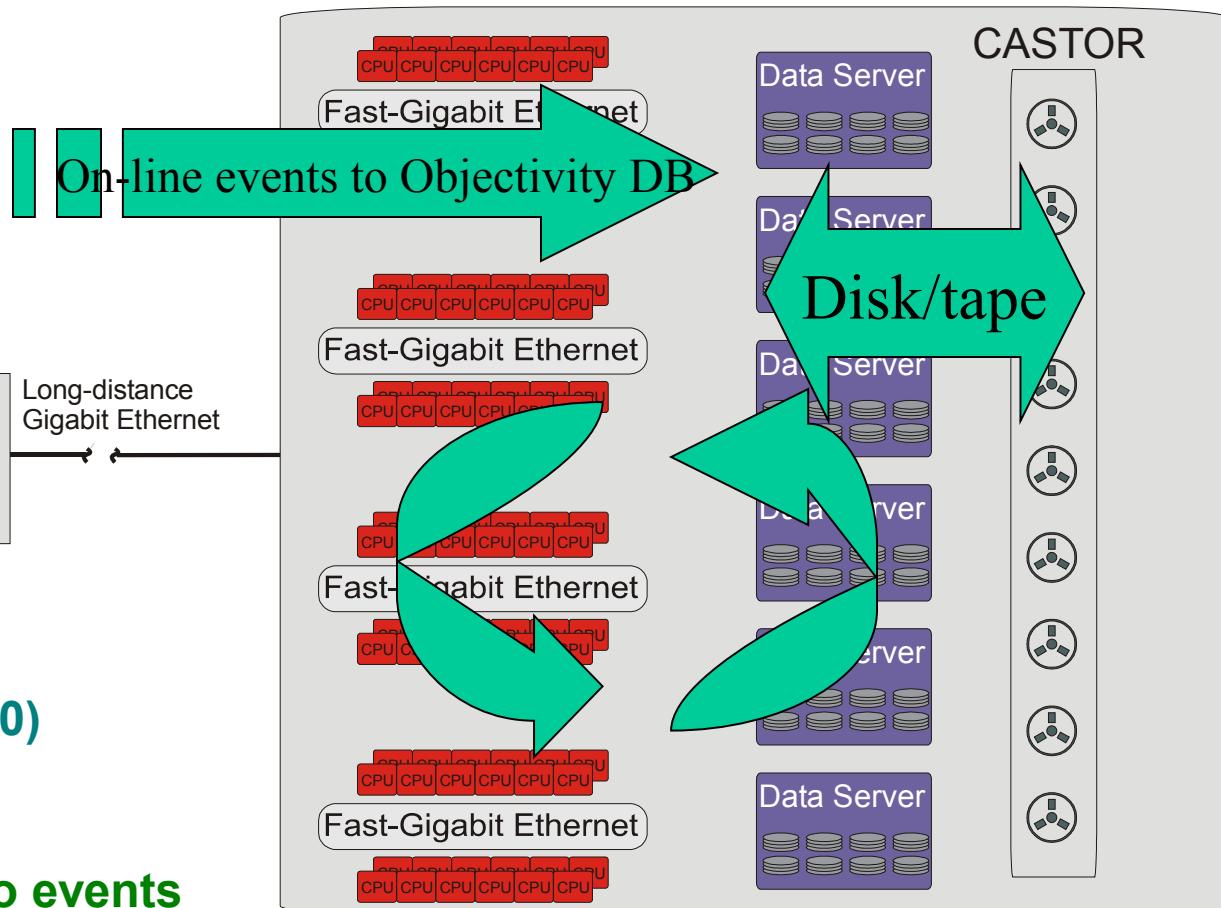
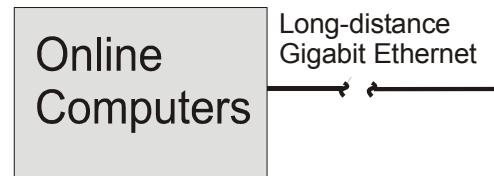
- ALICE DATE
- ROOT (COOOL)



# 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

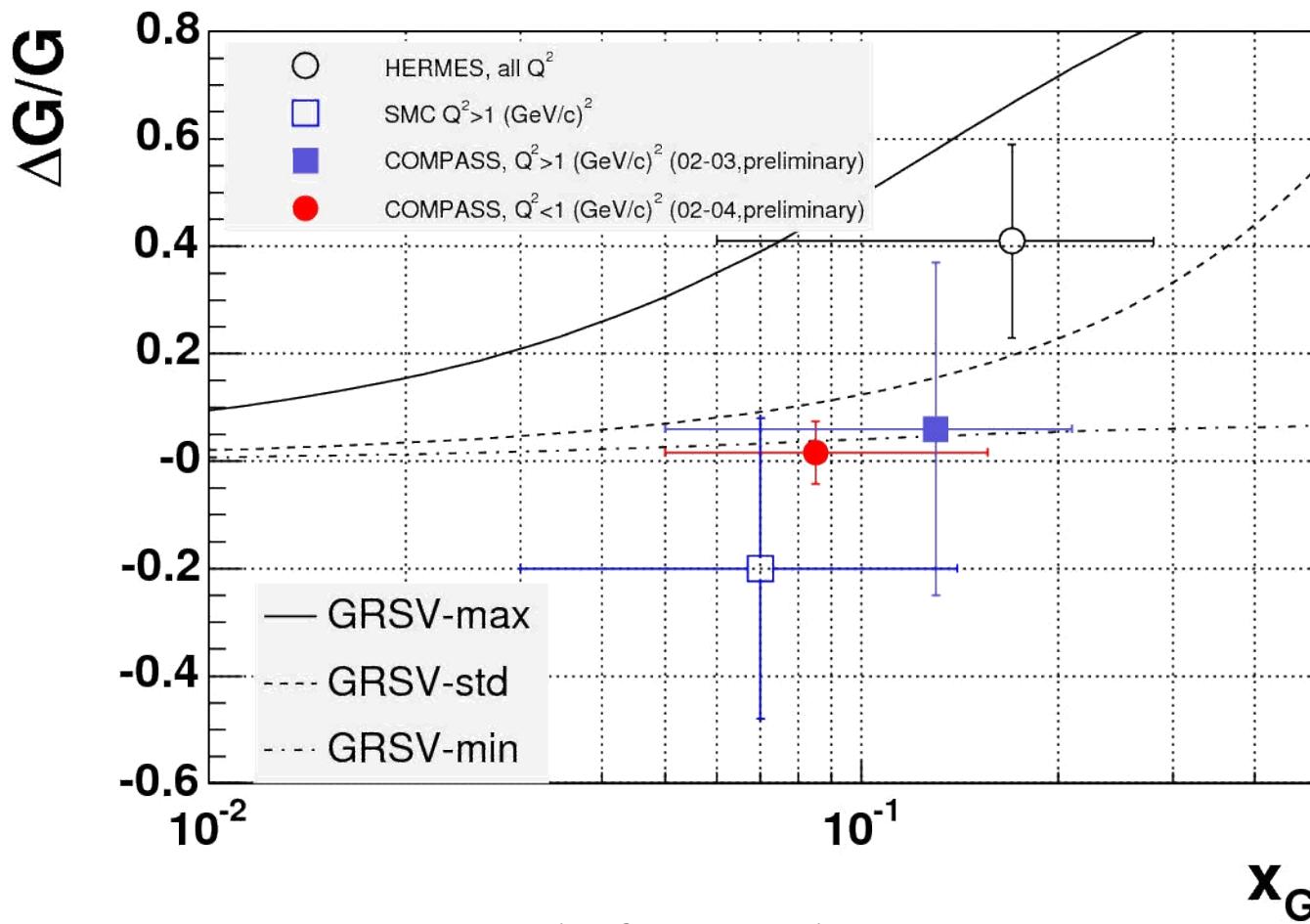


## 2002 - 2006

- 2002 160 GeV  $\mu$  beam &  ${}^6\text{LiD}$  Long/Transv ( $\sim 80/20$ )
- 2003 idem  $\rightarrow$
- 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



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



- GRSV-max strongly disfavoured