



L' ESPERIMENTO





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 - solo 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 ~ 3 volte maggiore
- n ha momento magnetico $\sim -2/3$ quello di p



L'evoluzione della conoscenza del protone

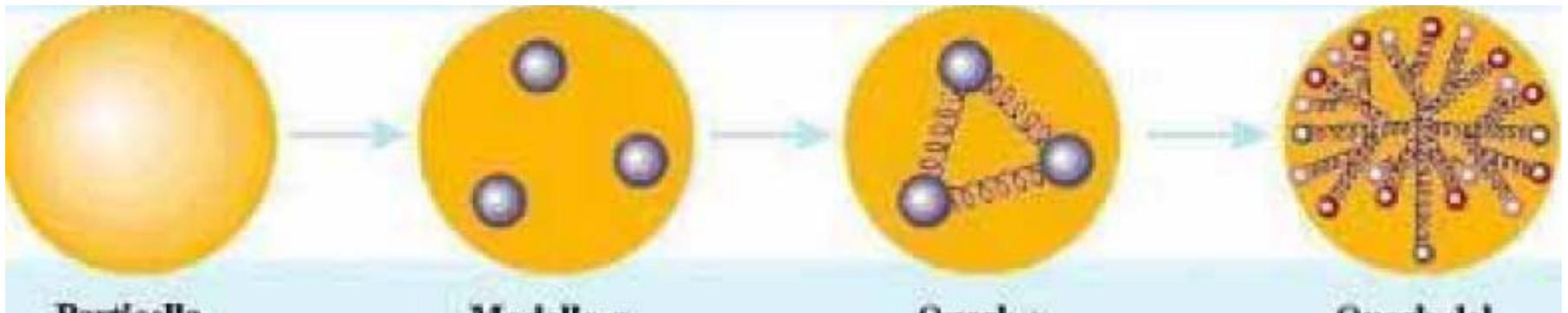
- Negli anni '50 a Stanford, in California si misura la dimensione finita (= non e' puntiforme !!!) del protone ($\sim 1\text{fm}$)
- Negli anni '60, sempre a Stanford, si scopre con sorpresa che il protone ha una struttura interna, fatta di partoni
- Classificazione degli adroni: si introducono i quark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

1919

anni 60

anni 70

anni 90

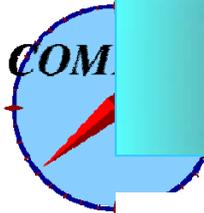


particella elementare

partoni

quark e gluoni

quark del mare



Il contesto

- 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



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 può consentire di rispondere a una domanda chiave: qual'è 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



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 (ΔD^{Λ}_q)

Spectroscopy

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

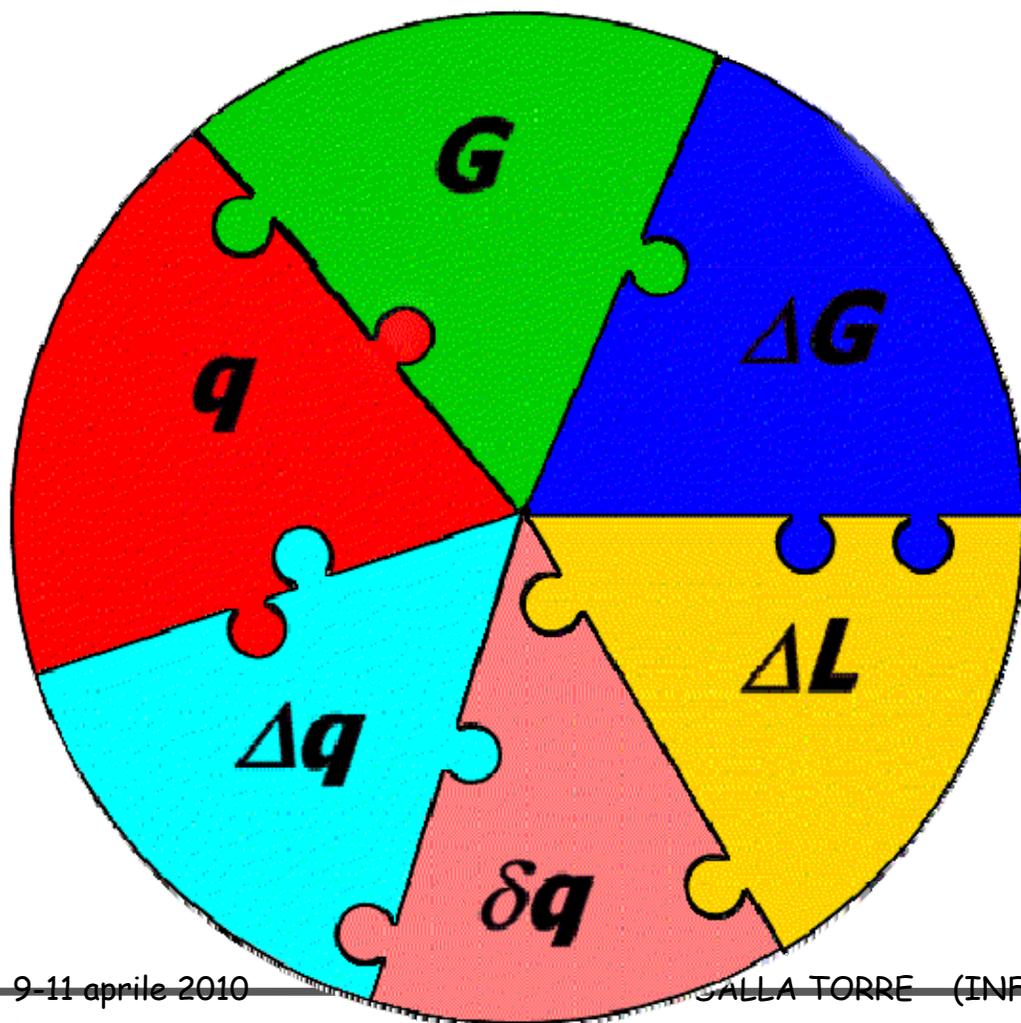


What are we after?

- 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



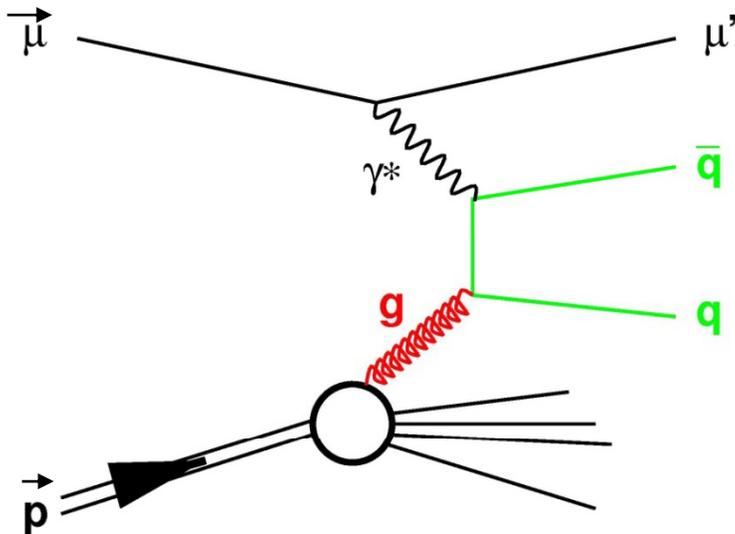
(spin) structure of the nucleon





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

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

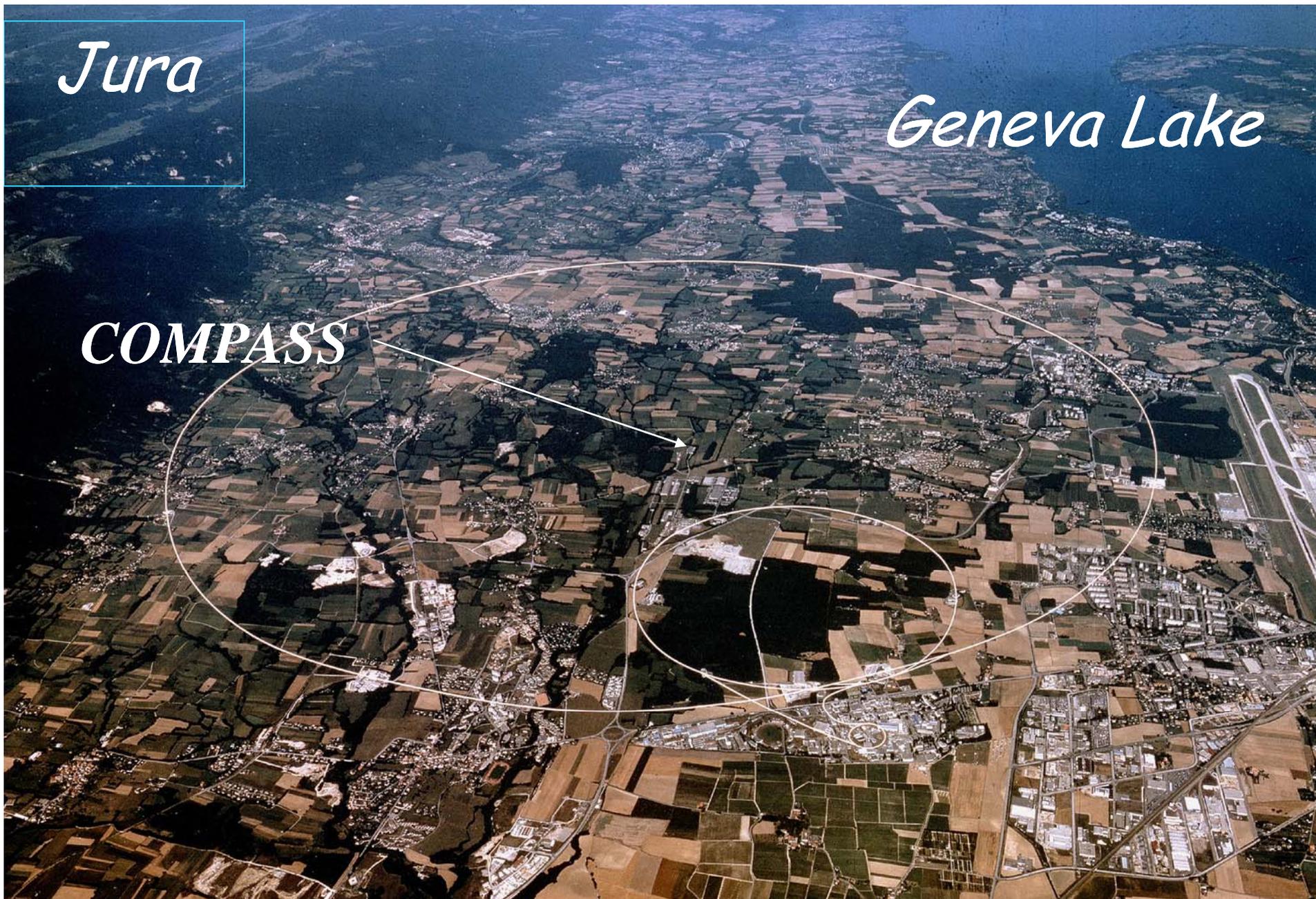


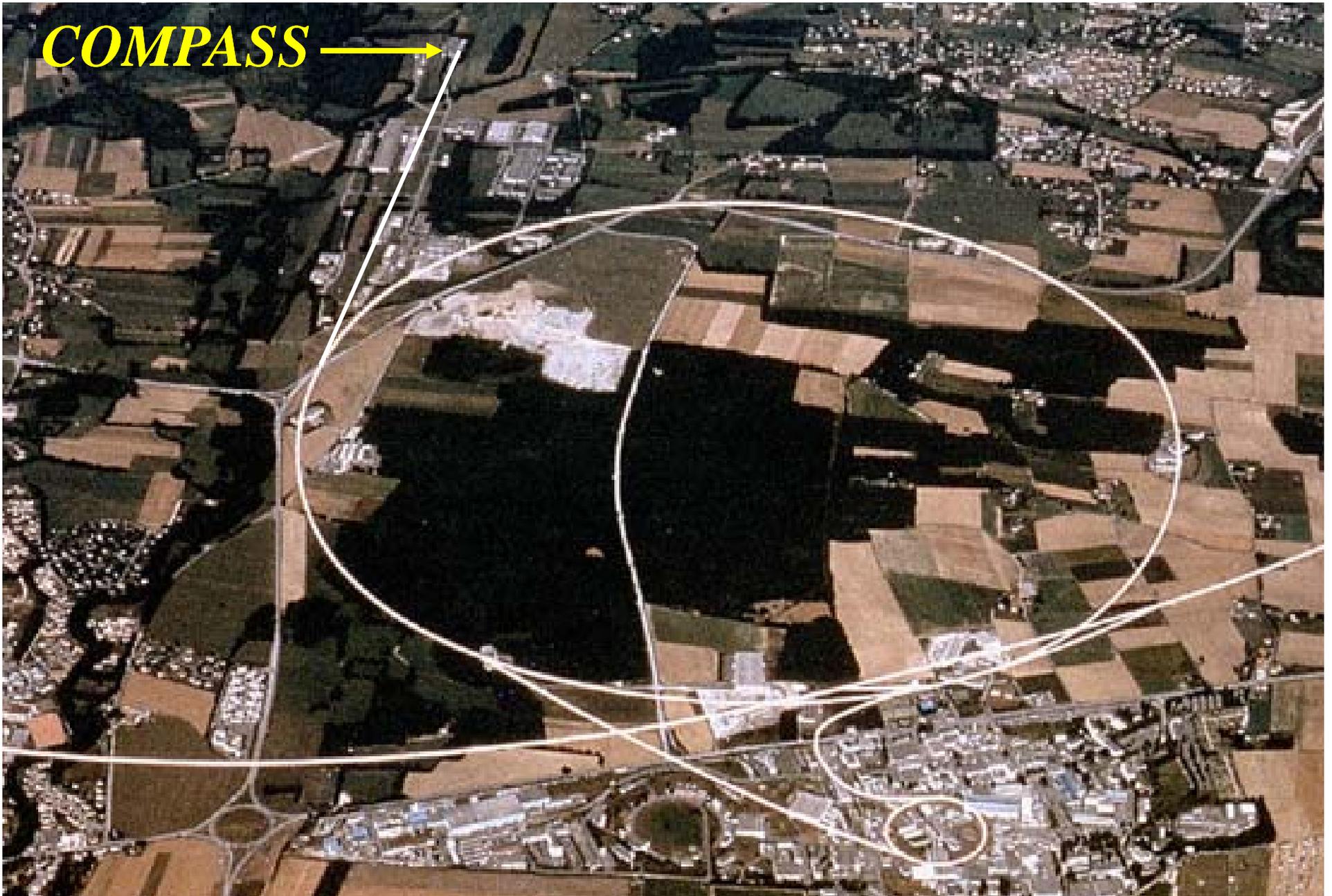
High p_T hadron pair $q\bar{q} \rightarrow hh$

Jura

Geneva Lake

COMPASS

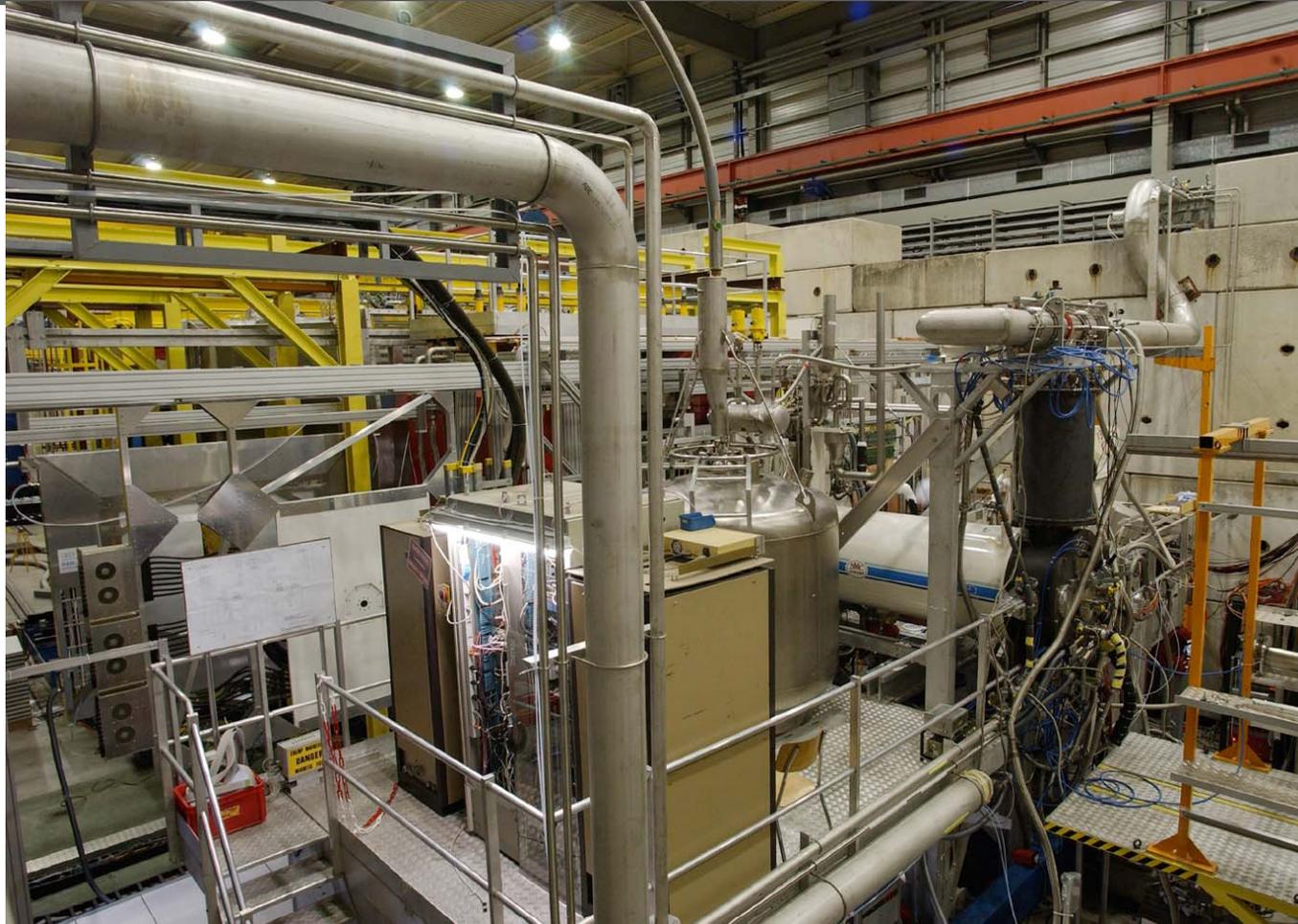




COMPASS →



The target region in the hall



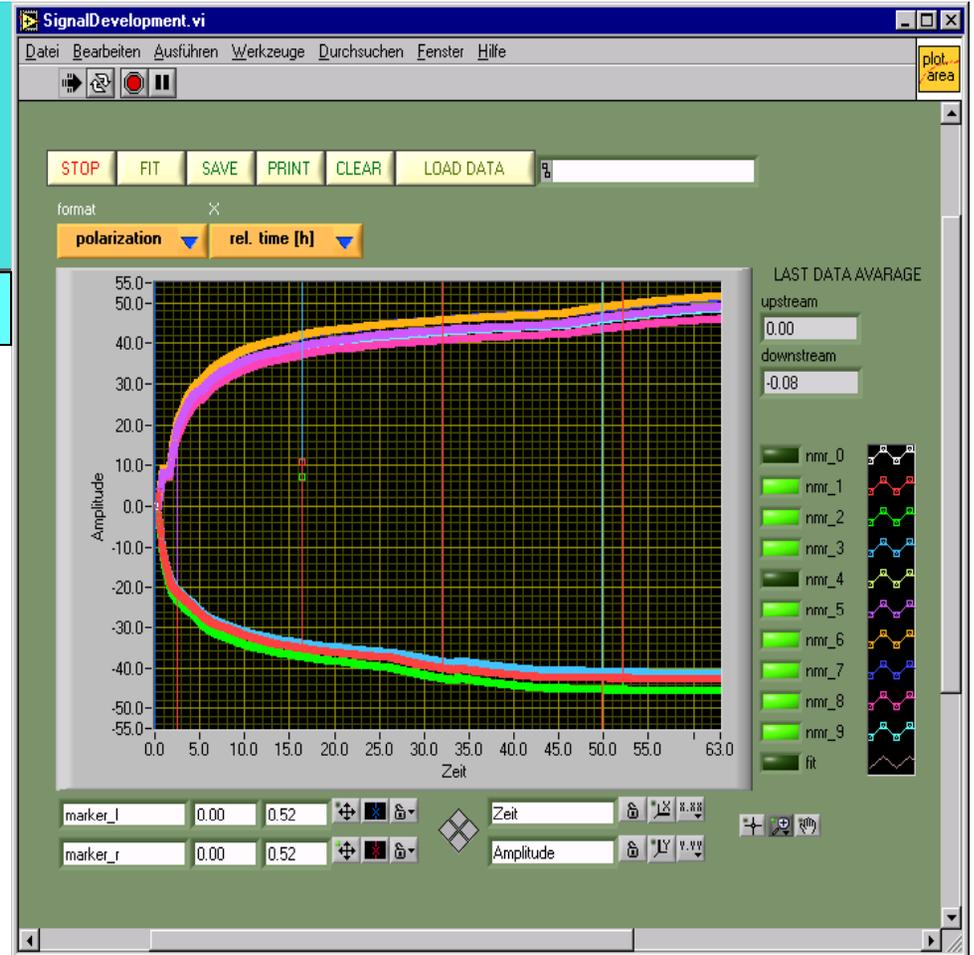
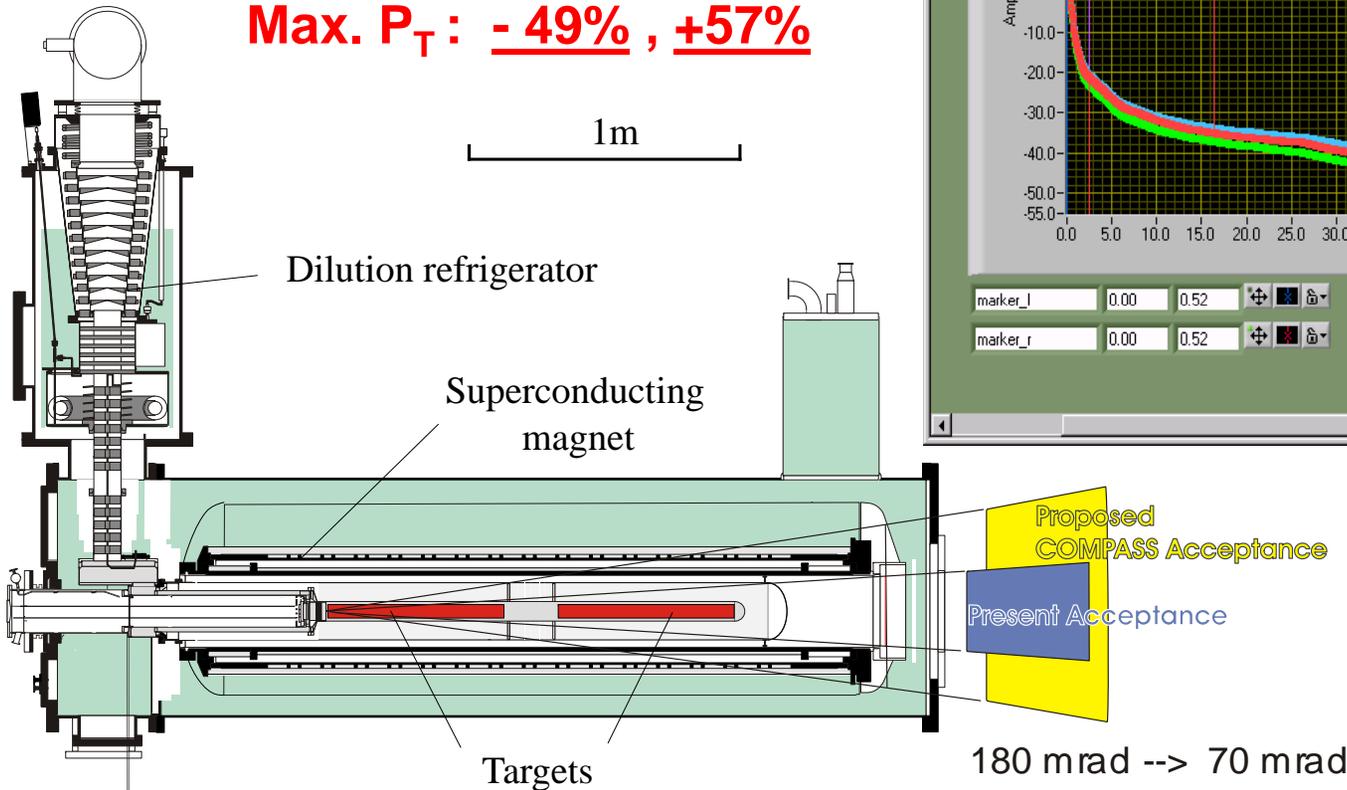


⁶LiD Target

2 halves polarised in opposite directions

Dynamic Nuclear Polarization
Frequency Modulation

Max. P_T : -49% , +57%



Dilution factor ~50%

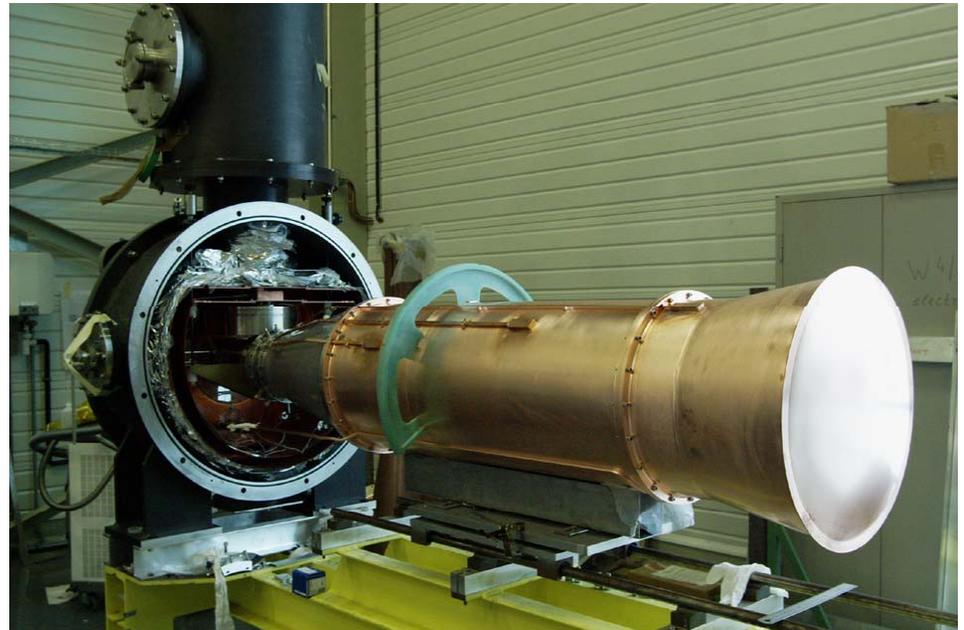
Solenoid: 2.5 T

Dipole: 0.5 T

Relaxation time:
>1000 h for 0.5 T



Polarized target upgrade, in 2006

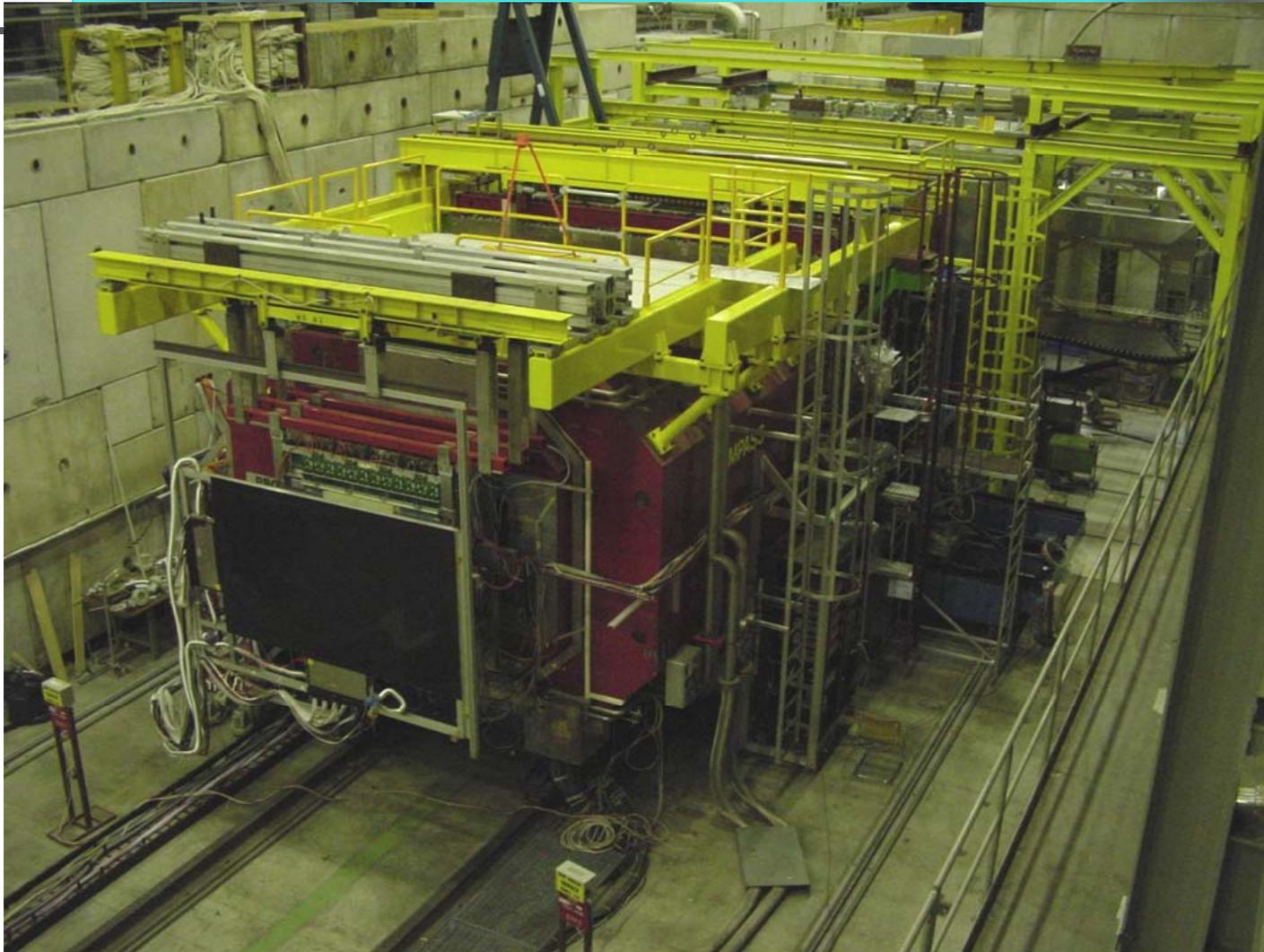


- New COMPASS target magnet
- → 180 mrad

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



SM2 and the LAS region





Scintillating Fibers Hodoscopes

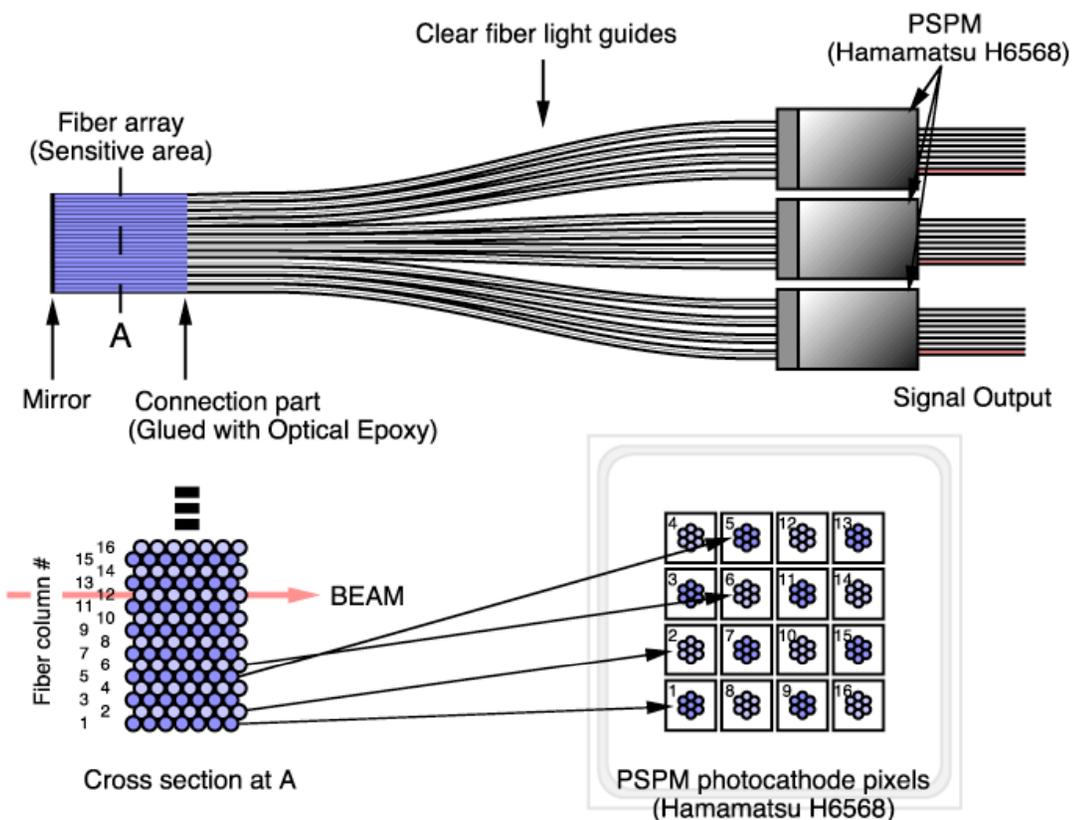
9 stations: 21 coordinates

*Rate capability > 5 MHz
per channel*

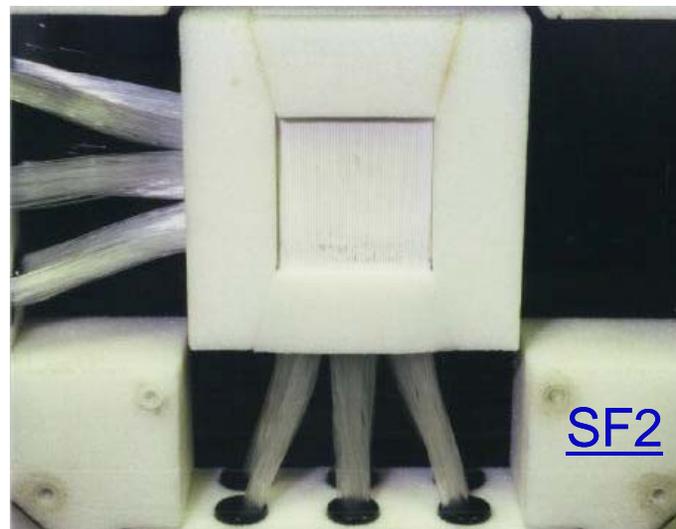
Efficiency: 99%

Space resol. 130 – 250 μm

Time resol. < 400 ps



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





$\mu\Omega$

Conversion

Ionizing particle
 e^-

3 mm

1 kV/cm

12 planes 40 x 40 cm²
Space resolution: 70 μm

Time resolution: 8 ns

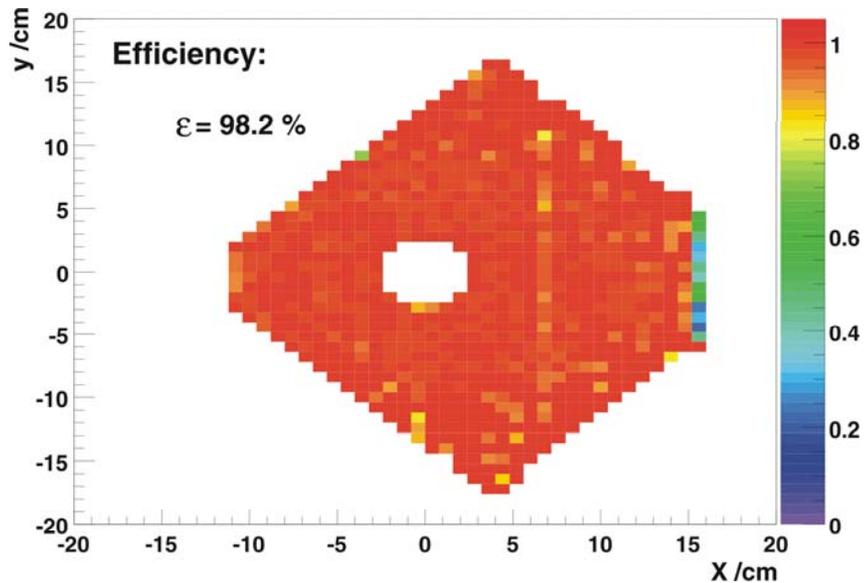
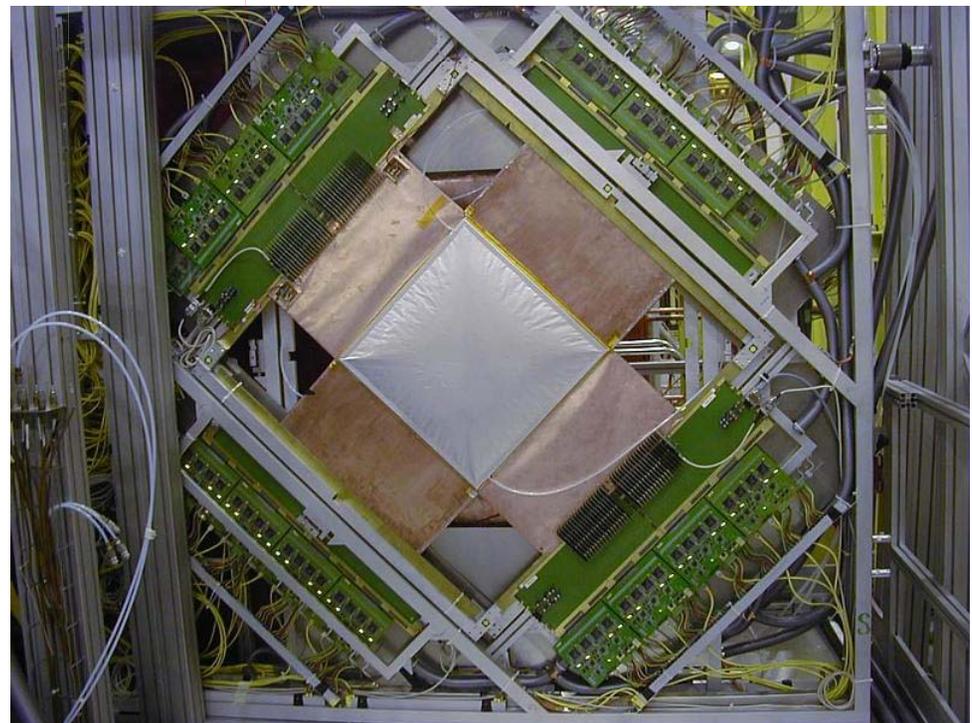
Amplification

Micromesh

Strips

100 μm

40 kV/cm



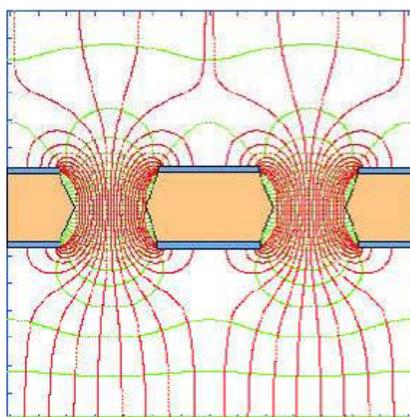
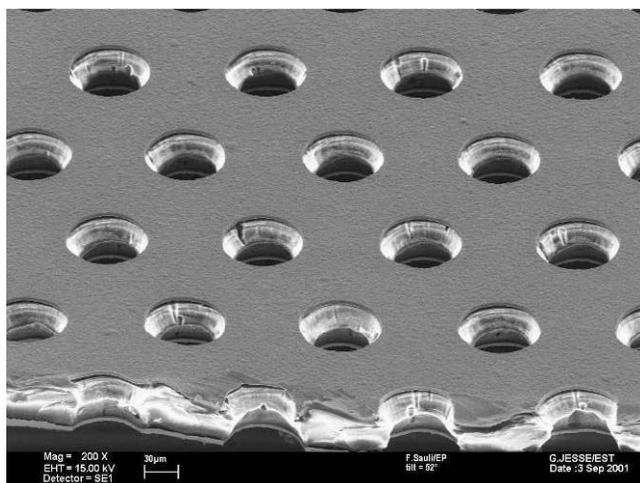
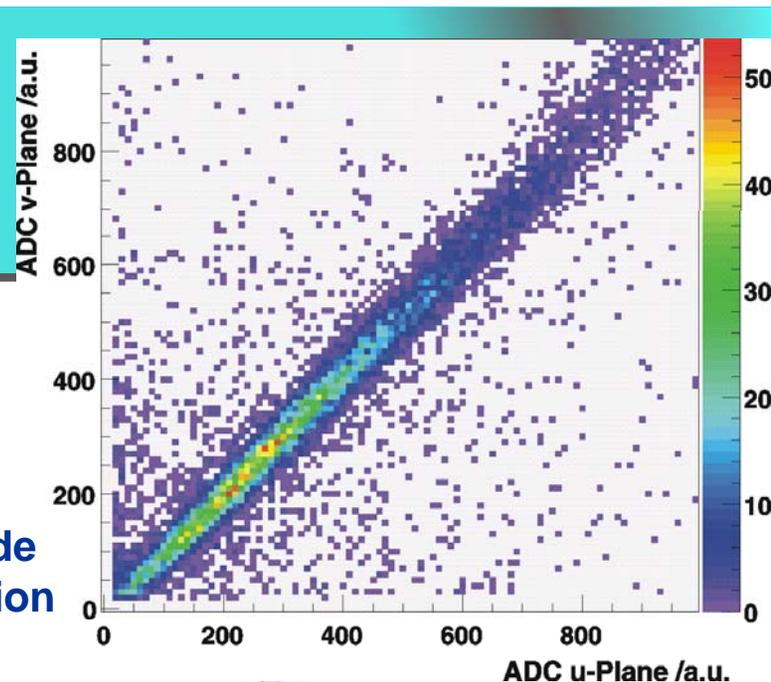


GEM

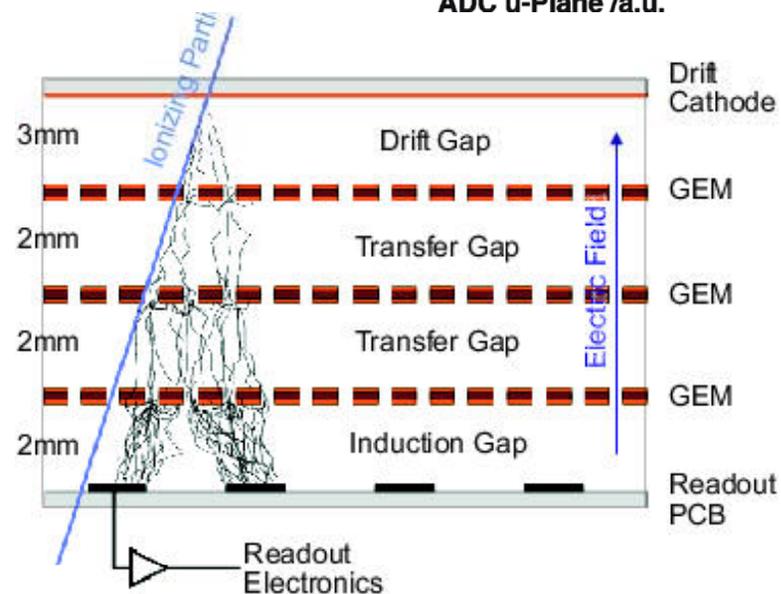
20 triple GEM detectors with 2 dimensional r/o

- Space resolution: 70 μm
- Efficiency $\sim 96 - 97\%$
- Time resolution: 15 ns

amplitude
correlation



(two dimensional)



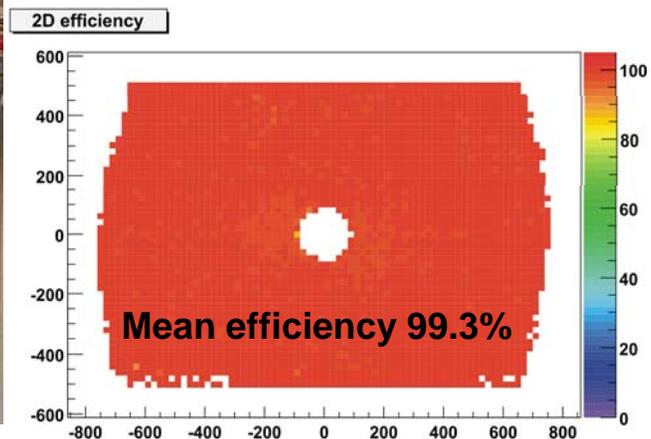
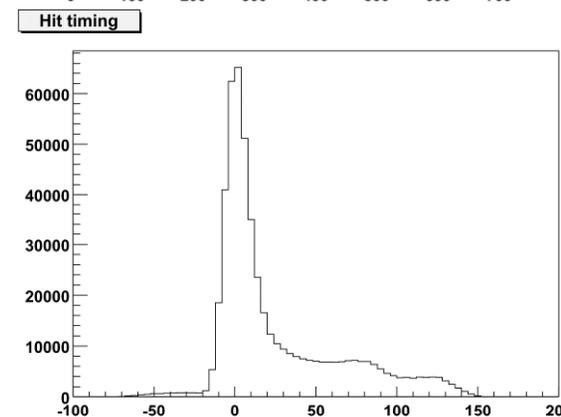
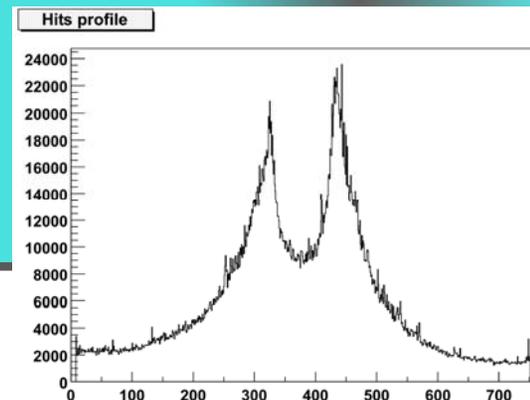
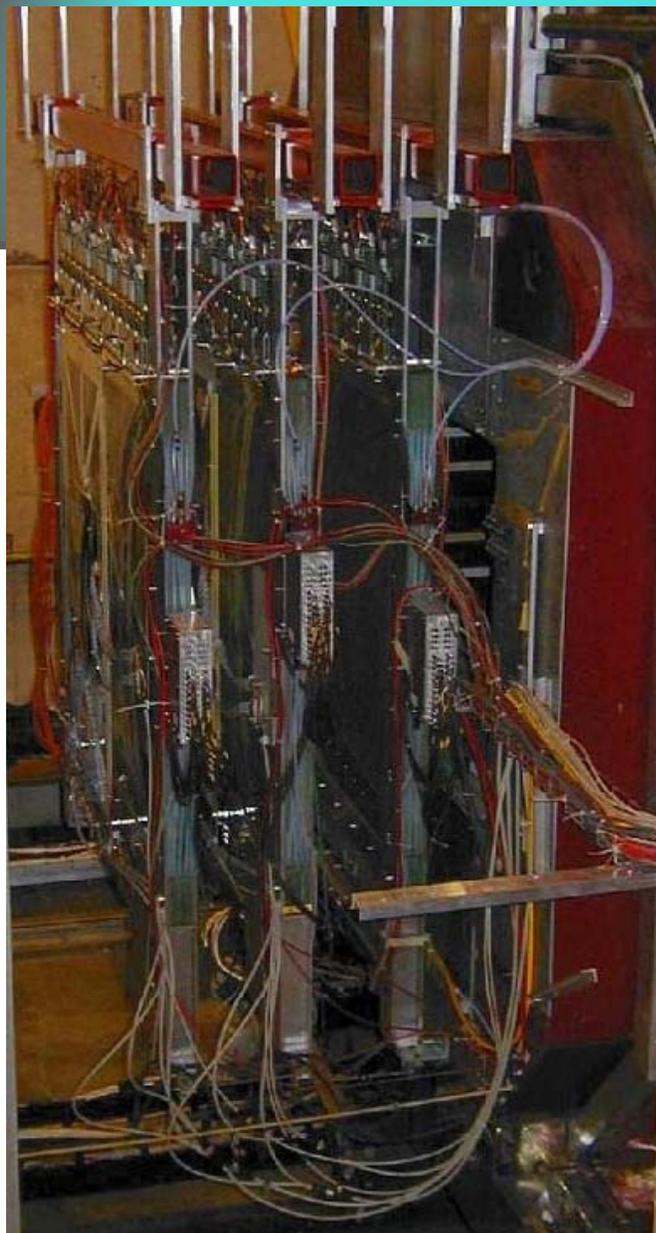


MWPCs

Total of 34 planes

SAS Tracking

- Gas mixture:
70% Ar, 20% CF₄, 10% CO₂
- High voltage: 4.25 kV
- Discr. threshold: 4fC

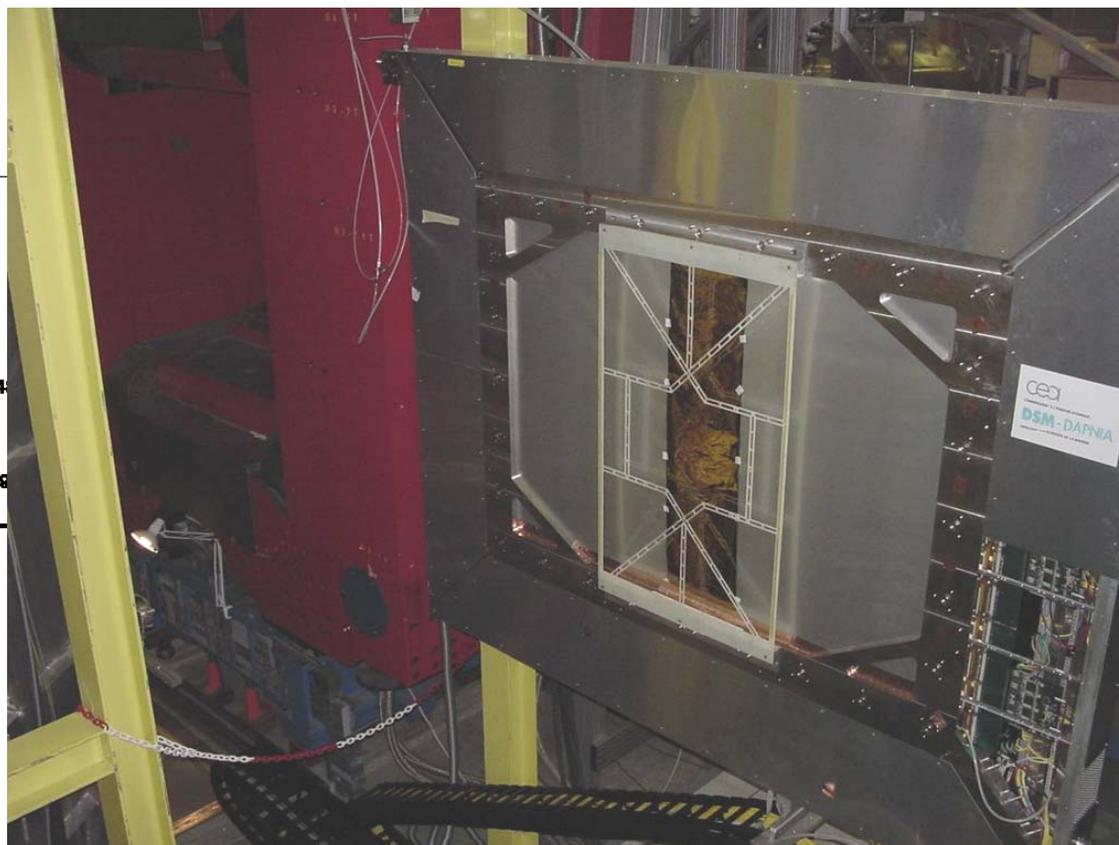
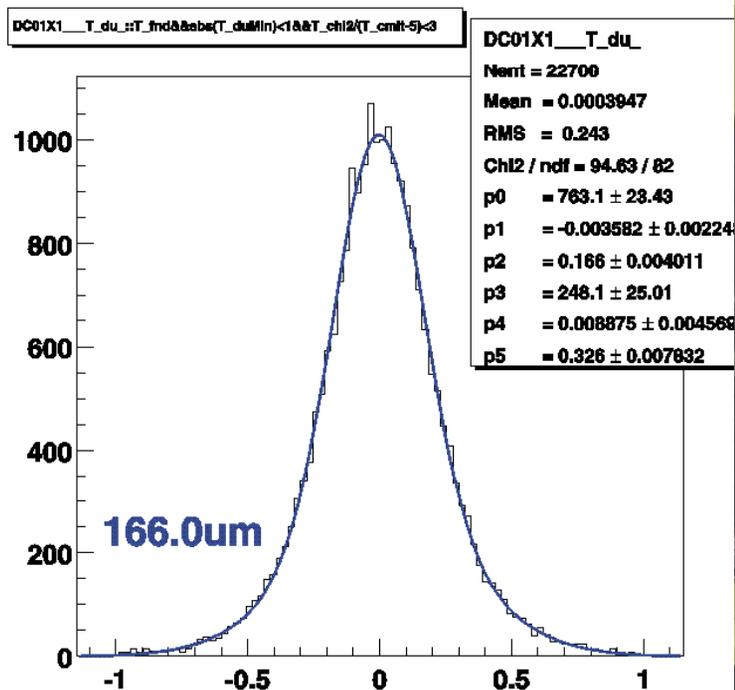




Drift Chambers for LAS

3 chambers with 8 coordinates each

Efficiency: 95 - 99.8 %





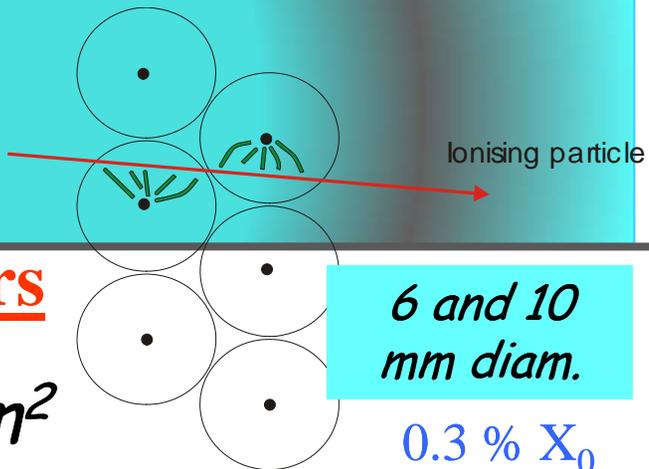
Drift Chambers for SAS





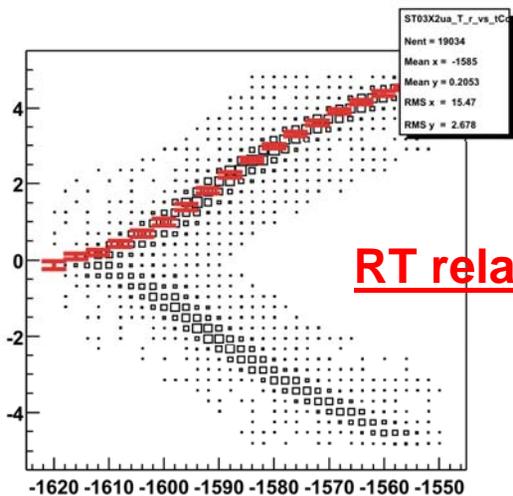
STRAWs

1 Module =
6 double layers

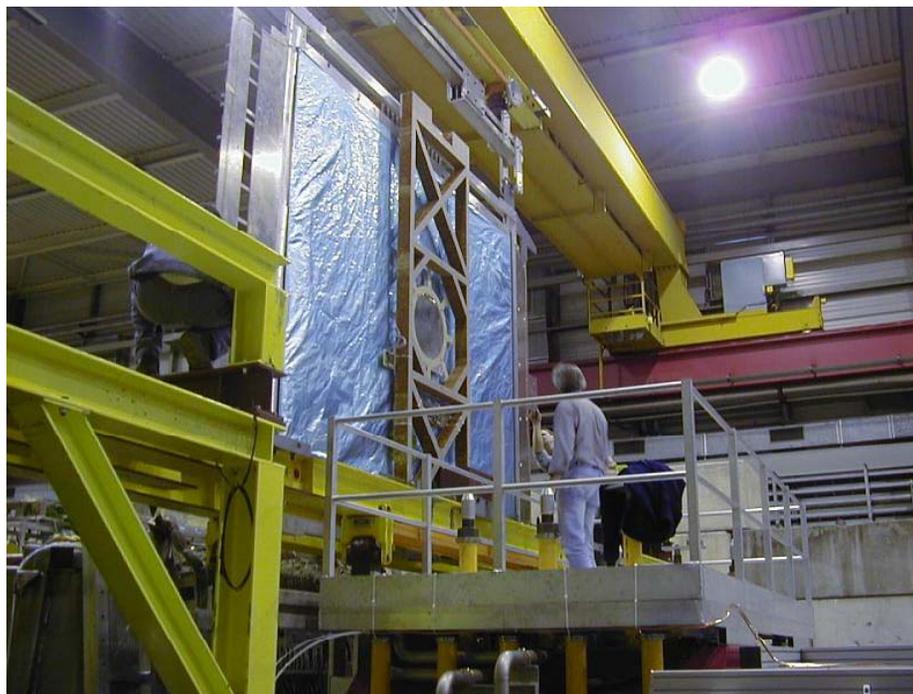
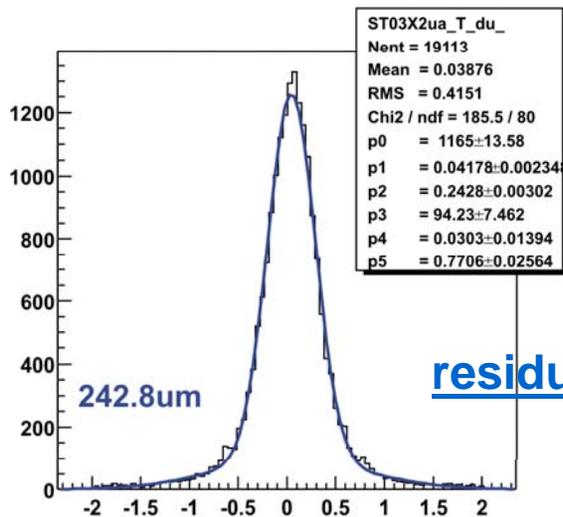


$3.2 \times 2.4 \text{ m}^2$

Installation of a double layer



RT relation





HCAL 1

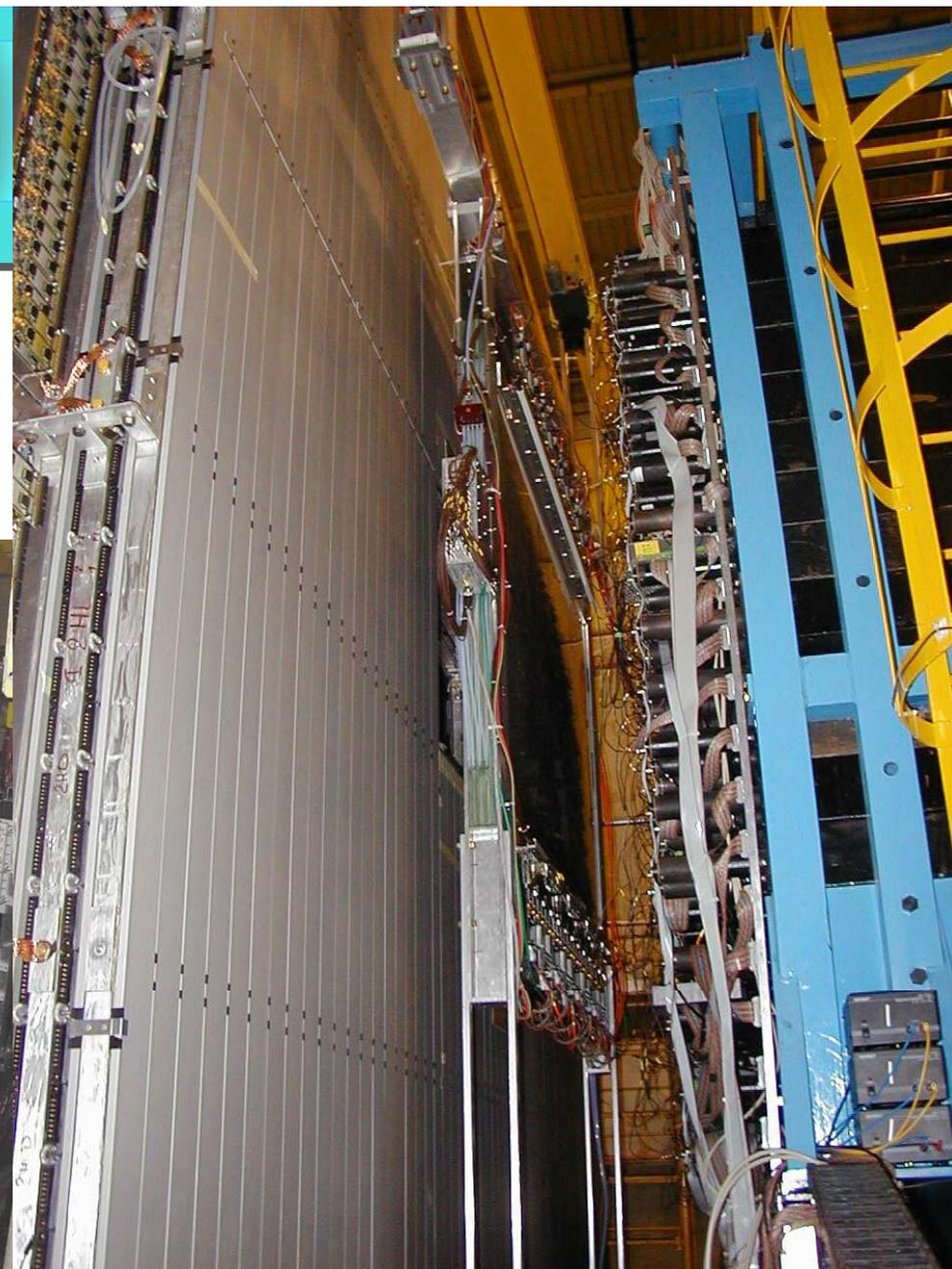




Muon Wall 1

and

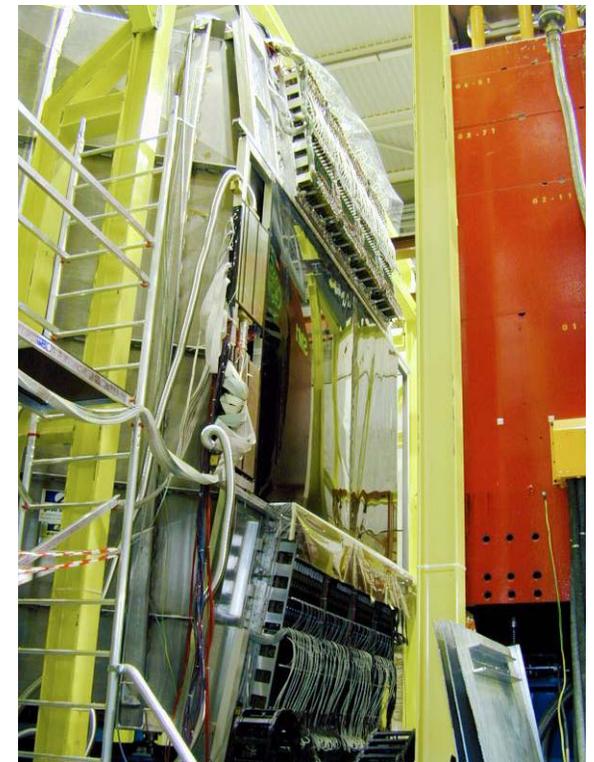
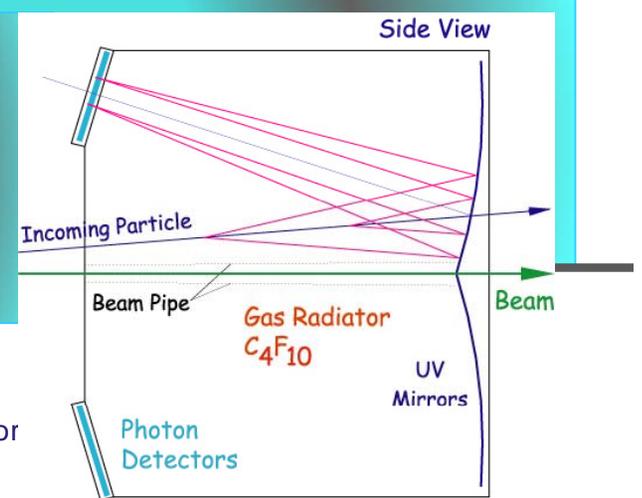
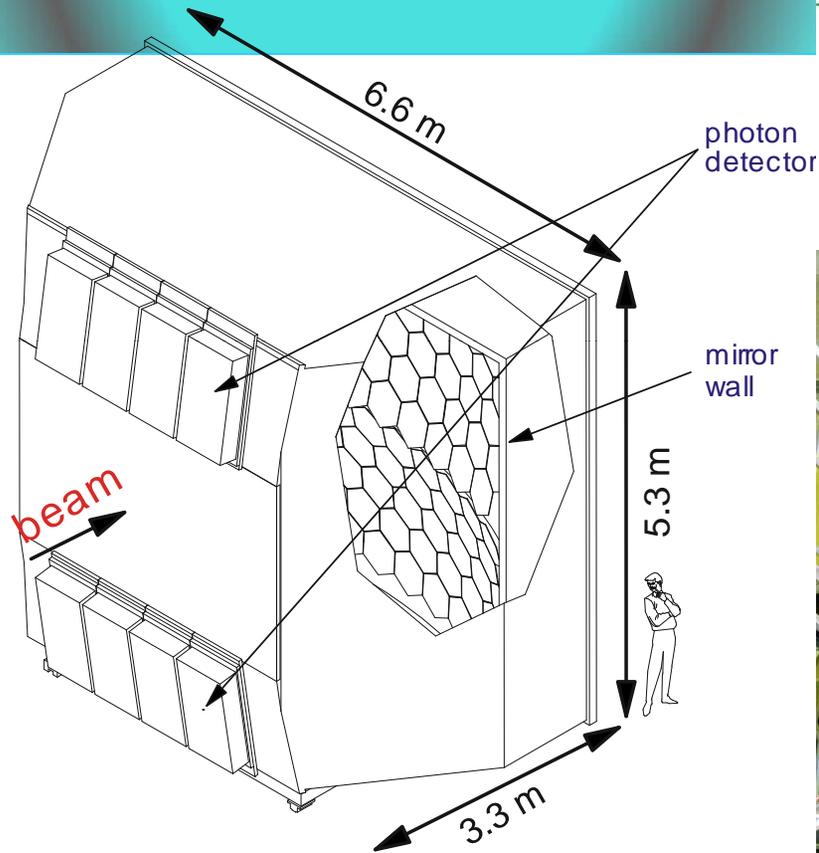
Muon Wall 2





RICH 1

- Radiator: 3 m C_4F_{10}
- Vessel volume: 90 m³
- 116 mirrors
- Focal length = 3 m
- 5.3 m² UV detectors:
 - MWPC with CsI photo-sensitive cathodes
 - 8x8 mm² pads
- 84k channels
- 10 bits ADC r/o
- Local thr. comparison and 0 suppression



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



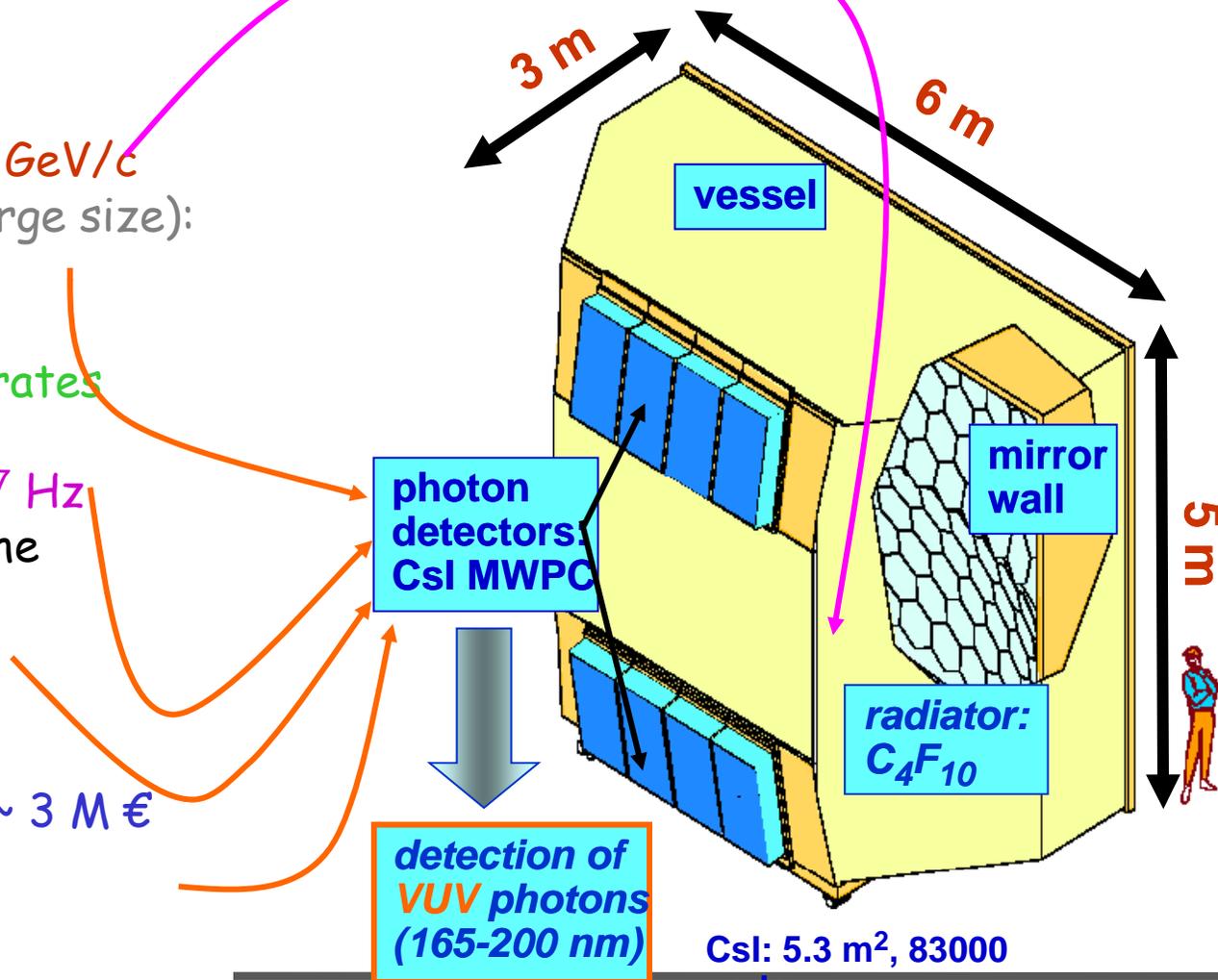
COMPASS RICH-1

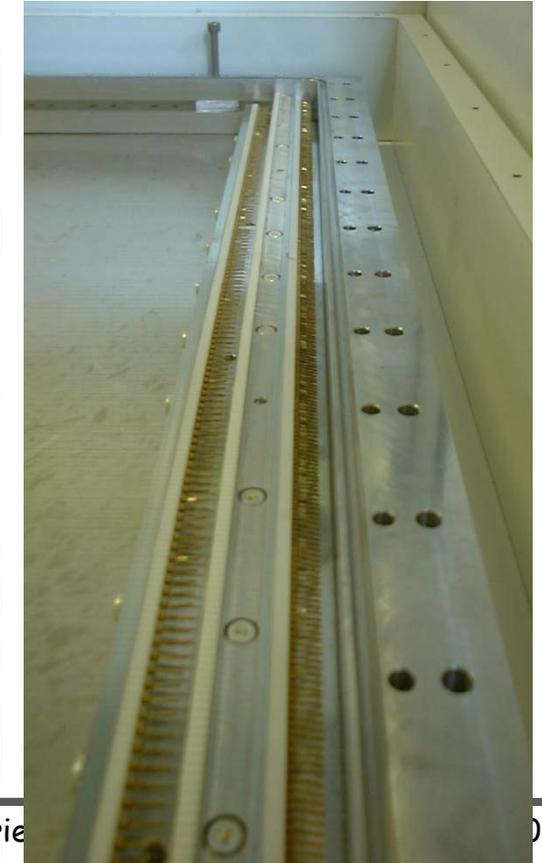
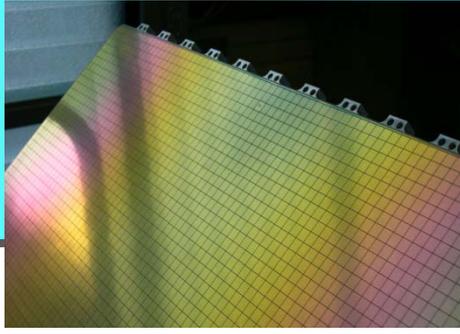
Trieste: INFN, Univ. & ICTP,
Turin: INFN and University,
Bielefeld University,
CERN technical support

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

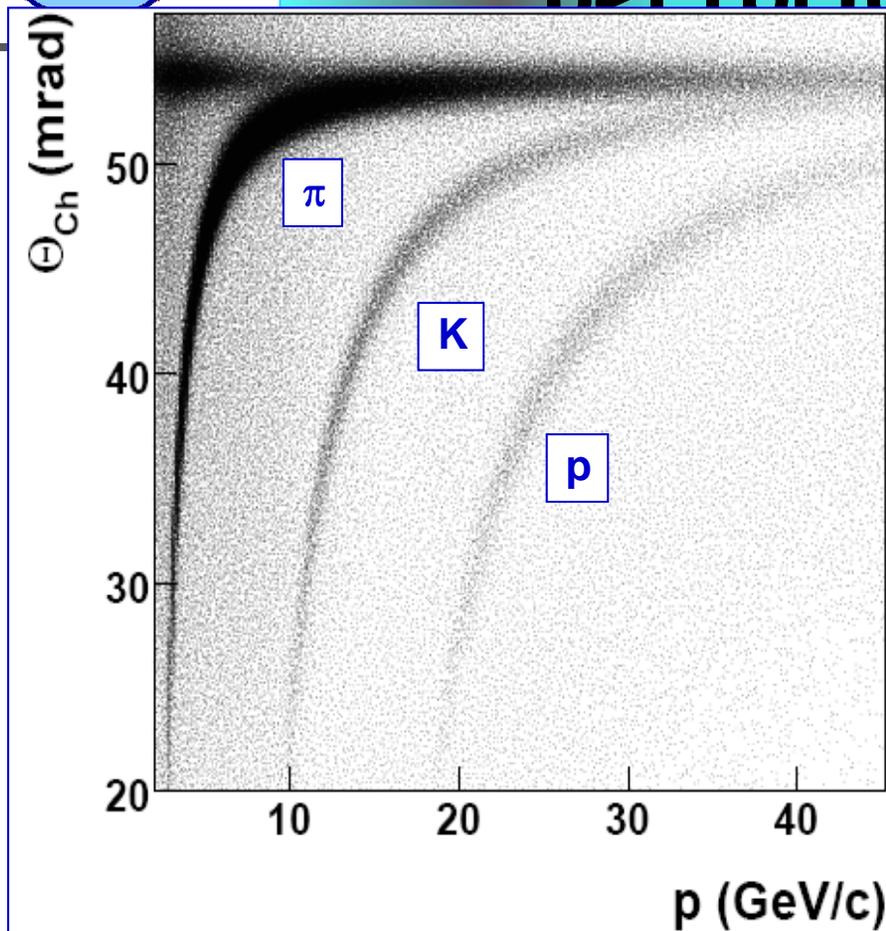
PROJECT COST : $\sim 3 \text{ M } \text{€}$







COMPASS RICH-1 performances



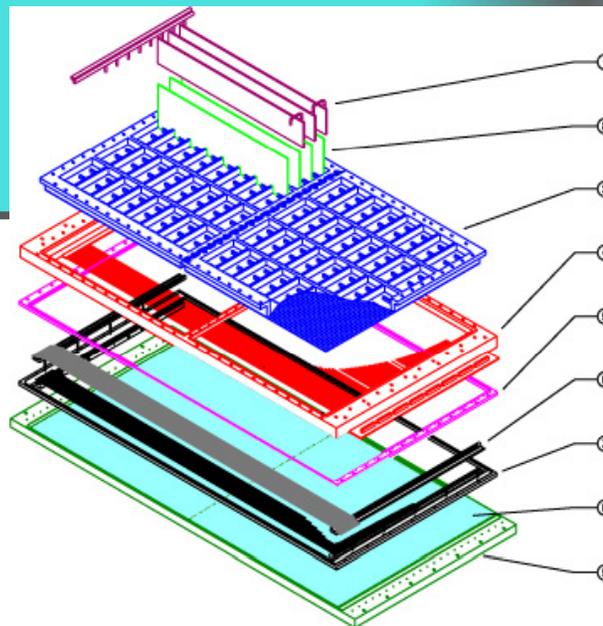
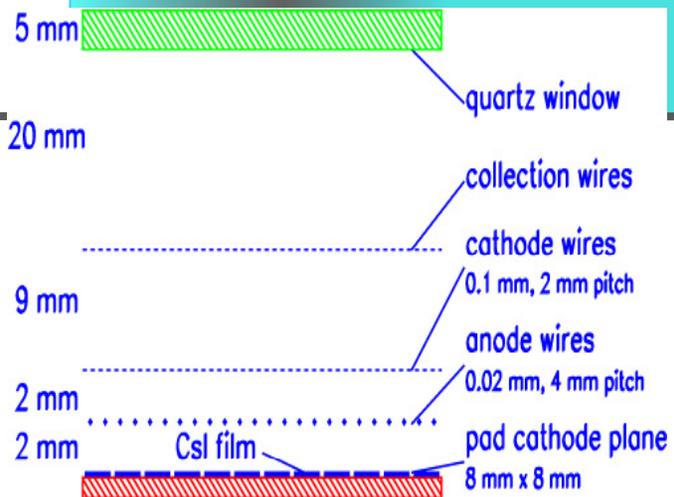
**RICH-1 is in operation
at COMPASS
since 2001**

- photons / ring ($\beta \approx 1$, complete ring in acceptance) : **14**
- $\sigma_{\theta-ph}$ ($\beta \approx 1$) : **1.2 mrad**
- σ_{ring} ($\beta \approx 1$) : **0.6 mrad**
- 2σ π -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) 127 ~~127~~ Albrecht et al, NIM A 553 (2005) 215

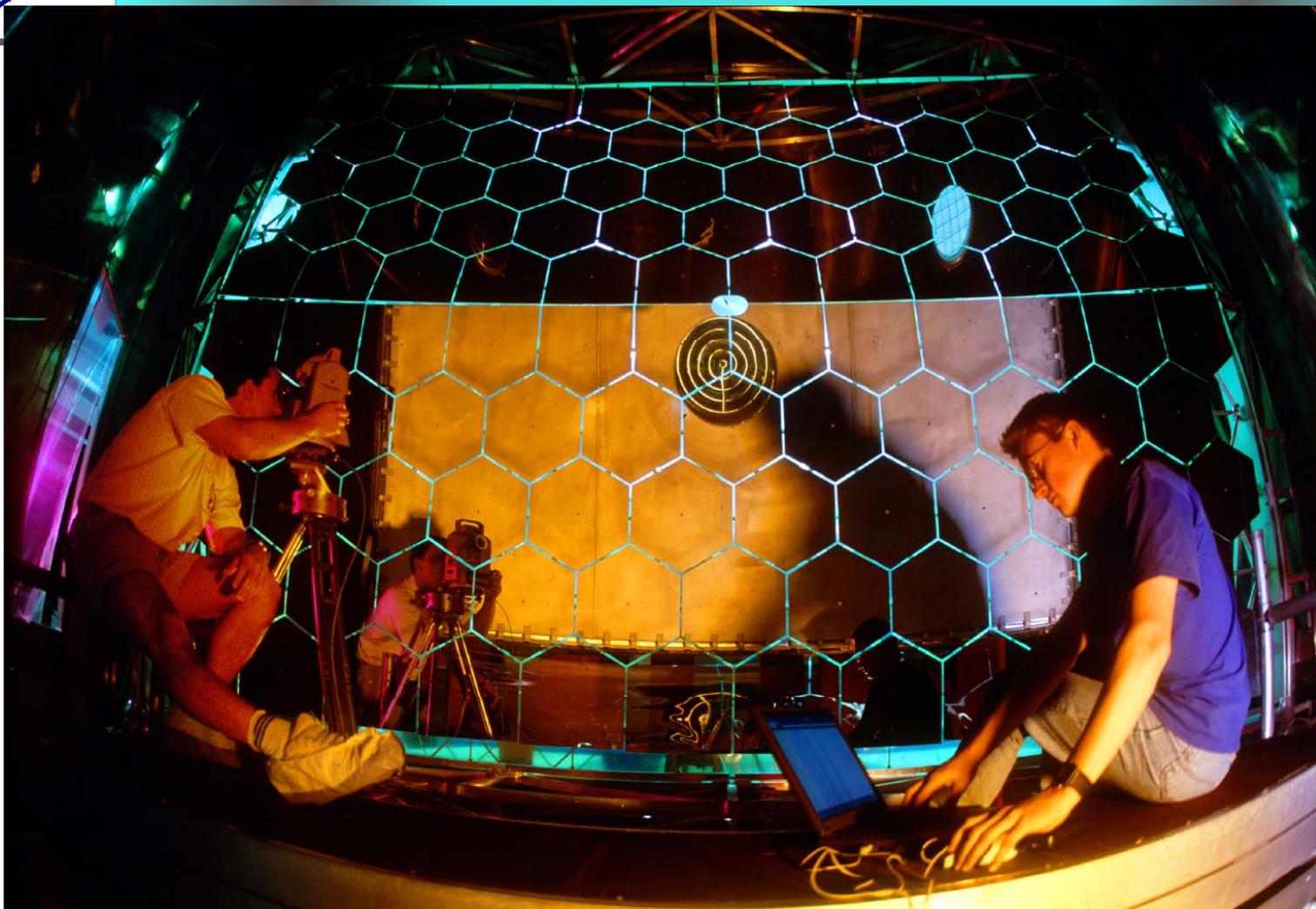


Photon Detectors



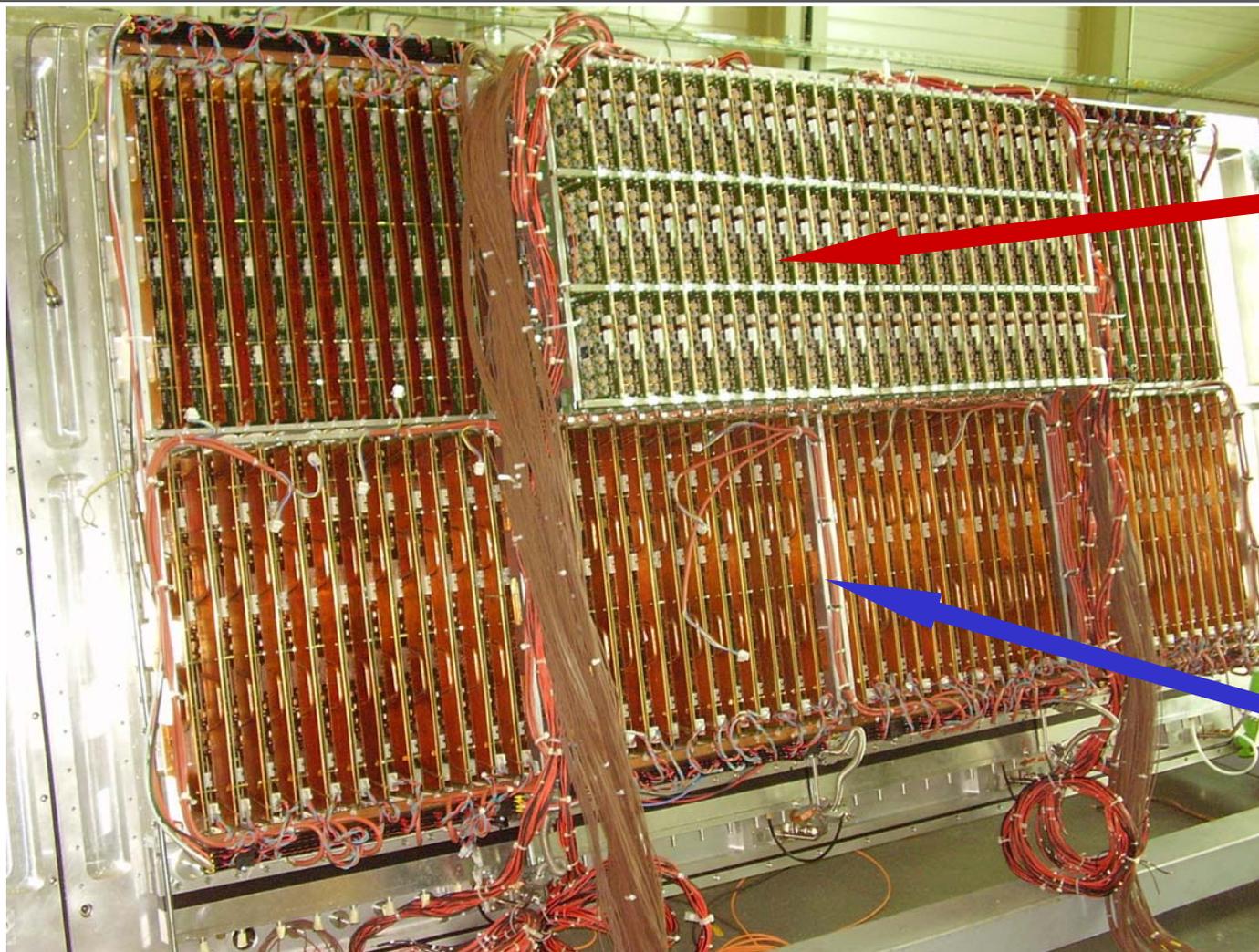


RICH Mirrors





RICH-1 upgrade, in 2006

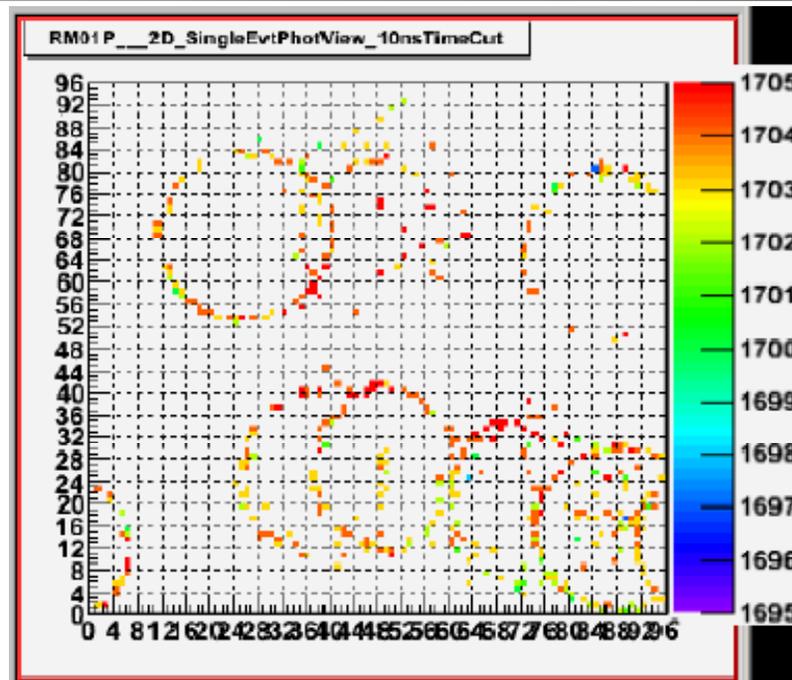
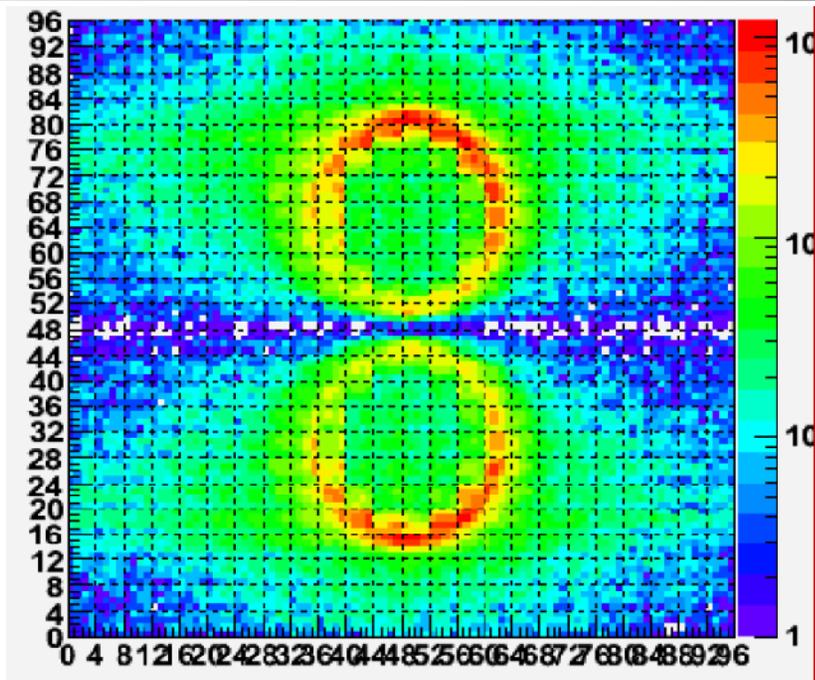


Lens system
+ MAPMTs
+ MAD4
+ F1

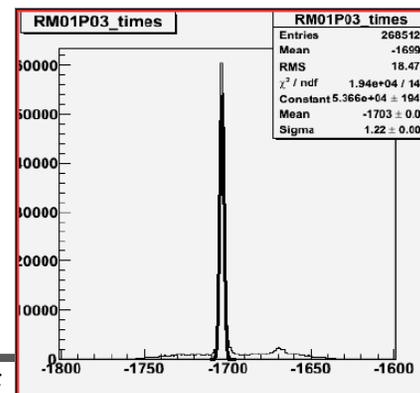
CsI MWPC
+ APV25S1
+ ADC



RICH-1 upgrade, MAPMTs "on-line"



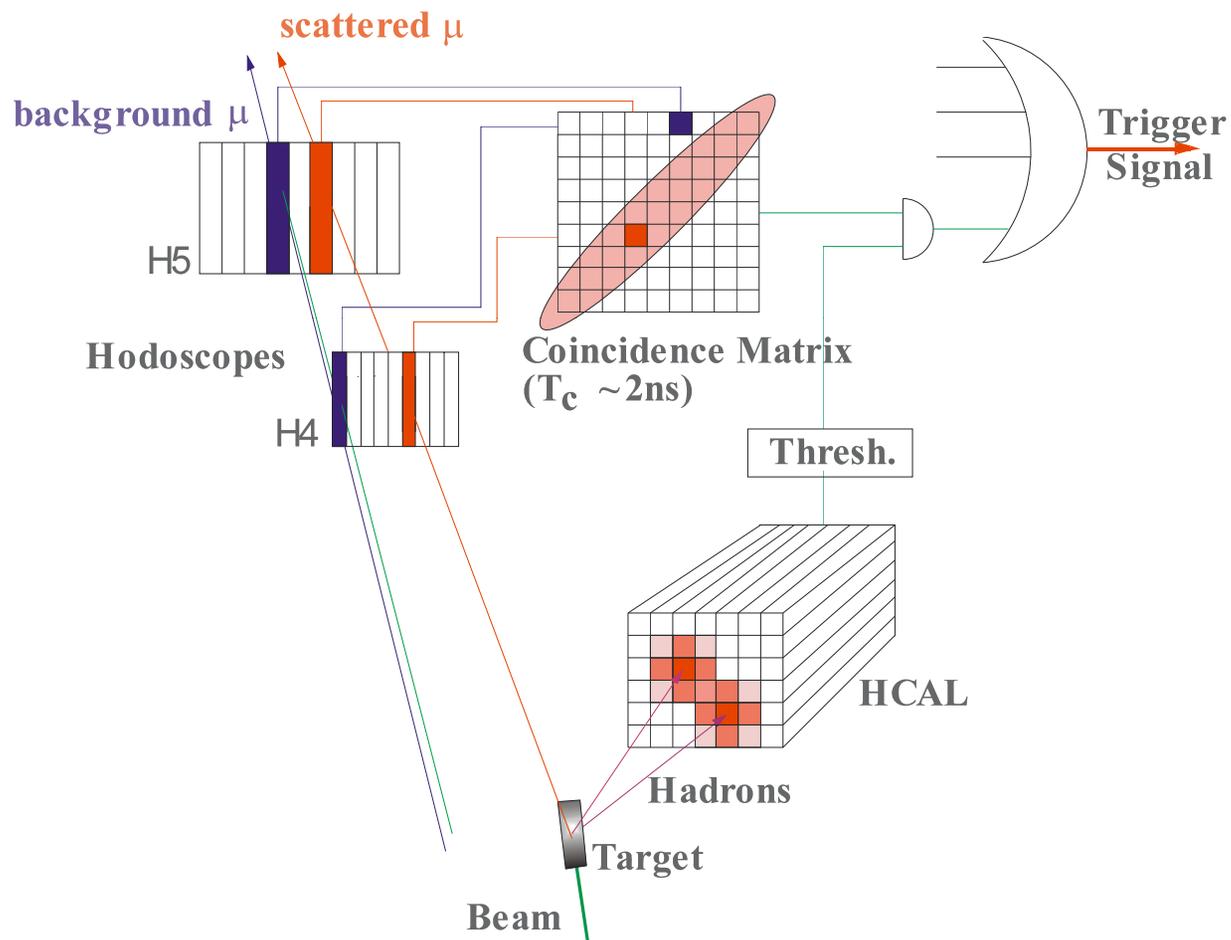
- Precise timing
- High photon statistics





Trigger concept

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

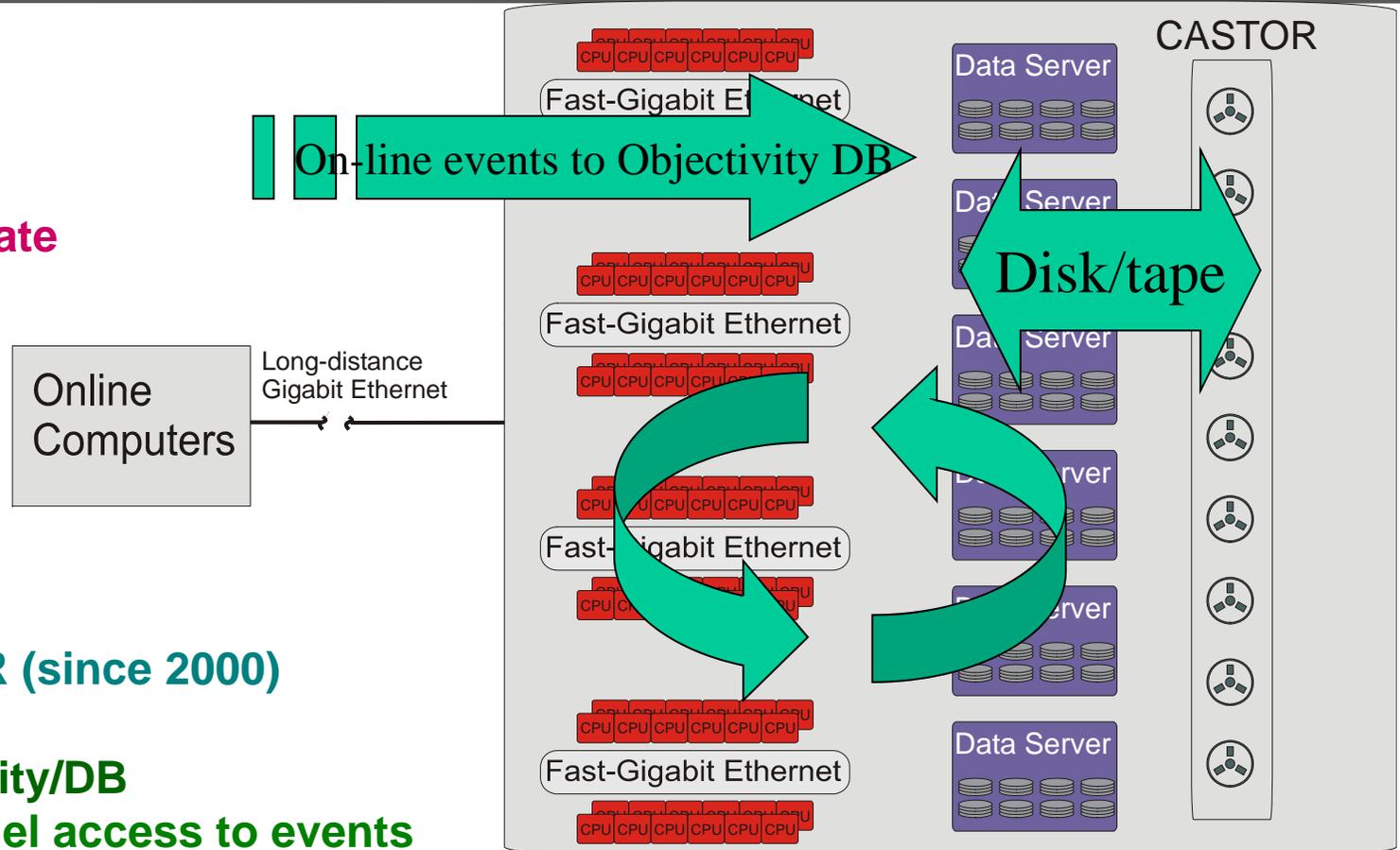




COMPASS Computing Farm

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

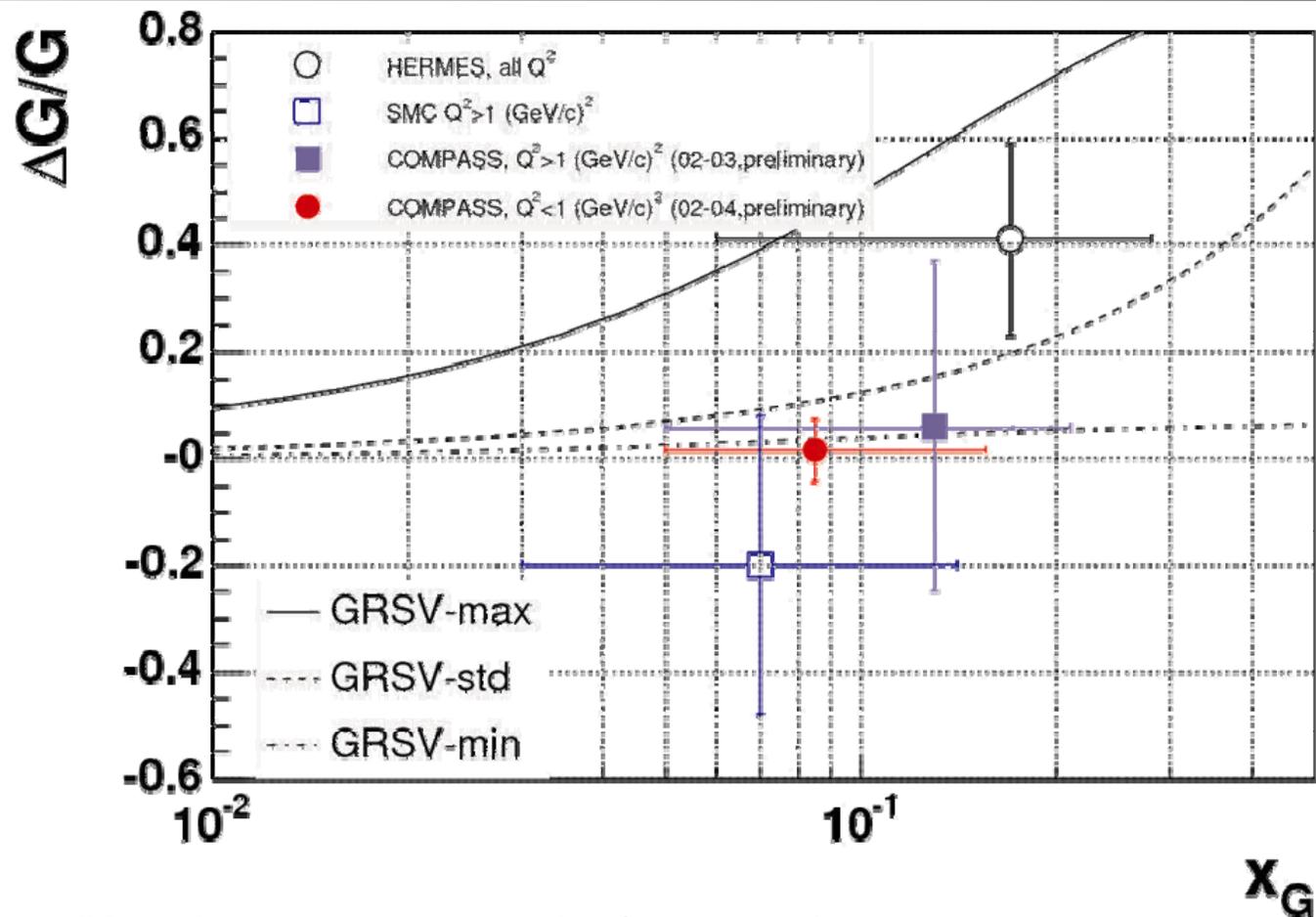


2002 - 2010

- 2002 160 GeV μ 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 μ beam & ${}^6\text{LiD}$ Long
- 2007 160 GeV μ beam & NH_3 Long/Transv
- 2008 hadron beam →
- 2009 hadron beam
- 2010 160 GeV μ beam & NH_3 Transv



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



- GRSV-max strongly disfavoured