



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 (ΔD^{Λ_n})

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

Spectroscopy

- Primakoff reactions
 - Polarizability of π 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** $\rightarrow$ 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 ~ 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



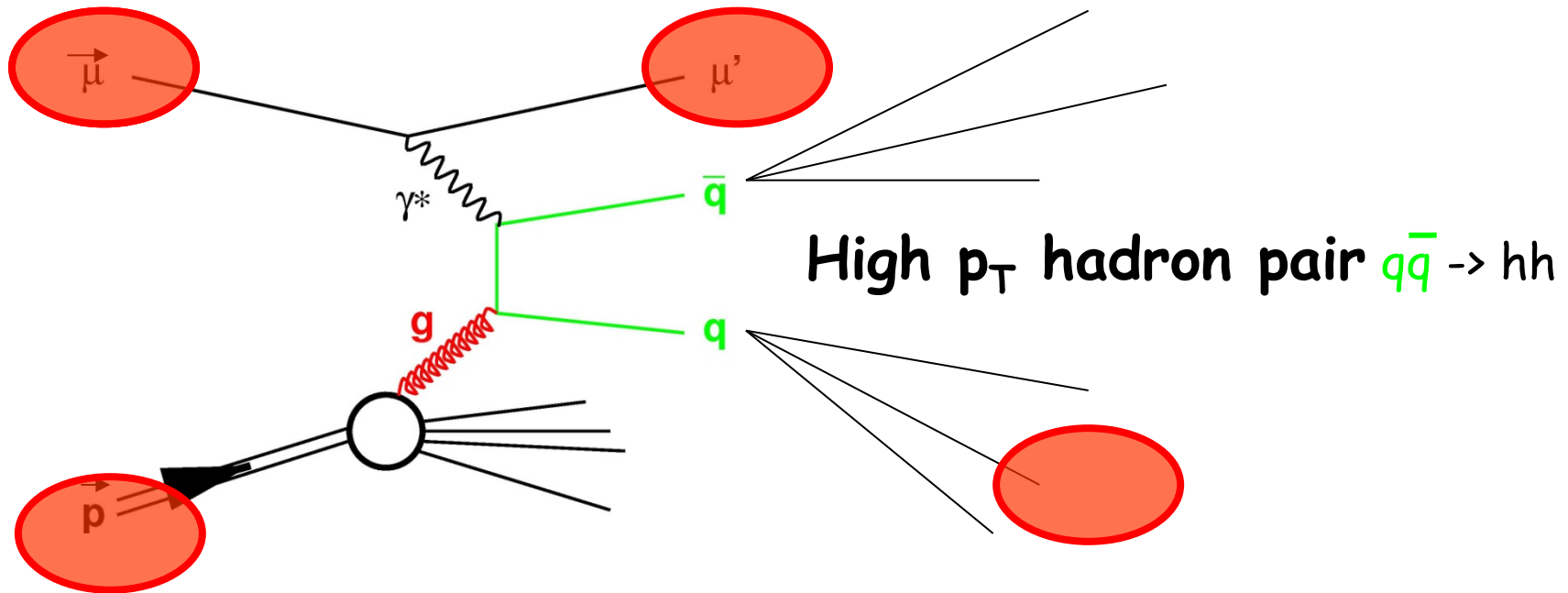
Il contesto

- 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 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

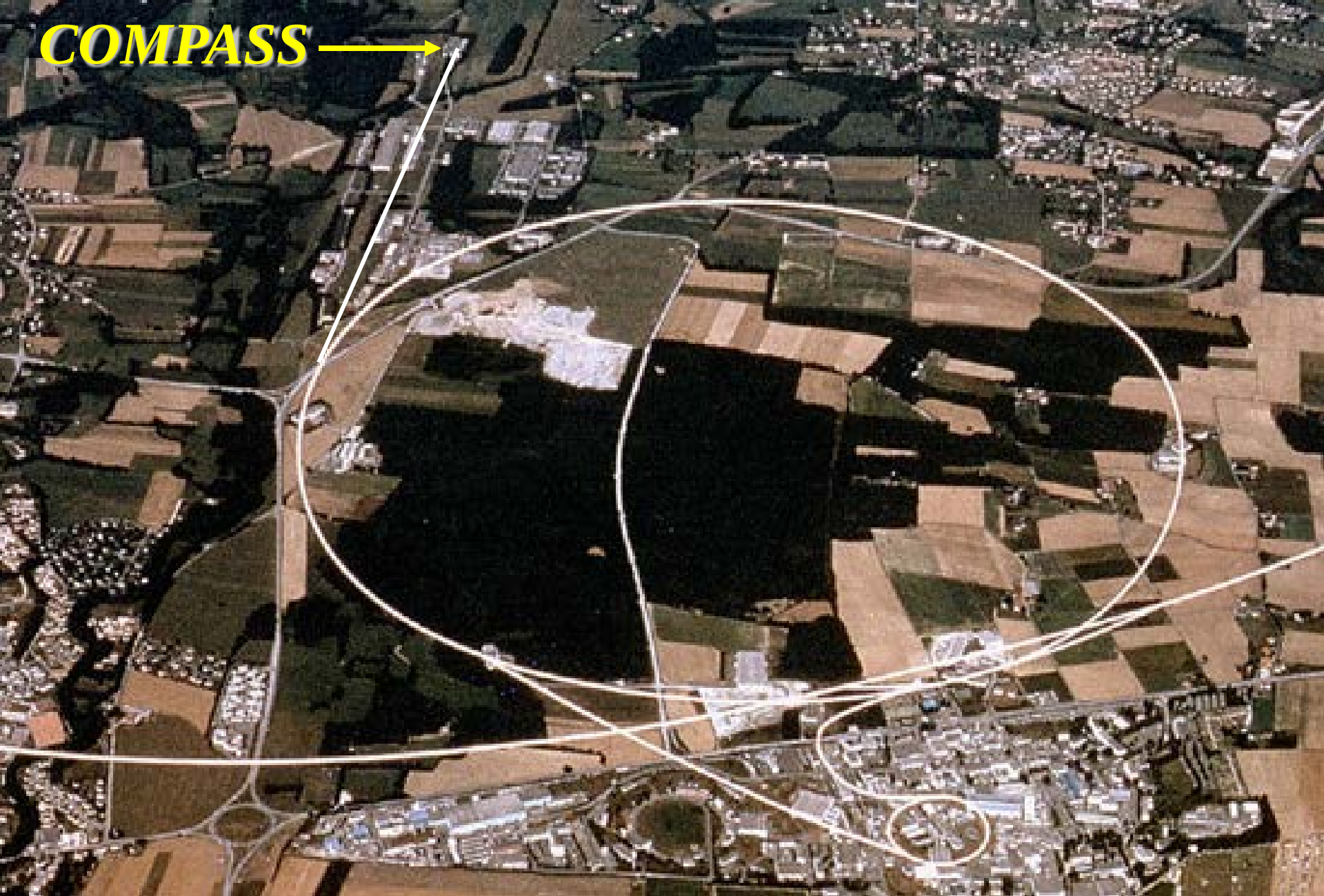
Jura

Geneva Lake

COMPASS



COMPASS →





THE COMPASS SPECTROMETER

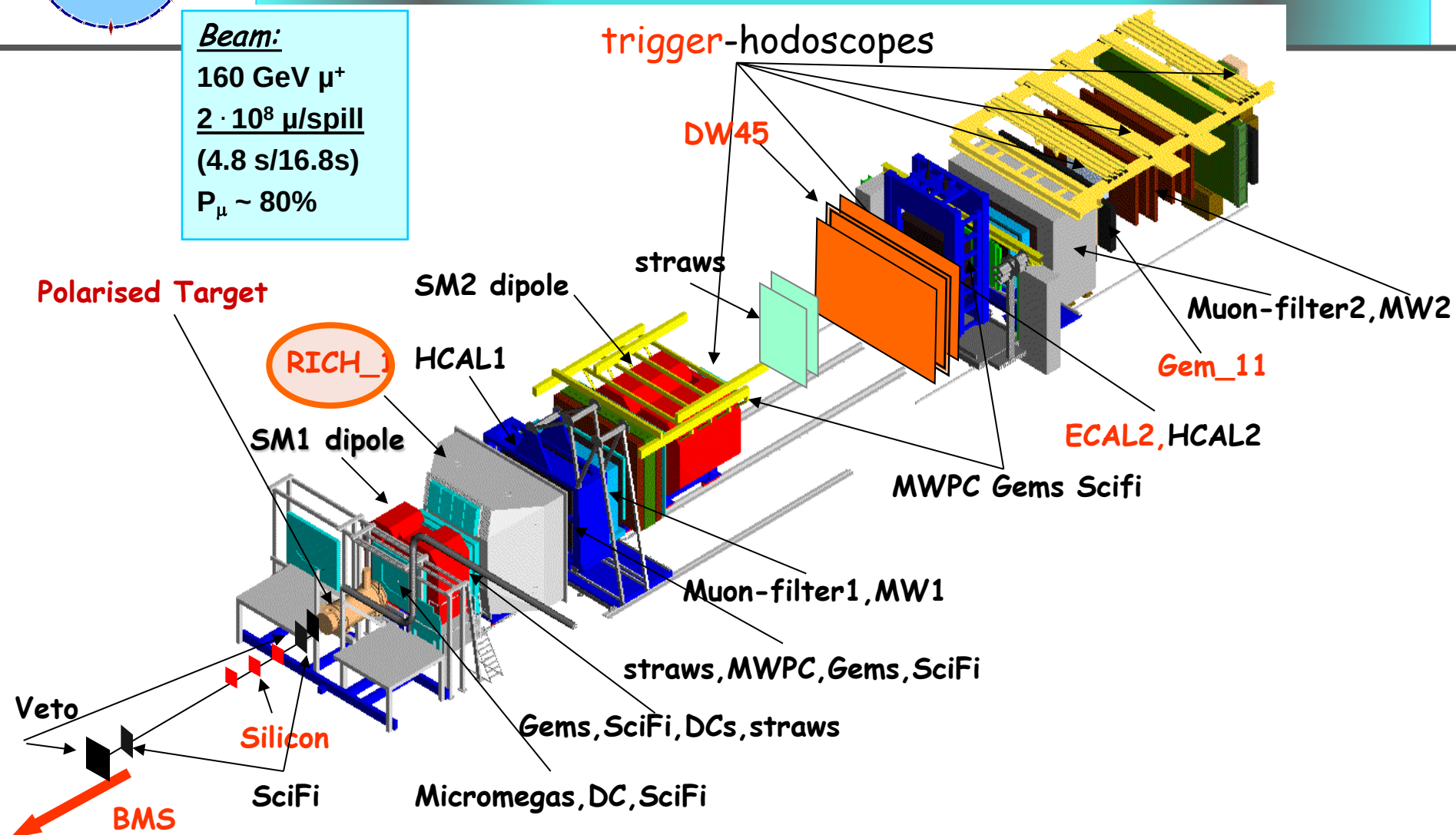
Beam:

160 GeV μ^+

$2 \cdot 10^8 \mu/\text{spill}$

(4.8 s/16.8s)

$P_\mu \sim 80\%$



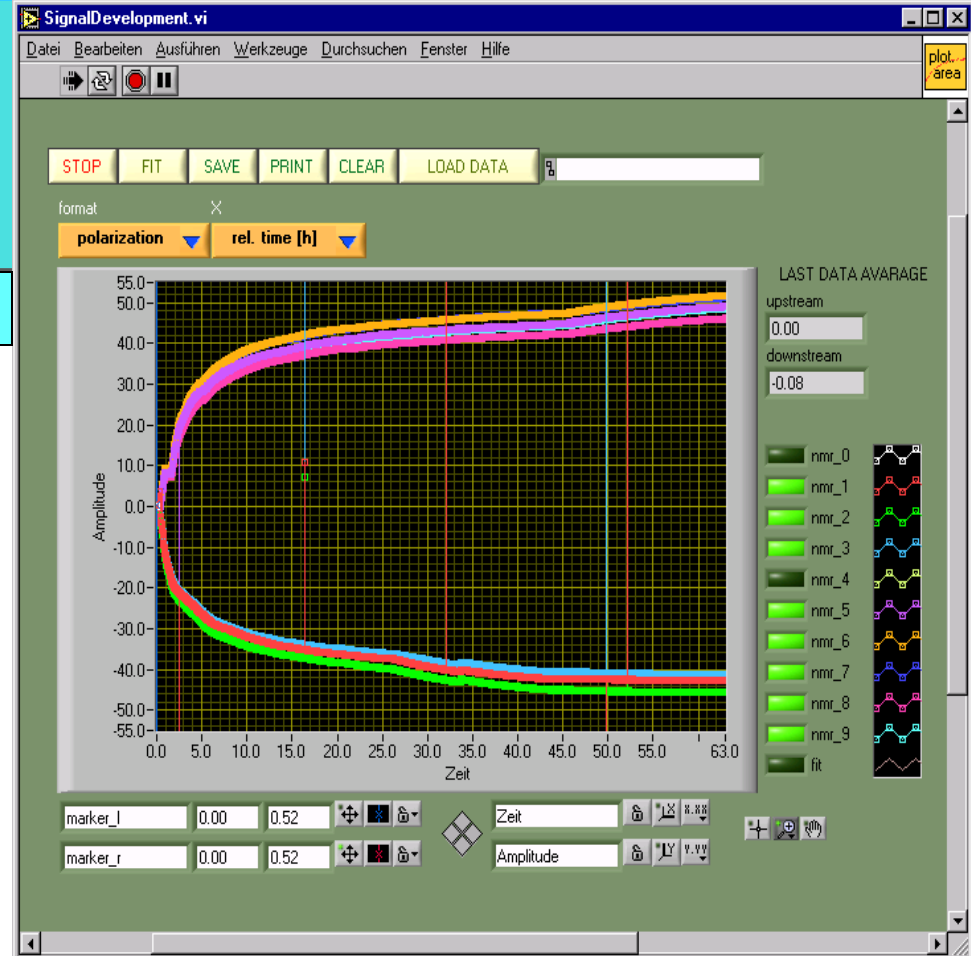
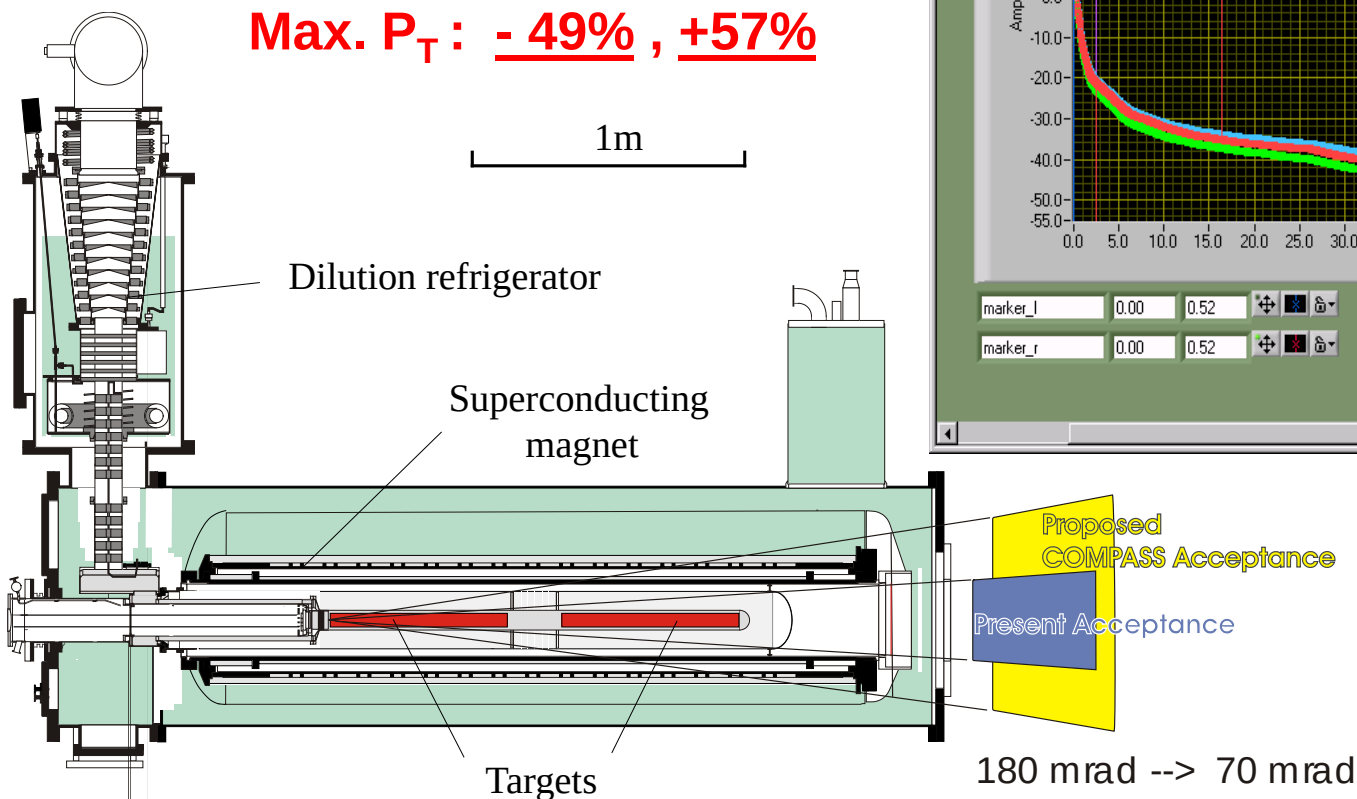


⁶LiD Target

2 halves polarised in opposite directions

Dynamic Nuclear Polarization
Frequency Modulation

Max. P_T : - 49% , +57%



Dilution factor ~50%

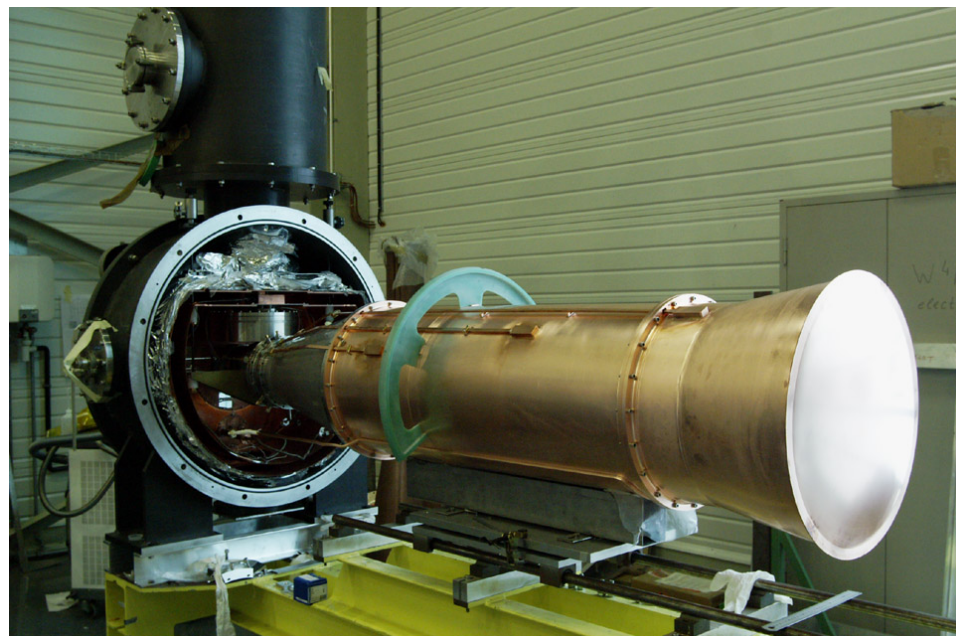
Solenoid: 2.5 T

Dipole: 0.5 T

Relaxation time:
>1000 h for 0.5 T



Polarized target upgrade, in 2006



+

-

-

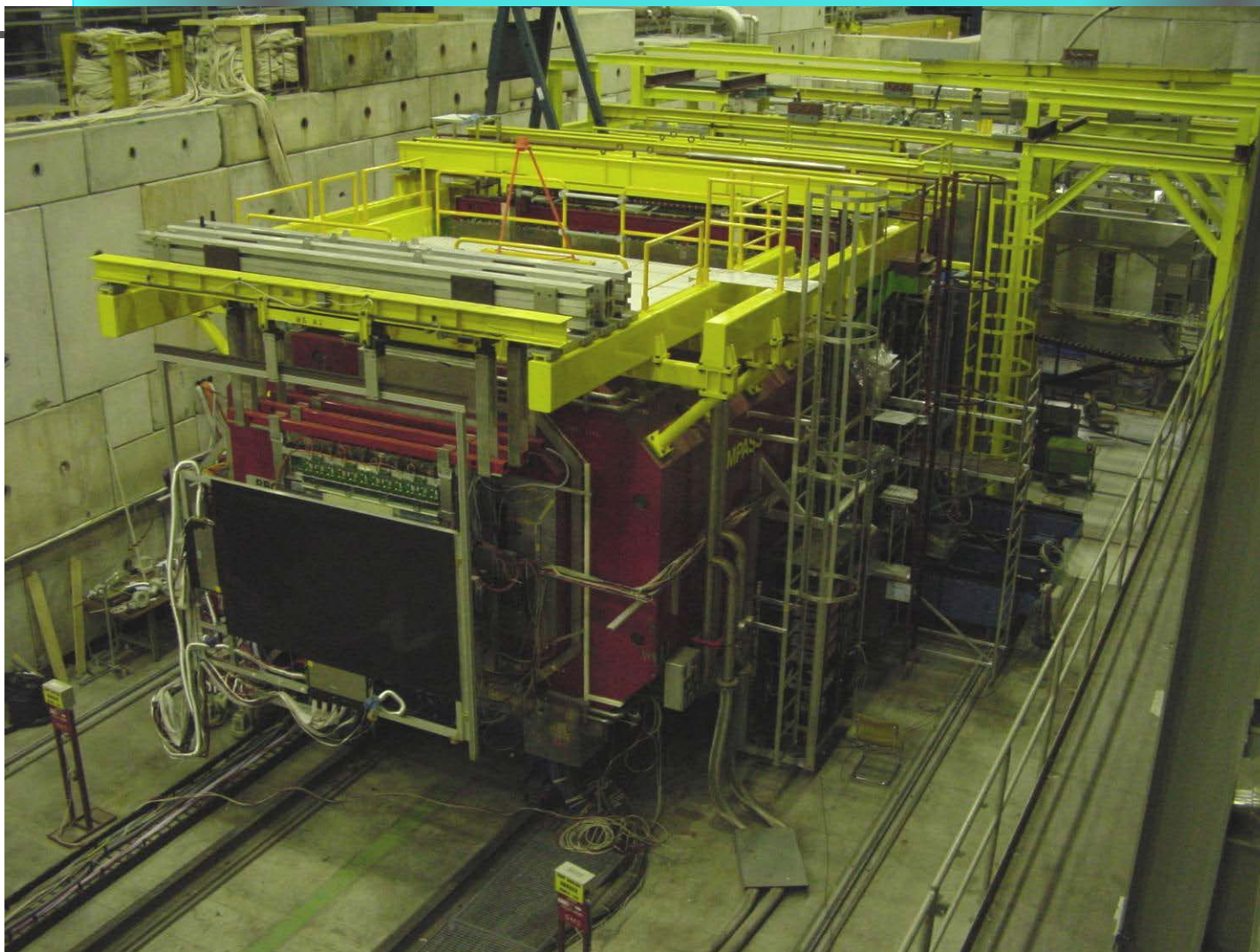
+

- New COMPASS target magnet
- $\rightarrow 180$ mrad

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



SM2 and the LAS region





Scintillating Fibers Hodoscopes

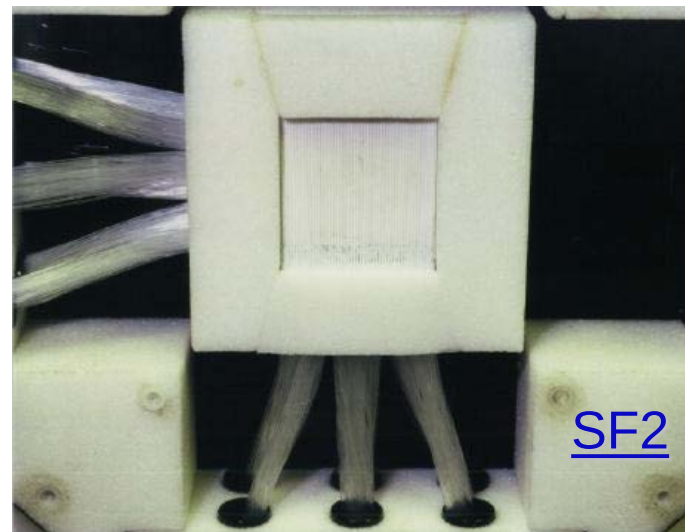
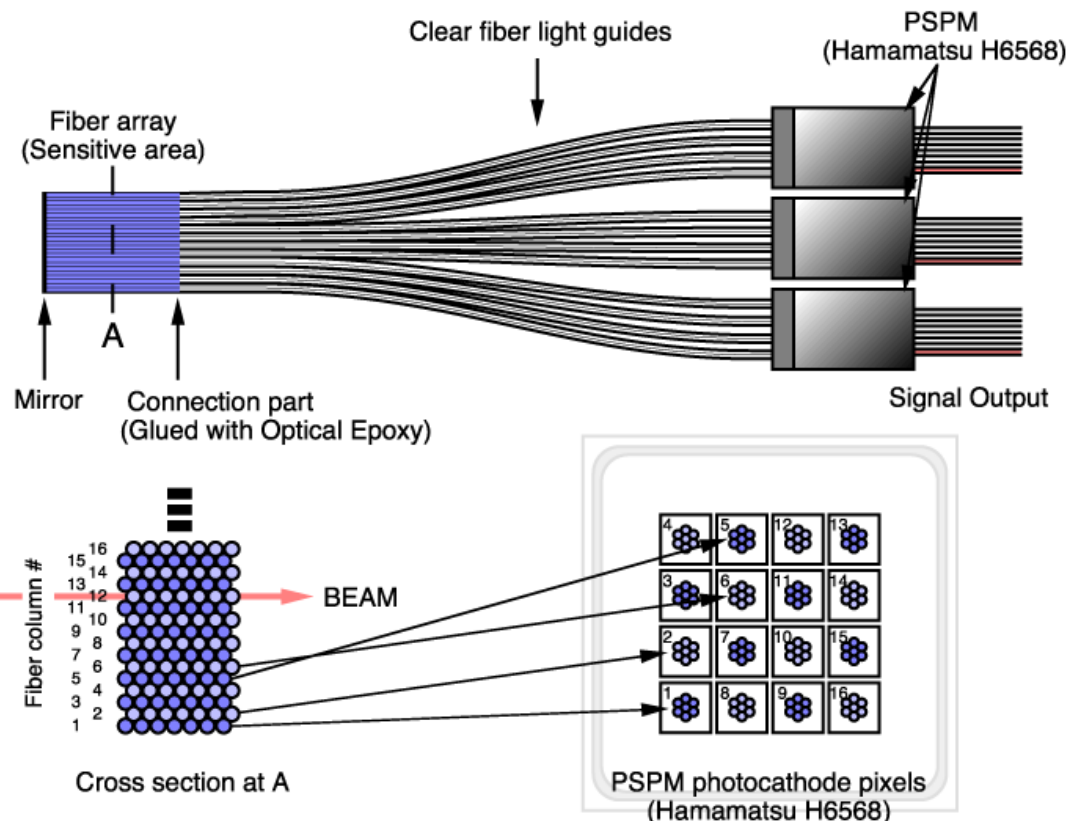
9 stations: 21 coordinates

*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 $\varnothing$



$\mu\Omega$

12 planes 40 x 40 cm²

Space resolution: 70 μm

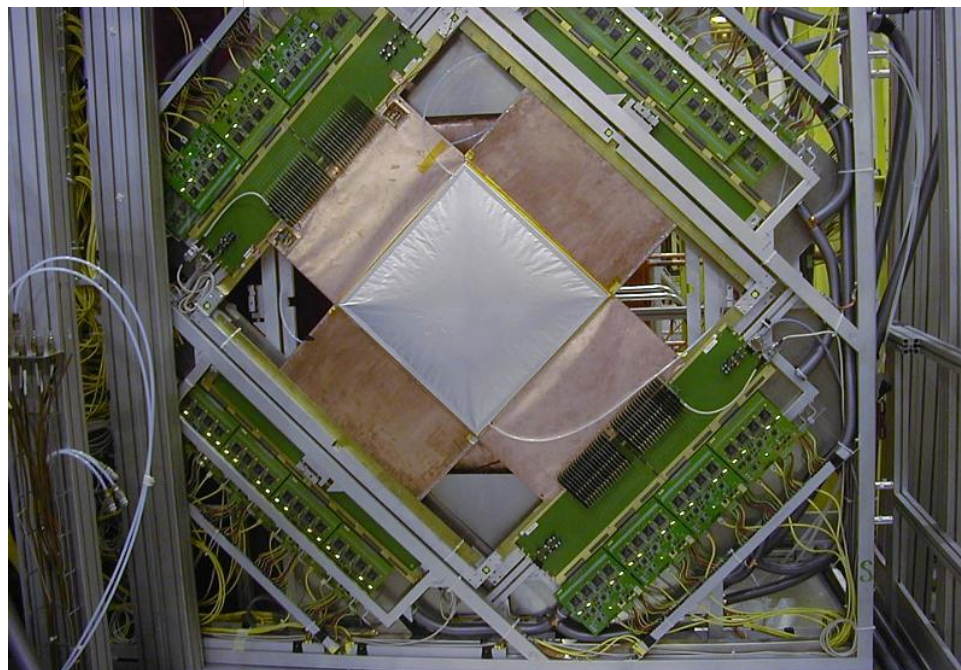
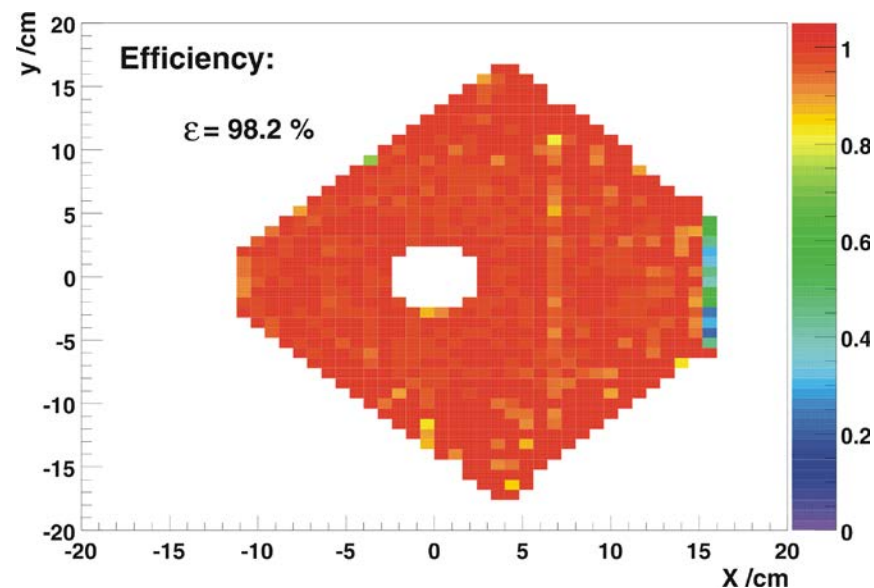
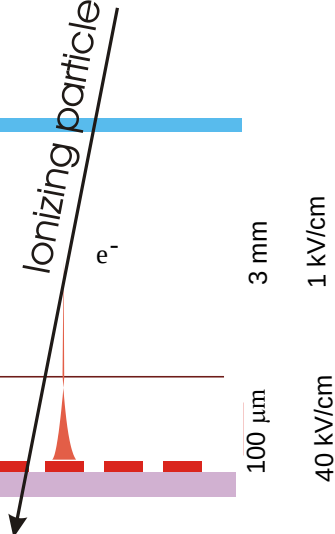
Time resolution: 8 ns

Conversion

Amplification

Micromesh

Strips



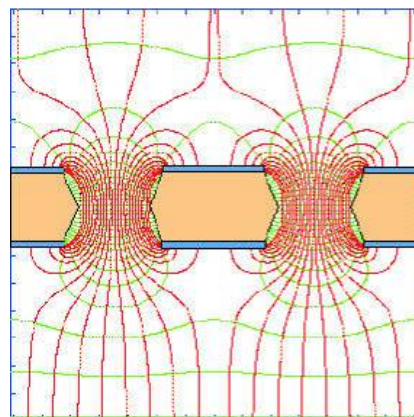
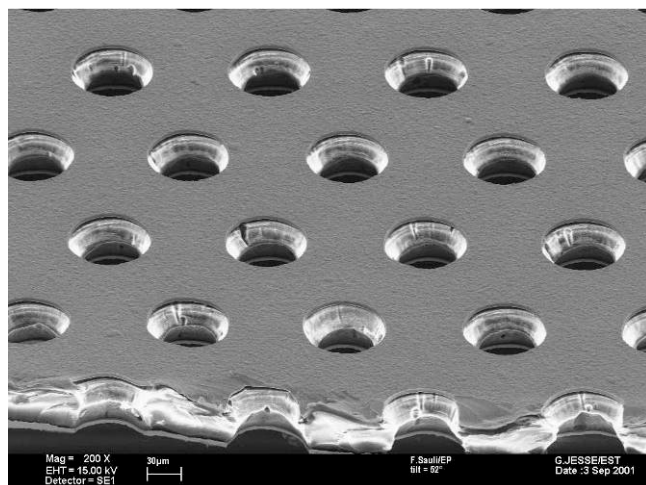
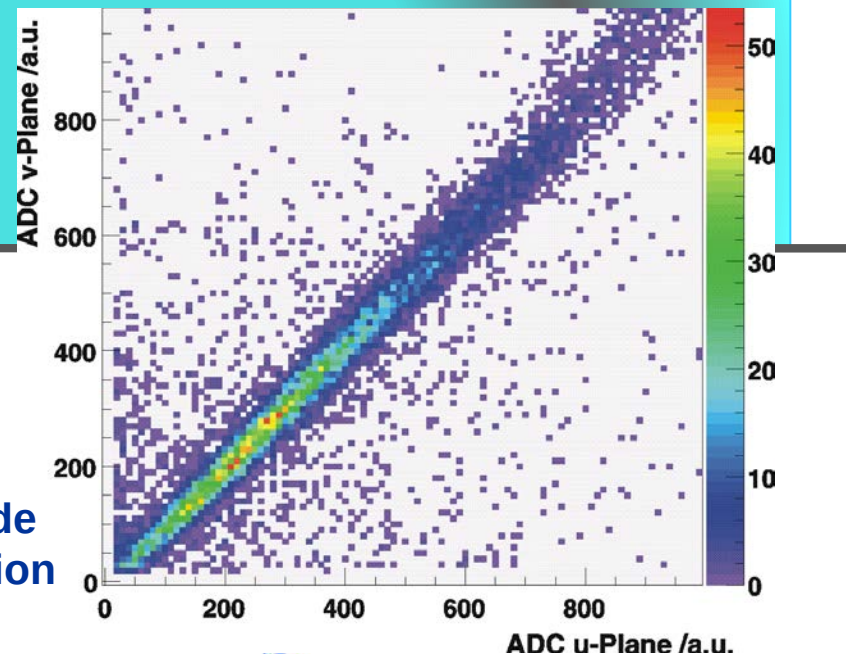


GEM

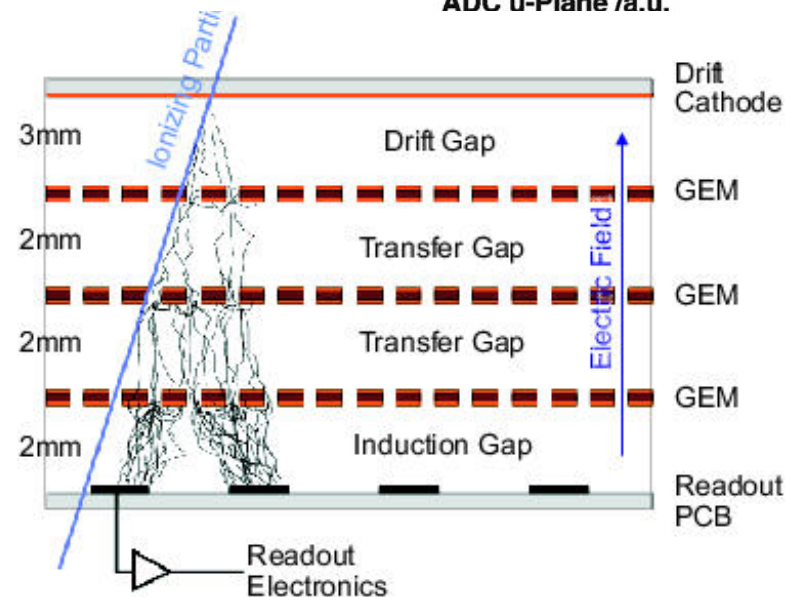
20 triple GEM detectors with 2 dimensional r/o

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

amplitude
correlation



(two dimensional)



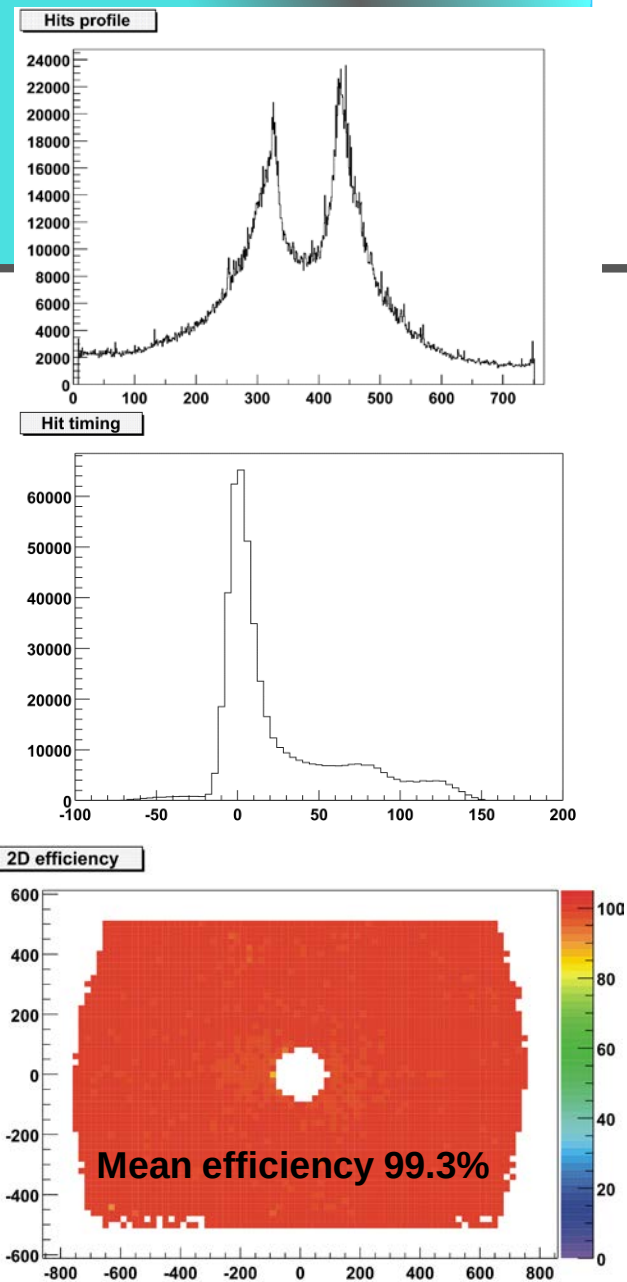


MWPCs

Total of 34 planes

SAS Tracking

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



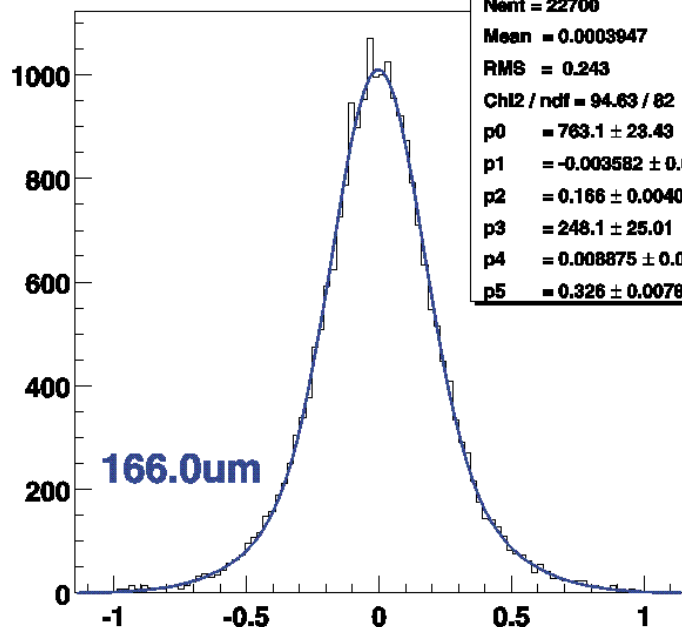


Drift Chambers for LAS

3 chambers with 8 coordinates each

Efficiency: 95 - 99.8 %

DC01X1__T_du_:'T_fnd&&abe(T_duflin)<1&&T_chi2(T_omit-5)<3



DC01X1__T_du_

Nent = 22700

Mean = 0.0003947

RMS = 0.243

Chi2 / ndf = 94.63 / 82

p0 = 763.1 ± 23.43

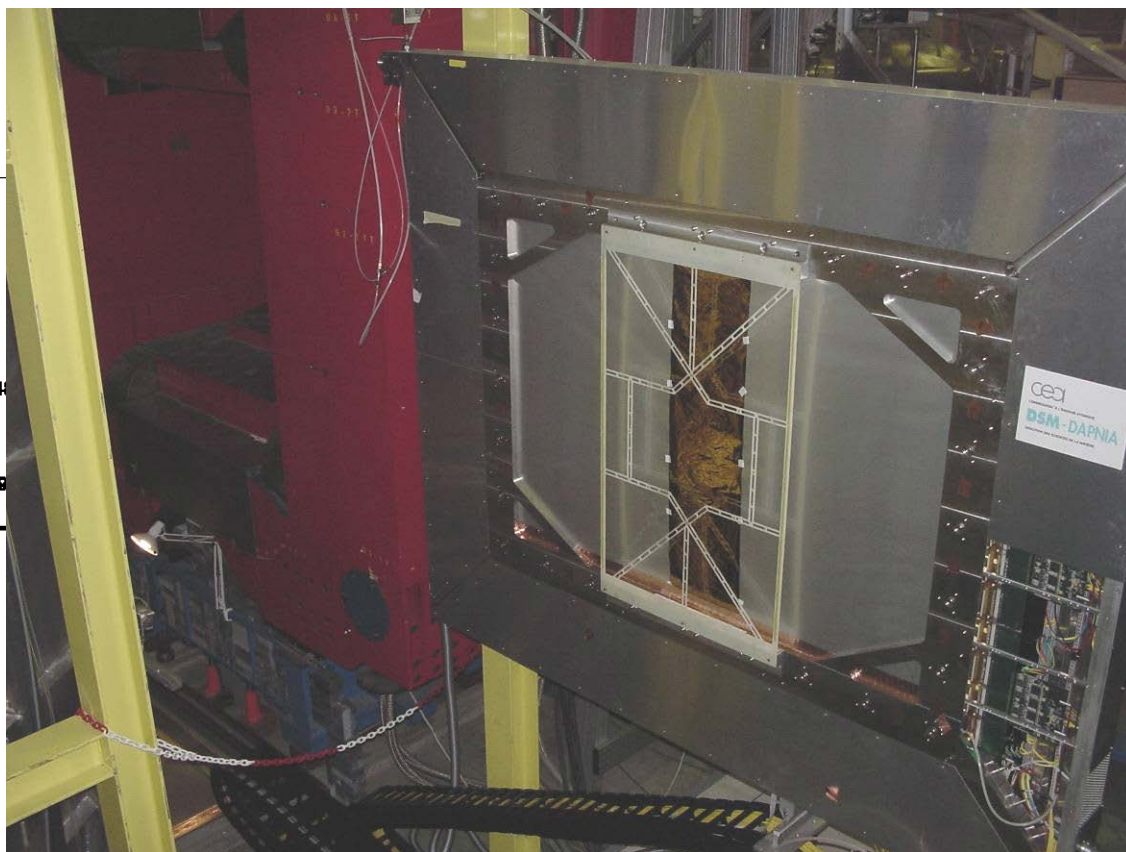
p1 = -0.003582 ± 0.00224

p2 = 0.166 ± 0.004011

p3 = 248.1 ± 25.01

p4 = 0.008875 ± 0.004569

p5 = 0.326 ± 0.007832





Drift Chambers for SAS



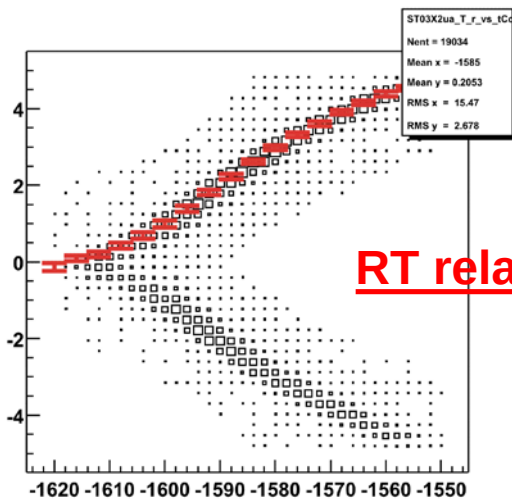
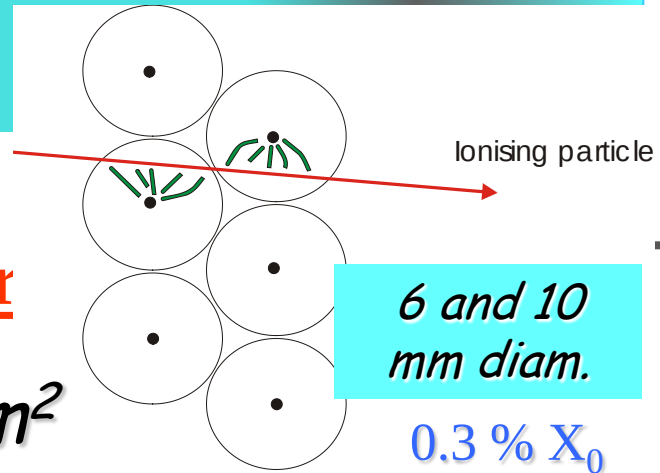


STRAWs

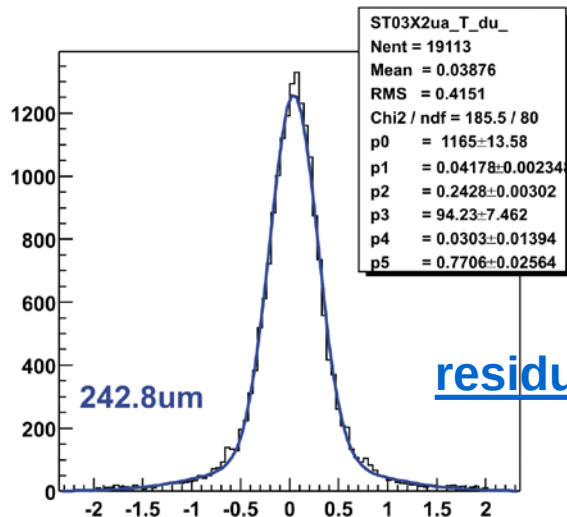
1 Module =
6 double layer

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

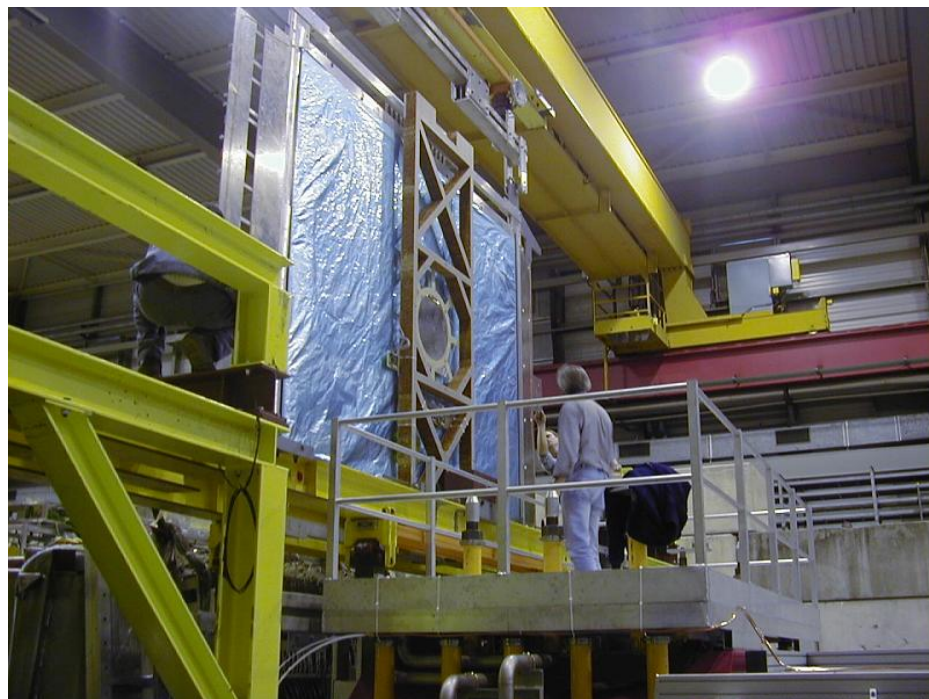
Installation of a double layer



RT relation



residuals





HCAL 1





Muon Wall 2



Muon Wall 1





RICH

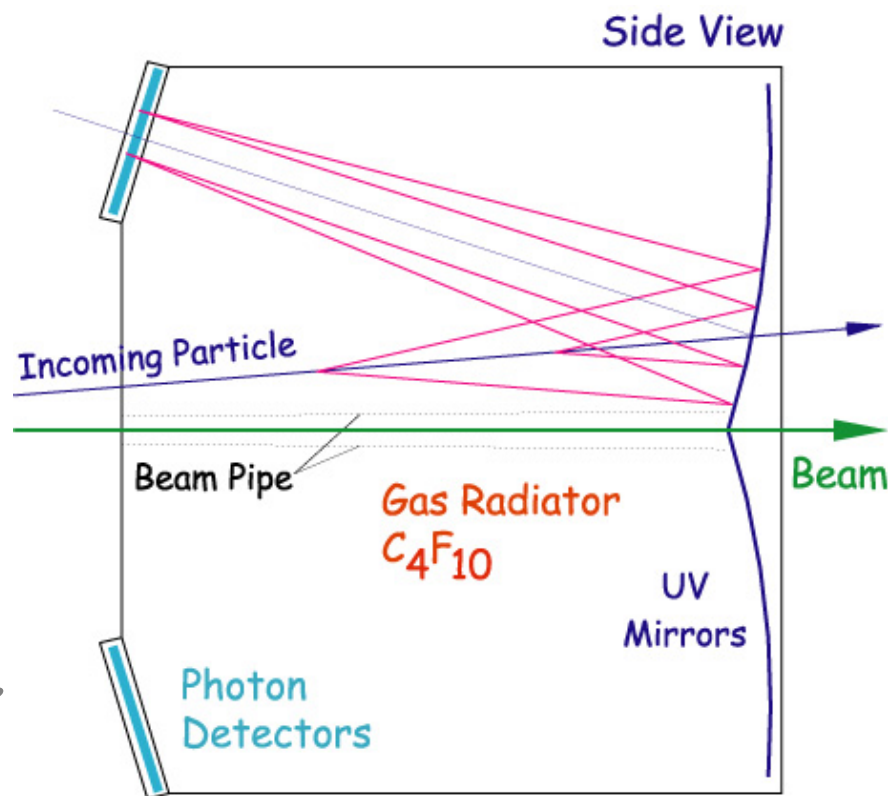
RICH =

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

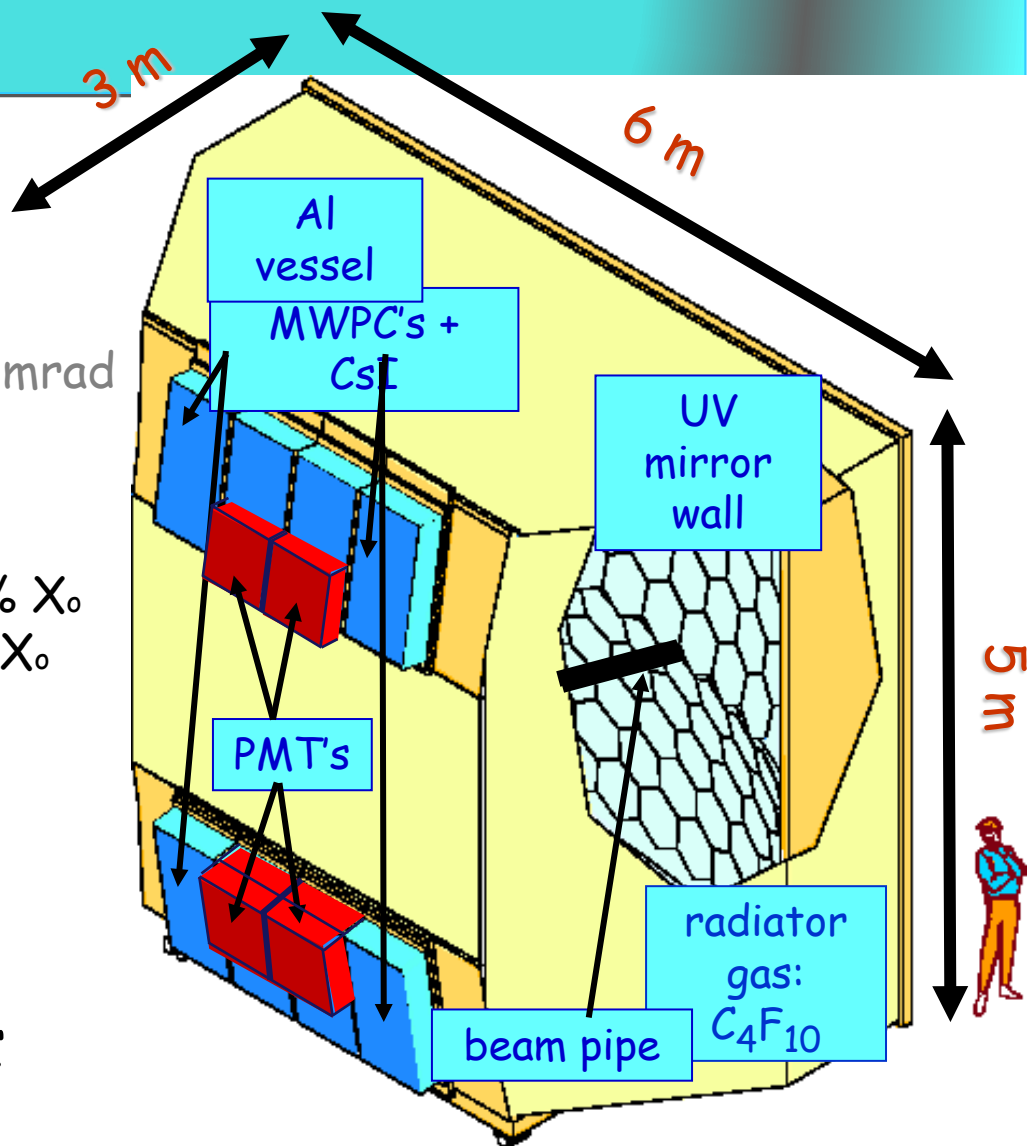
material in the acceptance: 22% X_0

detector designed in 1996

in operation since 2002

upgraded in 2006

total investment: ~ 4 M €

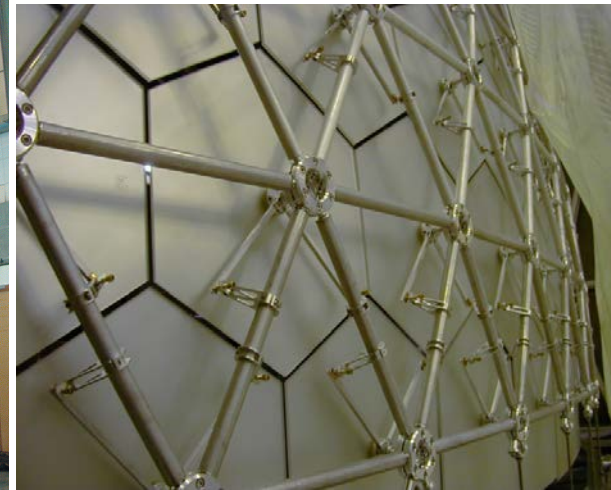
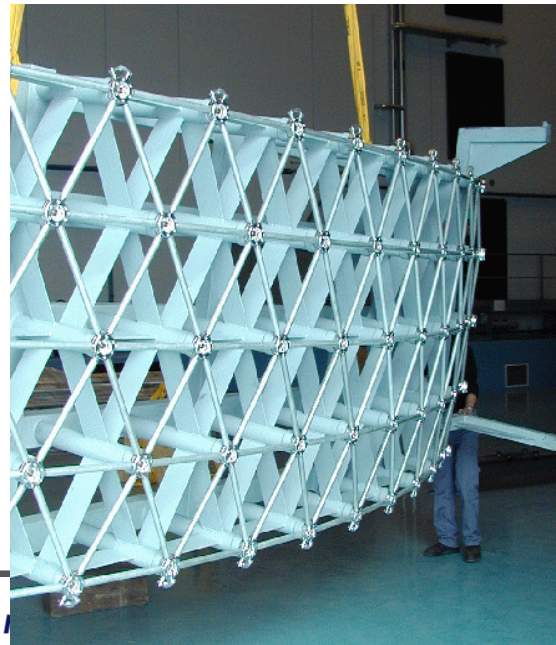


the vessel and the mirror

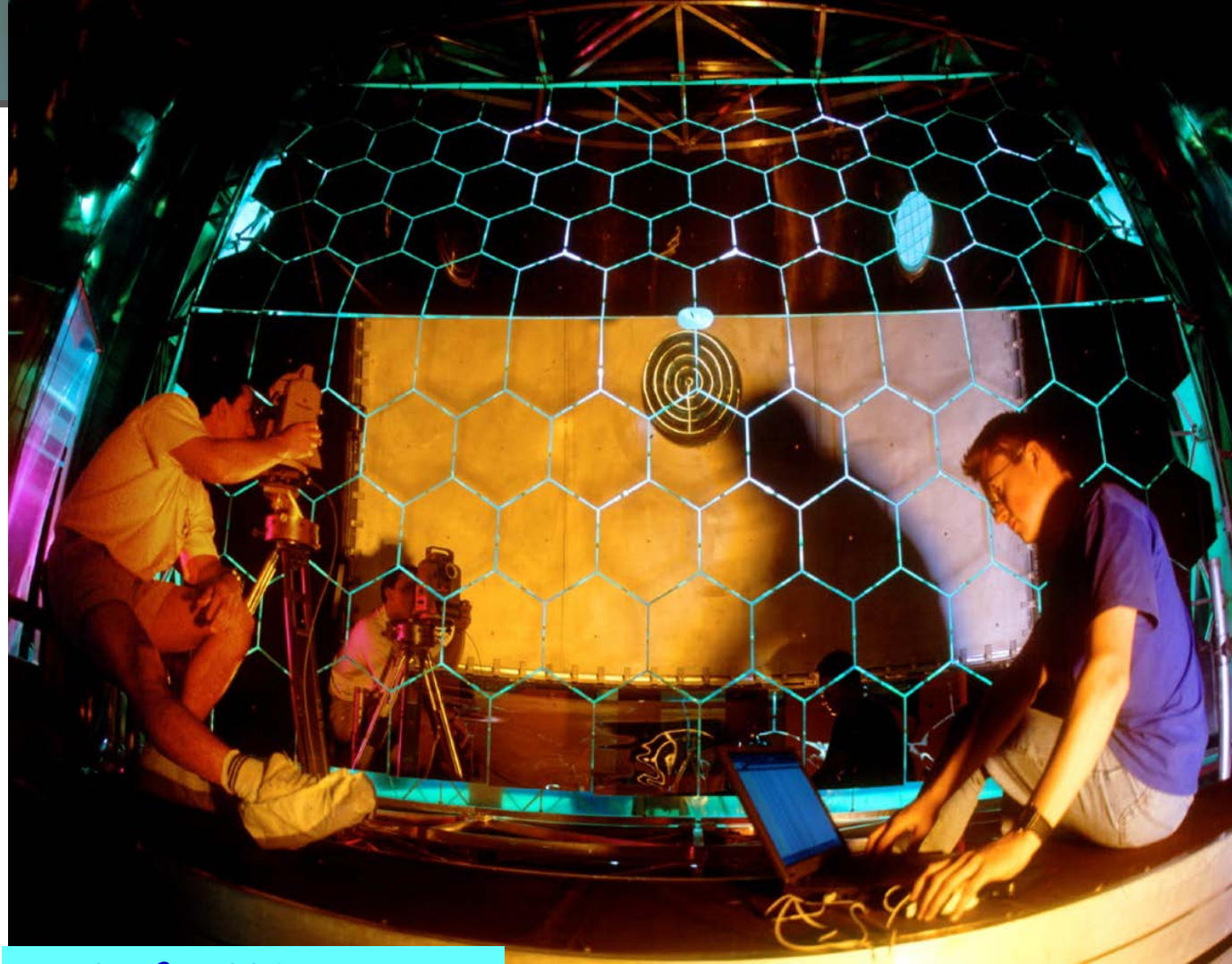


Large and accurate
mechanics

light front and rear windows



mirrors and alignment



*21 m², 116 mirrors
radius: 6.6 m*

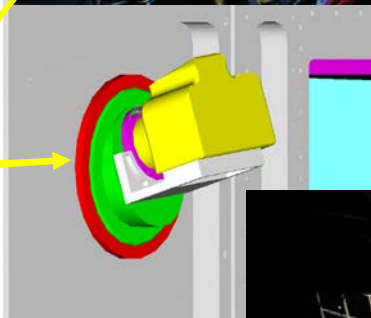
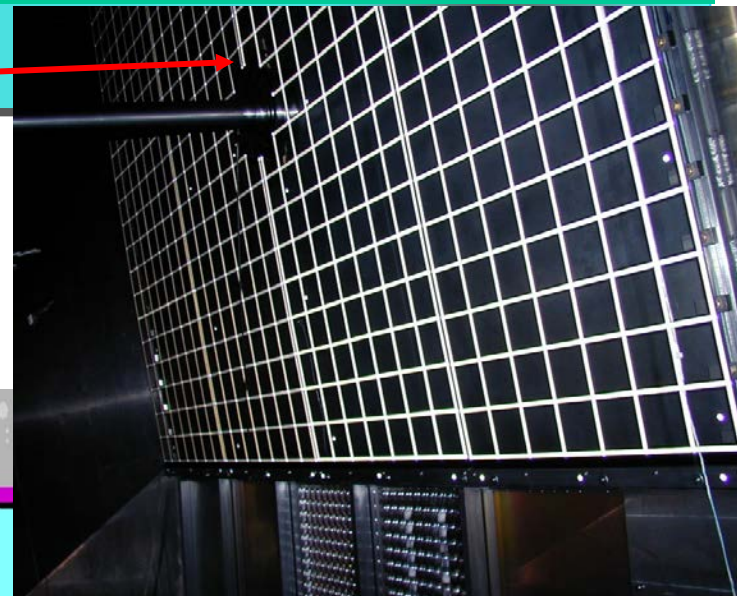
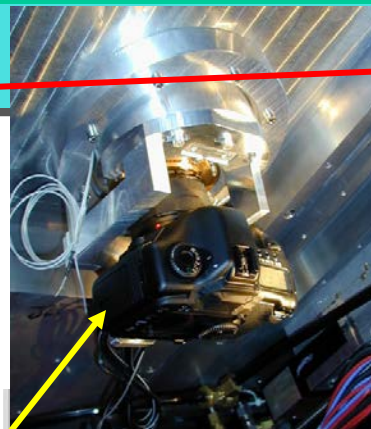
angular regulation screws



CLAM: mirror alignment monitoring

4 cameras
at corners
with LED's

retroreflecti
ve grid



CLAM system in
operation since

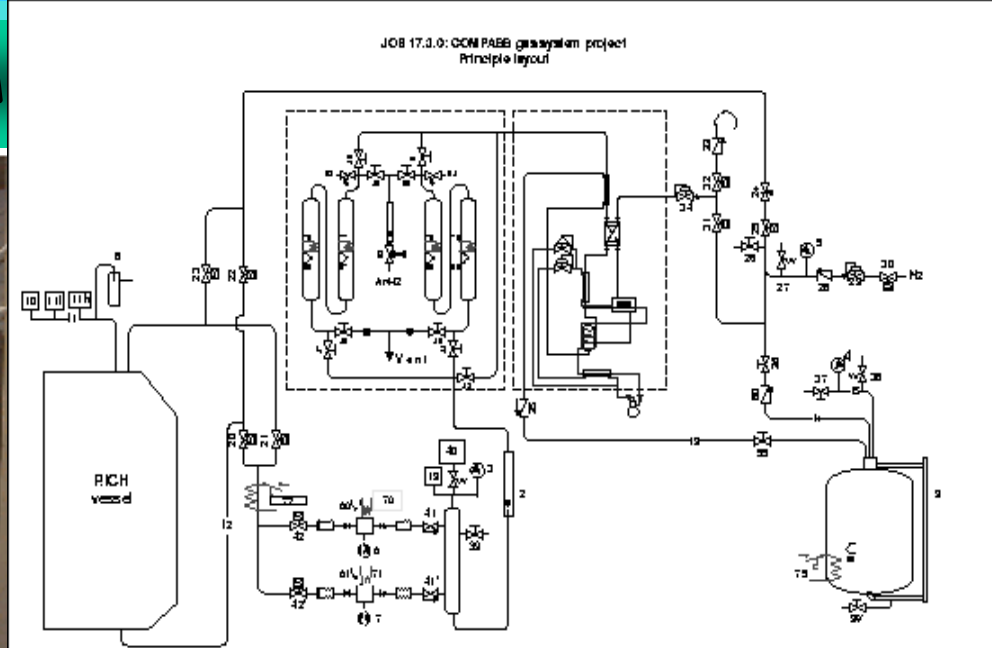
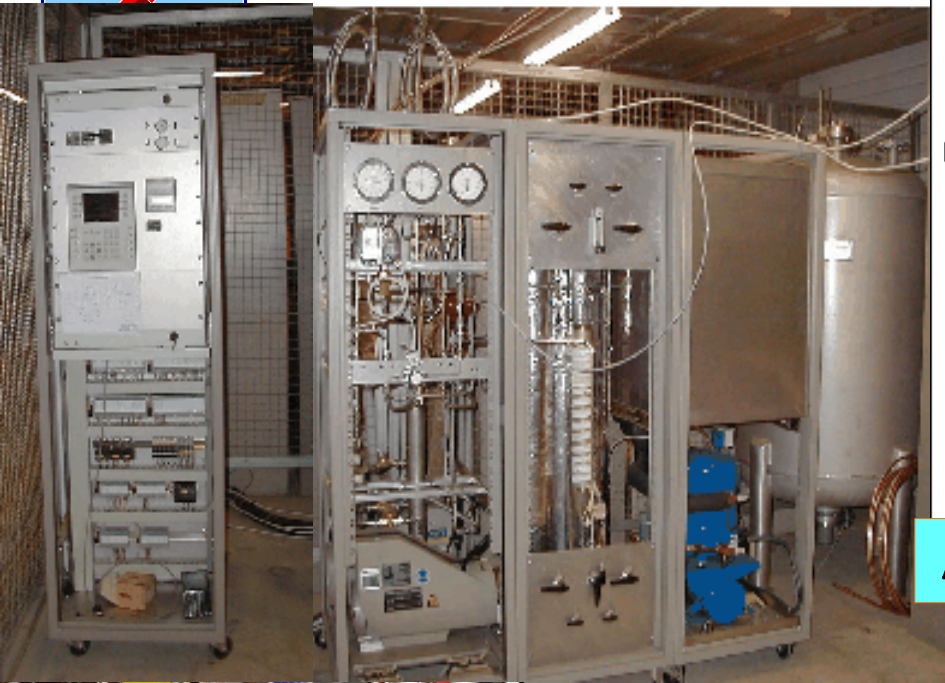
accuracy: $30 \mu\text{rad}$

photogrammetric
calibration of
cameras $\rightarrow$
measurement of
absolute mirror tilt



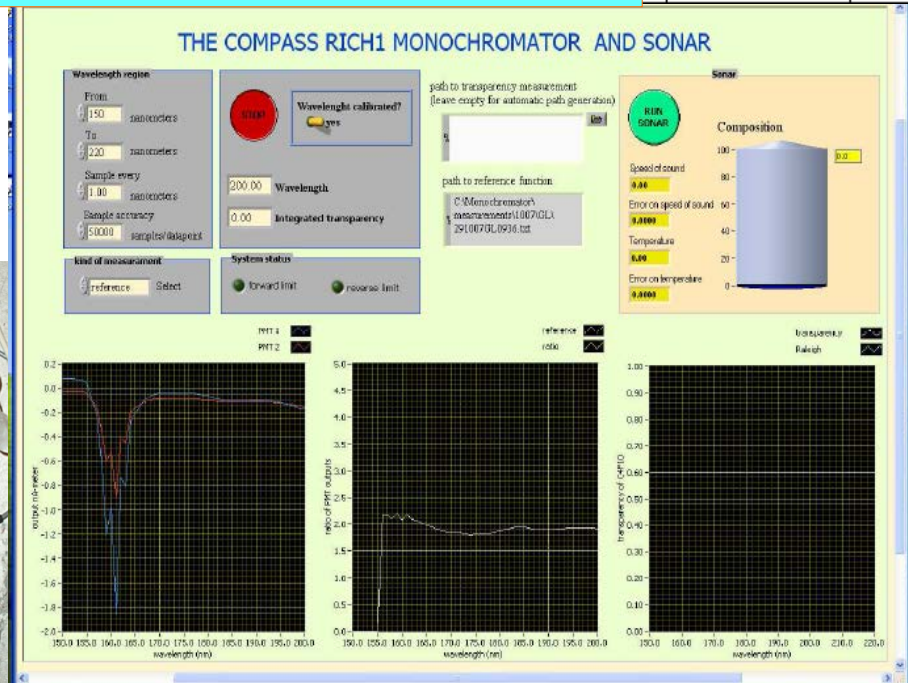
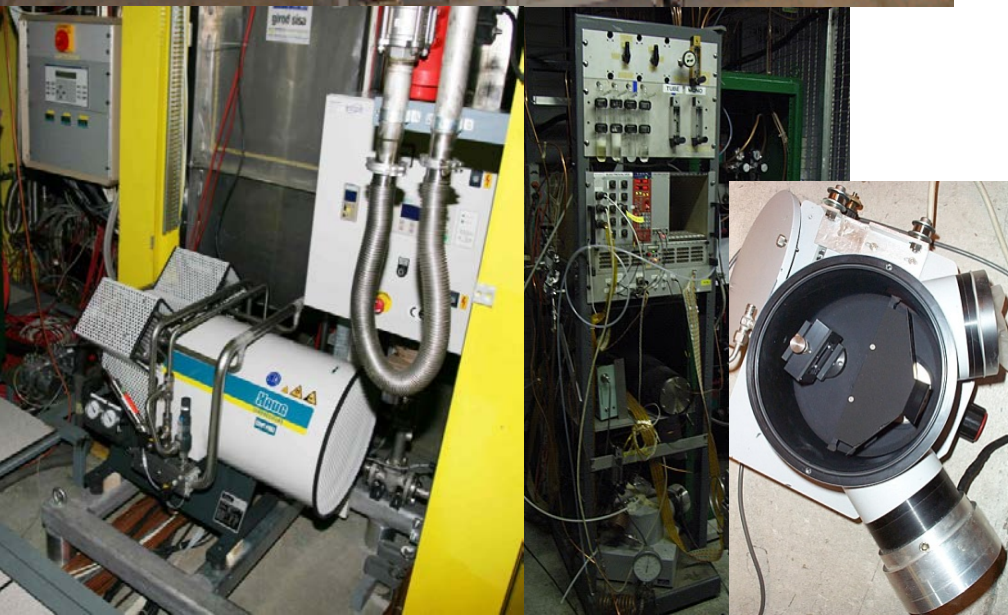
"CLAM" picture for mirror
monitoring

The radiator gas system



has excellent performances

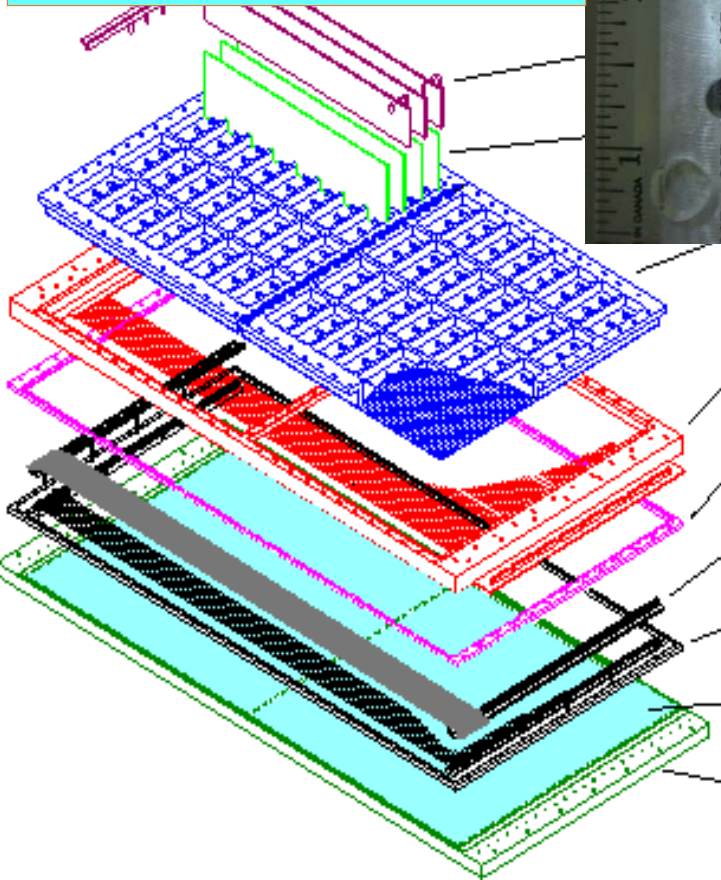
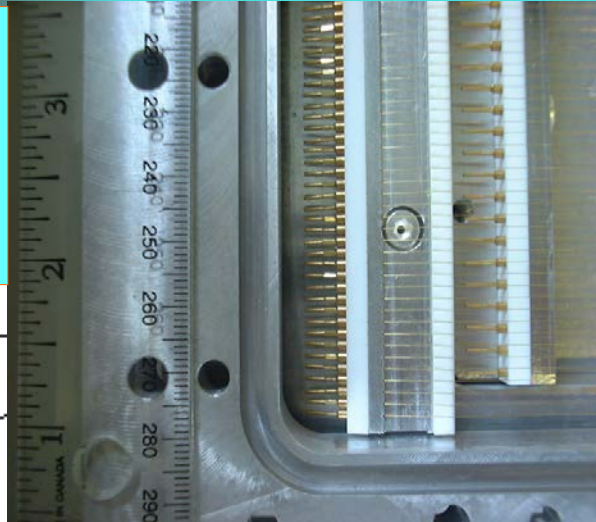
COMPASS RICH1 gas system	Basilevich M.
Principle layout	SCALE ..
CERN/ESTAS/SPF	21/03/00
	17.3.0





The 8 MWPC's with CsI photocathodes

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

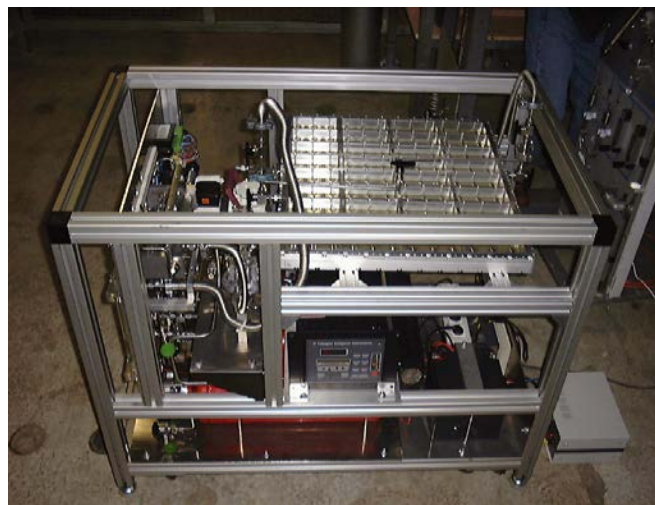
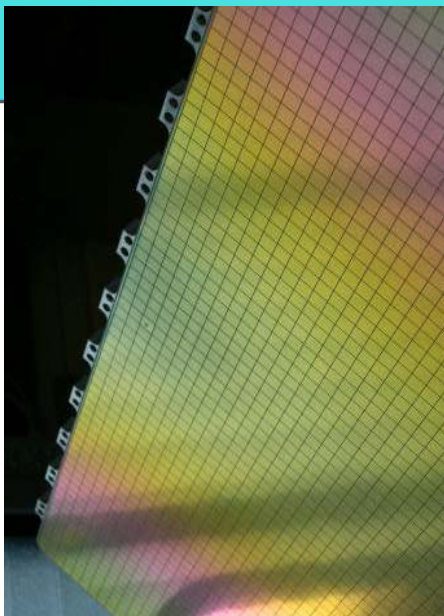


9-11 maggio 2014

Silvia DALLA TORRE (INFN Trieste)

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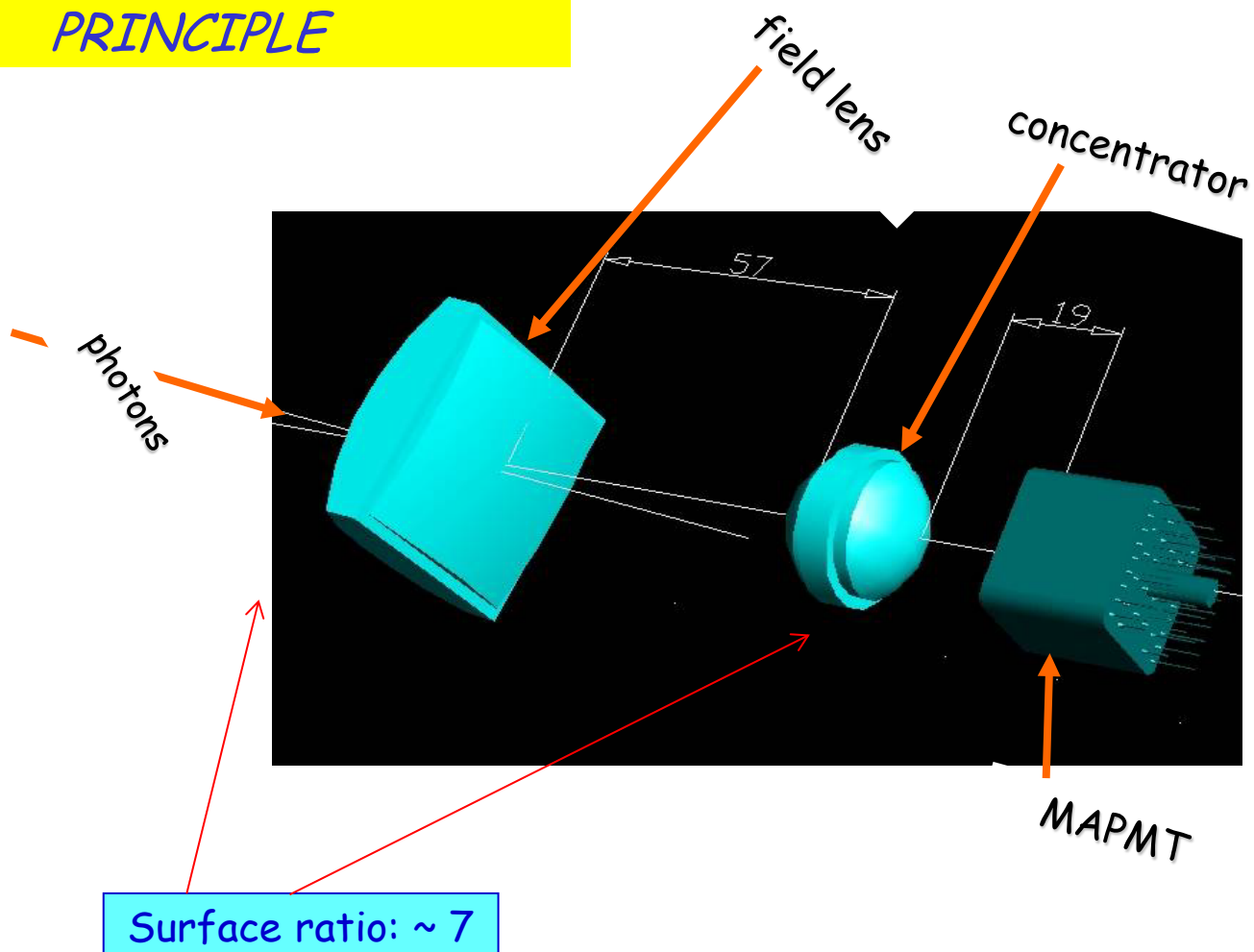
The CsI photocathodes

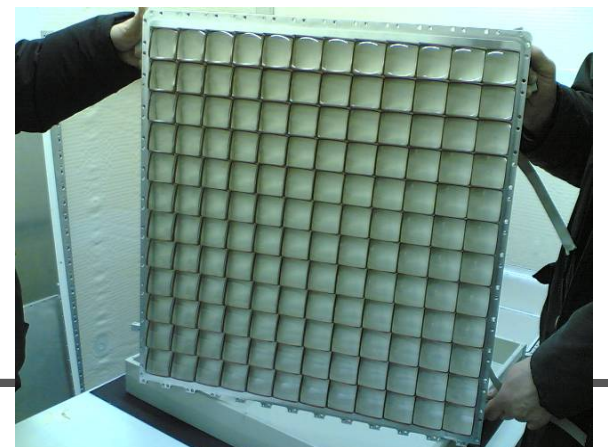
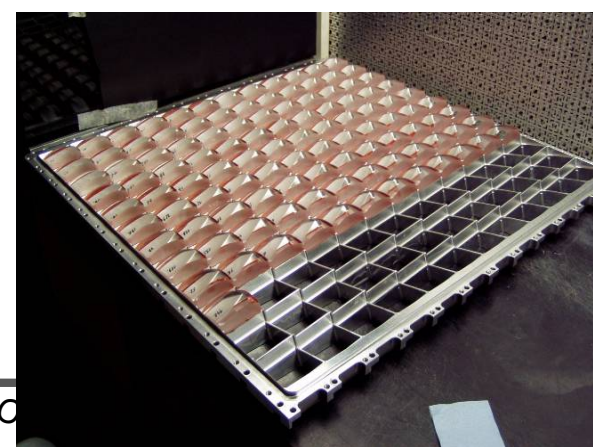
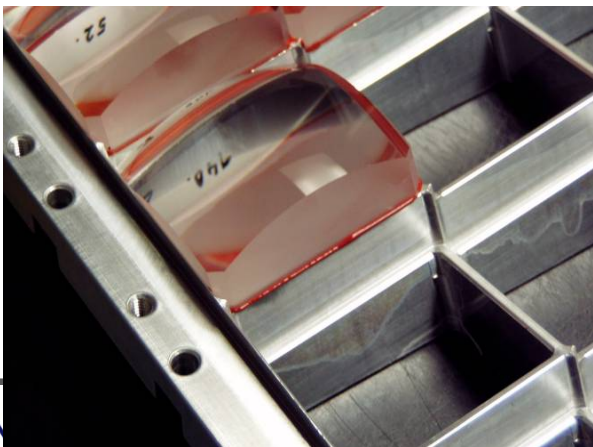


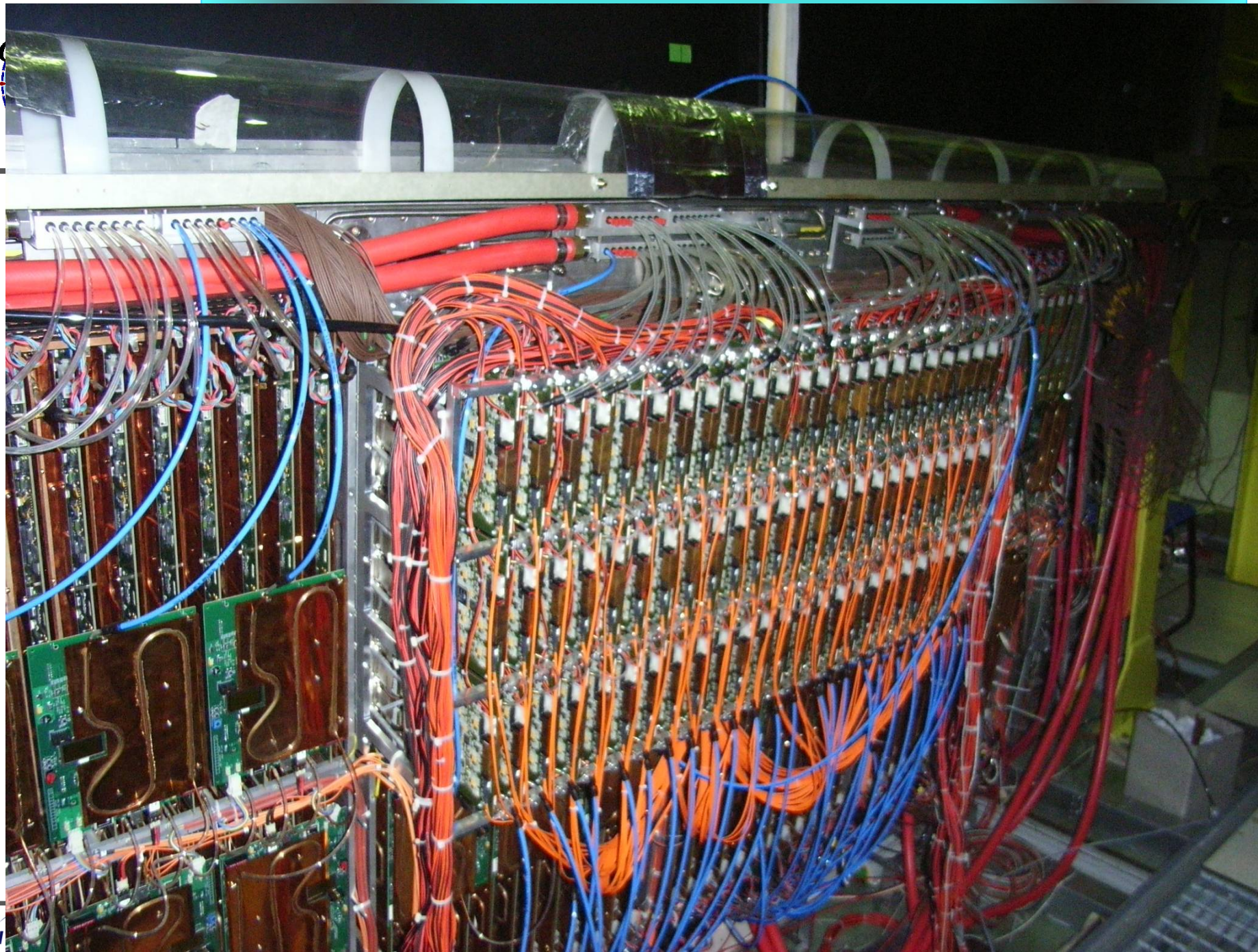


UPGRADE WITH MAPMT

PRINCIPLE

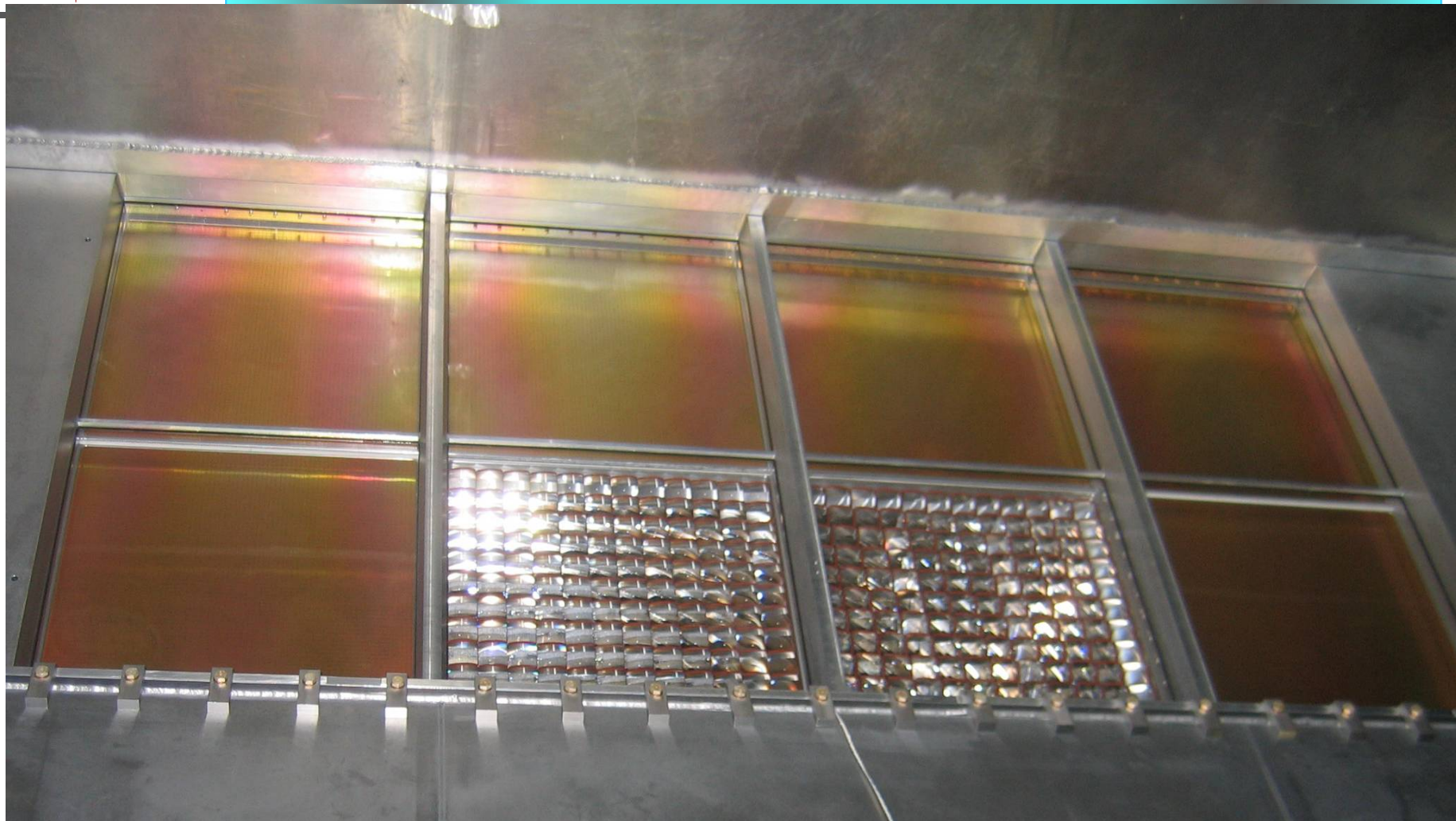






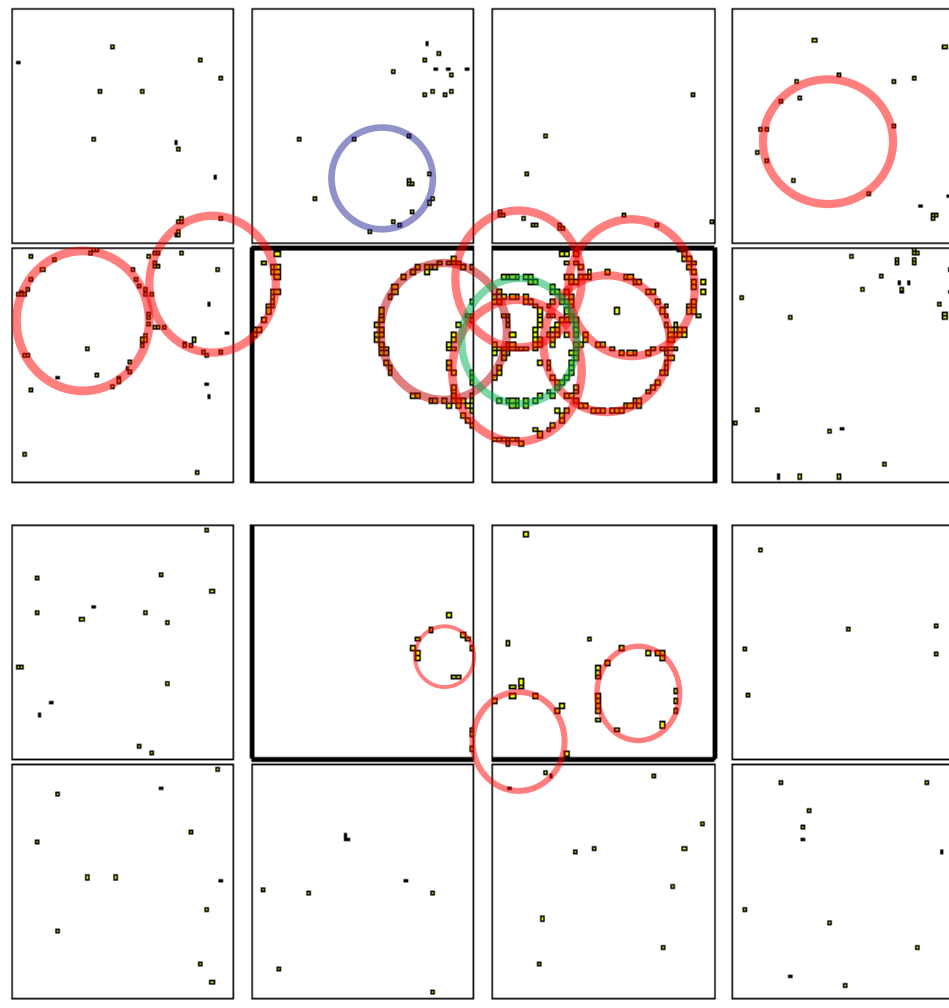


The Upper Detector from inside



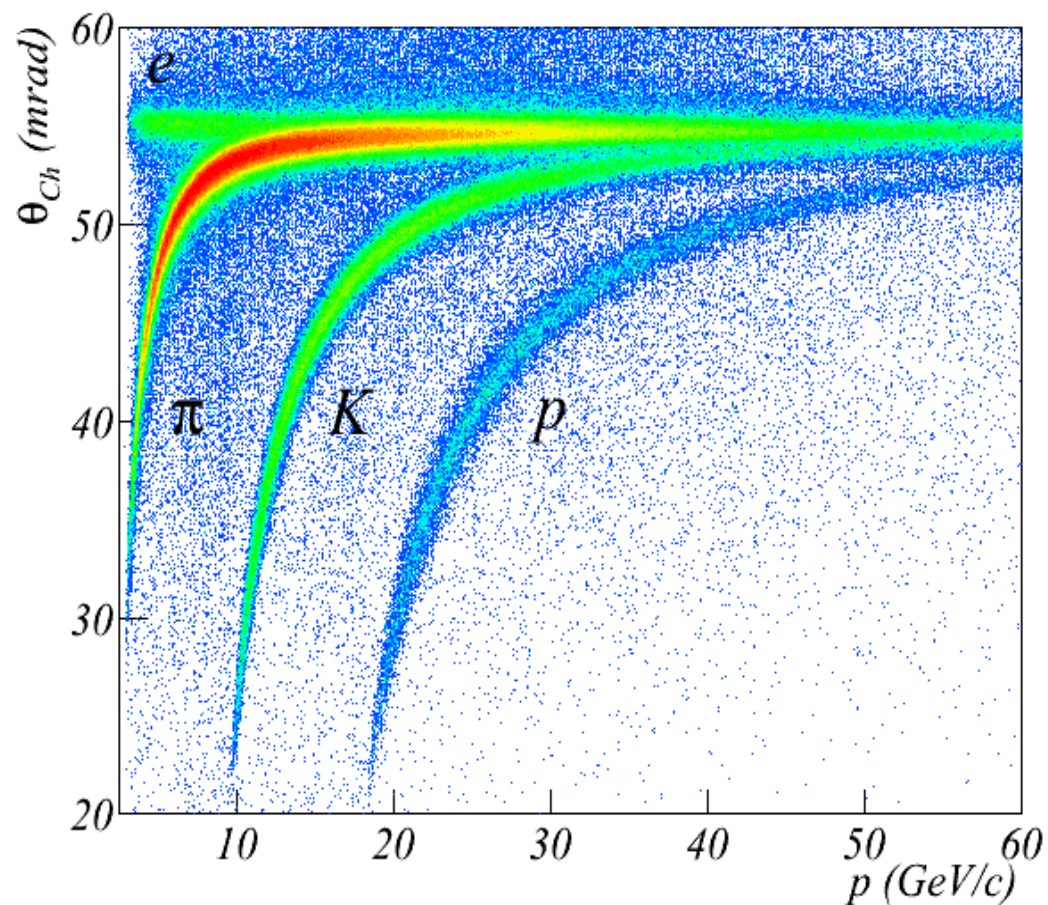


A typical event





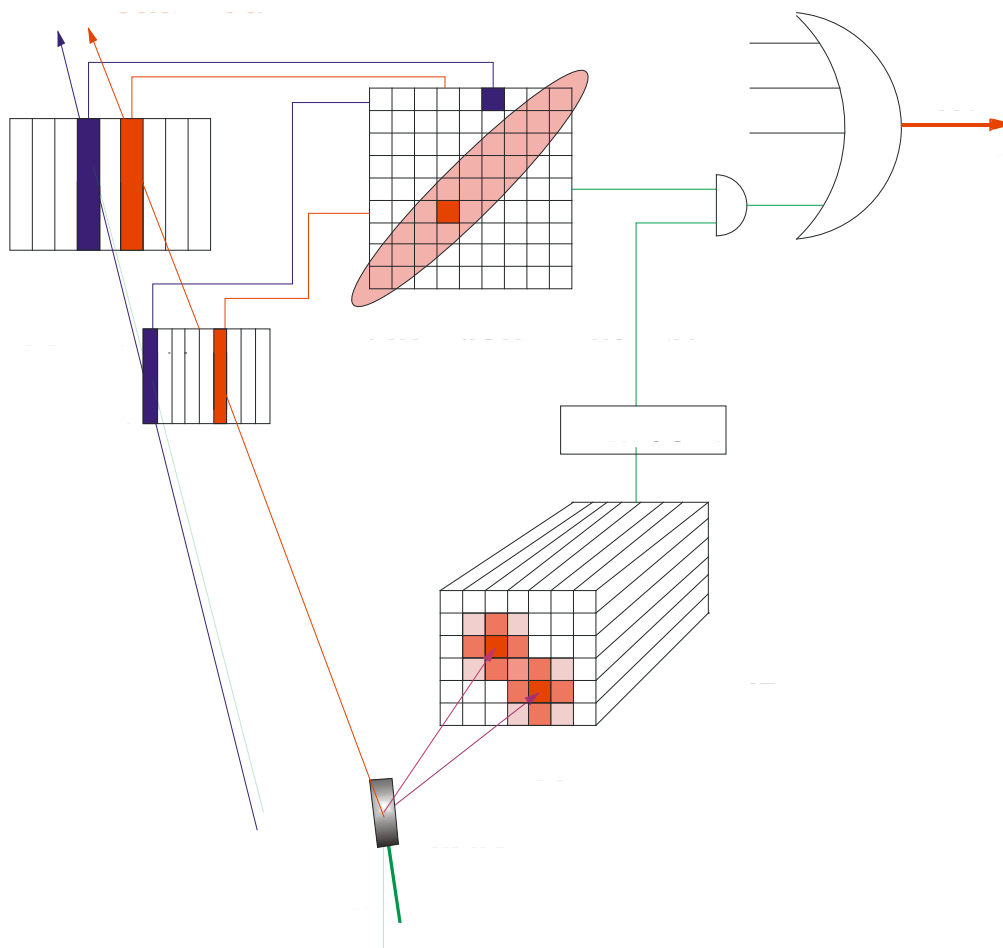
RESULTS





Trigger concept

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



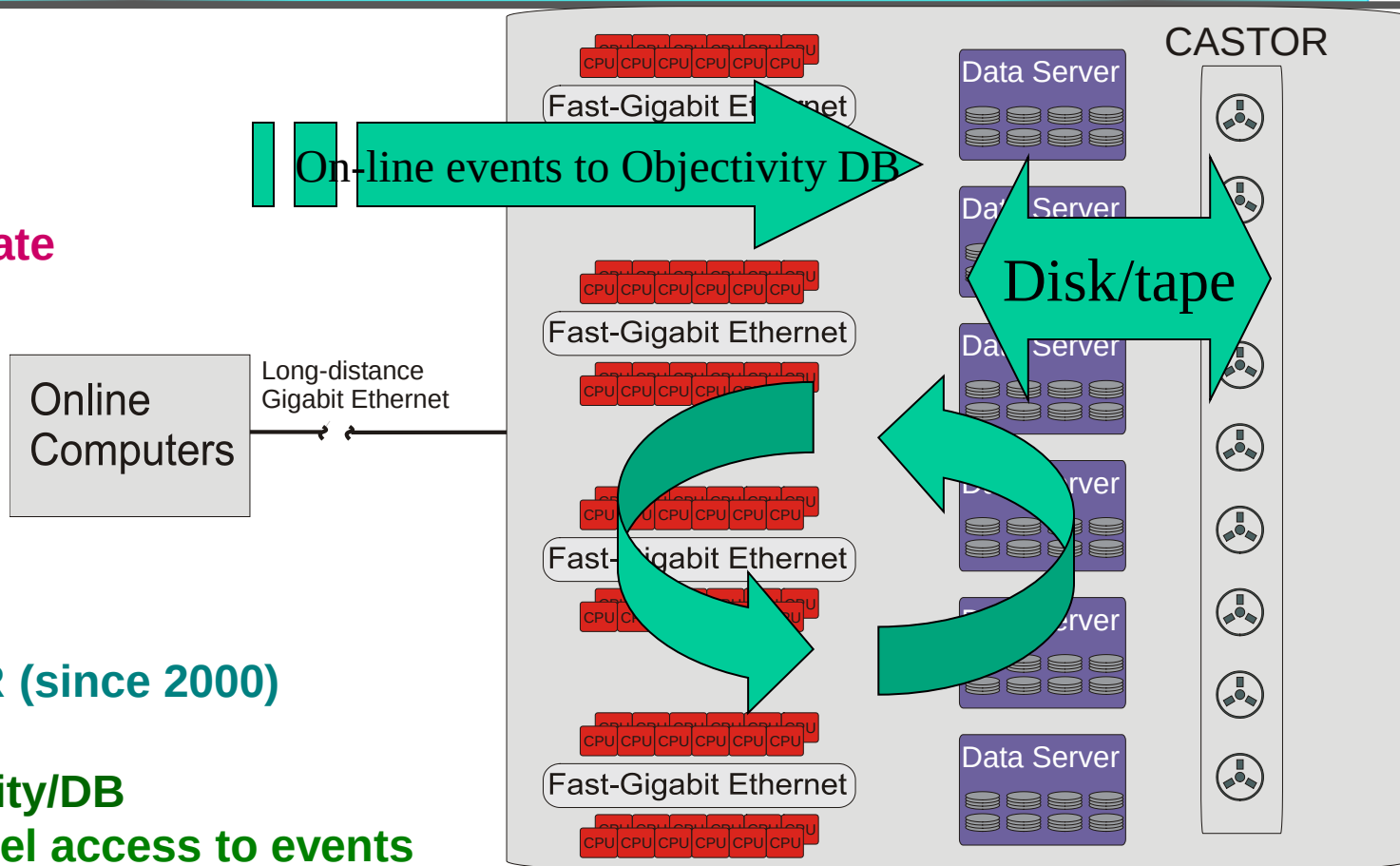


COMPASS Computing Farm

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 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
- 2011 160 GeV μ beam & NH_3 Long
- 2012 hadron beam / μ beam

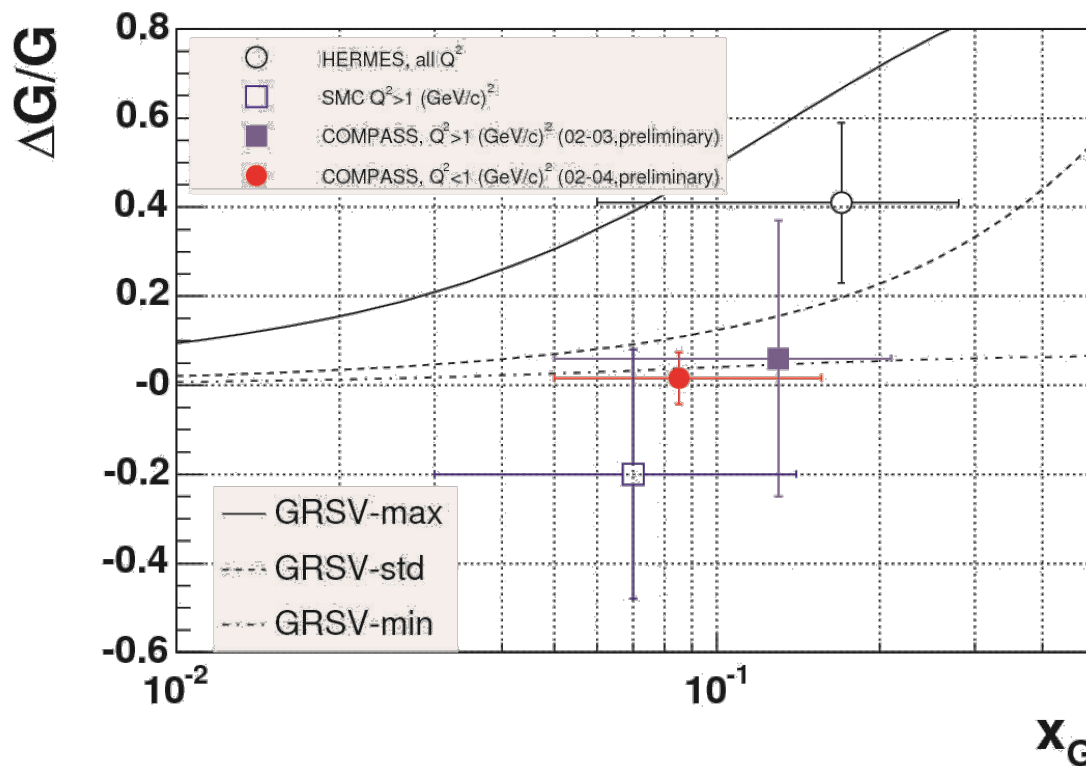
*Beam for COMPASS in 2014,
2015, 2016
Detailed calendar being
defined
(2013: CERN shut-down)*



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**



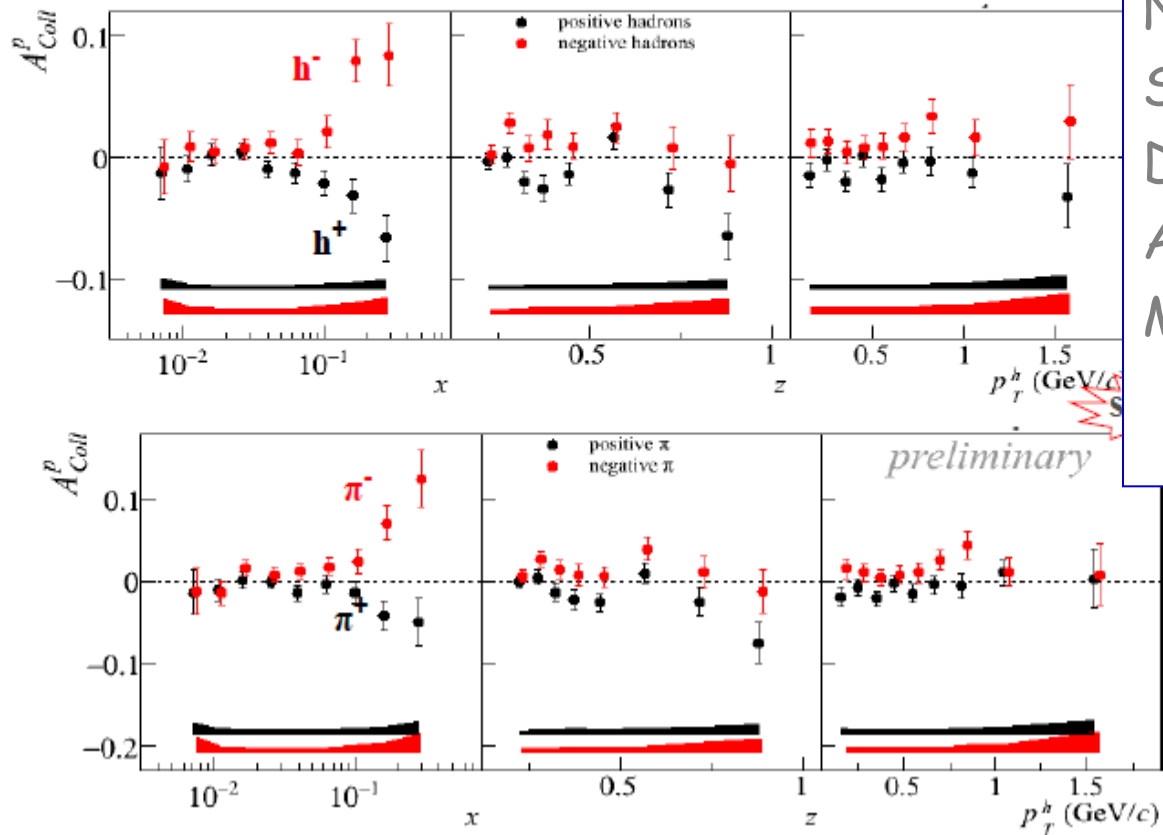
Systematic exploration of the N transverse spin structure

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 1st December 2010**