Hadron Production in COMPASS

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for the COMPASS collaboration

September 4th 2003

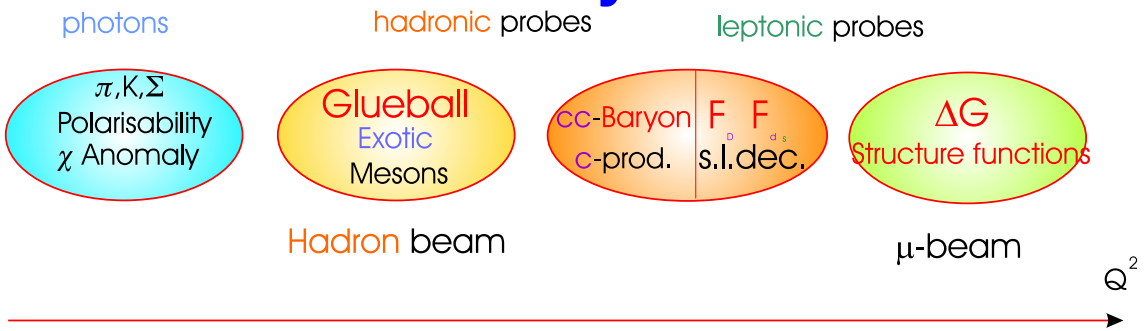
Hadron 2003, Aschaffenburg

- Introduction
- The Physics
- The Apparatus
- First Results from 2002
- Summary and Outlook

COMPASS

COmmon Muon and Proton Apparatus for Structure and Spectroscopy

The Physics



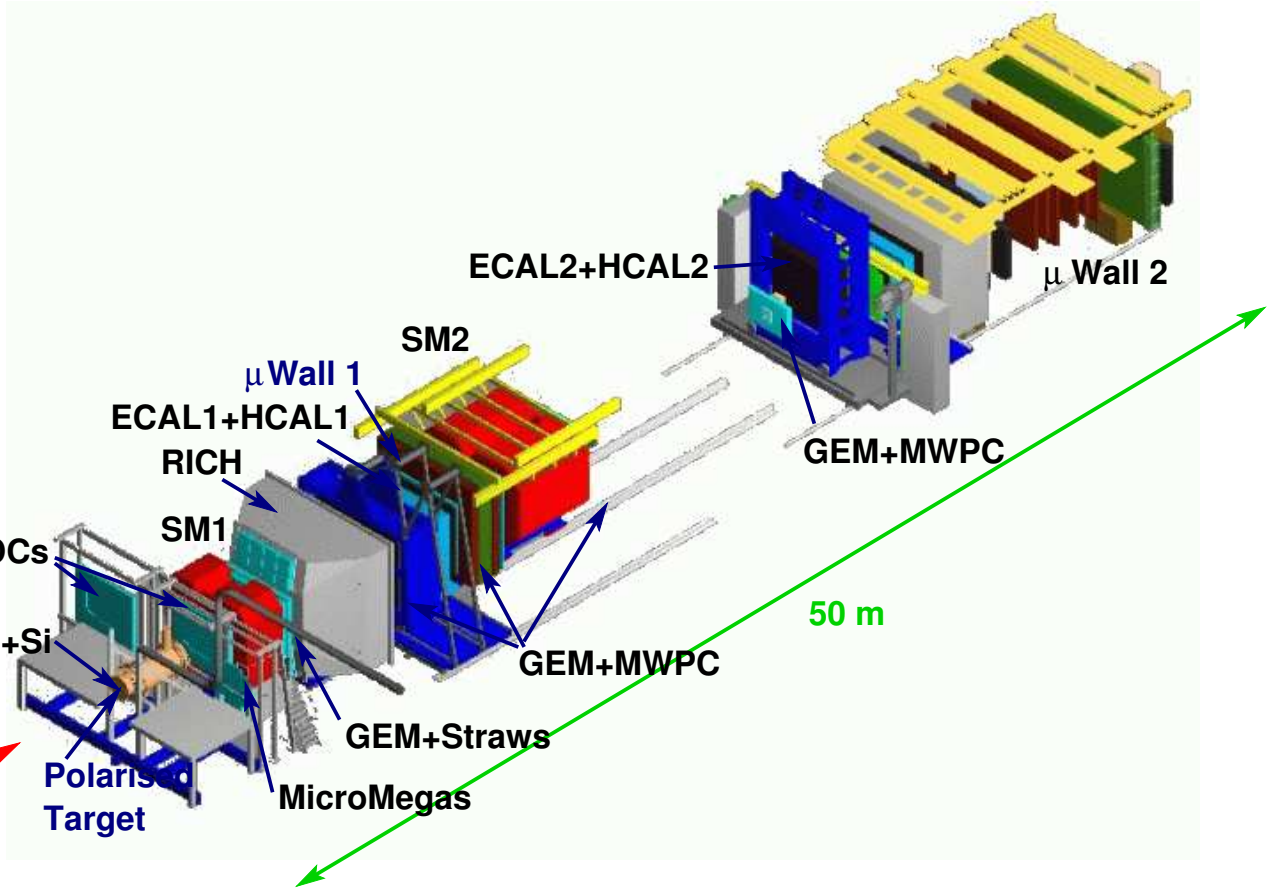
The Collaboration

Bielefeld, Bochum, Bonn (ISKP), Bonn (PI), Burdwan and Calcutta,
CERN, JINR Dubna, Erlangen, Freiburg, Heidelberg,
Helsinki, Mainz, Moscow (INR), Moscow (LPI), Moscow (State University),
München (LMU), München (Technische Universität), Nagoya, Protvino, Saclay,
Tel Aviv, Torino (University and INFN), Trieste (University, INFN and ICTP),
Warsaw (SINS), Warsaw (TU)

220 Physicists from 28 Institutes

COMPASS

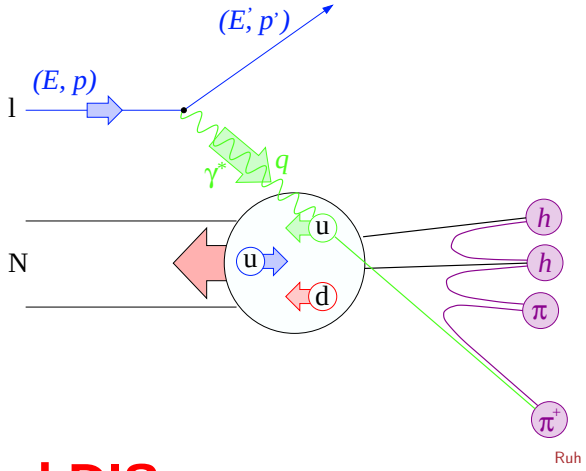
The Experiment



Fixed target experiment at the SPS at CERN

Two spectrometer stages, each equipped with tracking and PID

Polarized DIS



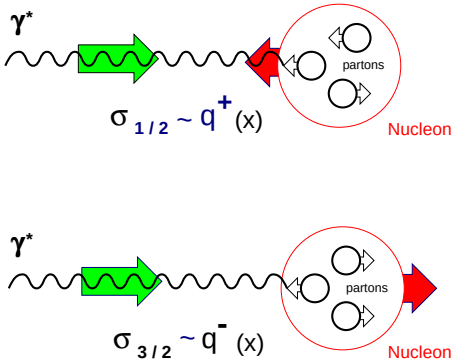
Polarized DIS:

$\vec{\gamma}$ selects quarks with opposite spin

Asymmetries:

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

$$= \frac{g_1 - \gamma^2 g_2}{F_1} \approx \frac{g_1}{F_1}$$



QPM: $g_1(x) = \frac{1}{2}\sum_f e_f^2 \Delta q_f(x)$, $g_2(x)$ small

Proton spin:

$$< s_z >= \frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + L_q + \Delta G + L_G$$

Status of Spin Structure:

Experiments EMC, SMC, SLAC, HERMES: $\Delta\Sigma = \Delta u + \Delta d + \Delta s \approx 0.3$

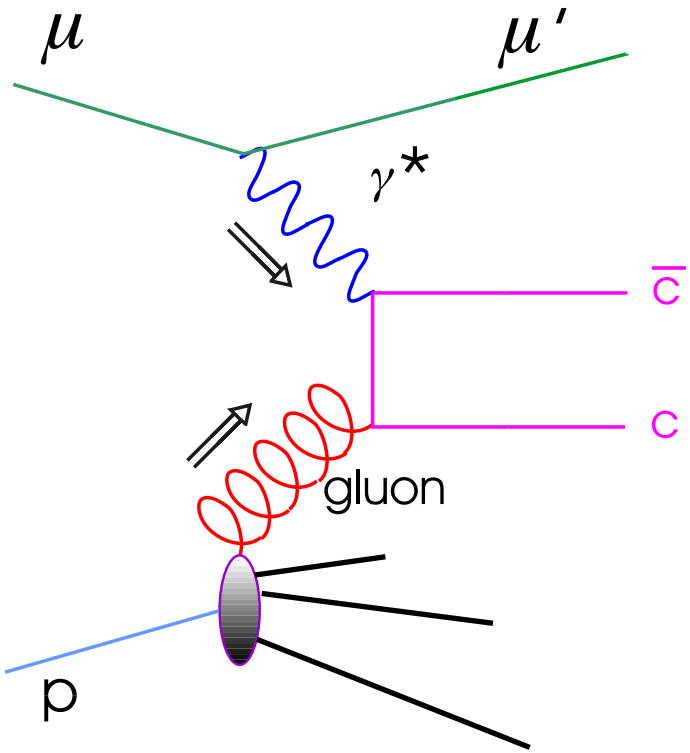
Where is the remaining part?

- Polarisation of gluons
- Orbital angular momentum
- **Not:** Δs small & negative

COMPASS μ-programme:

- Measurement of $\Delta G/G$
- Transverse spin distribution
- Flavour decomposition of Δq
- Longitudinal Λ polarisation

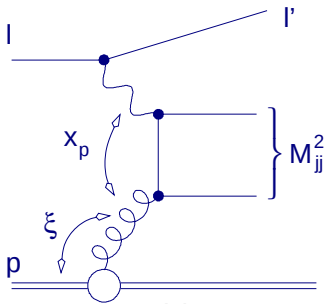
Measurement of $\Delta G/G$

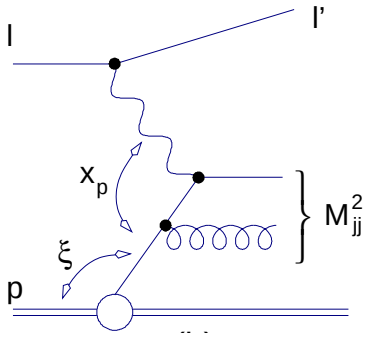


Photon gluon fusion:
accesses $\Delta G/G$

Charm production
- In leading order only by PGF
- Reconstruction of $D^0 \rightarrow K^-\pi^+$, Problem: no precise vertex
- Tagging via $D^{+*} \rightarrow D^0\pi^+$

Production of high-p_T hadron jets
- Higher yield → not statistics limited
- Background processes → large systematics
- Kinematical limits to the x_B-range





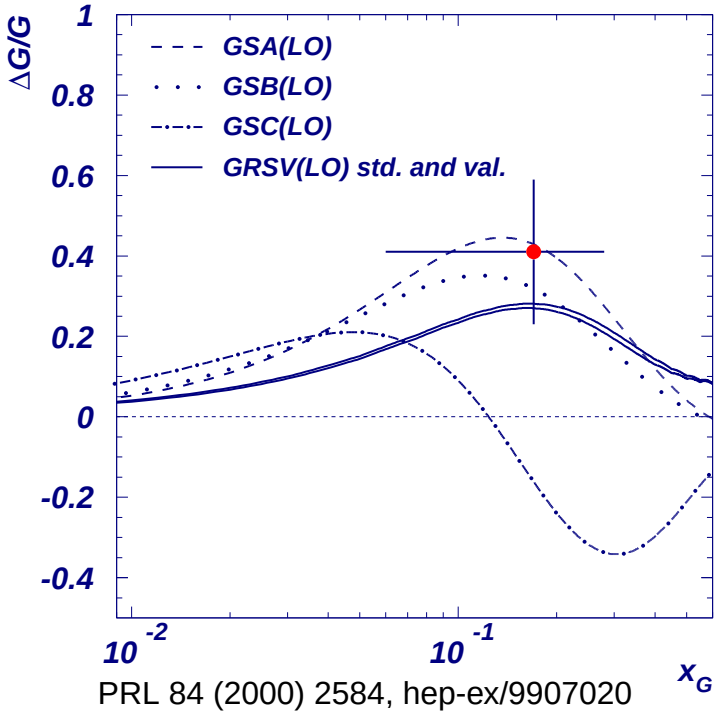
Competition for $\Delta G/G$

First hint from HERMES:

$$\Delta g/g = 0.41 \pm 0.18\ (\text{stat.}) \pm 0.03\ (\text{syst. expt.})$$

$$\langle x_g \rangle = 0.17; \quad \langle p_T^2 \rangle = 2.1\text{GeV}^2$$

$$\int_{0.006}^{0.028} \frac{\Delta g}{g} g(x)dx \approx 0.6$$



PRL 84 (2000) 2584, hep-ex/9907020

Expected accuracy in COMPASS:

- $\delta(\Delta g/g) \sim 0.14 - 0.10$ from charm
- $\delta(\Delta g/g) \sim 0.05$ from high p_T hadrons

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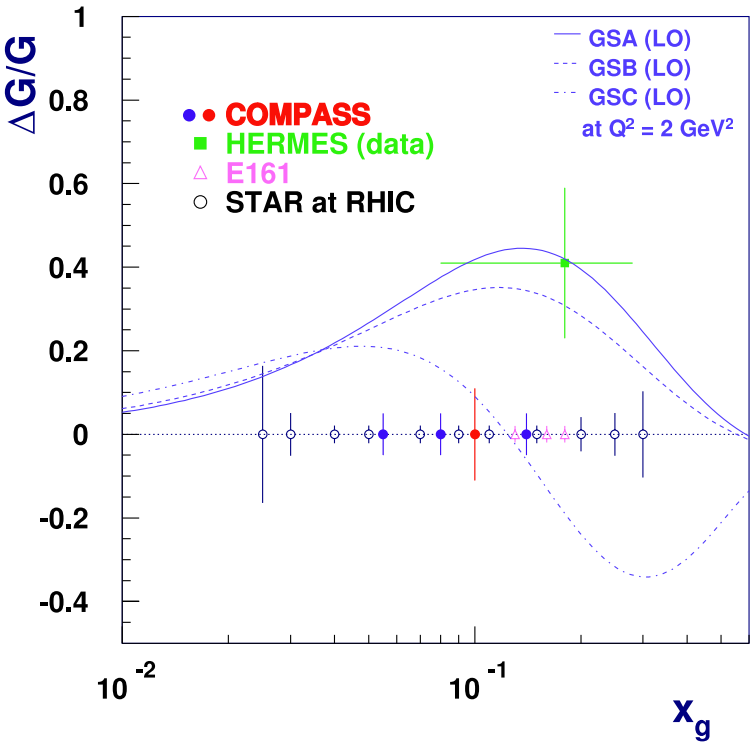

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Transversity

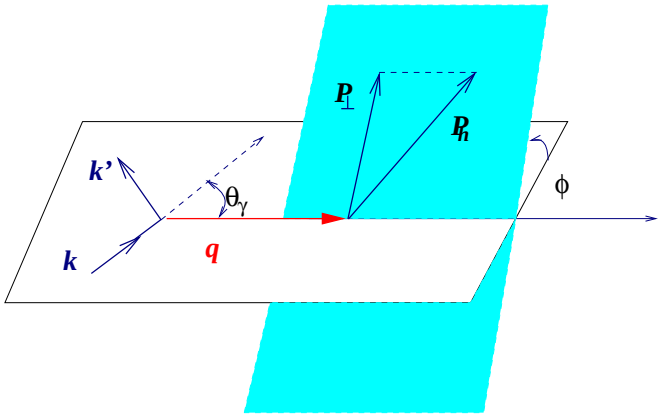
Structure Functions in DIS: f_1, g_1, h_1

$\rightarrow$ h_1 describes transverse polarisation
- Polarisation of product (e.g. Λ)
- Single pion azimuth (*Collins effect*)
- Two pion distributions (interference)

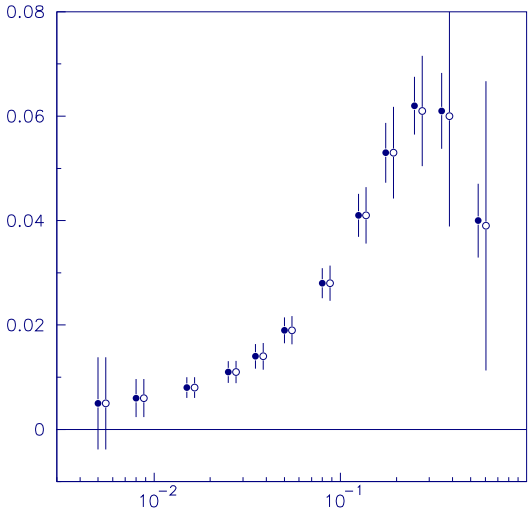
$\rightarrow$ measure convolution with some fragmentation function

Measurements of Transversity:

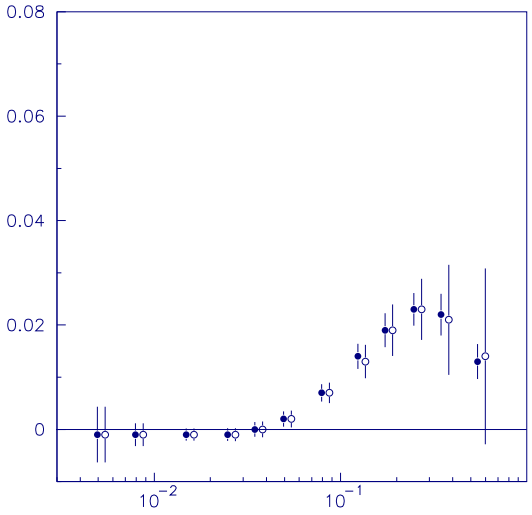
- **HERMES:** asymmetry from transverse component in γ^* frame
- **SMC:** short run with transverse polarisation
- **COMPASS:** 20% of data taking with transverse spin



DIS scattering planes



Proton h_1 sensitivity



Deuteron h_1 sensitivity

Primakoff Scattering

Primakoff Scattering: Compton-

Scattering in inverse kinematics

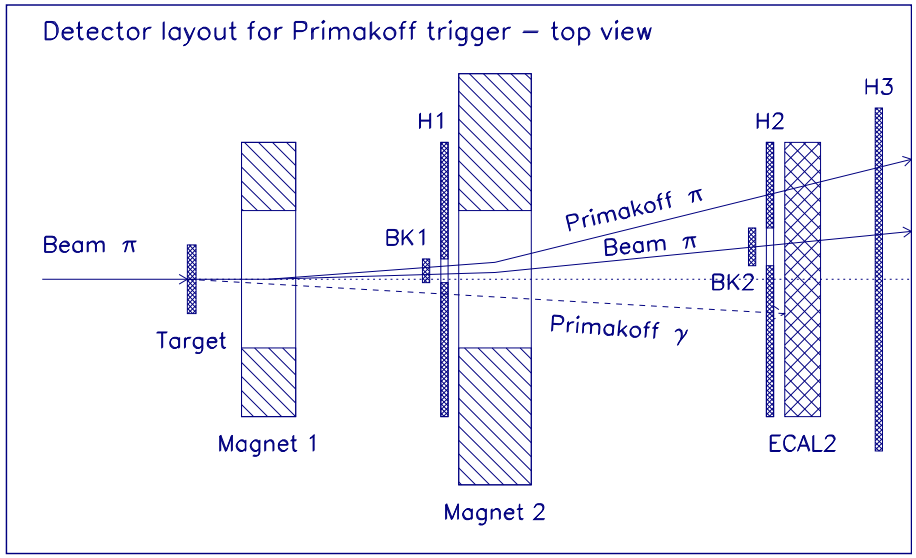
- Scatter particle in Coulomb field of heavy nuclei

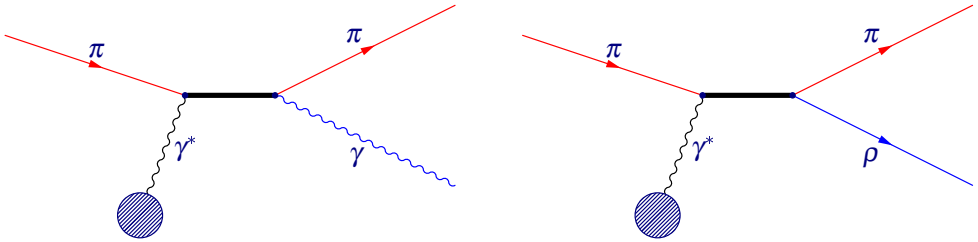
→ γ scattering on unstable particles

→ Measure polarisabilities of $\pi^{\pm}$ and $K^{\pm}$ (Classical: $\vec{d} = \alpha\vec{E}$ $\vec{\mu} = \beta\vec{B}$)

- Virtual γ becomes real

→ Instead of γ produce vector meson





Kinematics of Primakoff scattering:

- Very low t compared to diffractive BG

→ Need good t-resolution, good ECAL

→ Minimum energy in ECAL, cut on t

Contributions of COMPASS:

- protons, pions and Kaons as beams

→ Kaon polarisability for 1st time

- 5% error on electric polarisability of π
- 50 times higher statistics for $\pi\gamma \to \pi\pi$
- systematic studies in one experiment

Exotic QCD-States

QCD-states not fitting to $q\bar{q}$ or qqq:

Glueball: no valence quarks

Hybrid: $(q\bar{q})_8\, g$ (valence gluon)

4-Quark-State: $(q\bar{q})_8(q\bar{q})_8$ color octets
or $(q\bar{q})(q\bar{q})$ molecule

Pentaquark: $(qqq)(q\bar{q})$

Production mechanisms:

- Radiative J/ψ decays: γ + hadrons
- $p\bar{p}$-annihilation
- Hadronic production (diffractive, PP)

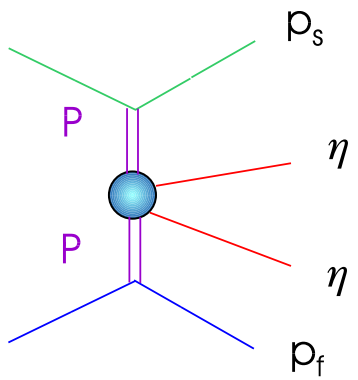
Experimental status:

- Glueball: $f_0(1500)$ (LEAR, SPS)

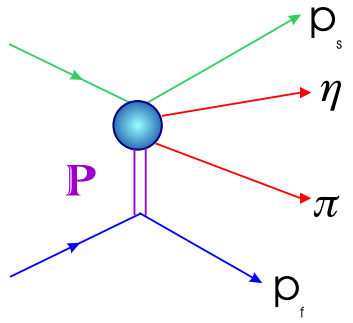
$\rightarrow$ mixture of $\sim$3 states

- 4-Quark $\pi_1(1400)$ (LEAR, AGS)
- Hybrid $\pi_1(1600)$ (AGS)
- Pentaquark $\Theta(1540)$ (TJNAF, ELSA, ITEP, SPring8)

Study of Exotic States in COMPASS:



Central Production

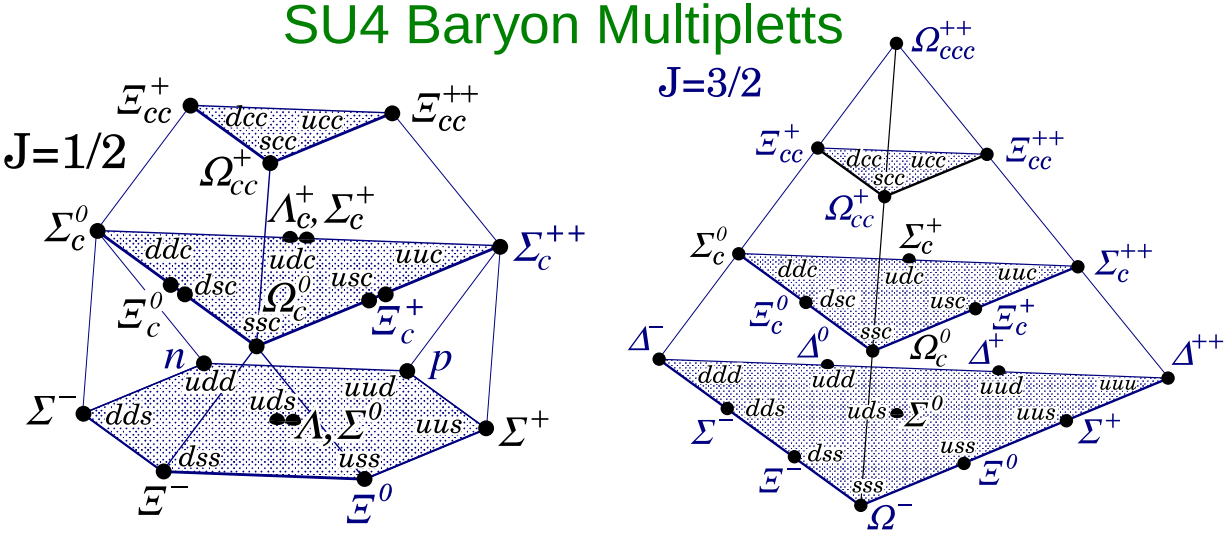


Diffractive Dissociation

- Very good acceptance due to
  - Double spectrometer
  - Target detector
- High statistics due to rate & acceptance
- Higher mass states accessible
- Varying beam particles
  $\rightarrow$ probe $s\bar{s}$ content with K-beam

Doubly Charmed Baryons

SU4 Baryon Multipletts



Masses and Lifetimes

	Quarks	Mass range (GeV/c^2)	Lifetime (ps)
Ξ_{cc}^{++}	(ucc)	3.48–3.74	0.46 ± 0.05
Ξ_{cc}^{+}	(dcc)	3.48–3.74	0.16 ± 0.05
Ξ_{cc}^{*}	(u/dcc)	3.61–3.86	
Ω_{cc}	(scc)	3.59–3.89	0.27 ± 0.06

Hadronic decay channels

- $\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$ (3%), $D^+\Lambda$ (2.5%)
- $\Xi_{cc}^{++} \to D^0 \Lambda \pi^+ \pi^+$ (5%), $\Lambda_c^+ K^- \pi^+ \pi^+$ (5%)
- $\Omega_{cc}^{+} \to \Omega_c^0 \pi^+$ (5%), $\Omega_c^0 \pi^+ \pi^+ \pi^-$ (4%)

First observation: Selex

$\Xi_{cc}^{+} \to \Lambda_c^+ K^- \pi^+$, 16 events

- m=3520 MeV, $\sigma = 3$ MeV/C^2
- Short lifetime $\tau < 33$ fs (90% CL)
- Strongly enhanced forward production

COMPASS plans:

- 280 GeV protons (10^8 / spill)
- New vertex detector
- Trigger: E_T, multiplicities, μ
- Online filter

Expected Yields:

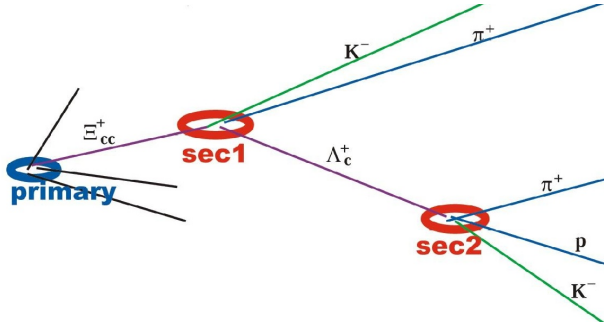
- Based on Selex: 10-17k

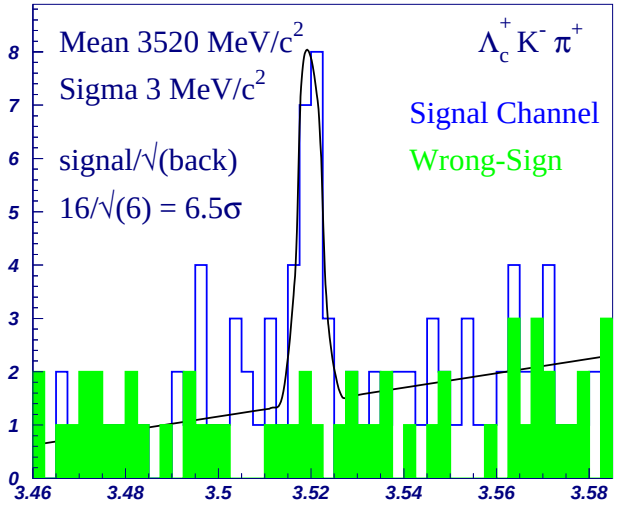
→ DCB spectroscopy?

- Conservative: 100-170

Doubly Charmed Baryons

Ξ_{cc}^{+} decay chain





PRL 89 (2002) 112002, hep-ex/0208014

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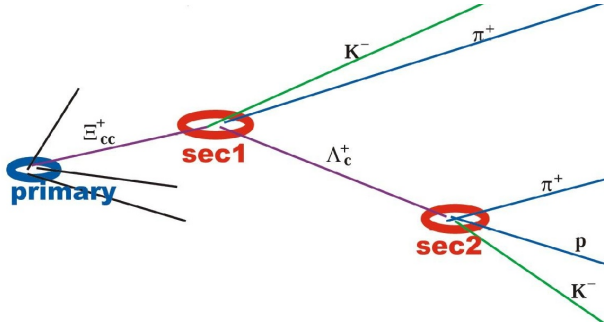

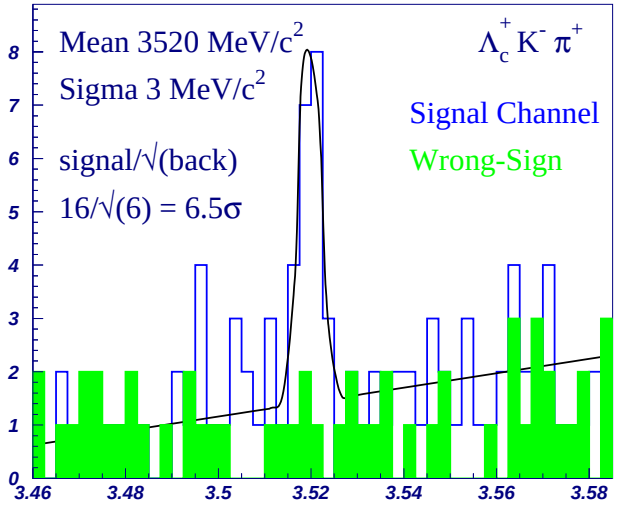

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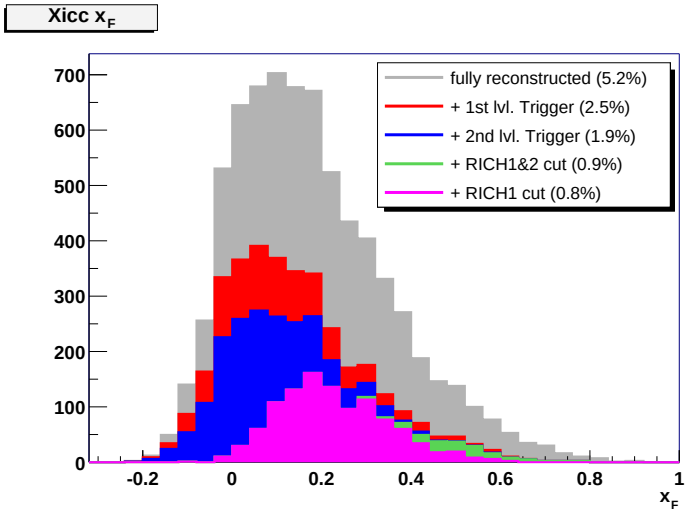

Acceptance and efficiencies of reconstruction, triggers and RICH vs. x_F from COMPASS MC

Hadronic decay channels

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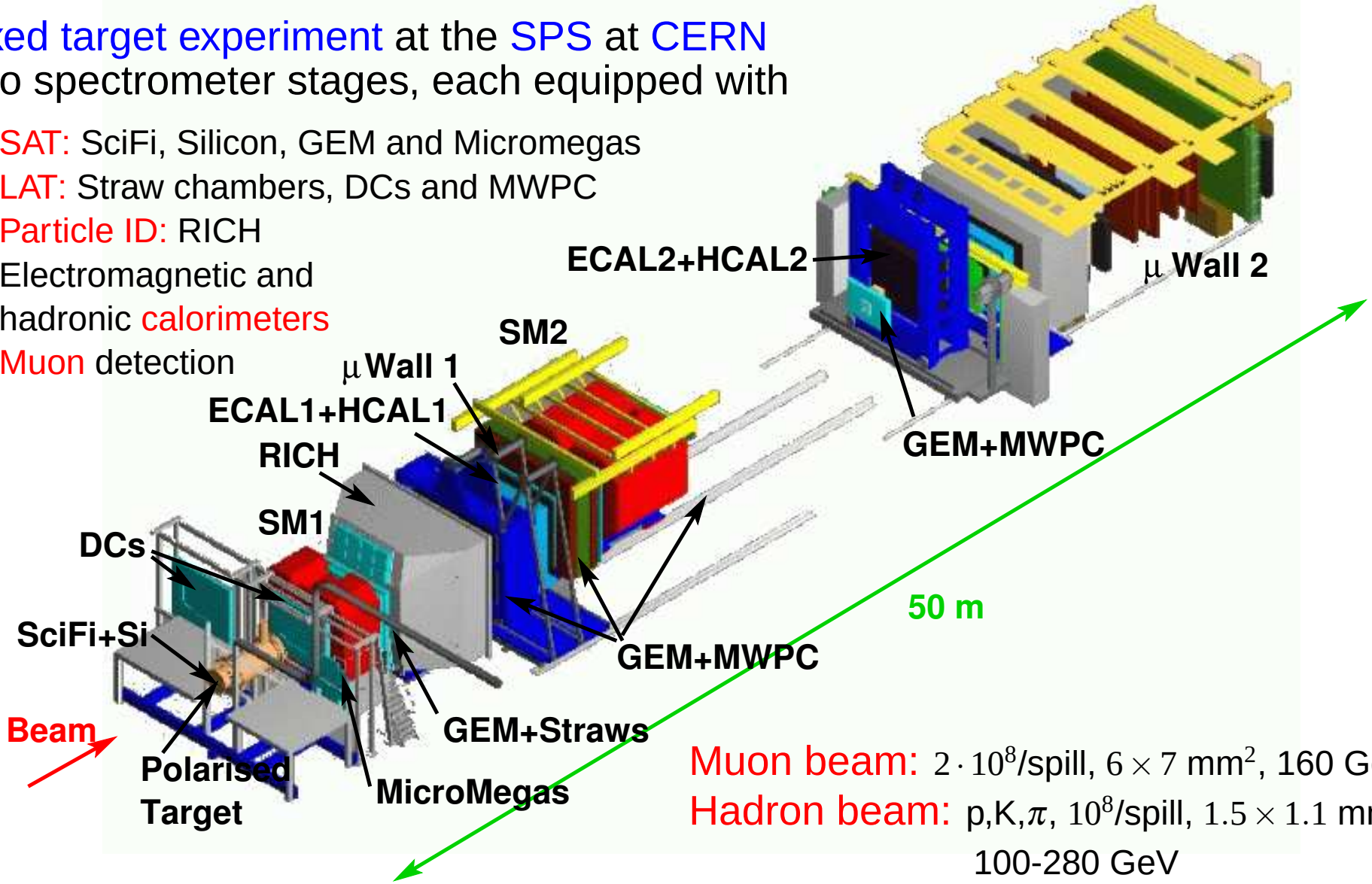
The COMPASS Spectrometer

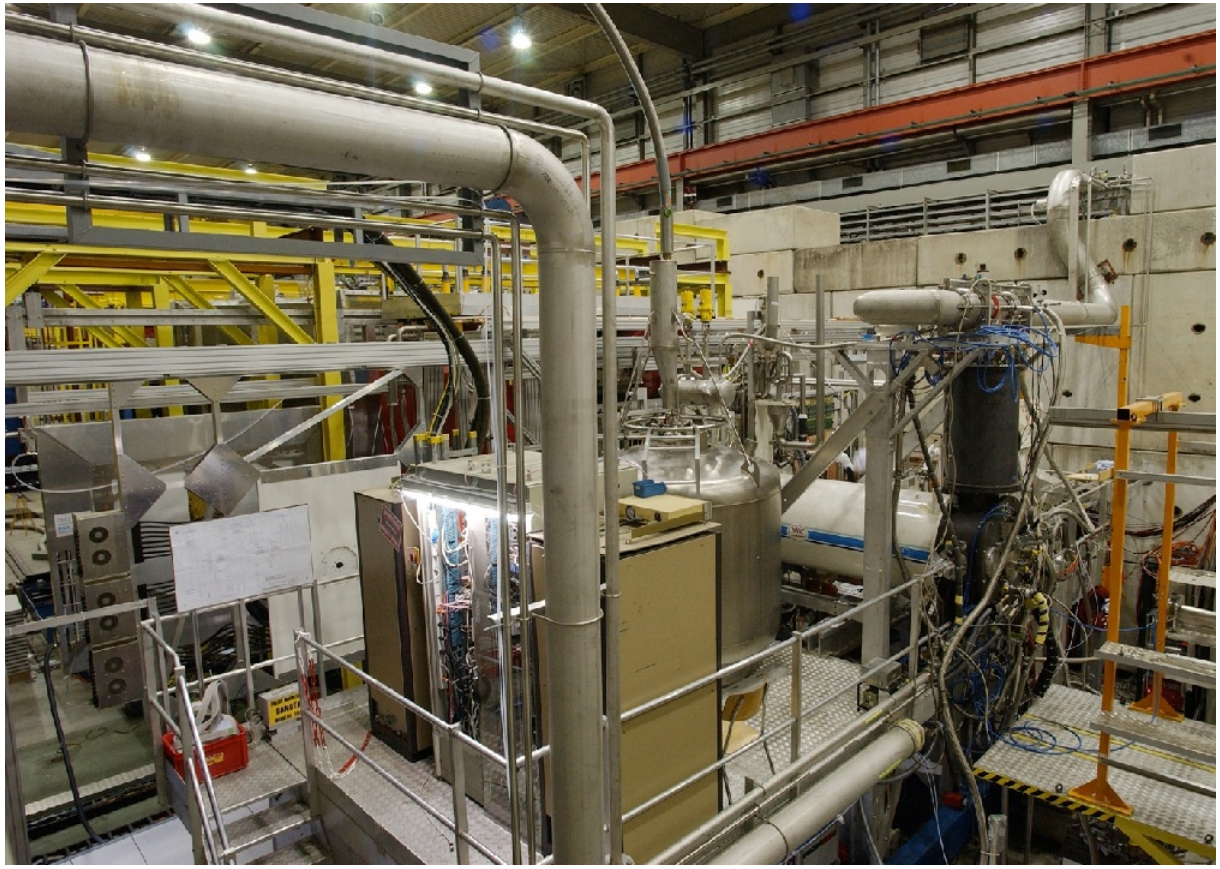
Fixed target experiment at the SPS at CERN
Two spectrometer stages, each equipped with

- SAT: SciFi, Silicon, GEM and Micromegas
  LAT: Straw chambers, DCs and MWPC
- Particle ID: RICH
- Electromagnetic and hadronic calorimeters
- Muon detection



Muon beam: $2 \cdot 10^8$/spill, 6×7 mm^2, 160 GeV
Hadron beam: p,K,π, 10^8/spill, 1.5×1.1 mm^2, 100-280 GeV

Polarised Target



The target infrastructure

Purpose: Study of the spin structure of p and n

$\rightarrow$ Polarised solid state target

- ^{6}LiD to study deuterons (neutrons)
- Ammonia to study protons

$\rightarrow$ low dilution factor of 50%

Method: DNP in 2.5T solenoid at 0.5K by microwaves

Freezing of polarisation at 50mK

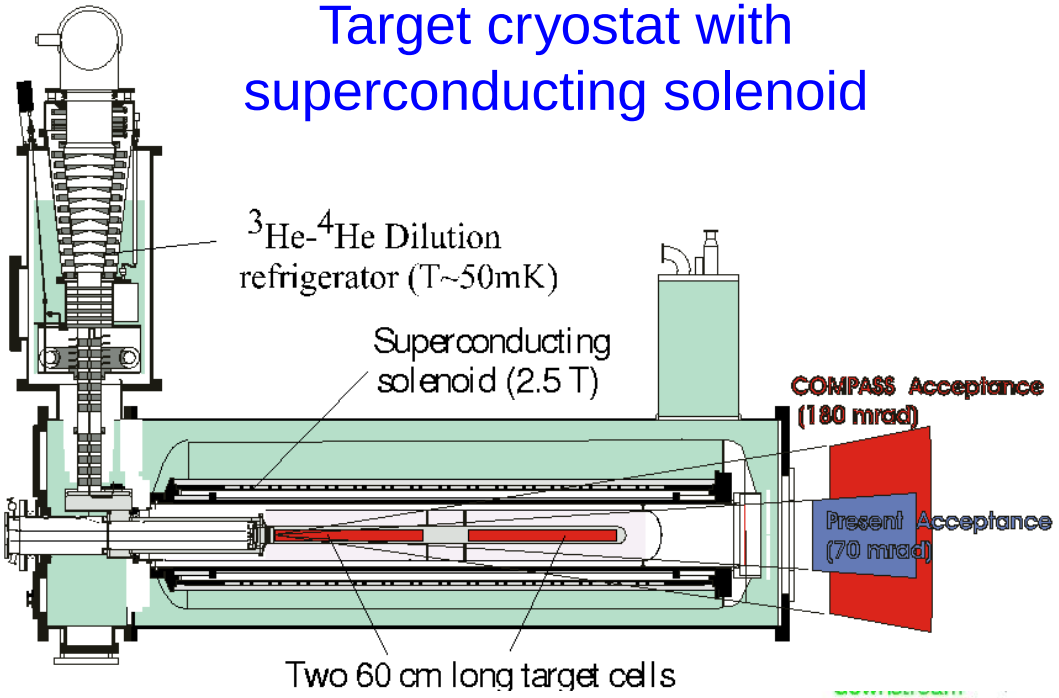
Operation: Field rotations by dipole $\sim$ every 8 hours

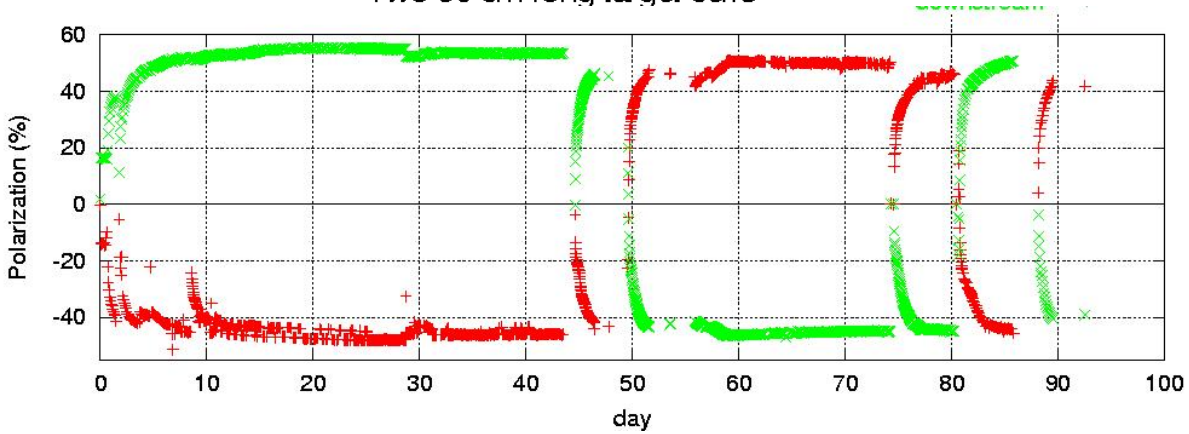
Transverse polarisation for 20% of run

Run 2002: World record polarisation +57% / - 49%

Polarised Target

Target cryostat with superconducting solenoid





Online average polarisation in 2002

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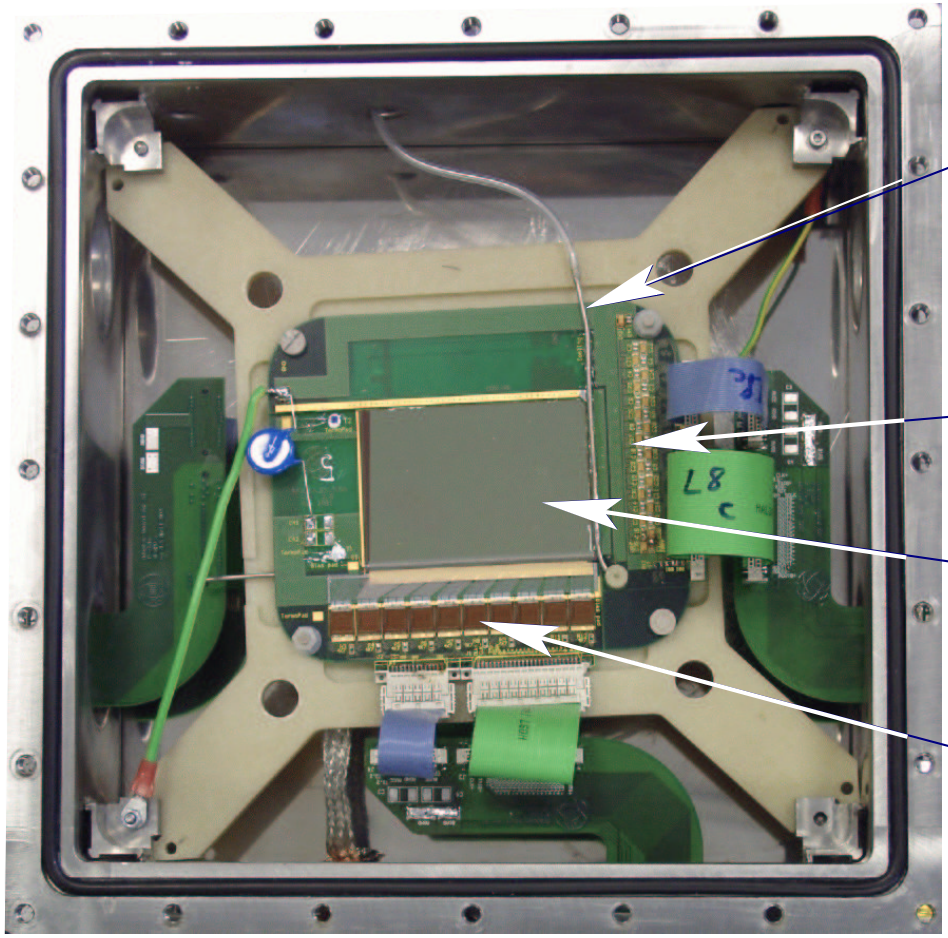
Silicon Detectors

- HERA-B silicon wafers
  - Rad. hard double sided silicon
  - Size 5x7 cm^2, 50μm pitch
  - Orth. strips on p- & n-side
  - 5° stereo angle between wafers mounted back to back
- Readout CMS APV25 ASIC
- Cryogenic cooling to limit radiation damages
- 2+3 stations for COMPASS (beam/scattering)
- Resolution $<$16 μm
- Time resolution
  $\sigma_t = (2.5 \pm 1)$ ns
  from signal shape sampling
- Efficiency $>$ 99%
- Cluster size $\sim$ 1.3



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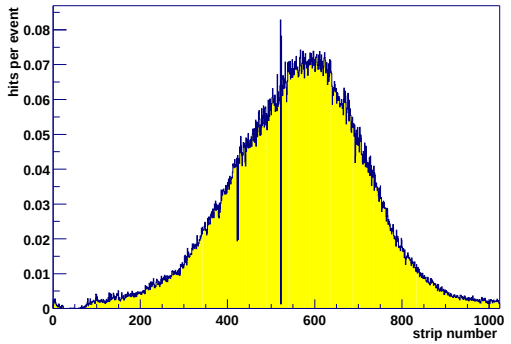

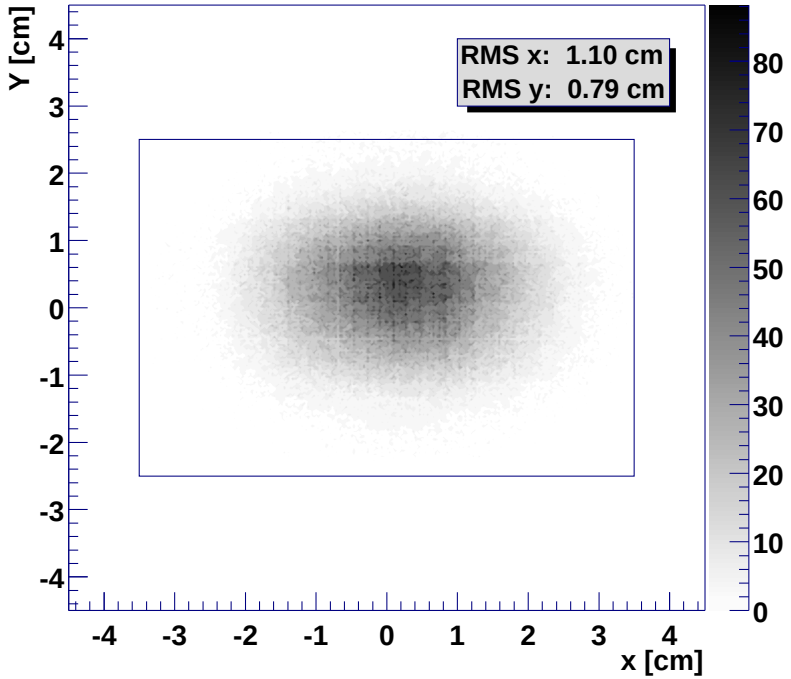

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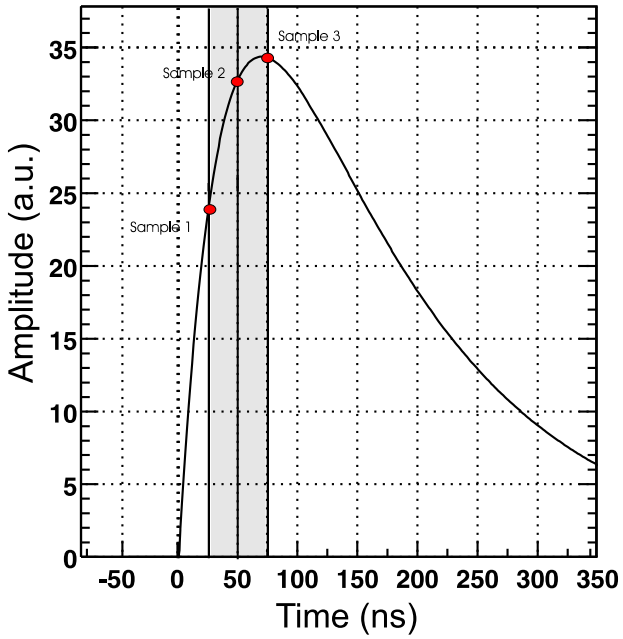
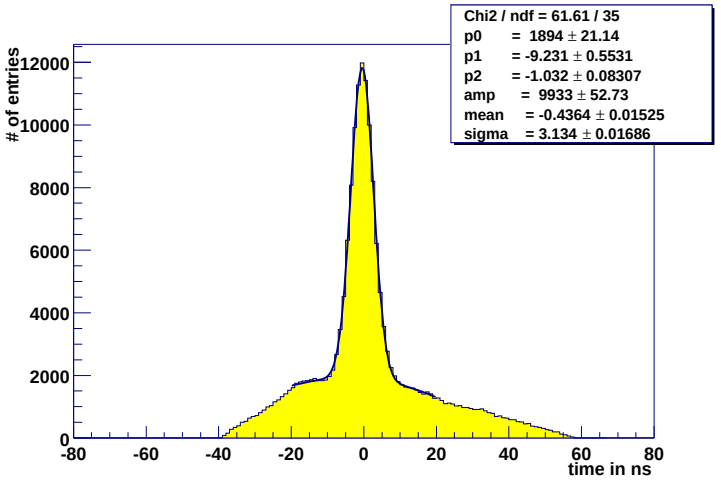
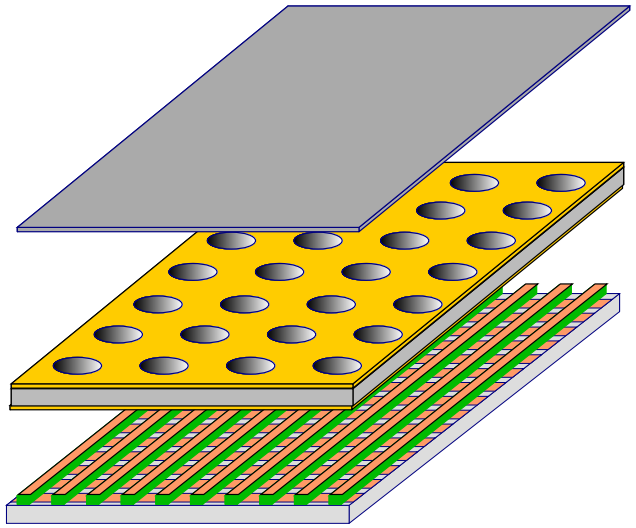
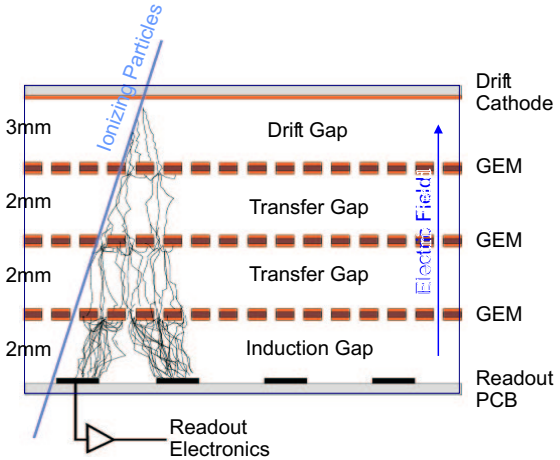




GEM Detectors





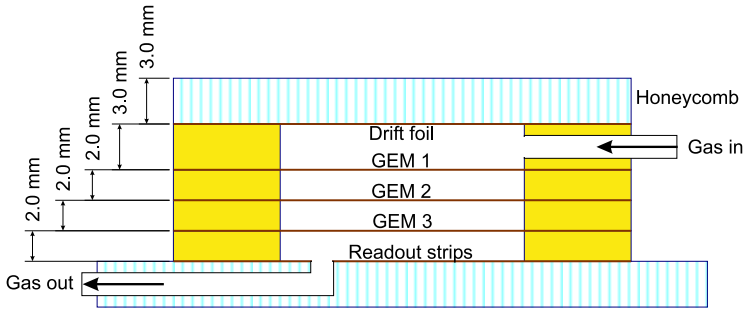
- GEM foil as amplification stage between drift cathode and readout anode

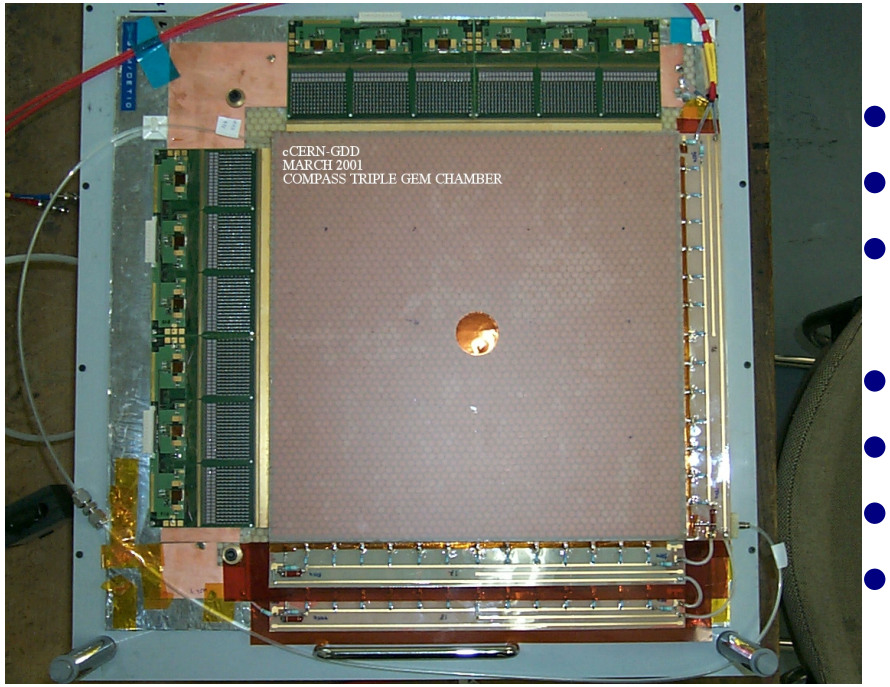
$\Rightarrow$ Readout electrodes on ground potential

- Possibility to cascade several GEM foils $\Rightarrow$ higher gain, safe operation
- Discharge protection: 3 GEM foils, asymmetric gains, sectorized foils, protection circuit
- Gas: Ar-CO_2 (70-30)
- Central Sector: ϕ 5 cm can be deactivated
- Anode strips: 2D, 2×768 strips, $400\,\mu$m pitch

  $\rightarrow$ Active area $30.7 \times 30.7\,\text{cm}^2$
- Readout: Analogue pipeline ASIC (APV25)
- Efficiencies $\sim$ 98%
- Space resolution $\sim$ 50 μm
- Time resolution $\sim$ 12 ns

GEM Detectors





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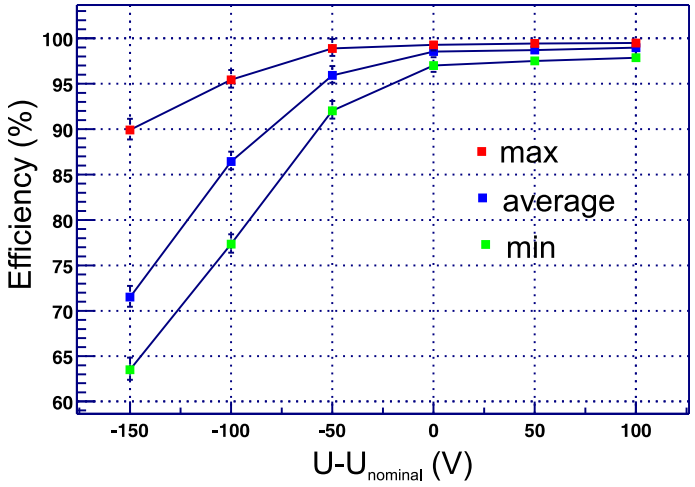

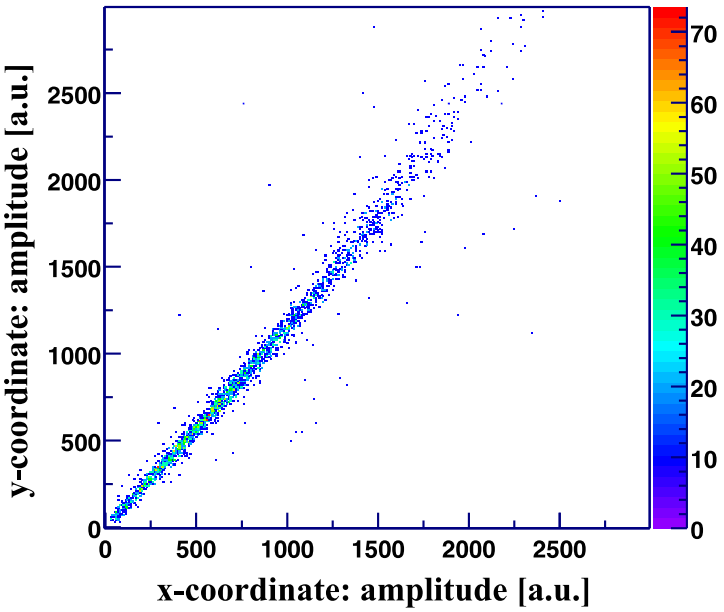

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COMPASS RICH-1

Features of the COMPASS RICH:

- Two segmented spherical mirrors
- Two photon chambers with segmented CsI photocathode with pad readout
  $\rightarrow$ 2D image, $8 \times 8\text{mm}^2$ pads
- Radiator gas C_4F_{10} for momenta 3–65 GeV

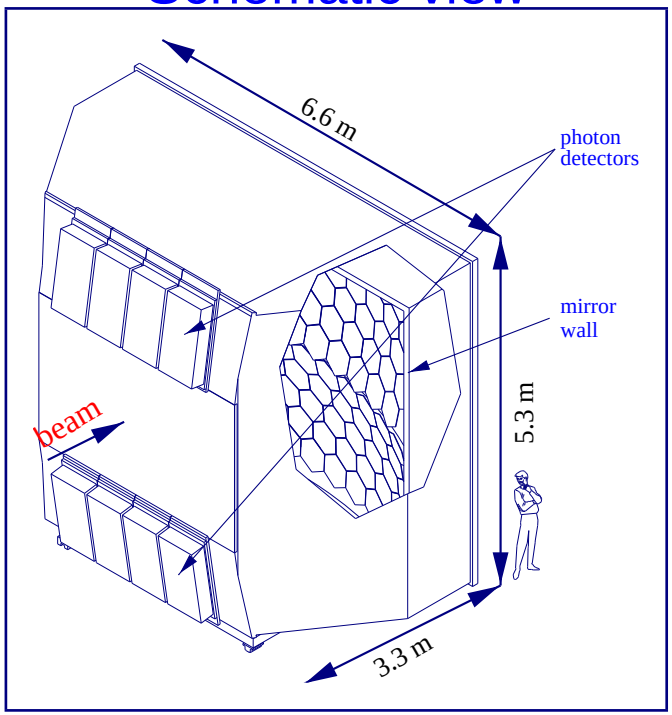
Readout:

- Segmented cathode with 69000 pads
- GASSIPLEX preamp with multiplexer
- BORA readout board with DSP and FPGA
- CATCH with optical Hotlink

Performance:

- Angular resolution $\sigma_{1photon} = 1.4$ mrad
- Photons per ring $\langle n_{ph.} \rangle = 14$

Schematic view



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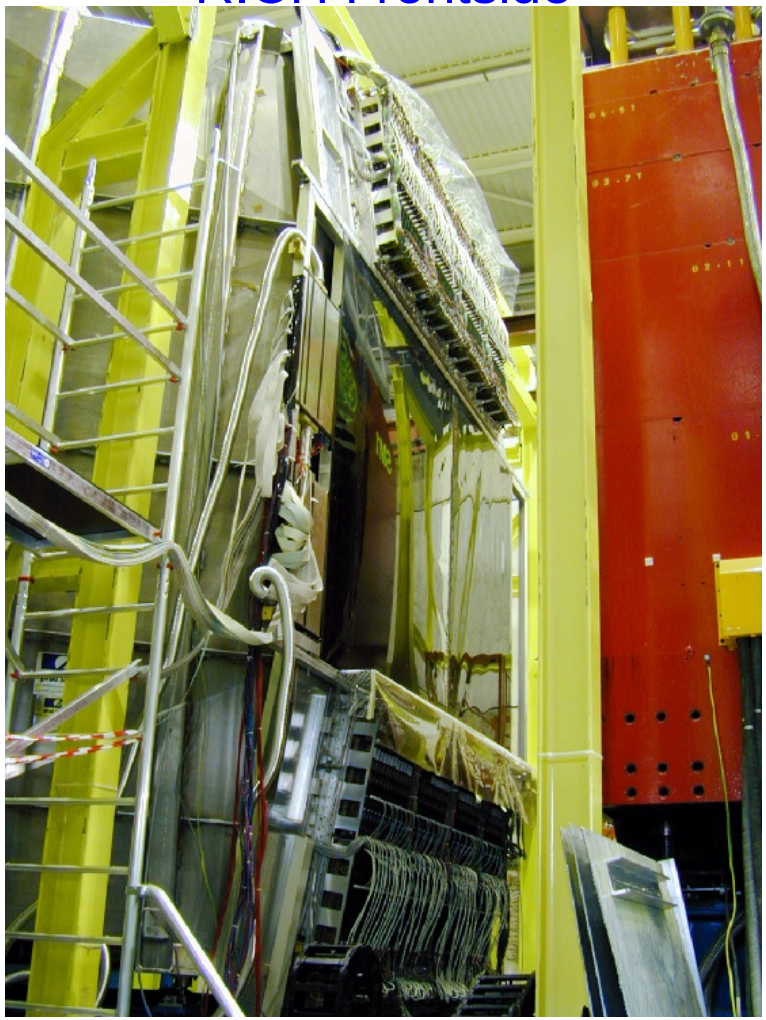
RICH Frontside



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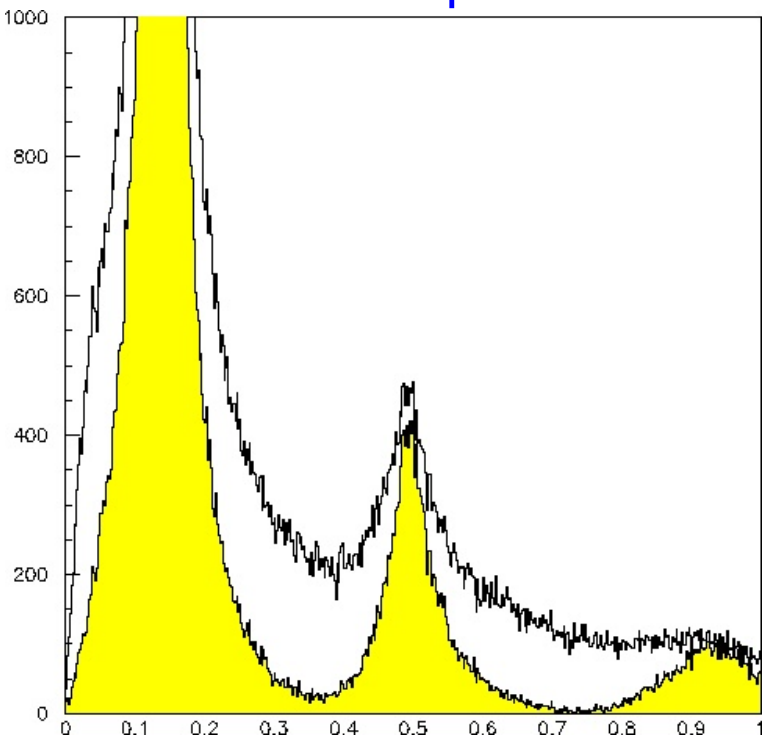
RICH mass spectrum

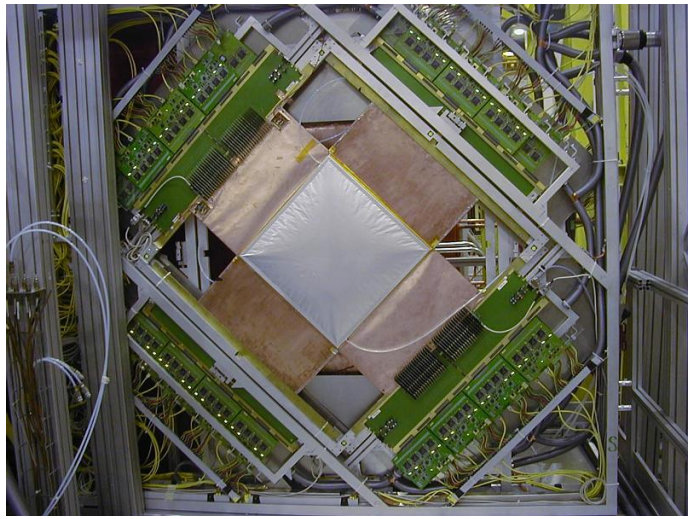


Mass spectrum raw and after likelihood cut,

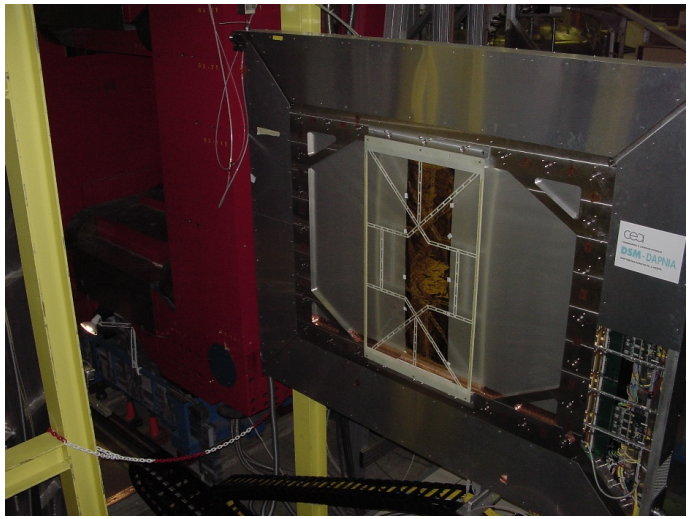
m(GeV)

Other Detectors

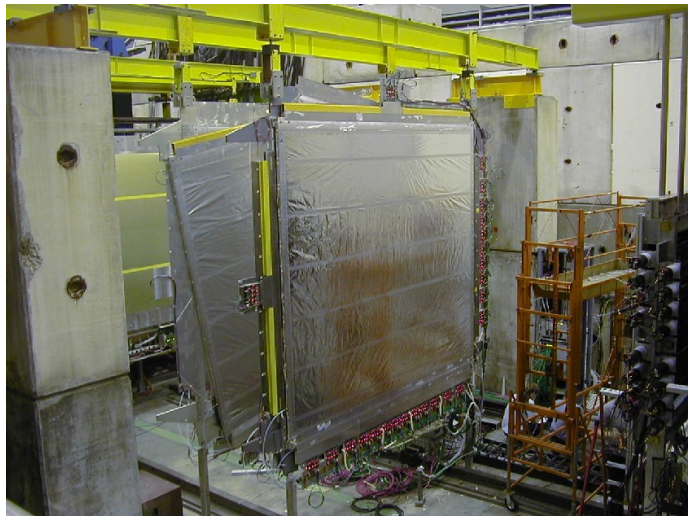
Micromegas



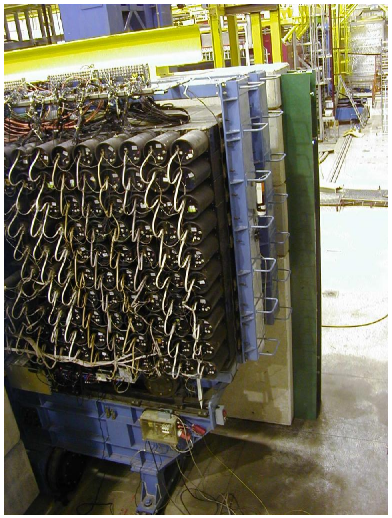
Saclay Drift Chambers



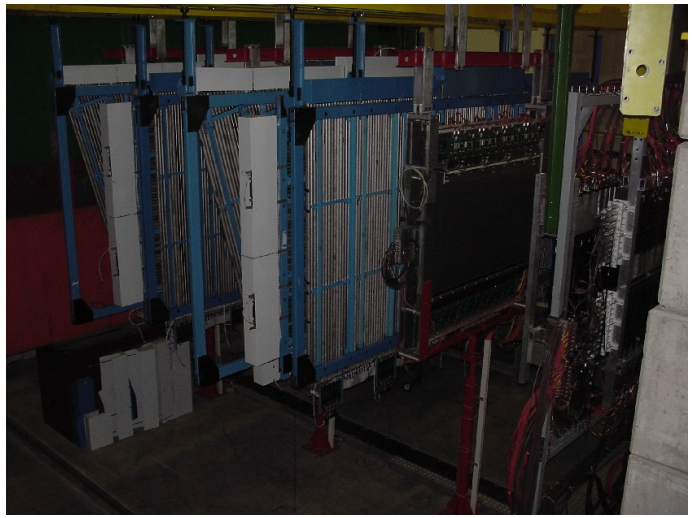
Straw Module



ECAL



HCAL

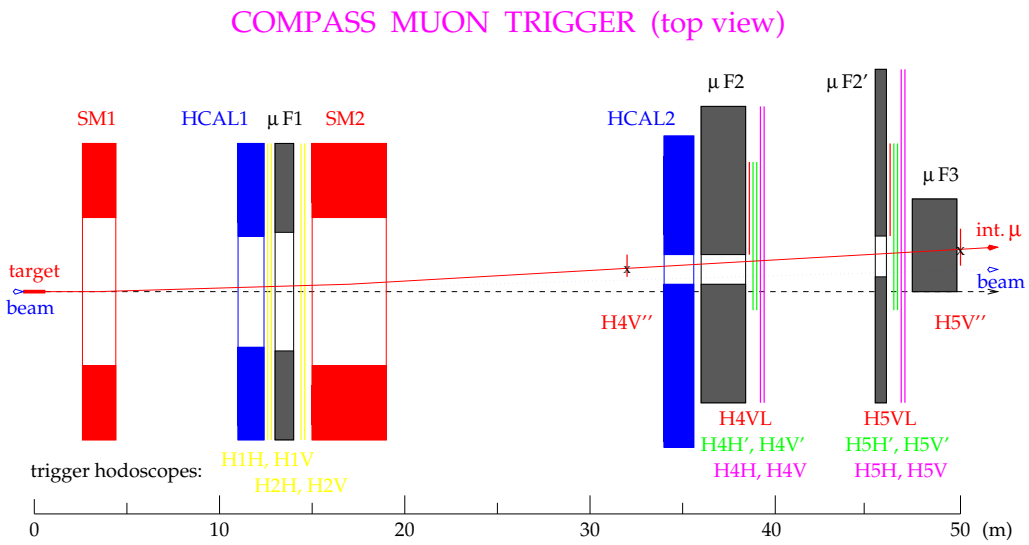


Muon Wall

Trigger

Trigger Setup:

- 4 sets of hodoscopes
- different subsystems
- Matrix correlation
- Target pointing



Δ G:

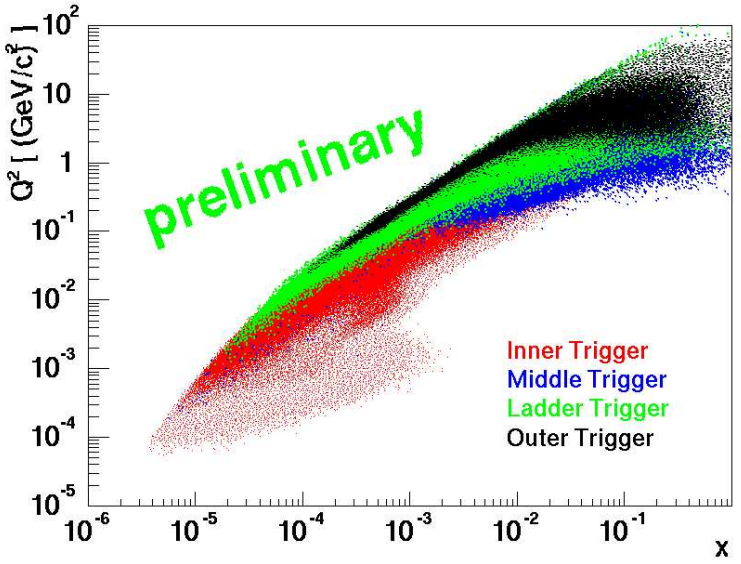
(H4V″ * H5V″) * (HCAL1 U HCAL2) (low v)

(H4VL * H5VL) * (HCAL1 U HCAL2) (high v)

Trigger Acceptance:

- Wide dynamic range
- Very low Q^2
- Small x_B

Q^2 vs. x



DAQ and Readout

Features:

- Pipelined readout architecture
- Data transfer via S-Link
- Buffering of bursts (SPS duty cycle $\sim$ 30%)
- Network eventbuilding

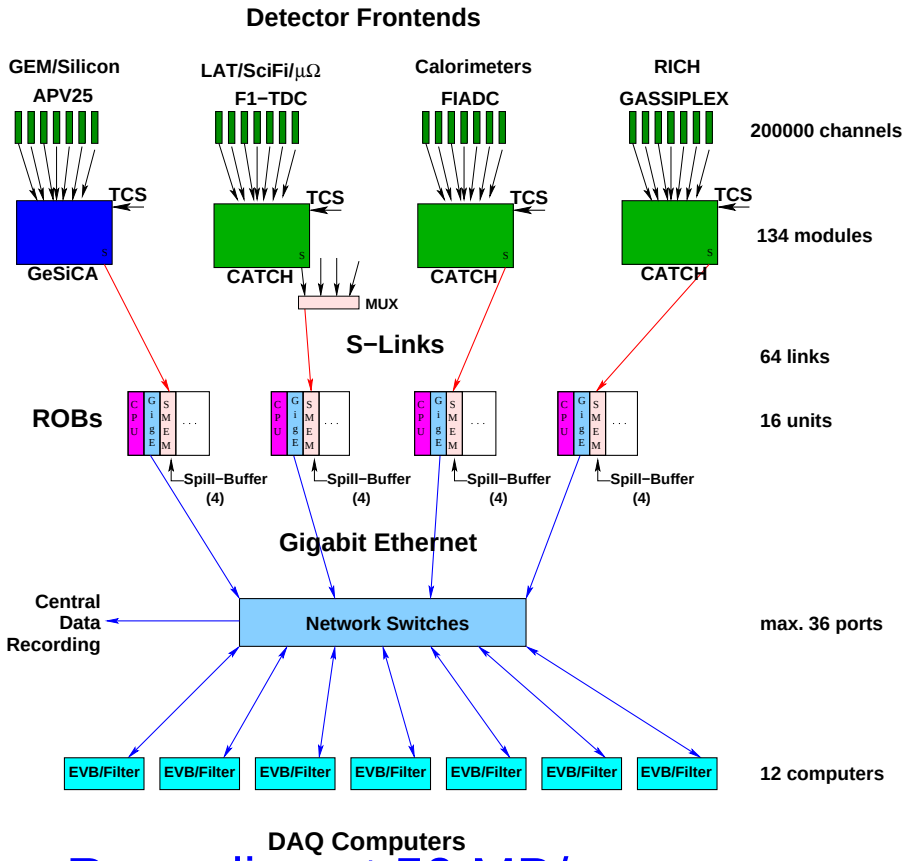
Requirements & performance:

- Total number of channels: 250000
- Trigger rates: 5-100 kHz
- Event size: $\sim$ 45 kB
- Data rates: 0.9-18 GB/SPS-spill

$\longrightarrow$ Online filter, first tests in 2003

Software:

- ALICE DATE for eventbuilding
- PCI DMA driver
- Run Logbook (TCL,PHP,MySQL)
- FE DB (MySQL)

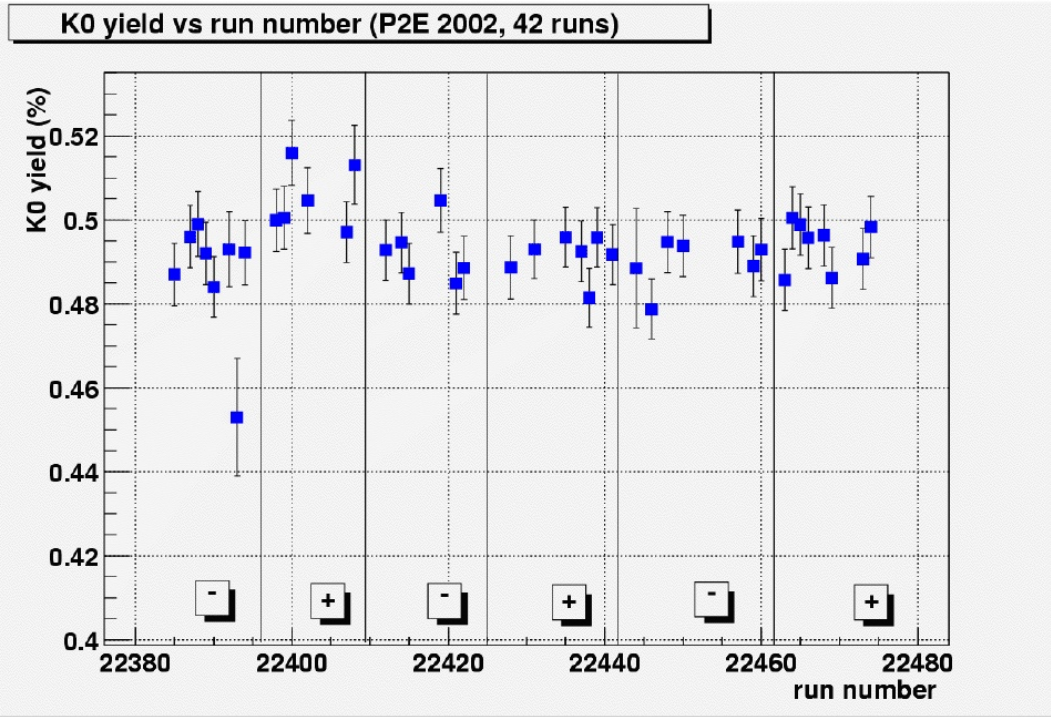


- Recording at 50 MB/s
- Accumulated Data: 260 TB, 5 G ev
- Luminosity $\sim 1.5\ \mathrm{fb}^{-1}$
- Storage: 260000 files

Data Taking

2002 Run

- 160 GeV/c muons, 2×10^8/spill, $P_{beam} \sim 80\%$
- Running with ^{6}LiD, $P_{target} \sim 50\%$
- Polarisation reversals every 8h in long. mode
- 40–45 kB/event
- 24d setup of new detectors, 57 days longitudinal, 19 days transverse
- 5 Gev, 260 TB of data



K^0 yield monitored over time

2003 Run

- More larger area trackers
- Smaller event size (35kB)
- Tests of online filter

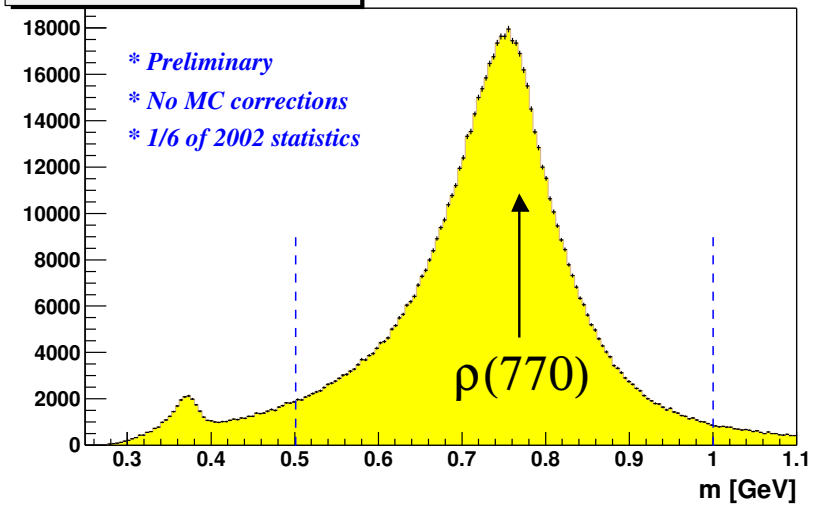
Analysis Results

All presented results are preliminary!

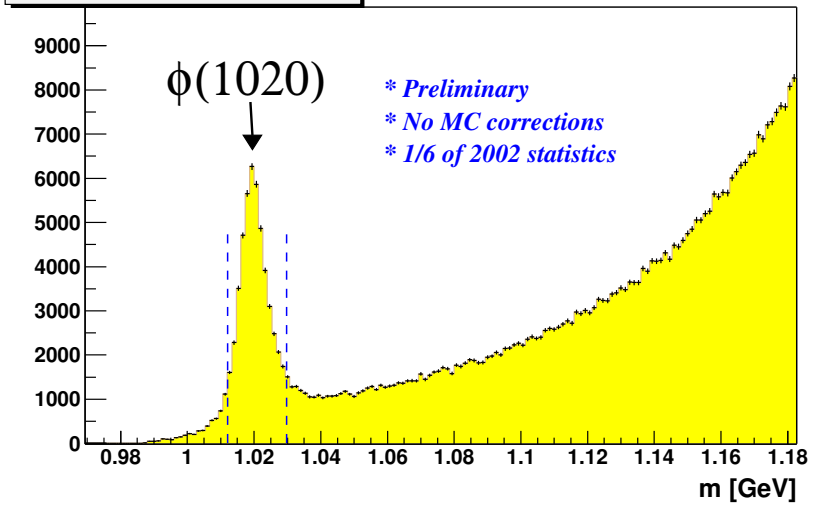
- Lambda polarisation (→ see talk by M. Sapozhnikov)
- Exclusive vector mesons
- J/Ψ production
- $\Delta G/G$ from high p_T hadrons
- D-mesons

Exclusive ρ and ϕ

$\pi^+\pi^-$ invariant mass



K^+K^- invariant mass.



Selection criteria & kinematics

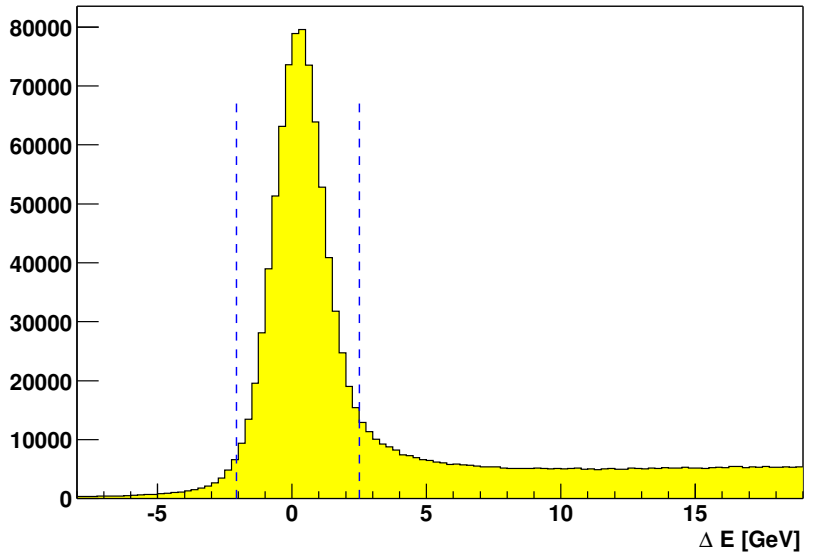
- $-2 < \Delta E < 2.5$ GeV

$$\Delta E = \frac{M_x^2 - M_{targ}^2}{2M_{targ}}$$

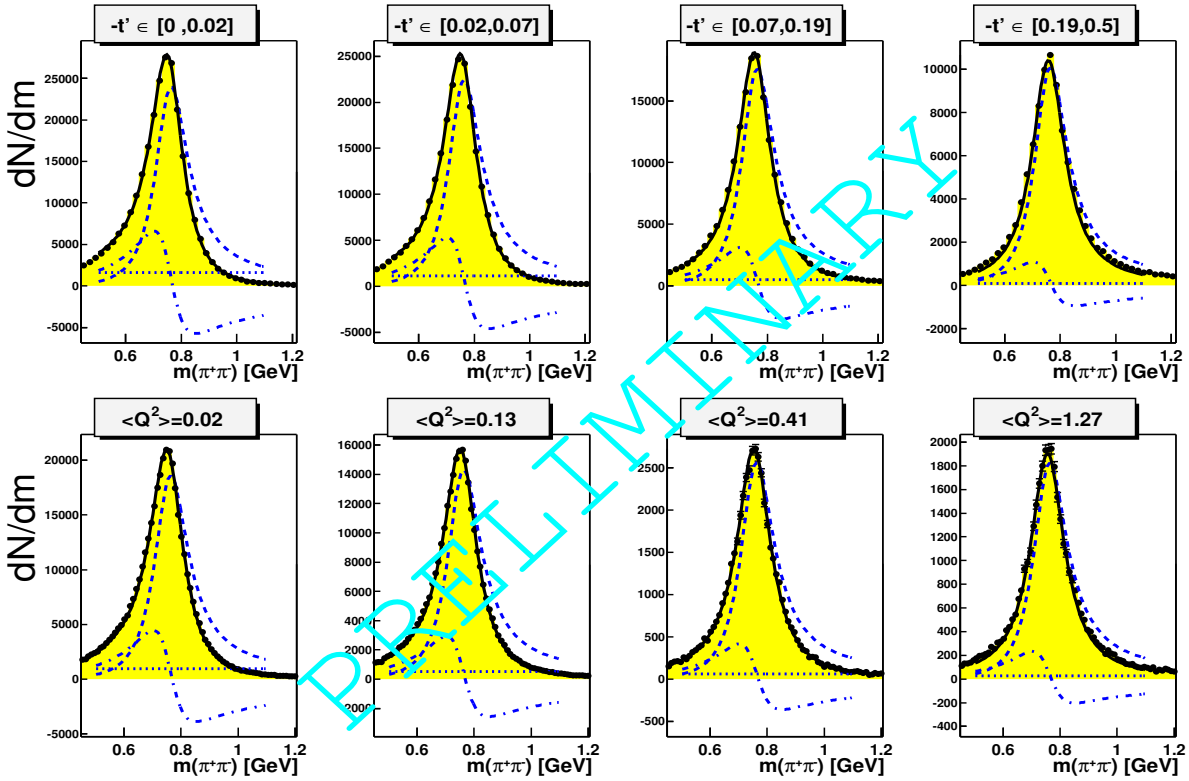
- $|t'| < 0.5$ GeV^2
- $7.5 < W < 16$ GeV
- $Q^2 > 10^{-3}$ GeV^2

	mass cut	statistics (1/6 of 2002)
ρ^0	$0.5 < m_{\pi\pi} < 1$ GeV	1.3×10^6
ϕ^0	$\lvert m_{KK} - m_\phi \rvert < 9$ MeV	42000

Missing Energy

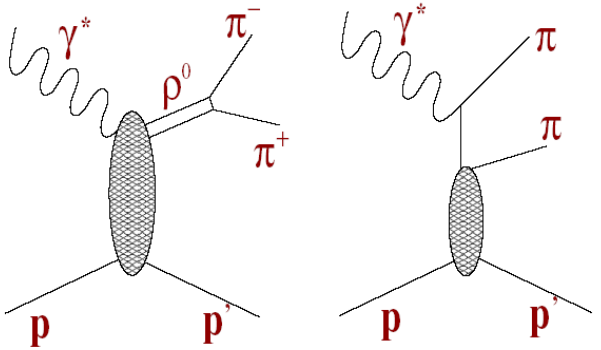


ρ-production

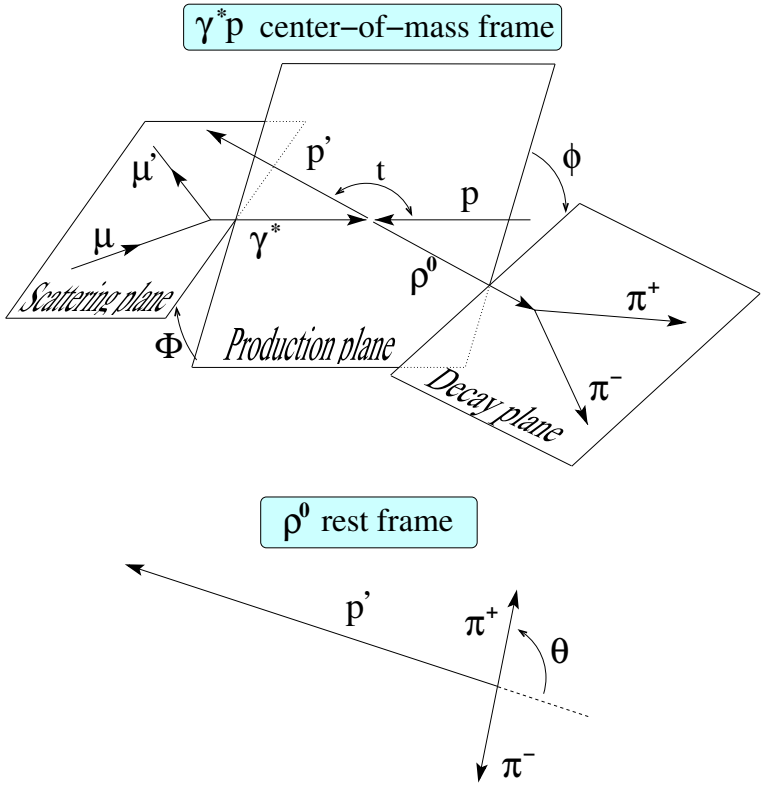


Interference of resonant and non-resonant production of ρ

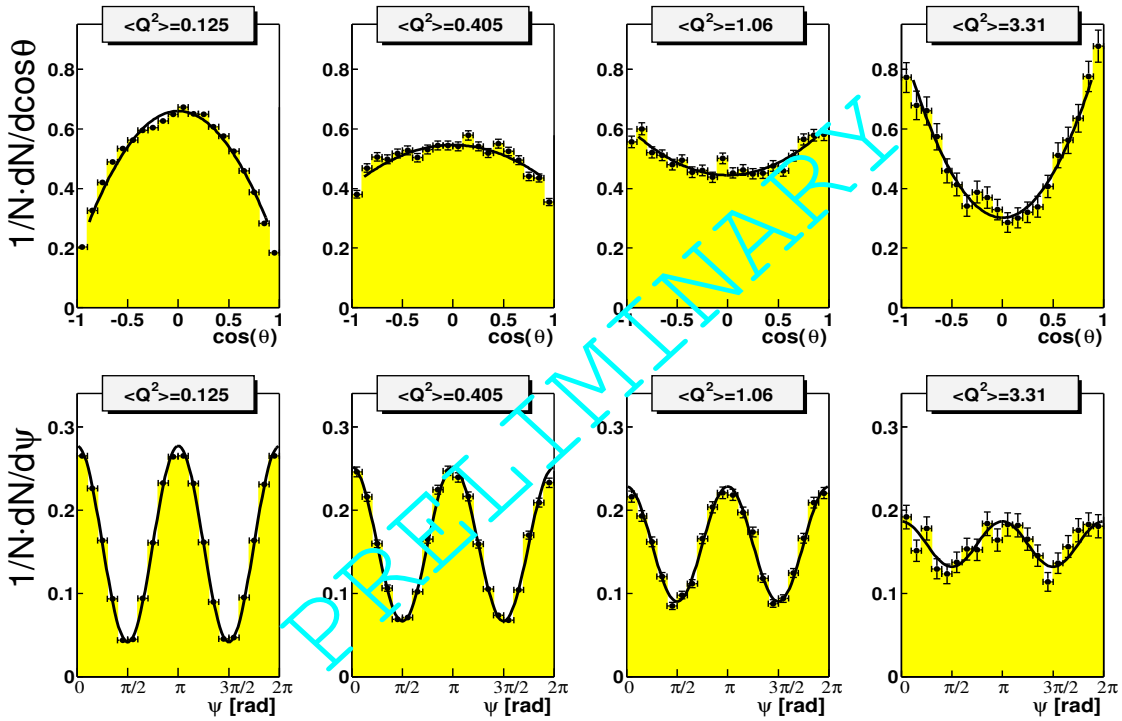
- No accpetance correction
- Non-exclusive contribution subtracted
- Fit with Söding parametrisation
- Non-resonant rising with Q^2 and $|t|$



Angular distributions of ρ



Definition of angles



Distributions in different t and Q^2 intervals

- SCHC valid (approximately)

$$\psi = (\phi - \theta)$$

$$W(\psi) = \frac{1}{2\pi}\left[1 + 2\varepsilon r^1_{1-1}\cos 2\psi\right]$$

- No acceptance corrections
- 1/6 of 2002 data
- $p_T > 0.15$ GeV/c, $Q^2 > 0.5$ (GeV/c)^2
- Fraction of longitudinally polarised ρ rises with $|t|$ and Q^2

J/Ψ production

Decay channel $J/\Psi \to \mu^+\mu^-$

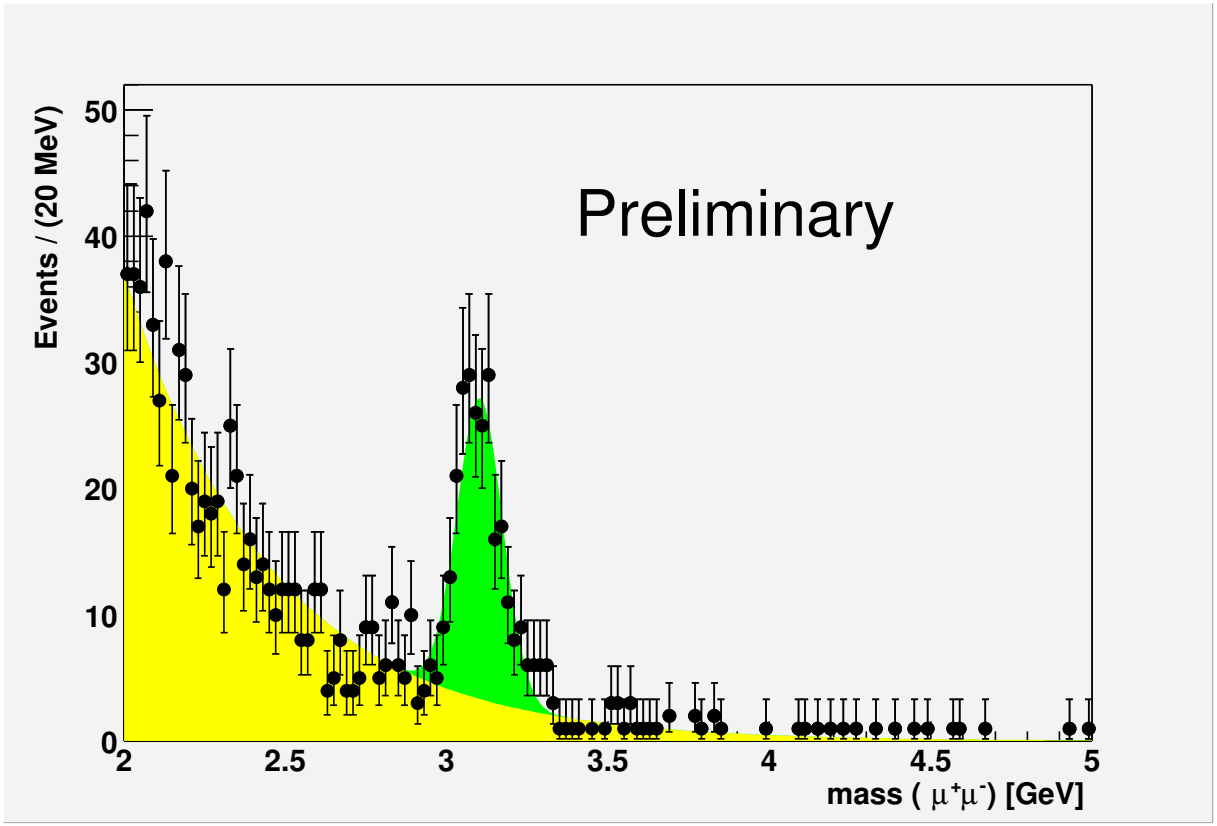
- First look, 20% of 2002 data
- Mainly elastic production

$\to$ not useful for direct $\Delta G/G$

- $N(J/\Psi) = 213 \pm 17$
- Mass $m(J/\Psi) = 3103 \pm 6$ MeV
- $\sigma = 71 \pm 7$ MeV

In 2002: J/Ψ suppressed by trigger

In 2003: Dedicated $J/\Psi \to \mu\mu$ trigger



$\Delta G/G$ from high p_T hadrons

Require μ, μ' and 2 hadrons
5 % of 2002 data

Cuts for $\Delta G/G$ analysis:

- $0.4 < y < 0.9$, $x_F > 0.1$
- $p_{T,1}^2 + p_{T,2}^2 > 2.5(\text{GeV}/c)^2$
- individual $p_T > 1.1$ GeV/c

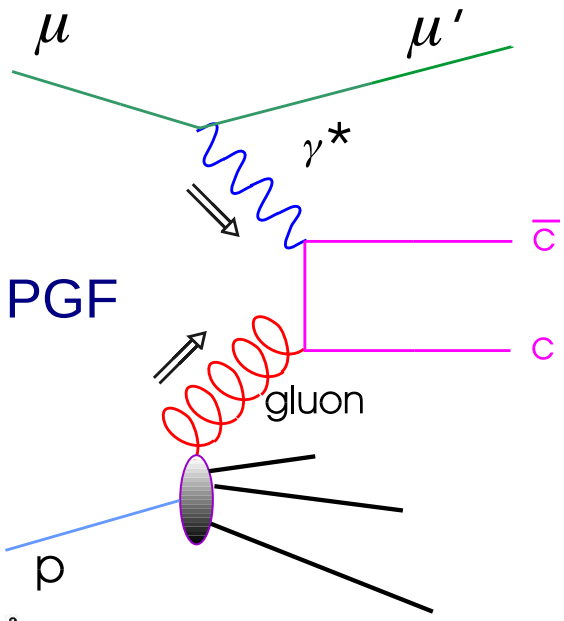
Extrapolation to full statistics:

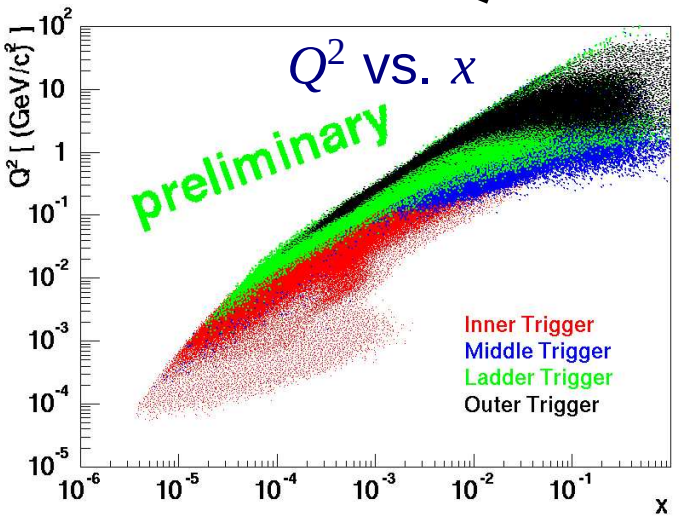
- $Q^2 > 1$ GeV^2: 18000 events

→ $\delta(\Delta G/G) \approx 0.31$

- all Q^2: 160000 events

→ Theoretically $\delta(\Delta G/G) \approx 0.1$
but: interpretable as PGF?
Resolved photons?





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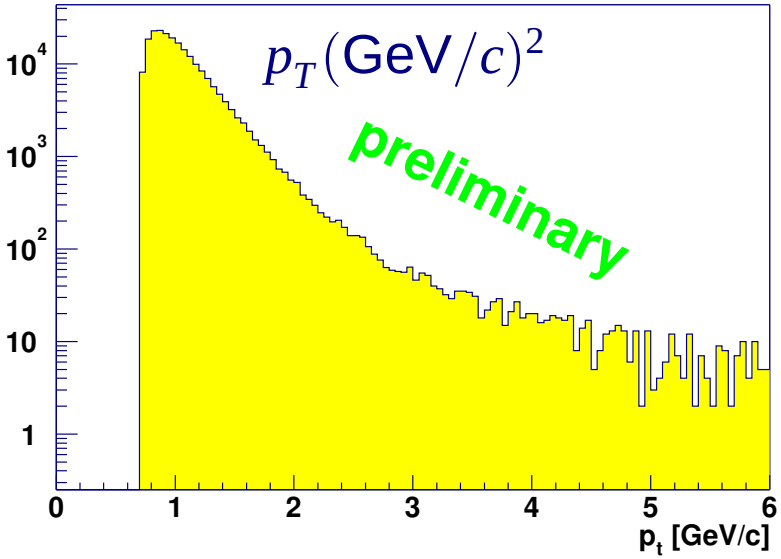

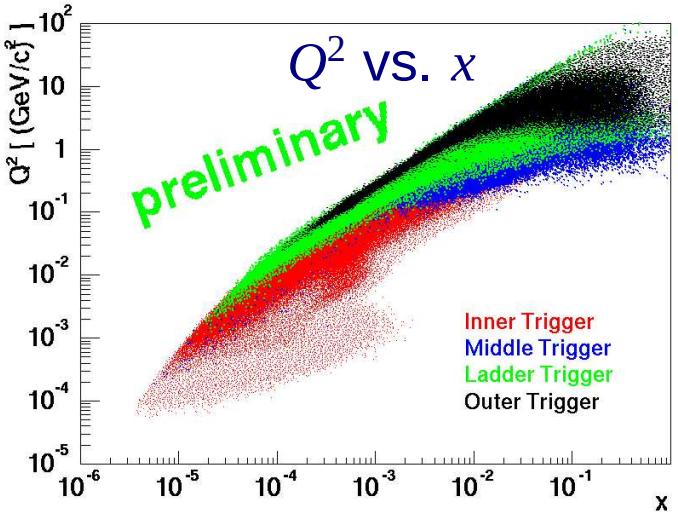

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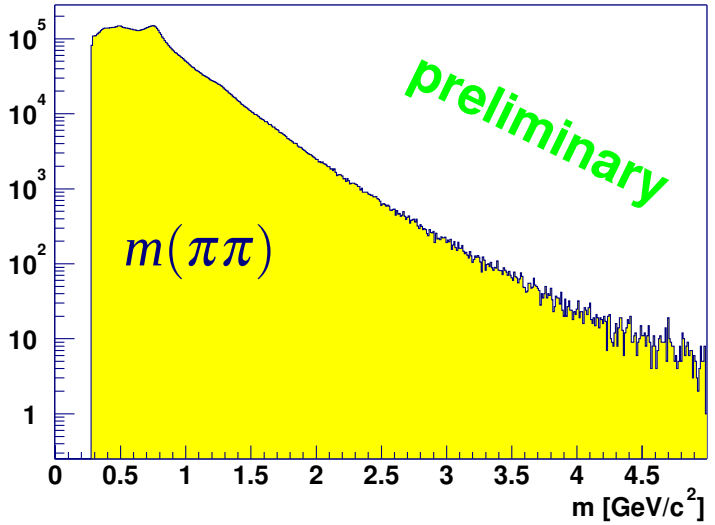
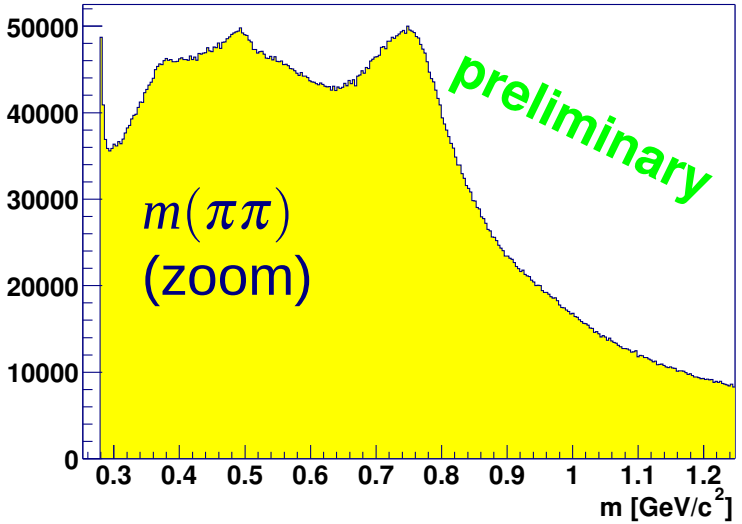




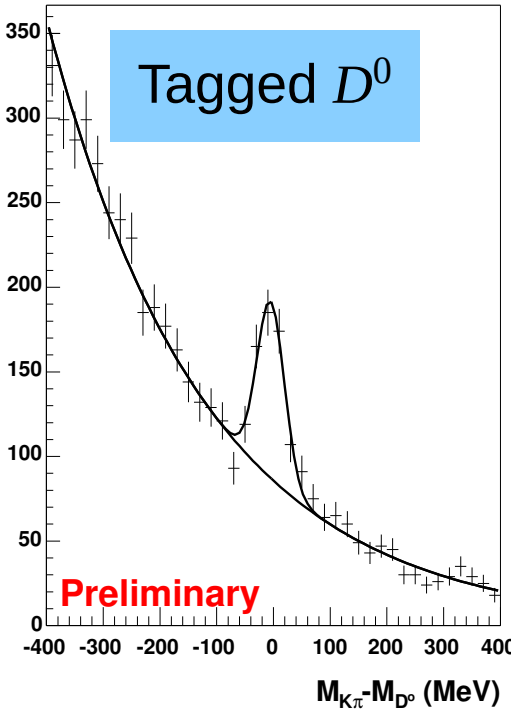
D mesons

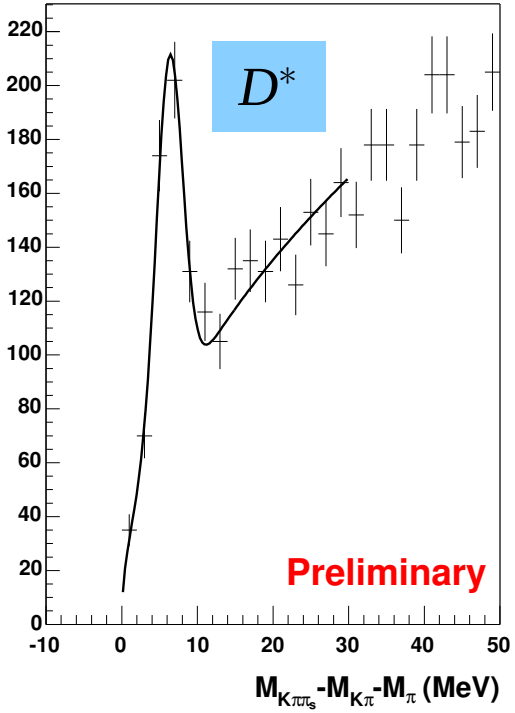
Selection Criteria for $D^* \to D^0\pi_s \to K\pi\pi_s + c.c.$:

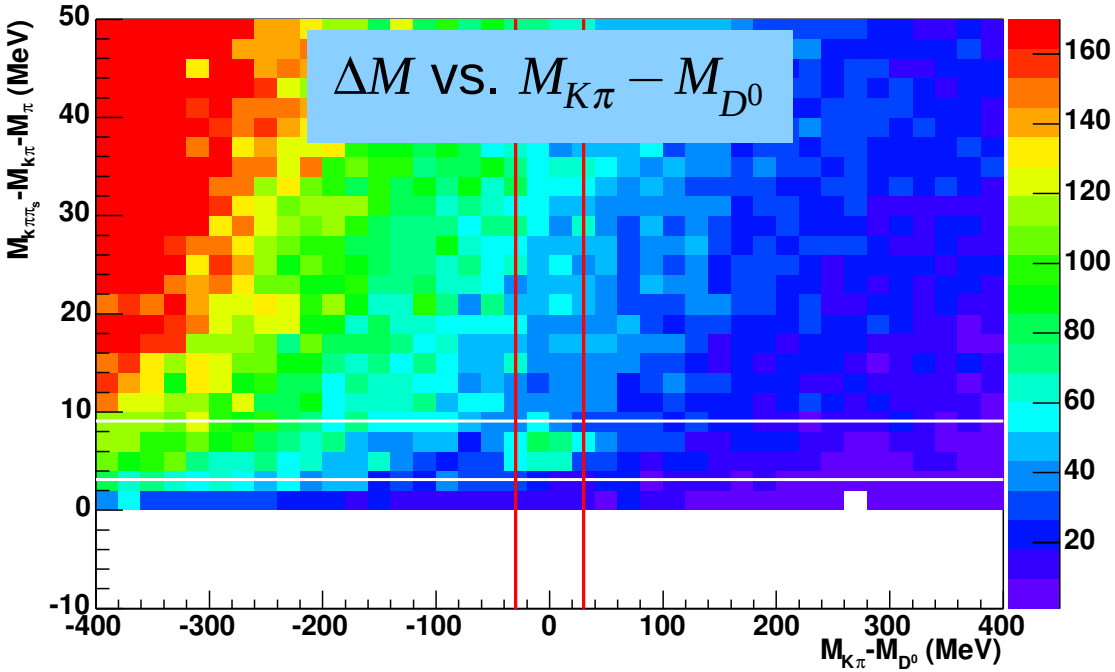
- $z_D > 0.2$, $|\cos(\theta^*)| < 0.85$ (S/B enhancement)
- Kaon ID with RICH, $10 < p_K < 35$ GeV/c (K momentum for RICH)
- $|M(K\pi) - M(D^0)| < 30$ MeV (cut around D^0 peak)

Tagging cut for D^0: $3.1 < \Delta M < 9.1$ MeV

$$\Delta M = M_{K\pi\pi_s} - M_{K\pi} - M_\pi$$







Summary and Outlook

- COMPASS has a very broad Physics Spectrum
- COMPASS Apparatus completed
- COMPASS is taking data
- Physics analysis shows first results
- 2003/2004 still in present Setup

$\rightarrow$ Good Precision for ΔG expected

- Upgrade for a Second Phase after 2005 in Preparation

$\rightarrow$ COMPASS will run well into the LHC Era