Physics with Hadron Beam at COMPASS

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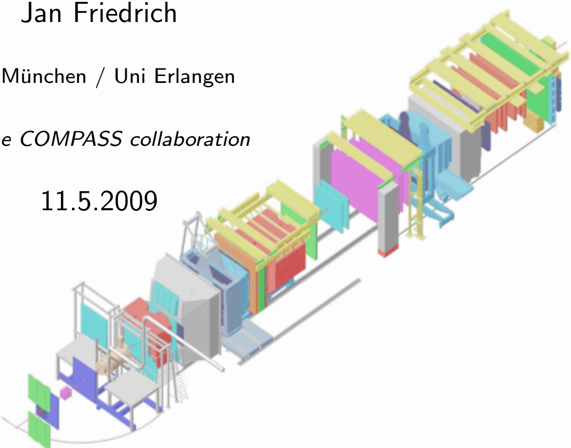
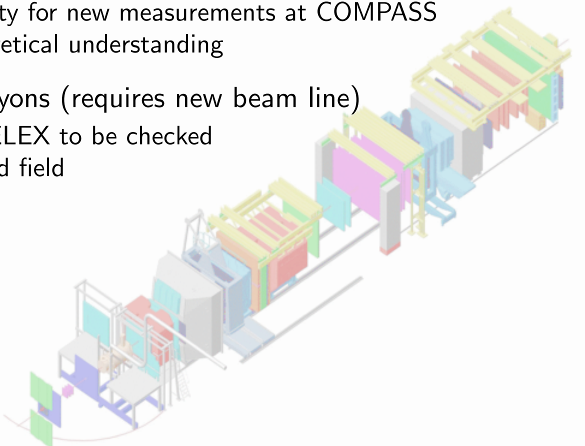
for the COMPASS collaboration

11.5.2009



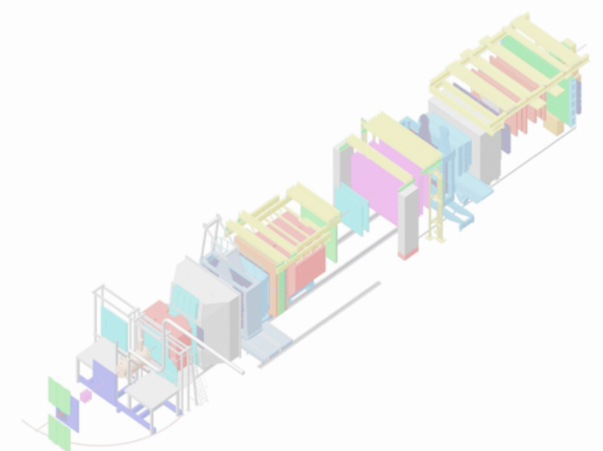
Outline

- Light meson spectroscopy
  - 2008 data analysis ongoing
  - 2009 data taking about to start
  - depending on results $\longrightarrow$ increase of statistics desirable
- Primakoff reactions (minor upgrades needed)
  - unique opportunity for new measurements at COMPASS
  - progress on theoretical understanding
- Doubly charmed baryons (requires new beam line)
  - evidence from SELEX to be checked
  - almost unexplored field



Goal of Primakoff program:
Measure exclusive *pion-photon* reactions

$$\pi + \gamma \rightarrow \begin{cases} \pi + \gamma & \text{Compton reaction} \\ \pi + \pi^0 & \text{neutral pion production} \\ \pi + \pi^0 + \pi^0 & \text{double pion production} \end{cases}$$



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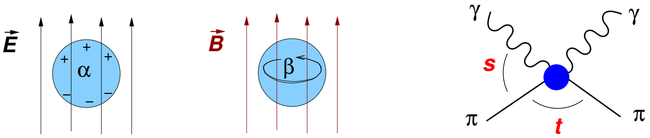
Compton reaction:
Leading deviation from pointlike $\leftrightarrow$ e.m. polarisability

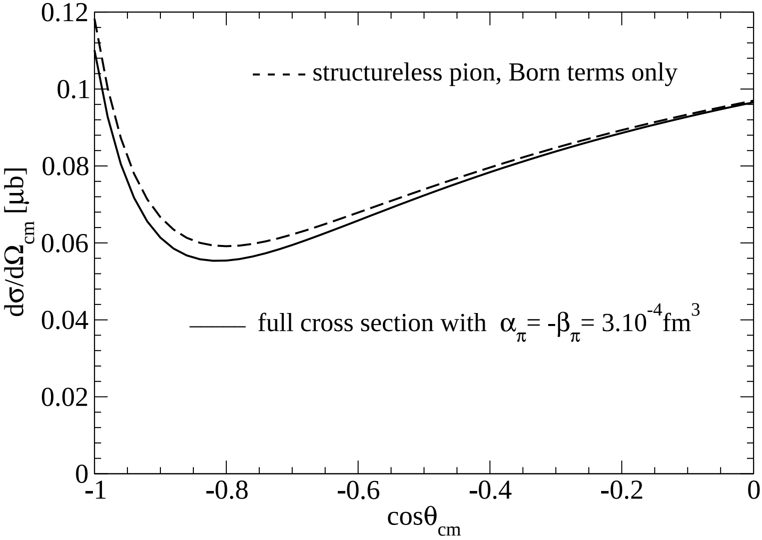


for $\alpha_\pi - \beta_\pi$ [10^{-4} fm^3]: $(\alpha_\pi \approx -\beta_\pi)$

Theory: 5.7±1.0 Experiments: 4 — 14

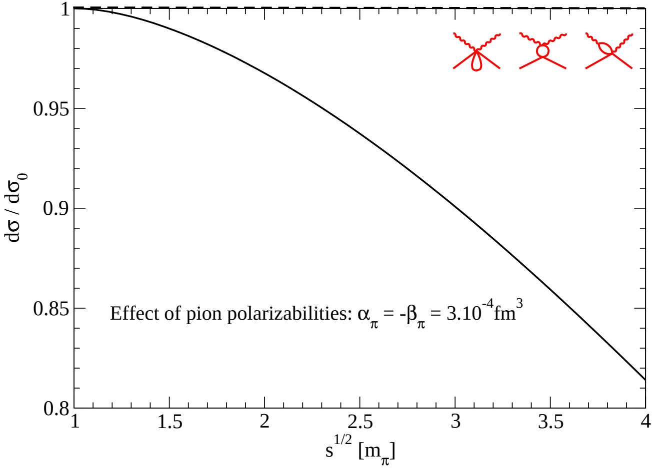
Pion Compton Scattering

Effect of $\alpha_\pi - \beta_\pi$ larger under backward CM angle



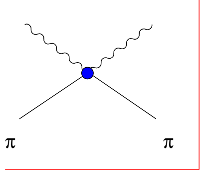
Pion Compton Scattering

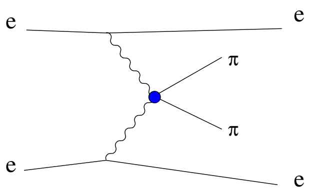
- *s*-dependence: polarisability $\leftrightarrow$ ChPT loop effects

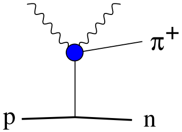


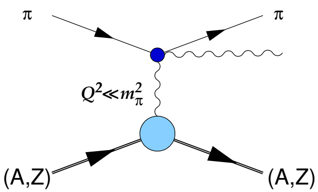
How to scatter photons on pions?

wanted:

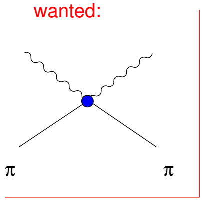


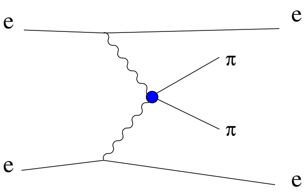


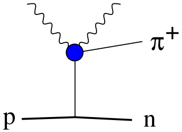


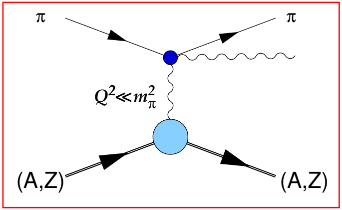


How to scatter photons on pions?









- only Primakoff technique allows direct kinematical access to the pion polarisability

Pion Polarisability: Theory and Data

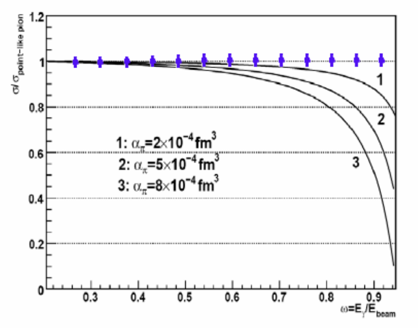
	$\alpha_\pi + \beta_\pi$ [10^{-4} fm^3]	$\alpha_\pi - \beta_\pi$ [10^{-4} fm^3]
Bürgi/Gasser (ChPT)	0.2 ± 0.1	5.7 ± 1.0
$e^+e^- \to e^+e^-\pi^+\pi^-$		
Mark II	$0.22 \pm 0.07 \pm 0.04$	4.8 ± 4.0(??)
CELLO	$0.33 \pm 0.06 \pm 0.01$	
$\gamma p \to n\pi^+\gamma$		
MAMI		$11.6 \pm 1.5 \pm 3.0 \pm 0.5$(??)
$\pi^- Z \to Z\pi^-\gamma$		
Serpukhov	$1.8 \pm 3.1 \pm 2.5$	12.3 ± 2.6
COMPASS	XX	XX± 0.8 [30 days]

COMPASS Primakoff measurement

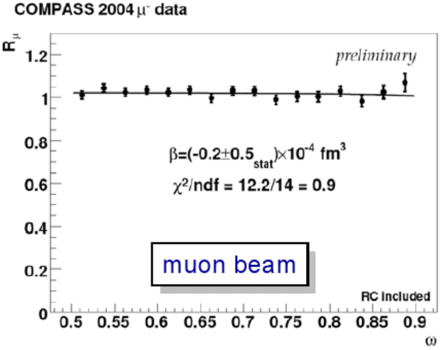
- high resolution for small Q^2
  - identify Primakoff events
  - tracking with SMDs, reduced material budget in the spectrometer
  - precise calorimetry and scattering angle of outgoing photons
- (pointlike) muon beam allows crucial systematic cross-check measurement
- specific trigger on high energy deposition in Ecal
  - implement sum of in-time signals in FPGA trigger electronics
- high statistics for full kinematical coverage
  - $\alpha_\pi - \beta_\pi$ is obtained with competitive precision in 30 days pion beam (assuming $\alpha_\pi = -\beta_\pi$)
  - Independent extraction of α_π and β_π requires a factor 4 more statistics
- K^- polarisability via Primakoff mechanism (CEDARs)

Prospects for 4 weeks

$$R(\omega) = \frac{N_{\exp}(\omega)}{N_{\mathrm{MC}}(\omega)} = \frac{d\sigma_{\gamma\pi}^{\mathrm{Prim}}}{d\sigma_{\gamma\pi}^{\mathrm{Thomson}}} \cong 1 + \frac{3}{2}\frac{m_\pi^3}{\alpha}\frac{\omega^2}{1-\omega}\overline{\beta}_\pi\,, \quad \left(\overline{\alpha}_\pi + \overline{\beta}_\pi = 0\right)$$

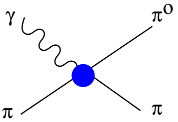


$R(\omega)$ for different values of α_π (β_π)

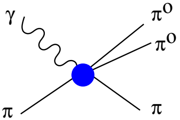


Cross check with μ beam

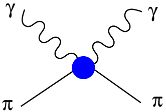
Primakoff neutral pion production



$$F_{\gamma 3\pi} \quad \sim \quad \frac{e}{4\pi^2 f_\pi^3} \qquad \text{(chiral anomaly)}$$



$$F_{\gamma 4\pi} \quad \sim \quad a_{IJ}$$



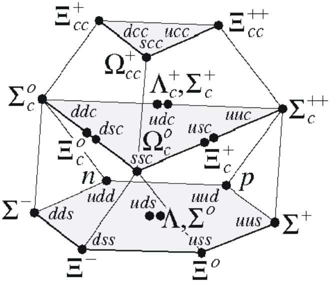
$$"F_{2\gamma 2\pi}" \quad \sim \quad \alpha_\pi, \beta_\pi$$

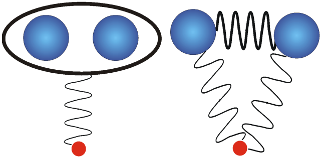
[s. N. Kaiser, J.F. Europ. Phys. J. A36 (2008), p.181-188]

all channels test QCD at low energy (Chiral Perturbation Theory)

Doubly Charmed Baryons

- B-like ground state ("heavy-light" system)
- excitation in c-c binding (molecular like)
- Mass spectrum calculable rather reliably
- First evidence of *cc*-systems
  - SELEX: fixed-target experiment at Fermilab
  - Σ^-, π^-, p beams at 600 GeV



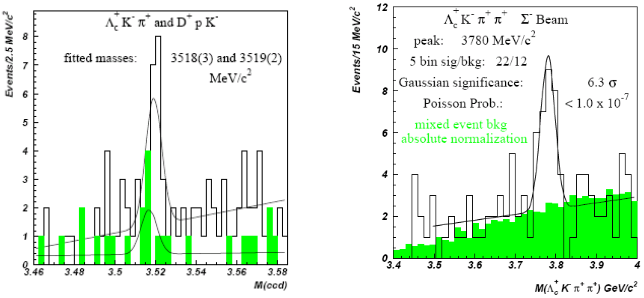


$\Xi_{cc}^{+}(ccd) \rightarrow pD^+K^-,\ \Lambda_c K^-\pi^+,\ \Xi_c^+\pi^-\pi^+$ M=3519 MeV/c^2

$\Xi_{cc}^{++}(ccu) \rightarrow \Lambda_c K^-\pi^+\pi^+$ M=3460 MeV/c^2

$\Xi_{cc}^{++*}(ccu) \rightarrow \Lambda_c K^-\pi^+\pi^+$ M=3780 MeV/c^2

Properties of *cc*-Baryons: Mass and Lifetime

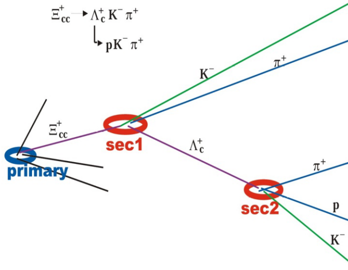


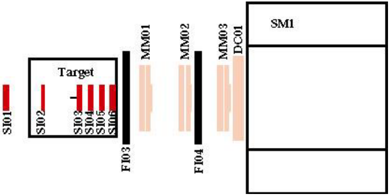
- Decay of baryons goverened by three processes (W-exchange, spectator decay, quark interference)
- Lifetime: SELEX $\tau(\Xi_{cc}^{+}) \sim 30$ fs
- Production observed in Σ^- beam, yield accounts for 50% of total Λ_c production (threshold effect?)
- No other experiment has observed these states (p, π beams)

needs clarification!

Doubly Charmed Baryons in COMPASS

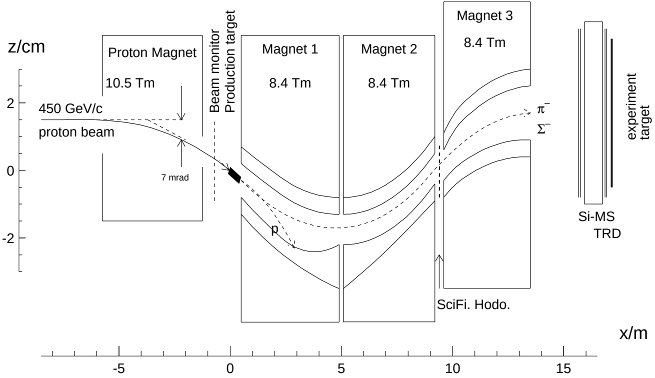
- fixed-target experiment:
  decay chain spatially resolvable
- use 450 GeV proton beam
- vertex detector system
- trigger
  - multiplicity > 5 charged tracks
  - high-p_t muons
    ($\sim$ 35% of decays)
  - transverse energy E_T
- CPU-farm
  (secondary vertex finding)
- yield (from SELEX signals):
  10-17k events
  incoherent cc-production:
  Factor 100-500 less





Beam for cc-baryon spectroscopy

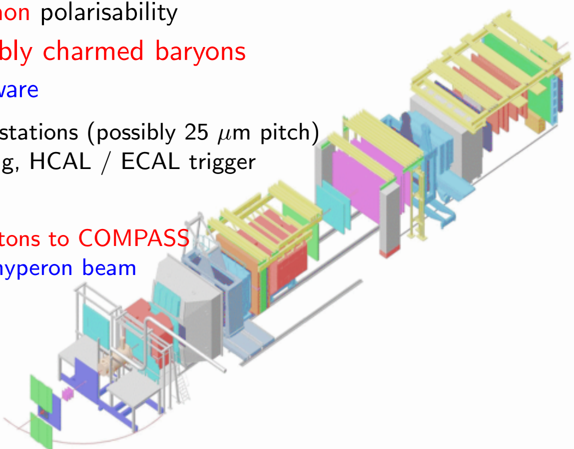
- First trial with proton beam of highest possible energy $\longrightarrow$ 450 GeV
- New beam line
- Best option: Hyperon beam (à la WA89): $p(450GeV) + \mathrm{Be} \rightarrow \Sigma^-(350GeV) + X$



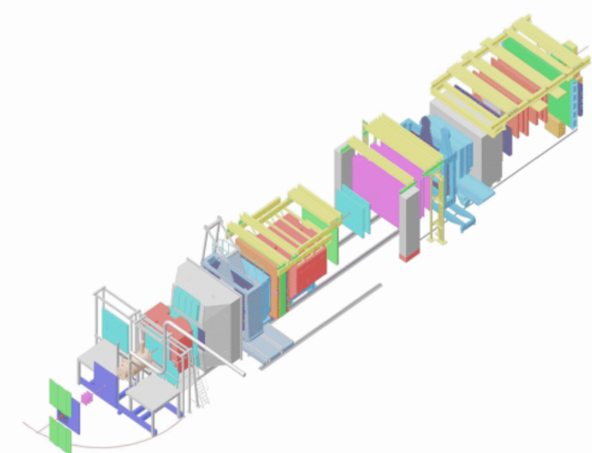
Summary

Hadron spectroscopy at COMPASS is an open field:

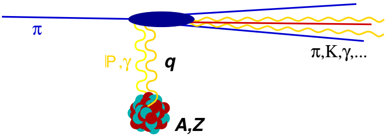
- Continue the search for exotics in the light meson sector
- Primakoff reactions
  - unique potential to clarify pion polarisability
  - Data for $F_{\gamma 3\pi}$ and $F_{\gamma 4\pi}$ allow test of low-energy QCD (ChPT)
  - First value for Kaon polarisability
- Spectroscopy of doubly charmed baryons
  - COMPASS hardware
    - More silicon stations (possibly 25 μm pitch)
    - online filtering, HCAL / ECAL trigger
  - Beam
    - 450 GeV protons to COMPASS
    - (re)build of hyperon beam

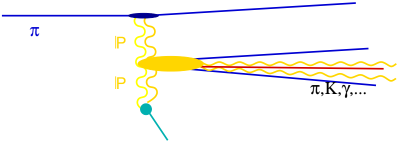


Backup



Pion-nucleus reaction mechanisms





Diffractive dissociation

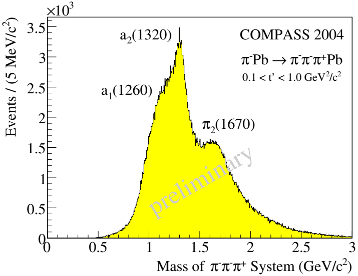
- projectile excitation
- exclusive reaction
- meson (exotic) spectrum

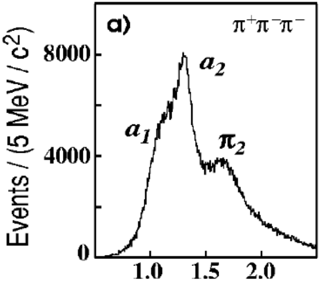
Central production

- target recoil
- projectile at high rapidity
- glueball search

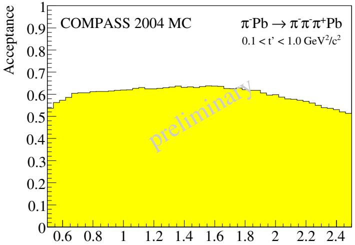
3π Data in the range $0.3 < t'/(\mathrm{GeV}^2/c^2) < 1$

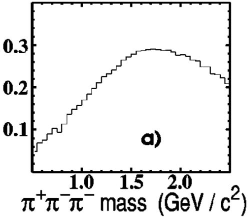
$\pi^-\pi^-\pi^+$ Mass Distributions and Acceptance

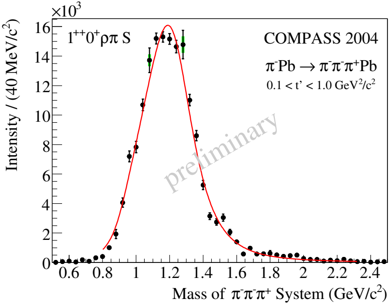


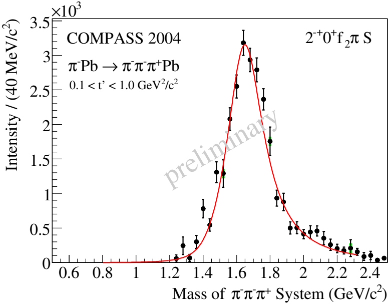


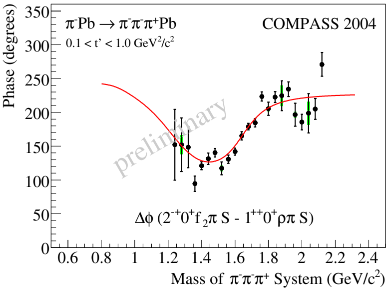
BNL-E852, Phys. Rev. **D65**, 072001, 2002











- BW for $a_1(1260)$ + background:

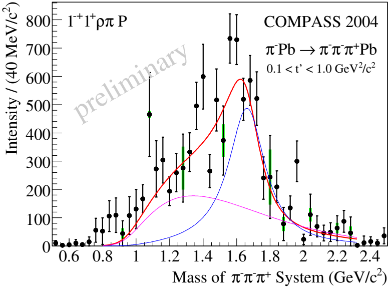
  $M = (1.256 \pm 0.006 \;^{+0.007}_{-0.017})$ GeV

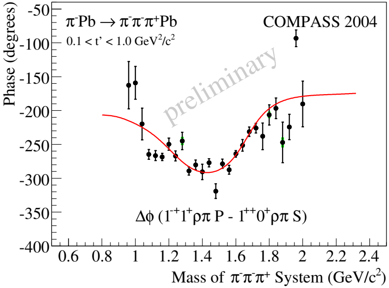
  $\Gamma = (0.366 \pm 0.009 \;^{+0.028}_{-0.025})$ GeV

- BW for $\pi_2(1670)$:

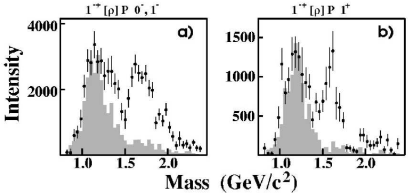
  $M = (1.659 \pm 0.003 \;^{+0.024}_{-0.008})$ GeV

  $\Gamma = (0.271 \pm 0.009 \;^{+0.022}_{-0.024})$ GeV





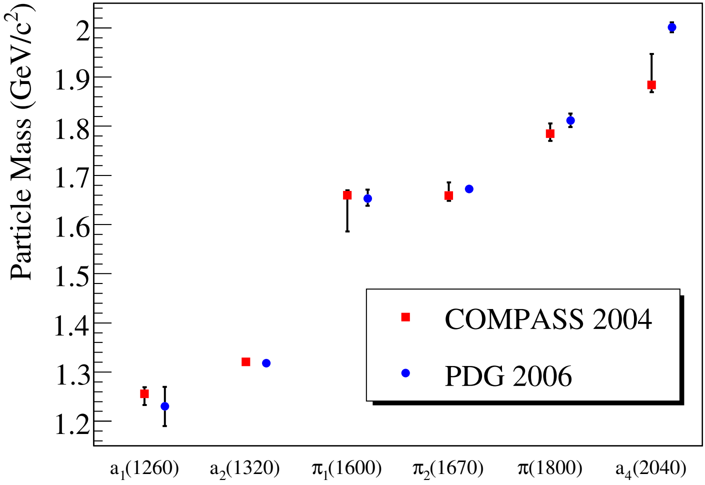
BNL E852 signal:



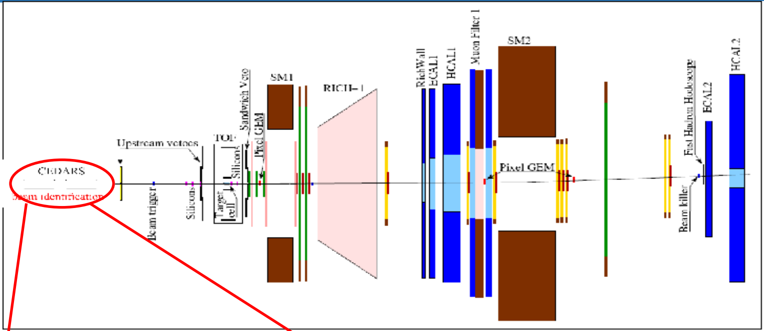
- Significant 1^{-+} amplitude consistent with resonance at $\sim 1.6\,\text{GeV}$
- No leakage observed
- BW for $\pi_1(1600)$ + background:

$$M = (1.660 \pm 0.010\ ^{+0.000}_{-0.064})\ \text{GeV}$$

$$\Gamma = (0.269 \pm 0.021\ ^{+0.042}_{-0.064})\ \text{GeV}$$

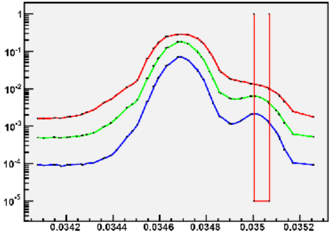


Particle Mass (GeV/c²)
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
COMPASS 2004
PDG 2006
a1(1260)
a2(1320)
π1(1600)
π2(1670)
π(1800)
a4(2040)

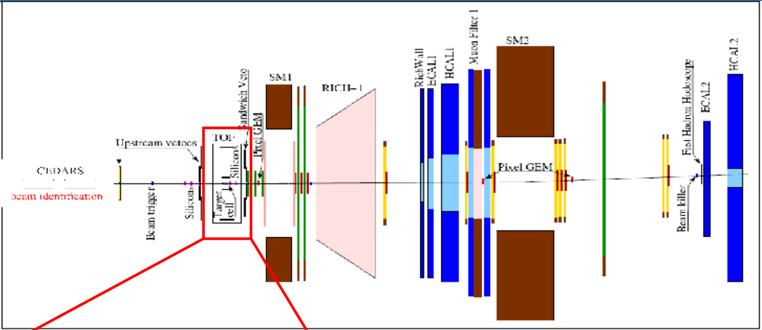


CEDARS
Beam identification
Beam trigger
Upstream vetoes
Silicons
TOF
Target cell
Silicons
Sandwich Veto
Pixel GEM
SM1
RICH-1
RichWall
ECAL1
HCAL1
Muon Filter 1
SM2
Pixel GEM
Fast Hadron Hodoscope
Beam killer
ECAL2
HCAL2

CEDAR N 05



1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
0.0342
0.0344
0.0346
0.0348
0.035
0.0352



CEDARS
beam identification
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Silicons
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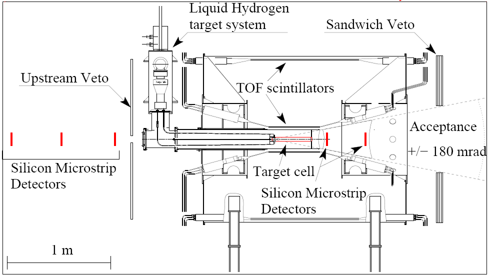
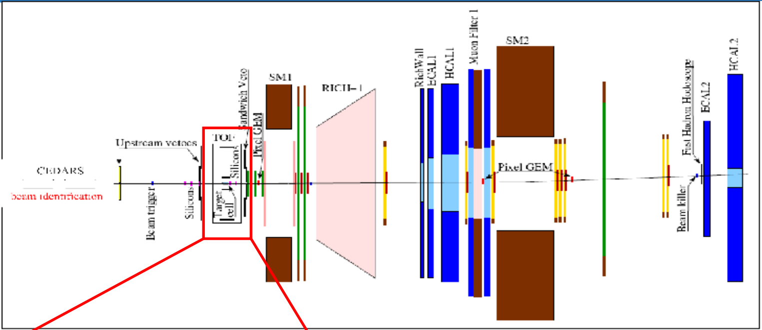
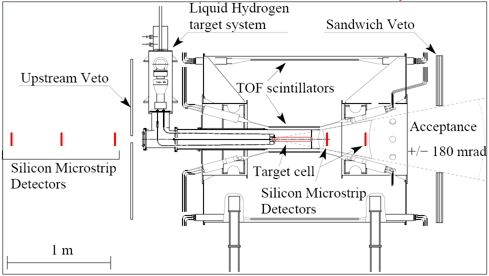
Beam killer
Fast Hadron Hodoscope
ECAL2
HCAL2



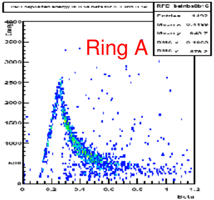
Liquid Hydrogen target system
Sandwich Veto
Upstream Veto
TOF scintillators
Acceptance
+/− 180 mrad
Silicon Microstrip Detectors
Target cell
Silicon Microstrip Detectors
1 m



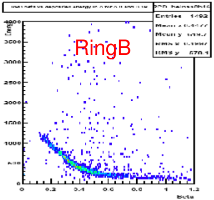
CEDARS
beam identification
Beam trigger
Silicons
Upstream vetoes
TOF
Target cell
Silicons
Sandwich Veto
Pixel GEM
SM1
RICH-1
RichWall
ECAL1
HCAL1
Muon Filter 1
SM2
Pixel GEM
Fast Hadron Hodoscope
Beam killer
ECAL2
HCAL2



Liquid Hydrogen
target system
Sandwich Veto
Upstream Veto
TOF scintillators
Acceptance
+/− 180 mrad
Silicon Microstrip
Detectors
Target cell
Silicon Microstrip
Detectors
1 m



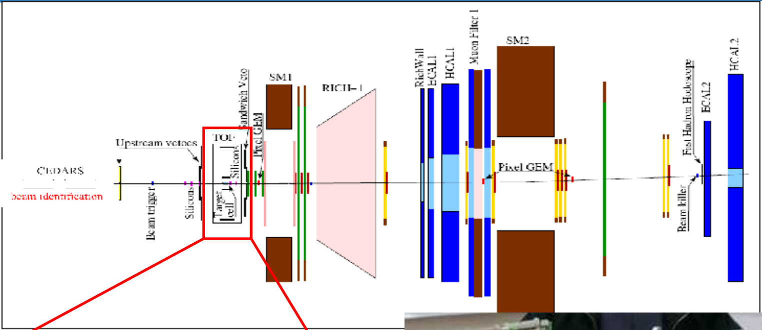
Ring A

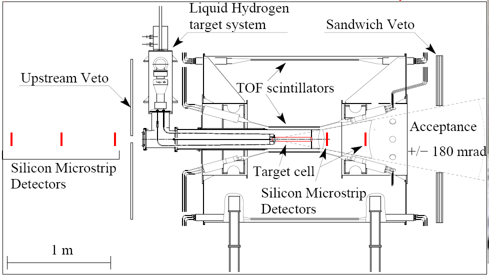


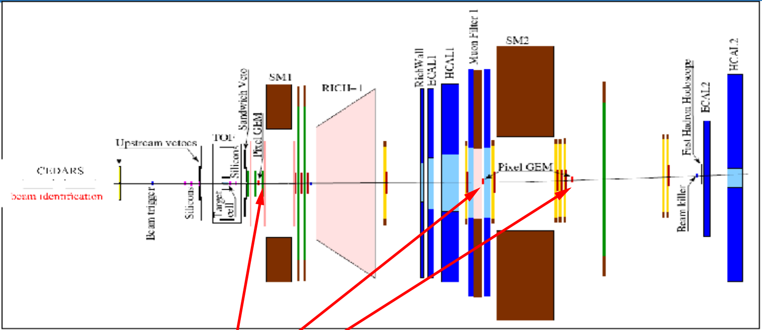
RingB

COMPASS Setup 2008

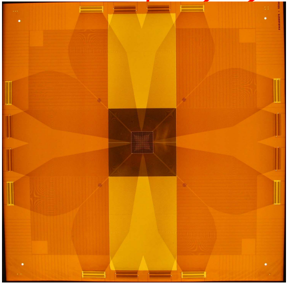
Target region: Silicon detectors

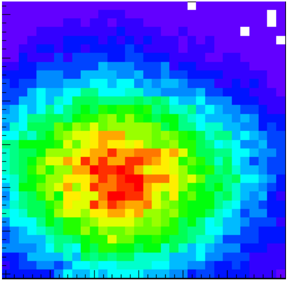






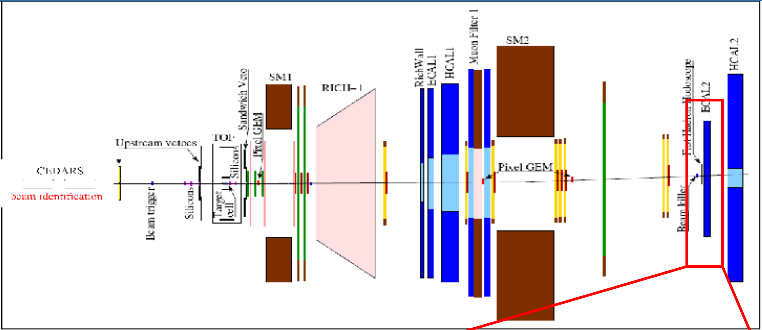
CEDARS
beam identification
Beam trigger
Upstream vetoes
Silicons
TOF
Target cell
Silicons
Sandwich Veto
Pixel GEM
SM1
RICH-1
RichWall
ECAL1
HCAL1
Muon Filter 1
SM2
Pixel GEM
Beam killer
Fast Hadron Hodoscope
ECAL2
HCAL2

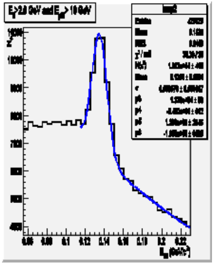


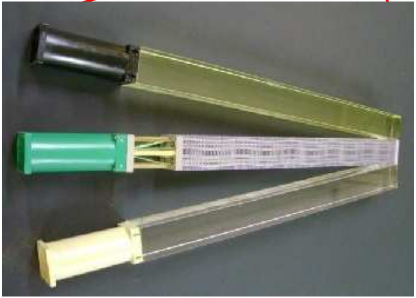


COMPASS Setup 2008

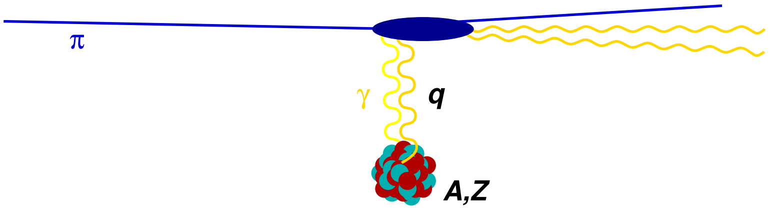
Calorimetry:

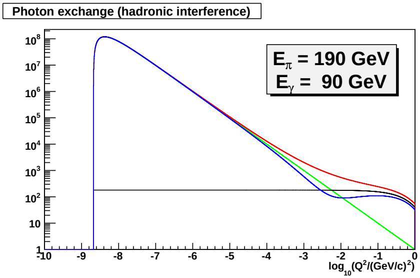


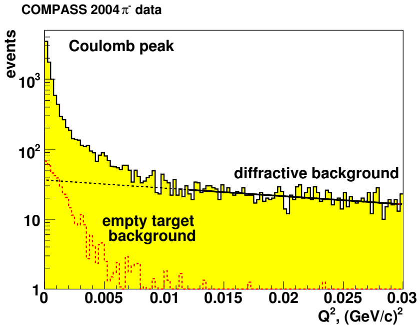




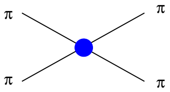
Primakoff $\pi\gamma$ reactions







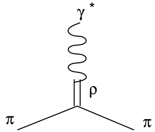
- Pion scattering lengths: 2-loop predictions
  - $a_0^0 m_{\pi^+} = 0.220 \pm 0.005$ confirmed in $K^+ \rightarrow \pi^+\pi^- e^+\nu_e$ (E865)
  - $(a_0^0 - a_0^2) m_{\pi^+} = 0.264 \pm 0.006$ confirmed in $K^+ \rightarrow \pi^+\pi^\circ\pi^\circ$ (NA48: 0.268 ± 0.010)

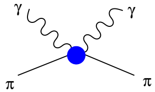


- Electromagnetic structure
  - Form factor described by coupling to $\rho(770)$ (resonance effect, VMD)
  - Polarisability
    accessible as contribution to Compton scattering; prediction obtained by the LEC relation to $\pi^+ \rightarrow e^+\nu_e\gamma$

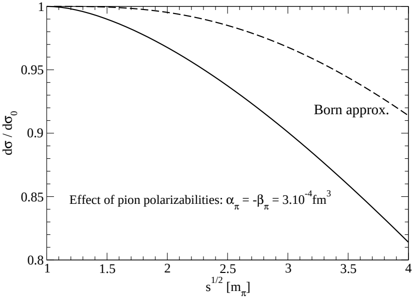
$$\begin{aligned}\alpha_\pi + \beta_\pi &= (0.2 \pm 0.1) \cdot 10^{-4}\mathrm{fm}^3 \\ \alpha_\pi - \beta_\pi &= (5.7 \pm 1.0) \cdot 10^{-4}\mathrm{fm}^3\end{aligned}$$

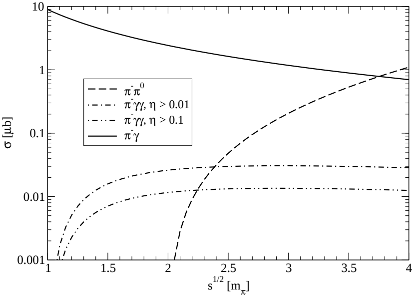
[Gasser, Ivanov, Sainio, Nucl. Phys. B745, 2006]





- s-dependence $\alpha_\pi(s)$ (as ChPT loop effect)
- interference with $\pi^-\pi^\circ$ Primakoff production
- e.m. radiative corrections, Coulomb corrections
- Beyond the Weizsäcker-Williams factorization



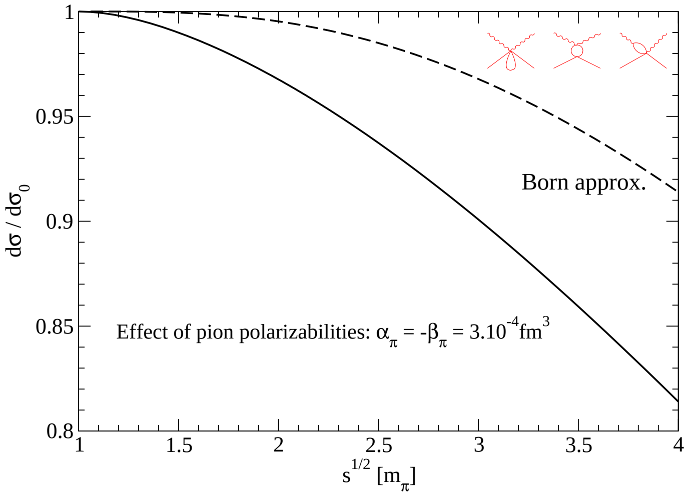


N. Kaiser, J.F.

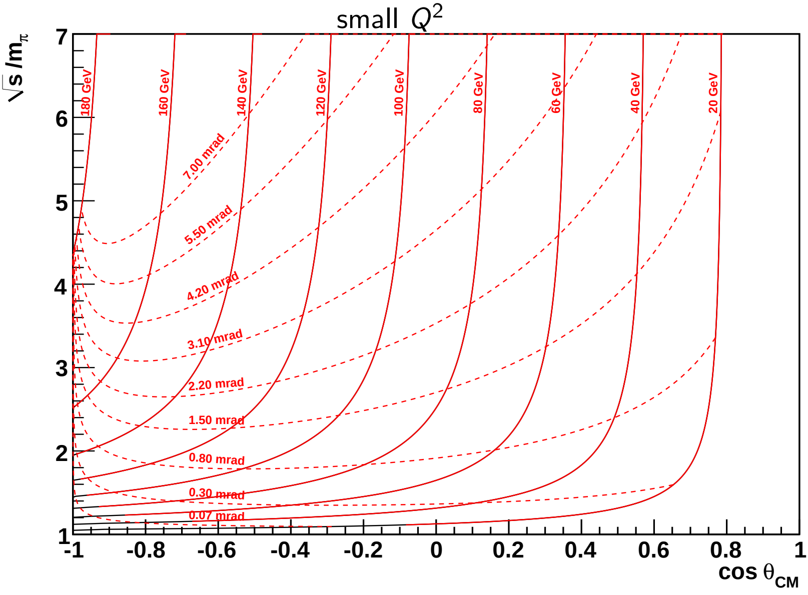
Europ. Phys. J. A36 (2008), p.181-188 (arXiv:0803.0995)
Nuclear Physics A812 (2008), p. 186-200 (arXiv:0806.2614)
Europ. Phys. J. A (arXiv:0811.1434)

Pion Compton Scattering

- s-dependence: polarisability $\leftrightarrow$ ChPT loop effects



Mandelstam $\{s,t\} \leftrightarrow$ Laboratory $\{E_\gamma,\ \theta_\pi\}$

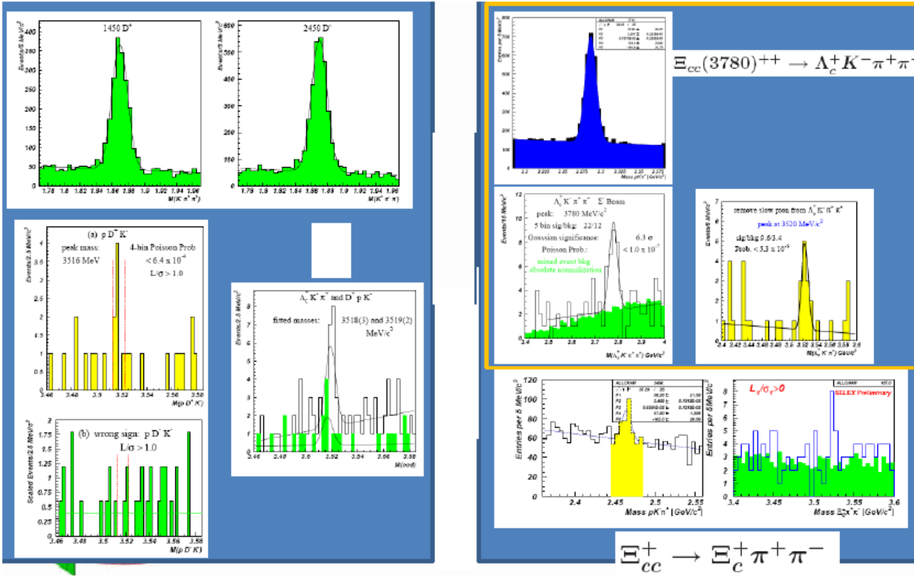


$\gamma\gamma \to \pi\pi$ and the pion polarisability

M.R. Pennington in the 2nd DAΦNE Physics Handbook,
"What we learn by measuring $\gamma\gamma \to \pi\pi$ at DAΦNE":

> All this means that the only way to measure the pion polarisabilities is in the Compton scattering process near threshold and not in $\gamma\gamma \to \pi\pi$. Though the low energy $\gamma\gamma \to \pi\pi$ scattering is seemingly close to the Compton threshold (...) and so the *extrapolation* not very far, the dominance of the pion pole (...) means that the energy scale for this continuation is m_π. Thus the polarisabilities cannot be determined accurately from $\gamma\gamma$ experiments in a model-independent way and must be measured in the Compton scattering region.

Update on the status - SELEX data



Perspectives for the yield

- Resolution
  - mass resolution Ξ_{cc}: 13 MeV/c^2
  - lifetime $\Leftrightarrow$ few 100 μm flight path
- Production
  - 10^8p/spill on 2% i.l. target (segmented diamond foils) – 100 effective days
  - Acceptance $x_F > -0.1$
  - Total acceptance $\times$ efficiency: 0.8%

- from SELEX yield (50% of all Λ_c from Ξ_{cc}) ($\sigma_{\Xi_{cc}} \sim 2\mu$b)
  - 50$\cdot$ 10^6 (ccq) produced
  - Expectation for COMPASS: 10-17k events
- Incoherent production: assuming $\sigma_{\Xi_{cc}} \sim \sigma_{tot} \cdot (10^{-3})^2$ $\sim$ 2-10 nb