Light mesons spectroscopy and search for non-$q\bar{q}$ mesons at COMPASS

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on behalf of the COMPASS collaboration

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Outline

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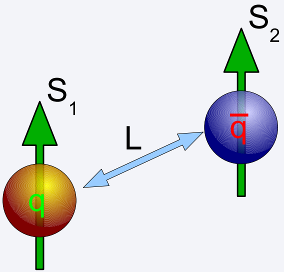
Conventional mesons

- Conventional mesons are composed of a $q\bar{q}$ pair
- Mesons quantum numbers are characterized by given J^{PC}



- $\vec{S} = \vec{S_1} + \vec{S_2}$
- $\vec{J} = \vec{L} + \vec{S}$
- $\mathbf{P} = (-1)^{L+1}$
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Allowed J^{PC} combinations: 0^{-+}, 0^{++}, 1^{--}, 1^{+-}, 1^{++}, ...

"Exotic" J^{PC} combinations: 0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, ...

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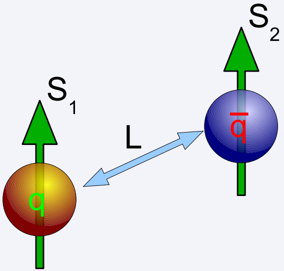

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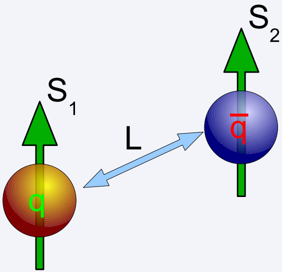

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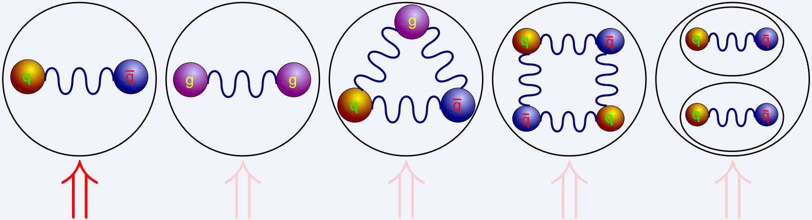
Mesons beyond the NQM



- The NQM only predicts mesons composed of $q\bar{q}$
- However, QCD allows the existence of non-$q\bar{q}$ mesons:
  - Glueballs: states with only valence gluons (gg, ggg)
  - Hybrids: $q\bar{q}$-systems with one additional valence gluon
  - $q\bar{q}q\bar{q}$ bound states and meson-meson molecules
- The unabiguous experimental identification of such states represents a fundamental test of non-perturbative QCD

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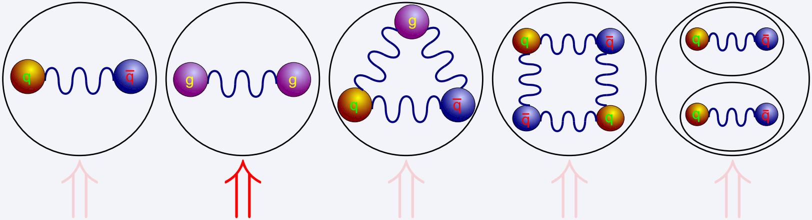

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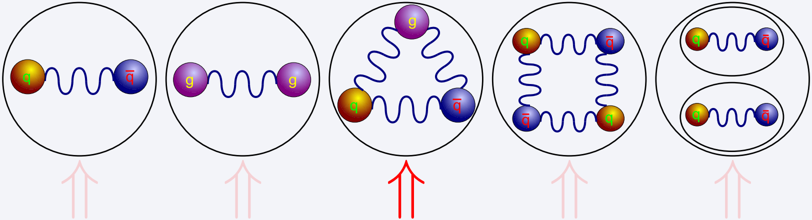

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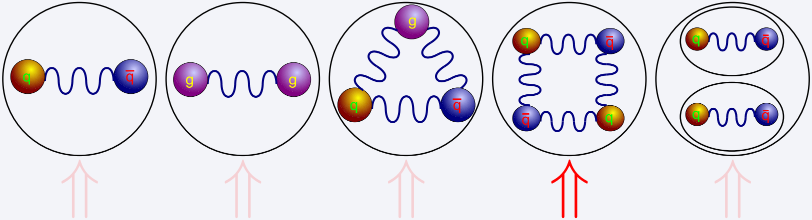

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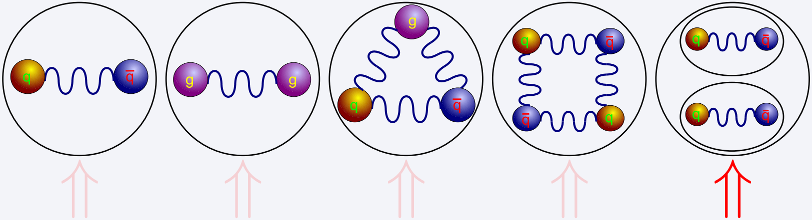

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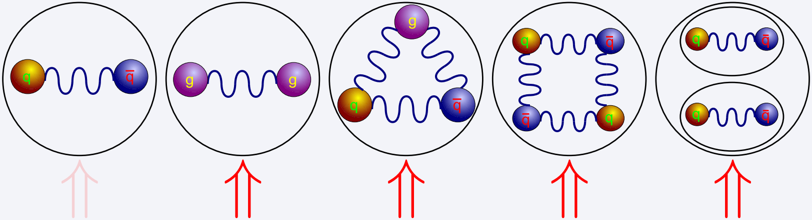

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Glueballs mass spectrum

Glueballs mass spectrum from quenched lattice calculations

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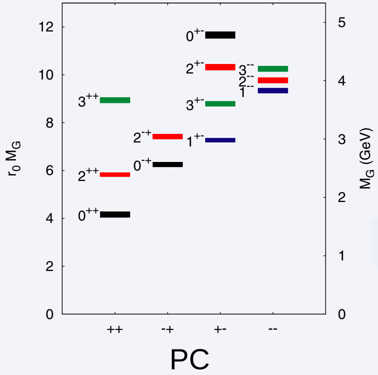
Phys. Rev. D 73 (2006) 014516



- Lower mass glueballs:
  - $J^{PC} = 0^{++}$ scalar $M \sim 1700$ MeV/c^2
  - $J^{PC} = 2^{++}$ tensor $M \sim 2400$ MeV/c^2
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mixing with nearby $q\bar{q}$ mesons

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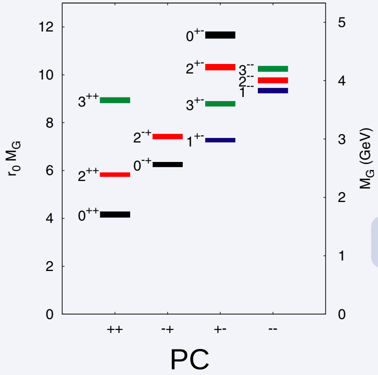

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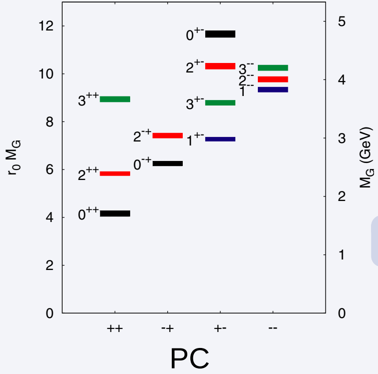

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- Glueballs can be identified by:
  - Flavour independence $\rightarrow BR(K\overline{K}) \approx BR(\pi\pi)$
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  - Enhancement in gluon-rich processes:
    - Central collisions
    - $p\overline{p}$ annihilations
    - J/Ψ radiative decays
  - Suppression in $\gamma\gamma$ collisions
  - Supernumerary states in established $q\overline{q}$ nonets
- Need to combine data from different production processes/decay patterns
- For states with non-exotic J^{PC}, mixing with nearby $q\overline{q}$ mesons complicates the picture. . .

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Hybrid Mesons

- QCD allows for the existence of colour singlet states composed of a $q\bar{q}$-pair and one valence gluon, the so-called hybrid mesons
- In total 8 nonets with quantum numbers
  $J^{PC} = 0^{\pm\mp}$, $1^{\pm\mp}$, $2^{\pm\mp}$ and $1^{\pm\pm}$
  have been predicted in flux-tube models
- Hybrids should have distinctive decay patterns (pairs of S- and P-wave mesons)
- Exotic quantum numbers are allowed for $q\bar{q}g$ states
- The lightest hybrid meson is predicted to be an exotic $J^{PC} = 1^{-+}$ object with a mass between 1.4 and 1.9 GeV/c^2
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Overview of glueball candidates

- Three $J^{PC} = 0^{++}$ states around 1500 MeV/c^2:
  - $f_0(1370)$, decaying into $\pi^+\pi^-$, $K\overline{K}$, $\eta\eta$, 4π
  - $f_0(1500)$, decaying into $\pi^+\pi^-$, $K\overline{K}$, $\eta\eta$, $\eta'\eta$, 4π
  - $f_0(1710)$, decaying into $\pi^+\pi^-$, $K\overline{K}$, $\eta\eta$
- Found in $p\bar{p}$ annihilation, central pp collisions and J/Ψ radiative decays
- None of the above states can be interpreted as pure glue $\rightarrow$ mixing with $q\bar{q}$
- Using WA102 (central production) and BES (J/Ψ decays) data, Close and Zhao conclude that:
  - $f_0(1370)$ is mainly an $n\bar{n}$ ($n = u, d$) object
  - $f_0(1500)$ is mainly made of glue
  - $f_0(1710)$ is mainly an $s\bar{s}$ object

Overview of glueball candidates - continued

- The $f_0(1370)$, $f_0(1500)$ and $f_0(1710)$ seem to be well established
- However, their interpretation in terms of mixing of the scalar glueball with $q\overline{q}$ states is not universally accepted
- Candidates for the tensor (2^{++}) and pseudoscalar (0^{-+}) are not yet assigned

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The $J^{PC} = 1^{-+}$ exotic mesons

- Three $J^{PC} = 1^{-+}$ mesons have been observed:
  - $\pi_1(1400)$, decaying into $\eta\pi$ and $\rho\pi$
  - $\pi_1(1600)$, decaying into $\eta'\pi$, $\rho\pi$, $f_1(1285)\pi$ and $b_1(1230)\pi$
  - $\pi_1(2000)$, decaying into $f_1(1285)\pi$ and $b_1(1230)\pi$
- $\pi_1(1400)$ and $\pi_1(1600)$ have been reported in diffractive πN scattering (VES and E852) and $\overline{p}p$ annihilations (Crystal Barrel/Obelix)
- $\pi_1(2000)$ has been only seen by E852

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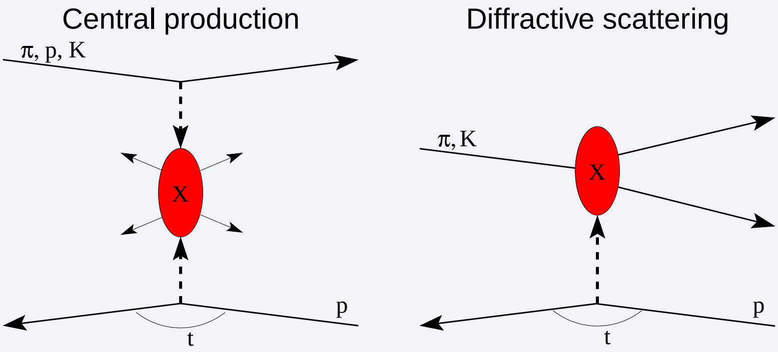


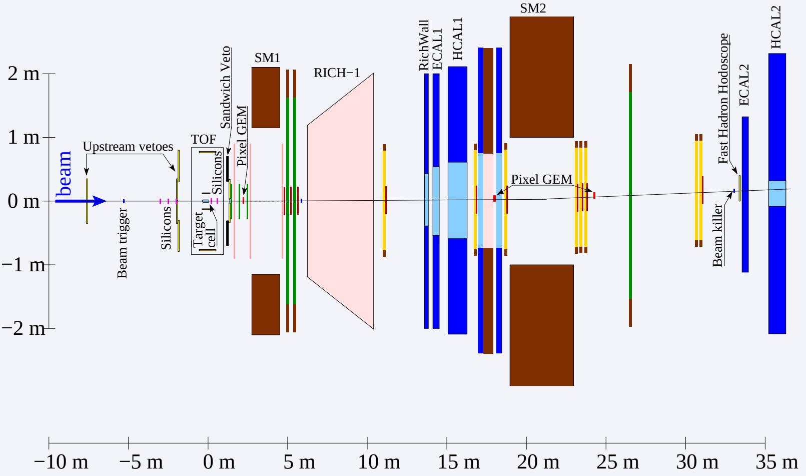
WA76, WA91, NA12/2, WA102 and E690

VES and E852

Target recoils with $-t \lesssim 1\ (\text{GeV}/c)^2$

The COMPASS experimental apparatus

Only elements specific to the measurements with hadron beams are marked



Main characteristics of the hadron setup

- Beam: 190 GeV negative hadrons
  $\sim$96% π^-, $\sim$3.5% K^-, $\sim$0.5% $\bar{p}$
- Beam particle identification by means of CEDAR counters
- Beam intensity: $\sim 5 \cdot 10^6$ had/s (10s bounches every 40s)
- Target: liquid hydrogen, 40 cm long
- Luminosity: 0.15 pb^{-1}/day
- Two-stage magnetic spectrometer with excellent momentum resolution
- Hadron identification up to $\sim$ 50 GeV (RICH-1)
- Electromagnetic and hadron calorimetry
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- Fast DAQ and high trigger rate capabilities, allowing for high beam intensities

Main characteristics of the hadron setup

- Beam: 190 GeV negative hadrons
  $\sim$96% π^-, $\sim$3.5% K^-, $\sim$0.5% $\overline{p}$
- Beam particle identification by means of CEDAR counters
- Beam intensity: $\sim 5 \cdot 10^6$ had/s (10s bounches every 40s)
- Target: liquid hydrogen, 40 cm long
- Luminosity: 0.15 pb^{-1}/day
- Two-stage magnetic spectrometer with excellent momentum resolution
- Hadron identification up to $\sim$ 50 GeV (RICH-1)
- Electromagnetic and hadron calorimetry
- Fast DAQ and high trigger rate capabilities, allowing for high beam intensities

Key features

- General pourpose spectrometer
  - Charged and neutral decay modes are accessible
  - Data from central production and diffractive scattering can be collected in parallel
- Large angle acceptance:
  - $\pm$180 mrad for charged particles
  - $\pm$140 mrad for gammas
- Wide kinematical coverage:
  - Full charged particle tracking up to the beam region
  - Good momentum determination for 1 GeV/c and above
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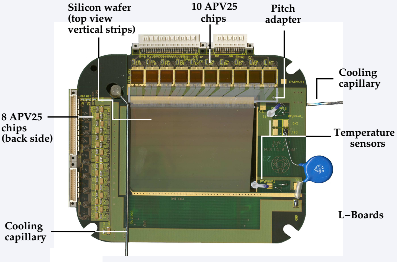
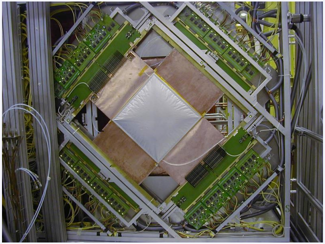
COMPASS tracking detectors (not complete. . .)

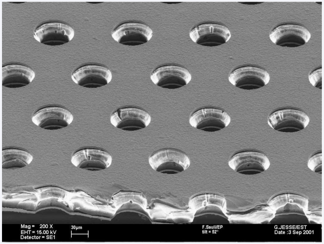
Silicon detectors (10 μm)



Micromegas (90 μm)



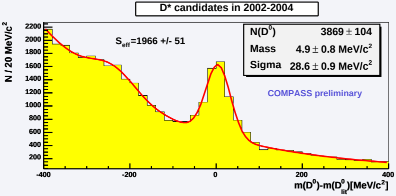
GEMs (70 μm)



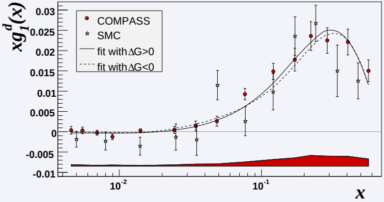
Straws (190 μm)

Selected COMPASS muon beam results

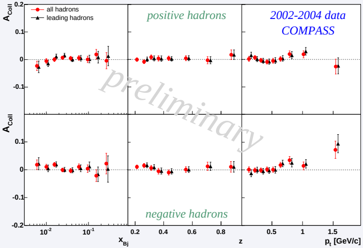
D^* reconstruction



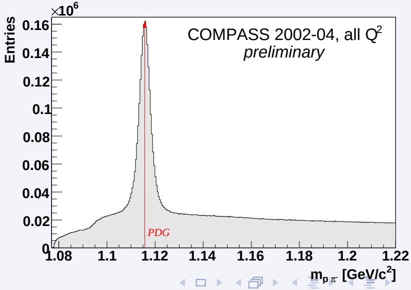
$xg_1^d(x)$



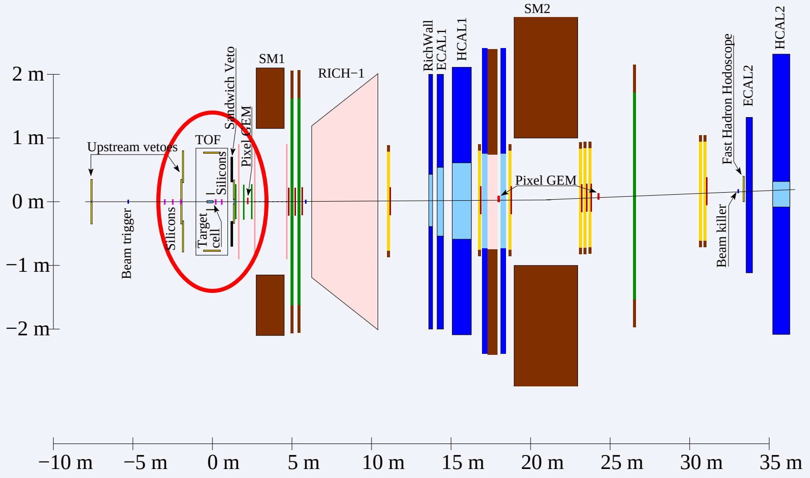
Collins asymmetries



Λ reconstruction



Target and target region



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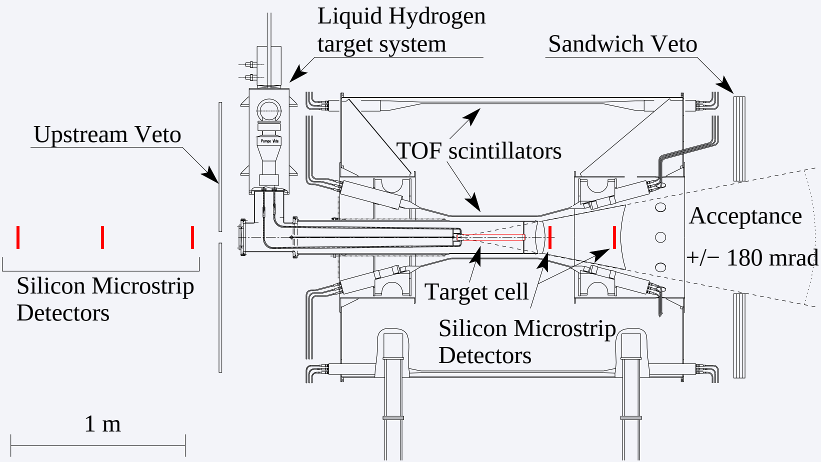
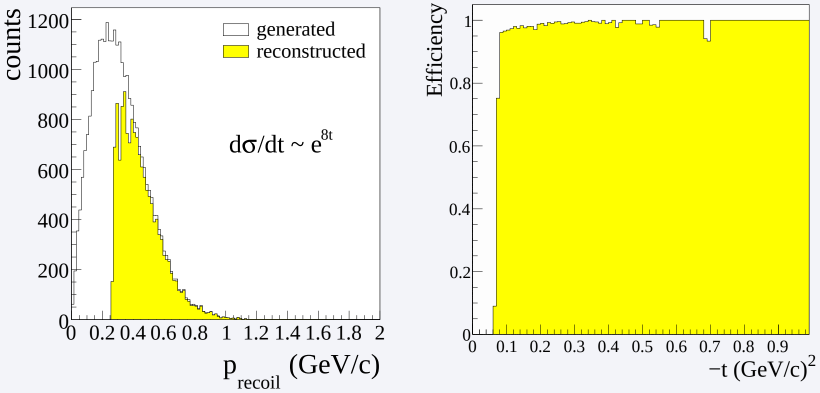


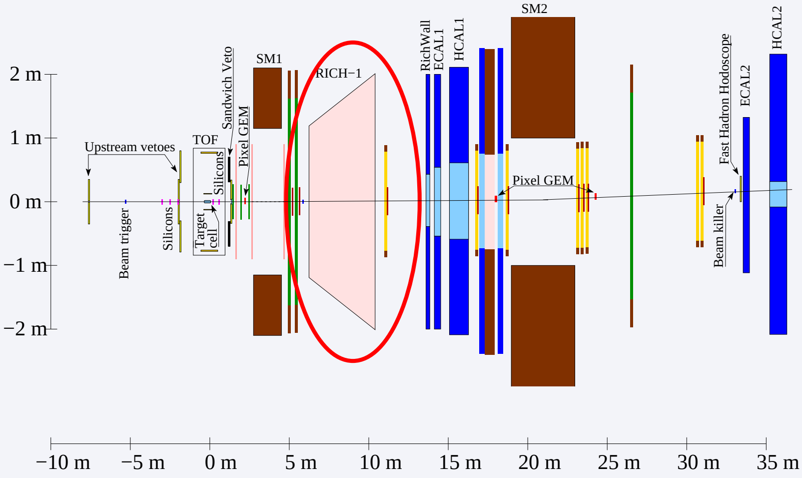
Detection of target recoil protons

Simulated recoil protons from diffractive $\pi^- p$ scattering



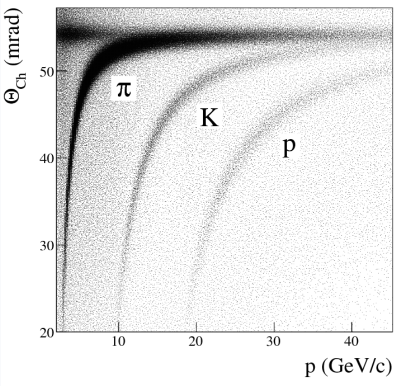
Full acceptance for $-t \gtrsim 0.06\ (\text{GeV}/c)^2$

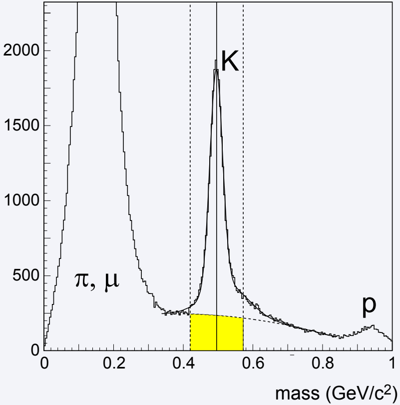
Hadron identification



Hadron identification

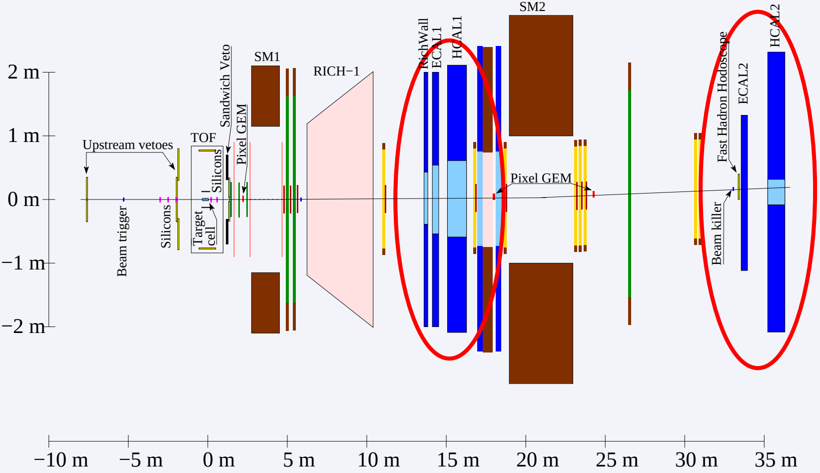
Hadron identification from RICH-1, 2004 muon beam data





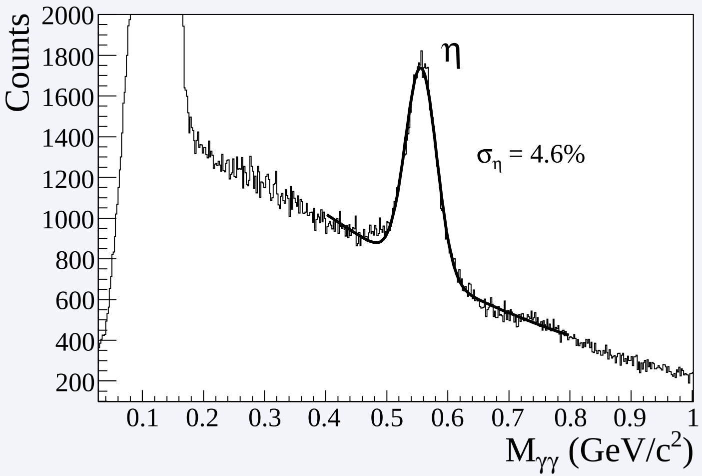
$\pi - K$ separation between $\sim$ 10 GeV/c and $\sim$ 45 GeV/c

Electromagnetic calorimetry



Electromagnetic calorimetry

2γ invariant mass reconstructed in ECAL2, 2004 hadron beam



Some results of CP & DP Monte Carlo simulations

- Full simulation of COMPASS detector response and event reconstruction was performed
- Some selected channels of central production and diffractive scattering studied:
  - Central production ($\pi^- p \rightarrow \pi^- X\ p_s$):
    - $X \rightarrow \eta\eta$, $M_X = 1.5, 2, 2.5$ GeV/c^2
    - $X \rightarrow 2\pi^+ 2\pi^-$, $M_X = 1.0, 1.5, 2$ GeV/c^2
  - Diffractive scattering ($\pi^- p \rightarrow X\ p_s$):
    - $X \rightarrow \pi^+ 2\pi^-$, $M_X = 1.6$ GeV/c^2
    - $X \rightarrow \eta\pi$, $M_X = 2.0$ GeV/c^2

Mass resolutions and reconstruction efficiencies

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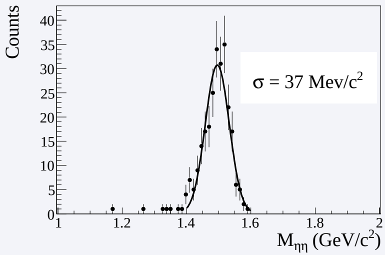
Mass resolutions and reconstruction efficiencies

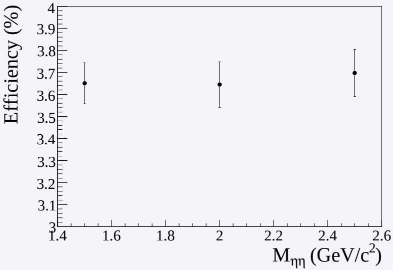
Central $\eta\eta$ production (simulated)

$$\pi^- p \rightarrow \pi^- X p_s, X \rightarrow \eta\eta, \eta \rightarrow 2\gamma$$

Reconstructed $\eta\eta$ invariant mass



Reconstruction efficiency vs. mass



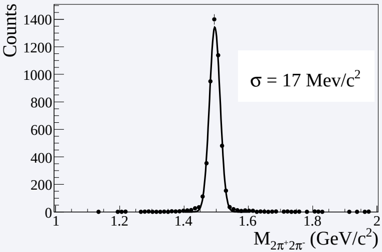
- γs from η decays detected in ECAL1&2
- Reconstruction efficiency is $\sim$ 3.5% up to 2.5 GeV/c^2
- We expect $\sim$ 100 $f_0(1500)$/day in $\eta\eta$ channel

$$\sigma(f_0(1500)) \simeq 3\ \mu\text{b},\ BR(f_0(1500) \rightarrow \eta\eta) \simeq 0.05,\ BR(\eta \rightarrow 2\gamma) = 0.39$$

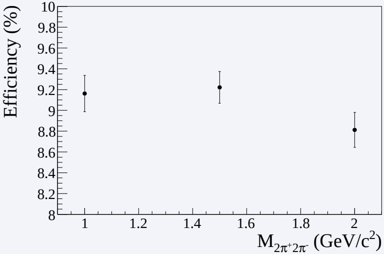
Central $2\pi^+2\pi^-$ production (simulated)

$$\pi^- p \rightarrow \pi^- X p_s, X \rightarrow 2\pi^+2\pi^-$$

Reconstructed $2\pi^+2\pi^-$ invariant mass



Reconstruction efficiency vs. mass



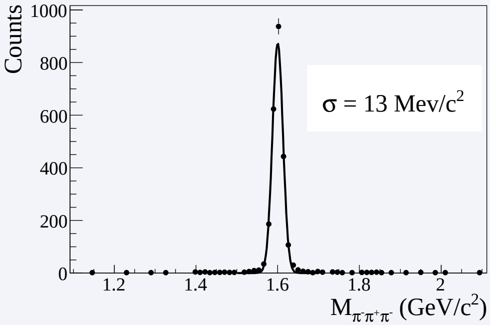
- Reconstruction efficiency is $\sim$ 9% up to 2.0 GeV/c^2
- We expect $\sim 6 \cdot 10^3$ $f_0(1500)$/day in $2\pi^+2\pi^-$ channel

$$\sigma(f_0(1500)) \simeq 3\ \mu b,\ BR(f_0(1500) \rightarrow 2\pi^+2\pi^-) \simeq 0.16$$

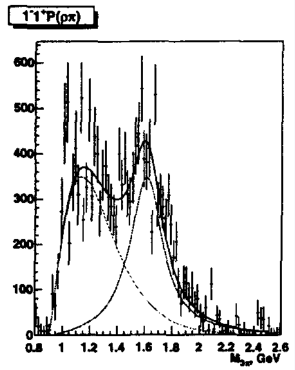
Diffractive $\pi^+2\pi^-$ production (simulated)

$$\pi^- \; p \;\rightarrow\; X(1600)\, p_S,\, X(1600) \;\rightarrow\; \pi^+2\pi^-$$

Reconstructed $\pi^+2\pi^-$ invariant mass



VES (Nucl. Phys. A663 (2000) 596c)



- Geometrical acceptance is $\sim 100\%$
- Reconstruction efficiency is $\sim 20\%$
- We expect $\gtrsim 6 \cdot 10^6$ events/day in $\pi^+2\pi^-$ channel

Outline

Conclusions

- Identification of glueballs and hybrids is still an open issue
- Several questions remain, among which:
  - Existence/assignment of the scalar glueball
    is the $f_0(1500)$ interpretation correct?
  - Systematic study of the ~ 2 GeV/c^2 mass region
  - Systematic study of the $J^{PC} = 1^{-+}$ mesons,
    to identify all states (hybrids, 4-qarks, ...)
- COMPASS can contribute to all those question, collecting in parallel:
  - data with π^- and K^- beams UNIQUE!
  - data for central and peripheral collisions

  with a state-of-the-art experimental appartus and DAQ
- First $h^- p$ run is planned for Autumn this year

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