COMPASS Hadron spectroscopy –
Neutral & kaonic final states

Frank Nerling
Universität Freiburg, Physikalisches Institut

on behalf of the
COMPASS Collaboration

11th Internationl workshop on Meson Production, Properties & Interaction
Krakow, Poland, 10-15 June 2010

Outline:

- **Introduction**
  - The COMPASS experiment & light meons spectroscopy
  - PWA method: 3π final states (diffractive, charged, 2004 data)
- **First results on diffractive production** (2008 data)**:**
  - **Neutral channels**
    - 3π final states neutral vs. charged mode (first PWA fits - main waves)
    - Further ongoing analyses
  - **Kaonic channels**
    - $(K\bar{K}\pi)^-$: $K_sK_s\pi^-$, $K^+K^-\pi^-$ mass spectra
    - Further ongoing analyses
- **Conclusions & outlook**

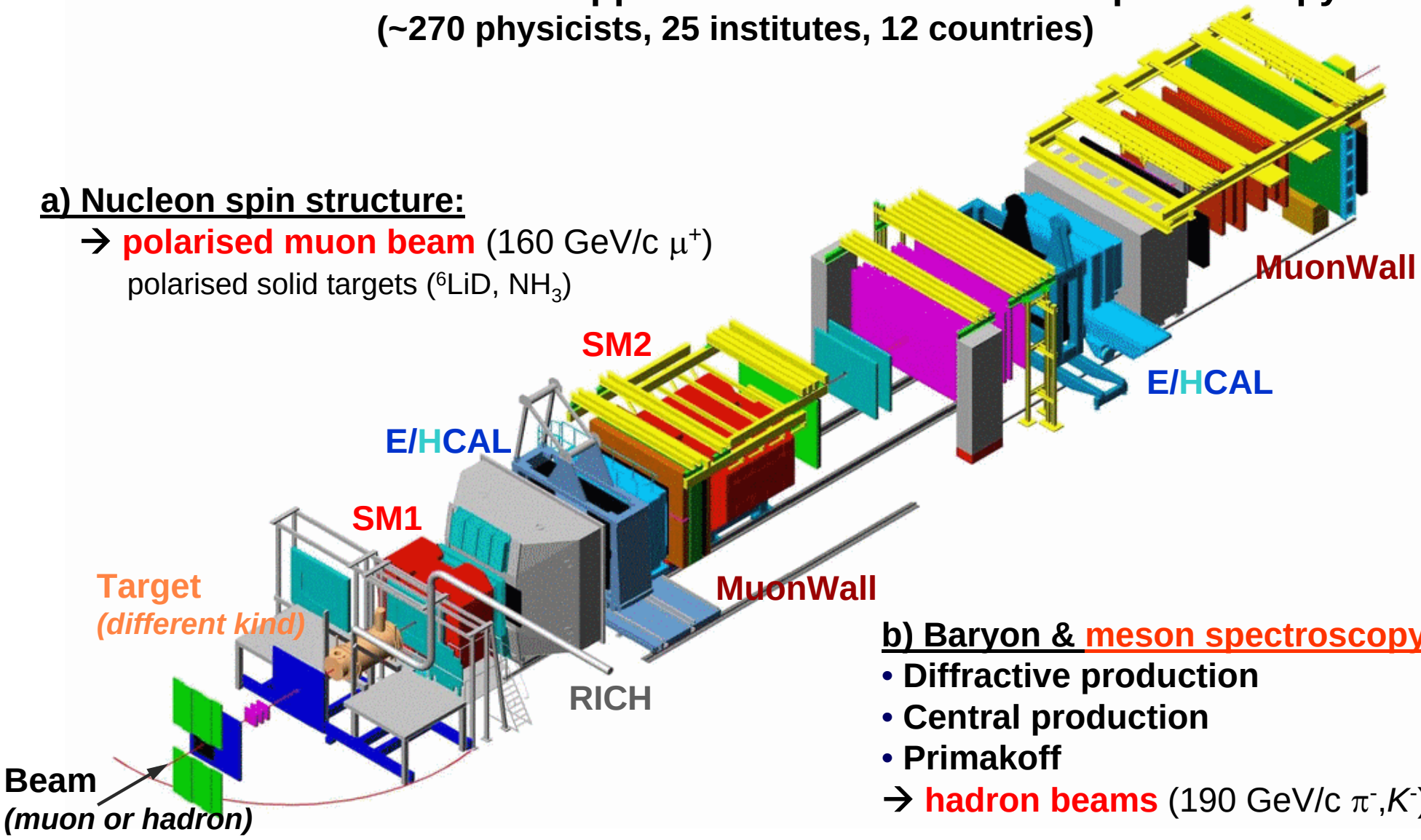
bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

The COMPASS experiment

COmmon Muon Proton Apparatus for Structure and Spectroscopy
(~270 physicists, 25 institutes, 12 countries)

a) Nucleon spin structure:

→ **polarised muon beam** (160 GeV/c μ^+)
polarised solid targets (^{6}LiD, NH_3)



b) Baryon & meson spectroscopy:

- **Diffractive production**
- **Central production**
- **Primakoff**

→ **hadron beams** (190 GeV/c π^-,K^-)

[hep-ex/0703049, NIM A 577, 455 (2007)]

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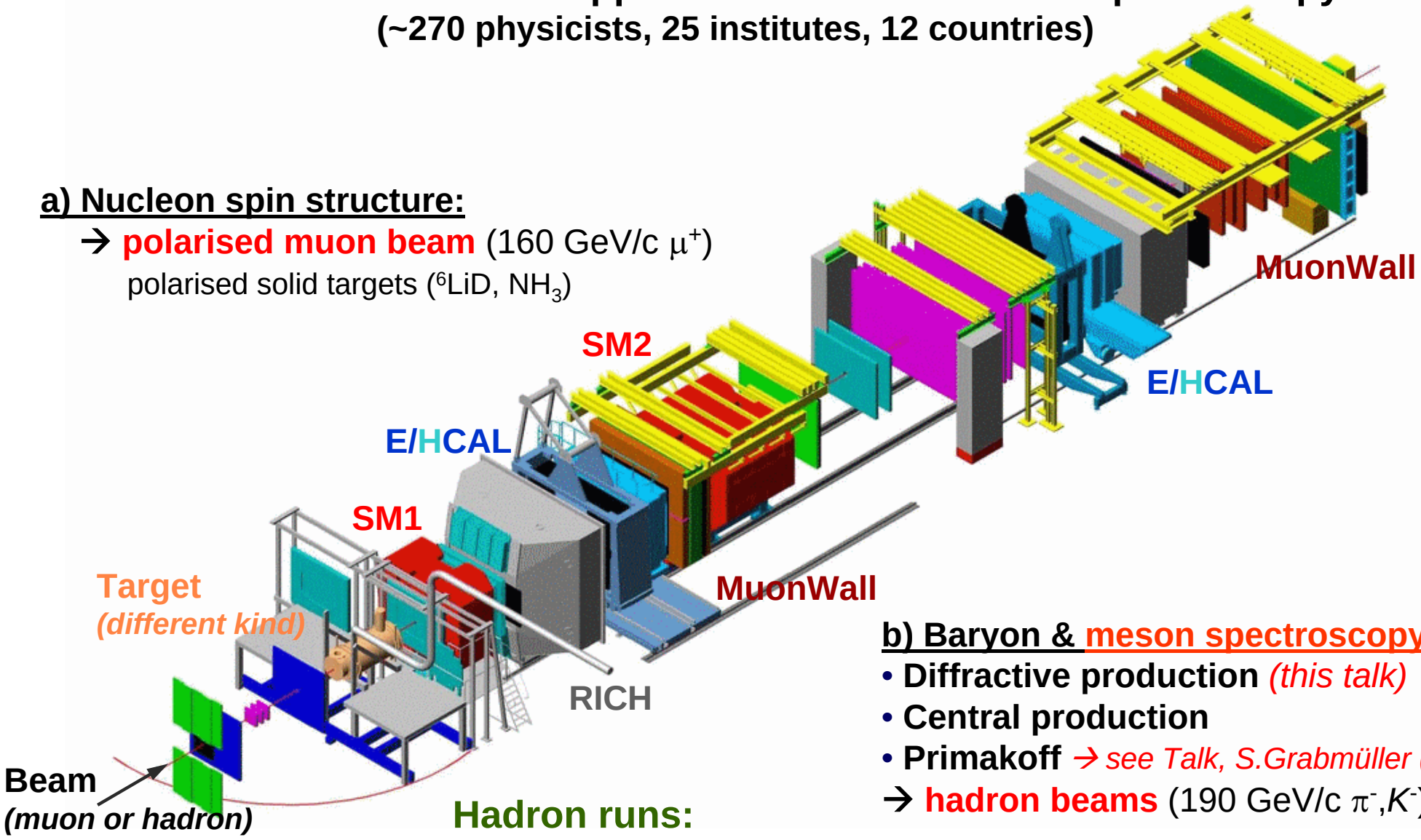


b) Baryon & meson spectroscopy:

- **Diffractive production** *(this talk)*
- **Central production**
- **Primakoff** → *see Talk, S.Grabmüller (B4)*

→ **hadron beams** (190 GeV/c π^-,K^-)

Hadron runs:

- **2004 pilot run** (4 days π^- on Pb target: ~BNL statistics)
- **2008/09** (10-100x world stats (LH_2), $\pi^\pm$, $K^\pm$, $p^\pm$ beam, *plus nuclear targets*)

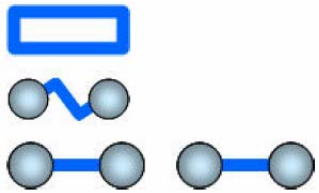
Mesons and Spin Exotic States

Constituent quark model

- color neutral $q\bar{q}$ systems
- Quantum numbers $I^G J^{PC}$
- $P = (-1)^{L+1}$ $C = (-1)^{L+S}$ $G = (-1)^{I+L+1}$
- J^{PC} *multiplets:* 0^{++} , 0^{-+}, 1^{--}, 1^{+-}, 1^{++}, 2^{++}, …
- *Forbidden:* 0^{--}, 0^{+-} , 1^{-+}, 2^{+-}, 3^{-+}, …

QCD: meson states beyond

- Glueballs: gg, ggg
- Hybrids: $q\bar{q}g$
- Tetraquarks: $(q\bar{q})(q\bar{q})$



Hybrid candidates (1.3 - 2.2 GeV/c²):

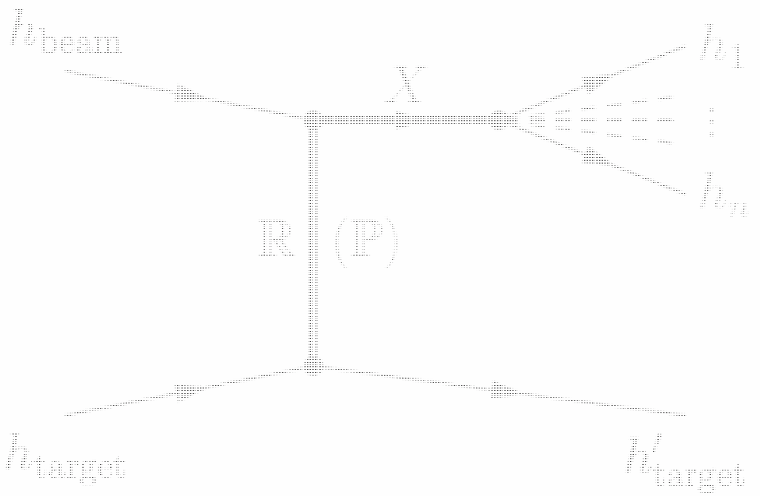
lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$

- $\pi_1(1400)$: VES, E852, Crystal Barrel –> $\eta\pi$
- $\pi_1(1600)$: E852, VES –> $\rho\pi$, $\eta'\pi$, $f_1\pi$, $b_1\pi$
- $\pi_1(2000)$: E852 –> $f_1(1285)\,\pi$, $b_1(1235)\,\pi$

…. *still controversial* → *COMPASS*

Diffractive scattering

- study of J^{PC} exotic mesons
- t-channel Reggeon exchange
- forwards kinematics, target stays intact



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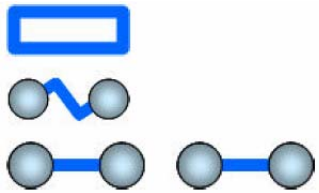

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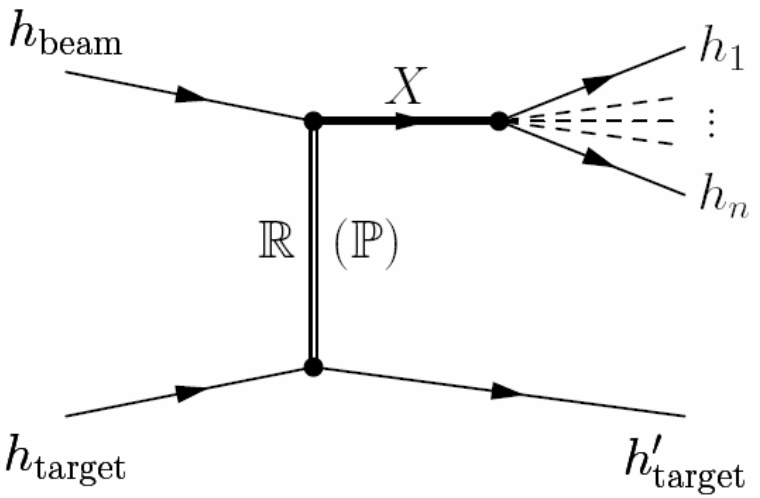

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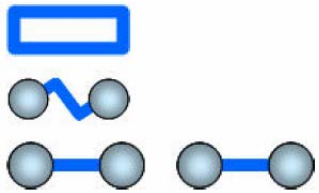

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Diffractive pion dissociation

- incoming π^- excited to resonance X^-
- X^- decays into final state, e.g. $(3\pi)^-$:
  π^- **p** —> $\pi^-\pi^+\pi^-$ **p** (charged mode)
- small momentum transfer

Diffractive scattering

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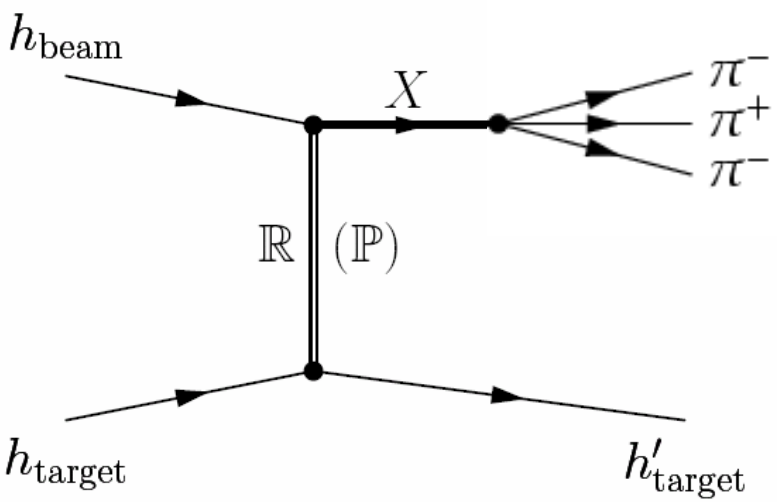
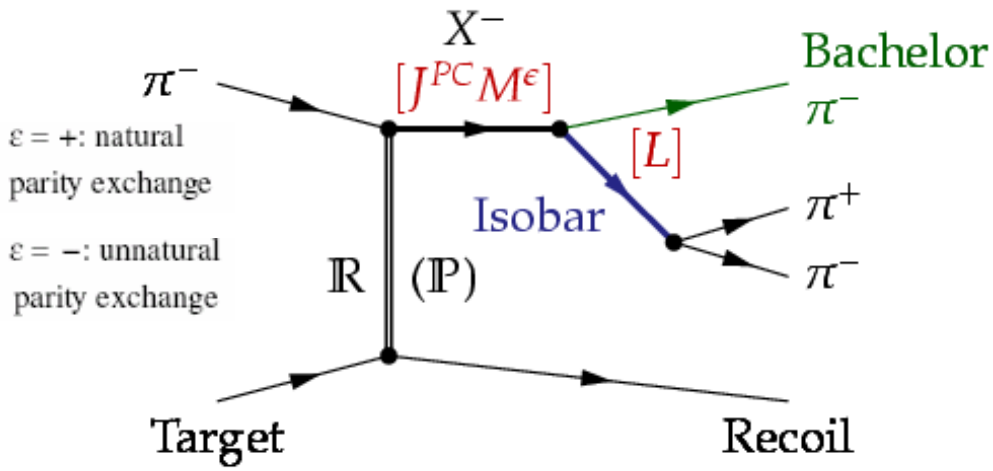


PWA using isobar model



X^- decay described using isobar model:

- Intermediate di-pion resonance (isobar)
  - *Spin S and rel. orbital angular momentum L w.r.t bachelor π^-*
  - *L+S couple to J*
- Partial waves (reflectivity basis): $J^{PC}\ M^{\varepsilon}$ [isobar] L

Partial wave analysis:

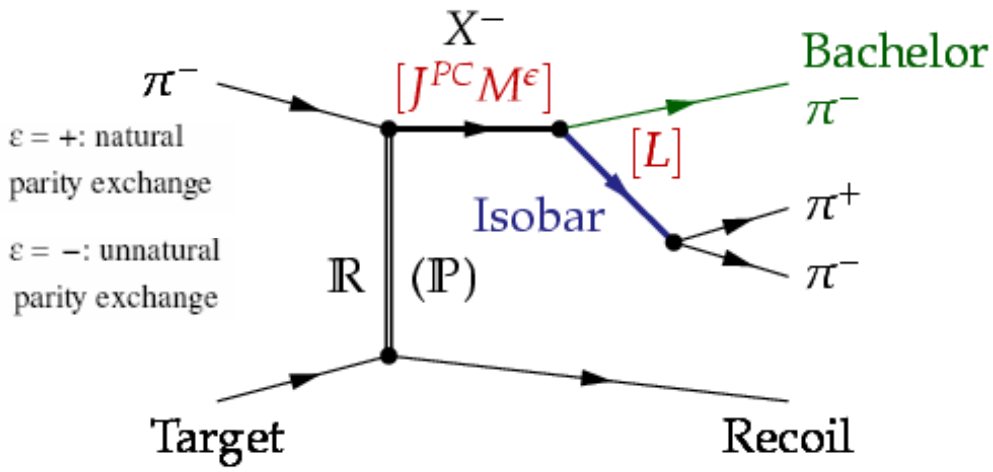
- **program:** Illinois/Protvino/Munich (D.Ryabchikov) software (IHEP/VES, TUM/COMPASS)
- **Isobars:** *$(\pi\pi)_S$ [broad $f_0(600)$+$f_0(1370)$], $f_0(980)$, $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$*
- **Acceptance:** corrections included (2004: ~60%, rather flat)

Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm1} \sum_{r=1}^{N_r} \left| \sum_i T^{\epsilon}_{ir} f^{\epsilon}_i(t') \psi^{\epsilon}_i(\tau, m) / \sqrt{\int \left|\psi^{\epsilon}_i(\tau', m)\right|^2 d\tau'} \right|^2$$

- Production amplitudes $T^{\epsilon}_{ir} \rightarrow$ extended maximum likelihood fit
- Decay amplitudes $\psi^{\epsilon}_i(\tau, m)$ (Zemach tensors, D functions)

PWA using isobar model



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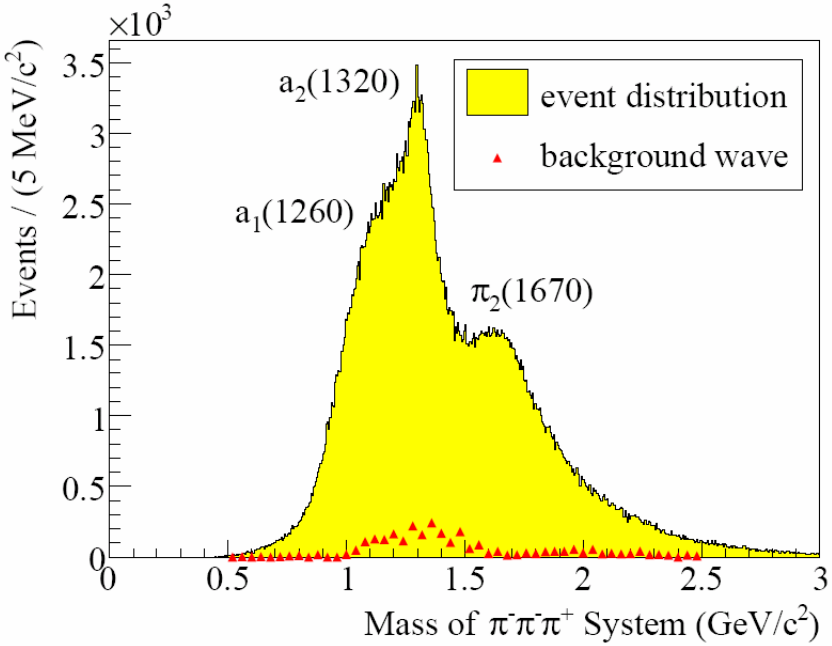
Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

Step 2) Mass dependent χ^2 fit: (to mass independent result)

- 6 main partial waves chosen, parameterised by Breit-Wigner
- Coherent background for some waves

Diffractive dissociation into 3π final states
(2004 data, Pb target) [PRL accepted]



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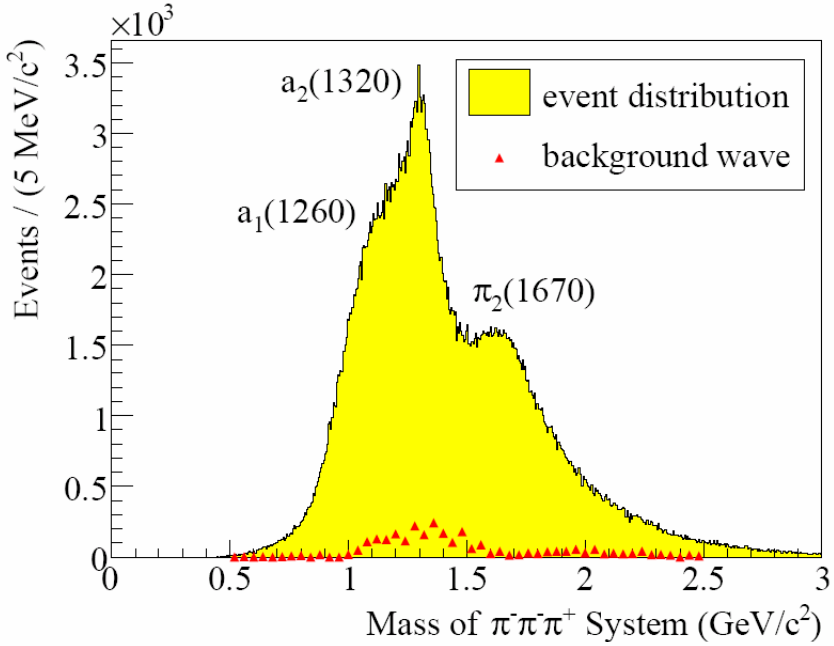

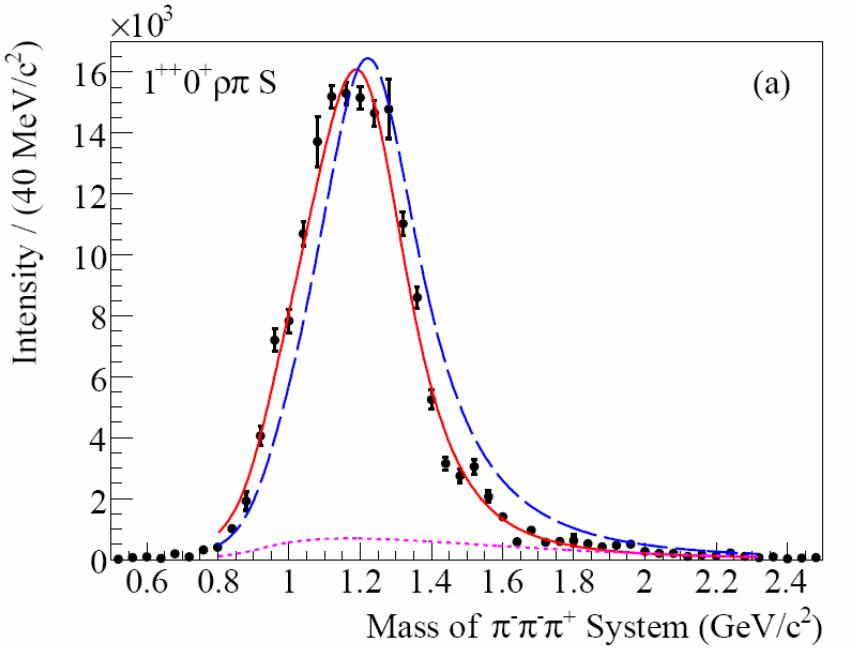

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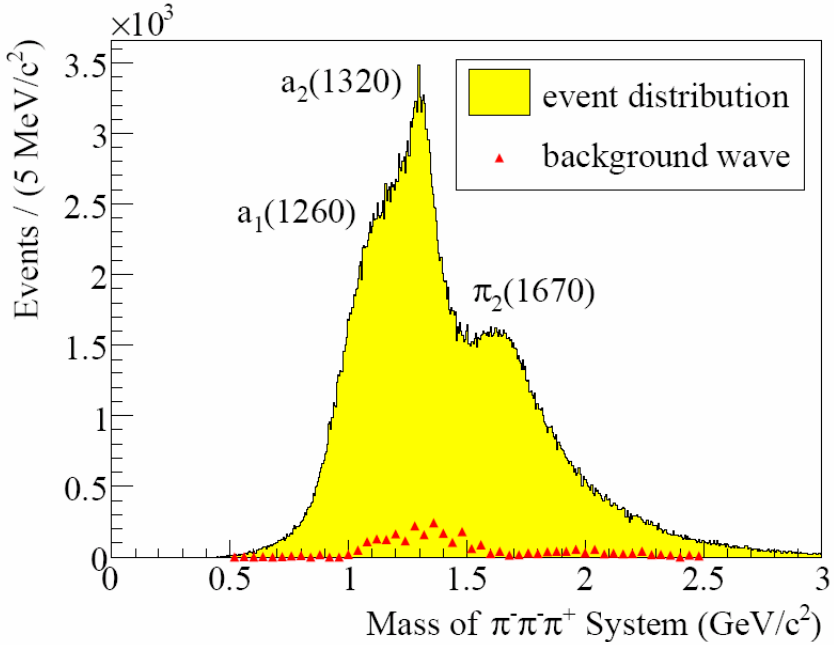

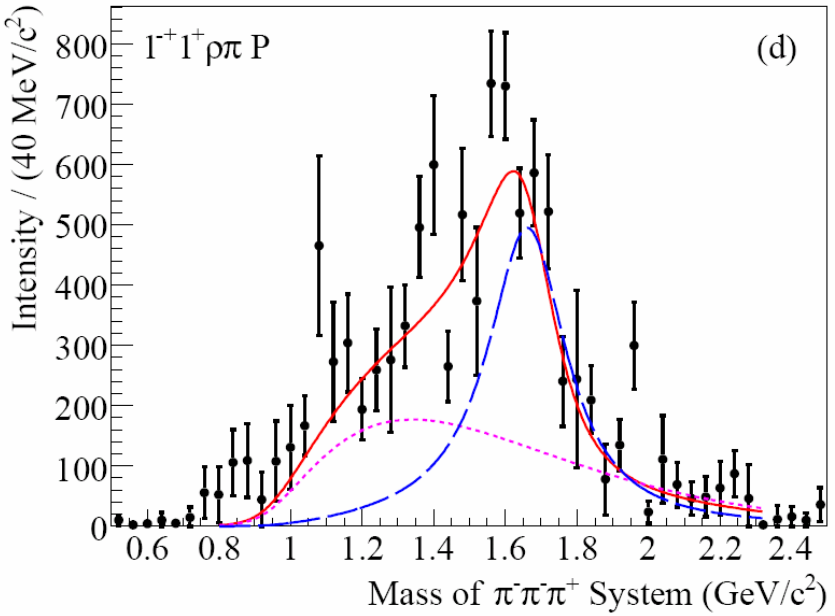

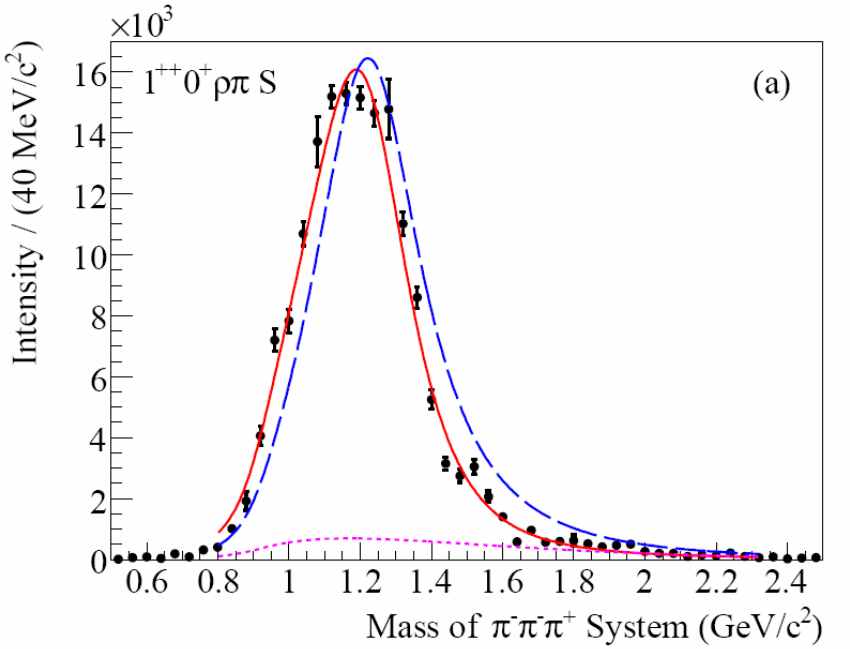

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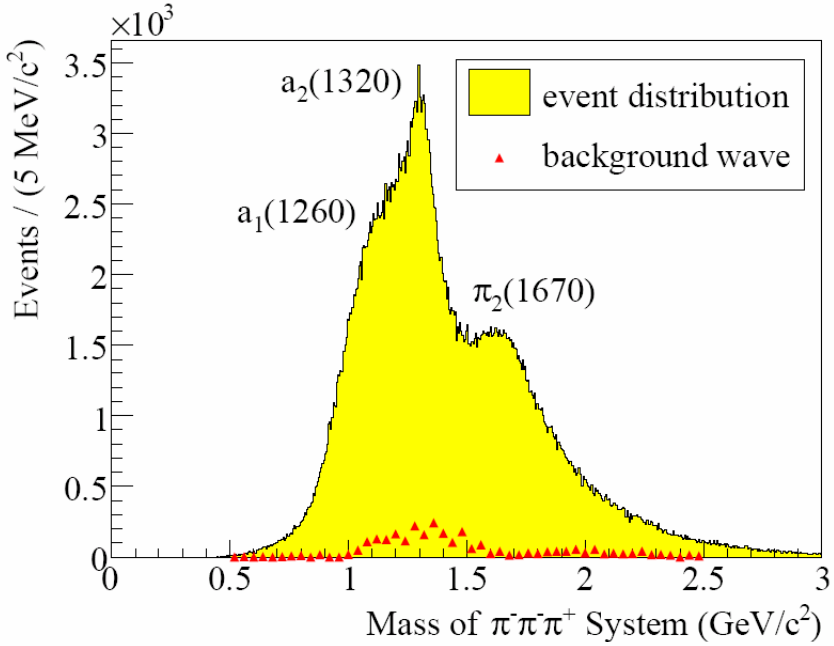

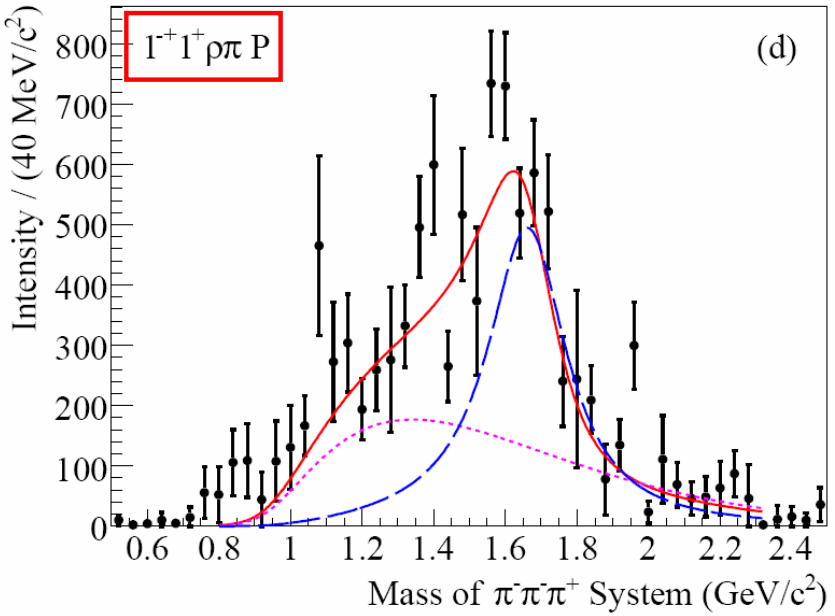

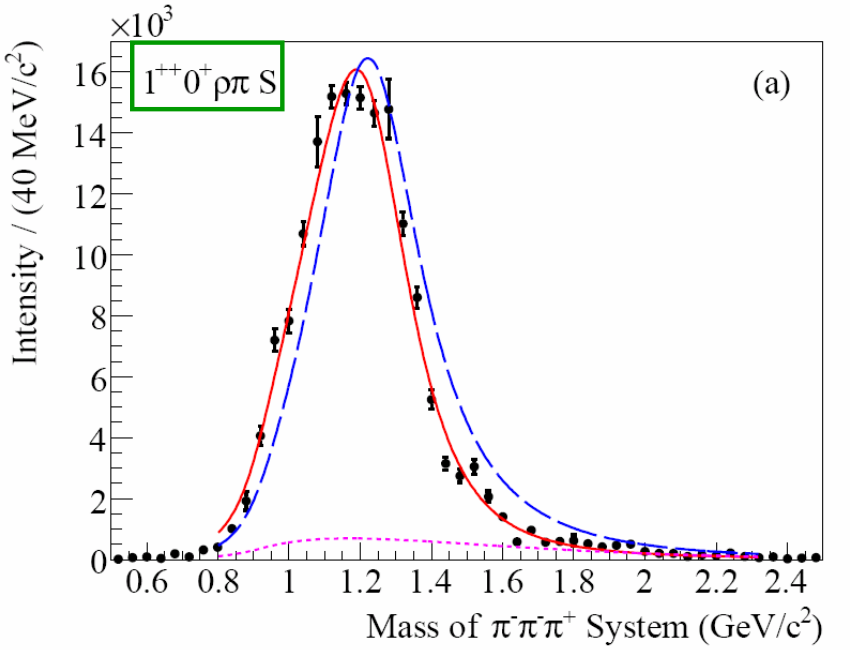

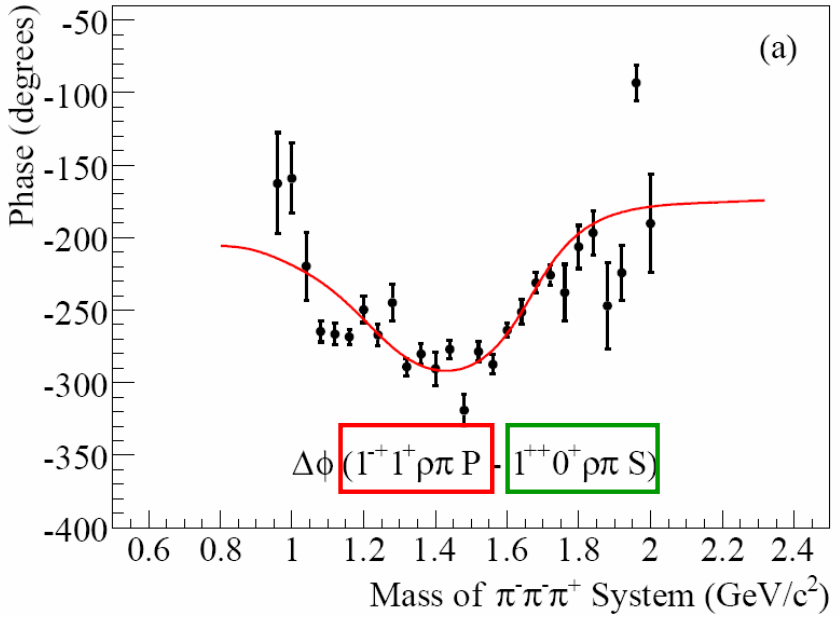

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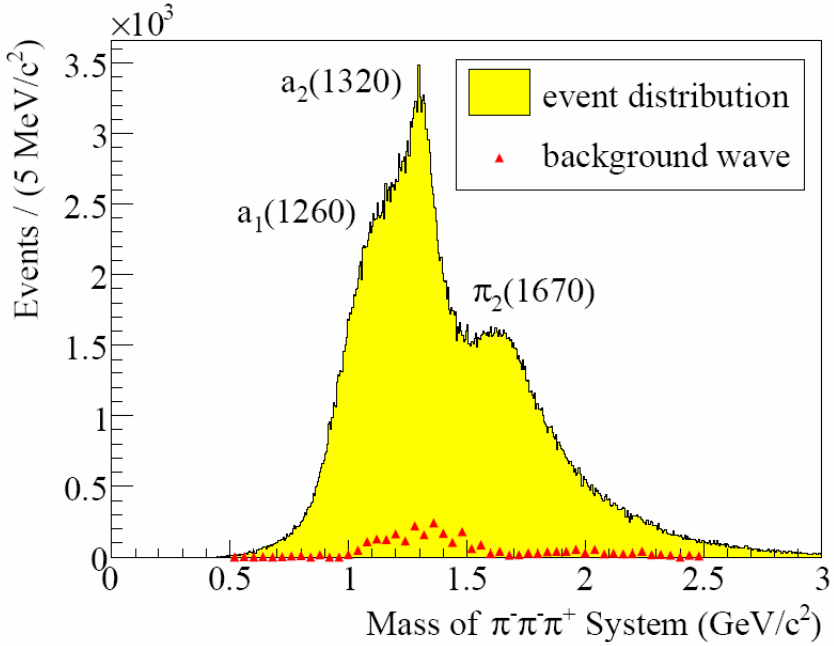
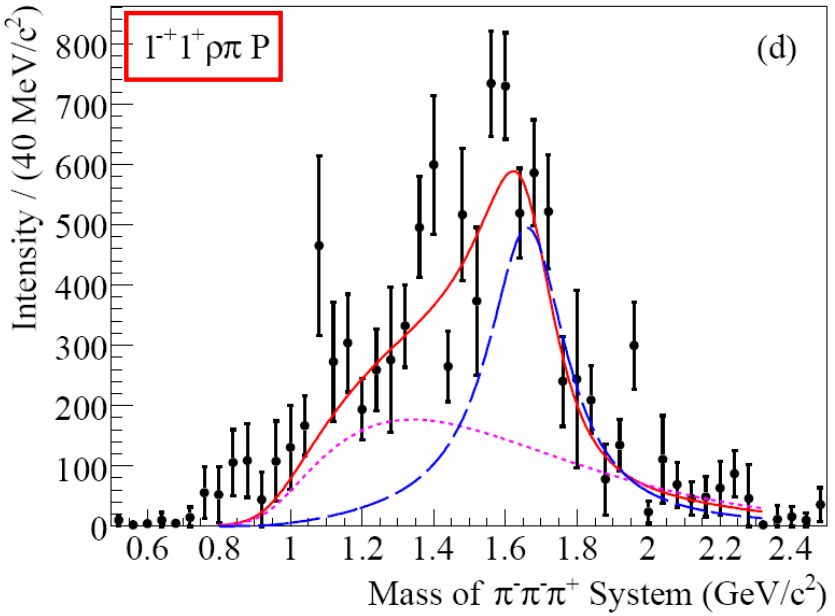
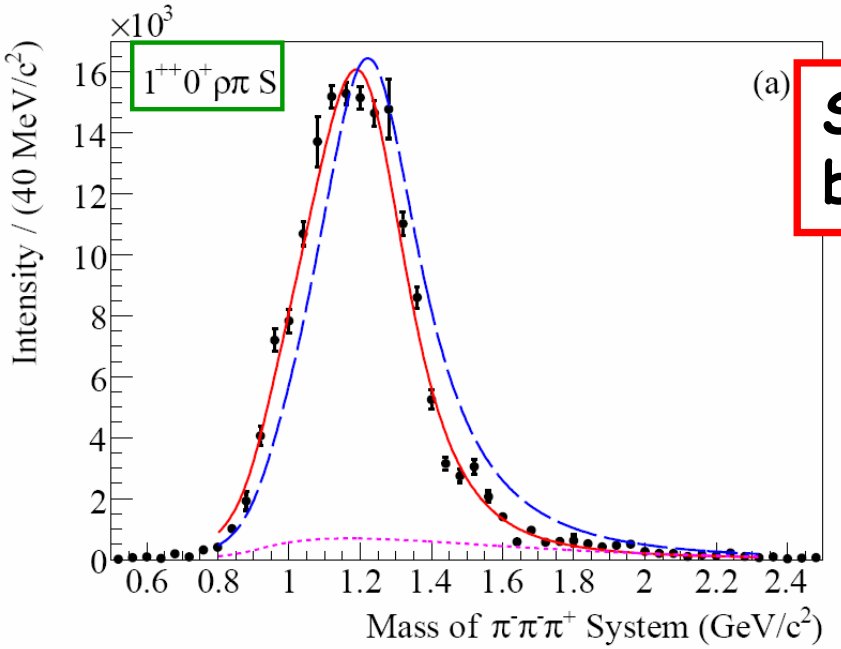
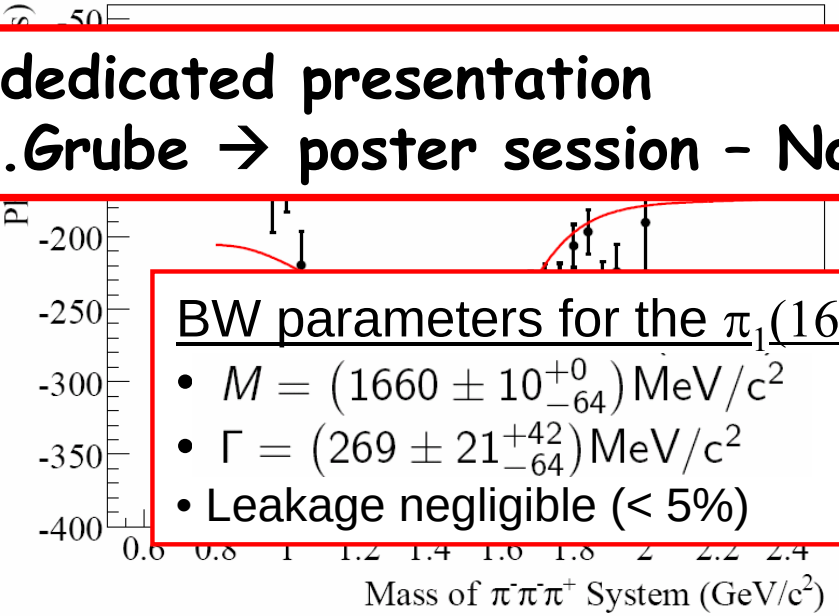






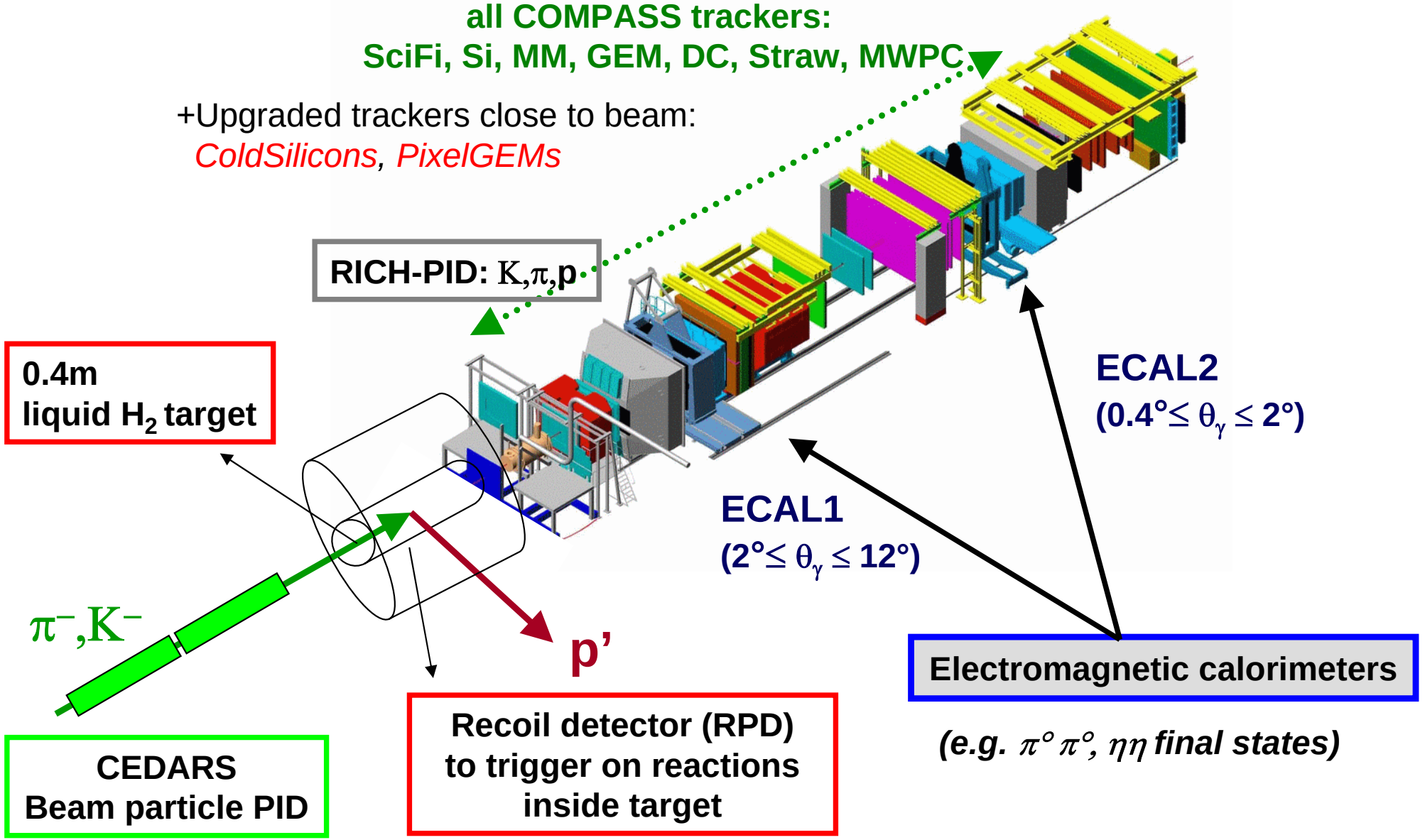


See dedicated presentation by B.Grube → poster session – No 14

BW parameters for the $\pi_1(1600)$:

- $M = \left(1660 \pm 10^{+0}_{-64}\right) \mathrm{MeV}/c^2$
- $\Gamma = \left(269 \pm 21^{+42}_{-64}\right) \mathrm{MeV}/c^2$
- Leakage negligible (< 5%)

COMPASS spectrometer: Hadron setup 2008/09



Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

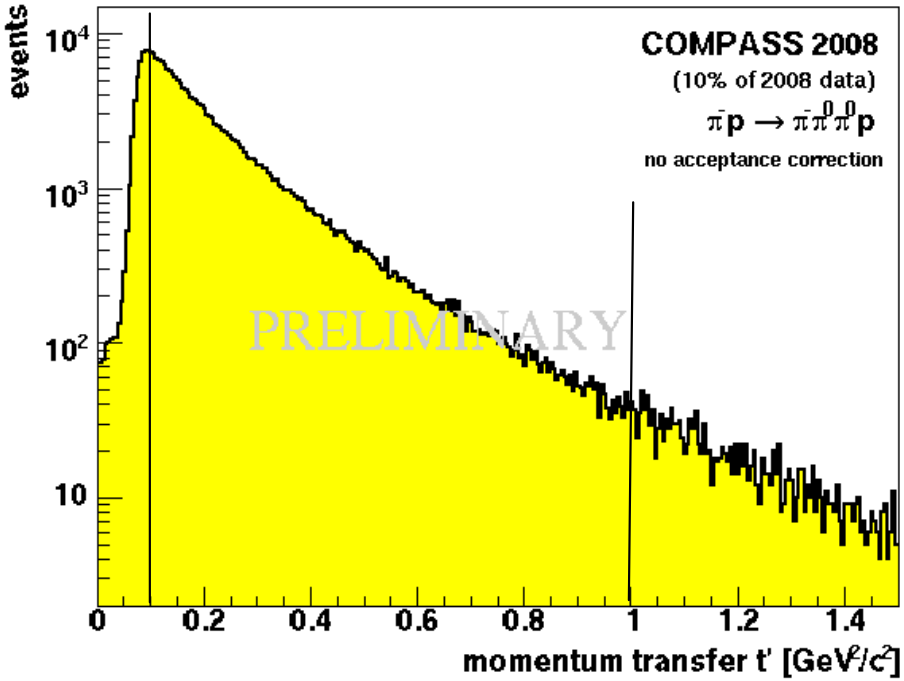
Analysis of 2008 data
(liquid hydrogen target, beam: 94.7% π^-, 4.6% K^-, 0.7% $\bar{p}$)

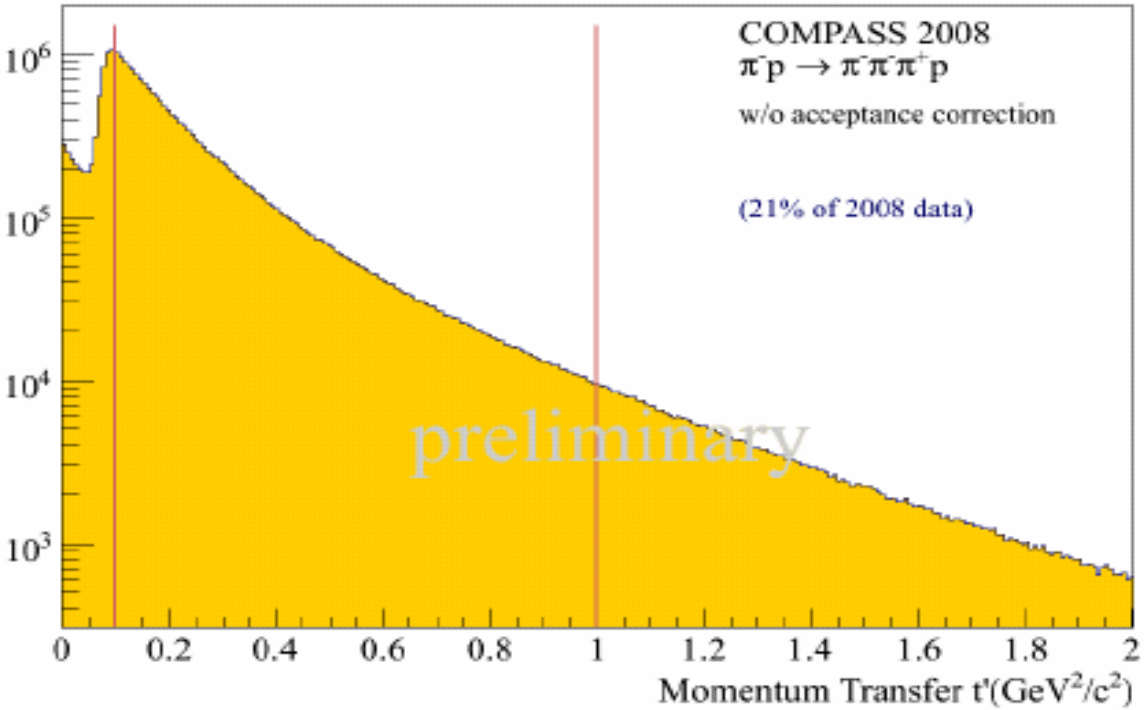
- **Simultanous observation in neutral mode:**
  - **-> 3π** *example:*
    - ✓ π^- **p** —> $\pi^-\pi^+\pi^-$ **p** (charged mode)
    - ✓ π^- **p** —> $\pi^-\pi^0\pi^0$ **p** (neutral mode)
  - **-> independent measurement** *(same apparatus)*
    - => important cross checks
    - => confirmation of any *new state observed*
  - **-> First look into charged vs. neutral mode** *(main waves)*
    - **=> Isospin symmetry check** *(mass independent fit)*

Diffractive dissociation into 3π final states
(2008 data, LH_2 target)

neutral mode

charged mode





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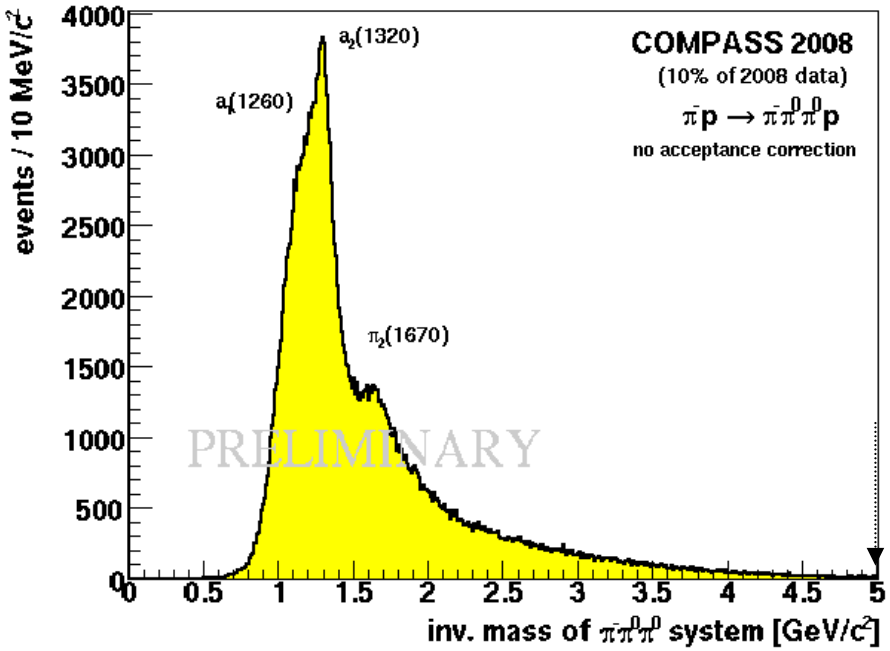
Mass of outgoing π system -- neutral mode



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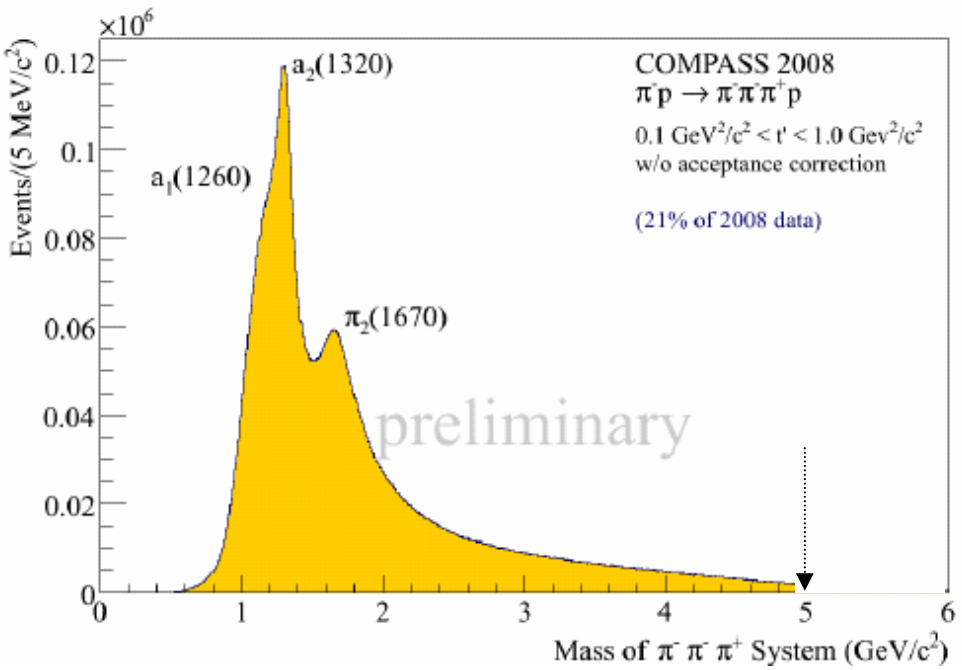
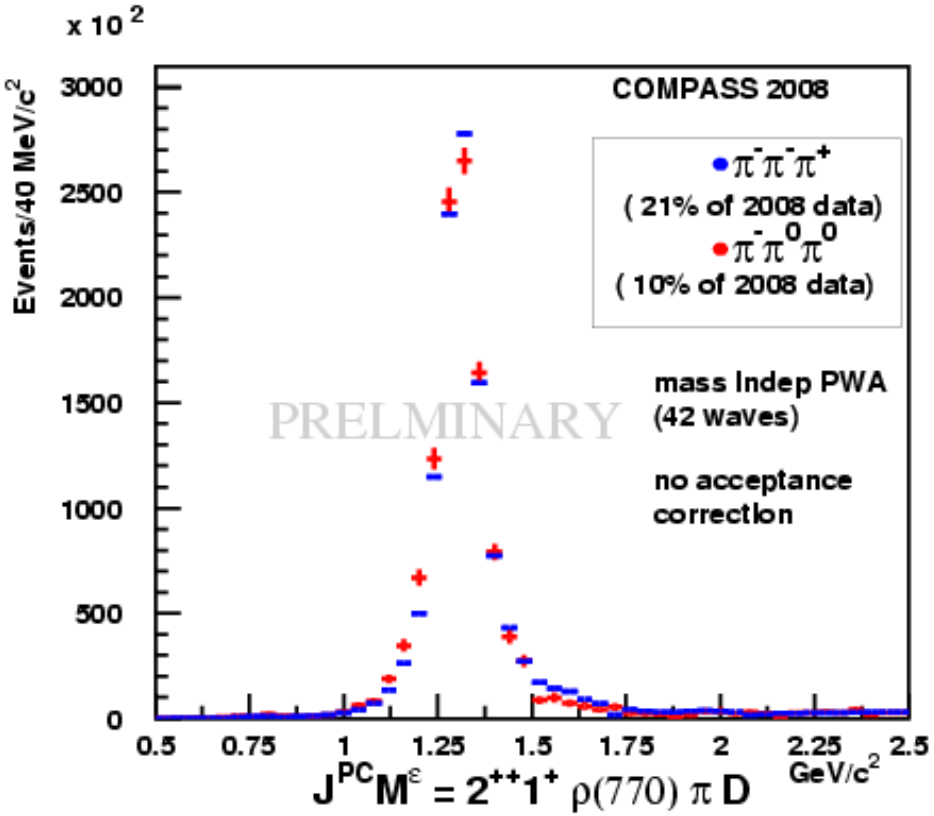
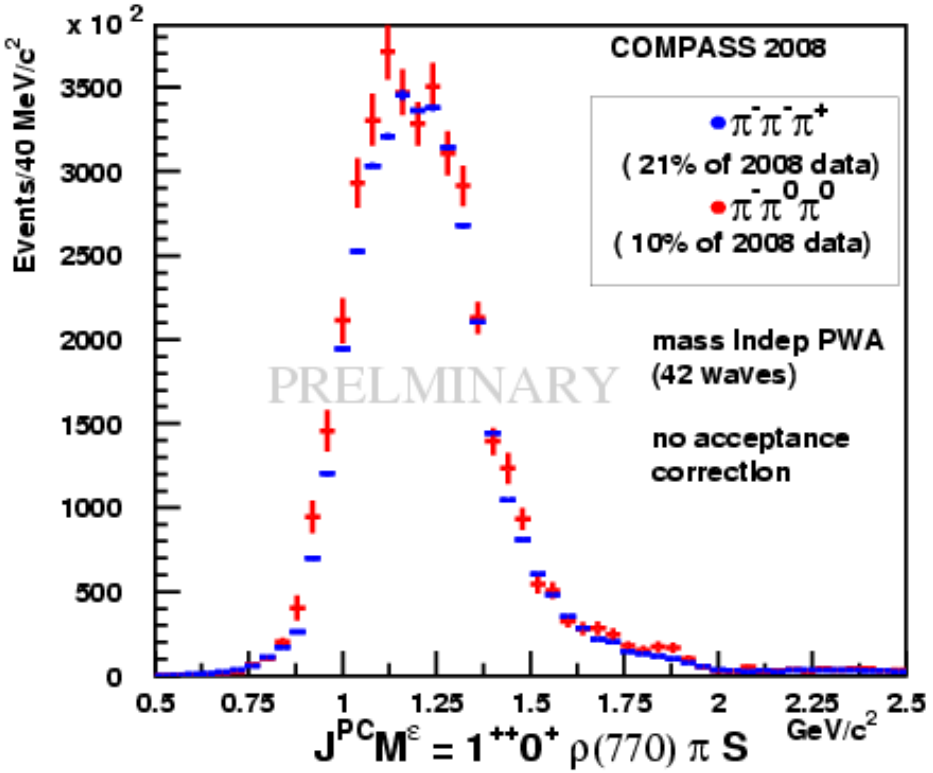


First comparison: Neutral vs. charged mode

$a_2(1320)$ – normalisation & $a_1(1260) \rightarrow \rho\pi$



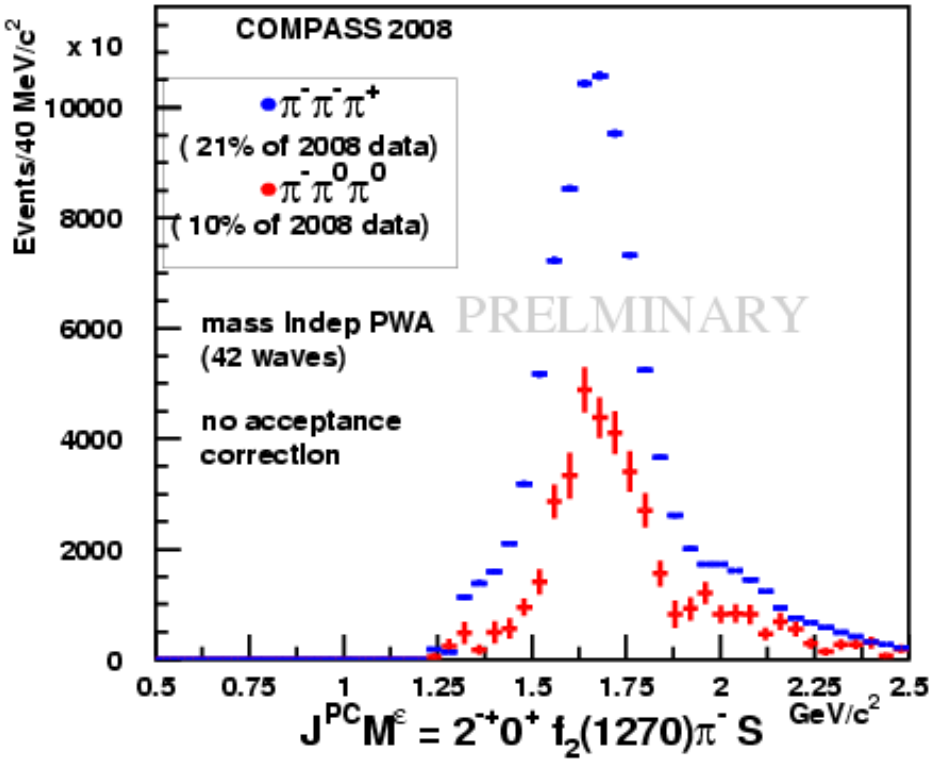


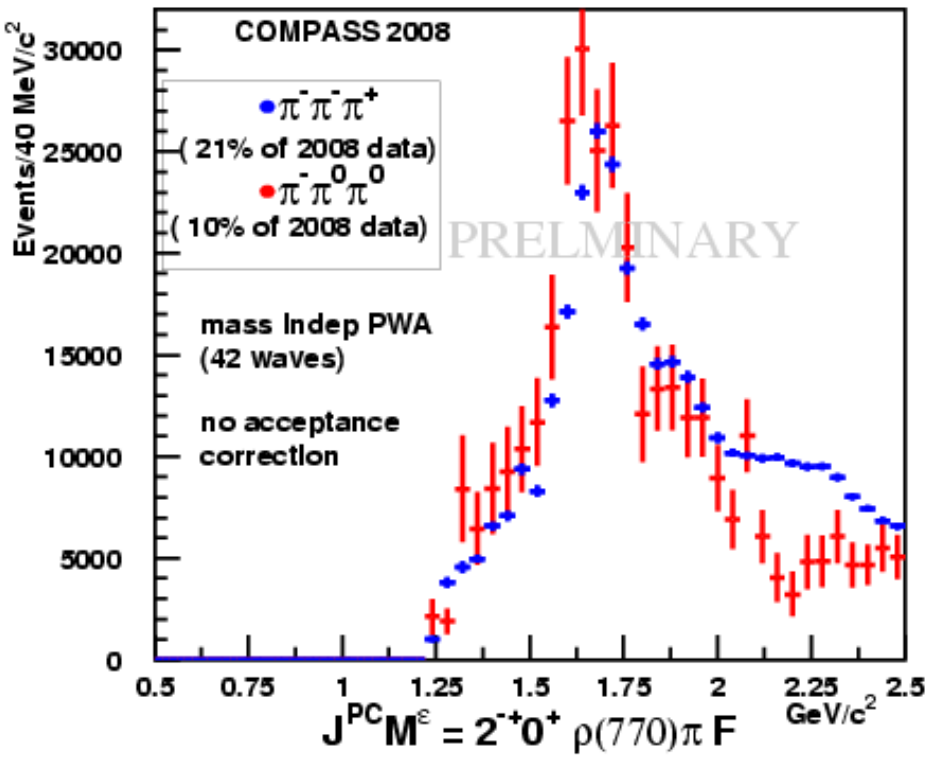
Isospin symmetry: neutral / charged mode

- isobar decaying into $f_2\,\pi$: 1/2 intensity expected
- isobar decaying into $\rho\,\pi$: 1/1 intensity expected

First comparison: Neutral vs. charged mode

$\pi_2(1670) \rightarrow f_2(1270)\,\pi$ & $\pi_2(1670) \rightarrow \rho(770)\,\pi$





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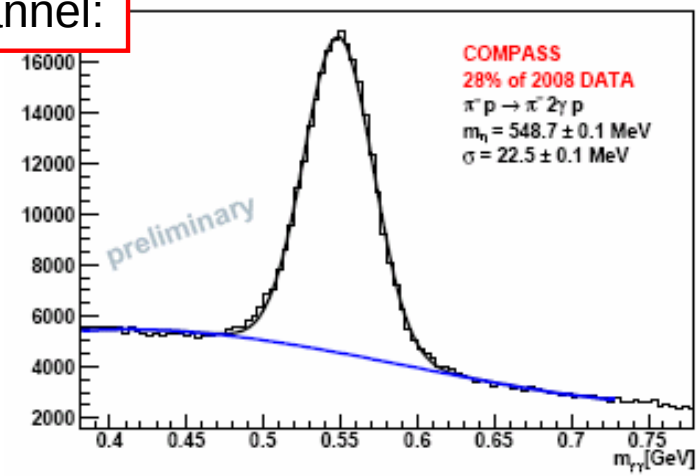
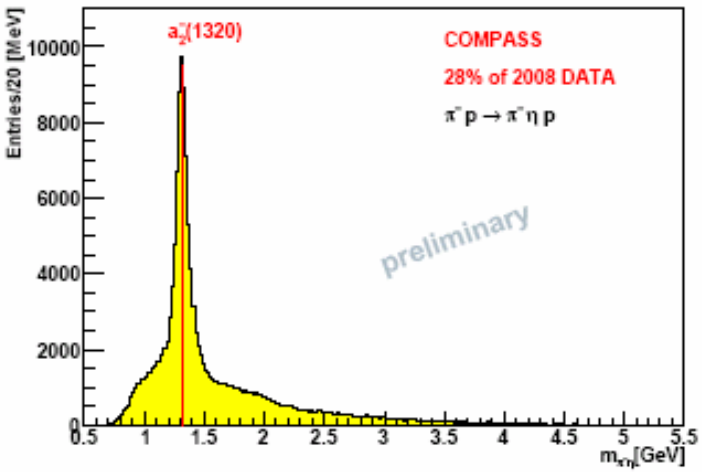
Further neutral channels (PWA ongoing):

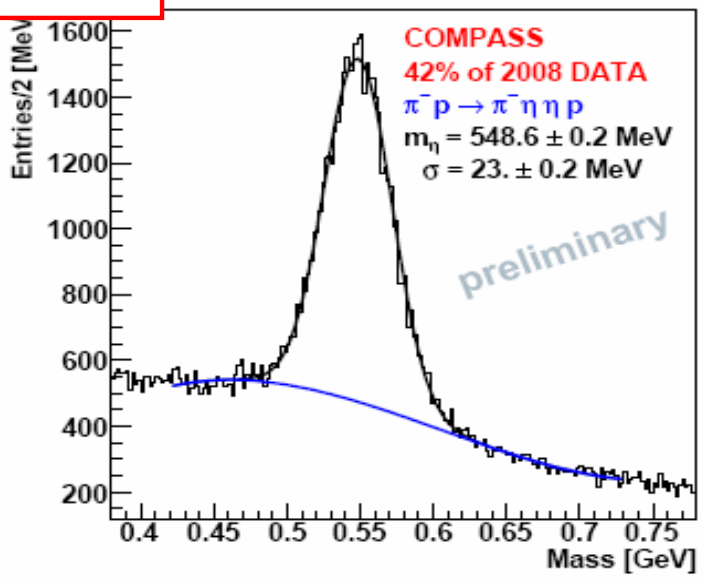
$\pi^- p \rightarrow \pi^- \eta p$ & $\pi^- p \rightarrow \pi^- \eta\eta p$

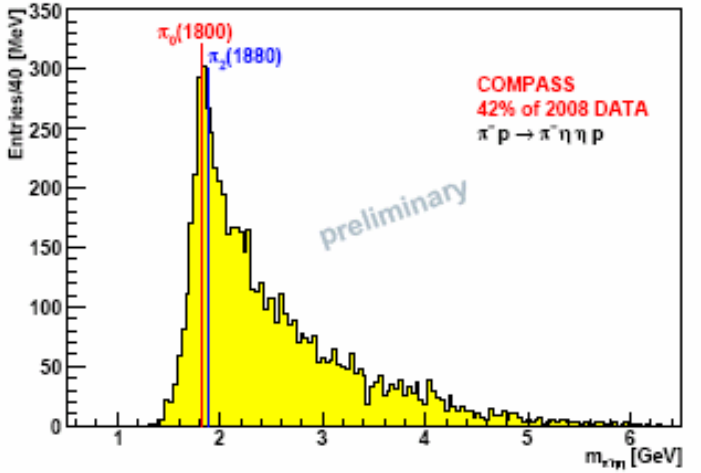
η masses in 2 γ channel:





η masses in 4 γ channel:





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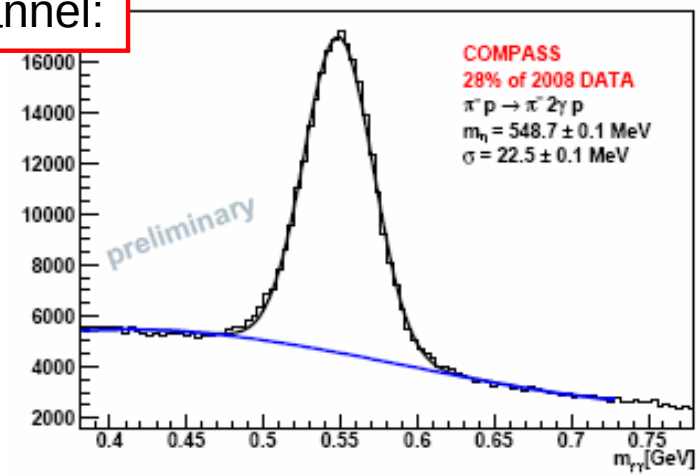
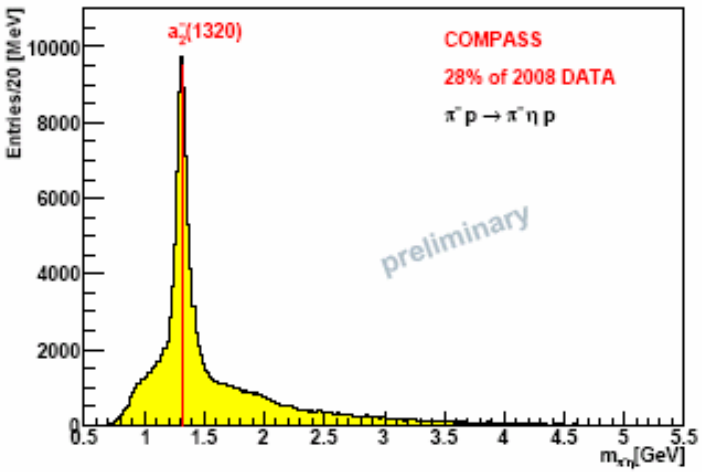
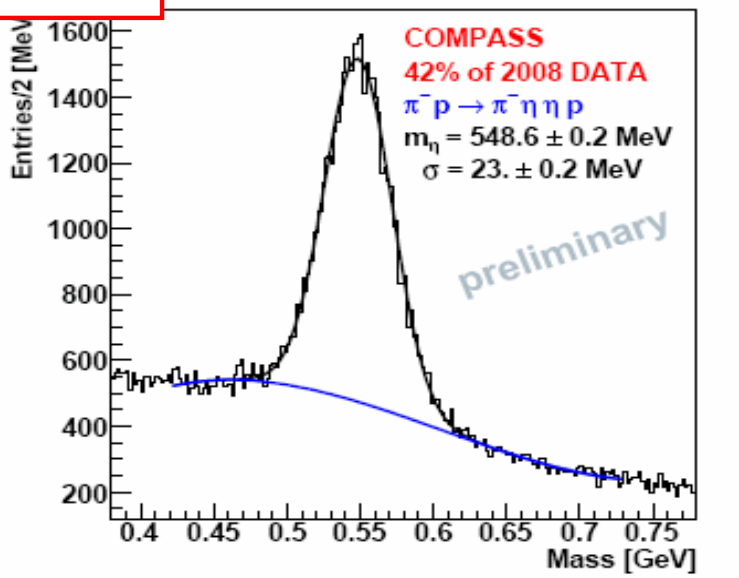
$\pi^- p \rightarrow \pi^- \eta p$ & $\pi^- p \rightarrow \pi^- \eta\eta p$

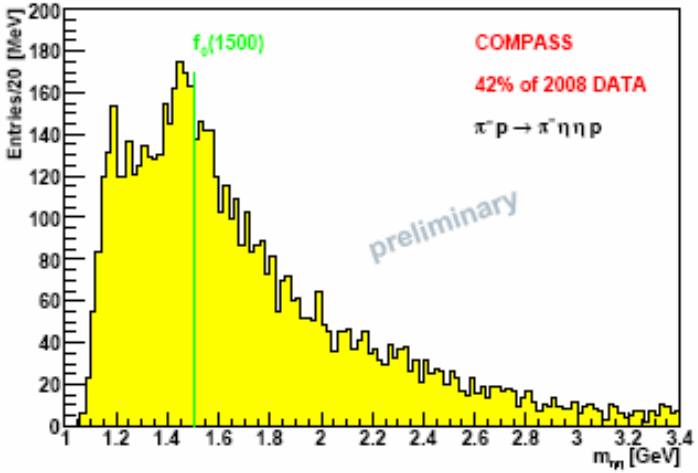
η masses in 2 γ channel:





η masses in 4 γ channel:

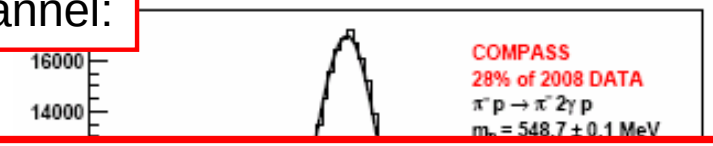


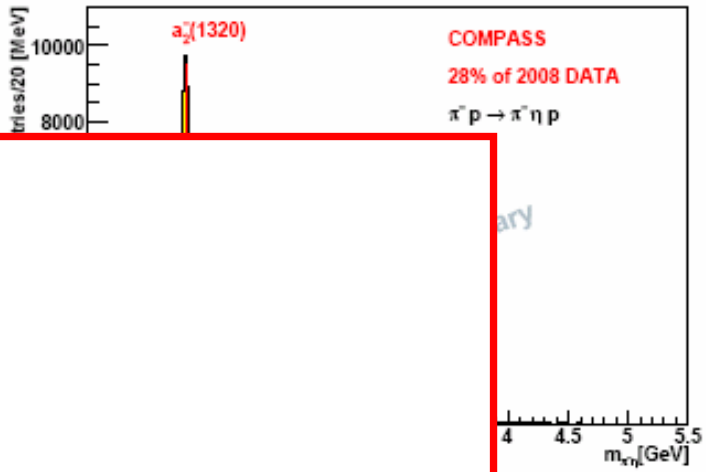


Further neutral channels (PWA ongoing):

$\pi^- p \rightarrow \pi^- \eta p$ & $\pi^- p \rightarrow \pi^- \eta\eta p$

η masses in 2 γ channel:





η ma

Further ongoing analyses (involving neutrals)

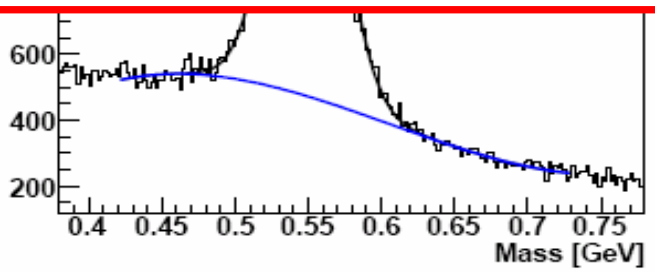
- $\pi^-\eta$, $\pi^-\eta\eta$ & $\pi^-\pi^-\pi^+\eta$ ($\eta \rightarrow \gamma\gamma$ & $\eta \rightarrow 3\pi$)
  - $\rightarrow \pi_1(1400) \rightarrow \pi^-\eta$,
  - $\rightarrow$ lightest glueball candidate $0^{++} \rightarrow \eta\eta$
- $\pi^-\pi^-\pi^+\pi^0$, $\pi^-\pi^-\pi^+\eta$ & $\pi^-\pi^-\pi^+\pi^0\pi^0$
  - => accessible intermediate isobars: f_1, b_1 η, η', ω → search for spin exotic states

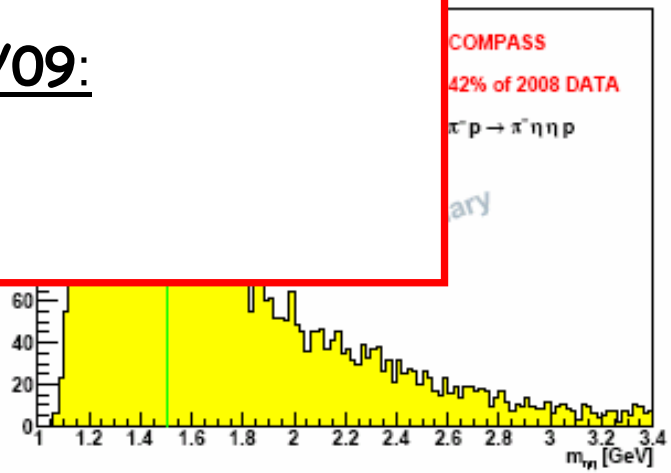
--> COMPASS: significantly more statistics w.r.t. previous experiments

After hardware upgrades introduced in 2008/09:

- Optimisation of ECals reconstruction *(under development)*
- important for all final states involving neutrals

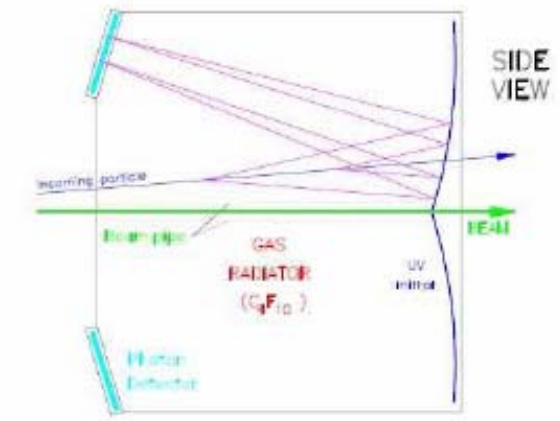
=> **Will improve statistics outcome & resolutions**

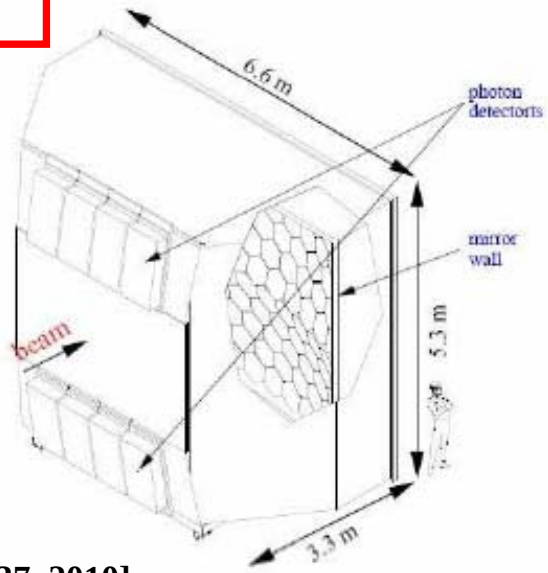


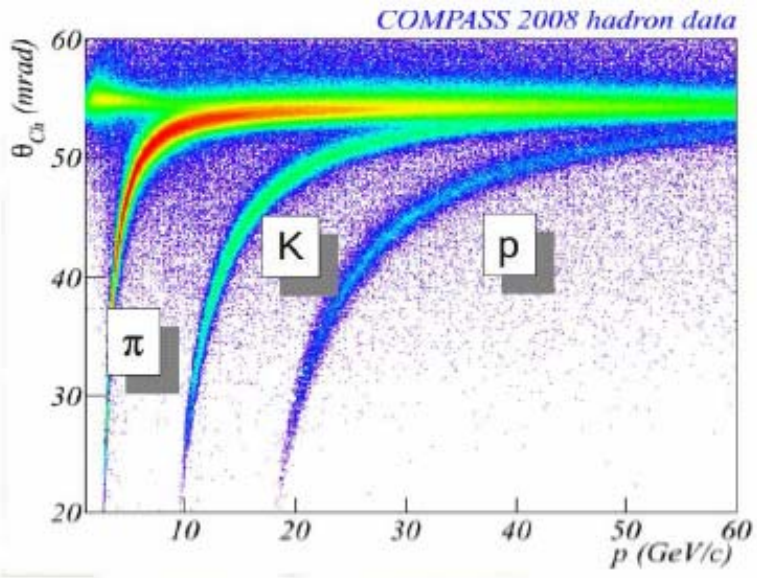


Studies of final states with (hidden) strangeness -- Kaonic channels

RICH: Final state particle ID

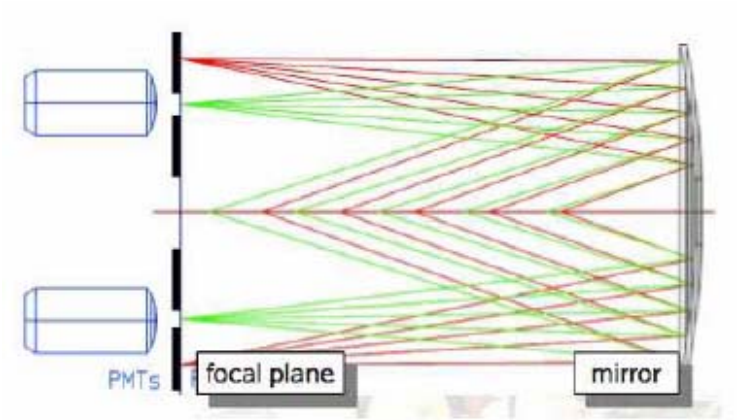






Major upgrade in 2006:
[NIM-A587:371-387, 2008], [NIM-A616:21-37, 2010]

CEDARs: Beam particle ID

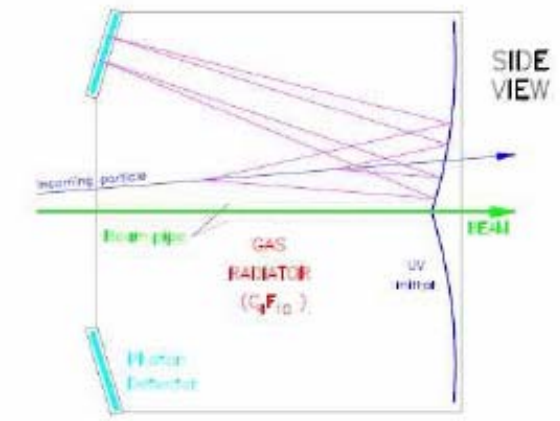


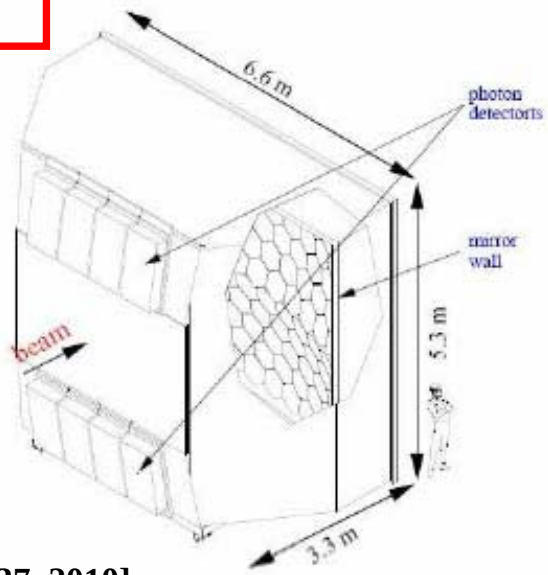
Motivation:

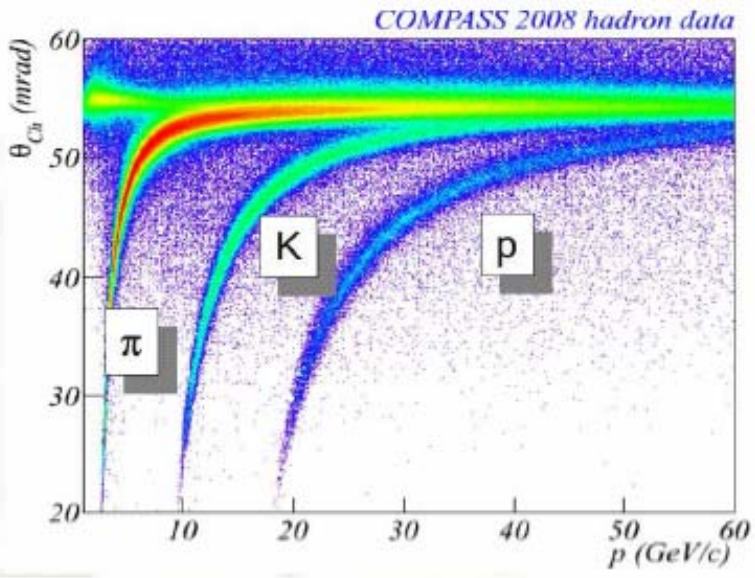
- Search for J^{PC} spin exotic mesons decaying via $K\bar{K}\pi$
- Study glueball candidates predicted to decay into $K\bar{K}$
- New insights on kaonic spectrum in general

Studies of final states with (hidden) strangeness -- Kaonic channels

RICH: Final state particle ID







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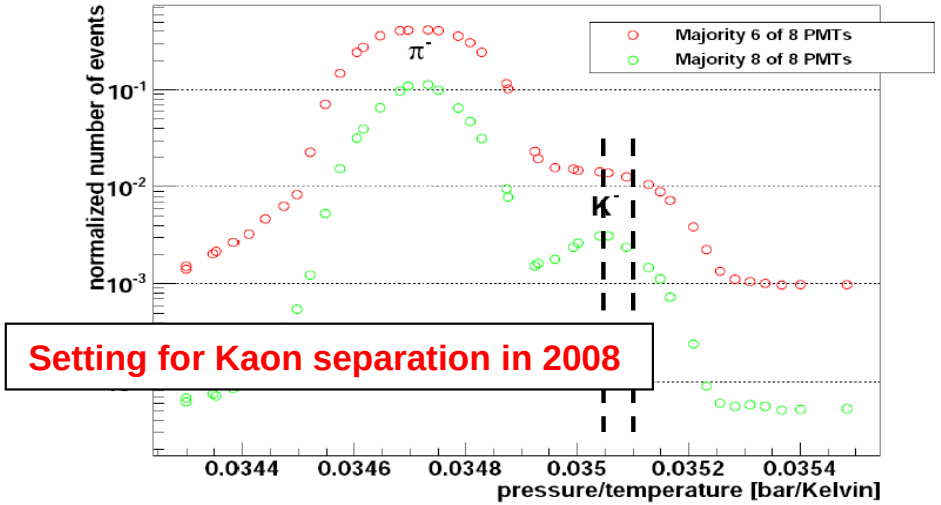
CEDARs: Beam particle ID



Setting for Kaon separation in 2008

Motivation:

- Search for J^{PC} spin exotic mesons decaying via $K\bar{K}\pi$
- Study glueball candidates predicted to decay into $K\bar{K}$
- New insights on kaonic spectrum in general

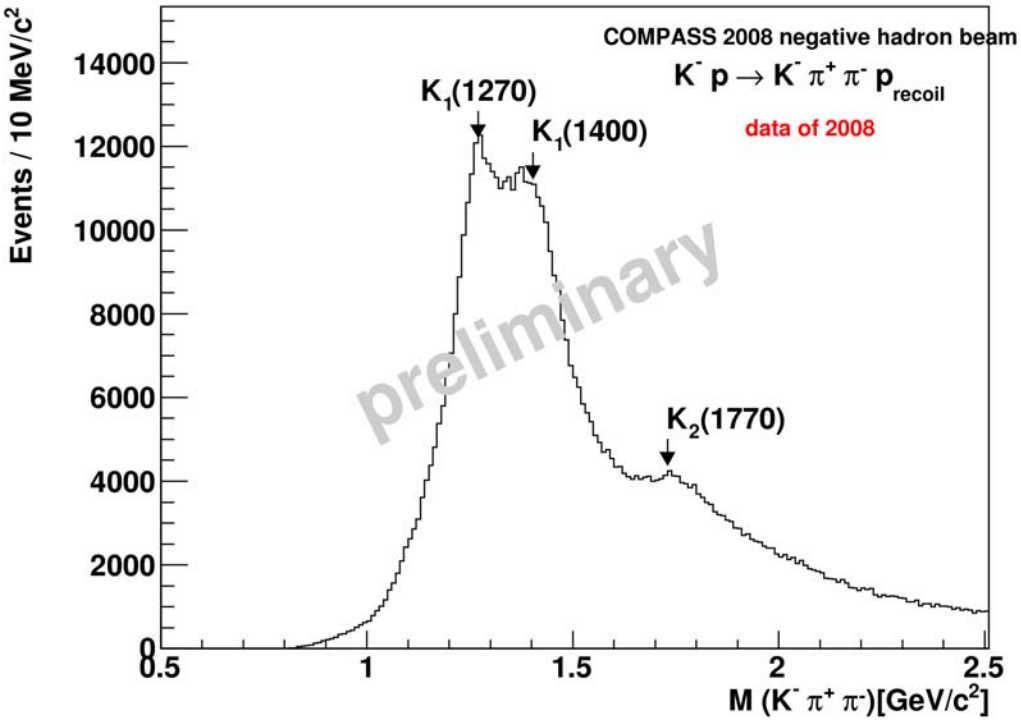
Kaonic channels I: Kaon diffraction

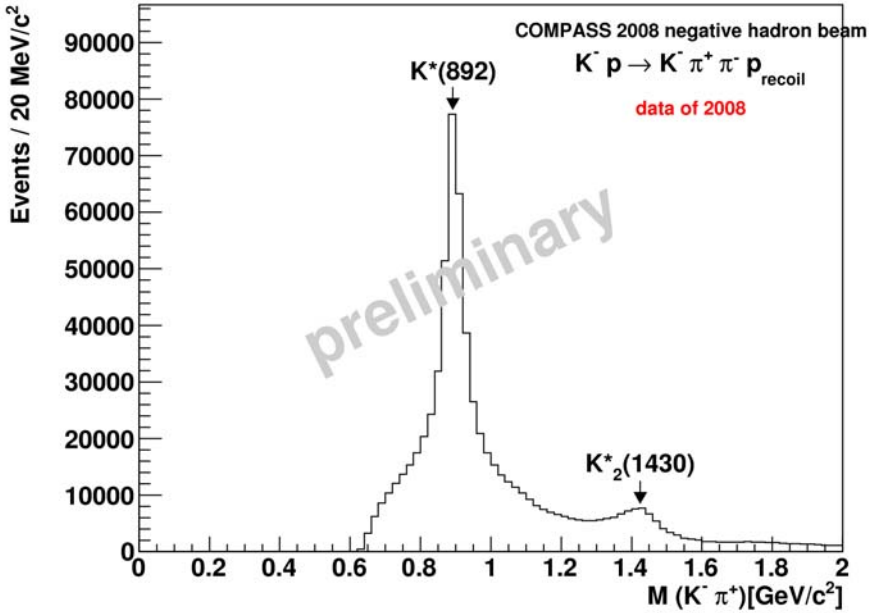
$K^- p \rightarrow K^- \pi^- \pi^+ p$

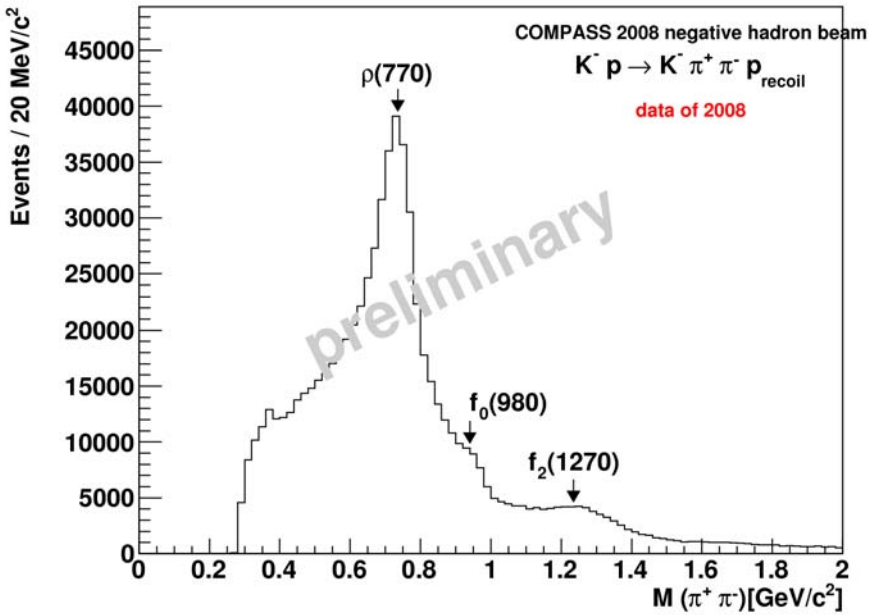
Main issues of selection:

- Beam kaon tagged by CEDARs
- Final state kaon identified by RICH
- ~600 k events on tape *(2008 data only)*

  → *to be compared with ~200 k events WA3*





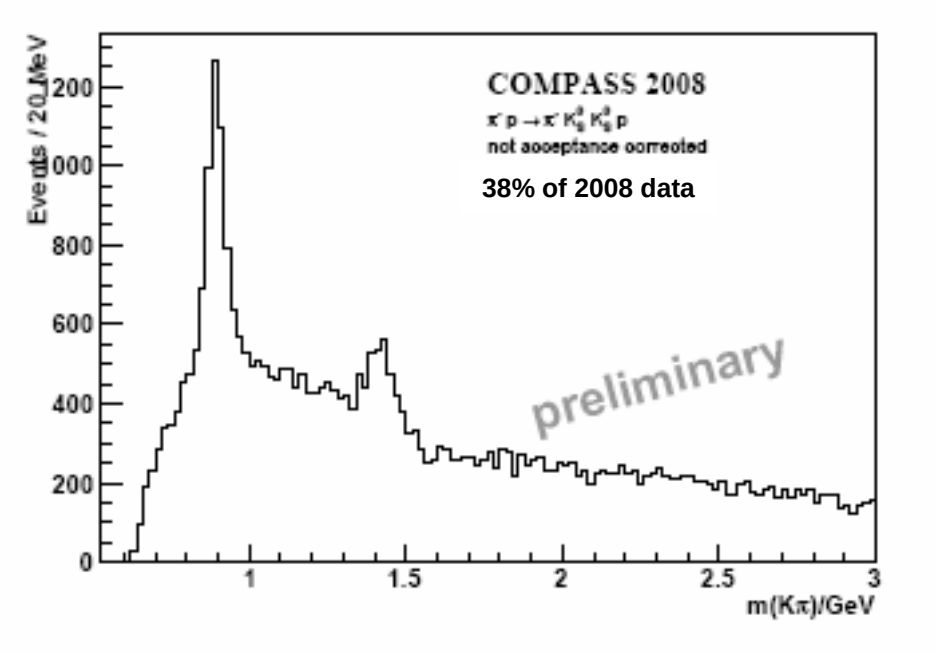


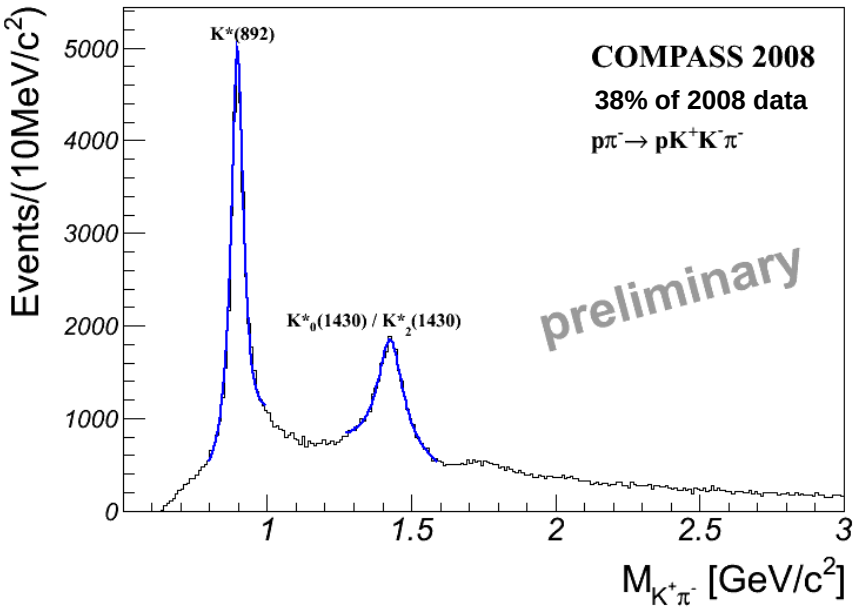
Kaonic channels II: $(K\bar{K}\pi)^-$

$\pi^- p \to \pi^- K_s K_s p$ vs. $\pi^- p \to \pi^- K^+ K^- p$

Main issues of selection:

- Beam kaon anti-tagged by CEDARs
- Final state kaon identified by V0 vertex ($K_s K_s$) or by RICH (K^+K^-)





- Combinatorics in $K_s\pi^-$ case
- Resonances: K*(892), K_2*(1430), K_3*(1780), also probably K_4*(2045)

Kaonic channels II: $(K\bar{K}\pi)^-$

$\pi^- p \to \pi^- K_s K_s p$ vs. $\pi^- p \to \pi^- K^+ K^- p$

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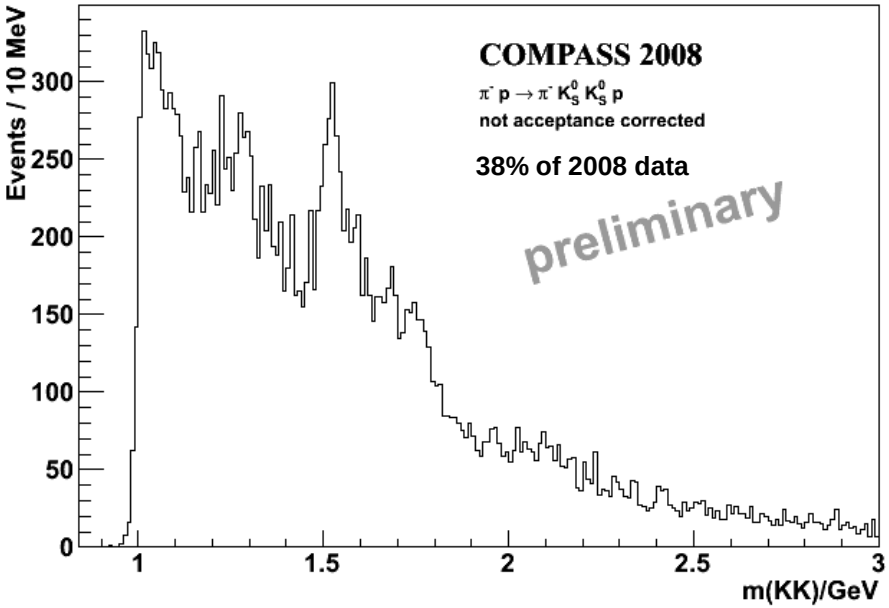
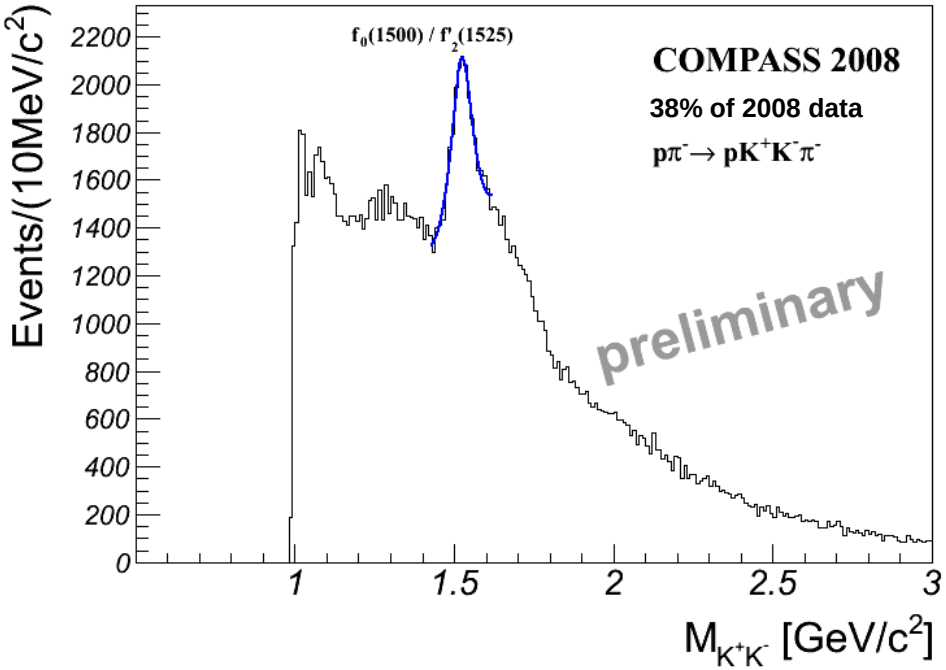




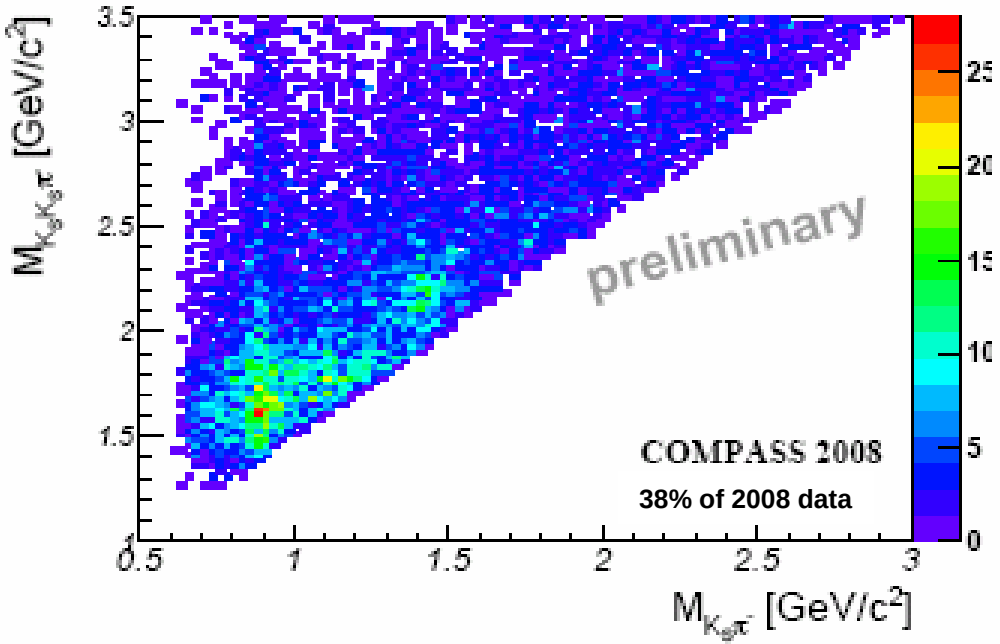
- Difference near threshold → momentum cut due to RICH
- known resonances seen as expected

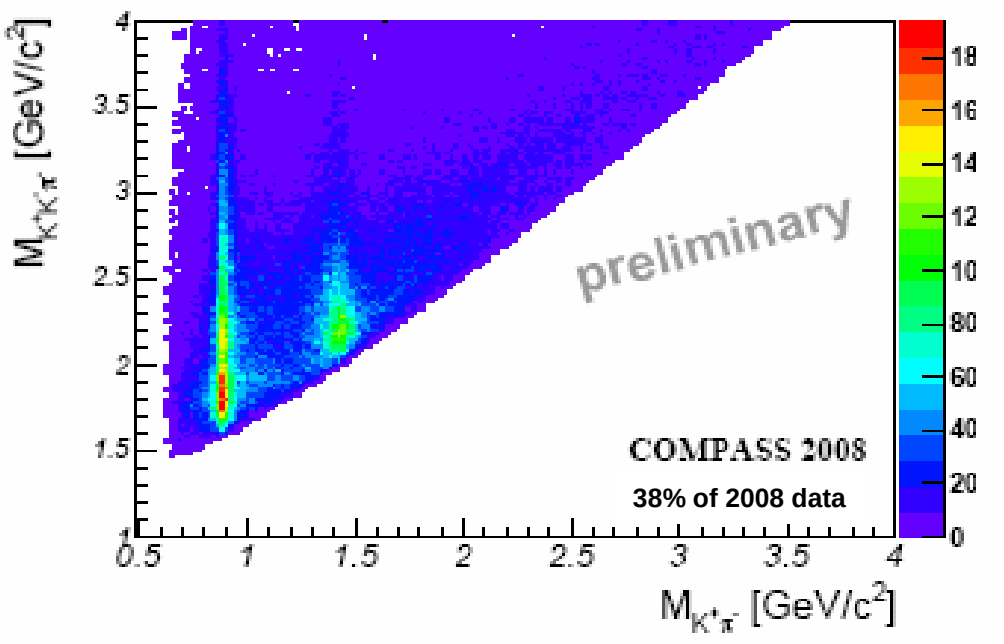
Kaonic channels II: $(K\bar{K}\pi)^-$

$\pi^- p \to \pi^- K_s K_s p$ vs. $\pi^- p \to \pi^- K^+ K^- p$

Main issues of selection:

- Beam kaon anti-tagged by CEDARs
- Final state kaon identified by V0 vertex ($K_s K_s$) or by RICH (K^+K^-)

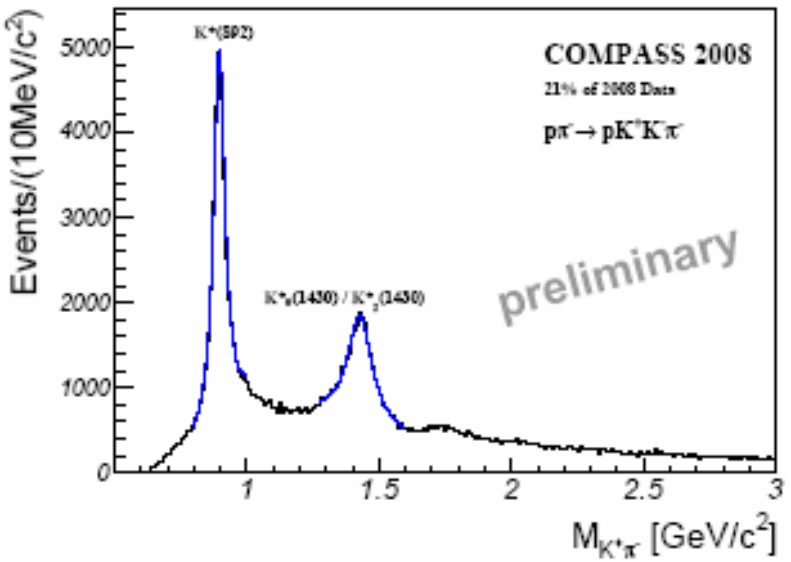


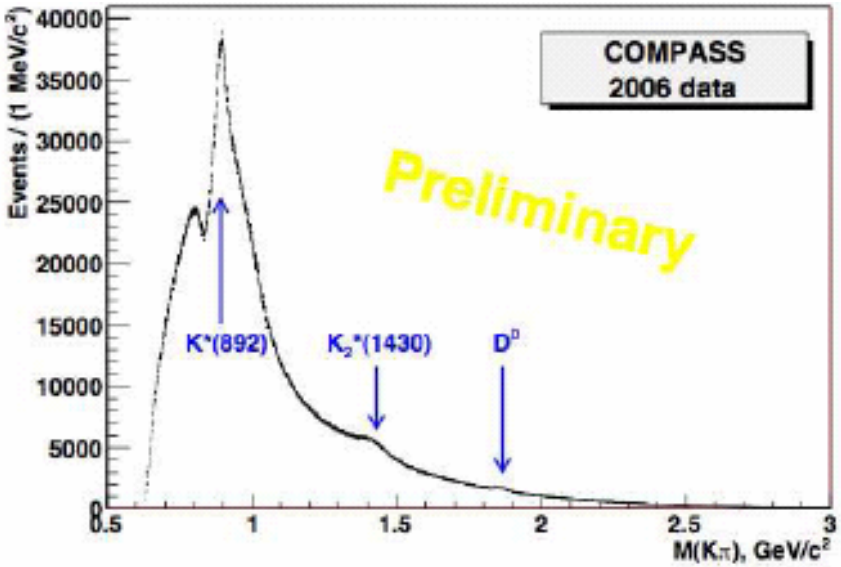


- Objects at 2.2 GeV, resonances decaying via K*s ?
- more structure near 3-body threshold in neutral channel (no momentum cut due to RICH)

Kaonic channels II: $(K\bar{K}\pi)^-$

π^- p –> $\pi^-K^+K^-$ p vs. muon data





Conclusions & outlook a)

- **COMPASS: high potential for Hadron Spectroscopy**
  - ✓ ***2004 data*: Observed exotic $J^{PC} \rightarrow \pi_1(1600)$** *(subm. Phys.Rev.Lett)*
  - ✓ ***2008/09: Data taken with hadron beams on proton & nuclear targets***
  - ✓ ***Very high statistics (10-100x world statistics)***

- **COMPASS measures Neutral & Charged channels**

- **First results on 3π final state (diffr. dissociation) 2008 data**
  - ✓ *First comparision neutral vs. charged mode (PWA: isospin symmetry)*

  => independent confirmation of new states within same experiment

- **First results on $\pi\eta\eta$ final states, 2008 data**
  - ✓ *First look promising (PWA underway)*

=> Will benefit from ongoing optimisation of ECal reco

(for full usage of hardware upgrades)

Conclusions & outlook b)

- **First results on kaonic final states (diffr. dissociation)**
  - ✓$(K\bar{K}\pi)^-$: *First comparison* $K_sK_s\pi^-$ *vs.* $K^-K^+\pi^-$ *(PWA underway)*
  - ✓Kaon beam: *First look into* $K^-\pi^+\pi^-$ *promising (2008 only: 3x WA32))*

Outlook: *Further ongoing & promising* $(K\bar{K}\pi)^0$*:*

$(K_s\bar{K}\pi)^0$ in $K_sK^{+/-}\pi^{-/+}\pi^-$ final states *(PWA started, higher masses (> 2.2 GeV)*

→ *PWA of* $f_1(1285)\pi$ *&* $f_1(1420)\pi$ *(→ never done before)*

=> more results soon

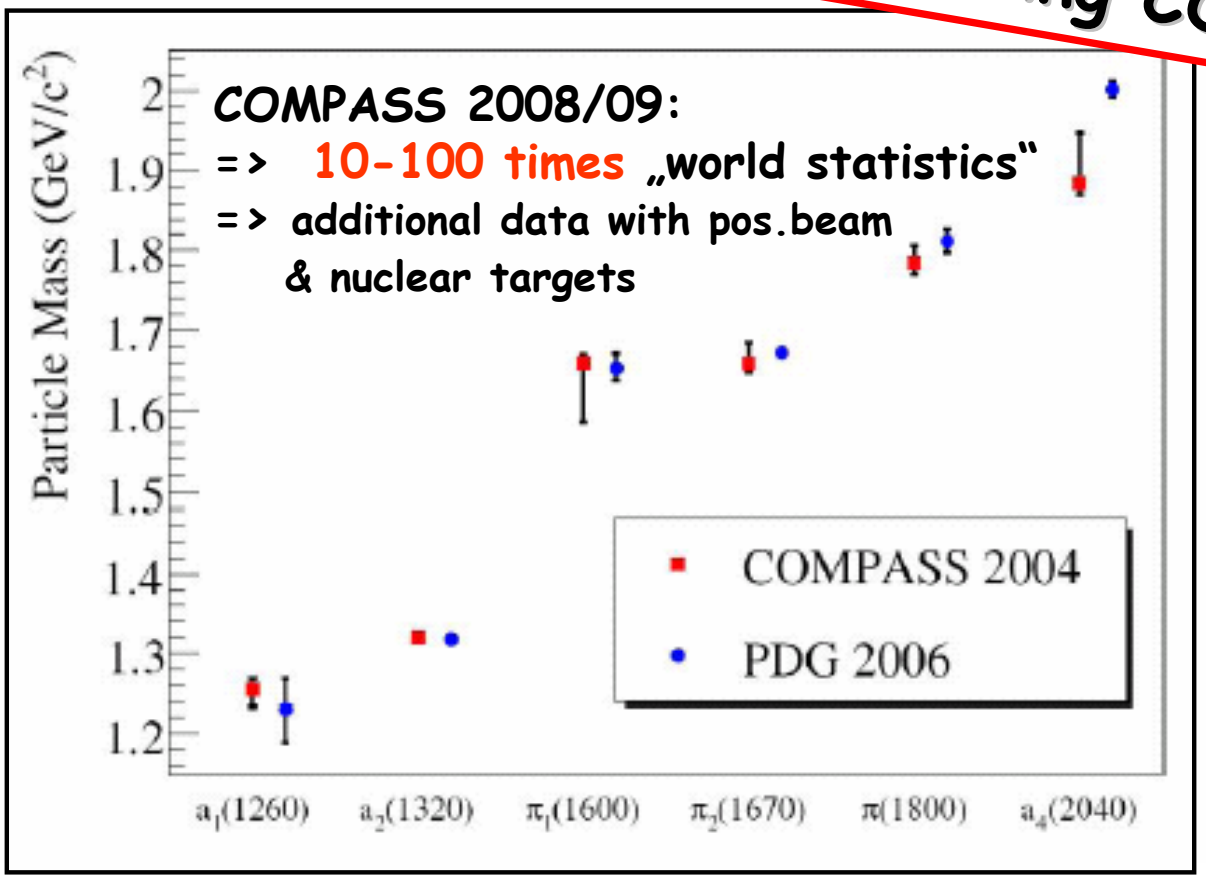
Further final states *currently analysed:*

- **5π** *(charged & neutral),*
- **4π** *(Central production, also* ***lepto-production*** *(2004/6/7 data)*
- **Baryon spectroscopy** *(charged & neutral),*

Also: 3π low t' & Primakoff → Talk by S.Grabmüller

Conclusions & outlook

Stay tuned for interesting COMPASS results …



THANK YOU !!!