

Hadron spectroscopy with COMPASS – First results



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on behalf of the
COMPASS Collaboration

*Rencontre de Moriond -- QCD and High energy Interactions,
La Thuile, March 13-20, 2010*

Outline:

- The COMPASS experiment
- Results on diffractive dissociation into 3π final states:
 - Observation of spin exotic $\pi_1(1600)$ (2004 data)
 - First results on 3π final states (2008 data)
 - first PWA fits (main waves)
- Conclusions



bmb+f - Förderschwerpunkt

COMPASS

Großgeräte der physikalischen
Grundlagenforschung

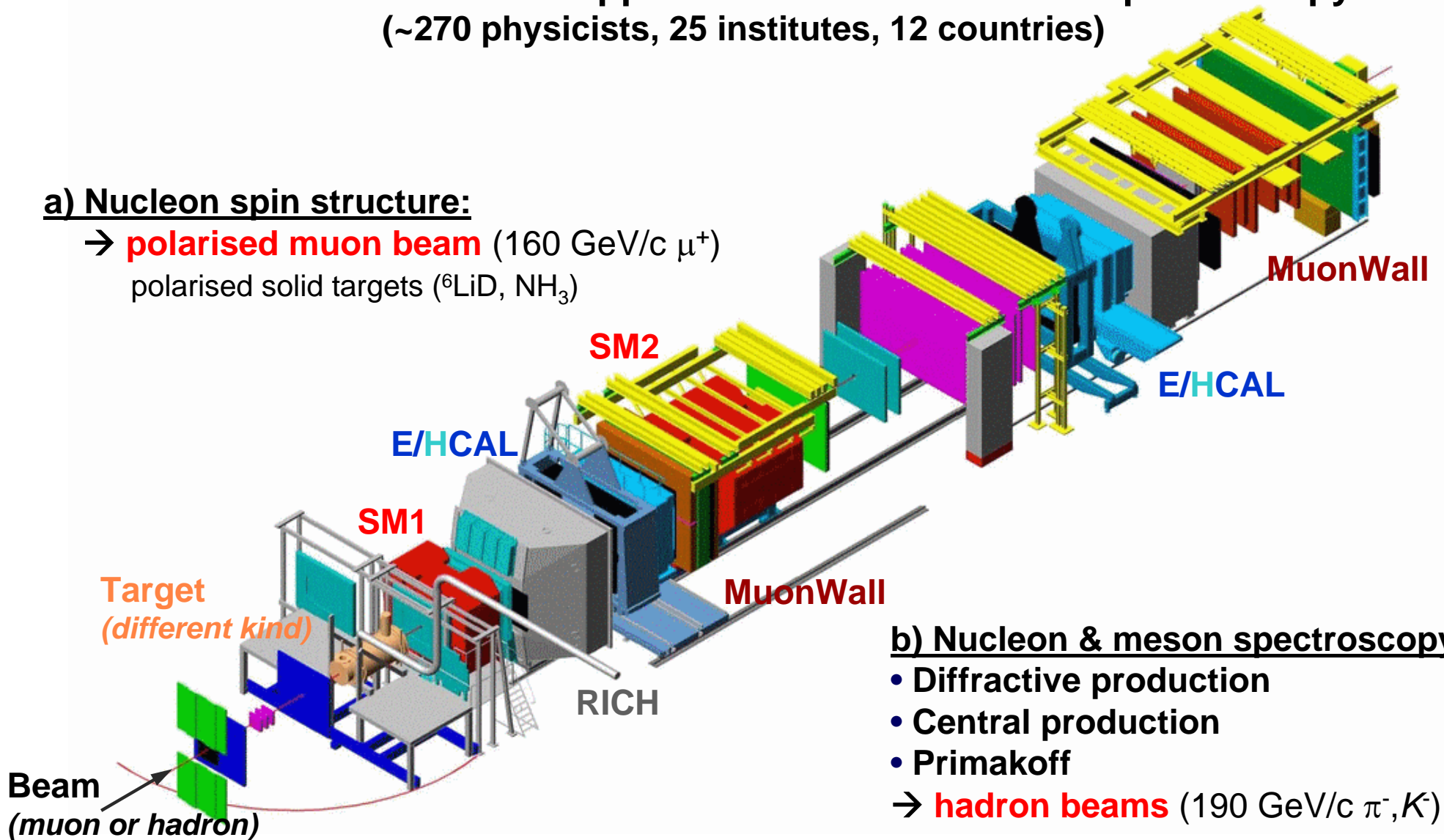


The COMPASS experiment

COmmun **M**uon **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
(~270 physicists, 25 institutes, 12 countries)

a) Nucleon spin structure:

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



b) Nucleon & meson spectroscopy:

- Diffractive production
 - Central production
 - Primakoff
- **hadron beams** (190 GeV/c π^- , K^-)

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

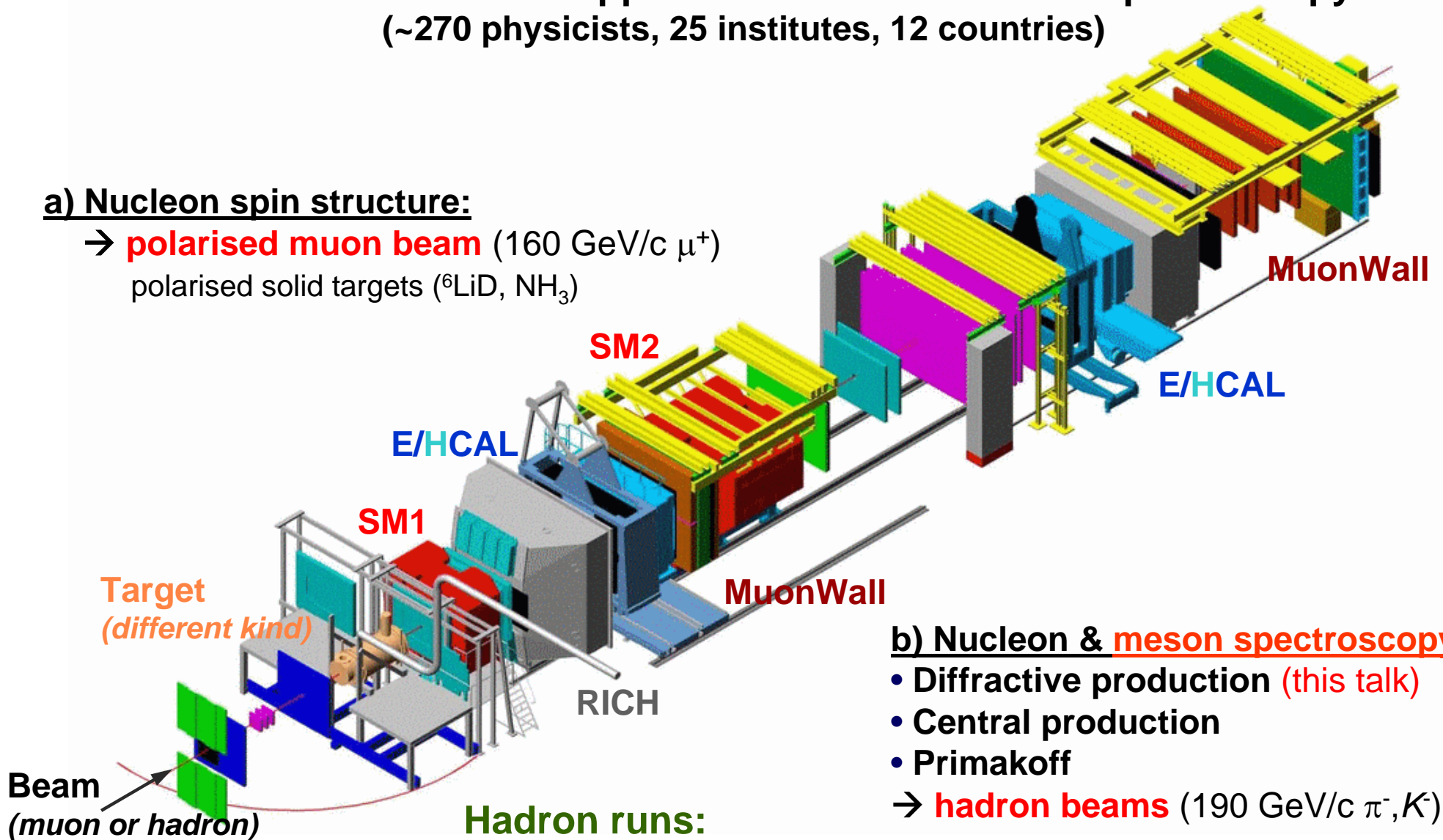


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Hadron runs:

- **2004 pilot run** (4 days π^- on Pb target: ~BNL statistics)
- **2008/09** (10-100x world stats (LH2), plus: positive beam, nuclear targets)



Mesons and Spin Exotic States



Constituent quark model

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

QCD predicts 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):

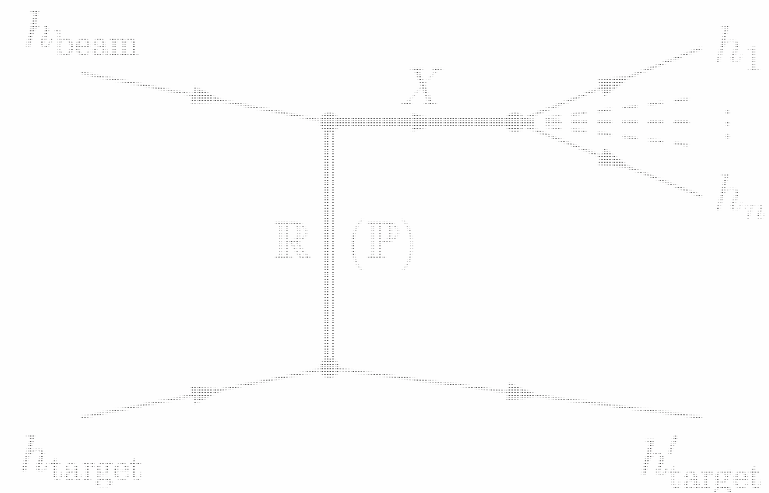
- lightest hybrid predicted: exotic $J^{PC} = 1^{-+}$
- $\pi_1(1400)$: VES, E852, Crystal Barrel
- $\pi_1(1600)$: E852, VES $\rightarrow \rho\pi, \eta'\pi, f_1\pi, b_1\pi$
- $\pi_1(2000)$: E852 $\rightarrow f_1(1285)\pi, b_1(1235)\pi$
- ... still controversial \rightarrow COMPASS

Diffractive scattering

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

Diffractive pion dissociation

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





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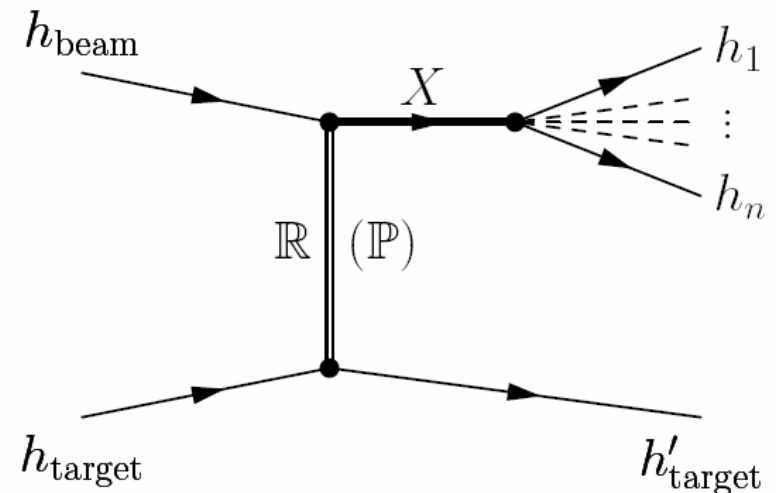
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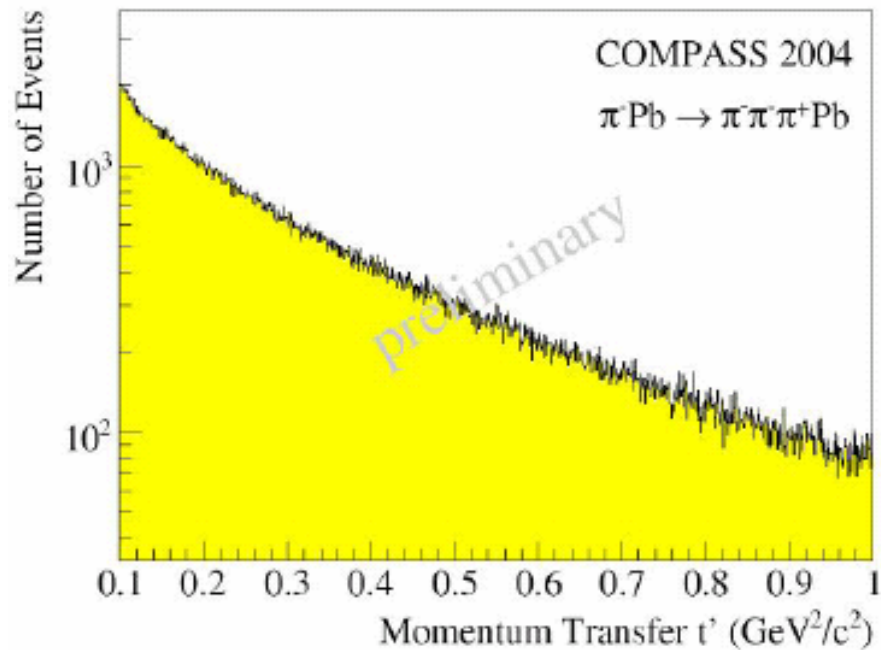
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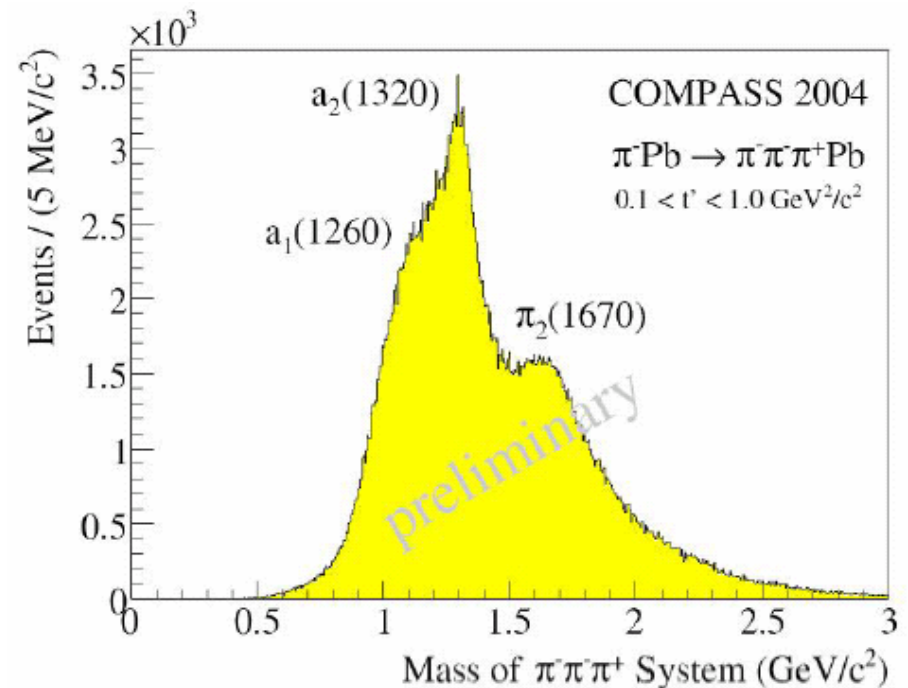


Diffractive dissociation into 3π final states (2004 data, Pb target) [arXiv:0910.5842]

Diffraction on Pb nucleons

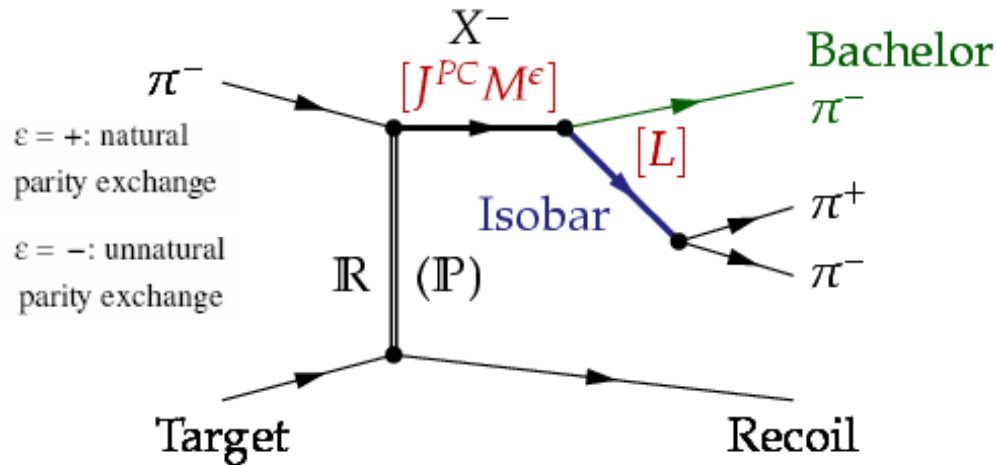


Invariant mass of outgoing pion system





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: $J^{PC} M^\epsilon$ [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)

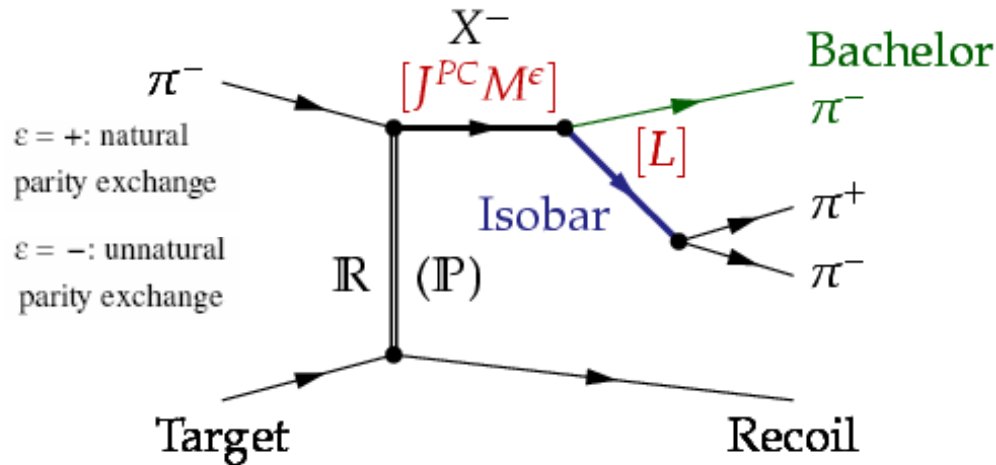
Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

$$\sigma_{indep}(\tau, m, t') = \sum_{\epsilon=\pm 1} \sum_{r=1}^{N_r} \left| \sum_i T_{ir}^\epsilon f_i^\epsilon(t') \psi_i^\epsilon(\tau, m) / \sqrt{\int |\psi_i^\epsilon(\tau', m)|^2 d\tau'} \right|^2$$

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



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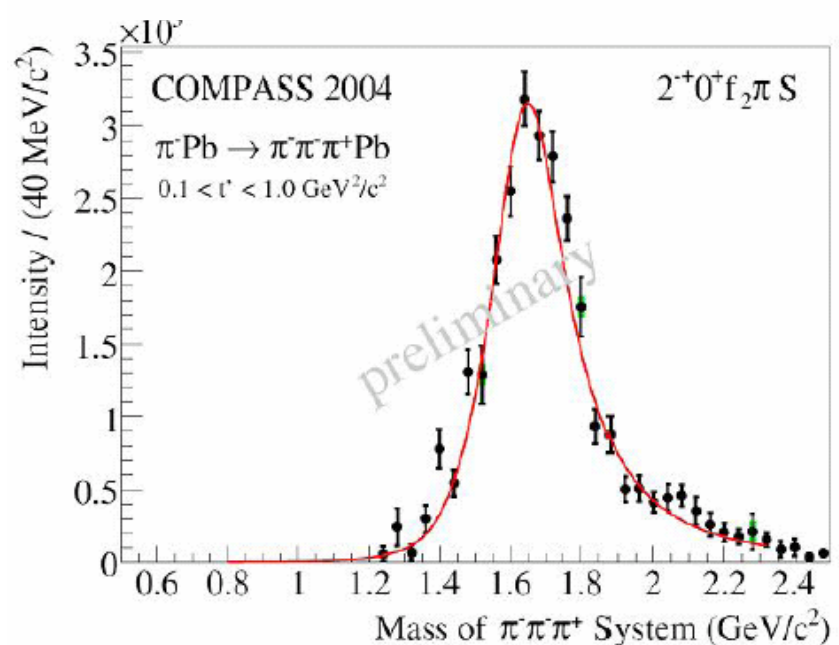
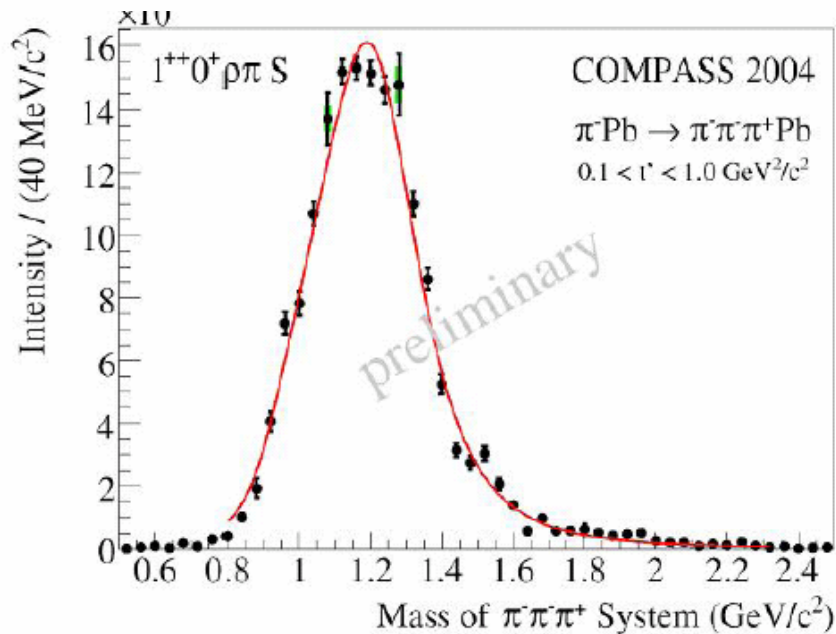
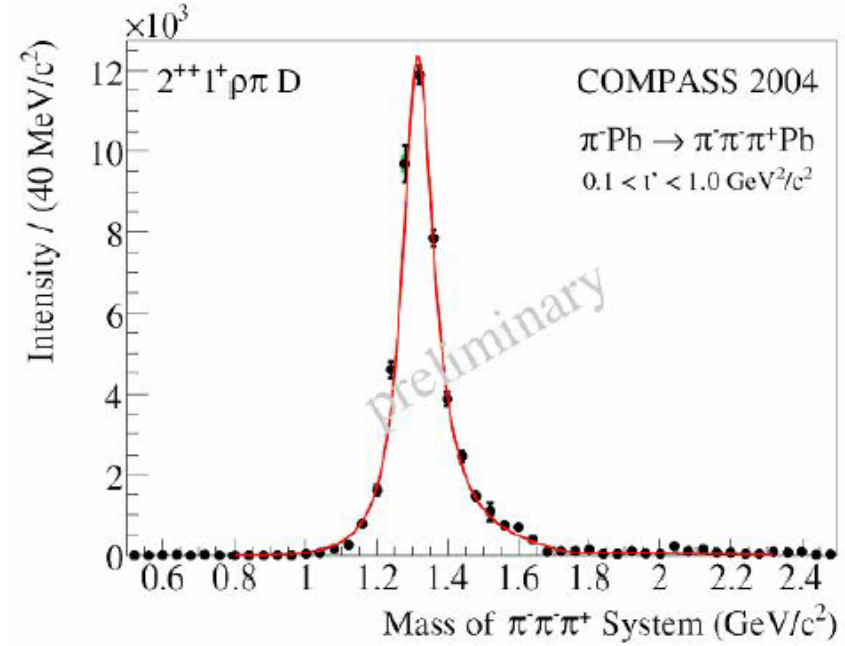
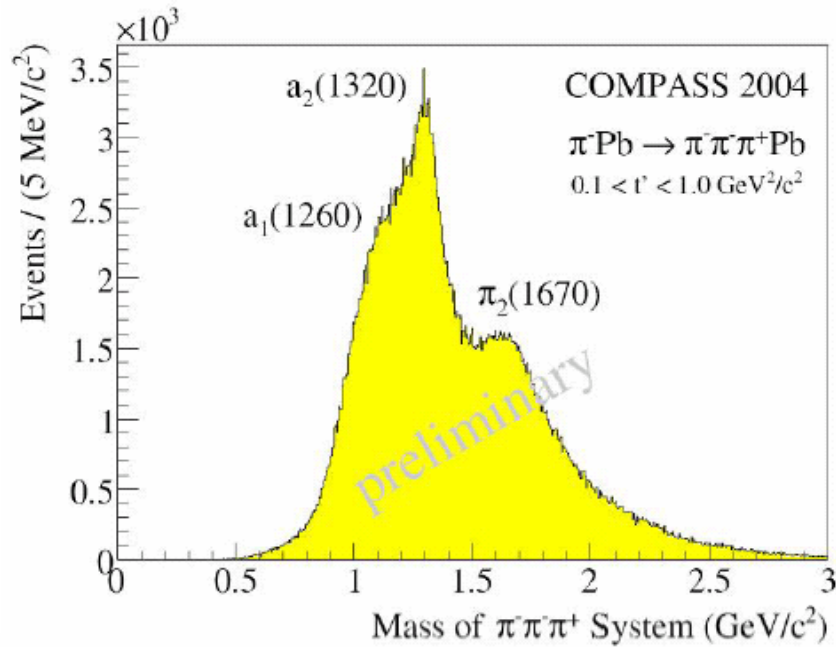
Step 1) Mass independent PWA: (40MeV/c² bins, 41+1 partial waves)

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

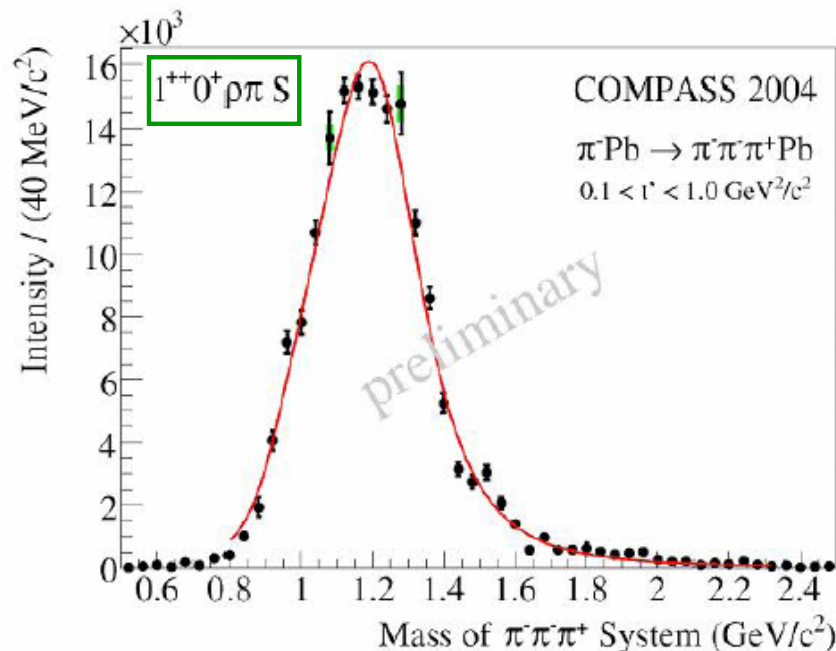
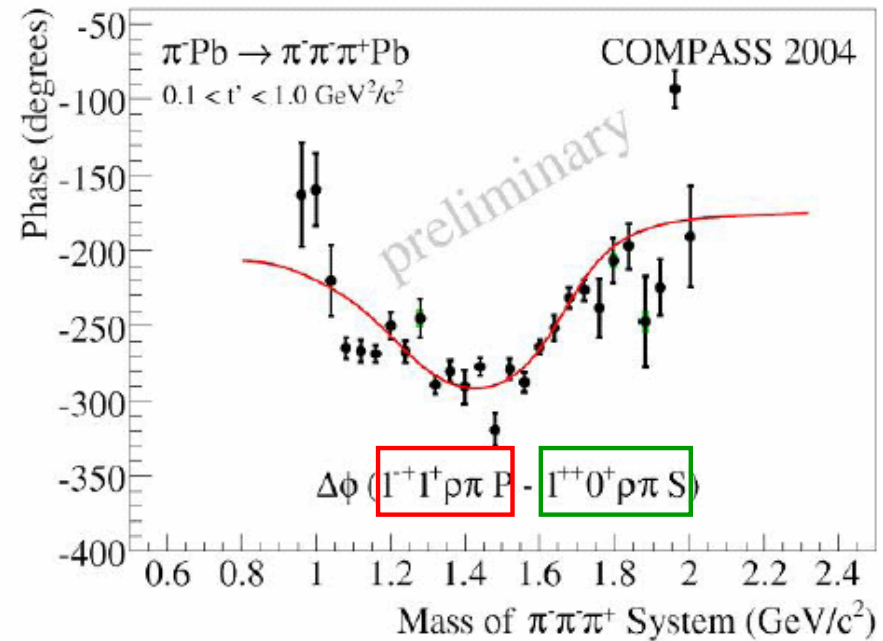
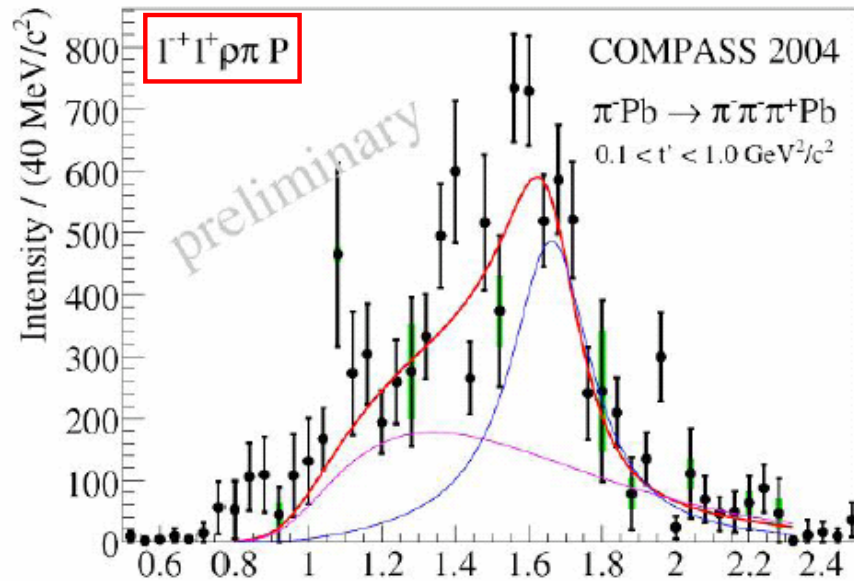


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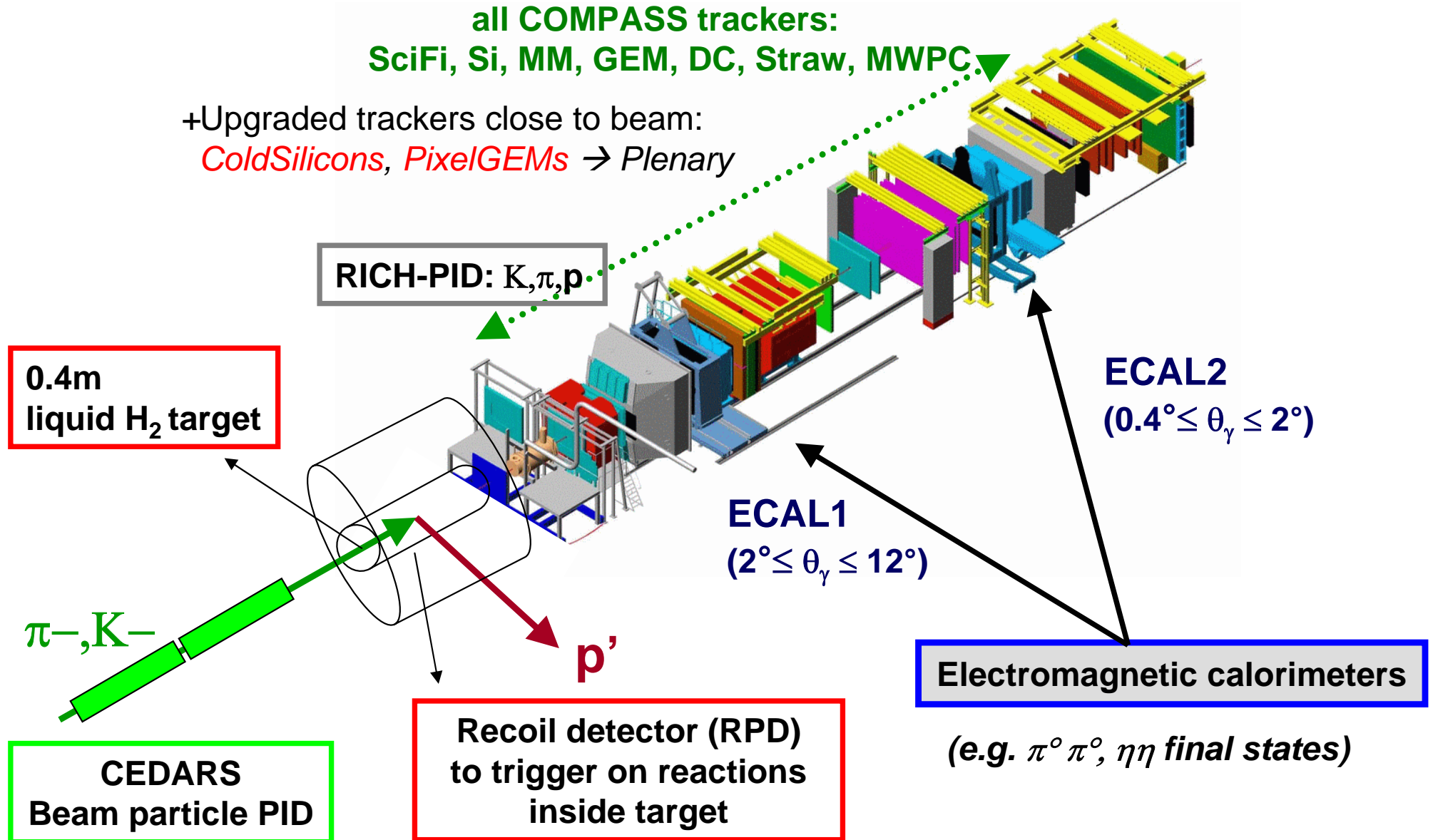
BW parameters for the $\pi_1(1600)$:

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

[arXiv:0910.5842]



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: 96% π^- , 3.5% K^- , 0.5% p)
- **Simultaneous** observation in **neutral mode**:
 - > 3π example:
 - ✓ $\pi^- \text{p} \longrightarrow \pi^- \pi^+ \pi^- \text{p}$ (charged mode)
 - ✓ $\pi^- \text{p} \longrightarrow \pi^- \pi^0 \pi^0 \text{p}$ (neutral mode)
 - > **independent measurement** (*same apparatus*)
 - => important cross check (*understand acceptance*)
 - => confirmation of any *new state observed*
- **First look into charged vs. neutral mode** (*main waves*)
 - > **Isospin symmetry check** (*mass independent fit*)

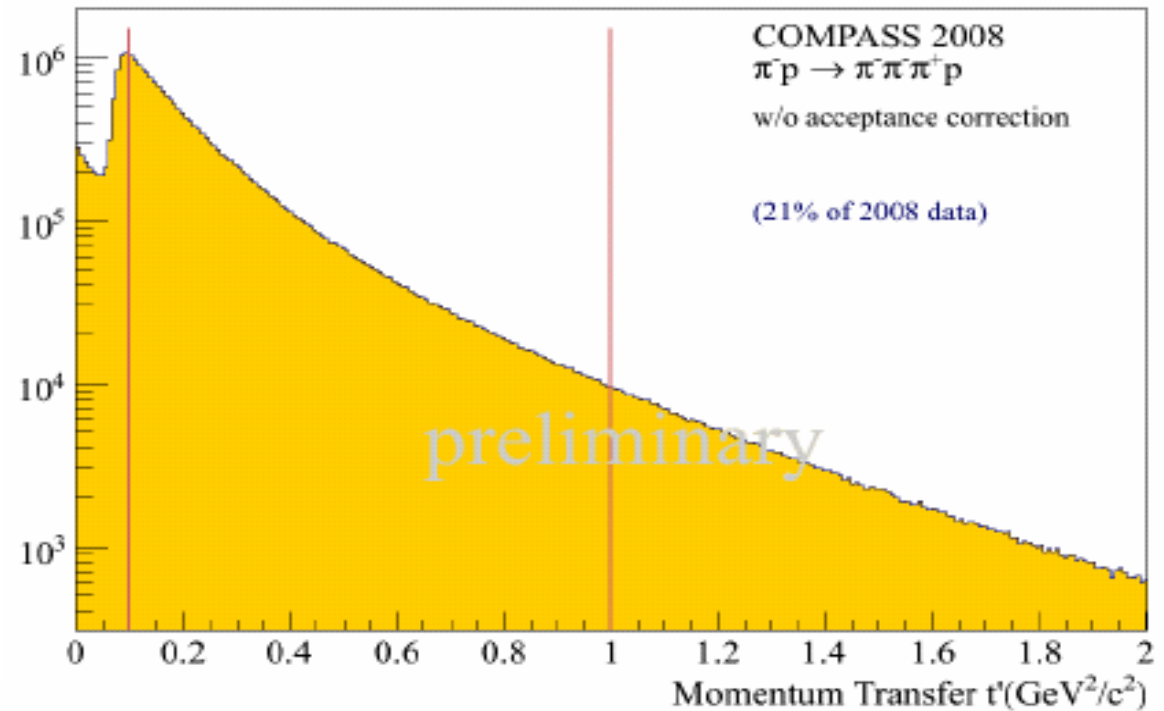
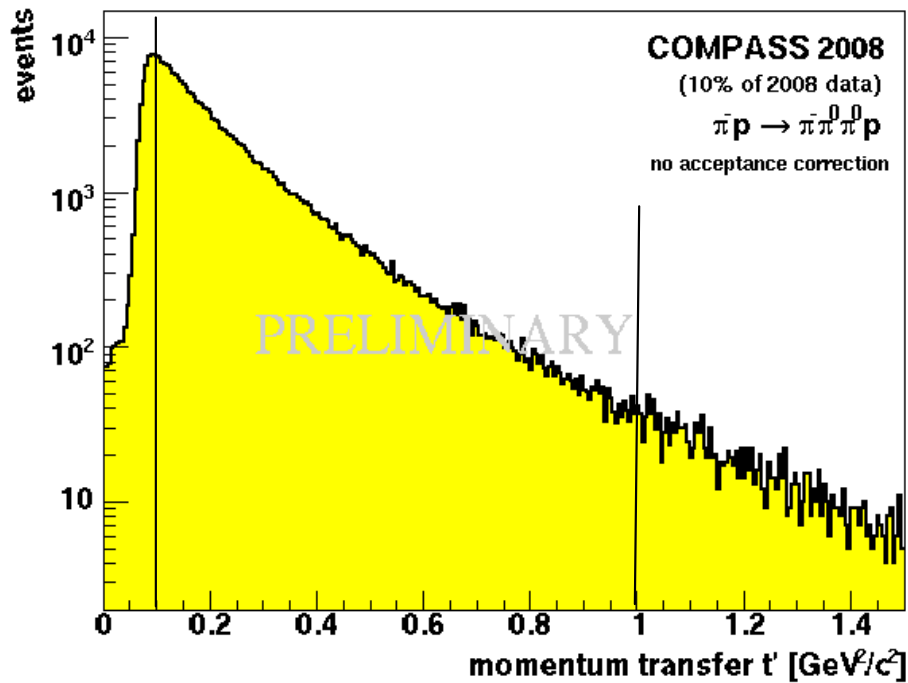


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neutral mode

charged mode



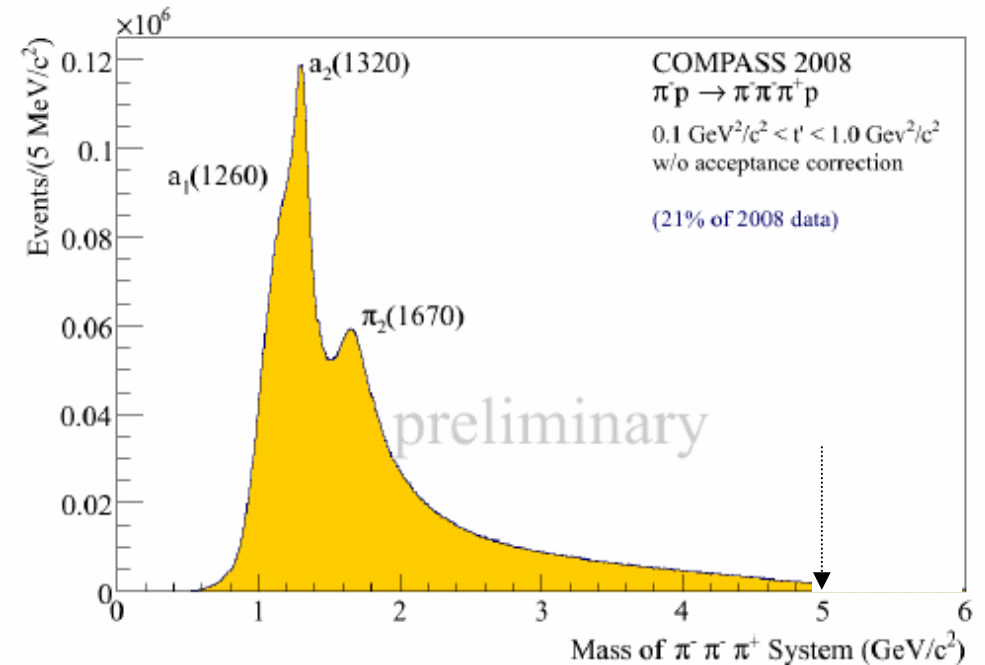
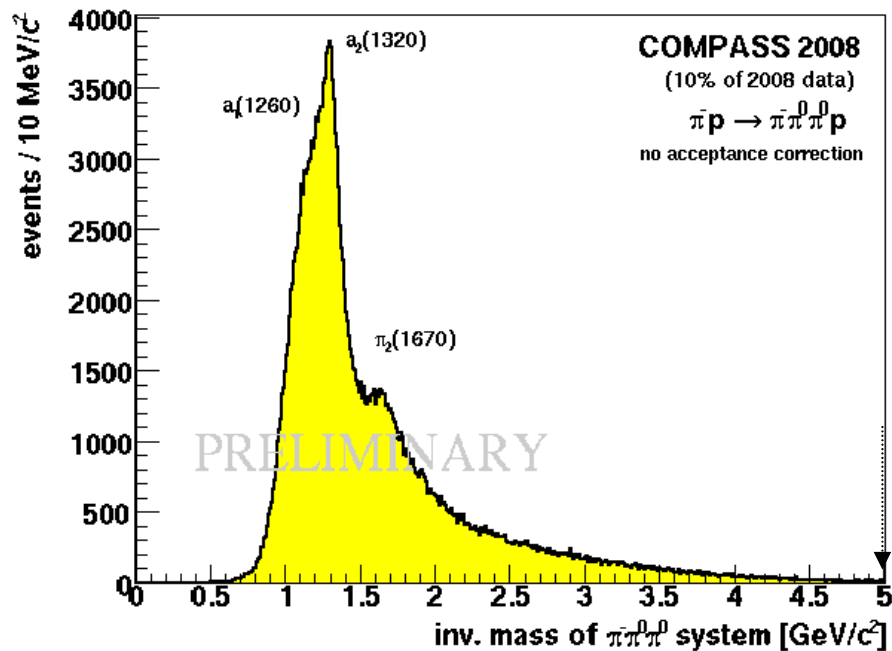


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Mass of outgoing π system -- **neutral mode**

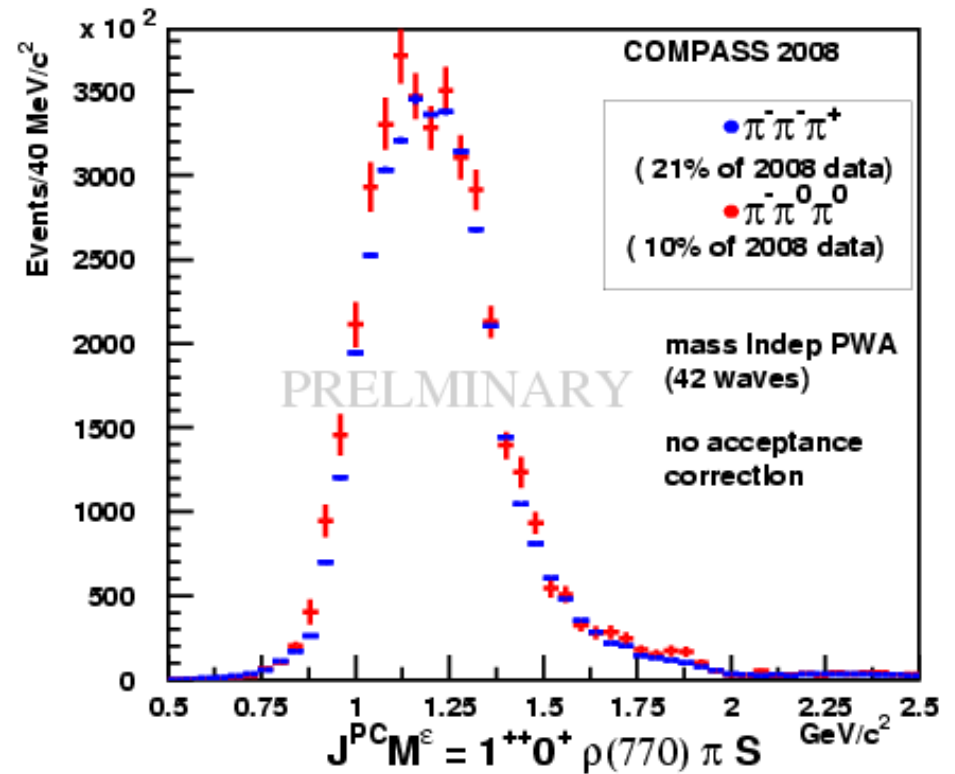
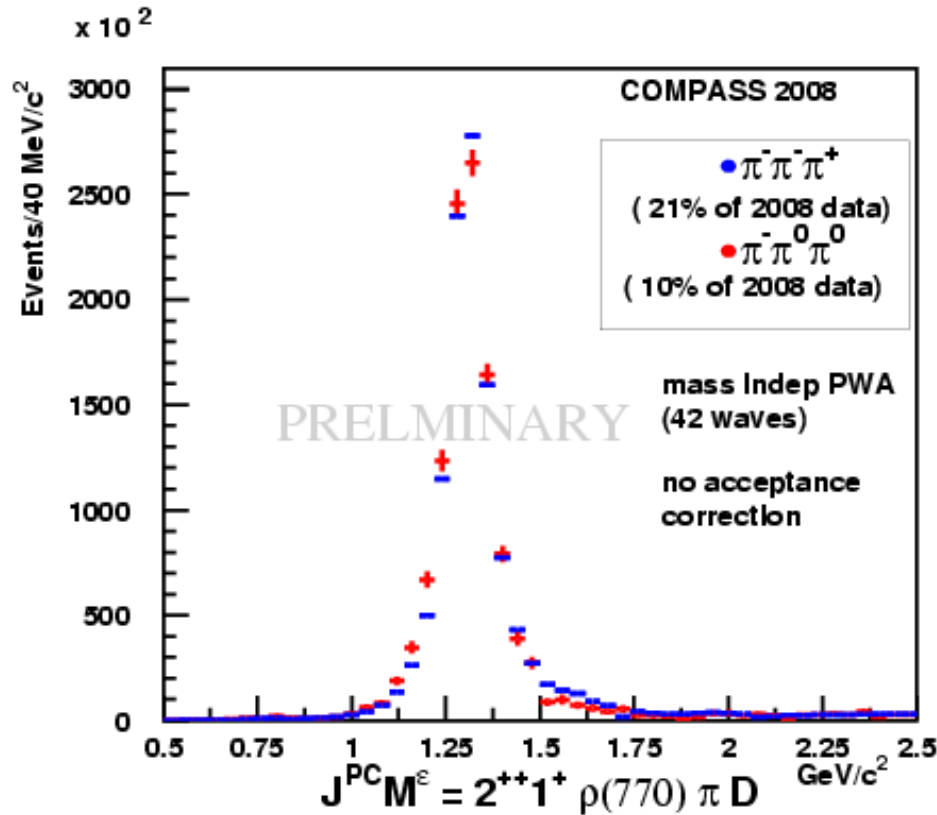
Mass of outgoing π system -- **charged mode**





First comparison: Neutral vs. charged mode

a_2 – normalisation & $a_1 \rightarrow \rho\pi$



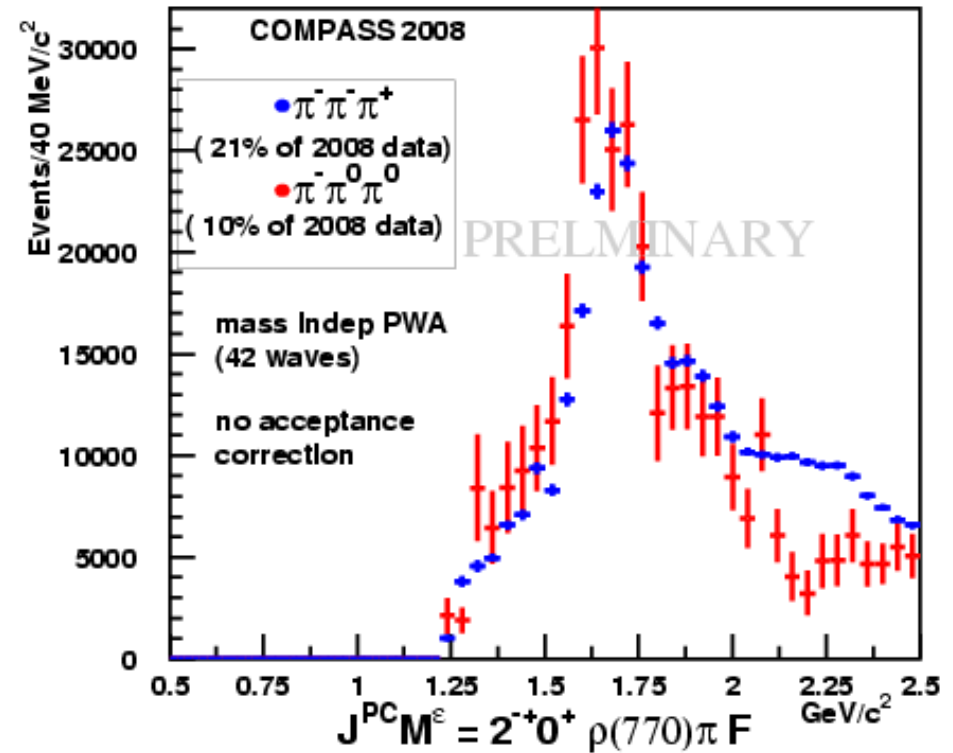
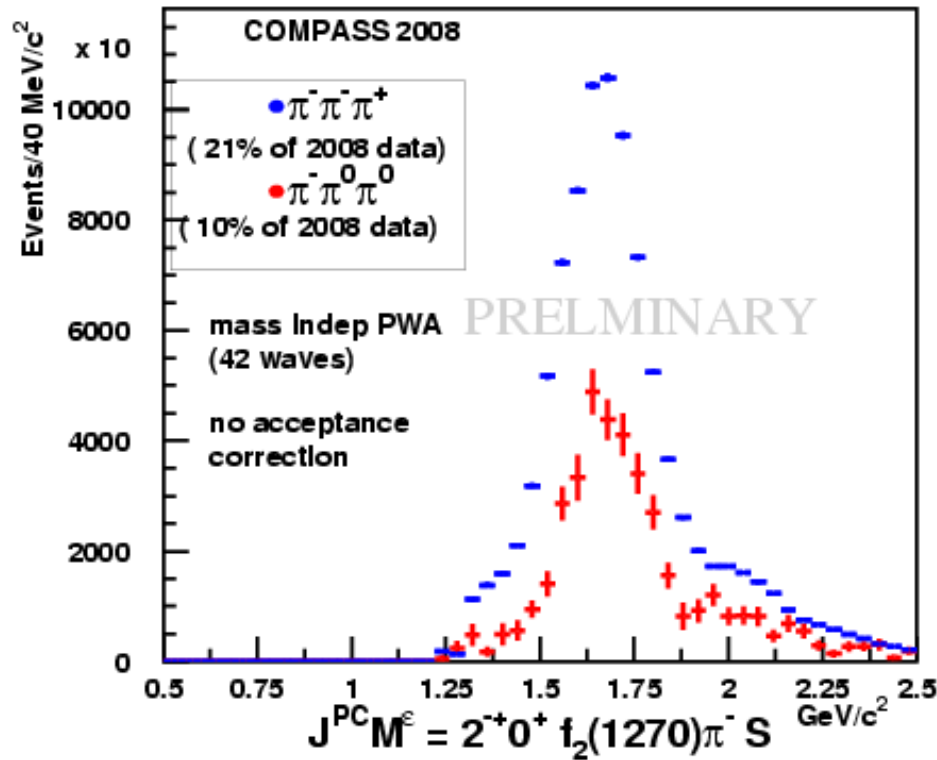
Isospin symmetry: neutral / charge mode

- 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

$$\pi_2 \rightarrow f_2(1285) \pi \quad \& \quad \pi_2 \rightarrow \rho(770) \pi$$



Isospin symmetry: neutral / charge mode

- isobar decaying into $f_2 \pi$: 1/2 intensity expected
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Conclusions & outlook



- **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 comparison neutral vs. charged mode*
 - ✓ *First look promising (mass spectra, main waves, isospin symmetry)*
- => **independent confirmation of any new state observed ($\rightarrow \pi_1(1660), \dots$)**



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Further final states *already under study*

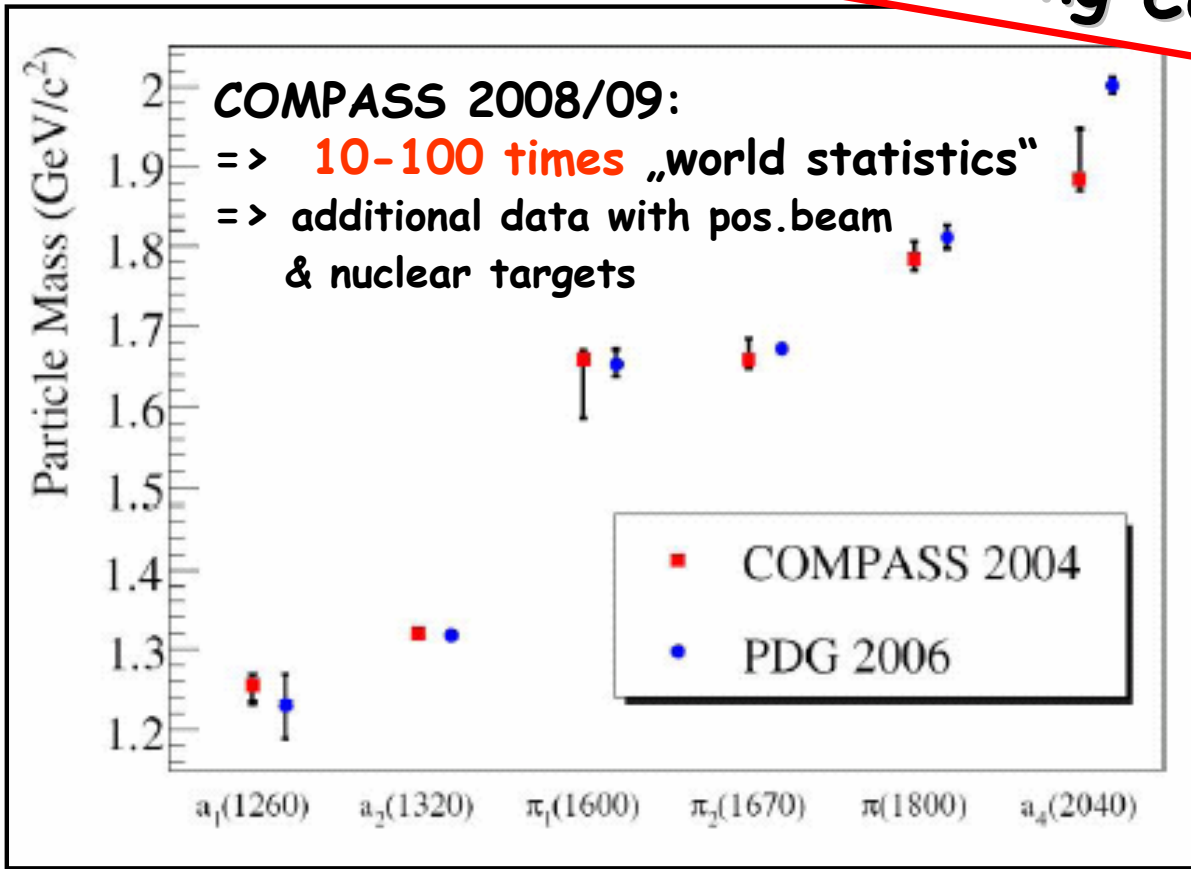
- 5π (*charged & neutral*),
- $\eta\pi, \eta\eta\pi$ (*also Central production*)
- 4π (*Central production, also muo-production (2004/6/7 data)*)
- Kaonic final states: $K\bar{K}\pi, K\bar{K}\pi\pi, K\bar{K}\eta$
=> *hidden strangeness, higher masses (> 2.2 GeV)*



Conclusions & outlook



Stay tuned for interesting COMPASS results ...



THANK YOU !!!