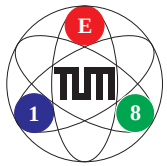
The COMPASS Hadron Spectroscopy Programme

Alex Austregesilo
for the
COMPASS Collaboration

3rd International Conference on Nuclear and Particle Physics
with CEBAF at Jefferson Lab
October 3-8, 2010
Dubrovnik, Croatia



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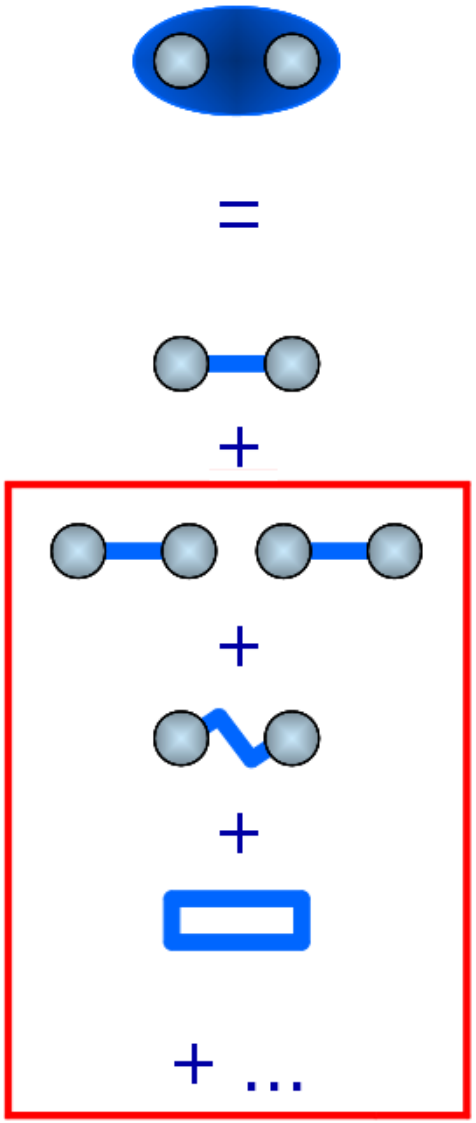
Outline

Meson Spectroscopy



$(q\bar{q})_0$

$(q\bar{q})(q\bar{q})$

$(q\bar{q})_8 g$

Hybrid

gg

Glueball

Quark model

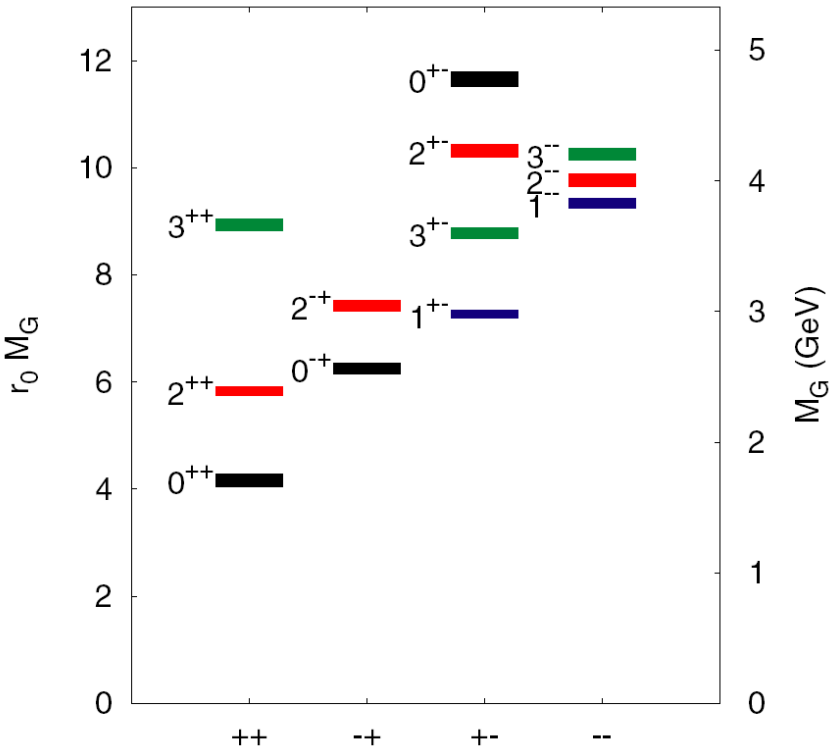
- Bound state of $q\bar{q}$
- Quantum numbers: $I^G(J^{PC})$

Quantum chromodynamics

- Colour-neutral configurations
- Study spectrum of mesons
  $\longrightarrow$ understand mass creation by strong interaction

Glueballs

Quenched LQCD prediction



[Y. Chen et al., Phys. Rev. D 73, 014516 (2006)]

Lightest glueballs

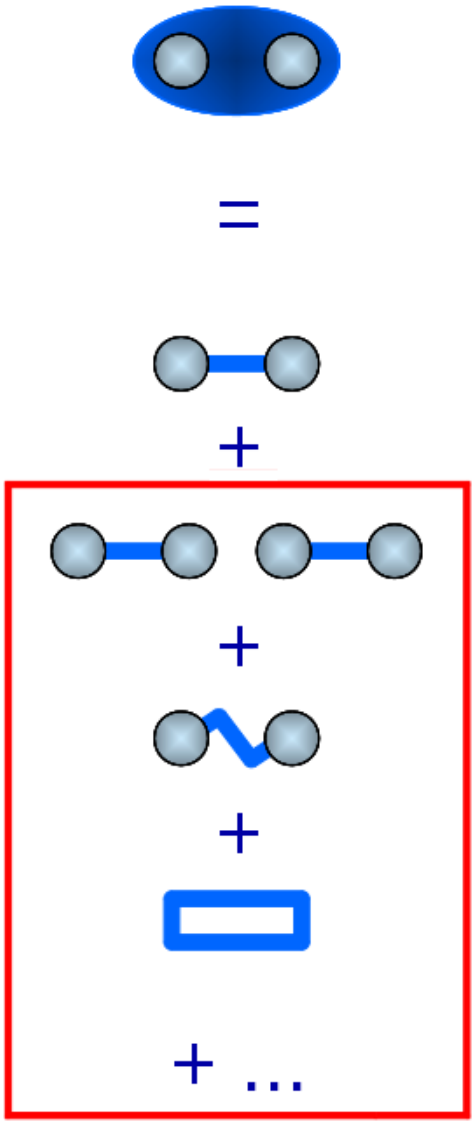
- $M \approx 1.7\,\mathrm{GeV}/c^2 \quad (J^{PC} = 0^{++})$
- $M \approx 2.4\,\mathrm{GeV}/c^2 \quad (J^{PC} = 2^{++})$

Experimental candidate

- $f_0(1500)$
  (CBAR, WA102)
- $J^{PC} = 0^{++}$
  $\Rightarrow$ mixing with isoscalar mesons

Meson Spectroscopy

Technische Universität München



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Hybrid

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Glueball

Quark model

- Bound state of $q\bar{q}$
- Quantum numbers: $I^G(J^{PC})$

Quantum chromodynamics

- Colour-neutral configurations
  $\Rightarrow$ Mixing
- Decoupling for narrow states or **vanishing qq̄-term**

$\Rightarrow$ Exotic J^{PC} : $0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$

Exotic $J^{PC} = 1^{-+}$ candidates

- $\pi_1(1400)$ (VES, E852, CBAR)
- $\pi_1(1600)$ (E852, VES)

$\Rightarrow$ controversial

Production Mechanisms

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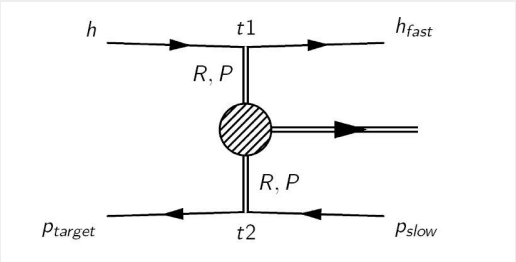
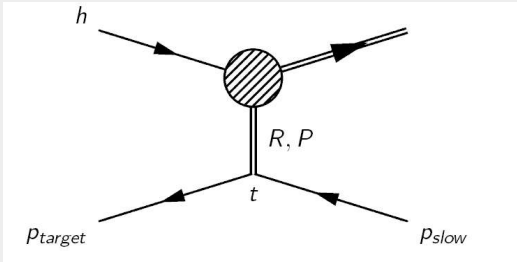
Central Production:



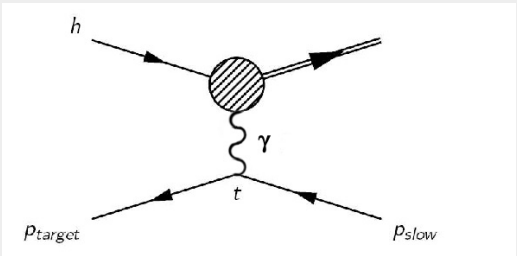
- Glue-rich meson resonances (DPE)
- Rapidity gap
- Decay products at large angles

Diffractive Dissociation:



- Study of spin-exotic mesons
- Forward kinematics
- Separation at small angles

Photo-production:



- Tests of chiral perturbation theory
- Measurement of radiative widths

⇒ Requirements for **precise detection of different decay modes**, both charged and neutral, to determine the nature of the resonances

The COMPASS Experiment

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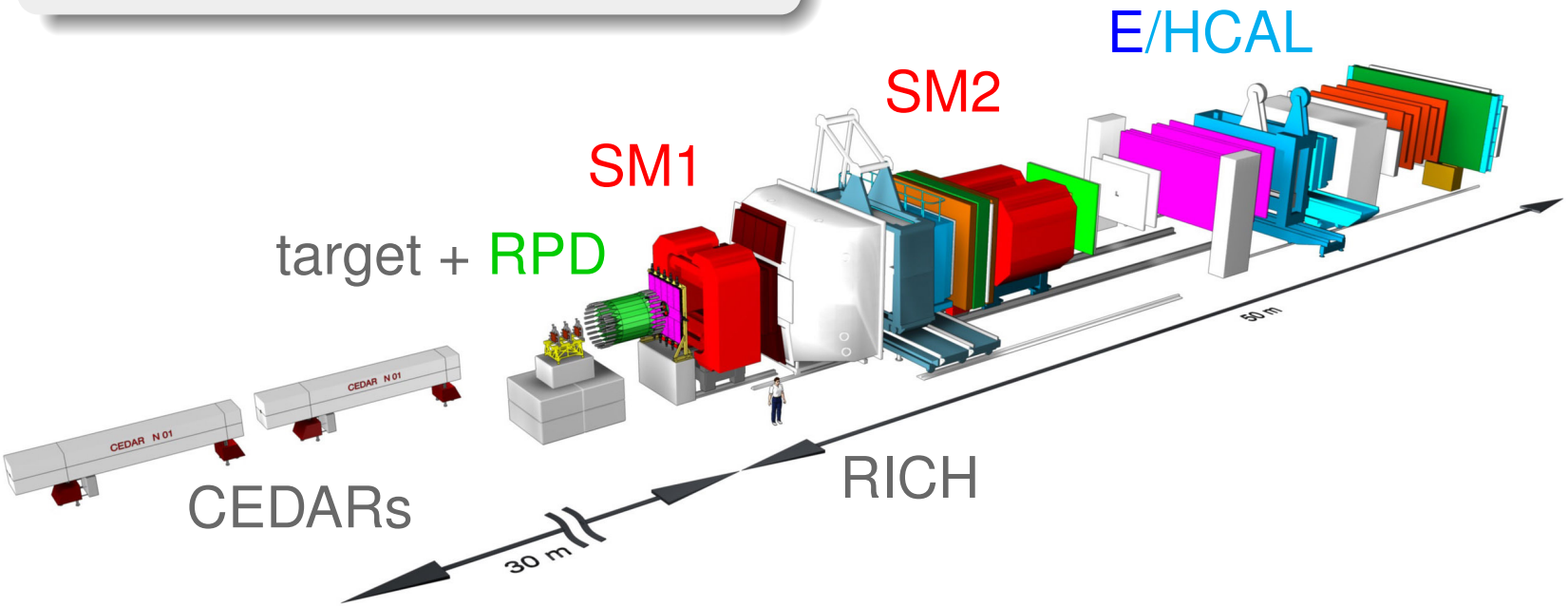
Two-stage magnetic spectrometer

- Large angular acceptance
- Broad kinematic range
- Tracking, calorimetry, particle ID



The COMPASS Hadron Programme

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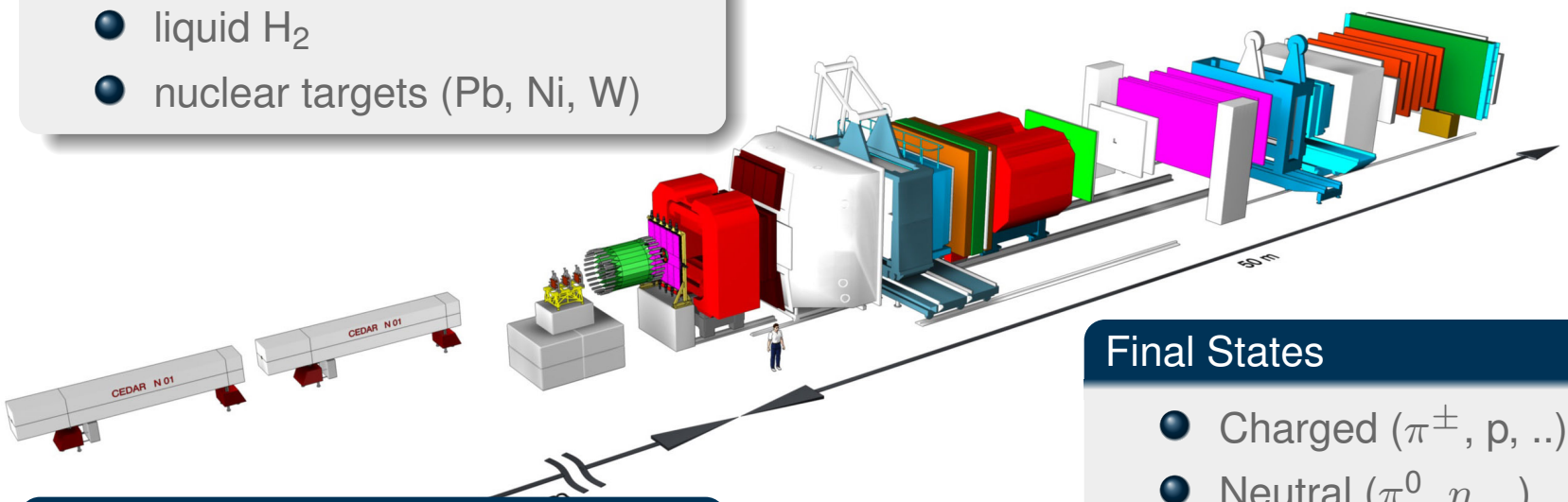
Targets

- liquid H_2
- nuclear targets (Pb, Ni, W)



Beams

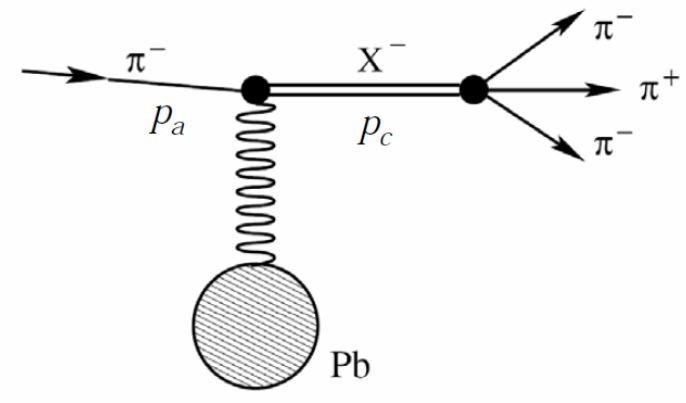
- 190 GeV/c π^-, K^-
- 190 GeV/c p, π^+, K^+

Final States

- Charged ($\pi^{\pm}$, p, ..)
- Neutral (π^0, η, ..)
- Kaonic ($K^{\pm}$, K_s, ..)

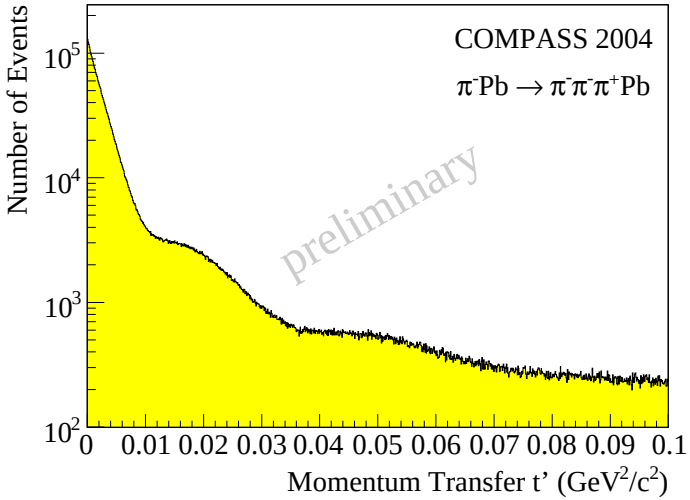
Diffractive Dissociation of Pions

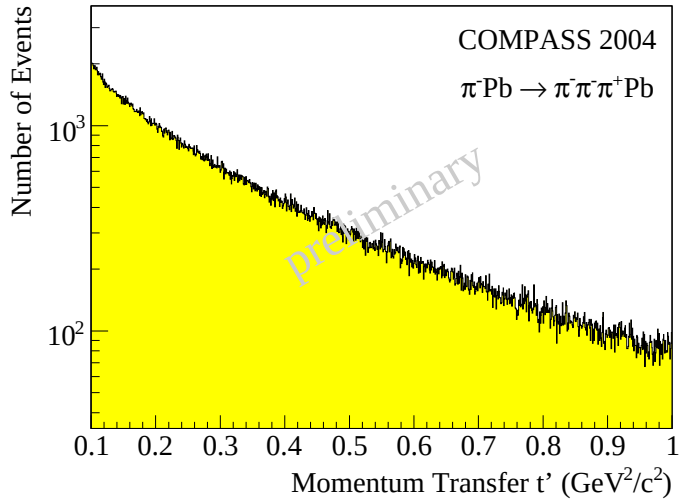
Diffractive Dissociation on Pb



$\pi^- + Pb \rightarrow \pi^-\pi^+\pi^- + Pb$

- 190 GeV/c π^- on Pb target
- Momentum transfer $0.1 < t' < 1(\mathrm{GeV}/c)^2$ $\rightarrow$ quasi-free nucleons in Pb
- $\approx$ 450 000 exclusive events recorded in 3 days





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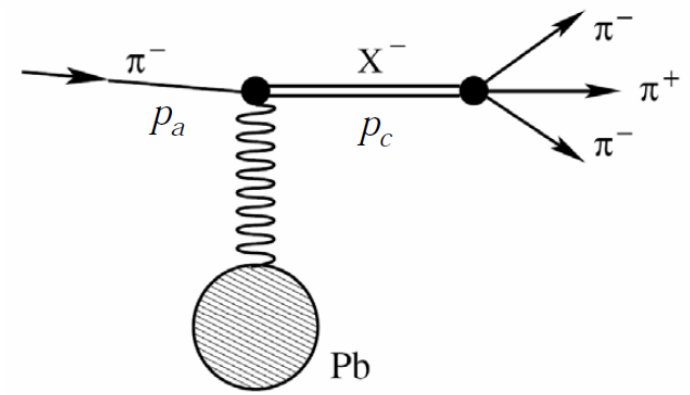

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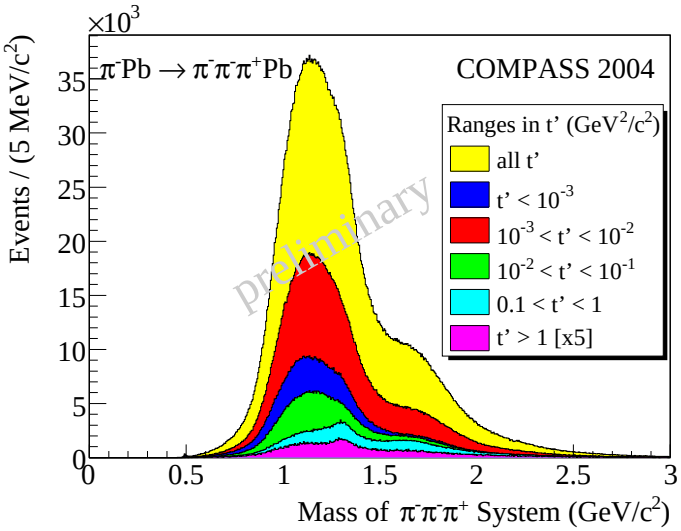
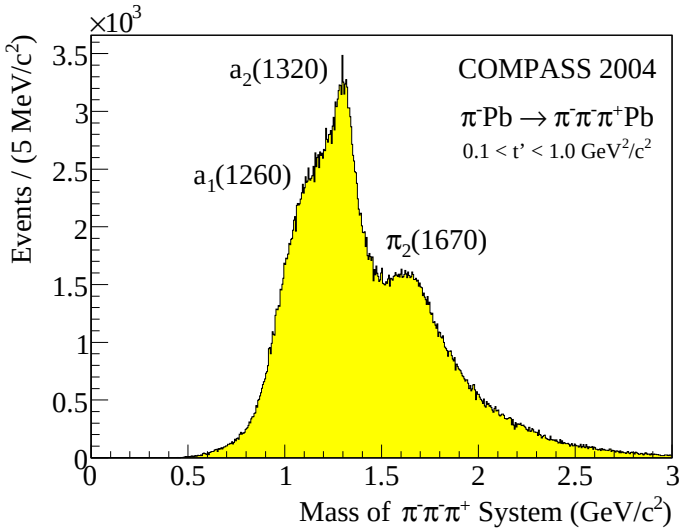
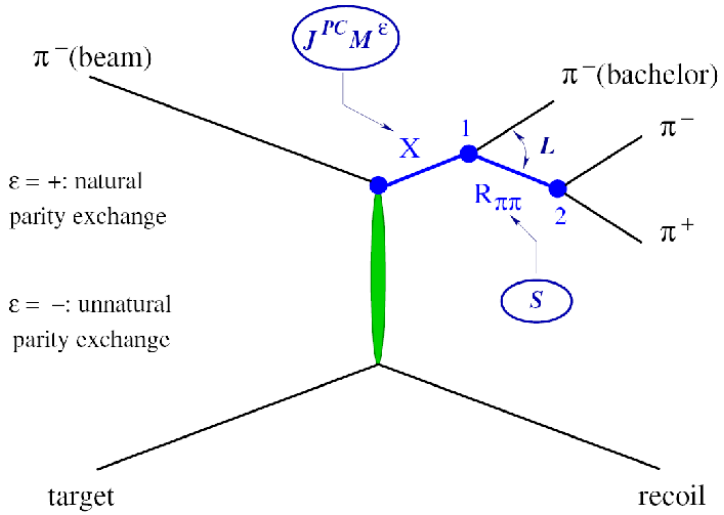




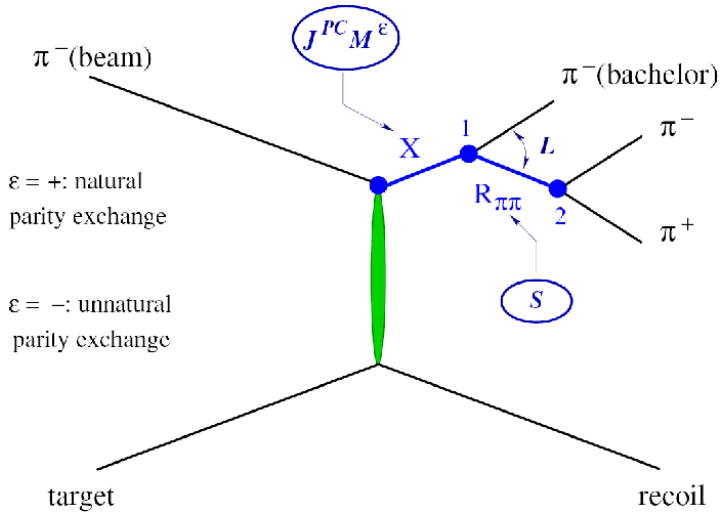
Partial-wave Analysis Technique



Model:

- *t*-channel Reggeon exchange
- Reflectivity basis
- Isobar model

Partial-wave Analysis Technique



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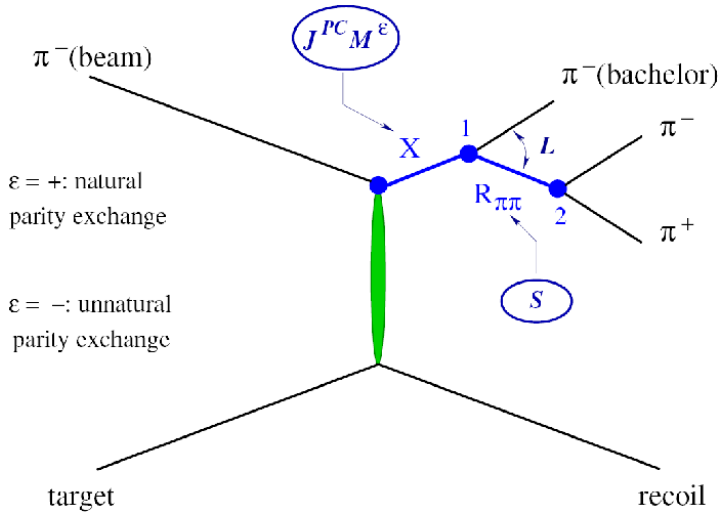
1. Mass Independent PWA

- Extended maximum likelihood fit in mass bins
- Set of partial waves with $J^{PC}\,M\epsilon\,R_{\pi\pi}\,L$ and isotropic flat wave

Partial-wave Analysis Technique

Technische Universität München



Model:

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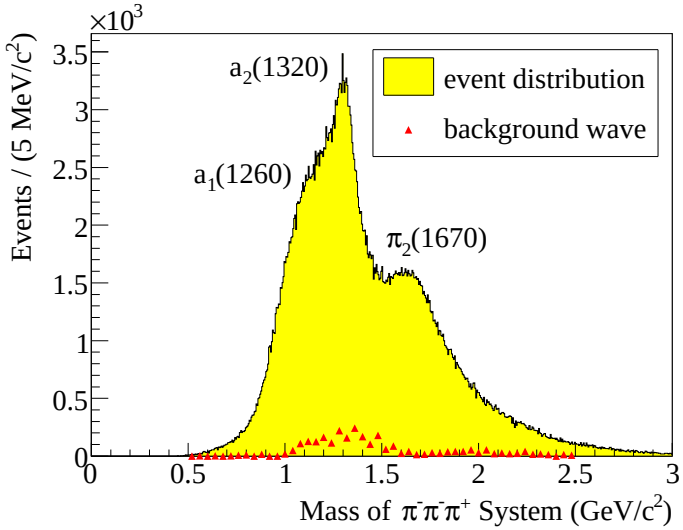
1. Mass Independent PWA

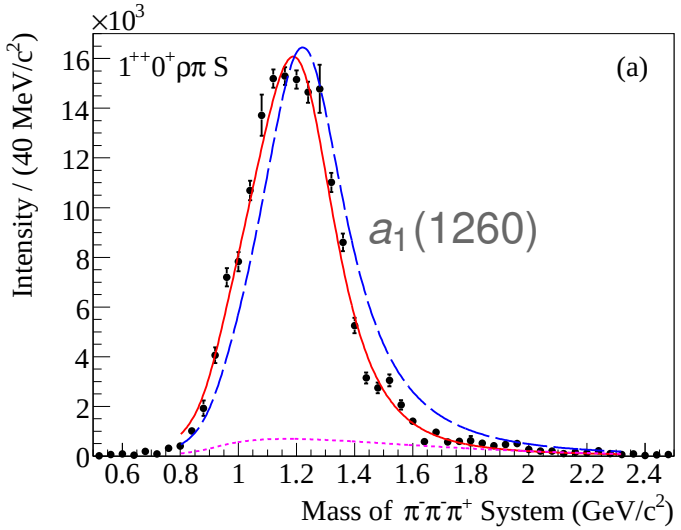
- Extended maximum likelihood fit in mass bins
- Set of partial waves with $J^{PC}\,M\epsilon\,R_{\pi\pi}\,L$ and isotropic flat wave

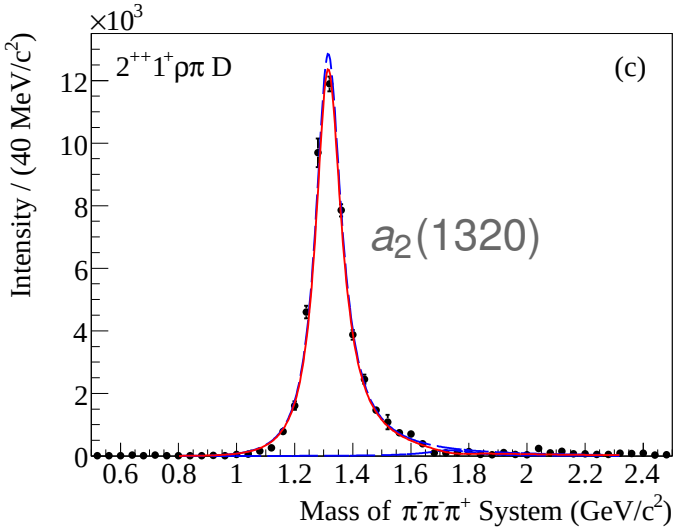
2. Mass Dependent PWA

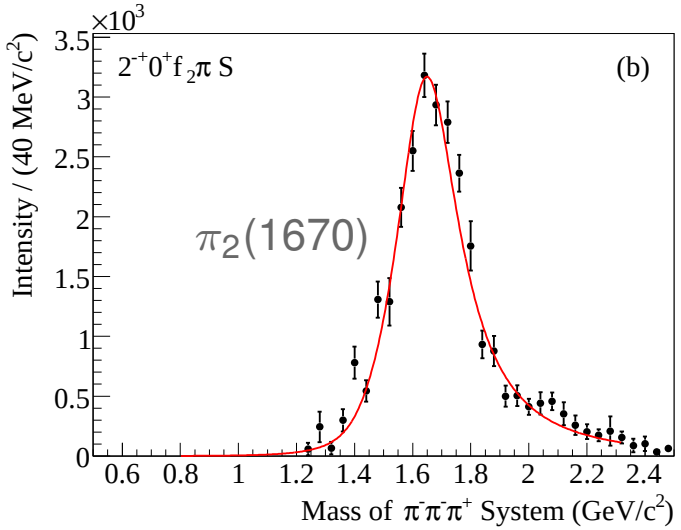
- χ^2-fit of mass dependence of spin-density matrix
- Subset of waves with significant intensity and phase motion
- Parametrisation: Breit-Wigner + coherent exponential background

Major Waves

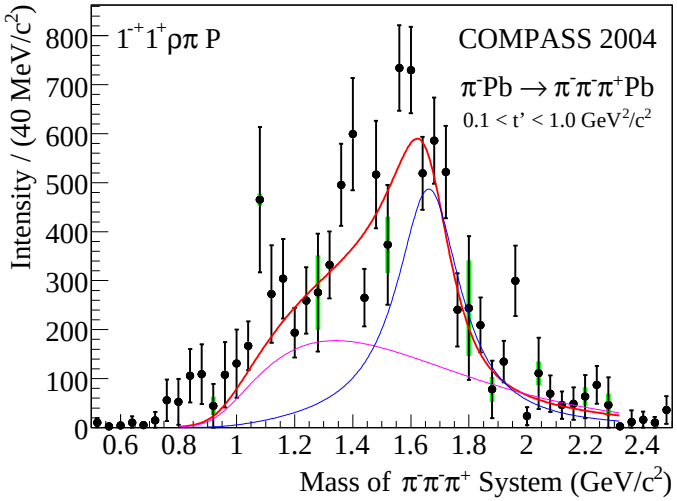

×10³
Events / (5 MeV/c²)
a₂(1320)
a₁(1260)
π₂(1670)
event distribution
background wave
Mass of π⁻π⁻π⁺ System (GeV/c²)

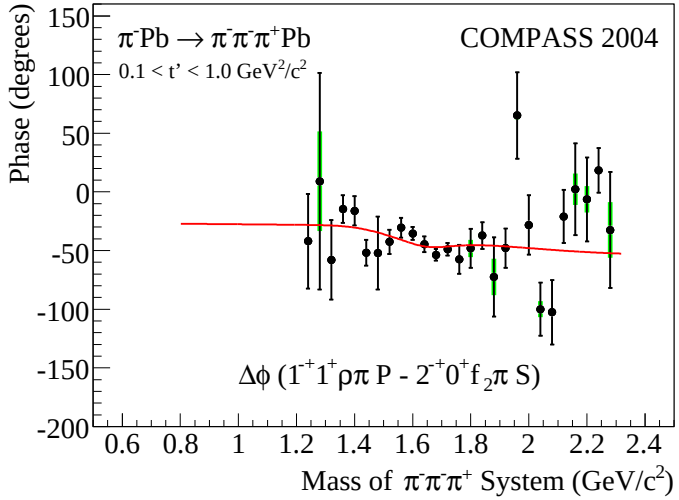

×10³
Intensity / (40 MeV/c²)
1⁺⁺0⁺ρπ S
(a)
a₁(1260)
Mass of π⁻π⁻π⁺ System (GeV/c²)

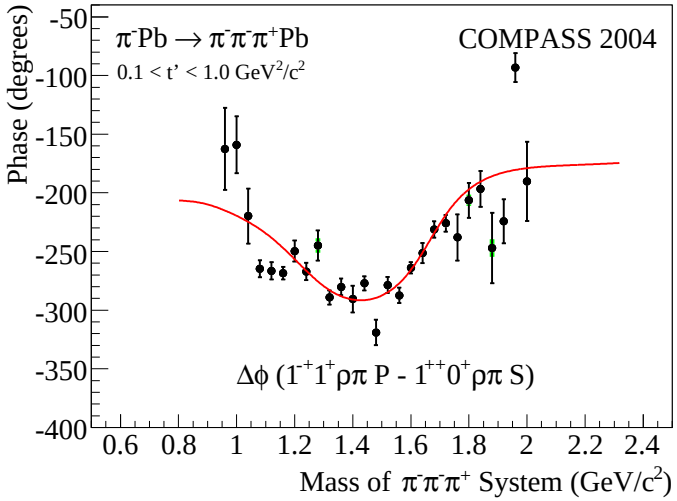

×10³
Intensity / (40 MeV/c²)
2⁺⁺1⁺ρπ D
(c)
a₂(1320)
Mass of π⁻π⁻π⁺ System (GeV/c²)


×10³
Intensity / (40 MeV/c²)
2⁻⁺0⁺f₂π S
(b)
π₂(1670)
Mass of π⁻π⁻π⁺ System (GeV/c²)

Spin-Exotic Wave







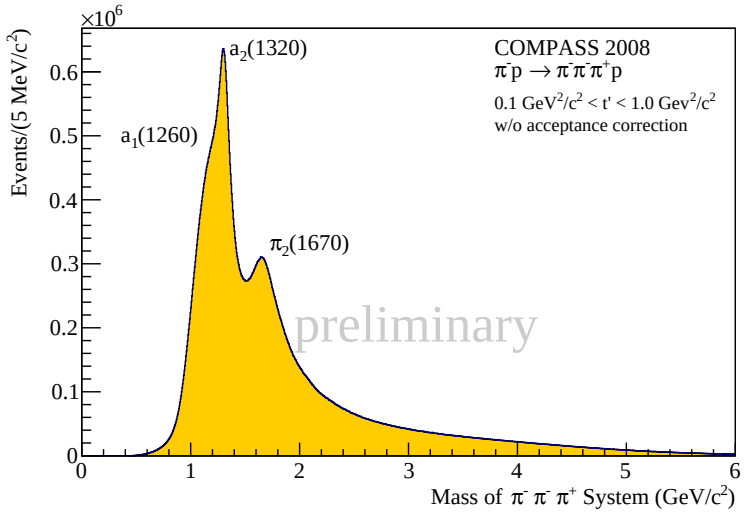
Significant $J^{PC} = 1^{-+}$ Wave

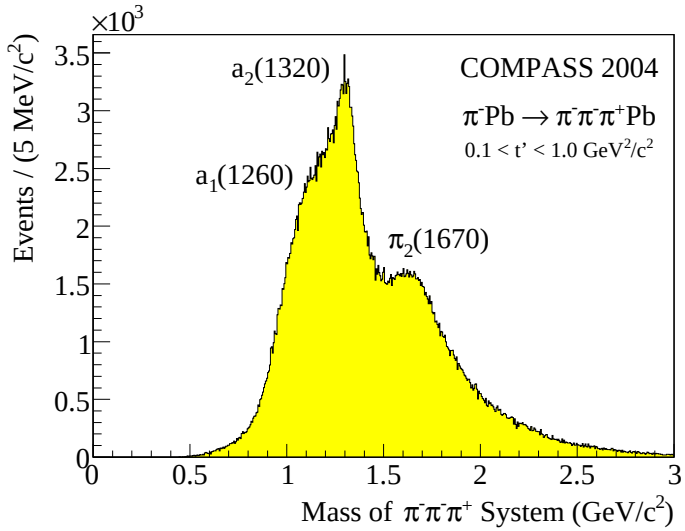
- $M = 1660 \pm 10^{+0}_{-64}$ MeV/c^2

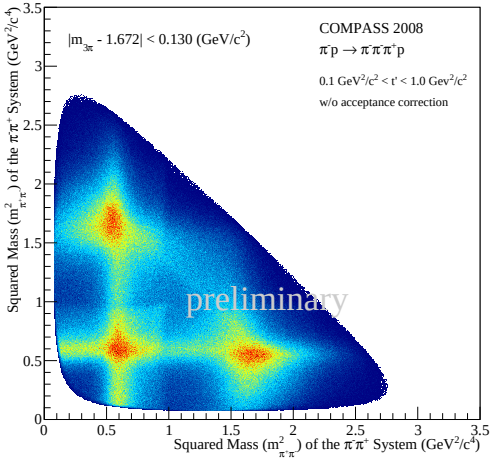
  $\Gamma = 269 \pm 21^{+42}_{-64}$ MeV/c^2
- consistent with $\pi_1(1600)$
- Negligible leakage ($< 5\%$)

[COMPASS, PRL 104, 241803 (2010)]

Diffractive Dissociation on H_2



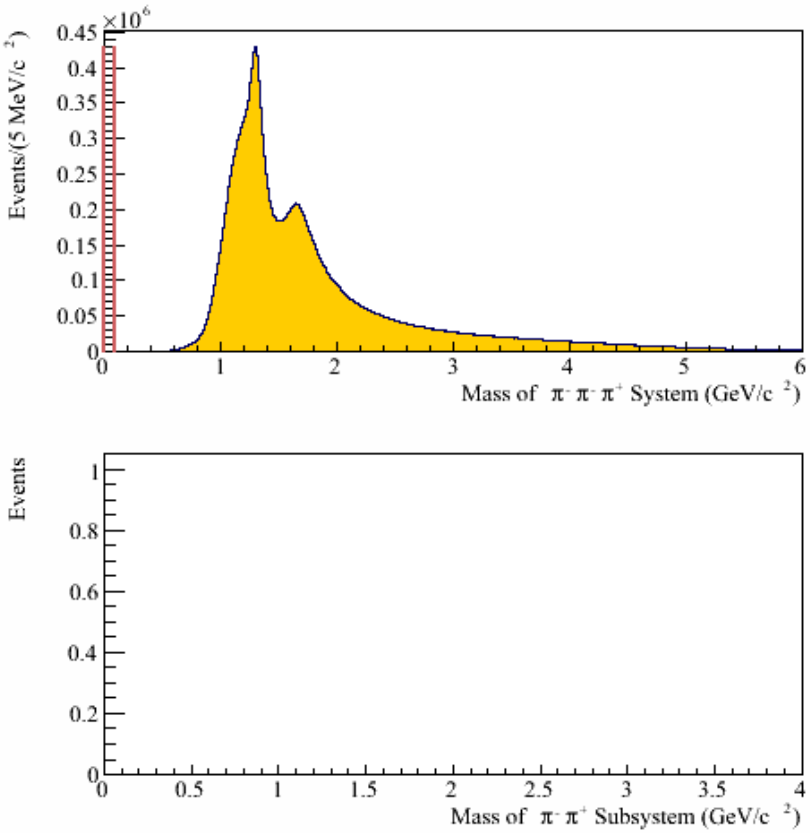


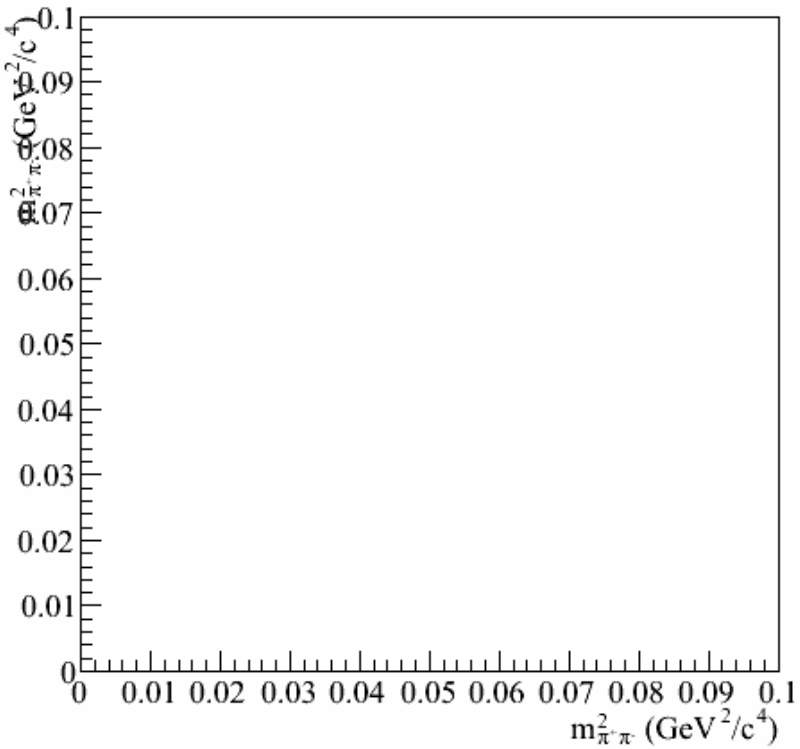


$\pi^- + p \longrightarrow \pi^-\pi^+\pi^- + p$

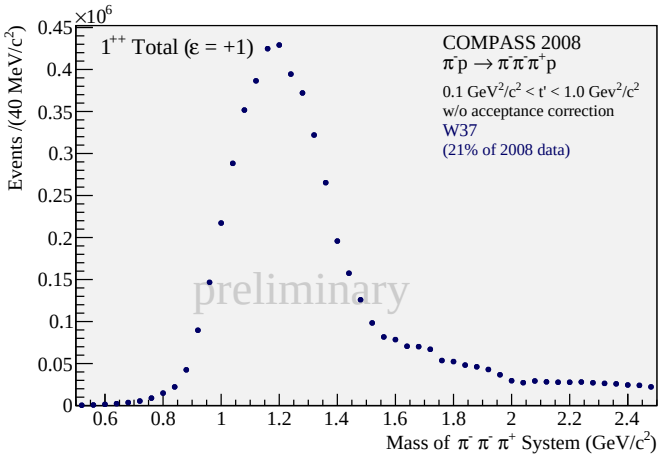
- 190 GeV/c π^- on H_2 target
- $\approx$ 96M events
  $\longrightarrow$ **unprecedented statistics**
- No acceptance correction yet

Diffractive Dissociation on H_2



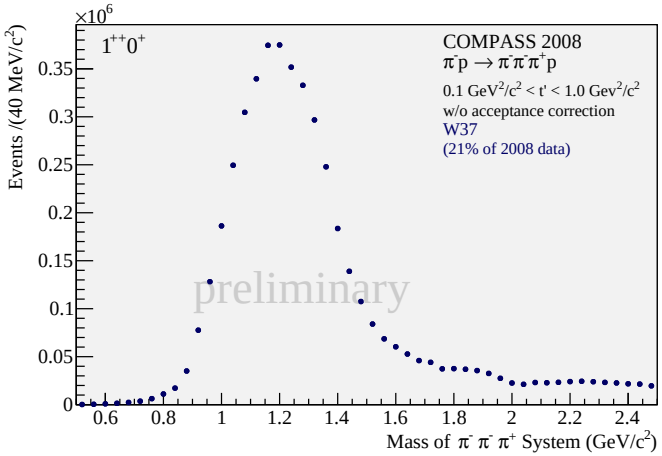


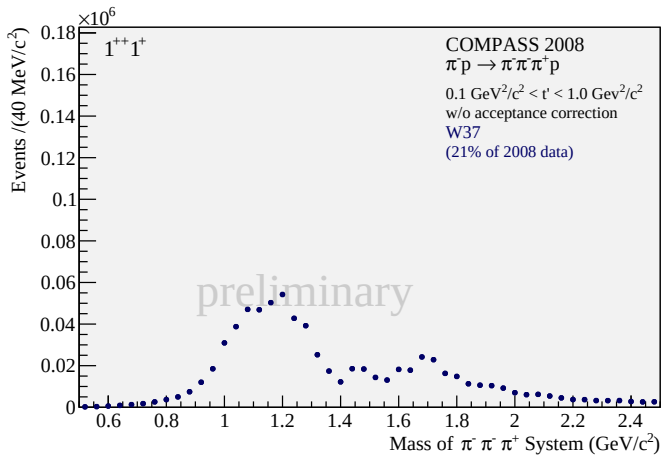
Nuclear Effect in Meson Production



Pb (2004) vs. H_2 (2008) target

- Normalised to $a_2(1320)$
- Different intensity of spin projections, i.e. of $J^{PC} = 1^{++}$





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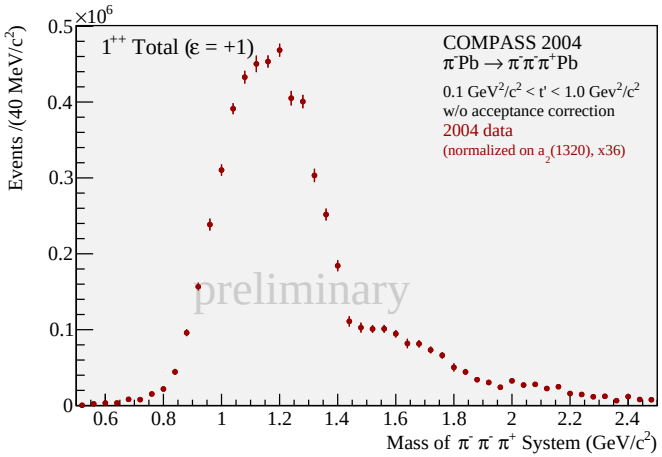
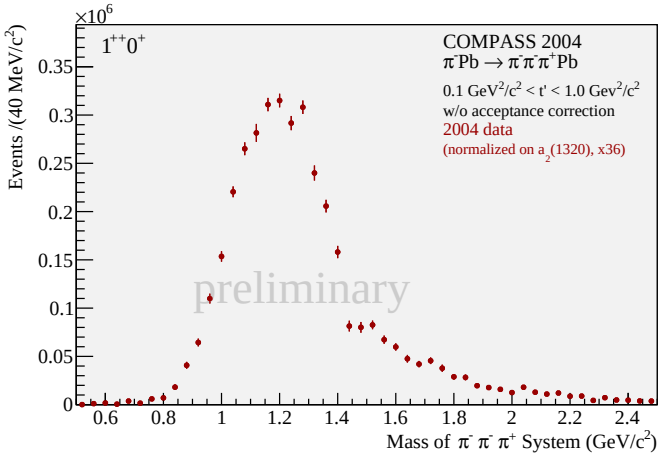
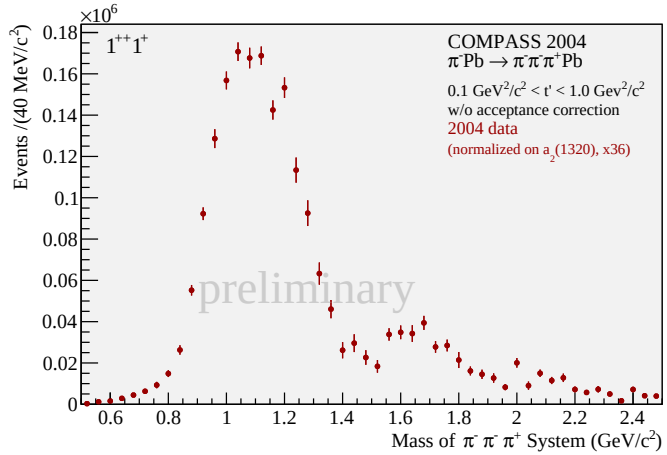


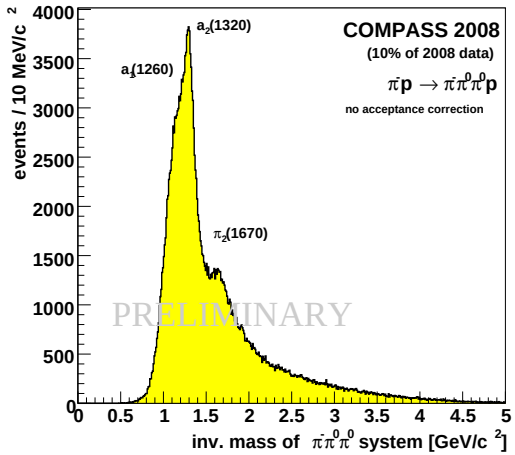


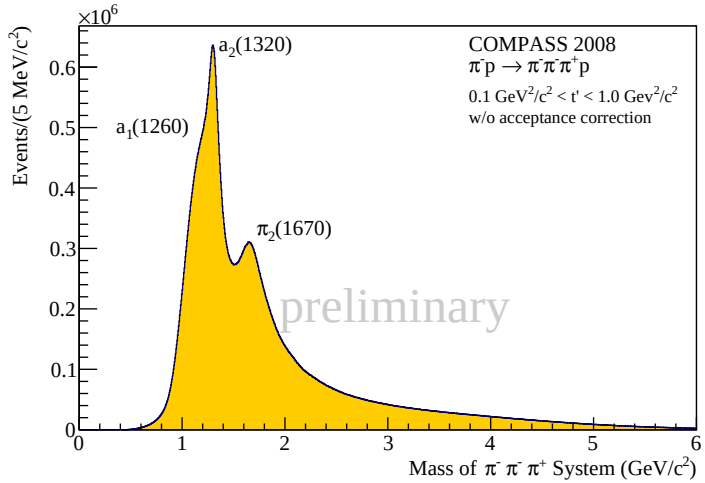
Pb (2004) vs. H_2 (2008) target

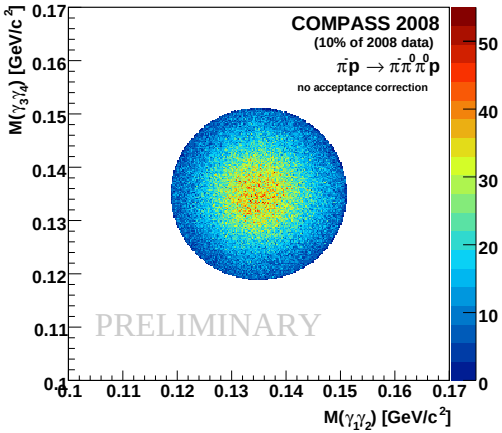
- Normalised to $a_2(1320)$
- Different intensity of spin projections, i.e. of $J^{PC} = 1^{++}$
- On Pb: **$M = 1$ enhanced**, $M = 0$ suppressed



Neutral Decay Mode



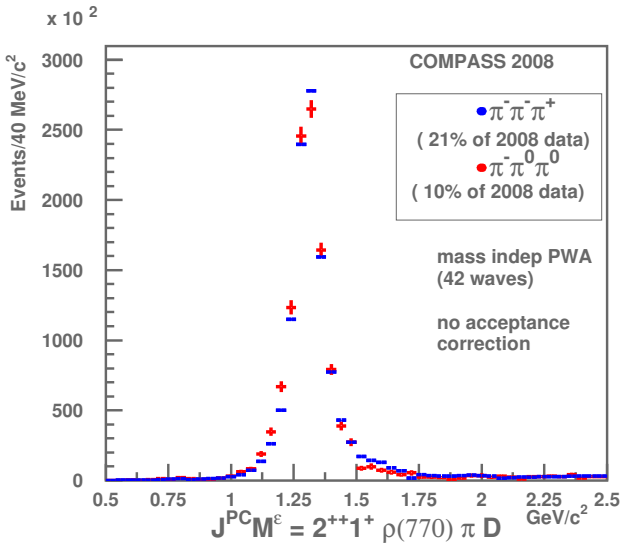




$\pi^- + p \to \pi^-\pi^0\pi^0 + p$

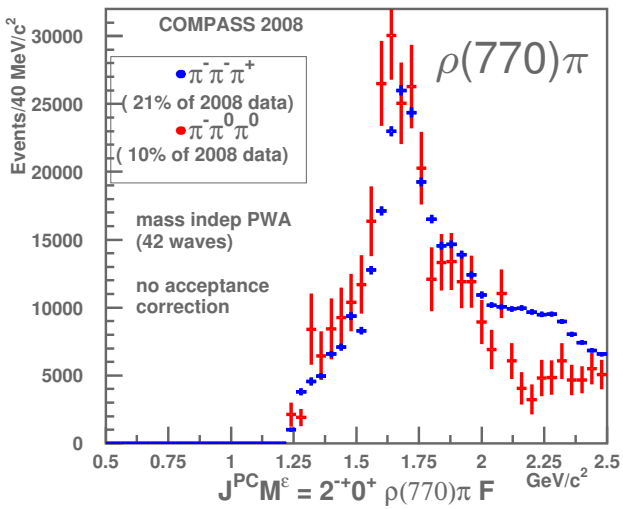
- Calorimetry upgrade allows for
- Comparison between neutral and charged decay modes

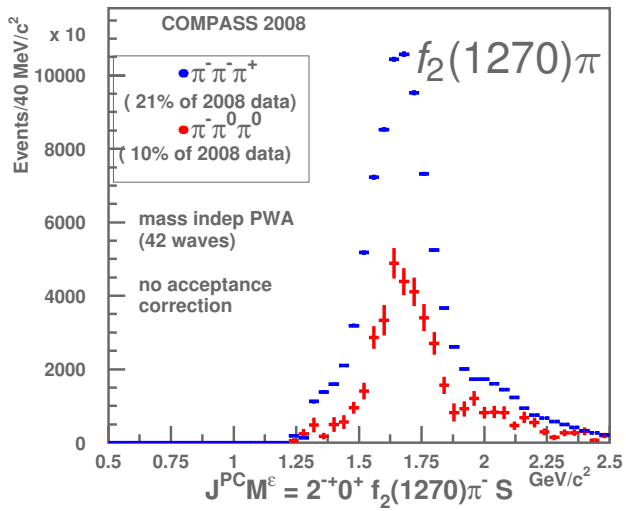
Isospin Symmetry



Charged vs. neutral decay mode

- Normalised to $a_2(1320)$
- Decay through $\rho(770)$ isobar: expected intensity ratio $\approx 1/1$
- Decay through $f_2(1270)$ isobar: expected intensity ratio $\approx 2/1$

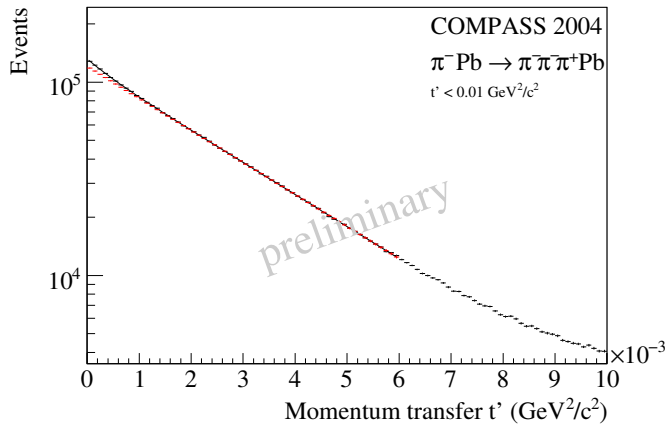




Interference with Photo-production

Momentum Transfer $t' < 10^{-3}(\mathrm{GeV}/c)^2$

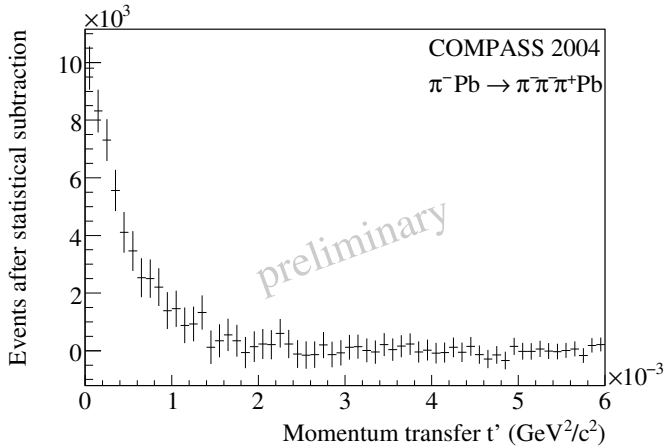
- Additional contribution to t' spectrum: **Photo-production**

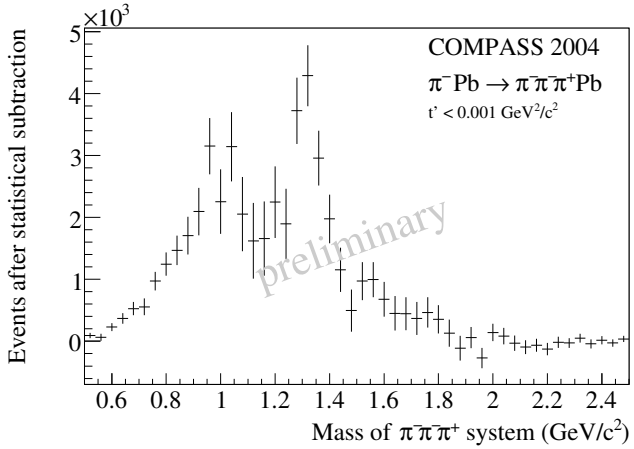


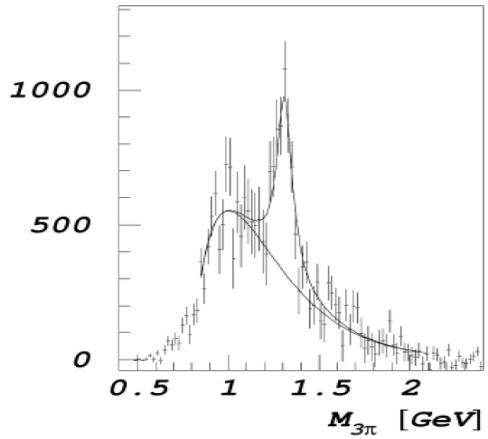
Interference with Photo-production

Momentum Transfer $t' < 10^{-3}(\mathrm{GeV}/c)^2$

- Additional contribution to t' spectrum: **Photo-production**
- Statistical subtraction $\longrightarrow$ invariant mass spectrum





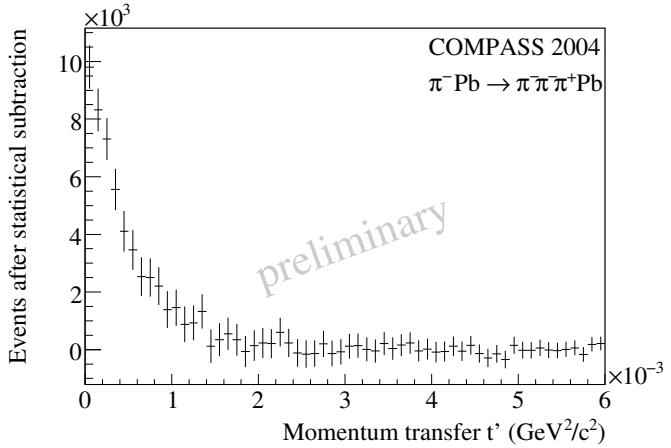


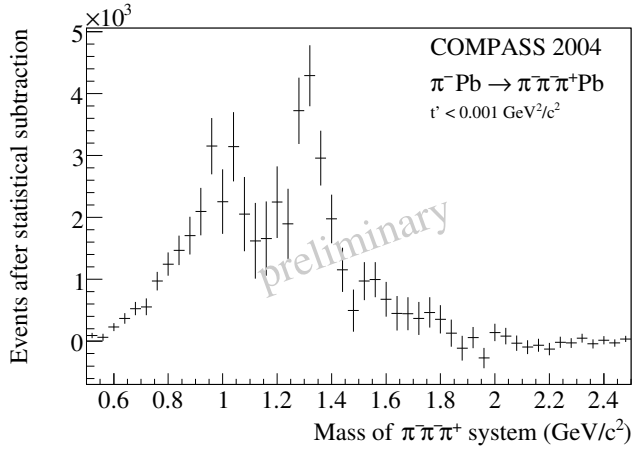
SELEX, [V. V. Molchanov et al, PLB 521, 171 (2001)]

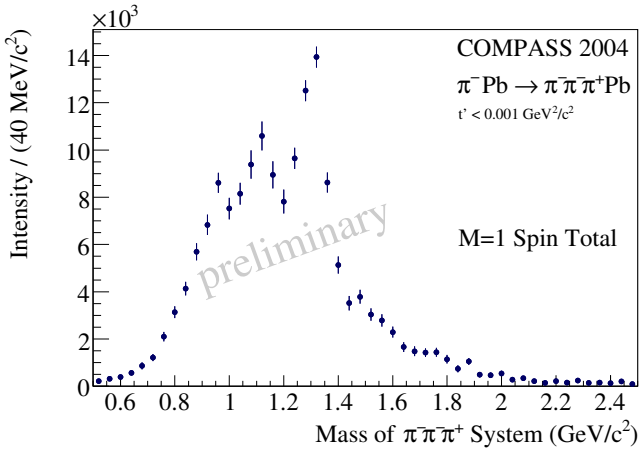
Interference with Photo-production

Momentum Transfer $t' < 10^{-3}(\mathrm{GeV}/c)^2$

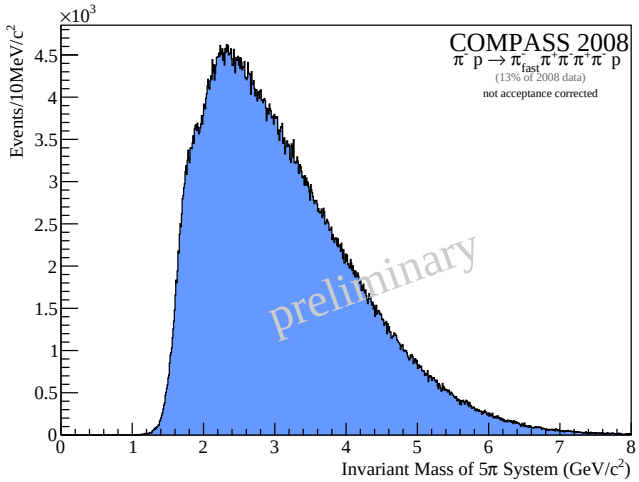
- Additional contribution to t' spectrum: **Photo-production**
- Statistical subtraction $\longrightarrow$ invariant mass spectrum
- PWA: Negligible diffractive contribution to $M = 1$ waves







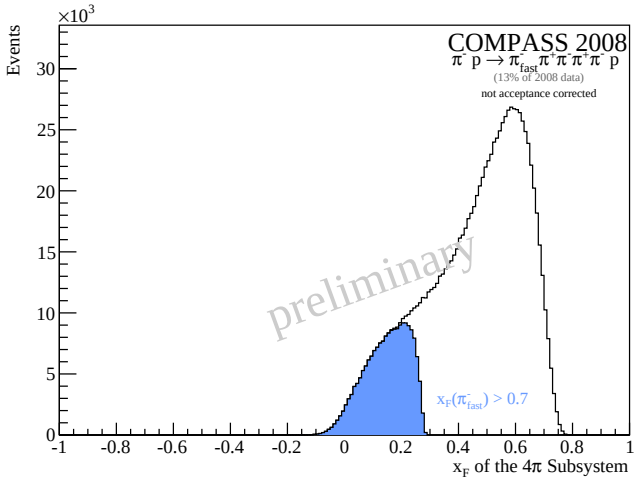
Production at Central Rapidities

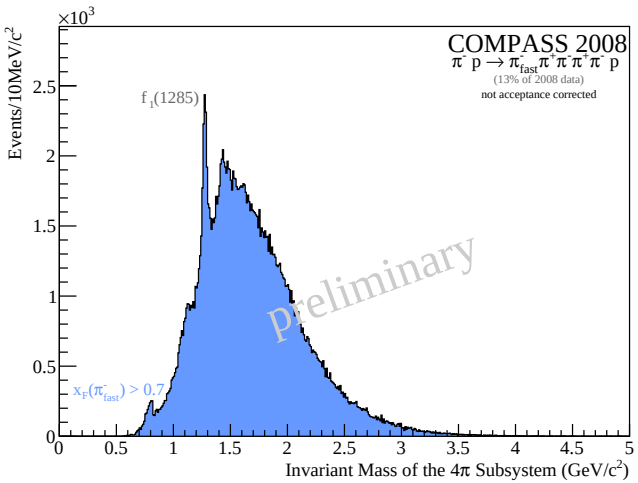


$\pi^- + p \to \pi^- \pi^+ \pi^- \pi^+ \pi^- + p$

- Prominent exotic decay into $f_1 \pi$

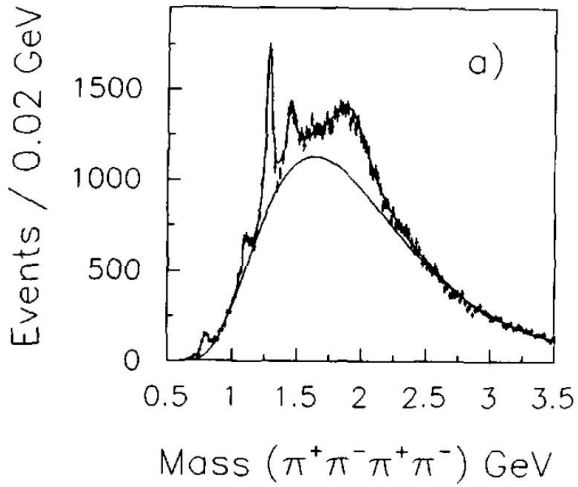
Production at Central Rapidities





$\pi^- + p \to \pi^-\pi^+\pi^-\pi^+\pi^- + p$

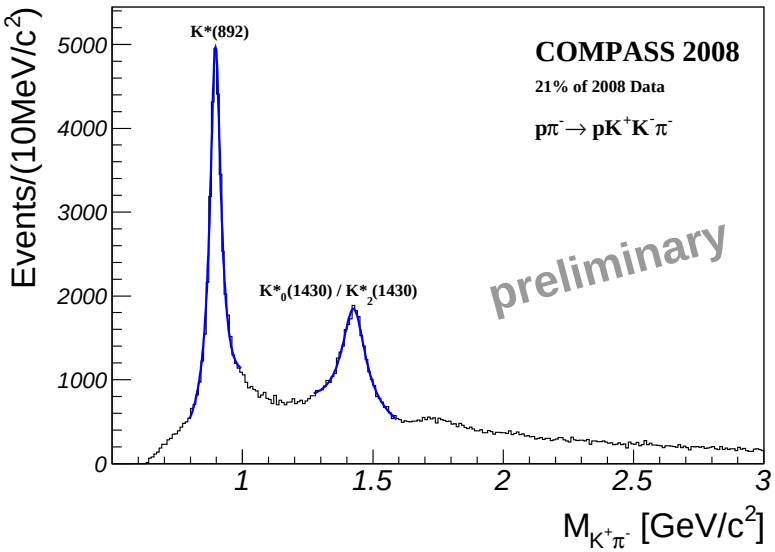
- Prominent exotic decay into $f_1\,\pi$
- Selection via cut on Feynman x_F
- Possibility to study scalar mesons around $1.5\,\mathrm{GeV}/c^2$
- Momentum transfer to the target provided by recoil proton detector



WA91, [F. Antinori et al., INC 107A, 10 (1994)]

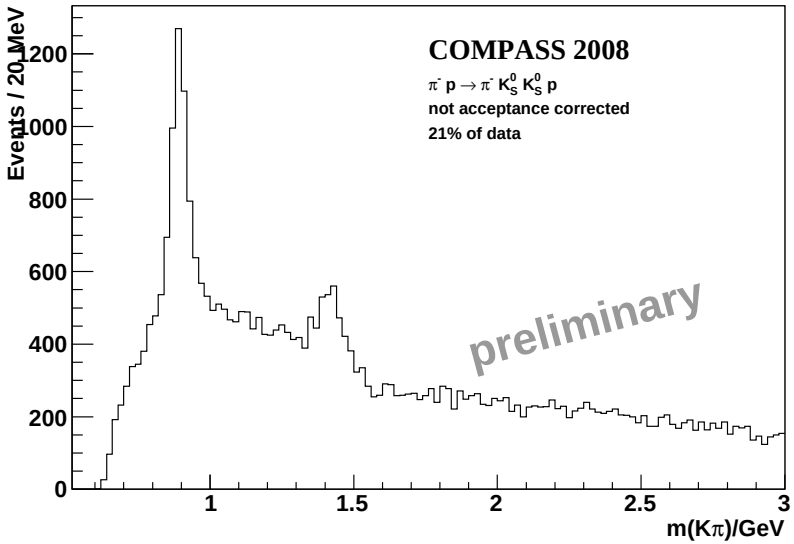
... adding strangeness

Strange Meson Production



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

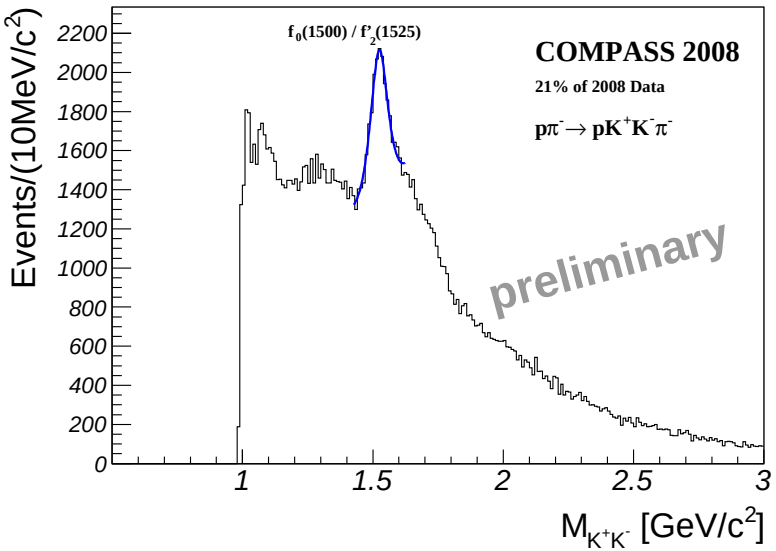
K^- identified by RICH



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

K_s identified by $\pi^+\pi^-$ decay

Strange Meson Production



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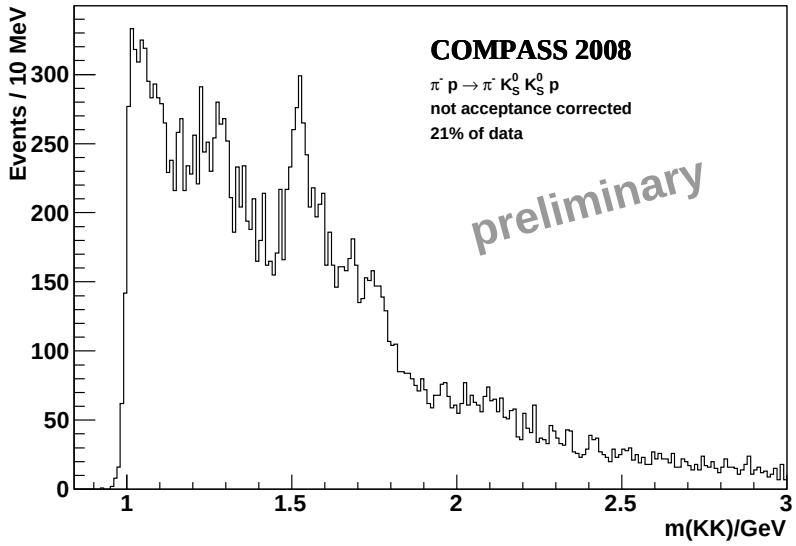

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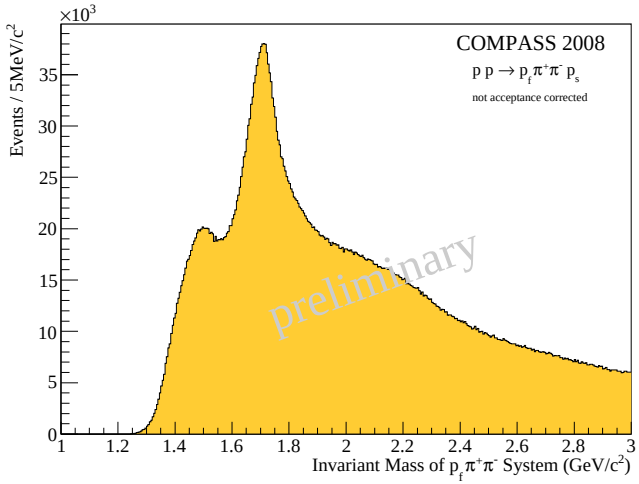
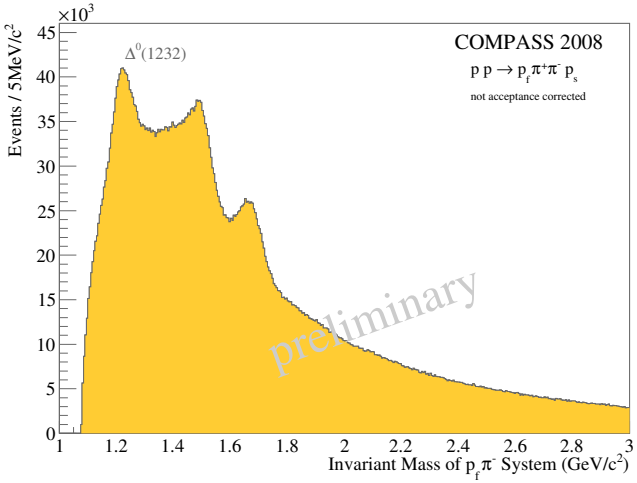
Diffractive Dissociation of Protons

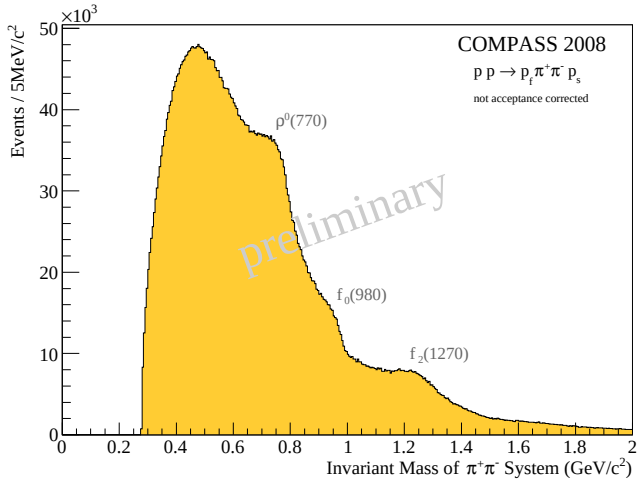
Diffractive Dissociation of Protons



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

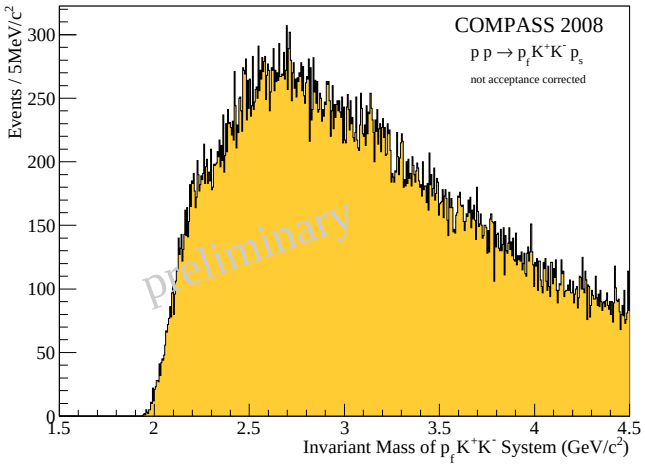
- Hadro-production complementary to existing experiments (CLAS, MAMI, ..)
- High mass and high angular momentum states accessible





Diffractive Dissociation of Protons

Technische Universität München



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

- Hadro-production complementary to existing experiments (CLAS, MAMI, ..)
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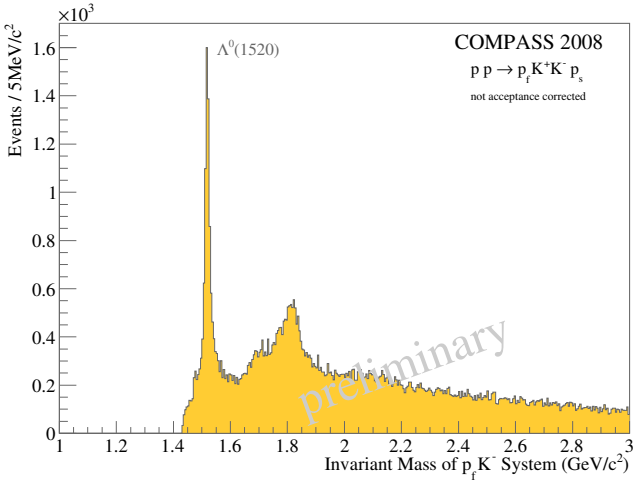

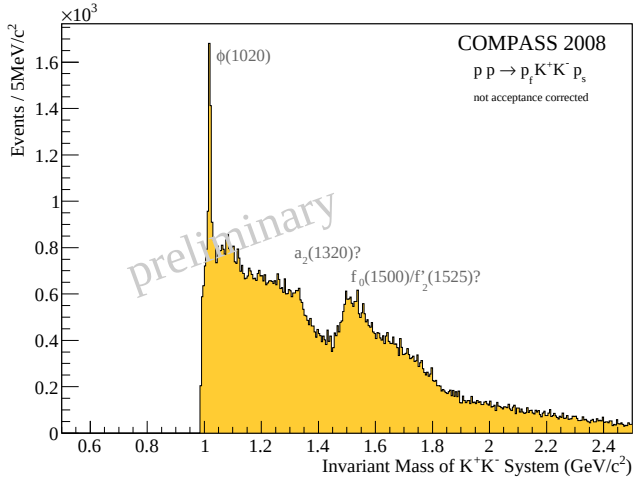

Conclusion and Outlook

and many more ...

High Potential for Hadron Spectroscopy at COMPASS

- 2004 pilot run: Observed exotic $J^{PC} = 1^{-+}$ consistent with $\pi_1(1600)$
- 2008/2009: Large data set with several beam/target combinations
- Outnumber previous experiments (BNL E852, WA102, ..) by more than a factor of 10
- PWA analysis elaborated and tested (real and MC data)

Conclusion and Outlook

High Potential for Hadron Spectroscopy at COMPASS

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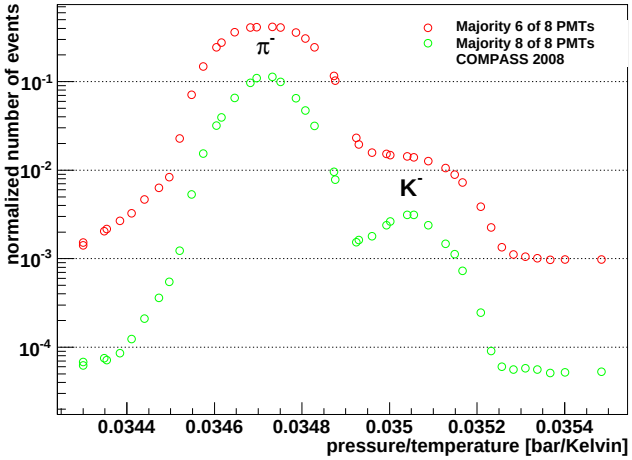
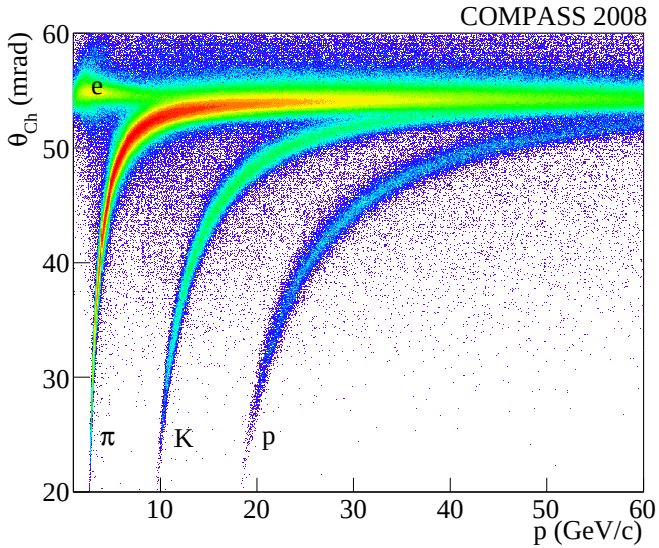
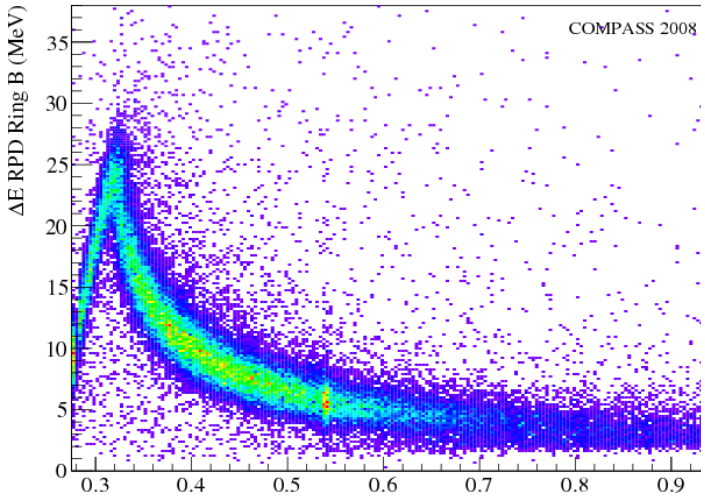
More exciting results soon ...

Backup Slides

Particle ID


Majority 6 of 8 PMTs
Majority 8 of 8 PMTs
COMPASS 2008
π⁻
K⁻
normalized number of events
pressure/temperature [bar/Kelvin]


COMPASS 2008
e
π
K
p
θCh (mrad)
p (GeV/c)


COMPASS 2008
ΔE RPD Ring B (MeV)

Waveset

$J^{PC}M^{\epsilon}$	L	Isobar π	Cut [GeV]
$0^{-+}0^{+}$	S	$f_0\pi$	1.40
$0^{-+}0^{+}$	S	$(\pi\pi)_s\pi$	-
$0^{-+}0^{+}$	P	$\rho\pi$	-
$1^{-+}1^{+}$	P	$\rho\pi$	-
$1^{++}0^{+}$	S	$\rho\pi$	-
$1^{++}0^{+}$	P	$f_2\pi$	1.20
$1^{++}0^{+}$	P	$(\pi\pi)_s\pi$	0.84
$1^{++}0^{+}$	D	$\rho\pi$	1.30
$1^{++}1^{+}$	S	$\rho\pi$	-
$1^{++}1^{+}$	P	$f_2\pi$	1.40
$1^{++}1^{+}$	P	$(\pi\pi)_s\pi$	1.40
$1^{++}1^{+}$	D	$\rho\pi$	1.40
$2^{-+}0^{+}$	S	$f_2\pi$	1.20
$2^{-+}0^{+}$	P	$\rho\pi$	0.80
$2^{-+}0^{+}$	D	$f_2\pi$	1.50
$2^{-+}0^{+}$	D	$(\pi\pi)_s\pi$	0.80
$2^{-+}0^{+}$	F	$\rho\pi$	1.20
$2^{-+}1^{+}$	S	$f_2\pi$	1.20
$2^{-+}1^{+}$	P	$\rho\pi$	0.80
$2^{-+}1^{+}$	D	$f_2\pi$	1.50
$2^{-+}1^{+}$	D	$(\pi\pi)_s\pi$	1.20
$2^{-+}1^{+}$	F	$\rho\pi$	1.20

$J^{PC}M^{\epsilon}$	L	Isobar π	Cut [GeV]
$2^{++}1^{+}$	P	$f_2\pi$	1.50
$2^{++}1^{+}$	D	$\rho\pi$	-
$3^{++}0^{+}$	S	$\rho_3\pi$	1.50
$3^{++}0^{+}$	P	$f_2\pi$	1.20
$3^{++}0^{+}$	D	$\rho\pi$	1.50
$3^{++}1^{+}$	S	$\rho_3\pi$	1.50
$3^{++}1^{+}$	P	$f_2\pi$	1.20
$3^{++}1^{+}$	D	$\rho\pi$	1.50
$4^{-+}0^{+}$	F	$\rho\pi$	1.20
$4^{-+}1^{+}$	F	$\rho\pi$	1.20
$4^{++}1^{+}$	F	$f_2\pi$	1.60
$4^{++}1^{+}$	G	$\rho\pi$	1.64
$1^{-+}0^{-}$	P	$\rho\pi$	-
$1^{-+}1^{-}$	P	$\rho\pi$	-
$1^{++}1^{-}$	S	$\rho\pi$	-
$2^{-+}1^{-}$	S	$f_2\pi$	1.20
$2^{++}0^{-}$	P	$f_2\pi$	1.30
$2^{++}0^{-}$	D	$\rho\pi$	-
$2^{++}1^{-}$	P	$f_2\pi$	1.30
FLAT			

Red: major waves used for mass-dependent fit