CERN NA58

# COMPASS実験におけるハドロン物理プログラム
# Hadron physics program at COMPASS experiment

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(Collaboration) Czech Republic, Finland, France, Germany, India, Israel, Italy, Japan, Poland, Portugal, Russia

28 Institutes, ~240 physicists

**COMPASS JAPAN Group**
Yamagata, KEK, Chubu, Miyazaki

# Outline

- Introduction to COMPASS
- Physics motivation
- Partial Wave Analysis technique
- Diffractive Dissociation of pions
  - $3\pi$ system at high t’ (Pomeron exchange)
  - $3\pi$ system at “Primakoff region”
  - $\eta'\pi$ system
- Diffractive Dissociation of kaons
- Other channels
- Summary

# COMPASS at CERN

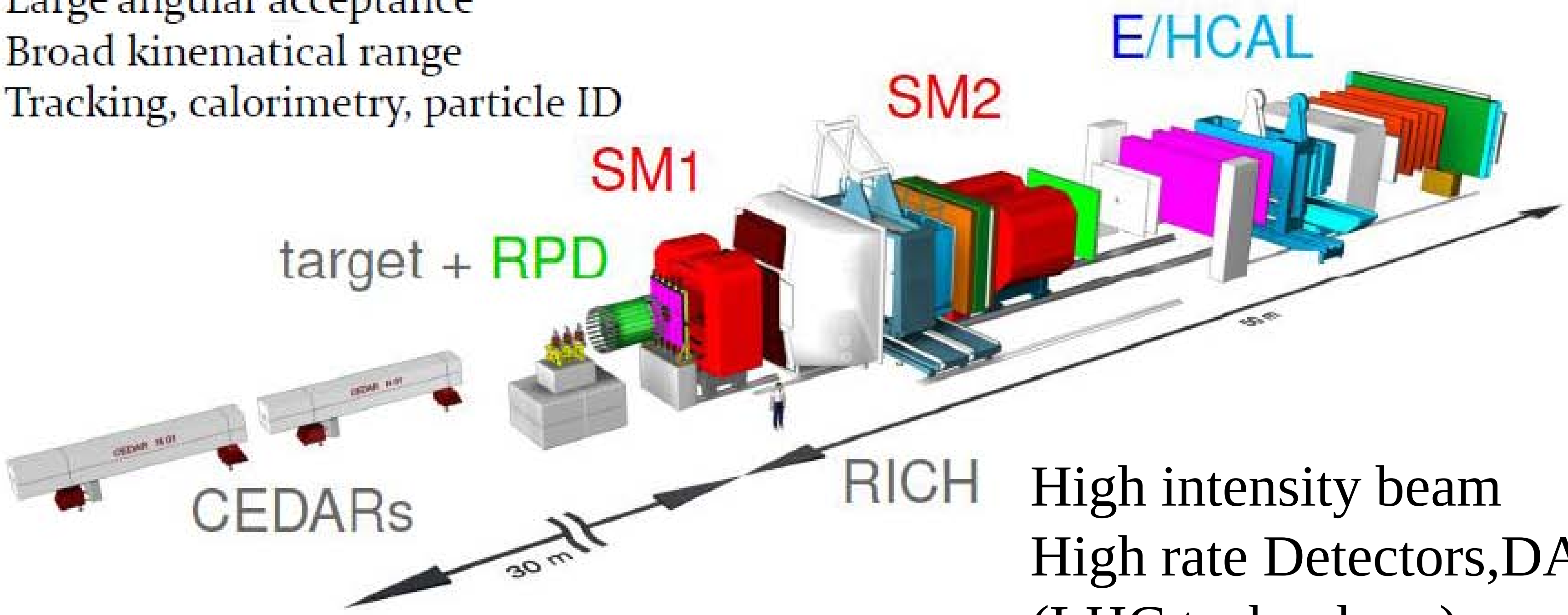
**CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

- 190GeV secondary hadrons ($\pi$, K, p...): $2 \cdot 10^7$/s
- 160GeV secondary $\mu$ (polarized): $4 \cdot 10^7$/s

# The COMPASS experiment

**Two-stage magnetic spectrometer:**

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




High intensity beam
High rate Detectors,DAQ
(LHC technology)

**Beam**: 190 GeV positive (p, $\pi^+$, $K^+$ ) or negative ($\pi^-$, $K^-$ ) hadron beam.
**Targets**: Liquid $H_2$, Nuclear targets (Pb, Ni, W).
**Final states**: charged ($\pi^\pm$, p, ...), neutral ($\pi^0$, η, η', ...),
kaonic ($K^\pm$, $K_S$, ...)

# Making of COMPASS proposal

(Of course I don't know such an old era…)

*Nucleon structure*

EMC → NMC → SMC(NA47) → HMC

*Meson spectroscopy*

GAMS(NA12/2), WA91 → GAMS-OMEGA (WA102) → CHEOPS

*Charmed strange baryon, H-dibaryon*

WA89 (Hyperon beam) → CHEOPS

CHEOPS (Charm Experiment with Omni Purpose Setup)

HMC + CHEOPS → COMPASS (NA58) → COMPASS-II (Drell-Yan, GPD, Primakoff)

**CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy

Nucleon spin structure + Meson Spectroscopy + Primakoff scattering

Muon beam — Hadron beam

Doubly charm baryon postponed

# *History of COMPASS collaboration*

*1997 : COMPASS proposal conditionally approved.*

*1998 : MOU signed.*

2001 : technical run.

2002-2004 : muon beam and

“ pilot run” with hadron beam (3 weeks plus) in 2004

(2005 : beam shutdown.)

2006-2007 : muon beam. (LHC accelerator started and broken in 2008)

2008-2009 : hadron (pion, Kaon, proton) beam.

*2010 : COMPASS-II proposal approved.*

2011 : muon beam.

2012 : hadron beam for Primakoff reaction *and test run of DVCS* .

*(2013 : beam will be shutdown.)*

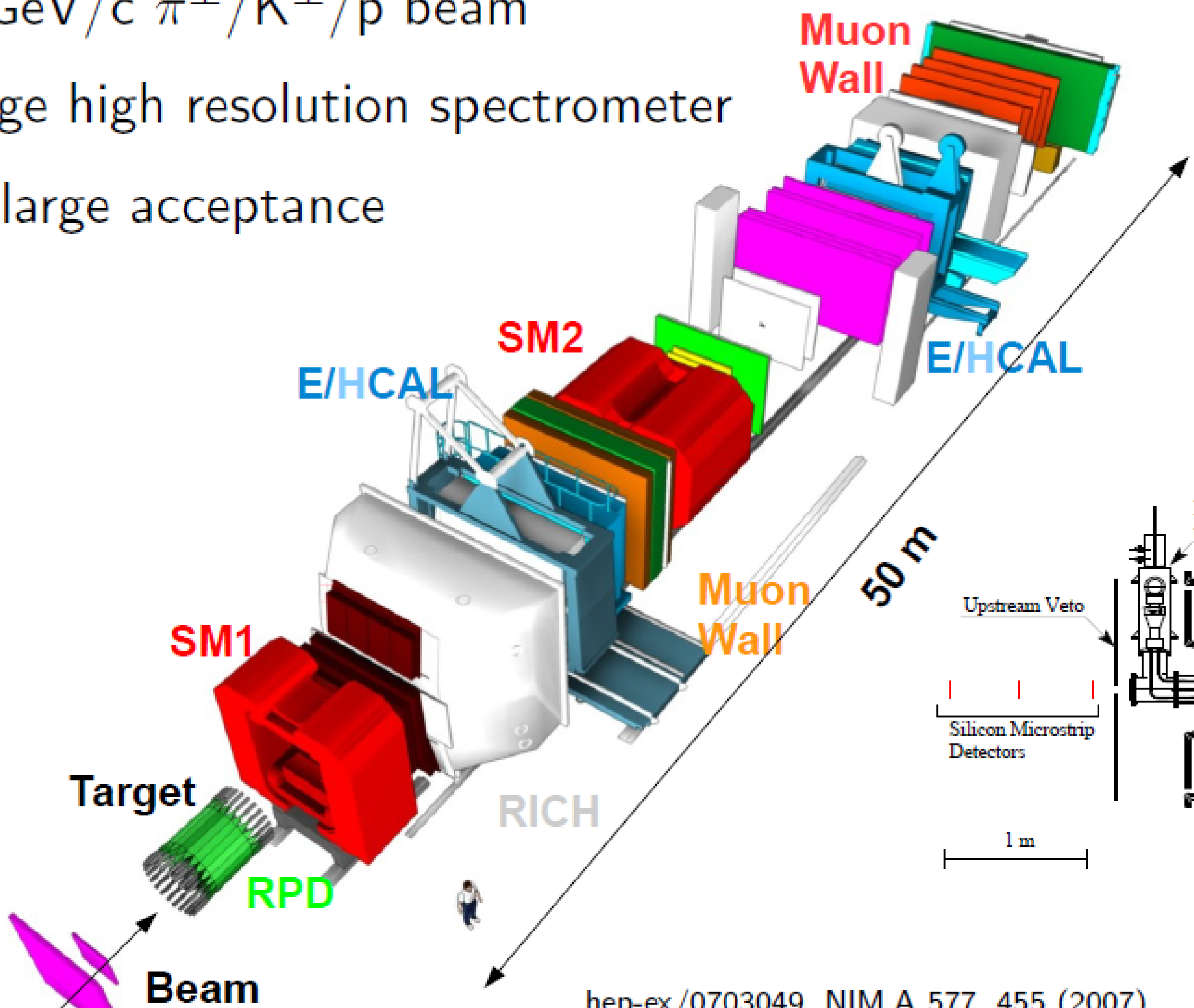
*2014- : beam will be back.*

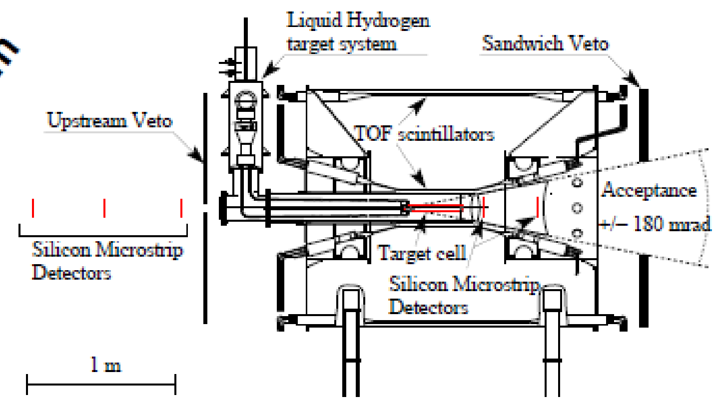
# The COMPASS spectrometer

190 GeV/c $\pi^{\pm}/K^{\pm}/p$ beam

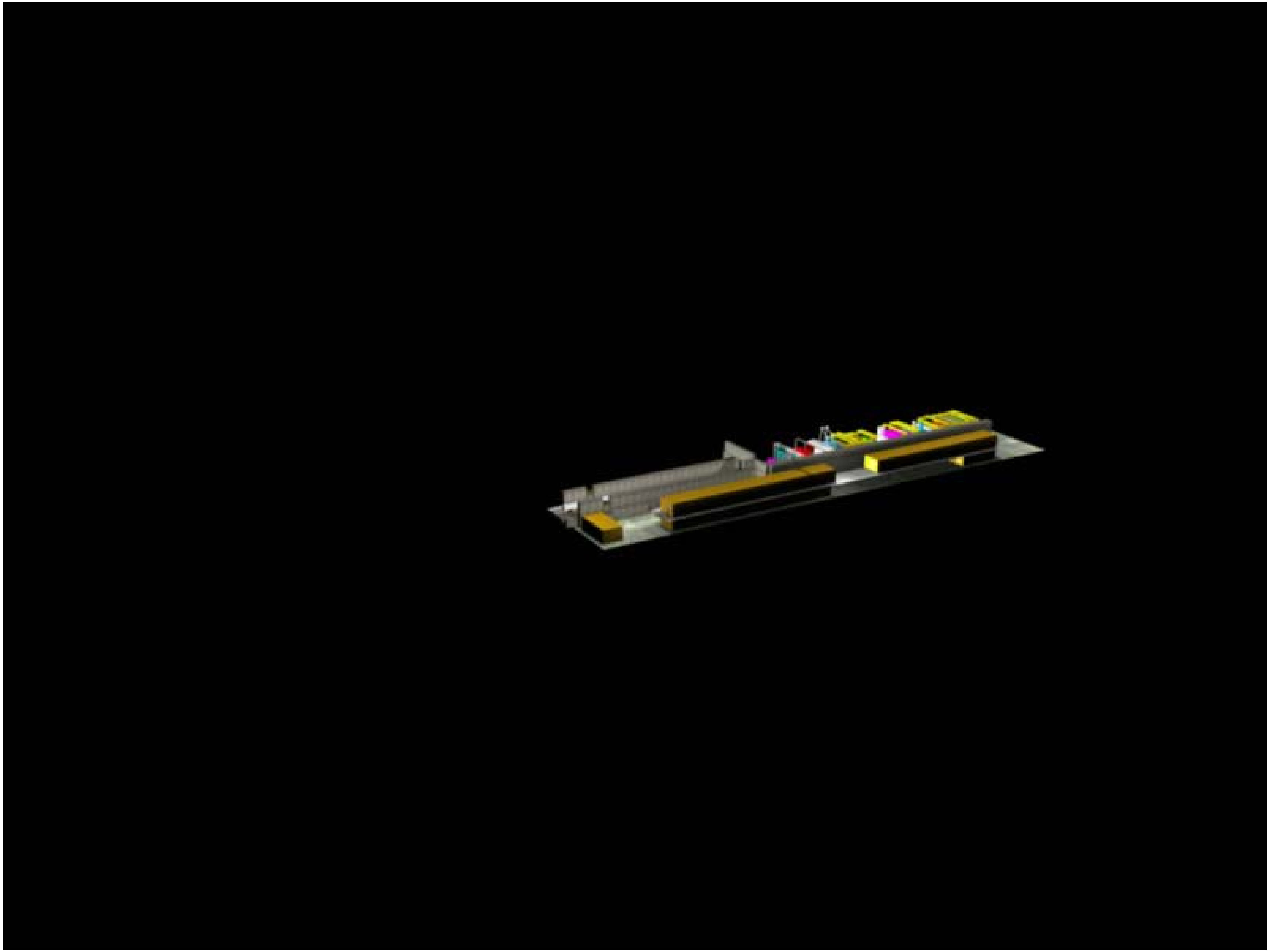
2 stage high resolution spectrometer

with large acceptance



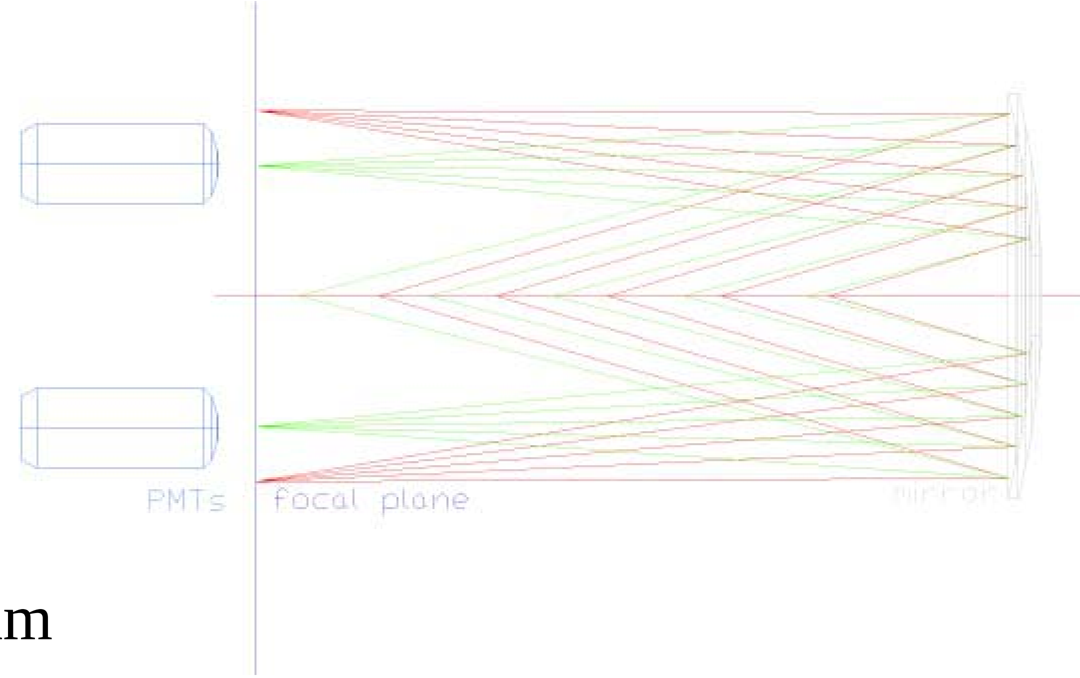

hep-ex/0703049, NIM A 577, 455 (2007)

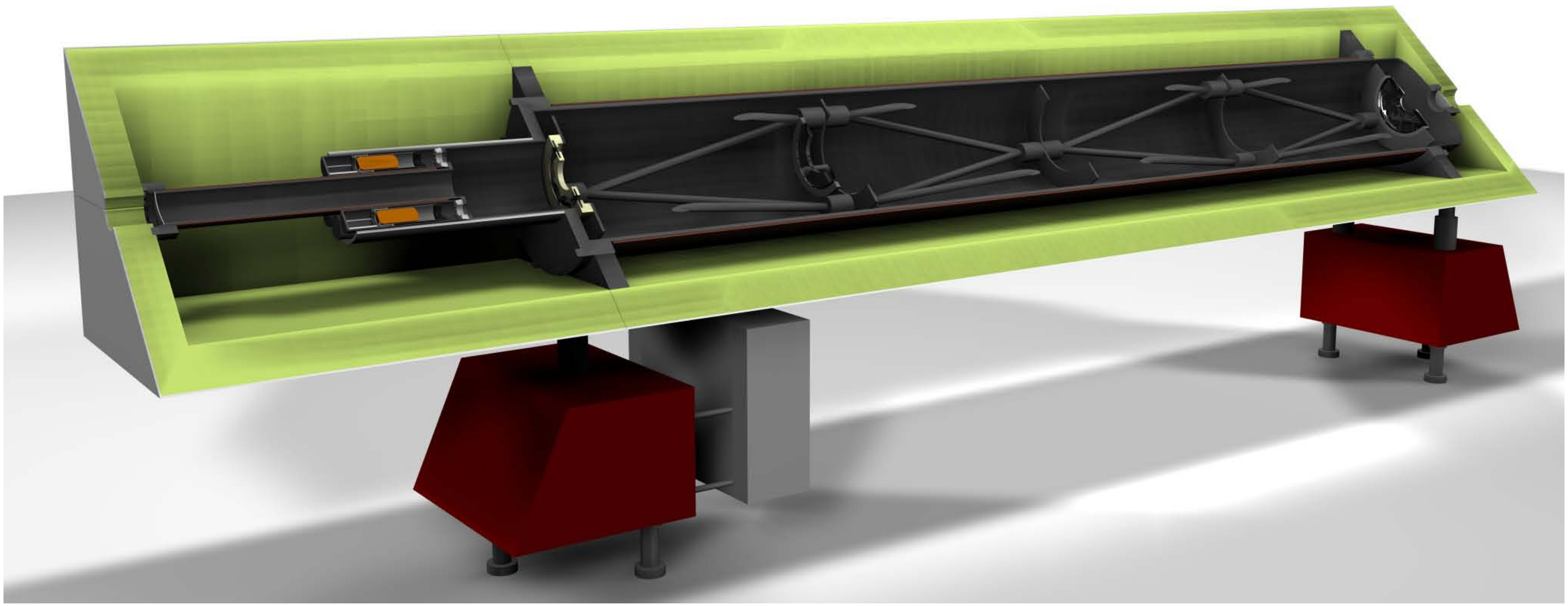


***CEDAR***

Identification of
Kaon beam from
pion beam.

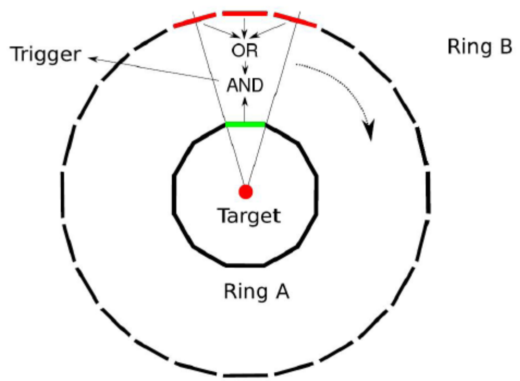
Differential- or RICH-like
Cherenkov detector for beam

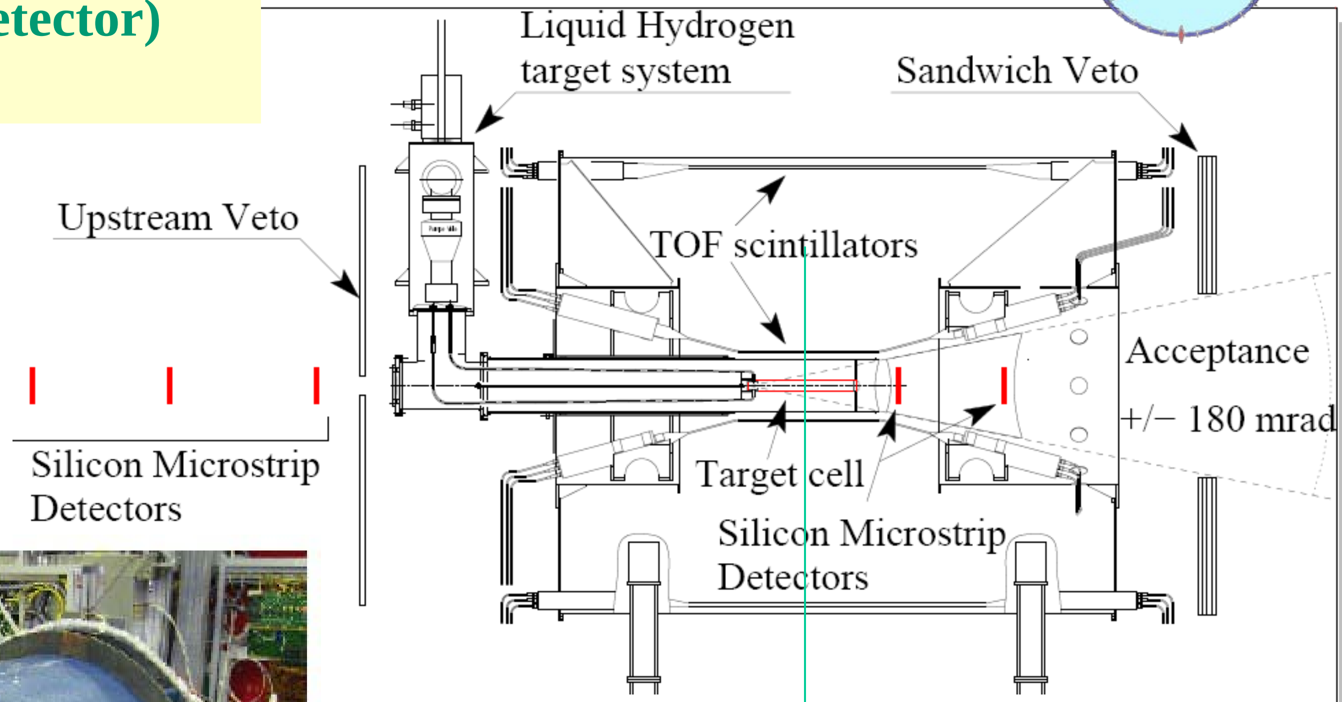


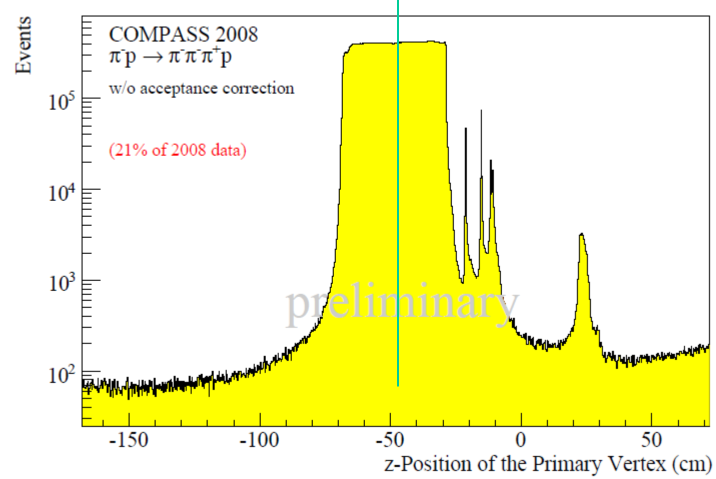



# TARGET PART IN HADRON PROGRAM

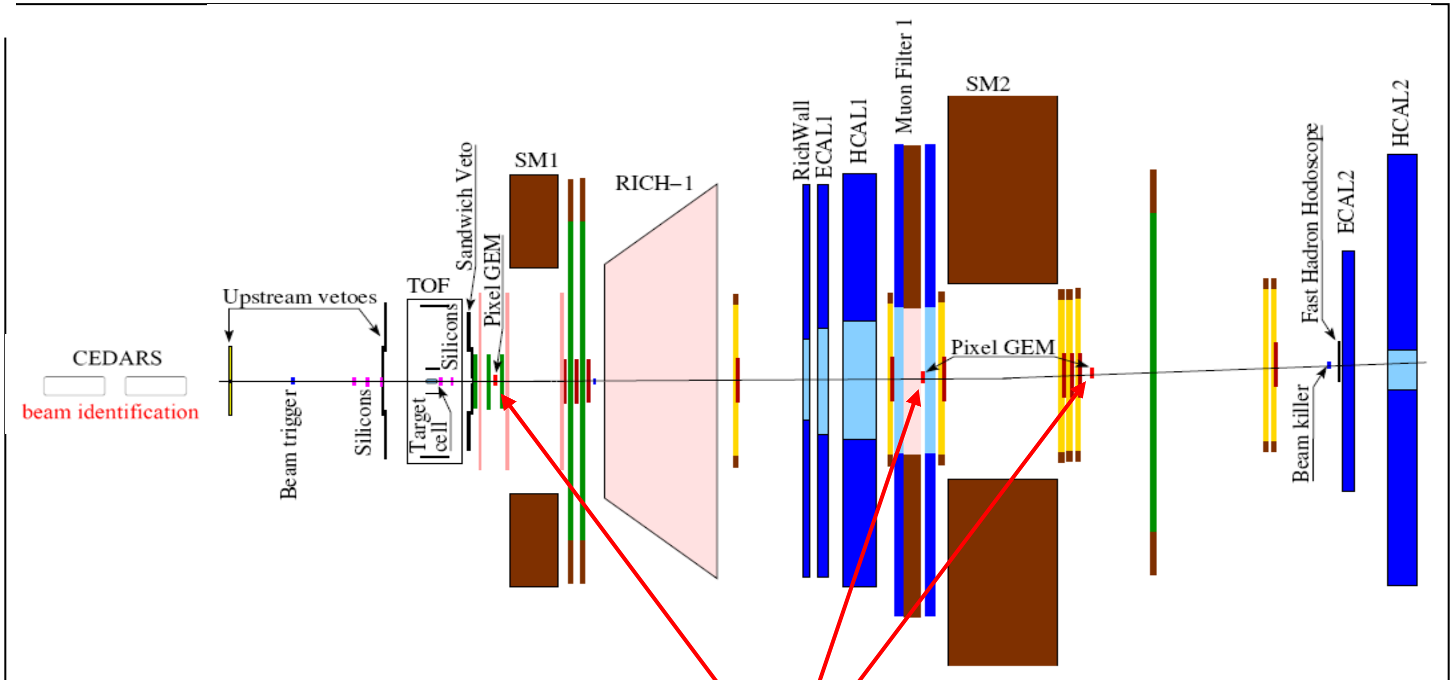
**RPD(Recoil Proton Detector)**
**Installed in 2007**

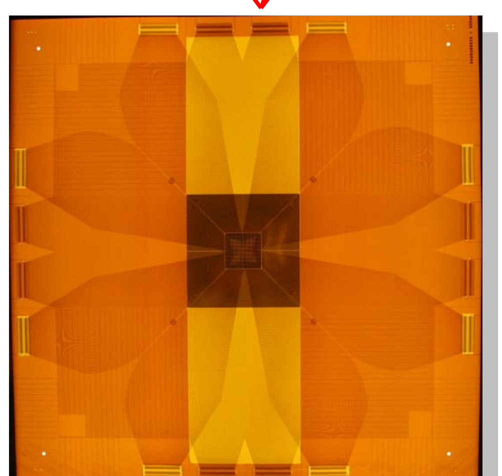


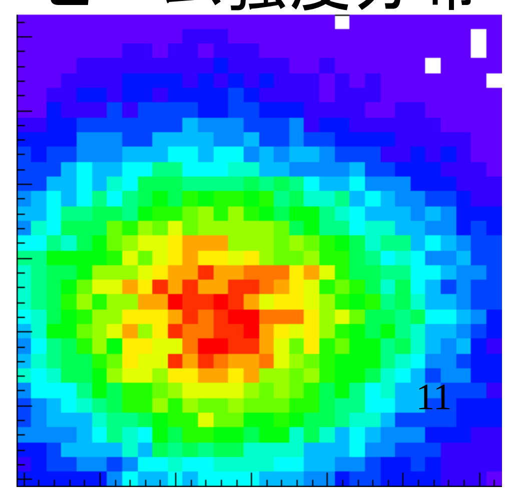



# COMPASS in 2008/2009



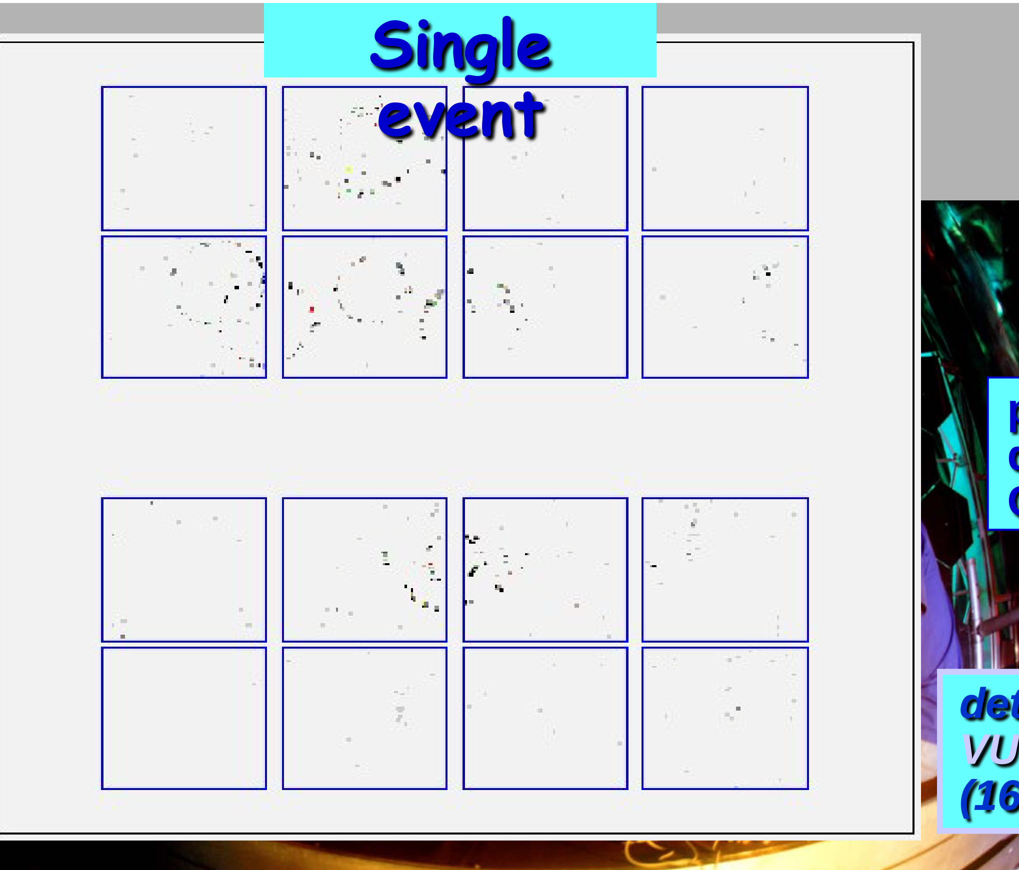
ビーム強度分布

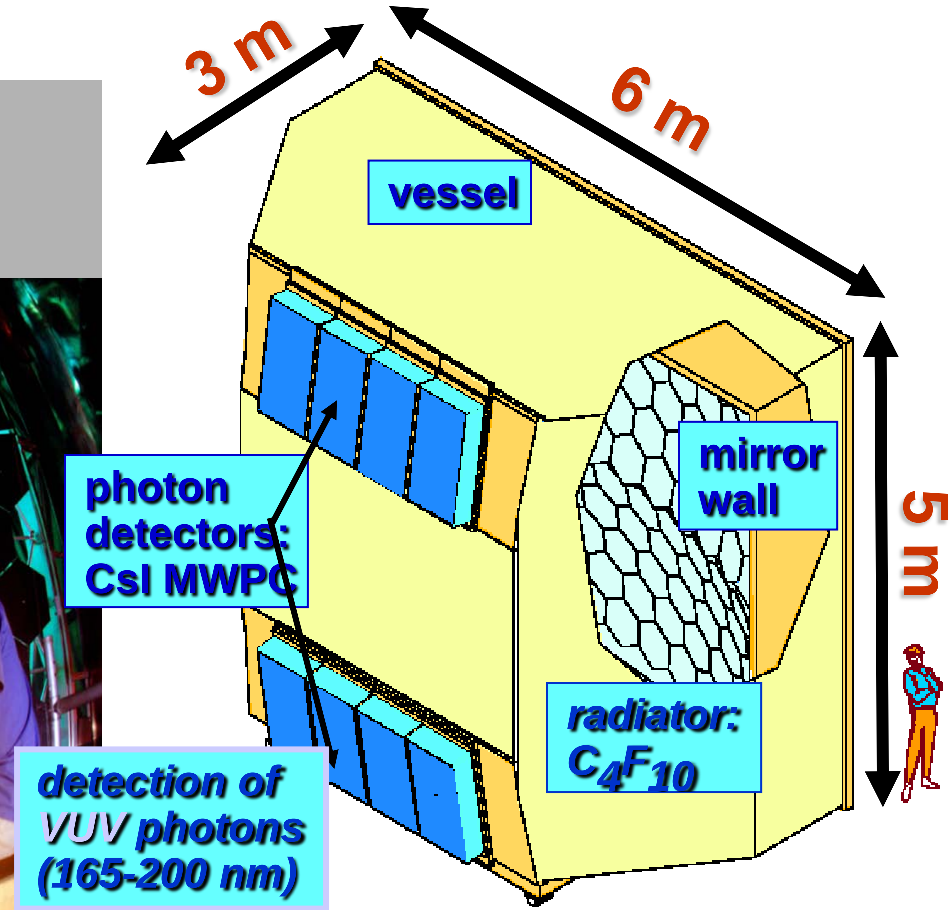


**PixelGEM detectors:**

- very low mass: 0.2% $X_0$
- high rates: ~$10^5$ $mm^{-2}s^{-1}$
- resolution: ~120 μm

# Ring Imaging CHerenkov Counter (RICH)




**Photon detection**

**5.3 m² MWPCs**

**16 CsI Photocathodes**

**84,000 analog readout channels**

+ lens MAPMT at center position

| | |
|---|---|
| *single photon:* | *s =1.2 mrad* |
| *ring:* | *s =0.4 mrad* |
| *photons/ring* | *n ~14* |
| *3s p /K sep.* | *up to 40 GeV/c* |

# RICHのperformance

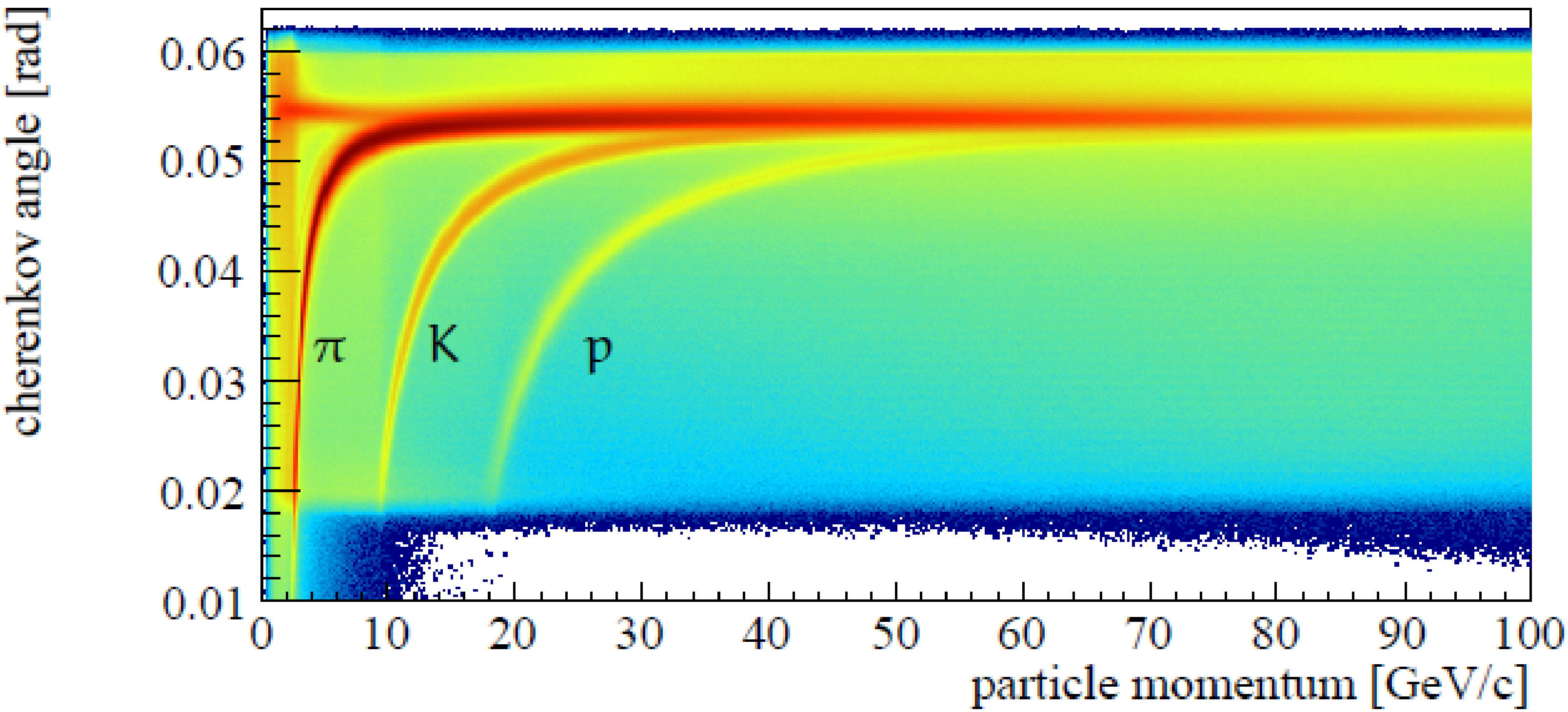



Figure 4.2: RICH reconstructed Cherenkov angles in the hadron beam 2008. Clear bands of pions, protons and kaons show up. A separation of kaons and pions becomes difficult for track momenta above 40 GeV/c. Protons can be distinguished from lighter particles up to 100 GeV/c.

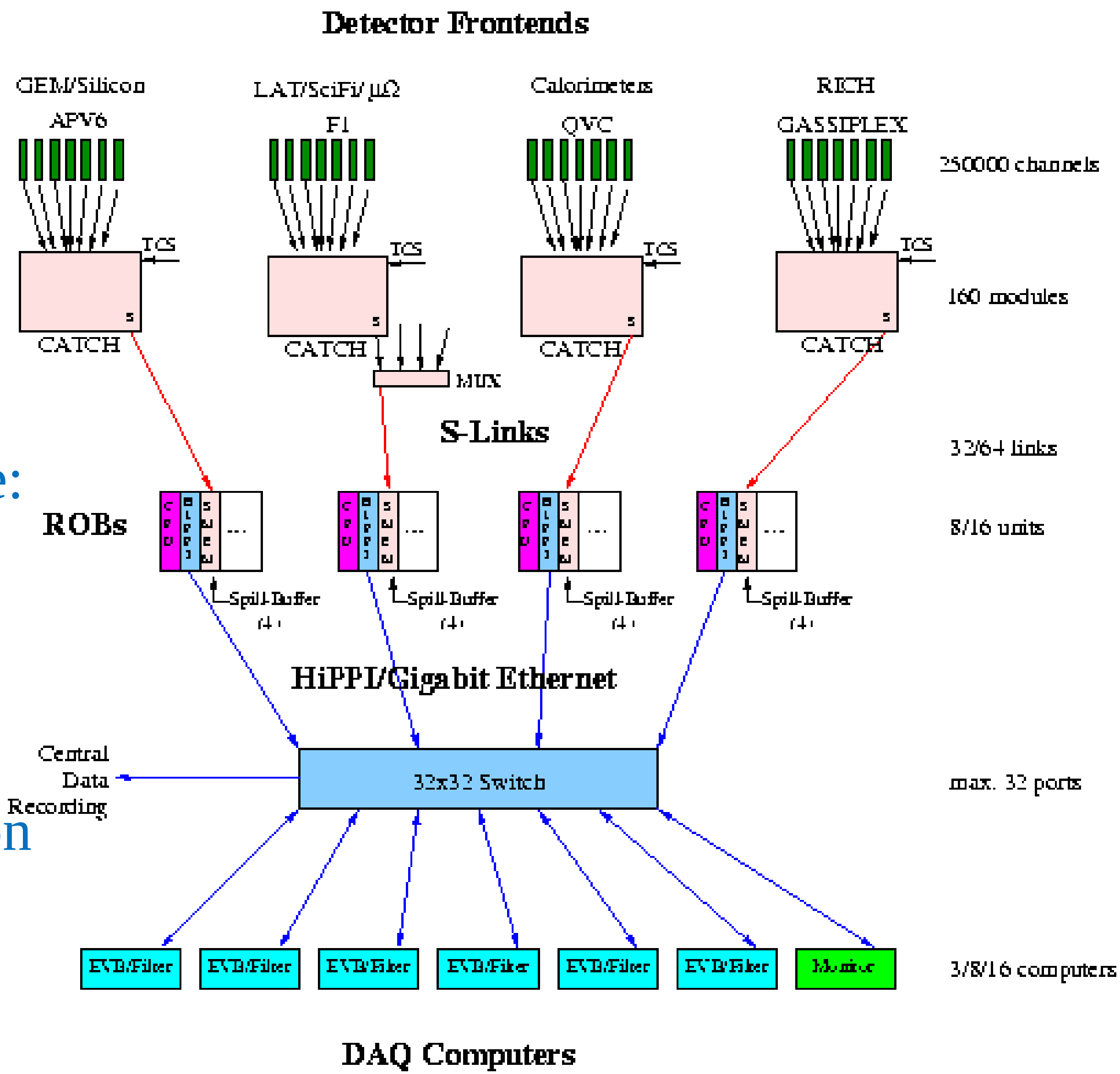
# COMPASS のデータ収集系の構成

250k detector channels

Typical event size: 35kB

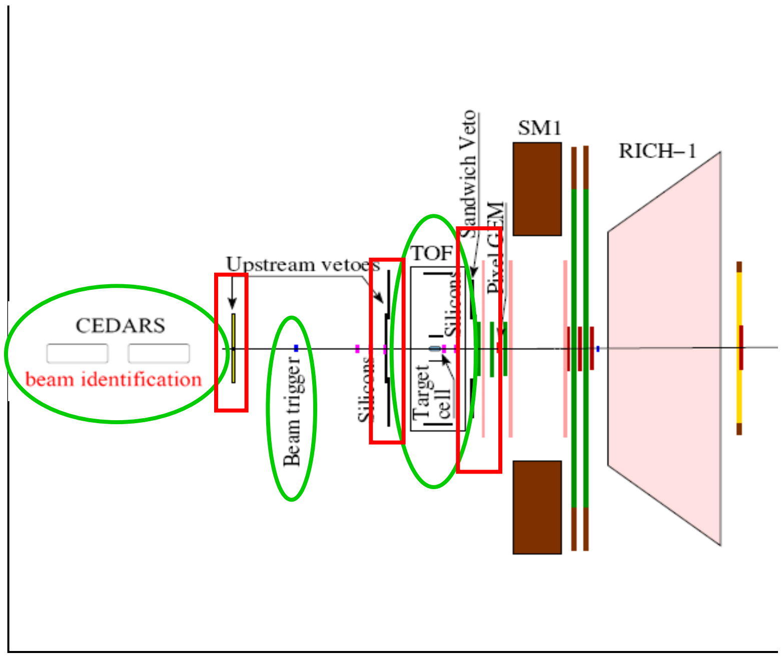
Design value:
10 kHz for muon
100kHz for hadron

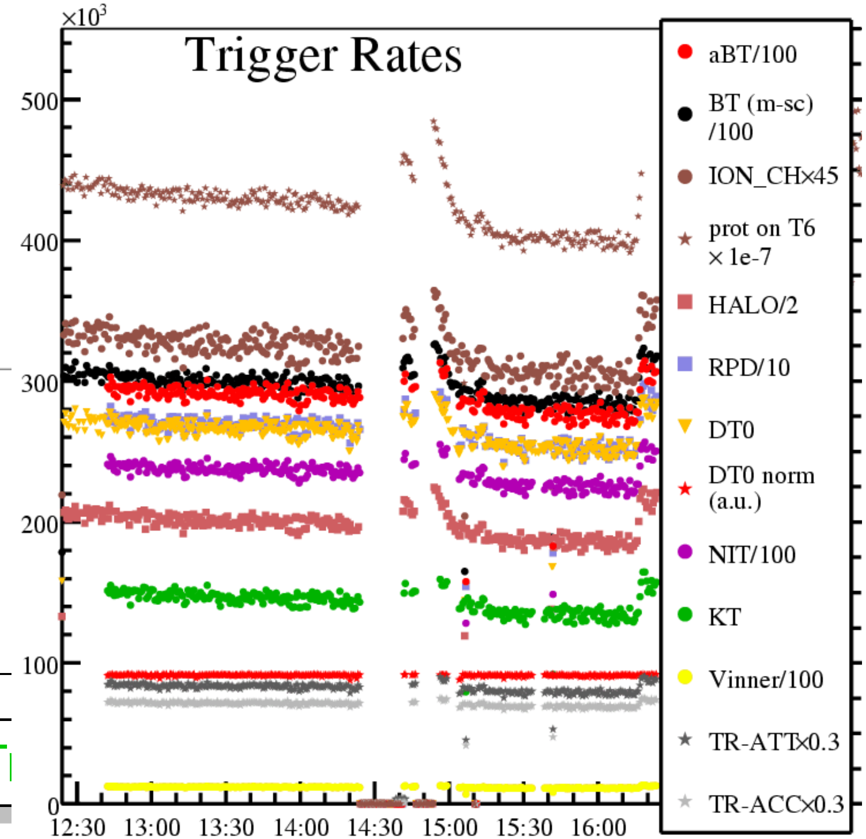
Record:
580TB/year




LHCのために開発された技術が活用されている。

# COMPASS in 2008/2009




Diffractive Tr

**Trigger components:**

- Beam trigger
- RPD
- Cedars
- Veto: Hodo || Sandwich || BK
- Mainz Counter
- Forward Hodoscope

例えば、KEK PS E179実験(1990年）では0.1～0.2k/spillであった。ちなみに繰り返しは4.2s。上の例ではMain trigger(DT0)では270k/spillくらいか。1000倍以上。但し、繰り返しはsuper Cycleでは40sあまりなので、実際は100倍くらい。

# Physics motivation of hadron exp.

**Quark model:** bound states of qq-bar

Quantum numbers: $I^G\ (J^{PC})$ $J^{PC}$=$0^{-+}$, $0^{++}$, $1^{--}$, $1^{+-}$, $1^{++}$, $2^{++}$, …

$$P=(-1)^{l+1},\ C=(-1)^{l+s},\ G=(-1)^{I+l+s}$$

**QCD:** other color-neutral configurations (exotic states)

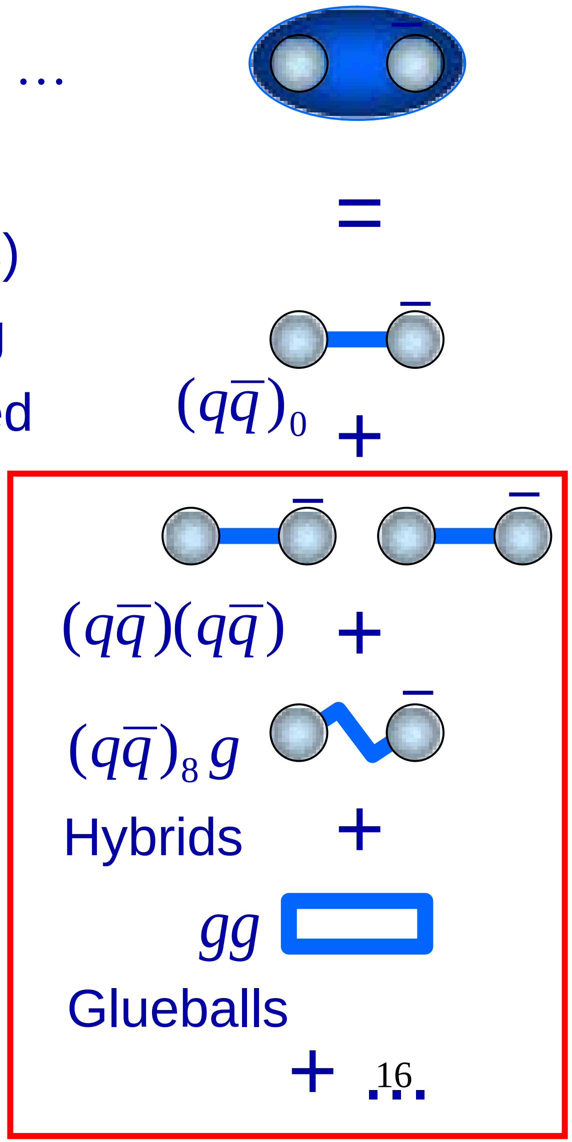
same quantum numbers with qq-bar ⇨ mixing

exotic quantum numbers ⇨uniquely determined

$$0^{--}, 0^{+-}, 1^{-+}, 2^{+-}, \ldots$$

**So far exotic state candidates were reported, but they are still disputed and no clear evidence is confirmed yet. (maybe…)**

**Still new precise data and new ideas are needed to solve this problem.**



# Physics motivation cont'd

**In <u>the light quark</u> meson spectrum**

**(Hybrid or tetraquark candidates)**

low mass states with spin parity exotic quantum number $J^{PC}=1^{-+}$ predicted

$\pi_1(1400)$ : VES, E852, Crystal Barrel, KEK

$\pi_1(1600)$ : E852, VES

Resonance interpretation still disputed

**(Glueball candidates)**

lowest states with $J^{PC}=0^{++}$ and/or $J^{PC}=0^{-+}$ predicted. But the quantum number is the same as the ordinary Quark Model state.

$f_0(1370)$, $f_0(1500)$, $f_0(1700)$ with $J^{PC}=0^{++}$ (at least one of them)

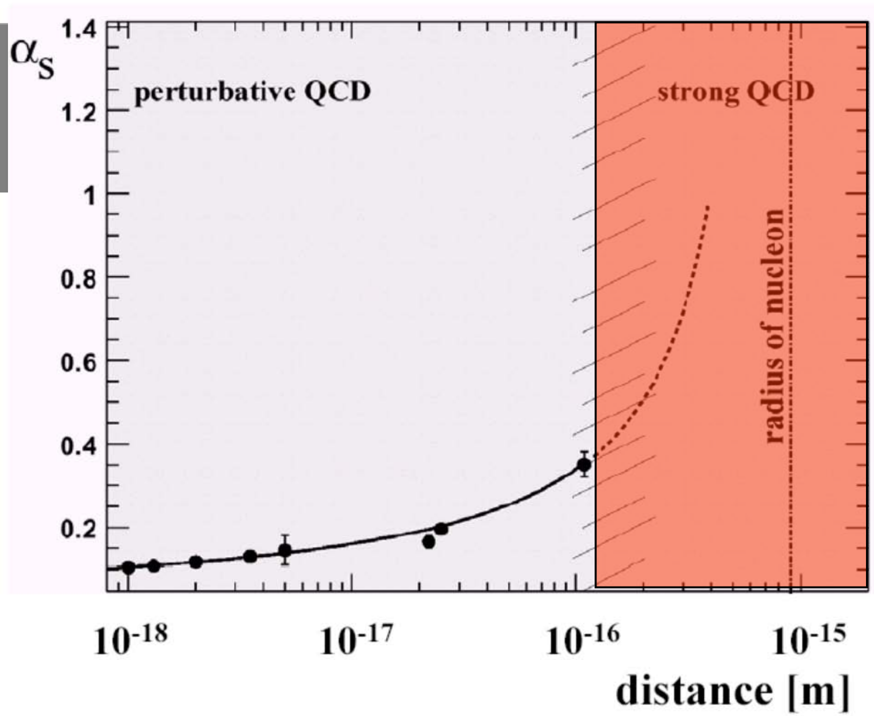
$\eta(1405)$ with $J^{PC}=0^{-+}$

Their interpretations are still disputed too.

# Physics of the COMPASS experiment

**Structure and dynamics of hadrons**

⇨ **non-perturbative regime of QCD**




**Theory:**

- Models: QM, bag, flux tube, ...
- Effective theories: $\chi$PT, ...
- Lattice-QCD

$Q^2$ ←

**Hard processes:**

⇨ Nucleon structure

- Helicity
- Transversity
- GPDs

**Spectroscopy:**

⇨ Hadron mass spectrum

⇨ Gluonic excitations

⇨ Multi-quark systems

**Scattering at very low $Q^2$:**

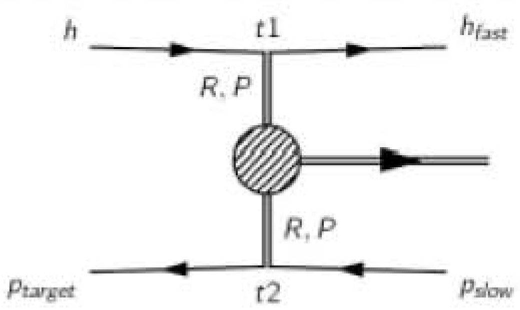
⇨ Polarizabilities of $\pi$, K

⇨ Chiral anomaly: $F_{3\pi}$

# The COMPASS experiment

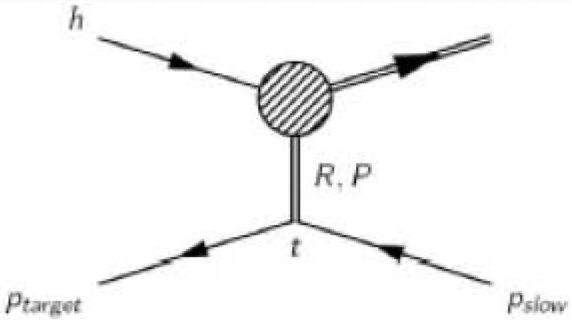
## Production mechanisms:

Central production:



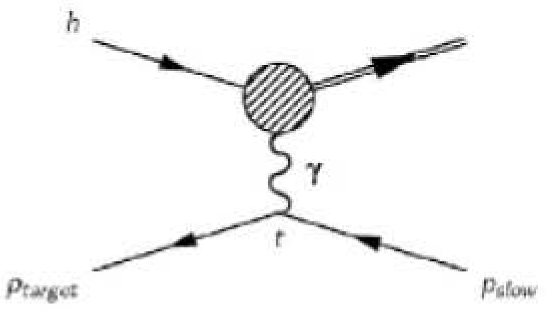

- Rapidity gap
- X carries ~10% of incoming energy
- cross section small (~10μb)
- X decay particles at large angles
- Possible source of glueballs

Diffractive dissociation:



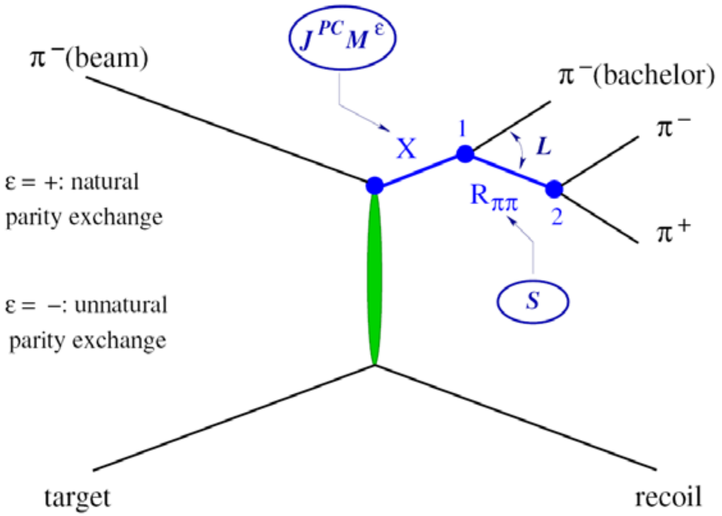

- X carries nearly all energy
- High t' (0.01<t'<0.1)
- Large cross section (~mb)
- X decay particles at small angles
- Study of $J^{PC}$-exotic mesons

Coulomb production:




- X carries nearly all energy
- low t' (0.001<t', 0.001<t'<0.1)
- Large cross section (~mb)
- X decay particles at small angles
- Test of ChPT
- Radiative widths

# PWA Technique of Diffractive dissociation




- t-channel Reggeon exchange
- Reflectivity basis in G-J frame
- At high $s$: $\varepsilon = \eta$ of Regge trajectory
- Isobar model

**1. Mass-independent PWA** of angular distributions in 40 MeV mass bins
MIPWA is very powerful tool because each waves can be extracted in model independent way.

**2. Mass-dependent $\chi^2$ fit** to results of step 1

- Parameterized by BW
- Coherent background for some waves

(But anyway we must know the origin and nature of background,,,) COMPASS

# (Example) Waves used in MIPWA

42 waves

| $J^{PC}M^{\epsilon}$ | $L$ | Isobar $\pi$ | 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 $\pi$ | 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 | | | |

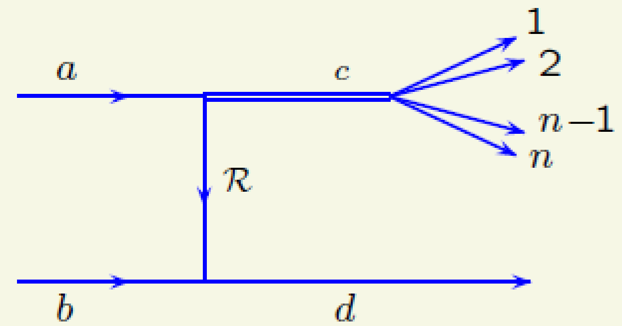
# Diffractive Dissociation into $\pi^-\pi^-\pi^+$ Final States

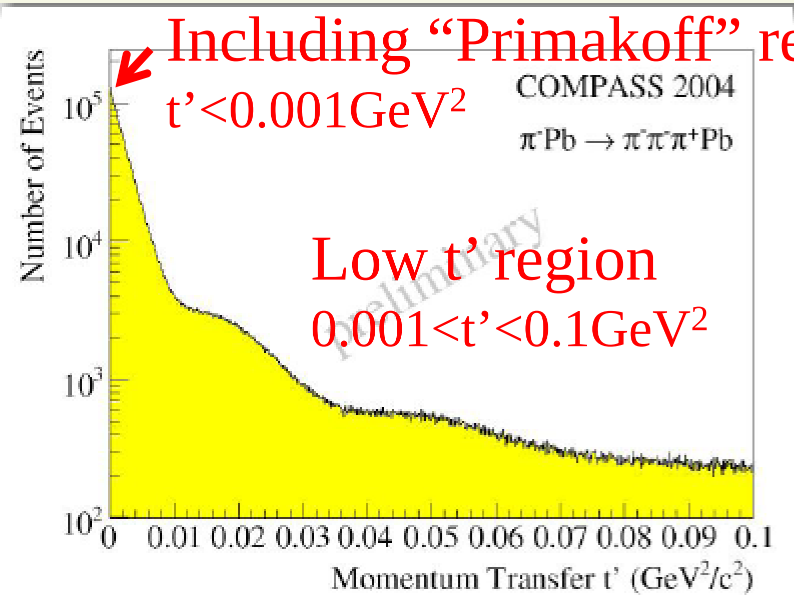
Technische Universität München

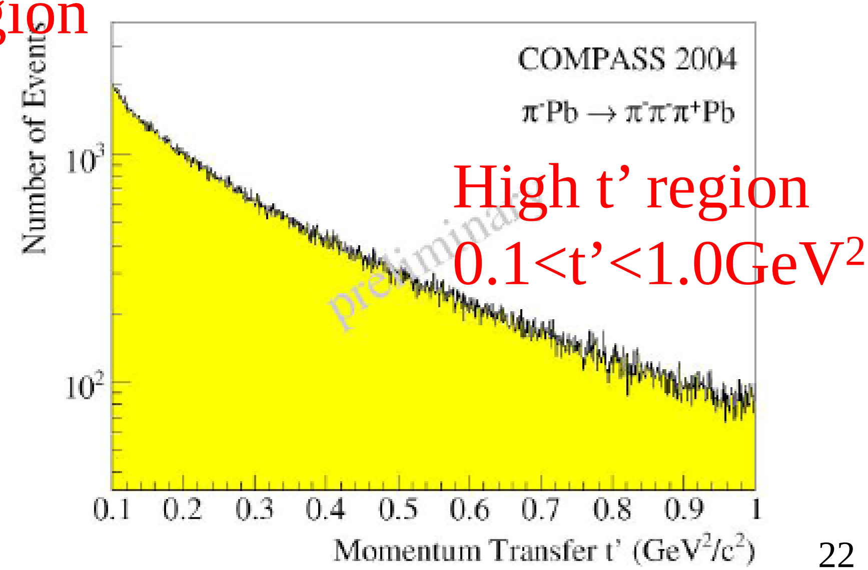
## Diffractive Dissociation

- Soft scattering of the beam $\pi^-$ off the target
  - Pb (2004, 2009)
  - $lH_2$ (2008)
  - W, Ni (2009)
- Target particle remains intact
- Pomeron exchange

## Reaction



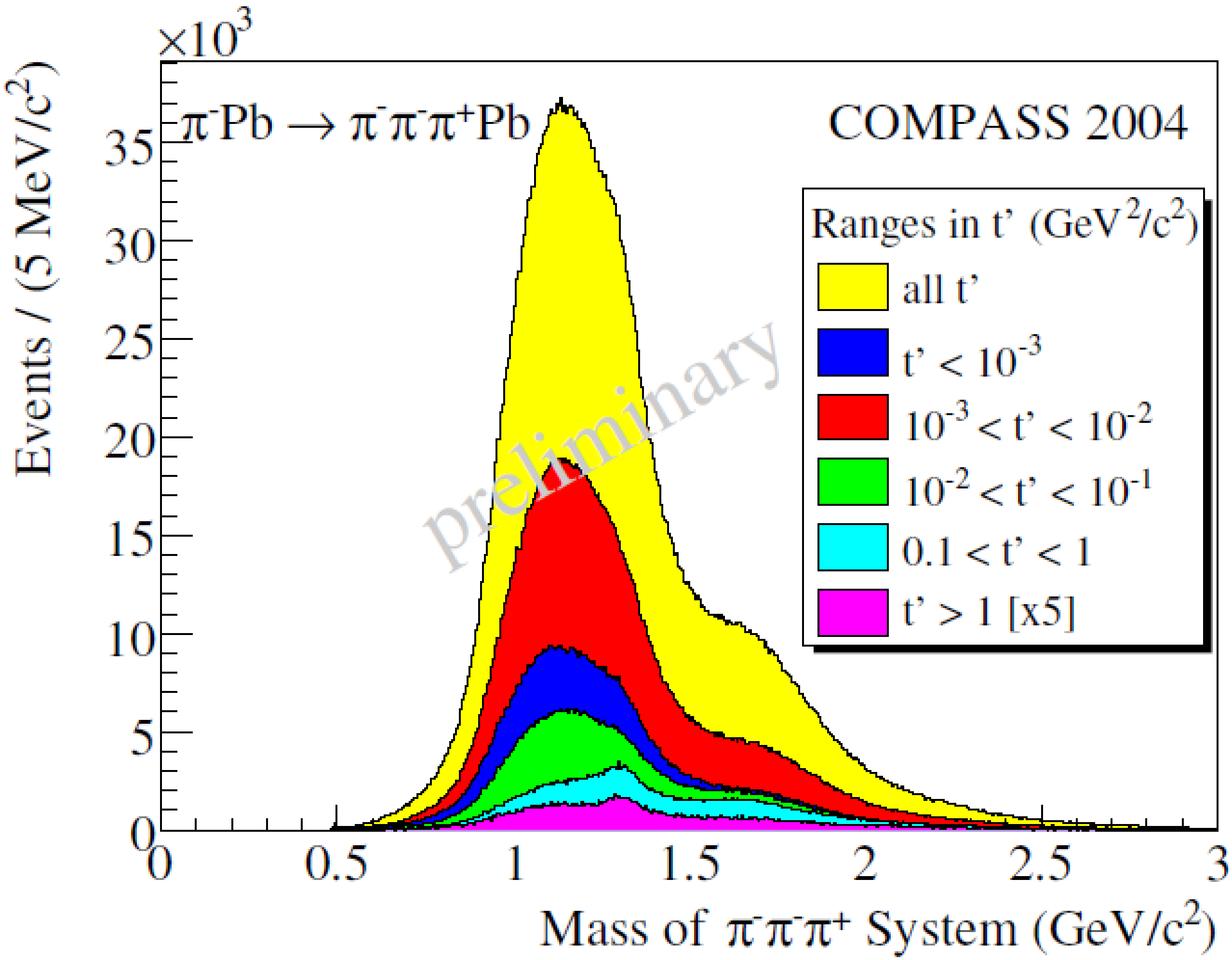



# ~~BACKUP~~: $3\pi$ Data Sample (2004)

## $\pi^-\pi^-\pi^+$ mass distribution

Different $t'$ ranges:




23

High t’ region

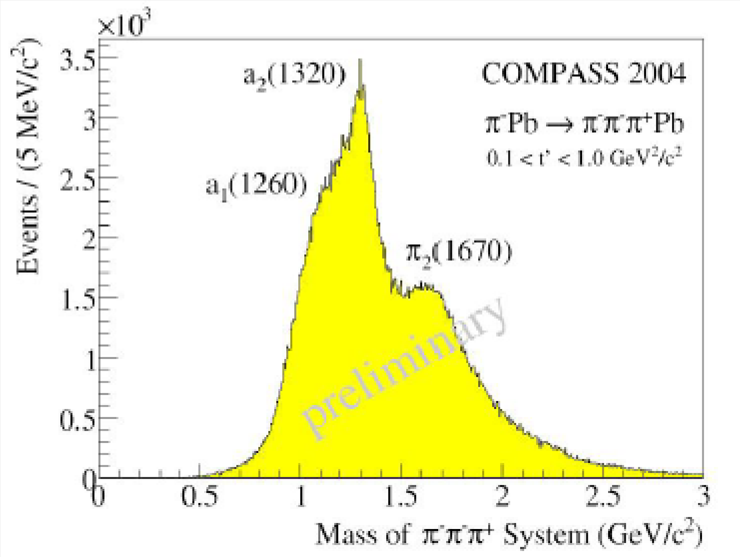
$0.1<t'<1.0\,GeV^2$

(Pomeron exchange dominates)

# Invariant Mass of $3\pi$ System

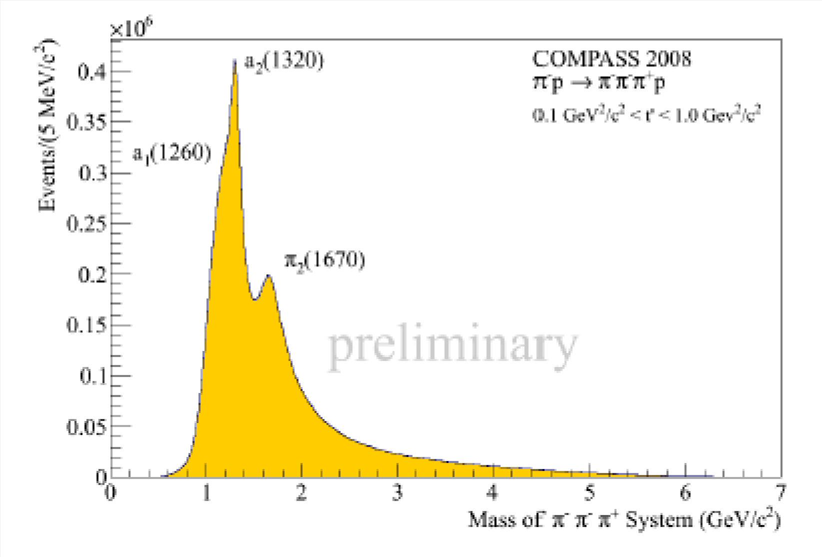


## $\pi^- Pb \rightarrow \pi^-\pi^-\pi^+ Pb$ (2004)




- $p_\pi = 190 GeV/c$
- 4M events (full t range)
- 450k events in (2 weeks run!) $0.1 < t' < 1.0\ GeV^2/c^2$

## $\pi^- p \rightarrow \pi^-\pi^-\pi^+ p$ (2008)



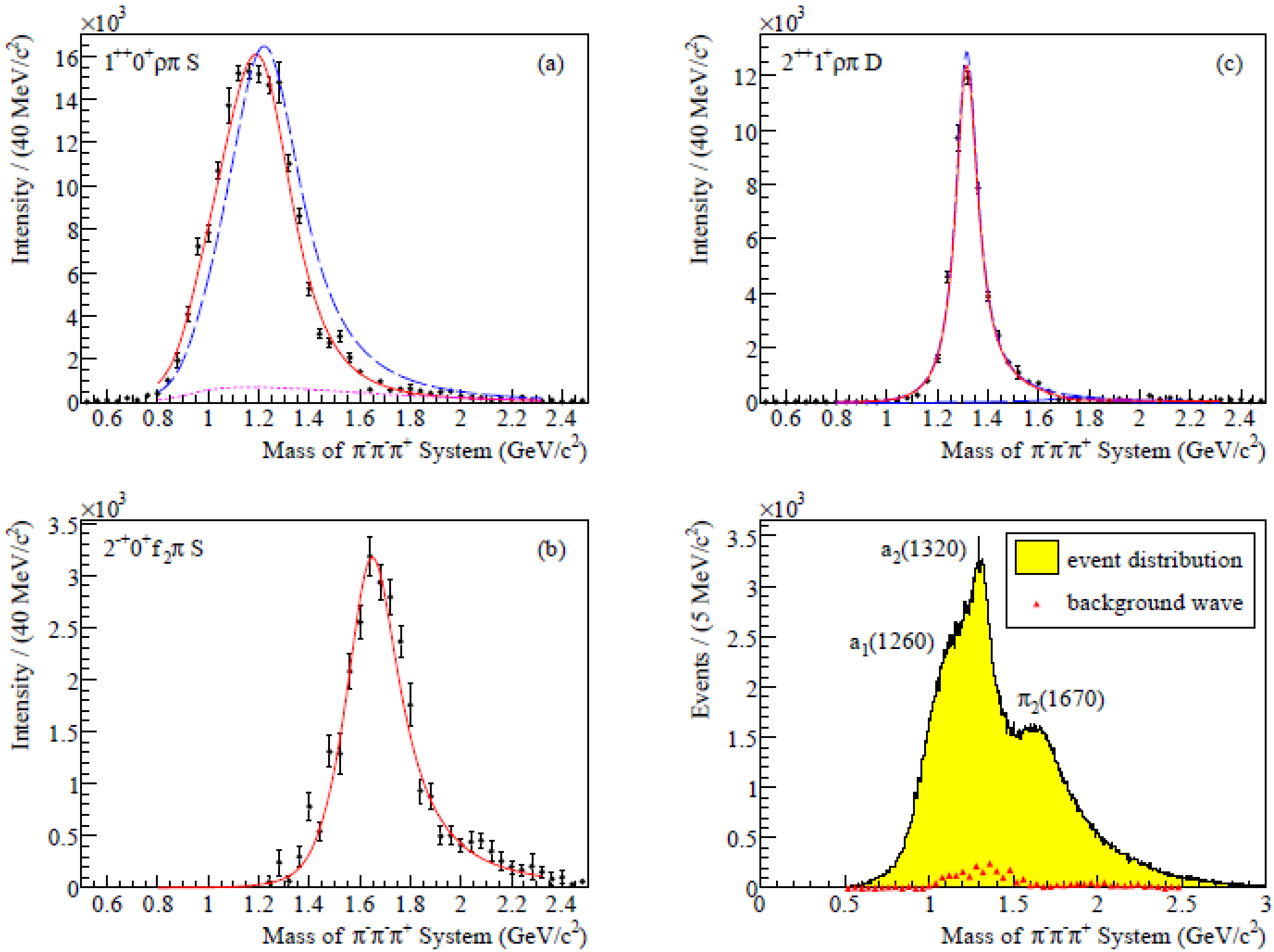

- $p_\pi = 190 GeV/c$
- $\sim$ 96M events in $0.1 < t' < 1.0\ GeV^2/c^2$

25

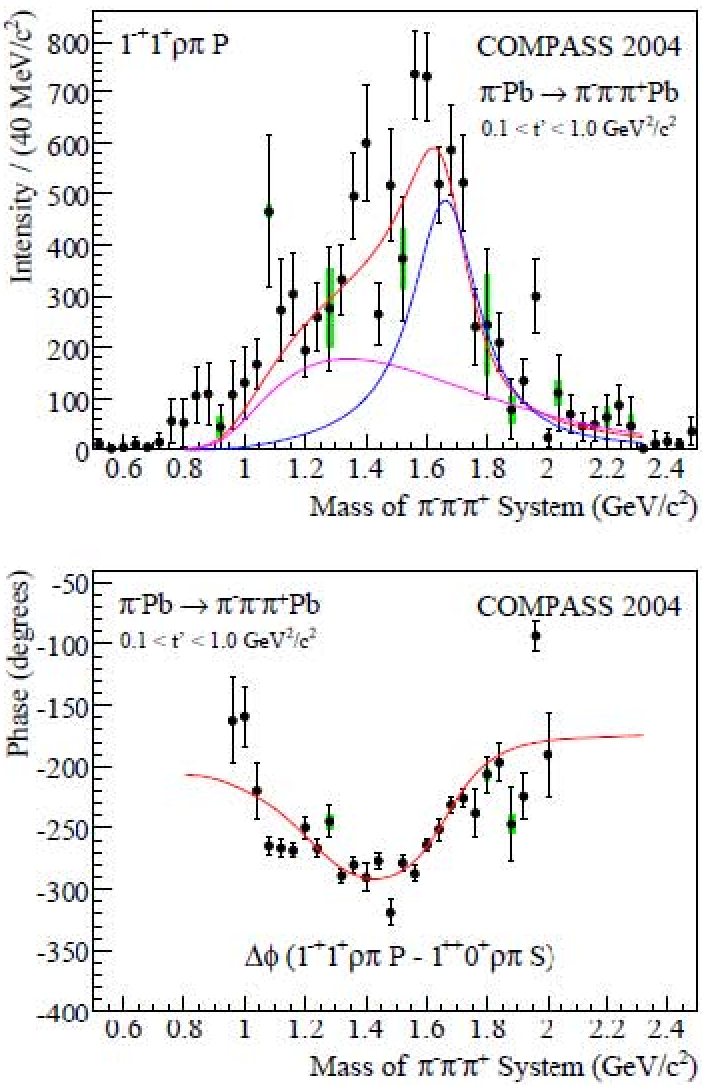
# $\pi^- Pb \rightarrow \pi^-\pi^-\pi^+ Pb$ (2004)

## Intensities of Major Waves





# Diffractive dissociation of pions




**Significant spin exotic $J^{PC} = 1^{-+}$ wave [1]**

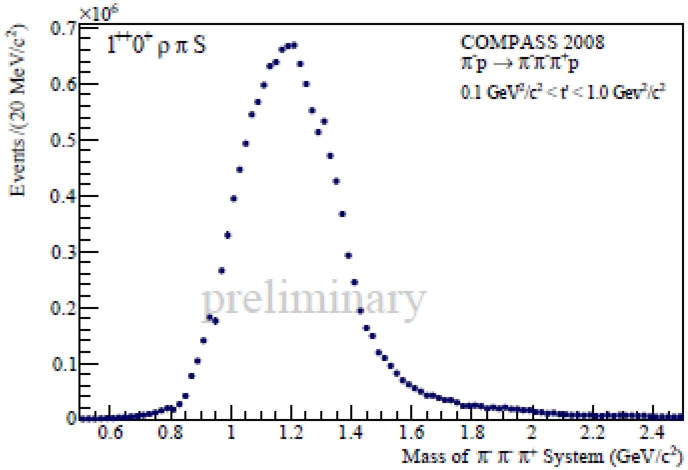
- $M = 1660 \pm 10^{+0}_{-64}$ MeV/c$^2$
  $\Gamma = 269 \pm 21^{+42}_{-64}$ MeV/c$^2$
- Consistent with $\pi_1(1600)$ seen by E852 and VES
- Negligible leakage from other waves

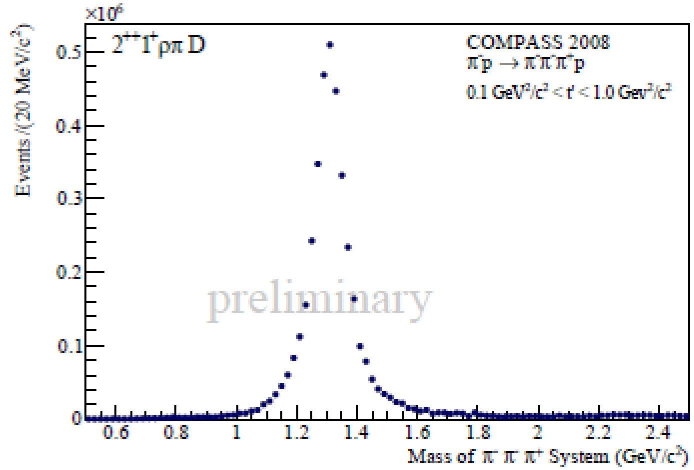
[1] COMPASS, Phys. Rev. Lett. 104 (2010) 241803

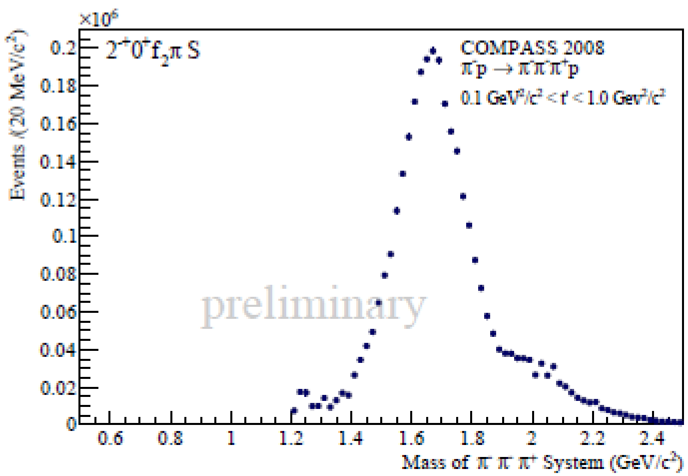
# $\pi^- p \rightarrow \pi^-\pi^-\pi^+ p$ (2008)
## Intensities of Major Waves

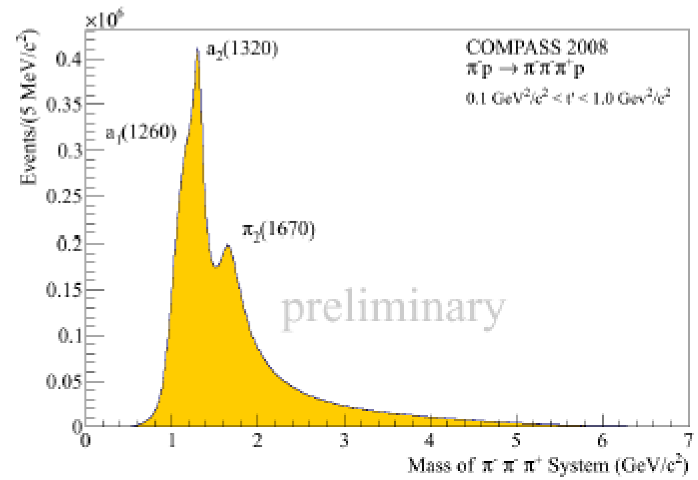
Presented at Hadron 2011 conf.



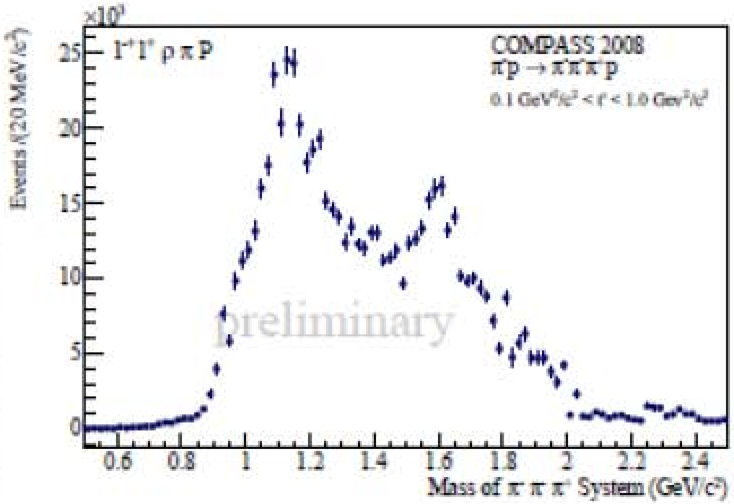


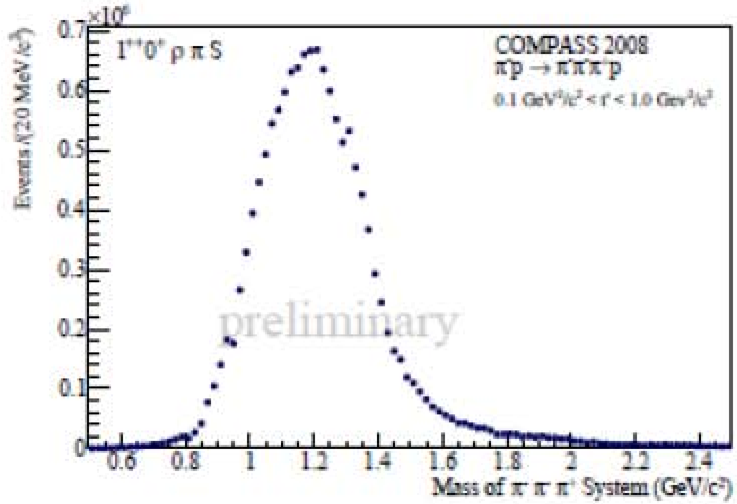



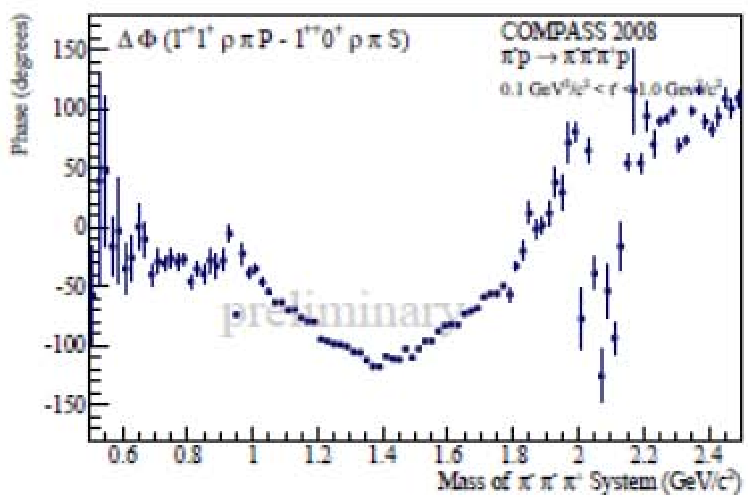



# Diffractive dissociation of pions




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




- Data from 2008
- 190 GeV/c $\pi^-$ on liquid hydrogen
- 24M events (all data from 2008/2009 70 M)
- Enhancement near the $\pi_1(1600)$ mass in the $1^{-+}$ wave, phase motion w.r.t $1^{++}$
- Leakage studies and mass dependent fit necessary for definite conclusions.
- Ongoing analysis of the $\pi^0\pi^0\pi^-$ final state offers a valuable consistency check.

# $\pi^- p \to \pi^-\pi^-\pi^+ p$ (2008)
## Additional Waves

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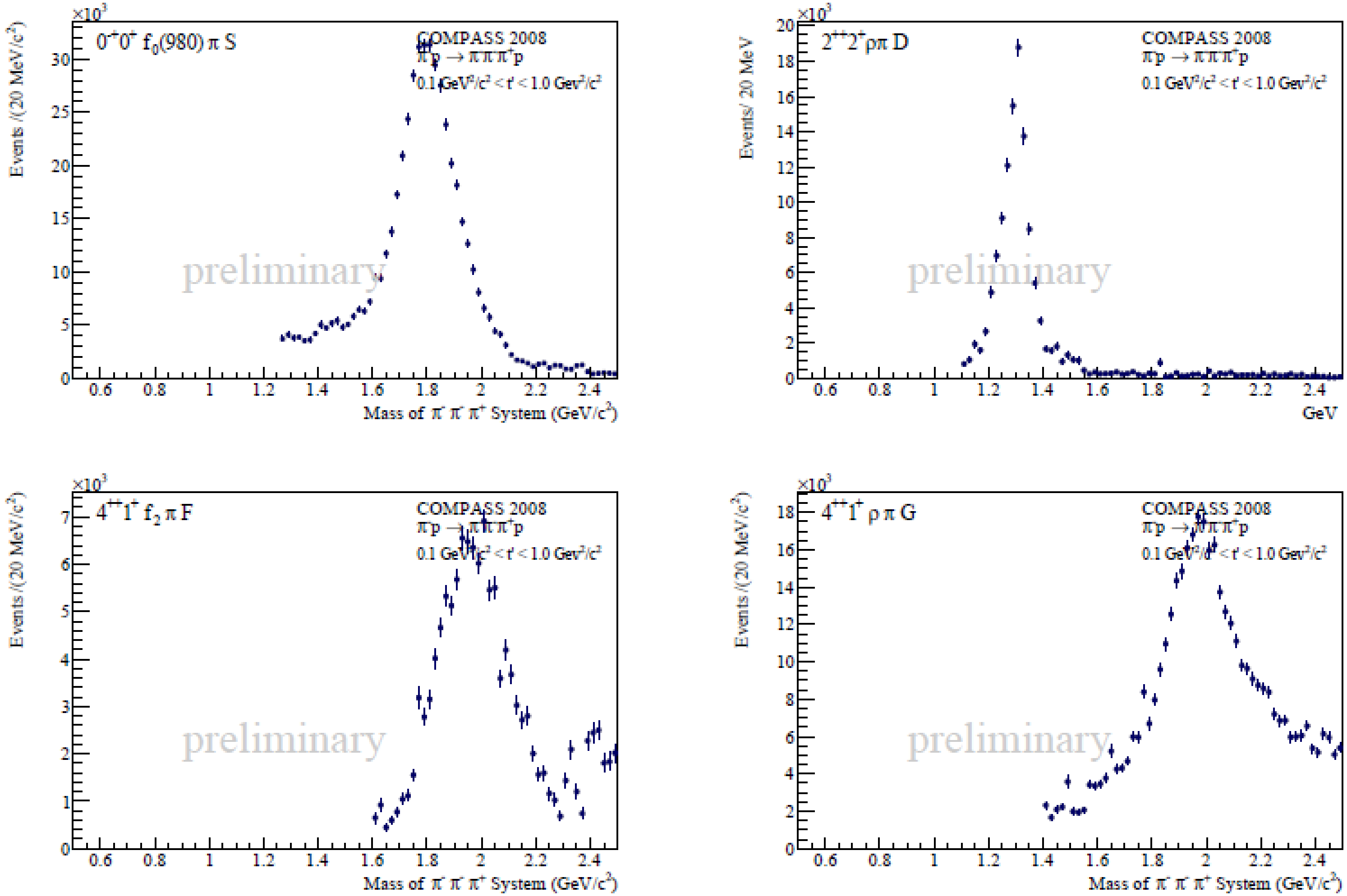
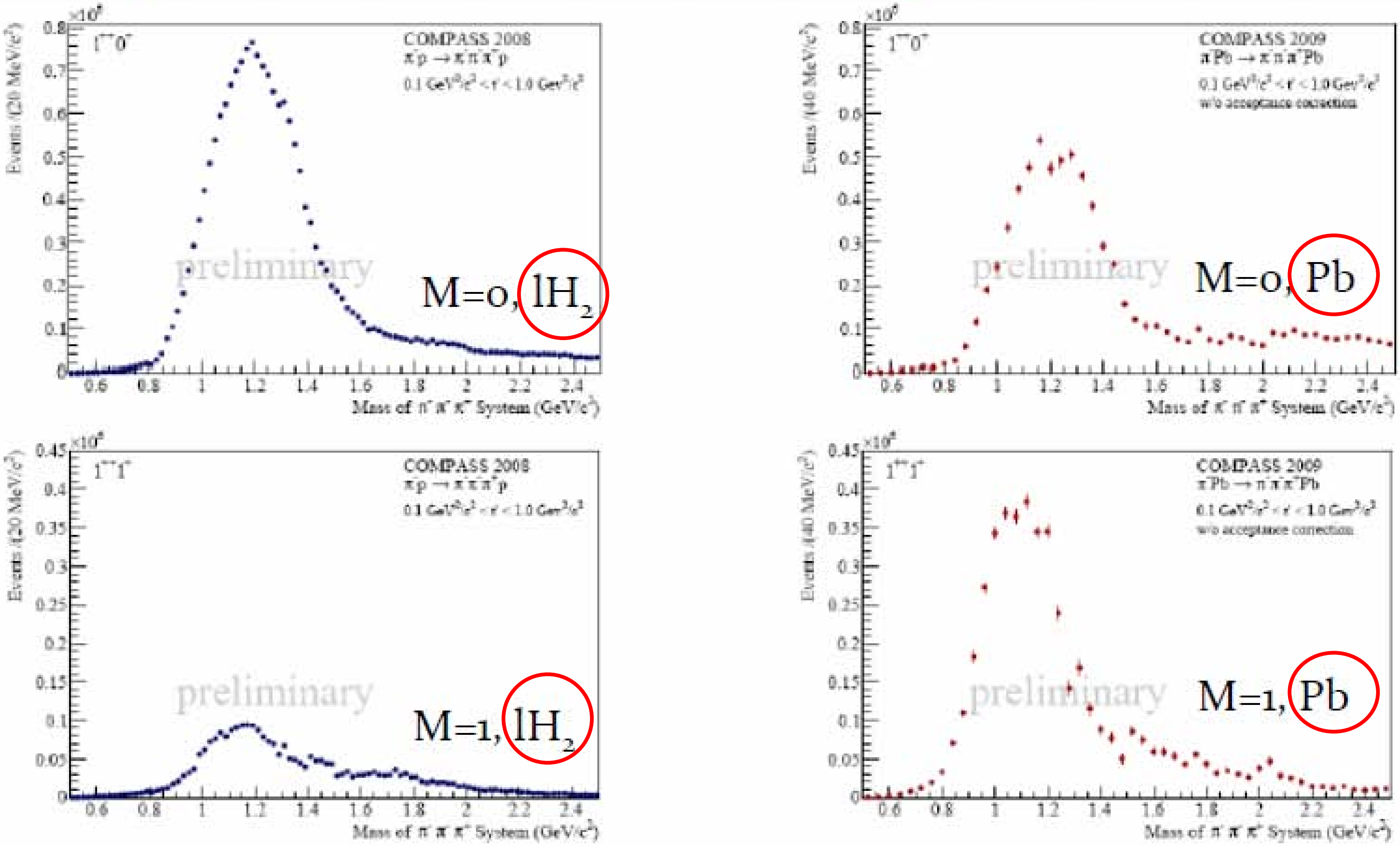


**$1^{++}$ wave**

# Dependence on M of target material




**Pb (2009) vs. $H_2$ (2008) target**

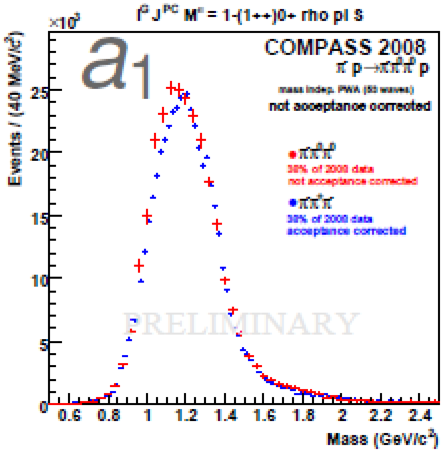
- Normalised to $a_2(1320)$
- On Pb: M = 1 enhanced, M = 0 suppressed

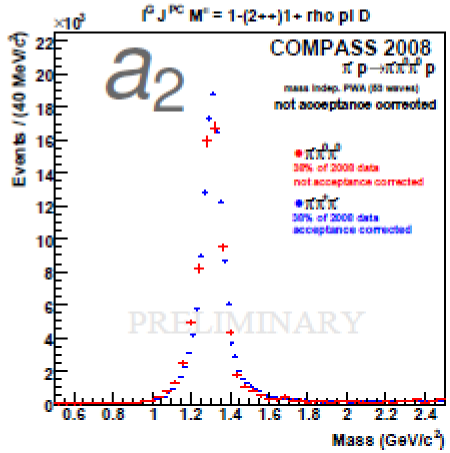
# COMPASS $\pi^-\pi^+\pi^-$ vs $\pi^-\pi^0\pi^0$

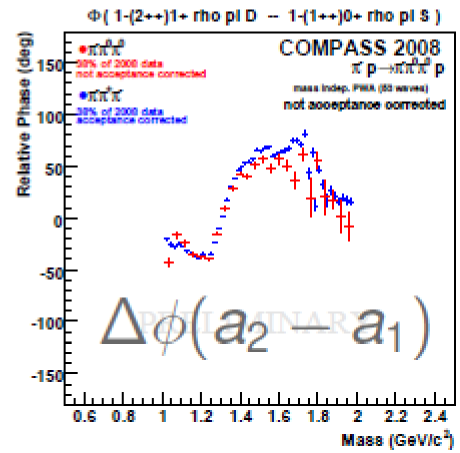
## Isospin Symmetry

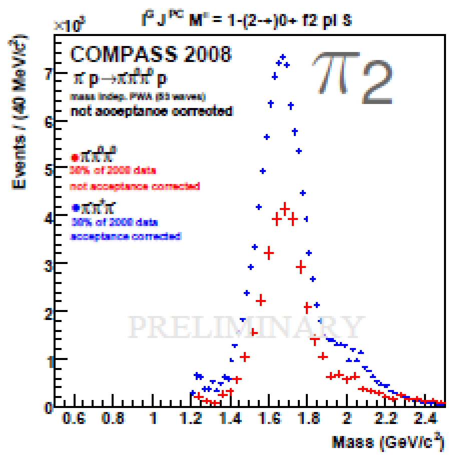
Technische Universität München

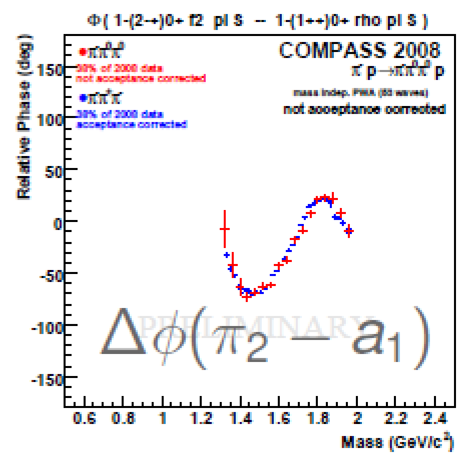
Partial wave intensities/phases: $\pi^-\pi^+\pi^-$ vs $\pi^-\pi^0\pi^0$ (normalized to $a_2$)




### Comparison

- $\pi^-\pi^0\pi^0$ not acceptance corrected yet
- Channels probe different parts of spectrometer
- Qualitative agreement

“Primakoff” region

$t' < 0.001 GeV^2$

(Primakoff reaction(M=1) and Pomeron exchange)

# Major intensities in m(3$\pi$)-bins (acceptance corrected)

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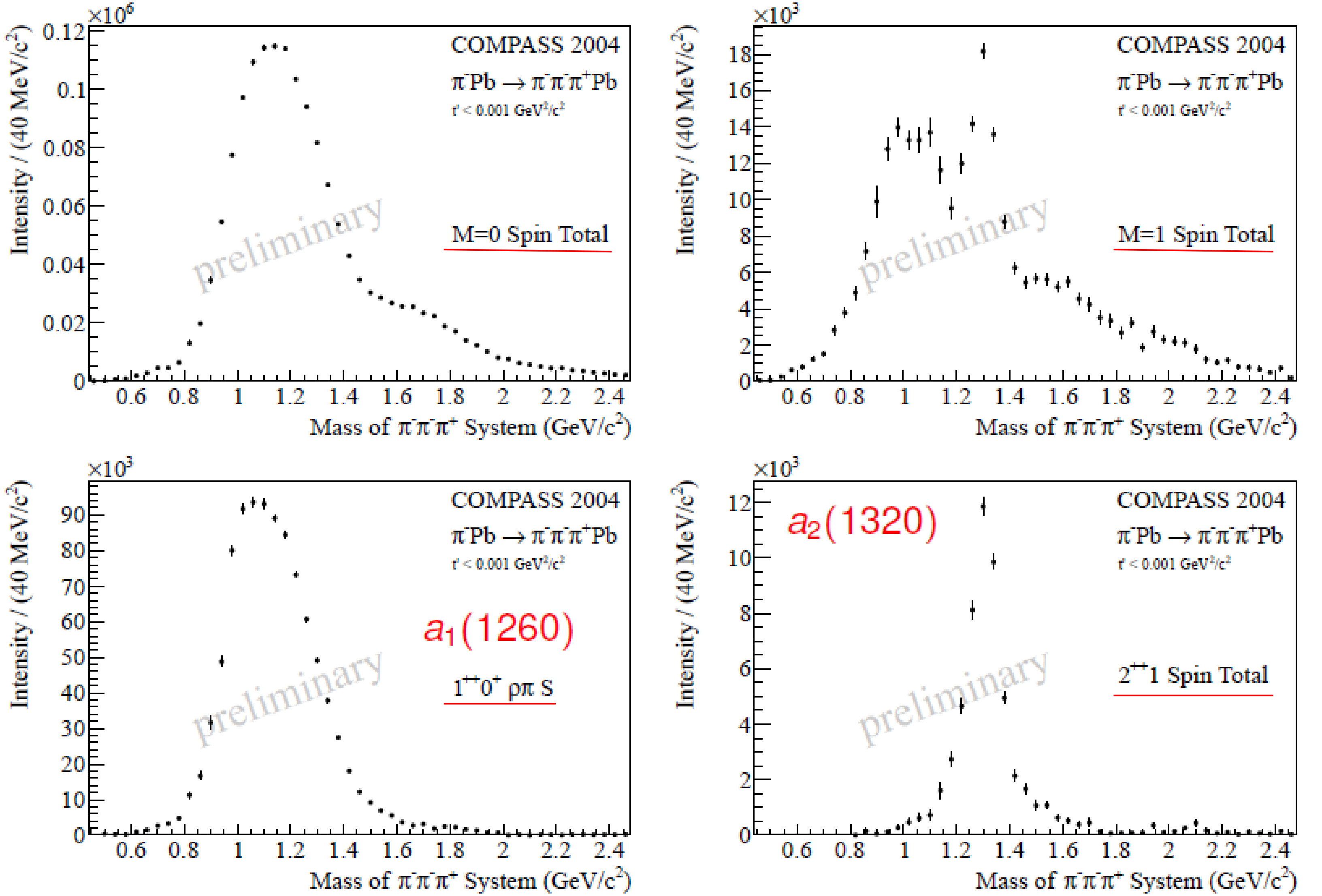
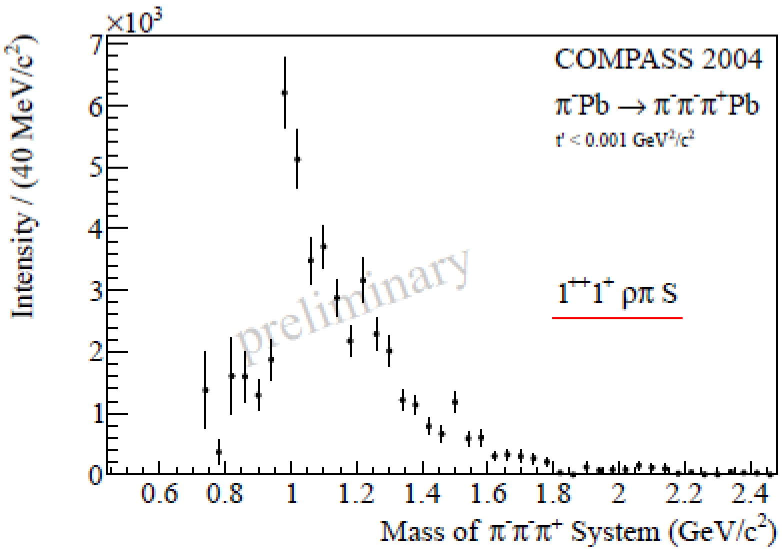
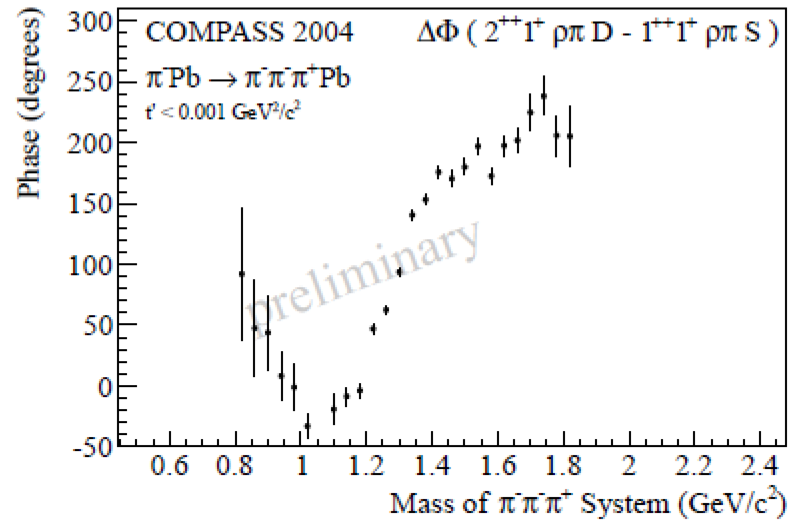
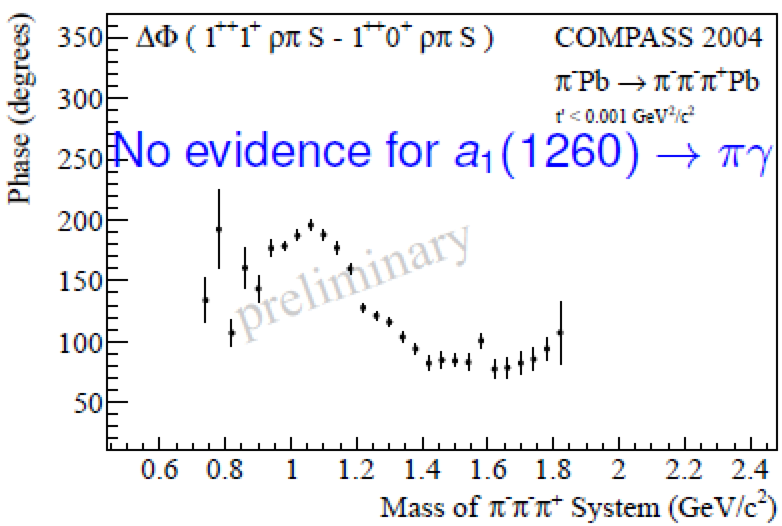


# Primakoff production of a1(1260); bottom left: E272 result

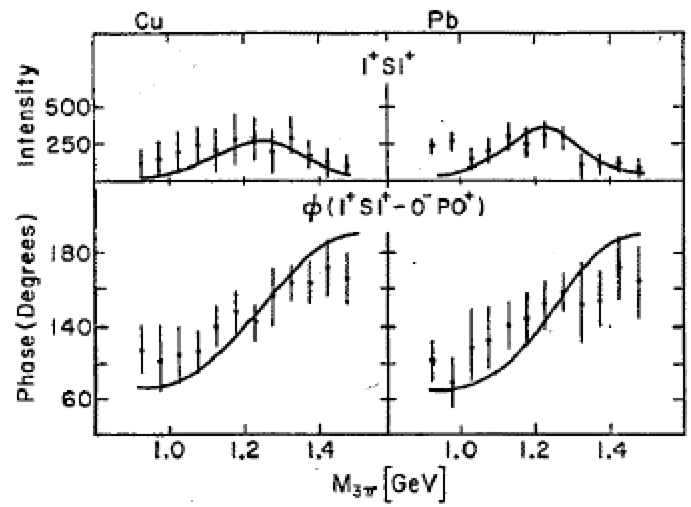
M=1がPrimakoff反応に対応



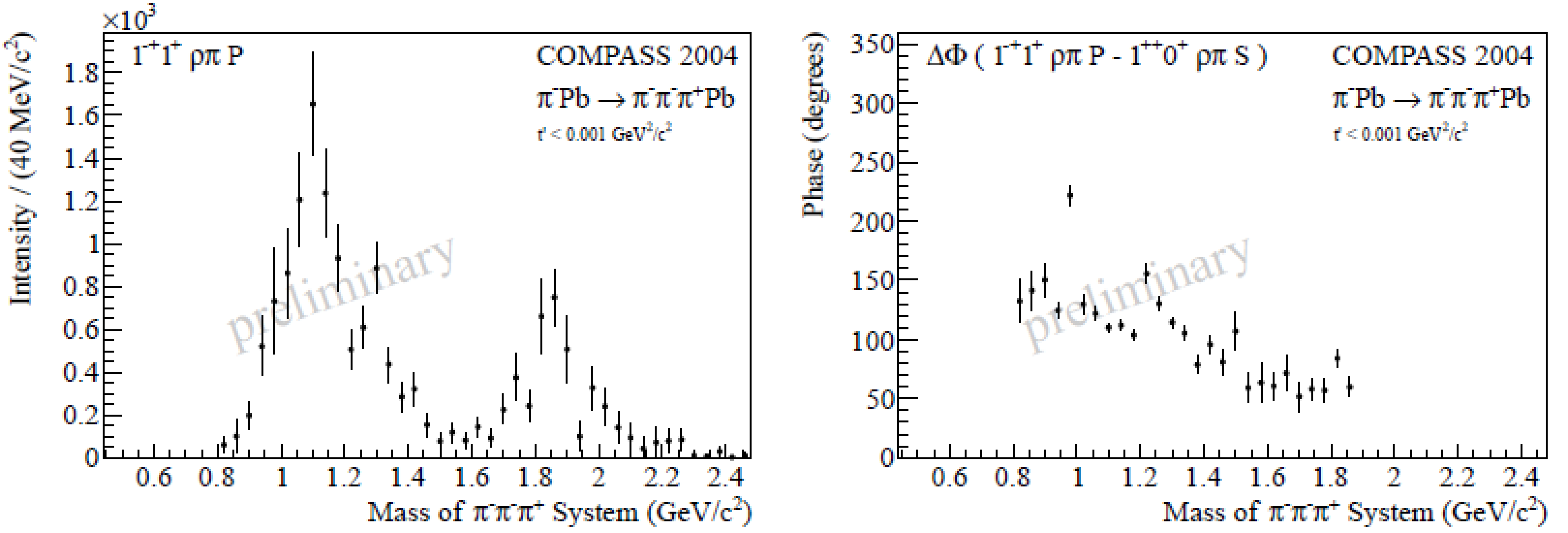




No evidence for $a_1(1260) \to \pi\gamma$ ?




M. Zielinski et al, Phys.Rev.Lett.vol.52, 14, 1195

# Primakoff production of exotic $1^{-+}$

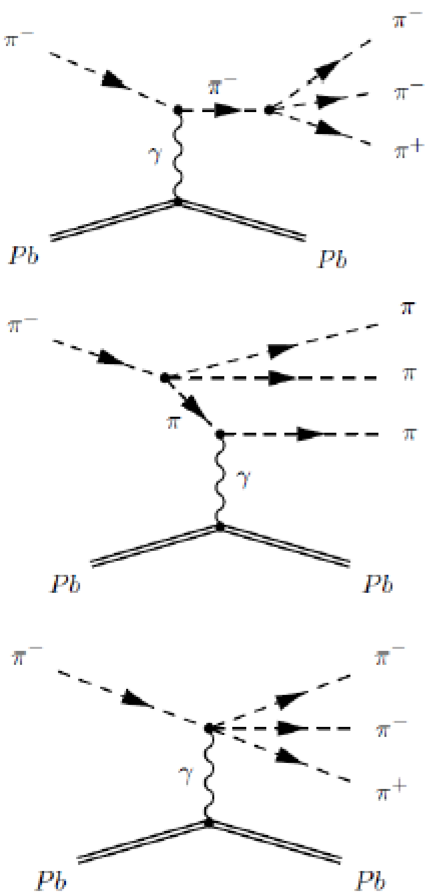



No evidence for $\pi_1(1600)$ Primakoff production

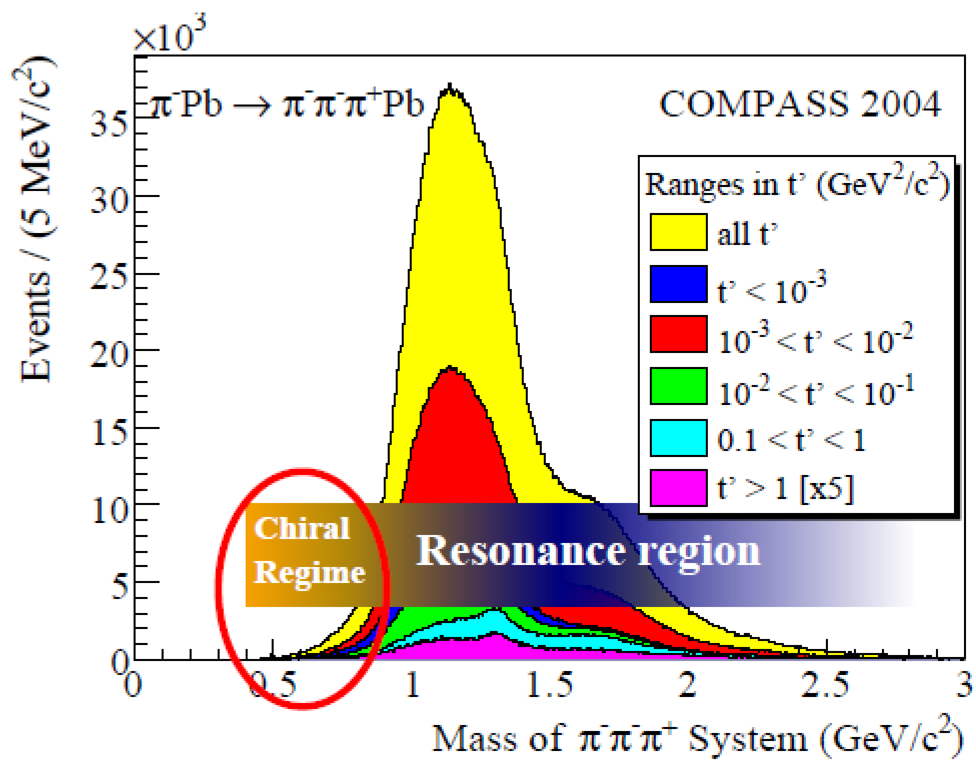
# Primakoff $3\pi$ Spectral Function from $\chi$PT

## Absolute Cross Section Measurement @ COMPASS

Technische Universität München



- Weizsäcker-Williams: heavy nucleus acts as a quasi-real photon source
- $\chi$PT amplitude included in PWA
- $\Rightarrow \gamma\pi^- \rightarrow \pi^-\pi^+\pi^-$ absolute cross section

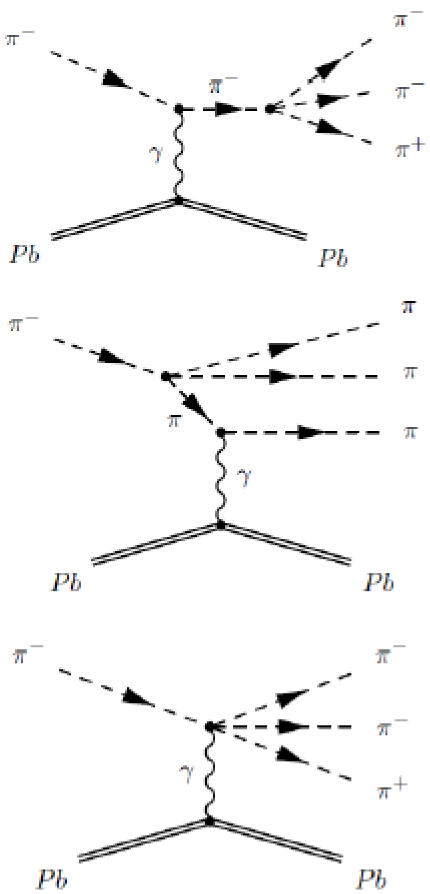


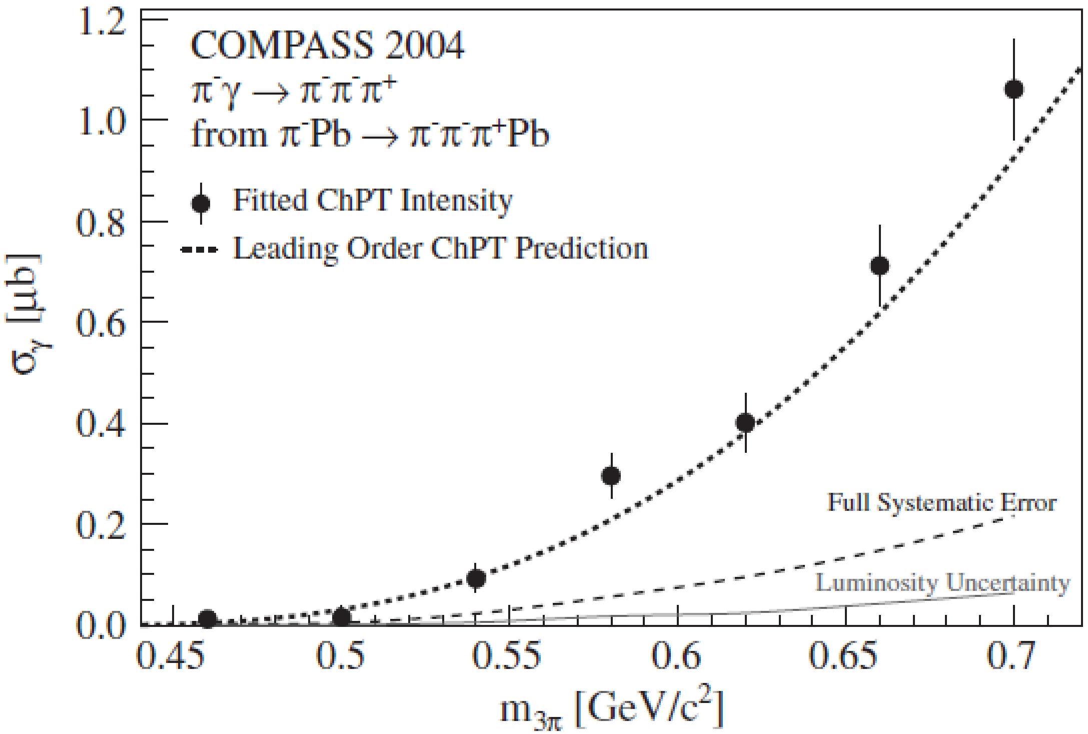
# Primakoff $3\pi$ Spectral Function from $\chi$PT

Absolute Cross Section Measurement @ COMPASS



- Weizsäcker-Williams: heavy nucleus acts as a quasi-real photon source
- $\chi$PT amplitude included in PWA
- $\Rightarrow \gamma\pi^- \to \pi^-\pi^+\pi^-$ absolute cross section




Published at PRL108,192001(2012).

38

(Hadron2011 conference talk)

# The Exotic $\eta'\pi^-$ Wave in 190 GeV $\pi^- p \rightarrow \eta'\pi^- p$ at COMPASS


Tobias Schlüter
for the COMPASS collaboration
Ludwig-Maximilians-Universität München


June 16, 2011

# $\pi\eta'$ in diffractive scattering

qq-bar exotic

Possible quantum numbers for the $\pi\eta'$ system:

| $L$ | $S$-wave | $P$-wave | $D$-wave | $F$-wave | $G$-wave | $\cdots$ |
|---|---|---|---|---|---|---|
| $J^{PC}$ | $0^{++}$ | $1^{-+}$ | $2^{++}$ | $3^{-+}$ | $4^{++}$ | $\cdots$ |

Hence: $P$-wave resonant $\rightarrow$ exotic meson.

This system has been studied by the following experiments:

| experiment | beam momentum | reaction | year published |
|---|---|---|---|
| VES | $37\,\mathrm{GeV}/c$ | $\pi^- N \rightarrow \eta'\pi^- N$ | 1993, 2005 |
| E852 | $18\,\mathrm{GeV}/c$ | $\pi^- p \rightarrow \eta'\pi^- p$ | 2001 |

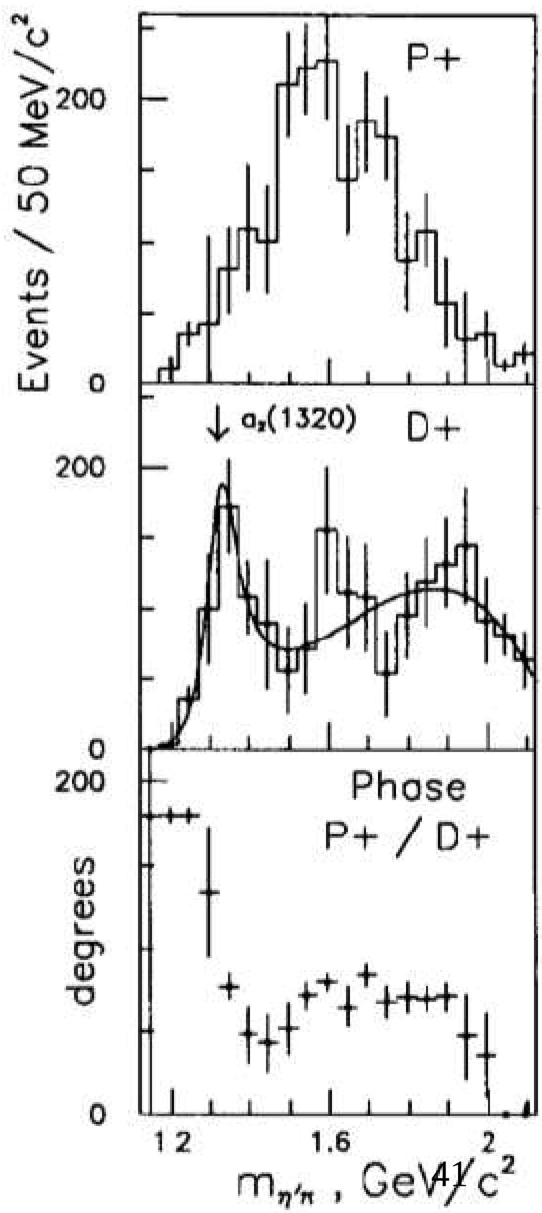
They all see a very strong $P$-wave.

# Previous $\pi\eta'$ results – VES

Results from VES (Be target, 37 GeV):

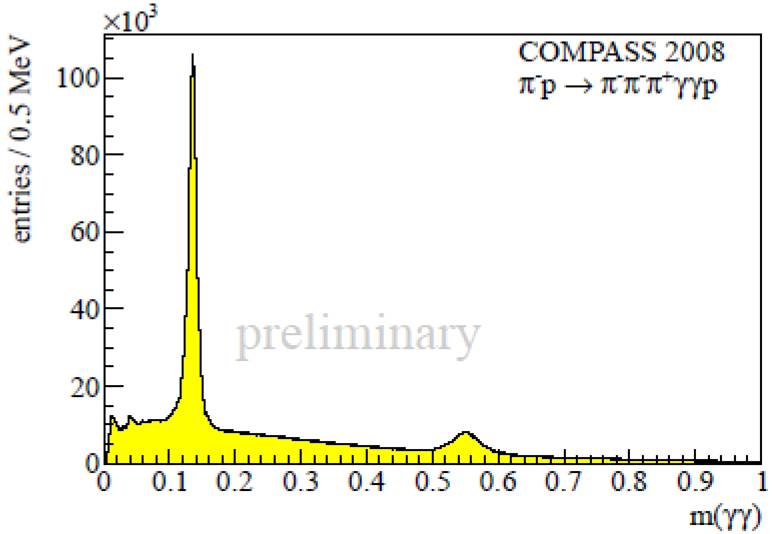
- VES sees the $a_2(1320)$ (peak in $D_+$-wave)
- VES says: "there may be an $a_2(1700)$" explaining the broad structure in the $D_+$-wave
- VES says: "there may be an exotic $\pi_1(1600)$"

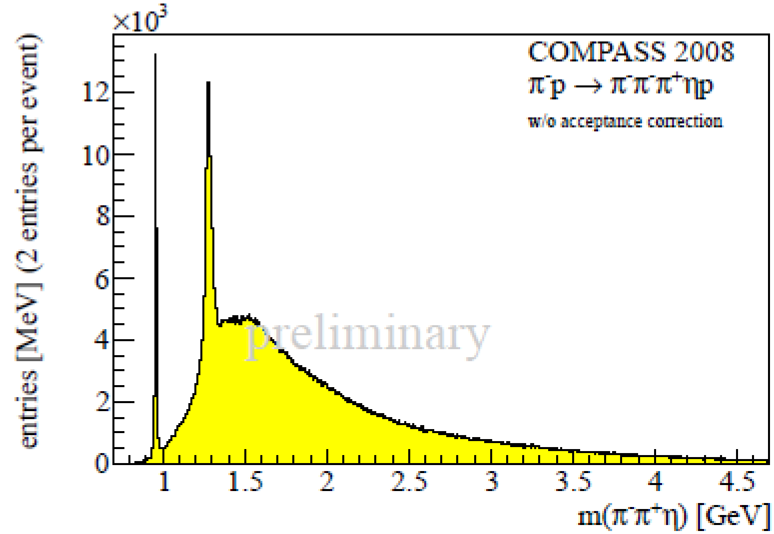
Note the jump in the relative $P_+ - D_+$ phase near 2 GeV

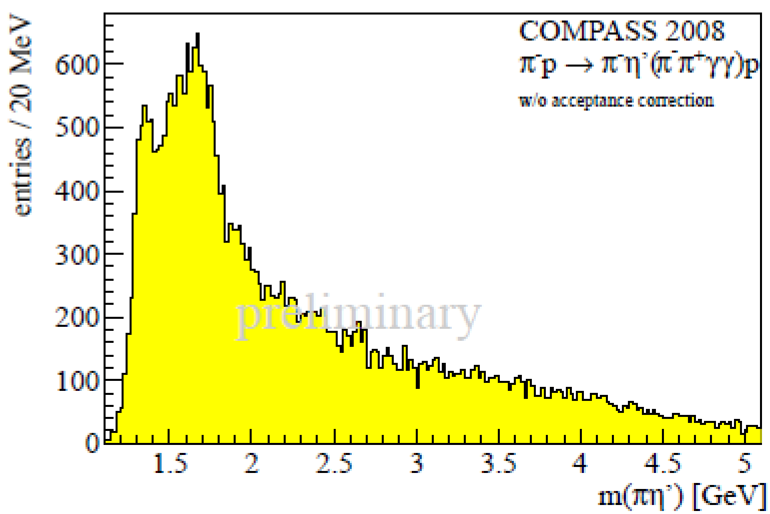


# Data selection

Final state selected: exclusive 3 tracks, 2 photons



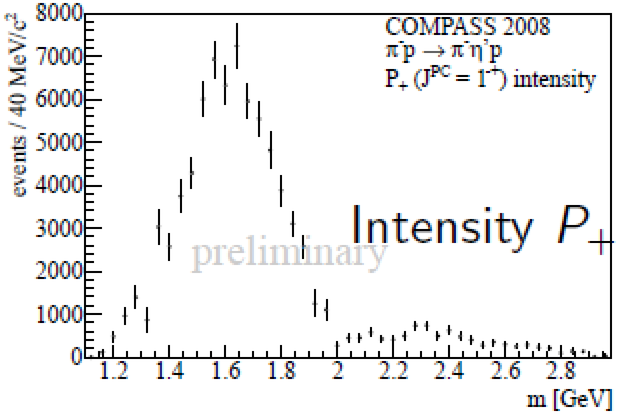



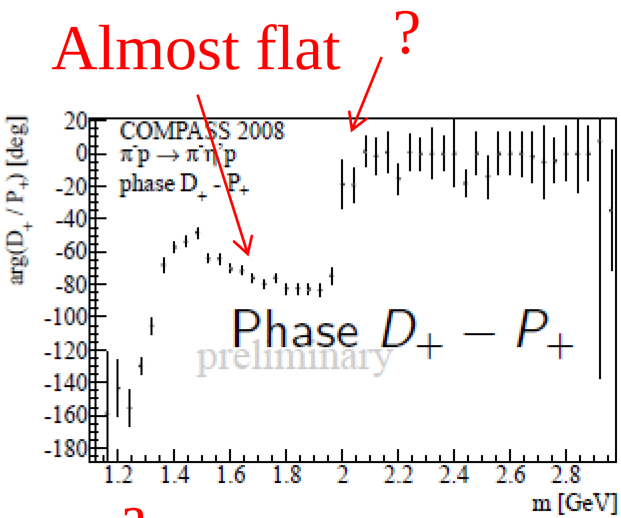



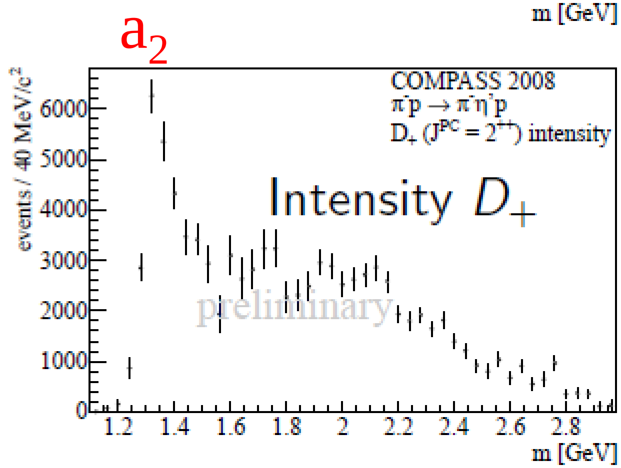

Result:

- 18 000 events with $m(\eta'\pi) < 2\,\mathrm{GeV}/c^2$, 35 000 total
- mass reach beyond $2\,\mathrm{GeV}/c^2$
- additionally, about 3 000 events in $\pi\eta'$, $\eta \to 3\pi$ channel

# PWA results – $P_+$ and $G_+$ waves

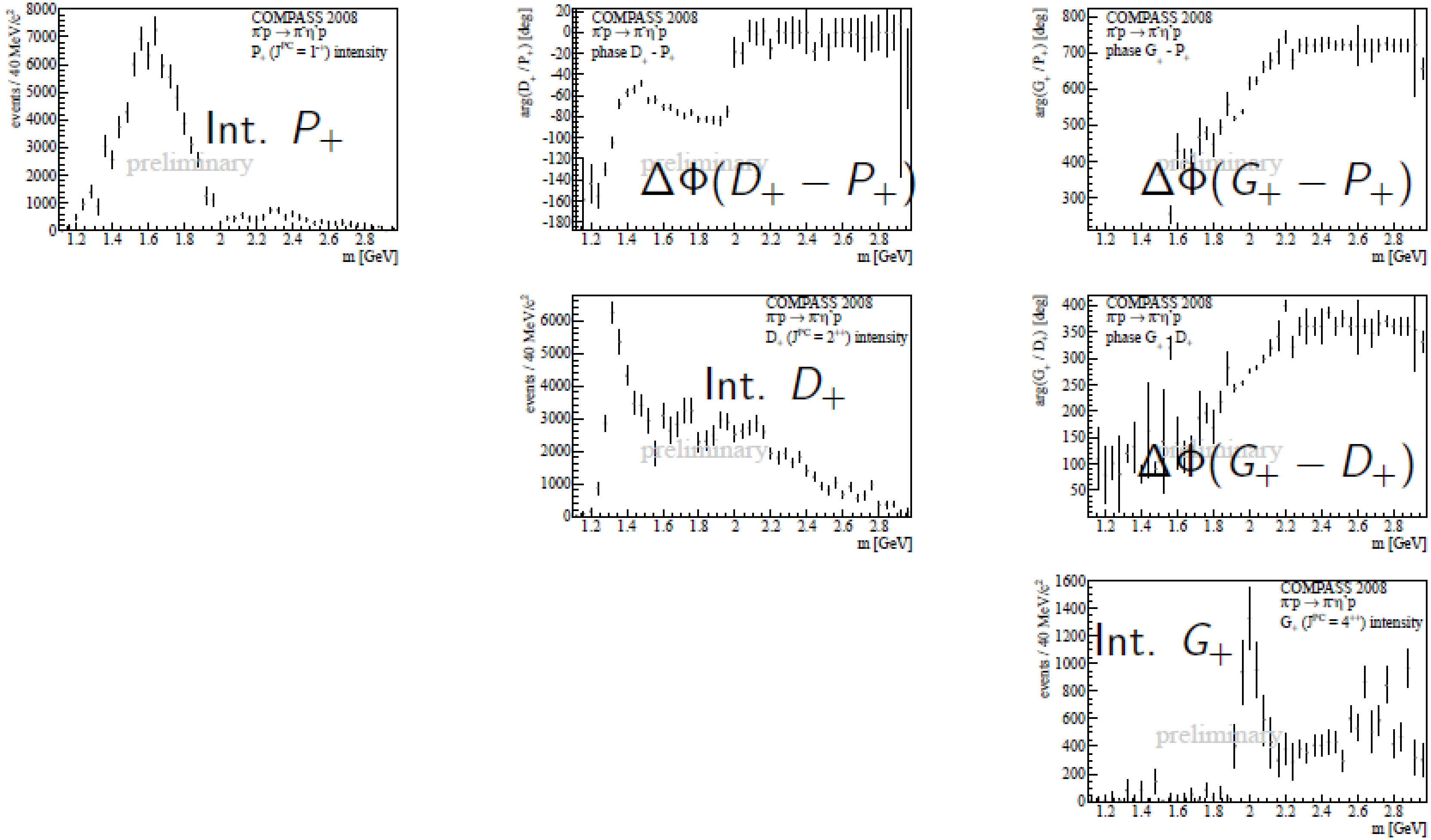


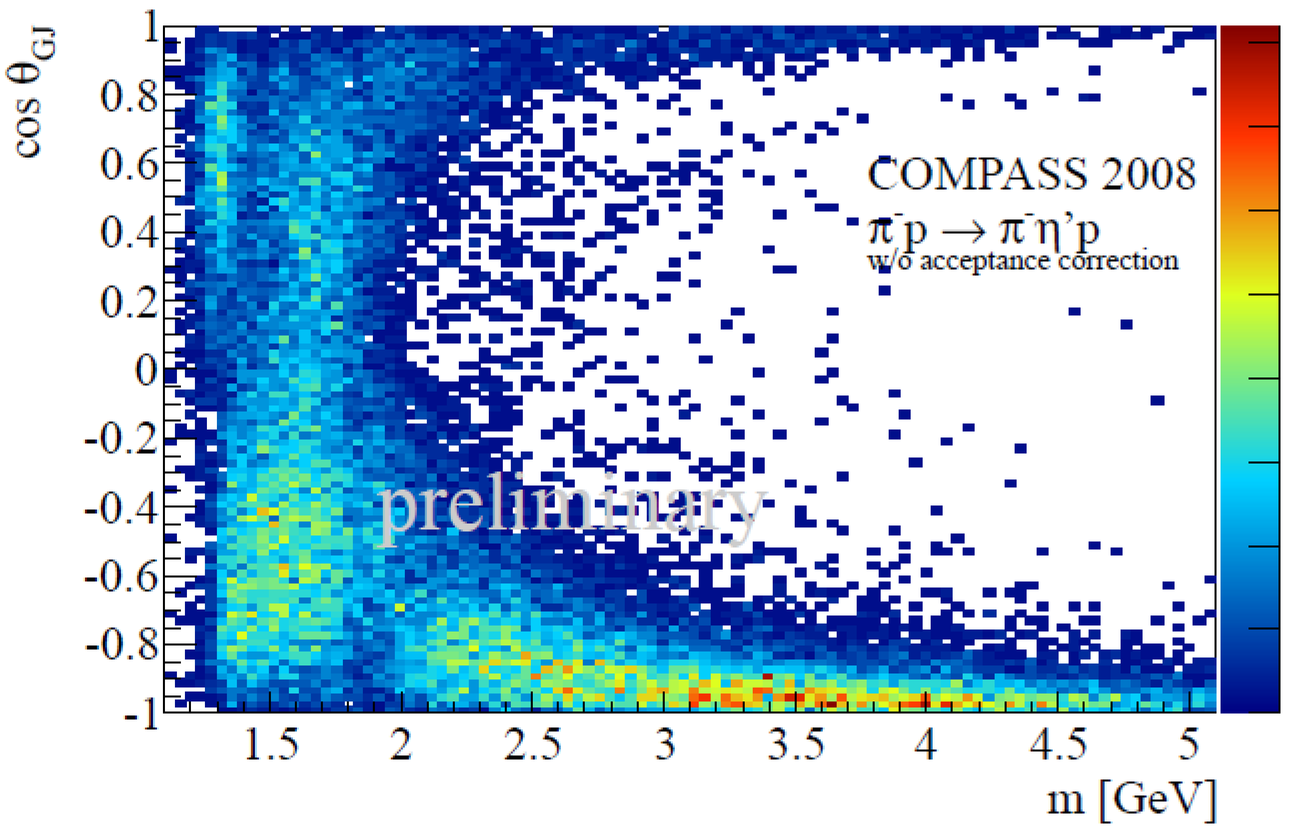

Clear phase-motion from $a_2(1320)$, jump in phase near $2\,\mathrm{GeV}$, slow phase-motion in range of $P_+$-wave intensity peak.

# PWA results – can the $G_+$-wave clarify the picture?




Clear phase-motion in $G_+$-wave relative to $D_+$ wave, compatible with $a_4(2040)$. Again: jump at 2 GeV in phase relative to $P_+$ wave. But: unlike between $P_+$ and $G_+$ no rapid phase jump between $D_+$ and $G_+$ waves at 2 GeV

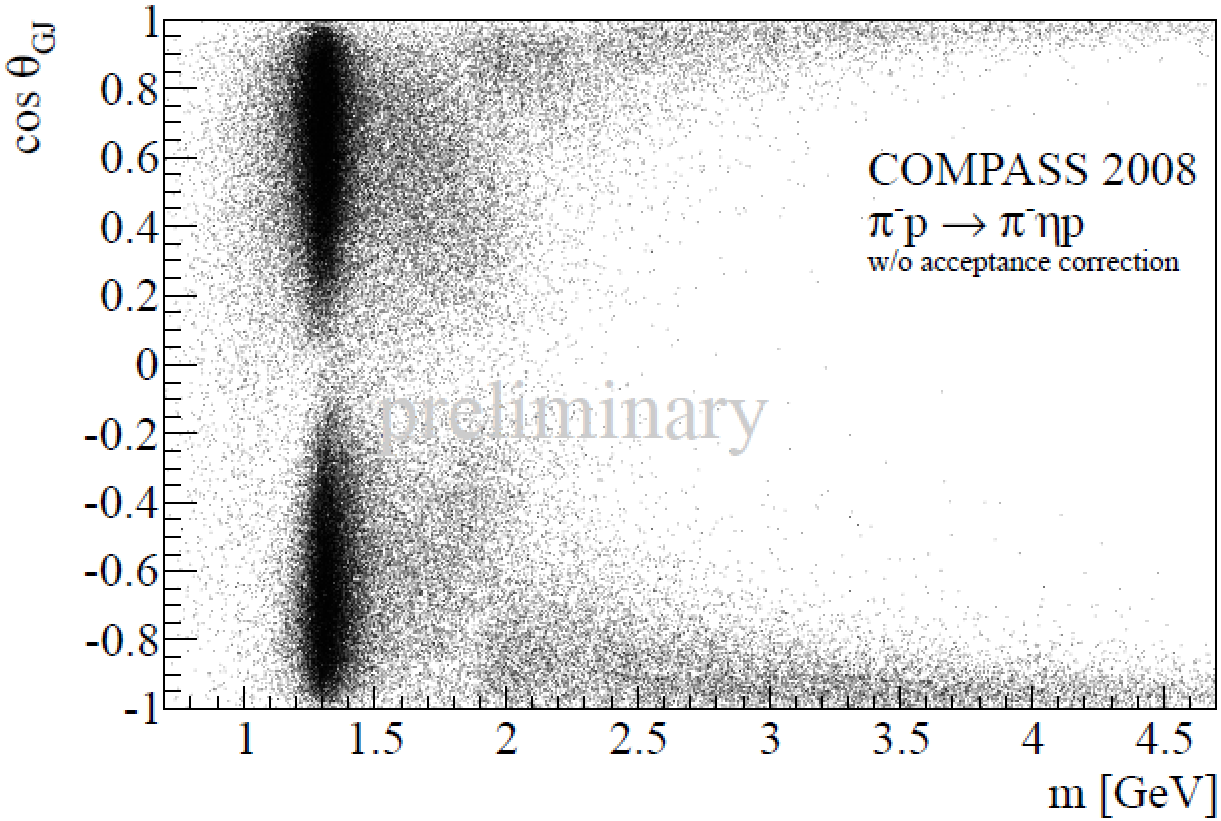
# Transition between different production processes?




Depicted: $\cos\theta_{\mathrm{GJ}}$ of the $\eta'$ in the $\pi^-\eta'$ GJ restframe vs. $m(\pi\eta')$.
Low masses show $P$ and $D$ wave interference, $a_4$ near $2\,\mathrm{GeV}/c^2$, above that strong forward/backward peaking indicative of central production.
Question: How does the forward/backward peaking at high masses affect the interpretation at low masses?

# Comparison to $\eta\pi$

We also selected the $\eta\pi^-$ final state along the same lines. No PWA yet, for comparison, here's the same plot as on the previous slide, but for the $\pi\eta$:



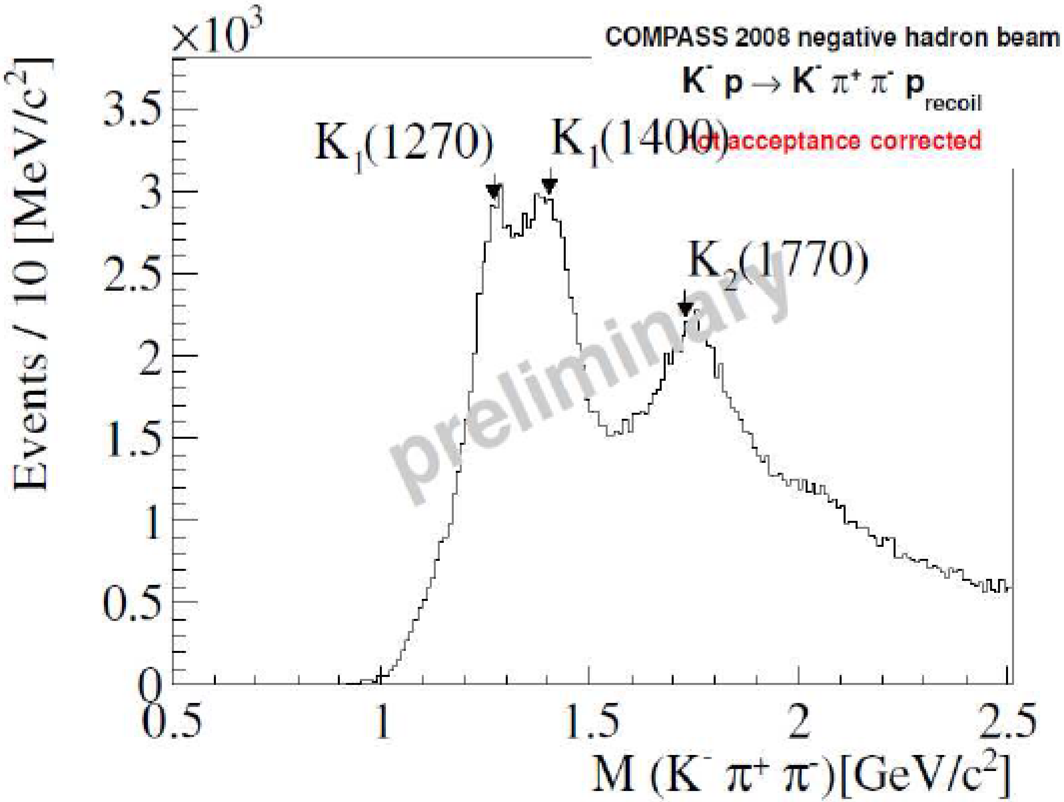

Depicted: $\cos\theta_{GJ}$ of the $\eta$ in the $\pi^-\eta$ GJ restframe vs. $m(\pi\eta)$. Dominated by $a_2(1320)$, structures due to $a_4(2040)$ visible, again forward/backward peaking at high masses.

# Kaon diffraction dissociation $K^- p \to K^- \pi^+ \pi^- p$

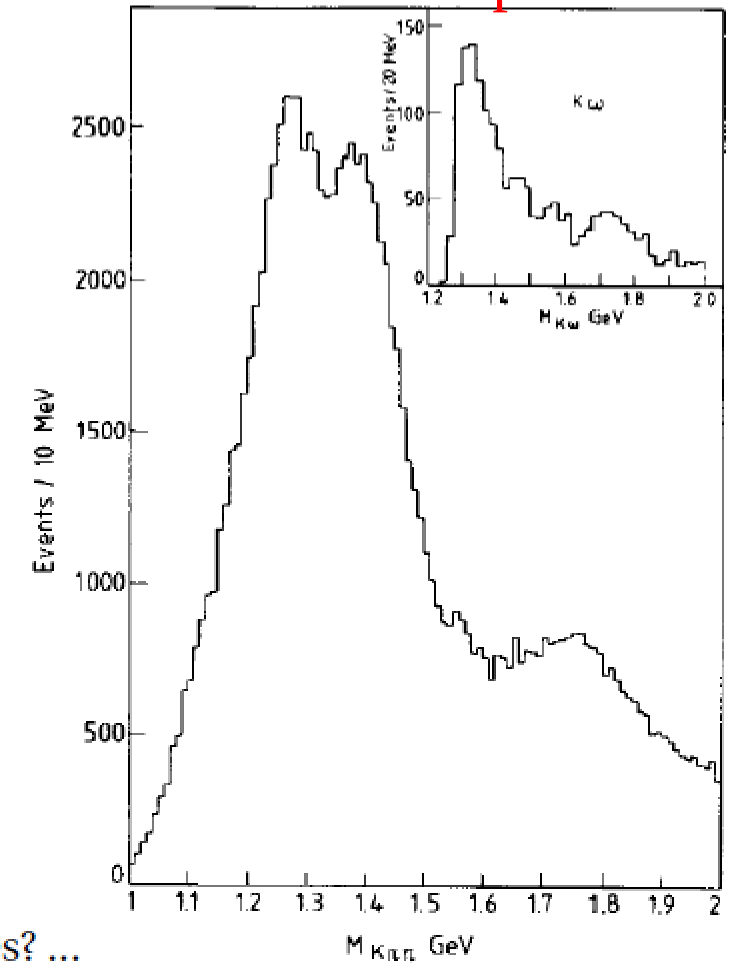
- COMPASS has taken kaon beam data by tagging incoming kaons as well as pions and proton/anti-protons.
- Until now most results of this channel came from the WA03 experiment (ACCMOR) .
- The results should be confirmed by other experiments.
- COMPASS provides more precise data with a few times the statistics and can give the opportunity to check and confirm the WA03 results.

# Invariant mass distribution ($K^- \pi^+ \pi^-$)

COMPASS




ACCMOR experiment




Are those resonances decaying directly into 3 particles? ...

Nuclear Physics B187 (1981) 1–41
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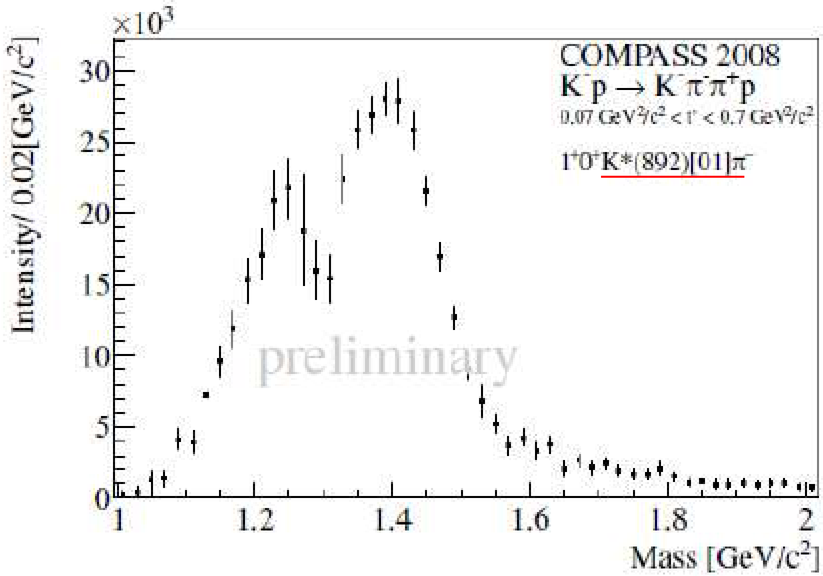
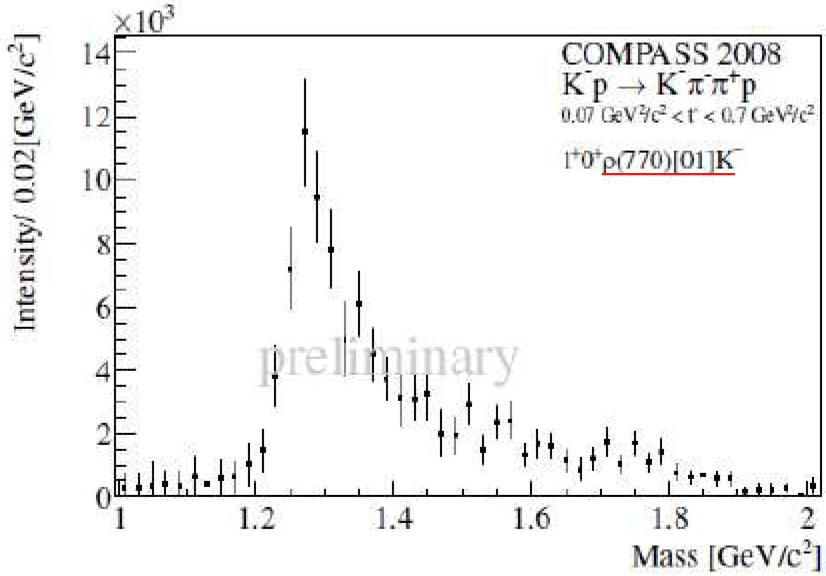
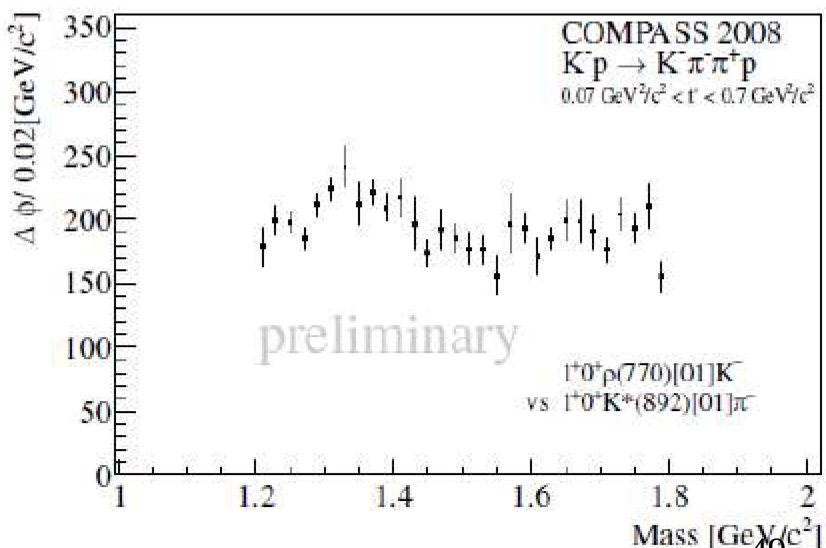
# $J^P = 1^+$ waves

## $K_1(1270)$ & $K_1(1400)$ ?



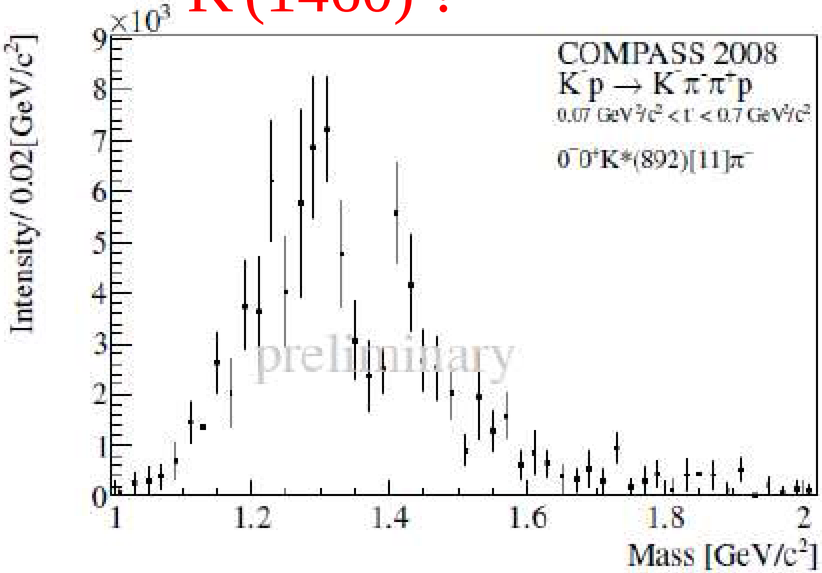



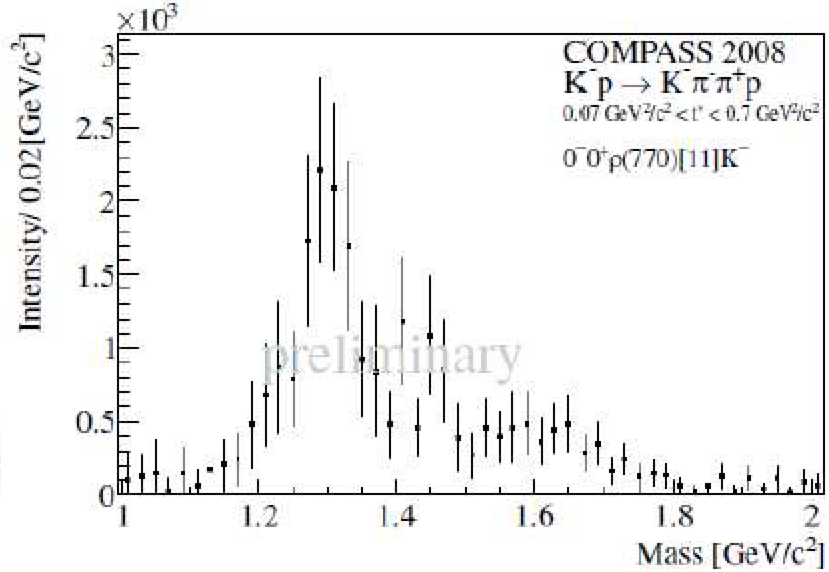



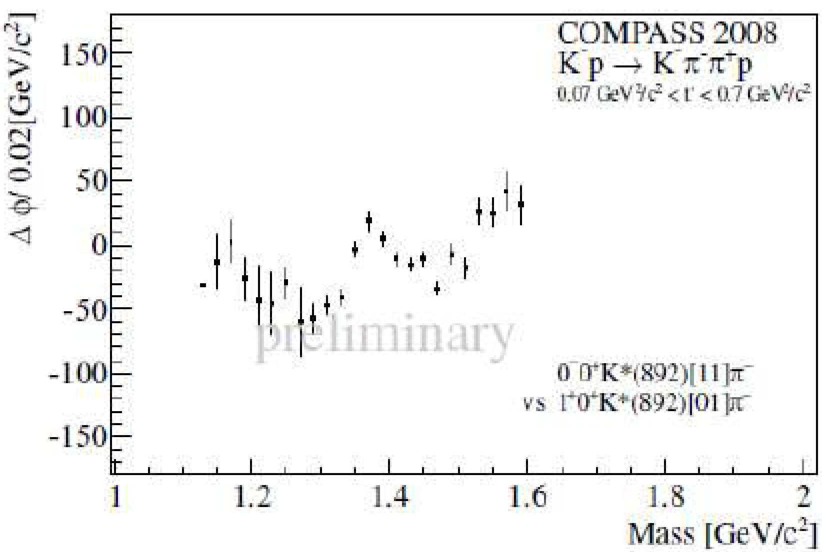

Mass Independent PWA was performed.

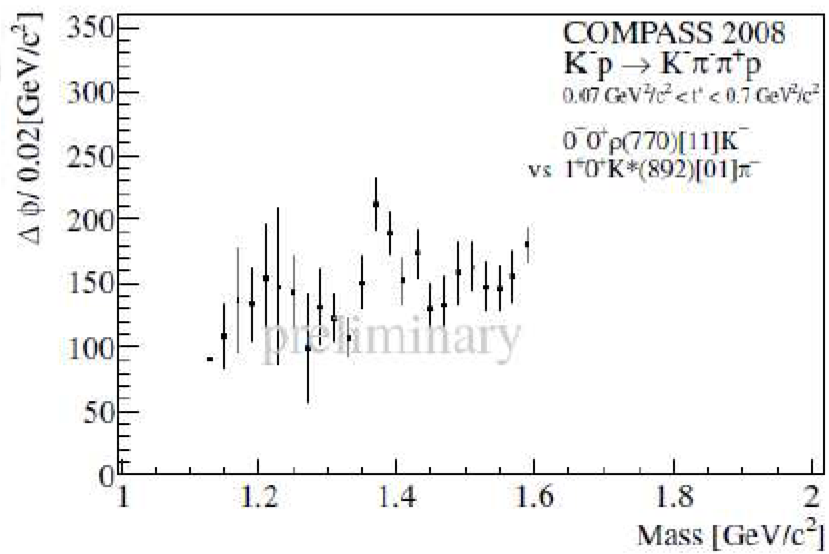
# $J^P = 0^-$ waves

K (1460) ?



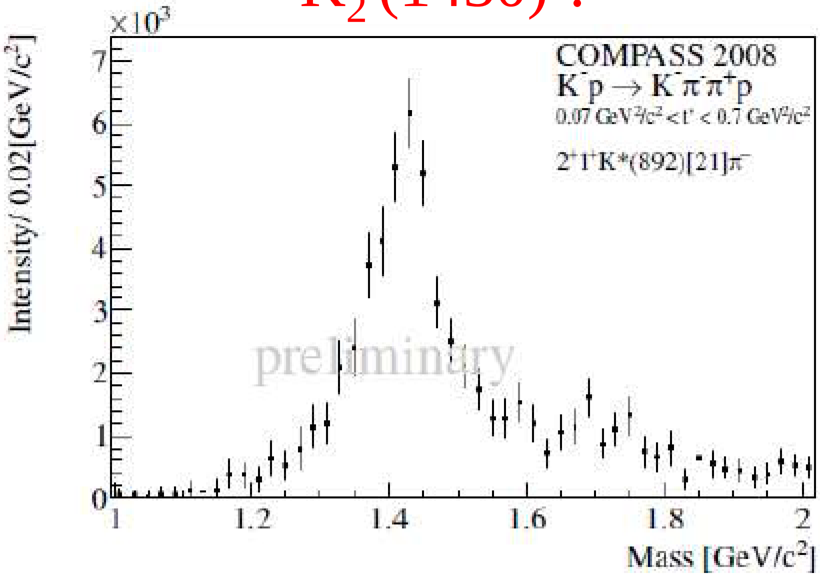



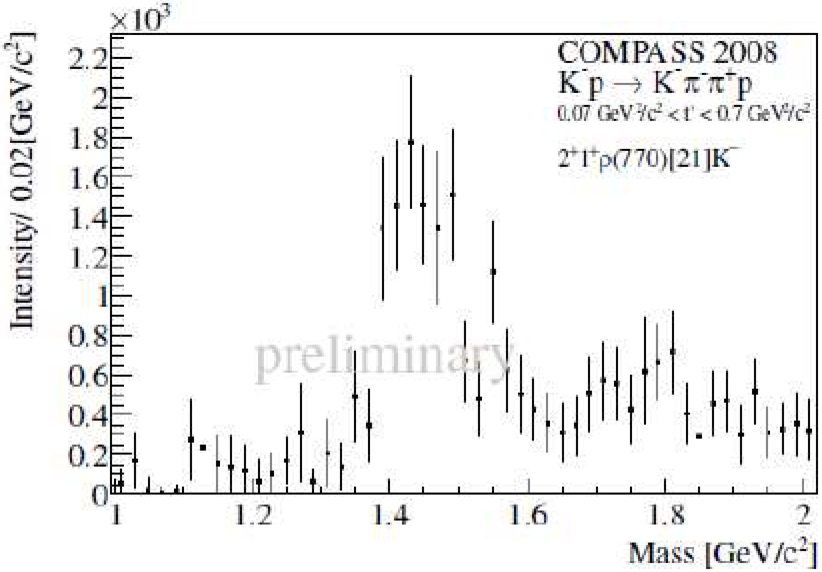



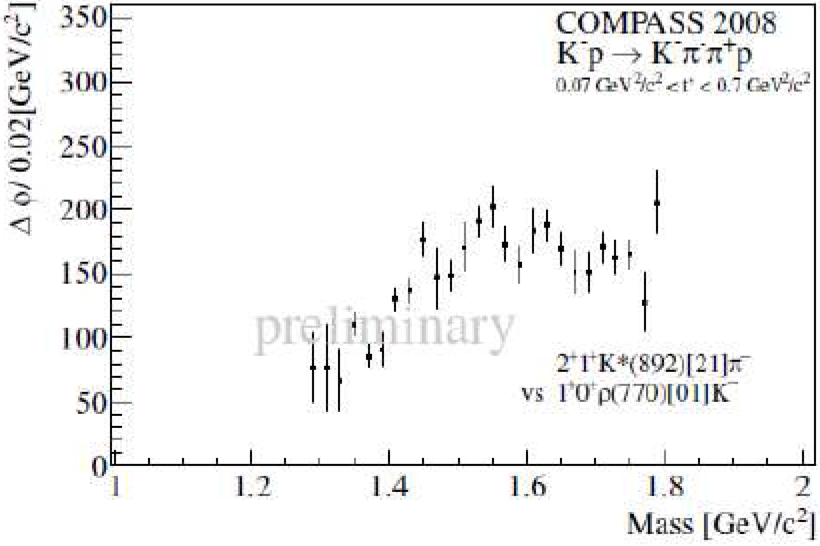



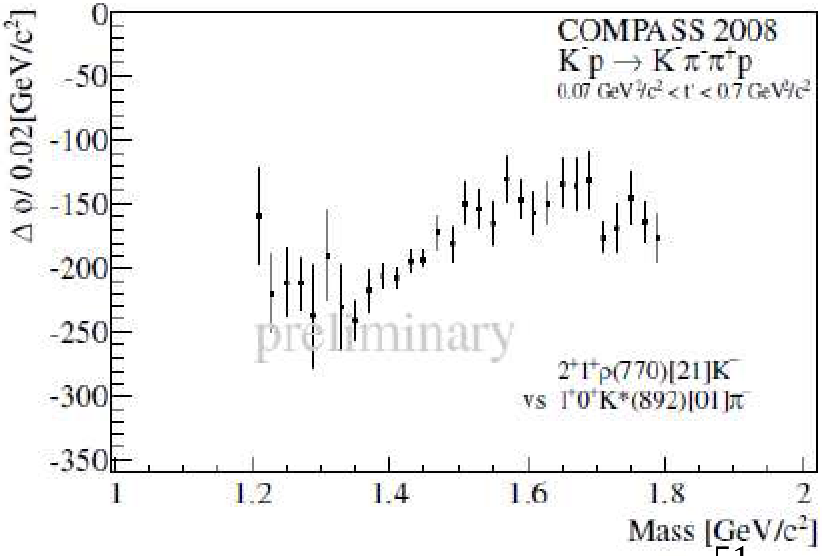
# $J^P = 2^+$ waves

$K_2(1430)$ ?



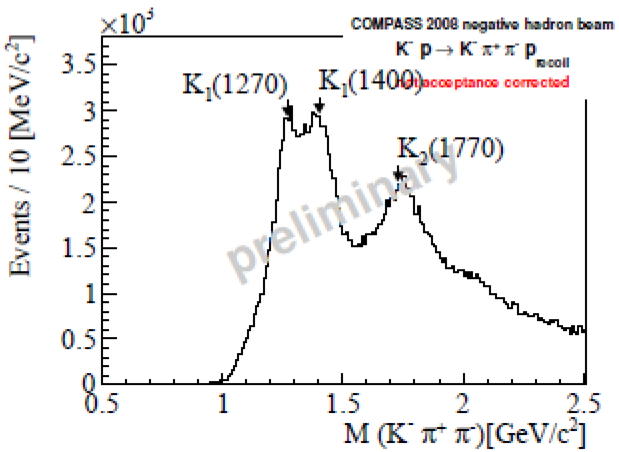



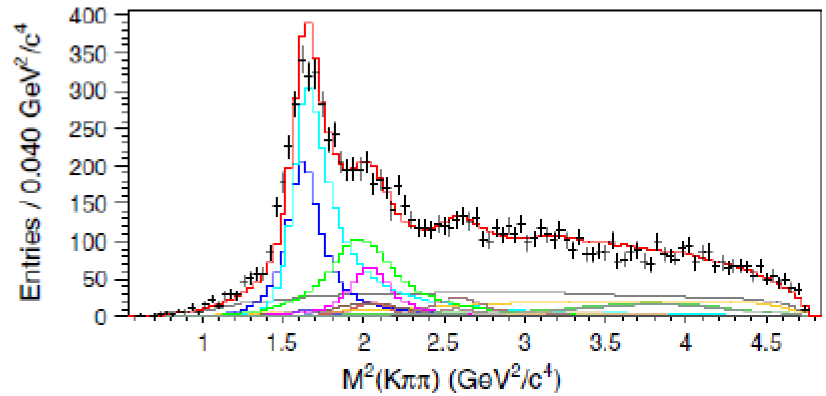
# Strangeness at COMPASS & BELLE

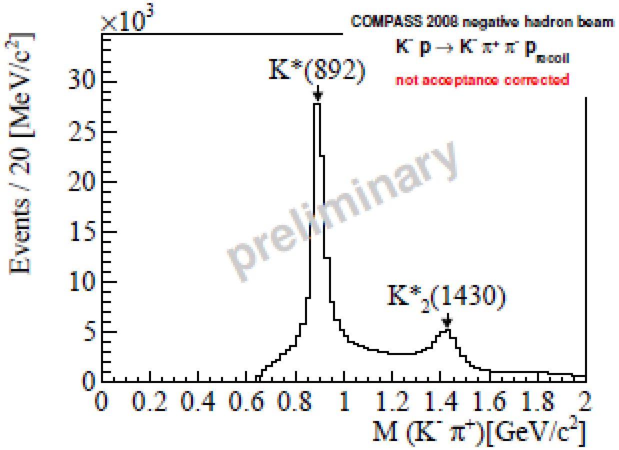


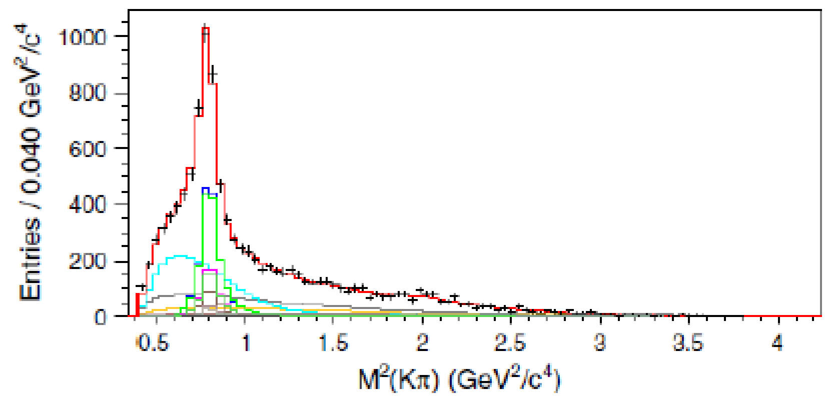
COMPASS: $K^- + p \to K^- \pi^+ \pi^- + p$
$\sim 270\,000$ events

BELLE @ $\Upsilon(4s)$: $B^+ \to J/\psi K^+ \pi^+ \pi^-$
$\sim 10\,000$ events



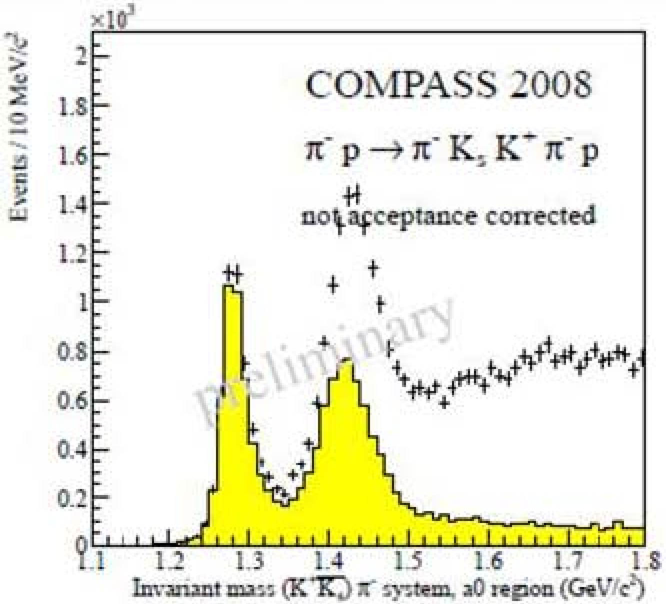



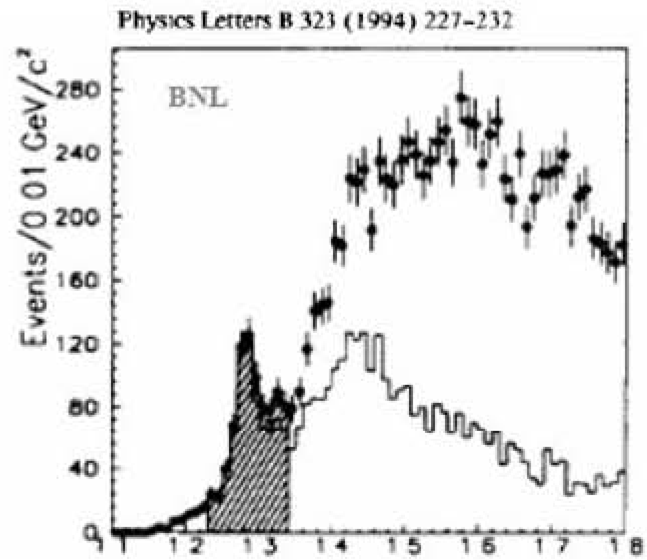



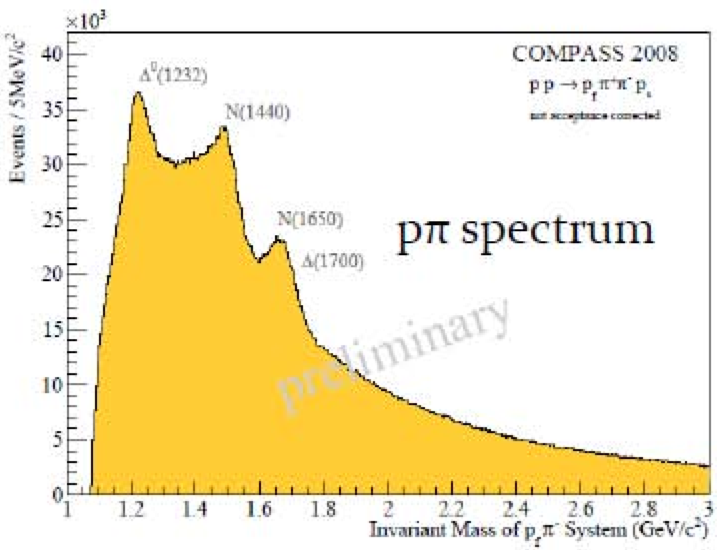

[PRD **83** (2011) 032005]

52

# More hadron physics with COMPASS

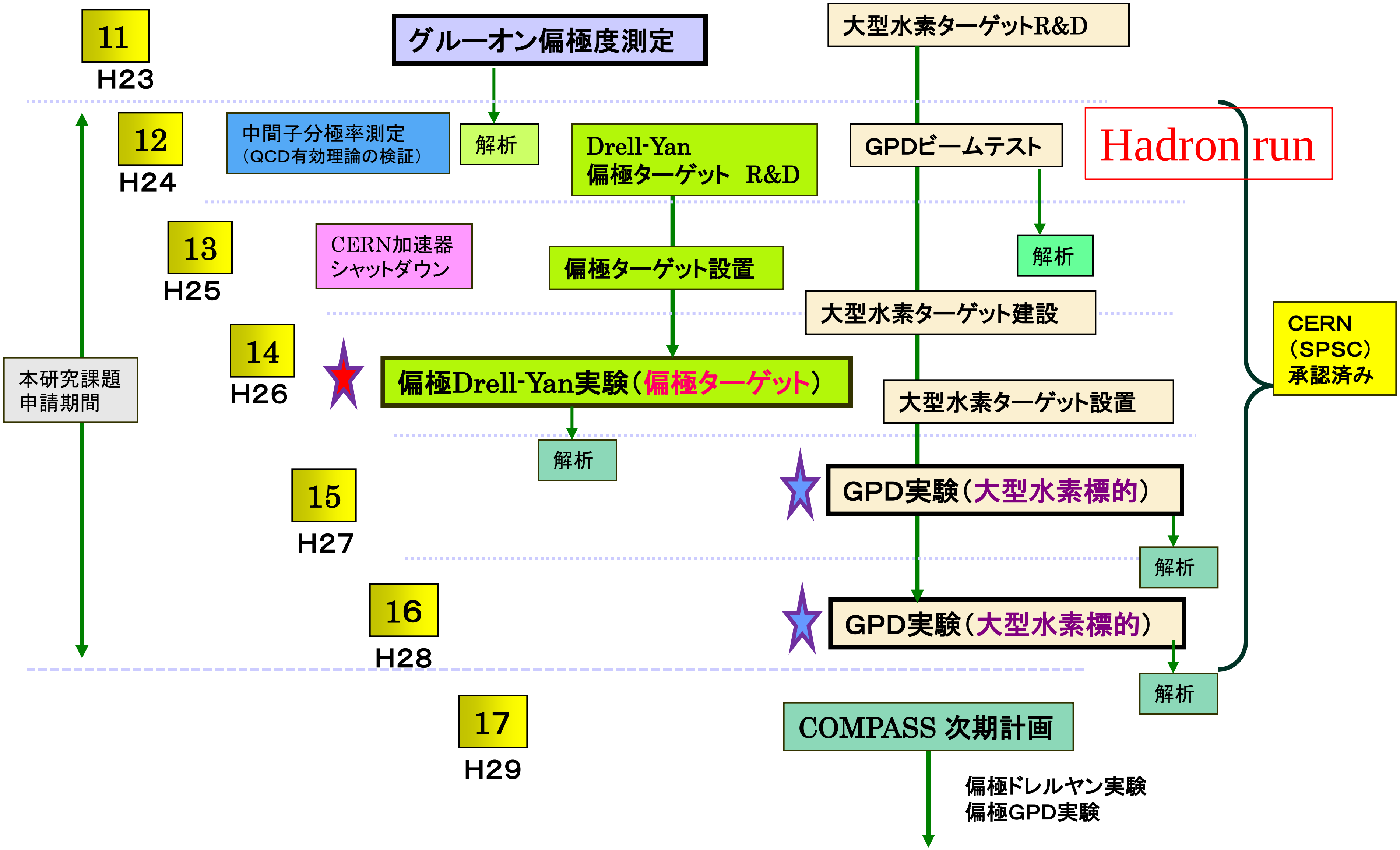



- Excellent potential for KKππ final states (high masses, $f_1(1285)\pi$ and $f_1(1420)\pi$ modes accessible).
- Search for glueballs in central *pp* collisions.
- Baryon spectroscopy.

# COMPASS国際共同研究　研究計画予定

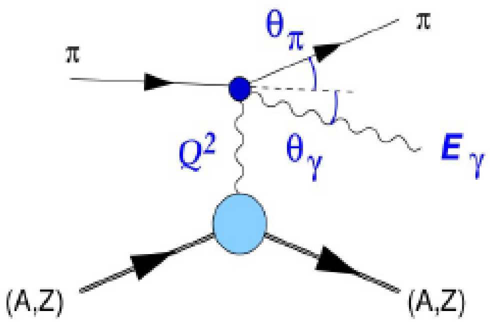


2012年のPrimakoff reactionのデータ収集をつい先日終了した。

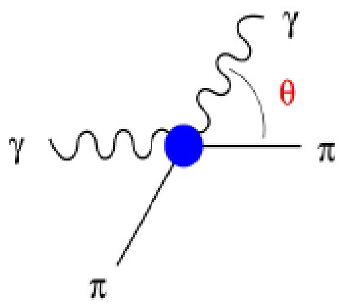
# Pion and Kaon Polarisabilities

Chiral Perturbation Theory (ChPT) can be tested using the Goldstone bosons (pions and Kaons) by describing its strong interaction dynamics.

The pions and Kaons inner structure is revealed in its response to the presence of an electromagnetic field ⇒ Pion and Kaon Polarisability



Primakoff



Compton

Studying Primakoff reactions and embedded inverse Compton scattering pion and Kaon polarisability represents a test to ChPT predictions.

# π中間子の電気、磁気分極率

- Primakoff reactionは系統誤差で、π中間子の分極率を与えると考えている。
- カイラル摂動論は電気分極率と磁気分極率の差がゼロでない値を与えており、COMPASSの結果でχPTの確認ができると期待している。

## これまでの測定結果

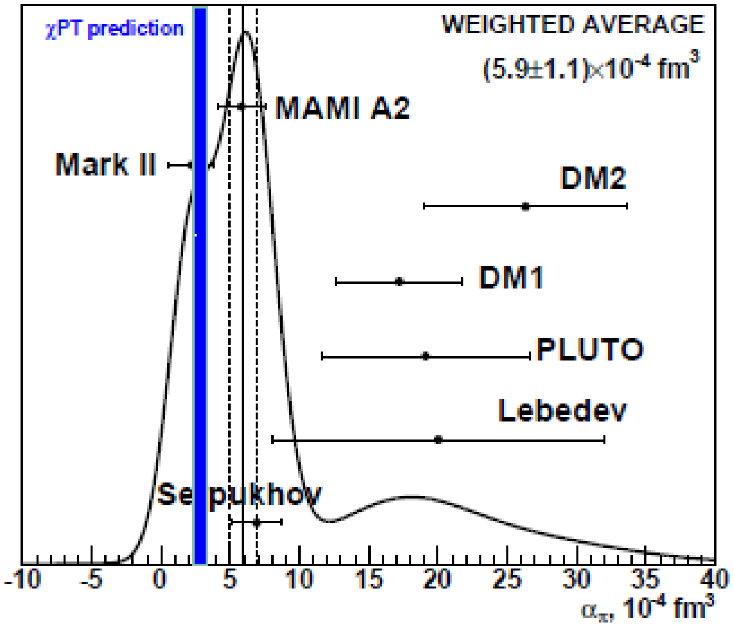



Figure 1: Global fit to the experimental data on the pion polarisability $\alpha_\pi$ as given in Table 1. The curve represents an ideogram of the data and their errors as described and used in the Review of Particle Physics [11] (cf. Sect. 5.2.2 therein).

| In 120 days (90 with $\pi$, 30 with $\mu$ beams) | $\alpha_\pi - \beta_\pi$ ($10^{-4}$ fm$^3$) | $\alpha_\pi + \beta_\pi$ ($10^{-4}$ fm$^3$) | $\alpha_2 - \beta_2$ ($10^{-4}$ fm$^3$) |
|---|---|---|---|
| 2-loop ChPT prediction | $5.7 \pm 1.0$ | $0.16 \pm 0.10$ | 16 |
| COMPASS sensitivity | $\pm$ 0.66 | $\pm$ 0.025 | $\pm$ 1.94 |

# Summary

- **COMPASS** light meson spectroscopy 実験を開始
  - 高エネルギービームによってフラットで、広いアクセプタンスを獲得し、
  - 荷電粒子、ガンマ線検出および粒子識別を同時に可能とし、
  - 新しい飛跡検出器と新しいエレキ、新しいデータ収集システムなどで、高統計実験を可能とし、
  - ビーム粒子の同定も行い、異なった反応チャンネルを同時に収集できるようになった。
- Hadron Beamで2004年に"Pilot run"を行い、

さらに、

- **Hadron beam** 液体水素標的を用いて、2008/2009でデータ収集した。
  - diffractive running with $\pi^-$ beam 2008/2009
  - Central production running with positive hadron beam 2009
  - Diffractive reactions: 10× world statistics in ~35 days
  - Central production: 10× world statistics in ~60 days

のデータを収集し、その結果、

# Summary cont'd

- COMPASS is accessing 3 different production mechanisms:

  diffraction dissociation,

  Central production,

  Coulomb production. (Primakoff scattering)
- $\pi^- Pb \rightarrow \pi^- \pi^+ \pi^- Pb$ data are analyzed at three different regions (low t', mid t' and high t')
- COMPASS has confirmed $\pi_1(1600)$ ($J^{PC}=1^{-+}$) from 2004 pilot run.
- Low t' data provide test of ChPT –first results agree with LO predictions.
- The analysese of $\pi^- p \rightarrow \pi^- \pi^+ \pi^- p$, $\pi^- \pi^0 \pi^0 p$ , $\eta' p$, $\eta p$, $KK\pi\pi p$ are ongoing.
- The analysis of $K^- p \rightarrow K^- \pi^+ \pi^- p$ is also ongoing.
- COMPASS also studies Baryon spectroscopy.
- And COMPASS has still more data to be analyze….