# Radiative Coupling of $a_2(1320)$ and $\pi_2(1670)$

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*on leave of absence from*

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*for the COMPASS collaboration*

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EINN2013, 1. November

Πάφος, Κύπρος

Bundesministerium
für Bildung
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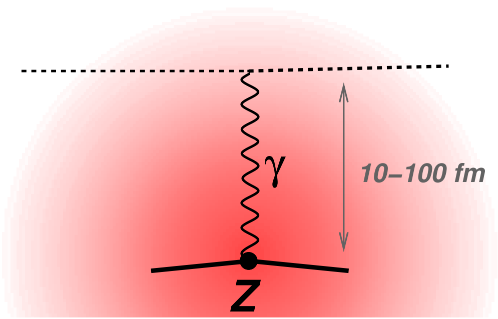
# Why Radiative Couplings?


- radiative coupling “map” wave functions of the involved particles (known transition matrix element)
  $\rightarrow$ information of shape and inner structure of the meson resonances
- Related *e.g.* to $\pi\rho$ decay channels (vector meson dominance)

# Outline

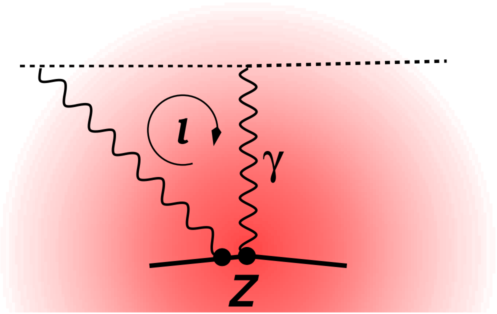
- Investigation of $\pi^-\gamma$ coupling through high-$E$ hadron scattering
  - Primakoff reactions
  - higher-order aspects
- The apparatus: COMPASS
- Partial-wave analysis for identification of resonance contributions

# High-$E$ Reactions: Momentum Transfer Regimes




- Small momentum transfer ⇔ large impact parameter in coordinate space
- At large distance: long-range *EM* potential dominates
- missing at this step:
  *EM* at higher order, finite size of nucleus, strong interaction

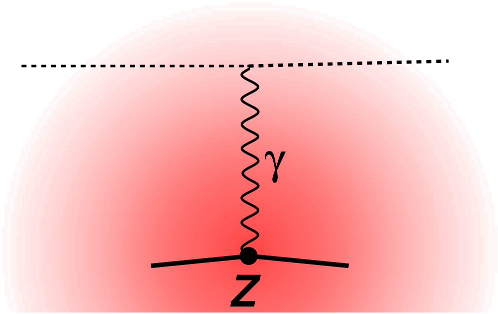
# High-*E* Reactions: Momentum Transfer Regimes




*EM* at higher order

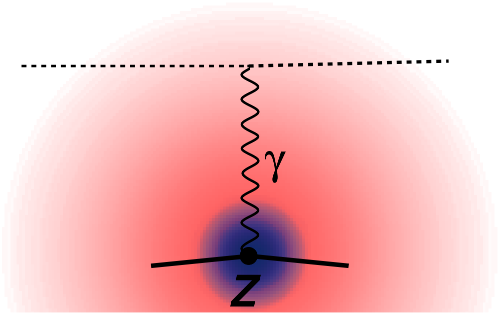
- corresponds to "multiple-photon exchange", but *e.g.* for lead $Z\alpha \approx 0.6$
- main effect (at low $Q^2$): distortion of the wave function in the potential, calculable in Glauber (eikonal) approach

# High-*E* Reactions: Momentum Transfer Regimes




- *EM* scattering becomes complex-valued, “Coulomb phase” ($\sim$ loops over resonance contributions)
- no observable effect for elastic scattering on static (heavy-mass) target

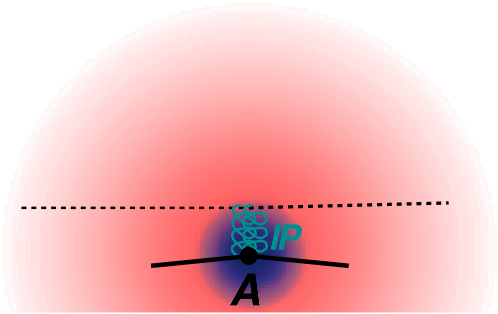
# High-$E$ Reactions: Momentum Transfer Regimes




Within the Glauber model

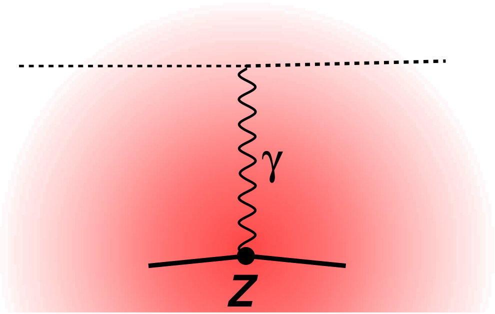
- also the charge extension (as modified potential) can be taken into account
- drawbacks: *e.g.* neglect of recoil, not QFT

# High-$E$ Reactions: Momentum Transfer Regimes




- at the same level, the (absorptive) nuclear potential can be taken into account $\rightarrow$ diffractive regime
- exchange "particle" (Pomeron) $\Leftrightarrow$ Fourier transform of potential

# High-$E$ Reactions: Momentum Transfer Regimes



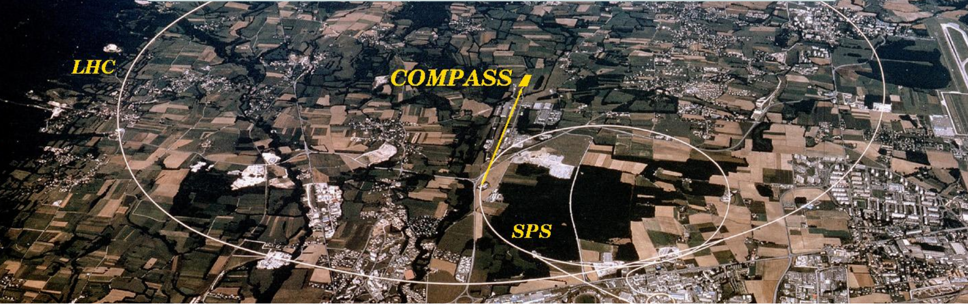

- with a high-energy pion beam on nuclei, $\pi\gamma$ reactions become accessible
- identification as a strong increase of cross-section at smallest $Q^2$, *Primakoff effect*

# COmmon Muon and Proton Apparatus for Structure and Spectroscopy

# COmmon Muon and Proton Apparatus for Structure and Spectroscopy

## CERN SPS: protons $\sim$ 400 GeV (5 – 10 sec spills)

- secondary $\pi$, $K$, $\overset{(-)}{p}$: up to $2{\cdot}10^7$ / s
  Nov. 2004, 2008-09, 2012:
  hadron spec. & Primakoff reactions
- tertiary muons: $4{\cdot}10^7$ / s
  2002-04, 2006-07, 2010-11: spin structure of the nucleon

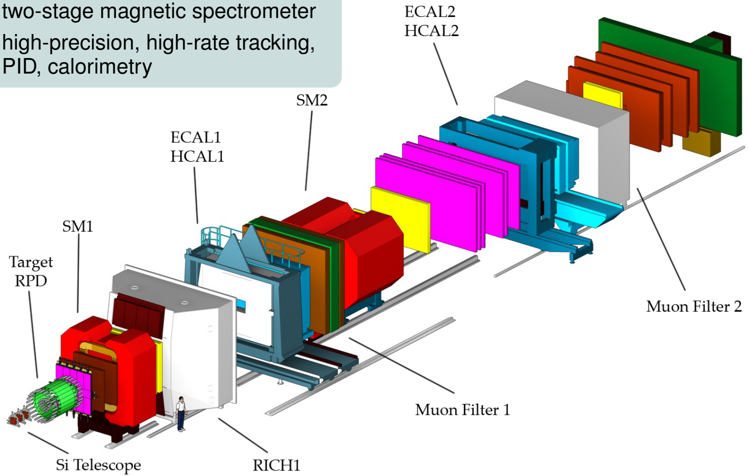


# COMPASS

## Experimental Setup

### Fixed-target experiment

- two-stage magnetic spectrometer
- high-precision, high-rate tracking, PID, calorimetry



# COMPASS

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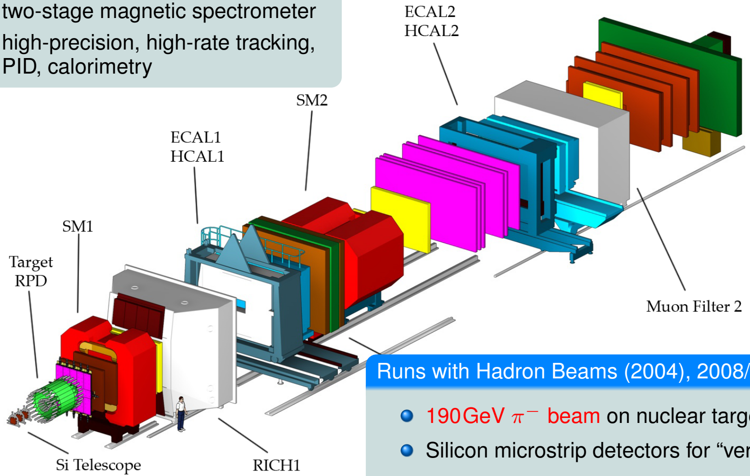
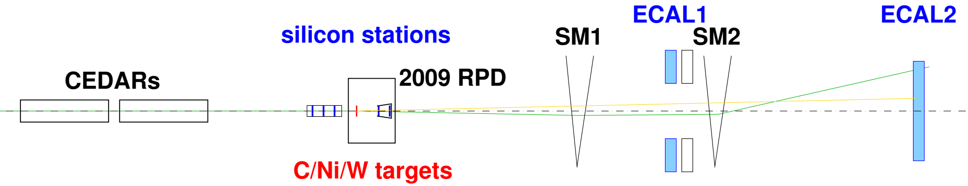



### Runs with Hadron Beams (2004), 2008/09, 2012

- 190GeV $\pi^-$ beam on nuclear targets (Ni, W)
- Silicon microstrip detectors for “vertexing”
- (digital) ECAL trigger

# Principle of the measurement




- Trigger on multiplicity of charged forward tracks or on energy deposit in EM calorimeter
- Kaon component of the beam identified in Cerenkov detectors
- Free decay of beam $K^-$ into $\pi^-\pi^0$, $\pi^-\pi^0\pi^0$ and $\pi^-\pi^-\pi^+$ allows for cross-section normalization

# Primakoff reactions accessible at COMPASS

Access to $\pi + \gamma$ reactions via the Primakoff effect:

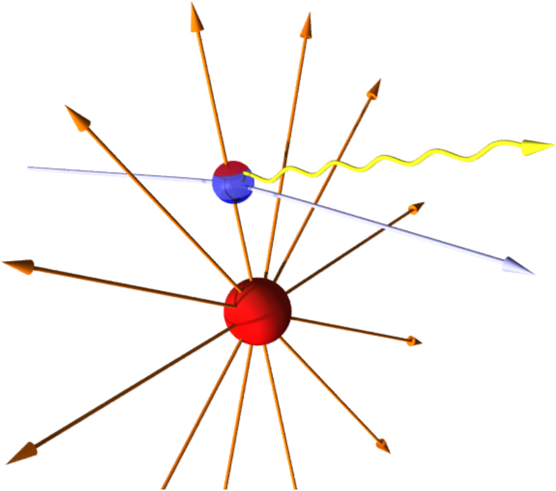
*At smallest momentum transfers* to the nucleus, high-energetic particles scatter predominantly off the electromagnetic field quanta ($\sim Z^2$)

$$\pi^- + \gamma \to \begin{cases} \pi^- + \gamma & \Longleftarrow \\ \pi^- + \pi^0 \; / \; \eta \\ \pi^- + \pi^0 + \pi^0 \\ \pi^- + \pi^- + \pi^+ \\ \pi^- + \pi^- + \pi^+ + \pi^- + \pi^+ \\ \pi^- + \ldots \end{cases}$$

*analogously: Kaon-induced reactions $K^- + \gamma \to \cdots$*

# Primakoff technique: pion polarisability

- Charged pion traversing the nuclear electric field
  - typical field strength at $r = 5R_{Ni}$: $E \sim 300$kV/fm
- Bremsstrahlung emission
  - particle scatters off *equivalent photons* (Weizsäcker-Williams)
  - pion (or muon) Compton scattering
- Polarisability contribution
  - Compton cross-section typically diminished
  - Theory prediction: $\alpha_\pi^{ChPT} = 2.9 \pm 0.5 \cdot 10^{-4}$ fm$^3$
  - expected charge separation $\sim 10^{-5}$fm $\cdot\, e$



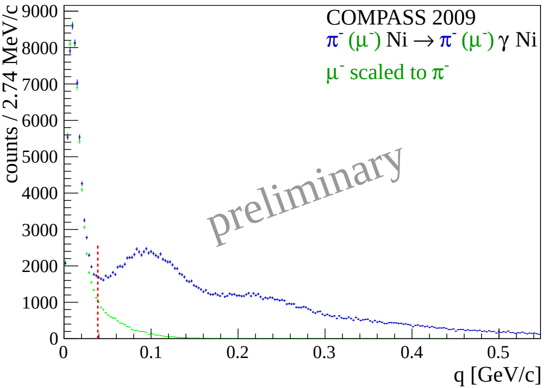
# Pion polarisability at COMPASS

| source of systematic uncertainty | estimated magnitude CL = 68 % $[10^{-4}\,\mathrm{fm}^3]$ |
|---|---|
| tracking | 0.6 |
| radiative corrections | 0.3 |
| background subtraction in $Q$ | 0.4 |
| pion electron scattering | 0.2 |
| quadratic sum | 0.8 |

COMPASS preliminary:

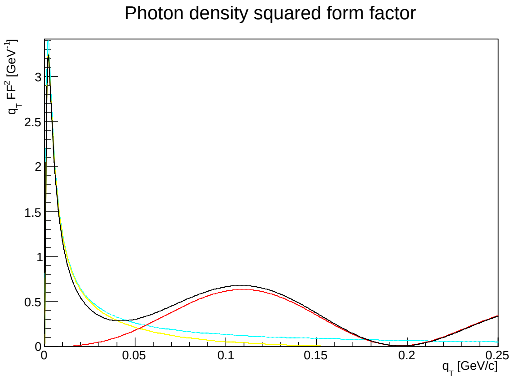
$$\alpha_\pi = \mathbf{1.9} \pm \mathbf{0.7}_{\text{stat}} \pm \mathbf{0.8}_{\text{syst}} \times \mathbf{10^{-4}}\,\mathrm{fm}^3$$

# Pion Compton Scattering: Primakoff peak




- $\Delta Q_T \approx 12$ MeV/c (190 GeV/c beam $\rightarrow$ requires few-$\mu$rad angular resolution)
- first diffractive minimum on Ni nucleus at $Q \approx 190$ MeV$/c$

# Coulomb-nuclear interference




- Calculation following a 2009 paper of Göran Fäldt (Uppsala)
- Eikonal approximation: pions cross Coulomb and strong-interaction potentials

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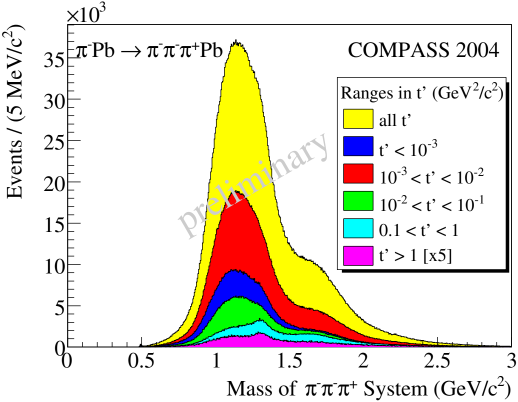
$$\pi^- + \gamma \rightarrow \begin{cases} \pi^- + \gamma \\ \pi^- + \pi^0 \;/\; \eta \\ \pi^- + \pi^0 + \pi^0 \\ \pi^- + \pi^- + \pi^+ \qquad \Longleftarrow \\ \pi^- + \pi^- + \pi^+ + \pi^- + \pi^+ \\ \pi^- + \ldots \end{cases}$$

*analogously: Kaon-induced reactions* $K^- + \gamma \rightarrow \cdots$

# Three charged-pions final state

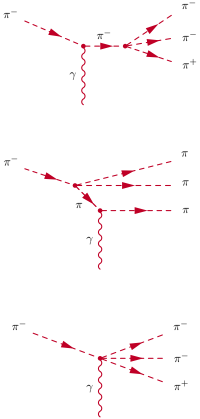
$\pi^-$ Pb $\rightarrow$ Pb $\pi^-$ $\pi^-$ $\pi^+$

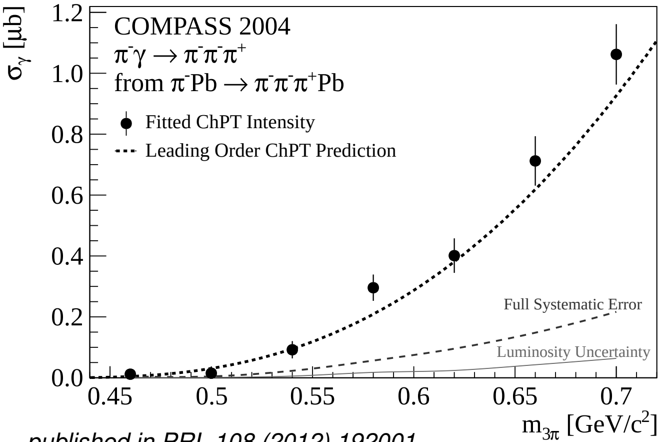



- "Low $t'$": $10^{-3}\,(\mathrm{GeV}/c)^2 < t' < 10^{-2}\,(\mathrm{GeV}/c)^2$ $\sim$ 2000000 events
- "Primakoff region": $t' < 10^{-3}\,(\mathrm{GeV}/c)^2$ $\sim$ 1000000 events

# First Measurement of $\pi\gamma \to 3\pi$ Absolute Cross-Section

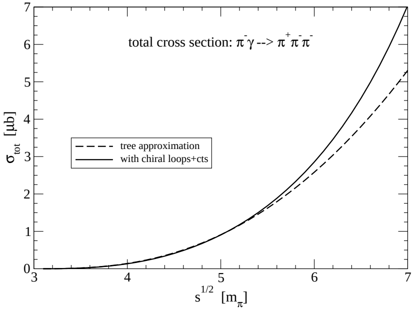
Measured absolute cross-section of $\pi^-\gamma \to \pi^-\pi^-\pi^+$

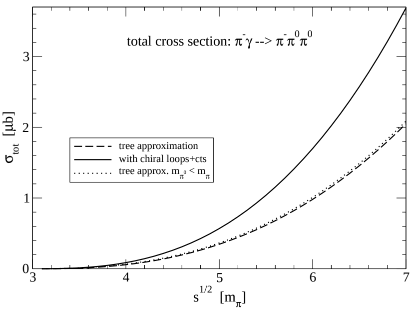



*published in PRL 108 (2012) 192001*

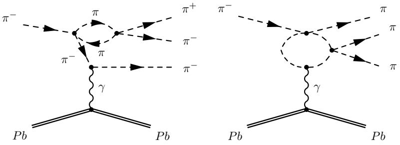
# Higher-order effects



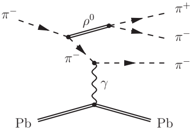




Chiral loops, e.g.

(N. Kaiser, NPA848 (2010) 198)

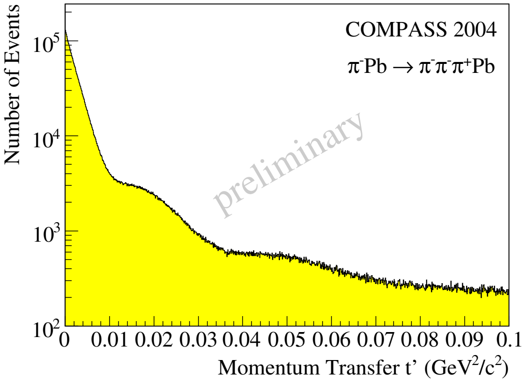



not (yet) included:



# 2004 Primakoff results on the resonances

$\pi^-$ Pb $\to$ Pb $\pi^-$ $\pi^-$ $\pi^+$

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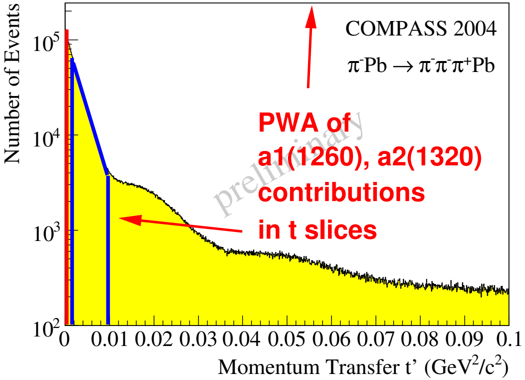
$$\pi^- \text{ Pb} \to \text{Pb}\, \pi^- \, \pi^- \, \pi^+$$

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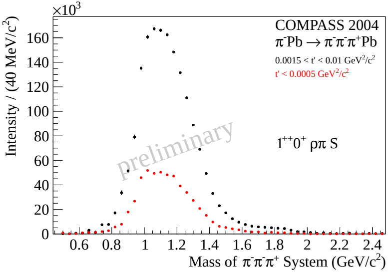
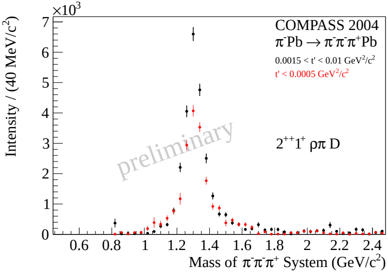
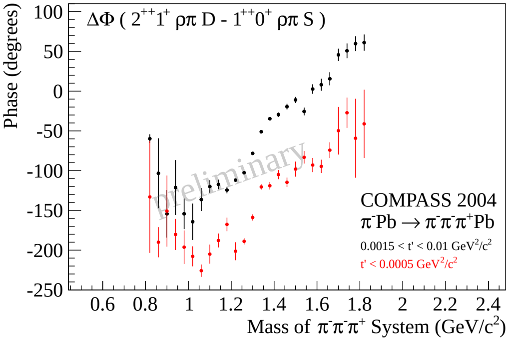
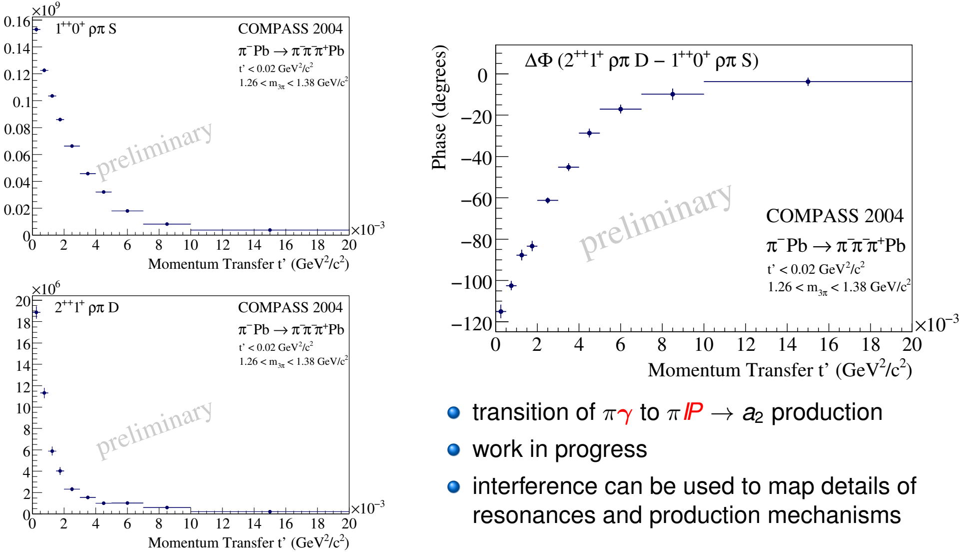
# PWA: $a_1$, $a_2$ and $\Delta\Phi$ in separated $t'$ regions



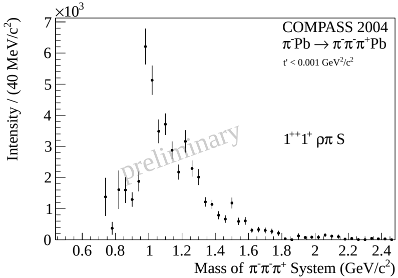



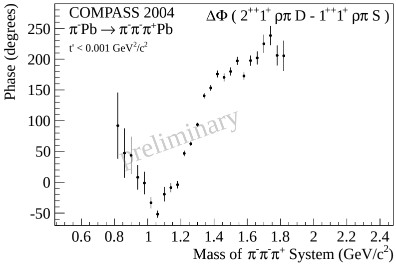
# Phase $a_2 - a_1$ in detail: $t'$ dependence

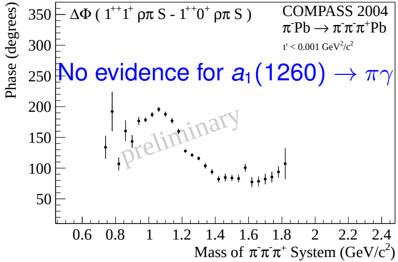



- transition of $\pi\gamma$ to $\pi I\!P \rightarrow a_2$ production
- work in progress
- interference can be used to map details of resonances and production mechanisms

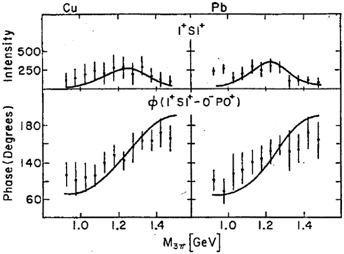
# Primakoff production of a1(1260) vs. E272 result



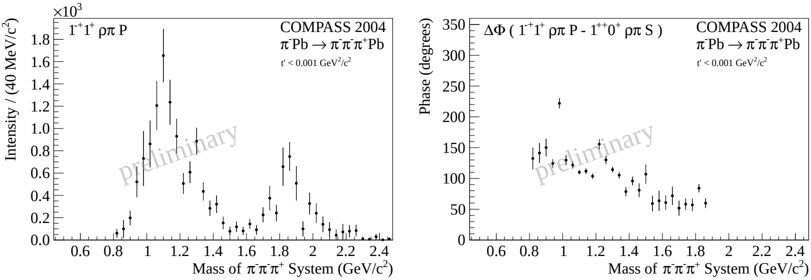




No evidence for $a_1(1260) \to \pi\gamma$



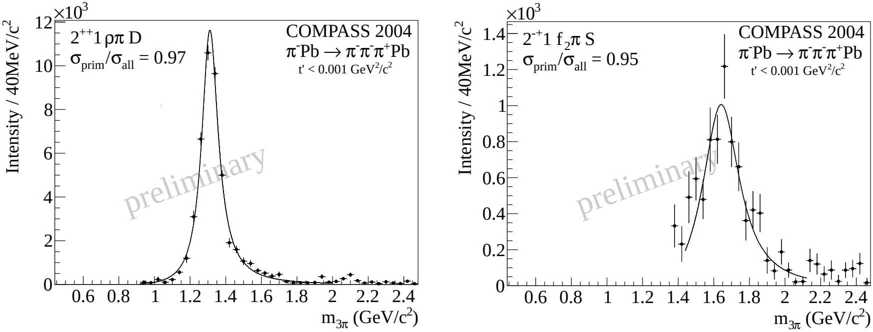

M. Zielinski et al, Phys.Rev.Lett.vol.52, 14, 1195

# Spin-exotic $1^{-+}$




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

# Radiative Coupling of $a_2(1320)$ and $\pi_2(1670)$



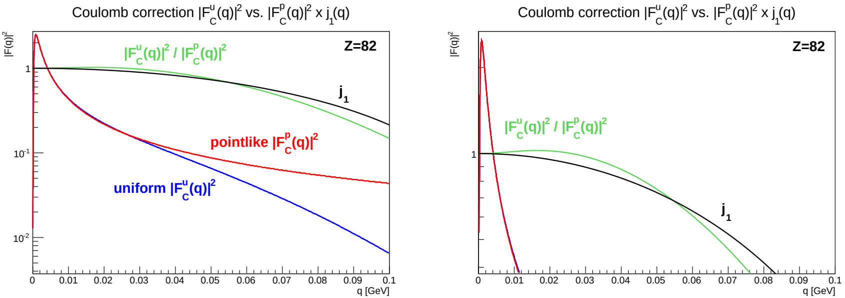

$\Gamma_0(a_2(1320) \to \pi\gamma)$ *M2*

$\Gamma_0(\pi_2(1670) \to \pi\gamma)$ *E2*

$\Leftrightarrow$ meson w.f.'s: $\Gamma_{i\to f} \propto |\langle\Psi_f|\, e^{-i\vec{q}\cdot\vec{r}}\,\hat{\epsilon}\cdot\vec{p}\,|\Psi_i\rangle|^2$, VMD

- normalization via beam kaon decays
- large Coulomb correction

# Coulomb and extended-charge correction




Calculations: G. Faeldt *et al.*,
PhysRevC.79.014607 (2009), 82.037603 (2010), 87.029903 (2013)

| | | |
|---|---|---|
| Effect on $a_2(1320)$ radiative width: | form factor alone | +6.5% |
| | Coulomb correction alone | +26.0% |
| | combined | +22.2% |

# Radiative widths - experiment and theory

| | $a_2(1320)$ | $\pi_2(1670)$ |
|---|---|---|
| COMPASS *preliminary* | $(358 \pm 6 \pm 42)$ keV | $(181 \pm 11 \pm 27)$ keV $\cdot \frac{0.56}{\mathrm{BR}_{f_2\pi}}$ |
| COMPASS $F_{\mathrm{eff}}^2 = j_1^2$ *prel.* | $(312 \pm 6)$ keV | $(151 \pm 9)$ keV $\cdot \frac{0.56}{\mathrm{BR}_{f_2\pi}}$ |
| SELEX[1] | $(284 \pm 25 \pm 25)$ keV | |
| S. Cihangir *et al.*[2] | $(295 \pm 60)$ keV | |
| E. N. May *et al.*[3] | $(460 \pm 110)$ keV | |
| VMD model[4] | $(375 \pm 50)$ keV | |
| Relativ. Quark model[5] | 324 keV | |
| Cov. Osc. Quark model[6] | 235 keV | |
| Cov. Osc. Quark model[7] | 237 keV | 335 keV / 521 keV |

[1] V. V. Molchanov et al., Phys. Lett. B 521, (2001) 171-180.
[2] S. Cihangir et al., Phys. Lett. 117 B, (1982) 119-122.
[3] E. N. May et al., Phys, Rev. D 16, (1977) 1983-1985.
[4] J. L. Rosner, Phys. Rev. D 23, (1981) 1127.
[5] I. G. Aznauryan and K. A. Oganesyan, Sov. J. Nucl. Phys. 47, (1988) 1097.
[6] S. Ishida, K. Yamada, and M. Oda, Phys. Rev. D 40, (1989) 1497-1512.
[7] T. Maeda, K. Yamada, M. Oda, and S. Ishada, to be published in Prog. Theor. Exp. Phys, arXiv:1013.7507 [hep-ph].

# Summary and Outlook

- Measurement of the pion polarisability at COMPASS
  - Most precise experimental determination
  - Systematic control: $\mu\gamma \to \mu\gamma$, $K^- \to \pi^-\pi^0$
- Chiral dynamics in $\pi\gamma \to \pi\pi\pi$ reactions
  - Charged-channel $\pi\gamma \to \pi^-\pi^-\pi^+$ tree-level ChPT prediction confirmed,
  - Neutral-channel $\pi\gamma \to \pi^-\pi^0\pi^0$ analysis ongoing
- Radiative coupling of meson resonances
  - Radiative width for $a_2(1320)$ roughly in agreement with earlier experimental determinations
  - First measurement of the radiative width for $\pi_2(1320)$, order of magnitude as expected from theoretical models
  - no significant radiative coupling for $a_1(1260)$ or $\pi_1(1600)$
- Future
  - analysis of 2009 data for $\pi^-\pi^0\pi^0$
  - investigation of Coulomb-nuclear interference
  - COMPASS 2012 run with high statistics for neutral channels: separate determination of $\alpha_\pi$ and $\beta_\pi$, quadrupole polarisabilities, measurement of $\alpha_K$