Meson Production from Diffractive Pion Dissociation at COMPASS *

Quirin Weitzel for the COMPASS Collaboration

Physik-Department E18
Technische Universität München

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Bundesministerium
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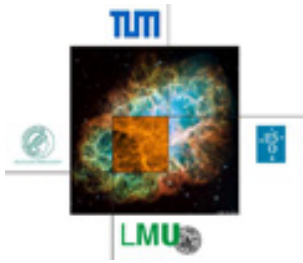

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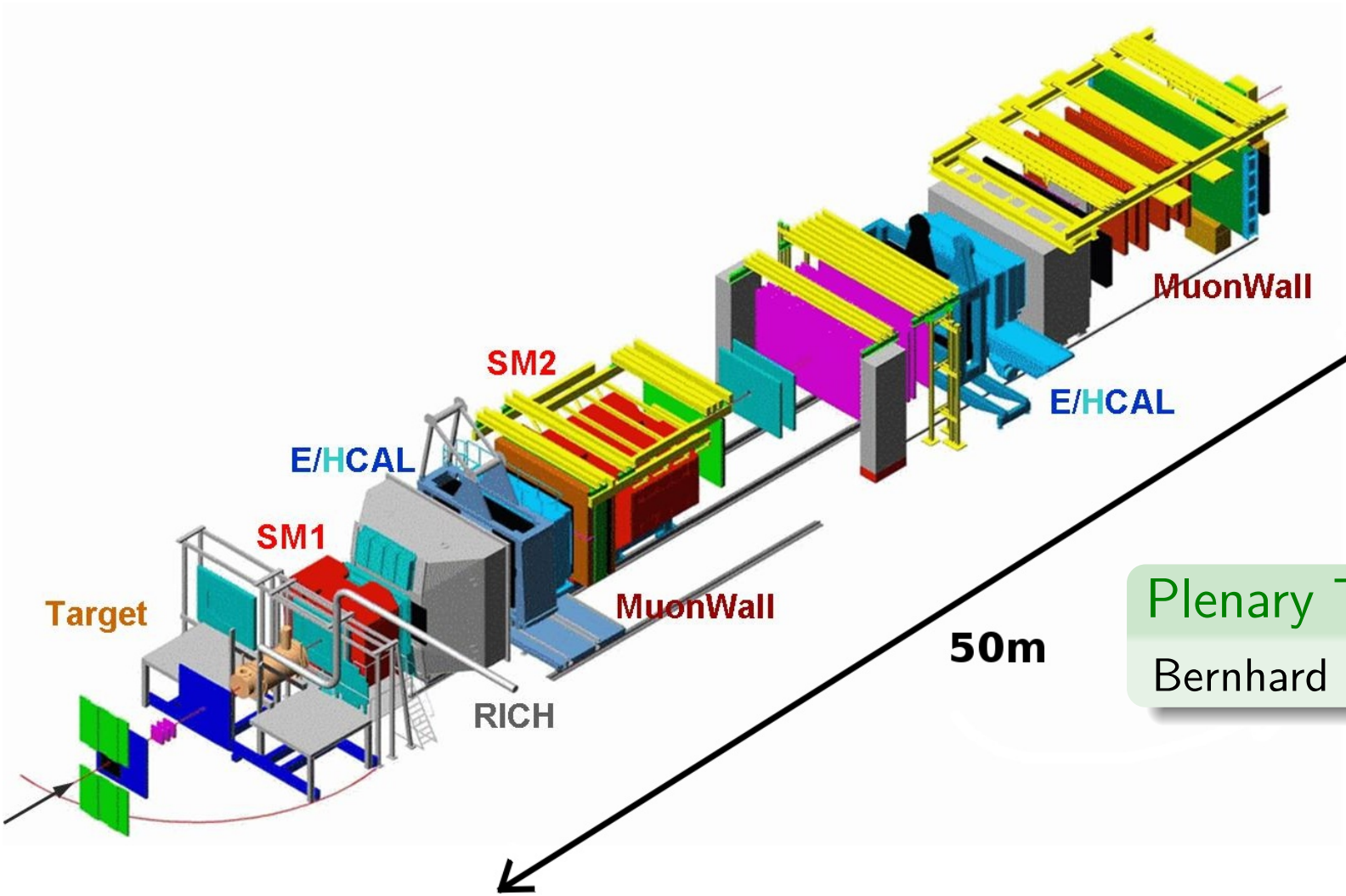
The COMPASS Experiment at CERN



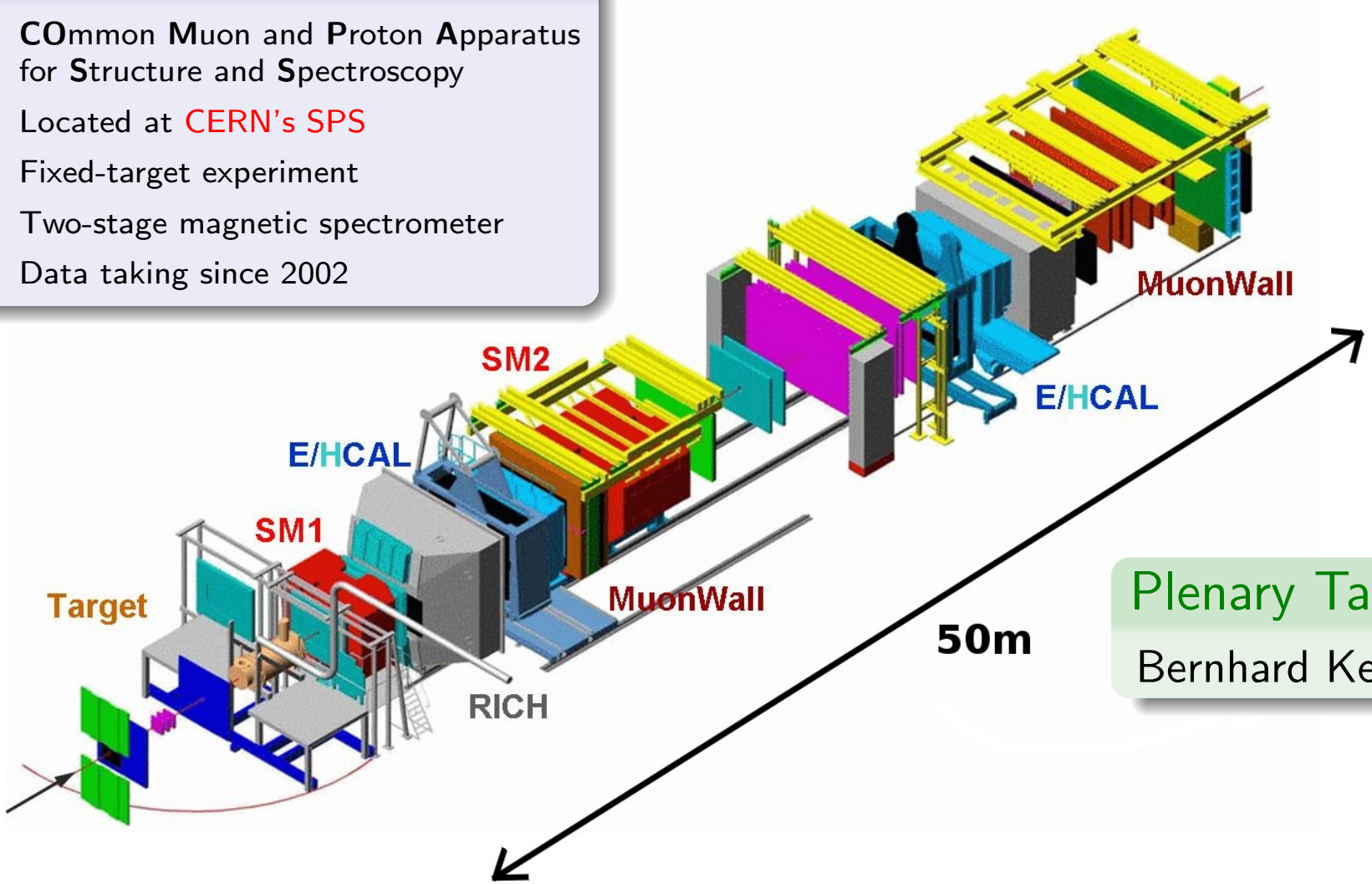
Plenary Talk

Bernhard Ketzer

The COMPASS Experiment at CERN

Overview

- **CO**mmon **M**uon and **P**roton **A**pparatus for **S**tructure and **S**pectroscopy
- Located at CERN's SPS
- Fixed-target experiment
- Two-stage magnetic spectrometer
- Data taking since 2002



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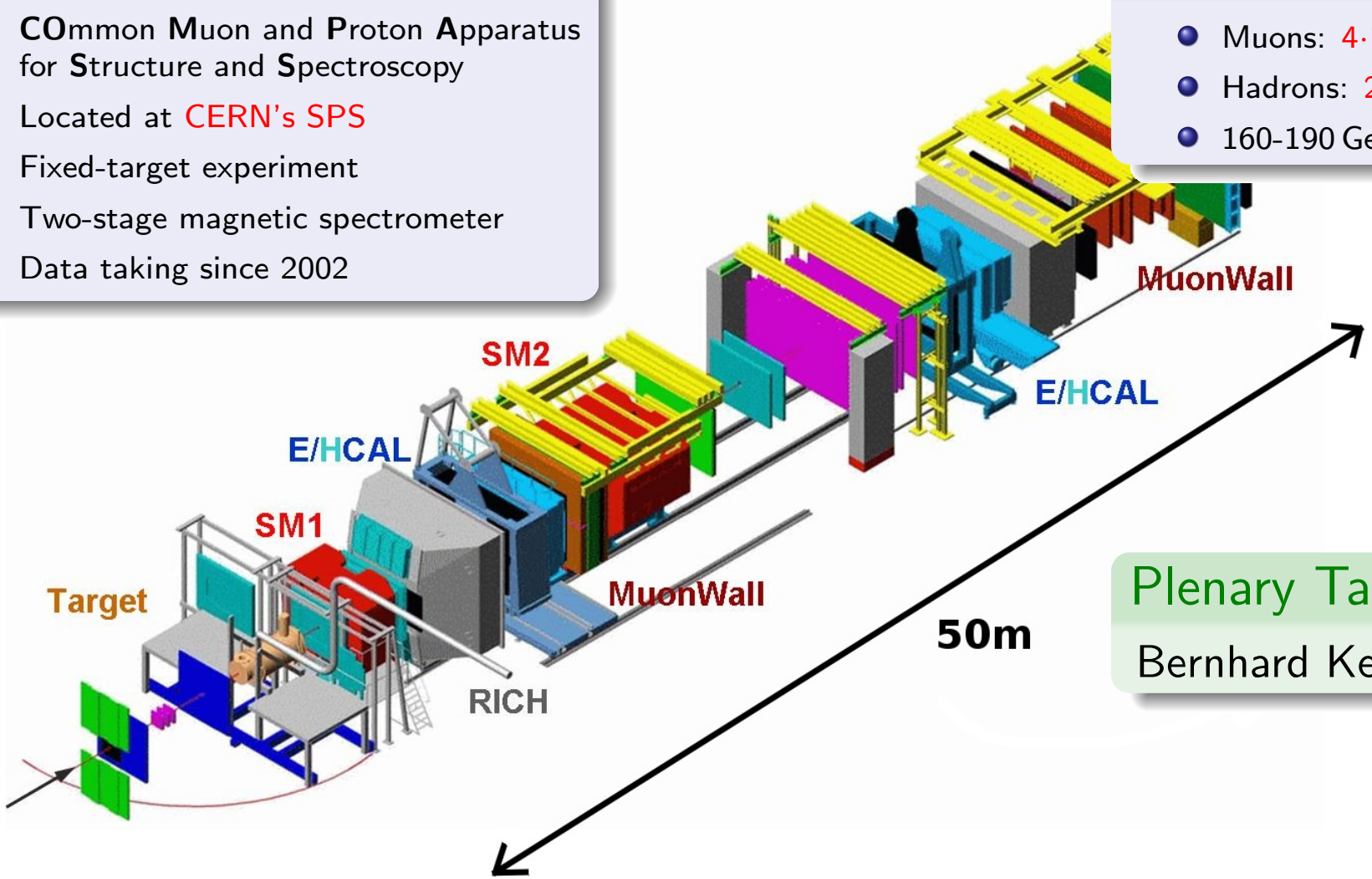
2 Types of Beam

- Muons: $4 \cdot 10^7 s^{-1}$
- Hadrons: $2 \cdot 10^7 s^{-1}$
- 160-190 GeV



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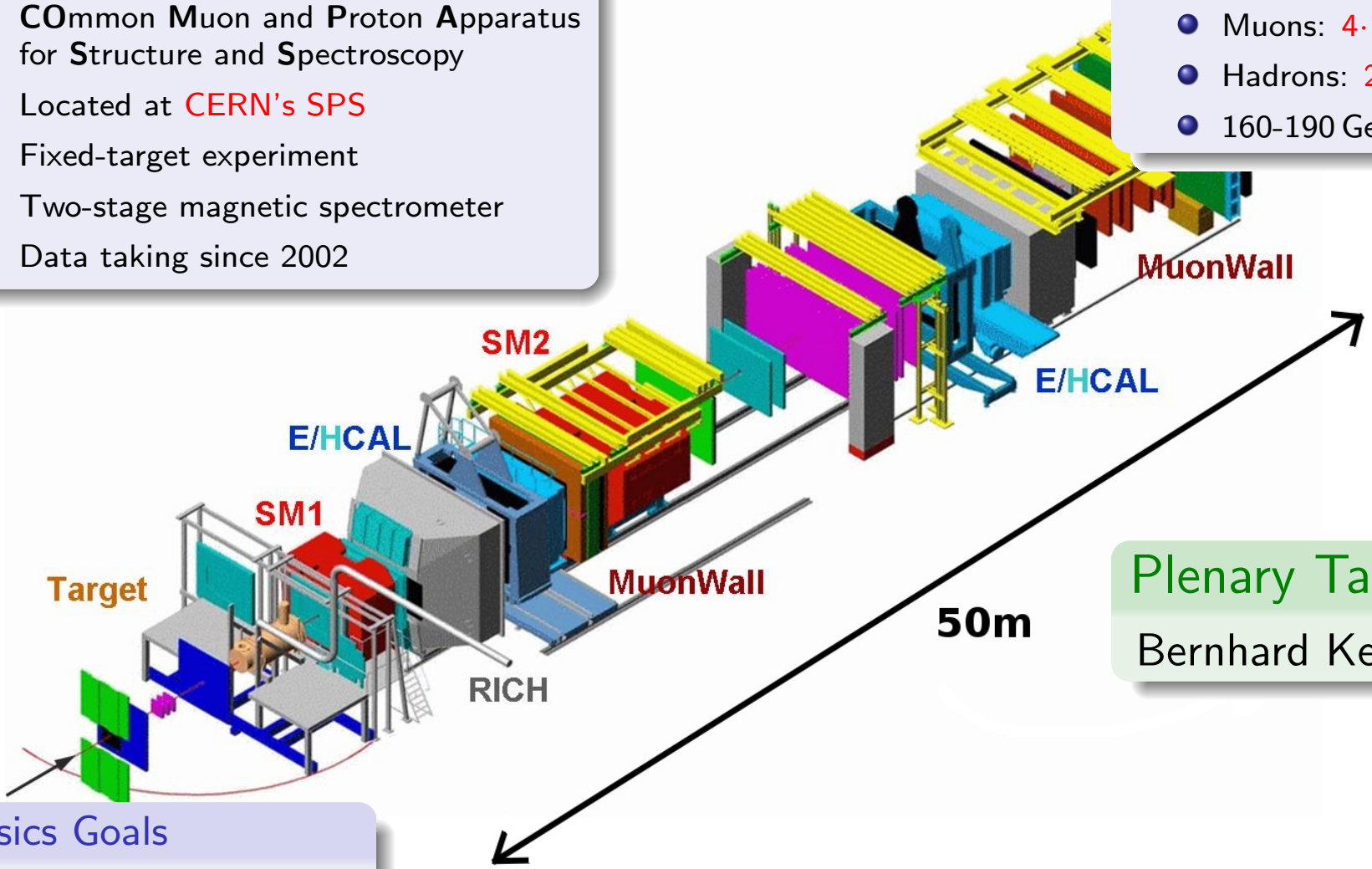

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Physics Goals

- Nucleon spin structure
- Hadron spectroscopy

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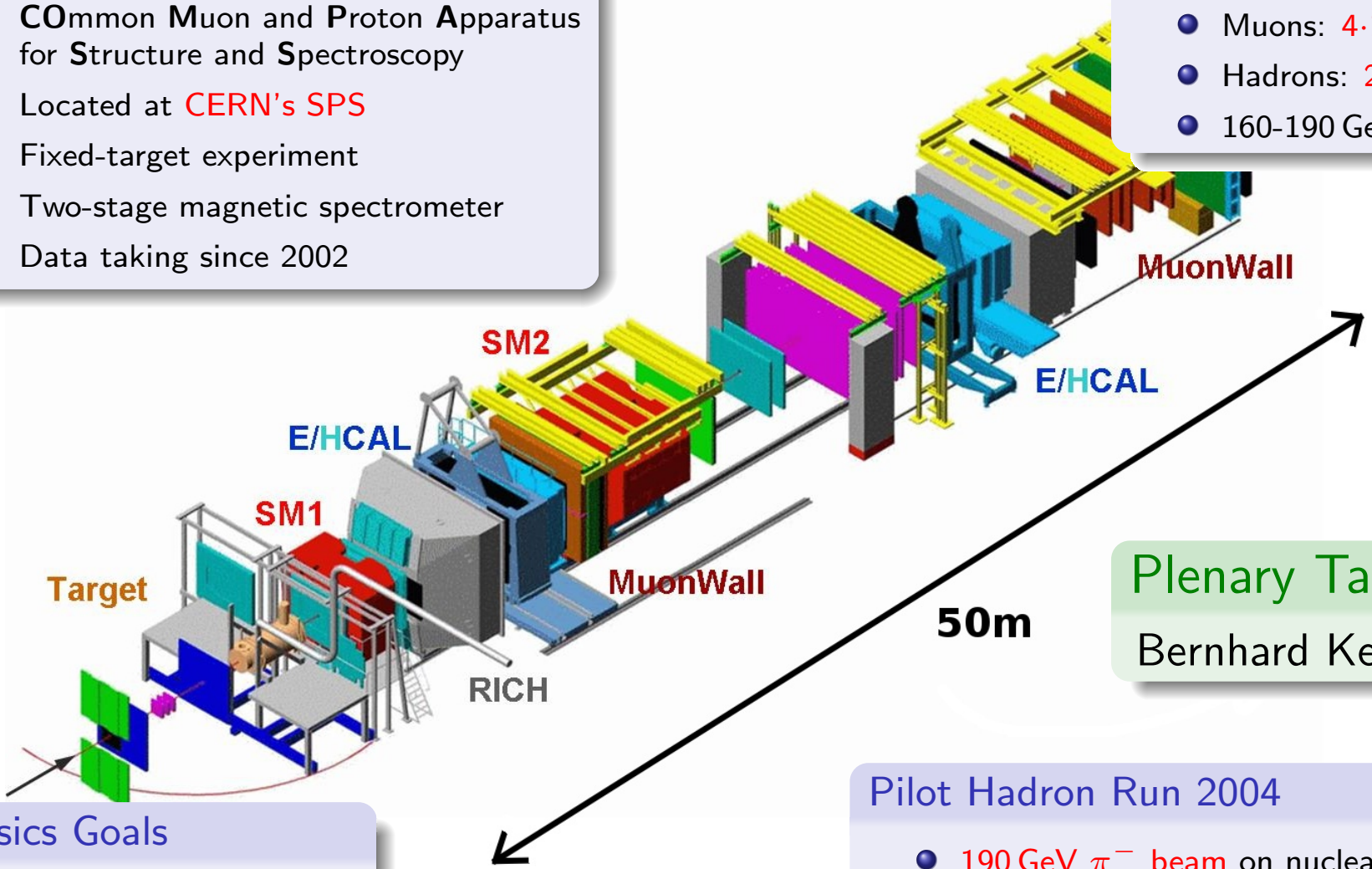

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Pilot Hadron Run 2004

- 190 GeV π^- beam on nuclear targets
- Tracking: Silicons, SciFis, GEMs, MicroMegas, MWPCs, Drift Chambers

Diffractive Dissociation from Pion Beams

Meson Spectroscopy and Search for Exotic States (non-$q\bar{q}$)

- Diffractive pion dissociation produces rich meson spectrum
- Evidences for spin-exotic $\pi_1(1600)$ state with $J^{PC} = 1^{-+}$ in $\pi^-\pi^-\pi^+$ data

  [BNL-E852, Phys. Rev. **D65**, 072001, 2002], [VES, Nucl. Phys. **A663**, 596, 2000]

controversial situation!

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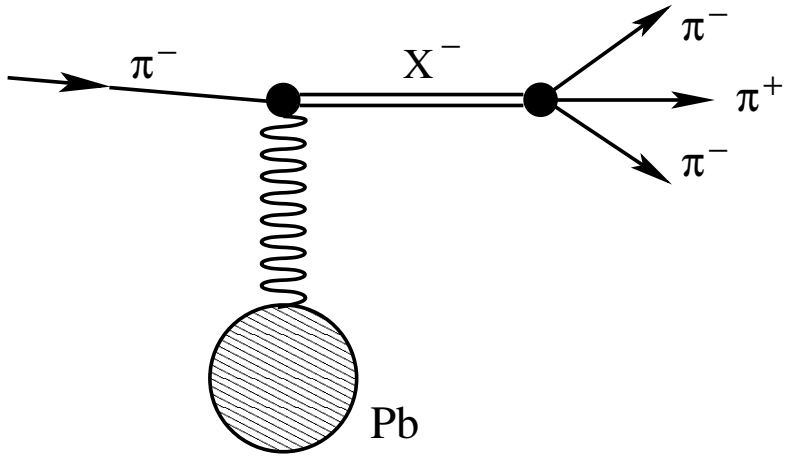
- Diffraction: incident particle only grazes the target, which remains intact
  $\Rightarrow$ strong interaction
- Dissociation: beam pion is excited to some resonance X^-, which further decays
  $\Rightarrow$ e. g. $\pi^-\mathrm{Pb} \Rightarrow X^-\mathrm{Pb} \Rightarrow \pi^-\pi^-\pi^+\mathrm{Pb}$



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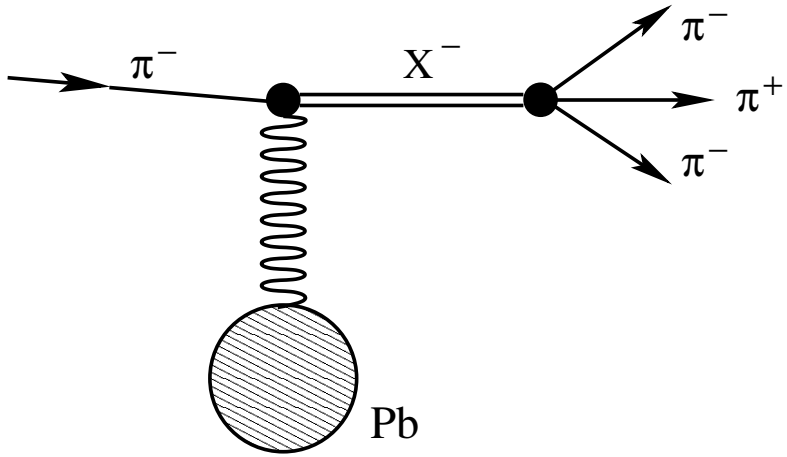
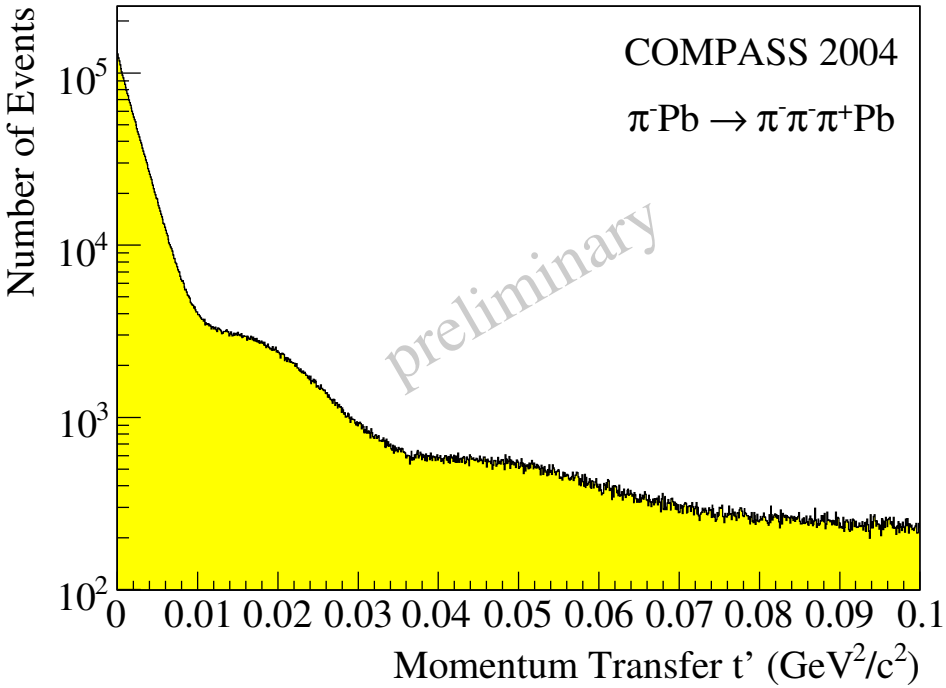


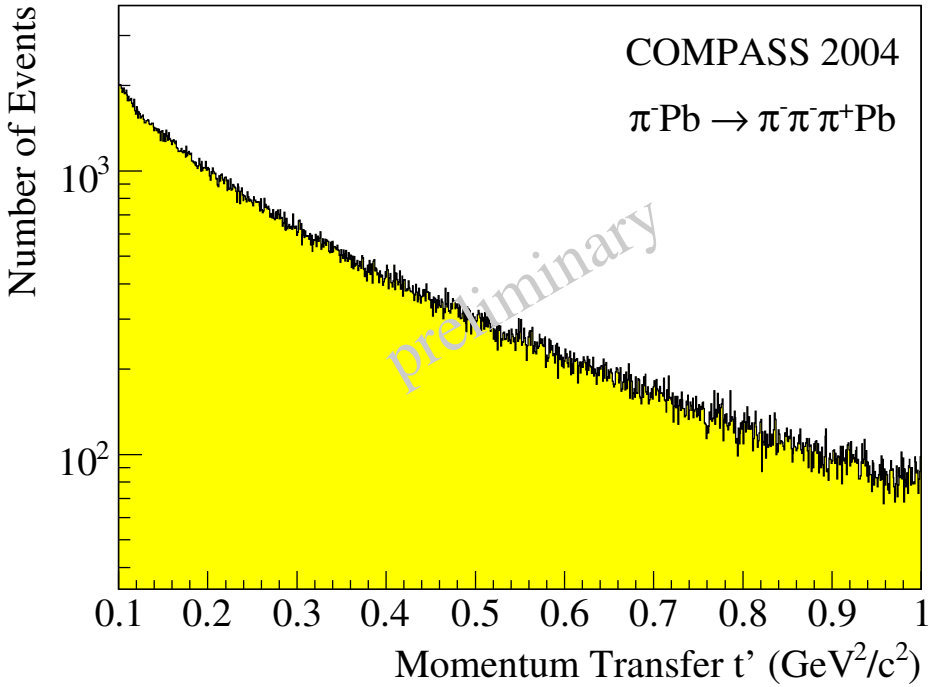
- Selection: primary vertex in target, 3 outgoing part. $(--+)$, exclusivity
- COMPASS 2004: $\sim 4\,000\,000$ 3π events on Pb (few days of running), $\sim 400\,000$ events with $0.1 < t' < 1.0$ GeV$^2/c^2$

Momentum Transfer Distributions

Momentum transfer from target: $-t = -(p_{\text{beam}} - p_{(\pi^-\pi^-\pi^+)})^2$

$\Rightarrow t' = |t| - |t|_{min}$



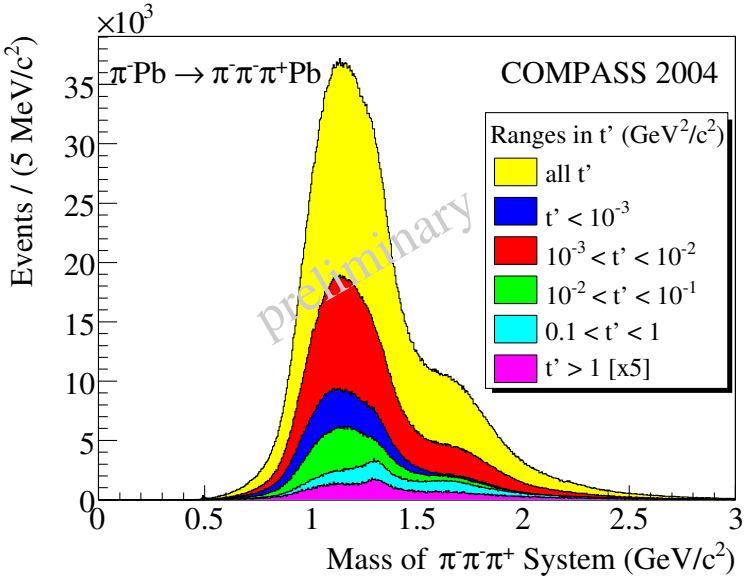


Diffraction pattern: Pb nucleus acts like "black disc" in optics

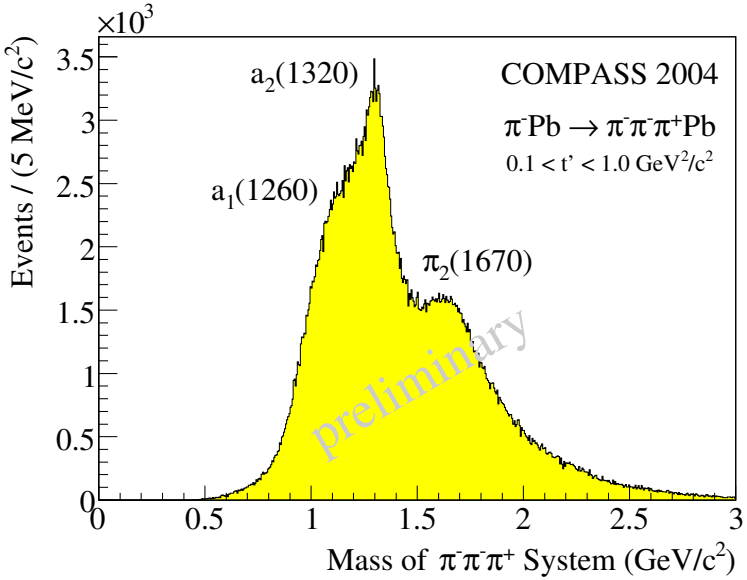
High-t': scattering on single nucleons inside Pb nucleus

$\pi^-\pi^-\pi^+$ Mass Distributions and Acceptance

Invariant mass for different t'



High-t' Spectrum



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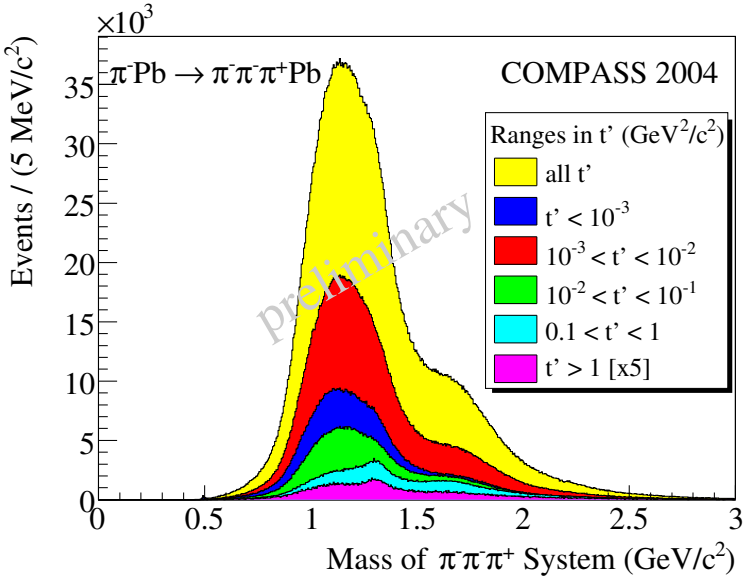

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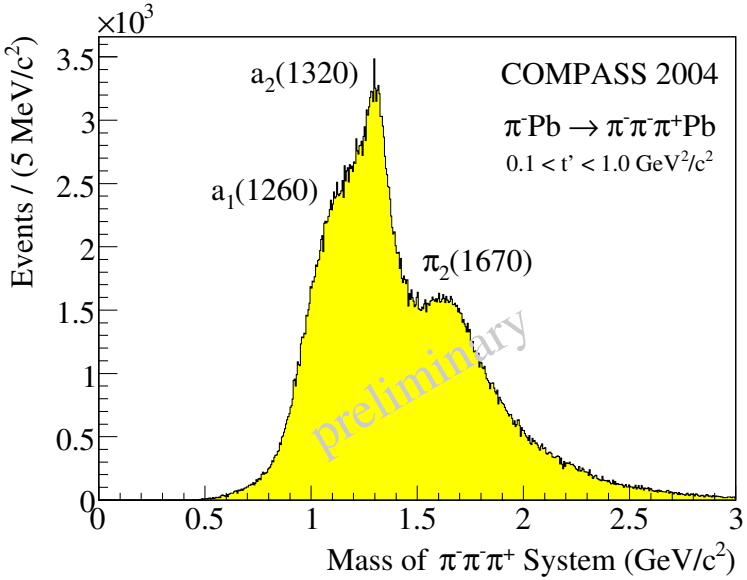
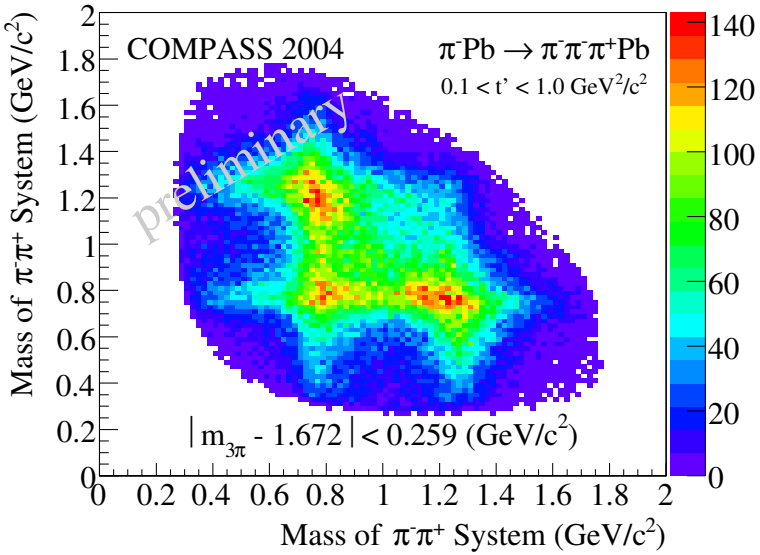
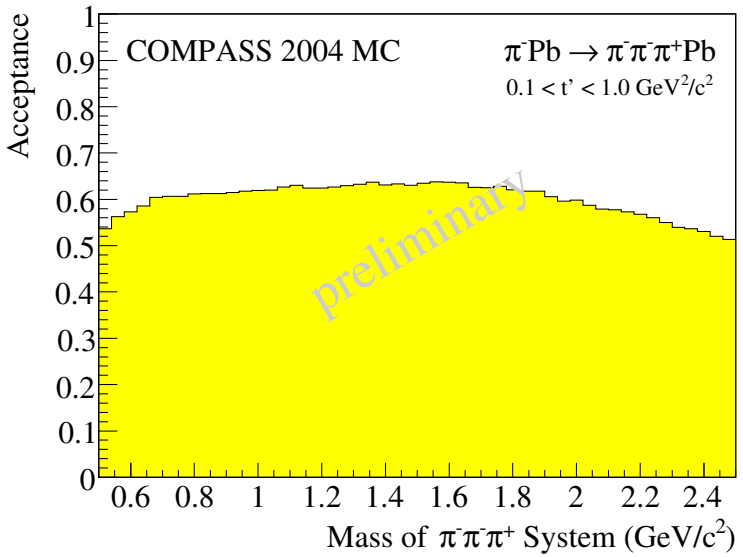


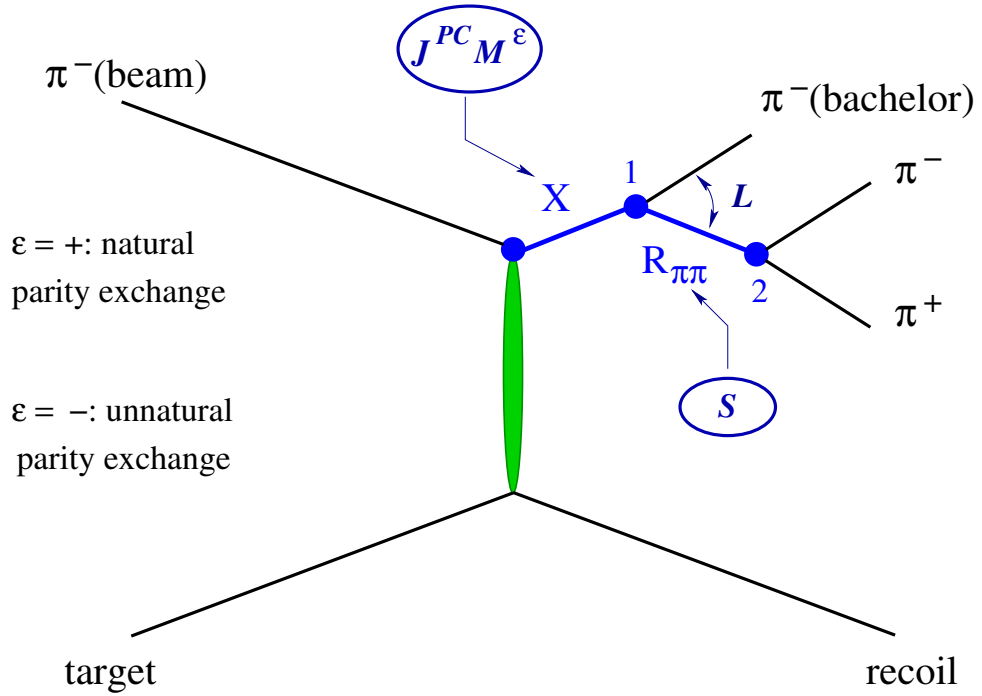
Dalitz plot for $\pi_2(1670)$ region



Flat acceptance: 55-60%



Overview of Partial Wave Analysis (high-t')



- Isobar model assumed
- Zemach formalism, reflectivity basis
- Reggeon exchange
- Partial wave: $J^{PC}\,M^{\epsilon}[isobar]L$
- Nucleon target $\Rightarrow$ rank 2

- Program: Illinois $\rightarrow$ Dubna $\rightarrow$ Protvino (D. Ryabchikov, VES/COMPASS)
- Mass-independent PWA ($40\,\mathrm{MeV}/c^2$ mass bins): 42 waves
  - Extended log-likelihood method (Ascoli/Kachaev fitter)
  - Acceptance corrections included
  - $\rho(770)$, $f_2(1270)$, $\rho_3(1690)$ from PDG, $(\pi\pi)_s$ with separated $f_0(980)$ from VES
  - Multiple solutions ($\Delta \ln L \leq 1$) added as additional error
- Mass-dependent χ^2-fit: 7 waves
  - X parameterized by Breit-Wigner (BW) functions
  - Coherent background added for some waves: $\exp(-\alpha p^2)$

Partial Wave Set for Mass-Indep. Fit (42 Waves)

$J^{PC}M^{\epsilon}$	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			

Partial Waves used in Mass-Dep. Fit (7 Waves)

$J^{PC}M^{\epsilon}$	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
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$1^{++}1^{+}$	P	$(\pi\pi)_s\pi$	1.40
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$2^{-+}1^{+}$	D	$f_2\pi$	1.50
$2^{-+}1^{+}$	D	$(\pi\pi)_s\pi$	1.20
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$2^{++}1^{+}$	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
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$2^{++}0^{-}$	D	$\rho\pi$	-
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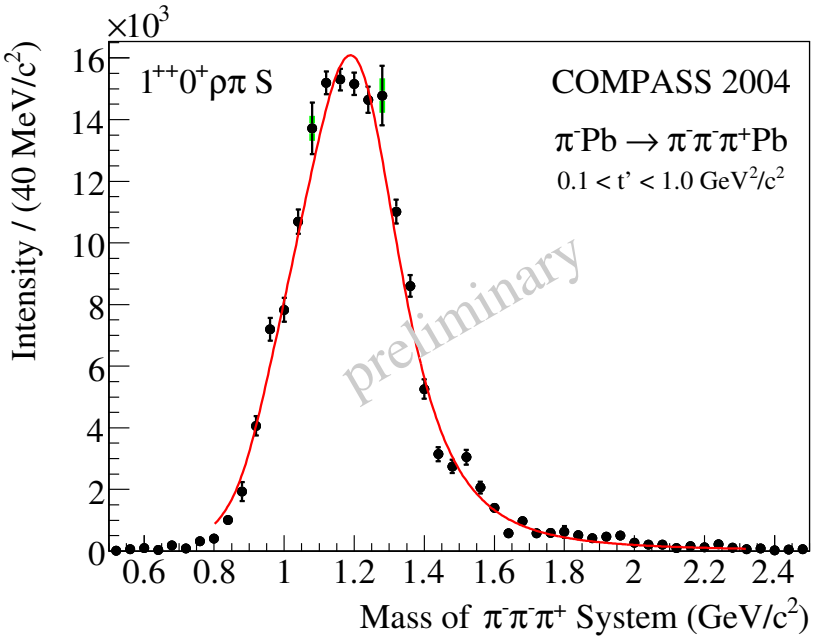
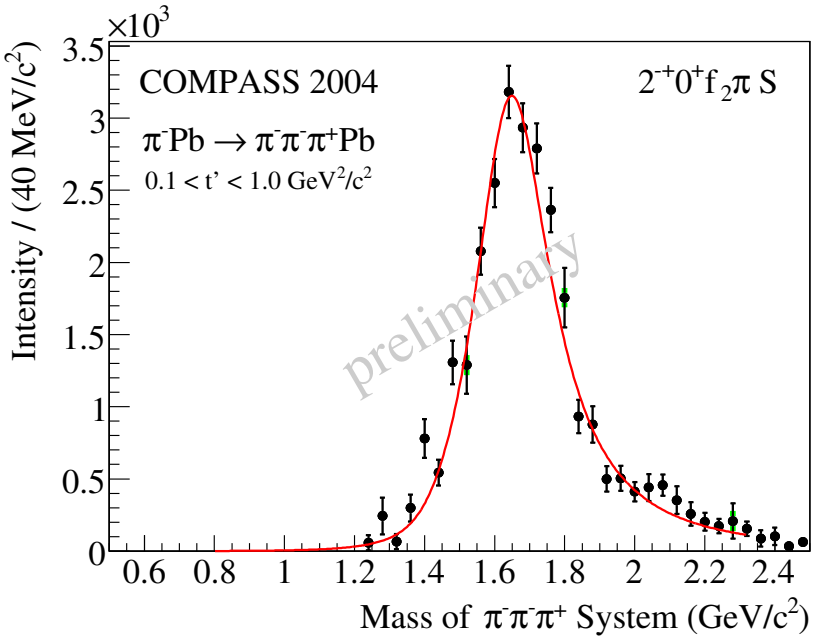
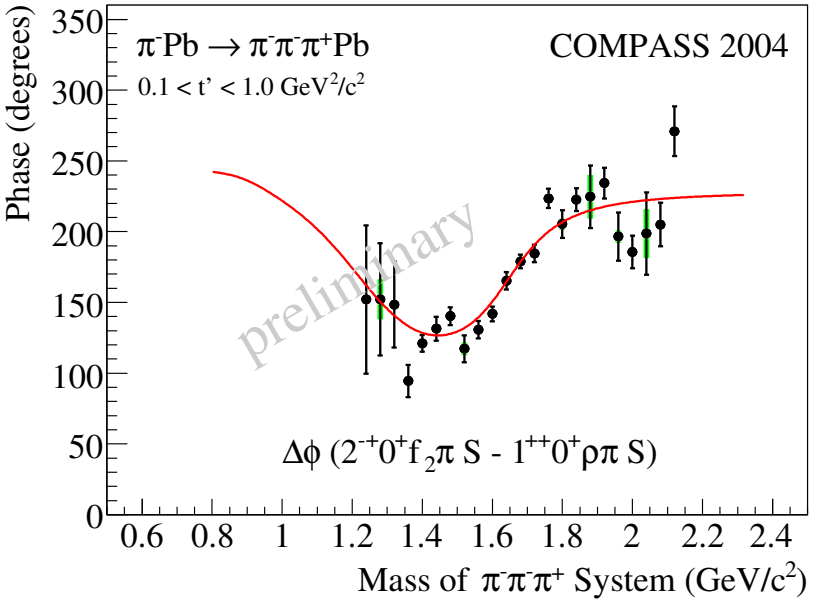
FLAT			

$1^{++}0^+\rho\pi S$ and $2^{-+}0^+f_2\pi S$







- BW for $a_1(1260)$ + background:

  $M = (1.256 \pm 0.006\ ^{+0.007}_{-0.017})$ GeV

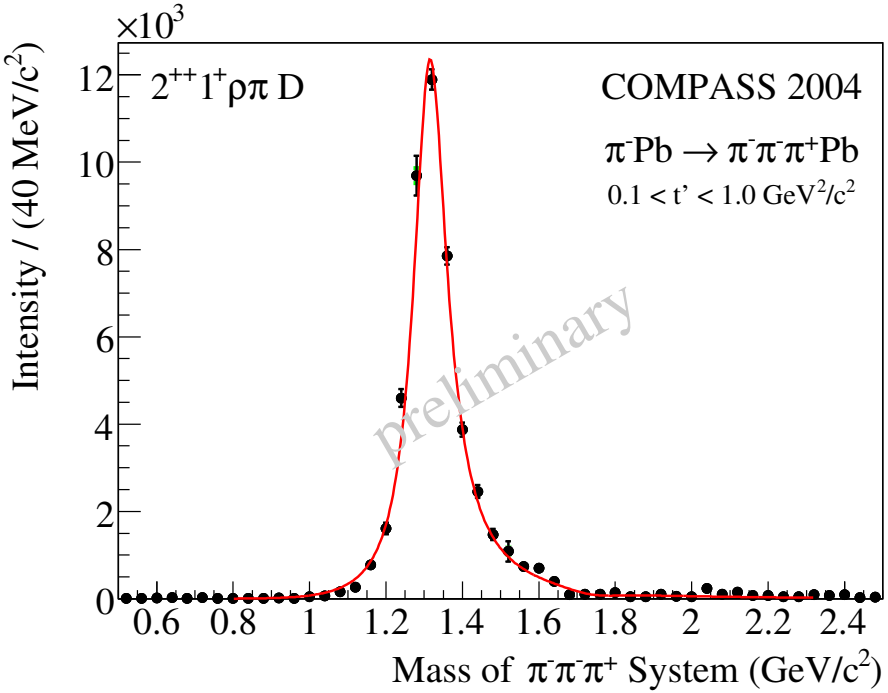
  $\Gamma = (0.366 \pm 0.009\ ^{+0.028}_{-0.025})$ GeV

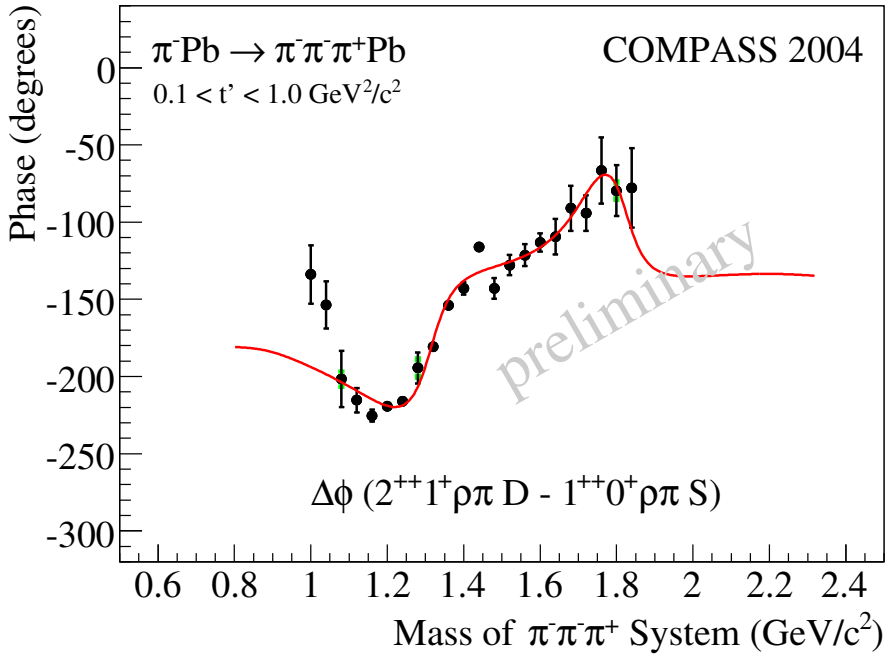
- BW for $\pi_2(1670)$:

  $M = (1.659 \pm 0.003\ ^{+0.024}_{-0.008})$ GeV

  $\Gamma = (0.271 \pm 0.009\ ^{+0.022}_{-0.024})$ GeV

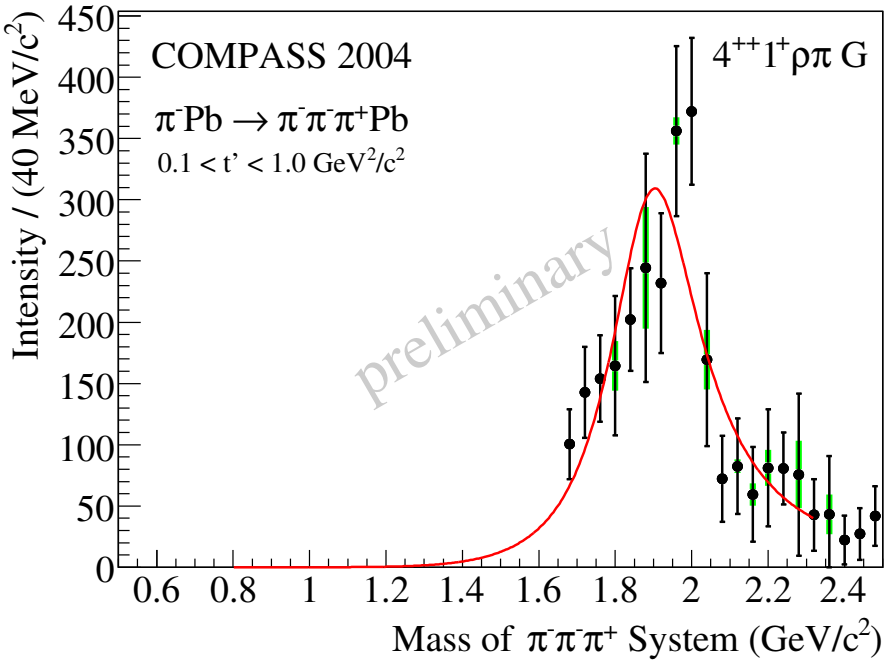
$2^{++}1^{+}\rho\pi D$

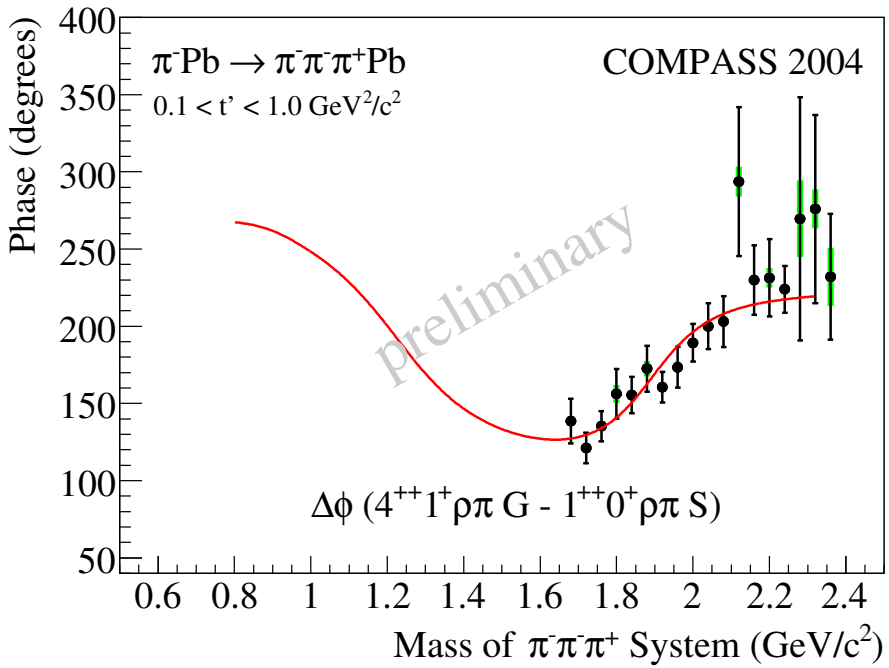




- Two Breit-Wigners needed to describe $2^{++}1^{+}\rho\pi D$ phase motion:
  BW1 for $a_2(1320)$ + BW2 for $a_2(1700)$
- $M = (1.321 \pm 0.001\ ^{+0.000}_{-0.007})\,\text{GeV}, \qquad \Gamma = (0.110 \pm 0.002\ ^{+0.002}_{-0.015})\,\text{GeV}$
- $a_2(1700)$ parameters fixed to PDG values: $M = 1.732\,\text{GeV}, \quad \Gamma = 0.194\,\text{GeV}$

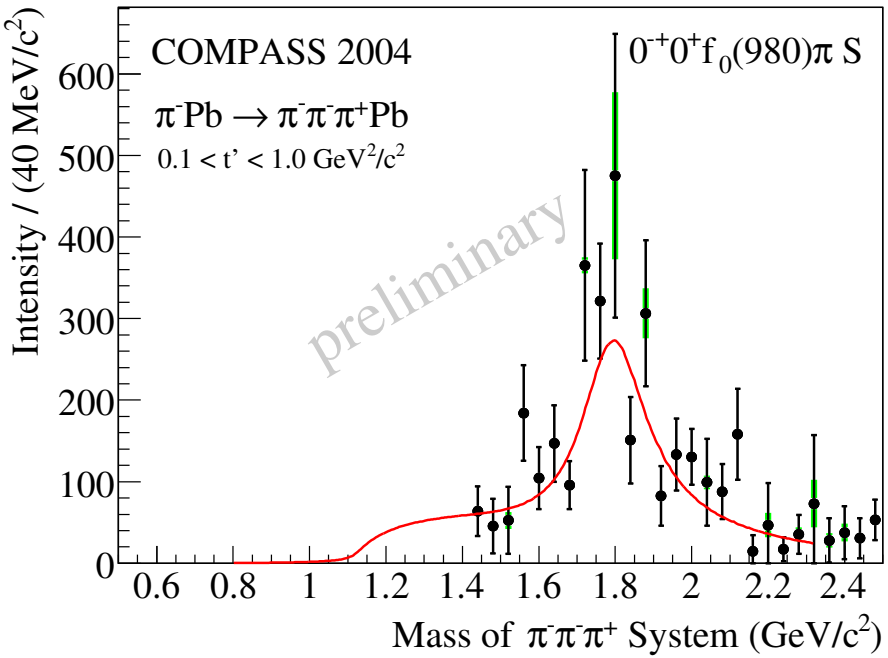
$4^{++}1^{+}\rho\pi\, G$

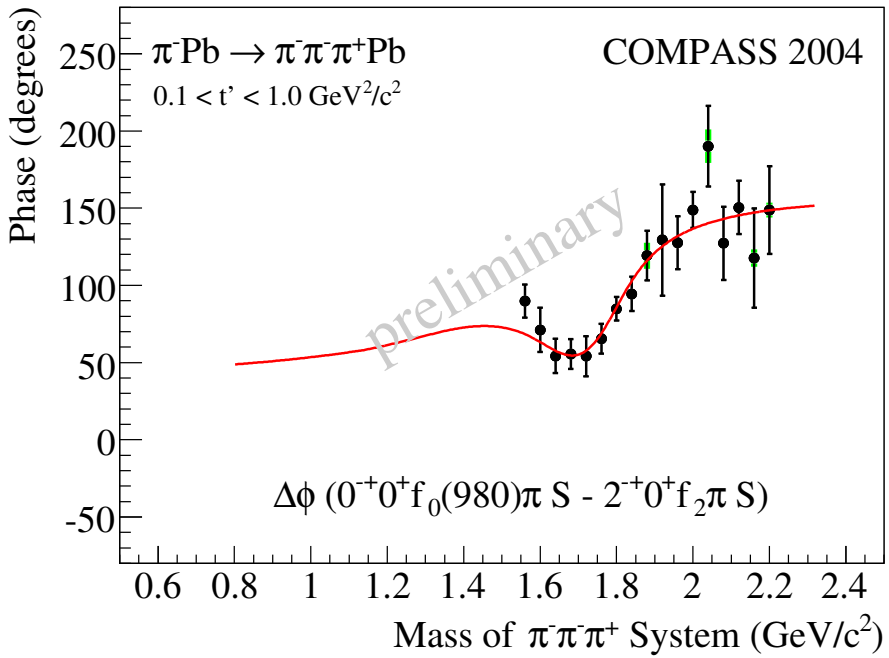




- Constant width Breit-Wigner used for $a_4(2040)$ (no branching ratios known)
- $M = (1.884 \pm 0.013\ ^{+0.050}_{-0.002})$ GeV, $\Gamma = (0.295 \pm 0.024\ ^{+0.046}_{-0.019})$ GeV

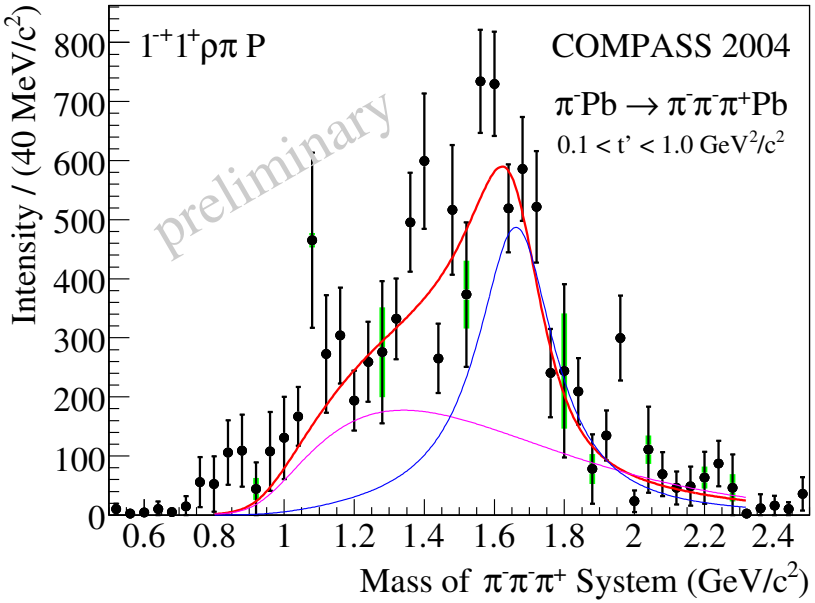
$0^{-+}0^{+}f_0(980)\pi S$

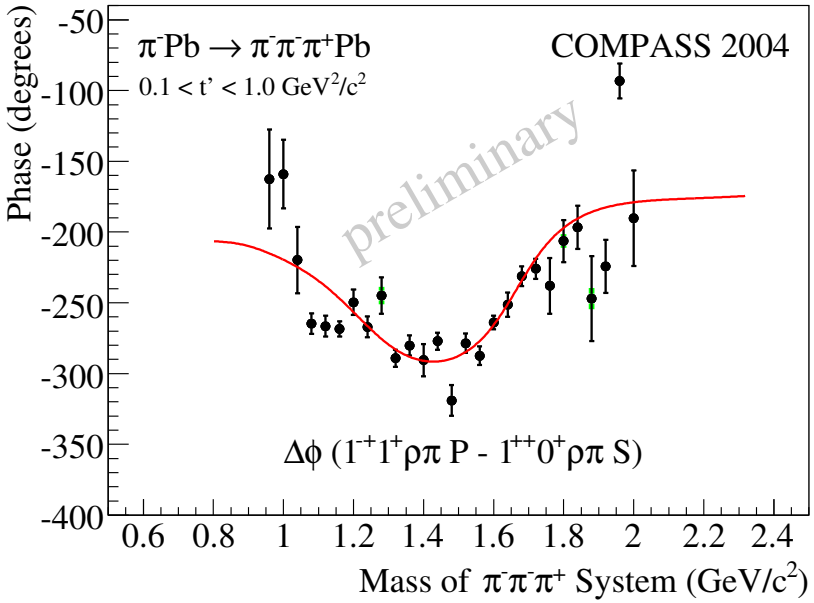


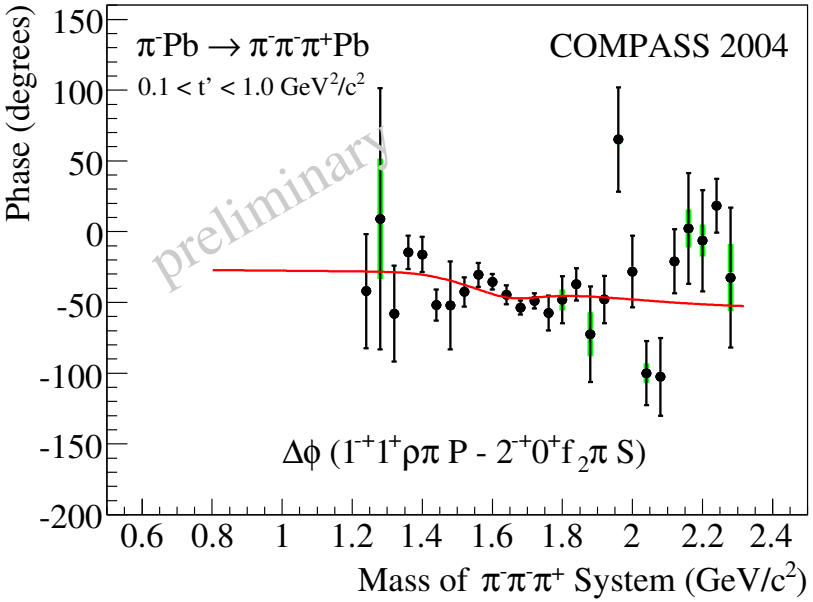


- Constant width Breit-Wigner for $\pi(1800)$ and low-mass background
- $M = (1.785 \pm 0.009\ ^{+0.012}_{-0.006})$ GeV, $\Gamma = (0.208 \pm 0.022\ ^{+0.021}_{-0.037})$ GeV

Exotic $1^{-+}1^{+}\rho\pi P$ Wave







- Significant 1^{-+} amplitude consistent with resonance at $\sim 1.6\,\text{GeV}$
- No leakage observed
- BW for $\pi_1(1600)$ + background:

  $M = (1.660 \pm 0.010\ ^{+0.000}_{-0.064})\,\text{GeV}$

  $\Gamma = (0.269 \pm 0.021\ ^{+0.042}_{-0.064})\,\text{GeV}$

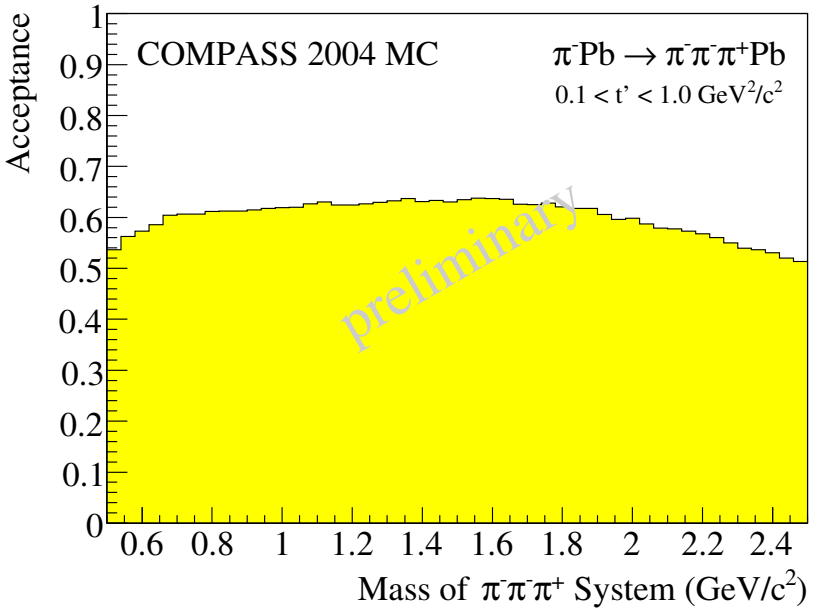
Summary and Outlook

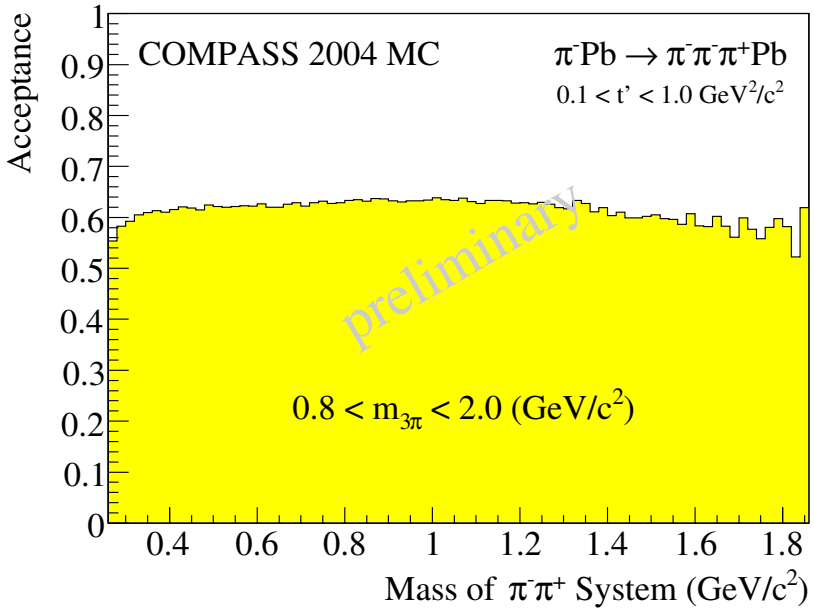
- COMPASS 2004 pilot run using a 190 GeV π^- beam
  - Diffractive dissociation on lead targets exploited for meson production
  - $\sim$ 4 000 000 events recorded within a few days of data taking
  - Large range in momentum transfer t' covered (10^{-3}-few GeV$^2/c^2$)
  - Excellent acceptance for diffractive $\pi^-\pi^-\pi^+$ events ($\sim$ 55-60%)

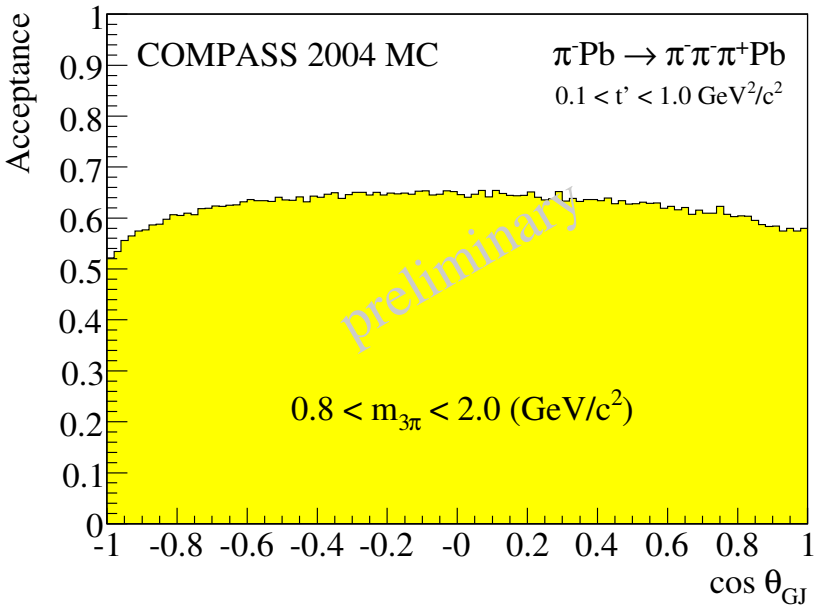
- Partial wave analysis has been performed on $\sim$ 400 000 $\pi^-\pi^-\pi^+$ events with $0.1 < t' < 1.0$ GeV$^2/c^2$
  - Dominant $a_1(1260)$, $a_2(1320)$ and $\pi_2(1670)$ states resolved
  - Also small, well-known resonances $\pi(1800)$ and $a_4(2040)$ can be fitted
  - Spin-exotic 1^{-+} state observed both in intensity and phase motion
    $\Rightarrow$ consistent with $\pi_1(1600)$ resonance

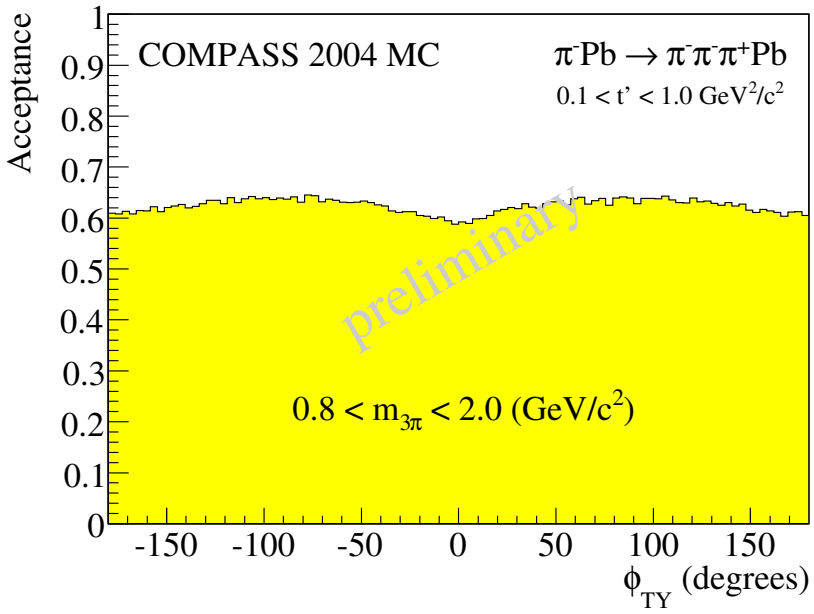
- Analysis of low-t' data from COMPASS 2004 will be performed
- COMPASS will resume data taking with hadron beams this summer
  - Change-over to liquid hydrogen target
  - Much more high-t' statistics will be collected

Backup Slides: COMPASS Acceptance for $\pi^-\pi^-\pi^+$ Events









Backup Slides: Important PWA Formulas

Mass-Independent Cross-Section and Spin Density Matrix

$$\sigma_{\text{indep}}(\tau) = \sum_{\epsilon} \sum_{r} \left| \sum_{i} T^{\epsilon}_{ir} \psi^{\epsilon}_{i}(\tau) \Big/ \sqrt{\int |\psi^{\epsilon}_{i}(\tau')|^2 \mathrm{d}\tau'} \right|^2 \quad , \quad \rho^{\epsilon}_{ij} = \sum_{r} T^{\epsilon}_{ir} T^{\epsilon *}_{jr}$$

- ϵ: reflectivity, r: rank of density matrix, i: different partial waves
- T: complex production amplitudes (fit parameters!)
- ψ: complex decay amplitudes
- τ: phase space coordinates (5 parameters for 3-body decay)

Likelihood Function

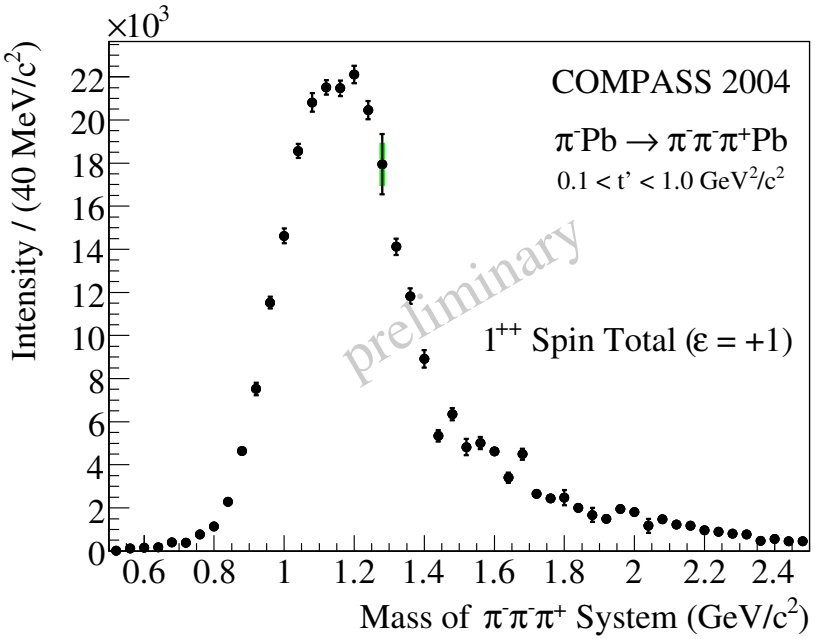
$$\ln L = \sum_{n} \ln \sigma_{\text{indep}}(\tau_n) - \int \sigma_{\text{indep}}(\tau') \text{Acc}(\tau') \mathrm{d}\tau'$$

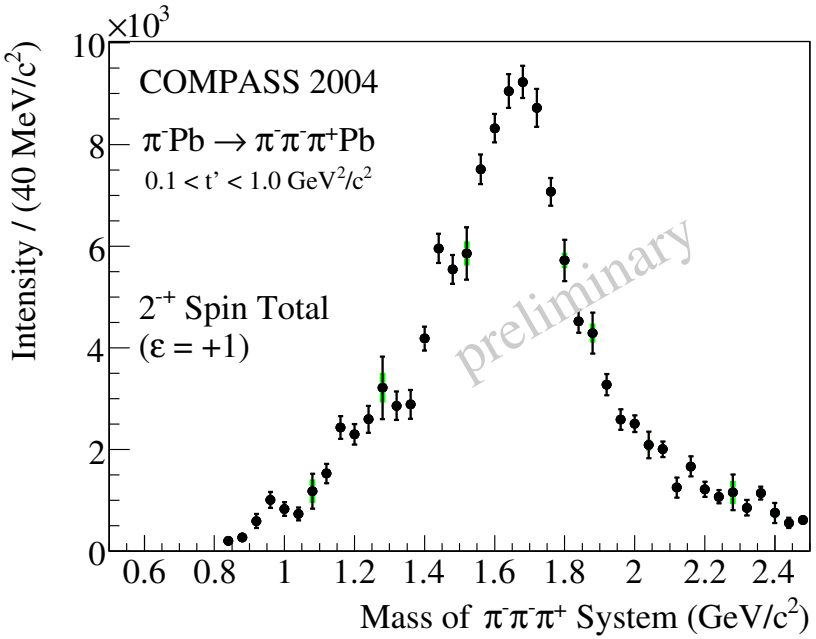
- n: analyzed events, Acc: Acceptance

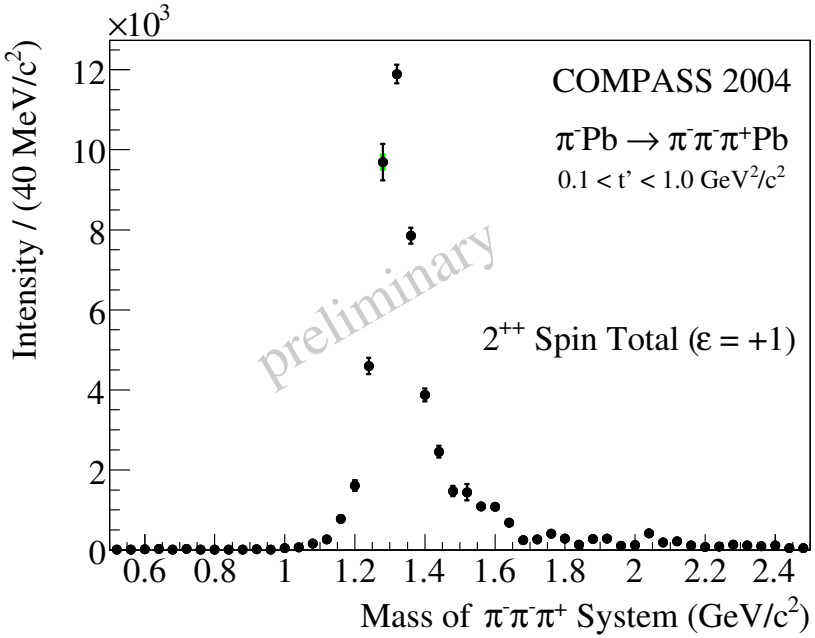
Mass-Dependent Fit

$$\rho^{\epsilon}_{ij} = \sum_{r} \left(\sum_{k} C^{\epsilon}_{ikr} \text{BW}_k(m) \sqrt{\int |\psi^{\epsilon}_{i}(\tau)|^2 \mathrm{d}\tau} \right) \left(\sum_{l} C^{\epsilon}_{jlr} \text{BW}_l(m) \sqrt{\int |\psi^{\epsilon}_{j}(\tau)|^2 \mathrm{d}\tau} \right)^*$$

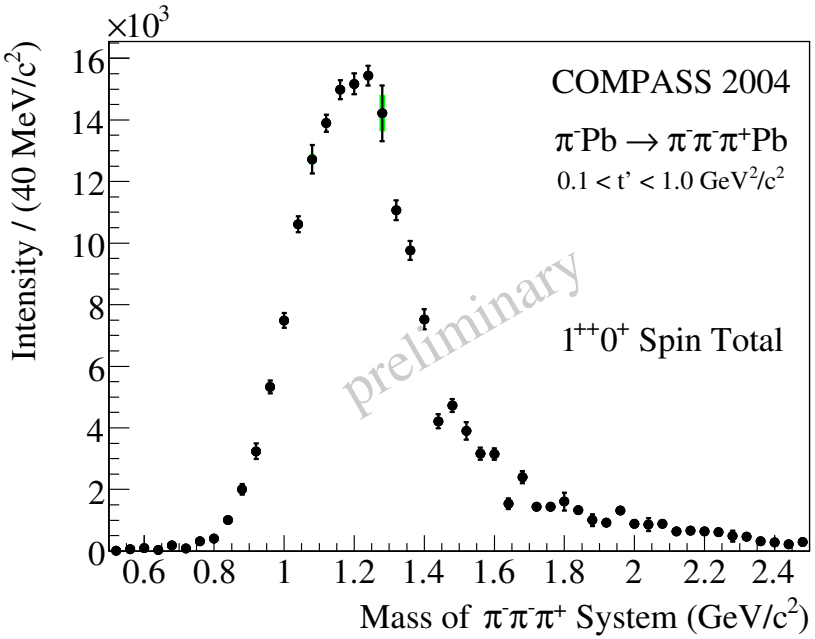
Backup Slides: Spin Totals

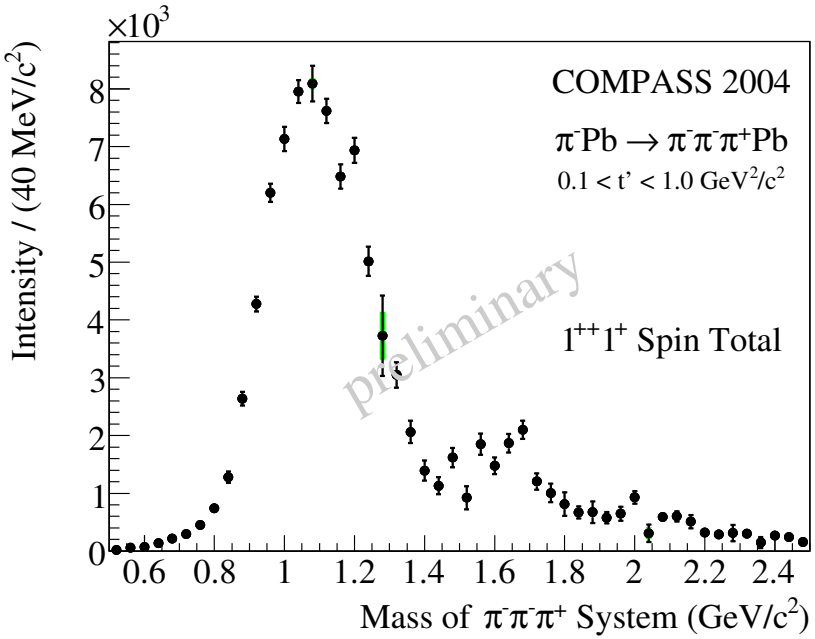


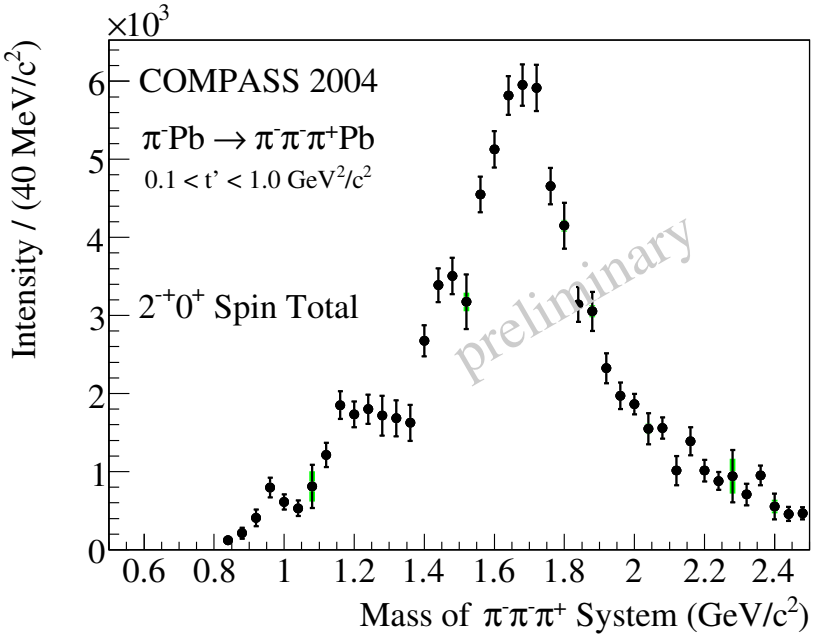


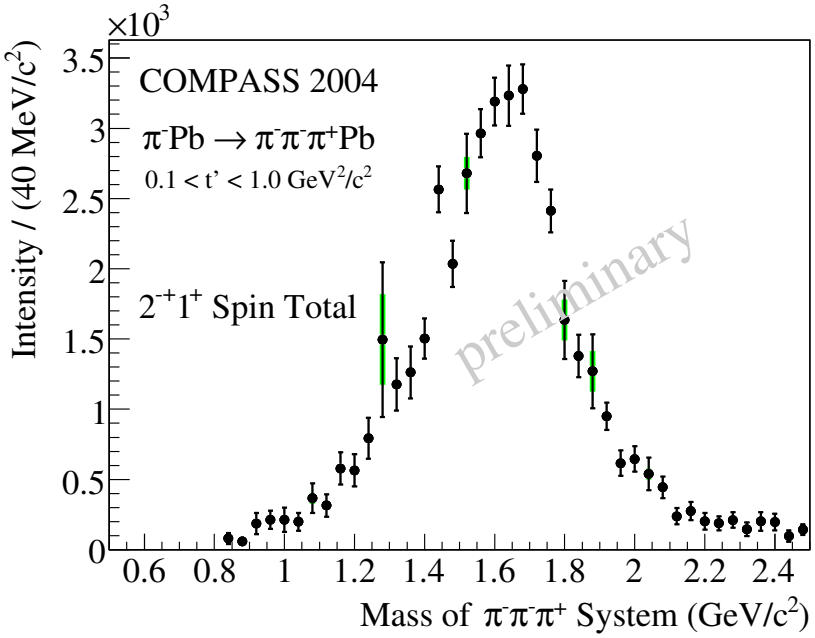


Backup Slides: $M = 0$ and $M = 1$ Spin Totals





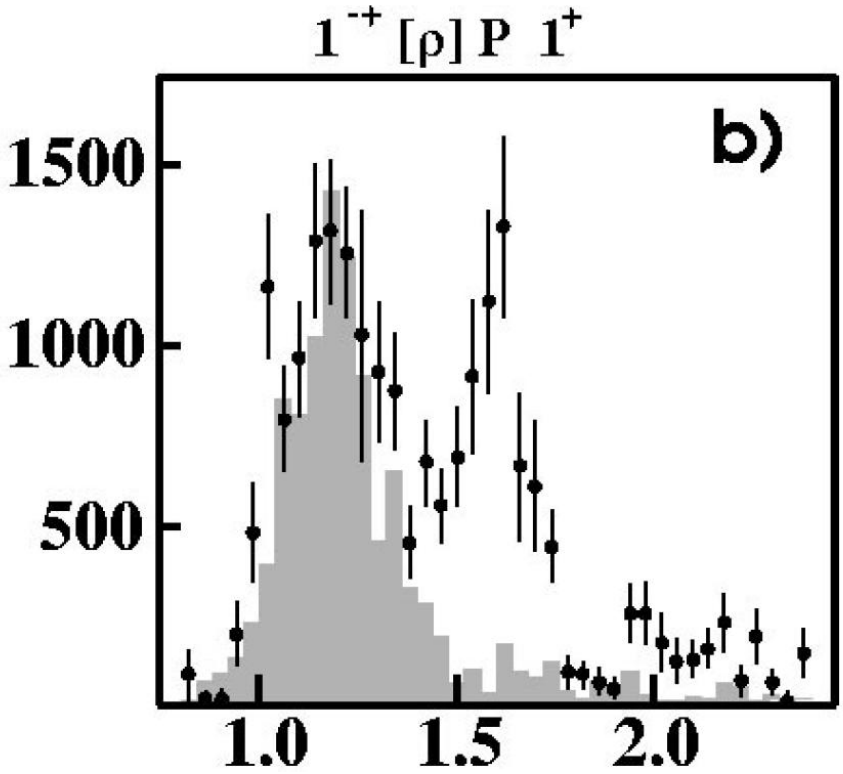




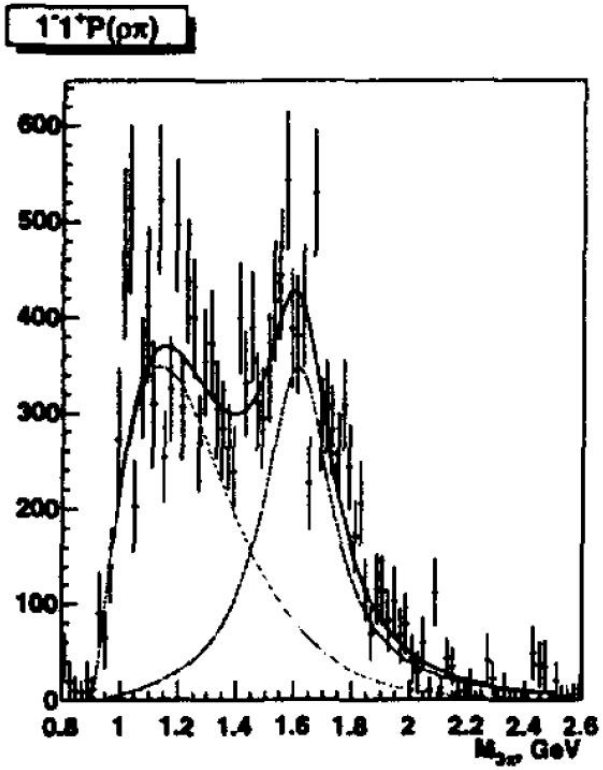
Summary of Results and Comparison to PDG (2006)

State	(GeV)	COMPASS $\pm$ stat $\pm$ syst	PDG
$a_1(1260)$	M	$1.256 \pm 0.006 + 0.007 - 0.017$	1.230 ± 0.040
	Γ	$0.366 \pm 0.009 + 0.028 - 0.025$	0.250 to 0.600
$a_2(1320)$	M	$1.321 \pm 0.001 + 0.000 - 0.007$	1.3183 ± 0.0006
	Γ	$0.110 \pm 0.002 + 0.002 - 0.015$	0.107 ± 0.005
$\pi_1(1600)$	M	$1.660 \pm 0.010 + 0.000 - 0.064$	$1.653^{+0.018}_{-0.015}$
	Γ	$0.269 \pm 0.021 + 0.042 - 0.064$	$0.225^{+0.045}_{-0.028}$
$\pi_2(1670)$	M	$1.659 \pm 0.003 + 0.024 - 0.008$	1.6724 ± 0.0032
	Γ	$0.271 \pm 0.009 + 0.022 - 0.024$	0.259 ± 0.009
$\pi(1800)$	M	$1.785 \pm 0.009 + 0.012 - 0.006$	1.812 ± 0.014
	Γ	$0.208 \pm 0.022 + 0.021 - 0.037$	0.207 ± 0.013
$a_4(2040)$	M	$1.884 \pm 0.013 + 0.050 - 0.002$	2.001 ± 0.010
	Γ	$0.295 \pm 0.024 + 0.046 - 0.019$	0.313 ± 0.031

Backup Slides: BNL-E852 and VES 1^{-+} Signal

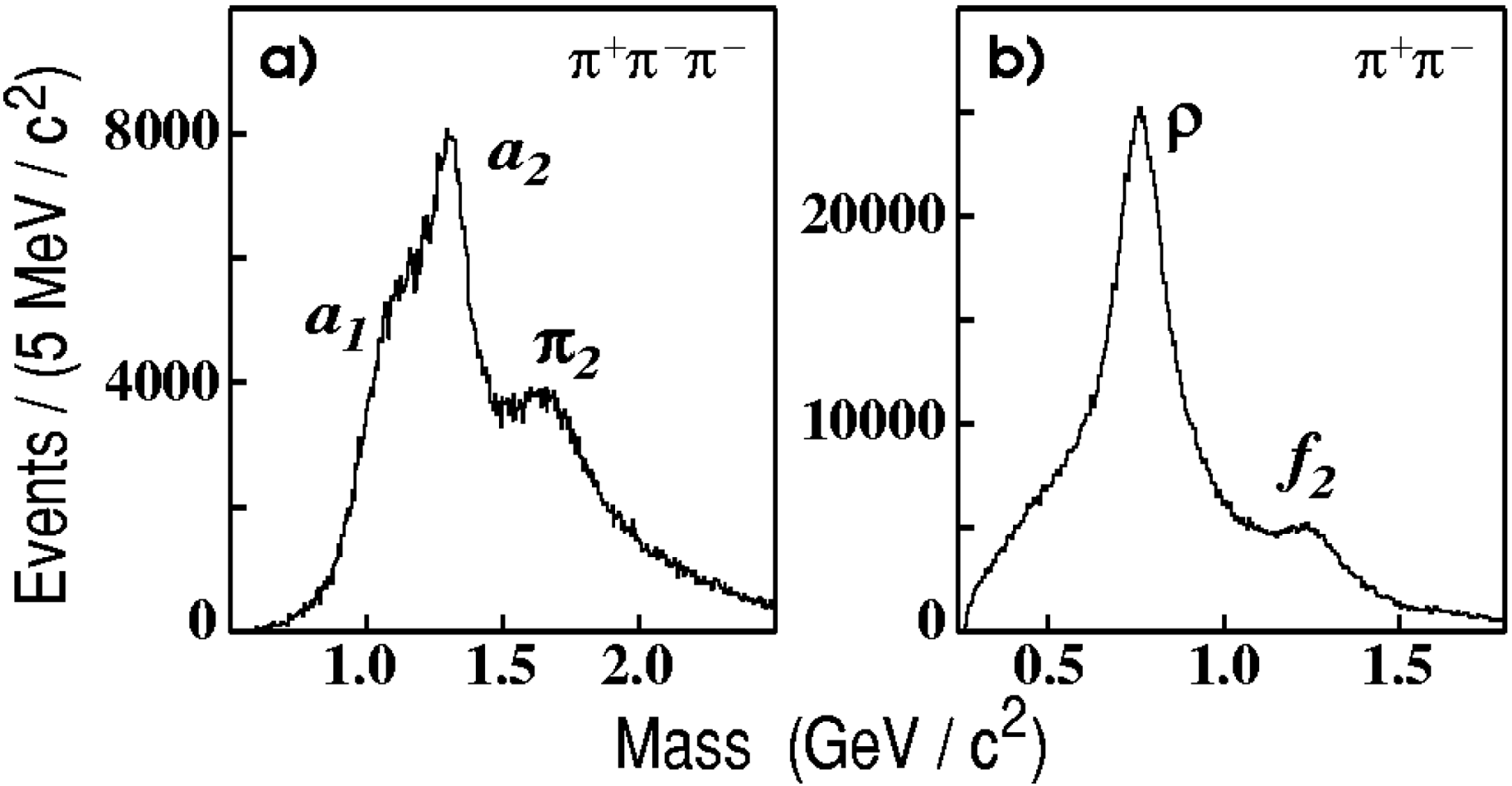


BNL-E852, Phys. Rev. **D65**, 072001, 2002



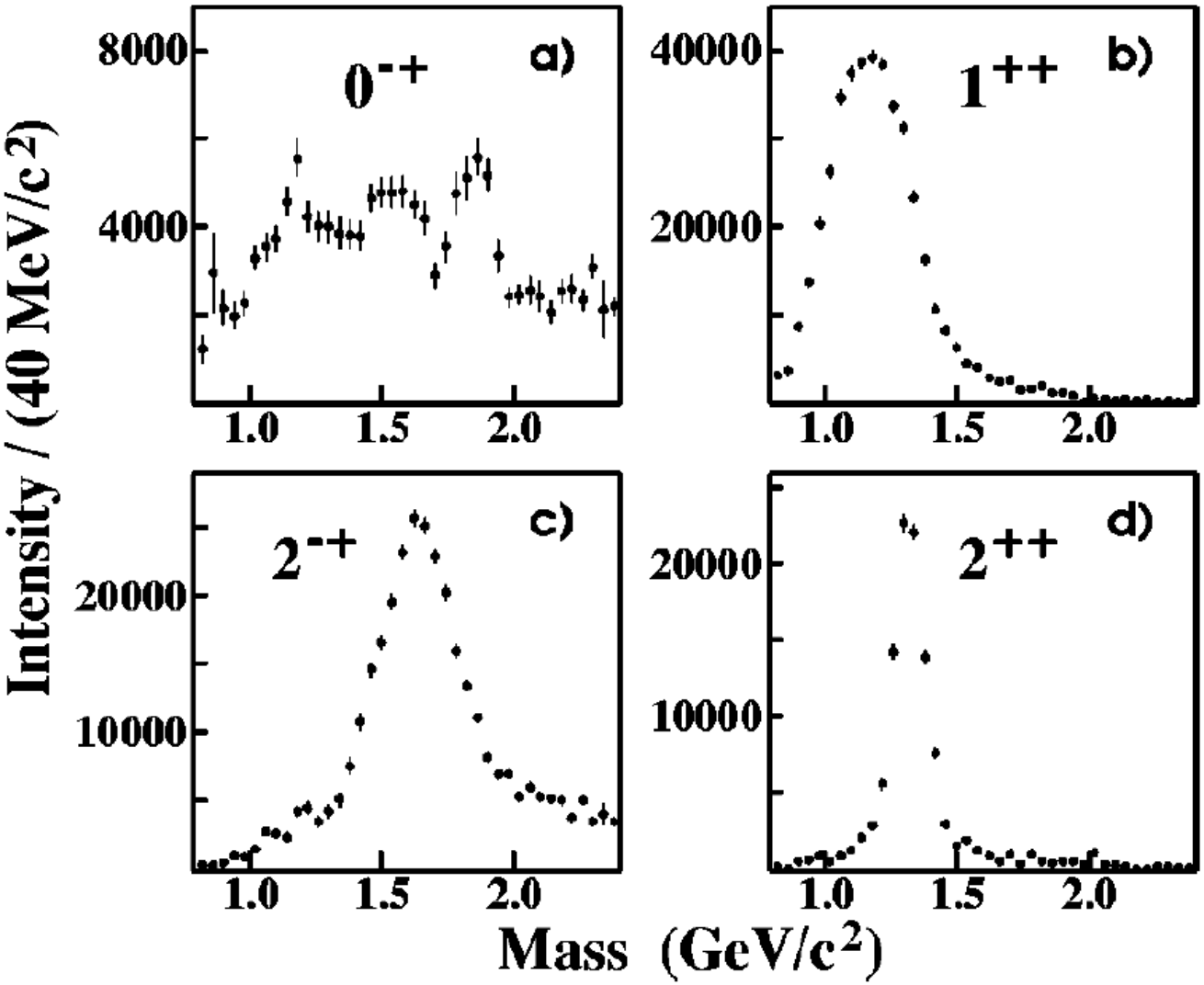
VES, Nucl. Phys. **A663**, 596, 2000

Backup Slides: BNL-E852 Comparison (proton target)



Phys. Rev. **D65**, 072001, 2002

Backup Slides: BNL-E852 Comparison (proton target)



Physical Review D, Volume 65, 072001, 2002