Light Scalar Mesons in Central Production at COMPASS

Alexander Austregesilo
for the
COMPASS Collaboration

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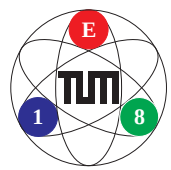

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Outline

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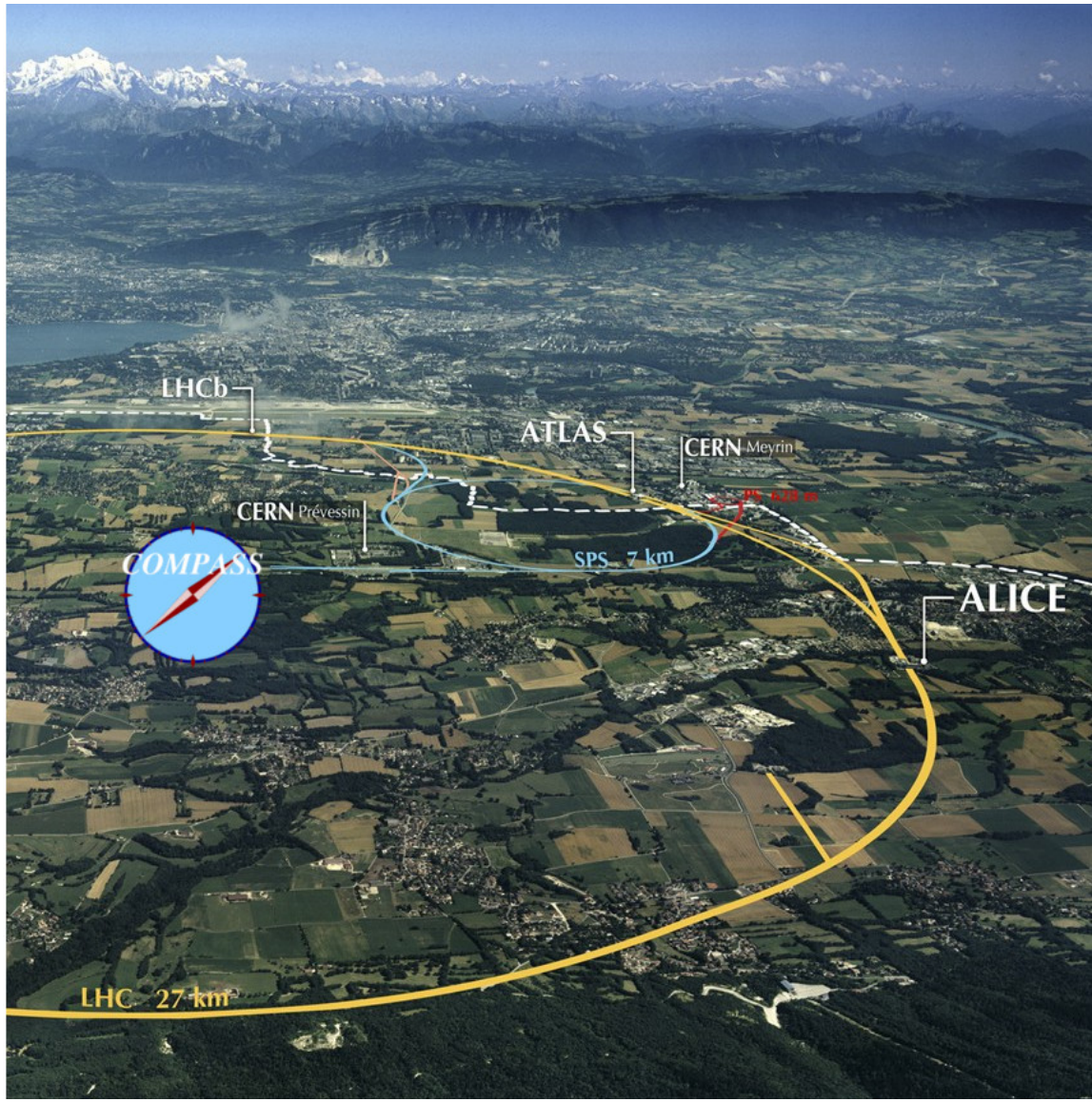
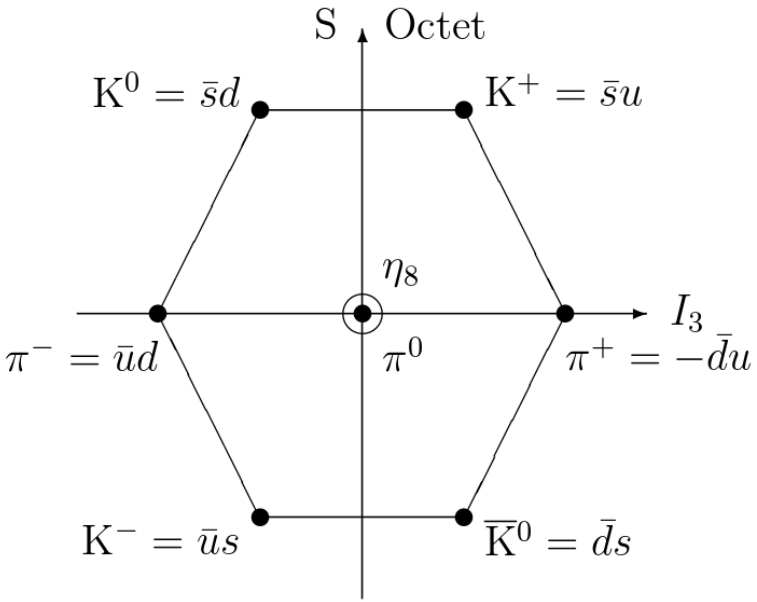
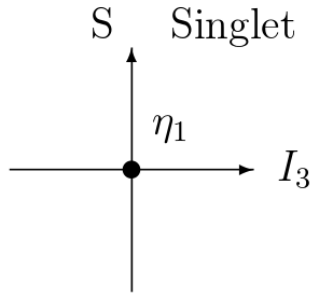


Light-Quark Meson Spectroscopy

- Flavour SU(3): Mesons are grouped into $3 \otimes 3 = 8 \oplus 1$ nonets





Light-Quark Meson Spectroscopy

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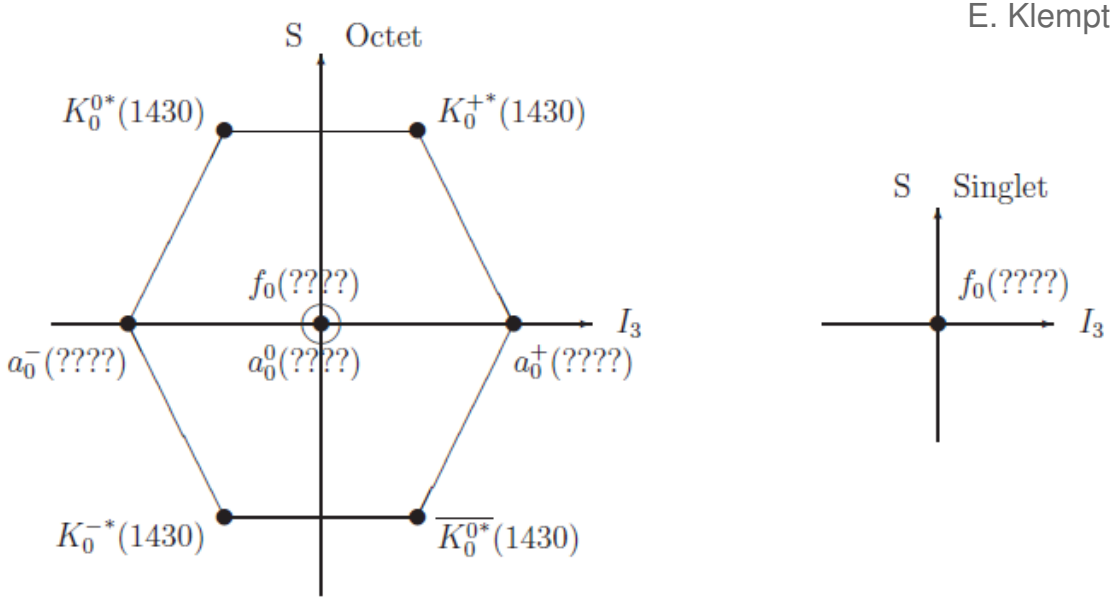
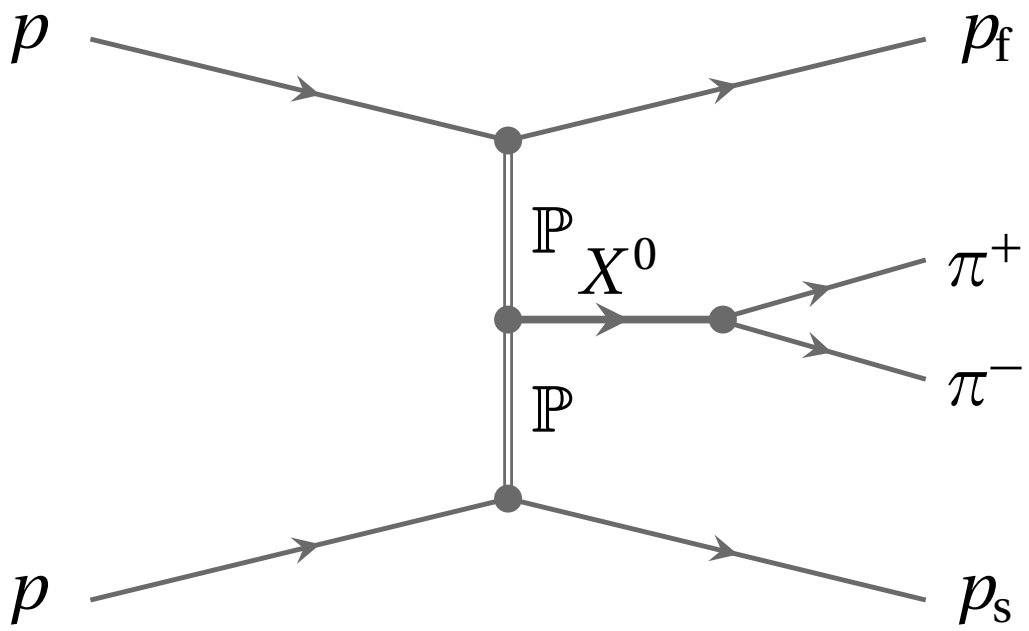
- Flavour SU(3): Mesons are grouped into $3 \otimes 3 = 8 \oplus 1$ nonets
- Scalar isoscalar mesons ($I^G\, J^{PC} = 0^+\, 0^{++}$):
  $f_0(500)$, $f_0(980)$, $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, ...

'ground state nonet of scalar mesons as most physicists in the field would agree upon'
E. Klempt [arXiv:hep-ex/0101031]



- **Super-numerous f_0 states** not understood by constituent quark models
  $\Rightarrow$ Mixing with **Glueballs?**

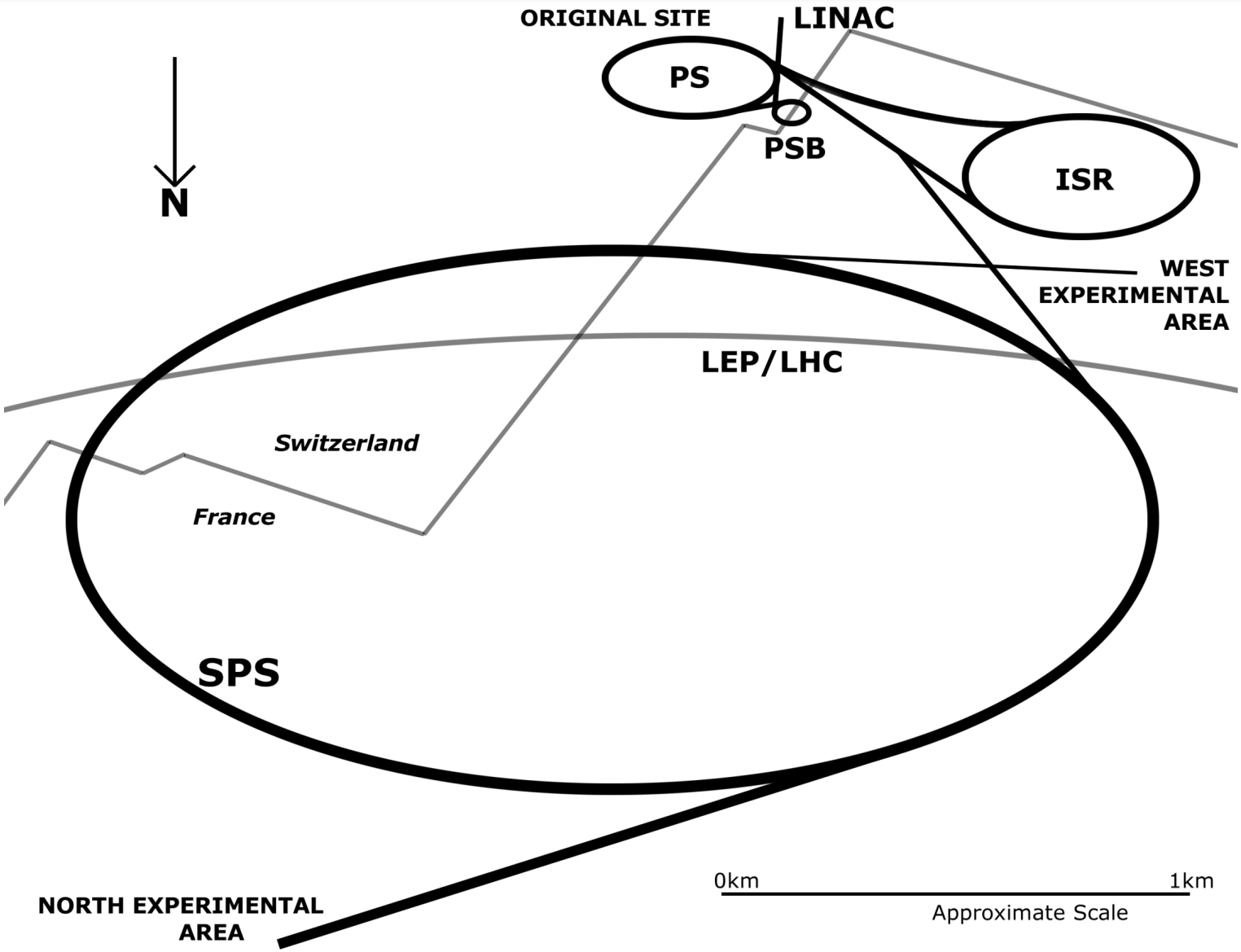
Central Production



$p\,p \to p_{\text{fast}}\,X\,p_{\text{slow}}$

- Proton beam impinging on proton target, both **stay intact** and are detected
- Double-Pomeron production of meson system (**gluon-rich environment**)
- Decay into two pseudoscalar mesons ($\boldsymbol{\pi^+\pi^-}$, $\pi^0\pi^0$, K^+K^-, $\eta\,\eta$, ..)

Central Production at CERN



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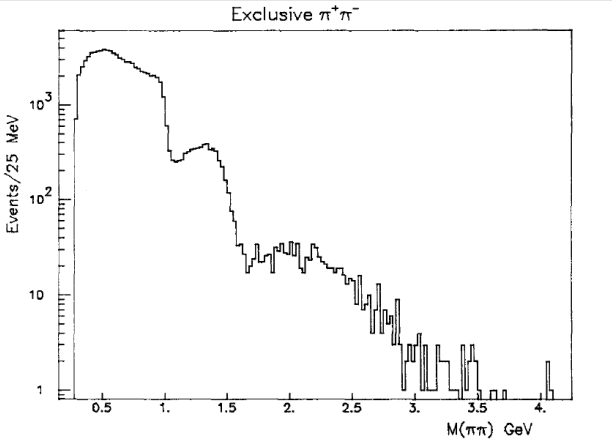

- **ISR**: First evidence for double-Pomeron exchange
  [Baksay et al., 1976]
  'definite evidence for dynamics beyond naive quark model'
  [Au, Morgan, Pennington, 1987]

Central Production at CERN

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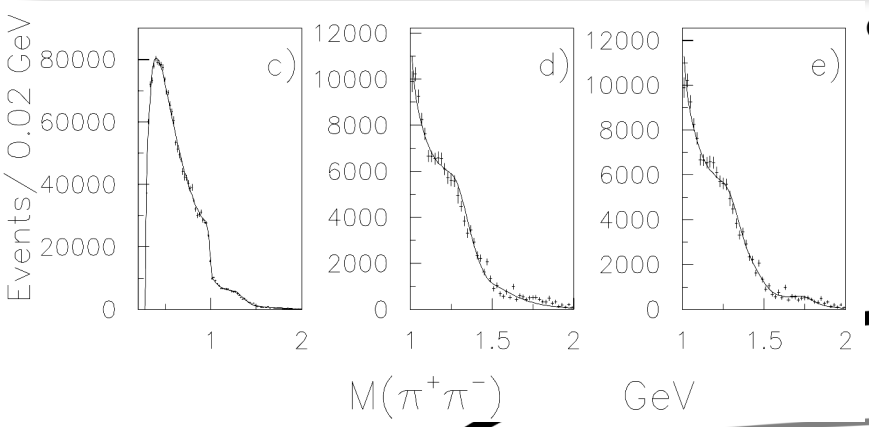

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  $f_0(1370)$, $f_0(1500)$, $f_0(1710)$, ...

Central Production at CERN

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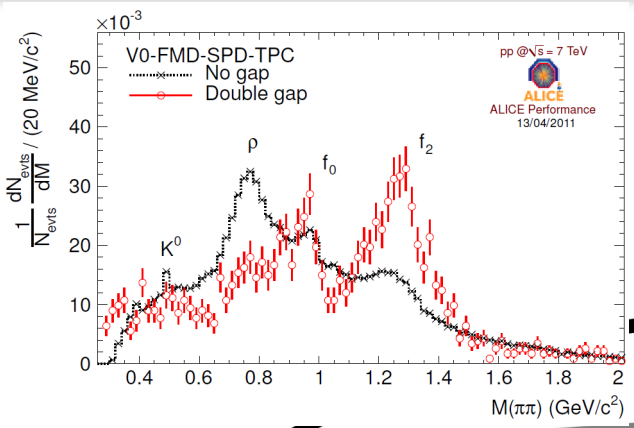

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Central Production at CERN

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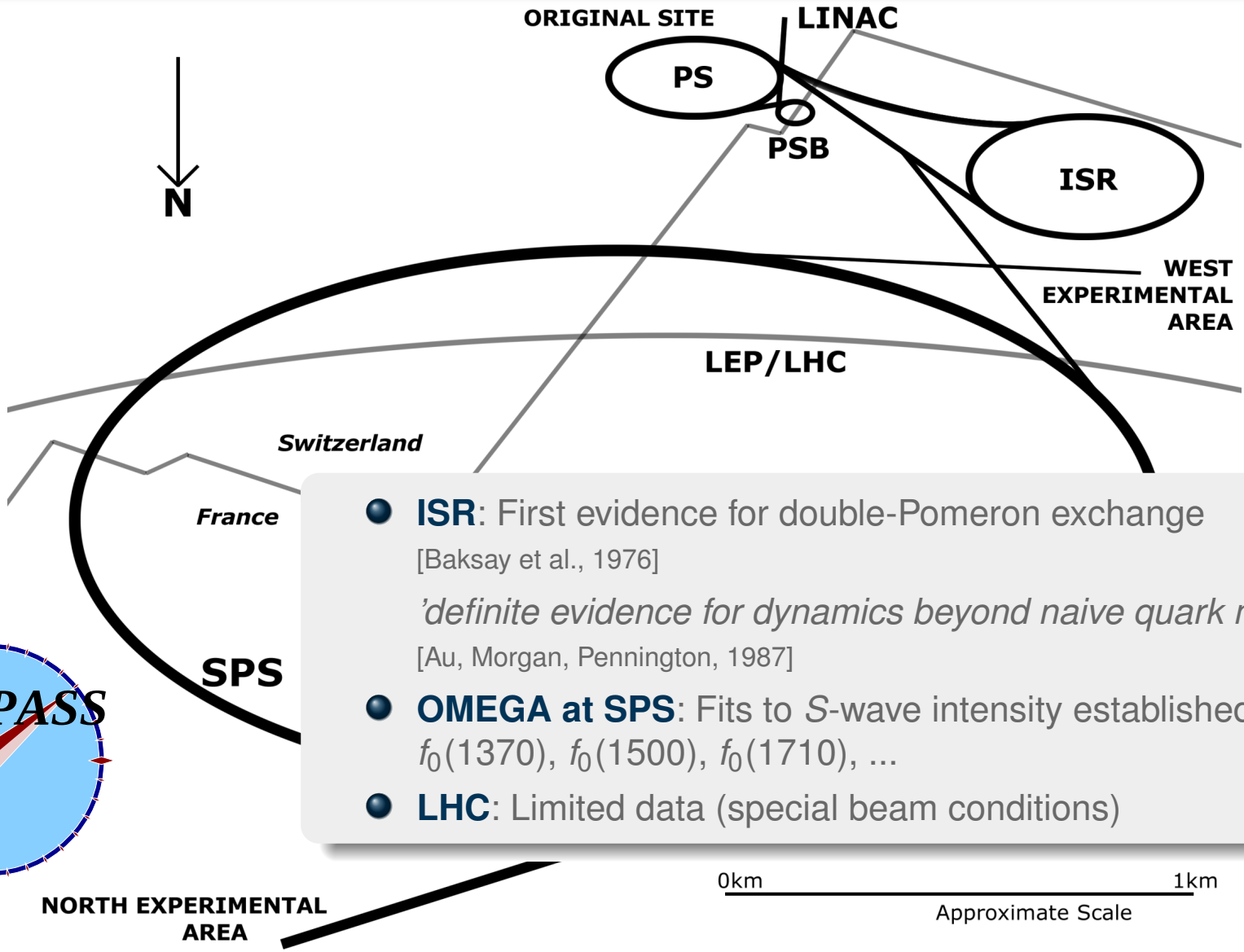

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The COMPASS Experiment

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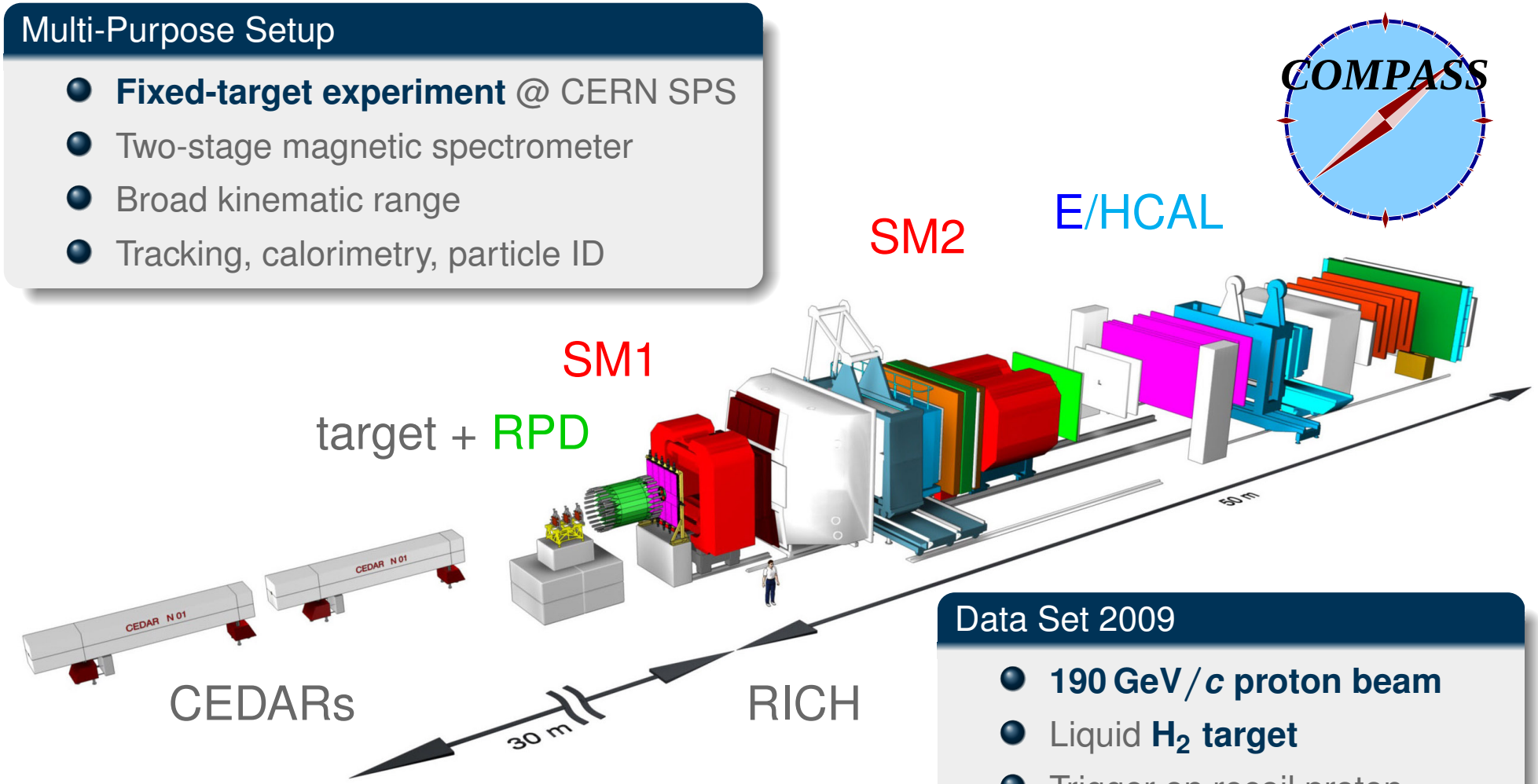
Multi-Purpose Setup

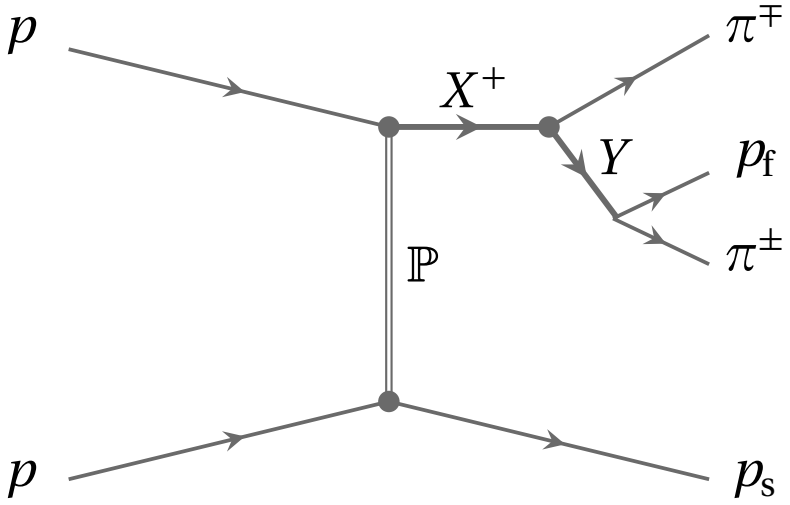
- **Fixed-target experiment** @ CERN SPS
- Two-stage magnetic spectrometer
- Broad kinematic range
- Tracking, calorimetry, particle ID

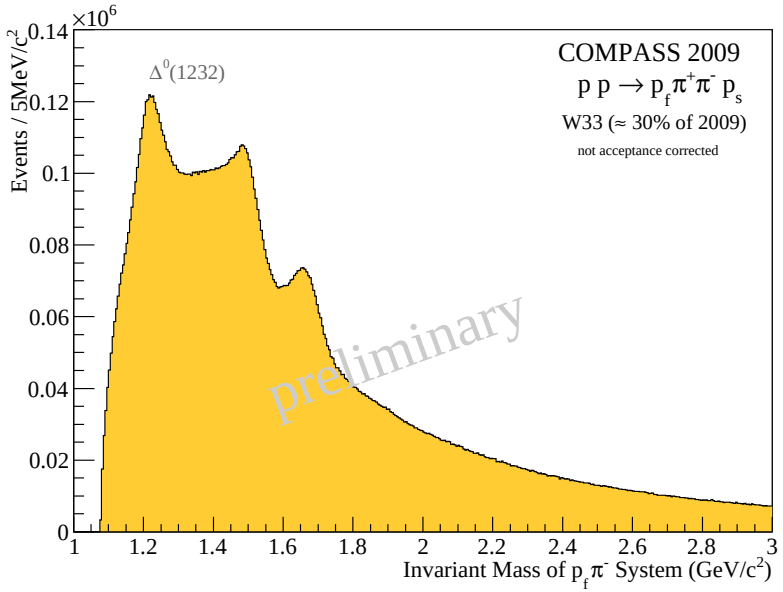


Data Set 2009

- **190 GeV/c proton beam**
- Liquid **H_2 target**
- Trigger on recoil proton
- $\pi^+\pi^-$, $\pi^0\pi^0$, K^+K^-, ...

Central Production of $\pi^+\pi^-$ System





- Baryon resonances in $p_f\pi^\pm$ subsystems
  $\rightarrow$ **Diffractive dissociation** of the beam proton as dominant process

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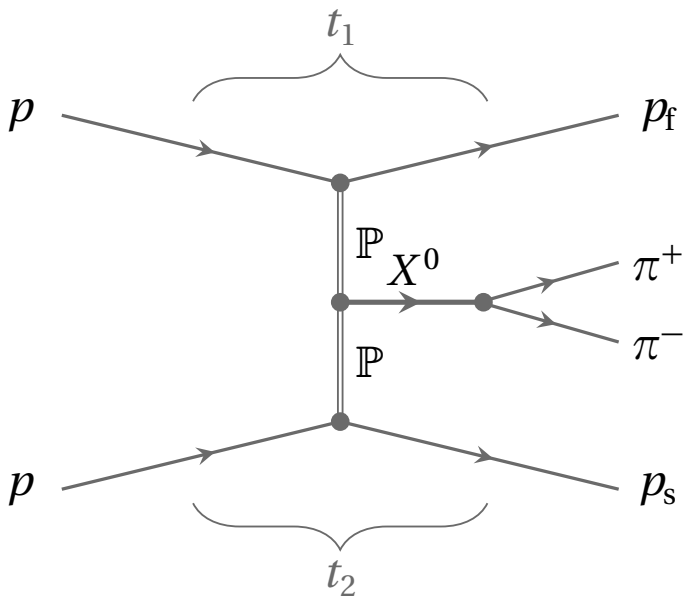
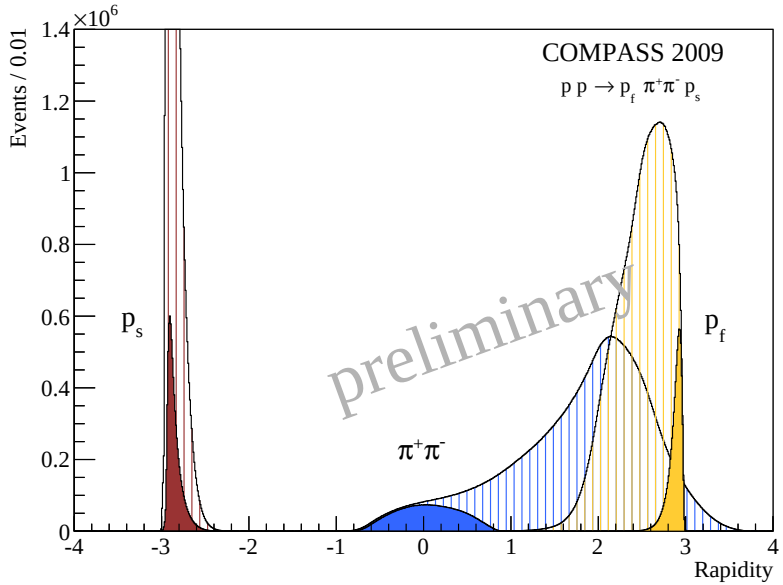
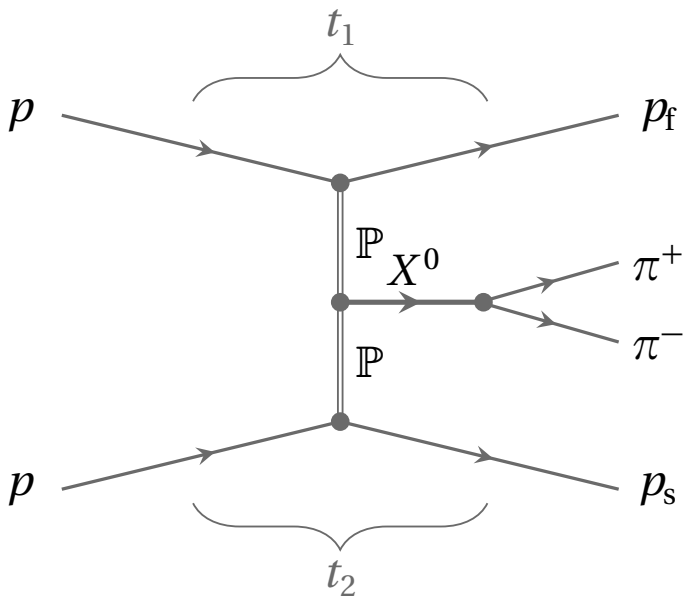
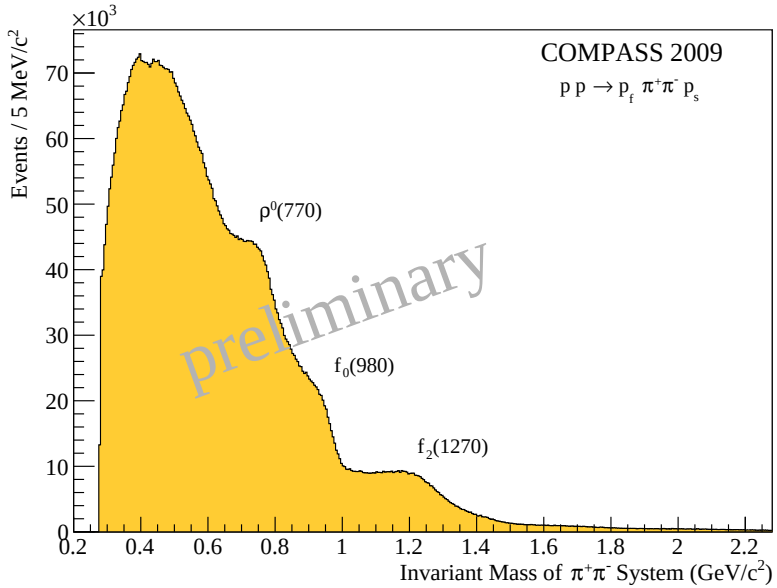




- Baryon resonances in $p_f\pi^\pm$ subsystems
  $\rightarrow$ **Diffractive dissociation** of the beam proton as dominant process
- **Kinematic separation** between p_f and $\pi^\pm$
- Separation between p_s and $\pi^\pm$ by trigger on recoil proton p_s

Central Production of $\pi^+\pi^-$ System

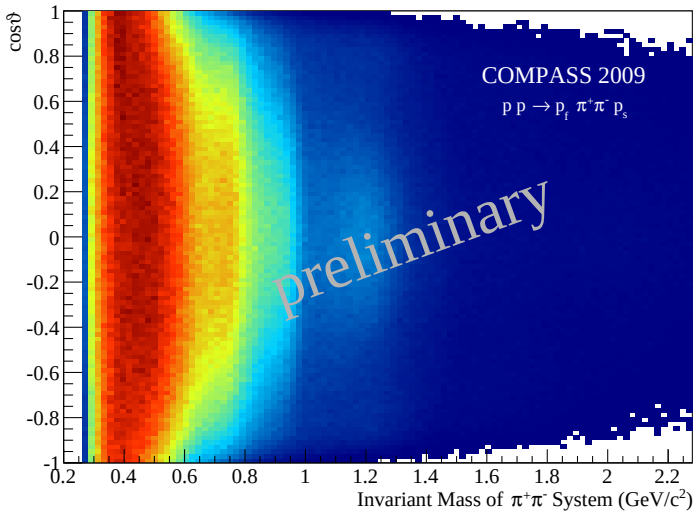


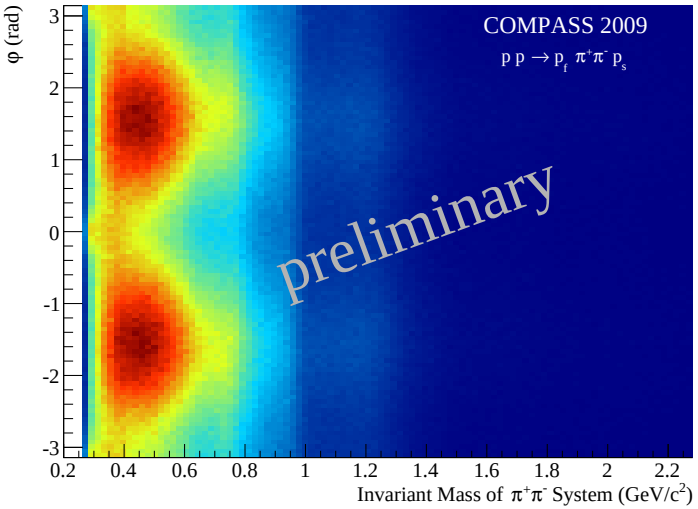


- Baryon resonances in $p_f\pi^\pm$ subsystems
  $\rightarrow$ **Diffractive dissociation** of the beam proton as dominant process
- **Kinematic separation** between p_f and $\pi^\pm$
- Separation between p_s and $\pi^\pm$ by trigger on recoil proton p_s
- $\rho(770)$ production $\rightarrow$ kinematic selection cannot isolate pure DPE sample

$\Rightarrow$ **Two-Body Partial-Wave Analysis (PWA)**

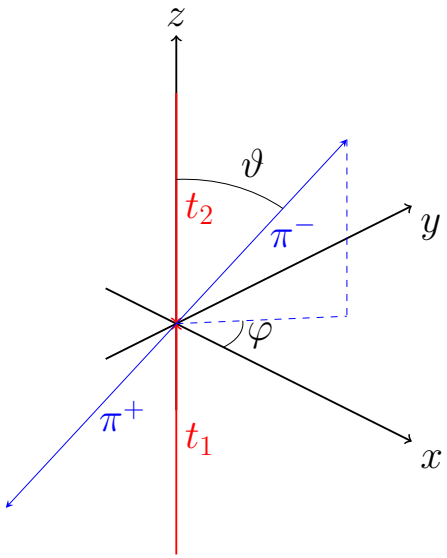
Partial-Wave Analysis



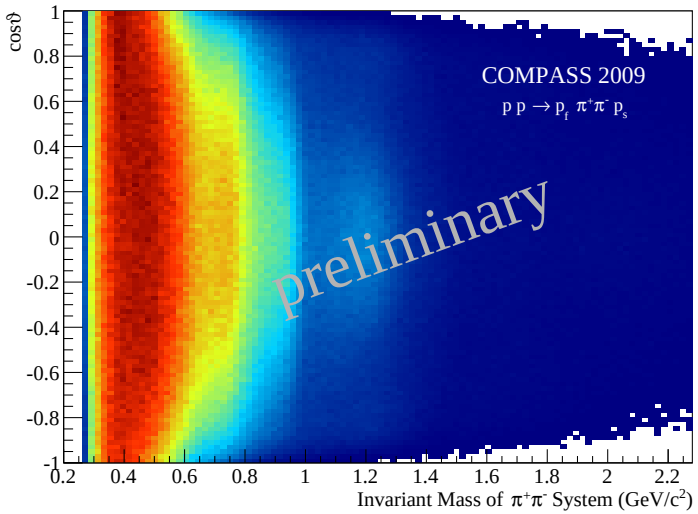


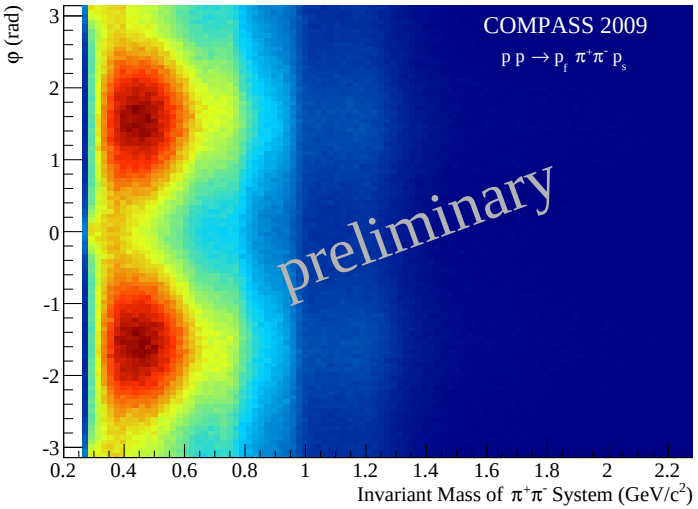
$X^0 \to \pi^+\pi^-$

- **Assumption:** collision of two space-like exchange particles
- Decay of X^0 fully described by $M(\pi^+\pi^-)$, $\cos\vartheta$ and φ



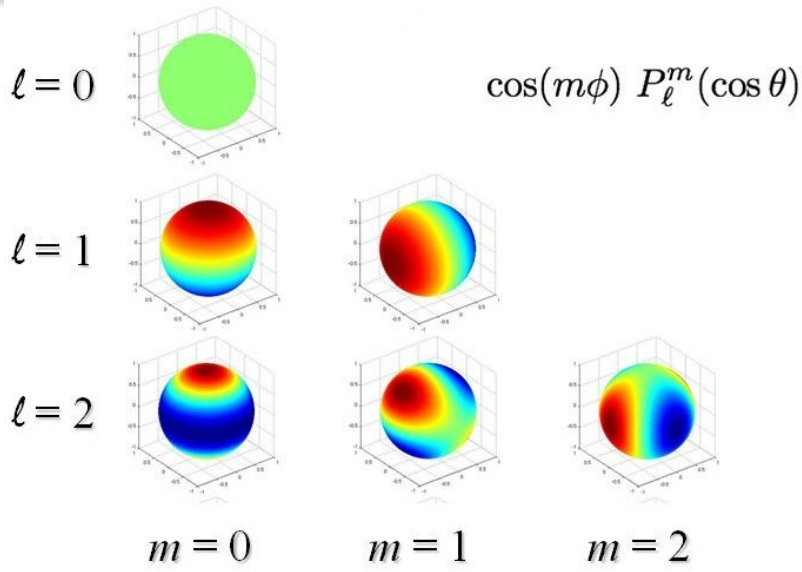
Partial-Wave Analysis





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

- **Assumption:** collision of two space-like exchange particles
- Decay of X^0 fully described by $M(\pi^+\pi^-)$, $\cos\vartheta$ and φ
- Decompose into complex-valued amplitudes (spherical harmonics) with definite spin and parity



Partial-Wave Decomposition

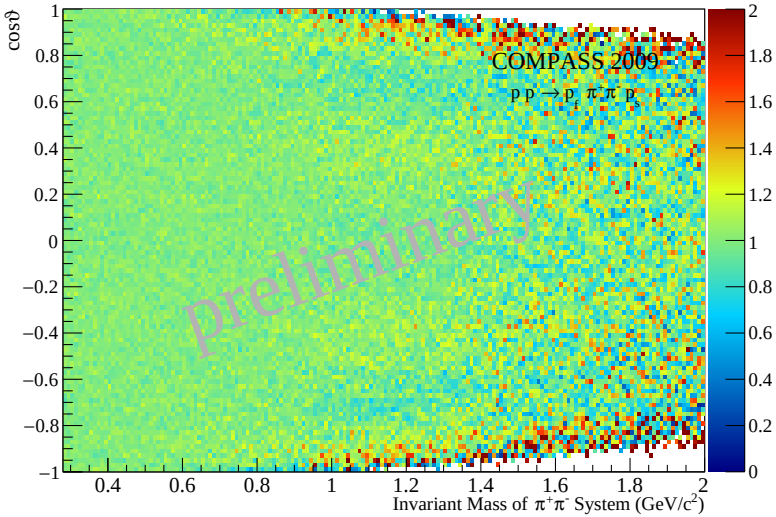
Expand intensity $I(\vartheta, \varphi)$ into partial-wave amplitudes in narrow mass bins ($10\,\mathrm{MeV}/c^2$):

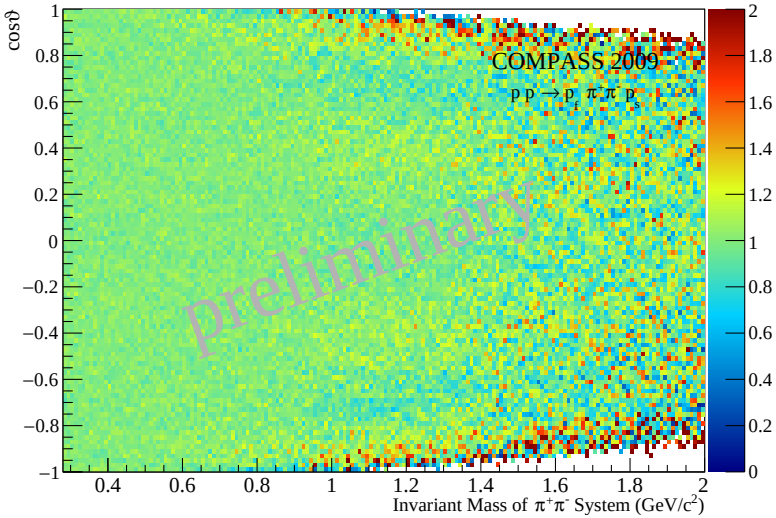
$$I(\vartheta, \varphi) = \left| \sum_{LM} T_{LM} Y_M^L(\vartheta, \varphi) \right|^2$$

- Quantum-mechanical interference between amplitudes with same $|\mathrm{i}\rangle$ and $|\mathrm{f}\rangle$
- **Complex-valued transition amplitudes T_{LM}**, no assumption on mass-dependence
- Significant contributions only from $L = S, P, D$ and $M \leq 1$

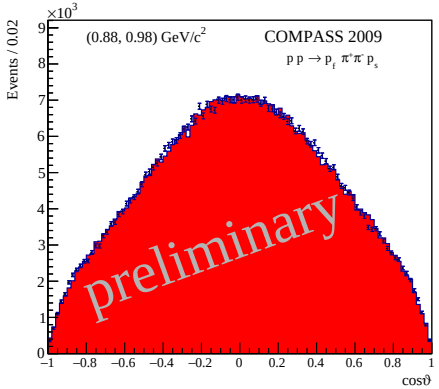
$\Rightarrow$ **Maximum Likelihood Fit in Mass Bins**

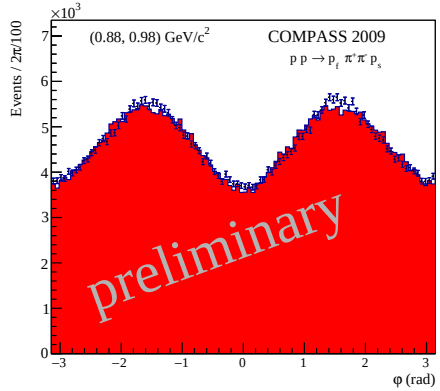
Evaluation of the Fit Quality

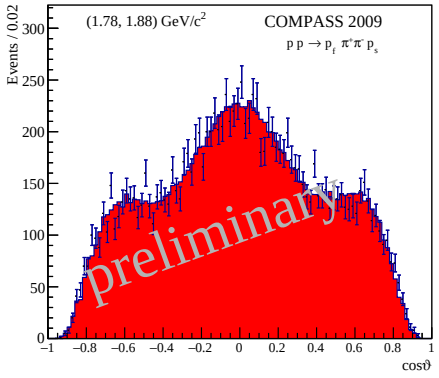


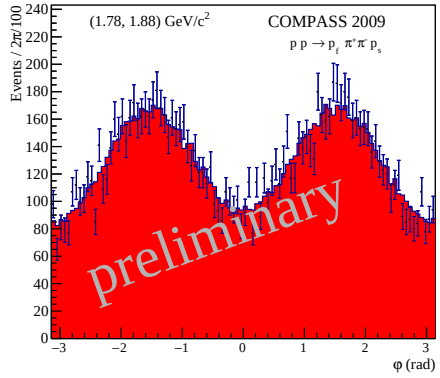


$$I(\vartheta,\varphi) = \left| \sum_{LM} T_{LM}\, Y_M^L(\vartheta,\varphi) \right|^2$$





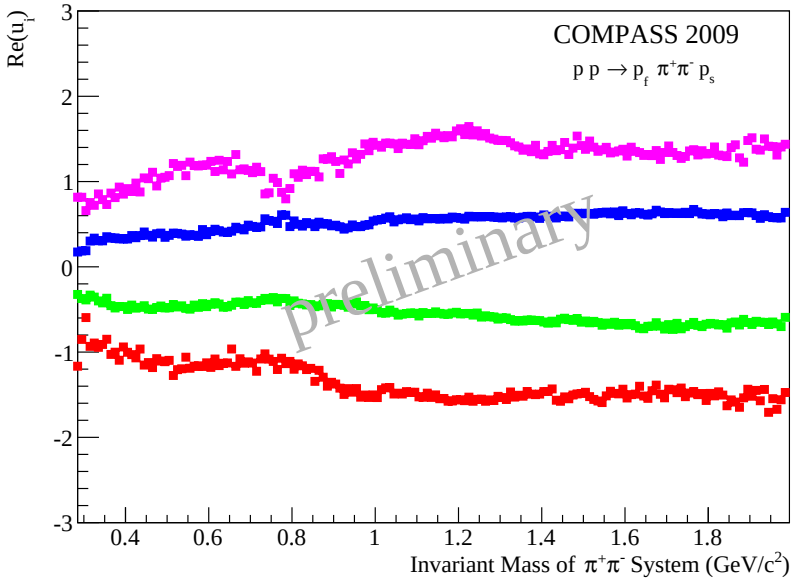


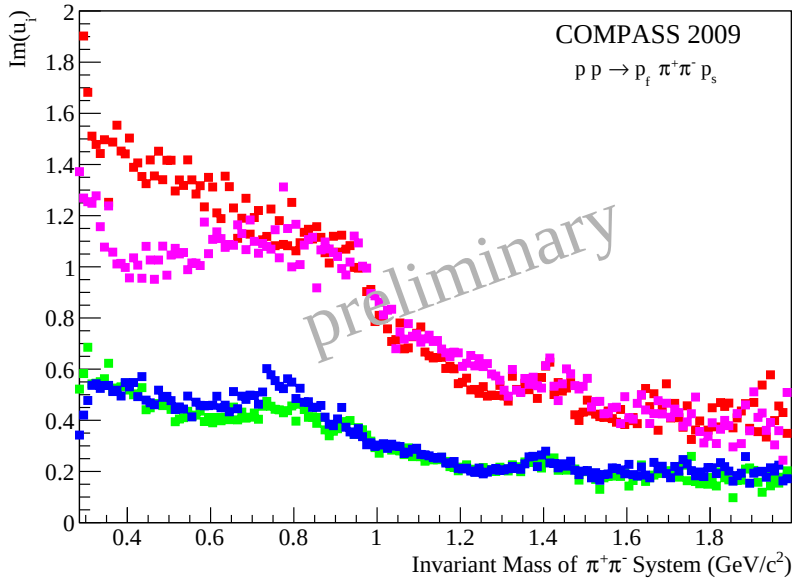


Ambiguities

- 8 mathematically ambiguous solutions result in the same angular distribution
- Analytical computation via method of **Barrelet Zeros**

S.-U. Chung, [Phys. Rev. D 56 (1997), 7299]





- Real (left) and imaginary (right) part of polynomial roots
- Well separated, imaginary parts do not cross the real axis

$\Rightarrow$ Solutions can be uniquely identified and linked from mass bin to mass bin

Ambiguities in the $\pi\pi$ Systems

$\pi^+\pi^-$ System

- 8 different solutions can be calculated analytically
- Differentiation requires additional input
  (e.g. behaviour at threshold, physics content)

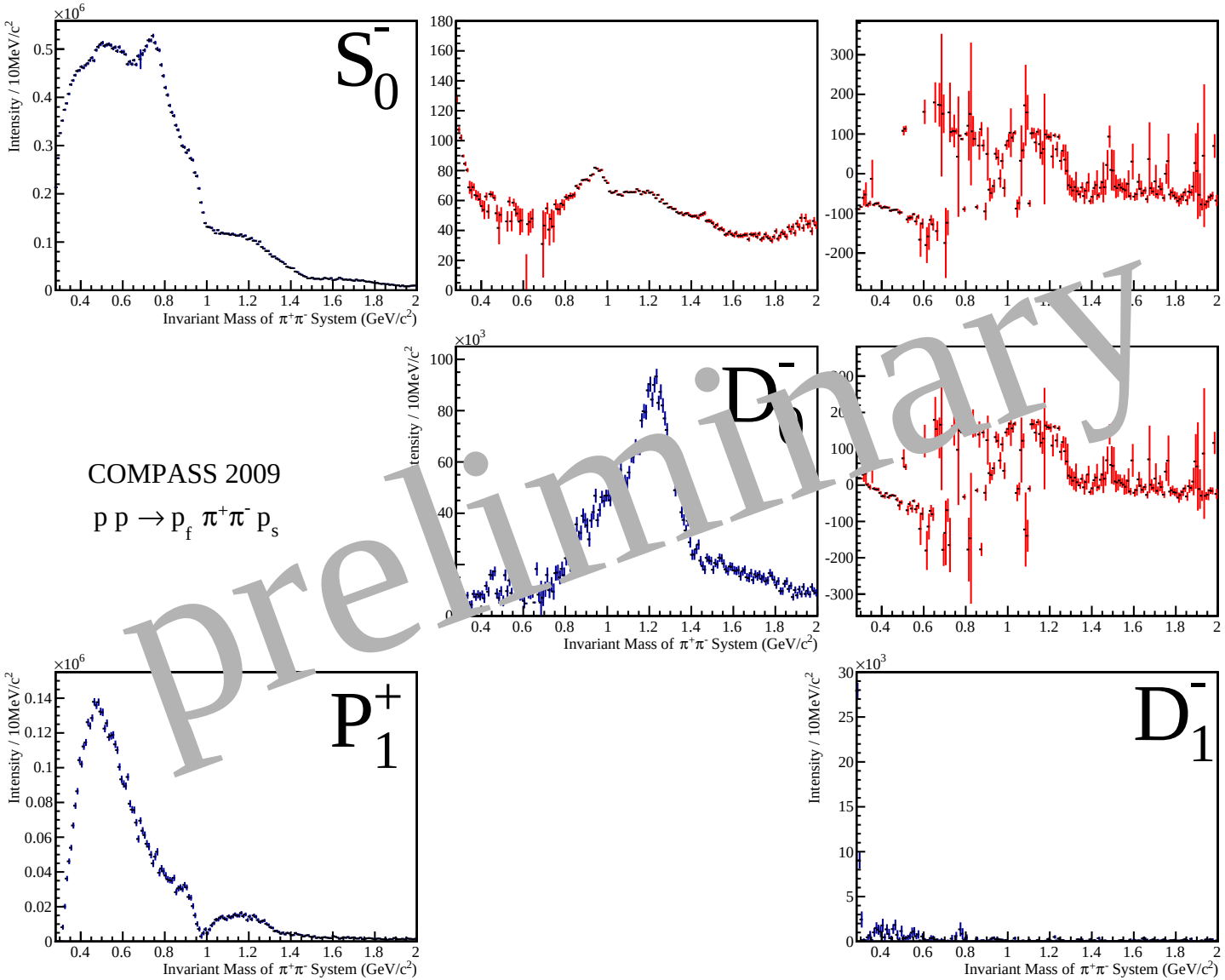
$\pi^0\pi^0$ System

- Identical particles, only even waves allowed
- Reduces number of ambiguities to 2

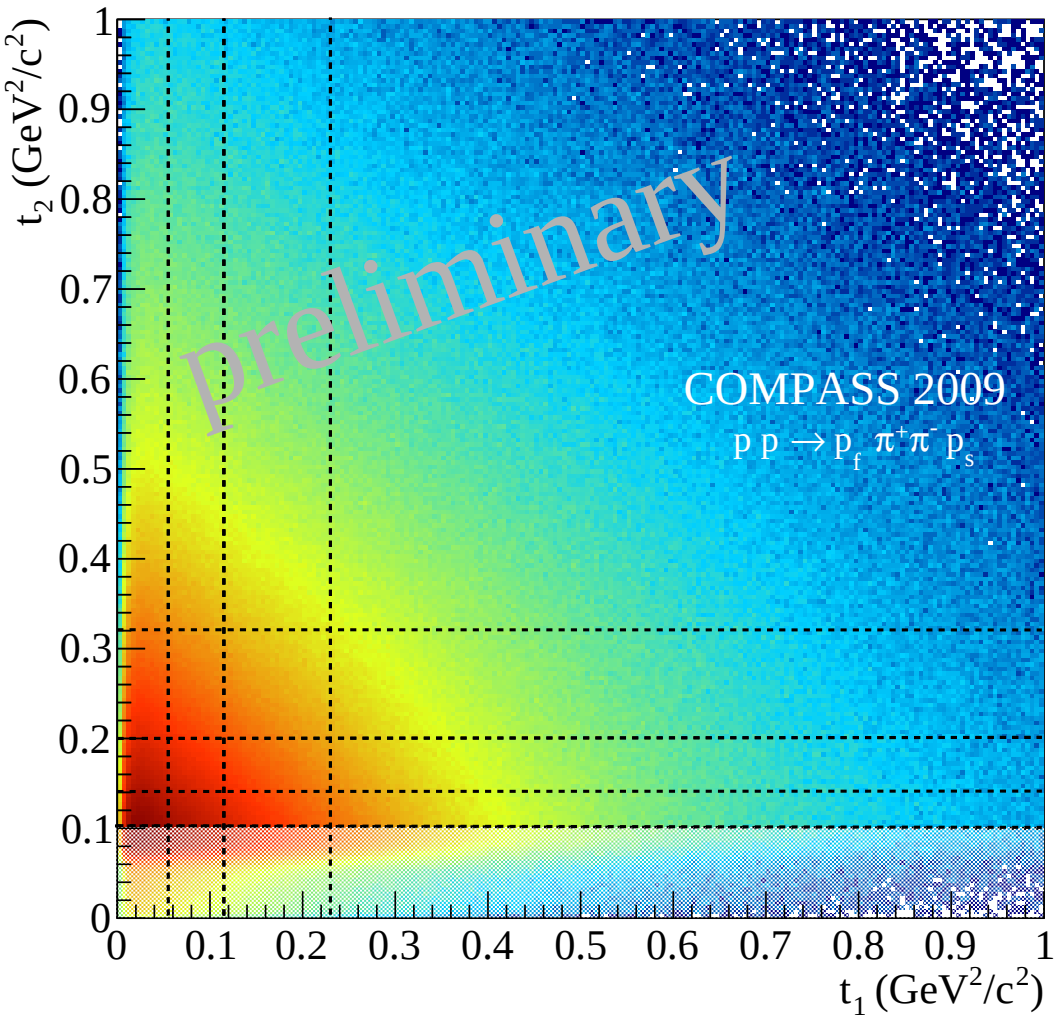
Combination of $\pi\pi$ Systems

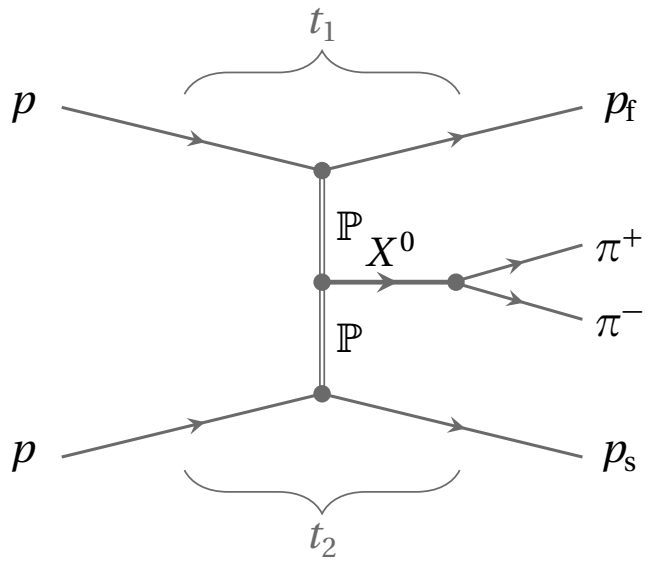
- Consistent picture of the reaction, measured with different parts of experimental setup

$\pi^+\pi^-$ System: Physical Solution



t-Dependent Analysis





- Disregarded $t_2 < 0.1\,\mathrm{GeV}^2/c^2$ due to trigger inefficiency
- 4×4 bins with approximately equal #events ($\approx 3 \cdot 10^5$)
- Not symmetric in $t_{1,2}$!

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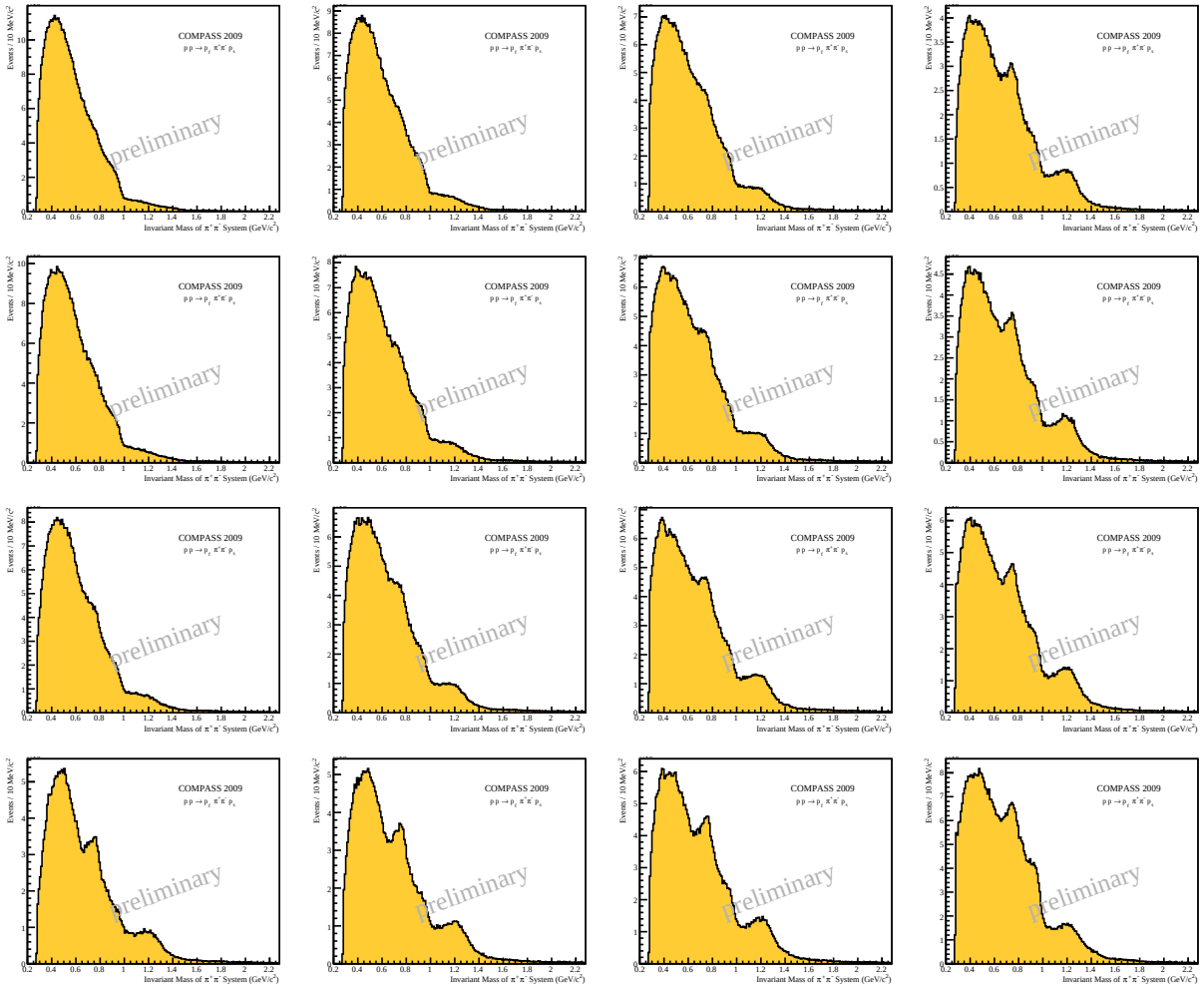

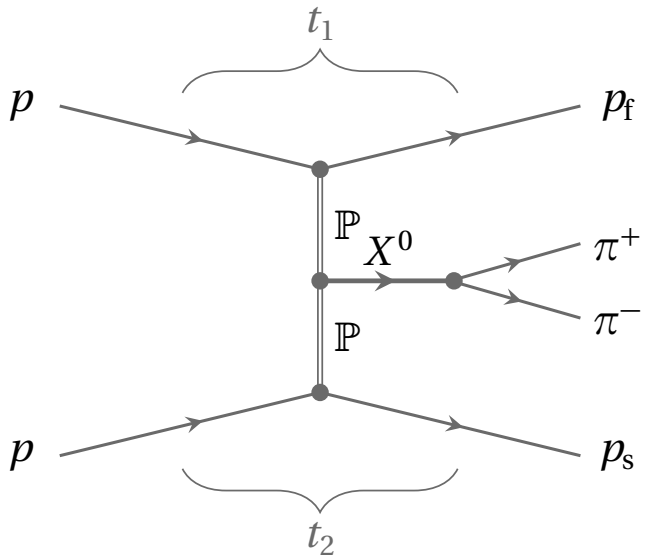

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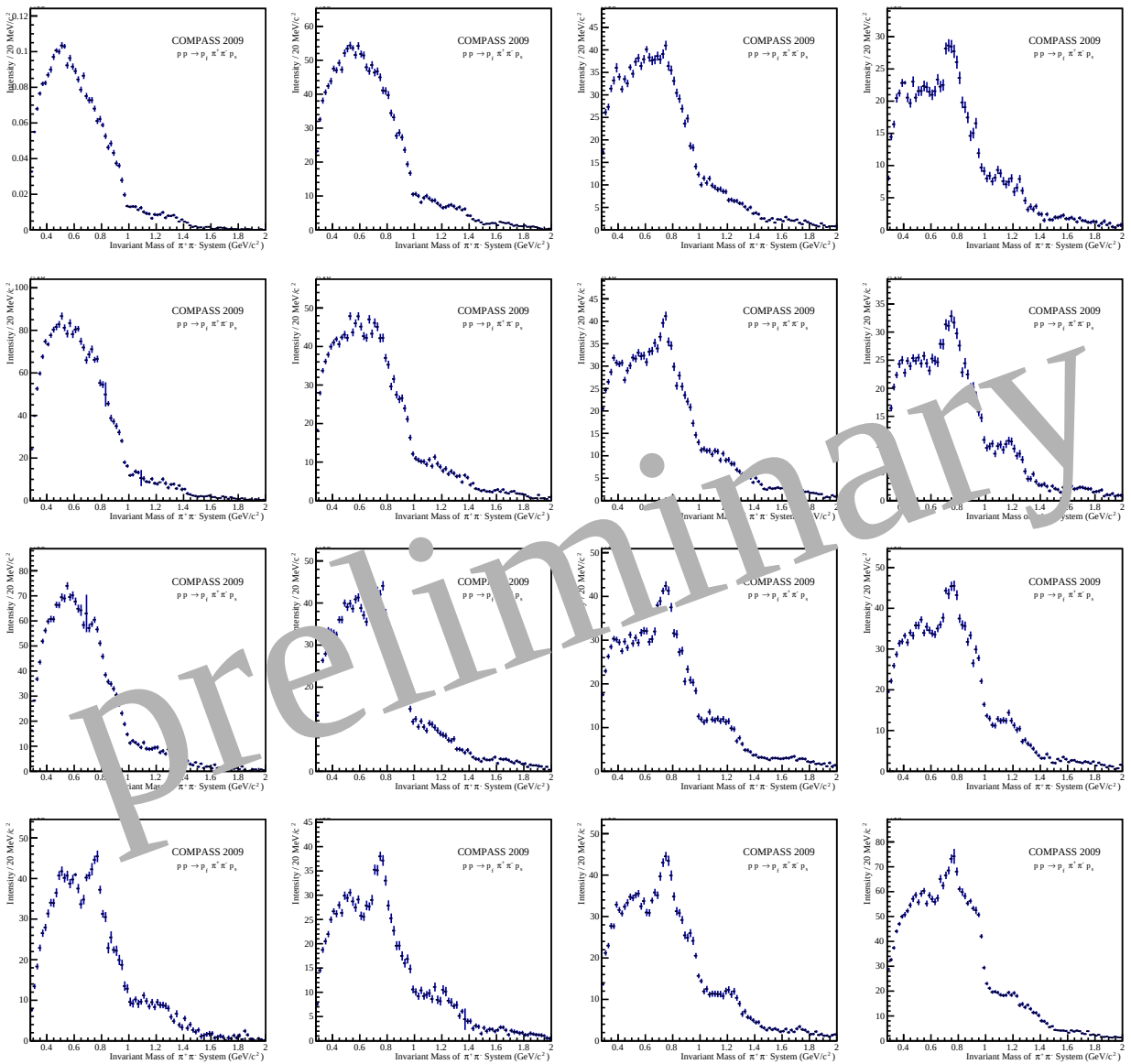
Fit to the $\pi^+\pi^-$ System:



preliminary

$t_1 \Rightarrow$ S_0^-

t_2

$\Downarrow$

- Pure *S*-wave for low $t_{1,2}$

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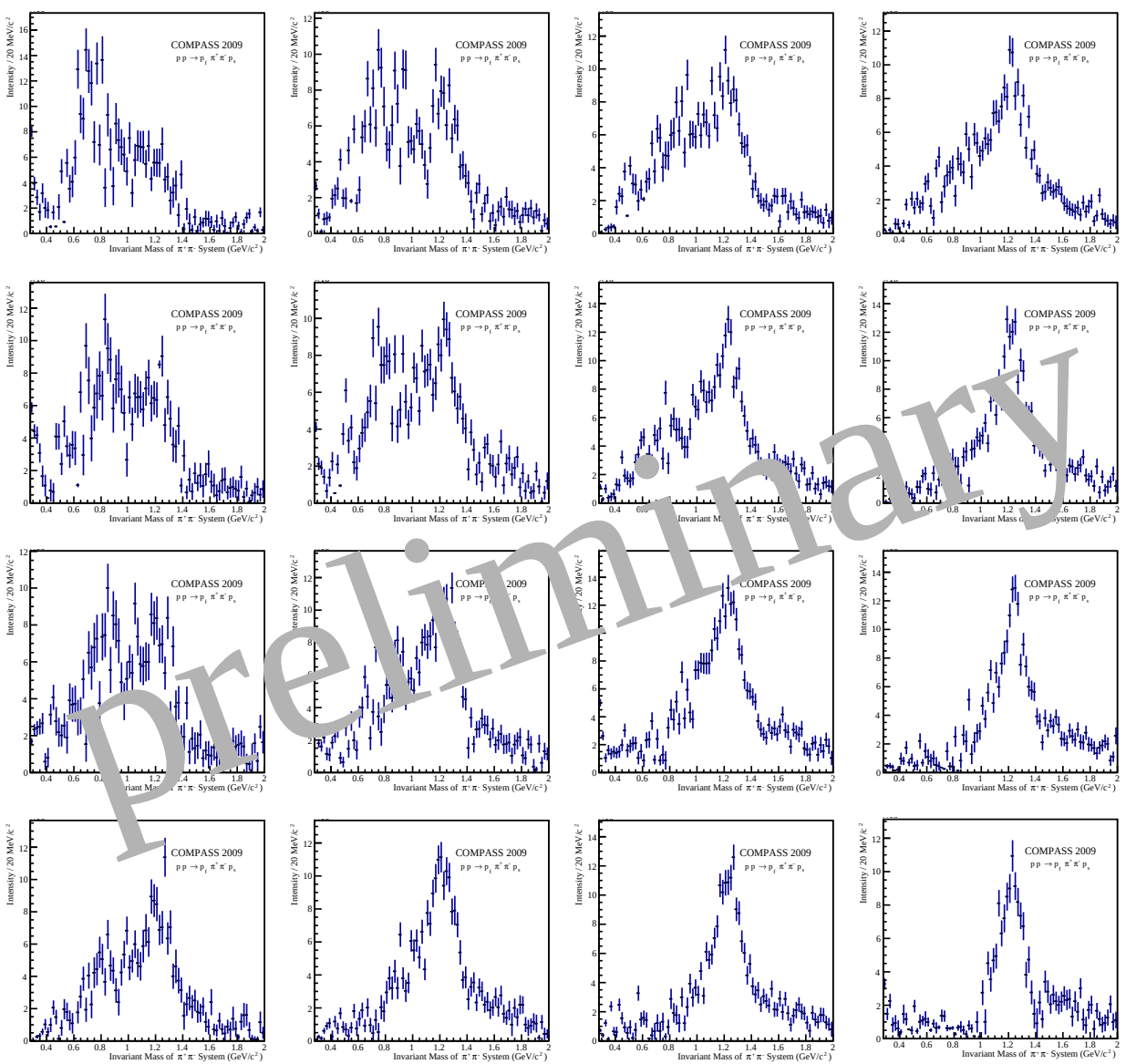

preliminary

$t_1 \Rightarrow$ D_0^-

t_2

$\Downarrow$

- Pure *S*-wave for low $t_{1,2}$
- Production of $f_2(1270)$ increases with $t_{1,2}$

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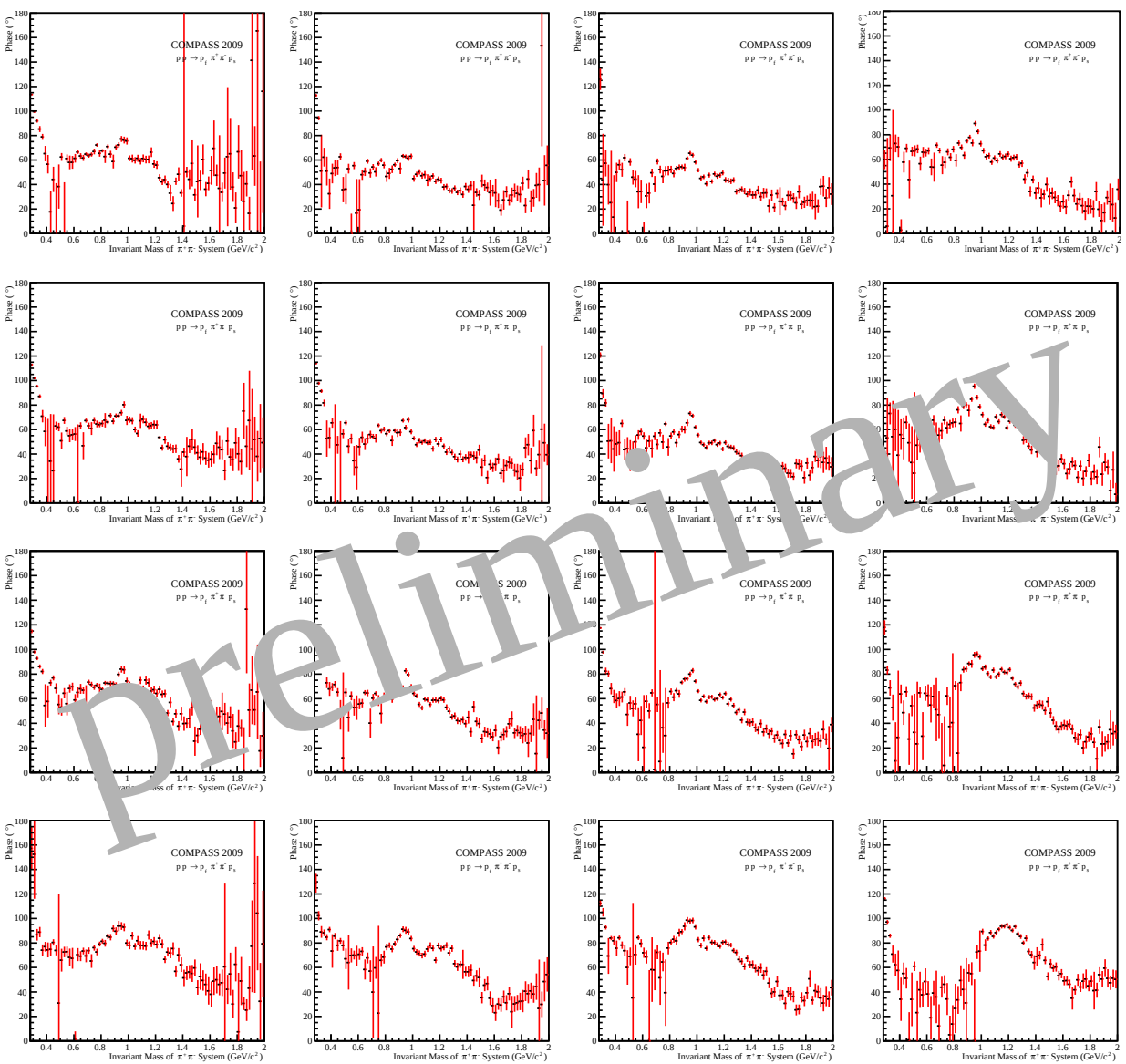


preliminary

$t_1 \Rightarrow$ $S_0^- - D_0^-$

t_2

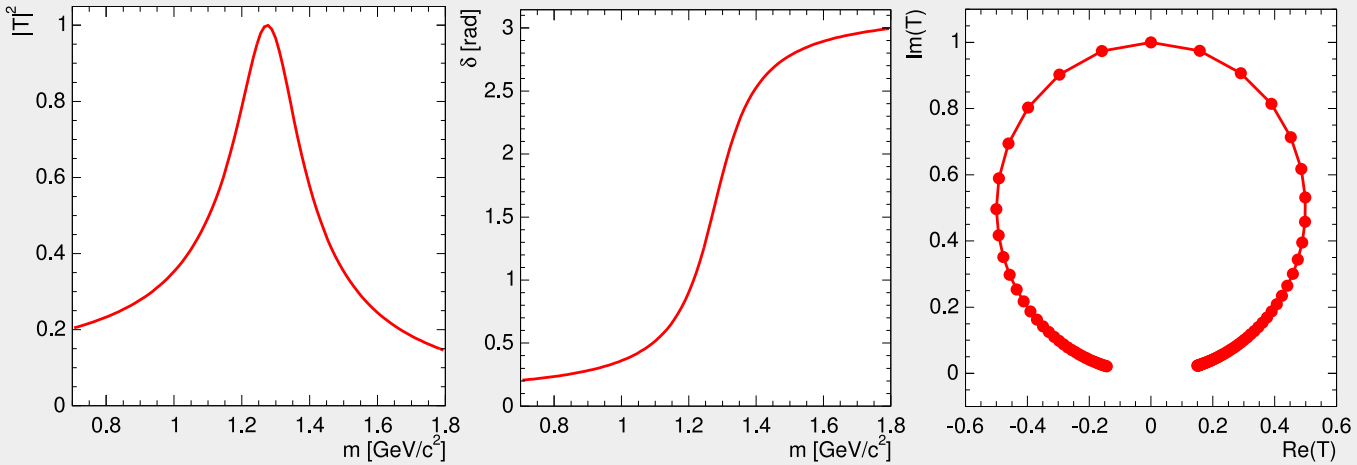
$\Downarrow$

- Pure *S*-wave for low $t_{1,2}$
- Production of $f_2(1270)$ increases with $t_{1,2}$
- Phase approx. stable $\Rightarrow$ *t*-dependence of production mechanisms

Model-Dependent Parametrisation

Resonance: Relativistic Breit-Wigner Function

[K. Peters, arXiv:hep-ph/0412069]

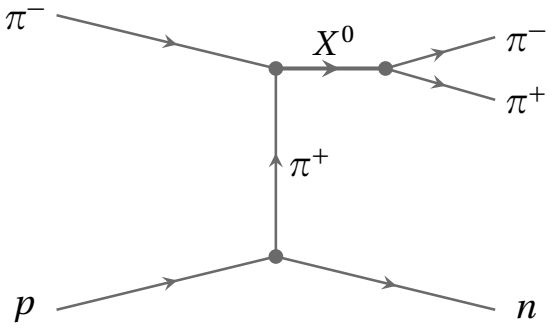


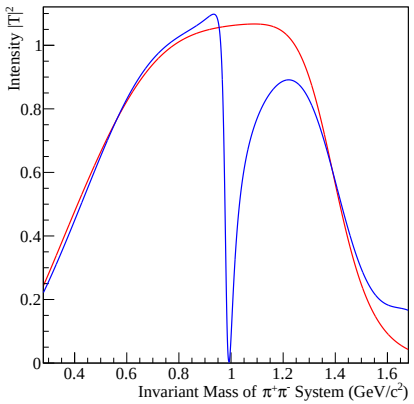
Non-Resonant Contribution

Phase-space with exponential damping (phenomenological)

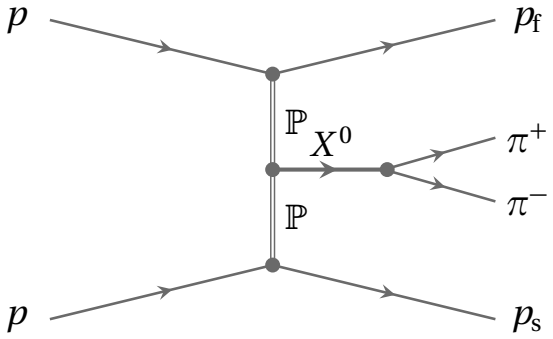
- Sum with complex-valued coefficient (**strength + phase**) for each component

Unitarity Constraints

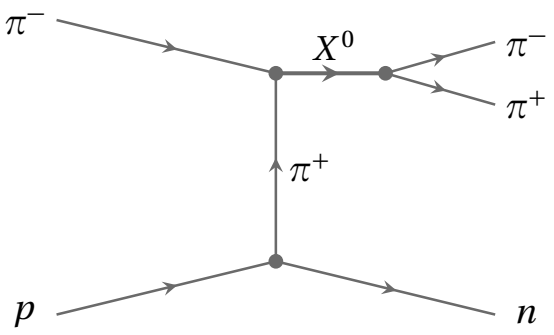


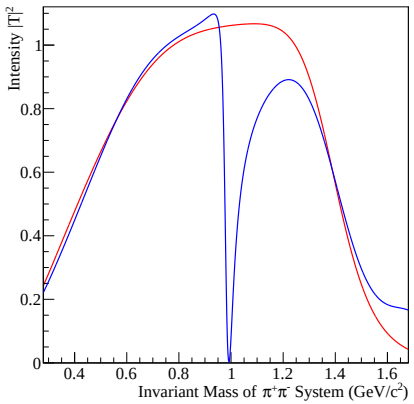


- **Watson theorem** relates phase of prod. processes
- M solution from
  Au, Morgan, Pennington
  Phys. Rev. D 35 (1987) 1633
- $\pi\pi$ ampl. vanishes near threshold (Adler zero)



Unitarity Constraints





- **Watson theorem** relates phase of prod. processes
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  Au, Morgan, Pennington
  Phys. Rev. D 35 (1987) 1633
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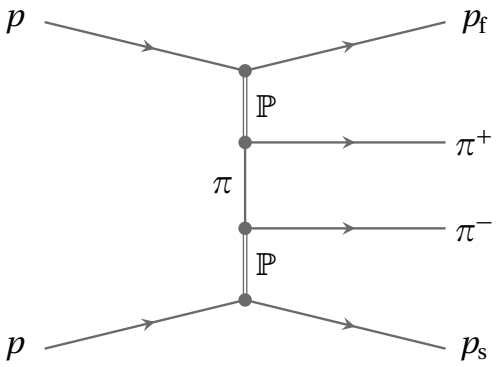

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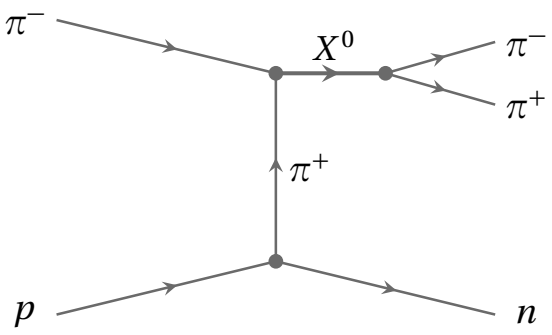

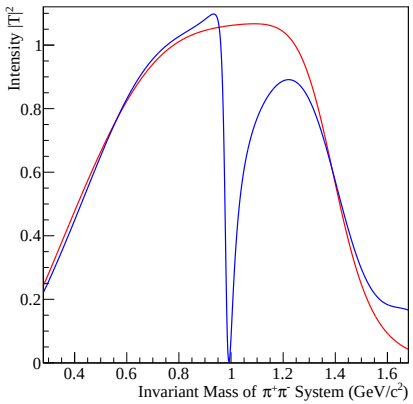

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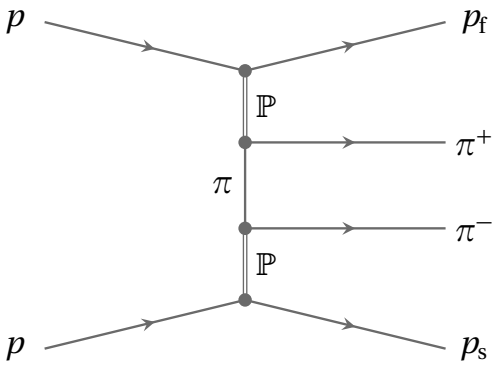

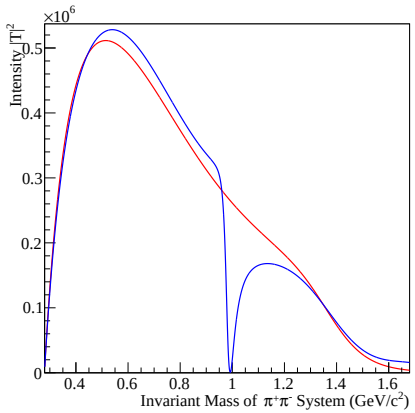

- First fit of S-wave amplitude **with interference** to D-wave
- **Constrain** masses below 1 GeV/c with $\pi\pi$ scattering data
- Interpretation with mass dependent parametrisation **on it's way**!

Summary

COMPASS is a unique experiment to study
Light Mesons in Central Production

- **Large samples** of **precision data** for many final states
- **Novel analysis schemes** provide insight in hadron dynamics
  - t-dependent analysis distinguishes between production mechanisms
  - Interference of S- and D-waves helps to identify resonant components
- **Consistent picture of scalar sector** through combination of different approaches

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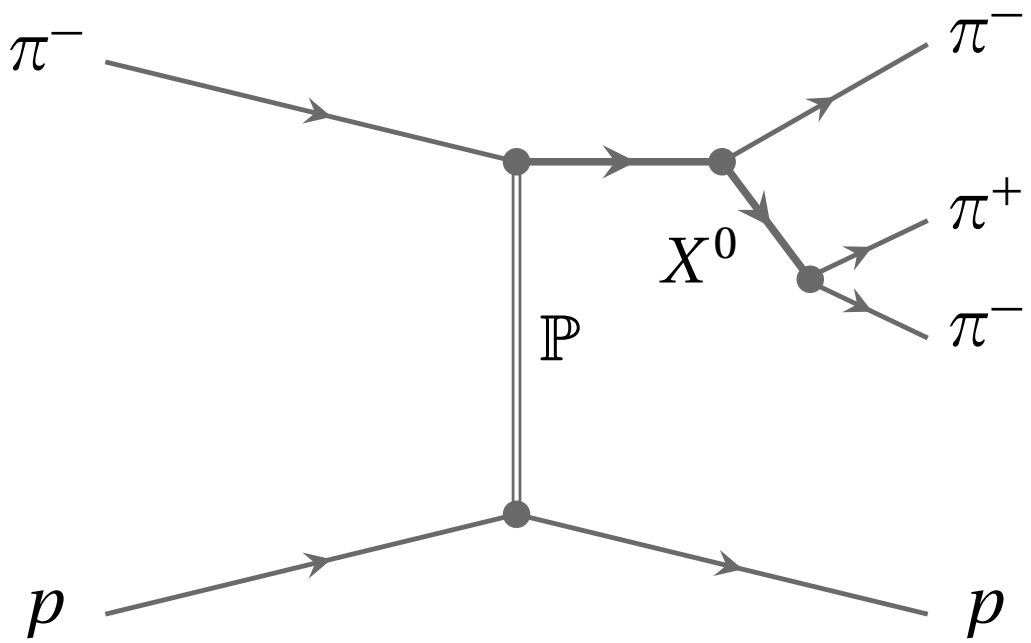
Thank you for your attention!

Subsystem in Diffractive Dissociation

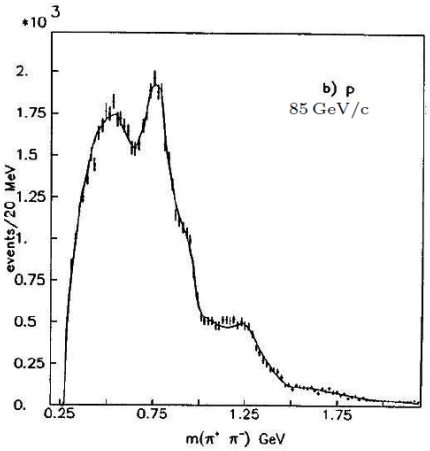


See F. Krinner's Presentation!

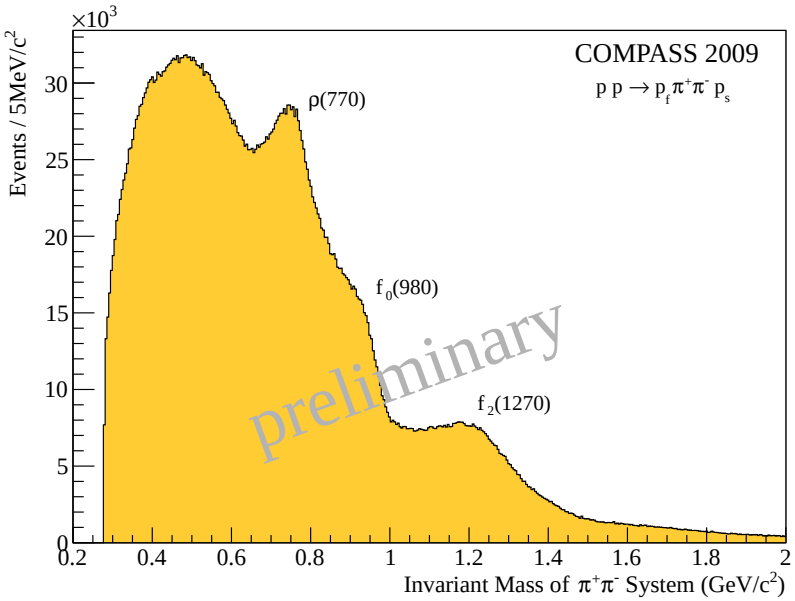
Backup Slides

$\sqrt{s}$-Dependence

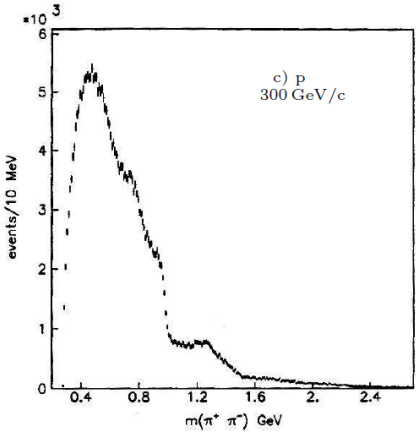
T.A. Armstrong et al. [Z. Phys. C51 (1991)]



$\sqrt{s} = 12.7\,\mathrm{GeV}/c^2$



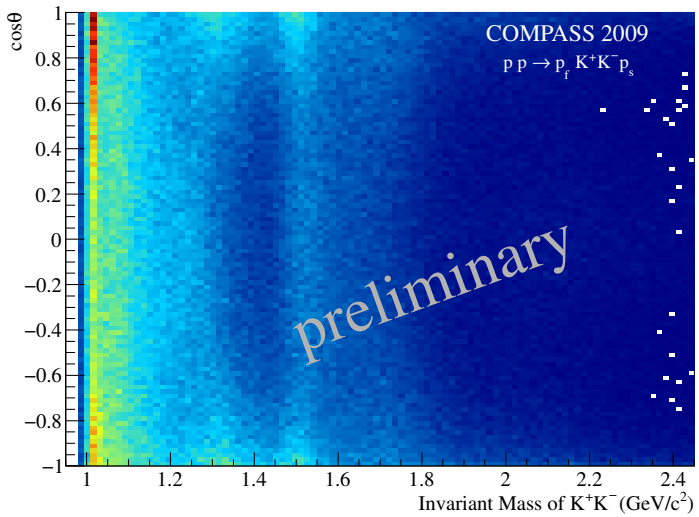
$\sqrt{s} = 18.9\,\mathrm{GeV}/c^2$

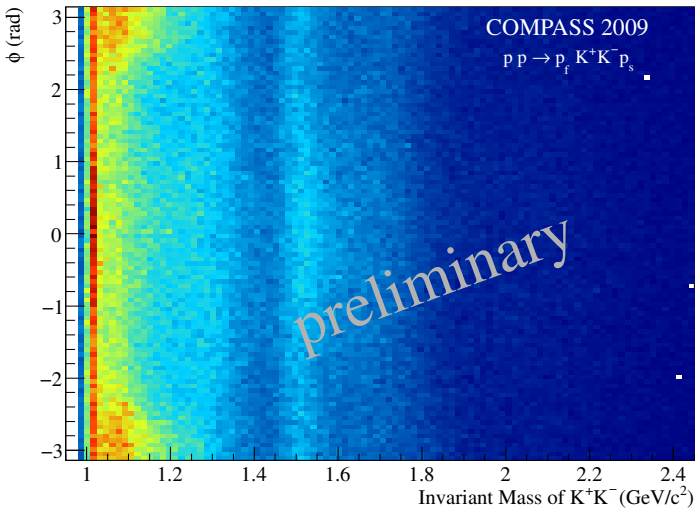


$\sqrt{s} = 23.7\,\mathrm{GeV}/c^2$

- Production of $\rho(770)$ disappears rapidly with increasing $\sqrt{s}$
- Low-mass enhancement and $f_0(980)$ remain practically unchanged
  $\rightarrow$ characteristic for s-independent Pomeron-Pomeron scattering
- Kinematic selection cannot single out pure DPE sample

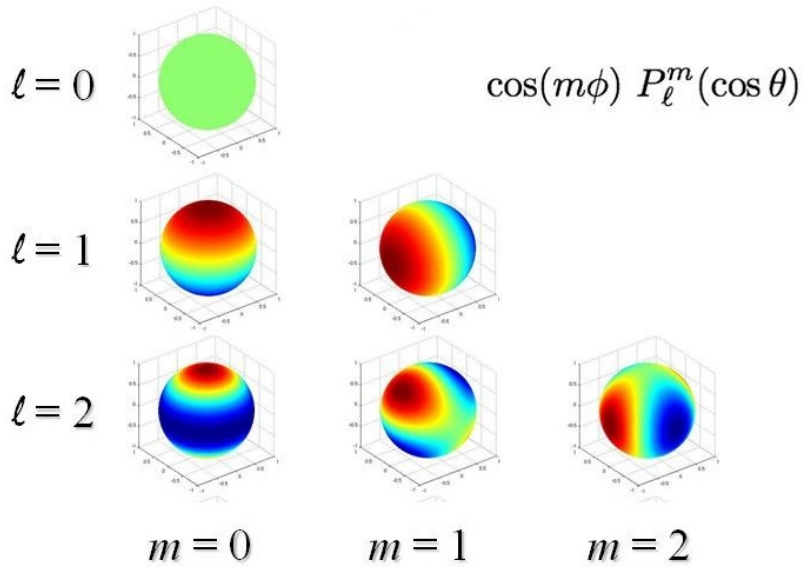
Partial-Wave Analysis



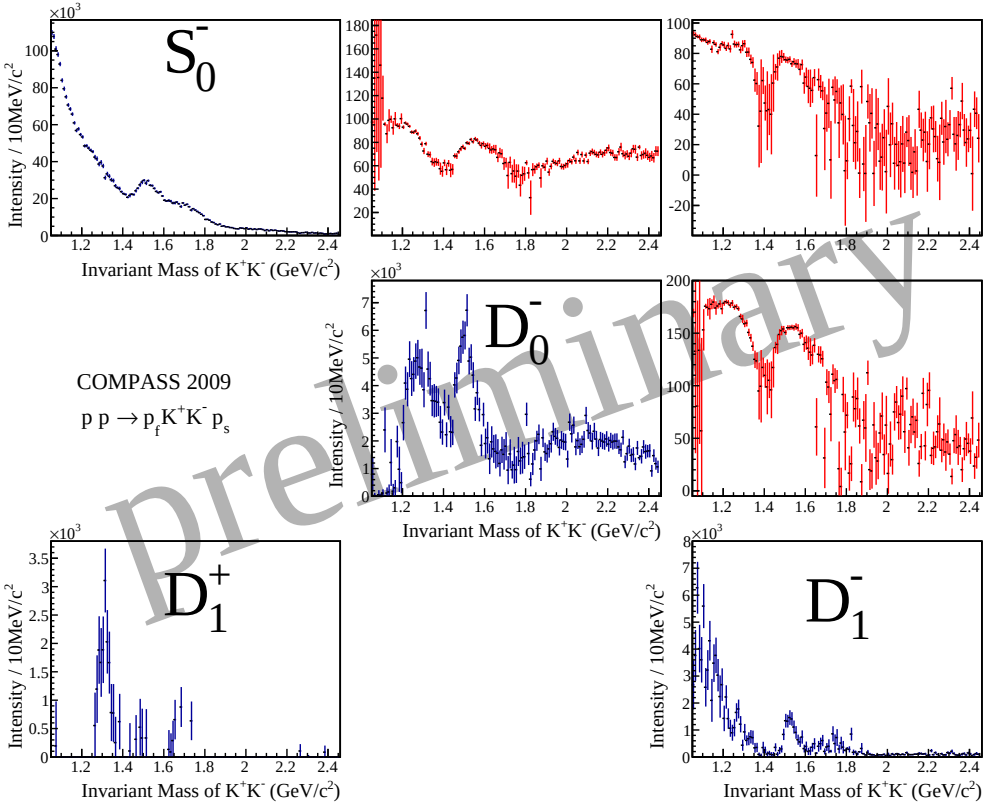


$X \to K^+K^-$

- **Assumption:** collision of two space-like exchange particles ($\mathbb{P}, \mathbb{R}$)
- Decay of X^0 fully described by $M(K^+K^-)$, $\cos(\vartheta)$ and φ
- Decompose into complex-valued amplitudes (spherical harmonics) with definite spin and parity



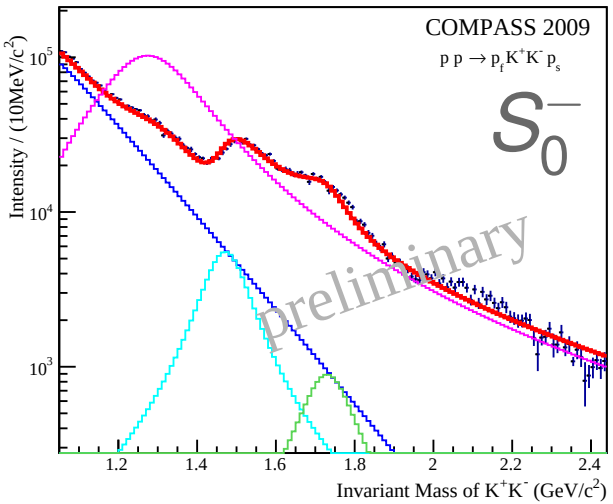
Fit to the K^+K^- System

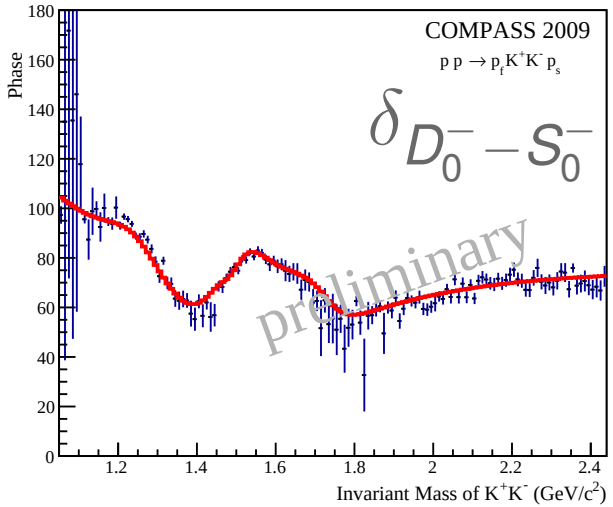


- Similar partial-wave analysis of K^+K^--system
- Odd waves do not play a significant role above the $\phi(1020)$-mass
  $\Rightarrow$ Reduction of ambiguities

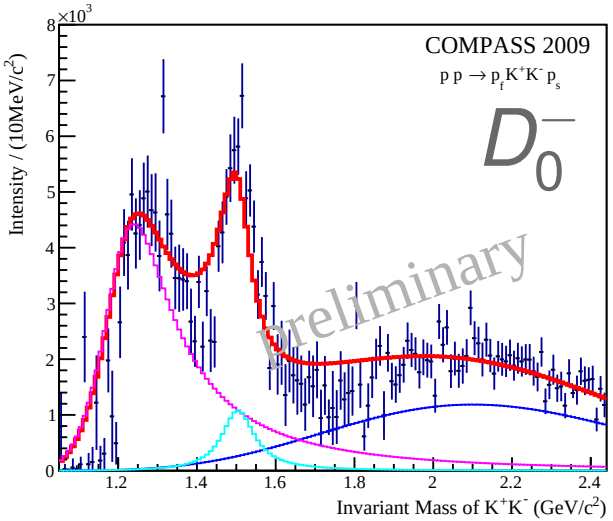
Mass-Dependence of K^+K^-

$f_0(1370)$
$f_0(1500)$
$f_0(1710)$





BW contributions
non-resonant contribution
coherent sum



$f_2(1270)$
$f_2'(1525)$

Interference of S and D

distinguish resonances from non-resonant contribution