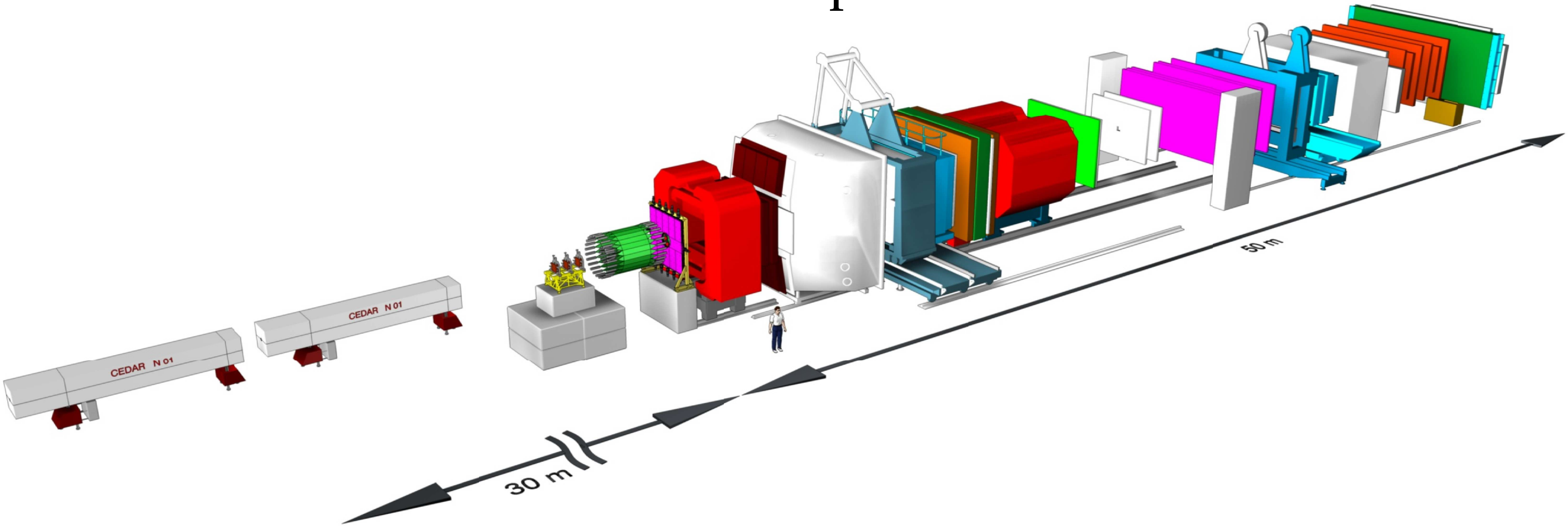
Analysis of diffractive dissociation of exclusive $K^- \pi^+ \pi^-$ events

In the high energetic hadron beam of the COMPASS-experiment



Prometeusz Jasinski
on behalf of the
COMPASS-Collaboration

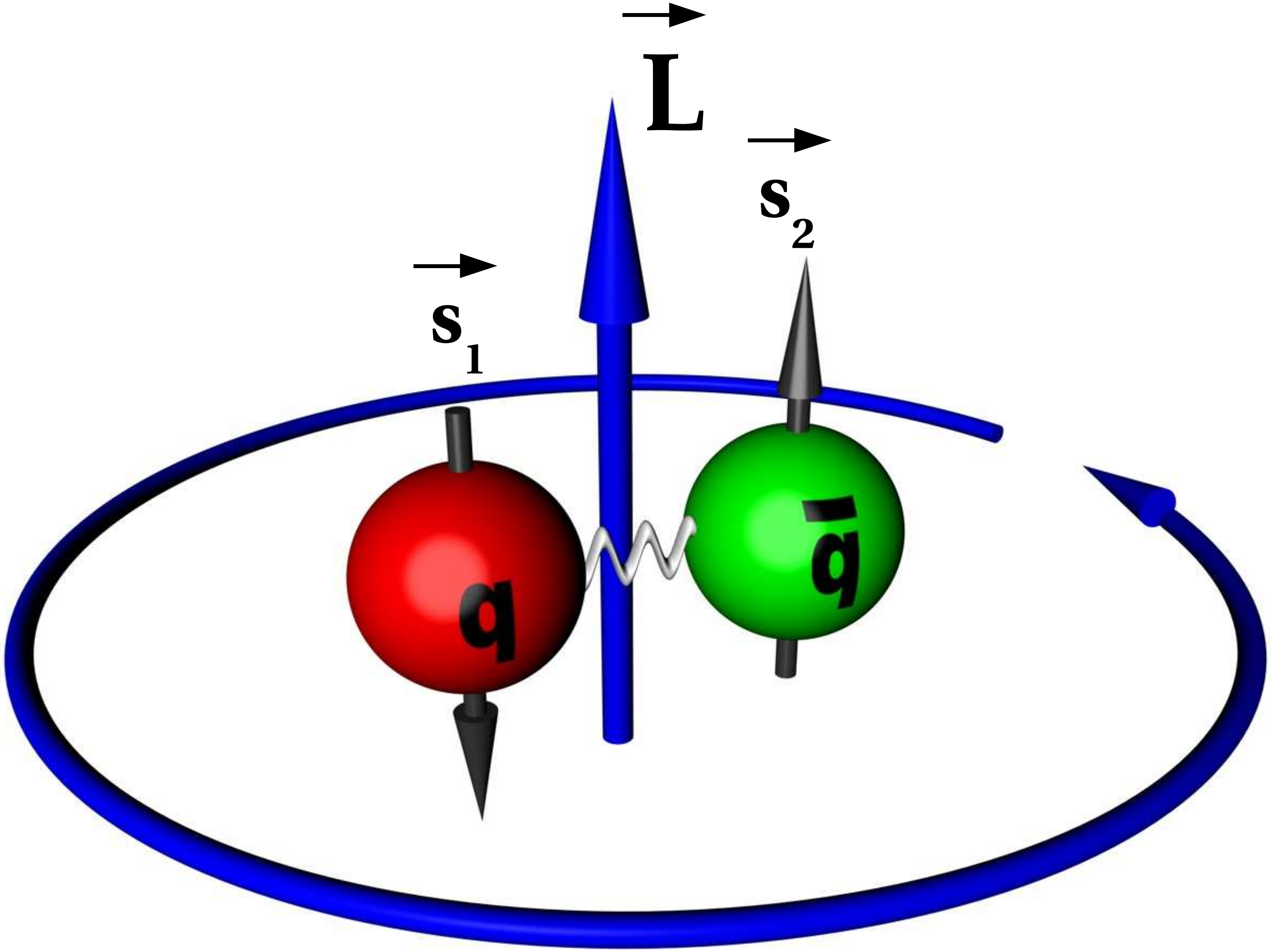
bmb+f - Förderschwerpunkt COMPASS Großgeräte der physikalischen Grundlagenforschung

COMPASS

JOHANNES GUTENBERG UNIVERSITÄT MAINZ

Hadron 2011
14.06.2011

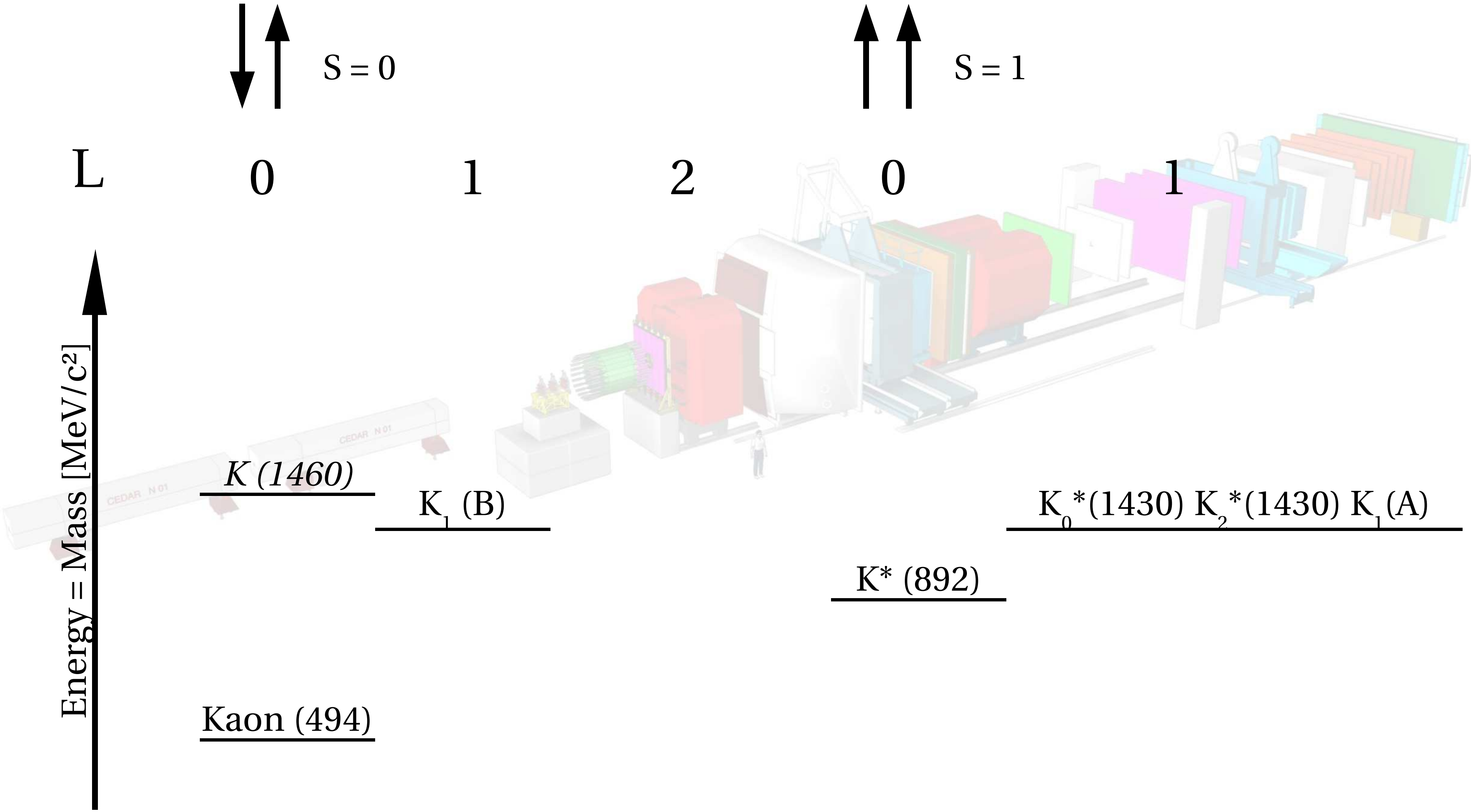
The $q\bar{q}$ model in a potential



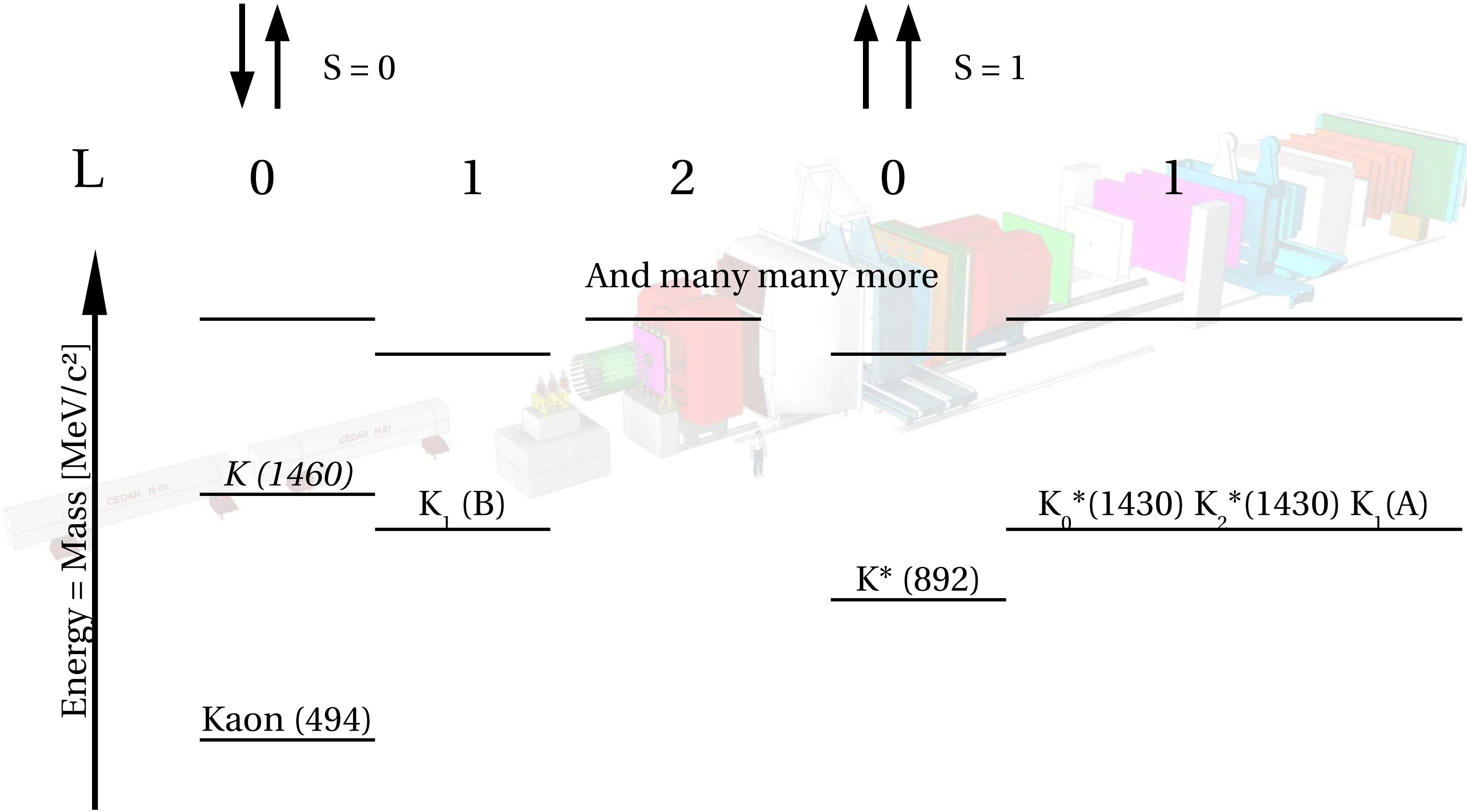
$|u\bar{s}>$ $|d\bar{s}>$ $|\bar{u}s>$ $|\bar{d}s>$ $\longrightarrow$ Isospin I = ½

Isospin = ½ light meson spectrum

$|\, u\bar{s} > \; |\, d\bar{s} > \; |\, \bar{u}s > \; |\, \bar{d}s >$

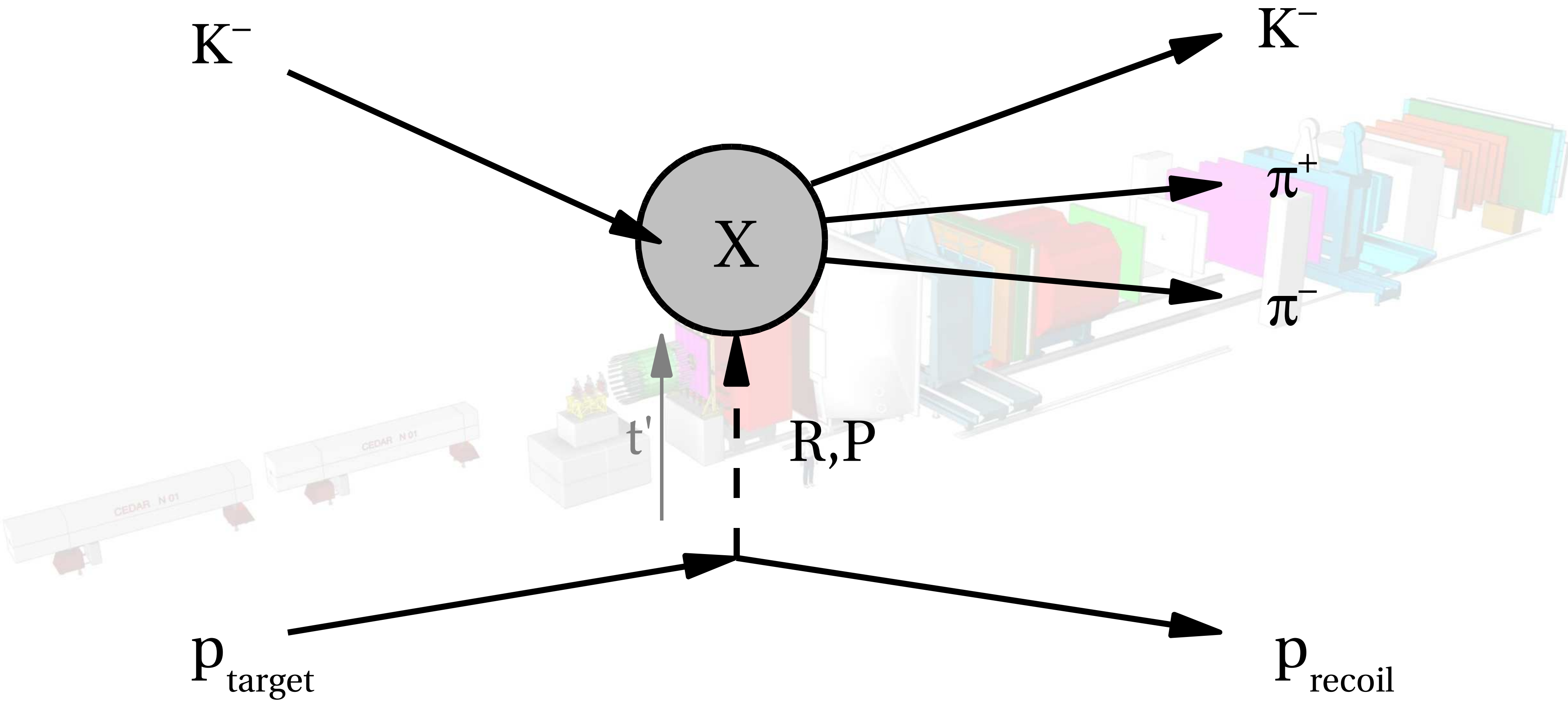


Isospin = ½ light meson spectrum

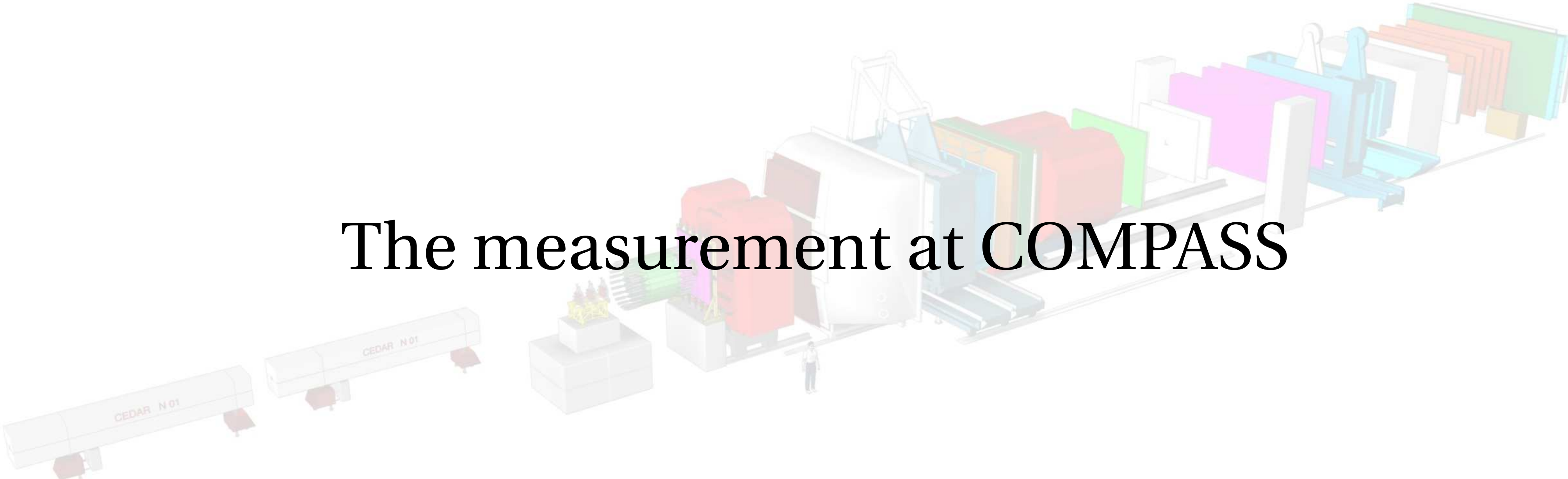


How do we produce those resonances?

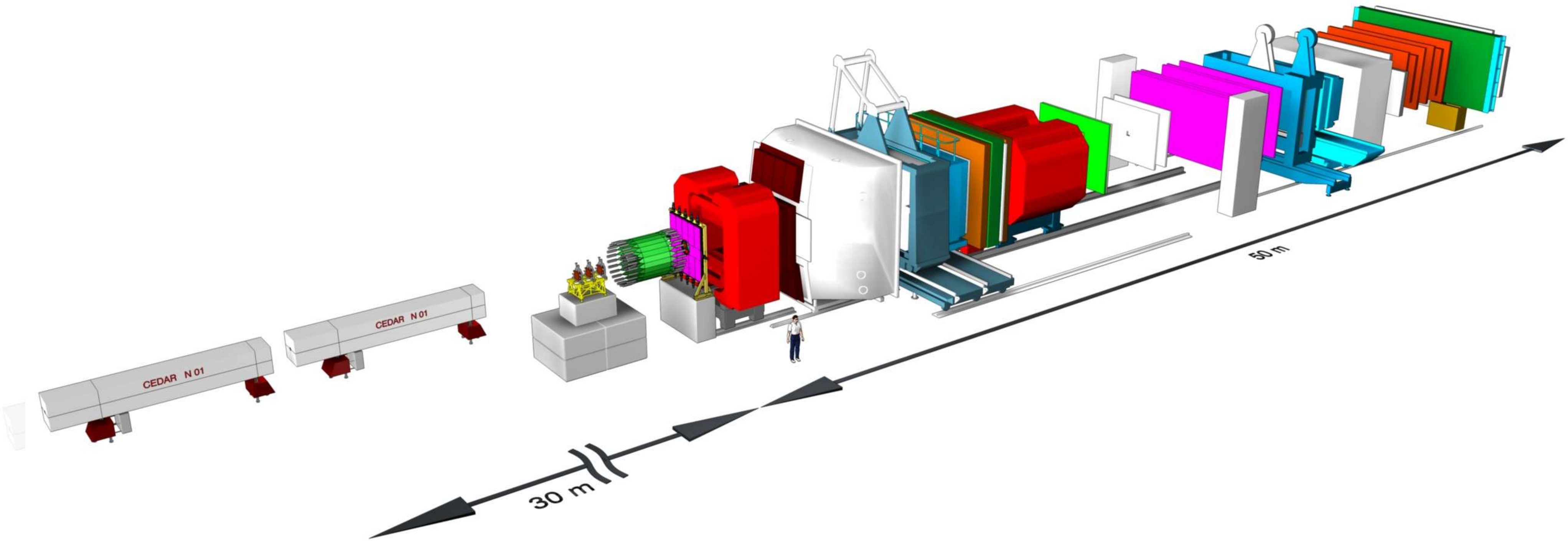
Diffractive dissociation into $K^- \pi^+ \pi^-$



The measurement at COMPASS



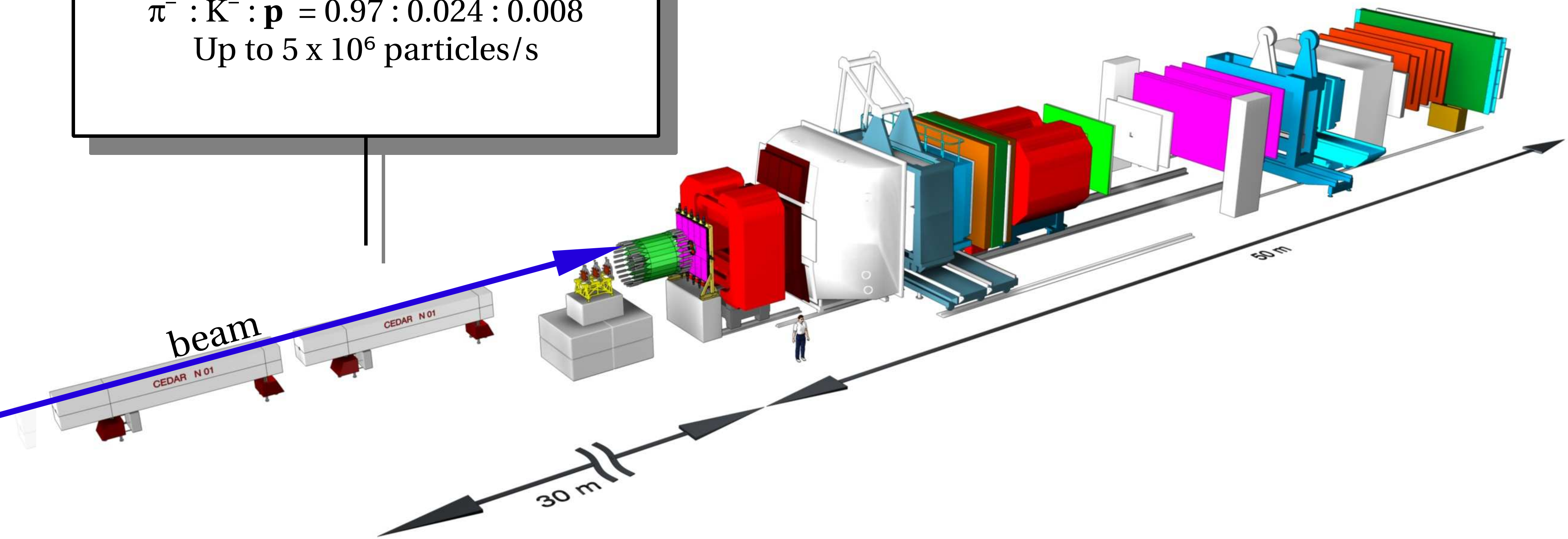
The COMPASS Spectrometer 2008/2009



The COMPASS Spectrometer 2008/2009

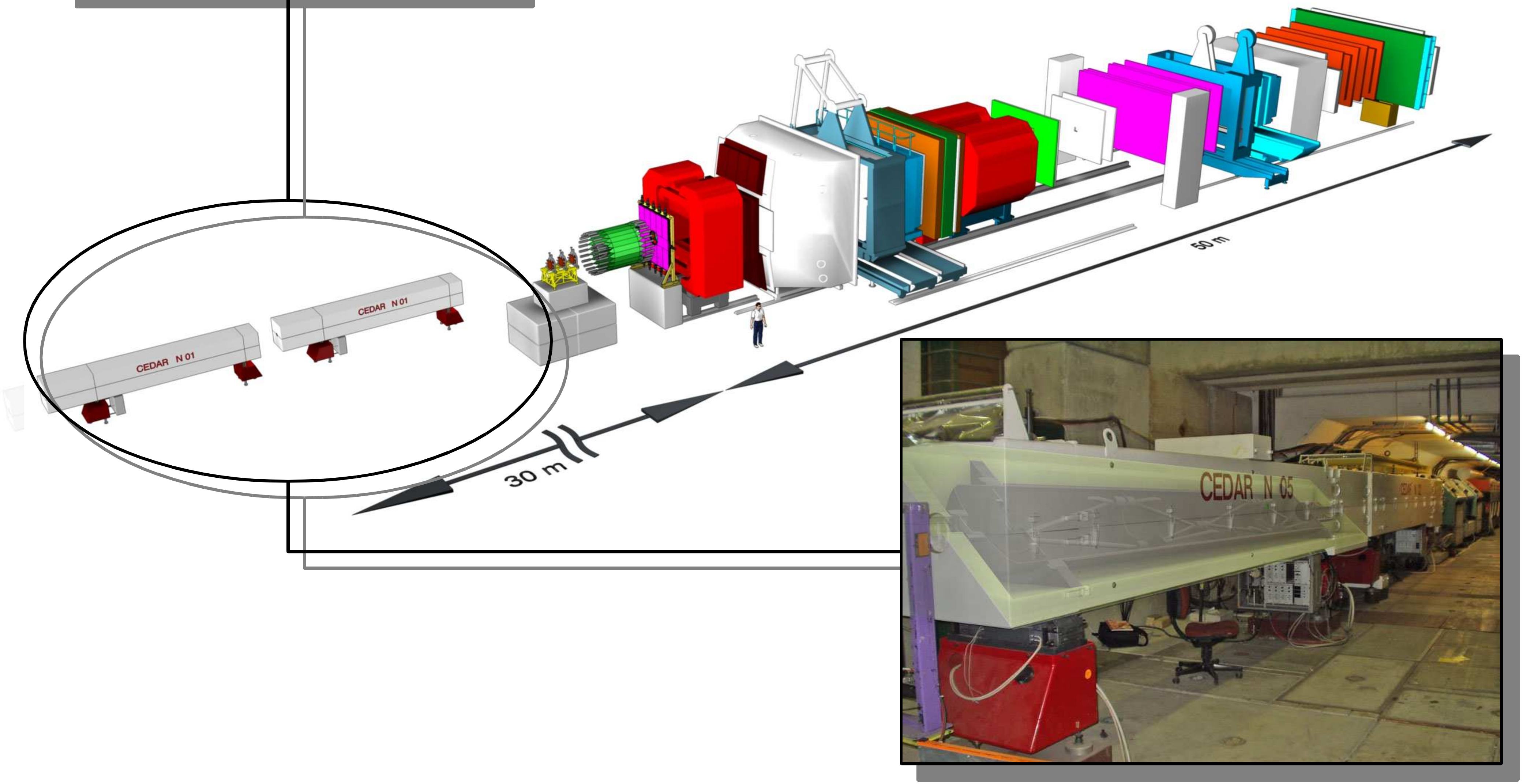
Beam properties

Beam momentum 190 GeV/c
Beam composition:
$\pi^- : K^- : \bar{\mathbf{p}} = 0.97 : 0.024 : 0.008$
Up to 5 x 10^6 particles/s

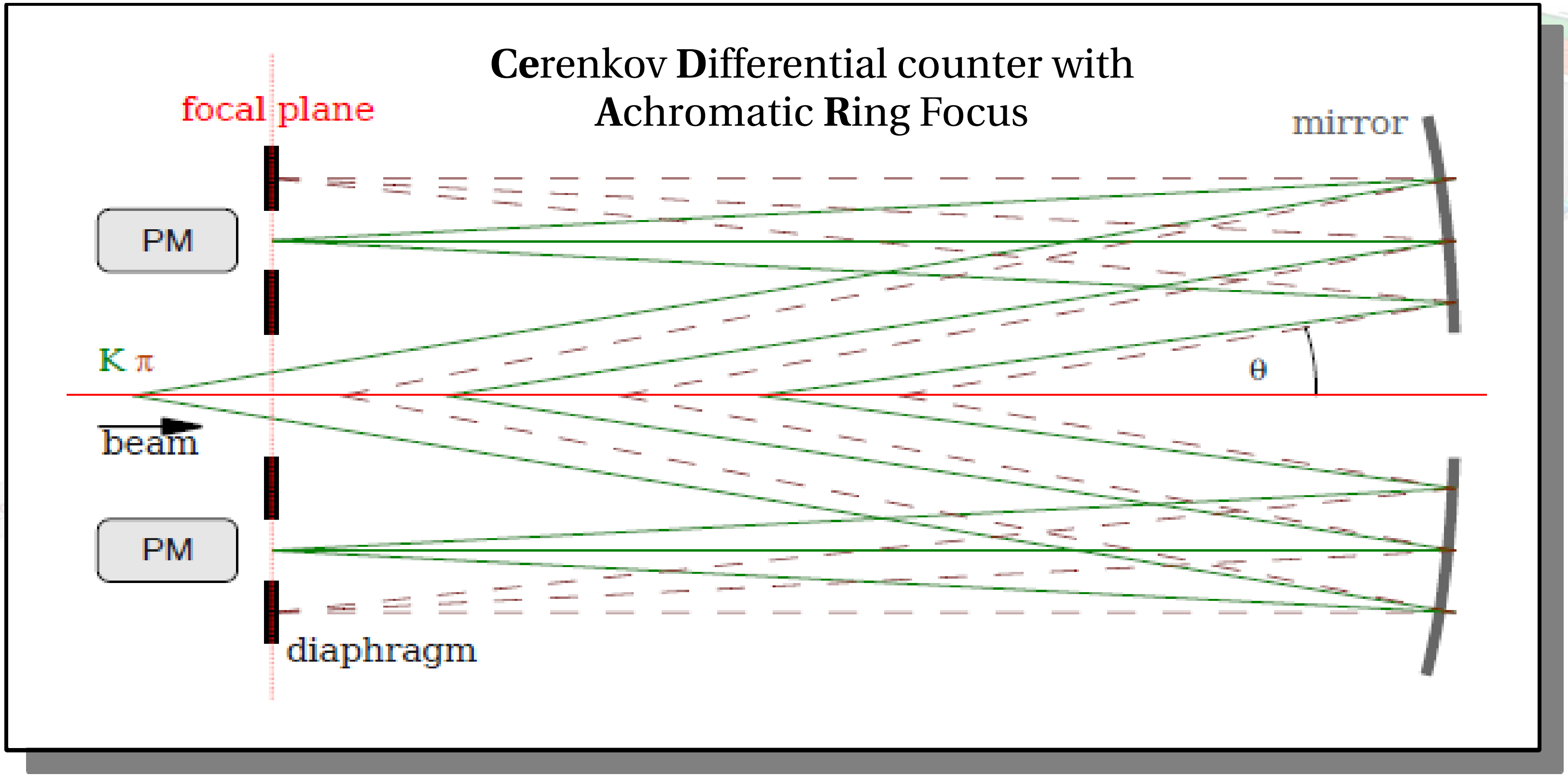


The COMPASS Spectrometer 2008/2009

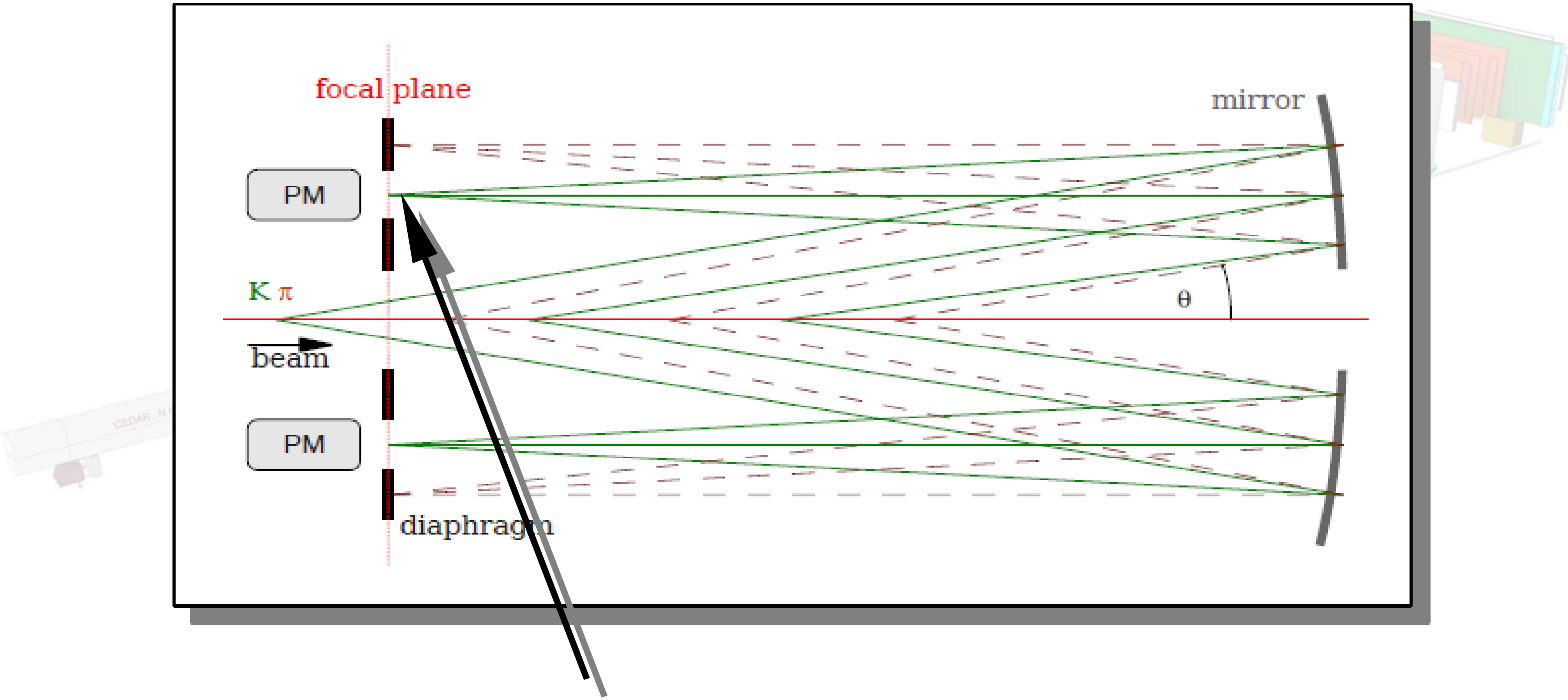
CEDAR detectors for beam particle identification



CEDAR particle identification



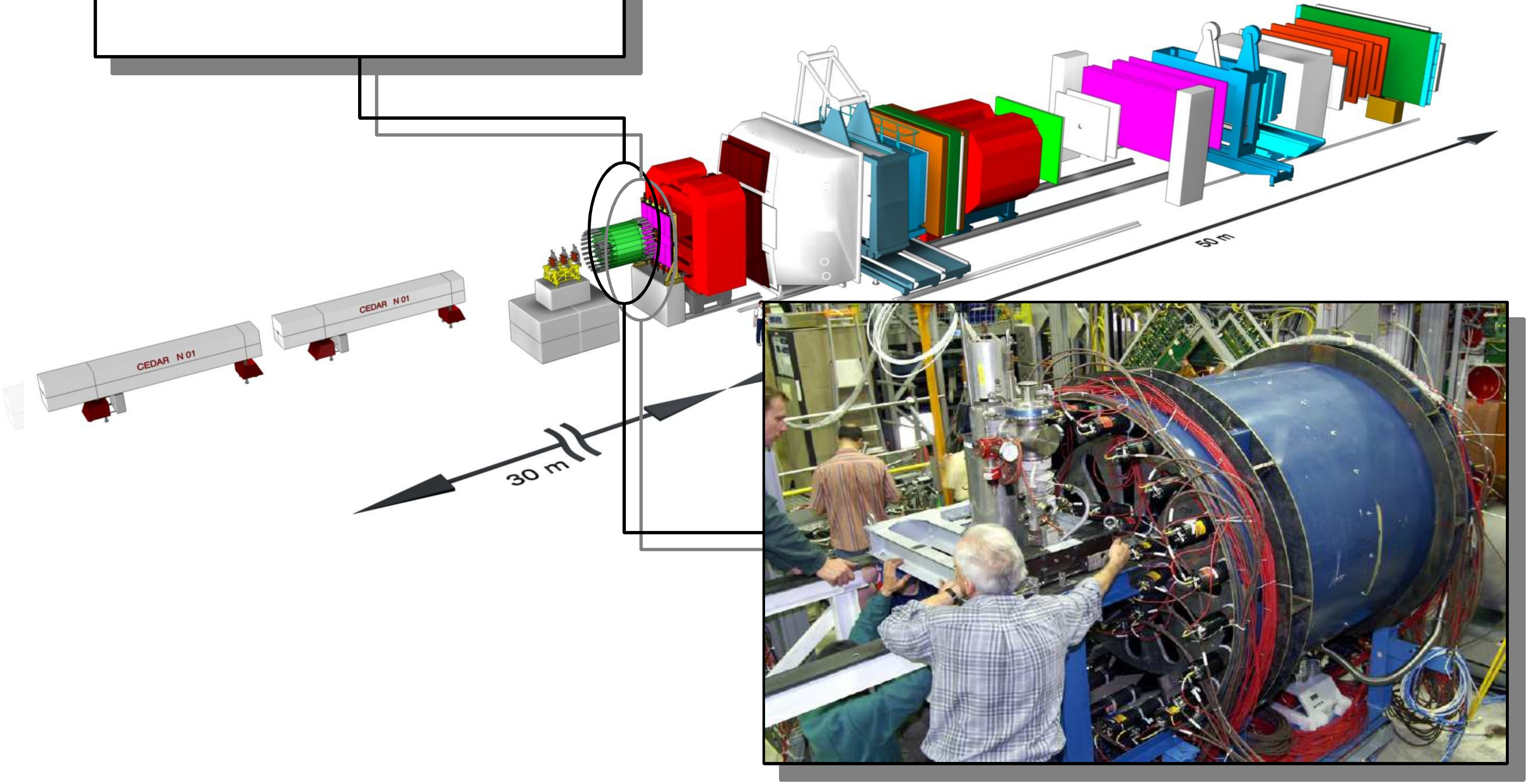
CEDAR particle identification



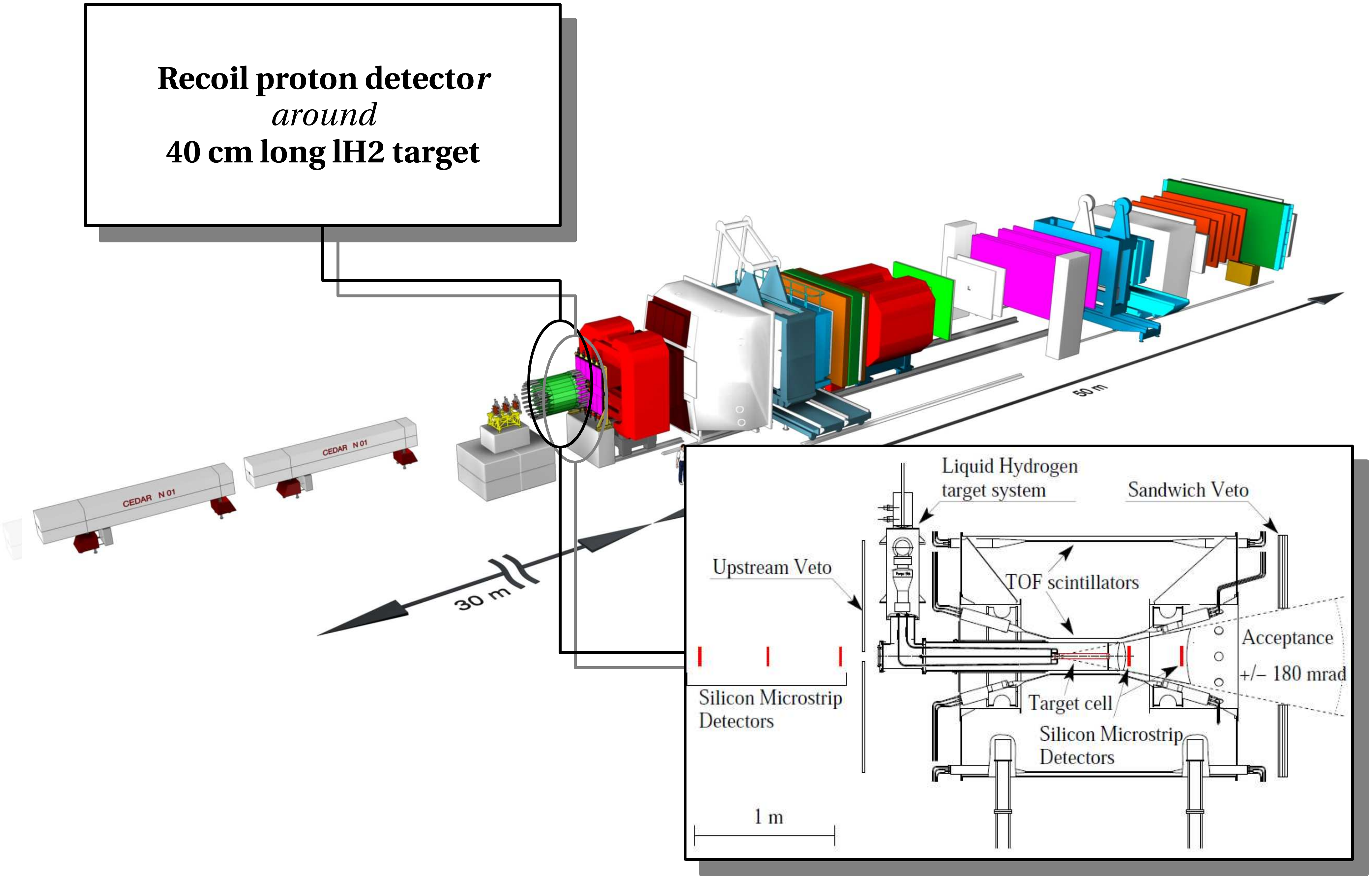
Difference of the cherenkov ring radii of a pion and a kaon
is below 0.1 mm at 190 GeV/c beam momentum !

The COMPASS Spectrometer 2008/2009

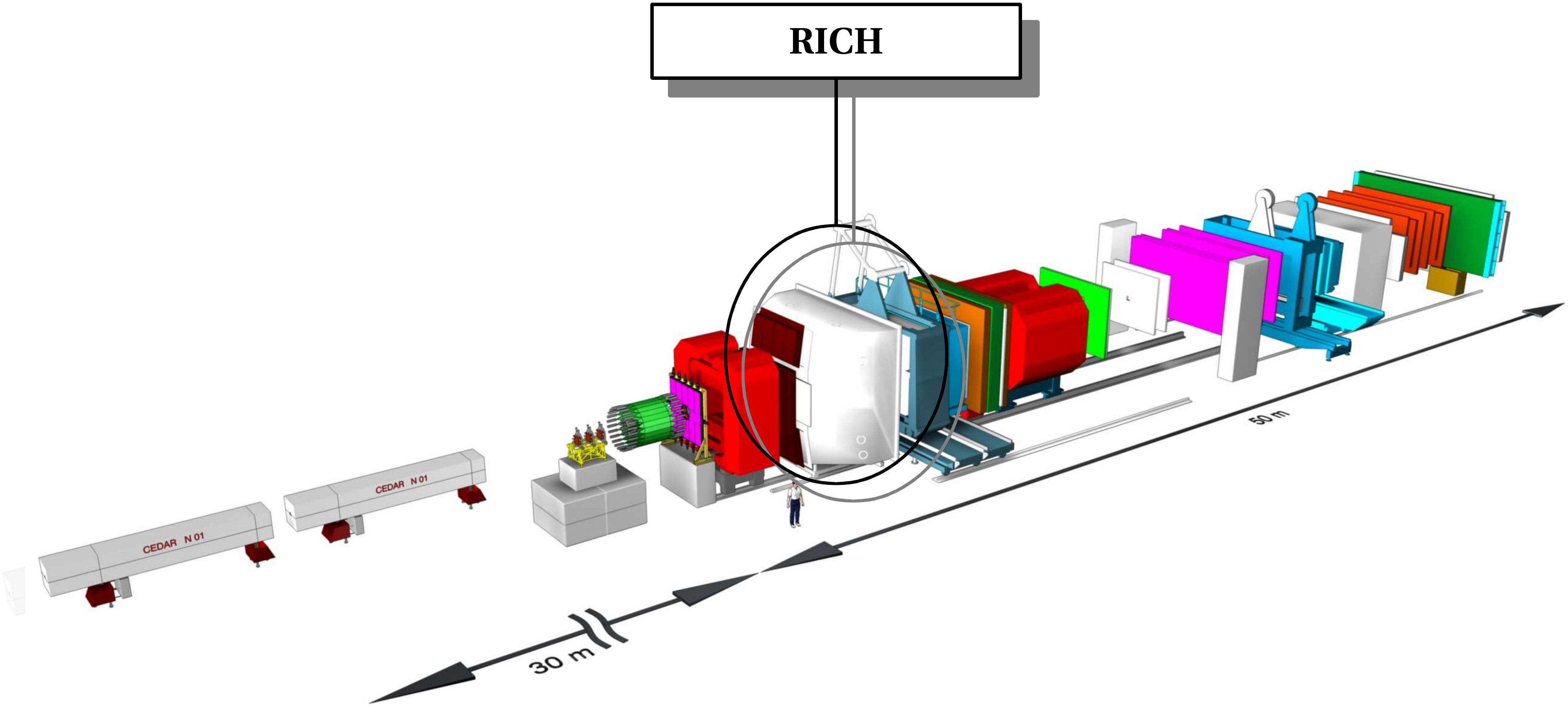
Recoil proton detector
around
40 cm long lH2 target



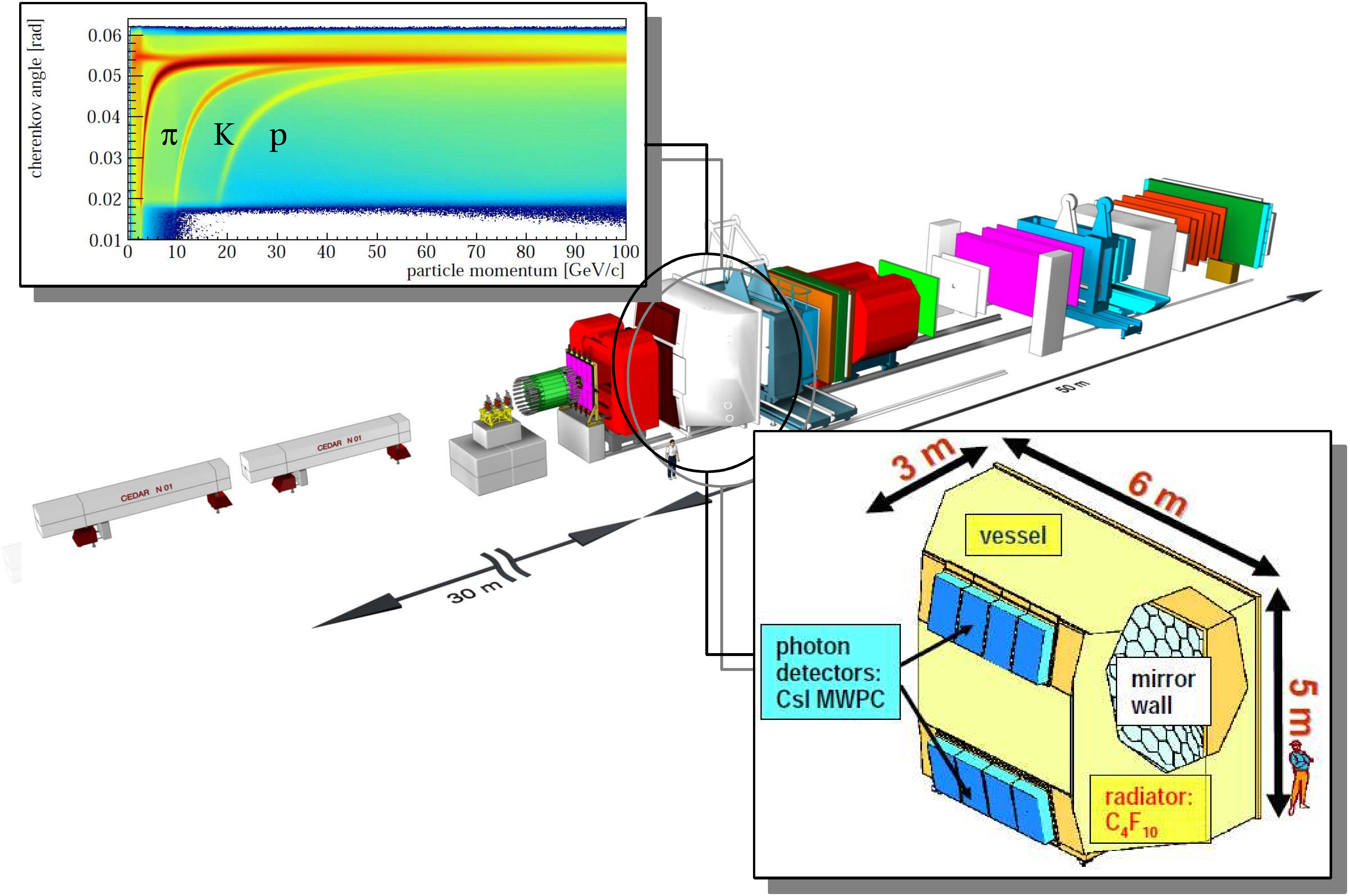
The COMPASS Spectrometer 2008/2009



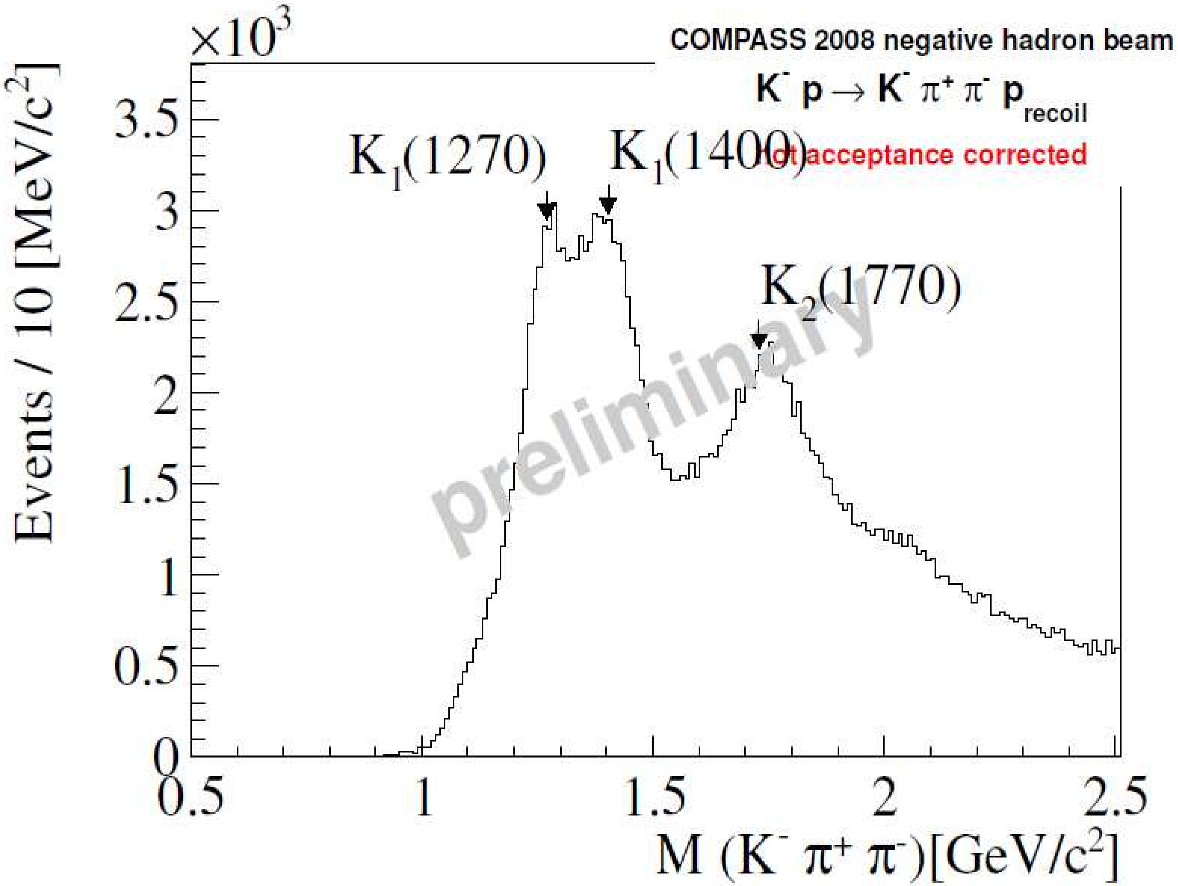
The COMPASS Spectrometer 2008/2009

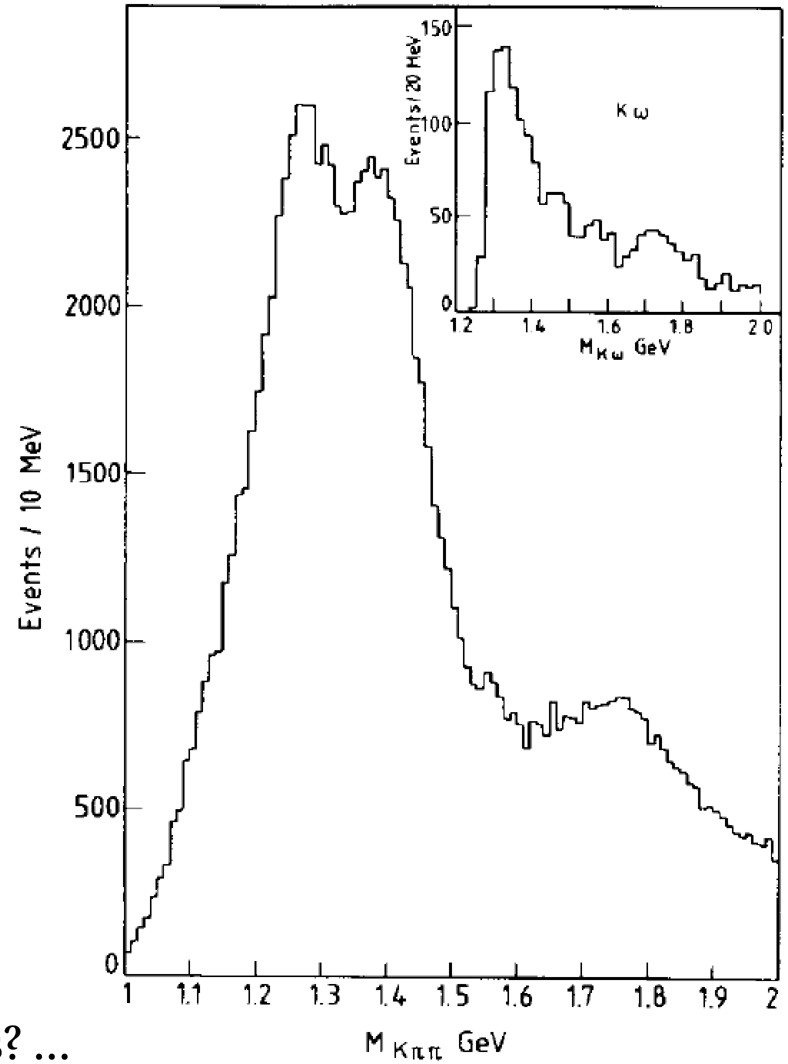


The COMPASS Spectrometer 2008/2009



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





Are those resonances decaying directly into 3 particles? …

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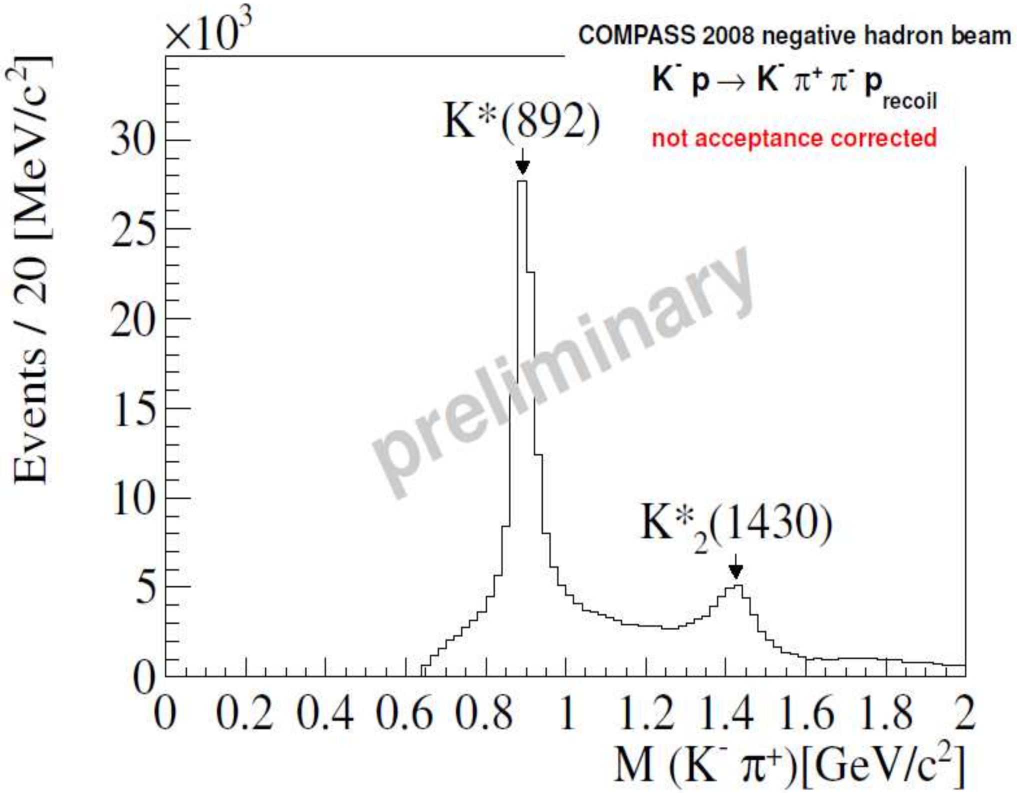
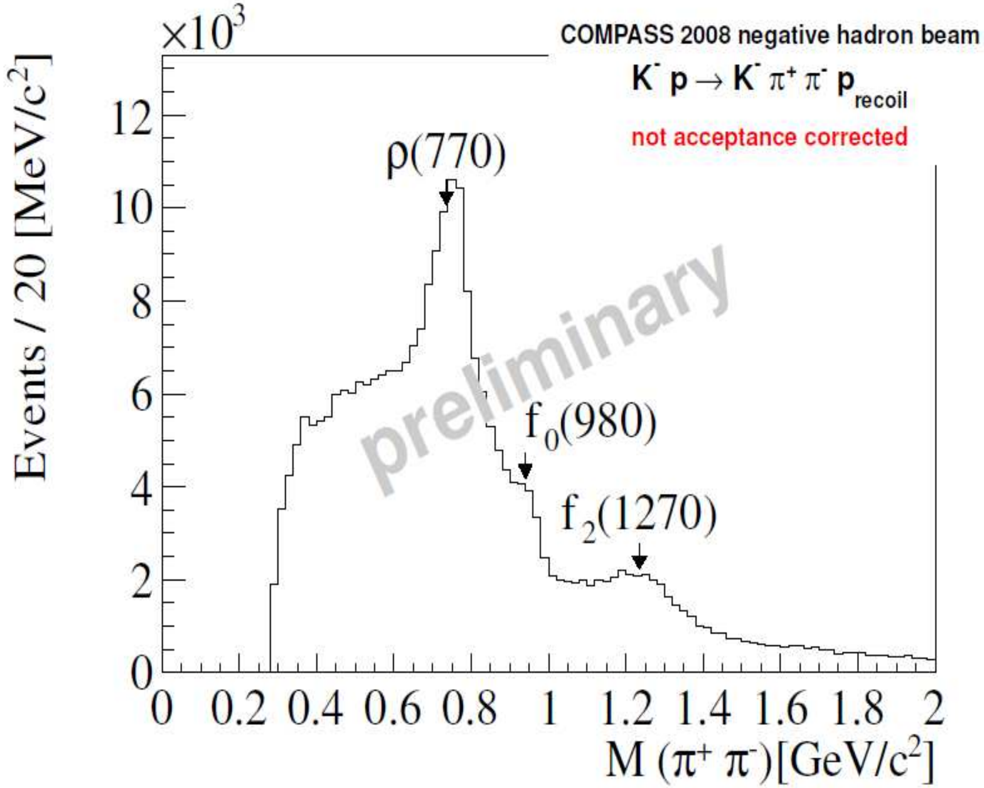
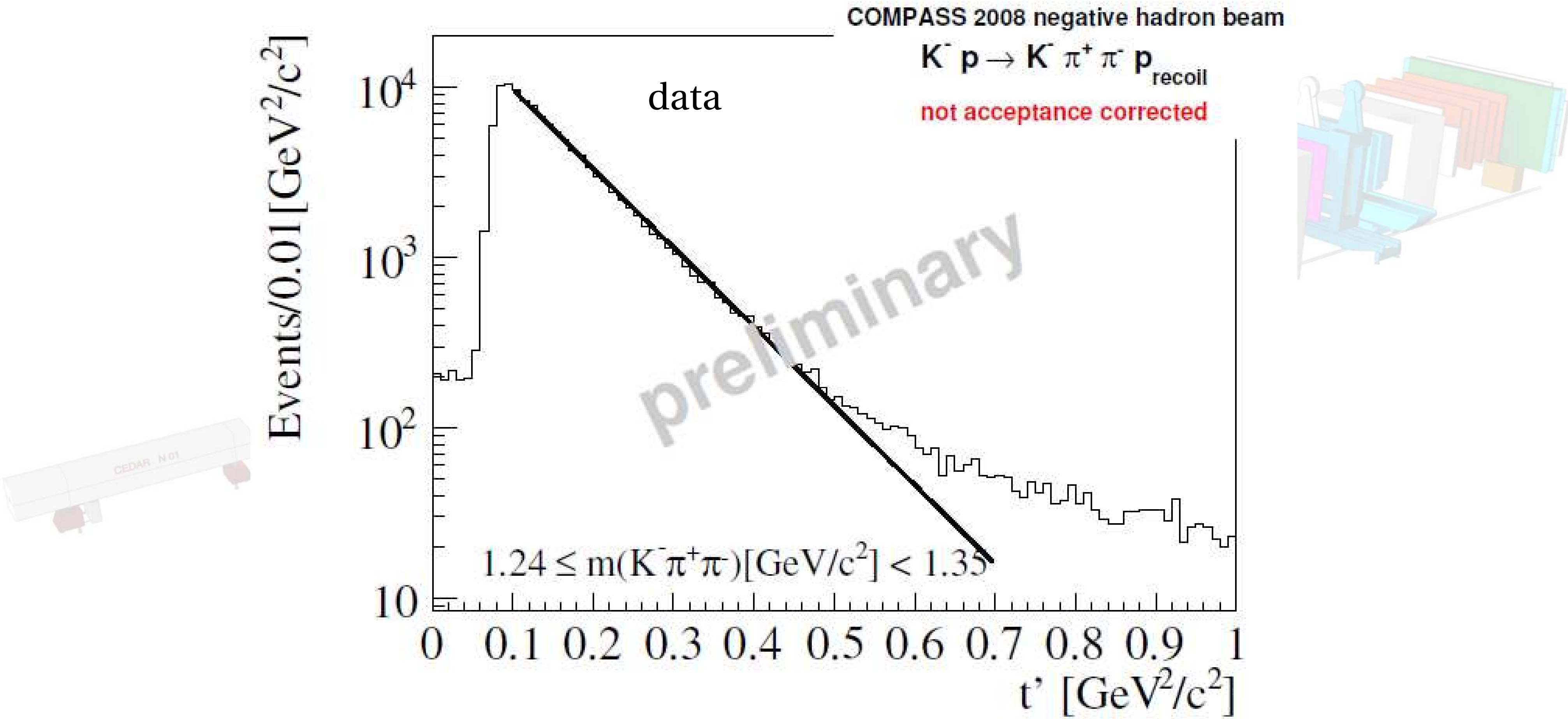
Invariant mass distributions ($K^- \pi^+$) and ($\pi^+ \pi^-$)

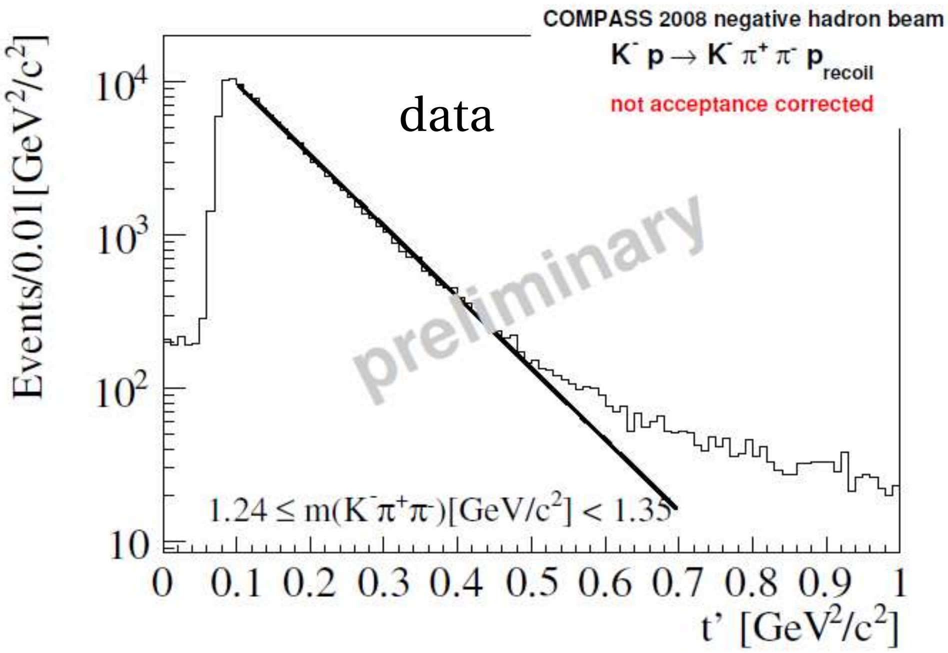


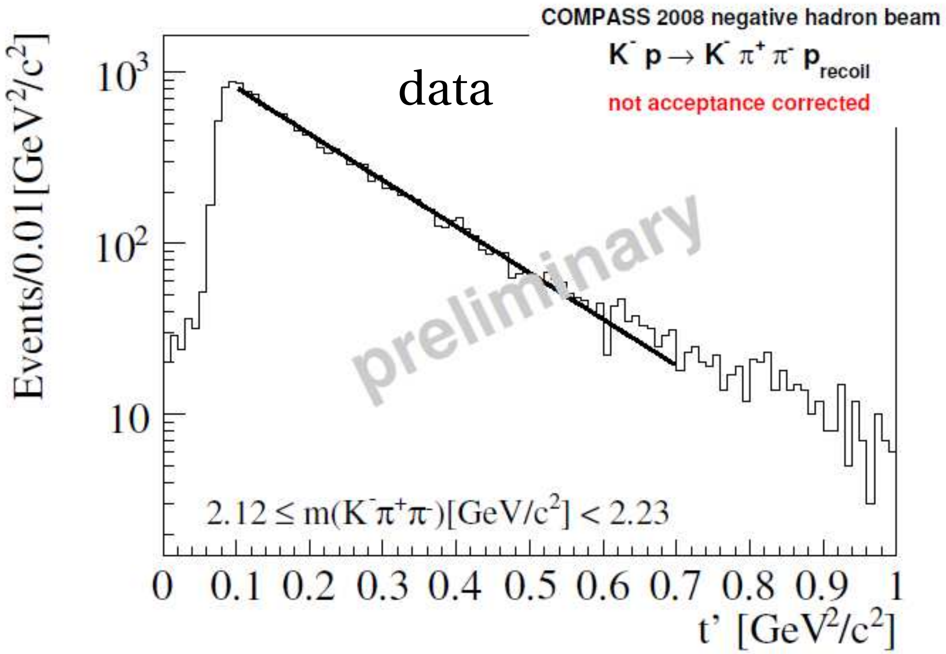


RPD: determination of t' slopes

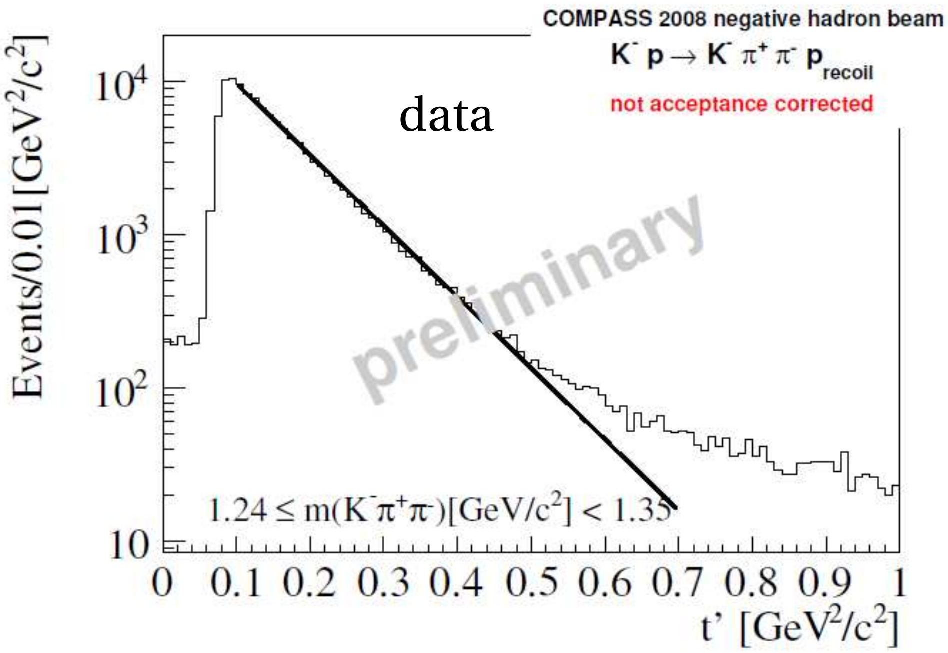


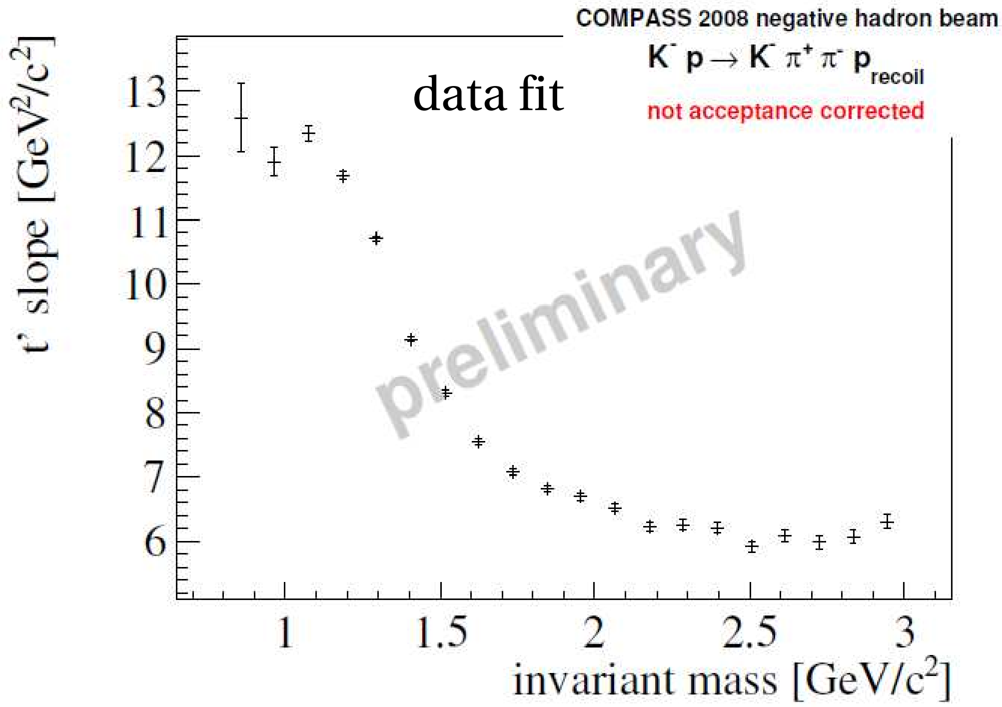
RPD: determination of t' slopes

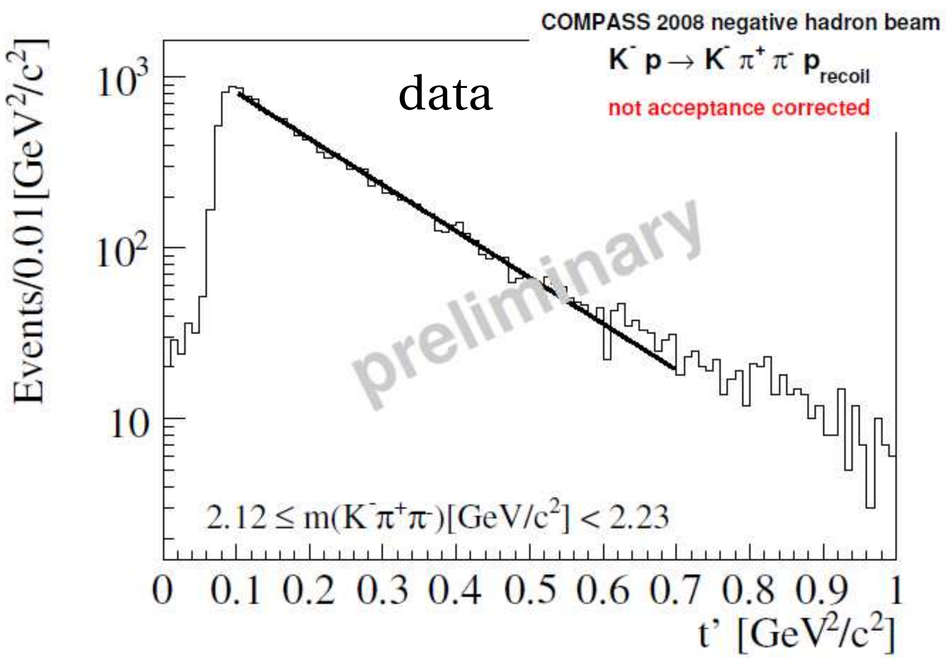




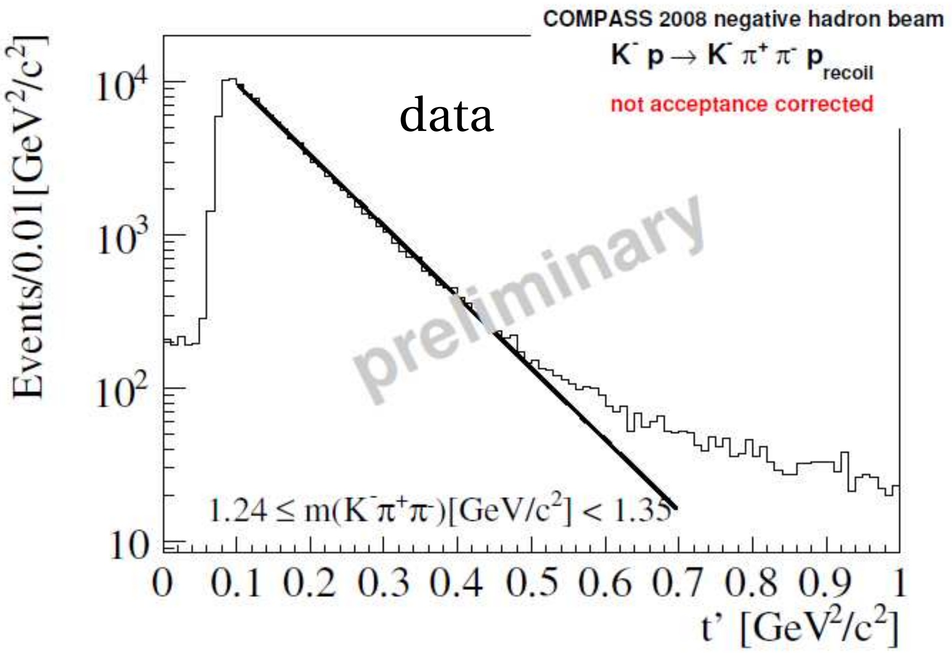
RPD: determination of t' slopes

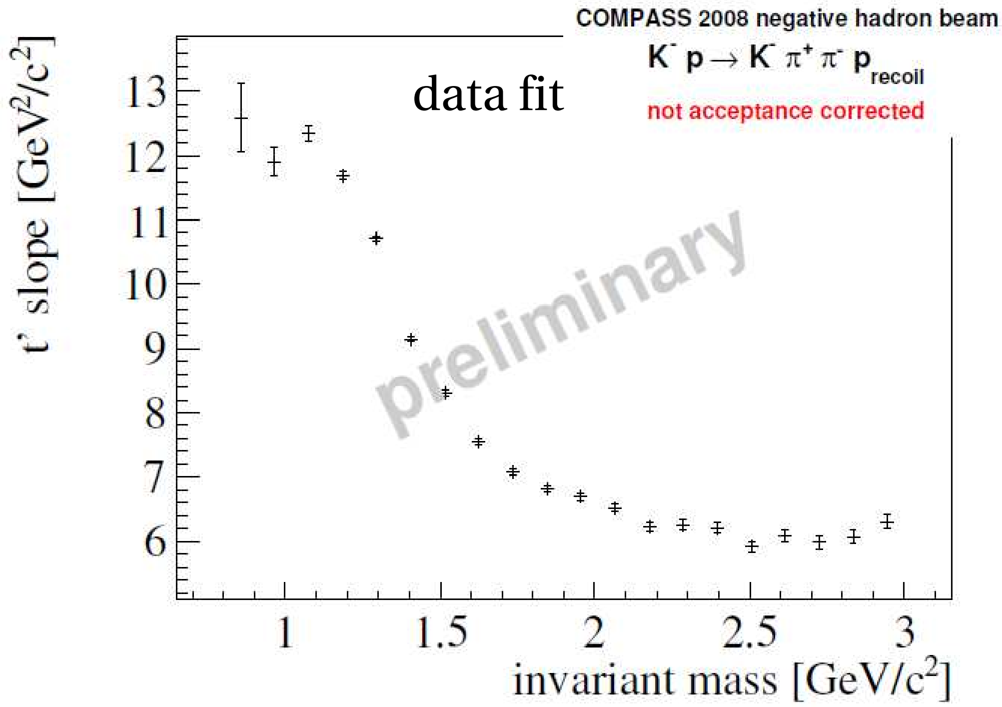


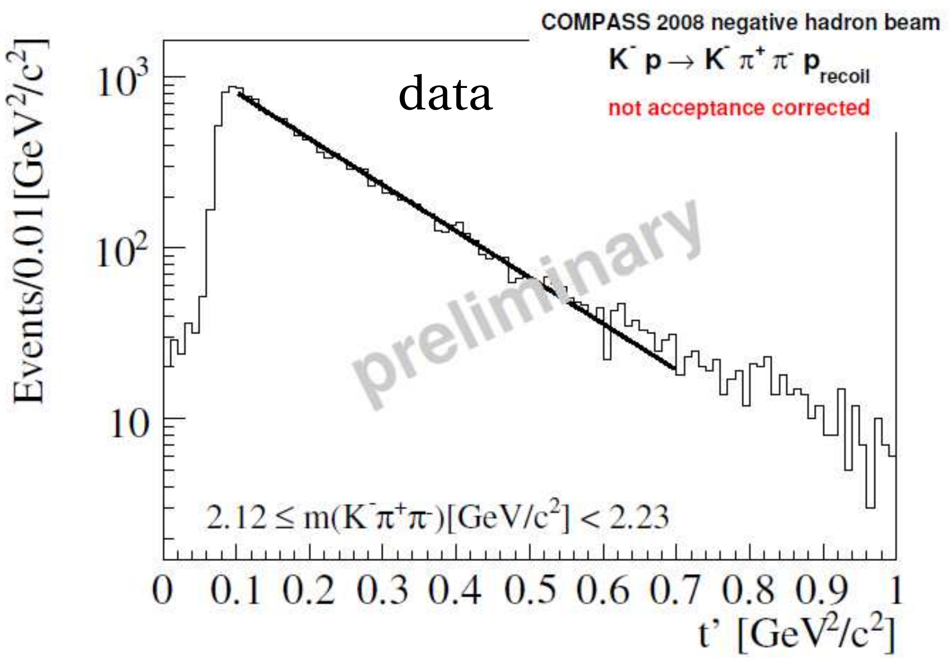


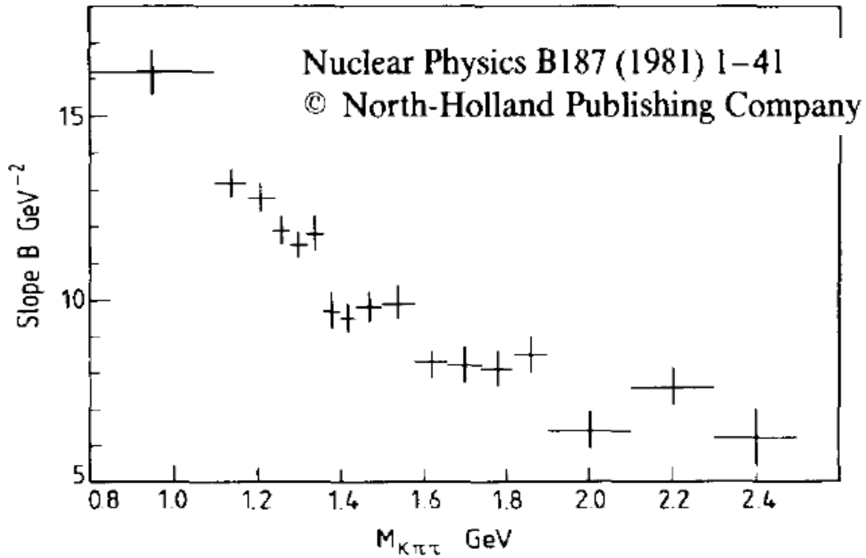


RPD: determination of t' slopes

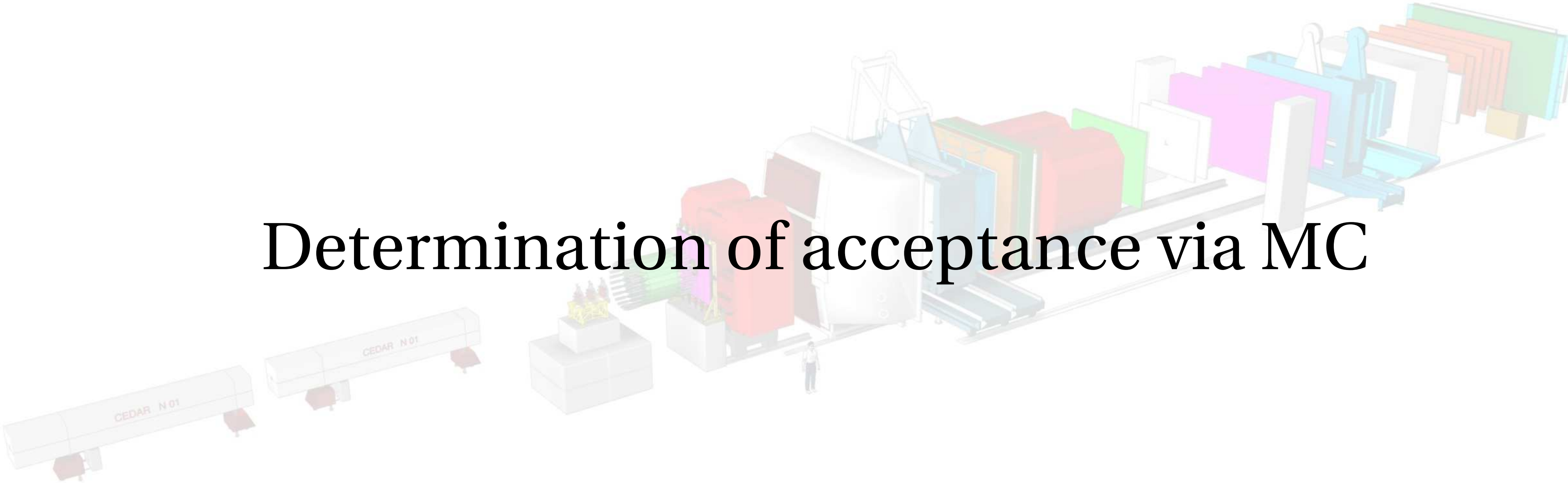




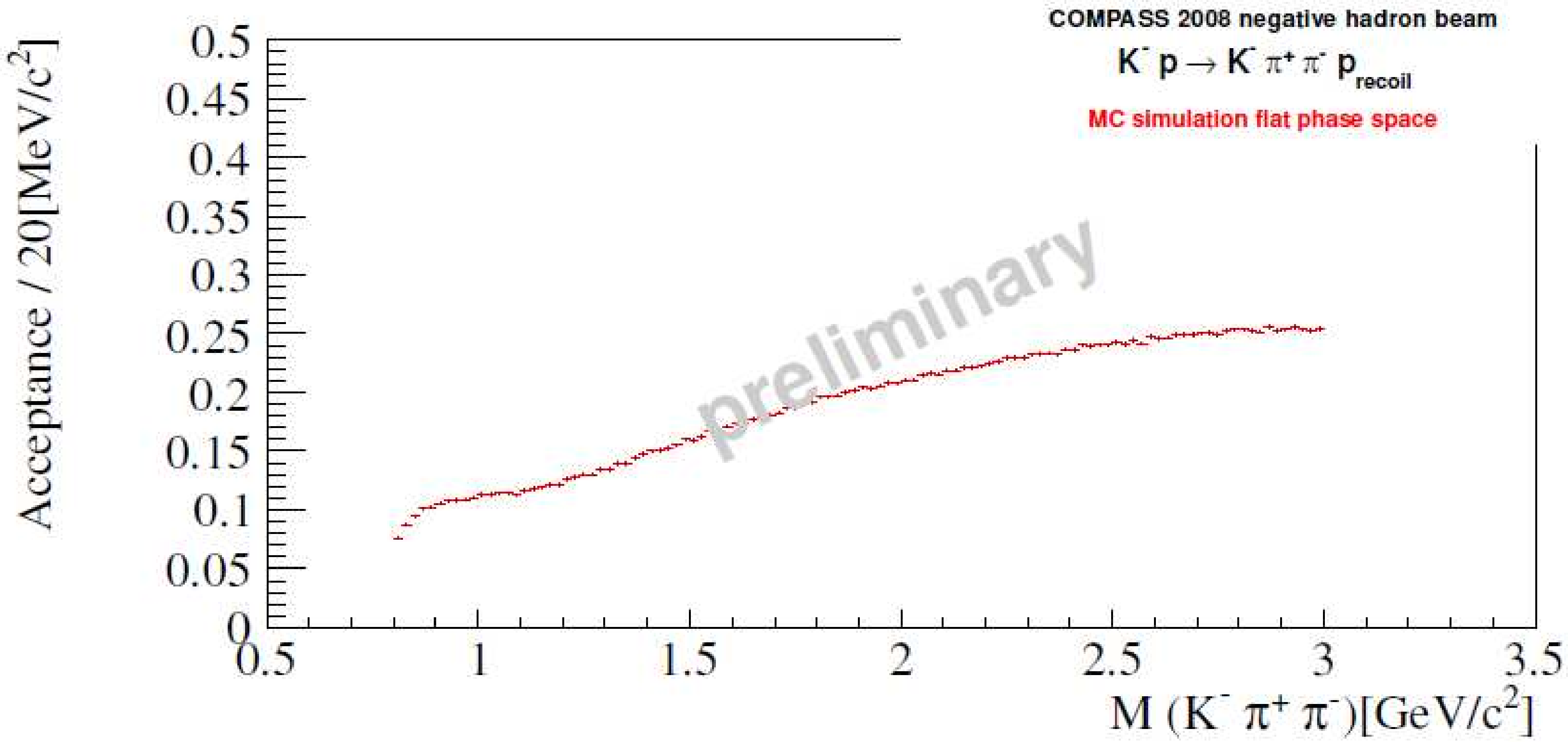




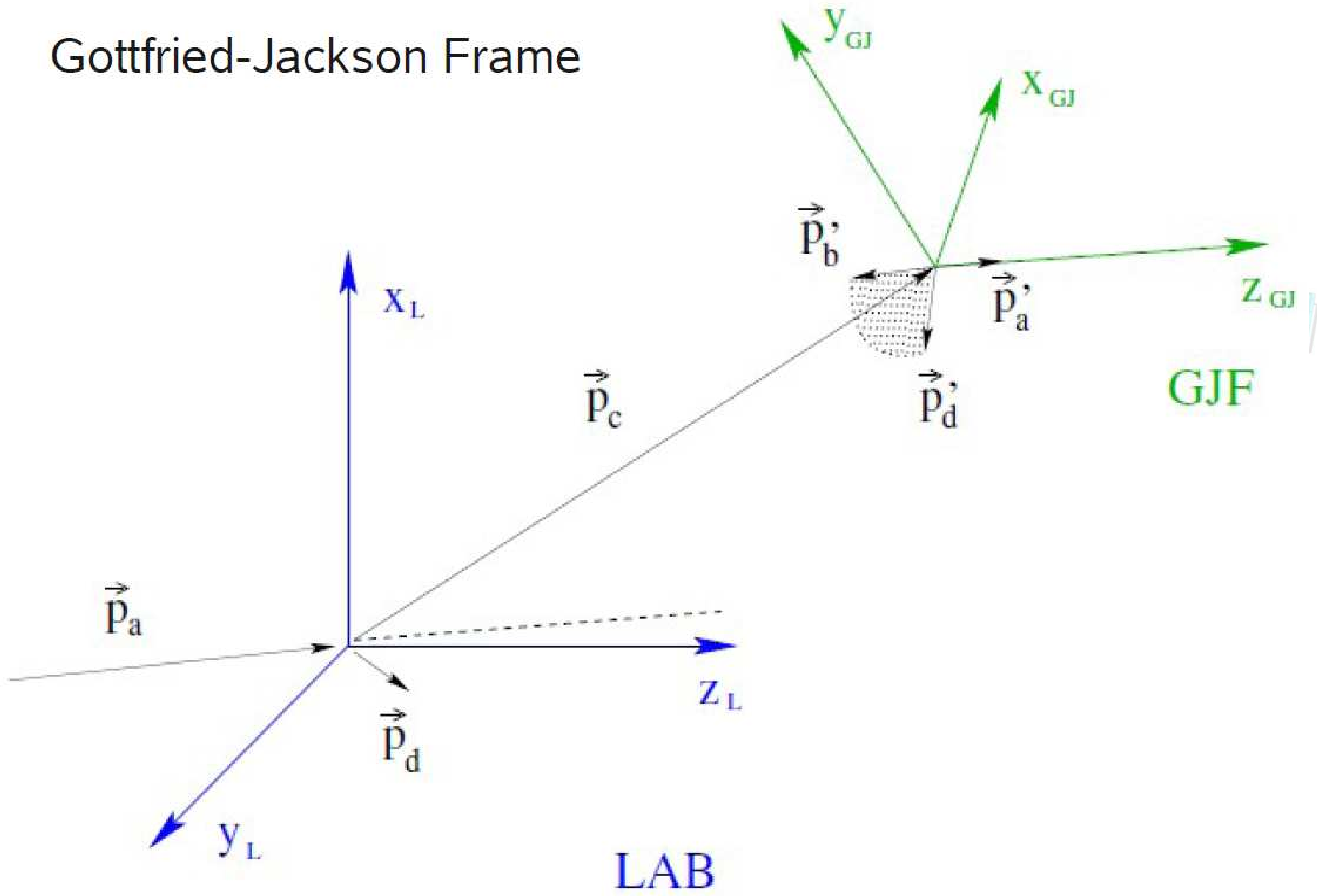
Determination of acceptance via MC



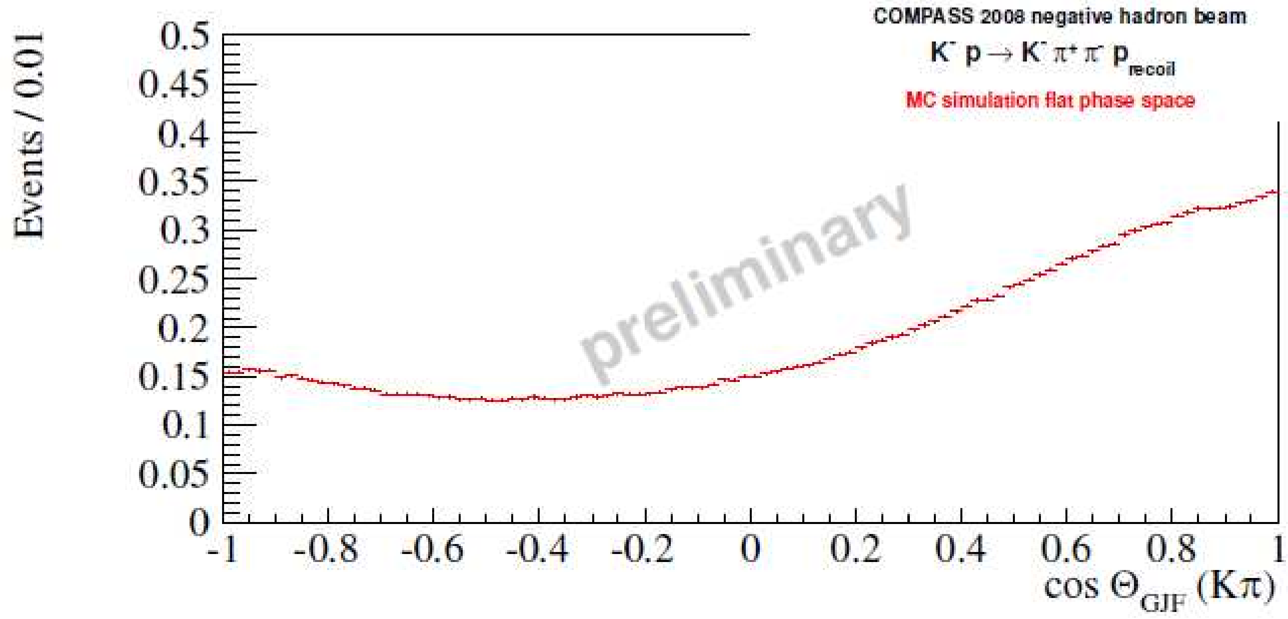
Acceptance in the $K^- \pi^+ \pi^-$ invariant mass

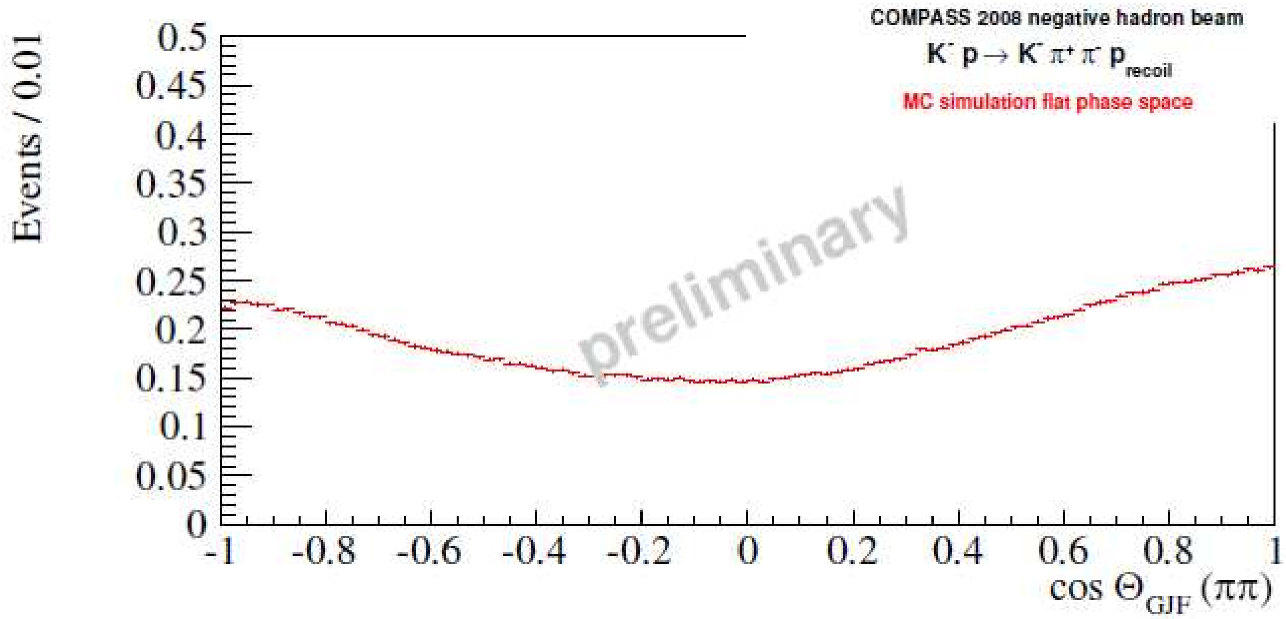


Gottfried-Jackson Frame

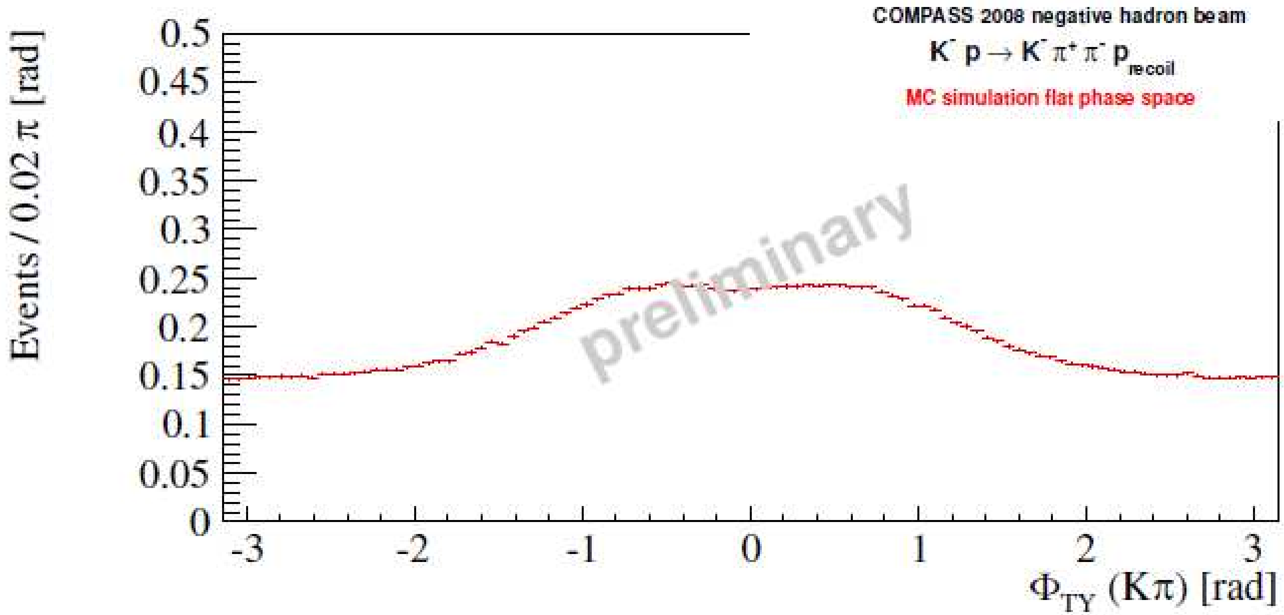


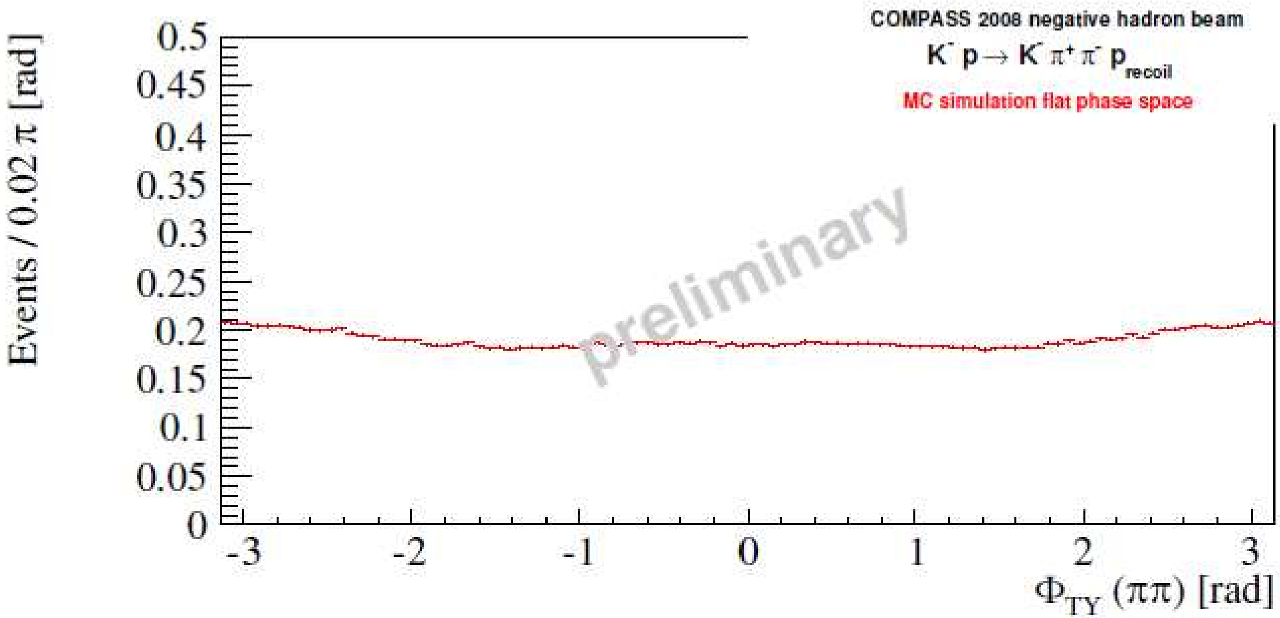
Acceptance in the Gottfried Jackson frame



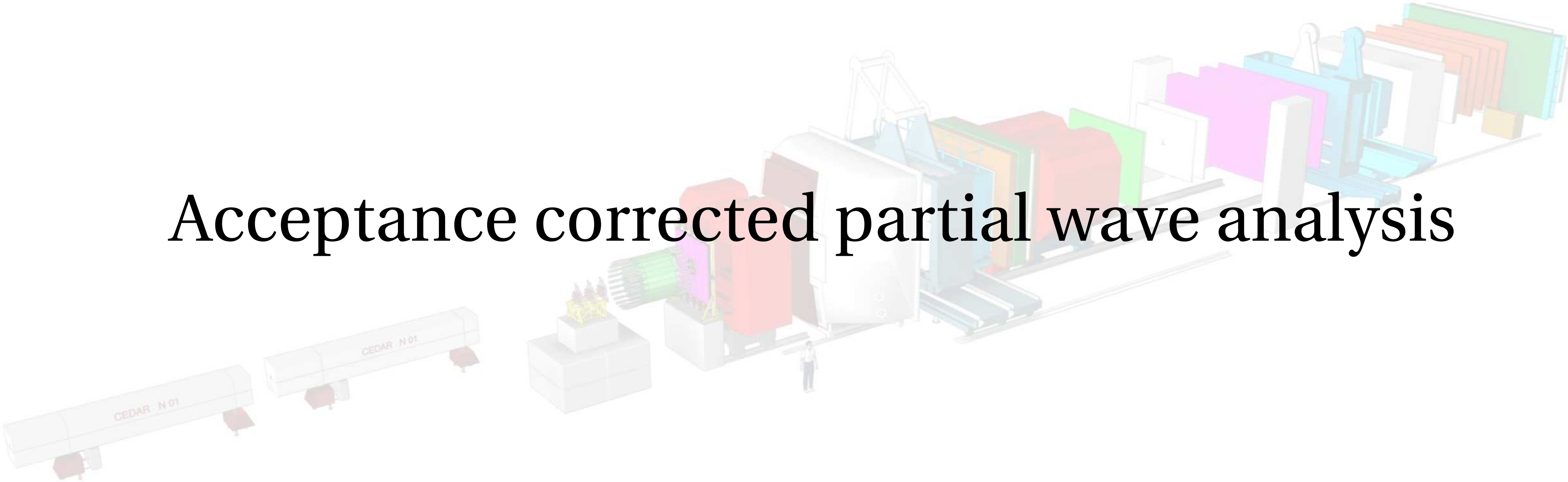


Acceptance in the Gottfried Jackson frame





Acceptance corrected partial wave analysis



Acceptance corrected partial wave analysis

Components of the LogLikelihood function:

Acceptance corrected
Phase space integral

Decay amplitudes

Kinematics

$$\ln L = \sum_{n=1}^{N_{\text{events}}} \ln \sum_{\epsilon} \sum_{i,j} \rho_{ij}^{\epsilon} \bar{\psi}_i^{\epsilon}(\tau_n) \bar{\psi}_j^{\epsilon}(\tau_n)^* - \sum_{\epsilon} \sum_{i,j} \rho_{ij}^{\epsilon} IA_{ij}^{\epsilon}$$

Spin density matrix (fit parameters)

Coherent sum over waves

Incoherent sum over reflectivities

Production amplitudes $\rightarrow$ Spin density matrix:

$$\rho_{ij}^{\epsilon} = \sum_{r} T_{ir}^{\epsilon} T_{jr}^{\epsilon *}$$

Normalized decay amplitudes:

$$\bar{\psi}_i^{\epsilon}(\tau) = \frac{\psi_i^{\epsilon}(\tau)}{\sqrt{\int |\psi_i^{\epsilon}(\tau')|^2 \mathrm{d}\tau'}}$$

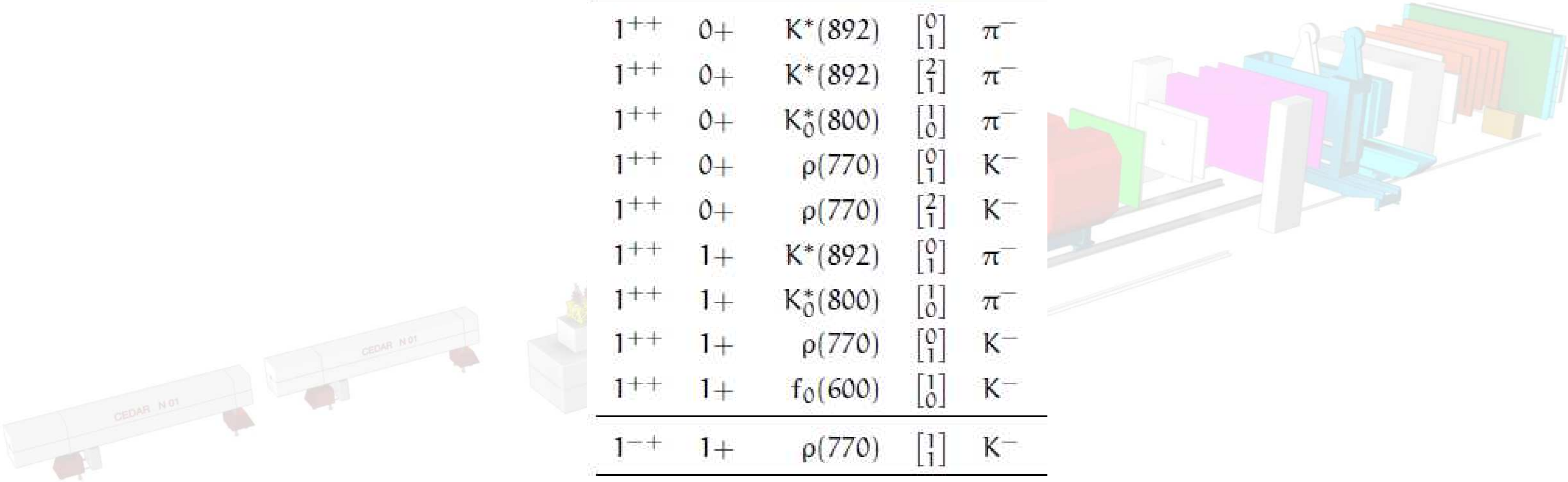
Phase space integrals (with acceptance):

$$IA_{ij}^{\epsilon} = \int \bar{\psi}_i^{\epsilon}(\tau_n) \bar{\psi}_j^{\epsilon}(\tau_n)^* Acc(\tau) \mathrm{d}\tau$$

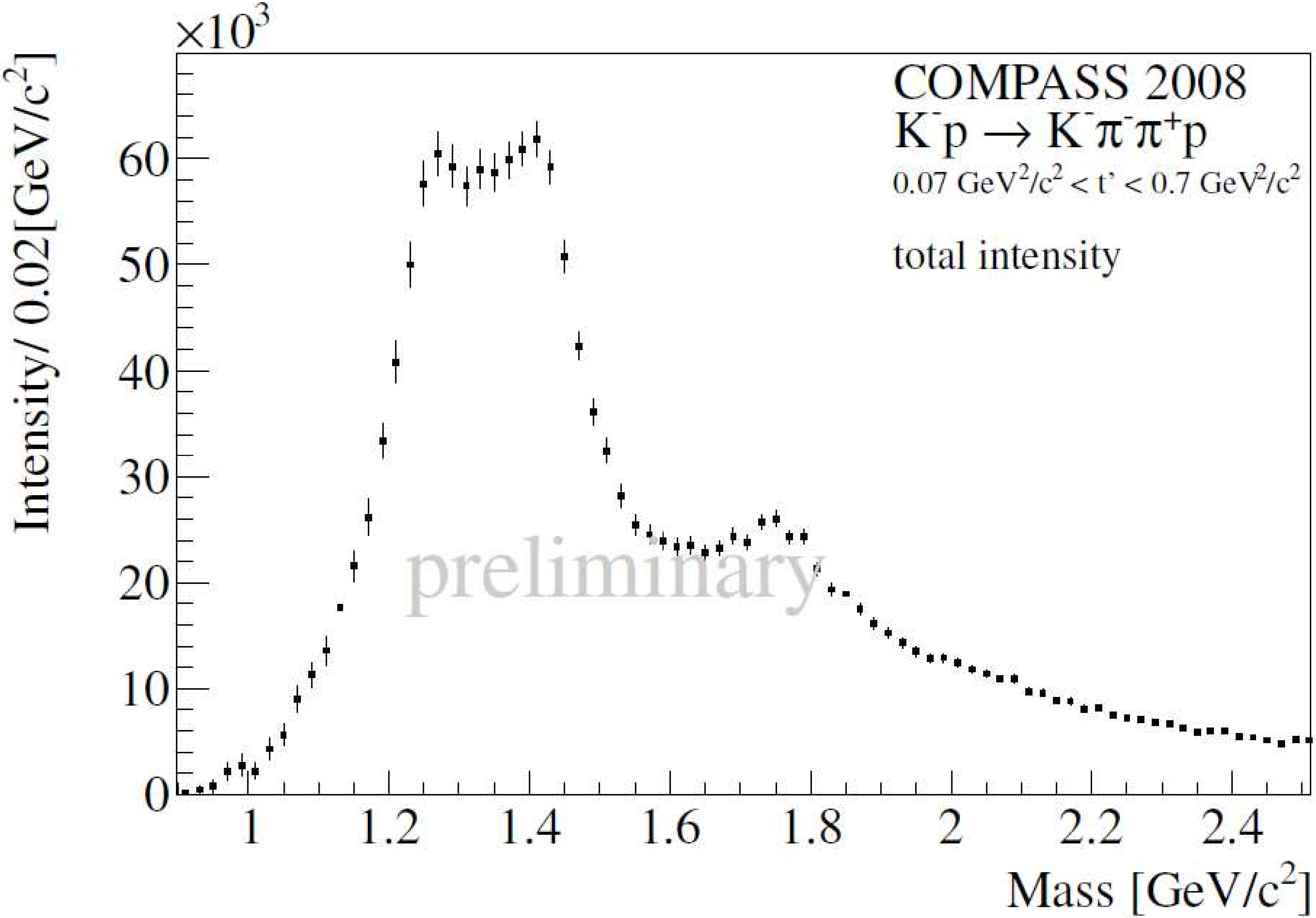
$$Acc(\tau) = \begin{cases} 0 \\ 1 \end{cases}$$

The partial wave set

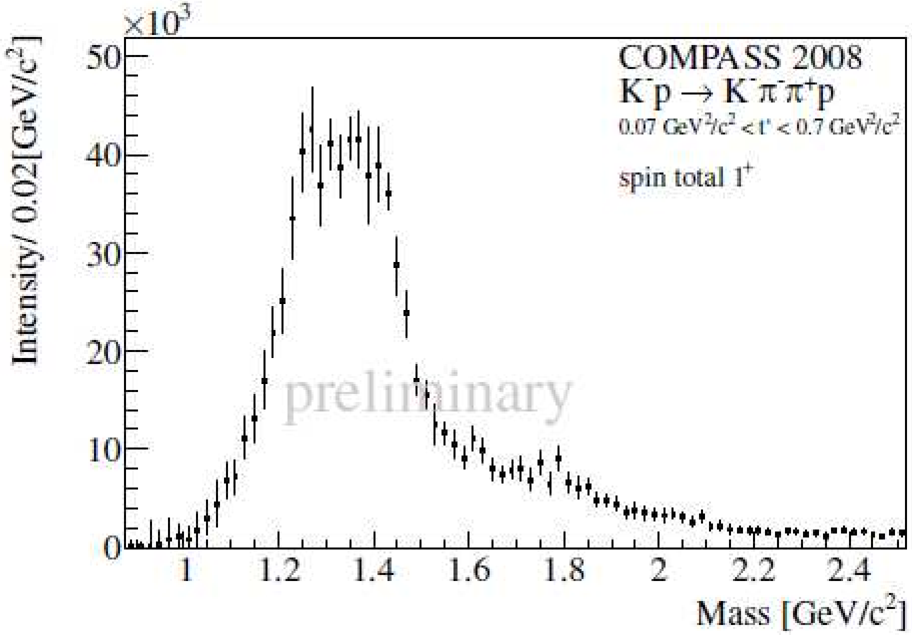
J^{PC}	$M\epsilon$	iso1	$\left[\begin{smallmatrix}l\\s\end{smallmatrix}\right]$	iso2
0^{-+}	$0+$	$K^*(892)$	$\left[\begin{smallmatrix}1\\1\end{smallmatrix}\right]$	π^-
0^{-+}	$0+$	$\rho(770)$	$\left[\begin{smallmatrix}1\\1\end{smallmatrix}\right]$	K^-
0^{-+}	$0+$	$f_0(600)$	$\left[\begin{smallmatrix}0\\0\end{smallmatrix}\right]$	K^-
1^{++}	$0+$	$K^*(892)$	$\left[\begin{smallmatrix}0\\1\end{smallmatrix}\right]$	π^-
1^{++}	$0+$	$K^*(892)$	$\left[\begin{smallmatrix}2\\1\end{smallmatrix}\right]$	π^-
1^{++}	$0+$	$K_0^*(800)$	$\left[\begin{smallmatrix}1\\0\end{smallmatrix}\right]$	π^-
1^{++}	$0+$	$\rho(770)$	$\left[\begin{smallmatrix}0\\1\end{smallmatrix}\right]$	K^-
1^{++}	$0+$	$\rho(770)$	$\left[\begin{smallmatrix}2\\1\end{smallmatrix}\right]$	K^-
1^{++}	$1+$	$K^*(892)$	$\left[\begin{smallmatrix}0\\1\end{smallmatrix}\right]$	π^-
1^{++}	$1+$	$K_0^*(800)$	$\left[\begin{smallmatrix}1\\0\end{smallmatrix}\right]$	π^-
1^{++}	$1+$	$\rho(770)$	$\left[\begin{smallmatrix}0\\1\end{smallmatrix}\right]$	K^-
1^{++}	$1+$	$f_0(600)$	$\left[\begin{smallmatrix}1\\0\end{smallmatrix}\right]$	K^-
1^{-+}	$1+$	$\rho(770)$	$\left[\begin{smallmatrix}1\\1\end{smallmatrix}\right]$	K^-
2^{++}	$1+$	$K^*(892)$	$\left[\begin{smallmatrix}2\\1\end{smallmatrix}\right]$	π^-
2^{++}	$1+$	$\rho(770)$	$\left[\begin{smallmatrix}2\\1\end{smallmatrix}\right]$	K^-
2^{-+}	$0+$	$K_2^*(1430)$	$\left[\begin{smallmatrix}0\\2\end{smallmatrix}\right]$	π^-
2^{-+}	$0+$	$K^*(892)$	$\left[\begin{smallmatrix}1\\1\end{smallmatrix}\right]$	π^-
2^{-+}	$0+$	$f_2(1270)$	$\left[\begin{smallmatrix}0\\2\end{smallmatrix}\right]$	K^-
2^{-+}	$0+$	$\rho(770)$	$\left[\begin{smallmatrix}1\\1\end{smallmatrix}\right]$	K^-

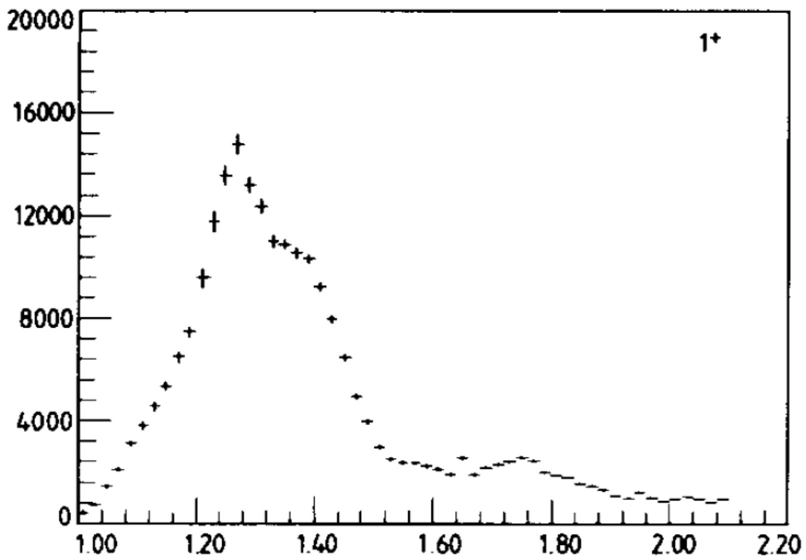


The total intensity



Spin totals





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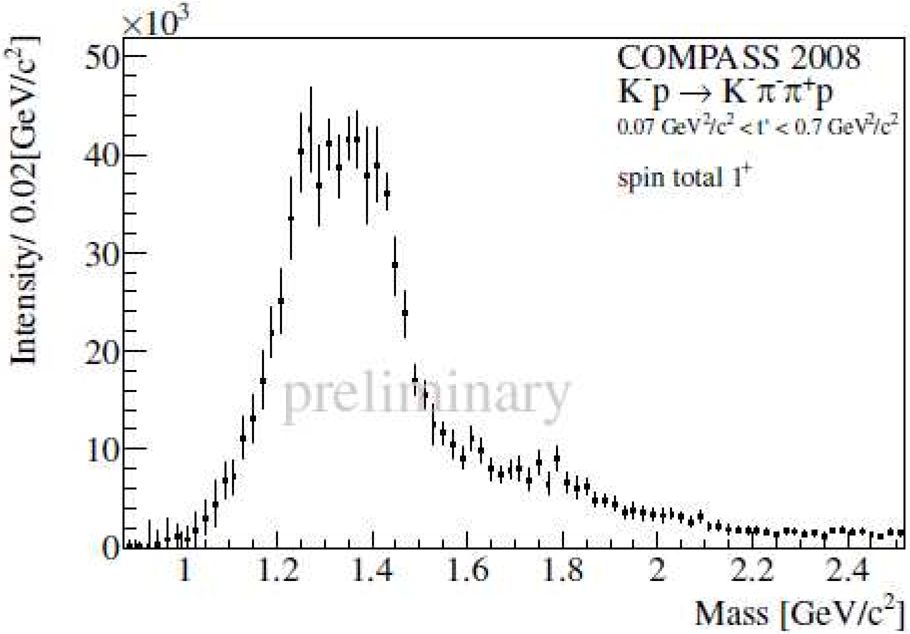
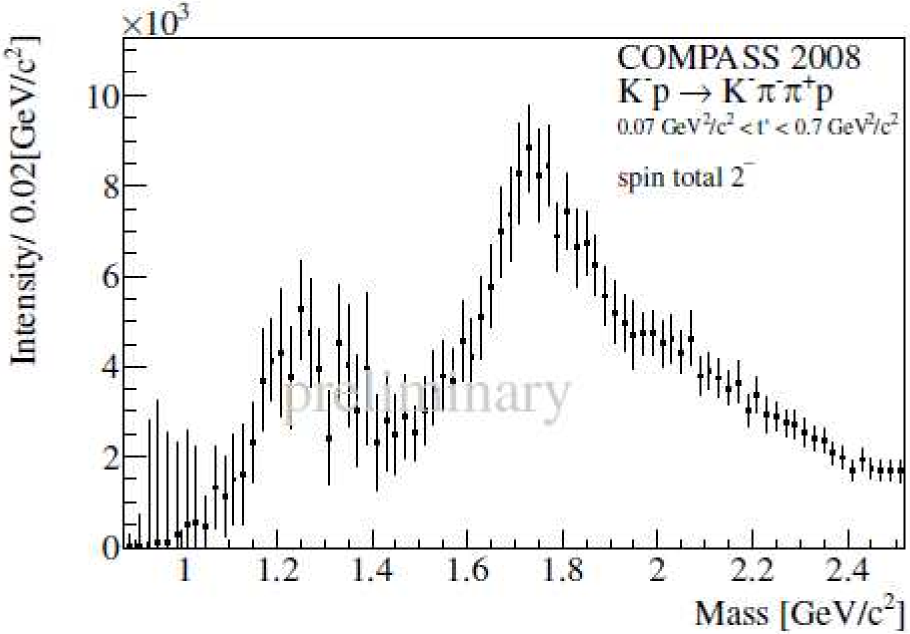
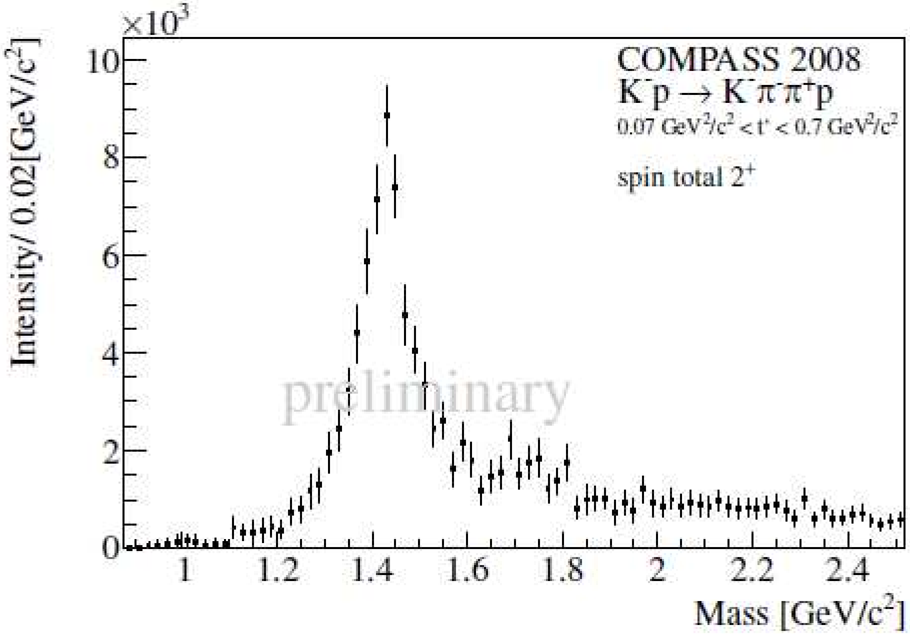
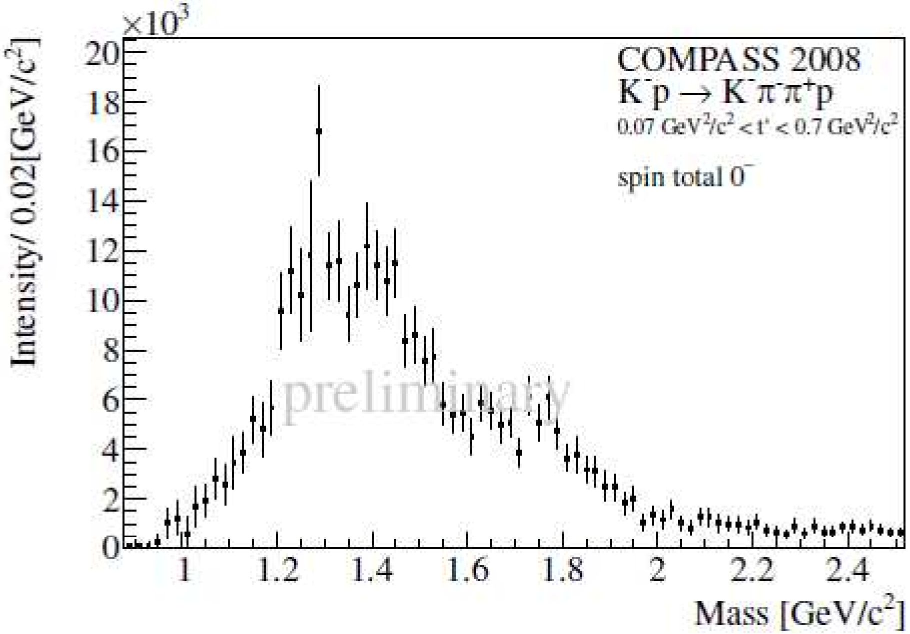
Spin totals

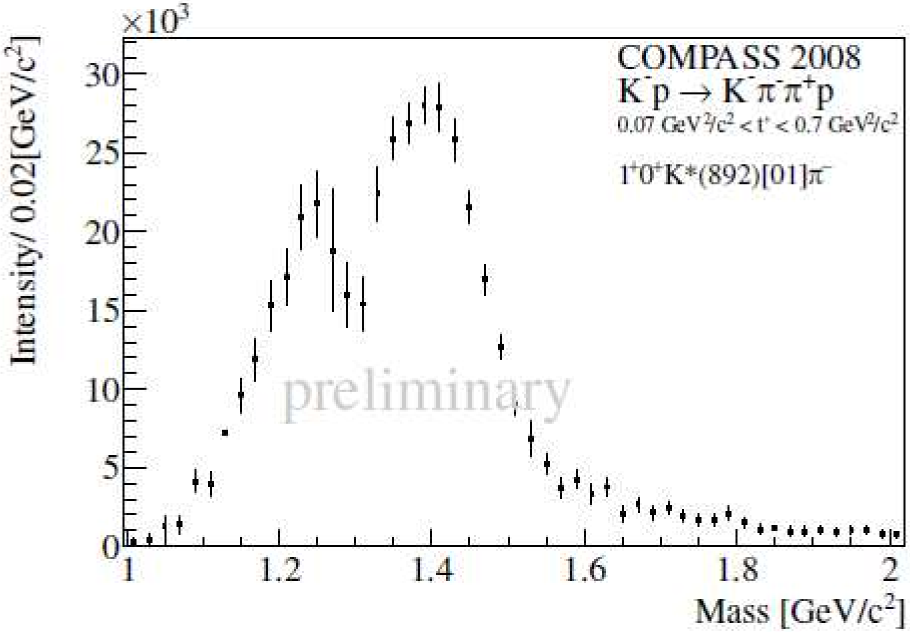

COMPASS 2008
$K^- p \rightarrow K^- \pi^- \pi^+ p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
spin total 1^+
preliminary
$\times 10^3$
Intensity/ 0.02[GeV/c^2]
Mass [GeV/c^2]

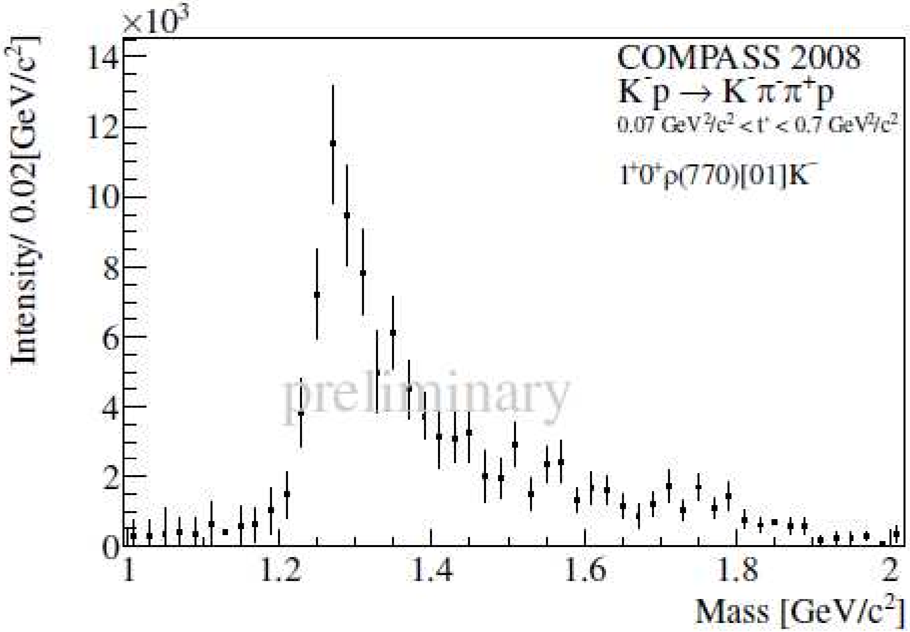

COMPASS 2008
$K^- p \rightarrow K^- \pi^- \pi^+ p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
spin total 2^-
preliminary
$\times 10^3$
Intensity/ 0.02[GeV/c^2]
Mass [GeV/c^2]

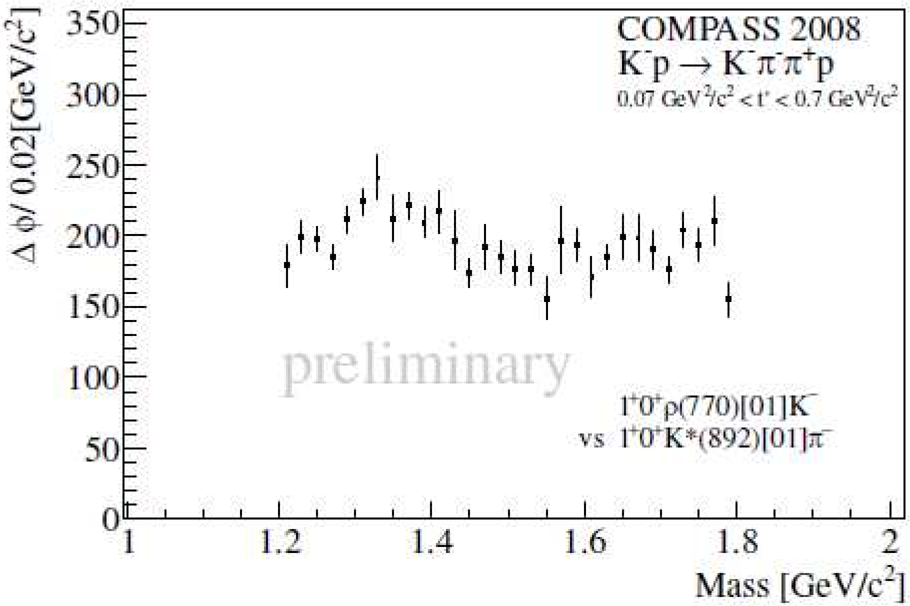

COMPASS 2008
$K^- p \rightarrow K^- \pi^- \pi^+ p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
spin total 2^+
preliminary
$\times 10^3$
Intensity/ 0.02[GeV/c^2]
Mass [GeV/c^2]


COMPASS 2008
$K^- p \rightarrow K^- \pi^- \pi^+ p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
spin total 0^-
preliminary
$\times 10^3$
Intensity/ 0.02[GeV/c^2]
Mass [GeV/c^2]

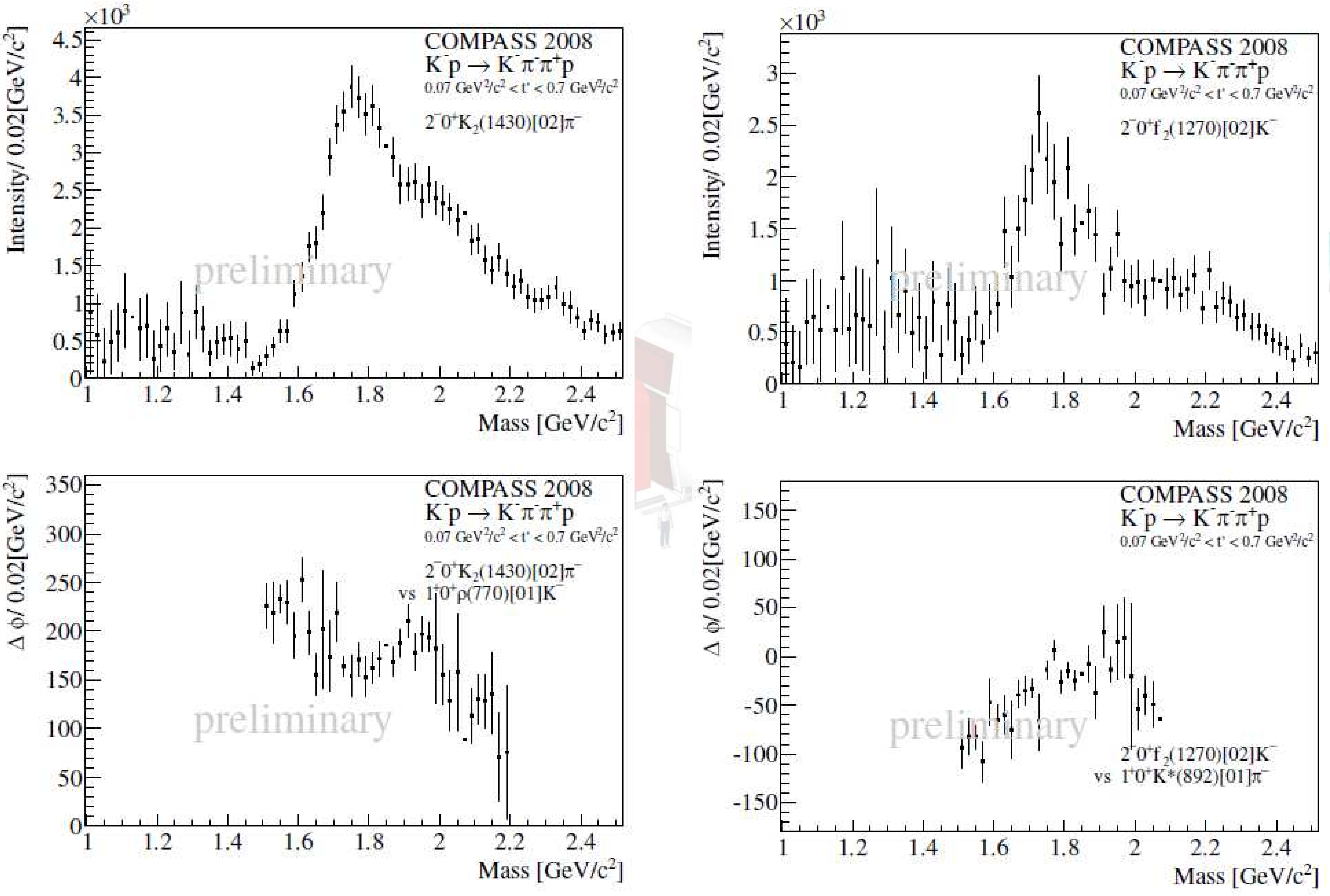
$J^P = 1^+$ waves


×10³
COMPASS 2008
K⁻p → K⁻π⁻π⁺p
0.07 GeV²/c² < t' < 0.7 GeV²/c²
1⁺0⁺K*(892)[01]π⁻
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]


×10³
COMPASS 2008
K⁻p → K⁻π⁻π⁺p
0.07 GeV²/c² < t' < 0.7 GeV²/c²
1⁺0⁺ρ(770)[01]K⁻
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]

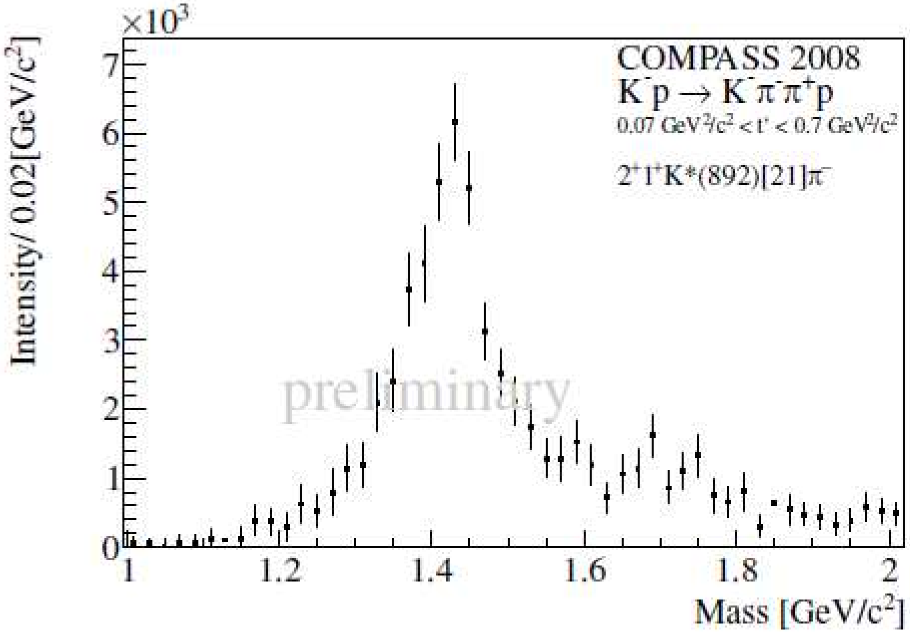

COMPASS 2008
K⁻p → K⁻π⁻π⁺p
0.07 GeV²/c² < t' < 0.7 GeV²/c²
preliminary
1⁺0⁺ρ(770)[01]K⁻
vs 1⁺0⁺K*(892)[01]π⁻
Δ φ/ 0.02[GeV/c²]
Mass [GeV/c²]

$J^P = 2^-$ waves

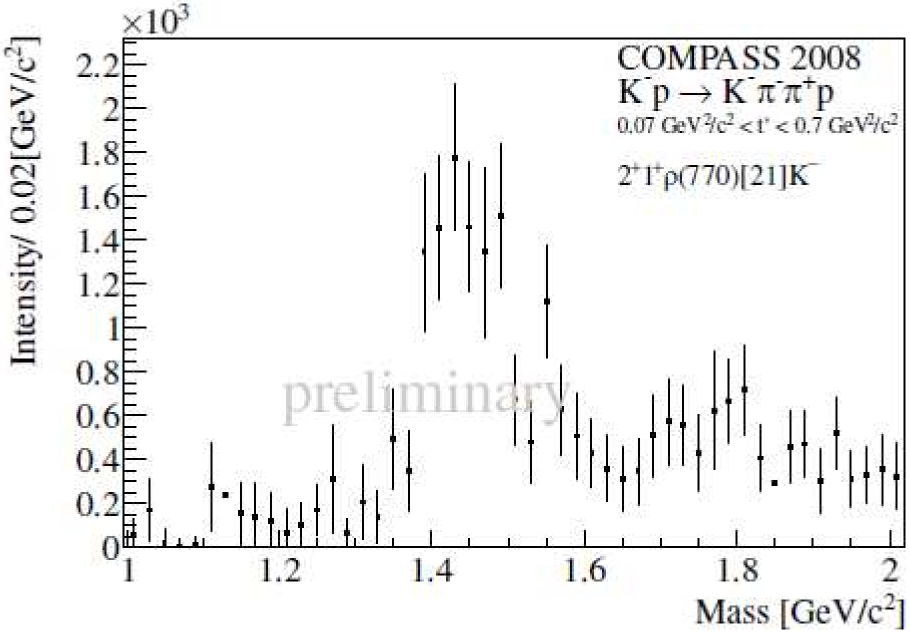


COMPASS 2008
$K^-p \to K^-\pi^-\pi^+p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
$2^-0^+K_2(1430)[02]\pi^-$
$2^-0^+f_2(1270)[02]K^-$
vs $1^+0^+\rho(770)[01]K^-$
vs $1^+0^+K^*(892)[01]\pi^-$
preliminary
Intensity/ 0.02[GeV/c^2]
$\Delta\phi$/ 0.02[GeV/c^2]
Mass [GeV/c^2]
$\times 10^3$

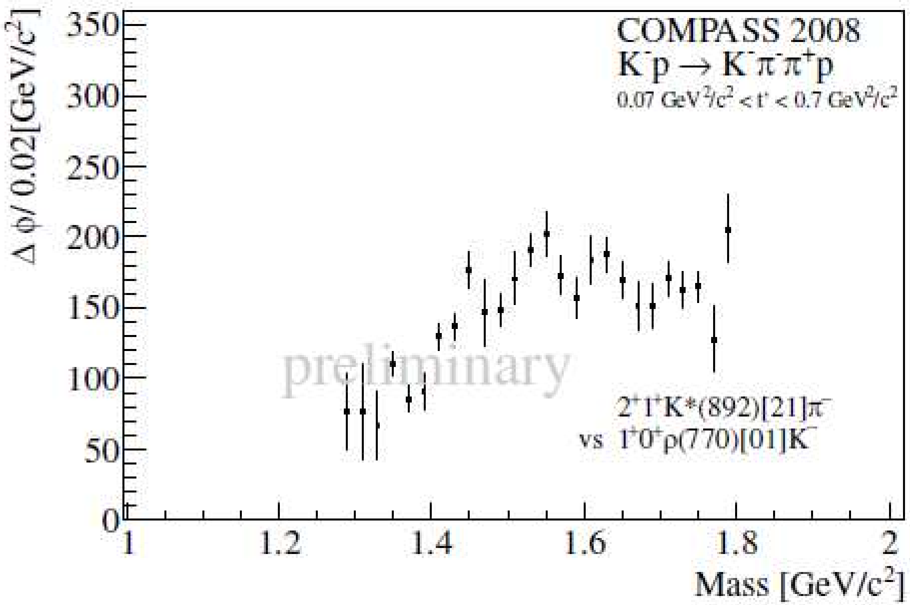
$J^P = 2^+$ waves



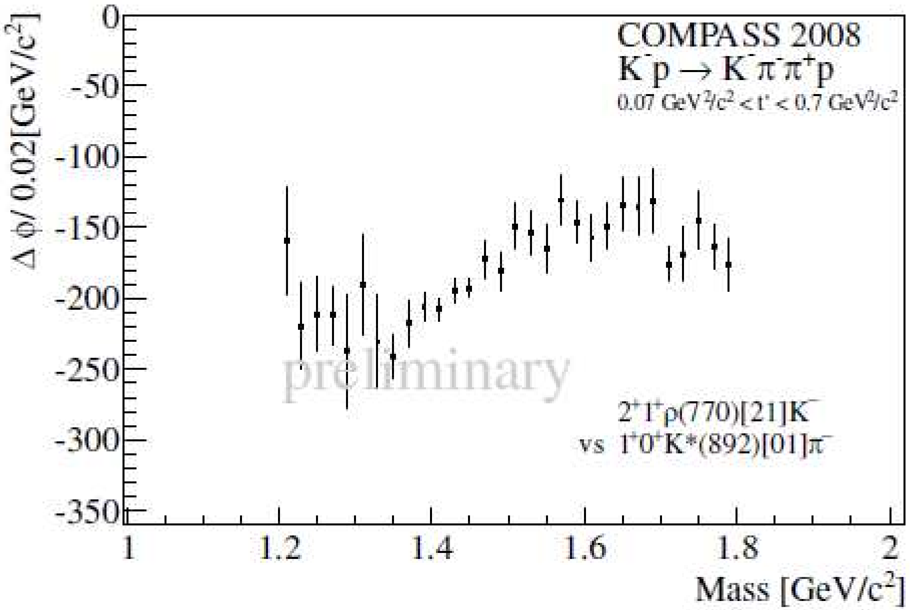
COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
$2^+1^+K^*(892)[21]\pi^-$
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]



COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
$2^+1^+\rho(770)[21]K^-$
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]

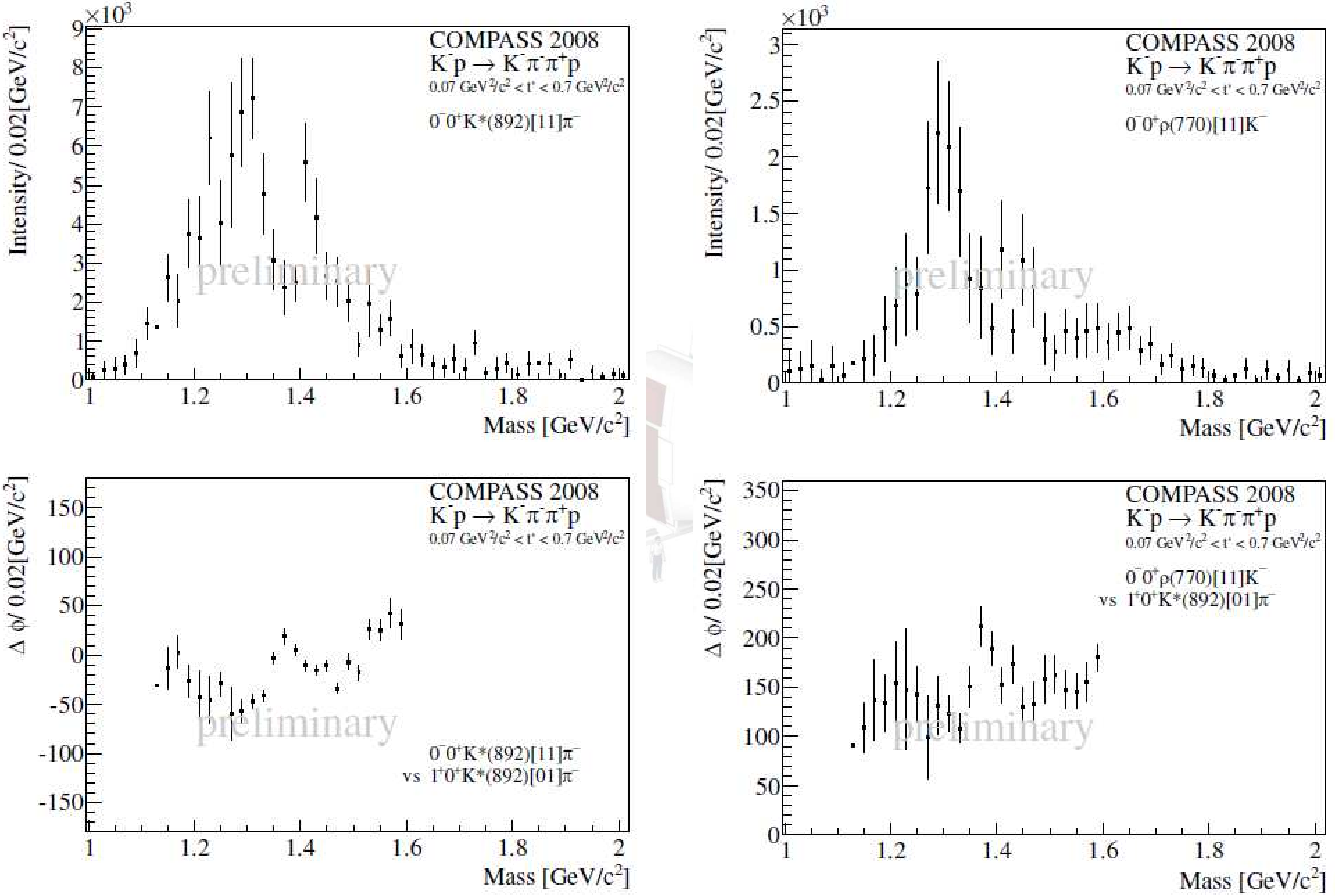


COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
preliminary
$2^+1^+K^*(892)[21]\pi^-$
vs $1^+0^+\rho(770)[01]K^-$
Δ φ/ 0.02[GeV/c²]
Mass [GeV/c²]



COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
preliminary
$2^+1^+\rho(770)[21]K^-$
vs $1^+0^+K^*(892)[01]\pi^-$
Δ φ/ 0.02[GeV/c²]
Mass [GeV/c²]

$J^P = 0^-$ waves


COMPASS 2008
$K^-p \to K^-\pi^-\pi^+p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
$0^-0^+K^*(892)[11]\pi^-$
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]
preliminary
$0^-0^+\rho(770)[11]K^-$
Δ φ/ 0.02[GeV/c²]
$0^-0^+K^*(892)[11]\pi^-$ vs $1^+0^+K^*(892)[01]\pi^-$
$0^-0^+\rho(770)[11]K^-$ vs $1^+0^+K^*(892)[01]\pi^-$

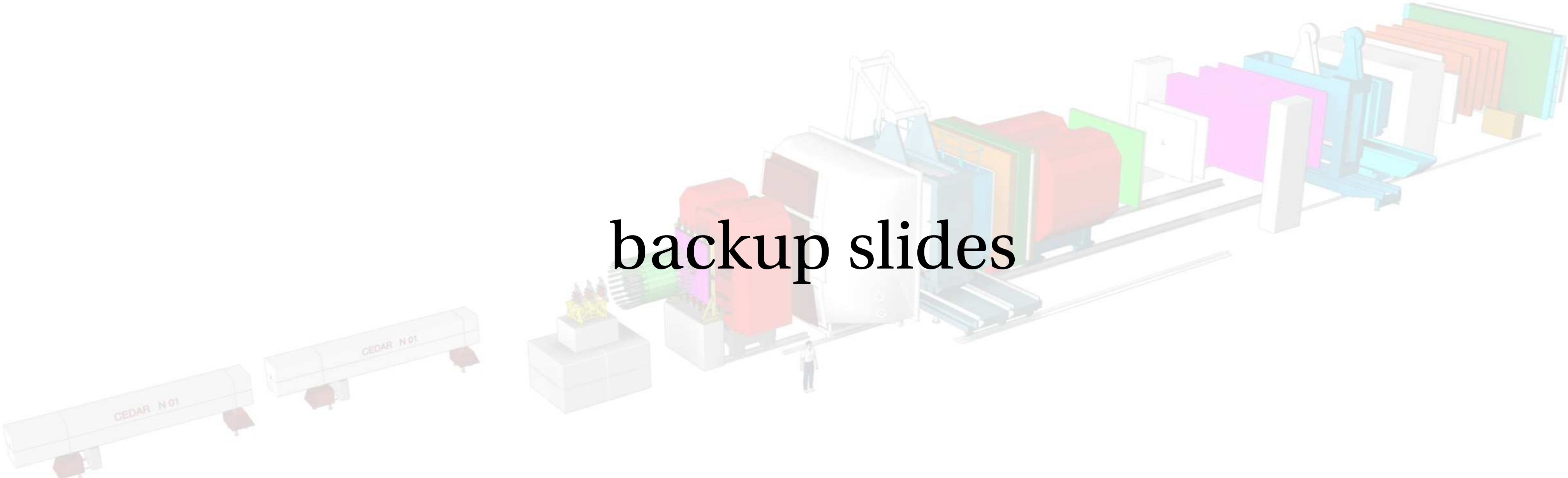
Summary and outlook

- Open strangeness single diffractive mechanisms show resonant behavior
- Those resonances are understood to be $q\bar{q}$ bar states with isospin ½
- The $K^- \pi^+ \pi^-$ final state is shown to decay via substates
- Tools of partial wave analysis (PWA) in the Ascoli approach are used to determine resonances
- A mass independent acceptance corrected PWA fit was performed
- Results are mostly in agreement with previous measurements but show also also some interesting features

- For a final conclusion a mass dependent fit has to be performed
- COMPASS is expected to double the number of events found in 2008 when having reconstructed data of 2009

Thank you!

backup slides



Measured strange meson level scheme

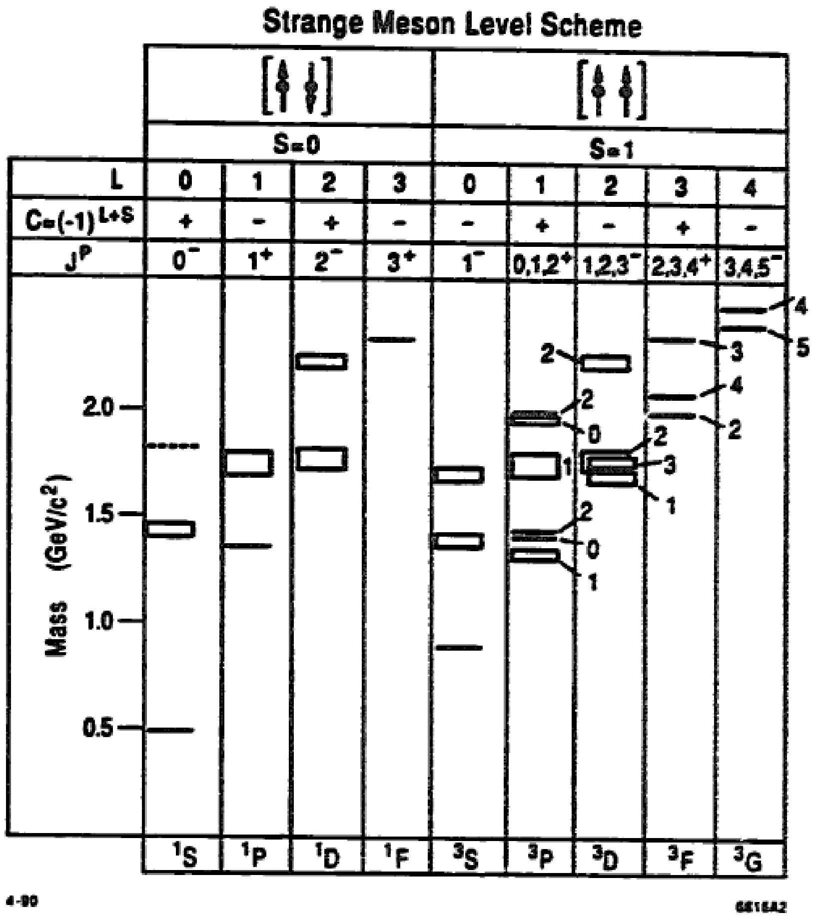


FIGURE 2
The quark model level diagram summarizing the status of strange meson spectroscopy; the C parity is that of the neutral, non-strange members of the relevant SU(3) multiplet.

resonances fitting the $q\bar{q}$ model

$n\,^{2s+1}\ell_J$	J^{PC}	$\mathrm{I}=1$ $u\bar{d},\ \bar{u}d,\ \frac{1}{\sqrt{2}}(d\bar{d}-u\bar{u})$	$\mathrm{I}=\frac{1}{2}$ $u\bar{s},\ d\bar{s};\ \bar{d}s,\ -\bar{u}s$	$\mathrm{I}=0$ f'	$\mathrm{I}=0$ f	θ_{quad} [°]	θ_{lin} [°]
$1\,^1S_0$	0^{-+}	π	K	η	$\eta'(958)$	-11.5	-24.6
$1\,^3S_1$	1^{--}	$\rho(770)$	$K^*(892)$	$\phi(1020)$	$\omega(782)$	38.7	36.0
$1\,^1P_1$	1^{+-}	$b_1(1235)$	$K_{1B}{}^{\dagger}$	$h_1(1380)$	$h_1(1170)$		
$1\,^3P_0$	0^{++}	$a_0(1450)$	$K_0^*(1430)$	$f_0(1710)$	$f_0(1370)$		
$1\,^3P_1$	1^{++}	$a_1(1260)$	$K_{1A}{}^{\dagger}$	$f_1(1420)$	$f_1(1285)$		
$1\,^3P_2$	2^{++}	$a_2(1320)$	$K_2^*(1430)$	$f_2'(1525)$	$f_2(1270)$	29.6	28.0
$1\,^1D_2$	2^{-+}	$\pi_2(1670)$	$K_2(1770)^{\dagger}$	$\eta_2(1870)$	$\eta_2(1645)$		
$1\,^3D_1$	1^{--}	$\rho(1700)$	$K^*(1680)$		$\omega(1650)$		
$1\,^3D_2$	2^{--}		$K_2(1820)$				
$1\,^3D_3$	3^{--}	$\rho_3(1690)$	$K_3^*(1780)$	$\phi_3(1850)$	$\omega_3(1670)$	32.0	31.0
$1\,^3F_4$	4^{++}	$a_4(2040)$	$K_4^*(2045)$		$f_4(2050)$		
$1\,^3G_5$	5^{--}	$\rho_5(2350)$					
$1\,^3H_6$	6^{++}	$a_6(2450)$			$f_6(2510)$		
$2\,^1S_0$	0^{-+}	$\pi(1300)$	$K(1460)$	$\eta(1475)$	$\eta(1295)$		
$2\,^3S_1$	1^{--}	$\rho(1450)$	$K^*(1410)$	$\phi(1680)$	$\omega(1420)$		

$$f' = \psi_8 \cos\theta - \psi_1 \sin\theta$$

$$f = \psi_8 \sin\theta + \psi_1 \cos\theta$$

$$\psi_8 = \frac{1}{\sqrt{6}}(u\bar{u} + d\bar{d} - 2s\bar{s})$$

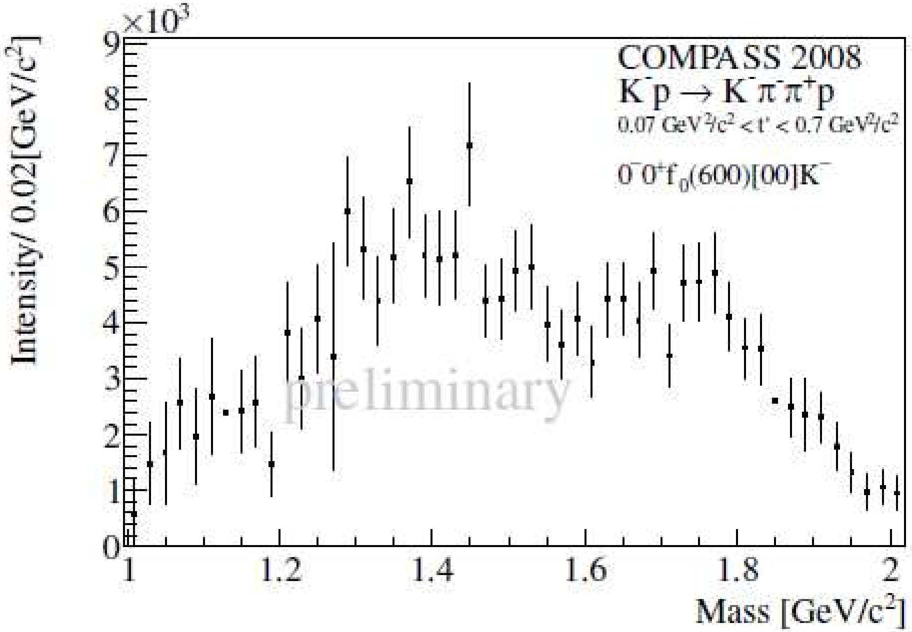
$$\psi_1 = \frac{1}{\sqrt{3}}(u\bar{u} + d\bar{d} + s\bar{s})$$

† The $1^{+\pm}$ and $2^{-\pm}$ isospin $\frac{1}{2}$ states mix. In particular, the K_{1A} and K_{1B} are nearly equal (45°) mixtures of the $K_1(1270)$ and $K_1(1400)$. The physical vector mesons listed under 1^3D_1 and 2^3S_1 may be mixtures of 1^3D_1 and 2^3S_1, or even have hybrid components.

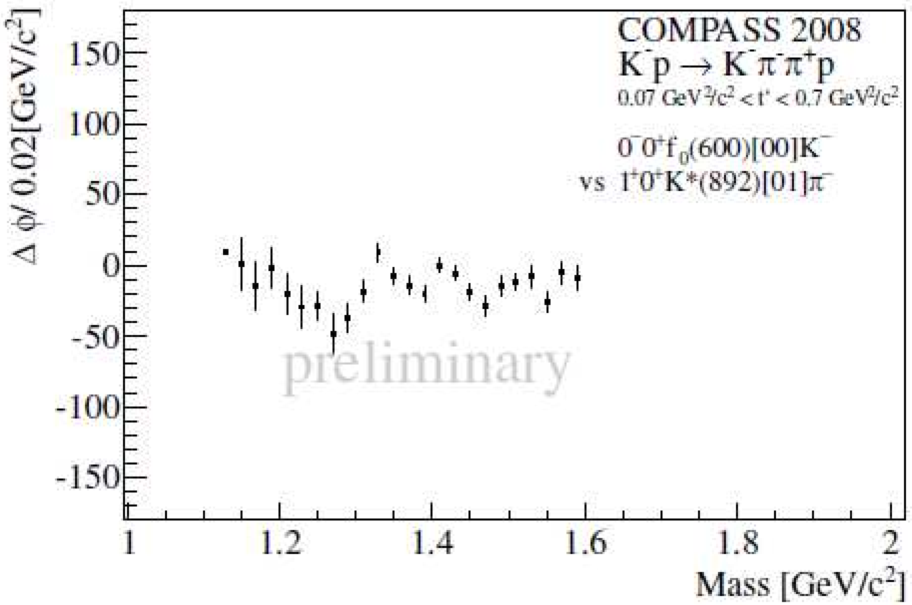
Resonances as listed in the PDG review

J^P	name	mass	width	seen in $K^\pm\pi^\mp\pi^\pm$	note
0^-	K	0.494	–	–	
0^-	$K(1460)$	1.460	0.260	1.460 Γ 0.260	needs confirmation
0^-	$K(1830)$	1.830	0.250	–	needs confirmation
0^+	$K_0^*(1430)$	1.425	0.270	–	
0^+	$K_0^*(1950)$	1.945	0.201	–	needs confirmation
1^-	$K^*(892)$	0.892	0.051	–	
1^-	$K^*(1410)$	1.414	0.232	–	
1^-	$K^*(1680)$	1.717	0.322	–	
1^+	$K_1(1270)$	1.272	0.090	1.270 Γ 0.090	
1^+	$K_1(1400)$	1.403	0.090	1.410 Γ 0.195	
1^+	$K_1(1650)$	1.650	0.150	1.800 Γ 0.250	needs confirmation
2^-	$K_2(1580)$	1.580	0.110	1.580 Γ 0.110	needs confirmation
2^-	$K_2(1770)$	1.773	0.186	1.780 Γ 0.210	
2^-	$K_2(1820)$	1.816	0.276	1.840 Γ 0.230	
2^-	$K_2(2250)$	2.247	0.180	–	needs confirmation
2^+	$K_2(1430)$	1.426	0.099	1.421 Γ 0.100	
2^+	$K_2^*(1980)$	1.973	0.373	–	needs confirmation
3^-	$K_3(1780)$	1.776	0.159	–	
3^+	$K_3(2320)$	2.324	0.180	–	needs confirmation
4^-	$K_4^*(2500)$	2.490	0.250	–	needs confirmation
4^+	$K_4^*(2045)$	2.045	0.198	–	
5^-	$K_5^*(2380)$	2.382	0.178	–	needs confirmation

$J^P = 0^-$ waves

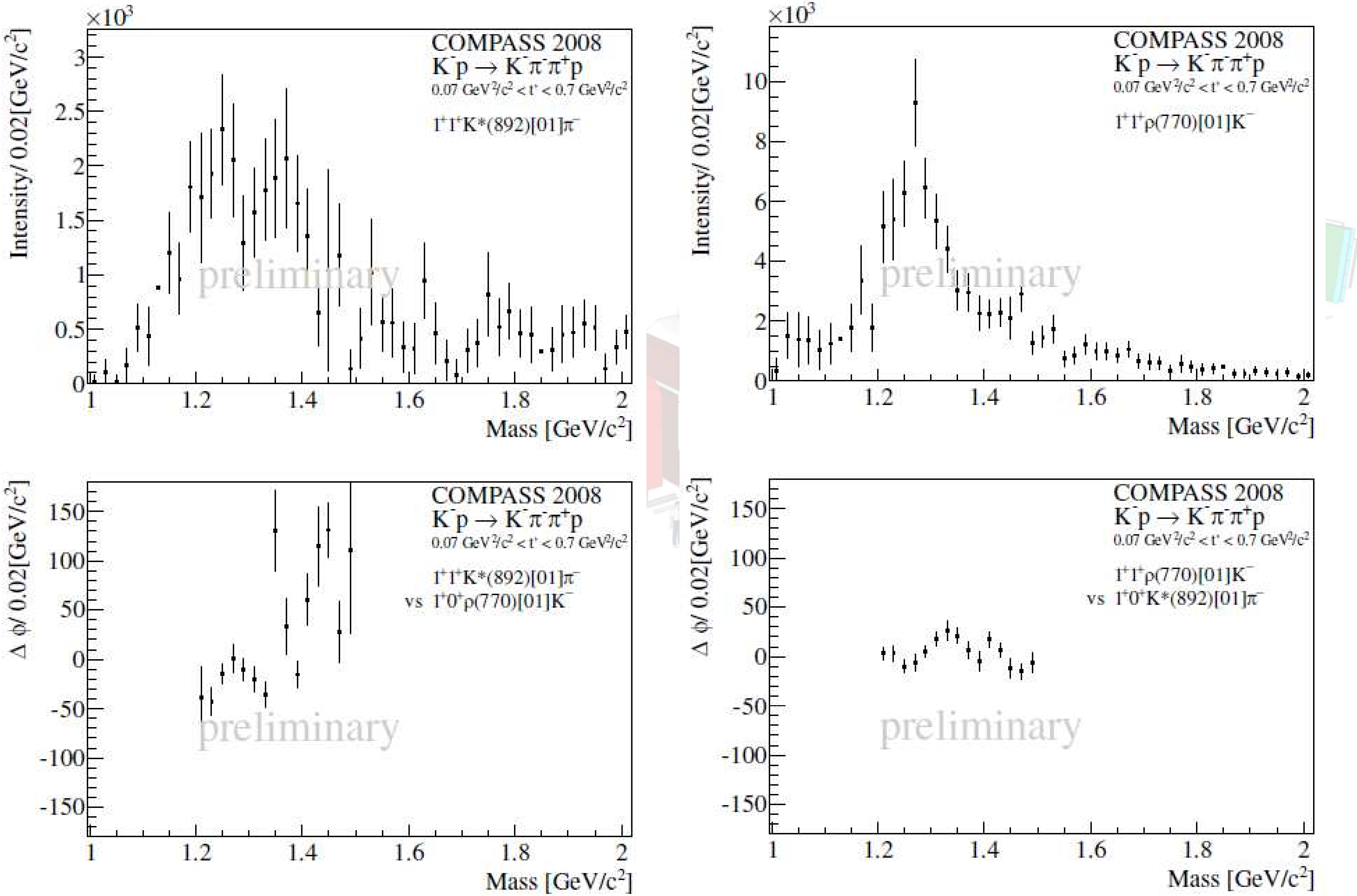


COMPASS 2008
K⁻p → K⁻π⁻π⁺p
0.07 GeV²/c² < t' < 0.7 GeV²/c²
0⁻0⁺f₀(600)[00]K⁻
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]



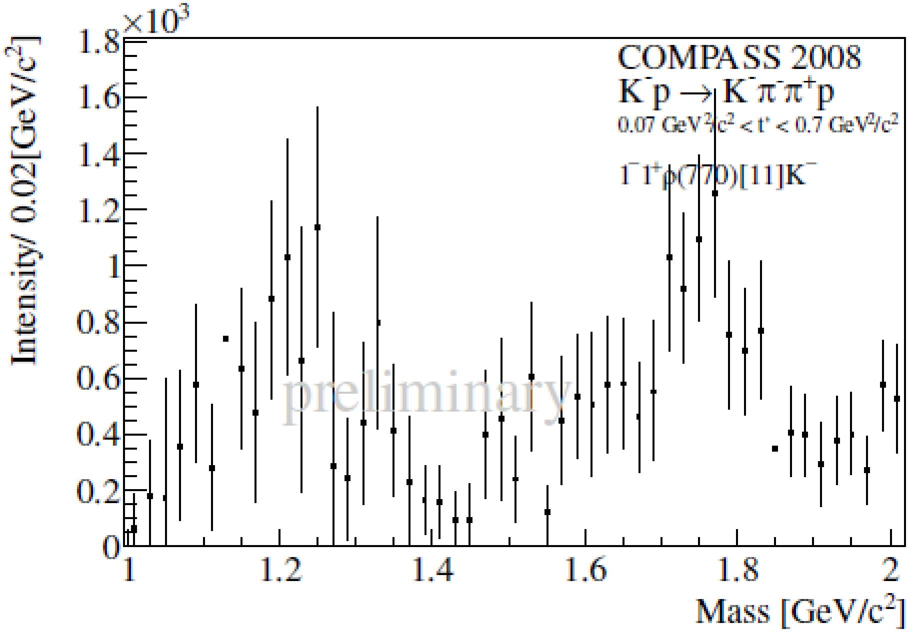
COMPASS 2008
K⁻p → K⁻π⁻π⁺p
0.07 GeV²/c² < t' < 0.7 GeV²/c²
0⁻0⁺f₀(600)[00]K⁻
vs 1⁺0⁺K*(892)[01]π⁻
preliminary
Δ φ/ 0.02[GeV/c²]
Mass [GeV/c²]

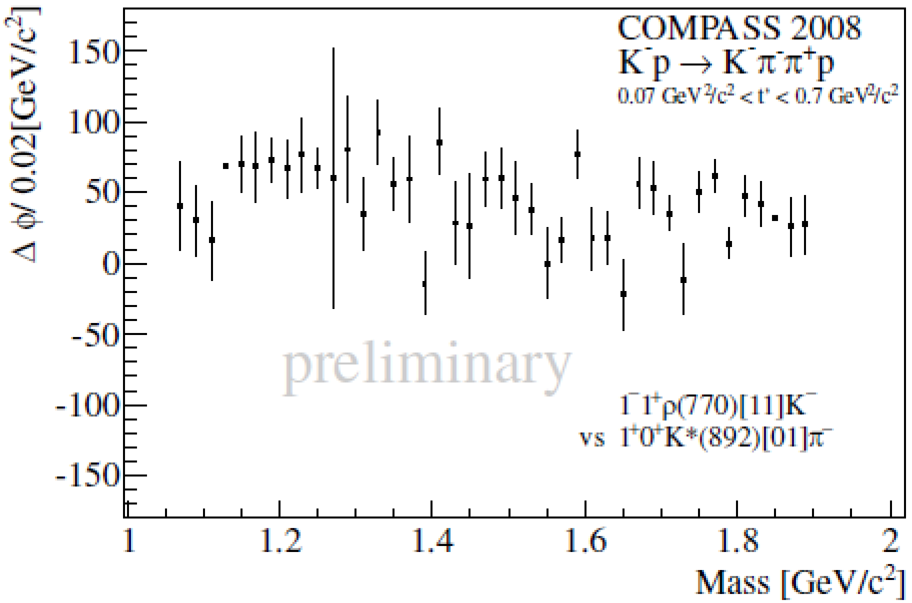
$J^P = 1^+$ M=1 waves



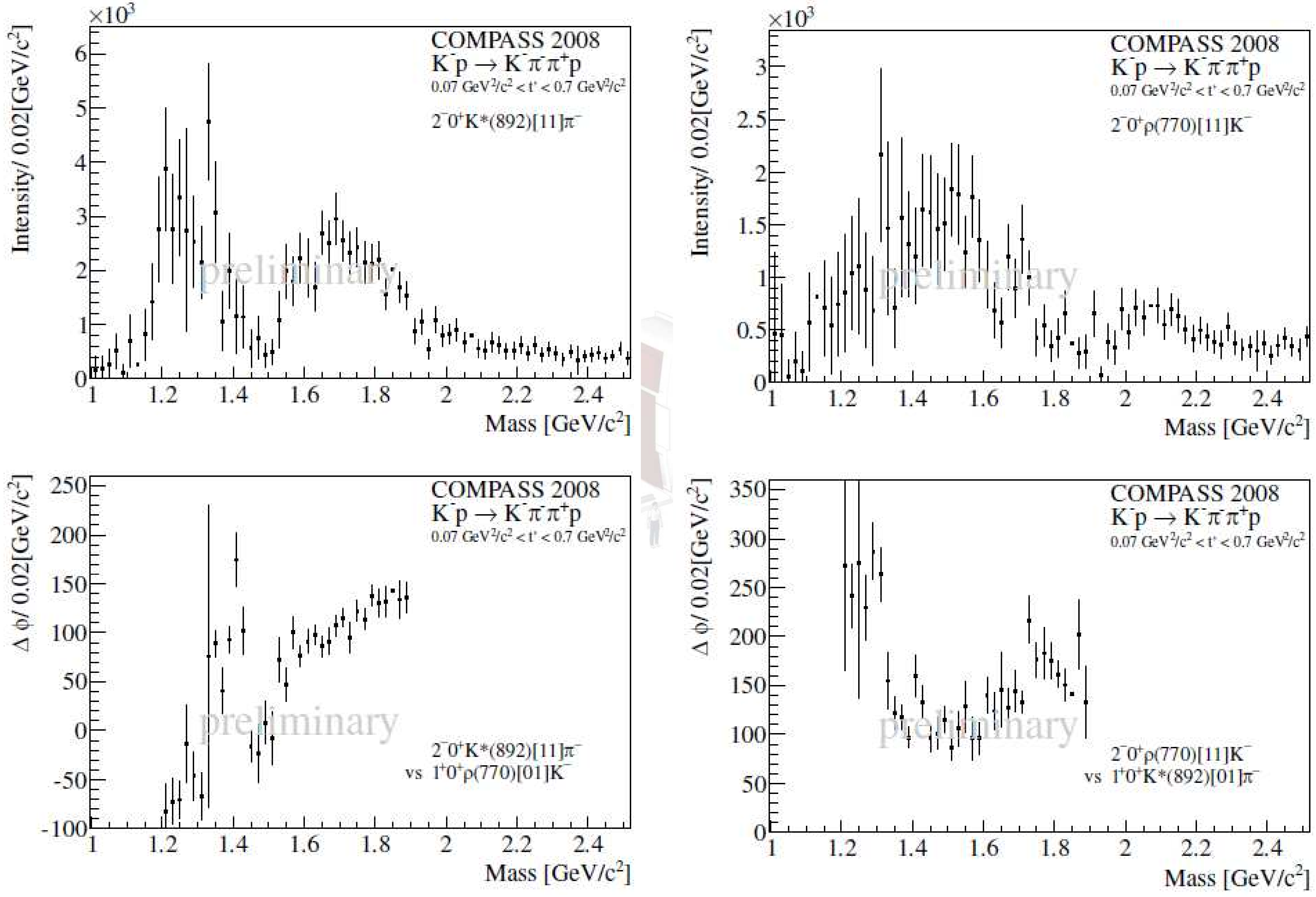
COMPASS 2008
$K^- p \rightarrow K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
$1^+1^+K^*(892)[01]\pi^-$
$1^+1^+\rho(770)[01]K^-$
$1^+1^+K^*(892)[01]\pi^-$ vs $1^+0^+\rho(770)[01]K^-$
$1^+1^+\rho(770)[01]K^-$ vs $1^+0^+K^*(892)[01]\pi^-$
Intensity/ 0.02[GeV/c²]
Δ φ/ 0.02[GeV/c²]
Mass [GeV/c²]
preliminary

$J^P = 1^-$ waves


COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
$1^- 1^+ \rho(770)[11]K^-$
preliminary
Intensity/ 0.02[GeV/c²]
Mass [GeV/c²]


COMPASS 2008
$K^- p \to K^- \pi^- \pi^+ p$
0.07 GeV²/c² < t' < 0.7 GeV²/c²
preliminary
$1^- 1^+ \rho(770)[11]K^-$
vs $1^+ 0^+ K^*(892)[01]\pi^-$
Δ ϕ/ 0.02[GeV/c²]
Mass [GeV/c²]

$J^P = 2^-$ waves


COMPASS 2008
$K^-p \rightarrow K^-\pi^-\pi^+p$
$0.07\ GeV^2/c^2 < t' < 0.7\ GeV^2/c^2$
$2^-0^+K^*(892)[11]\pi^-$
$2^-0^+\rho(770)[11]K^-$
$2^-0^+K^*(892)[11]\pi^-$ vs $1^+0^+\rho(770)[01]K^-$
$2^-0^+\rho(770)[11]K^-$ vs $1^+0^+K^*(892)[01]\pi^-$
preliminary
Intensity/ 0.02[GeV/c^2]
$\Delta\phi$/ 0.02[GeV/c^2]
Mass [GeV/c^2]
$\times 10^3$