$K\pi$ Scattering Study with K_L Beam Factory and GlueX

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Outline

I. Introduction and Motivation

- Test of *ChPT*
- Strange Meson Spectroscopy
- Standard Model Test

II. $K\pi$ Hadroproduction in K_L Facility

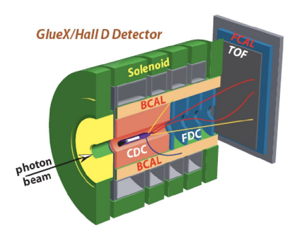
III. $K\pi$ Photoproduction in GlueX

IV. Conclusion

Introduction and Motivation

$K_L p \longrightarrow (K\pi)_J X$

X: p, n, Δ^{++}



Kπ Scattering Study

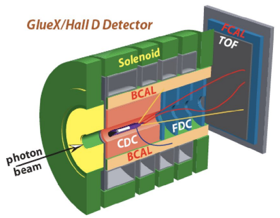
K*(892) production at 3.9 GeV with charged kaon beam: σ = 575 ± 19 μb.
Phys. Rev. D **4**, 2583

- Test of *ChPT*
- Strange Meson Spectroscopy
- Standard Model Test and New Physics

Test of *ChPT*

$K_L p \longrightarrow (K\pi)_J X$

X: p, n, Δ^{++}



Kπ Scattering Study

Test of *ChPT*

Strange Meson Spectroscopy

Standard Model Test and New Physics

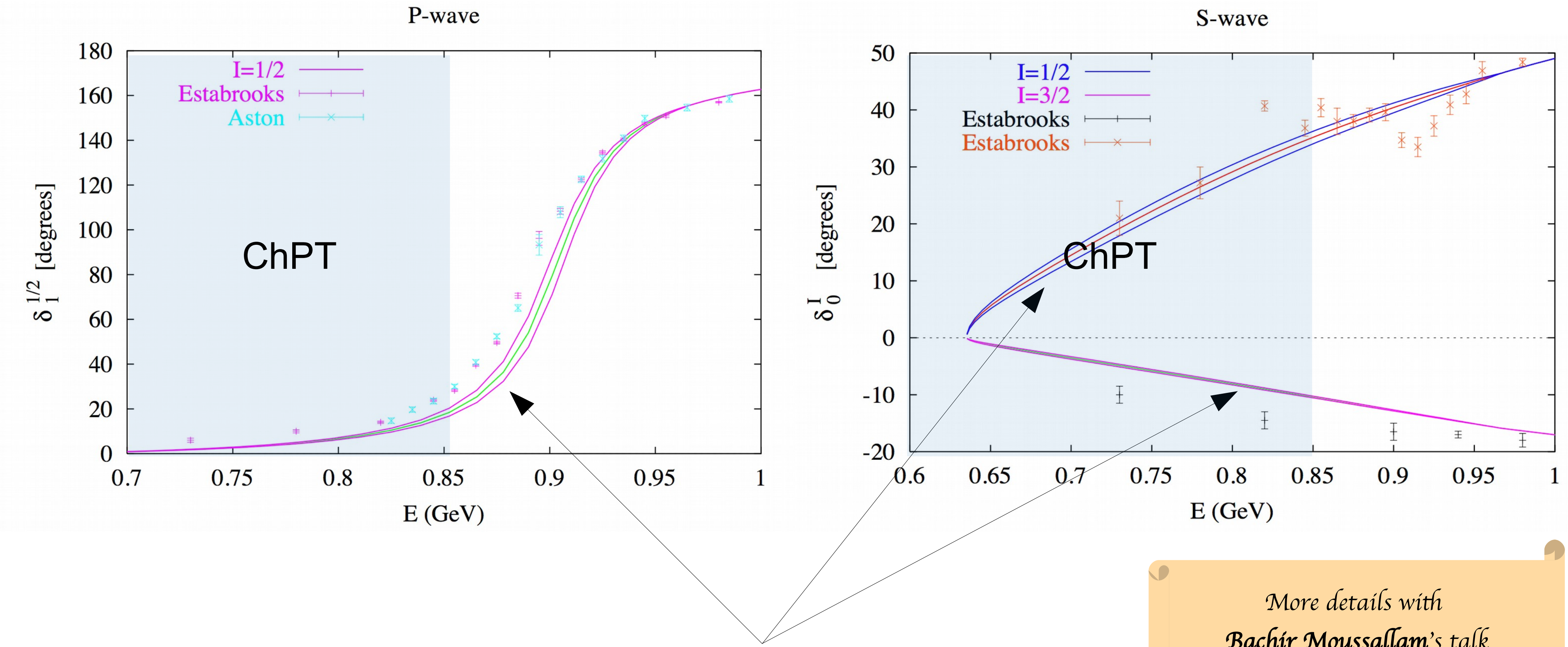
Test of *ChPT*

- In a limited kinematical region of the non perturbative QCD regime, it is possible to use an effective Lagrangian where π, η and K (Goldstone Bosons) are the fundamental degrees of freedom.
- *ChPT*: dynamics of π, η and K ($\{\pi\pi\}$, $\{\pi\eta\}$, $\{\pi K\}$) [Phys. Rev. 183 (1969) 1261, …].

	$\pi\pi$ interaction	$\pi\eta$ interaction	πK interaction
Scattering Study at Low Energy	Intensively studied	Several studies have been made & other studies ongoing (GlueX, ...)	The main studies have been made performed in the 70s and 80s.
Experiments (At Low Energy)	CLAS, MAMI, CERN, PLUTO, HERA, GlueX ...	CLAS, MAMI, CERN, PLUTO, GlueX ...	CERN 70-80 (e.g. WA7, ...), SLAC (LASS) , CLAS, COMPASS, ...
Experimental/Phenomenological comparison	SU(2) ChPT very successful	less successful	Poor agreement w/ ChPT SU(3)

Test of *ChPT*

Data with charged Kaon-production (LASS):

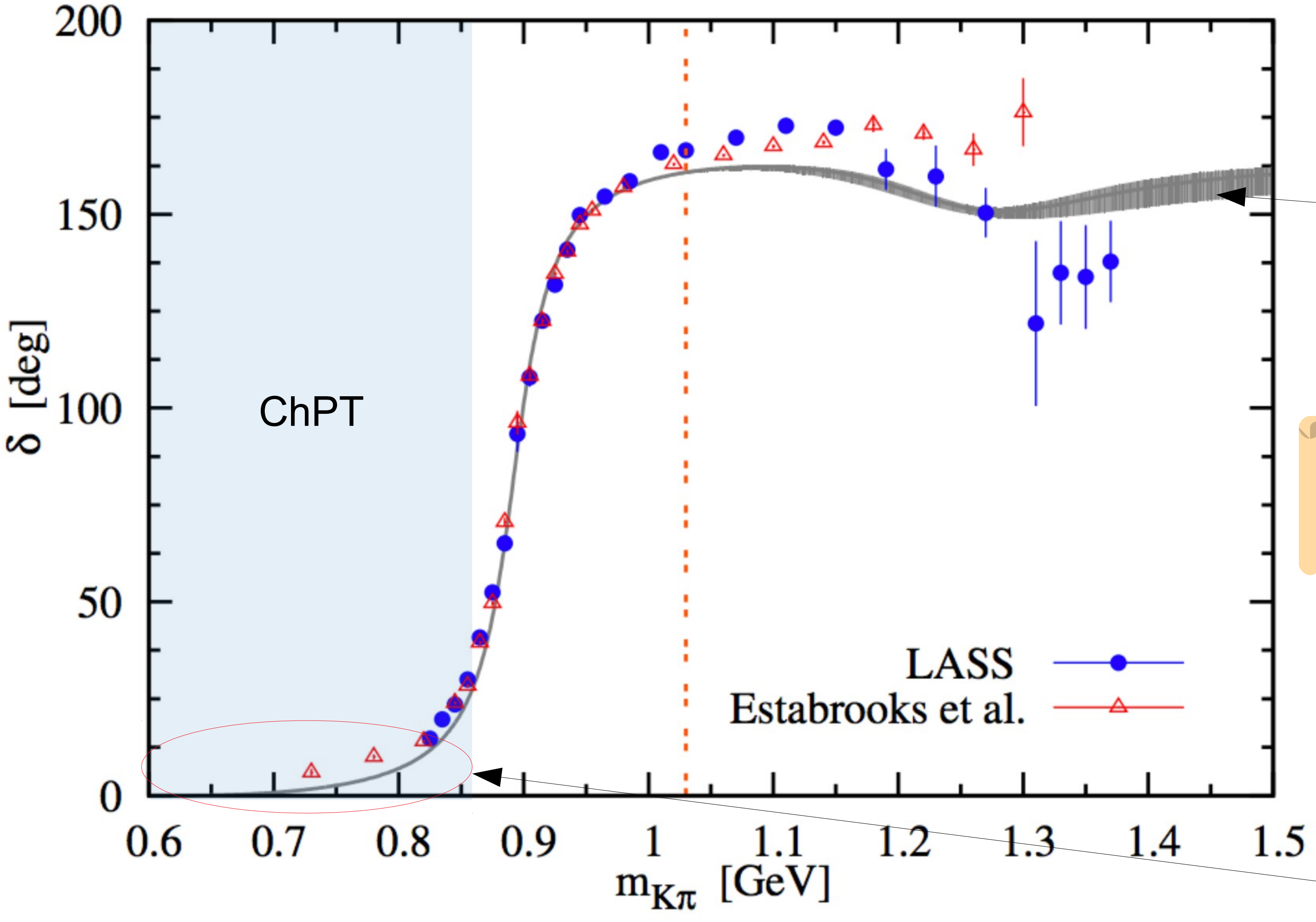


Buettiker, Descotes-Genon, Moussallam'04

More details with
***Bachir Moussallam**'s talk*

Test of *ChPT*

Boito, Escribano & Jamin'10 (Fit)



$\tau \to K \pi \nu_\tau$

Data from Belle

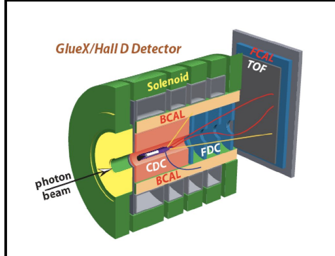
Require more data

More details with
Denis Epifanov*'s talk*

Hadron Spectroscopy

$K_L p \longrightarrow (K\pi)_J X$

X: p, n, Δ^{++}



$K\pi$ Scattering Study

- Test of *ChPT*
- Strange Meson Spectroscopy
- Standard Model Test and New Physics

Strange Meson Spectroscopy

- Hadron Spectroscopy plays an important to understand QCD in the non-perturbative domain:
  - Quantitative understanding of quark and gluon confinement
  - Determination of resonance and their nature.
  - Validate Lattice QCD prediction.
- *K*π scattering amplitude:
  - S-wave: K(800), $K_0^*(1430)$, ….
  - P-wave: $K^*(892)$, $K^*(1680)$, ….
  - D-wave: $K_2^*(1430)$, ….
- K_L Facility can improve the feature of the K* mesons with low mass:
  - S-wave: search for K(800) state, study the $K_0^*(1430)$.
  - P-wave: mass/width difference between hadroproduction and meson decays.

S-wave: K(800) (Kappa)

- The indications on the presence of Kappa resonance have been reported based on the data of the E791 and BES collaborations.
- The results of from Roy-Steiner dispersive representation [ref] not in agreement with low energy experimental data.

	M_κ (MeV)	Γ_κ (MeV)
This work	658 ± 13	557 ± 24
Zhou, Zheng [16]	694 ± 53	606 ± 89
Jamin et al. [18]	708	610
Aitala et al. [7]	$721 \pm 19 \pm 43$	$584 \pm 43 \pm 87$
Pelaez [19]	750 ± 18	452 ± 22
Bugg [9]	750^{+30}_{-55}	684 ± 120
Ablikim et al. [20]	$841 \pm 23^{+64}_{-55}$	$618 \pm 52^{+55}_{-87}$
Ishida et al. [14]	877^{+65}_{-30}	668^{+235}_{-110}

S. Descotes-Genon and B. Moussallam'06

- The confirmation of this pole in the amplitude for elastic πK scattering requires more data at low energy.

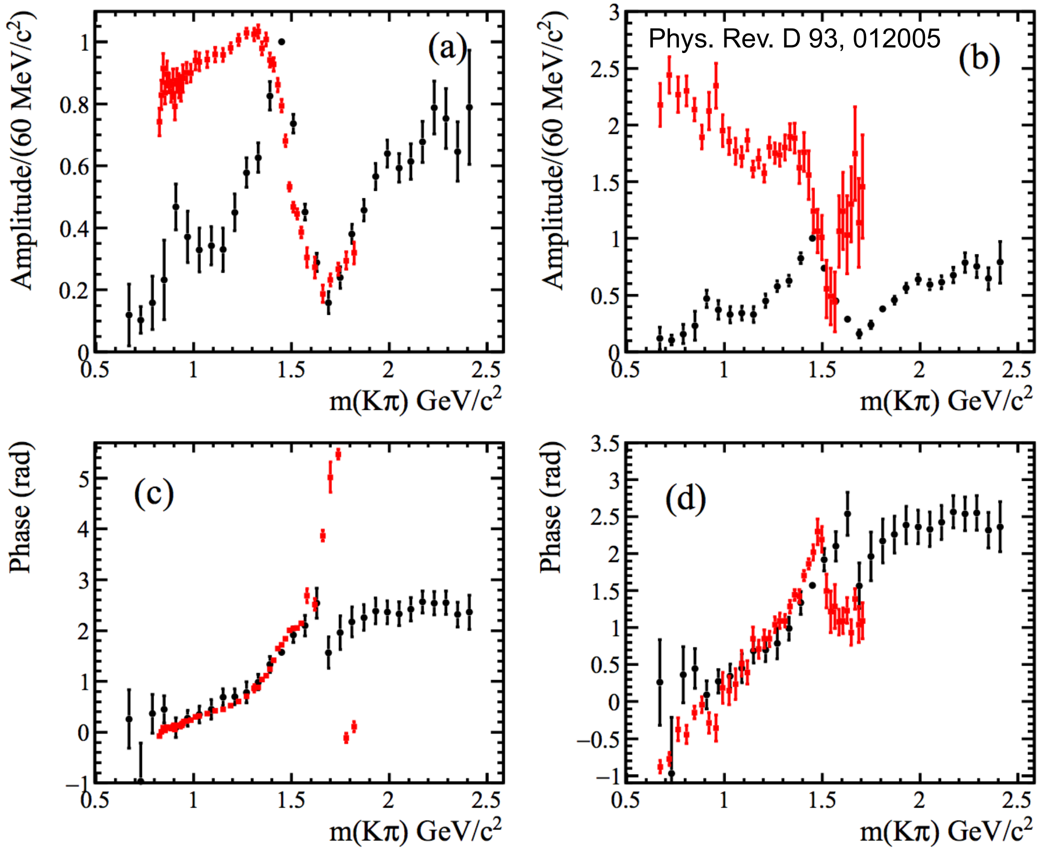
S-wave: $K^*_0(1403)$

- K^*_0(1403) PDG: mass = 1425 ± 50, width = 270 ± 80.
- Recently, the $K\pi$ S-wave amplitude extracted from $\eta_c \rightarrow KK\pi$ found to be very different with respect to the amplitude measured by LASS and E791.

LASS (a,c) { $Kp \rightarrow K\pi p$ } and E791(b,d) { $D \rightarrow KK\pi$ }.

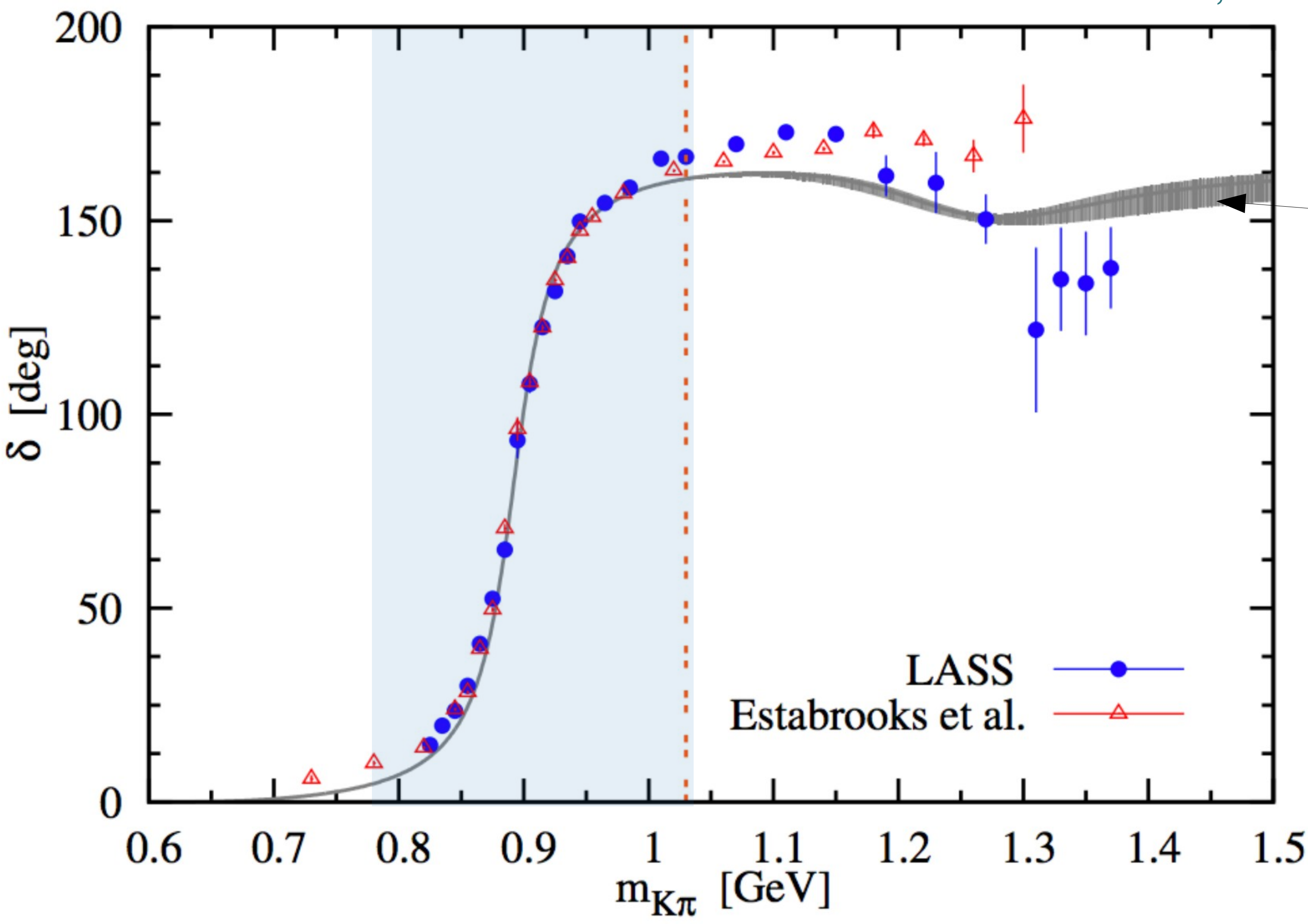
BaBar { $\eta_c \rightarrow KK\pi$ }.

More details with
Antimo Palano*'s talk*



P-wave: K*(892)

Boito, Escribano & Jamin'10 (Fit)

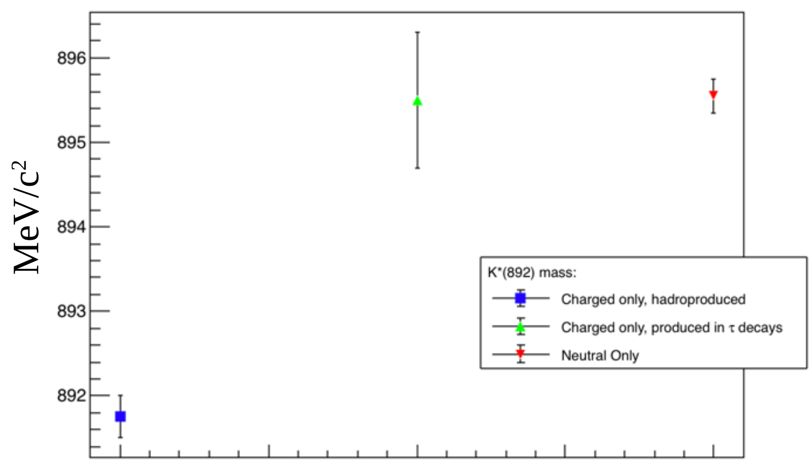


$\tau \to K \pi \nu_\tau$

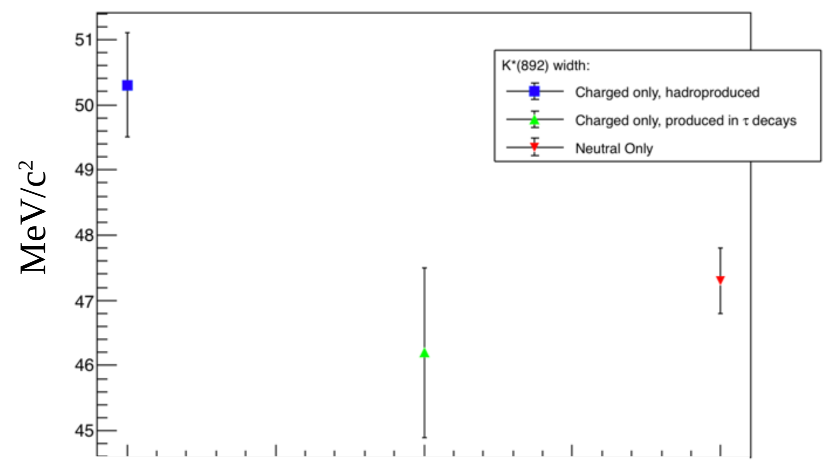
Data from Belle

P-wave: K*(892)

mass



width



$K_L p \rightarrow (K\pi)^+ n$

$K_L p \rightarrow (K\pi)^0 p$

$K_L p \rightarrow (K\pi)^- \Delta^{++}$

$$m_{K^*(892)^0} - m_{K^*(892)^{+-}} = 6.7 \pm 1.2 \quad MeV$$

Decay Modes

Mode		Fraction (Γ_i/Γ)
Γ_1	$K\pi$	$(100)\%$
Γ_2	$(K\pi)^{+-}$	$(99.900 \pm 0.009)\%$
Γ_3	$(K\pi)^0$	$(99.754 \pm 0.021)\%$
Γ_4	$K^0\gamma$	$(2.46 \pm 0.21) \times 10^{-3}$
Γ_5	$K^\pm\gamma$	$(1.00 \pm 0.09) \times 10^{-3}$
Γ_6	$K\pi\pi$	$< 7 \times 10^{-4}$

Strange Meson Spectroscopy
($Kp \to K\pi p$, $K\pi\pi p$, $K\Phi p$, $\Lambda\bar{p}X$)

- K
- K(800) : Needs confirmation
- K*(892)
- K_1(1270)
- K_1(1400)
- K*(1410)
- K_0*(1430)
- K_2*(1430)

More details with
Alessandra Filippi's talk

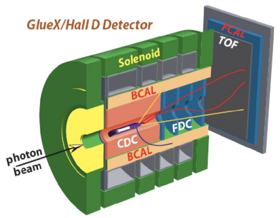
More details with
Boris Grube's talk

- K(1460) : Observed in $K\pi\pi$ partial-wave analysis
- K_2(1580) : Seen in PWA of the $K\pi\pi$ system, need confirmation
- K(1630) : Seen as a narrow peak, compatible with the experimental resolution, in the invariant mass of the $K\pi\pi$ system produced in πp interaction at high t.
- K_1(1650): reported in PWA in 1600- 1900 of $m_{K\pi\pi}$
- K*(1680)
- K_2(1770)
- K_3*(1780)
- K_2*(1820)
- K(1830): Seen in PWA in $K\Phi$. Needs confirmation
- K_0*(1950): Seen in PWA of $K\pi$ *(LASS)*. Needs confirmation.
- K_0*(1980): Needs confirmation
- K*(2045)
- K_2(2250): reported in 2150 – 2260 in $\Lambda\bar{p}$
- K_2*(2320): Seen in $J^P=3^+$ wave on antyhyperon-nucleon system. Needs confirmation
- K_5*(2380): Needs confirmation.
- K_4(2500): Needs confirmation.
- K(3100): Narrow peak observed in ($\Lambda\bar{p}$+ pions and c.c.). If due to strong decays, this state has exotic quantum numbers (B=0,Q=+1,S=−1). Needs confirmation.

SM Test and New Physics

$K_L p \longrightarrow (K\pi)_J X$

X: p, n, Δ^{++}



Kπ Scattering Study

Test of *ChPT*

Strange Meson Spectroscopy

Standard Model Test and New Physics

SM Test and New Physics

- The determination of the CKM matrix elements V_{us} is mainly performed using τ or Kaon decays:

$$\Gamma(K \to \pi l \nu) \propto N |V_{us}|^2 |f_+^{K\pi}(0)|^2 I_K^l, \qquad t = (p_K - p_\pi)^2,$$

$$I_K = \int dt \frac{1}{m_K^8} \lambda^{3/2} F(\tilde{f}_+(t), \tilde{f}_0(t)).$$

- The strangeness changing scalar $f_0(t)$ and vector $f_+(t)$ form factor in the low energy region can be obtained from Lattice QCD, or from the study of the $K\pi$ scattering (dispersion relation) [V. Bernard et al., PRD 80 (2009)].

$$\tilde{f}_+(t) = \exp\left[\frac{t}{m_\pi^2}(\Lambda_+ - H(t))\right]$$

$$\tilde{f}_0(t) = \exp\left[\frac{t}{m_K^2 - m_\pi^2}(\ln(C) - G(t))\right]$$

*More details with **Michael Doering**'s talk*

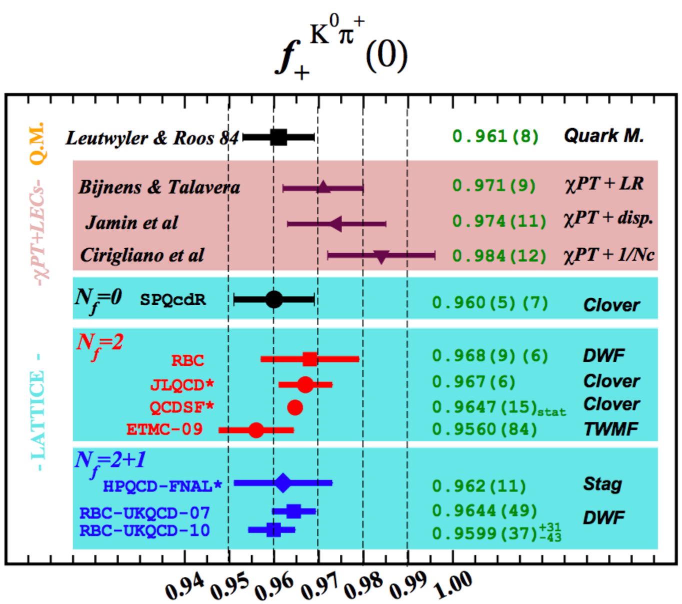
- H(t) and G(t) evaluated from $K\pi$ scattering data and given as polynomials.

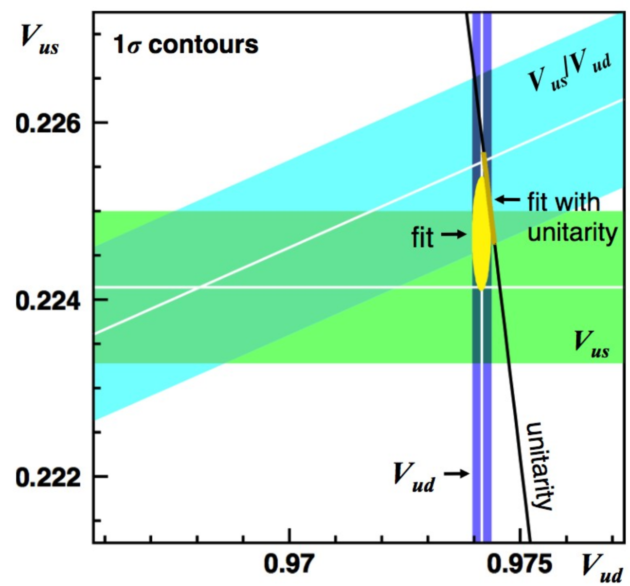
SM Test and New Physics

$f_+(0)V_{us}$ → V_{us} ⇒ Test of unitarity: $|V_{ud}|^2 + |V_{us}|^2 + |V_{ub}|^2 = 1 + \Delta_{CKM}$

- $|V_{ud}|^2$: β decay
- $|V_{us}|^2$: K_{l3} or τ decays
- $|V_{ub}|^2$: B decays (negligible)
- Δ_{CKM}: Deviation from SM (New Physics)

Ref: FlaviaNet KaonWG 2010





$V_{ud} = 0.97416(21)$

$V_{us} = 0.2248(7)$

$\Delta_{CKM} = -0.0005(5)$

SM Test and New Physics

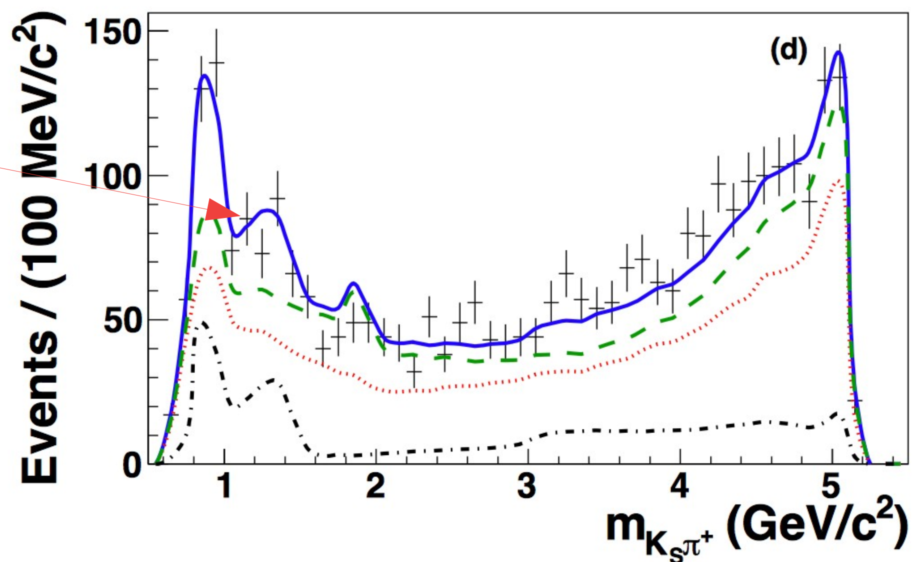
More details with
Alessandro Pilloni's talk

- CP violation is mainly studied using *B*, *D* and *K* decays.
- Several decay include $K\pi$ interaction in the final state.
- Most of the analyses, specially with three-body decay, use a model dependent analysis (isobar model, K-matrix, …) to describe the data, *e.g.* $B \to (D \to K_s\pi\pi)\, K_s,\;\; B \to K_s\pi\pi,\;\; D_s \to K_s\pi\pi \ldots$
- The modeling of the S-wave $K\pi$ components are not well established, and can be the main source of systematics, which will affect the accuracy of the fundamental parameter measurements.

BABAR-PUB-14/011, $B^+ \to K_s\pi^+\pi^0$

More details with
Rafael Silva Coutinho's talk

K*(1430):
Lesniac Model?
LASS Model?
RBW?
...

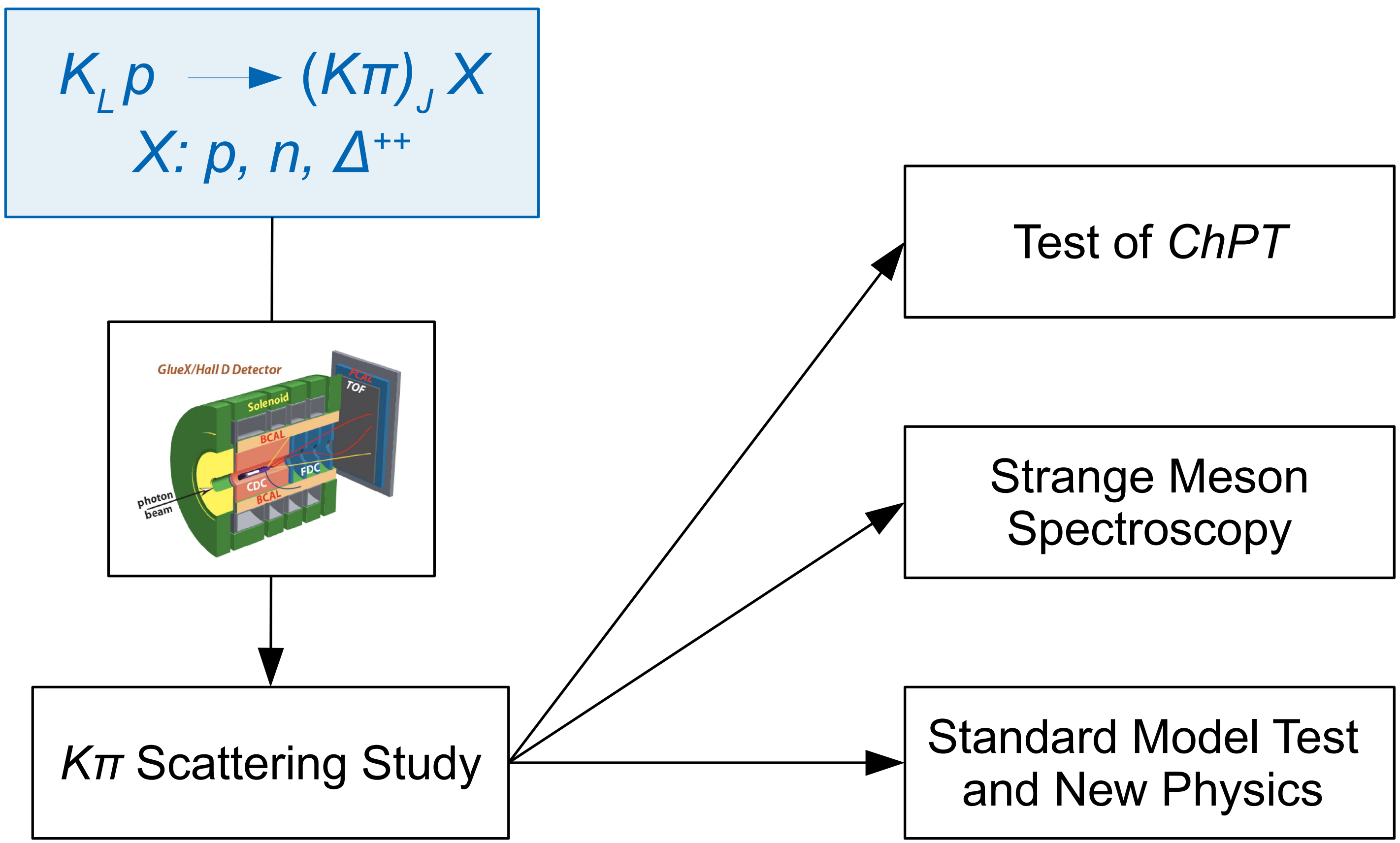


SM Test and New Physics

TABLE XI: Combined $B^{\pm}$ fit: Systematic uncertainties for the branching fraction measurements, including uncertainties due to the signal model.

Source \ Resonant contribution	Relative Variations of branching fraction (%)					
	Inclusive	$K^*(892)^0$	$K^*(892)^+$	$K_0^*(1430)^0$	$K_0^*(1430)^+$	$\rho(770)^+$
Correctly reconstructed $m_{\rm ES}$ and ΔE PDF (fixed parameters)	0.8	1.1	0.6	1.1	0.7	1.2
Correctly reconstructed and self crossfeed signal $\rm BDT_{out}$ PDFs	3.3	3.3	3.4	3.4	4.2	4.0
Self crossfeed signal $m_{\rm ES}$ and ΔE PDF models	3.0	4.3	3.1	1.3	1.8	7.5
Fit bias	0.3	0.9	0.6	0.5	0.7	0.9
$B\overline{B}$ background $m_{\rm ES}$, ΔE and $\rm BDT_{out}$ PDFs	0.3	0.4	0.2	0.3	0.5	0.6
$B\overline{B}$ background yields	0.7	1.2	0.6	0.9	2.0	1.8
Background model in Dalitz plot	1.5	3.7	2.8	2.8	2.7	3.5
Signal efficiency model	0.3	1.8	1.0	0.4	0.4	0.8
$K^*(892)$ mass and width	0.1	0.7	0.3	0.1	0.2	0.1
$K_0^*(1430)$ mass and width	3.2	3.8	2.1	8.1	5.5	4.0
$\rho(770)^+$ mass and width	< 0.1	0.2	0.1	0.1	0.2	0.3
Blatt-Weisskopf radius	2.3	4.4	2.9	7.4	2.9	3.7
Subtotal	6.3	9.1	6.6	12.0	8.5	11.0
Neutral pion efficiency	1.0	1.0	1.0	1.0	1.0	1.0
K_S^0 efficiency	1.1	1.1	1.1	1.1	1.1	1.1
Charged particle identification efficiency	1.0	1.0	1.0	1.0	1.0	1.0
Tracking efficiency	1.0	1.0	1.0	1.0	1.0	1.0
$N_{B\overline{B}}$	0.6	0.6	0.6	0.6	0.6	0.6
Total	6.6	9.4	7.0	12.2	8.7	11.2
Changes due to signal model	$\Delta\mathcal{B}\ (10^{-6})$					
$(K\pi)_0^{*0}/(K\pi)_0^{*+}$ parametrization	+8.0	−0.3	−0.3	–	–	−1.4
$\rho(1450)^+$	+2.3	+0.3	−0.4	+2.7	−0.8	−2.0
$K_2^*(1430)^0$ and $K_2^*(1430)^+$	+1.4	−0.3	+0.3	−2.6	−0.8	−0.3
$K^*(1680)^0$ and $K^*(1680)^+$	+1.8	−0.1	−0.1	+0.6	−1.4	−0.2
Total (+)	+8.6	+0.3	+0.3	+2.7	+0.0	+0.0
Total (−)	−0.0	−0.4	−0.5	−2.6	−1.8	−2.4

$K\pi$ hadroproduction



$K\pi$ hadroproduction

- The $K\pi$ hadroproduction has been studied in LASS with charged Kaon beam. They parametrized the $K\pi$ production mechanism using a model consisting of exchange degenerate Regge poles together with non-evasive "cut" contributions (*P. Estabrooks et al*. Nuclear Physics B133 (1978) 490-524).
- The LASS parametrization of the naturality amplitude $L^{\pm}_{\lambda}$ for the $K\pi$ production:

$$L_0 = \frac{\sqrt{-t}}{m_\pi^2 - t} G^L_{K\pi}(m_{K\pi}, t),$$

$$L_1^- = \sqrt{\frac{1}{2}L(L+1)}\, G^L_{K\pi}(m_{K\pi}, t)\, \gamma_c(m_{K\pi}) \exp(b_c(m_{K\pi})(t - m_\pi^2)),$$

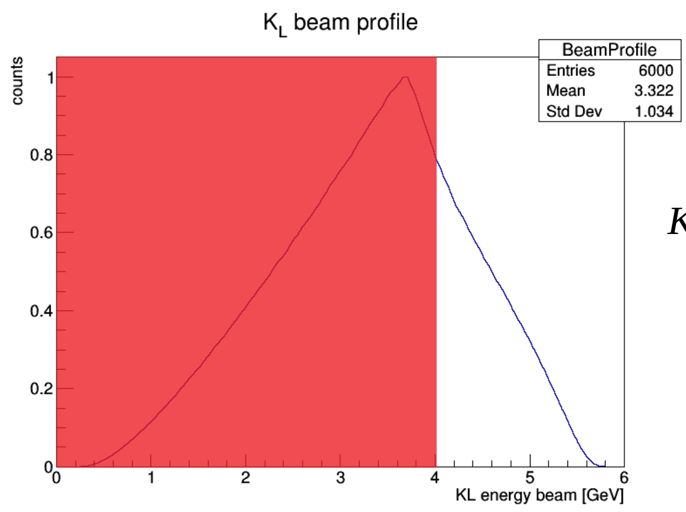
$$L_1^+ = \sqrt{\frac{1}{2}L(L+1)}\, G^L_{K\pi}(m_{K\pi}, t)[\gamma_c(m_{K\pi}) \exp(b_c(m_{K\pi})(t - m_\pi^2)) - 2i\gamma_a(m_{K\pi}) \exp(b_a(m_{K\pi})|t'|(t - m_\pi^2))],$$

$$L_\lambda^{+-} = 0, \quad \lambda \geqslant 2 \quad .$$

$$G^L_{K\pi}(m_{K\pi}, t) = N \frac{m_{K\pi}}{\sqrt{q}} a_L(m_{K\pi}) \exp(b_L(m_{K\pi})(t - m_\pi^2)), \quad a_L^I = \sqrt{(2L+1)}\, \epsilon^I \sin\delta_L^I e^{\delta_L^I}$$

  - q: center-of-mass momentum, L: angular momentum,
  - λ: t-channel helicity , by natural (+) and unnatural (-) parity exchange.

$K\pi$ hadroproduction

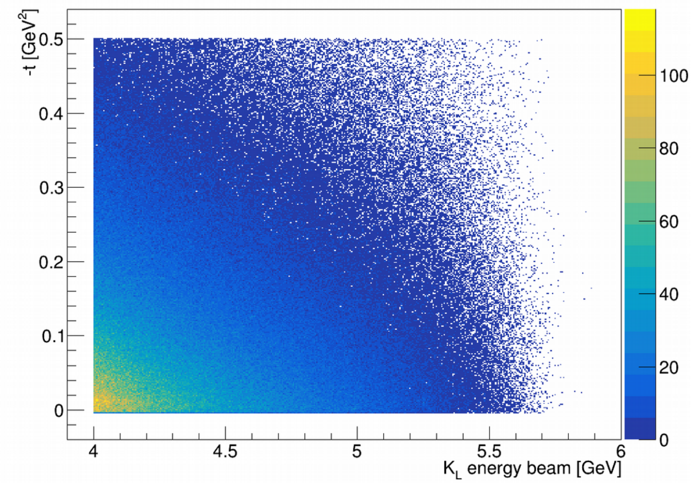


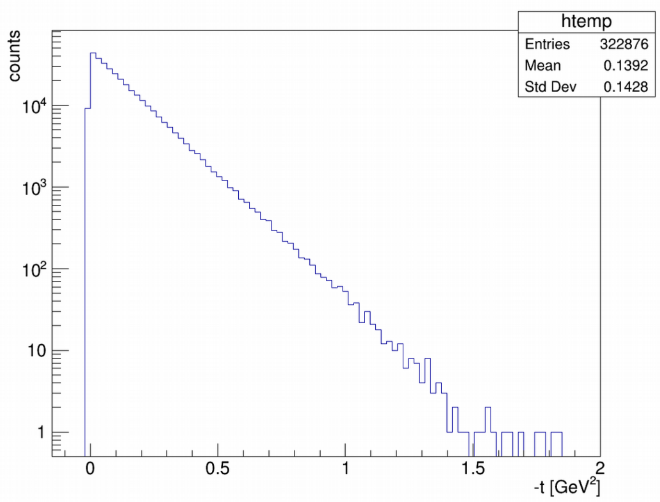
$K\pi$ Production (Estabrook Model)

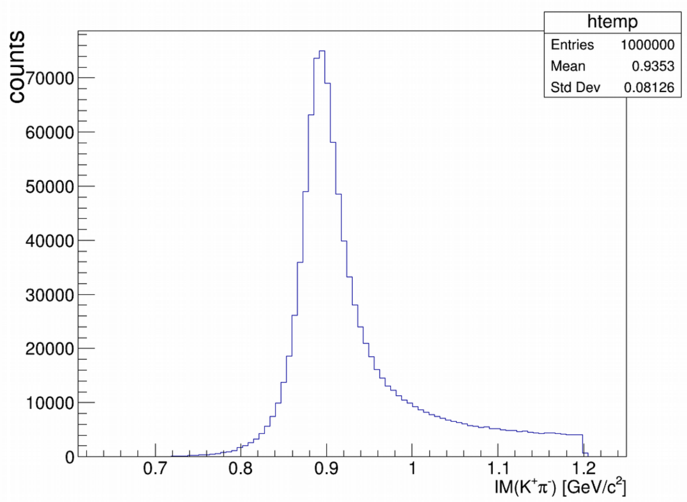
→

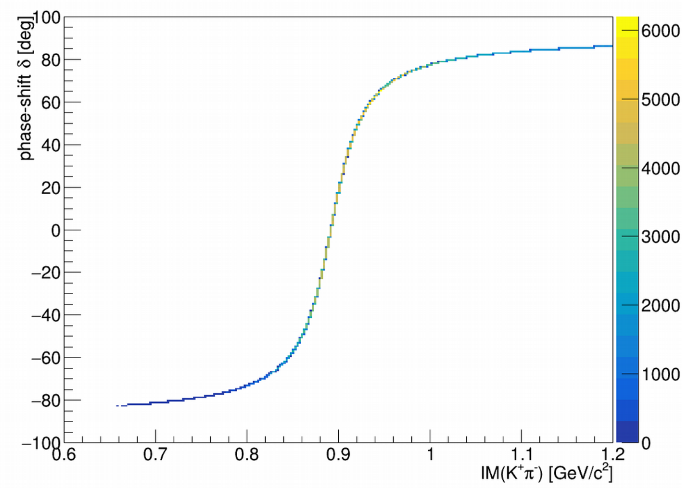
Only P-Wave ($K^*(892)$)

Assuming similar to the $K\pi$ production mechanism with charged kaon beam.





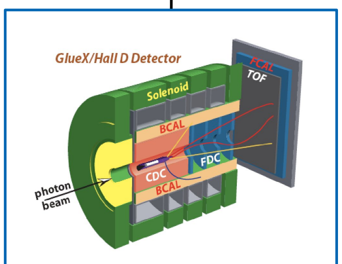




$K\pi$ Hadro-Production

$K_L p \longrightarrow (K\pi)_J X$

X: p, n, Δ^{++}



Kπ Scattering Study

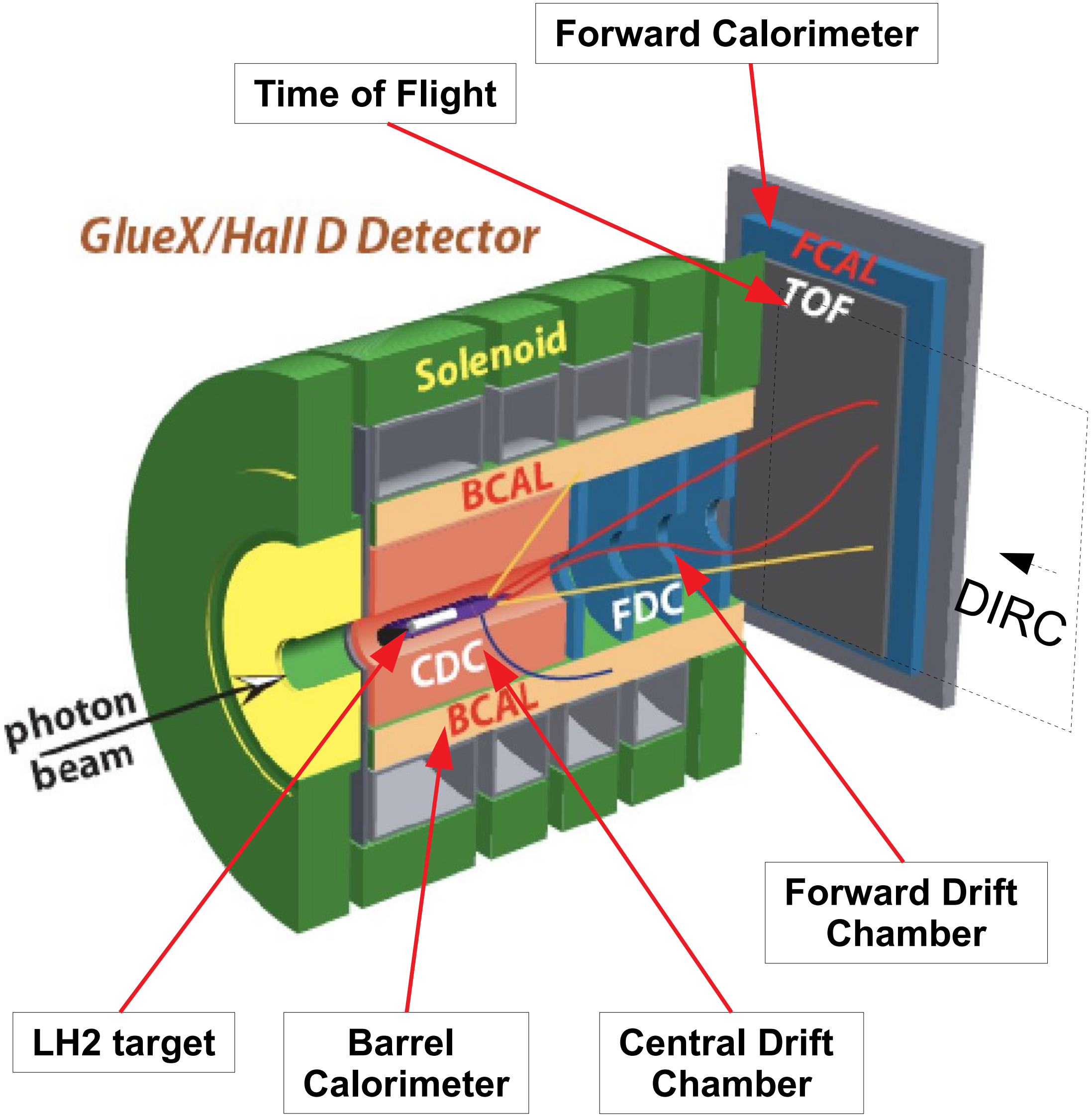
Test of *ChPT*

Strange Meson Spectroscopy

Standard Model Test and New Physics

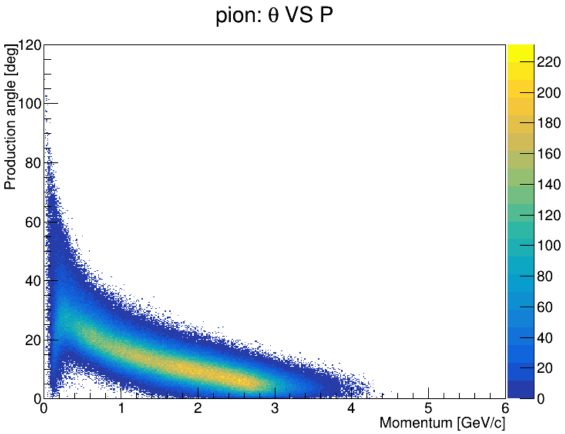
GlueX Detector

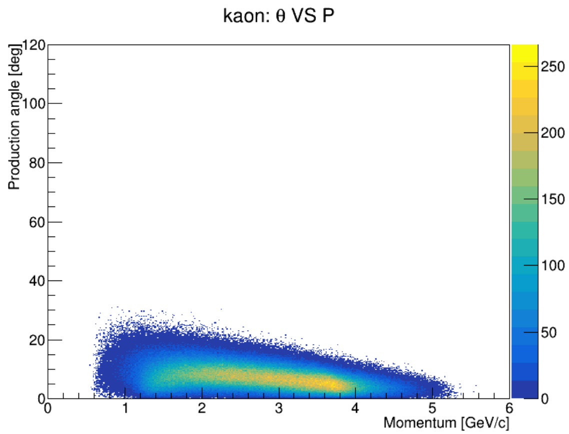
- Acceptance θ = 1º-120º
- Charged particles: drift chambers $\sigma_p/p \sim$ 1-3%
- Photon: electromagnetic calorimeters
  $\sigma_E/E = 6\%/\sqrt{E} \oplus 2\%$
- Timing: Start Counter, time of flight
- PID: All identifiable particle (dE/dx, E/p, Δt, θ_c)

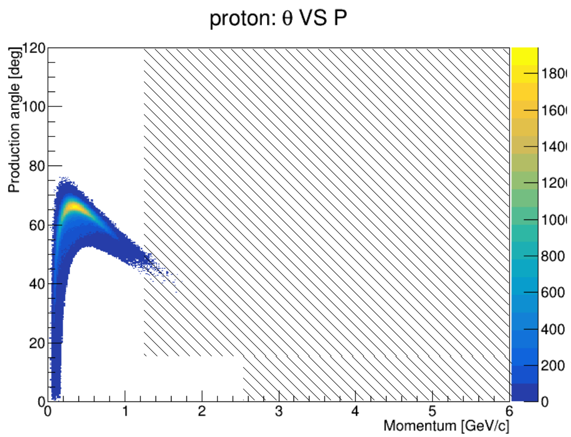


Kπ Hadro-Production in GlueX

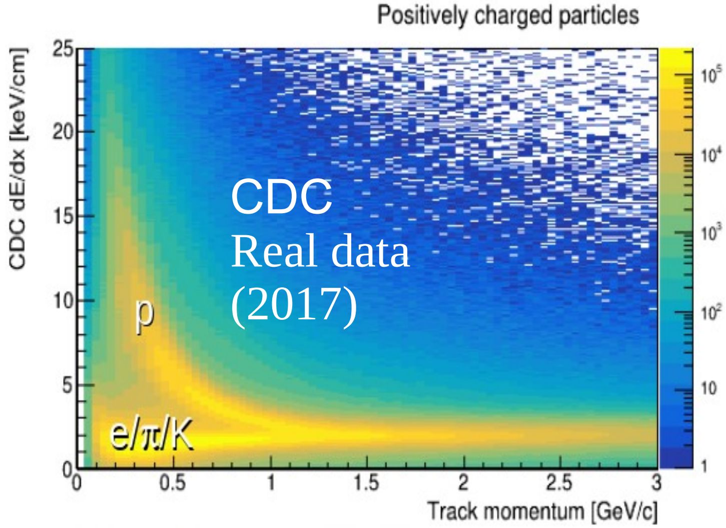
$$K_L p \longrightarrow K^*(892)\{\longrightarrow K^+\pi^-\}\, p$$

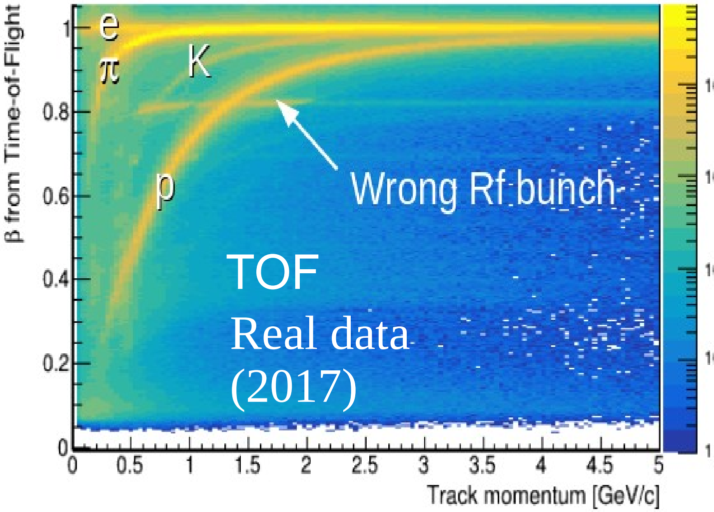






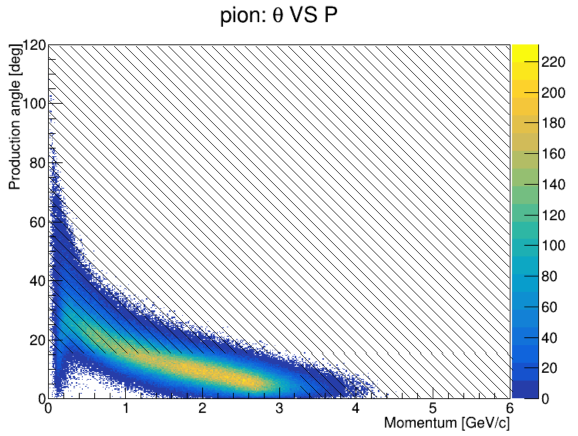
GlueX particle identification performance

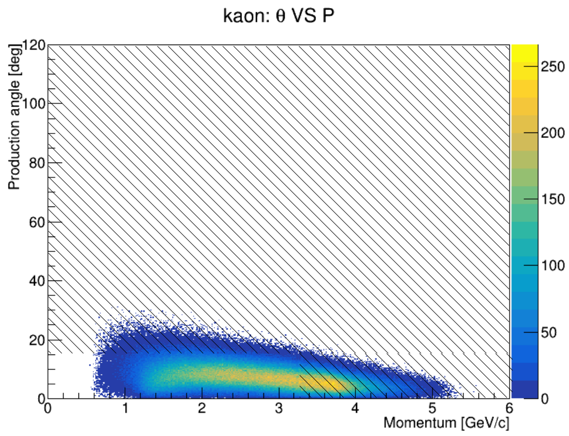


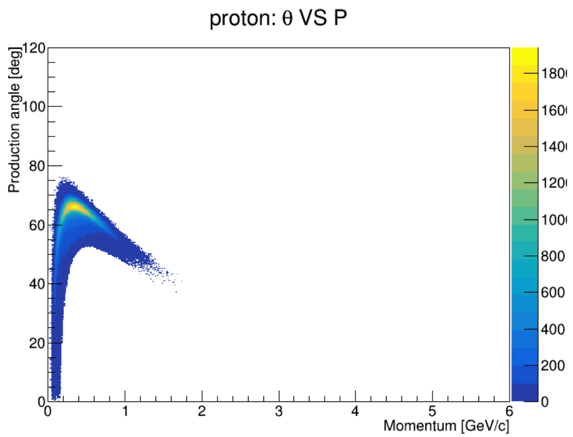


$K\pi$ Hadro-Production in GlueX

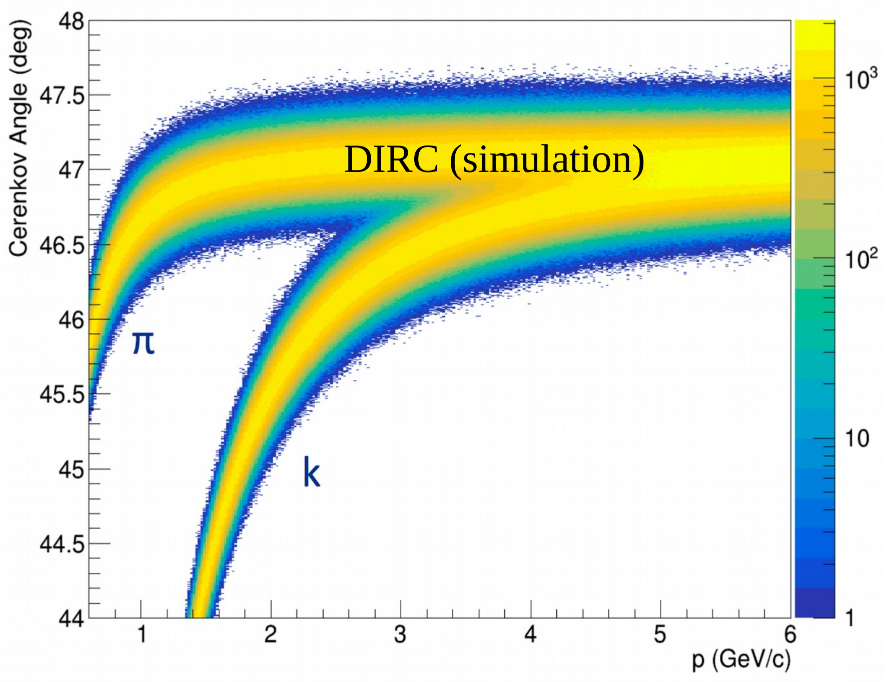
$$K_L p \longrightarrow K^*(892)\{\longrightarrow K^+\pi^-\}\, p$$





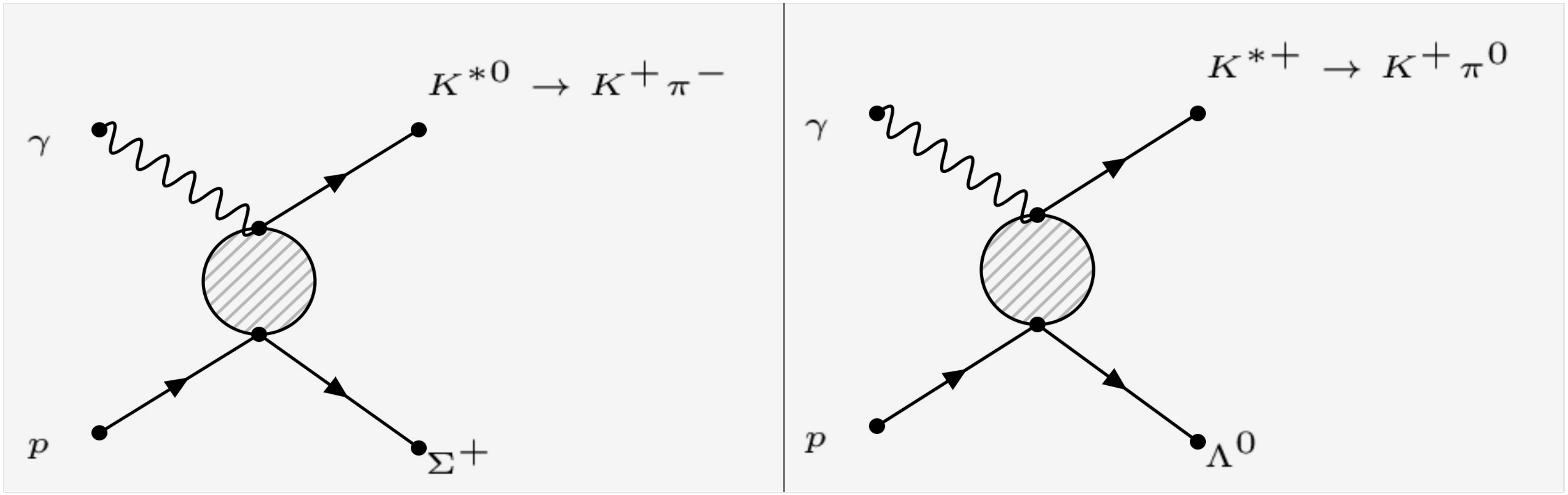


GlueX particle identification performance



$K\pi$ Photo-Production in GlueX

- $K\pi$ can be produced with photon beams:



- Possible $K\pi$ photo-production mechanism:
  - t-channel: K^*, K, κ exchanges.
  - s-channel: N, Δ diagrams.
  - u-channel: Λ, Σ, Σ* diagrams.

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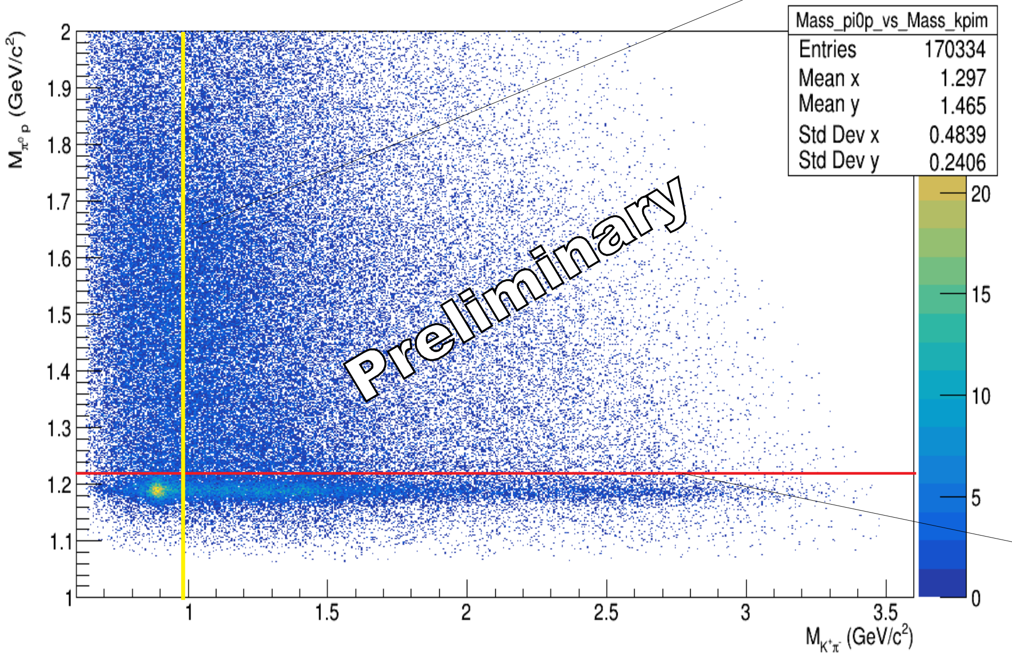
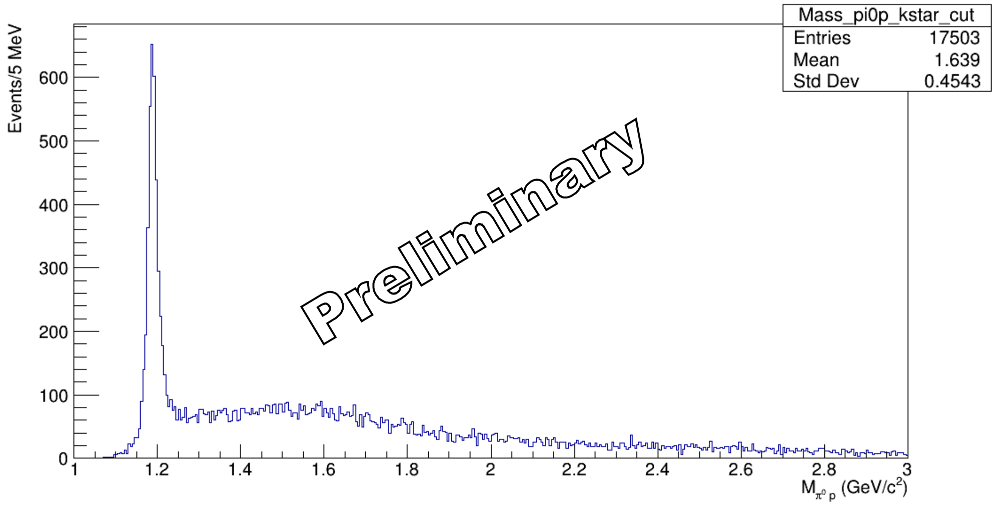
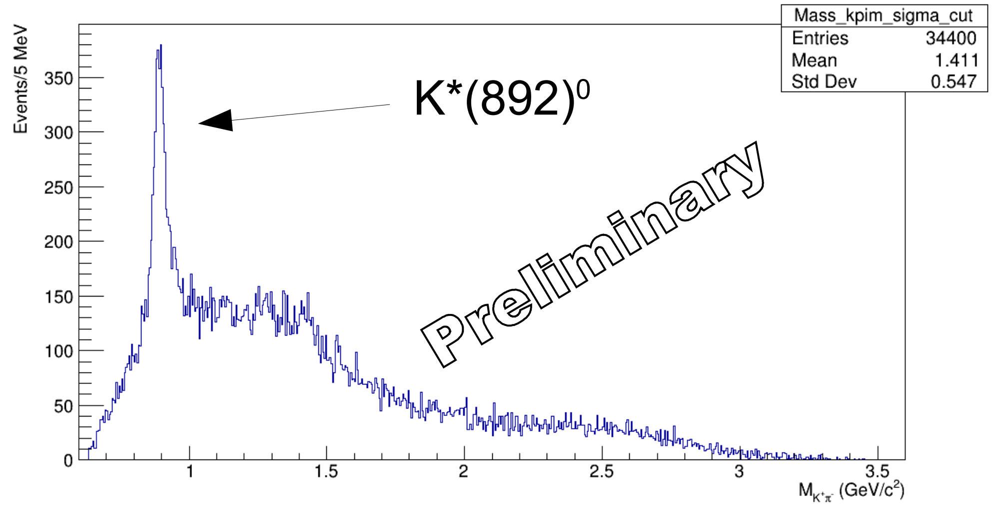
$K\pi$ photoproduction in GlueX

$\gamma\, p \rightarrow (K\pi)_J^0\, \Sigma^+(\rightarrow p\pi^0)$ (GlueX Spring 2017 data)

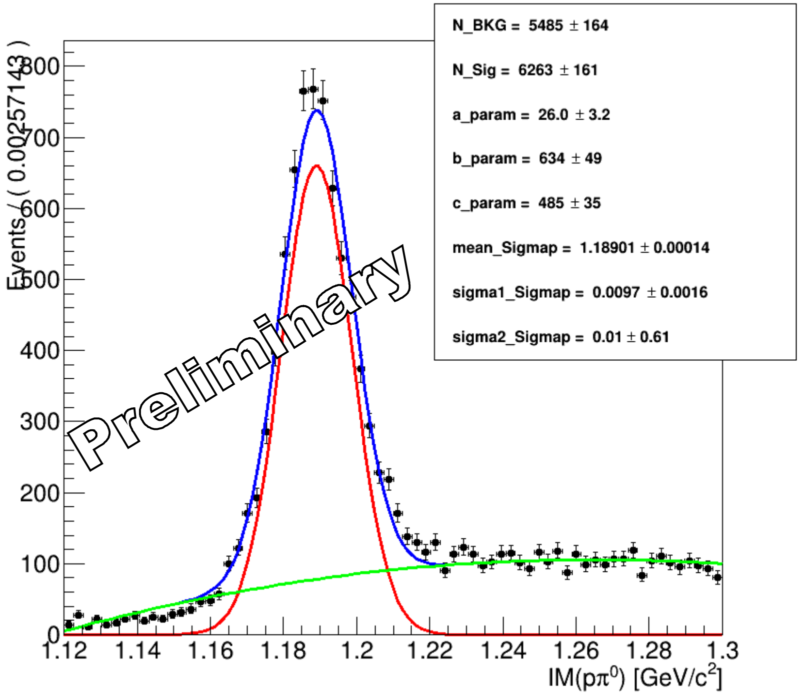


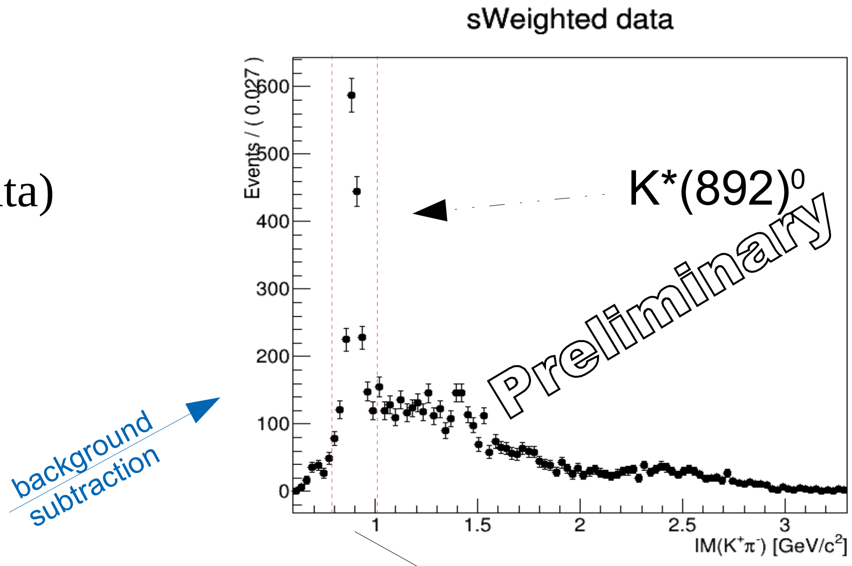


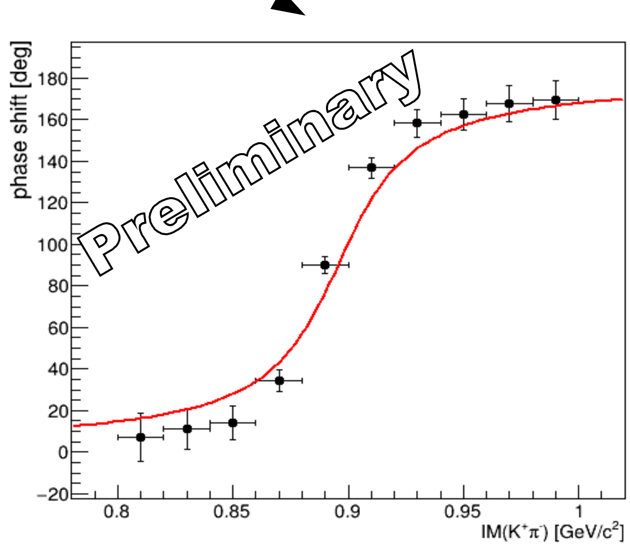


$K\pi$ photoproduction in GlueX

$\gamma\, p \rightarrow (K\pi)_J^0\, \Sigma^+(\rightarrow p\pi^0)$ (GlueX Spring 2017 data)

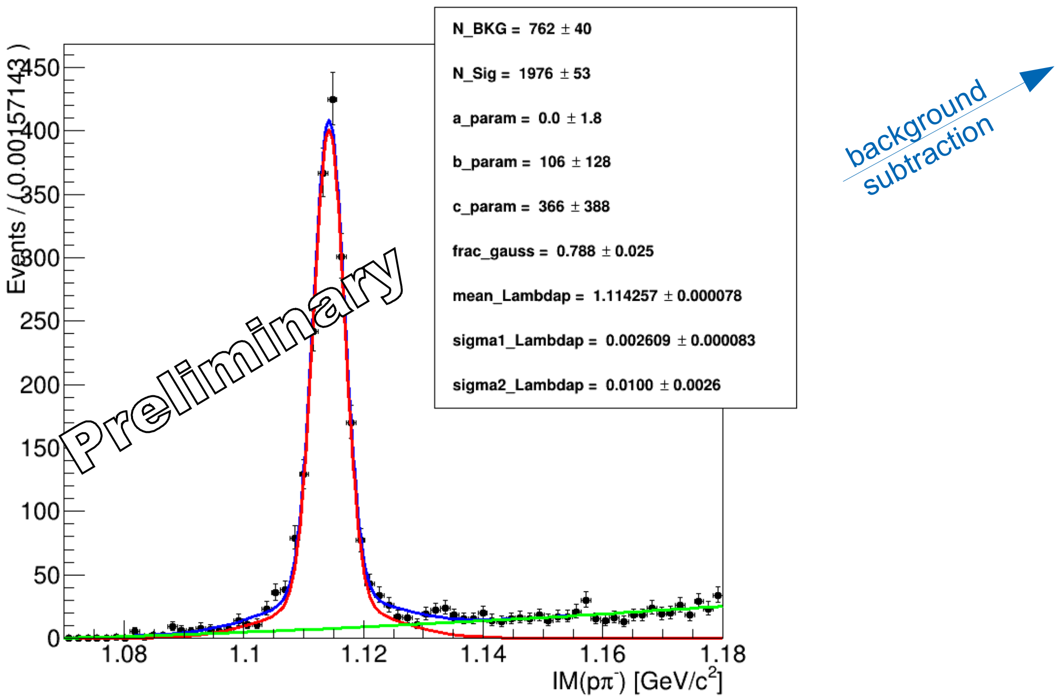


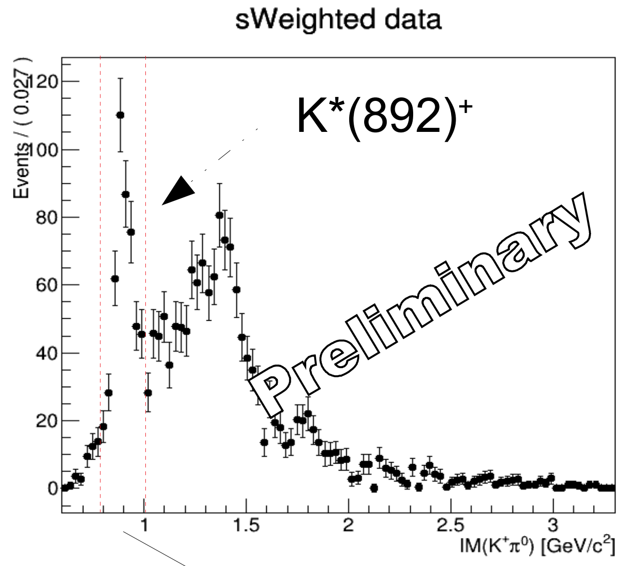


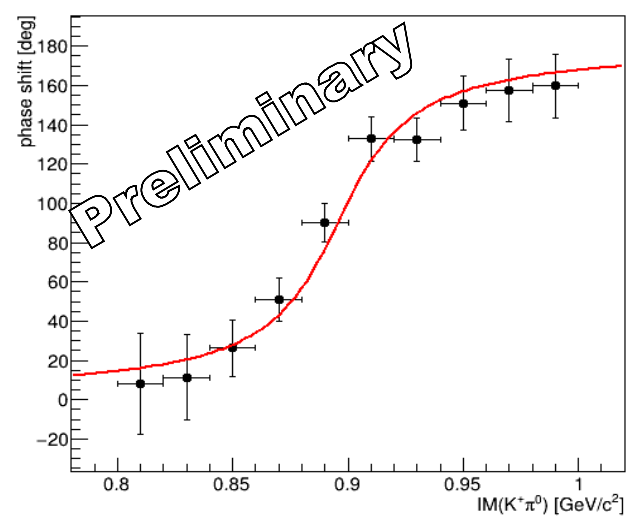


Kπ photoproduction in GlueX

$\gamma\, p \rightarrow (K\pi)_J^+ \,\Lambda^0(\rightarrow p\pi^-)$ (GlueX Spring 2017 data)







Conclusion

- The study of the $K\pi$ scattering is very important for:
  - Testing the Chiral perturbation theory at low energy.
  - The determination of the strange meson state parameters.
  - The determination of the strangeness changing form factors.
  - Describing the $K\pi$ interaction in the final state of heavy meson decays used to test *CP* violation.
  - ….
- The proposed K_L Facility can improve the $K\pi$ scattering study by increasing significantly the statistics of $K\pi$ production with low energy.
- The data collected by GlueX looks promising to study the $K\pi$ interaction.
- The search for the scalar κ meson can be made by studying the photoproduction of K^* in GlueX.

Appendix

ChPT

As it is well known, the QCD lagrangian is symmetric under chiral $SU(3)_L \times SU(3)_R$ transformations in the limit of vanishing quark masses. This symmetry is not realized in the particle spectrum, but rather spontaneously broken down to its vectorial subgroup $SU(3)_V$ with the appearance of the eight pseudoscalar mesons π, K, η. A standard parametrization is given in terms of the unitary 3×3 matrix Σ [11],

$$\Sigma = \exp\{i\Phi\},$$

$$F_0\Phi = \begin{pmatrix} \pi^0 + \sqrt{\frac{1}{3}}\,\eta & -\sqrt{2}\,\pi^+ & -\sqrt{2}\,K^+ \\ \sqrt{2}\,\pi^- & -\pi^0 + \sqrt{\frac{1}{3}}\,\eta & -\sqrt{2}\,K^0 \\ \sqrt{2}\,K^- & \sqrt{2}\,\bar{K}^0 & -\sqrt{\frac{4}{3}}\,\eta \end{pmatrix}, \qquad (2.1)$$