$K\pi$ Scattering Study with K_L Beam Factory

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Outline

I. Introduction and Motivation

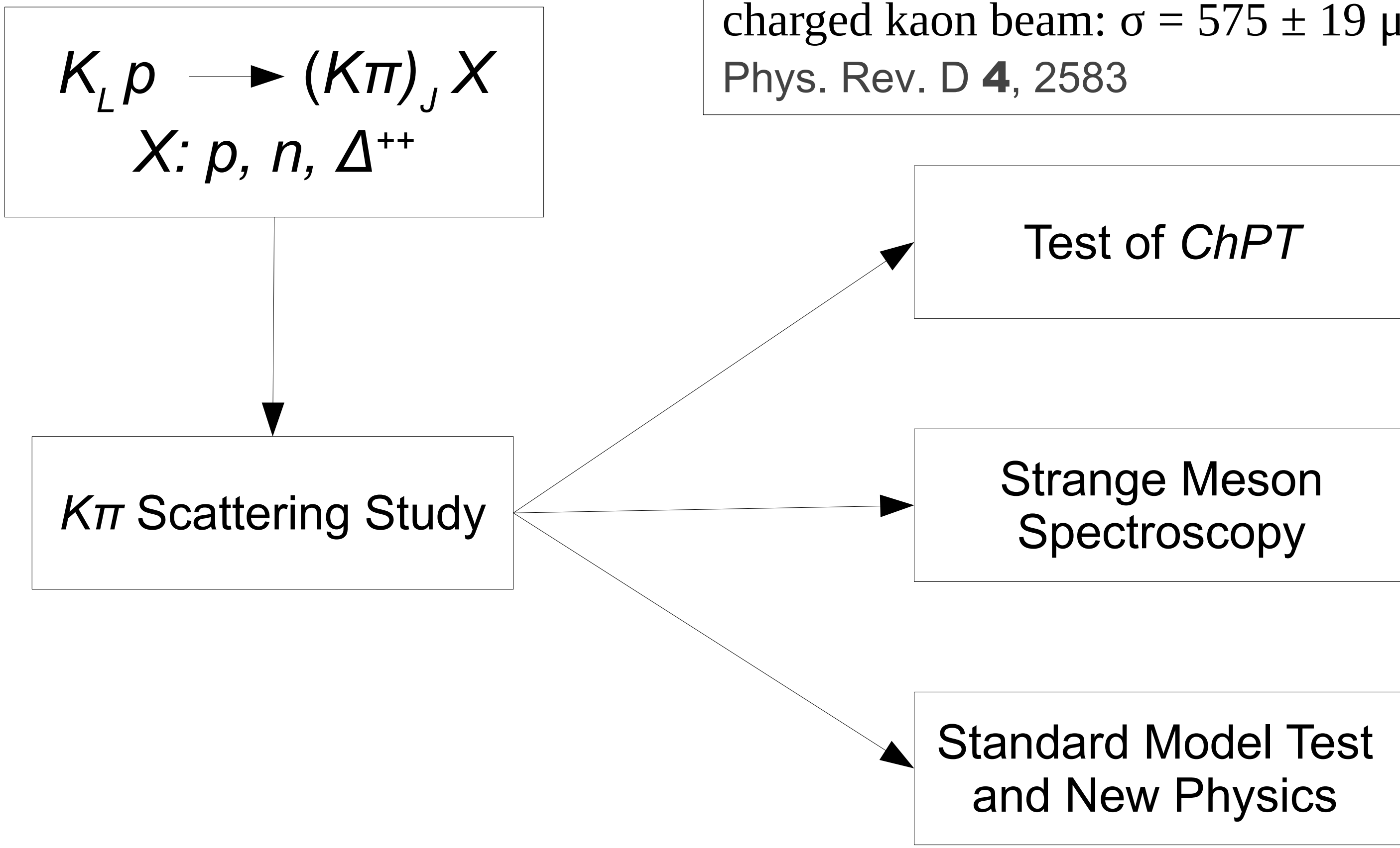
- Test of *ChPT*
- Strange Meson Spectroscopy
- Standard Model Test

II. $K\pi$ Hadroproduction and Simulation

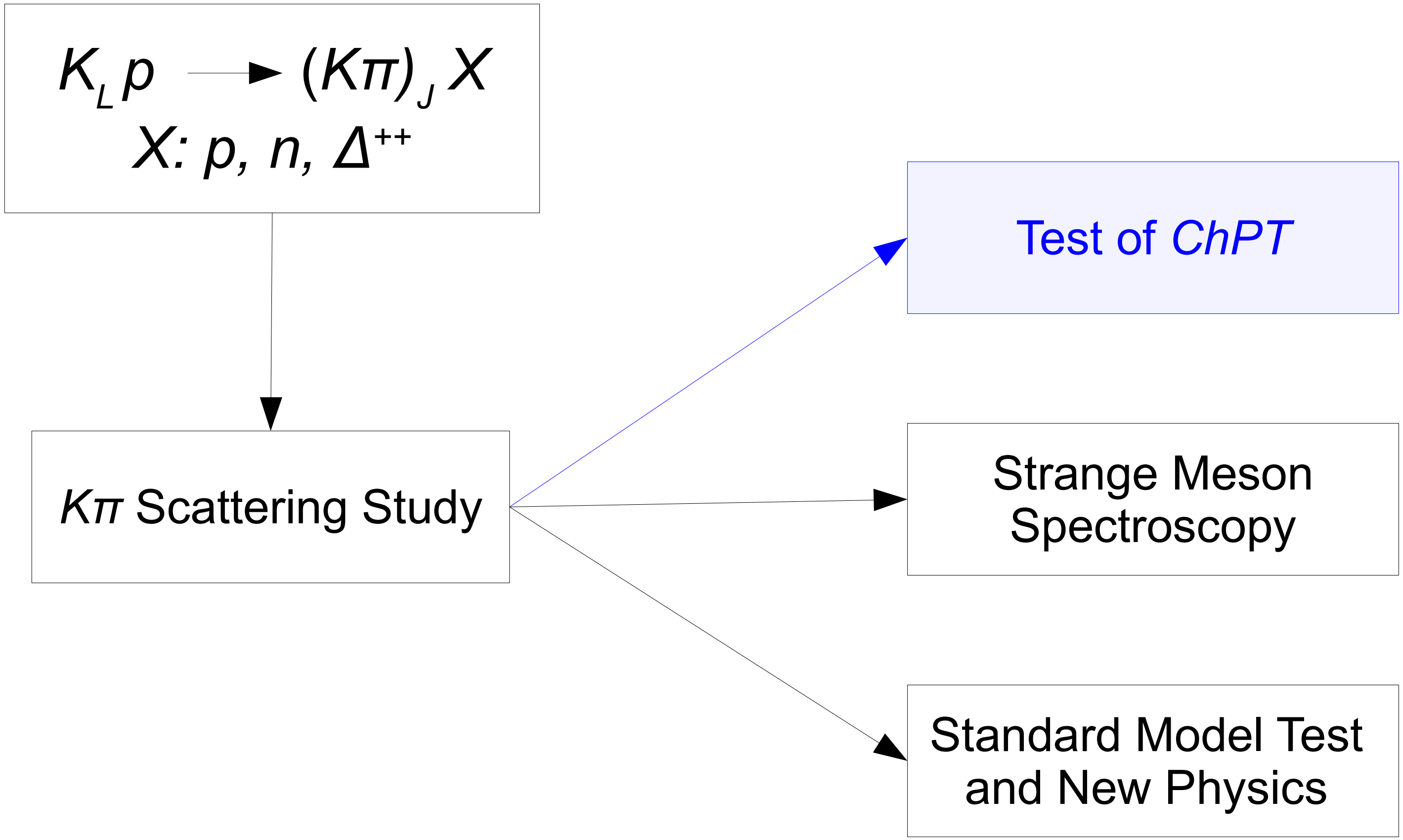
III. Conclusion

Introduction and Motivation

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



Test of *ChPT*


$K_L p \longrightarrow (K\pi)_J X$
X: p, n, Δ^{++}
$K\pi$ Scattering Study
Test of *ChPT*
Strange Meson Spectroscopy
Standard Model Test and New Physics

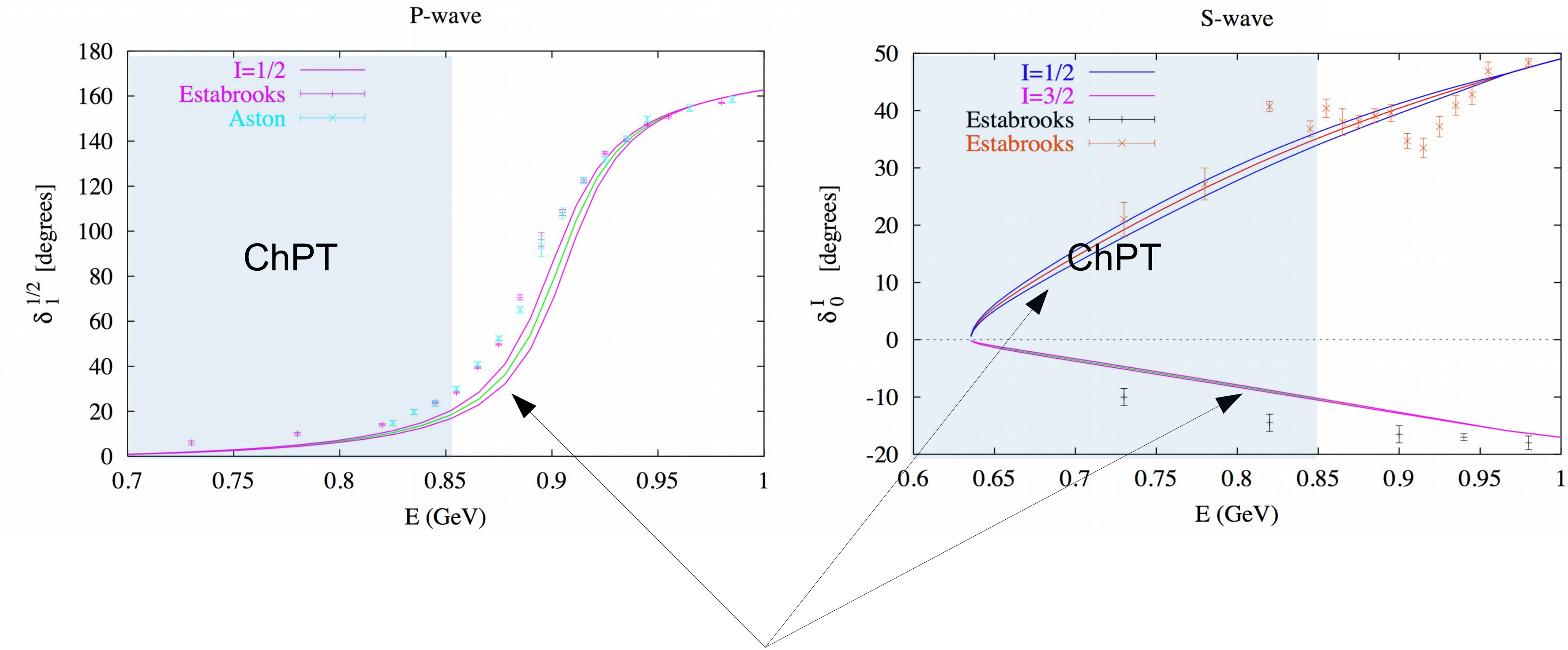
Test of *ChPT*

- 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, …].

- Experimental data on the $\{\pi\pi\}$, $\{\pi\eta\}$ and $\{\pi K\}$ at low energy:
  - $\pi\pi$: intensively studied.
  - $\pi\eta$: data widely available (CLAS, Mami, GlueX, ….).
  - πK: experimental data with hadroproduction (LASS [4, 11 and 13 GeV], BCGM [9 GeV], FNAL [50 GeV] ...), with heavy meson (J/Ψ, D, B), lepton (τ) decays (CLEO, BES, LHCb, BABAR ….).
- Experimental studies $\leftrightarrow$ Phenomenology (at low energy):
  - $\pi\pi$: SU(2) ChPT very successful, πK: poor agreement with SU(3) ChPT.

Test of *ChPT*

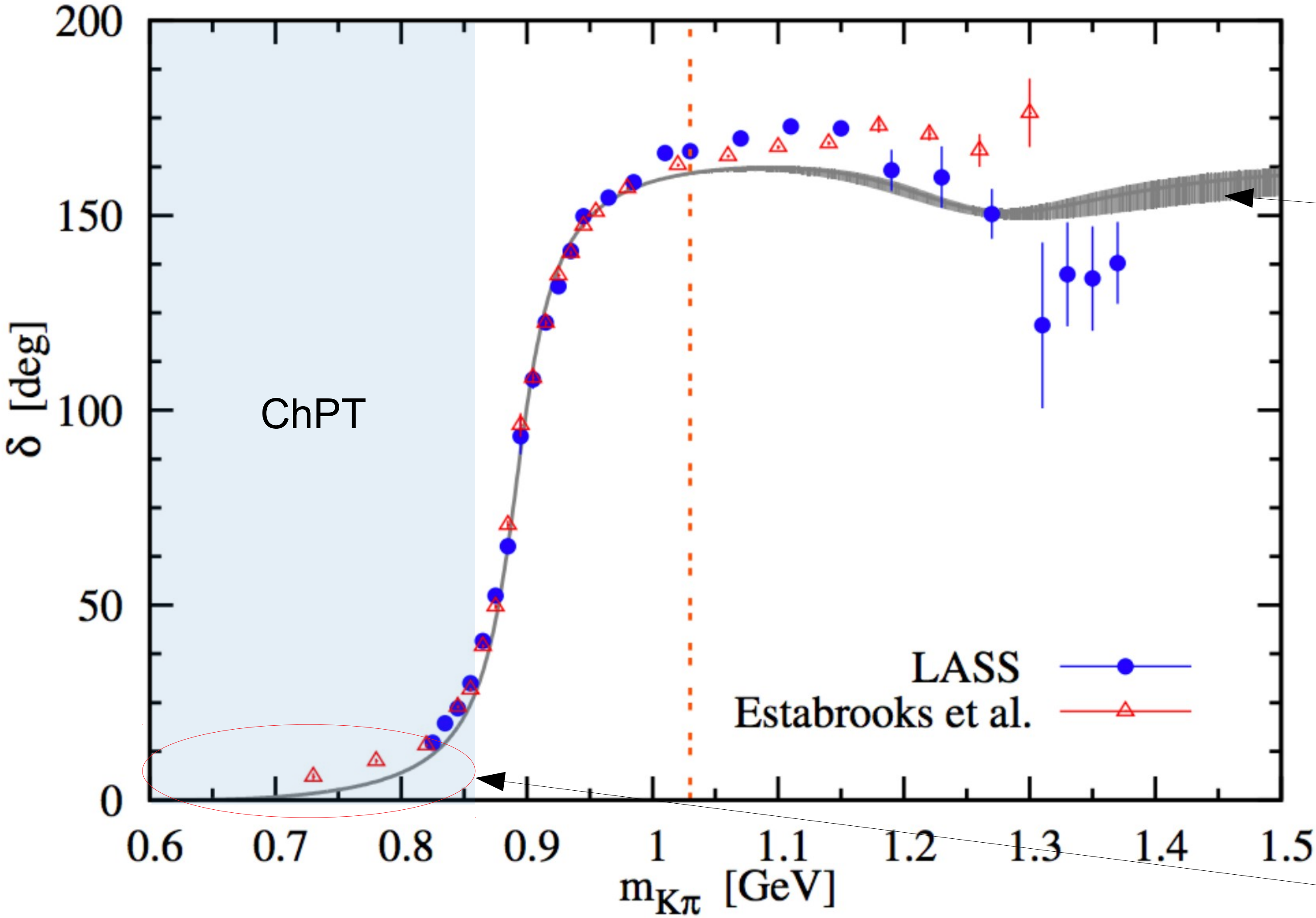
Data with Kaon-production (LASS):



Buettiker, Descotes-Genon, Moussallam'04

Test of *ChPT*

Boito, Escribano & Jamin'10 (Fit)

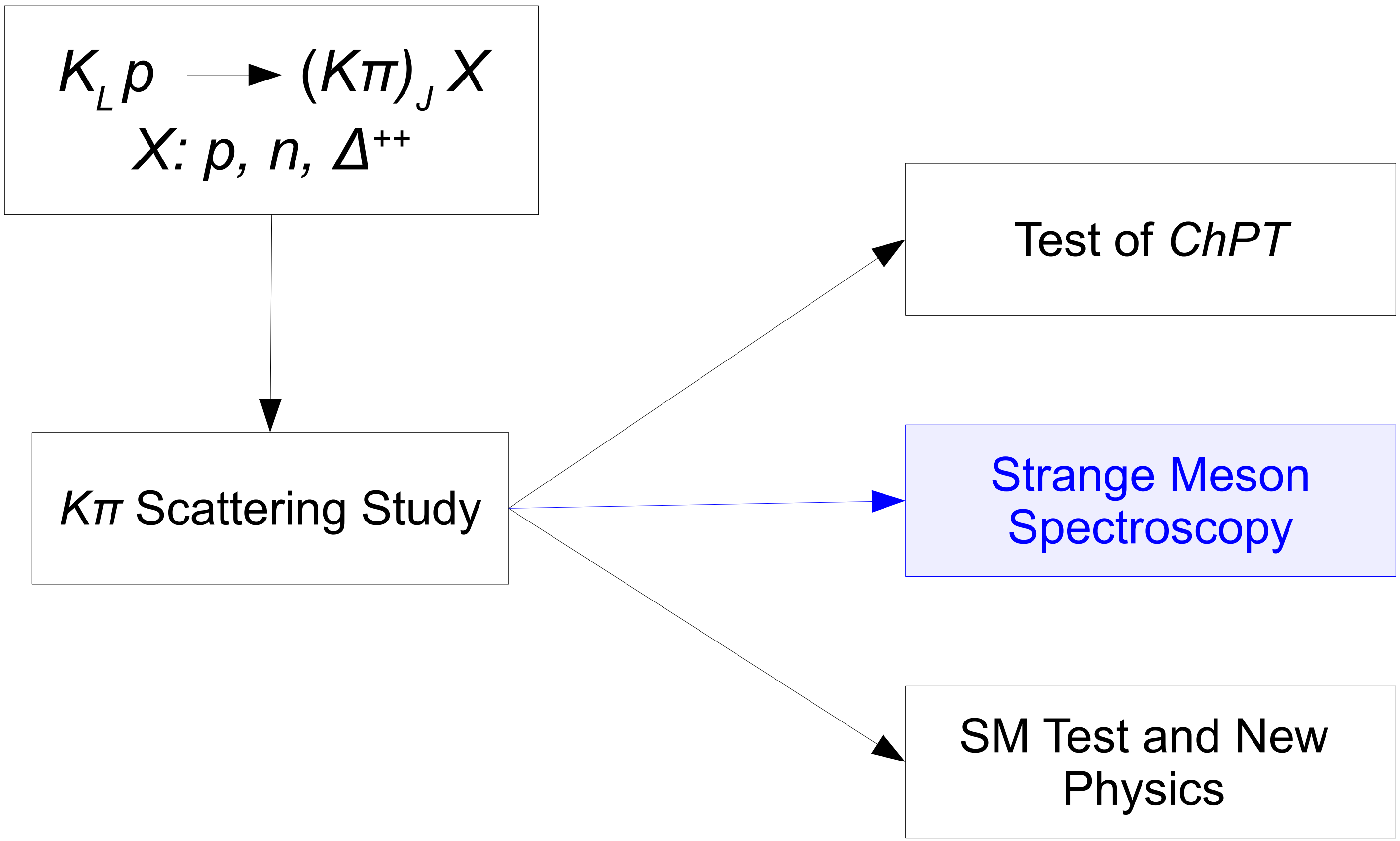


$\tau \to K \pi \nu_\tau$

Data from Belle

Require more data

Hadron Spectroscopy



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: $K^*(892)$, $K_1^*(1410)$, ….
  - D-wave: $K_2^*(1430)$, $K_2^*(1580)$, ….
- 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.

ref: S. Descotes-Genon and B. Moussallam

	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}

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

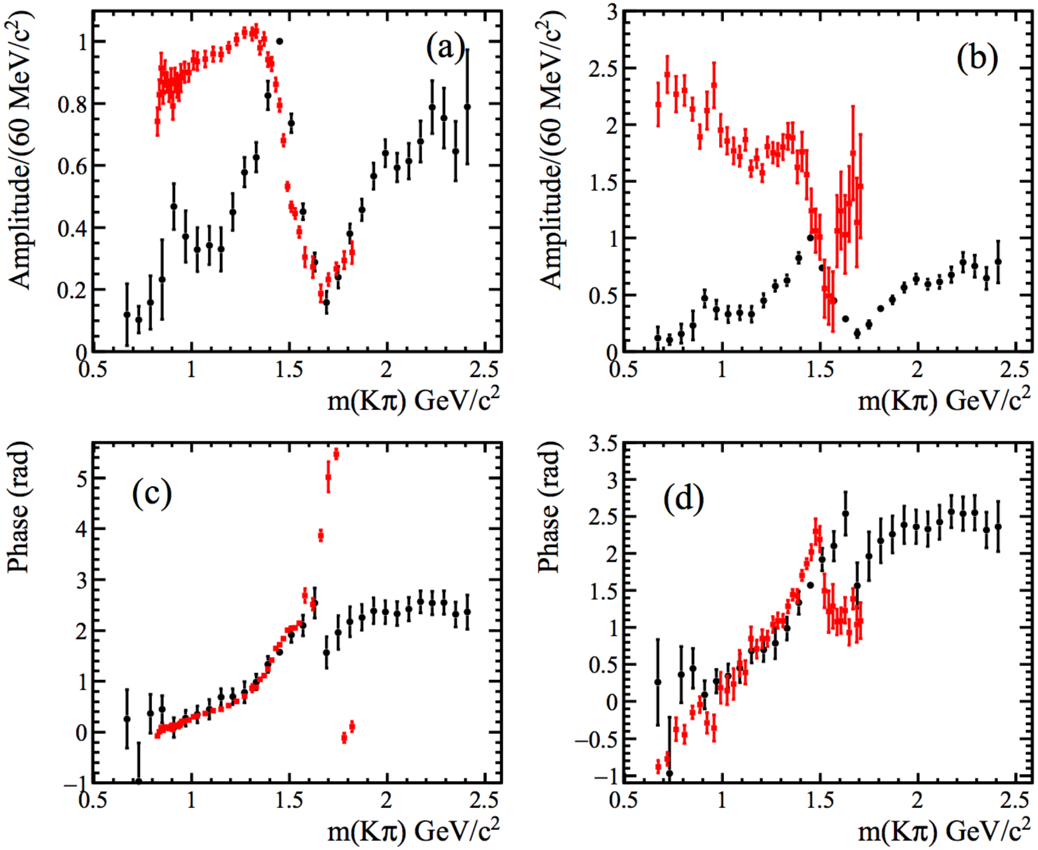
S-wave: $K^*_0(1403)$

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

PRD 93, 012005 (2016)

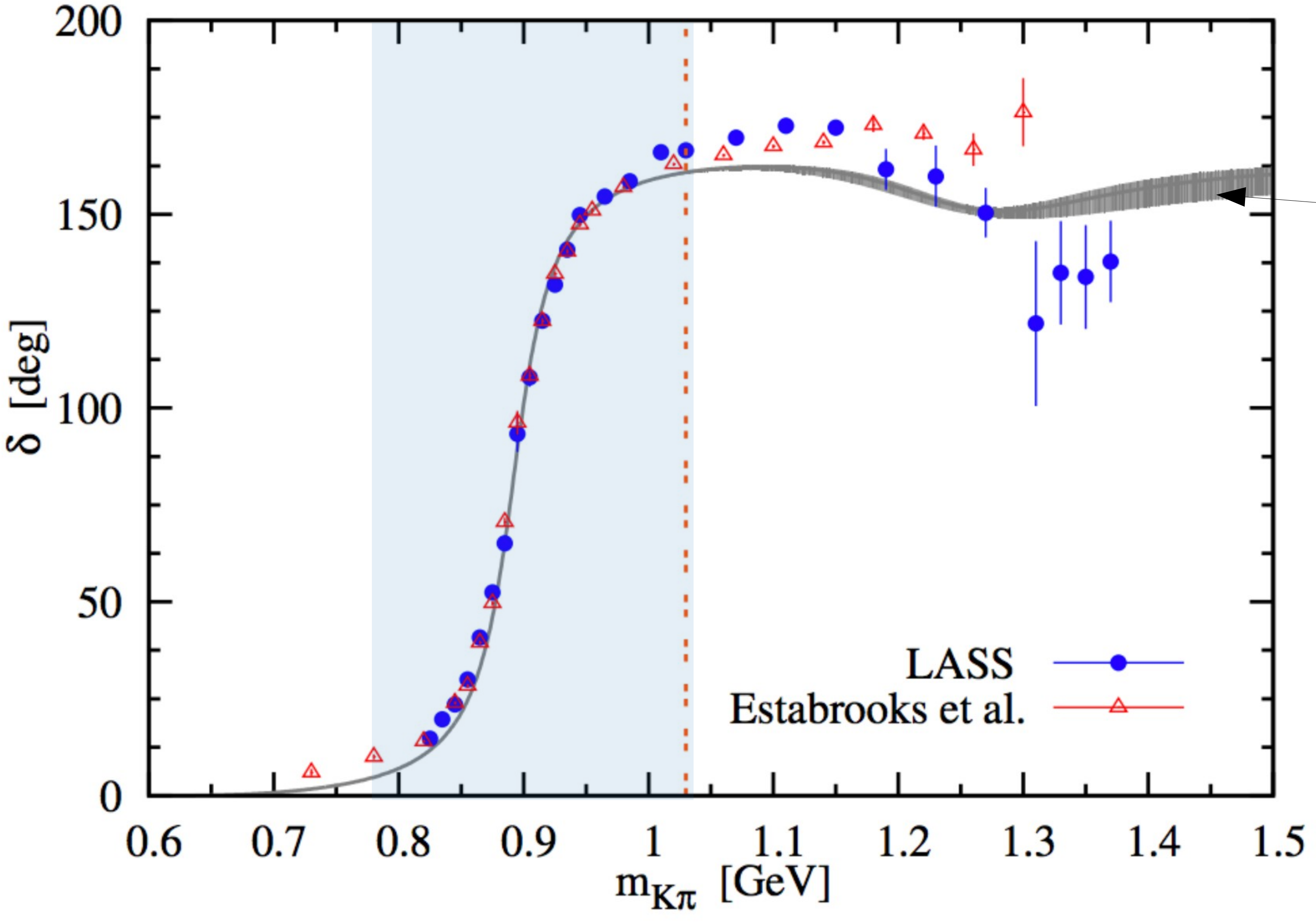
LASS (a,c) { $Kp \to K\pi p$ } and
E791(b,d) { $D \to KK\pi$ }.

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



P-wave: K*(892)

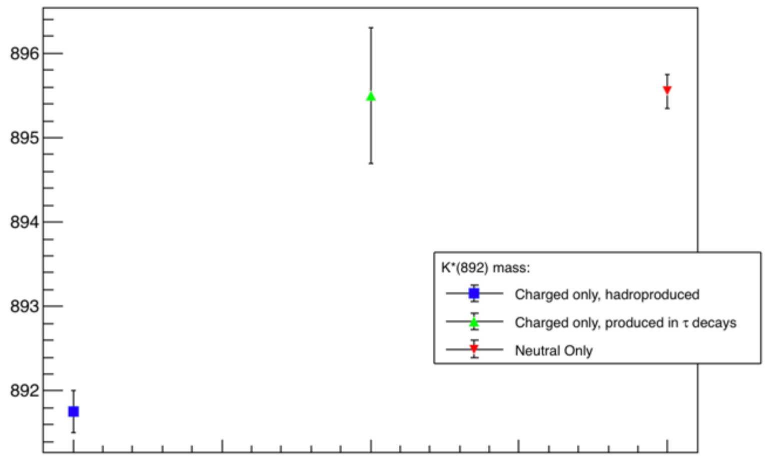
Boito, Escribano & Jamin'10 (Fit)



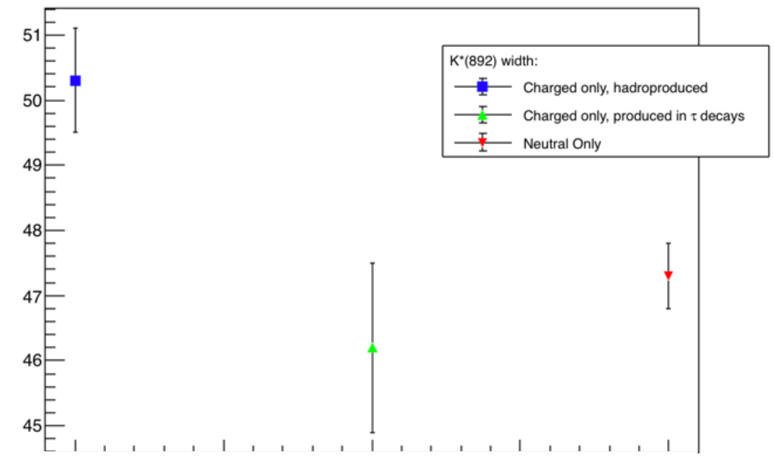
$\tau \to K\pi\nu_\tau$
Data from Belle

P-wave: K*(892)

mass



width



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

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

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

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

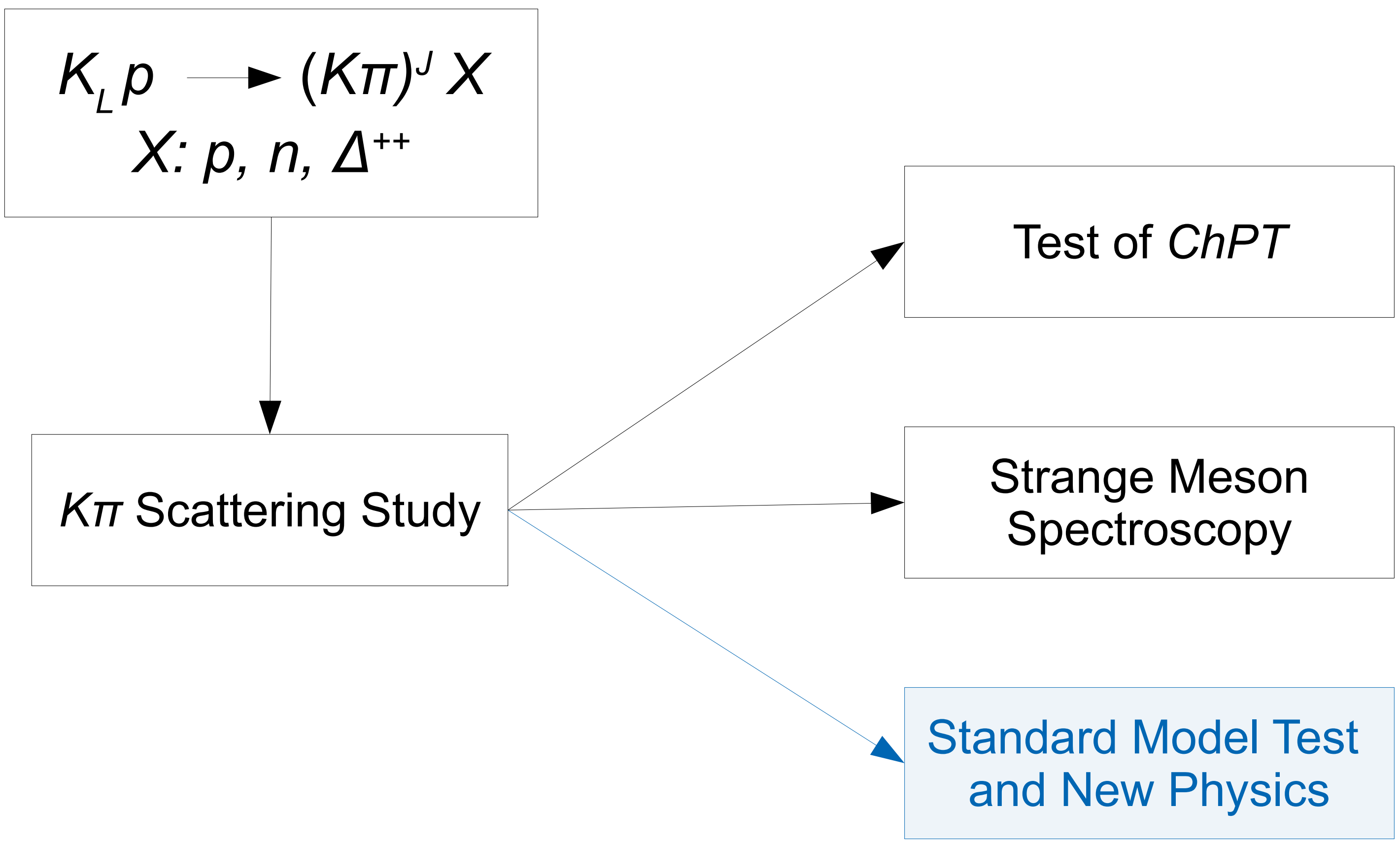
Decay Modes

Mode		Fraction (Γ_i/Γ)
Γ_1	$K\pi$	(100)%
Γ_2	$(K\pi)^{+-}$	(99.900 ± 0.009)%
Γ_3	$(K\pi)^0$	(99.754 ± 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 ($Kp \rightarrow K\pi p, K\pi\pi p, K\Phi p, \Lambda\bar{p}X$)

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



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)].

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

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

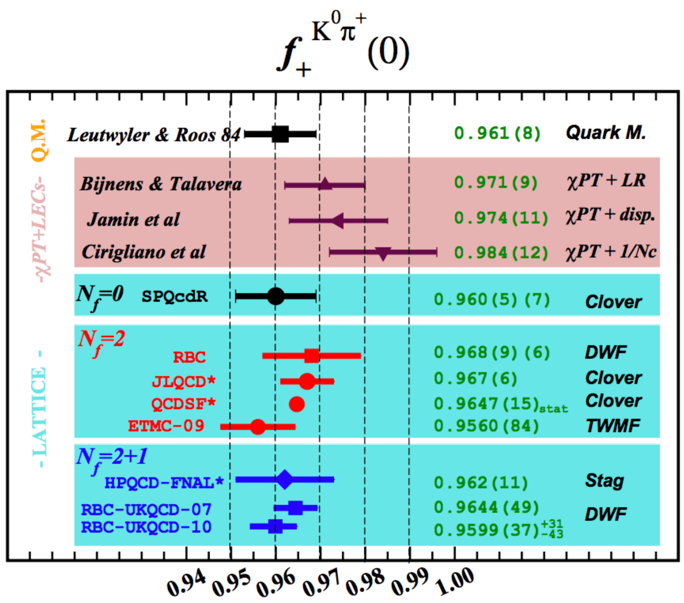
- H(t) and G(t) evaluated from $K\pi$ scattering data and given as polynomials.

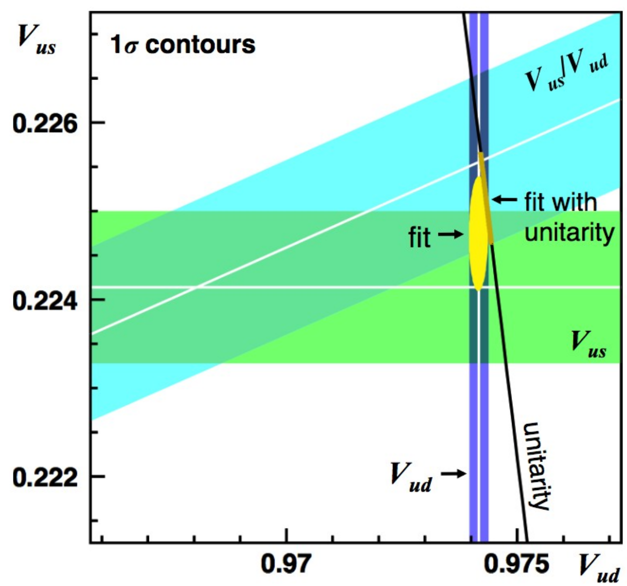
SM Test and New Physics

$f_+(0)V_{us}$ → 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





$V_{ud} = 0.97416(21)$

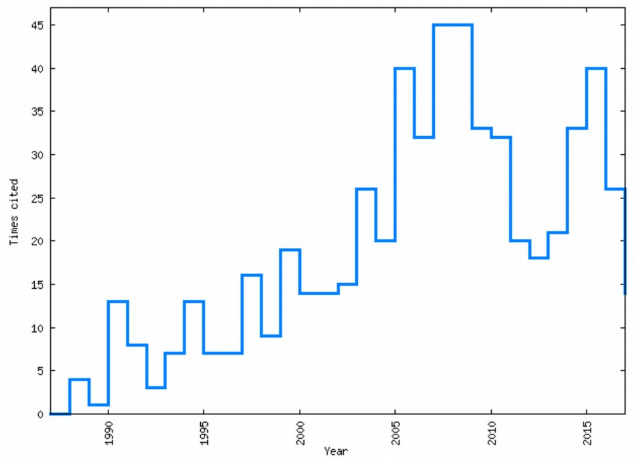
$V_{us} = 0.2248(7)$

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

SM Test and New Physics

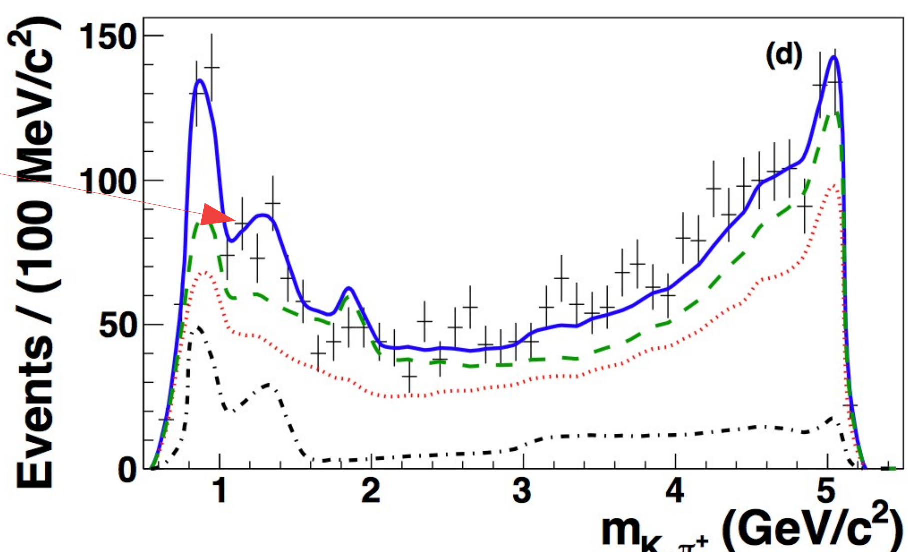
- CP violation is mainly studied using *B*, *D* and *K* decays.
- Several decay include $K\pi$ interaction in the final state.
- Most of the analyses, specially with three-body decay, use a model dependent analysis (isobar model, K-matrix, …) to describe the data, *e.g.* $B \to (D \to K_s\pi\pi)\, K_s$, $B \to K_s\pi\pi$, $D_s \to K_s\pi\pi$ …
- 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.

Citation history of LASS parameterization
Nucl.Phys. B296 (1988) 493-526



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

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

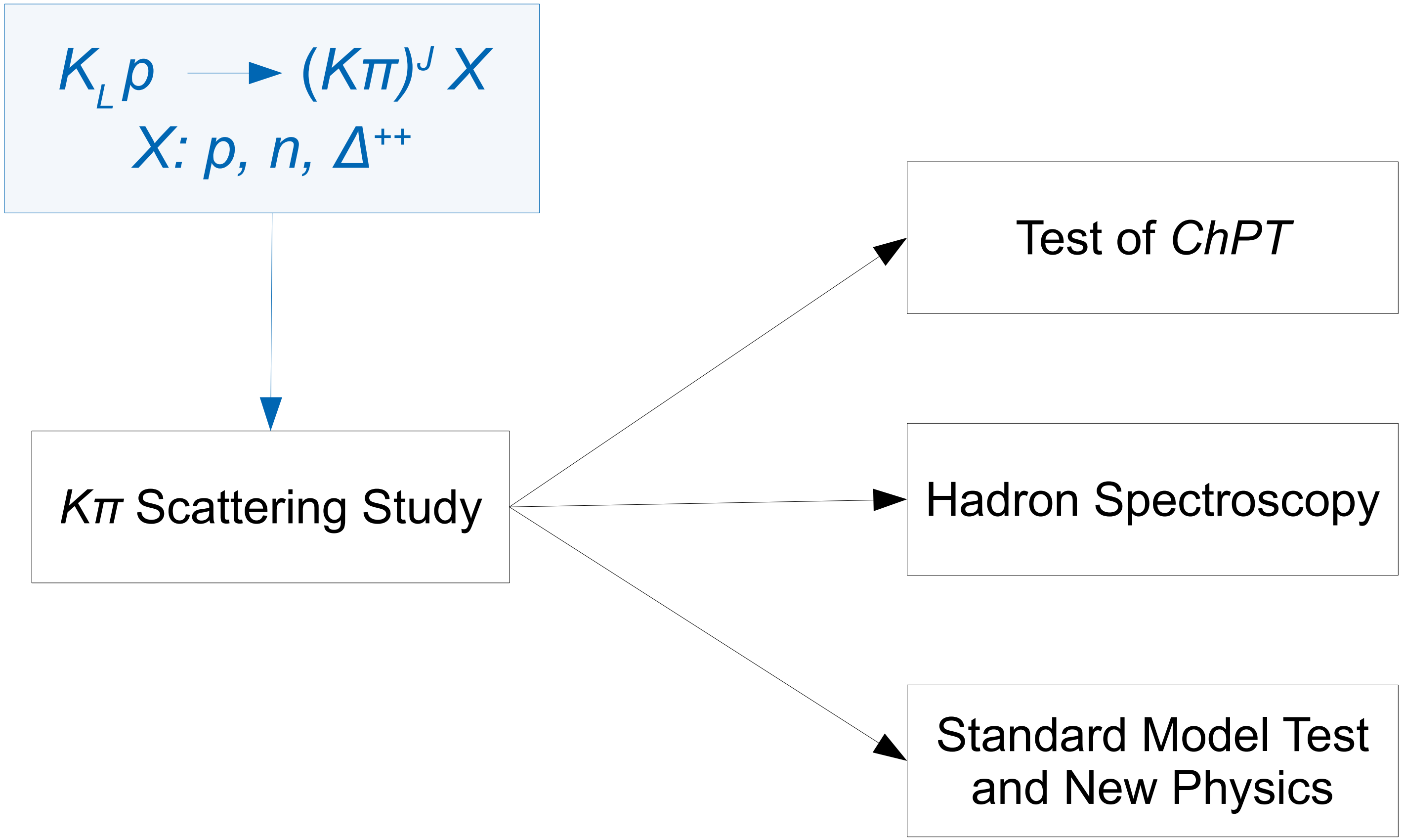


SM Test and New Physics

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_{ES} and ΔE PDF (fixed parameters)	0.8	1.1	0.6	1.1	0.7	1.2
Correctly reconstructed and self crossfeed signal BDT_{out} PDFs	3.3	3.3	3.4	3.4	4.2	4.0
Self crossfeed signal m_{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_{ES}, ΔE and 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

$K\pi$ production



$K\pi$ production

- The $K\pi$ hadroproduction has been studied in LASS with charged Kaon beam. They parametrized the $K\pi$ production mechanism based on multiple exchanges (Nuclear Physics B133 (1978) 490-524).
- The LASS parametrization of the naturality amplitude $L^{\pm}_{\lambda}$ for the $K\pi$ production:

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

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

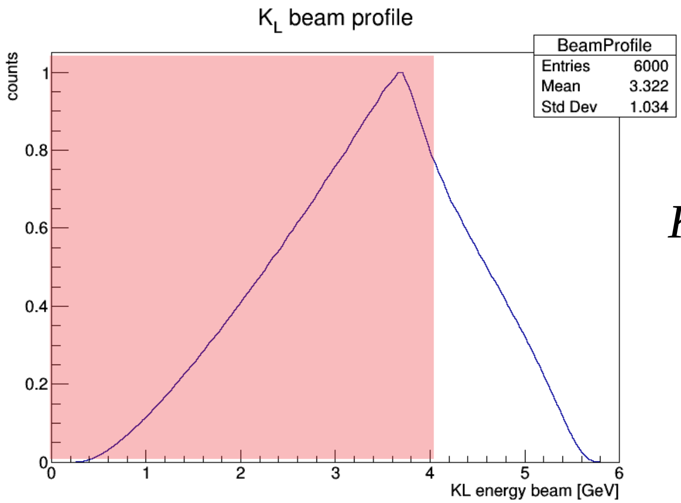
$$L_1^+=\sqrt{\frac{1}{2}L(L+1)}G^L_{K\pi}(m_{K\pi},t)[\gamma_c(m_{K\pi})\exp(b_c(m_{K\pi})(t-m_\pi^2))-2i\gamma_a(m_{K\pi})\exp(b_a(m_{K\pi})|t'|(t-m_\pi^2))],$$

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

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

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

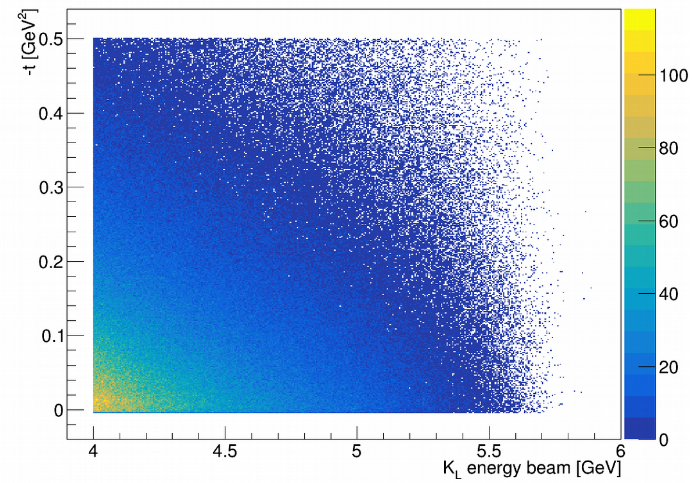
$K\pi$ production

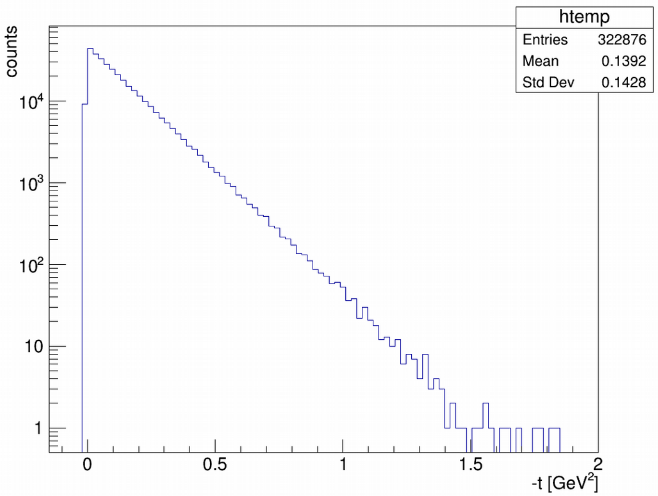


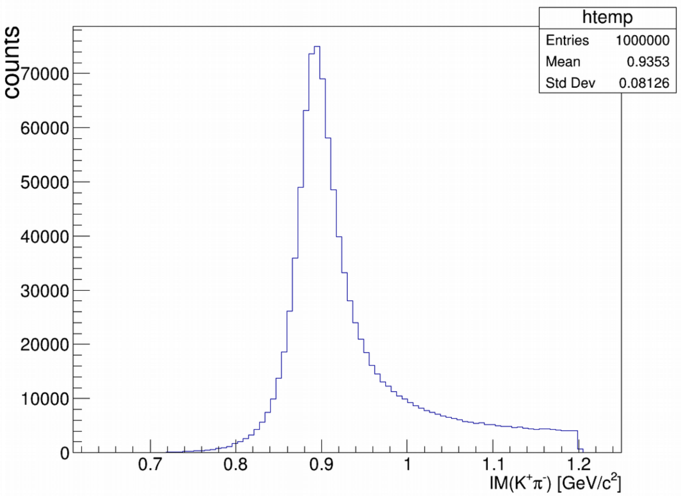
$K\pi$ Production (LASS Model)

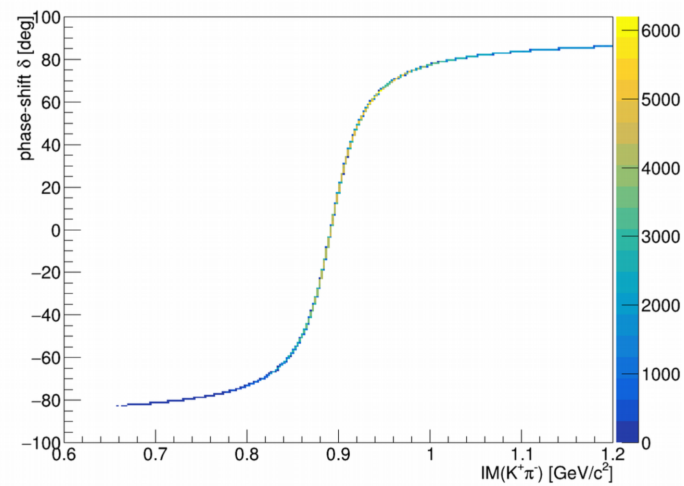
Only P-Wave

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



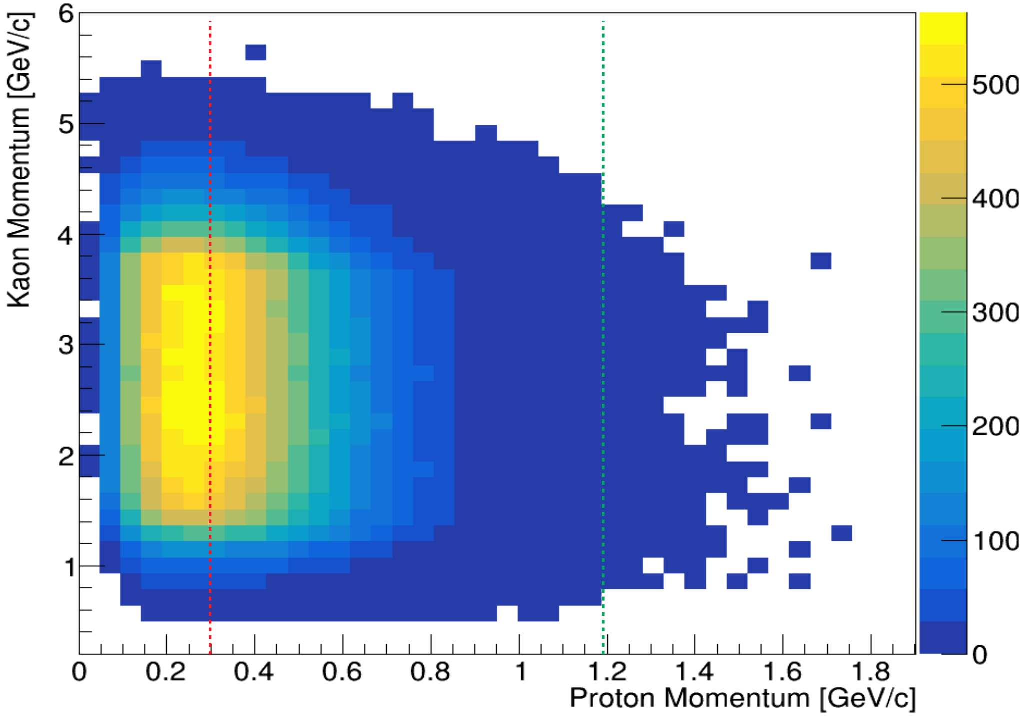


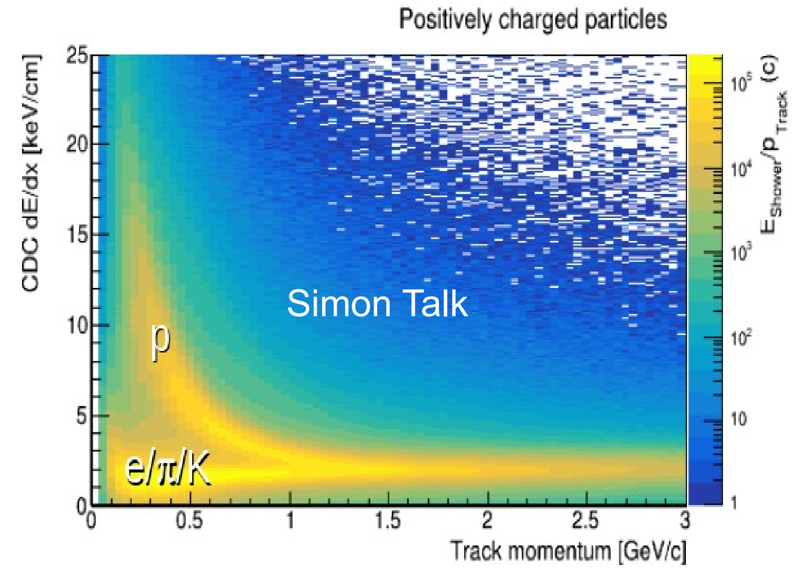


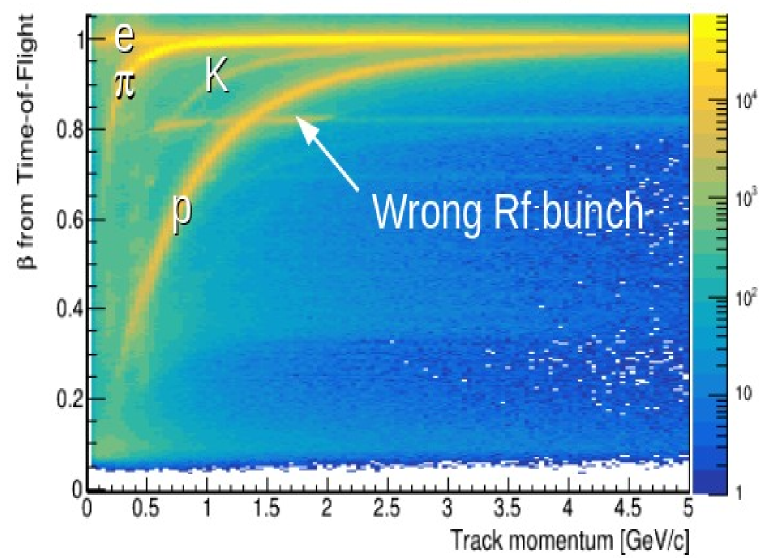


$K\pi$ production

Proton momentum VS Kaon momentum

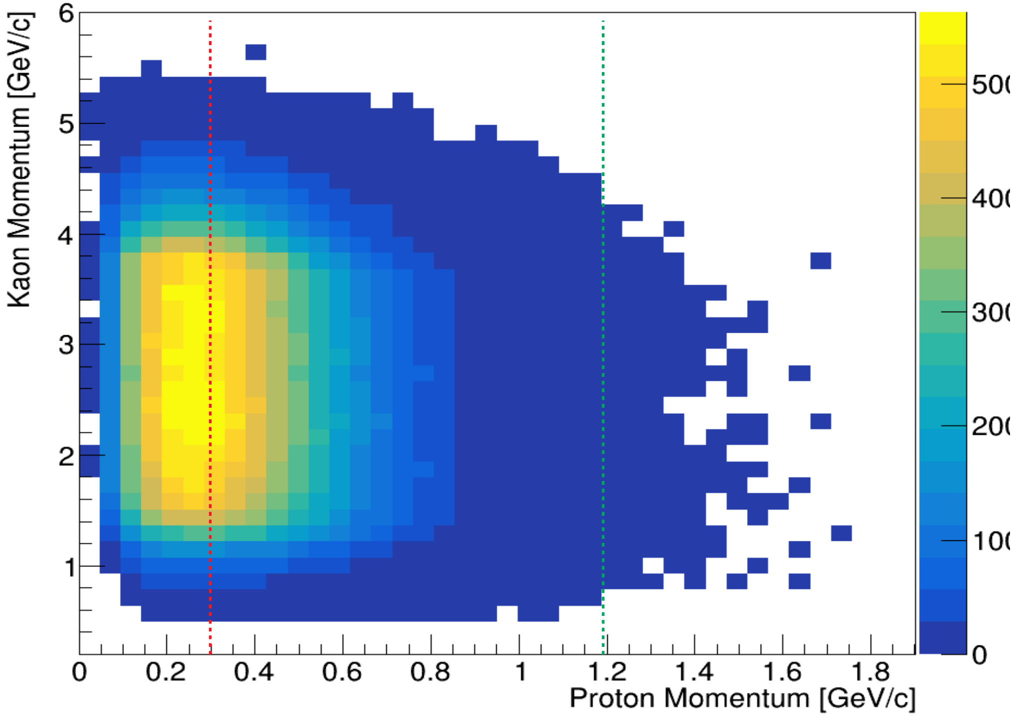




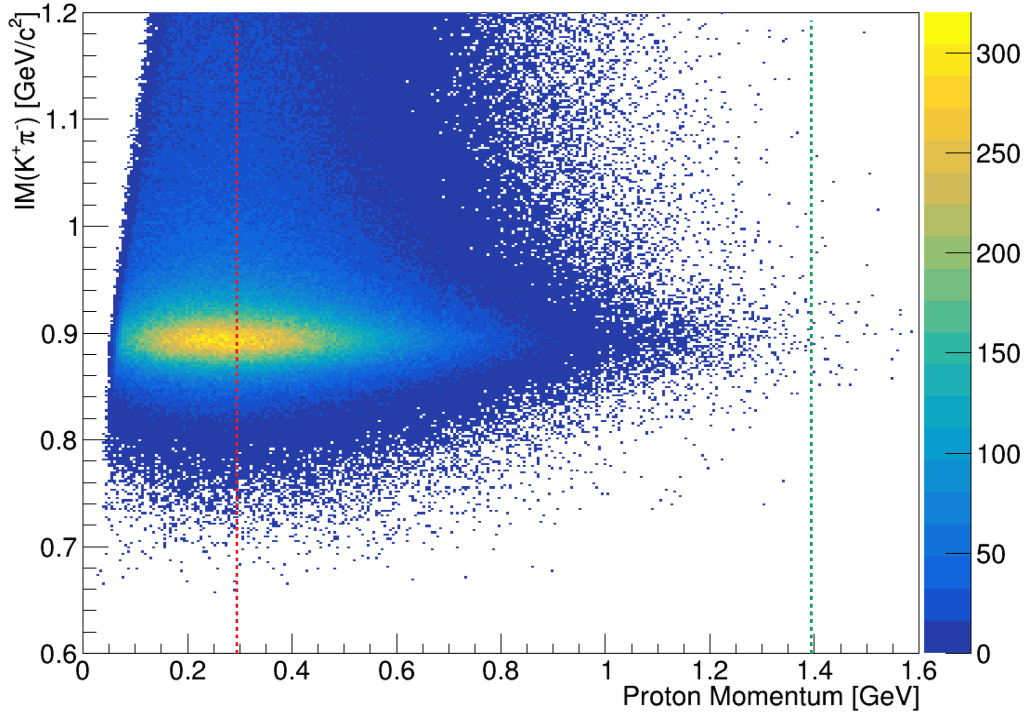


$K\pi$ production

Proton momentum VS Kaon momentum

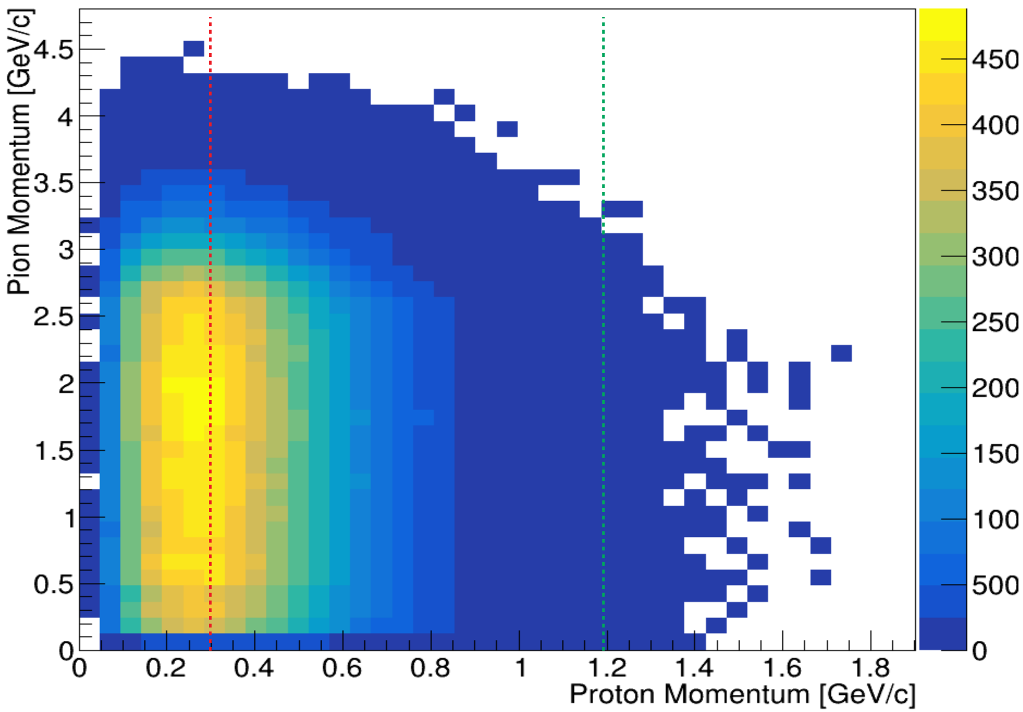


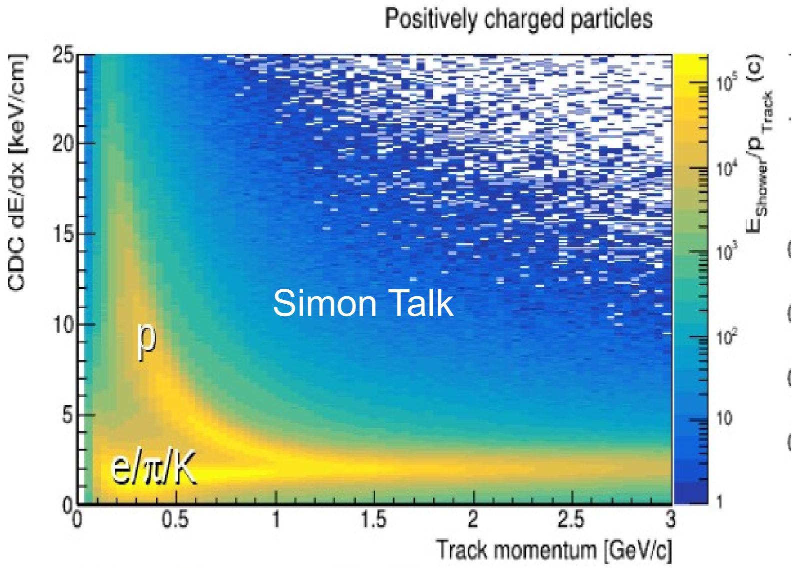
Proton momentum VS $K\pi$ invariant mass

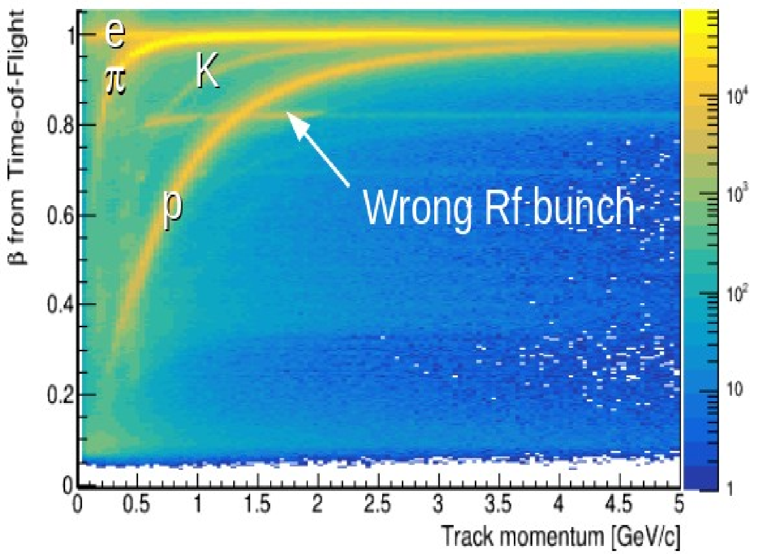


$K\pi$ production

Proton momentum VS Pion momentum

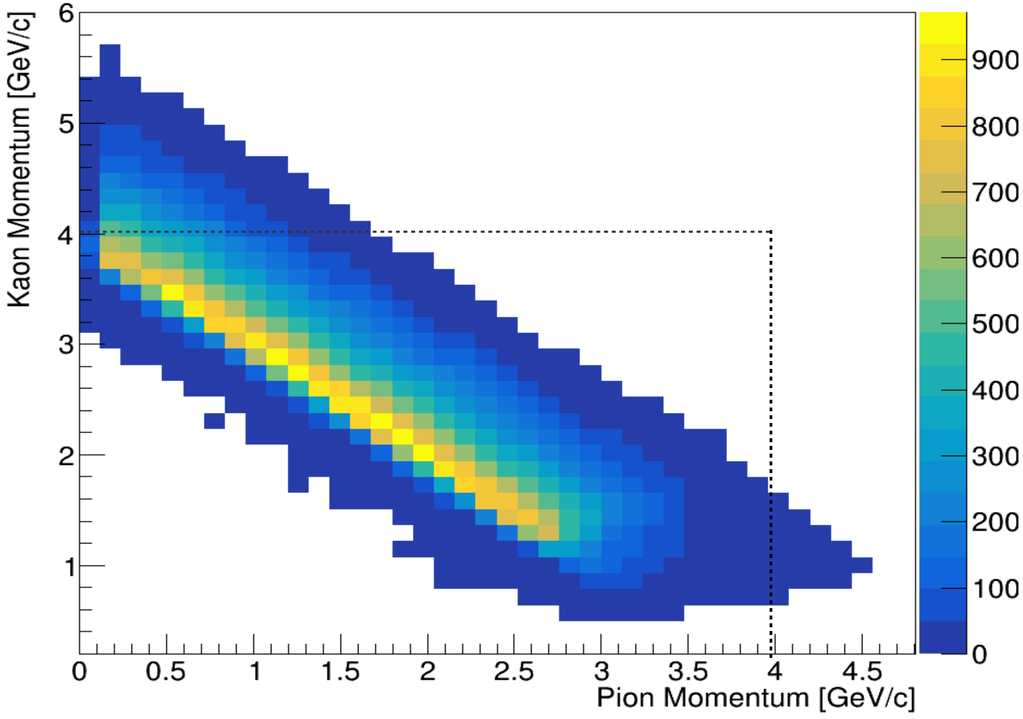


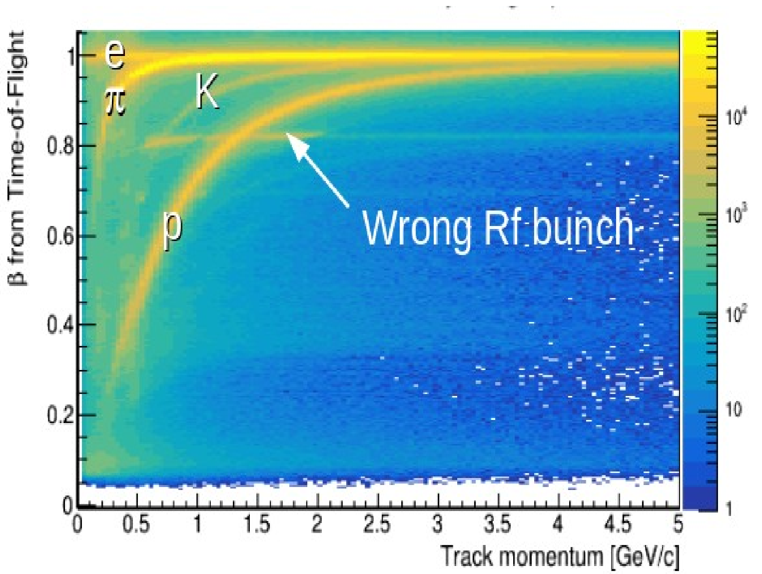




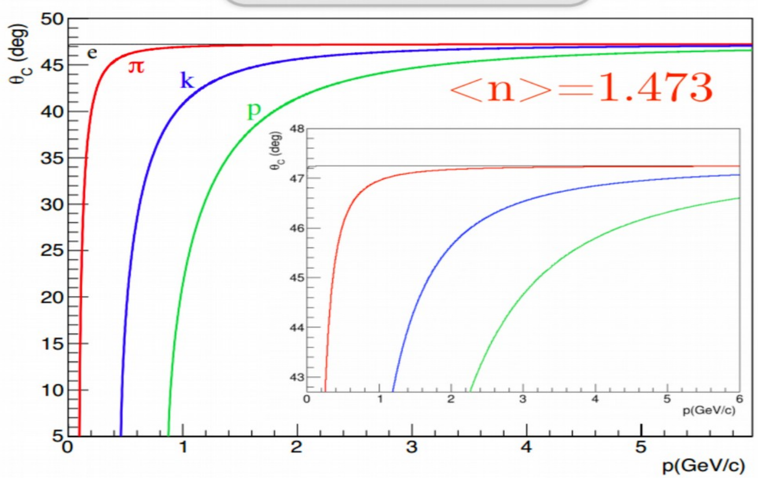
$K\pi$ production

Pion momentum VS Kaon momentum



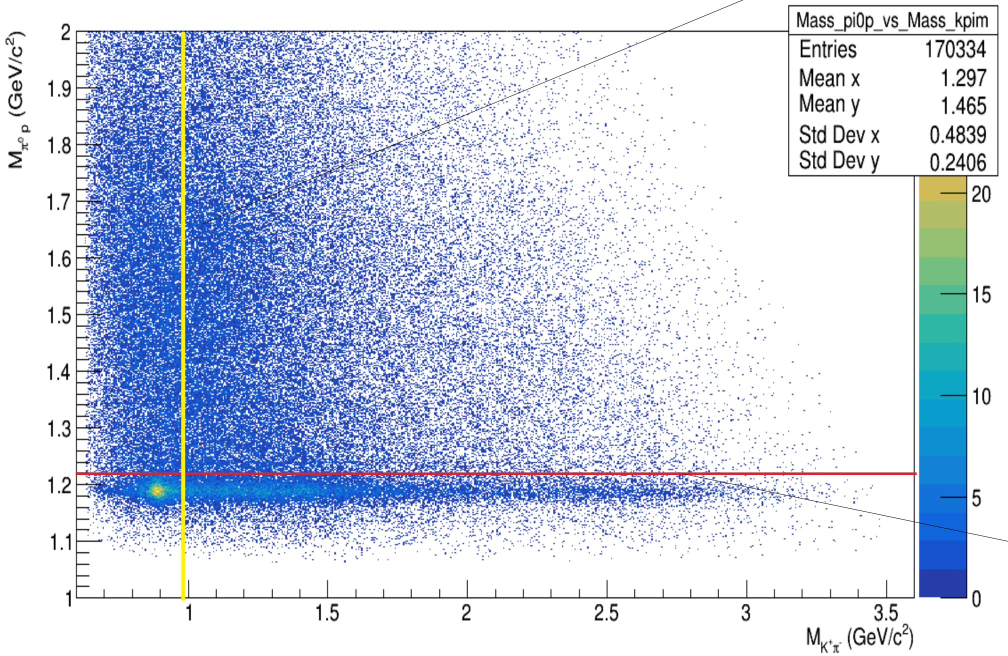


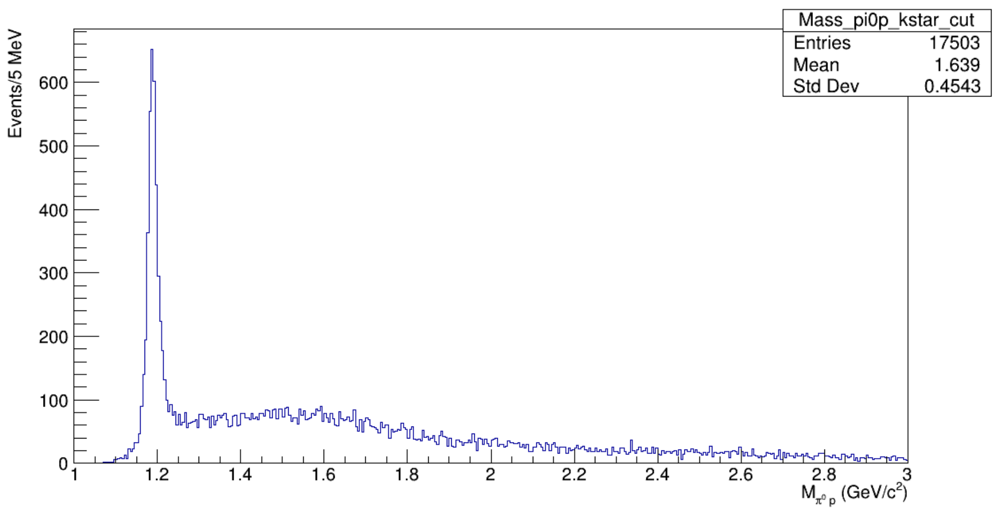
$$cos(\theta_C) = 1/n\beta$$

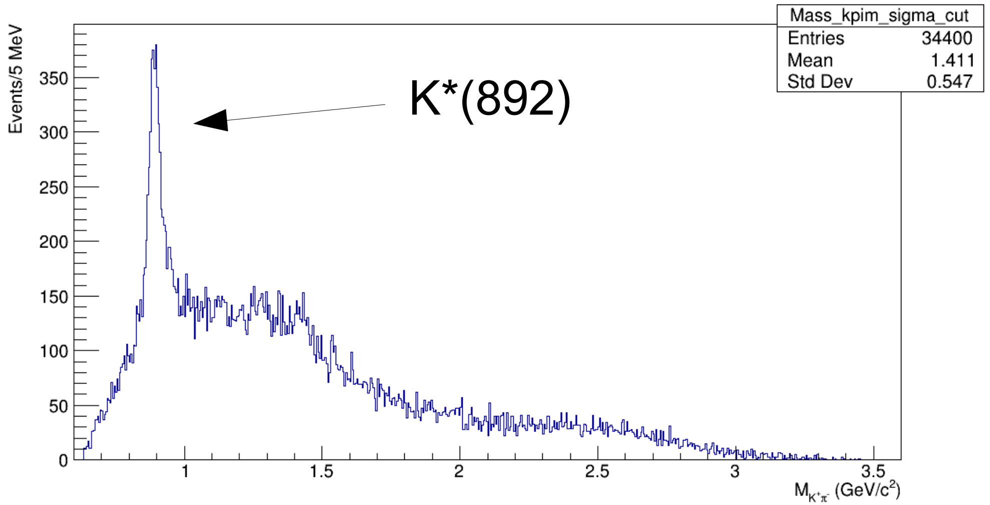


$K\pi$ photoproduction in GlueX

$$\gamma\, p \rightarrow (K\pi)_J^0\, \Sigma^+(\rightarrow p\pi^0) \quad \text{(2017 data)}$$







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.

- In progress: Improving the simulation of the generated data in GlueX detector.

PiKi 2018

Pion-Kion Interactions Workshop
February 14-16, 2018
Thomas Jefferson National Accelerator Facility
Newport News, VA

Circular

The pi-K scattering enables direct investigations of scalar and vector K* states, including the not yet established S-wave k(800) state. These studies are also needed to get precise values of vector and scalar form factors: to independently extract CKM matrix element Vus and to test the Standard Model unitarity relation in the first row of CKM matrix, to study CP violation from the Dalitz plot analysis of open charm D meson decays and in a charmless decays of B mesons in Kpipi final states. Significant progress is made lately in Lattice QCD, in the phenomenology and in the Chiral Perturbation Theory to describe different aspects of pi-K scattering. The main source of experimental data is based on experiments performed in SLAC almost five decades ago at 1970-80s. The recently proposed KL Facility incorporating the GlueX spectrometer at JLab will be able to improve the pi-K scattering database by about three orders of magnitude in statistics. The workshop will discuss the necessity for and the impact of the future high statistics data obtained at JLab on pi-K scattering.

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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],

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

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