Three-body Decays of τ and All That

Simon Eidelman

Budker Institute of Nuclear Physics,
Novosibirsk, Russia

Outline

1. Motivation
2. τ
3. B/D decays
4. Conclusions

Motivation

A number of physical problems involve studies of mass spectra and Dalitz plots for various three-body final states in τ, D and B meson decays:

- Decays of τ lepton to three pions – $\pi^-\pi^+\pi^-\nu_\tau$ and $\pi^-\pi^0\pi^0\nu_\tau$ have a large branching fraction of about 18.3% and provide a copious source of 3π in the axial-vector state $a_1(1260)$ ($a_1(1640)$?)
- Cabibbo-suppressed decays to $K\pi\pi\nu_\tau$ ($K^-\pi^+\pi^-\nu_\tau$, $K^-\pi^0\pi^0\nu_\tau$, $K^0_{S(L)}\pi^-\pi^0\nu_\tau$) have in total $\mathcal{B} \sim 1\%$ resulting in huge data samples sufficient for detailed studies of production mechanisms via Dalitz plots
- Cabibbo-allowed decays to $K\bar{K}\pi\nu_\tau$ ($K^+K^-\pi^-\nu_\tau$, $K^o\bar{K}^0\pi^-\nu_\tau$, $K^-K^0\pi^0\nu_\tau$) ($\mathcal{B} \sim 0.5\%$) are good for K^* spectroscopy and Wess-Zumino anomaly studies
- Studies of CP violation in the $D^0 - \bar{D}^0$ and $B^0 - \bar{B}^0$ systems deal with huge data samples collected at B factories and are impossible without clear understanding of the 3-body dynamics

This necessitates preparing adequate Monte Carlo generators

K^* Mesons with Three-body Decays

τ decays into kaons can improve our knowledge of K^* spectroscopy

Meson	J^P	Decay Modes
$K_1(1270)$	1^+	$K\rho,\ K_0^*(1430)\pi,\ K^*(892)\pi$
$K_1(1400)$	1^+	$K^*(892)\pi$
$K^*(1410)$	1^-	$K^*(892)\pi$
$K_2^*(1430)$	2^+	$K^*(892)\pi,\ K\rho$
$K(1460)$	0^-	$K^*(892)\pi,\ K\rho,\ K_0^*(1430)\pi$
$K_2(1580)$	2^-	$K^*(892)\pi,\ K_0^*(1430)\pi$
$K_1(1650)$	1^+	$K\pi\pi$
$K^*(1680)$	1^-	$K\rho,\ K^*(892)\pi$

with $K^*(892),\ K_0^*(1430)$ predominantly decaying to $K\pi$

Pattern of $a_1(1260)$ decays from $\tau \to 3\pi\nu_\tau$

$\tau \to 3\pi\nu_\tau$ decays are known to be dominated by the $\tau \to a_1(1260)\nu_\tau$.
CLEO used 37k $\tau^- \to \pi^-\pi^0\pi^0\nu_\tau$ to study mechanisms of $a_1(1260)$ decays

Fractions of various mechanisms in %
(do not sum to 100% because of interference effects)

$\rho\pi_S$	$\rho\pi_D$	$\rho(1450)\pi_S$	$\rho(1450)\pi_D$
60.2	1.3	0.6	2.0
$f_0(600)\pi$	$f_0(1370)\pi$	$f_2(1270)\pi$	$K\bar{K}^*$
18.8	7.4	1.2	3.3

D.M. Asner et al., Phys. Rev. D61, 012002 (2000)
CMD-2 used the $a_1\pi$ dominance in $e^+e^- \to 2(\pi^+\pi^-)$ to study $a_1 \to 3\pi$
R.R. Akhmetshin et al., Phys. Lett. B 466, 392 (1999)

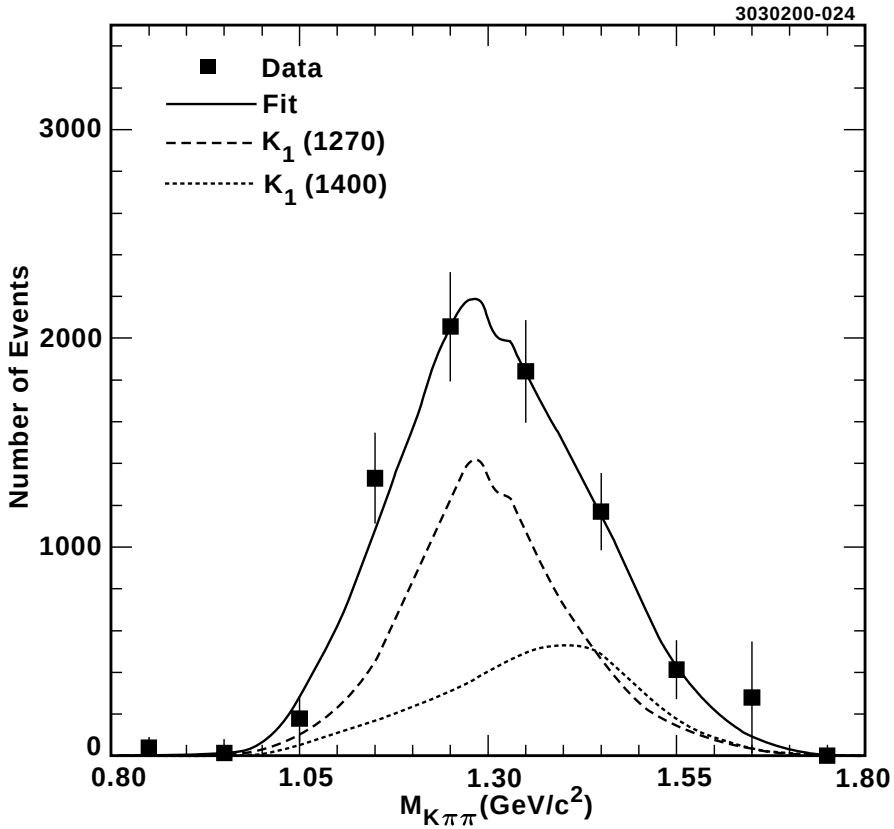
$\tau^- \to K^-\pi^+\pi^-\nu_\tau$ at CLEO – I

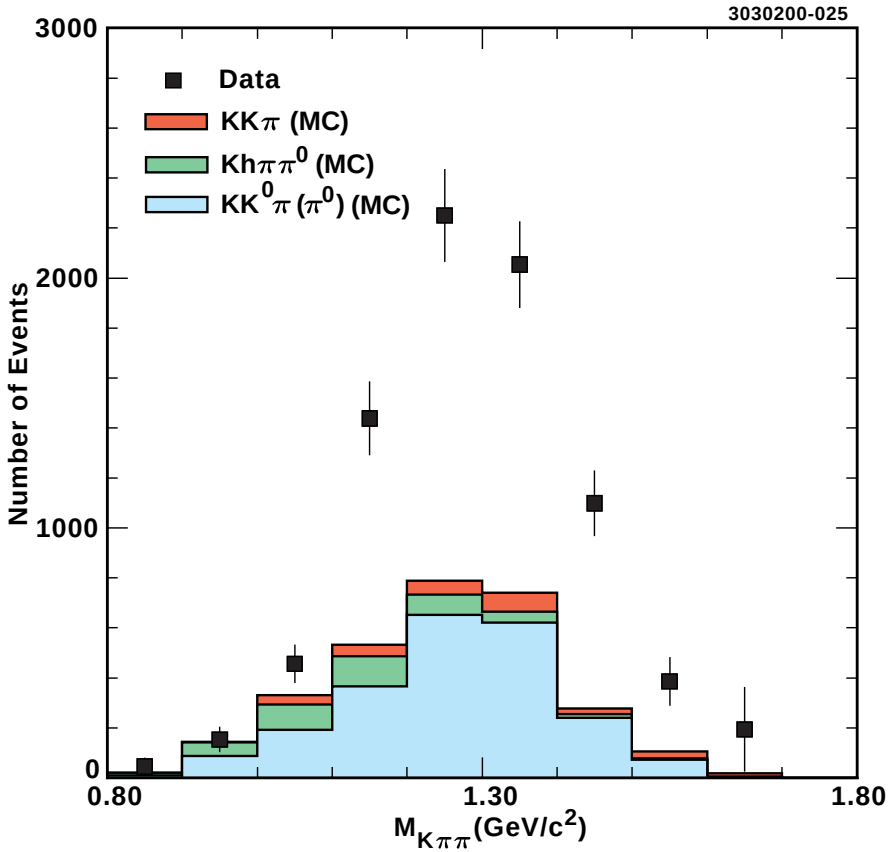
CLEO used 7k $\tau^- \to K^-\pi^+\pi^-\nu_\tau$ decays to study decay mechanisms

- They assume that decays are saturated by $K_1(1270)$ and $K_1(1400)$
- The fraction of $K_1(1270)$ is $0.66 \pm 0.19 \pm 0.13$
- The fraction of $K\rho$ in $K\pi\pi$ is $0.48 \pm 0.14 \pm 0.10$
- There are significant cross-feed backgrounds, i.e., backgrounds from other τ decays (e.g., with additional π^0)

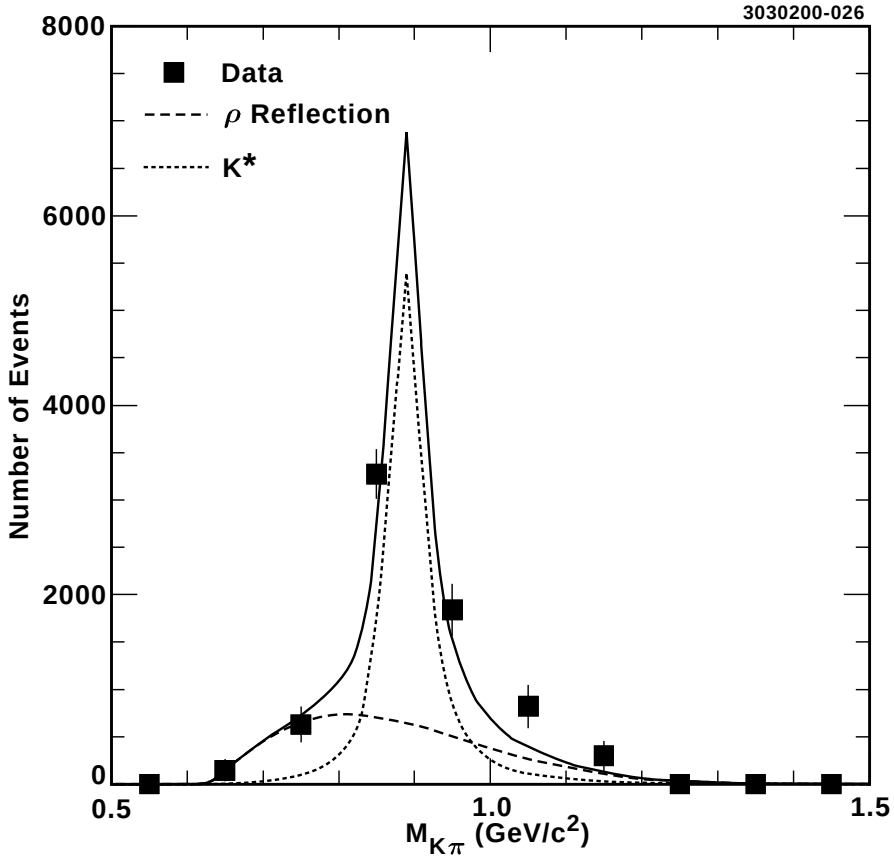
D.M. Asner et al., Phys. Rev. D62, 072006 (2000)

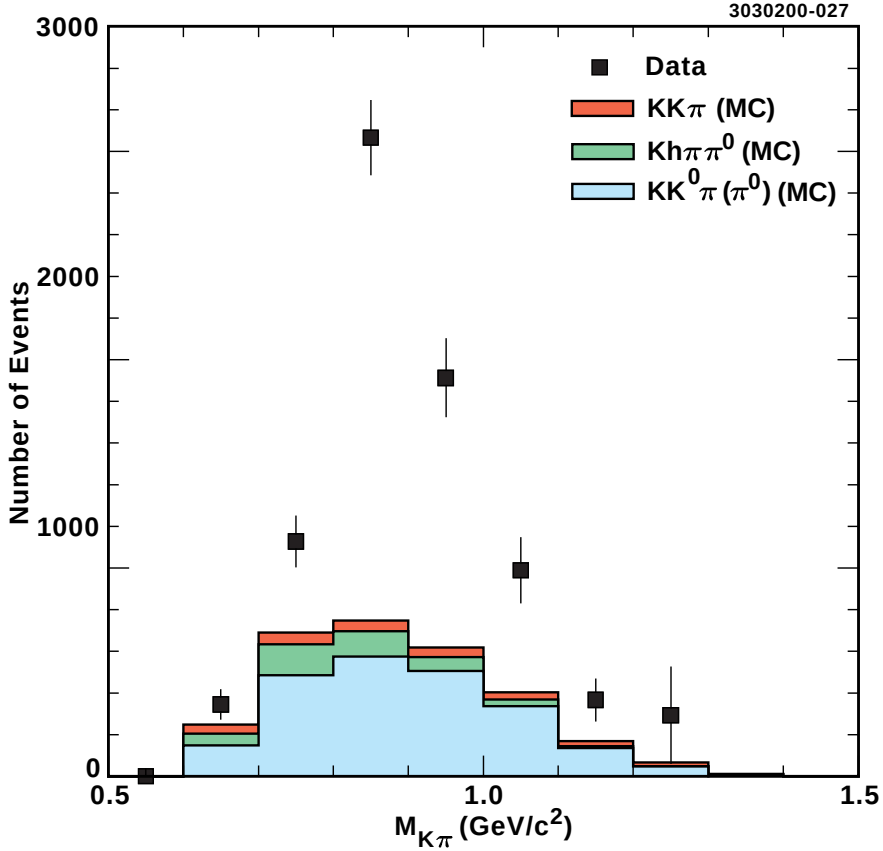
$\tau^- \to K^-\pi^+\pi^-\nu_\tau$ at CLEO – II



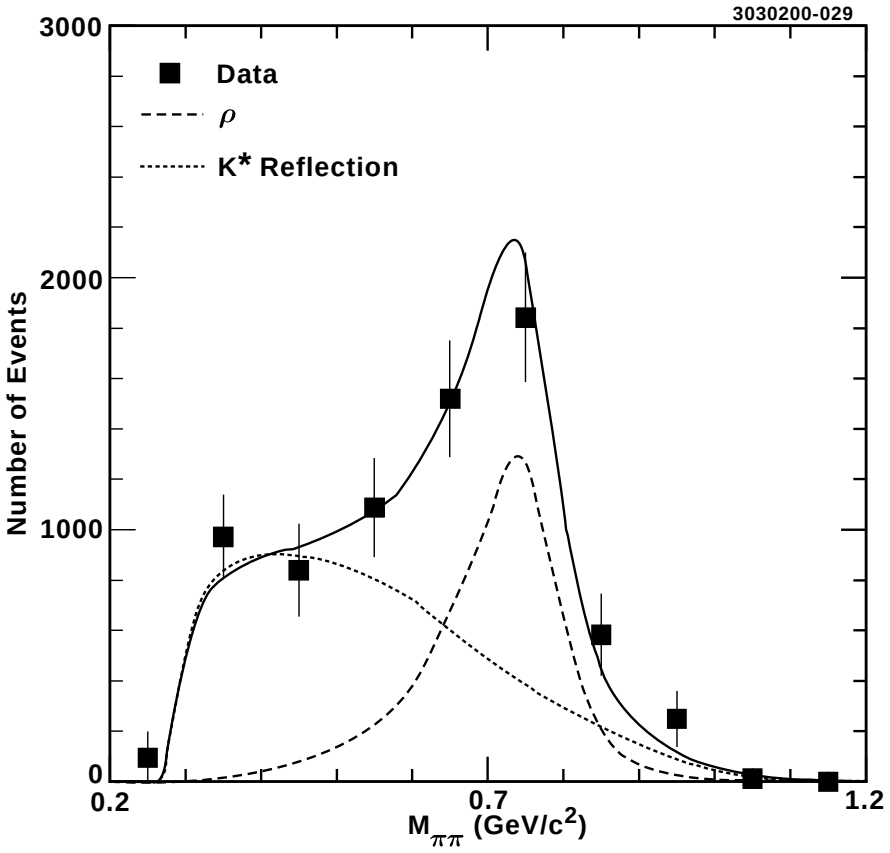


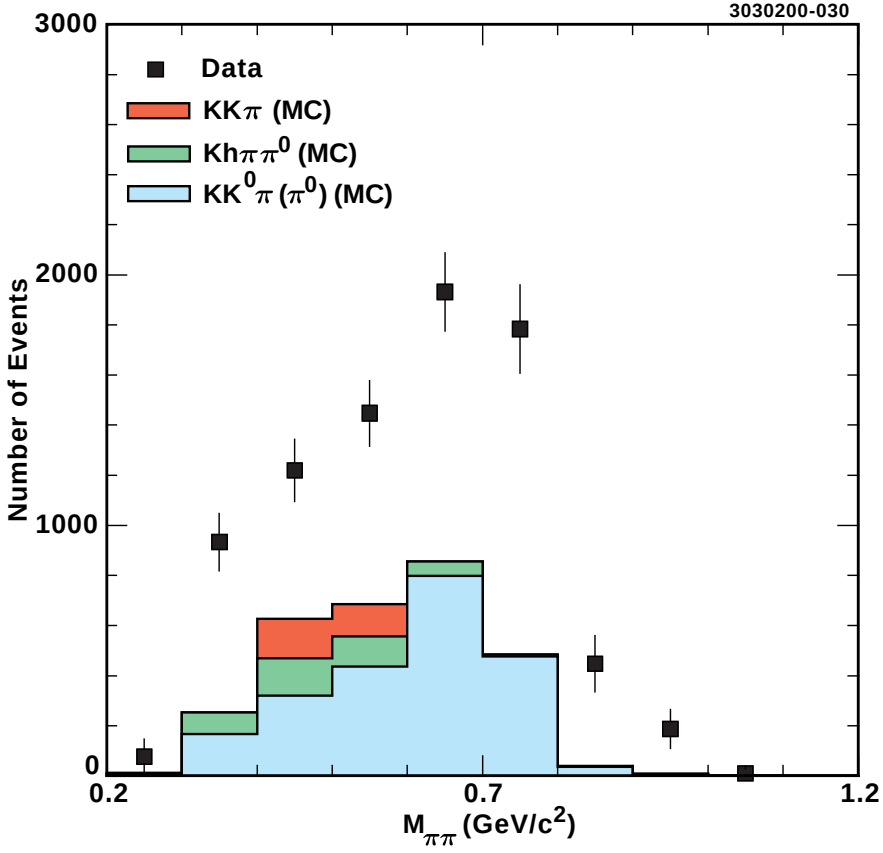
$\tau^- \to K^-\pi^+\pi^-\nu_\tau$ at CLEO – III





$\tau^- \to K^-\pi^+\pi^-\nu_\tau$ at CLEO – IV





$\tau^- \to h^- h'^+ h''^- \nu_\tau$ at Belle – I

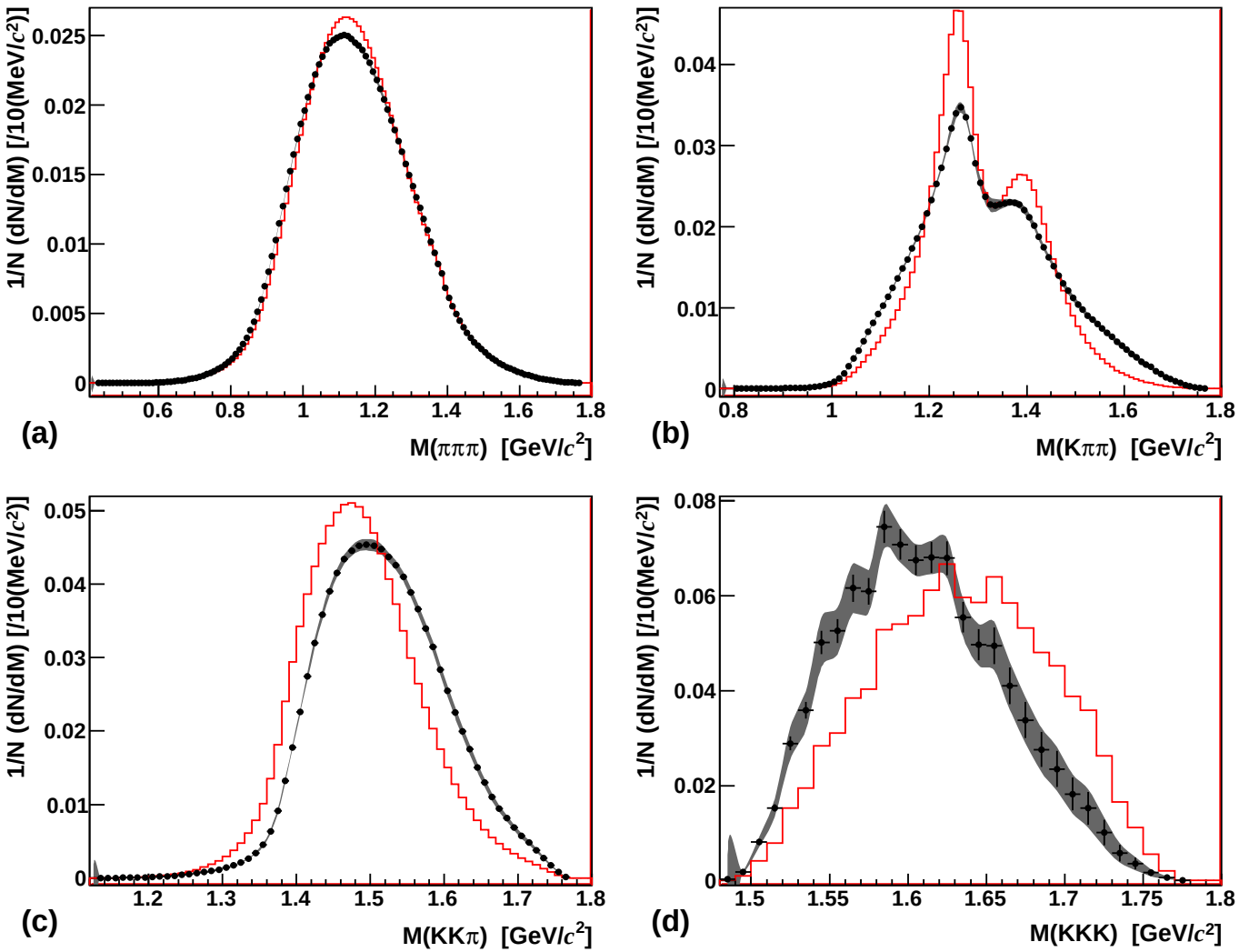
Belle made a high-statistics ($\times$100 compared to LEP and CLEO)
study of τ decays with three charged hadrons ($\pi^\pm$, $K^\pm$) in the final state.
They perform unfolding of the raw spectra to measure
branching fractions and obtain invariant mass spectra

Data samples

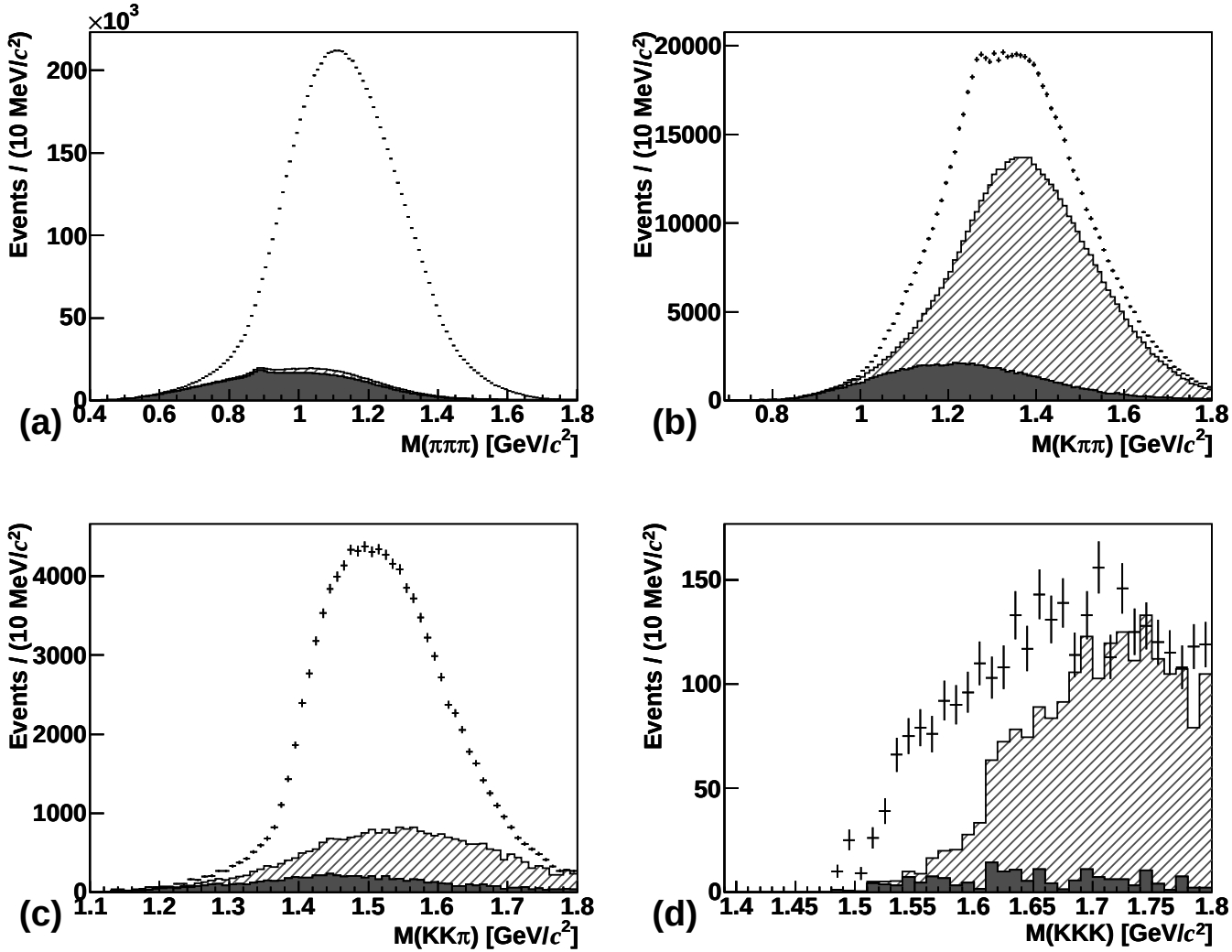
Mode	$\pi^-\pi^+\pi^-\nu_\tau$	$K^-\pi^+\pi^-\nu_\tau$	$K^-K^+\pi^-\nu_\tau$	$K^-K^+K^-\nu_\tau$
Events	$8.9 \cdot 10^6$	$7.9 \cdot 10^5$	$1.1 \cdot 10^5$	$3.2 \cdot 10^3$

M.J. Lee et al., Phys. Rev. D81, 113007 (2010)

$\tau^- \to h^- h'^+ h''^- \nu_\tau$ at Belle – II

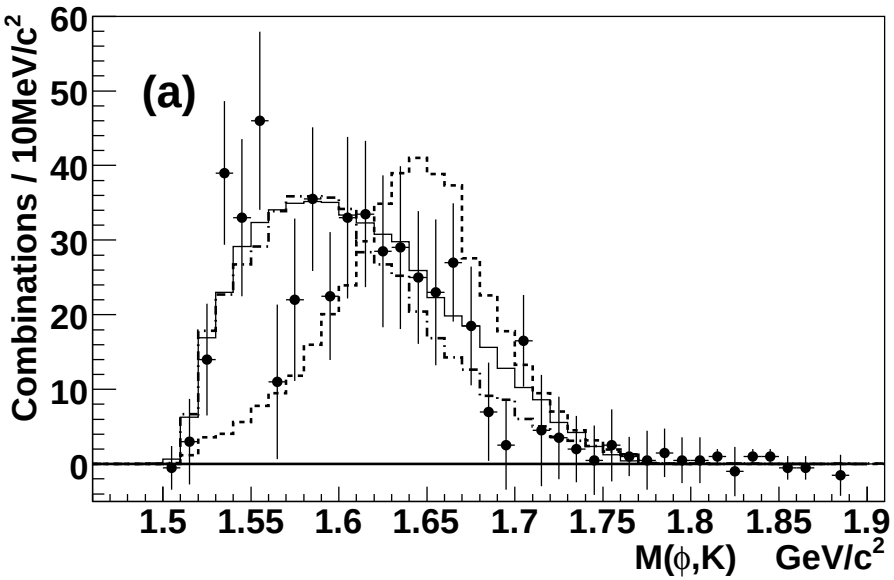


$\tau^- \to h^- h'^+ h''^- \nu_\tau$ at Belle – III



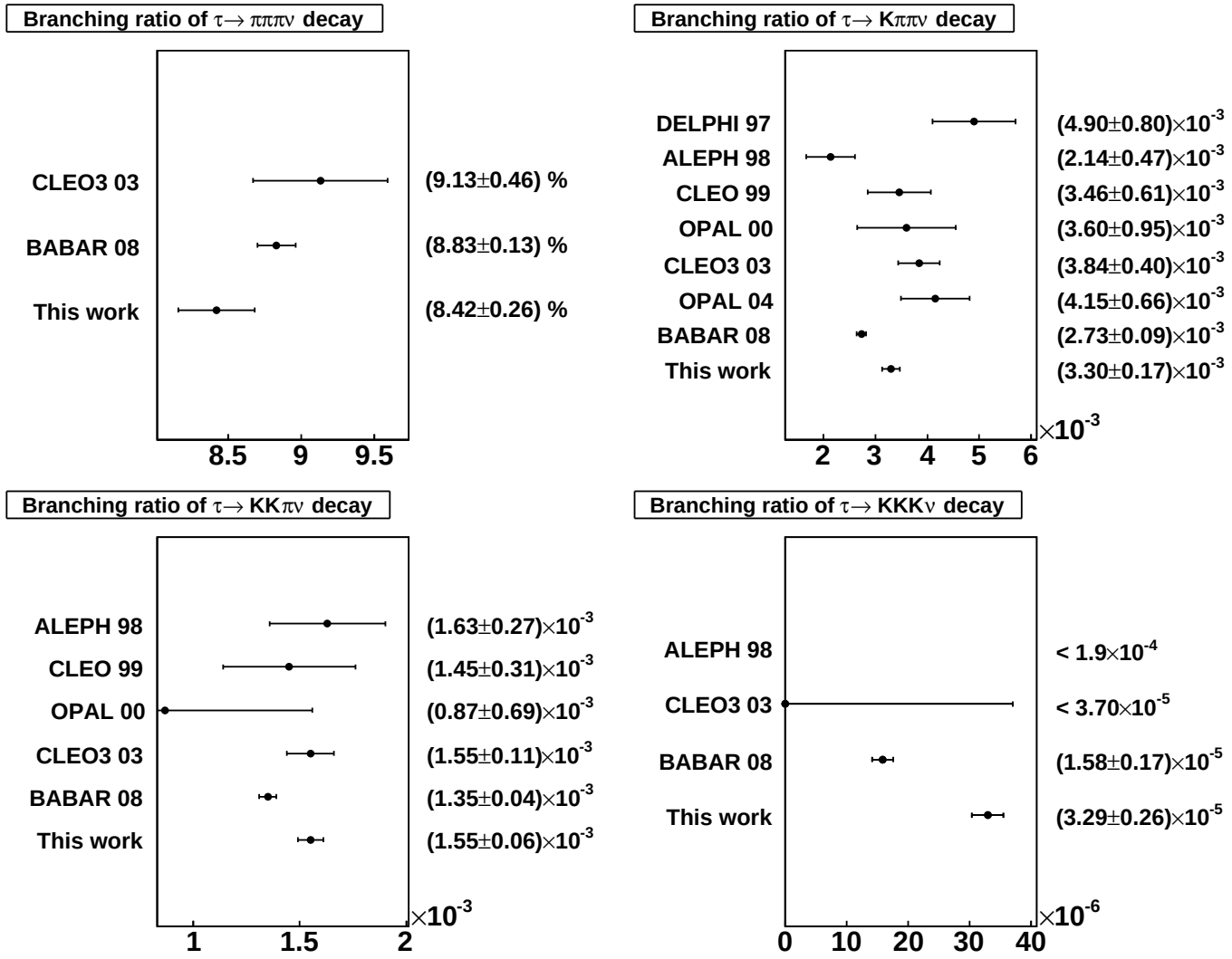
$\tau^- \to \phi K^- \nu_\tau$ at Belle

Belle discovered a rare decay $\tau^- \to \phi K^- \nu_\tau$ ($\mathcal{B} \sim 4 \cdot 10^{-5}$)
and observed 550 events with three final kaons



K. Inami et al., Phys. Lett. B643, 5 (2006)

$\tau^- \to h^- h'^+ h''^- \nu_\tau$ at Belle – IV



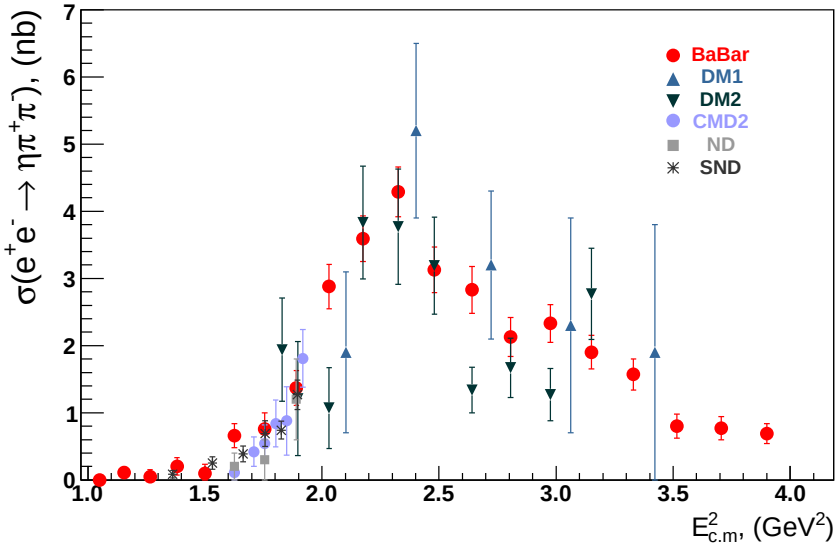
Some general comments about models for τ

1. The existing version of TAUOLA is mostly based on the old models created by H. Kühn and Co in early 90'ies
2. There exist partial data-driven updates from CLEO/ALEPH
3. There are data-driven models using adaptable MC approach (Z.Was) and theory-driven with some parameters fit from data:

   - Models based on Resonance Chiral Theory (Valencia group),
     $\eta\pi\pi$ – P. Roig. Nucl. Phys. B (Proc. Suppl.) 207, 145 (2010);
     3π – D. Gomez Dumm et al., Phys. Rev. D 81, 034031 (2010);
     $K\bar{K}\pi$ – D. Gomez Dumm et al., Phys. Lett. B 685, 158 (2010)
   - CVC based models (Novosibirsk group),
     4π – A. Bondar, SE, ..., ZW et al., Comp. Phys. Commun. 146, 139 (2002);
     $\eta\pi\pi$ – V. Cherepanov and SE, JETP Lett. 89, 429 (2009)

4. Most of the models are based on fits of mass spectra.
   not enough for high precision - angular info needed!

Summary of $e^+e^- \to \eta\pi^+\pi^-$ Measurements

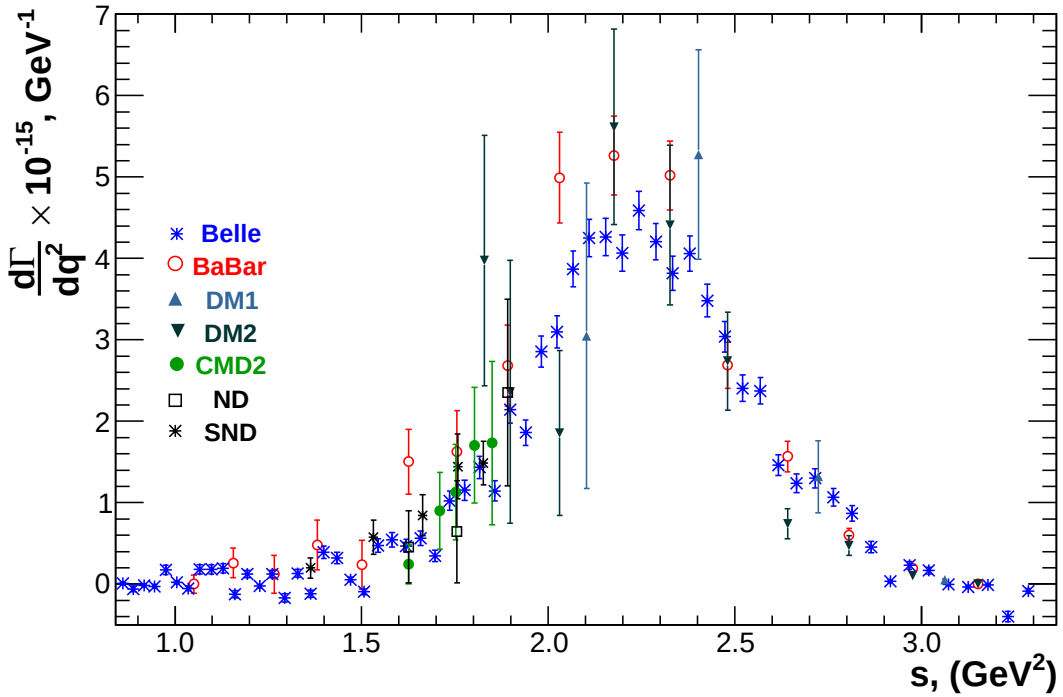


BaBar data are much more precise than those at DM1, DM2 above 1.4 GeV

Are BaBar points higher below 1.4 GeV?

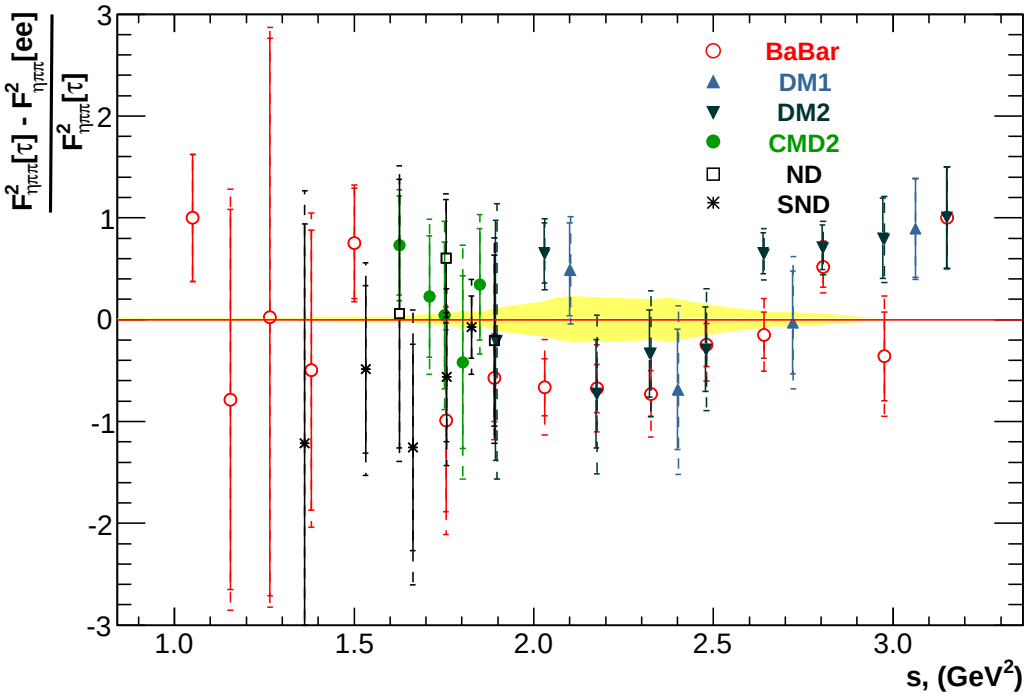
V. Cherepanov and SE, arXiv:1012.2564

Comparison with Belle – I



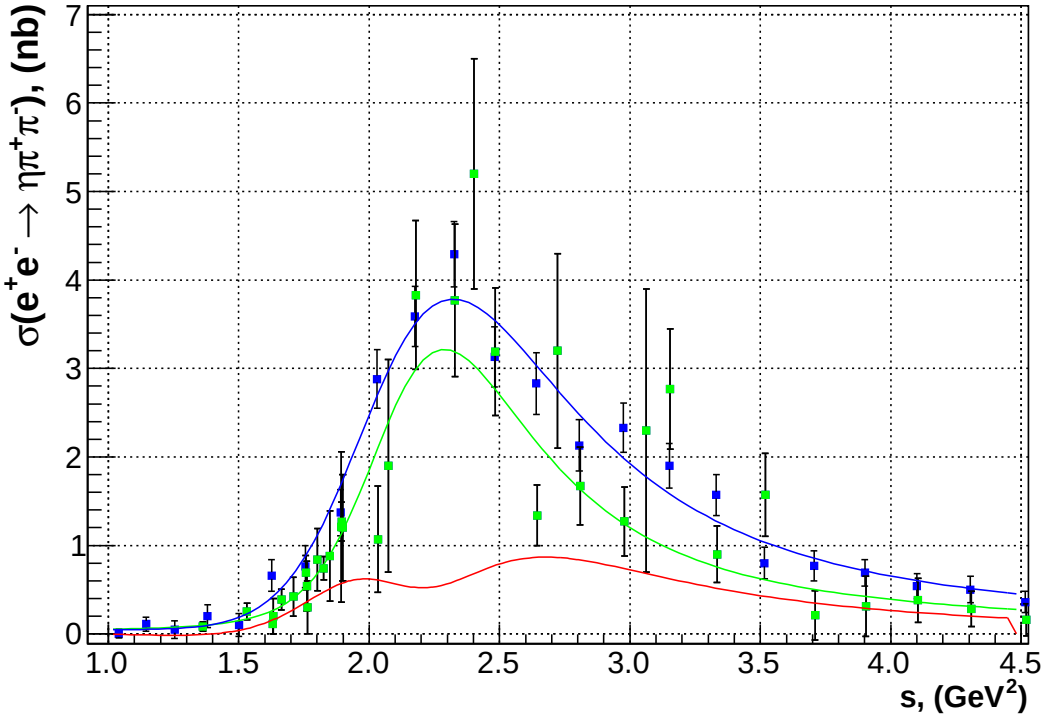
In general, τ spectra are consistent with e^+e^-

Comparison with Belle – II



This can be seen better from the "difference" plot taking into account a 5.3% syst. error of Belle

Difference between new (BaBaR) and old + SND e^+e^- data



Some excess of the "BaBaR" data is confirmed

although critical analysis of the fits needed

Work (with HC and ZW) is in progress to update PHOKHARA and TAUOLA

Three-body Decays of D and B Mesons

- Studies of CP violation as well as of mechanisms of D and B meson decays require good description of the Dalitz plots
- This necessitates creation of complicated models involving a large number of $\pi\pi$, $K\bar{K}$ and $K\pi$ resonances taking into account various fine effects, e.g., $\rho - \omega$ interference
- In contrast to τ lepton decays, there is no theory to describe such decays, not even QCD-based models $\Rightarrow$ simple isobar-type models are used (sum of Breit-Wigners)

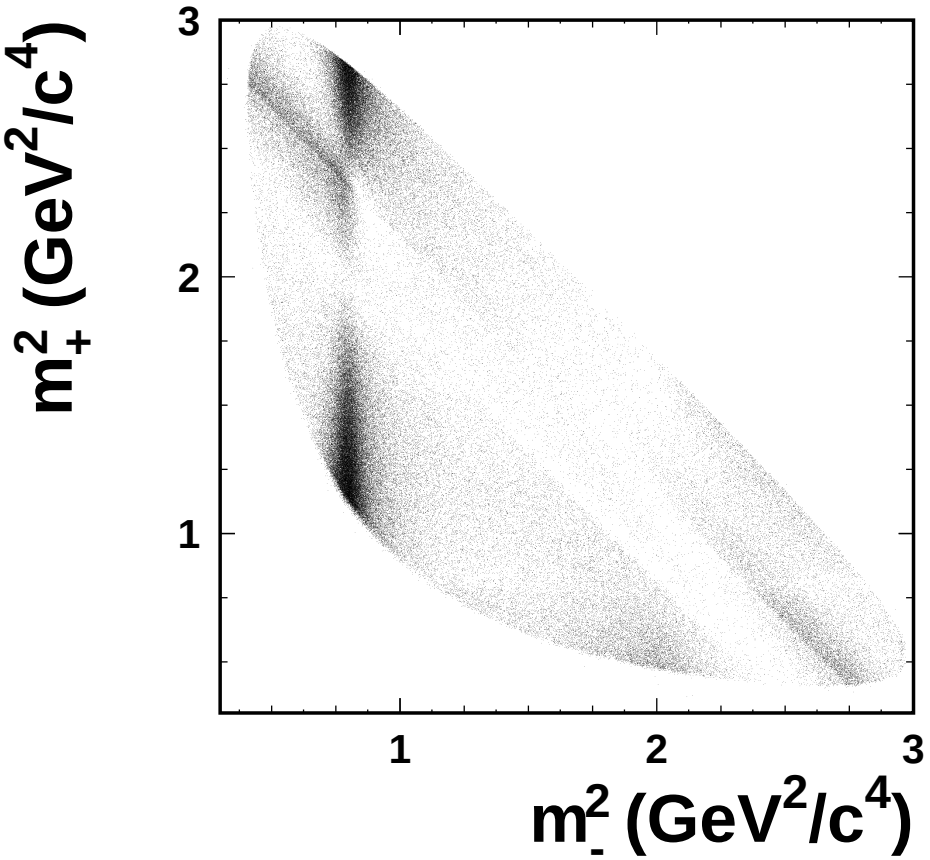
$D^0 \to K^0_S\pi^+\pi^-$ at Belle – I

Belle used 534k events of $D^0 \to K^0_S\pi^+\pi^-$
to study $D^0 - \bar{D}^0$ mixing and CP violation
using time-dependent Dalitz plot analysis.

Their model includes a number of resonances:
$K^*(892)^\pm$, $K^*(1410)^\pm, K^*_0(1430)^\pm, K^*_2(1430)^\pm, K^*(1680)^\pm$,
ρ, ω, $f_0(980)$, $f_0(980)$, $f_0(980)$, $f_0(980)$

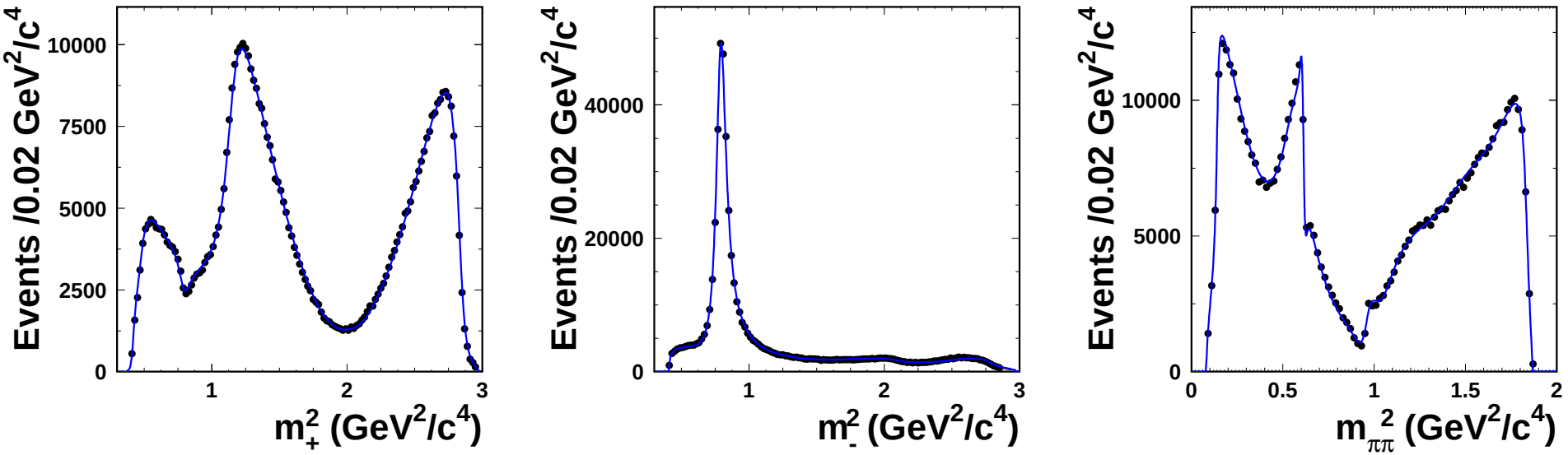
L.-M. Zhang et al., Phys. Rev. Lett. 99, 131803 (2007)

$D^0 \to K^0_S\pi^+\pi^-$ at Belle – II



Here $m^2_{\pm} = m^2_{K_S\pi^{\pm}}$

$D^0 \to K^0_S\pi^+\pi^-$ at Belle – III



Conclusions

- We already have and expect even higher precision measurements ⇒ new requirements for both experiment and analysis
- Higher precision imposes special constraints on the description of physical processes, i.e. their dynamics, in particular using full information about events
- There is serious progress with studies of three-body systems in τ lepton and D/B meson decays
- We have to learn how to better model the observed dynamics and provide good input for the corresponding MC generators