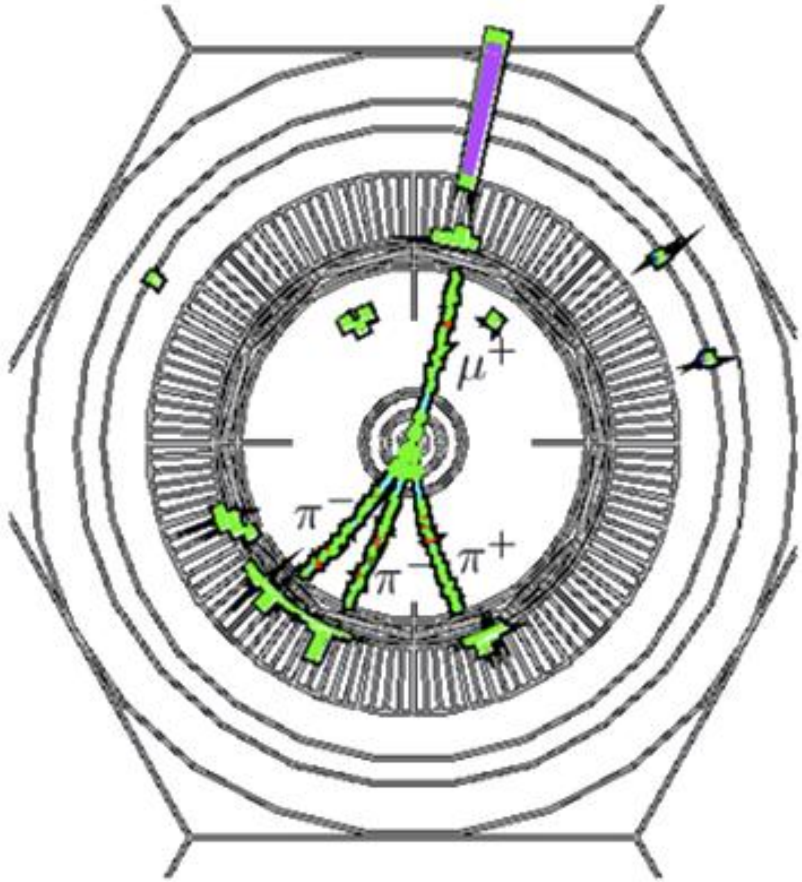
Confronting Theoretical Models with Experimental Data

- Perspectives on $\tau^- \to h^- h^- h^+ \nu$ -



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Alexander von Humboldt Stiftung/Foundation

Outline

Why τ Decays

- Motivation: What physics do τ decays provide?

The Experiments

- τ Leptons and the B-Factories...
- An introduction to the Experiments
- Results from BaBar

Confronting Theory with Experiment

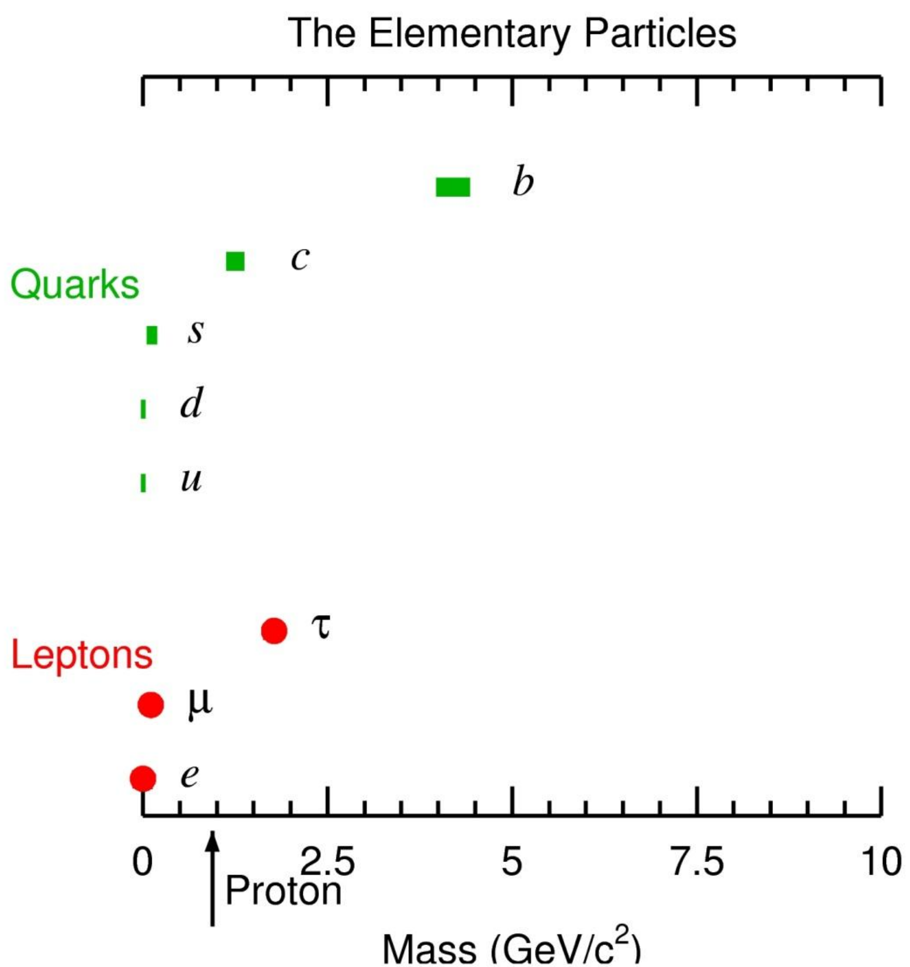
- Strategies...
- Comparison to Tauola++ 1.05 and RChL currents

Outlook

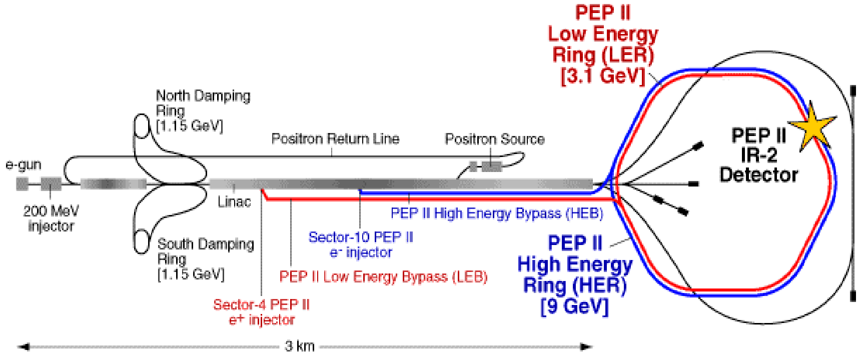
What Physics does the τ Provide Access to?

The τ is the most massive charged lepton,
as such it provides:

- A unique environment to determine $|V_{us}|$
- Test the Charged Lepton Universality assumption in the Standard Model
- Provides a clean environment to study QCD
  - Strong coupling constant $\alpha_s(M_\tau)$
  - Search for second class currents (allowed by QCD but never observed)
  - Wess-Zumino Anomaly
  - Resonance structure
  - Okubo-Zweig-Iizuka Suppression
  - Test of Charged Vector Current (CVC)
- Search for New Physics
  - Lepton Flavour Violation (LFV)
- τ mass measurement
- τ life time measurement

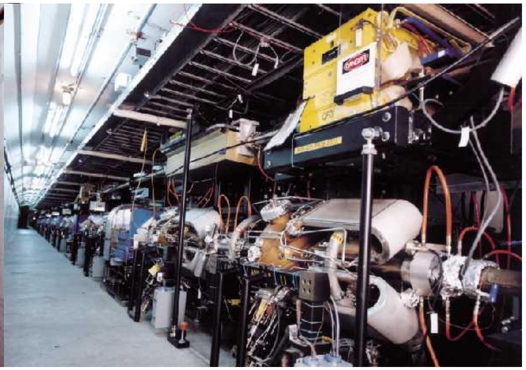


The BaBar Detector at SLAC



The PEP II ring is an asymmetric e^+e^- collider located at SLAC with a CM energy of 10.58 GeV (the Υ(4s) resonance).

PEP II. The BaBar Detector was only detector on the PEP II ring.



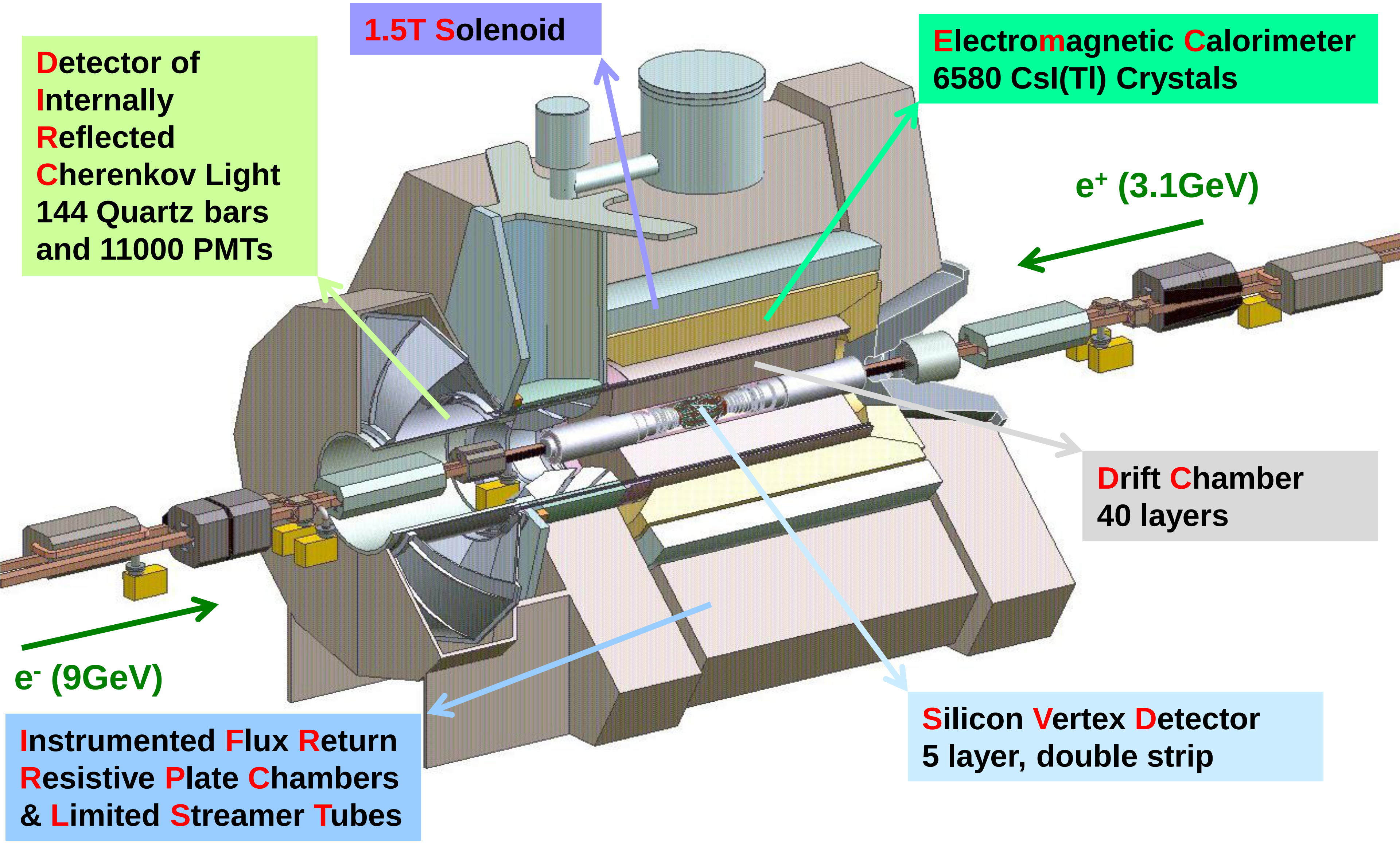
LER ~3.1GeV

HER ~9.0GeV

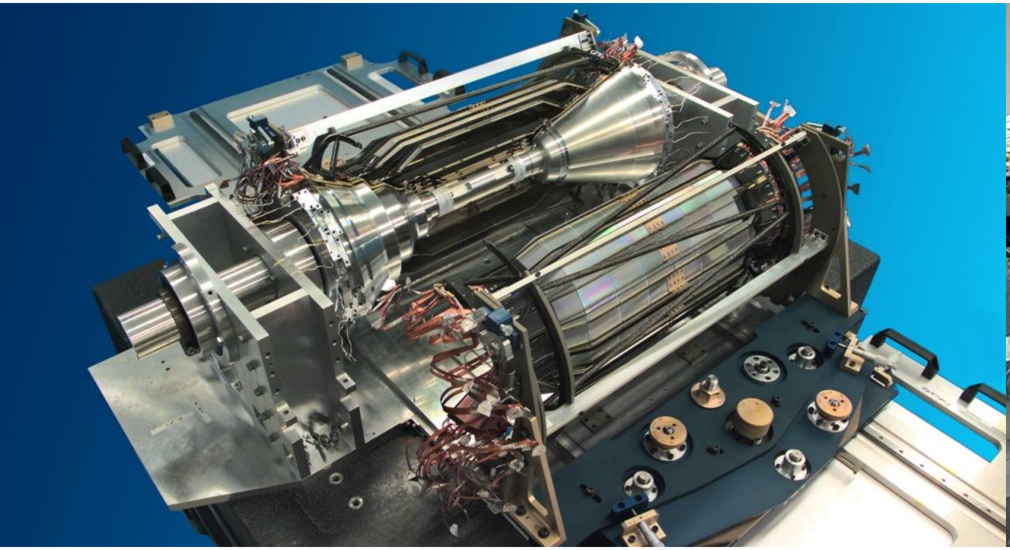
$\Rightarrow$ τ particle are highly relativistic

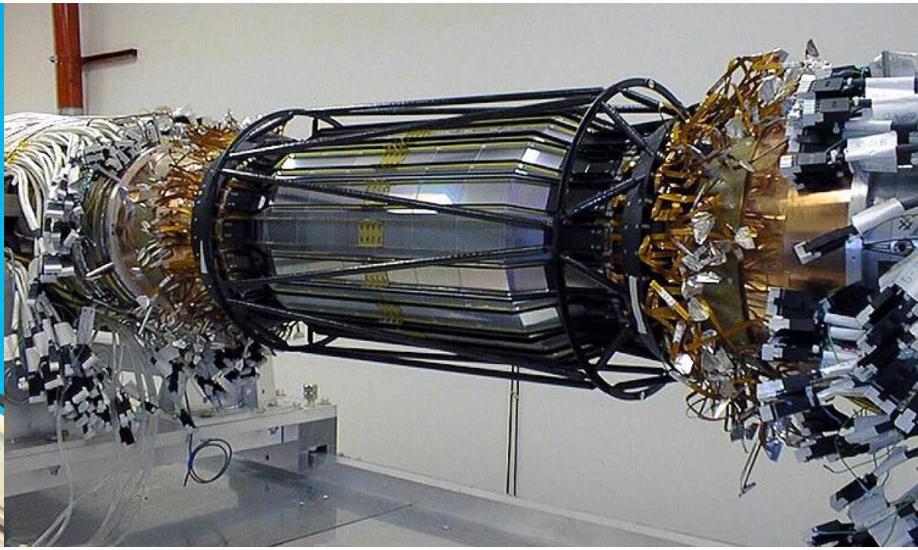
β=~0.94c

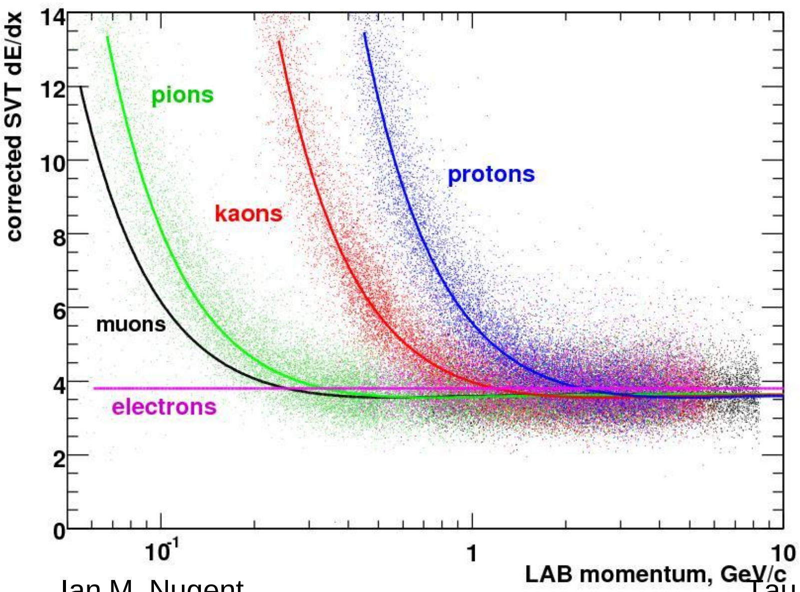
The BaBar Detector at SLAC



Silicon Vertex Tracker



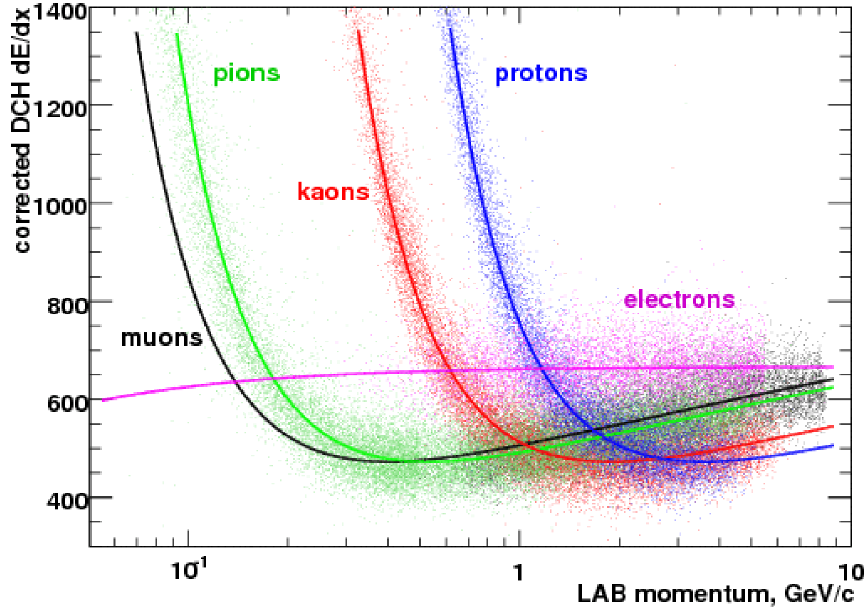


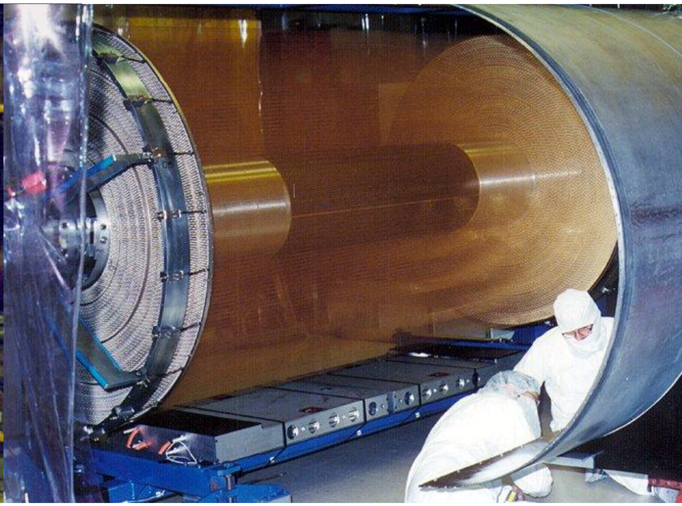


SVT is used for vertexing, to measure the momentum and some dE/dx information for particle ID

Drift Chamber

DCH measures the dE/dx for charged particle for particle ID and measures the track trajectory and momentum of charged tracks

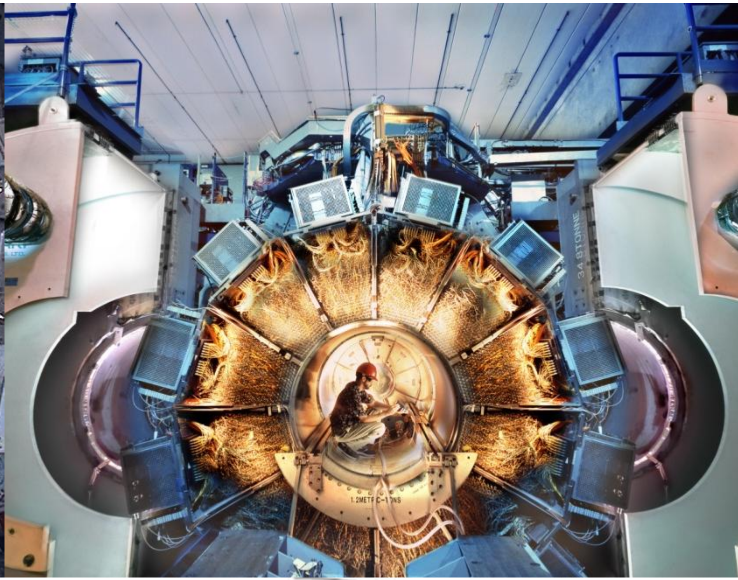


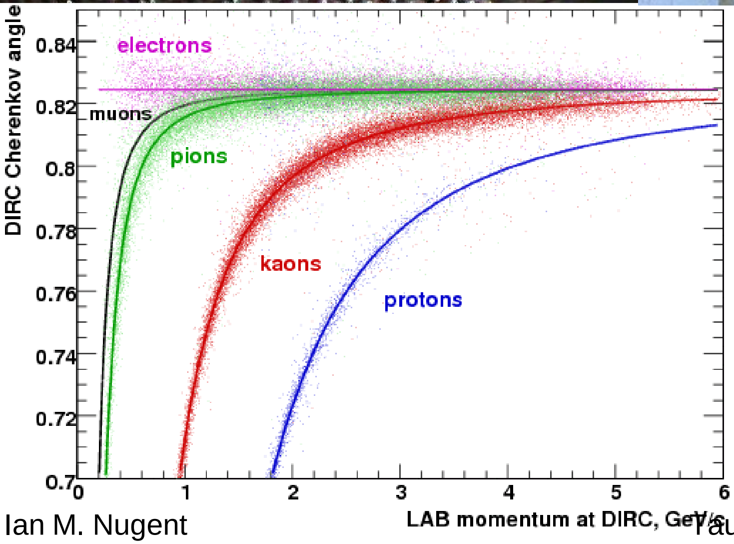


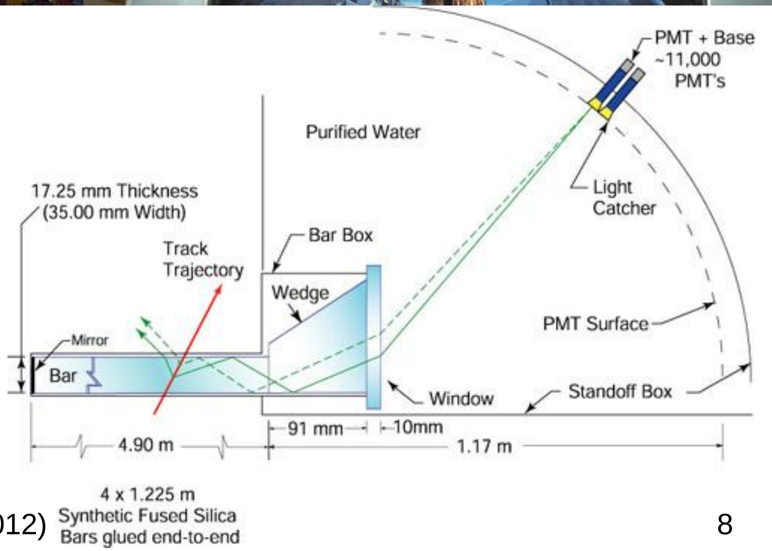
Detector of Internally Reflected Cherenkov Light

The DIRC measures the velocity of charged particles

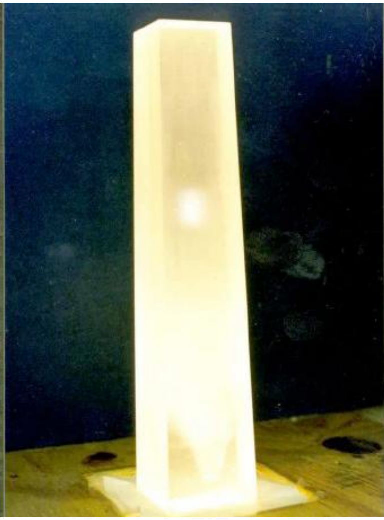
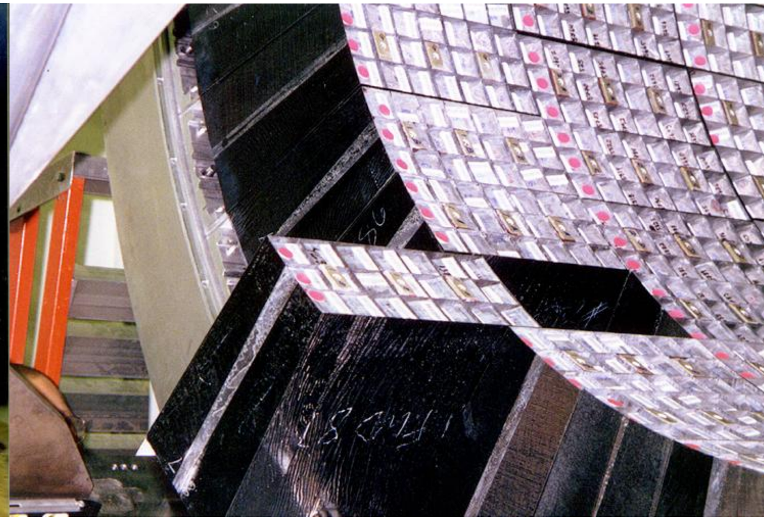




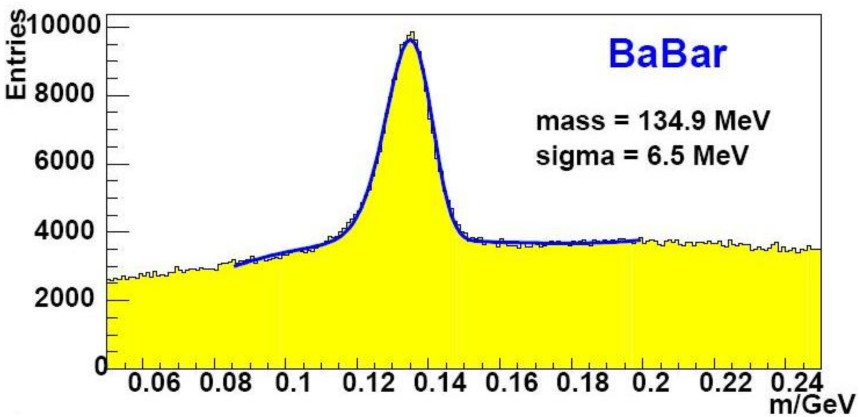


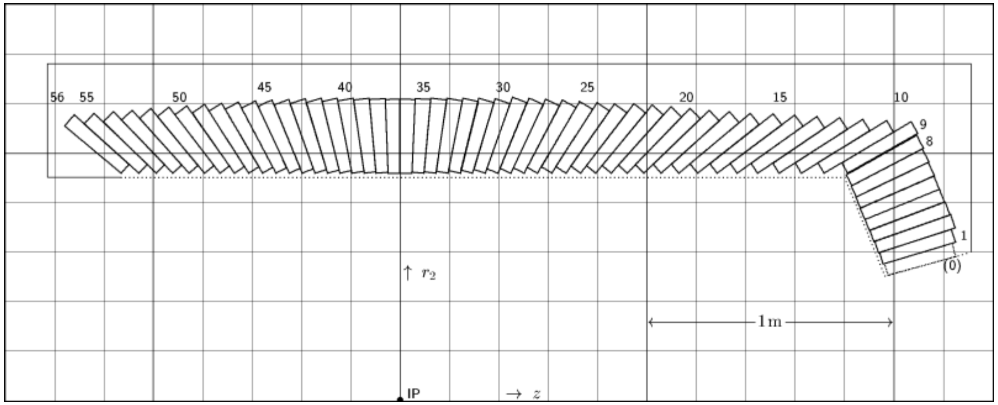


Electromagnetic Calorimeter

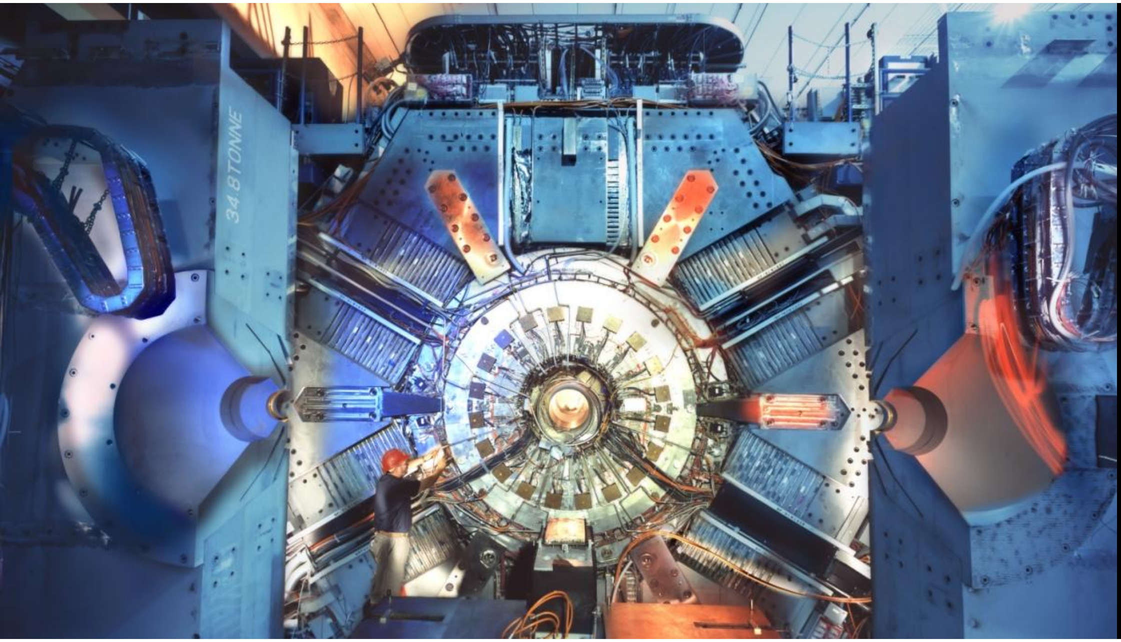

Electromagnetic calorimeter (EMC) used to identify electron and measure photon energy

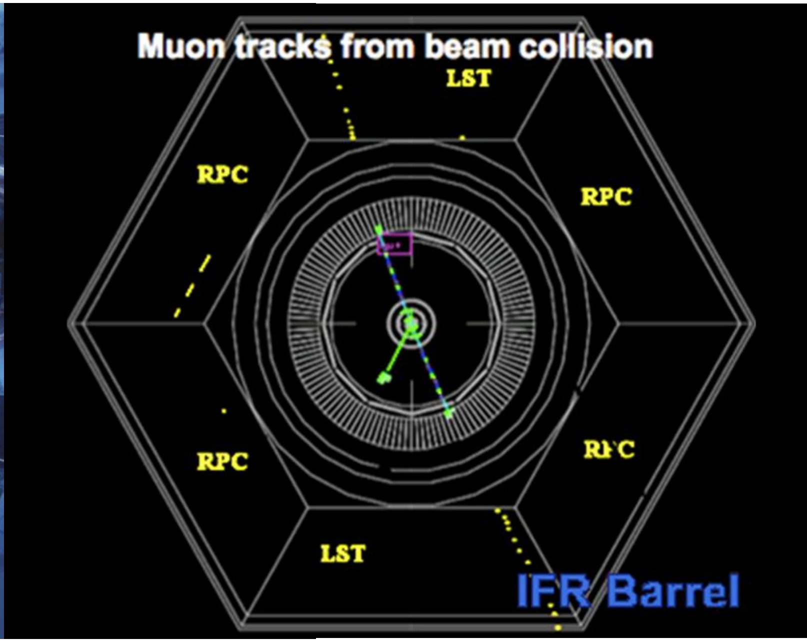


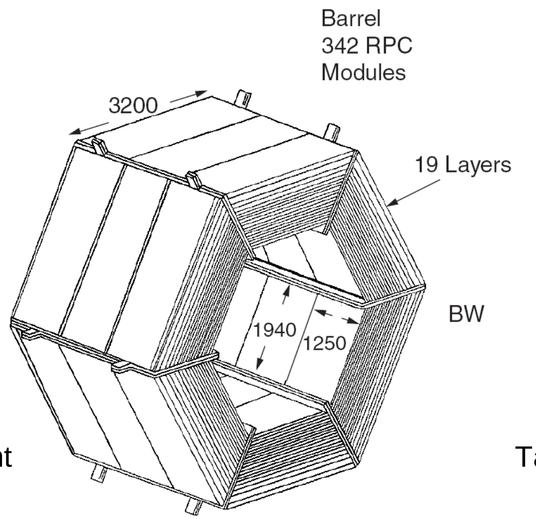


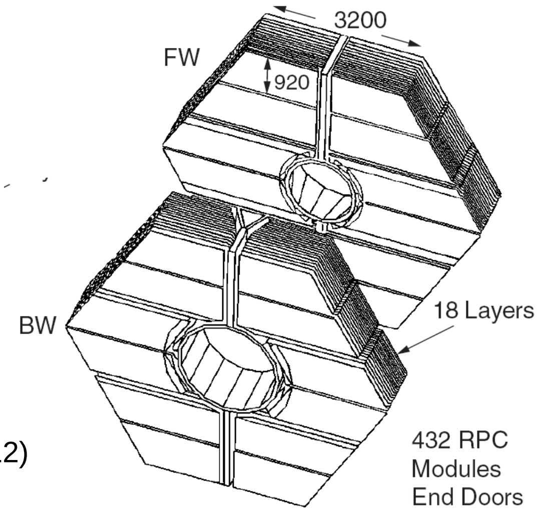
Instrumented Flux Return

IFR (RPC and now LST) used to identify muons









Identifying τ Decays at B-Factories

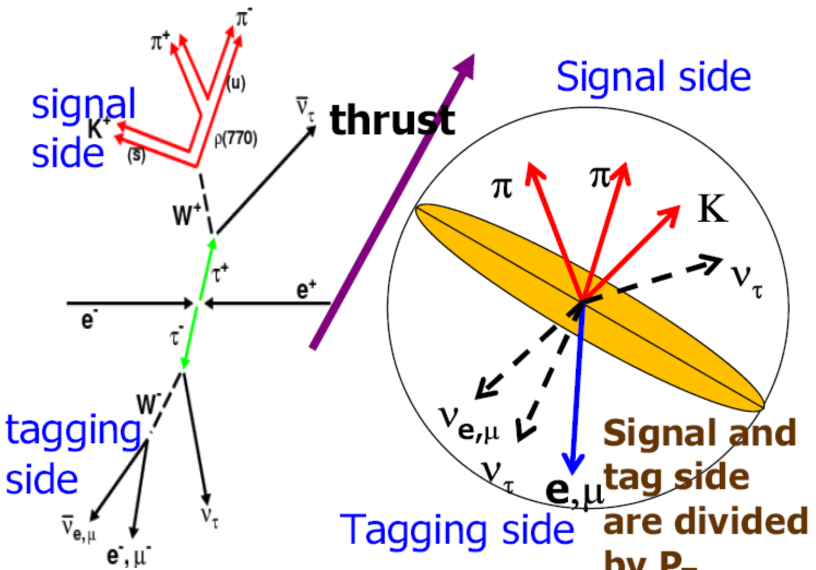
Primary production mechanism at a low energy e^+e^- collider:

$e^+e^- \to \tau^+\tau^-$

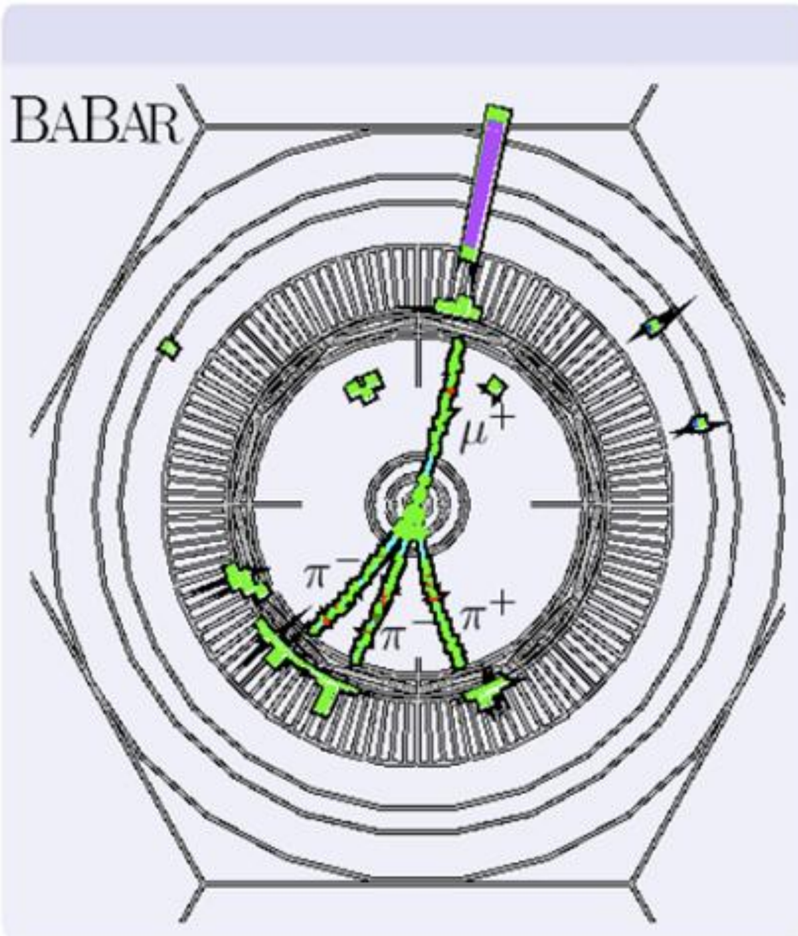
Cross Section at ϒ(4s) [10.58GeV]
$\sigma(\tau^+\tau^-)=(0.919\pm0.003)$nb
Phys. Rev. D 77, 054012 (2008)

BaBar	$L=531fb^{-1}$	$\Rightarrow\sim5\times10^8$ τ Pairs
Belle	$L=1ab^{-1}$	$\Rightarrow\sim10\times10^8$ τ Pairs

Thrust is used to separate the two τ decays:



τ-Pair Signature:
Leptonic+Hadronic Decay



Summary of Results from BaBar: BR

Branching Ratio/Fraction Measurements

$(\tau^- \to \mu^- \nu \nu)/(\tau^- \to e^- \nu \nu)$	Phys.Rev.Lett.105:051602,2010	$(0.9796 \pm 0.0016 \pm 0.0036)$
$(\tau^- \to \pi^- \nu)/(\tau^- \to e^- \nu \nu)$	Phys.Rev.Lett.105:051602,2010	$(0.5945 \pm 0.0014 \pm 0.0061)$
$\tau^- \to \pi^- \pi^- \pi^+ \nu$ (ex. K_S^0)	Phys.Rev.Lett.100:011801,2008	$(8.83 \pm 0.01 \pm 0.13) \times 10^{-2}$
$\tau^- \to f_1(1285) \pi^- \nu$ [$f_1 \to 2\pi^- 2\pi^+$]	Phys.Rev.D72:072001,2005	$(3.90 \pm 0.70 \pm 0.50) \times 10^{-4}$
$\tau^- \to f_1(1285) \pi^- \nu$ [$f_1 \to \pi^- \pi^+ \eta$]	Phys.Rev.D77:112002,2008	$(3.19 \pm 0.18 \pm 1.00) \times 10^{-4}$
$\tau^- \to 3\pi^- 2\pi^+ \nu$ (ex. K_S^0)	Phys.Rev.D72:072001,2005	$(8.56 \pm 0.05 \pm 0.42) \times 10^{-4}$
$\tau^- \to 2\pi^- \pi^+ \eta \nu$	Phys.Rev.D77:112002,2008	$(1.60 \pm 0.05 \pm 0.11) \times 10^{-4}$
$\tau^- \to \pi^- \eta' \nu$	Phys.Rev.D77:112002,2008	$< 7.2 \times 10^{-6}$ @ 90% C.L.
$\tau^- \to \pi^- \omega \nu$	Phys.Rev.Lett.103:041802,2009	SCC/FCC < 0.69% @ 90% C.L
$\tau^- \to \pi^- \varphi \nu$	Phys.Rev.Lett.100:011801,2008	$(3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$
$(\tau^- \to K^- \nu)/(\tau^- \to e^- \nu \nu)$	Phys.Rev.Lett.105:051602,2010	$(0.03882 \pm 0.00032 \pm 0.00057)$
$\tau^- \to K^- \pi^0 \nu$	Phys.Rev.D76:051104,2007	$(0.416 \pm 0.003 \pm 0.018) \times 10^{-2}$
$\tau^- \to K^- \pi^- \pi^+ \nu$ (ex. K_S^0)	Phys.Rev.Lett.100:011801,2008	$(0.273 \pm 0.002 \pm 0.009) \times 10^{-2}$
$\tau^- \to K^- \pi^- K^+ \nu$	Phys.Rev.Lett.100:011801,2008	$(1.346 \pm 0.010 \pm 0.036) \times 10^{-3}$
$\tau^- \to K^- K^- K^+ \nu$	Phys.Rev.Lett.100:011801,2008	$(1.58 \pm 0.13 \pm 0.12) \times 10^{-5}$
$\tau^- \to K^- \varphi \nu$	Phys.Rev.Lett.100:011801,2008	$(3.39 \pm 0.20 \pm 0.28) \times 10^{-5}$
$\tau^- \to K^- K^- K^+ \nu$ [ex. ϕ]	Phys.Rev.Lett.100:011801,2008	$< 2.5 \times 10^{-6}$ @ 90% CL
$\tau^- \to K^- \eta \nu$	Phys.Rev.D83:032002,2011	$(1.42 \pm 0.11 \pm 0.07) \times 10^{-4}$

Unpublished (Proceedings)

$\tau^- \to K^0 \pi^- \nu$	arXiv:0808.1121 [hep-ex]	$(0.840 \pm 0.004 \pm 0.023) \times 10^{-2}$
$\tau^- \to K^0 \pi^- \pi^0 \nu$	arXiv:0910.2884 [hep-ex]	$(0.342 \pm 0.006 \pm 0.015) \times 10^{-2}$

Summary of Results from BaBar: Mass Spectra

Mass Spectra Available from BaBar….

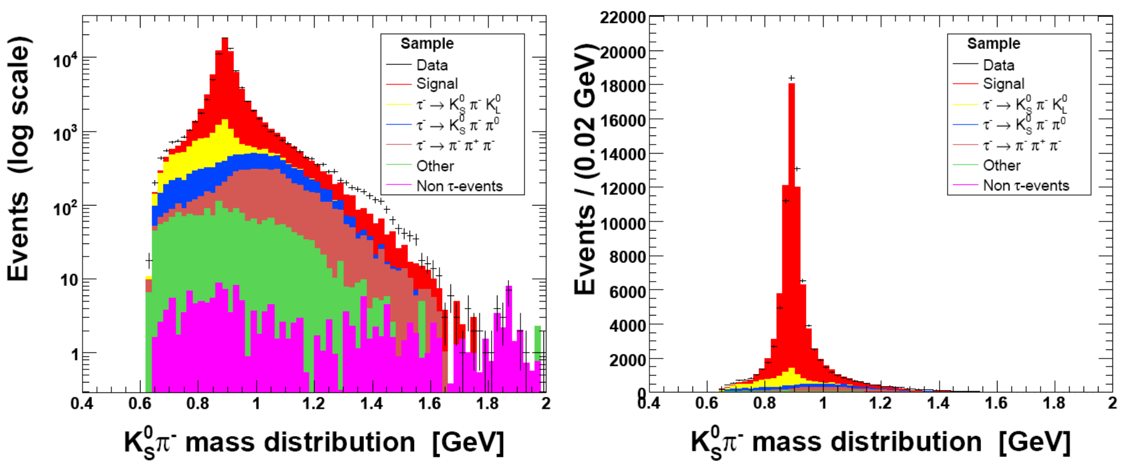
- Raw Data/MC Comparison have been presented publicly for many BR publications
- However, these can not be used to update Tauola

There are no published papers available:

- Only preliminary results and BaBar Thesis results.

Mass Spectra Fit to Analytic Functions

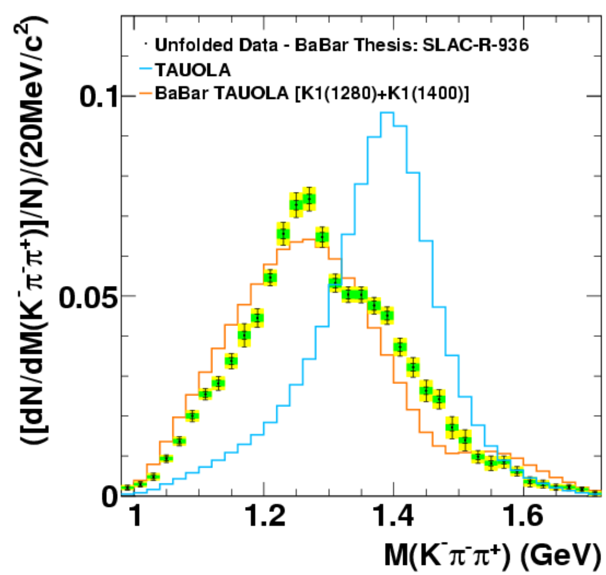
arXiv:0808.1121 [hep-ex]



Unfolded Mass Spectra

BaBar Thesis:

THESIS-11/006 (SLAC-R-936)



Analysis Strategy for $\tau^- \to h^- h^- h^+ \nu_\tau$

$$\sum_j M_{ij} N_j^{Sig} = (N_i^{Data} - N_i^{Bkg(MC)})$$

$$\Rightarrow N_j^{Sig} = \sum_i \left(M^{-1}\right)_{ij} (N_i^{Data} - N_i^{Bkg(MC)})$$

$$\mathrm{Br}_j = \frac{\mathrm{N}_j^{\mathrm{Sig}}}{2\mathrm{L}\sigma_{\tau^+\tau^-}}$$

i=Channels Selected
j=Decay Mode

Particle Identification (PID) Efficiency Matrix				
Candidates	**Decay Modes (MC Truth)**			
	$\tau^- \to \pi^-\pi^-\pi^+\upsilon$	$\tau^- \to K^-\pi^-\pi^+\upsilon$	$\tau^- \to K^-\pi^-K^+\upsilon$	$\tau^- \to K^-K^-K^+\upsilon$
$\tau^- \to \pi^-\pi^-\pi^+\upsilon$	97.40%	22.49%	4.73%	1.02%
$\tau^- \to K^-\pi^-\pi^+\upsilon$	1.42%	74.87%	16.43	6.38%
$\tau^- \to K^-\pi^-K^+\upsilon$	0.01%	0.49%	59.63%	25.54%
$\tau^- \to K^-K^-K^+\upsilon$			0.26%	50.87%
Characteristic Efficiency (excluding PID)				
ε	2.8%	3.1%	3.5%	3.9%

Backgrounds for $\tau^- \to h^- h^- h^+ \nu_\tau$

Backgrounds – General Strategies		
τ bkg	Cross feed: $\tau^- \to \pi^-\pi^-\pi^+\nu_\tau$, $\tau^- \to K^-\pi^-\pi^+\nu_\tau$, $\tau^- \to K^-\pi^-K^+\nu_\tau$, $\tau^- \to K^-K^-K^+\nu_\tau$.	MC efficiencies (from matrix), corrected with data control samples
	$\tau^- \to K^-K^-K^+\pi^0\nu_\tau$ (bkg with only upper limit)	With and without MC normalized to upper-limit (phase-space model)
	Other τ bkg	Scale Br by $\pm\sigma$ from PDG for main modes (shape from MC)
Non-τ bkg	$\mu^-\mu^+$ bkg	Control samples (well modelled) Scaling cross section by $\pm\sigma$
	Bhabha	Side band to set upper limit and studying removal of electron veto on 1,2,3 hadrons. Side Band: $2P_{Lep,CM}/E_{PEP,CM}$
	Two-Photon	Control sample to get an upper-limit
	$q\bar{q}$, backgrounds	Side band to normalize the background: $M(h^-h^-h^+)>1.82 GeV/c^2$

Particle Identification for $\tau^- \to h^- h^- h^+ \nu_\tau$

Method for Validating Particle Identification		
1) Tracks restricted to regions where particle identification is well understood		
2) Control samples to correct MC	Electron	$e^+e^- \to e^+e^-(\gamma)$
	Muons	$e^+e^- \to \mu^+\mu^-(\gamma)$
	Pions	$D^{*+} \to \pi^+ D^0 (D^0 \to \pi^+ K^-)$
	Kaon	$D^{*+} \to \pi^+ D^0 (D^0 \to \pi^+ K^-)$
3) Control samples to evaluate uncertainty based on data-MC agreement	$\tau^- \to K^- K^- \pi^+ \nu_\tau$	
	$\tau^- \to \pi^- \pi^- K^+ \nu_\tau$	
	High mass: $1.65\,\mathrm{GeV}/c^2 < M(K^-\pi^-\pi^+) < 1.82\,\mathrm{GeV}/c^2$	
4) Environmental uncertainty from difference in PID between $\tau^- \to h^- h^- h^+ \nu_\tau$ events and $D^{*+} \to \pi^+ D^0 (D^0 \to \pi^+ K^-)$ based on MC Truth		
5) P, θ, and ϕ distributions verified for agreement after correction and in control samples		

Systematic Uncertainties for $\tau^- \to h^- h^- h^+ \nu_\tau$

	$\tau^- \to \pi^- \pi^- \pi^+ \upsilon$	$\tau^- \to K^- \pi^- \pi^+ \upsilon$	$\tau^- \to K^- \pi^- K^+ \upsilon$	$\tau^- \to K^- K^- K^+ \upsilon$
Statistical Uncertainty				
Data Statistical	0.1%	0.7%	0.7%	8.2%
Systematic Uncertainty				
Luminosity	0.9%	0.9%	0.9%	0.9%
$\sigma_{e^+e^- \to \tau^+\tau^-}$	0.3%	0.3%	0.3%	0.3%
MC Stat and Particle-ID	0.4%	3.0%	1.9%	4.9%
Modelling	0.2%	0.2%	1.3%	2.0%
EMC and DCH Response	0.8%	0.9%	0.8%	1.2%
Trigger	0.1%	0.1%	0.1%	0.1%
Backgrounds	0.4%	0.7%	0.4%	5.5%
Total	1.4%	3.4%	2.7%	7.8%

Unfolding Data

When measuring a physical observable - imperfections of the apparatus generally cause distortions in the measured observable. These distortions are typically caused:

- Finite resolution of the detector
- Non-linear response of the scale and/or the resolution of the detector over the distribution of the observable
- Probability of acceptance which may vary over the distribution of the observable.

The process of correcting these effect to obtain the "true" distribution is called:

"Unfolding"

Common Unfolding Techniques in particle physics:

- Singular Value Decomposition
- **Bayesian Unfolding**
- parameterization of the detectors response with spline interpolations
- simple bin by bin migration

Unfolding Procedure

Procedure:

- Background subtraction
  - Includes cross-feed corrected with 3d invariant mass iterative reweighting
  - MC for other τ-pair, μ-pair and $\bar{q}q$ backgrounds
  - Bhabha and two-Photon contamination cover by systematic uncertainties
- Apply Bayesian Unfolding
  - Iterative method based on Bayes' Theorem (NIM. A362:487-498, 1995)

posterior probability

Conditional Probability (from MC Response/Eff)

Prior Probability for the cause (MC Truth for 1st try)

$$P(C_i|E) = \frac{P(E|C_i)P(C_i)}{\sum_{l=1}^{n_c} P(E|C_l)P(C_l)}$$

$$\hat{n}'(C_i) = n(E)P(C_i|E)$$

$$P'(C_i) = \hat{n}'/N_{total}$$

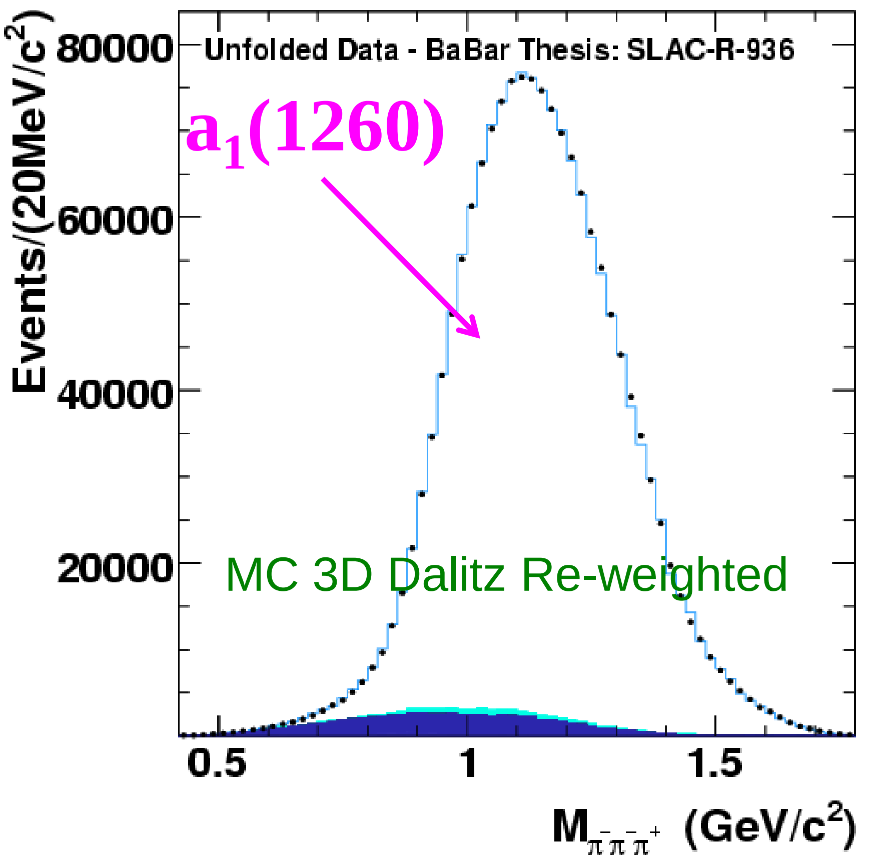
"True" Dist.

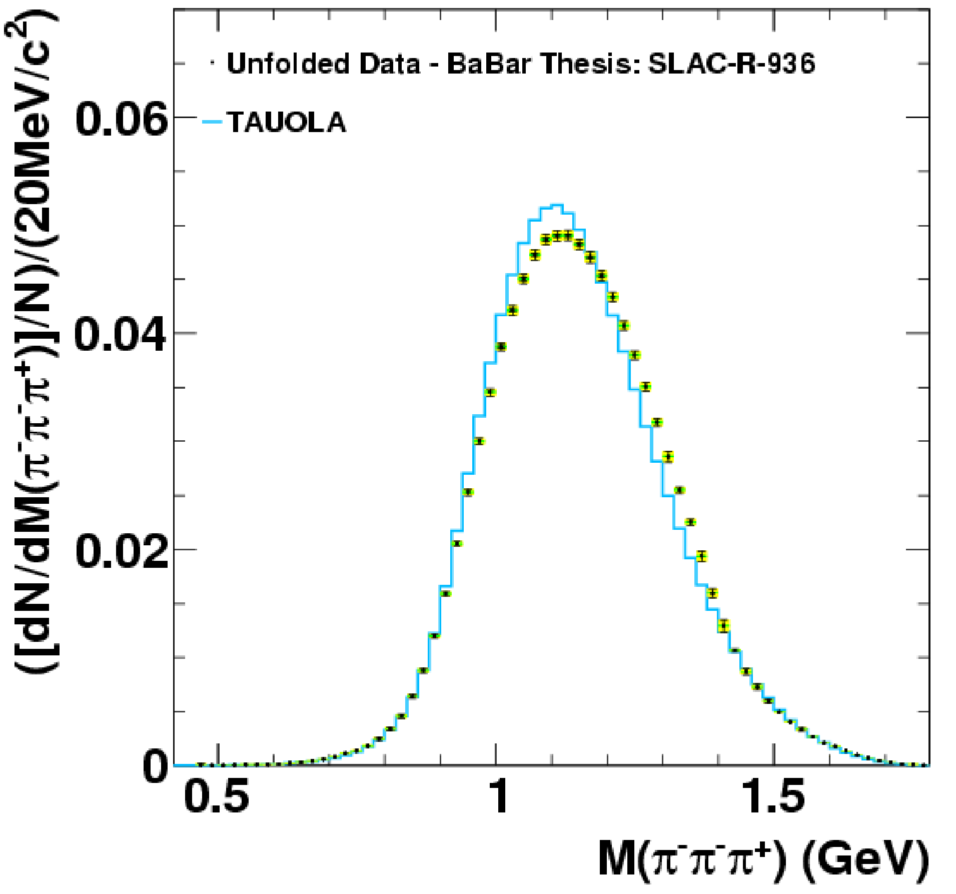
Data Dist.

  - Bias estimated using MC with 3d invariant mass iterative reweighting
  - Unfolded events are then efficiency correct (bin by bin) and normalized to unit area

** Thesis analysis performed with both SVD and Bayesian Unfolding give equivalent results

Invariant Mass Plots $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$

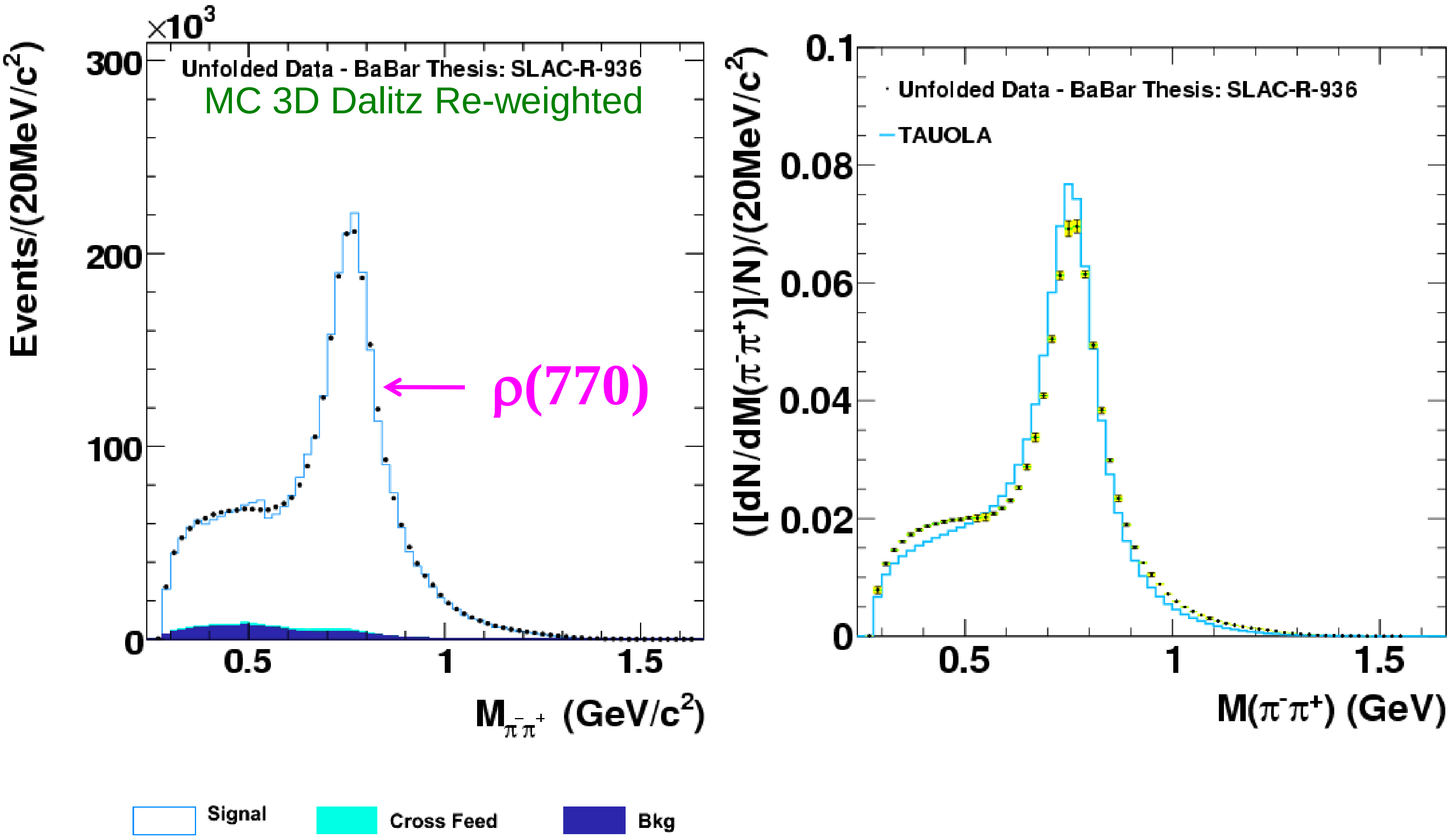




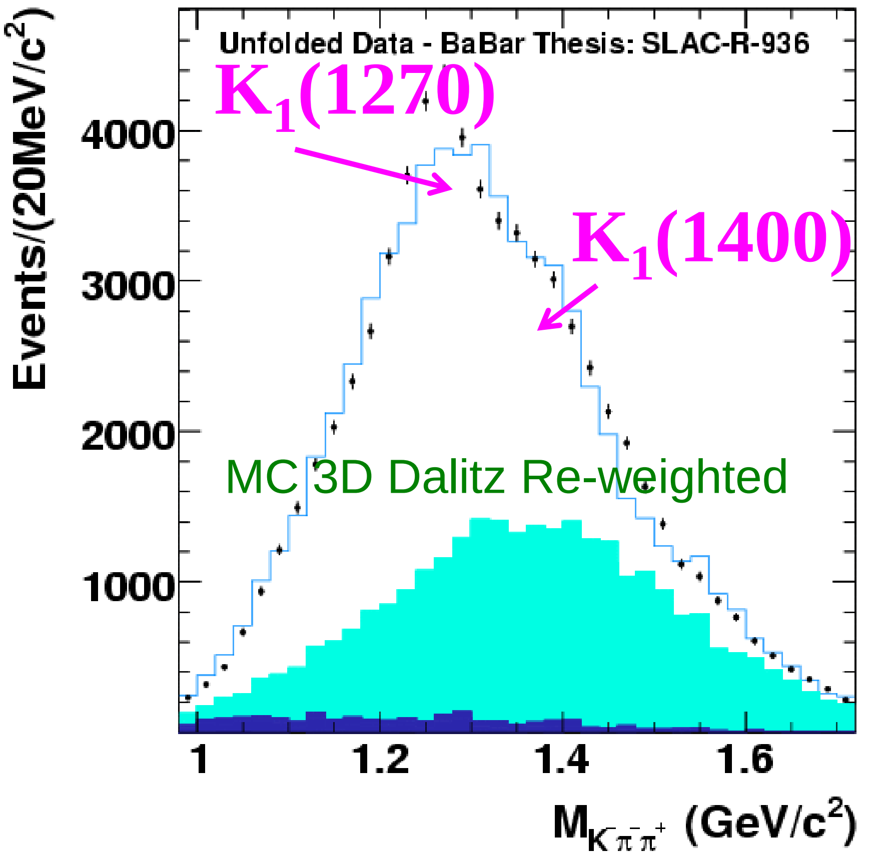
N^{Data}	$(1.5953 \pm 0.0013) \times 10^6$
N^{Bkg}	$(0.0642 \pm 0.0002) \times 10^6$

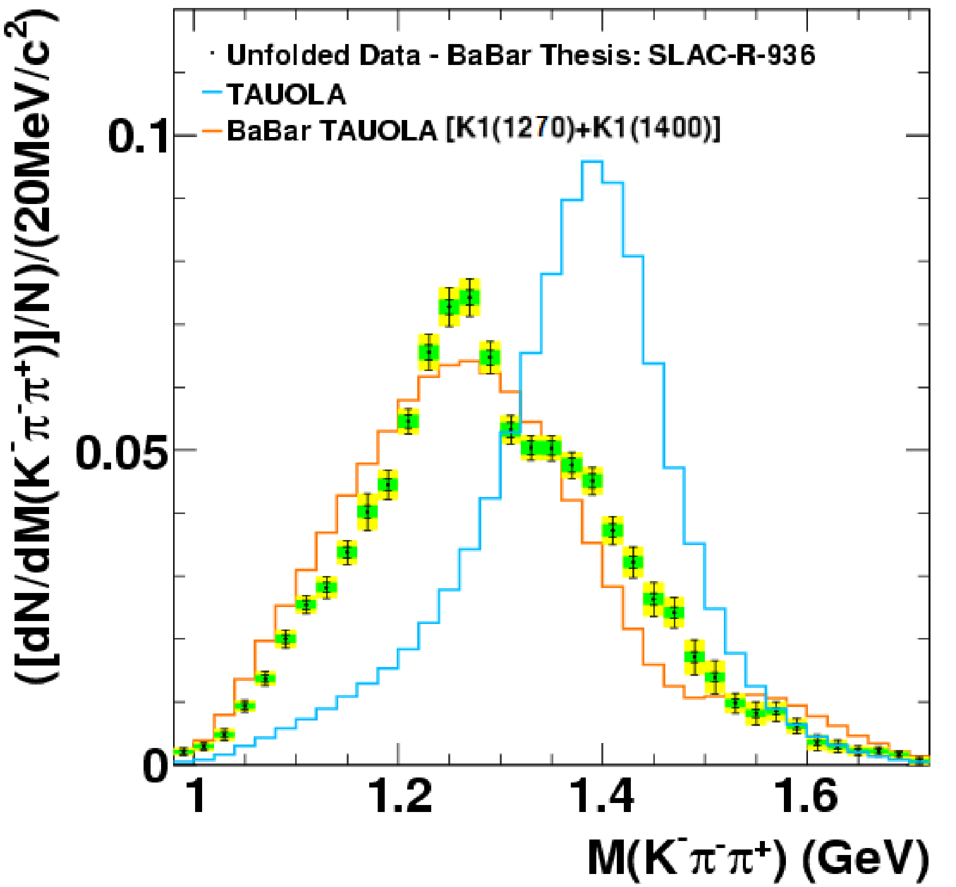
Signal　Cross Feed　Bkg

Invariant Mass Plots $\tau^- \rightarrow \pi^-\pi^-\pi^+\nu_\tau$



Invariant Mass Plots $\tau^- \to K^- \pi^- \pi^+ \nu_\tau$

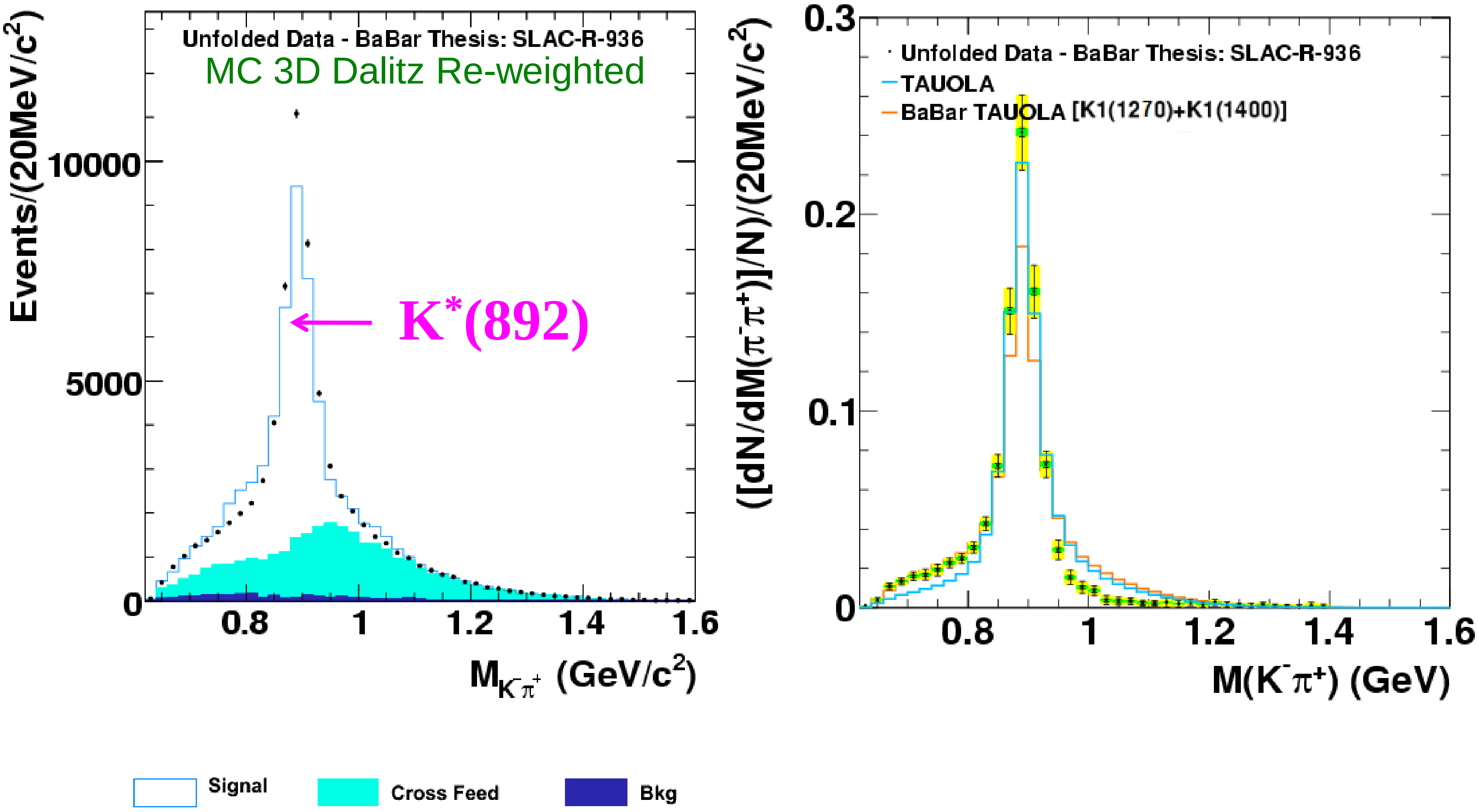




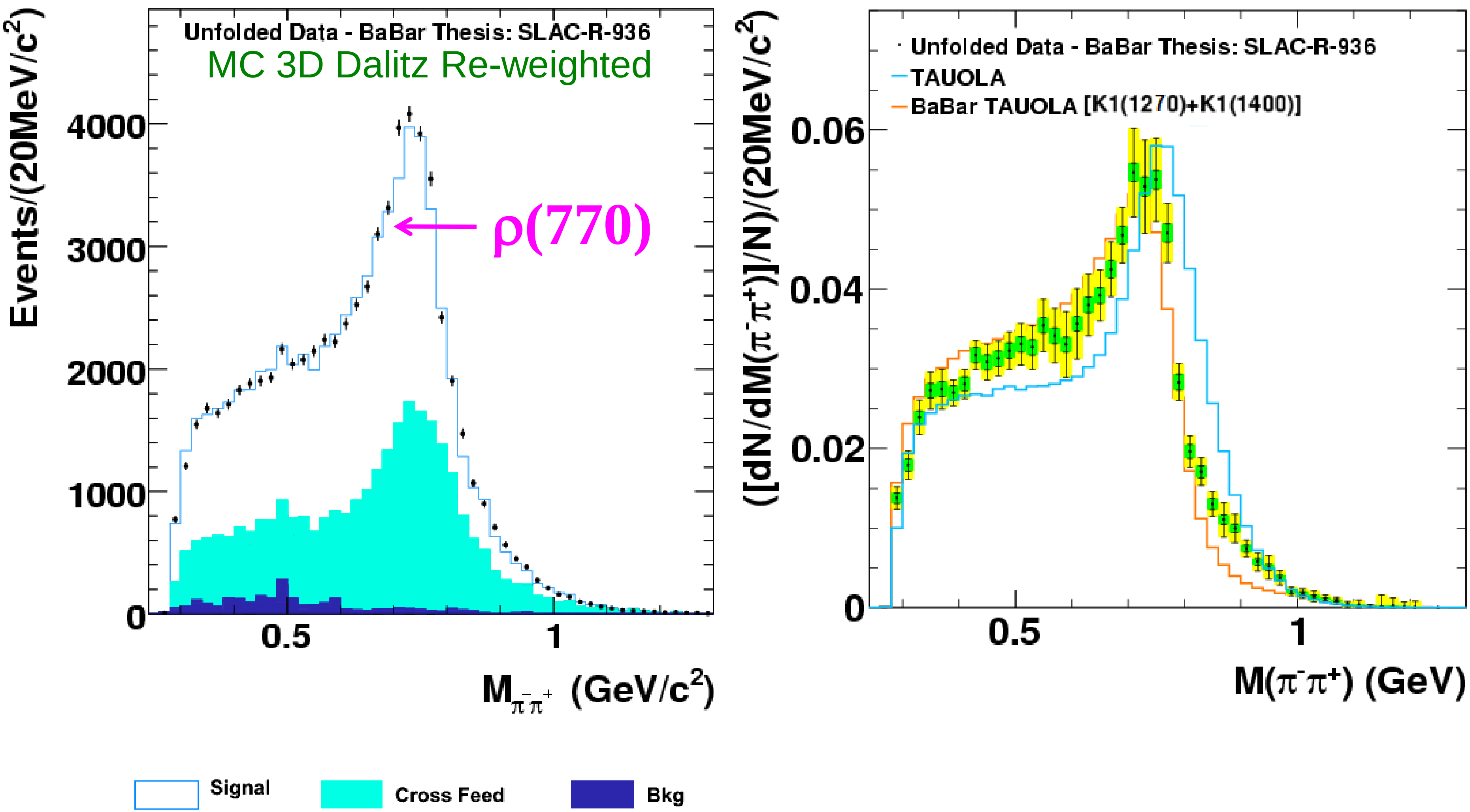
N^{Data}	$(6.956 \pm 0.0026) \times 10^4$
N^{Bkg}	$(0.2263 \pm 0.0064) \times 10^4$

Signal — Cross Feed — Bkg

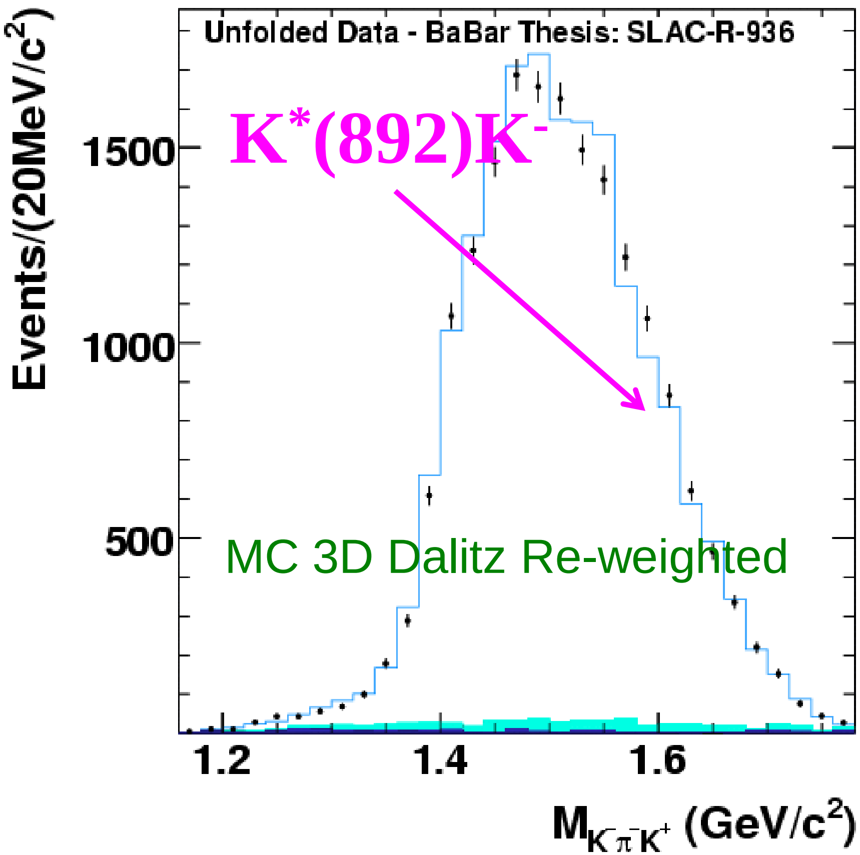
Invariant Mass Plots $\tau^- \to K^- \pi^- \pi^+ \nu_\tau$

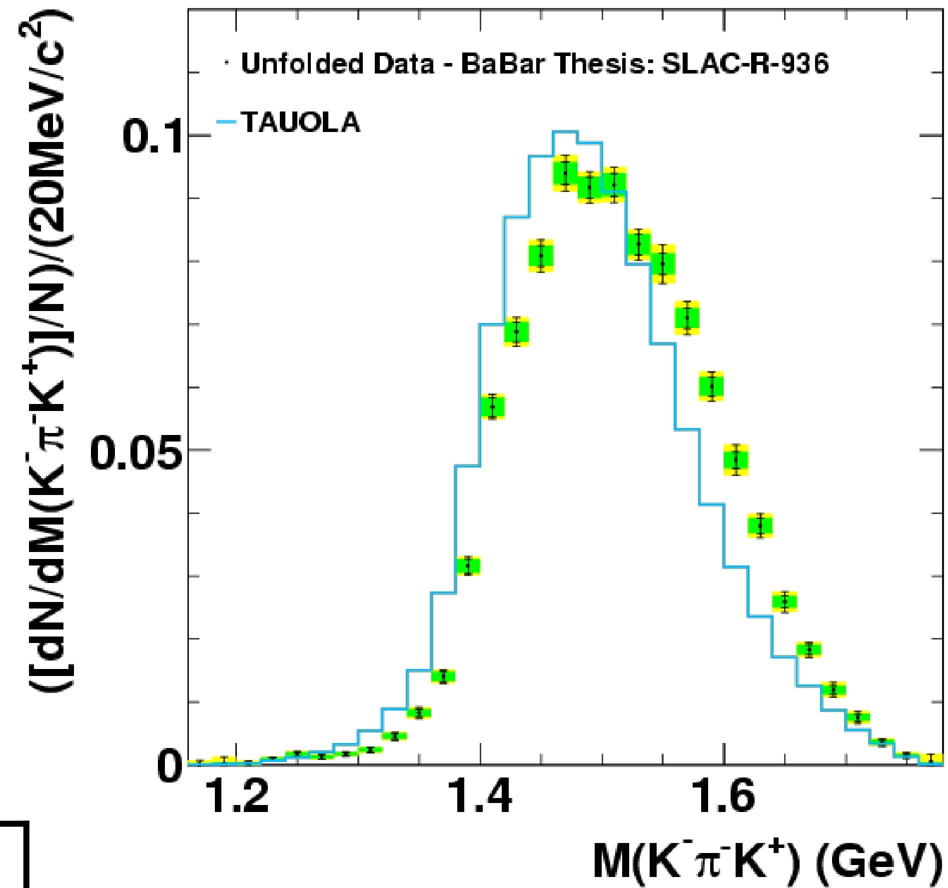


Invariant Mass Plots $\tau^- \to K^- \pi^- \pi^+ \nu_\tau$



Invariant Mass Plots $\tau^- \to K^-\pi^-K^+\nu_\tau$

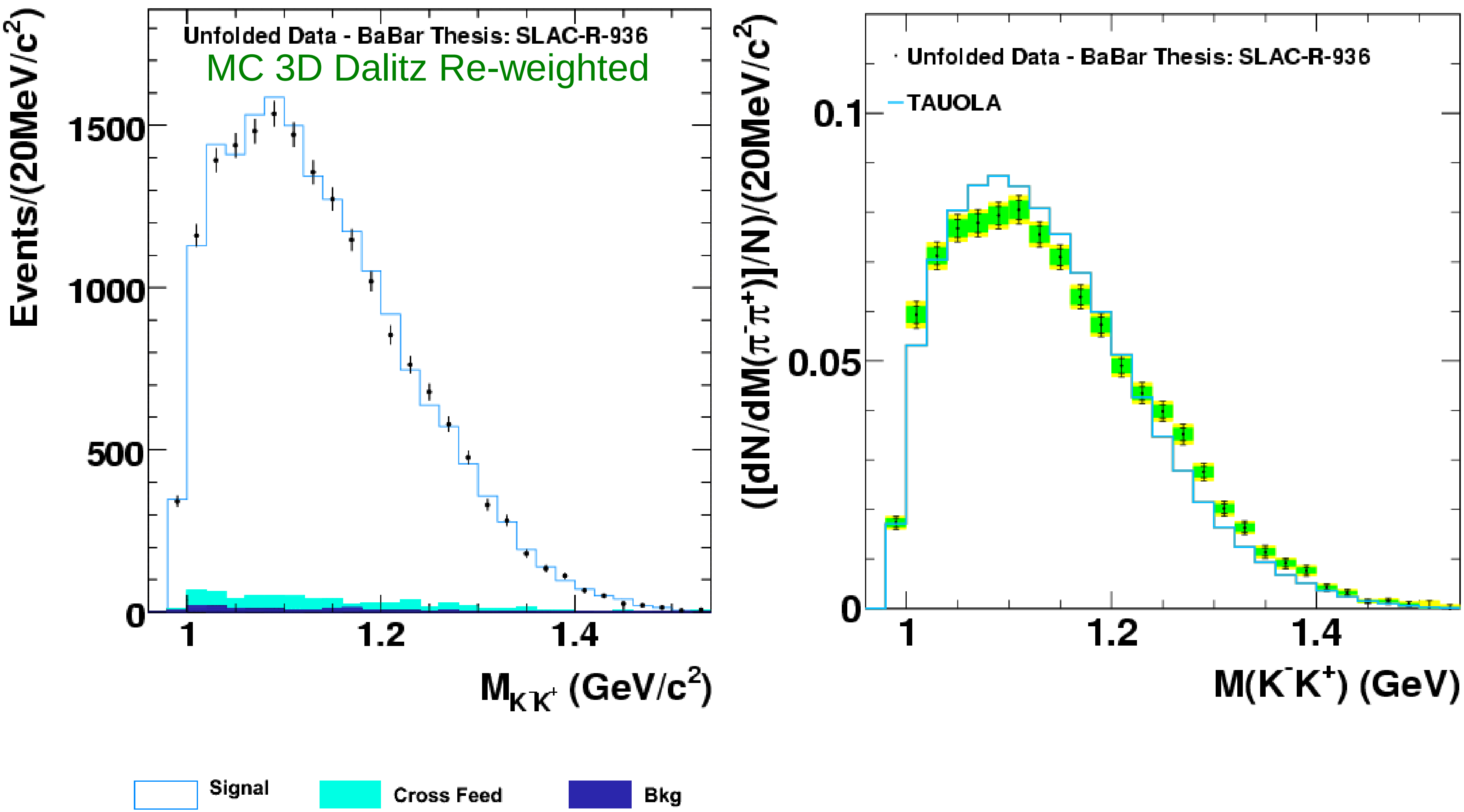




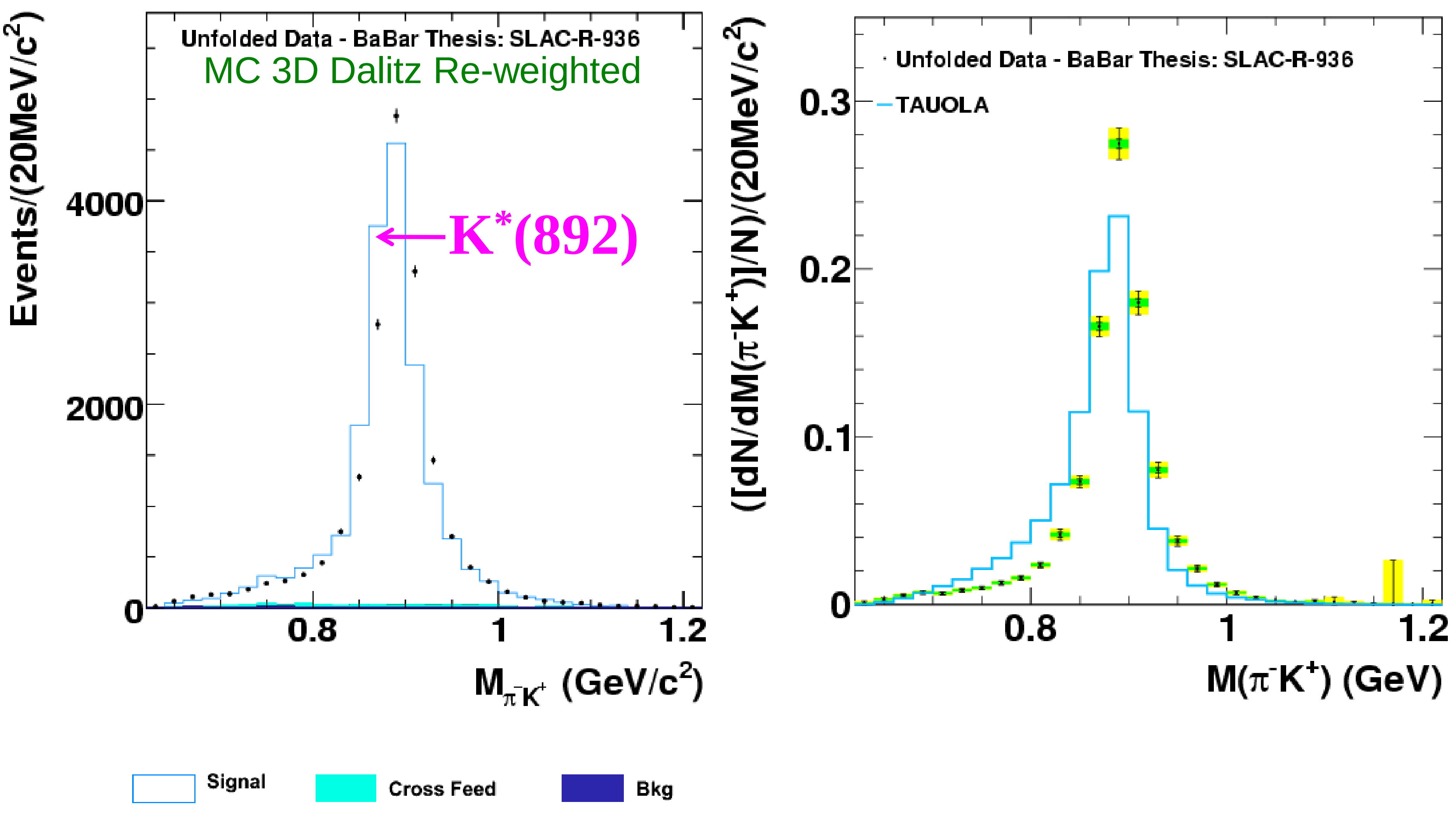
N^{Data}	$(1.819\pm0.013)\times10^4$
N^{Bkg}	$(0.0145\pm0.0008)\times10^4$

Signal Cross Feed Bkg

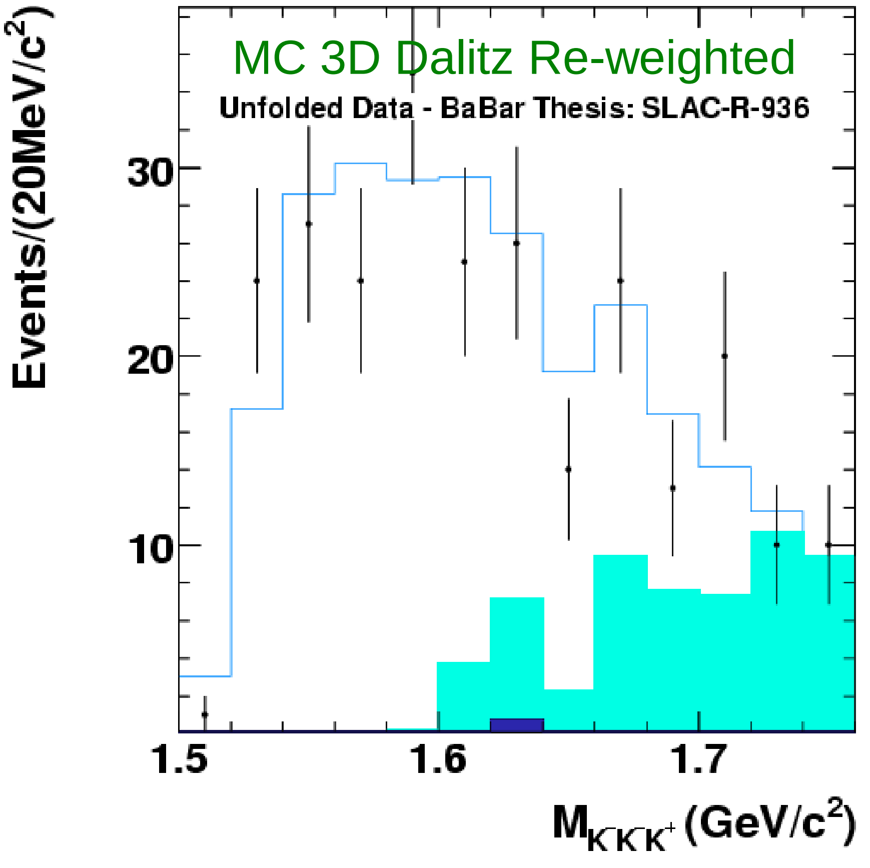
Invariant Mass Plots $\tau^- \to K^- \pi^- K^+ \nu_\tau$

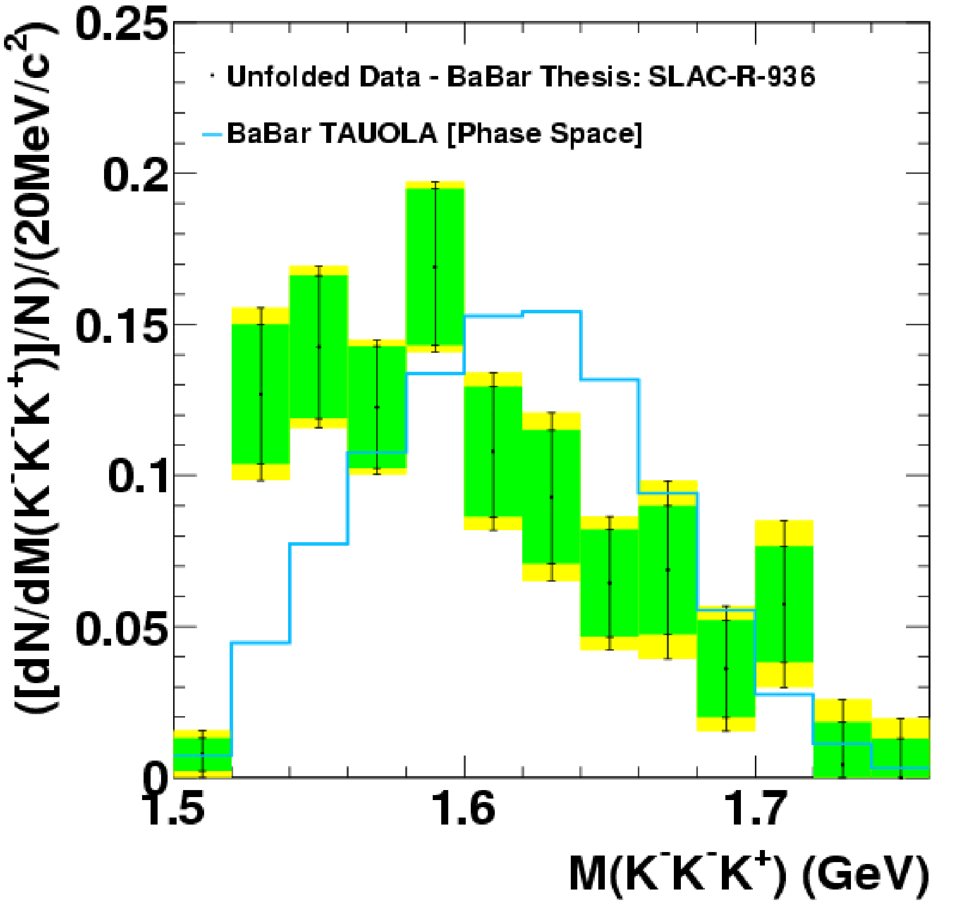


Invariant Mass Plots $\tau^- \to K^- \pi^- K^+ \nu_\tau$



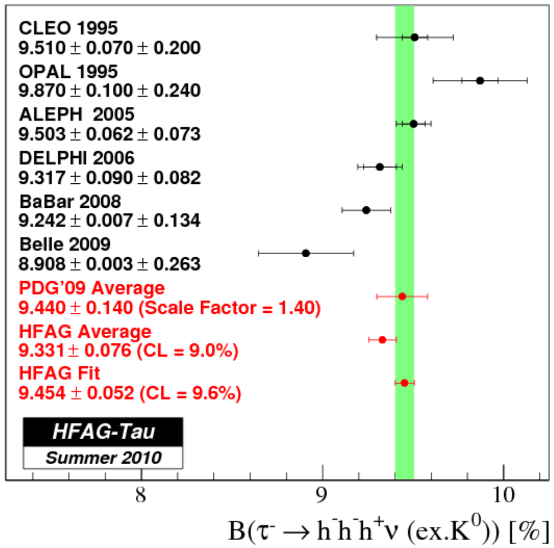
Invariant Mass Plots $\tau^- \to K^- K^- K^+ \nu_\tau$

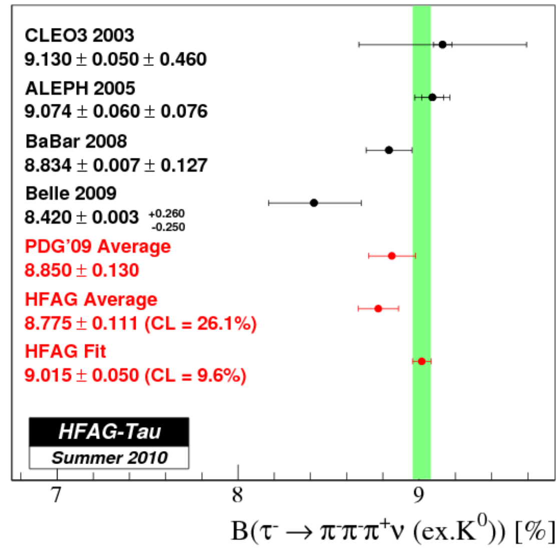


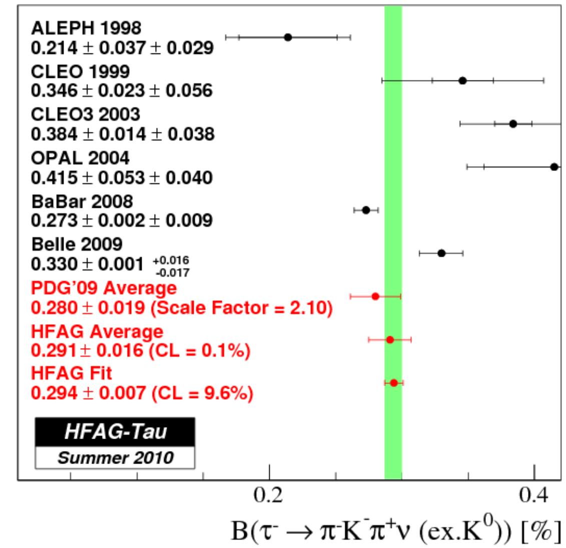


N^{Data}	275±17
N^{Bkg}	2.5±1.5

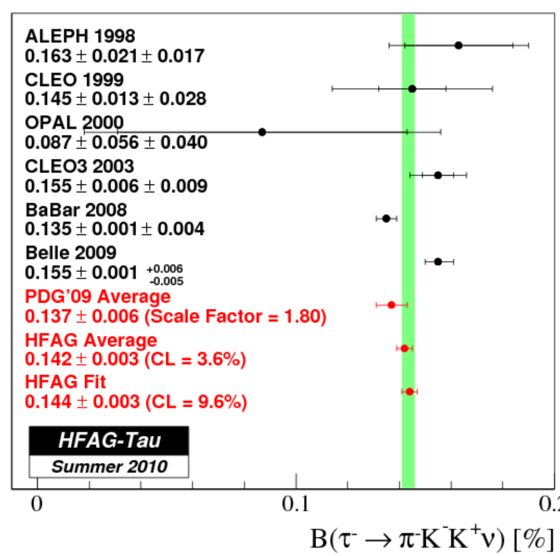
$\tau \to K^- \pi^- \pi^+ \nu$ and $\tau \to K^- K^- K^+ \nu$

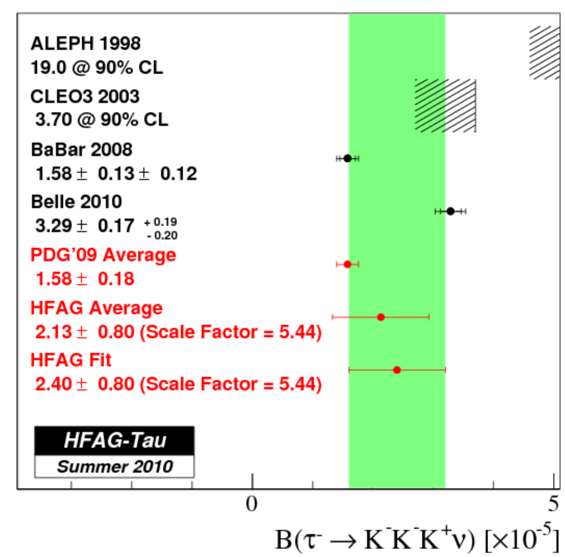




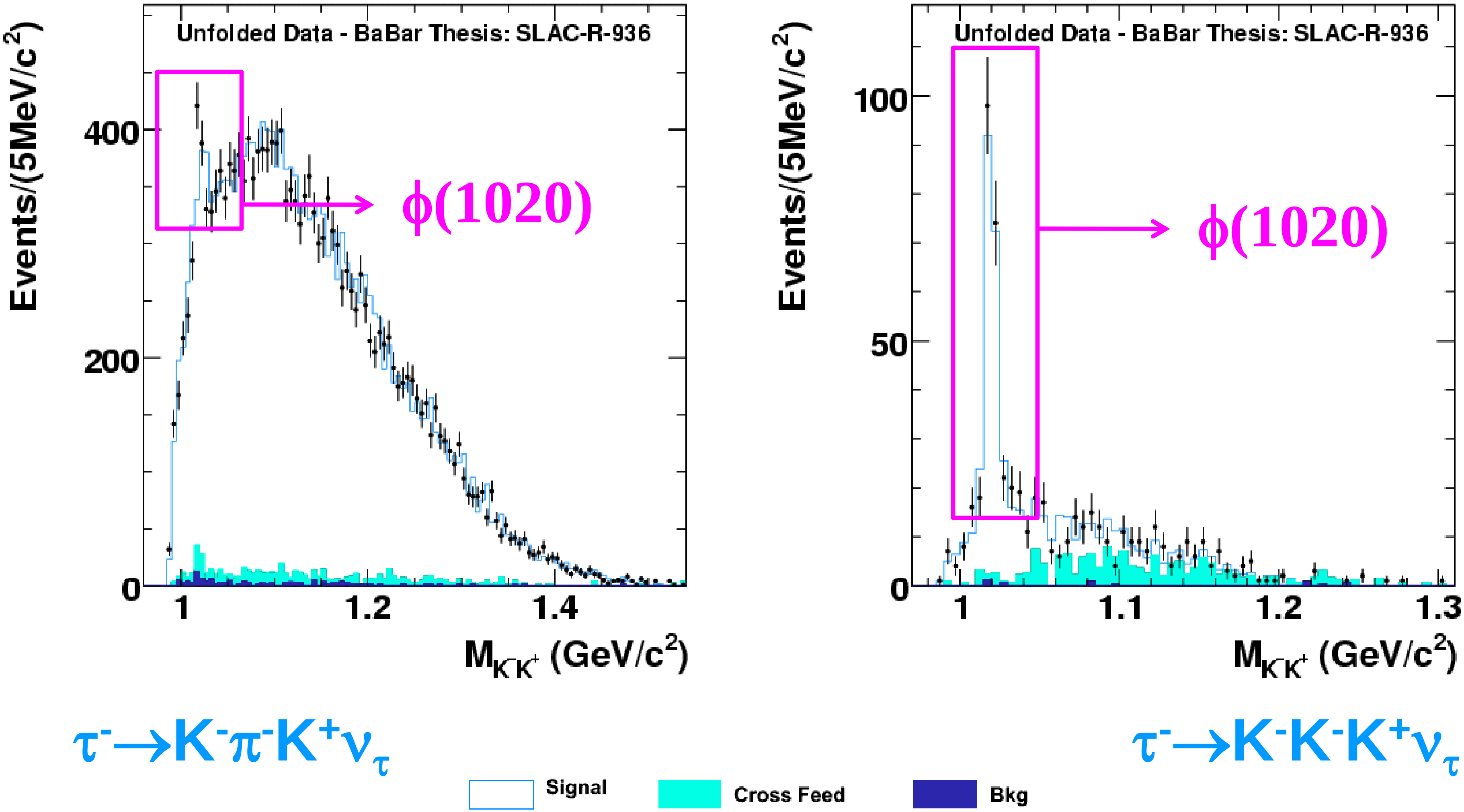


PRL100, 011801 (2008)





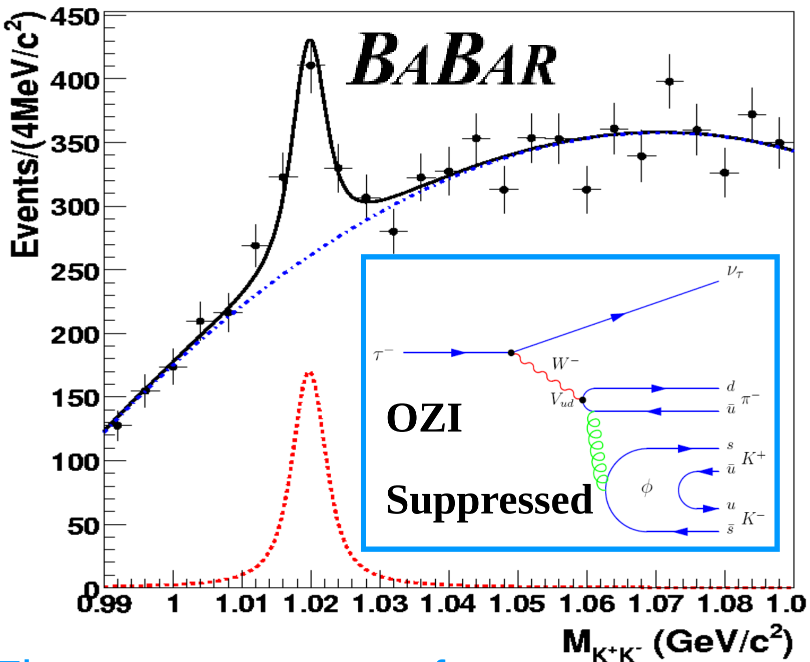
K^-K^+ Invariant Mass Plots

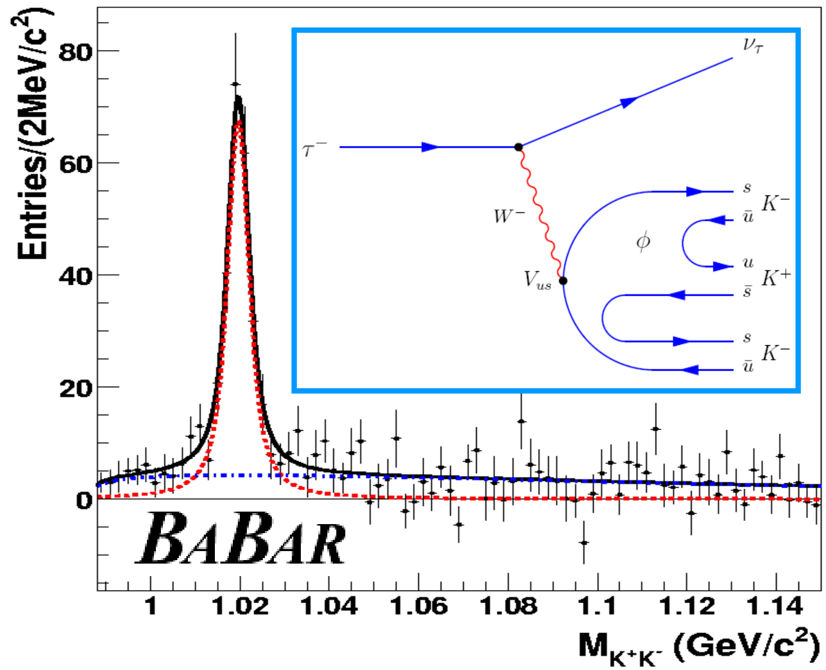


$\tau^- \to K^-\pi^-K^+\nu_\tau$

$\tau^- \to K^-K^-K^+\nu_\tau$

ϕ Peak in $K\pi K\nu_\tau$ and $KK K\nu_\tau$





First measurement of:

$B(\tau^- \to \pi^- \phi \nu) = (3.42 \pm 0.55 \pm 0.25) \times 10^{-5}$

Significance: 5.7σ

Measured:

$B(\tau^- \to K^- \phi \nu) = (3.39 \pm 0.20 \pm 0.28) \times 10^{-5}$

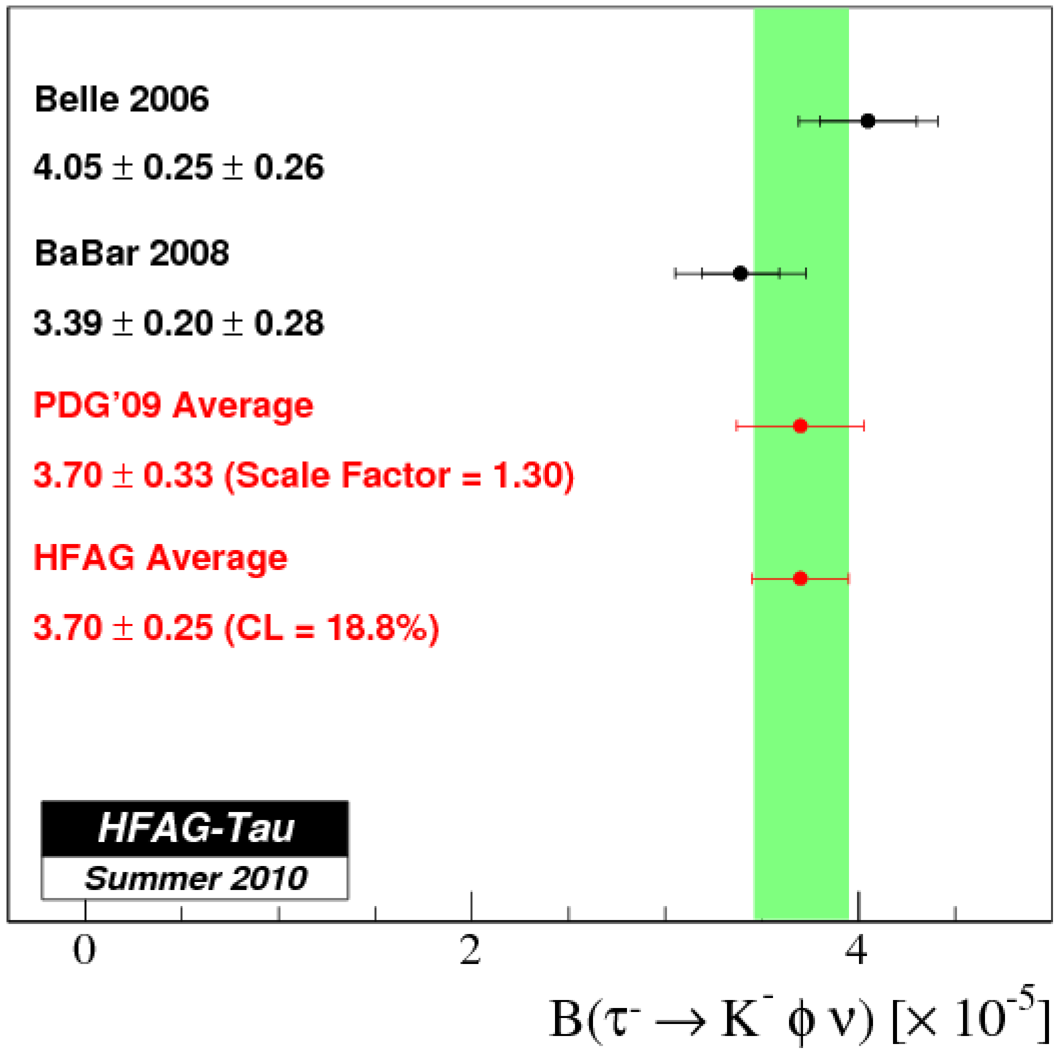
Significance : 9.9σ

$\tau^- \to \pi^- \phi \nu$ is consistent with CVC prediction from $e^+e^- \to \phi \pi^0$

M. Davier et al., hep-ph 0803.0979
B. Aubert et al., *Phys. Rev. D77:092002*, 2008

First Limit: $B(\tau^- \to K^- \phi \nu) =< (0.25) \times 10^{-5}$ @90% CL

ϕ Peak in $K\pi K\nu_\tau$ and $KKK\nu_\tau$



Confronting Theory with Experiment

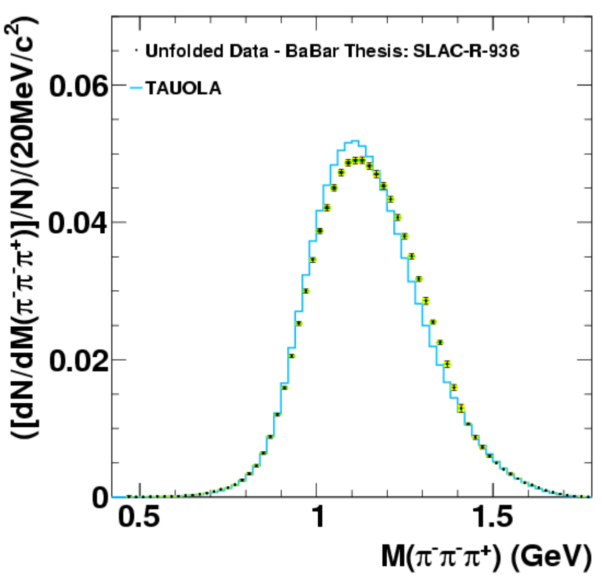
There are two general strategies available for comparing theory to experiment:

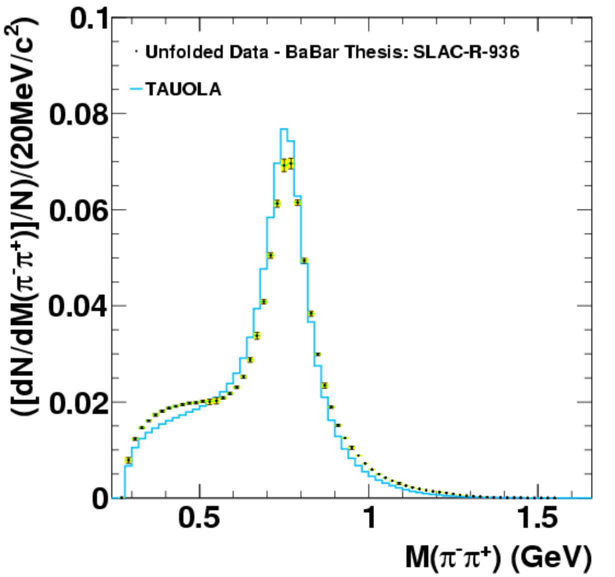
1) Full Monte Carlo Simulation [Event Simulation + Detector Simulation] to raw data

2) Compare unfolded data corrected for detector resolutions and efficiency to theory

Start with Comparison of RCHL Current to: $\tau^- \to \pi^- \pi^- \pi^+ \nu_\tau$

- Experimentally this is the cleanest and simplest mode to measure
- Excellent agreement between BaBar Thesis results and published Belle results

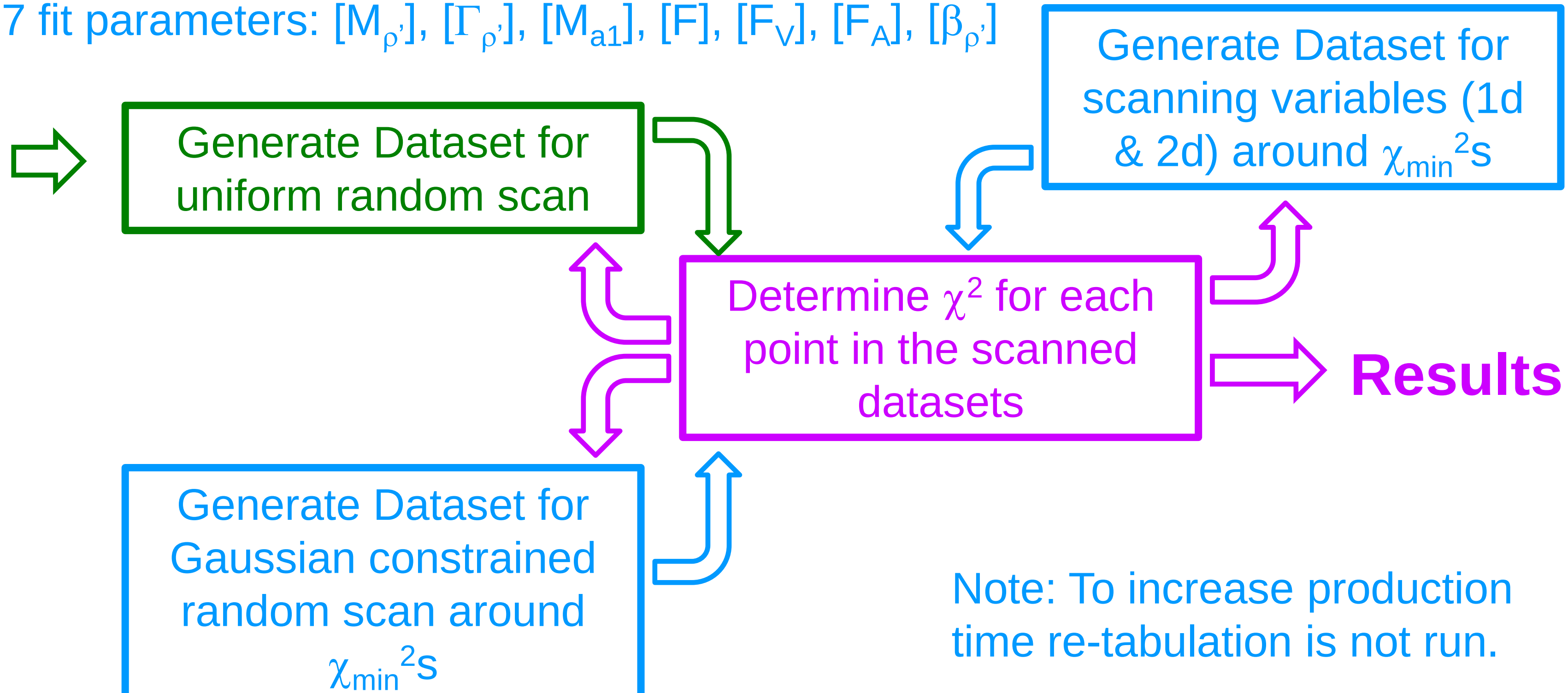




Confronting Theory with Experiment

General Strategy:

- Use Tauola++ with RCHL currents in Tauola to reweight Events Generated with Tauola++ 1.0.5
- Generated statistics size is ~3x Experimental Data set ($N_{MC}>>N_{Data}$)
- Use χ^2 fit with full covariance matrix for errors
- 7 fit parameters: [$M_{\rho'}$], [$\Gamma_{\rho'}$], [M_{a1}], [F], [F_V], [F_A], [$\beta_{\rho'}$]



Note: To increase production time re-tabulation is not run.

Fitting Parameters and RCHL Theory

Fit parameters:

[M_{a1}=MMA1], [F=FPI_RPT], [F_V=FV_RPT], [F_A=FA_RPT]

Expected to be weak: [$\beta_{\rho'}$ =BETA_RHO], [M_ρ'=MRHO1], [Γ_ρ'=GRHO1]

$$F_1^{\chi}(q^2,s_1,s_2) = -\frac{2\sqrt{2}}{3},$$

$$F_1^{\rm R}(q^2,s_1,s_2) = \frac{\sqrt{2}\,F_V\,G_V}{3\,F^2}\left[\frac{3\,s_1}{s_1-M_\rho^2-iM_\rho\Gamma_\rho(s_1)} - \left(\frac{2G_V}{F_V}-1\right)\left(\frac{2q^2-2s_1-s_3}{s_1-M_\rho^2-iM_\rho\Gamma_\rho(s_1)} + \frac{s_3-s_1}{s_2-M_\rho^2-iM_\rho\Gamma_\rho(s_2)}\right)\right]$$

$$F_1^{\rm RR}(q^2,s_1,s_2) = \frac{4\,F_A\,G_V}{3\,F^2}\,\frac{q^2}{q^2-M_A^2-iM_A\Gamma_A(q^2)}\left[-(\lambda'+\lambda'')\frac{3\,s_1}{s_1-M_\rho^2-iM_\rho\Gamma_\rho(s_1)} + H\left(\frac{s_1}{q^2},\frac{m_\pi^2}{q^2}\right)\frac{2q^2+s_1-s_3}{s_1-M_\rho^2-iM_\rho\Gamma_\rho(s_1)} + H\left(\frac{s_2}{q^2},\frac{m_\pi^2}{q^2}\right)\frac{s_3-s_1}{s_2-M_\rho^2-iM_\rho\Gamma_\rho(s_2)}\right]$$

$$F_2(q^2,s_2,s_1) = F_1(q^2,s_1,s_2)$$

$$F_4^{\chi}(q^2,s_1,s_2) = \frac{2\sqrt{2}}{3}\,\frac{m_\pi^2[3(s_3-m_\pi^2)-q^2(1+2\kappa R^{3\pi})]}{2q^2(q^2-m_\pi^2)}$$

$$F_4^{\rm R}(q^2,s_1,s_2) = -\frac{\sqrt{2}\,F_V\,G_V}{3\,F^2}\left[\alpha_2(q^2,s_2,s_1)+\alpha_2(q^2,s_1,s_2)\right]$$

$\kappa = 1$ for $\tau^-\to\pi^-\pi^-\pi^+\nu_\tau$

$$\alpha_2(q^2,s_1,s_2) = \frac{3G_V}{F_V}\,\frac{s_1}{q^2}\,\frac{m_\pi^2}{q^2-m_\pi^2}\,\frac{s_3-s_2}{s_1-M_\rho^2-iM_\rho\Gamma_\rho(s_1)}$$

$$G_V = F^2/F_V$$

$$H(x,y) = -\lambda_0\,y + \lambda'\,x + \lambda''$$

$$\lambda' = \frac{F^2}{2\sqrt{2}F_AG_V}$$

$$\lambda'' = -\left(1-2\frac{G_V^2}{F^2}\right)\lambda'$$

$$4\lambda_0 = \lambda'+\lambda''$$

$$\frac{1}{M_\rho^2-q^2-iM_\rho\Gamma_\rho(q^2)} \longrightarrow \frac{1}{1+\beta_{\rho'}}\left[\frac{1}{M_\rho^2-q^2-iM_\rho\Gamma_\rho(q^2)} + \frac{\beta_{\rho'}}{M_{\rho'}^2-q^2-iM_{\rho'}\Gamma_{\rho'}(q^2)}\right]$$

Current Best Fit

The current best fit values is presented below…

Fit Parameters							
	$M_{\rho'}$	$\Gamma_{\rho'}$	M_{a1}	F	F_V	F_A	$\beta_{\rho'}$
Min.	1.44	0.32	1.00	0.0920	0.12	0.10	-0.36
Max.	1.48	0.39	1.24	0.0924	0.24	0.20	-0.18
Default	1.453	0.40	1.12	0.0924	0.18	0.149	-0.25
Fit	1.4302	0.376061	1.21706	0.092318	0.121938	0.11291	-0.208811

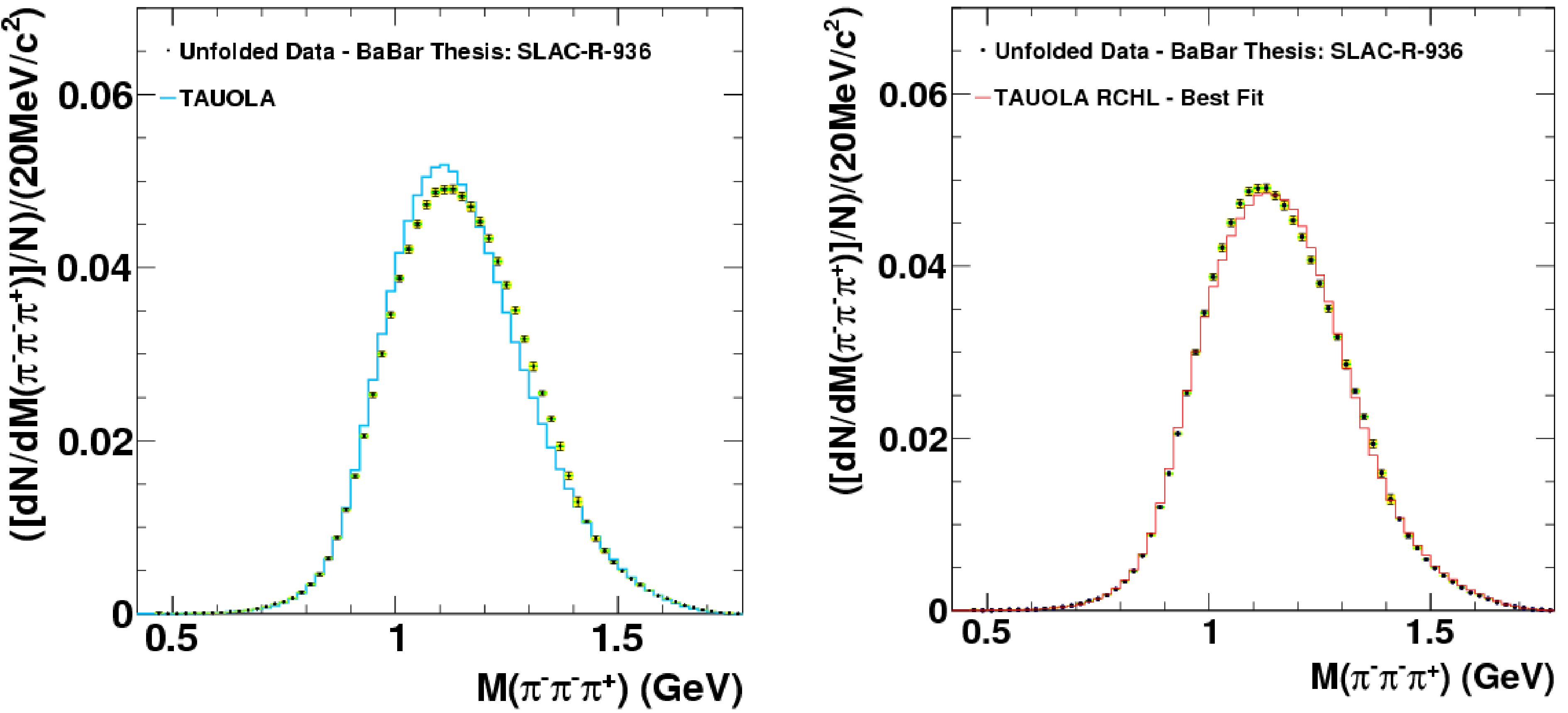
χ^2= 2262.12

ndf=132

Note:

- The fit is a work in progress – not necessarily the minimum
- Reliable errors estimates are not available yet

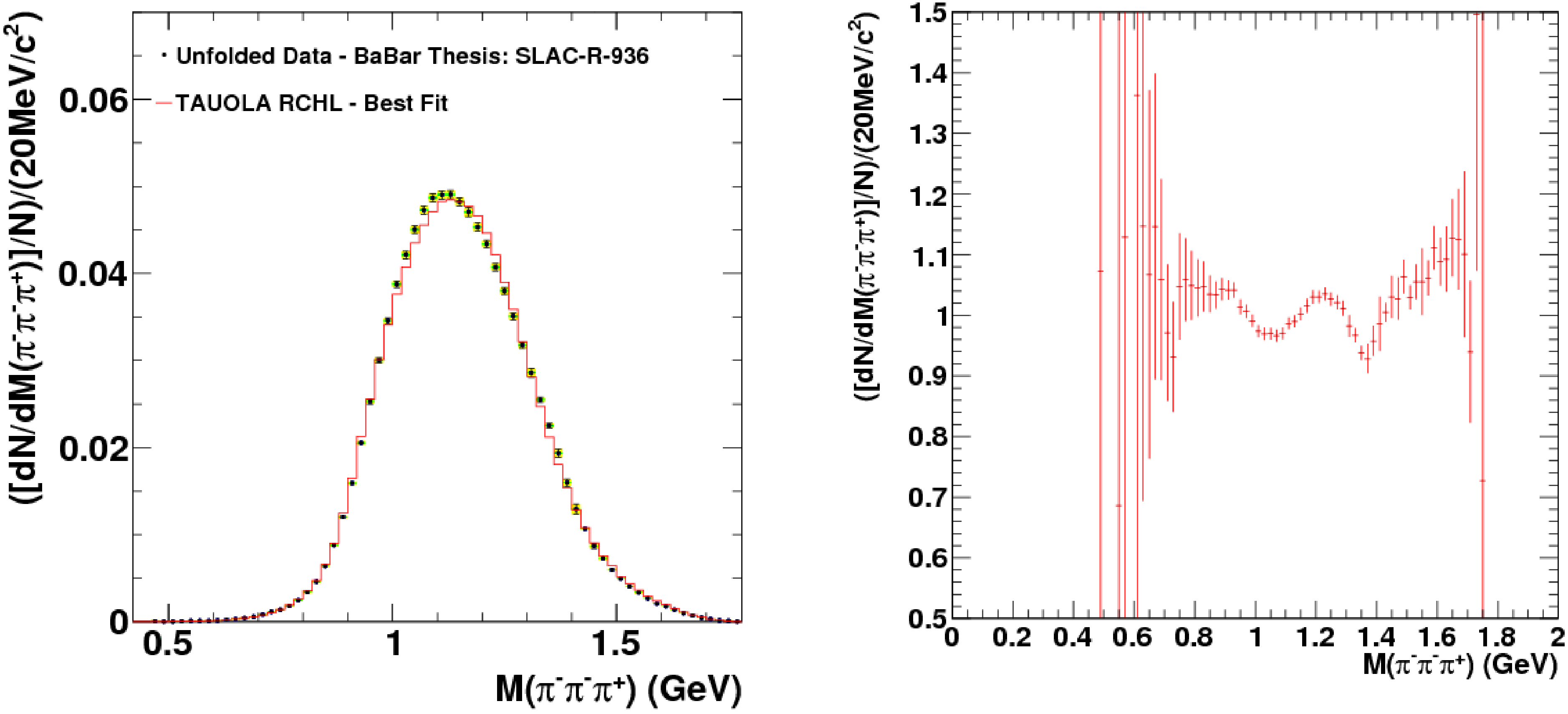
Comparison of Data to Best Fit



For the $\pi^- \pi^- \pi^+$ invariant mass:

- RCHL Current is in better agreement then Tauola 1.05
- a_1(1260) mass is lower but there is still some disagreement (FSR?)

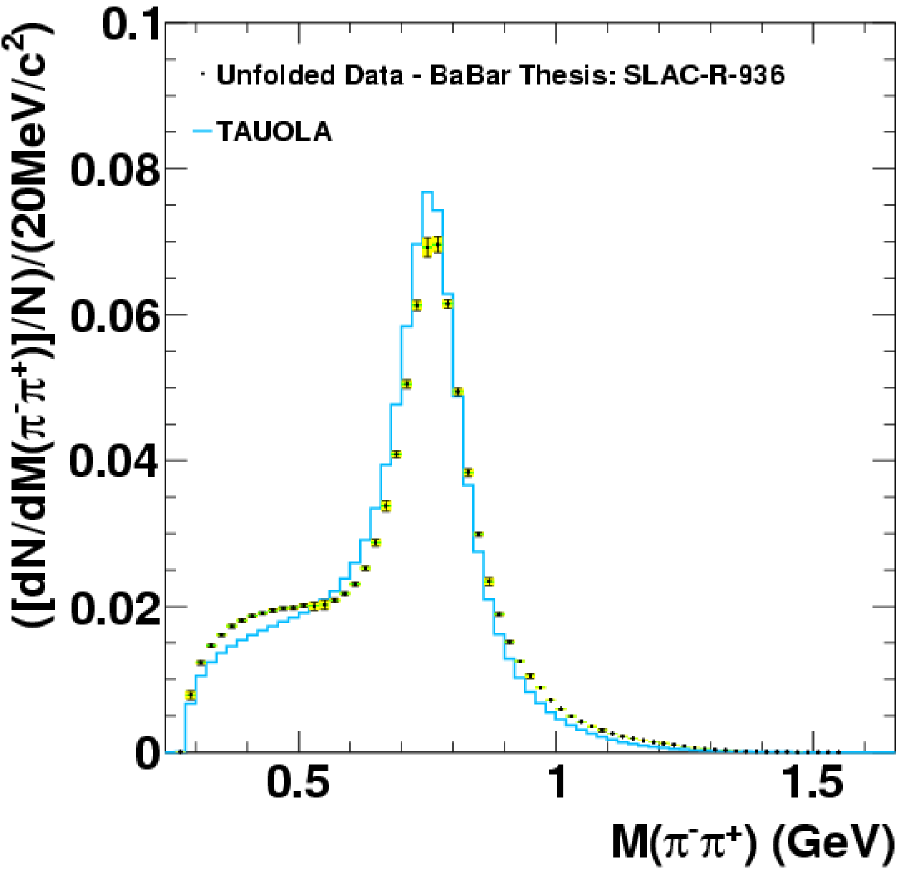
Comparison of Data to Best Fit

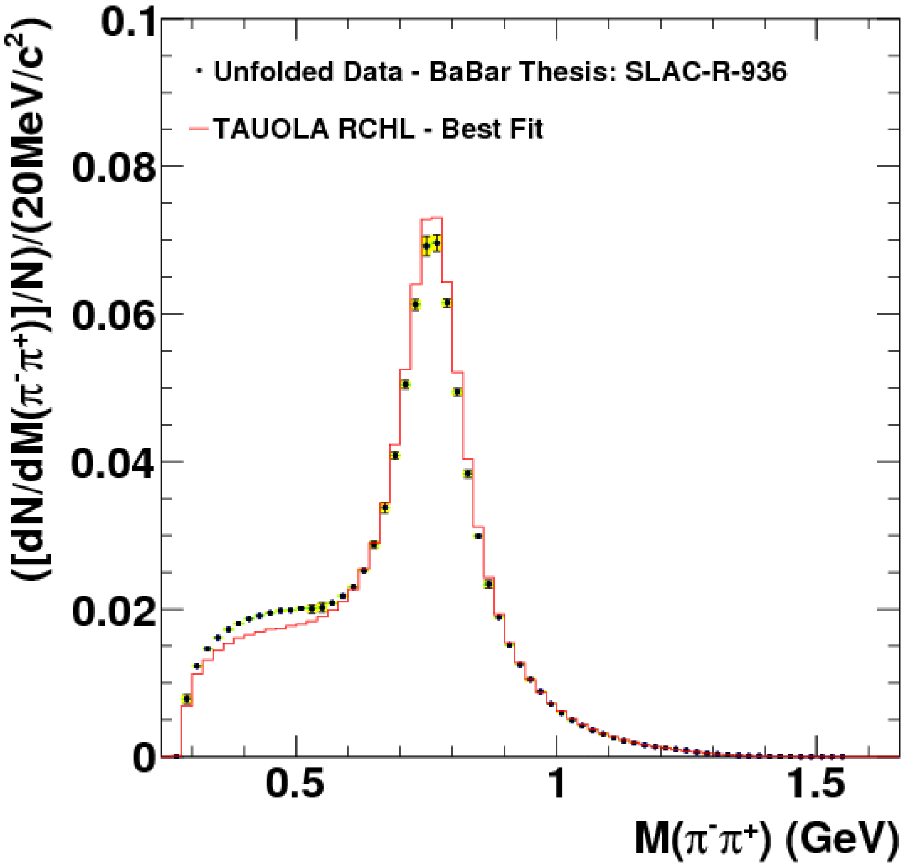


For the $\pi^- \pi^- \pi^+$ invariant mass:

- RCHL Current is better then 7% for $\pi^-\pi^-\pi^+$ mass

Comparison of Data to Best Fit

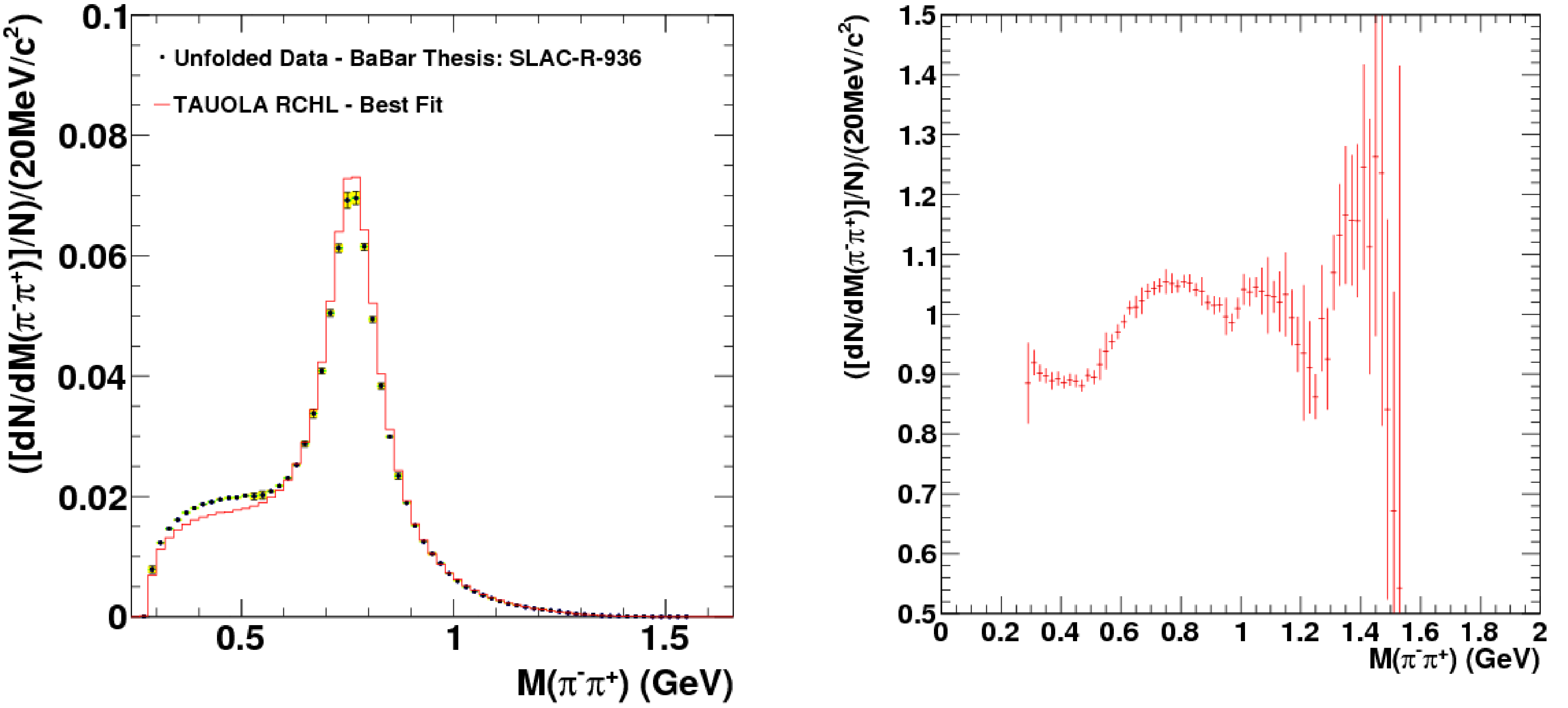




For the $\pi^-\pi^+$ invariant mass:

- RCHL Current is in better agreement then Tauola 1.05
- Disagreement is visible in the low mass region – however fitting is not complete

Comparison of Data to Best Fit



For the $\pi^-\pi^+$ invariant mass:

- RCHL Current is better then 12% for $\pi^-\pi^+$ mass

Outlook…

Fitting of the RCHL Currents to the $\tau^- \to \pi^- \pi^- \pi^+ \nu_\tau$ BaBar Thesis Data has begun.

Minimization is already providing results better then current Tauola Tune

Fit procedure could be optimized with input from Theorists

- Fit strategy – ie reduce number of variable in initial fit
- Dependence on re-tabulation of tables has not been started
- Theoretical constraints on fit parameters?
- Missing Physics in Model? Radiation (FSR)?
- Phase space contribution to $a_1(1260)$ decay? σ resonance contribution?

Dependency of parameter on other decay modes

- $\tau^- \to K^- \pi^- \pi^+ \nu_\tau$, $\tau^- \to K^- \pi^- K^+ \nu_\tau$, $\tau^- \to K^- K^- K^+ \nu_\tau$