Modeling Tau Decays for the Energy and Luminosity Frontiers.

CAP Congress 2014
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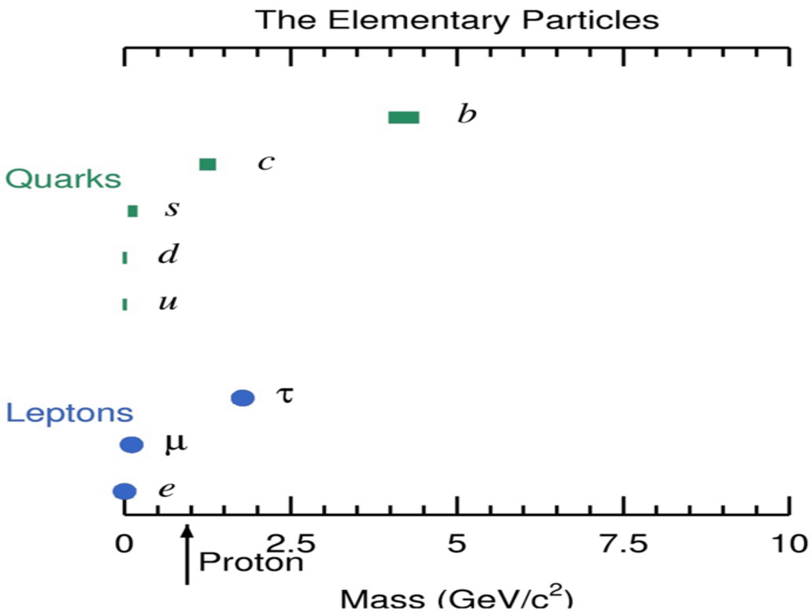
Outline

Introduction



Physics at the LHC:

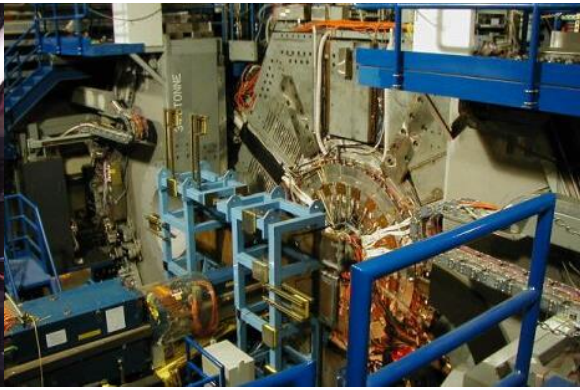
- Study electro-weak physics
  - → SM Measurements: $W \rightarrow \tau\nu$, $Z \rightarrow \tau\tau$
  - → Higgs $\rightarrow \tau\tau$
- Search for new physics:
  - → Susy
  - → Lepto-quarks
  - → Charged Higgs Doublet

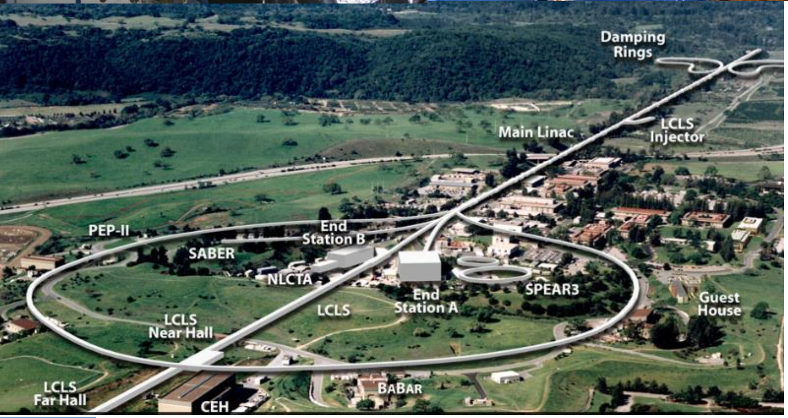
τ are the heaviest of the leptons and provide unique oppertunities

Physic at B-Factories:

- Searches for new Physics
  - → Lepton Flavour Violations
  - → CP Violation
- Study electro-weak physics
  - → Electro-weak couplings: $|V_{us}|/g_e/g_\mu/g_\tau$
  - → Michel Parameters
  - → τ EDM
- Low energy QCD
  - → $\alpha(s)$ strong
  - → g-2 measurements
  - → Second Class Currents
  - → Resonances structure
  - → $K_1(1280)$ and $K_1(1400)$ mixing
- τ properties
  - → mass, life-time, ...

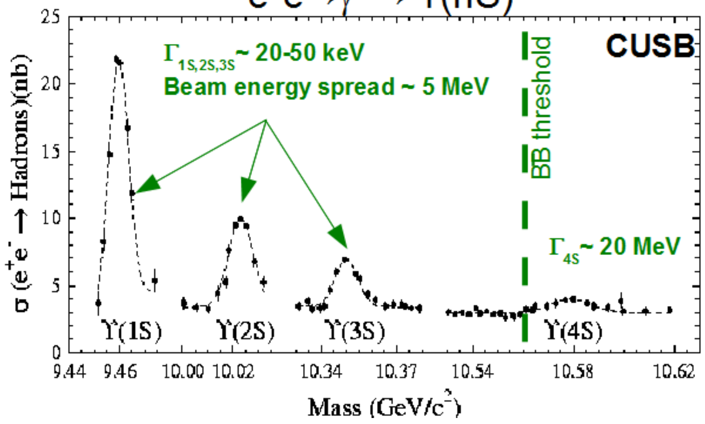
SLAC and BaBar





The BaBar Detector is located on the PEP II, an e^+e^- collider, at SLAC. Collected data from 1999-2008.

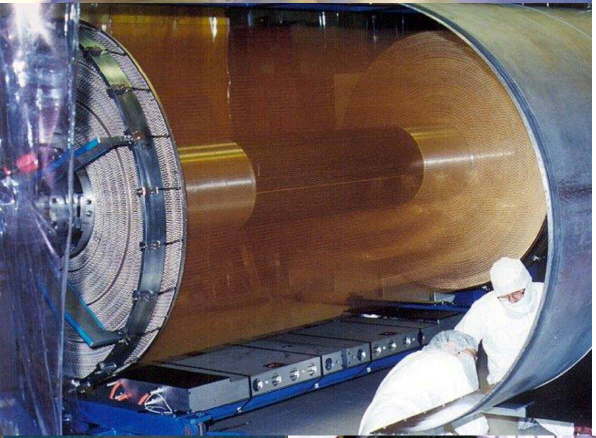
$e^+e^- \to \gamma^* \to \Upsilon(nS)$

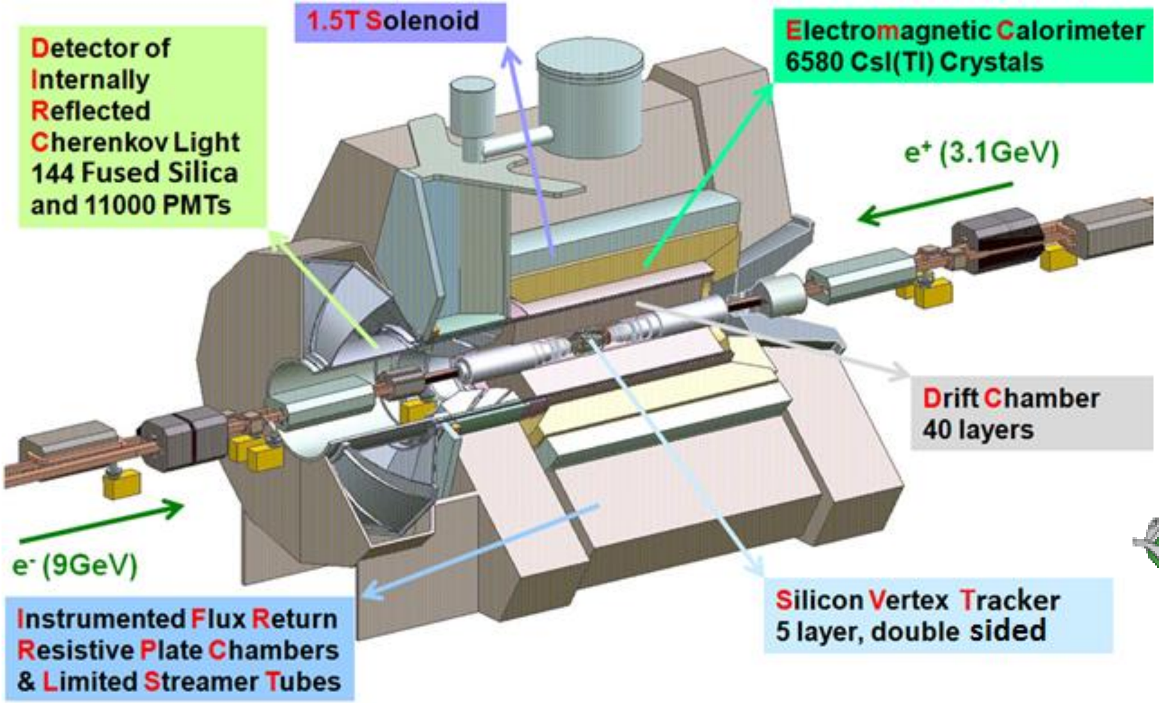


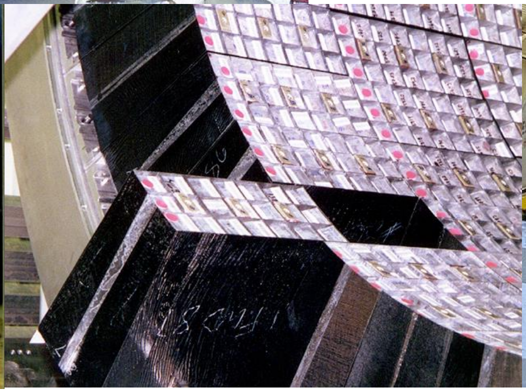
BABAR collected about 531 fb^{-1} of data

~470 x 10^6 events Υ(4S)
~120 x 10^6 events Υ(3S) (10x Belle)
~100 x 10^6 events Υ(2S) (10x CLEO)
~ 18 x 10^6 events Υ(1S) from $\Upsilon(2S) \to \pi^+\pi^- \Upsilon(1S)$

BaBar Detector







Extracting $|V_{us}|$ in τ Decays

Branching Ratio

Theory Uncertainty: 0.5%

$$\frac{B(\tau^- \to K^- \nu_\tau)}{B(\tau^- \to \pi^- \nu_\tau)} = \frac{f_K^2 |V_{us}|^2}{f_\pi^2 |V_{ud}|^2} \frac{(1 - m_K^2 / m_\tau^2)^2}{(1 - m_\pi^2 / m_\tau^2)^2}$$

Branching Fraction

Theory Uncertainty: 0.7%

$$B(\tau \to K\upsilon) = \frac{G^2 \tau_\tau m_\tau^3 f_K^2 S_{EW} |V_{us}|^2}{16\pi\hbar} (1 - m_K^2 / m_\tau^2)^2$$

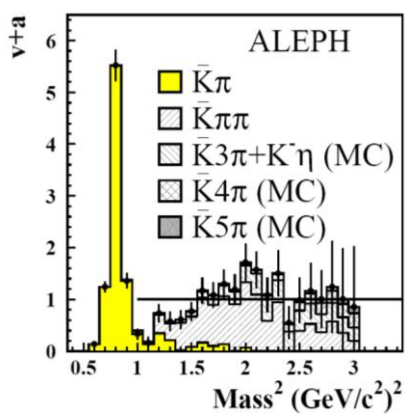
Finite Energy Sum Rules

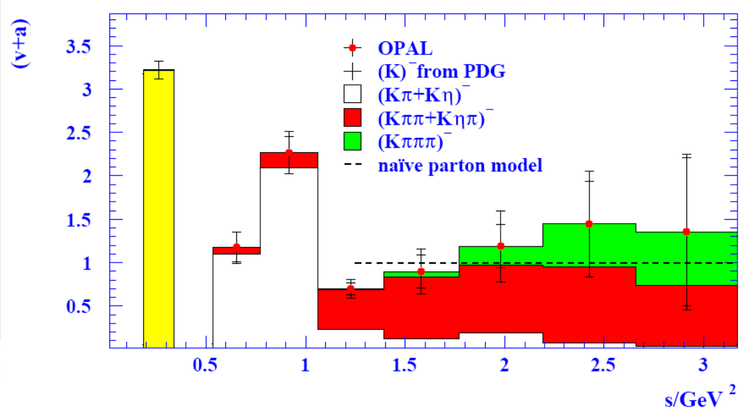
Theory Uncertainty: 0.2-0.5%

$$|V_{us}|^2 = \frac{R^w_{\tau,strange}}{R^w_{\tau,non-strange} / |V_{ud}|^2 - \delta R^w_\tau}$$

Requires SDF for Finite Energy Sum Rules:

- Branching fraction for all τ decay modes
- Invariant mass for all measured τ decay modes
- Upper limit on all unobserved τ decay modes

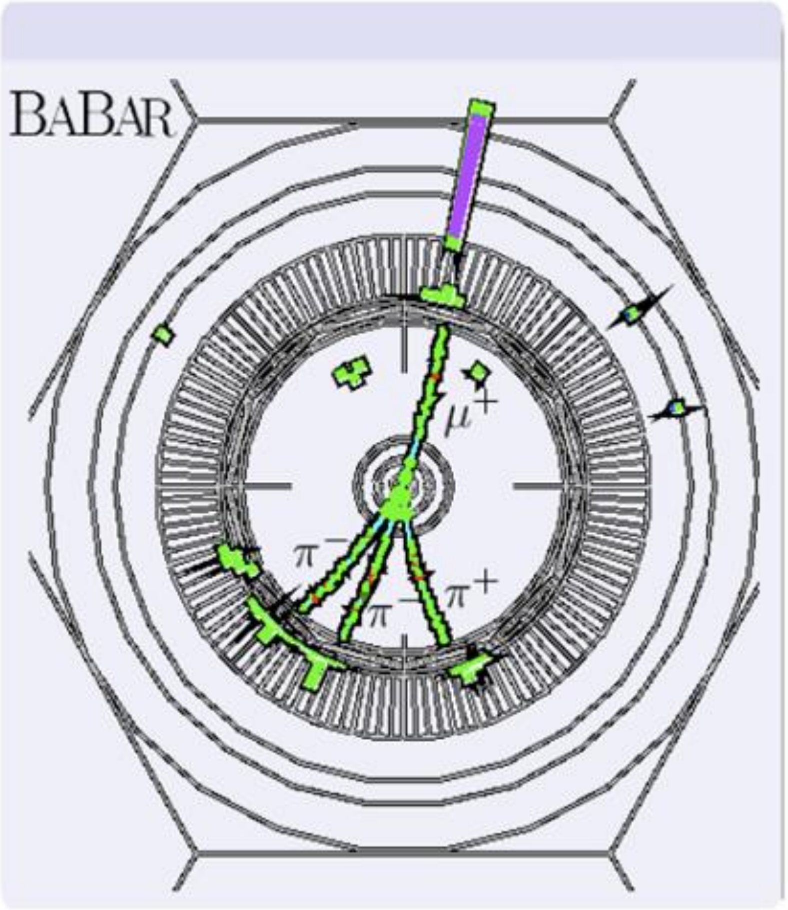




τ at the B-Factories

τ-Pair Signature:

Leptonic vs Hadronic Decay

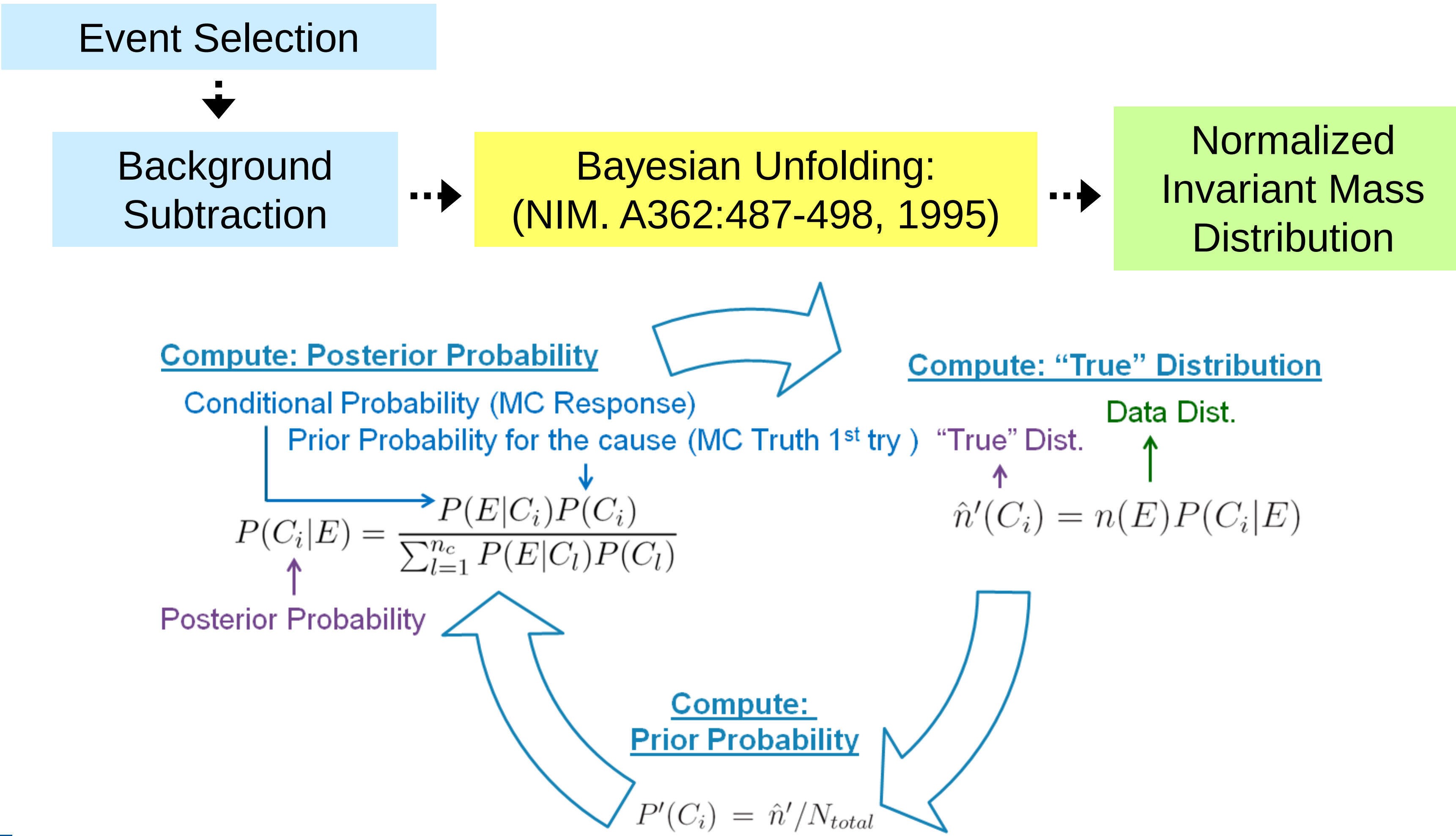


Backgrounds	Discriminants
Bhabha, μ-pair	Lepton Momentum Multiplicity Conversion veto $\cos(\theta)$
Two-Photon	Missing Transverse Momentum Missing Mass $\cos(\theta^{Miss})$ Thrust Total Reconstructed Energy
$e^+e^- \rightarrow \bar{q}q$ q=u,d,s,c,b	Thrust Invariant mass Multiplicity

Once the τ-pairs are identified, selection criteria are applied to the signal hemisphere:
-K/π separation
-Neutral Identification: π^0,η,γ

Unfolding Procedure

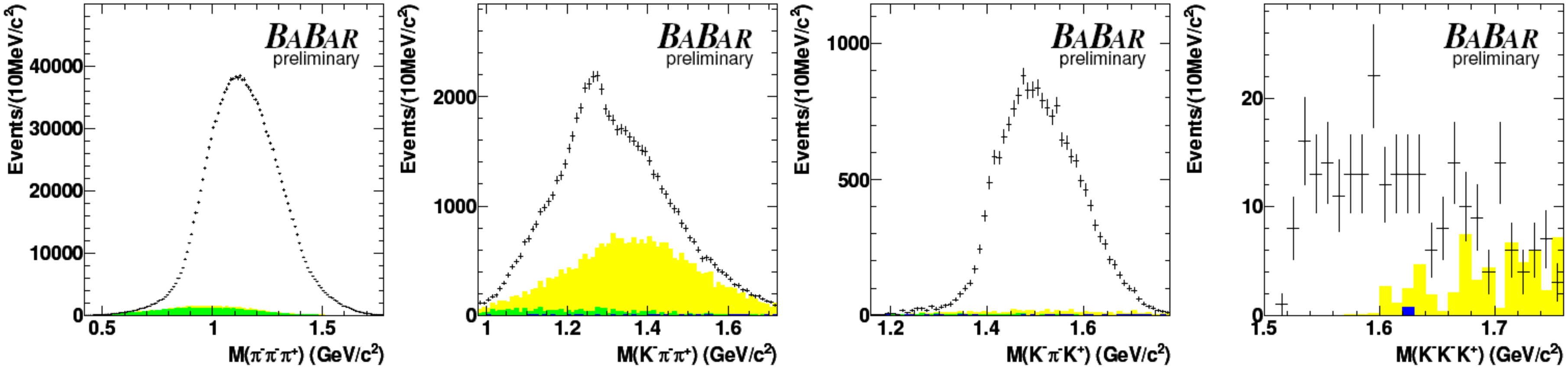
Distributions are unfolded to remove detector scale and resolution effect and are efficiency corrected to obtain the true distribution…



Hadronic Structure of $\tau\rightarrow hhh\nu$

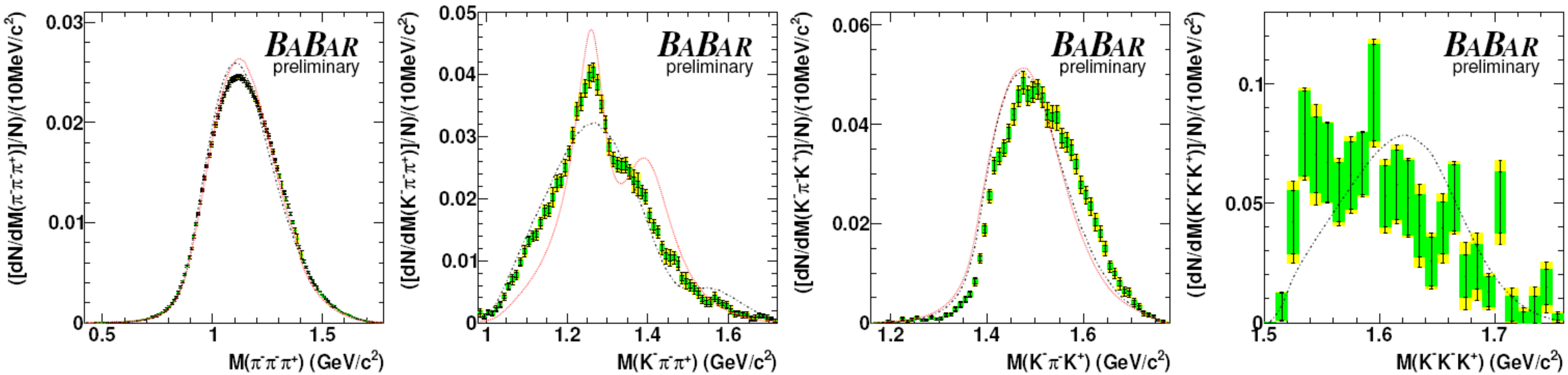
BaBar-Preliminary [arXiv:1301.7105]

Cross-Feed   Other τ-Bkg   Other Bkg



CLEO Tauola Tune'98   BaBar Tauola MC

Stat.Error (Data)   Stat.⊕Sys. Error (Data)



Hadronic Structure of $\tau \rightarrow hhh\nu$

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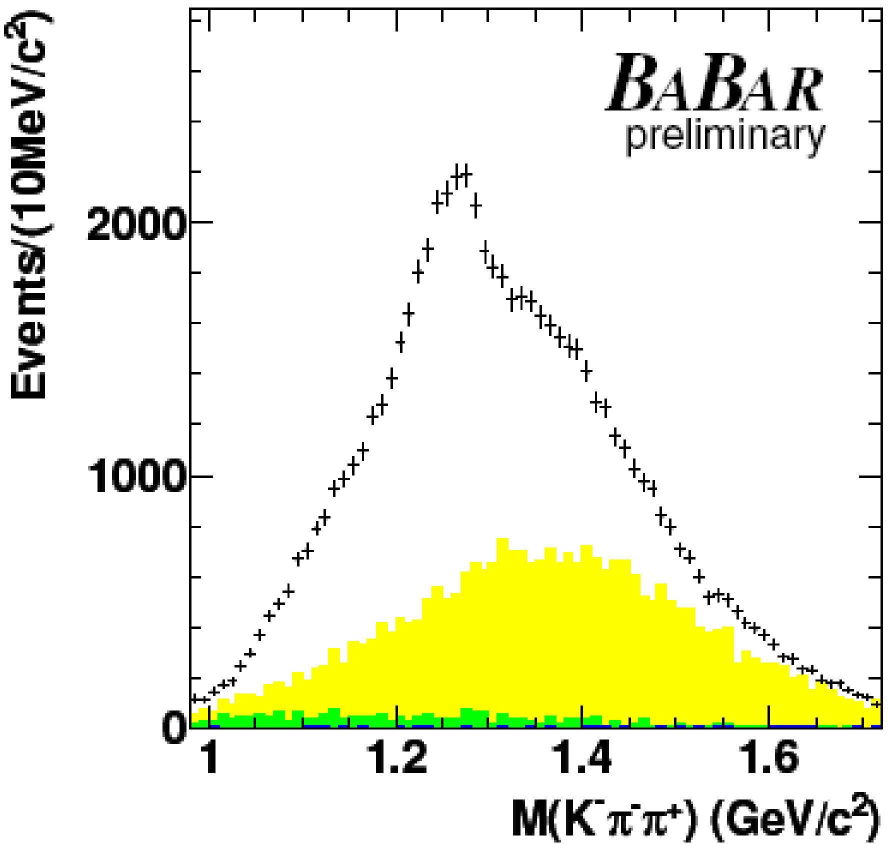
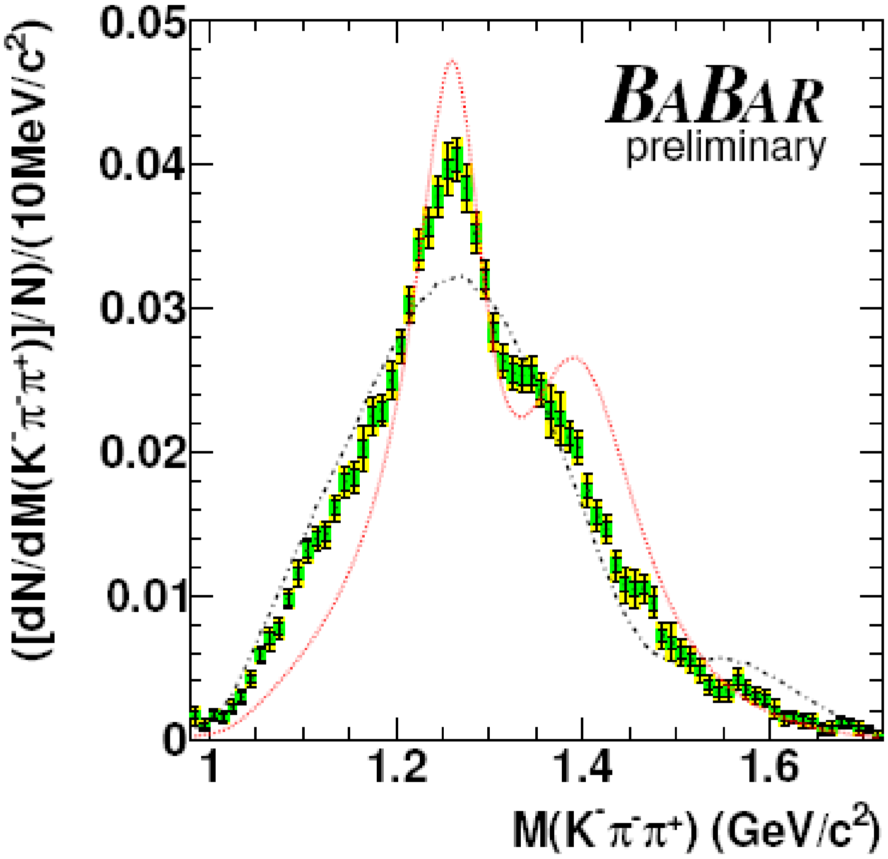




- Cross-Feed
- Other τ-Bkg
- Other Bkg

- CLEO Tauola Tune'98
- BaBar Tauola MC
- Stat.Error (Data)
- Stat.$\oplus$Sys. Error (Data)

Hadronic Structure of $\tau \to \pi\pi\pi\nu$

The CLEO, OPAL, DELPHI, ARGUS, + … Experiments have used model dependent Fits: Törnqvist Unitarized Quark Model, Kühn Santamaria Model, Isgur, Morningstar and Reader (IMR) Model, Flux Tube Models, + …

[Nucl.Phys.Proc.Suppl. 123 (2003) 40-46], [Z.Phys. C75 (1997) 593-605]

[Phys. Lett. B bf 426, 411 (1998)], [Phys.Rev. D61 (2000) 012002] and many more …

"The models used are not unique, as significant variations in their form and content can lead to similar features in the distributions of observable quantities. In addition, no model has so far given a fully satisfactory description of the data."

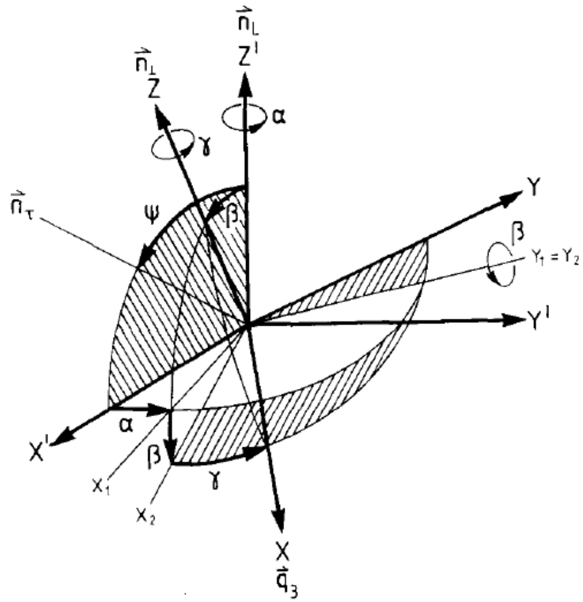
[Phys.Rev. D61 (2000) 052004]

Hadronic Structure of $\tau\to\pi\pi\pi\nu$

Moments for the structure functions have been measured based on the method proposed by:

[Z. Phys. C 56, 661 (1992) and Erratum Z. Phys. C67, 364 (1995).]

Both the OPAL and CLEO experiments have the structure functions where α has been integrated over. [Z.Phys. C75 (1997) 593-605][Phys.Rev. D61 (2000) 052004]



$$W_A=(x_1^2+x_3^2)|F_1|^2+(x_2^2+x_3^2)|F_2|^2+2(x_1x_2-x_3^2)\mathrm{Re}(F_1F_2^*),$$
$$W_B=x_4^2|F_3|^2,$$
$$W_C=(x_1^2-x_3^2)|F_1|^2+(x_2^2-x_3^2)|F_2|^2+2(x_1x_2+x_3^2)\mathrm{Re}(F_1F_2^*),$$
$$W_D=2[x_1x_3|F_1|^2-x_2x_3|F_2|^2+x_3(x_2-x_1)\mathrm{Re}(F_1F_2^*)],$$
$$W_E=-2x_3(x_1+x_2)\mathrm{Im}(F_1F_2^*),$$
$$W_F=2x_4[x_1\,\mathrm{Im}(F_1F_3^*)+x_2\,\mathrm{Im}(F_2F_3^*)],$$
$$W_G=-2x_4[x_1\,\mathrm{Re}(F_1F_3^*)+x_2\,\mathrm{Re}(F_2F_3^*)],$$
$$W_H=2x_3x_4[\mathrm{Im}(F_1F_3^*)-\mathrm{Im}(F_2F_3^*)],$$
$$W_I=-2x_3x_4[\mathrm{Re}(F_1F_3^*)-\mathrm{Re}(F_2F_3^*)],$$
$$W_{SA}=Q^2|F_4|^2,$$
$$W_{SB}=2\sqrt{Q^2}[x_1\,\mathrm{Re}(F_1F_4^*)+x_2\,\mathrm{Re}(F_2F_4^*)],$$
$$W_{SC}=-2\sqrt{Q^2}[x_1\,\mathrm{Im}(F_1F_4^*)+x_2\,\mathrm{Im}(F_2F_4^*)],$$
$$W_{SD}=2\sqrt{Q^2}x_3[\mathrm{Re}(F_1F_4^*)-\mathrm{Re}(F_2F_4^*)],$$
$$W_{SE}=-2\sqrt{Q^2}x_3[\mathrm{Im}(F_1F_4^*)-\mathrm{Im}(F_2F_4^*)],$$
$$W_{SF}=-2\sqrt{Q^2}x_4\,\mathrm{Im}(F_3F_4^*),$$
$$W_{SG}=-2\sqrt{Q^2}x_4\,\mathrm{Re}(F_3F_4^*).$$

$\tau\to K\pi\pi\nu$ - **mixing of $K_1(1280)$ and $K_1(1400)$ related to theory error on $|\alpha-\alpha_{eff}|$**

$\tau\to K\pi\pi\nu$ /$K\pi K\nu$ - **Wess-Zunimo Anomaly**

[Phys. Lett. B37B (1971) 95][Phys.Rev. D47 (1993) 4012-4021]

Fitting the Hadronic Spectra

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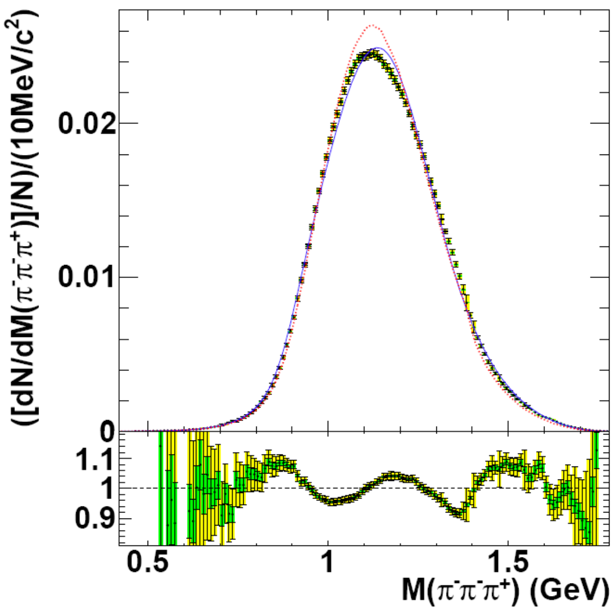
To improve the modeling of τ decays Tauola authors tuned Tauola using BaBar data

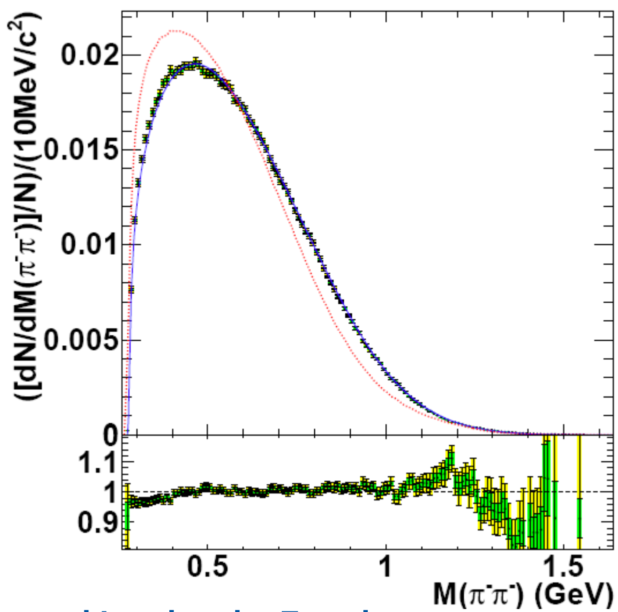
Model based on a RCHL model [Phys.Rev. D88 (2013) 093012].

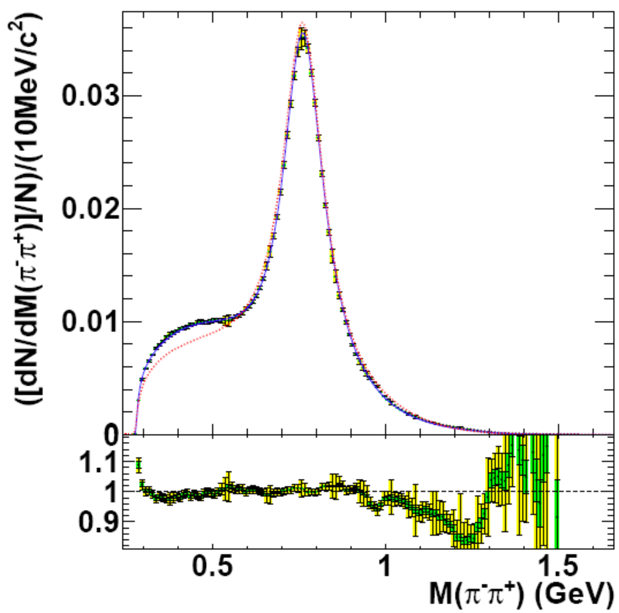
Main discrepancies point to the resonances measured by CLEO and other former experiments…

[Phys.Rev. D61 (2000) 012002] [Nucl.Phys.Proc.Suppl. 123 (2003) 40-46].

σ model is constructed based on a Breit-Wigner and a exponential function. The large width and numerical instability suggest problems with the σ description.







Hadronic Spectra Tunes

Legend

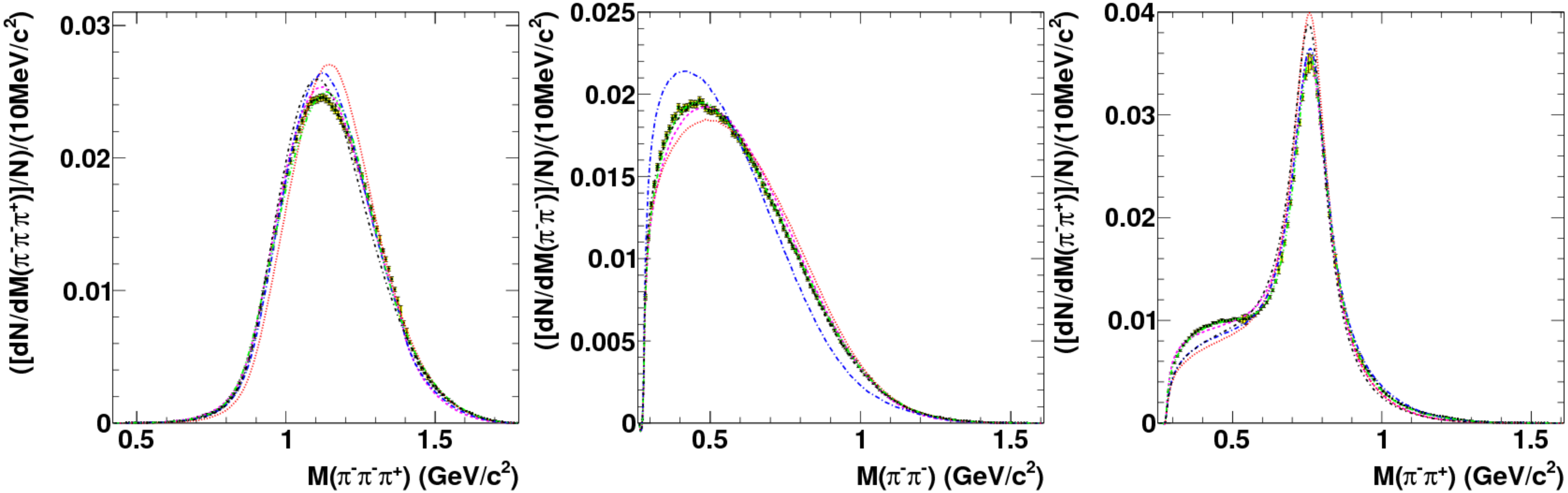
- - - BaBar Experiment Tauola MC.

- - - CLEO Experiment Model [Pythia: arXiv:1211.6730] - Phys.Rev. D61 (2000) 012002

- - - [Pythia: arXiv:1211.6730] - R. Decker, et al., Z.Phys. C58 (1993) 445–452.

- - - Tauola CLEO'98 Tune - Comput.Phys.Commun. 174 (2006) 818-835.

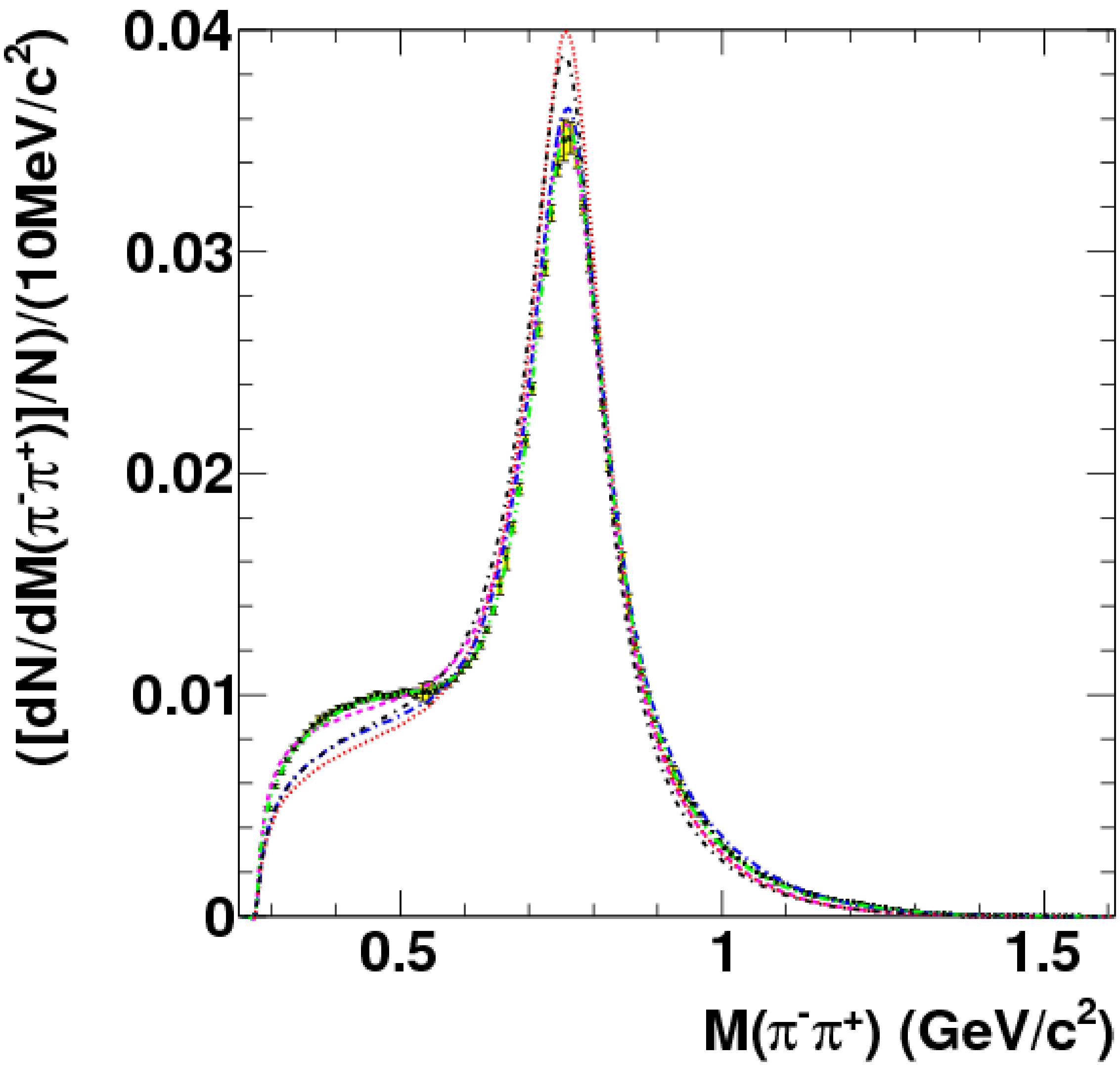
- - - RCHL Models Tauola - Phys.Rev. D88 (2013) 093012.



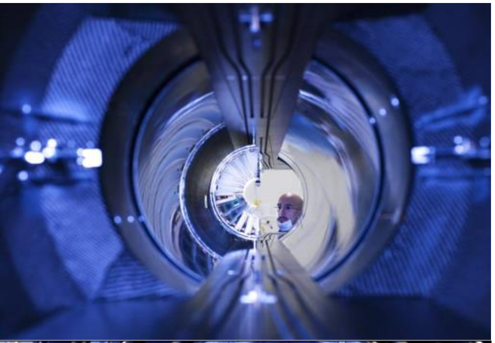
Hadronic Spectra Tunes

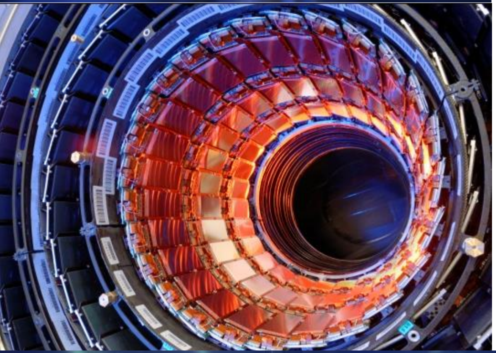
Legend

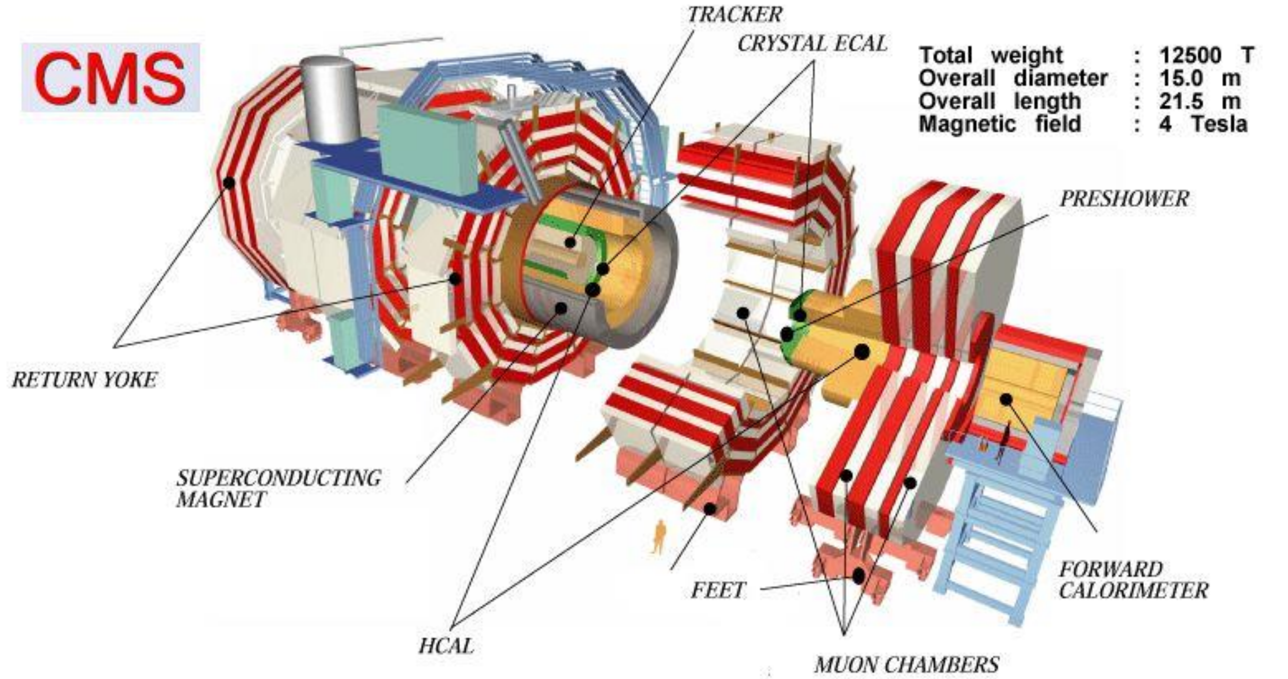
- BaBar Experiment Tauola MC. (black dashed)
- CLEO Experiment Model [Pythia: arXiv:1211.6730] - Phys.Rev. D61 (2000) 012002. (magenta dashed)
- [Pythia: arXiv:1211.6730] - R. Decker, et al., Z.Phys. C58 (1993) 445–452. (red dashed)
- Tauola CLEO'98 Tune - Comput.Phys.Commun. 174 (2006) 818-835. (blue dashed)
- RCHL Models Tauola - Phys.Rev. D88 (2013) 093012. (green dashed)

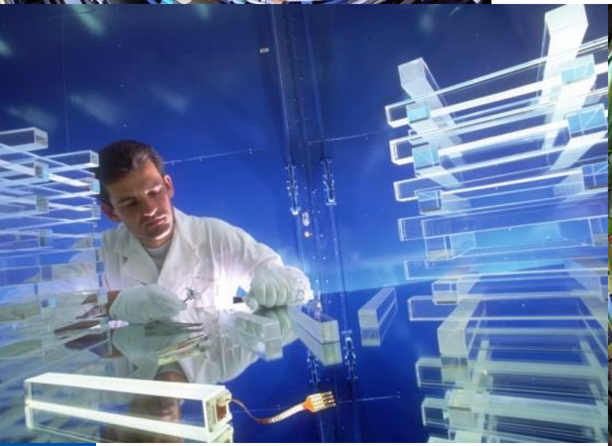


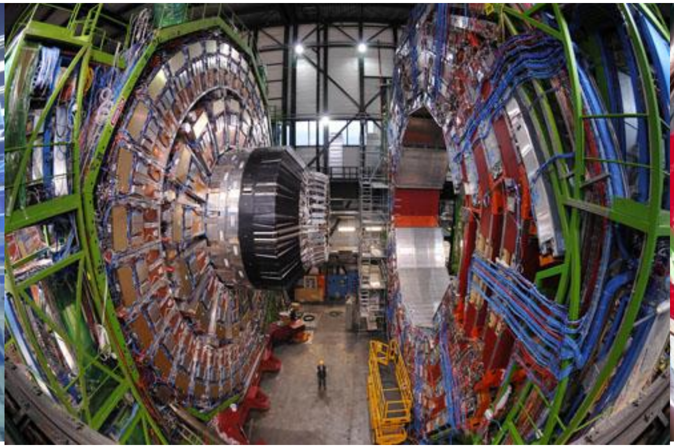
The CMS Detector











Motivation: τ's at the LHC

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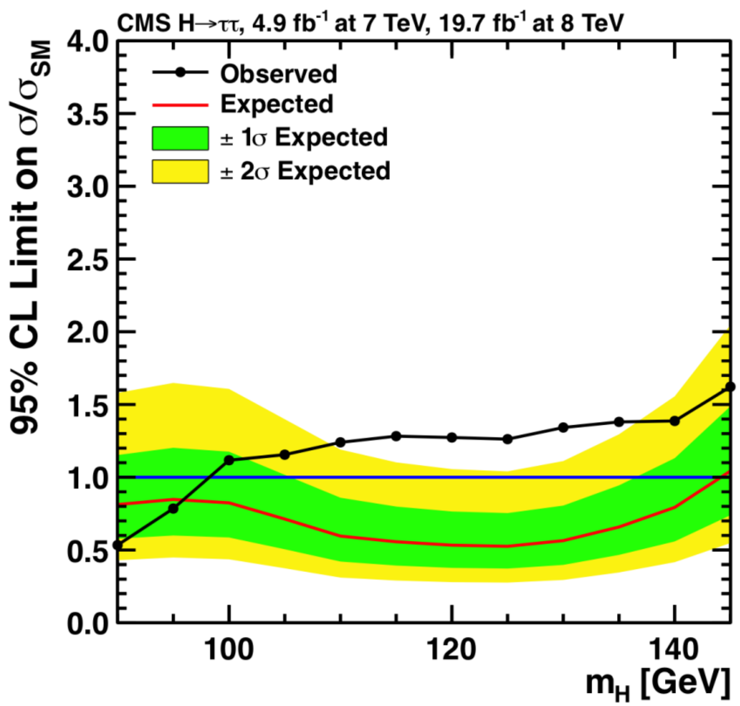
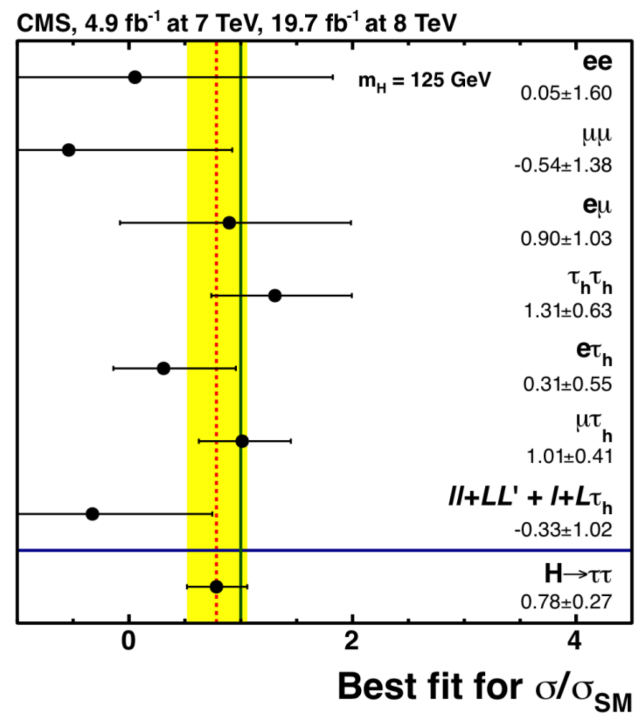
Many interesting channels at the LHC contain a τ lepton:

SM Bosons, Higgs, SUSY, Lepto-Quarks



CMS: HIG-13-004
arXiv: 1401.5041

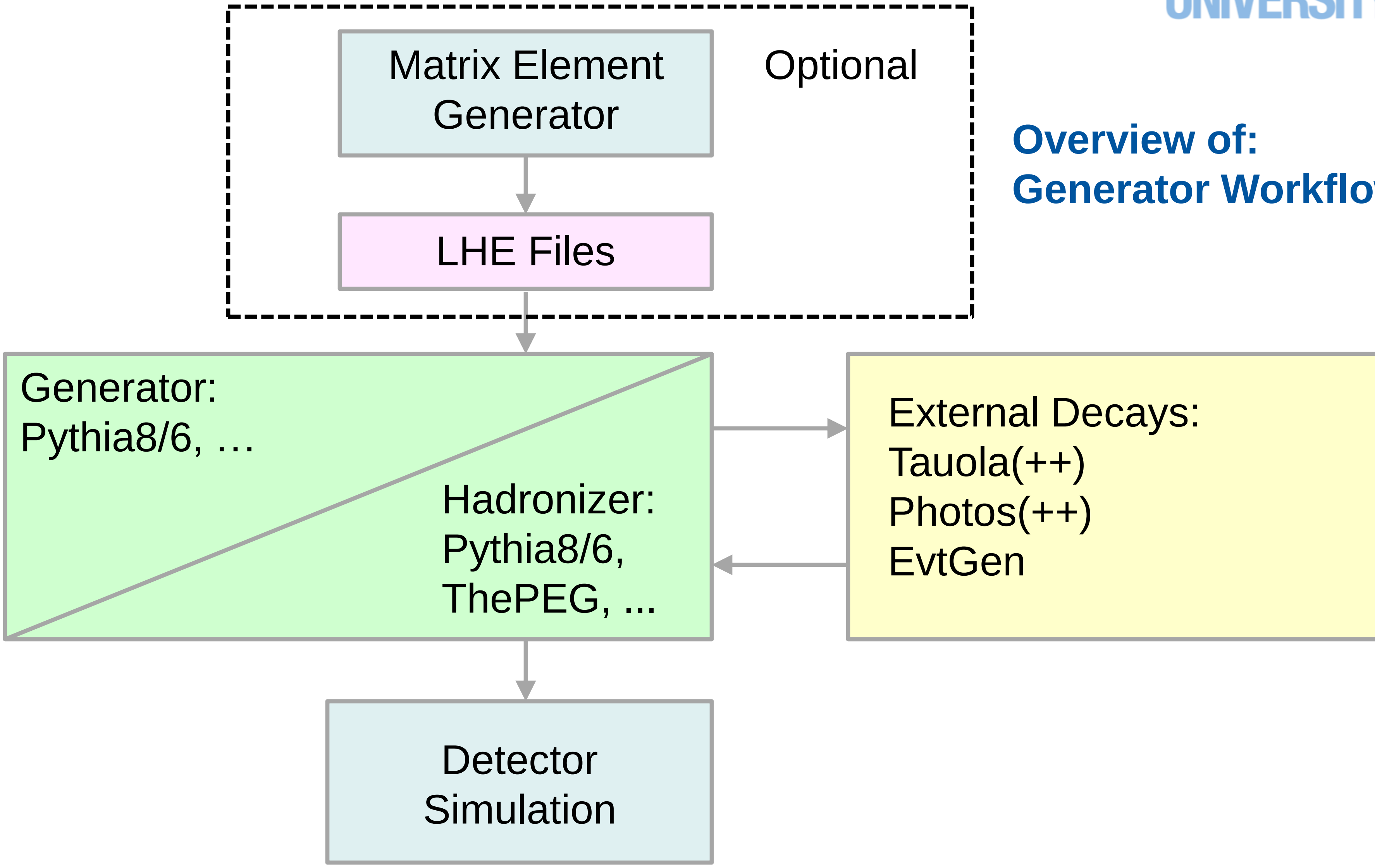


CMS: HIG-13-004
arXiv: 1401.5041

$H \rightarrow \tau\tau$ results from LHC: Atlas (4.2σ) and CMS (3.2σ).

Expect Z value of greater then 5σ in Run II

Monte-Carlo Simulation at CMS



Overview of: Generator Workflow

Monte-Carlo Simulation at CMS

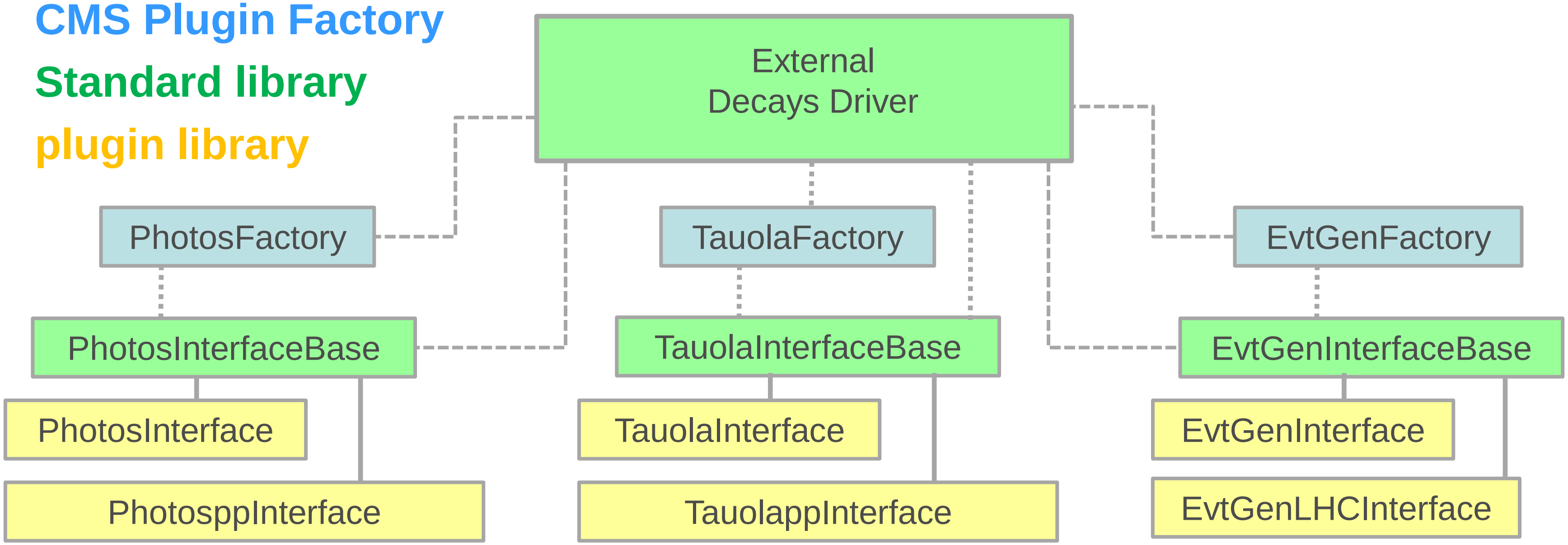
In CMS software framework the MC Generators are built as RPMs which are accessed through interfaces in CMSSW.

Legend

CMS Plugin Factory

Standard library

plugin library

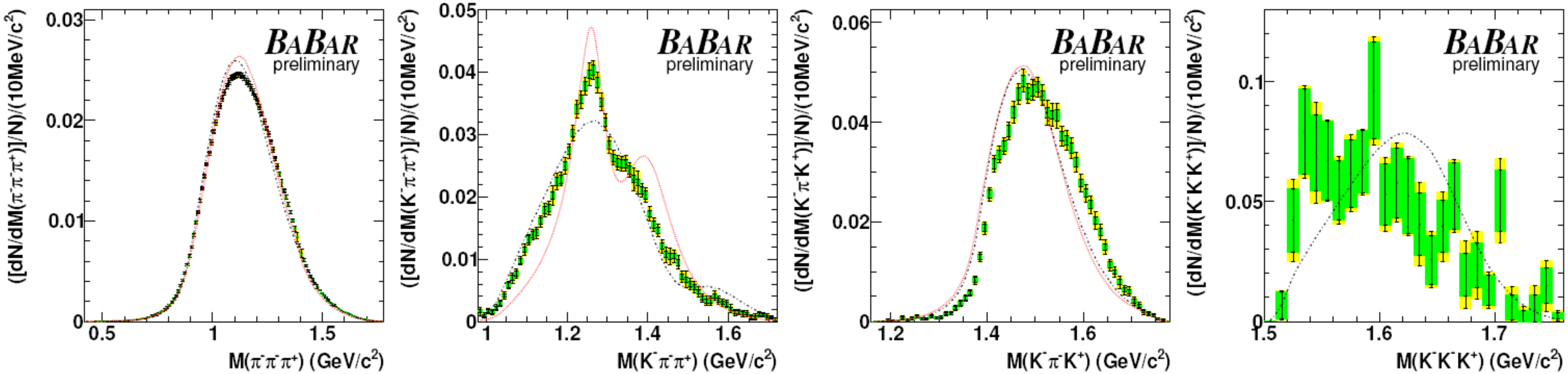


For reproducibility of the MC, the default generators are not allowed to change in a given release series.

To allow for upgrades and patches for the external decays the software was upgraded to use plugins: EvtGen, Photos++, TauSpinner(Tauola++).

Conclusions & Outlook

τ decays provide a unique opportunity to probe the SM:



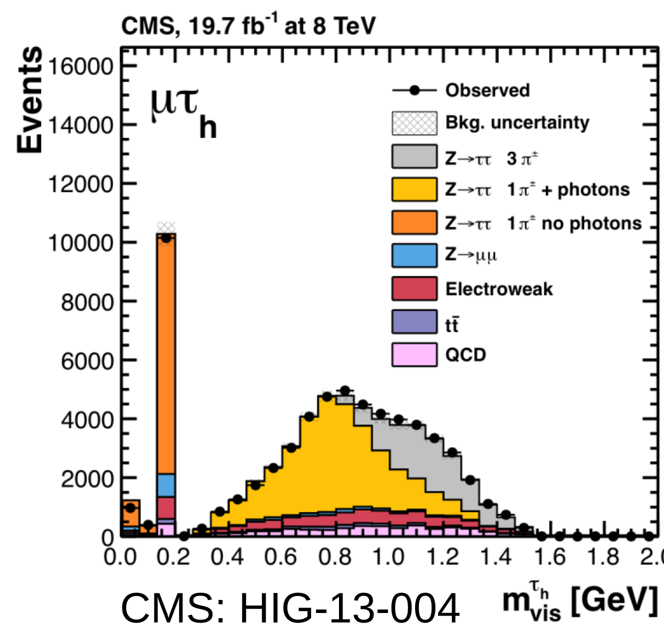
Low energy QCD, Electro-weak couplings

Many interesting channels at the LHC contain τ: Higgs/Susy/Lepto-Quarks/…

Simulation of τ decays is essential for any analysis that uses τ at the LHC.

→ Upgrade of external generators include:

- » EvtGen 1.3.0
- » Tauola++
- » Photos++



CMS: HIG-13-004
arXiv: 1401.5041

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Thank you!
Merci!

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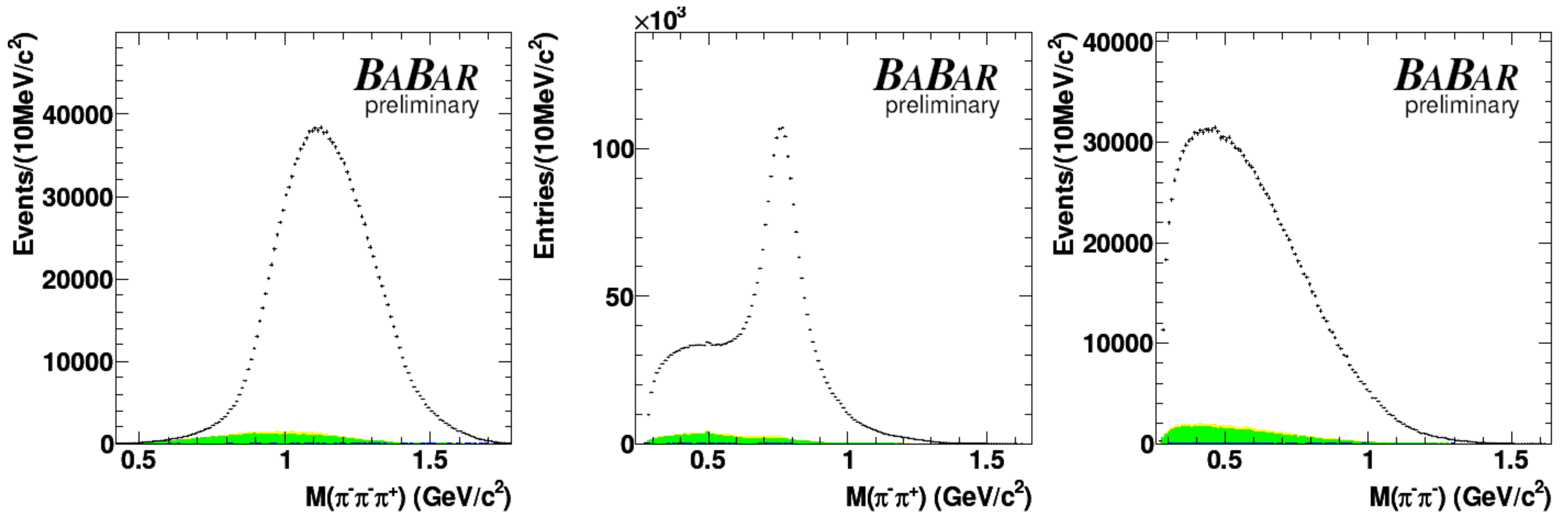
Raw Invariant Mass Distributions

Raw Invariant mass distributions for: $\tau^- \to \pi^-\pi^-\pi^+\nu$

Cross-Feed   Other τ-Bkg   Other Bkg



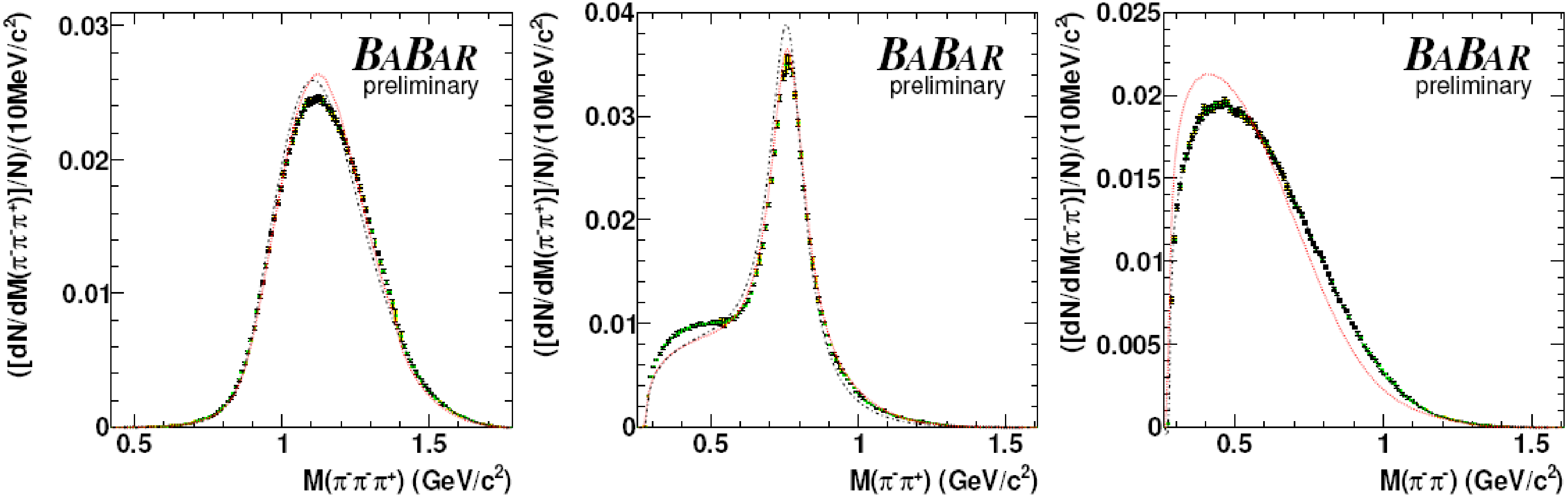
Main background: $\tau^- \to \pi^-\pi^-\pi^+\pi^0\nu$ (~3.6%)

Unfolded Invariant Mass Distributions

Invariant mass distributions for: $\tau^- \rightarrow \pi^- \pi^- \pi^+ \nu$

CLEO Tauola Tune (98) BaBar Tauola MC

Stat. Error (Data) Stat. ⊕ Sys. Error (Data)



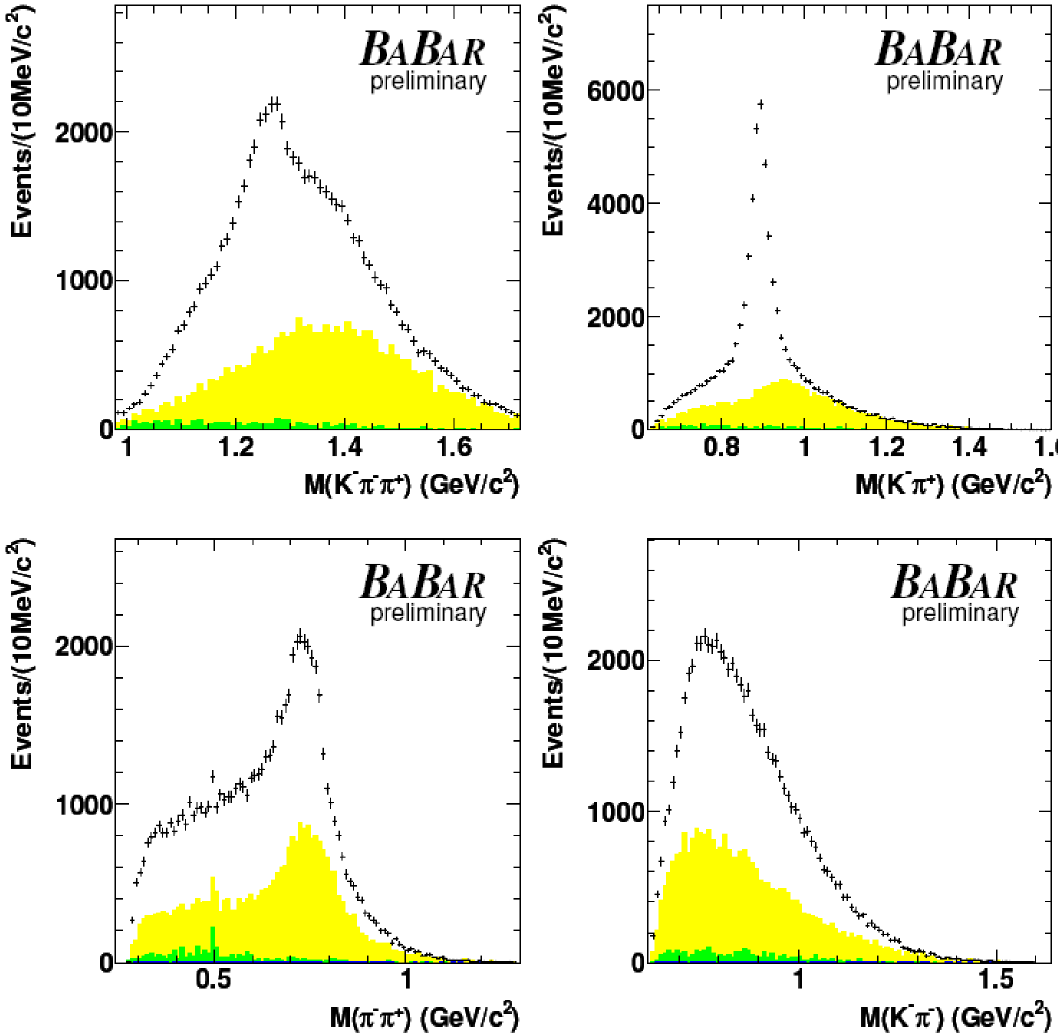
Raw Invariant Mass Distributions

Raw Invariant mass distributions for: $\tau^- \to K^- \pi^- \pi^+ \nu$

Cross-Feed

Other τ-Bkg

Other Bkg



Main background: Cross-feed (~38%)

Unfolded Invariant Mass Distributions

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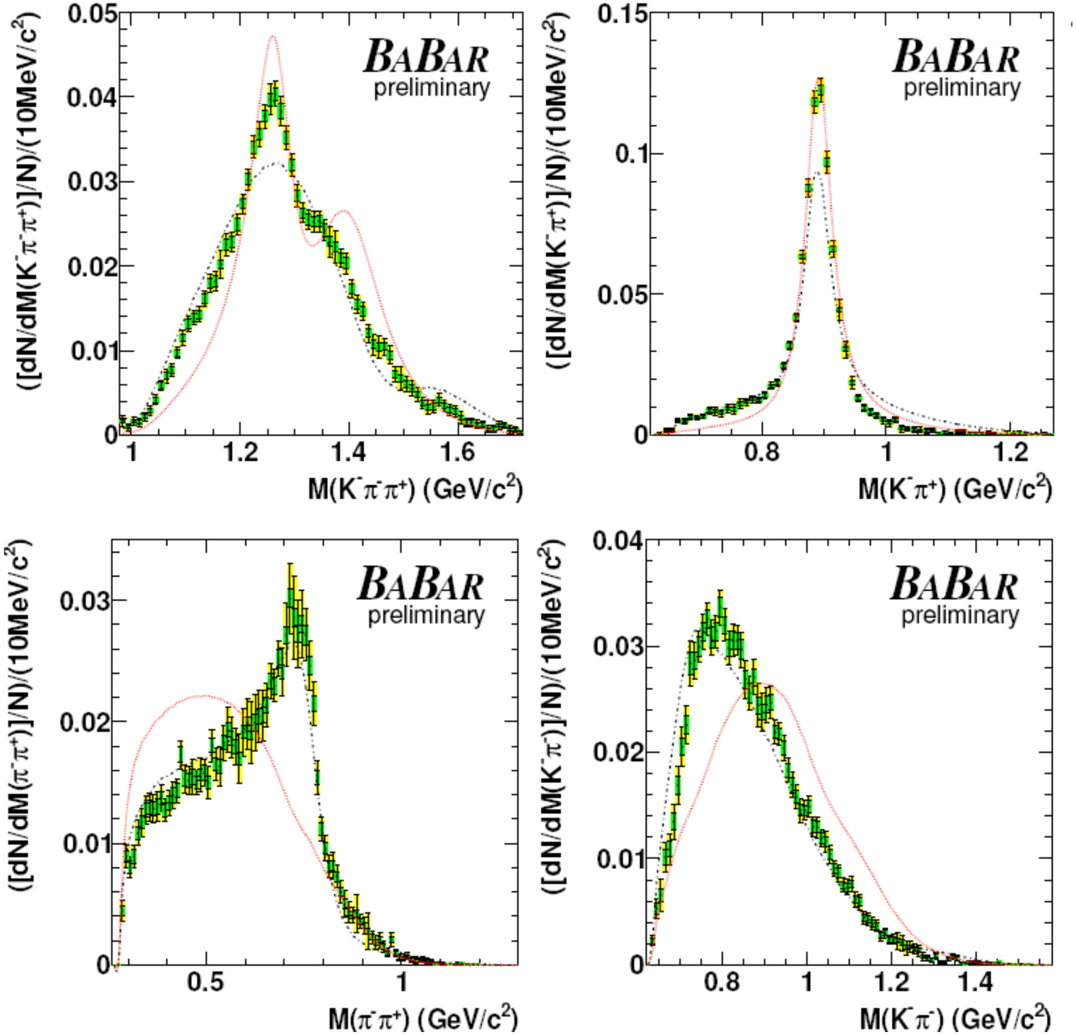
Invariant mass distributions for: $\tau^- \rightarrow K^- \pi^- \pi^+ \nu$

CLEO Tauola Tune (98)

BaBar Tauola MC

Stat. Error (Data)

Stat. $\oplus$ Sys. Error (Data)



Raw Invariant Mass Distributions

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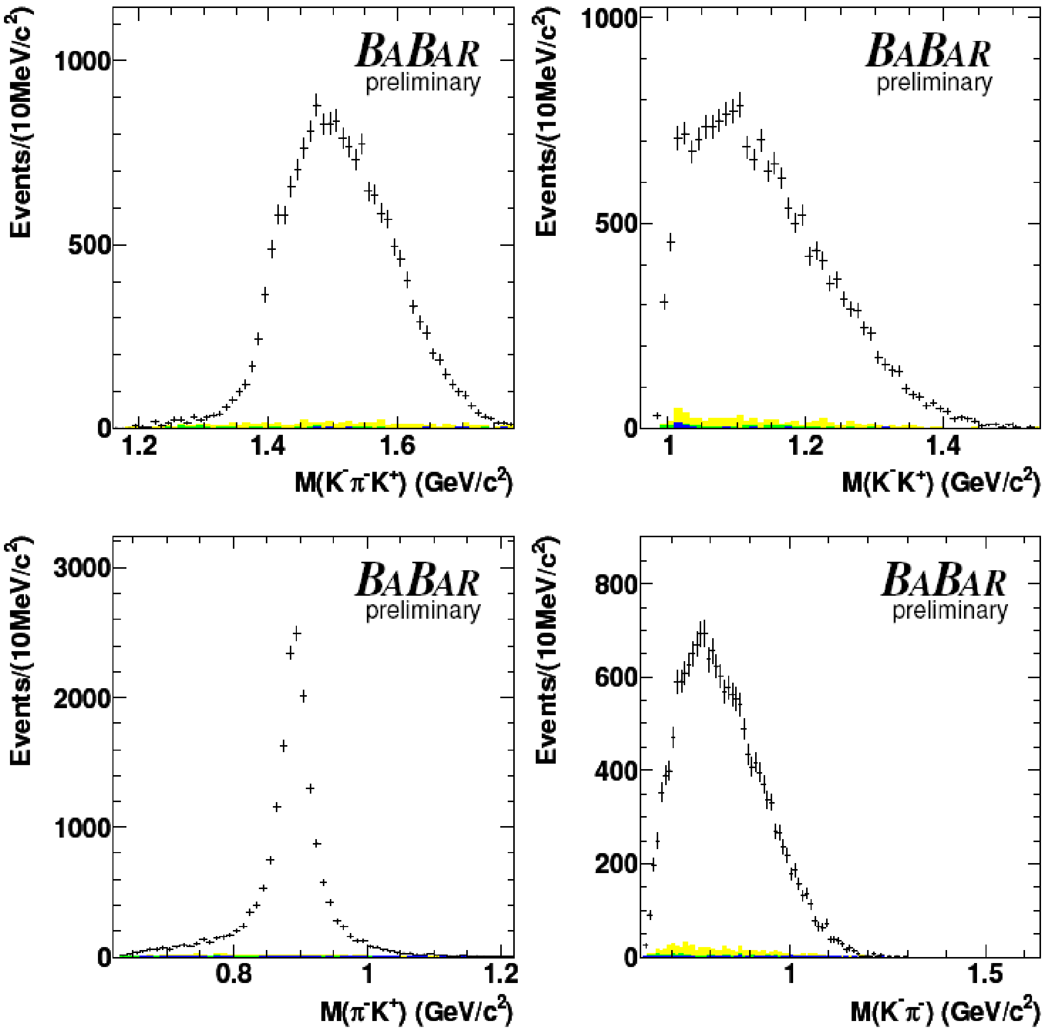
Raw Invariant mass distributions for: $\tau^- \to K^- \pi^- K^+ \nu$

Cross-Feed

Other τ-Bkg

Other Bkg

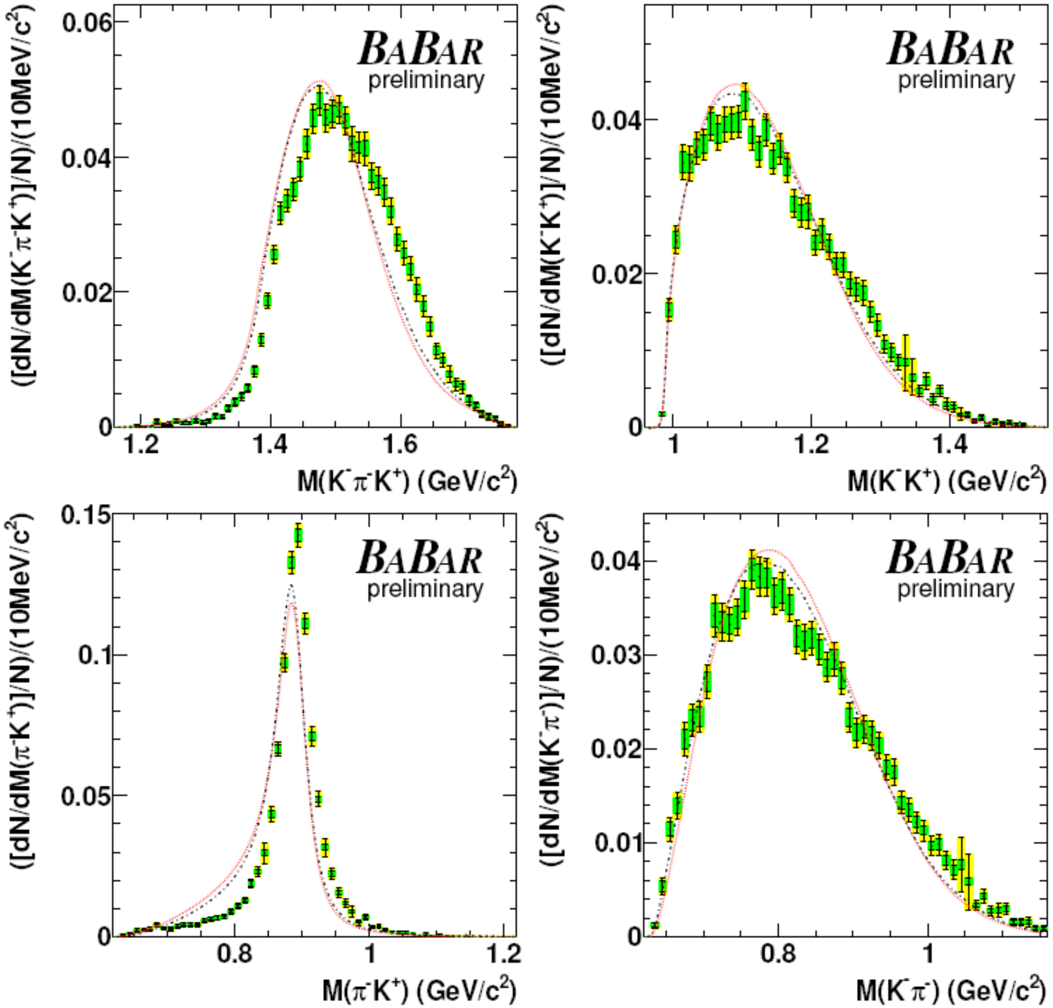


Main background: Cross-feed (~2.8%)

Unfolded Invariant Mass Distributions

Invariant mass distributions for: $\tau^- \to K^- \pi^- K^+ \nu$

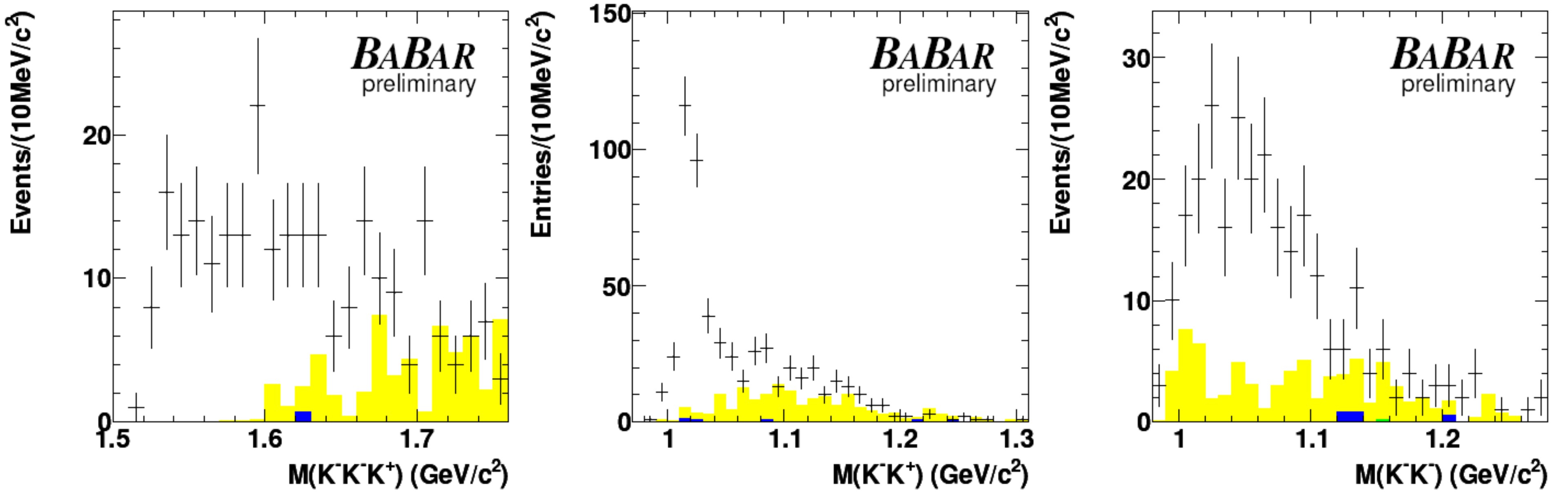
- CLEO Tauola Tune (98) (red dotted line)
- BaBar Tauola MC (black dotted line)
- Stat. Error (Data) (green)
- Stat. ⊕ Sys. Error (Data) (yellow)



Raw Invariant Mass Distributions

Raw Invariant mass distributions for: $\tau^- \rightarrow K^- K^- K^+ \nu$

Cross-Feed Other τ-Bkg Other Bkg



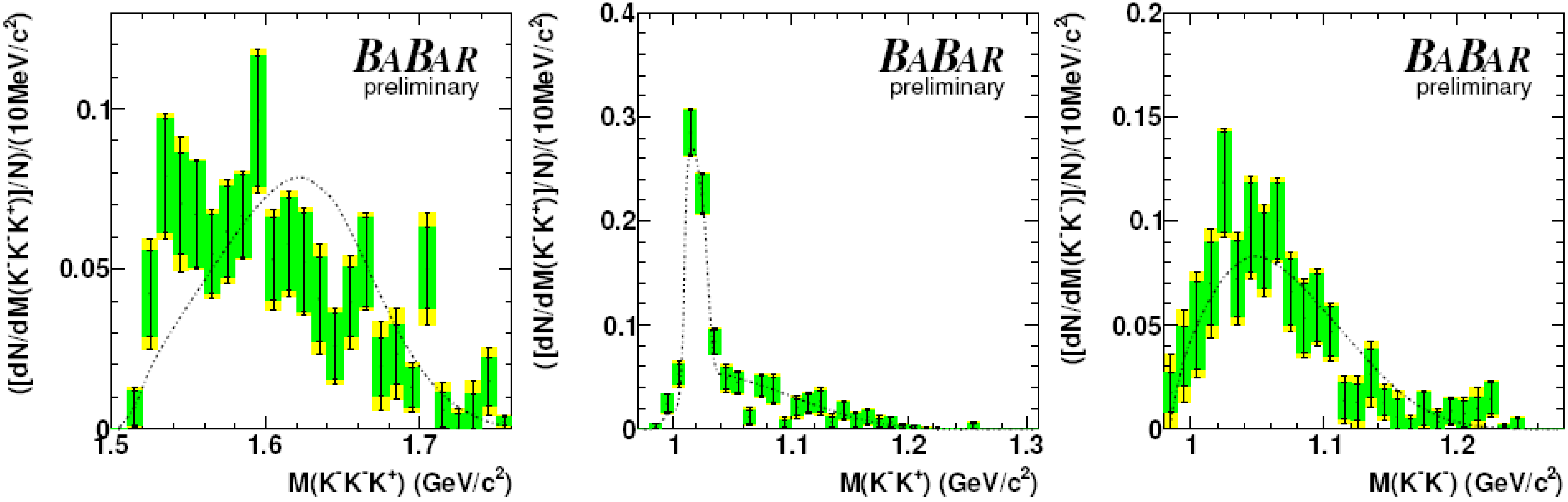
Main background: Cross-feed (~28%)

Unfolded Invariant Mass Distributions

Invariant mass distributions for: $\tau^- \rightarrow K^- K^- K^+ \nu$

······ BaBar MC ($\tau^- \rightarrow \phi K^- \nu$)

Stat. Error (Data)   Stat. ⊕ Sys. Error (Data)



Upper edge of M(K-K-K+) Plot: 1.76GeV/c^2 PDG: $M(\nu_\tau)$<18.2MeV/c^2 @ 95% CL