τハドロニック崩壊
$\tau \to \pi\eta\nu / \pi\eta'\nu$の探索

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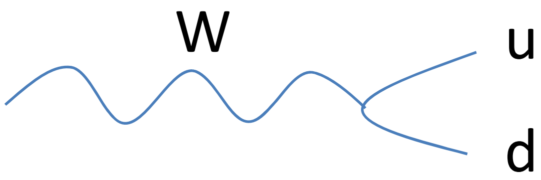
セカンドクラスカレント

- 弱い相互作用→parity, spin とG-parity で分類

$PG(-1)^J$

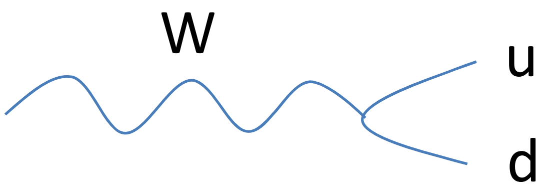
1st class current



$J^{PG}=0^{--}(\pi),1^{-+}(\rho),1^{+-}(a_1),\cdots$

$\propto m_u + m_d$

2nd class current



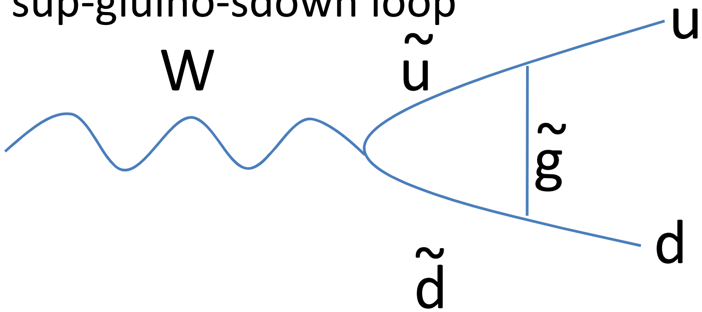
$J^{PG}=0^{+-}(a_0),1^{++}(b_1),\cdots$

$\propto m_u - m_d$

2nd class current が小さいので、新しい物理現象が先に見えることも？

例：SUSY による sup-gluino-sdown loop

(induced 2nd class current)



τ崩壊とセカンドクラスカレント

$\tau \rightarrow W\nu \quad PG(-1)^J = -1$

$a_0(J^{PG}=0^{+-}) \rightarrow \pi(J^{PG}=0^{--}) + \eta^{(\prime)}(J^{PG}=0^{-+})$

$b_1\ (J^{PG}=1^{++}) \rightarrow \pi(J^{PG}=0^{--}) + \omega(J^{PG}=1^{--})$

a_0,b_1 を経ていなくてもOK

$\tau \rightarrow \pi\eta\nu$探索が最も盛ん。

理論予測:$Br(\tau \rightarrow \pi\eta\nu) \sim O(10^{-5\sim-6})$

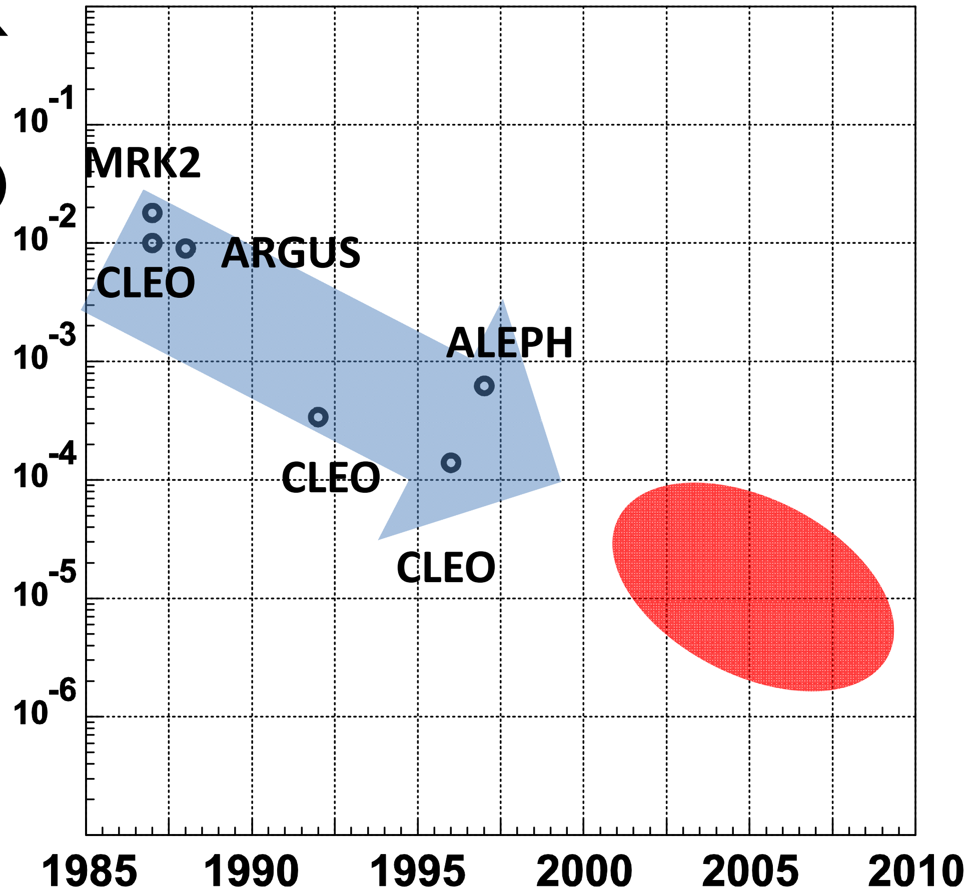
$\tau \rightarrow \pi\eta\nu$ の現在の上限値

Current UL@95% (PDG08)

$Br<1.4\times10^{-4}$ by CLEO

世界最高統計量のBelle実験で
収集されたデータを用いて探索

$\tau \rightarrow \pi\eta\nu$ 探索の歴史



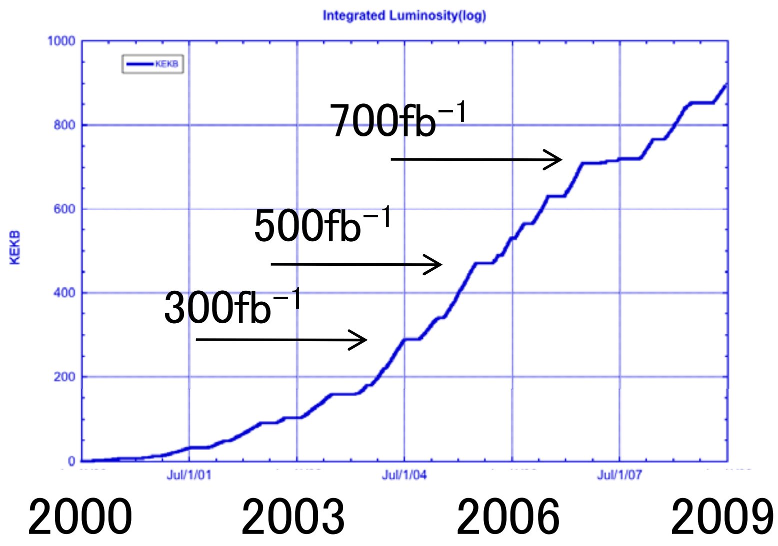
KEKB/Belle実験

- 超高ルミノシティー
  - 1.71x10^{34} /cm^2/s
  - ~850 fb^{-1}
  - タウファクトリー

世界最高記録

$$\sigma(\tau\tau) = 0.9\text{nb}, \sigma(b\bar{b}) = 1.1\text{nb}$$

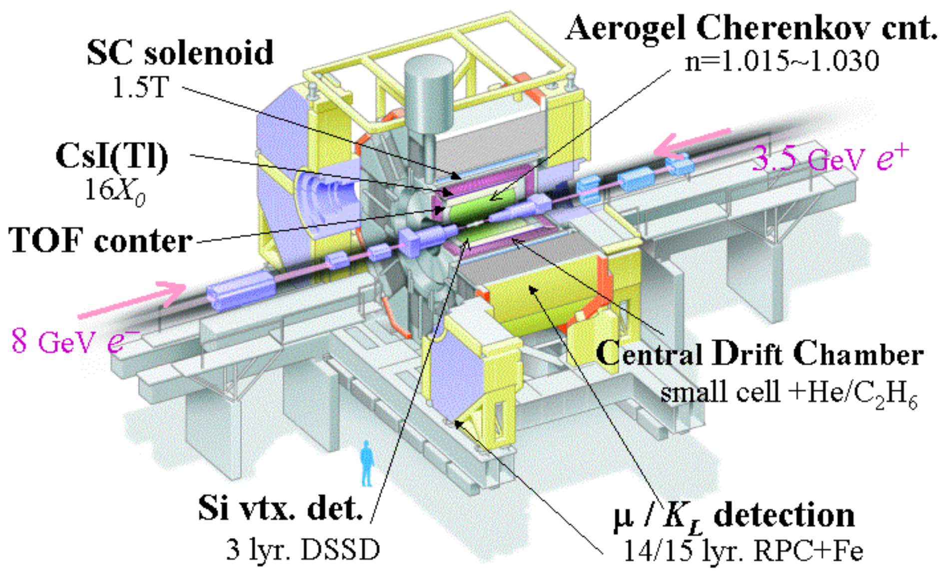
➡ タウ稀崩壊研究に最適



- Good PID
  - π/K 分離能力

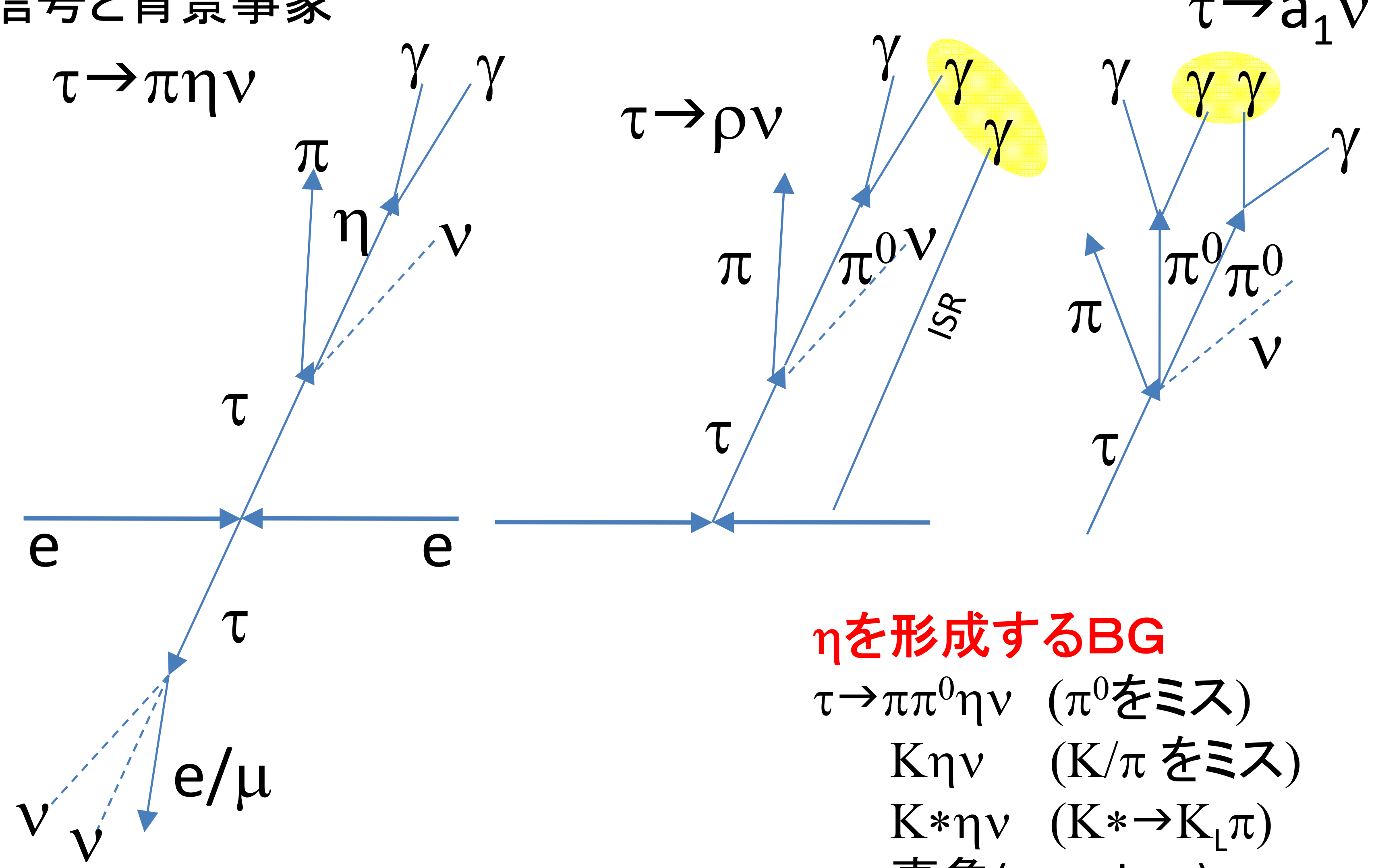
- 670 fb^{-1} データを使用 (~6.2x10^8 τ対)

Belle Detector



$\tau \to \pi\eta\nu$ / $\eta \to \gamma\gamma$

- $\eta \to \gamma\gamma$ はη 崩壊のメイン崩壊(~40%)/分解能～１２MeV
- 信号と背景事象



ηを形成するBG

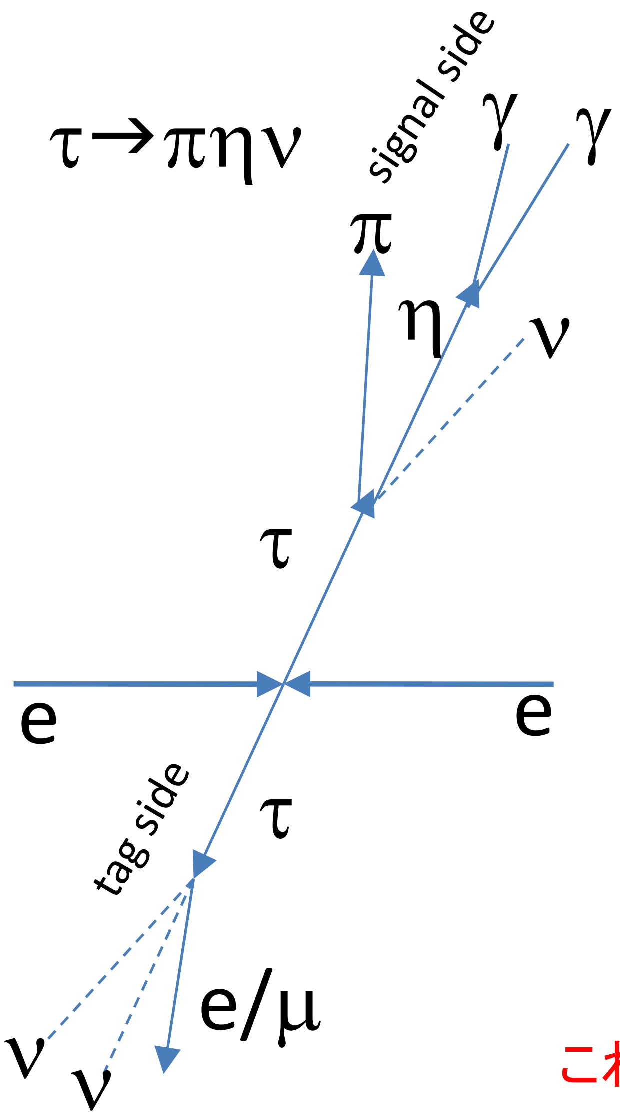
$\tau \to \pi\pi^0\eta\nu$ (π^0をミス)

$K\eta\nu$ (K/π をミス)

$K^*\eta\nu$ ($K^* \to K_L\pi$)

qq 事象(q=u,d,s,c)

事象選別



事象選別条件
荷電飛跡x1 – 荷電飛跡x1
（信号側）　　（タグ側）

タグ側 : 荷電飛跡→電子 or ミューオン
光子x 0 or 1
M_{tag}<1.8GeV/c^2

信号側 : 荷電飛跡x1→ π
光子x2
荷電飛跡と光子の開き角
M_{sig}<1.8GeV/c^2

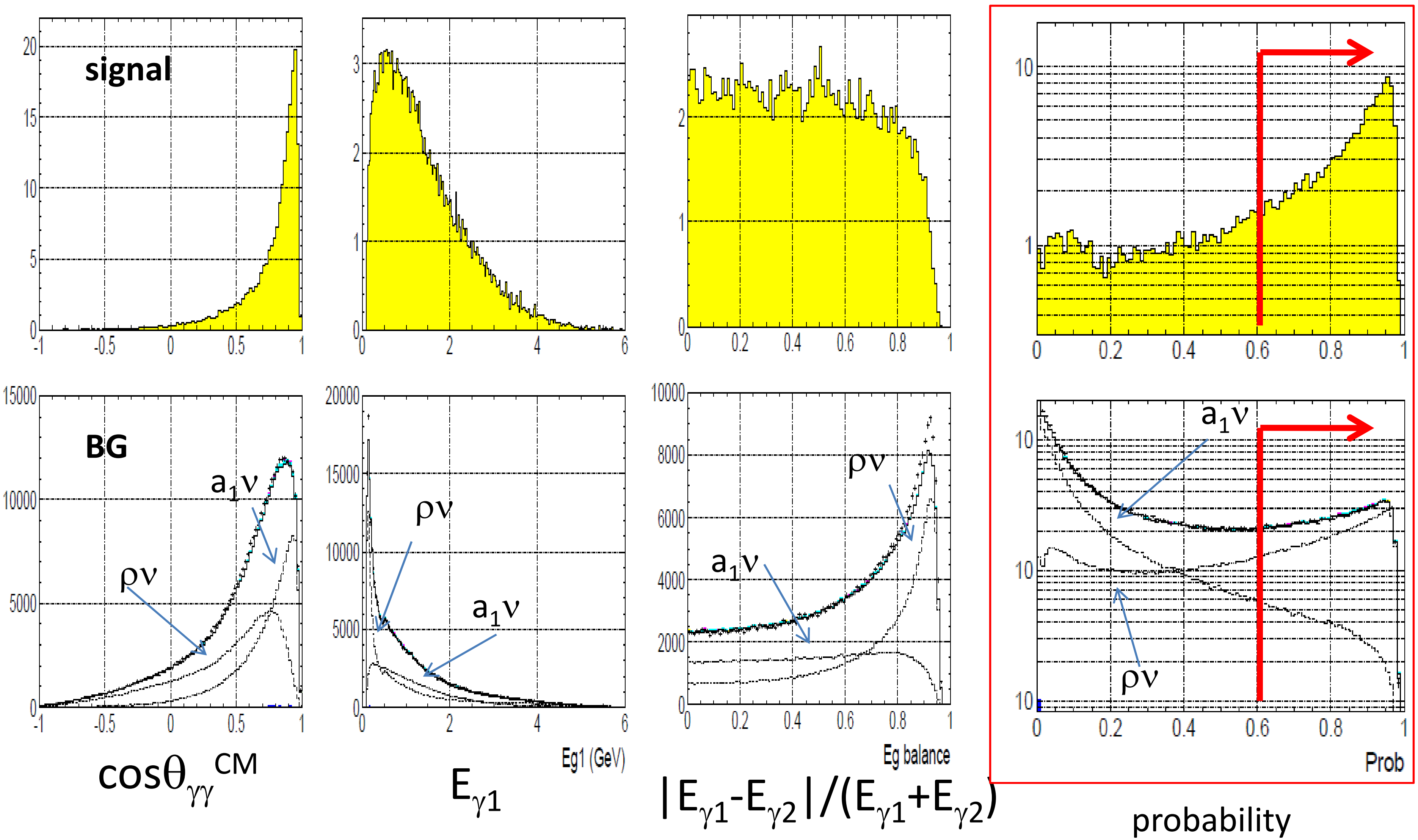
欠損運動量 : 検出器内にある
（ττの特徴）

M(γ,γ)分布のηピークの数から信号事象数を評価

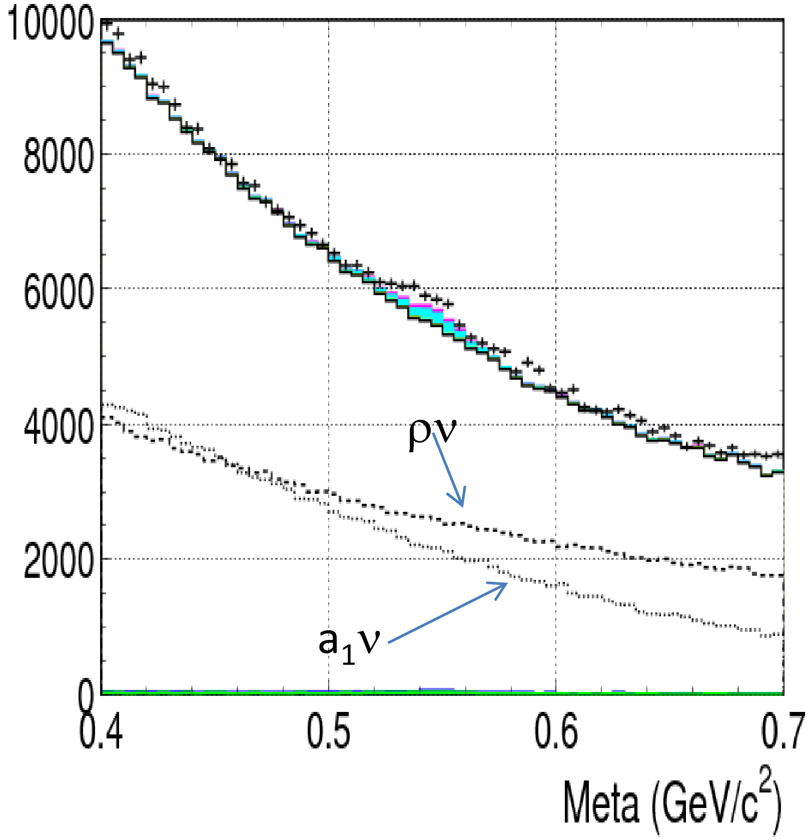
これでもまだγγによる背景事象が多いのでさらなる選別を
γγに関わる物理量でlikelihoodを組む

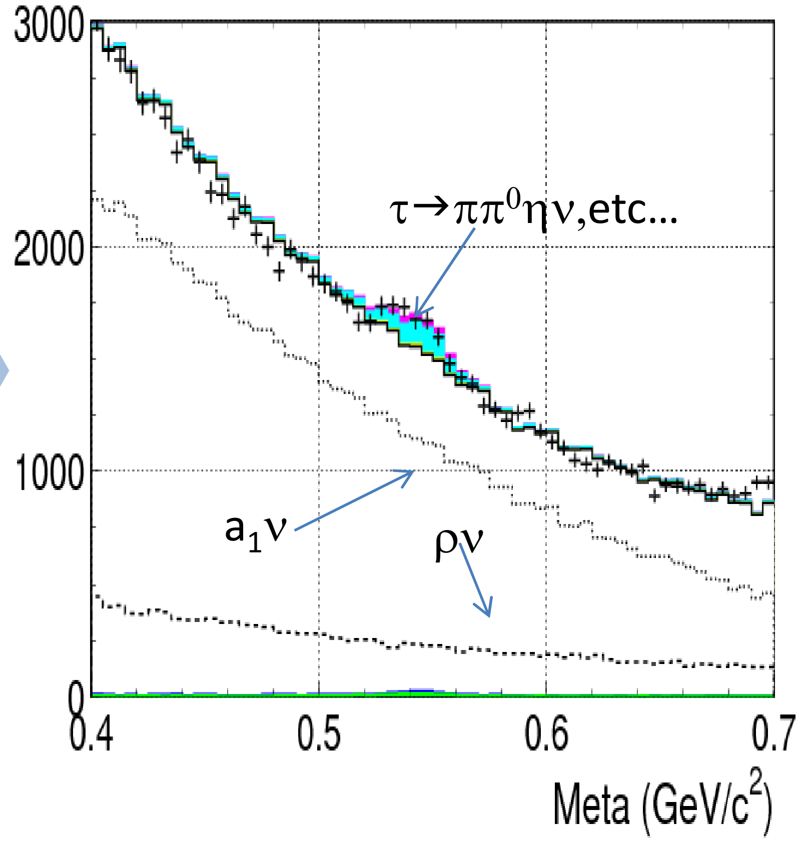
Likelihoodの定義

$\cos\theta_{\gamma\gamma}^{CM}, E_{\gamma1}, \cos\theta_{\gamma1}, E_{\gamma2}, \cos\theta_{\gamma2}, \cos\theta_{\eta\pi}^{CM}$ and $|E_{\gamma1}-E_{\gamma2}|/(E_{\gamma1}+E_{\gamma2})$の信号と背景事象のPDFを使ってlikelihoodを定義



Likelihoodによる背景事象の抑制





- Likelihood 特に $\tau \to \rho\nu$ の抑制に効果的

$\tau \to \rho\nu : \tau \to a_1\nu \sim 1:1$ ➡ $1:4$

選別後のγγ分布とη数の評価

- data中のη数

N_η^{fit}=1110.8+-165.5

- ττBGからのη数

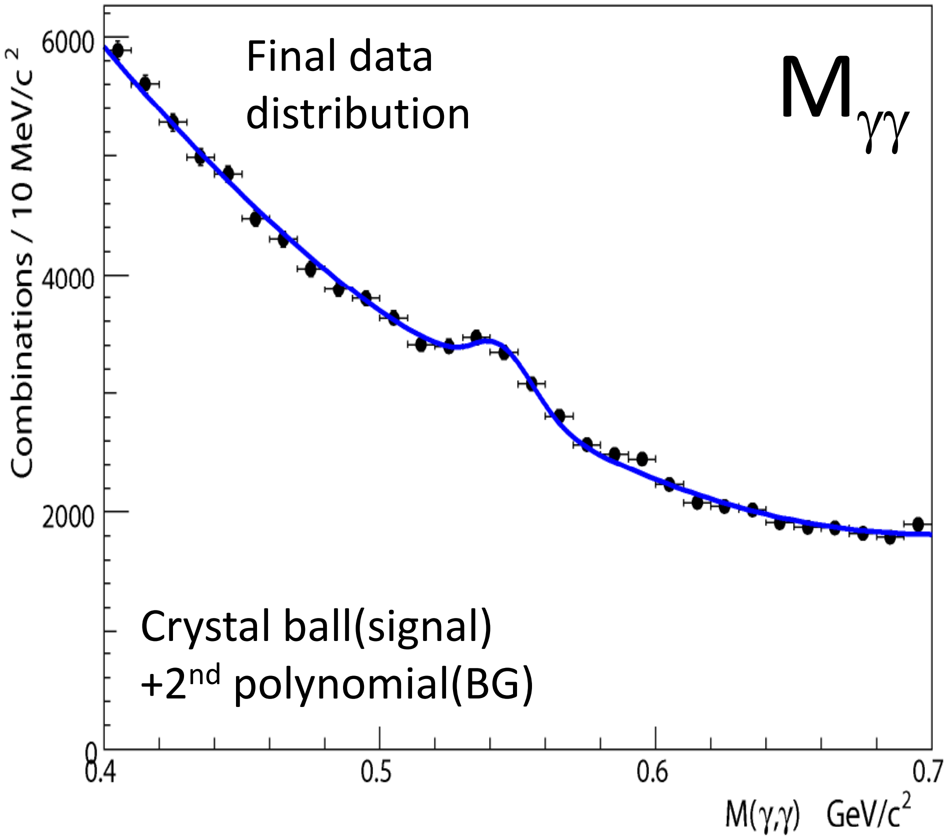
$N_\eta^{\tau\tau}$=1009.5+-77.8

- qqBGからのη数

N_η^{qq}=84.4+-19.2

- 信号候補数

N_η^{sig}=16.9+-183.9



信号検出効率：1.00%

Br=(0.14+-1.51)x10^{-5}

（統計誤差のみ）

$\tau \to \pi\eta\nu$ / $\eta \to \pi\pi\pi^0$

- $\eta \to \pi\pi\pi^0$ はη 崩壊分岐比 約23%

  π^0をmass constraint fit　→分解能良~4MeV
- 信号検出効率:低い　荷電飛跡x4,光子x2
- 背景事象
  - $\tau \to \pi\pi\pi\pi 0\nu$: 終状態が$\tau \to \pi\eta\nu$ / $\eta \to \pi\pi\pi^0$と同じ

    事象選別条件で区別がほぼ不可
  - ηを含む背景事象は$\eta \to \gamma\gamma$と同様

    $\tau \to \pi\pi 0\eta\nu$,$K\eta\nu$, $K*\eta\nu$

    qq 事象(q=u,d,s,c)
- ゆるい事象選別条件で解析

選別後の$\pi\pi\pi^0$分布とη数の評価

- data中のη数

N_η^{fit}=774.3+-99.3

- $\tau\tau$BGからのη数

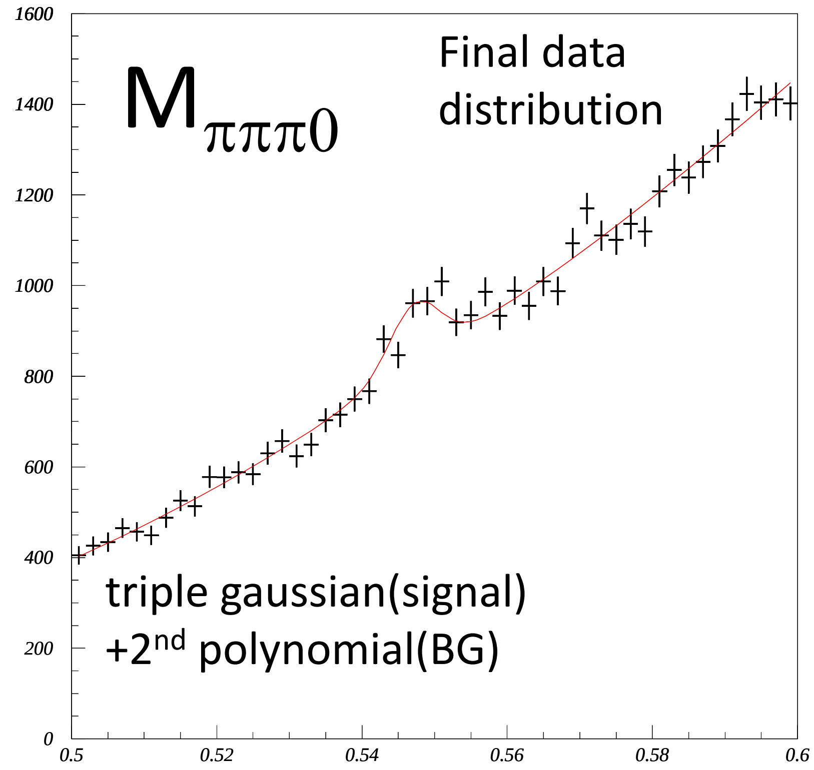
$N_\eta^{\tau\tau}$=535.3+-11.4

- qqBGからのη数

N_η^{qq}=152.6+-29.2

- 信号候補数

N_η^{sig}=86.5+-104.1



信号検出効率:0.38%

Br=(1.85+-2.23)x10^{-5}

（統計誤差のみ）

系統誤差について

$\eta \to \gamma\gamma$

sources	uncertainty (%)
Luminosity	1.4
corss section	0.326
track	1.0 9 + 0.3
π/K-ID	0.98
lepton-ID	2.5
trigger	1.3
MC stat.	0.41
η	2.8
$\eta \to \gamma\gamma$	0.5

Total 4.8%
Fit /Peking BG 66ev.

$\eta \to \pi\pi\pi 0$

sources	uncertainty (%)
Luminosity	1.4
corss section	0.326
track	3.20 + 0.3
π/K-ID	0.93
lepton-ID	2.50
trigger	0.175
MC stat.	0.738
π^0	1.27
$\eta \to \pi\pi\pi^0$	1.28

Total 5.51%
Fit/Peaking BG 51ev.

もっとも大きな寄与は信号候補からη-BGを引く時に用いる $\tau \to \pi\pi^0\eta\nu$, $\tau \to K\eta\nu$, $\tau \to K^*\eta\nu$ の分岐比のもつ誤差 → PDGではなくBelleの最新の結果を利用

$\eta \to \gamma\gamma$と$\eta \to \pi\pi\pi^0$の結果の統合

- Br=(0.14+-1.51+-0.55)x10^{-5} ($\eta \to \gamma\gamma$)
- Br=(1.85+-2.05+-0.52)x10^{-5} ($\eta \to \pi\pi\pi^0$)
- Br=(0.69+-1.32) x10^{-5} (combined)

  <2.9x10^{-5} @ 95%CL (1.64σ)

  <2.4x10^{-5} @ 90%CL (1.28σ)

cf. Br<1.4x10^{-4} @ 95%CL by CLEO (PDG08)

$\tau \to \pi \eta' \nu$

ηとη'はG-parity や parity は同じ

→$\tau \to \pi \eta \nu$と同様に崩壊は抑制

・現在の上限値　Br<7.4×10^{-5}@90%CL by BaBar with $384 fb^{-1}$

$489 fb^{-1}$ の Belle 実験データを用いて探索

信号数:η'　の数で評価

選別条件:　$\eta' \to \pi\pi\eta$ (~45%) → $\tau \to \pi\eta\nu/\eta \to \pi\pi\pi^0$とほぼ同じ。

主なBG: $\tau \to \pi\pi\pi\pi^0(\to\gamma\gamma)\nu$, $\tau \to \pi\pi^0(\to ee\gamma)\nu$,

（$\tau \to K\eta'\nu$ 未観測）

選別後のη’分布と fit の結果

$M_{\eta'}$=957.8MeV/c^2

Fit によるη’候補の数

$N_{\eta'}=-2.87^{+24.46}_{-23.71}$

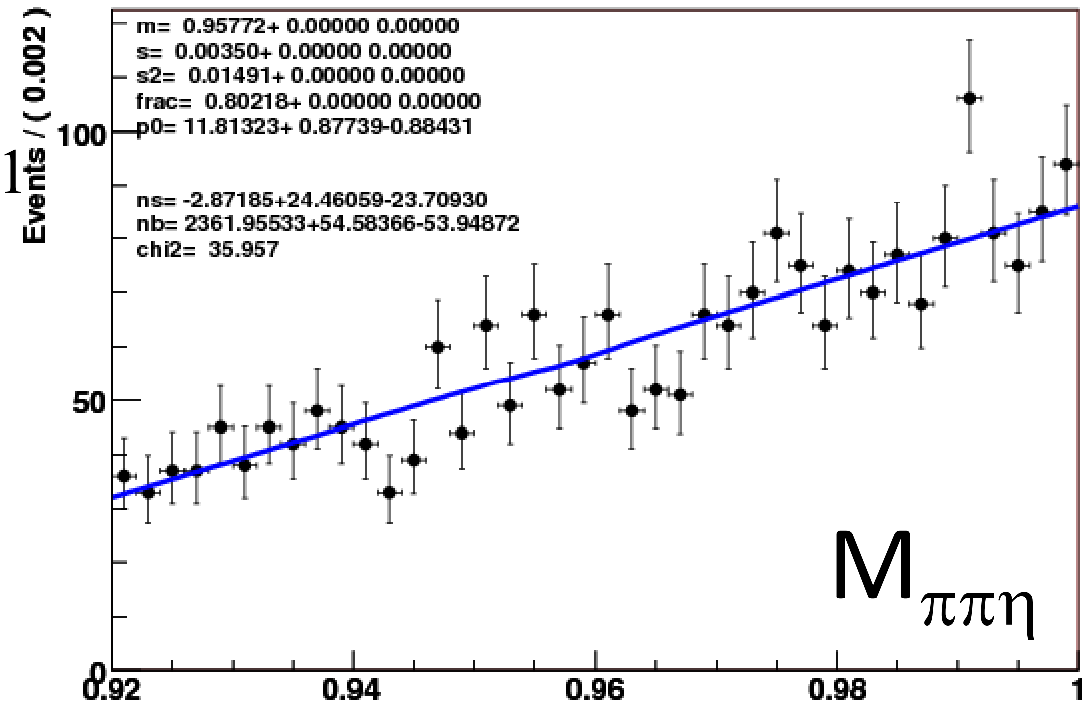
検出効率

$\varepsilon=1.13\%$

系統誤差

6.43%

TrackingとBr(η’→πππη)の誤差~3%



double gaussian + leaner func.

$Br=(-0.47^{+3.97}_{-3.85}+-0.26)\times10^{-6}$

90% CL upper limit: $Br<4.6\times10^{-6}$

$Br<7.4\times10^{-6}$
(BaBar)

まとめ

- Belle実験で収集された670fb^{-1}のデータを用いてセカンドクラスカレントによって引き起こされる$\tau \to \pi\eta\nu$崩壊の探索を行った。
  - η候補として$\eta \to \gamma\gamma$ だけではなく$\eta \to \pi\pi\pi^0$も使った。
  - η背景事象の評価にPDGではなく独自に測定した分岐比を使った。
  - 十分に信号は観測されず95%信頼度の上限値を評価し、Br<2.9x10^{-5} を得た。
- $\tau \to \pi\eta'\nu$の探索も同様に行い分岐比の上限値を90%の信頼度でBr<4.6x10^{-6}と設定した。

Expected BG for η cand.

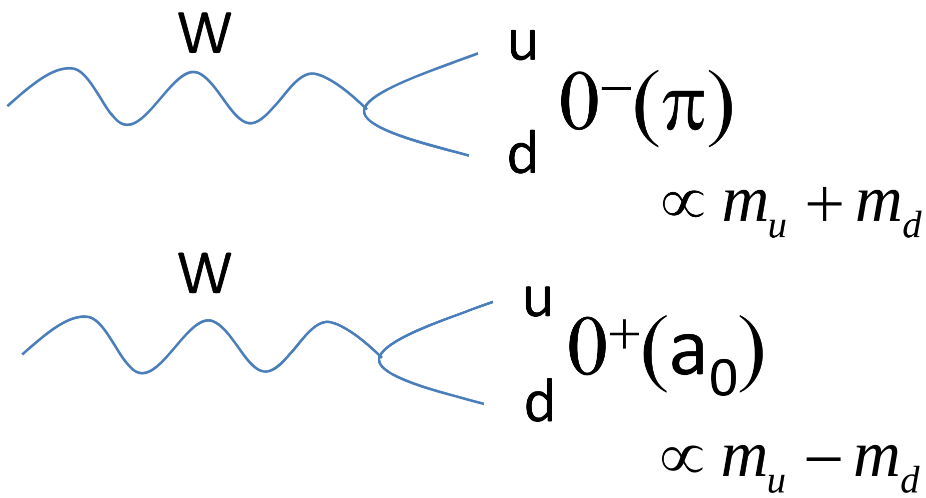
- Main BG events are expected to be τ decays including η in the final state and qq events.
  - Recently, $\tau\rightarrow K\eta\nu$, $\tau\rightarrow\pi\pi^0\eta\nu$, $\tau\rightarrow K^*\eta\nu$,... are measured with high accuracy.
    - $\tau\rightarrow K\eta\nu$ remains by mis-ID, $\tau\rightarrow\pi\pi^0\eta\nu$ remains by mis-π^0, $\tau\rightarrow K^*\eta\nu$ with $K^*\rightarrow\pi KL$ / KL is recognized as missing.
    - To evaluate them, Brs from our recent result are taken.
  - Basically, by requiring for the tag side track to be lepton, qq events are strongly rejected. And, qq events including η are evaluated with qq enriched data sample.

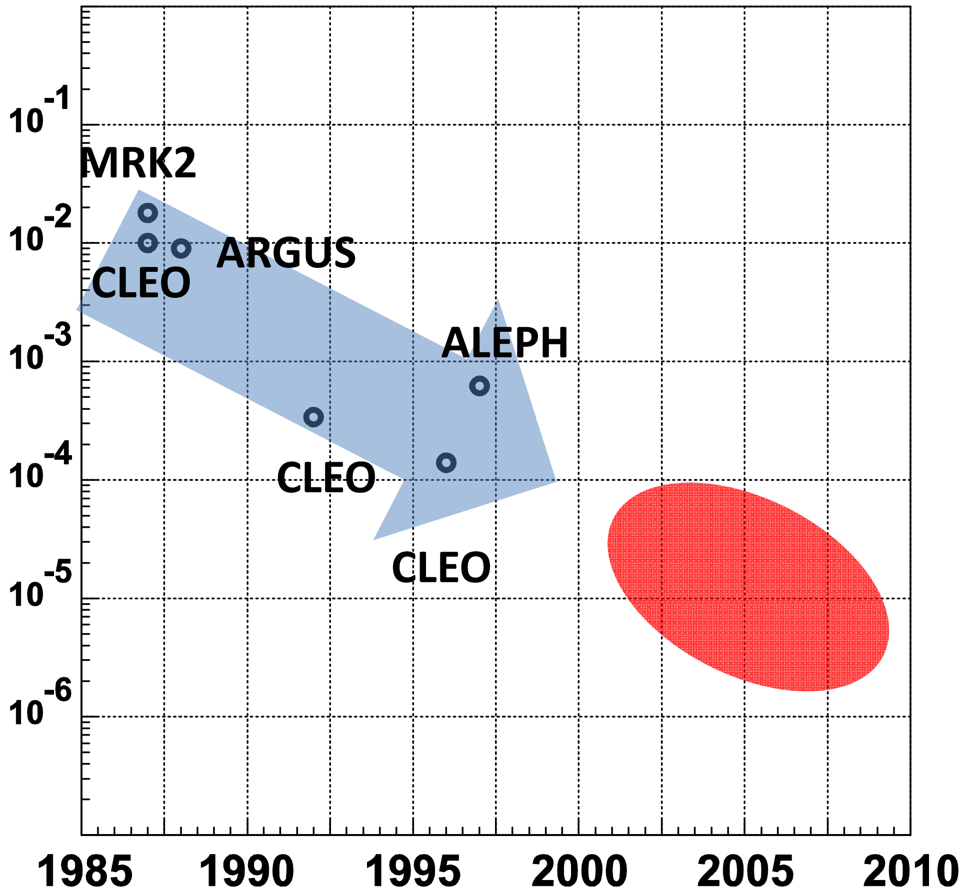
These uncertainties become main contribution of systematic uncertainties.

$\tau\rightarrow\pi\eta\nu$ is searched with $\eta\rightarrow\gamma\gamma$ as well as $\eta\rightarrow\pi\pi\pi^0$ decays.

Introduction

$\tau \rightarrow a_0 \nu$ decay is strongly suppressed by isospin symmetery. When isospin symmetry Is not broken, its BR should be zero.





$a_0 \rightarrow \pi\eta$:dominant (PDG08)

$\tau \rightarrow \pi\eta\nu$ has been searched:

Current UL@95% (PDG08)

$Br < 1.4 \times 10^{-4}$

Selection criteria

good charged track	$p_t > 0.06$ GeV$/c$, $-0.6235 < \cos\theta_{\rm trk} < 0.8332$ $p_t > 0.1$ GeV$/c$, $-0.8660 < \cos\theta_{\rm trk} \leq -0.6235$ or $0.8332 \leq \cos\theta_{\rm trk} < 0.9563$
good gamma	$E_\gamma > 0.05$ GeV, $-0.8660 < \cos\theta_\gamma < 0.9563$
	1–1 prong and net charge = 0
tag side	$N_\gamma^{\rm tag} \leq 1$, $M_{\rm tag} < 1.8$ GeV$/c^2$ μ-ID$_{\rm tag} > 0.8$ or e-ID$_{\rm tag} > 0.8$
signal side	$N_\gamma^{\rm sig} = 2$, $M_{\rm sig} < 1.8$ GeV$/c^2$ $E_\gamma > 0.1$ GeV for η daughters π-ID$^{\rm sig} > 0.9$, μ-ID$^{\rm sig} < 0.9$, e-ID$^{\rm sig} < 0.9$ $-0.6 < \cos\theta_{\pi^\pm}^{\rm sig} < 0.843$, $0.852 < \cos\theta_{\pi^\pm}^{\rm sig}$ $\cos\theta_{\pi^\pm-\gamma}^{\rm sig} < 0.995$
missing	$p_{\rm miss} > 1$GeV$/c^2$, $-0.8660 < \cos\theta_{\rm miss} < 0.9563$
likelihood cut	$L > 0.6$

To avoid qq, lepton and few gamma are required in tag side.
To avoid 2 photon, lepton is rejected in signal side.
To avoid K eta nu, ACC region is required in signal side.
Main BG is $\tau\tau$ event. To reduce them, likelihood is introduced.

BaBar's result

C. Limit on the $\tau^- \to \eta'(958)\pi^-\nu_\tau$ branching fraction

A limit on the $\tau^- \to \eta'(958)\pi^-\nu_\tau$ branching fraction can be set by searching for decays of the $\eta'(958)$ to the $\eta\pi^-\pi^+$ final state. This τ decay mode proceeds through a forbidden second-class current and is not expected to produce an observable signal [18].

A fit to the $\eta\pi^-\pi^+$ mass distribution is performed with a Gaussian function for the $\eta'(958)$ and a polynomial function for the background (see Fig. 4). The mean of the Gaussian is fixed to the mass of the $\eta'(958)$ meson. The width of the Gaussian distribution is fixed to the value obtained in a fit to a data sample containing a significant number of $\eta'(958)$ mesons. This data sample is created by removing all selection criteria except the loose preselection described in Sec. II.

We observe 19 ± 13 candidates which gives a $\tau^- \to \eta'(958)\pi^-\nu_\tau$ branching fraction of $(4.1 \pm 2.4) \times 10^{-6}$ where the error is statistical. To set a limit, we treat all of the events in the $\eta'(958)$ peak as signal; in particular, the branching fraction of the allowed $\tau^- \to \eta'(958)K^-\nu_\tau$ channel is assumed to be zero. We assume that the efficiency for selecting $\tau^- \to \eta'(958)\pi^-\nu_\tau$ events is the same as the $\tau^- \to f_1(1285)\pi^-\nu_\tau$ selection efficiency. The systematic uncertainty is dominated by a 7% error due to the uncertainty in the mass resolution of the $\eta'(958)$. The remaining systematic errors are the same as those described in the previous section. The results give a 90% confidence level upper limit on the $\tau^- \to \eta'(958)\pi^-\nu_\tau$ branching fraction of 7.2×10^{-6}.

A 90% confidence level upper limit on the branching fraction of the $\tau^- \to \eta'(958)\pi^-\nu_\tau$ decay is measured to be 7.2×10^{-6}. This is an order of magnitude lower than the previous 90% confidence level upper limit of 7.4×10^{-5} set by the CLEO Collaboration [2]. No significant evidence for this second-class current decay mode of the τ is observed.

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Br=$(4.1\pm 2.4)\times 10^{-6}$

Br<7.2×10^{-6} w/o systematics

$4.1+2.4\times 1.28=7.17$