Selected electroweak results using τ leptons at BABAR

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(on behalf of BABAR Collaboration)

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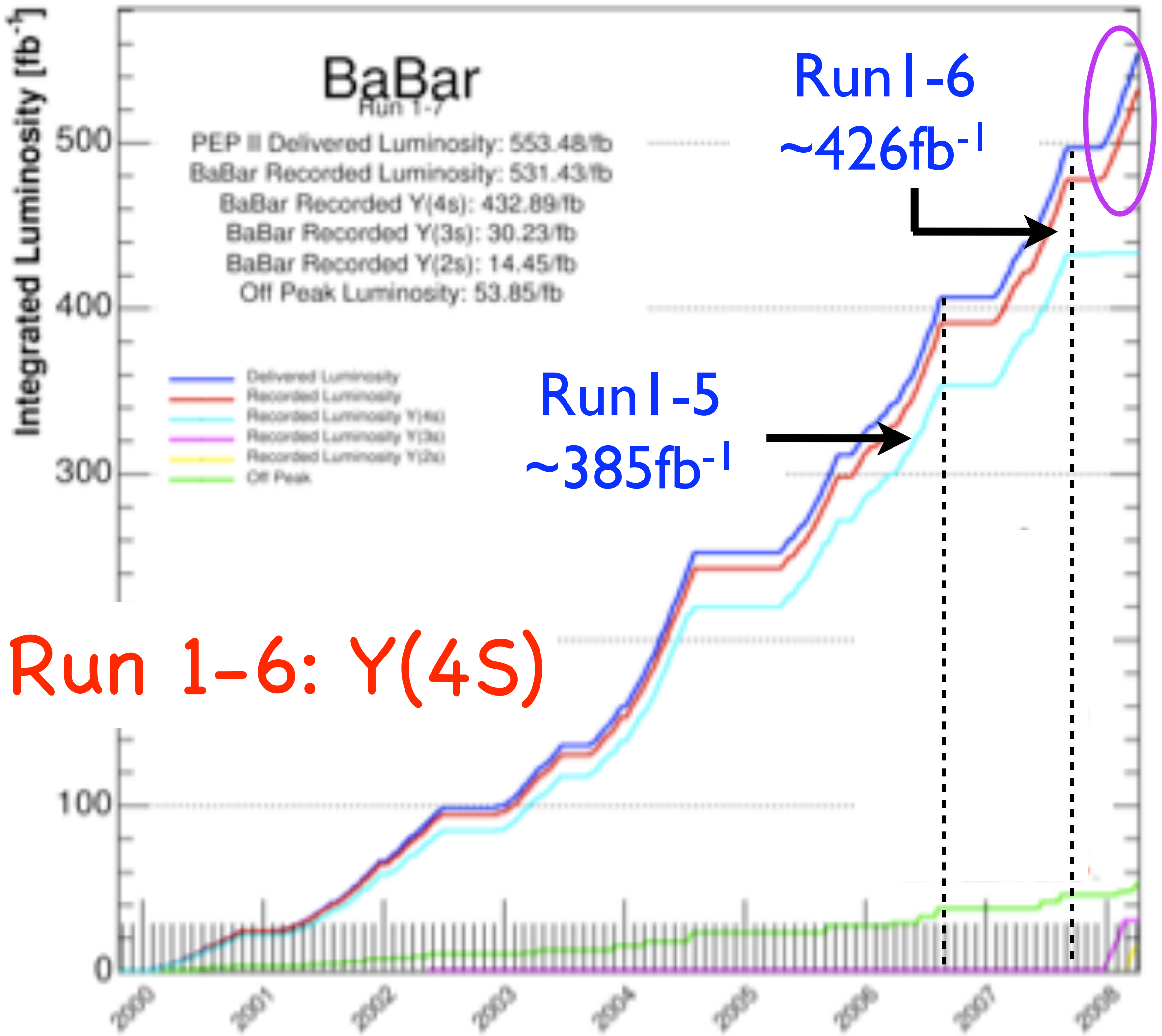
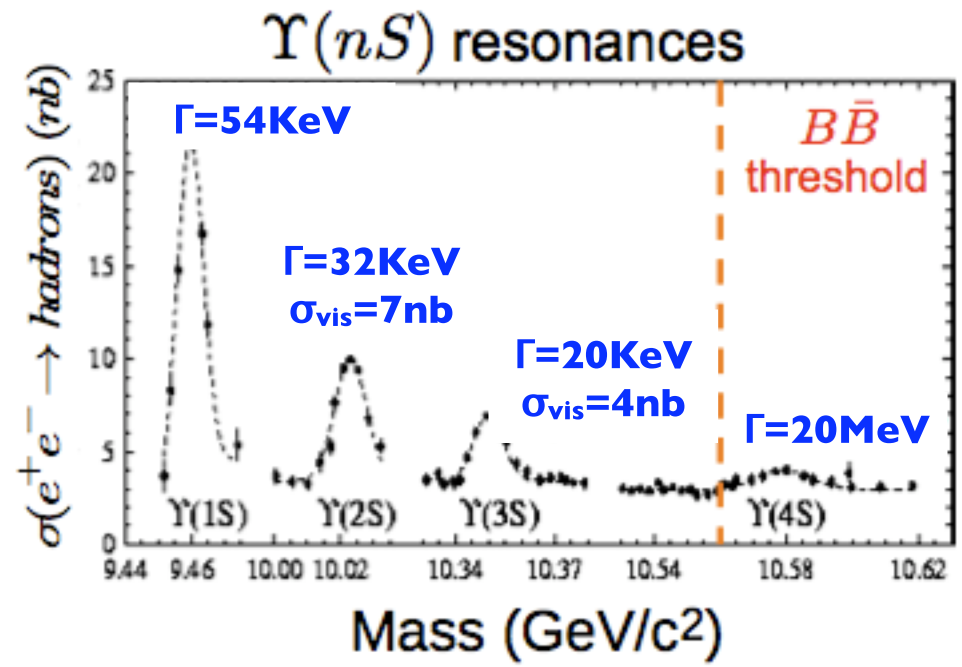
Outline

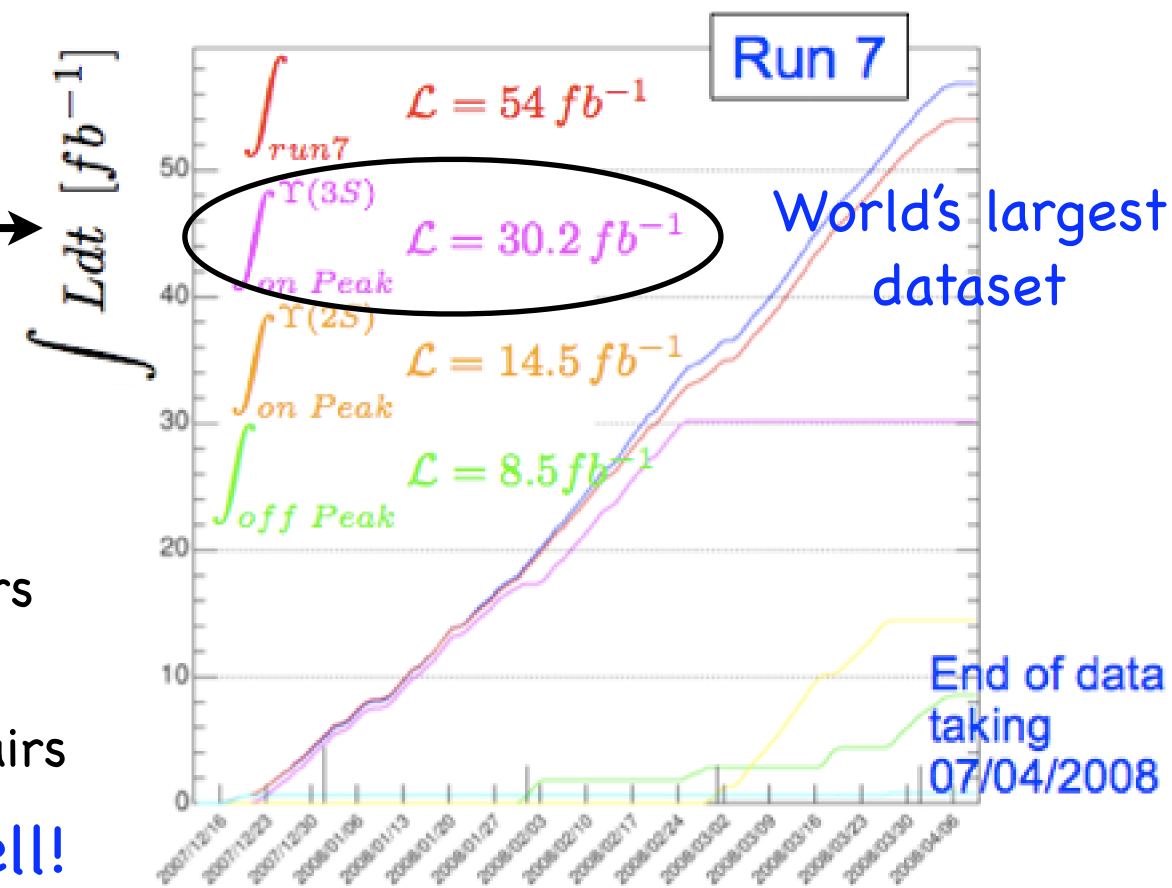
- ✓ Some recent results from BABAR on:
  - ✓ Lepton Universality test in Υ(1S) decays → FPCP '09
  - ✓ $BR(\tau^- \to \bar{K}^0 \pi^- \nu_\tau)$ measurement — arXiv:0808.1121 → Tau '08
  - ✓ Precision measurement of: → Tau '08
    - ✓ τ mass → Tau '08
    - ✓ τ^+-τ^- mass difference → Tau '08
- ✓ Conclusions

BABAR data samples

- ✓ PEP-II asymmetric energy e^+e^--collider operating at the Υ resonances
- ✓ BABAR recorded luminosity







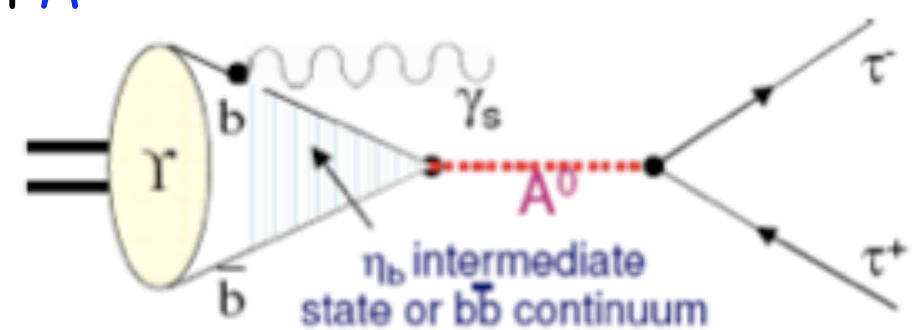
- ✓ $\sigma(e^+e^- \to b\bar{b})$ @ Υ(4S) ~ 1.05 nb ⇒ ~ $4.4 \cdot 10^8$ $b\bar{b}$ pairs
- ✓ $\sigma(e^+e^- \to \tau^+\tau^-)$ @ Υ(4S) ~ 0.92 nb ⇒ ~ $3.9 \cdot 10^8$ $\tau^+\tau^-$ pairs

⟶ BABAR is a τ-factory as well!

Lepton Universality Test

1. Theory

- ✓ In the SM couplings between gauge bosons and leptons are independent of lepton flavour
- ✓ SM expectation for $R_{ll'} = BR(\Upsilon(1S)\to l^+l^-)/BR(\Upsilon(1S)\to l'^+l'^-)$ is 1 (except for small lepton-mass effects, $R_{\tau\mu} \sim 0.992$)
- ✓ NMSSM: deviations of $R_{ll'}$ from SM expectation are possible in the hypothesis of existence of a light pseudo-scalar Higgs boson A^0
- ✓ A^0 may mediate the decay chain of the $\Upsilon(1S)$:



$$\Upsilon(1S)\to A^0\gamma,\ A^0\to l^+l^- \quad (1)$$

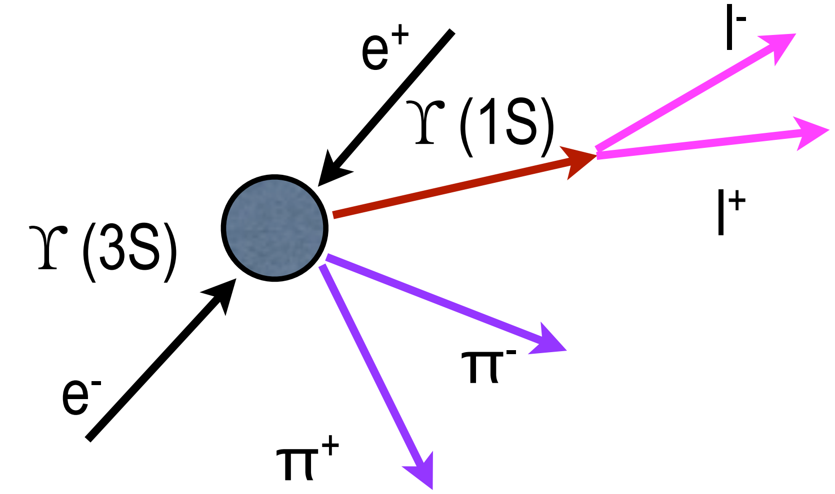
$$\Upsilon(1S)\to \eta_b\gamma,\ \eta_b\to A^0\to l^+l^- \quad (2)$$

Int.J.Mod.Phys.A19, 2183 (2004); Phys.Lett B653, 67 (2007)

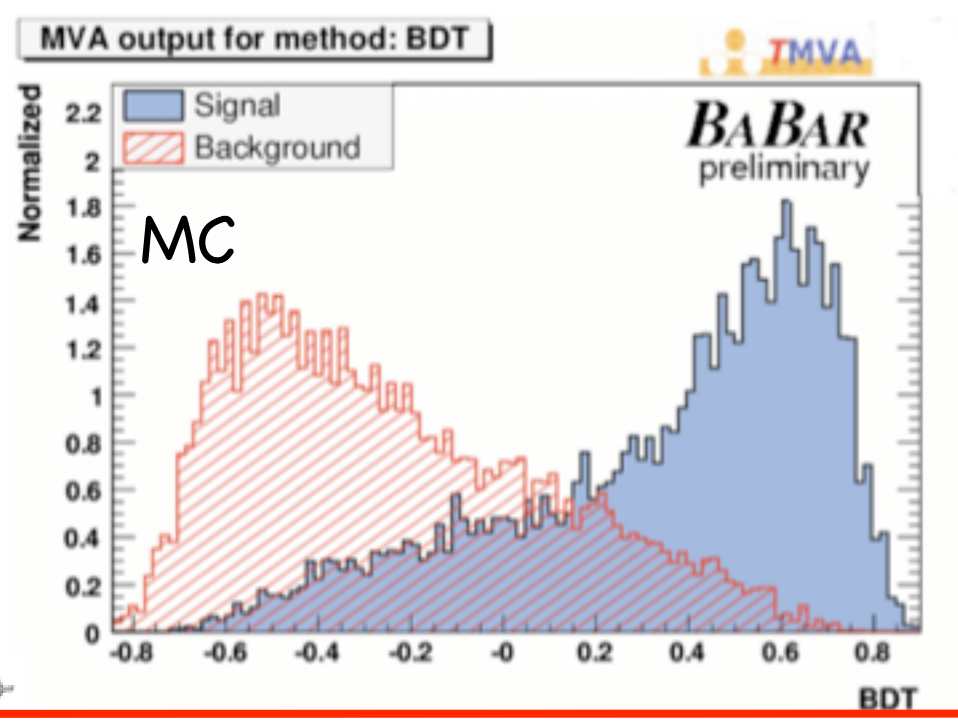
- ✓ If the photon is undetected, the lepton pair would be ascribed to the $\Upsilon(1S)$
- ✓ It can result in a deviation of $R_{ll'}$ from SM expectation (lepton universality breaking) →NP effect
- ✓ Effect more evident when one of the leptons is a τ (up to 10%) → $R_{\tau\mu}$

2. Strategy

- ✓ 28 fb^{-1} of data collected at $\Upsilon(3S)$ CM energy → ~ $122 \cdot 10^6$ $\Upsilon(3S)$
- ✓ Tag $\Upsilon(1S)$ exploiting $\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-$, $\Upsilon(1S)\to\tau^+\tau^-$ and $\mu^+\mu^-$ events:
  - ✓ $BF(\Upsilon(3S)\to\Upsilon(1S)\pi^+\pi^-) \sim 5\%$
  - ✓ select τ 1-prong decays
  - ✓ 4-charged tracks final state topology



- ✓ Separate selections for $\Upsilon(1S)\to\tau^+\tau^-$ (D_τ) and $\mu^+\mu^-$ events (D_μ)
- ✓ A multivariate analysis approach in $\tau^+\tau^-$ channel



- ✓ Signal extraction efficiencies (estimated on MC simulations):

$$\epsilon_{\mu\mu} \sim 45\%$$

$$\epsilon_{\tau\tau} \sim 17\%$$

3. Signal extraction

- Extended and unbinned maximum-likelihood fit:
  - in D_μ a 2-dim likelihood based on ΔM and $M_{\mu+\mu-}$
  - in D_τ a 1-dim likelihood based on $M_{\pi+\pi-}^{reco}$

$\Delta M = M(\Upsilon(3S)) - M(\Upsilon(1S))$

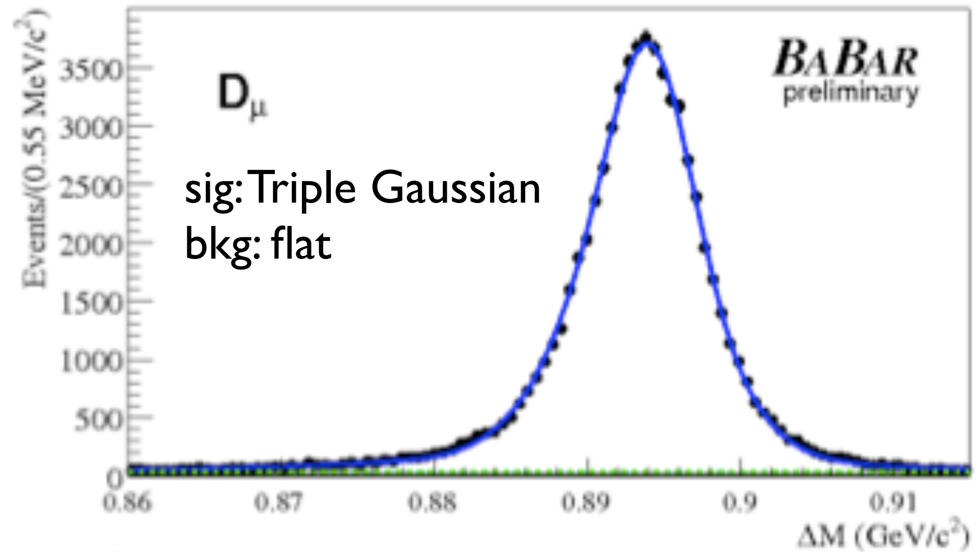
$M_{\mu+\mu-}$ invariant $\mu^+\mu^-$ mass

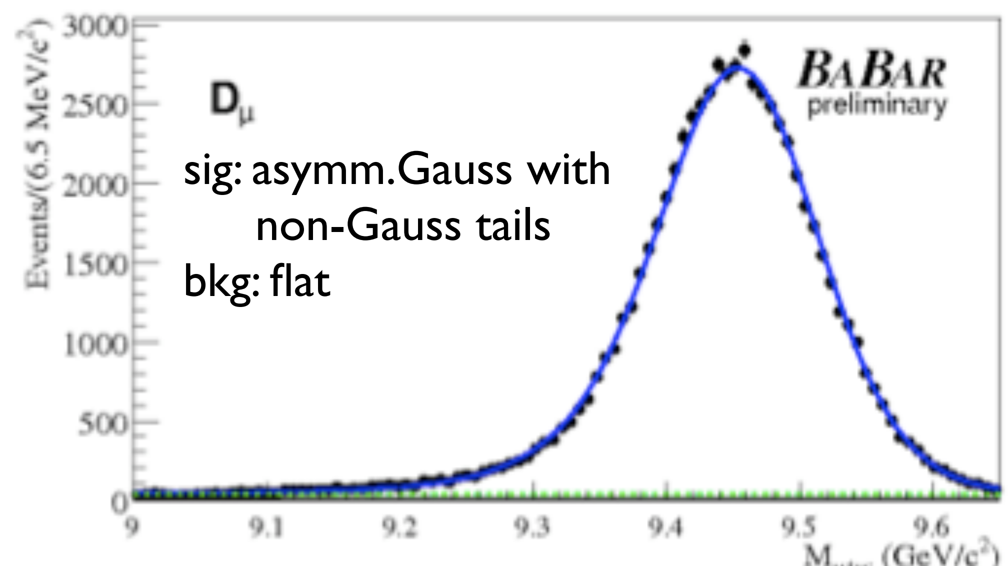
$$M_{\pi+\pi-}^{reco} = \sqrt{s + M^2_{\pi^+\pi^-} - 2 \cdot s \cdot \sqrt{M^2_{\pi^+\pi^-} + p^2_{\pi^+\pi^- CM}}}$$

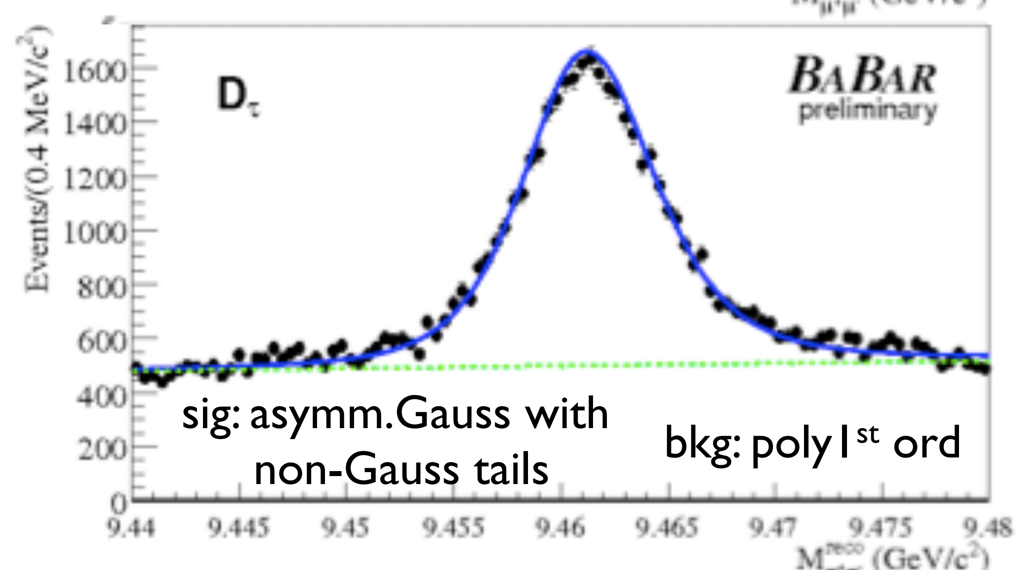
- Fit performed simultaneously to the 2 datasets
  - signal PDFs fixed
  - bkg PDFs floating
- $R_{\tau\mu}$ returned

dashed line: bkg

solid line: signal+bkg







4. Results

- Correction for known differences between data and simulation efficiencies
- Systematic uncertainty contributions (up to 2.4%):
  - event selection efficiency;
  - particle identification (for μ leptons);
  - trigger efficiency;
  - imperfect knowledge of signal and bkg shapes.

Still working to reduce systematics

- **BABAR preliminary**:

$R_{\tau\mu}(\Upsilon(1S))$: 1.009 ± 0.010 (stat.) ± 0.024 (syst.)

[Previous best result: $R_{\tau\mu}(\Upsilon(1S))$: 1.02 ± 0.02 (stat.) ± 0.05 (syst.) by CLEO]

Phys.Rev.Lett.98, 052002 (2007)

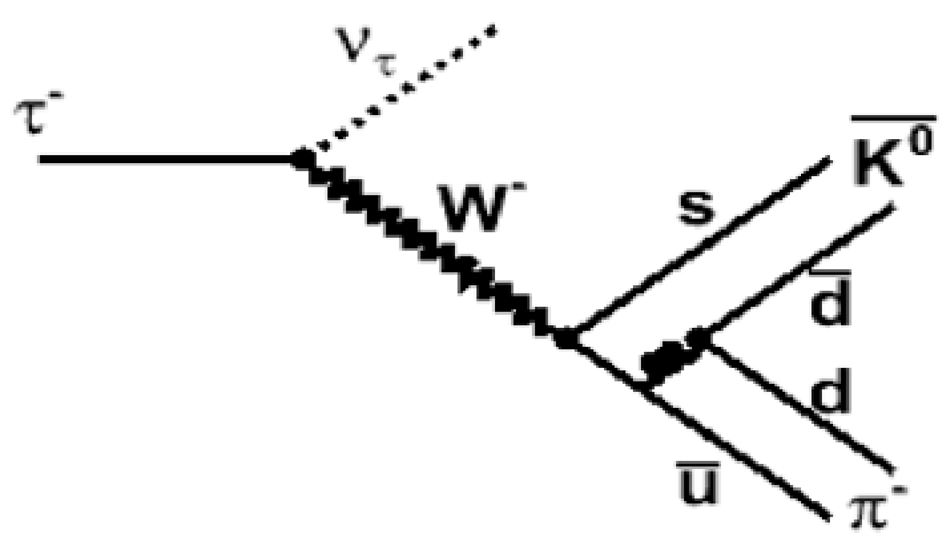
- Sensitive improvement in precision

No significant deviations w.r.t. SM expectations

Measurement of BF($\tau^- \to \bar{K}^0 \pi^- \nu_\tau$)

1. Motivations

- ✓ Hadronic τ decays: access to vector (V) and axial-vector (A) spectral functions → insight into QCD dynamics at intermediate scales and test of SM
- ✓ Hadrons from τ decays are produced via a W emission
- ✓ Strangeness changing τ decays are suppressed relative to Cabibbo-allowed modes
- ✓ Resonant decay dominates ($K^* \to K\pi$ for V current, $K_1 \to K\rho$ (or $K^*\pi \to K\pi\pi$) for A current)



- ✓ Previous measurements by
  - ALEPH Eur.Phys.J. C22, 31 (2001)
  - CLEO Phys.Rev.Lett 90, 181802 (2003)
  - and OPAL Eur.Phys.J. C35, 437 (2004)
  - (limited by statistics)

Belle $351 fb^{-1}$

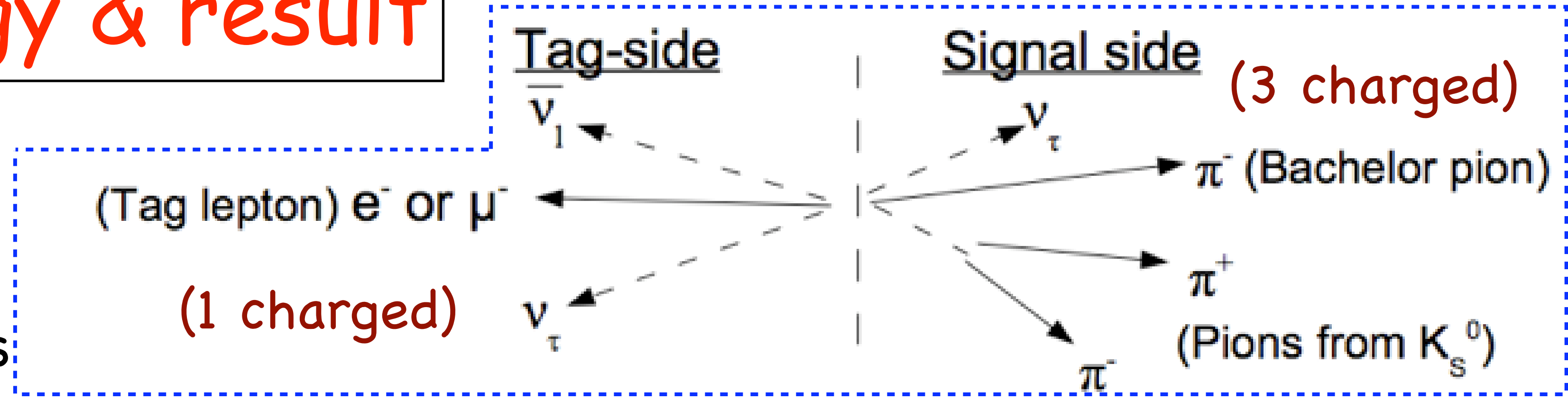
- ✓ Best measurement by BELLE Phys.Lett B654, 65 (2007)

$$\mathcal{B}(\tau^- \to \bar{K}^0 \pi^- \nu_\tau) = (0.808 \pm 0.004(\text{stat.}) \pm 0.026(\text{syst.}))\%$$

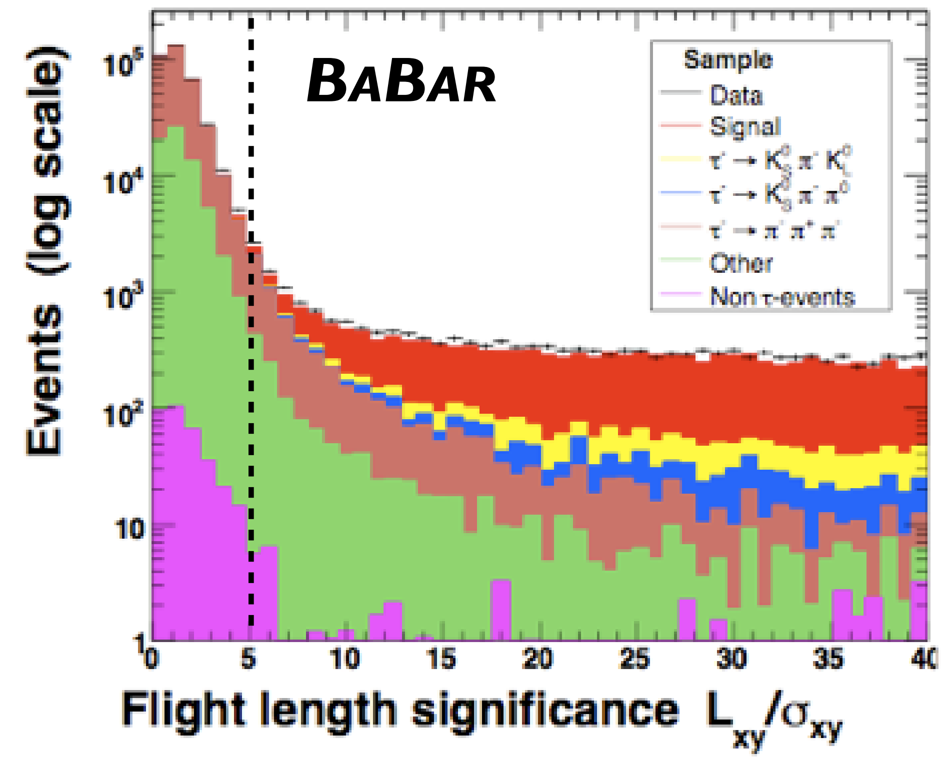
- ✓ BABAR exploits $385 fb^{-1}$ of statistics → ~ $3.5 \cdot 10^8$ events

2. Strategy & result

- ✓ Only looking for $\tau^- \to K_S^0 \pi^- \nu_\tau$ ($K_S^0 \to \pi^+\pi^-$) final states
- ✓ Event divided in two hemispheres



- ✓ Event selection reduces non-τ bkg, Bhabha and μ-pair events with a converted photon, and $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ events (rejected at 90% thanks to a cut on K_S^0 flight length significance)
- ✓ Main sources of bkg: $\tau^- \to K_L^0 K_S^0 \pi^- \nu_\tau$ and $\tau^- \to \pi^0 K_S^0 \pi^- \nu_\tau$ (additional neutrals undetected)
- ✓ After the selection: signal purity ~80% and efficiency ~1.1%
- ✓ Efficiency corrections needed (due to particle identification and K_S^0 reconstruction efficiency)
- ✓ Systematics uncertainty up to 2.72% (main contributions: particle ID and tracking)



- ✓ Measurement of the branching fraction (combining e-and μ-tag):

$$BR(\tau^- \to \overline{K}^0 \pi^- \nu_\tau) = (0.840 \pm 0.004(\text{stat.}) \pm 0.023\ (\text{syst.}))$$

BABAR preliminary the world's most precise single measurement

Analysis of the $K_S^0\pi^-$ mass spectrum on-going

Precision measurement of τ mass and τ^+-τ^- mass difference

1. Motivations & method

- ✓ CPT invariance fundamental symmetry of SM
- ✓ Measurement of differences in mass (or lifetime) between particles and their anti-particles is the most common CPT test
- ✓ In **BABAR** with τ leptons
- ✓ Current best values:

$M_\tau = (1776.84 \pm 0.17)\ \mathrm{MeV}/c^2$

$$\frac{M(\tau^+) - M(\tau^-)}{M_{Average}} < 2.8 \cdot 10^{-4}$$

[PDG '08]

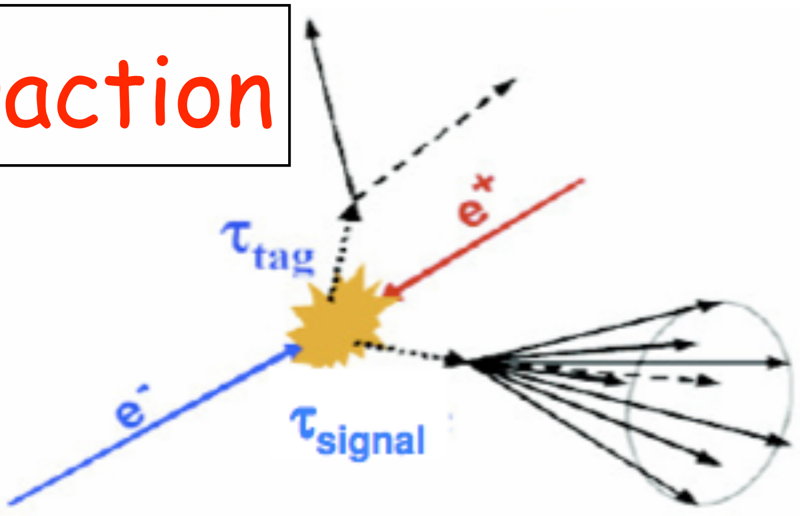
- ✓ Pseudomass endpoint measurement (ARGUS Phys.Lett. B292, 221 (1992) and BELLE Phys.Rev.Lett. 99, 011801 (2007))
- ✓ For hadronic τ decays: $\tau^\pm \to h^\pm \nu_\tau$ (h is the total hadronic system)

$$M_\tau = \sqrt{M_h^2 + 2(\sqrt{s}/2 - E_h^*)(E_h^* - P_h^* \cos\theta^*)}$$

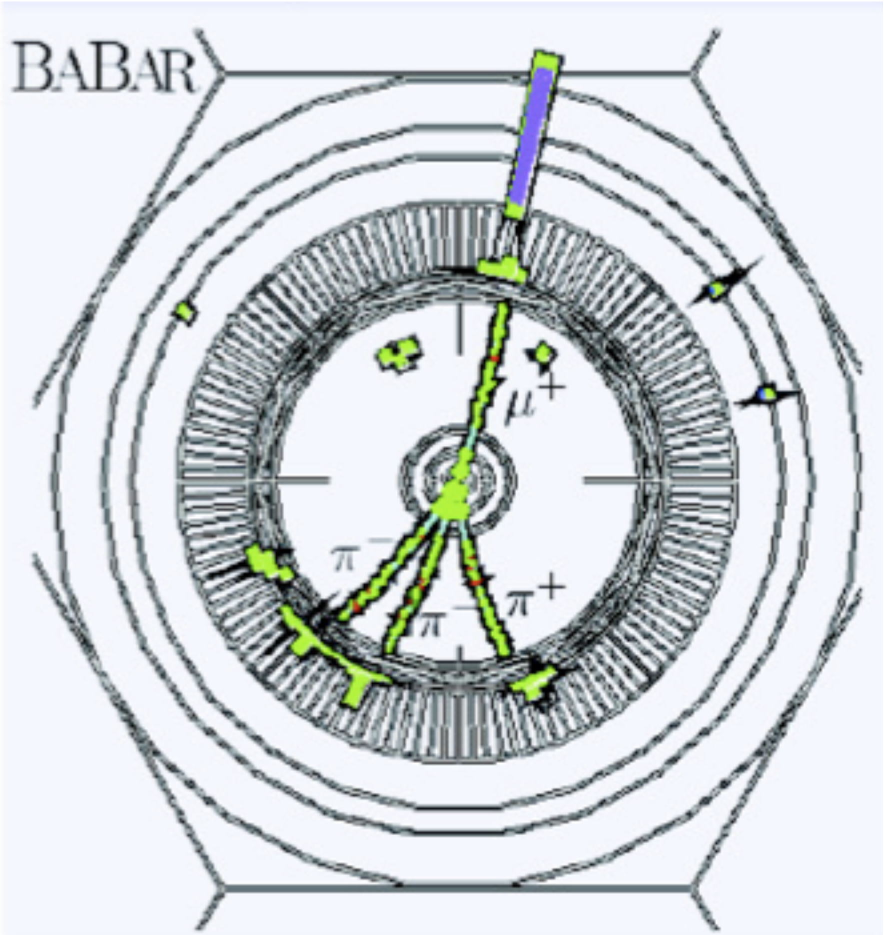
$$M_p \equiv \sqrt{M_h^2 + 2(\sqrt{s}/2 - E_h^*)(E_h^* - P_h^*)} \le M_\tau$$

- ✓ $M_p = M_\tau(\vartheta^*=0)$
- ✓ Sharp kinematic cutoff at $M_p = M_\tau$
- ✓ Smearing due to ISR/FSR and detector resolution

2. Event selection & signal extraction



- $423\ fb^{-1}$ of data collected at the $\Upsilon(4S)$ energy
- Events well separated in the space:
- Select $\tau^\pm \to \pi^\pm\pi^+\pi^-\nu_\tau$ [BR~(8.99±0.06)%; high signal purity; large statistics in endpoint region]
- Leptonic tag

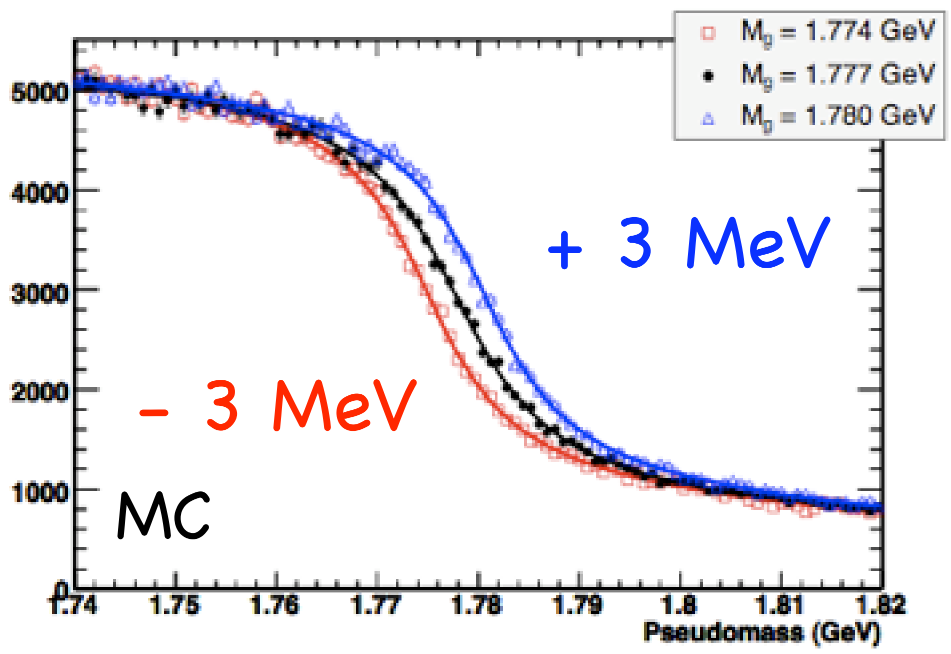


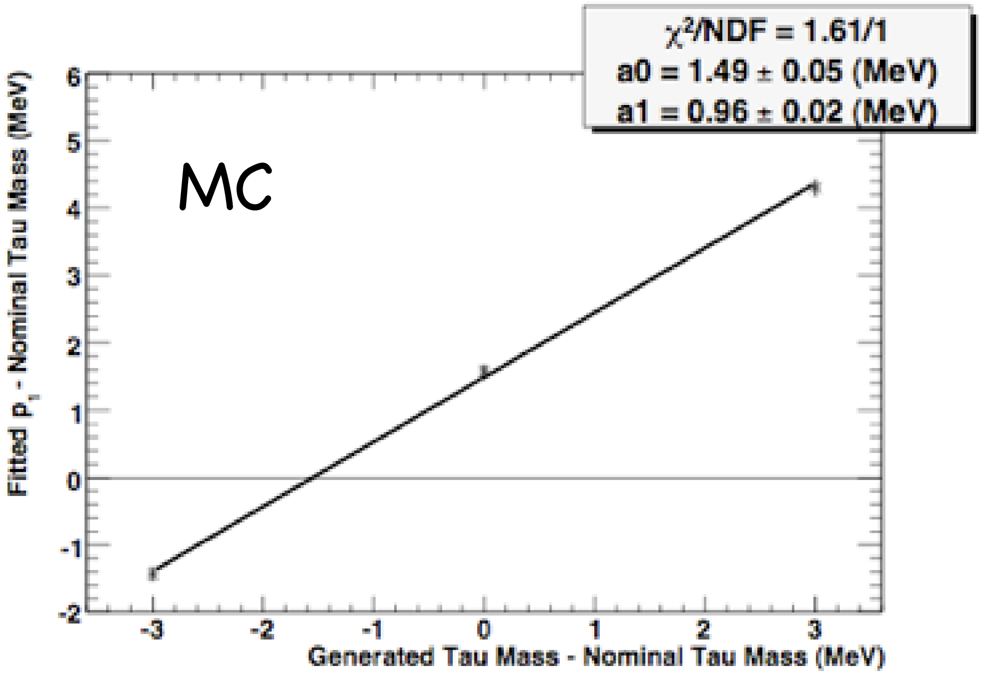
typical τ event in BABAR

- Charged and neutral kaons and protons vetoed
- 3 tracks not identified as a lepton on the signal side
- Less than 5 photons and total neutral energy < 300 MeV
- Signal efficiency ~2.0% in the signal region
- Purity ~96% in the signal region
- To determine the endpoint from M_P distribution this empirical fit function is used:

$$F(x) = (p_3 + p_4 x)\tan^{-1}\left(\frac{p_1 - x}{p_2}\right) + p_5 + p_6 x$$ (BELLE)

- Relation between M_P endpoint and M_τ determined with Monte Carlo simulations





- Linear relationship with a slope of unity and y-intercept=0 is expected
- ISR/FSR and imperfect detector resolution → non-zero offset, used to determine M_τ from the endpoint fit to data
- Several cautions to take into account the possible bad reconstruction of tracks momenta

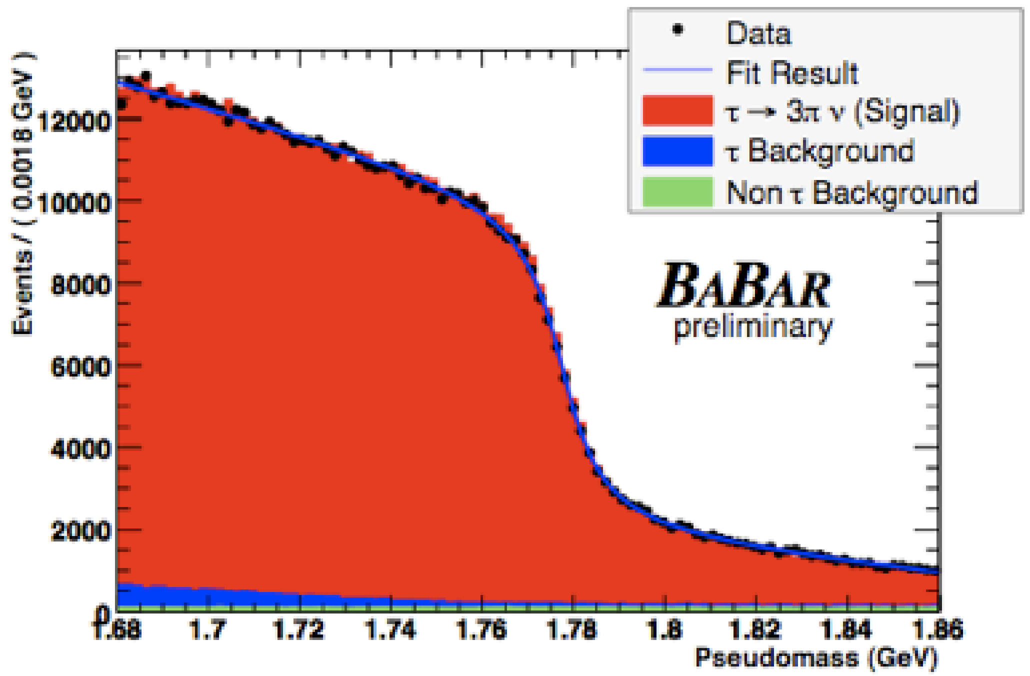
Detector Parameter	p_1 Shift (MeV)
SVT Material +20.0 %	+0.30
Sol Field +0.02 %	+0.10
B1/Q1 Field +20.0 %	+0.20
Correction	+0.60
Systematic	0.39

Table 4: Total systematics

Systematic	Uncertainty
MC Statistics	0.05
Parameterization	0.03
Fit Range	0.05
Beam Energy	0.09
Boost	0.00
Resolution	0.00
MC Modeling	0.05
ν_τ Mass	0.00
ϕ Dependence	0.00
Tracking Bias	0.39
Total	0.41

- Bias in momentum scale reconstruction is the greatest systematic uncertainty contribution

3. Result

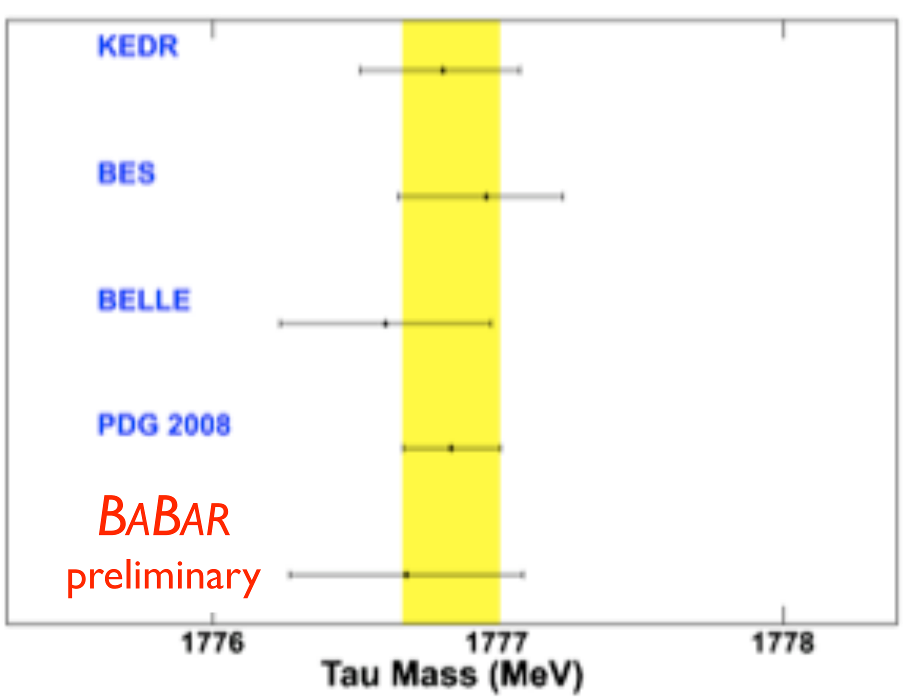


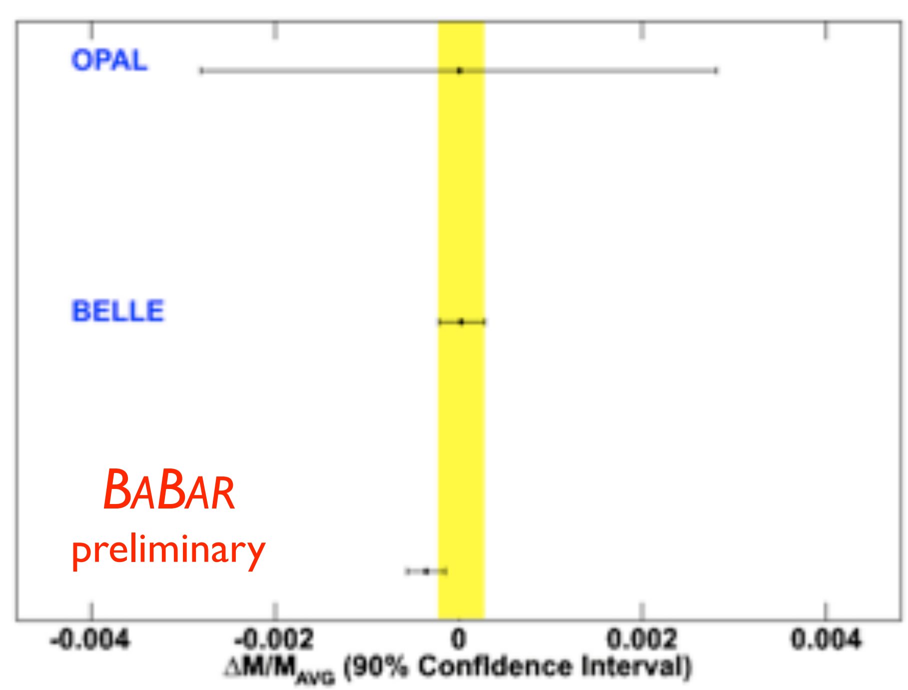
- ✓ Data split in 2 samples (based on the total 3π charge)
- ✓ Both average and separate measurements of $M(\tau^+)$ and $M(\tau^-)$

$$M_\tau = (1776.68 \pm 0.12(\text{stat.}) \pm 0.41(\text{syst.}))\ \text{MeV}/c^2$$

$$\frac{M(\tau^+) - M(\tau^-)}{M_{Average}} = (-3.5 \pm 1.3) \cdot 10^{-4}$$

- ✓ Comparison with previous measurements for average τ mass and τ^+–τ^- mass difference





Conclusions

- BABAR data are a rich harvest for electroweak physics results:
  - several important (and different) tests on SM are possible exploiting the data collected
- Now finalizing most of the analyses using the full dataset at Υ(4S) energy
- Υ(3S) and Υ(2S) datasets will yield important results, in many fields but also for electroweak physics
- Preliminary results on:
  - Lepton Universality in Υ(1S) decays
  - BR($\tau^- \to \overline{K}^0 \pi^- \nu_\tau$) measurement
  - τ mass and τ^+-τ^- mass difference
- Final results awaited for soon. Stay tuned!

BACKUP SLIDES

The BaBar detector

Cherenkov Detector

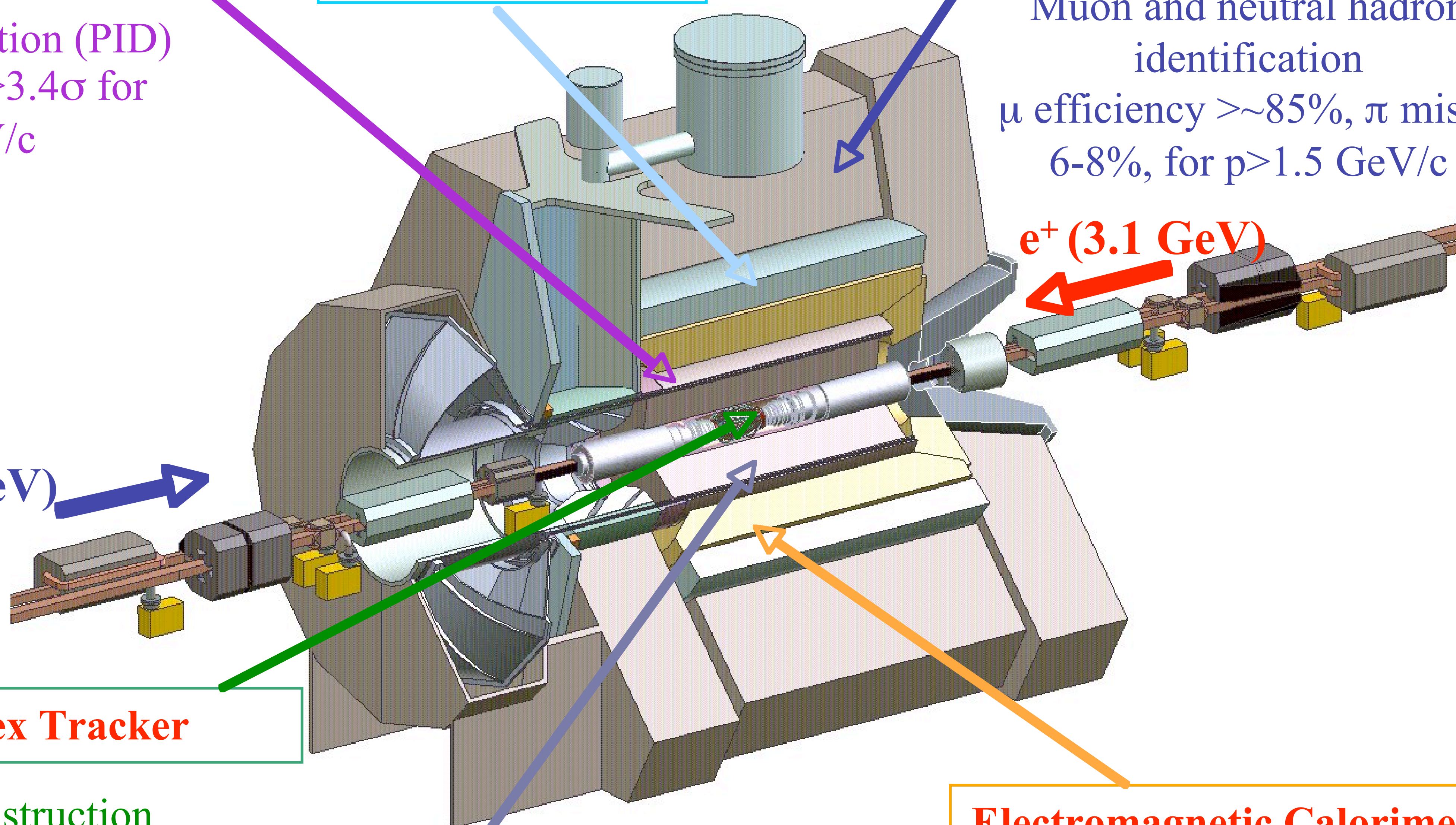
Particle identification (PID)
K-π separation >3.4σ for
p<3.5GeV/c

Solenoid 1.5T

Instrumented Flux Return

Muon and neutral hadron identification
μ efficiency >~85%, π mis-id 6-8%, for p>1.5 GeV/c

e^- (9 GeV)



Silicon Vertex Tracker

Vertex reconstruction
and tracking + dE/dx.
Efficiency ~ 97%

Drift Chamber

Momentum measurement for
charged particles + dE/dx.
$\sigma(p_T)/p_T = 0.13\% p_T \oplus 0.45\%$

Electromagnetic Calorimeter

Electron and photon energy
measurement. $\sigma(E)/E = 1.33\% E^{-1/4} \oplus 2.1\%$

Lepton Universality

- Likelihood written as:

$$\mathcal{L}_{ext} = \frac{e^{-N'}(N')^N}{N!}\prod_{i=1}^{N}\mathcal{P}_i$$

where $\mathcal{P}_i$ is:

$$\mathcal{P}_i \equiv N_\mu \mathcal{P}_i^{\mu\mu}(\Delta M, M_{\mu^+\mu^-}) + N_{bkg\mu}\mathcal{P}_i^{bkg\mu}(\Delta M, M_{\mu^+\mu^-}) +$$
$$+\frac{\epsilon^{D_\tau}_{\tau\tau}}{\epsilon^{D_\mu}_{\mu\mu}} N_\mu R_{\tau\mu}\mathcal{P}_i^{\tau\tau}(M^{reco}_{\pi^+\pi^-}) + N_{bkg\tau}\mathcal{P}_i^{bkg\tau}(M^{reco}_{\pi^+\pi^-})$$

- Asymmetric Gaussian with non-Gaussian tails functional form:

$$\mathcal{F}(x) = exp\Big\{-\frac{(x-\mu)^2}{2\sigma^2(L,R)+\alpha(L,R)(x-\mu)^2}\Big\}$$

- Summary of systematic uncertainties:

	$\mu^+\mu^-$	$\tau^+\tau^-$
event selection	1.5%	
PID	0.6%	—
Trigger	0.18%	0.10%
BGF	negl.	negl.
$P.d.f.$'s parameters	1.7%	
Bkg $p.d.f.$	0.28%	
Agreement $\mu^+\mu^-$ $vs.$ $\tau^+\tau^-$ in $MassPiPiReco$	—	0.10%
MC statistics	0.08%	0.09%
TOTAL	2.4%	
Corrections :		
PID	1.023	—
Trigger	—	1.020

Measurement of BF($\tau \rightarrow K^0 \pi^- \nu_\tau$)

- Summary of event selection:
  - K_S^0 reco from 2 oppositely charged tracks with a mass within 25MeV of the PDG value
  - K_S^0 transverse flight length significance $L_{xy}/\sigma_{xy} > 5$ (to reduce (@90% level) the # of $\tau^- \to \pi^-\pi^+\pi^-\nu_\tau$ events)
  - π^+-π^- nearest point < 0.2 cm (to increase the likelihood they come from a K_S^0)
  - $|\cos\theta_{hel}| < 0.97$ (to reduce the # of converted γ)
  - Event neutral energy < 0.5 GeV and signal side neutral energy < 0.25 GeV (to reduce the # of $\tau^- \to K_S^0\pi^0\pi^-\nu_\tau$ and $\tau^- \to K_S^0K_L^0\pi^-\nu_\tau$ events)
- Summary of systematic uncertainties:

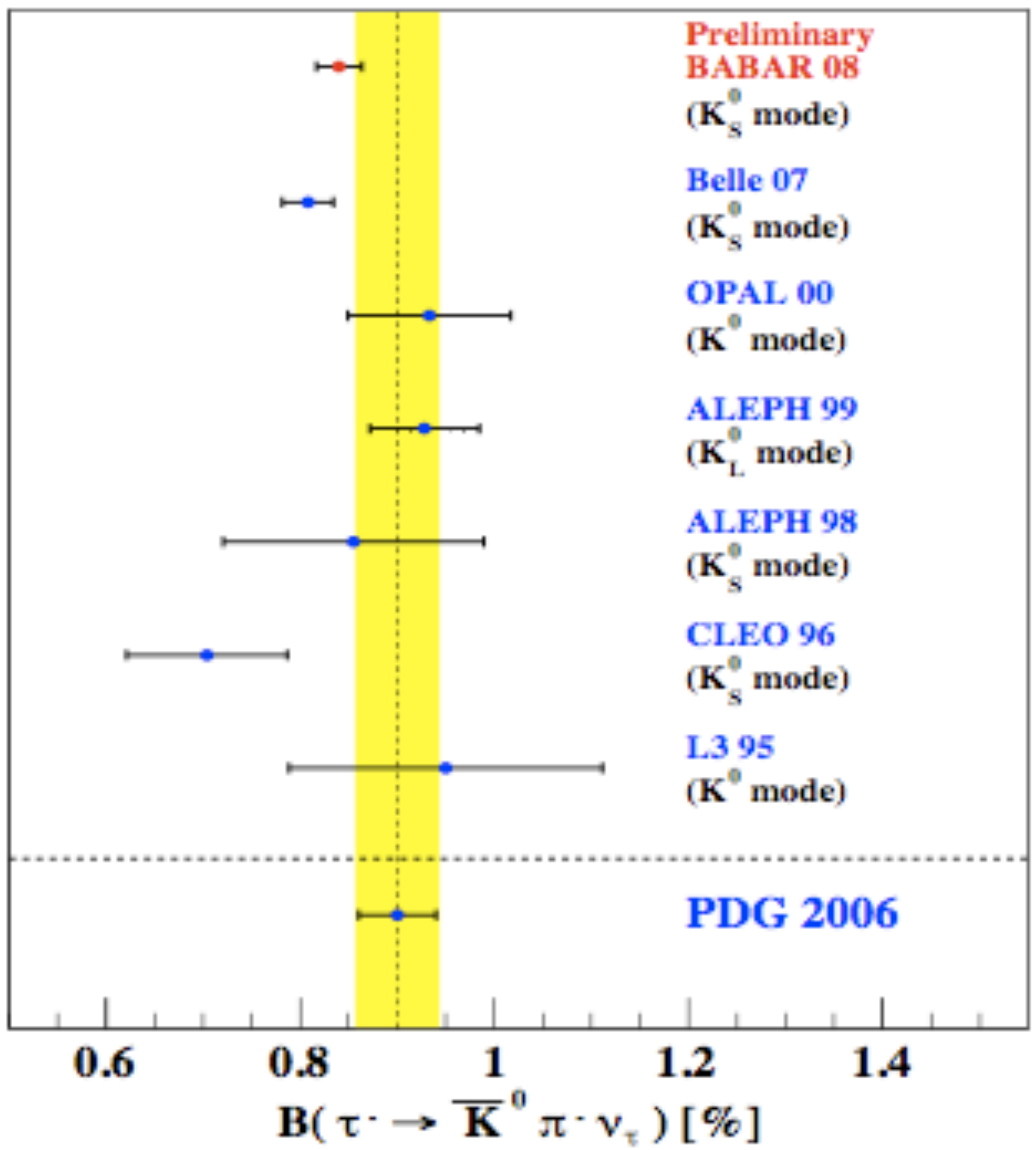
Table 2: Summary of the systematic uncertainties as they feed into the measurement of $\mathcal{B}(\tau^- \to K^0\pi^-\nu_\tau)$

Systematic	e-tag	μ-tag	Combined
Tracking	0.58%	0.58%	0.58%
K_S^0 Efficiency	1.40%	1.40%	1.40%
PID	1.45%	1.68%	1.50%
$\mathcal{L} \times \sigma_{\tau\tau}$	0.83%	0.83%	0.83%
Statistical efficiency error	0.51%	0.56%	0.38%
MC background statistics	0.28%	0.30%	0.20%
τ backgrounds	1.37%	1.37%	1.37%
Modelling efficiency	0.37%	0.37%	0.37%
Total	2.73%	2.87%	2.72%

✓ $BR(\tau \to K^0 \pi^- \nu_\tau) = 1/2N_{\tau\tau} \cdot (N_{data} - N_{bkg})/\epsilon_{sig}$

[$N_{\tau\tau}$ # of $\tau^+\tau^-$ pairs in real data;
N_{data} # of selected ev. in real data;
N_{bkg} # of bkg ev. estimated on MC;
ϵ_{sig} signal efficiency]

$N_{\tau\tau} = \sigma_\tau \cdot \mathcal{L}_{data} = (353.4 \pm 2.3) \cdot 10^6$



Precision measurement of τ mass and τ^+-τ^- mass difference

- Summary of tracking bias:

Detector Parameter	p_1 Shift (MeV)
SVT Material +20.0 %	+0.30
Sol Field +0.02 %	+0.10
B1/Q1 Field +20.0 %	+0.20
Correction	+0.60
Systematic	0.39

- Energy loss in material (SVT) underestimation:
  - K_S^0 control sample (non-zero flight length, useful to probe uncertainty in the detector material looking at the reconstructed K_S^0 mass at different decay lengths)
  - Several possibilities studied: best option is increasing the amount of SVT material of 20%
- Solenoidal field: very accurately measured (0.02%)
- Final beam-bending magnets show a variation in the permeability of 20%
- Shifts due to the increased tracking volume material, solenoidal field and final bending magnets in quadrature to determine the systematic due to the tracking bias
- Almost all the syst. cancel out when measuring the mass difference
  - π^+ and π^- different interaction with the detector material
  - effect evaluated comparing the reconstructed mass of some well measured hadronic resonances ($D^+ \to K^-\pi^+\pi^-$, $D^+ \to \phi\pi^+$, $D_s^+ \to \phi\pi^+$)