Lepton Universality Test in $\Upsilon(1S)$ decays at BABAR

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Outline:

- ✓ Theoretical motivations
- ✓ Previous measurement
- ✓ BABAR analysis
- ✓ Future developments

Theoretical motivations (I)

- In the SM couplings between gauge bosons and leptons are independent of lepton flavour

- BR(Υ(1S)→l^+l^-) does not depend on the lepton considered

$$\Gamma^{(em)}_{\Upsilon\to\ell\ell} = 4\alpha^2 Q_b^2 \frac{|R_n(0)|^2}{m_\Upsilon^2}(1+2x_\ell)(1-4x_\ell)^{1/2}$$

- $R_n(0)$ non-relativistic radial wave function of the $b\bar{b}$ state
- $x_\ell = m_\ell^2/m_\Upsilon^2$

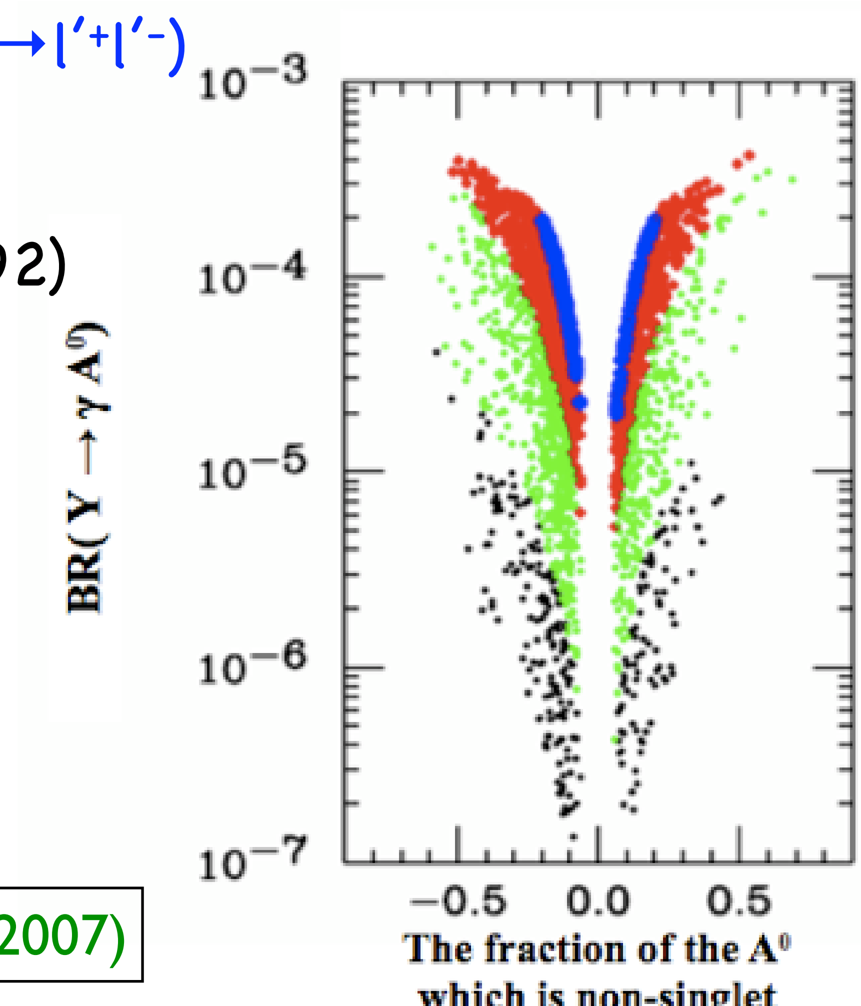
- SM expectation for $R_{ll'}$ = BR(Υ(1S)→l^+l^-)/BR(Υ(1S)→$l'^+l'^-$) is **1**

  (except for small lepton-mass effects, $R_{\tau\mu}$ ~ 0.992)

- Beyond the SM deviations of $R_{ll'}$ from SM expectation are possible

- In the NMSSM hypothesis of existence of a light pseudo-scalar Higgs boson A^0 (possibly escaped to LEP bounds)

Phys.Rev. D76, 051105 (2007)



Theoretical motivations (II)

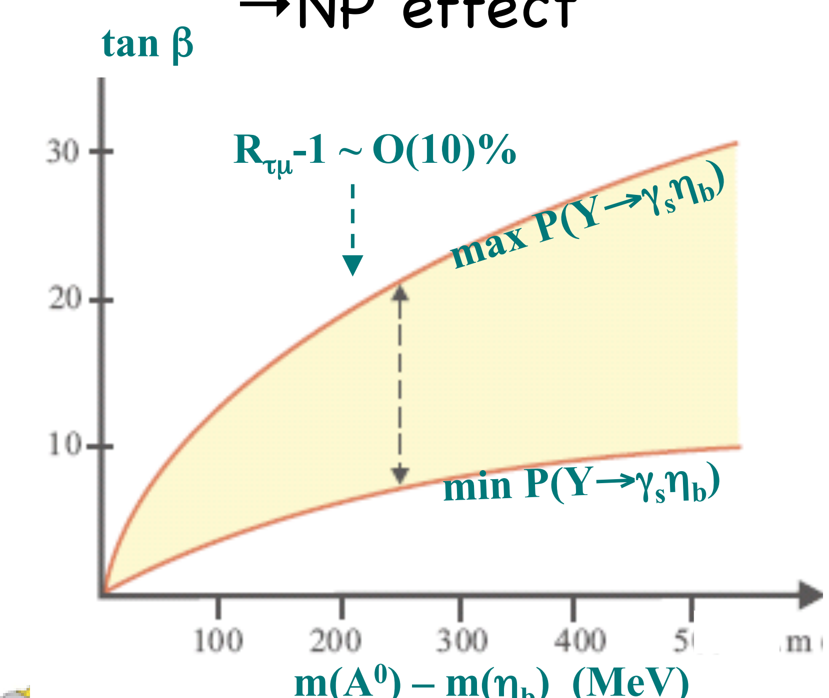
Int.J.Mod.Phys.A19, 2183 (2004);
Phys.Lett B653, 67 (2007)

- ✓ A^0 may mediate the decay chain of the $\Upsilon(1S)$:

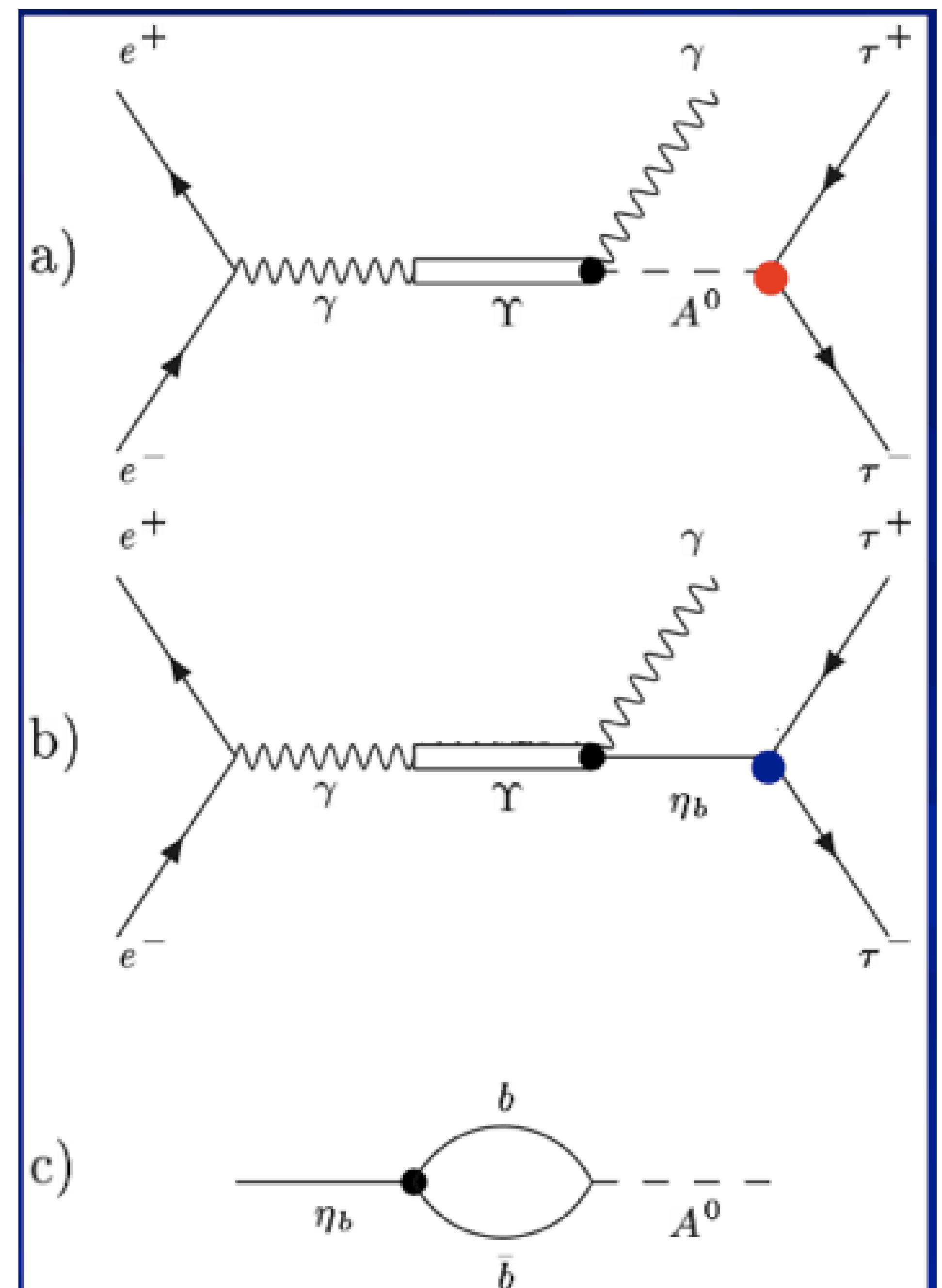
$\Upsilon(1S) \to A^0\gamma,\ A^0 \to l^+l^-$	a)
$\Upsilon(1S) \to \eta_b\gamma,\ \eta_b \to A^0 \to l^+l^-$	b) & c)

mixing

- ✓ If the photon was present but 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



- ✓ The coupling of A^0 is proportional to the lepton mass
- ✓ Effect more evident when one of the leptons is a τ (up to 10%) → $R_{\tau\mu}$

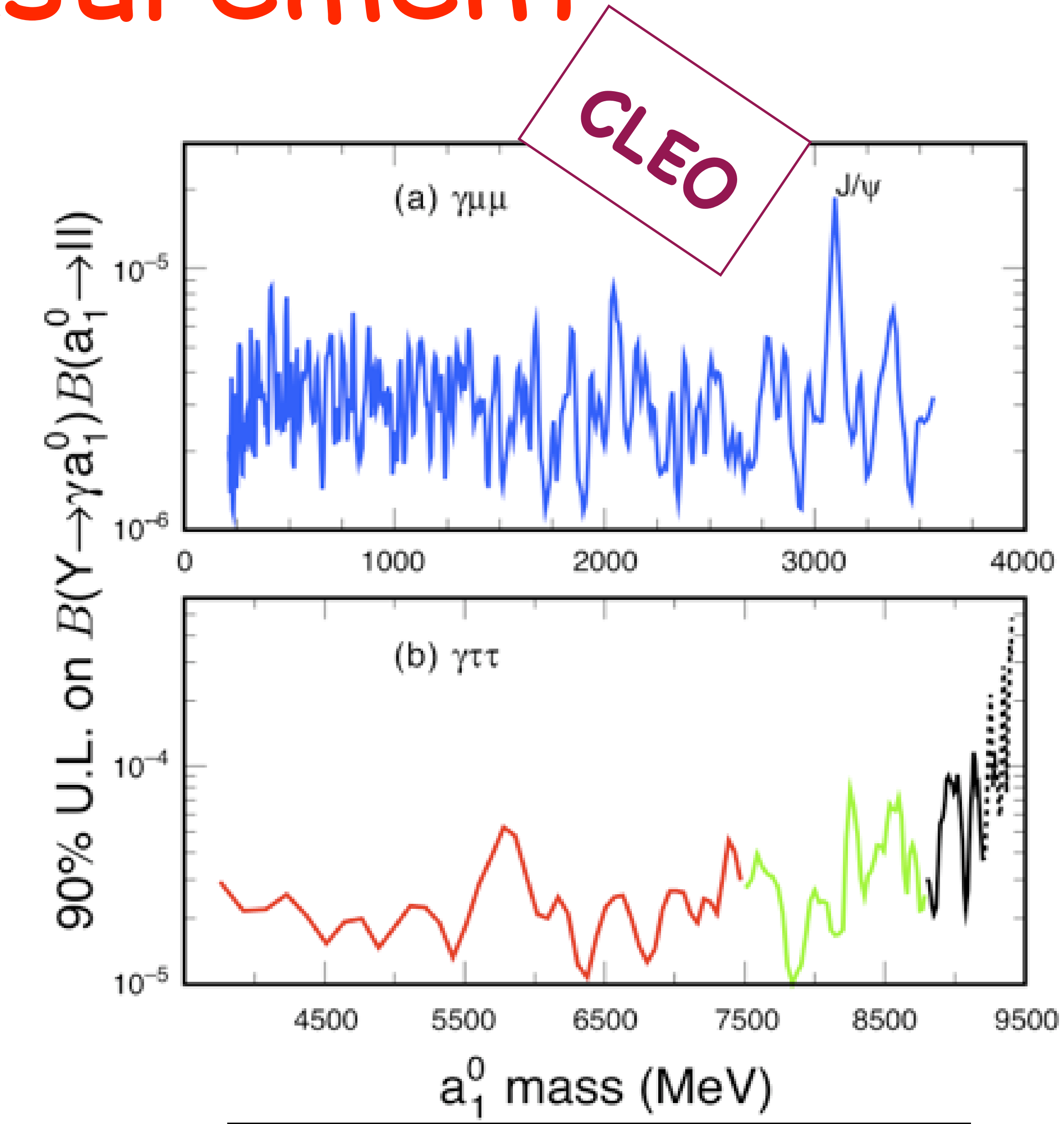


Previous measurement

- Previous best result by **CLEO**:

$R_{\tau\mu}(\Upsilon(3S))$: 1.07 ± 0.08 (stat.) ± 0.05 (syst.)
$R_{\tau\mu}(\Upsilon(2S))$: 1.04 ± 0.04 (stat.) ± 0.05 (syst.)
$R_{\tau\mu}(\Upsilon(1S))$: 1.02 ± 0.02 (stat.) ± 0.05 (syst.)
$BR(\Upsilon(1S)\rightarrow\eta_b)\cdot BR(\eta_b\rightarrow A^0\rightarrow\tau^+\tau^-)$ < 0.27% @ 95% C.L.

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



Phys.Rev.Lett.101, 151802 (2008)

- Statistics exploited: ~1.2fb^{-1} at each Υ peak
  → ~ 10^7 Υ resonances

- No results by **Belle**

- This is the first result by **BABAR** for $R_{\tau\mu}(\Upsilon(1S))$

Updated results from **BABAR** in Y.Kolomensky talk (on Tuesday Higgs Physics session)

The BABAR detector

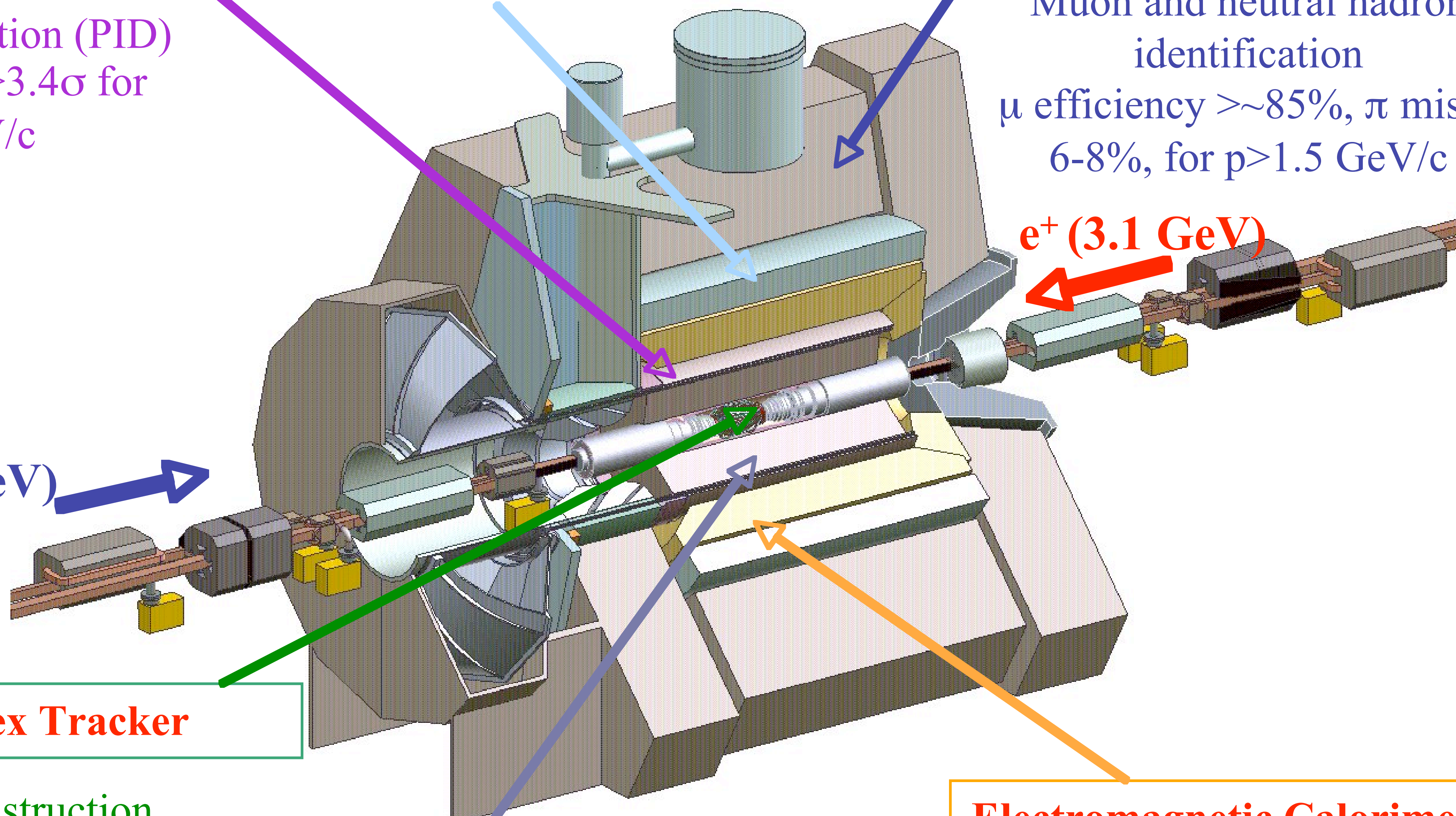
Cherenkov Detector

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



Silicon Vertex Tracker

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

Drift Chamber

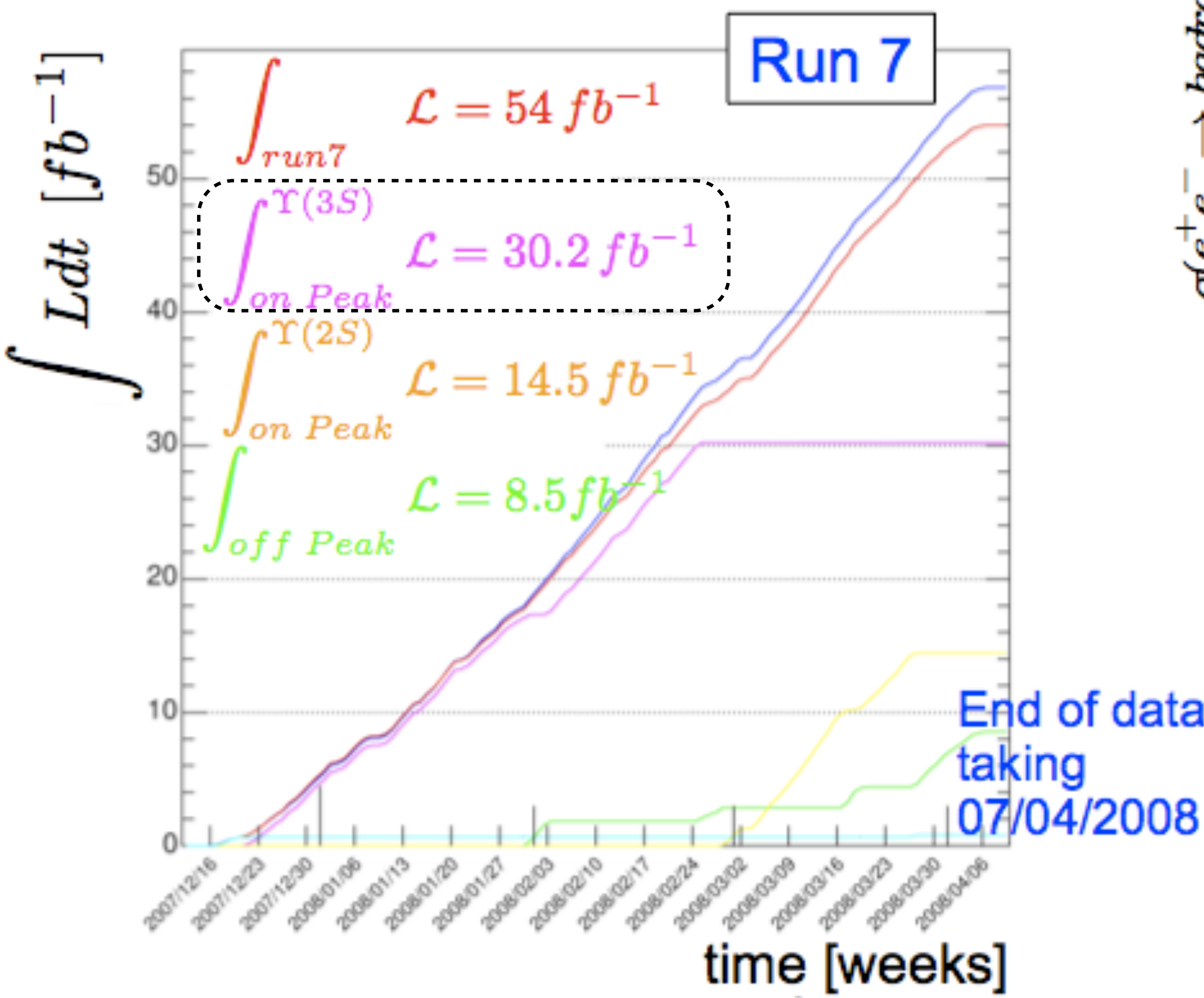
Momentum measurement for charged particles + dE/dx.
$\sigma(p_T)/p_T=0.13\%p_T\oplus0.45\%$

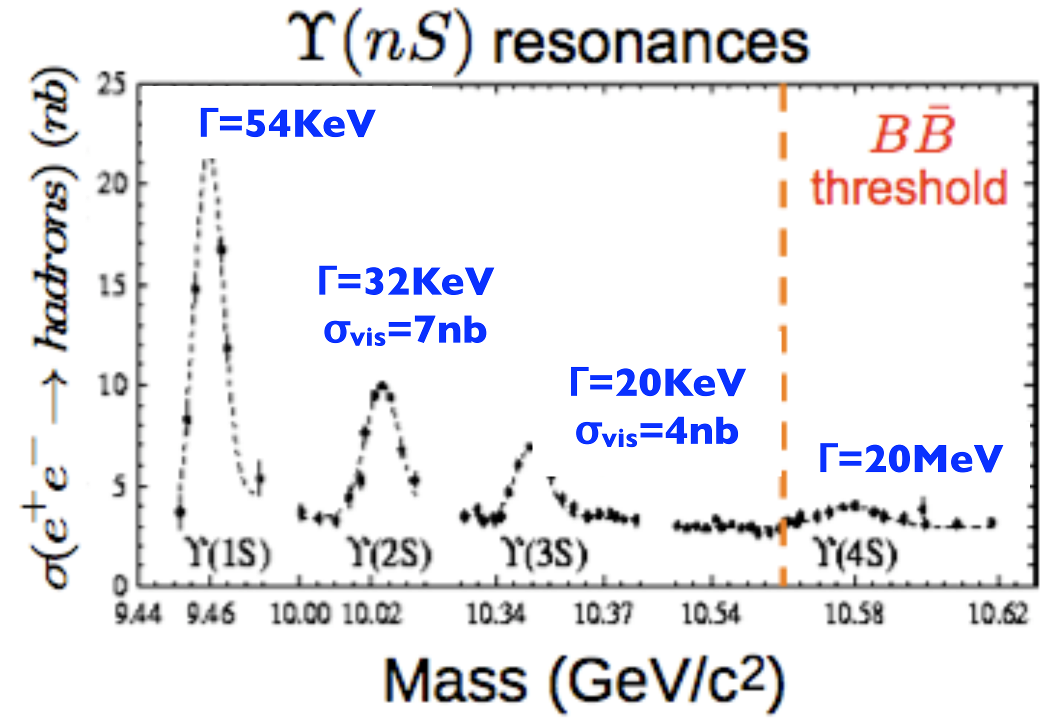
Electromagnetic Calorimeter

Electron and photon energy measurement. $\sigma(E)/E=1.33\%E^{-1/4}\oplus2.1\%$

BABAR data samples

- PEP-II asymmetric energy collider operating at the Υ resonances
- BABAR recorded luminosity



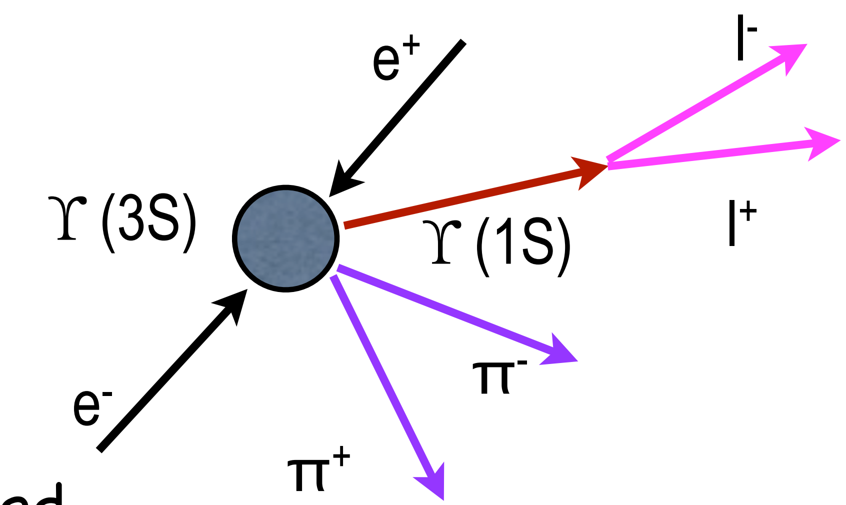


- Bottomonium datasets

Υ	2S	3S
BABAR	100M	120M
CLEO	9M	6M
BELLE	50M	11M

Analysis strategy (I)

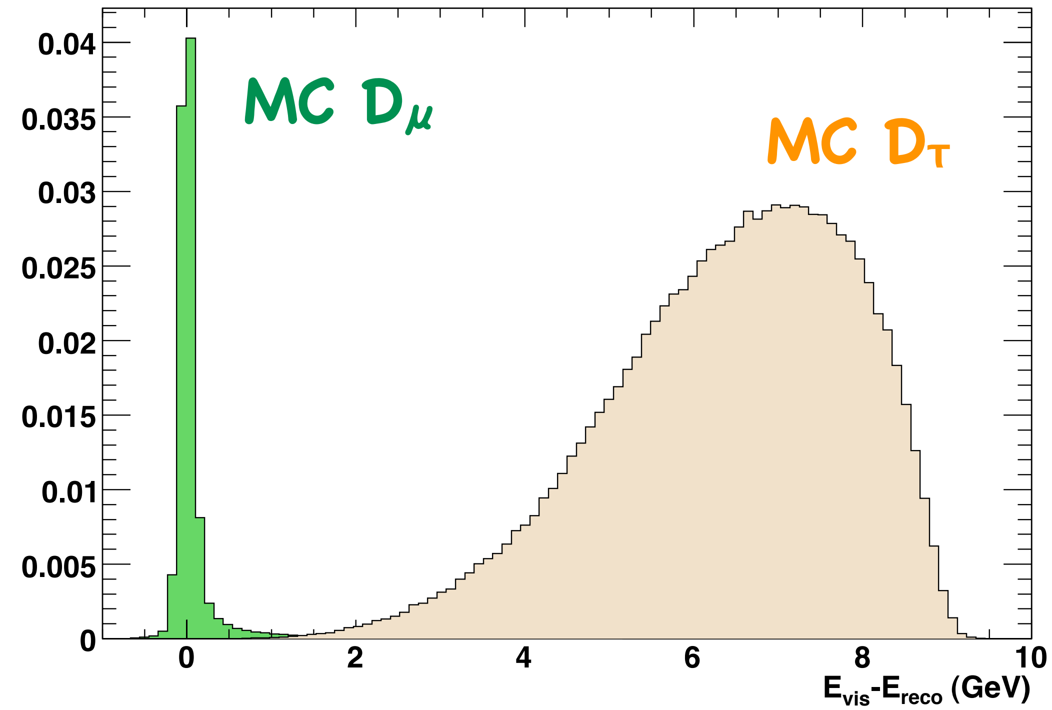
- ✓ 28 fb^{-1} of data collected at $\Upsilon(3S)$ CM energy → ~ $122 \cdot 10^6$ $\Upsilon(3S)$
- ✓ Tag $\Upsilon(1S)$ exploiting $\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-, \Upsilon(1S) \to \tau^+\tau^-$ and $\mu^+\mu^-$ events:
  - ✓ $BF(\Upsilon(3S) \to \Upsilon(1S)\pi^+\pi^-)$ ~ 5%
  - ✓ select τ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



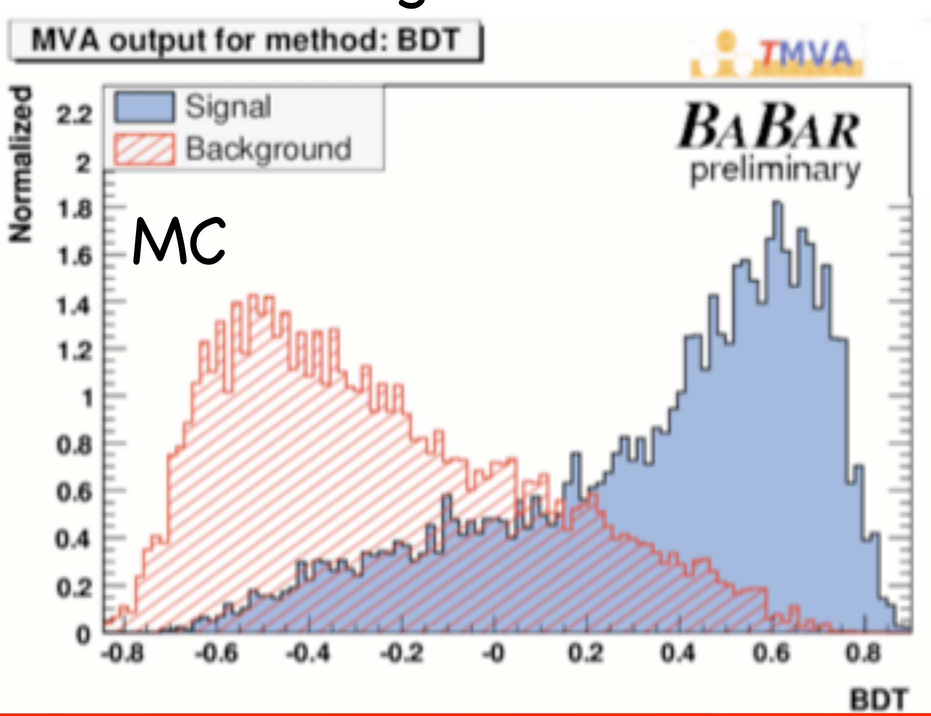
- ✓ $\Upsilon(1S) \to \mu^+\mu^-$ events (**D_μ**) completely reconstructed
- ✓ $\Upsilon(1S) \to \tau^+\tau^-$ events (**D_τ**) cannot be completely reconstructed
- ✓ Separate selections for **D_τ** and **D_μ** (optimized using Monte Carlo simulated samples)
- ✓ Main sources of bkg: $q\bar{q}$- and $\tau^+\tau^-$-continuum; Bhabha events; generic $\Upsilon(1S)$ decays (peaking)

Analysis strategy (II)

- A cut on the difference between the visible and the reconstructed energy of the event separates D_μ and D_τ events



- A multivariate analysis approach in D_τ
  - Boosted decision tree discriminator
  - Several kinematic and shape variables exploited
  - Good separation between signal and background



- Signal extraction efficiencies (estimated on MC simulations):

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

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

Signal extraction (I)

- 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 $M_{\pi+\pi-}^{reco}$

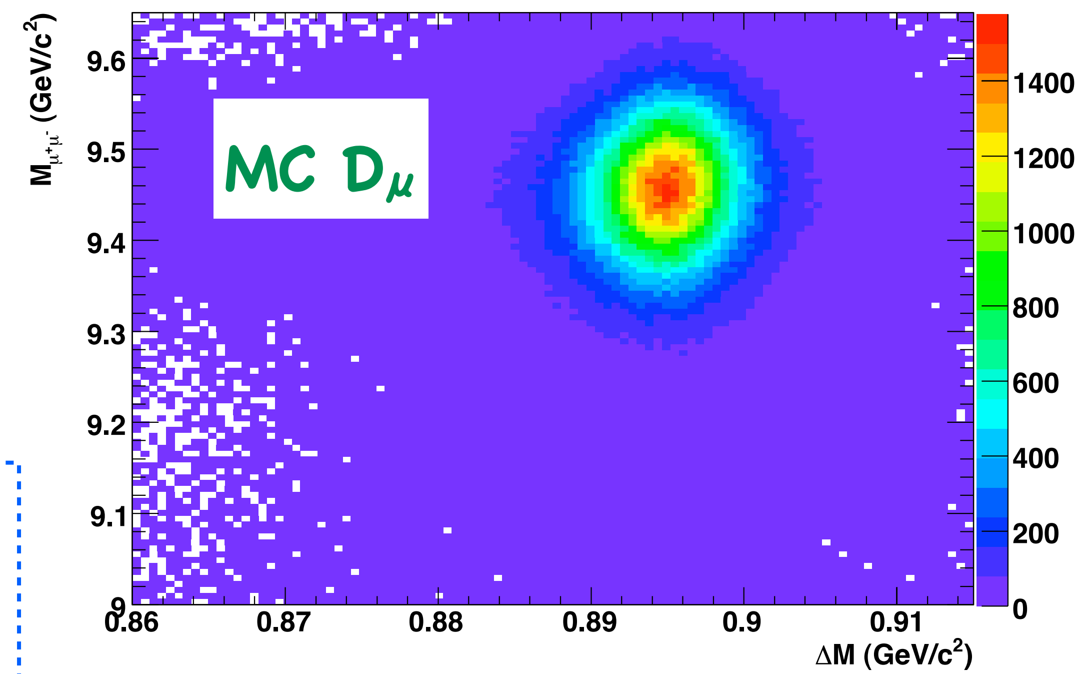
ΔM = $M(\Upsilon(3S))-M(\Upsilon(1S))$

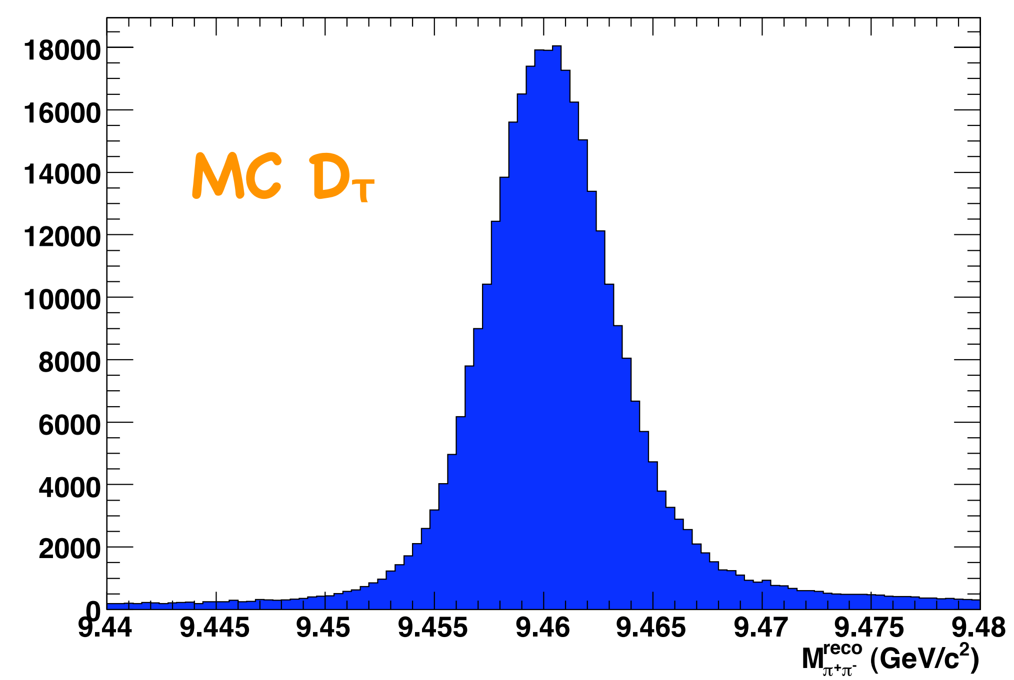
$M_{\mu+\mu-}$ invariant $\mu^+\mu^-$ mass

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

($\sqrt{s}$ is the nominal beam energy)

- Signal probability density functions (PDFs) chosen:
  - in D_μ from a sub-sample of data (discarded by the nominal fit)
  - in D_τ from D_μ distribution for $M_{\pi+\pi-}^{reco}$ (variable sensitive only to Y(3S)→Y(1S)$\pi^+\pi^-$ transition)





Syst. accounting for the possible discrepancy

Signal extraction (II)

- Summary of signal and background PDFs:

Variable	Signal PDF	Background PDF
ΔM	Triple Gaussian	flat
$M_{\mu^+\mu^-}$	$\mathcal{F}$	flat
$M^{reco}_{\pi^+\pi^-}$	$\mathcal{F}$	poly 1^{st} order

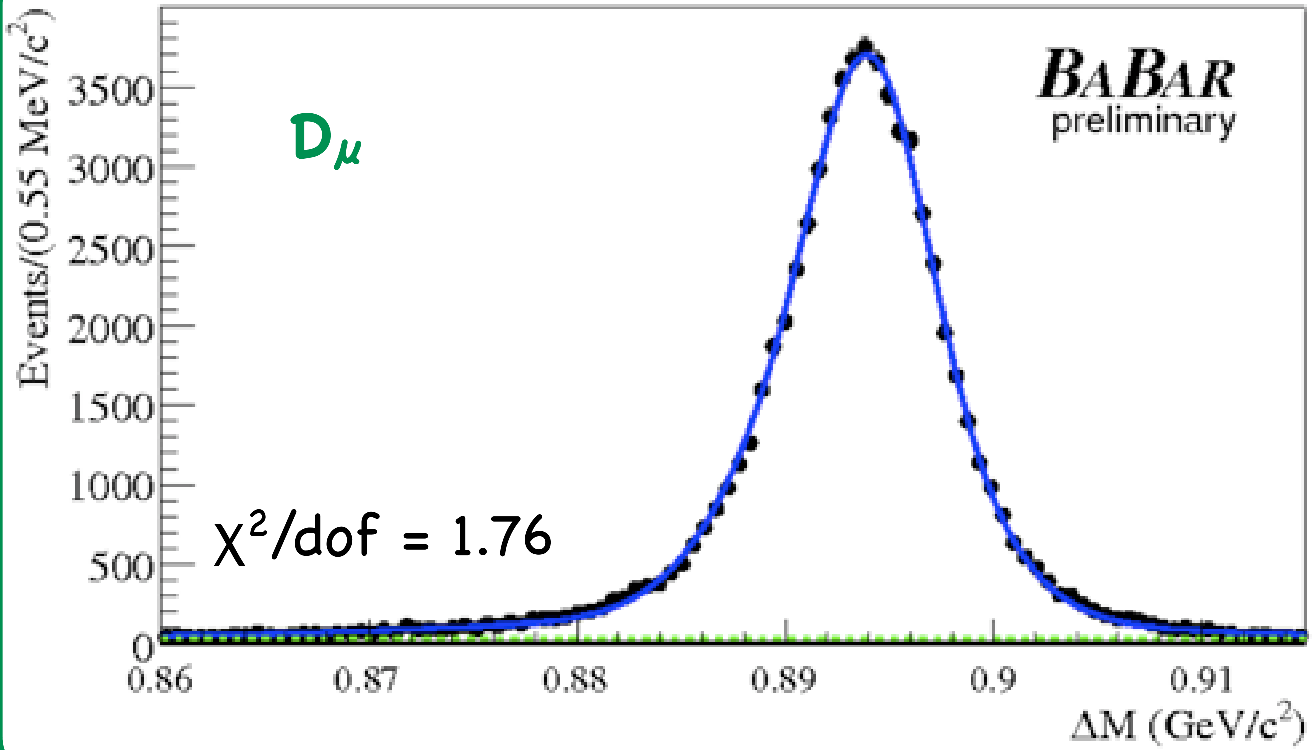
where $\mathcal{F}$ is an analytical function approximating a Gaussian with asymmetric widths and non Gaussian tails:

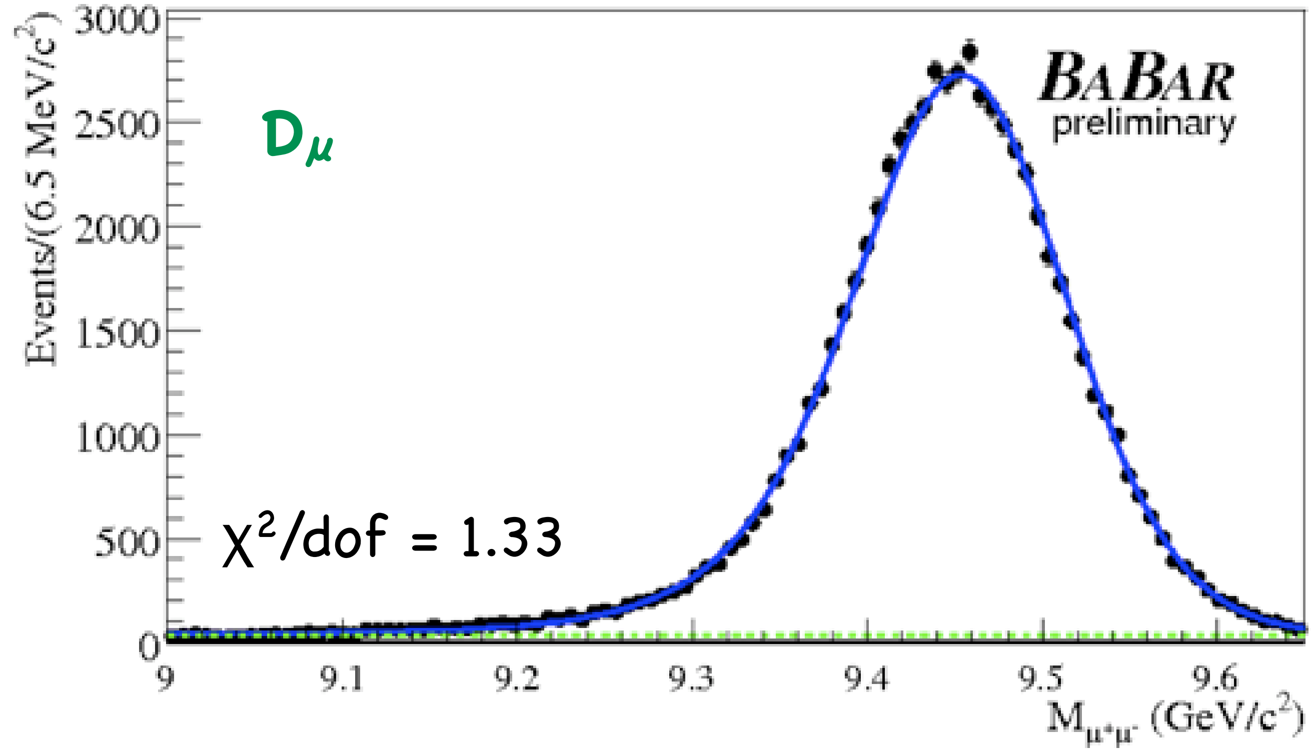
$$\mathcal{F}(x) = exp\left\{ - \frac{(x-\mu)^2}{2\sigma^2(L,R) + \alpha(L,R)(x-\mu)^2} \right\}$$

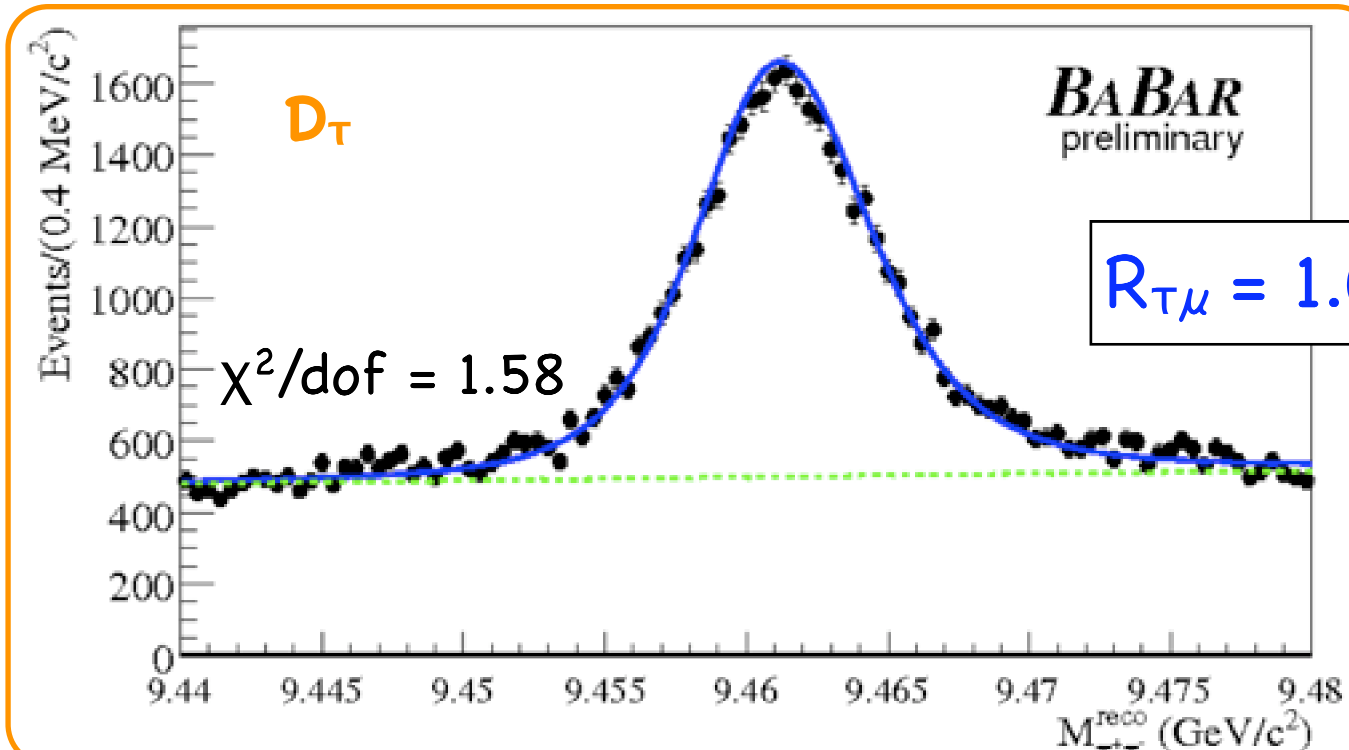
(where x is the variable, $M_{\mu+\mu-}$ or $M_{\pi+\pi-}^{reco}$, described by the function)

- Fit performed **simultaneously** to D_μ and D_τ
  - signal PDFs fixed (parameters determined on the control samples)
  - bkg PDFs floating
- $R_{\tau\mu}$ returned

Fit results







dashed line: bkg

solid line: signal+bkg

$R_{\tau\mu}$ = 1.006 ± 0.010(stat.)

Systematic uncertainties

- Since we measure a ratio of branching fractions, several systematic uncertainties cancel out (luminosity, $\Upsilon(3S)$ production cross section, $BR(\Upsilon(3S)\rightarrow\Upsilon(1S)\pi^+\pi^-)$, track reconstruction efficiency and the common selection)
- Residual uncertainties from:
  - event selection efficiency;
  - particle identification (PID) efficiency (μ leptons);
  - trigger and background filters (BGF) efficiencies;
  - imperfect knowledge of signal & background shapes.
- Total contribution up to **2.4%**
- **Still room for reducing this uncertainty**
- Corrections for known differences between data and simulation efficiencies

Systematic error :	$\Upsilon(1S)\rightarrow\mu^+\mu^-$	$\Upsilon(1S)\rightarrow\tau^+\tau^-$
Event selection	1.5%	
PID	0.6%	—
Trigger	0.18%	0.10%
BGF	negl.	negl.
PDF parameters	1.7%	
Background PDFs	0.28%	
Agreement $\mu^+\mu^-$ vs. $\tau^+\tau^-$ in $M^{reco}_{\pi^+\pi^-}$	—	0.11%
MC statistics	0.08%	0.09%
TOTAL	2.4%	

Preliminary result

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 (factor > 2), both in statistical and systematic errors

No significant deviations w.r.t. SM expectations

- ✓ Still working to reduce systematic uncertainty for the final result

Conclusions

- ✓ Lepton Universality test is an important check of SM
  - ✓ possible Lepton Universality breaking in Υ decays foreseen in the hypothesis of existence of A^0 (entering the Υ decay chain)
- ✓ **BABAR preliminary** result

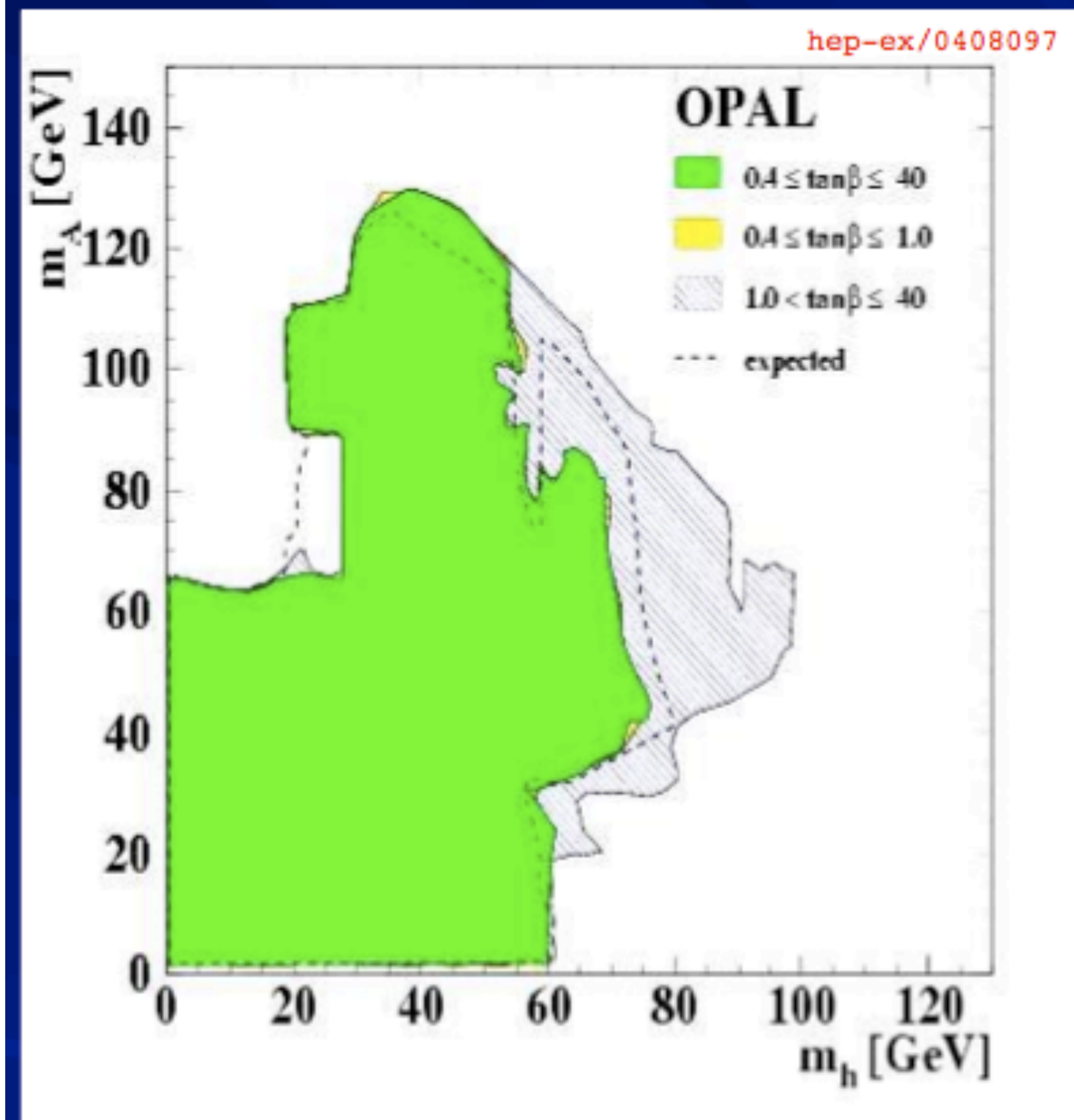
  $R_{\tau\mu}(\Upsilon(1S))$: 1.009 ± 0.010 (stat.) ± 0.024 (syst.)

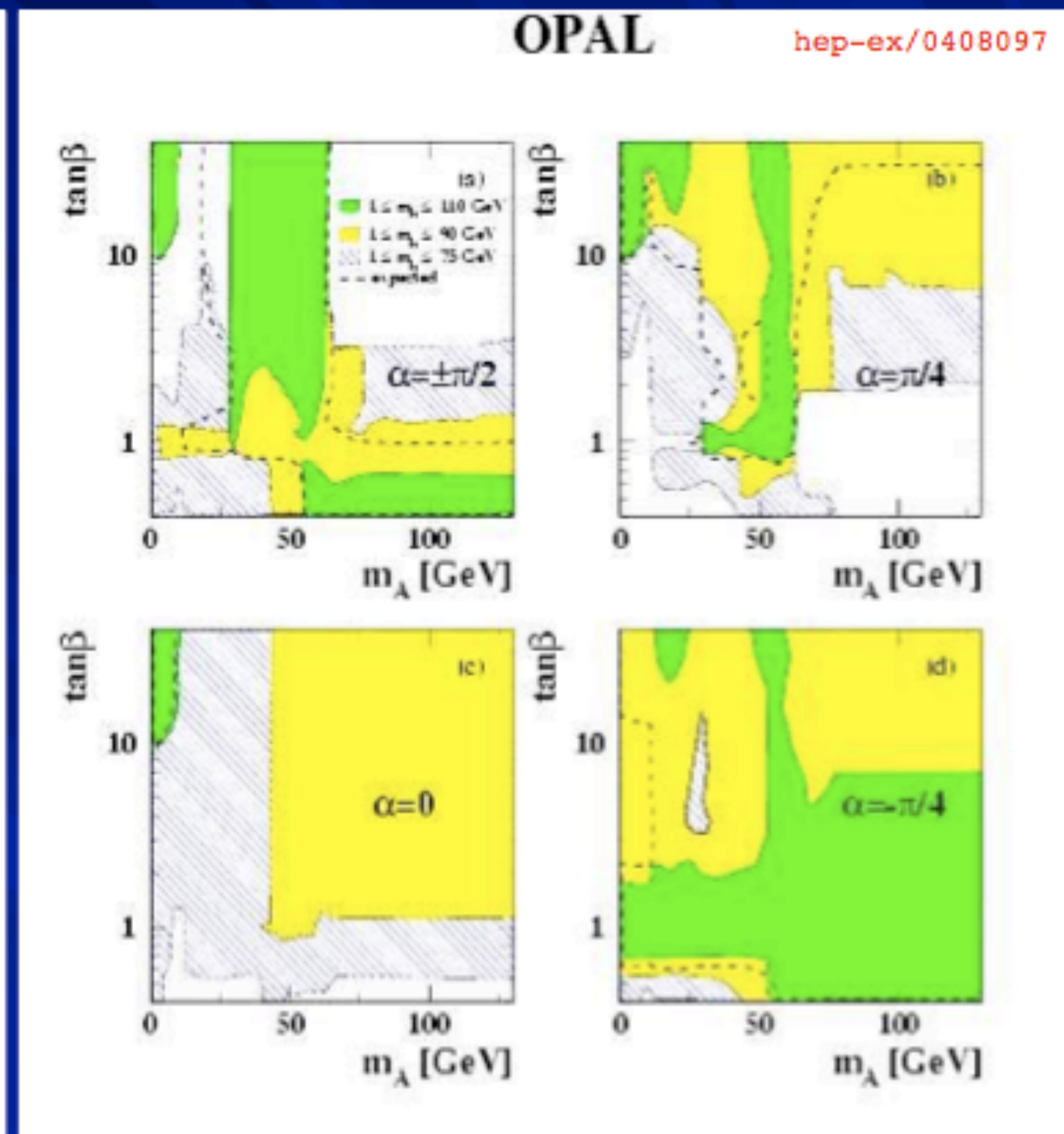
  - ✓ exploits the 28 fb^{-1} of data collected at the Υ(3S) energy
  - ✓ sensitive improvement in the precision (both statistical and systematic uncertainties are reduced of a factor > 2 w.r.t. the previous best result of CLEO)
  - ✓ further improvement in systematic error expected for the final result
- ✓ Stay tuned!

BACKUP SLIDES

LEP bounds on A^0

Light Higgs windows at LEP (2HDM(II))

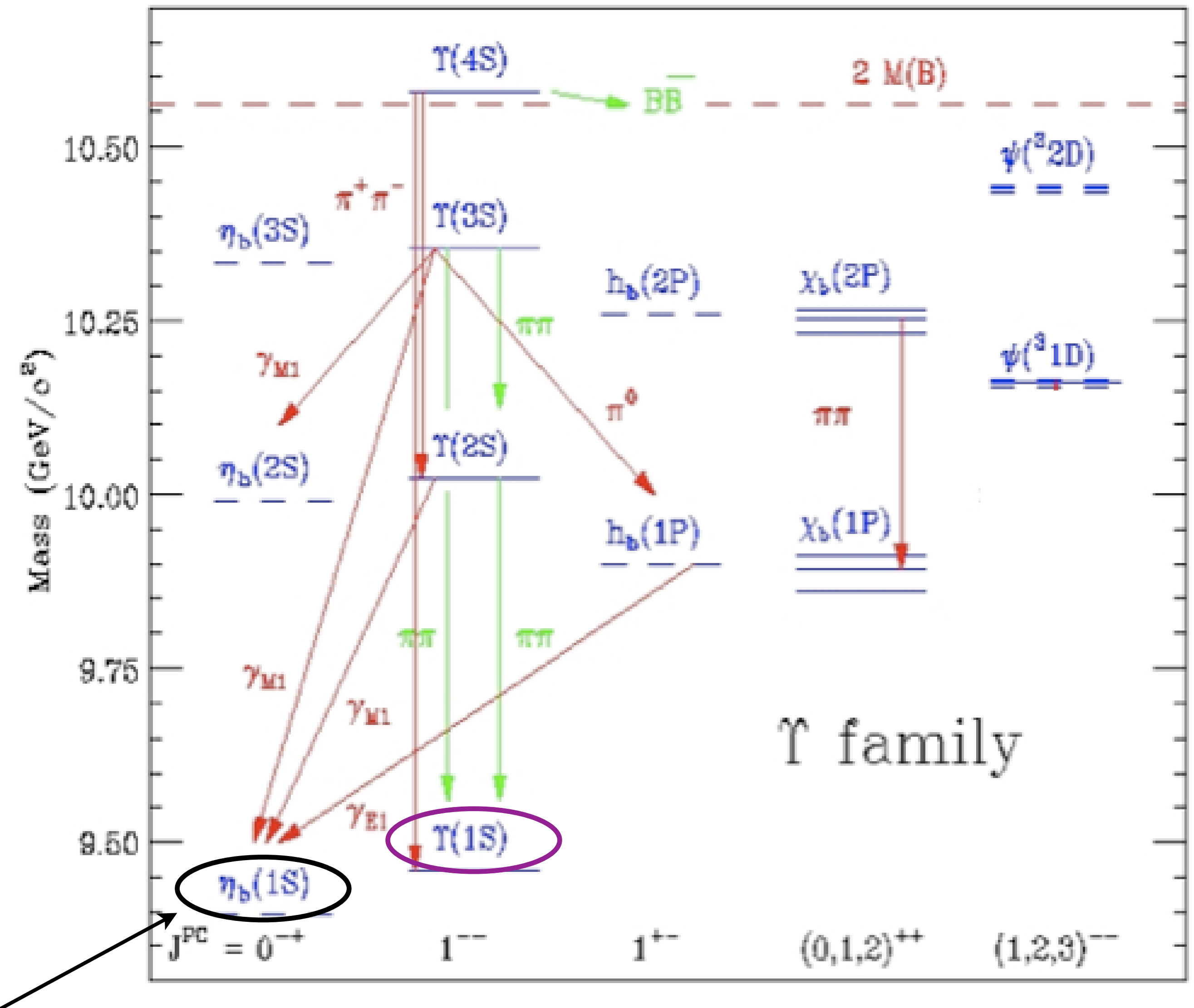




Excluded (m_A,m_h) region independent of the CP even Higgs mixing angle α from flavor-independent and b-tagging searches at LEP interpreted according to a 2HDM(II)

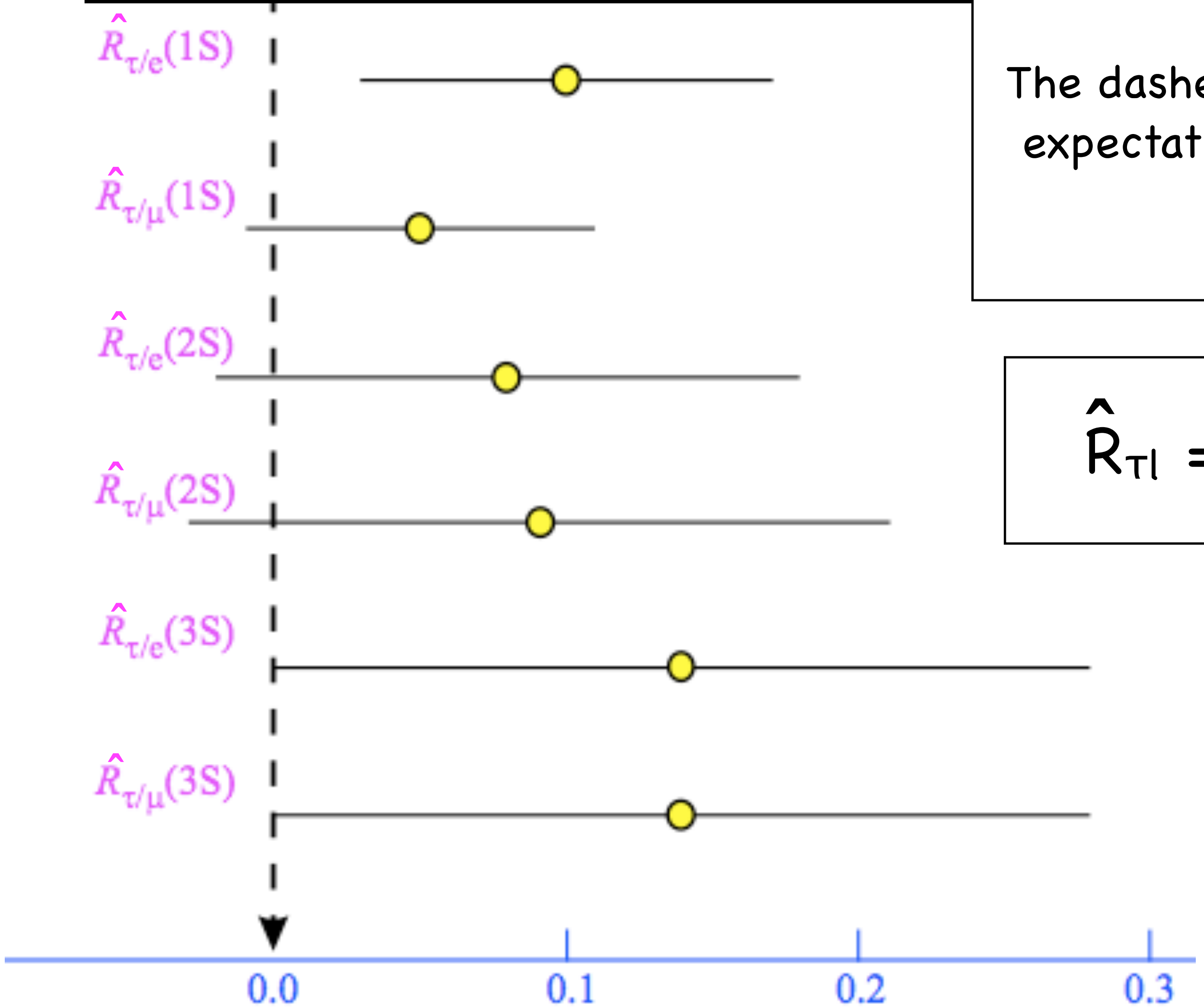
Excluded regions in the (m_A,tanβ) plane for different choices of α. In the MSSM $-\pi/2 \le \alpha \le 0$; in a general 2HDM(II) $-\pi/2 \le \alpha \le \pi/2$

The bottomonium family



Phys.Rev.Lett. 101 (2008) 071801

Status of Lepton Universality according to PDG



The dashed line shows the SM expectation (not phase space corrected)

$$\hat{R}_{\tau l} = R_{\tau l} - 1$$

Details on systematic uncertainties estimate

1. Event selection:

- Evaluated by performing the fit procedure removing one cut of the selection at a time, both on data and on simulation
- Systematic discrepancy between the changes in the efficiencies **1.5%**
- The main contribution arises from the cut on the **mva** output variable

2. PID:

- It only applies to $\Upsilon(1S) \rightarrow \mu^+\mu^-$ events
- 2 independent samples:
  - sample (A) requiring 2 μ's identified
  - sample (B) requiring exactly 1 μ identified **0.6%**
- $\mathbf{r(\epsilon)_{MC} = [\epsilon(A)/(\epsilon(A)+ \epsilon(B))]_{MC}}$ and $\mathbf{r(\epsilon)_{DATA} = [\epsilon(A)/(\epsilon(A)+ \epsilon(B))]_{DATA}}$
- The ratio $\mathbf{r(\epsilon)_{MC}/r(\epsilon)_{DATA}}$ is quoted as systematic discrepancy

3. Fit procedure:

1. systematics deriving from **fixing the parameters** of the signal p.d.f.'s (fit procedure repeated, changing one parameter at a time of $\pm1\sigma$) — **1.7%**

2. systematics deriving from choosing a parameterization for the **bkg** (fit procedure repeated, changing the p.d.f. of each distribution) — **0.28%**

3. systematic discrepancy between the sample used to determine the p.d.f.'s parameters and the data sample where the signal extraction is performed — **0.11%**

- ✓ in D^{μ} we use 1/10 of data to fix the p.d.f. → no bias expected
- ✓ in D^{τ} we use D^{μ} → we have to take into account possible discrepancies between the 2 samples
- ✓ repeat the fit procedure, re-weighting the parameters with the ratio between the results of the fit to the 2 Monte Carlo samples
- ✓ Additionally, fit procedure repeated while letting the global width of signal D^{τ} PDF to float

• full red: $\Upsilon(1S)\to\tau^+\tau^-$ simulation
• empty blue : $\Upsilon(1S)\to\mu^+\mu^-$ simulation