Search for LFV in $\tau \to l\gamma$ and $\tau \to lll$ at BaBar

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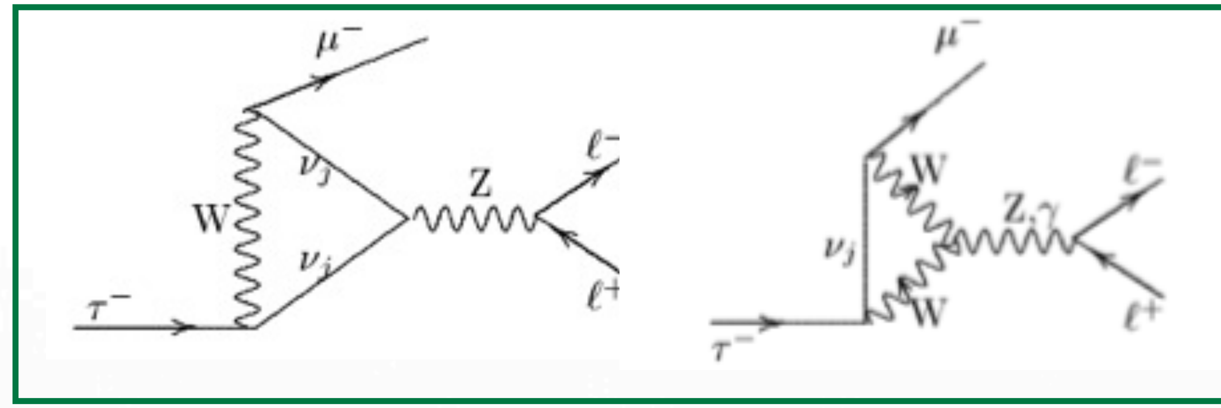
Outline

- Theory Overview
- The BaBar Detector
- $\tau \to l\gamma$
- $\tau \to lll$
- Conclusion

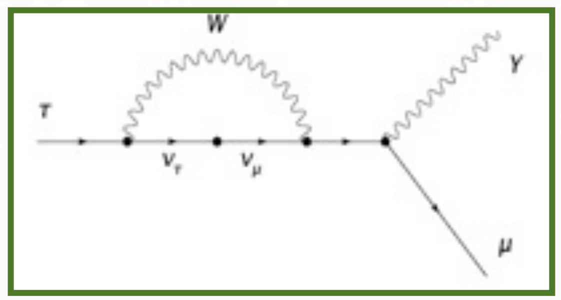
LFV in τ decays theory

SM allows LFV: observed in neutral sector.



In charged sector may happen via loops with small expected BR (e.g. $BR_{SM}(\tau \rightarrow \mu\gamma) < 10^{-54}$).

Even less in τ→ 3l

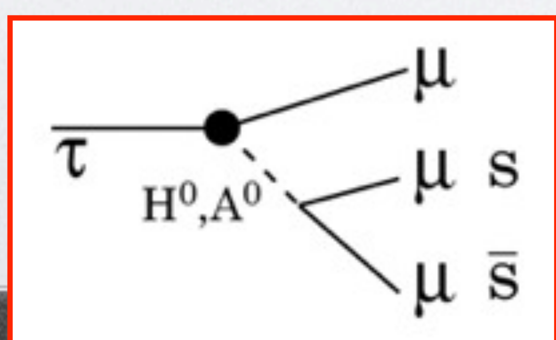


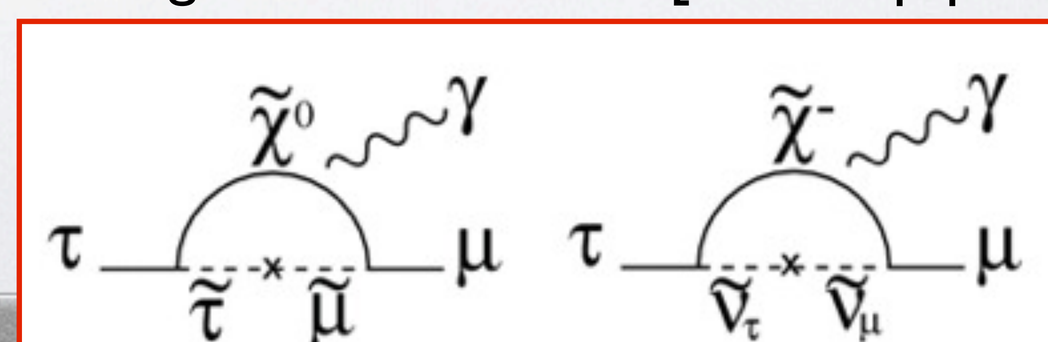
If detected, LFV would imply New Physics with present (and near future) luminosities.

Many New Physics models predict τ LFV BR up to [$O(10^{-8})$].

If detected in more than one channel it provides

Useful information on NP flavor structure, by looking at LFV BF Ratios. [arxiv:hep-ph0610344v3]





Some Predictions

		$\tau \to \mu\gamma$	$\tau \to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	Undetectable	
SUSY Higgs	Dedes, Ellis, Raidal, PLB 549 (2002) 159 Brignole, Rossi, PLB 566 (2003) 517	10^{-10}	10^{-7}
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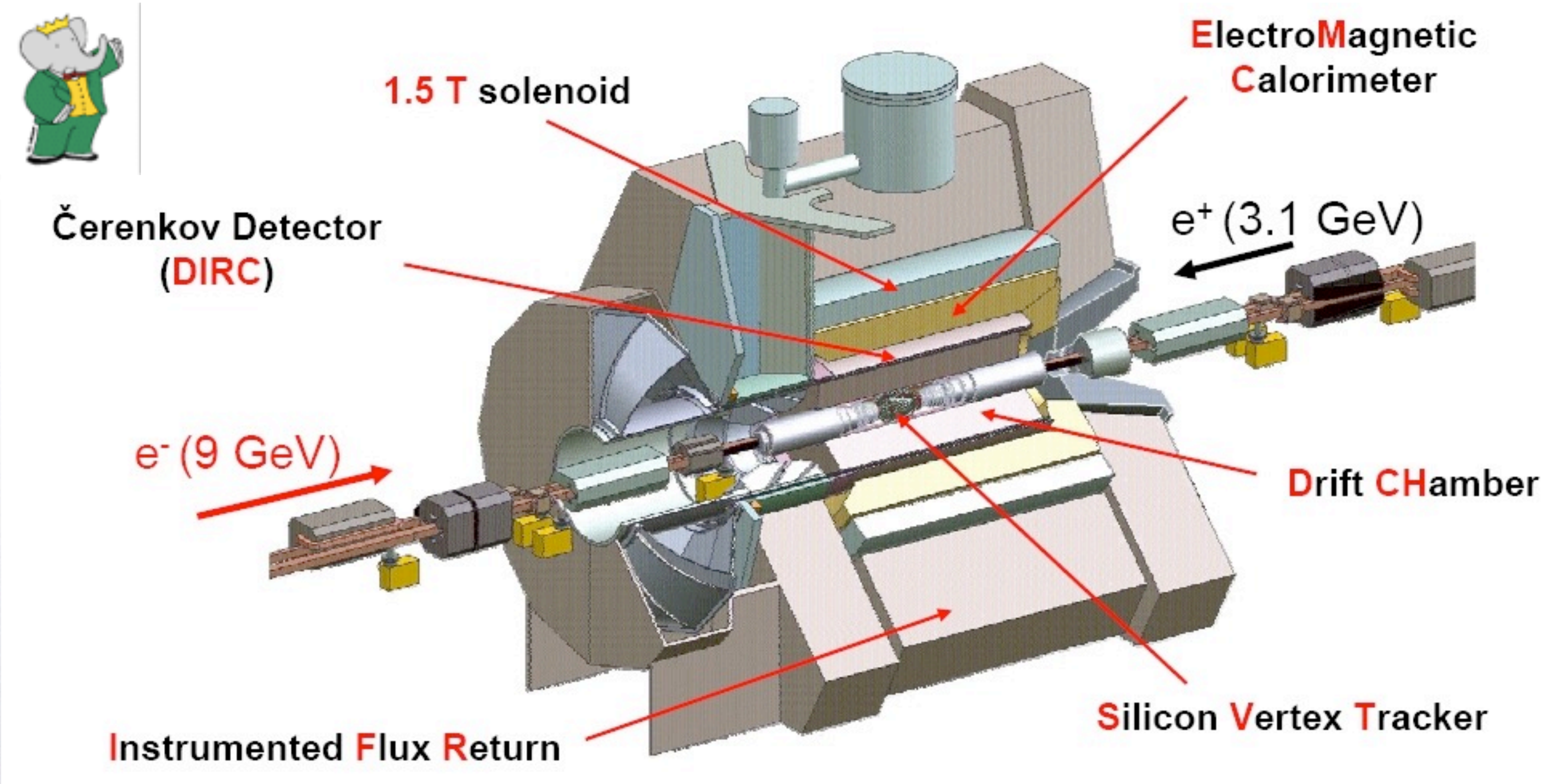
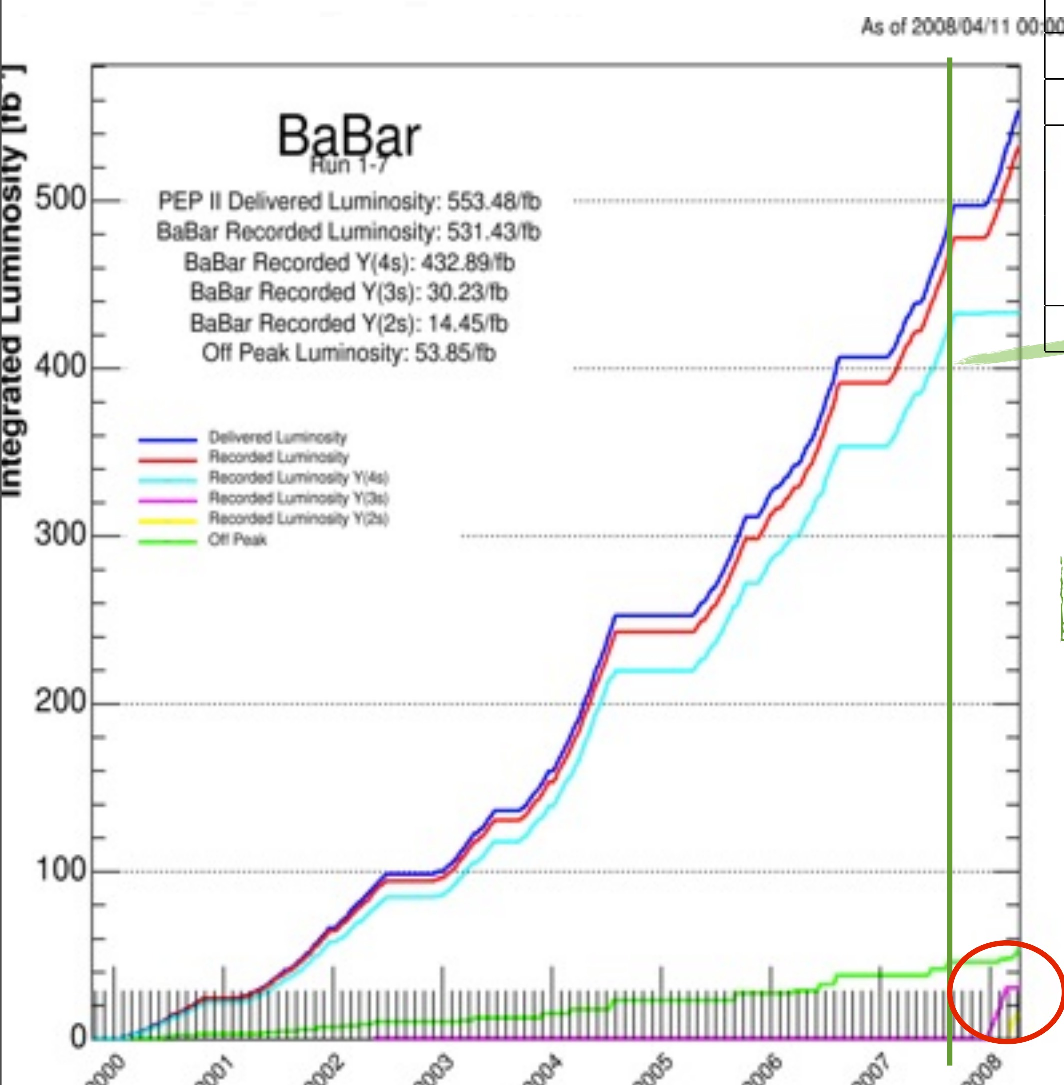
mSUGRA + Seesaw	Ellis, Gomez, Leontaris, Lola, Nanopoulos, EPJ C14 (2002) 319 Ellis, Hisano, Raidal, Shimizu, PRD 66 (2002) 115013	10^{-7}	10^{-9}

BaBar


ElectroMagnetic
Calorimeter
1.5 T solenoid
Čerenkov Detector
(DIRC)
e+ (3.1 GeV)
e- (9 GeV)
Drift CHamber
Silicon Vertex Tracker
Instrumented Flux Return

Data Sample

Results from 8 different channels, different data sets used:



$\tau \to \ell\ell\ell$				$\tau \to \ell\gamma$			
$\tau^+ \to e^+e^-e^+$ $\tau^+ \to e^+\mu^-e^+$ $\tau^+ \to e^+e^-\mu^+$		$\tau^+ \to \mu^+\mu^-\mu^+$ $\tau^+ \to \mu^+e^-\mu^+$ $\tau^+ \to \mu^+\mu^-e^+$		$\tau^+ \to e^+\gamma$		$\tau^+ \to \mu^+\gamma$	
Data Sets							
Sample	σ (nb)	N events (10^6)	$\mathcal{L}_{MC}/\mathcal{L}_{Data}$	Sample	σ (nb)	N events (10^6)	$\mathcal{L}_{MC}/\mathcal{L}_{Data}$
bb	1.1	1470	3.3	bb	1.1	1470	3.3
$c\bar{c}$	1.3	1132	1.8	$cc\bar{c}$	1.3	1301	1.9
uds	2.09	938	1.1	uds	2.09	1773	1.6
$\tau^+\tau^-$	0.92	184	1.5	$\tau^+\tau^-$	0.92	811	1.7
Data	$\mathcal{L} = 468 fb^{-1}$			Data	$\mathcal{L} = 515 fb^{-1}$		

Used only data taken during Υ(4S) data taking period: 861M τ pairs

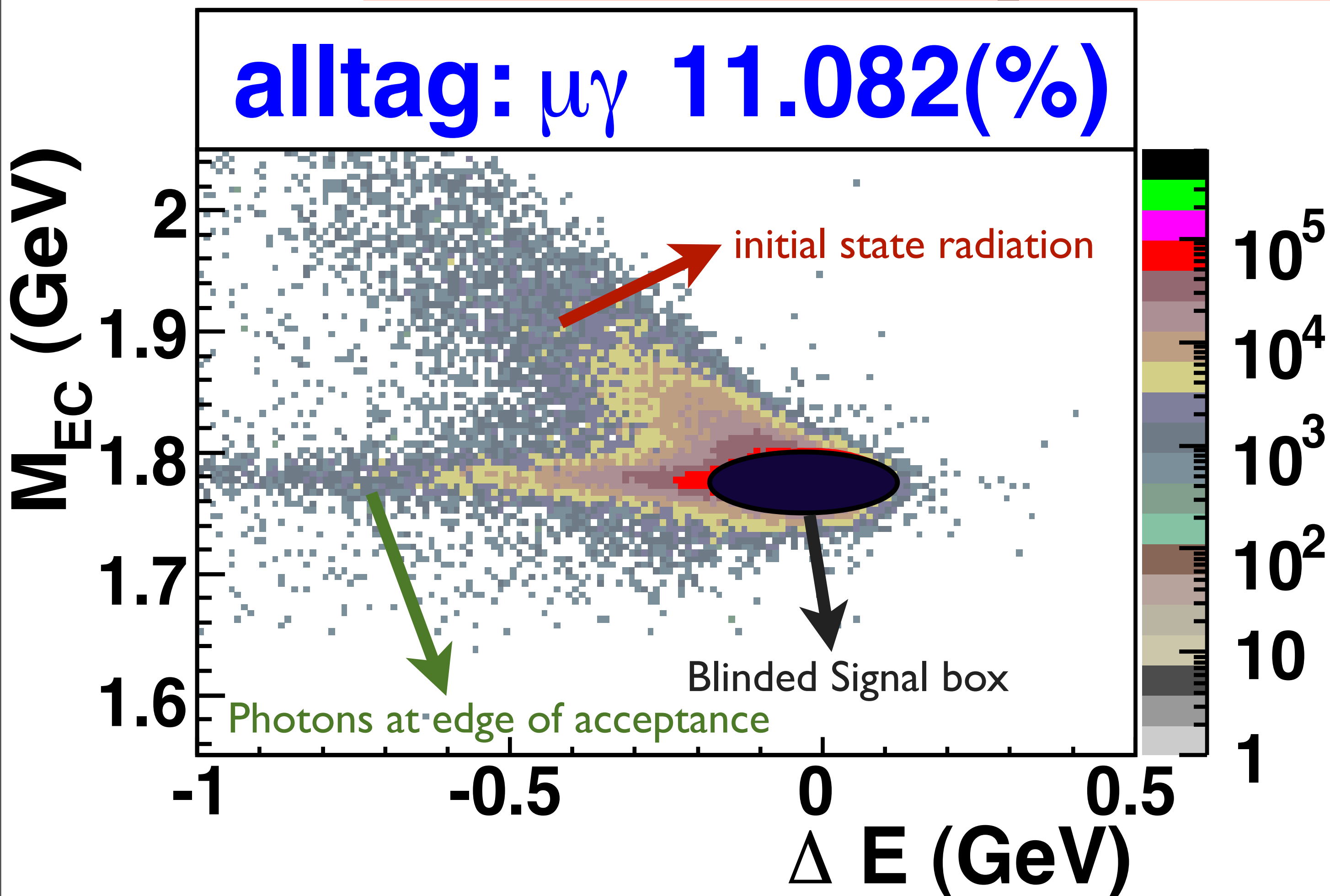
Used Both data from Υ(4S) and Υ(nS) data, where τ-pair production cross section is larger.
N_τ = 963 ± 7 M (515 fb^{-1})
(Belle: N_τ = 983 ± 7 M (535 fb^{-1}))

Search for $\tau \rightarrow \mu/e\, \gamma$

Signal Characteristics

$$M_{ec} = M^{\star}_{\mathrm{INV}}(\ell\gamma) \qquad \sigma(M_{ec}) = 8\ \mathrm{MeV}$$

$$\Delta E = E^{\mathrm{CM}}(\ell\gamma) - \frac{\sqrt{s}}{2} \qquad \sigma(\Delta E) = 42\ \mathrm{MeV}$$



ΔE resolution dominated by ISR effects and neutral energy reconstruction

M_{ec} dominated by tracking resolution and EMC performances

σ(Inv. Mass) = 18 MeV

Blinded region ±3σ ellipsis around (0,m_{τ})

Signal selection

Event selection requires:

- events to be in ΔE, M_{ec} signal box
- signal track identified as an e (eγ) or μ (μγ)
- Signal candidates are divided in 5 categories, depending on decay in tag side and different selection is applied for each category

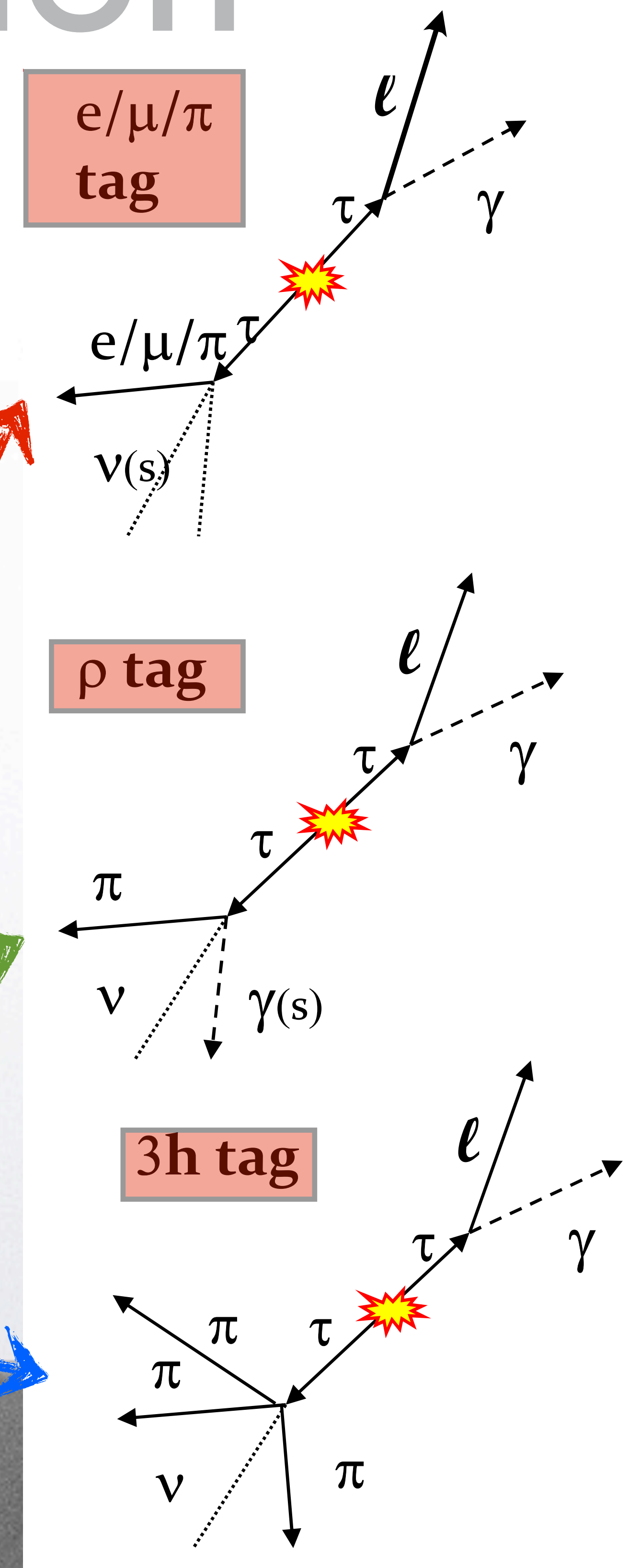
e-tag: tag track ID as electron, neutral energy in tag side < 200 MeV (e/μ)

μ-tag: tag track ID as μ, neutral energy in tag side < 200 MeV (e/μ)

π-tag: tag track ID neither e nor μ, neutral energy in tag side < 200 MeV (e/μ)

ρ-tag: tag track ID neither e nor μ, one π^0 candidate in tag side $m_{\pi} \in [90, 165]$ MeV

3h-tag: 3 tracks in tag side, not identified as e or μ



Signal Selection II

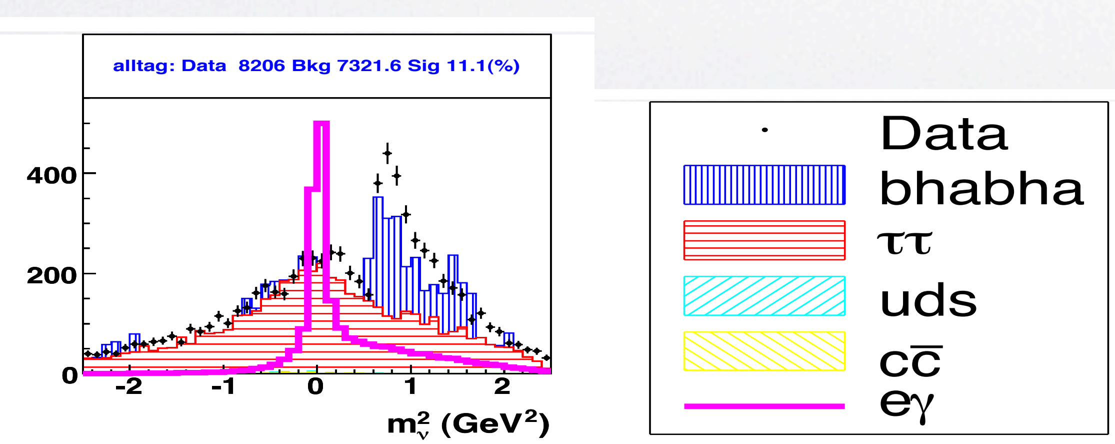
Further selection is applied using three groups of selectors, and a Neural Network

Signal Side selection

- $\cos\theta_{opening}$: opening angle between lepton and track
- π^0 reconstruction consistency
- $E\gamma$ >1 GeV & no further γ over 100 MeV
- $2\Sigma P^{CM}/\sqrt{s}$ <0.77

Tag side selection:

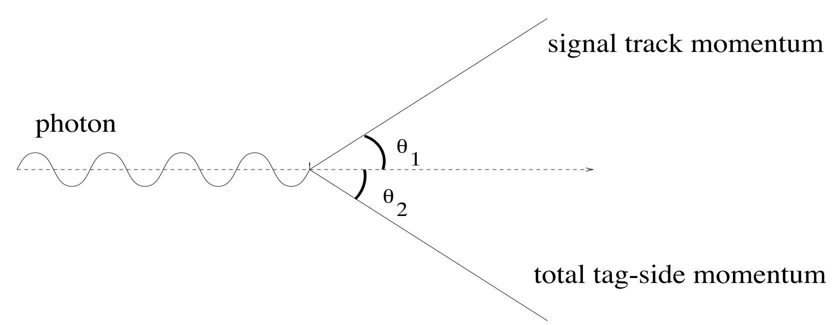
- m_ν in the hypothesis that the signal side is fully reconstructed.
- $2\Sigma P^{CM}/\sqrt{s}$
- Pseudomass: reconstructed mass in the hypothesis ν is colinear with signal τ and has a cutoff at m_τ



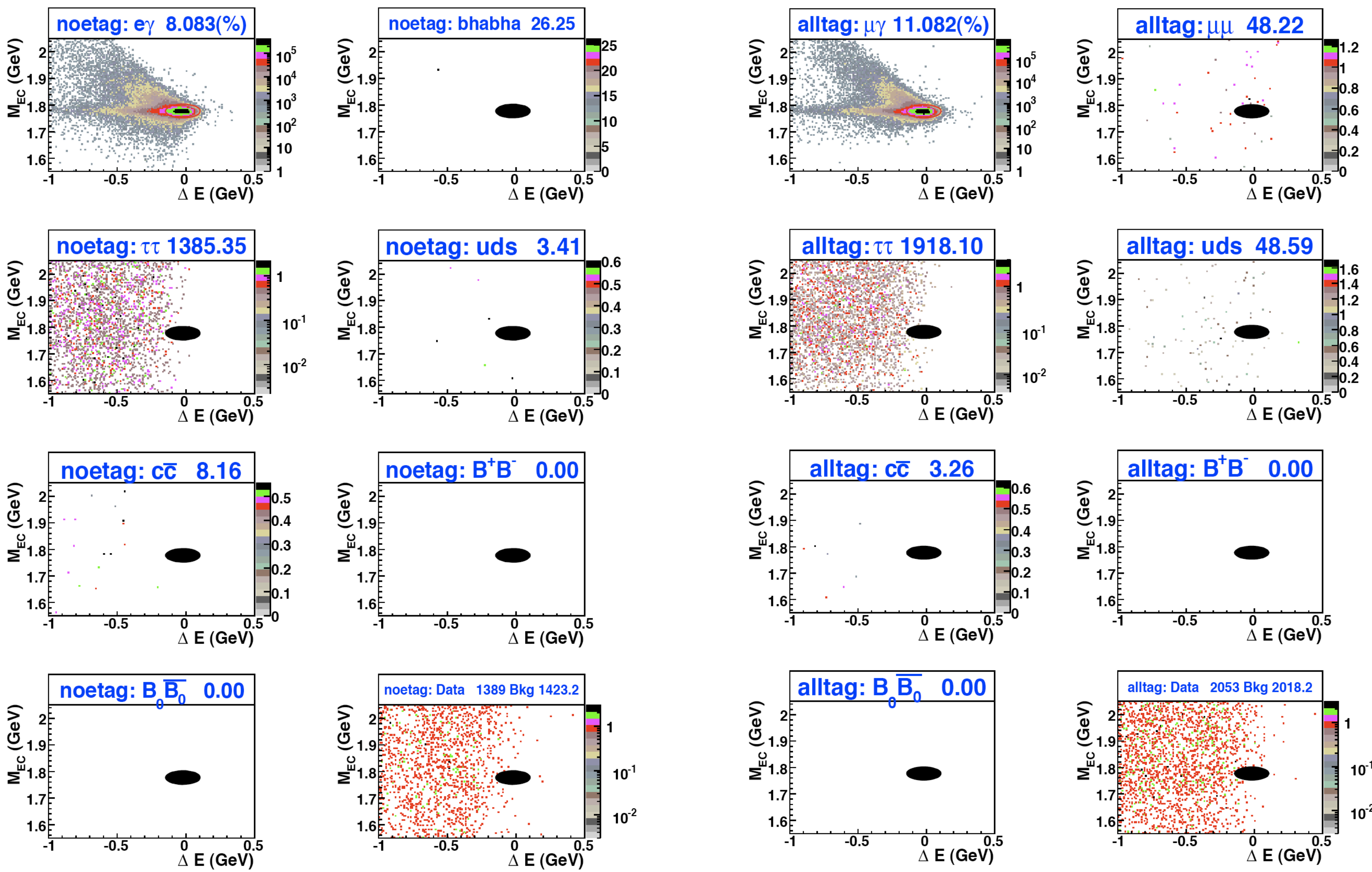
Global Selection

- $\cos\theta_{miss}$ & p^T_{miss} are used to reduce QED bkg
- $\cos\theta_{recoil}$:angle between reconstructed tau directions.
- ΔE_γ : neglecting track masses

$$\Delta E_\gamma = \frac{E_\gamma^{CM}}{\sqrt{s}} - \frac{|\sin(\theta_1+\theta_2)|}{\sin(\theta_1)+\sin(\theta_2)+\sin(\theta_1+\theta_2)}$$



After Selection



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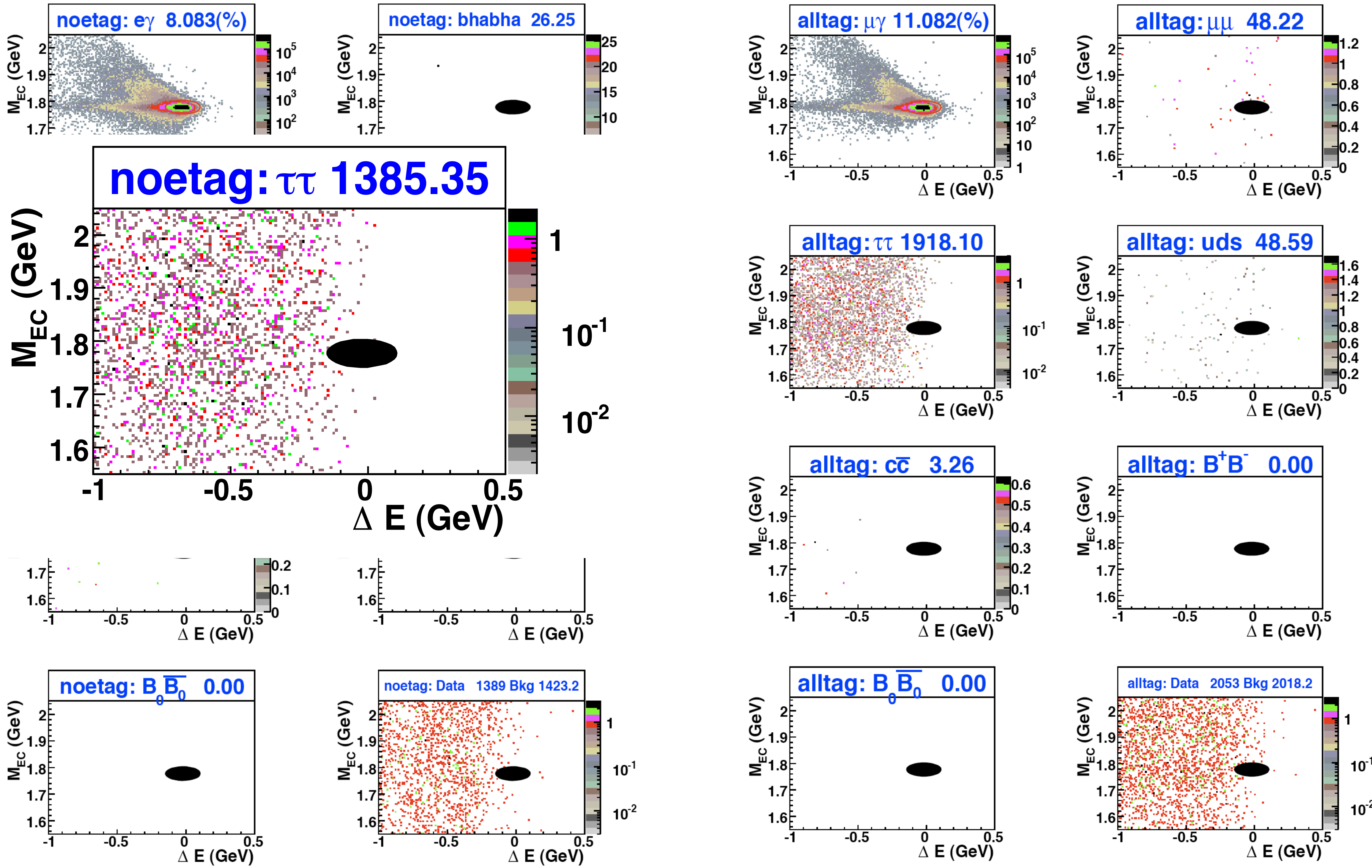

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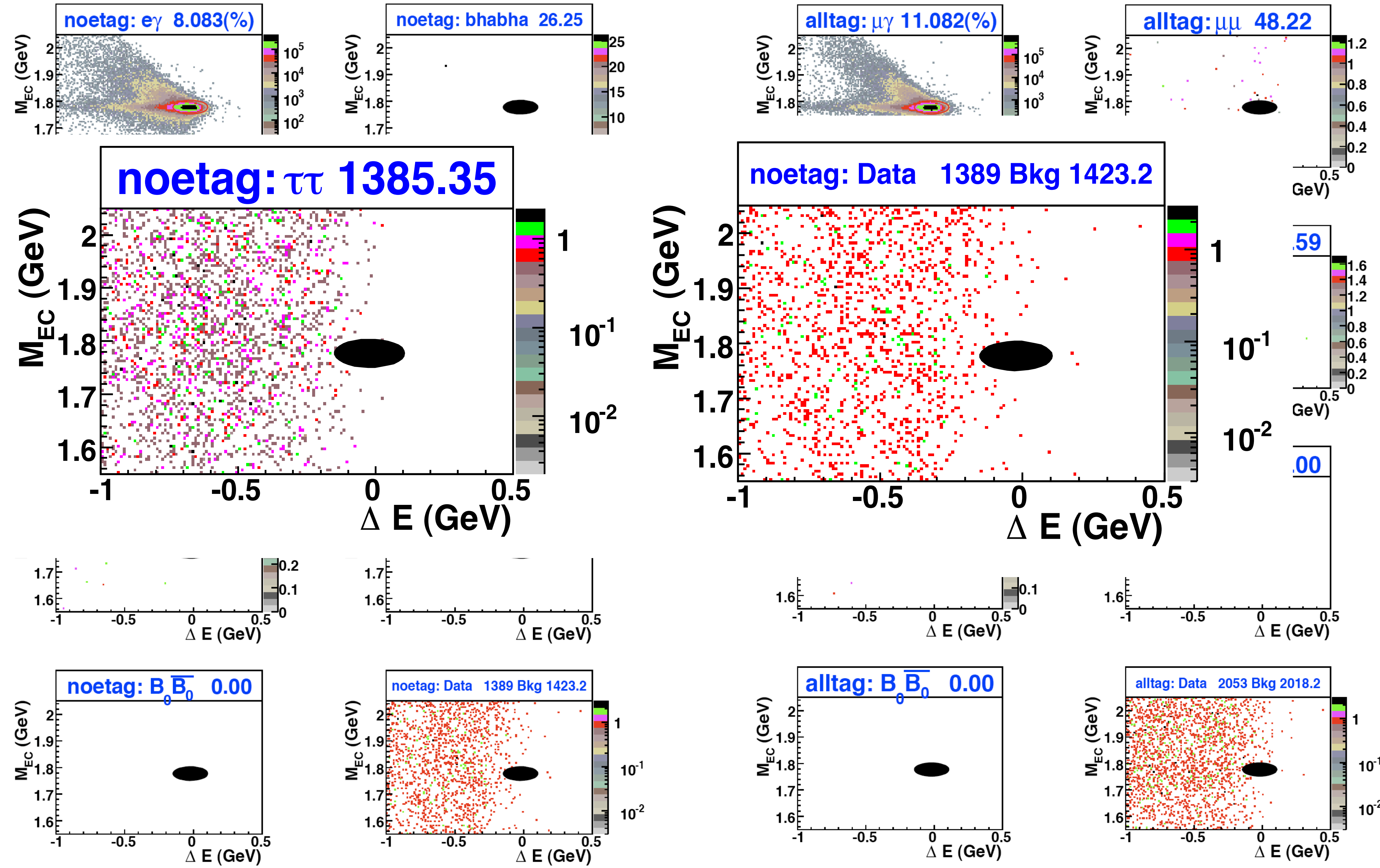


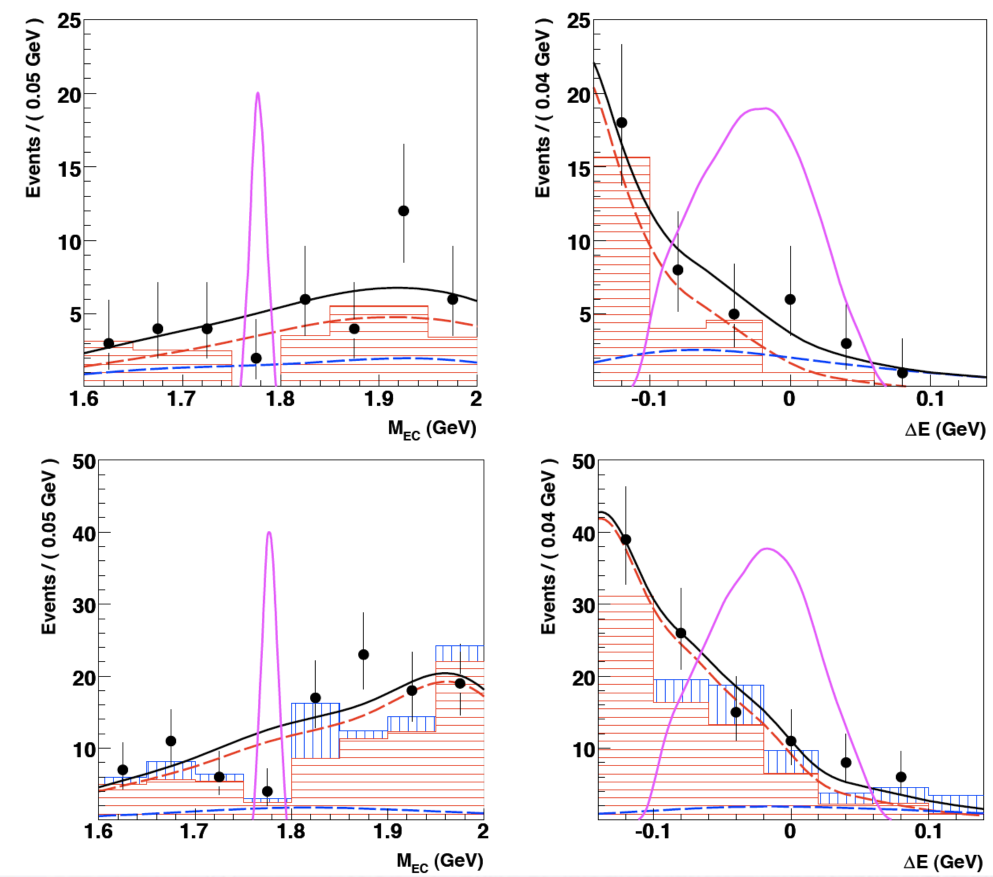
Background Estimation

Number of background events in the 2σ ellipse is estimated as:

$$N_{2\sigma}^{data} = \frac{\int_{2\sigma} PDF_{tot}}{\int_{FitBox-3\sigma} PDF_{tot}} \times N_{FitBox-3\sigma}^{data}$$

$\tau^{\pm} \to e^{\pm}\gamma$:

$\tau^{\pm} \to \mu^{\pm}\gamma$:



PDF are extracted from MC samples and normalized to the Data using unblinded data sidebands

Bhabha PDF is extracted using data enriched data samples

Decay modes	# of events	-9σ	-5 σ	0	+5 σ	+9 σ
$\tau^{\pm} \to e^{\pm}\gamma$	Observed	2	1	?	2	2
	Expected	1.2±0.2	1.4±0.2	1.6±0.3	1.9 ±0.3	2.1±0.3
$\tau^{\pm} \to \mu^{\pm}\gamma$	Observed	3	1	?	4	6
	Expected	2.8±0.3	3.1±0.3	3.6±0.4	4.2±0.4	4.8±0.5

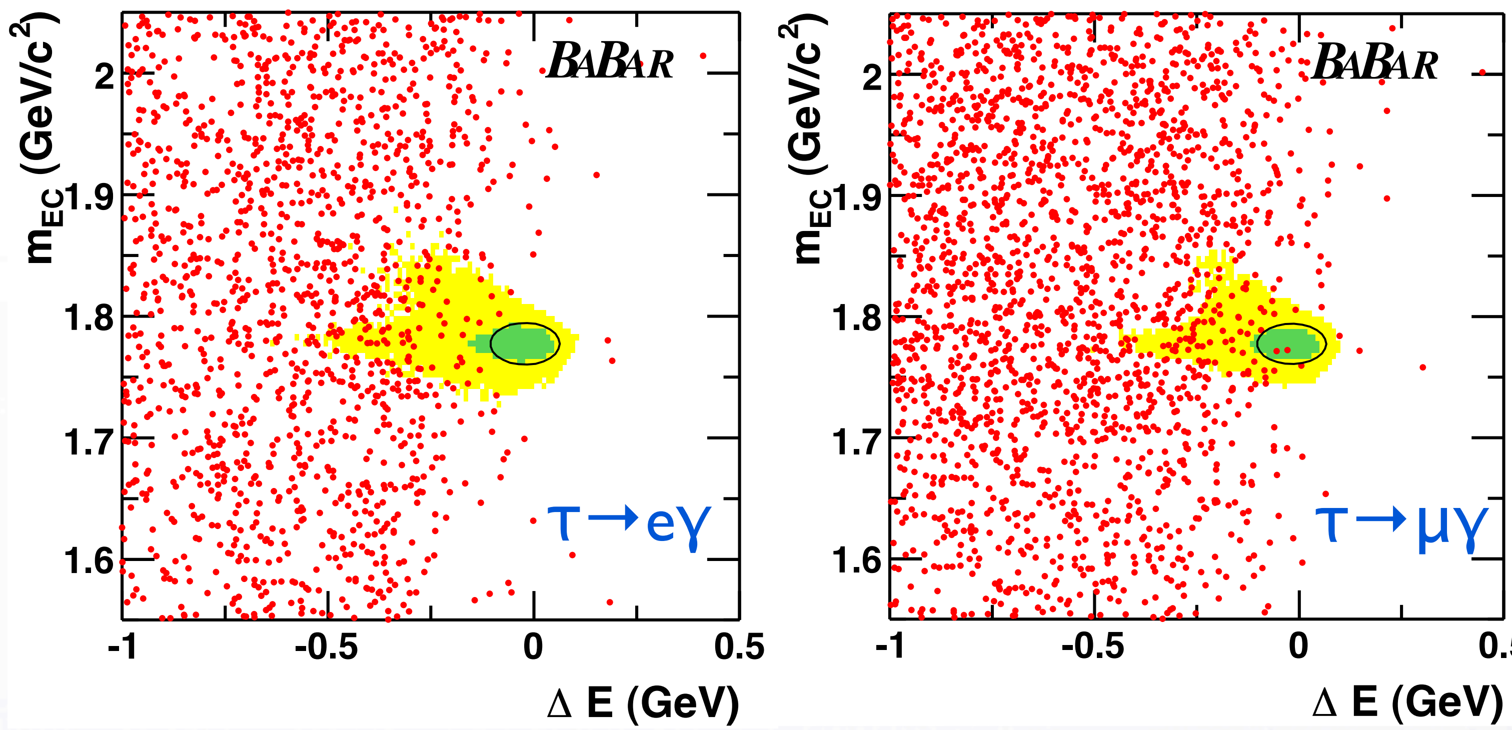
Results

N_τ = 963 ± 7 M (515 fb^{-1})

$\tau \to e\gamma$

- Efficiency (2σ) = 3.9 ± 0.3 %
- Expected Bkg = 1.6 ± 0.5 events
- Expected Upper Limit: 9.8 x 10^{-8}
- Observed Number of events: 0

- Previous Limits:
  - BaBar (232 fb-1): 1.1x 10^{-7}
  - Belle (535 fb-1): 1.2 x 10^{-7}



$$\mathcal{B}\ (\tau^\pm \to e^\pm\gamma) < 3.3 \times 10^{-8}$$

$$\mathcal{B}\ (\tau^\pm \to \mu^\pm\gamma) < 4.4 \times 10^{-8}$$

PRL104,021802(2010)

$\tau \to \mu\gamma$

- Efficiency (2σ) = 6.1 ± 0.5 %
- Expected Bkg = 3.6 ± 0.6 events
- Expected Upper Limit: 8.1 x 10^{-8}
- Observed Number of events: 2

- Previous Limits:
  - BaBar (232 fb-1): 6.8x 10^{-8}
  - Belle (535 fb-1): 4.5 x 10^{-8}

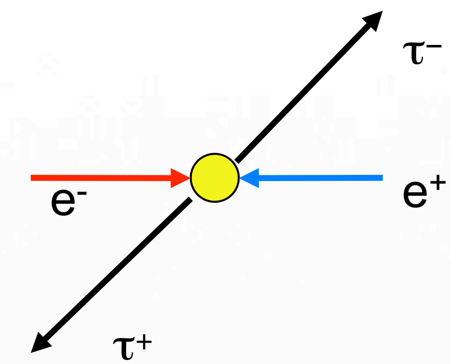
Belle: Phys.Lett.B666:16,2008

Search for $\tau \rightarrow lll$

Analysis strategy

Low multiplicity events selected and event space divided in two hemispheres using thrust.

- Signal side: tracks and neutrals coming from LFV decay
- Tag side: standard 1-prong decay



Center of mass system

Blind analysis performed

Background reduced using PID and kinematical informations, multivariate algorithms ($\tau \to \mu\gamma$)

Optimization performed for Best UL
(in Belle: optimization for best discovery significance)

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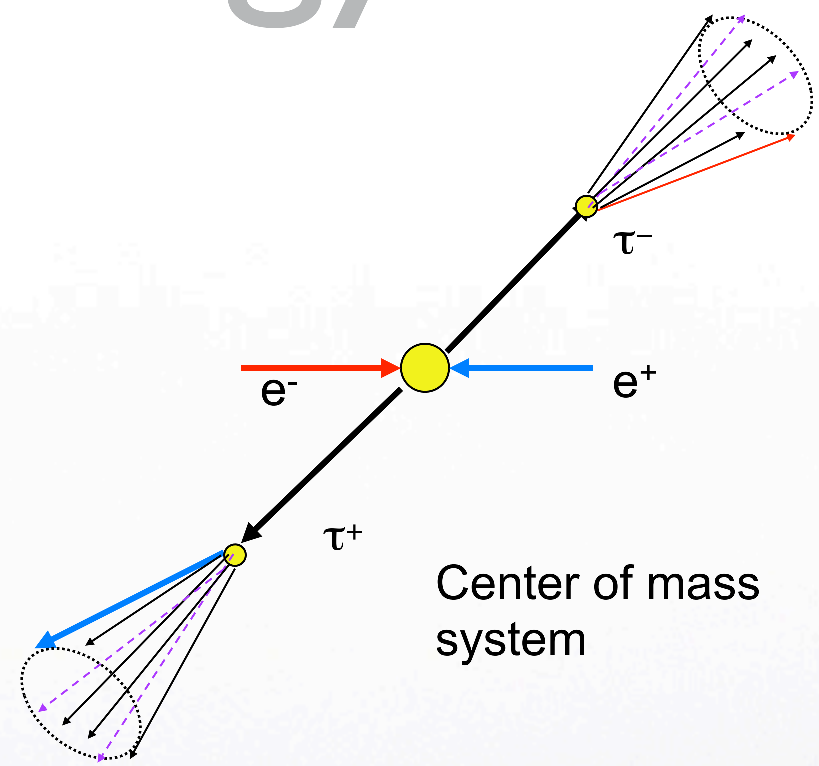

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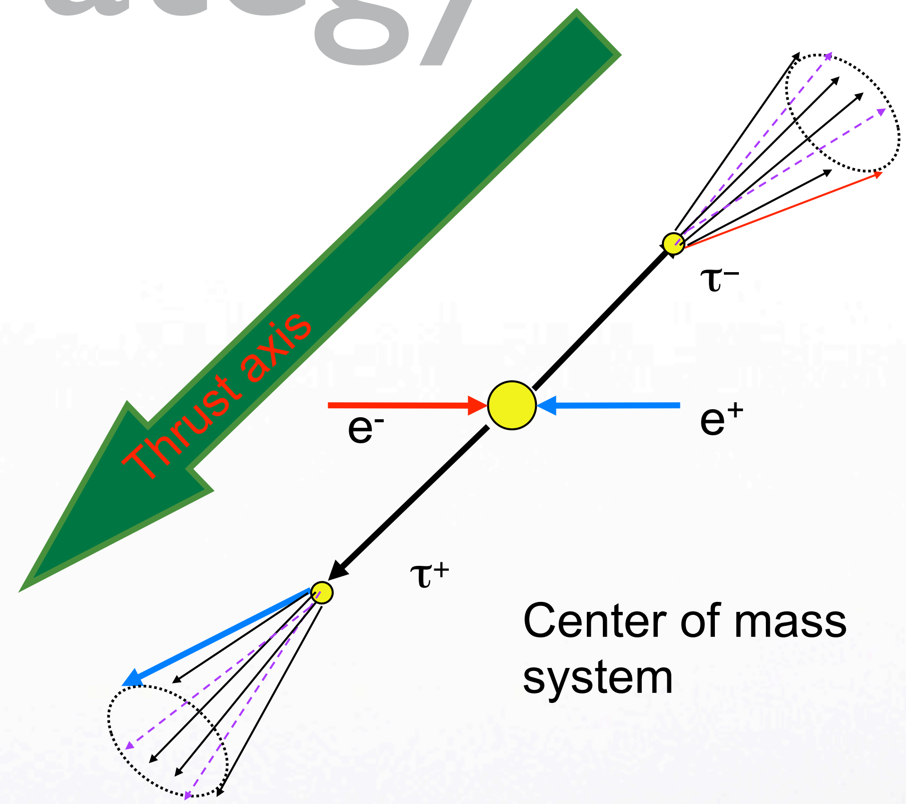

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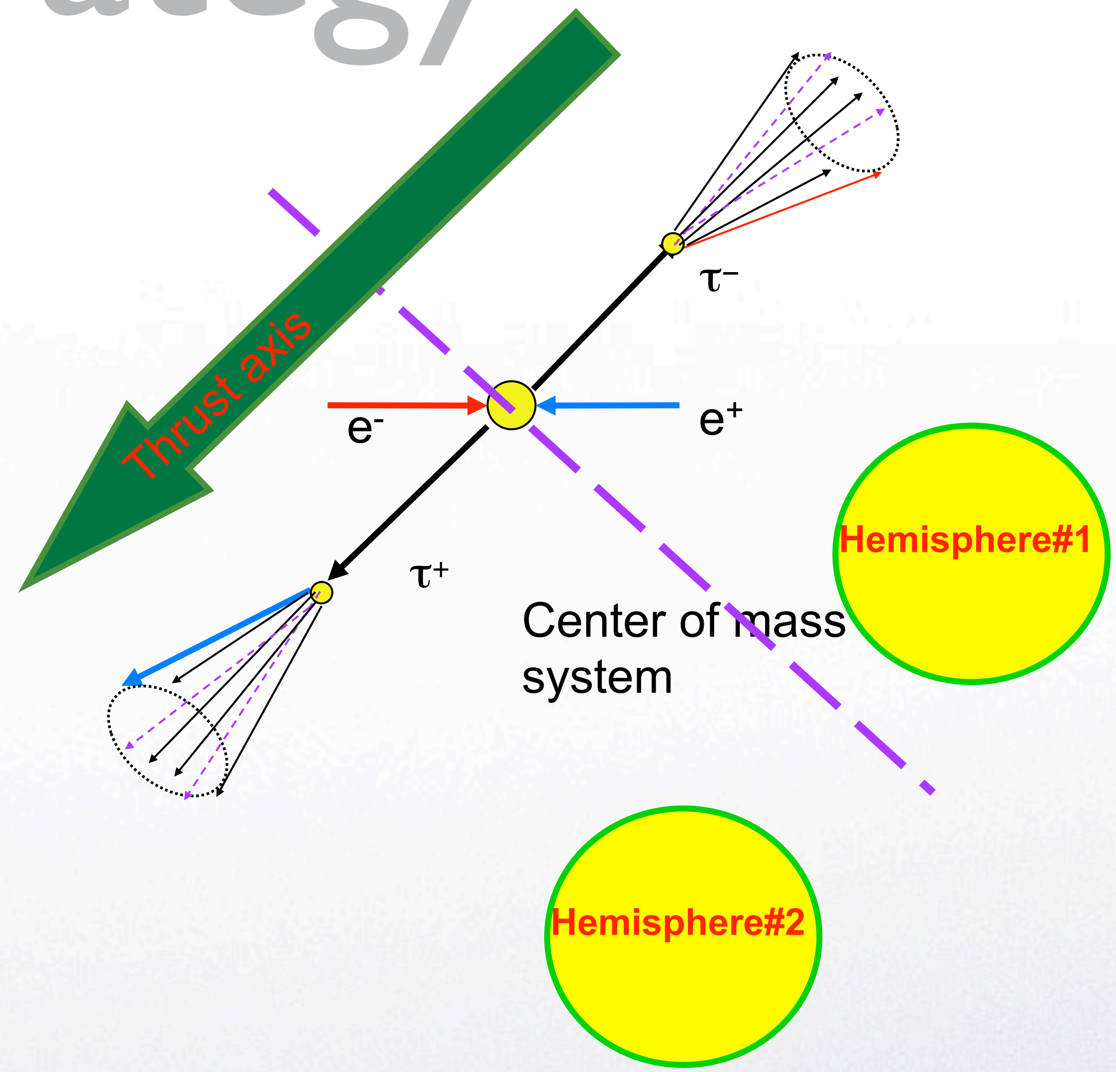

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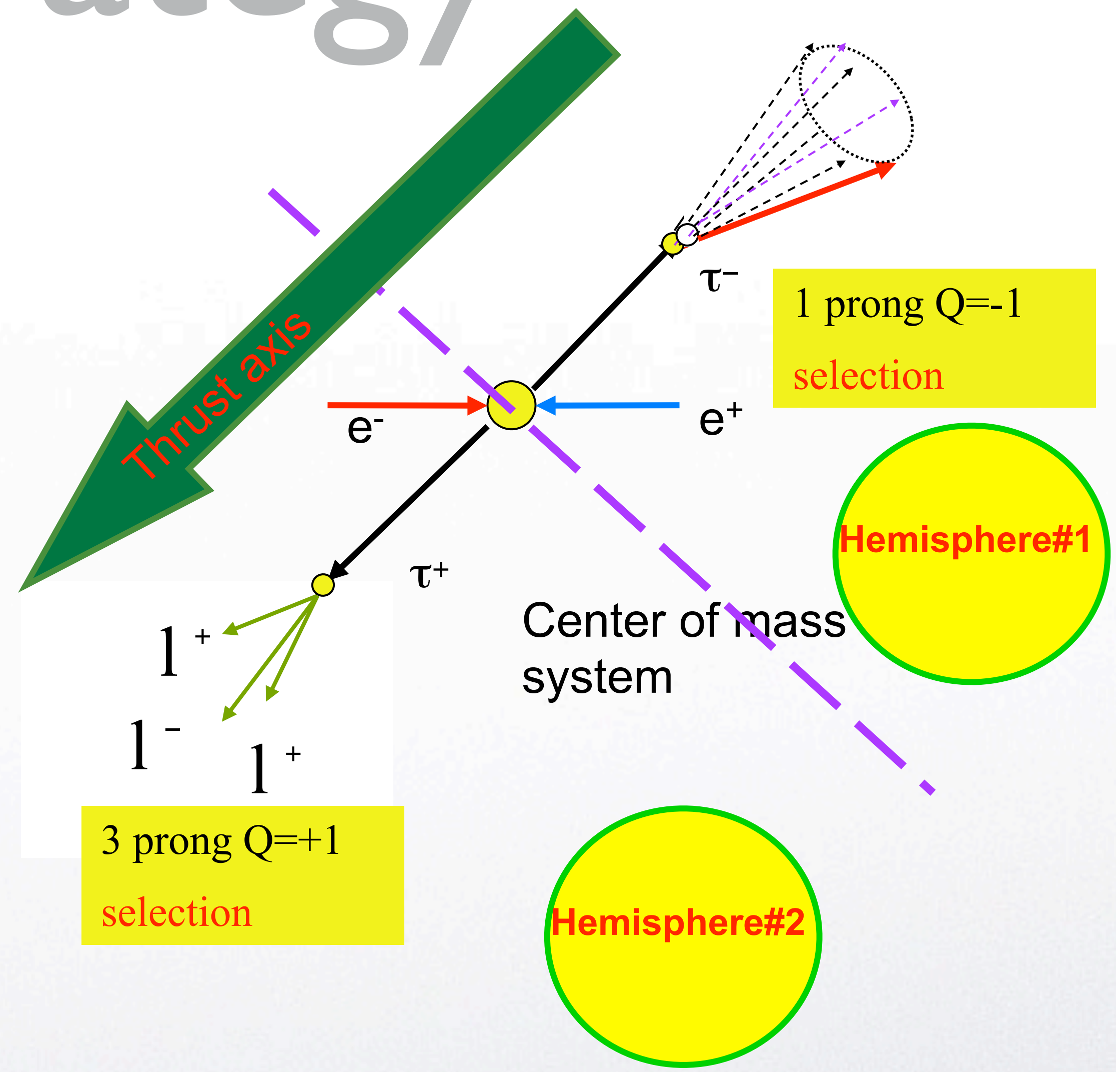
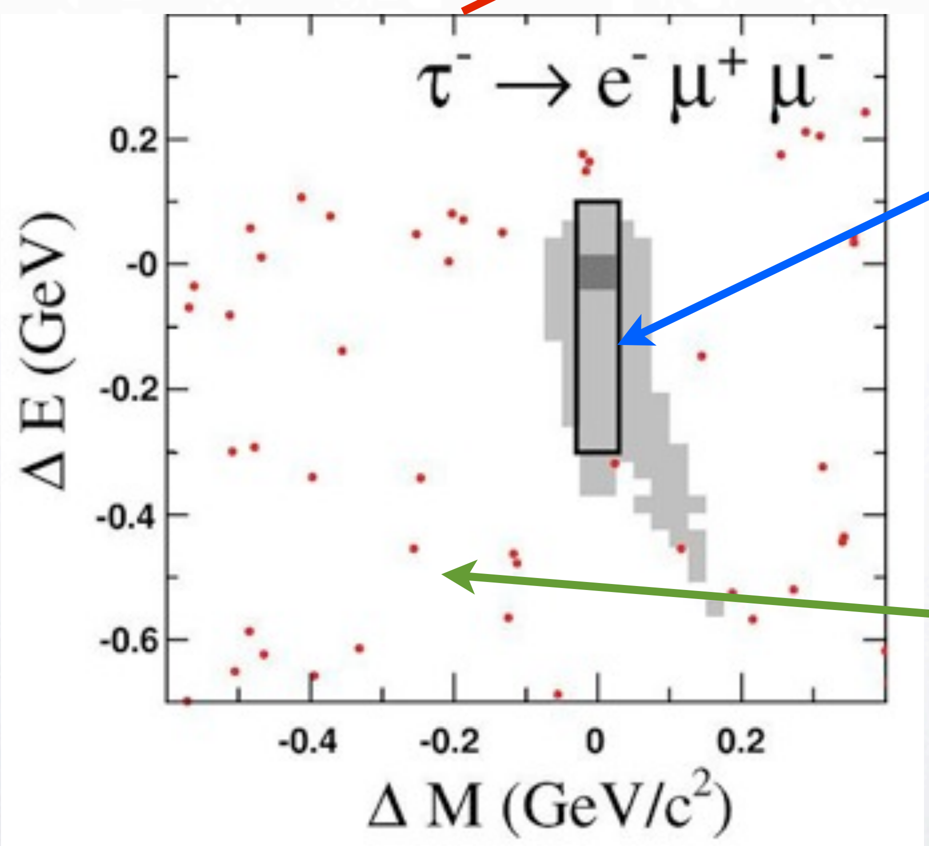


Selection Strategy

Large Box (LB): identical for all channels. Almost all signal events lie in this region



$$\Delta M = M_{ec} - m_\tau$$

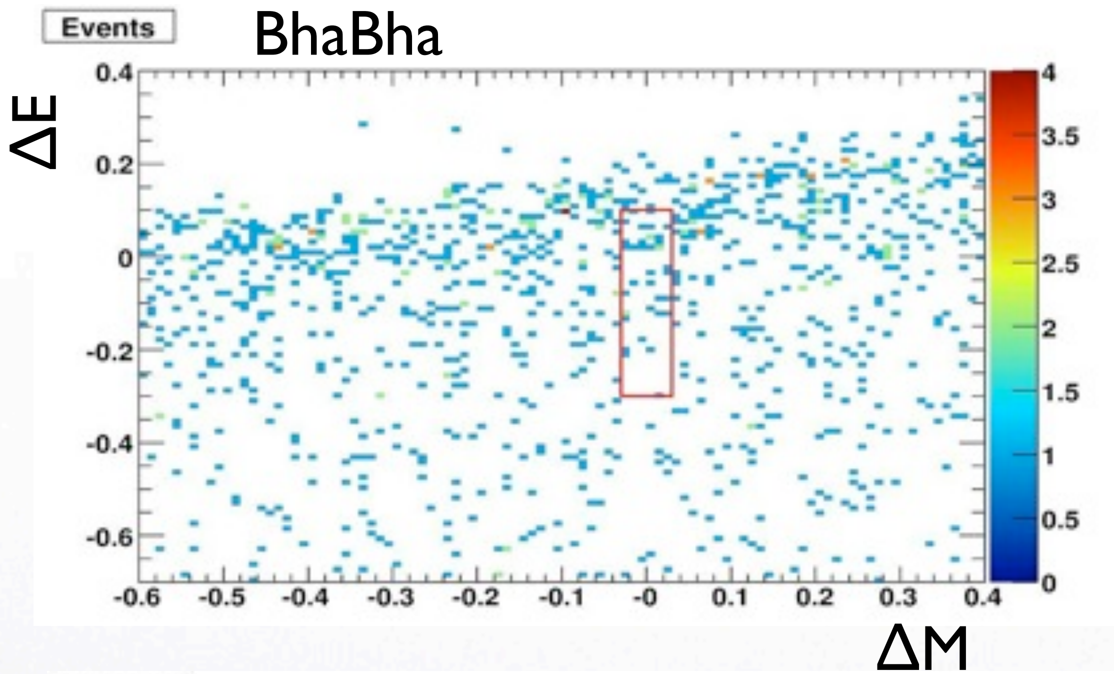
Signal Box (SB): different for each channel, dimension optimized to give the best UL for each channel.

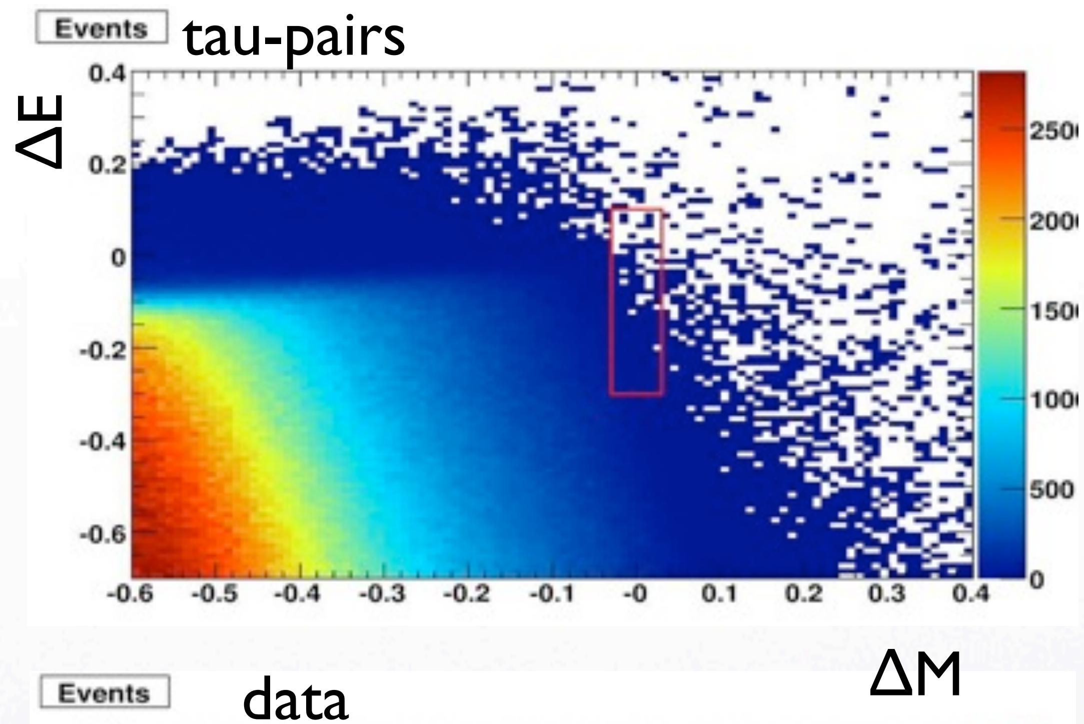
Data events in this region are BLIND

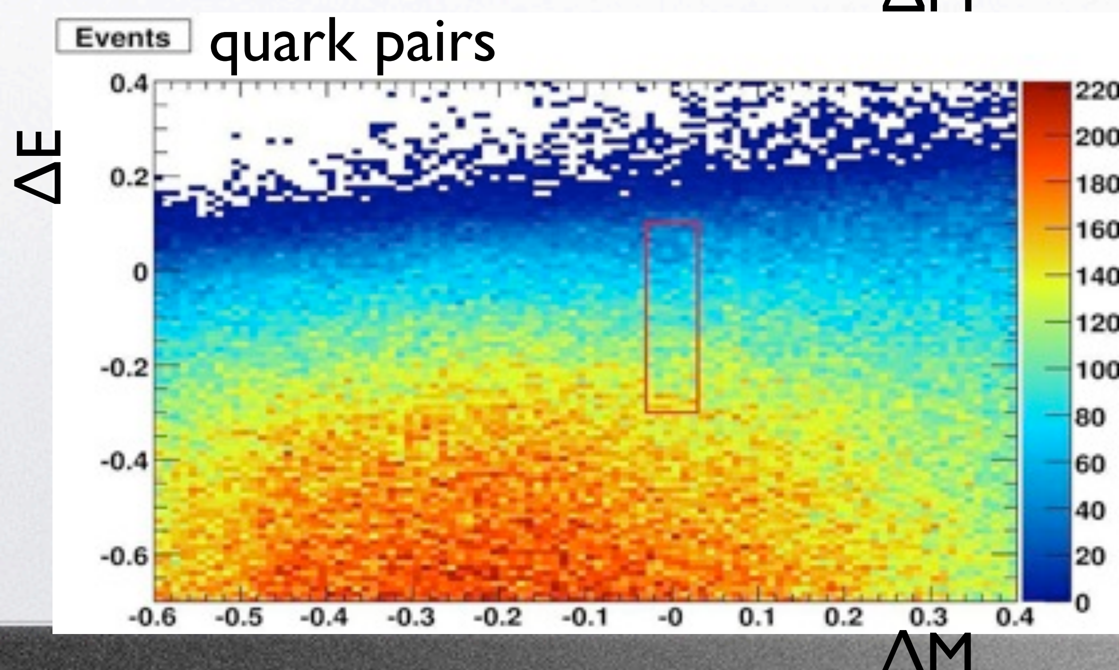
Grand Sideband (GS): is the unblinded region of the LB.

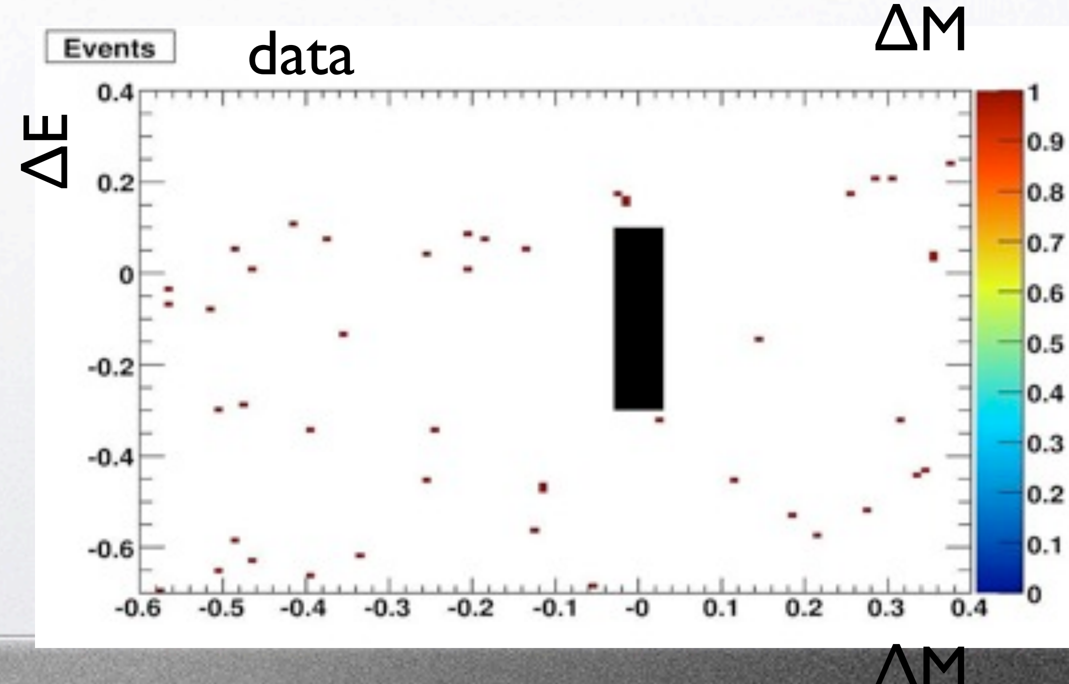
Background estimation made extrapolating data from GS to SB

Backgrounds



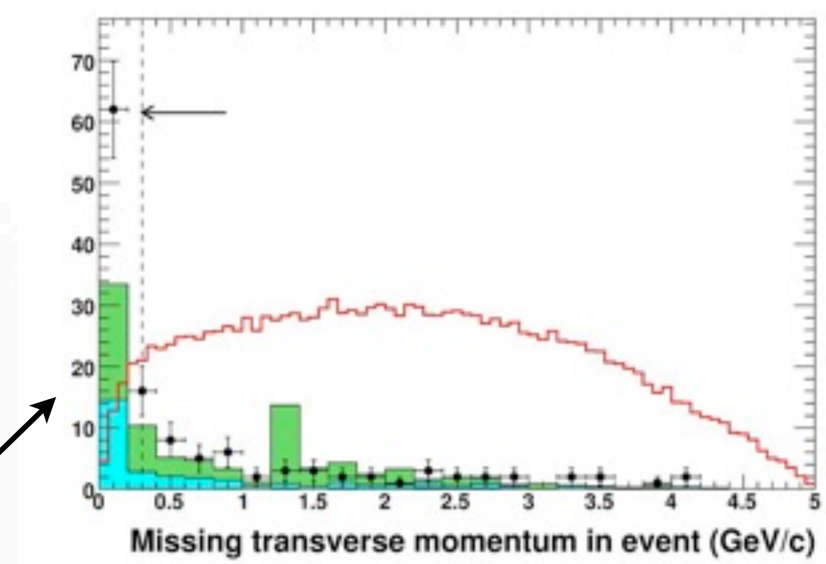


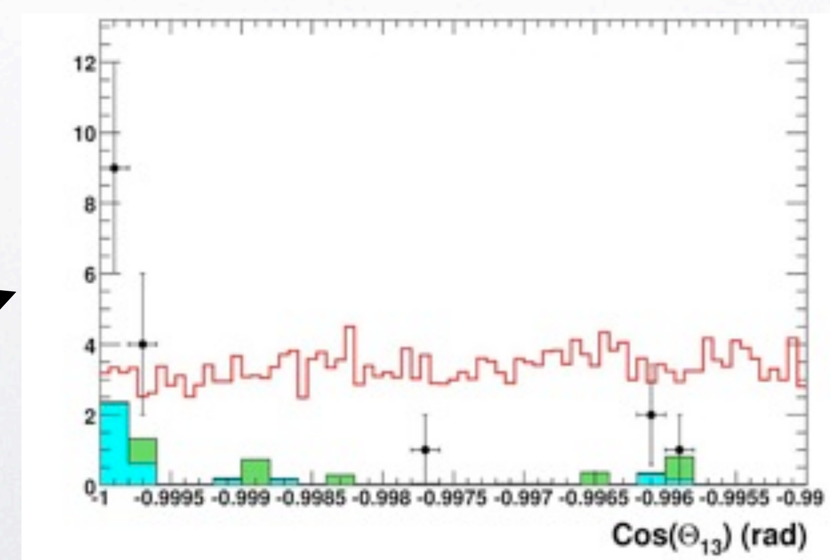




Background estimation

- PID applied to all signal tracks: identified as either e or muon depending on channel
- Tag track p_t<4.8 GeV (suppress QED bkgs)
- One prong Pid veto:
  - No electron for $e^-e^+e^-$, $e^-\mu^+\mu^-$
  - No muon for $\mu^-\mu^+\mu^-$ $\mu^-e^+e^-$ $e^-\mu^+e^-$
- One prong mass compatible with tau mass
- Missing transverse momentum
  - >0.1 GeV/c for $e^-\mu^+e^-$
  - >0.2 GeV/c for $\mu^-\mu^+\mu^-$, $e^-\mu^+\mu^-$
  - >0.3 GeV/c for e^-e^+e, $\mu^-e^+e^-$
- Cosine of the angle between the reconstructed 3 prong tracks and 1 prong track momenta





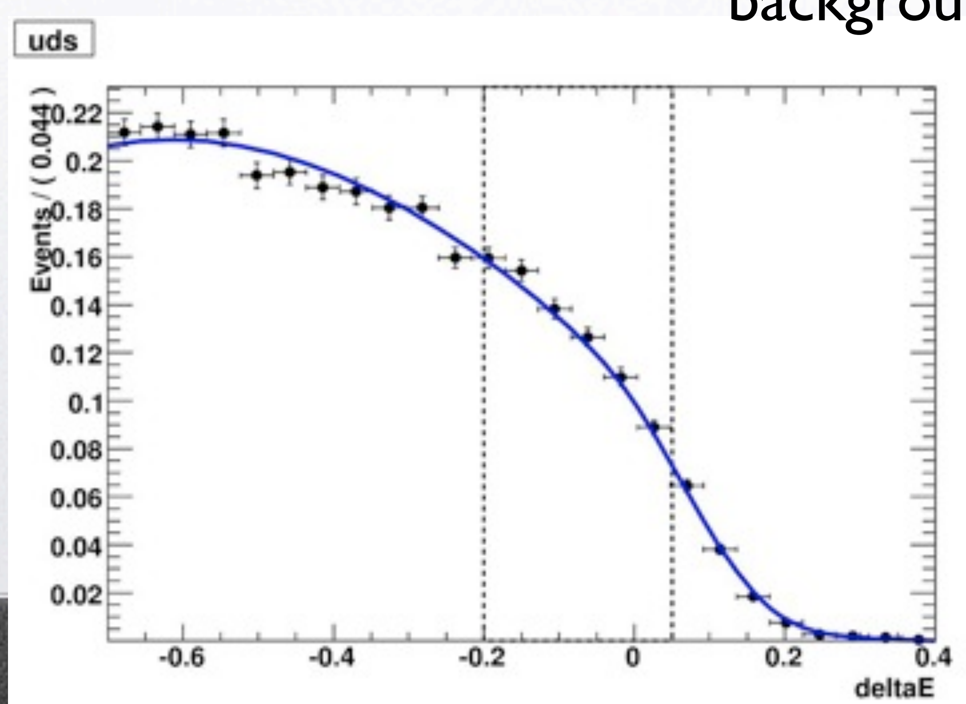
Bakground Estimation

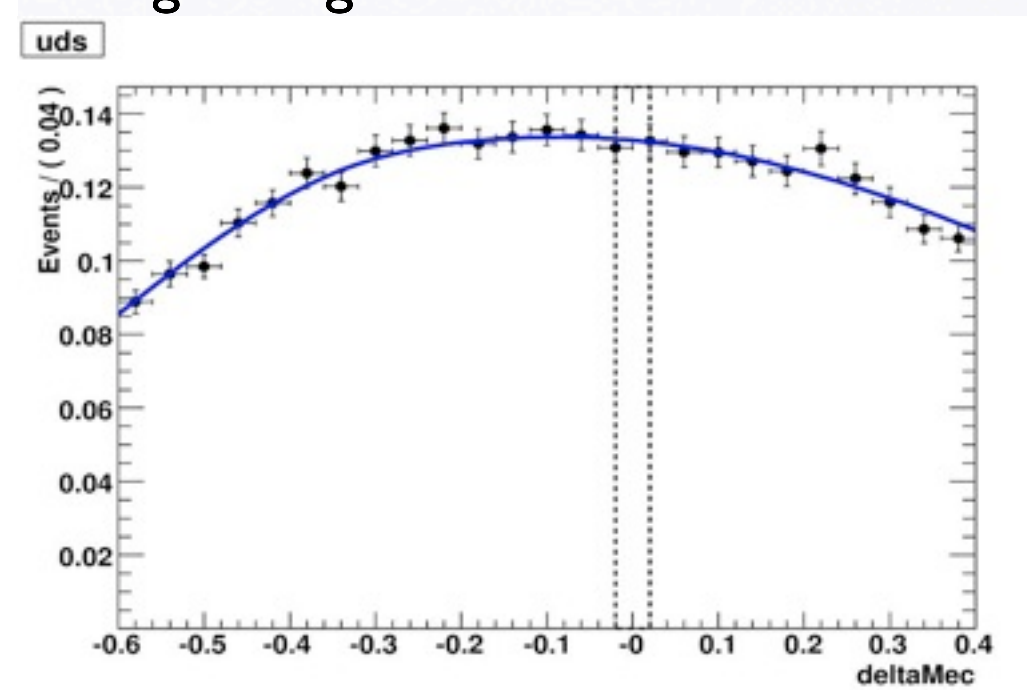
Backgrounds are extracted by a 2-dimensional fit in (ΔM,ΔE) plane

Bkg PDF are obtained from unblinded sidebands

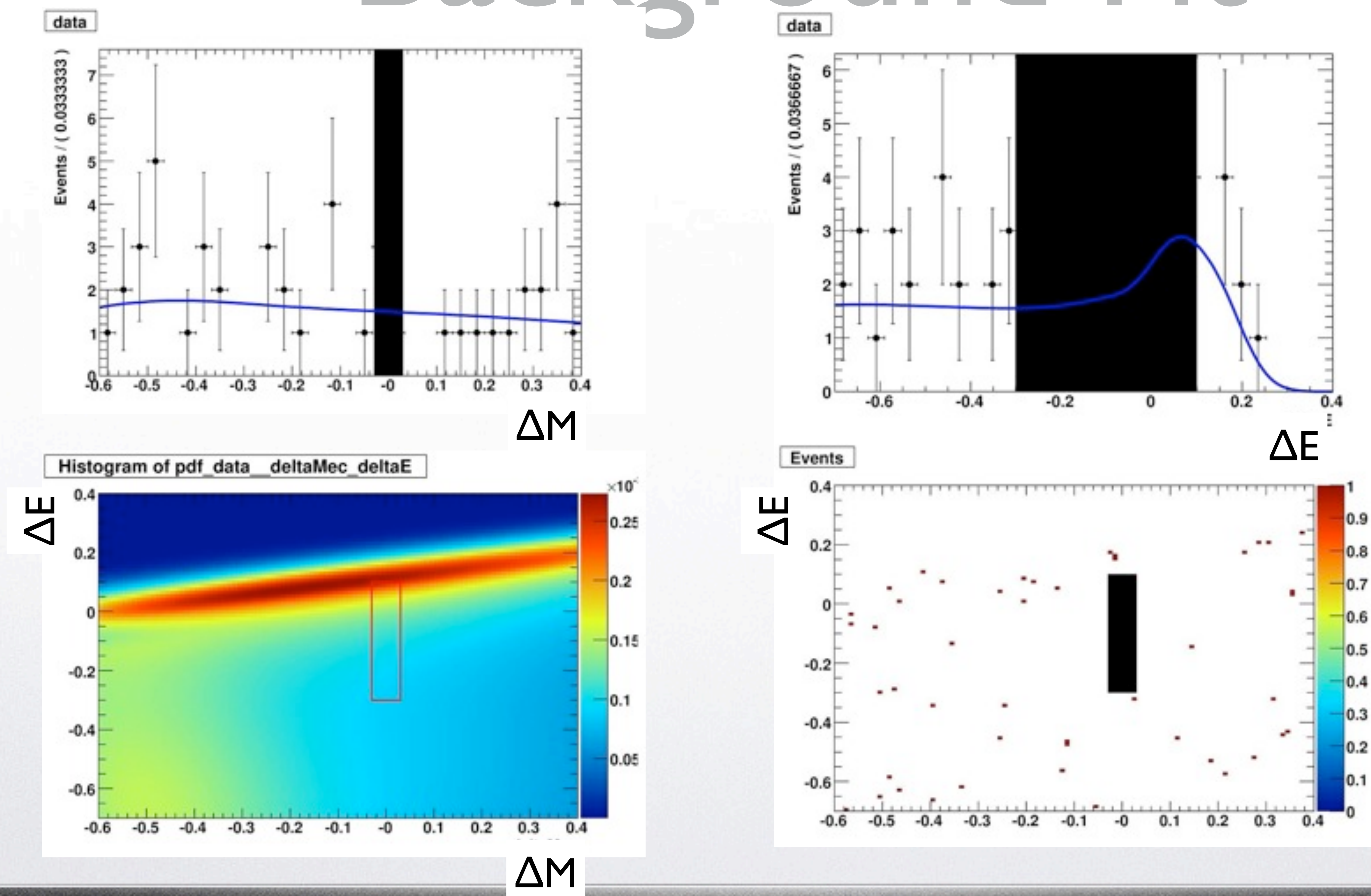
PDF for QED (Bhabha and di-muon) are obtained by fitting data enriched control samples

Data PDF is obtained as sum of the Bkg PDFs contributions fitted to the data, the Data PDF is then integrated over signal region in order to extract expected background in signal region





Background Fit



Results

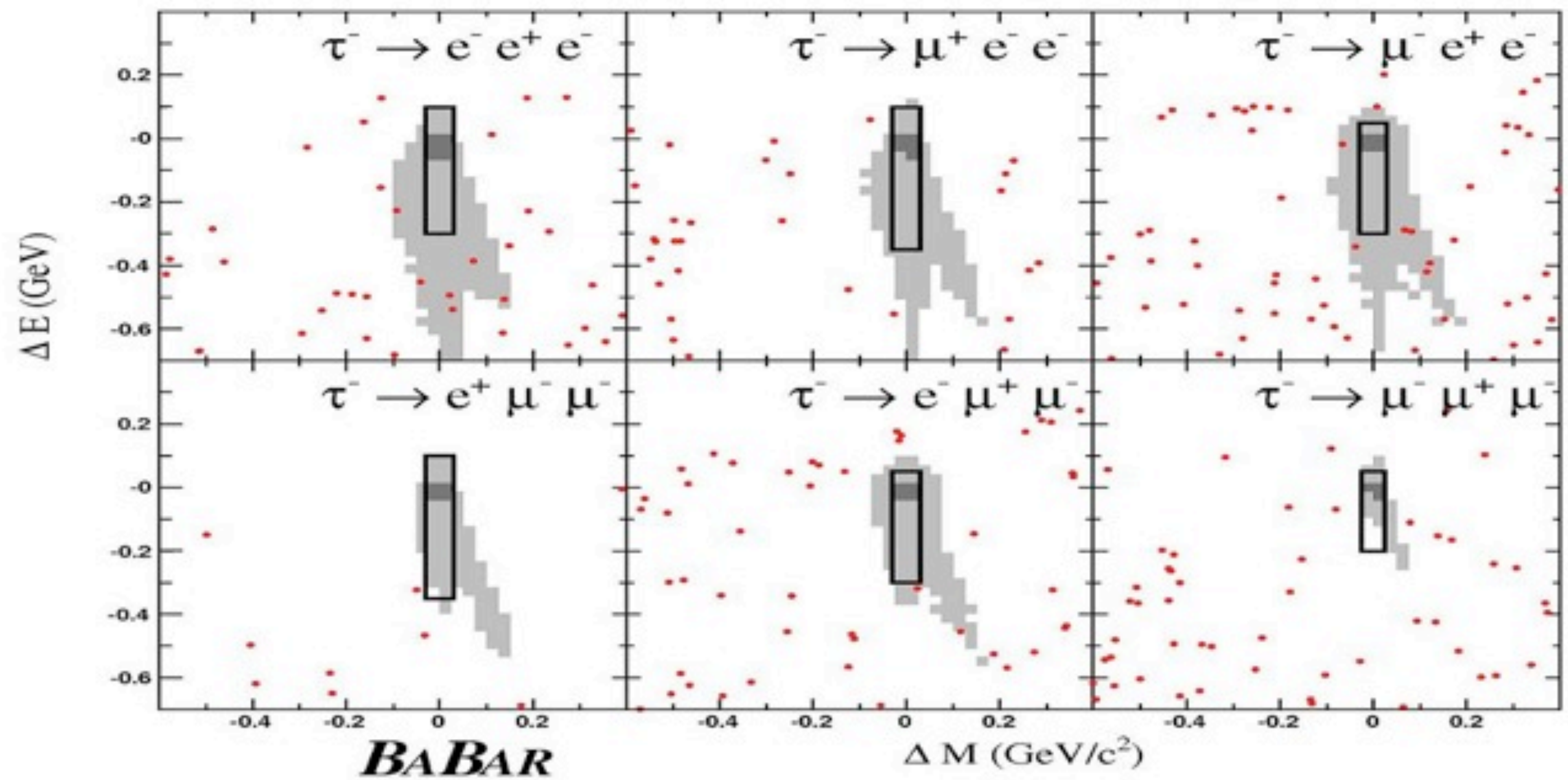
Big improvement w.r.t previous BaBar results, thanks to better PID and tracking.

μ ID eff 66% → 77%
e ID eff 89% → 91%
with reduced systematics

Results scaled better than Lumi scaling only.

Errors dominated by:
PID uncertainty (signal efficiency)
Fit to the Data (bkg extraction)

N_τ = 861M (468 fb^{-1})



Phys. Rev. D 81, 111101(R) (2010)

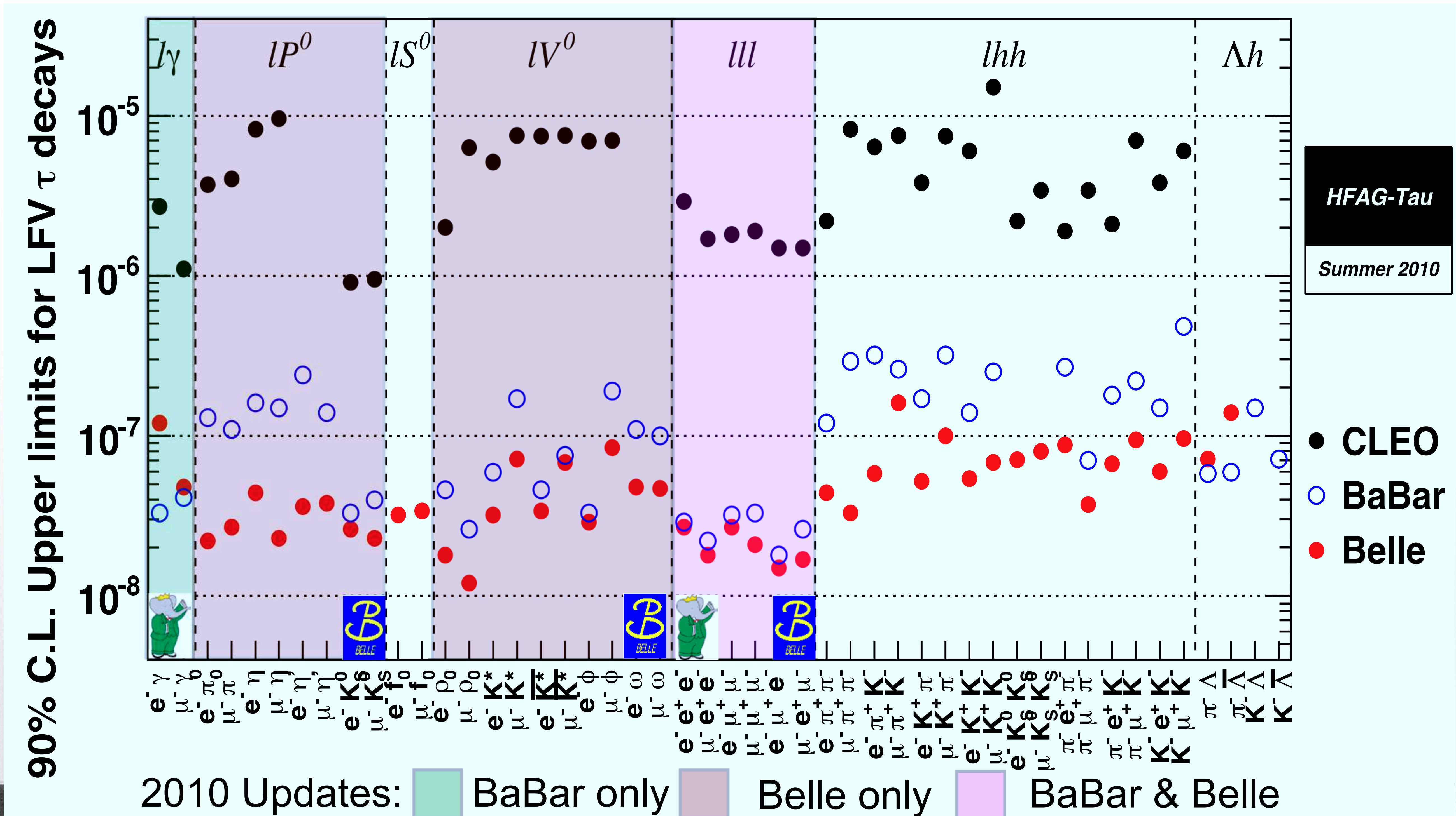
Channel	Efficiency (%)	N_{bgd}	Exp. UL	N_{obs}	UL
$e^+e^-e^+$	8.6 ± 0.2	0.12 ± 0.02	3.4×10^{-8}	0	2.9×10^{-8}
$e^+e^-\mu^+$	8.8 ± 0.5	0.64 ± 0.19	3.7×10^{-8}	0	2.2×10^{-8}
$e^+e^+\mu^-$	12.6 ± 0.7	0.34 ± 0.12	2.2×10^{-8}	0	1.8×10^{-8}
$e^+\mu^-\mu^+$	6.4 ± 0.4	0.54 ± 0.14	4.6×10^{-8}	0	3.2×10^{-8}
$e^-\mu^+\mu^+$	10.2 ± 0.6	0.03 ± 0.02	2.8×10^{-8}	0	2.6×10^{-8}
$\mu^+\mu^-\mu^+$	6.6 ± 0.6	0.44 ± 0.17	4.0×10^{-8}	0	3.3×10^{-8}

Latest Belle results

Mode	ε (%)	N_{BG}^{EXP}	σ_{syst} (%)	UL ($\times 10^{-8}$)
$e^-e^+e^-$	6.0	0.21+-0.15	9.8	**2.7**
$\mu^-\mu^+\mu^-$	7.6	0.13+-0.06	7.4	**2.1**
$e^-\mu^+\mu^-$	6.1	0.10+-0.04	9.5	**2.7**
$\mu^-e^+e^-$	9.3	0.04+-0.04	7.8	**1.8**
$\mu^-e^+\mu^-$	10.1	0.02+-0.02	7.6	**1.7**
$e^-\mu^+e^-$	11.5	0.01+-0.01	7.7	**1.5**

Phys.Lett.B687:139-143,2010

A broader look



Conclusions

- B-Factories have proven to be versatile machines for the search for new physics in over a decade
- Thanks to the high luminosity achieved and the constant development of new analysis techniques results have greatly improved over the years for LFV searches in the tau sector
- Many bounds on NP models parameters were set thanks to B-Factories and Super Flavor factories are expected to reach unprecedented sensitivities making it possible to rule out most of the present theoretical expectations or discover NP for the first time

		$\tau \to \mu\gamma$	$\tau \to lll$
SM + ν mixing	Lee, Shrock, PRD 16 (1977) 1444 Cheng, Li, PRD 45 (1980) 1908	Undetectable	
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SM + heavy Maj ν_R	Cvetic, Dib, Kim, Kim , PRD66 (2002) 034008	10^{-9}	10^{-10}
Non-universal Z'	Yue, Zhang, Liu, PLB 547 (2002) 252	10^{-9}	10^{-8} ?
SUSY SO(10)	Masiero, Vempati, Vives, NPB 649 (2003) 189 Fukuyama, Kikuchi, Okada, PRD 68 (2003) 033012	10^{-8} ?	10^{-10}
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Thanks for your attention