"Radiative corrections" and LFU measurements (e/μ)

LAPTh

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TH

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LAL, Orsay

- Why ?
- The fate of an electron
- What do we know experimentally ?

Why ?

Jerome Charles at the B Workshop in Marseille :

Naively QED corrections are suppressed by $\alpha/\pi \sim 0.3\%$. However infrared (soft and collinear) divergences generate enhancement factors

$$\log^k \left[\frac{(\textit{large scale})}{(\textit{small scale})} \right]$$

In B decays we may encounter m_e, m_μ, m_π, m_D, $m_B \ldots$. Note that $\log(m_B/m_e) \sim 9$, $\log(m_B/m_\mu) \sim 4$, so that QED corrections can easily reach a few %.

Jerome :

However even in the soft photon approximation not all terms are taken into account by PHOTOS. A more detailed interplay between theorists and experimentalists will be needed to check that the potentially neglected contributions remain under control.

In addition there exists enhanced QED corrections that are not captured by the $\log(E_\gamma)$ terms. An explicit example has been found for $B \to \mu^+\mu^-$, that is both power and logarithmically enhanced [Beneke *et al.*]:

$$m_B \int_0^\infty \frac{d\omega}{\omega}\, \phi_{B+}(\omega) \log^k(\omega) \sim \frac{m_B}{\lambda_B}\sigma_k \sim 30$$

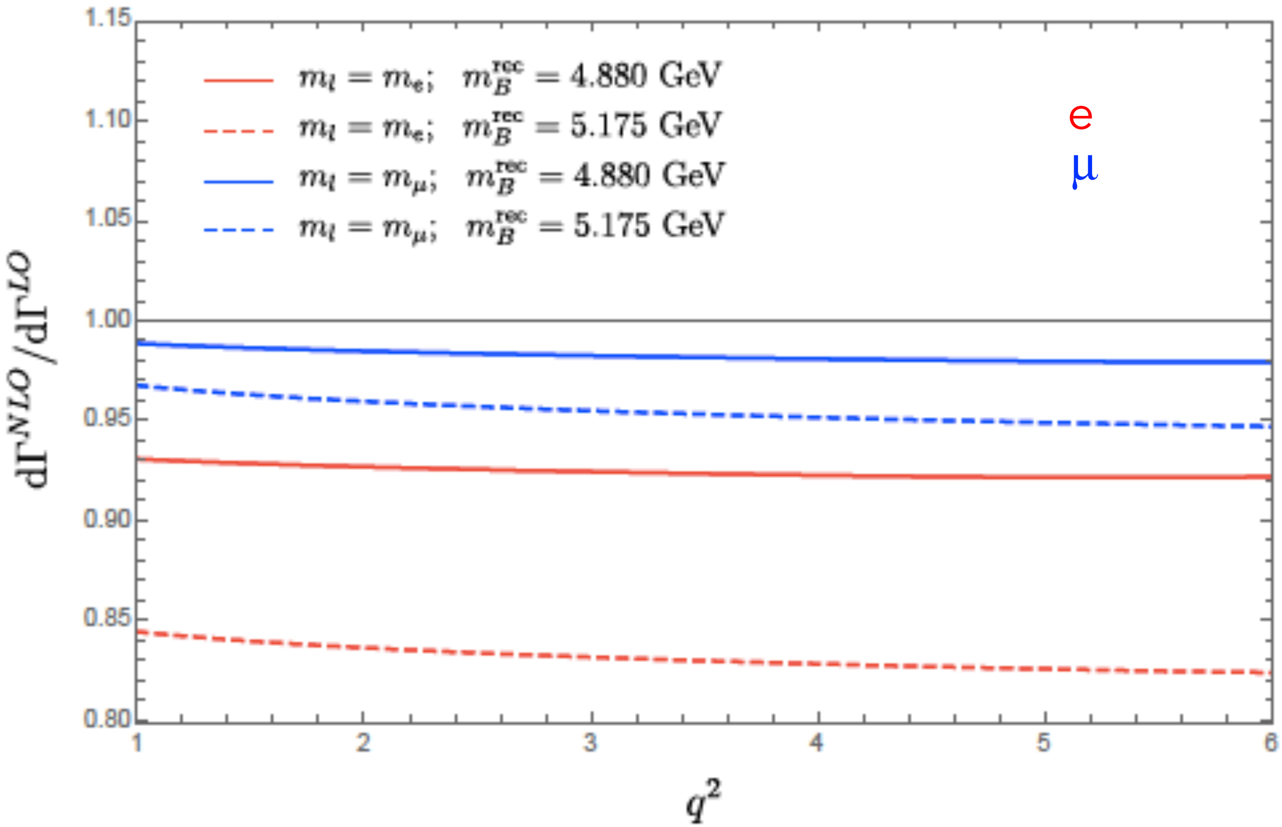
These 'new' enhanced contributions depend on poorly known non local matrix elements (B meson distribution amplitudes) and induce a non trivial light mass dependence to the decay amplitudes.

In the end for $B \to \mu\mu$ the total correction does not exceed the 1% level due to numerical cancellations between terms of different signs. However it is not clear to which extent this order of magnitude is valid for all B decays.

But there is a publication on radiative corrections on RK and RK* : arXiv:1605.07633
Marzia Bordone, Gino Isidori, Andrea Pattori

Effects could be large depending on :

- the q^2 region
- the cut placed on the reconstructed B mass



But

arXiv:1605.07633

- we do not use the same mB cut for electrons and muons
- we use PHOTOS which is in agreement with these calculations at the 1% level

What is not taken into account in arXiv:1605.07633 ?

$$R_{K^+}[1.0,\ 6.0]^{\rm SM} = 1.00 \pm 0.01_{\rm QED}\ ,$$

$$R_{K^*}[1.1,\ 6.0]^{\rm SM} = 1.00 \pm 0.01_{\rm QED}\ ,$$

$$\begin{aligned} R_{K^*}[0.045, 1.1]^{\rm SM} &= 0.906 \pm 0.020_{\rm QED} \pm 0.020_{\rm FF} \\ &= 0.906 \pm 0.028_{\rm th}\ . \end{aligned}$$

$$\begin{aligned} R_{K^*}[0.1, 1.1]^{\rm SM} &= 0.983 \pm 0.010_{\rm QED} \pm 0.010_{\rm FF} \\ &= 0.983 \pm 0.014_{\rm th}\ . \end{aligned}$$

Enough stat with Run1 + Run2 to use this bin definition

The fate of an electron

Final State Radiation

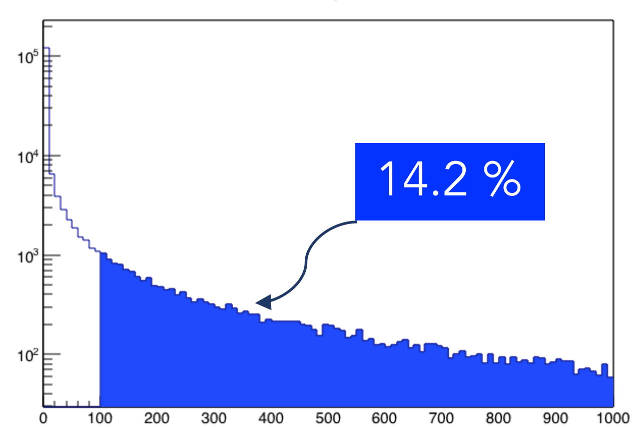
Abstract (APS)
We report the first observation of the (radiative) decay $J\psi \to e^+e^-\gamma$. Our data are from an experiment in which $J\psi$ is formed in antiproton-proton annihilations. The observed rate is consistent with a QED calculation based on final state radiation. Our measurement gives a branching ratio for this mode of $(8.8\pm1.3\pm0.4)\times10^{-3}$ for γ energy>100 MeV.

Phys.Rev. D54 (1996) 7067-7070

$BR(J/\Psi \to ee\gamma)/BR(J/\Psi \to ee) = (8.8 \pm 1.3 \pm 0.4)\ 10^{-3} / (59.71 \pm 0.32)\ 10^{-3} \sim 14.7\ \%$

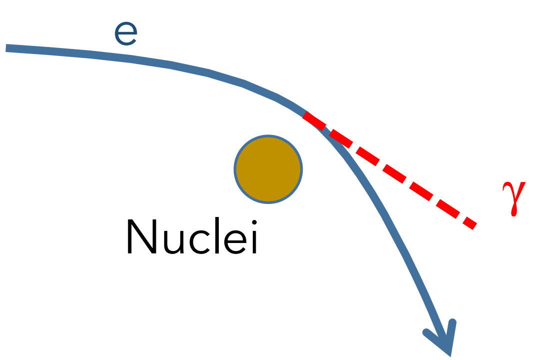
$$\boxed{(\alpha/\pi)\log^2(m_B/m_\ell)}$$

E_γ in the J/Ψ rest frame



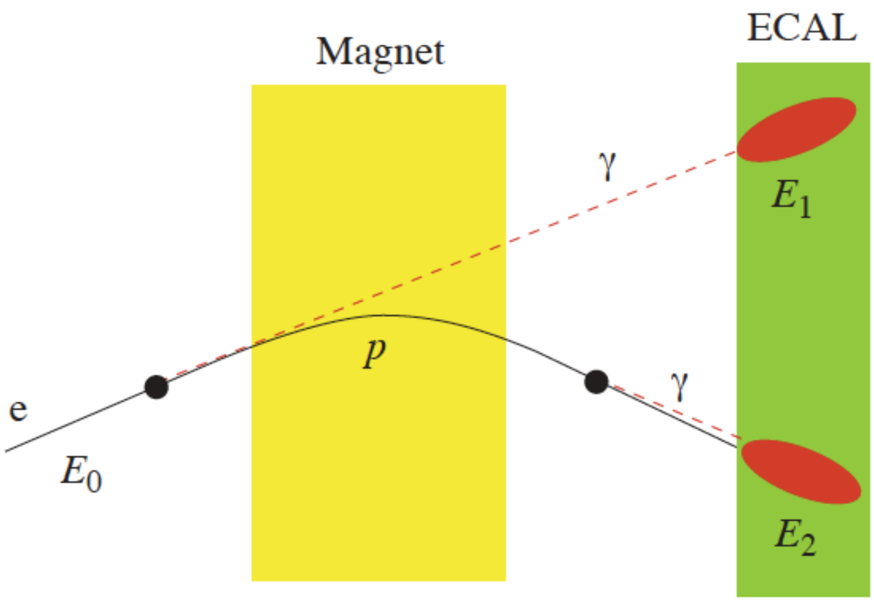
Detector-independent
Calculable
Modelled by PHOTOS

Bremsstrahlung emission



$\sigma \propto 1/m_l^2$

Energy loss $\propto E_e$
Energy loss $\propto$ material



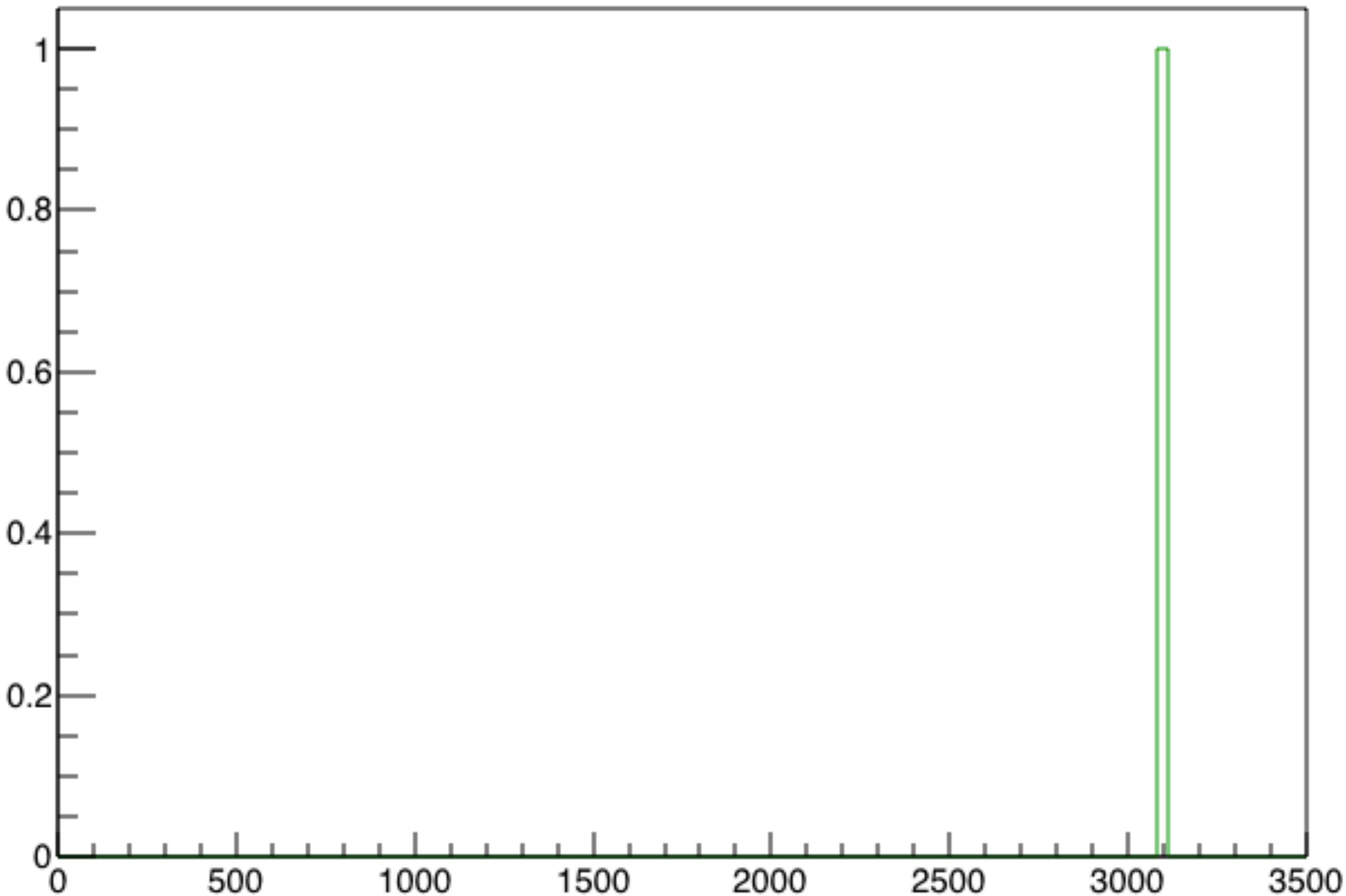
Before the magnet

- electron can be swept out (=lost !)
- kinematics are "wrong"

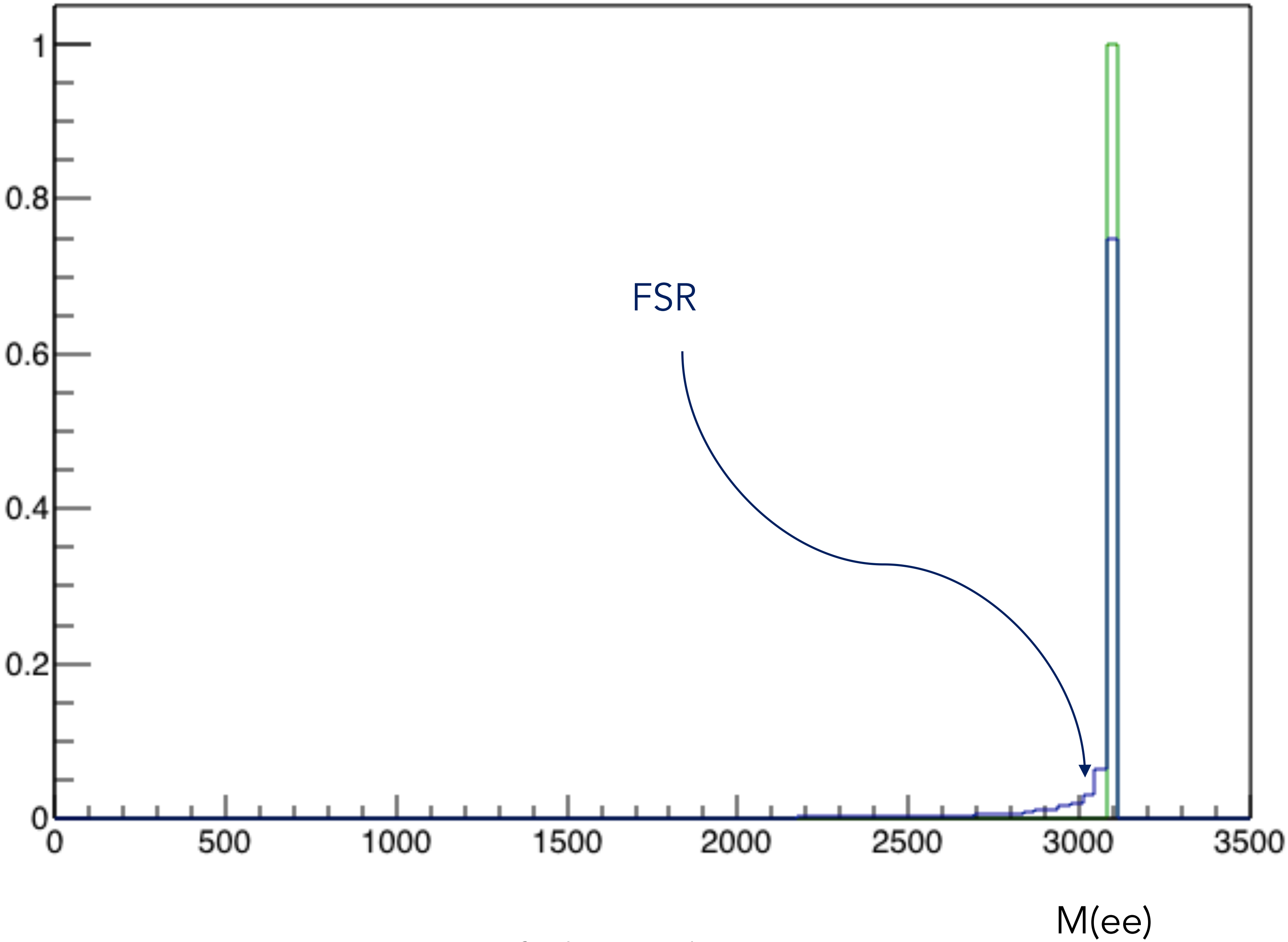
After the magnet

- not a problem

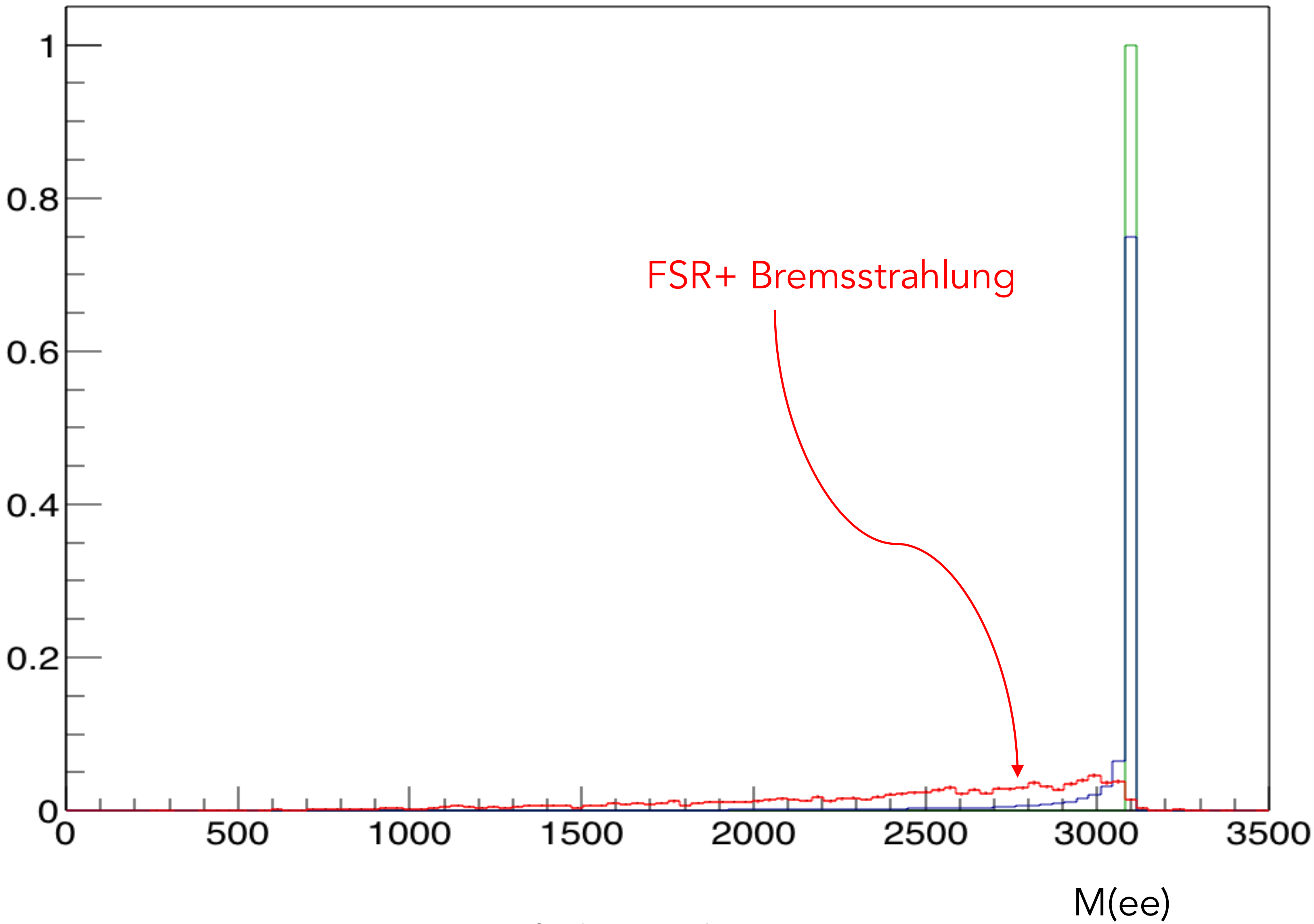
Detector and kinematics dependent
Modelled by GEANT4

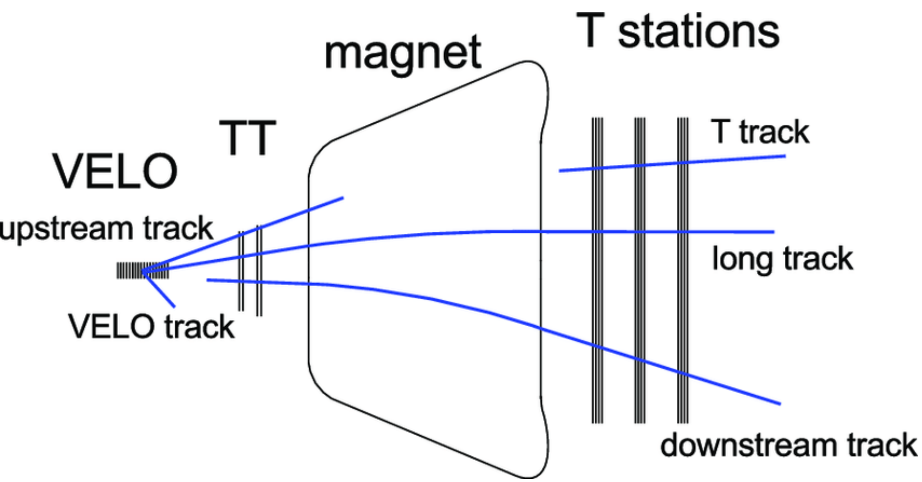


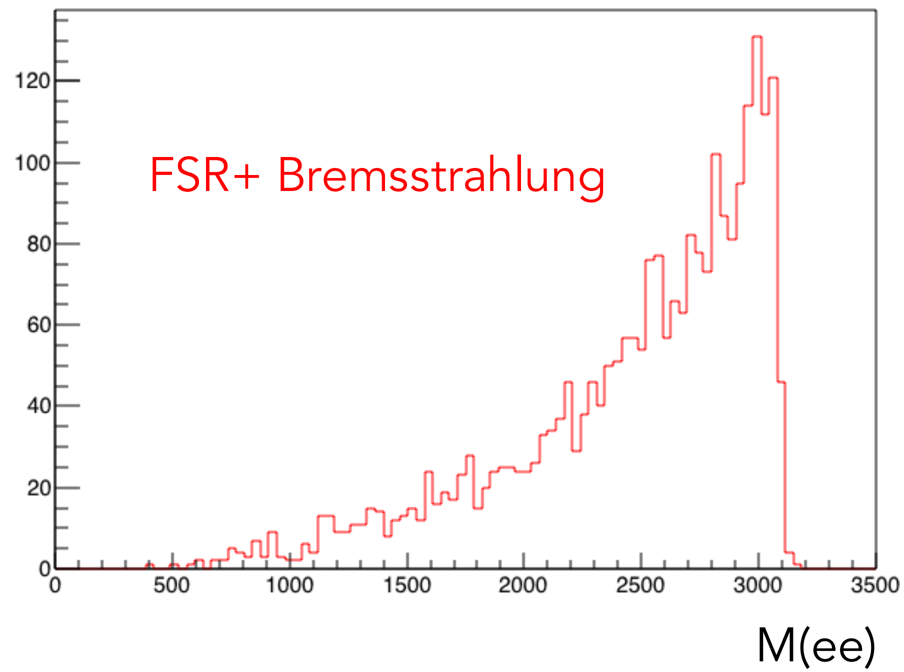
M(ee)



1
0.8
0.6
0.4
0.2
0
FSR
0
500
1000
1500
2000
2500
3000
3500
M(ee)

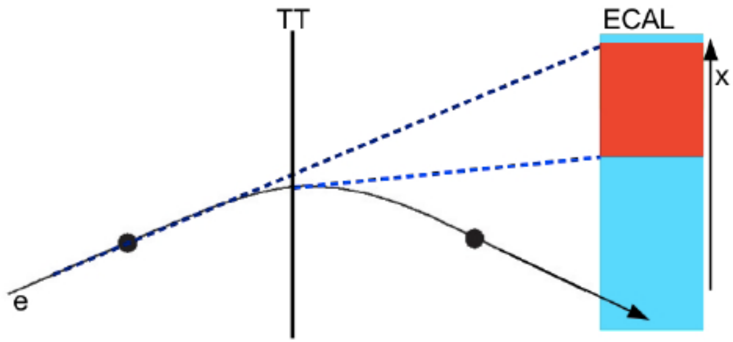

FSR+ Bremsstrahlung
1
0.8
0.6
0.4
0.2
0
0
500
1000
1500
2000
2500
3000
3500
M(ee)

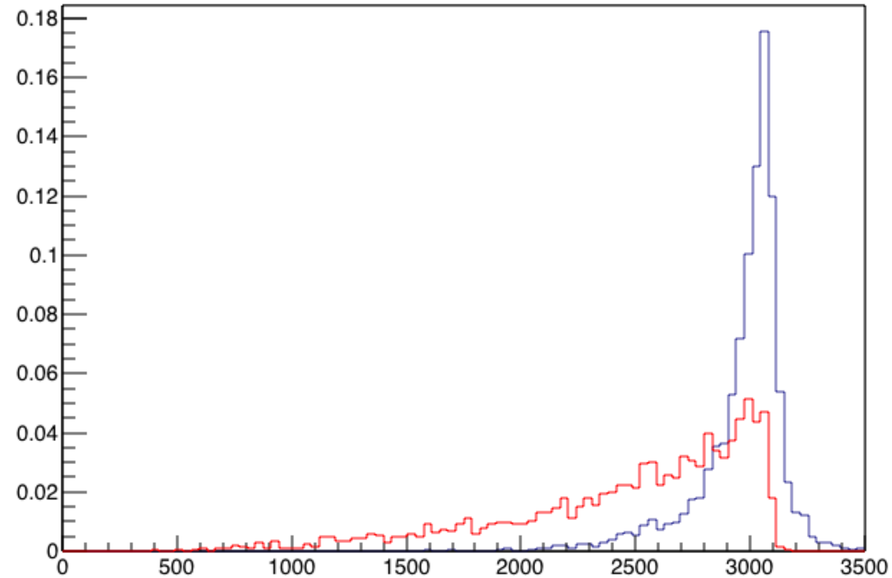




Large Bremsstrahlung tail
Loss of events (electrons swept out by the magnetic field)

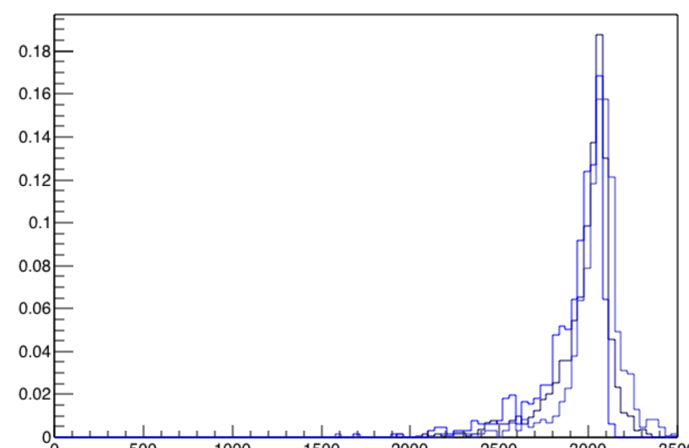
Bremsstrahlung recovery algorithm





M(ee)

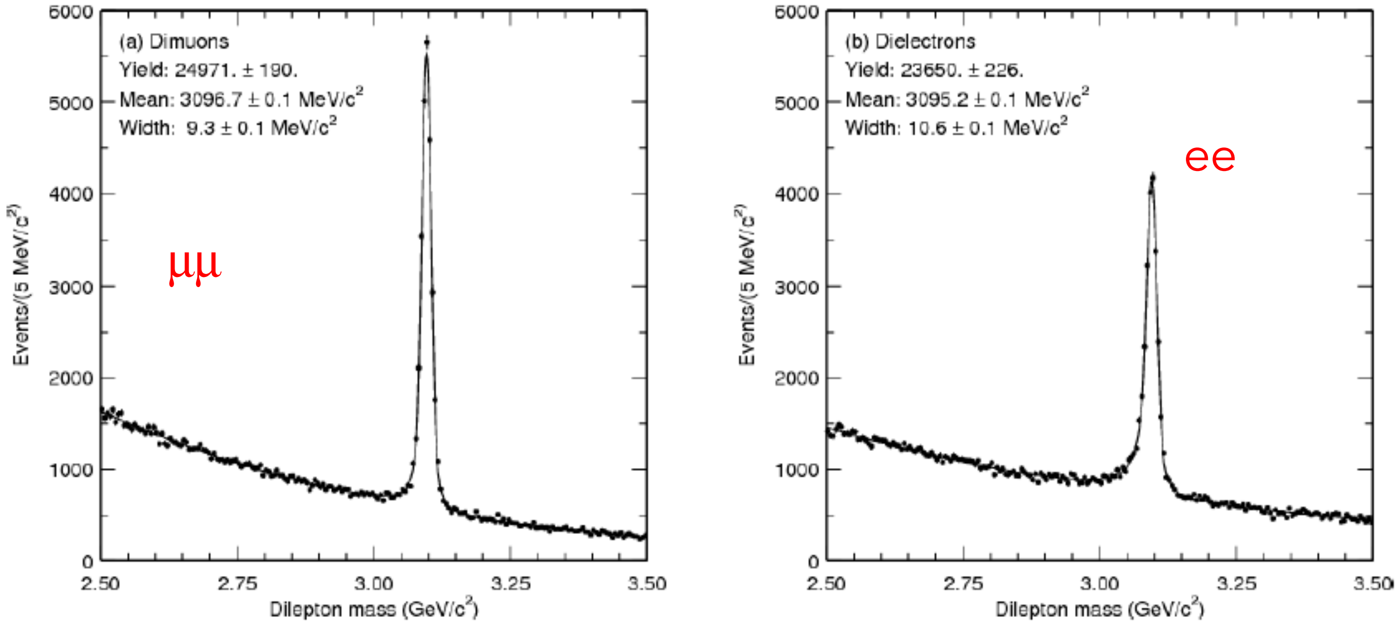
Bremsstrahlung tail still visible
widening of the distribution due to the calorimeter reconstruction



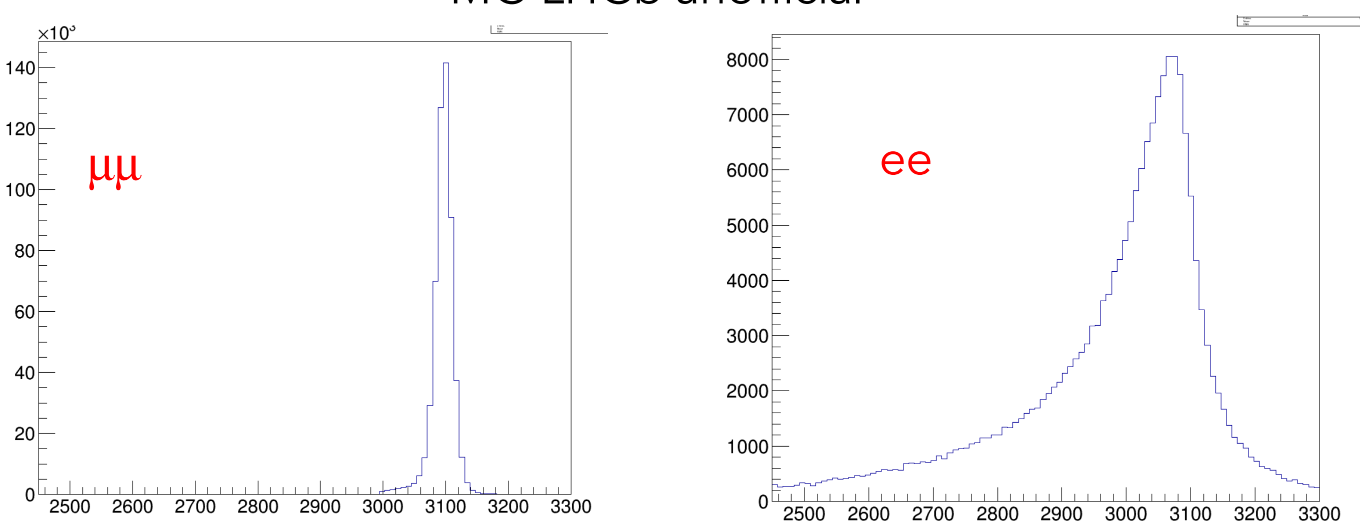
M(ee)

Belle

arXiv:0211047



MC LHCb unofficial

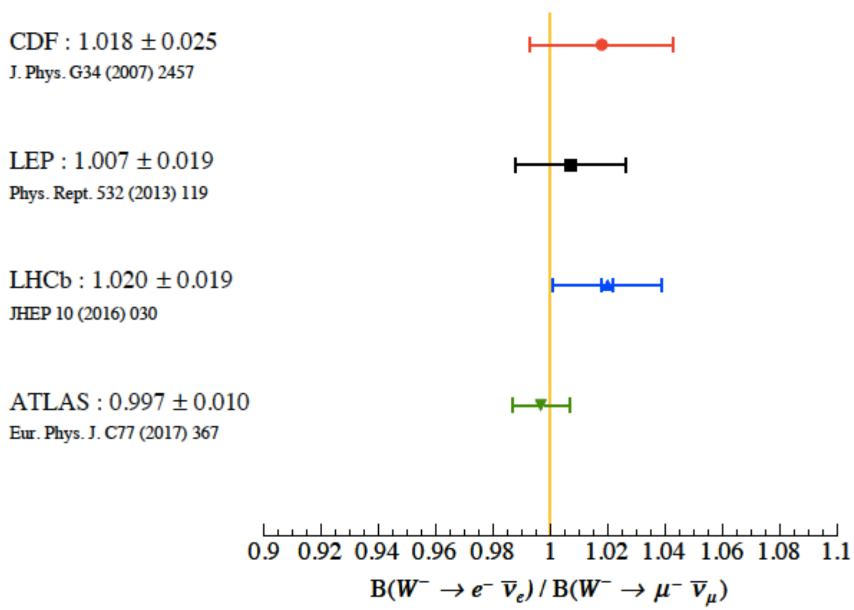


Experimental knowledge

Experimental knowledge: electroweak sector

The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, the LEP Electroweak Working Group, the SLD Electroweak and Heavy Flavour Groups, *Precision Electroweak Measurements on the Z Resonance*, Phys. Rept. **427** (2006) 257, arXiv:hep-ex/0509008.

$$\frac{\Gamma_{Z\to\mu^+\mu^-}}{\Gamma_{Z\to e^+e^-}} = 1.0009 \pm 0.0028$$



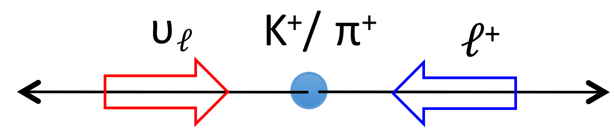
$$\frac{\mathcal{B}(W^-\to e^-\overline{\nu}_e)}{\mathcal{B}(W^-\to \mu^-\overline{\nu}_\mu)} = 1.004 \pm 0.008$$

W is less precise.

Experimental knowledge: K/π decays

$$\left(\frac{\Gamma_{K^- \to e^- \overline{\nu}_e}}{\Gamma_{K^- \to \mu^- \overline{\nu}_\mu}}\right)$$ far from 1 due to helicity suppression

Spin of the K/π : 0
Spin of the lepton and neutrino : ½



Left-handed neutrino

Impossible if $m_\ell = 0$

$(-3.78 \pm 0.04)\%$

$$\left(\frac{\Gamma_{K^- \to e^- \overline{\nu}_e}}{\Gamma_{K^- \to \mu^- \overline{\nu}_\mu}}\right)^{\mathrm{SM}} = \left(\frac{M_e}{M_\mu}\right)^2 \left(\frac{M_K^2 - M_e^2}{M_K^2 - M_\mu^2}\right)(1 + \delta_{QED}) = (2.477 \pm 0.001) \times 10^{-5}$$

Precise predictions (0.04 %) because there is only one scale (different case wrt B decays)

$$\left(\frac{\Gamma_{\pi^- \to e^- \overline{\nu}_e}}{\Gamma_{\pi^- \to \mu^- \overline{\nu}_\mu}}\right)^{\mathrm{SM}} = (1.2352 \pm 0.0001) \times 10^{-4}$$ (0.008 %)

V. Cirigliano and I. Rosell, *The Standard Model prediction for* $R_{e/\mu}^{(\pi,K)}$, Phys. Rev. Lett. 99 (2007) 231801, arXiv:0707.3439.

Measurements

Tests of LU

$$\frac{\Gamma_{K^-\to e^-\overline{\nu}_e}}{\Gamma_{K^-\to \mu^-\overline{\nu}_\mu}} = (2.488 \pm 0.009) \times 10^{-5}$$

$$\frac{Meas}{Pred} = 1.004 \pm 0.004$$

$$\frac{\Gamma_{\pi^-\to e^-\overline{\nu}_e}}{\Gamma_{\pi^-\to \mu^-\overline{\nu}_\mu}} = (1.230 \pm 0.004) \times 10^{-4}$$

$$\frac{Meas}{Pred} = 0.996 \pm 0.003$$

Experimental knowledge: semileptonic decays

D→K l ν

PDG

$\overline{K}^0 e^+ \nu_e$	$(8.73 \pm 0.10)\%$
$\overline{K}^0 \mu^+ \nu_\mu$	$(8.74 \pm 0.19)\%$
$K^- e^+ \nu_e$	$(3.530 \pm 0.028)\%$
$K^- \mu^+ \nu_\mu$	$(3.31 \pm 0.13)\%$

B→D l ν

Belle arXiv:1809.03290

$$\frac{\mathcal{B}(B^0 \to D^{*-} e^+ \nu)}{\mathcal{B}(B^0 \to D^{*-} \mu^+ \nu)} = 1.01 \pm 0.01 \pm 0.03$$

Use of PHOTOS

Experimental knowledge: τ decays

Following: A. Pich, *Precision Tau Physics*, Prog. Part. Nucl. Phys. **75** (2014) 41, arXiv:1310.7922.

$$\Gamma_{\ell\to\ell'} \equiv \Gamma[\ell^- \to \ell'^- \bar\nu_{\ell'}\nu_\ell(\gamma)] = \frac{G_{\ell'\ell}^2 m_\ell^5}{192\pi^3} f(m_{\ell'}^2/m_\ell^2) \left(1+\delta_{RC}^{\ell'\ell}\right)$$

where $f(x) = 1 - 8x + 8x^3 - x^4 - 12x^2 \log x$, and [24–32]

$$\delta_{RC}^{\ell'\ell} = \frac{\alpha}{2\pi}\left[\frac{25}{4} - \pi^2 + \mathcal{O}\left(\frac{m_{\ell'}^2}{m_\ell^2}\right)\right] + \cdots$$

inclusively in $\delta_{RC}^{\ell'\ell}$. Higher-order electroweak corrections and the non-local structure of t
are usually incorporated into the effective coupling [33, 34]

$$G_{\ell'\ell}^2 = \left[\frac{g^2}{4\sqrt{2}M_W^2}\,(1+\Delta r)\right]^2 \left[1 + \frac{3}{5}\frac{m_\ell^2}{M_W^2} + \frac{9}{5}\frac{m_{\ell'}^2}{M_W^2} + \mathcal{O}\left(\frac{m_{\ell'}^4}{M_W^2 m_\ell^2}\right)\right]$$

$$\left(\frac{\Gamma_{\tau\to\mu\nu\nu}}{\Gamma_{\tau\to e\nu\nu}}\right)^{SM} = 0.9726$$

m_τ	(1776.82 ± 0.16) MeV
τ_τ	$(290.29 \pm 0.53) \times 10^{-15}$ s
$\mathrm{Br}(\tau^- \to \nu_\tau e^- \bar{\nu}_e)$	$(17.818 \pm 0.041)\%$
$\mathrm{Br}(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu)$	$(17.392 \pm 0.040)\%$
B_μ / B_e	0.9761 ± 0.0028
$\mathrm{Br}(\tau^- \to \nu_\tau \pi^-)$	$(10.811 \pm 0.053)\%$
$\mathrm{Br}(\tau^- \to \nu_\tau K^-)$	$(0.6955 \pm 0.0096)\%$

arXiv 1310.7922

$$g_\mu / g_e = 1.0018 \pm 0.0014$$

$$\Rightarrow \quad \frac{\left(\frac{\Gamma_{\tau\to e\nu\nu}}{\Gamma_{\tau\to\mu\nu\nu}}\right)^{Exp}}{\left(\frac{\Gamma_{\tau\to e\nu\nu}}{\Gamma_{\tau\to\mu\nu\nu}}\right)^{SM}} = 0.9964 \pm 0.0029$$

Similar results in the PDG

Experimental knowledge: $(c\bar{c})$ and $(b\bar{b})$ decays

$$\frac{\Gamma_{J/\psi \to e^+e^-}}{\Gamma_{J/\psi \to \mu^+\mu^-}}$$

PDG

1.0016 ± 0.0031		**OUR AVERAGE**			
1.0022 ±0.0044 ±0.0048	1	AULCHENKO	2014	KEDR	3.097 $e^+e^- \to e^+e^-, \mu^+\mu^-$
1.0017 ±0.0017 ±0.0033	2	ABLIKIM	2013R	BES3	$\psi(2S) \to J/\psi\pi^+\pi^-$

Use of PHOTOS

ψ(2S) (precision worse ~ 8 %, complicated fit) PDG

Υ(1S)

Γ_2	e^+e^-	$(2.38 \pm 0.11)\%$
Γ_3	$\mu^+\mu^-$	$(2.48 \pm 0.05)\%$

Dominated by $\Upsilon(2S) \to \Upsilon(1S)\pi\pi$

PDG

$$\frac{\Gamma_{\Upsilon\to ee}}{\Gamma_{\Upsilon\to\mu\mu}} = 0.960 \pm 0.048$$

Other Υ : worse precision (~ 10 %)

Experimental knowledge: ρ,ω,ϕ decays

ρ^0

Γ_{11}	$\mu^+\mu^-$	[1]	$(4.55 \pm 0.28) \times 10^{-5}$
Γ_{12}	e^+e^-	[1]	$(4.72 \pm 0.05) \times 10^{-5}$

ω

Γ_9	e^+e^-	$(7.36 \pm 0.15) \times 10^{-5}$
Γ_{15}	$\mu^+\mu^-$	$(7.4 \pm 1.8) \times 10^{-5}$

ϕ

Γ_9	e^+e^-	$(2.973 \pm 0.034) \times 10^{-4}$
Γ_{10}	$\mu^+\mu^-$	$(2.86 \pm 0.19) \times 10^{-4}$

For all these 3 cases the electronic part is in fact determined with ee→ ρ/ω/ϕ

… This is not exactly then what we are interested in

Experimental knowledge: B→cc K$^{(*)}$ BaBar internal

Measurement of branching fractions and charge asymmetries for exclusive B decays to charmonium

BaBar Collaboration (Bernard Aubert *et al.*) Afficher les 612 auteurs

Dec 2004 - 7 pages

Phys.Rev.Lett. 94 (2005) 141801
DOI: 10.1103/PhysRevLett.94.141801
SLAC-PUB-10926, BABAR-PUB-04-044
e-Print: hep-ex/0412062 | PDF
Experiment: SLAC-PEP2-BABAR

There is no splitting in terms of e/μ unfortunately .

Worthwhile publishing ? (with all stat .. this is only 124 millions of BB)

… while all the work has been done : BAD#797

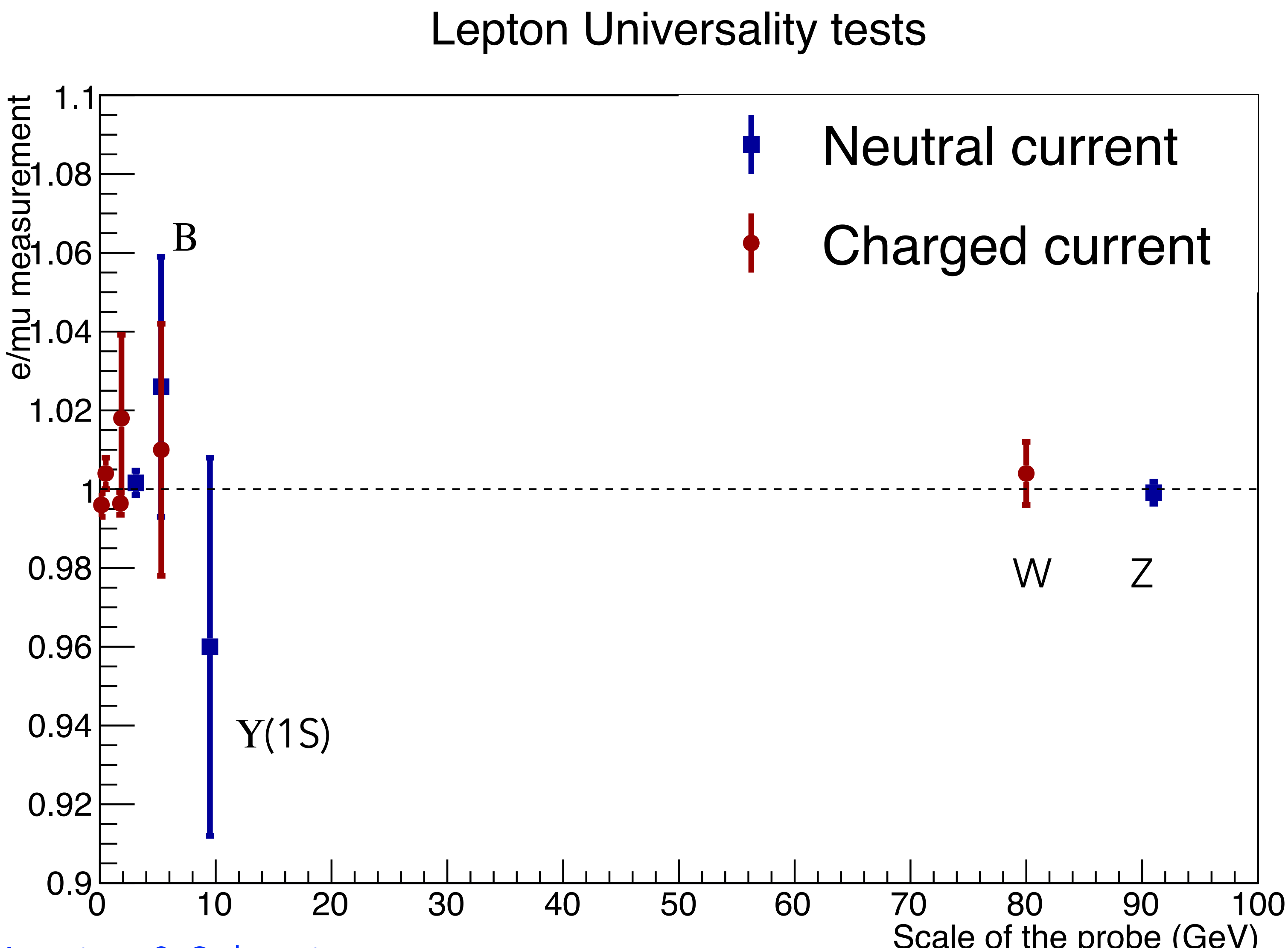
Decay channel		Branching fraction ($\times 10^4$)	
$B^0\overline{B}^0 \to J/\psi\ K^{*0}\ (K^+\ \pi^-)$	e^+e^-	$13.66\pm0.38\pm0.97$	±0.27
	$\mu^+\mu^-$	$13.72\pm0.37\pm1.09$	±0.57
$B^+B^- \to J/\psi\ K^+$	e^+e^-	$10.81\pm0.24\pm0.50$	±0.16
	$\mu^+\mu^-$	$10.40\pm0.20\pm0.49$	±0.19

$$\frac{\Gamma_{B\to J/\psi(\to ee)K^*}}{\Gamma_{B\to J/\psi(\to\mu\mu)K^*}}=0.996 \pm 0.060$$

$$\frac{\Gamma_{B\to J/\psi(\to ee)K}}{\Gamma_{B\to J/\psi(\to\mu\mu)K}}=1.039 \pm 0.039$$

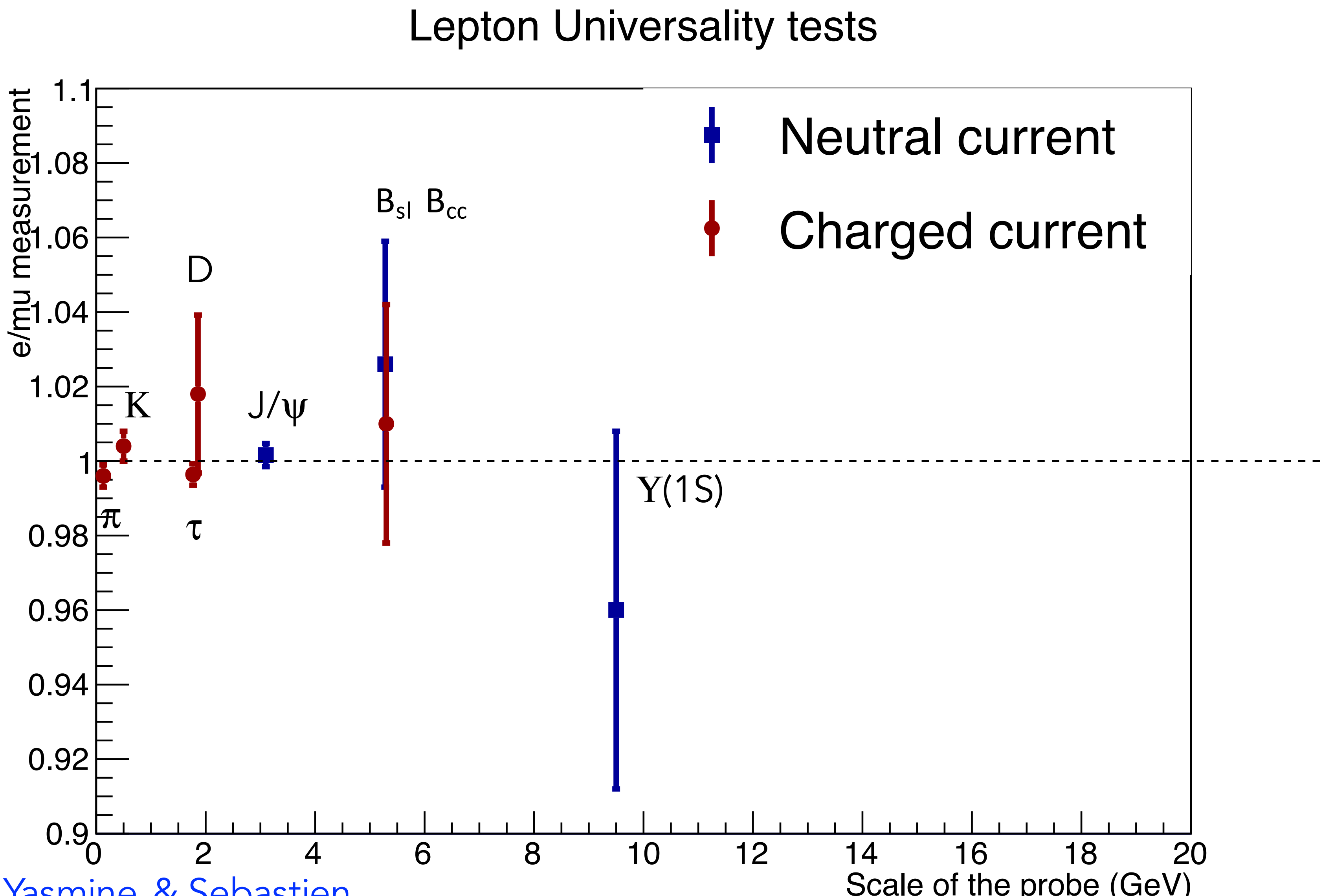
Putting all numbers together the precision could be similar to the semileptonic from Belle

Experimental knowledge: summary



Idea : Yasmine & Sebastien

Experimental knowledge: summary



Idea : Yasmine & Sebastien

Andreas Juttner (University of Southampton) at LHCb Implication Workshop 2018

Isospin breaking:
EM effects

Factorisation Γ = Weak x EM x Strong

lattice will no longer compute decay constants and form factors but aim directly at decay rate

Two major technical difficulties:
- photon is massless and induces large finite-size effects
- IR singularities (Bloch-Nordsiek) need to be dealt with

So

- Is there a problem ?
- Is there some interest for a joint exp/th work ?
- We have quite a lot of measurements (not all very precise), how could they used to put some constraints ?
- …

Backup slides

Experimental knowledge: $(c\bar{c})$ and $(b\bar{b})$ decays

ψ(2S)

Γ_6	e^+e^-	$(7.93 \pm 0.17) \times 10^{-3}$
Γ_7	$\mu^+\mu^-$	$(8.0 \pm 0.6) \times 10^{-3}$

$\frac{\Gamma_{\psi(2S)\to ee}}{\Gamma_{\psi(2S)\to \mu\mu}}$=0.991 ± 0.077

These 2 values are extracted from a complicated fit
(~ no correlation between these 2)

Experimental knowledge: Υ decays

Υ(1S)

Dominated by
Υ(2S)→Υ(1S)ππ

Γ_2	e^+e^-	$(2.38 \pm 0.11)\%$
Γ_3	$\mu^+\mu^-$	$(2.48 \pm 0.05)\%$

$$\frac{\Gamma_{\Upsilon\to ee}}{\Gamma_{\Upsilon\to\mu\mu}} = 0.960 \pm 0.048$$

Υ(2S)

Γ_4	$\mu^+\mu^-$	$(1.93 \pm 0.17)\%$
Γ_5	e^+e^-	$(1.91 \pm 0.16)\%$

Υ(3S)

Γ_{14}	$\mu^+\mu^-$	$(2.18 \pm 0.21)\%$
Γ_{15}	e^+e^-	$(2.18 \pm 0.20)\%$

Tau PDG

Standard Model prediction including mass effects is 0.9726.

VALUE (10^{-2})	*EVTS*	*DOCUMENT ID*		*TECN*	*COMMENT*
97.62 ± 0.28	**OUR FIT**				
97.9 ± 0.4	**OUR AVERAGE**				
$97.96 \pm 0.16 \pm 0.36$	731k	[1] AUBERT	2010F	BABR	467 fb^{-1} $E^{ee}_{\text{cm}} = 10.6$ GeV
$97.77 \pm 0.63 \pm 0.87$		[2] ANASTASSOV	1997	CLEO	$E^{ee}_{\text{cm}} = 10.6$ GeV
$99.7 \pm 3.5 \pm 4.0$		ALBRECHT	1992D	ARG	$E^{ee}_{\text{cm}} = 9.4 - 10.6$ GeV

[1] Correlation matrix for AUBERT 2010F branching fractions:

(1) $\Gamma(\tau^- \to \mu^- \bar{\nu}_\mu \nu_\tau) / \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$

(2) $\Gamma(\tau^- \to \pi^- \nu_\tau) / \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$

(3) $\Gamma(\tau^- \to K^- \nu_\tau) / \Gamma(\tau^- \to e^- \bar{\nu}_e \nu_\tau)$

	(1)	(2)
(2)	0.25	
(3)	0.12	0.33

[2] The correlation coefficients between this measurement and the ANASTASSOV 1997 measurements of B($\mu \bar{\nu}_\mu \nu_\tau$), B($e \bar{\nu}_e \nu_\tau$), B($h^- \nu_\tau$), and B($h^- \nu_\tau$)/B($e \bar{\nu}_e \nu_\tau$) are 0.58, −0.42, 0.07, and 0.45 respectively.