

**Do we expect problems with theory error in the  
luminosity measurement using double-tag Bhabha at  
25-100 mrads, 1-3 TeV?**

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## Acknowledgements

We thank W. Płaczek and T. Riemann for discussion and help.

## WARNING

**All numerical results are PRELIMINARY**

**Most of them are x-checked but they may still change!**

## Appologies

We did not have time to use latest results  
on the hadronic vacuum polarization

These transparencies are here <http://jadach.home.cern.ch/jadach/>

**Expected important sources of TH error of  $\sigma_{Bhabha}^{tot}$  at 1-3TeV, 25-100mrad:**

- QED photonic corrections
- EW corrections to  $Z_t$
- Hadronic vacuum polarization

**Basic difference with LEP1:**

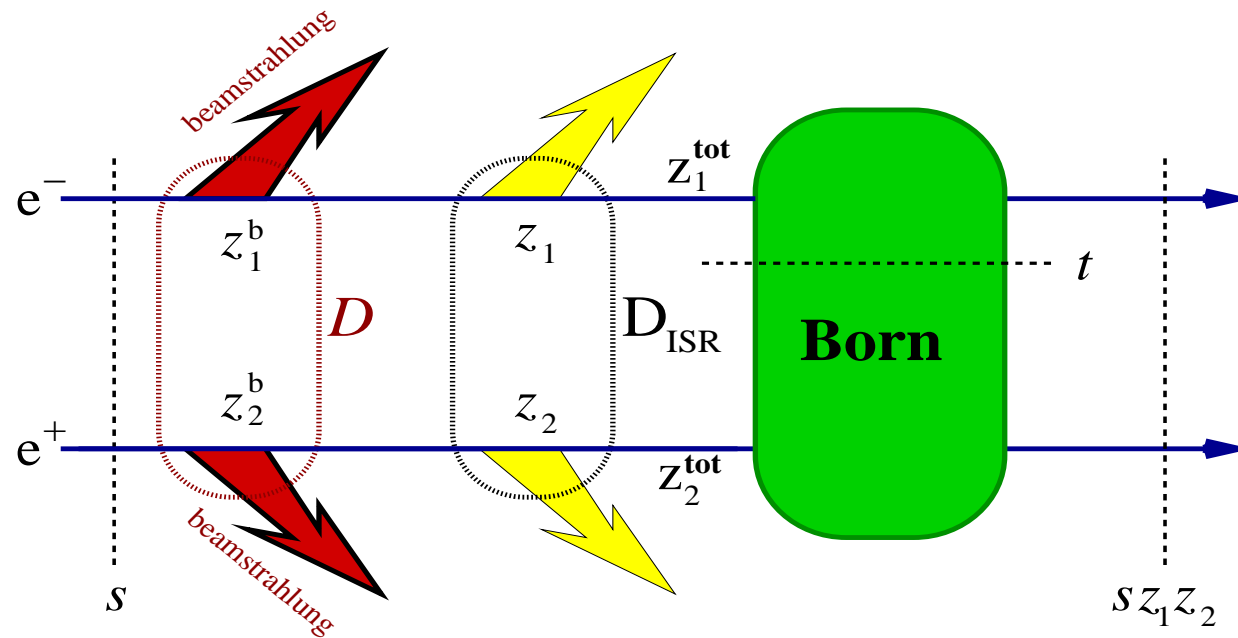
The average transfer  $\sqrt{|t|} \sim 75\text{GeV}$  instead of  $\sqrt{|t|} \sim 2\text{GeV}$  !

$t$ -channel  $Z$  becomes important, hadronic vacuum polarization possibly bigger.

Photonic QED corrections scale with  $\sim \alpha \ln(|t|/m_e^2) \ln(\vartheta_{max}/\vartheta_{min})$  and might be bigger by a factor  $\sim \ln(3\text{TeV}/M_Z) / \ln(M_Z/m_e) \sim +30\%$ .

**Due to beamstrahlung luminosity is a function  $\mathcal{L}(z_1, z_2)$ , not a number!**

## Kinematics of LumTeV



$$\sigma(s) = \int_0^1 dz_1^b dz_2^b \mathcal{D}(z_1^b, z_2^b) \int_0^1 dz_1 dz_2 D_{\text{ISR}}^{\text{LL}}(z_1, z_2) \int dt \frac{d\sigma}{dt}(s z_1^{\text{tot}} z_2^{\text{tot}}, t) \Theta(\vartheta_1, \vartheta_2).$$

where

$\mathcal{D}(z_1^b, z_2^b)$  is beamstrahlung function normalized to one,

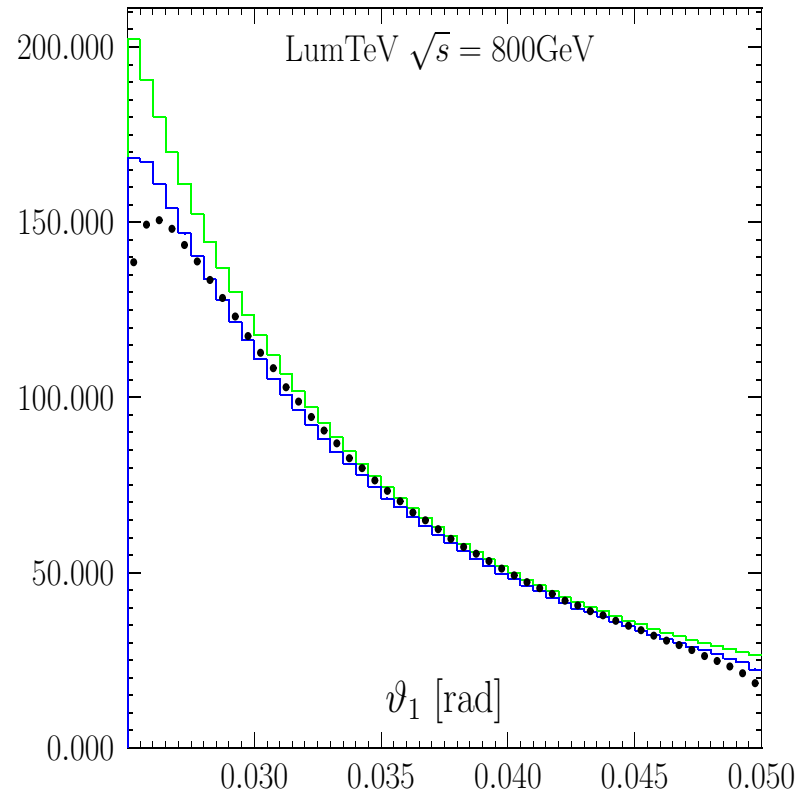
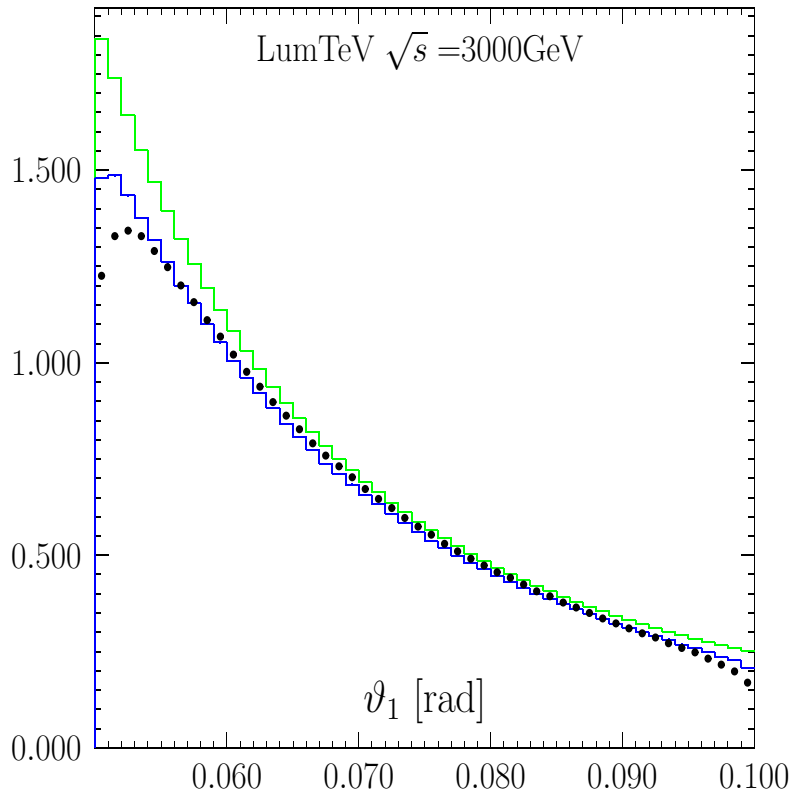
$D_{\text{ISR}}^{\text{LL}}(z_1, z_2)$  is the QED leading-Log (LL) ISR structure function (Jadach, Skrzypek, Ward).

Acceptance  $\Theta(\vartheta_1, \vartheta_2) = 1$  only if  $\vartheta_{\text{min}} < \vartheta_i < \vartheta_{\text{max}}$  for both  $\vartheta_i$  in CMS.

**LumTeV main points**

- LumTeV is not a replacement for finite  $p_T$  photons MC like BHLUMI/BHWIDE!  
LumTeV is for testing and prototyping future MC based on (modified) BHLUMI.
- Basic MC algorithm of LumTeV is that of LUMLOG (implementing  $\Theta(\vartheta_1, \vartheta_2)$ ).
- 5-dimensional integral done using Foam, 25M events/hour.  
Very efficient, 95% acceptance rate (Vegas could do  $\sim 1\%$  accept. only).
- Beamstrahlung SF  $\mathcal{D}(z_1^b, z_2^b)$  is an **arbitrary** “user provided function”,  
presently SF’s of Circe of T. Ohl is used (with  $\delta(1 - z)$  singularities!).
- QED ISR structure function  $D_{\text{ISR}}^{\text{LL}}(z_1, z_2)$  (Jadach, Skrzypek, Ward) is implemented:  
in exponentiated form at  $\mathcal{O}(\alpha^i)_{exp}$   $i = 0, 1, 2, 3$   
and also without exponentiation at  $\mathcal{O}(\alpha^i)$   $i = 0, 1, 2$  (as in LUMLOG).
- 4-momenta in CMS are provided – ISR photons have all  $p_T = 0$ .
- Programmed in g77 (pseudoclass).

Angular distribution



Photonic QED corrections and beamstrahlung are of similar size.

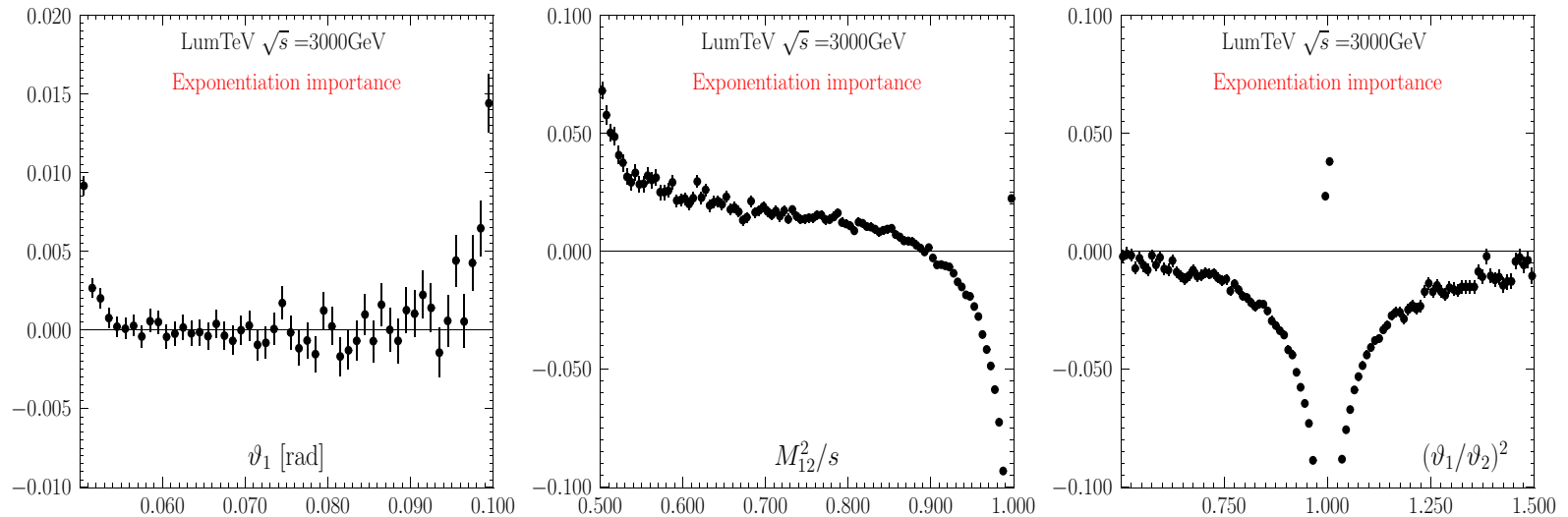
Green continuous line: Born

Blue dotted line: photonic QED (LL)

Black dotted line: photonic QED (LL) + beamstrahlung, (Circe TESLA)

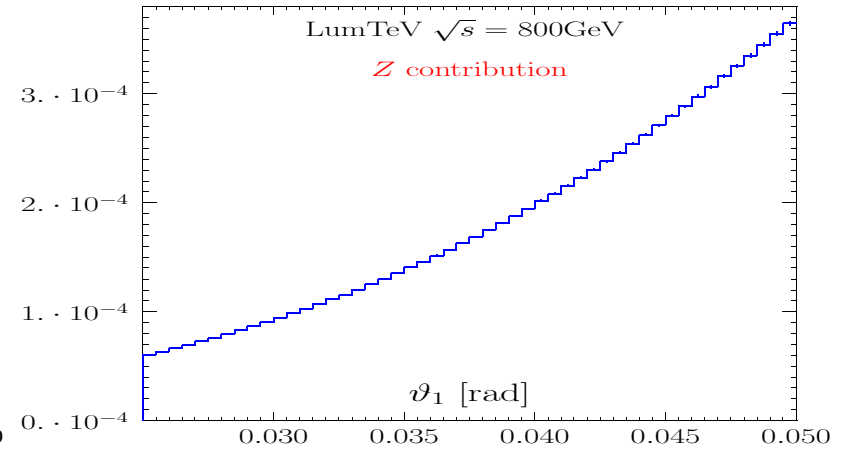
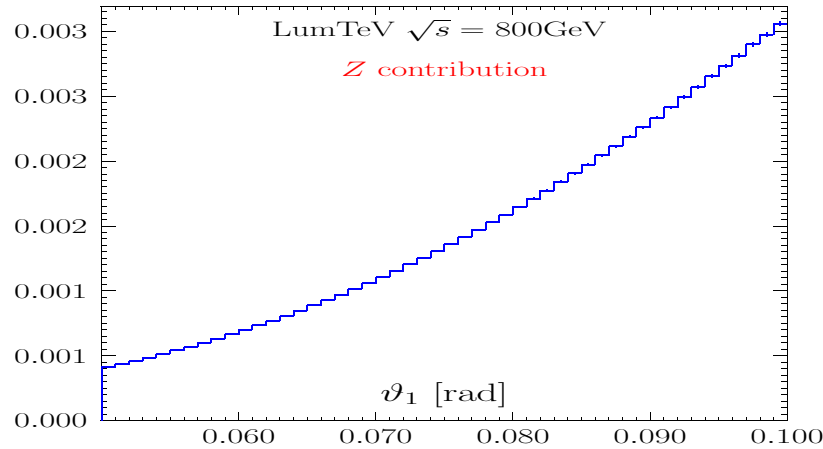
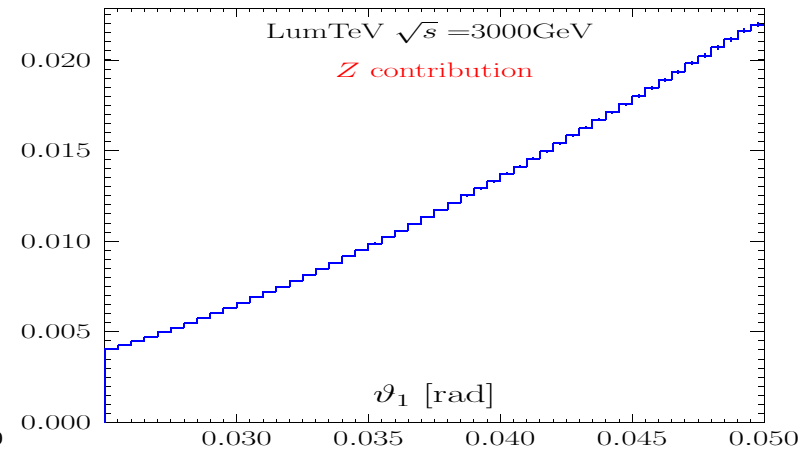
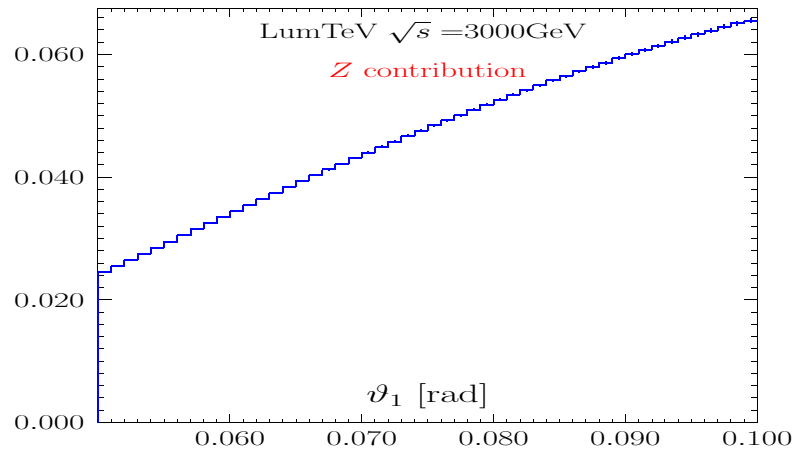
**Is exponentiation important?**

The difference  $\mathcal{O}(\alpha^3)_{exp} - \mathcal{O}(\alpha^2)$  in LL approximation (ISR only) gives us hint **how wrong** the calculation in  $\mathcal{O}(\alpha^2)$  **without exponentiation** actually is:



**Conclusion: Exponentiation of photonic QED is absolute necessity!**

Note that  $M_{12}/s = z_1 z_2$  and  $\vartheta_1/\vartheta_2 \simeq z_1/z_2$  are basic variables for determination of the luminosity distribution. Effects close to  $\vartheta$ -edges are due to soft ISR photons.



*t*-channel Z contribution is sizeable, up to 6%.

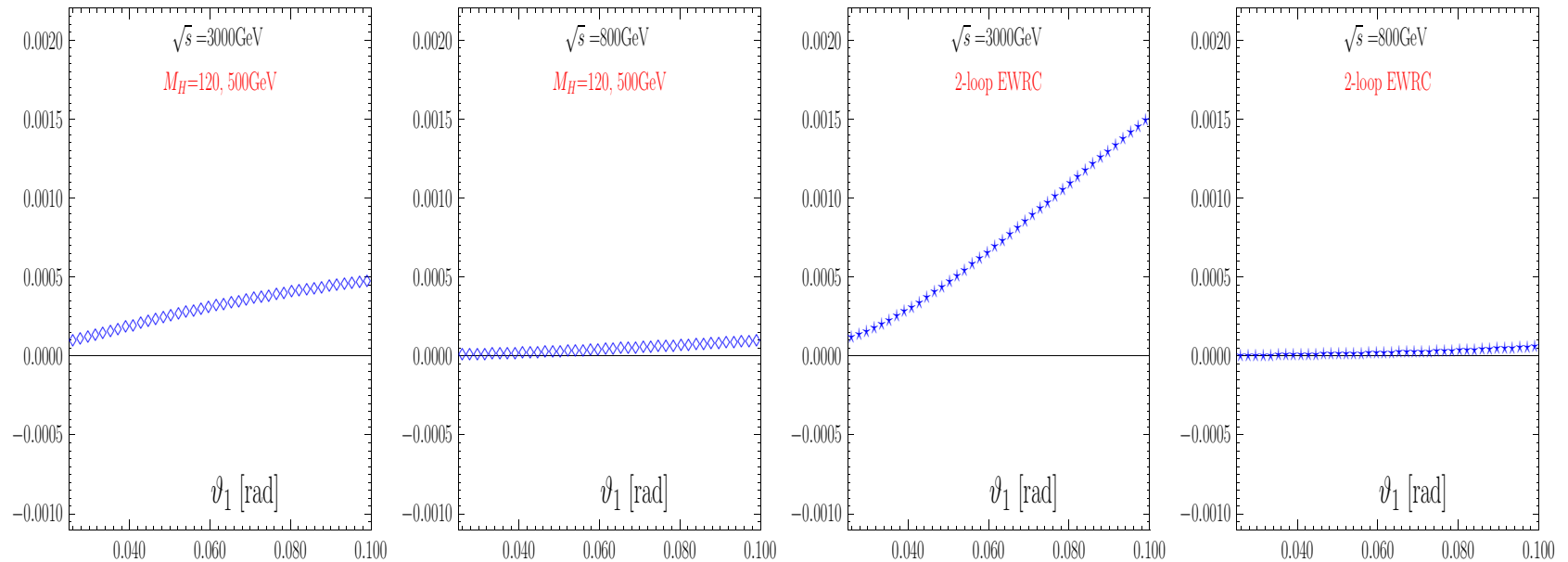
This result was x-checked with 2 Born programs of BHWIDE and DIZET.

NB. *s*-channel Z +  $\gamma$  is negligible  $< 10^{-4}$ .

How big is uncertainty of Z-contribution due to EW corrections?



How big is uncertainty of  $Z$ -contribution, due to EW corrections?



Answer from DIZET 6.35: Below 0.1%. Negligible at lower  $\sqrt{s}$  and/or angles

Above we varied  $M_H = 120 \rightarrow 500 \text{ GeV}$ . Changing  $M_t = 165 \rightarrow 185 \text{ GeV}$  has similar effect.

Changing  $\text{NPAR}(2)=3 \rightarrow \text{NPAR}(2)=4$  manipulates non-leading 2-loop EW corrections

$\mathcal{O}(G_F^2 M_t^2 M_Z^2)$ , Degraasi et.al., leading 2-loop EW corrections  $\mathcal{O}(G_F^2 M_t^4)$  are kept.

Summarizing we find 0.09% as a conservative estimation of Theor. Uncert. due to known subleading 2-loop EWRC at 3TeV, 50-100mrad.

How big is uncertainty due to hadronic vacuum polarization?

Type of Vac.Pol. (Authors)	Cross section [nb]	Relative change
$\sqrt{s} = 3000\text{GeV}, \vartheta \in (0.50, 0.100) [\text{rad}], \sqrt{ t } \in (75, 150) [\text{GeV}]$		
No vacuum polarization	$\sigma_0 = 0.036141$	
Burkhardt 1981,1989	$\sigma_1 = 0.040978$	$\frac{\sigma_1 - \sigma_0}{\sigma_0} = 0.133839$
Eidelman&Jegerlehner 1995	$\sigma_2 = 0.040921$	$\frac{\sigma_2 - \sigma_1}{\sigma_1} = -0.001405$
Burkhardt&Pietrzyk 1995	$\sigma_3 = 0.040918$	$\frac{\sigma_3 - \sigma_1}{\sigma_1} = -0.001476$
Eidelman&Jegerlehner(95)+ERROR	$\sigma_4 = 0.040865$	$\frac{\sigma_4 - \sigma_1}{\sigma_1} = -0.001354$
$\sqrt{s} = 92\text{GeV}, \vartheta \in (0.25, 0.050) [\text{rad}], \sqrt{ t } \in (1.15, 2.3) [\text{GeV}]$		
No vacuum polarization	$\sigma_0 = 147.418$	
Burkhardt 1981,1989	$\sigma_1 = 153.329$	$\frac{\sigma_1 - \sigma_0}{\sigma_0} = 0.040092$
Eidelman&Jegerlehner 1995	$\sigma_2 = 153.289$	$\frac{\sigma_2 - \sigma_1}{\sigma_1} = -0.000258$
Burkhardt&Pietrzyk 1995	$\sigma_3 = 153.288$	$\frac{\sigma_3 - \sigma_1}{\sigma_1} = -0.000266$
Eidelman&Jegerlehner(95)+ERROR	$\sigma_4 = 153.240$	$\frac{\sigma_4 - \sigma_1}{\sigma_1} = -0.000321$

This table is obtained using LumTeV with Born&VacPol taken from BHWIDE.

We did not include latest improvements (to be done).

The above result was also x-checked with DIZET 6.35 (using Eidelman& Jegerlehner 1995).

Error due to Hadronic vac.pol.  $\times 4$  bigger than at LEP1, possibly dominant!

Conclusions from numerical results:

- Pure QED photonic probably only 30% bigger than at LEP1 (due to dominance of the  $t$ -channel exchange)
- EW corrections can be important; at 3TeV EW uncertainty  $< 0.1\%$
- Error due to hadronic vacuum polarization  $\sim 0.1\%$  seems to dominate
- Exponentiation unavoidable

**QUESTION:** Do we expect problems with theory error at the level of 0.1%

in the luminosity measurement using double-tagged Bhabha within 25-100mrad, at 1-3 TeV?

**ANSWER:** Total error  $< 0.1\%$  looks feasible

LumTeV Monte Carlo is our 1-st step towards combined analysis of QED and beamstrahlung – needed more input on the detector resolution, lumin. spectra, etc.