Inclusive radiative and semileptonic B decays as a probe for New Physics

- **Motivation**
  - **CP-Violation in the Standard Model**
- **Radiative Penguin Decays**
  - **Inclusive $B \rightarrow X_s\gamma$ Decays**
  - **Constraints on New Physics**
- **Semileptonic B Decays**
  - **Inclusive Decays: $|V_{cb}|$ & $|V_{ub}|$**
  - **Heavy Quark Parameters: m_b, m_c, μ_π^2…**
- **Consistency of Standard Model**

Henning Flächer

CERN

April 7th, 2008

CERN EP Seminar

CKM-Matrix and Unitarity Triangle

In the Standard Model, couplings between quarks of different flavour are described by the CKM matrix. It relates weak to mass eigenstates.

Unitarity condition

$$1+\frac{V_{ud}V_{ub}^*}{V_{cd}V_{cb}^*}+\frac{V_{td}V_{tb}^*}{V_{cd}V_{cb}^*}=0$$

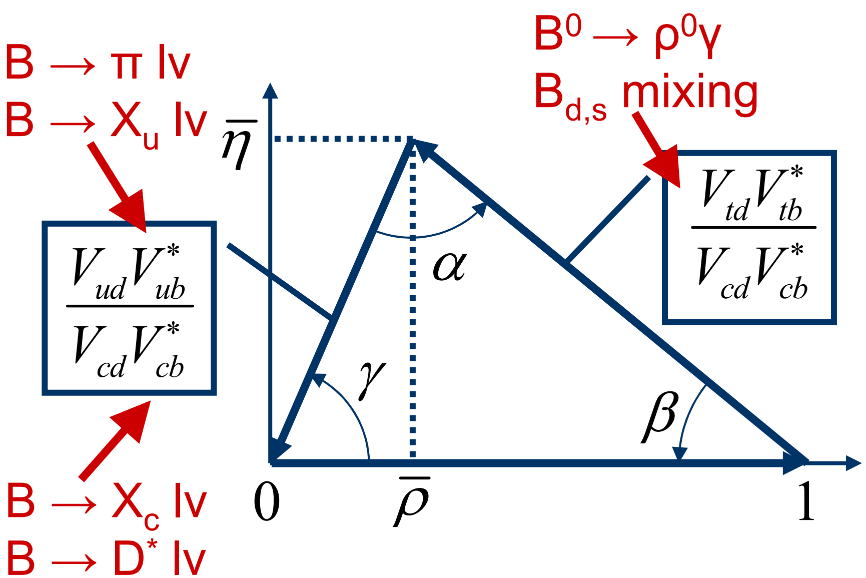
can be visualised as triangle:

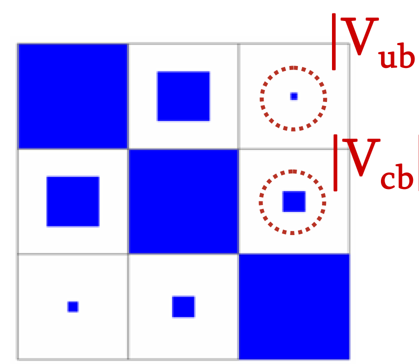
unitary!

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

semi-leptonic decays

radiative decays, $B_{d,s}$ mixing

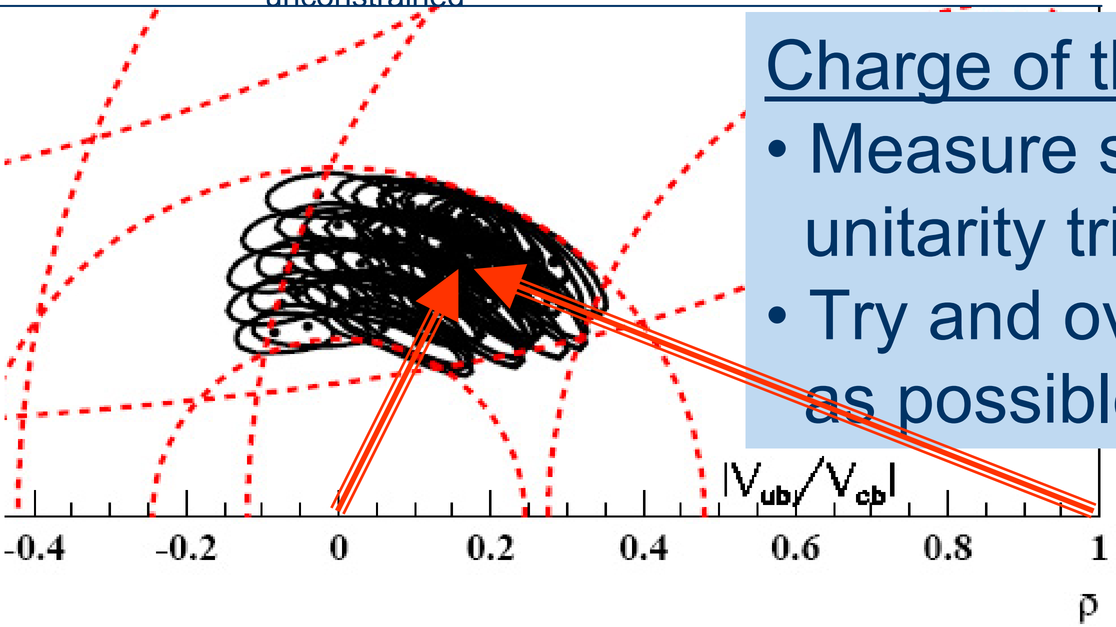




A look at the past…

~1998

- unitarity triangle basically unconstrained



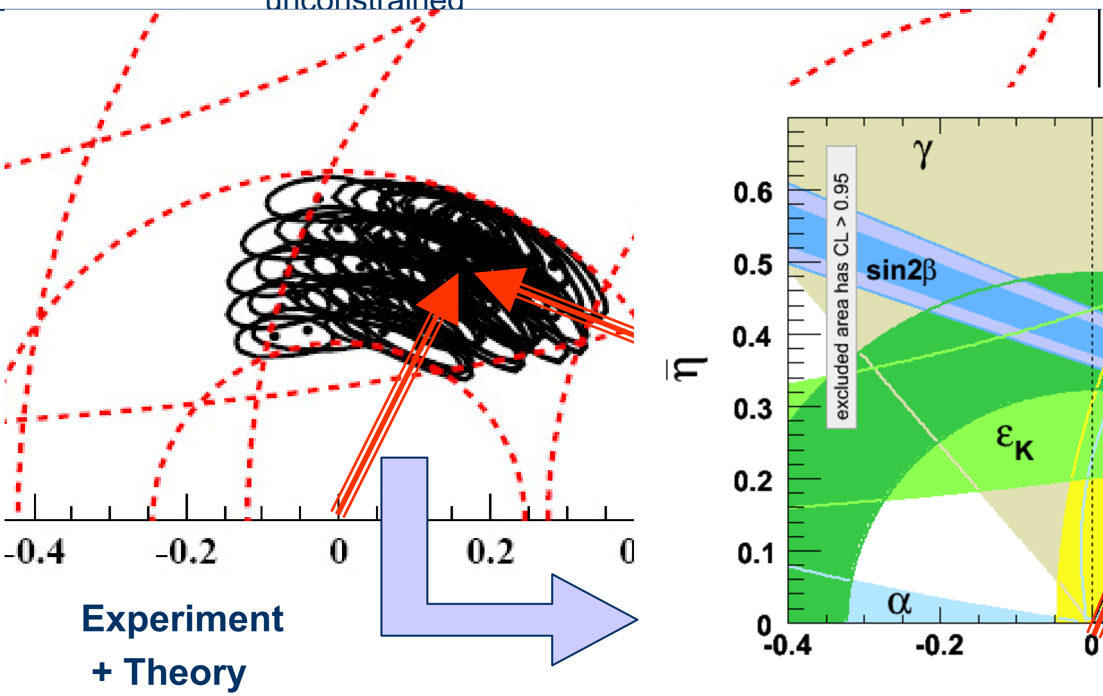
<u>Charge of the B-Factories:</u>

- Measure sides and angles of the unitarity triangle
- Try and overconstrain UT as much as possible

The situation today

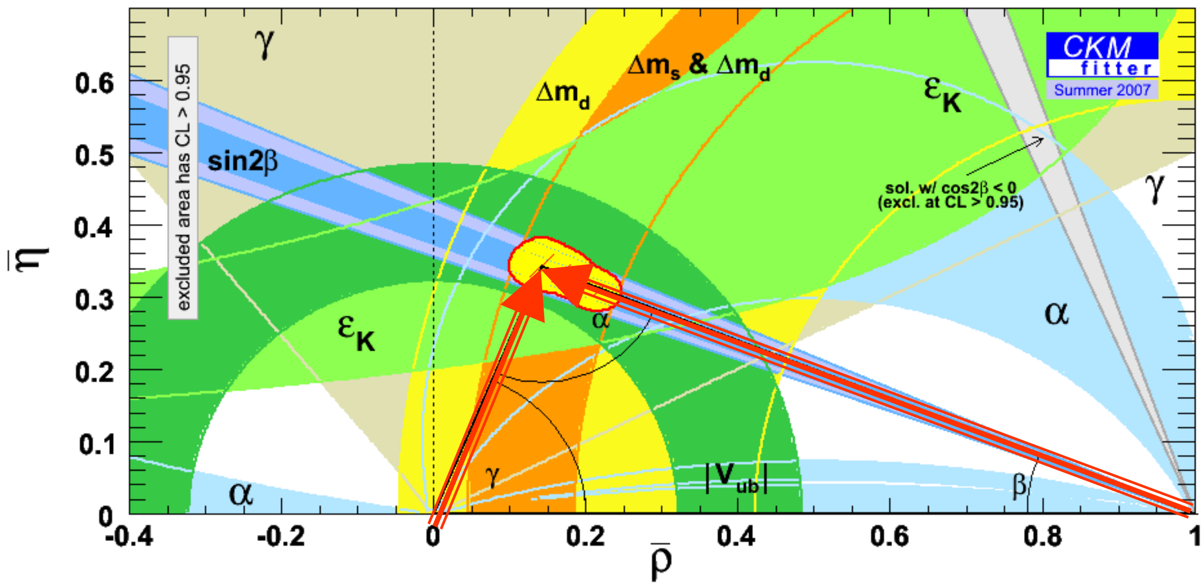
~1998

- unitarity triangle basically unconstrained



2007

- precision measurement
- Data ~consistent with CKM Unitarity



The situation today

~1998

- unitarity triangle basically unconstrained

2007

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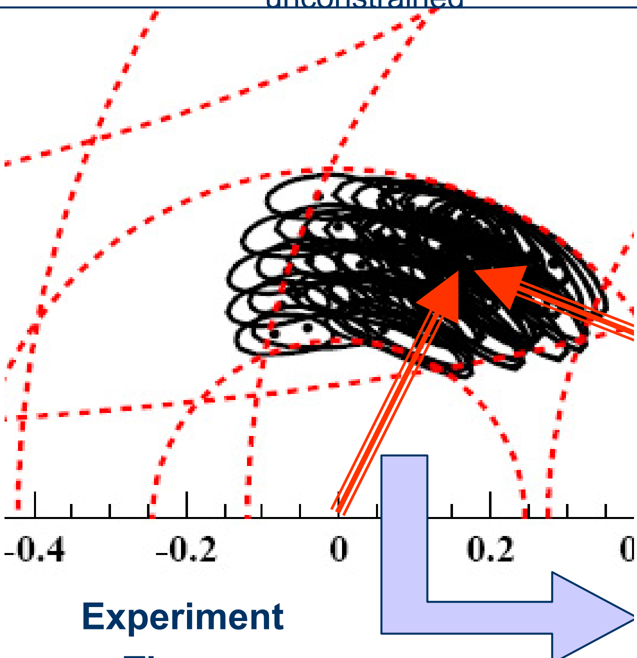
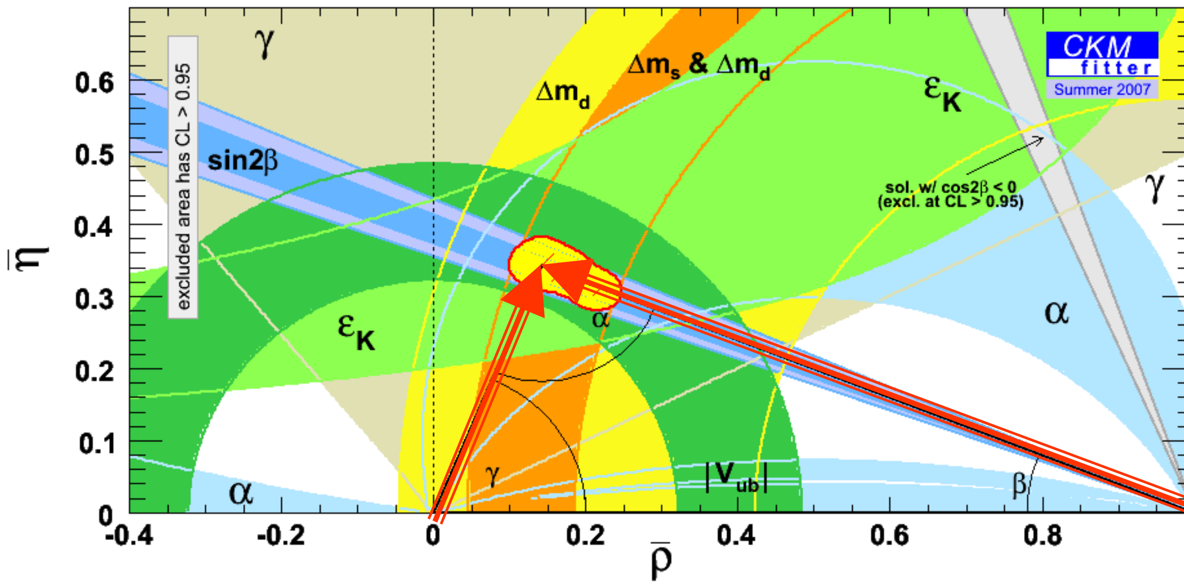
- Data ~consistent with CKM Unitarity



Experiment + Theory



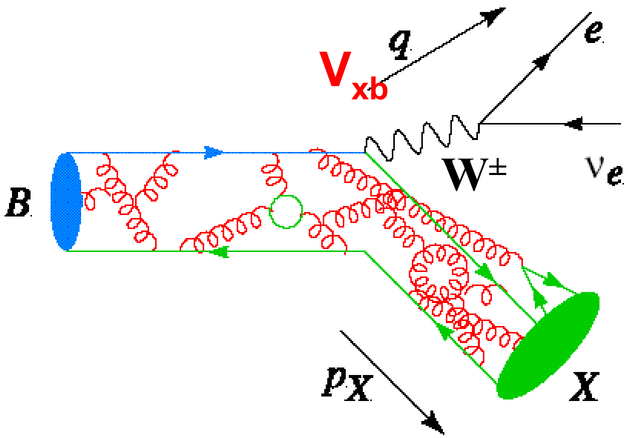
Standard Model description of CP violation is a success!

We are looking for small deviations from SM when looking for New Physics.

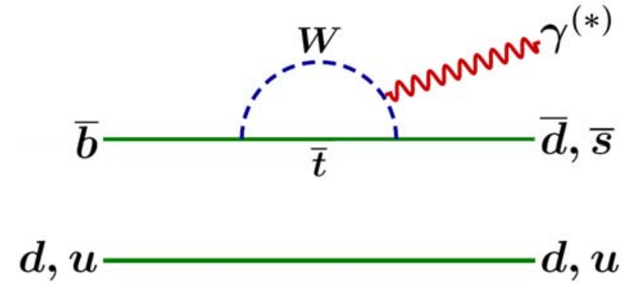
In this talk: Agreement between sin2β and $|V_{ub}|$

What makes semileptonic and radiative B decays so interesting?

Semileptonic decays are tree-level decays
→ free of New Physics contributions for
W→eν and W→μν
c.f. sin2β: mixing (box diagrams)

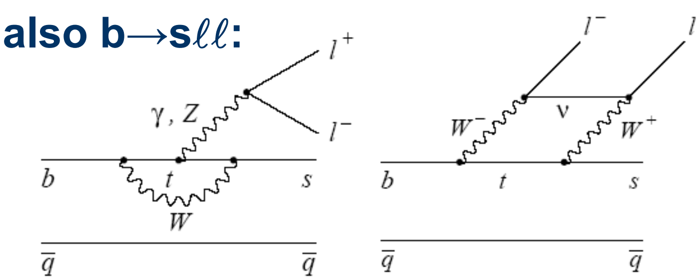


- **Hadronic and leptonic currents factorise**
- **theoretical uncertainties under control**
- **reliable determination of $|V_{ub}|$ and $|V_{cb}|$**



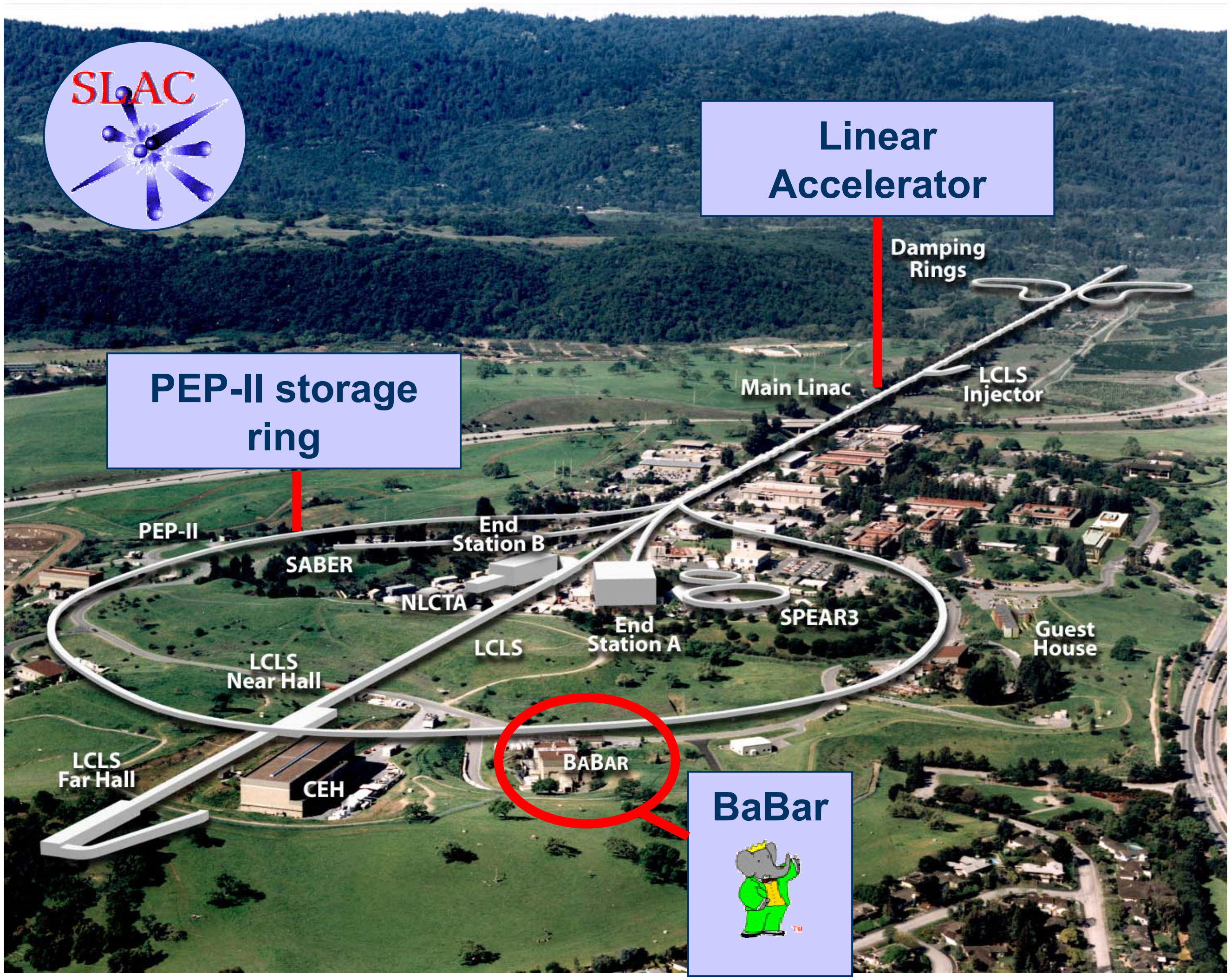
\`radiative penguin'

- **b → s,d transition is a**
  Flavour Changing Neutral Current
  - **In Standard Model forbidden at tree-level**
  - **exists only at loop level**
- **heavy particles dominate in the loop**
- **But also b→sℓℓ:**



Both decays can be treated in the framework of Heavy Quark Effective Theory, relating parton level decay rate to meson decay rate with the help of Operator Product Expansions

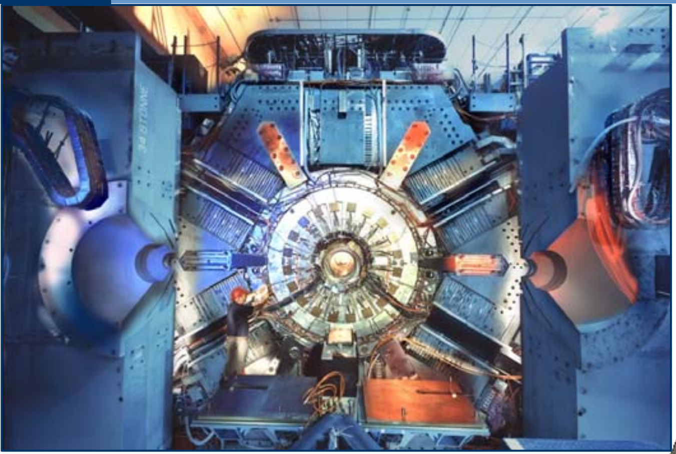
PEP-II and BaBar at SLAC



- asymmetric e^{+}-e^{-} storage ring
- 9 GeV e^{-} on 3.1 GeV e^{+}
- Y(4S) boost $\beta\gamma$~0.56

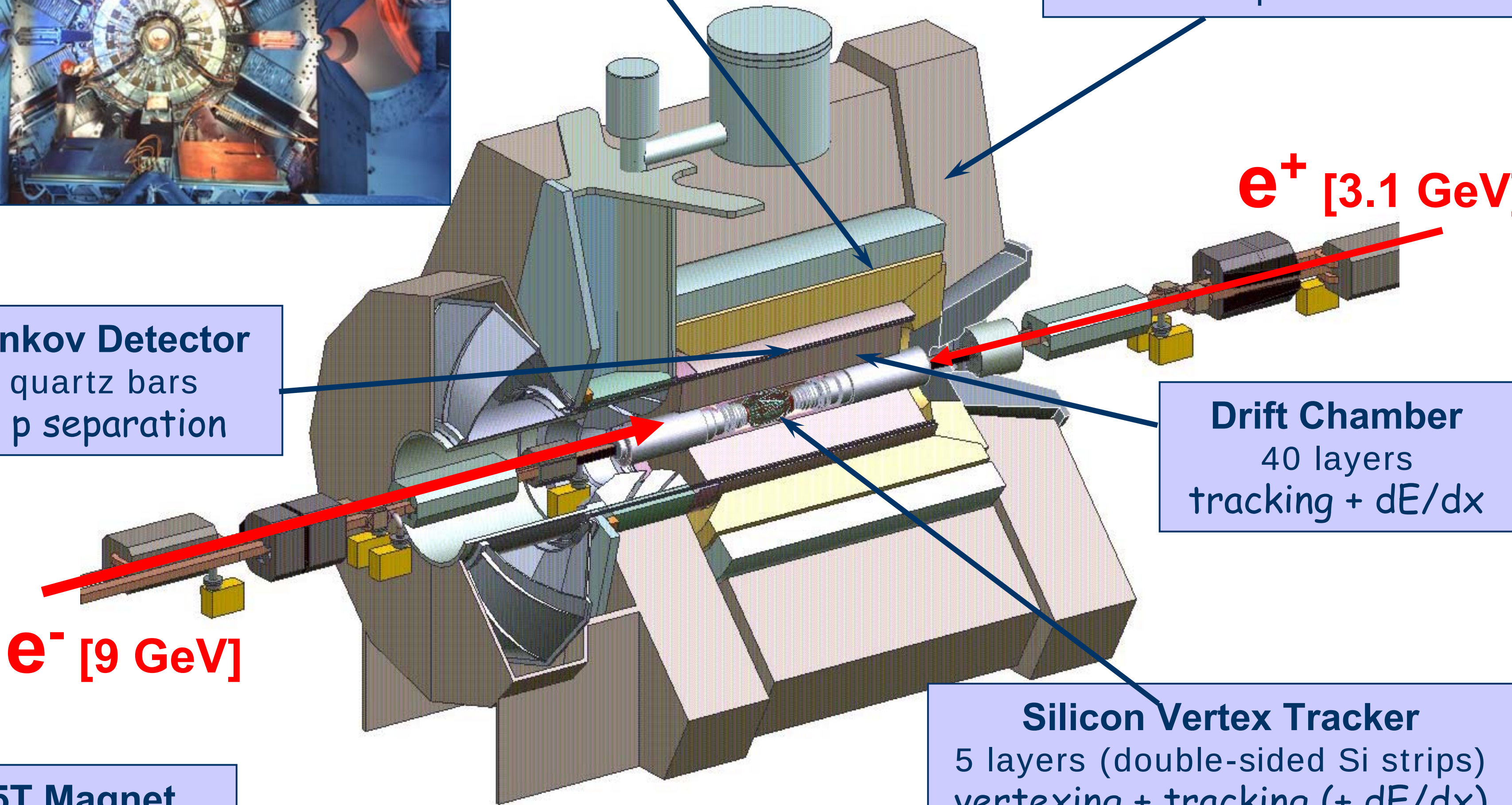
Peak luminosity of 1.2×10^{34} cm^{-2} s^{-1} (more than 3x design!)

BaBar Detector



Electromagnetic Calorimeter
6580 CsI crystals
e+ ID, π^0 and γ reco

Instrumented Flux Return
19 layers of RPCs (+LSTs)
μ ID



Cherenkov Detector
144 quartz bars
K, π, p separation

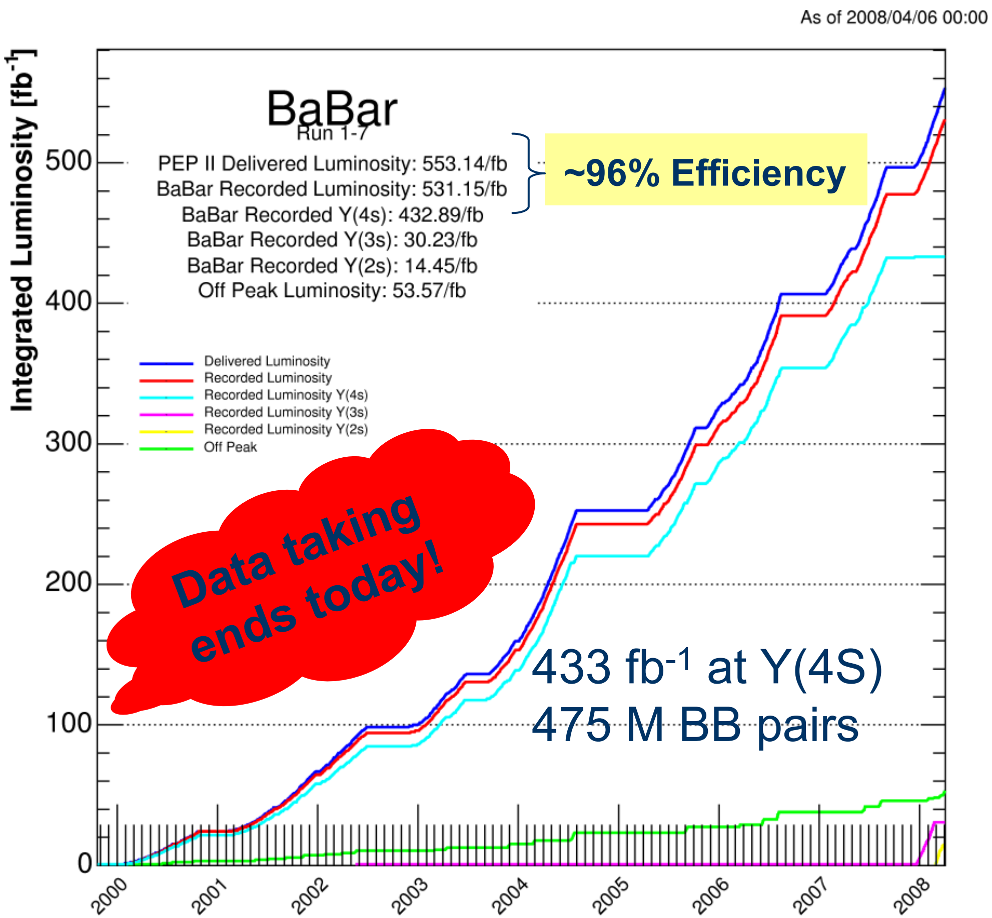
Drift Chamber
40 layers
tracking + dE/dx

Silicon Vertex Tracker
5 layers (double-sided Si strips)
vertexing + tracking (+ dE/dx)

1.5T Magnet

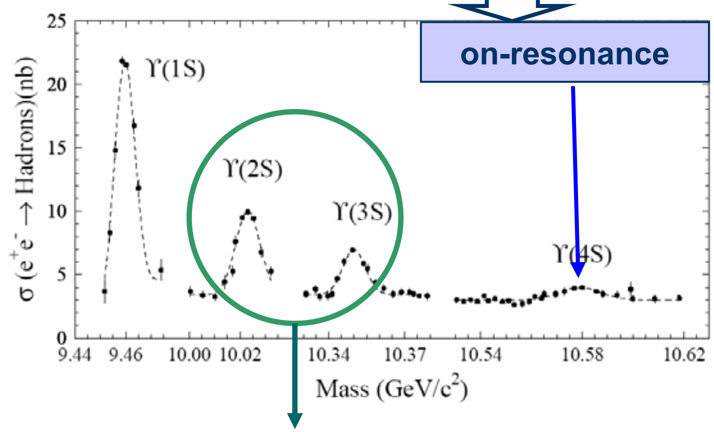
Production of B-Mesons

- For the study of rare decays it needs millions of B-mesons
- Branching fractions of 10^{-6} and less!



Mechanism:

$$e^+e^- \rightarrow \Upsilon(4S) \rightarrow B\overline{B}$$

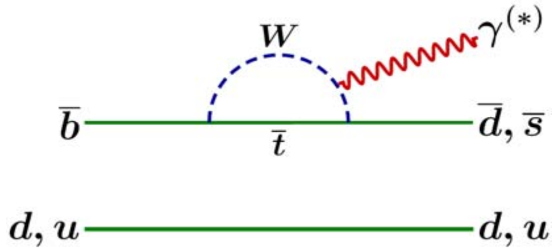


- **since December: centre-of-mass energy at Y(3S) and Y(2S) resonances**
- **Aim: Search for rare decays (deviations from SM) and detailed bottonium spectroscopy with 140 million Y(3S) and Y(2S) decays each**

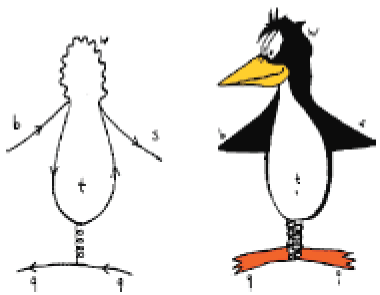
$B \rightarrow X_s \gamma$

Electroweak Penguin Decays

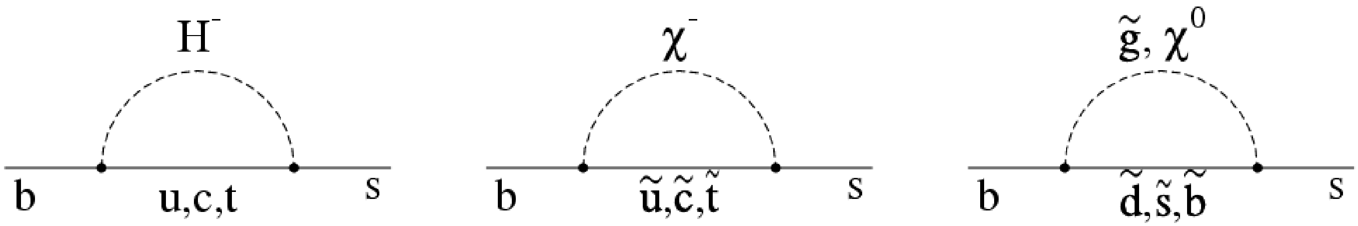
- $b \rightarrow s,d$ transition with high-energetic photon in final state



\`radiative penguin'



- FCNC, New Physics appears at same order as SM process

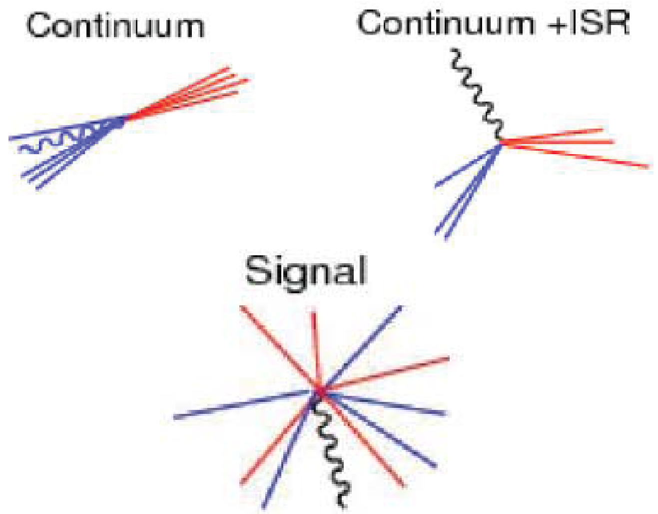


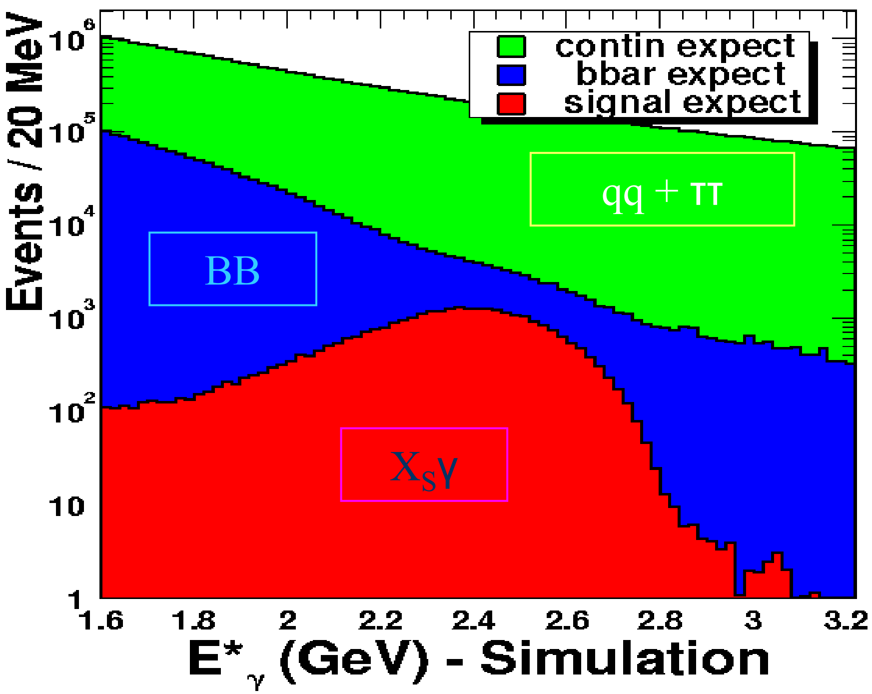
- Measurement of $B \rightarrow X_s\gamma$ branching fraction can constrain parameter space of many SUSY models

- Interesting with regard to LHC

The radiative decay $b \to s\gamma$

- <u>Experimental challenge:</u>
- **overwhelming photon background from continuum (u,d,s,c) and other B decays**
  - **make use of event shape variables**



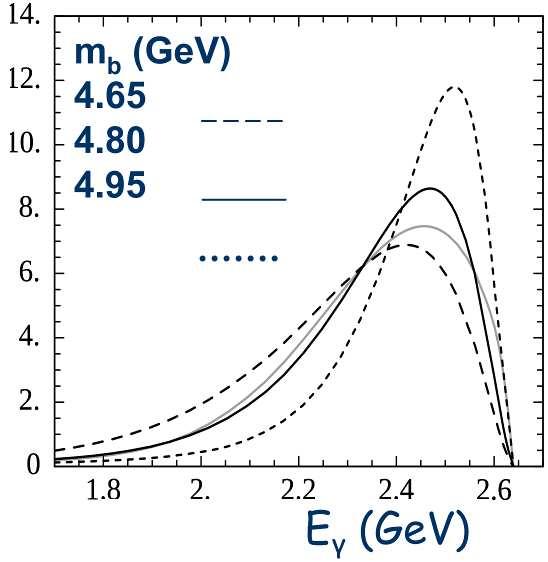


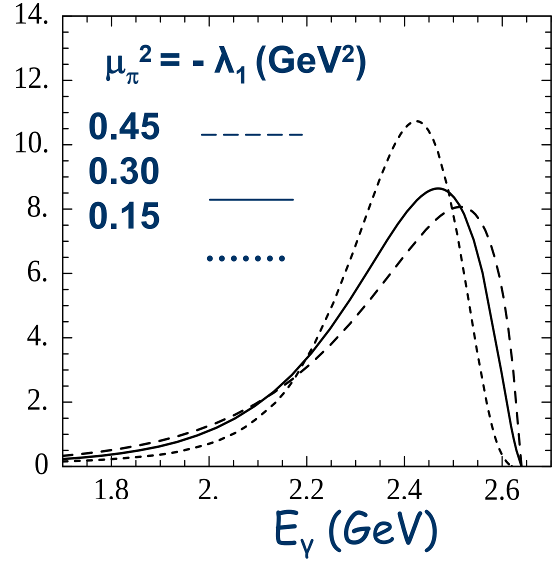
- **Veto π^0 and η decays**
  - **on average 3.4 π^0 in continuum**
  - **2.3 π^0 in Y(4S) events**
- **measure to E_γ as low as possible**

- <u>Theoretical predictions:</u>
  NNLO calculations of E_γ > 1.6 GeV:
  Misiak et al: BF(B→Xsγ) = (3.15 ± 0.23) 10^{-4}
  Becher et al: BF(B→Xsγ) = (2.98 ± 0.26) 10^{-4}
  Andersen et al: BF(B→Xsγ) = (3.47 ± 0.48) 10^{-4}

The radiative decay $b \rightarrow s\gamma$

Spectrum modelled with help of two Heavy Quark parameters:
b-quark mass and Fermi momentum μ_π^2 (motion of b-quark within B meson)



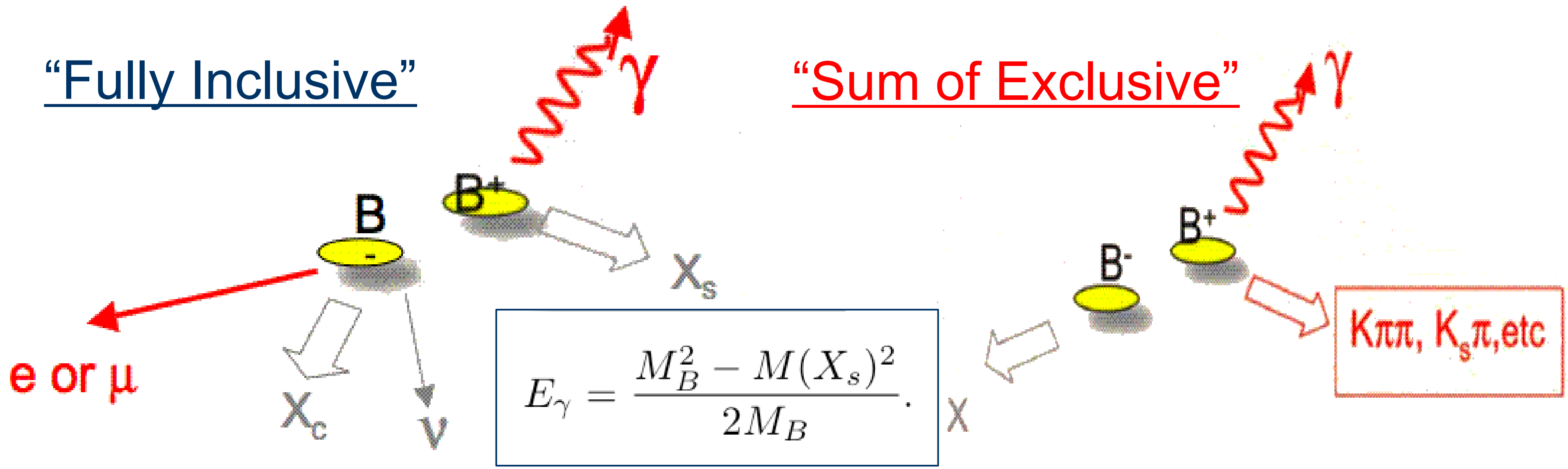


Eur.Phys.J.C7:5-27,1999

Moments of the photon spectrum:

- **Sensitive to HQ parameters**
- **$m_b \sim E_\gamma/2$**
- **$\mu_\pi^2 \sim \langle E^2 - \langle E \rangle^2 \rangle$**
- **b-quark mass interesting as SM parameter**
- **HQ parameter important input for $|V_{ub}|$**

Experimental Strategies for $B \to X_s\gamma$



$$E_\gamma = \frac{M_B^2 - M(X_s)^2}{2M_B}.$$

"Fully Inclusive"

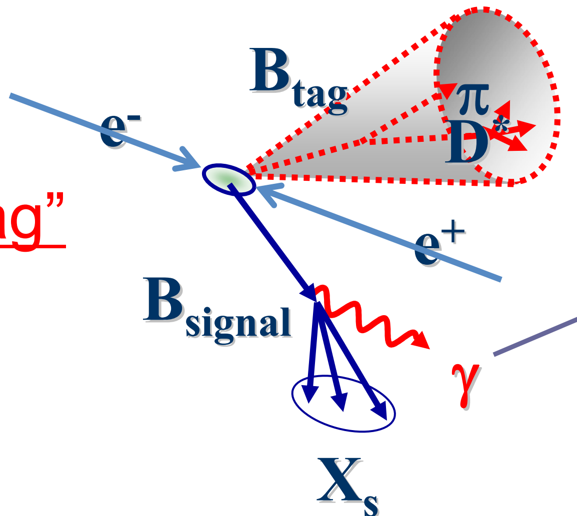
- Ignore X_s system
- Reconstruct only the γ
- Pros
  - No X_s fragmentation sensitivity
  - theoretically clean
- Cons
  - High background
  - Measure E_γ^* in Y(4S) frame

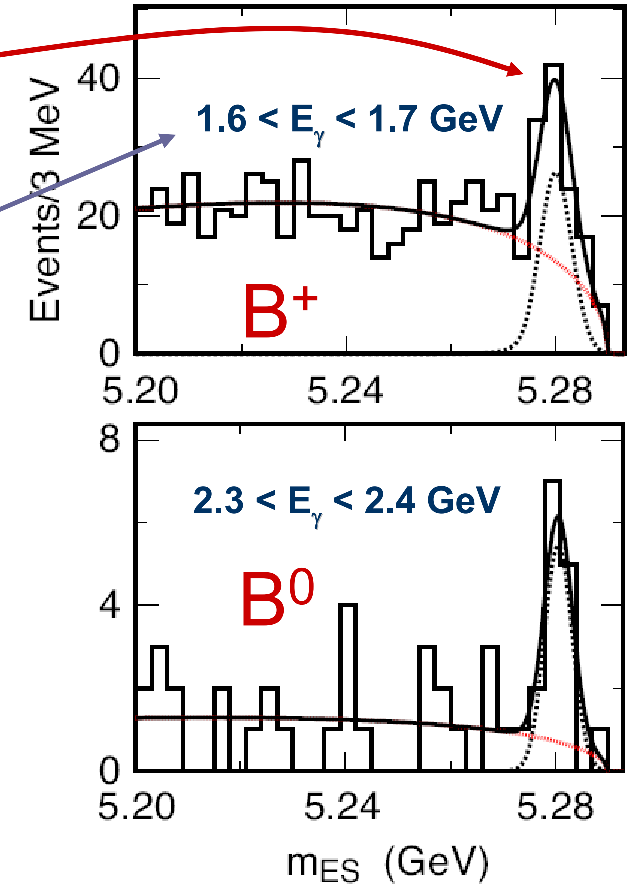
"Sum of Exclusive"

- Fully reconstruct subset of X_s final states
- Pros
  - Lower background
  - Good E_γ resolution in B-frame
- Cons
  - X_s fragmentation systematic
  - Missing X_s decay modes

Fully inclusive with B tag

“Breco tag”





Phys.Rev.D77, 051103 (2008)

- identification of one isolated photon
- possibility to reconstruct the X_s

- Pros:
  - 4-momentum, charge and flavour determined!
  - asymmetry measurements: A_{CP}, Δ_{0-}
  - photon spectrum in B frame

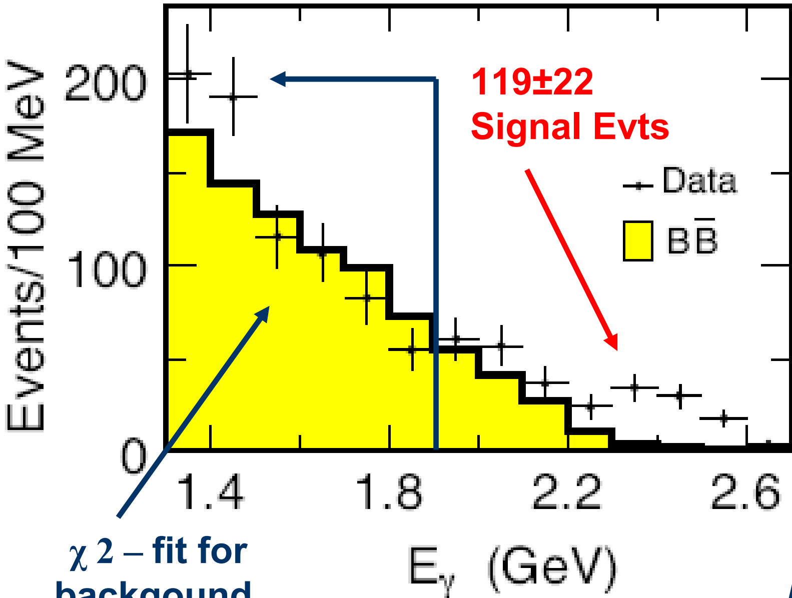
  - number of tag Bs gives normalisation
  - small efficiency extrapolation
  - continuum subtracted through m_{ES} fit

- Cons
  - small efficiency for full B reconstruction: ~0.4%

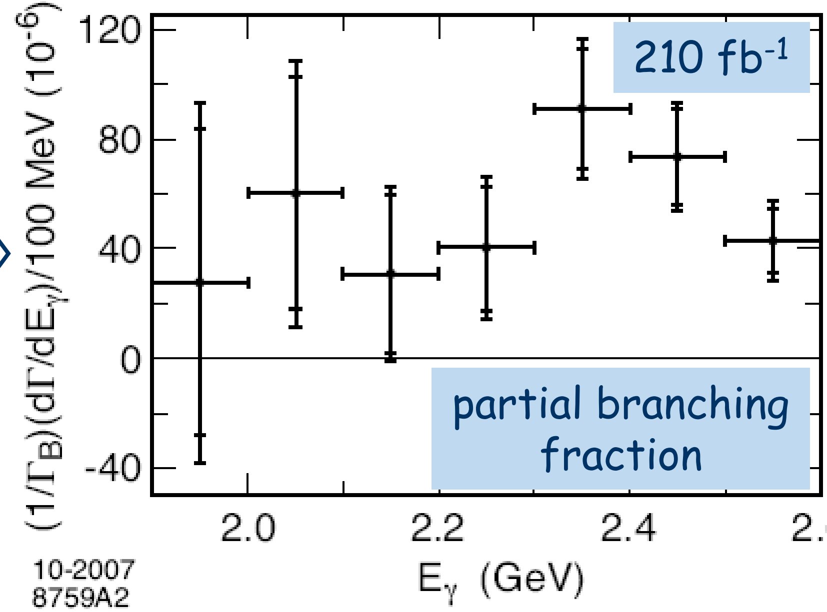
Signal and BB background determined from fit to m_{ES} distribution in bins of photon energy:

$$m_{ES} = \sqrt{(E^*_{beam})^2 - P^2_{B_{reco}}}$$

$B \to X_s \gamma$: E_γ spectrum

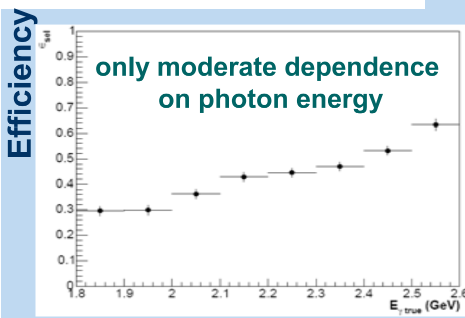


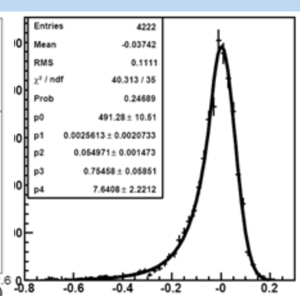
$\chi 2$ – fit for backgound normalisation



Phys.Rev.D77, 051103 (2008)

resolution and efficiency correction





Branching fraction (E_γ > 1.9 GeV):

$$\mathcal{B}(B \to X_s\gamma) = (3.66 \pm 0.85_{\mathrm{stat}} \pm 0.60_{\mathrm{syst}}) \times 10^{-4}$$

CP asymmetry:

$$A_{CP} = 0.10 \pm 0.18_{\mathrm{stat}} \pm 0.05_{\mathrm{syst}}$$

Isospin asymmetry:

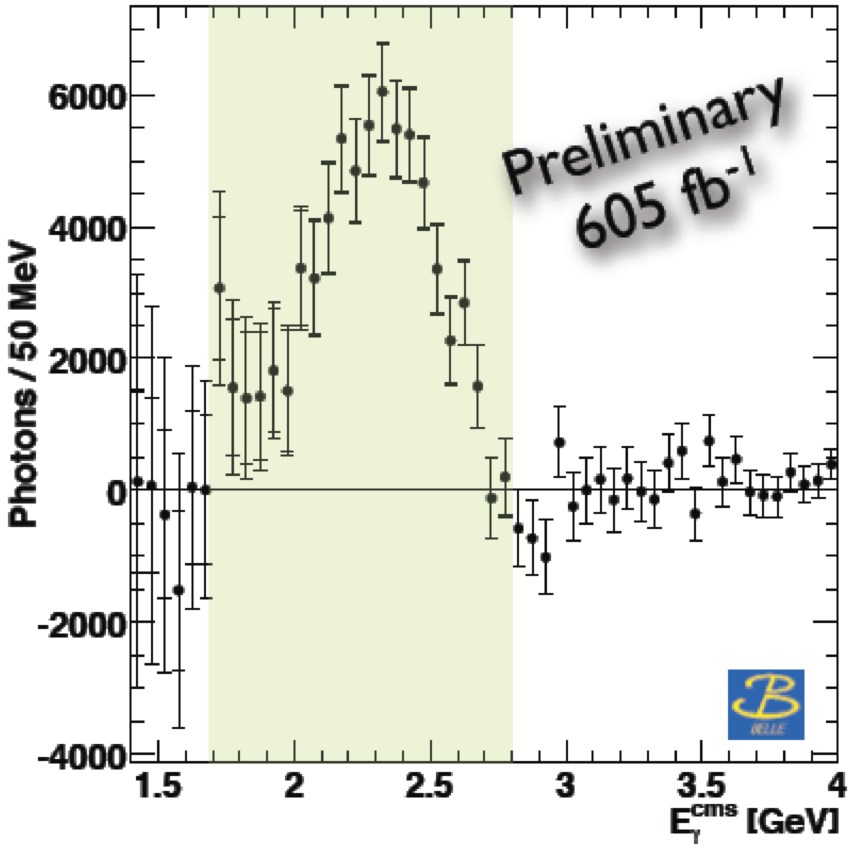
$$\Delta_{0-} = -0.06 \pm 0.15_{\mathrm{stat}} \pm 0.07_{\mathrm{syst}}$$

New Belle measurement

3-7 times larger data sample
compared to existing measurements!

Moriond
EW 08

- X_s system ignored
- only photon reconstructed
- Pros
  - ➤ No uncertainty through X_s fragmentation model
  - ➤ theoretically clean
- Cons
  - ➤ very large background → continuum
  - ➤ E_γ^* measurement in $\Upsilon(4s)$ frame



Branching fraction:

E(cut) [GeV]	PBF [10-4]
1.70	3.31 ± 0.16 ± 0.37 ± 0.01
1.80	3.24 ± 0.15 ± 0.24 ± 0.01
1.90	3.12 ± 0.14 ± 0.16 ± 0.02
2.00	2.94 ± 0.13 ± 0.12 ± 0.02
2.10	2.62 ± 0.12 ± 0.10 ± 0.05

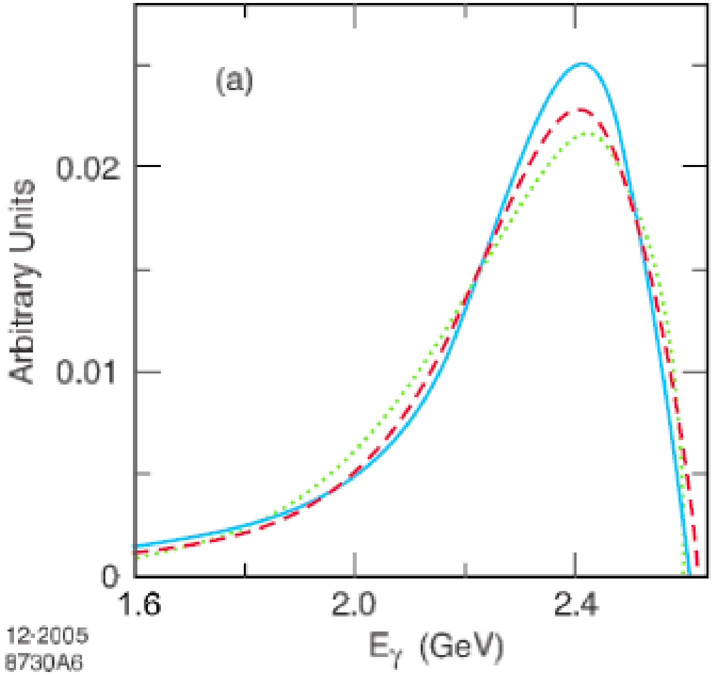
World average for BR($B \to X_s \gamma$)

- Partial branching fractions are measured above different photon energies
- Need to be extrapolated to $E_\gamma > 1.6$ GeV to compare with theory
- Extrapolation factors based on HQE fit to $b \to cl\nu$ and $b \to s\gamma$ moments

Branching fractions (10^{-4})

Mode	Reported $\mathcal{B}$	E_{min}	$\mathcal{B}$ at E_{min}
CLEO Inc. [5]	$321 \pm 43 \pm 27^{+18}_{-10}$	2.0	$306 \pm 41 \pm 26$
Belle Semi.[6]	$336 \pm 53 \pm 42^{+50}_{-54}$	2.24	–
BABAR Semi.[7]	$327 \pm 18^{+55+4}_{-40-9}$	1.9	$327 \pm 18^{+55+4}_{-40-9}$
BABAR Inc. [8]	–	1.9	$367 \pm 29 \pm 34 \pm 29$
BABAR Full [3]	$366 \pm 85 \pm 60$	1.9	$366 \pm 85 \pm 60$
Belle Inc.[4]	$332 \pm 16 \pm 37 \pm 1$	1.7	$332 \pm 16 \pm 37 \pm 1$

photon energy spectrum constrained with m_b und μ_π^2



SM prediction:
$3.15 \pm 0.23 \times 10^{-4}$ Misiak et al. (hep-ph/0609232)
$2.98 \pm 0.26 \times 10^{-4}$ Becher et. al. (hep-ph/0610067)
$3.47 \pm 0.48 \times 10^{-4}$ Andersen et al. (hep-ph/0609250)

World average for BR($B\to X_s\gamma$)

- Partial branching fractions are measured above different photon energies
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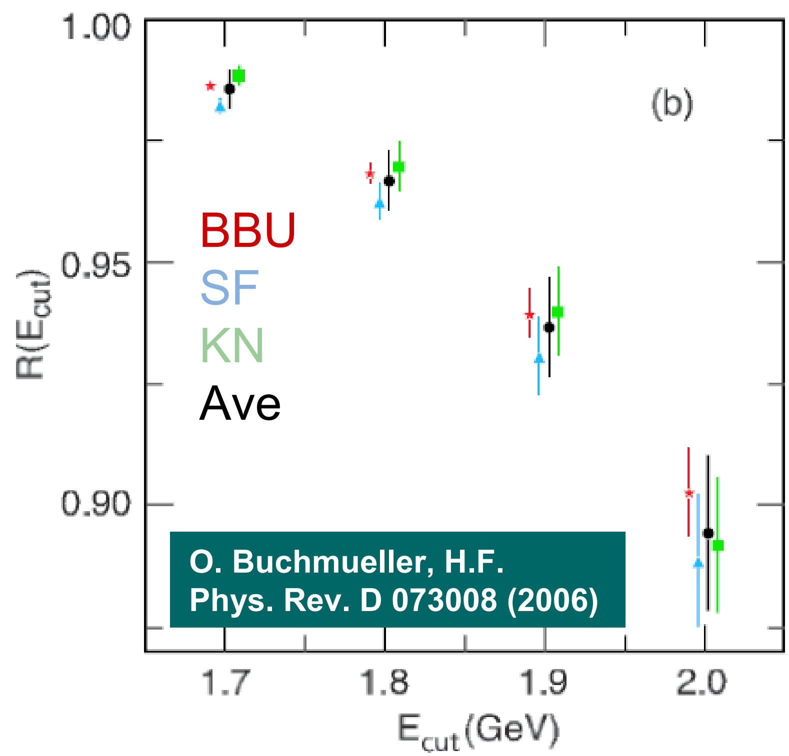
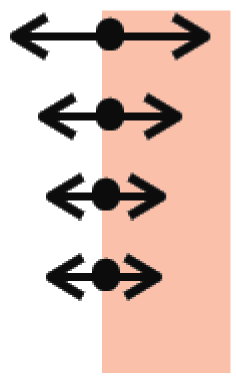
Extrapolation factors for BF



Application of extrapolation factors to new Belle analysis:



HFAG 06 average

E_γ>E (GeV)	Belle 605/fb
1.7	3.36 ± 0.41
1.8	3.35 ± 0.29
1.9	3.33 ± 0.23
2.0	3.29 ± 0.21

Consistent results when extrapolating from different E_{min}

Summary of measurements

CLEO Phys.Rev.Lett.87,251807(2001)
$BR(B\to X_s\gamma) = (3.29 \pm 0.53)\ 10^{-4}$ ($9.1\ fb^{-1}$)

Belle Semi Phys.Lett.B511:151(2001)
$BR(B\to X_s\gamma) = (3.29 \pm 0.53)\ 10^{-4}$ ($5.8\ fb^{-1}$)

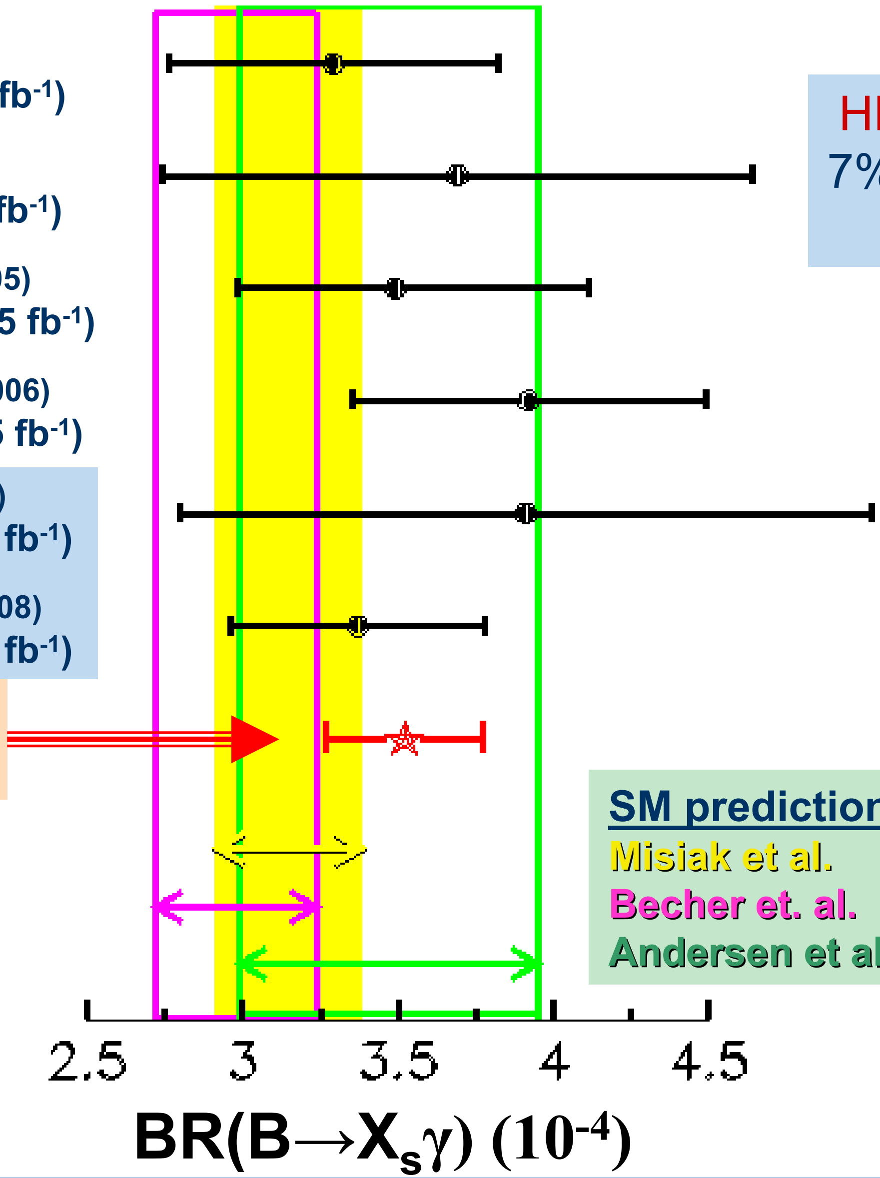
BaBar Semi Phys.Rev.D72:052004(2005)
$BR(B\to X_s\gamma) = (3.29^{+0.62}_{-0.50})\ 10^{-4}$ ($81.5\ fb^{-1}$)

BaBar Incl Phys.Rev.Lett.97:171803(2006)
$BR(B\to X_s\gamma) = (3.92 \pm 0.56)\ 10^{-4}$ ($81.5\ fb^{-1}$)

BaBar Full Phys.Rev.D77:051103(2008)
$BR(B\to X_s\gamma) = (3.91 \pm 1.11)\ 10^{-4}$ ($210\ fb^{-1}$)

BELLE Incl (A. Limosani, Moriond EW08)
$BR(B\to X_s\gamma) = (3.37 \pm 0.41)\ 10^{-4}$ ($605\ fb^{-1}$)

HFAG Average 08 (preliminary)
$BR(B\to X_s\gamma) = (3.52 \pm 0.25)\ 10^{-4}$

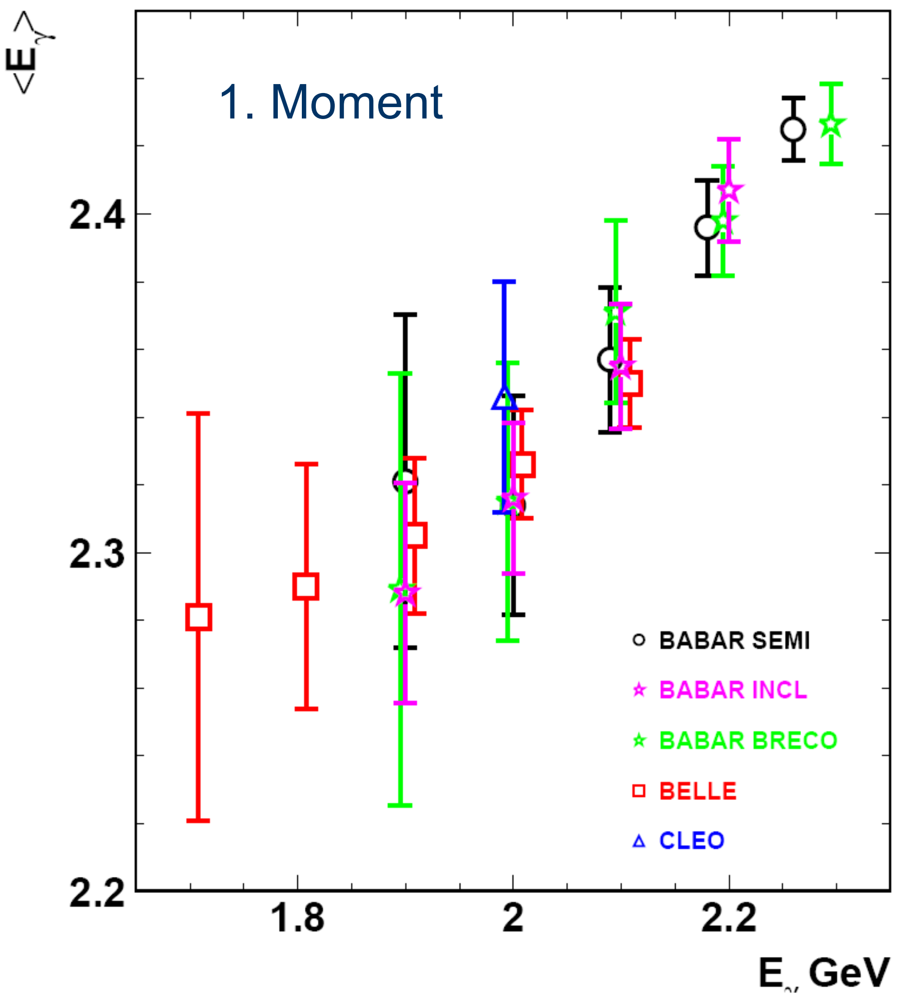


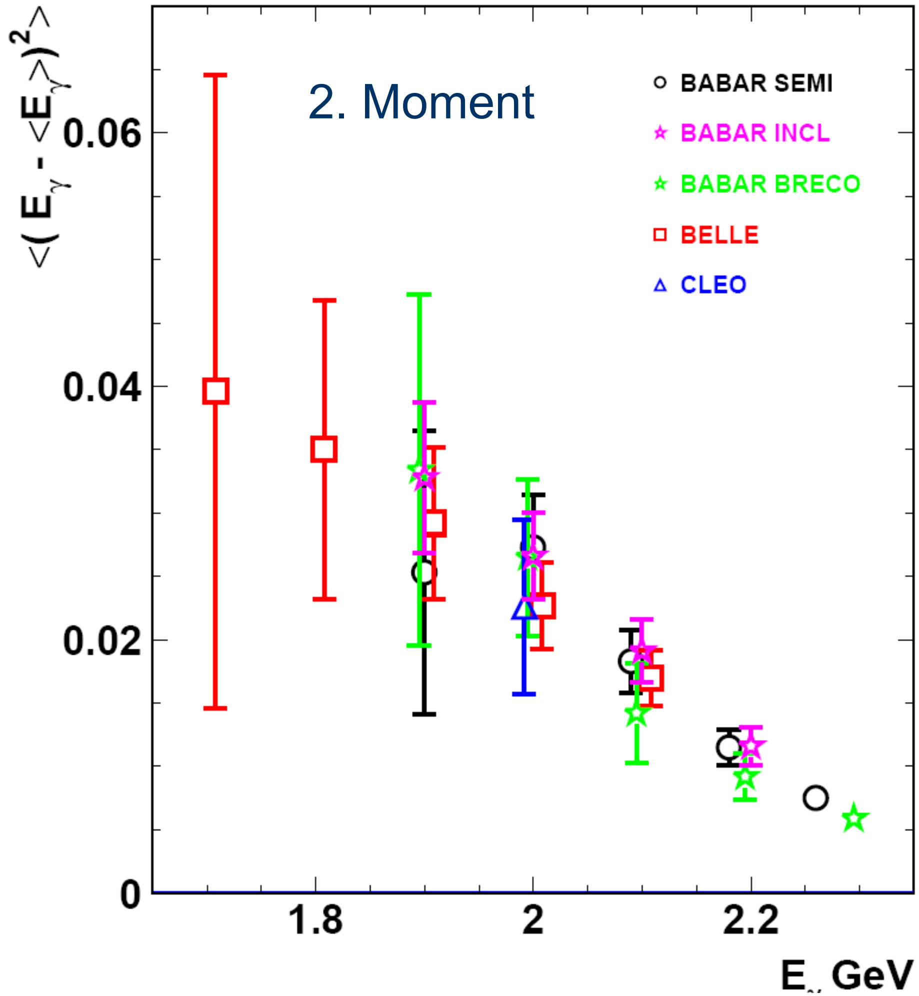
HFAG average:
7% experimental uncertainty

SM predictions:
- Misiak et al. (hep-ph/0609232)
- Becher et. al. (hep-ph/0610067)
- Andersen et al. (hep-ph/0609250)

Very good agreement between experiments and analysis methods!

Summary of measurements

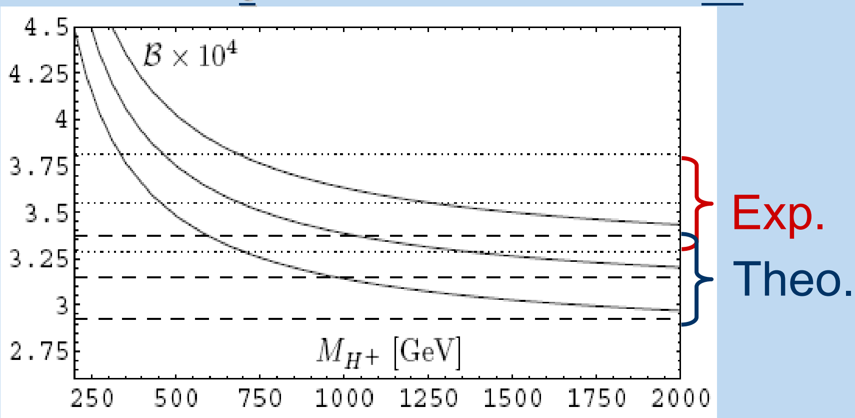




Very good agreement between experiments and analysis methods!

Constraint on 2HDM (type II)

BF($B \rightarrow X_s \gamma$) dependence on M_{H+}



Misiak et. al, Phys.Rev.Lett.98:022002,2007 & Gambino, Misiak, private communication

BF($B \rightarrow \tau\nu$) dependence on M_{H+} and tanβ:

$$BR_{2HDM} = BR_{SM} \left(1 - (\tan\beta\, m_B/m_H)^2\right)^2$$

Hou, Phys.Rev.D48:2342-2344,1993

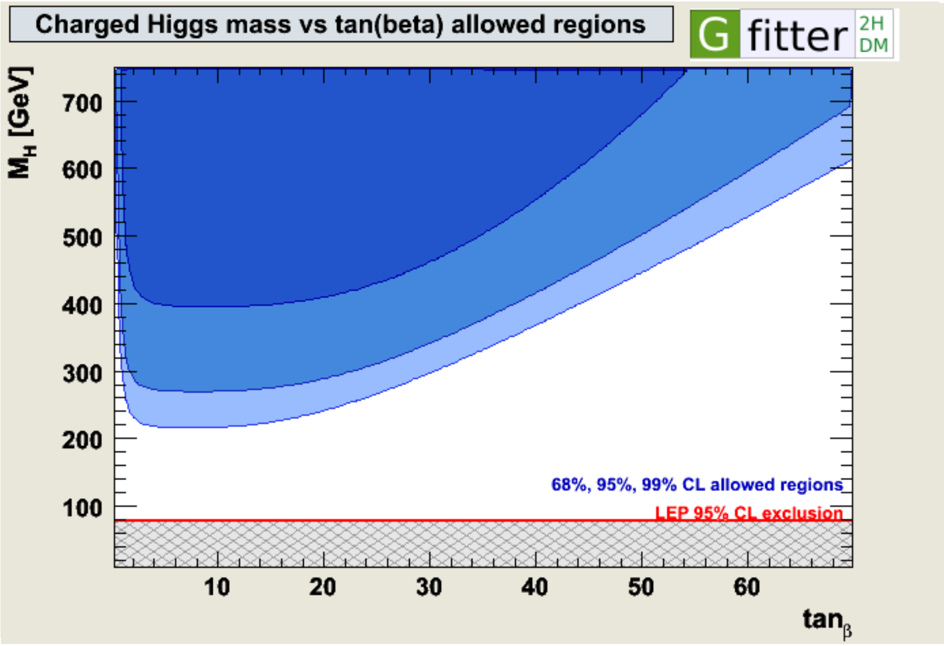
Similar for $B \rightarrow D\tau\nu$ and $K \rightarrow \mu\nu$

Experimental measurements:

BF($B \rightarrow X_s \gamma$) = (3.55 ± 0.26) 10^{-4}

BF($B \rightarrow \tau\nu$) = (1.41 ± 0.43) 10^{-4}

Combined fit to BF($B \rightarrow X_s \gamma$) and BF($B \rightarrow \tau\nu$) measurements:

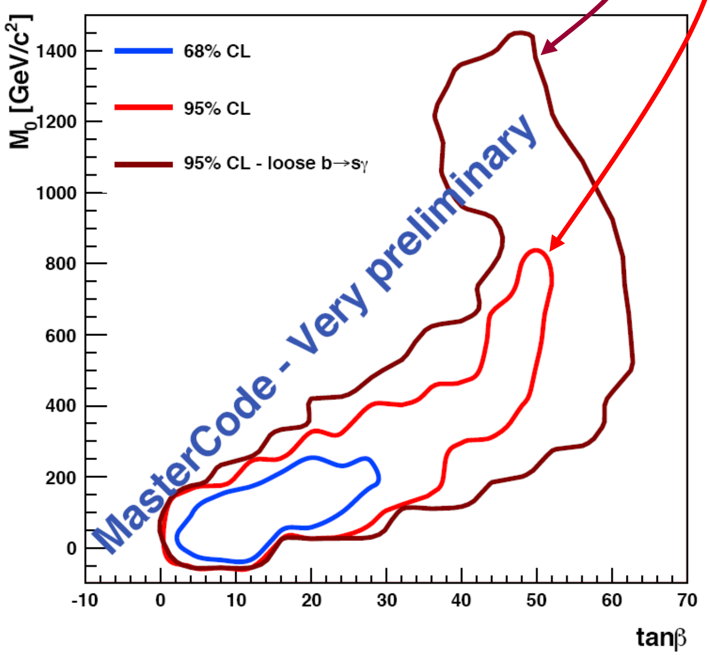


Gfitter Project:

H.F., M.Göbel ,J.Haller, A.Höcker,K. Mönig, J.Stelzer
https://twiki.cern.ch/twiki/bin/view/Gfitter/WebHome

CMSSM (mSugra) parameter space

Importance of $B \rightarrow X_s \gamma$:
Exp: $(3.55 \pm 0.26)\ 10^{-4}$
SM : $(3.15 \pm 0.23)\ 10^{-4}$
$\rightarrow$Exp/SM = 1.127 ± 0.12
Uncert. x3: 1.127 ± 0.36



Collaboration of experiment and theory
Phys.Lett.B657:87-94,2007

- **5 free parameters**
  - **M_0 – common scalar mass (at GUT scale)**
  - **$M_{1/2}$ – common gaugino mass (at GUT scale)**
  - **A_0 – tri-linearer mass parameter (at GUT scale)**
  - **tanβ – ratio of Higgs vacuum expectation values**
  - **sign(μ) – sign of Higgs mixing parameter**

- uses a total of ca. 30 elektroweak precision observables and low-energy observables (e.g. $B \rightarrow X_s \gamma$, $B \rightarrow \tau \nu$, etc.) to constrain CMSSM parameter space
- sampling of parameter space via Markov Chain Monte Carlo

See also talk by Frederic Ronga:
„Prediction for the lightest Higgs Boson Mass in the framework of CMSSM"
Rencontres de Physique de la Vallee d'Aoste 08

$|V_{cb}|$

from inclusive decay distributions

- can also be determined from exclusive $B \to D^* l\nu$ and $B \to D\, l\nu$ decays
- still sizable uncertainties from FormFactors (theory)
- Valuable to compare incl. and excl. measurements
- very different theory uncertainties

Fit to Moments of Inclusive Decay Distributions

Heavy Quark Expansions connect the inclusive decay width to $|V_{cb}|$:

Γ_{SL} proportional to $|V_{cb}|^2$, but perturbative and non-perturbative corrections to free quark decay needed → double expansion in α_s and $1/m_b$

$$\Gamma_{cl\nu} = \frac{G_F m_b^5}{192\pi^3}|V_{cb}|^2(1+A_{ew})A_{pert}A_{nonpert} \cong |V_{cb}|^2 f_{OPE}(m_b, m_c, a_i)$$

4 parameters at order α_s^2 and $1/m_b^3$

Need to determine non-perturbative parameters!

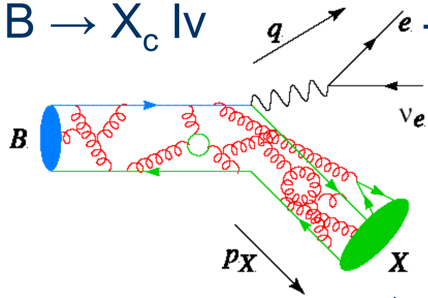
⟶ Use moments of inclusive distributions where same parameters appear:

$$< X^n > (E_{cut}) = \left. \frac{\int (X - X^0)^n \frac{d\Gamma}{dX} dX}{\int \frac{d\Gamma}{dX} dX} \right|_{E_l > E_{cut}} \cong f'_{OPE}(m_b, m_c, a_i)$$

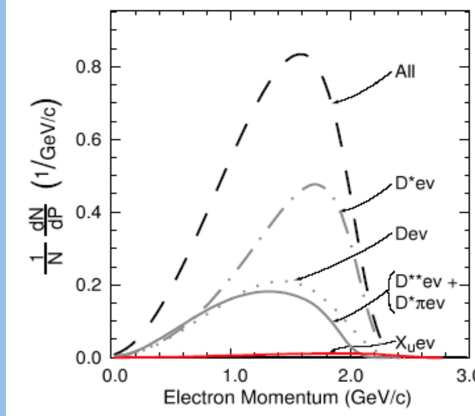
- Hadronic Mass distribution $\langle M_X^n \rangle \rightarrow \langle M_X \rangle(m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s)$
- Lepton Energy spectrum $\langle E_\ell^n \rangle \rightarrow \langle E_\ell^n \rangle(m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s)$
- Photon Energy spectrum $\langle E_\gamma^n \rangle \rightarrow \langle E_\gamma^n \rangle(m_b, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s)$.

Observables

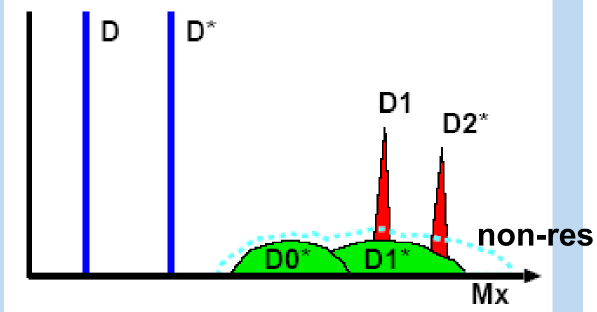
$B \rightarrow X_c l\nu$



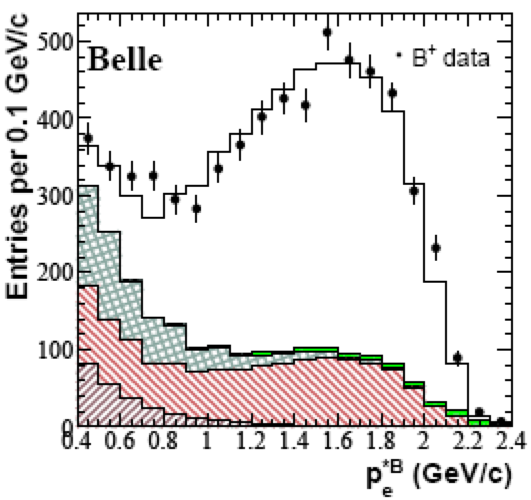
lepton energy

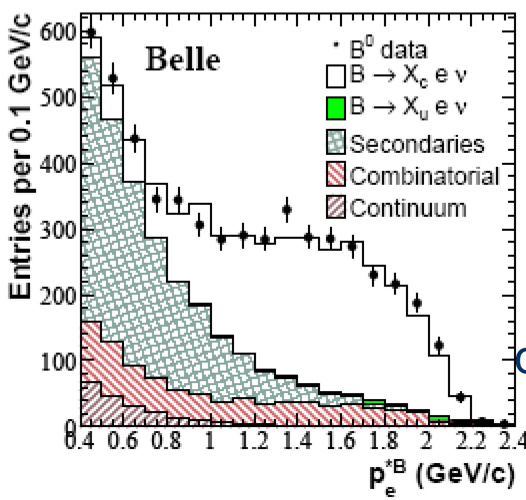


hadronic mass

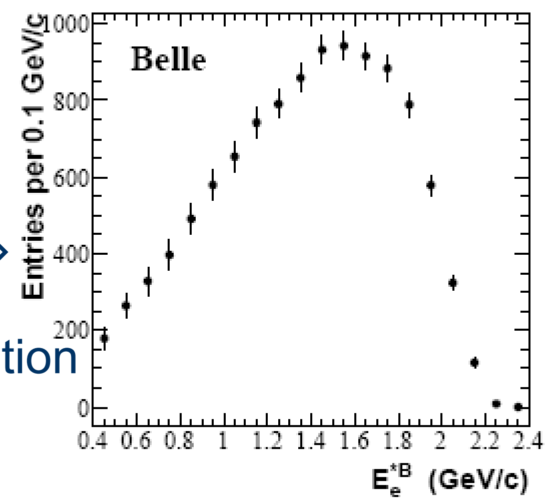


Belle lepton spectrum:

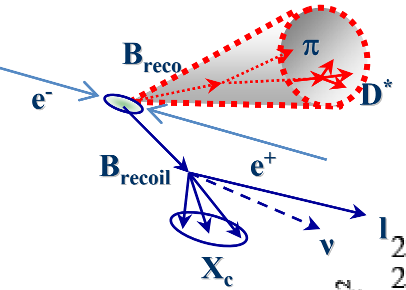




deconvolution

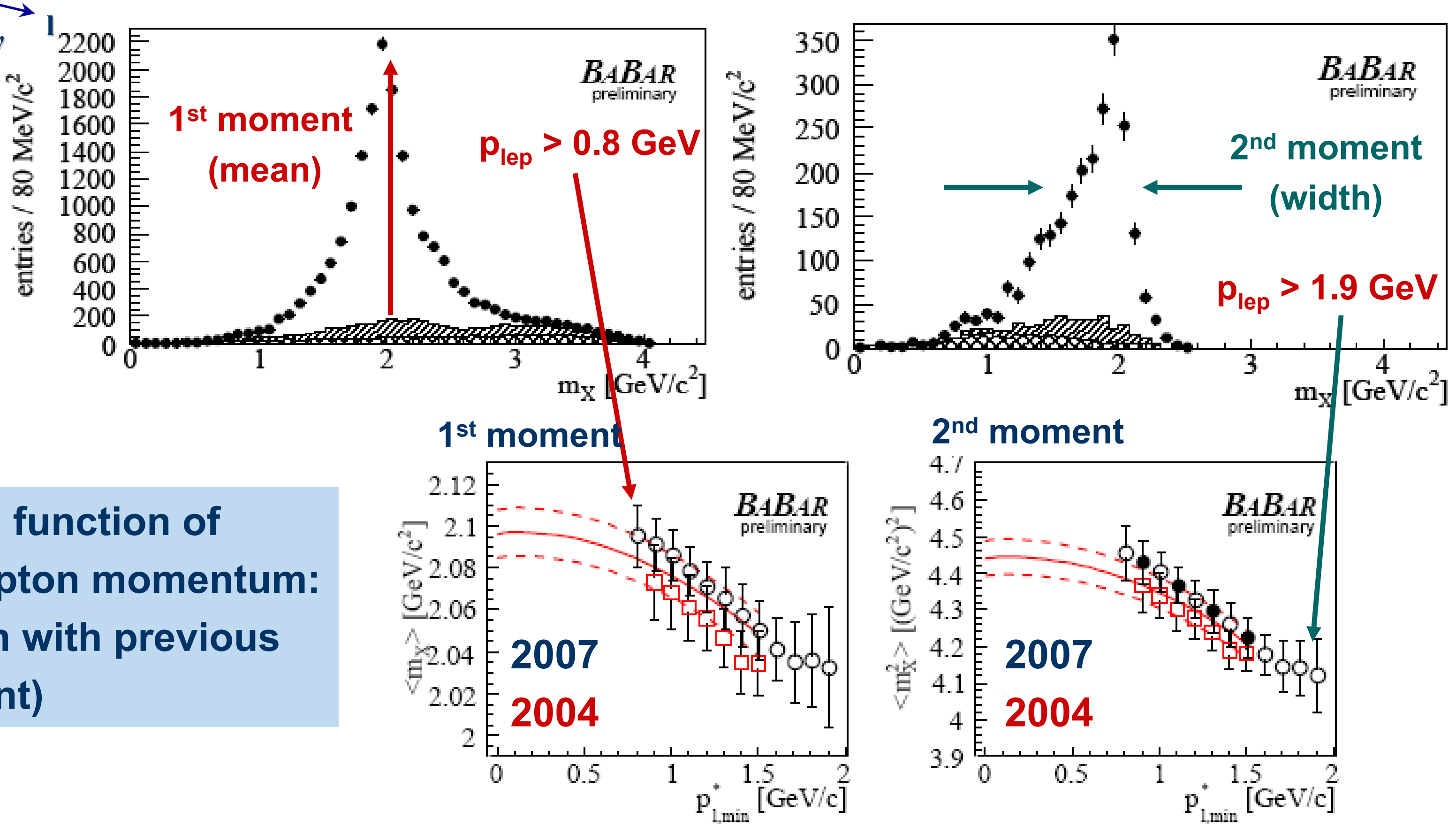


Hadronic mass moments



New BaBar measurement!
Full reconstruction tag

Based on 232M BB events
arXiv:0707.2670 [hep-ex]



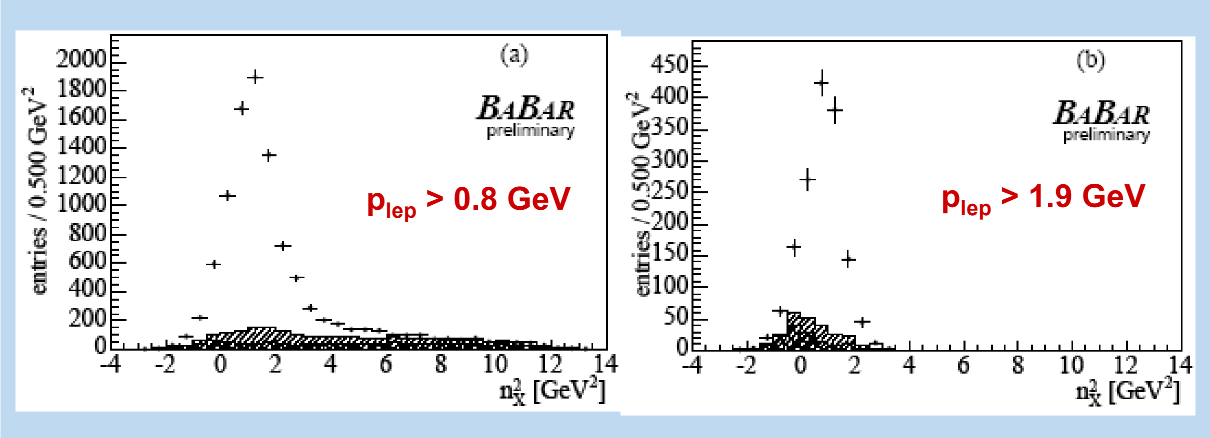
Moments as function of minimum lepton momentum: (comparison with previous measurement)

+ higher order moments

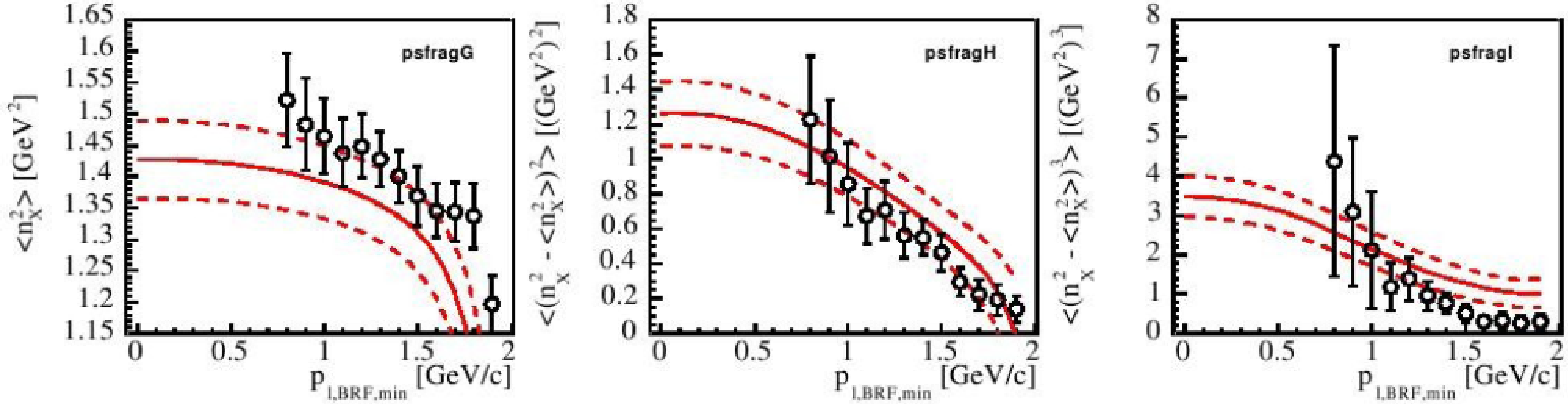
Mixed Hadronic Mass and Energy Moments

In addition modified moments: $\mathcal{N}_X^2 = M_X^2 - 2\tilde{\Lambda}E_X + \tilde{\Lambda}^2$ (Λ=0.65 GeV)

combination of hadronic Mass and Energy Moments
→ higher sensitivity to higher order parameters



Preliminary comparison with theo. calculations:

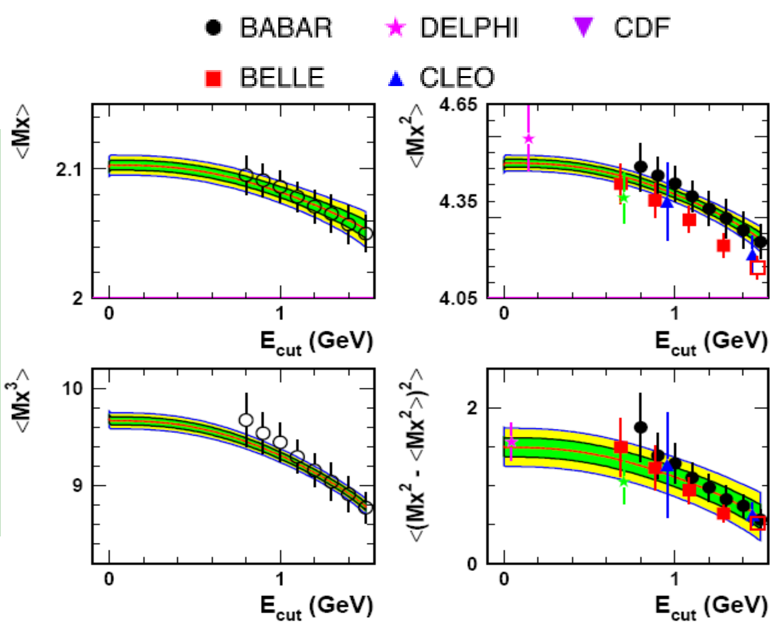


Inclusive $|V_{cb}|$ - Fit to Moments

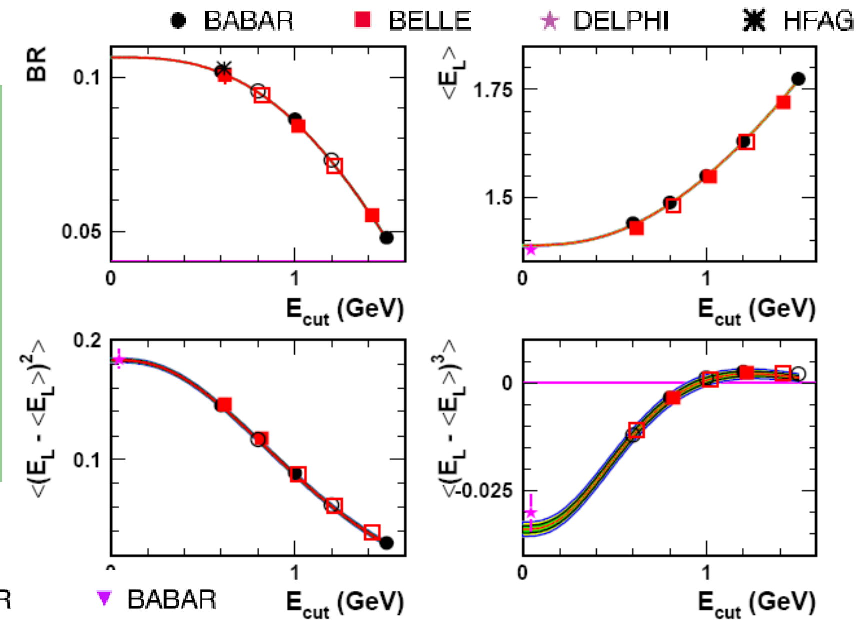
Based on calculations in kinetic scheme:

Benson, Bigi, Mannel & Uraltsev, hep-ph/0410080
Gambino & Uraltsev, hep-ph/0401063
Benson, Bigi & Uraltsev, hep-ph/0410080

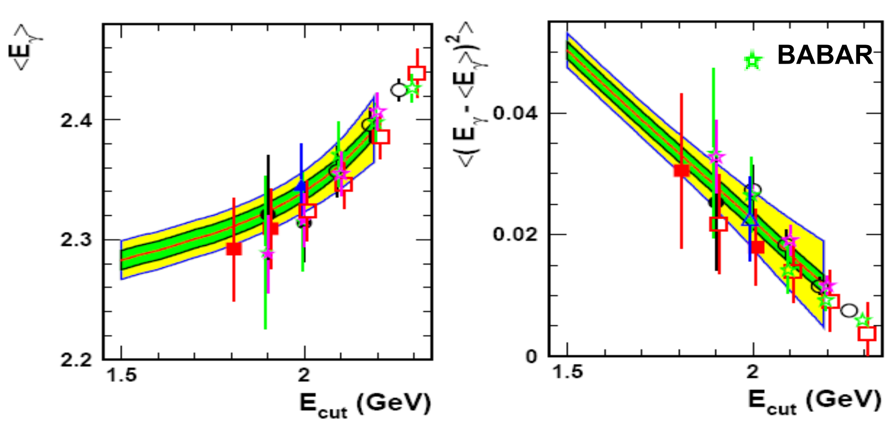
Hadron Moments



Lepton Moments



Photon Moments



Measurements are correlated!

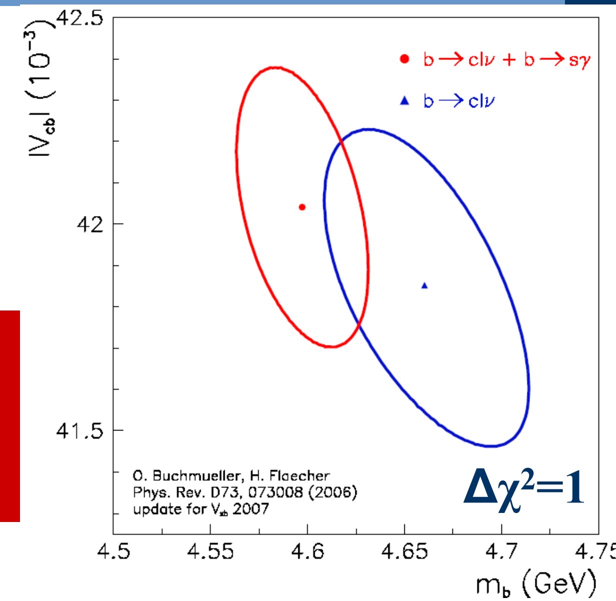
O. Buchmueller, H.F.
Phys. Rev. D 073008 (2006)
update for V_{xb} 07, Heidelberg

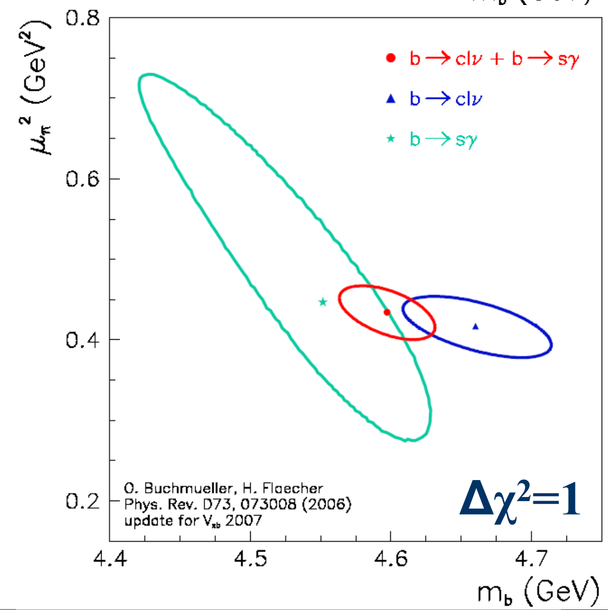
Inclusive $|V_{cb}|$ Determination

Result of the combined fit in kinetic scheme:

		exp	HQE	Γ_{SL}
$\lvert V_{cb}\rvert$ =	(42.04	± 0.19	± 0.28	± 0.59) 10^{-3}
m_b =	4.597	± 0.021	± 0.027	GeV
m_c =	1.163	± 0.032	± 0.039	GeV
μ_π^2 =	0.434	± 0.016	± 0.029	GeV^2
μ_G^2 =	0.267	± 0.015	± 0.036	GeV^2
ρ_D^3 =	0.203	± 0.009	± 0.018	GeV^3
ρ_{LS}^3 =	-0.184	± 0.052	± 0.068	GeV^3
$BR_{cl\nu}$ =	10.64	± 0.09	± 0.07	%

$|V_{cb}|$ @ 2%
m_b < 1%
m_c @ 5%





In $\overline{MS}$ scheme:
$\overline{m}_b(\overline{m}_b)$ = 4.21 ± 0.04 GeV
$\overline{m}_c(\overline{m}_c)$ = 1.26 ± 0.06 GeV

Thanks to N.Uraltsev

Comparison of m_b and m_{top}:
m_{top} = 172.6 ± 1.4 GeV
(0.8%)
m_b = 4.597 ± 0.034 GeV
(0.7%)

O. Buchmueller, H.F., Phys. Rev. D 073008 (2006)
update for V_{xb} 07, Heidelberg

Inclusive $|V_{cb}|$ Determination

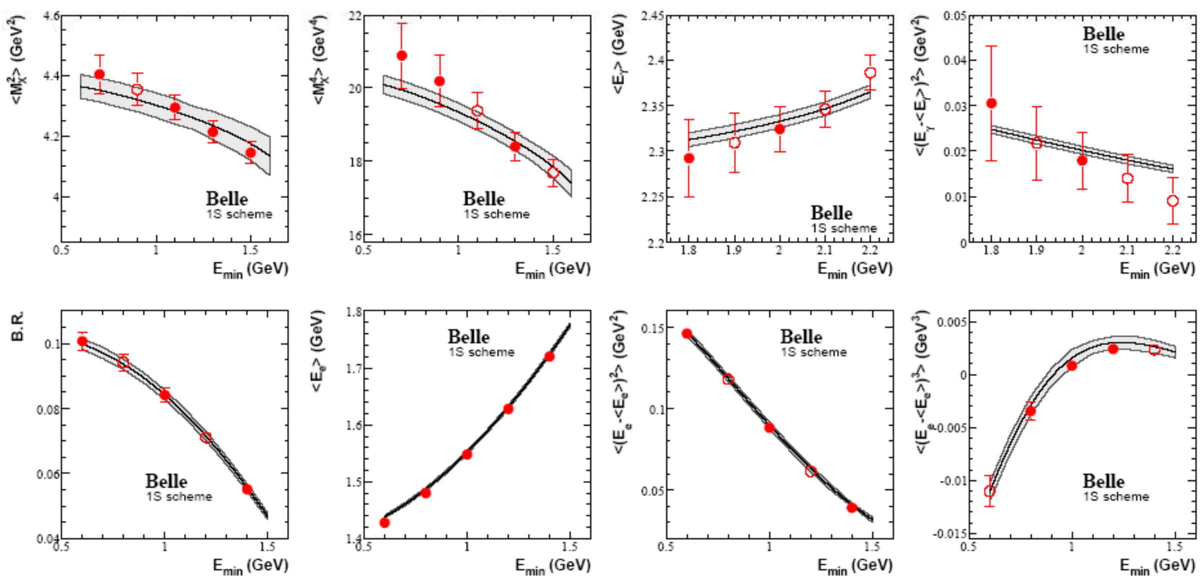
Belle's OPE fit (1S)

Belle preliminary, update of ICHEP'06

- 1S scheme parameters: m_b^{1S}, λ_1, τ_1, τ_2, τ_3, ρ_1 + $|V_{cb}|$
- 7 m_X moments, 11 E_e moments, 3 partial $\mathcal{B}$, 4 E_γ moments

$$|V_{cb}| = (41.56 \pm 0.68_{\text{fit}} \pm 0.08_{\tau_B}) \times 10^{-3} \; (\chi^2/ndf = 7.3/18)$$

$$|V_{cb}| = (41.52 \pm 0.69_{\text{fit}} \pm 0.08_{\tau_B} \pm 0.58_{\text{th}}) \times 10^{-3} \text{ (Belle kinetic fit)}$$



$\langle m_X^2\rangle$, $\langle m_X^4\rangle$, $\langle E_\gamma\rangle$, $\langle (E_\gamma - \langle E_\gamma\rangle)^2\rangle$

$\Delta\mathcal{B}$, $\langle M_n^\ell\rangle$

New

$B \to X_c \ell^- \bar{\nu}$ moments and OPE fits — M. Nakao — p.15

>100 moment measurements and many HQE fit results…

OB & HF Phys.Rev.D73:073008,2006
$|V_{cb}| = 42.0 \pm 0.2_{exp} \pm 0.3_{HQE} \pm 0.6_{\Gamma_{SL}}$

BABAR Phys.Rev.Lett.93:011803,2004
$|V_{cb}| = 41.7 \pm 0.4_{exp} \pm 0.4_{HQE} \pm 0.6_{\Gamma_{SL}}$ *

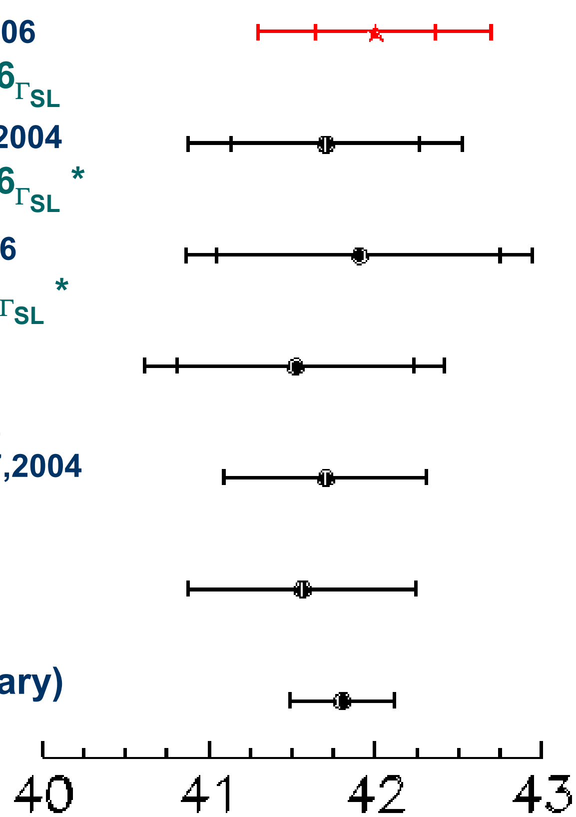
DELPHI Eur.Phys.J.C45:35-59,2006
$|V_{cb}| = 41.9 \pm 0.6_{exp} \pm 0.6_{FIT} \pm 0.6_{\Gamma_{SL}}$ *

BELLE arXiv 0803.2158
$|V_{cb}| = 41.5 \pm 0.7_{fit} \pm 0.1_{\tau} \pm 0.6_{\Gamma_{SL}}$

Bauer et al. Phys.Rev.D70:094017,2004
$|V_{cb}| = 41.7 \pm 0.6_{fit} \pm 0.1_{\tau}$ *

BELLE arXiv 0803.2158
$|V_{cb}| = 41.6 \pm 0.7_{fit} \pm 0.1_{\tau}$

BELLE Global V_{xb} 07 (preliminary)
$|V_{cb}| = 41.8 \pm 0.3_{fit} \pm 0.1\tau$



Fits in kinetic scheme
Based on hep-ph/0401063

Fits in 1S scheme
Based on hep-ph/0408002

* rescaled to common lifetime
$\tau_B = 1.585 \pm 0.007$ ps
all $|V_{cb}|$ values $\times 10^{-3}$

Very good agreement
$|V_{cb}|$ @ <2%

But: comparison with exclusive $|V_{cb}|$
$(38.8 \pm 0.6_{exp} \pm 1.0_{theo})\ 10^{-3}$
incl. – excl. = 3.2 ± 1.3 (2.5 σ)

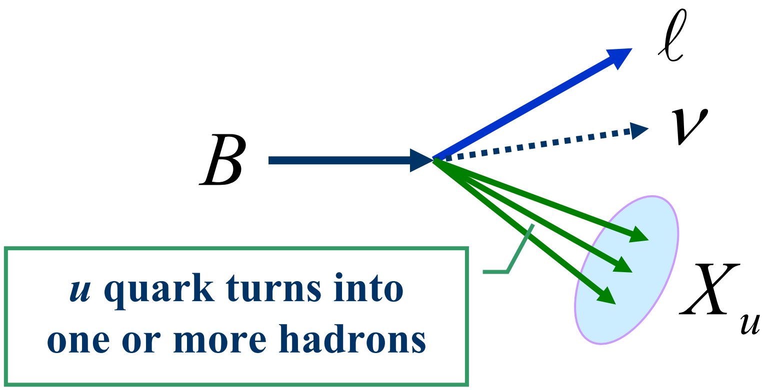
$|V_{ub}|$

from inclusive decay distributions

- can also be determined from exclusive
  $B \to \pi\, l\nu$ and $B \to \rho\, l\nu$ decays
- still sizeable uncertainties from FormFactors (theory)
- $B \to \pi$ FF improved from lattice

Inclusive $b \to u l \nu$: Strategies

- Very large backgound from b→clv decays: $|V_{cb}|^2 >> |V_{ub}|^2$ ~50!
- We use 3 variables to describe $B \to X l \nu$ decays:



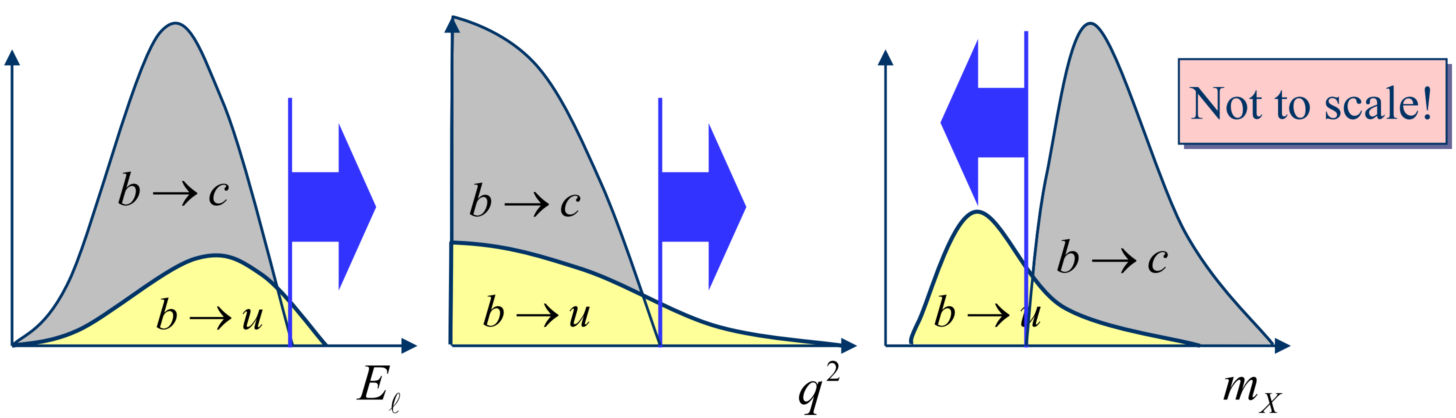
E_ℓ = lepton energy

q^2 = lepton-neutrino mass squared

m_X = hadron system mass

Combine cuts on these variables to maximise phase space and minimise theory uncertainty

- Signal events have smaller $m_X \to$ larger E_l and q^2



Inclusive Vub

- $|V_{ub}|$ measurement in different regions of phase space
  - consistency!

$|V_{ub}|$ measurement:

$$\Gamma\left(B \to X_u \ell \nu\right) \times f_C = \left|V_{ub}\right|^2 \zeta_C$$

signal fraction surviving cuts

Cut dependent constant (from Theory)

Total rate:

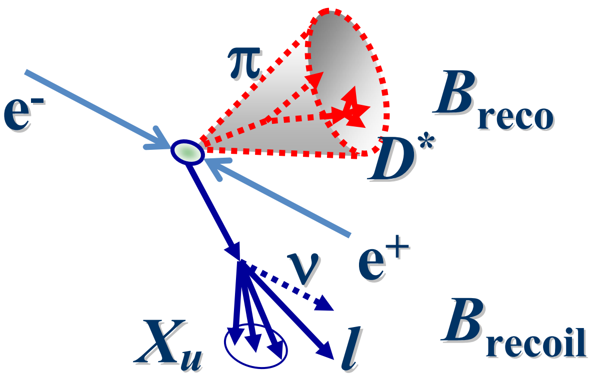
$$\Gamma\left(B \to X_u \ell \nu\right) \sim \left|V_{ub}\right|^2 m_b^5$$

largest syst. uncertainty!
Use HQE fit result!

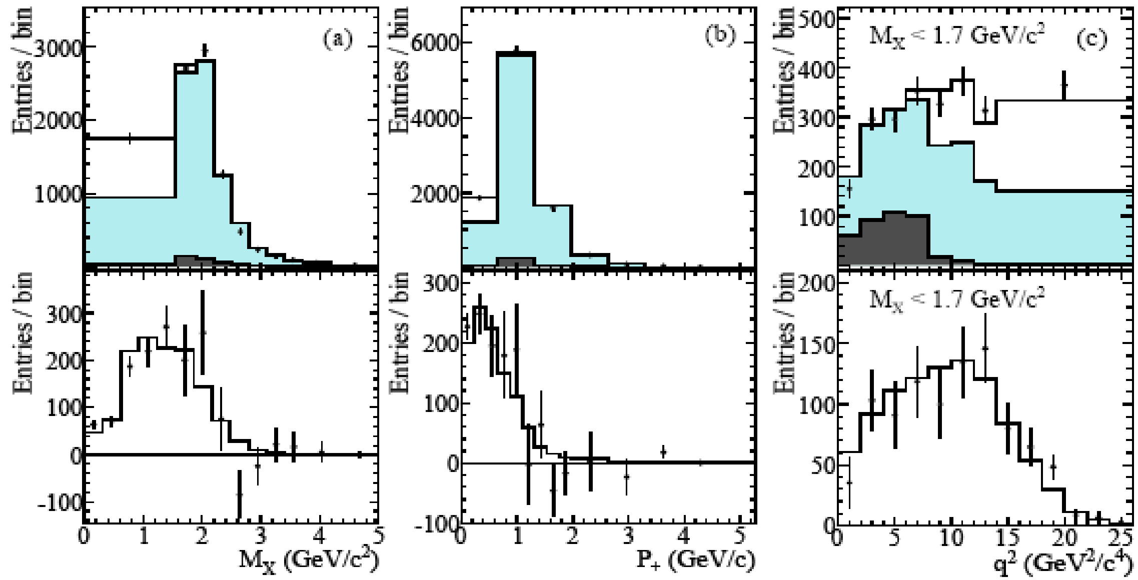
- Connection between b → sγ and b → ulν
  - restricted kinematics compromise convergence of OPE
  - hadronic physics needs to be encoded in non-perturbative shape function
    - light cone distribution of b-quark (shape function) at leading order the same for b → ulν and b → sγ (universal, not process dependent)
    - detailed shape not known, in particular the tail
    - but mean and r.m.s can be constrained from moment measurements in b → clν, b → sγ

$|V_{ub}|$: Full reconstruction tag

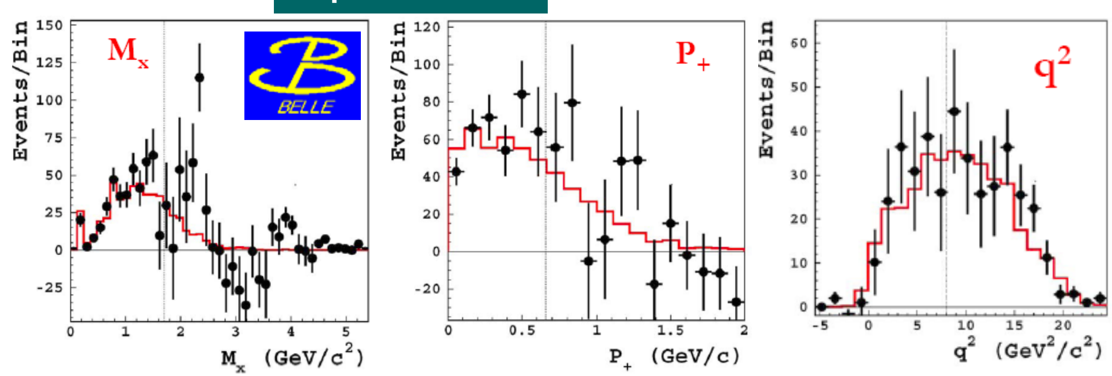
Full reconstruction analysis:



Babar: arXiv:0708.3702



Belle: hep-ex/0505088



Advantages:

- clean sample
- kinematics known
- B flavour known

Disadvantage:

- low statistics

$|V_{ub}|$: Full reconstruction tag

Babar: arXiv:0708.3702

Cuts	Method	N_u	$\|V_{ub}\| \times (10^{-3})$	
M_X<1.55 GeV	M_X	803 ± 60	$4.27 \pm 0.16 \pm 0.13 \pm 0.30$	[4]
			$4.56 \pm 0.17 \pm 0.14 \pm 0.32$	[5]
$P_+=E_X-\|p_X\|$ <0.66	P_+	633 ± 63	$3.88 \pm 0.19 \pm 0.16 \pm 0.28$	[4]
			$3.99 \pm 0.20 \pm 0.16 \pm 0.24$	[5]
M_X<1.7GeV, q^2>8GeV	M_X, q^2	562 ± 55	$4.57 \pm 0.22 \pm 0.19 \pm 0.30$	[4]
			$4.64 \pm 0.23 \pm 0.19 \pm 0.25$	[5]
			$4.93 \pm 0.24 \pm 0.20 \pm 0.36$	[6]

[4] Bosch, Lange, Neubert, Paz
Phys.Rev.Lett.93,221801,(2004)
Bosch,Neubert,Paz
Phys.Rev.D72,073006(2005)
[5] Andersen, Gardi
JHEP 0601, 097 (2006)
[6] Bauer, Ligeti, Luke
Phys.Rev.D64,113004(2001)

Around 9% uncertainty from single analysis

Belle: Phys.Rev.Lett.95,241801(2005)

$\Delta\Phi$	$\|V_{ub}\| \times 10^3$	stat	syst	$b \to u$	$b \to c$	SF	th.		Cuts
M_X/q^2	4.70	5.0	4.4	3.1	2.7	4.2	$^{+4.8}_{-5.2}$	[4]	M_X<1,7GeV, q^2>8GeV
M_X	4.09	4.6	3.5	3.1	1.1	4.5	$^{+3.5}_{-3.8}$	[4]	M_X<1.7 GeV
P_+	4.19	4.7	4.6	3.2	4.4	5.8	$^{+3.4}_{-3.5}$	[4]	$P_+=E_X-\|p_X\|$ <0.66

Different phase space acceptances result in different theory errors!

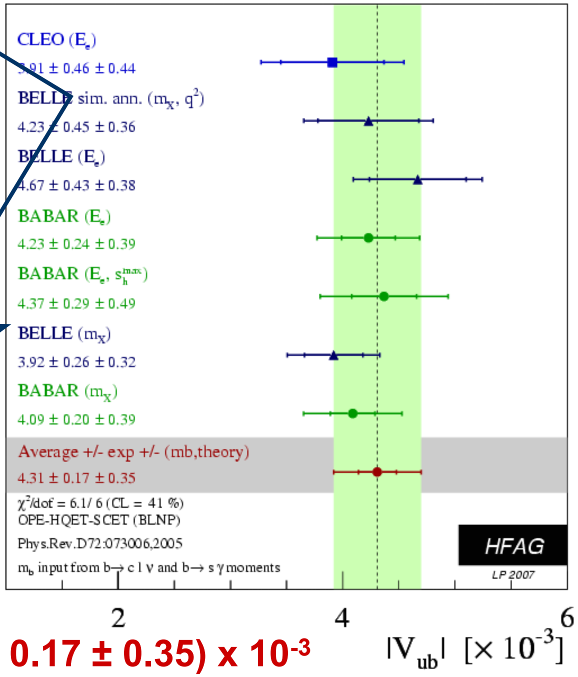
$|V_{ub}|$ Summary

Great effort on exp. and theo. side over the past few years

reduced uncertainty thanks to more precise measurements of heavy quark parameters

- **m_b uncertainty reduced from 60 MeV → 35 MeV**
- **Uncertainty on $|V_{ub}|$ due to HQ Parameters from 8% → ~4% - 6%**
- **8% total uncertainty (exp + theo)**

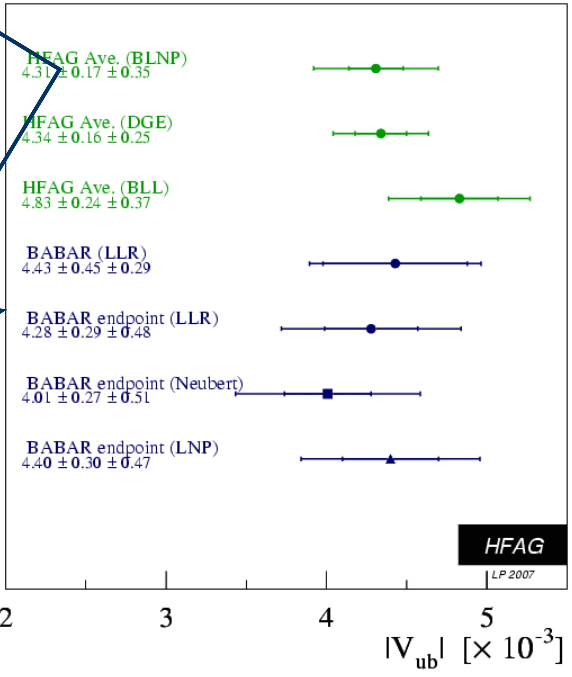
Theoy: BLNP measurements in different regions of phase space



uses PRD, 073008 (2006) for m_b

$|V_{ub}|=(4.31 \pm 0.17 \pm 0.35) \times 10^{-3}$

Many different theoretical calculations



Comparison with exclusive measurement: $|V_{ub}| = 3.17 \pm 0.10\ ^{+0.74}_{-0.44}$ (HPQCD 2007)

incl. – excl. = 1.14 ± 0.84 (1.4 σ)

Moments in $B \to X_u l\nu$ decays

arXiv:0801.2985 [hep-ex]

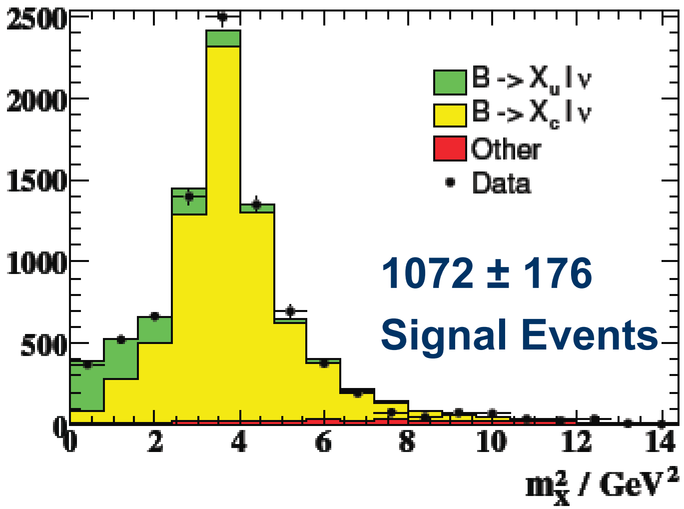
Measure hadronic mass spectrum over full range

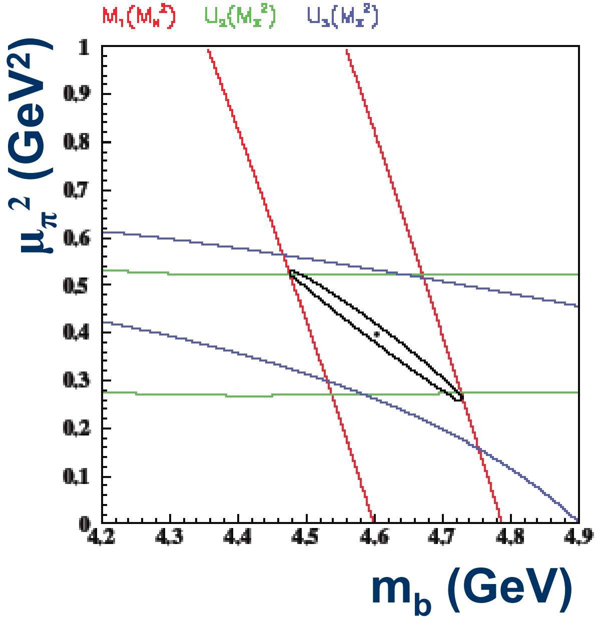
OPE as in case for $B \to X_c l\nu$

Mass moments related to m_b

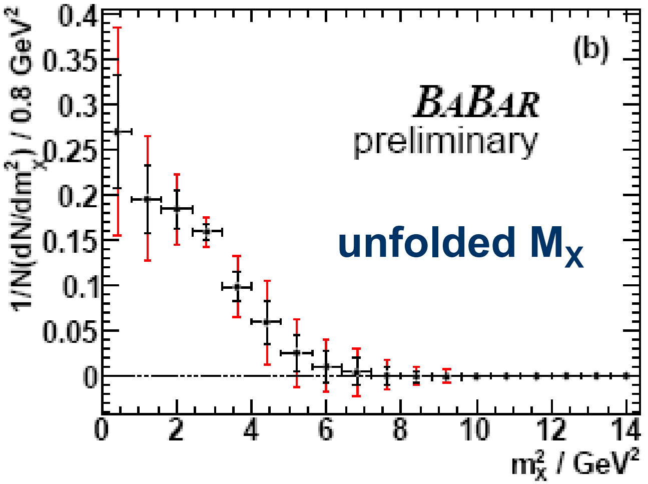
$$M_1 = (1.96 \pm 0.34(\text{stat}) \pm 0.53(\text{syst}))\ \text{GeV}^2$$
$$U_2 = (1.92 \pm 0.59(\text{stat}) \pm 0.87(\text{syst}))\ \text{GeV}^4$$
$$U_3 = (1.79 \pm 0.62(\text{stat}) \pm 0.78(\text{syst}))\ \text{GeV}^6$$

for $M_X < 6.2$ GeV





First measurement of m_b in $B \to X_u l\nu$ decays:
$m_b = 4.604 \pm 0.250$ GeV
(kinetic scheme)

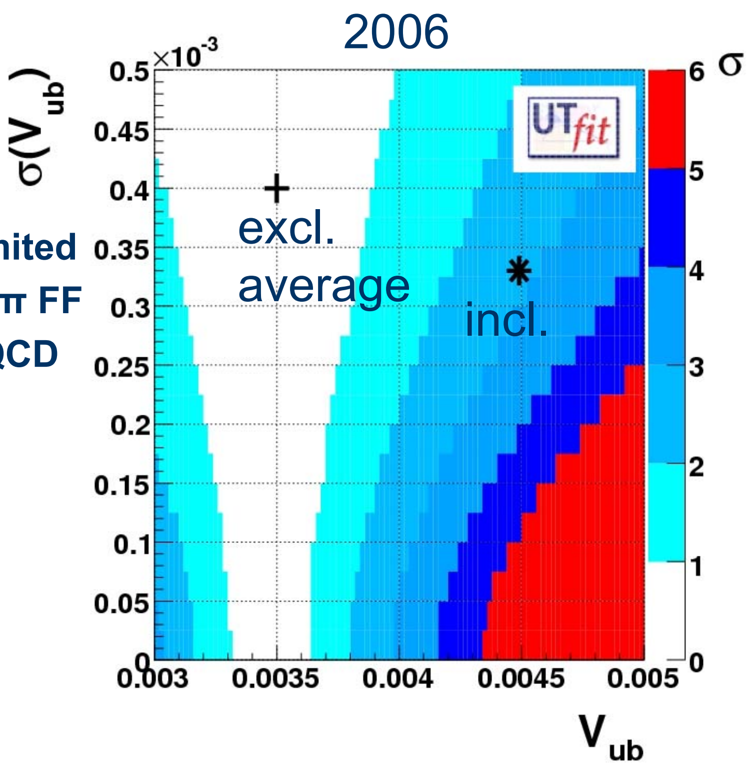


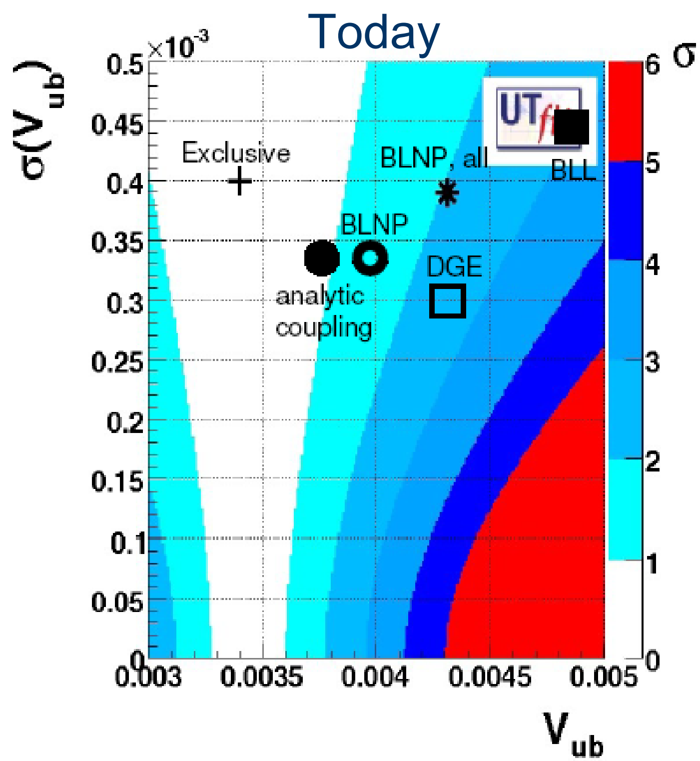
Calculations of
Gambino, Ossola, Uraltsev
hep-ph/0505091

Consistency of CKM description

Comparison of indirect determination of $|V_{ub}|$ from CKM fit (prediction through other observables, sin2β etc.) and directly measured values:

Excl. limited by B → π FF from LQCD





- All inclusive detrminations give higher values than excl. average
  - Need to have consistent excl. and incl. $|V_{ub}|$ to confront sin2β
- More detailed studies by Theory and Experiment are necessary

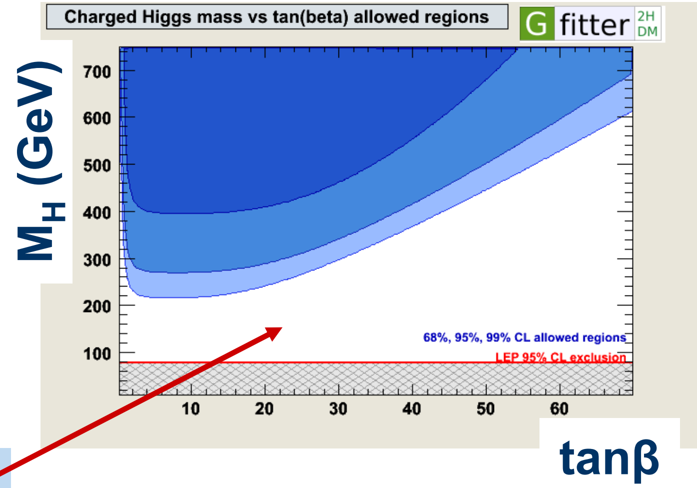
Conclusions

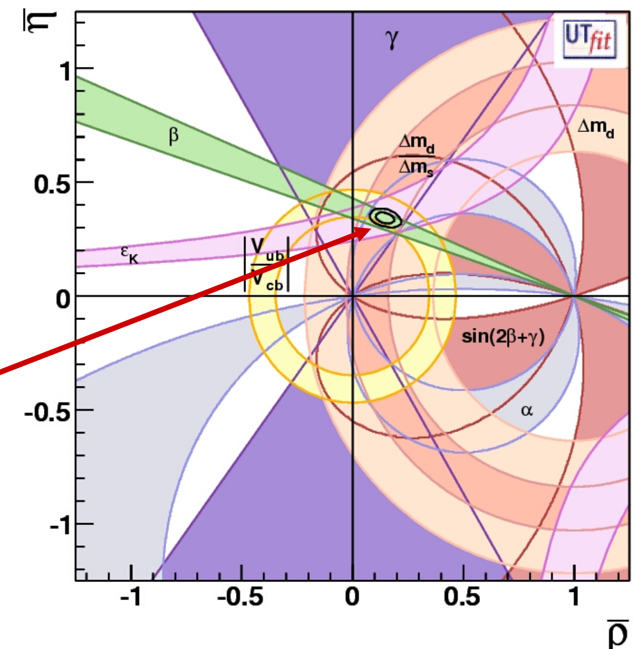
- Analyses on larger datasamples still to come

- Consistency between experimental results for inclusive decay distributions (moments)
- Good agreement for Heavy Quark Parameters from semileptonic and radiative B decays

- Radiative B decays
  - BR($B \rightarrow X_s \gamma$) @ 7%
  - important constraint on many New Physics models
  - CP-Asymmetries sensitive to New Physics

- Precision measurement of 4 SM Parameters:
  - $|V_{cb}|$ with 2% uncertainty
  - $|V_{ub}|$ with ~8% uncertainty testing consistency with sin(2β) and hence SM
  - m_b (<1%) and m_c (5%)

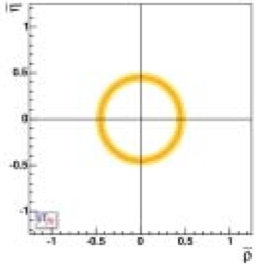




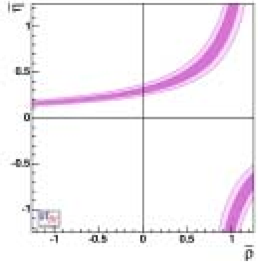
Backup

Constraints on the UT triangle

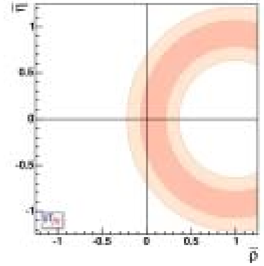
$|V_{ub}/V_{cb}|$



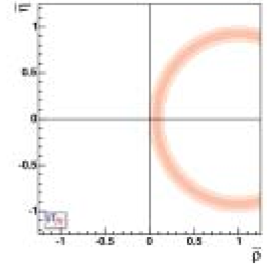
εK



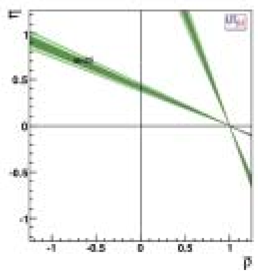
Δm_d



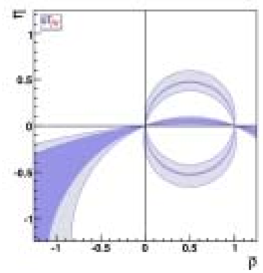
$\Delta m_d/\Delta m_s$



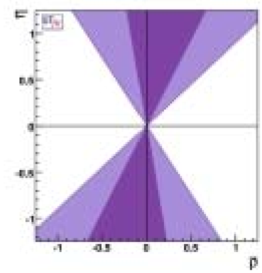
$\sin 2\beta$



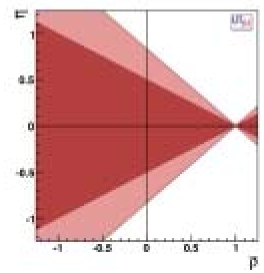
α



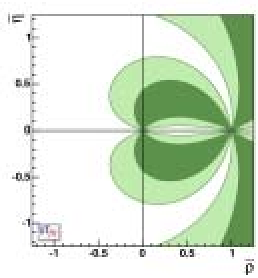
γ



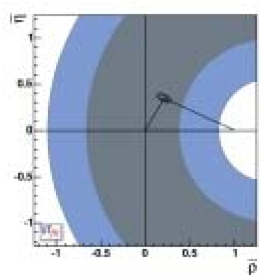
$\cos 2\beta$



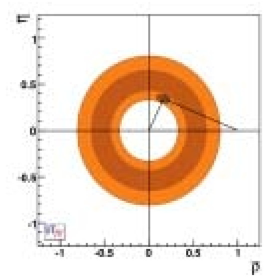
$\sin(2\beta+\gamma)$



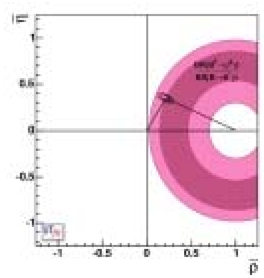
$K \to \pi \nu\nu$



$B \to \tau\nu$

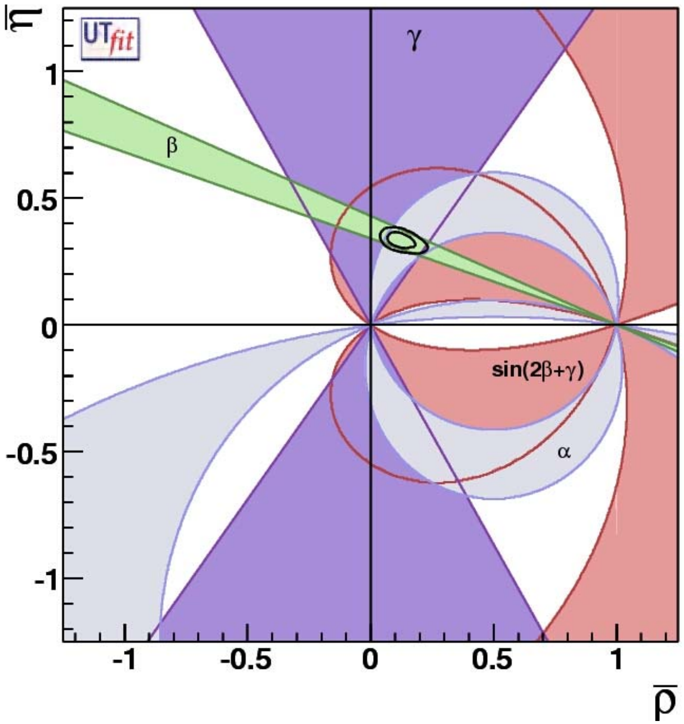


$(B \to \rho/\omega\ \gamma)/(B \to K^* \gamma)$



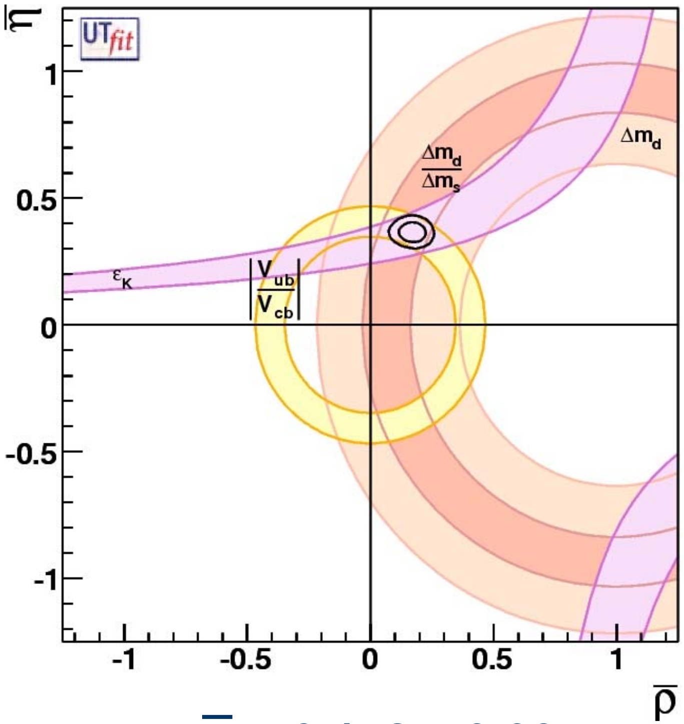
Vergleich von Seiten und Winkeln

UT from Angles



$\bar{\rho}$ = 0.120 ± 0.038
$\bar{\eta}$ = 0.332 ± 0.021

UT from Sides

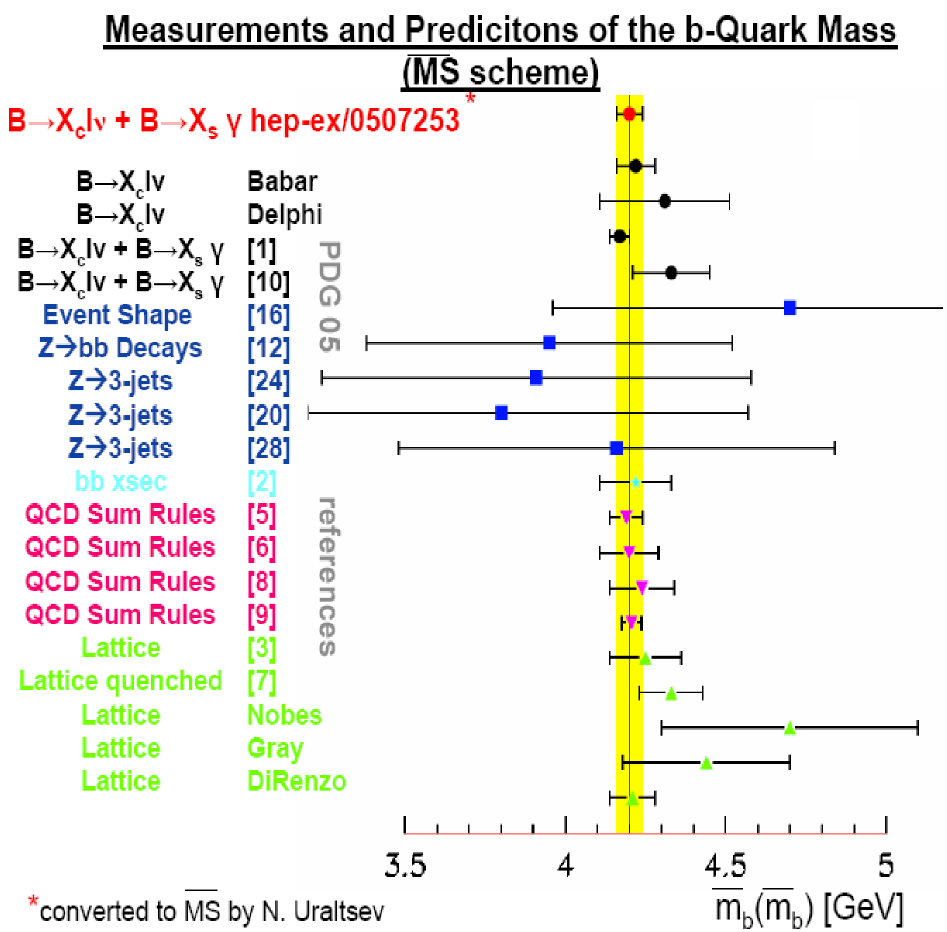


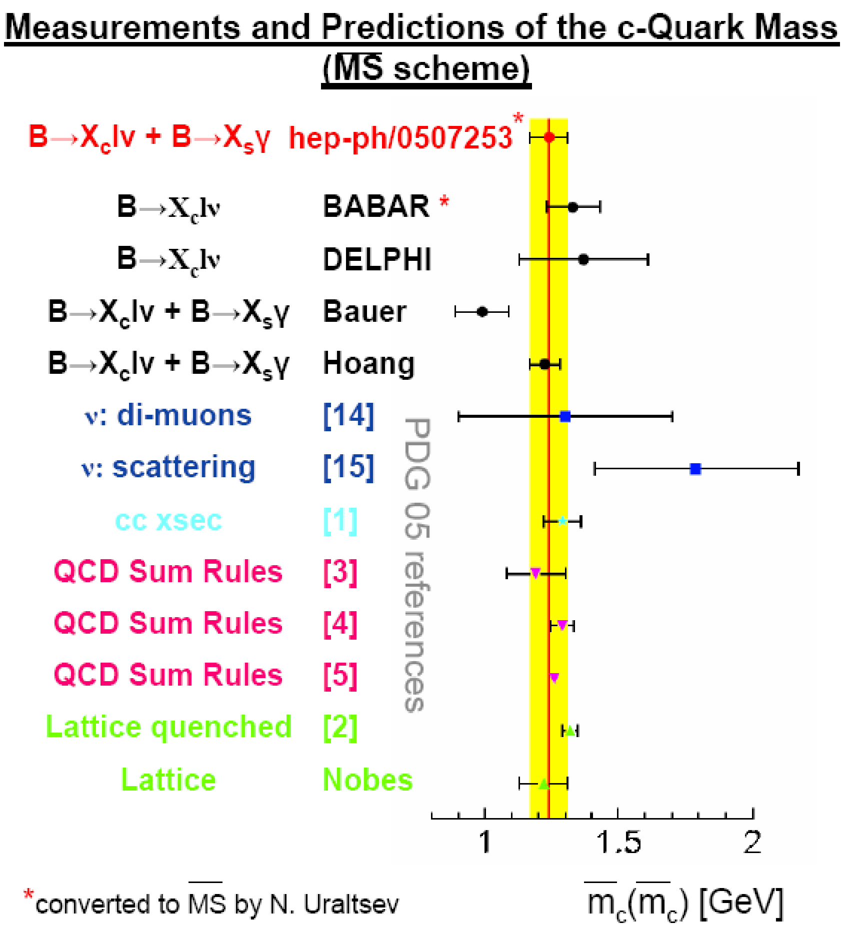
$\bar{\rho}$ = 0.172 ± 0.037
$\bar{\eta}$ = 0.365 ± 0.026

$\bar{\rho} - \bar{\rho}$ = -0.052 ± 0.053
$\bar{\eta} - \bar{\eta}$ = -0.033 ± 0.033

Keine signifikante Diskrepanz

Übersicht Quark Massen:





$$\overline{m}_b(\overline{m}_b) = 4.20 \pm 0.04 \text{ GeV}$$

$$\overline{m}_c(\overline{m}_c) = 1.24 \pm 0.07 \text{ GeV}$$

Conversion from kinetic mass scheme to $\overline{\text{MS}}$ scheme with hep-ph/9708372, hep-ph/0302262
See also report from CKM WS hep-ph/0304132

Fit to Moments of Inclusive Decay Distributions

The Operator Product Expansion separates perturbative from non-perturbative scales in a systematic way:

$$\Gamma_{SL}(B \to X_c l \nu) = \frac{G_F^2 m_b^5}{192\pi^3} |V_{cb}|^2 (1 + A_{ew}) A_{pert}(r,\mu)$$

$$\times \left[z_0(r) \left(1 - \frac{\mu_\pi^2 - \mu_G^2 + \frac{\rho_D^3 + \rho_{LS}^3}{m_b}}{2m_b^2} \right) - 2(1-r)^4 \frac{\mu_G^2 + \frac{\rho_D^3 + \rho_{LS}^3}{m_b}}{m_b^2} + d(r)\frac{\rho_D^3}{m_b^3} + O(1/m_b^4) \right]$$

kinetic expec. value (μ_π^2)

chromomagnetic expec. value (μ_G^2)

Darwin term (ρ_D^3)

spin-orbit (ρ_{LS}^3)

kinetic scheme

$r \equiv (m_c / m_b)^2$

Benson, Bigi, Mannel & Uraltsev, hep-ph/0410080
Gambino & Uraltsev, Eur.Phys.J. C34, 181 (2004)

Moments of hadronic mass, lepton energy and photon energy in b→sg distribution depend on same heavy quark parameters:

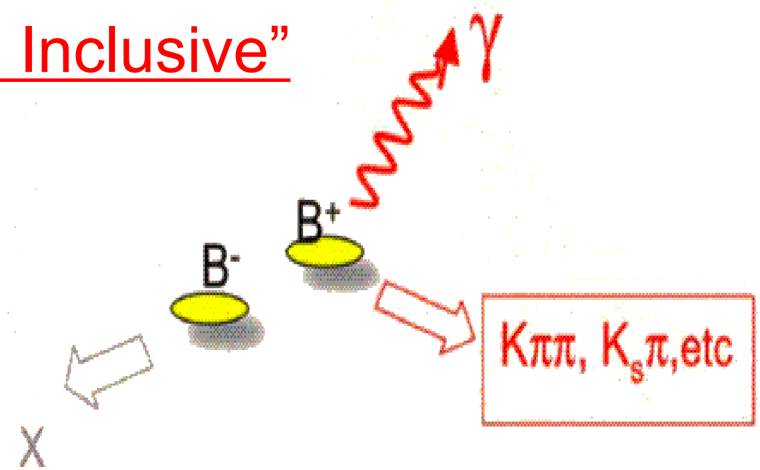
$$\langle M_X^n \rangle \rightarrow \langle M_X \rangle (m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s)$$
$$\langle E_\ell^n \rangle \rightarrow \langle E_\ell^n \rangle (m_b, m_c, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s)$$
$$\langle E_\gamma^n \rangle \rightarrow \langle E_\gamma^n \rangle (m_b, \mu_\pi^2, \mu_G^2, \rho_D^3, \rho_{LS}^3, \alpha_s) \quad .$$

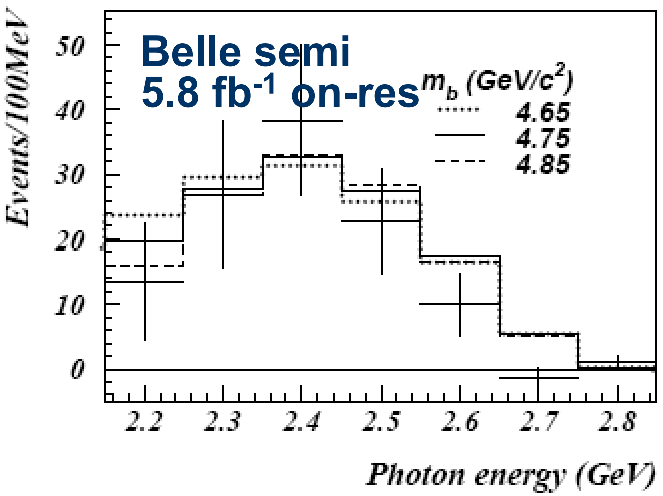
mb and μ_π^2 are used to parameterise both B→Xs γ and B→Xu lν spectra

Many moment measurements (~50) allow to fit for all parameters up to $1/m_b^3$

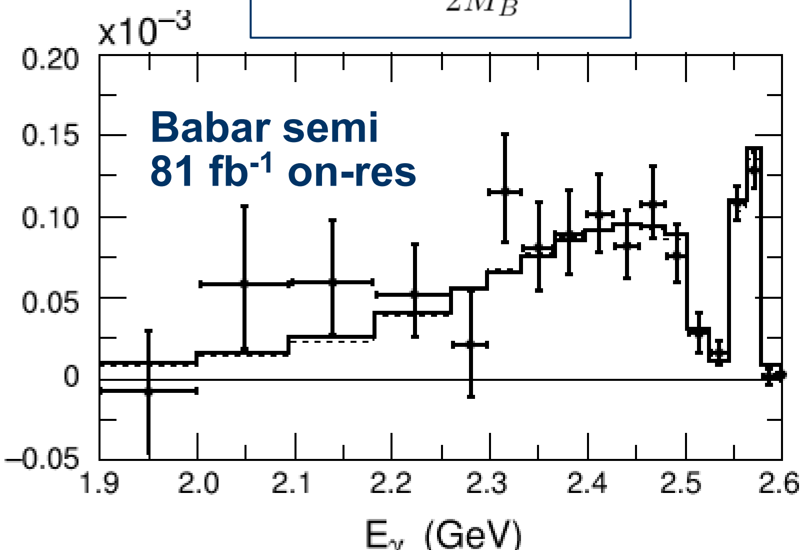
Summe exklusiver Endzustände

"Semi Inclusive"



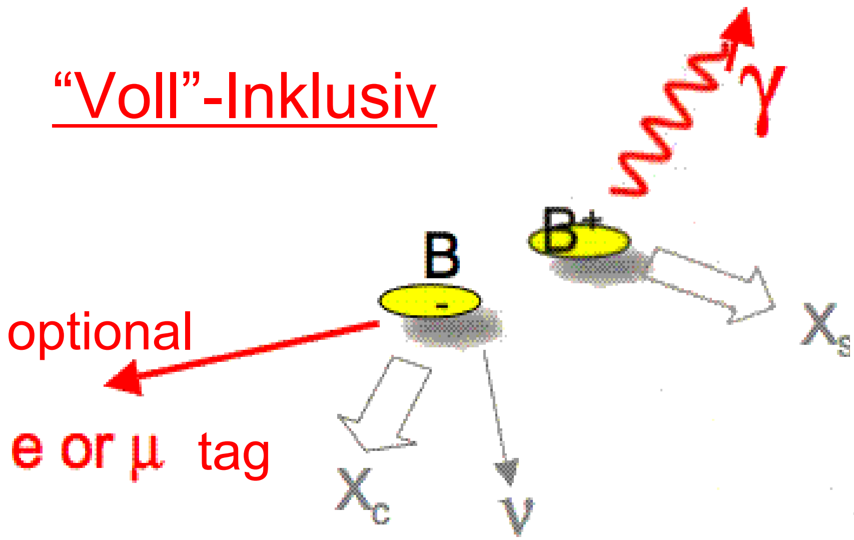


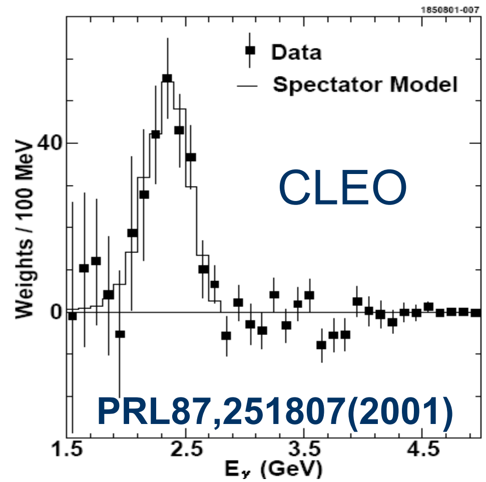
$$E_\gamma = \frac{M_B^2 - M(X_s)^2}{2M_B}.$$



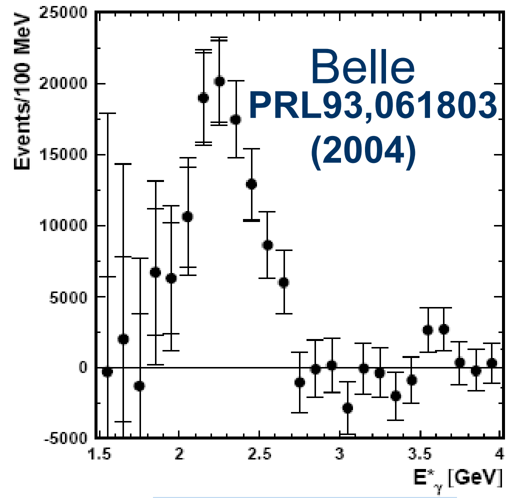
- Volle Rekonstruktion von möglichst vielen X_s Endzuständen (bis zu 38!)
- Pros
  - Niedriger Untergrund
  - Gute E_γ Auflösung im B-Bezugssytem
- Cons
  - Systematische Unsicherheiten der X_s Fragmentation
  - Fehlende X_s Zerfallskanäle

„Voll“-Inklusive Rekonstruktion



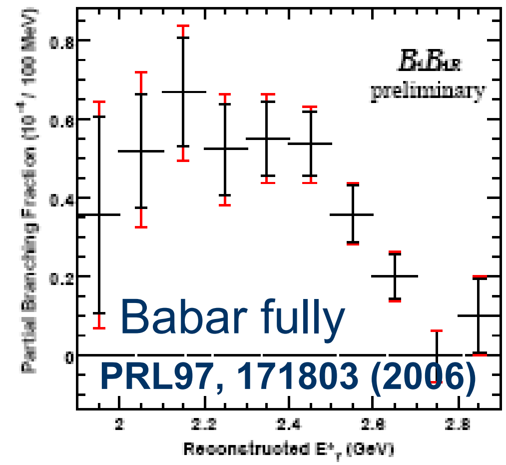


9.1 fb^{-1} on-res
4.4 fb^{-1} off-res



140 fb^{-1} on-res
15 fb^{-1} off-res

- X_s System wird nicht benötigt
- Nur das Photon wird rekonstruiert
- Pros
  - Keine Unsicherheit durch X_s Fragmentationsmodell
  - theoretisch sauber
- Cons
  - Grosser Untergrund → Kontinuum
  - E_γ* Messung im Υ(4s) System



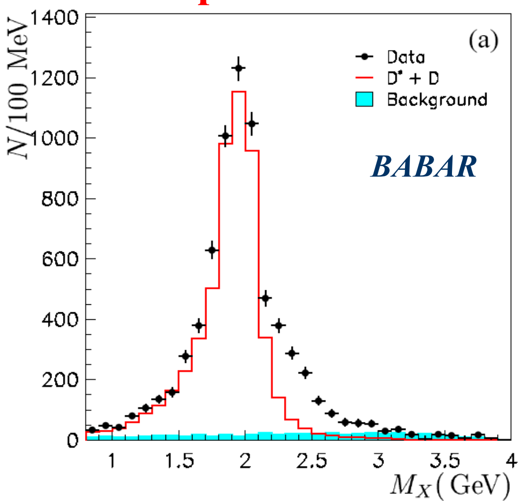
81.5 fb^{-1} on-res
9.6 fb^{-1} off-res

Hadronic Mass Moments

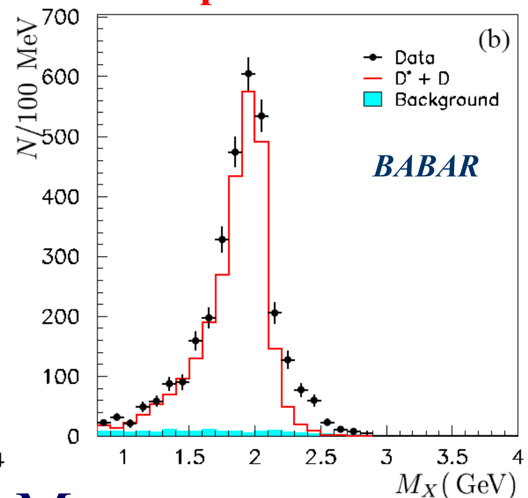
BaBar, Belle and CLEO measure full spectrum

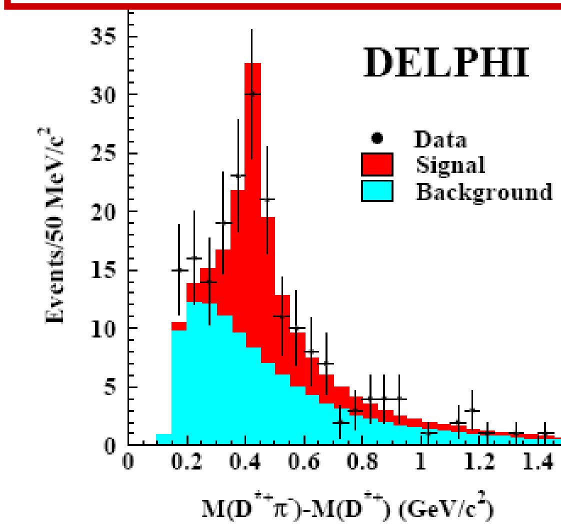
Delphi and CDF only measure higher resonances

$p^* > 0.9$ GeV



$p^* > 1.6$ GeV





M_X