Study of Charmless Inclusive Semileptonic B Decays and Measurement of the CKM Matrix Element $|V_{ub}|$ with the BaBar Detector

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CP violation

Cabibbo- Kobayashi - Maskawa (CKM) matrix:

. CP violation -> third generation of quarks

. Strength of flavour-changing weak decays

. Weak interaction eigenstates related to quark mass eigenstates:

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

.Unitarity constrain

. Several parameterizations with 4 independent parameters:

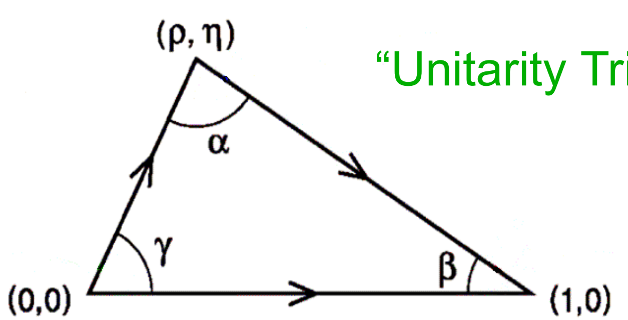
.. 3 angles and 1 phase or 4 variables

.. Wolfenstein shows hierarchy of couplings in terms of power of $\lambda = \sin \theta_c$

$$V \approx \begin{pmatrix} 1 - \lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1 - \lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho - i\eta) & A\lambda^2 & 1 \end{pmatrix} + O(\lambda^4)$$

phase

“Unitarity Triangle”



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

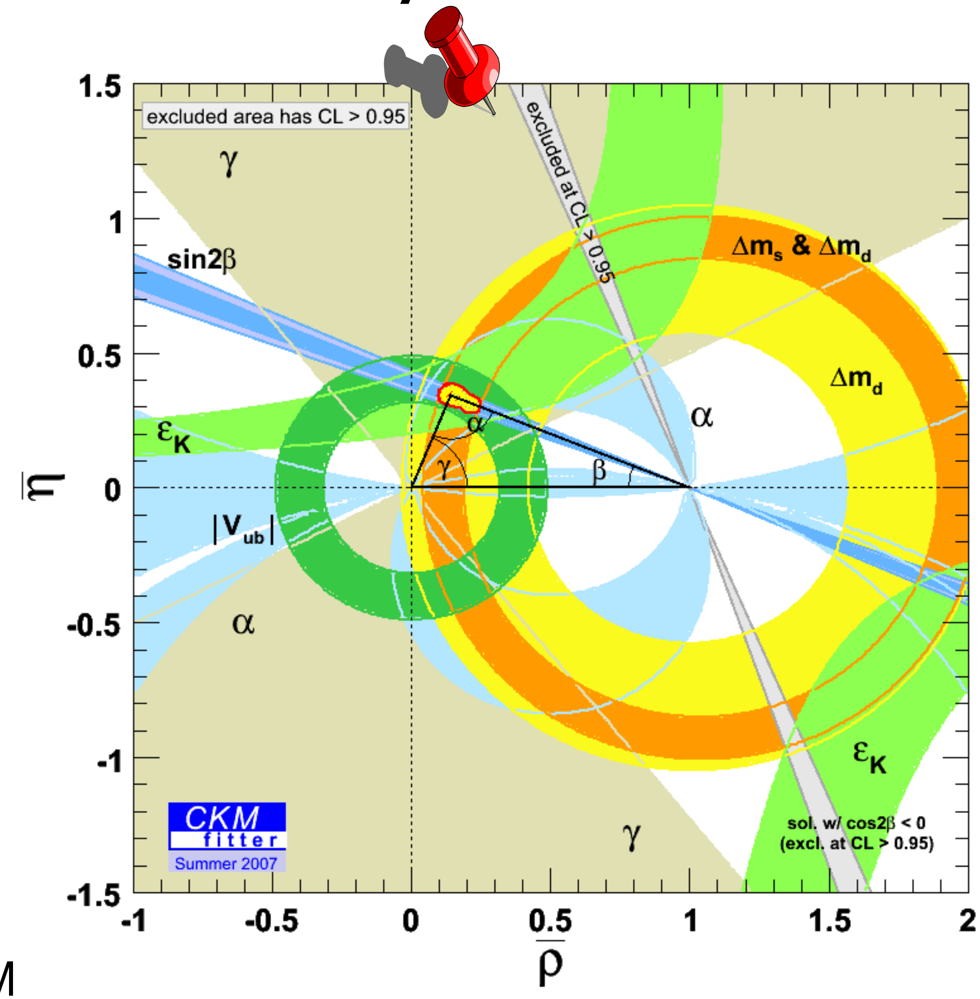
From experiments:[PDG]

- $\lambda = \sin(\theta_{cabibbo}) \approx 0.22$
- $A \approx 0.815$ 2
- $(\rho^2 + \eta^2)^{1/2} \approx 0.4$

UT: in search for New Physics

. if CP symmetry is violated
-> non zero area
as if CP is conserved
-> triangle collapses into a line

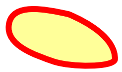
. if unitarity $V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0$
is violated
-> triangle remains open
-> new physics !!



Charge of the B-Factories:
- over-constrain the apex (ρ,η)
  to test the completeness of the CKM
- we need redundancy and precision
  to compare different measurements (sides and angles)

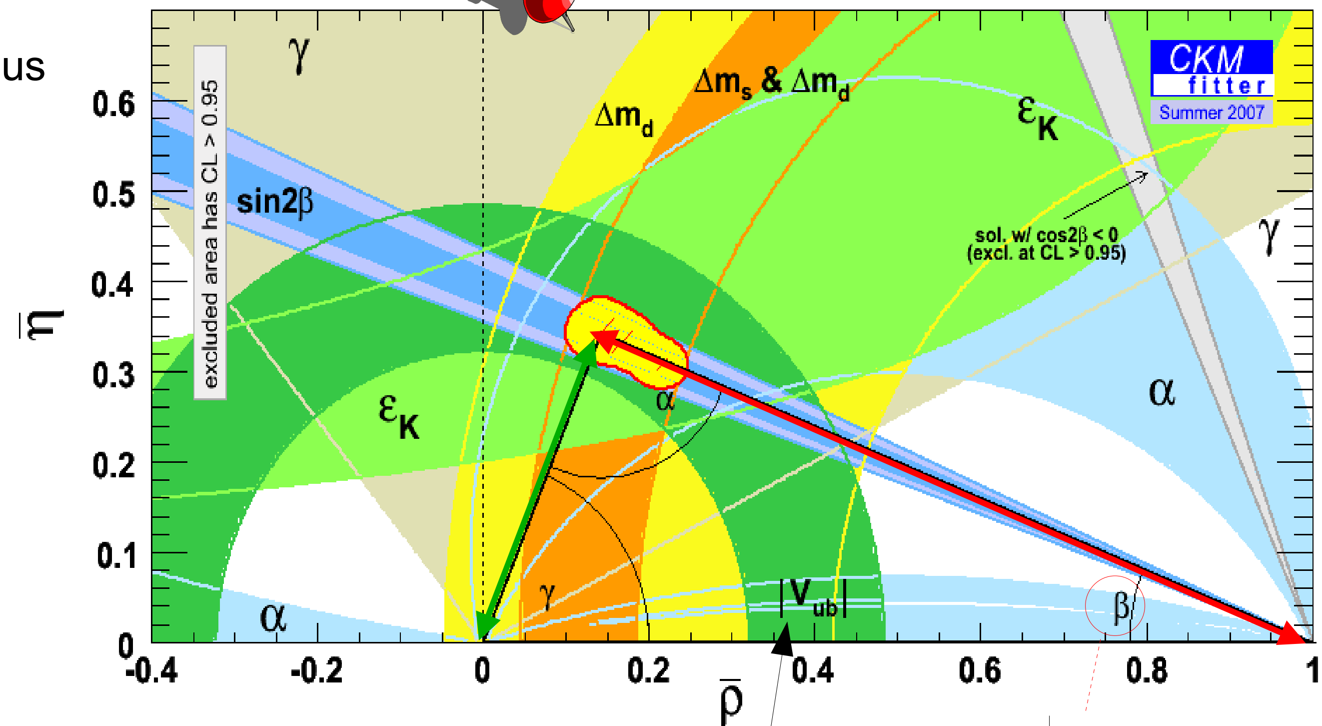
... if the SM is the whole story
-> they must all overlap !

Why study $|V_{ub}|/|V_{cb}|$?

At the scale we are, the  tells us this is true
but
still room for new physics to hide

$|V_{cb}|$, $\sin 2\beta$, $|V_{td}/V_{ts}|$:
"easy" (theo. and exp. both tractable)

$\mathbf{V_{ub}}$, α, γ :
HARD



	$\sin\beta$ (HFAG)
WA	0.680 ± 0.025
% error	3.7%

$|V_{cb}|$ known with a precision of ~ 2%

$|V_{ub}|$ current uncertainty ~ 8%

Uncertainty dominated by errors on $|V_{ub}|$
→ precision is improving (it was 18% in 2004)

→ **GOAL:** Measure $|V_{ub}|$ with **< 5%** precision

reduce
$|V_{ub}|/|V_{cb}|$ band !!

S. Eidelman et al. [Particle Data Group], Phys. Lett. B 592 (2004) 1.
W. M. Yao et al. [Particle Data Group], J. Phys. G 33 (2006) 1.

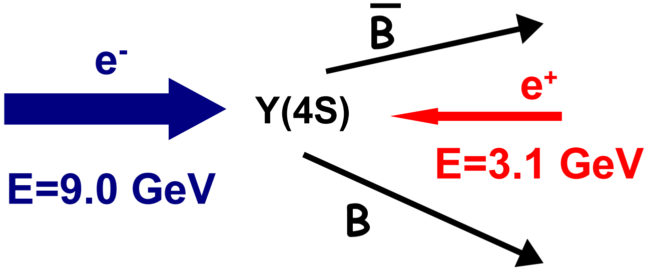
PEP-II B Factory at SLAC

High Luminosity e+ e- asymmetric collider:

- Center-of-mass energy tuned ~ 10.58 GeV

- $\Upsilon(4S)$ is a $b\bar{b}$ bound state, decays to B meson pairs: B^+B^- or $B^0\bar{B}^0$

- Produces ≈ 10 $B\bar{B}$ pairs per second



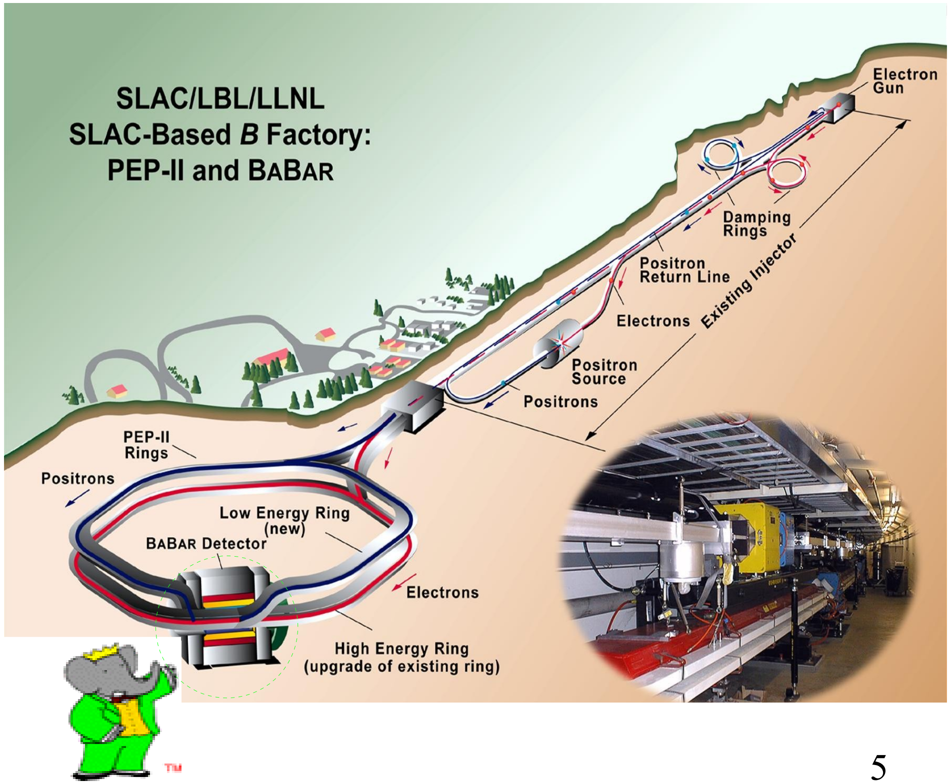
B Factories peculiarities:

- Asymmetry
  $\longrightarrow$ separation of the decays vertices of two B

- Lab frame boost ($\gamma\beta$ = 0.56):
  $\longrightarrow$ reco of decay vertex and time
  $\longrightarrow$ time dependent CP asymmetries

- $\mathcal{BR}(\Upsilon(4S) \to B^+B^-) \sim \mathcal{BR}(\Upsilon(4S) \to B^0\bar{B}^0) \sim 0.5$
  $\longrightarrow$ clear environment
  $\longrightarrow$ high signal-to-bkg ratio, $\sigma_{b\bar{b}} / \sigma_{had} \approx 0.28$

- Absence of fragmentation
  $\longrightarrow$ combinatorial background reduction

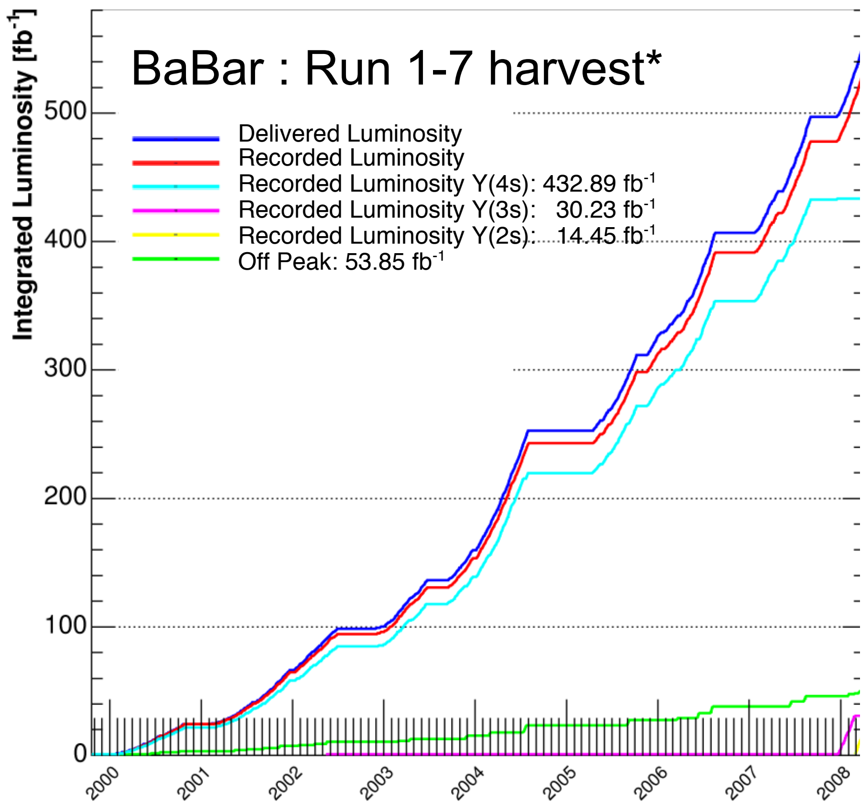


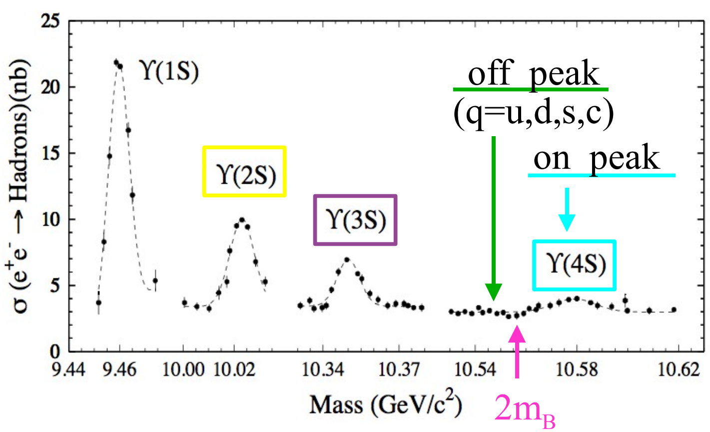
PEP-II performance & BaBar Luminosity

. Peak $\mathcal{L}$ = 1.2x 10^{34} $cm^{-2}s^{-1}$
~ 4 times the design luminosity !
(design: 3.0x10^{33} $cm^{-2}s^{-1}$)

. PEP-II Delivered 553.48 fb^{-1}
BABAR Recorded 531.43 fb^{-1}
> 530 M B$\underline{B}$ pairs Recorded

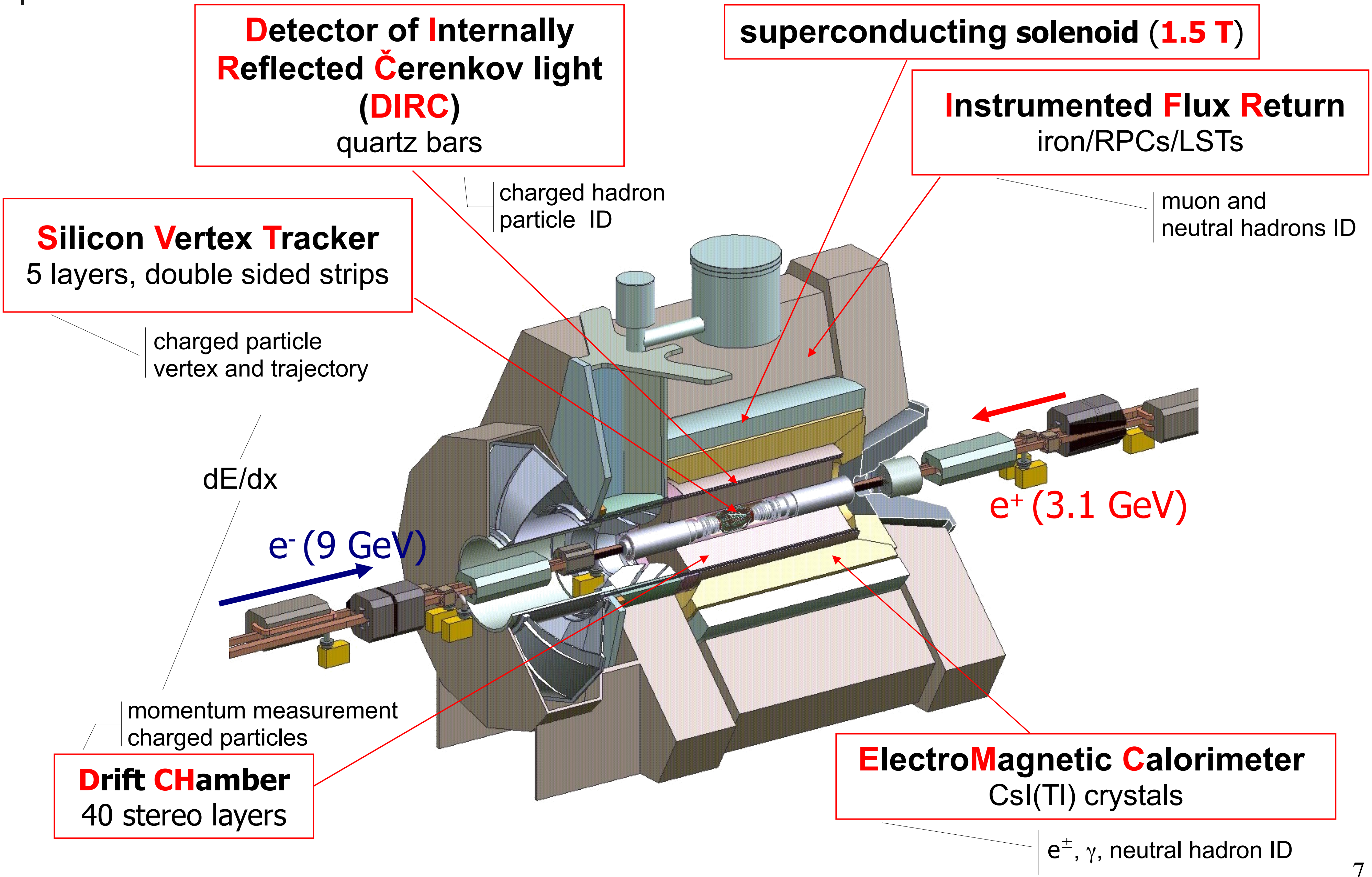
. Achieved Records
0.89 fb-1 in a day (~ 1M B$\underline{B}$ couples)
5.25 fb-1 in a week (~ 5.8 M B$\underline{B}$ couples)





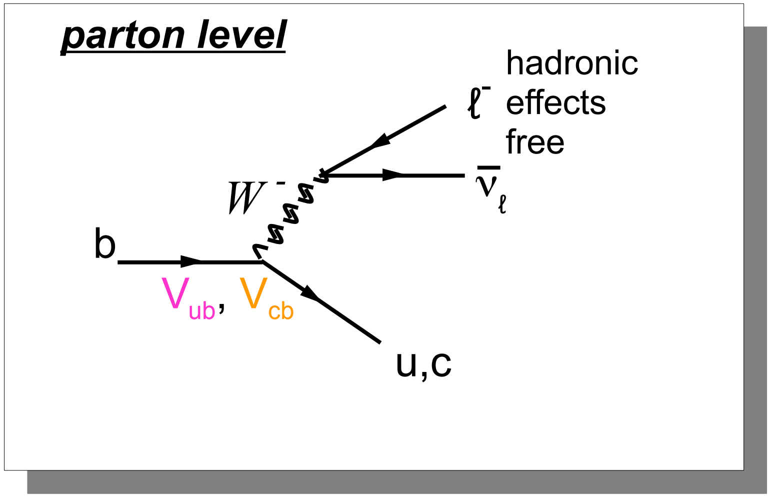
*all the history: Lumi up-to-08/04/11

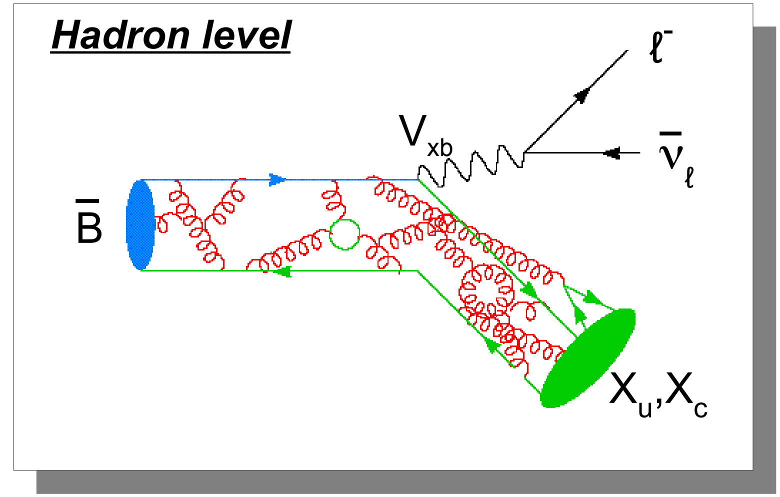
the BaBar detector



Semileptonic B decays

. Tree level semileptonic decays provide an excellent laboratory $\rightarrow$ free of NP contribution





. Theoretically simple at parton level

. leptonic and hadronic currents factor out cleanly, thus one can probe strong interactions in B mesons

.. Explore structure of B meson

.. Allow test of e.g. Lattice QCD

. Rate depends directly on CKM elements $|V_{ub}|$ and $|V_{cb}|$, the quark masses m_b and m_c

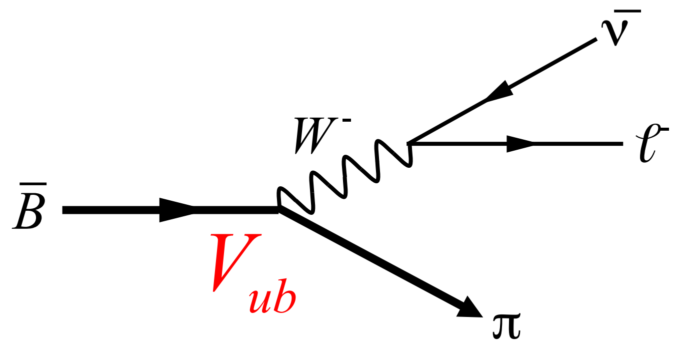
$$\Gamma(b \rightarrow u\ell\nu) = \frac{G_F^2}{192\pi^3} |V_{ub}|^2 m_b^5$$

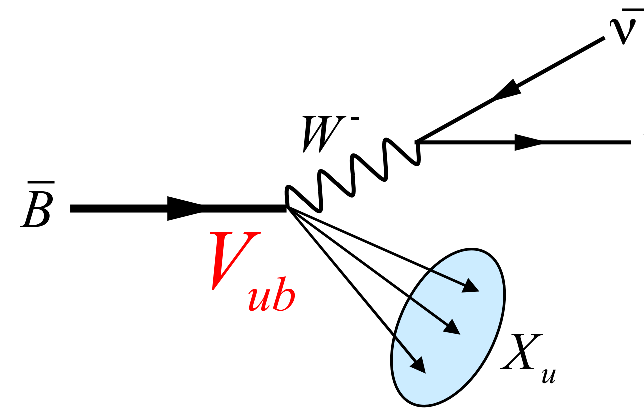
$$\Gamma(b \rightarrow c\ell\nu) = \frac{G_F^2}{192\pi^3} |V_{cb}|^2 m_b^2 (m_b - m_c)^3$$

. Branching fractions are prominent 10.5 % for semi-electronic and semi- muon

Exclusive vs Inclusive measurements

2 possible approaches to the decays





Exclusive Decays

hadronic final states X_u reconstructed

Low signal rate, better bkg reduction and kinematic constraints

Need Form Factor $F(q^2)$ to describe the hadronization process $u \to \pi, \rho, \ldots$

Measurement as function of q^2

Inclusive Decays

select lepton and look at the rest of the event inclusively

Large signal rate, high $b \to c\ell\nu$ bkg

"Easy" to calculate (OPE/HQE)

Need Shape Function (b-quark motion inside B meson) .

Constrain SF param. m_b, μ_π^2 with $b \to s\gamma$ or $b \to c\ell\nu$

Inclusive approach:

- Introduction to theory
- Ingredients

Understanding the inclusive SL decays

. The **O**perator **P**roduct **E**xpansion provides a systematic method of separating

perturbative ($\leftrightarrow$ short distance physics, weak b quark decay) from

non-perturbative scales ($\leftrightarrow$ formation of hadronic final state, b quark binding to valence anti-quark)

. OPE + Heavy Quark symmetry* $\rightarrow$ **H**eavy **Q**uark **E**xpansion

HQE gives the total $B \rightarrow X_u l \nu$ decay rate

known to $O(\alpha_s^2)$

suppressed by $1/m_b^2$

$$\Gamma(B \rightarrow X_u l \nu) = \underbrace{G_F^2 m_b^5/192 \pi^3 |Vub|^2}_{\text{free quark decay}} \underbrace{[1+A_{ew}] A_{pert}}_{\text{perturbative corrections } (\alpha_s(m_b) \text{ dependent})} \underbrace{A_{nonpert}}_{\text{Non-perturbative power corrections } ((1/m_b)^n \text{ dependent})}$$

Dominant error from m_b^5

m_b measured to ± 1% $\rightarrow$ ± 2.5 % on $|V_{ub}|$

* soft gluons cannot probe heavy quark properties

Kinematic Cuts: enhancing Signal/Background

Inclusive decay width cannot be directly measured

$$\frac{\Gamma(b \to u\, l\, \bar{\nu})}{\Gamma(b \to c\, l\, \bar{\nu})} \approx \frac{|V_{ub}|^2}{|V_{cb}|^2} \approx \frac{1}{50}$$

Experiments need to measure partial widths in limited region of phase space

. smaller acceptances

. poor convergence of HQE in region where $B \to X_c \ell \nu$ are kinematically forbidden

. theory uncertainties increase due to more sensitivity to non-perturbative effects

[~ $O(1/m_b)$ instead of $O(1/m_b^2)$]

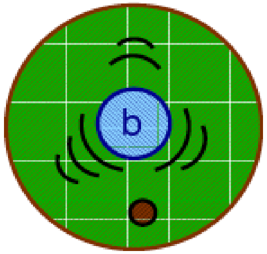
Possible solutions:

Experimental: . maximize acceptance, or

. choose "smart" regions/variables

Theoretical: non-perturbative Shape Function (SF) must be used to calculate partial rates

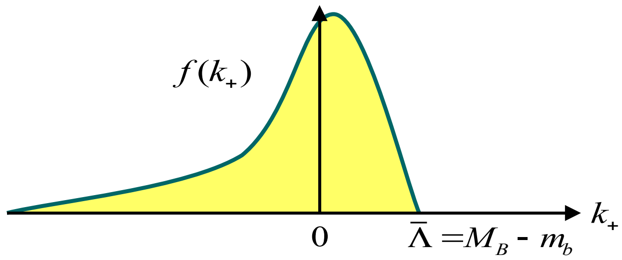
The (in)famous Shape Function



k+: residual momentum of the b quark in the B meson.

Starting point: b quark essentially carries all the momentum of the hadron,
→ decompose $p_b^{\mu} = m_b v^{\mu} + k+^{\mu}$

Development of a function f(k+):
probability of finding a b quark with residual moment k+ inside the B meson



Mannel-Neubert (1994):
structure function centered at k+=0
with a width of order 200-300 MeV

Physical decay distribution : parton level ⊗ Shape Function

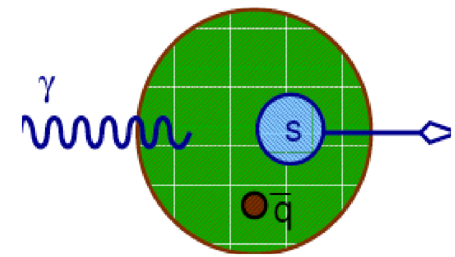
- replacing $m_b^* = m_b + k+$!!

→ <u>smear kinematic spectra</u>

SF:
. describes Fermi motion of *b* quark inside B meson
. is Universal property of a B meson (to Leading Order) but...
... subleading SFs arise at each order in $1/m_b$

Extraction of the Shape Function

SF cannot be computed → must be determined experimentally:

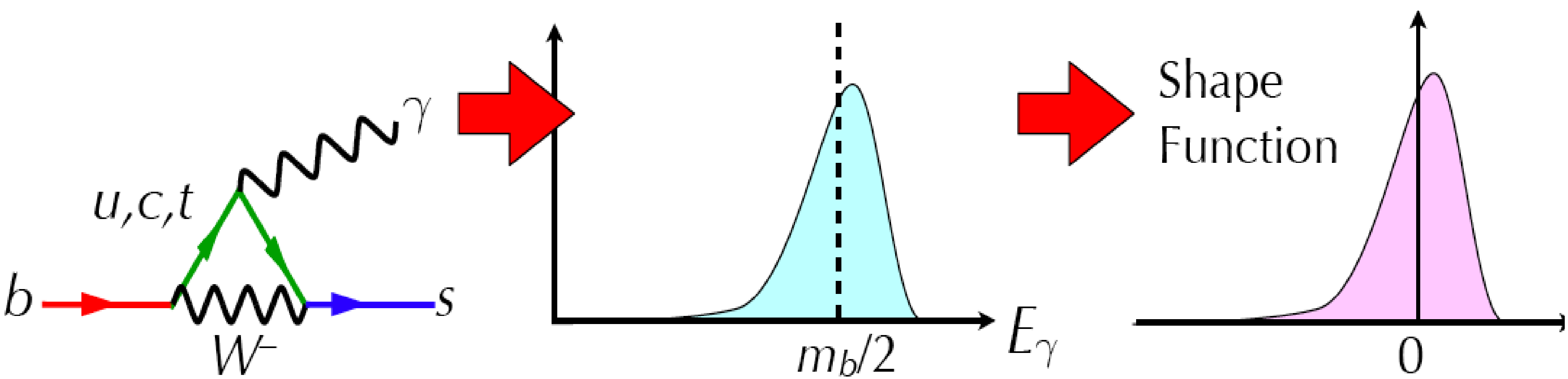


. Directly we can fit the $b \to s\gamma$ spectrum with theory prediction

must assume a functional form of $f(k_+)$

for example:

$$f(k_+) = N(1-x)^a e^{(1+a)x}; \quad x = \frac{k_+}{\bar{\Lambda}}$$



Measurement limited by statistics and background

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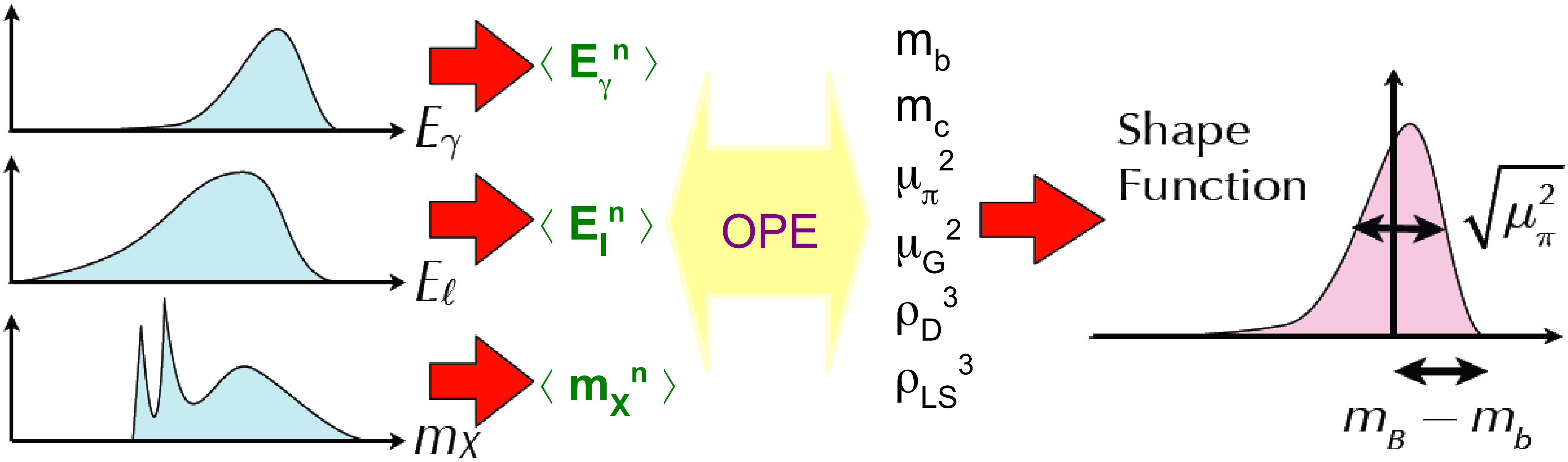
Extraction of the Shape Function

Two ways to determine the Shape Function from data:

. <u>Indirectly</u> from fitting the $B \to X_c l \nu$ and $B \to X_s \gamma$ decays
OPE predicts observables integrated over large phase space as functions of m_b, m_c, and non-perturbative parameters



Global fit can determine the OPE parameters, which constrain the Shape Function

Inclusive $B \to X_c l \nu$

Full reco B-tag & inclusively the second B

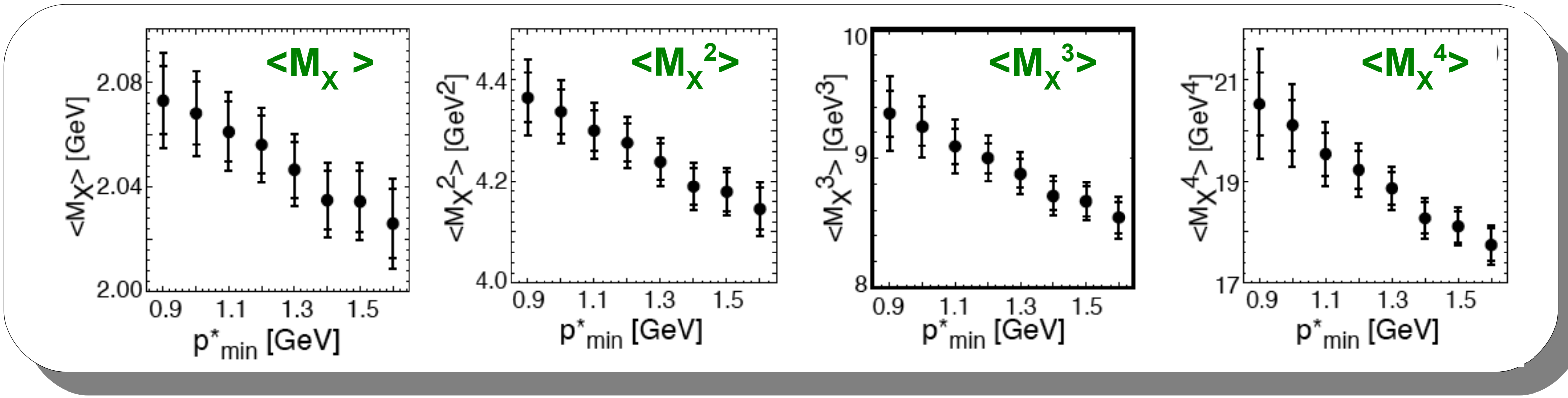
Observables: E_l (lepton energy) and m_X (hadron mass)

biases correction:
. BaBar: calibration curves
. Belle: unfolding

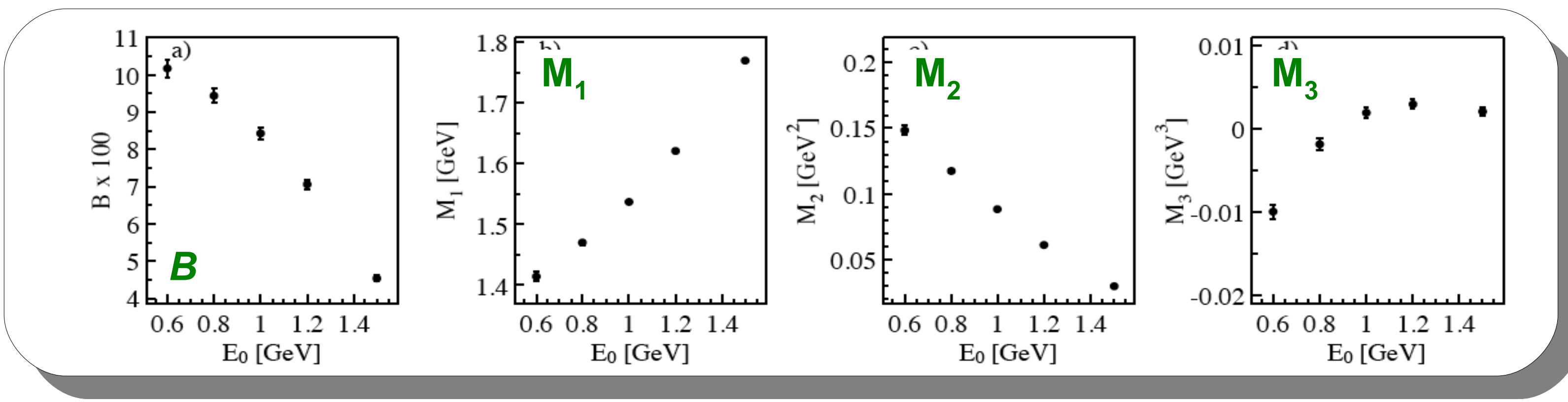
	$\langle E_l^{\,n} \rangle$	n	$\langle m_x^{\,n} \rangle$	n
BABAR	PRD 69:111104, 47 fb^{-1}	0, 1, 2, 3	PRD 69:111103, 81 fb^{-1}	1, 2, 3, 4
Belle Prelim.	hep-ex/0610012, 140 fb^{-1}	0, 1, 2, 3, 4	hep-ex/0611044, 140 fb^{-1}	2, 4

Measure moments as functions of minimum-E_l cut

BABAR
PRD 69:111103



BABAR
PRD 69:111104



Global OPE fit

BABAR PRD69:111103 PRD69:111104
PRD72:052004 hep-ex/0507001
Belle PRL93:061803 hep-ex/0508005
CLEO PRD70:031002 PRL87:251807
CDF PRD71:051103
DELPHI EPJC45:35

Buchmüller & Flächer (**PRD73:073008**)
fit data from 10 measurements with an OPE calculation
by Gambino & Uraltsev (**EPJC34:181**)

kinetic, chromomagnetic: $O(1/m_b^2)$

- Fit parameters: $|V_{cb}|$, m_b, m_c, $\mathcal{B}(B \to X_c l \nu)$, μ_π^2, μ_G^2, ρ_D^3, ρ_{LS}^3,

spin-orbit, Darwin: $O(1/m_b^3)$

V_{cb} = ($41.96 \pm 0.23_{exp} \pm 0.35_{OPE} \pm 0.59_{\Gamma sl}$) x 10^{-3}

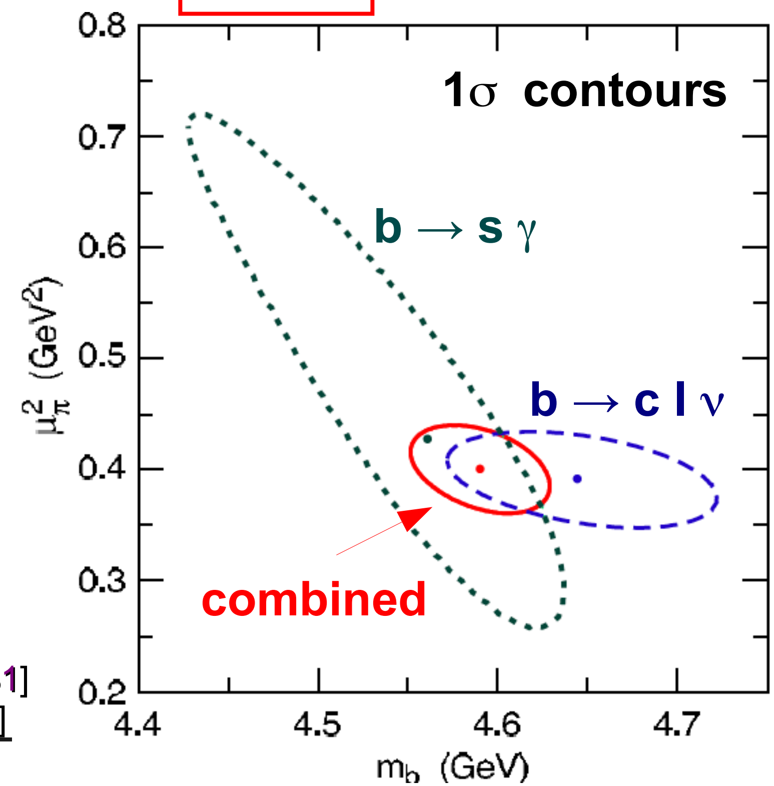
$m_b = 4.590 \pm 0.025_{exp} \pm 0.030_{OPE}$ GeV

$m_c = 1.142 \pm 0.037_{exp} \pm 0.045_{OPE}$ GeV

$\mu_\pi^2 = 0.401 \pm 0.019_{exp} \pm 0.035_{OPE}$ GeV^2

Needed for V_{ub}

- $|V_{cb}|$ error ±2%, m_b error ±1%
- Consistency between $X_c l \nu$ and $X_s\gamma$ add confidence to the theory



Different mass schemes available
. Kinetic [Gambino & Uraltsev, Phys J C34, 181]
. 1S [Bauer *et al.*, Phys Rev D70, 094017]

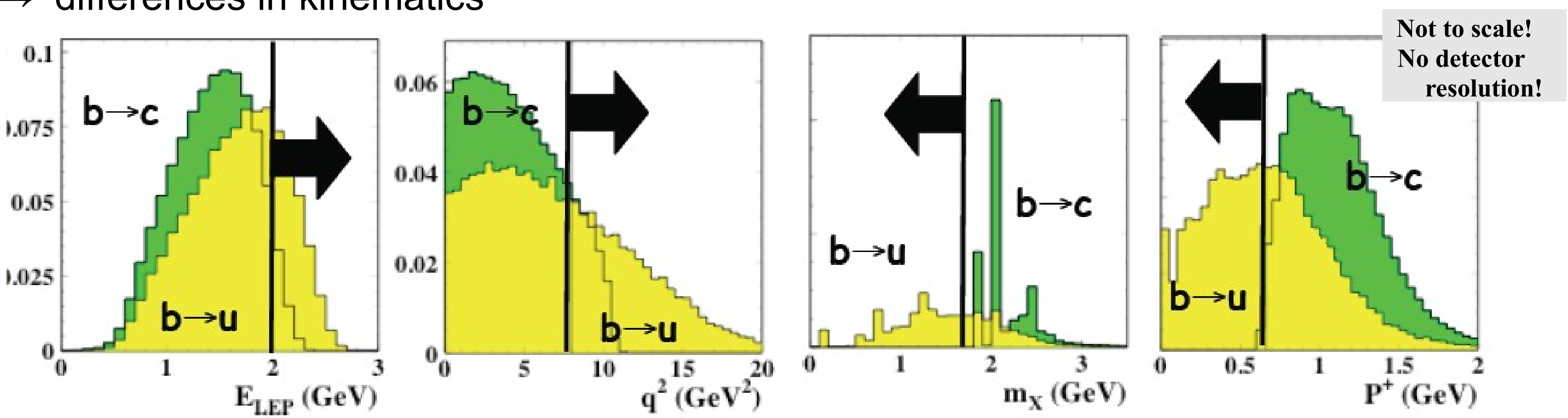
Inclusive approach:

- Experimental path
- base camp: partial Branching Fraction
- first peak: $|V_{ub}|$ BaBar results
- second top: $|V_{ub}|$ World Average

Inclusive b →u l ν : how to measure it ?

Need to suppress the dominant b → c l ν background $\Gamma(b \to c\, l\, \nu) \sim 50\, \Gamma(b \to u\, l\, \nu)$

$m_u << m_c$ → differences in kinematics



E_{LEP} = lepton energy

q^2 = momentum transfer squared = $(p_B - p_X)^2 = (p_l + p_n)^2$

m_X = mass of the hadronic system

$P^+ = E_X - |p_X|$ = light-cone component of X momentum

. Particle Identification and reconstruction

. Apply selection cuts

. Measure partial Branching Fraction $\Delta\mathcal{B}(B \to X_u l\nu)$ in a region where ...

. the signal/background is good, and

. the partial rate $\Delta\Gamma_u$ is reliably calculable

Large $\Delta\Gamma_u$ generally good, but not always

. To reduce systematic uncert., we measure first a ratio of partial BF

. get space acceptance $\zeta(\Delta\Phi)$ from theory

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})}{\tau_b \cdot \zeta(\Delta\Phi)}}$$

Effects of cuts for Theory

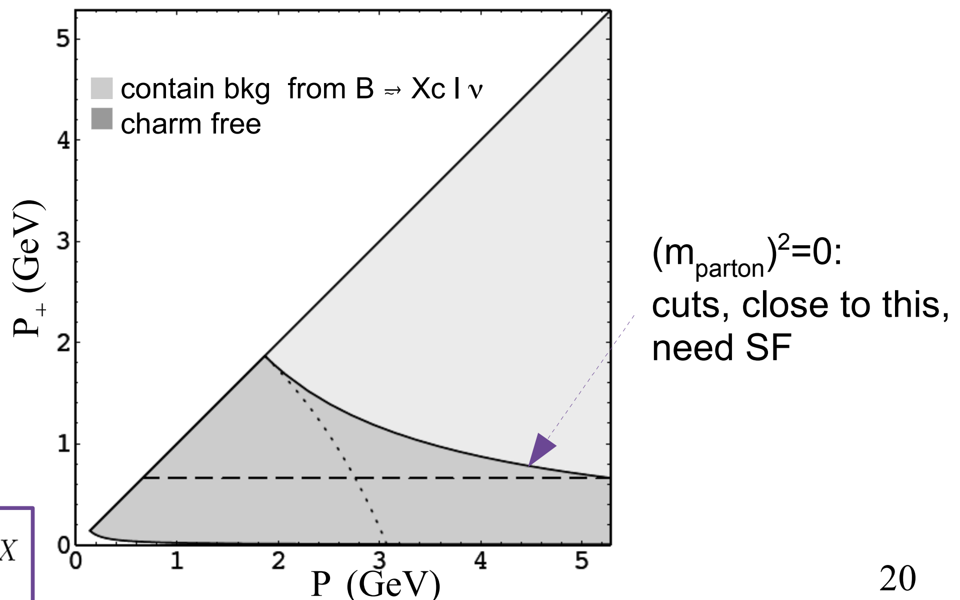
Typical cuts to reject charm:

. Cut on the lepton energy $E_l > (m_B^2 - m_D^2) / 2m_B$
. Cut on the hadronic invariant mass $m_X < m_D$ [—]
. Cut on the dilepton invariant mass $q^2 > (m_B - m_D)^2$ [······]
. Combined lepton-hadronic invariant mass cut
. Cut on light cone component of hadronic momentum $P_+ < m_D^2 / m_B$ [- - - -]

They can be visualized in the phase space diagram

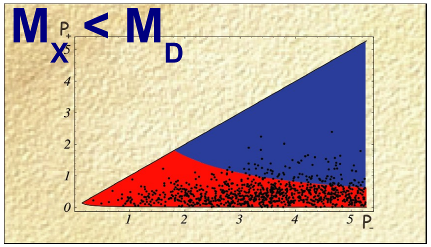
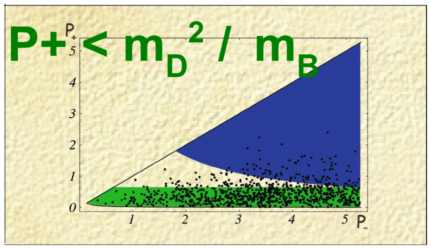
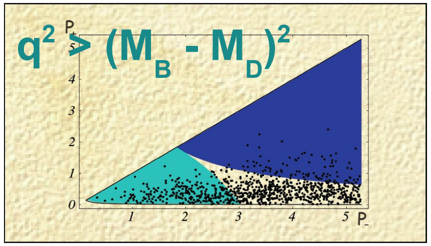
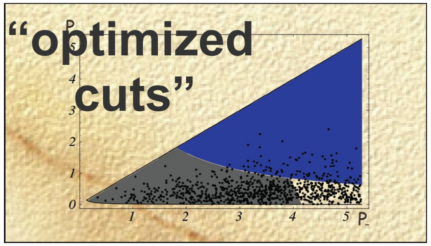
. Some cuts include the "shape function region", others don't
. Cuts including shape function region need information beyond OPE

$$P_- = \bar{n} \cdot P_X = E_X + |\vec{P}_X|$$
$$P_+ = n \cdot P_X = E_X - |\vec{P}_X|$$

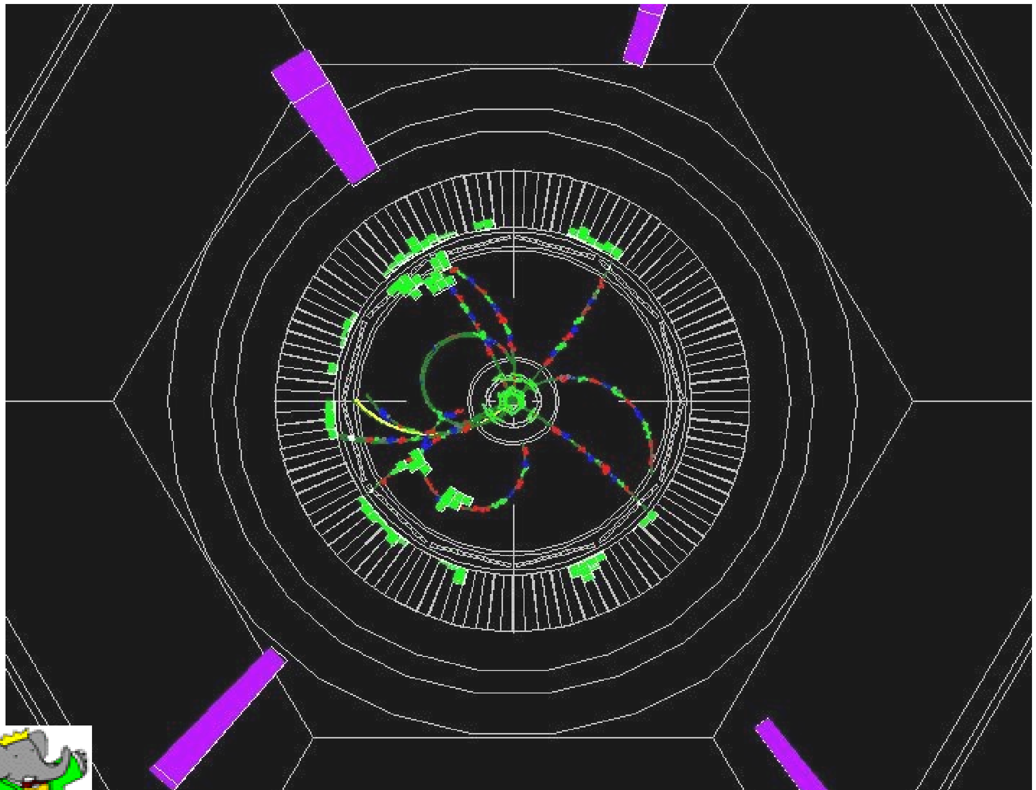


Problems and Triumphs

$m_u << m_c$

Cut	% of rate	Good	Bad
	~ 80 %	lots of rate	depends on f(k+) (and subleading)
	~ 70 %	- still lost of rate - relation to radiative decays simplest	depends on f(k+) (and subleading)
	~ 30 %	insensitive to f(k+)	- very sensitive to m_b - WA corrections may be substantial - effective expansion parameters is Λ_{QCD}/m_c
	~ 45 %	insensitive to f(k+)	- still "only" 45% of rate - less rate than M_X cut, & more complicate to meas.

Particle Selection



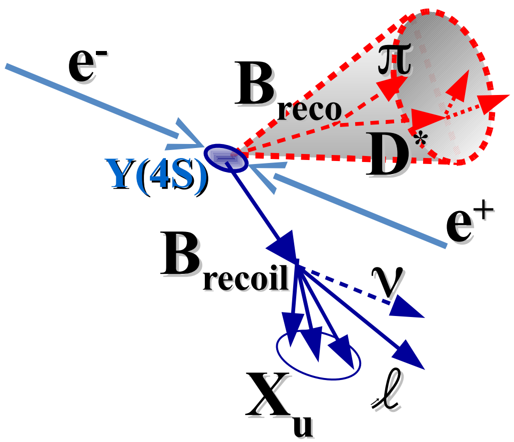
Charged particles selection

Select tracks with	Cut
Distance in x-y plane	$\lvert d_{x\text{-}y}\rvert <$ 1.5 cm
Distance in z axis	$\lvert d_z\rvert <$ 5 cm
Geom. acceptance	$0.410 < \theta_{lab} < 2.54$ cm
Max momentum	$p_{lab} < 10$ GeV/c
Min momentum	$p_{\perp,lab} > 0.06$ GeV/c
Minimum number of DCH hits	$N_{DCH} > 0$ if $p_t > 0.2$ GeV

Neutral particles selection

Select clusters with	Cut
Number of crystals	$N_c > 2$
Cluter Energy	$E_{clus} > 50$ MeV
Lateral moment	$LAT < 0.6$
Geometrical acceptance	$0.32 < \theta_{clus} < 2.44$

Recoil Analysis technique



B_{reco}

- Full reconstruction of tag B:

$B \rightarrow D^{(*)} Y$

D: charm meson (D^0, D^+,D^{*0},D^{*+})

Y: hadrons collection of charge $\pm$ 1

($n_1\ \pi^{\pm} + n_2\ K^{\pm} + n_3\ K_S^{\ 0} + n_4\ \pi^0$)

- Kinematic consistency is checked:

. beam energy-substituted mass:

$$m_{ES} = \sqrt{s/4 - \tilde{p}_B}$$

. energy difference:

$$\Delta E = E_B - \sqrt{s}/2 = 0$$

B_{recoil}

- SemiLeptonic selection:

. presence of charged lepton: $P_l > 1$ GeV

. system X reconstructed using charged tracks and photons

. neutrino momentum inferred $P_{miss} = P_{Y} - P_{Breco} - P_l - P_X$

- Signal selection:

. require 1 charged lepton: $P_l > 1$ GeV

. Charge Conservation: $Q_{tot} = 0$

. Charge Correlation: $Q_l\ Q_{reco} < 0$ (correct for B^0 mixing)

. Missing Mass Squared: $M_{miss}^{\ 2} < 0.5$ GeV ^{2}

. veto on $K^{\pm}$ or K_S to perform the measurement

(Enriched signal region)

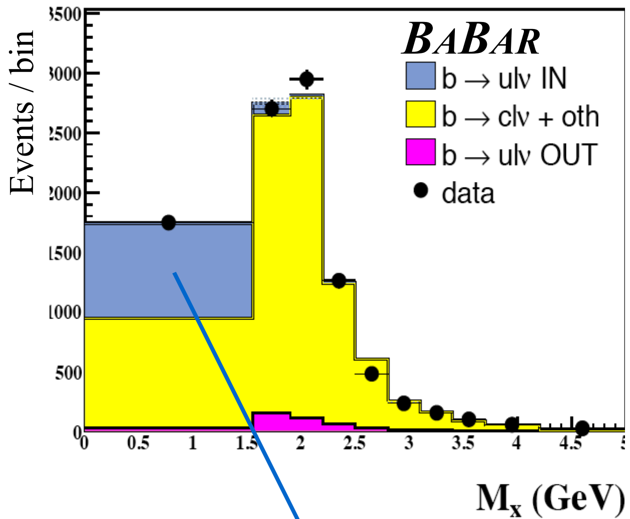
allow one o more K in the event control sample

(Depleted signal region)

. Explicitely veto $B^0 \rightarrow D^*$ l n events

using partial reconstruction technique

Background subtraction



. kinematic variable divided into bins

. get number of events for each bin performing a maximum likelihood fit to the m_{ES} distribution

.. Continuum and combinatoric $B\underline{B}$ background subtracted with [16]

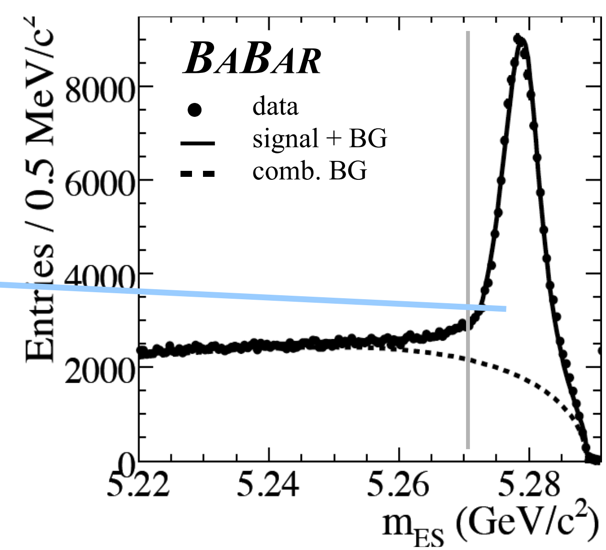
.. Signal distribution described by [17] **NEW**

. binned χ^2 fit to data (with MC normalization free to float) to subtract b →c background

N_{signal}

$$\Delta R_{u/sl} = \frac{\Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})}{\mathcal{B}(\bar{B} \to X \ell \bar{\nu})}$$

$N_{SL} - BG_{SL}$



note: Normalise to SL events to be independent of tagging efficiency

[16] [ARGUS Collaboration] H. Albrecht et al., Phys. Lett. B 318, 397 (1993).
[17] [BABAR Collaboration] B. Aubert et al., Phys. Rev. D 74, 091105 (2006).

Overview fit method

signal events that migrate
from OUTside the kinematic region
into the signal region,
kinematic included
. mES fit in bins of kinematical variable

signal events fitted IN the sample
after all cuts, kinematic included
. mES fit in bins of kinematical variable

bkg events after all cuts other than signal,
kinematic included
. mES fit in bins of kinematical variable
. shape from b->clν simulation
. normalization floating
in a χ^2 fit to kinematic distribution

$$\Delta R_{u/sl} = \frac{\Delta\mathcal{B}(\bar{B} \to X_u l \bar{\nu})}{\mathcal{B}(\bar{B} \to X l \bar{\nu})} = \frac{(N_u - N_u^{out} - BG_u) / (\varepsilon_{sel}^{u}\,\varepsilon_{kin}^{u})}{(N_{sl} - BG_{sl})} \times \frac{\varepsilon_l^{sl}\,\varepsilon_t^{sl}}{\varepsilon_l^{u}\,\varepsilon_t^{u}}$$

number of semileptonic events
. mES fit
. lepton ID

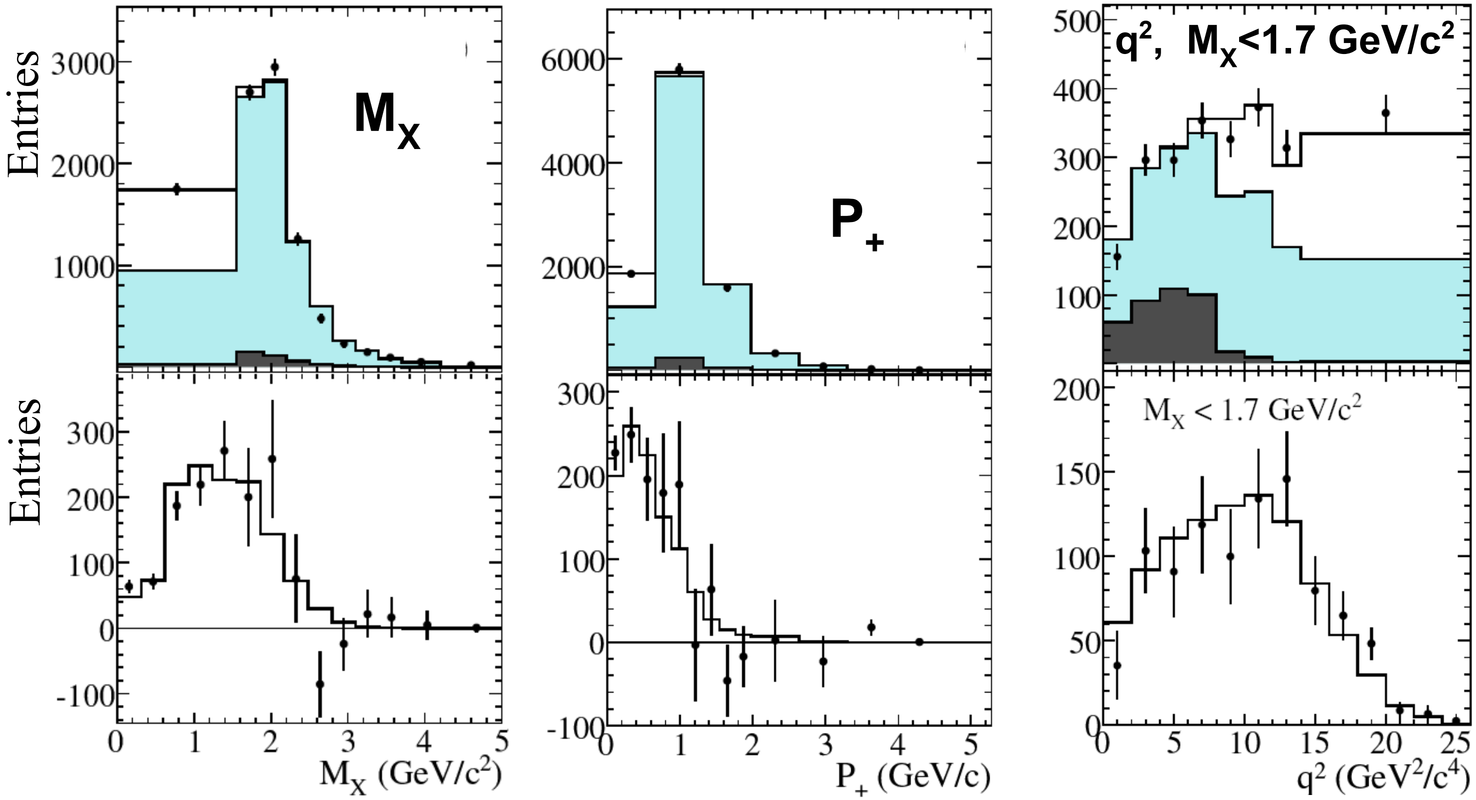
Signal efficiency
. sel: taken from b->ulν simulation (DFN)
. kin: depends on theoretical model

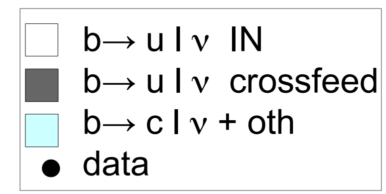
Efficiency for semileptonic and
B reconstruction ~ 1
. lepton ID

L_{data}: ~ 348 fb^{-1}
$L_{generic\ MC}$: ~1.1 ab^{-1}
$L_{Signal\ MC}$: ~ 3.7 ab^{-1}

Partial Branching Fraction results

PRL 100, 171802 (2008)





note:
Measured Distributions, not efficiency corrected

BABAR

kinematic region	N_u	N_{SL}	$\varepsilon^u_{sel}\varepsilon^u_{kin}$	$\varepsilon^u_l\varepsilon^u_t/\varepsilon^{sl}_t\varepsilon^{sl}_l$	$\Delta B(B\to X_u l\nu)$ 10^{-3} stat syst th
m_X < 1.55 GeV/c^2	803 ± 60	181074 ± 706	0.331 ± 0.003	0.76 ± 0.02	1.18 ± 0.09 ± 0.07 ± 0.01
P_+ < 0.66 GeV/c	633 ± 63	181074 ± 706	0.344 ± 0.003	0.81 ± 0.02	0.95 ± 0.10 ± 0.08 ± 0.01
m_X < 1.7 GeV/c^2 q^2 > 8.0 GeV^2/c^4	562 ± 55	181074 ± 706	0.353 ± 0.005	0.79 ± 0.03	0.81 ± 0.08 ± 0.07 ± 0.02

Systematic uncertainties

Method	Detector	m_{ES} fit	Monte Carlo	Shape function	$B(\bar{B} \to X u \ell \bar{\nu})$ $Xu = \pi, \rho, ..$	Gluon splitting	$B(\bar{B} \to X c \ell \bar{\nu})$	$B \to D^* l^- \bar{\nu}$ form factors	B(D)	**Total**
$\mathbf{M_X}$	1.92	3.71	3.22	0.90	2.08	1.62	0.87	0.21	0.44	**6.07**
$\mathbf{P_+}$	3.88	3.98	4.62	1.31	2.22	1.47	2.80	0.39	0.73	**8.38**
$\mathbf{M_X, q^2}$	3.83	5.17	4.29	2.43	2.71	1.02	1.17	0.55	0.79	**8.81**

Dominant systematic errors:

. MC statistic (4.0%)

. detector effects (3.2%) are understood and not yet dominating.

. selection often involves complex fitting technique (mES) (4.3%)
.. more data improves fit convergence
.. more data will mean more detail to account for (e.g. background studies and new PDFs)

. dominant systematics are in the modeling of signal and background contributions
.. b → u l n (resonances, non-resonance contributions)
.. b → c l n (D, D*, D**)
.. continuum

Getting $|V_{ub}|$ from the partial rate

Take the recent theory calculations and convert the partial rates into $|V_{ub}|$:

$$|V_{ub}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{B} \to X_u \ell \bar{\nu})}{\tau_b \cdot \zeta(\Delta\Phi)}}$$

OPE gives good results for full phase space but breaks down in the "SF region"(low M_X and low q^2)

↓

various approach to solve the problem

$\zeta(\Delta\Phi)$: theoretical acceptance, computed by using different theoretical frameworks
$\Delta\Phi$: global fit* (m_b^{SF},$\mu_\pi^{2\ SF}$) param
m_b = (4.59 +- 0.04) GeV/c^2
μ_π^2= (0.40 +- 0.04) GeV^2/c^2
kinetic scheme

. **DFN** (De Fazio, Neubert) → **HQE with ad-hoc inclusion of SF**
JHEP9906:017(1999)

. **BLNP** (Bosch, Lange, Neubert, Paz) → **HQE with systematic incorporation of SF**
PRD72:073006(2005)

. **BLL** (Bauer, Ligeti, Luke) → **HQE for m_X< m_D and q^2>8 ('non SF region') to minimize SF effect**
PRD64:113004(2001)

(BLNP, BLL: Predicted rate)

. **DGE** (Anderson,Gardi) → **use "Dressed Gluon Exponentiation" to convert on-shell b quark calculation into meson decay spectra**
JHEP0601:097(2006)

NEW

*** Buchmüller & Flächer : PRD73:073008**

L_{data}: ~ 348 fb^{-1}
383 M $B\bar{B}$ pairs

results of $|V_{ub}|$

PRL 100, 171802 (2008)

Kinematic region	$\Delta\mathcal{B}(B\to X_u l \nu)$ Δ (stat. sys. th.)	$\lvert V_{ub}\rvert$ (10^{-3}) Δ (stat. sys. th.)	Theory
M_X < 1.55 GeV/c^2	1.18 ± 0.09 ± 0.07 ± 0.01	4.27 ± 0.16 ± 0.13 ± 0.30 4.56 ± 0.17 ± 0.14 ± 0.32	BLNP DGE
P_+< 0.66 GeV/c^2	0.95 ± 0.10 ± 0.08 ± 0.01	3.88 ± 0.19 ± 0.16 ± 0.28 3.99 ± 0.20 ± 0.16 ± 0.24	BLNP DGE
M_X < 1.7 GeV/c^2 & q^2 >8.0 GeV^2/c^2	0.81 ± 0.08 ± 0.07 ± 0.02	4.57 ± 0.22 ± 0.19 ± 0.30 4.64 ± 0.23 ± 0.19 ± 0.25 4.93 ± 0.24 ± 0.20 ± 0.36	BLNP DGE BLL

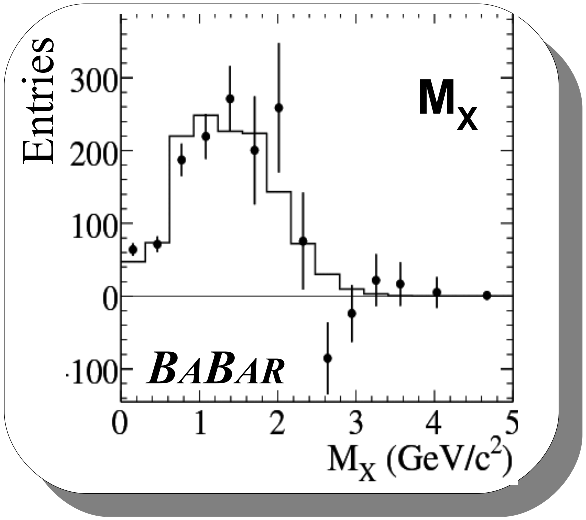
1 Data Set and
3 overlapping phase space

7 values for $|V_{ub}|$!

All errors correlated!
Stat: 3.8%
Syst: 3.0%
Theory: 7 % (SF errors dominate, mb)

in BLNP framework, experimental correlation
. agreement at 1 σ level for the M_X and combined (M_X,q^2)
. P_+ differs from the two others at a 2.5 σ level.

The M_X analysis
. largest portion of phase space
. most precise determination of $|V_{ub}|$



BLNP and DGE frameworks give consistent results, within the theoretical uncertainty

Virginia Azzolini

Current Inclusive $|V_{ub}|$ Measurements

HFAG results are rescaled to common HQE inputs:
$m_b(SF) = 4.707^{+0.059}_{-0.053}$ GeV
$\mu_\pi^2 = 0.216^{+0.054}_{-0.076}$ GeV^2

BLNP - HFAG

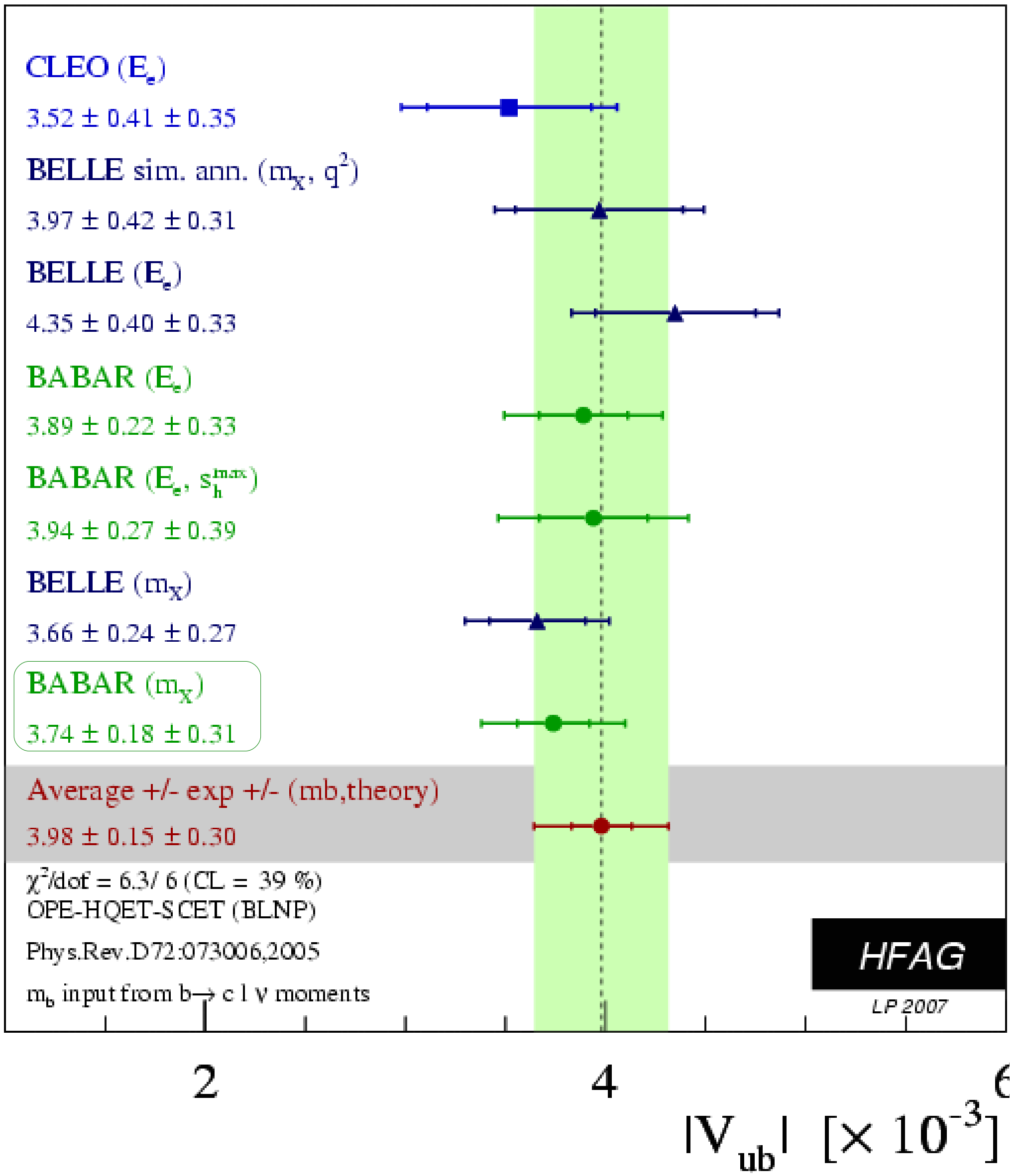
$|V_{ub}| = (3.98 \pm 0.15_{exp} \pm 0.30_{mb+theory}) \times 10^{-3}$

Total Error: 8.3 % total

$\pm 2.0_{stat}$ $\pm 2.5_{exp}$
$\pm 1.8_{bc\ model}$ $\pm 1.1_{bu\ model}$ } Exp. 3.9%

$\pm 6.3_{HQE\ param}$ $\pm 0.4_{SF\ form}$
$\pm 0.7_{sub\ SF}$ $\pm 3.6_{matching}$ $\pm 1.4_{WA}$ } Theory 8.1%

BNLP + only b→ c l ν moments



Use only the partial B from m_X for the Breco analyses as experimental correlation among the variables are not published

CKM consistency

. Indirect determination from CKM fit vs directly measured values.

.. $|V_{ub}|$ from exclusive decays = $(3.33\pm0.21^{+0.58}_{-0.38})\times10^{-3}$

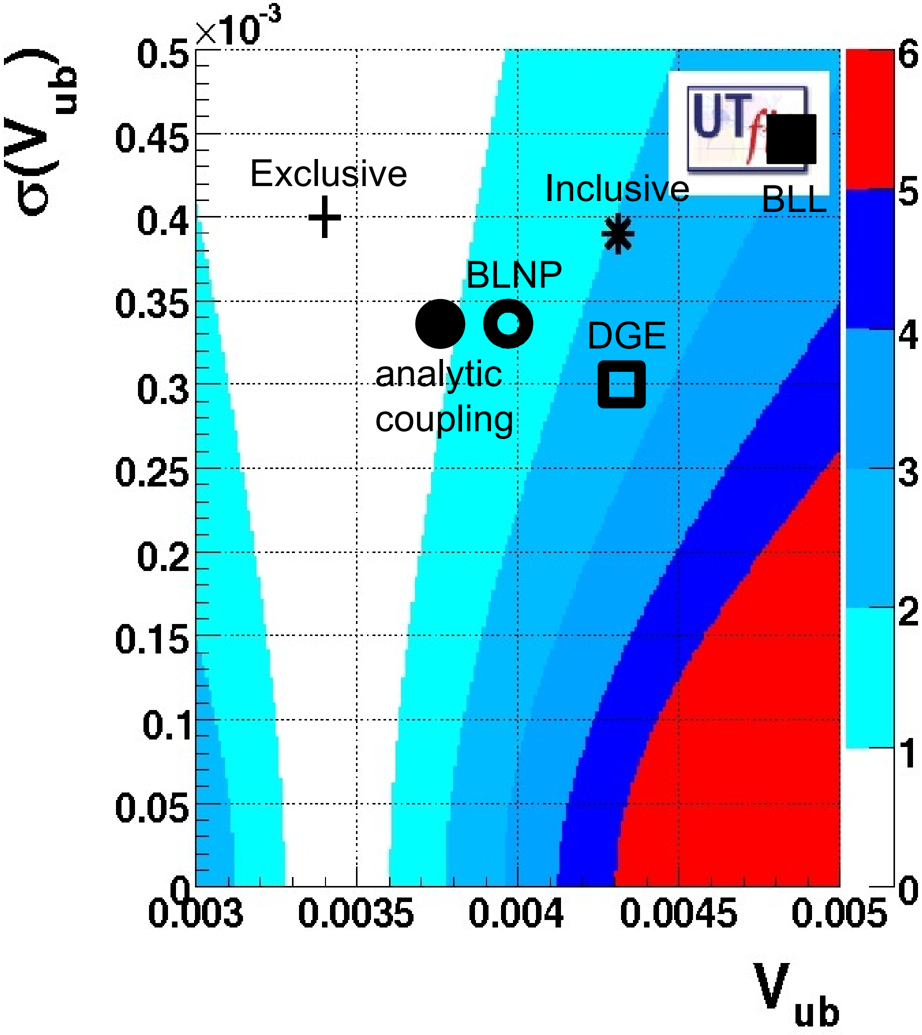
.. Consistent with global UT fit $(3.44\pm0.16)\times10^{-3}$ [UT_{fit}]

.. $|V_{ub}|$ from inclusive decays = $(3.98\pm0.15\pm0.30)\times10^{-3}$

. lots of work in the inclusive decays to improve current calculations of $|V_{ub}|$

. "Tension" with exclusive decays:
gone? still there?
new physics? or something wrong?

unlikely NP:
.. statistical fluctuation
.. pbl with theoretical calculation and/or estimation of the uncertainties



→ Still work on the experimental and theoretical side needed to understand current results

Future experiments

. Future *B* physics program will pursue New Physics through CP violation and rare decays

e.g $b \to sss$, $b \to s\gamma$, $b \to s\ell^+\ell^-$, $B \to \tau\nu$, $B \to D\tau\nu$, $B_s \to \mu^+\mu^-$

$|V_{ub}/V_{cb}|$ provides a crucial New Physics-free constraint

. Will they improve $|V_{ub}|$ to << 5% ?

Super *B* factory can produce high-statistics, high purity, hadronic tag sample to measure $b \to u\ell\nu$

LHCb's primary strength lies in *B* physics

Observable	B Factories(2 ab^{-1})	SuperB(75 ab^{-1})
$|V_{ub}|$ (exclusive)	8%	3.0%
$|V_{ub}|$ (inclusive)	8%	2.0%

BUT the real challenge lies in theory

precision data can inspire and validate theoretical advances

(Lattice QCD holds the key for exclusive measurements)

→ would be nice to see inclusive and exclusive $|V_{ub}|$ converge!

Conclusions

Great effort on experimental and theoretical side over the past few years

. Many different methods on how to suppress the background

. Many different theoretical calculation

Reduced uncertainty thanks to more precise measurements of Heavy Quark parameters

. m_b uncertainty reduced

. Uncertainty on $|V_{ub}|$ due to HQ Parameters from 8% → ~4% -6%

We have measured the partial branching fractions for $B \to X_u \ell \nu$ decays in three overlapping regions of phase space.

We elect M_X analysis for its

. largest portion of phase space

. most precise determination of |Vub|

. overall theoretical precision agreement

$|V_{ub}|$: 8% Total Uncertainty (exp + theo)..... soon better?

Statistics alone will not be enough but it will help

. Exp: improved with higher statistics and reduced systematics.

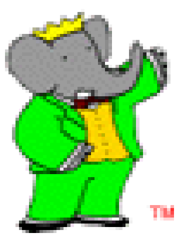
.Theor: need work on SF parameters, WA constraint, $b \to c\ell\nu$ and $b \to u\ell\nu$ modelling

New work to do ... more enthusiasm!

Universitat de València

CSIC

Study of Charmless Inclusive Semileptonic B Decays and Measurement of the CKM Matrix Element $|V_{ub}|$ with the BaBar Detector



Virginia Azzolini

thank you

BACKUP

Gambino,Giordano,Ossola,Uraltsev

Inclusive determination: limitations of the OPE

All theoretical information is encoded in the triple differential width

$$\frac{d^3\Gamma}{dq^2\, dq_0\, dE_\ell} = \frac{G_F^2|V_{ub}|^2}{8\pi^3}\left\{q^2W_1 - \left[2E_\ell^2 - 2q_0E_\ell + \frac{q^2}{2}\right]W_2 + q^2(2E_\ell - q_0)W_3\right\}$$

Structure functions *W1-3* receive both perturb. and non-perturb. (power suppressed) correct.

$$|V_{ub}| = \sqrt{\frac{\Gamma^{exp}_{cuts}}{\frac{1}{|V_{ub}|^2}\int_{cuts}\frac{d^3\Gamma_{th}}{dq_0\, dq^2\, dE_\ell}}}$$

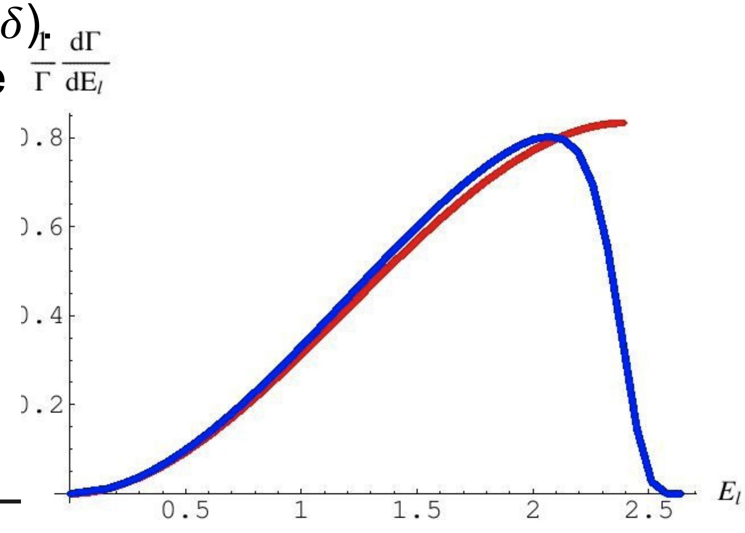
Experiment

Theory

Inclusive decays potentially most accurate way to determine |Vub|, through a measurement of the decay rate:

limitations of the OPE:

- The local OPE describes the partonic decay $b \to u\, \ell\, \nu$. There is a kinematical region of the hadronic decay that cannot be populated by the free quark decay.
- 1/mb corrections to the OPE lead to increasingly singular contributions to the triple differential width (higher derivatives of the Dirac δ). Predictions need to be"smeared" over sufficiently large regions of the phase space.
- Near the threshold nonlocal effects become important: leading terms of the OPE must be resummed into a universal distribution function, that describes the motion of the heavy quark inside the meson (Fermi motion).



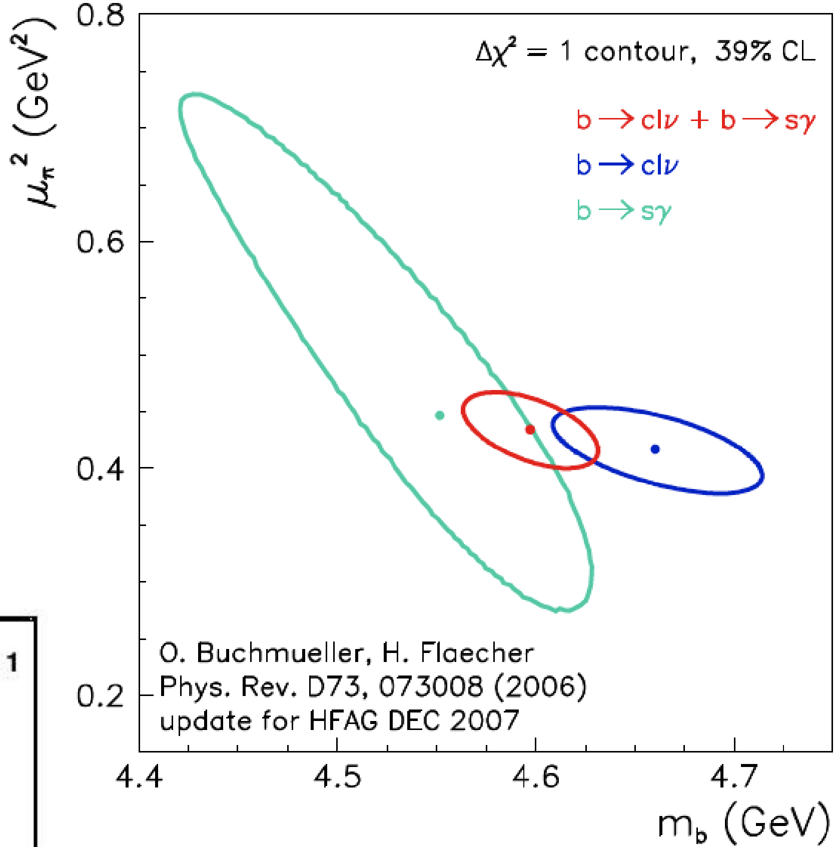
Fit in the kinetic scheme: what's new?

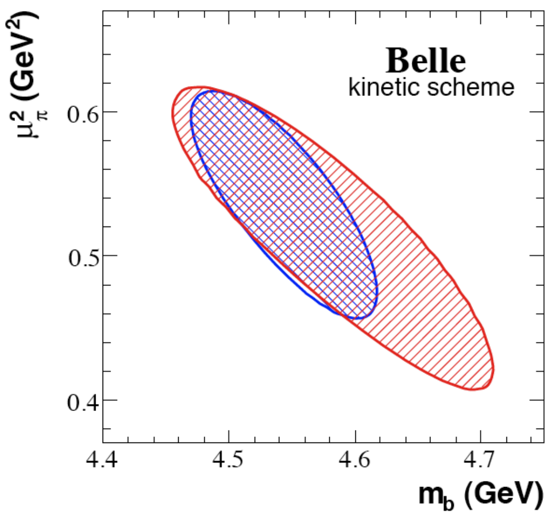
• The latest global fit pointed out some tension between results including or excluding photon energy moments. M. Neubert et al. suggested not to use photon energy moments in the fit.

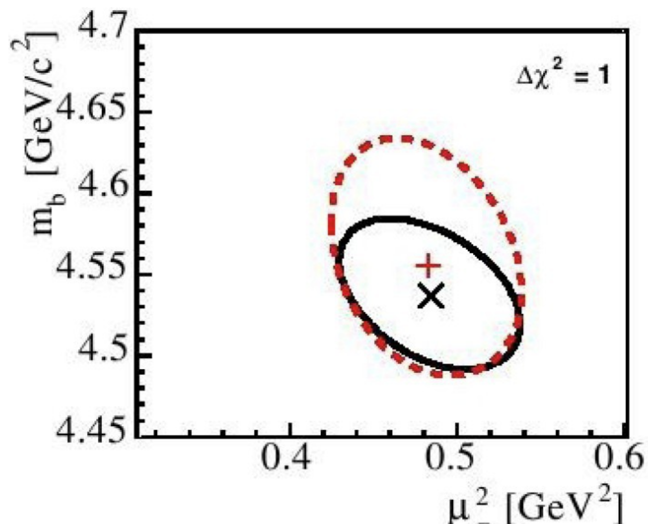
• No tension seems to be present in the latest Belle fit and in the preliminary Babar analysis.

• A refinement of the codes used in the fit (theory side) is about to be completed.

• Full 2-loop corrections to the charmed decay recently appeared and will soon be added.

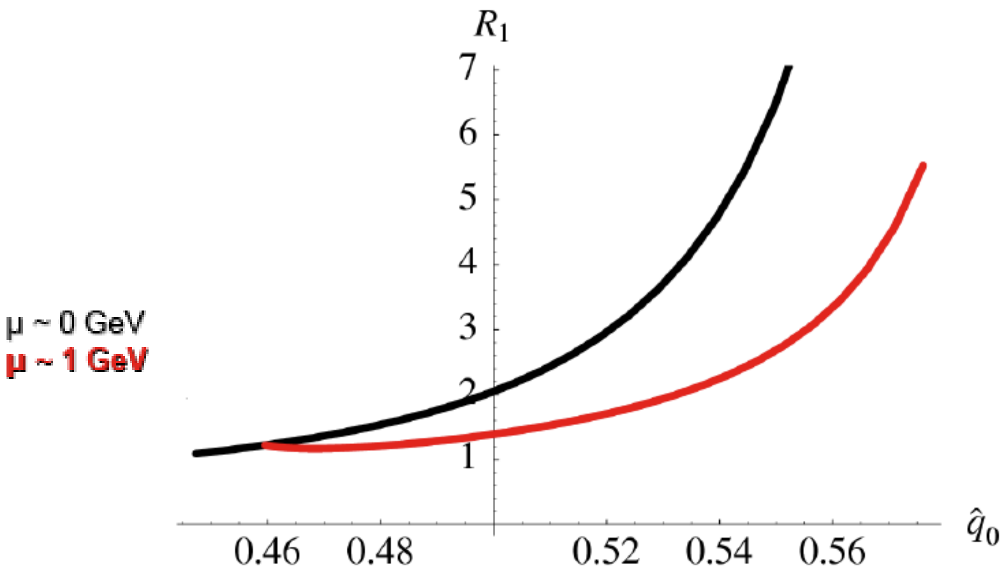






The kinetic scheme

. The perturbative and nonperturbative regimes are separated by a hard Wilsonian cutoff μ ~ 1 GeV.



. Contributions of soft gluons are absorbed in the definitions of the OPE parameters AND of the distribution function: $m_b(\mu)$, $m\pi^2(\mu)$, $\rho D^3(\mu)$

. Structure functions diverge less severely (left divergences due to collinear effects).

. The kinetic scheme was applied successfully to $B \Rightarrow X_c\, l\, \nu$ and $B \Rightarrow X_s\ \gamma$

. A whole set of new calculations has been performed to account for the cutoff. $O(\alpha_s^2\, \beta_0)$ corrections included for the first time.

R1: real gluon emission
q0: total leptonic energies in the B meson rest frame

The GGOU framework: main features

Gambino,Giordano,Ossola,Uraltsev
JHEP10(2007)058

. Provide the triple differential width of in the whole phase space,
including all known perturbative and nonperturbative contributions.

↓

The decay rate and the moments of any spectrum can be computed with any combination of cuts (common to BLNP and DGE methods).

- Work in the kinetic scheme, to separate perturbative and nonperturbative contributions consistently (cutoff μ ~ 1 GeV).
- Include all leading and subleading shape function effects, with an OPE based approach.
- local OPE breaks down at high q2: need to model the tail, consistent with positivity, Weak Annihilation naturally emerge.
- Triple diff distribution including all known pert and non pert effects,
C++ code, available for experiments.

The Fermi motion

. The moments of the distribution function are determined by the q0 moments of the local OPE.

. The leading order shape function is independent of the process and shared by radiative decays. Subleading effects break universality → there is a different SF for each of the 3 structure functions W13 and for each value of q2:

Leading SF resums leading twist effects, $m_b \to \infty$ universal, q^2 indep

Finite m_b distribution functions include all $1/m_b$ effects, non-universal no need for subleading SFs

$$F(k_+) \longrightarrow F_i(k_+, q^2, \mu)$$

Structure function (i = 1,2,3)

q^2 dependence

cutoff dependence (gluons with $E_g < \mu$)

. do NOT splitting between dominant and subdominant contributions... more efficient than many SF

. Hadronic structure functions are defined *via* the convolution of the distribution functions with the perturbative structure functions:

$$W_i(q_0, q^2) = m_b^{n_i}(\mu) \int dk_+ \; F_i(k_+, q^2, \mu) \; W_i^{pert}\left[q_0 - \frac{k_+}{2}\left(1 - \frac{q^2}{m_b M_B}\right), q^2, \mu\right]$$

see also Benson, Bigi, Uraltsev for bsγ

The high q2 tail: the symptoms

Higher order terms in the OPE become increasingly important at high q2, giving rise to a number of pathological features, origin in the non-analytic square root (e.g. negative variance of the distribution functions)

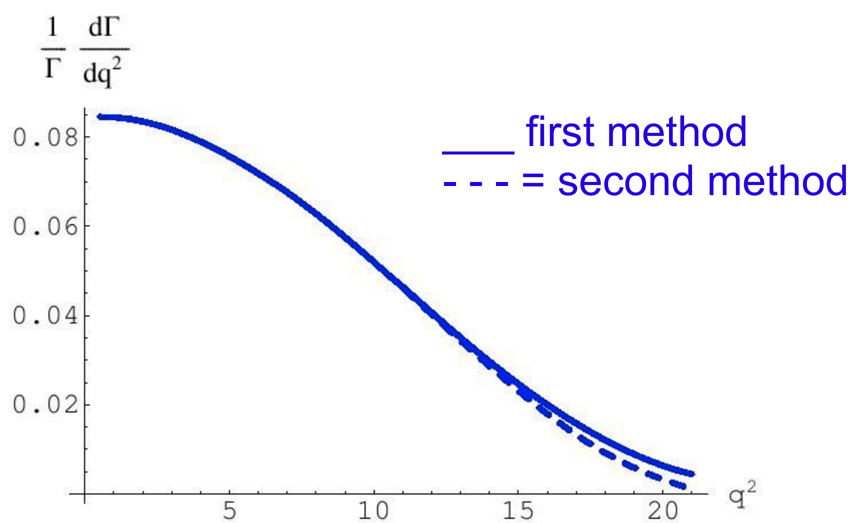
→ The formalism developed at low q2 is no more applicable:

$$\frac{d\Gamma}{dq_0\, dq^2} \propto \sqrt{q_0^2 - q^2} \quad \Rightarrow \quad \frac{d\Gamma}{dq^2} \sim -\sum_{n=1}^{\infty} \frac{(-1)^n\, b_n(\hat{q}^2)}{(1-\hat{q}^2)^{n-2}} \left(\frac{\bar{\Lambda}}{m_b}\right)^n$$

In the integrated rate the $1/m_b^3$ singularity is removed by the new WA operator: needs modelling for q2 spectrum

$$\delta\Gamma \sim \left[C_{\rm WA}\, B_{\rm WA}(\mu_{\rm WA}) - \left(8\ln\frac{m_b^2}{\mu_{\rm WA}^2} - \frac{77}{6}\right)\frac{\rho_D^3}{m_b^3} + \mathcal{O}(\alpha_s)\right]$$

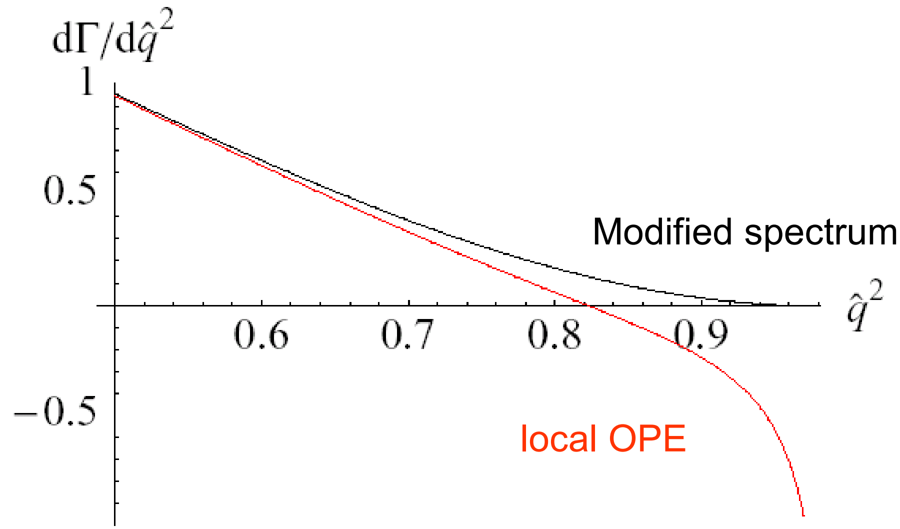
but since we are also interested in differential distributions, we must find a way to model the high q2 region.
Two different models are employed.



The high q2 tail: the cure

First method (default):

- Model the tail, requiring well-behaved positive spectra.
- Introduce a WA contribution: X $\delta(1-q^2)$ (good)
- Does not provide a triple differential distribution at high q2 (bad).
- Still matches local OPE moments to a great accuracy.



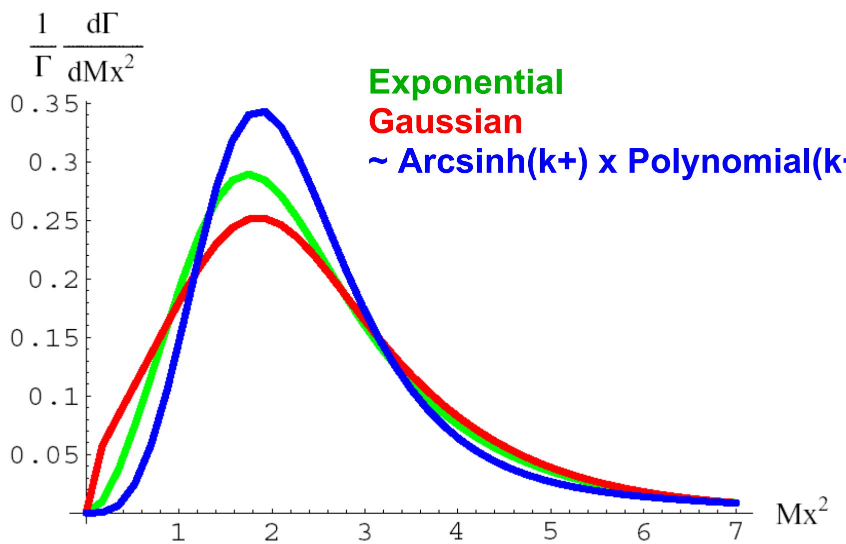
Second method:

- "Freeze" the distribution functions at $q^2 \sim 11$ GeV^2 and use them for the convolution at higher q2.
- Provides a triple differential width in the whole phase space (good).
- Does not match local OPE moments at high q2.

Theoretical errors

Gambino,Giordano,Ossola,Uraltsev
JHEP10(2007)058

. Parametric errors generally dominant,
in particular mb, 3-4%
. Moderate error due to
higher pert orders and to shape functional form
. Modelling of the q^2 tail and WA,
depending on cut, from 0 to 7%
WA tends to decrease V_{ub}



high q2 tail

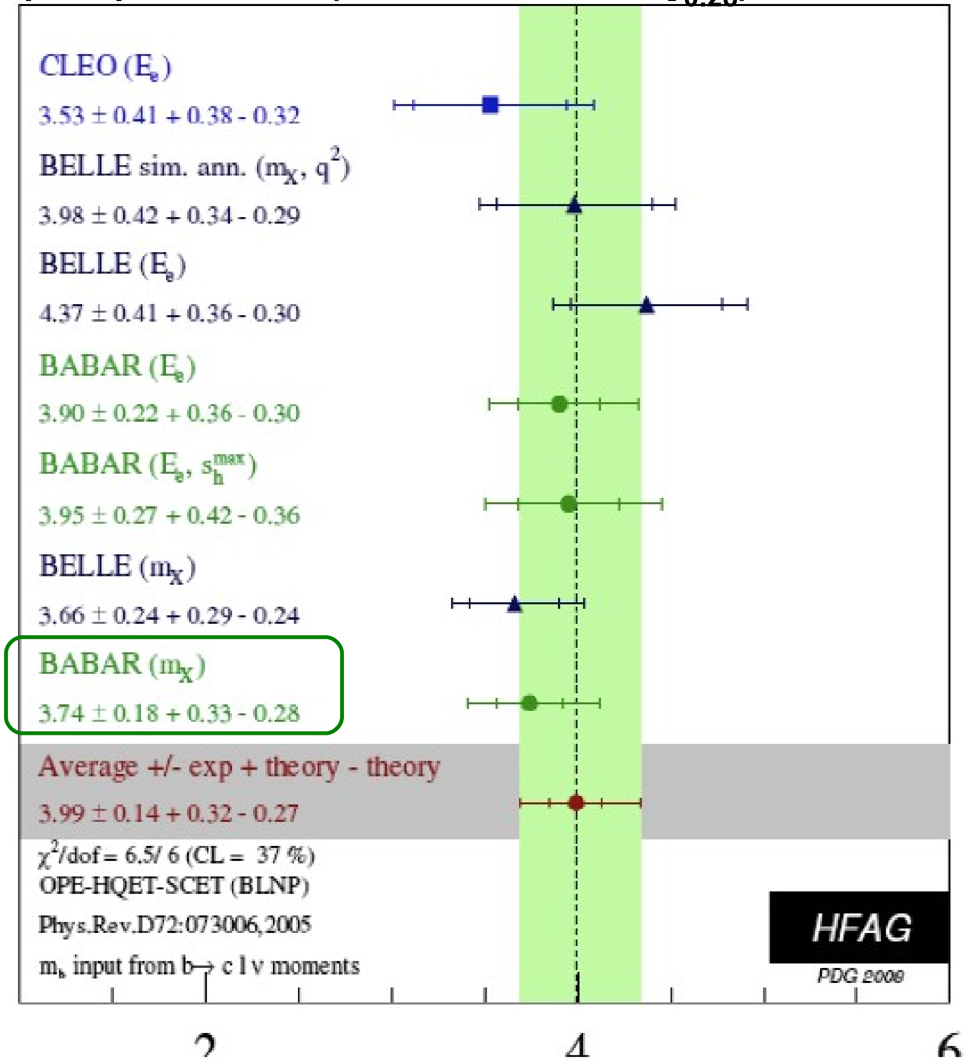
cuts	$\lvert V_{ub}\rvert \times 10^3$	f	exp	par	pert	tail model	q^2_*	X	ff	tot th
A [28]	3.87	0.71	6.7	3.5	1.7	1.6	2.0	$^{+0.0}_{-2.7}$	$^{+2.4}_{-1.1}$	$\pm 4.7^{+2.4}_{-3.8}$
B [28, 29]	4.44	0.38	7.3	3.5	2.6	3.0	4.0	$^{+0.0}_{-5.0}$	$^{+1.4}_{-0.5}$	$\pm 6.6^{+1.4}_{-5.5}$
C [30]	4.05	0.30	5.7	4.2	3.3	1.8	0.9	$^{+0.0}_{-6.2}$	$^{+1.2}_{-0.7}$	$\pm 5.7^{+1.2}_{-6.9}$

A= M_X cut -- Belle, B= (M_x,q^2) cut -- Belle+**BaBar**, C= E_l cut -- **Babar**

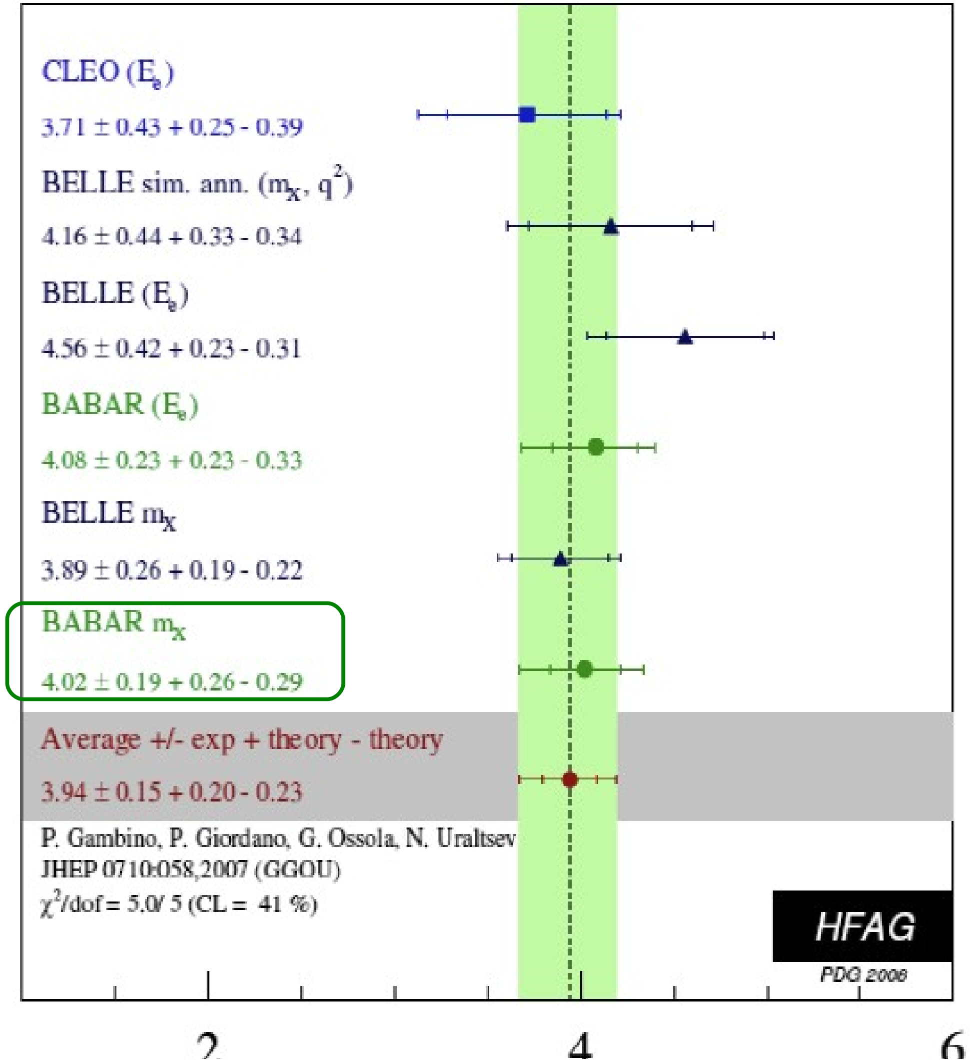
→ **Overall theory errors are 5-9%, depending on the cuts.**

Some updated results for **PRL 100, 171802 (2008)**

|Vub|- BNLP = (3.74 +/- 0.18 $^{+0.33}_{-0.28}$) x10-3



|Vub|- GGOU = (4.02 +/- 0.19 $^{+0.26}_{-0.29}$) x10-3



HFAG (preliminary)
thanks to F. Di Lodovico

. Asymmetric theoretical errors.
Agreement with other determinations !!

Inclusive B-> Xu l ν DGE

Andersen, Gardi :
- Dressed Gluon Exponentiation
- (JHEP 0601 (2006) 097)

shortly:

- Extend perturbative calculation beyond usual limit
- Treat b quark as on-shell ➔No Shape Function
- Use mb and α_s as inputs: Nonperturbative physics only in MB – mb
- $B \to Xul\nu$ and $B \to Xs\gamma$ spectra have been calculated.. with good approx of the spectrum [HFAG]

qualitatively:

. inclusive heavy–to–light decay spectra: decaying b quark is not on-shell
. The Fermi motion involves momenta of $O(\Lambda)$
  $\to$ expected $O(\Lambda)$ smearing of the perturbative spectrum by non-perturbative effects.

But:

. Spectrum in the peak region is strictly beyond the limits of perturbative QCD and a systematic on-shell calculation (with resummation of the perturb expansion) yields a <u>good approximation to the B decay spectrum</u> $\to$:) starting point for quantifying non-perturb corrections
. on-shell approx is physically natural because:
  ..b quark carries most of the momentum of the B meson.
  ..b quark virtuality, $O(\Lambda)$, is much smaller than the mass.
  ..in total rate , translates into a syst. expansion in 1/mb,
    leading corrections, $O(\Lambda^2/m_b^2)$, numerically small.

make the differ between the on-shell approximation and the physical meson decay

. on-shell spectrum is infrared and collinear safe = non-perturb effects appear in moment space only through power corrections

summability of the expansion issue: a) Cutoff–based separation procedures [GGOU]
b) Separation at the level of powers (Principal Value Borel summation) [DGE]

Inclusive $B \to X_s \gamma$

Observables: E_γ (photon energy)

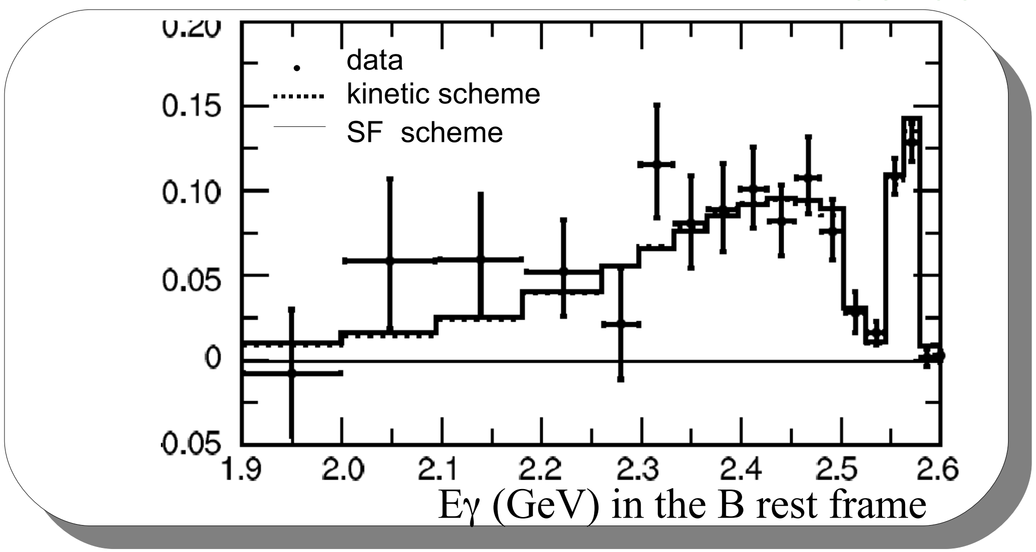
	$\langle E_\gamma^n \rangle$	*technique*
BABAR	PRD 72:052004, 81 fb-1	sum of exclusive
BABAR	hep-ex/0607071, 81 fb-1	fully inclusive
Belle	PRL 93:061803, 140 fb-1	fully inclusive

reconstruct exclusive X_s decays and sum up

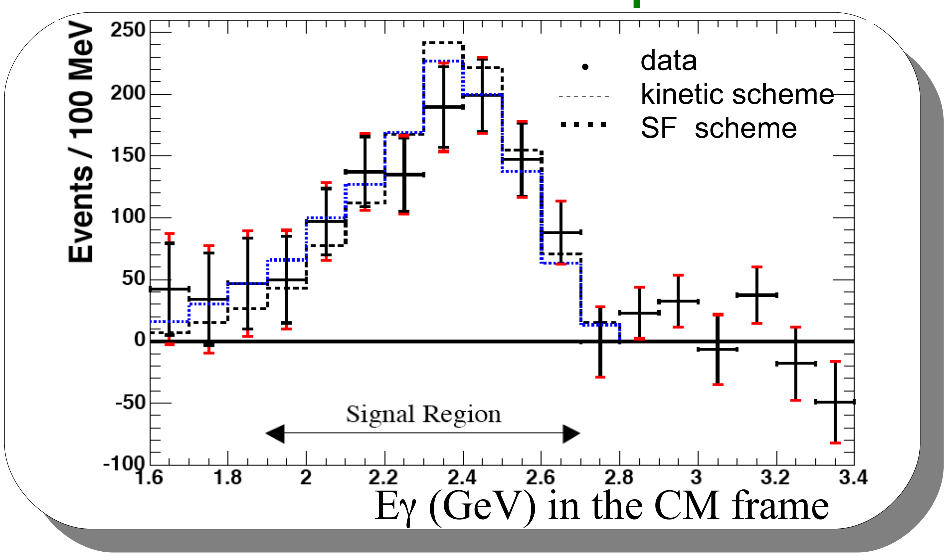
measure inclusive photon spectrum

Small rate and high background makes it tough to measure

BABAR
PRD 72:052004



BABAR
hep-ex/0607071



Global OPE fit: update HFAG dec 2007

Buchmüller & Flächer & kinetic scheme

V_{cb} = (42.04 ± 0.34_{fit} ± $0.59_{\Gamma sl}$) x 10^{-3}

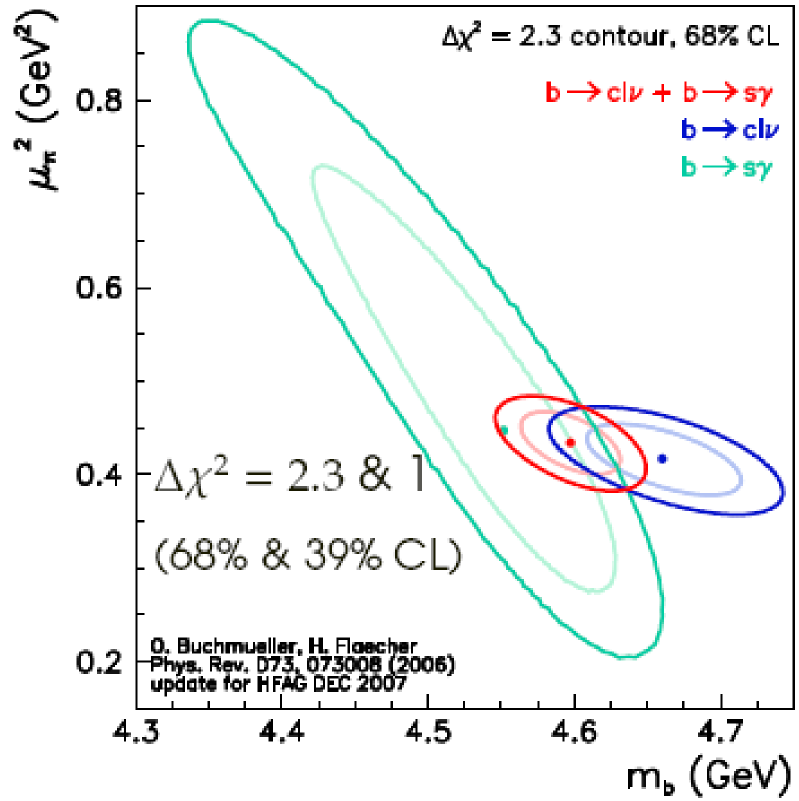
$m_b^{kinetic}$ = 4.597 ± 0.034_{fit} GeV

m_c = 1.1634 ± 0.051_{fit} GeV

μ_π^2 = 0.4341 ± 0.033_{fit} GeV^2

Needed for V_{ub}

1.6% precision on $|V_{cb}|$, 0.7% on m_b



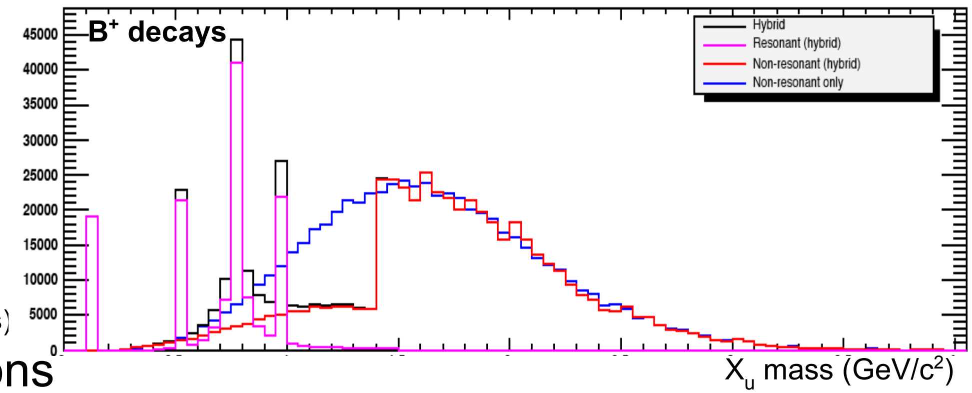
Belle E_l 152M BB, PRD75, 032001 (2007)
Belle m_X 152M BB, PRD75,032005 (2007)
BaBar m_X 232M BB, arXiv:0707.2670 (2007)

Global fit also includes moments from CLEO, CDF, and DELPHI

Different mass schemes available
. Kinetic [Gambino & Uraltsev, Phys J C34, 181]
. 1S [Bauer *et al.*, Phys Rev D70, 094017]

Simulation of B -> X_u l ν decays

Exclusive c-less SL are simulated using the ISGW2 model.
Branching ratios adjusted in a reweighting procedure to match the current PDG values.



Inclusive based on De Fazio and Neubert (DFN)
for theoretical area $M_X > 2m_\pi$ (OPE)

- triple differential decay rate $d^3\Gamma / ds_H dq^2 dE_l |_{\alpha(s)}$
  in terms of M_X, q^2 and E_l up to $O(\alpha_s)$ corrections
- describe the non-perturbative QCD by Shape Function

$$F(k_+) = N(1-x)^a e^{(1+a)x}$$

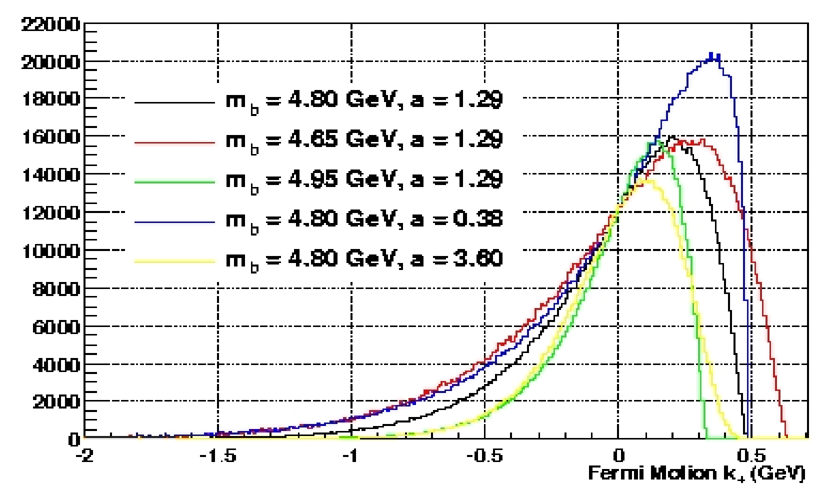
$x = k_+ / \bar{\Lambda}^{SF} \leq 1$,

$\bar{\Lambda}^{SF} = (m_B - m_b)$

$a = -3 (\bar{\Lambda}^{SF})^2 / \lambda_1^{SF} - 1$

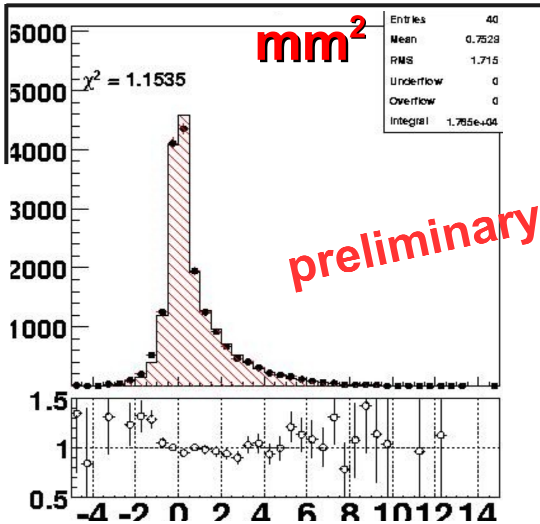
k_+ : b-quark momentum in B-meson

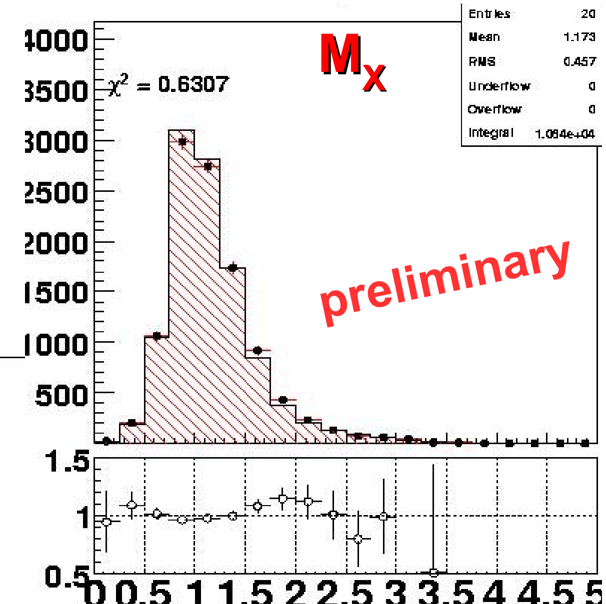
incorporated by parton level $\otimes$ Shape Function



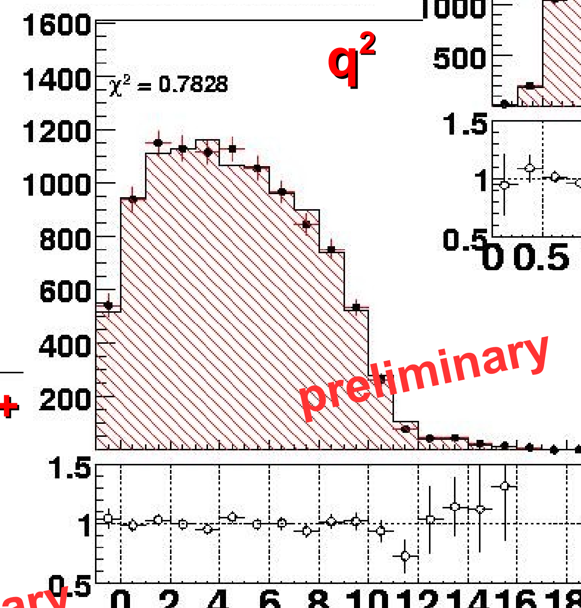
ISGW2: N. Isgur and D. Scora, Phys. Rev. D52 (1995) 2783
DFN: JHEP 9906, 017 (1999)

Data MC comparison

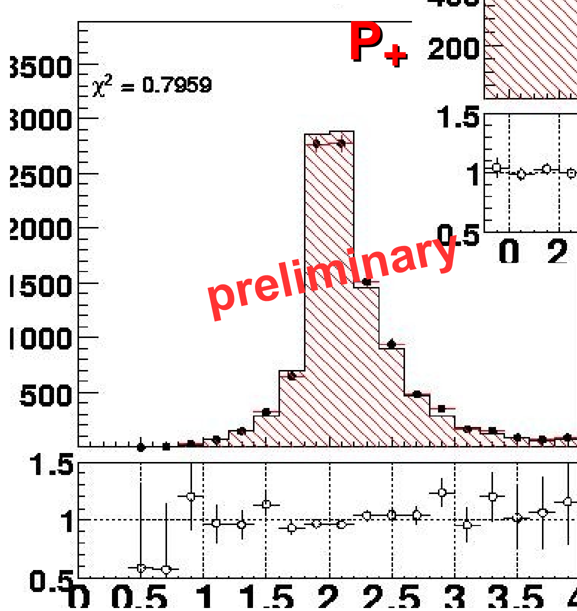




The measurement technique
has been extensively tested using MC samples.



Comparison between
DATA and MC for
some relevant variables
for b → c transitions
shows good agreement



all cuts applied
except the one
on the plotted variable,
bkg subtracted (mES)
- generic MC
- data

An insight into NEW m_{ES} fits

m_{ES} fits are a crucial point since they enter in each component of the formula:

$$\Delta R_{u/sl} = \frac{N_u^{meas} - N_u^{out} - BG_u}{N_{sl}^{meas} - BG_{sl}} \cdot \frac{1}{\varepsilon_u \varepsilon_{kin}} \cdot \frac{\varepsilon_l^{sl}\varepsilon_t^{sl}}{\varepsilon_l^{u}\varepsilon_t^{u}}$$

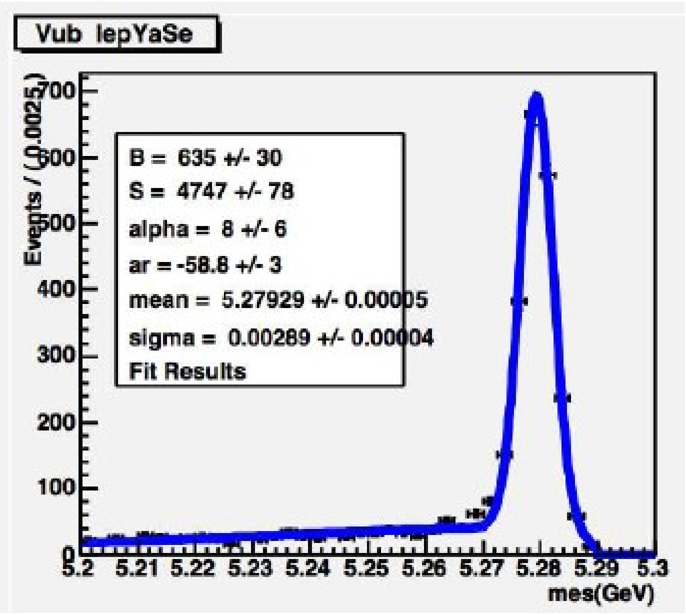
from data

from MC

high statistics samples

old published PRL [3] approach was to fit m_{ES} distribution using Argus + Crystal Ball PDF.

PROBLEMS WITH FITS ON LARGE SAMPLES !!



- m_{ES} distribution for events where daughters of the two B mesons are lost o misassigned has broad peaking component: "peaking background" not fitted by Crystal Ball

After many studies the most stable configuration to fit both high statistics and low statistics samples is

. ARGUS for combinatoric background [16]
. 7 parameters 3-wise function for signal [17]

[3] Phys. Rev. Lett. 92, 071802 (2004).
[16] [ARGUS Collaboration] H. Albrecht et al., Phys. Lett. B 318, 397 (1993).
[17] [BABAR Collaboration] B. Aubert et al., Phys. Rev. D 74, 091105 (2006).

Systematic uncertainties

All errors are in percentage

Source	$M_X < 1.55\ GeV/c^2$	$P_+ < 0.66\ GeV/c^2$	$M_X < 1.7\ GeV/c^2$, $q^2 > 8\ GeV^2/c^4$
Statistical Error	7.27	10.11	9.72
MonteCarlo statistics	3.22	4.62	4.29
Tracking efficiency	0.71	0.49	1.07
Neutral efficiency	1.42	2.88	2.45
PID eff. & misID	0.86	1.52	2.51
K_L	0.51	0.61	1.02
Fit related			
m_{ES} fit parameters	2.99	3.55	4.14
combinatoric bkg.	2.20	1.80	3.10
Signal knowledge			
SF parameters	-1.01 +0.71	-1.25 +0.42	-2.26 +1.65
SF form	0.56	1.25	1.78
Exclusive decays	2.08	2.22	2.71
Gluon splitting	1.62	1.47	1.02
Background knowledge			
K_S veto	0.44	1.34	0.40
B SL branching ratio	0.87	2.80	1.17
D decays	0.44	0.73	0.79
$B \to D^* l\nu$ form factor	0.21	0.39	0.55
Total systematics	-6.09 +6.05	-8.42 +8.34	-8.88 +8.74
Total error	-9.65 +9.63	-13.08 +13.03	-13.22 +13.13

Preliminary

Dominant systematic errors
. MC statistic (4.0%)
.detector (3.2%))
. mES fit technique (4.3%)
. modeling of signal and background contrib.

Systematic uncertainties

DETECTOR RELATED

. Charged particle tracking: applying Run dependent track killing

. Neutral particles selection: 1.8% uncertainty per photon in the efficiency

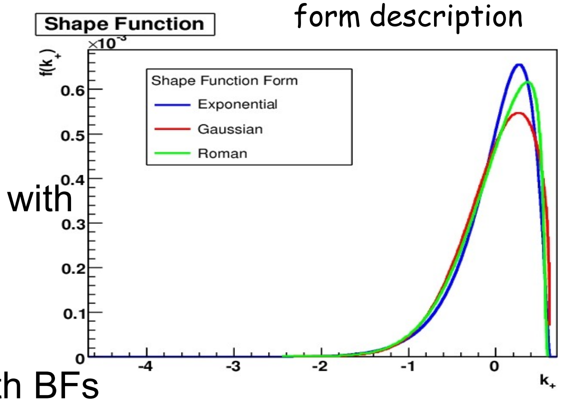
. K_L interactions: correct K_L detection efficiency rejecting neutral clusters truth-matched to a K_L with a probability dependent of K_L momentum. correct Data/MC disagreement for K_L production rate.

. K_s production rate: random removal of K_s from their list with 10% prob. for $p_{Ks} < 0.5$ GeV/c

. PID: varied electron and kaon ID eff. by 2%, muon ID eff. by 3%

. Mis-ID: mis-ID probability varied by 15% for all particles

SF form: used Gaussian and Roman form description



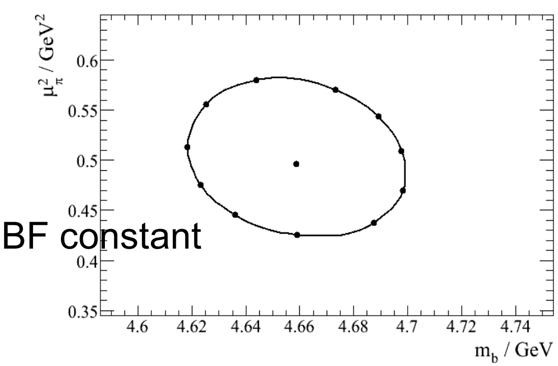
FITTING TECHNIQUE

. Breco combinatorial background: use pseudo truth-matching and take the difference with m_{ES} fits; varied fixed parameters in m_{ES} fits

BACKGROUND KNOWLEDGE

. BR of B and D mesons: Systematic uncertainties evaluated by repeating analysis with BFs varied within their experimental errors randomly.
Updated BgD/D*/D** In BF and D decays BF to latest averages.

. Form Factors in D*ln decays: Implemented Caprini-Lellouch-Neubert parametrization used in the latest BaBar measurement [hep-ex/0602023]
Varied parameters R_1,R_2, r^2 within their errors.



SIGNAL KNOWLEDGE

. Charmless SL decays modelling: updated BF values to PDG 07 averages and varied each BF within its uncertainty, keeping the total c-less semilep BF constant

. ssbar pair production: signal events with gluon split varied by 30%

. Shape Function: SF parameters (m_b and m_π^2) varied along the $\Delta\chi^2$=1 contour in the Kagan-Neubert Scheme from Buchmüller and Flächer results

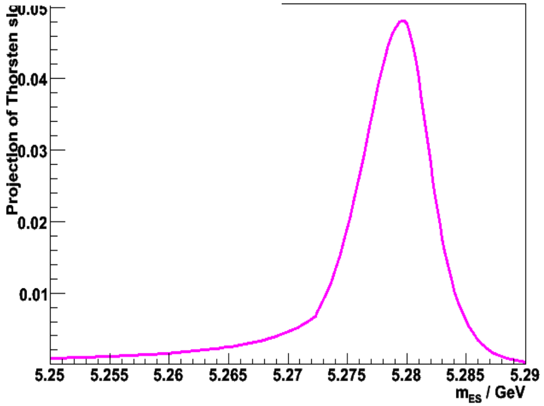
2007 signal and background PDFs

Continuum bkg: Argus function
x_{max} is the cutoff parameter
χ the shape parameter.
No peaking background is visible.

$$f_{ag} = N_{ag} x \sqrt{1-(x/x_{max})^2} \exp -\chi(1-(x/x_{max})^2)$$

Signal: modified CB (with $f_{tahnh'(x)}$ instead of Gaussian) & sum of derivative of tanh(x)

$$f_{sig}(x) = N \times \begin{cases} C\, f_{sigL}(m_{\mathrm{ES}}, x_c, \sigma_L, \alpha, n) & x \leqslant \ldots \\ f_{sigR}(m_{\mathrm{ES}}, x_c, r, \sigma_{R1}, \sigma_{R2}) & x > \ldots \end{cases}$$



Left side:

$$f_{sigL}(x) = \begin{cases} N_{cb}\, \frac{exp^{(-\frac{x-x_c}{\sigma_L})}}{(1+exp(-\frac{x-x_c}{\sigma_L}))^2} & x \geqslant x_c - \alpha\sigma_L \\ N_{cb}\, \frac{B}{(A+x_c-x)^n} & x < x_c - \alpha\sigma_L \end{cases}$$

width of tanh' component: σ_L
alpha_{cb}: α
N_{cb}: n

Right side:

$$f_{sigR}(x) = N\frac{r}{\sigma_{R1}} f_{\tanh'}(\frac{x-x_c}{\sigma_{R1}}) + N\frac{1-r}{\sigma_{R2}} f_{gauss}(\frac{x-x_c}{\sigma_{R2}})$$

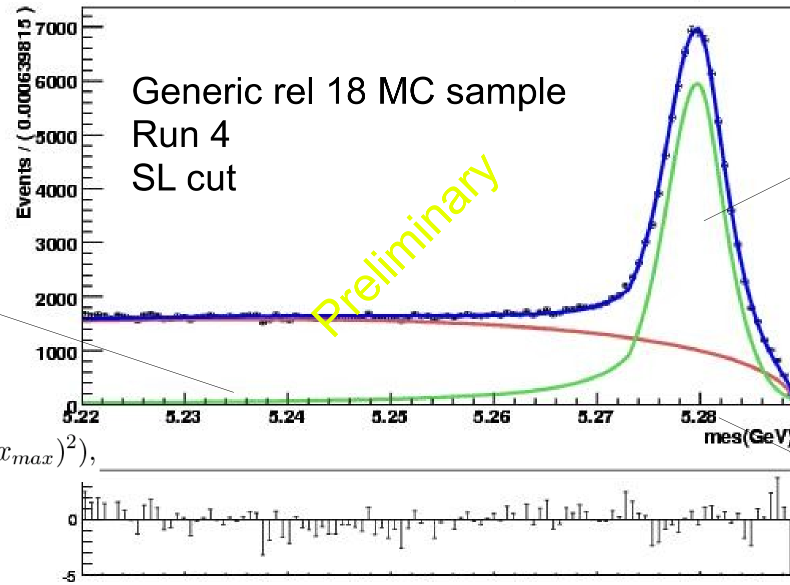
Peak position: x_c
gauss and tanh' component: r
width gaussian: σ_{R2}
width tanh': σ_{R1}

BaBar collaboration. Phys. Rev. D 74, 091105 (2006)

Ar + CB OR Ar + “Frankenstein” ??

BB Combinatorial bkg and continuum event:
► Argus (red)

$$f_{ag} = N_{ag} x \sqrt{1-(x/x_{max})^2} \exp -\chi(1-(x/x_{max})^2),$$



Signal:(green)
► 3 region function*
modified CB

$$f_{sig}(x) = N \times \begin{cases} C\, f_{sigL}(m_{\rm ES}, x_c, \sigma_L, \alpha, n) & x \leqslant x_c \\ f_{sigR}(m_{\rm ES}, x_c, r, \sigma_{R1}, \sigma_{R2}) & x > x_c \end{cases}$$

$$C = f_{sigR}(x_c)/f_{sigL}(x_c).$$

Peaking Background
tough issue !!

stable & reliable Frankenstein PDF model

PRO: better attitude in fitting all the three region, at high stat samples too
CON: needs more tuning (cross Runs common parameters)

Yields variation, due to keeping these parameters fixed, ~ 1% at most.

fixed parameters on **MC**		SL CUTS	ALL CUTS
Thorsten's function	alpha	3.2847	3.6800
	N	1.5520	2.0758
	R	0.94670	0.70901
	σ_{r2}	0.0015540	0.0032550
Argus:	cutoff	5.2895	5.2895

Truth-matching studies on R-18

Ideal standard truth matching: modeB = truemodeB

yield (signal) = 4792,

peaking (argus) = 487

Ad hoc truth matching:

neureco : number of reconstructed neutral daughters

neutrue : number of true neutral daughters

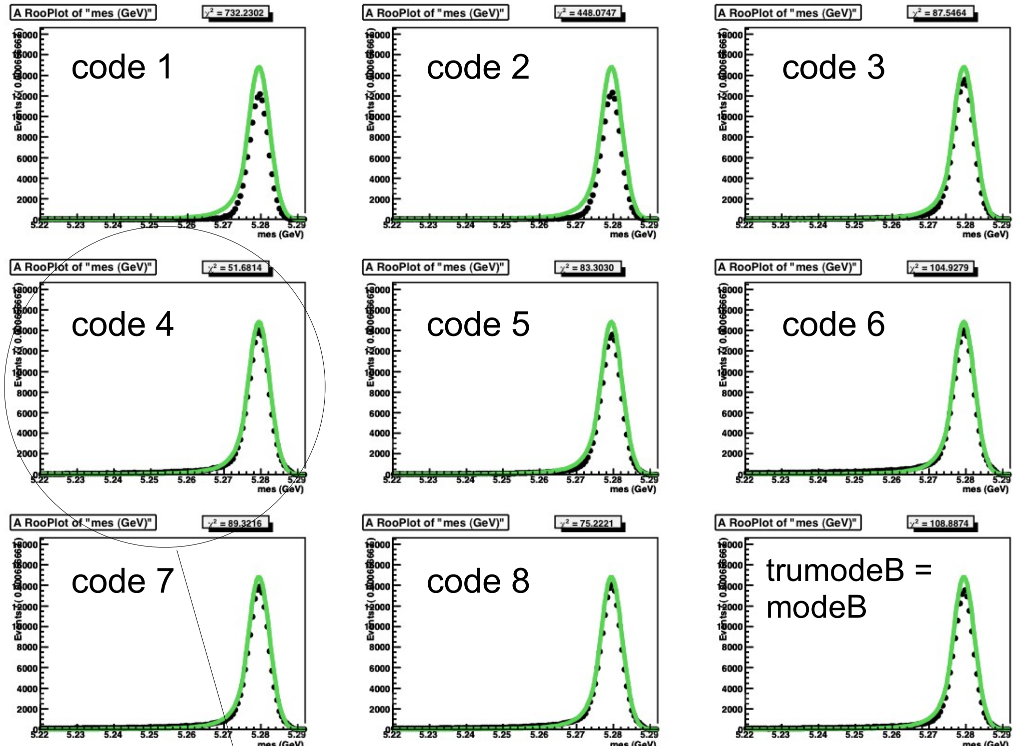
neutm : number of truth matched neutral daughters of the reconstructed Breco

+ analogous numbers for the charged daughters.

CODE	|neureco-neutm|	|neutrue-neutm|	|chgreco-chgtm|	|chgtrue-chgtm|
1	0	0	0	0
2	< 3	0	0	0
3	< 3	< 2	0	0
4	< 3	< 3	0	0
5	< 3	< 2	< 2	< 0
6	< 3	< 2	< 2	< 2
7	< 2	< 2	< 2	< 2
8	< 2 (sum neu+chg)	< 3 (sum neu+chg)	< 2 (sum neu+chg)	<3 (sum neu+chg)
9	truemodeB==modeB			

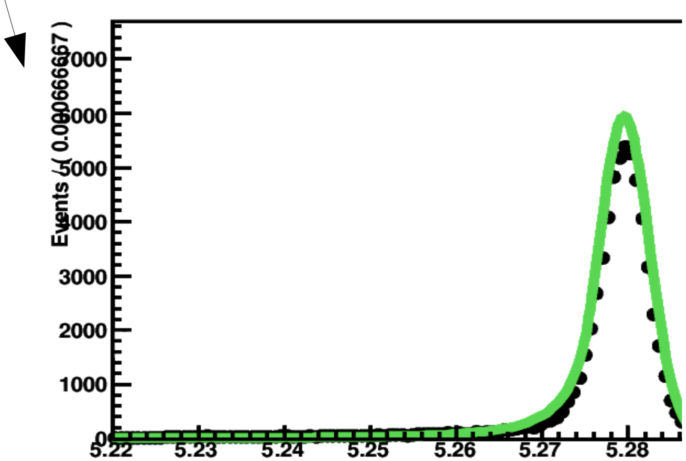
Algorithm # 4 : why ?

generic MC



– : full mES distribution fit result
• : truth-matched signal components

CODE	signal (truth-fitted)	ratio sig truth/sig fit	bkg (truth-fitted)	ratio bkg truth/ bkg fit
1	48338 (-20012)	0.707213	51199 (20246)	1.65409
2	48932 (-19418)	0.715903	50605 (19652)	1.6349
3	54770 (-13580)	0.801317	44767 (13814)	1.44629
4	57522 (-10828)	0.84158	42015 (11062)	1.35738
5	55120 (-13230)	0.806437	44417 (13464)	1.43498
6	59388 (-8962)	0.868881	40149 (9196)	1.2971
7	58428 (-9922)	0.854835	41109 (10156)	1.32811
8	59211 (-9139)	0.866291	40326 (9373)	1.30281
9	57889 (-10461)	0.84695	41648 (10695)	1.34552



minimize the peaking background
Numbers of event surviving the truth-matching is closer to the fitted events for signal wrt other truth-matching algorithms

Getting $|V_{ub}|$ from the partial rate

Take your favorite theory calculation and convert the partial rates into $|V_{ub}|$:

OPE gives good results for full phase space but break down in the "SF region" (low M_X and low q^2)

$$|\mathbf{V_{ub}}| = \sqrt{\frac{\Delta\mathcal{B}(\bar{\mathbf{B}} \to \mathbf{X_u}\ell\bar{\nu})}{\tau_{\mathbf{b}} \cdot \zeta(\mathbf{\Delta\Phi})}}$$

$\zeta(\Delta\Phi)$: theoretical acceptance, computed by using different theoretical frameworks

Theoretical frameworks

- **DFN** (De Fazio, Neubert) → **HQE with ad-hoc inclusion of SF** — **JHEP9906:017(1999)**
- **BLNP** (Bosch, Lange, Neubert, Paz) → **HQE with systematic incorporation of SF** — **PRD72:073006(2005)**

  Handle SF region by introducing a parameterization
  - Shape function form is unknown -> assume form
  - Shape function moments are related to HQE parameters (m_b, μ_π^2) -> can be measured
  - Leading shape functions universal in b->clv, b->ulv, b->sγ
  - Subleading shape functions depend on decay
- **BLL** (Bauer, Ligeti, Luke) → **HQE for m_X< m_D and q^2>8 ('non SF region') to minimize SF effect** — **PRD64:113004(2001)**
  - Residual dependence on SF effects
  - Only depend on m_b
- **DGE** (Anderson,Gardi) → **use "Dressed Gluon Exponentiation" to convert on-shell b quark calculation into meson decay spectra** — **JHEP0601:097(2006)**
  - Only depend on m_b

BLNP PRD72:073006(2005)

BLL PRD64:113004(2001)

DGE JHEP0601:097(2006)

Theoretical frameworks

Bosch, Lange, Neubert, Paz → **HQE with systematic incorporation of SF**

. Shape function form is unknown-> assume form

. Shape function moments are related to HQE parameters (m_b,m_π^2) -> can be measured

Debatable:
no full shape of γ spectrum, only first 2 moments-> ? verify
Perturbative error, varying the scale of α_s in the different terms
Sub-leading SFs: 3 functions, 9 models each, scan over 9^3 = 729 combinations
WA: take as fixed % of rate

Bauer, Ligeti, Luke → **HQE for m_X< m_D and q^2>8 (‘non SF region’) to minimize SF effect**

. OPE assumed to be valid for combined cut

. LO SF sensitivity estimated by convoluting tree level decay rate with ("tree level SF" model - funct model)

. only depends on mb

Debatable:
BNLP analysis doesn't find reduced SF sensitivity
Sub-leading Sfs assumed to be small, not assessed
Residual dependence on SF effects (~ 3%)
BLL should updated ana, e.g. estimate SF sensit.
beyond tree level, sublead SFs contribution etc

Anderson,Gardi → **use “Dressed Gluon Exponentiation” to convert on-shell b quark calculation into meson decay spectra**

. “All is perturbative” approach

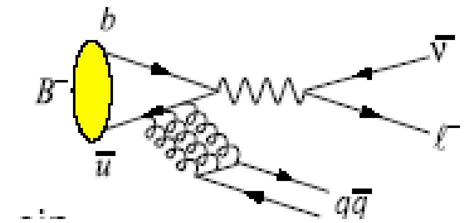
. Only input parameter mb and α_s

Debatable:
No error associated with LO SF.
C param <--?--> SF uncertainty in other approaches
Unclear how the OPE result is recovered beyond LO in 1/mb
No error from subleading SF
DGE No power corrections are included or estimated "present exp. data no power correction are needed"

arXiv:0708.1753 [hep-ex]

383M $B\bar{B}$

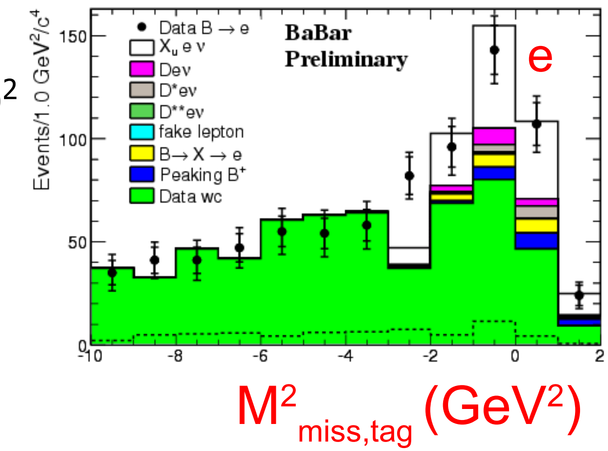
Weak Annihilation



Small contribution to $B \to X_u \ell \nu$ decay (<3% of total rate)

– Compare $B^0 \to X_u \ell \nu$ partial rate to charge-averaged $B \to X_u \ell \nu$ rate in WA-enhanced region (large p_ℓ and large q^2)

- Tagging: $B^0 \to D^{*+} \ell^- \nu X$ with partial D^* reconstruction
- Neutrino mass derived from kinematics $m_\nu^2 = (P_B - P_{D^*} - P_\ell)^2$
- Measure B for $P_\ell > 2.2$-2.4 GeV



ΔP_ℓ	$\Delta\mathcal{B}(B^0) \cdot 10^4$
$2.2 - 2.6\ \mathrm{GeV}/c$	$2.62 \pm 0.33 \pm 0.16$
$2.3 - 2.6\ \mathrm{GeV}/c$	$1.30 \pm 0.21 \pm 0.07$
$2.4 - 2.6\ \mathrm{GeV}/c$	$0.76 \pm 0.15 \pm 0.05$

- Extract charge asymmetry, using info from untagged $B \to u \ell \nu$ from endpoint analysis (Phys.Rev.D73:012006,2006)

$$A^{+/0} = \frac{\Delta\Gamma^+ - \Delta\Gamma^0}{\Delta\Gamma^+ + \Delta\Gamma^0}$$

- Limit on contribution from WA for interval $2.3 < E_l < 2.6$ GeV:

$$\frac{|\Gamma_{WA}|}{\Gamma_u} = \frac{2 \cdot f_u(\Delta P_\ell)}{f_{WA}(\Delta P_\ell)} \cdot A^{+/0} < \frac{3.8\ \%}{f_{WA}(2.3 - 2.6)}, \quad \text{at } 90\%\ \text{C.L.}$$

$\Gamma_{WA} = \Gamma^+ - \Gamma^0$

$f_{WA}(\Delta P_\ell)$= fraction of WA in interval ΔP_ℓ

Reducing model dependence

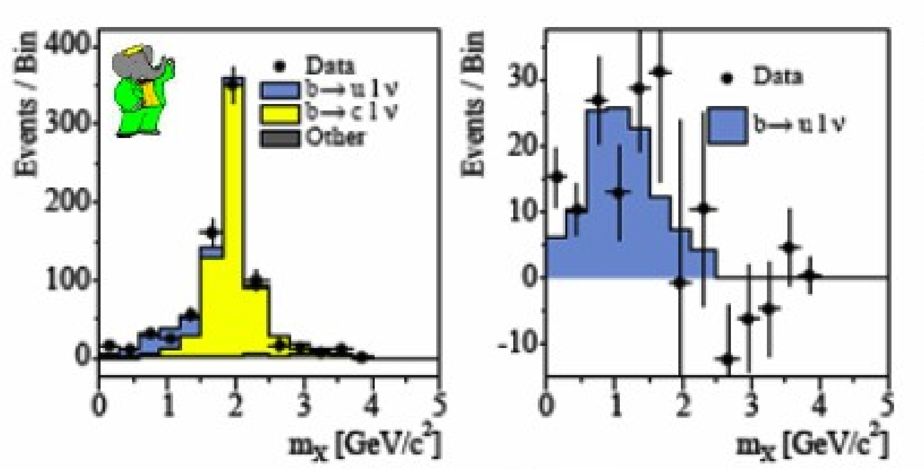
- Relate charmless SL rate to $b \to s\gamma$ spectrum

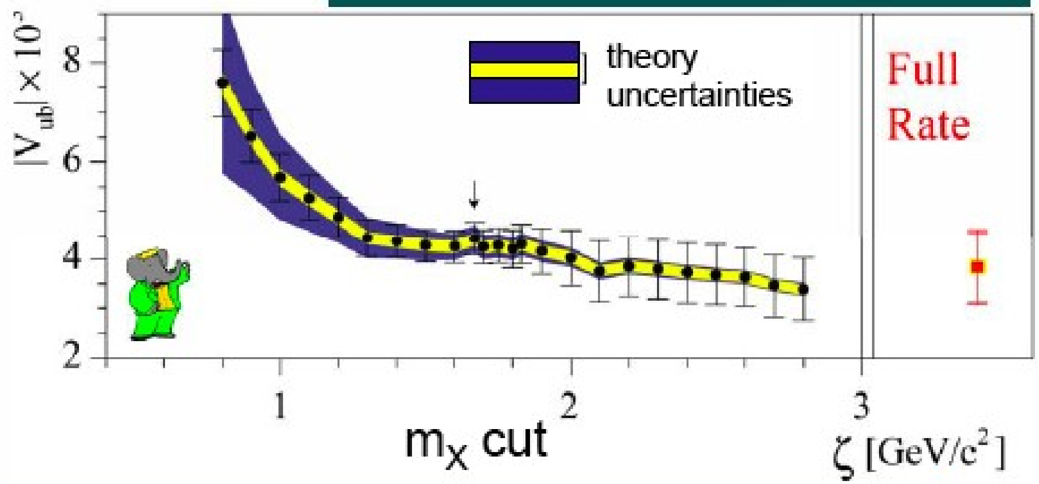
$$\Gamma(B \to X_u l \nu) = \frac{|V_{ub}|^2}{|V_{ts}|^2} \int W(E_\gamma) \frac{d\Gamma(B \to X_s \gamma)}{dE_\gamma} dE_\gamma$$

Weight function

- Reduced dependence from shape function
- Recoil analysis on 88M $B\bar{B}$

based on Leibovich, Low, Rothstein
PL B486, 86 (2000), PL B513, 83 (2001)





NEW!

hep-ex/0601046
submitted to PRL

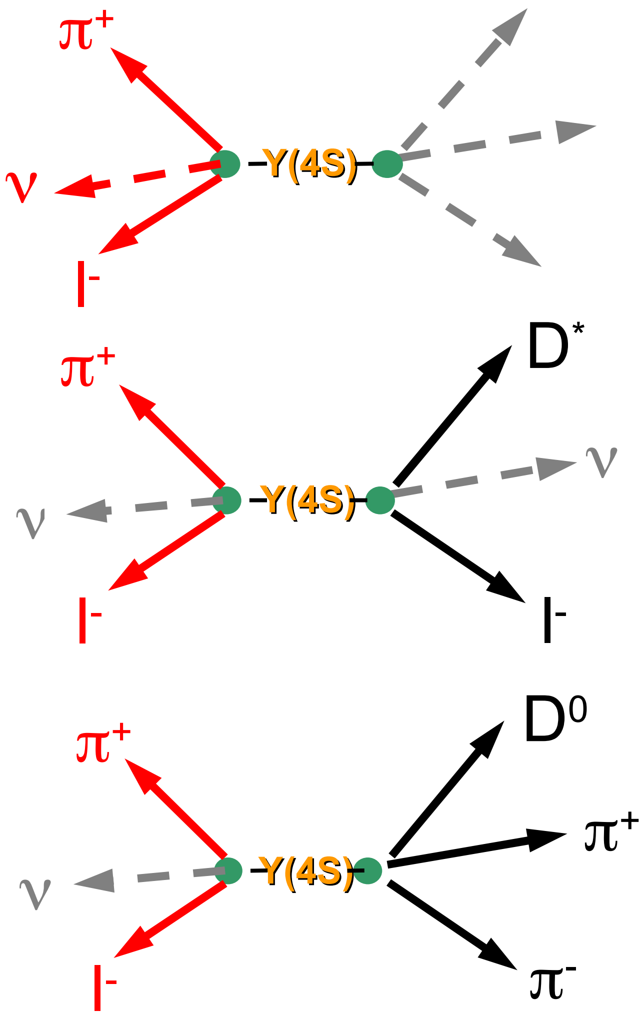
LLR : $M_X < 1.67$ GeV:
$|V_{ub}| = (4.43 \pm 0.38_{stat} \pm 0.25_{syst} \pm 0.29_{theo})\ 10^{-3}$

OPE: $M_X < 2.50$ GeV:
$|V_{ub}| = (3.84 \pm 0.70_{stat} \pm 0.30_{syst} \pm 0.10_{theo})\ 10^{-3}$

Experimental approaches: tagging method

PURITY ↓ EFFICIENCY ↑

Complementary approaches: . different systematic errors
. statistically independent samples



Untagged:

High statistics

High backgrounds and cross-feed

→ Fully reconstruct signal side (ν reco.)

Semileptonic Tag:

Reconstruct $B \to D^{(*)} l \nu$ and study recoil

- **Full reconstruction of $D^{(*)}$**
- **Partial reconstruction of D^* (only l, π_{soft})**

Two ν → tag-B kinematics incomplete

Hadronic Tag:

Fully reconstruct hadronic decay of one B:

$B \to D^{(*)} + (\pi^+, \pi^0, K^+, K^0)$ ≈ 1000 modes

→ know kinematics of other B

untagged

☹ lower signal purity and restricted phase space

☺ high signal efficiency

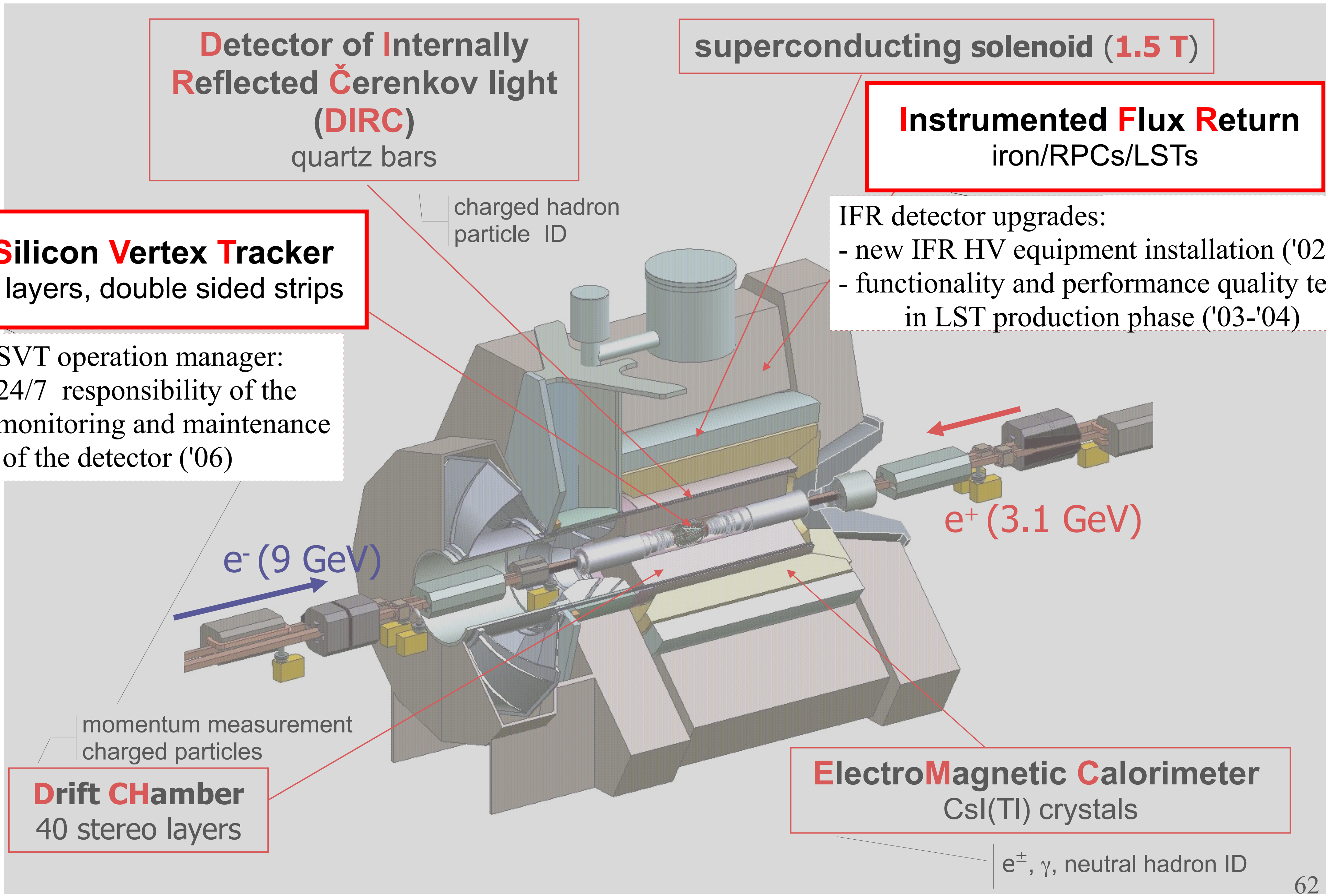
tagged

☺ high signal purity for almost all phase space

☹ low signal efficiency

Only B-Factories could explore tagged technique

the BaBar detector: personal tasks



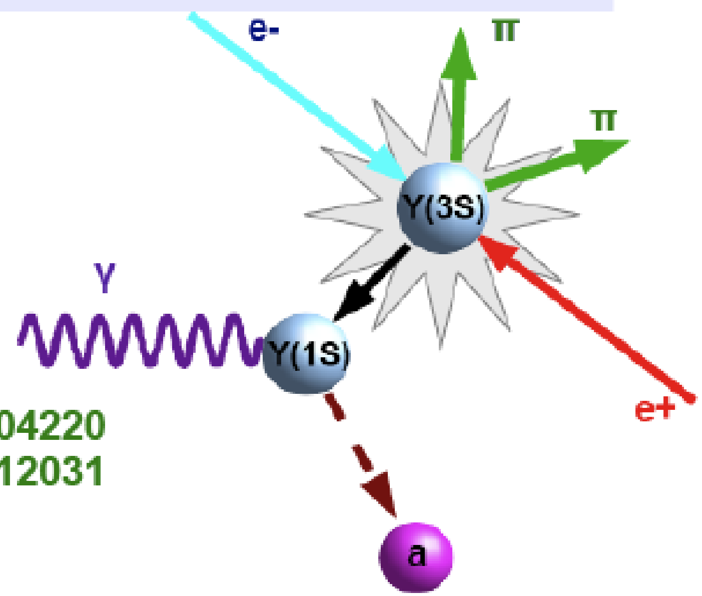
New Analysis Opportunities: Beyond the Y(4S)

- 2008 Run plan: 30 fb^{-1} @ Y(3S), 25 @ Y(2S), 10 > Y(4S)

  10x existing data samples

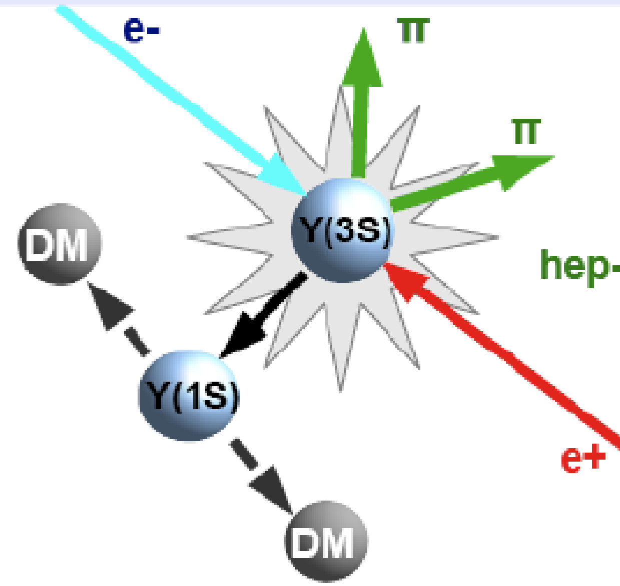
  - Spectroscopy: find the η_b, look for bb versions of Y(4260)...
  - Test *l* universality: Y(nS)$\rightarrow$*ee*:Y(nS)$\rightarrow\mu\mu$:Y(nS)$\rightarrow\tau\tau$

Search for low mass Higgs boson



hep-ph/0404220
hep-ph/0612031

Search for light dark matter candidates



hep-ph/0506151