Fisica teorica del B a Torino

Paolo Gambino
INFN Torino

INFN Istituto Nazionale di Fisica Nucleare

GRUPPO di TORINO

Paolo Gambino
Giovanni Ossola
Andrea Piccione
Paolo Giordano

TO23, Cofin,
Marie Curie ERG

Collaborazioni attive

Giudice

Slavich

Davidson

Ridolfi

Uraltsev

Misiak

Ferroglia

Degrassi

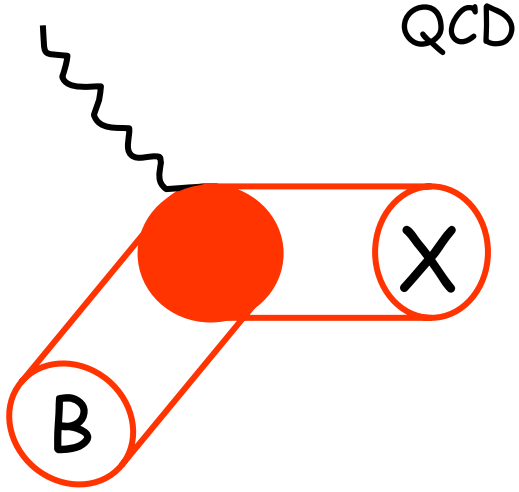
Di che cosa ci occupiamo?

Misura precisa della matrice di CKM

Decadimenti rari nel MS e con nuova fisica (susy ecc)

in decadimenti semileptonici e radiativi **inclusivi** del B

Una corrente ew o em sonda la dinamica del B: se controlliamo QCD otteniamo info sulle proprieta' della corrente



INCLUSIVE	EXCLUSIVE
OPE: non-pert physics described by B matrix elemnts of local operators can be extracted by exp suppressed by $1/m_b^2$	Form factors: computed by non pert methods (lattice, sum rules,...) symmetry can provide normalization

The CKM paradigm

Cabibbo 1963

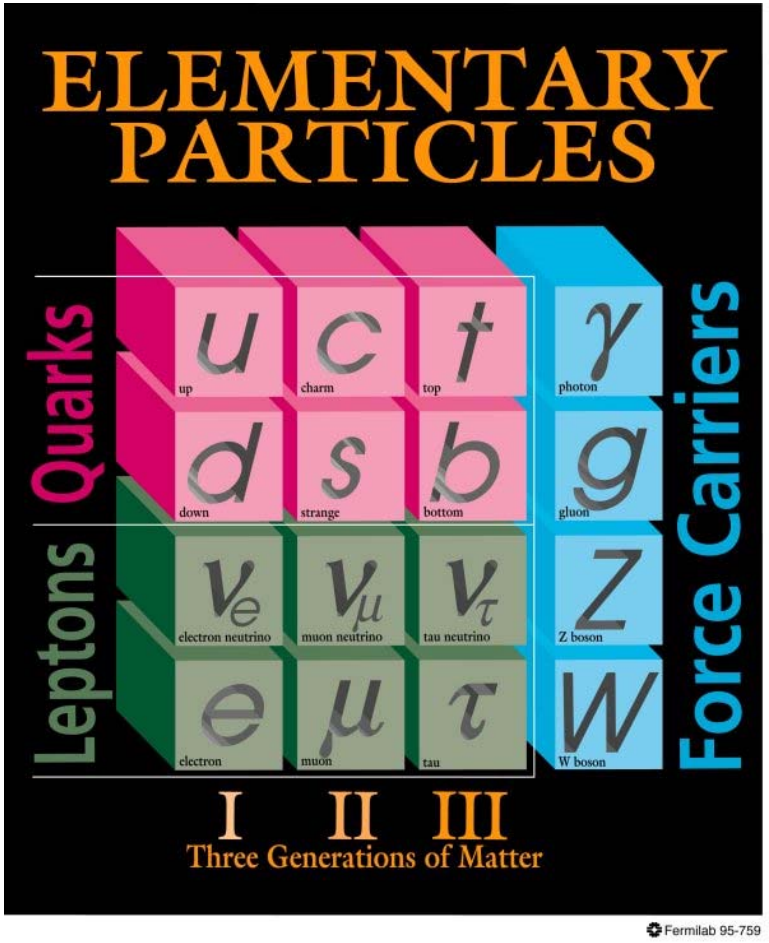
Kobayashi & Maskawa 1973

Flavour in the Standard Model

3 generations of matter spin $\frac{1}{2}$ fields (quark and leptons)

mechanism of mass generation is still unknown (Higgs?)

Variety of masses and mixing (Yukawa sector) is a mystery, but in the **quark sector** is parameterized by CKM matrix & masses



The CKM matrix

describes Flavor Violation (mixing between generations of quarks) in the SM

$$L_W = -\frac{g}{2\sqrt{2}} V_{ij}\,\bar{u}_i \gamma^\mu W_\mu^+ (1-\gamma^5) d_j + \text{h.c.}$$

Wolfenstein parameterization

$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} = \begin{pmatrix} 0.9740 \pm 0.0010 & 0.2196 \pm 0.0023 & 0.0040^{+0.0006}_{-0.0007} \\ 0.224 \pm 0.016 & 0.91 \pm 0.16 & 0.0402 \pm 0.0019 \\ < 0.010 & \simeq 0.0400 & 0.99 \pm 0.29 \end{pmatrix}$$

3 angles and 1 phase with strong hierarchy:
$\lambda \sim 0.22$ sine of Cabibbo angle, $A, \rho, \eta = O(1)$

The CKM phase is the **only source of CP violation** in the SM

Why precision flavour studies?

We are able to describe the observed flavor violation very well

But we have no theory of flavor.

The SM does not address flavor, but rather accomodates it

Similarly, **CP violation** is (accidentally) accounted for in the CKM

Most models of new physics include new CP and Flavor violation but measurements are surprisingly close to SM prediction

scale $\Lambda_{NP} >> TeV$ ➔ ➔ the flavor & CP problems

Need **precision** studies to uncover new dynamics and/or degrees of freedom, testing the CKM paradigm.

Strong interactions make CKM studies hard. Learning slowly but steadily at crossroad of many different fields.

Theory errors dominate almost everywhere.

The unitarity triangle

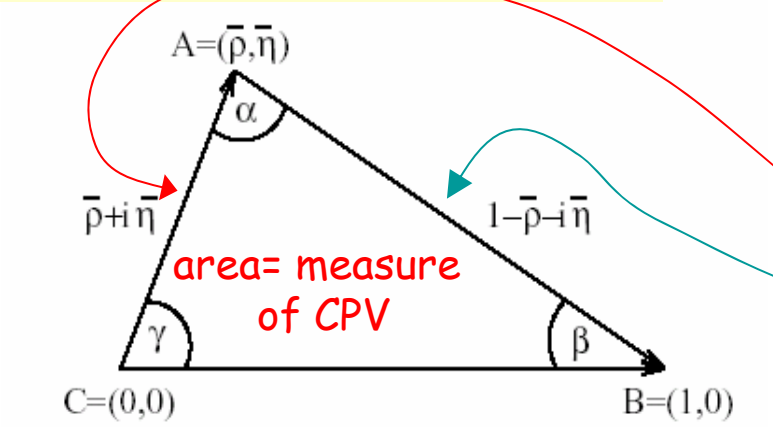
$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

$$V_{ij} V_{jk}^* = \delta_{ik}$$

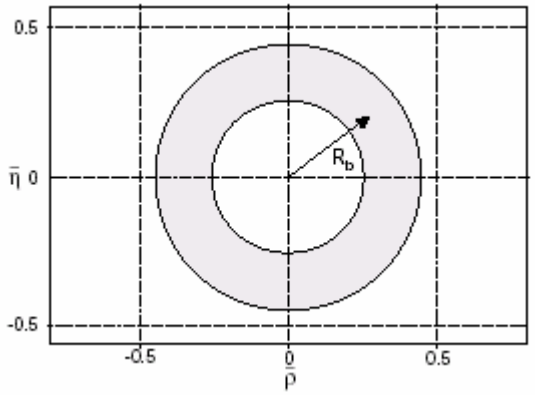
Unitarity determines several triangles in complex plane

$$V_{ud} V_{ub}^* + V_{cd} V_{cb}^* + V_{td} V_{tb}^* = 0 \qquad O(\lambda^3)$$

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

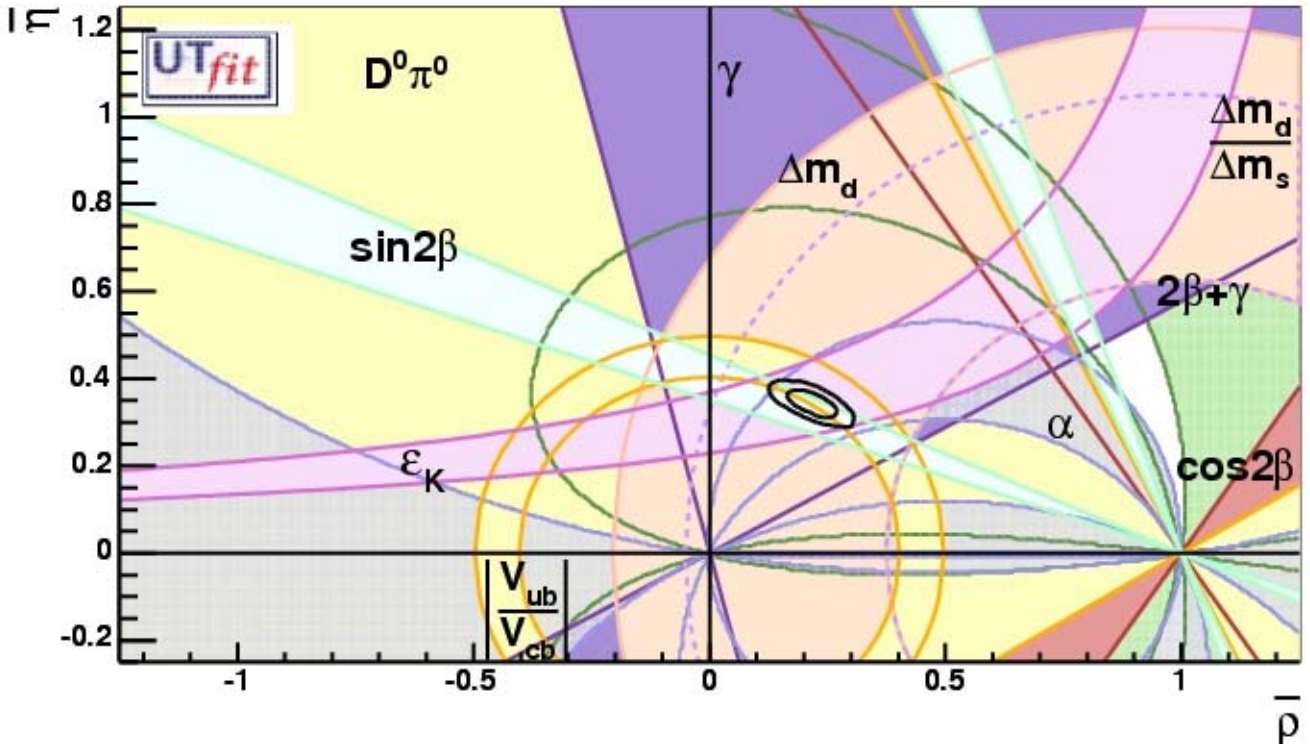


the $|V_{ub}/V_{cb}|$ clock



V_{td} cannot be accessed directly: we resort to loop transitions FCNC **sensitive to new physics**

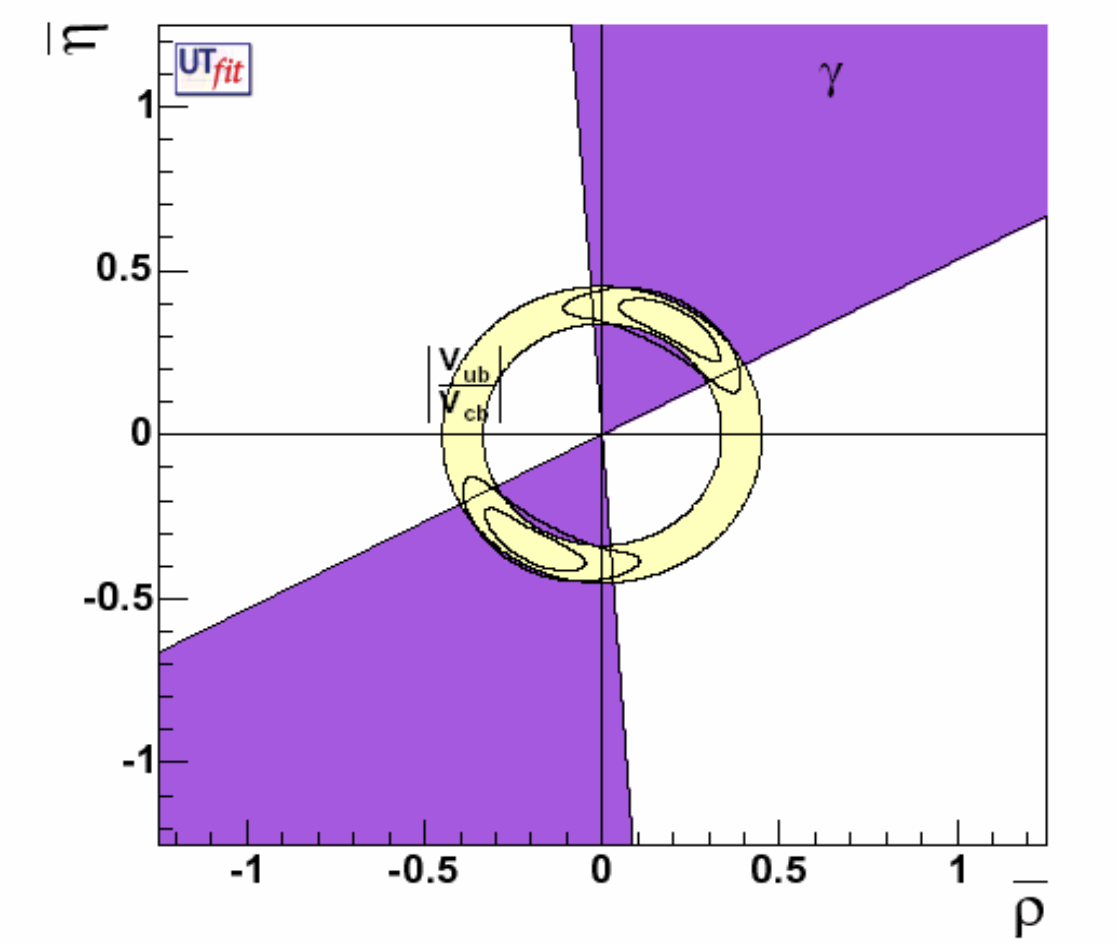
Global fit results



$\bar{\rho} = 0.216 \pm 0.036$ $\bar{\eta} = 0.342 \pm 0.022$

http://www.utfit.org

Strictly tree level

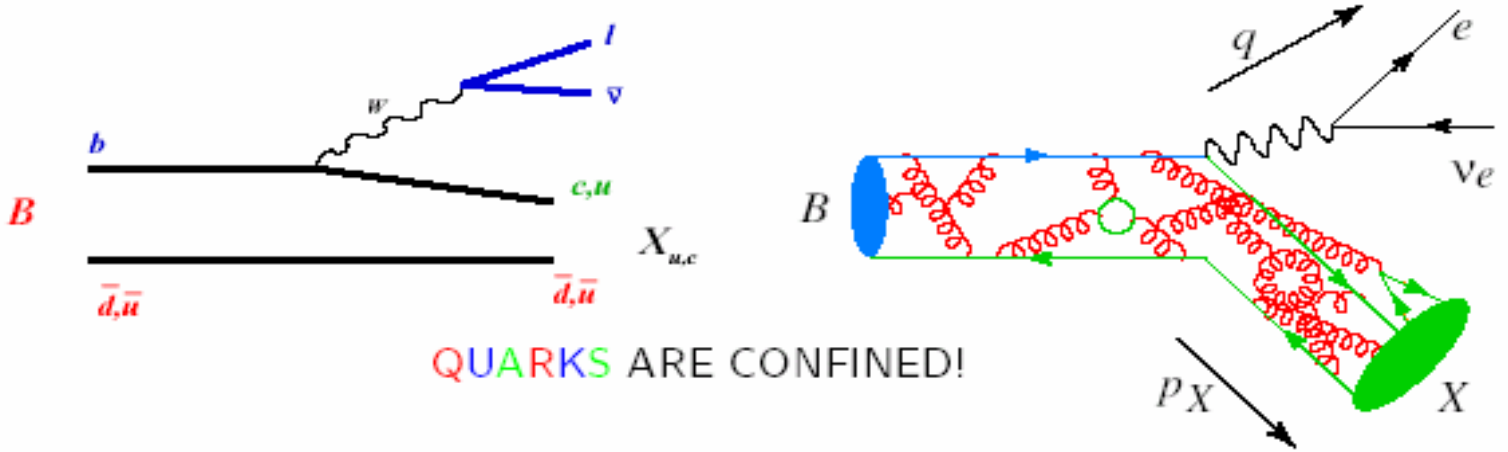


...toward a Universal Unitarity Triangle Buras,PG,Gorbahn,Jaeger,Silvestrini

Risultati recenti: $|V_{cb}|$ inclusivo

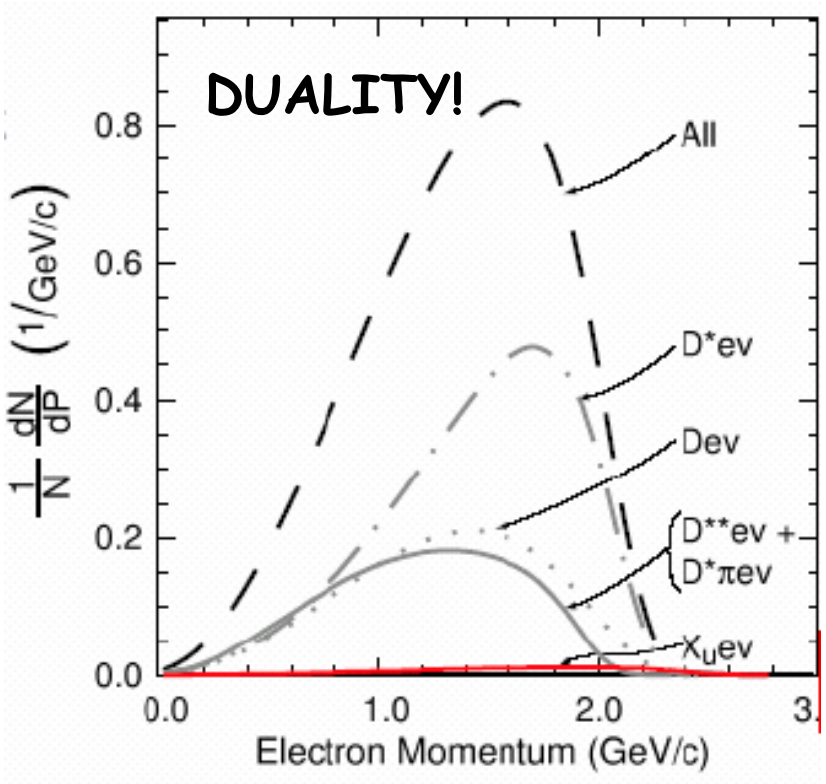
$\Lambda_{QCD} \ll m_b$: inclusive decays admit systematic expansion in Λ_{QCD}/m_b
Non-pert corrections are generally small and can be controlled

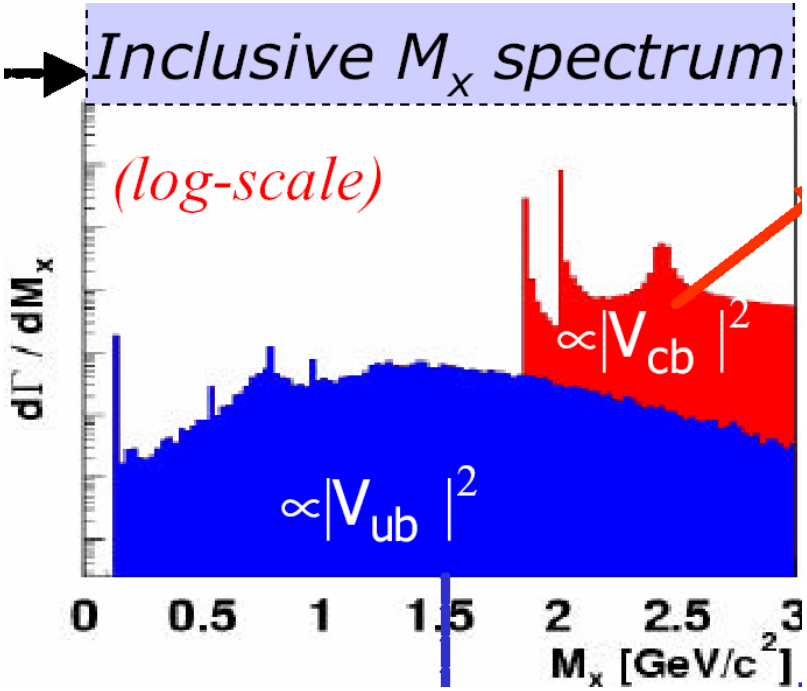
Hadronization probability =1 because we sum over all states
Approximately insensitive to details of meson structure as $\Lambda_{QCD} \ll m_b$
(as long as one is far from perturbative singularities)



$\frac{d^2\Gamma}{dE_l dq^2 dq_0}$ can be expressed as double series in α_s and Λ_{QCD}/m_b (OPE)
with parton model as leading term **No $1/m_b$ correction!**

Leptonic and hadronic spectra





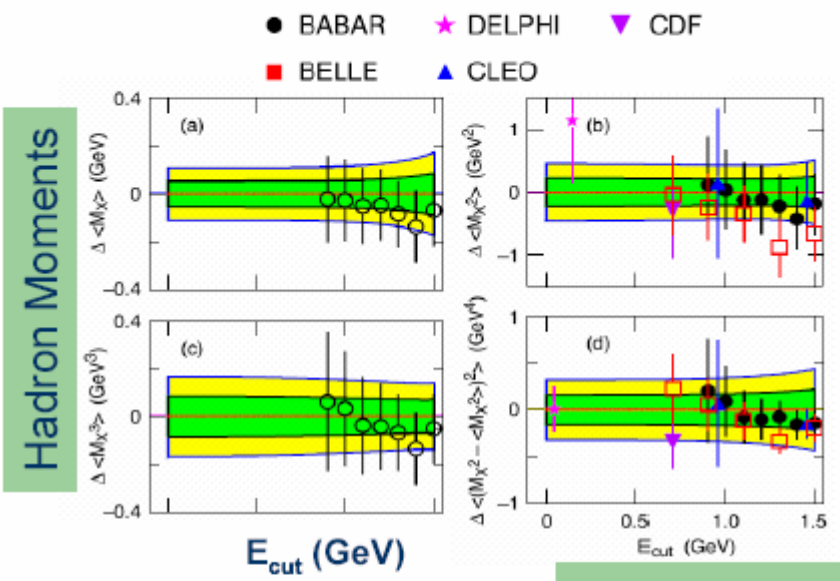
Total **rate** gives CKM elmnts; global **shape** parameters tell us about B structure (HQE parameters)

Global fit to $|V_{cb}|$, BR_{sl}, HQE parmts

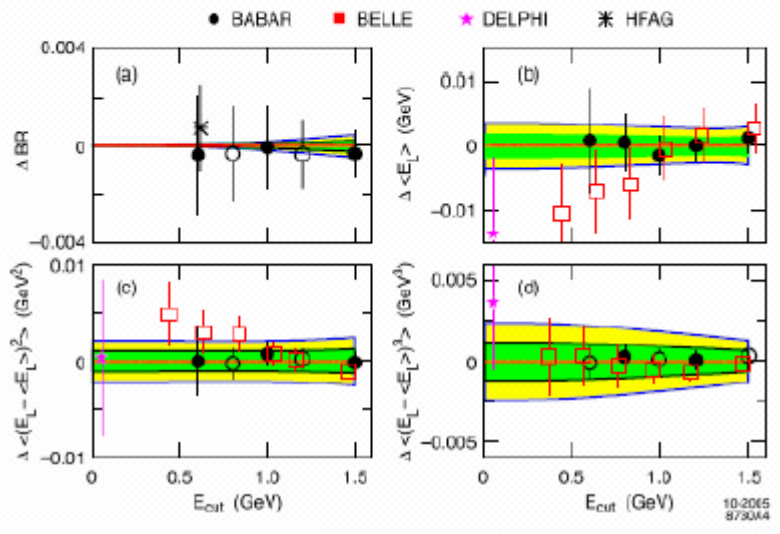
Aquila,PG,Ridolfi,Uraltsev, hep-ph/0503083
Benson, Bigi, Mannel & Uraltsev, hep-ph/0410080
Gambino & Uraltsev, hep-ph/0401063
Benson, Bigi & Uraltsev, hep-ph/0410080

Based on calculations in kinetic scheme:

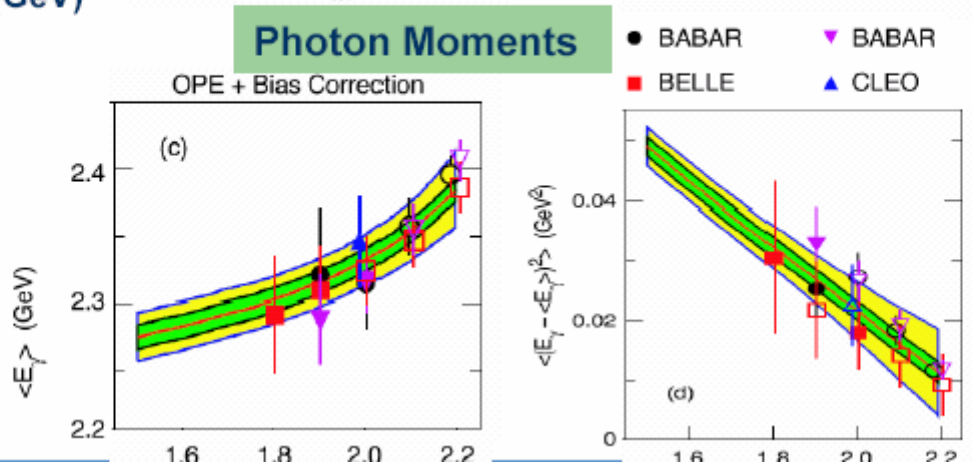
Hadron Moments



Lepton Moments



Photon Moments



Measurements highly correlated!

O. Buchmueller,H.F. hep-ph/0507253

H.Flacher slide

Global fit to $|V_{cb}|$, BR_{sl},HQE

Result of fit to all moment measurements:

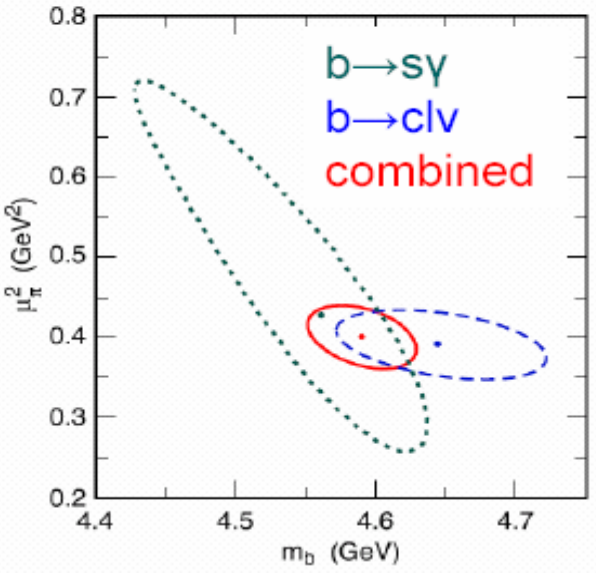
$|V_{cb}|$ @ 2%
m_b < 1%
m_c @ 5%

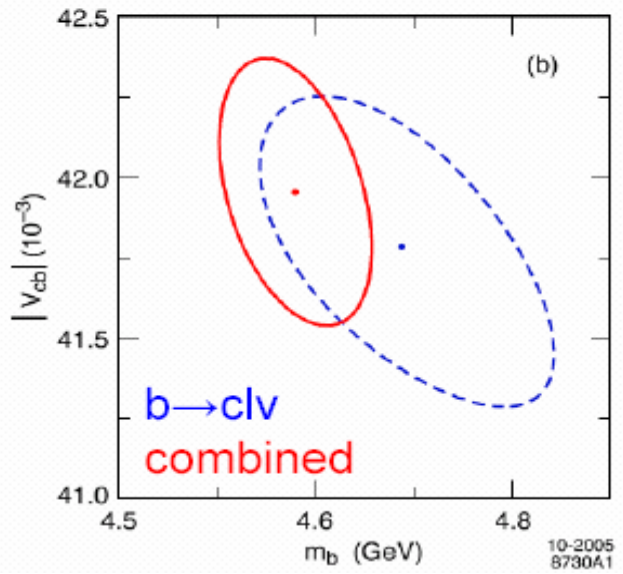
In $\overline{MS}$ scheme:
$\overline{m}_b(\overline{m}_b) = 4.20 \pm 0.04$ GeV
$\overline{m}_c(\overline{m}_c) = 1.24 \pm 0.07$ GeV
$\overline{m}_c(\mu)/\overline{m}_b(\mu) = 0.235 \pm 0.012$

courtesy of N.Uraltsev

		exp	HQE	Γ_{SL}
$\|V_{cb}\|$ =	(41.96	± 0.23	± 0.35	± 0.59) 10^{-3}
m_b =	4.590	± 0.025	± 0.030	GeV
m_c =	1.142	± 0.037	± 0.045	GeV
μ_π^2 =	0.401	± 0.019	± 0.035	GeV^2
μ_G^2 =	0.297	± 0.024	± 0.046	GeV^2
ρ_D^3 =	0.174	± 0.009	± 0.022	GeV^3
ρ_{LS}^3 =	-0.183	± 0.054	± 0.071	GeV^3
BR_{clv} =	10.71	± 0.10	± 0.08	%

hep-ph/0507253





Good agreement with other similar analyses:
Bauer et al. hep-ph/0408002
DELPHI hep-ex/0510024

Current project: improve th error in determination $|V_{ub}|$ (not so much) inclusive

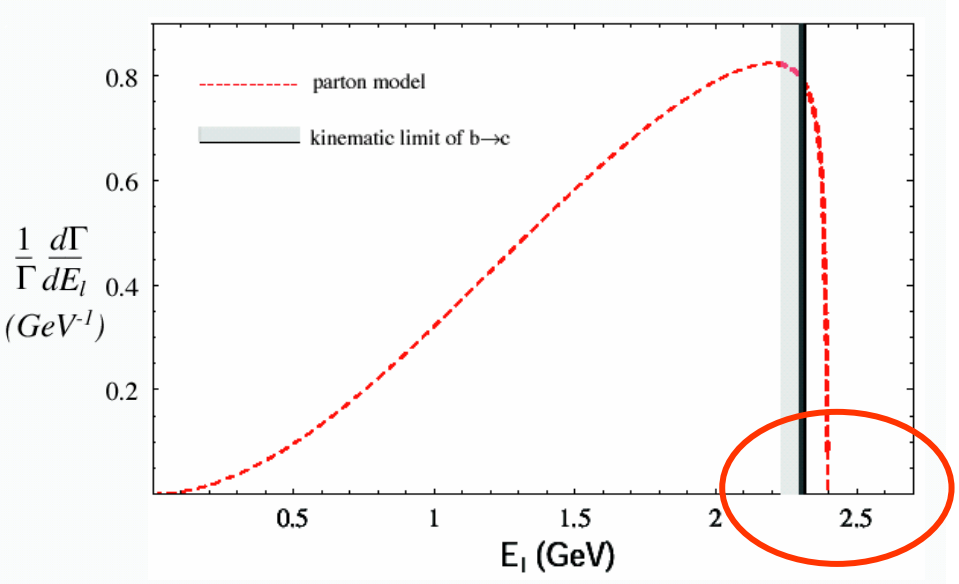
$|V_{ub}|$ from total BR($b\to u l\nu$) almost exactly like incl $|V_{cb}|$ but we need kinematic cuts to avoid the ~100x larger $b\to c l\nu$ background:

$m_X < M_D$ $\quad E_l > (M_B^2-M_D^2)/2M_B$ $\quad q^2 > (M_B-M_D)^2$ ...

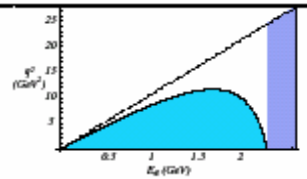
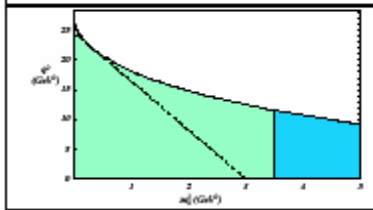
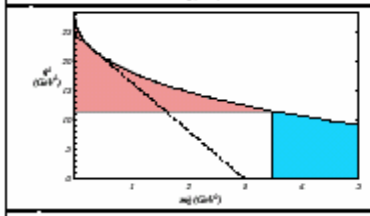
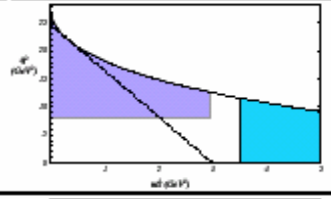
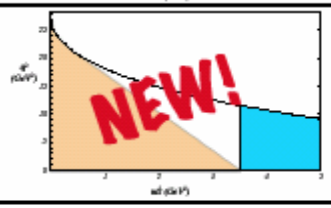
or combined (m_X, q^2) cuts

The cuts destroy convergence of the OPE, supposed to work only away from pert singularities

Rate becomes sensitive to "local" b-quark wave function properties (like Fermi motion ➔ at leading order in $1/m_b$ **SHAPE function**)



Each strategy has pros and cons

cut	% of rate	good	bad
 $E_\ell > \frac{m_B^2 - m_D^2}{2m_B}$	~10%	don't need neutrino	- depends on f(k^+) (and subleading corrections) - WA effects largest - reduced phase space - duality issues?
 $s_H < m_D^2$	~80%	lots of rate	- depends on $f(k^+)$ (and subleading corrections) - need shape function over large region
 $q^2 > (m_B - m_D)^2$	~20%	insensitive to $f(k^+)$	- very sensitive to m_b - WA corrections may be substantial - effective expansion parameter is $1/m_c$
 "Optimized cut"	~45%	- insensitive to $f(k^+)$ - lots of rate - can move cuts away from kinematic limits and still get small uncertainties	- sensitive to m_b (need +/- 60 MeV for 5% error in best case)
 $P_+ > m_D^2/m_B$	~70%	- lots of rate - theoretically simplest relation to b→sγ	depends on $f(k^+)$ (and subleading corrections)

Luke, CKM workshop 2005

Towards a 5% error on $|V_{ub}|$ incl.

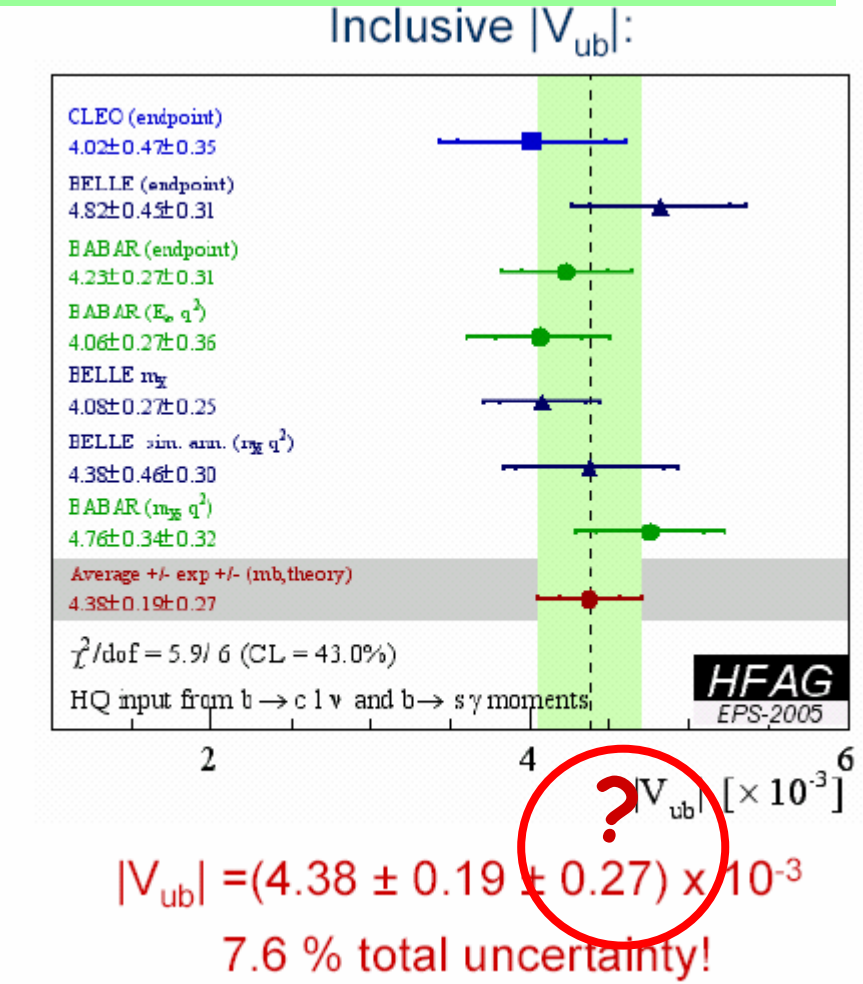
Intense theoretical activity:

- ✓subleading shape functions
- ✓optimization of cuts (P_+,P_- etc)
- ✓weak annihilation contribs.
- ✓Resum. pert. effects
- ✓relation to $b\to s\gamma$ spectrum

A lot can be learned from exp

(on shape function from $b\to s\gamma$, WA, indirect constraints on s.f., subleading effects from cut dependence,...)

REQUIRES MANY COMPLEMENTARY MEASUREMENTS (affected by different uncert.)



$|V_{ub}| = (4.38 \pm 0.19 \pm 0.27) \times 10^{-3}$

7.6 % total uncertainty!

Event generator (with up-to-date theory input) **in progress**

Rare B decays: a more direct way to New Physics in the Flavour sector

Rare processes are interesting when their suppression is associated to some conservation law

Flavor Changing Neutral Currents have no tree level SM sensitive to new degrees of freedom (eg H^+) and to new sources of flavor violation (eg gluino FCNC)

Inclusive rare B decays allow precision tests (OPE+RGE improved pert theory) of the SM and its extensions

$B \to X_s \gamma$: a new physics killer

It is the best measured rare decay
Good agreement with SM strongly constrains most new physics models

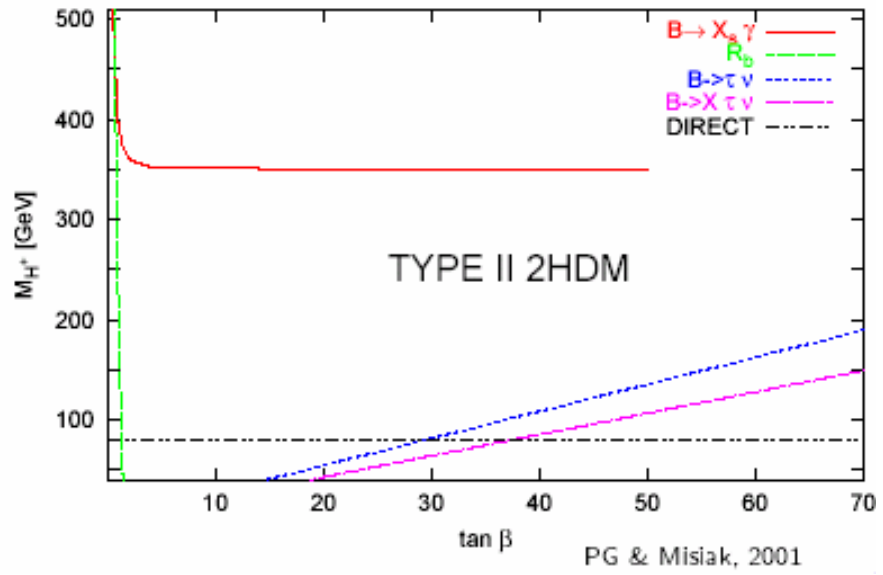
Exp: $\mathcal{B}(B \to X_s \gamma) = (3.55 \pm 0.24) \times 10^{-4}$

SM: $\mathcal{B}(B \to X_s \gamma) = (3.61 \pm 0.30) \times 10^{-4}$

($E_\gamma > 1.6$ GeV) Gambino-Misiak

Need to match ~5% exp error at end of B factories:
NNLO calculation under way
(collaboration with Ferroglia)

charged Higgs mass bounds in typeII 2HDM



Does not carry over to MSSM!
But very strong bounds there too

NEW: Complete NLO calculation in the MSSM with MFV Degrassi,PG,Slavich

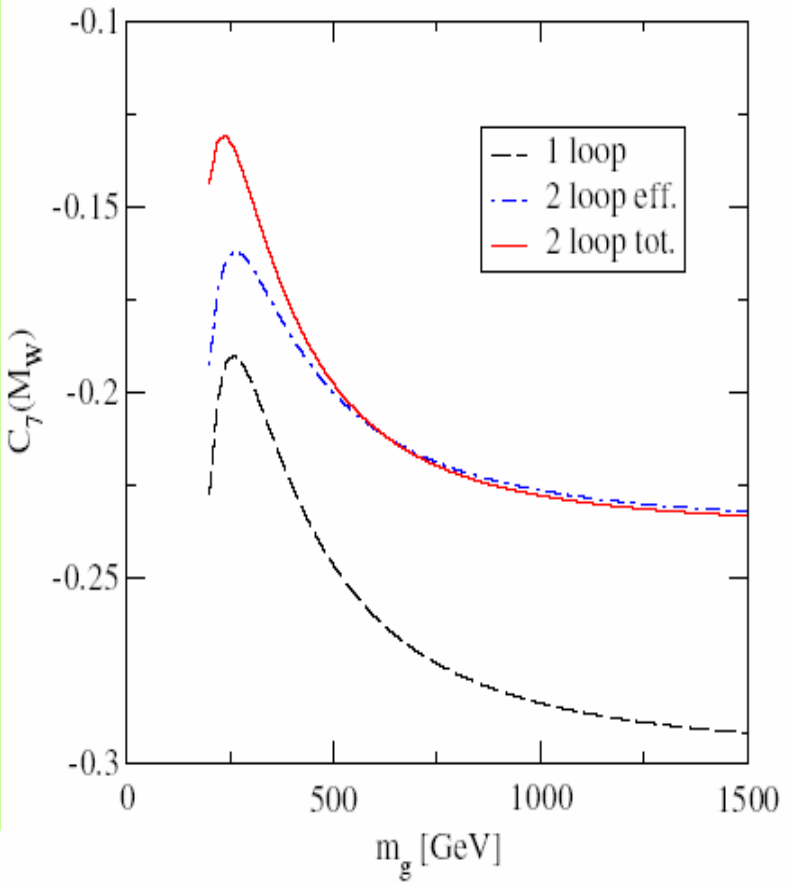
Because of good agreement with SM, FV in the squark sector plausibly small..

Under Minimal Flavor Violation (MFV) the only source of flavor violation is the CKM matrix.

In this predictive framework it is important to have th accuracy ~SM but NLO very tough due to new enhance ment factors etc

For relatively light superpartners results may differ significantly from existing calculations

A representative example



Sommario

Predizioni teoriche all'altezza della precisione sperimentale delle B factories: calcolo di effetti pert e non-pert, studio dell'errore teorico, codici per Babar&Belle, ricerca delle migliori strategie sperimentali.

Decadimenti semileptonici b→c: importanti progressi negli scorsi 2 anni. Ora correzioni radiative EW, update del codice, calcolo di effetti di ordine superiore per permettere 1% su $|V_{cb}|$

Decadimenti semileptonici b→u: studio degli effetti di leading e subleading shape functions, weak annihilation, e perturbativi di ordine superiore; event generator in corso di completamento

Decadimenti radiativi: calcolo NNLO dello spettro del fotone, NLO in MSSM (codice in preparazione)

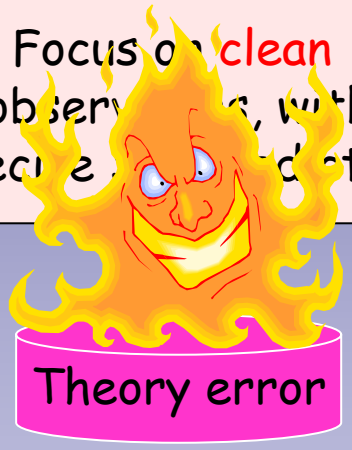
Input di precisione da fisica del flavor saranno importanti nell'analisi dei risultati di LHC per capire gli scenari ancora aperti e la struttura di flavor con essi compatibile

Precision measurements

Probe the quantum structure of the SM

Quantum effects introduce sensitivity to new mass scales beyond reach of present exps

Focus on clean observables, with precise predictions



Indirect signals for New Physics

Indirect searches are complementary to direct searches at accelerators; often anticipate results (charm,top)

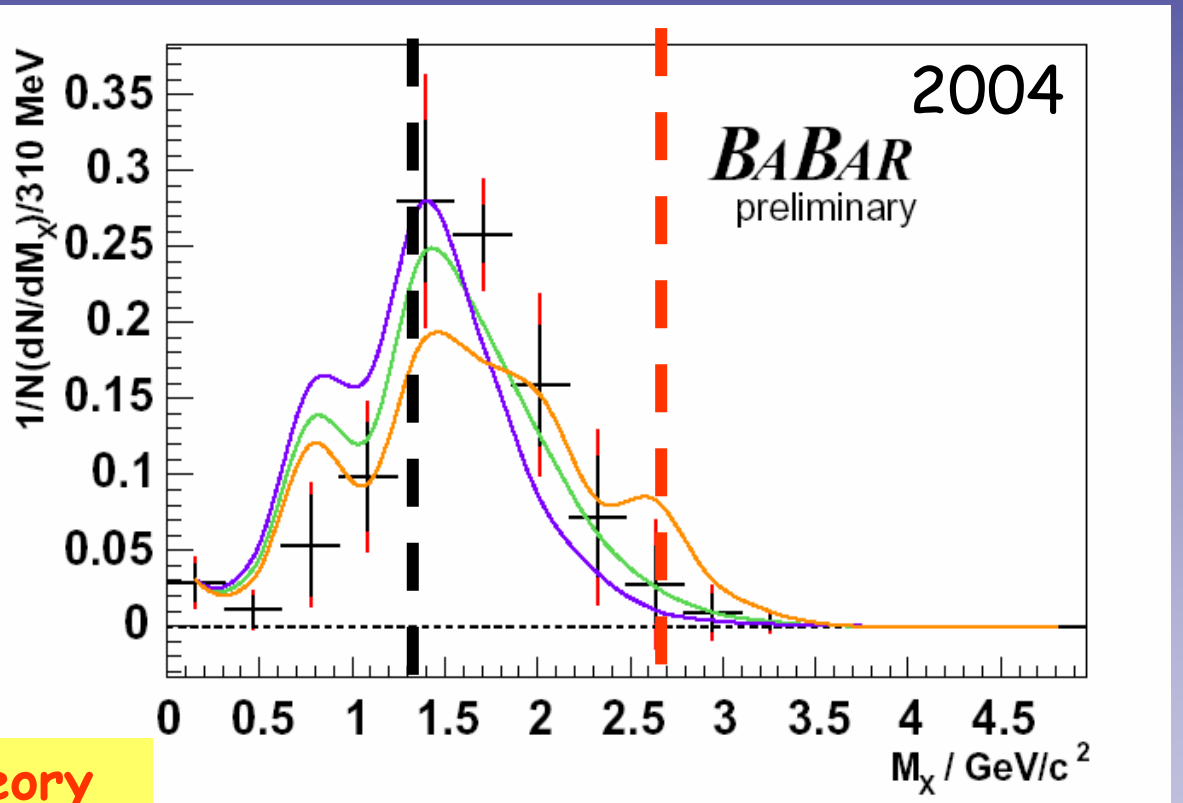
To test **consistency** among DIRECT & INDIRECT data combine constraints from vastly different energies (from m_e to 200 GeV)

Cutting the cuts...

New exp analyses based on fully reconstructed events allow high discri mination of charmed final states

Babar measured M_X moments. Results can be improved by cutting in a milder way than usual

It's time to start using b->u data to constrain sf!



Unfolded M_X spectrum

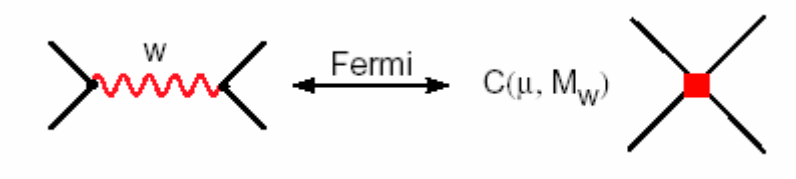
Useful to validate theory and constrain $f(k_+)$ & WA

PG,Ossola,Uraltsev

Un'altra linea di ricerca: b → s transitions

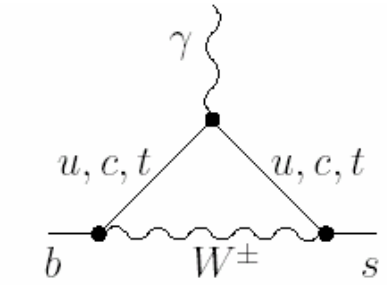
$\Lambda_{QCD} \ll m_b \ll M_W$

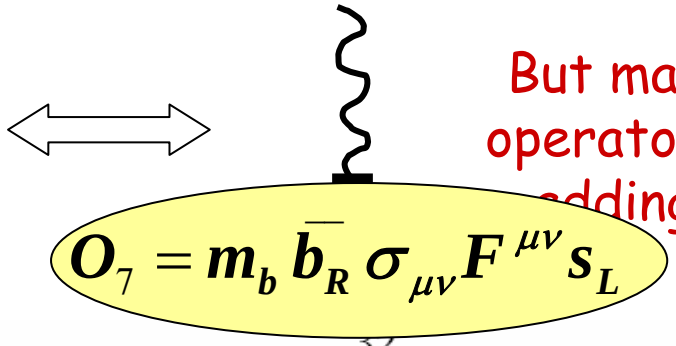
Large L=log m_b/M_W must be resummed.
LO: $\alpha_s^n L^n$, NLO: $\alpha_s^n L^{n-1}$



Tower of local ops
OPE

$m_b \ll M_W$





But many more operators appear adding gluons

$$\mathcal{H}_{eff} = \frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} \sum_{i=1}^{32} C_i(\mu) Q_i$$

The current is not conserved and runs between M_W and m_b
We have AT LEAST 3 scales

Inclusive decays are described by OPE (except charm loop contributions!)