Determination of V_{ub} from semileptonic B decays

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Introduction

- extraction of V_{ub}
  - inclusive/exclusive decays $B \to X_u\, l\nu$ / $B \to \pi/\rho/\eta/\eta'/\omega\; l\nu$
  - $B \to \tau\nu$ (see Y. Kwon talk) WA determination to 14%: not (yet) competitive.
- A precise knowledge of $|V_{ub}|$ is important
  - First point in A. Buras talk...
- Dealing with semileptonic decays relatively easy (reads: non perturbative physics parameterized...)
  - standard determination based upon the assumption that tree-level not significantly affected by new physics at current level of achievable precision;
  - even so, evidence for new physics may arise through inconsistencies between independent determinations

- exclusive approach
  main theoretical uncertainty due to calculations of the form factors, e.g.

$$\frac{d\Gamma(B \to \pi l \nu)}{dq^2} = \frac{G_F^2}{24\pi^3}|V_{ub}|^2 p_\pi^3 |f_+(q^2)|^2$$

V_{ub} [10^{-3}]	FF calculation	
$3.34 \pm 0.12 + 0.55 - 0.37$	Ball-Zwicky (2005)	LC sum rules
$3.40 \pm 0.20 + 0.59 - 0.39$	HPQCD (2006-2007)	unquenched lattice, NRQCD
$3.62 \pm 0.22 + 0.63 - 0.41$	FNAL (2005)	unquenched lattice, HQET
3.38 ± 0.36	FNAL (2009)	different q^2 dependence

- indirect determination of $|V_{ub}|$ by UTfit

$$|V_{ub}| = (3.60 \pm 0.12)\text{x}10^{-3}$$

- inclusive approach (HFAG)

V_{ub} [10^{-3}]	Collab.
$4.06 \pm 0.15 + 0.25 - 0.27$	BLNP
$4.25 \pm 0.15 + 0.21 - 0.17$	DGE
$4.03 \pm 0.15 + 0.20 - 0.25$	GGOU
$3.84 \pm 0.13 + 0.23 - 0.20$	ADFR
$4.87 \pm 0.24 + 0.38 - 0.38$	BLL

Standard Inclusive determination

- OPE factorization of short and long distance dynamics (see Thorsten Ewerth talk)
  - Nonperturbative input given by matrix elements of local operators
  - Coefficients of the operators perturbatively calculated
- parameterization of heavy quark dynamics by means of HQET
  - double series in α_s and Λ/m_b
  - dependence on quark masses and HQET expensions parameters (2 parameters at O($1/m_b^2$), 2 more at O($1/m_b^3$)...)
  - input parameters, included quark masses, determined by a momentum fit with $B \to X_c l\nu$ and $B \to X_s\gamma$ in a particular quark mass scheme

Phase-space region

- the large $b \to c$ background implies cuts and use of differential rate
  - no more "enough" inclusive
- available phase–space to QCD partons strongly reduced; regions where OPE fails become relevant

$$m_X \ll E_X$$

  - Final gluon radiation strongly inhibited $\Rightarrow$ soft and collinear singularities $\Rightarrow$ perturbative expansion of spectra affected by large logarithms $\approx \alpha_S^n \log^{2n}(2E_X/m_X) \Rightarrow$ logs resummation needed to all orders in α_S
  - non–perturbative effect related to a small vibration of the b quark in the B meson (Fermi motion) enhanced at $m_X \approx \sqrt{\Lambda E_X}$

Experimental cuts

- background given by $B \to X_c l\nu$ suppressed by means of different experimental cuts

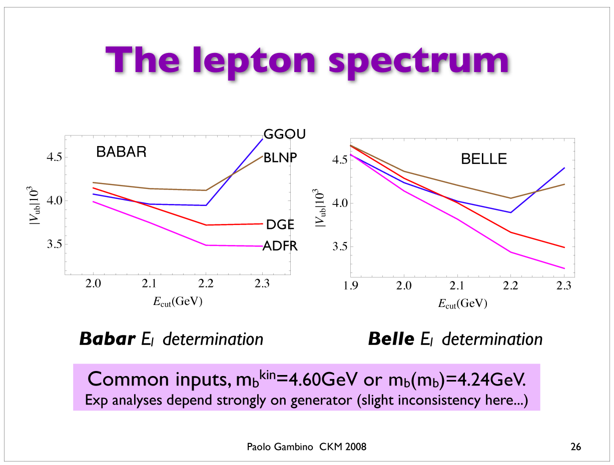
$$E_l > (m_B^2 - m_D^2)/2m_B, \qquad m_X < m_D, \qquad q^2 > (m_B - m_D)^2, \qquad p_+ < m_D^2/m_B$$

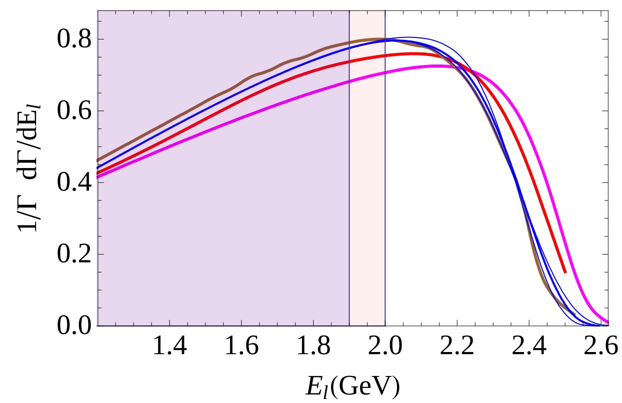
E_l energy of the charged lepton, m_X hadronic invariant mass of the final state, q^2 invariant mass squared of the lepton-neutrino pair, p_+ plus component of the total momentum of the final- state hadrons. From HFAG

1) *BABAR* (E_ℓ) 06	2) Belle (E_ℓ) 05	3) CLEO (E_ℓ) 02	4) *BABAR* (m_X) 08
5) Belle (m_X) 05	6) *BABAR* ((m_X, q^2)) 08	7) Belle ((m_X, q^2)) 04	8) *BABAR* (P_+) 08

	ADFR	DGE	BLNP	GGOU
1)	$3.46 \pm 0.14^{+0.24}_{-0.23}$	$4.06 \pm 0.27^{+0.27}_{-0.26}$	$4.18 \pm 0.24^{+0.29}_{-0.31}$	$4.05 \pm 0.23^{+0.22}_{-0.32}$
2)	$3.26 \pm 0.17^{+0.22}_{-0.22}$	$4.56 \pm 0.42^{+0.28}_{-0.24}$	$4.64 \pm 0.43^{+0.29}_{-0.31}$	$4.53 \pm 0.42^{+0.22}_{-0.30}$
3)	$3.49 \pm 0.20^{+0.24}_{-0.24}$	$3.58 \pm 0.42^{+0.28}_{-0.25}$	$3.83 \pm 0.45^{+0.32}_{-0.33}$	$3.68 \pm 0.43^{+0.24}_{-0.38}$
4)	$4.04 \pm 0.19^{+0.25}_{-0.26}$	$4.23 \pm 0.20^{+0.21}_{-0.16}$	$4.02 \pm 0.19^{+0.27}_{-0.29}$	$3.98 \pm 0.19^{+0.26}_{-0.28}$
5)	$3.93 \pm 0.26^{+0.24}_{-0.24}$	$4.03 \pm 0.27^{+0.26}_{-0.20}$	$3.90 \pm 0.26^{+0.24}_{-0.26}$	$3.86 \pm 0.26^{+0.18}_{-0.21}$
6)	$4.15 \pm 0.27^{+0.24}_{-0.24}$	$4.26 \pm 0.28^{+0.23}_{-0.19}$	$4.32 \pm 0.28^{+0.29}_{-0.31}$	$4.22 \pm 0.28^{+0.38}_{-0.35}$
7)	$3.97 \pm 0.42^{+0.23}_{-0.23}$	$4.20 \pm 0.44^{+0.23}_{-0.18}$	$4.23 \pm 0.45^{+0.29}_{-0.310}$	$4.14 \pm 0.44^{+0.33}_{-0.34}$
8)	$3.56 \pm 0.23^{+0.23}_{-0.23}$	$3.70 \pm 0.24^{+0.31}_{-0.24}$	$3.65 \pm 0.24^{+0.25}_{-0.27}$	$3.43 \pm 0.22^{+0.28}_{-0.27}$

From Gambino talk at CKM08





recent results from Belle $p_l^{\star B} > 1.0$ GeV/c
(arXiv:0907.0379):

$$V_{ub}\,10^3 = 4.37\ \text{(BLNP)}$$
$$= 4.46\ \text{(DGE)}$$
$$= 4.41\ \text{(GGOU)}$$

compatible with other models
overall uncertainty $\sim 7\%$

Four Different approaches

- predictions based on parameterizations of shape function, and OPE constraints
  - BLNP B.O. Lange, M. Neubert and G. Paz, Phys. Rev. D72:073006 (2005), and references therein.
  - GGOU P. Gambino, P. Giordano, G. Ossola, N. Uraltsev, JHEP 0710:058,2007
- predictions based on resummed pQCD
  - DGE Dressed Gluon Exponentiation, J.R. Andersen and E. Gardi, JHEP 0601:097 (2006); [arXiv:0806.4524]
  - ADFR - U. Aglietti, F. Di Lodovico, G. Ferrera , G. Ricciardi, EPJC, Vol. 59 (2009), U. Aglietti, G. Ferrera and G. Ricciardi, Nucl. Phys. B768, 85 (2007) and references therein.

A Shape function primer

in the threshold region OPE and the heavy quark expansions fail (dynamics is influenced by soft and collinear gluons)

$$m_X^2 \sim E_X \, \Lambda_{QCD}$$

an inclusive description is still possible, with the introduction of a non perturbative distribution function (shape function)

- Shape function takes care of singular terms in the theoretical spectrum
  it has the role of a momentum distribution function of the b quark in the B meson.

- at leading order is universal
  It can be measured in the radiative decay $\bar{B} \to X_s \, \gamma$ and the results applied to the calculation of the $\bar{B} \to X_u \, l \, \bar{\nu}_l$ (or independent relation between observable) (f.i Mannel, Recksiegel, 1999)

- Subleading shape functions are difficult to constrain and are not process independent
  only first two moments of the leading shape function reasonably well constrained, (related to m_b and μ_π respectively)

- the cuts give rise to a large dependence on m_b

resummed pQCD approaches

Exploit the way in which the Sudakov resumming can provide guidance in parameterizing non perturbative Fermi motion effects

In the Mellin space, at $N \to \infty$, the triple differential distributions factorize to all orders

$$d\Gamma \sim HJS$$

The function J and S in the partonic process satisfy Sudakov evolution equations

The soft factor S depends on the softest scale and includes non perturbative corrections

- DGE

  Solutions of Sudakov evolution equations, are formulated at all order as a scheme invariant Borel sum. The DGE prescription consist into integrating the Borel integral by using the principal value prescription. A definite prediction for the parametric form of the power corrections emerge from the resummation formalism and parameters are fitted by data.

- ADFR

  It introduce nonperturbative effects by introducing an effective, infrared-safe, low energy QCD coupling constant, which mimics, in this specific threshold framework, non perturbative Fermi motion effects

ADFR idea is to introduce *some* (the significative ones for the process) non perturbative effects in the purely perturbative resumming formula itself, by a proper effective QCD coupling

physical picture: assume that B fragmentation into the b-quark and the spectator quark can be described as a radiation process off the b with a proper coupling

main points

- universality of perturbative threshold resummation

- non-perturbative effect (Fermi motion) relegated into an effective QCD coupling, which is inserted in the standard soft-gluon resummation formulas
  - resummation formulas are automatically regulated, no need for a prescription
  - universality of the coupling (radiative decay processes as well as B fragmentation processes)
  - coupling constructed on the basis of minimal analyticity arguments
  - no free parameters

- no need to add non perturbative contribution through shape function

Soft and collinear resumming

In PT the shape function has a resummed expression in N moment space

$$f_N = \exp \int_0^1 dy \frac{(1-y)^{N-1}-1}{y} \left\{ \int_{Q^2y^2}^{\mu_{0F}^2} \frac{dk^2}{k^2} A[\alpha_S(k^2)] + D[\alpha_S(Q^2y^2)] \right\}, \qquad y \equiv \frac{E_X - p_X}{E_X + p_X} \simeq \frac{m_X^2}{4E_X^2}$$

$\mu_{0F} \approx Q$ is a hard factorization scale

- A, D soft radiation collinearly and non collinearly enhanced
- soft scale Q^2y^2, goes to zero very fast for $y \to 0^+$, i.e. in the threshold region.
  - $\Rrightarrow$ the coupling leaves the perturbative phase and the resummation scheme breaks down
  - Resummed perturbation theory signals a non-perturbative effect coming into play, namely Fermi motion.

Relation between B fragmentation and B decay

In B fragmentation a similar factorization formula holds in PT (Mele, Nason, 1991, Collins, 1998)

$$e^+ e^- \to Z \to B + X$$

the initial condition of the fragmentation function D^{ini} has the same resummed expression as the shape function:

$$D_N^{\text{ini}} = f_N \,.$$

- explicitly checked up to and including the single logarithm at two loop by Feynman diagram computation (the coefficient D_2 is the same)
- believed to be true to all orders by a general argument based on Wilson lines (Gardi, 2005)

the perturbative shape-function includes soft effects from perturbative origin only (as soft gluon radiation), but cannot describe truly non-perturbative effects

We assume that the non-perturbative effects in the shape function and in the initial fragmentation function can be described by the same effective low-energy QCD coupling
more precise B fragmentation data can be used to tune the model

Prescription for the effective coupling

minimal possible "shifting" from standard QCD coupling

$$\alpha_S^{lo}(Q^2) = \frac{1}{\beta_0 \log Q^2/\Lambda_{QCD}^2},$$

the effective coupling

1. has the same physical discontinuity as α_S along the cut $Q^2 < 0$ (related to the decay of a time-like gluon into secondary parton);

2. is analytic elsewhere in the complex plane (thus removing the unphysical simple pole for $Q^2 = \Lambda^2$–"Landau ghost")

3. includes secondary emissions off the radiated gluons, with the absorptive parts of the gluon polarization function(the "$-i\pi$" terms)

$$\tilde{\alpha}_S(k_\perp^2) = \frac{i}{2\pi} \int_0^{k_\perp^2} ds \, \mathrm{Disc}_s \frac{\bar{\alpha}_S(-s)}{s}$$

where $\bar{\alpha}_S$ is the ghost–less coupling built according to the preceding prescriptions.

1.2. By requiring only the same discontinuity of the standard coupling (Landau pole subtracted) at one loop:

$$\bar{\alpha}_S(Q^2) = \frac{1}{\beta_0}\left[\frac{1}{\log Q^2/\Lambda^2} - \frac{\Lambda^2}{Q^2-\Lambda^2}\right]$$

the last term produces a series of power corrections expanded for $Q^2 \gg \Lambda^2$.

3. fragmentation and decay data are better described by $\tilde{\alpha}_S$, including secondary emissions off the radiated gluons

Secondary emissions produce the decay of the radiated gluons into secondary partons.

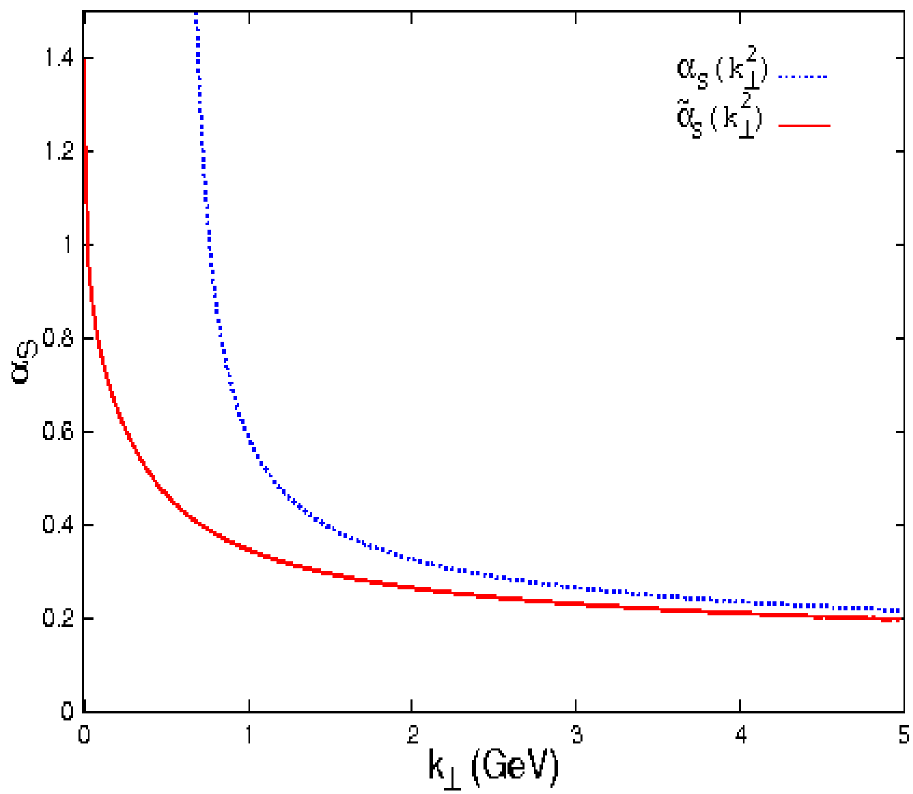
In the case of form factors, inclusive with respect to gluon decays, the effect is replacing the tree-level coupling with an effective coupling evaluated at the transverse momentum of the primary emitted gluon

$$\tilde{\alpha}_S(k_\perp^2) = \frac{i}{2\pi}\int_0^{k_\perp^2} ds\, \mathrm{Disc}_s\, \frac{\bar{\alpha}_S(-s)}{s}$$

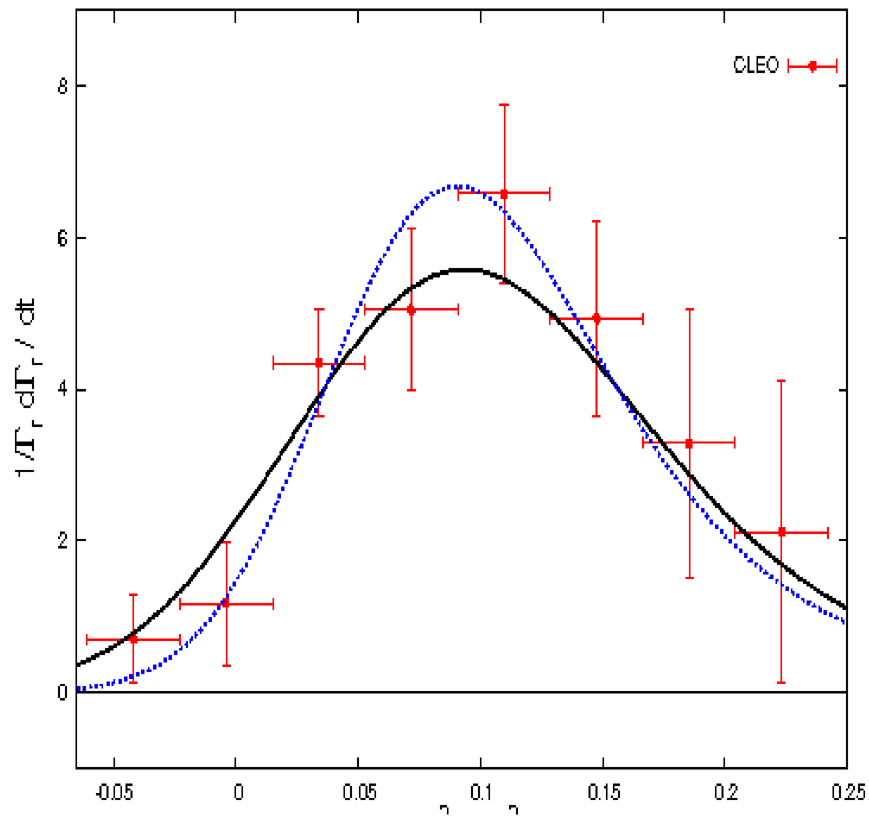
By including the $-i\pi$ terms in the integral over the discontinuity — i.e. the absorptive effects — the effective coupling

$$\tilde{\alpha}_{lo}(k_\perp^2) = \frac{1}{2\pi i\beta_0}\left[\log\left(\log\frac{k_\perp^2}{\Lambda^2} + i\pi\right) - \log\left(\log\frac{k_\perp^2}{\Lambda^2} - i\pi\right)\right]. \qquad (1)$$

QCD couplings in NNLO (blu, standard, red, effective)



Radiative decay $B \to X_s\gamma$ photon spectrum from CLEO data
t=m_X^2/m_B^2



theoretical errors estimates

- different methods are compared to determine the error on the value of $|V_{ub}|$

$$\mathcal{B}\,[p \in (a,b)] = \tau_B\,\Gamma\,[B \to X_u\,l\,\nu_l,\ p \in (a,b)] \qquad \text{vs} \qquad = \frac{\mathcal{B}_{\mathrm{SL}}}{1+\mathcal{R}_{c/u}}\,\frac{\Gamma\,[B \to X_u\,l\,\nu_l,\ p \in (a,b)]}{\Gamma\,[B \to X_u\,l\,\nu_l]}$$

where

$$\mathcal{B}_{\mathrm{SL}} \equiv \frac{\Gamma(B \to X_c\,\ell\,\nu_\ell) + \Gamma(B \to X_u\,\ell\,\nu_\ell)}{\Gamma\,[B \to (\text{anything})]} \qquad \mathcal{R}_{c/u} \equiv \frac{\Gamma(B \to X_c\,\ell\,\nu_\ell)}{\Gamma(B \to X_u\,\ell\,\nu_\ell)}$$

the two methods basically involve different inclusive quantities, this error allows a cross–check of their evaluations (f.i. b and c masses adopted)

- inclusive quantities are computed both in the $\overline{MS}$ and pole schemes for the quark masses. Since in general higher–order corrections are different in the two schemes, that should provide an estimate of the size of unknown higher–order effects

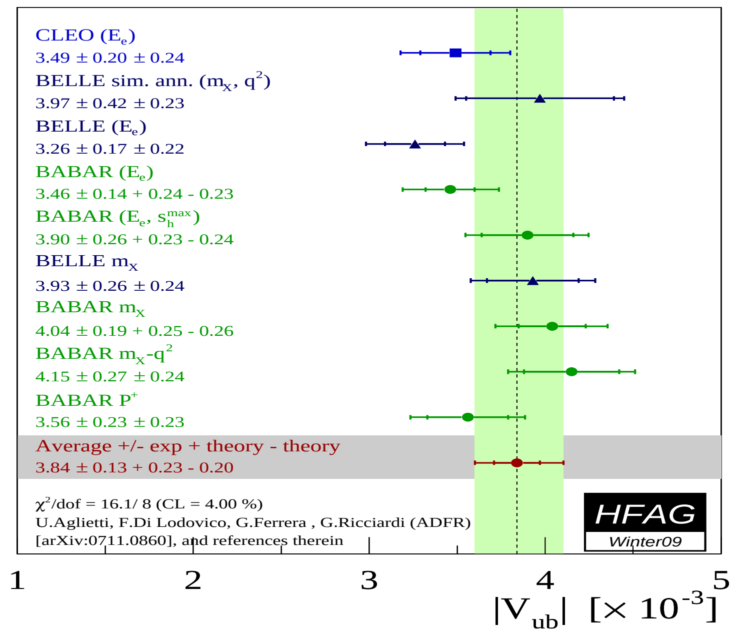
- the order at which the rate is computed is varied from the exact NLO to the approximate NNLO; that should provide a reasonable estimate on the truncation error

- all the parameters which enter in the computation of $|V_{ub}|$ are varied within their errors, as given by the PDG

- the error on the modelling of the threshold region can only be estimated by considering different decay spectra, in which presumably threshold effects enter in different ways.

Extracted values of $|V_{ub}|$ for all the uncorrelated analyses and their corresponding average

errors are experimental and theoretical, respectively. The experimental error includes both the statistical and systematic errors



Conclusions

- The larger data sets now available allow less restrictive kinematic cuts ($\sim$ 90% of the total rate)
  significant reduction of the impact of theoretical uncertainties
  A preliminary result from BELLE uses $E_l > 1.0$ GeV, and quotes an experimental uncertainty of 7% on $|V_{ub}|$

- on the theoretical side, space for improvement on all approaches
  WA diagrams impact, high q^2 singularity in the shape function, further constraints on SL shape function and value of m_b

- model for QCD non–perturbative effects based on an effective ghostless QCD coupling.
  no free parameters, consistency with radiative decays, and B-meson fragmentation data at the Z^0 peak
  smaller Sudakov suppression compared to literature (larger hadronic form factors and smaller $|V_{ub}|$'s)

- possible new physics distinguishing between exclusive and inclusive