First Measurement of the Ratio $B(t \to Wb)/B(t \to Wq)$ and Associated Limit on the CKM Element V_{tb}

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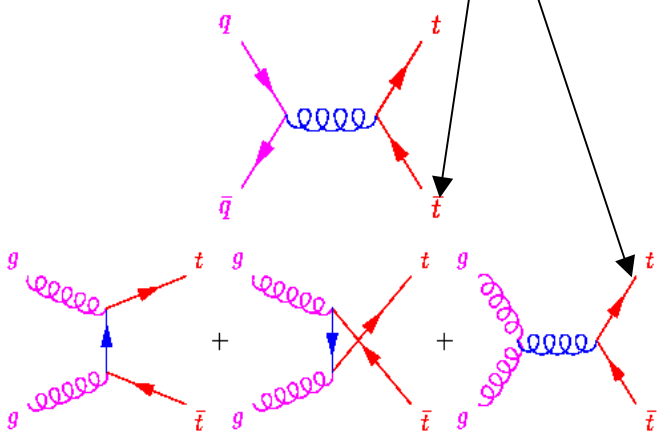
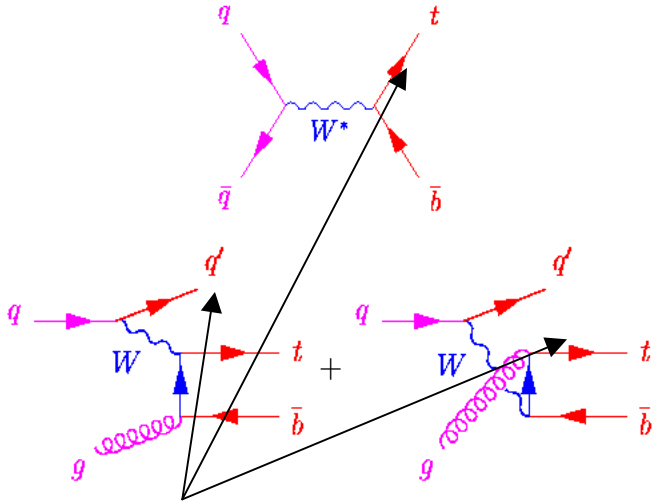
to be submitted to Phys.Rev. Lett.

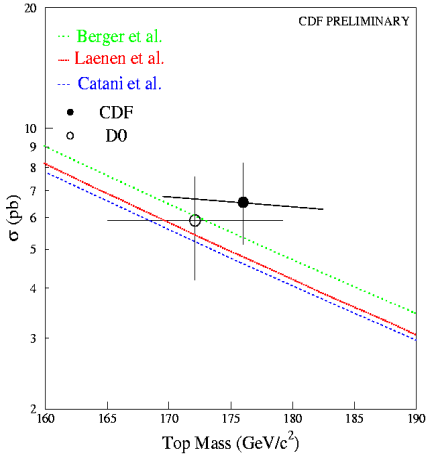
Top and the Wtb vertex

In usual ttbar production Wtb vertices appear in the top decay chain

In "single top" processes production is proportional to the Wtb vertex







As a reminder: CDF measures only ttbar pair production under the assumption that the branching fraction

$$\mathcal{R} \equiv B(t \to Wb)/B(t \to Wq) = 1$$

This is the first time we check this assumption

The CKM Element V_{tb}

In the Standard Model (SM) quark mass states are NOT the weak eigenstates.

The mixing matrix for the six quarks is known as the CKM matrix

- ⇨ named after N.Cabibbo (who first used this parametrization in the sixties with a 2x2 matrix) and
- ⇨ M. Kobayashi and T.Maskawa generalization to 3 quark doublets (in 1973)

$$\Rightarrow A_{ij} = \begin{matrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{matrix}$$

- ⇨ The matrix can be expressed in terms of 3 angles and one phase. The latter being usually held responsible for CP violation in weak interactions.

The CKM matrix, part II

- Most important (and well known) is the unitarity of the matrix, which has several implications (more later)
- Its elements can (in principle) be obtained by studying the weak decays and interactions of the quark in question (naïve approach). Take top quark for example:
  $\Gamma = (192\pi^3)^{-1} G_F m_t^5 \mid V_{tb} \mid^2 f(m_b, M_W, m_t)$
  $f \propto m_t^{-2}(1-M_W^2/m_t^2)^2(1+2M_W^2/m_t^2)$
  and m_b has been neglected
- As a matter of fact top is not typical, for example in the extraction of V_{cb} from B semileptonic decays large uncertaintes come from:
  - → quark masses
  - → QCD corrections to final states
- The extraction of a CKM element is an art.

From top to V_{tb}

V_{tb} has never been measured directly

⇨ Assuming 3 generation unitarity, from a global fit to the CKM matrix :

$|V_{tb}| = 0.9989 \div 0.9993$ (at 90% CL)

Notice: with more than 3 generations:

$|V_{tb}| = 0. \div 0.9993$ (at 90% CL)

The *direct* determination of V_{tb} can proceeds through the measurement of the single top cross section (which is $\propto$ to V_{tb})

⇨ Experimental perspectives for this measurement will not be discussed here

However $|V_{tb}|$ is ***connected*** to

⇨ $\mathcal{R}(t \to Wb) = B(t \to Wb)/B(t \to Wq)$

$$R = \frac{|V_{tb}|^2}{|V_{ts}|^2 + |V_{td}|^2 + |V_{tb}|^2}$$

Our measurement:
$\mathcal{R}(t\to Wb) = B(t \to Wb)/B(t \to Wq)$

We measure the ratio $\mathcal{R}$ of Branching Fractions of top into final states containing b with respect to top into all final states

- Assumptions:
  - Decays of top into final states not containing W are negligible
  - Those decays are not a "background" to $t\to Wb$
- Basic idea
  - Obtain a top sample selected without the requirement of b-tagging
  - Measure $\mathcal{R}$ by studying the b-tags in the event in our sample

Top Sample (109.4 pb^{-1})

- Dilepton sample (DIL)
  - two leptons (e or μ) with P_t>20 GeV/c
  - Missing E_t> 25 GeV
  - two jets with E_t> 10 GeV in $|\eta|$ < 2.0
  - 75< $M_{\mu\mu}$,M_{ee} < 105 GeV/c^2
- Kinematical sample (l+jets)
  - one lepton (e or μ) with P_t>20 GeV/c , $|\eta|$ < 1
  - Missing E_t> 20 GeV
  - 3 jets with E_t> 15 GeV and $|\eta|$ < 2 and a 4^{th} jet with E_t> 8 GeV and $|\eta|$ < 2.4
  - very much similar to the top mass sample but for the removal of a χ^2 cut on the top mass hypothesis
- Samples have no overlap
  - in 110 pb^{-1} of CDF data: 163 W4J and 9 DIL

Apply b-tagging

Secondary Vertex Tagging (SECVTX)

- search jets for displaced vertices with 2 or more tracks
  - efficiency to tag a single b jet in a top event: $\varepsilon_s = (37. \pm 3.7)$ %
  - fake rate $\approx$ 0.5 %

Soft Lepton Tagging (SLT)

- search for low (>2GeV/c) Pt tracks (e,μ) matched with calorimeter clusters and segments in muon chambers
  - efficiency $\varepsilon_l = (10.2 \pm 1.0)$ %
  - fake rate: $\approx$ 2 %

Procedure to extract $\mathcal{R}$

Model the data (divided in bins according to their b-tagging status)

- keep $\mathcal{R}$ as a parameter
- use a likelihood procedure to extract $\mathcal{R}$

- as input to the likelihood (besides the data itself):
  - acceptances
  - background
  - b-tagging efficiencies

Tagging status of samples:

To optimize the use of the tagging information, each sample is divided in 4 bins

- ⇨No SVX or SLT tags
- ⇨No SVX, at least 1 SLT tag
- ⇨1 SVX tag
- ⇨2 SVX tags

class	NoSVX No SLT	NoSVX 1 SLT	1 SVX	2 SVX
	00	01	1	2
DIL	6	n/a	3	0
l+jets	126	14	18	5

Modeling of data

The number of events in each class is described in terms of $a_i$cceptances (to have 0,1,2 b jets in a top event), tagging $\varepsilon_l$fficiencies and backgrounds (F_i) as:

$$N_{00} = N_{t00} + F_{00}$$
$$N_{01} = N_{t01} + F_{01}$$
$$N_1 = N_{t1} + F_1$$
$$N_2 = N_{t2} + F_2$$

$$N_{t00} = n_0 + n_1(1-\varepsilon_s)(1-\varepsilon_l) + n_2(1-\varepsilon_s)^2(1-\varepsilon_l)^2$$
$$N_{t01} = n_1\varepsilon_l(1-\varepsilon_s) + 2n_2\varepsilon_l(1-\varepsilon_s)^2$$
$$N_{t1} = n_1\varepsilon_s + 2n_2\varepsilon_s(1-\varepsilon_s)$$
$$N_{t2} = n_2\varepsilon_s^2$$

$$n_0 = N_{top}(a_0 + a_1(1-R) + a_2(1-R)^2)$$
$$n_1 = N_{top}(a_1R + 2a_2R(1-R))$$
$$n_2 = N_{top}a_2R^2$$

Input to the fit-acceptances

Accepances (and efficiencies) are obtained using a ttbar Monte Carlo (Pythia) combined with a detailed simulation of the detector response.
Acceptances are defined per jet:
a_i is the fraction of events containing i (i=0,1,2) b jets

To reduce impact of systematical uncertainties only ratios are considered and the total number of ttbar events is left as a parameter

DIL sample

- acceptance ratios:
  - $a_1/a_0 = 14.4 \pm 1.4$
  - $a_2/a_0 = 58.5 \pm 5.8$

l+jets sample

- acceptance ratios
  - $a_1/a_0 = 11.8 \pm 1.2$
  - $a_2/a_0 = 38.7 \pm 3.9$

Input to the fit-background

Background in the untagged sample:
mainly due to associated production of W+light quark jets

Background in the tagged sample:
mainly due to associated production of W+heavy quark jets
with smaller contribution due to bbar, dibosons, DY, $Z \rightarrow \tau\tau$

Starting values of background calculated a la Method 2 but the fitting procedure allows iterative correction for $\mathcal{R} \neq 1$

DIL sample

- backgrounds
  - $F = 2.4 \pm 0.5$
  - $F_1 = 0.1 \pm 0.04$
  - F_2 n/a (negligible)

l+jets sample

- backgrounds
  - $F = 119 \pm 11$
  - $F_{01} = 7.2 \pm 1.6$
  - $F_1 = 3.3^{+2.3}_{-1.2}$
  - $F_2 = 0.2 \pm 0.1$

Backgrounds to non tagged events obtained iteratively by the fitting procedure as: $F_{00} = F-(F_{01}-F_1-F_2)$

The Likelihood function

The binned likelihood function assumes as input:

- acceptances, efficiencies, background (each with associated uncertainties)
- number of events in each class

returns (along with other parameters)

$\mathcal{R}(t \to Wb)$

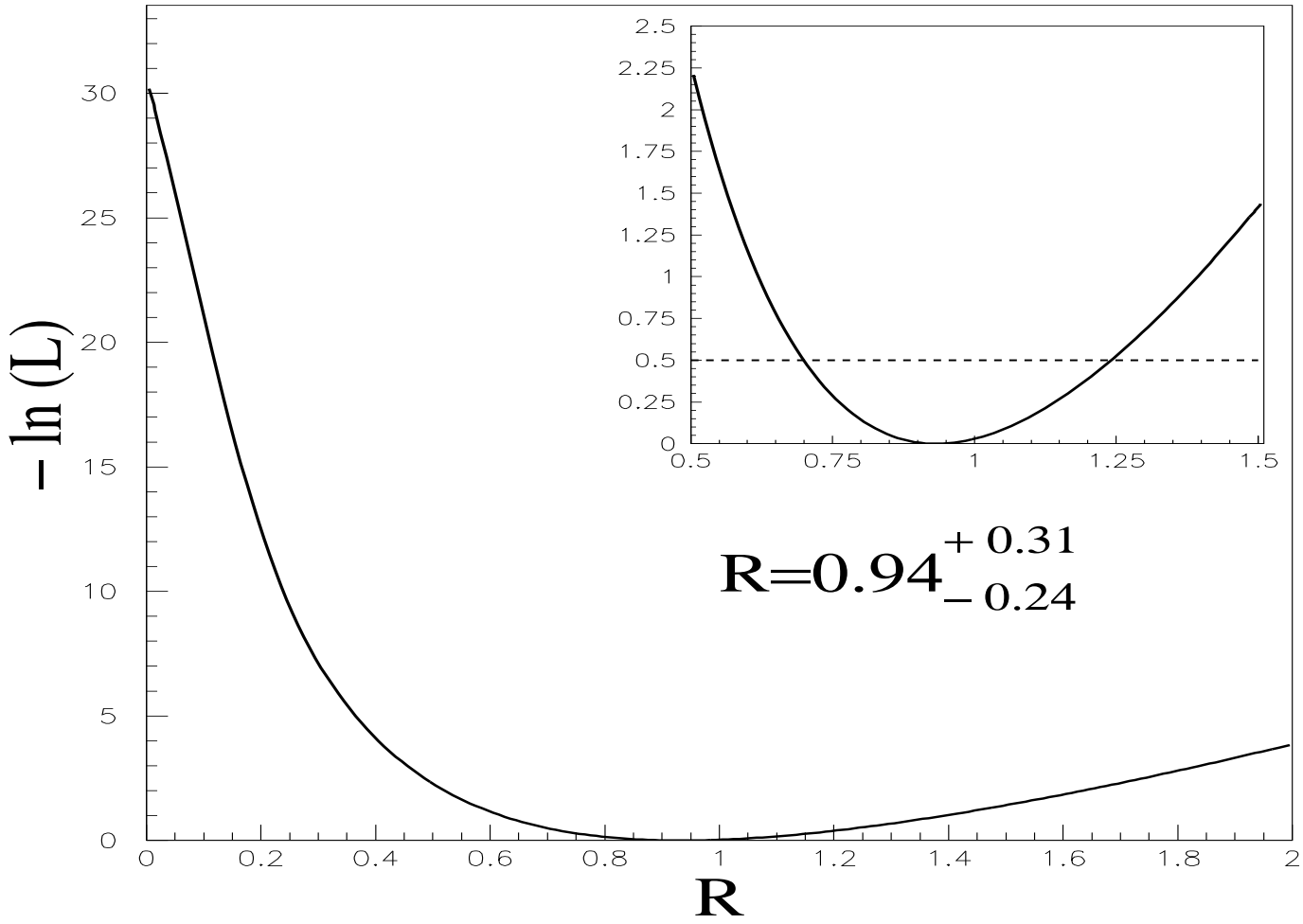
without any a priori assumption on its value

- As the two samples are orthogonal, the likelihood is the product of the two likelihoods:

$$L = L_{_l+jets} L_{_dil}$$

Fit Result

Fit returns the value for $\mathcal{R}$, the ratio of branching fractions. We plot -ln (L):



The Likelihood function

A few questions:

- are we sensitive to $\mathcal{R}\neq 1$?
- is the returned error reasonable?
- what is the impact of systematical uncertainties?

- yes

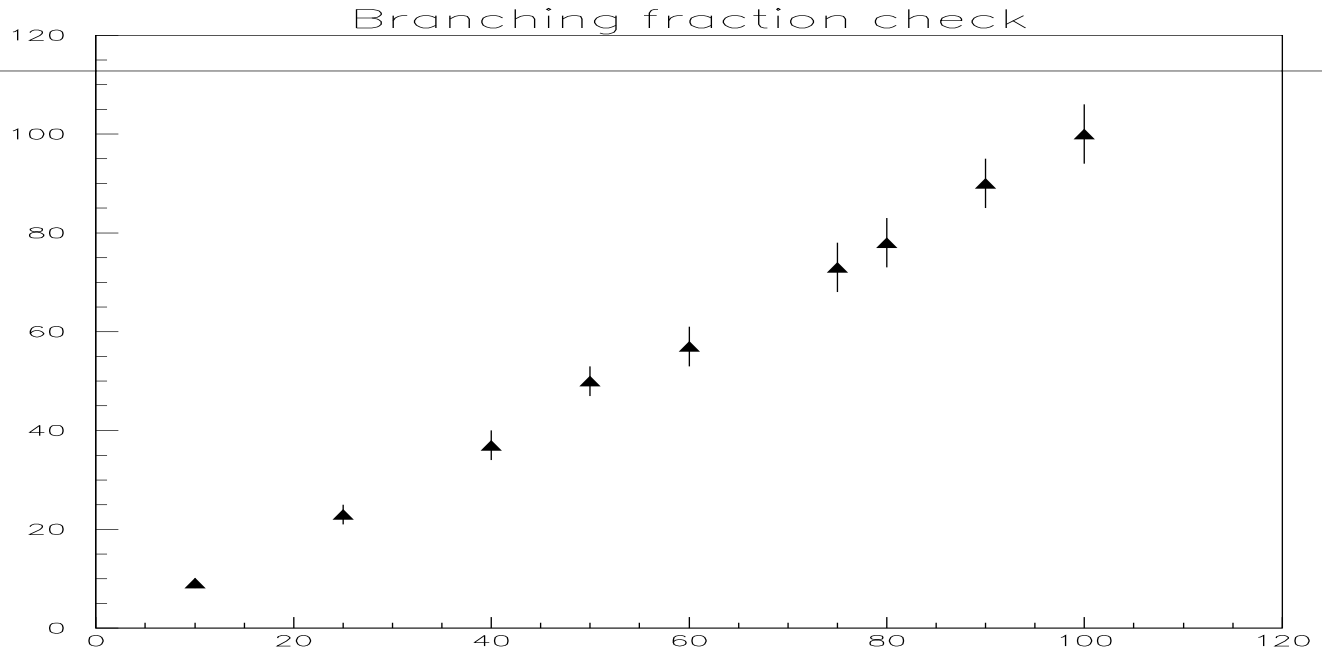
- yes

- accounts for about .16 out of $\approx$.29 (symm.)

Sensitivity

We performed a check using a toy MC:

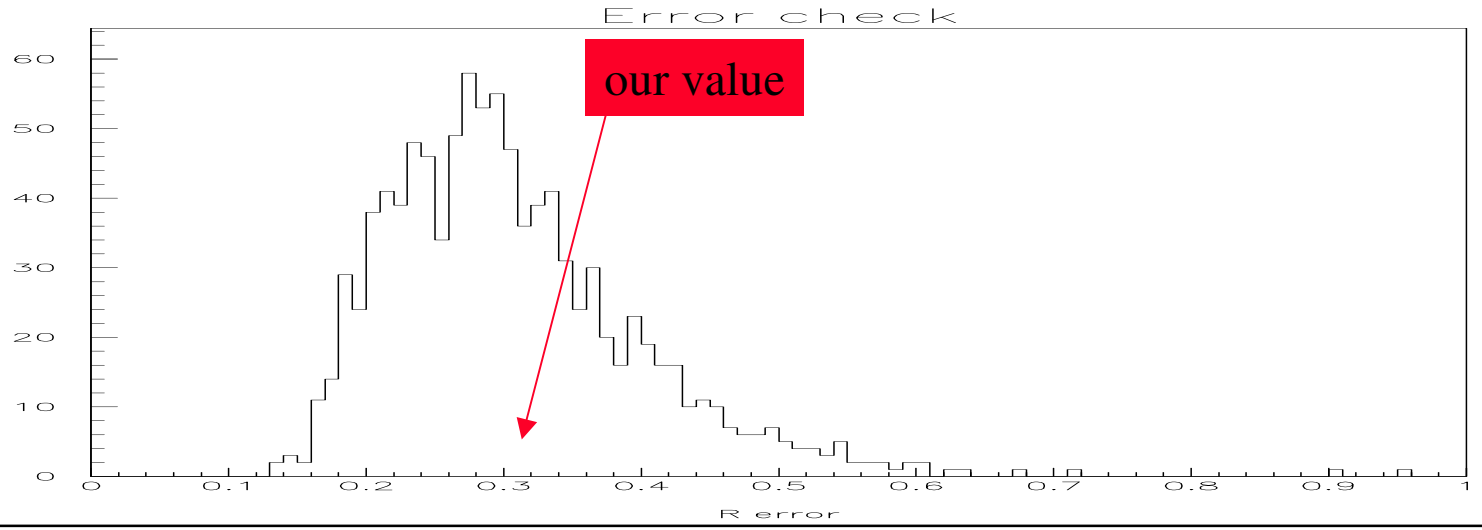
- take a MC sample, generated with $\mathcal{R}$=1
- change by hand the branching fractions
  - reassign number of event in each class according to the new BF
  - plot reconstructed $\mathcal{R}$ vs generated:



Error estimates

Does our likelihood return a reasonable value?

- Check by running a zillion pseudoexperiment and look at the output. Recipe:
  - Fix the total number of events in a given sample
    - → extract the total number of bckgd events
    - → subtract this number to the total number of events (this defines the size of the ttbar subsample)
    - → Now split the ttbar events in the different bins
    - → split bck events in each bin according to our S/B ratio



Uncertainty on $\mathcal{R}$

The two contributions can be *separated* in

- ☞≈0.24 (stat.)
- ☞≈0.16 (syst.)
  - ⇨ We studied a bunch of systematical effects
    - → As most of the systematical uncertainty comes from the uncertainties on SVX and SLT tagging efficiencies, we take the same approach as the x-s paper and do not quote it separately
    - → The second biggest source is due to the background subtraction
    - → in the result there are also included smaller effects from Energy scale (mainly on the acceptances) etc.

☞ However, the CL limit does not change by an appreciable value, as it is dominated by the statistical error.

Confidence Limits

Limits for R at 90 and 95 % CL are obtained in a standard way:

$$P_{R>\bar{R}} = \frac{\int_{\bar{R}}^{1} dR \int d^n\vec{x}\, \mathcal{L}(R,\vec{x})}{\int_{0}^{1} dR \int d^n\vec{x}\, \mathcal{L}(R,\vec{x})}$$

Result is R >0.61 (0.56) @90 (95) % C.L.

From $\mathcal{R}$ to V_{tb}

We measure $\mathcal{R}$, however:

- people are mostly interested in V_{tb}
- $\mathcal{R}$ and V_{tb} are strictly related: under the 3 generation hypothesis and using the unitarity property of the CKM matrix: $\mathcal{R} = |V_{tb}|^2$ from which:

  - $\Rightarrow |V_{tb}| = 0.97^{+0.16}_{-0.12}$ or
  - $\Rightarrow |V_{tb}| > 0.78\ (0.75)$ at 90 (95) % C.L.

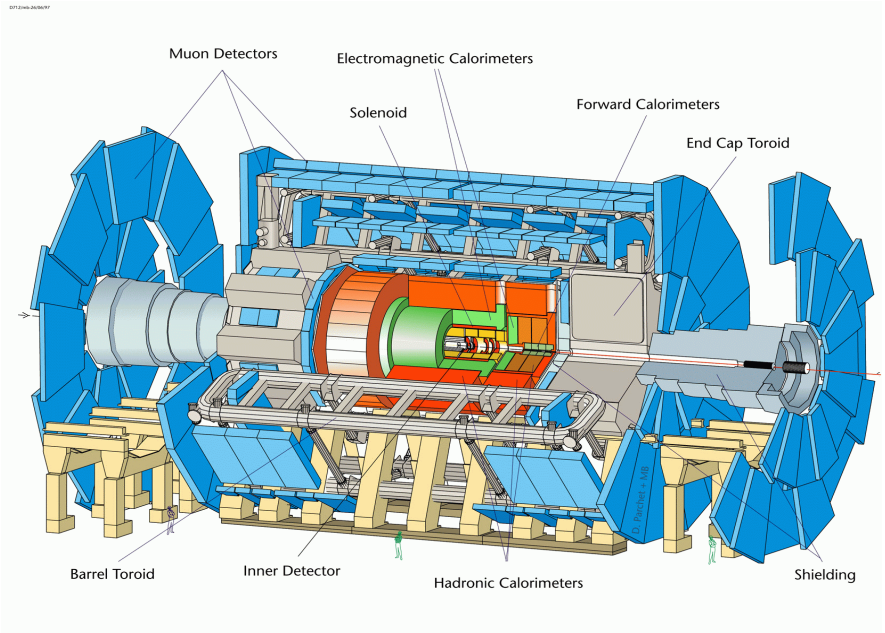
- This result, although limited by statistics is consistent with indirect limits obtained from global fits

From $\mathcal{R}$ to V_{tb} -II

If we release the 3 generation hypothesis very little can be said, unless we make further assumptions:

- $R = |V_{tb}|^2/(|V_{tb}|^2+|V_{td}|^2+|V_{ts}|^2+|V_{tb'}|^2)$
- again the denominator is equal to 1 (4x4 unitarity).
  - if we assume that $|V_{tb'}|=0$ we can obtain some limits on Vtb, otherwise we are not sensitive
  - In other words our measurement of $\mathcal{R}$ provides information on the *relative* size of V_{tb} with respect to the other CKM elements related to top decays

Perspectives for the future

As my personal conclusion I want to thanks the gods for pushing us through this long period.

It took very long to write this paper, as we were involved in the future of our field, and possibly of $\mathcal{R}$ and V_{tb} measurement…