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Rare decays at LHCb

Edinburgh
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LHCb: What, where, when

A second generation *B*-physics experiment.

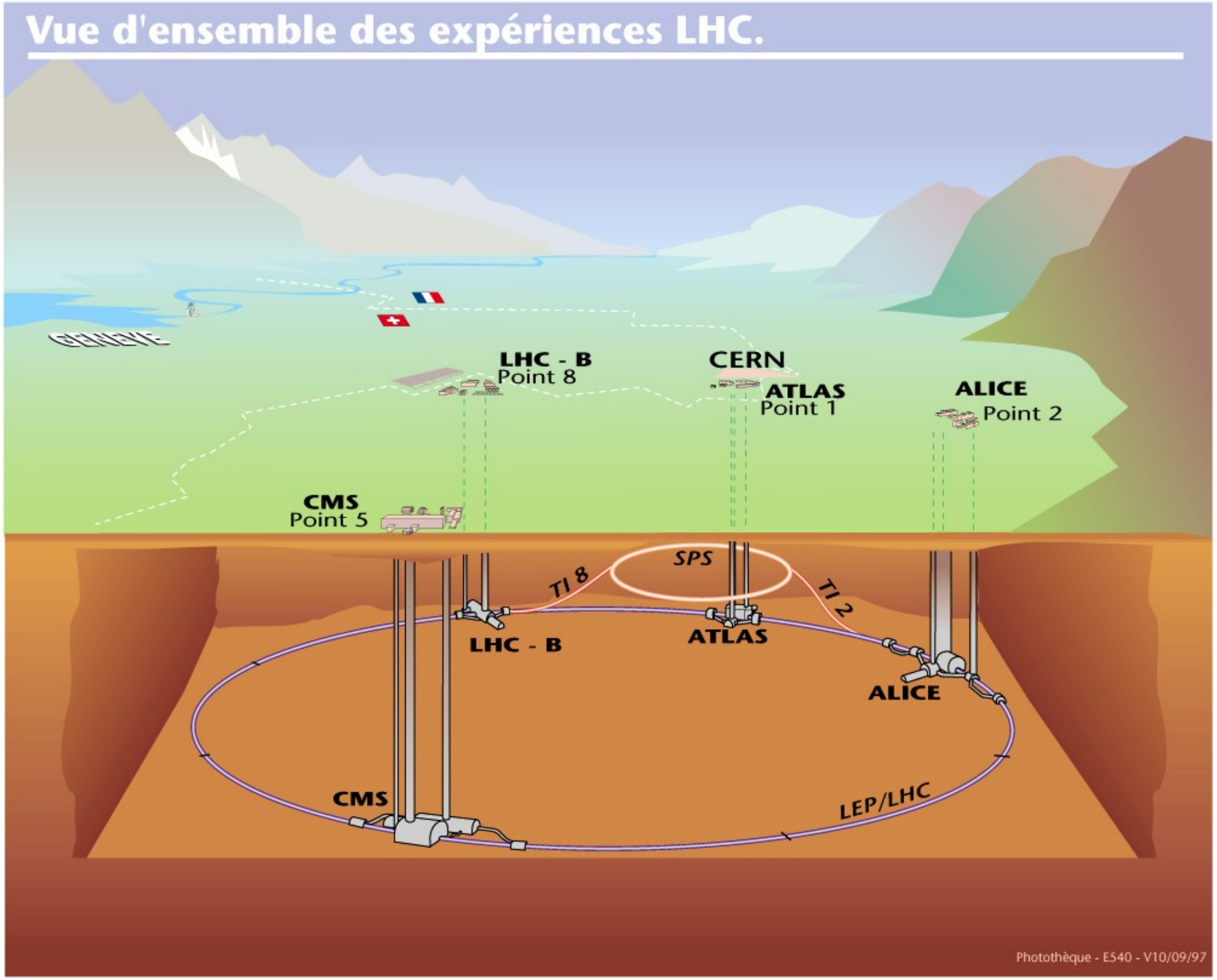
CP violation, oscillations and rare decays.

Source of *B*-mesons will be from the 14 TeV proton-proton collisions at the LHC.

Low integrated luminosity pilot run in 2007.

Expect design luminosity of 2×10^{32} cm^{-2} s^{-1} in 2008

Maybe increase luminosity towards 10^{33} cm^{-2} s^{-1} later



Why a B factory?

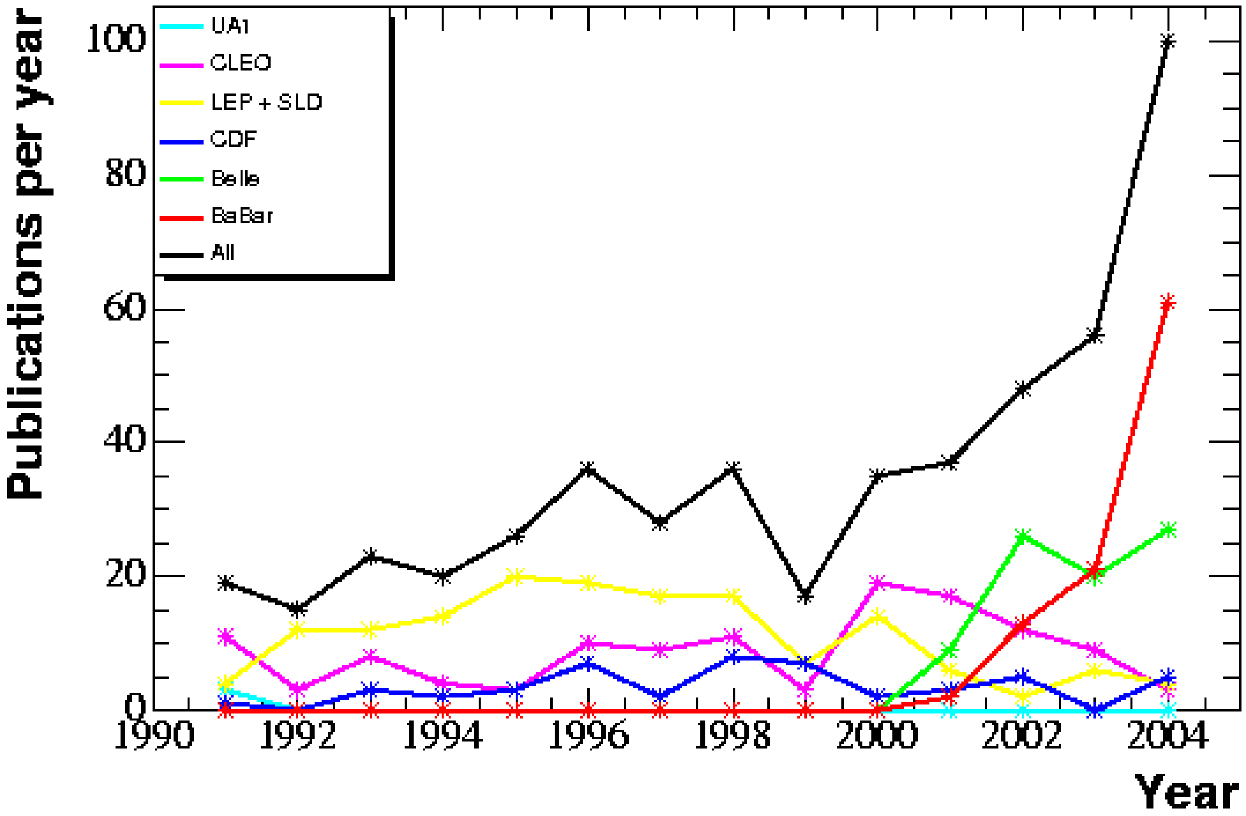
- Physics beyond the Standard Model has to explain the lack of Flavour Changing Neutral Currents:
  - New physics must be sensitive to flavour.
  - Flavour physics is the only way to investigate this.
- We have direct or indirect access to all the matrix elements of the CKM matrix.
- Discover New Physics from analysis of loop and penguin mediated processes.
  - CP violation effects are large.
  - Inconsistencies between different *B* decays.
  - Phases in SUSY or other New Physics only visible through *CP* violation studies.
- Search for rare *B* decays.

Why a *B* factory?

- Will be complimentary to direct searches at ATLAS and CMS for new physics.
- Anything else is worse!
  - Hadronic effects make all (but a few very rare) decays in the Kaon sector hard to interpret in terms of CKM elements.
  - SM phases in *D*-meson decays very small.
    - Any measurement of *CP* violation will be a sign of New Physics.
    - In addition most extensions to SM predict small effects though.
    - Interpretation difficult
  - The top quark is too hard to produce and decays too fast.

Is *B* physics an active field?

Number of publications in the last 15 years.



Numbers are my own and has uncertainties – articles wrongly categorised, some proceedings included etc.

The field is indeed very active - lots more to come

Rare decays

Lots of Physics beyond the SM will lead to effects for di-lepton rare decays.

Model	B_d Unitarity	Time-dep. CPV	Rare B decay	Other signals
mSUGRA(moderate $\tan\beta$)	-	-	-	-
mSUGRA(large $\tan\beta$)	B_d mixing	-	$B \to (D)\tau\nu$ $b \to s\ell^+\ell^-$	$B_s \to \mu\mu$ B_s mixing
SUSY GUT with ν_R	-	$B \to \phi K_S$ $B \to K^*\gamma$	-	B_s mixing τ LFV, n EDM
Effective SUSY	B_d mixing	$B \to \phi K_S$	$A_{CP}^{b\to s\gamma}$, $b \to s\ell^+\ell^-$	B_s mixing
KK graviton exchange	-	-	$b \to s\ell^+\ell^-$	-
Split fermions in large extra dimensions	B_d mixing	-	$b \to s\ell^+\ell^-$	$K^0\overline{K}^0$ mixing $D^0\overline{D}^0$ mixing
Bulk fermions in warped extra dimensions	B_d mixing	$B \to \phi K_S$	$b \to s\ell^+\ell^-$	B_s mixing $D^0\overline{D}^0$ mixing
Universal extra dimensioins	-	-	$b \to s\ell^+\ell^-$ $b \to s\gamma$	$K \to \pi\nu\overline{\nu}$

hep-ph/0503261

Theoretical language for rare decays

The Standard Model works very well to describe all of experimental particle physics.

The flavour sector

$$\mathscr{L}_{\text{SM}} = \mathscr{L}_{\text{gauge}}(A_i, \Psi_j; \mathbf{Y}, \mathbf{C}) + \mathscr{L}_{\text{Higgs}}(A_i, \Psi_j, \phi; \langle\phi\rangle)$$

A_i : The fermion fields

Ψ_j : The gauge boson fields

ϕ : The Higgs field

$\mathbf{Y}$: Yukawa couplings (masses)

$\mathbf{C}$: CKM matrix

$\langle\phi\rangle$: Expectation value

An effective theory for New Physics

Several problem areas though

- The unexplained family replication
- No candidate for the Dark Matter in the Universe
- No field to describe Dark Energy
- No unification with Gravity
- Many free parameters like all the fermion masses

To look at New Physics in a general way we can view the Standard Model as a low energy effective model

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{gauge}} + \mathscr{L}_{\text{Higgs}} + \sum_{d>4} \frac{c_n}{\Lambda^{d-4}} O_n^d$$

An effective theory for New Physics

$$\mathscr{L}_{\text{eff}} = \mathscr{L}_{\text{gauge}}(A_i, \Psi_j; \mathbf{Y}, \mathbf{C}) + \mathscr{L}_{\text{Higgs}}(A_i, \Psi_j, \phi; \langle\phi\rangle) +$$

$$\sum_{d>4} \frac{c_n}{\Lambda^{d-4}} O_n^d$$

O_d^n: All possible operators with heavy d.o.f

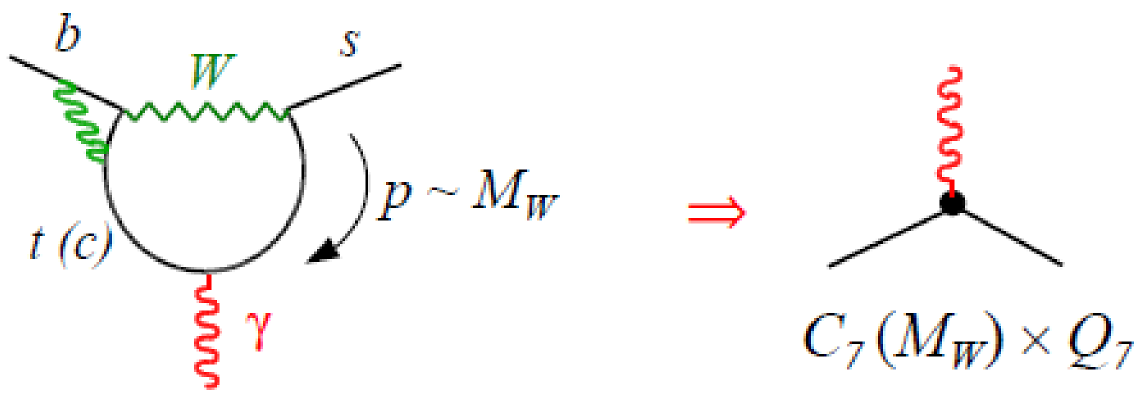
c_n: Parameters arising from New Physics

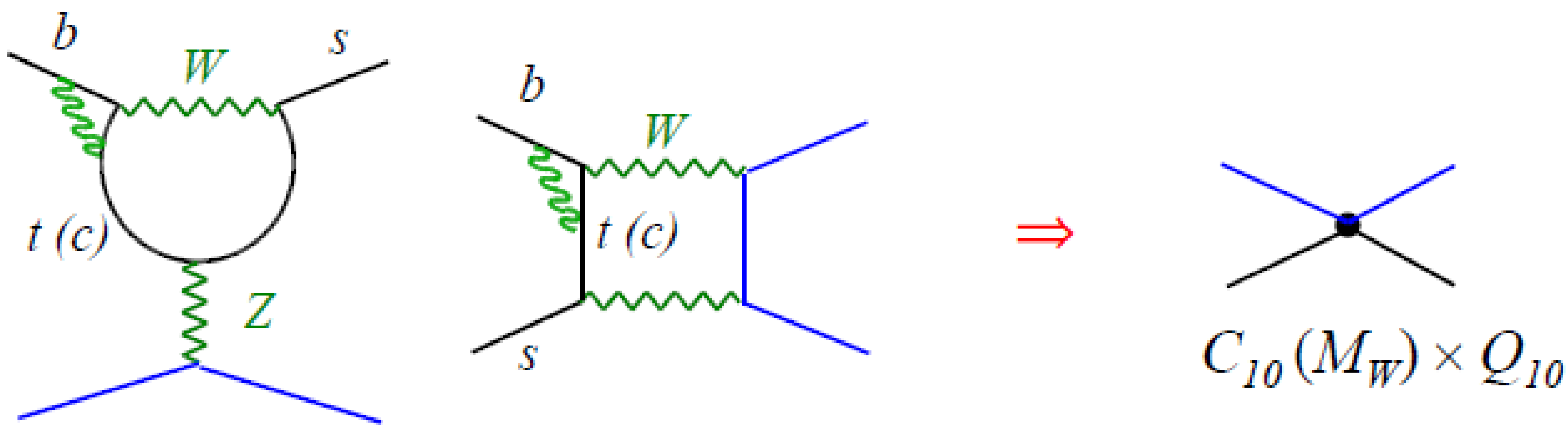
Λ: Energy scale of New Physics

Separate terms for left and right handed currents

- Some left handed (C7, C10) are present through loops in the SM
- All right handed currents represent NP.

SM processes in higher order operators

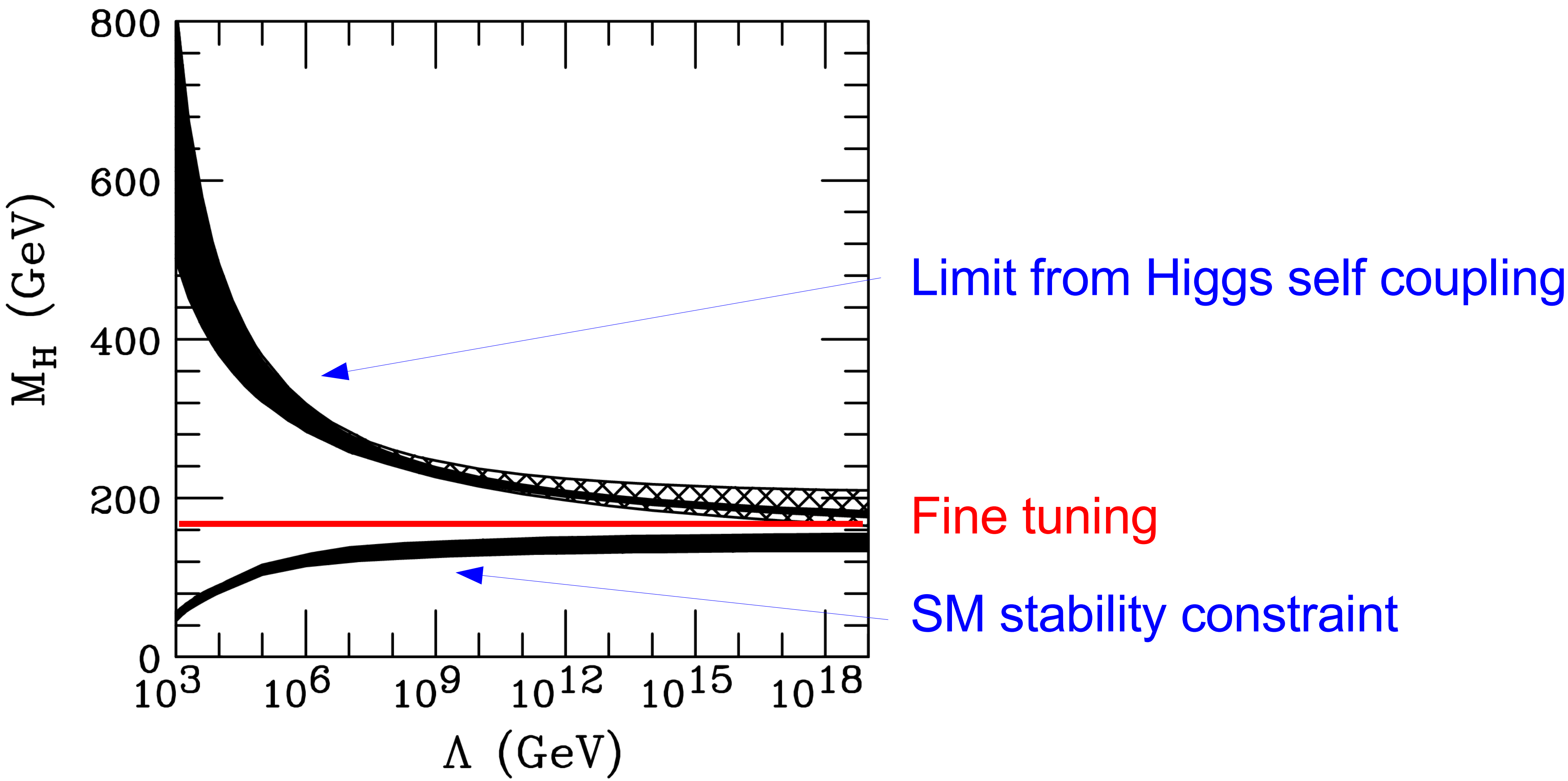




An effective theory for New Physics

- This Lagrangian is no longer renormalisable but still valid for energies below Λ.
- So what is the size of Λ?
  - Quantum corrections to Higgs self-coupling gives an upper limit
    - SM has to be stable up to Λ.
  - Study of indirect evidence in loop processes
    - Deviations from SM in rare decays probe much higher energy scale

The size of Λ



Thomas Hambye, Kurt Riesselmann,
Phys.Rev. D55 (1997) 7255-7262

The flavour problem

- The Higgs sector without fine tuning requires that $\Lambda \sim 1$ TeV
- But if we assume that effective couplings are of the order 1 we get $\Lambda >$ 100 TeV from neutral Kaon mixing
- Two ways around this problem
  - Optimistic scenario is that $\Lambda \sim 1$ TeV and flavour mixing is protected by additional symmetries given small effective couplings
    - Minimal flavour violation, MFV
  - Pessimistic scenario is that the Higgs sector is fine tuned and $\Lambda > 100$ TeV
    - Disaster for direct searches
    - No promise that rare decays will discover New Physics but there is sensitivity

A parallel to Newtonian mechanics

Imagine we are in the year 1900

You are unhappy with Newtonian mechanics as you can't get it to agree with Maxwell's equations and experimental results.

You create an effective theory based on Newton's laws

$$E_{\text{eff}} = \frac{1}{2}\frac{p^2}{m} + \sum_{d>2} k_d \frac{1}{\lambda^{d-2}} \frac{p^d}{m^{d-1}}$$

First part is simply Newtonian mechanics.

Second part is an expansion that should be valid as long as *pλ/E* is small

If we naively assume $k_d = 1$ we can make measurements and get a measurement of *λ* which is the velocity scale of new physics.

$$d = 4 \Rightarrow \lambda = 8c \qquad\qquad d = 6 \Rightarrow \lambda = \frac{48}{3}c$$

A parallel to Newtonian mechanics

Now Einstein comes along and shows

$$E = \sqrt{p^2 c^2 + m^2 c^4}$$

... or if we expand for small momenta

$$E = \frac{1}{2}\frac{p^2}{m} - \frac{1}{8}\frac{p^2}{m^3 c^2} + \frac{3}{48}\frac{p^6}{m^5 c^4} - \cdots$$

We see that the *k* factors are smaller than one and the scale of new physics is indeed the speed of light.

Which rare decays to look at

- We need decays with the following attributes:
  - No SM tree level contribution
    - Flavour changing neutral current decays
  - Small SM loop or penguin contribution
    - This ensures that New Physics is not masked by the SM contribution
    - So SM process should involve V_{ts}, V_{td}, V_{ub} or V_{cb}
  - SM prediction should have high precision
    - Short range effects should dominate
- This leads to the selection of B decays with dileptons or photons in the final state.

Categorise the decays

th. error $\lesssim 10\%$
(grey) = exp. error $\lesssim 10\%$
(white) = exp. error $\sim 30\%$

FLAVOUR COUPLING:

ELECTROWEAK STRUCTURE

	$b \to s$ $(\sim\lambda^2)$	$b \to d$ $(\sim\lambda^3)$	$s \to d$ $(\sim\lambda^5)$
$\Delta F=2$ box	ΔM_{B_s}, $A_{CP}(B_s \to \psi\phi)$	ΔM_{B_d}, $A_{CP}(B_d \to \psi K)$	ΔM_K, ε_K
$\Delta F=1$ 4-quark box	$B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to \pi\pi$, $B_d \to \rho\pi$, ...	ε'/ε, $K \to 3\pi$, ...
gluon penguin	$B_d \to X_s \gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d \gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
γ penguin	$B_d \to X_s l^+ l^-$, $B_d \to X_s \gamma$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to X_d \gamma$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, ...
Z^0 penguin	$B_d \to X_s l^+ l^-$, $B_s \to \mu\mu$, $B_d \to \phi K$, $B_d \to K\pi$, ...	$B_d \to X_d l^+ l^-$, $B_d \to \mu\mu$, $B_d \to \pi\pi$, ...	ε'/ε, $K_L \to \pi^0 l^+ l^-$, $K \to \pi\nu\nu$, $K \to \mu\mu$, ...
H^0 penguin	$B_s \to \mu\mu$	$B_d \to \mu\mu$	$K_{L,S} \to \mu\mu$

I will concentrate on these

Table from Gino Isidori

$B_s \to \mu^+\mu^-$

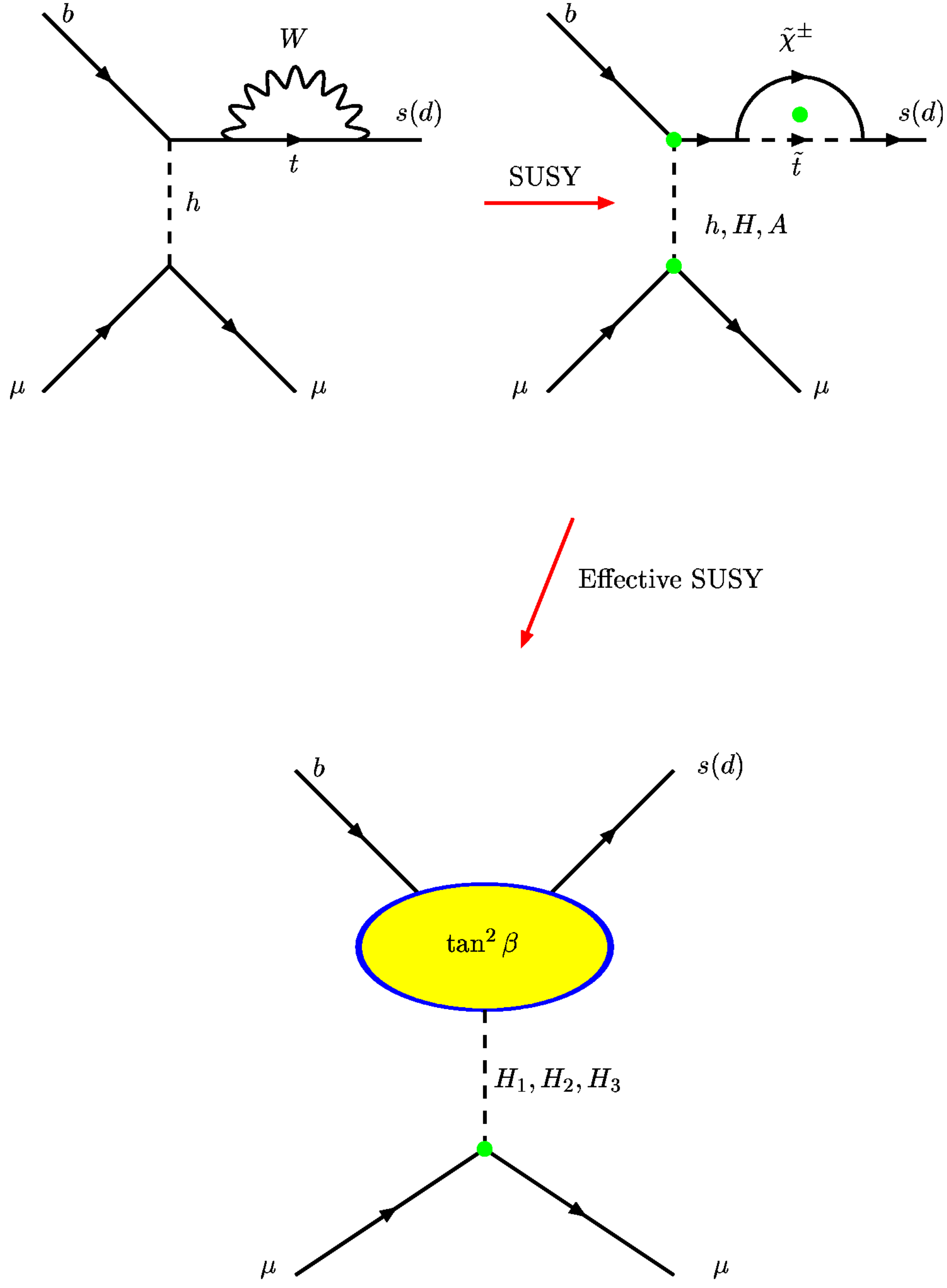
Cross sections for Higgs mediated processes in SUSY theories are enhanced by a factor $\tan^6\beta$.

- Turns the decay into one of the most sensitive SUSY probes.

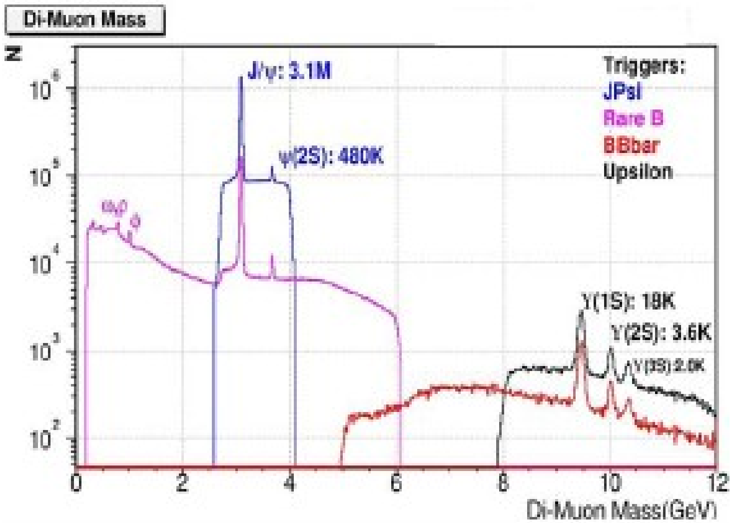
At the same time SM prediction has very low uncertainty.

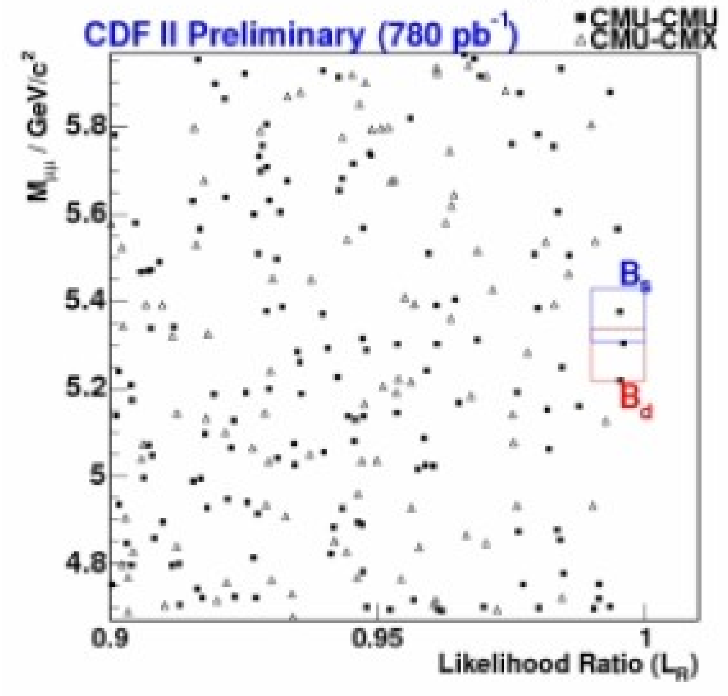
$$B(B_s \to \mu\mu) \sim 5 \times 10^{-7} \left(\frac{\tan\beta}{50}\right)^6 \left(\frac{300GeV}{M_A}\right)^4$$

SM BR is ~ $3.5\ 10^{-9}$



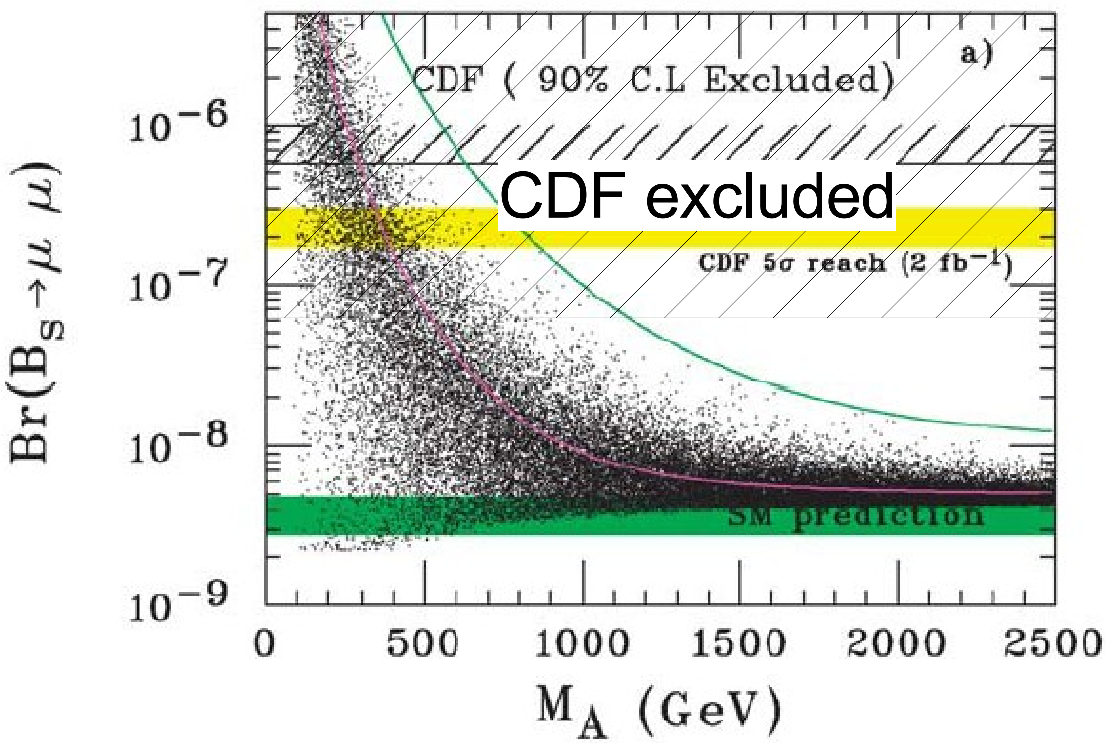
Experimental limit on BR($B_s \rightarrow \mu^+\mu^-$)





Latest CDF result from 780 pb^{-1} at FPCP 2006.

BR($B_s \rightarrow \mu^+\mu^-$) < 8 10^{-8} @ 90% CL



Experimental prospects for $B_s \to \mu^+\mu^-$

Results are currently dominated by the Tevatron

LHCb will face serious competition from ATLAS/CMS here.

	1 year	$B_s \to \mu^+ \mu^-$ signal (SM)	$b \to \mu$, $b \to \mu$ background	Inclusive bb background	All backgrounds
LHCb	2 fb^{-1}	17	< 100	< 7500	
ATLAS	10 fb^{-1}	7	< 20		
CMS (1999)	10 fb^{-1}	7	< 1		

$b \to s\, \mu^+\mu^-$

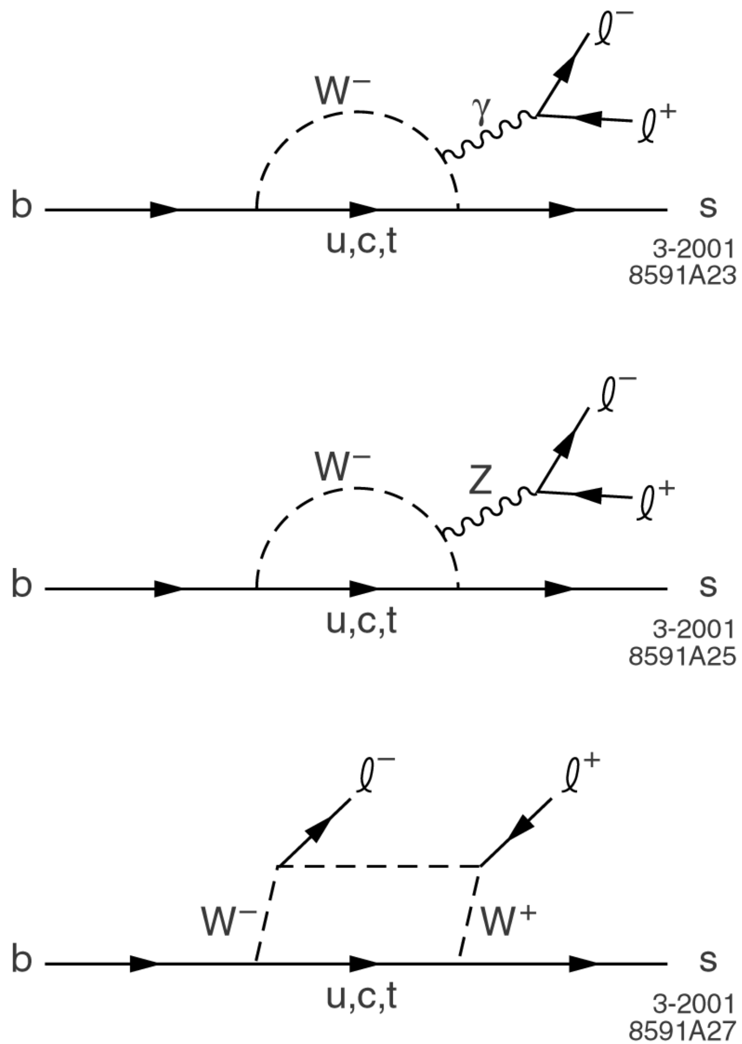
From theoretical point of view inclusive process is far preferable.

- But at least initially we have to limit ourselves to
  - $B_d \to K^{*0}\mu^+\mu^-$;
  - $B^+ \to K^+\mu^+\mu^-$;
  - $\Lambda_b \to \Lambda\mu^+\mu^-$;
  - $B_s \to \varphi\mu^+\mu^-$;

Branching fraction, and forward backward asymmetry carries information.

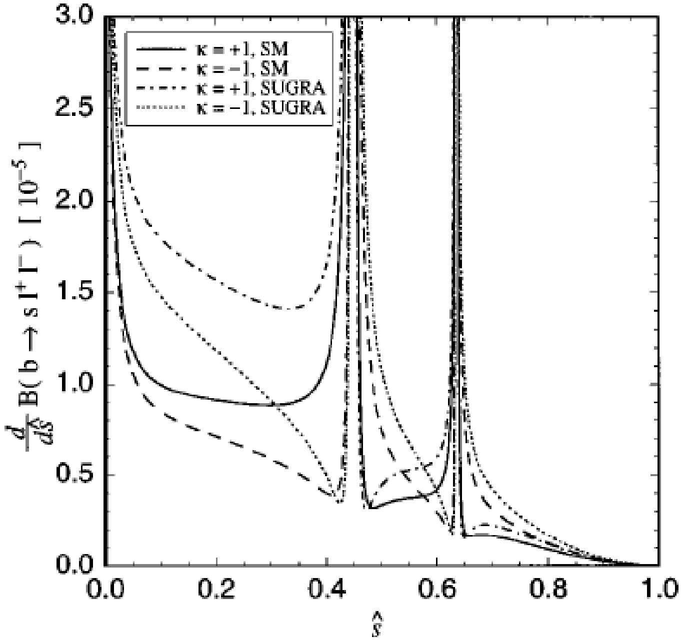
Deviations from SM by

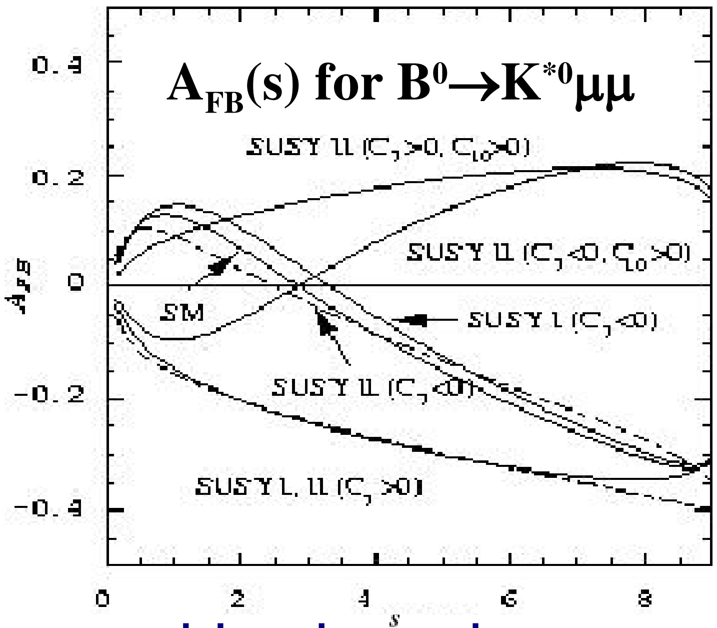
- SUSY, graviton exchanges, extra dimensions ...



$b \to s\ \mu^+\mu^-$

Look at differentials with respect to $\hat{s} = \frac{m_{l^+l^-}}{max(m_{l^+l^-})}$





Branching fraction

- Theory predictions are good outside cc resonance regions.

Forward-backward asymmetry

- Direction of the positive lepton wrt the B flight direction in di-lepton restframe.

Zero point and integral at high s are safe predictions.

Expected performance for $B_d \to K^{*0}\mu^+\mu^-$ in LHCb

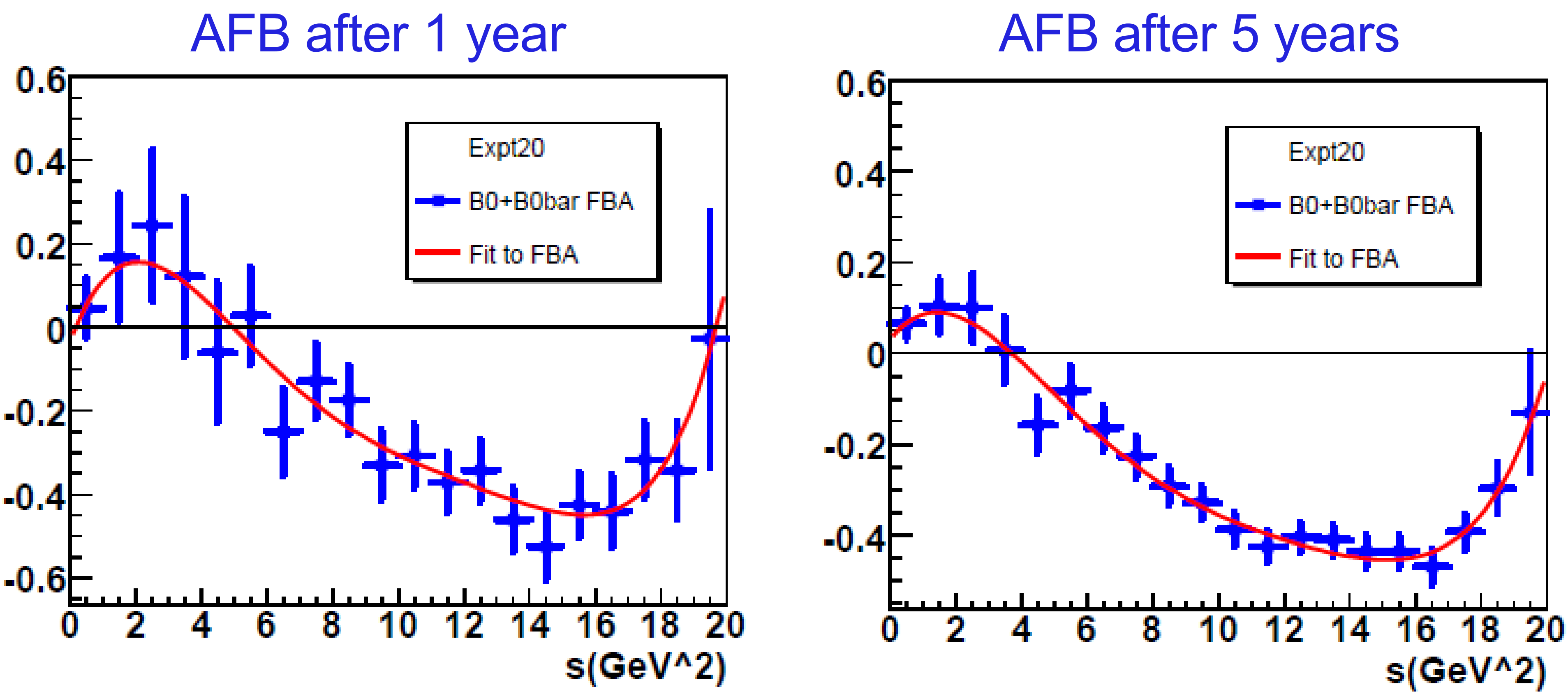
We expect 4400 events per year in one standard year.

Background/Signal in the region 0.2 – 2.6 expected.

Zero point from SM simulation:

4.0 ± 1.2 GeV^2 in 1 year

4.0 ± 0.5 GeV^2 in 5 years



Other variables to look at

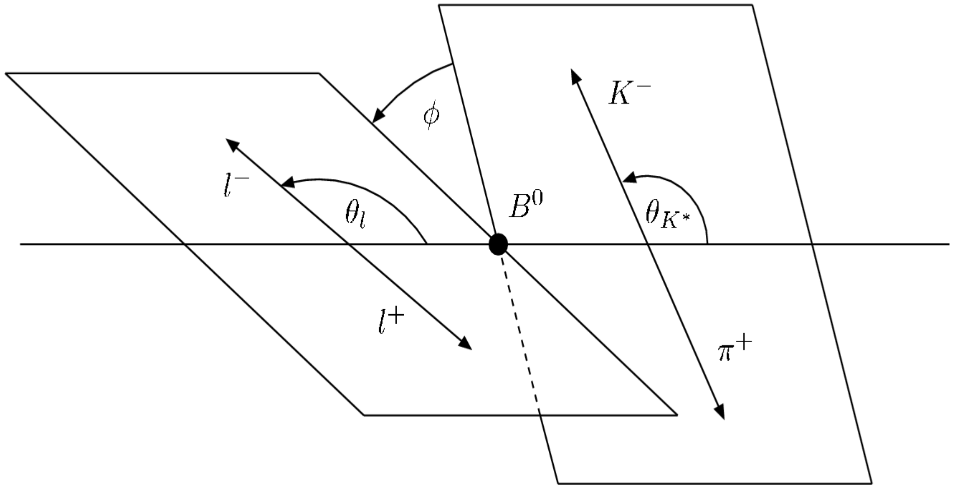
Recent theoretical work has highlighted other asymmetries to look at

See EPS 2005 talk by Quim Matias

Look at decay in terms of transversity amplitudes $A_\perp, A_\parallel, A_0$ for left and right handed currents.

$$d^4\Gamma = \frac{9}{32\pi} I(s, \theta_l, \theta_{K^*}, \phi) ds\, d\cos\theta_l\, d\cos\theta_{K^*}\, d\phi$$

$$I = I_1 + I_2 \cos 2\theta_l + I_3 \sin^2\theta_l \cos 2\phi + I_4 \sin 2\theta_l \cos\phi + I_5 \sin\theta_l \cos\phi + I_6 \cos\theta_l + I_7 \sin\theta_l \sin\phi + I_8 \sin 2\theta_l \sin\phi + I_9 \sin^2\theta_l \sin 2\phi.$$



$$I_2 = \left(1 - \frac{4m_l^2}{s}\right)\left[\frac{1}{4}(|A_{\perp L}|^2 + |A_{\parallel L}|^2)\sin^2\theta_{K^*} - |A_{0L}|^2\cos^2\theta_{K^*} + (L \to R)\right] \equiv c\sin^2\theta_{K^*} + d\cos^2\theta_{K^*},$$

$$I_3 = \frac{1}{2}\left(1 - \frac{4m_l^2}{s}\right)\left[(|A_{\perp L}|^2 - |A_{\parallel L}|^2)\sin^2\theta_{K^*} + (L \to R)\right] \equiv e\sin^2\theta_{K^*},$$

$$I_4 = \frac{1}{\sqrt{2}}\left(1 - \frac{4m_l^2}{s}\right)\left[\mathrm{Re}(A_{0L}A^*_{\parallel L})\sin 2\theta_{K^*} + (L \to R)\right] \equiv f\sin 2\theta_{K^*},$$

Etc ...

Observables

Good variables with very small theoretical error in the Standard Model can now be identified.

Transverse asymmetries:

$$A_T^{(1)}(s) = \frac{-2\mathrm{Re}(A_{\parallel} A_{\perp}^*)}{|A_{\perp}|^2 + |A_{\parallel}|^2}, \quad A_T^{(2)}(s) = \frac{|A_{\perp}|^2 - |A_{\parallel}|^2}{|A_{\perp}|^2 + |A_{\parallel}|^2}.$$

K* polarization parameter:

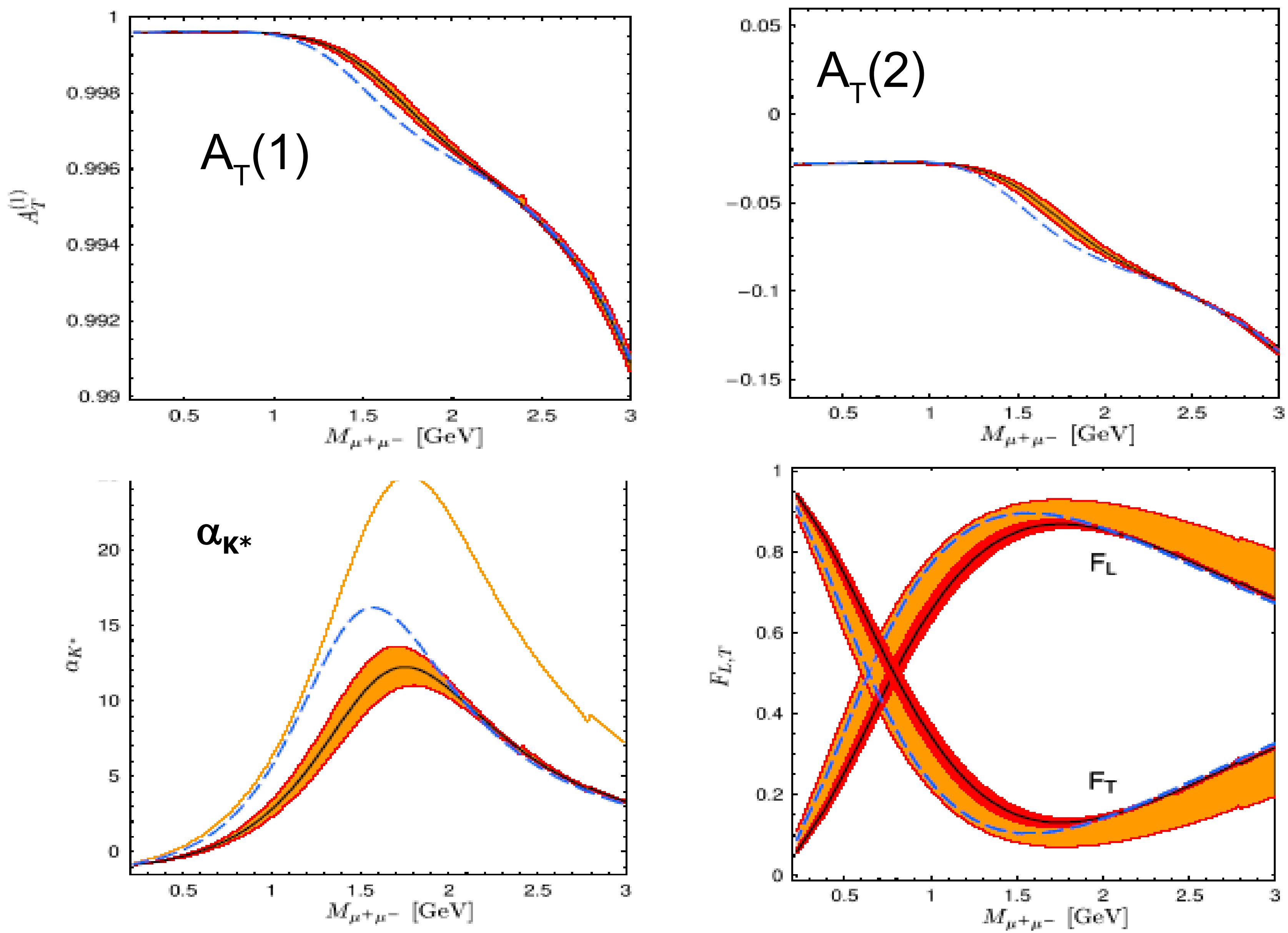
$$\alpha_{K^*}(s) = \frac{2|A_0|^2}{|A_{\parallel}|^2 + |A_{\perp}|^2} - 1$$

Fraction of K* polarization:

$$F_L(s) = \frac{|A_0|^2}{|A_0|^2 + |A_{\parallel}|^2 + |A_{\perp}|^2} \qquad F_T(s) = \frac{|A_{\perp}|^2 + |A_{\parallel}|^2}{|A_0|^2 + |A_{\parallel}|^2 + |A_{\perp}|^2}$$

Current work to identify ways to actually measure these without performing a full 11 parameter fit (6 amplitudes, 5 phases) in each bin of *s*.

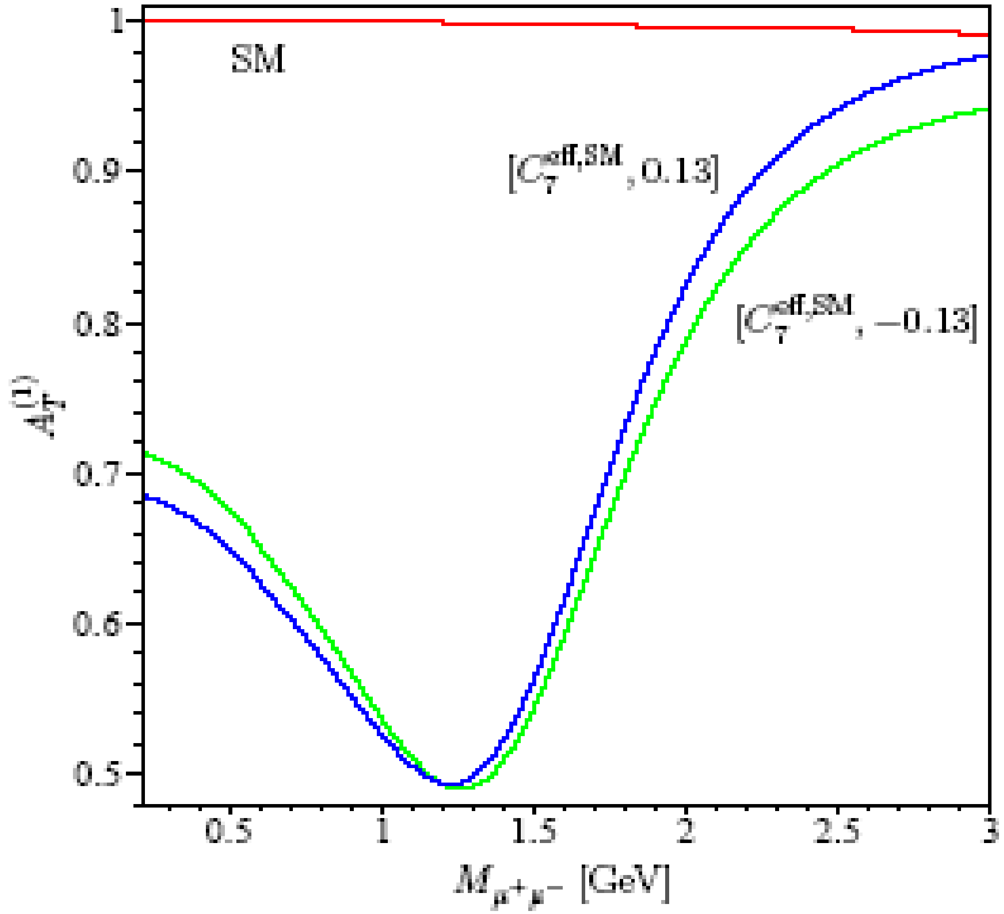
Standard Model predictions including uncertainties

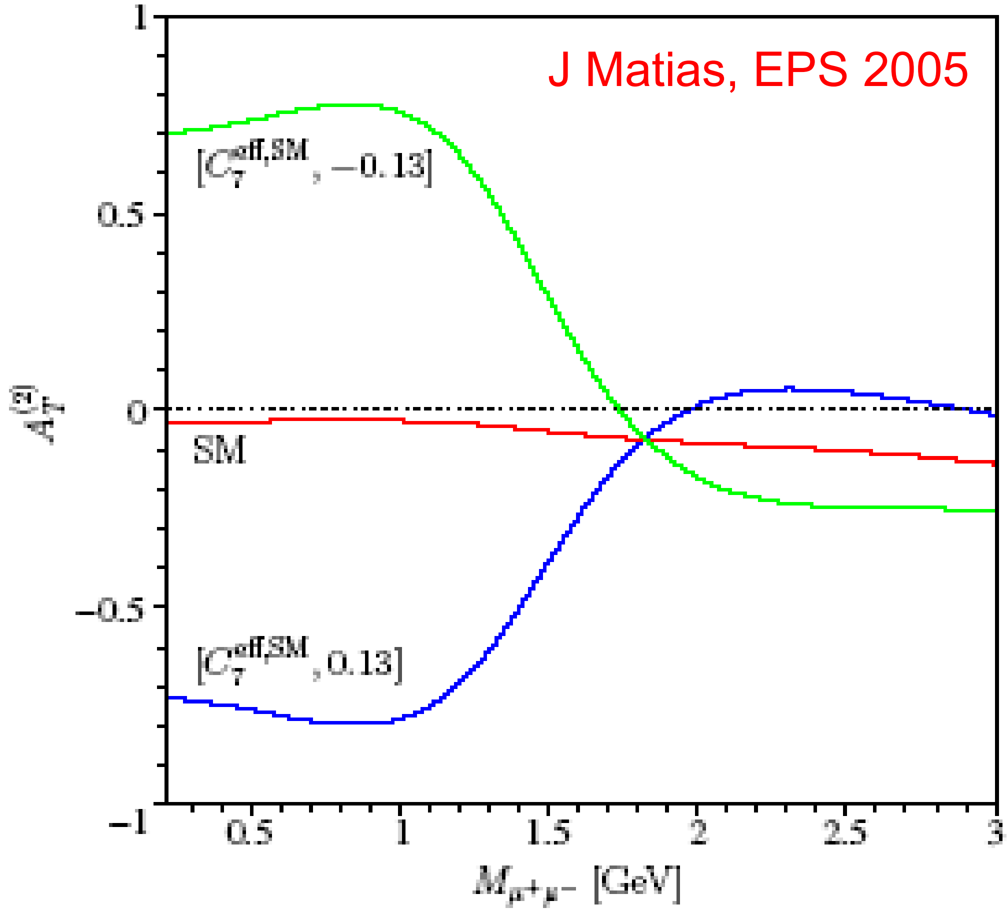


J Matias, EPS 2005

$A_T^{(1,2)}$: NP in C'^{eff}_7 and $C_{9,10}$ SM-like

Only test models which are compatible with experimental BR(b → sγ)





Small contribution from right handed currents produces striking effects .

Sensitive to the sign of C'7eff at low dimuon mass.

$B^+ \to K^+ \ell^+ \ell^-$

Measure the ratio: [Hiller & Krüger, hep-ph/0310219]

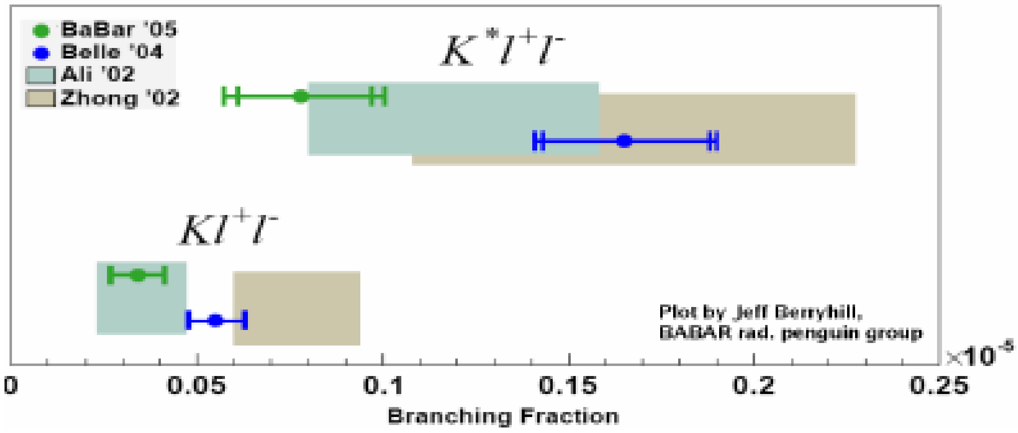
$$R_{\mathrm{H}} = \frac{\int_{4m_\mu^2}^{q^2_{\max}} \mathrm{d}q^2 \frac{d\Gamma(\mathrm{B}\to\mathrm{H}\mu^+\mu^-)}{\mathrm{d}q^2}}{\int_{4m_\mu^2}^{q^2_{\max}} \mathrm{d}q^2 \frac{d\Gamma(\mathrm{B}\to\mathrm{He}^+\mathrm{e}^-)}{\mathrm{d}q^2}} = \begin{cases} 1.000 \pm 0.001 & \mathrm{H} = \mathrm{K} \\ 0.991 \pm 0.002 & \mathrm{H} = \mathrm{K}^* \end{cases}$$

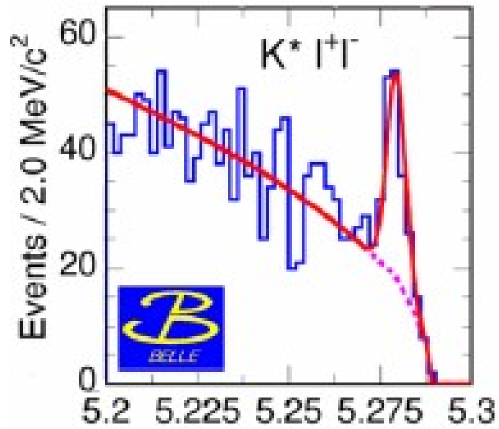
Corrections to unity can be order 10% in models that distinguish lepton flavours.

- Typically extra neutral Higgs bosons.
- Integration range not important, just need to be the same and avoid charm resonances.

Current experimental status for $b \to s\,\mu^+\mu^-$

Measurement of exclusive branching fractions





Sum of exclusive modes

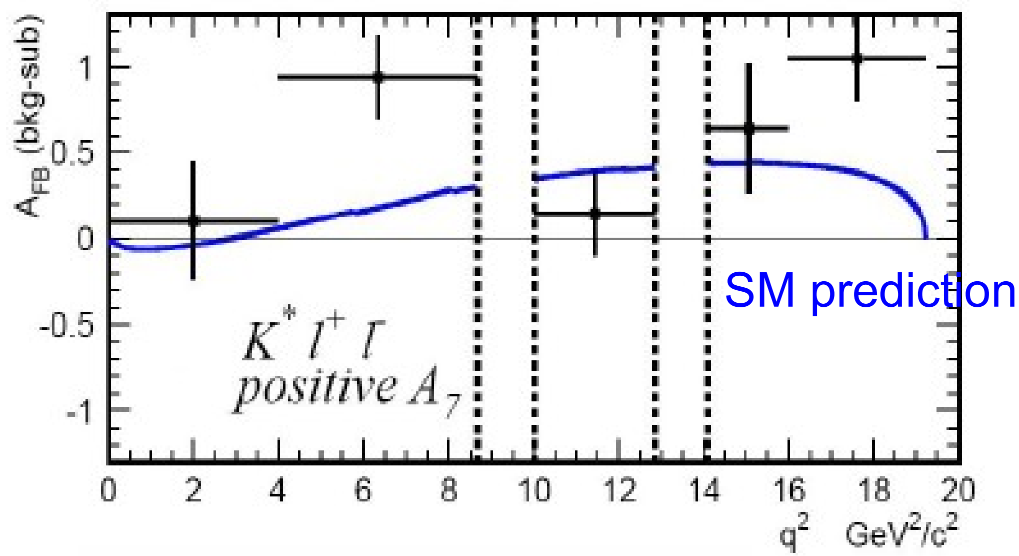
- Measure BF in bins of s (units of 10^{-6})
- Opposite sign C_7 excluded at 3σ

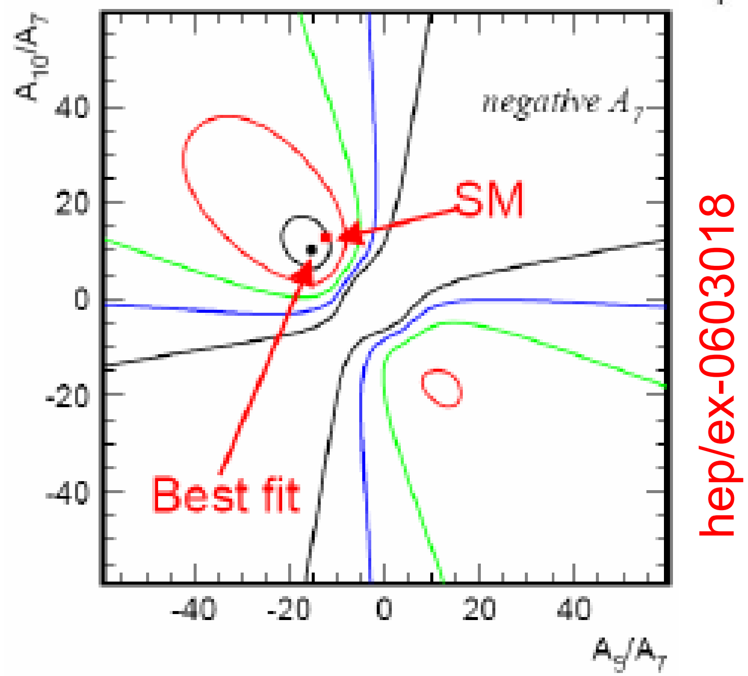
Range in s	BaBar	Belle	Average	SM	$C_7=-C_7^{SM}$
1-6 GeV^2	1.8±0.9	1.5±06	1.6±0.5	1.6±0.2	3.3±0.3
$>4\,m_\mu^2$	5.6±2.0	4.1±1.1	4.5±1.0	4.4±0.7	8.8±1.0

Gambinoet.al., PRL 94 061803 (2005)

Belle measurement of forward backward asymmetry

- Analysis based on 113±6 events
  - Shows raw asymmetry for $B_d \to K^{*0}\mu^+\mu$.
  - Then try to fit C_9/C_7 anf C_{10}/C_7 keeping C_7 fixed and C_7^{SM} or $-C_7^{SM}$.
- Analysis seems to carry a lot of assumptions.
  - Demonstrates possibility of this analysis though.



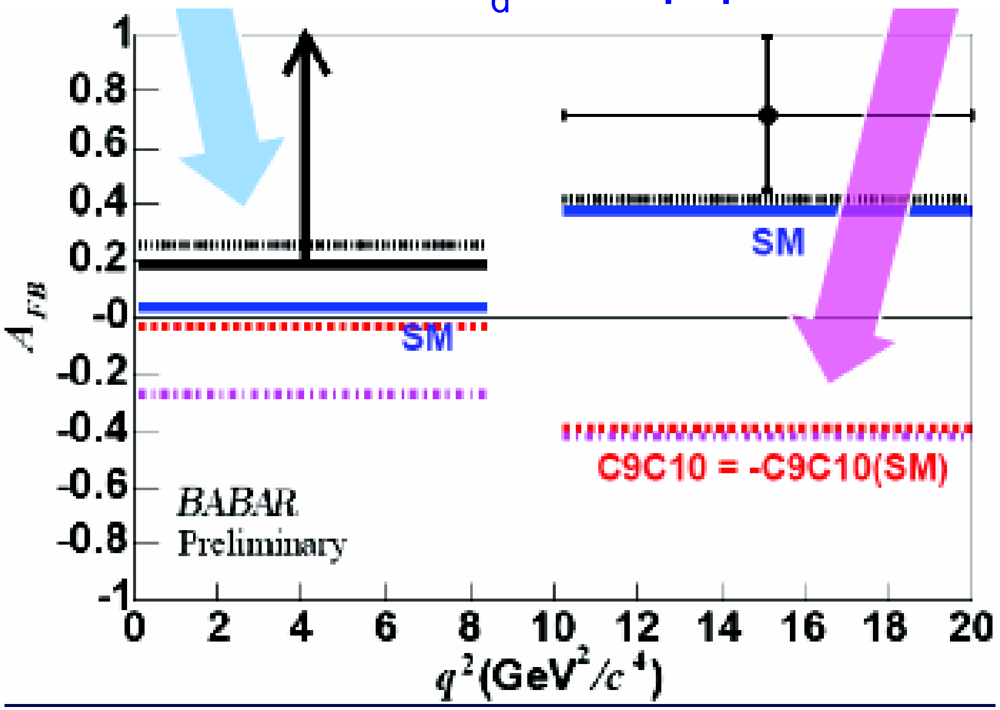


BaBar measurement of forward backward asymmetry

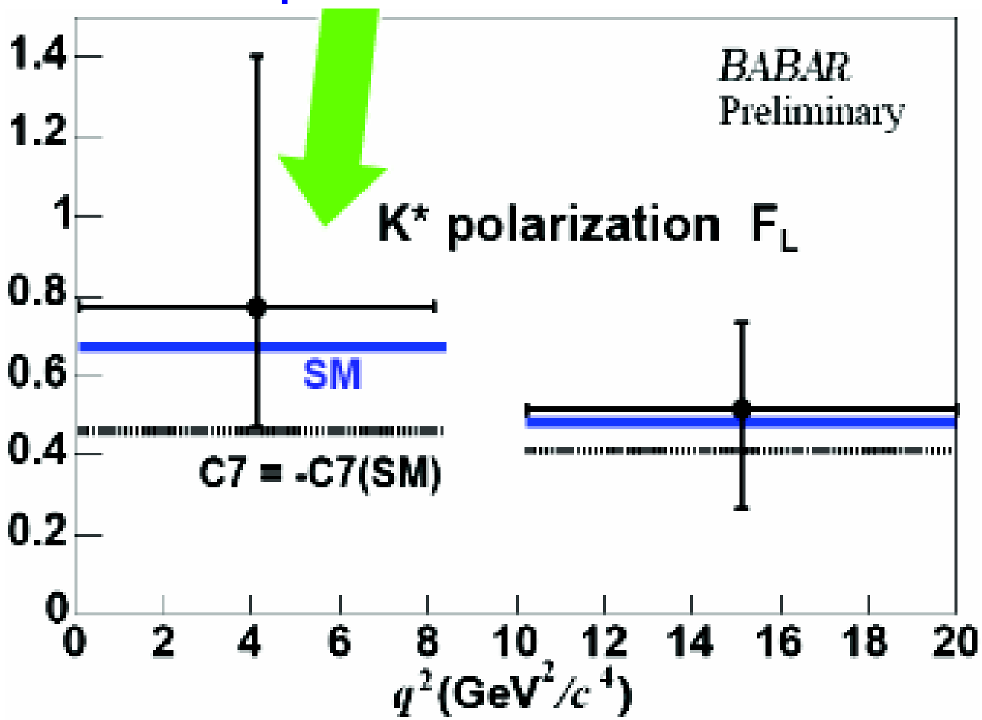
Performs analysis in both $B_d \to K^{*0}\mu^+\mu^-$ and $B^+ \to K^+\mu^+\mu^-$.

- In latter an asymmetry only possible if there are right handed currents
- AFB in $B_d \to K^{*0}\mu^+\mu^-$ excludes SM prediction at 98% CL ...

AFB in $B_d \to K^{*0}\mu^+\mu^-$

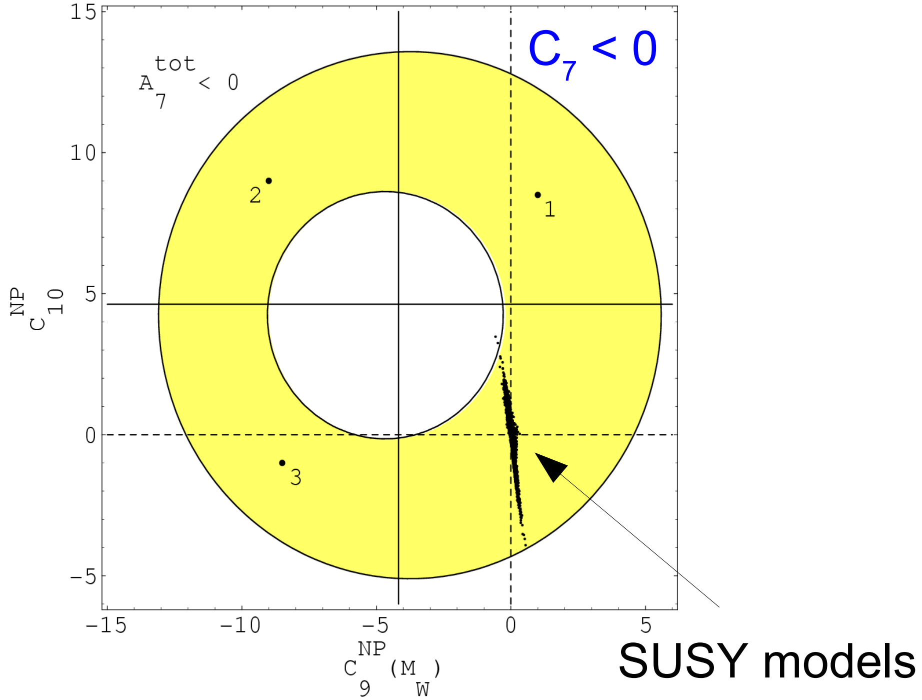


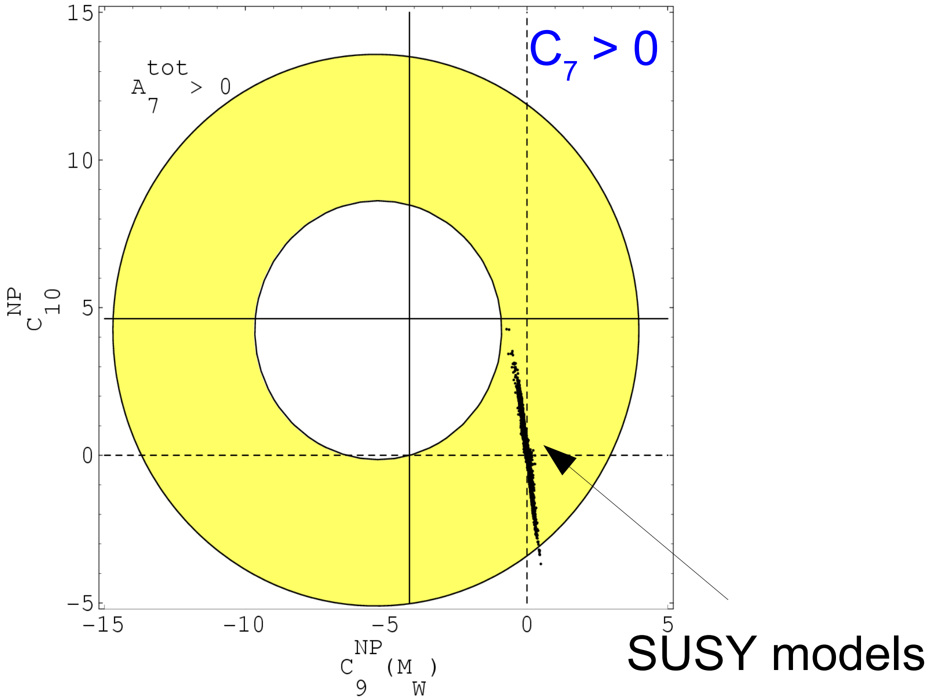
K* polarisation fraction



Model predictions and experimental constraints

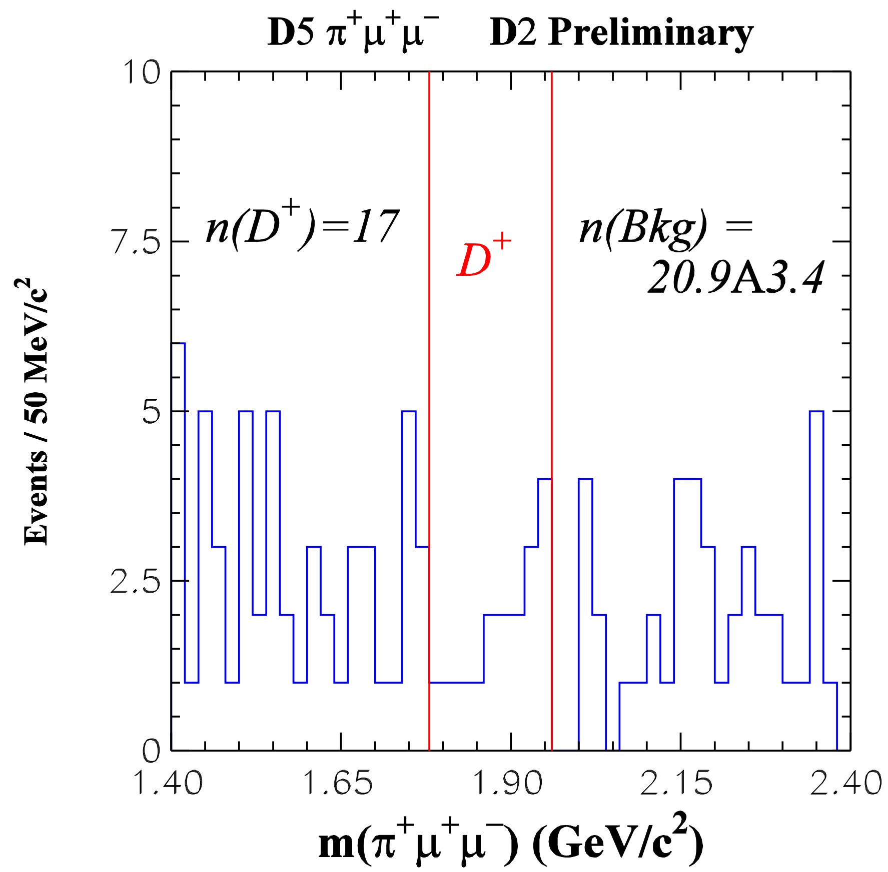
- In Ali et. al. (PRD 66,034002 (2002)) predictions are made for the values of NP contributions to C_9 and C_{10}
  - Experimental radiative decay branching ratios imposed as constraint
  - Right handed currents ignored
- I predict plots of this type will be the "CKM triangle plots" at conferences in future years.





D0 limit on exclusive FCNC c → d l^+l^-

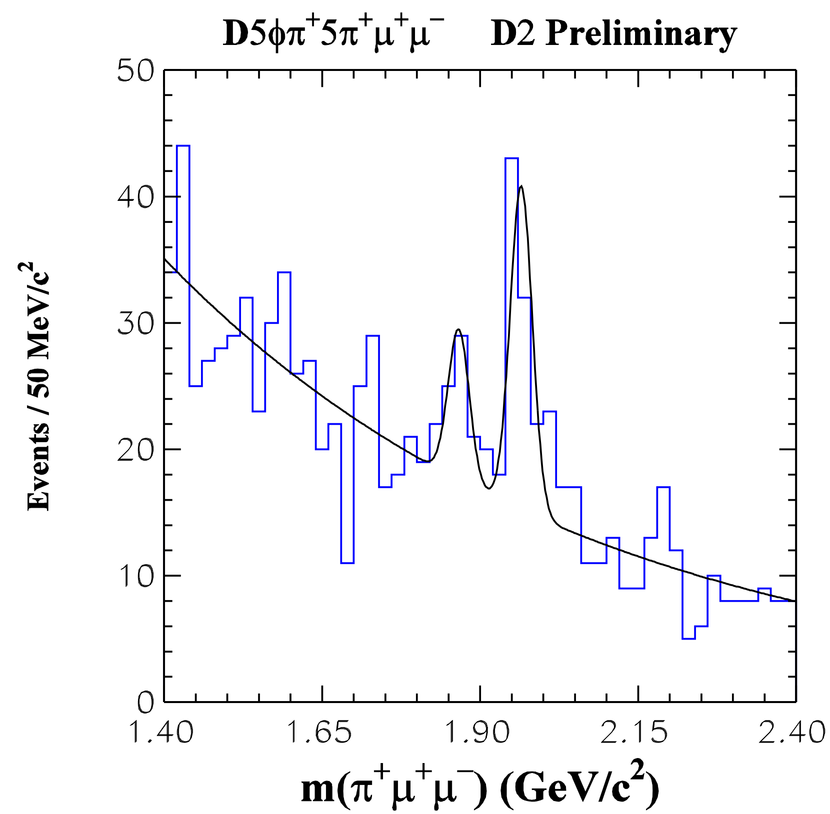
BR($D^+ \rightarrow \pi^+\mu^+\mu^-$) < 4.7 10-6 @ 90% CL



$0.2 < m(\mu\mu) < 0.96$ GeV/c^2
$1.06 < m(\mu\mu) < 1.76$ GeV/c^2

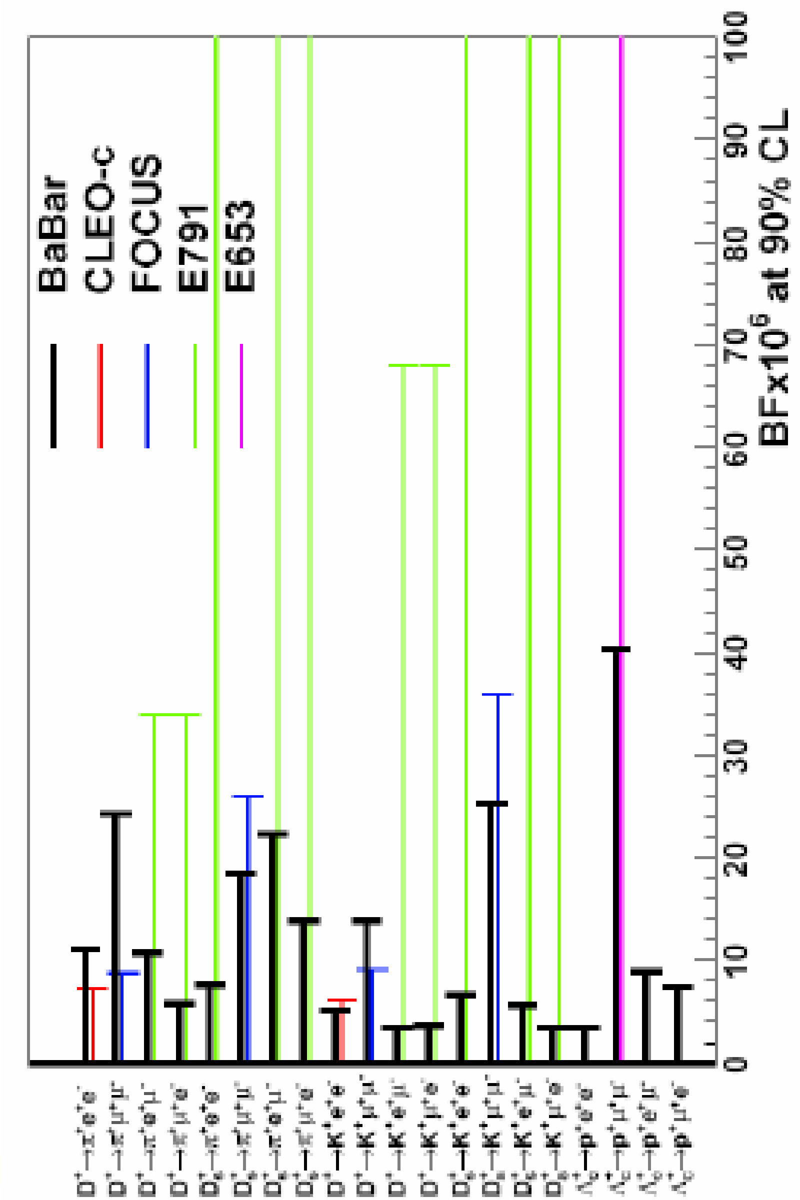
Control looking for $D_{(s)}^+ \rightarrow \pi^+\varphi$ with $\varphi \rightarrow \mu^+\mu^-$

Cuts relaxed for this control



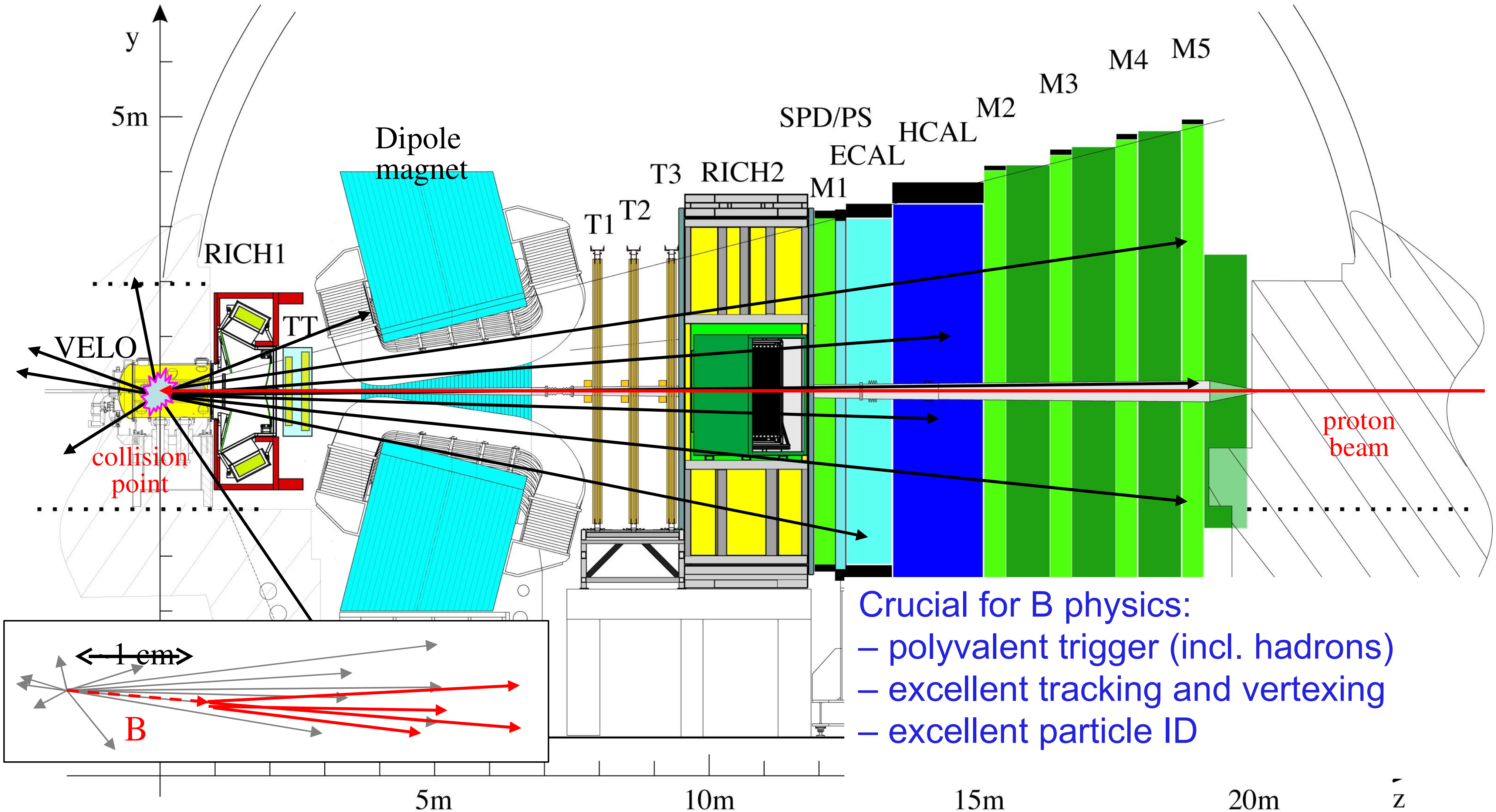
BaBar limits on exclusive FCNC $c \to d\, l^+ l^-$

Decay mode	Yield (events)	BF×10^6 (90% CL)
$D^+ \to \pi^+ e^+ e^-$	$24.0^{+25.0+3.4}_{-24.1-5.1}$	< 11.2
$D^+ \to \pi^+ \mu^+ \mu^-$	$1.5^{+20.1+3.4}_{-19.3-2.6}$	< 24.4
$D^+ \to \pi^+ e^+ \mu^-$	$4.1^{+17.8+3.1}_{-16.3-2.1}$	< 10.8
$D^+ \to \pi^+ \mu^+ e^-$	$-12.1^{+15.5+3.2}_{-14.8-0.0}$	< 5.9
$D_s^+ \to \pi^+ e^+ e^-$	$-1.7^{+5.3+0.2}_{-4.6-2.0}$	< 7.6
$D_s^+ \to \pi^+ \mu^+ \mu^-$	$-9.4^{+5.0+0.2}_{-4.4-1.4}$	< 18.5
$D_s^+ \to \pi^+ e^+ \mu^-$	$4.8^{+4.7+0.8}_{-3.9-0.3}$	< 22.3
$D_s^+ \to \pi^+ \mu^+ e^-$	$0.5^{+4.0+1.0}_{-3.3-0.1}$	< 13.9
$D^+ \to K^+ e^+ e^-$	$5.9^{+8.9+3.8}_{-7.8-0.3}$	< 5.2
$D^+ \to K^+ \mu^+ \mu^-$	$2.9^{+8.0+0.2}_{-7.0-3.7}$	< 14.0
$D^+ \to K^+ e^+ \mu^-$	$-3.4^{+6.5+1.0}_{-5.6-0.1}$	< 3.6
$D^+ \to K^+ \mu^+ e^-$	$-4.4^{+7.1+1.4}_{-6.1-3.0}$	< 3.7
$D_s^+ \to K^+ e^+ e^-$	$-3.8^{+6.2+1.5}_{-5.3-1.3}$	< 6.6
$D_s^+ \to K^+ \mu^+ \mu^-$	$5.0^{+6.5+0.1}_{-6.1-0.3}$	< 25.4
$D_s^+ \to K^+ e^+ \mu^-$	$-3.7^{+5.1+1.4}_{-4.4-1.4}$	< 5.6
$D_s^+ \to K^+ \mu^+ e^-$	$-6.5^{+4.9+0.2}_{-4.3-1.1}$	< 3.6
$\Lambda_c^+ \to p e^+ e^-$	$0.9^{+4.1+0.4}_{-3.4-0.1}$	< 3.6
$\Lambda_c^+ \to p \mu^+ \mu^-$	$6.9^{+4.7+0.3}_{-3.7-0.6}$	< 40.4
$\Lambda_c^+ \to p e^+ \mu^-$	$0.2^{+2.9+0.5}_{-2.0-0.5}$	< 8.9
$\Lambda_c^+ \to p \mu^+ e^-$	$-0.2^{+2.5+0.5}_{-1.7-0.9}$	< 7.5



Comparison between LHCb and Super B

The LHCb detector design



Crucial for B physics:
– polyvalent trigger (incl. hadrons)
– excellent tracking and vertexing
– excellent particle ID

Trigger

- The big challenge at hadronic machines is the trigger.
  - Cross section for B production is about 500 μb.
  - The total inelastic cross section is about 80 mb.
  - the B decays we are interested in all have low branching ratios (typically 10^{-4}).
- We have to reduce ingoing rate of 40 MHz to tape rate of 2 kHz.
- Hadron and electron trigger required for high efficiency in wide range of modes.
- A (di-)muon trigger will give access to rare decays and $B \to J/\Psi\, X$ decays.
  - Decays with several neutrals still out of reach
  - Very inclusive analysis will be hard/impossible

Trigger Rates Overview

Level-0 (40 MHz → 1 MHz)

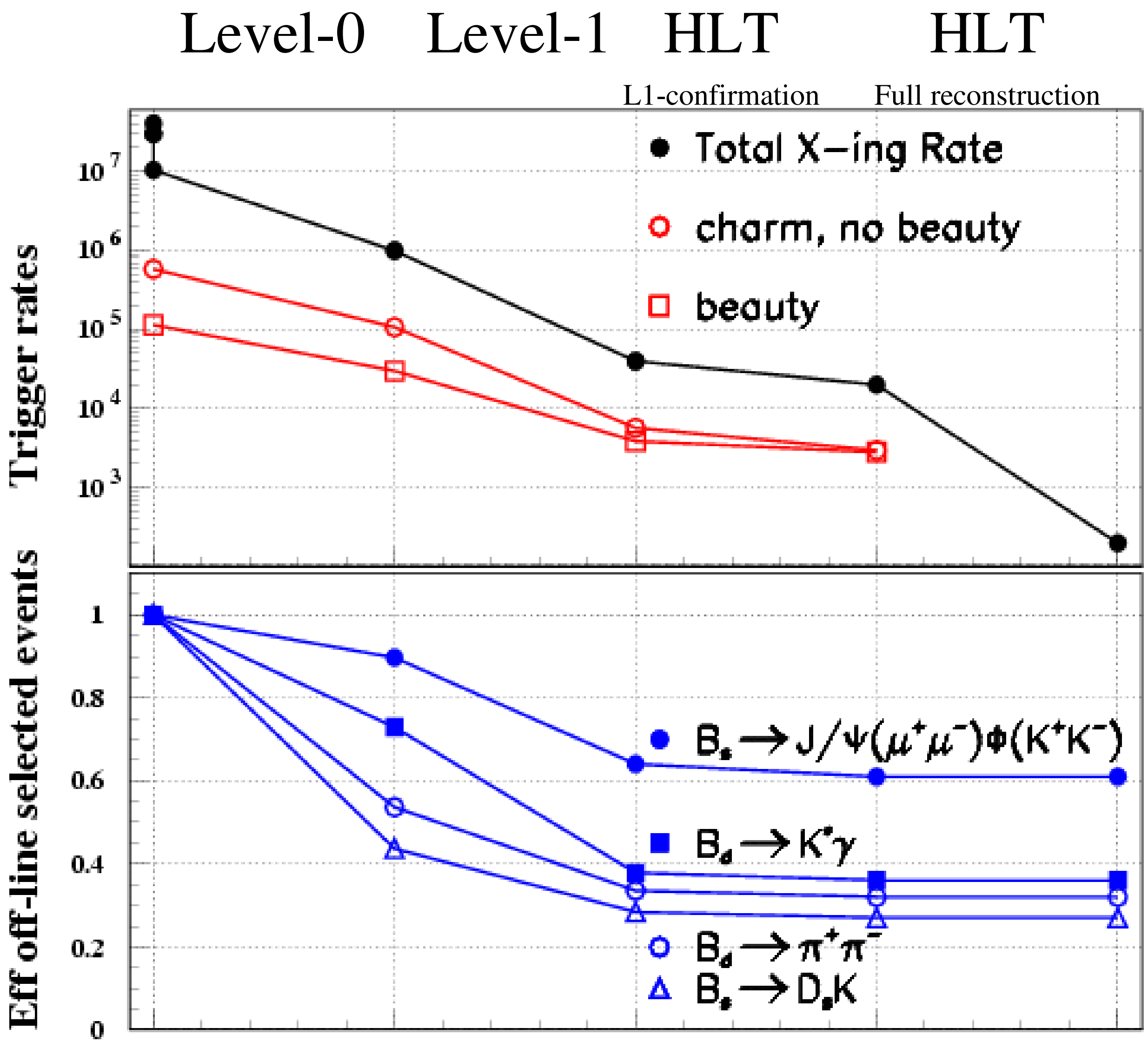
- Multiplicity/Pile-Up
- $E_T(\mu_1, \mu_2, h, e, \gamma, \pi^0)$

Level-1 (1 MHz → 40 kHz)

- Impact parameter
- Transverse momentum
  $\sigma(p_T)/p_T \approx 30\%$
- Invariant mass of muon pairs.

High Level Trigger
(40 kHz → 2 kHz)

- Redo L1 with full tracking
  $\sigma(p_T)/p_T \approx 1\%$
- Full reconstruction of final states

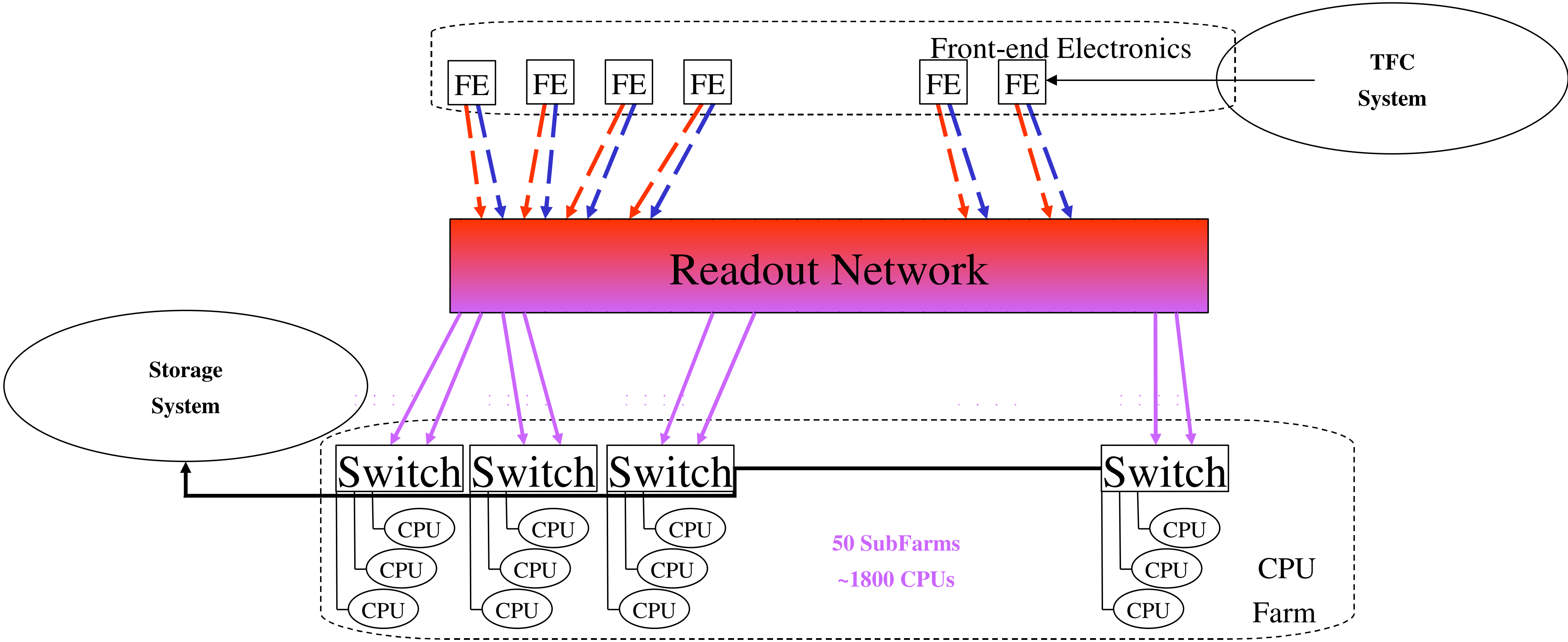


Recent trigger developments

DAQ has been changed to read out full detector at 1MHz

- This means that data will only pass through system once

As everything past L0 is s/w this gives full flexibility.



Systematics

Charge asymmetries in production and detection.

- Flavour specific channels like $B_d \to J/\Psi K^*$ and $B_s \to D_s^- \pi^+$ can be used to calibrate this.
- Magnetic dipole field will be regularly reversed.

Proper time resolution

- Important for B_s decays due to fast oscillation.
- It is a very hot topic at the moment how to calibrate this.

Flavour tagging

- Again flavour specific decays can be used. Important to use decay with similar kinematics (so $B_s \to D_s^- \pi^+$ for $B_s \to D_s^- K^+$ analysis).

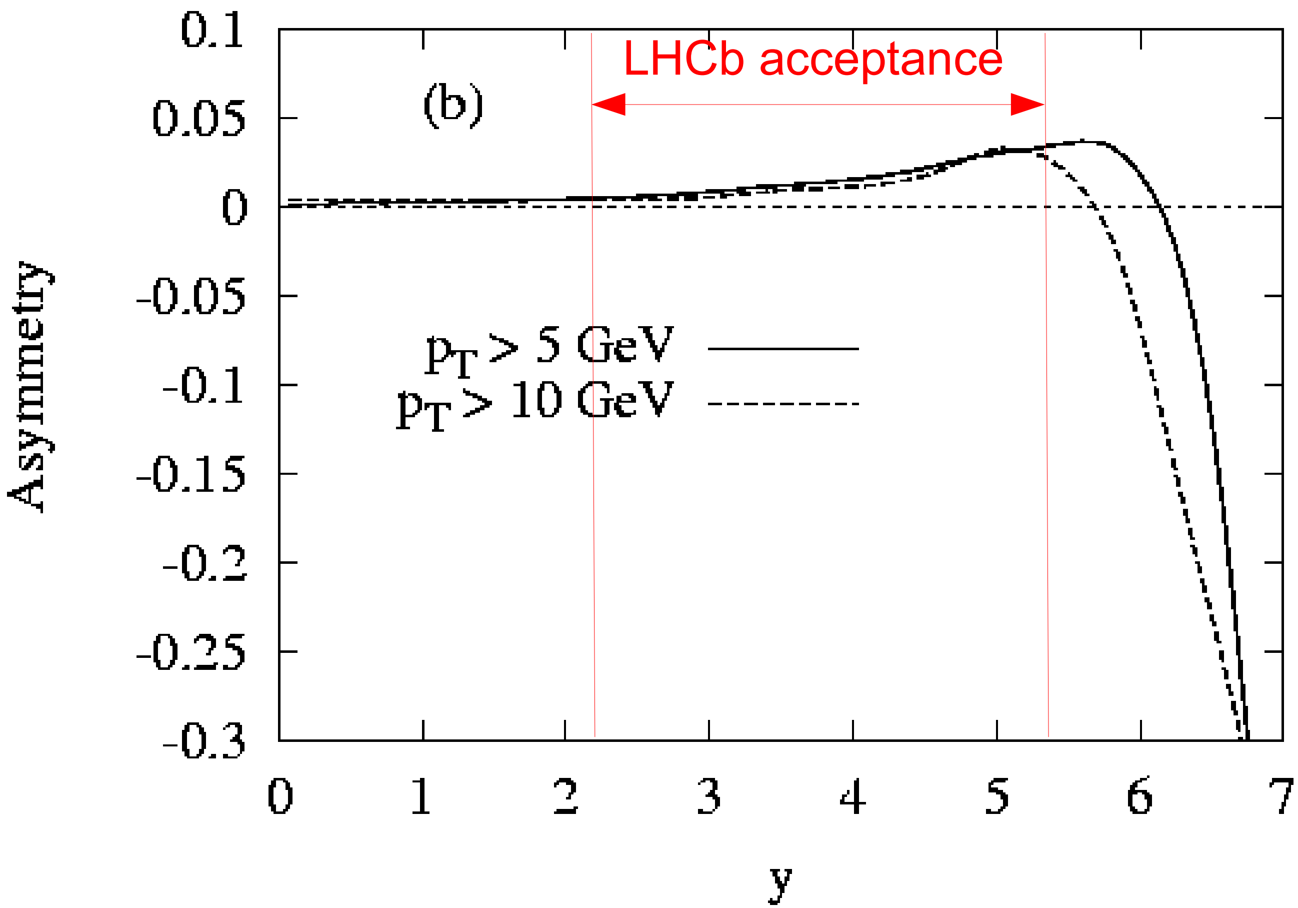
Trigger efficiencies

- Events triggered by more than one trigger category can be used for this.

Systematic effects

Predicted production asymmetry.

$$A = \frac{\sigma(B^0) - \sigma(\overline{B^0})}{\sigma(B^0) + \sigma(\overline{B^0})}$$



Towards the future

- TeVatron ($p\bar{p}$ collisions at $\sqrt{s}$=2 TeV)
  - CDF and D0 record large samples of *B*-mesons
  - Observation of B_s oscillations fantastic result
- LHC (pp collisions at $\sqrt{s}$=14 TeV)
  - LHC*b* is the dedicated *B* experiment at LHC.
  - 10^{12} *B*'s will be produced in interaction region per year.
  - From 2007 this will be the next generation *B* experiment.
- Why do indirect searches for New Physics when we have ATLAS and CMS to discover SUSY particles.
  - The short answer is that the methods are very complimentary
- A Super B-factory might be on the way
  - On comparable time scales not competitive with LHCb for radiative penguin decays

Conclusion

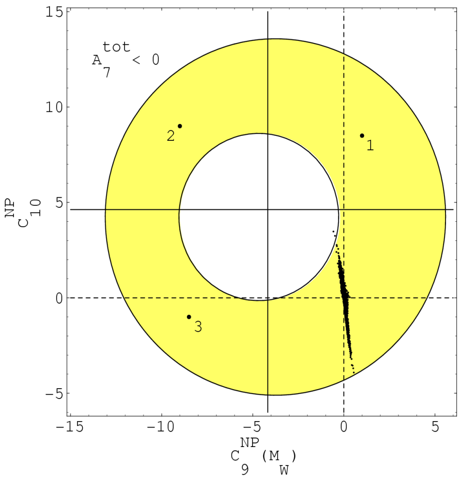
The analysis of Flavour Changing Neutral Decays of B hadrons provides one of the best insights into New Physics

In the rare decay sector the very first measurements are arriving from the B factories now.

LHCb has great prospects in this area from increased statistics

- I predict it will be the most prominent area of LHCb physics

We are now at the point in rare decays where the CKM triangle was before the B factories started



Plots like this will present our results

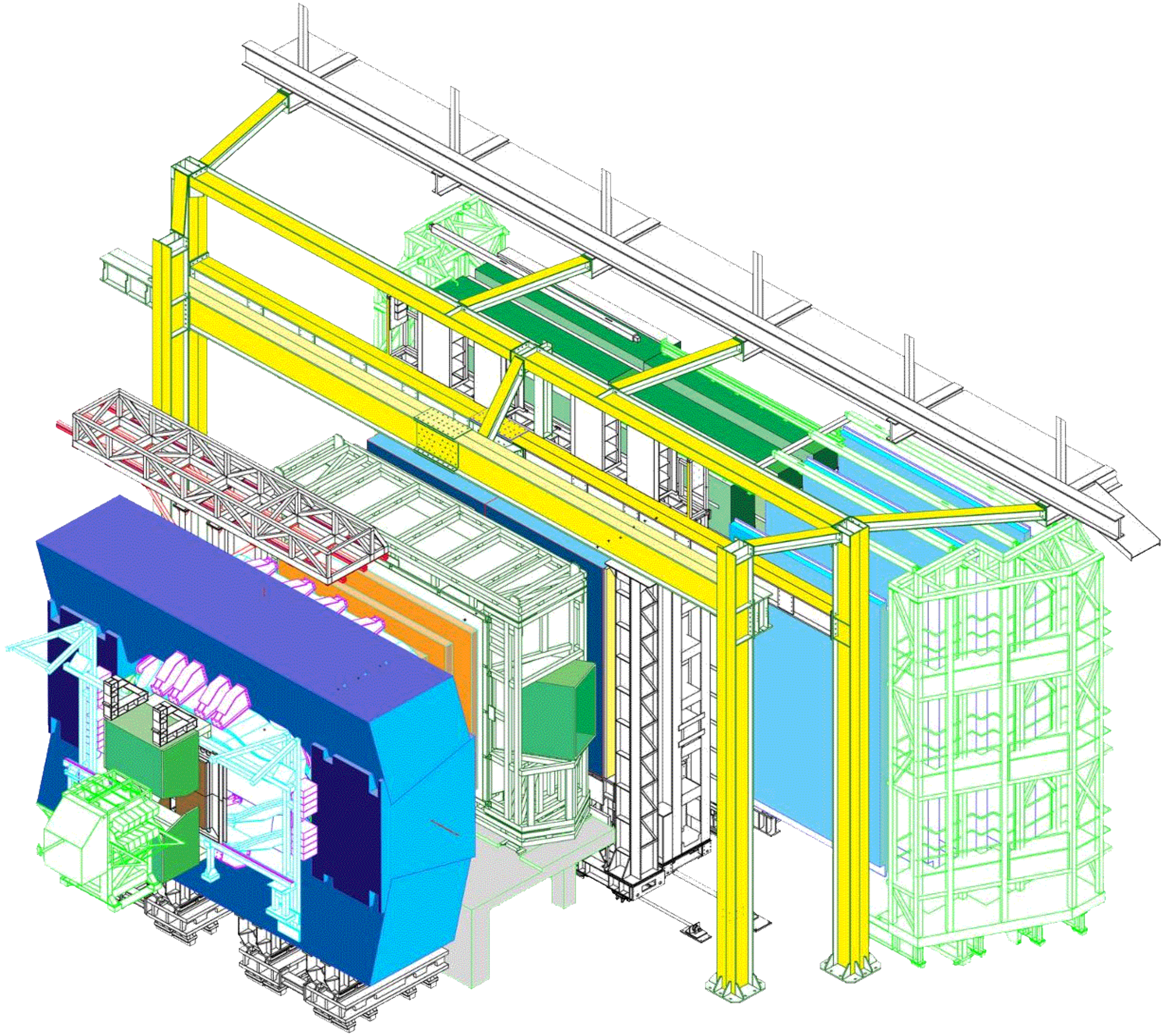
BACKUP SLIDES

The LHCb detector design

Large parts of the detector already installed.

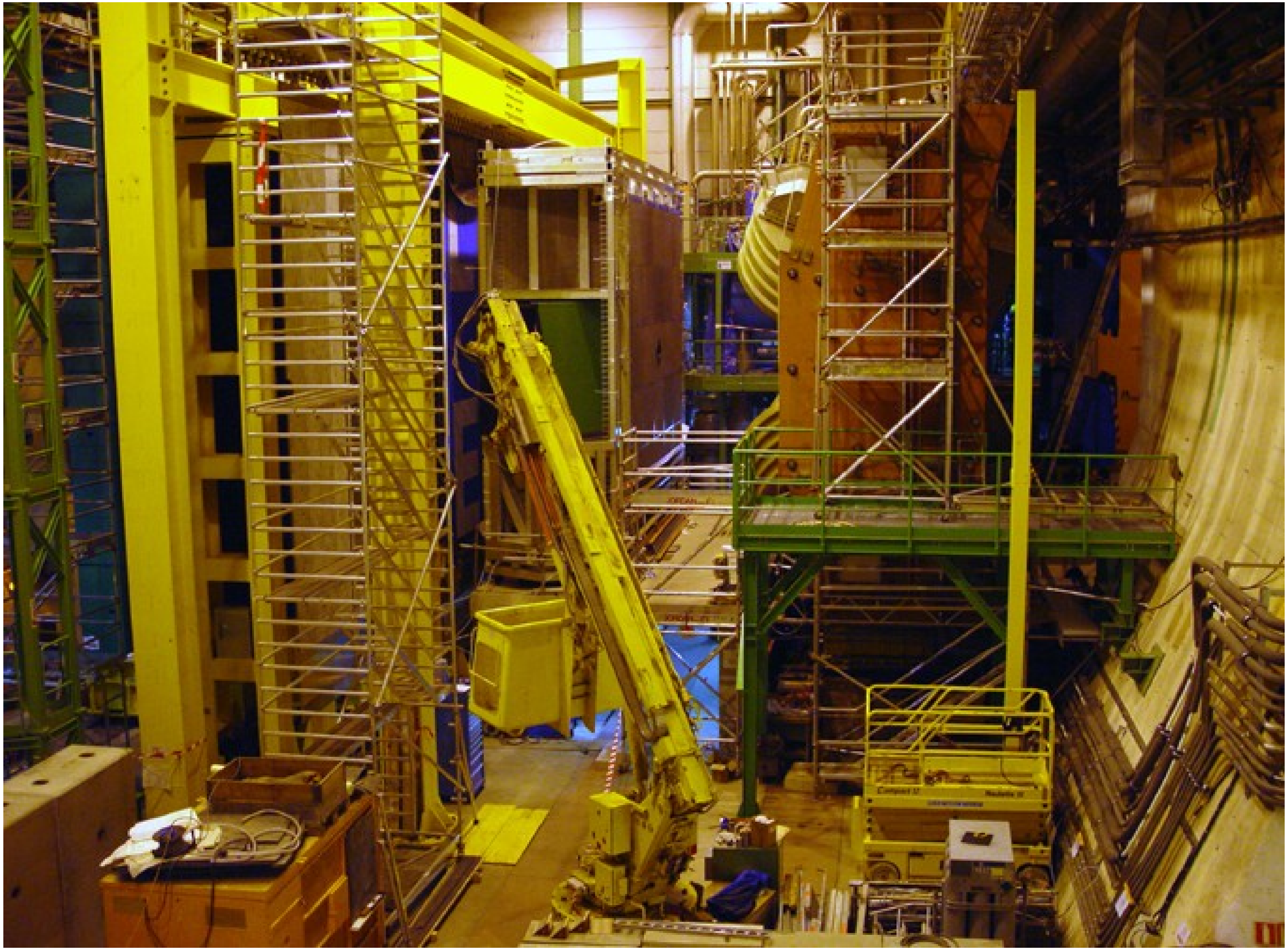
Schedule is tight but it is still realistic to have everything installed when first data arrives.

Commissioning already taking place for some detectors.



Pit in January 2005

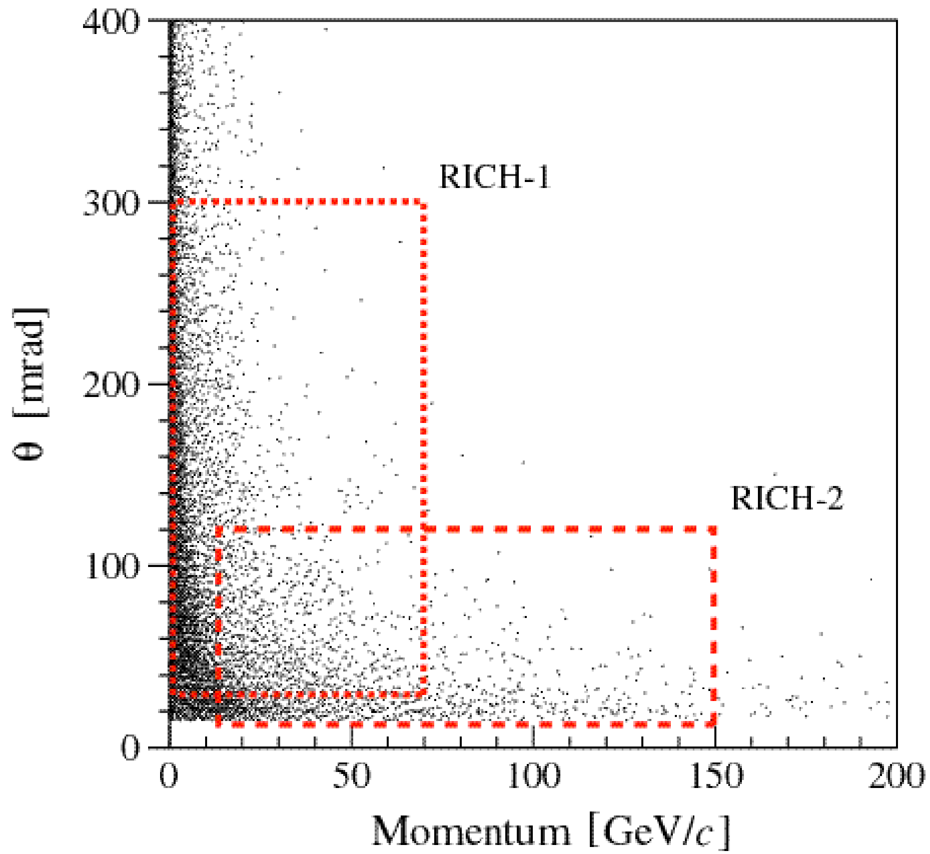
Pit in February 2006

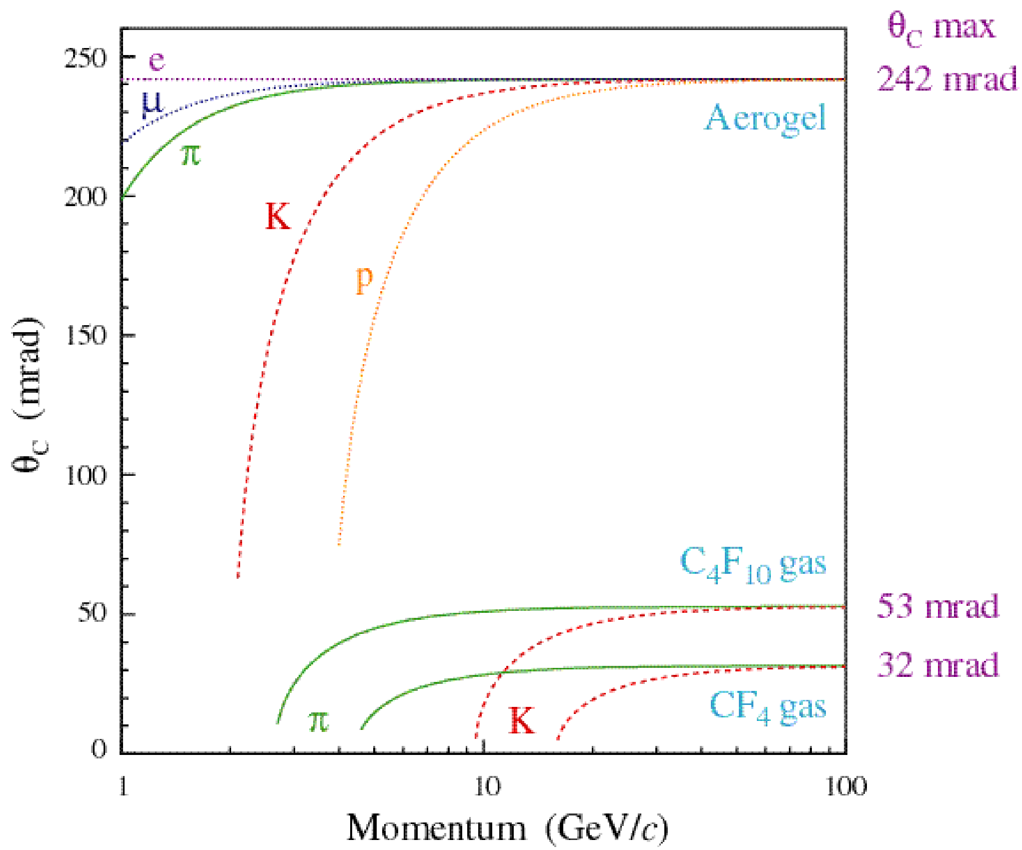


Imperial involvement

RICH detectors

Two detectors with 3 radiators to cover full momentum range





RICH-1 mechanics

Magnetic shielding box

Gas enclosure

Installation of RICH 2 detector

The CKM matrix

We nearly always use the Wolfenstein parametrisation.

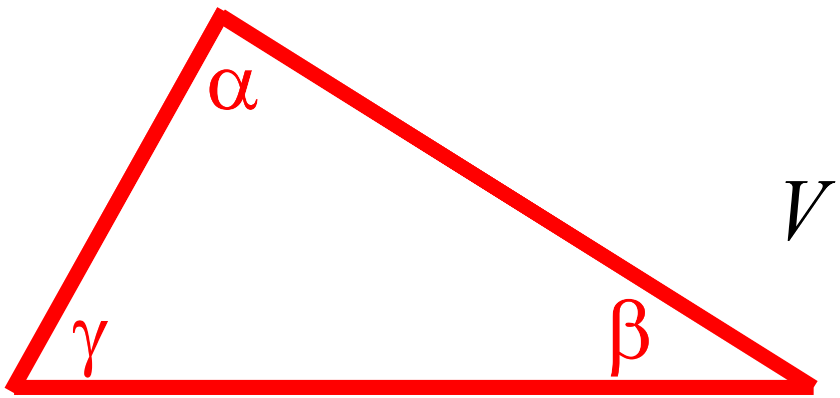
$$-|V_{ub}|e^{-i\gamma}$$

$$V_{CKM}=\begin{pmatrix} 1-\frac{\lambda^2}{2}+\frac{\lambda^4}{4} & \lambda & A\lambda^3(\rho-i\eta) \\ -\lambda+\frac{A^4\lambda^4}{2}-A^2\lambda^5(\rho+i\eta) & 1-\frac{\lambda^2}{2}+\frac{\lambda^4(1-2A^2)}{4} & A\lambda^2 \\ A\lambda^3(1-\bar{\rho}-i\bar{\eta}) & -A\lambda^2+A\lambda^4(\frac{1}{2}-\rho-i\eta) & 1-\frac{A^2\lambda^4}{2} \end{pmatrix}+O(\lambda^6)$$

$$-|V_{td}|e^{-i\beta} \qquad |V_{ts}|e^{i\chi}$$

Notice: Only one independent phase even if we here represent it as 3 phases.

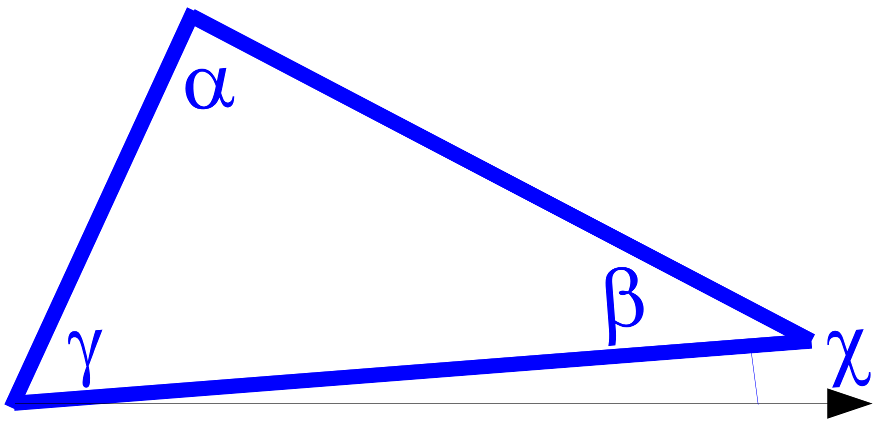
Unitarity triangles



$$V_{CKM} = \begin{pmatrix} V_{ud} & V_{us} & -|V_{ub}|e^{-i\gamma} \\ V_{cd} & V_{cs} & V_{cb} \\ -|V_{td}|e^{-i\beta} & |V_{ts}|e^{i\chi} & V_{tb} \end{pmatrix}$$

Unitarity states that $VV^\dagger = V^\dagger V = I$.

- 6 conditions normalising columns and rows.
  - Built into parametrisation
- 6 conditions expressing columns and rows are orthogonal.
  - Can be depicted as a triangle with 3 vectors adding up to zero.
- 4 very flat triangles
- 2 almost identical triangles.



Current state of angles and sides

The SM with its single phase explanation shows great agreement.

- In the future we can only look for small deviations from this picture

β

- Measurements much better than for any other angle. Will within a few years hit theoretical limit.

α

- Some further progress can be made at current experiments. Theoretically clean methods will take a long time to get enough statistics.

γ

- The first tentative measurements are made. Will really need to wait for hadron machine experiments.

χ

- Requires large amount of B_s decays so will have to wait for LHC.

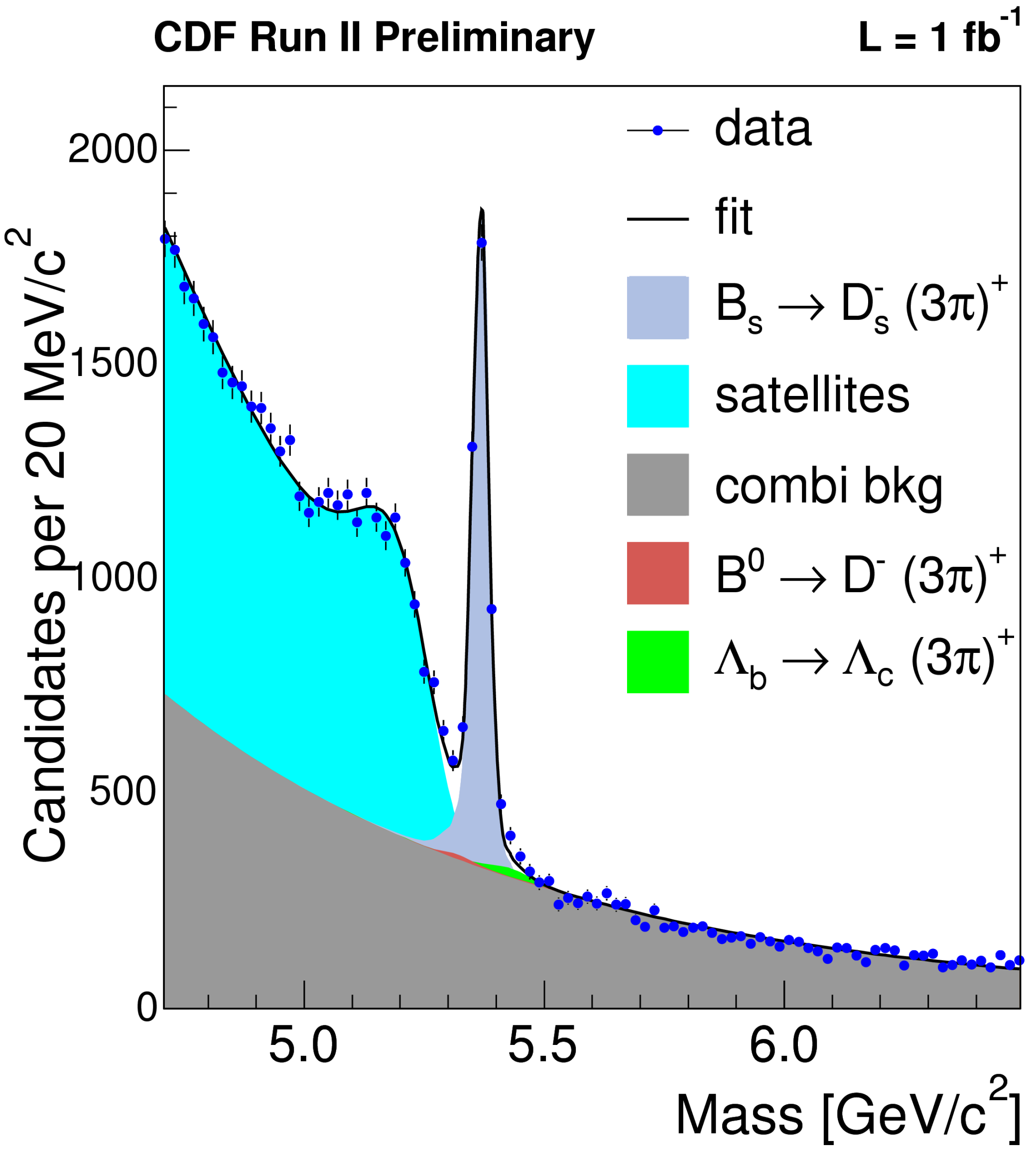
CDF Δm_s measurement

CDF result

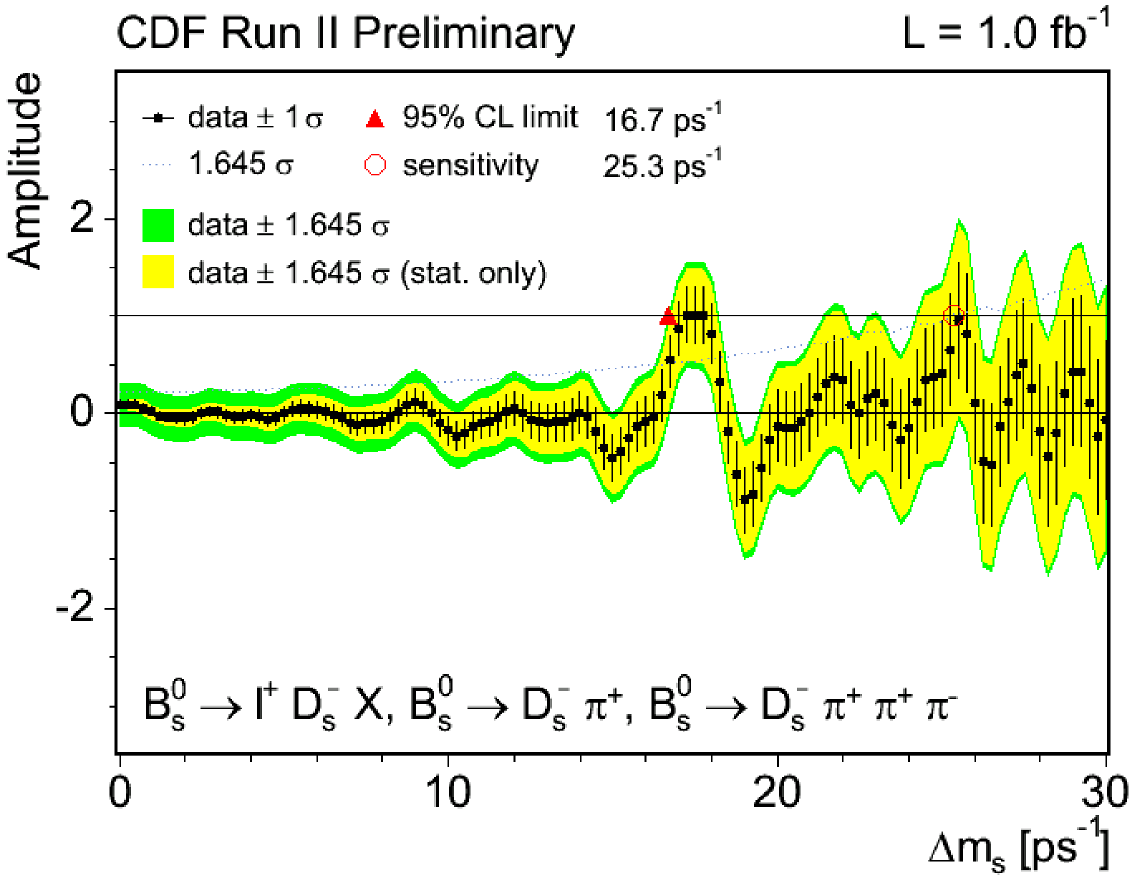
- Main dataset is hadronic $B_s \rightarrow D_s \pi$ decays

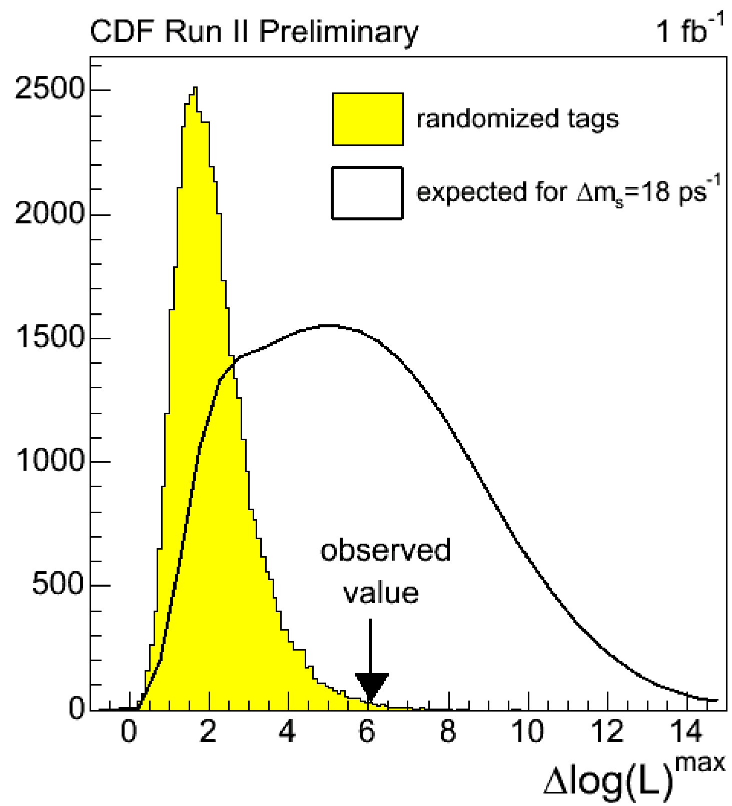
Overall result

- $\Delta m_s = 17.33$ $+0.42-0.2$(stat) ±0.07(sys)

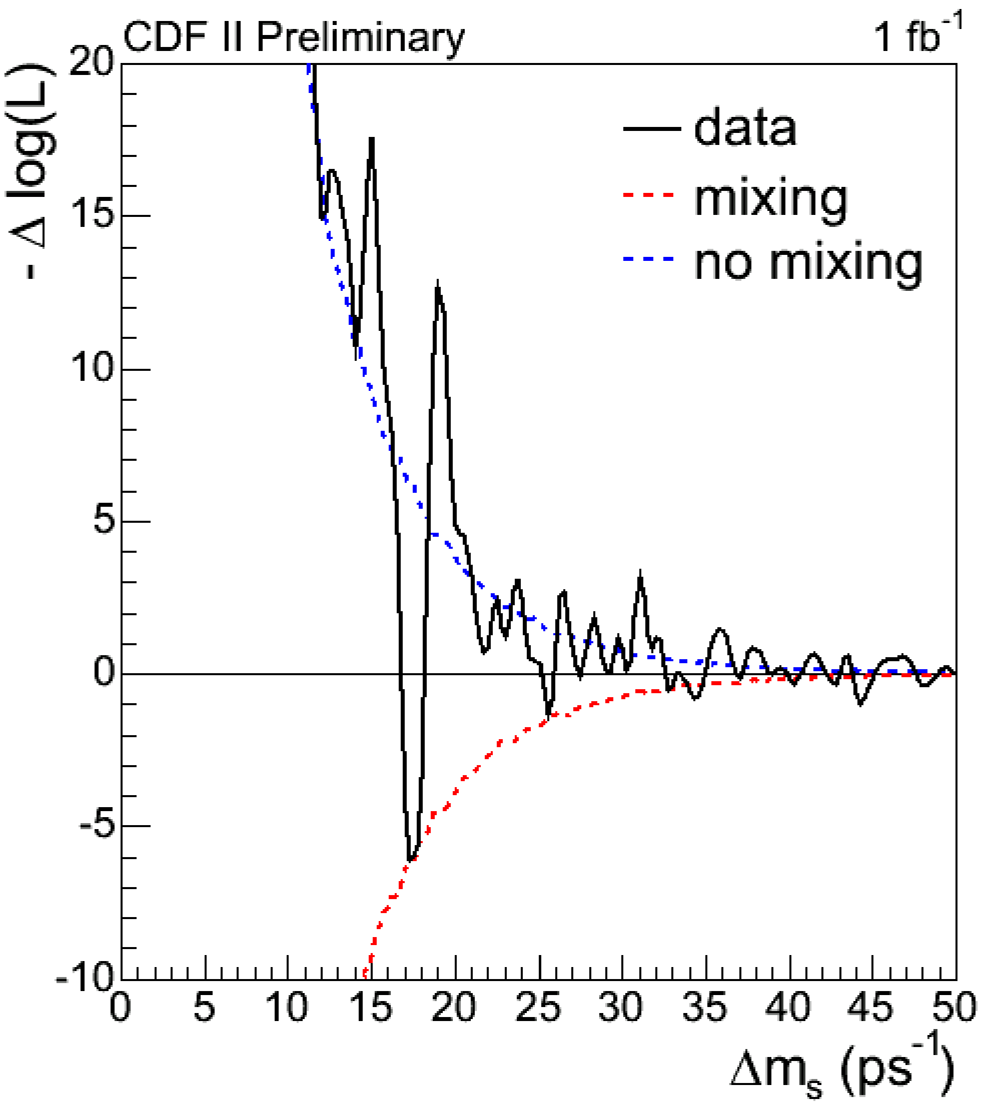


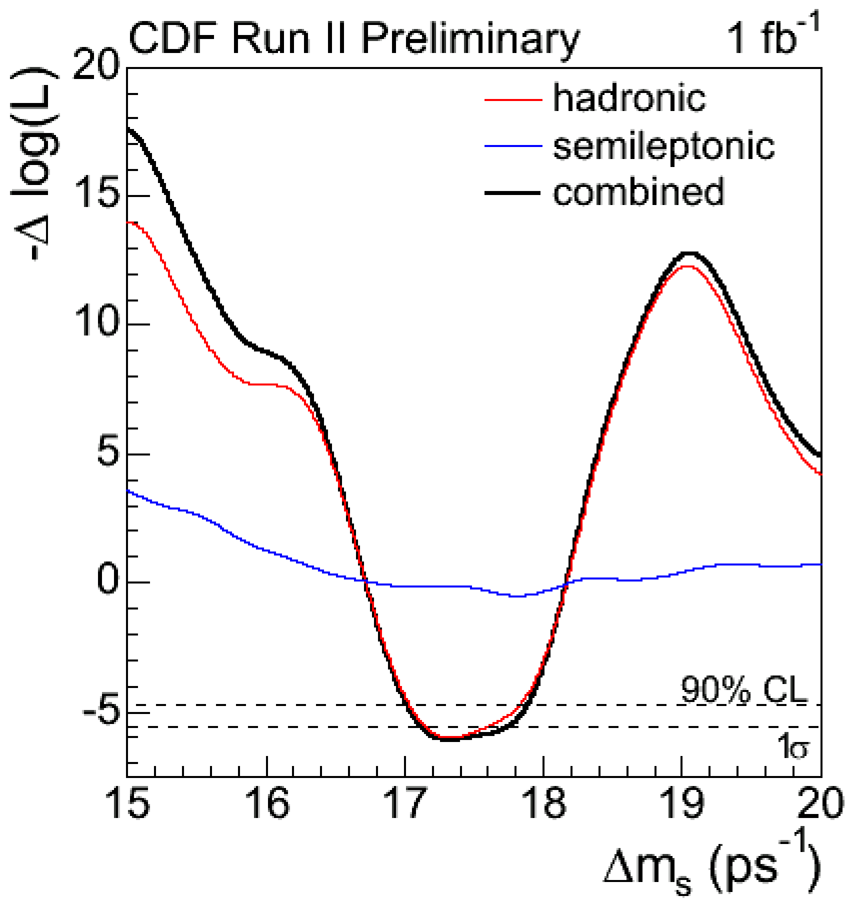
CDF Δm_s measurement





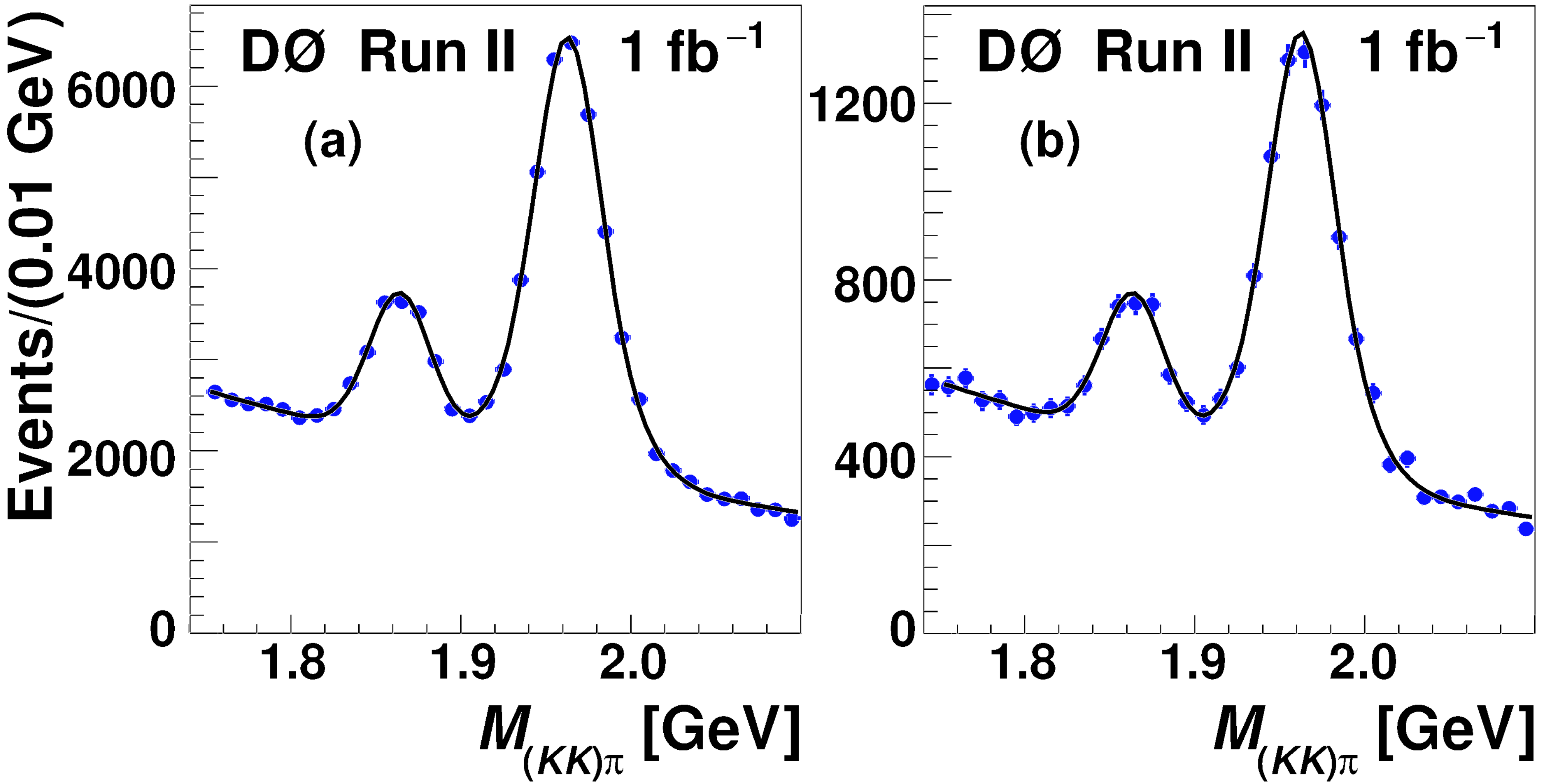
CDF Δm_s measurement





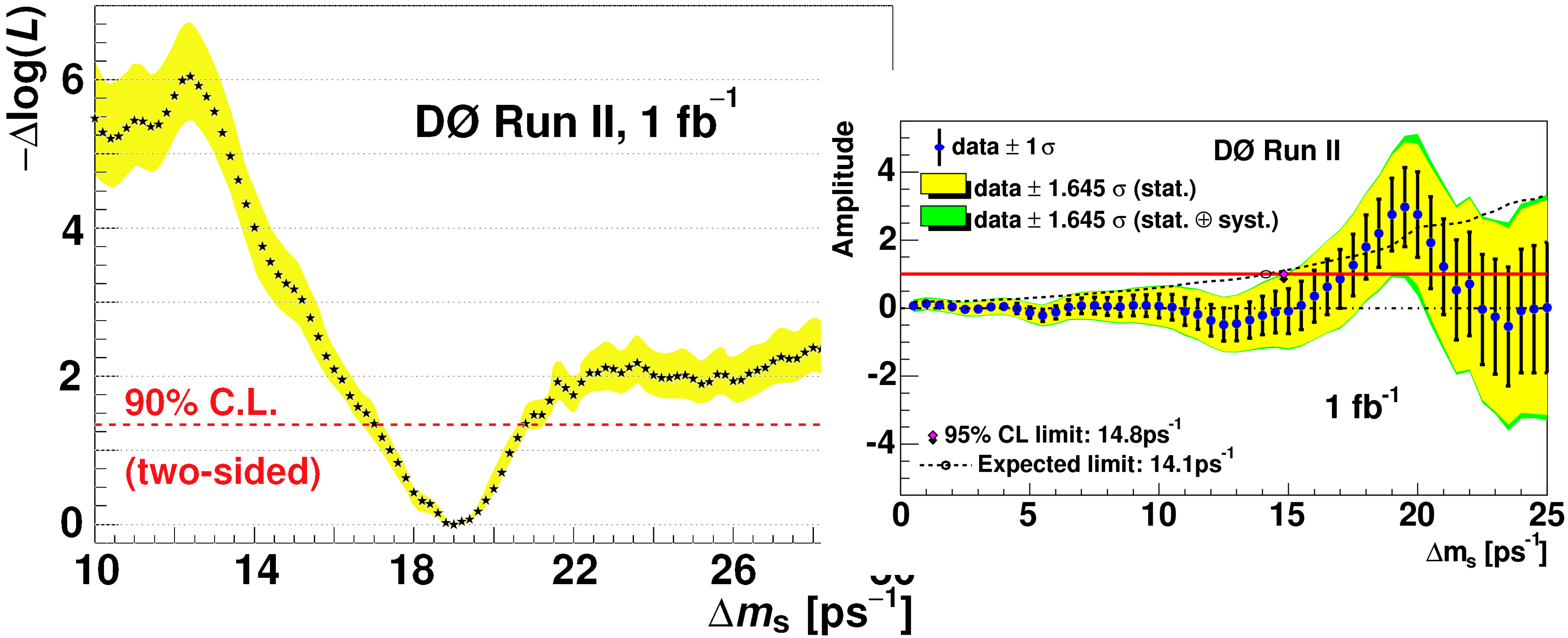
D0 Δm_s measurement

D0 data in semileptonic channel



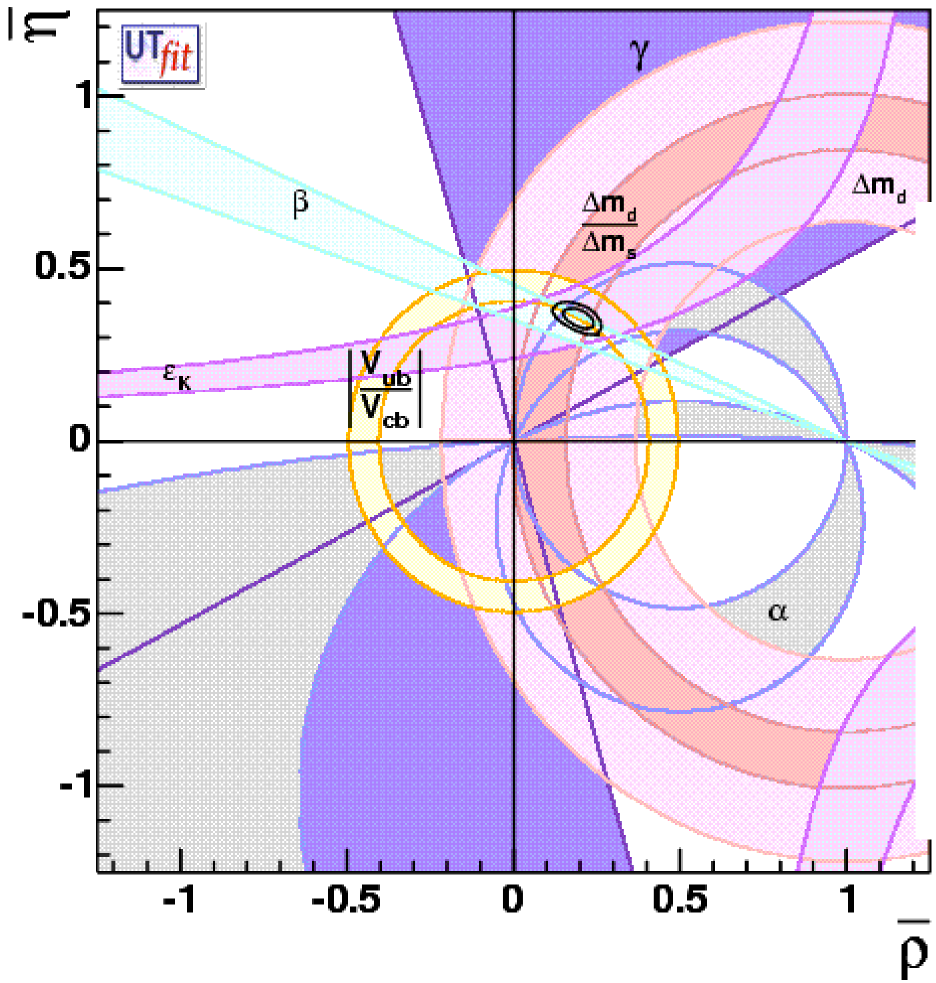
D0 Δm_s measurement

D0 result using semi-leptonic decays and opposite side tagging



Influence on fits in (ρ,η) plane

Fit including new Δm_s measurements



Fit summer 2005