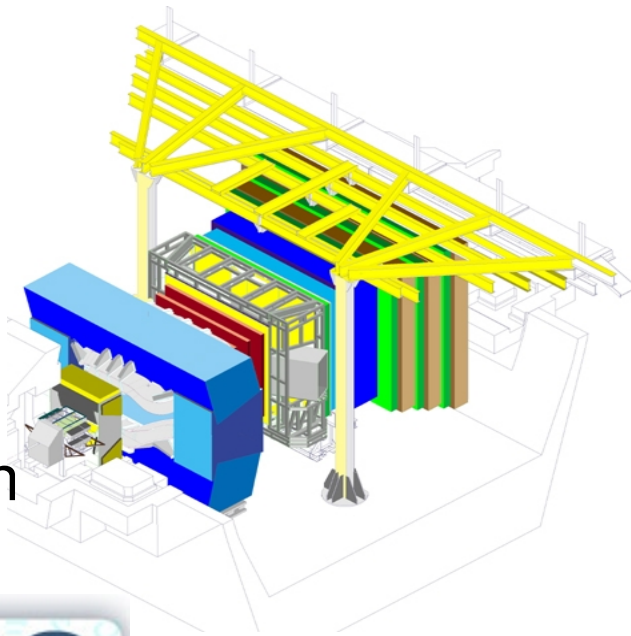
physics program

(searching new physics hidden in beauty and charm)

S. T'Jampens

LAPP

(CNRS/IN2P3 and Université de Savoie)



On behalf of the LHCb collaboration

BEACH 2008

The 8th International Conference on Hyperons, Charm, and Beauty Hadrons

22 - 28 June 2008 UNIVERSITY OF SOUTH CAROLINA

Outline

Flavor Physics: the Quest of New Physics

LHCb experiment

- B Physics at Hadron Collider
- LHCb spectrometer
- Tracking, PID, Flavor tagging, Trigger schemes and performances

Expected physics performance (examples)

- $\sin 2\beta$
- Measurements of γ
- B_s mixing phase $2\beta_s$
- $b \to s\bar{s}s$ penguins
- $B_s \to \mu^+\mu^-$
- $B_s \to K^* ll$
- Charm physics

Flavor Physics: The Quest of New Physics

The main purpose of B (D and K) physics is now to search for new physics effects in flavor-mixing, CP violation and rare decays.

➔ the 2nd generation "b-physics" experiments: pursuing the NP searches with precision measurements (and if NP is discovered, put constraints on its flavor structure)

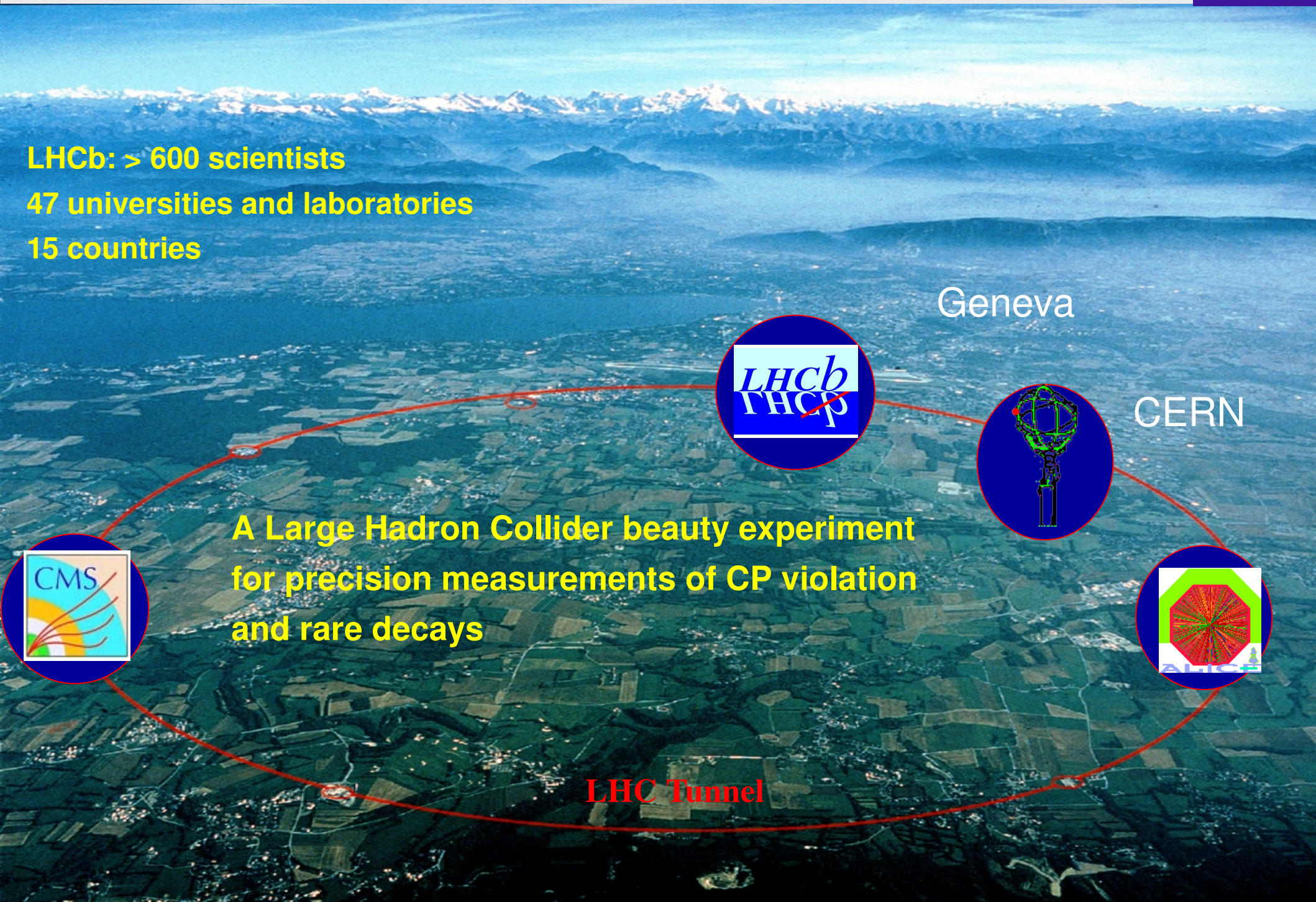
Three major themes:

1) precision determination of CKM elements to seek deviations from SM
2) New physics via CP-violating phases
3) New physics via rare decays

Look for everywhere:

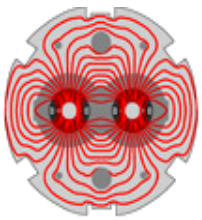
- consistency check of UT (angles and sides): need more statistics, esp. need improvement for γ (for "Reference UT" in Tree vs Loop) and Lattice QCD
- compare different measurements of the same quantities, one which is insensitive and another one which is sensitive to NP (e.g., sin2β from $B^0 \to J/\psi\, K_S$ and $B^0 \to \phi K_S$)
- V_{ts} (loop-induced processes):
  - $|\Delta F|=1$ FCNC rare decays (e.g., $b \to s\gamma$, $b \to s l^+ l^-$, $B_{(s)} \to \mu\mu$)
  - $|\Delta F|=2$ FCNC mixing (e.g., B_s mixing phase $2\beta_s$ with $B_s \to J/\psi\, \phi$)
- etc.

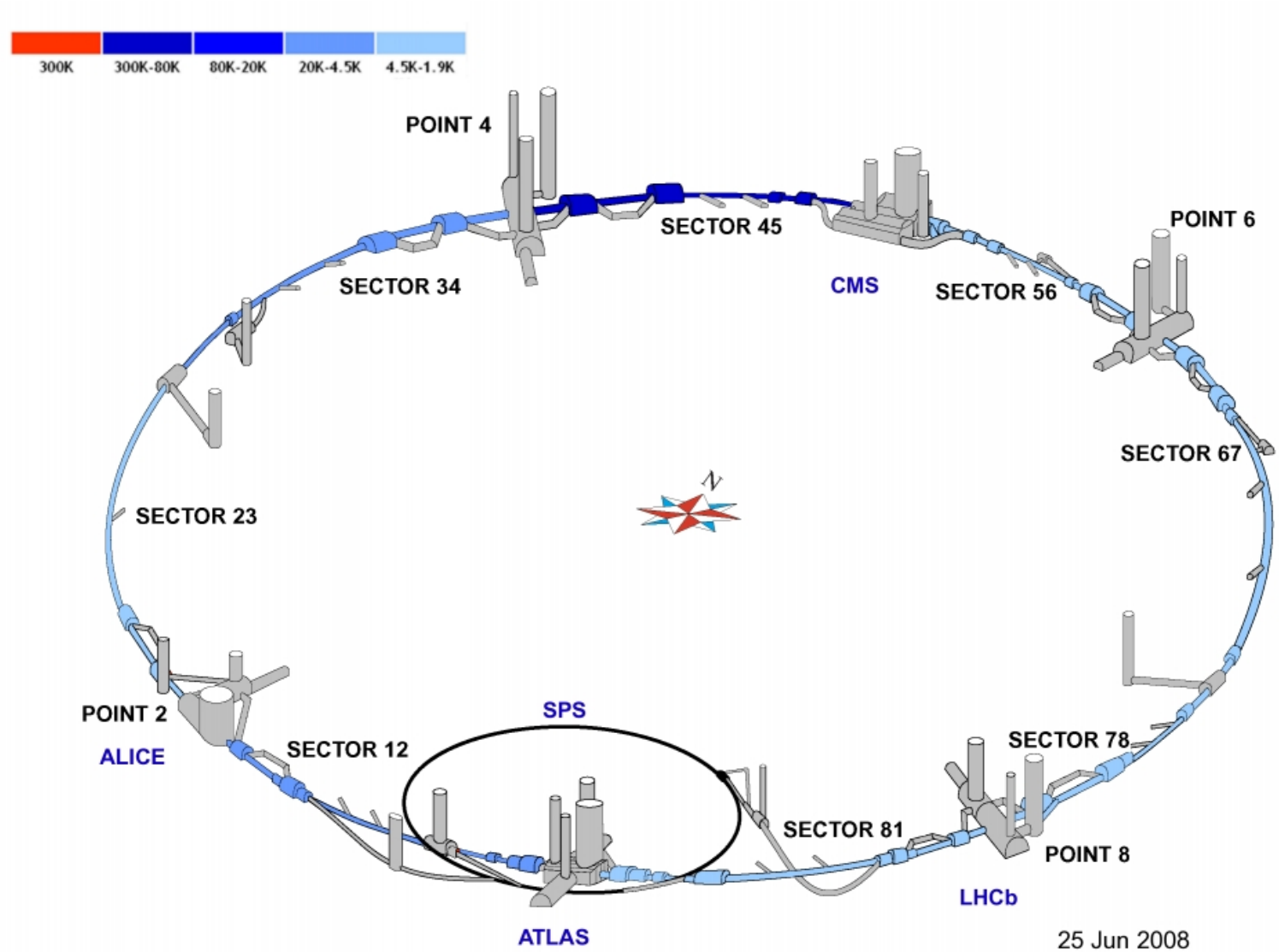
LHCb@LHC


LHCb: > 600 scientists
47 universities and laboratories
15 countries
Geneva
CERN
A Large Hadron Collider beauty experiment
for precision measurements of CP violation
and rare decays
CMS
LHC Tunnel

LHC cooling status and startup

- Cooling down is performing well, aiming for machine cooled down in early July
- Beam injected end July - early August. First collisions 1-2 months later
- Luminosity $\sim 10^{31}$ cm^{-2}s^{-1}, $\sqrt{s}$ = 10 TeV





LHCb environment @LHC

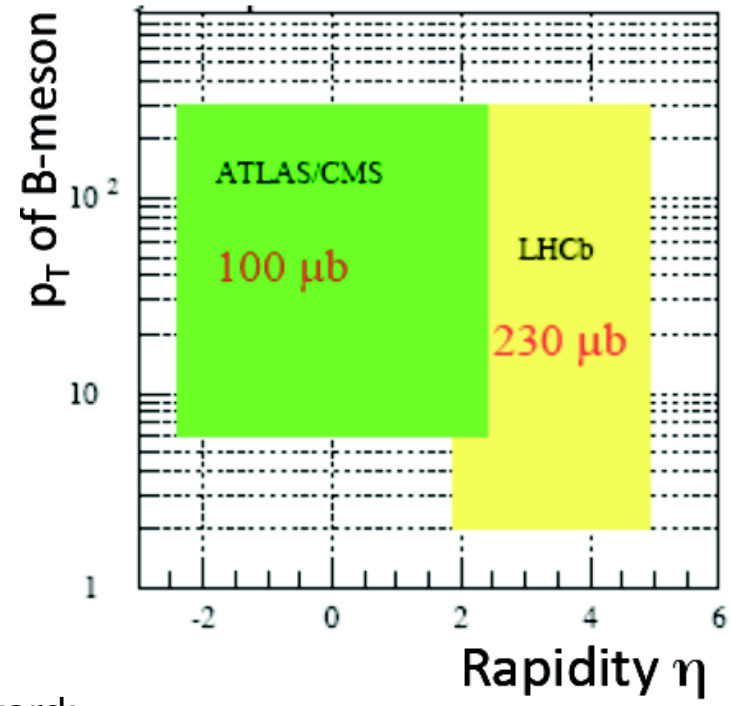
large cross section:

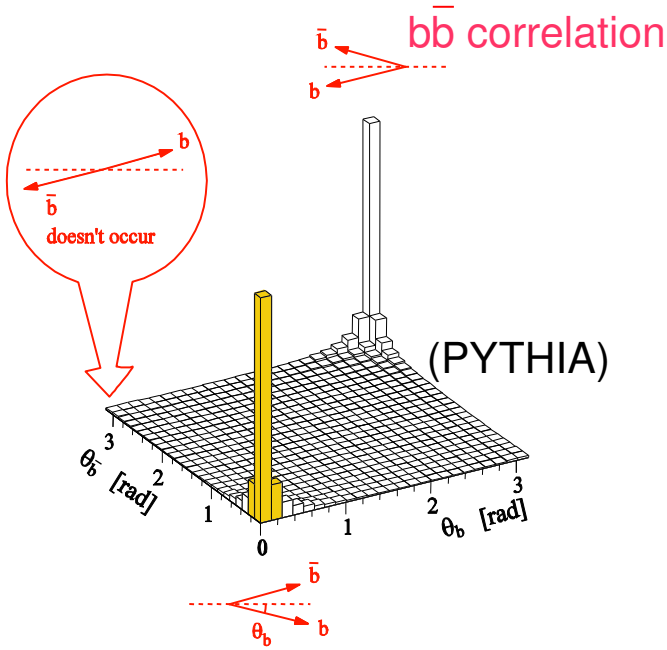
- 500 μb (230 μb in 4.9 > η >1.9 (forward region))

All species of B hadrons produced:

- ($B^{\pm}$, B_d, B_s, B_c, b-baryons) [40%,40%,10%,0.1%,10%]

$\sigma_{bb}/\sigma_{inel}$ = 0.6% at LHC: trigger is a major issue



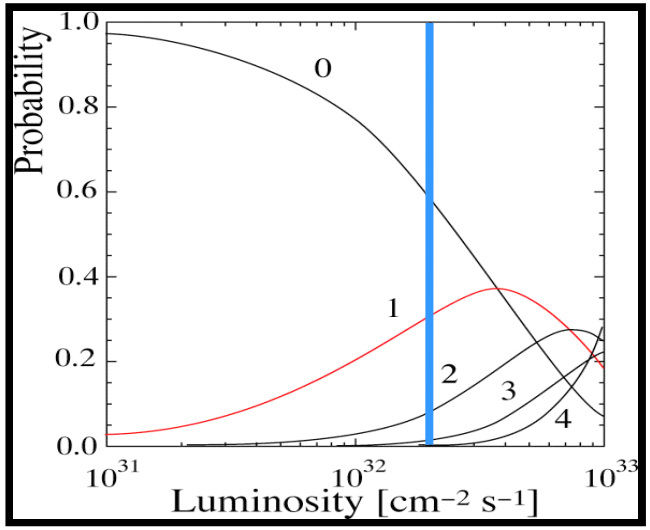


$b\bar{b}$ production correlated and sharply peaked forward backward: single-arm spectrometer is OK since b quarks are correlated

➔ important for tagging

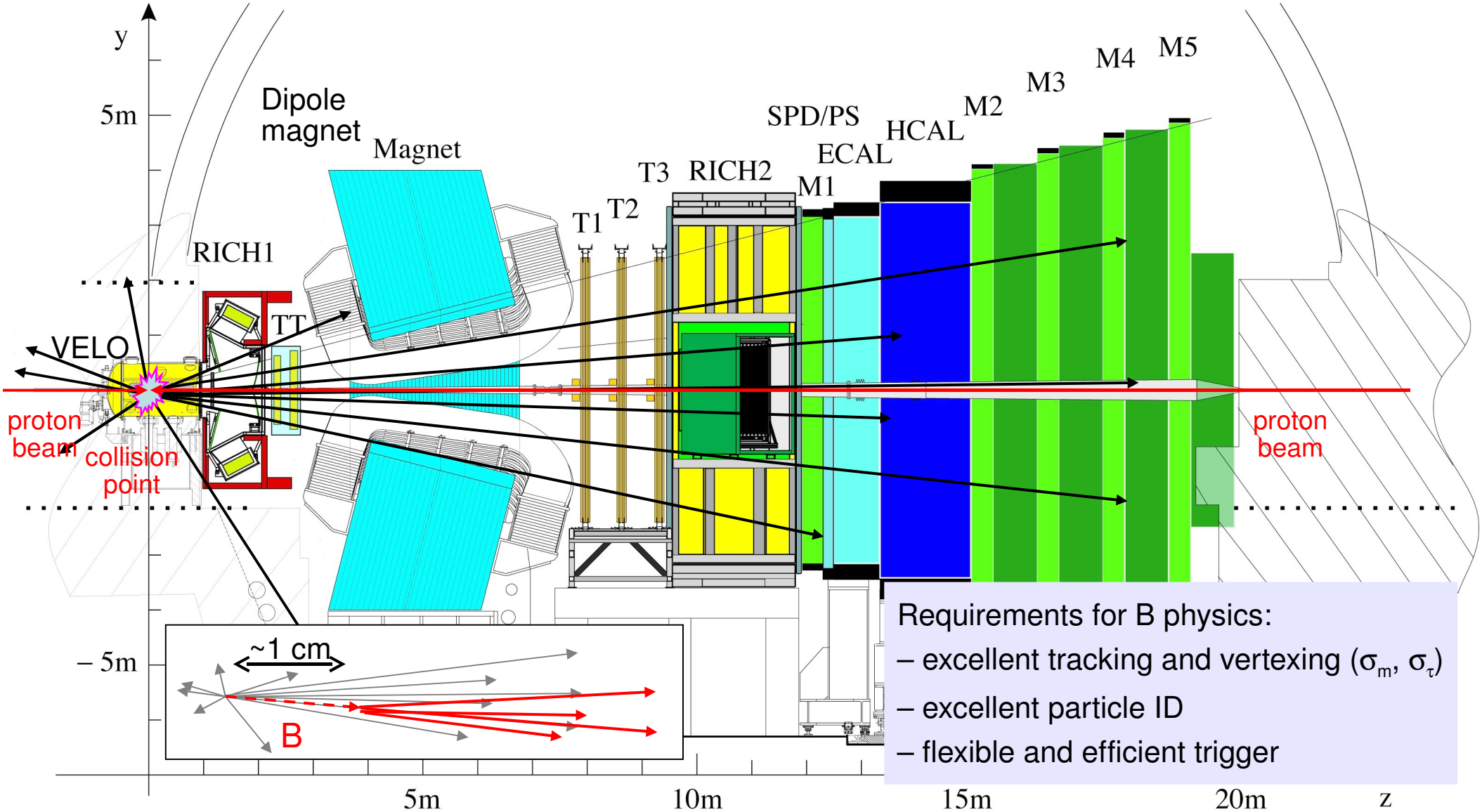
Luminosity $\mathcal{L}$=2x10^{32} cm^{-2}s^{-1} (de-tuned beams):

- clean environment (⟨n⟩ = 0.5)
- less radiation damage
- 5 10^{11} B hadrons (in acceptance) in 10^{7} sec (1 year, 2 fb^{-1})
- 10 fb^{-1} by 2013



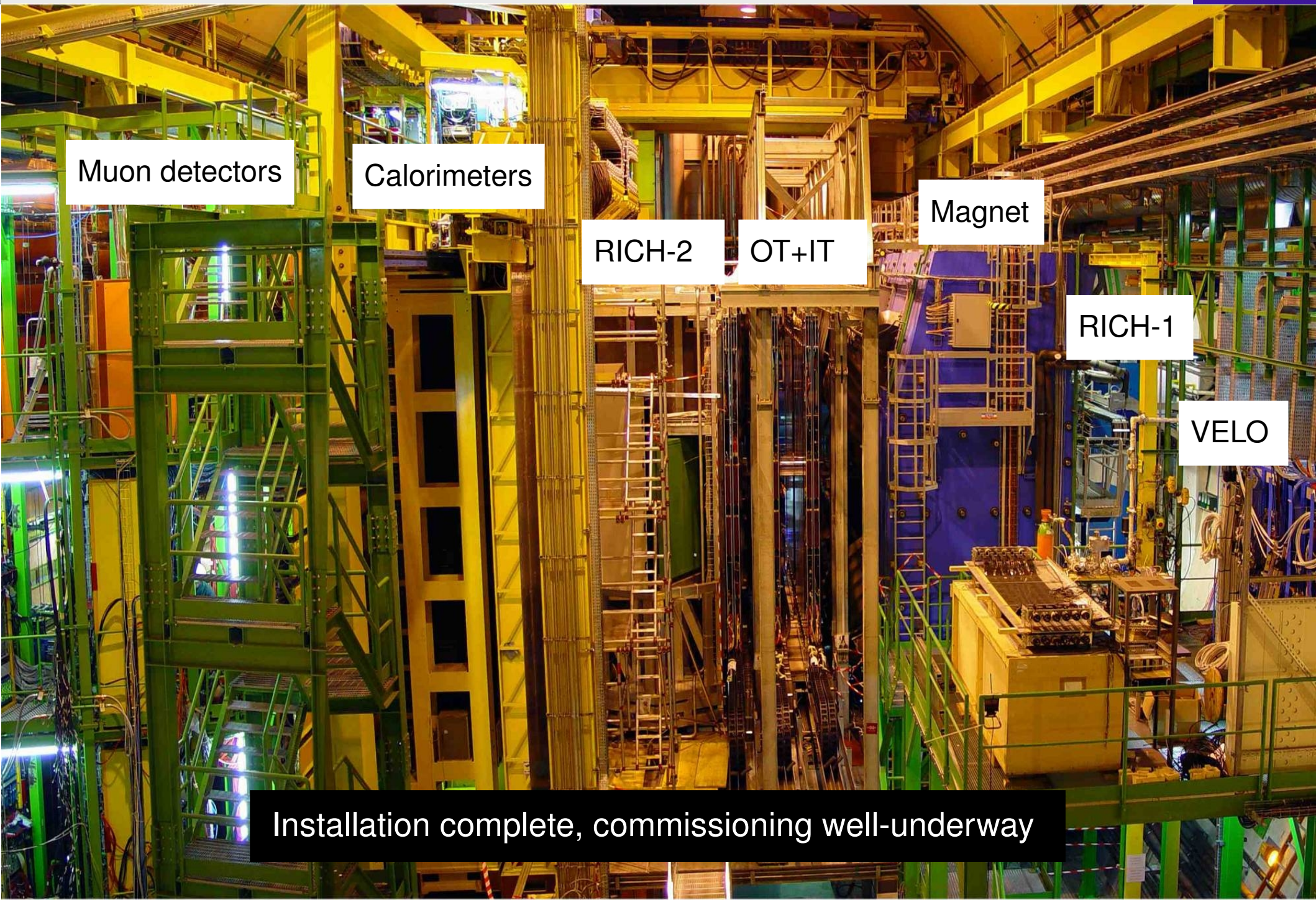
LHCb: Forward Spectrometer

VELO: Vertex Locator (around interaction point)
TT, T1, T2, T3: Tracking stations
RICH1-2: Ring Imaging Cherenkov detectors
ECAL, HCAL: Calorimeters
M1–M5: Muon stations



Requirements for B physics:
– excellent tracking and vertexing (σ_m, σ_τ)
– excellent particle ID
– flexible and efficient trigger

View of the LHCb cavern



Installation complete, commissioning well-underway

PID, tracking and tagging performances

Average b-decay track resolutions:

- impact parameter: ~30 μm
- momentum: ~0.36%

Typical B resolutions:

- proper time: ~40 fs (essential for B_s physics)
- mass: 8 – 18 MeV/c^2

	Mass resolution
$B_s \to \mu\mu$	18 MeV/c^2
$B_s \to D_s \pi$	14 MeV/c^2
$B_s \to J\psi \phi$	16 MeV/c^2
$B_s \to J/\psi \phi$	8 MeV/c^2 *

(*) with J/ψ mass constraint

PID average performance:

- kaon ID efficiency: 95%
- π mis-ID: 5%

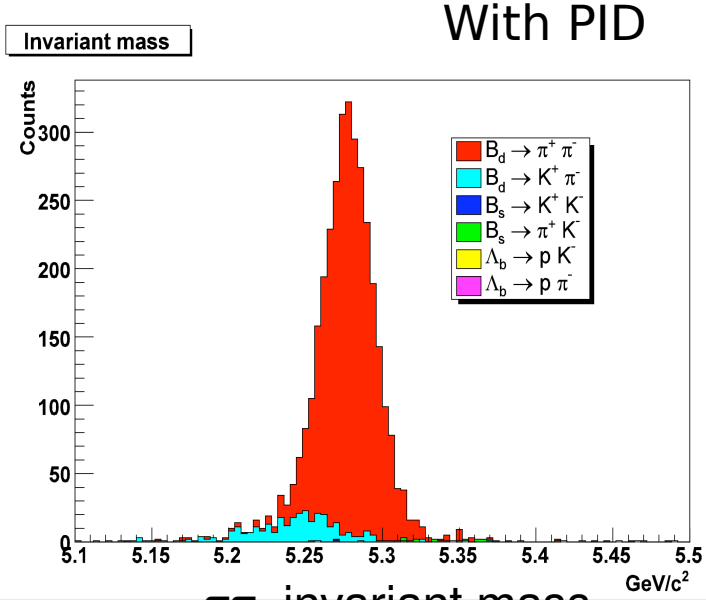
Good K/π separation in the 2 – 100 GeV/c range

Expected tagging performance:

(on triggered and selected MC events)

- $\varepsilon(1-2\omega)^2$= 7 – 9% for B_s
- $\varepsilon(1-2\omega)^2$= 4 – 5% for B_d

With PID



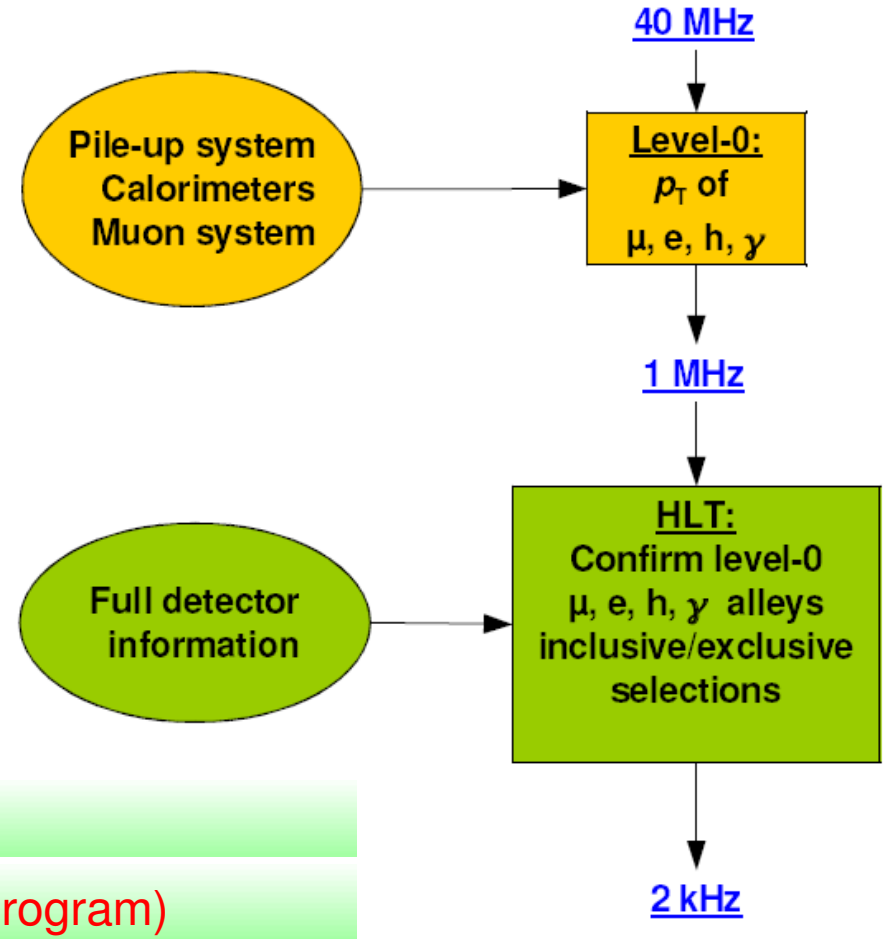
ππ invariant mass

Trigger Performance and Rates

Algorithms and performances:

➔ Johannes Albrecht's talk

- Hardware level (L0), max. 1 MHz output rate:
  algorithms mature
- Software level (HLT=High Level Trigger):
  prototype available within time budget for a limited set of channels
- L0*HLT efficiencies:
  typically 30%–80% for offline-selected signal events, depending on channel



Event size: ~ 50kB

Output rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, b→J/ψX (unbiased)
300 Hz	D* candidates	Charm
900 Hz	Inclusive b (e.g., b → μ)	B (data mining)

LHCb: Physics Program (examples)

http://lhcb-phys.web.cern.ch/lhcb-phys/DC04_physics_performance/

Sin2β with $B^0 \to J/\psi\, K_s$

Expected to be one of the first CP measurement:

"Yesterday's sensation is Today's calibration and Tomorrow's background" – hep physics' adage

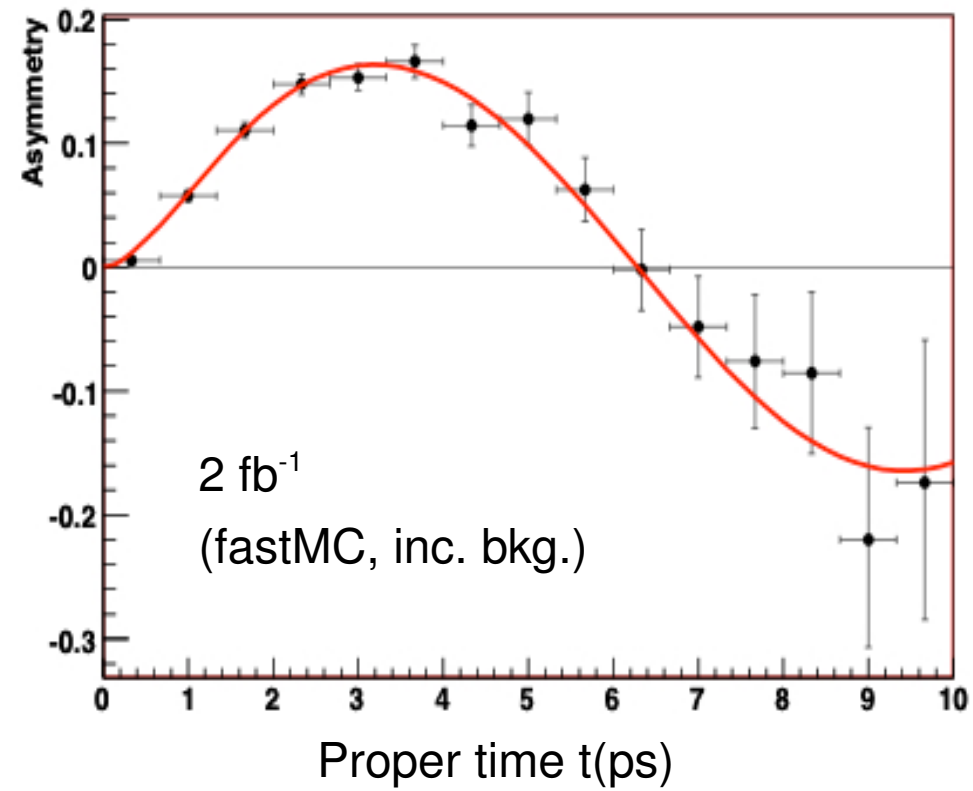
Demonstrate (already with ≤ 0.5 fb-1) that we can keep under control the main ingredient of a CP analysis, in particular the tagging performance extraction from the control sample $B^0 \to J/\psi\, K^{0*}$

$$A_{CP}(t) = \frac{N(\overline{B}^0 \to J/\psi K_S) - N(B^0 \to J/\psi K_S)}{N(\overline{B}^0 \to J/\psi K_S) + N(B^0 \to J/\psi K_S)}$$

Sensitivity: 236k events/2 fb^{-1} with B/S= 0.6 (bb) and 7.7 (prompt J/ψ)

➔ σ(sin2β) = 0.020

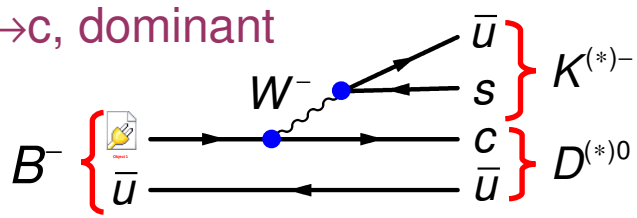
[B factories: 0.025 (850 fb^{-1})]



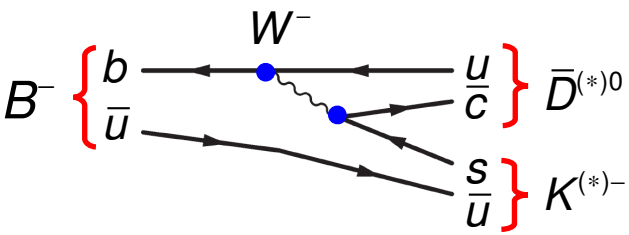
Measurements of the angle γ

$B^+ \to D^{(*)0} K^{(*)+}$:

Tree: b→c, dominant

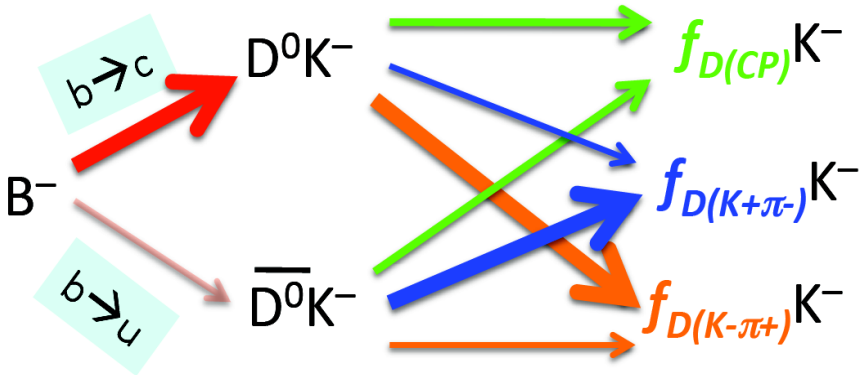


Tree: b→u, color-suppressed



Reconstruct D in final states accessible to both D^0 and $\bar{D}^0$:

- GLW: D decays to CP eigenstates
- ADS: D decays to flavor states
- GGSZ: D decays to $K_S\pi^+\pi^-$ (interference in Dalitz plot)



B mode	D mode	Method	$\sigma_{stat}(\gamma)$ [2 fb^{-1}]
$B^+ \to DK^+$	$K\pi$, $KK/\pi\pi$	counting,ADS+GLW	11 – 14°
$B^+ \to DK^+$	$K_S\pi\pi$	Dalitz, GGSZ	7 - 12°
$B^+ \to DK^+$	$KK\pi\pi$	4-body Dalitz	18°
$B^0 \to D^0K^{*0}$	$K\pi$, KK, $\pi\pi$	counting,ADS+GLW	9°

tree decays only

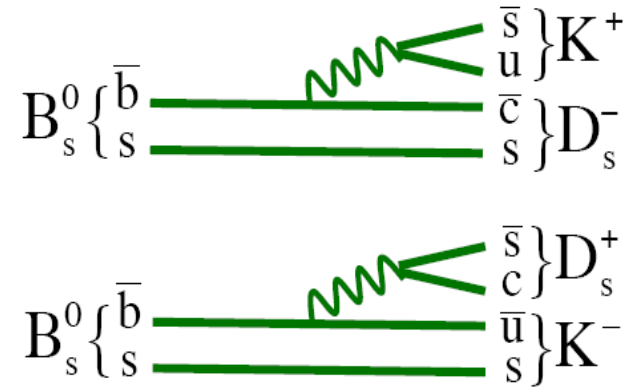
Other modes under study: $B^+ \to D^*(D \to K\pi, KK, \pi\pi)K^+$, $B^+ \to D(\to K\pi\pi\pi)K^+$, ...

$2\beta_s+\gamma$ from $B^0_s \to D_s K$

Two tree decays ($b \to c$ and $b \to u$), which interfere via B_s mixing:

- can determine $2\beta_s+\gamma$ hence γ in a clean way

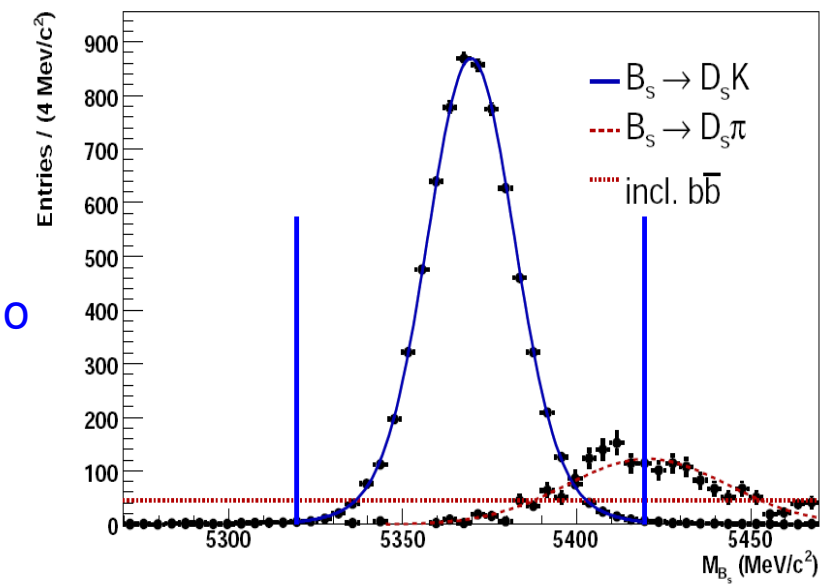
  similar to $2\beta+\gamma$ extraction with $B^0 \to D^* \pi$, but with the advantage that the two decay amplitudes are similar ($\sim\lambda^3$) and therefore their ratio can be extracted from data



LHCb expects 6.2k events/2 fb^{-1}

$B_{bb}/S < 0.18$ (@90 CL)

$B_s \to D_s \pi$ background 15±5% after PID cuts



- extract $2\beta_s+\gamma$, strong phase difference and amplitude ratio

($B_s \to D_s \pi$ (140k/2 fb^{-1}) also used in the fit to constrain other parameters (mistag rates, Δm_s, $\Delta\Gamma_s$, ...))

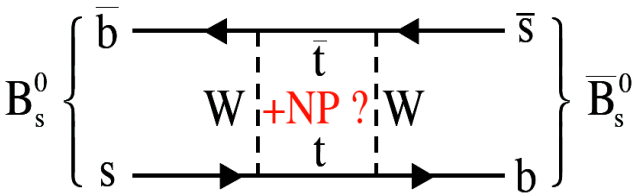
➔ $\sigma(2\beta_s+\gamma) = 9 - 12°$ with 2 fb^{-1}

$2\beta_s$: B_s mixing phase with $b \to c\bar{c}s$

$2\beta_s$ is the strange counterpart of 2β:

CKMfitter Summer 2007

- β_s very small in SM and well-predicted: $(1.054^{+0.051}_{-0.049})°$
- Could be much larger in presence of New Physics



Golden $b \to ccs$ mode is $B_s \to J/\psi\phi$:

- but ... angular analysis needed to disentangle CP-even and CP-odd contributions

$$A_{CP}(t) = \frac{-\eta_f \sin 2\beta_s \sin(\Delta m_s t)}{\cosh(\Delta\Gamma_s t/2) - \eta_f \cos 2\beta_s \sinh(\Delta\Gamma_s t/2)}$$

Current experimental situation:

- CDF: 2k, 1.35 fb^{-1} – $+2\beta_s \in [0.32, 2.82]$ @68% CL PRL 100, 161802 (2008)
- D0: 2k, 2.8 fb^{-1} – $+2\beta_s = 0.57^{+0.24}_{-0.30}{}^{+0.07}_{-0.02}$ arXiv:0802.2255 [hep-ex]

LHCb sensitivity with 2 fb^{-1}:

131k $B_s \to J/\psi(\mu\mu)\phi$ events (before tagging),

$B_{bb}/S = 0.12$, $\sigma_t = 36$ fs

➔ $\sigma_{stat}(2\beta_s) = 0.023$

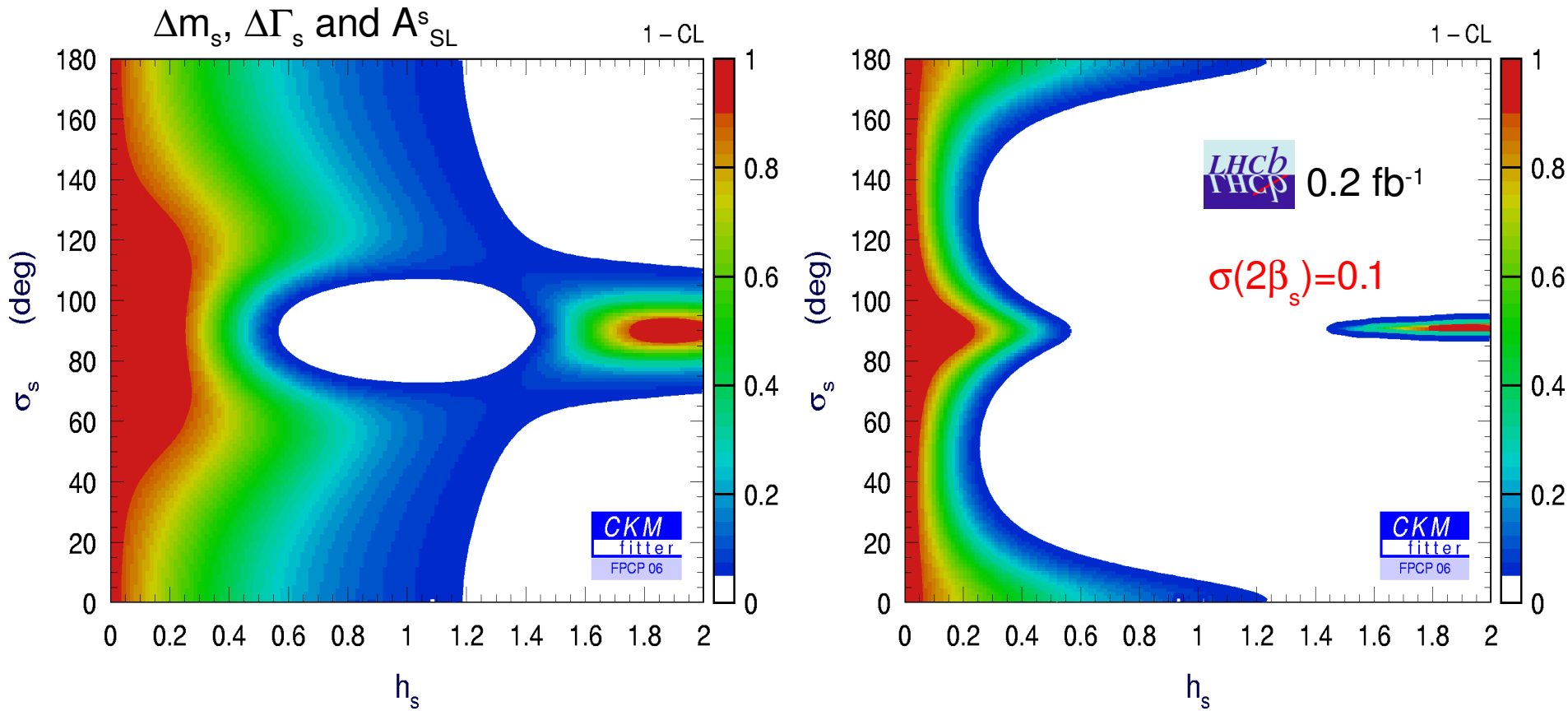
➔ $\sigma_{stat}(\Delta\Gamma_s/\Gamma_s) = 0.0092$

- Add also pure CP modes ($J/\psi\eta^{(\prime)}$, $\eta_c\phi$, D_sD_s)
  low yields, high background
  ~25k, $\sigma_{stat}(2\beta_s) = 0.046$
- With 10 fb^{-1}, obtain >3σ evidence of CP violation ($2\beta_s \neq 0$), even if only SM

Constraints on NP from $2\beta_s$ measurement

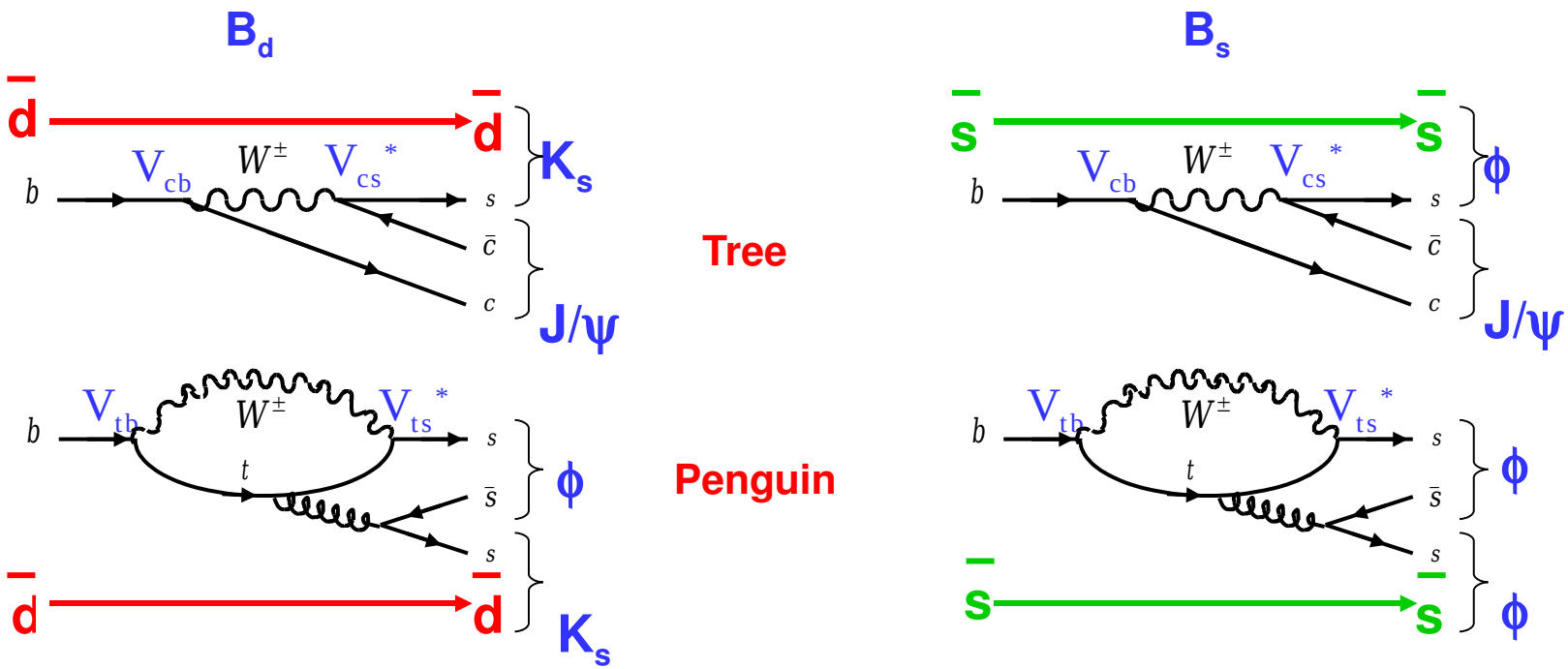
NP in B_s mixing:

- amplitude M_{12} parametrized with h_s and σ_s: $$M_{12} = \left(1 + h_s e^{2i\sigma_s}\right) M_{12}^{SM}$$



LHCb can exclude already a significant region of allowed phase space with the very first data or ...

$b \to s\bar{s}s$ hadronic penguin decays

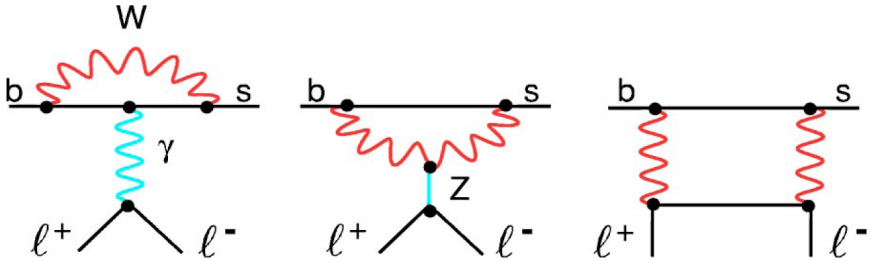


- Time dependent CP analysis of pure penguin decays into CP eigenstates ($B_s \to \phi\phi$: CP violation < 1% in SM, angular analysis required)

Channel	Yield (2 fb^{-1})	B/S	Weak phase
$B \to \phi K_s$	920	< 1.1	$\sigma(\sin(2\beta_{eff})) = 0.23$
$B_s \to \phi\phi$	3100	< 0.8	$\sigma(2\beta_{s,eff}) = 0.11$

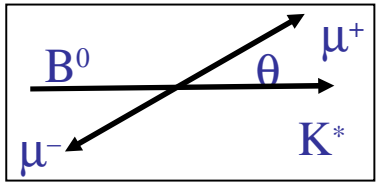
$B \to K^* l^+ l^-$

Electroweak penguins. Many observables:



- Forward-Backward asymmetry:

$A_{FB}(s=m^2_{ll})=(N_F - N_B)/(N_F+N_B)$



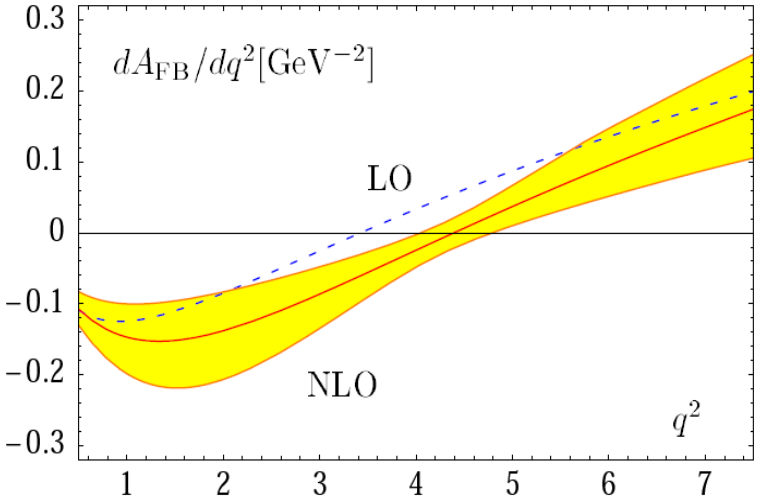
- Zero of $A_{FB}(s)$ [$s_0^{SM}=4.31^{+0.31}_{-0.30}$ GeV^2/c^4]
- F_L and $A_T^{(2)}$ (long. pol. and trans. asym.)
- Ratio of ee and μμ modes

QCDF: EPJ C41 (2005) 173
SCET: EPJ C47 (2006) 625

Current experimental situation:

$BR(B^0_d \to K^{*0} \mu^+\mu^-)$ [10^{-6}]= $0.98^{+0.22}_{-021}$

HFAG Winter 2008
[Belle, BABAR, CDF]



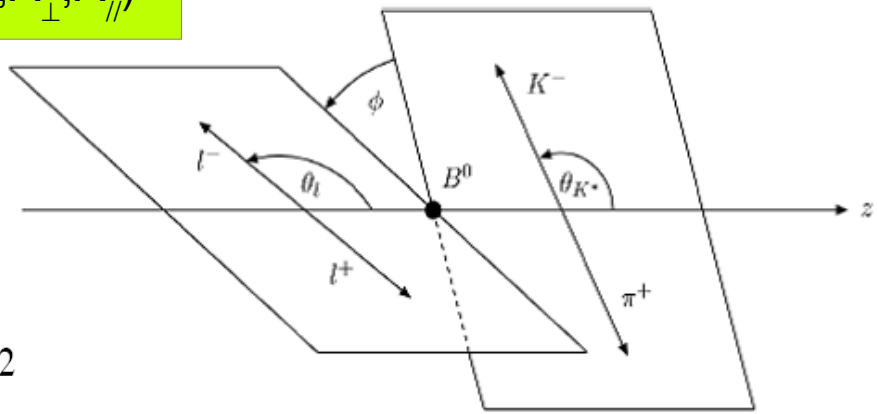
Sensitivity (2 fb^{-1}):

- 7200 evts, B/S~0.5

➔ $\sigma(s_0)$ = 0.5 GeV^2/c^4

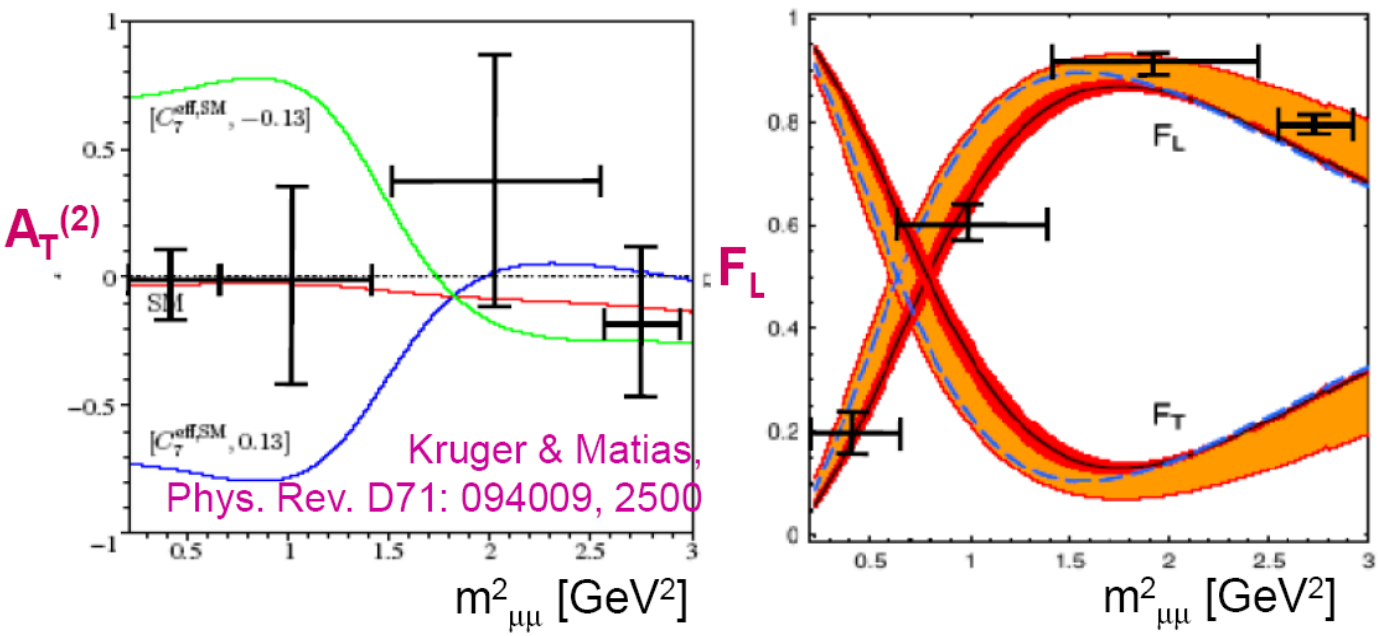
other observables based on tranversity amplitudes (A_0,$A_\perp$,$A_{//}$)

- Fitting projections of ϕ,θ_l,θ_{K^*} angular distributions can give access to the fraction of longitudinal polarization F_L and the transverse asymmetry $A_T^{(2)}$



$$A_T^{(2)}(s) = \frac{|A_\perp|^2 - |A_{//}|^2}{|A_\perp|^2 + |A_{//}|^2} \qquad F_L(s) = \frac{|A_0|^2}{|A_0|^2 + |A_{//}|^2 + |A_\perp|^2}$$

Points LHCb 2 fb^{-1}



Stat. precisions in the region $s = m^2_{\mu\mu} \in [1, 6]$ (GeV/c^2)^2 where theory calculations are most reliable

	2 fb^{-1}	10 fb^{-1}
$A_T^{(2)}$	±0.42	±0.16
F_L	±0.016	±0.007
A_{FB}	±0.020	±0.008

$B^0_s \to \mu^+\mu^-$

$B_s \to \mu\mu$ helicity suppressed:

sensitive to NP with S or P couplings

Well predicted in SM:

$BR(B_s \to \mu\mu)\ [10^{-9}] = 3.14^{+0.15}_{-0.25}$ **CKMfitter Summer 2007**

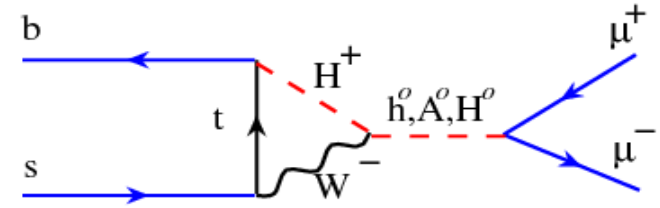
Event selection:

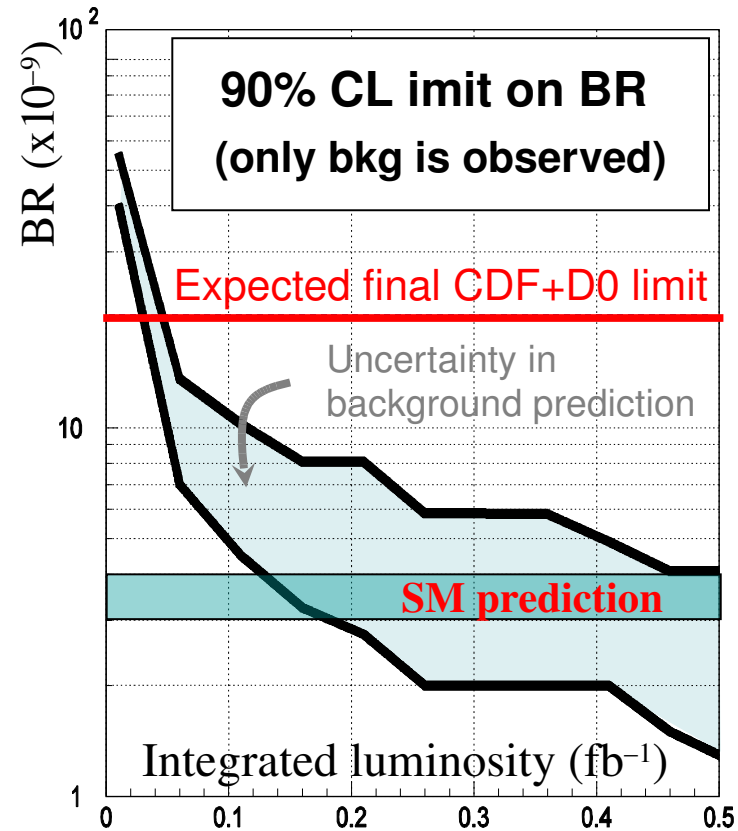
- main issue: background rejection, dominated by combinatorial $bb \to \mu\mu X$ (suppressed by mass and vertex resolutions)
- SM Yield (2 fb^{-1}): Signal: 30 – Bkg: 83

Current limits from Tevatron:

CDF: BR < 5.8×10^{-8} @95% CL **PRL 100, 101802 (2008)**

D0: BR < 9.3×10^{-8} @95% CL **Note 5344-CONF**





0.05 fb^{-1}	$\Rightarrow$	overtake CDF+D0
0.5 fb^{-1}	$\Rightarrow$	exclude BR values down to SM
2 fb^{-1}	$\Rightarrow$	3σ evidence of SM signal
6 fb^{-1}	$\Rightarrow$	5σ observation of SM signal

Charm Physics

LHCb will collect a large tagged $D^* \to D^0 \pi$ sample: (also used for PID calibration)

- a dedicated D* trigger is foreseen for this purpose

  tag D^0 and anti-D^0 flavor with π from $D^{*\pm} \to D^0 \pi^\pm$

D*-tagged signal yields in 2 fb^{-1} (from b hadrons only)	
$D^0 \to K^+\pi^-$ right sign	12.4 M
$D^0 \to K^+\pi^-$ wrong sign	46.5 k
$D^0 \to K^+K^-$	1.6 M

Interesting (sensitive to NP) and promising searches/measurements:

- Time-dependent D^0 mixing with wrong-sign $D^0 \to K^+\pi^-$

  $\sigma_{stat}(x'^2) \sim 0.14 \times 10^{-3}$, $\sigma_{stat}(y') \sim 2 \times 10^{-3}$ with 2 fb^{-1}
- Direct CP violation with $D^0 \to K^+K^-$

  $A_{CP} \leq 10^{-3}$ in SM, up to 1% (~current limit) with New Physics

  Expect $\sigma_{stat}(A_{CP}) \sim O(10^{-3})$ with 2 fb^{-1}
- $D^0 \to \mu^+\mu^-$

  BR $\leq 10^{-12}$ in SM, up to 10^{-6} (~current limit) with New Physics

  Expect to reach down to $\sim 5 \times 10^{-8}$ with 2 fb^{-1}

Conclusion

Very interesting results will come already with first 0.5 fb^{-1} (~end of 2009) of data:

- $B_s \to J/\psi\phi$: $2\beta_s$ measurement with ~0.05 precision
- $B_s \to \mu\mu$: BR limit down to SM value
- $B_d \to K^{0*}\mu\mu$: ~1800 events, overtaking B-Factories statistics

This was only MC! The startup of LHC is coming:

- looking forward to starting working with real data and successful machine startup

> "*A new era in human knowledge has just started...*
> *...a lot has already been found,*
> *but what is still to be discovered is more!*"

[Galileo speaking with Sagredo in "Galileo's life", by B. Brecht]