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CP Violation and B Physics at the LHC

Robert Fleischer
Theory Division, Department of Physics, CERN
CH-1211 Geneva 23, Switzerland

R. Hori

L.T.HUE

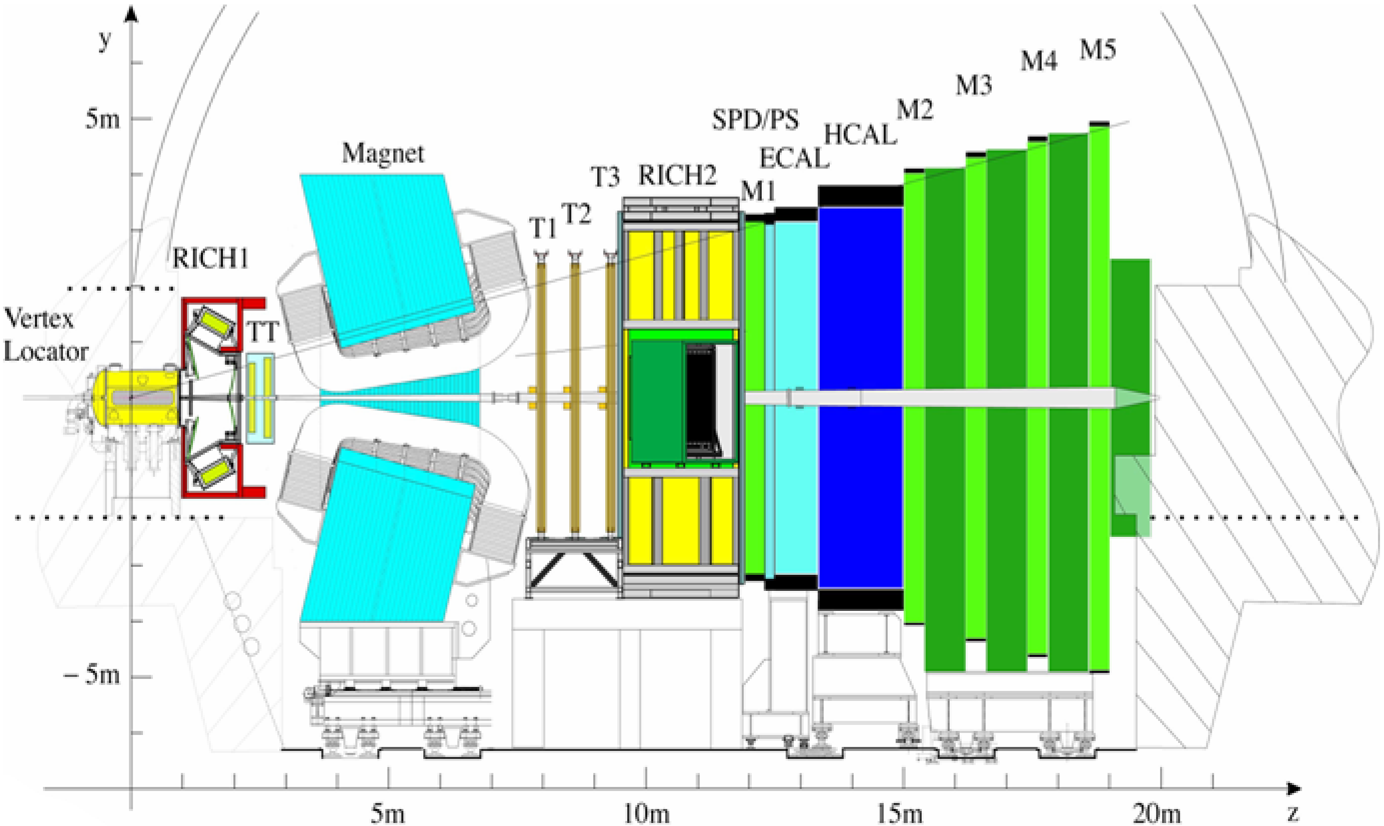
Motivation

- CP violation (CPV) and flavor physics have interests with new physics (NP).
  - extension of Standard Model (SM)?
    - SUSY, left-right-symmetric models, extra Z', extra dimensions, little Higgs…?
  - Beyond Standard Model (BSM)?
  - The Baryon asymmetry of the Universe?
    - Why matter is dominating anti-matter?
  - The decay of heavy Majorana neutrinos?

CP violate term

$$V = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \simeq \begin{pmatrix} 1-\lambda^2/2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\lambda^2/2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

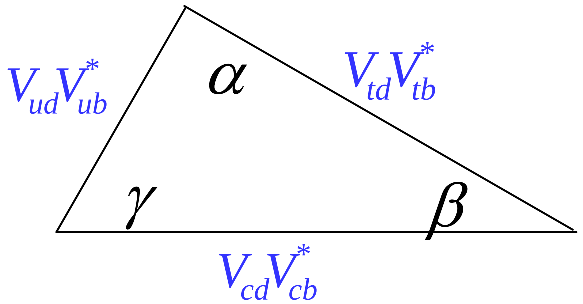
LHCb Detector view



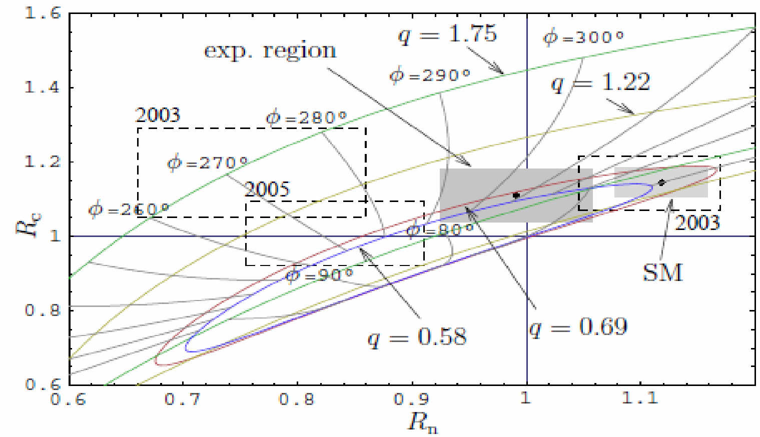
- More information->backup slides.

Topics of B meson CPV in LHCb

The Unitarity triangle



π K Puzzle



- Many topics

$$B_d \to \pi^+ K^-, \pi^- K^+, \pi^0 K^0$$ **π K Puzzle**

$$B_s \to D_s^{\pm} K^{\mp} \quad B_d \to D^{\pm}\pi^{\mp}$$ **Determine γ**

$$B_d \to \pi^+\pi^- \quad B_s \to K^+K^-$$ **b->s transition**

$$B_{s,d} \to \mu^+\mu^- \quad B_d^0 \to K^*\mu^+\mu^-$$ **Rare decay**

- We explain about $B_s^0 \to J/\psi\phi$. (Mixing)

$B_q - \overline{B}_q$ mixing

- The off-diagonal element of the mass matrix.
  - $M^{(d)}_{12}$: obtain from experiment
  - $M^{d,SM}_{12}$: SM model value.

$$M_{12}^{(d)} = M_{12}^{d,\mathrm{SM}} \left(1 + \underbrace{\kappa_d}_{\text{constant}} \underbrace{e^{i\sigma_d}}_{\text{phase}}\right)$$

$$\Delta M_d = \Delta M_d^{\mathrm{SM}} + \Delta M_d^{\mathrm{NP}} = \Delta M_d^{\mathrm{SM}} \left|1 + \kappa_d e^{i\sigma_d}\right|$$

$$\phi_d = \phi_d^{\mathrm{SM}} + \phi_d^{\mathrm{NP}} = \phi_d^{\mathrm{SM}} + \arg(1 + \kappa_d e^{i\sigma_d}),$$

- From experiment

Problem!

$B_d \to J/\psi K^*$	V_{ub} determination	B_d-$\overline{B_d}$ mixing
$\phi_d = (42.4 \pm 2)^0$	$\phi_d^{NP}\|_{excl.} = -(3.4 \pm 7.9)^\circ$ $\phi_d^{NP}\|_{incl.} = -(11.0 \pm 4.3)^\circ$	$\Delta M_d = 0.5\, ps^{-1}$ $\dfrac{\Delta\Gamma_d}{\Gamma_d} \approx 0$

$B_d - \overline{B}_d$ mixing

- The prediction from SM $\sin\Phi_d = 0.695 \pm 0.055$

- The results of experiment : $\rightarrow$ $\sin\phi_d = \begin{cases} 0.741 \pm 0.075 & \text{babar} \\ 0.719 \pm 0.082 & \text{belle} \end{cases}$

  ->SM agrees with experiment, then no conclusions can be drawn at the moment.

$B_s - \overline{B}_s$ mixing

- Considering B_s system
- Just replace d by s .Then
- with SM : $\Delta M_s = O(20\,ps^{-1})$
- $B_s^o - \overline{B}_s^0$ oscillations are very rapid, consequently.
- Γ_s is small, so is needed to measure precisely.
- calculation $\frac{\Delta\Gamma_s}{\Gamma_s} \approx o(0.1)$
- Tevatron : $\frac{\Delta\Gamma_s}{\Gamma_s} = \begin{cases} 0.65^{+0.25}_{-0.33} \pm 0.01 (CDF) \\ 0.24^{+0.28+0.03}_{-0.38-0.04} (D0) \end{cases}$ They have large error!

CPV of phase in the SM $\phi_s^{SM} = -2\lambda^2\eta = -2^0$

Measurement ΔM_s

D0	$17\,\mathrm{ps}^{-1} < \Delta M_s < 21\,\mathrm{ps}^{-1} \quad (90\%\ \mathrm{C.L.}),$	2.5σ
CDF	$[17.77 \pm 0.10(\mathrm{stat}) \pm 0.07(\mathrm{syst})]\ \mathrm{ps}^{-1}$	5.0σ
HPQCD	$20.3\ \mathrm{ps}^{-1}$	
JLQCD	$16.1 \pm 2.8\ \mathrm{ps}^{-1}$	
HP＋JLQCD	$23.4 \pm 3.8\ \mathrm{ps}^{-1}$	

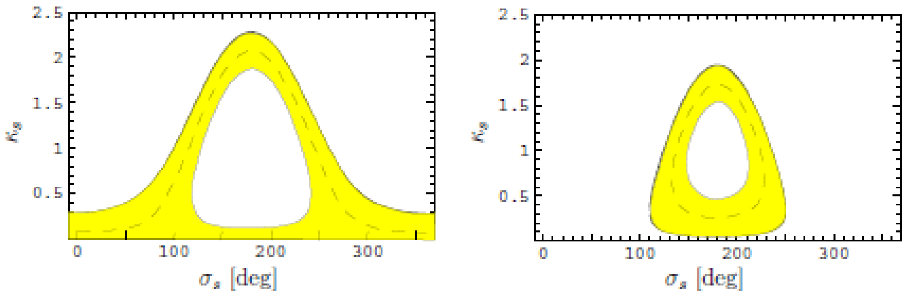
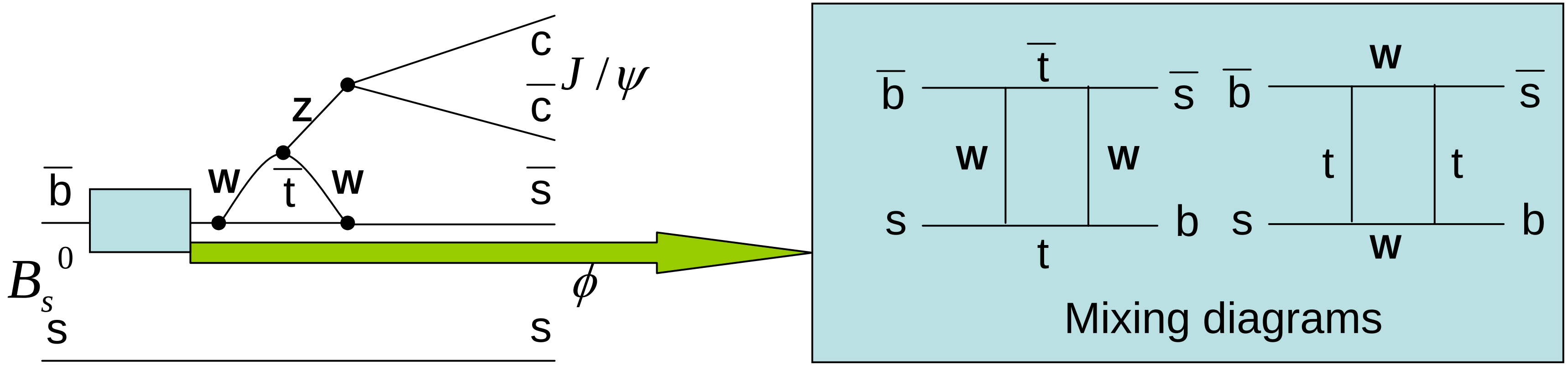


Figure 5: The allowed regions (yellow/grey) in the σ_s–κ_s plane. Left panel: JLQCD lattice results. Right panel: (HP+JL)QCD lattice results.

The decay $B_s^0 \to J/\psi\phi$

- This decay is counterpart of the $B_s^0 \to J/\psi\phi$.
- Two vector meson->mixture different CP eigenstates.
  - Eigenstates can distinguish by angular distribution of meson.
- This Feinman diagram has no phase (b->s, b->t and t->s)
  - Hadronic matrix element is cancel.

-> $B_s^0 - \overline{B}_s^0$mixing observable!

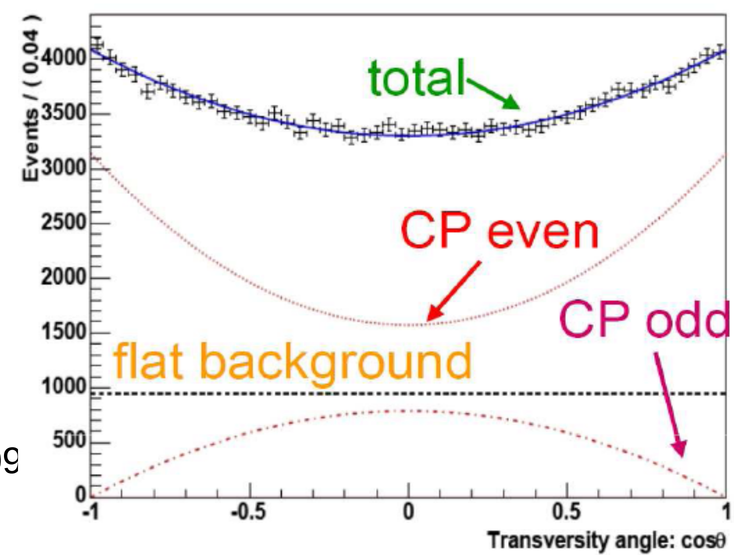


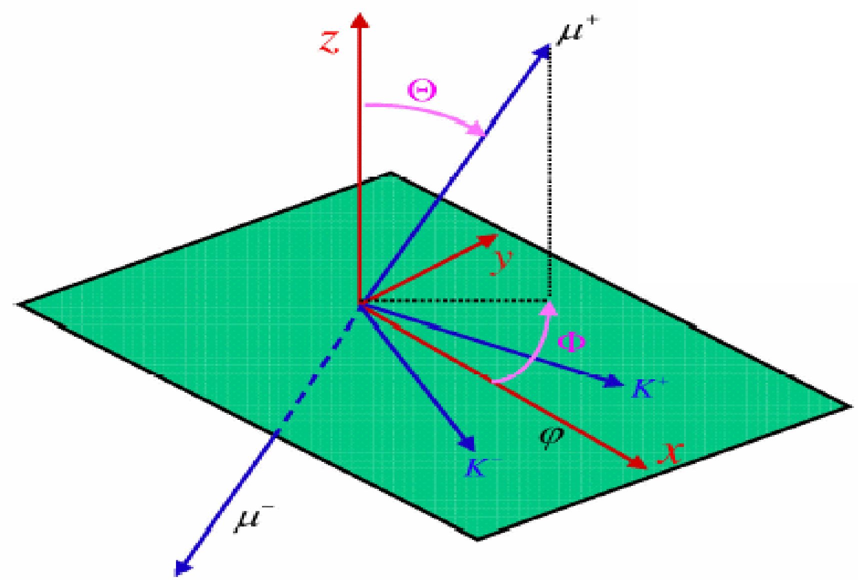
$B_s^{\ 0}$ CP eigenstates

- This decay mode has 3 linear polarization amplitude.
  - A_0 and $A_{//}$ correspond CP even.
  - $A_\perp$ corresponds CP odd.

$$\frac{d\Gamma(B_s^0(t) \to J/\psi\phi)}{d\cos\Theta} \propto \overbrace{\left(|A_0(t)|^2 + |A_\parallel(t)|^2\right)\frac{3}{8}\left(1+\cos^2\Theta\right)}^{\text{CP even}} + \overbrace{|A_\perp(t)|^2\frac{3}{4}\sin^2\Theta}^{\text{CP odd}}.$$

  - Θ is the angle of l+ (from J/ψ decay) to KK plane in J/ψ rest frame.





CP violation measurement (1)

- Then we defined: $P_+(t) \equiv |A_0(t)|^2 + |A_\parallel(t)|^2, \quad P_-(t) \equiv |A_\perp(t)|^2,$
- CPV asymmetry:

$$\frac{P_\pm(t) - \overline{P}_\pm(t)}{P_\pm(t) + \overline{P}_\pm(t)} = \pm\left[\frac{2\sin(\Delta M_s t)\sin\phi_s}{(1\pm\cos\phi_s)e^{+\Delta\Gamma_s t/2} + (1\mp\cos\phi_s)e^{-\Delta\Gamma_s t/2}}\right].$$

- Angle distribution allows to measure $\Delta\Gamma_s$ and ΔM_s in the CPV asymmetry.

- Derive also $\Delta\Gamma_s = \Gamma(B_s^L) - \Gamma(B_s^H)$ ($\Delta\Gamma_s/\Gamma_{sSM}$ ~0.1)

$B_s \to J/\psi\phi$

If Δm_s~20 ps^{-1}

	$\sigma(\sin\phi_s)$	$\sigma(\Delta\Gamma_s/\overline{\Gamma}_s)$	$\mathscr{L}$
LHCb	~0.06	0.018	2 fb^{-1}
ATLAS	~0.04	0.012	30 fb^{-1}
CMS	~0.03	0.015	30 fb^{-1}

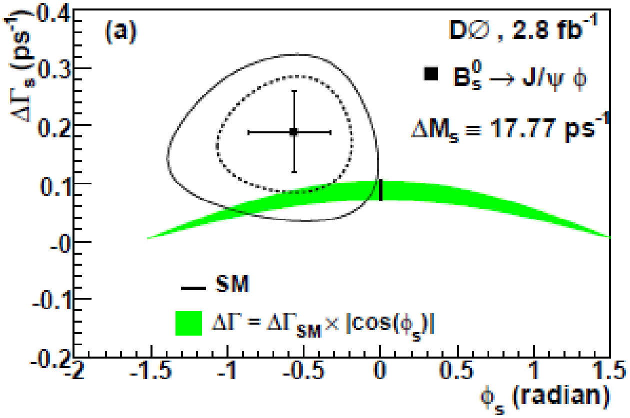
- LHCb has the best resorution about B_s CPV in LHC experiment.

CP violation measurement (2)

- ϕ_s measurement.

SM	-0.0037 ± 0.0002
D0 (2.8fb^{-1})	$-0.79 \pm 0.56(stat.)^{+0.14}_{-0.01}(syst.)$
LHCb1(SM) (2fb^{-1})	-0.04 ± 0.02
LHCb2(NP) (2fb^{-1})	-0.20 ± 0.02
ATLAS, CMS (10fb^{-1})	O(0.1)

D0 result



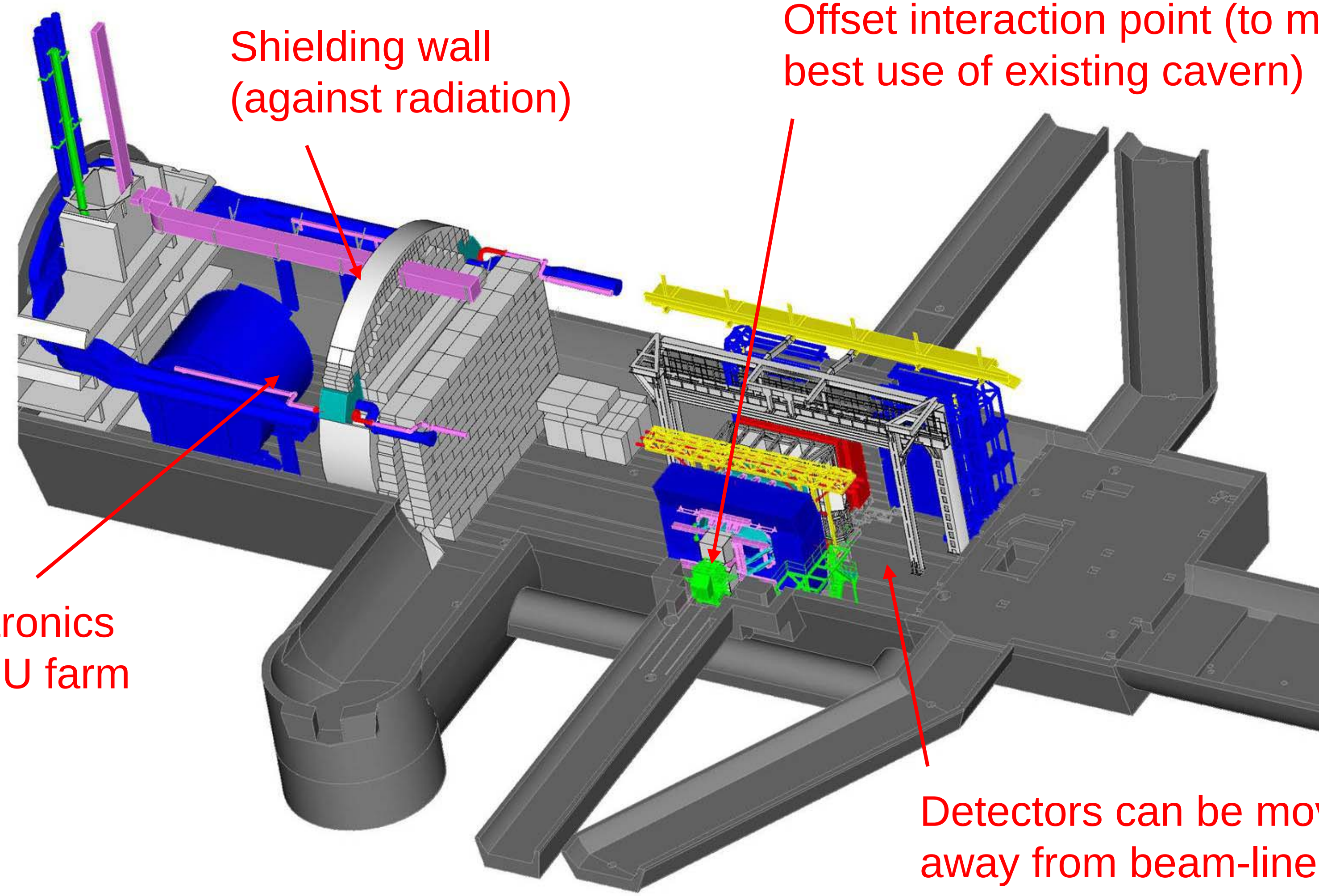
- LHCb will be the most precise measurement ϕ_s.

Conclusion

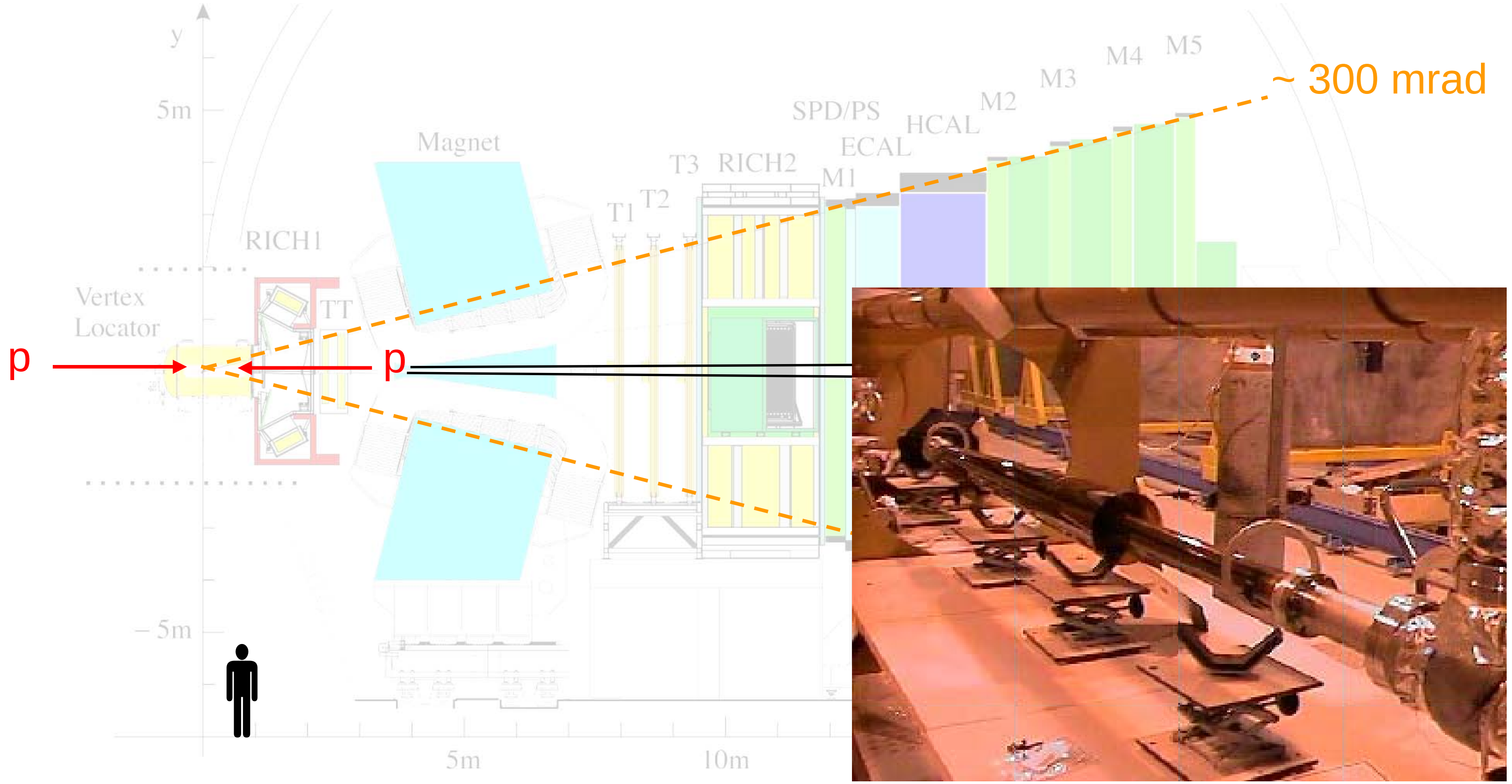
- LHCb can measure ϕ_s in 2σ signal by $2fb^{-1}$ data (by 2010) by B_s mixing.
- Another goals.
  - α, β, γ measurements in several channels.
  - access to rare decays.

Backups and others

LHCb in its cavern

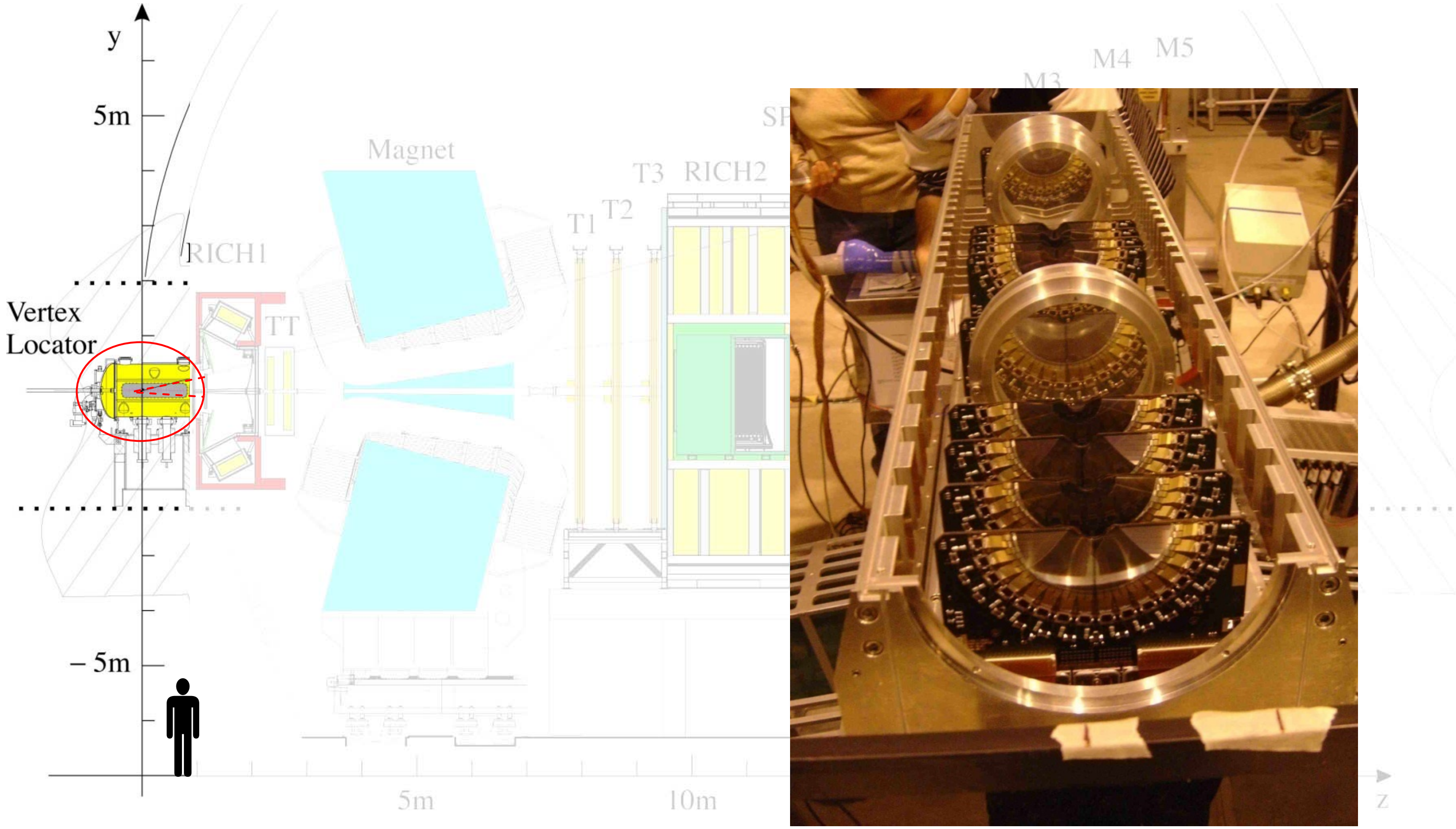


LHCb detector



Forward spectrometer (running in pp collider mode)
Inner acceptance 10 mrad from conical beryllium **beam pipe**

LHCb detector

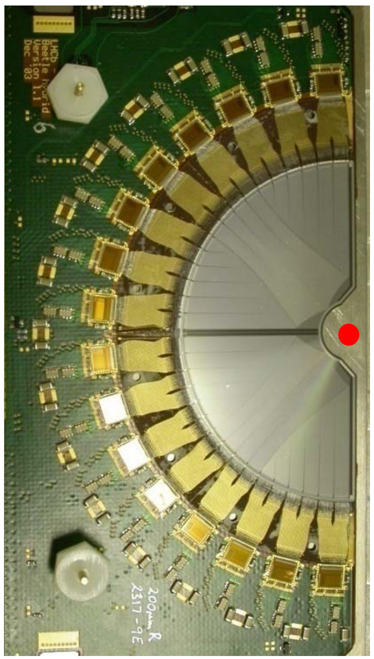


Vertex locator around the interaction region

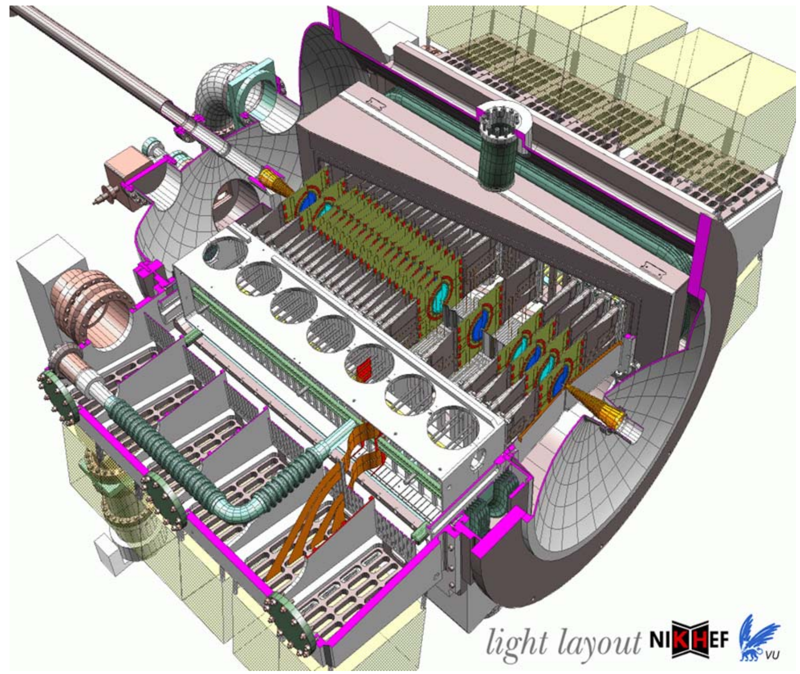
Silicon strip detector with ~ 30 μm impact-parameter resolution

Vertex detector

- Vertex detector has silicon microstrips with $r\phi$ geometry approaches to 8 mm from beam (inside complex secondary vacuum system)
- Gives excellent proper time resolution of ~ 40 fs (important for B_s decays)

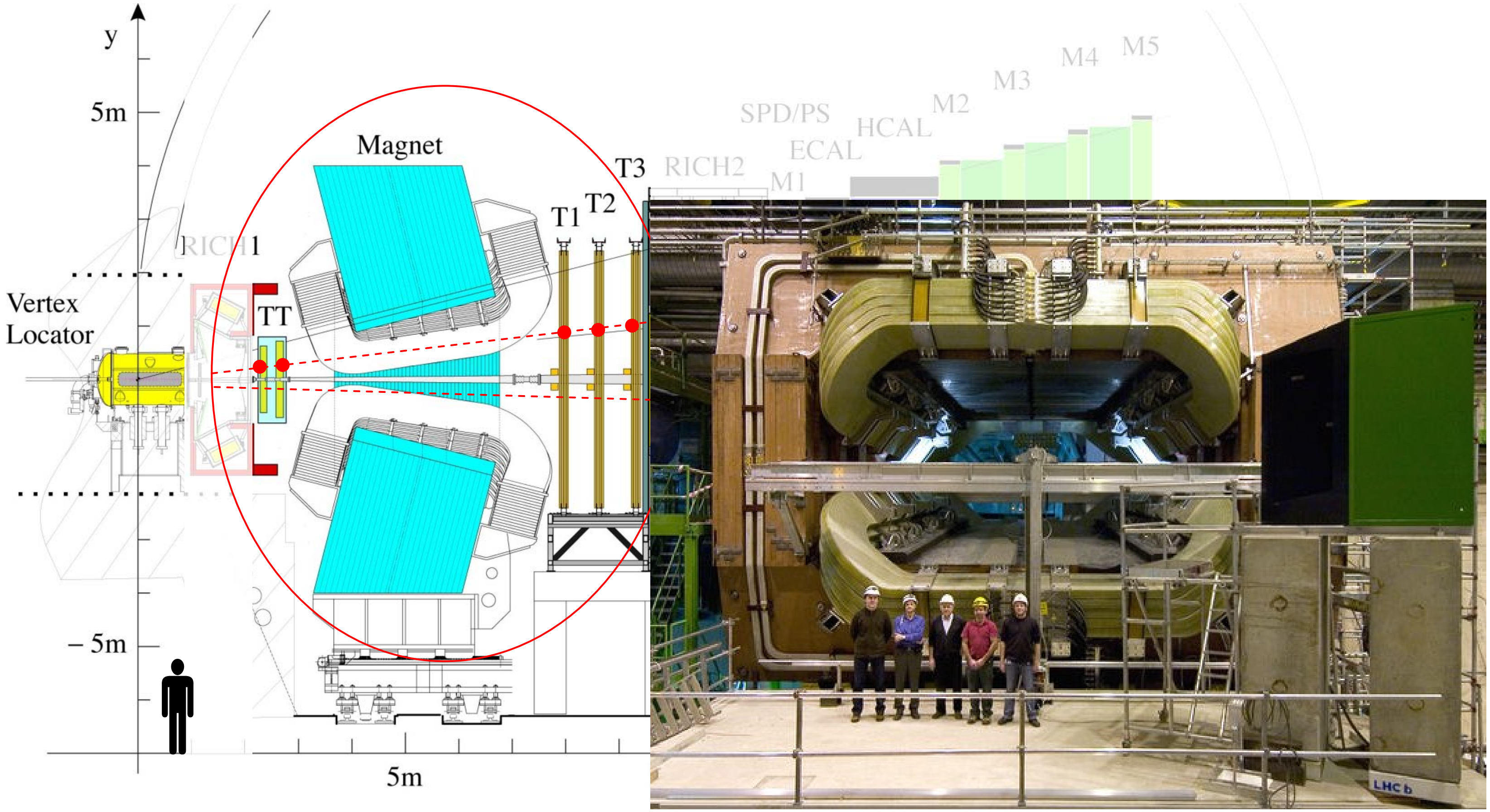


Beam



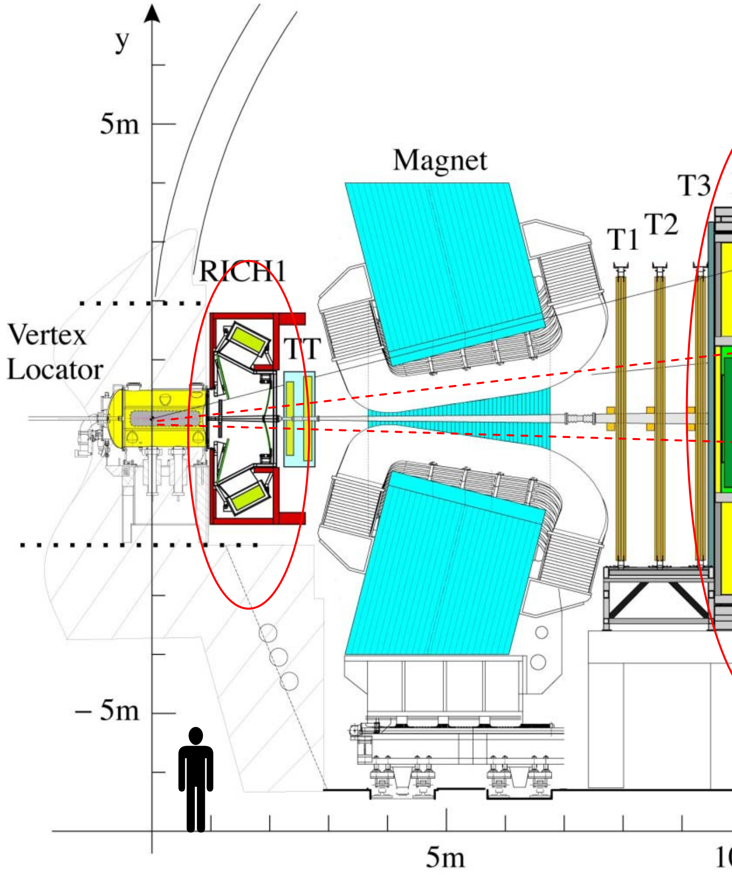
Vertex detector information is used in the trigger

LHCb detector



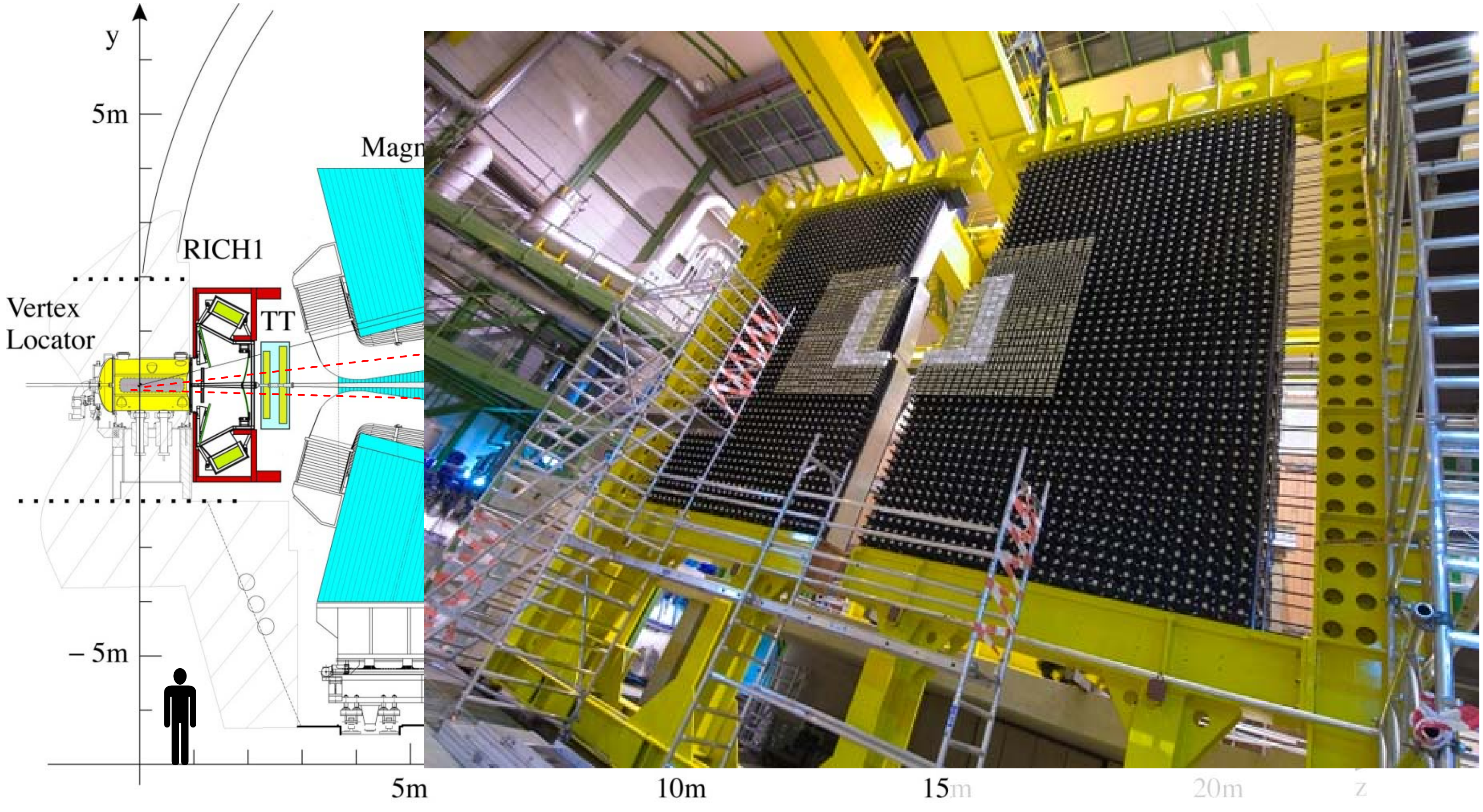
Tracking system and dipole magnet to measure angles and momenta $\Delta p/p$ ~ 0.4 %, mass resolution ~ 14 MeV (for $B_s \rightarrow D_sK$)

LHCb detector



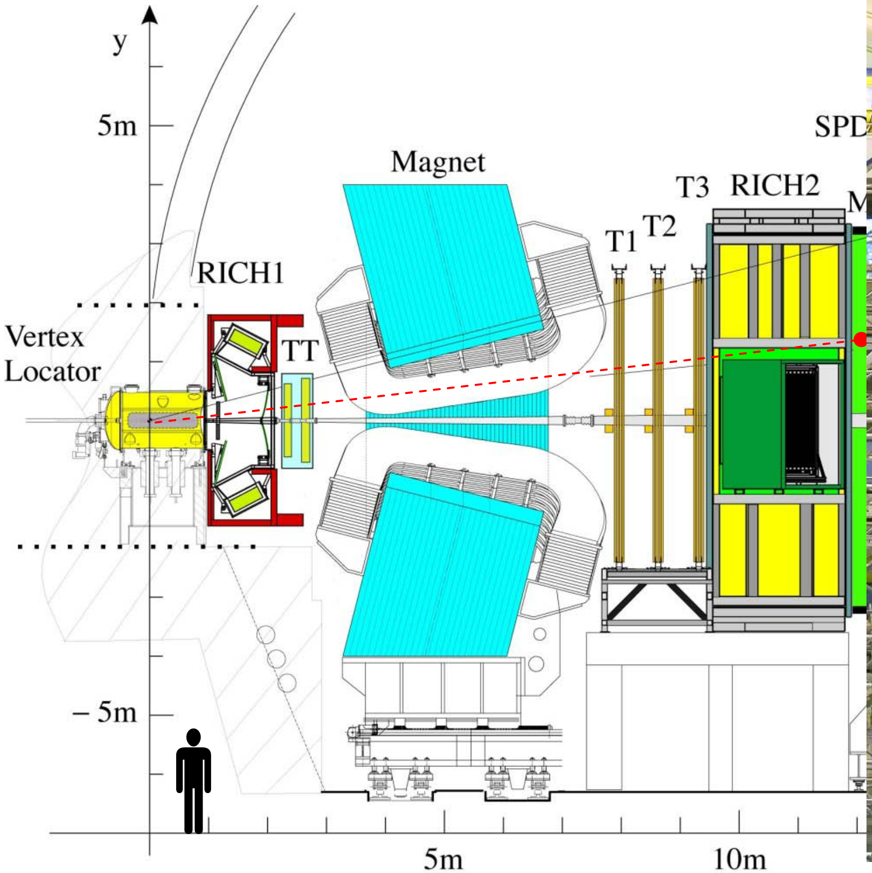
Two **RICH** detectors for charged hadron identification

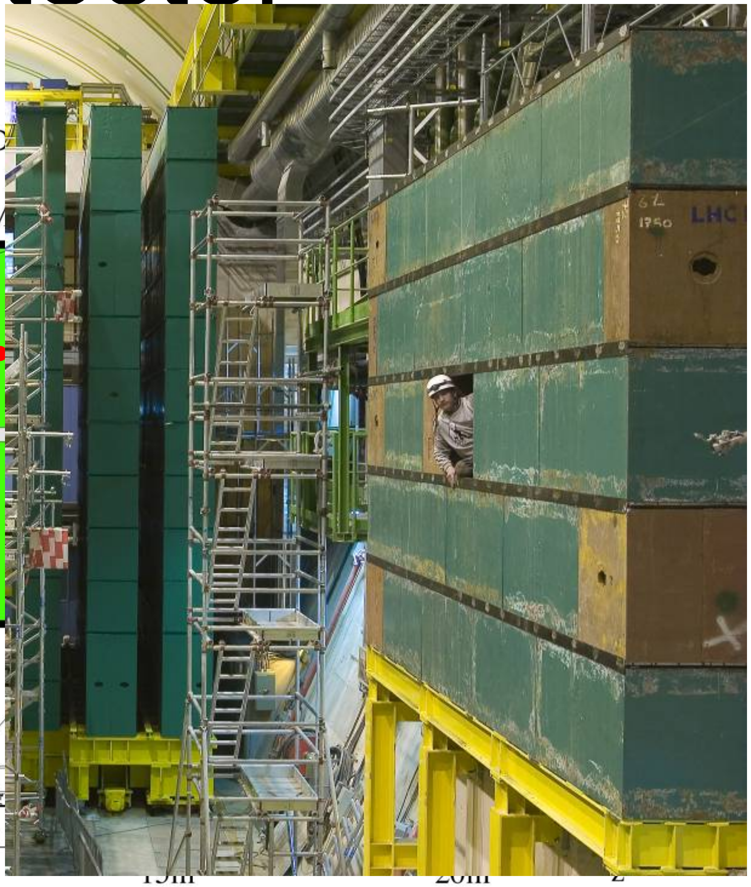
LHCb detector



Calorimeter system to identify electrons, hadrons and neutrals. Important for the first level of the trigger

LHCb detector





Muon system to identify muons, also used in first level of trigger

Another news

- SU(3) breaking parameter

$$\xi \equiv \frac{f_{B_s}\hat{B}_{B_s}^{1/2}}{f_{B_d}\hat{B}_{B_d}^{1/2}}$$

$$\frac{\rho_s}{\rho_d} = \lambda^2 \underbrace{\left[1 - 2R_b \cos\gamma + R_b^2\right]}_{=R_t^2} \left[1 + \mathcal{O}(\lambda^2)\right] \frac{1}{\xi^2} \frac{M_{B_d}}{M_{B_s}} \frac{\Delta M_s}{\Delta M_d},$$