13th Lomonosov Conference on Elementary Particle Physics, Moscow 2007

LHCb

Physics, Status, and Perspectives

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Universität Dortmund

on behalf of the LHCb Collaboration

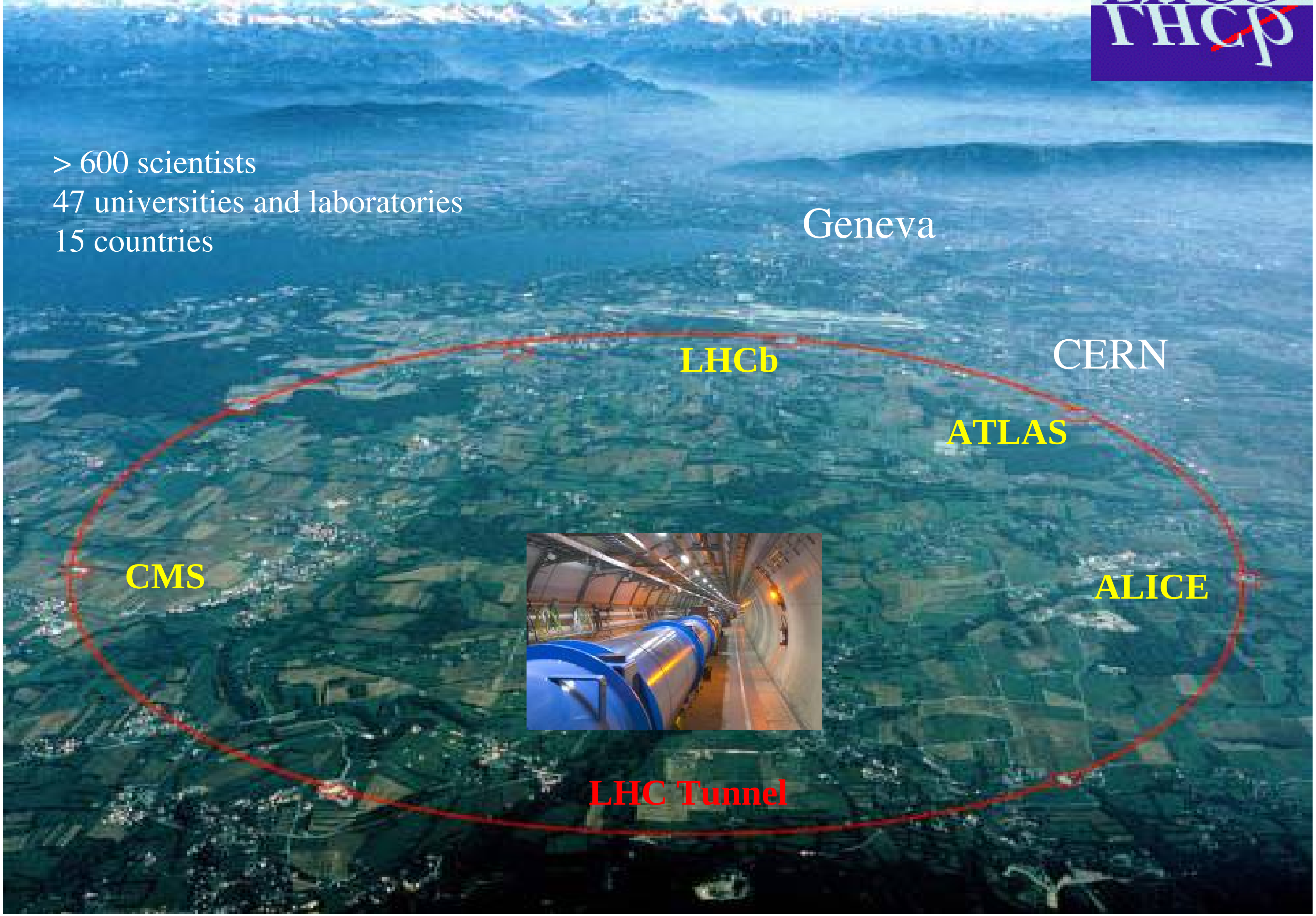
- Motivation
  - CP Violation, Search for New Physics
- LHCb
  - Design, Status, Physics

Conclusions

Supported by bmbf:
bmb+f - Förderschwerpunkt
LHCb
Großgeräte der physikalischen Grundlagenforschung

LHCb: a dedicated B-Physics Experiment at the LHC

> 600 scientists
47 universities and laboratories
15 countries

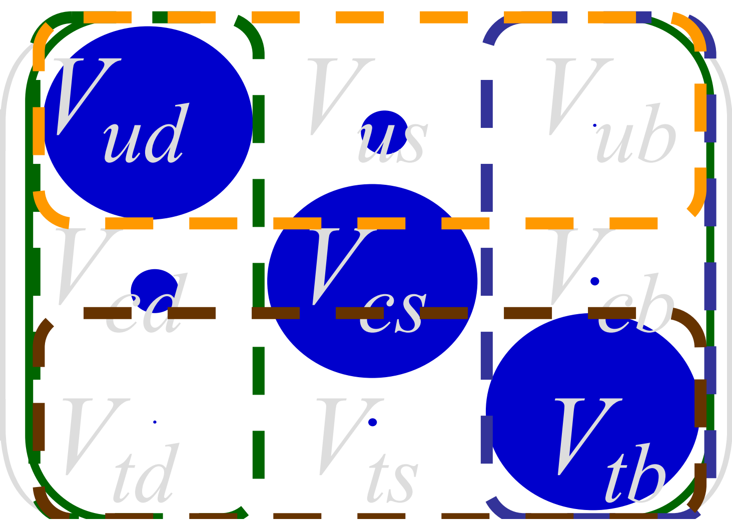


CP-Violation in the Standard Model

Standard model: Origin of CP-Violation: Higgs-Sector!
⇒**C**abibbo **K**obayashi **M**askawa (CKM) Matrix

CKM Matrix: complex, unitary
4 parameters: 3 Euler angles, 1 Phase ↔ ~~CP~~

Test of the Standard Model wrt origin of CP Violation
⇒ test unitarity of CKM matrix!



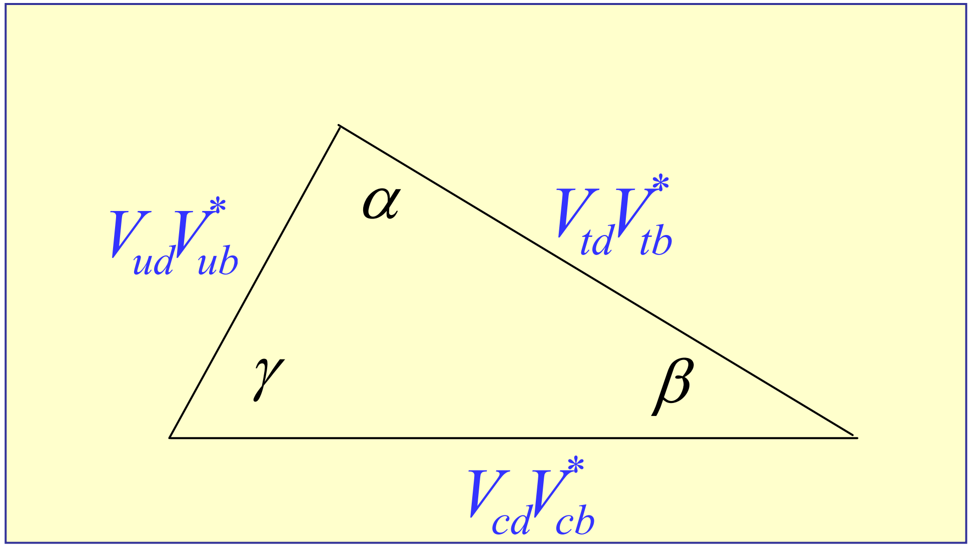
$$V_{ud}\cdot V_{ub}^{*}+V_{cd}\cdot V_{cb}^{*}+V_{td}\cdot V_{tb}^{*}=0$$

$$V_{ud}\cdot V_{td}^{*}+V_{us}\cdot V_{ts}^{*}+V_{ub}\cdot V_{tb}^{*}=0$$

Representation as „Unitarity Triangles“:

Unitarity Test of the CKM-Matrix:

$$V_{ud} \cdot V_{td}^{*} + V_{us} \cdot V_{ts}^{*} + V_{ub} \cdot V_{tb}^{*} = 0$$



Unitarity Test:

$\Rightarrow$ **overconstrain Unitarity Triangles**

$\Rightarrow$ **determine angles and magnitude of sides**

CKM Parametrizations

V has 4 observable parameters and an infinite number of choices for these 4

L. Wolfenstein 1983:

λ, A, ρ, η

$\lambda = 0.22 \cong \sin \vartheta_C$

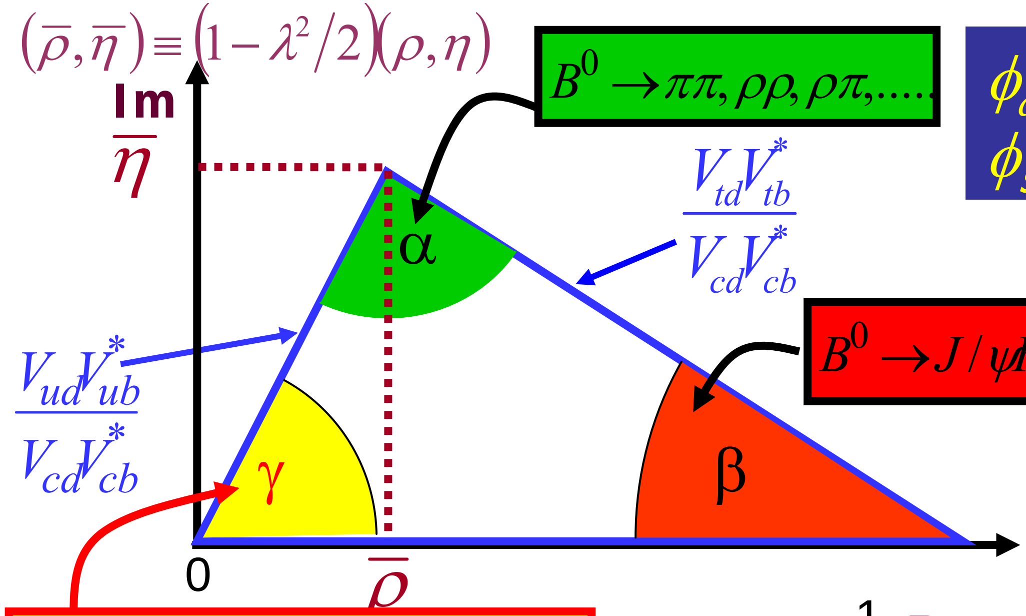
$$V = \begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix} + \delta V$$

relevant for B_s

$$\delta V = \begin{pmatrix} 0 & 0 & 0 \\ -iA^2\lambda^5\eta & 0 & 0 \\ A\lambda^5(\rho+i\eta)/2 & -A\lambda^4(1/2-\rho-i\eta) & 0 \end{pmatrix}$$

Expect sizeable „phases“ for: V_{ub}, V_{td}, and V_{ts}

Unitarity Triangles

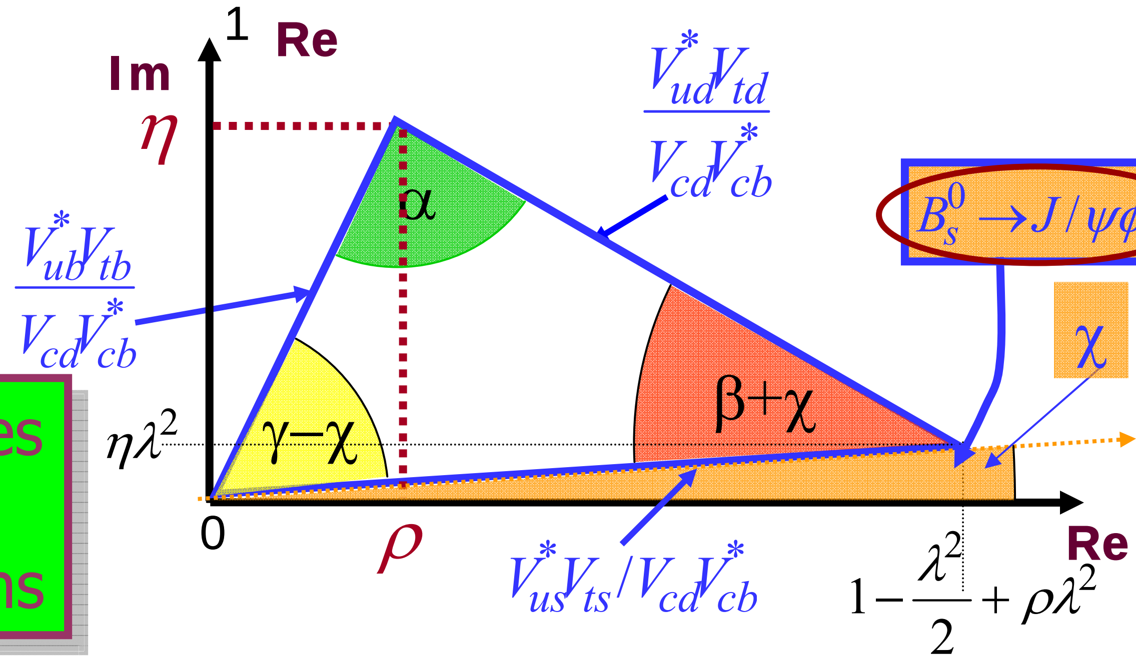


$\phi_d = \;\; 2\beta$: B_d mixing phase
$\phi_s = -2\chi$: B_s mixing phase

Wolfenstein: $V_{ub} \Leftrightarrow e^{-i\gamma}$

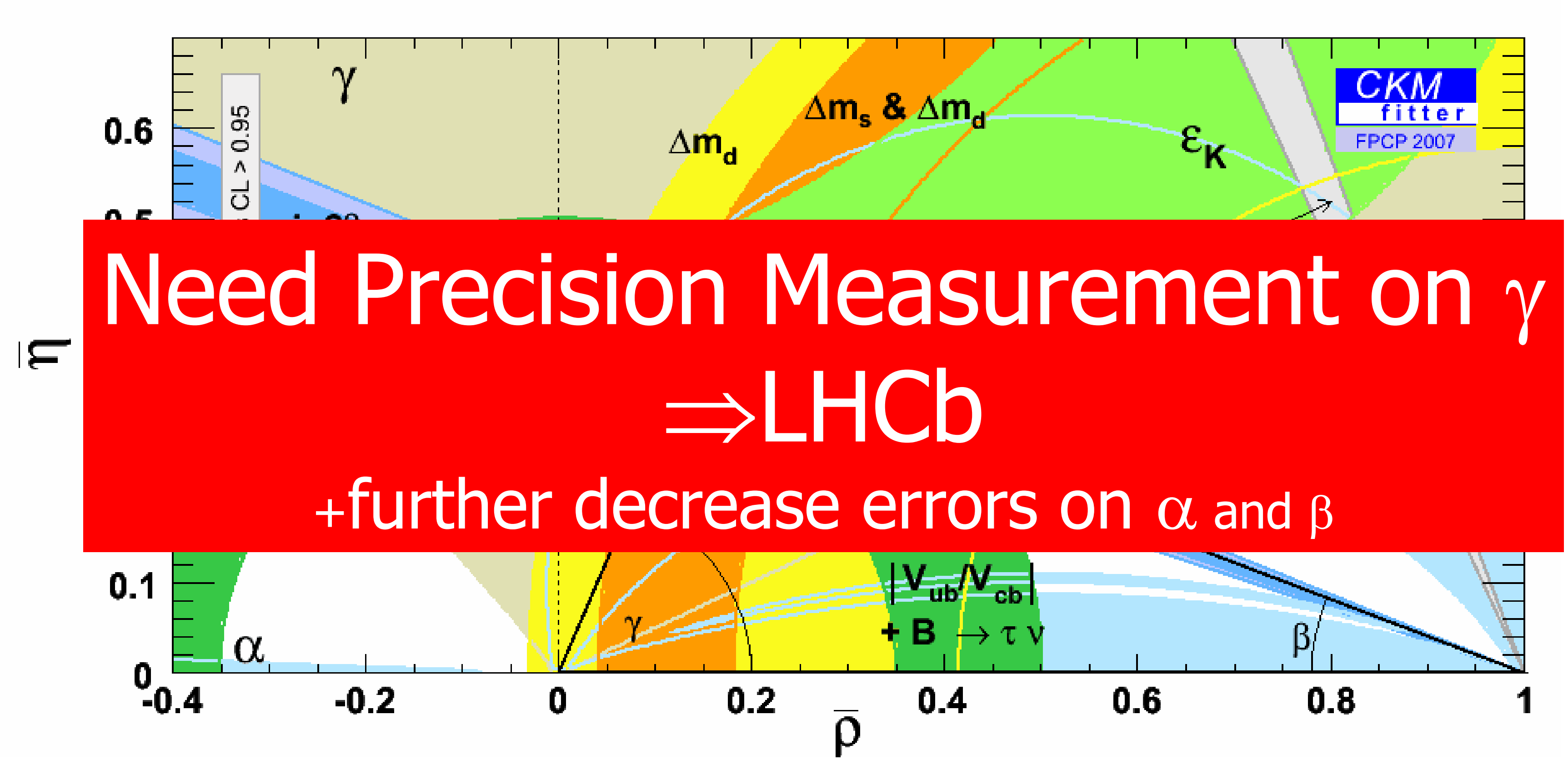
Almost identical triangles
(differences at the percent level)

$B_d \to DK, DK^*, K\pi, \ldots$
$B_d \to \pi^+\pi^-$ and $B_s^0 \to K^+K^-$
$B_s \to D_s K$ $\quad (\gamma - 2\chi)$
$B_d \to D^*\pi$ $\quad (\gamma + 2\beta)$



Precision Test requires measurements with B_u-, B_d-, and B_s-mesons

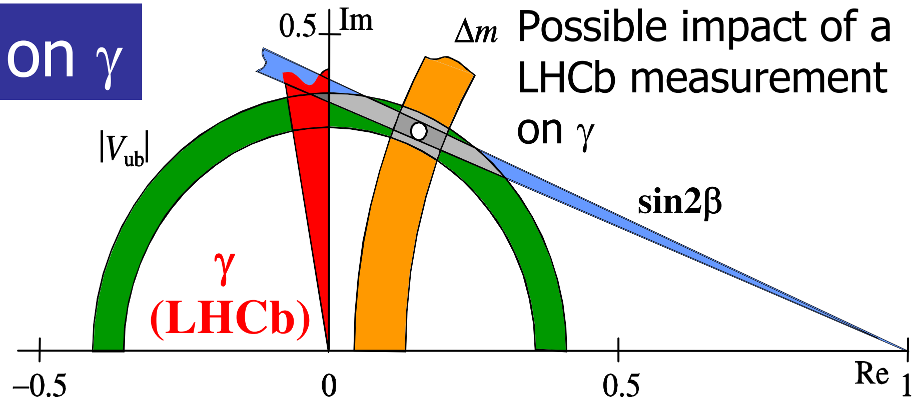
Unitarity Triangle - 2007



Need Precision Measurement on γ ⇒LHCb

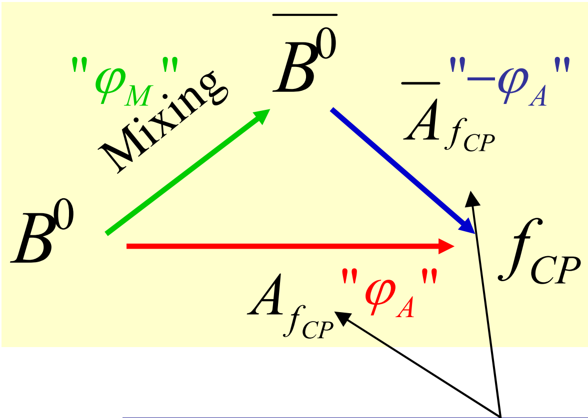
+further decrease errors on α and β

Hardly any significant constraint on γ

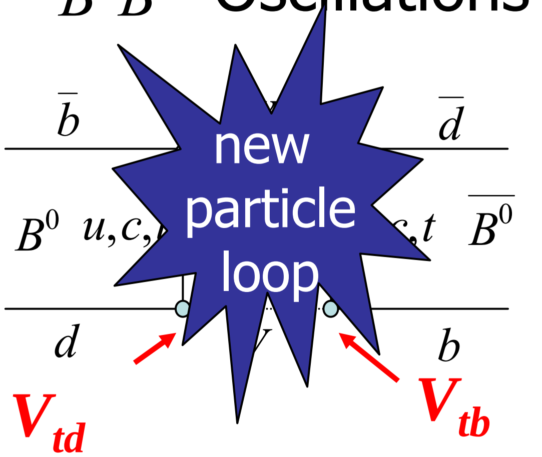


Possible impact of a LHCb measurement on γ

$\not{CP}$ in Interference between Mixing and Decay
$B^0 \to J/\psi K_S$ and $B_s \to J/\psi \phi$



$B^0\overline{B}^0$ Oscillations



dominated by top quark

$\varphi_M \propto \arg V_{tb}^* V_{td}$ $\quad B_d^0$

$\varphi_M \propto \arg V_{tb}^* V_{ts}$ $\quad B_s^0$

Wolfenstein: only „real" CKM elements in decay → no weak phase

$\Rightarrow \varphi_M - \varphi_A \approx \arg(V_{td}) \to -\beta$

$\Rightarrow \varphi_M - \varphi_A \approx \arg(V_{ts}) \to \chi + \pi$

need to consider δV

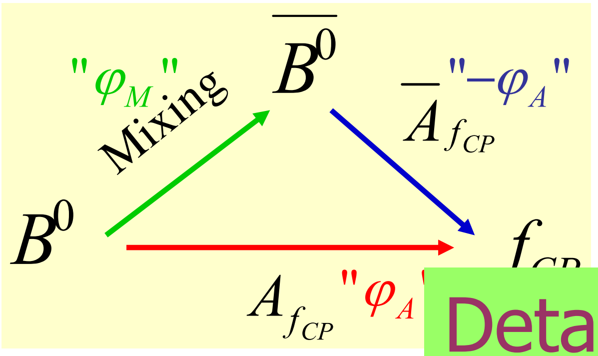
Time resolved measurements!

$A_{CP} \propto \sin 2\chi \sin \Delta m t$

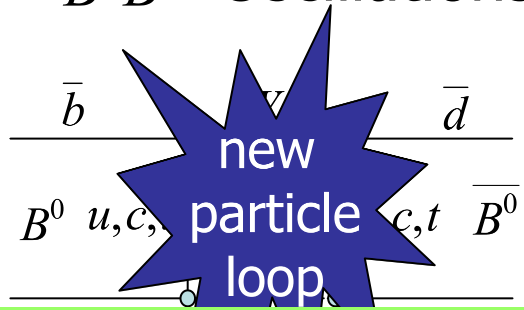
New Physics may influence mixing Phase! ⇒β shifted!

Interference between Mixing and Decay

$$B_s \to \phi\phi$$



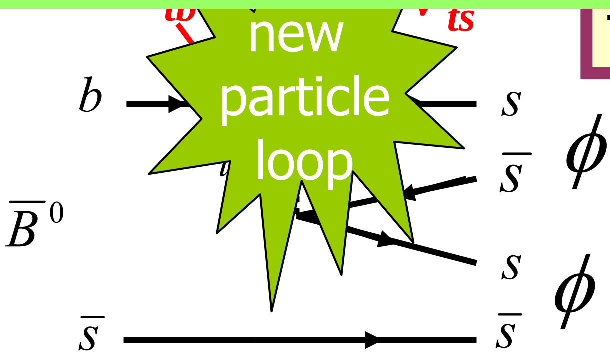
$B^0\overline{B}^0$ Oscillations



dominated by top quark

$$+ \quad \varphi_M \propto \arg V_{tb}^* V_{ts} \qquad B_s^0$$

Details on CKM angle measurements @LHCb ⇒ Talk of Sergey Barsuk



$$\Rightarrow \varphi_M - \varphi_A = 0$$

$$\varphi_A \propto \arg V_{tb}^* V_{ts}$$

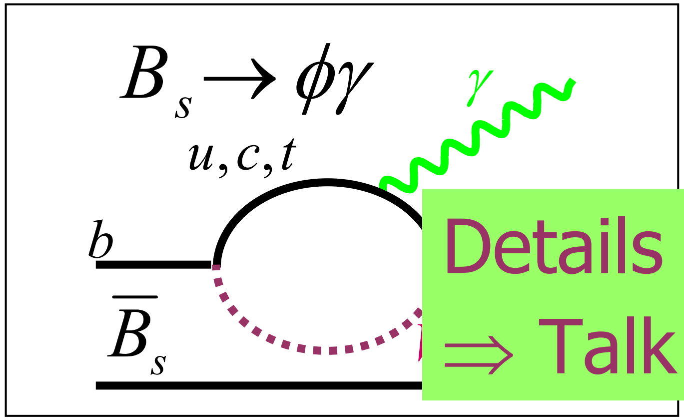
An Observation of CP Violation ⇒ New Physics!

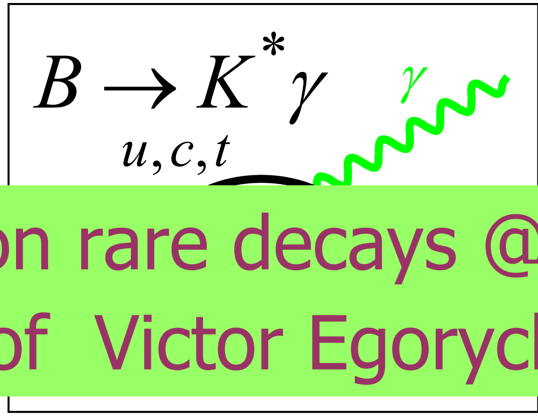
Rare decays

More interesting (penguin) mediated modes:

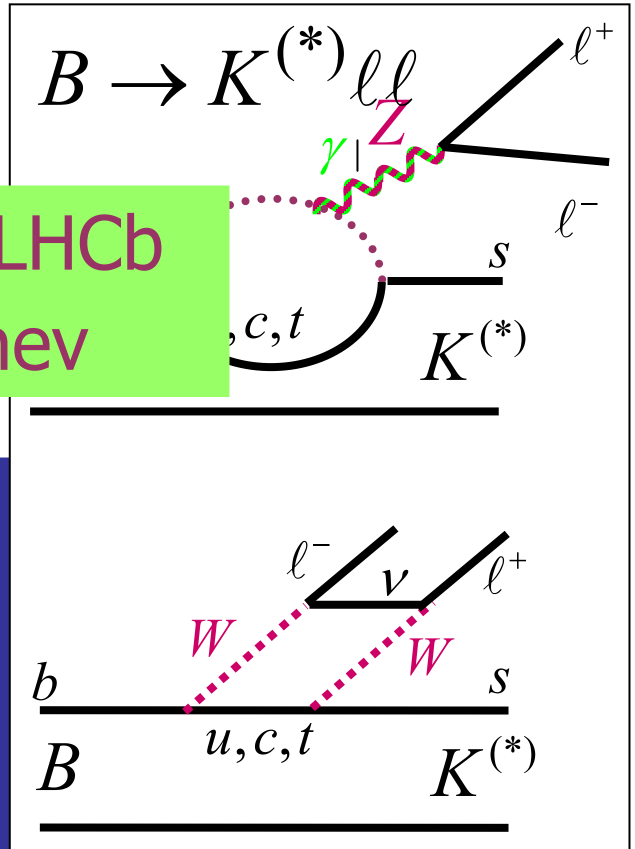
Small Branching Fractions

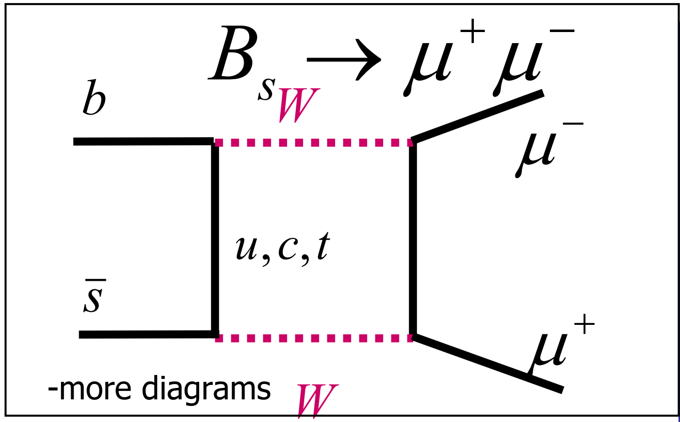
e.g. $B \to \phi\gamma, K^{(*)}\gamma, K^{(*)}\ell\ell, \mu^+\mu^-$





Details on rare decays @LHCb
⇒ Talk of Victor Egorychev





Need huge statistics!
⇒LHCb

LHCb Physics Programme

precision measurements of CKM angles

Sergey Barsuk

rare decays

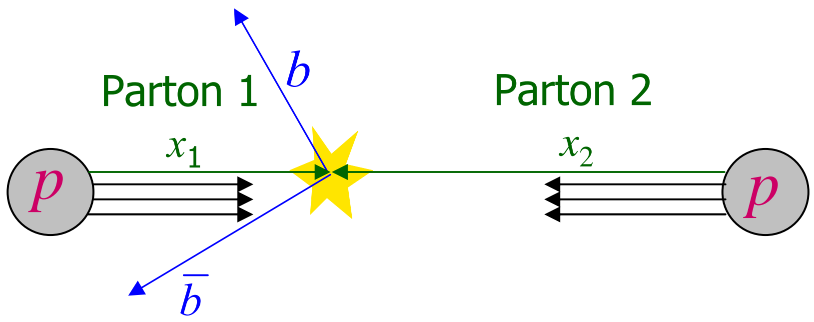
Victor Egorychev

Search for New Physics

+

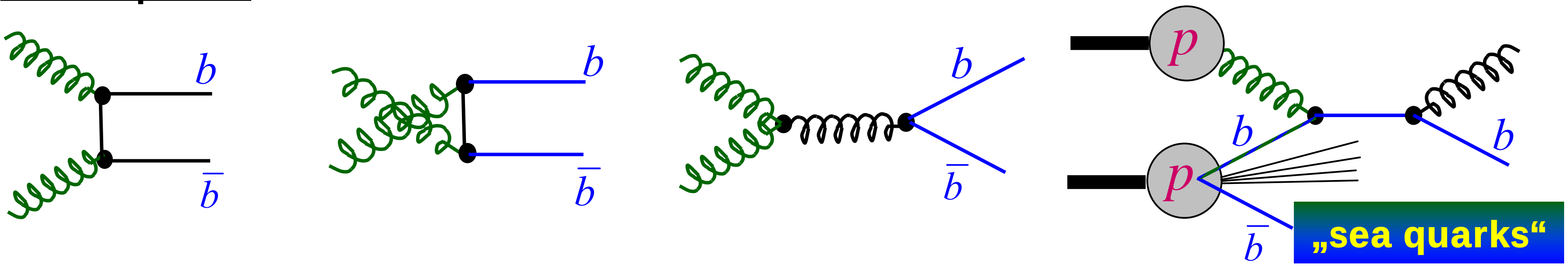
B production,
B_c , b-baryon physics
charm decays (e.g. D-mixing)
tau lepton flavour violation

B production in pp Collisions at $\sqrt{s}$ = 14 TeV (LHC)



Interactions of 2 partons (quarks, gluons) with fractional momenta x_i

Examples:



all b-hadron species are produced:

$$B^+, B_d^0, B_s^0, B_c, \Lambda_b, \ldots$$

~40% ~40% ~10% ~10%

$$\sigma_{b\bar{b}} \approx 500\,\mu b$$

$$\sigma_{inelastic} \approx 80 mb$$

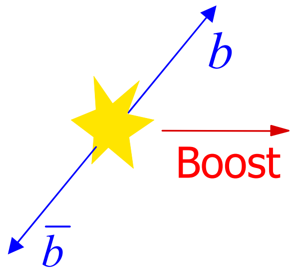
Challenge

$$\Rightarrow \frac{\sigma_{b\bar{b}}}{\sigma_{inelastic}} \approx 0.006$$

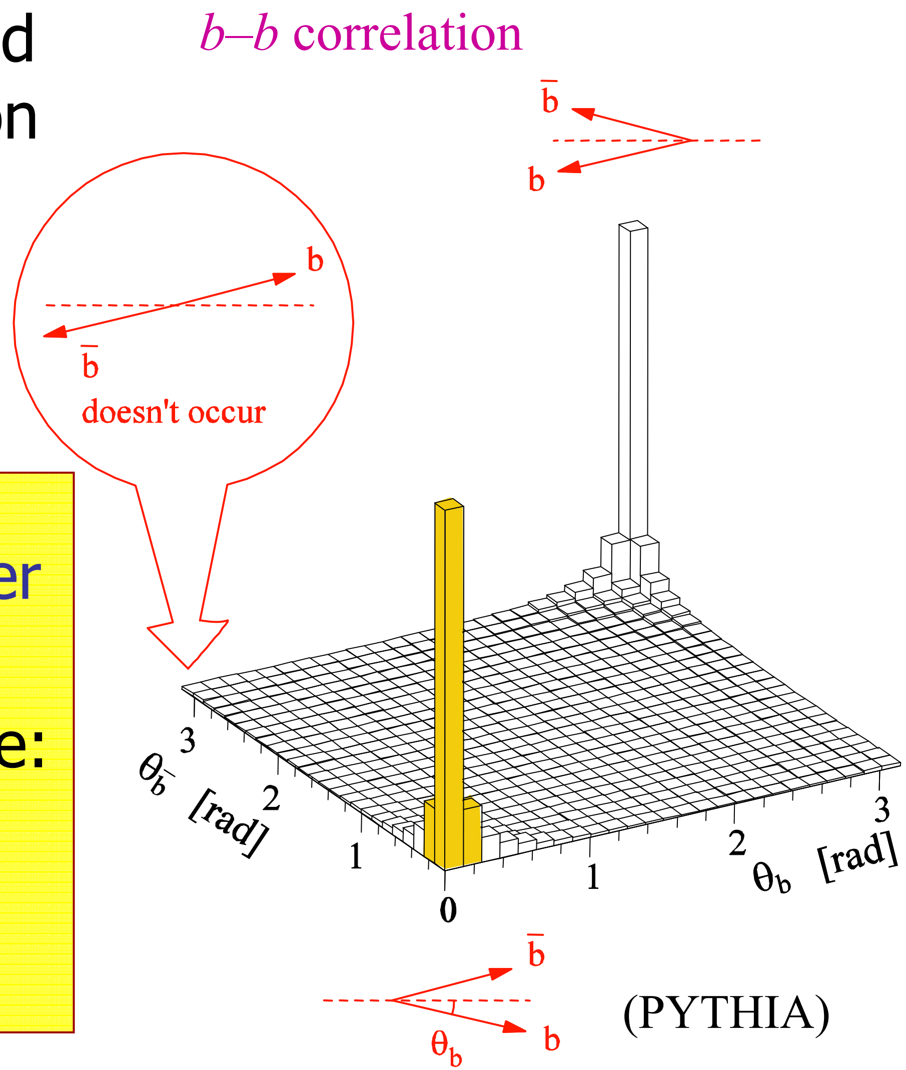
compare with ≈ 0.000001 @ HERA B

B production

- B hadrons are mostly produced in the forward (beam) direction



- Choose a forward spectrometer 10–≈300 mrad
- Both b and $\bar{b}$ in the acceptance: important for tagging the production state of the B hadron

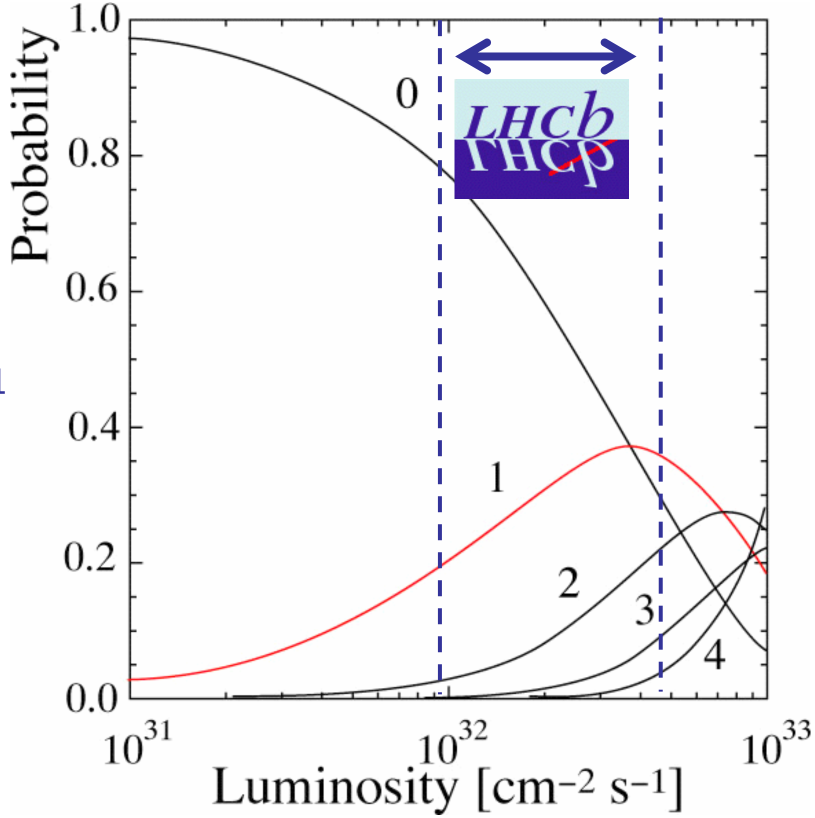


LHC environment

- Bunch crossing frequency: 40 MHz
- $\sigma_{inelastic}$ = 80 mb
  → at high L >> 1 pp collision/crossing
  ⇒ run at <L> ~ 2 × 10^{32} $cm^{-2}s^{-1}$
  → dominated by single interactions
- in acceptance region: $\sigma_{bb} \cong 230\ \mu b$
  ⇒ collect 10^{12} $b\bar{b}$ events/year

- Beams are less focused locally to maintain optimum luminosity even when ATLAS and CMS run at <L> ~ 10^{34} $cm^{-2}s^{-1}$
- Reconstruction easier
  - e.g. b-quark vertex identification
- Lower radiation level
- LHCb-detector must be able to operate in a high rate and high multiplicity environment

Inelastic pp collisions/crossing



Time Resolved Measurements

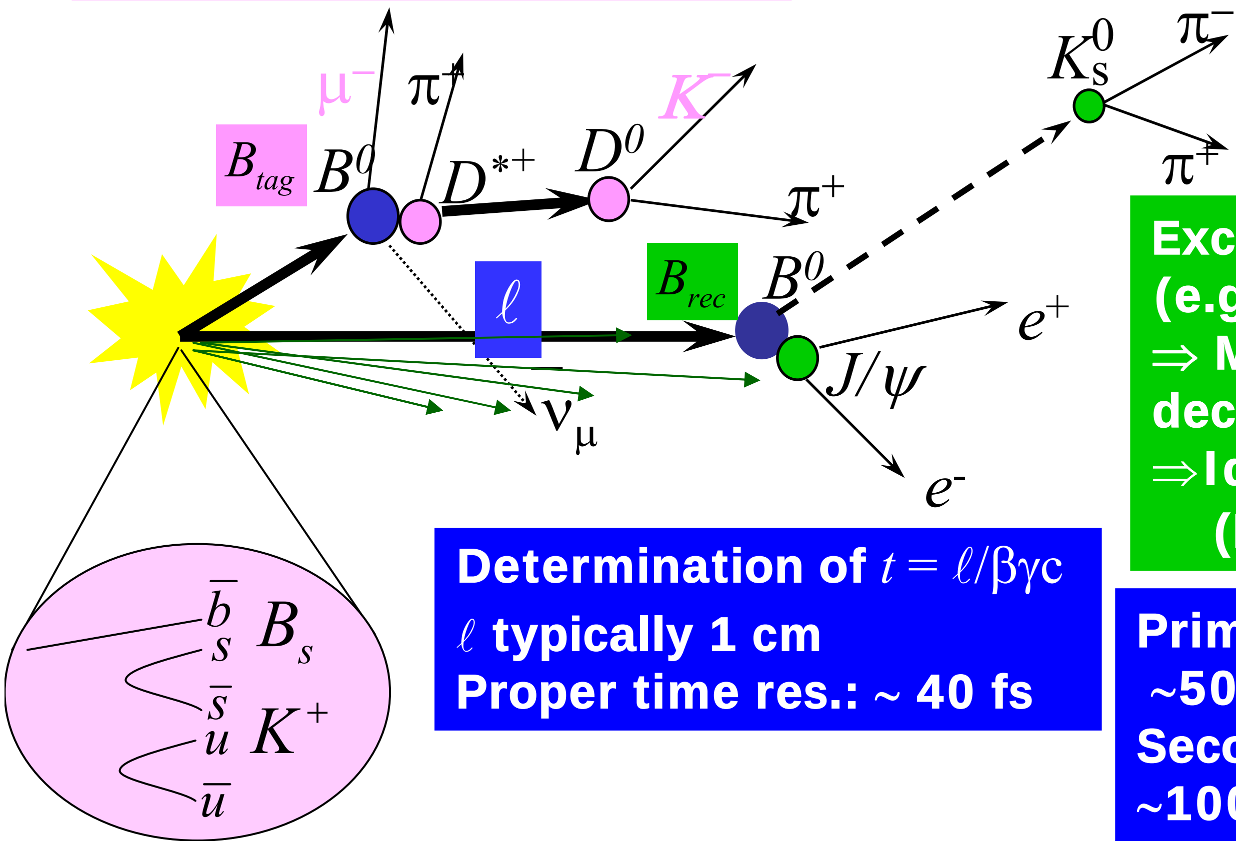
→sin2β, sin2α, (γ), sin2χ, etc., Oscillations Measurements, ..

Flavour-determination of other b-Quark („tag“)
⇒ Flavour of B_{rec} at t=0

- opposite side lepton and kaon tag
- same side kaon tag (for B_s)
- opposite B vertex charge tagging

$B_d^0 : \varepsilon_{tag}(1-2w)^2 \cong 4-5\%$

$B_s^0 : \varepsilon_{tag}(1-2w)^2 \cong 7-9\%$

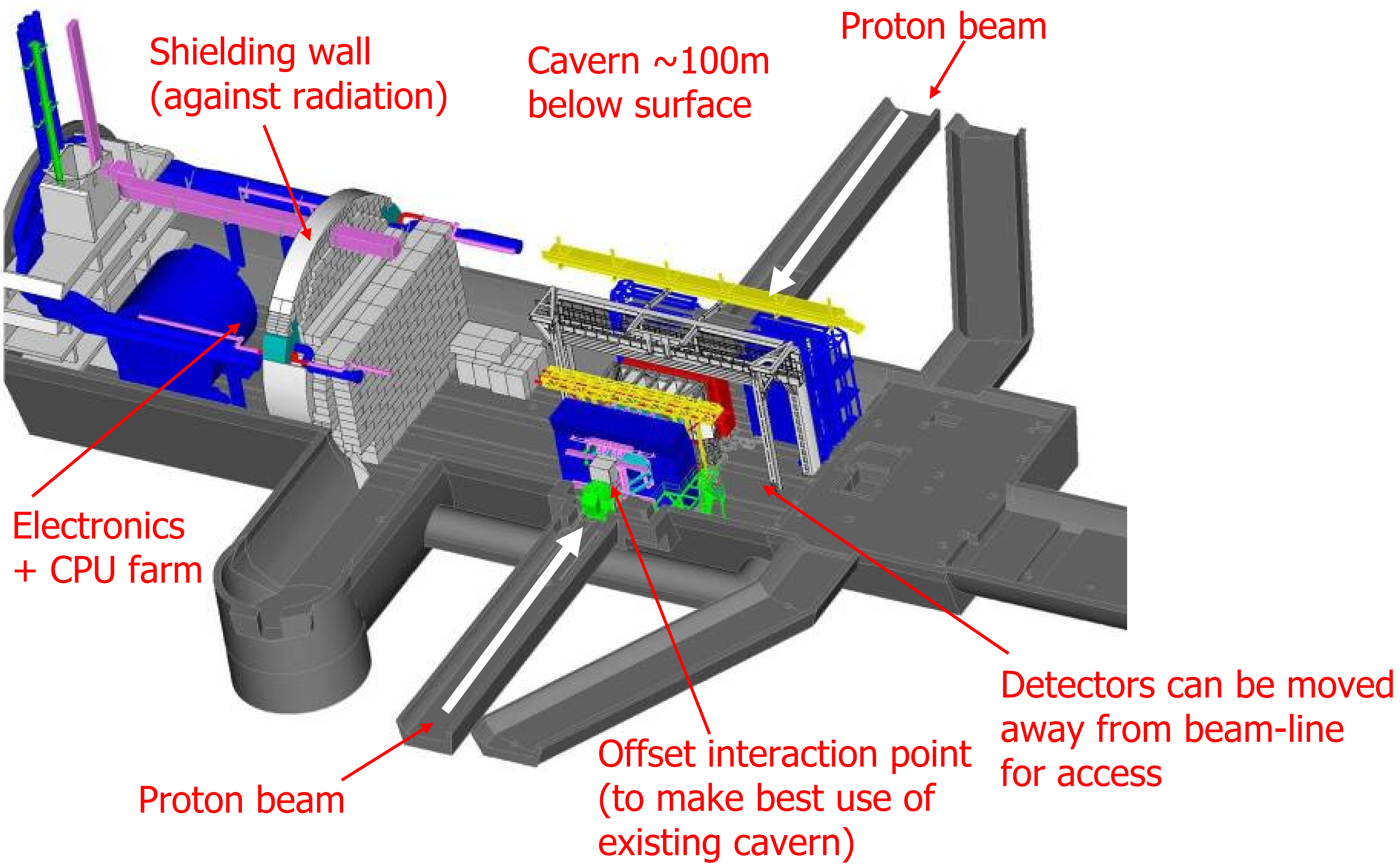


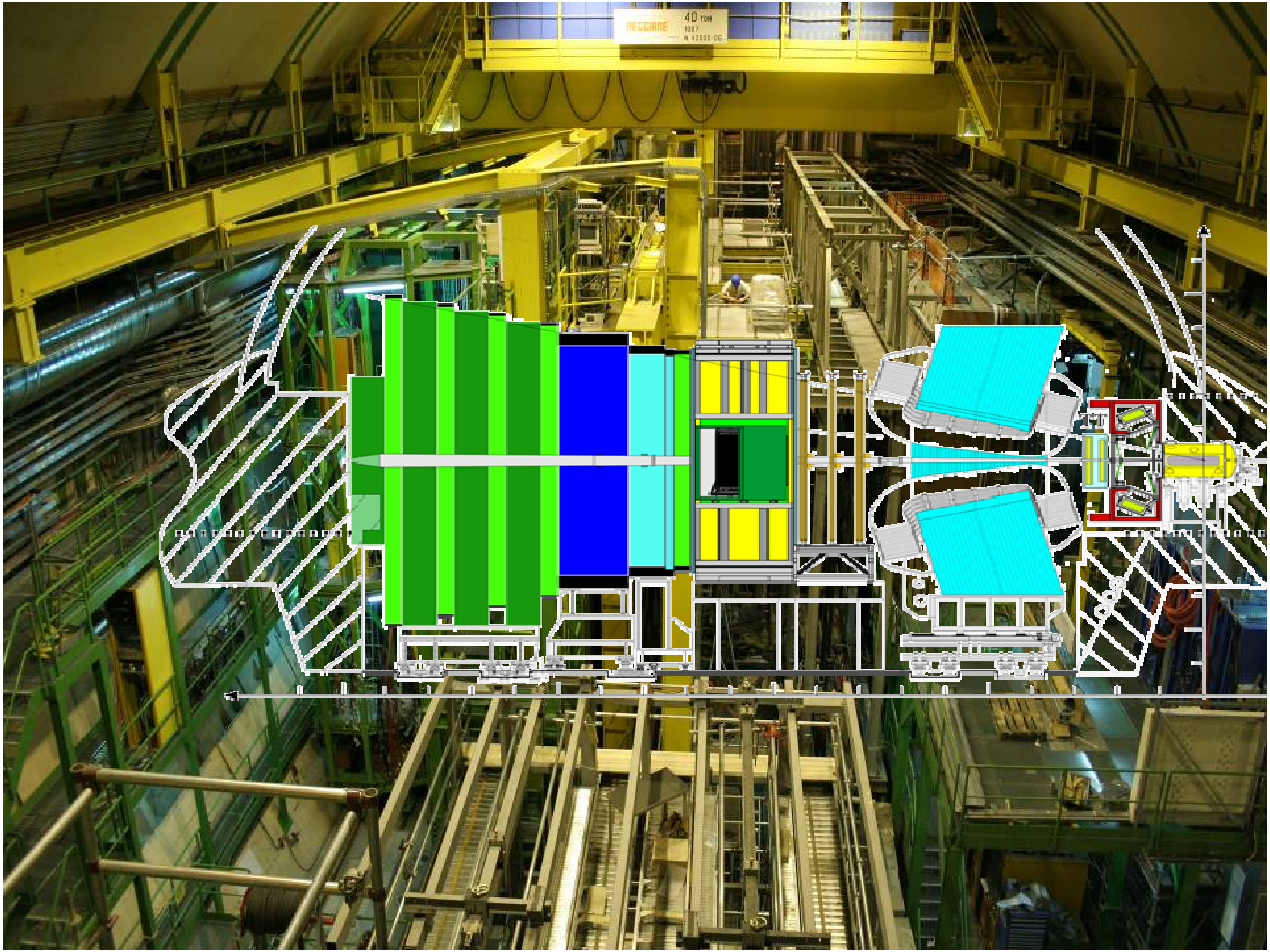
Exclusive B-reconstruction (e.g. CP Eigenstates)
⇒ Measure momentum p from decay products (1-100 GeV/c)
⇒Identify decay products (Leptons, π/K separation)

Determination of $t = \ell/\beta\gamma c$
ℓ typically 1 cm
Proper time res.: ~ 40 fs

Primary Vertex res.:
~50 μm in z, ~10 μm in xy
Secondary Vertex res.:
~100 μm in z, ~10 μm in x,y

LHCb - Cavern


Shielding wall
(against radiation)
Cavern ~100m
below surface
Proton beam
Electronics
+ CPU farm
Proton beam
Offset interaction point
(to make best use of
existing cavern)
Detectors can be moved
away from beam-line
for access



LHCb

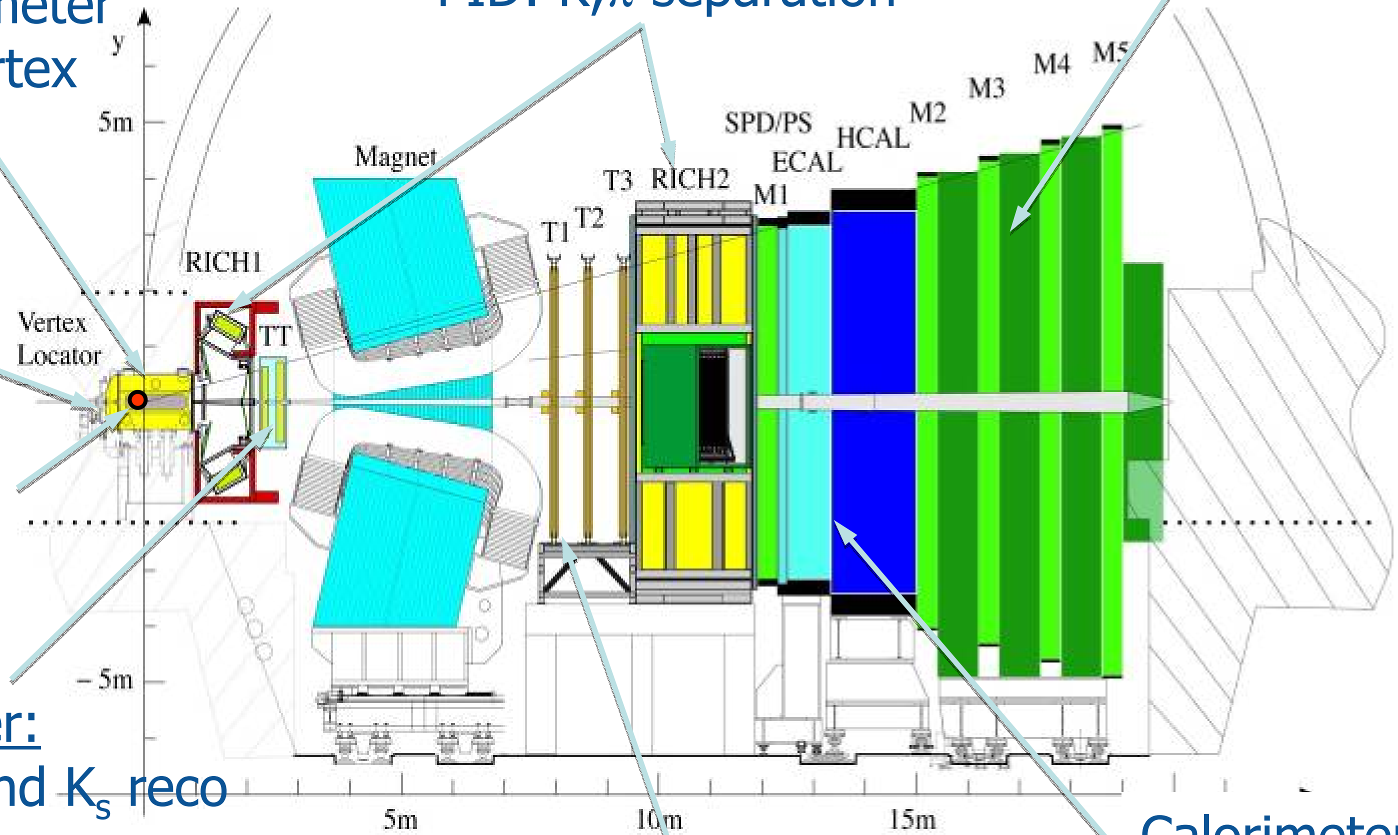
<u>VELO:</u>
primary vertex
impact parameter
displaced vertex

<u>RICHES:</u>
PID: K,π separation

<u>Muon System</u>

<u>PileUp System</u>

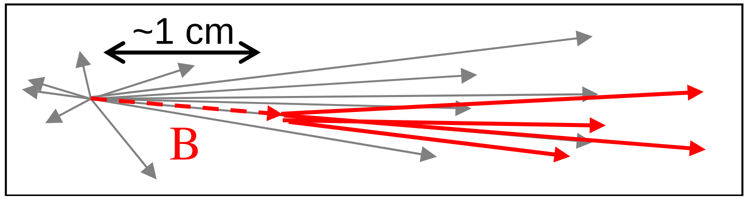
Interaction region



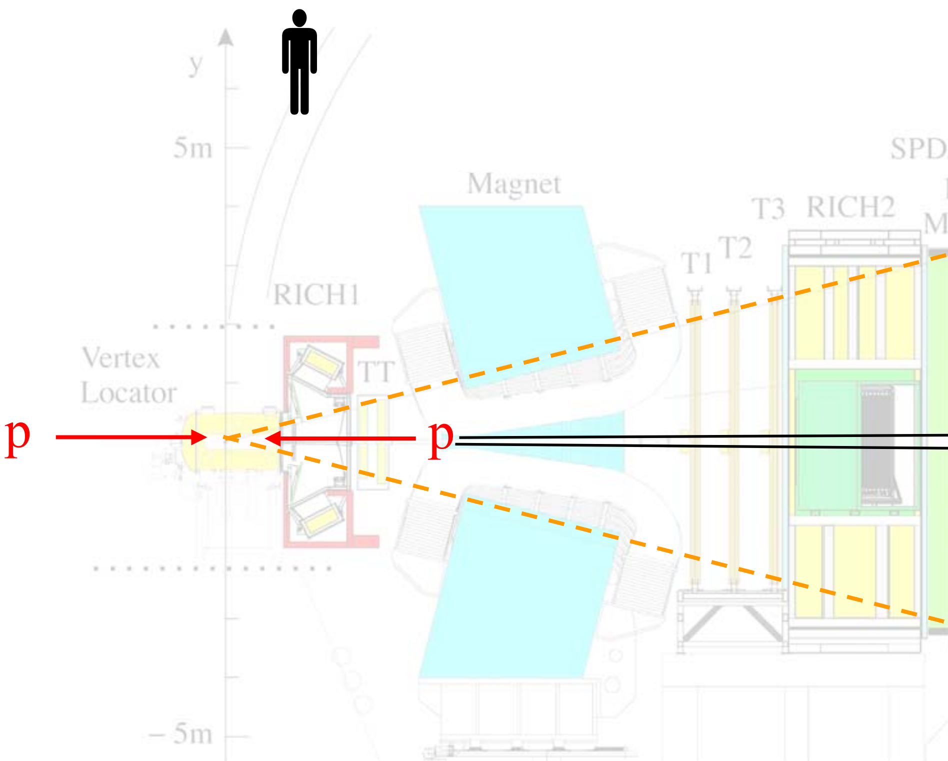
<u>Trigger Tracker:</u>
p for trigger and K_s reco

<u>Tracking Stations:</u>
p of charged particles

<u>Calorimeters:</u>
PID: e,γ, π^0



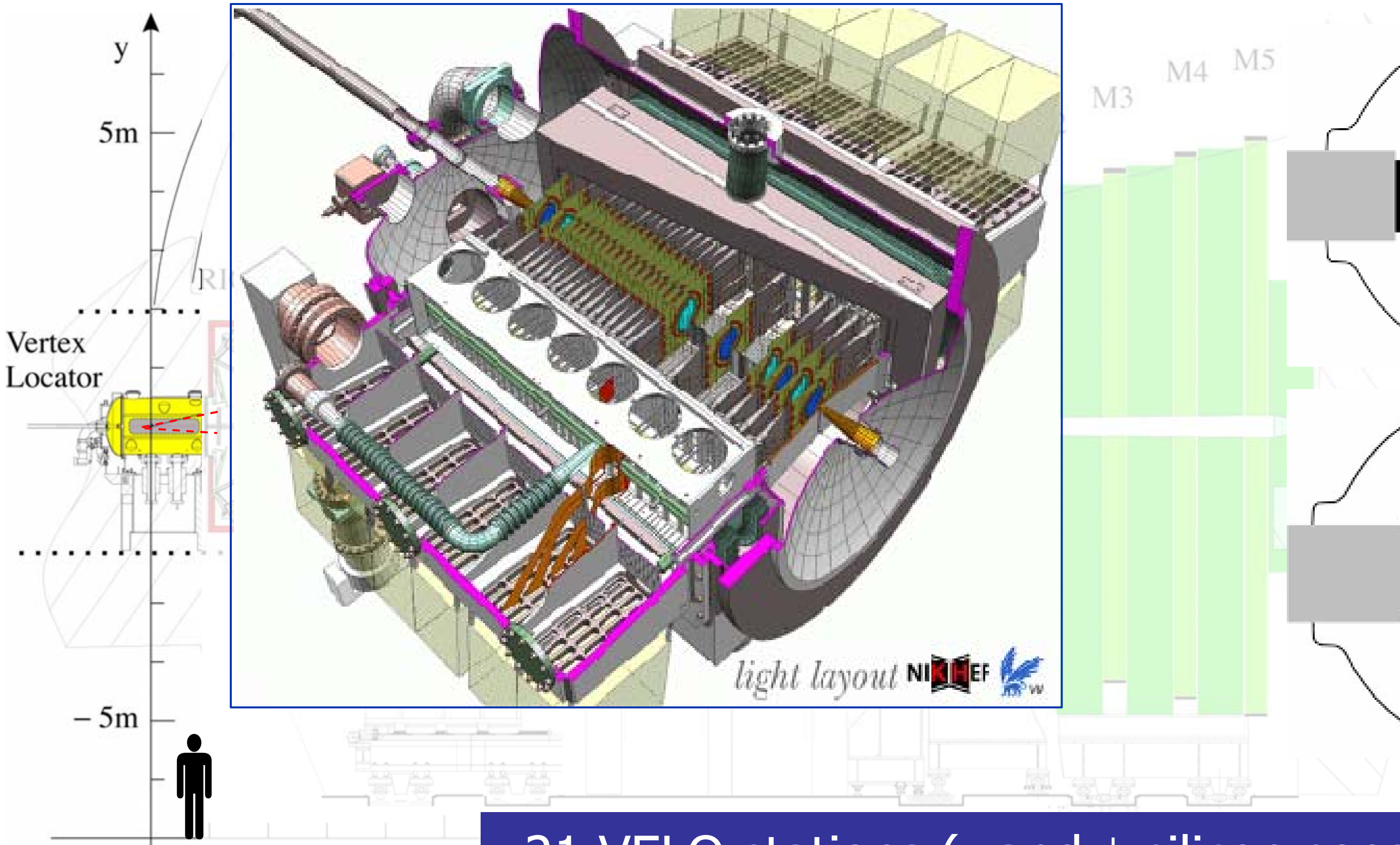
LHCb

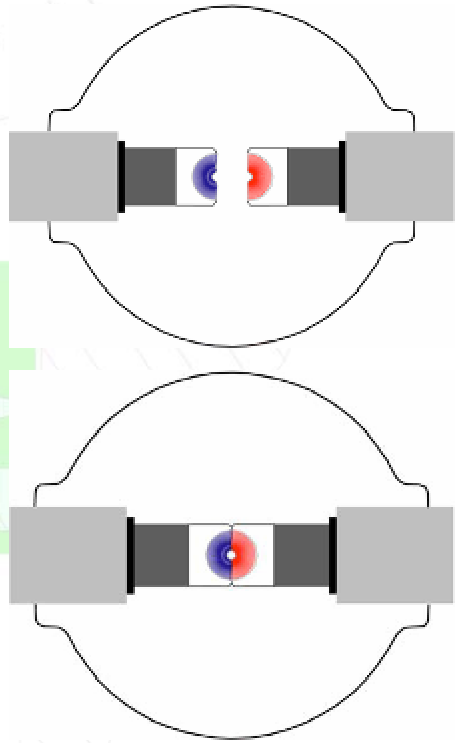


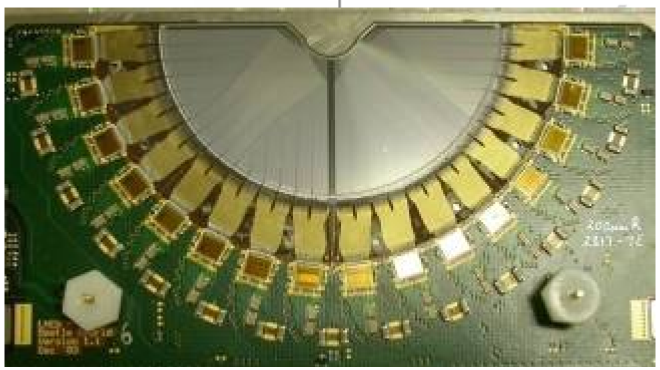
Beam Pipe (produced in Russia)
Beryllium
Status: installed, fully tested

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

Vertex Locator (VELO)

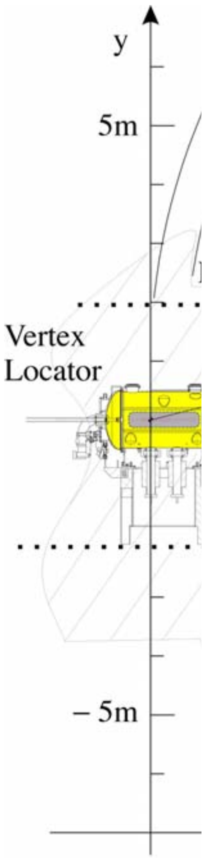


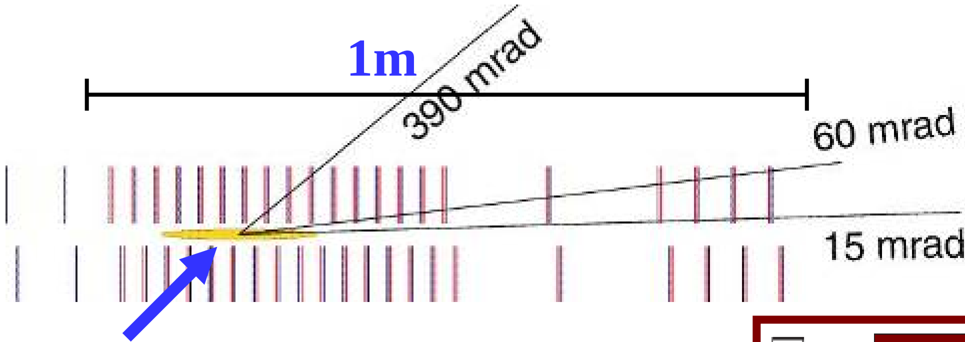


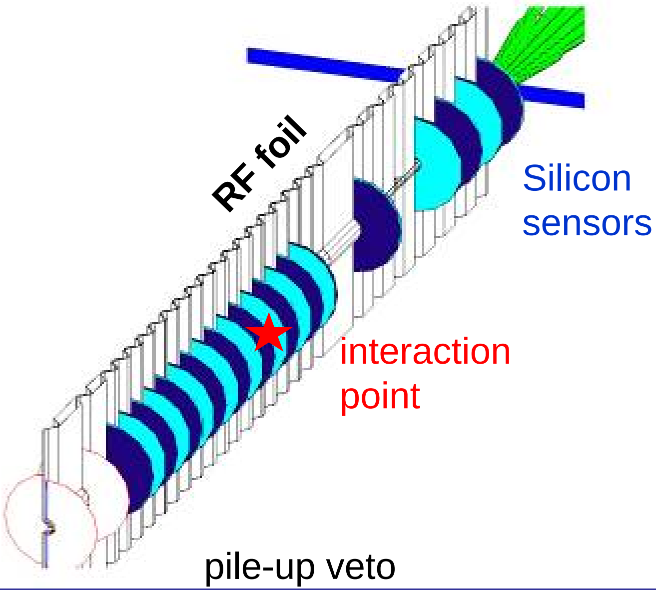


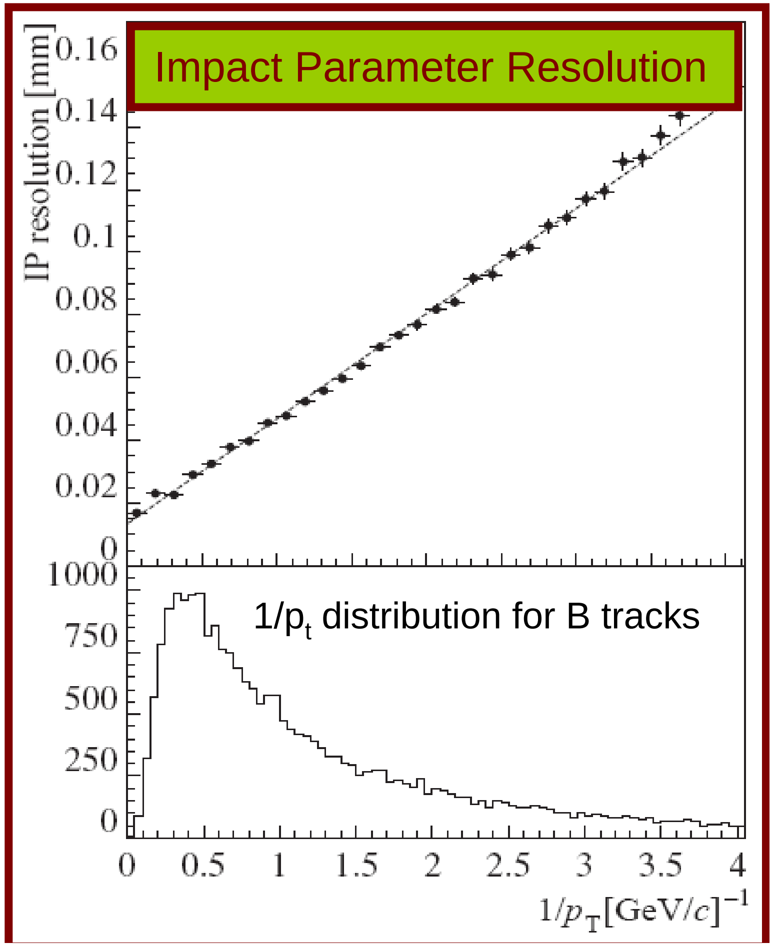
- 21 VELO stations (r and ϕ silicon sensors)
- Placed in a secondary vacuum vessel
- 3cm separation, 8mm from beam
- Separated by a 300 μm of Al RF foil
- Detector halves retractable for injection
- ~ 30 μm impact-parameter resolution

VELO



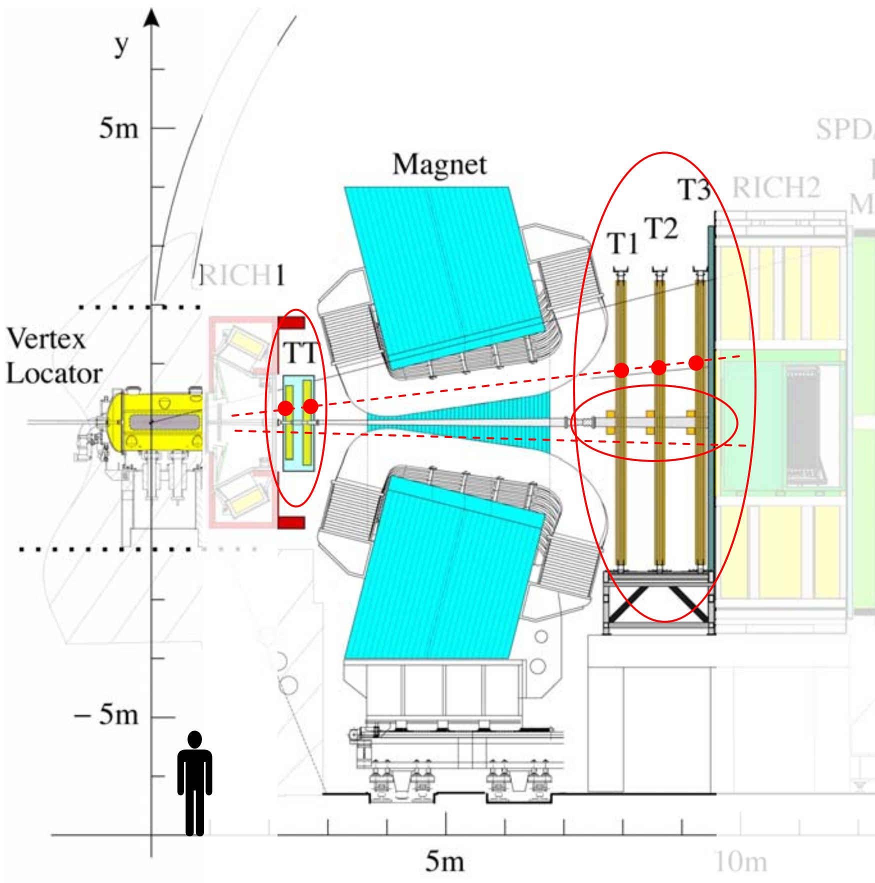




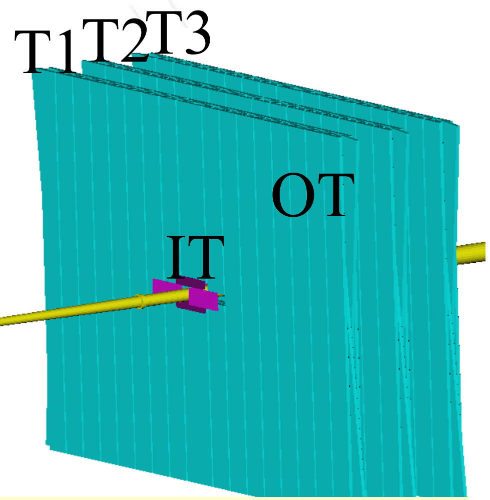


Status: installation of completed detector halves starting

Tracking



Inner Tracker
Silicon strips
2% of area
20% of tracks



TT: 144k channels, Silicon Strip

IT: 129k channels, Silicon Strip

installation proceeding

OT: 54k channels, Straw Tubes

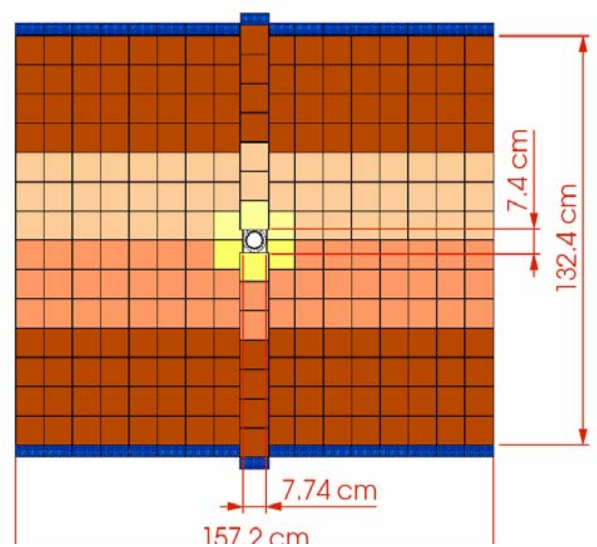
installed

Tracking system and dipole magnet to measure angles and momenta

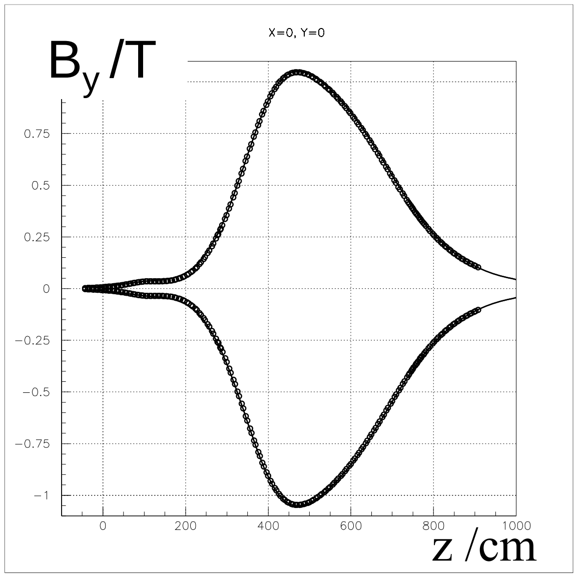
B-mass resolution ~ 15 MeV, $\Delta p/p \sim 0.4$ %

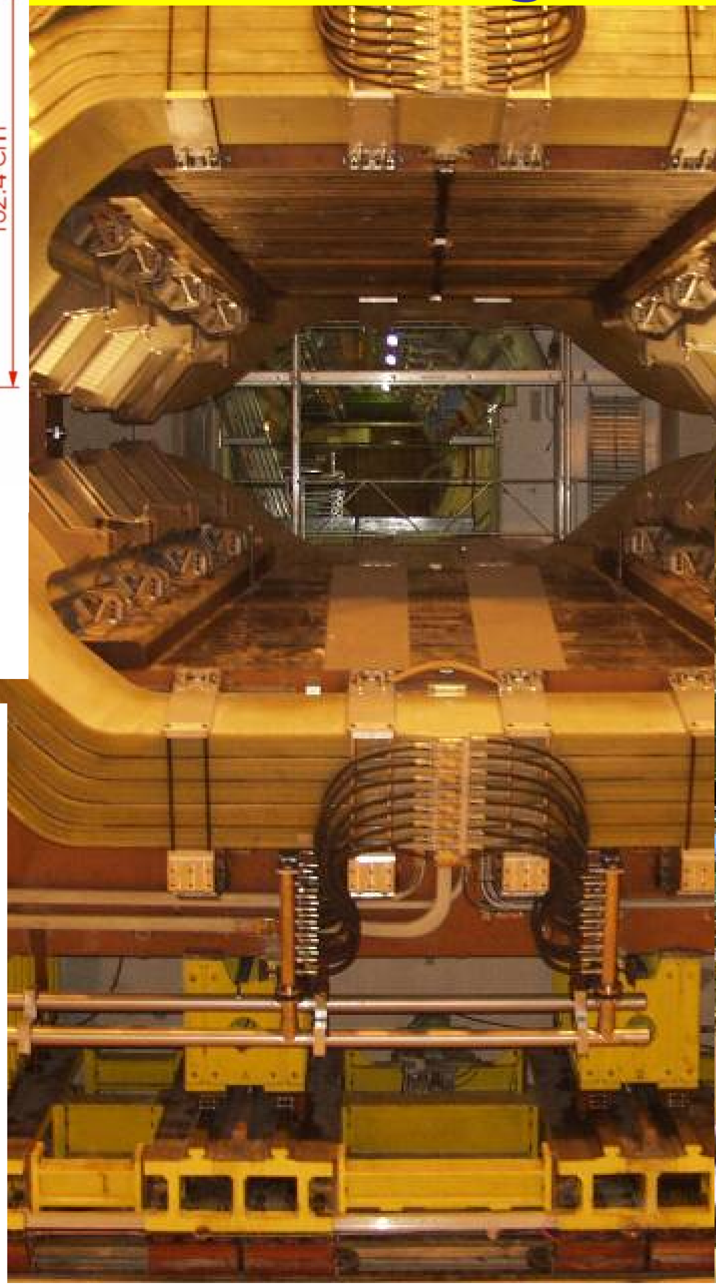
Magnetic field will be reversed to reduce experimental systematics

Tracking



Trigger Tracker
Silicon strips
p_T information for trigger

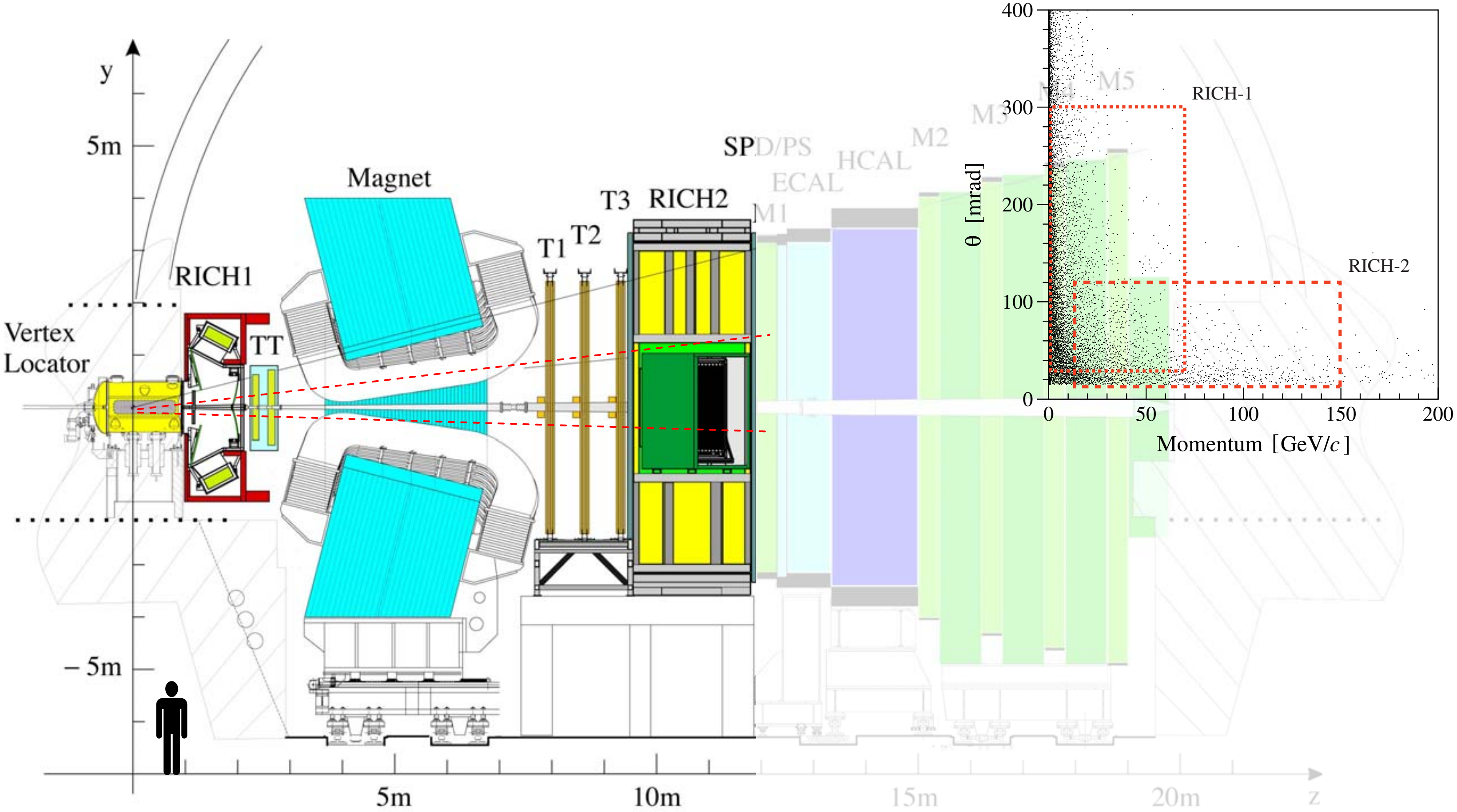




Inner Tracker

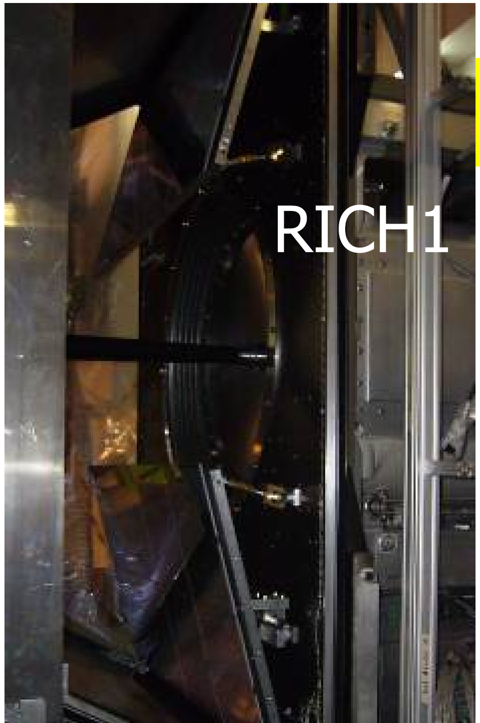
Outer Tracker

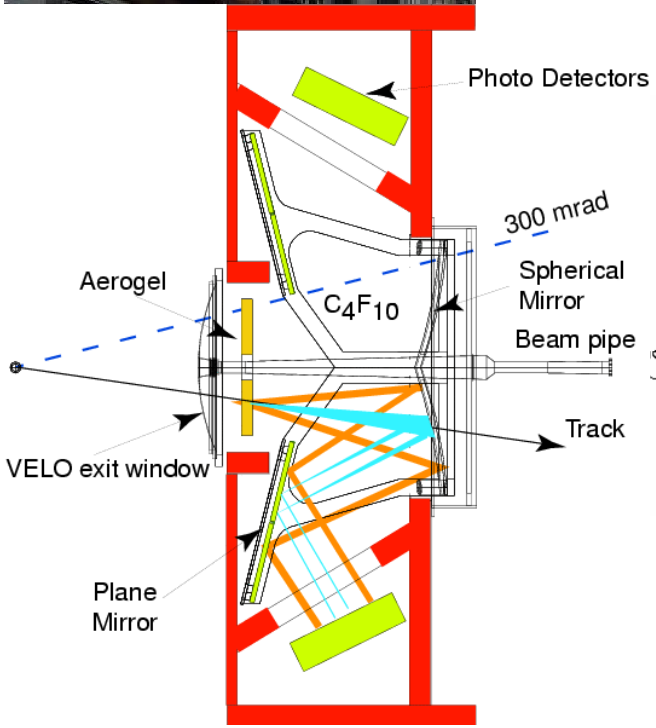
Particle Identification - RICH

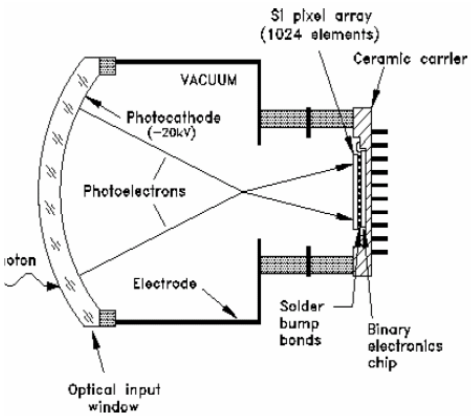


Two **Cherenkov** detectors (RICH) for charged hadron identification
⇒ excellent π–K separation for momenta up to 100 GeV/c

RICH





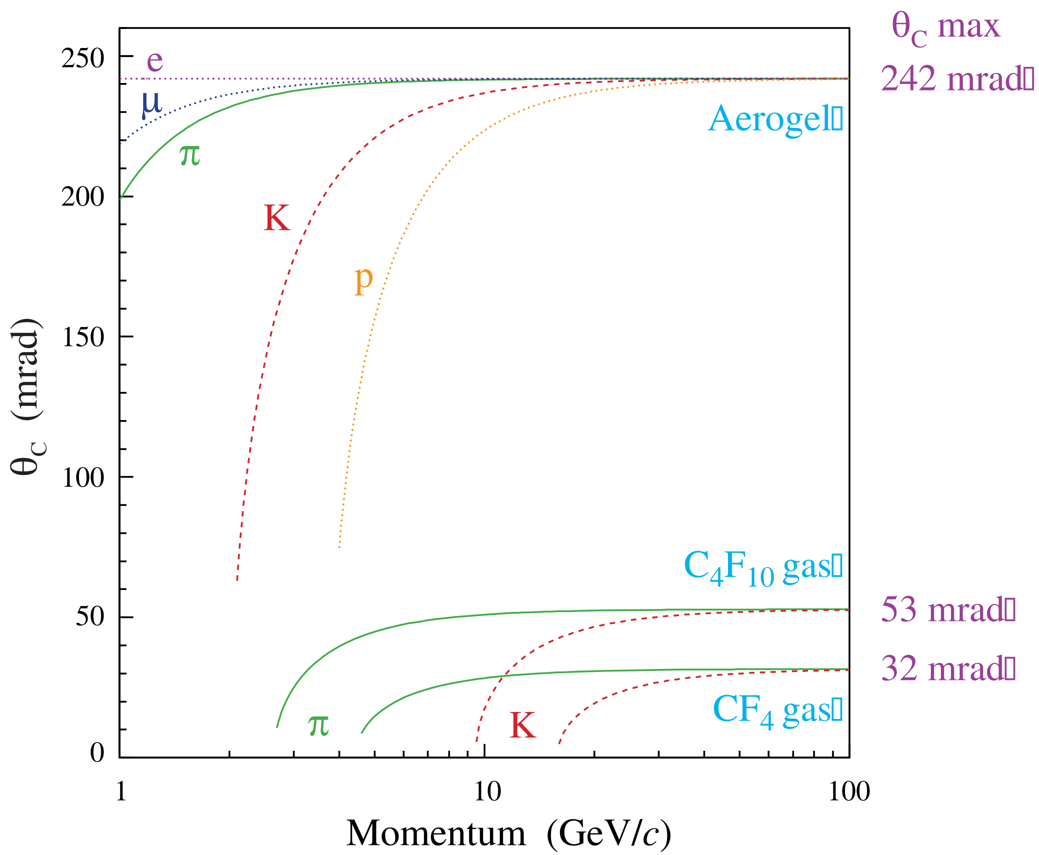


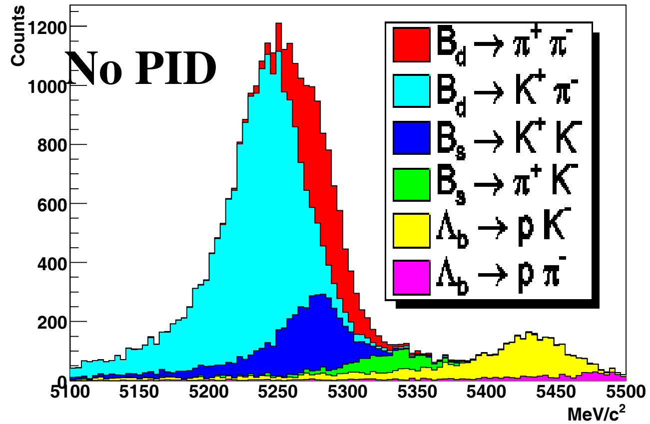
Readout: Hybrid PhotoDiodes HPD
– 1024 pixels – LHCb development

RICH Detectors

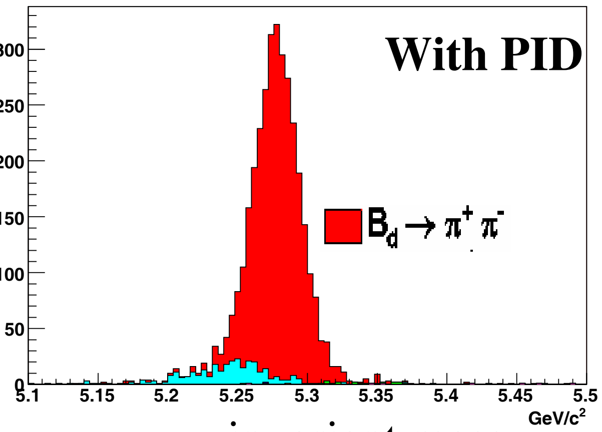
3 radiators: RICH1 Aerogel (2-10 GeV), C_4F_{10} (10-60 GeV)

RICH2 CF_4 (16-100 GeV)





ππ invariant mass

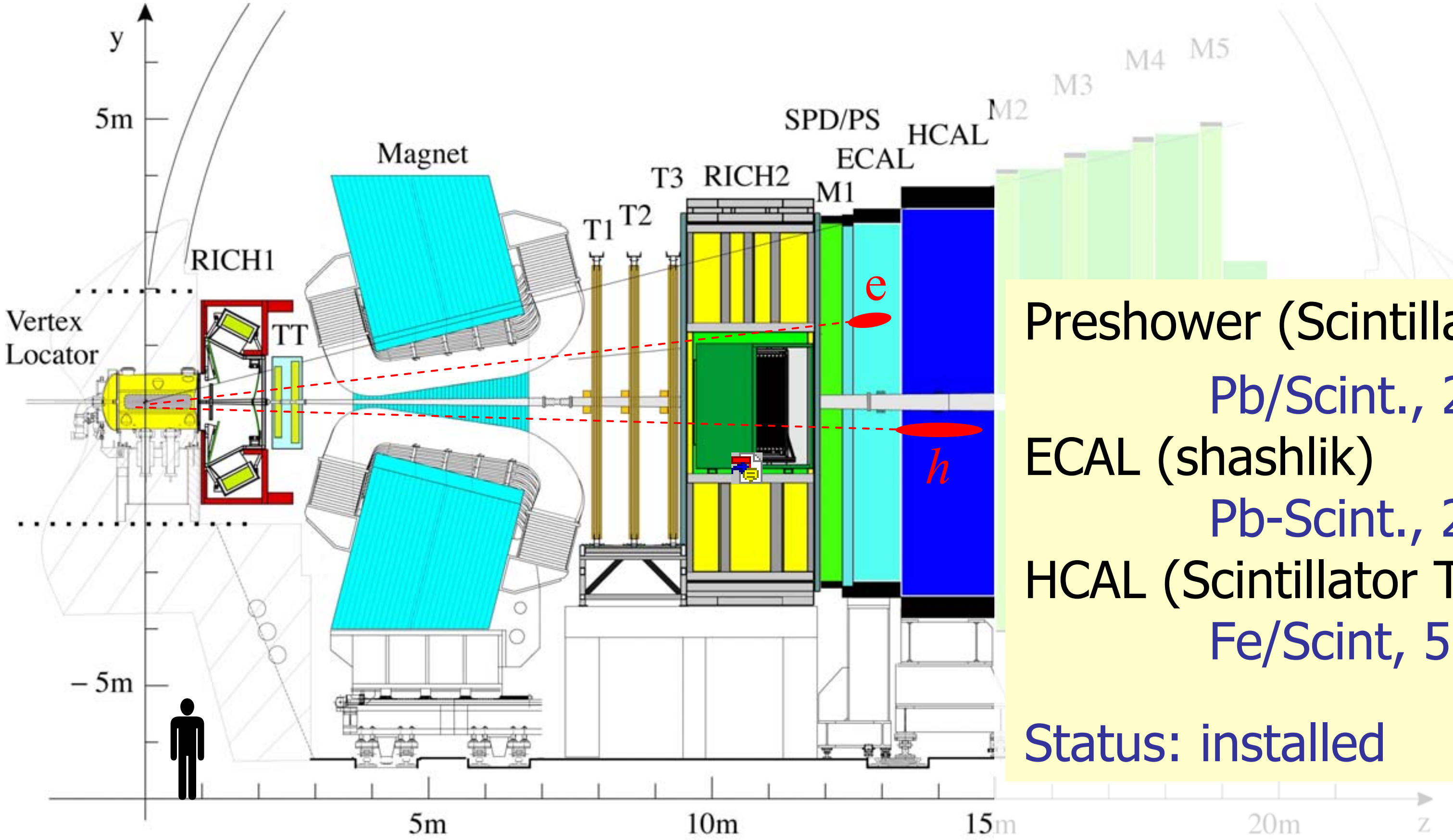


ππ invariant mass

Status: RICH2 installed

RICH1 installed Aug 2007

Calorimeters



Preshower (Scintillator Pad)

Pb/Scint., 2.5 X_0

ECAL (shashlik)

Pb-Scint., 25 X_0

HCAL (Scintillator Tile)

Fe/Scint, 5.6 λ_0

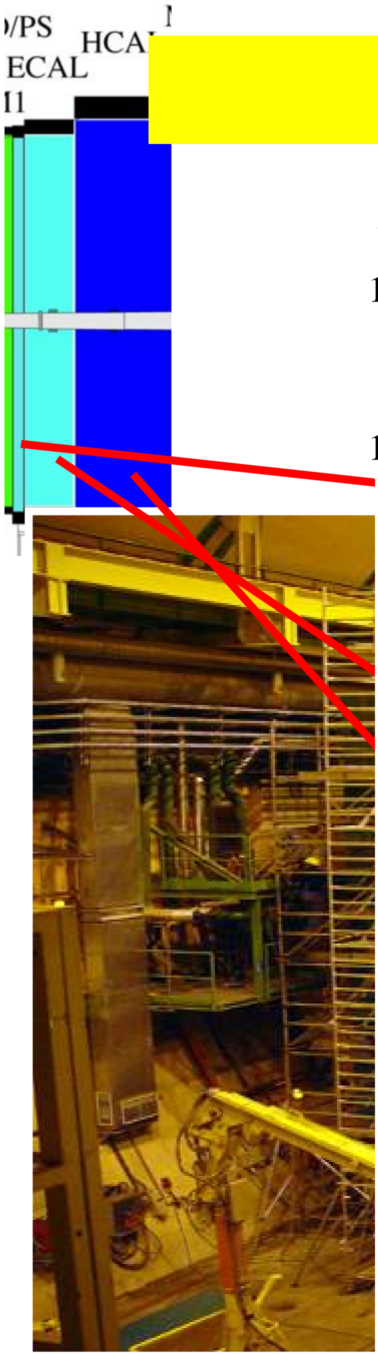
Status: installed

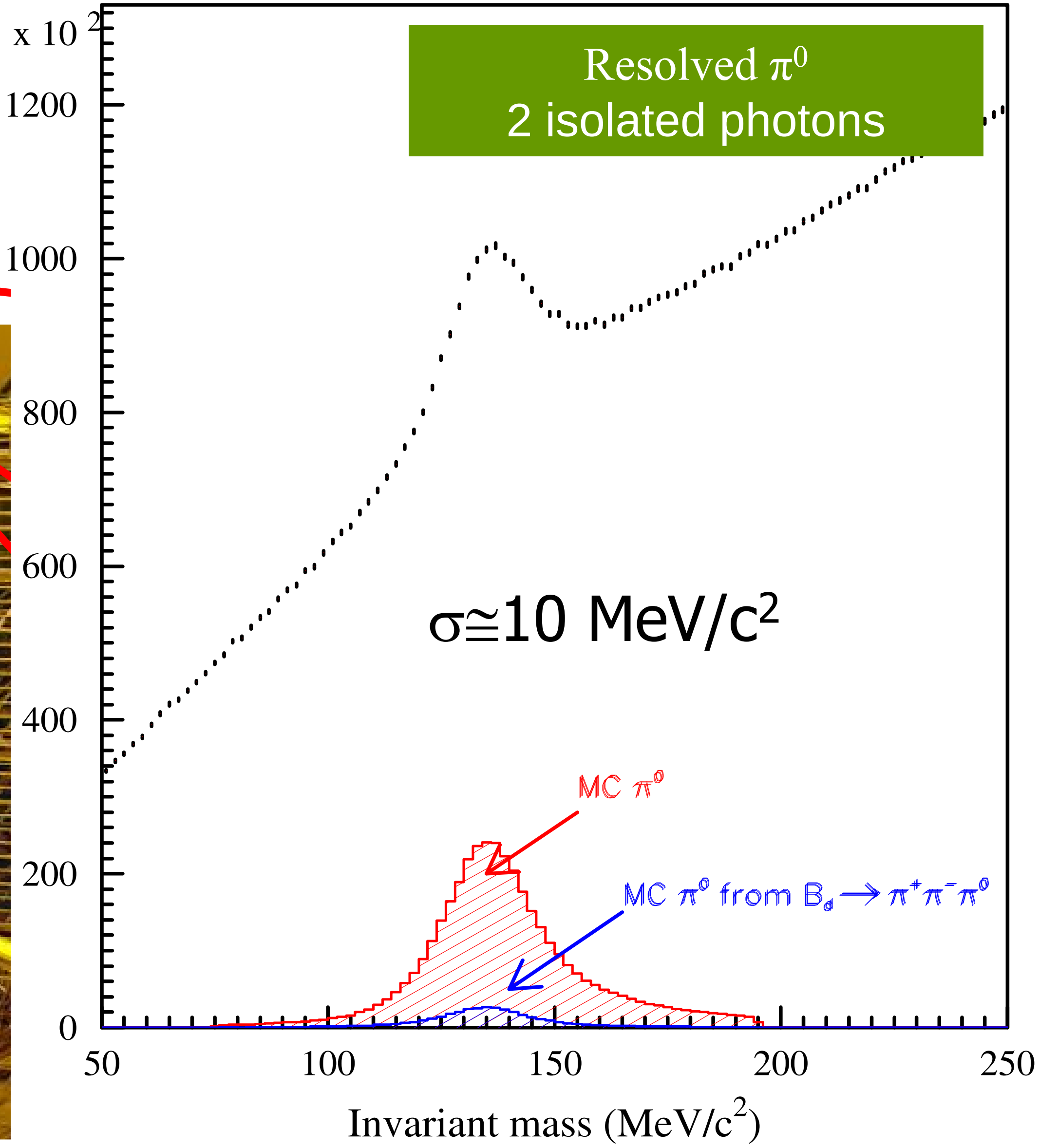
Calorimeter system (Preshower PS/SPD, ECAL and HCAL) provides Identification of electrons, hadrons and neutrals

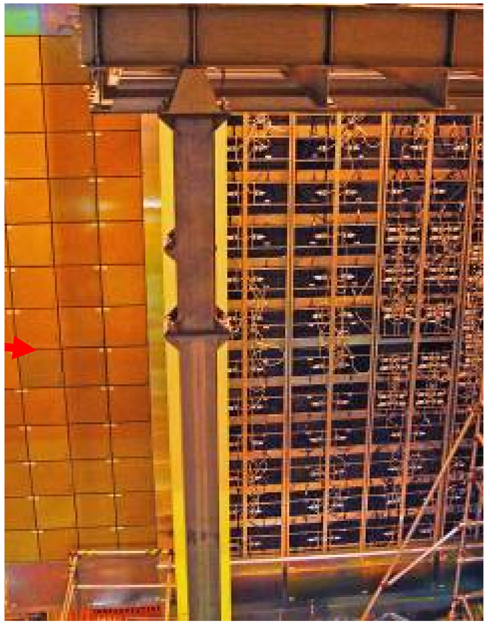
Important for the first level of the trigger

Major russian contribution to the experiment!

Calorimeters







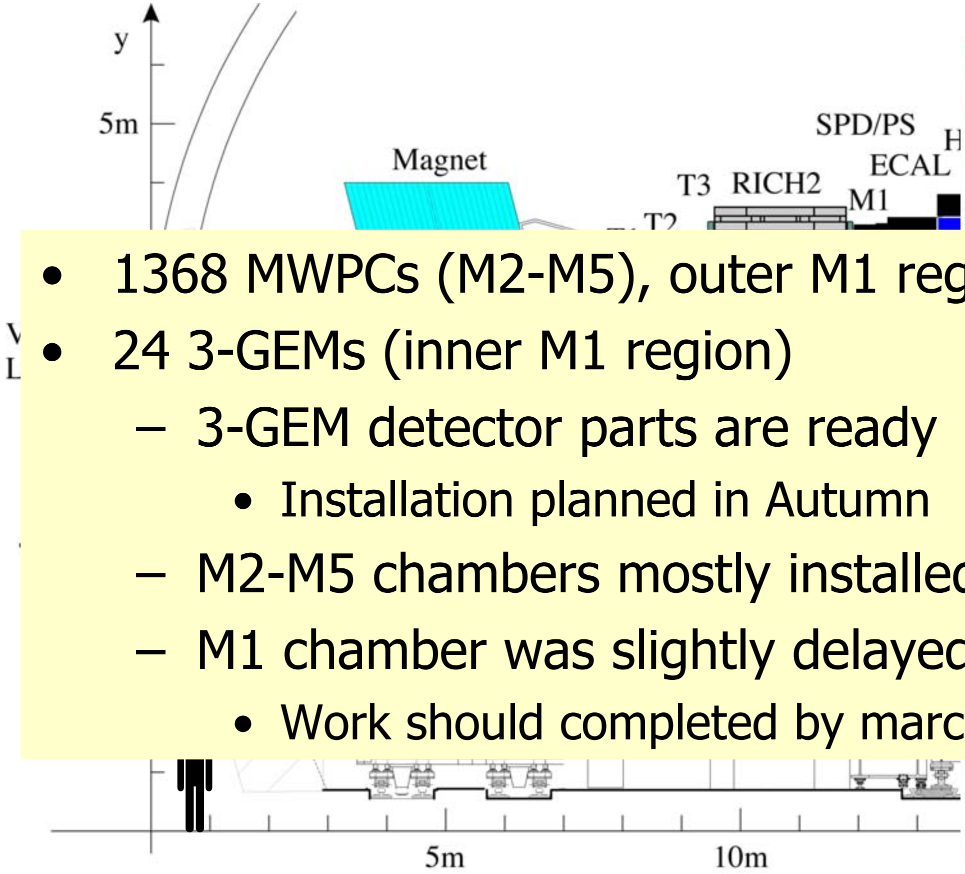
ECAL:

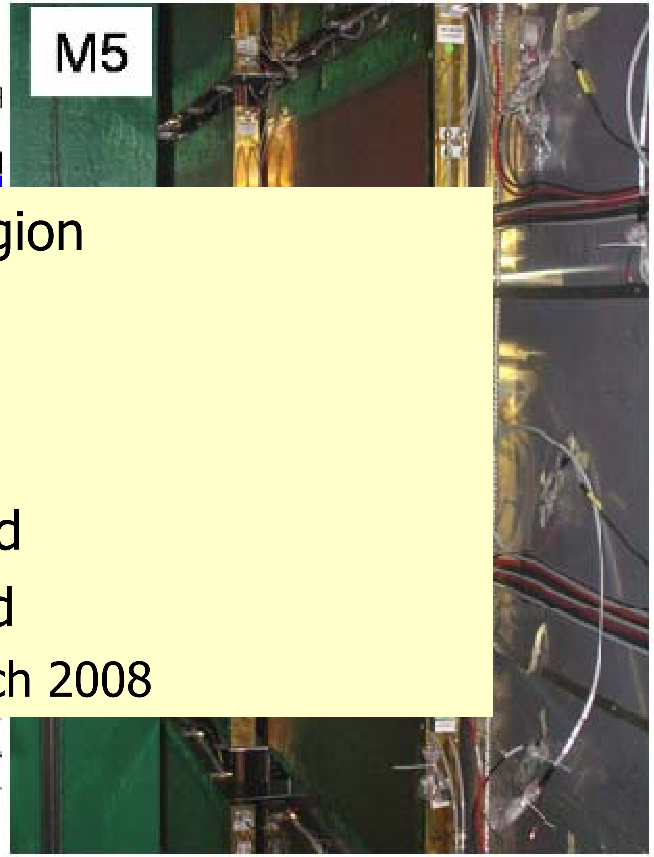
$$\frac{\sigma_E}{E} = \frac{10\%}{\sqrt{E}} \oplus 1\%$$

HCAL:

$$\frac{\sigma_E}{E} = \frac{80\%}{\sqrt{E}} \oplus 10\%$$

Muon System





- 1368 MWPCs (M2-M5), outer M1 region
- 24 3-GEMs (inner M1 region)
  - 3-GEM detector parts are ready
    - Installation planned in Autumn
  - M2-M5 chambers mostly installed
  - M1 chamber was slightly delayed
    - Work should completed by march 2008

Muon system to identify muons, also used in first level of trigger
Efficiency ~ 95% for pion misidentification rate < 1%

Trigger

Efficient and selective trigger crucial for LHCb:

10 MHz (visible bunch crossings)

Hardware trigger (L0)

- Fully synchronized (40 MHz), 4 μs fixed latency
- High p_T particles: μ, μμ, e, γ and hadron
  - (typically p_T ~1-4 GeV/c)
- reject multiple interactions (PileUp system)

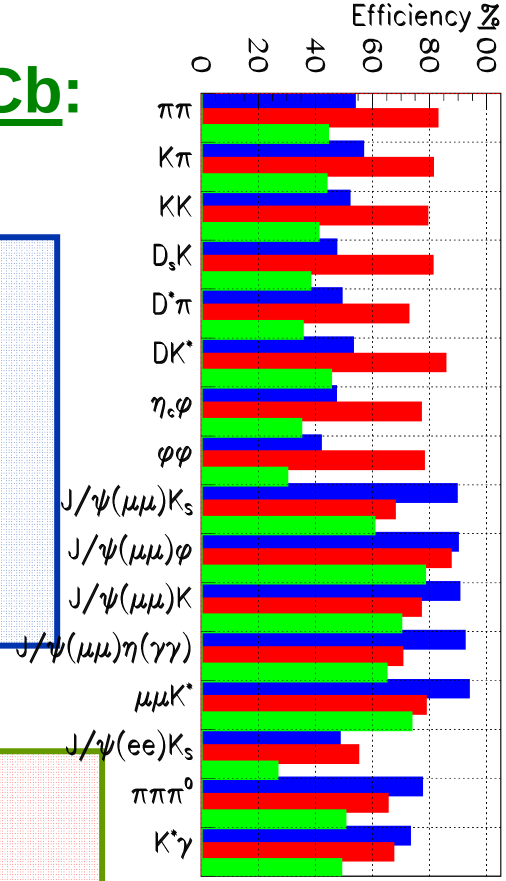
1 MHz (readout of all detector compnents)

Software trigger (HLT)

- Full detector info available, only limit is CPU time
- Use more tracking info to re-confirm L0 decision + high IP
- Full event reconstruction: exclusive and inclusive streams tuned for specific final states

PC farm of ~1000 nodes (multicore)

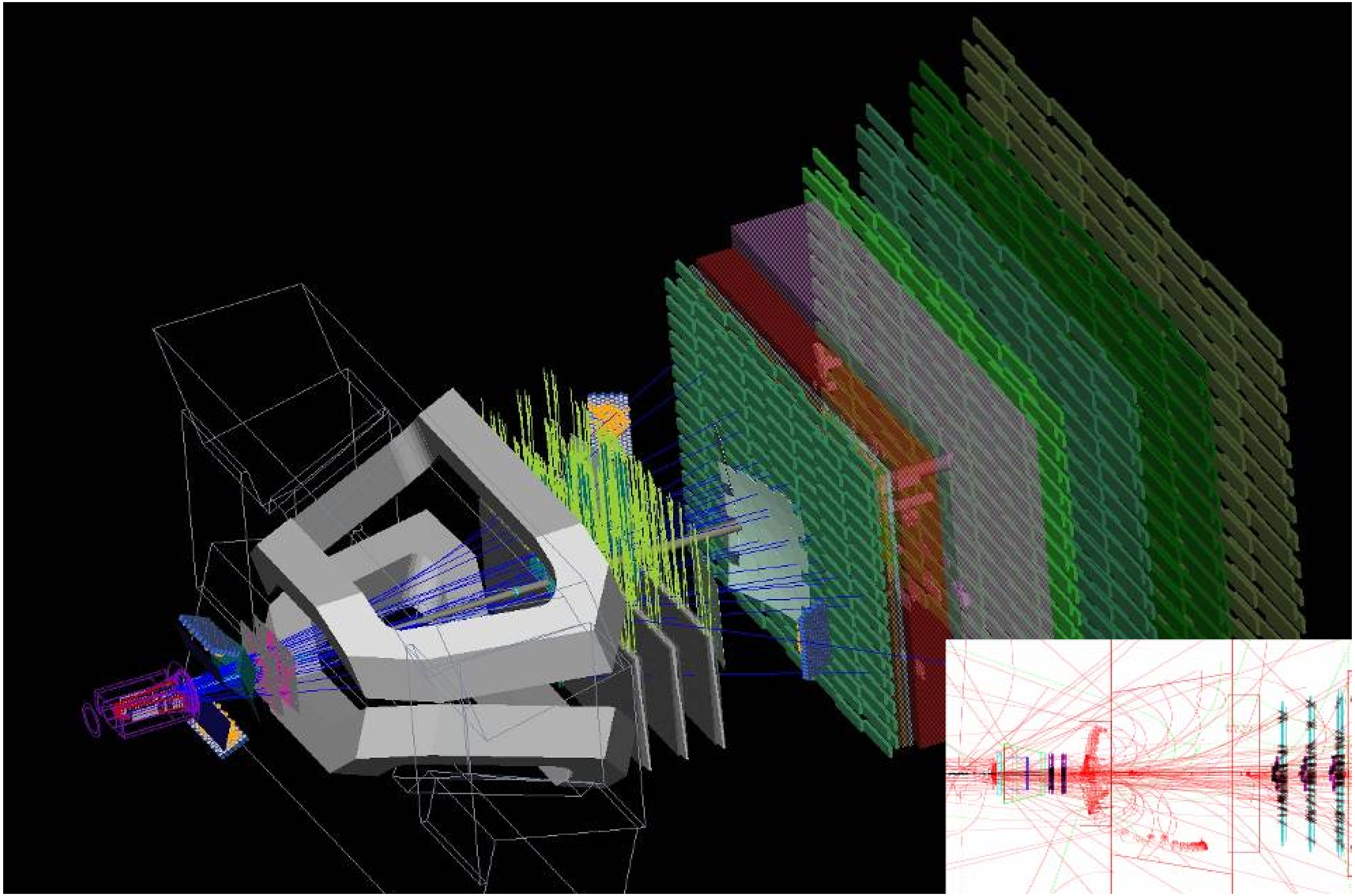
≤ 2 kHz (storage: event size ~35kB)



L0, HLT and L0×HLT efficiency

$\varepsilon >\approx 30\%$

Simulated Event

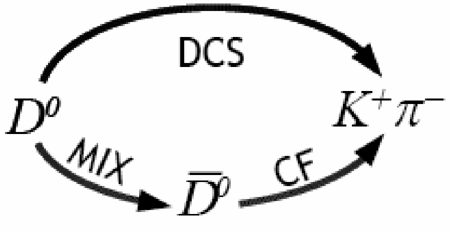


Performance figures (1 year, 2 fb^{-1})

	Channel	Yield	B/S	Precision
γ	$B_s \to D_s^{-+} K^{+-}$	5.4k	< 1.0	$\sigma(\gamma)$~13°
	$B_d \to \pi^+ \pi^-$	36k	0.46	$\sigma(\gamma)$ ~ 4°
	$B_s \to K^+ K^-$	36k	< 0.06	
	$B_d \to D^0$ (Kπ,KK) K^{*0}	3.4 k, 0.5 k, 0.6 k	<0.3, <1.7, < 1.4	$B_s \to D_s K$ & $B_{u,d} \to DK$ $\Rightarrow \sigma(\gamma) \cong 4^\circ$
	$B^- \to D^0 (K^-\pi^+, K^+\pi^-) K^-$	28k, 0.5k	0.6, 4.3	
	$B^- \to D^0 (K^+K^-, \pi^+\pi^-) K^-$	4.3 k	2.0	
	$B^- \to D^0 (K_S\pi^+\pi^-) K^-$	1.5 - 5k	< 0.7	
α	$B_d \to \pi^+ \pi^- \pi^0$	14k	< 0.8	$\sigma(\alpha)$ ~ 10°
	$B \to \rho^+\rho^0, \rho^+\rho^-, \rho^0\rho^0$	9k, 2k, 1k	1, <5, < 4	$\sigma(\alpha)$~8°-14°
β	$B_d \to J/\psi(\mu\mu)K_S$	216k	0.8	$\sigma(\sin 2\beta)$ ~ 0.022
Δm_s	$B_s \to D_s^- \pi^+$	80k	0.3	$\sigma(\Delta m_s)$ ~ 0.01 ps^{-1}
ϕ_s	$B_s \to J/\psi(\mu\mu)\phi$	131k	0.12	$\sigma(\phi_s)$ ~ 1.3°
Rare decays	$B_s \to \mu^+\mu^-$	17	< 5.7	
	$B_d \to K^{*0} \mu^+\mu^-$	7.7 k	**0.5**	$\sigma(C_7^{eff}/C_9^{eff})$ ~0.13
	$B_d \to K^{*0} \gamma$	**75k**	**0.71**	$\sigma(A_{CP})$ ~0.01
	$B_s \to \phi\gamma$	**11.5k**	**<0.95**	
charm	$D^{*+} \to D^0 (K^-\pi^+) \pi^+$	100 M		

Perfect U-Spin symmetry

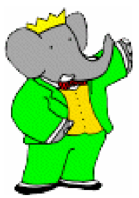
e.g. D$\bar{\text{D}}$ Mixing



Mixing modifies exponential decay-time distribution:

$$\frac{dN}{dt} \propto e^{-\bar{\Gamma}t}\left[R_D + \sqrt{R_D}\, y'\left(\bar{\Gamma}t\right) + \frac{x'^2 + y'^2}{4}\left(\bar{\Gamma}t\right)^2 \right]$$

DCS — interference — mixing



$\mathcal{L}$=384fb^{-1}

$$x'^2 = \left(-0.022 \pm 0.030 \pm 0.021\right)\%$$
$$y' = \left(0.97 \pm 0.44 \pm 0.31\right)\%$$

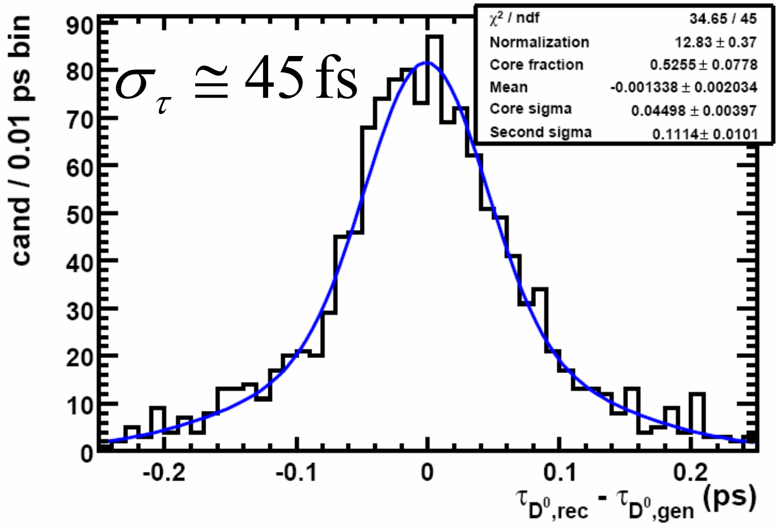
LHCb

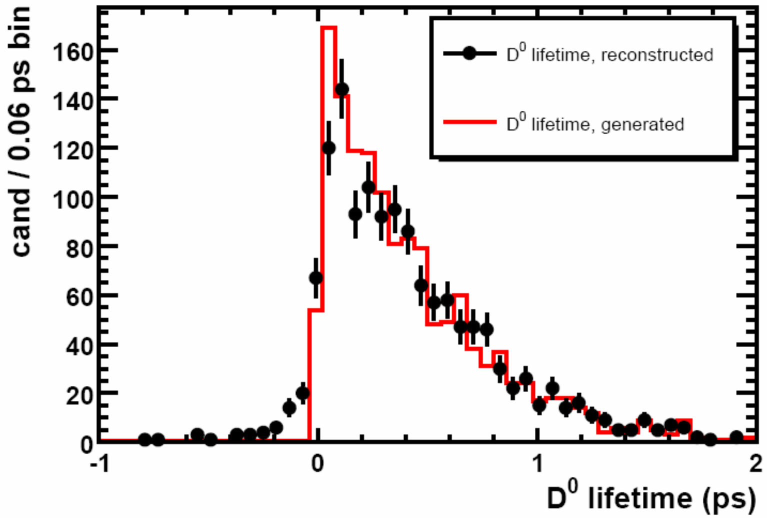
$\mathcal{L}$=10fb^{-1}

$$x'^2 \Rightarrow \sigma_{stat}(x'^2) \cong 0.0064\%$$
$$y' \Rightarrow \sigma_{stat}(y') \cong 0.087\%$$

Estimated yield from $B \to D^{*+}X$

$$N_{D^0 \to K^-\pi^+} \cong 250 \cdot 10^6$$





Conclusions

LHCb: a dedicated B-Physics Experiment at LHC
all B-Hadron species are accessible
huge statistics compared to B-Factories

- Construction of the experiment is progressing well
- Commissioning started
- ready for data taking in 2008 $\Rightarrow$ full detector
- ready for early physics – competitive measurements even with low LHC luminosity! (e.g. γ, χ, Δm_s , $B_s \rightarrow \mu\mu$, ...)

LHCb will contribute significantly to the search for New Physics! via precise and complementary measurements of CKM angles and of rare decays

LHCb also started to investigate option for a possible detector upgrade $\rightarrow$ SuperLHCb