The SM and beyond at LHCb

Thomas Nikodem

Outline

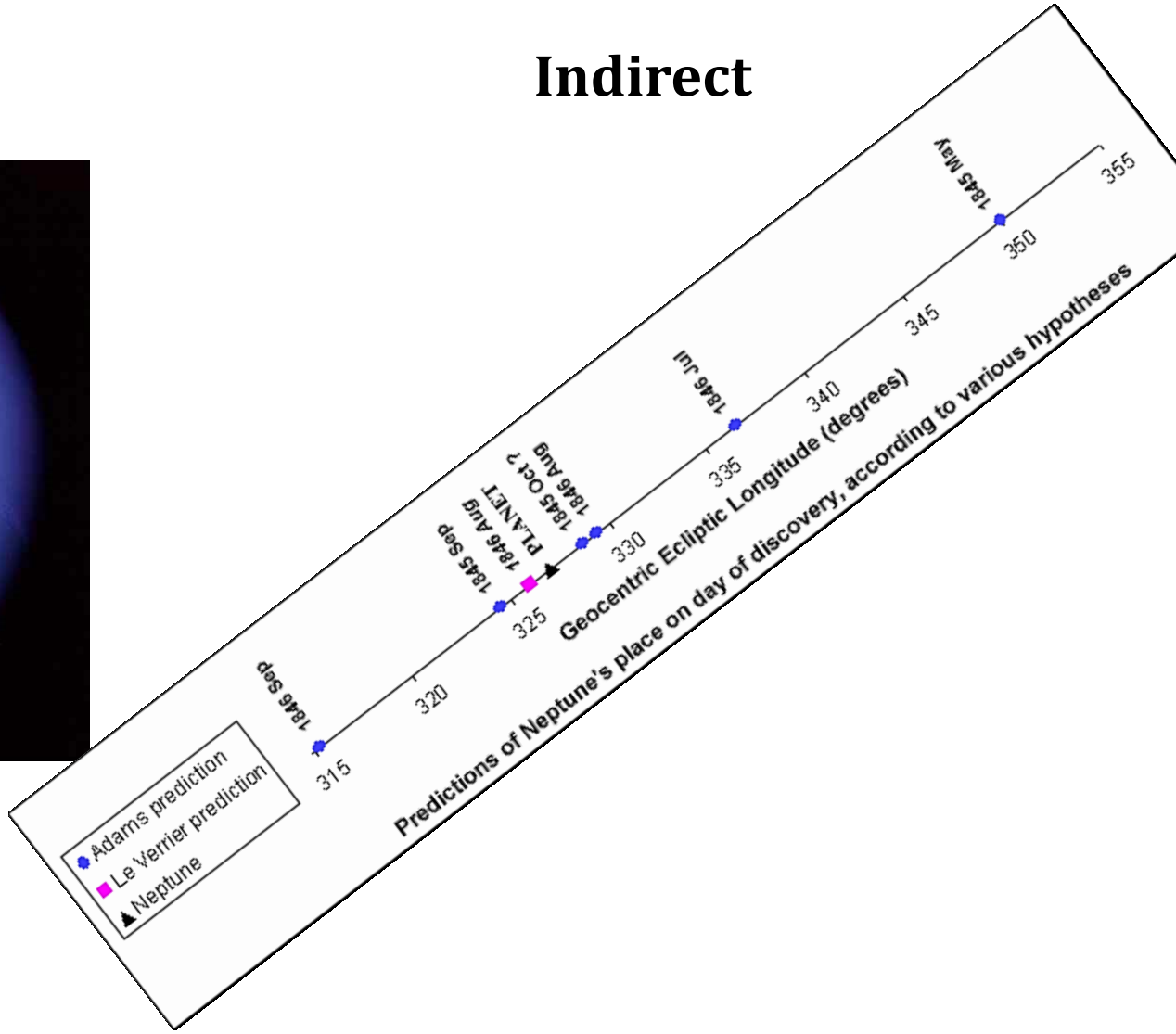
- Why LHCb? ←
- Insides in LHCb
- Angular Measurement

New Physics - Direct vs. Indirect Searches

Direct

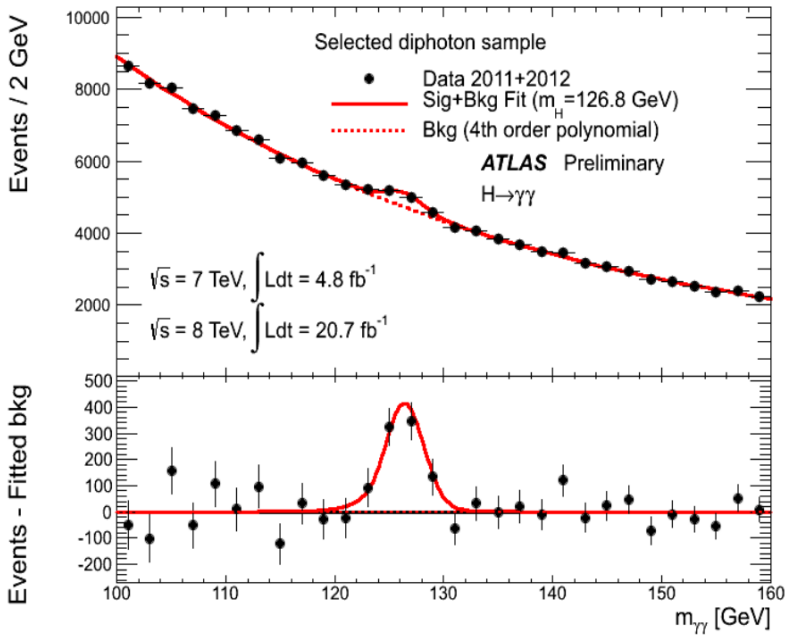
1989: Voyager 2

Indirect

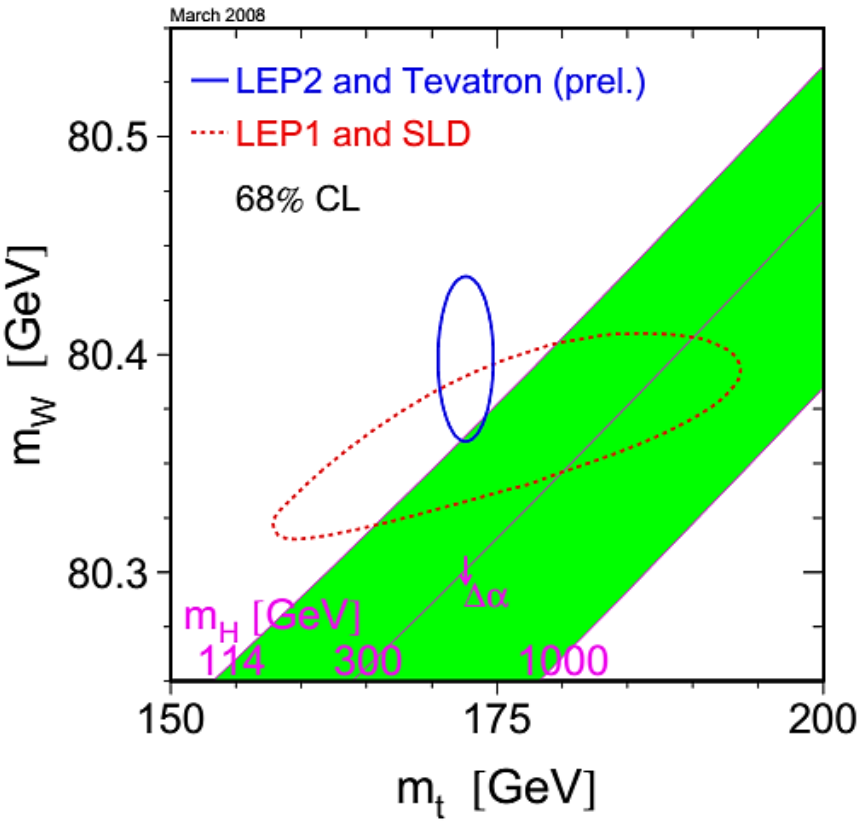


New Physics - Direct vs. Indirect Searches

Direct



Indirect



Indirect searches

Advantage:

- Model Independent:
  "Here is something going wrong."

- Search beyond limits of direct search:
  i.e. virtual particles

Challenge:

- Precise theory predictions (SM)

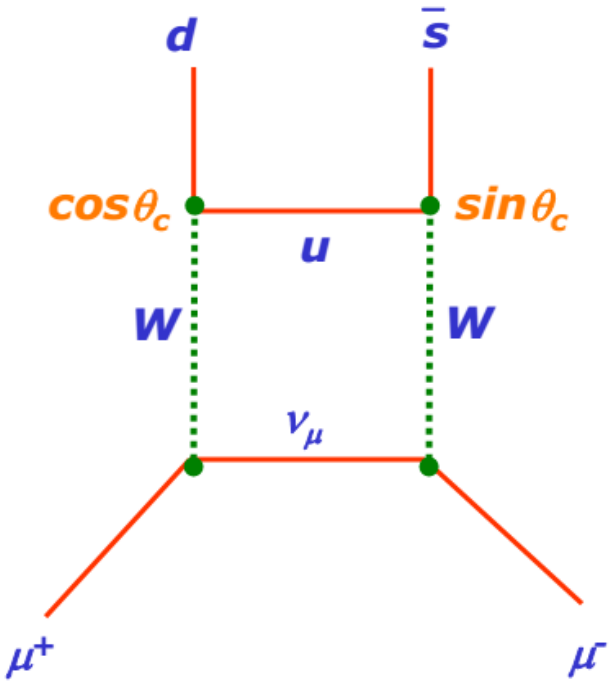
- Precise measurements (LHC)

Example from the past

1969: 3 quarks: u quark couples to d and s

$$|d^I\rangle = \cos\Theta_c\,|d\rangle + \sin\Theta_c\,|s\rangle$$

$$K_L \to \mu^+\mu^-$$



Example from the past

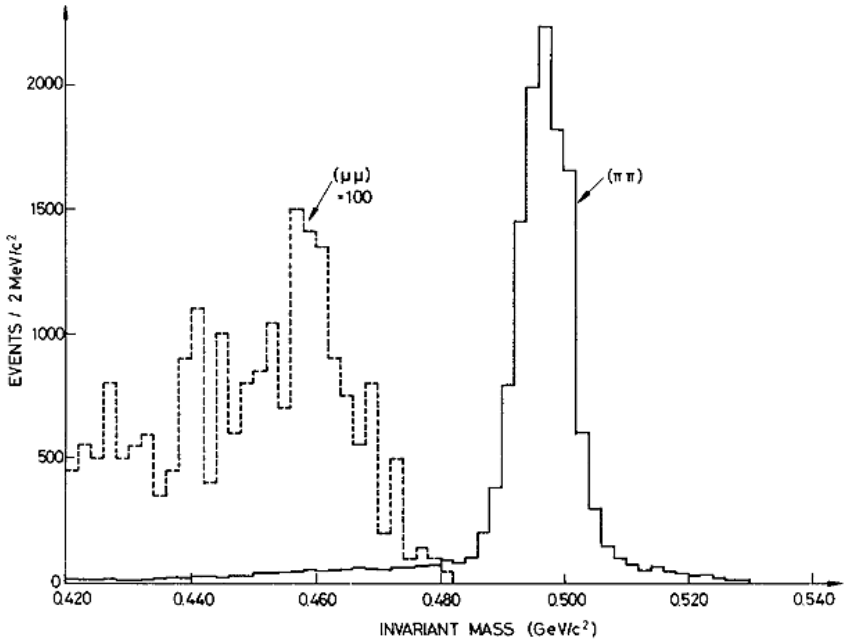
SEARCH FOR $K_L \to \mu^+\mu^-$ AND $K_L \to e^+e^-$ DECAYS

H. FOETH, M. HOLDER, E. RADERMACHER, A. STAUDE
III. Physikalisches Institut der Technischen Hochschule, Aachen, Germany

P. DARRIULAT, J. DEUTSCH *, K. KLEINKNECHT, C. RUBBIA, K. TITTEL
CERN, Geneva, Switzerland

M. I. FERRERO and C. GROSSO
Istituto di Fisica dell'Università, INFN Sezione di Torino, Torino, Italy

Received 19 September 1969



Alternatively, in terms of branching ratios, results are as follows:

$$\frac{\Gamma(K_L \to \mu^+\mu^-)}{\Gamma(K_L \to \text{all})} \leqslant 2.1 \times 10^{-7}$$

$$\frac{\Gamma(K_L \to e^+e^-)}{\Gamma(K_L \to \text{all})} \leqslant 1.5 \times 10^{-7} \text{ (90\% confidence).}$$

The results improve upper limits of ref. 4. They are, however, still one order of magnitude larger than the predictions of the electromagnetically induced effect, $\Gamma(K_L \to \mu^+\mu^-) \sim 0.3\ \text{sec}^{-1}$. Inserting the present results in the formulae by Ioffe and Shabalin [5], we find for the intermediate vector boson theory a cut-off, $\Lambda \simeq 60$ GeV, which in turn limits the mass of the W boson, $m_W \leqslant 4.8$ GeV. In the framework of universal current-current interaction we get $\Lambda \approx 20$ GeV, which is probably much too low for the weak interactions to produce their own cut-off. Therefore, at least according to the theory of Ioffe and Shabalin [5], something new is expected to happen to leptonic weak interactions already at energies accessible hopefully in a not too distant future.

Example from the past

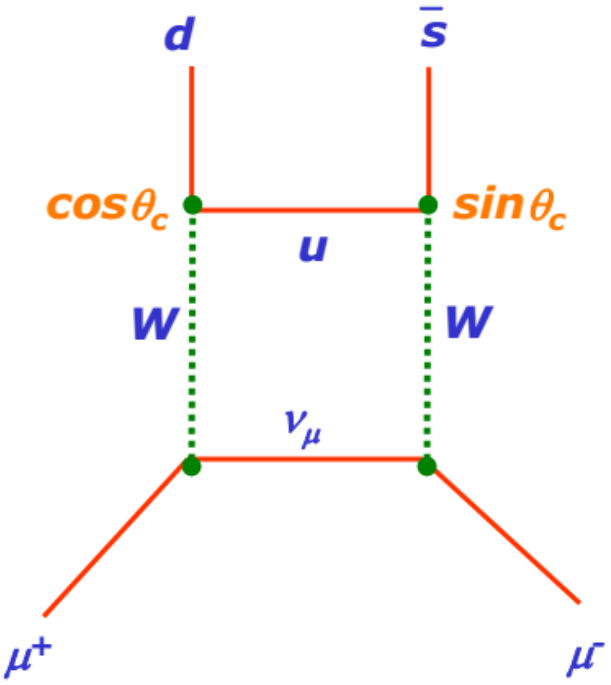
Weak Interactions with Lepton-Hadron Symmetry*

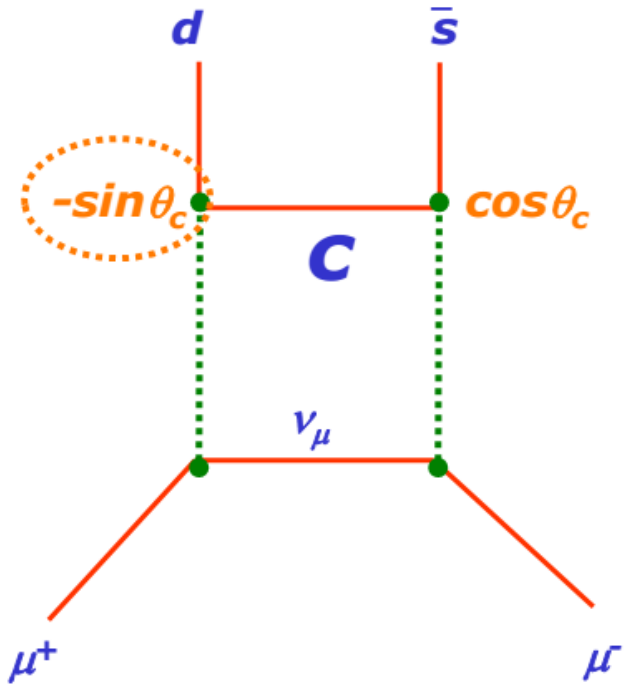
S. L. Glashow, J. Iliopoulos, and L. Maiani†
Lyman Laboratory of Physics, Harvard University, Cambridge, Massachusetts 02139
(Received 5 March 1970)

Solution:
Additional Amplitude in decay due to 4th quark (named charm)

Mixing Matrix
Unitarity -> 2D: only 1 free parameter

$$\begin{pmatrix} d' \\ s' \end{pmatrix} = \begin{pmatrix} \cos\theta_c & \sin\theta_c \\ -\sin\theta_c & \cos\theta_c \end{pmatrix} \begin{pmatrix} d \\ s \end{pmatrix}$$





The CKM Matrix

Nobel Prize 2008

Toshihide Masukawa

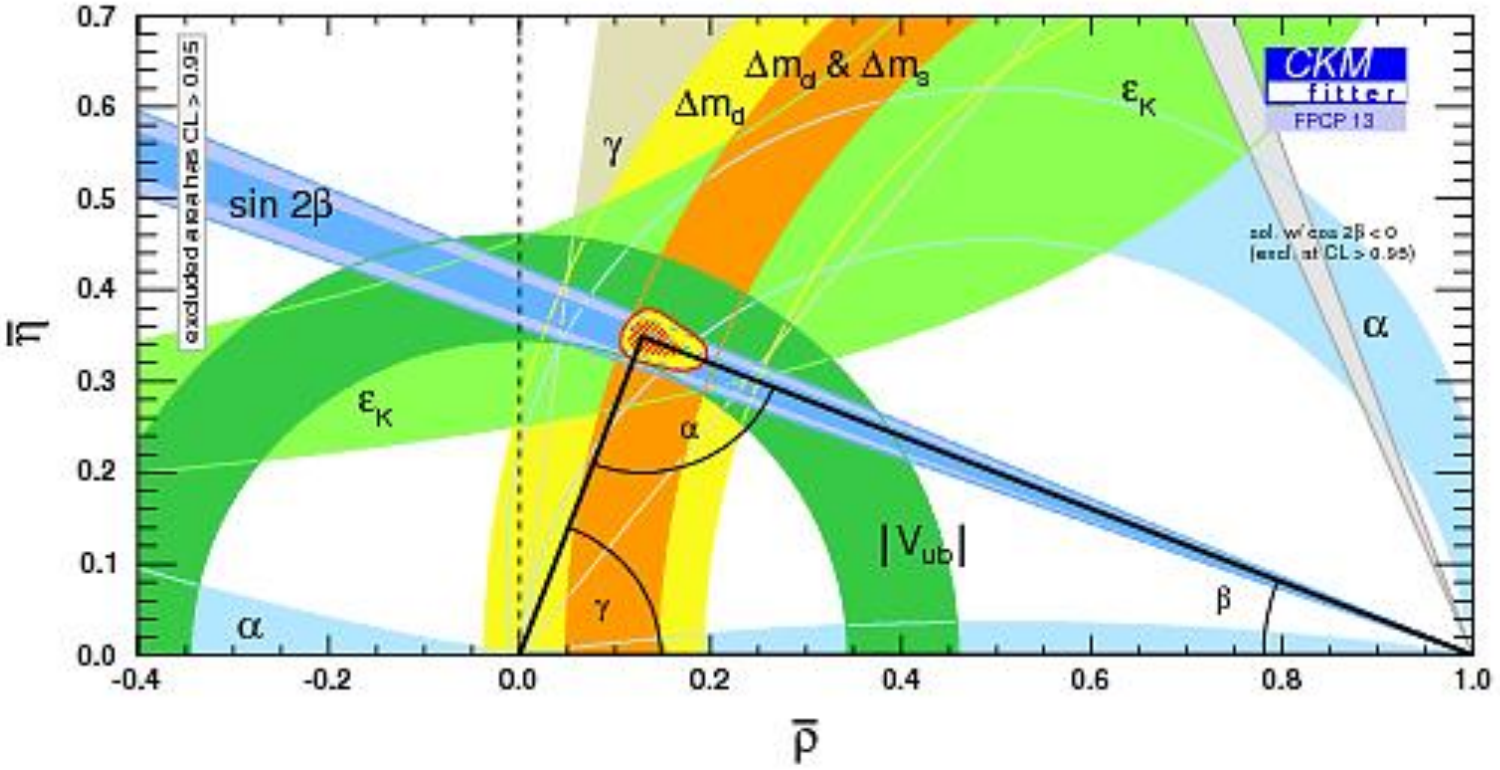
Makoto Kobayashi

$$\begin{pmatrix} d^I \\ s^I \\ b^I \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

Mixing Matrix

3D: 4 free parameter, 3 real, 1 complex!

“The” CKM triangle



Why “b” ?

Theory:

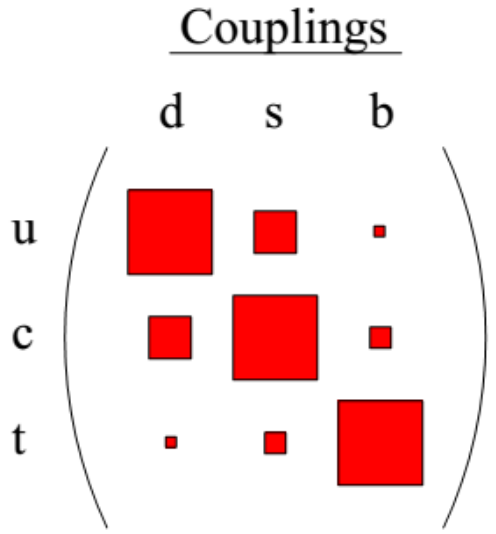
- CKM: b quark prefers to decay in top quark → Forbidden!

→ Second order diagrams up to same size as first order diagrams

- b sector well understood

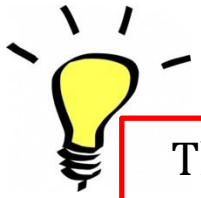
Experiment:

- large cross section
- about 400 different B+ decays observed
- clean detection signature



LHCb-PUB-2009-029
16 February 2010

Roadmap for selected key measurements of LHCb



Theory uncertainties cancel in ratio:
particle/antiparticle
forward direction/backward direction

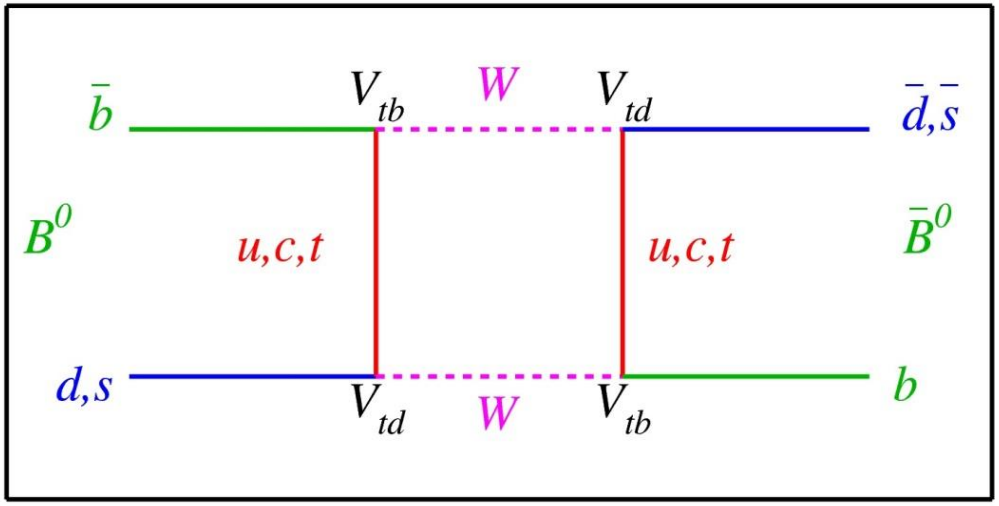
1.1 Key measurements

Particles associated to new physics would make additional contributions in the loop processes of the flavour-changing neutral current, such as penguin and box diagrams. Amplitudes of those processes could then:

1. change the phases of the couplings; = CP violation
2. change their absolute values; = branching ratio of rare decays
3. change the Lorentz structure. = angular distribution

B Box Diagram

Feynman Diagram



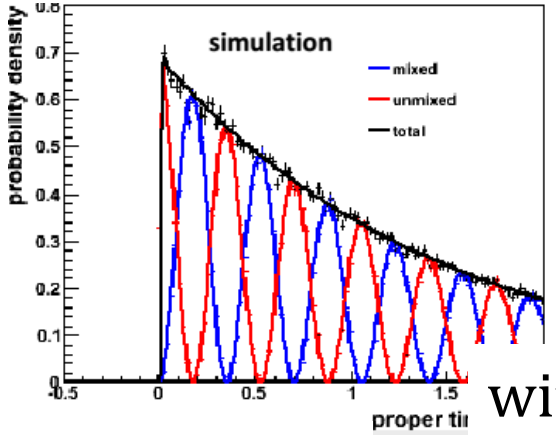
Schrödinger equation

$$i\frac{d}{dt}\begin{pmatrix}\mathrm{B}_s\\ \overline{\mathrm{B}}_s\end{pmatrix} = \left(M - \tfrac{i}{2}\Gamma\right)\begin{pmatrix}\mathrm{B}_s\\ \overline{\mathrm{B}}_s\end{pmatrix}$$

nondiagonal matrices

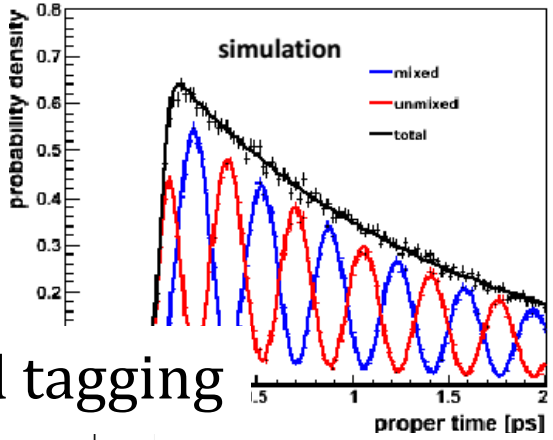
B oscillation

ideal case

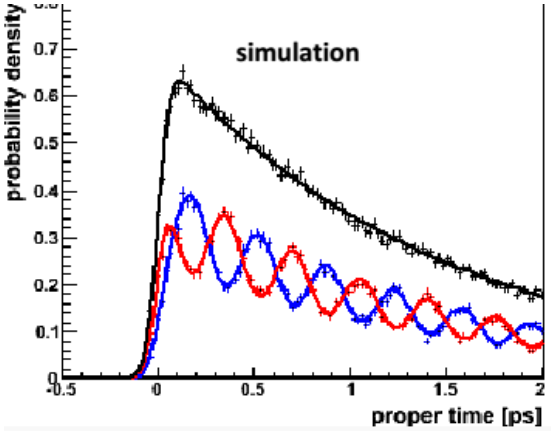


$B_s^0 \to D_s^- \pi^+$

with resolution



with resolution and tagging

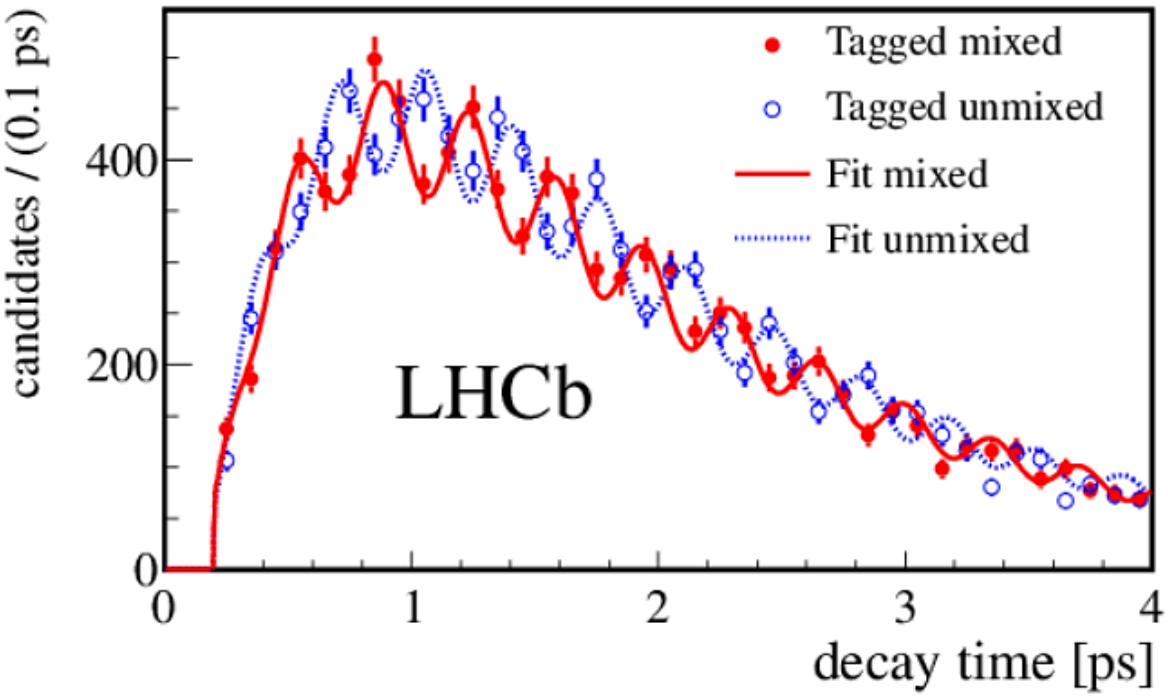


Unmixed: $B_s^0 \to D_s^- \pi^+$

Mixed: $B_s^0 \to \overline{B^0}_s \to D_s^+ \pi^-$

B oscillation

$B_s^0 \to D_s^- \pi^+$



Unmixed: $B_s^0 \to D_s^- \pi^+$

Mixed: $B_s^0 \to \overline{B^0}_s \to D_s^+ \pi^-$

Decay time resolution
~40-50fs

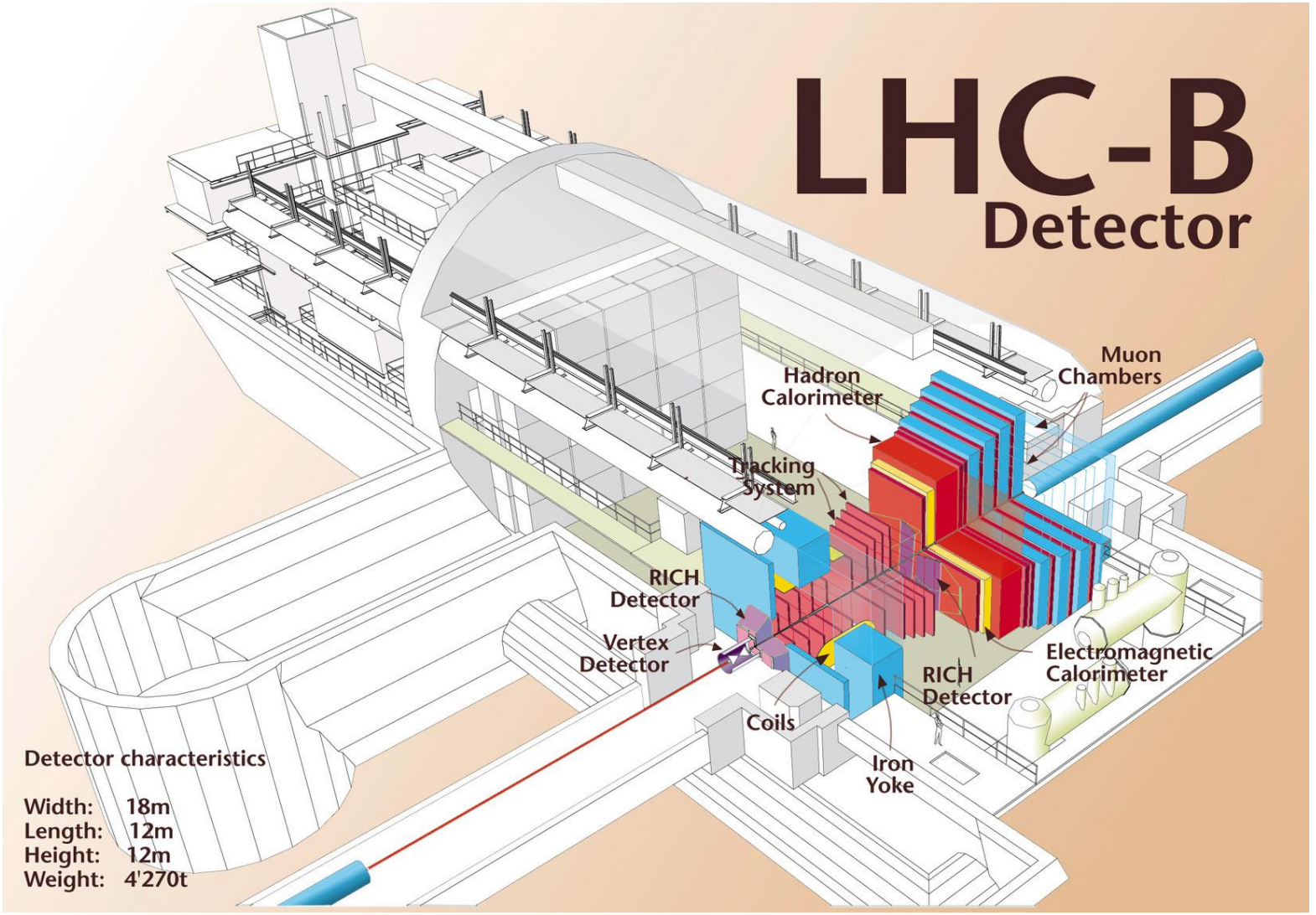
Requirements on the detector

- decay time resolution
- momentum resolution
- background rejection
  - vertexing
  - particle identification
- less significant: luminosity

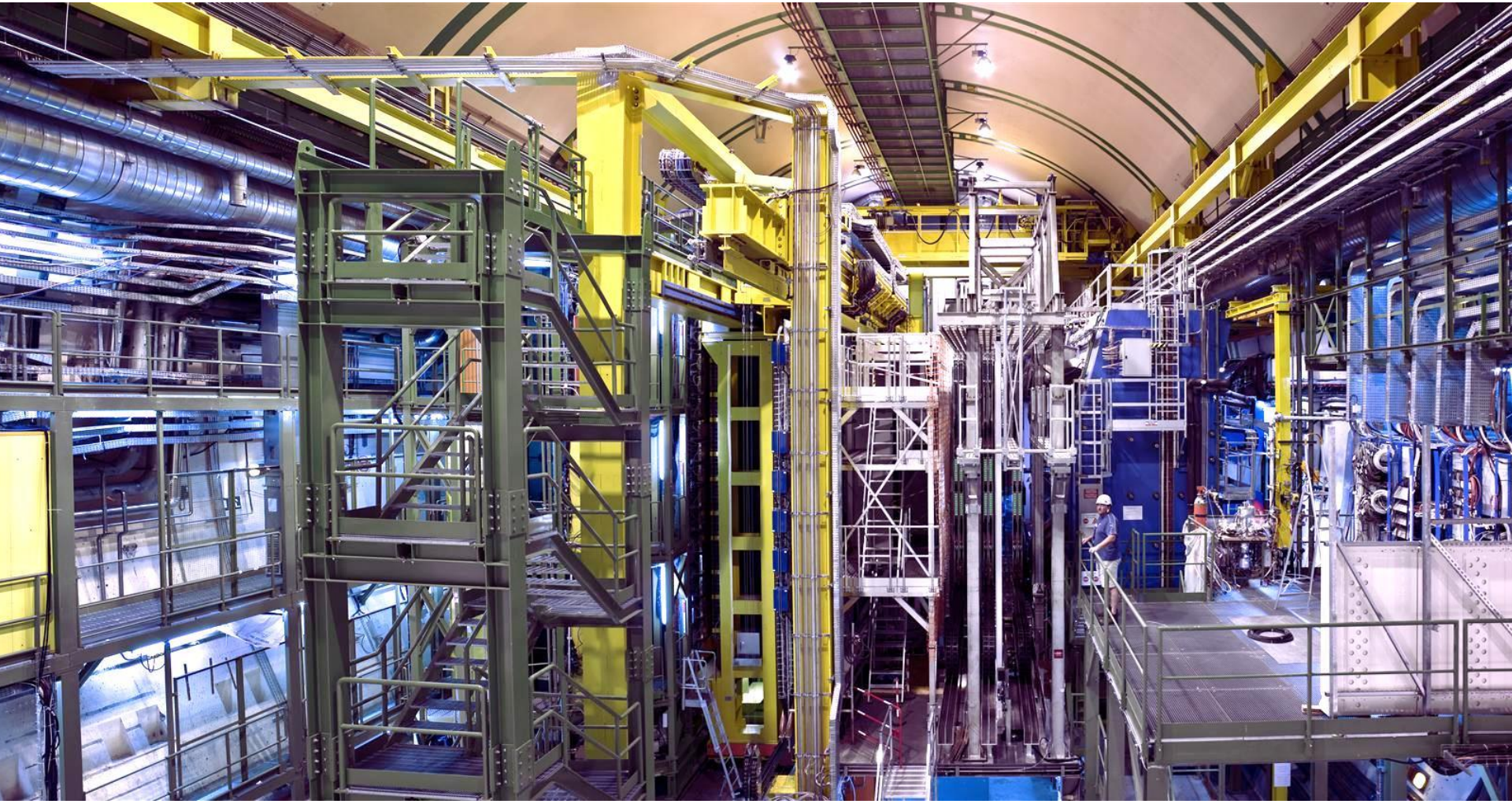
LHCb collaboration

1048 Members, 67 Institutes, 16 Countries (15. Apr. 2014)

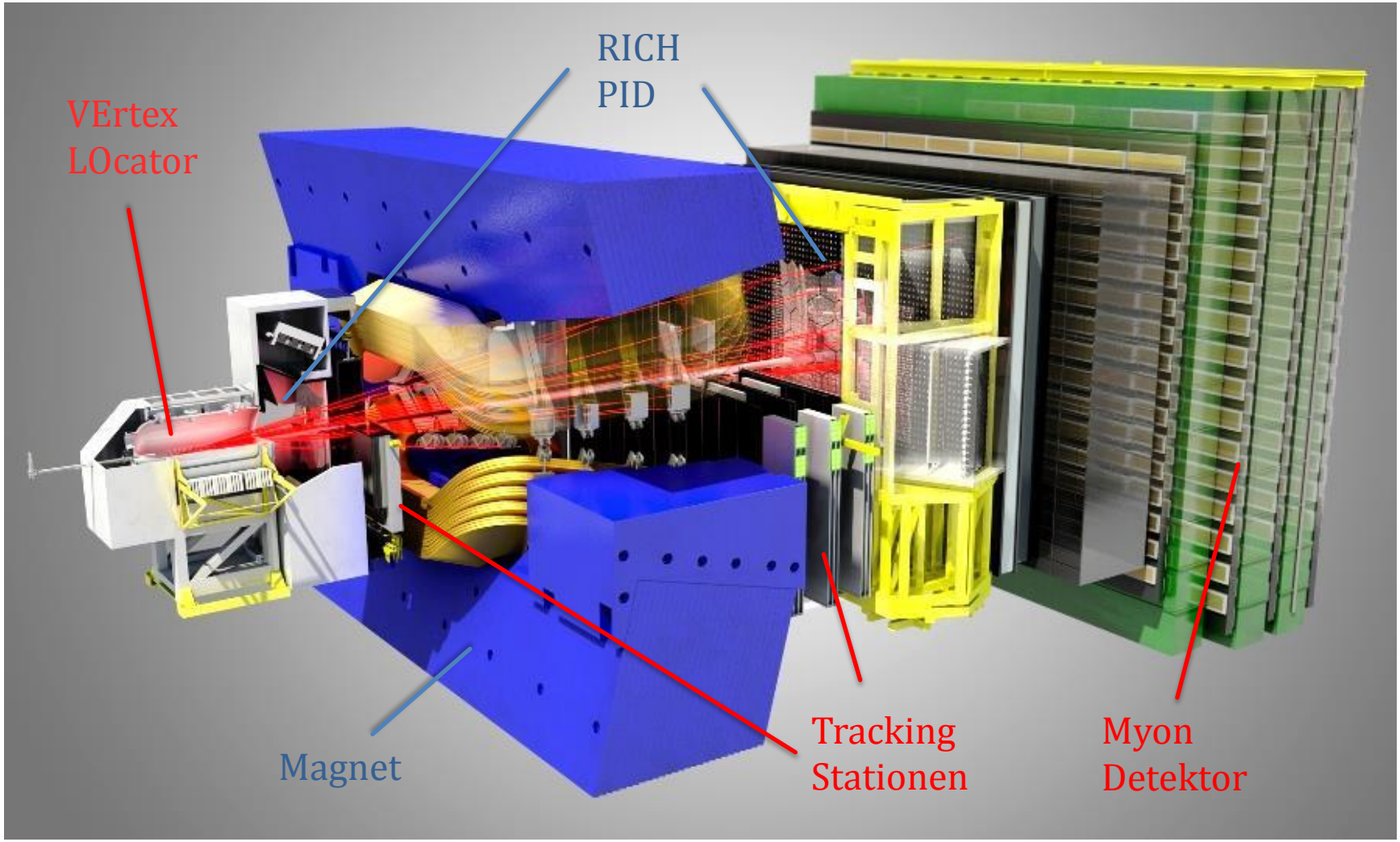
The Cavern


LHC-B
Detector
Muon Chambers
Hadron Calorimeter
Tracking System
RICH Detector
Vertex Detector
Electromagnetic Calorimeter
RICH Detector
Coils
Iron Yoke
Detector characteristics
Width: 18m
Length: 12m
Height: 12m
Weight: 4'270t

The Detector

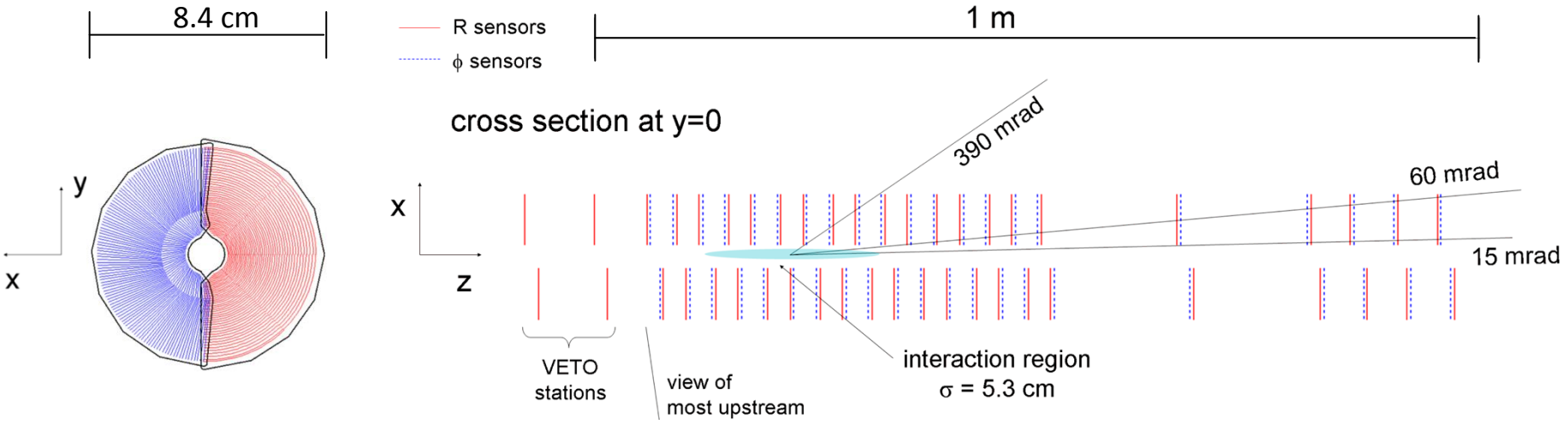


The Detector

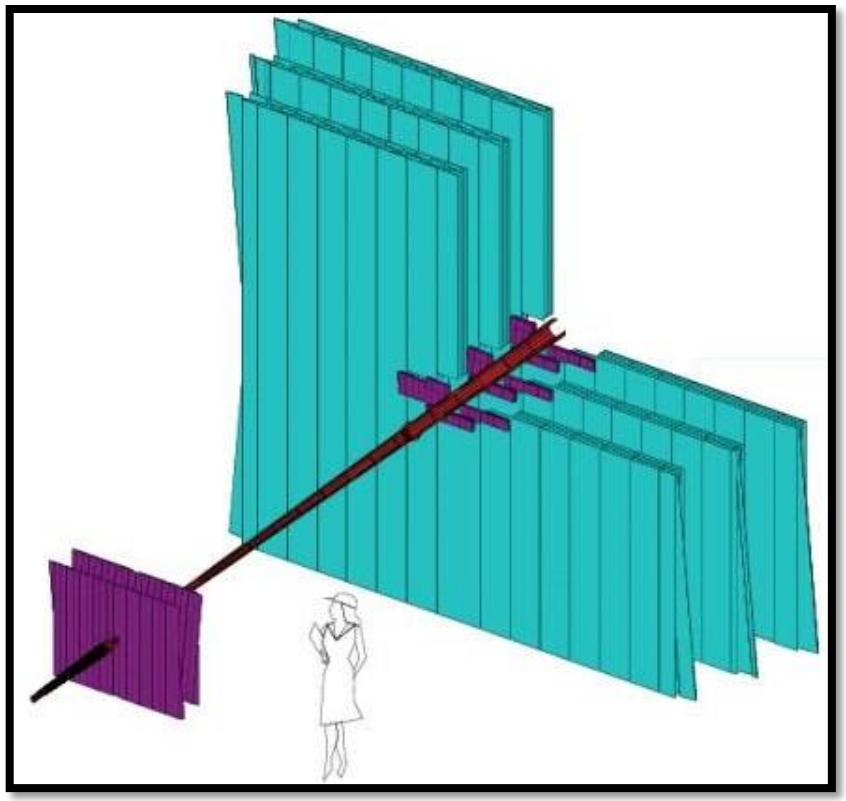


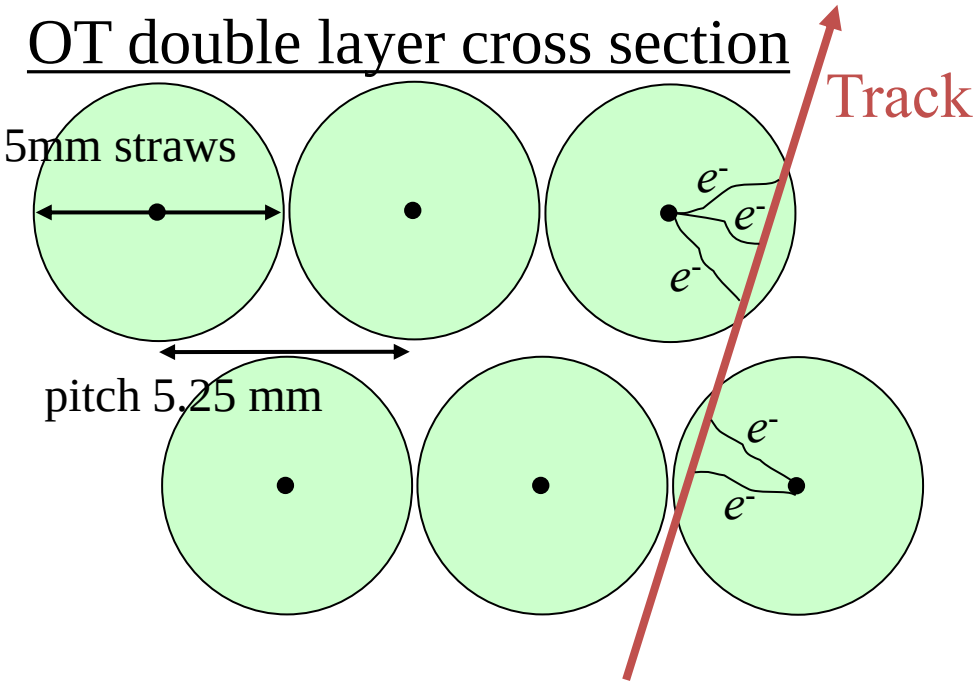
VErtex LOcator

Primary Vertex resolution			
	LHCb	**ATLAS**	**CMS**
$\sigma_{x,y}$	15 μm	60 μm	30 μm
σ_z	80 μm	100 μm	50 μm
Decay time resolution			
σ_{ct}	~45fs	~150fs	~78fs



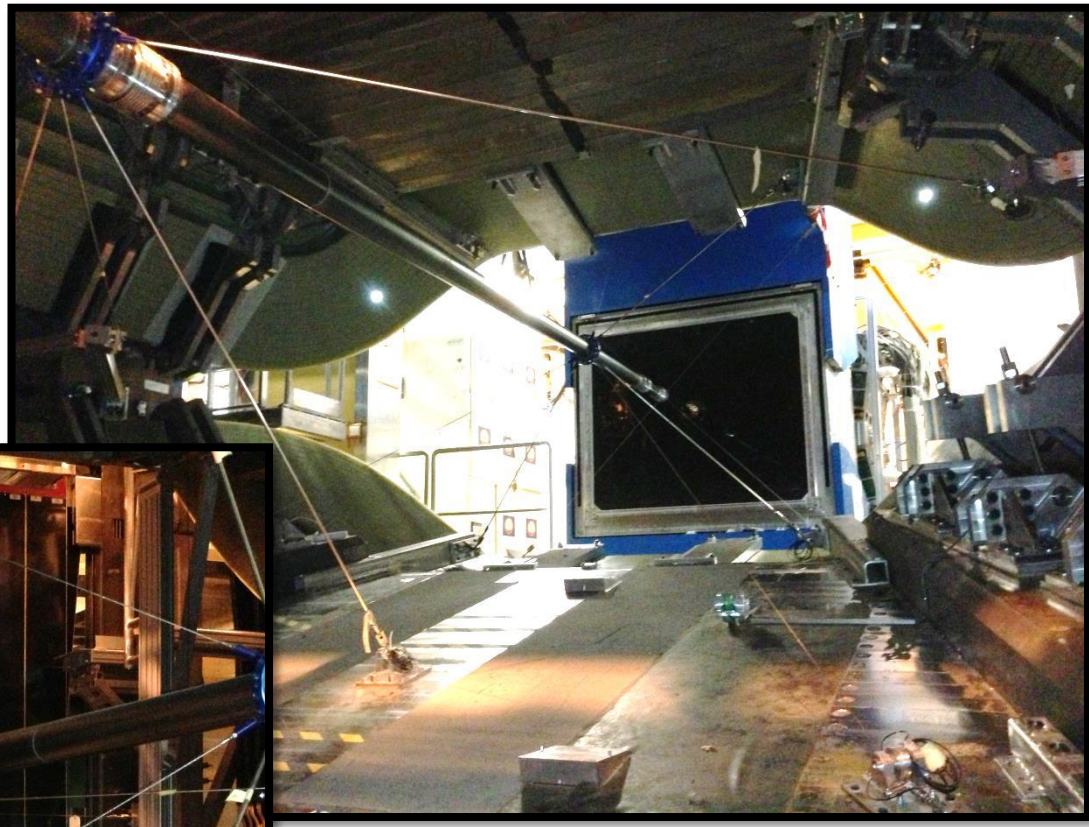
Outer Tracker (Heidelberg!)



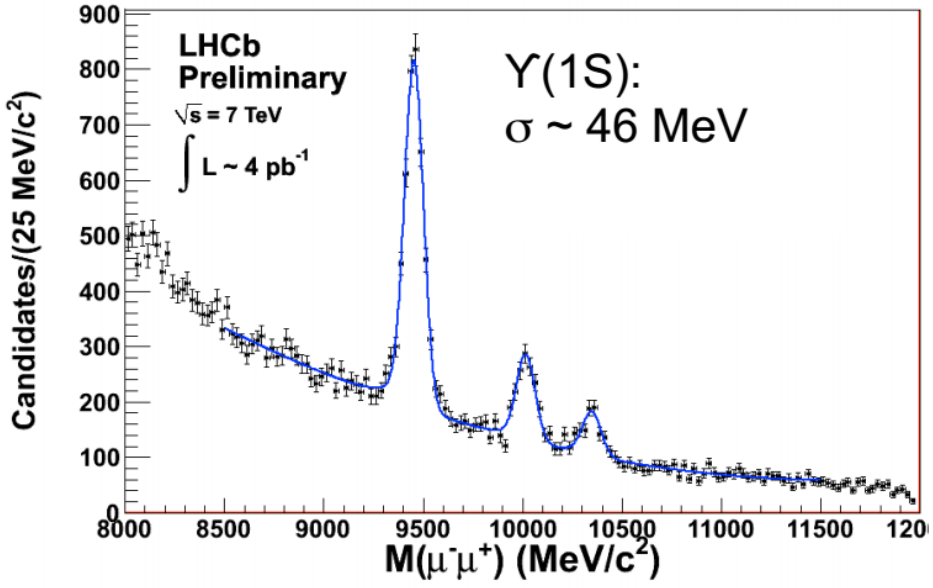


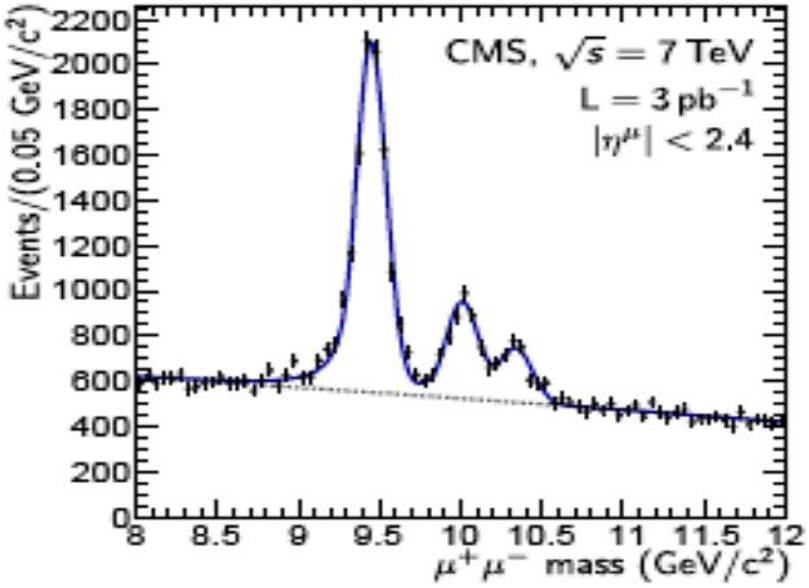
Similar to Geiger-Müller counter

View through the Magnet



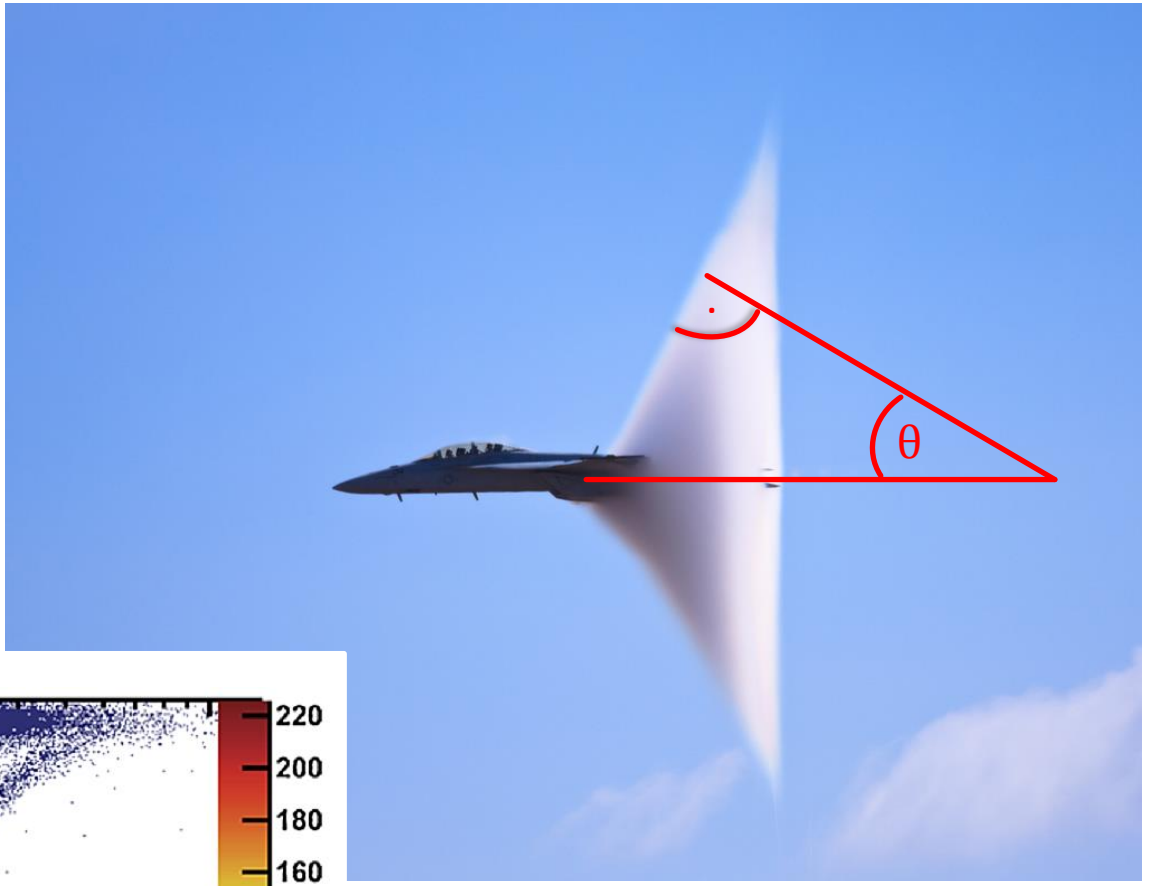
Momentum and Mass resolution

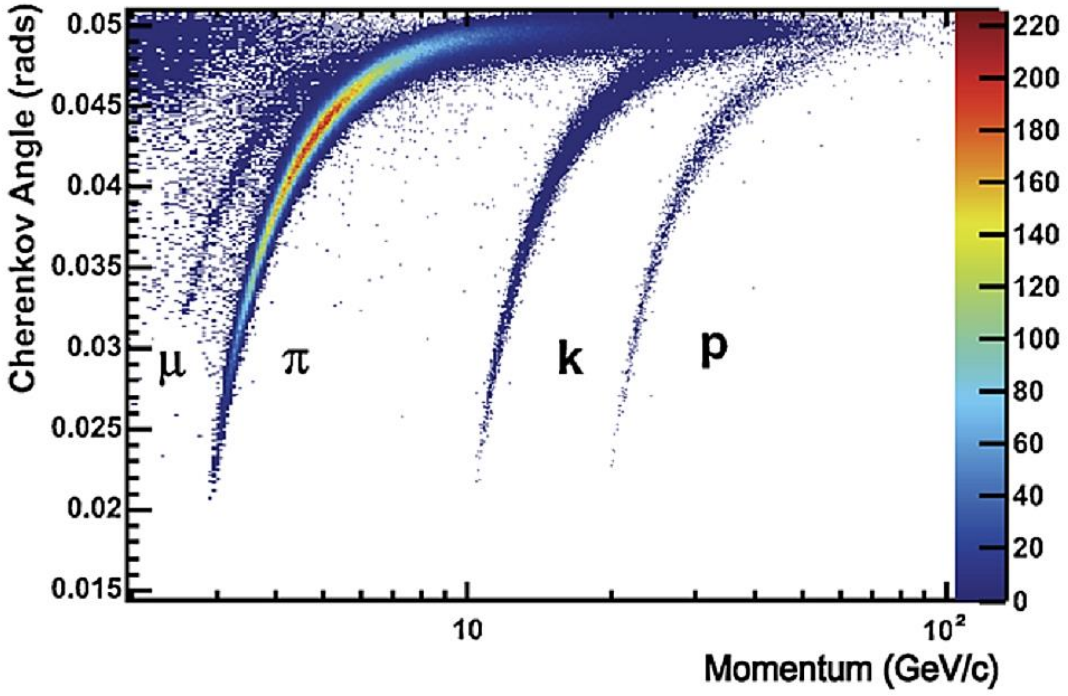




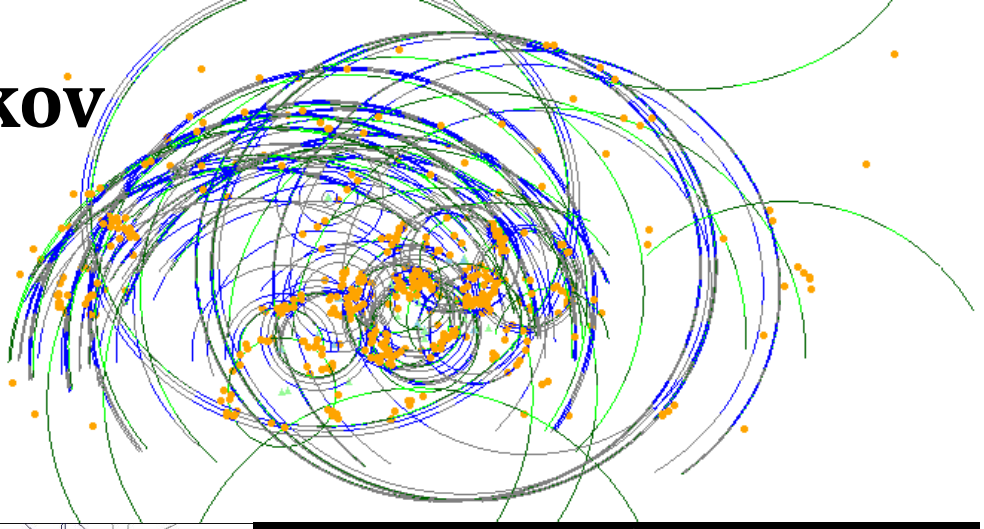
	momentum resolution	mass resolution $J/\Psi \to \mu^+\mu^-$
LHCb	0.4-0.6%	13 MeV
CMS	1-3%	40 MeV
ATLAS	5-6%	71 MeV

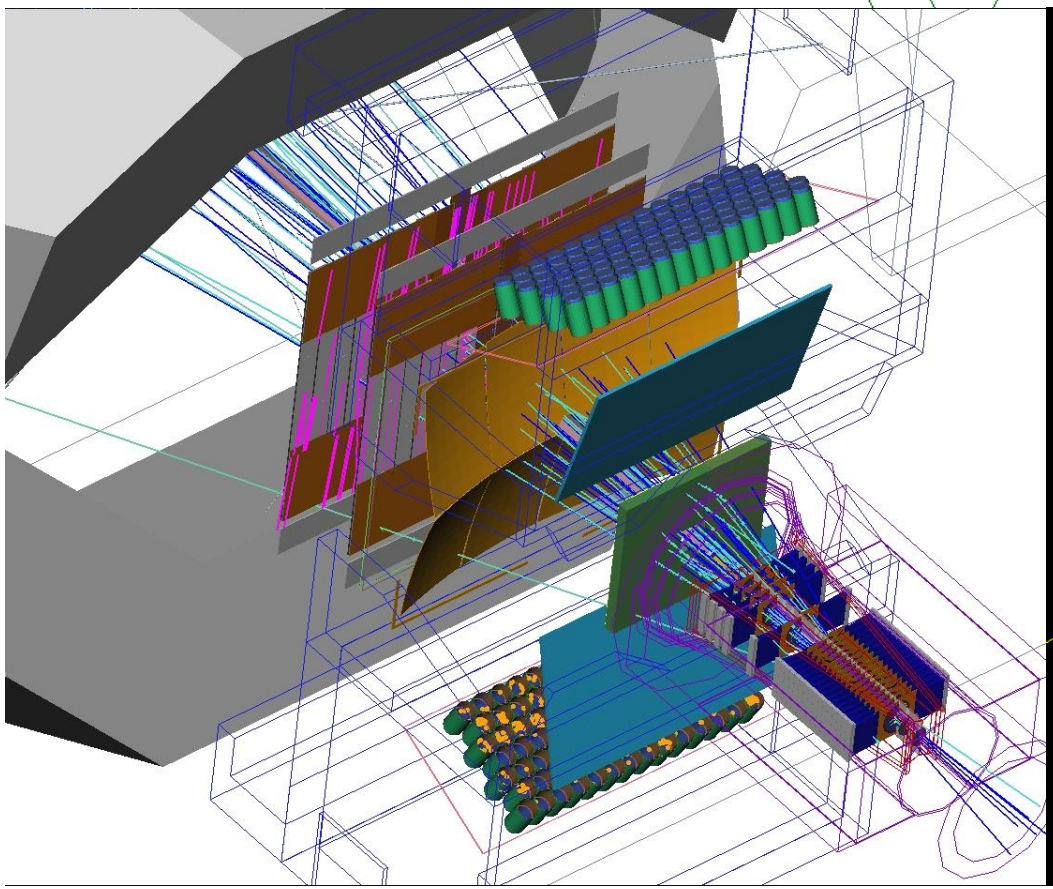
Cherenkov Light

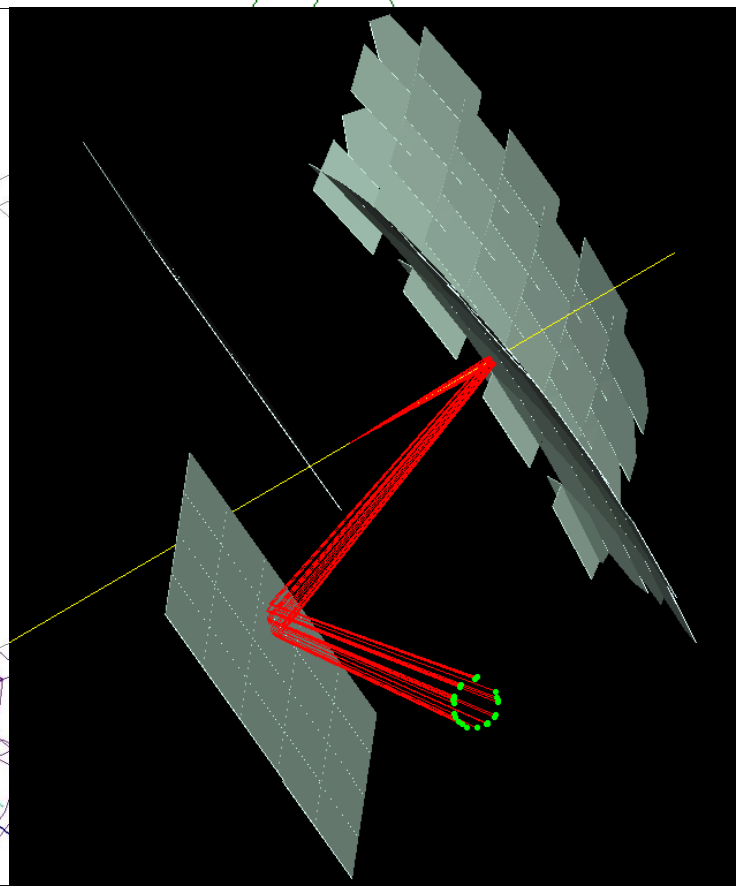




Ring Imaging CHerenkov Detector

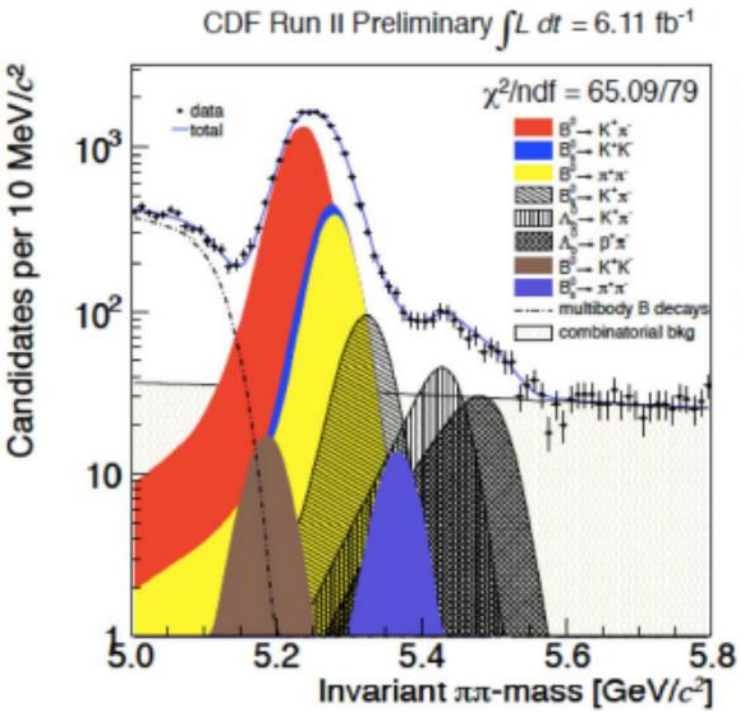






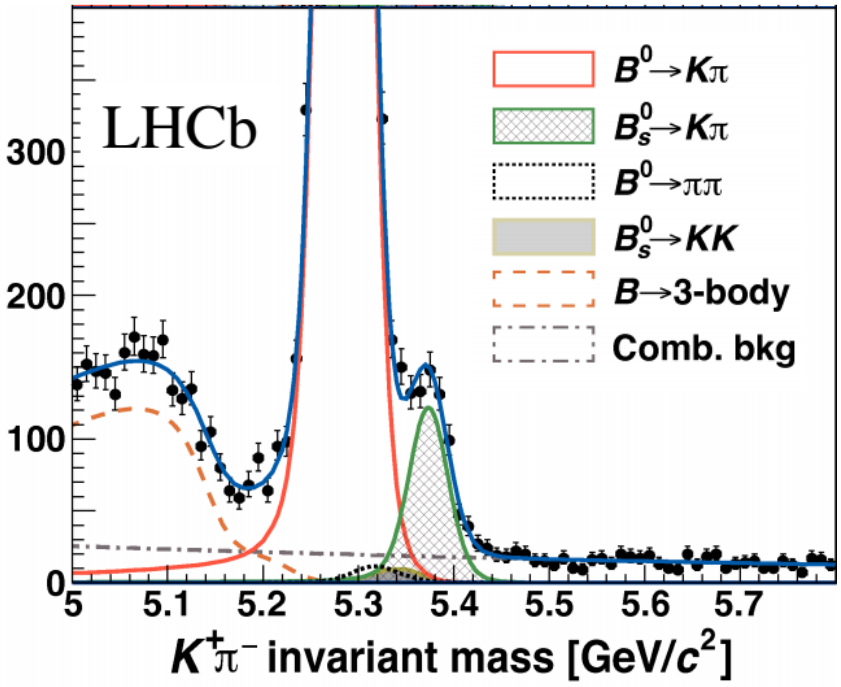
Without RICH

"pion" = pion or kaon



With RICH

pion = pion, kaon = kaon



Summary

- Indirect searches for new Physics
- B system perfect location to look at
- LHCb detector optimized for best precision