

# *Running status and first results from LHCb*

Wouter Hulsbergen (Nikhef)  
*on behalf of the LHCb collaboration*

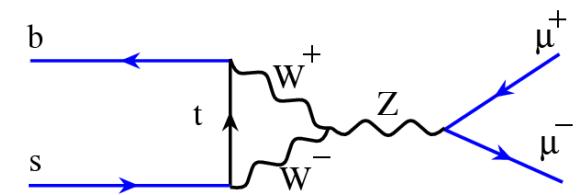
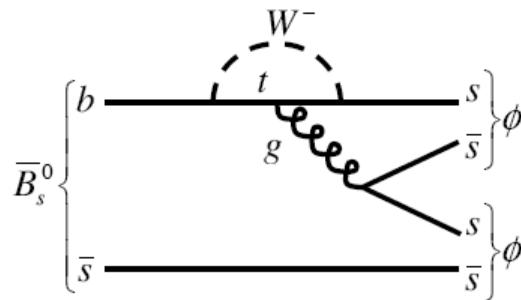
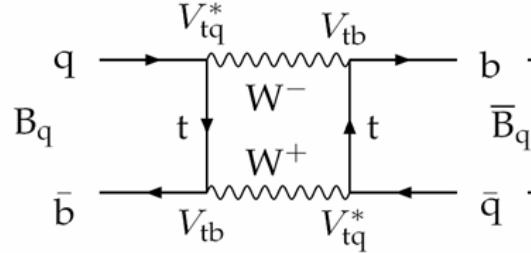
Moriond EW 2010

## Outline

- flavour physics
- LHCb experiment
- results from the 2009 run
- outlook

# charm and beauty physics

- weak decays of c and b hadrons feature rich phenomenology, with well understood SM predictions
  - many decay modes, some very rare
  - CP violation and mixing
  - forward-backward asymmetries, ...
- processes dominated by **loop diagrams** are very sensitive to **high mass scales**



→ new particles in loops change branching fractions, phases, etc

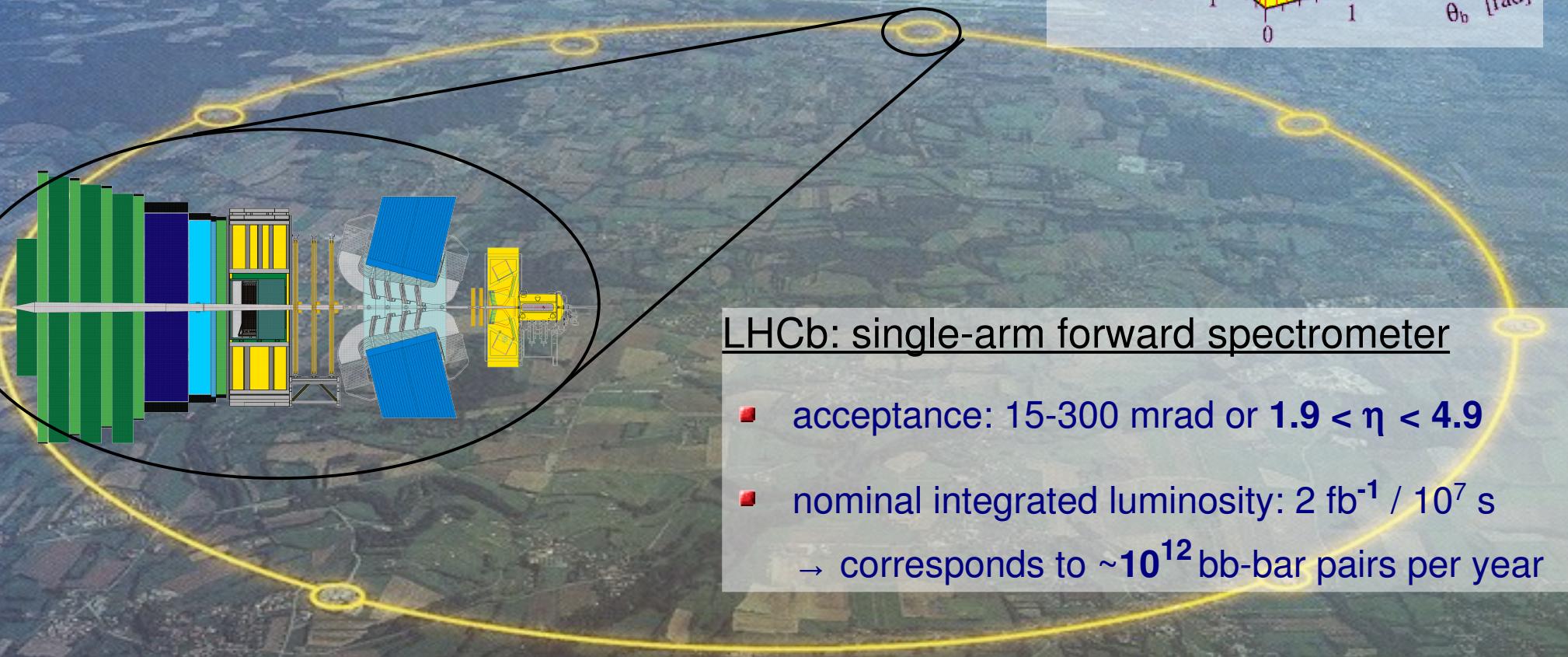
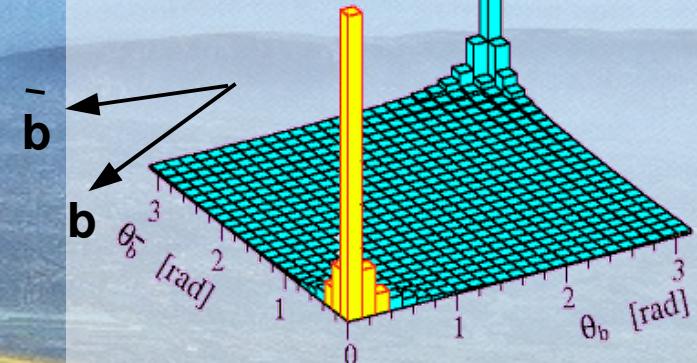
- $e^+e^-$  B-factory and Tevatron results already put severe **constraints on flavour structure** of TeV scale NP
- LHCb will significantly tighten these 'low-energy' constraints, in particular in  **$b \rightarrow s$  transitions**
  - don't be surprised if this is where NP will show up first!

# LHC: a hadronic B factory

## 14 TeV proton-proton collider

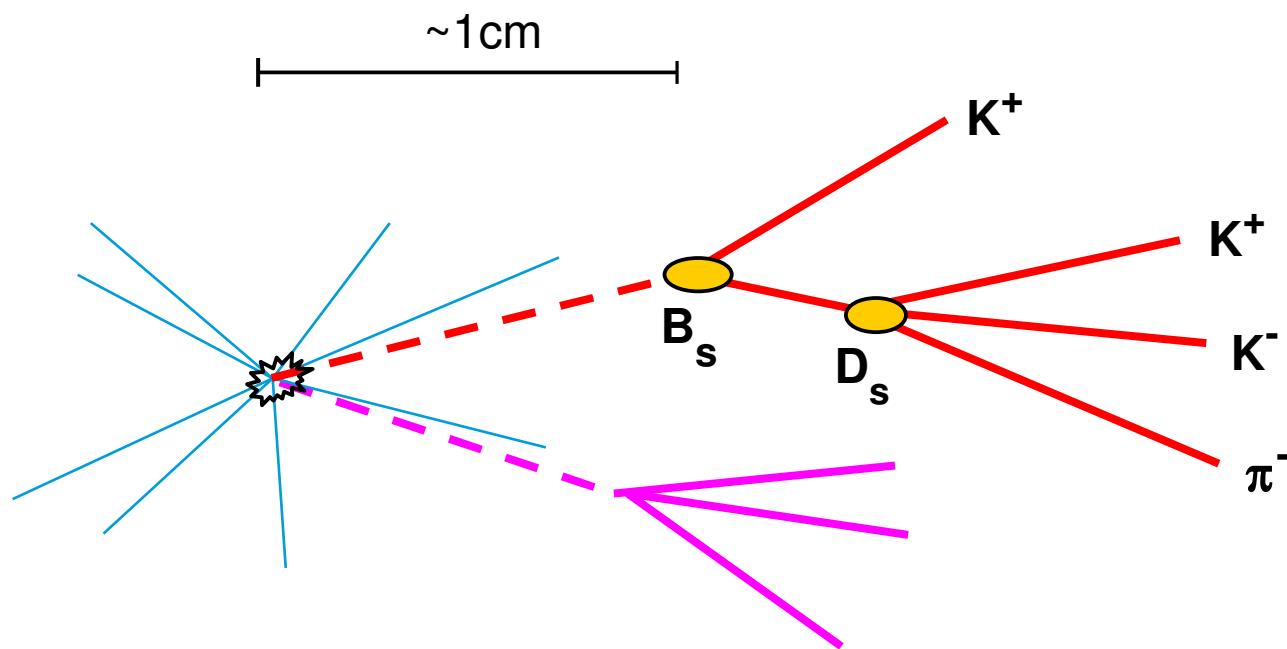
- large  $b$  cross-section:  $\sim 500 \mu\text{b}$ , about 0.6% of total
- all species of B hadrons ( $B^+$ ,  $B^0$ ,  $B_s$ ,  $\Lambda_b$ ,  $\Lambda_c$ )
- $b$ -quark **pairs** produced from 'asymmetric' partons: highly forward or backward

polar angle of produced b quark pairs



# key features of a beauty experiment

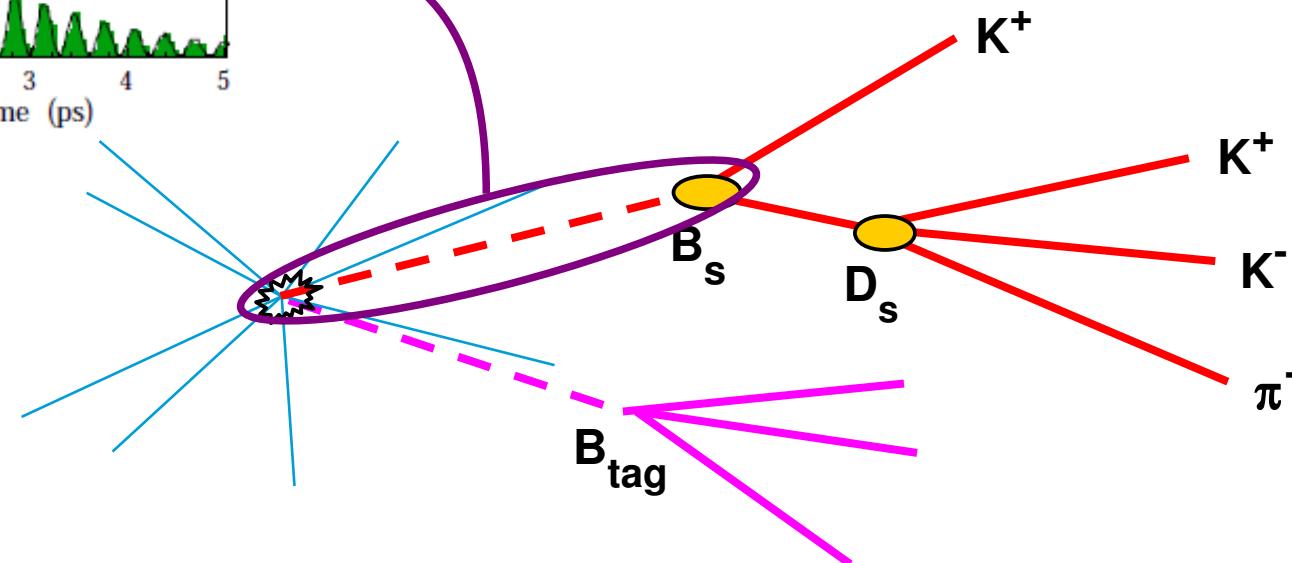
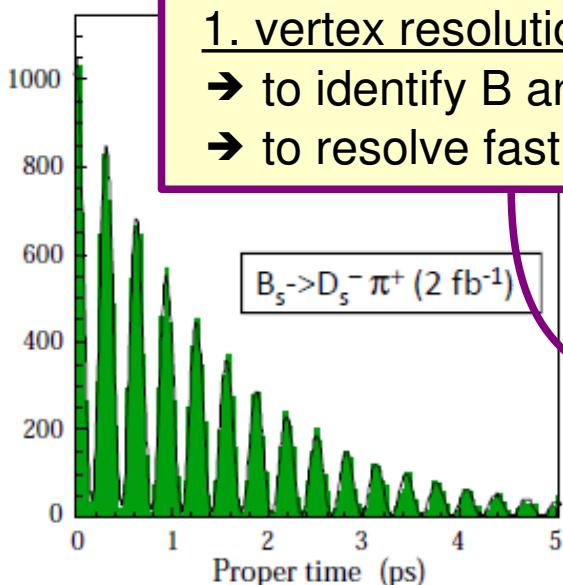
Example:  $B_s \rightarrow D_s K$



# key features of a beauty experiment

## 1. vertex resolution

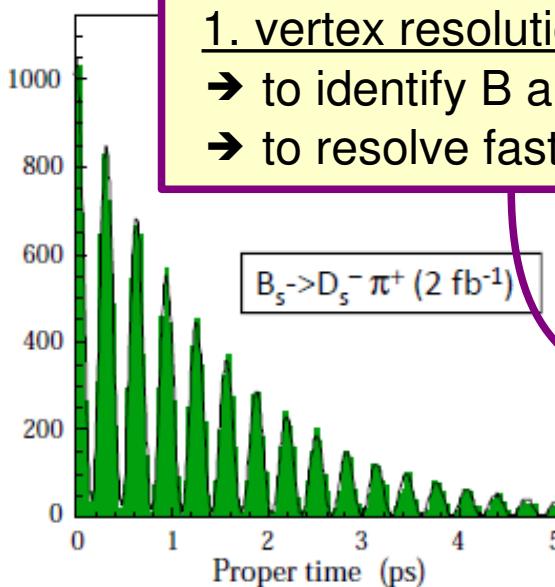
- to identify B and D hadrons
- to resolve fast oscillations



# key features of a beauty experiment

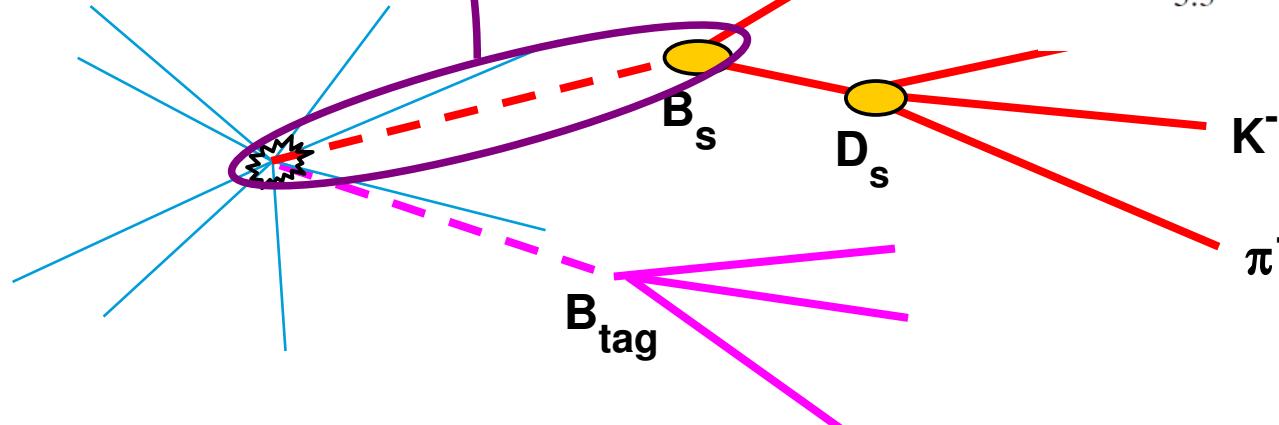
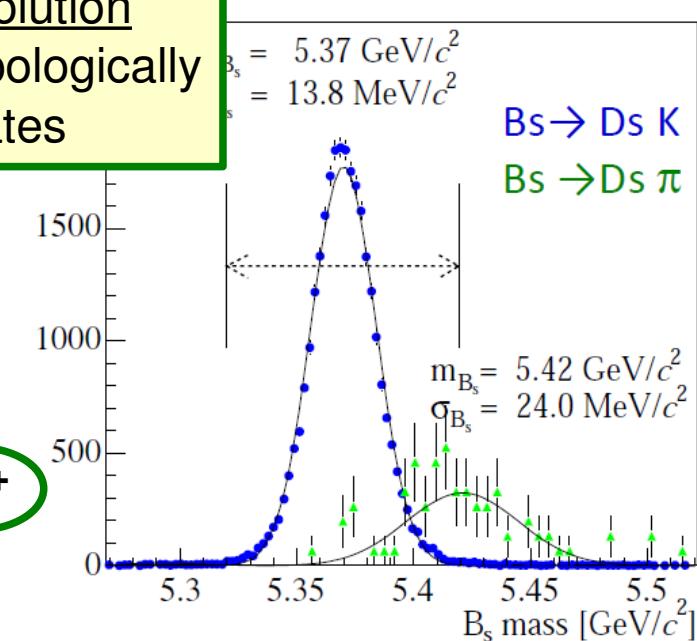
## 1. vertex resolution

- to identify B and D hadrons
- to resolve fast oscillations



## 2. momentum resolution

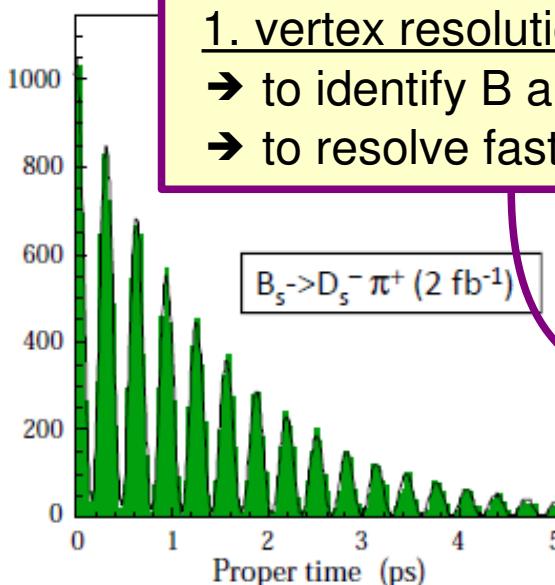
- to separate topologically similar final states



# key features of a beauty experiment

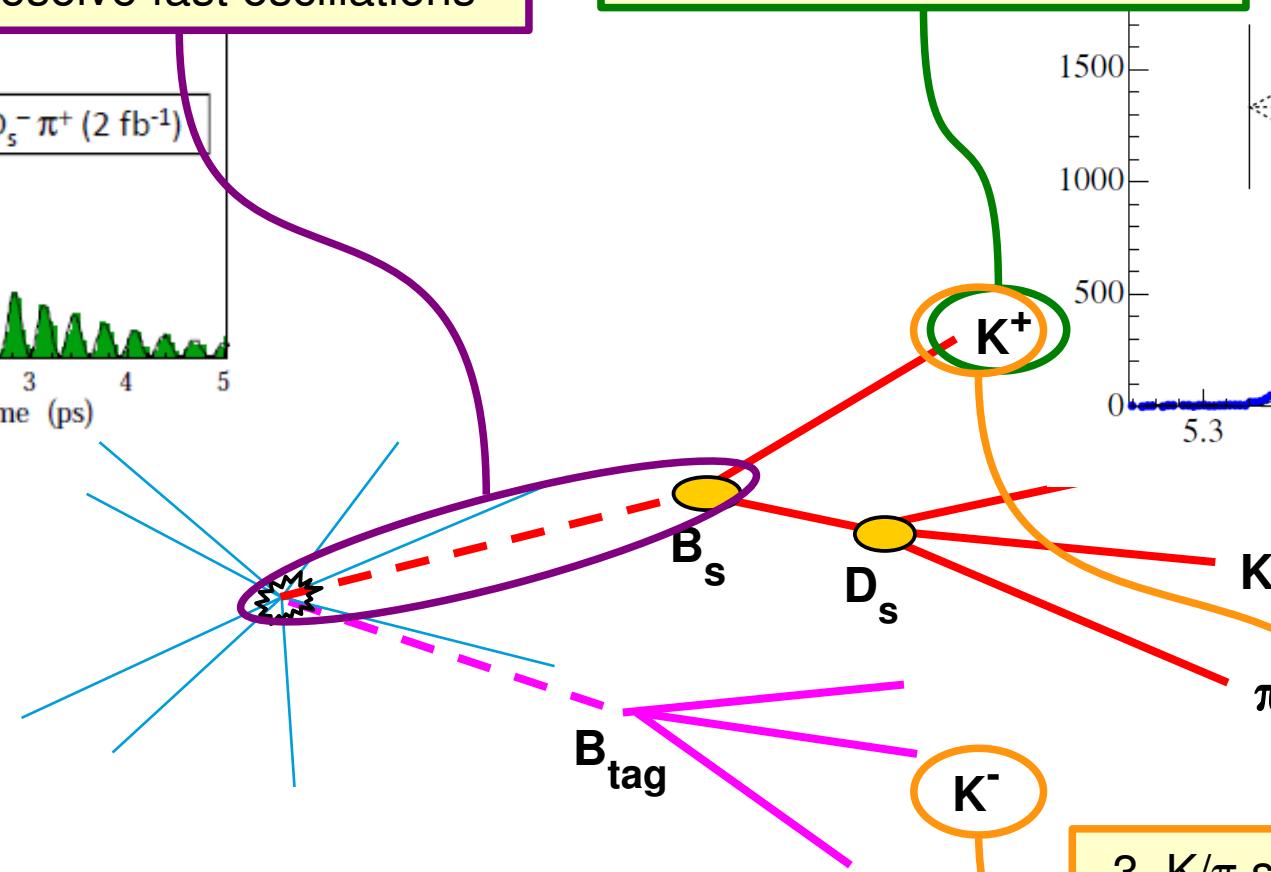
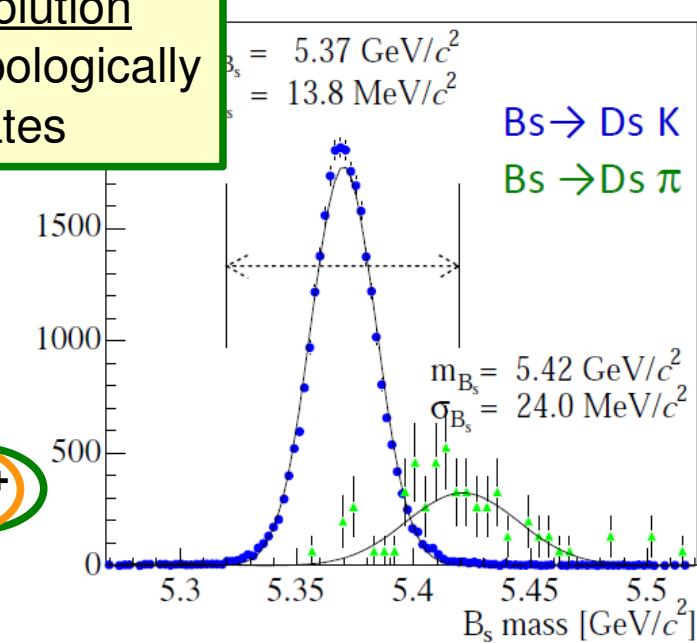
## 1. vertex resolution

- to identify B and D hadrons
- to resolve fast oscillations



## 2. momentum resolution

- to separate topologically similar final states



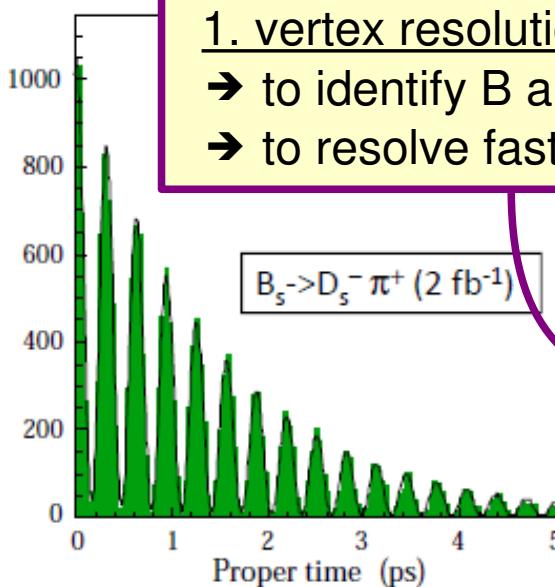
## 3. $K/\pi$ separation

- to separate topologically similar final states
- to tag B flavor

# key features of a beauty experiment

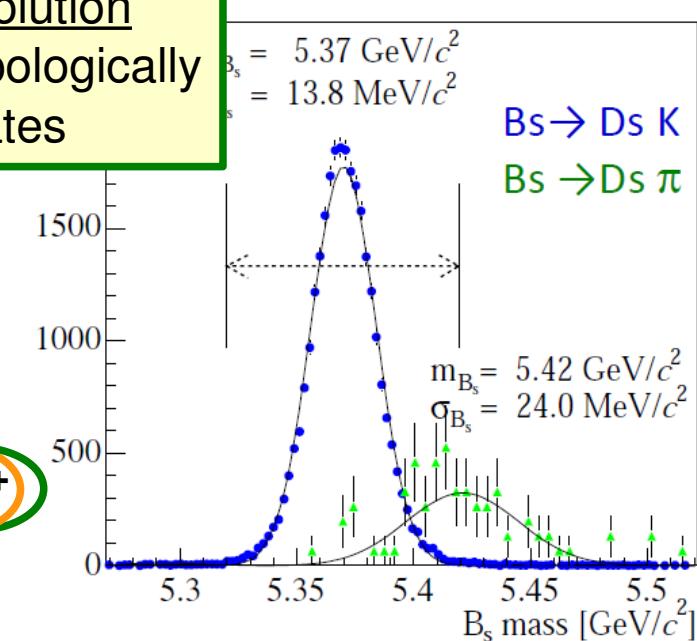
## 1. vertex resolution

- to identify B and D hadrons
- to resolve fast oscillations



## 2. momentum resolution

- to separate topologically similar final states



## 4. muon, electron and photon ID

- for various other interesting final states
- to tag B flavor

## 5. highly selective trigger

- to reduce rate to acceptable level
- based on muons, electrons, high pT hadrons, large IP tracks

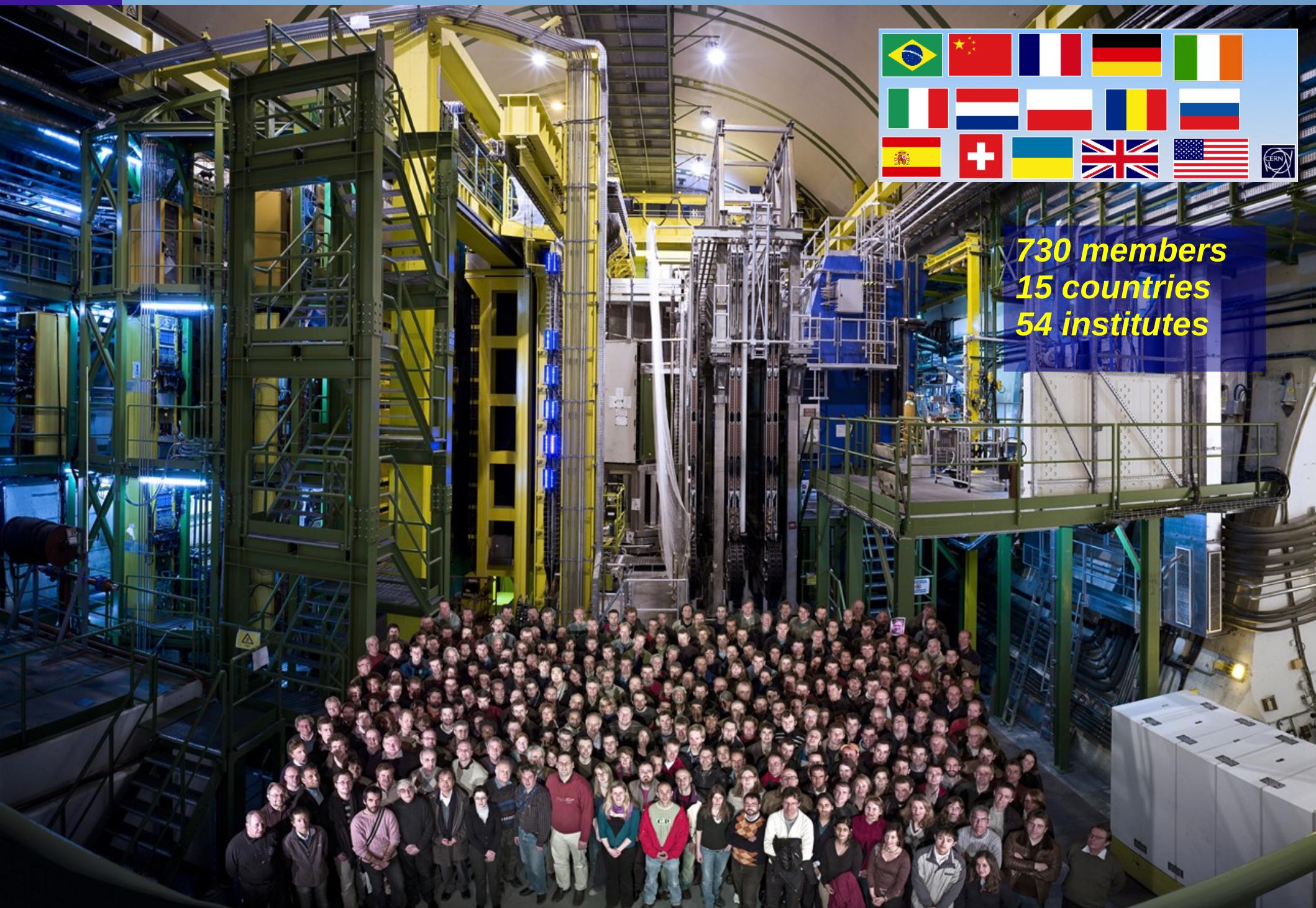
tag

 $K^-$  $K^+$  $K^-$  $\pi^-$ 

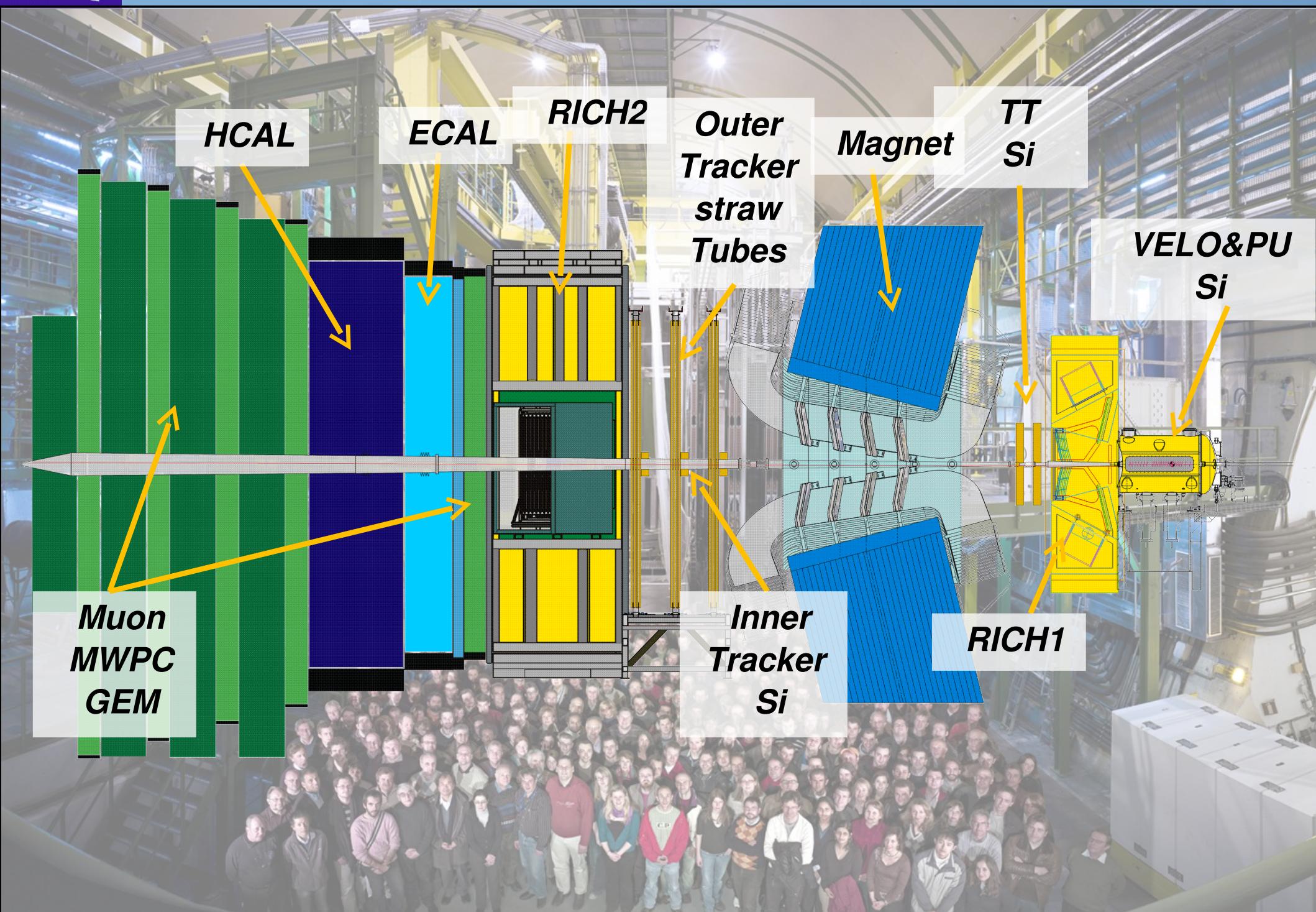
## 3. $K/\pi$ separation

- to separate topologically similar final states
- to tag B flavor

# The LHCb Collaboration



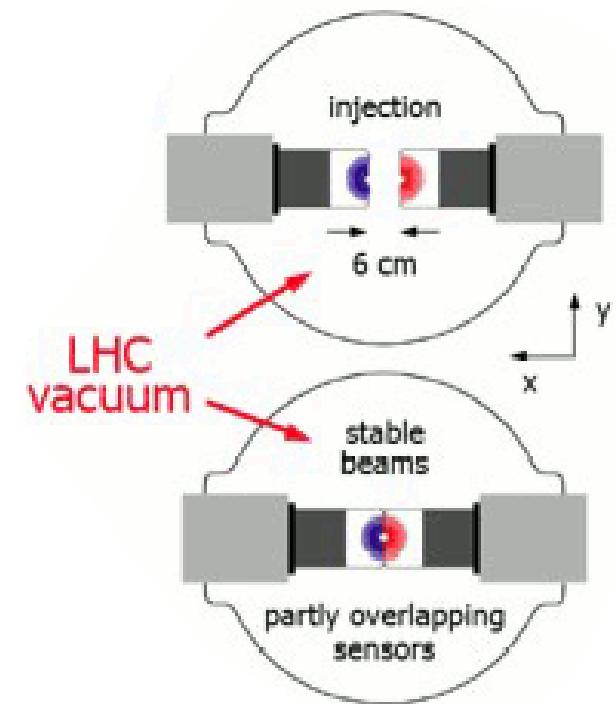
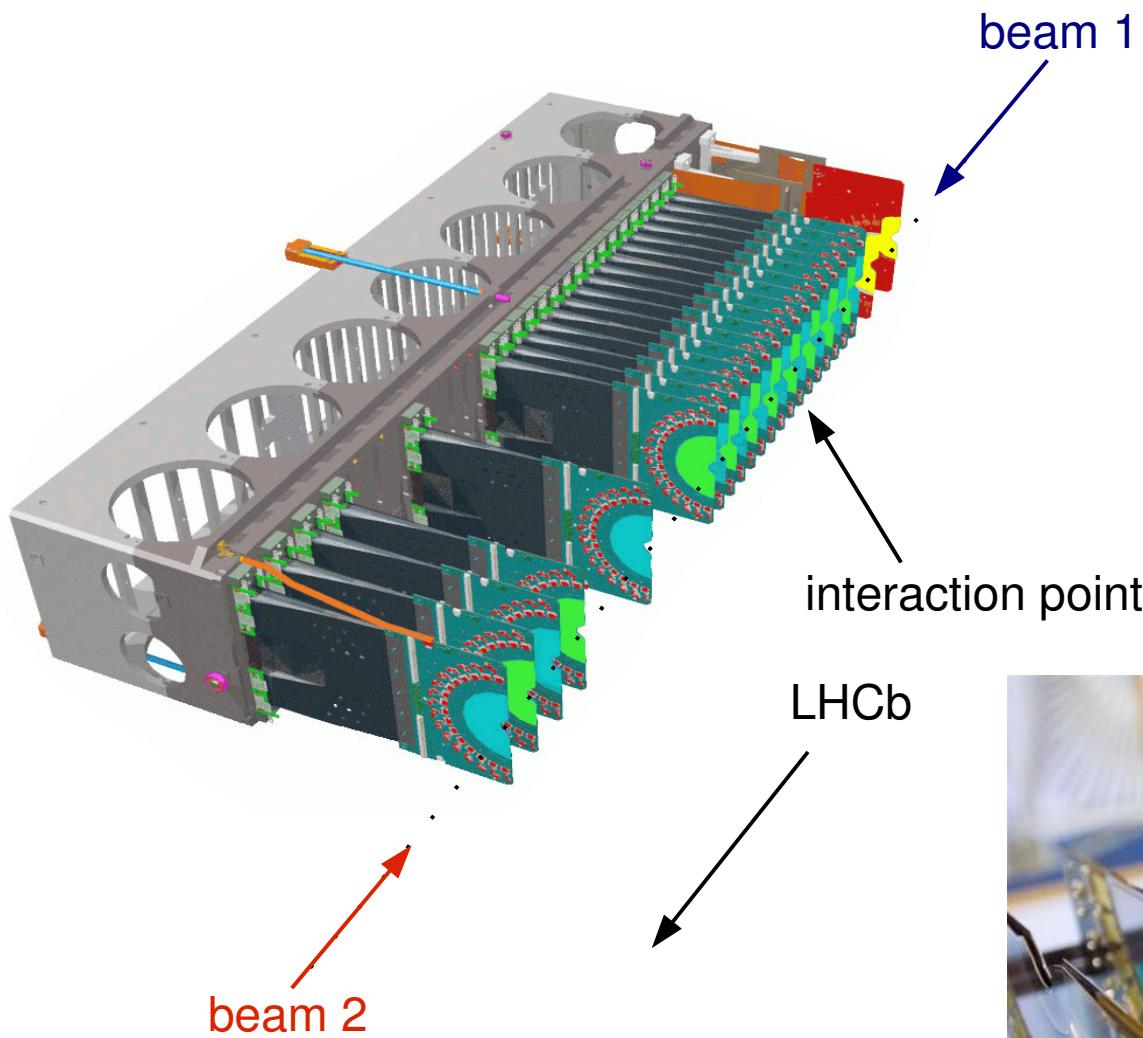
*730 members  
15 countries  
54 institutes*



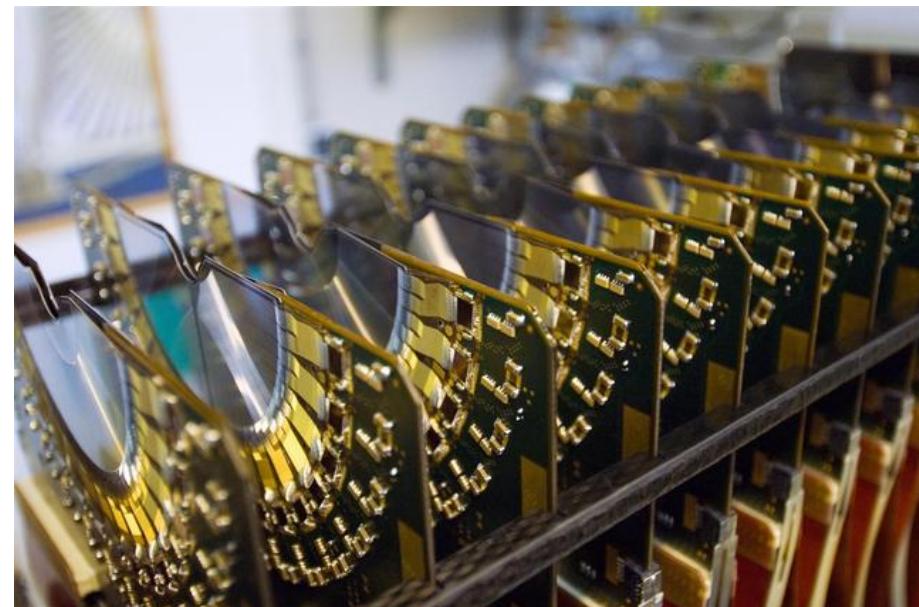
- commissioning data (2008-2009)
    - cosmics: several million events
      - alignment, time alignment of OT, CALO, MUON systems
    - injection line beam-dump: several 1000 'splash' events
      - alignment of VELO, TT, IT (silicon systems)
  - 2009 LHC run
    - first events ~ November 21
    - physics run 6/12/09 - 15/12/09
    - recorded ~  $6 \mu\text{b}^{-1}$  integrated luminosity with “minimum bias” trigger
      - minimal deposit in HCAL& SPD, or
      - muon candidate, or
      - ‘backward velo planes’
    - about **260k pp-collisions** at 450 GeV (beam gas subtracted)
    - about **80k beam gas interactions**
- 
- time-alignment,  
spatial alignment*
- 
- first 'magnet-on' data*

# 450 GeV beams: velo partially 'open'

- LHCb vertex detector consists of two movable halves

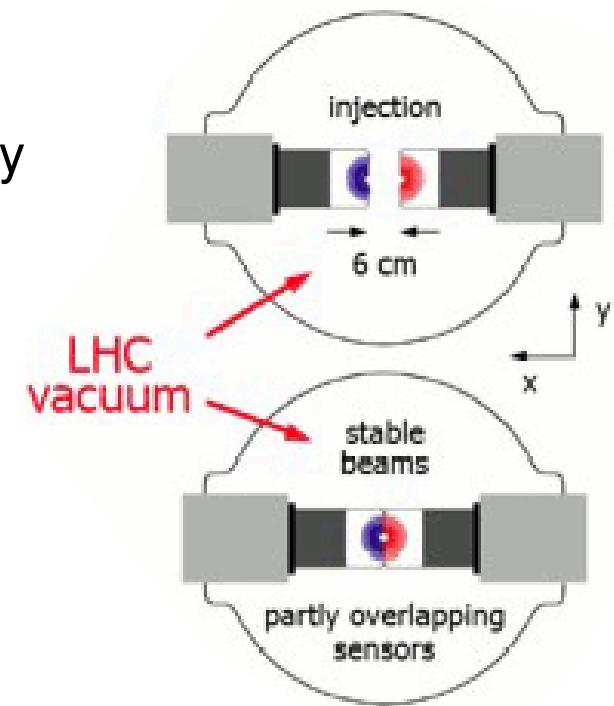
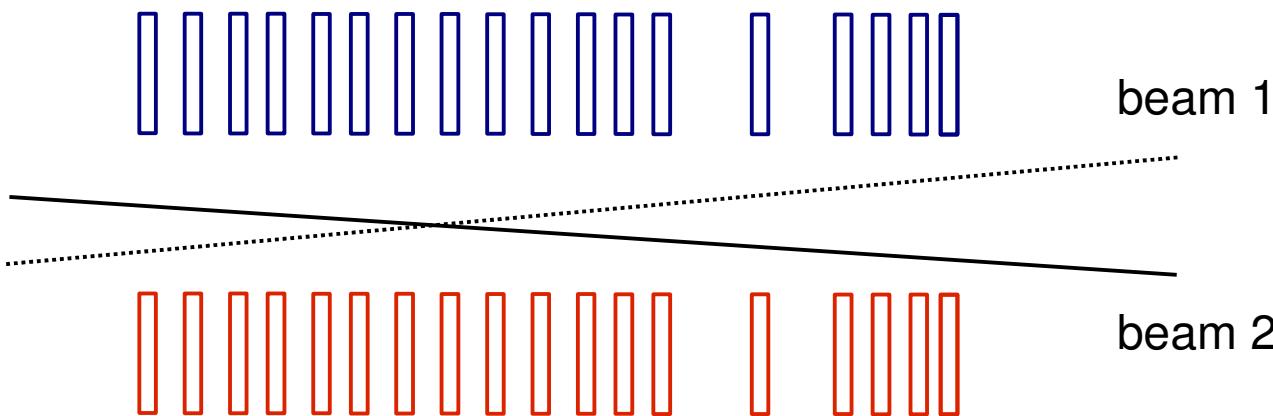


LHCb

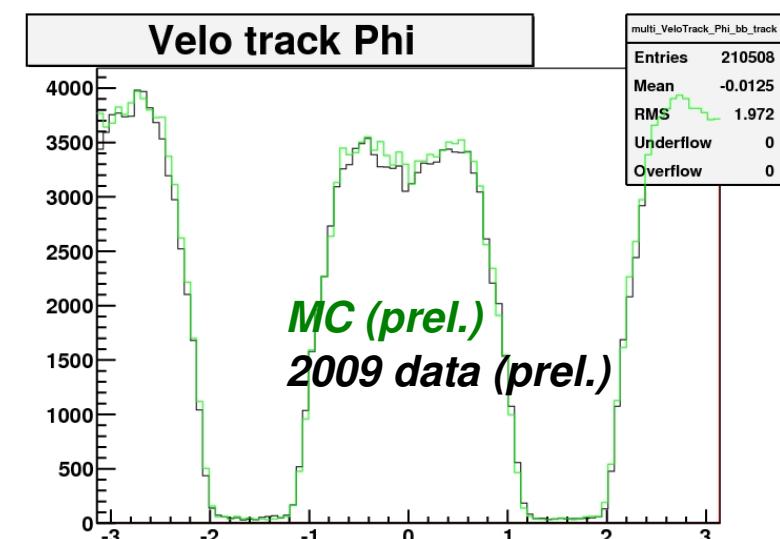


# 450 GeV beams: 'open' velo

- LHCb vertex detector consists of two movable halves
- to correct for di-pole, angle of beams depends on energy



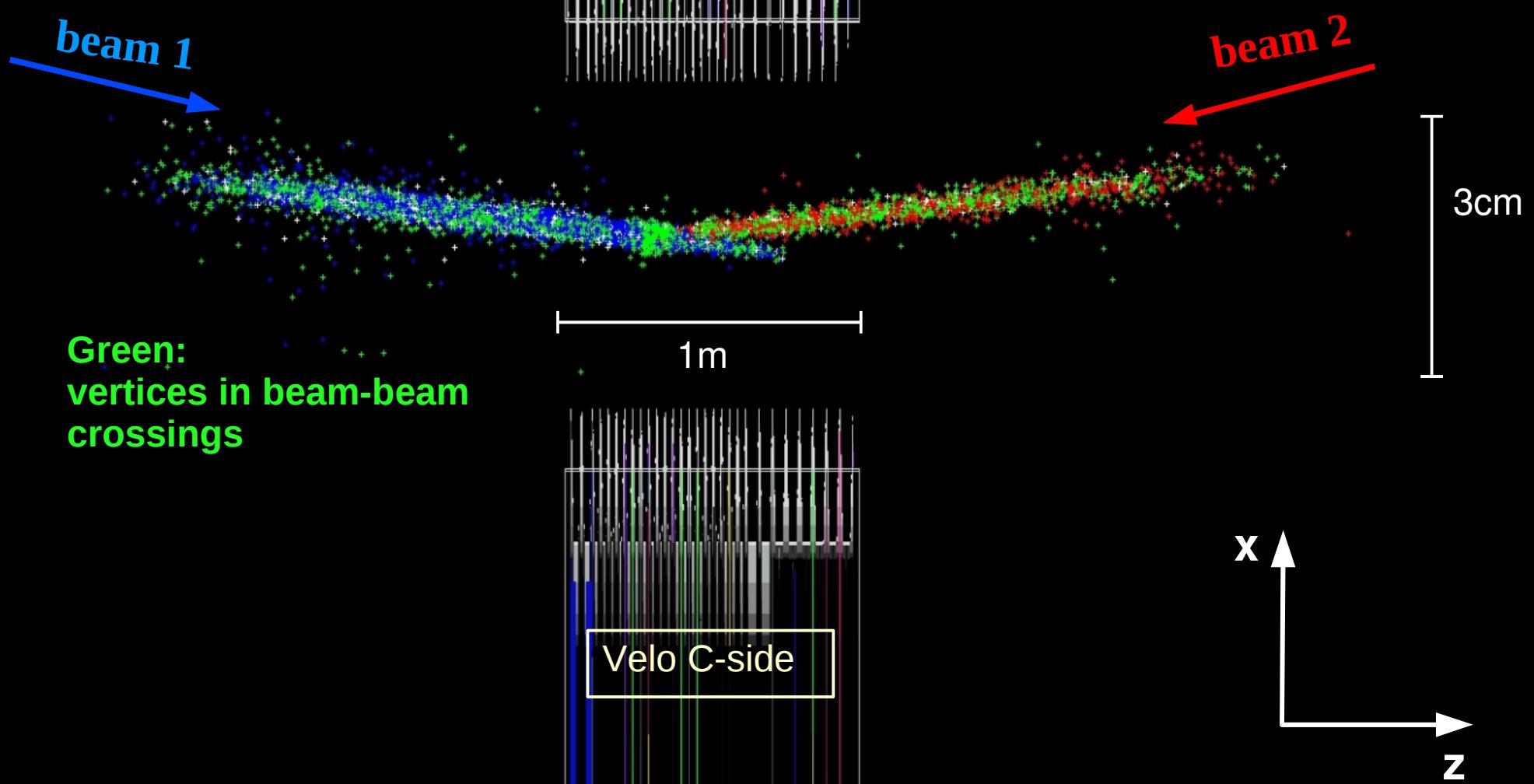
- velo can only be safely closed if  $E_{\text{beam}} > 2\text{TeV}$
- at 450+450 GeV
  - reduced phi acceptance
  - poorer vertex resolution  
(but in agreement with expectation)



## primary vertices for beam-beam and beam-gas collisions

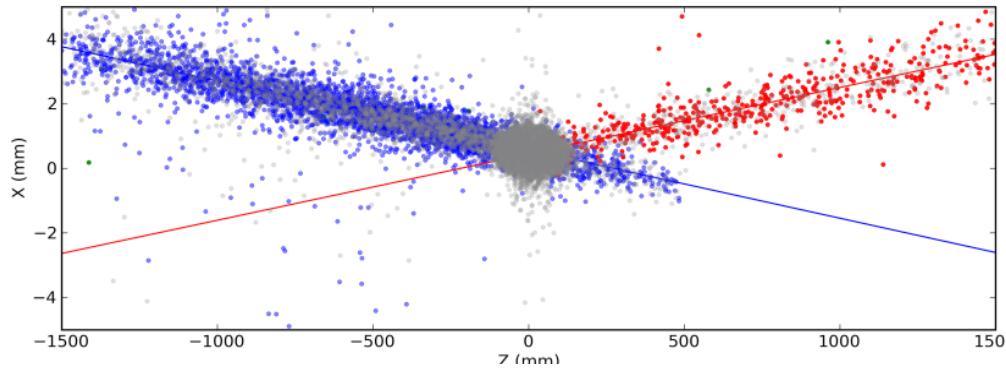
Blue:  
vertices in beam1-empty  
crossings

Red:  
vertices in beam2-empty  
crossings

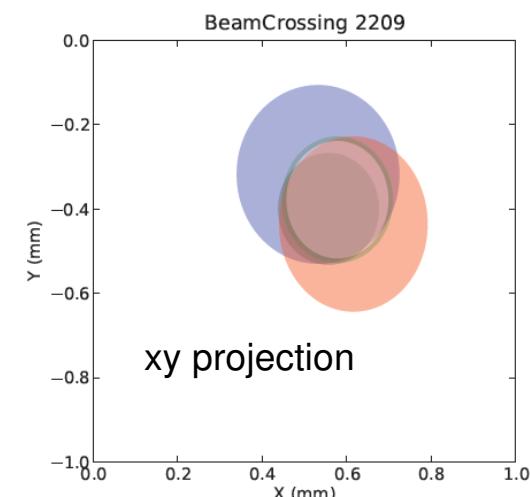
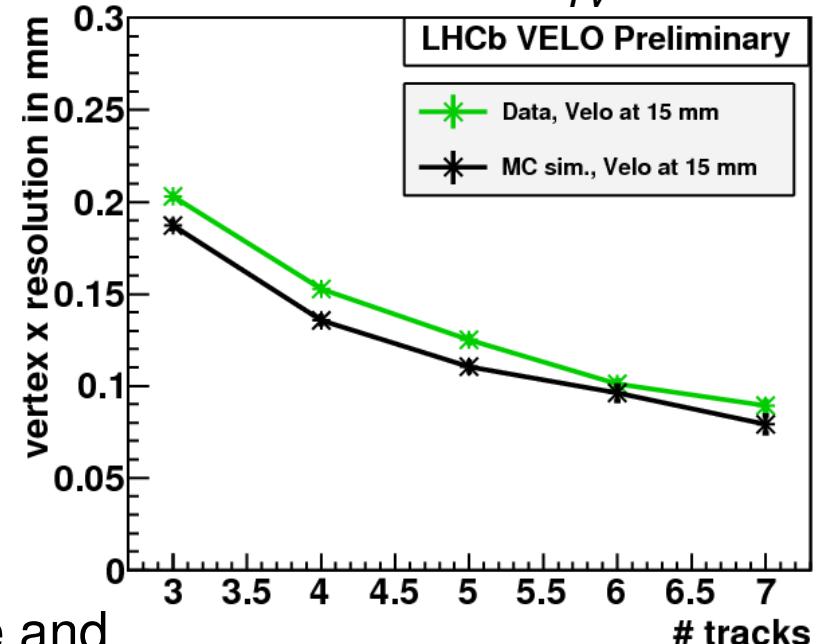


# vertex resolution

- vertex resolution measurement
  - in each event, randomly split track set in 2
  - reconstruct PV with both sets
  - estimate resolution from difference
- ➔ within 10% of expectation from MC
- excellent PV resolution allows to measure size and position of both beams
  - feedback for LHC (e.g. VdM scan)
  - allows direct measurement of luminosity at LHCb



*resolution of difference in  $x_{PV}$  vs # tracks*

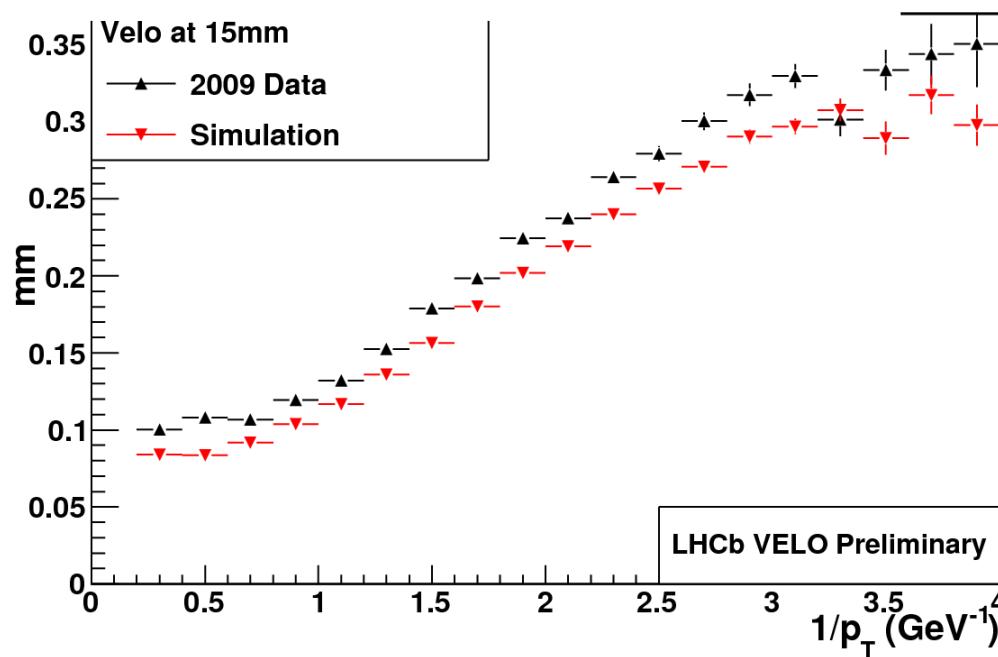


See also YSF: P. Hopchev,  
*“Luminosity measurement at LHCb”*

# impact parameter resolution

- good impact parameter crucial for prompt background rejection
  - performance also representative for proper time resolution
- in LHCb usually presented as function of  $1/p_T$ :

***resolution of distance of track to PV versus  $1/p_T$***



note: VELO *open*

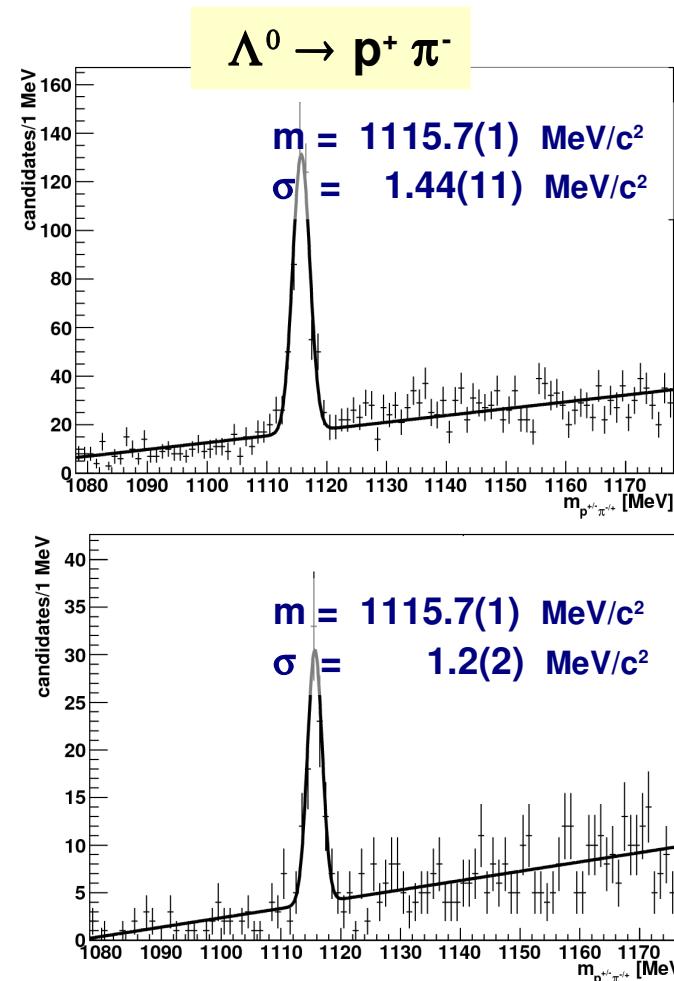
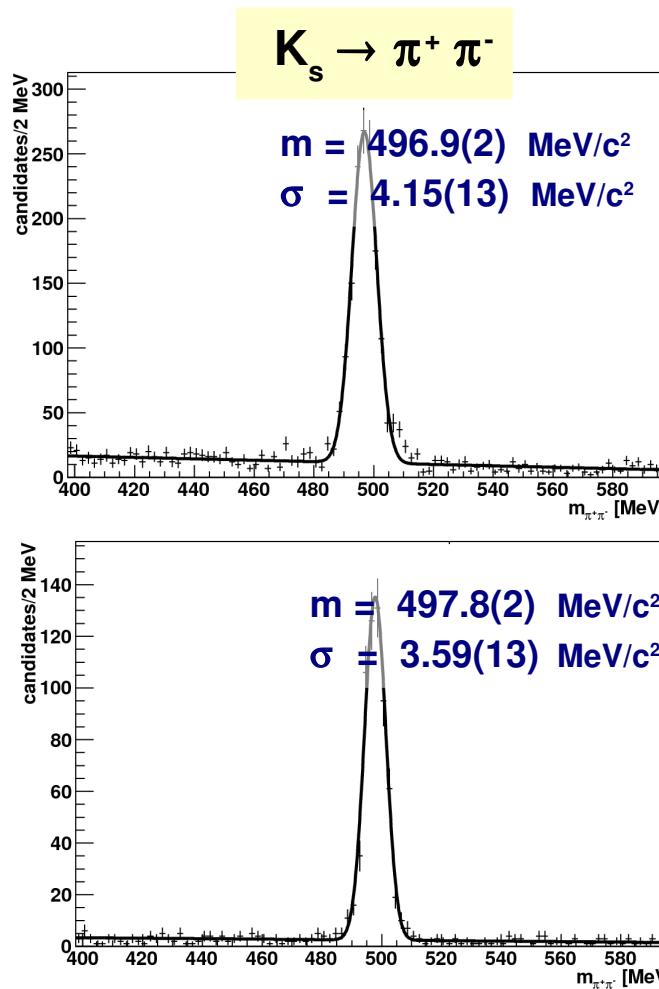


**factor ~2 improvement  
with VELO *closed***

- IP resolution within ~20% of expectation
  - more than sufficient for trigger and physics analysis
  - improvement expected with better alignment

# momentum resolution

- spectrometer performance estimated from mass resolution of V0 signals



**LHCb 2009 data  
(preliminary)**

**LHCb 2009 MC  
(preliminary)**

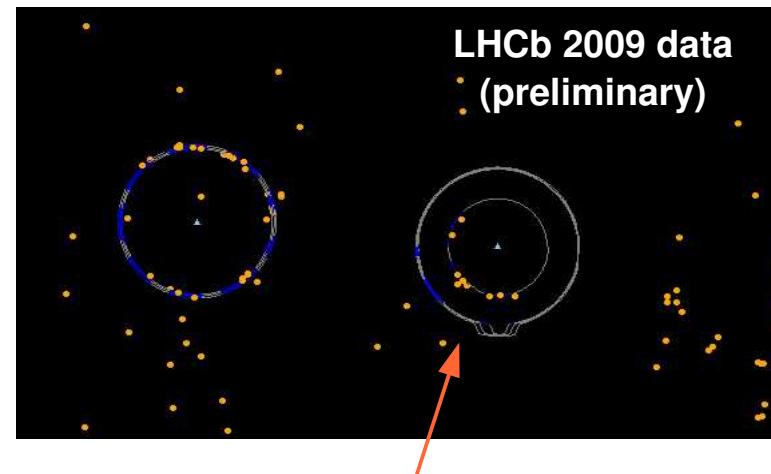
- momentum resolution about 20% worse than in simulation
  - analysis of spectrometer alignment in full swing
  - expect significant improvement once we have collected large  $J/\psi \rightarrow \mu\mu$  sample

See also YSF: S. Stahl, "Ks reconstruction performance in LHCb"

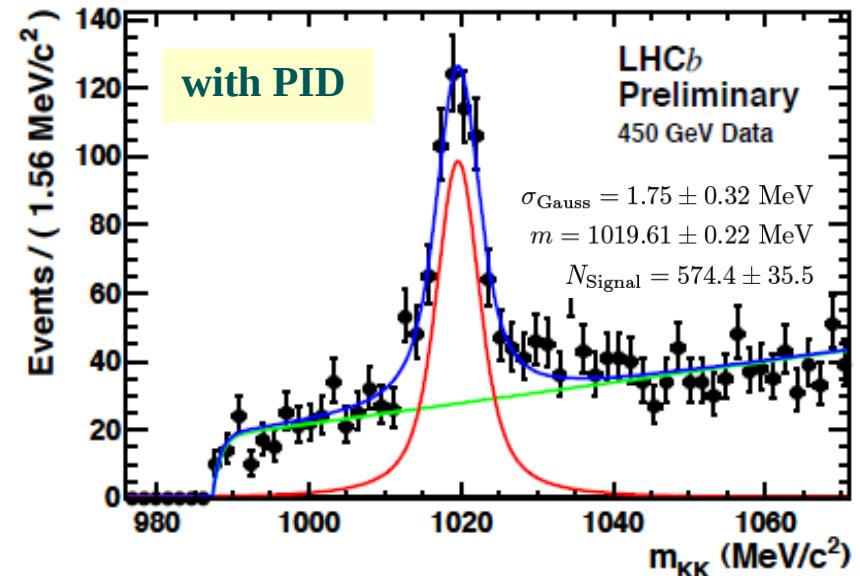
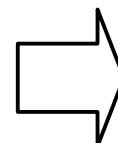
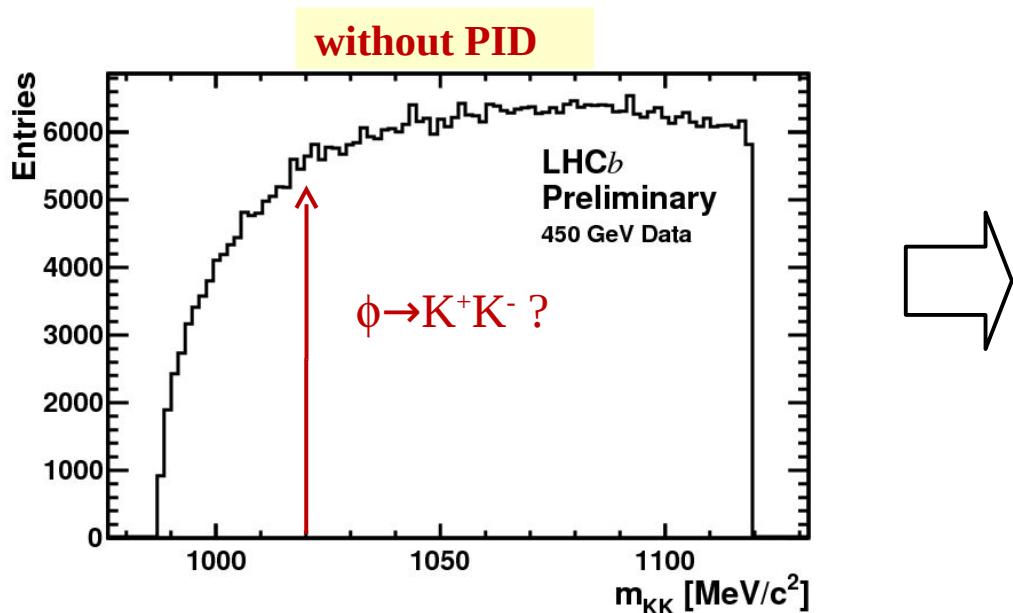
# p/K/π identification with RICH

- LHCb's 2 RICH detectors provide K/π separation between 2 and 100 GeV
- power of kaon ID demonstrated with  $\phi$  signal

*kaon candidate in RICH2*



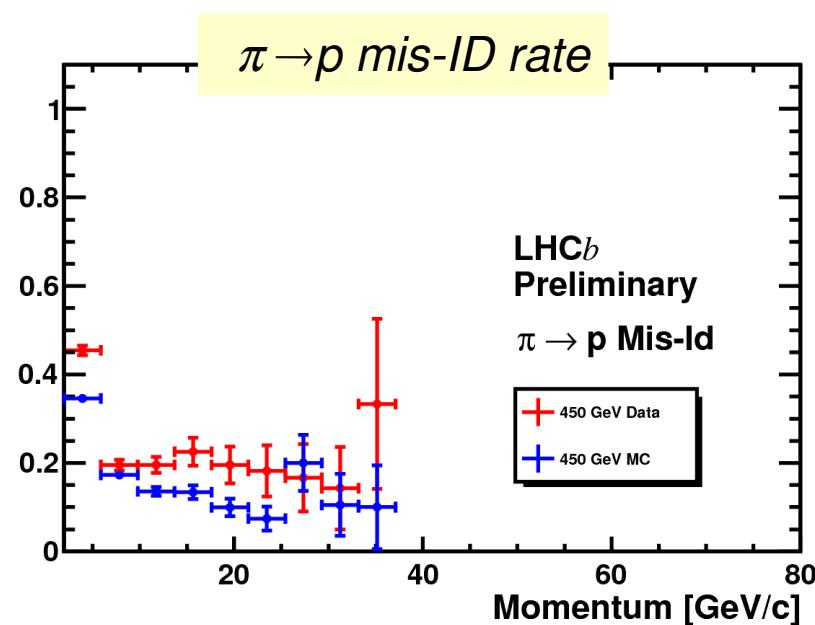
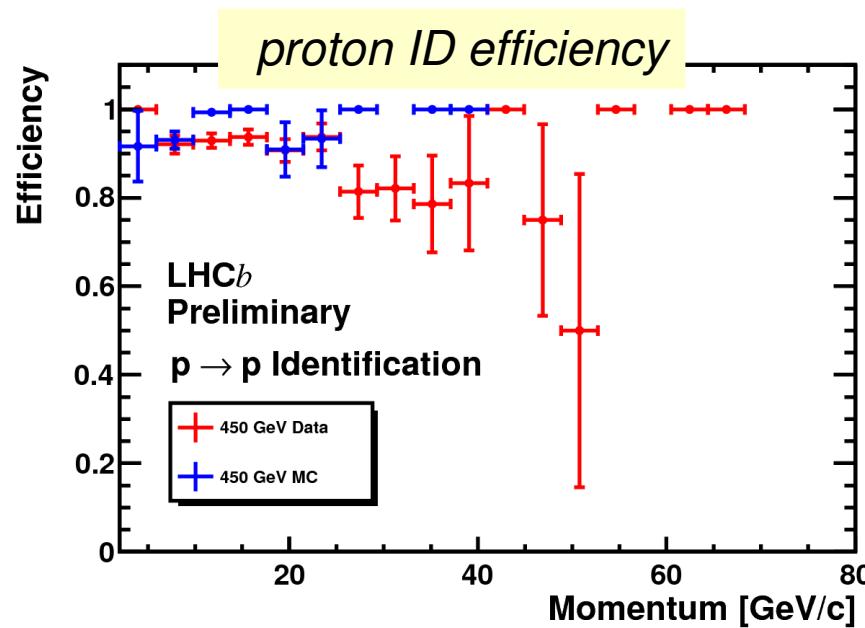
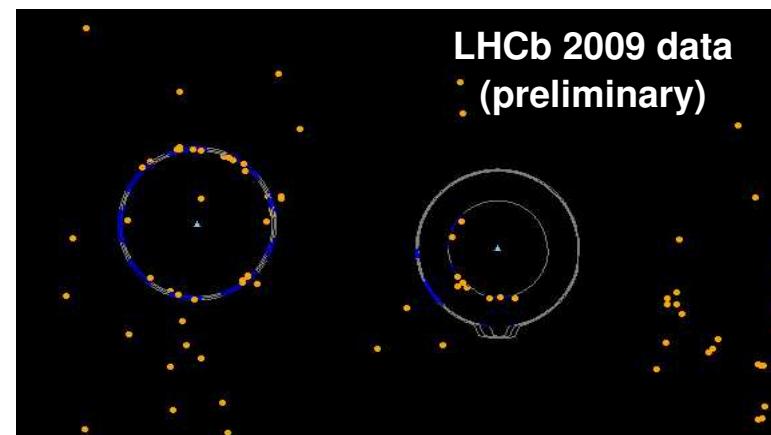
inner circle: *kaon hypothesis*  
 outer circle: *pion hypothesis*  
 (proton below threshold)



# p/K/π identification with RICH

*kaon candidate in RICH2*

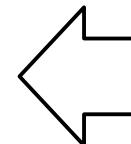
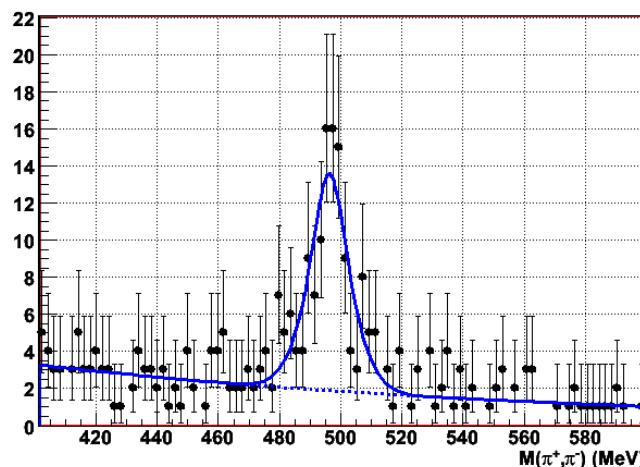
- LHCb's 2 RICH detectors provide K/π separation between 2 and 100 GeV
- efficiency/misID rate measured with V0 signals



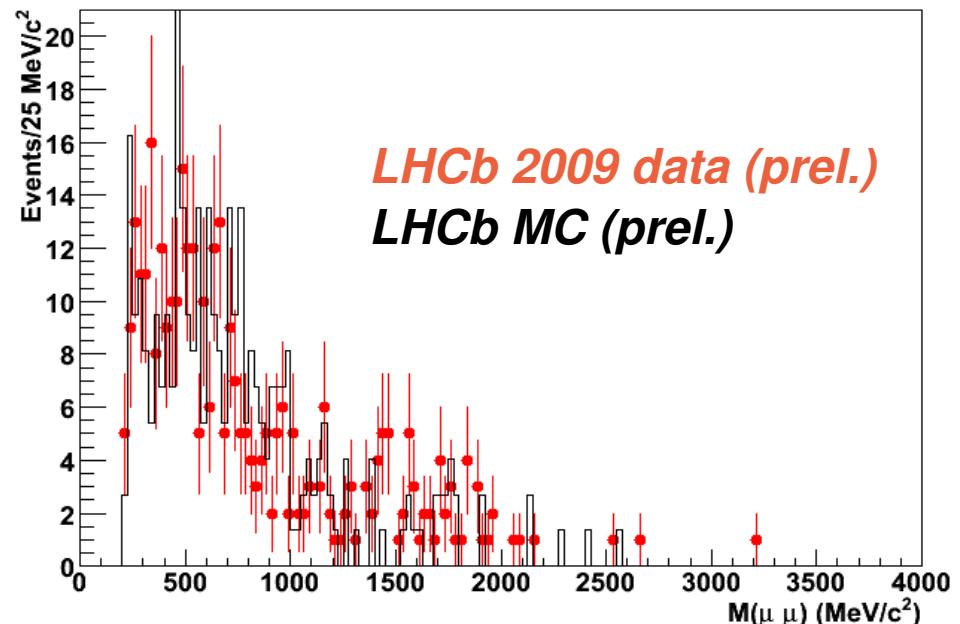
- performance within ~10-20% of simulation
  - will improve with better alignment of RICH mirrors

# muon ID performance

- muon ID very important
  - $B \rightarrow \psi X$ ,  $B \rightarrow \mu\mu X$ ,  $B \rightarrow \mu\mu$ , ...
  - B flavour tagging
- detector fully functional  
efficiency of detector planes >99%
- first estimate of muon mis-ID rate  
extracted from  $K_s \rightarrow \pi\pi$  :



*di-muon invariant mass*



$K_s \rightarrow \pi\pi$  candidates with one  $\pi$  in  
**MUON acceptance and identified as  $\mu$**

LHCb 2009 data (prel.):  $\epsilon(\pi \rightarrow \mu) = 3.8 \pm 0.7 \%$   
LHCb MC (prel.) :  $\epsilon(\pi \rightarrow \mu) = 2.3 \pm 0.4 \%$

- preliminary performance worse on data, but likelihood not yet calibrated

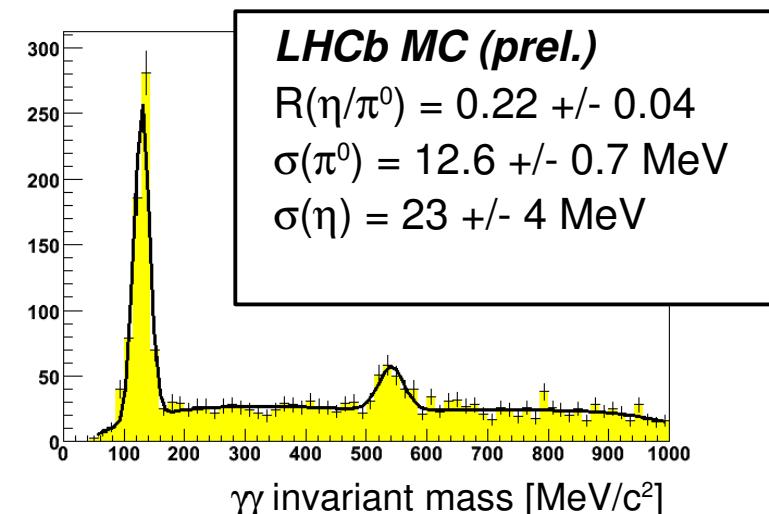
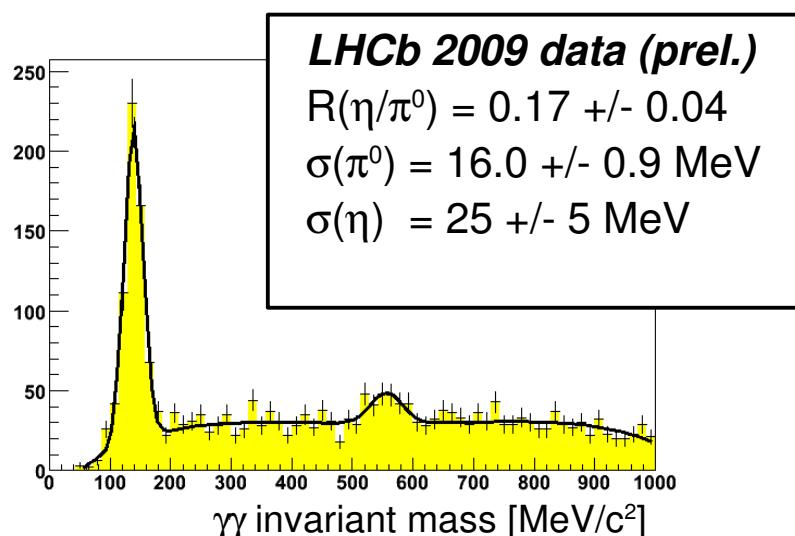
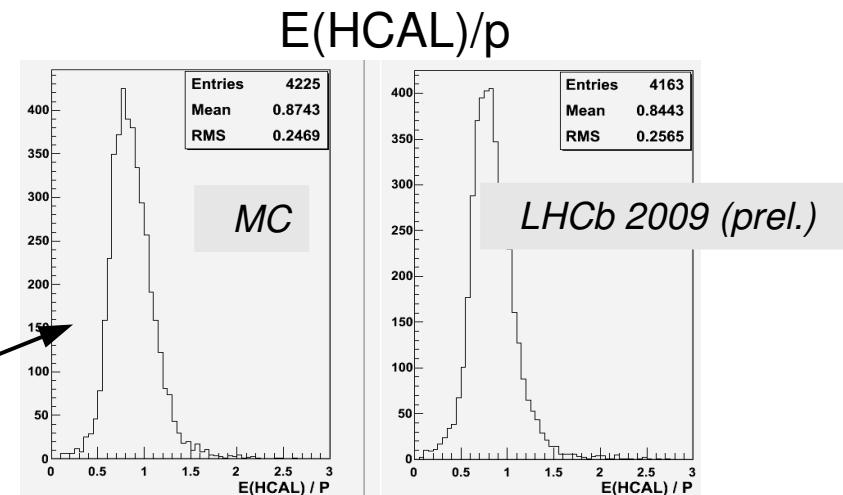
See also YSF: Xabier Cid Vidal,  
“Muon Identification in the LHCb experiment”

# calorimeter performance

- LHCb's calorimeter consists of

- HCAL → *high pT hadron trigger*
  - ECAL
  - SPD
  - PRS
- } *electron/photon ID and trigger*

- HCAL performing as expected



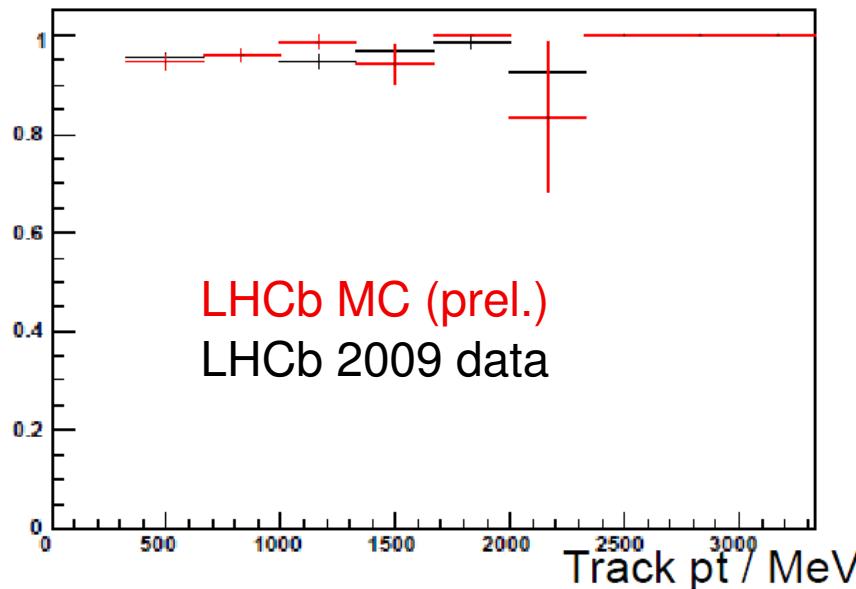
- optimal ECAL resolution not yet reached

- from 2009 data cell-to-cell inter-calibration at level of 7%
- expect about 25% better  $\pi^0$  resolution once calibration at 1% level

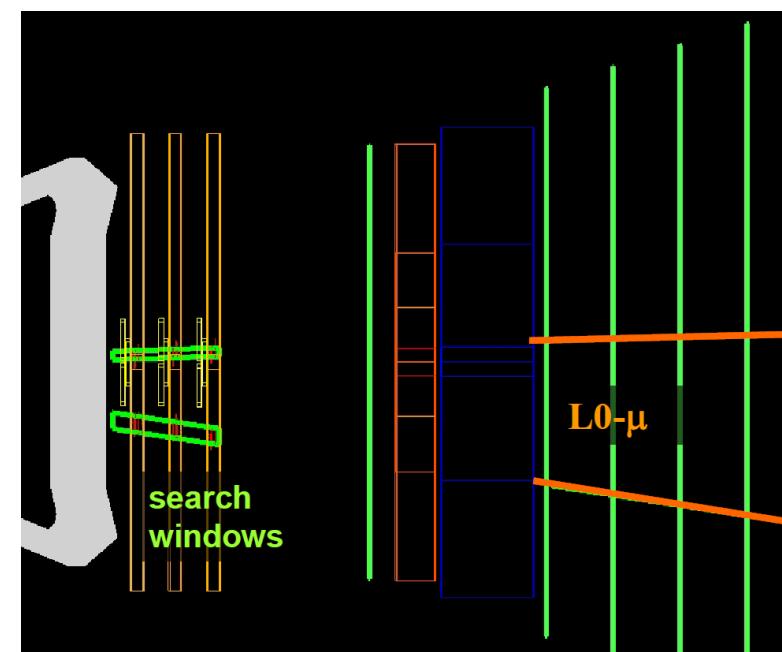
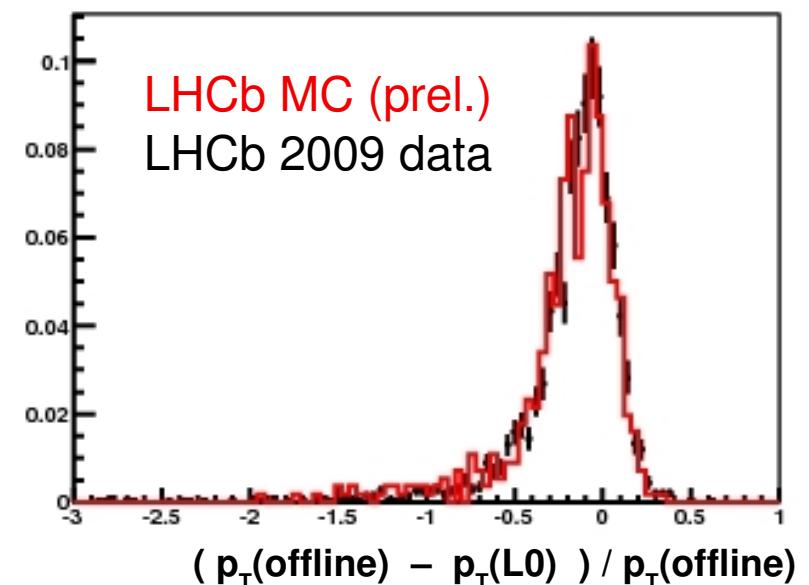
# trigger status

- LHCb trigger
  - L0 (hardware):
    - hadron  $E_T$ , muon  $p_T$ , photon, electron
  - HLT(software):
    - L0 confirmation, impact parameters, full tracking, ...., exclusive decays
- firsts tests: compare L0 and HLT to offline reconstruction

$$\text{efficiency} = \frac{\text{reconstructed T - track matched to offline muon}}{\text{offline muon & L0-}\mu}$$



*L0 MUON  $p_T$  resolution compared to offline*



→ HLT 'L0 confirmation efficiency' as expected

# Physics prospects

- plans with 2009 450-GeV data
    - charged particle multiplicities, kinematic distributions
    - V0 production: pT,  $\eta$ ,  $\Lambda/K_s$ ,  $\Lambda/\bar{\Lambda}$
    - jet multiplicity
- LHCb has unique  $\eta$  coverage*

- expectations for 2010 ( $0.2 \text{ fb}^{-1}$ ) and 2011 ( $1 \text{ fb}^{-1}$ )

	$\sigma(3.5+3.5\text{TeV})$ [mbarn]	events in LHCb acceptance	
		2009	2010
total	100		
$b\bar{b}$	0.2	$40 \cdot 10^9$	$200 \cdot 10^9$
$c\bar{c}$	2	$400 \cdot 10^9$	$2 \cdot 10^{12}$

*absolute luminosity  
2009: ~20% error  
201X: ~5% error*

- event yields for subset of bench-mark exclusive decays

	2010	2011
$J/\psi \rightarrow \mu^- \mu^-$ (prompt)	60M	300M
$B_s \rightarrow J/\psi \phi$	6k	30k
$B^0 \rightarrow K^{0*} \mu^+ \mu^-$	300	1500
$B^0 \rightarrow K^+ \pi^-$	11k	55k
$B_s \rightarrow K^+ K^-$	4k	10k
$B_s \rightarrow \phi \gamma$	240	3k
$D^{*-} \rightarrow D(K^- \pi^+) \pi^-$ (WS)	10k	50k

*conservative estimates  
of cross-sections*

*comparable with total  
 $e^+ e^-$  B-factory yield*

*LHCb will be competitive  
right from the start*

# CP violation in $B_s \rightarrow J/\psi \varphi$

- J/ $\psi$   $\varphi$  is CP eigenstate
  - accessible to both  $B_s$  and  $B_s$ -bar
  - interference mixing/decay  $\Rightarrow$  time-dependent CP violation

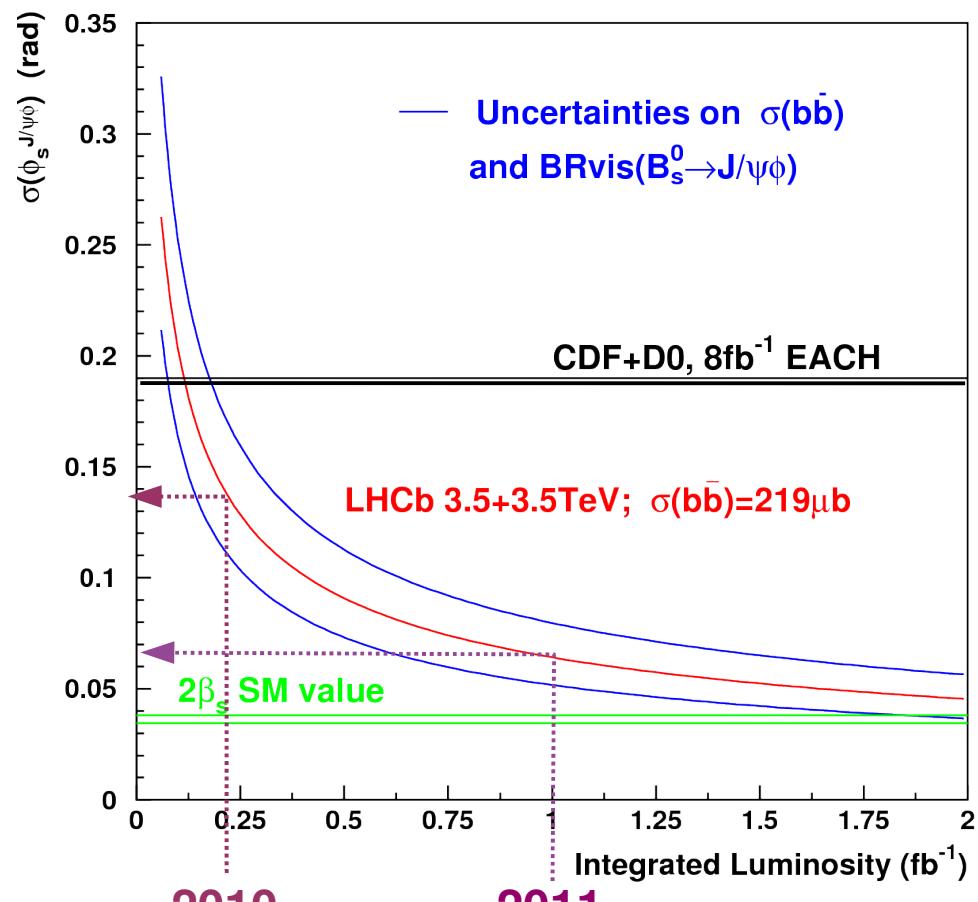
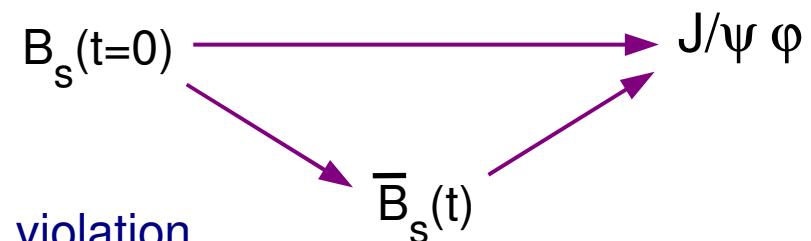
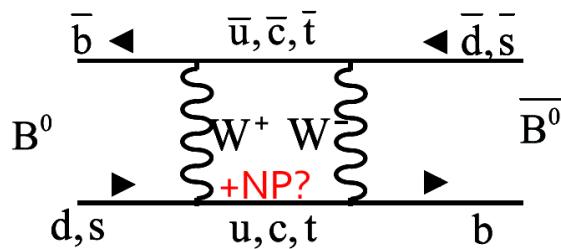
$$A_{CP}(t) \sim \sin(\phi_s) \sin(\Delta m t)$$

(ignoring  $\Delta\Gamma_s$ )

- phase precisely predicted in SM

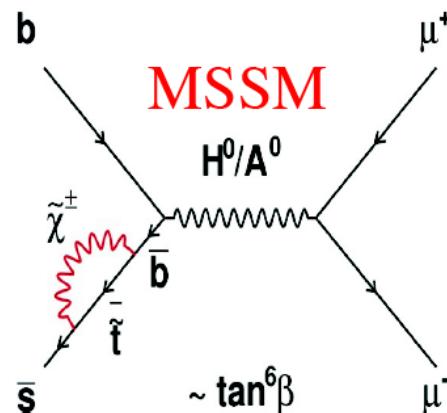
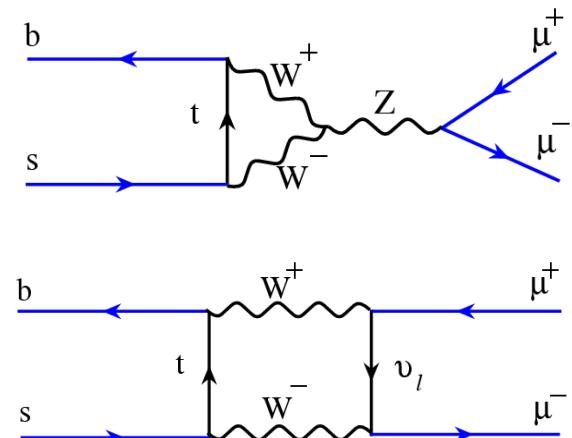
$$\phi_s = -2 \beta_s = -0.036 \pm 0.002$$

- very sensitive to new contributions to mixing box

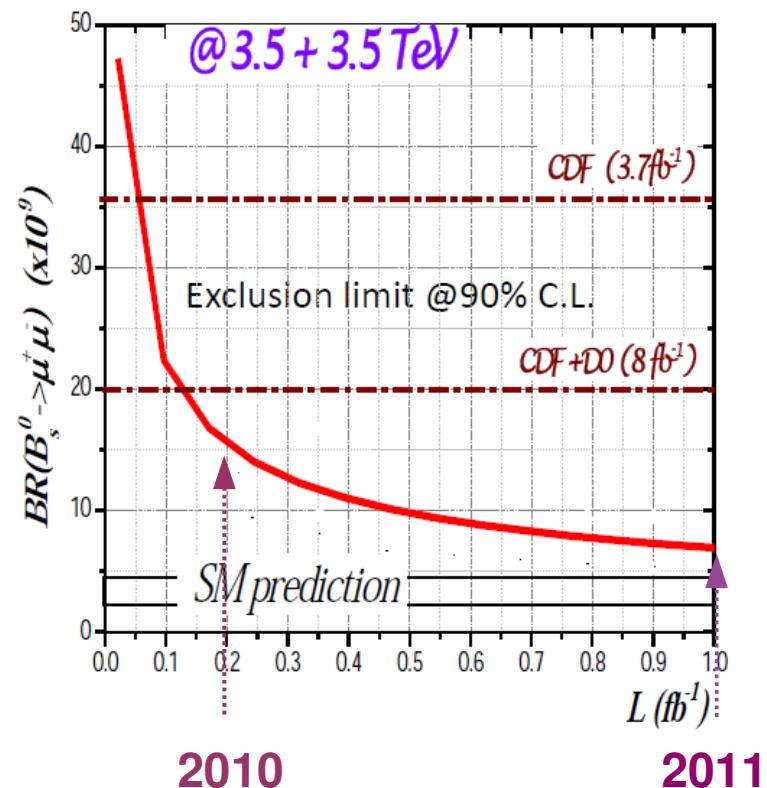


$B_s \rightarrow \mu^+ \mu^-$ 

- very rare decay in SM:  $\text{BR} = (3.6 \pm 0.4) \times 10^{-9}$ 
  - mainly Z-penguin and W-box
  - helicity suppressed, CKM suppressed
  - theoretical uncertainty small
- large possible beyond-SM contributions
  - e.g. in MSSM:  $\text{BR} \sim \tan(\beta)^6$

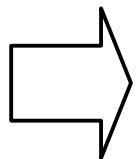


- 2010-2011 dataset will significantly constrain MSSM-like contribution
  - discovery of 'SM-decay' only in 2013



# and much more ...

- CP angle gamma, the least well known angle of the Unitary Triangle
  - from trees:  $B^- \rightarrow D^0(CP)K^-$
  - from loops:  $B^0 \rightarrow \pi\pi + B^s \rightarrow K\bar{K}$
  - from mixing:  $B^s \rightarrow D^s K$
- combined precision with 1 fb<sup>-1</sup> at 3.5+3.5 TeV:  
 $\sigma(\gamma) \approx 10^\circ$
- forward-backward asymmetry in  $B \rightarrow K^*\mu^+\mu^-$
- CP violation in radiative decays:  $B \rightarrow K^*\gamma$ ,  $B \rightarrow \phi\gamma$
- charm physics:  $D^0$  mixing, CP violation
- quarkonium production, QCD, non-SM Higgs decays
- ...



a very rich physics program lies ahead of us!

# summary

- LHCb experiment dedicated to the study of charm and beauty decays
- LHCb has collected about 260k proton-proton collisions in 2009
- performance close to expectation in key requirements
  - vertex resolution (VELO)
  - momentum resolution (TT/IT/OT)
  - PID performance (RICH, CALO, MUON)
- significant improvements ahead from better calibration and alignment
- expect for the first 1/fb, collected by the end of 2011
  - $\sigma(\beta_s) \approx 0.06$
  - $\sigma(\gamma) \approx 0.17$
  - $\text{BF}(B_s \rightarrow \mu^+ \mu^-) < 7 \cdot 10^{-9}$  (at 90% CL)

but first serious measurements will appear well before that!

Don't forget LHCb talent at YSF:

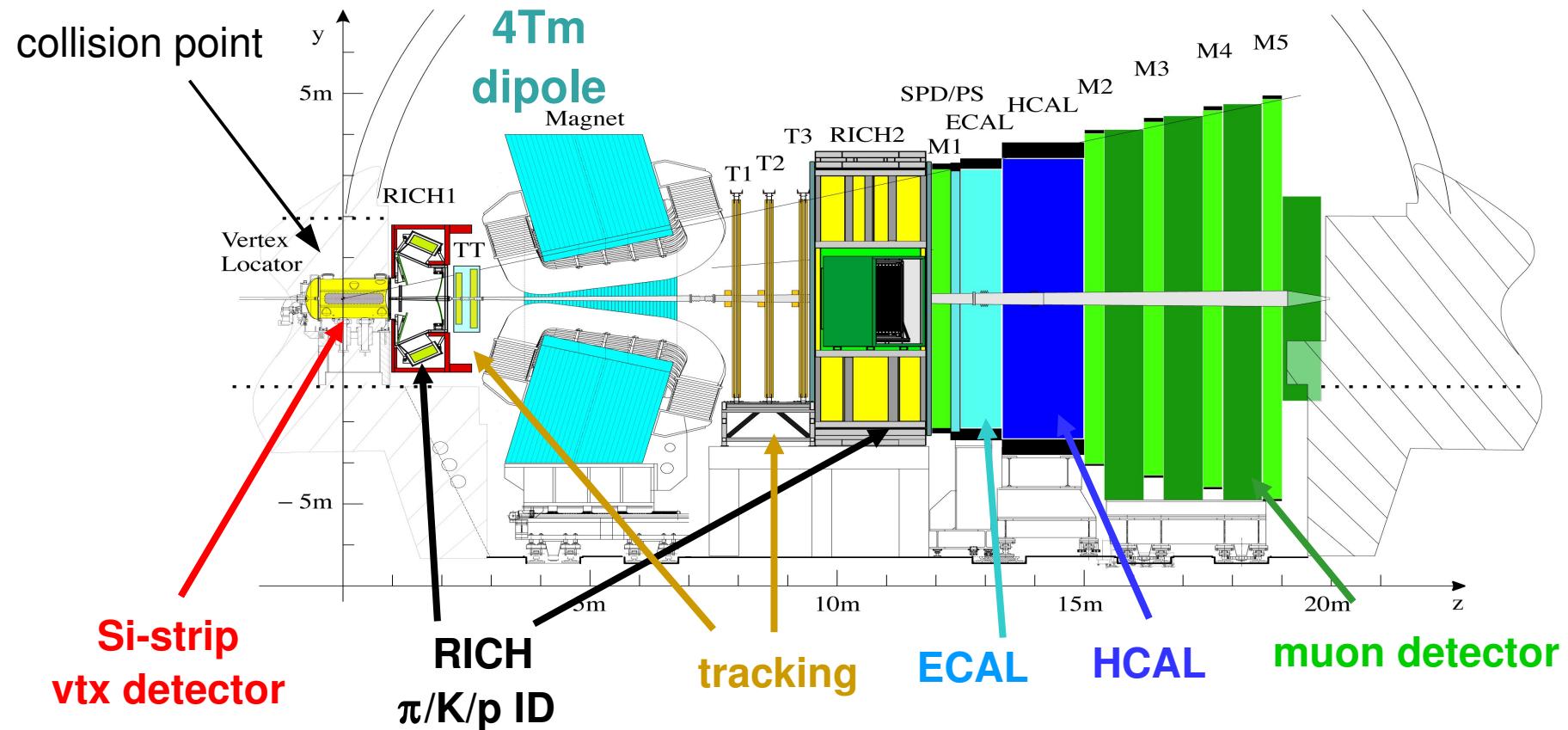
**Sascha Stahl:**  *$K_s$  reconstruction performance*

**Plamen Hopchev:** *Luminosity determination*

**Xabier Cid Vidal:** *Muon identification*

# backup

# the LHCb detector



momentum resolution:  
 $\sigma(p)/p \sim (0.4 + 1.5 p/\text{TeV})\%$   
 $\sigma(m[B_s \rightarrow \mu\mu]) \sim 20 \text{ MeV}$

vertex resolution:  
 $\sigma(\text{proper time}) \sim 40-100 \text{ fs}$   
 $\sigma(\text{IP}) \sim 14\mu\text{m} + 35\mu\text{m}/p_T$

PID performance:  
kaon-ID: 88% for 3%  $\pi$  misID  
mu-ID: 95% for 5% hadron misID

track reconstruction efficiency:  
95% for tracks with  $p > 5 \text{ GeV}$  and  $1.9 < \eta < 4.9$

B flavour tag efficiency:  
 $\epsilon D^2 \sim 4.3\%$  for  $B_d$  and  $\sim 7.5\%$  for  $B_s$