The LHCb RICH Detectors

Ulrich Kerzel
University of Cambridge

LHC at CERN

14 TeV pp collisions

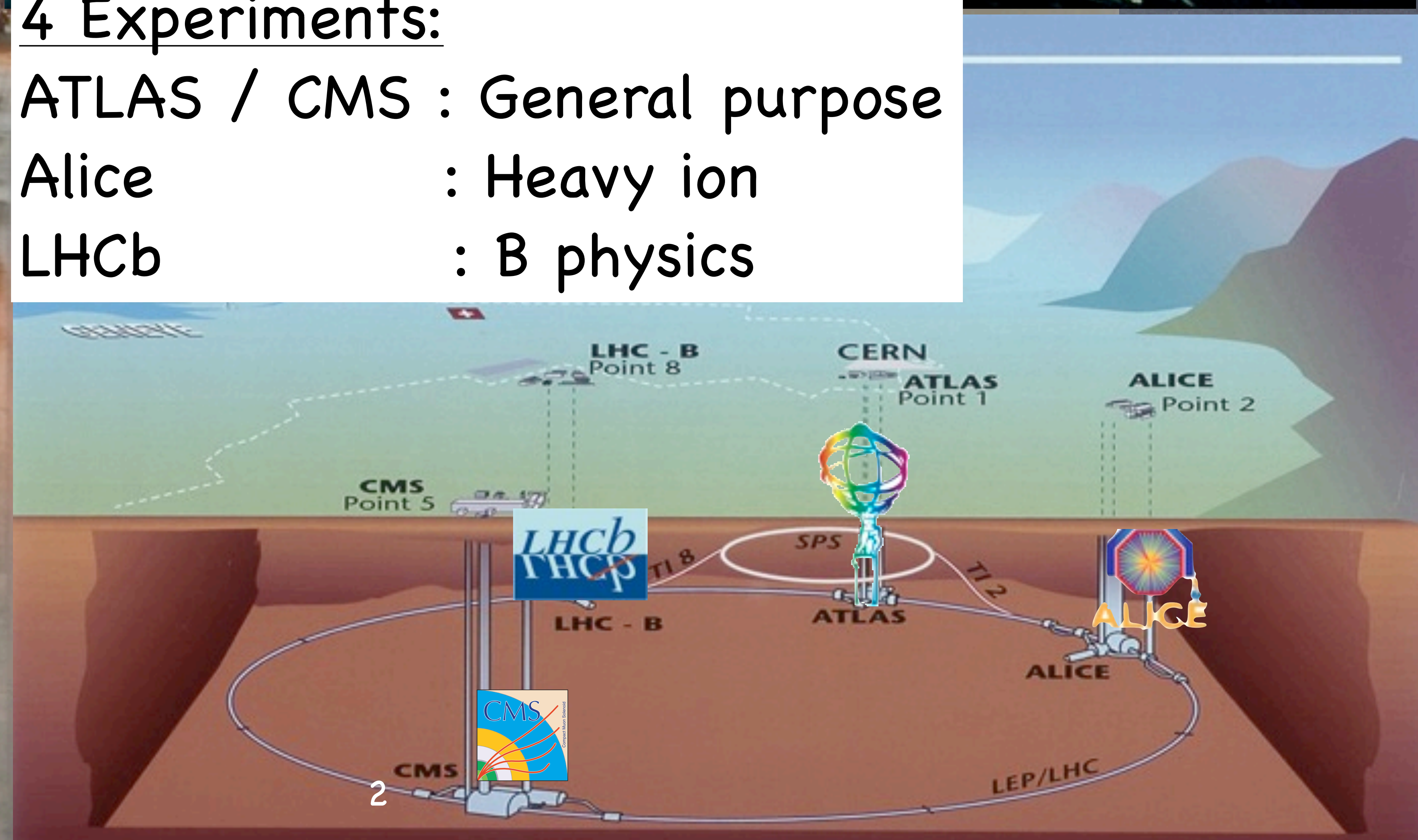
25ns beam structure

<u>4 Experiments:</u>

ATLAS / CMS : General purpose

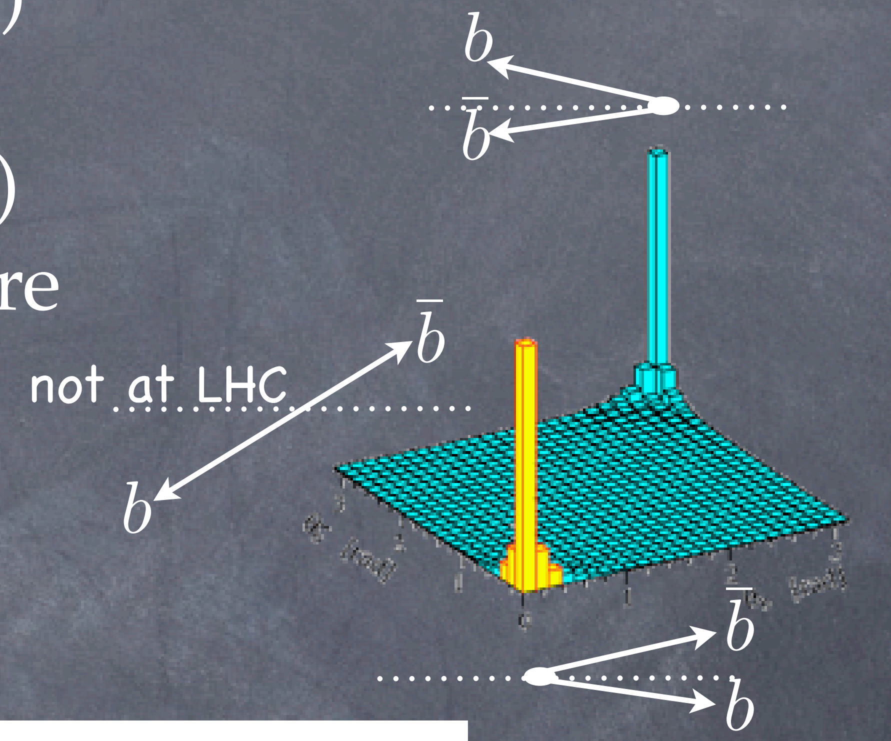
Alice : Heavy ion

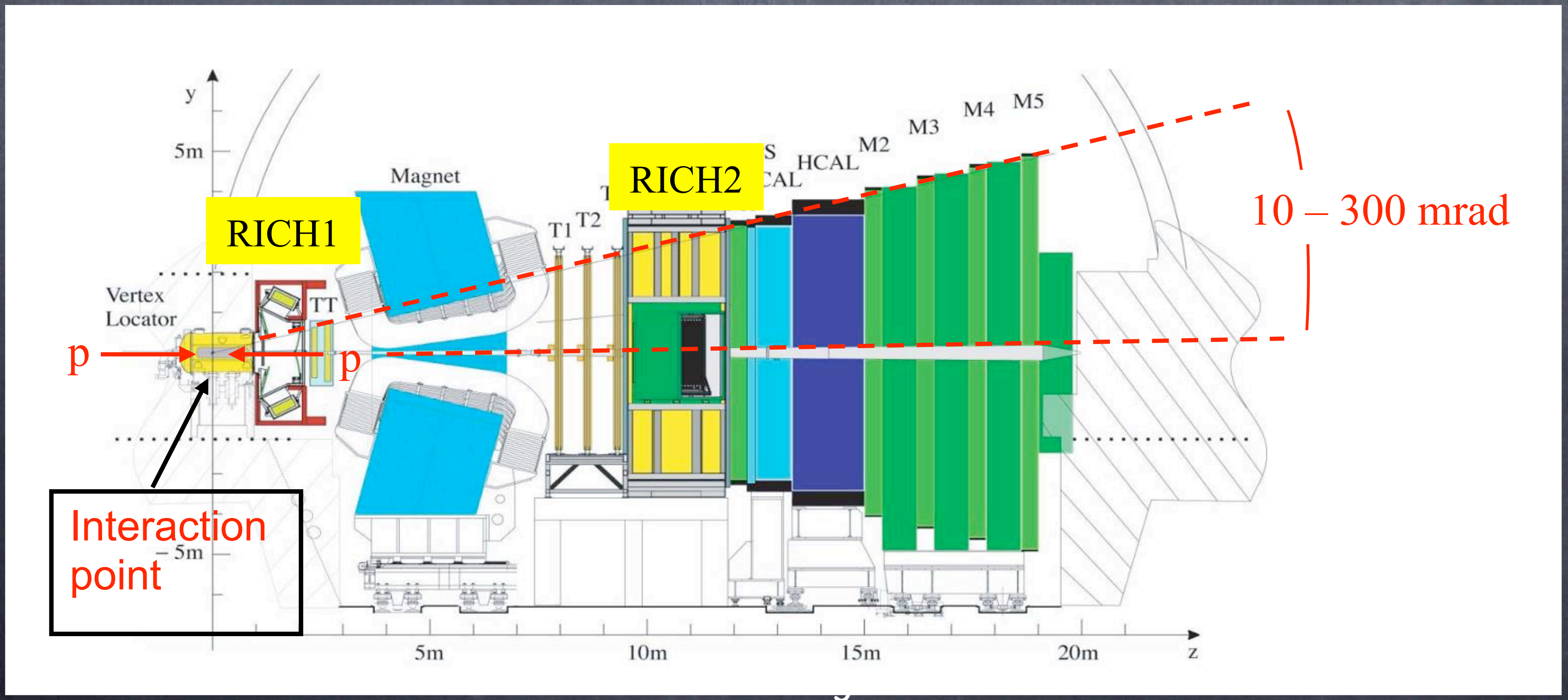
LHCb : B physics

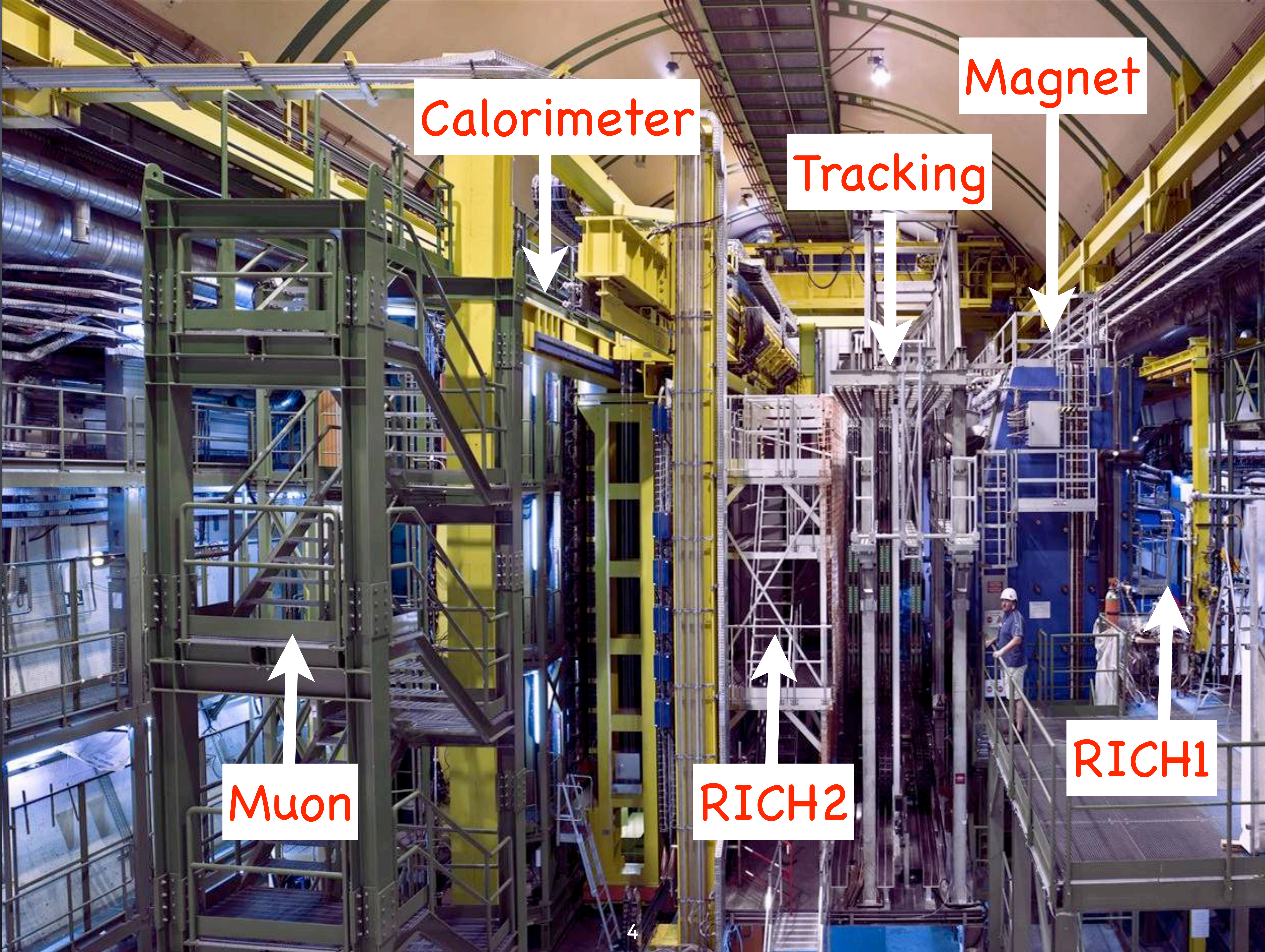


LHCb at LHC

- Observe 14 TeV pp collisions
- Dedicated to heavy flavour (charm / beauty)
- All B species produced
  - 10^{12} $b\bar{b}$ produced per nominal year (2 fb^{-1})
  - B quarks produced in the same hemisphere
- Single arm forward spectrometer
- Precision measurements of D,B decays
- Search for rare decays

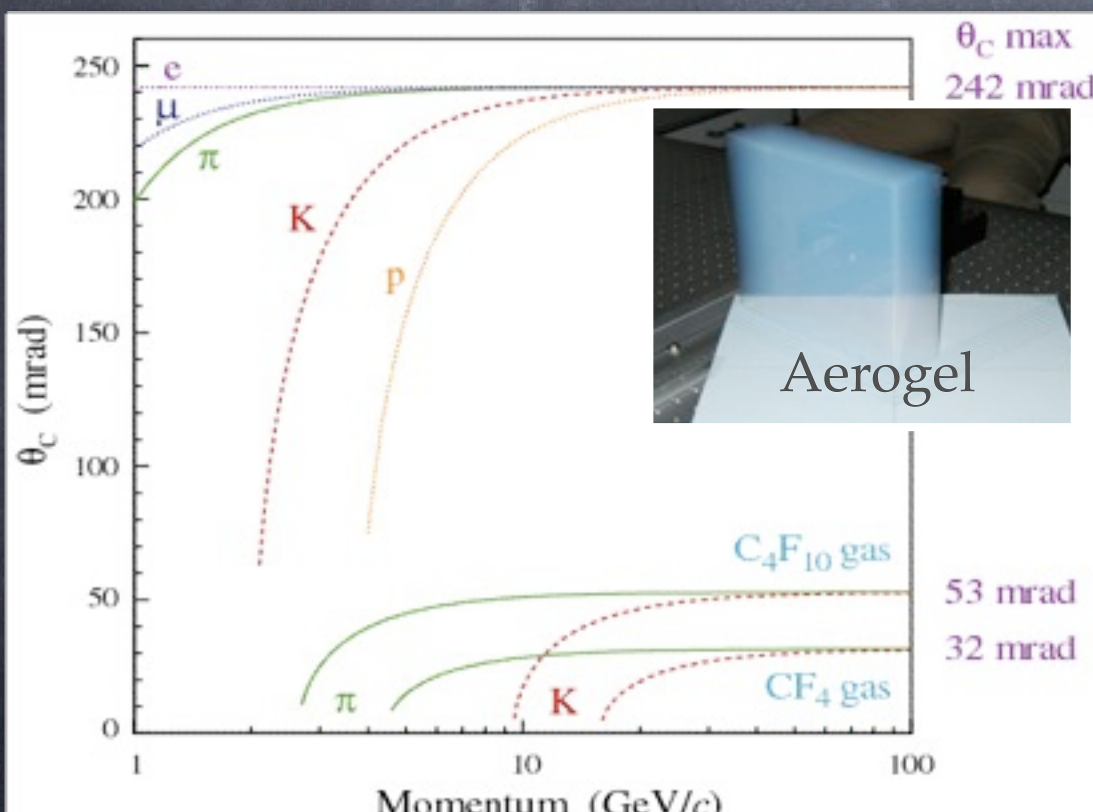


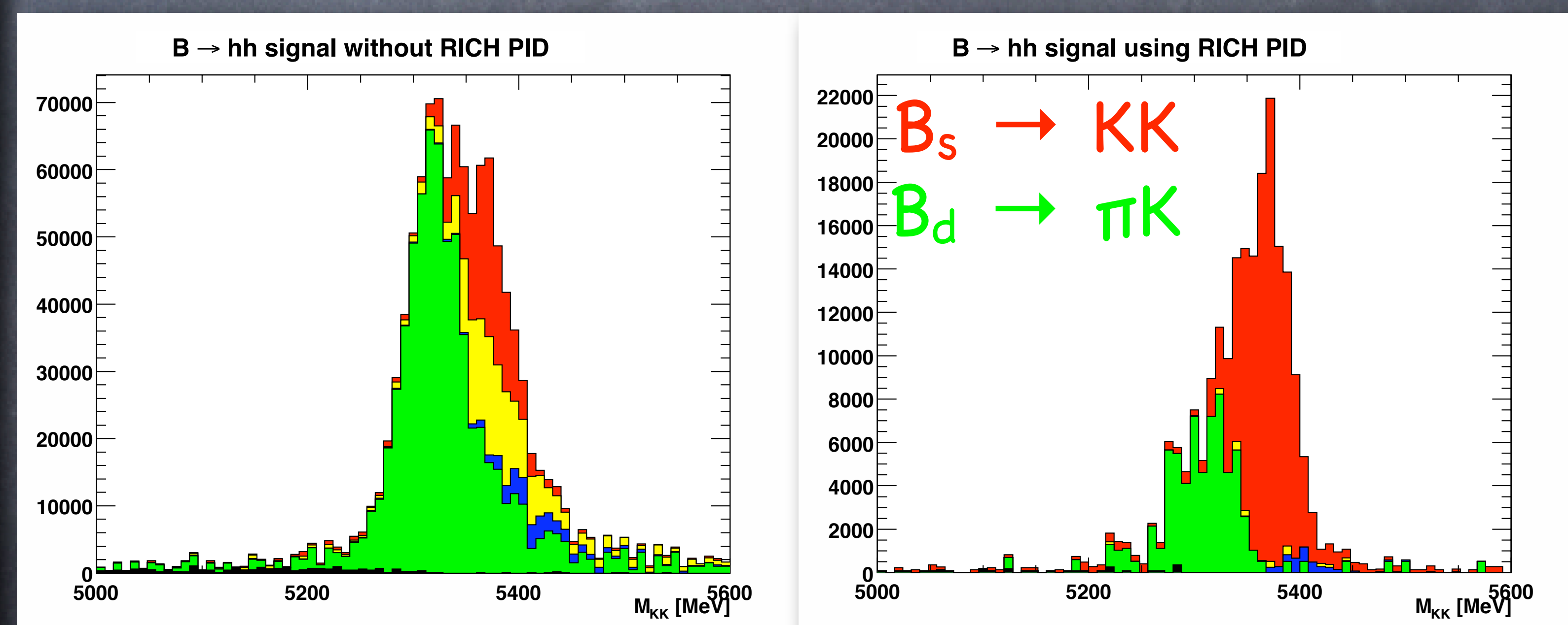



Calorimeter
Magnet
Tracking
Muon
RICH2
RICH1

Particle ID

- Excellent PID required for ambitious physics programme:
  - μ, e, γ : muon chambers and calorimeter
  - π / p / K : <u>R</u>ing <u>I</u>maging <u>Ch</u>erenkov Detectors + Tracker
    - Cherenkov angle ($\cos\theta_c = 1/\beta n$) and momentum → PID
    - Tune radiator materials to cover wide momentum range



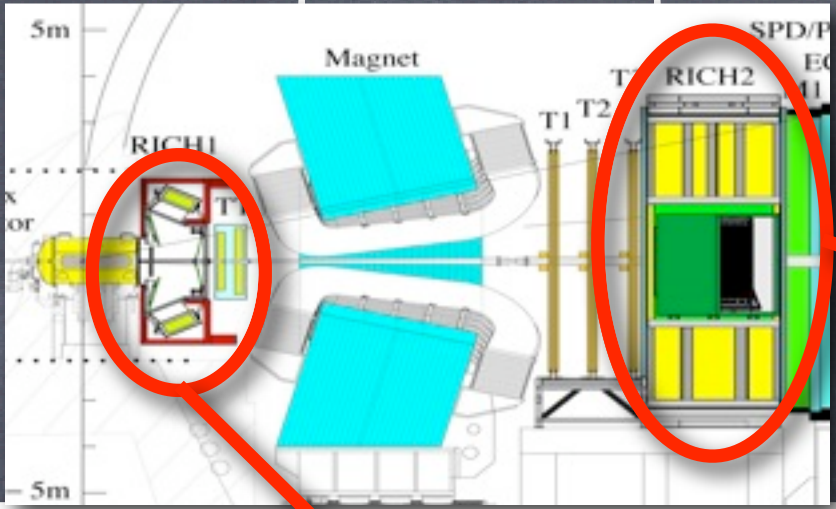


e. g. charmless two-body B decays

- Silica Aerogel (2-10 GeV/c)
- C_4F_{10} (10-60 GeV/c)
- CF_4 (16-100 GeV/c)

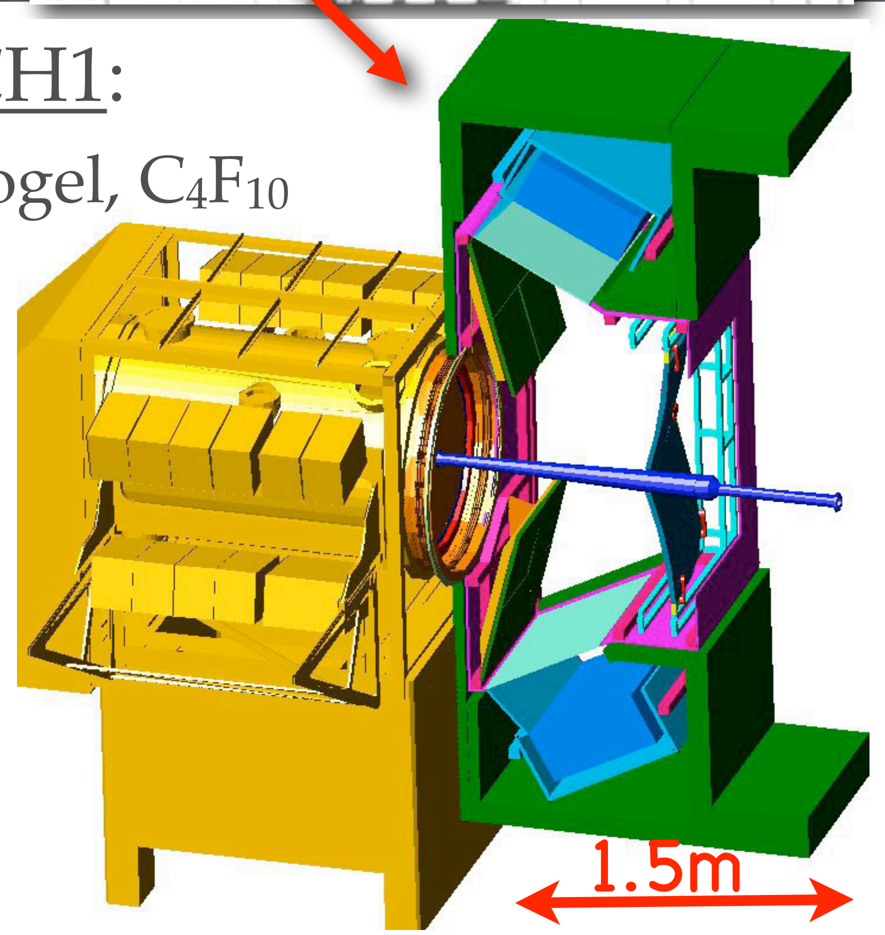
RICH Detectors

- RICH1: π/K separation up to 10 GeV/c (Aerogel) and 60 GeV/c (C_4F_{10})
- RICH2: π/K separation up to 100 GeV/c



RICH1:

Aerogel, C_4F_{10}



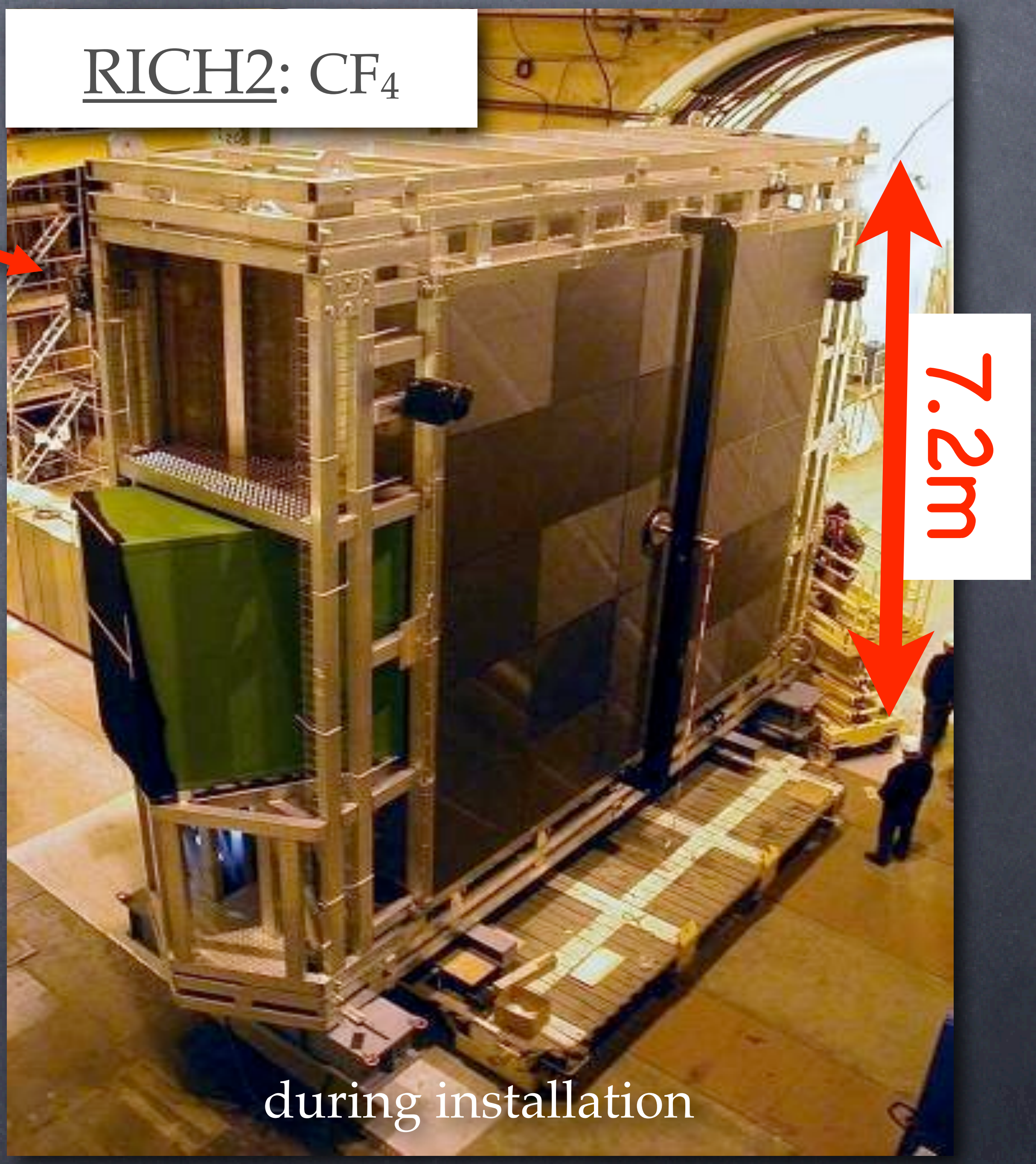
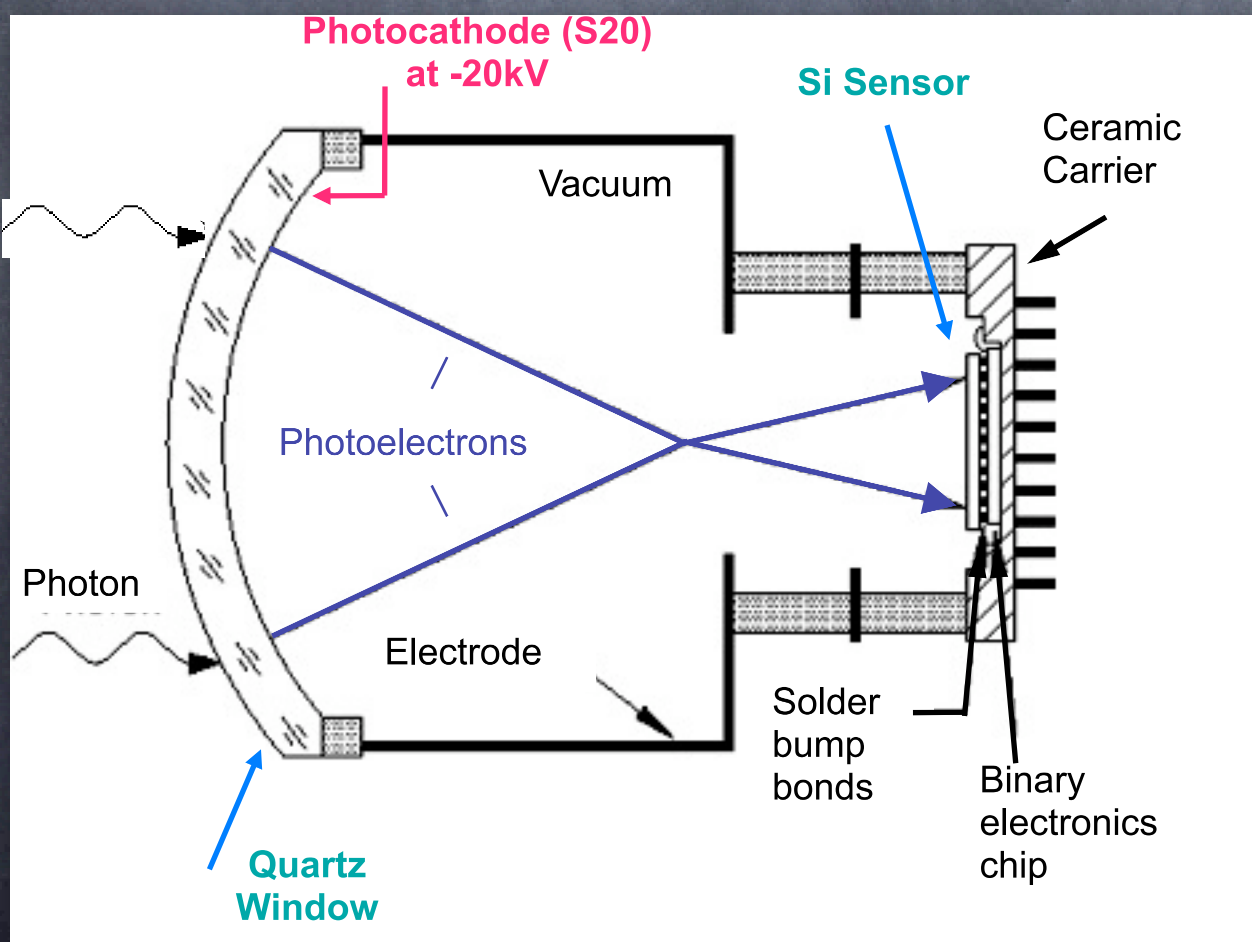
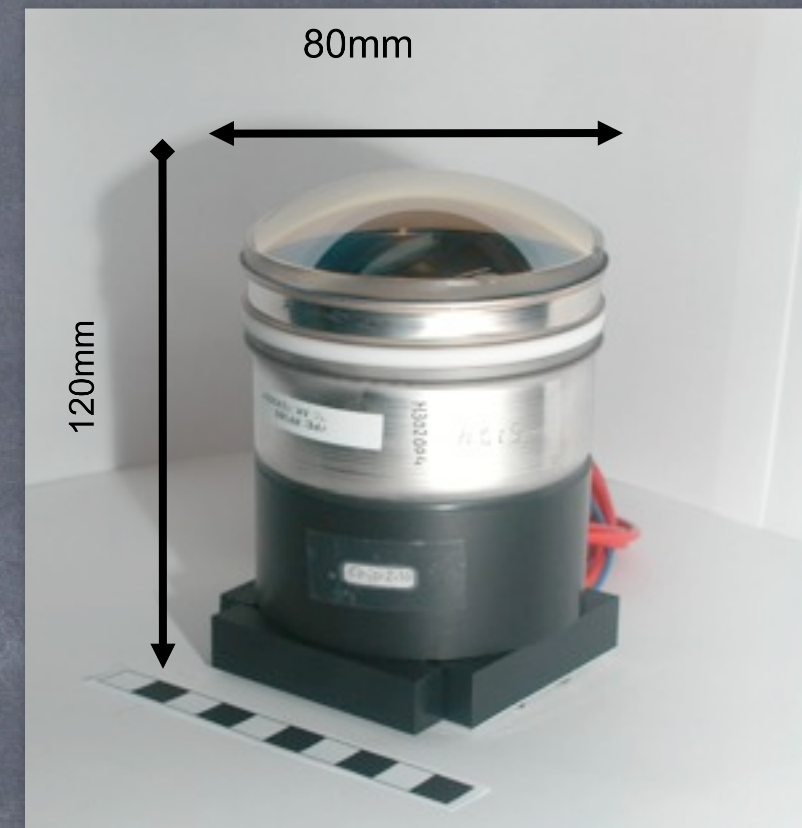


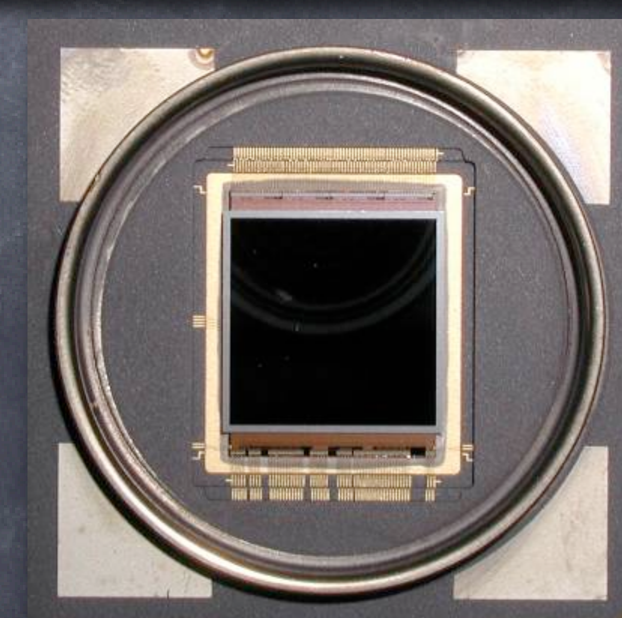
Photo Detectors

Custom Hybrid Photo Detector (HPD)

- 484 HPDs in both RICH detectors
- Binary read out via Si pixel chip: 1024 channels
- 2.5 × 2.5 mm^2 granularity at cathode window
- ~500'000 pixels over ~3 m^2 area
- Single photon sensitivity between 200 - 600 nm



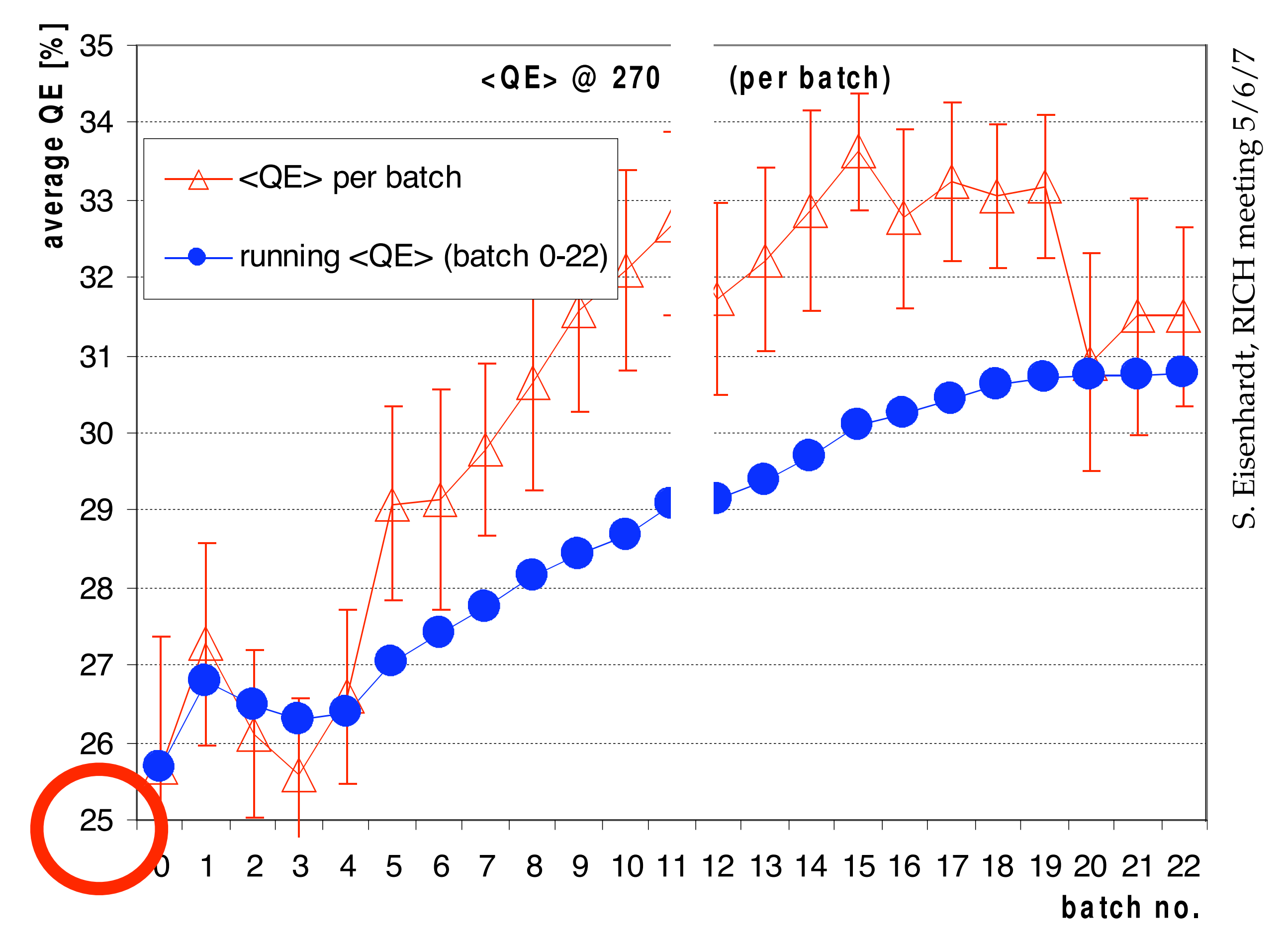




Si pixel chip

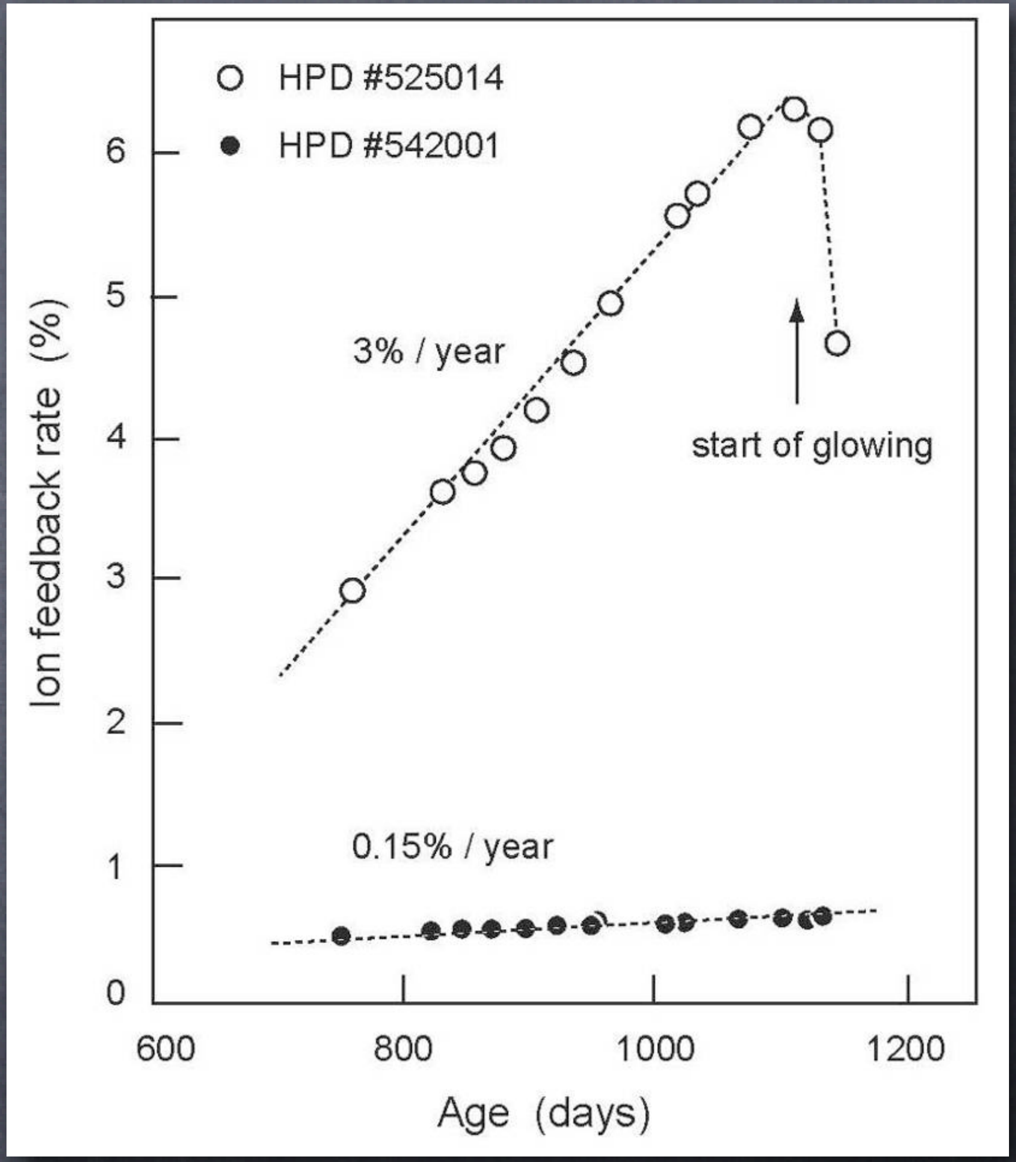
Quantum Efficiency

- Q.E. determines efficiency to convert photon to electron
- All HPD produced <u>exceed requirement</u>: Q.E. > 20.0%
- Significant learning-process at manufacturer (DEP):
  - ➥ 24% improvement in Q.E. with delivered HPD batches
  - ➥ Optimise HPD placement w.r.t. anticipated hit occupancy



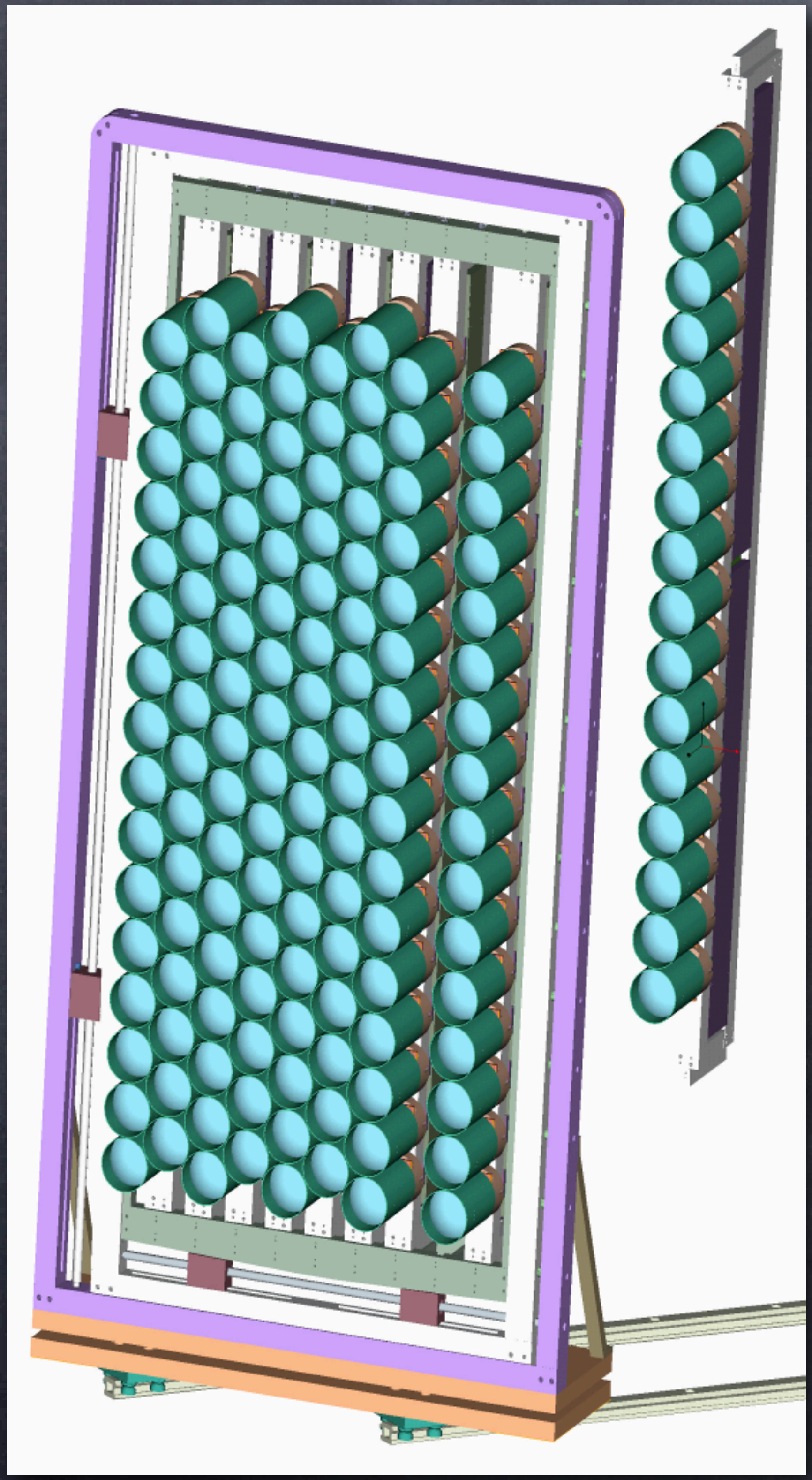
HPD Aging

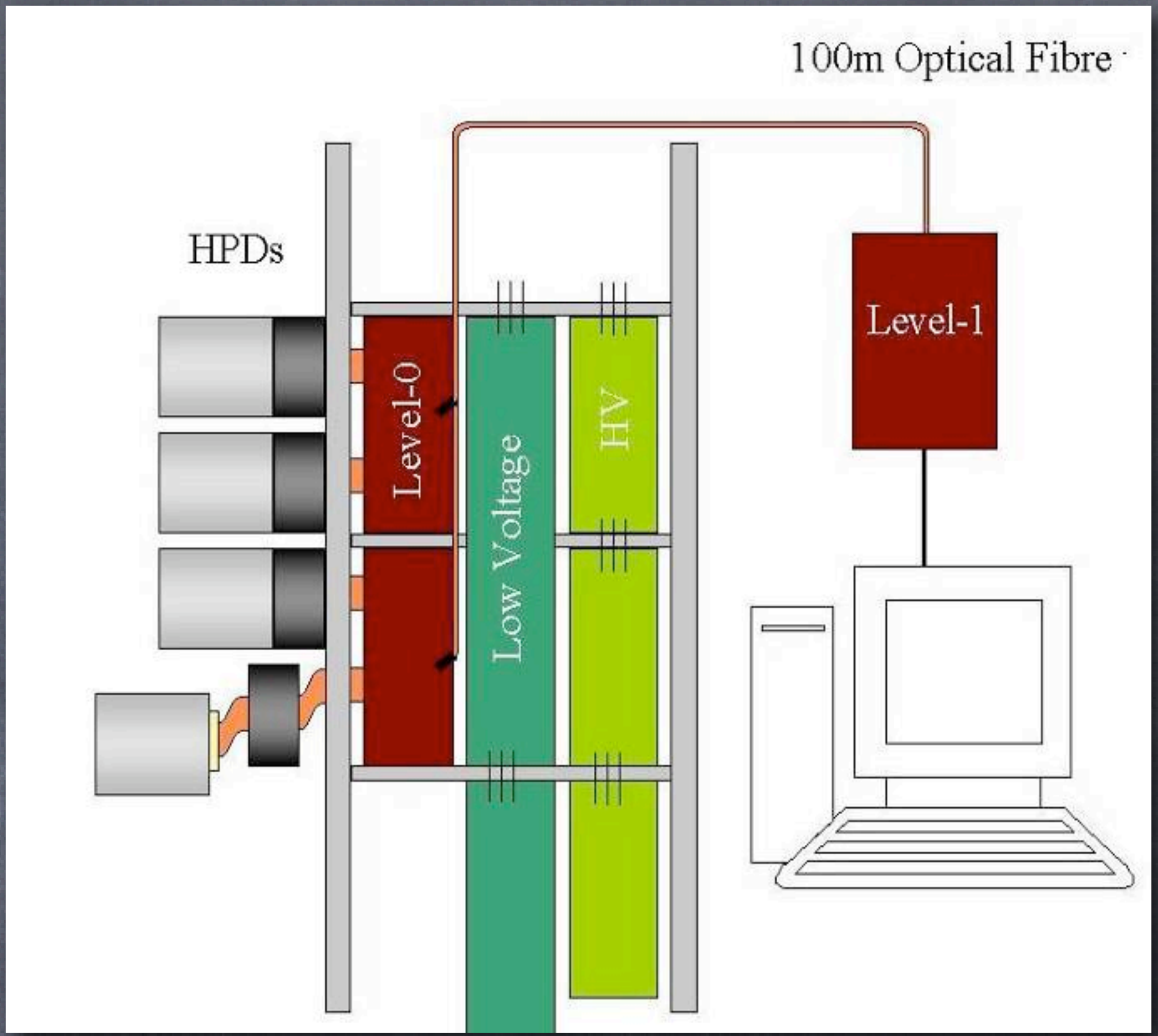
- **Ion feedback (IFB):**
  Photo-electron hits residual ion in HPD vacuum
  ➥ Measure of vacuum quality
  - Rate determined using fractions of large clusters (> 5 hits)
  - Regularly measured in past 18 months
- Most show linear increase with shallow gradient, noisy HPDs with steeper gradient
- Estimate to replace ~11 HPDs/year (~2%/year) over lifetime of experiment



- More details about HPDs on dedicated Poster → S. Eisenhardt

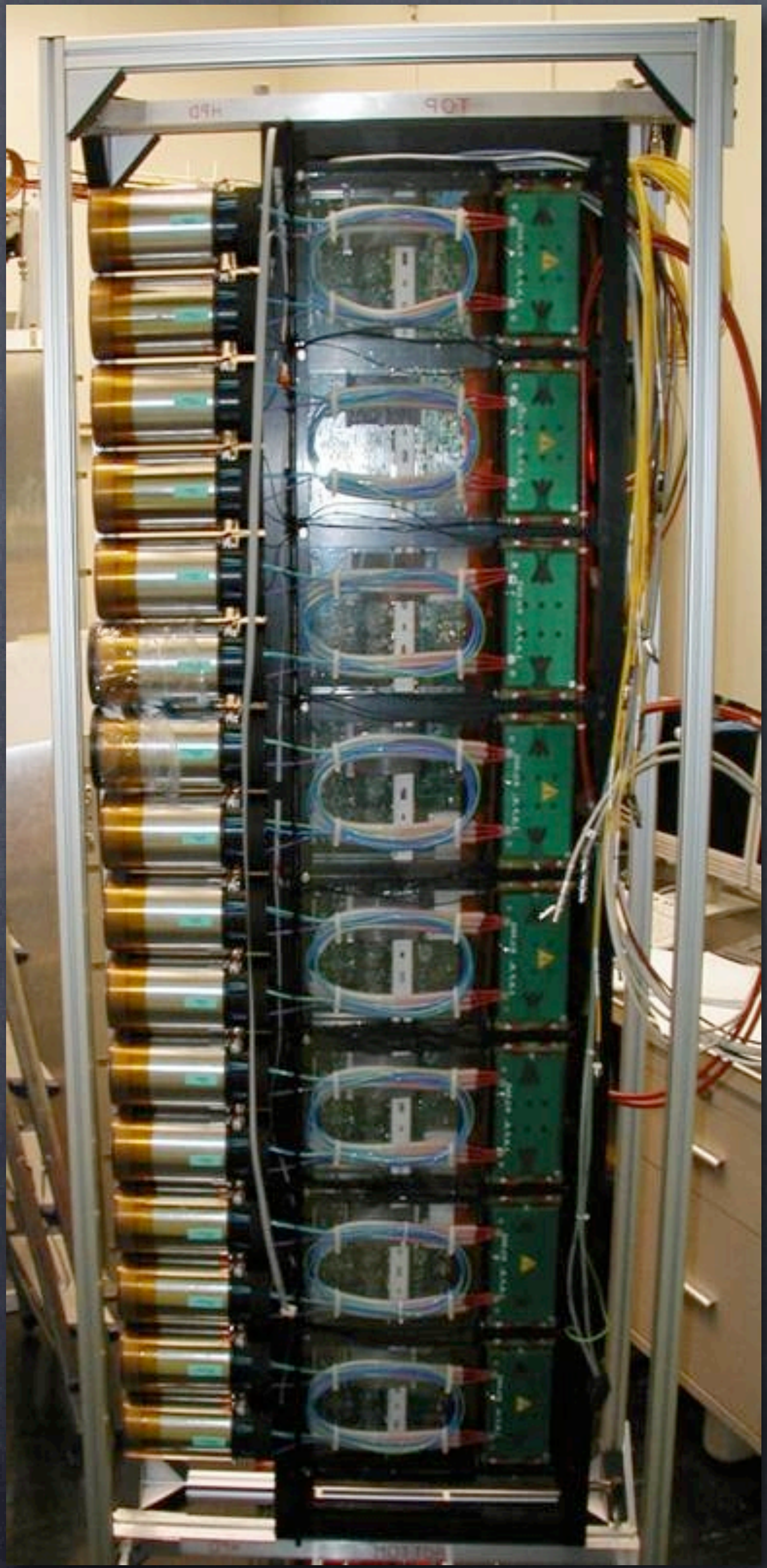
HPD Integration





- HPDs mounted in columns
- μMetal magnetic shield around each tube
- Services for power-supply and front-end electronics mounted in frame

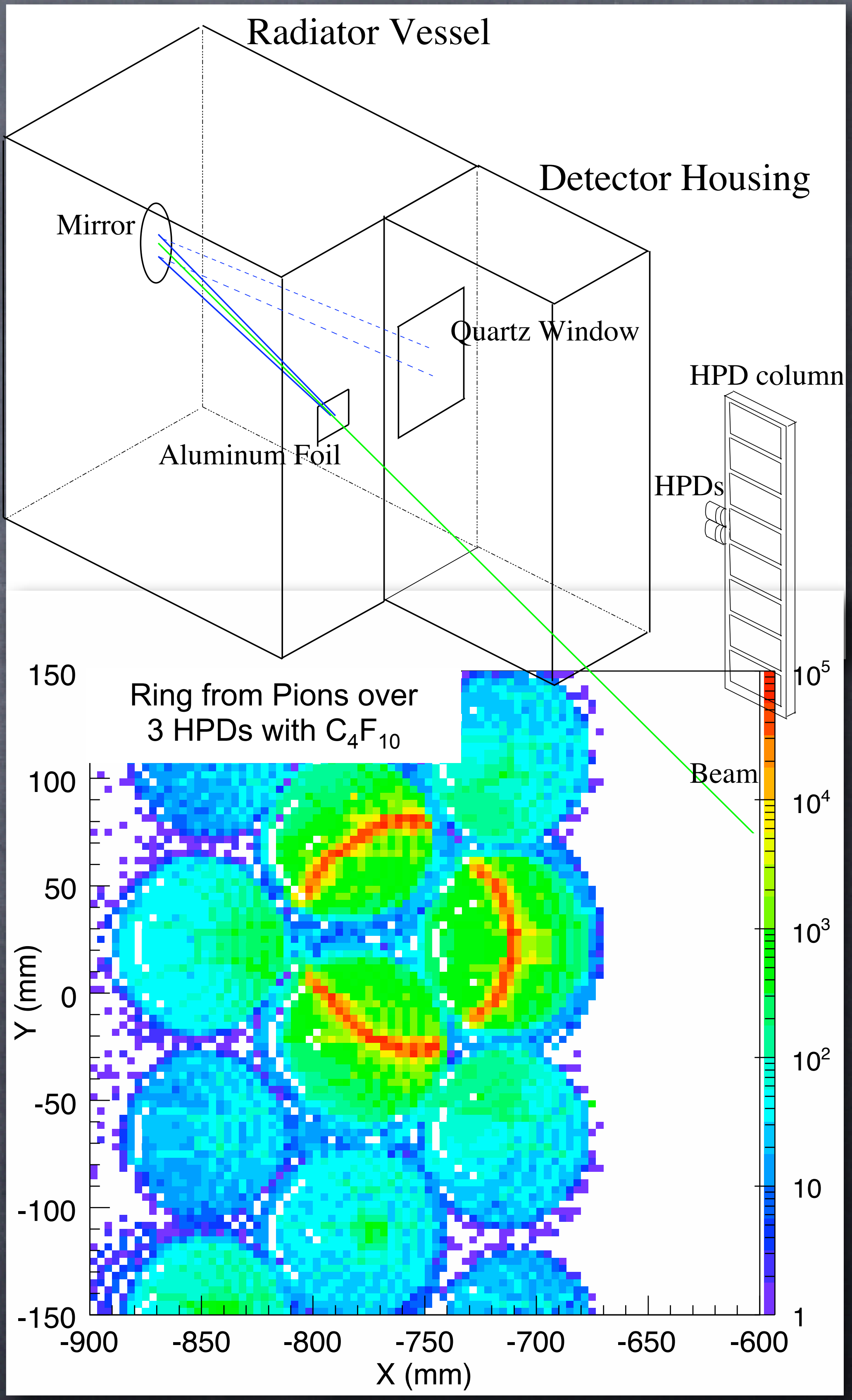
Fully Equipped Plane



Beam Tests

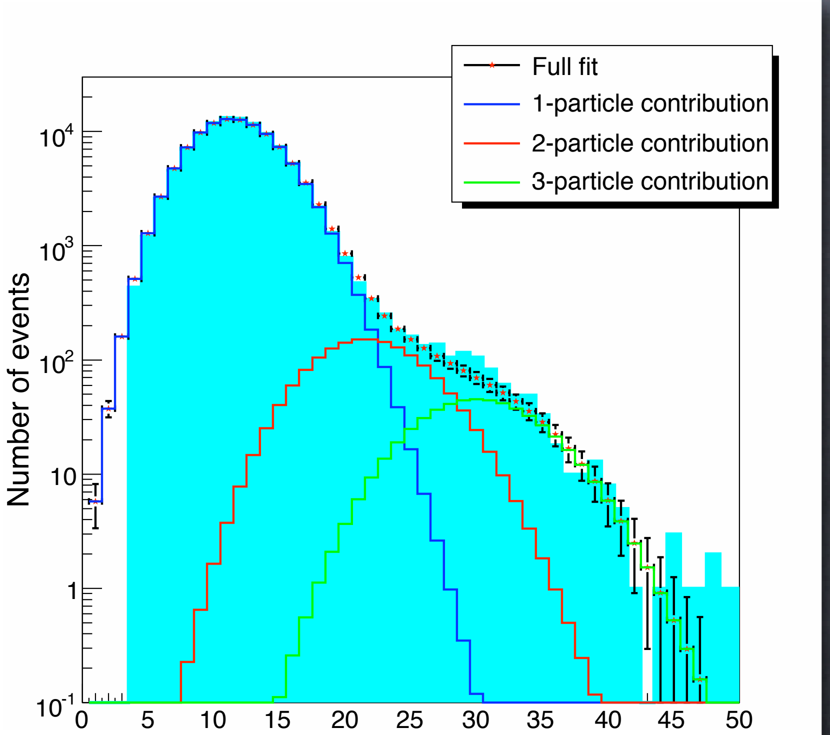
- Performance of components monitored in multiple beam tests
- Sep. 2006: beam test using CERN's SPS:
  - 25 ns beam structure matching LHC conditions
  - N_2 and C_4F_{10} used as radiators
    - C_4F_{10} also in RICH1
  - As realistic environment as possible prior to LHC operations
    - HPDs / DAQ electronics from final production
    - Data recorded using LHCb online software

➥ Important milestone: test all aspects from photon detection to analysis prior to LHC start

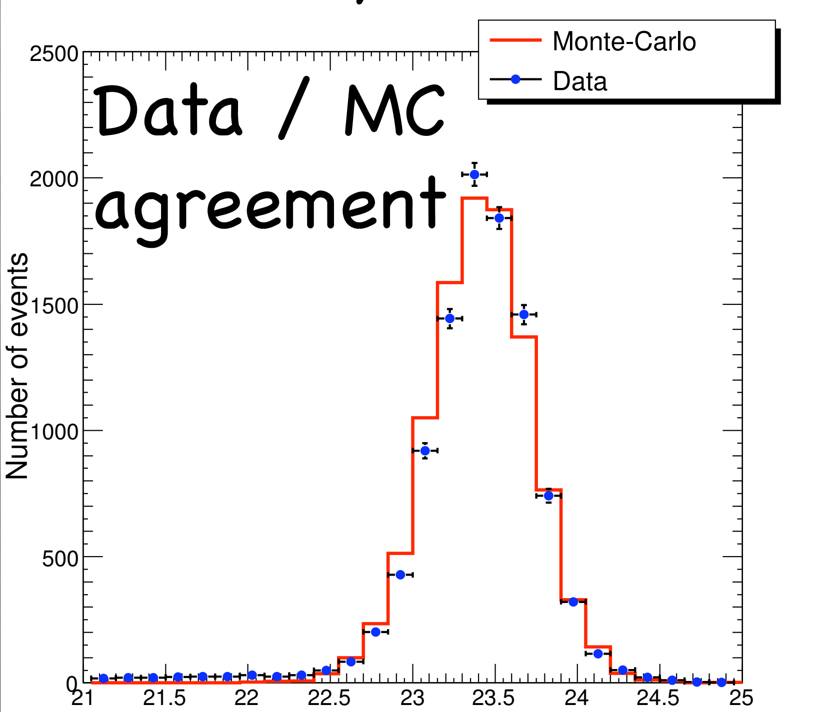


Beam Test - Analysis

- Analysis done using official LHCb reconstruction software
- Simulated events obtained using full LHCb simulation software based on Geant
  - Tune simulation to first available data
  - Systematic studies comparing data / MC
- Photon Yield and Cherenkov angle resolution key measurements
  - Photon yield in excellent agreement with predictions
    - Including multiple physics BG
  - Cherenkov angle resolution
    - $\sigma(\Theta_c) \approx 0.3$ mrad for N_2
    - $\sigma(\Theta_c) \approx 0.16$ mrad for C_4F_{10}
- NIM A 603, Issue 3 (2009) p. 287-293

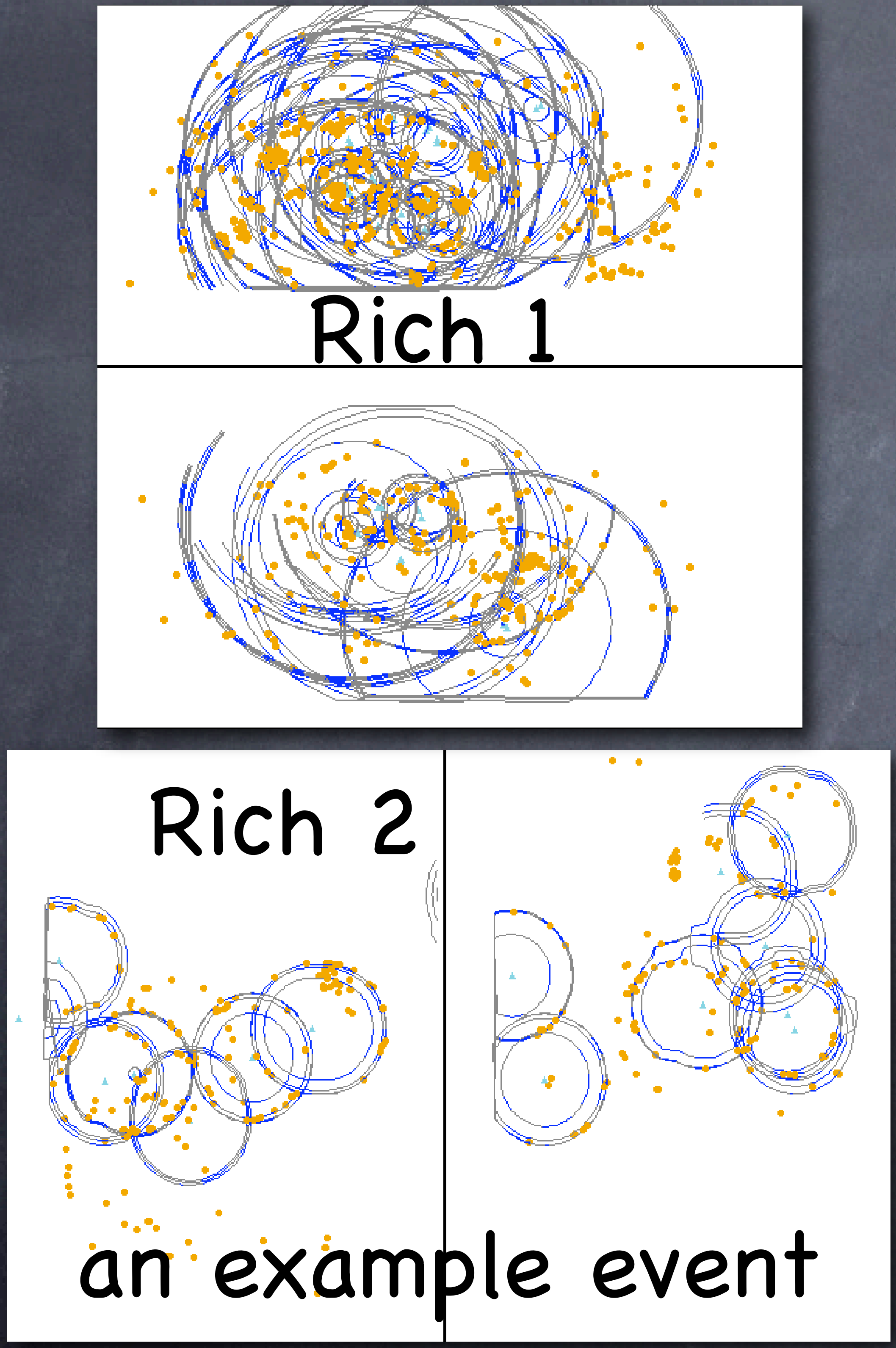


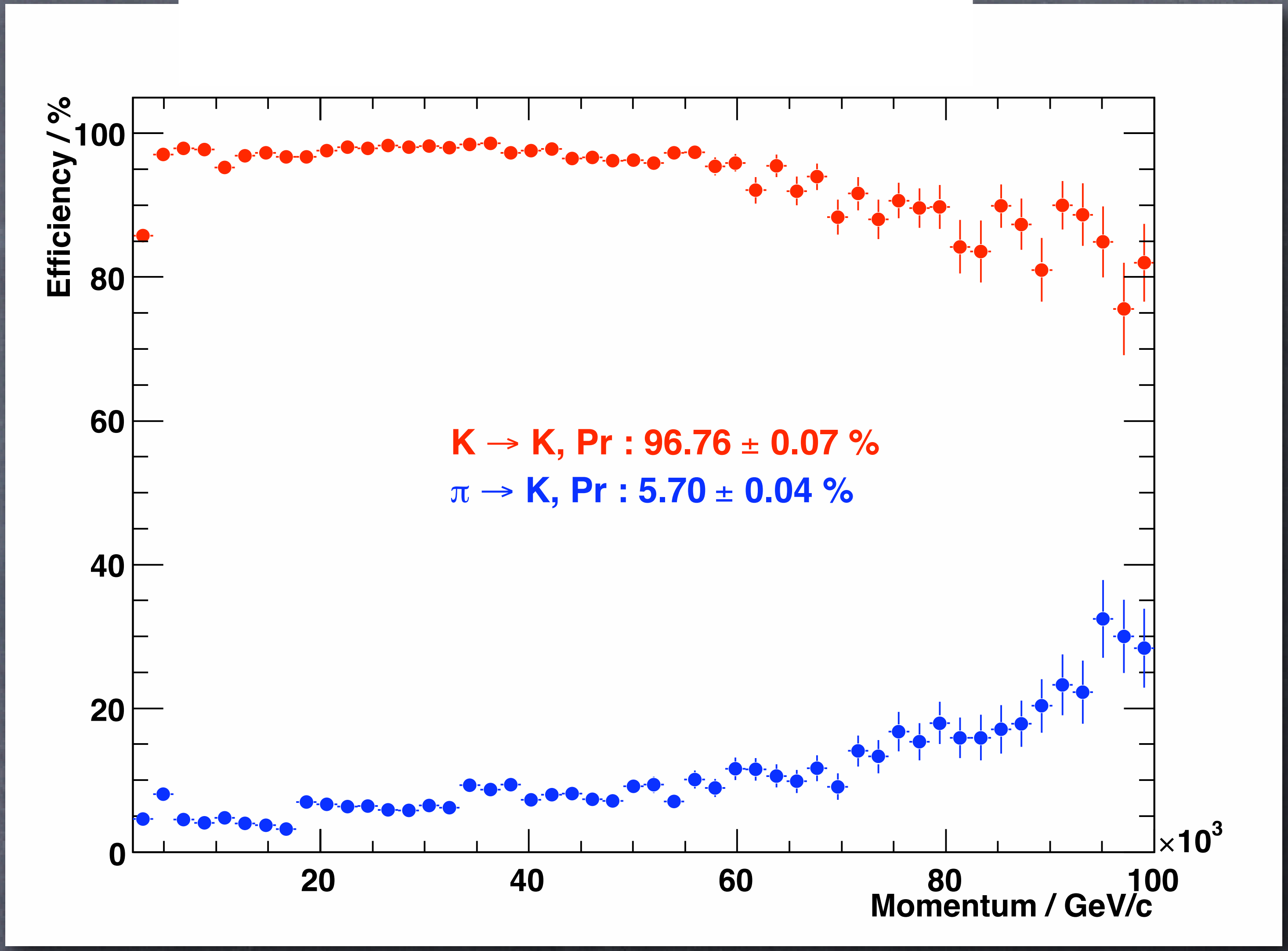
Photon yield for N_2



Cherenkov angle for N_2

Expected Performance





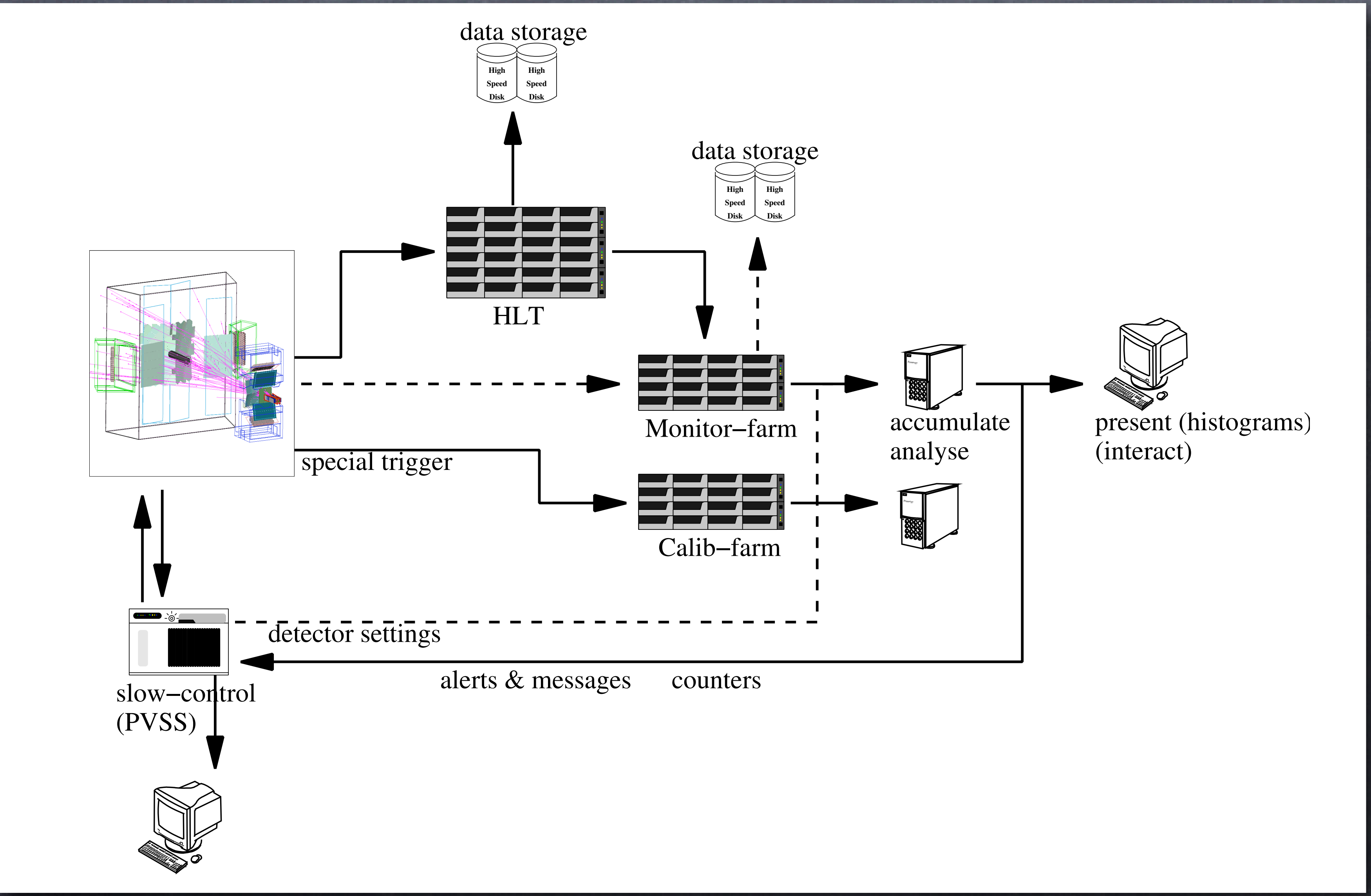
<u>Performance estimated from realistic simulation:</u>

$K \to K,p$: 97% effficiency

$\pi \to K,p$: 6% misID rate

Monitoring & Data Quality

- Complex detector: ~500 HPDs with 1024 channels each
- PID crucial to most LHCb analyses!
  ➥ rigorous scheme of online monitoring and data quality

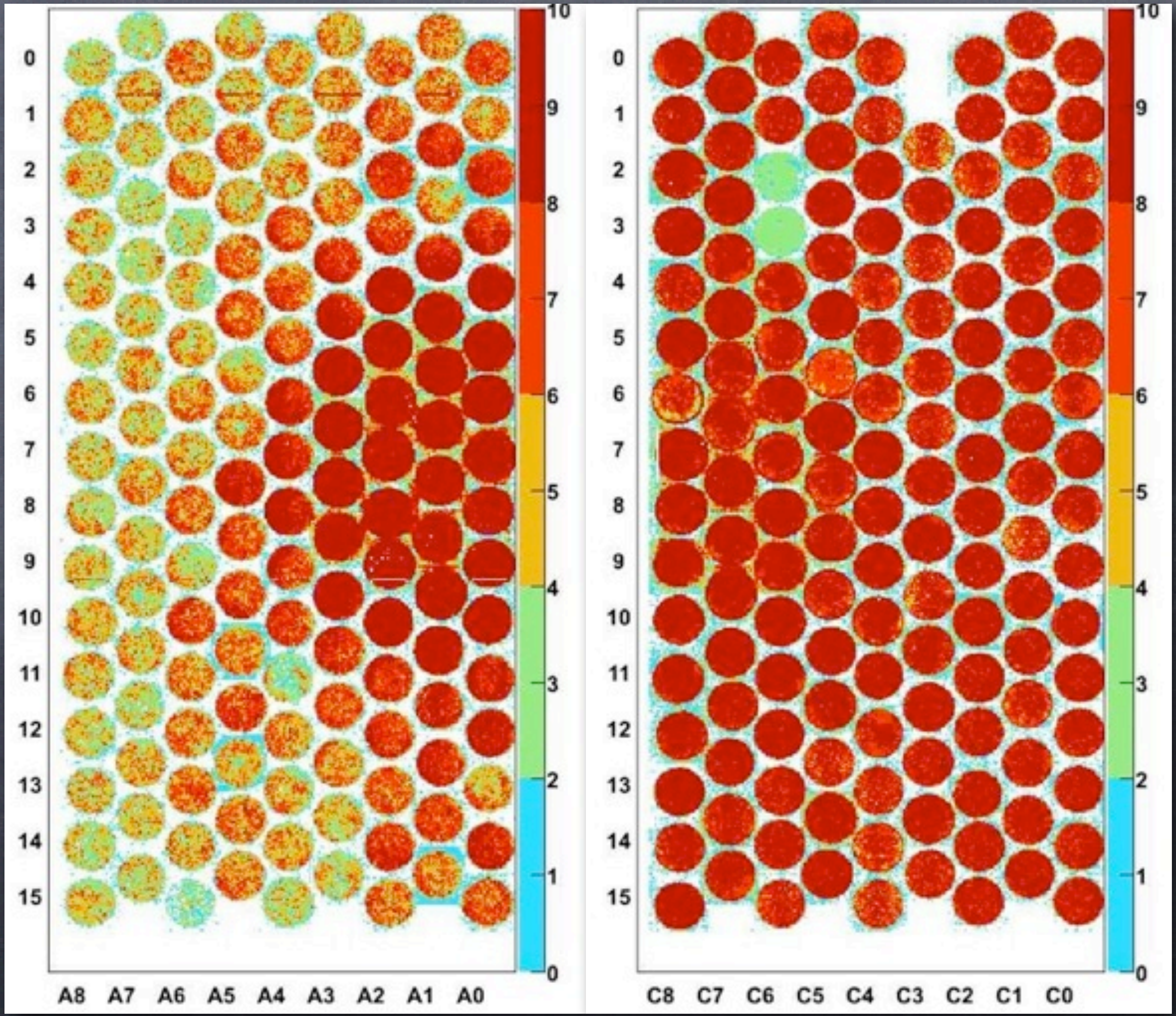


Monitoring & Data Quality

- Crucial for both RICH safety and PID performance
  ➥ Identify issues as early as possible
- Monitoring and DQ on multiple levels:
  - **Online:**
    - Low level: Data integrity, occupancy, ..
    - Mid Level: Alignment, refractive index, ion feedback, Testpattern, ...
    - High Level: PID performance using exclusive decays
  - **“Express stream”** :5Hz stream covering long period
    ➥ monitor longer trends
  - **Offline:**
    - PID performance during reconstruction (full statistics)
- More information on dedicated Poster (U.K.)

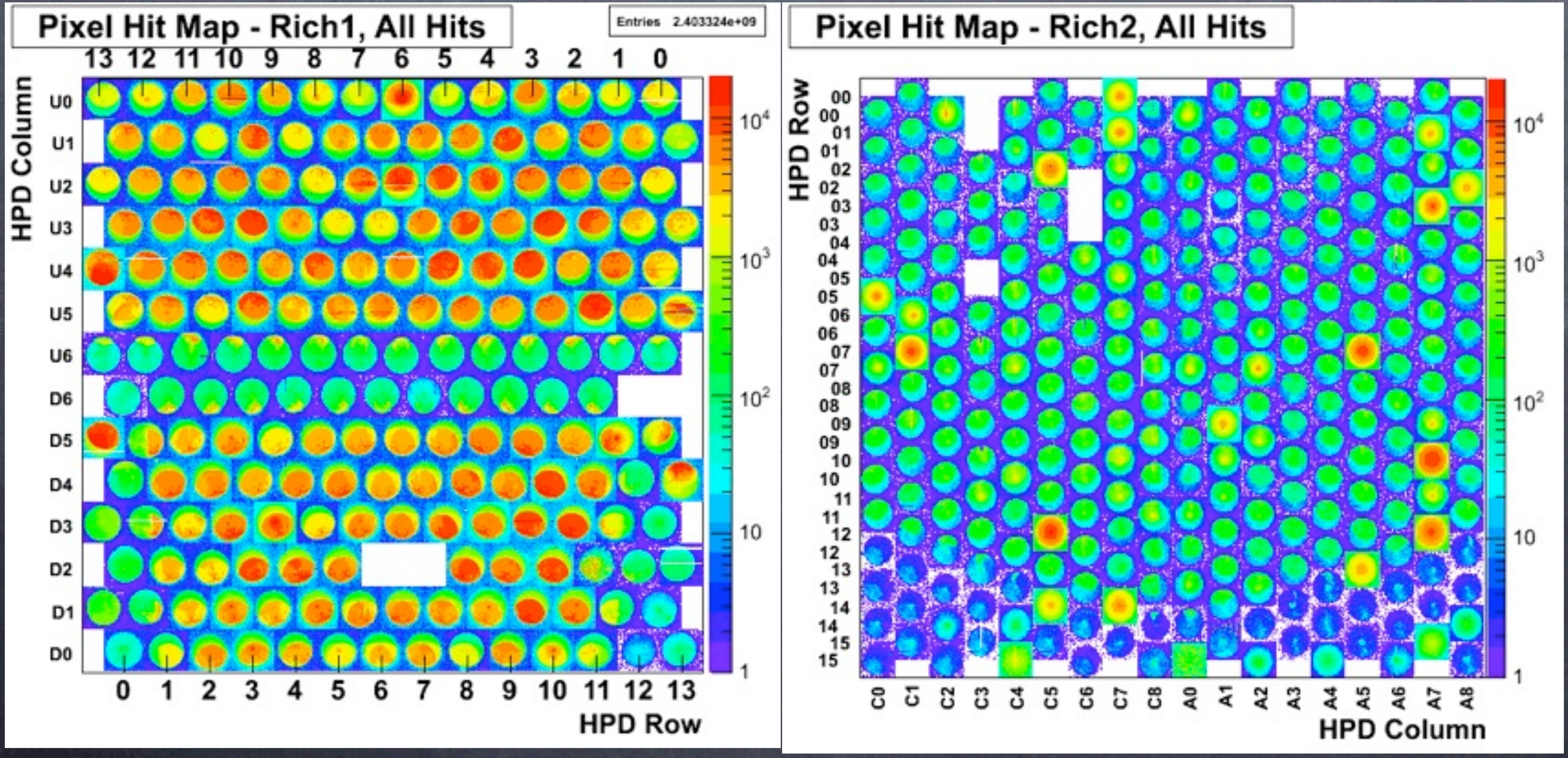
LHC Start-Up

High intensity shower from particles created when LHC beam was shot on a beam stopper (TED) close to LHCb



Laser Scan

- Laser installed in RICH gas enclosure
  ➥ Uniformly illuminate HPD plane (shadows from μMetal shielding)
- Commissioning: read out whole RICH detector
  - Optimise DAQ, control software, ...
  - Closely monitor HPD behaviour and status (in absence of beam)
  - Perform calibration scans

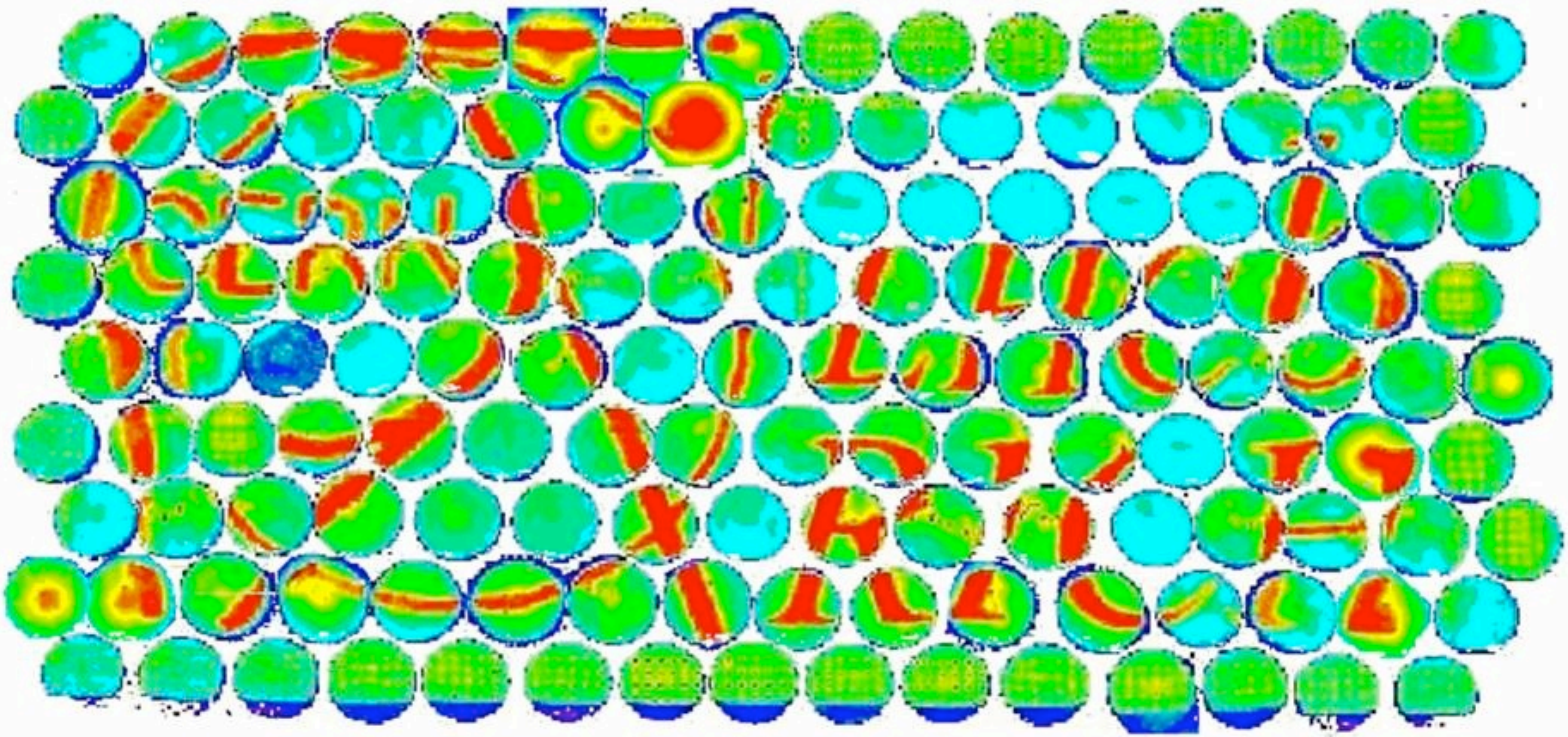


Summary

- LHCb RICH detectors installed and ready for data-taking
- Integration test using final components using a beam as close as possible to LHC conditions
  - ➥ Analysis done using LHCb reconstruction and simulation software
- Successful running during LHC startup Sep 2008
- HPD status closely monitored while further preparing for beam
- Rigorous monitoring and data-quality checks being implemented
  - Low level (data-integrity) to high level (PID performance)
  - Regularly tested at Full Experiment Scale Tests (FEST) at nominal data-taking rate.

- LHCb (RICH) is ready for collisions at LHC start-up !

Backup



Single photon accumulated image taken shining from a projector (the same used for the magn. distortion) on the C-side of RICH2. The light level over the whole surface is ~100 phel per event.

Flavour Physics

Weak Eigenstates are non-trivial superposition of flavour Eigenstates
→ CKM matrix
➥ Phase gives rise to CP violation

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Standard Model very successful - but many open questions
  - Origin of mass (→ Higgs)
  - Cosmic abundance of matter (→ further sources of CP violation)
  - ...
- Searching for New Physics
  - Direct searches: Expect NP at TeV scale (→ ATLAS / CMS)
  - Indirect searches (→ LHCb)
    - Complement direct searches
    - Measure properties, flavour structure of NP
    - E.g.
      - Enhancing rare decay branching ratios
      - Precision measurements - theoretical expectations

Flavour Physics

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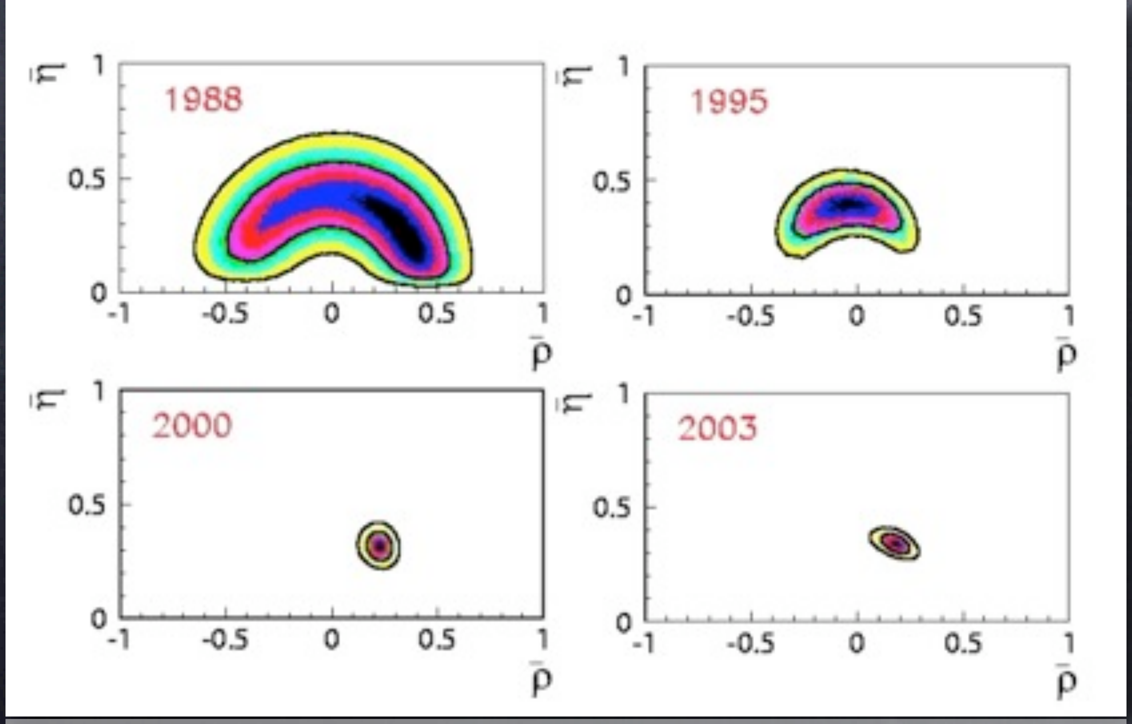
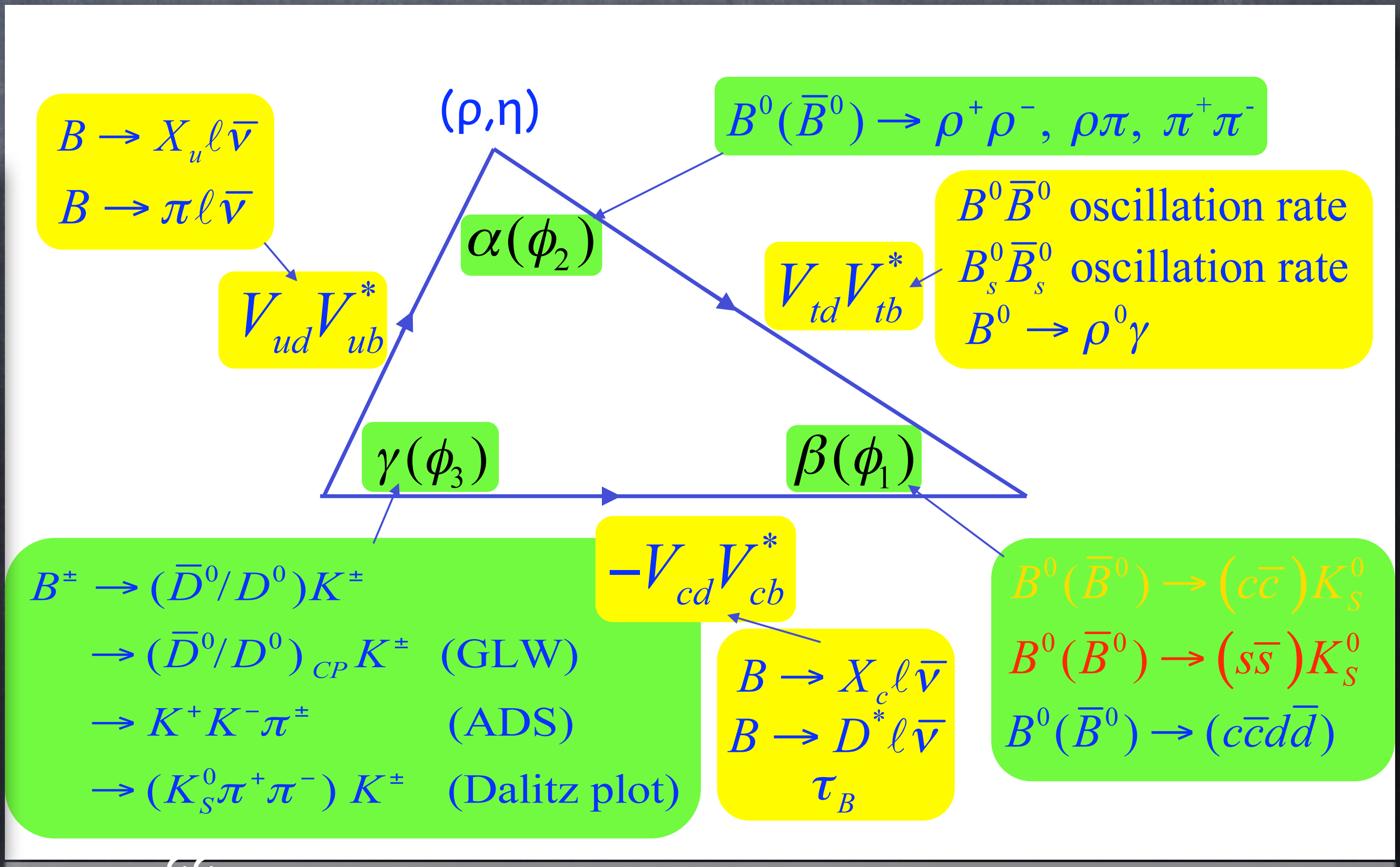
→ CKM matrix

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \underbrace{\begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}}_{V_{CKM}} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

- Phases in some of the V_{xy}
  - ➥ CP violation: matter treated differently from anti-matter
- Popular parametrisation: Wolfenstein → ρ,η, λ, A
  - triangle in complex ρ,η plane
- Precision tests of CP violation:
  - Over-constrain triangle
  - Ongoing effort !





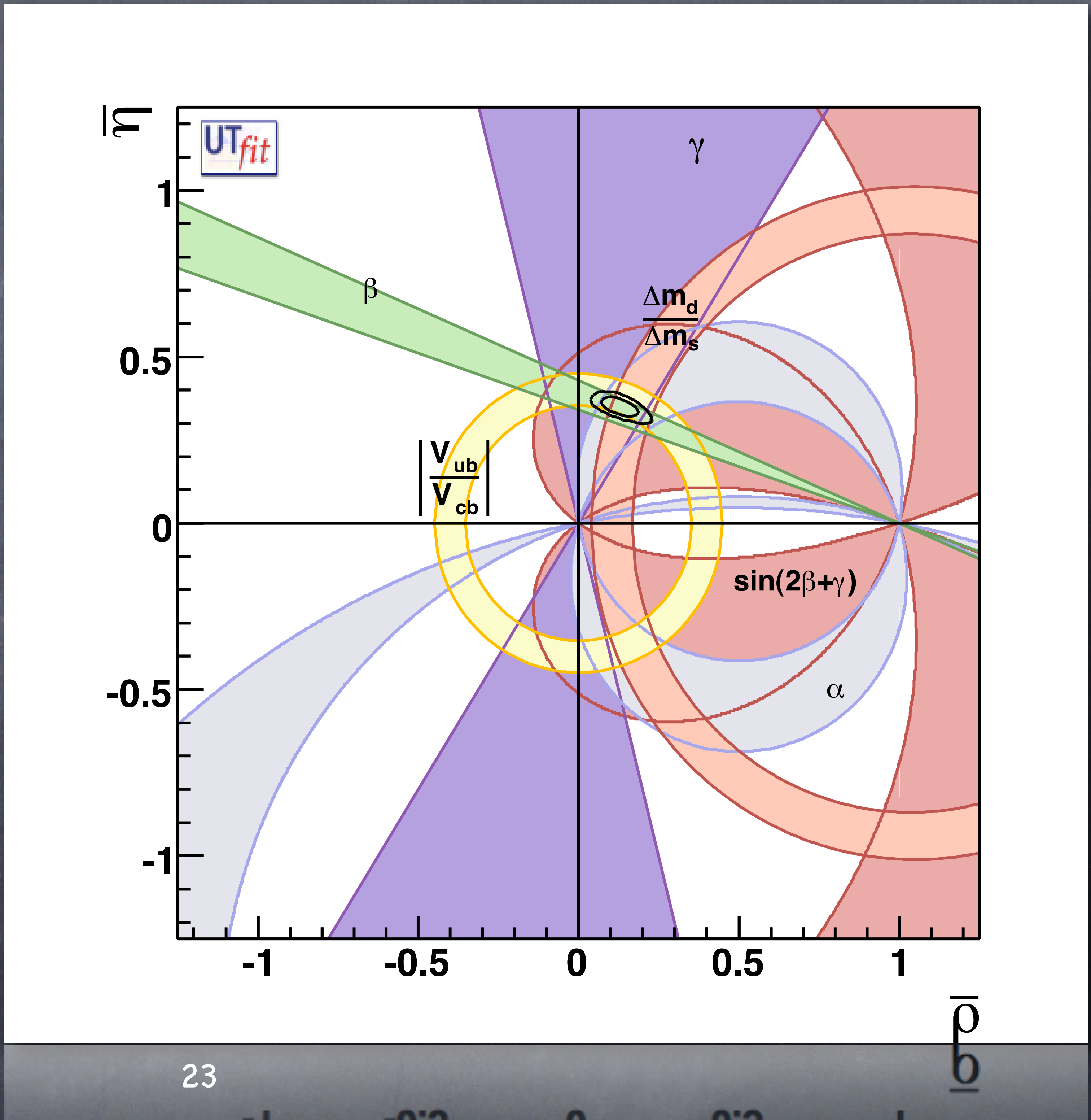
C. Matteuzzi, Moriond 2009

Flavour Physics

- Current averages / summary from the UTFit collaboration

ρ = 0.1454 ± 0.022
η = 0.342 ± 0.014
α = 92.0 ± 3.2 °
β = 22.0 ± 0.8 °
γ = 65.6 ± 3.3 °
....

(many more ... worth a summary talk on its own...)

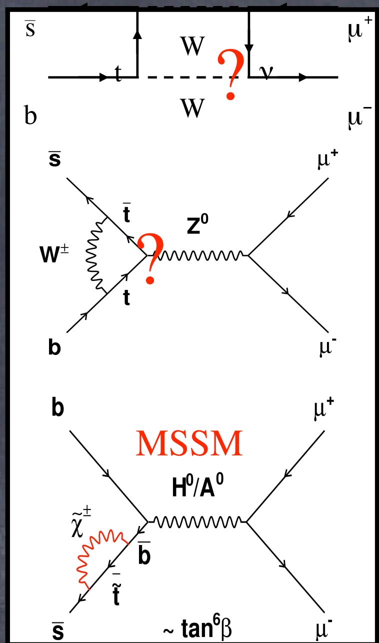


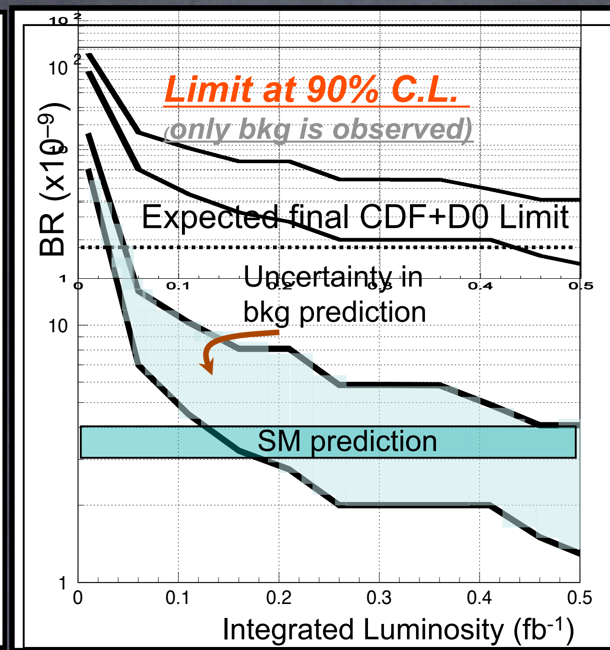
LHCb physics

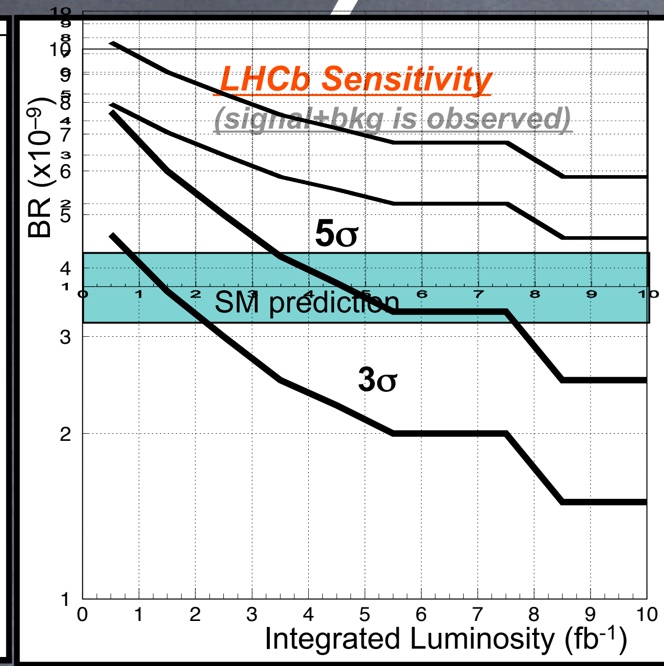
- Dedicated B physics experiment
- Covering all aspects of Charm and Bottom physics
  - Cross-section, rare decays, lifetimes, spectroscopy, ...
- Higher cross-section than FNAL, better detector, trigger
  ➥ more B (D) per fb^{-1}

Channel	1 fb^{-1} at LHCb = ... fb^{-1} at Tevatron	
$D^0 \rightarrow K\pi$	20	50M / 2fb^{-1} at LHCb 0.5M / 0.35fb^{-1} at CDF
$B \rightarrow hh$	30	200k / 2fb^{-1} at LHCb 6.5k / 1fb^{-1} at CDF
$B^+ \rightarrow J/\psi\ K^+$	60	1.7M / 2fb^{-1} at LHCb 3.4k / 0.25fb^{-1} at CDF
$B_s \rightarrow D_s\ \pi$	10	120k / 2fb^{-1} at LHCb 5.6k / 1fb^{-1} at CDF

LHCb - Key Analyses



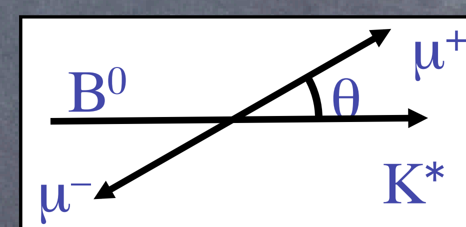




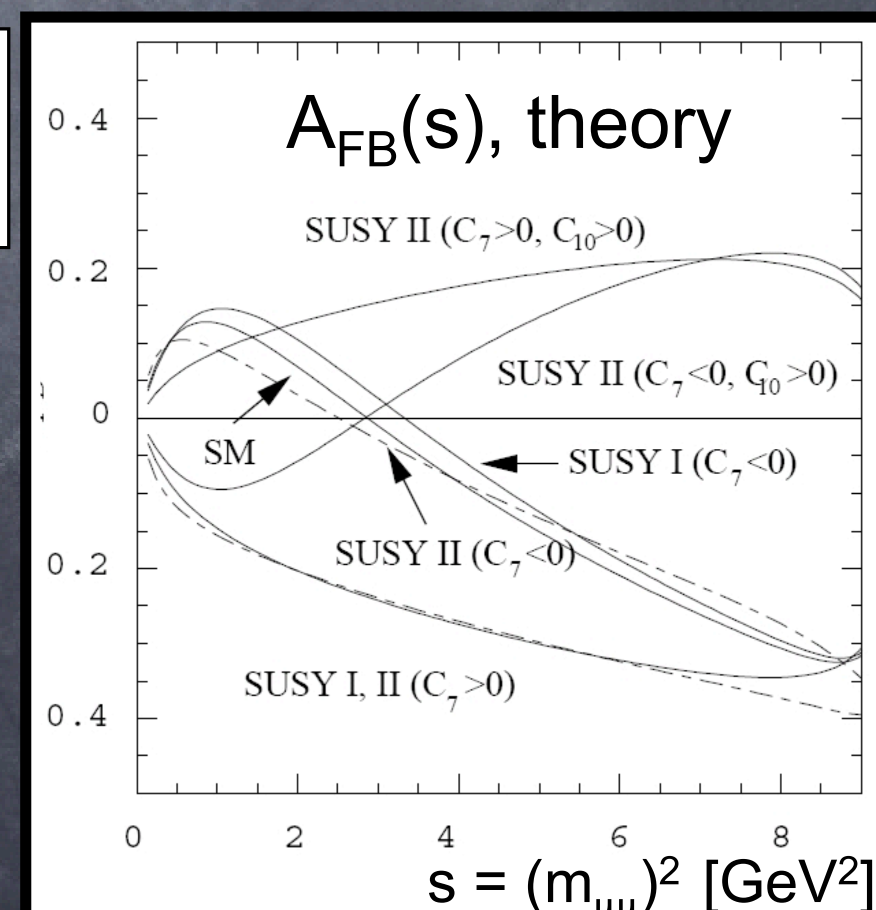
$B_s \to \mu\mu$

- Very rare decay
- Strongly enhanced in some SUSY models

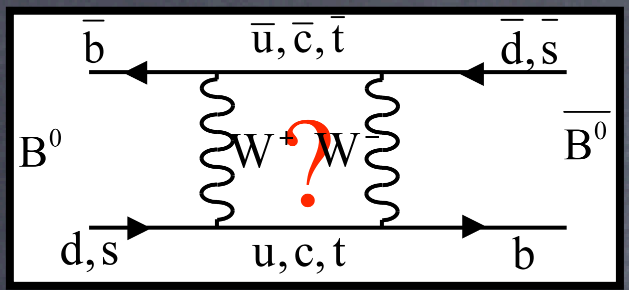
A_{FB} in $B^0 \to K^* \mu\mu$



- Suppressed loop decay
- $A_{FB}(s)$ in μμ rest-frame probe of NP
  - Shape of distribution
  - Zero crossing
- Determine ratio of Wilson coefficients C_7/C_9 with 13% stat. uncertainty



LHCb - Key Analyses

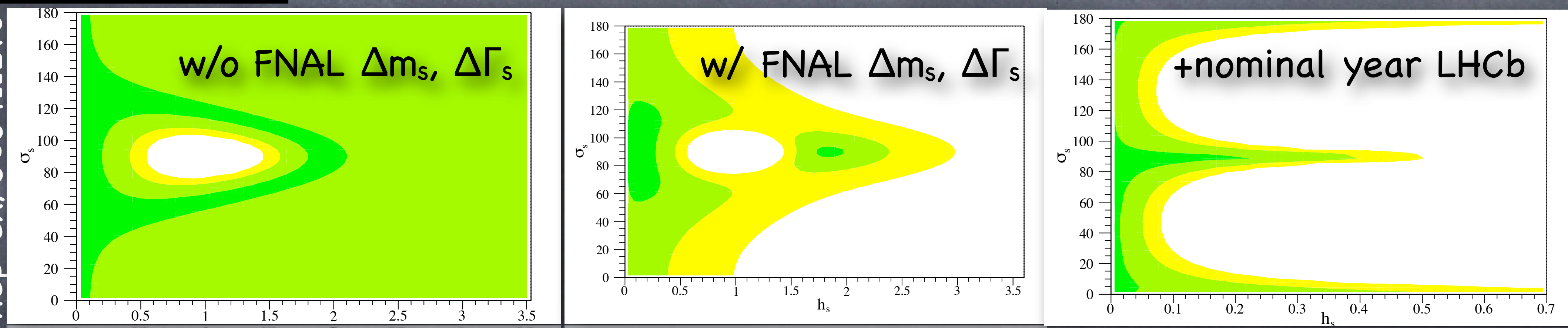


Bs mixing phase ϕ_s very small in SM

➥ potentially large contributions from NP

Analyses: $B_s \rightarrow J/\psi\phi$, $J/\psi\eta$, D_sD_s || $c\tau(B) \rightarrow \Delta\Gamma$ ...

hep-ex/0604112v3



CKM angle γ

Tree Level:

$B_s \rightarrow D_sK$

$B_d \rightarrow D^{(*)}\pi$

$B^\pm$, $B_d \rightarrow D^{(*)}K^{(*)}$, with D^0 decaying to:

2 bodies: πK, KK, ππ

3 bodies: KS ππ, KS KK, KS Kπ

4 bodies: Kπππ, KKππ

Penguin Level:

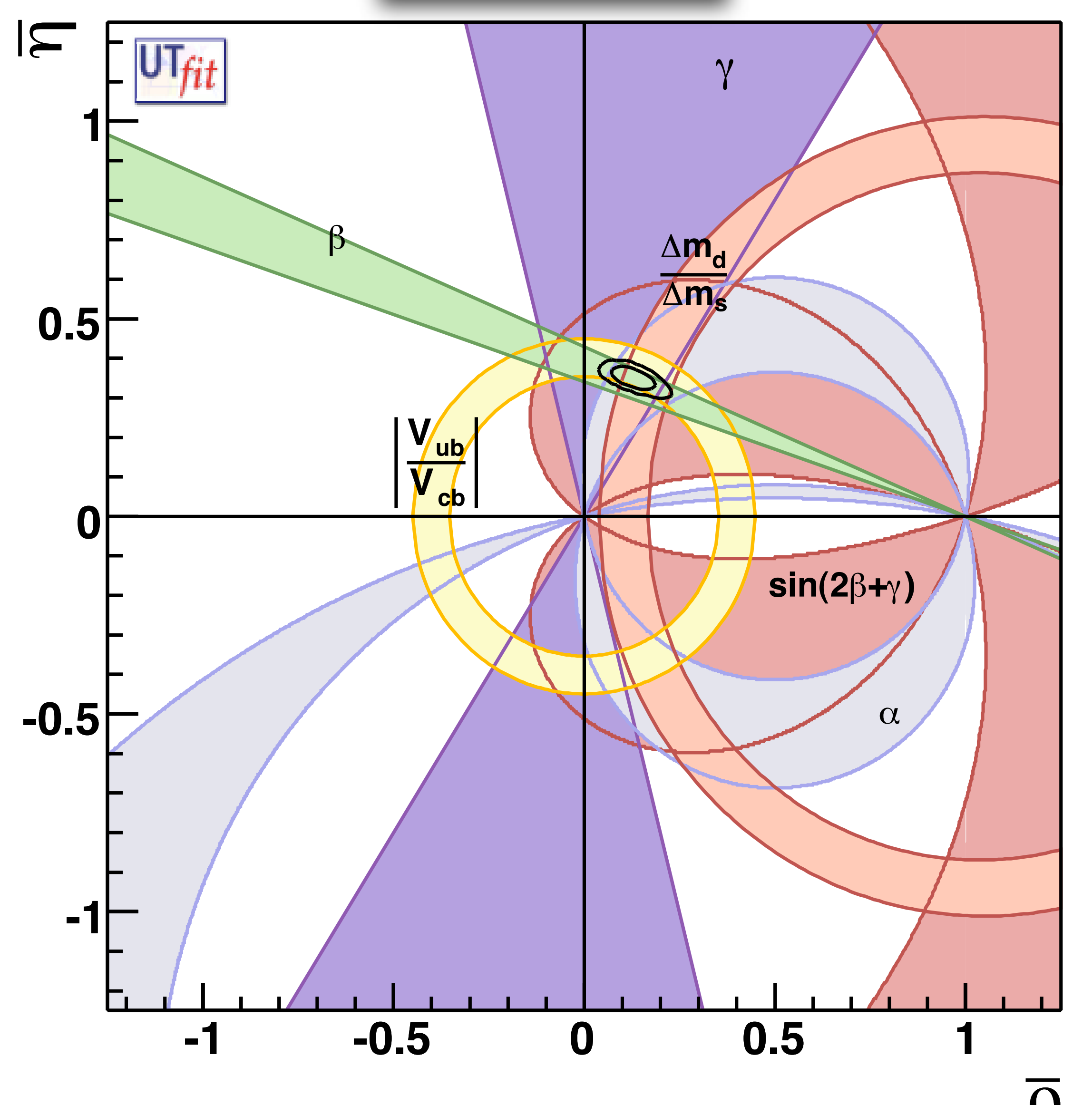
$B_s \rightarrow KK$, $B_d \rightarrow \pi\pi$

➥ PID paramount

U spin approach

5+ years later ?

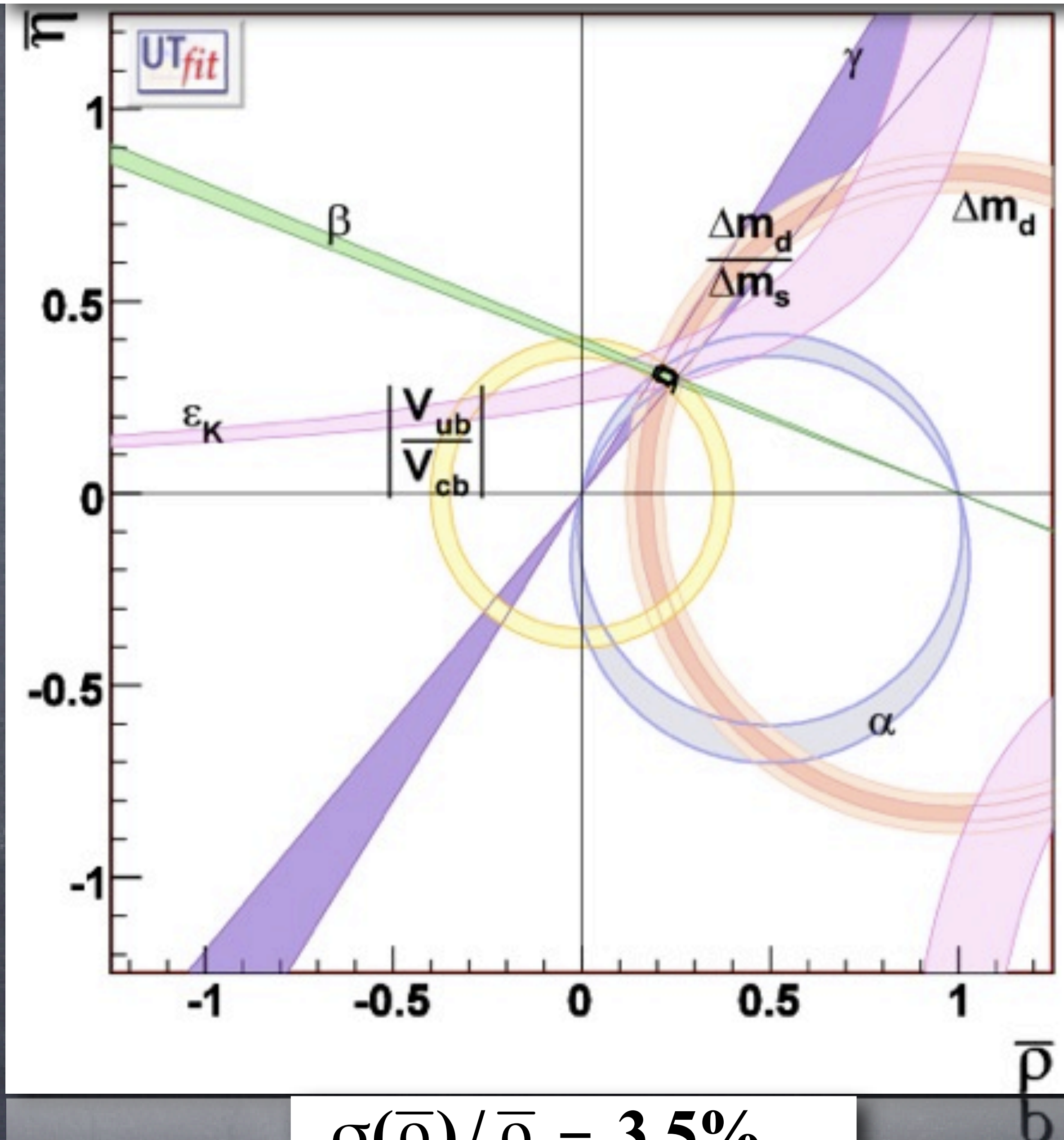
Now ...



$\sigma(\overline{\rho})/\overline{\rho}$ = **17%**

$\sigma(\overline{\eta})/\overline{\eta}$ = **4.7%**

LHCb projection (10 fb^{-1})

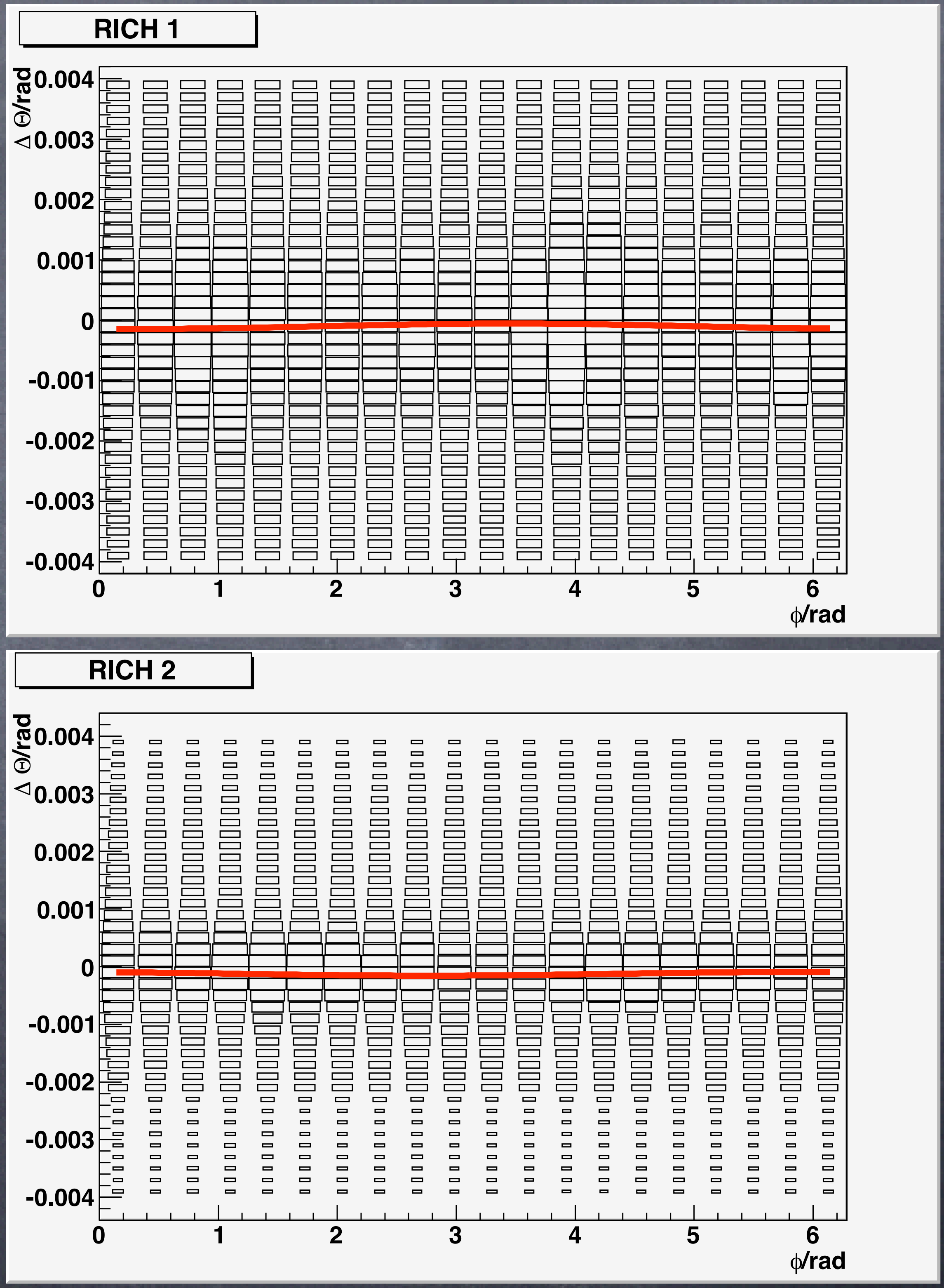


$\sigma(\overline{\rho})/\overline{\rho}$ = **3.5%**

$\sigma(\overline{\eta})/\overline{\eta}$ = **1.7%**

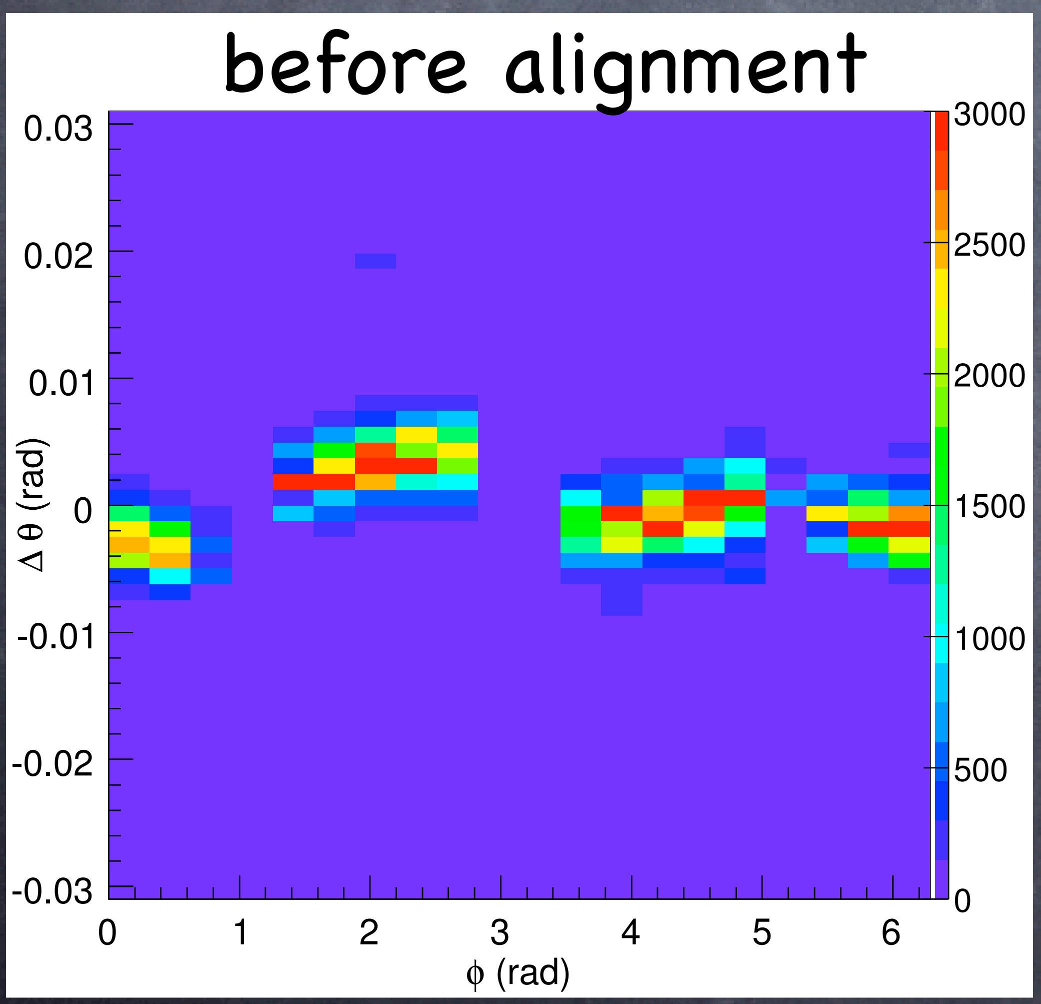
Mirror Alignment

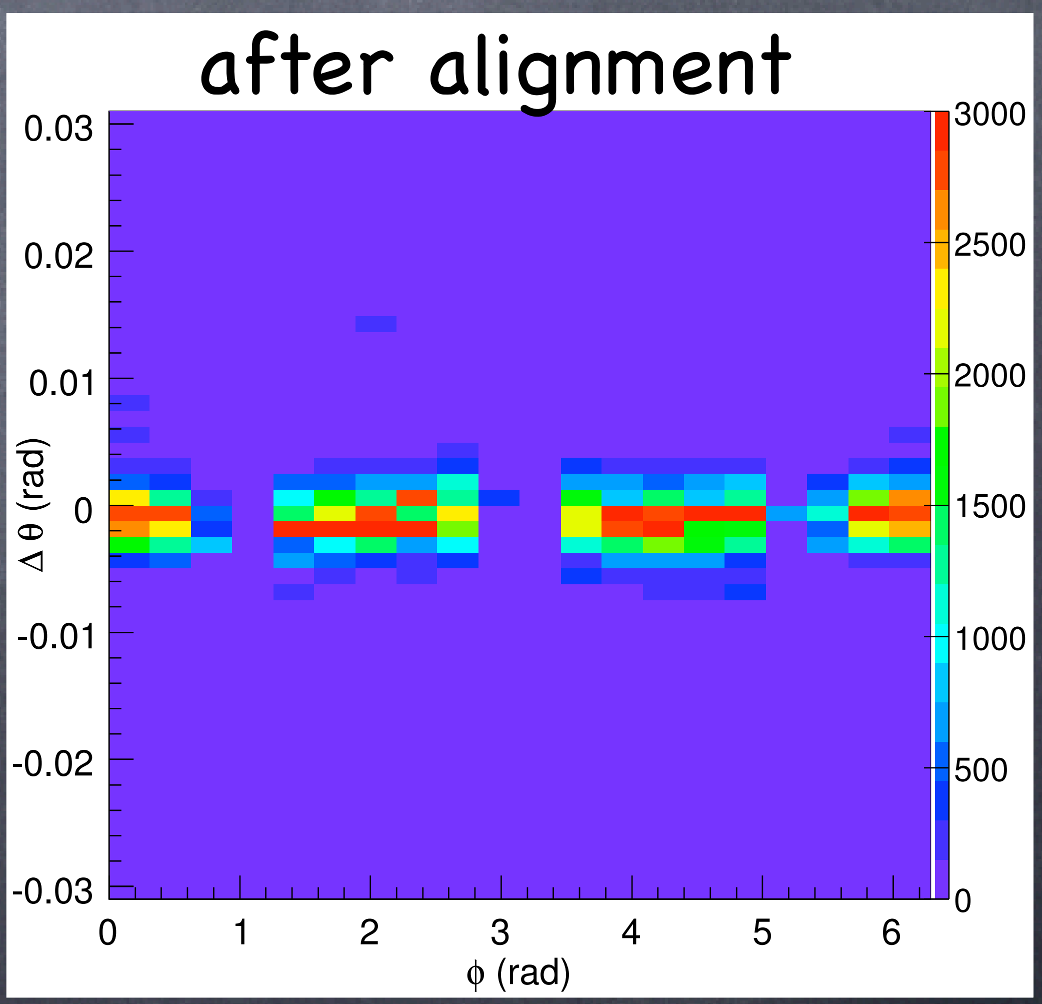
- Photo-Detectors mounted outside detector acceptance
- Cherenkov radiation reflected on to HPDs with high-quality mirrors
- Result in variation of measured Cherenkov angle at different positions around the ring
  ➥ visible as sinusodial variation of fit to expected Θ_c distribution
- Iterative alignment procedure using data only.



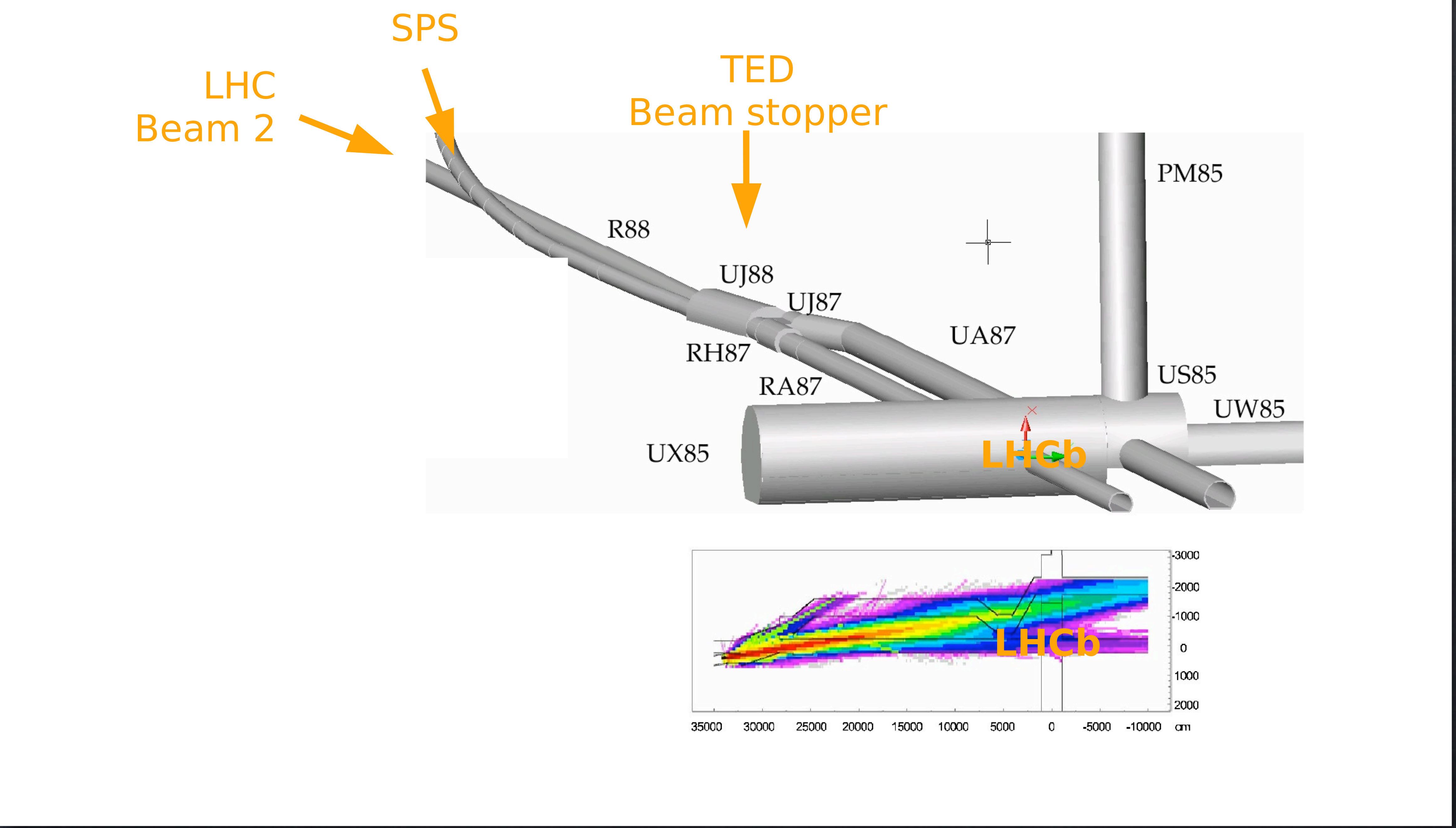
Mirror Alignment

- Alignment procedure successfully verified using data from beam - tests.
  - Disjoint structure from test-setup geometry



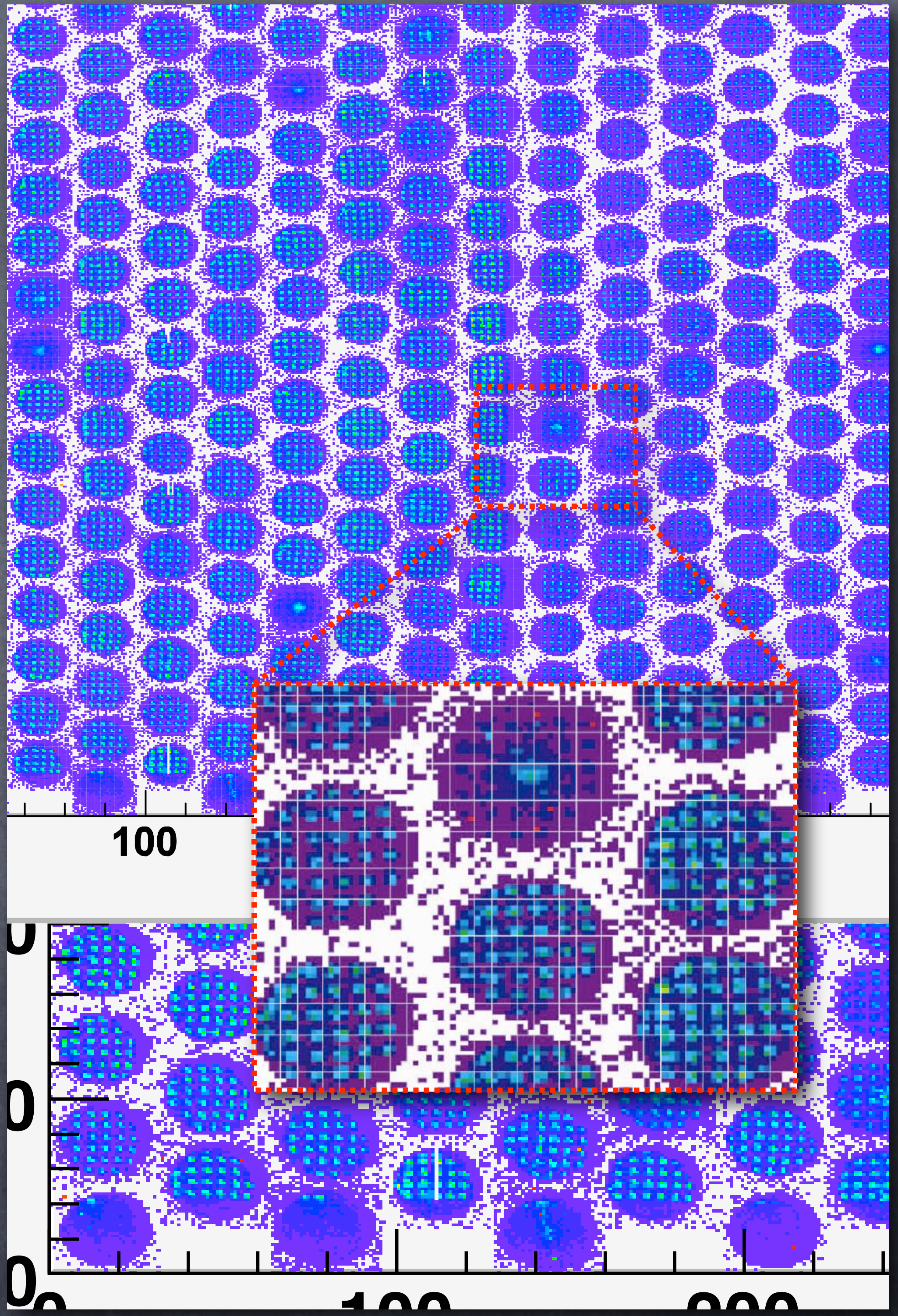


TED Beam Setup



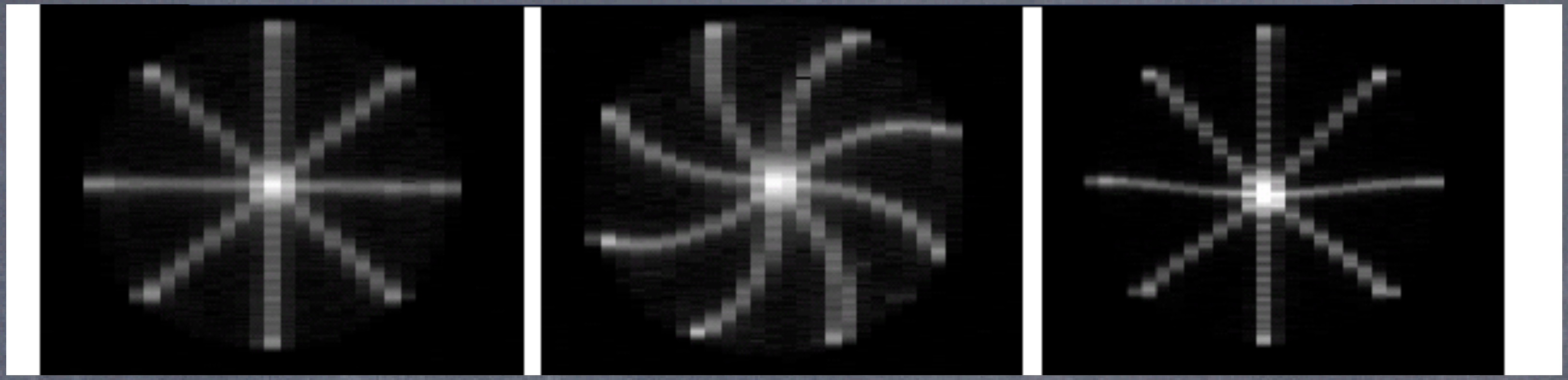
Test Pattern

- Project regular pattern onto HPD plane
- Uniform response with very low noise for almost all HPDs
- Few noisy HPDs (Ion Feedback)



Magnetic Distortions

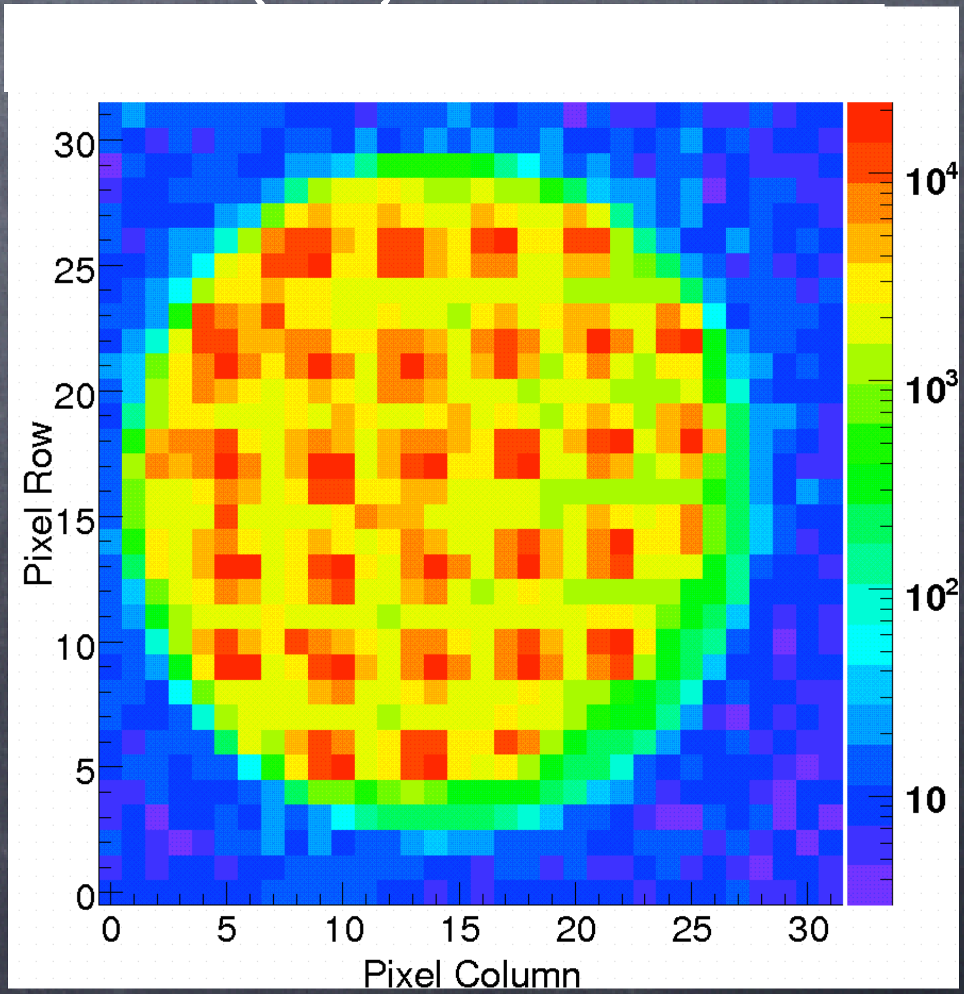
- Minor distortions to HPD image expected from finge field of magnet

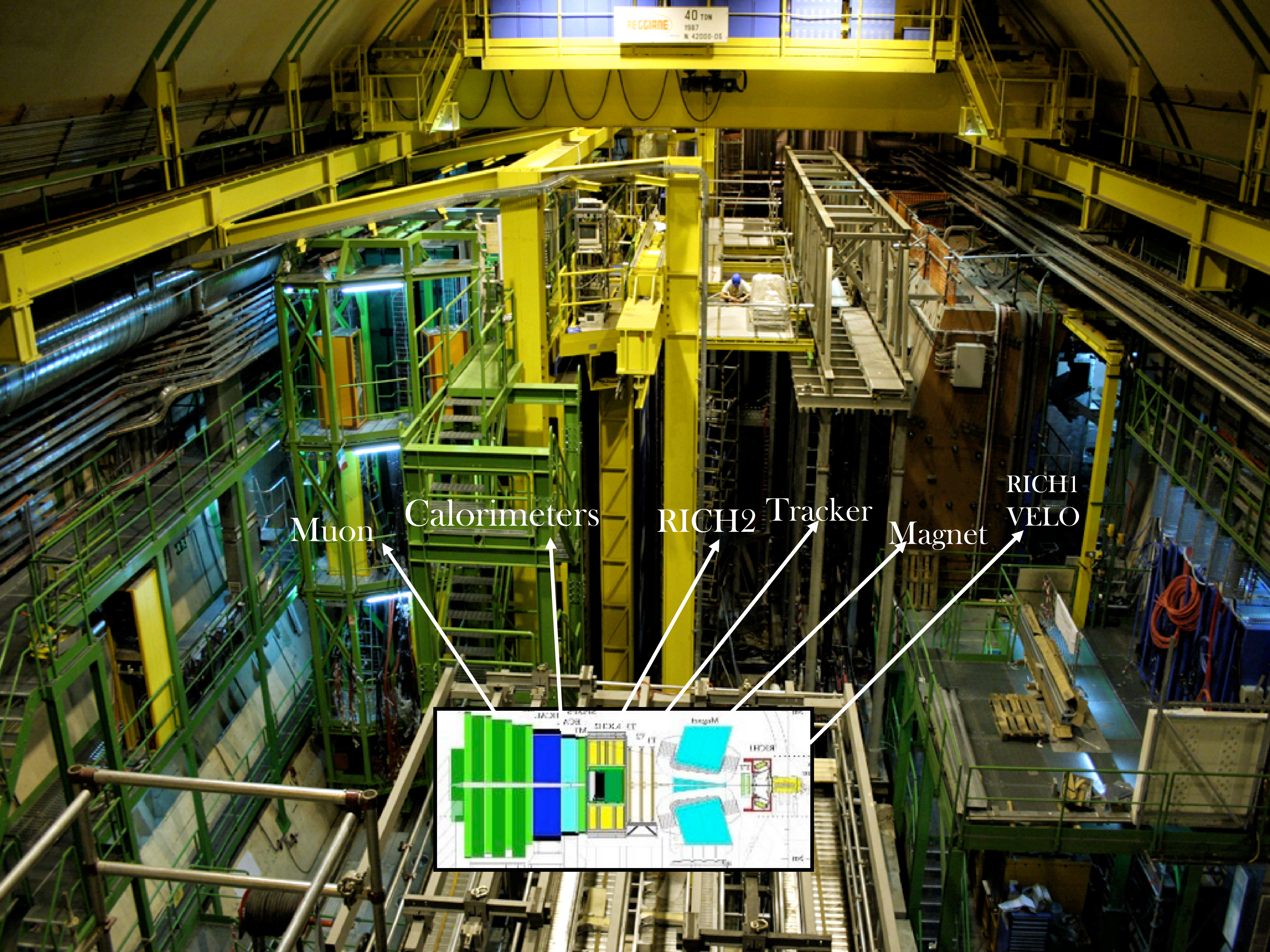


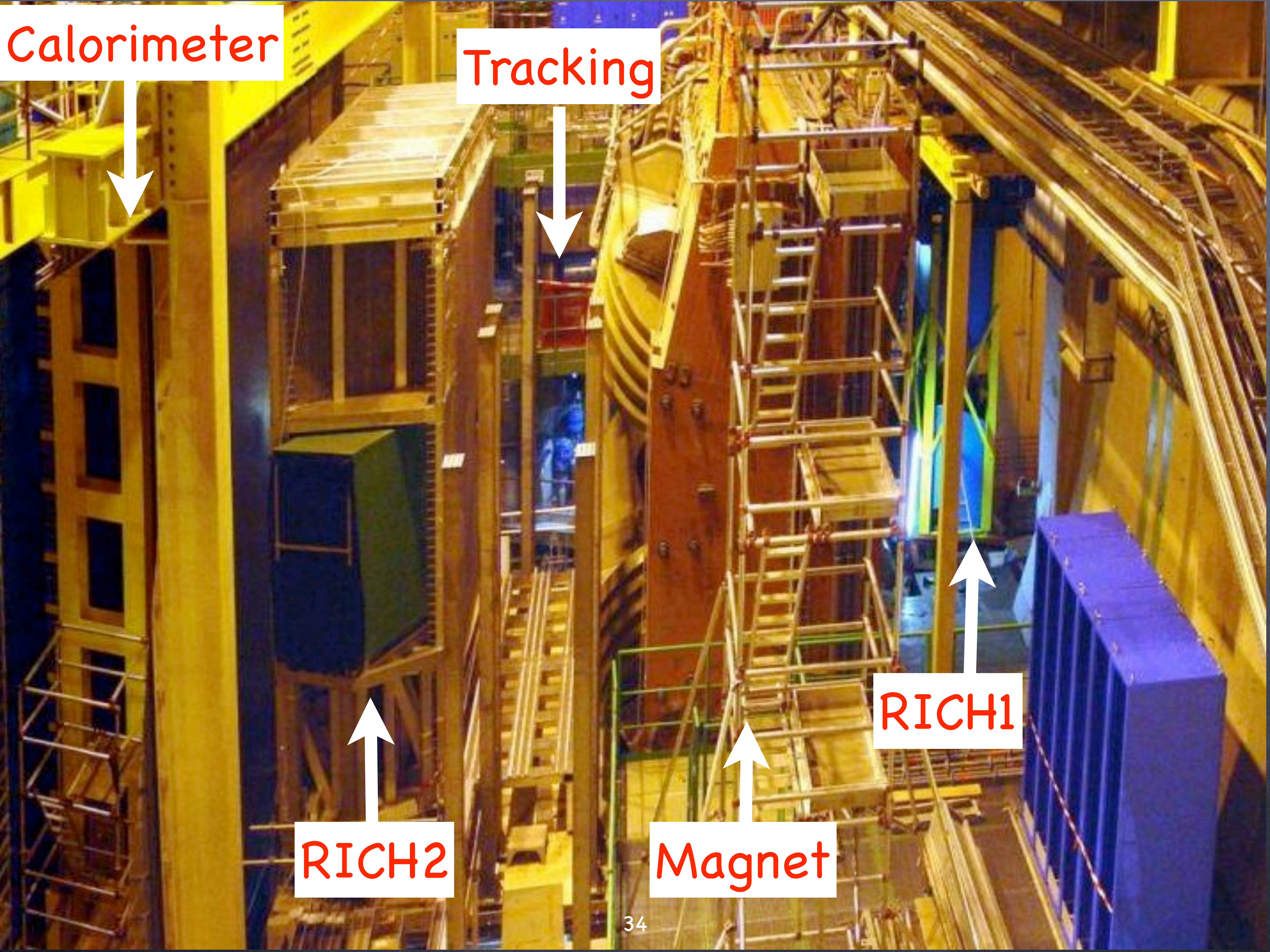
Test pattern: B=0 B axial (30G) B transv. (50G)

- Calibration using test-pattern with LHCb magnet off and on (both polarities)

- Distortion can be parameterised with few constants per HPD




Muon
Calorimeters
RICH2
Tracker
Magnet
RICH1
VELO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