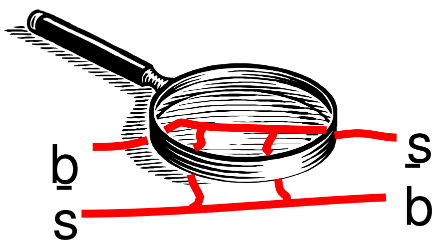
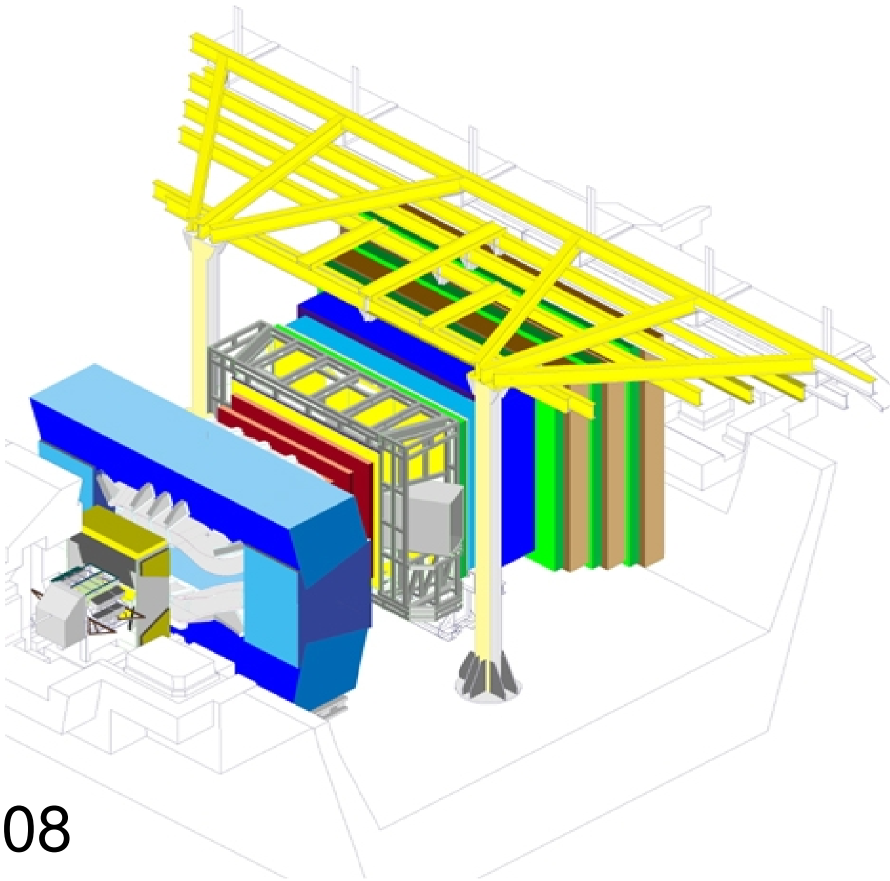
LHCb: Searching New Physics hidden in charm and beauty



S. T'Jampens

LAPP
(CNRS/IN2P3 and
Université de Savoie)



KEK-IPNS Seminar – April 8th 2008

Outline

- Introduction

    Motivation, search strategy for New Physics (NP)

- LHC and LHCb experiment

    LHC: Lord of the ring

    B production and LHC experimental conditions

    Acceptance, luminosity, pileup

    LHCb spectrometer

    Tracking, PID, Flavor tagging

    Trigger schemes and performance

- Expected physics performance (examples)

    sin2β

    Measurements of γ

    B_s mixing phase $2\beta_s$

    Other $b \to s$ boxes and penguins

    $B_s \to \mu^+\mu$

    Charm physics

Flavor Physics

What is Flavor Physics?

Flavor Physics is about interactions that distinguish between the fermion generations ➔ masses and mixing

***The physics of flavor* is the field with the highest complexity and the richest phenomenology, with phenomena ranging from the spectra of mesons and baryons, from CP–violation, from weak decays up to exotics phenomena like neutrino oscillation.**

H. Fritzsch - hep-ph/0407069

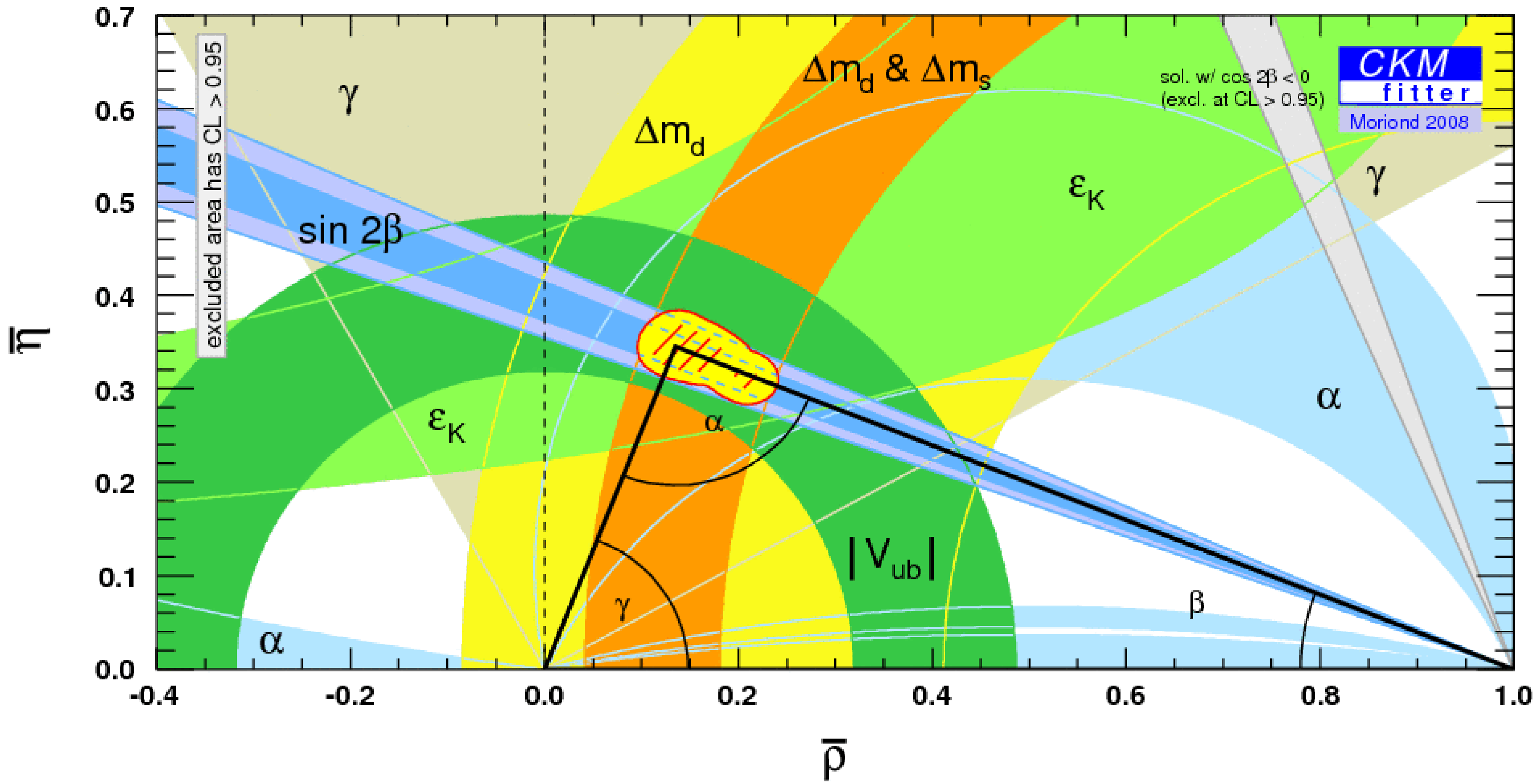
In the SM, weak charged $W^{\pm}$ transitions mix quarks of different generations (mismatch between Yukawa and gauge interactions) [similar in the lepton sector]

➔ CKM quark-mixing matrix.

Bonus: CPV KM mechanism [3 generations: 1 single CP-violating phase]

Masses and mixing are the main sources of free parameters in the SM.

Why believe the KM mechanism?



The great success of the B factories and Tevatron (and the Standard Model):

the KM mechanism is the dominant source of CPV at the EW scale.

But the UT is not the whole story!

Standard Model: many unanswered questions

Questions:

Y. Nir – arXiv:0708.1872 [hep-ph]
T.E. Browder *et al.*, arXiv:0802.3201 [hep-ph]

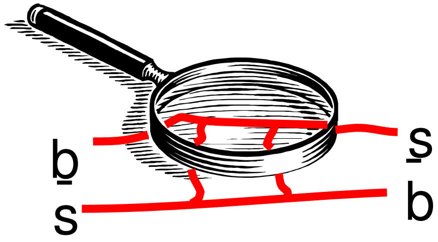
- Why several generations? Why 3?
- Why hierarchy of masses?
- Why do we observe a hierarchy in the quark-mixing matrix and not in the leptons?
- What is the origin of CP violation?
- Bariogenesis [CPV in SM too weak to explain matter antimatter asymmetry of the Universe ➔ need extra sources of CPV]

SM puzzle (the second, third and fourth questions)

The SM is viewed as a low-energy effective theory of a more fundamental theory at a higher energy scale, whose limitations to be overcome by adding new elements, such as new interactions and new fundamental particles.

Flavor physics and the physics of CP violation can discover new physics or probe it before it is directly observed in experiments (access higher scales), e.g.,

- Δm_K: successful prediction of the charm mass
- Δm_d: successful prediction of the top mass



↳ Indirect approach in the search of NP

New Physics Flavor Puzzle

Example: ΔF = 2 flavor changing operators (dim 6, 4 fermions) give:

Y. Grossman *et al.*, PL B407 (1997) 307
T. Hansmann & T. Mannel, PRD68 (2003) 095002
Y. Nir – arXiv:0708.1872 [hep-ph]

$$\mathcal{L}_{\Delta F=2} = \frac{z_{sd}}{\Lambda^2_{\text{NP}}}(\overline{d_L}\gamma_\mu s_L)^2 + \frac{z_{cu}}{\Lambda^2_{\text{NP}}}(\overline{c_L}\gamma_\mu u_L)^2 + \underbrace{\frac{z_{bd}}{\Lambda^2_{\text{NP}}}(\overline{d_L}\gamma_\mu b_L)^2}_{\text{contributes to } \Delta m_B} + \underbrace{\frac{z_{bs}}{\Lambda^2_{\text{NP}}}(\overline{s_L}\gamma_\mu b_L)^2}_{\text{contributes to } \Delta m_{Bs}}$$

$$\Rightarrow \quad \Lambda_{\text{NP}} \gtrsim \begin{cases} \sqrt{\mathcal{I}m(z_{sd})}\ 2\times 10^4\ TeV & \epsilon_K \\ \sqrt{z_{sd}}\ 1\times 10^3\ TeV & \Delta m_K \\ \sqrt{z_{cu}}\ 8\times 10^2\ TeV & \Delta m_D \\ \sqrt{z_{bd}}\ 5\times 10^2\ TeV & \Delta m_B \\ \sqrt{z_{bs}}\ 2\times 10^2\ TeV & \Delta m_{B_s} \end{cases}$$

1) Either New Physics has a generic flavor structure (ie $z_{ij} \sim 1$)) then $\Lambda_{NP} > 10^2 - 10^3$ TeV

➔ problem with the hierarchy problem (radiative corrections to Higgs mass): $\Lambda_{NP} \sim 1$ TeV

2) Or $\Lambda_{NP} \sim 1$ TeV and then its flavor structure is far from generic: $z_{ij} \ll 1$

→ *Once NP is discovered, it is important to understand its flavor structure, including new phases*

Search Strategy for NP

Explore as much as possible all FCNC ($b\to s$, $b\to d$, $s\to d$), where NP may show up

— eg measure B_s oscillations

Measure processes which are very suppressed in the SM, where NP may show up as a relatively large contribution

— very rare K decays, rare D decays

— B_s mixing phase, mixing and width difference

— $b\to s\gamma$, $b\to s l^+ l^-$, $B_{(s)}\to\mu\mu$

Improve measurement precision of CKM elements

— compare different measurements of the same quantities, one which is insensitive and another one which is sensitive to NP

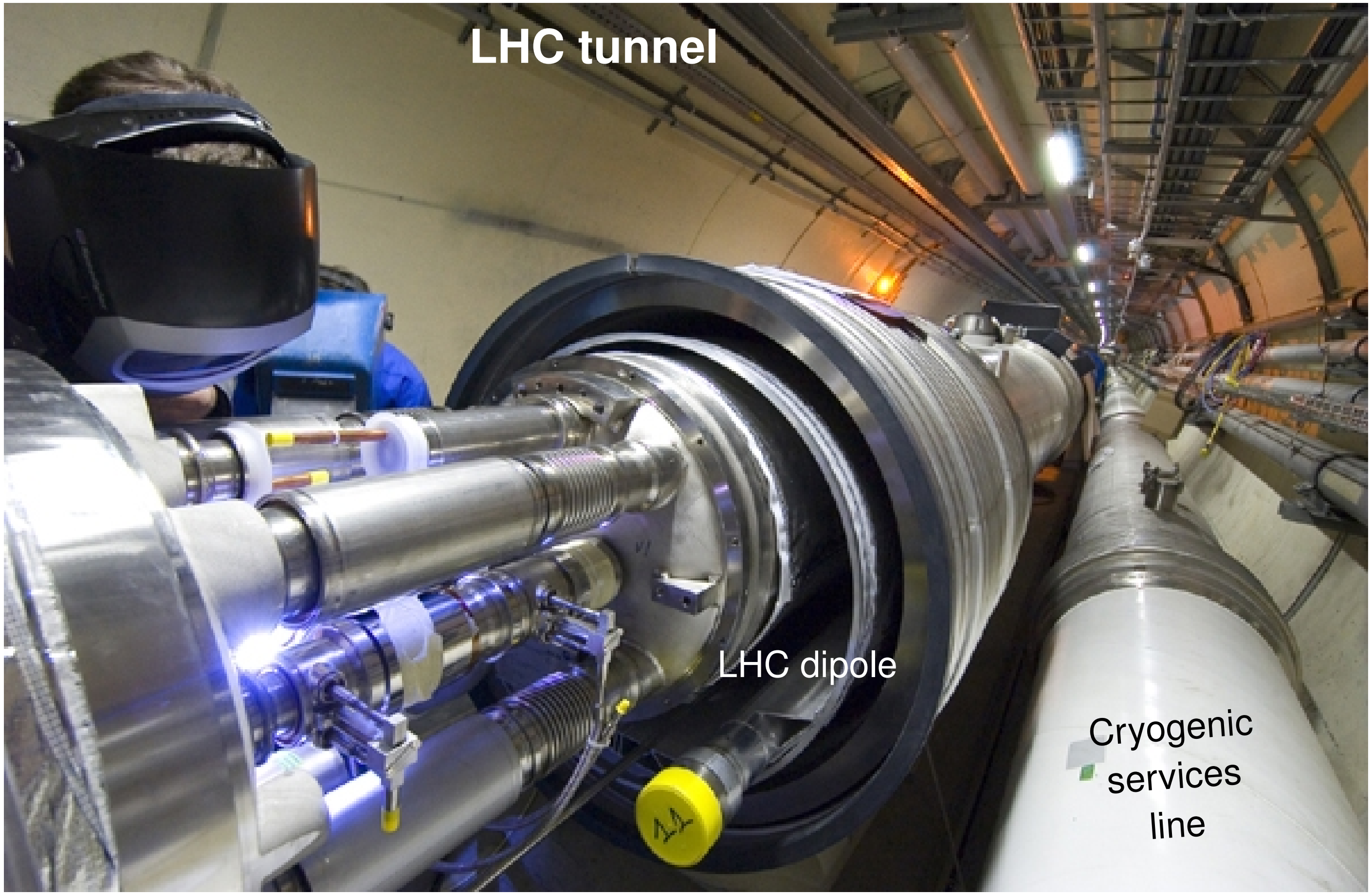
- $\sin 2\beta$ from $B^0\to J/\psi\, K_S$ and $B^0\to\phi K_S$

— measure all angles and sides of the UT to find inconsistencies: sign of NP. But watch out for theoretical uncertainties! (reducing and understanding them must go in parallel with experiments ➔ LQCD)

If NP found by ATLAS/CMS, LHCb **provides complementary information** by probing NP flavor structure

Otherwise, **explore much higher scales** than those reached by the direct search

LHC



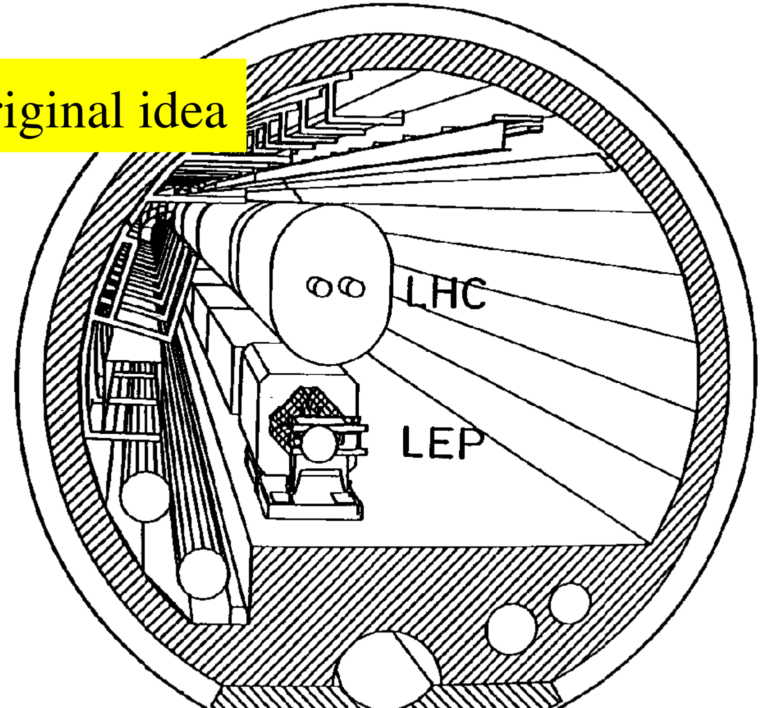
LHC: The Life of an Experiment

The life of an experiment

1984	Workshop in Lausanne on installing a Large Hadron Collider (LHC) in the LEP tunnel
1987	CERN's long-range planning committee chaired by Carlo Rubbia recommends LHC as the right choice for lab's future
1989	ECFA Study Week on instrumentation technology for a high-luminosity hadron collider; Barcelona; LEP collider starts operation
1990	ECFA LHC workshop, Aachen
1992	General meeting on LHC physics and detectors, Evian-les-Bains
1993	Letters of intent for LHC detectors submitted
1994	Technical proposals for ATLAS and CMS approved
1998	Construction begins
2000	CMS assembly begins above ground; LEP collider closes
2003	ATLAS underground cavern completed and assembly started
2004	CMS cavern completed
2007	Experiments ready for beam
2007	First proton–proton collisions
2008	First results
2010	Reach design luminosity
>2014	Upgrade LHC luminosity by factor of 10

CERN Courier

original idea

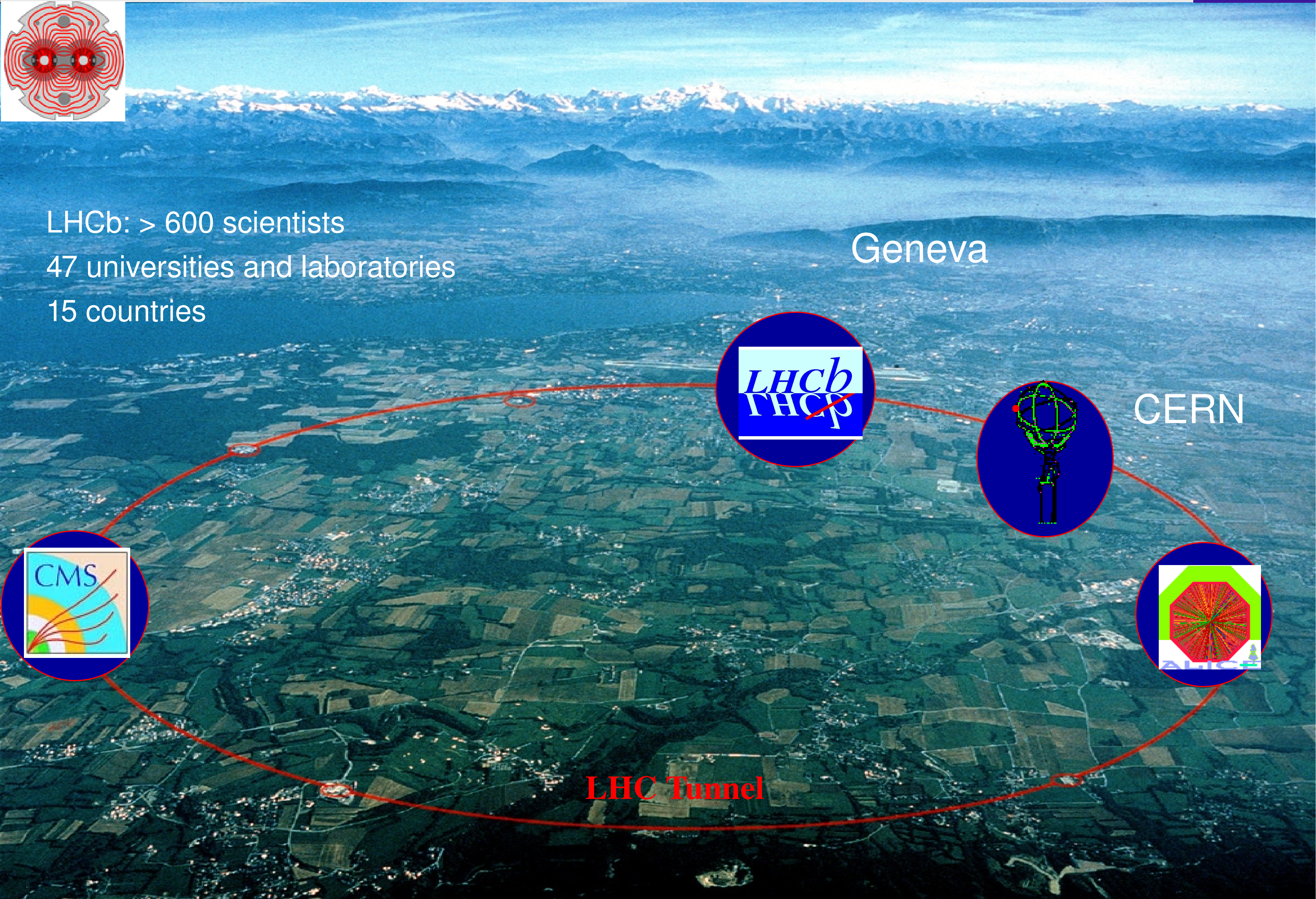


reality

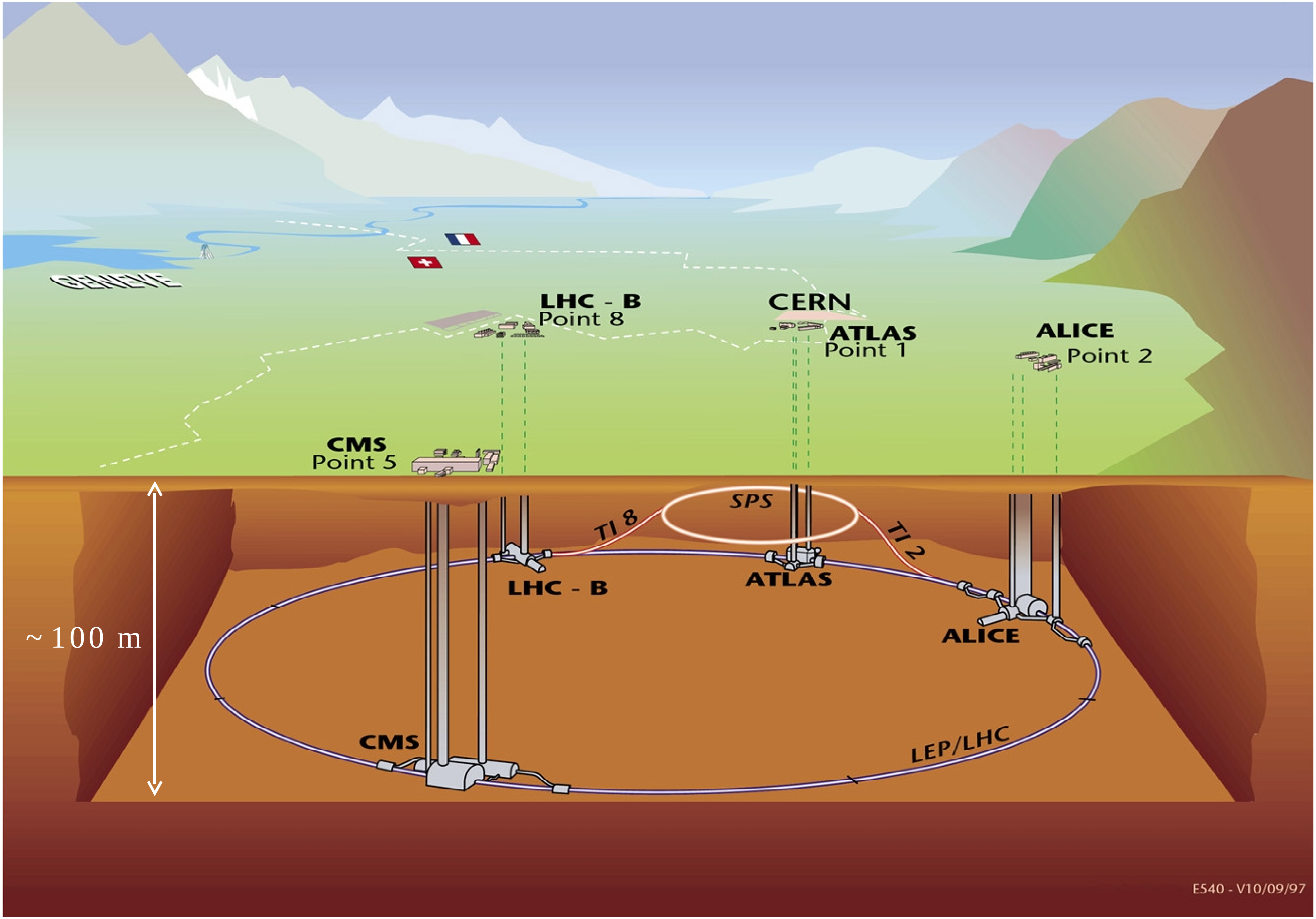
LHCb: Aug '95 LOI

Sept '98 Technical proposal approved

LHC


LHCb: > 600 scientists
47 universities and laboratories
15 countries
Geneva
CERN
CMS
LHC Tunnel

LHC

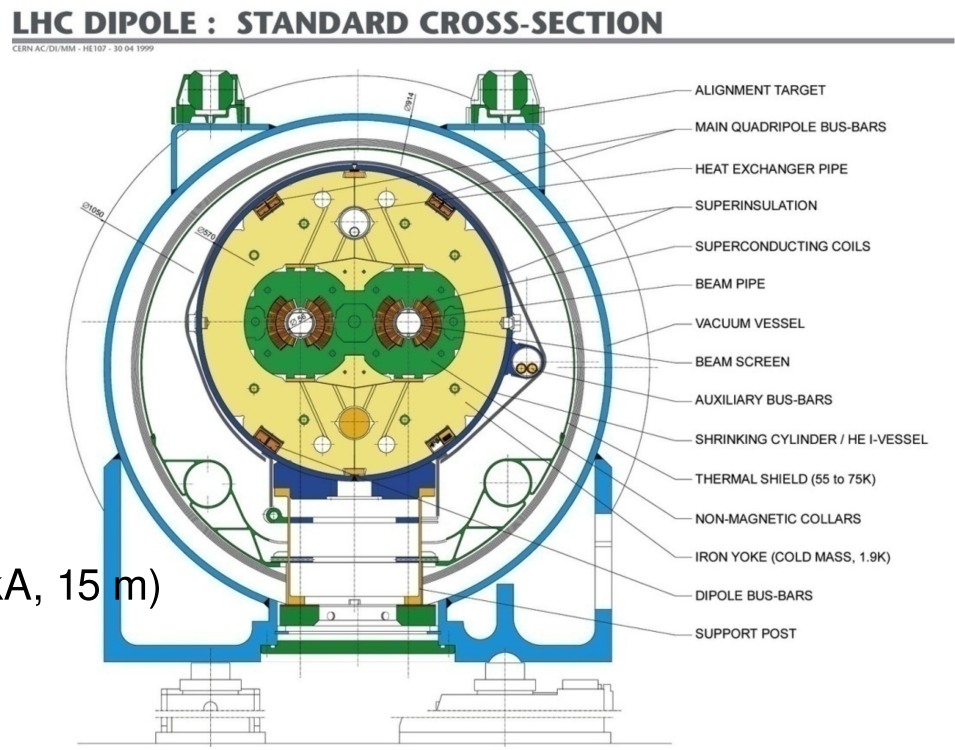


GENEVE
LHC - B
Point 8
CERN
ATLAS
Point 1
ALICE
Point 2
CMS
Point 5
~ 100 m
SPS
TI 8
TI 2
LHC - B
ATLAS
ALICE
CMS
LEP/LHC
E540 - V10/09/97

LHC: the Lord of the Ring

LHC:

- 26.7 km circonference
- proton-proton collision, $\sqrt{s}$ = 14 TeV
- design luminosity: 10^{34} cm^{-2} s^{-1}
- bunch crossing: 25 ns [40 MHz]
- 2808 bunches, 1.15 $\times 10^{11}$ protons/bunch
- total energy ~ 700 MJ ➔ protection is crucial



Magnets:

- 1232 Dipole magnets for beam steering (B~8.3 T, 12 kA, 15 m)
- 386 Quadrupole focusing magnets
- Last was lowered on 26 April '07 [first March '05]
- Closure of continuous cryostat on 5 Nov. '07
- A quenched dipole will require a beam dump in a single turn - 7 TeV (690 MJ) dissipated in 89 μs!

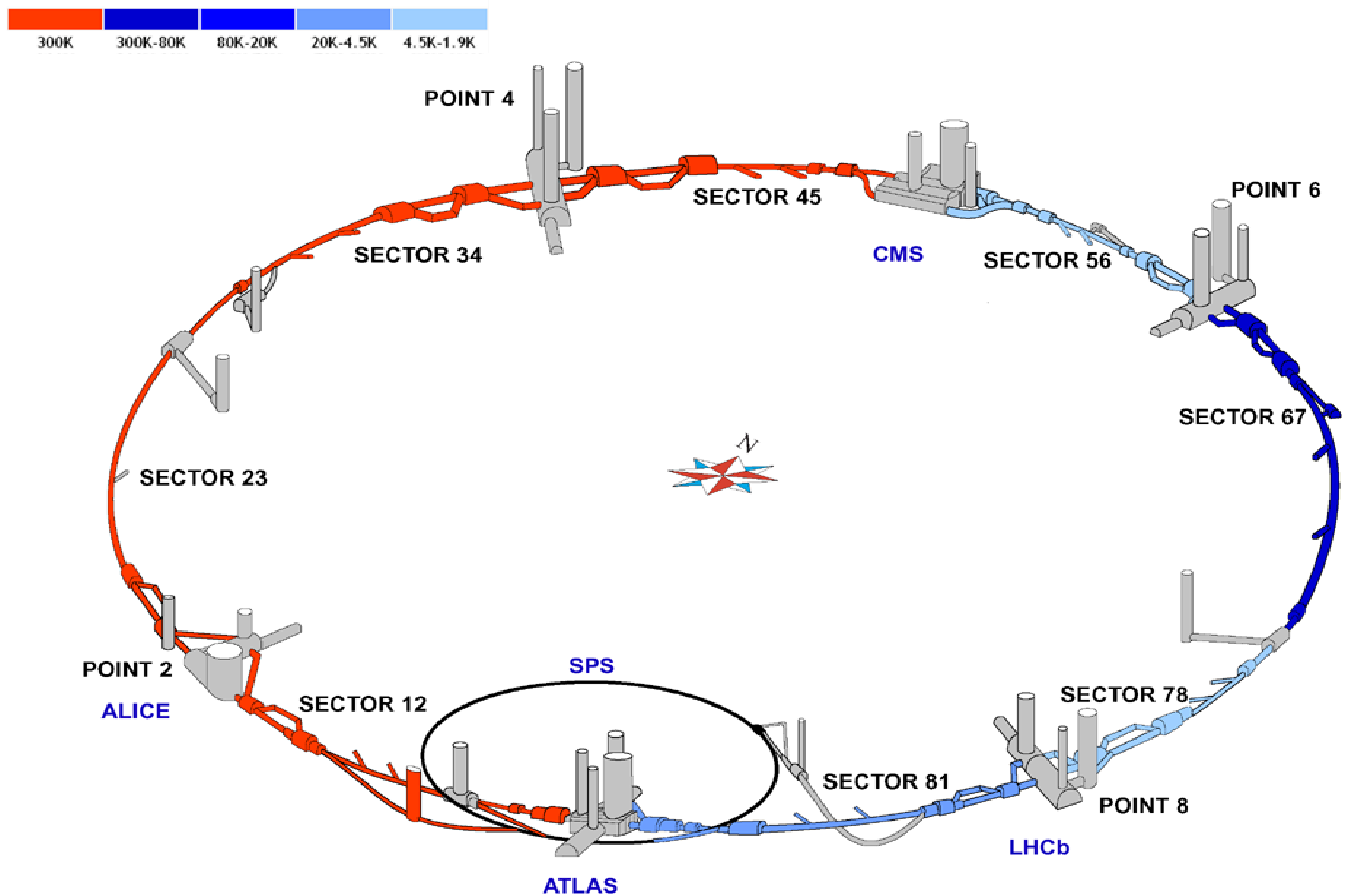
Cryogenics:

- largest cryogenics installation in the world
- 1.9K superfluid Helium distributed along the 27km circonference (–271 ºC, colder than outer space!)
- 700,000 liters of liquid helium, 12 millions of liquid Nitrogen
- 31,000 tons of materials to cool down

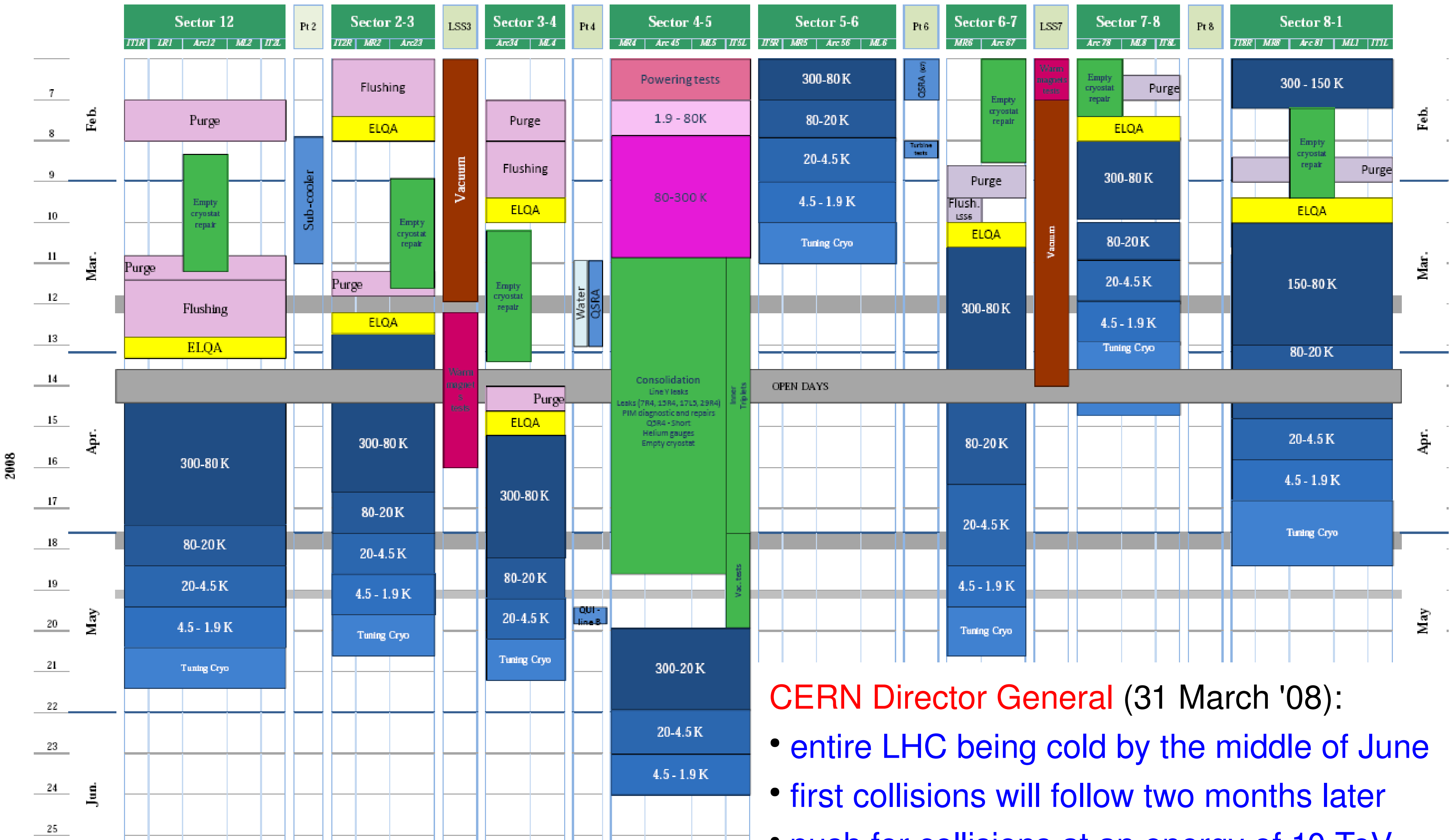
The machine components are now fully installed in the 27 km tunnel.
Commissioning is well underway

Summary LHC Cryogenics (8 April 2008)

http://hcc.web.cern.ch/hcc/field.php



Schedule as of 06 March 2008



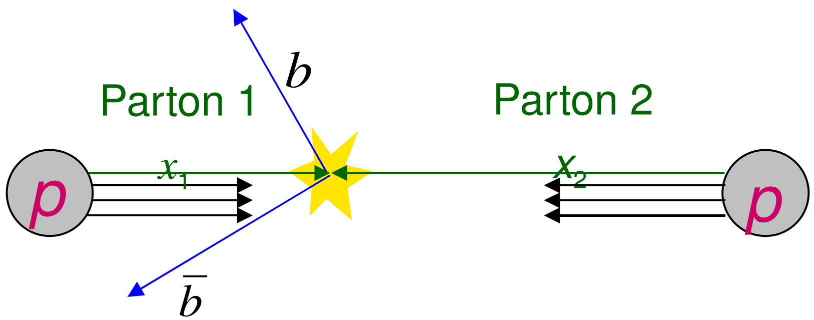
CERN Director General (31 March '08):

- entire LHC being cold by the middle of June
- first collisions will follow two months later
- push for collisions at an energy of 10 TeV this year (14 TeV to follow over the winter shutdown) [The Bulletin issue 13-14/2008]

http://foraz.web.cern.ch/foraz/schedule.pdf

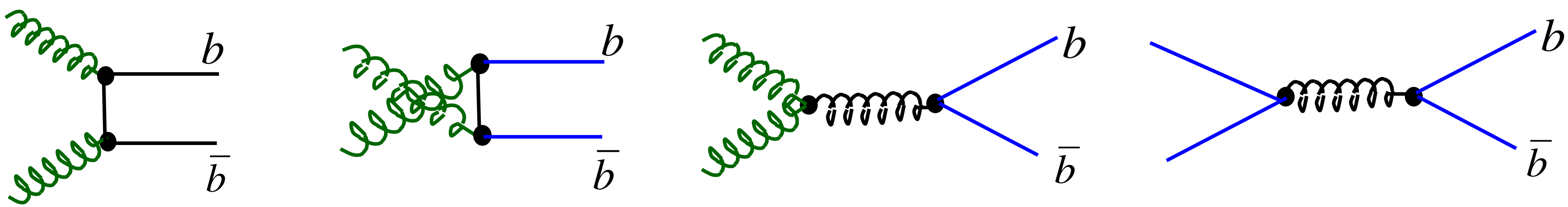
B production and
LHC experimental conditions

b-quark production at LHC ($\sqrt{s}$ = 14 TeV)



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

b quarks produced by pairs, mainly by gluon fusion:



all b-hadron species are produced:

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

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

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

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

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

Challenge

(trigger will be a crucial ingredient)

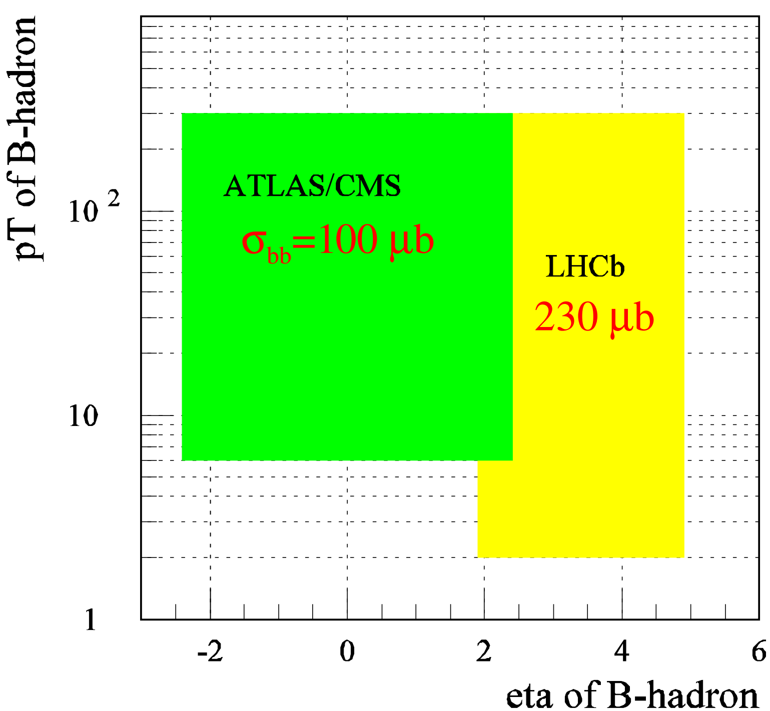
PDF at $\sqrt{s}$ = 14 TeV will be one of the first key measurement at LHC!

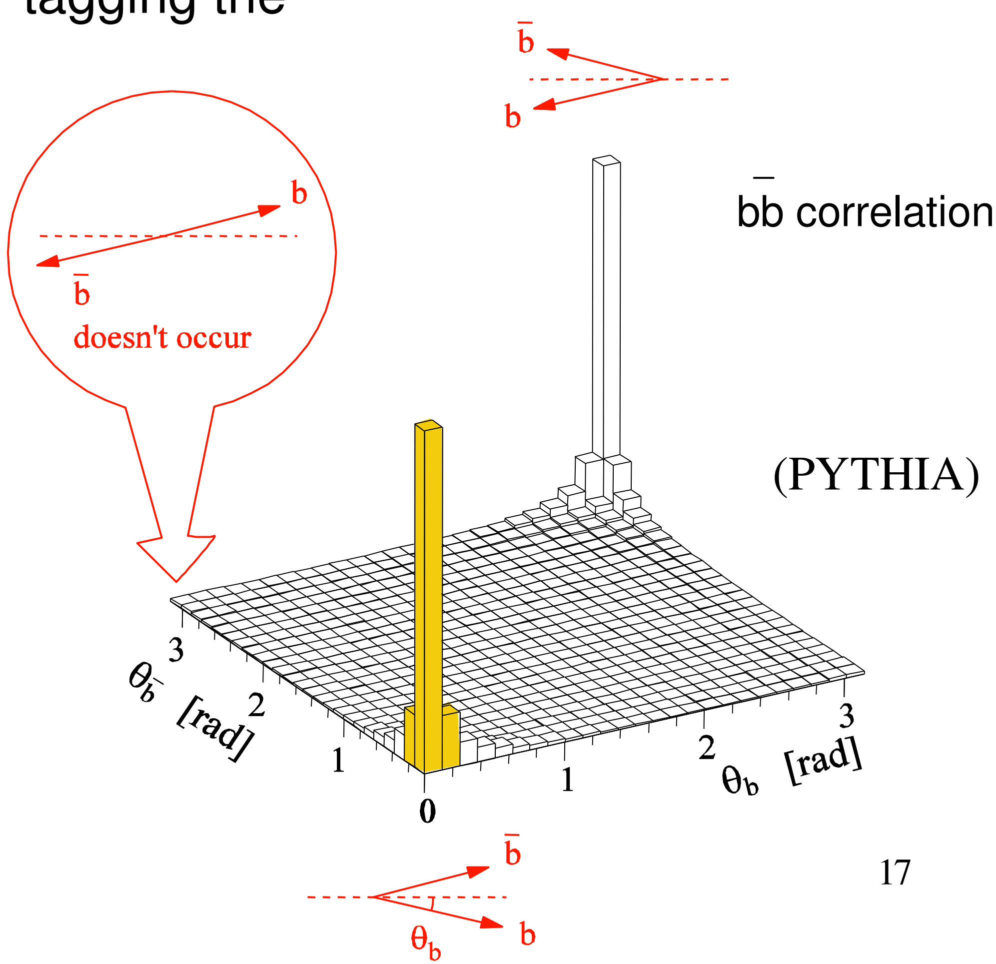
B hadrons are mostly produced in the forward (backward) beam direction (asymmetric x fractions of partons)

Choose a forward spectrometer 15–≈300 mrad (1.9 < η < 4.9)

[single arm is OK since b quarks are correlated]

Both b and $\bar{b}$ in the acceptance: important for tagging the production state of the *B* hadron





Luminosity and Pile-up

Pileup:

- number of inelastic pp interactions in a bunch crossing is Poisson-distributed with mean $n = L\sigma_{inel}/f$

L: instantaneous luminosity
f: non-empty bunch crossing rate
σ_{inel} ~ 80 mb

ATLAS/CMS (f = 32 MHz)

- Want to run at highest luminosity available
- Expect L < 2×10^{33} cm^{-2}s^{-1} (n < 5) for first 3 years
- At L = 10^{34} cm^{-2}s^{-1} (n = 25), expect only $B \to \mu\mu$ still possible

10 fb^{-1} / year
30 fb^{-1} total at low L

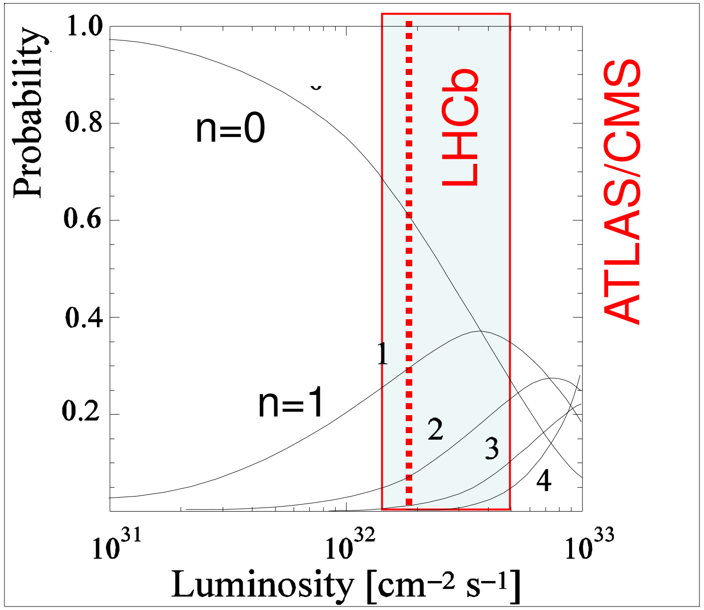
LHCb (f = 30 MHz)

- L tuneable by defocusing the beams
- Choose to run at <L> ~ 2×10^{32} cm^{-2}s^{-1} (max. 5×10^{32} cm^{-2}s^{-1})

2 fb^{-1} / year
10 fb^{-1} in first 5 years

Clean environment (n = 0.5)
Less radiation damage
LHCb 8 mm from beam, ATLAS 5 cm, CMS 4 cm
Will be available from "first" physics run

pp interactions/crossing



(nominal year = 10^7 s)

B Physics at LHC: (dis)advantages

	$e^+e^- \to \Upsilon(4S) \to B\bar{B}$ PEPII, KEKB	$pp \to b\bar{b}X$ ($\sqrt{s}$ = 14 TeV, Δt_{bunch}=25 ns) LHC (LHCb–ATLAS/CMS)	
Production σ_{bb}	1 nb	~500 μb	☺
Typical $b\bar{b}$ rate	10 Hz	100–1000 kHz	
$b\bar{b}$ purity	~1/4	$\sigma_{bb}/\sigma_{inel}$ = 0.6% Trigger is a major issue !	☹
Pileup	0	0.5–5	
b-hadron types	B^+B^- (50%) $B^0\bar{B}^0$ (50%)	B^+ (40%), B^0 (40%), B_s (10%) B_c (< 0.1%), b-baryons (10%)	☺
b-hadron boost	Small	Large (decay vertexes well separated)	
Production vertex	Not reconstructed	Reconstructed (many tracks)	
Neutral B mixing	Coherent $B^0\bar{B}^0$ pair mixing	Incoherent B^0 and B_s mixing (extra flavor-tagging dilution)	☹
Event structure	$B\bar{B}$ pair alone	Many particles not associated with the two b hadrons	

Hadron Collider

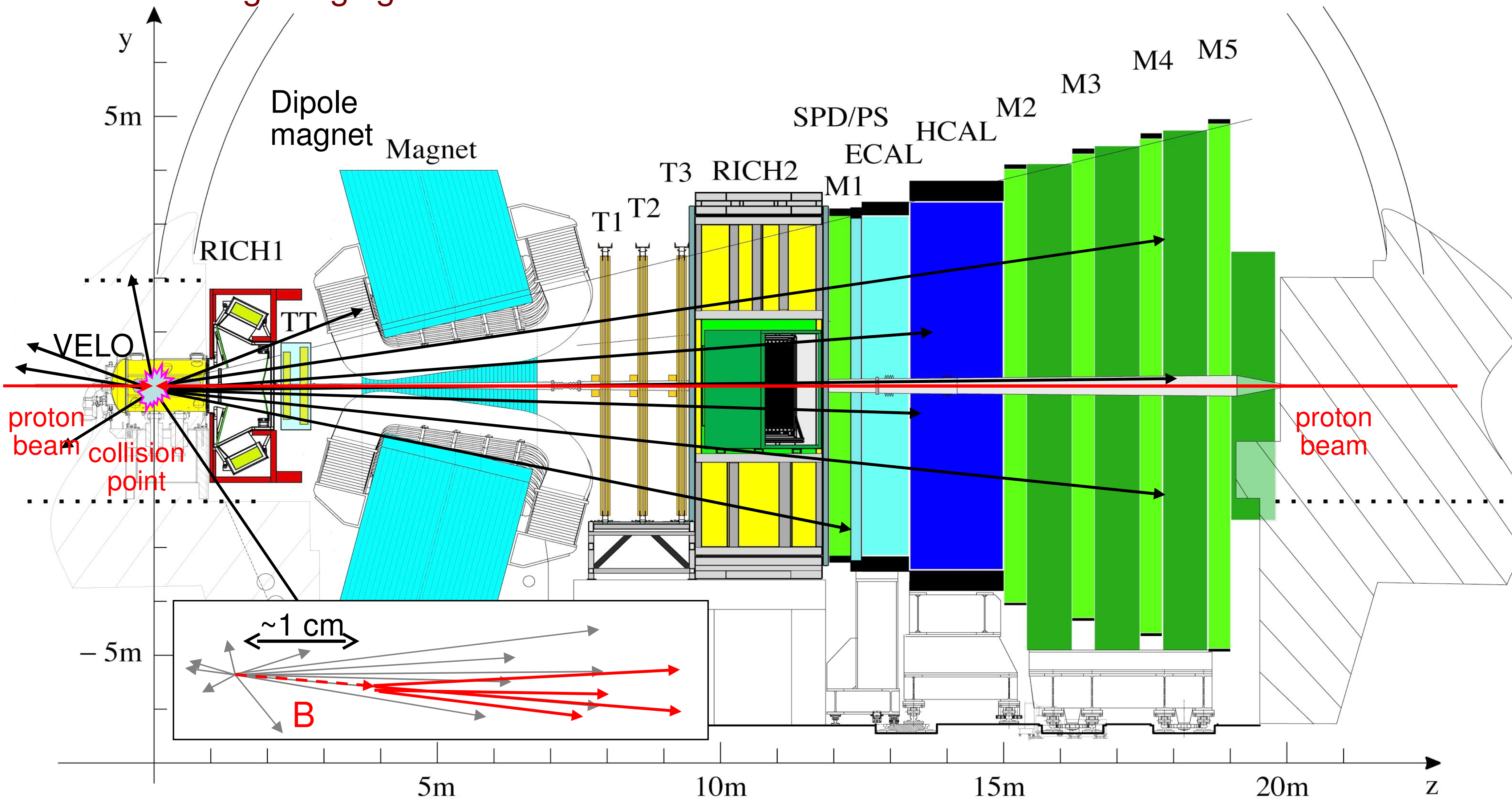
	Tevatron II (2001–2009)	LHC (≥2007) LHCb	LHC (≥2007) ATLAS/CMS
beams, $\sqrt{s}$	$p+\bar{p}$, 2 TeV	p+p, 14 TeV	
σ_{bb}	0.1 mb	0.5 mb	
σ_{cc}	1mb	3.5 mb	
$\sigma_{visible}$		~63 mb	
$\sigma_{inelastic}$	60 mb	80 mb	
σ_{total}	75 mb	100 mb	
$\omega_{bunch\ crossing}$	1.7 MHz	40 MHz	
$\Delta t_{bunch\ crossing}$	396 ns	25 ns	
$\sigma_{z\ (luminous\ region)}$	30 cm	5.3 cm	
L [cm^{-2}s^{-2}]	0.5×10^{32}	2×10^{32}	10^{33} (10^{34})
$<n_{inel.\ pp\ int.}$ / bx>	1.7	0.53	2.5 (25)

Cross sections at LHC have large uncertainties (not yet measured)

LHCb Spectrometer

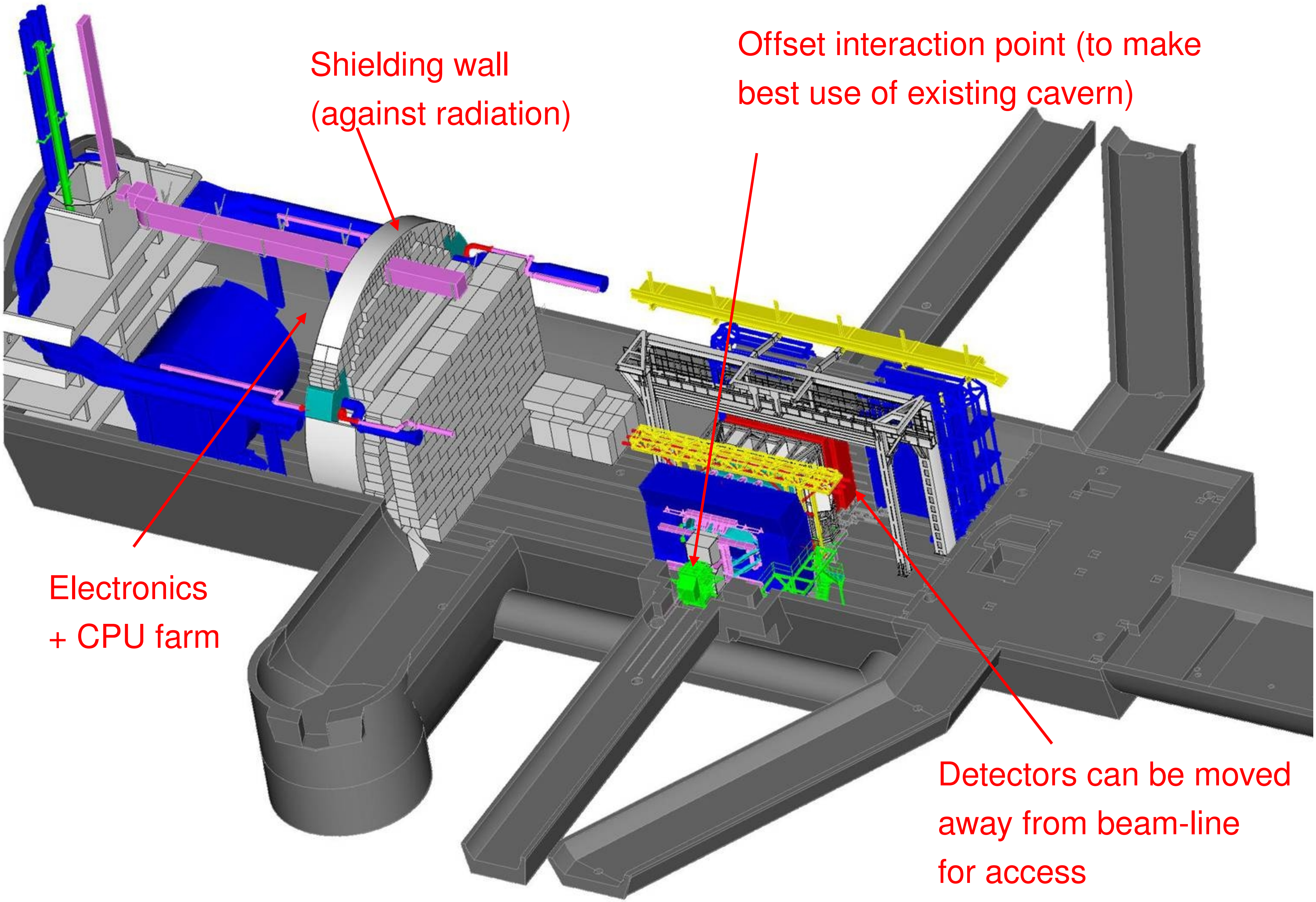
LHCb: Forward Spectrometer

VELO: Vertex Locator (around interaction point)
TT, T1, T2, T3: Tracking stations
RICH1-2: Ring Imaging Cherenkov detectors
ECAL, HCAL: Calorimeters
M1–M5: Muon stations

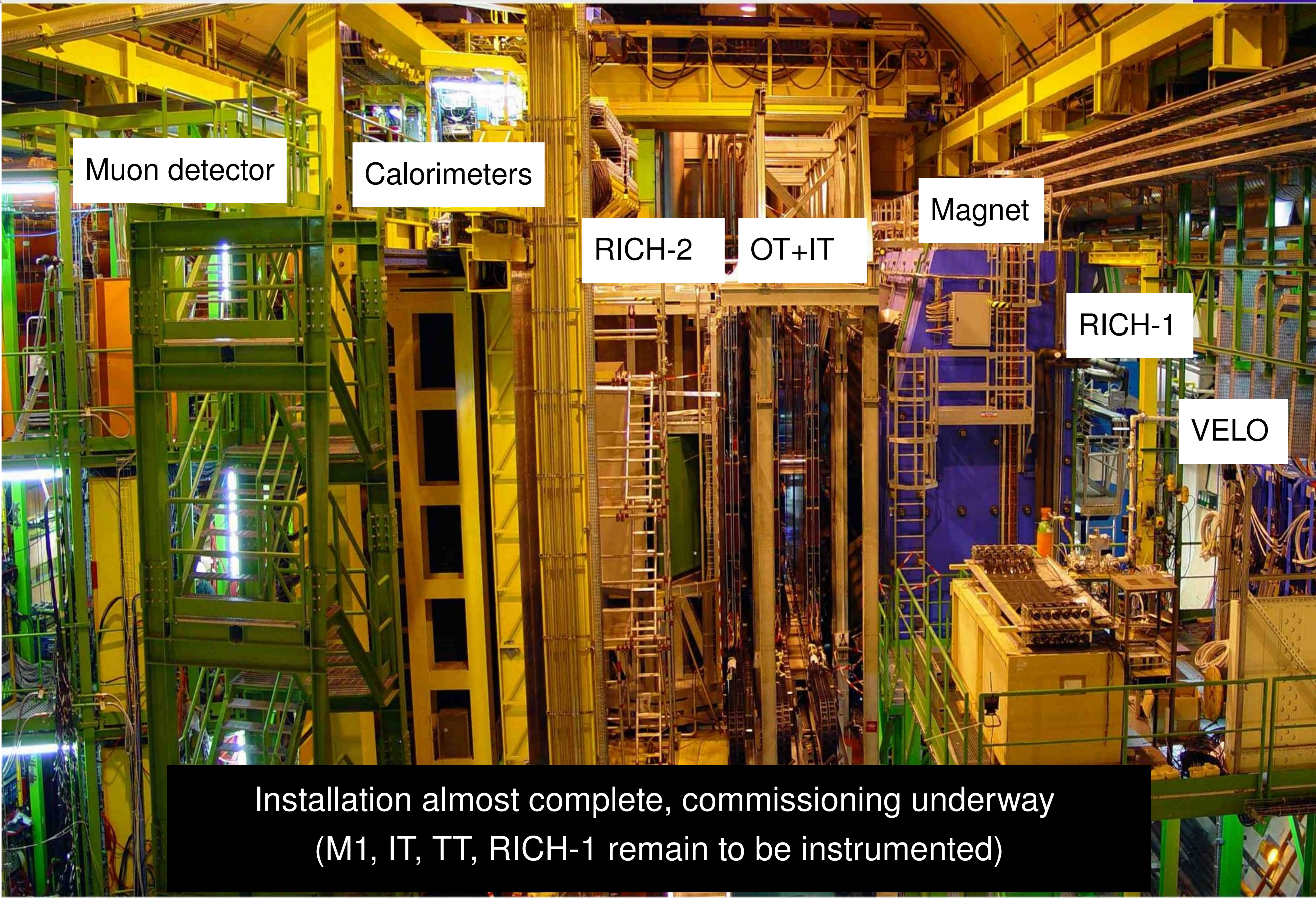


Acceptance: 15-300 mrad (bending) --- 15-250 mrad (non-bending)

LHCb in its Cavern (Point 8)



View of the LHCb cavern: it's full!



Installation almost complete, commissioning underway
(M1, IT, TT, RICH-1 remain to be instrumented)

VErtex LOcator (VELO)

21 stations

- each disk measures r or ϕ
- 300 μm thick sensor
- short strip – 40 – 100 μm

2 additional disks for pile-up system

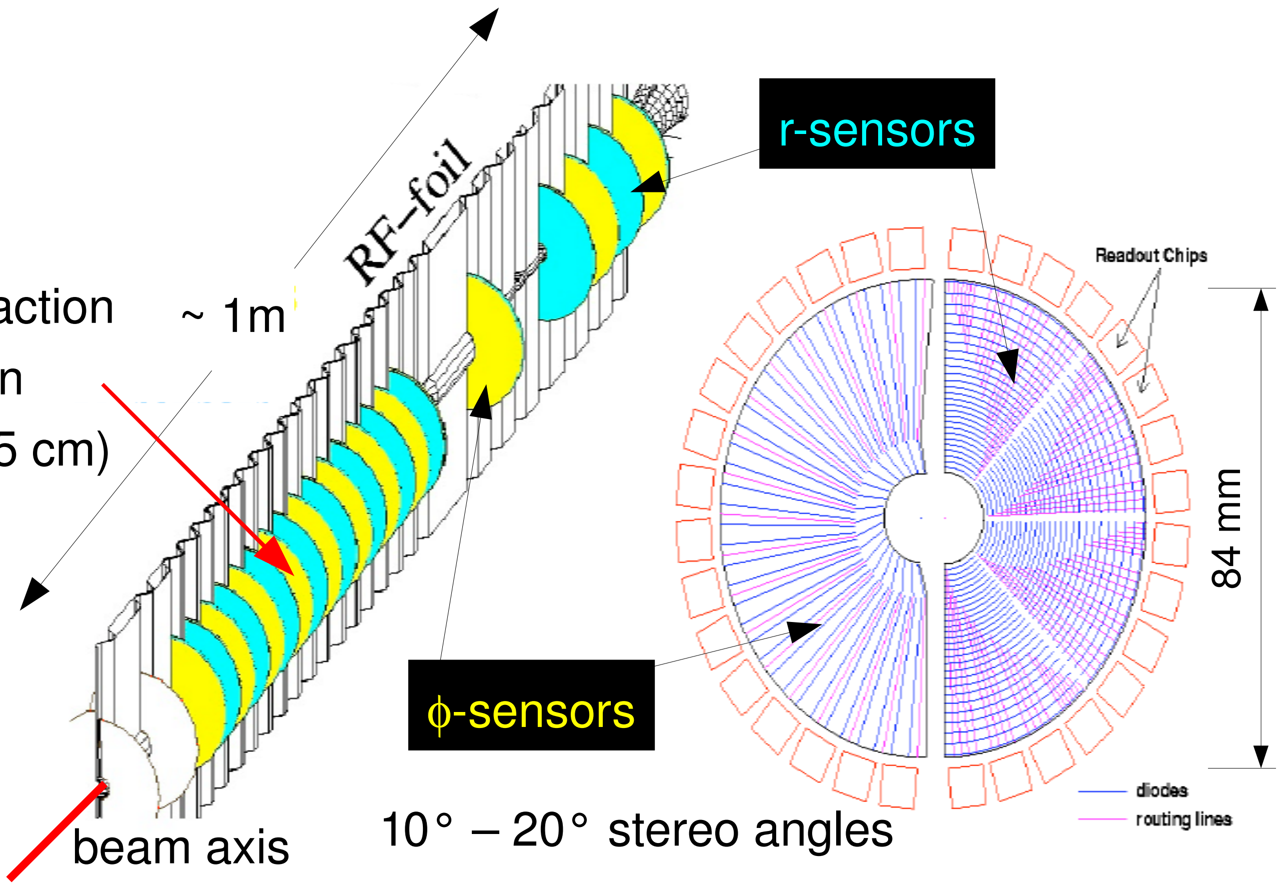
- each measures r only

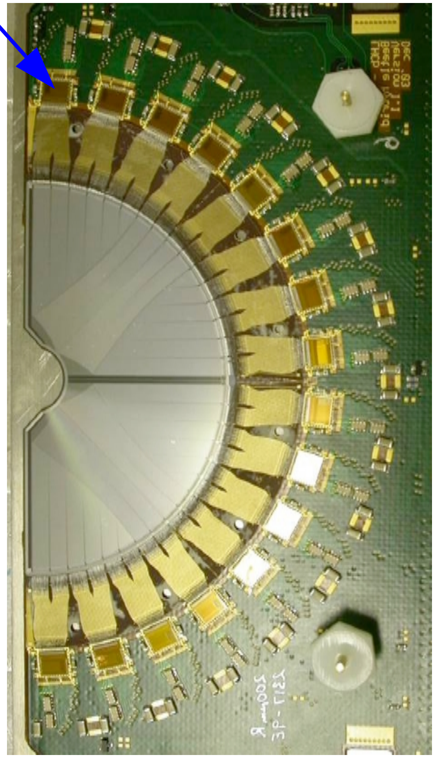
Radiation hardness:

- Active Si 8 mm from beam where $\sim 10^{14}\ n_{eq}/cm^2/y$ is expected

Analogue readout:

- Beetle chip, ~180 k channels

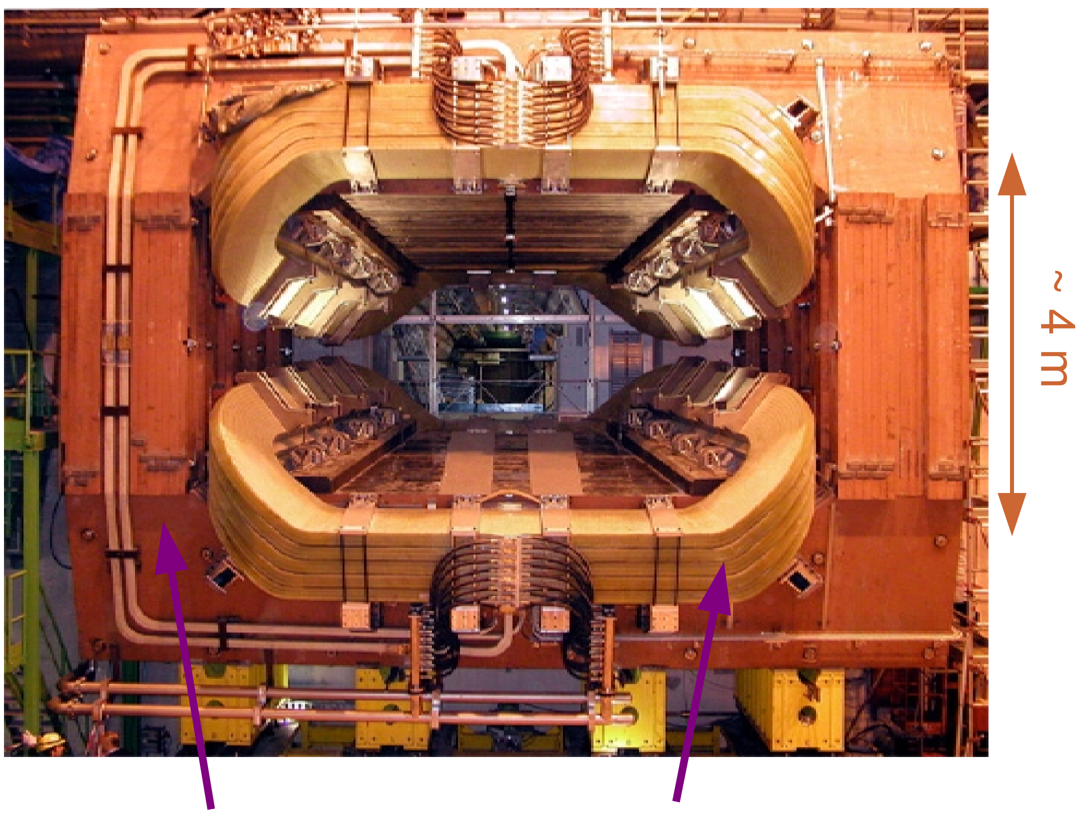




Magnet

Warm dipole magnet:

- $\int B\, dL = 4$ Tm
- Regular field reversal planned for systematic control of CP asymmetries ($\Delta B/\langle B\rangle \sim 3\ 10^{-4}$)

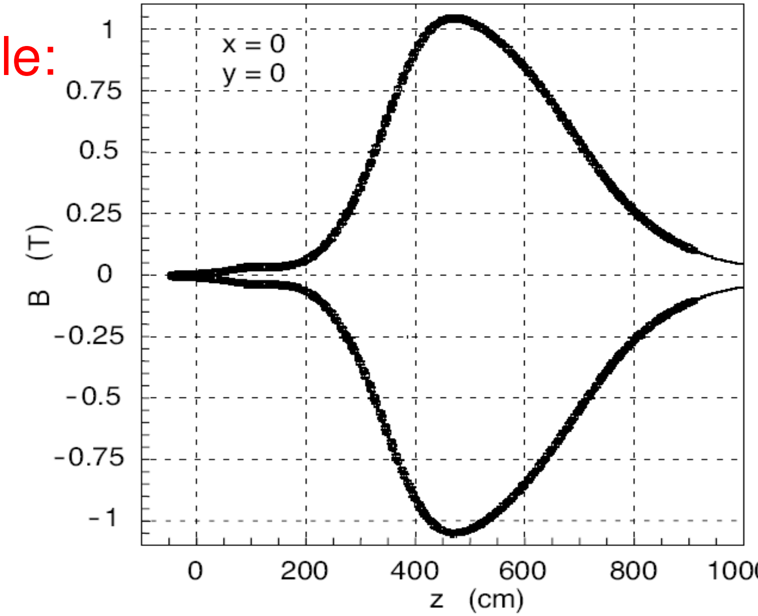


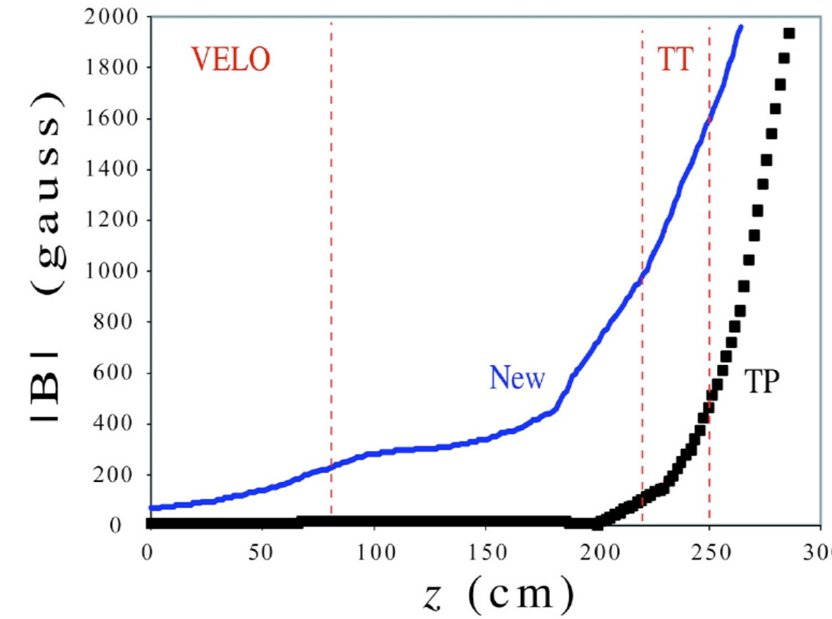
Fe yoke (1.45 kt)

Al coil (2x25t)

4.2 MW power at 1 T field

B-field profile:





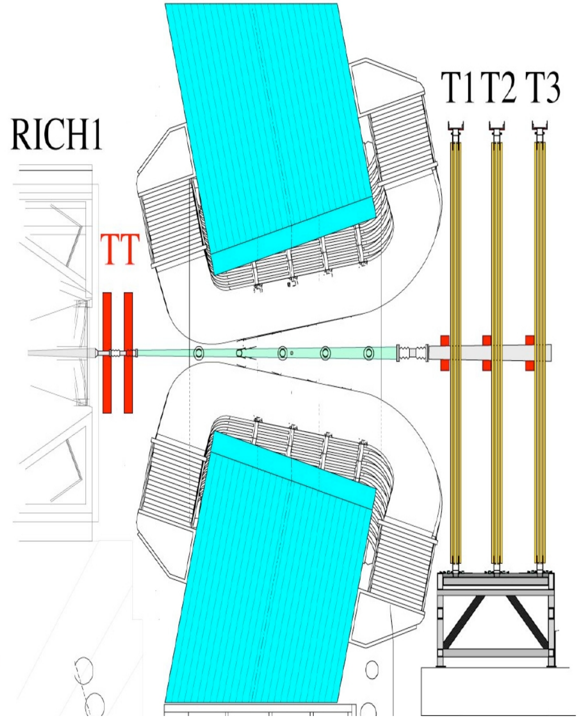
Designed evolved: no more shield in upstream region to measure track p_T with VELO and TT at trigger level

Tracking System

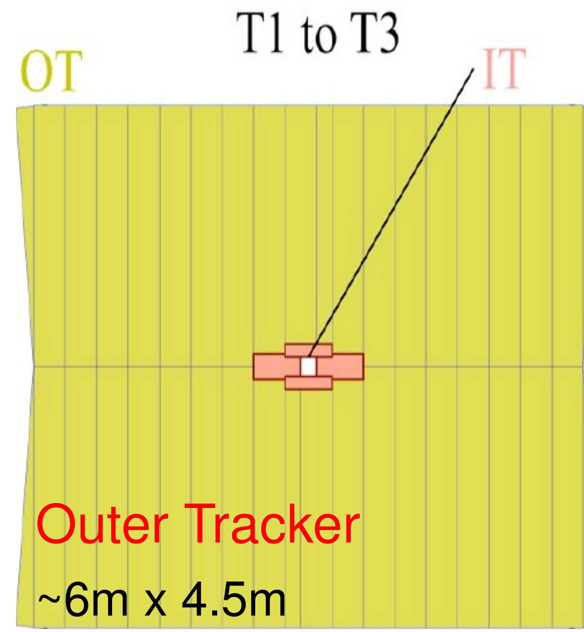
Trigger Tracker

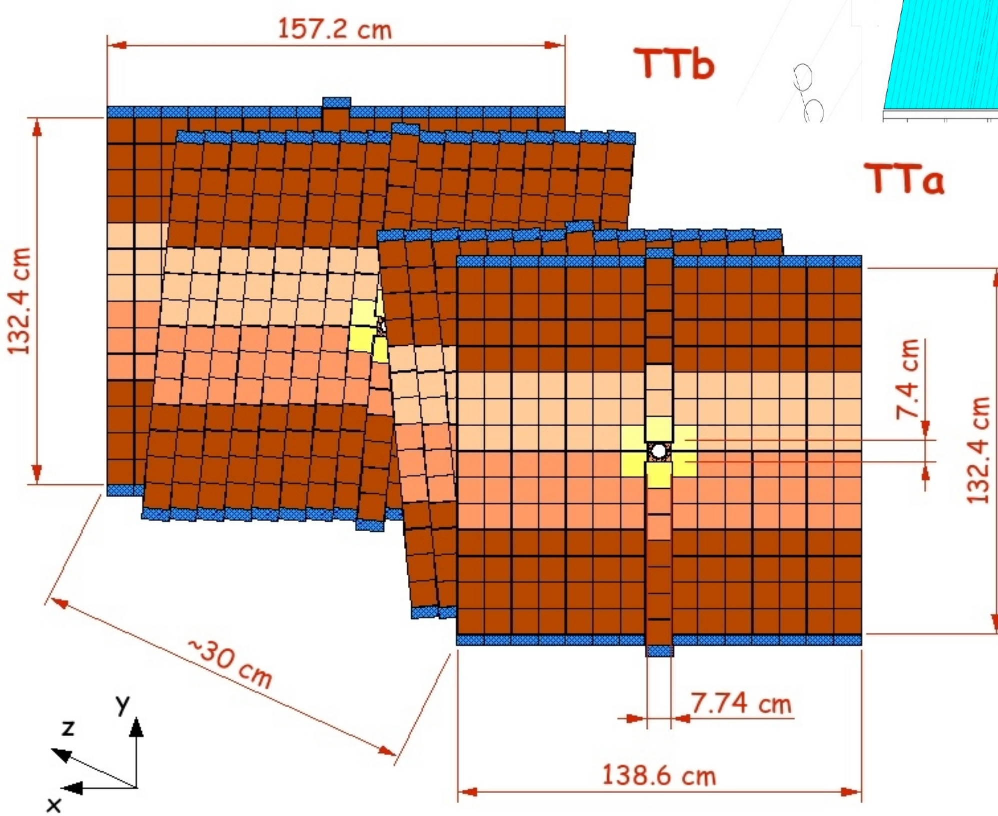
(together with VELO,
measure track P_T for trigger)

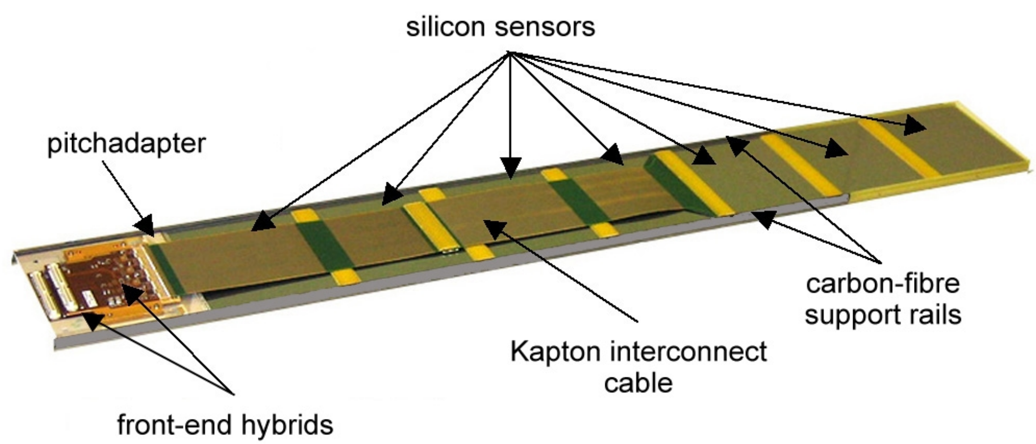
- 500 µm Si, 183 µm pitch
- 2+2 layers:
  x, u, (30 cm gap), v, x



Inner Tracker







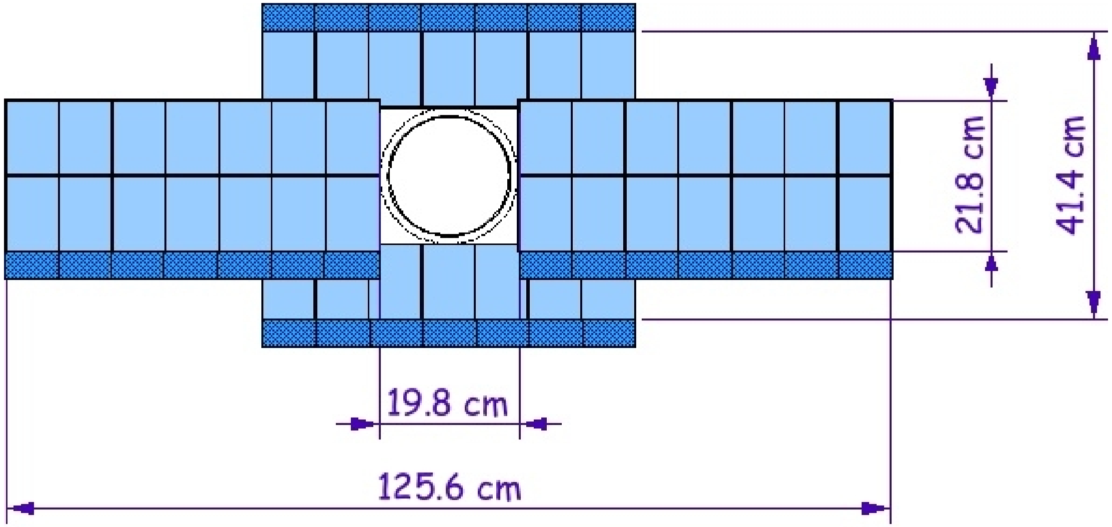
Inner/Outer Tracker

High track multiplicity region close to the beam pipe:

- Area: IT: 2%, OT: 98%
- Tracks: IT: 20%, OT: 80%

Inner Tracker:

- Si-strip detector arranged in 4 boxes/station around the beam pipe
- 4 Si xuvx planes/box, 7 detector modules/plane
- 198 μm pitch, ~ 130k channels



Outer Tracker:

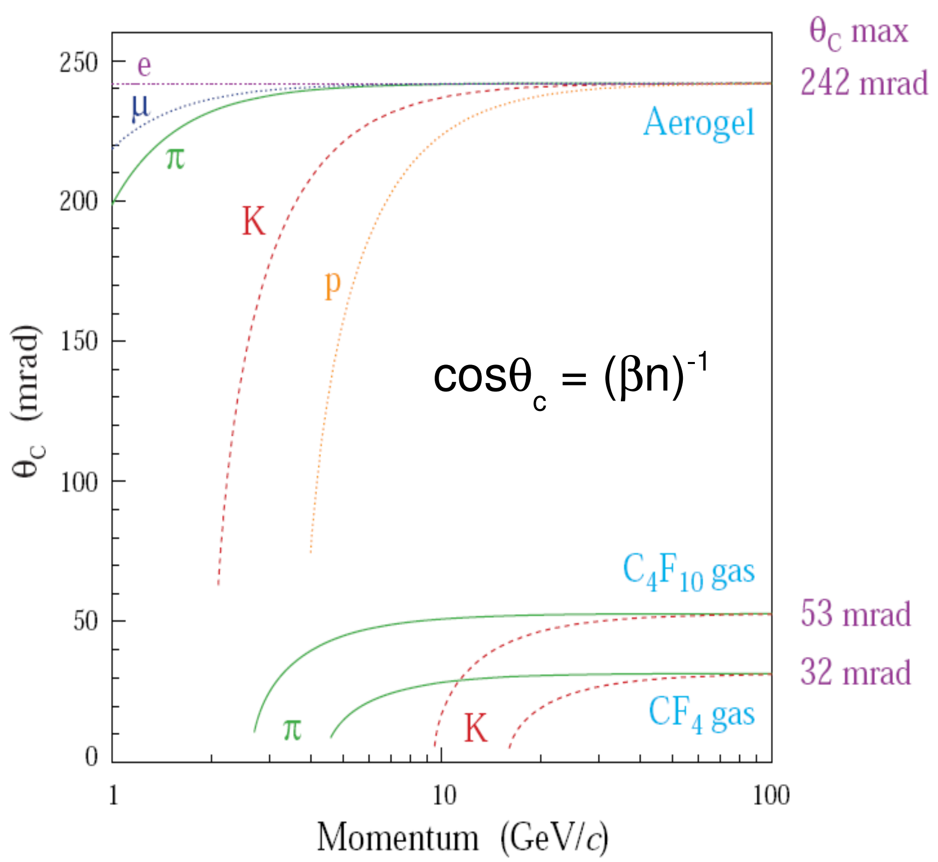
- Straw tubes, 5 mm diameter, 5 m length
- 3 stations, each 4 layers (x-u-v-x geometry)

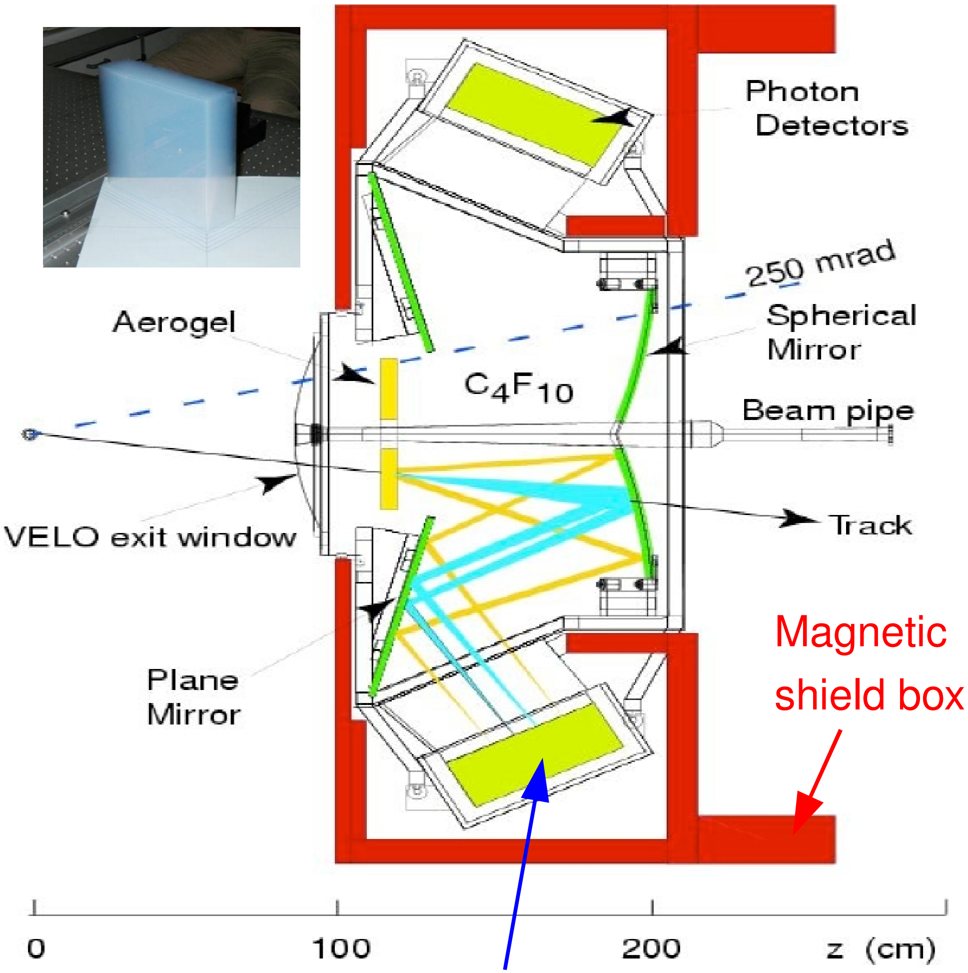
Modules with 5° stereo angle

RICH 1 and 2

Ring Imaging Cherenkov detector with two radiators (for particle ID)

Aerogel: n=1.03 (p: 2→~10 GeV/c), C_4F_{10} gas: n=1.0014 (p: 10→~ 60 GeV/c)





RICH2: covers the low-angle region with high-momentum tracks

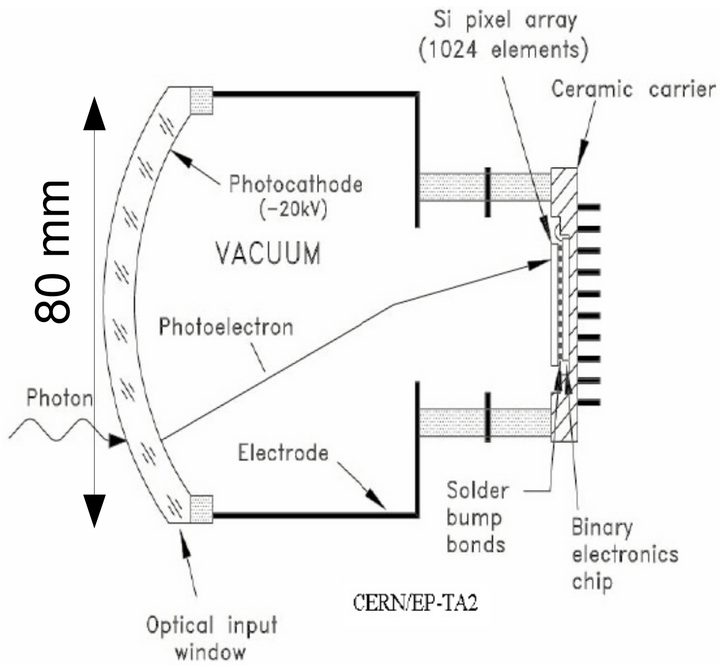
CF4 gas: n=1.0005 (p: 16→~100 GeV/c)

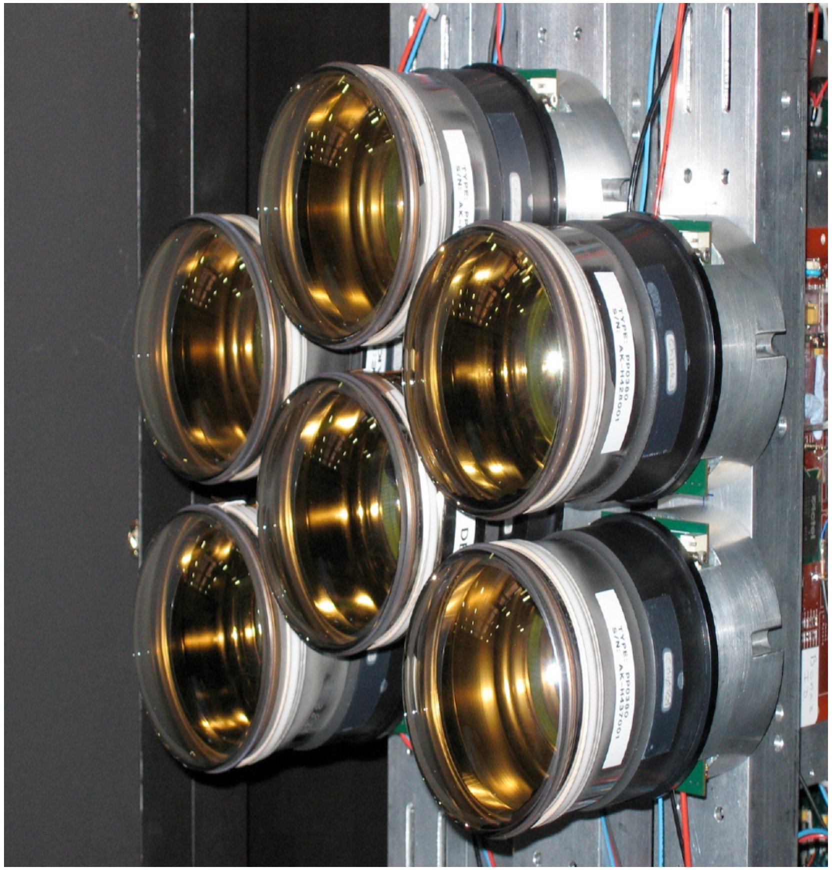
Reconstruct up to two concentric rings per track on the photon-detector plane → θ_{c1}, θ_{c2}

Hybrid Photon Detector

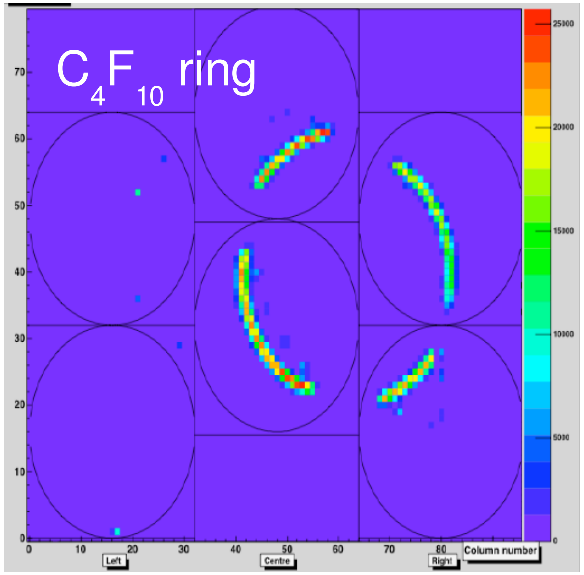
Novel photon detector, developed for LHCb RICH1 and RICH2 detectors

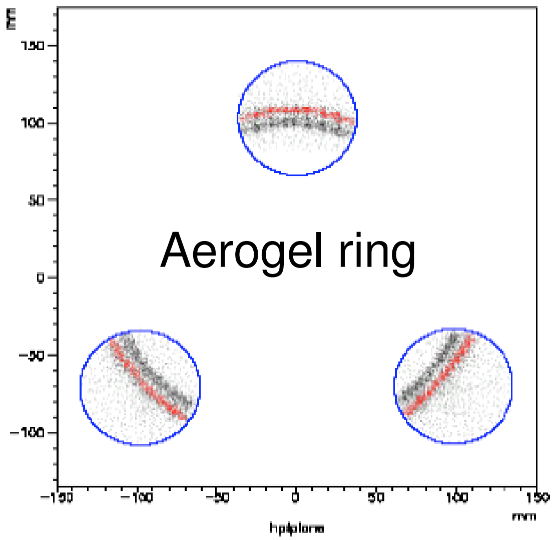
- ~ 500 tubes, with 1024 pixels each
- 2.5 x 2.5 mm^2 granularity → $\sigma(\theta)$=1.66 mrad (RICH1)



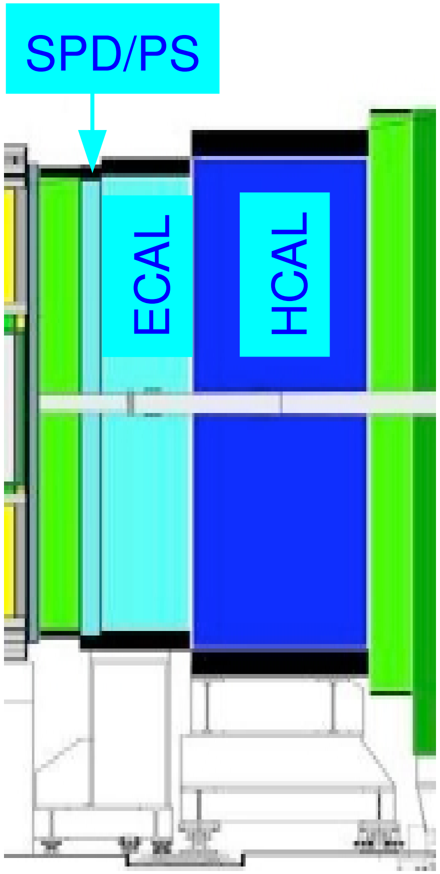


test beam results





Calorimeters



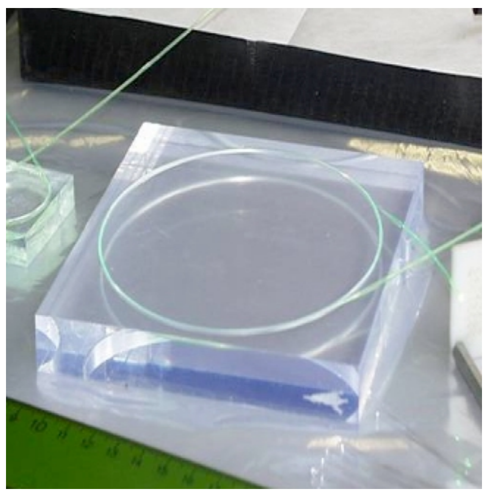
Preshower: scintillating pads+WLS fibers + 2.5 X_0 Pb

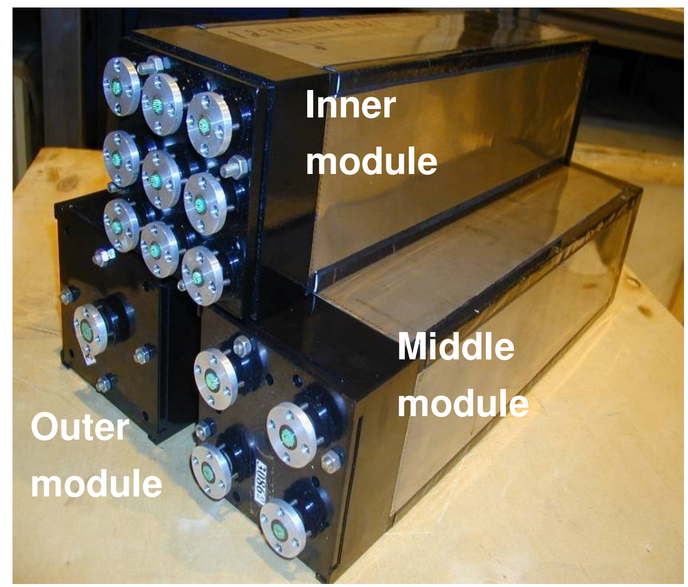
Electromagnetic: Pb-scintillator Shashlik calorimeter, 25 X_0

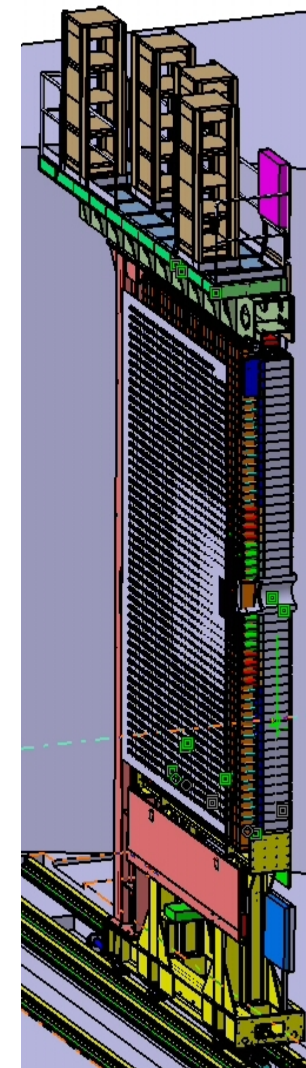
$\sigma_E/E = 10\%/\sqrt{E} \oplus 1\%$

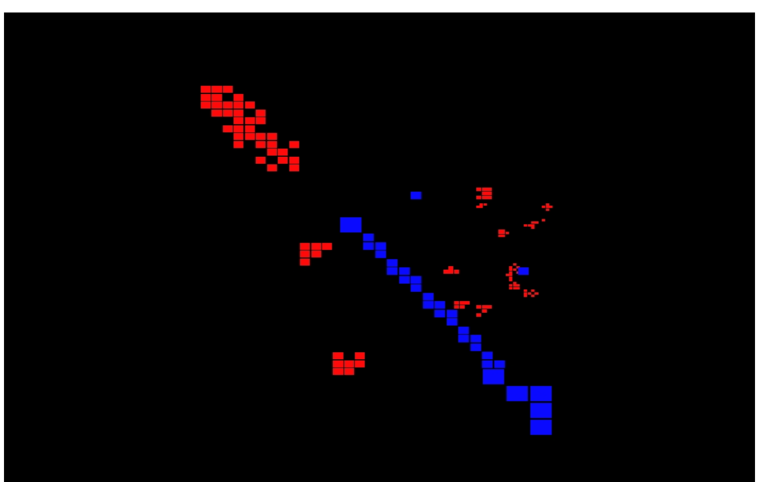
3 segmentations: inner/middle/outer

Hadronic: Fe-scintillator tile calorimeter, 5.6 λ_I





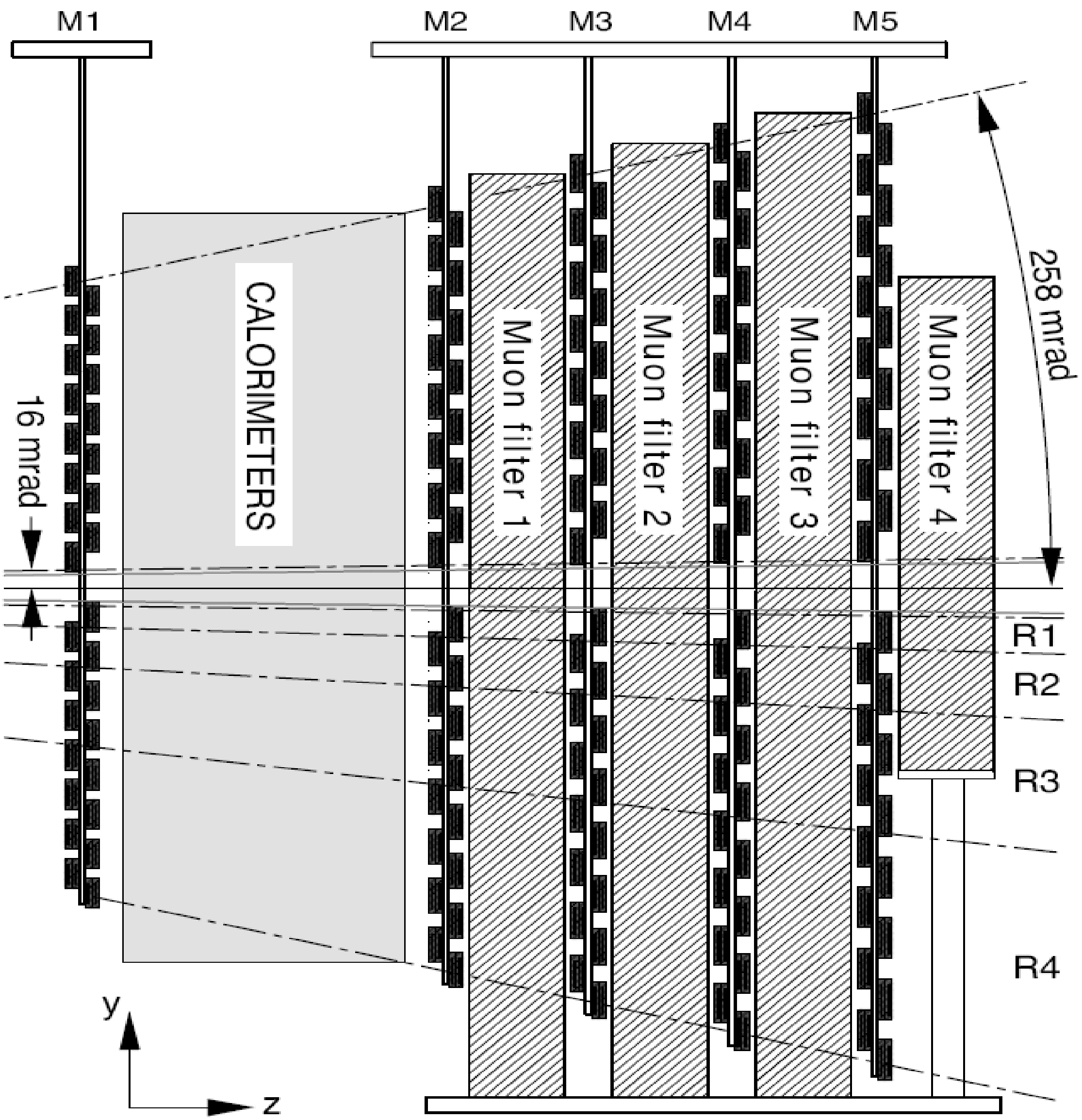


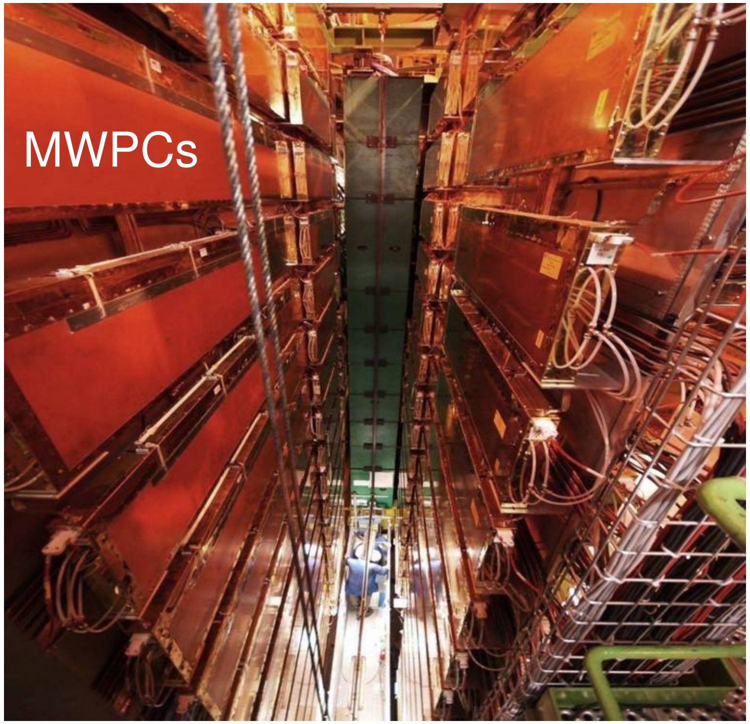


Cosmic ray in ECAL and HCAL (feb '08)

Muon

1380 MWPCs are used for all 5 stations except for the inner part of M1 where triple-GEMs are used instead (high occupancy region)





Muon filter:

80 cm thick iron absorber

$p_{M5} > 6$ GeV/c

Use of M1 in front of Calorimeters to improve p_T determination in L0-trigger

LHCb: expected performances

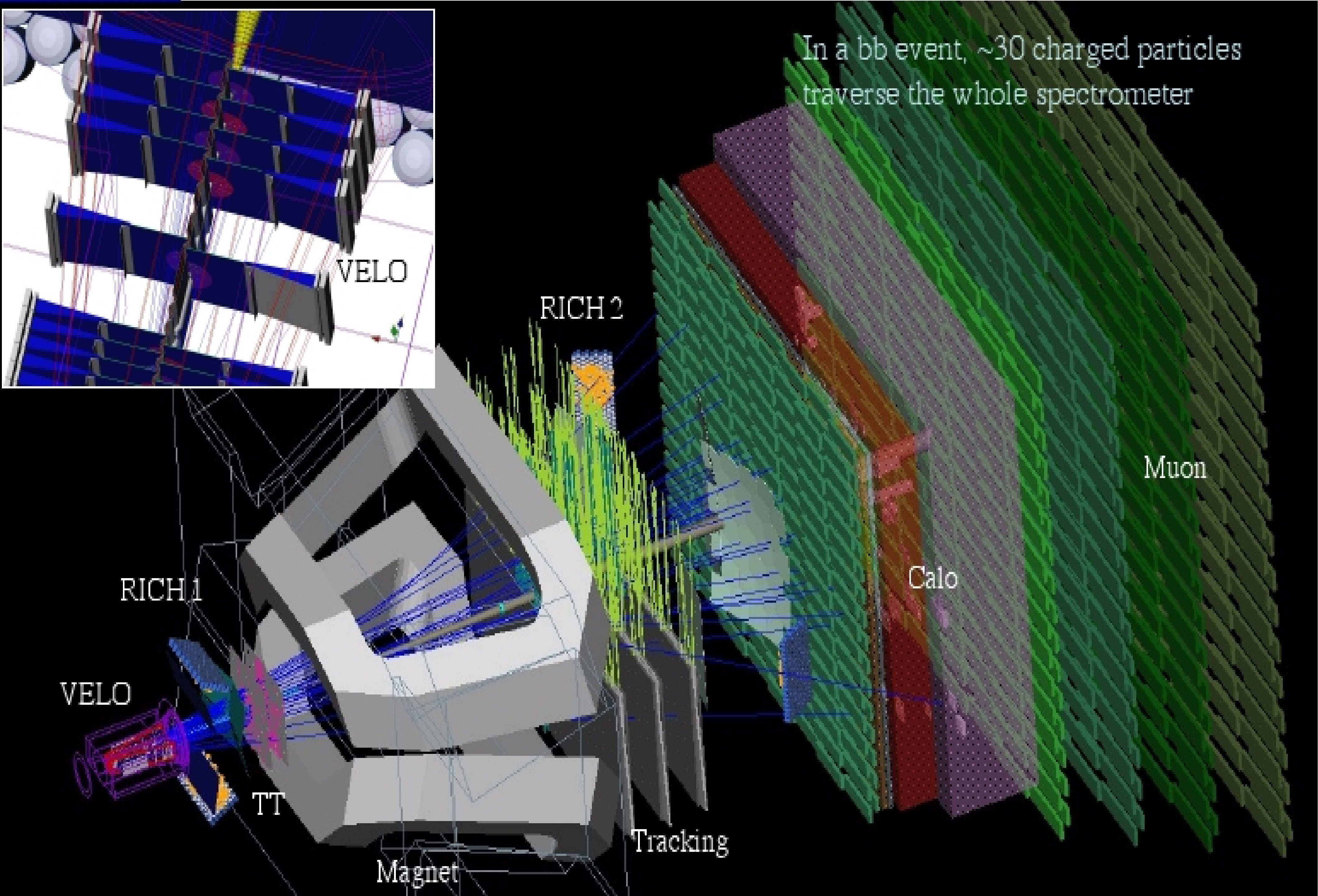
Crucial for B physics:

– excellent tracking and vertexing (σ_m, σ_τ)

– excellent particle ID

– polyvalent trigger (incl. hadrons)

PHYTHIA+GEANT4 Full Simulation



Expected LHCb Tracking Performance

Track finding:

efficiency > 95% for long tracks from B decays

- ~ 4% ghosts

for p_T > 0.5 GeV/c

$K_S \rightarrow \pi^+\pi^-$ reconstruction

75% efficient for decay in the VELO, lower otherwise

Average b-decay track resolutions:

Impact parameter: ~ 30 µm

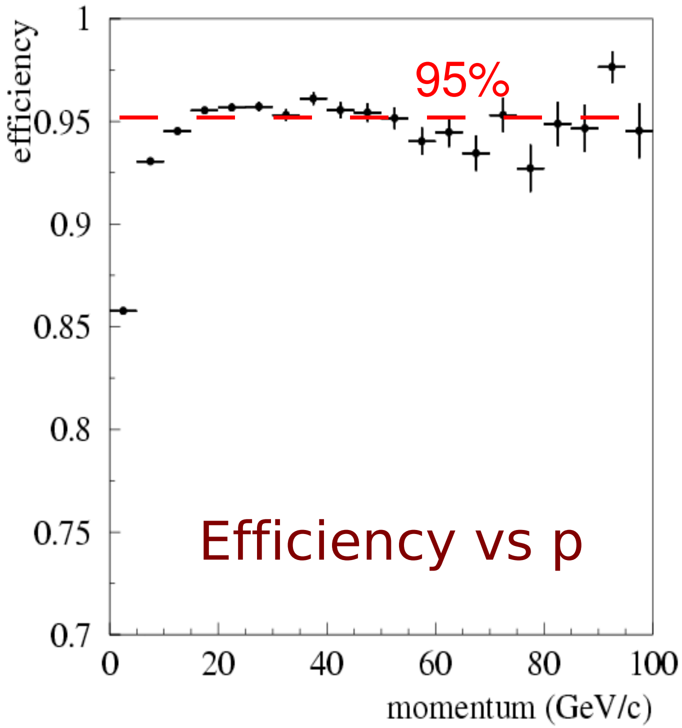
Momentum: ~ 0.36%

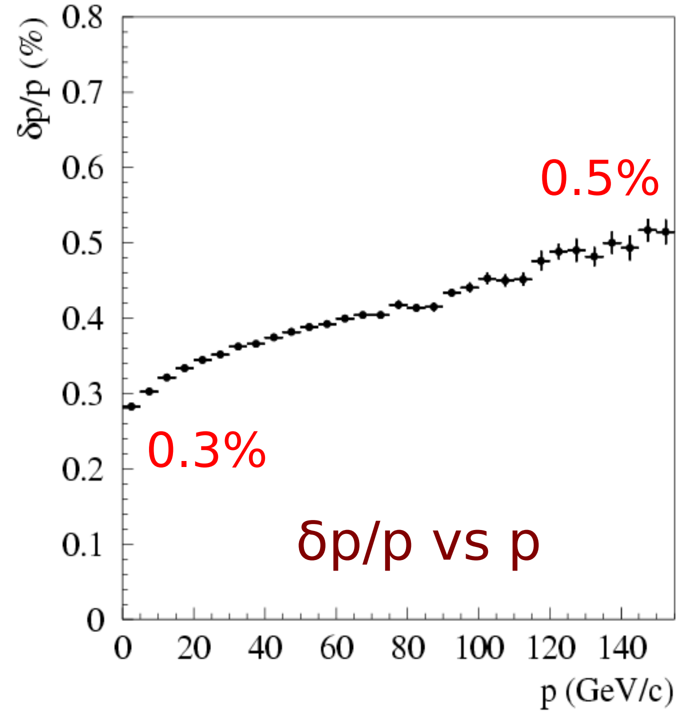
Typical B resolutions:

Proper time: ~ 40 fs

(essential for Bs physics)

Mass: 8–18 MeV/c^2





	Mass resolution
$B_s \rightarrow \mu\mu$	18 MeV/c^2
$B_s \rightarrow D_s\,\pi$	14 MeV/c^2
$B_s \rightarrow J\psi\,\phi$	16 MeV/c^2
$B_s \rightarrow J/\psi\,\phi$	8 MeV/c^2 *

(*) with J/ψ mass constraint

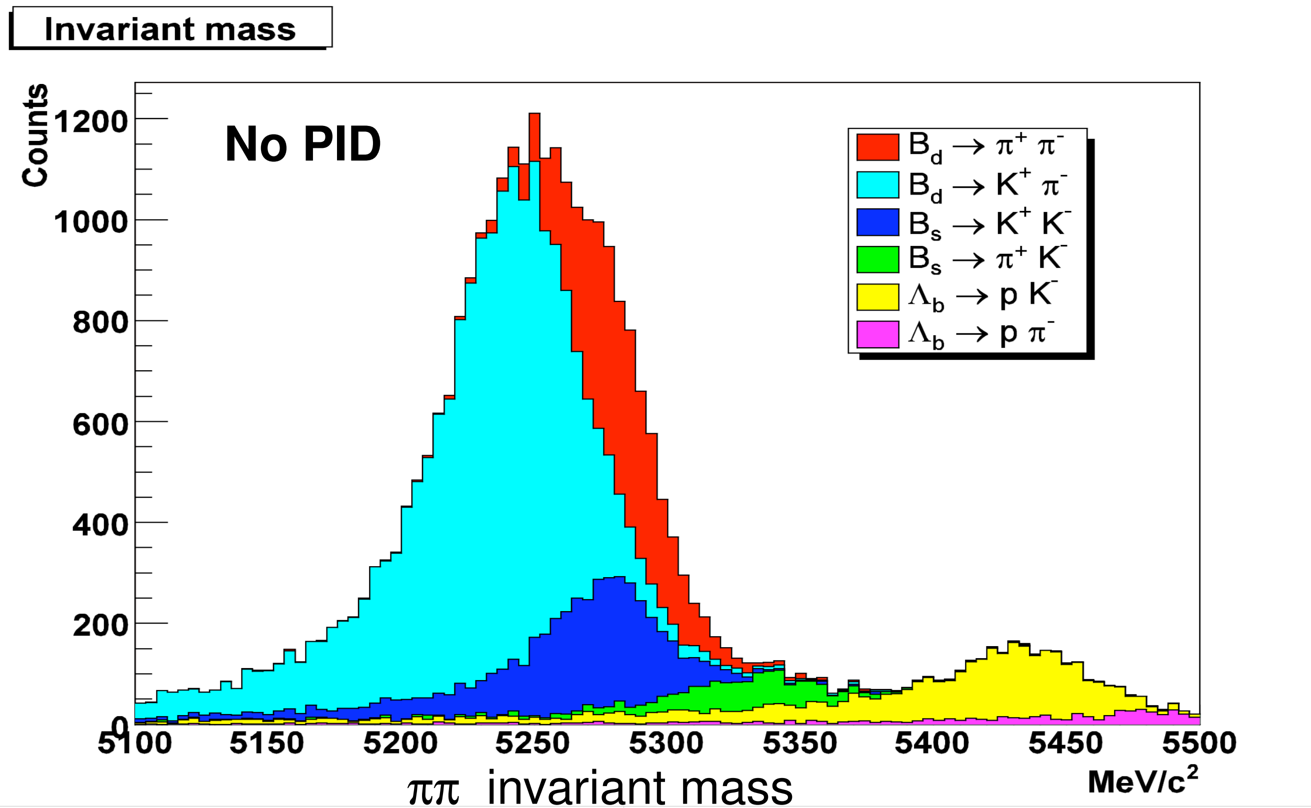
Particle ID performance with RICH

Average performance:

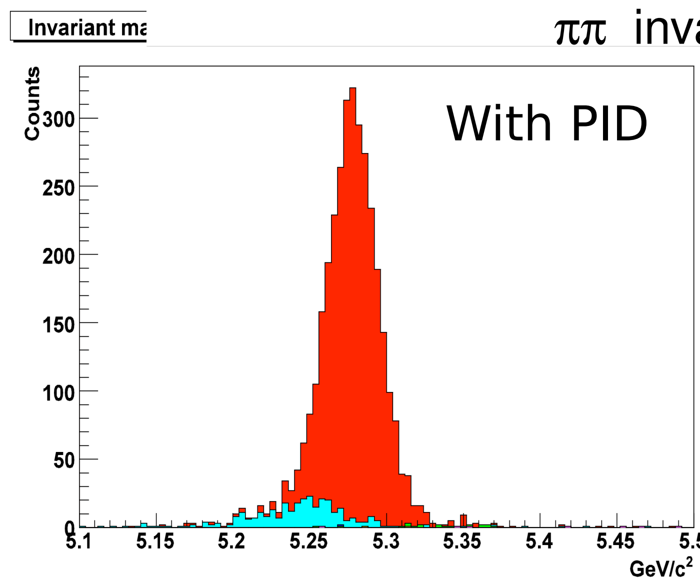
- kaon ID eff. = 88%
- π mis-ID = 3%

Good K/π separation in 2–100 GeV/c range

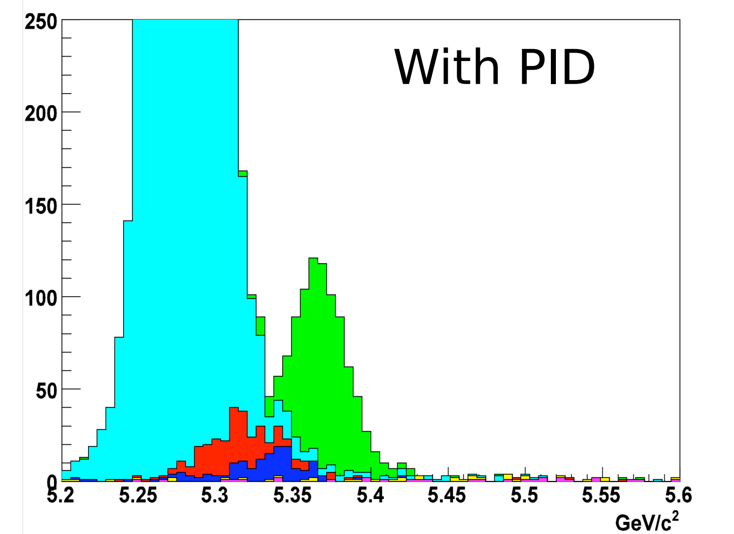
- Low momentum
  - Tagging kaons
- High momentum
  - clean separation of the different $B_{d,s} \rightarrow hh$ modes
  - will be best performance ever achieved at a hadron collider



ππ invariant mass



ππ invariant mass

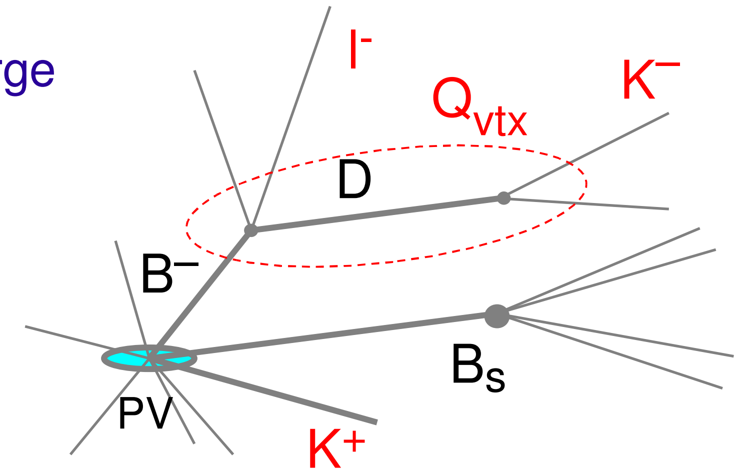


Kπ invariant mass

Flavor Tagging

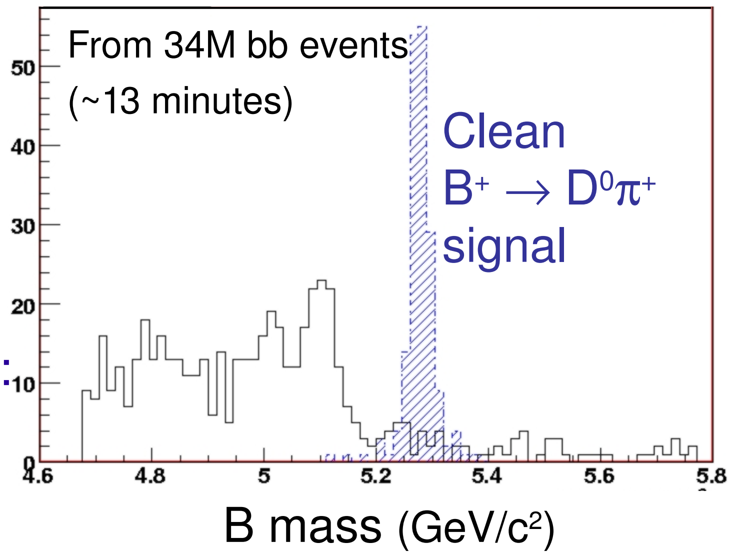
Several tags:

- Opposite side (OS): electron, muon, kaon, vertex charge
- Same side (SS): pion (B^0) or kaon (B_s)
  - most powerful tags: SS kaon and OS kaon
- Expected combined performance on triggered and selected MC events:
  - **$\varepsilon D^2 = \varepsilon(1-2w)^2$ = 4–5% for B^0**
  - **$\varepsilon D^2 = \varepsilon(1-2w)^2$ = 7–9% for B_s**



Using data:

- Reconstruct and select several control samples
  - High-statistics flavour-specific B decay modes
- Look at tags one by one:
  - assess performance (mistag rate w)
  - tune tag selection



Control channel	**0.1 fb^{-1} yield**	**B_{bb}/S**
$B^+ \to J/\psi(\mu\mu)K^+$	**85k**	**0.4**
$B^0 \to J/\psi(\mu\mu)K^{*0}$	**45k**	**0.2**
$B^+ \to D^0\pi^+$	**50k**	**0.1**
$B_s \to D_s^+\pi^-$	**7k**	**0.2**
$B^+ \to D^0\mu^+\nu X$	**120k**	**0.8**
$B^0 \to D^{*-}\mu^+\nu$	**460k**	**0.3**
$B_s \to D_s\mu^+\nu X$	**55k**	**0.4**

Trigger Performance and Rates

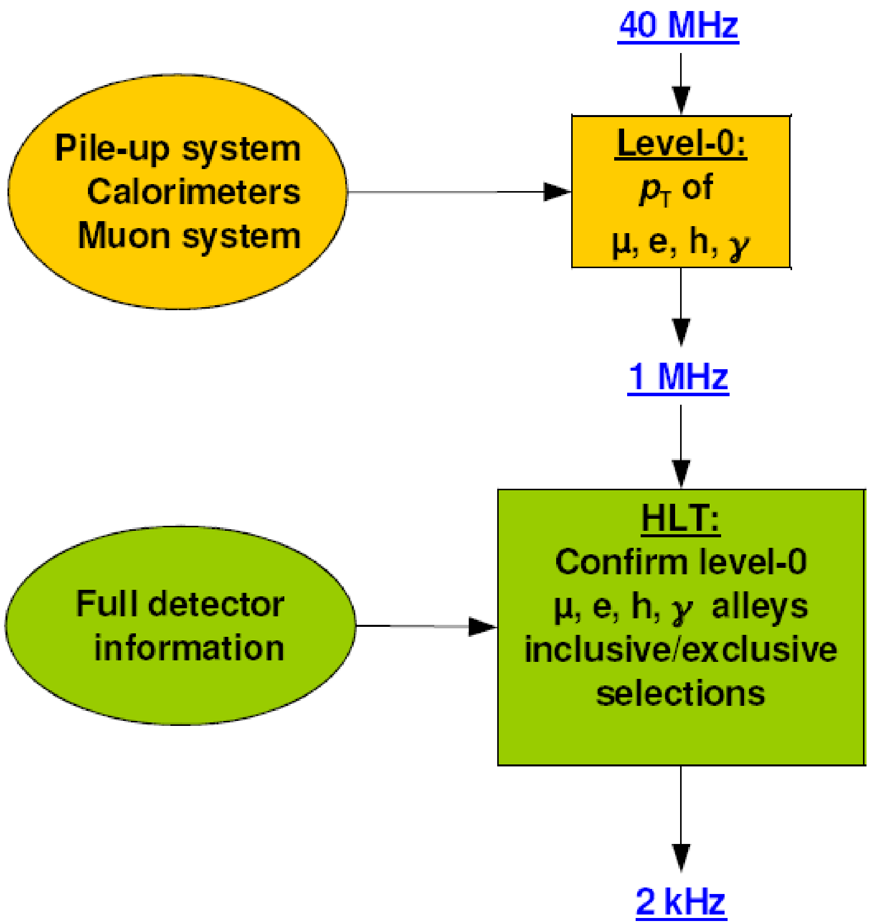
Algorithms and performance:

- Hardware level (L0), max. 1 MHz output rate:
  - algorithms mature
- Software level (HLT = High Level Trigger):
  - prototype available within time budget for a limited set of channels
- L0*HLT efficiencies:
  - typically 30%–80% for offline-selected signal events, depending on channel

HLT output rates:

- Indicative rates
  - split between streams still to be determined
- Large inclusive streams to control calib. & syst.
  - trigger, tracking, PID, tagging

Output rate	Event type	Physics
200 Hz	Exclusive B candidates	B (core program)
600 Hz	High mass di-muons	J/ψ, $b \to J/\psi X$ (unbiased)
300 Hz	D* candidates	Charm
900 Hz	Inclusive b (e.g. $b \to \mu$)	B (data mining)



Integrated Luminosity

2008: [unofficial "possible" scenario]

—LHC startup with full detector installed

—Establish running procedures, time and space alignment of the detectors

—Calibration of momentum, energy and particle ID

—Integrated luminosity for physics ~ 0.1 fb^{-1}

2009:

—Complete commissioning of trigger

—Start of significant physics data taking, assume ~ 0.5 fb^{-1}

2010–:

—Stable running, assume ~ 2 fb^{-1}/year

—If found to be advantageous for physics, push average luminosity from 2.10^{32} to 5.10^{32} $cm^{-2}s^{-1}$

Availability of physics results:

—with 0.5 fb^{-1} in ~2010

—with 2 fb^{-1} in ~2011

—with 10 fb^{-1} in ~2015

LHCb: Physics (examples)

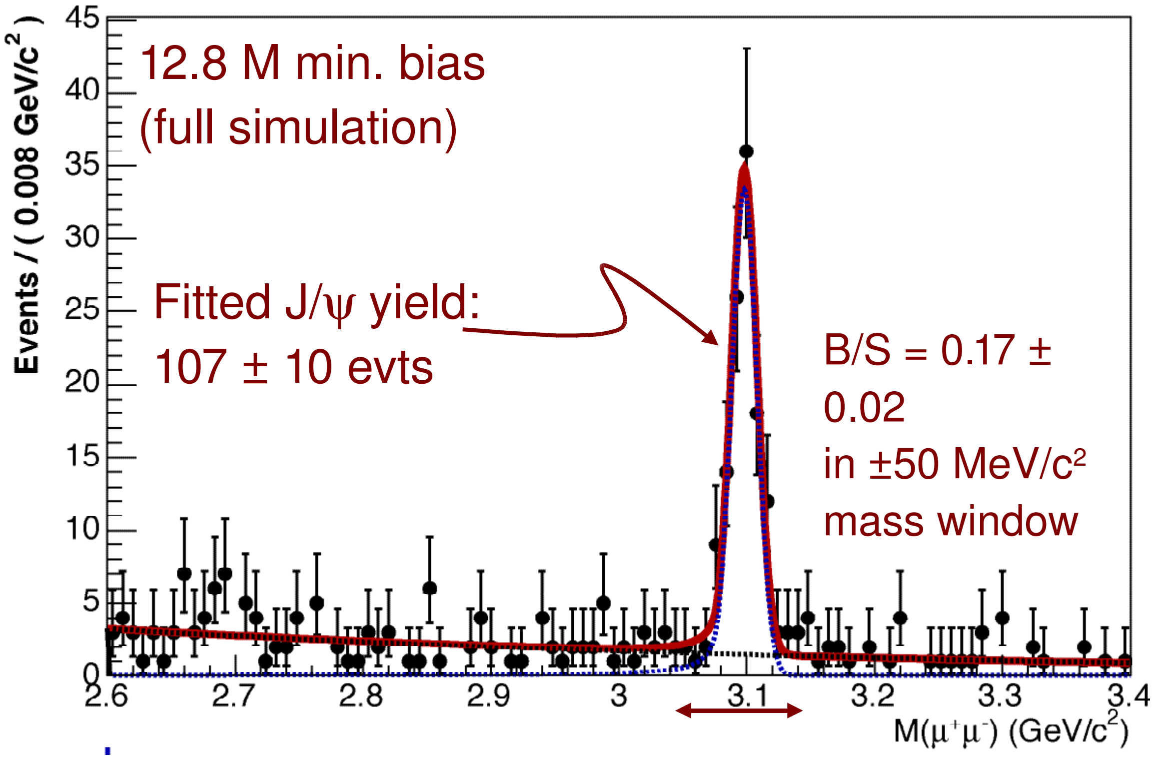
http://lhcb-phys.web.cern.ch/lhcb-phys/DC04_physics_performance/

Physics with very early data

- Minimum bias events:
  - e.g. 10^8 events in ~20 hours at 2×10^{28} $cm^{-2}s^{-1}$ with interaction trigger
  - First look at 14 TeV data: everything new !
    - (Ratio of) multiplicities vs η, pT, φ of charged tracks (+/–, π/K/p)
    - Reconstruction and production studies of K_S, Λ, ϕ, D, …

- J/ψ → μμ events:

  ~1M J/ψ → μμ in 1 pb^{-1}
  (little bit of trigger needed)
    - Fraction of J/ψ from b decays or prompt production vs p_T
    - First exclusive B → J/ψX peaks
    - Measurements of bb production cross section, …

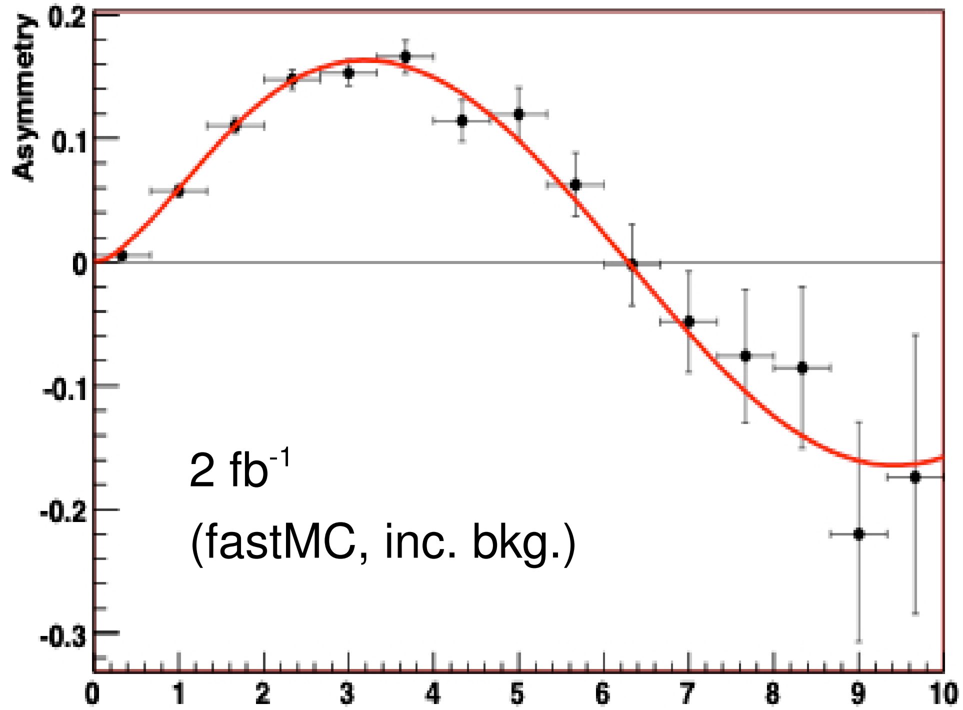


Sin2β with $B^0 \to J/\psi K_S$

Expected to be one of the first CP measurement:

- Demonstrate (already with ≤ 0.5 fb-1) that we can keep under control the main ingredient of a CP analysis, in particular the tagging performance extraction from the control sample $B^0 \to J/\psi K^{0*}$
- Sensitivity:
  - 236k events/2 fb^{-1} with B/S= 0.6 (bb) and 7.7 (prompt J/ψ)
  - ➔ σ(sin2β) = 0.020

$$A_{CP}(t) = \frac{N(\overline{B}^0 \to J/\psi K_S) - N(B^0 \to J/\psi K_S)}{N(\overline{B}^0 \to J/\psi K_S) + N(B^0 \to J/\psi K_S)}$$



Proper time t(ps)

With 10 fb-1:

- should be able to reach σ(sin2β) = 0.010
- Can also push further to search for direct CP violation term ∝ cos(ΔM t)

LHCb measurements of the angle γ

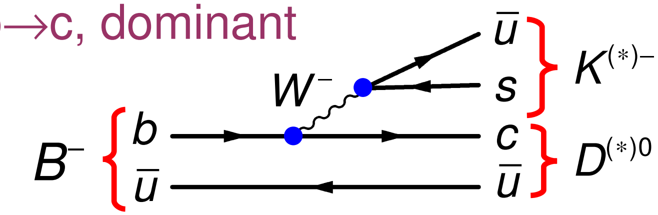
$B^+ \to D^{(*)0} K^{(*)+}$:

GLW : D^0 decays into CP eigenstate

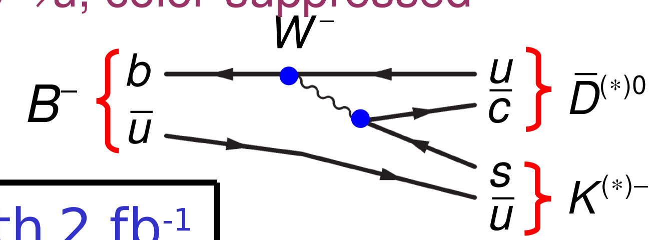
ADS : D^0 decays to $K^-\pi^+$ (favored) and $K^+\pi^-$ (suppressed)

GGSZ : D^0 decays to $K_S\pi^+\pi^-$ (interference in Dalitz plot)

Tree: b→c, dominant



Tree: b→u, color-suppressed



B mode	D mode	Method	$\sigma(\gamma)$ with 2 fb^{-1}
$B^+ \to DK^+$	$K\pi$ + $KK/\pi\pi$ + $K3\pi$	counting,ADS+GLW	5º–13º
$B^+ \to D^*K^+$	$K\pi$ ($D^* \to D+\pi, \gamma$)	counting,ADS+GLW	Under study
$B^+ \to DK^+$	$K_S\pi\pi$	Dalitz, GGSZ	8-12º
$B^+ \to DK^+$	$KK\pi\pi$	4-body Dalitz	18º
$B^+ \to DK^+$	$K\pi\pi\pi$	4-body Dalitz	Under study
$B^0 \to D^0K^{*0}$	$K\pi$ + KK + $\pi\pi$	counting,ADS+GLW	9º
$B^0 \to D^0K^{*0}$	$K_S\pi\pi$	Dalitz, GGSZ	Under study
$B_s \to D_sK$	$KK(\phi)\pi$	tagged, A(t)	~10º
$B^0 \to \pi^+\pi^-$, $B_s \to K^+K^-$	-	U-spin symmetry	5^0 - 10^0

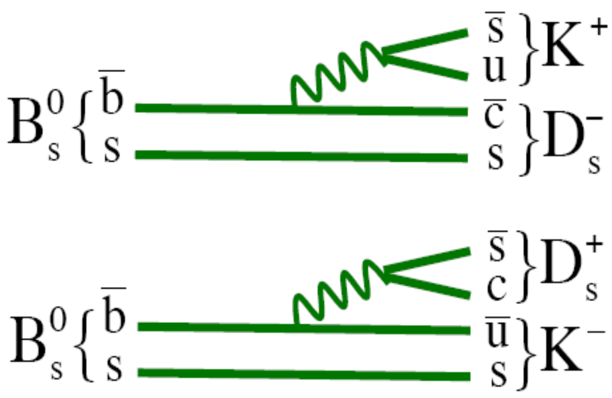
tree decays only

γ from $B^0_s \to D_s K$

Two tree decays ($b \to c$ and $b \to u$), which interfere via B_s mixing:

can determine $2\beta_s + \gamma$ hence γ in a clean way

- similar to $2\beta+\gamma$ extraction with $B^0 \to D^* \pi$, but with the advantage that the two decay amplitudes are similar ($\sim\lambda^3$) and that their ratio can be extracted from data



LHCb expects 6.2k events/2 fb^{-1},

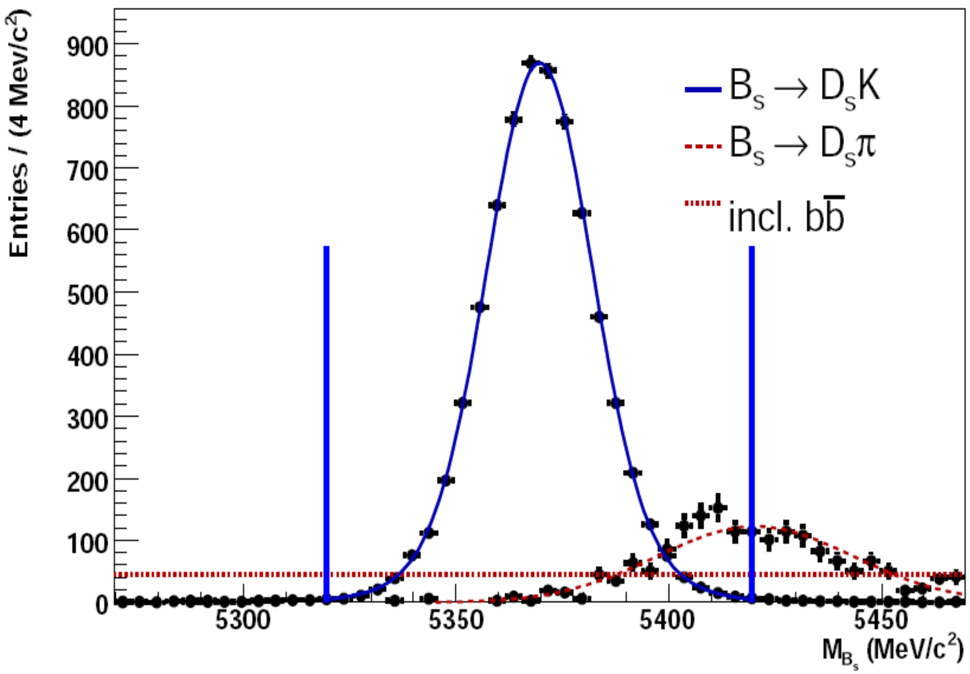
$B_{bb}/S < 0.18$ (@90 CL)

$B_s \to D_s \pi$ background 15±5% after PID cuts

Fit 4 tagged and 2 untagged time-dependent rates:

- extract $2\beta_s+\gamma$, strong phase difference and amplitude ratio ($B_s \to D_s \pi$ also used in the fit to constrain other parameters (mistag rates, Δm_s, $\Delta\Gamma_s$

➔ $\sigma(2\beta_s+\gamma) = 10°$ with 2 fb^{-1}



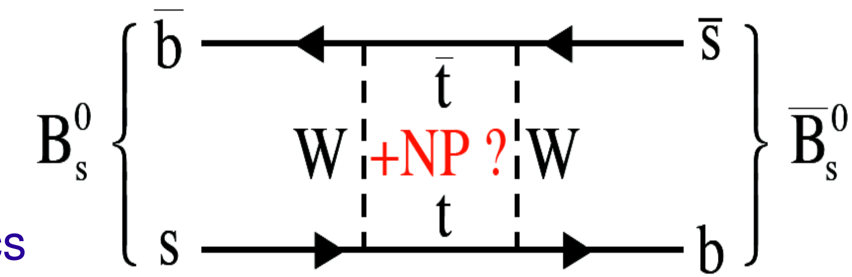
$2\beta_s$: B_s mixing phase with $b \to c\bar{c}s$

$2\beta_s$ is the strange counterpart of 2β:

β_s very small in SM and well-predicted:

-1.054 [+0.051 -0.049] [CKMfitter Summer '07]

Could be much larger in presence of New Physics



Golden $b \to ccs$ mode is $B_s \to J/\psi\phi$:

Single decay amplitude

Angular analysis needed to separate CP-even and CP-odd contributions

Time-dependent CP asymmetry:

$$A_{CP}(t) = \frac{\Gamma\left(\bar{B}_s^0(t) \to f\right) - \Gamma\left(B_s^0(t) \to f\right)}{\Gamma\left(\bar{B}_s^0(t) \to f\right) + \Gamma\left(B_s^0(t) \to f\right)}$$

For a final state f with CP eigenvalue η_f:

$$A_{CP}(t) = \frac{-\eta_f \sin 2\beta_s \sin(\Delta m_s t)}{\cosh\left(\Delta\Gamma_s t/2\right) - \eta_f \cos 2\beta_s \sinh\left(\Delta\Gamma_s t/2\right)}$$

Current experimental situation:

- No evidence of CP violation found
- D0 result (2.8 fb^{-1}, ~2k $B_s \to J/\psi\phi$)

$2\beta_s = -0.57 +0.24 -0.30 +0.07 -0.02$
[arXiv:0802.2255 [hep-ex]]

LHCb sensitivity with 0.5 fb^{-1}:

$\sigma_{stat}(2\beta_s) = 0.046$

~33k $B_s \to J/\psi(\mu\mu)\phi$ events (before tagging),

$B_{bb}/S = 0.12$, $\sigma_t = 36$ fs

Eventually:

Add also pure CP modes ($J/\psi\eta^{(\prime)}$, $\eta_c\phi$, D_sD_s)

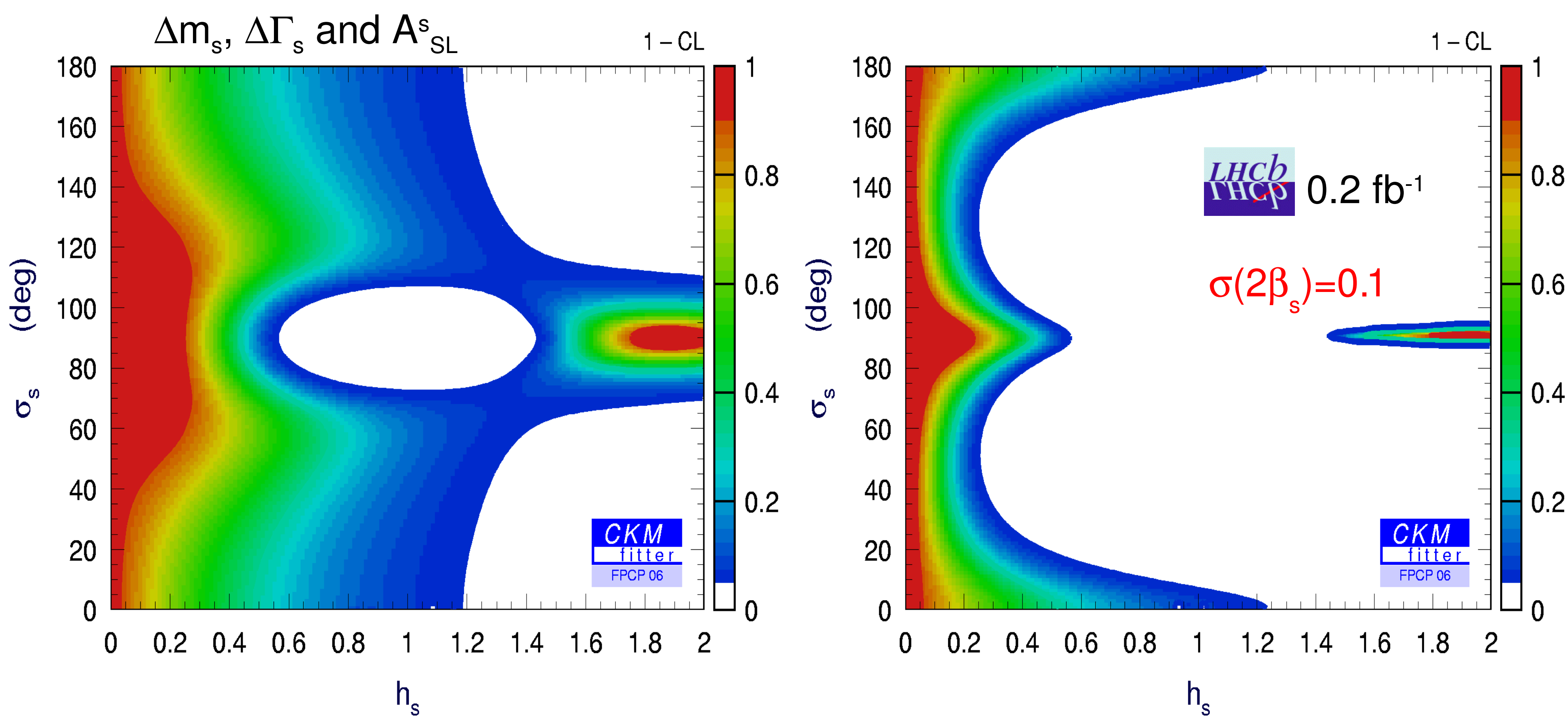
With 10 fb^{-1}, obtain >3σ evidence of CP violation ($2\beta_s \neq 0$), even if only SM

Constraints on NP from $2\beta_s$ measurement

NP in Bs mixing:

amplitude M12 parametrized with h_s and σ_s

$$M_{12} = \left(1 + h_s e^{2i\sigma_s}\right) M_{12}^{SM}$$

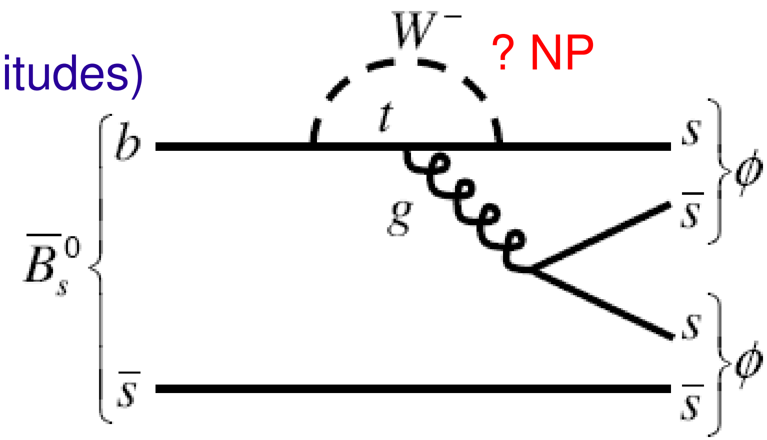


LHCb can exclude already a significant region of allowed phase space with the very first data or ...

Time dependent CP analysis of pure penguin decays into CP eigenstates

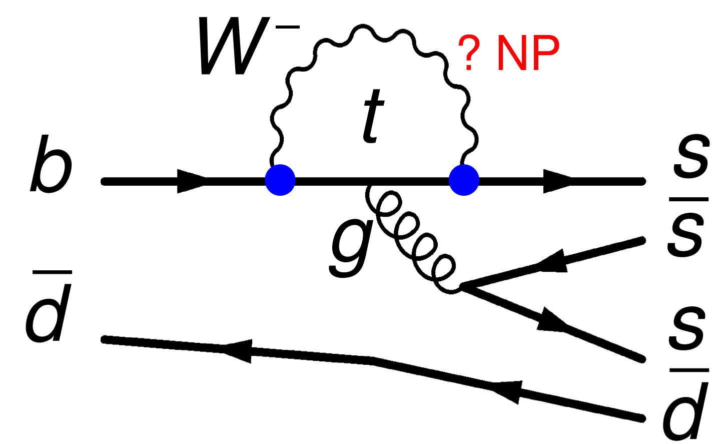
"Golden mode" is $B_s \to \phi\phi$:

- CP violation < 1% in SM
  (cancellation: V_{ts} enters both in mixing and decay amplitudes)
- Significant CP-violating phase can only be due to NP
- Vector Vector mode: angular analysis required
- 3.1k events/2 fb^{-1}, B/S<0.8 (@90% CL)
- sensitivity on NP phase: $\sigma(\phi_{NP})$=0.05 for 10 fb^{-1}

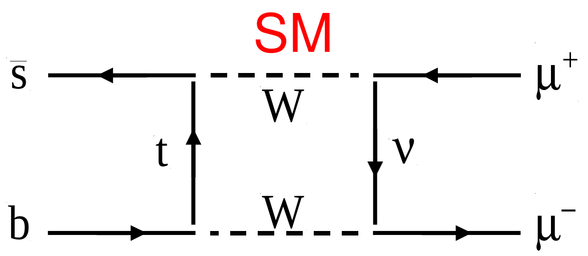


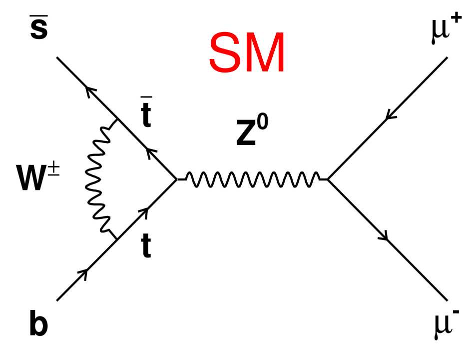
$B0 \to \phi K_S$:

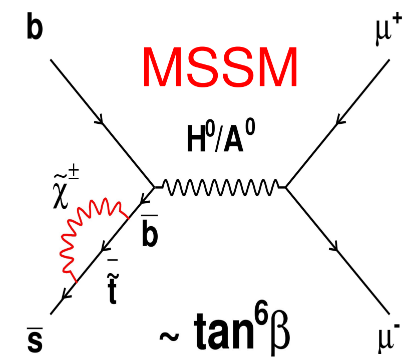
- 920 signal events/2 fb^{-1}, B/S<1.1 (@90% CL)
- after 10 fb^{-1}, $\sigma_{stat}(\sin 2\beta_{eff})$=0.10
  - to be compared with 0.12 from BABAR+Belle analyses



$B^0_s \to \mu^+\mu^-$







Very rare loop decay, sensitive to new physics:

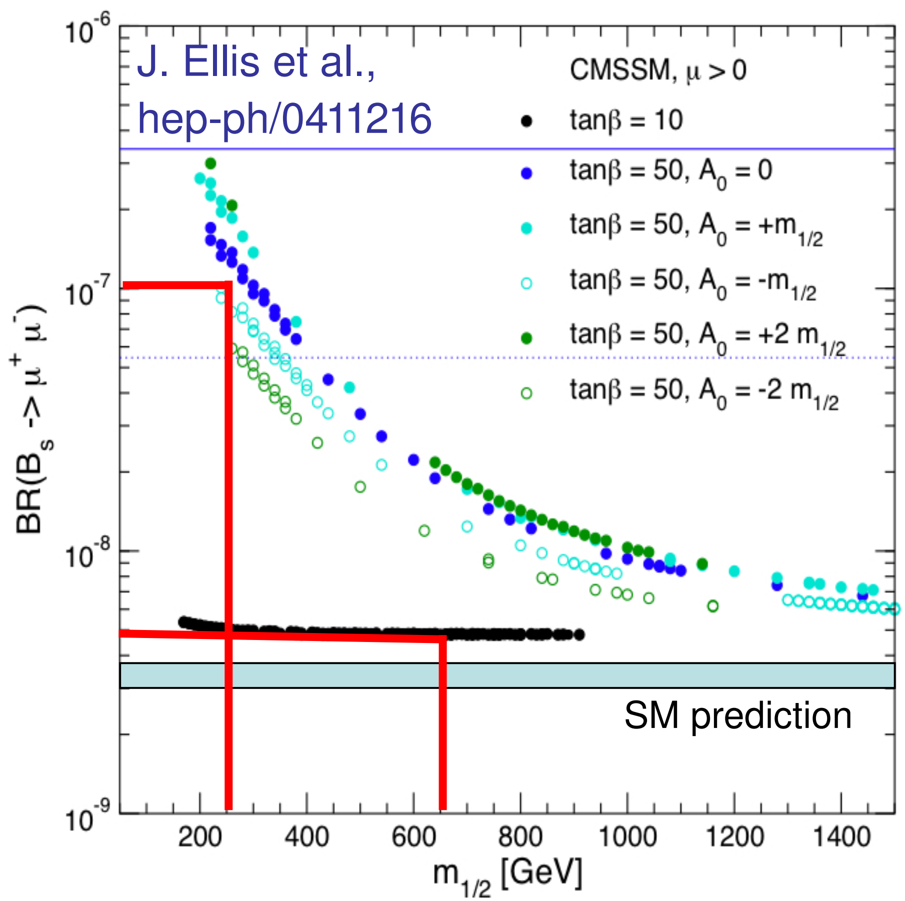
- $BR_{SM} = (3.14 + 0.15 - 0.25) \times 10^{-9}$
- Can be strongly enhanced in SUSY:

  e.g. current measurement of $g_\mu - 2$ suggests gaugino mass ($m_{1/2}$) between 250 and 650 GeV/c²

  $\Rightarrow$ $BR(B_s \to \mu^+\mu^-)$ up to 100×10^{-9} within the CMSSM for high tanβ
- Current 90% CL limits:

  $47 \times 10^{-9} = 15 \times BR_{SM}$ (CDF, 2 fb^{-1}, prel)

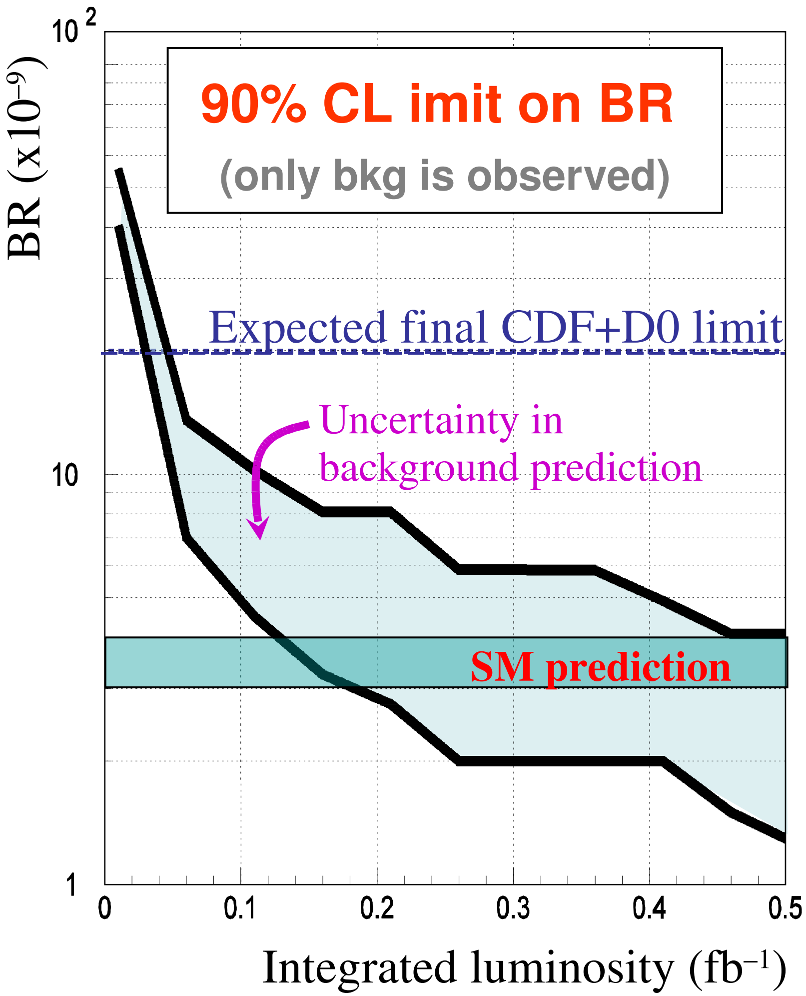
  $75 \times 10^{-9} = 24 \times BR_{SM}$ (D0, 2 fb^{-1}, prel)



$B^0_s \to \mu^+\mu^-$

"Easy" for LHCb to trigger and select

- Large total efficiency (10%)
- Main issue is background rejection
  - study based on limited MC statistics
  - largest background is $b \to \mu$, $b \to \mu$
  - specific background dominated by $B_c \to J/\psi(\mu\mu)\mu\nu$
- Exploit good detector performance:
  - muon ID
  - vertexing (topology)
  - mass resolution (18 MeV/c^2)



0.05 fb^{-1} ⇒ overtake CDF+D0

0.5 fb^{-1} ⇒ exclude BR values down to SM

2 fb^{-1} ⇒ 3σ evidence of SM signal

6 fb^{-1} ⇒ 5σ observation of SM signal

LHCb's best NP discovery potential with the very early data !

LHCb will collect a large tagged $D^* \to D^0 \pi$ sample (also used for PID calibration)

a dedicated D* trigger is foreseen for this purpose

- tag D^0 and anti-D^0 flavor with π from $D^{*\pm} \to D^0 \pi^\pm$

Tagged signal yields in 2 fb^{-1} (from b hadrons only)	
right-sign $D^0 \to K^- \pi^+$	12.4M
wrong-sign $D^0 \to K^+ \pi^-$	46.5k
$D^0 \to K^+ K^-$	1.6M

Performance studies just started

Interesting (sensitive to NP) and promising searches/measurements:

- Time-dependent D0 mixing with wrong-sign $D^0 \to K^+ \pi^-$
- Direct CP violation with $D^0 \to K^+ K^-$
  - $A_{CP} \leq 10^{-3}$ in SM, up to 1% (~current limit) with New Physics
  - Expect $\sigma_{stat}(A_{CP}) \sim O(10^{-3})$ with 2 fb^{-1}
- $D^0 \to \mu^+ \mu^-$
  - BR $\leq 10^{-12}$ in SM, up to 10^{-6} (~current limit) with New Physics
  - Expect to reach down to ~5×10^{-8} with 2 fb^{-1}

LHCb B Physics Examples with 0.5 fb^{-1}

Decay mode	0.5 fb^{-1} yield	0.5 fb^{-1} stat. sensitivity	Rough stat. break-even point with competition *
$B_d \rightarrow J/\psi(\mu\mu)K_S$	59k	$\sigma(\sin(2\beta)) = 0.04$	2 fb^{-1}
$B_s \rightarrow D_s^- \pi^+$	35k	$\sigma(\Delta m_s) = 0.012\ ps^{-1}$	0.2 fb^{-1}
$B_s \rightarrow D_s K^\pm$	1.6k	$\sigma(\gamma) = 21$ deg	–
$B_s \rightarrow J/\psi(\mu\mu)\phi$	**33k**	**$\sigma(2\beta_s) = 0.046$**	**0.3 fb^{-1}**
$B_d \rightarrow \phi K_S$	230	$\sigma(\sin(2\beta_{eff})) = 0.46$	8 fb^{-1}
$B_s \rightarrow \phi\phi$	780	$\sigma(\Delta\phi^{NP}) = 0.22$	–
$B^+ \rightarrow D(hh)K^\pm$ $B^+ \rightarrow D(K_S\pi\pi)K^\pm$	16k 1.3k	$\sigma(\gamma) = 12–14$ deg	0.3 fb^{-1}
$B_d \rightarrow \pi^+\pi^-$	8.9k	$\sigma(S, C) = 0.074, 0.086$	1–2 fb^{-1}
$B_s \rightarrow K^+K^-$	9.0k	$\sigma(S, C) = 0.088, 0.084$	–
$B_d \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0$	3.5k	α	2 fb^{-1}
$B_d \rightarrow K^{*0}\gamma$	15k	A_{CP}	0.4 fb^{-1}
$B_s \rightarrow \phi\gamma$	2.9k	$A_{CP}(t)$	–
$B_d \rightarrow K^{*0}\mu^+\mu^-$	1.8k	$\sigma(q^2_0) = 0.9\ GeV^2$	0.1 fb^{-1}
$B_s \rightarrow \mu^+\mu^-$	**18**	**BR_{SM} at 90%CL**	**0.05 fb^{-1}**

* Assuming naive $1/\sqrt{N}$ scaling of stat. uncertainty of existing results at Tevatron ($\rightarrow$ 16 fb^{-1}) or current B factories ($\rightarrow$ 1.75 ab^{-1})

– For many measurements based on B_s, or untagged B^0, B^+ decays only few 0.1 fb^{-1} are necessary to produce the world's best results

Conclusion

Startup:

First beam and first collisions with LHCb magnet off:

- **Establish** running procedure, check/adjust **time alignment**
- **Exercise reconstruction** software on real data, **align detector in space**

First collisions with magnet on (+ second polarity, once possible):

- **Calibrate** momentum, energy, PID, … + check alignment
- Study crucial distributions (resolutions, …) and **commission trigger**
- **Exercise computing model** with real data (use of Tier1 centers + Grid analysis)
- Want/push to get 25ns bunch-spacing and 2×10^{32} $cm^{-2}s^{-1}$ as soon as possible

Physics:

- Early bread-and-butter measurements (e.g. J/ψ production, σ_{bb}, …)
- Most "core physics" to be started already with 0.1–0.5 fb^{-1}
- **Search for new physics starts immediately** with highly promising and competitive results to get out asap, e.g.

$B_s \to \mu\mu$

$2\beta_s$ with $B_s \to J/\psi\phi$

But ... this is only MC! Looking forward to start working with real data, with complete LHCb detector and successful machine startup