CP violation and related issues

Part 13+14: Experiments at hadron machines

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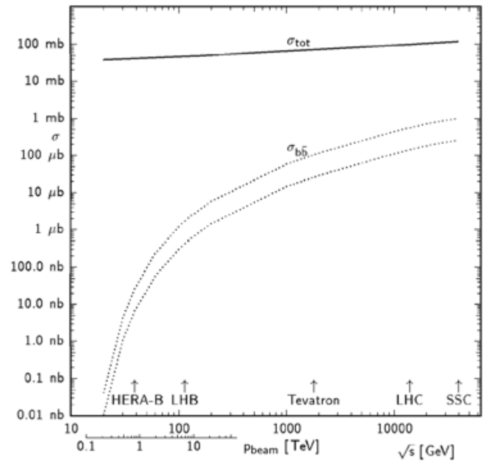
Contents

- B production at hadron machines
- Tevatron: CDF, BTeV
- HERA: HERA-B
- LHC: LHCb

Why hadron machines?

- large bb production rates
- large boosts -> <L> = <$\beta\gamma$> 480 μm
- in addition to B^0/B^{+-} also B_s, B_c, Λ_b,..

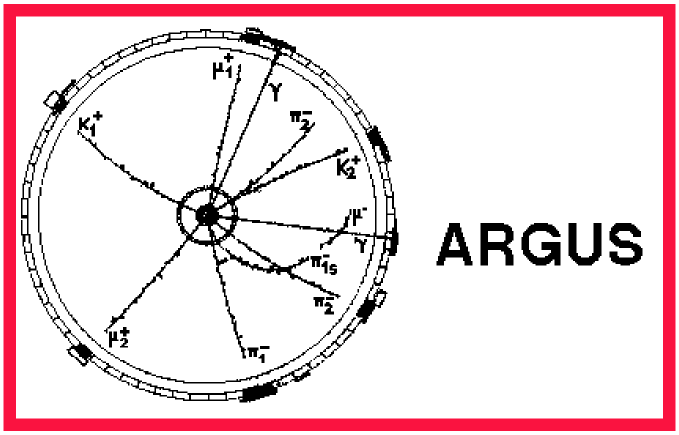


Why hadron machines?

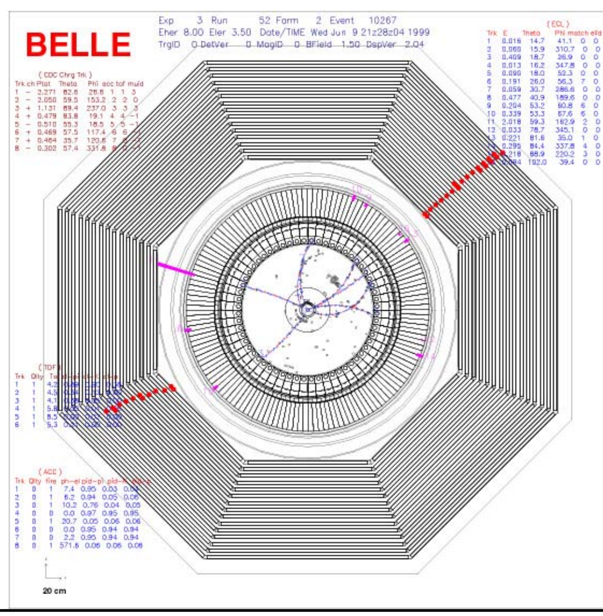
Production	$e^+e^- \to \Upsilon(4s) \to B\bar{B}$	$e^+e^- \to Z^0 \to b\bar{b}$	$pA \to b\bar{b}X$	$p\bar{p} \to b\bar{b}X$	$p\bar{p}(p) \to b\bar{b}X$ forward
Accelerator	CESR, DORIS PEPII, KEKB	LEP, SLD	HERA p	Tevatron	Tevatron, LHC
Spectrometer	CLEO, ARGUS BaBar, BELLE	ALEPH, DELPHI, L3, OPAL, SLD	HERA-B	CDF, D0	BTeV, LHCb
$\sigma(b\bar{b})$	≈ 1 nb	≈ 6 nb	≈ 12 nb	≈ 50 μb	≈ 100 μb (≈ 500 μb)
$\sigma(b\bar{b}):\sigma(had)$	0.26	0.22	10^{-6}	10^{-3}	$2 \cdot 10^{-3}$ ($6 \cdot 10^{-3}$)
B^0, B^+	yes	yes	yes	yes	yes
$B_s^0, B_c^+, \Lambda_b^0$	no	yes	yes	yes	yes
boost $< \beta\gamma >$	0.06 (0.5)	6	≈ 20	$\approx 2-4$	$\approx 4-20$
$b\bar{b}$ production	B's at rest (in c.m.s)	$b\bar{b}$ back-to-back	$b\bar{b}$ not back-to-back	$b\bar{b}$ not back-to-back	$b\bar{b}$ not back-to-back
multiple events	no	no	yes, 4	yes	yes, 2
trigger	inclusive	inclusive	lepton pairs (high p_t hadrons)	leptons only (high p_t hadrons)	displaced vertex

$b\bar{b}$ events at e^+e^- machines

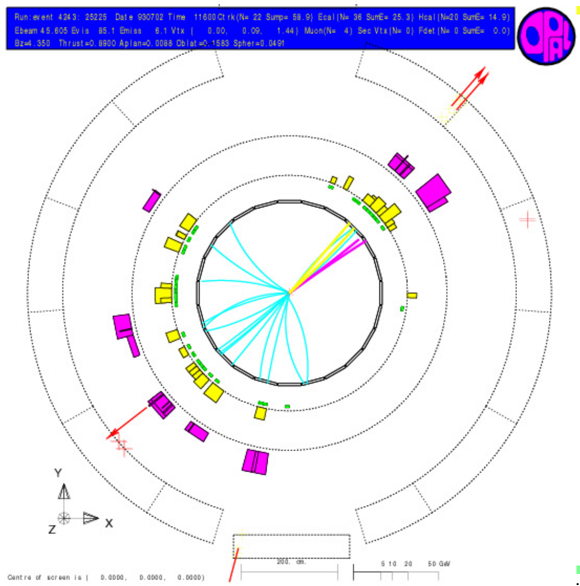
ARGUS and CLEO at Y(4s)



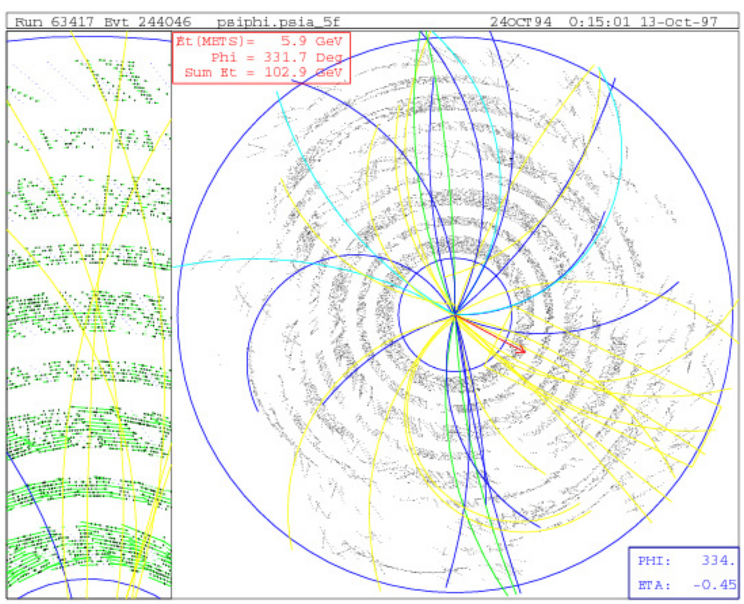
$b\bar{b}$ events at e^+e^- machines: BELLE



bb events at e^+e^- machines: OPAL at LEP

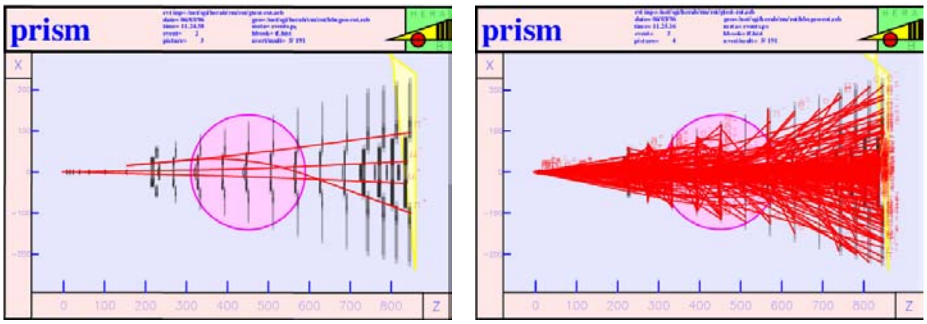


bb event at CDF



bb event at HERA-B:

Needle in haystack...



B decay and the rest

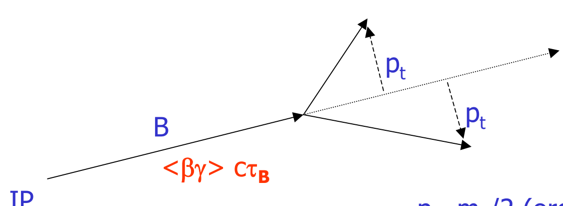
B detection in hadron collisions

What do we have to consider when designing a detector for b mesons and baryons at a hadron machine?

High particle fluxes -> radiation hard detectors

Early selection of interesting events -> selective triggers

Use the characteristic features of a B decay



$p_t \sim m_B/2$ (order of magnitude)

B detection in hadron collisions

Early selection of interesting events -> selective triggers:

•high p_t decay products: B -> $\mu\nu X$, B-> J/ψ Ks -> $\mu^+\mu^-$ $\pi^+\pi^-$, B -> $\pi^+\pi^-$ (helps because in B decay products carry a lot of momentum - typically ~1-2 GeV/c - perpedicularly to the flight direction (p_t), while backgrounds have low p_t

• displaced vertex: <L> = <βγ> $c\tau_B$ = <βγ> 480 μm (helps because other decay products are promt = originate directly in the interaction point)

Proof of principle: CDF, D0 at the Tevatron collider.

Tevatron: proton anti-proton collider

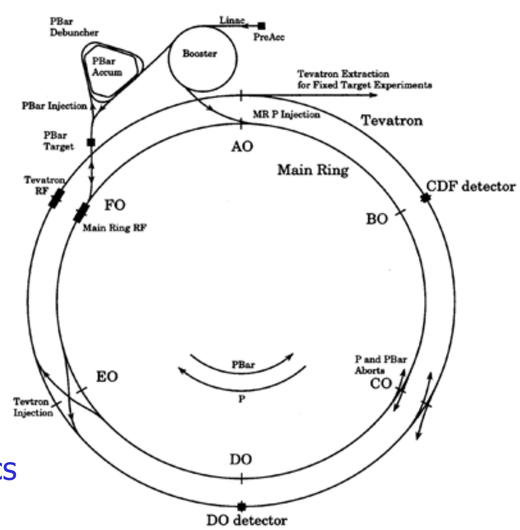
E_{cms} = 1980 GeV

Two general purpose collider experiments:

•CDF

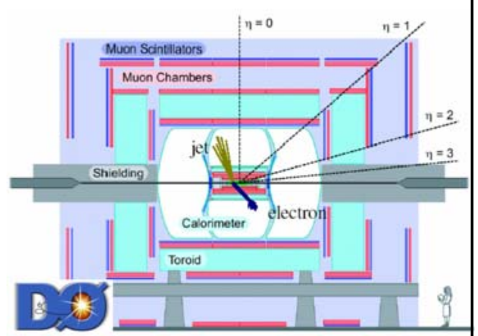
•D0

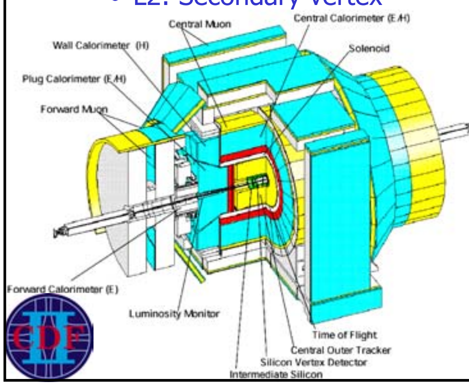
Cancelled: BTeV, forward spectrometer for b physics (similar to LHCb) at C0.



Detectors

- CDF:
  - Excellent mass resolution
  - Particle ID: dE/dx, TOF
  - Tracking triggers (Hadronic B's):
    - L1: Tracks
    - L2: Secondary vertex

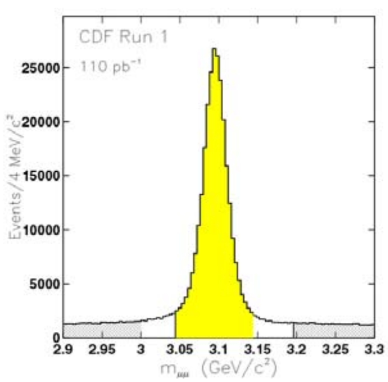


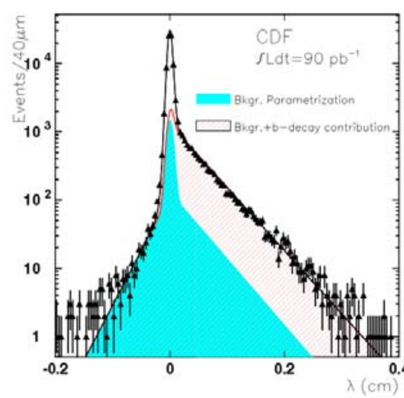


- D0:
  - Excellent muon and tracking coverage
    - Tracking up to $|\eta|<3$
    - Muons up to $|\eta|<2$

CDF performance, run 1

Mass resolution on J/ψ: 16 MeV

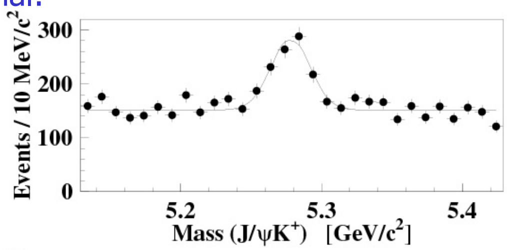




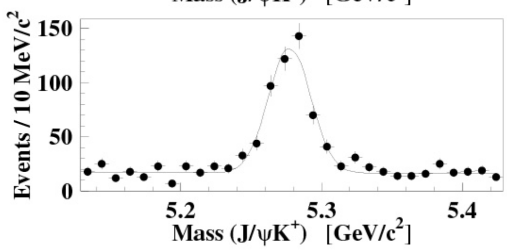
Decay length resolution: 40-50 μm

CDF performance , run 1

Cleaning up the J/ψ K^+ signal:



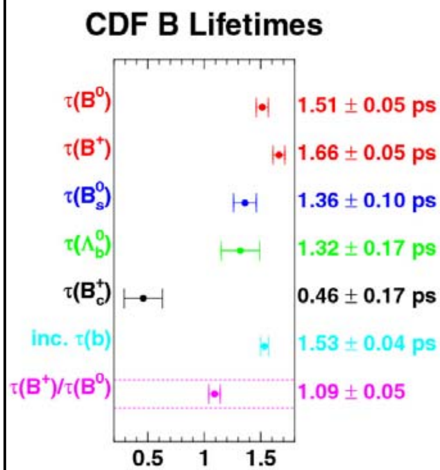
cut on decay length
(>100 μ m)

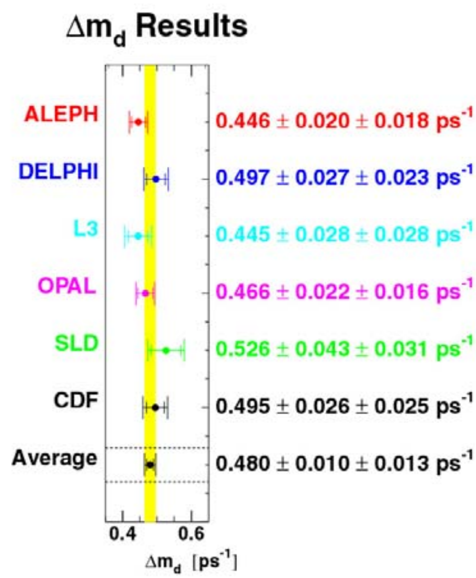


CDF run 1 results

- σ(p bar p -> bX) larger then theoretical predictions by about factor of 2
- masses of B_s, Λ_b, B_c
- lifetimes
- polarization in the B_s -> J/ψ ϕ decay (input for $\Delta\Gamma_s/\Gamma_s$ measurement)
- B_s mixing: lower limit Δm_s > 5.8/ps (95 %)
- first observation of B_c
- B_d mixing measurements
- measurement of $\sin2\beta$=0.79+0.41-0.44
- rare decays

CDF run 1 results, status 2001





CDF, Tevatron upgrade

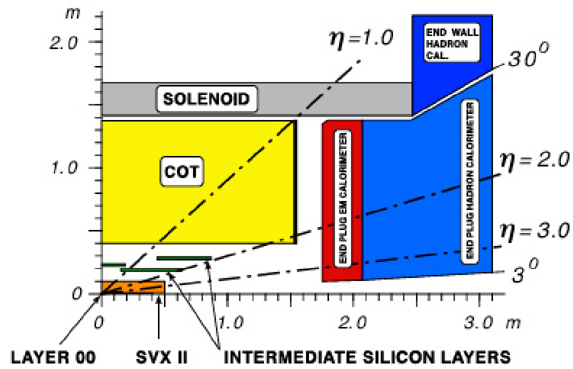
For Run II the injector and anti-proton source were upgraded. Expected: 2 fb-1 in 2001-02, 15 fb-1 until 2004 (compared to 0.1 fb-1 in Run I).

The bunch spacing changed from 3.5 μs -> 396 ns (132 ns).

Detector upgrade:

- increase muon system coverage
- increase silicon detector coverage
- improve vertex resolution with additional silicon layer L00 (for B_s mixing)
- add time-of-flight counter (for π/K separation up to 1.6 GeV/c)
- new central tracker, drift chamber with additional silicon layers
- trigger upgrade: fast tracker in L1, silicon vertex tracker in L2 -> lower p_t threshold for μ, two track trigger

CDF upgrade



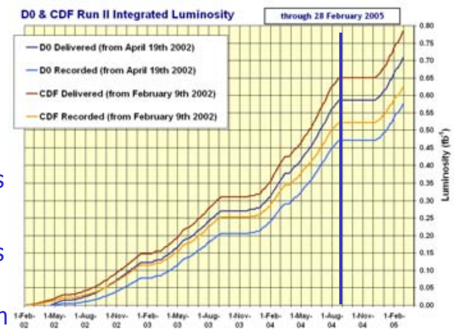
CDF physics plans, 2fb-1

- measure sin2β with 0.043 error
- B_s mixing up to x_s=60 at 5 sigma
- measure $\Delta\Gamma_s/\Gamma_s$ (with 0.05 error) for B_s mesons through $B_s \to J/\psi\ \phi$
- A_{FB} in $B_d \to K^* \mu\mu$
- b bar-b production section
- $B_c \to J/\psi\ l\nu$, $J/\psi\ \pi$

However...

Data sets

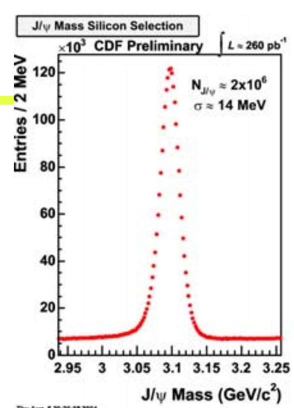
- CDF/D0 use data collected in the period 2002-2004
  - ~ 600 pb^{-1} recorded
  - D0:
    - ~ 220-450 pb^{-1} used for B physics
  - CDF:
    - ~ 240-360 pb^{-1} used for B physics
    - Lost ~ 100 pb^{-1} due to Central Tracking Chamber ageing problem

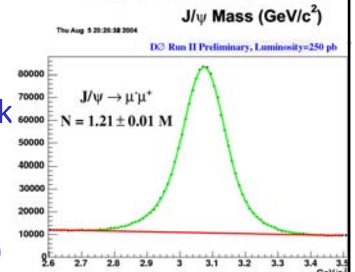


Much less data taken than anticipated...

Data samples

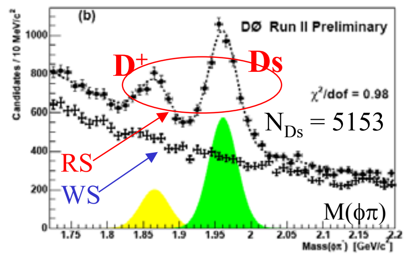
- J/ψ samples:
  - Millions! ~ 20% are from B's
  - Reconstruct exclusive $B/\Lambda_B \rightarrow J/\psi\ K/\Lambda^0$ modes
- Semi-leptonic $B \rightarrow D\ l\nu\ X$ samples:
  - ~ 100 K events with fully recon. D
    - D0 has larger muon acceptance
    - CDF lowers lepton trigger p_t by requiring additional displaced track
- Fully hadronic decays (CDF only)
  - ~ 10 K events fully reconstructed B's
  - Requires trigger on sec. vertex (SVT)

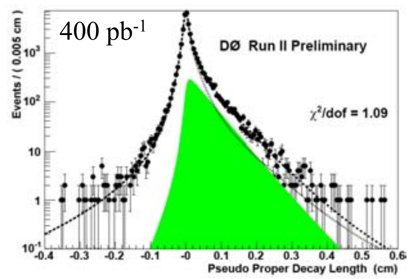




Lifetimes with Bs→lνDsX modes

- First high statistics B_s lifetime measurement from D0
  - Use $D_s^+ \rightarrow \phi\pi^+$ decay
  - Difficult background systematics:
    - Combinatorial
    - Physical: $B \rightarrow D^{(*)}D^{(*)}$
    - Prompt: c-cbar, b-bbar, D+fake
  - Currently best measurement
    $\tau(Bs)$ = 1.420±0.043±0.057 ps



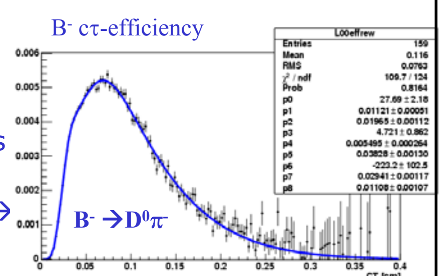


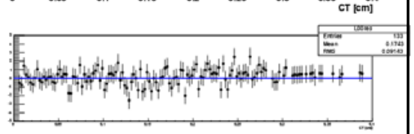
Systematics Summary (μm)

Source	$\Delta c\tau$ (μm)
Detector alignment [8]	±5.0
Background estimate	±15.0
Selection criteria	+3.6
Decay length resolution	±1.6
K–factor determination	$^{+3.5}_{-4.1}$
Non-combinatorial background	$^{+3.6}_{-4.4}$
Total	**±17.0**

Lifetime with hadronic decays

- CDF:
  - First measurement with Secondary Vertex Trigger biased samples
  - Trigger/analysis cτ-efficiency curves from "realistic" MC
- Check by emulating trigger cuts on $B^+ \rightarrow J/\psi\ K^+$
- Use several final states
  - $B^\pm$: $D^0\pi^\pm$ [8380 ev.] ($D^0 \rightarrow K\pi$)
  - B^0: $D^\pm\pi^\mp$ [5280 ev.] ($D^\pm \rightarrow K\pi\pi$)
    $D^\pm 3\pi$ [4173 ev.] ($D^\pm \rightarrow K\pi\pi$)
  - Bs: Ds $\pi^\pm$ [465 ev.] (Ds→φπ)
    Ds 3π [133 ev.] (Ds→φπ)
    - **Important for Δm_s measurement**





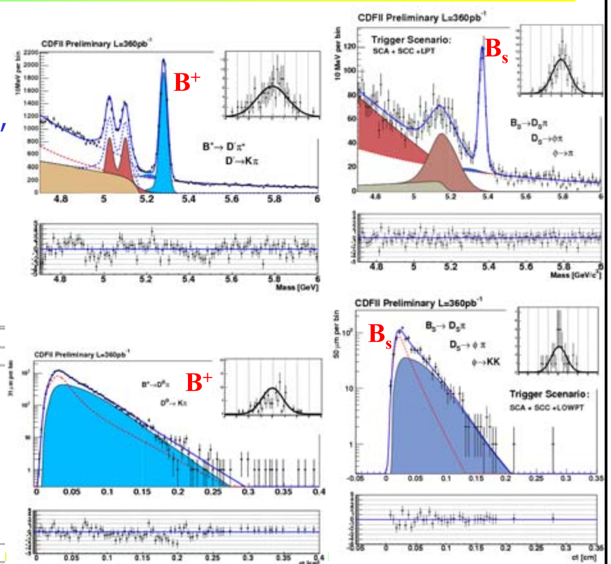
Lifetimes with hadronic decays

- More statistical power than J/ψ modes
  - Slightly larger systematics (efficiency, backgrounds)

$\tau(B^+) = \mathbf{1.661 \pm 0.027 \pm 0.013}$ **ps**
$\tau(B^0) = \mathbf{1.511 \pm 0.023 \pm 0.013}$ **ps**
$\tau(B_s) = \mathbf{1.598 \pm 0.097 \pm 0.017}$ **ps**

Systematics (μm)

Effect	Variation(μm) B^0	Variation(μm) B_s
MC input $c\tau$	negligible	negligible
p_T reweight	1.9	1.9
Scale Factor	negligible	negligible
Bkg ct description	1.1	1.1
Bkg fraction	2.0	2.0
I.P. correlation	1.0	1.0
Eff. parameterization	1.5	1.5
L_{xy} significance	negligible	2
$\Delta\Gamma_s$	-	1.0
Alignm. + others	2.4	2.4
Total	4.2	4.7

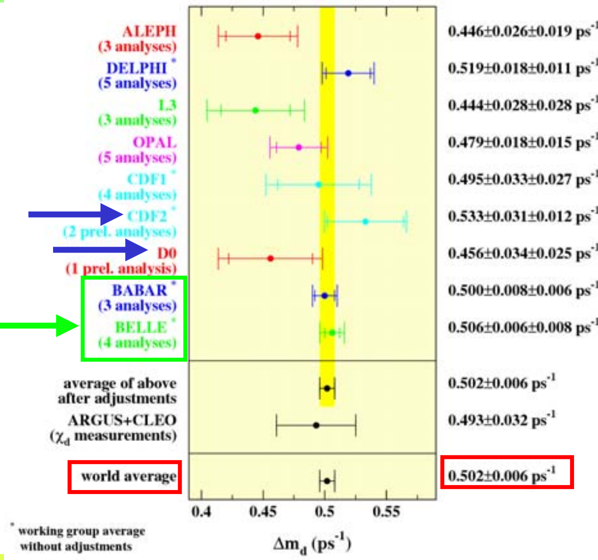


B mixing

- Basic ingredients for the measurement:
  - High statistics samples of neutral B's in flavor specific decays
    - CDF: $J/\psi K^*$, $D\pi$, $l\nu DX$
    - D0: $J/\psi K^*$, $l\nu DX$
  - Proper decay length reconstruction
    - Fully reconstructed modes provide better accuracy
  - Tagging of flavor at production (flavor tagging)
    - Key problem at the Tevatron!
    - Equivalent statistical power: $N\,\varepsilon D^2$
      - **ε = tagging efficiency**
      - **D = tagging dilution = 1-2*w (w = probability of wrong tag)**
- Measure:
  - N_u (N_m): number of B's with same (different) flavor at production and decay
  - Mixing measurement calibrates dilution
    - Impossible for B_s until oscillation observed

B_d Mixing

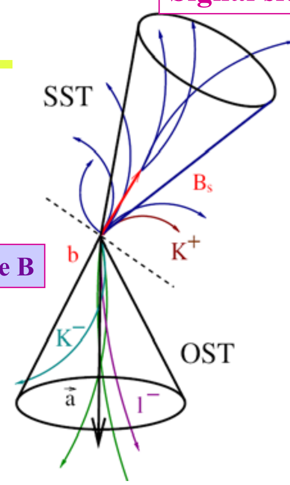
- Summary based on results presented in summer 2004
- World Average dominated by BaBar/Belle

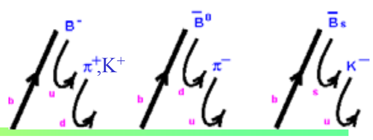


Flavor tagging

- Opposite side techniques (OST):
  - CDF: total $\varepsilon D^2 \sim 1.1 - 1.4$ %
    - Soft Muon Tag
    - Soft Electron Tag
    - Jet Charge Tag
  - D0: $\varepsilon D^2 \sim 1.1\%$
    - Enhanced muon tag $\varepsilon D^2 \sim 1.1\%$
- Same side techniques (SST):
  - Sign of nearby track is correlated to b type (SST)
    - Tagging power depends on B type
    - PID helps for B_s

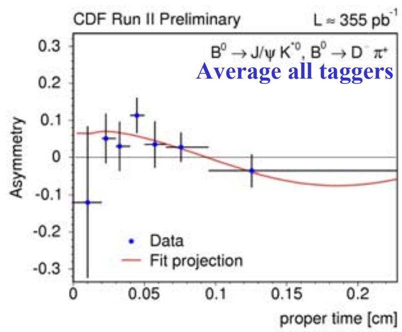
    $\varepsilon D^2 \sim 1\%$ for CDF&D_0 in B_d





B_d mixing

- 2 recent results from CDF using 355 pb^{-1} and OST
  - Semi-leptonic sample: 124k lD^0 (24k lD^{*+}), 53k lD^+
    - $\Delta m_d = 0.497 \pm 0.028(stat.) \pm 0.015(syst.)\ ps^{-1}$
  - Hadronic sample: 5.3k ψK^+, 2.2k ψK^+, 6.2k $D^0\pi^-$, 5.6k $D^-\pi^+$
    - $\Delta m_d = 0.503 \pm 0.063(stat.) \pm 0.015(syst.)\ ps^{-1}$



B_s oscillations

Fit the data in a different way: fix Δm_s and fit the oscillation amplitude A

$$P_m = \frac{1}{2}\Gamma_q e^{-\Gamma_q t}\left[1 - A\cos(\Delta m_q t)\right]$$

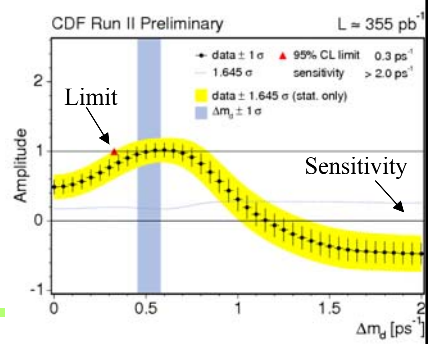
If A consistent with 0 -> no mixing.
Mixing established if A=1, and A=0 excluded with high significance.

However: amplitude gets reduced by dilution D! Measured: A*D. To extract A, have to know D -> calibation with data (similarly as in B factories, but a harder job here).

Test with B_d Mixing

- These results obtained using many features important for B_s mixing
  - Unbinned fit
  - Parametrized dilutions
  - Calibrate dilutions
- Test amplitude scan on fully reconstructed B_d
  - Fit D*A*cos(Δm t) at fixed Δm
  - Expect A=1 for $\Delta m \sim \Delta m_d$
  - Limit (95% CL):
    - Δm such that $A+1.645\sigma_A = 1$
  - Sensitivity: Δm such that $1.645\sigma_A = 1$

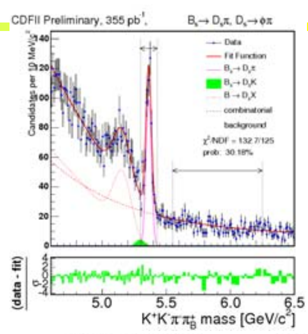
Tagg	CDF had %	CDF semi %	D0 semi %
OST μ	0.46	0.50	1.07
OST e	0.18	0.28	
OST jet	0.49	0.61	
Total OST	1.13±0.18	1.38±0.10	1.07



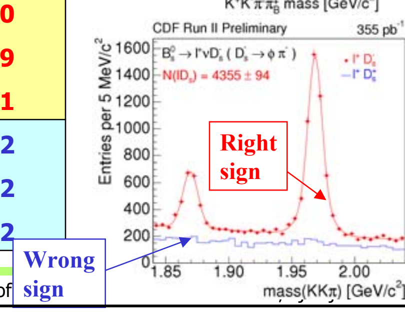
H. G. Moser, A. Roussarie, NIM **A384** (1997)

CDF: Bs mixing (signals)

- Hadronic analysis: Bs→Dsπ
  - ~ 900 events
- Semi-leptonic analysis: Bs→Dslν
  - ~ 7.5k events

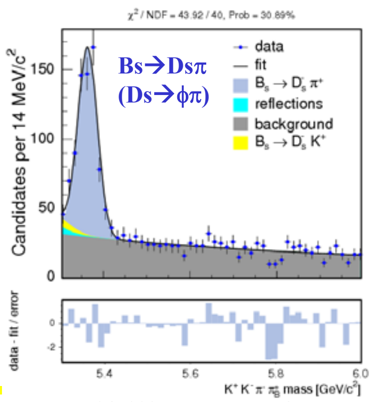


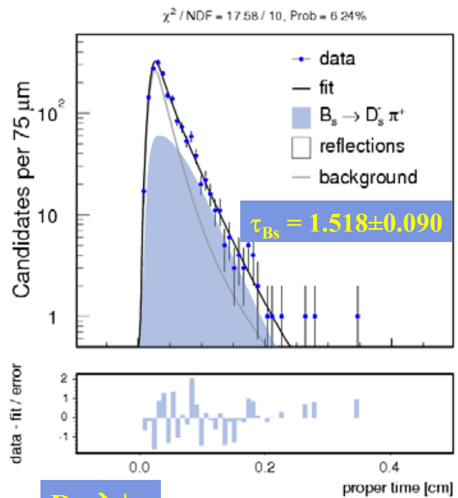
Channel	Yield	S/B
Bs→Dsπ (Ds→$\phi\pi$)	526±33	1.80
Bs→Dsπ (Ds→K*K)	254±21	1.69
Bs→Dsπ (Ds→3π)	116±18	1.01
Bs→Dslν (Ds→$\phi\pi$)	4355±94	3.12
Bs→Dslν (Ds→K*K)	1750±83	0.42
Bs→Dslν (Ds→3π)	1573±88	0.32



CDF: Bs mixing (cross-checks)

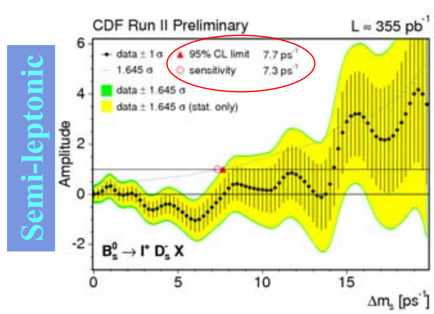
- Mass and lifetime projections
  - Mass and lifetime consistent with World Avg. values/D0

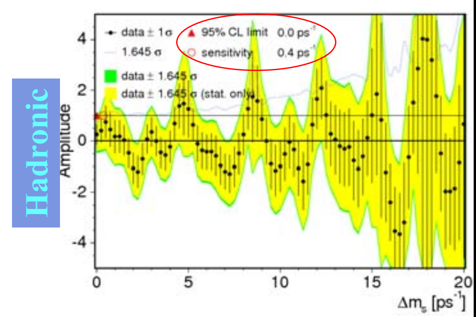




CDF: Bs Mixing

- Amplitude scans all statistics dominated





- Combined scan results:
  - 7.9 ps^{-1} 95% CL limit
  - Sensitivity: 8.4 ps^{-1}

Summary CDF (and D0) run 2

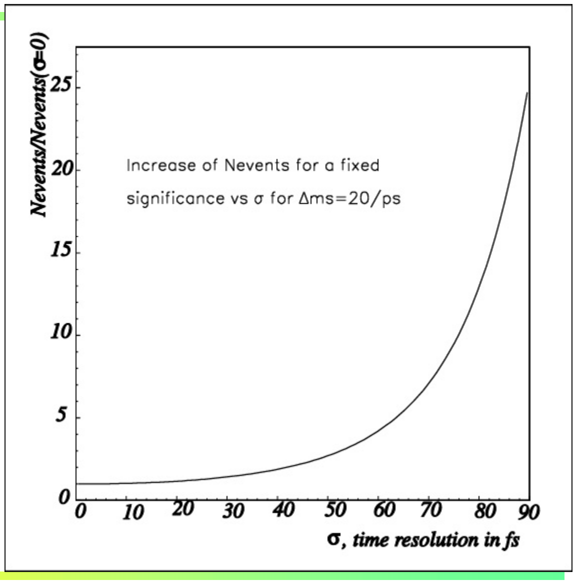
- Many new results
- New results in B_s sector
  - Lifetime updated and more to come
  - First CDF B_s mixing limits
    - Lower than expected
    - Additional improvements could reduce the statistical error on the amplitude by up to a factor two with same data set
    - It is a very difficult analysis, but they seem to be back in business

Why is the performance different from the expectations? 1

- Overall statistics (collider perfomance)
- Proper time resolution is not as good as the best resolution used for the projections. They are at about 100fs, already above the limit (50fs) where it starts to hurt. Going from 80fs->100fs: error on A in the amplitude fit -> x2! (see plot ->)
- Flavor tagging effectiveness (εD^2) is almost a factor ten worse than the value used in the projections. Part of this difference is a result of their not having applied the same-side kaon tagging technique to the data yet. The performance of this tag cannot be measured using B^0 or B^+ mesons. ->....

B_s mixing: influence of proper time resolution

Increase in the number of events needed for a given significance vs resolution.



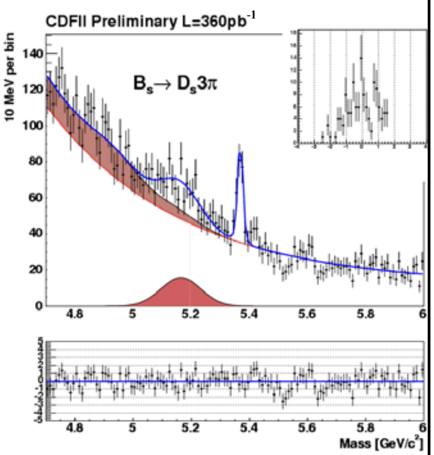
Why is the performance different from the expectations? 2

... ->Until they do not observe B_s mixing, limit on Δm_s with this tag will require a prediction of the dilution from Monte Carlo...

- Triggering on hadronic final states: needed vertexing. Unexpected problems: the beamline was not actually located at the nominal center of the detector -> detrimental to the tracking efficiency of silicon patterns used in the silicon-based 2nd level trigger.
- General remark: Monte Carlo does not predict correctly the acceptance and kinematics of the opposite side B hadron that is used for flavor tagging.

CDF Future Mixing Improvements

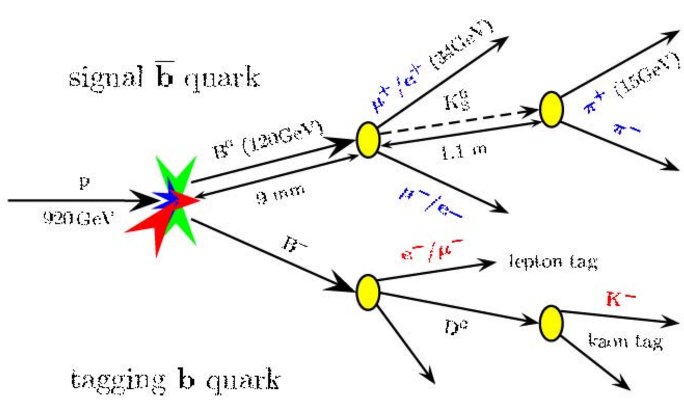
- Include Same Side (Kaon) Taggin
  - Expect twice tagging power than OST combined
- Improve accuracy of primary vertex
- Add more channels:
  - Bs→Ds3π
  - Bs→Ds*π, Bs→Dsρ⁺
    - Partial reconstruction can treat as semi-leptonic case



HERA-B

Fixed target B - Factory at HERA (DESY)

Originally designed for measurement of CP violation in B->J/ψK_S^0



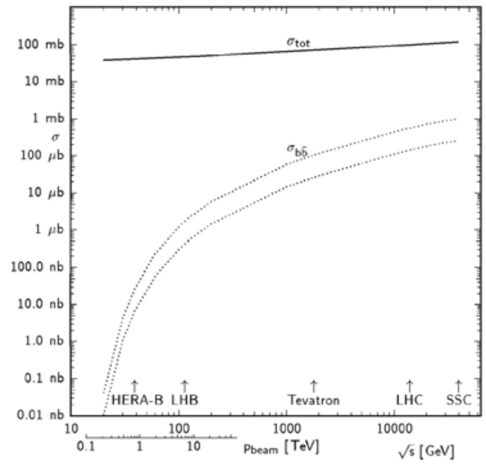
HERA-B

proton energy is 920 GeV, sqrt(s)=42 GeV

σ(b bar-b) ~ 12 nb -> σ(b bar-b)/ σ(inel) ~10^{-6}

BR for interesting decays of ~ 10^{-5}-10^{-4}

-> 11 orders of magnitude



HERA-B: Wire in the beam halo

Parasitic running

Interesting decays (e.g. B -> J/ψ K_S^0), triggered and reconstructed signal come 1 in about 4 10^{11} inelastic ('minimum bias') interactions

Need about 1000 signal events in 1 year = 10^7 s -> run at 4 x 10^7 interactions per second = 40 MHz

Proton bunch spacing in HERA: 96ns, event frequency 10 MHZ

-> Need multiple events for 40 MHz interaction rate

HERA proton beam looses about 10^8 protons per second

-> A parasitic target has to catch these protons very efficiently, about 1 out of 2.

HERA-B: Wire in the beam halo

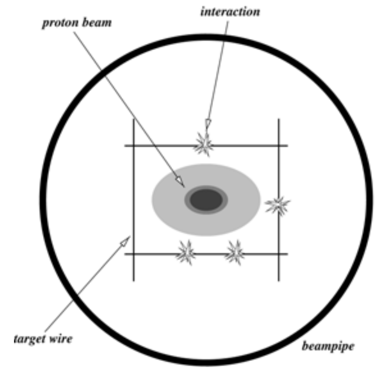
Needed:

•target in beam halo

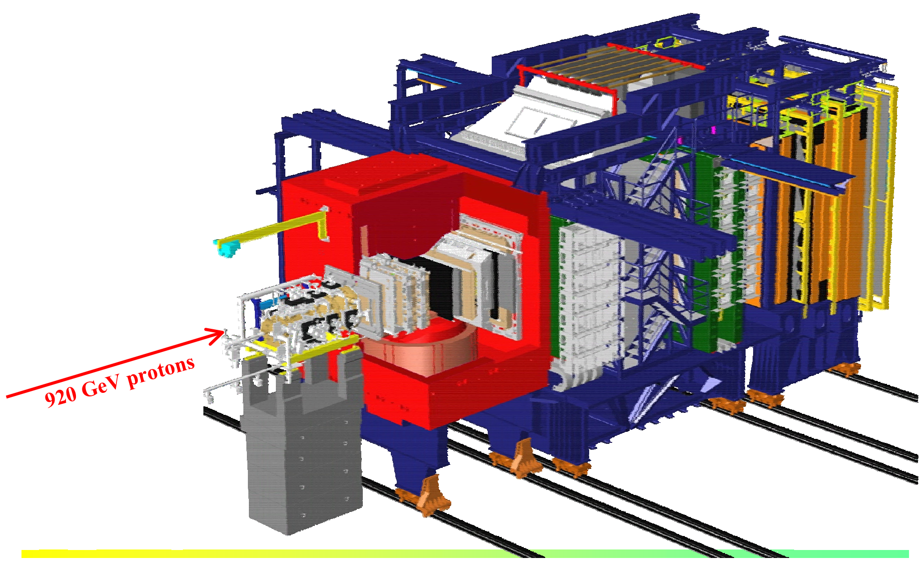
•efficient separation of primary vertices for high interaction rates.

2 stations with 4 thin wires (50 μm times 500 μm) in proton beam halo, target material: C, Ti, W, Al

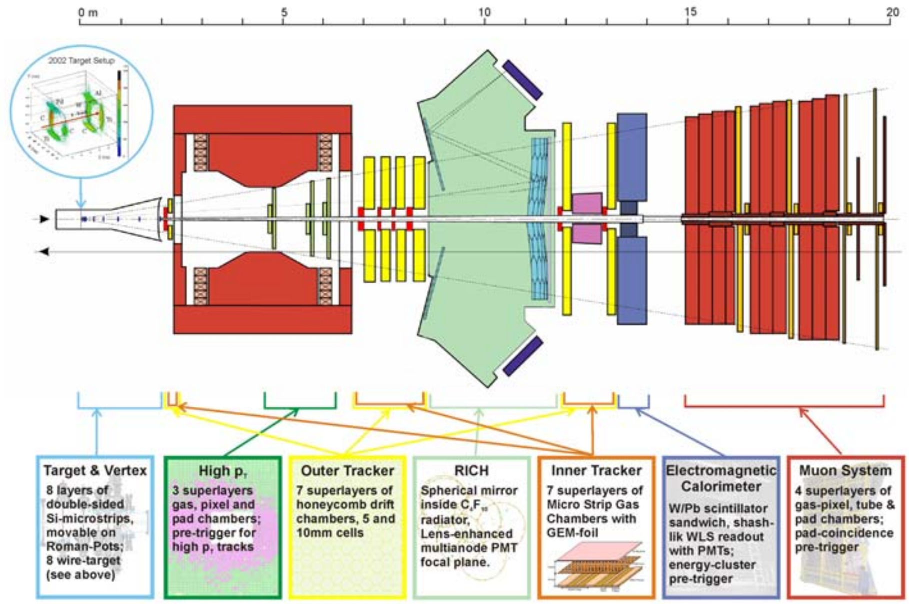
Operation of the wire target has been reliable for years, little interference with HERA ep operation



HERA-B spectrometer



HERA-B spectrometer



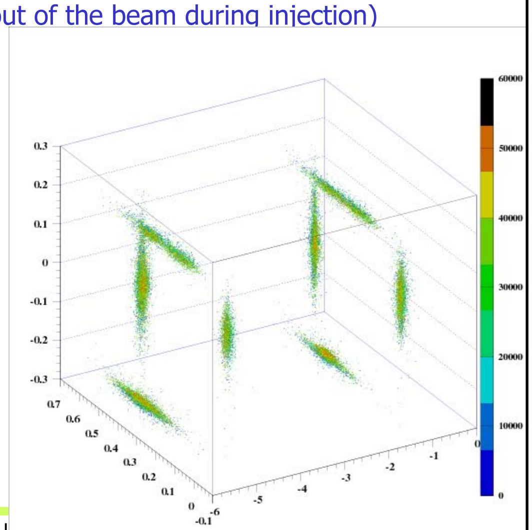
HERA-B: SVD

Silicon vertex detector: 8 double-sided silicon detector layers with retractable geometry (to move out of the beam during injection)

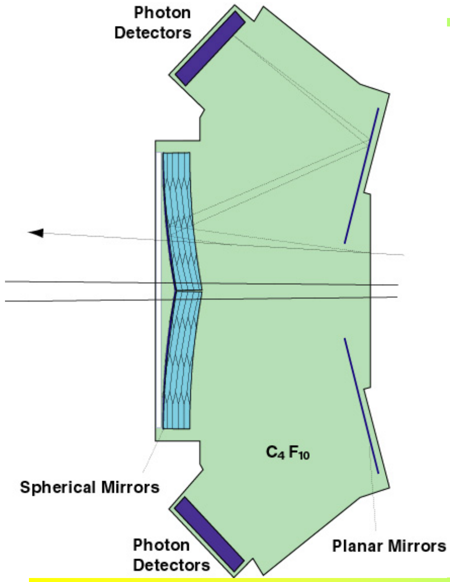
Excellent and reliable operation.

Reconstructed vertices

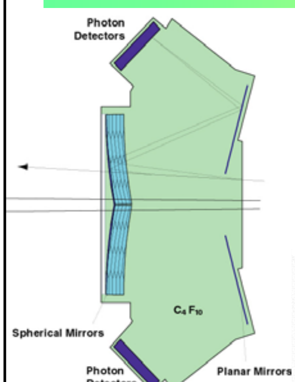
On eight target wires ->



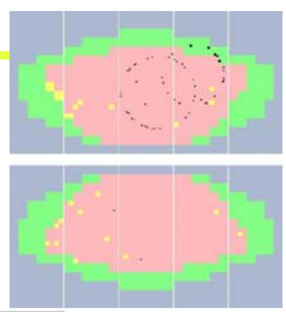
HERA-B RICH: collaboration of UB and UL



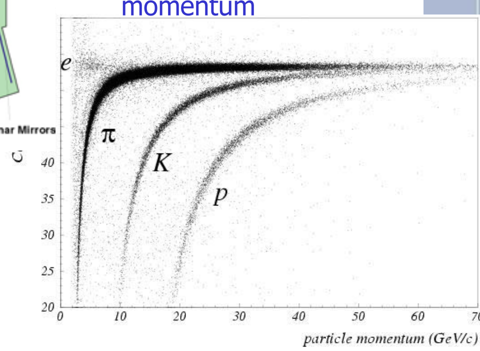
HERA-B RICH



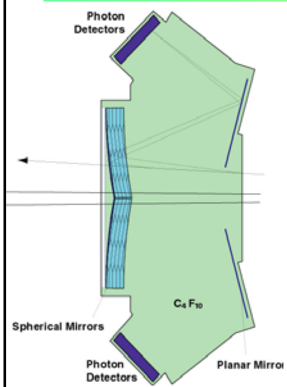
Event display with two isolated rings



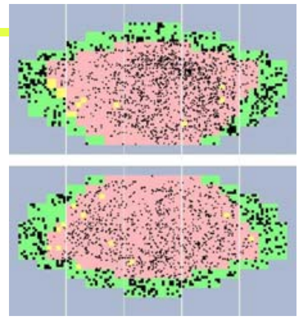
Cherenkov angle vs momentum



HERA-B RICH

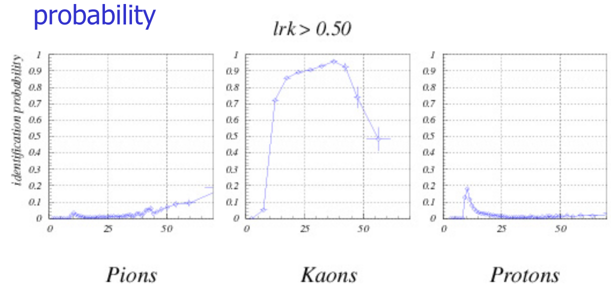


Typical event -->



Still: it works actually very well!

Kaon efficiency and pion, proton fake probability



The Dilepton Trigger

HERA-B detector: data is read out and buffered for 12 μs (proton bunches cross every 96 ns, 0.5 interactions/BX)

5 MHz

Pretriggers: ECAL cluster or hit coincidence in muon detector as trigger seed (custom hardware)

3 MHz

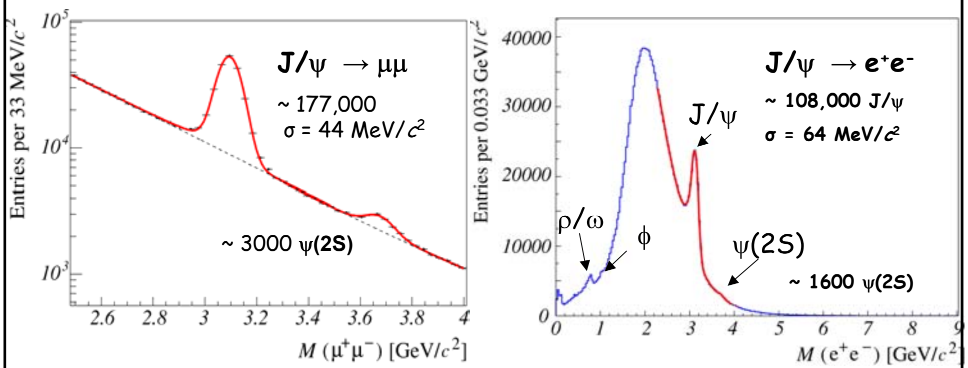
First Level Trigger (FLT): Track trigger in hardware using tracking detectors behind magnet, seeding by pretriggers

20 kHz

Second Level Trigger (SLT): FLT tracking confirmed, extrapolation to vertex detector, vertex fit (PC farm)

100 Hz

HERA-B: J/ψ Production



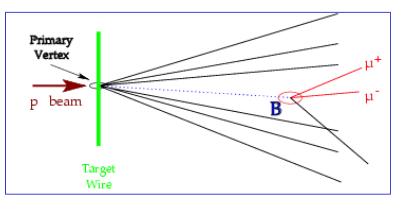
HERA-B: Open Beauty Production

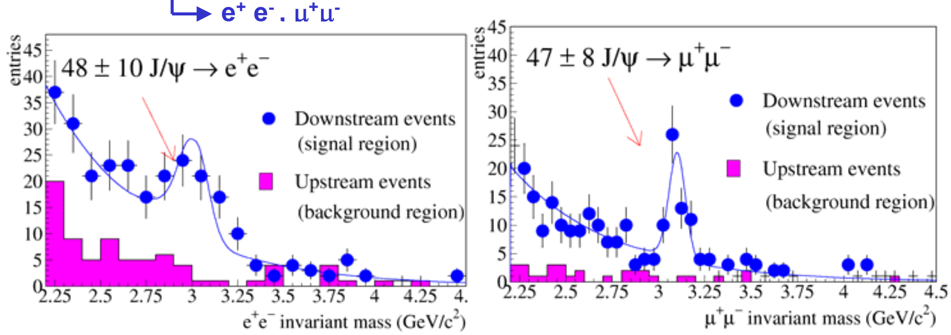
Detached vertex analysis

$pA \to b\,\bar{b} + X$

$\hookrightarrow J/\psi + X'$

$\hookrightarrow e^+ e^- . \mu^+\mu^-$





HERA-B Summary

- First LHC like experiment before the LHC
- Designed with a very ambitious goal
- Many components behaved extremly well (e.g. SVD, RICH)
- Several critical components were less successful (tracking)
- Trigger efficiency (which heavily relied on the tracking system efficiency) was >10x lower than expected
- ->No precision tests in B physics were possible
- Still: a solid physics program could be carried out (i.e. bb and cc production cross sections a limit on D->μμ, pentaquark searches)
- HERA-B experience: An important input for LHC experiments

b-production in pp collisions

- Pairs of $b\bar{b}$ quarks are mostly produced in the forward/backward direction:

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

$10^{12} b\bar{b}$ produced per year

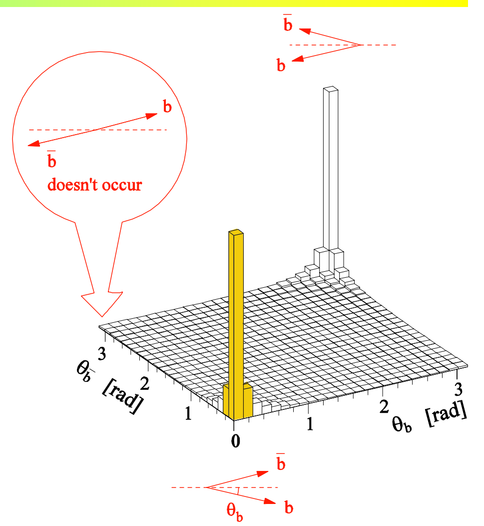
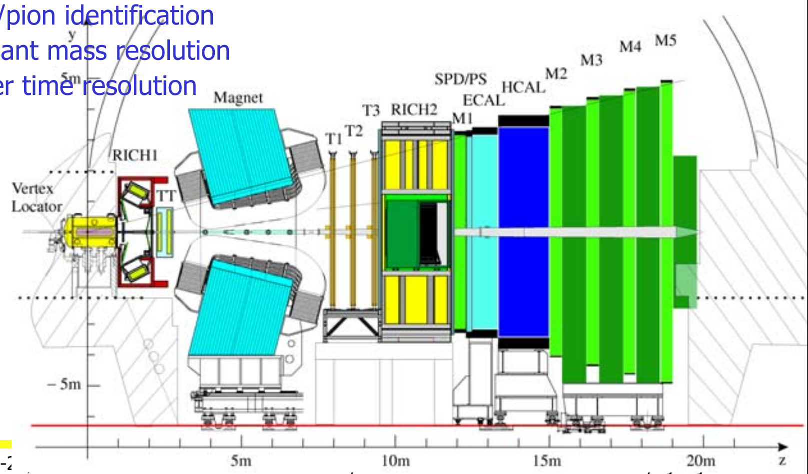


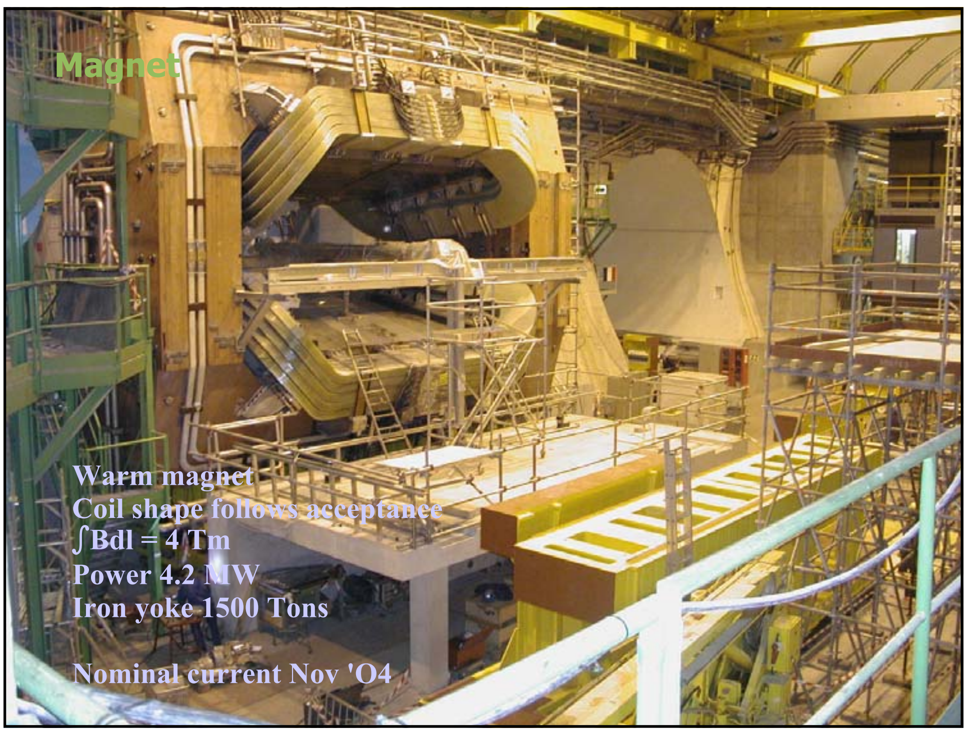
Figure 2.1: Polar angles of the b- and $\bar{b}$-hadrons calculated by the PYTHIA event generator.

LHCb

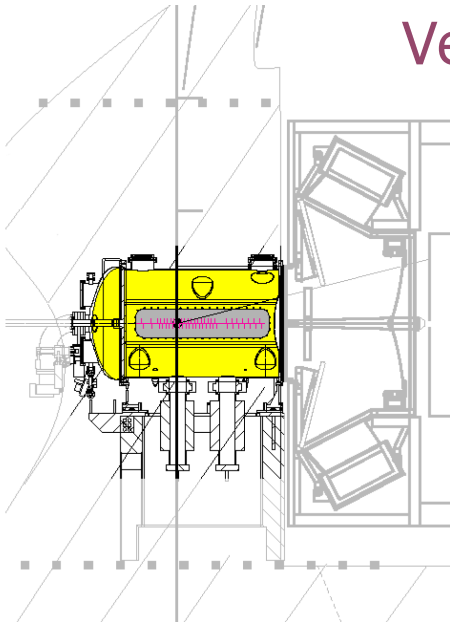
LHCb is a forward spectrometer:
- Acceptance 10-300 mrad
- Efficient B-mesons trigger
- Good Kaon/pion identification
- Good invariant mass resolution
- Good proper time resolution



Magnet



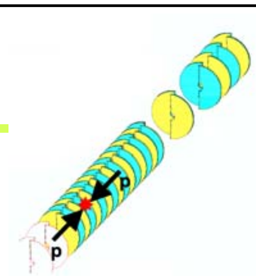
Vertex locator...



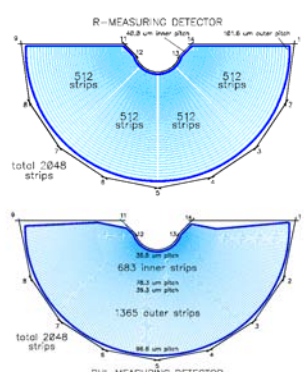
Key element surrounding the IP:

- Measure the position of the primary and the $B_{d,s}$ vertexes
- Used in L1 trigger.

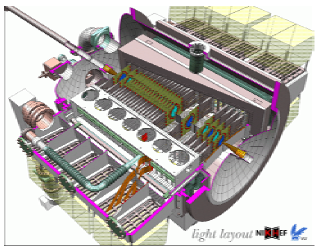
Vertex locator



- 21 pairs of silicon strip detectors arrange in two retractable halves:
  - Strips with an R-φ geometry:
    - R strip pitch: 40-102 μm
    - φ strip pitch: 36-97 μm
  - 172k channels.
- Operated:
  - In vacuum, separated from beam vacuum by an Al foil
  - Close to the beam line (7 mm)
  - Radiation ≤ 1.5×10^{14} n_{eq}/cm^2 per year
  - Cooled at -5 °C



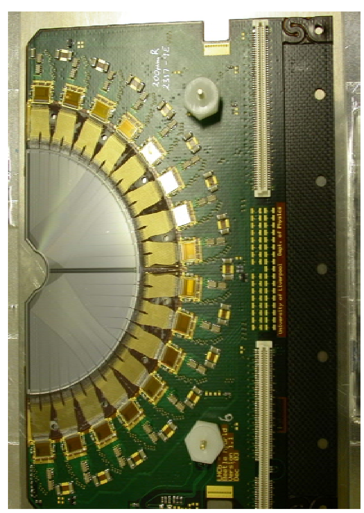
Status of the vertex locator



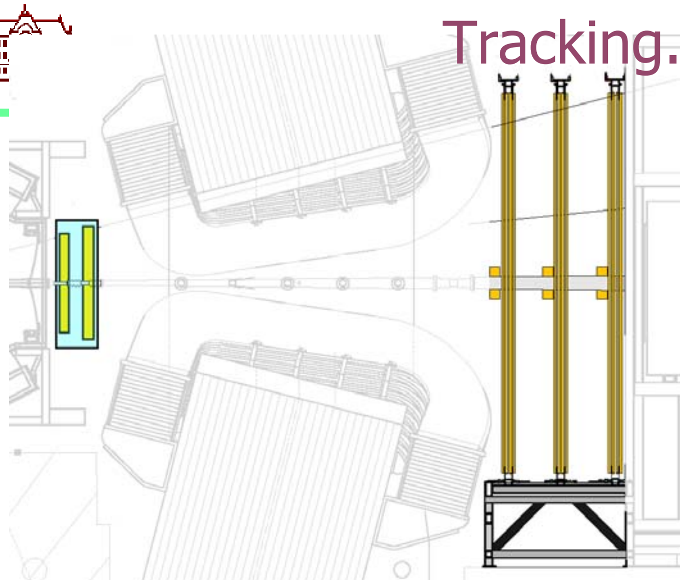
- Many others pieces in production.
- Installation in UX85: November '05

Sensors

- Characteristics:
  - n+n type
  - Double metal layers
  - thickness 300 μm
  - Laser cut
- Front-end electronics (beetle chip)mount on a thin kapton sheet connected to the sensor via pitch adapters
- Alignment of complete half detectors in test beam in June '06

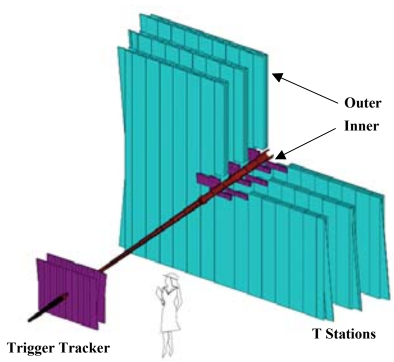


Tracking...



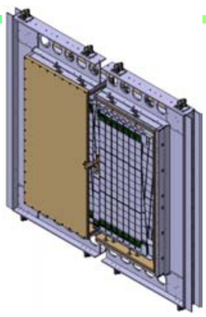
Key elements to find tracks and to measure their momentum.

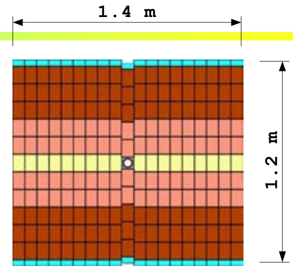
Overview of the tracking system



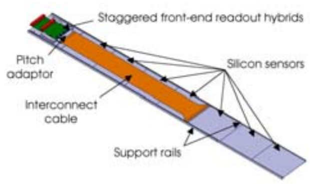
- Trigger Tracker:
  - Microstrip silicon detector
  - 144k channels
- Three T stations:
  - Inner tracker:
    - Microstrip Silicon detector
    - 130k channels
  - Outer tracker:
    - Straw tube (5 mm)
    - 56k channels

Trigger Tracker



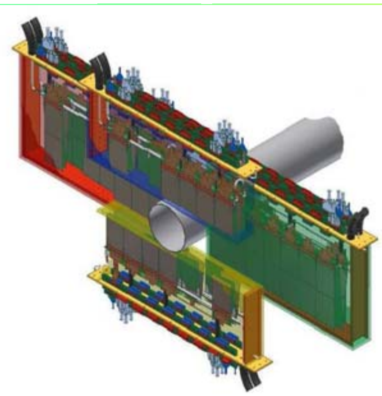


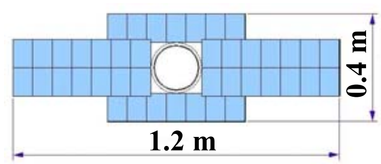
0° layer



- Microstrips silicon detector
  - Two groups of two layers (0°, +5°, -5°, 0°) separated by 30 cm
  - Strip pitch 198 μm
    Strip length 11, 22 and 33 cm
  - Radiation ≤ 9×10^{12} n_{eq}/cm^2 over 10 years
  - Cooled at -5 °C

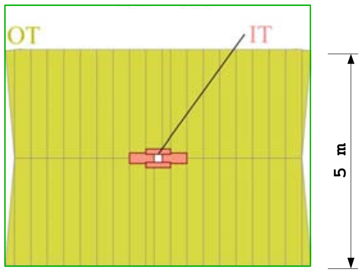
T Station: inner tracker part

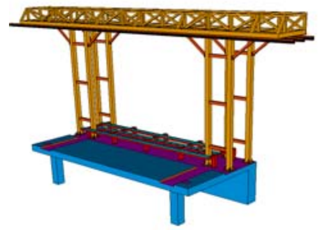




- Microstrips silicon detector:
  - Same sensors as Trigger Tracker
  - Four layers (0°, +5°, -5°, 0°)
  - Strip length 11, 22 cm
  - Radiation ≤ 9×10^{12} n_{eq}/cm^2 over 10 years
  - Cooled -5 °C

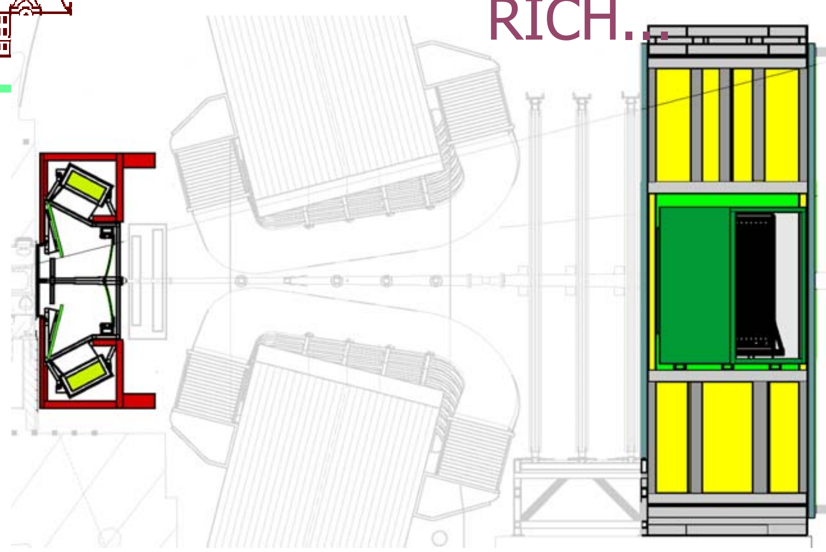
T station: outer tracker part





- Straw tubes:
  - Four double layers (0°,+5°,-5°,0°)
  - Straw length 5 m read on both sides
  - $Ar/CF_4/CO_2$

RICH…



Key elements to identify pion and kaon in the momentum range $p \in [2, 100]\,\mathrm{GeV}/c$

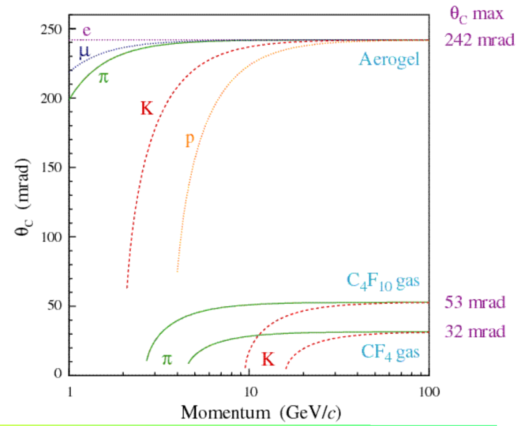
Overview of the RICH

- RICH system divided in two detectors equipped with 3 radiators to cover the full acceptance and momentum range:

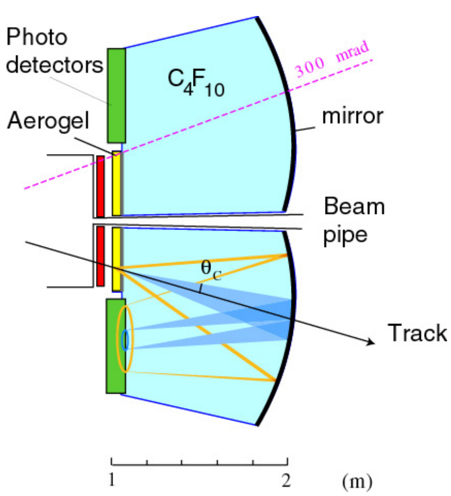
•from a few GeV (tagging kaons)

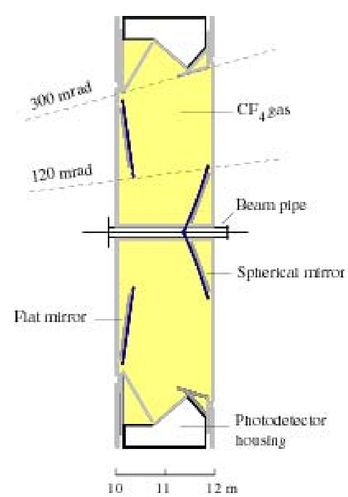
•up to 100 GeV: two body B decays

General rule: a RICH with a single radiator can cover a factor of 4-7 in momentum for 3σ from threshold to the max. p. Larger region -> more radiators!

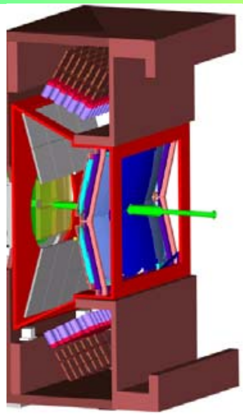


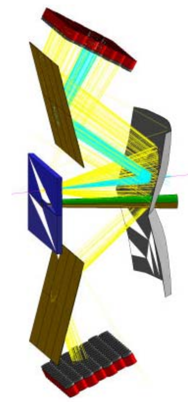
RICH with three radiators





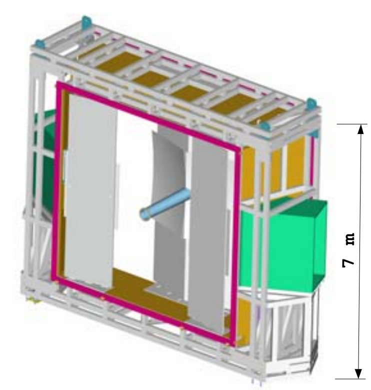
RICH1





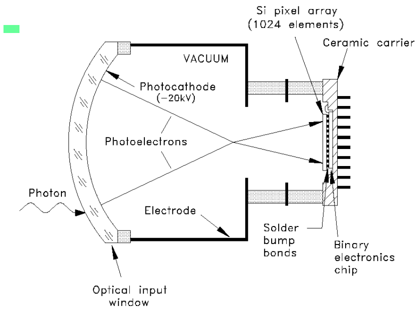
- RICH1 in production
  Installation in UX85 start end April '05

RICH2

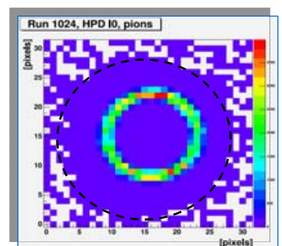


- Transport and installation in July '05

Photon detector HPD



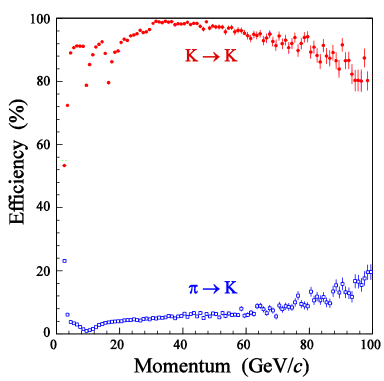
- Novel photodetector:
  - 32×32 pixel sensor array (500×500 μm²)
  - 20 kV operation voltage
  - Demagnification factor ~5
- Production of ~500 tubes started.



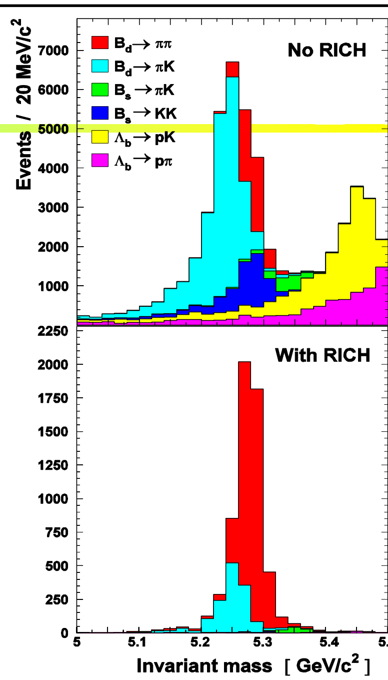
N_2 radiator

Particle Identification

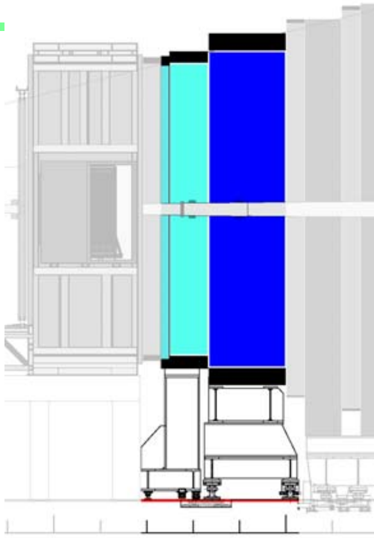
Kaon identification efficiency:



<K Efficiency>: 88%
<π misidentification> 3%



Calorimeters...



Key element to identify γ, π^0 and to measure their energy.

Used in L0 trigger.

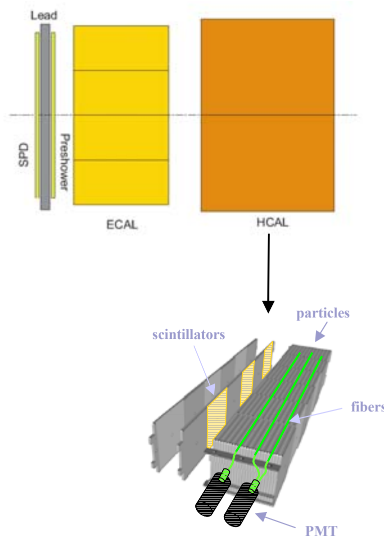
Overview of the Calorimeters

- System subdivided in 3 parts:

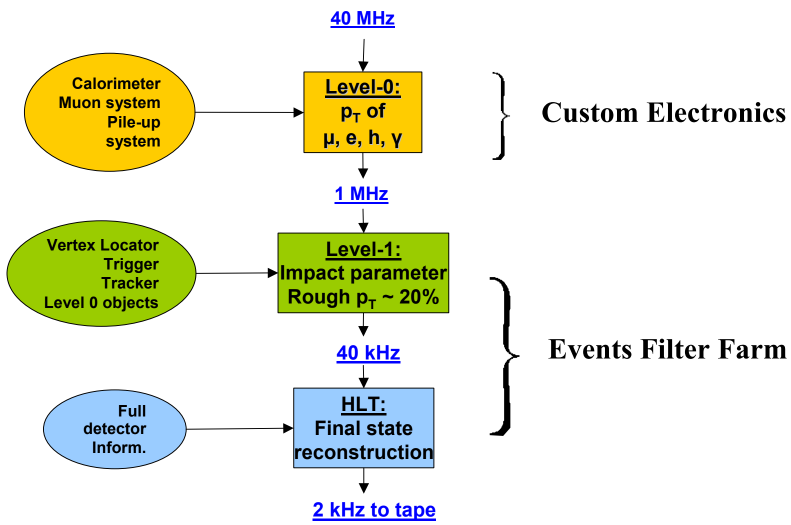
  Scintillating Pad Detector (SPD) and Preshower:
  - Two plans of scintillator pads separated by a 1.5cm lead converter

  Electromagnetic Calorimeter (ECAL):
  - Shashlik types,
  - Lead+ scintillator tiles
  - 25 X_0

- Hadronic calorimeter (HCAL):
  - Iron + scintillator tiles
  - 5.6 λ_I
- A total of 19k channels readout by Wave Length Shifter fibres connected to PMs or MaPMTs.



Triggers...



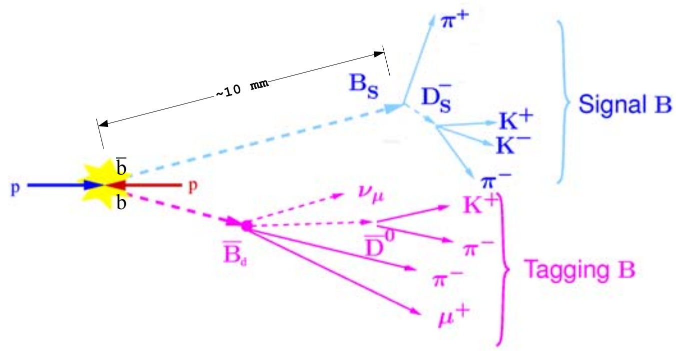
HLT Output rate

HLT rate	Event type	Use for calibration/systematics	Use for physics
200 Hz	Exclusive B	Control channels (tagging,...)	B (core program)
600 Hz	High mass dimuon	Tracking	$b \rightarrow J/\psi X$ (unbiased)
300 Hz	D*	Hadron PID	Charm (mixing+CPV)
900 Hz	Inclusive b (eg $b \rightarrow \mu$)	Trigger	B (data mining)

LHCb physics program

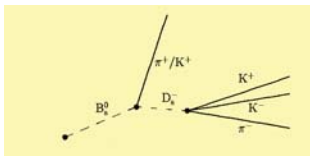
- B_s system parameters
- Angles of the unitarity triangle: precise measurements
- FCNC processes
- Measurement of angle γ (ϕ_3)

Time dependent asymmetry at LHCb

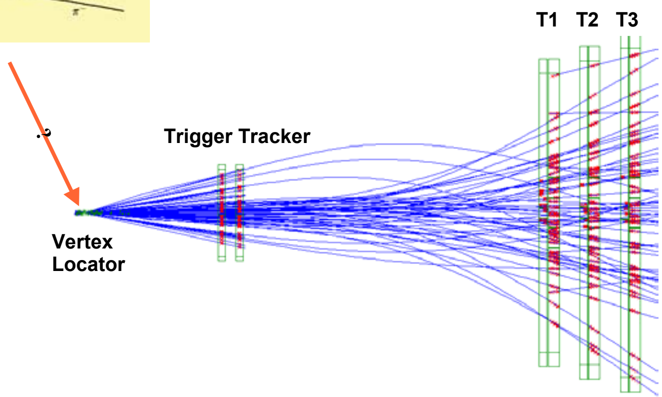


- The proper time of the signal B decay is measured via:
  - the position of the primary and secondary vertexes;
  - the momentum of the signal B state from its decay products.

Event selection: (1)



$$B_s \rightarrow D_s^{\pm} K^{\mp} \rightarrow \left(K^+ K^- \pi^{\pm}\right) K^{\mp}$$



Reconstructed event: ~72 tracks

Event selection: (2)

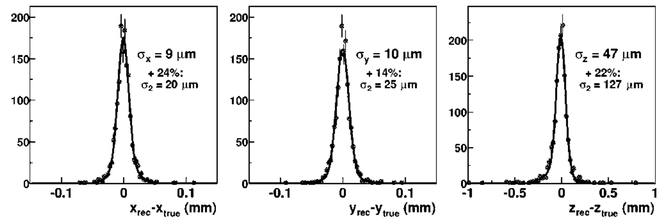
$$B_s \rightarrow D_s^{\pm} K^{\mp} \rightarrow \left(K^+ K^- \pi^{\pm}\right) K^{\mp}$$

1) Primary vertex.
2) D_s meson by using identified kaon and pion and a vertex constrained to the D_s mass.
3) B_s meson by combining a D_s with a kaon forming a vertex (no mass constraint).
4) Select B_s with an impact parameter ~0 and an invariant mass in the window $m_{B_s} \pm 50\,\mathrm{MeV}/c^2$

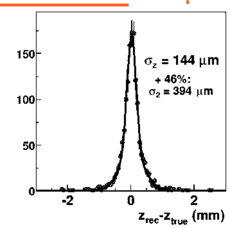
Resolution:

$$B_s \rightarrow D_s^{\pm}K^{\mp} \rightarrow (K^+K^-\pi^{\pm})K^{\mp}$$

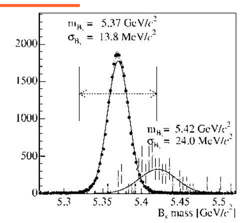
Primary vertex: 47µm



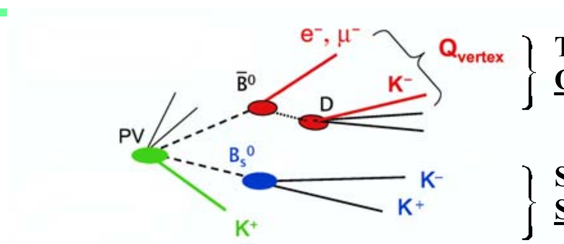
Bs vertex: 144µm



Bs mass: 14 MeV/c^2



Flavour Tagging



Tagging B
Opposite side

Signal $B_{d,s}$
Same side

- Several algorithms to determine the flavour of the signal B meson at production:
  - Opposite side:
    - e, µ from semileptonic b decays;
    - $K^{\pm}$ from b decays chain;
    - Inclusive vertex charge.
  - Same side:
    - $K^{\pm}$ from fragmentation accompanying B_s meson.

Performance of Flavour Tagging

After passing trigger and offline cuts

Channel	ε_{tag} (%)	w (%)	ε_{eff} (%)
$B^0 \to \pi^+\pi^-$	41.8±0.7	34.9±1.1	3.8±0.5
$B^0 \to K^+\pi^-$	43.2±1.4	33.3±2.1	4.8±1.0
$B^0 \to J/\psi\,(\mu\mu)K^0_S$	45.1±1.3	36.7±1.9	3.2±0.8
$B^0 \to J/\psi\,(\mu\mu)K^{*0}$	41.9±0.5	34.3±0.7	4.1±0.3
$B^0_s \to K^+K^-$	49.8±0.5	33.0±0.8	5.8±0.5
$B^0_s \to \pi^+K^-$	49.5±1.8	30.4±2.6	7.6±1.7
$B^0_s \to D^-_s\pi^+$	54.6±1.2	30.0±1.6	8.7±1.2
$B^0_s \to D^\mp_s K^\pm$	54.2±0.6	33.4±0.8	6.0±0.5
$B^0_s \to J/\psi\,(\mu\mu)\phi$	50.4±0.3	33.4±0.4	5.5±0.3

- Effective tagging efficiencies vary between 3 and 9% depending on the final state.
- In real physics analysis, the wrong tag fraction will be measured using control channels with similar topology, e.g.

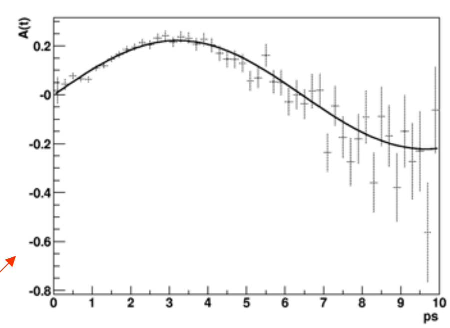
$$B_d \to J/\psi K^{*0} \text{ for } B_d \to J/\psi K_S$$

The phase β in the usual channel $B_d \to J/\psi(\mu^+\mu^-)K_S(\pi^+\pi^-)$

- Decay is dominated by a tree amplitude with Im(λ) = sin2β
- The wrong tag fraction ω is determined with the self-tagging mode

$$B_d \to J/\psi K^{*0}$$

- Sensitivity for 2 fb^{-1}: resolution of 0.02 on sin2β



The B_s system...

$$\Delta m_s \text{ in } B_s \to D_s^- \pi^+$$

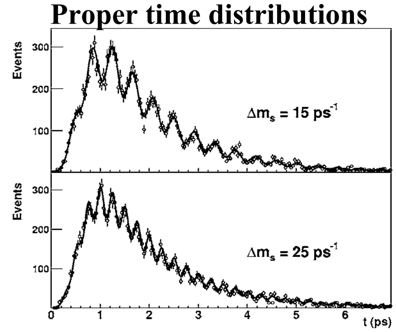
$$\Delta\Gamma_s \text{ and } \varphi_s \text{ in } B_s \to J/\psi\varphi$$

Oscillation frequency Δm_s

- Flavour-specific B decay:

$$B_s \to D_s^-\left(K^+K^-\pi^-\right)\pi^+$$

Proper time distributions



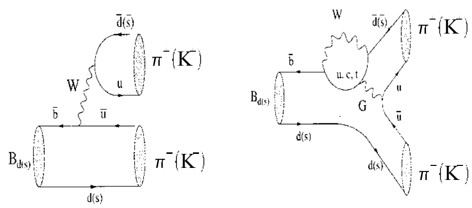
- Sensitivity for 2 fb^{-1}:

Δm_s	15	20	25	30
$\sigma(\Delta m_s)$	0.009	0.011	0.013	0.016

- Highest Δm_s measurable = 68 ps^{-1} (statistical significance of at least 5σ)

The phase γ in $B_s \to K^+K^-$ and $B_d \to \pi^+\pi^-$

- Tree and penguin amplitudes:



- By exchanging all $d(\bar{d})$ in $s(\bar{s})$,

$B_d \to \pi^+\pi^-$ becomes $B_s \to K^+K^-$

$$\begin{cases} A^{dir}_{\pi\pi} = f^{dir}(d, \vartheta, \gamma) \\ A^{mix}_{\pi\pi} = f^{mix}(d, \vartheta, \gamma, \beta) \end{cases} \quad \begin{cases} A^{dir}_{KK} = f^{dir}(d', \vartheta', \gamma) \\ A^{mix}_{KK} = f^{mix}(d', \vartheta', \gamma, \varphi_s) \end{cases}$$

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The phase γ in $B_s \to K^+K^-$ and $B_d \to \pi^+\pi^-$

$$\begin{cases} A^{dir}_{\pi\pi} = f^{dir}(d, \vartheta, \gamma) \\ A^{mix}_{\pi\pi} = f^{mix}(d, \vartheta, \gamma, \beta) \end{cases} \quad \begin{cases} A^{dir}_{KK} = f^{dir}(d', \vartheta', \gamma) \\ A^{mix}_{KK} = f^{mix}(d', \vartheta', \gamma, \varphi_s) \end{cases}$$

$$de^{i\vartheta} = \left| \frac{penguins}{tree} \right|_{B_d \to \pi\pi} \qquad d' e^{i\vartheta'} = \left| \frac{penguins}{tree} \right|_{B_d \to KK}$$

Use SU(3) flavour symmetry to relate $d = d'$ and $\vartheta = \vartheta'$

If β and φ_s are known, four observables to determine d, ϑ and γ

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Events yield for rare decays

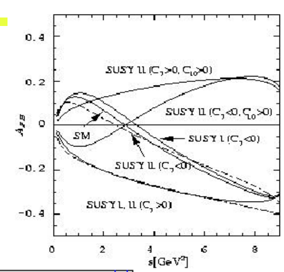
- For 2 fb^{-1} after trigger and offline selection:

Channel	B.R.	Yield	B/S(90%CL)
$B_d \to K^{*0}(K^+\pi^-)\gamma$	2.9×10^{-5}	3.5×10^{4}	<0.7
$B_s \to \varphi(K^+K^-)\gamma$	2.1×10^{-5}	9.3×10^{3}	<2.4
$B_d \to \omega(\pi^+\pi^-\pi^0)\gamma$		40	<3.5
$B_d \to K^{*0}(K^+\pi^-)\mu^+\mu^-$	8×10^{-7}	4.4×10^{3}	<2.0
$B_d \to \varphi(K^+K^-)K_S(\pi^+\pi^-)$	1.4×10^{-6}	0.8×10^{3}	<0.2
$B_s \to \varphi(K^+K^-)\varphi(K^+K^-)$	1.3×10^{-6}	1.2×10^{3}	<1.1
$B_s \to \mu^+\mu^-$	3.5×10^{-9}	17	<5.7

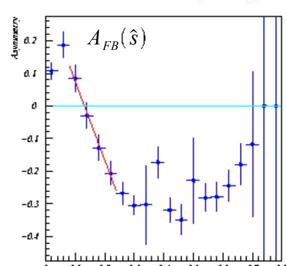
- Promising physics potential to study numerous loop-induced rare decays.
  Still room to adjust trigger in order to increase the rate for channels of topical interest

$A_{FB}(s)$ $B^0 \to K^{*0}\mu^+\mu^-$

- Forward-backward asymmetry in the μμ rest frame $A_{FB}(s)$ is a sensitive probe of new physics



- Sensitivity for 2 fb^{-1}: zero point location to +-0.04 in $\hat{s} = (m_{\mu\mu}/m_B)^2$



$\hat{s} = (m_{\mu\mu}/m_B)^2$

LHCb summary

- LHCb is a single arm forward detector to study CP violation and rare decays in the beauty sector.
- The installation is progressing well.
- It will be ready for the first proton-proton collisions in 2007.
- The commissioning and running will surely bring suprises...