Univerza v Ljubljani

THE UNIVERSITY OF TOKYO

Flavour Physics at B-factories and Hadron Colliders

Part 14: Experiments at hadron machines

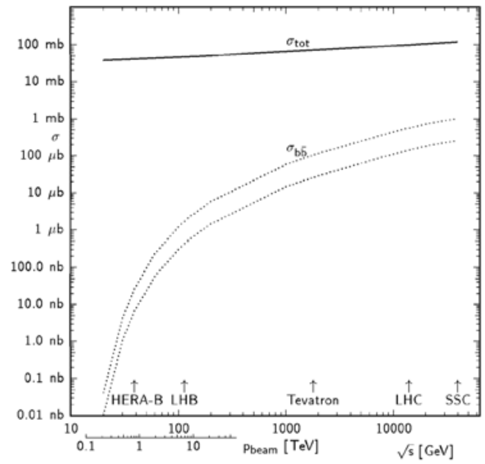
Peter Križan
University of Ljubljana and J. Stefan Institute

Contents

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

Why hadron machines?

- large bb production rates (compare to 1.1nb at Y(4s)
- large boosts -> <L> = <βγ> 480 μm
- in addition to B^0/B^{+-} also B_s, B_c, Λ_b,..

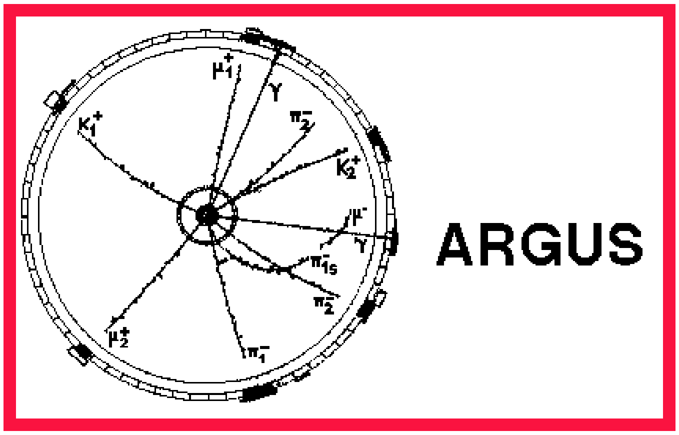


Why hadron machines?

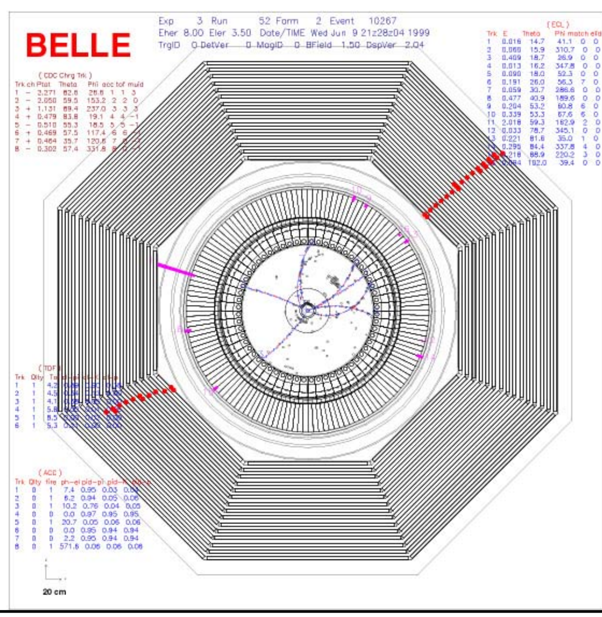
Production	$e^+e^- \to \Upsilon(4s) \to B\bar{B}$	$e^+e^- \to Z^0 \to b\bar{b}$	$pA \to b\bar{b}X$	$p\bar{p} \to b\bar{b}X$	$p\bar{p}(p) \to b\bar{b}X$ forward
Accelerator	CESR, DORIS PEPII, KEKB	LEP, SLD	HERA p	Tevatron	Tevatron, LHC
Spectrometer	CLEO, ARGUS BaBar, BELLE	ALEPH, DELPHI, L3, OPAL, SLD	HERA-B	CDF, D0	BTeV, LHCb
$\sigma(b\bar{b})$	≈ 1 nb	≈ 6 nb	≈ 12 nb	$\approx 50\ \mu$b	$\approx 100\ \mu$b ($\approx 500\ \mu$b)
$\sigma(b\bar{b}):\sigma(had)$	0.26	0.22	10^{-6}	10^{-3}	$2 \cdot 10^{-3}$ $(6 \cdot 10^{-3})$
B^0, B^+ $B^0_s, B^+_c, \Lambda^0_b$	yes no	yes yes	yes yes	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

bb events at e^+e^- machines

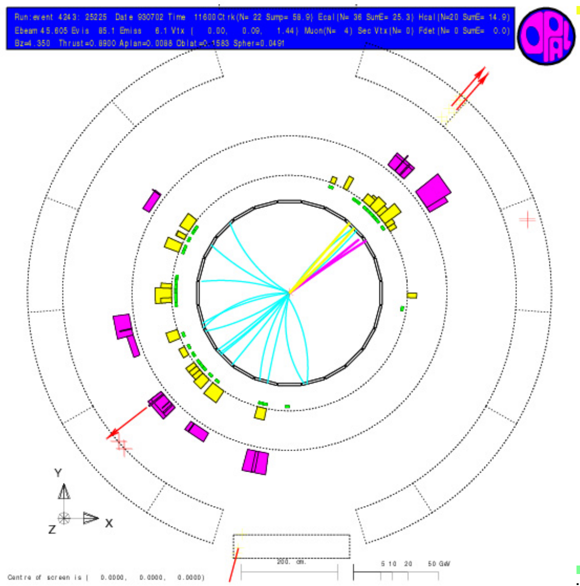
ARGUS and CLEO at Y(4s)



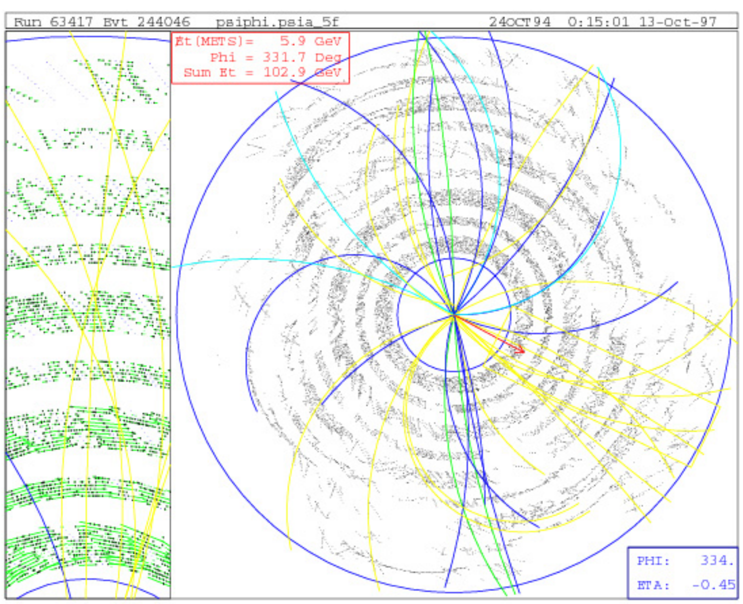
bb events at e^+e^- machines: BELLE



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

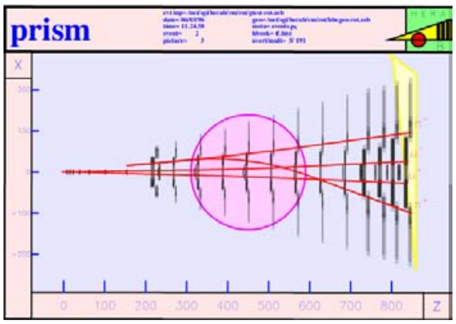


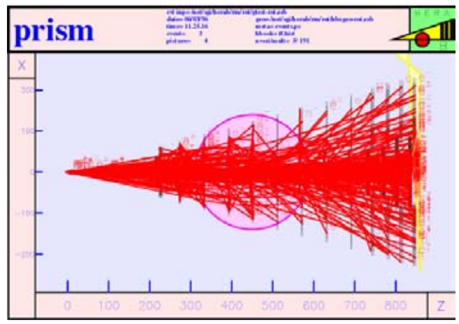
bb event at CDF



bb event at HERA-B:

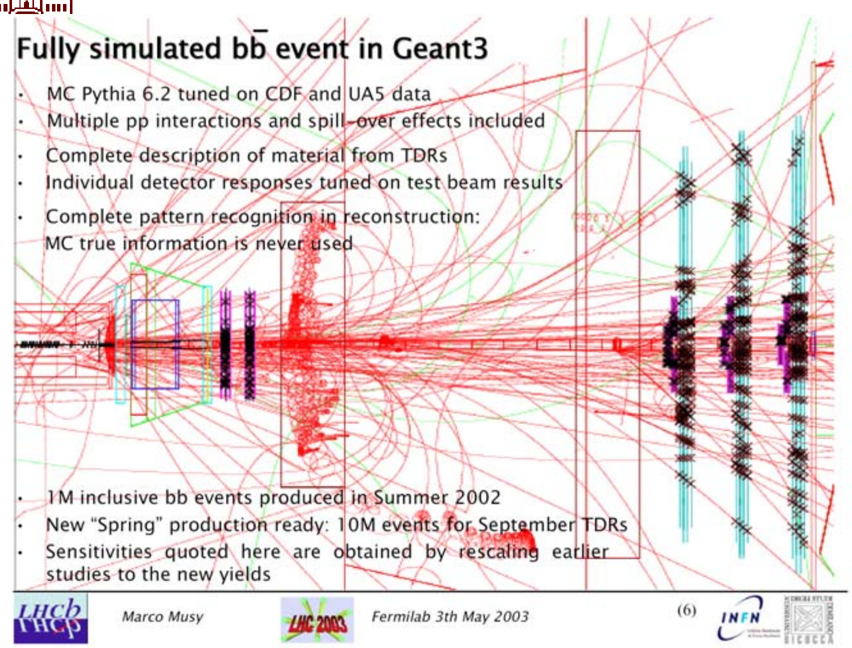
Needle | in haystack...





B decay | and the rest

bb event at LHCb:



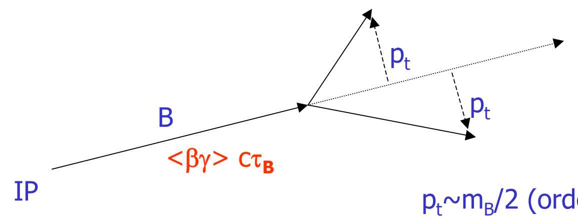
B detection in hadron collisions

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: $B \to \mu\nu X$, $B \to J/\psi\ Ks \to \mu^+\mu^-\ \pi^+\pi^-$, $B \to \pi^+\pi^-$
→helps because 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: $<L> = <\beta\gamma>\ c\tau_B = <\beta\gamma>\ 480\ \mu m$ → helps because other decay products are promt = originate directly in the interaction point

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

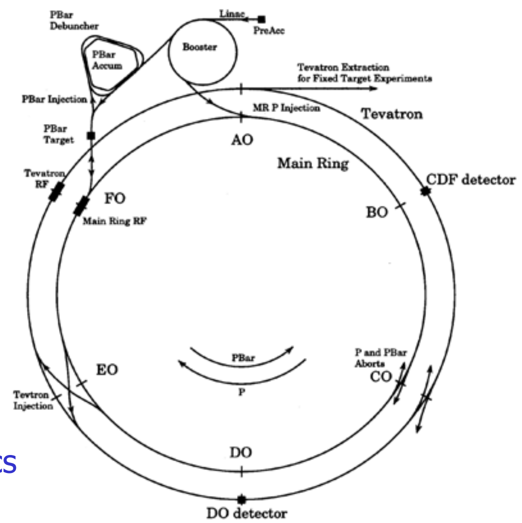
Tevatron: proton anti-proton collider

E_{cms} = 1980 GeV

Two general purpose collider experiments:

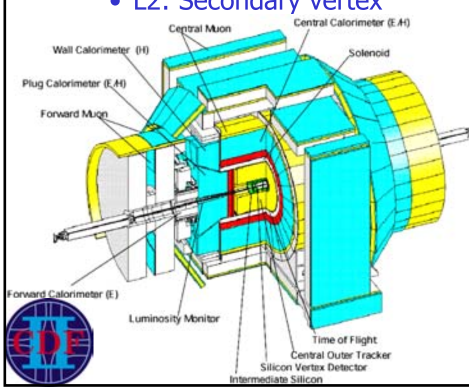
- CDF
- D0

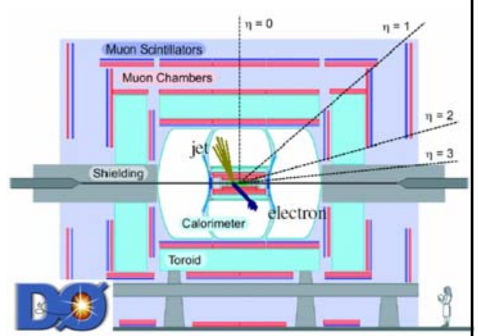
Cancelled: BTeV, forward spectrometer for b physics (similar to LHCb) at C0.



Detectors

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

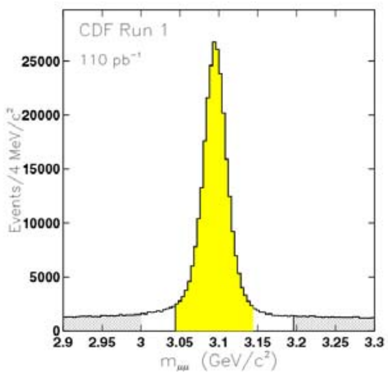


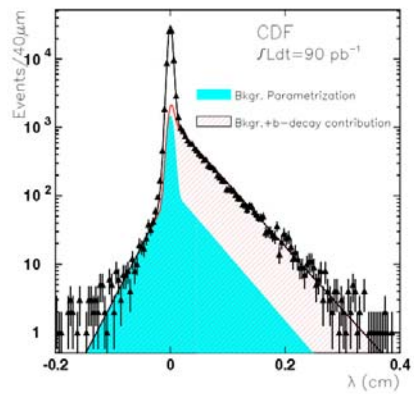


- D0:
  - Excellent muon and tracking coverage
    - Tracking up to |η|<3
    - Muons up to |η|<2

CDF performance, run 1

Mass resolution on J/ψ: 16 MeV

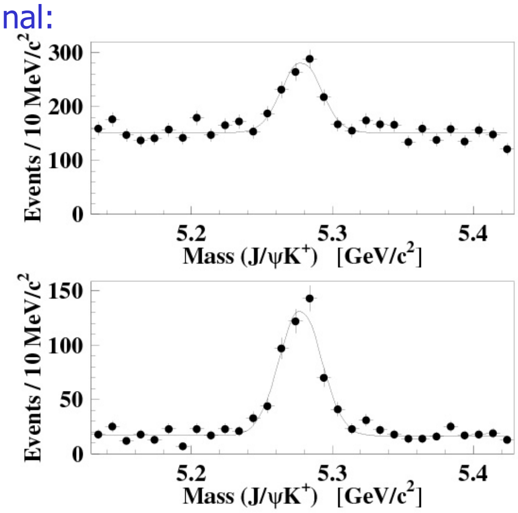




Decay length resolution: 40-50 μm

CDF performance , run 1

Cleaning up the J/ψ K^+ signal:

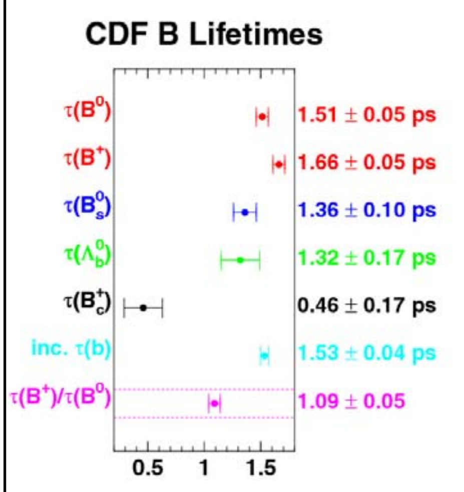


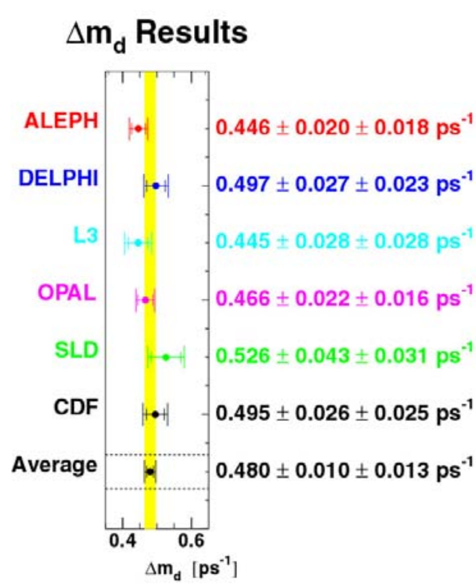
cut on decay length (>100 μ m)

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 $\sin 2\beta$=0.79+0.41-0.44
- rare decays

CDF run 1 results, status 2001





CDF, Tevatron upgrade

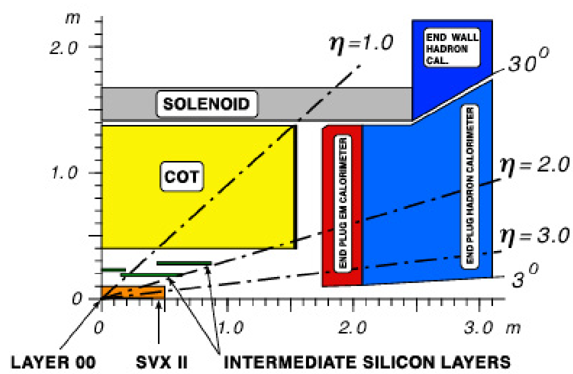
For Run II the injector and anti-proton source were upgraded. Expected: 2 fb-1 in 2001-02, 15 fb-1 until 2004 (compared to 0.1 fb-1 in Run I).

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



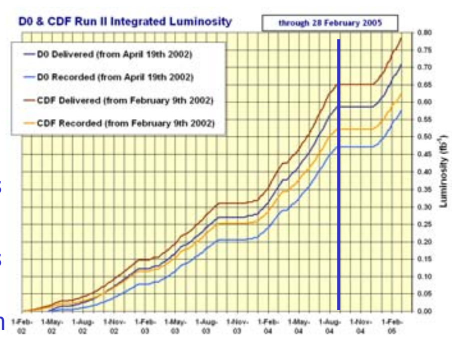
CDF physics plans, 2fb-1

- 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...

B_s oscillations

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

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

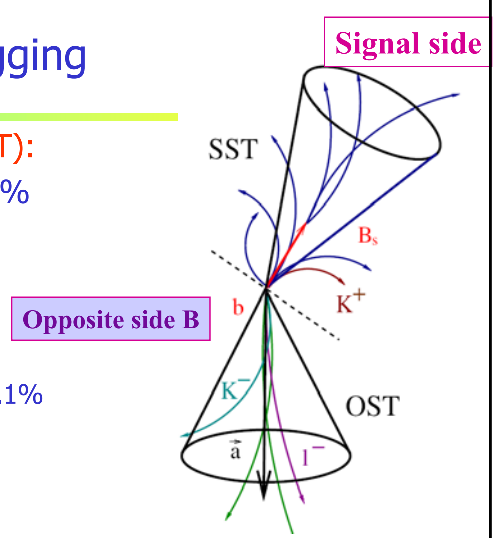
If A consistent with 0 -> no mixing.
Mixing established if A=1, and A=0 excluded with high significance.

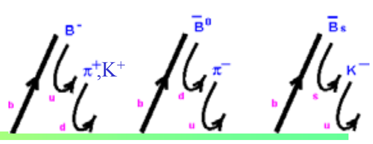
However: amplitude gets reduced by dilution D! Measured: A*D. To extract A, have to know D -> calibation with data (similarly as in B factories, but a harder job here).

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

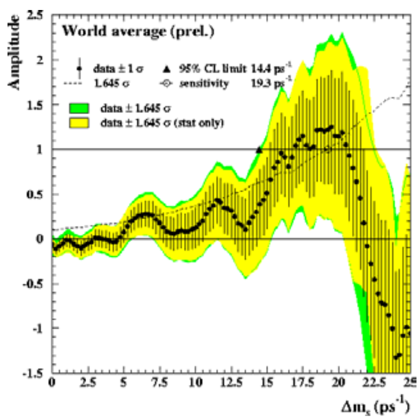
    $\varepsilon D^2 \sim 1\%$ for CDF&D_0 in B_d



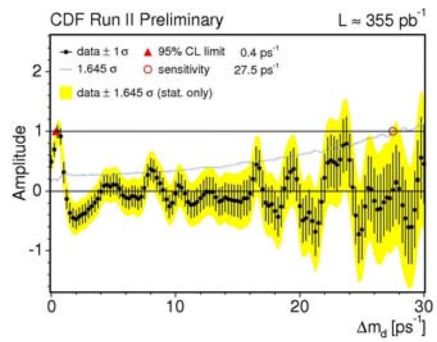


Status 2005

LEP dominated w.a.



CDF 2005

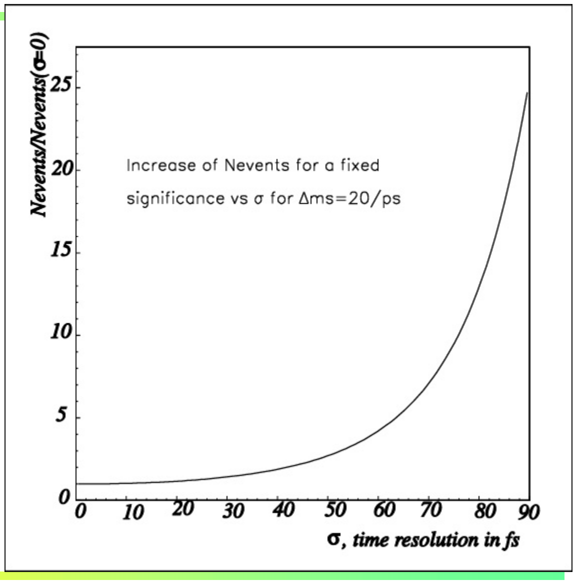


Why is the performance different from the expectations? 1

- 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.

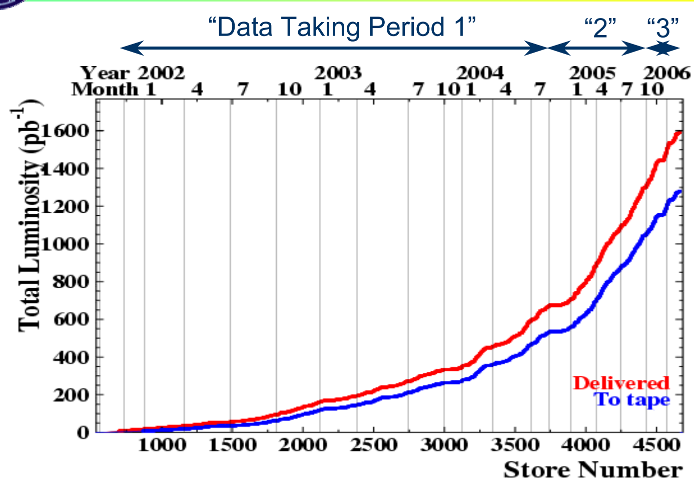


Why is the performance different from the expectations? 2

... ->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.

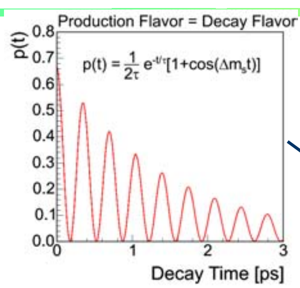
Tevatron Luminosity



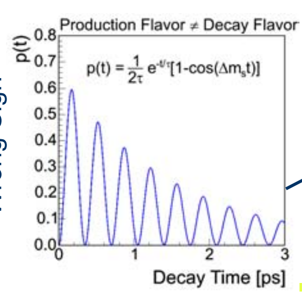
This analysis: Feb 2002 – Jan 2006 --> 1 fb^{-1}

Measurement .. In a Perfect World

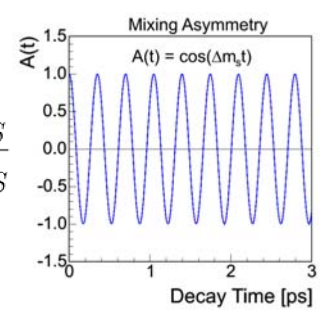
"Right Sign"



"Wrong Sign"



$$A(t) = \frac{N_{RS} - N_{WS}}{N_{RS} + N_{WS}}$$



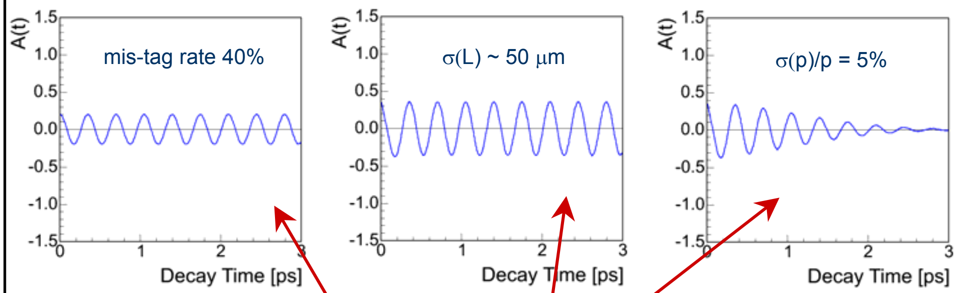
what about detector effects?

Realistic Effects

flavor tagging power, background

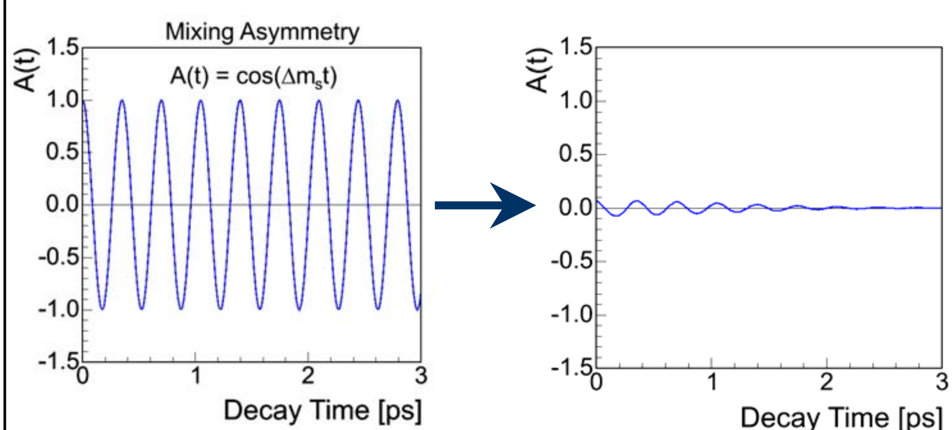
displacement resolution

momentum resolution

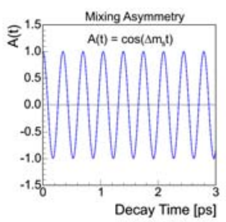


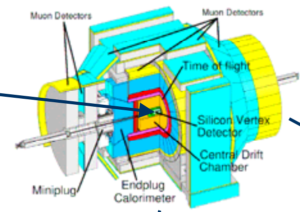
$$\frac{1}{\sigma} = \sqrt{\frac{S\epsilon D^2}{2}} e^{-\frac{(\Delta m_s \sigma_t)^2}{2}} \sqrt{\frac{S}{S+B}}$$

All Effects Together

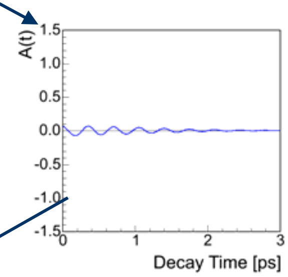


Real Measurement Layout





Data



momentum resolution
displacement resolution
flavor tagging power

scan for signal:

$A(\Delta m_s = 15\ ps^{-1}) = ?$

Unbinned Likelihood Fitter

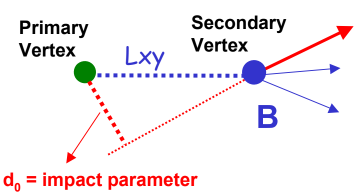
measure frequency:

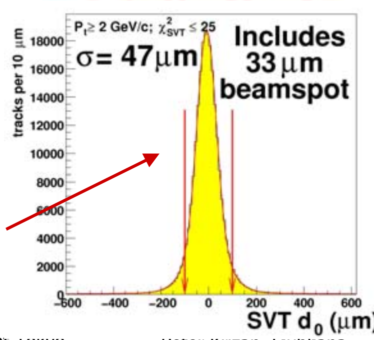
$\Delta\ m_s = ?$

$p \sim e^{-t/\tau}[1 + AD \cos\Delta mt] - R(t)$

Triggering On Displaced Tracks

- trigger $B_s \rightarrow D_s^- \pi$, $B_s \rightarrow D_s^- l^+$





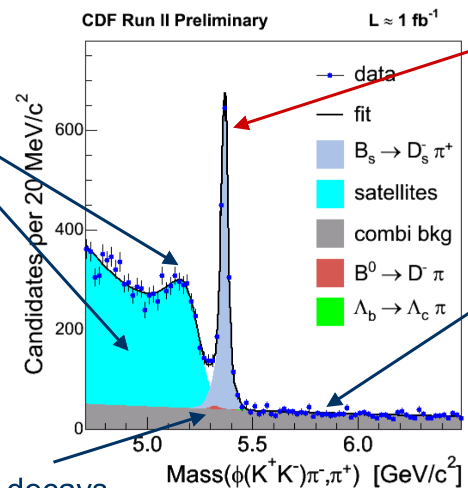
trigger extracts 20 TB /sec

“unusual” trigger requirement:

two displaced tracks:
(p_T > 2 GeV/c, 120 μm<$|d_0|$<1mm)

Example Mass Spectrum

partially reconstructed B mesons (satellites)



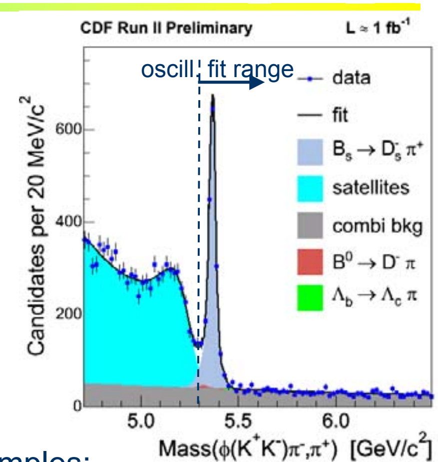
signal B_s--> $D_s\pi$, D_s --> $\phi\pi$, ϕ --> K^+K^-

combinatorial background

B^0--> $D^-\pi$ decays

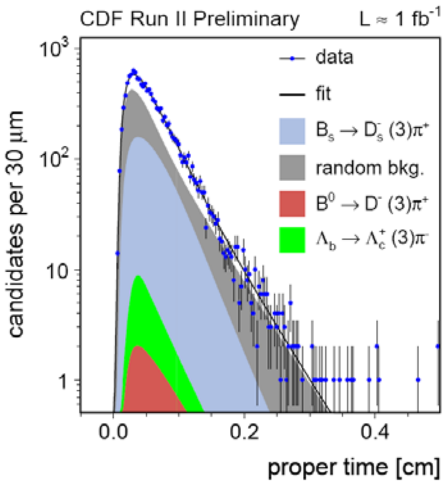
Signal Yield Summary: Hadronic

	Yield
B_s--> $D_s\pi$ ($\phi\pi$)	1600
B_s--> $D_s\pi$ (K^* K)	800
B_s--> D_s π (3π)	600
B_s--> $D_s3\pi$ (ϕ π)	500
B_s--> $D_s3\pi$ (K^*K)	200
Total	3700



- high statistics light B meson samples:
  B^+ ($D^0\pi$): 26k events
  B^0 ($D^-\pi$): 22k events

Hadronic Lifetime Results



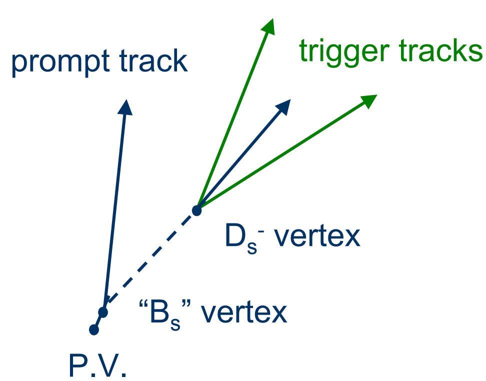
Mode	Lifetime [ps] (stat. only)
$B^0 \to D^- \pi^+$	1.508 +- 0.017
$B^- \to D^0 \pi^-$	1.638 +- 0.017
$B_s \to D_s \pi(\pi\pi)$	1.538 +- 0.040

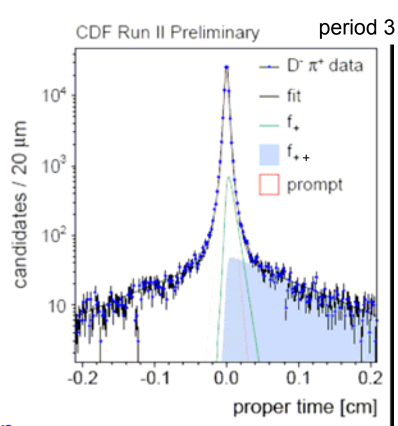
- World Average:

B^0 --> 1.534 +- 0.013 ps^{-1}
B^+ --> 1.653 +- 0.014 ps^{-1}
B_s --> 1.469 +- 0.059 ps^{-1}

Excellent agreement-->

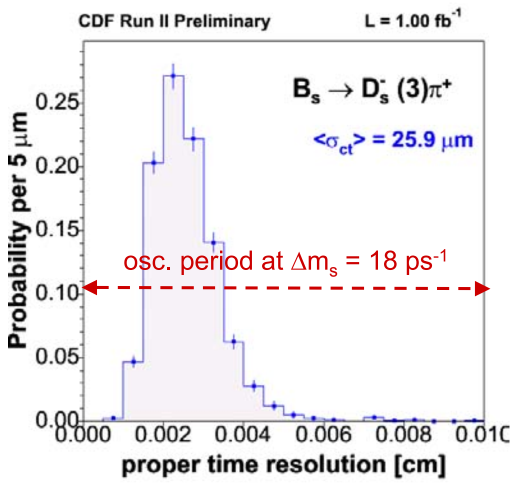
Calibrating the Proper Time Resolution





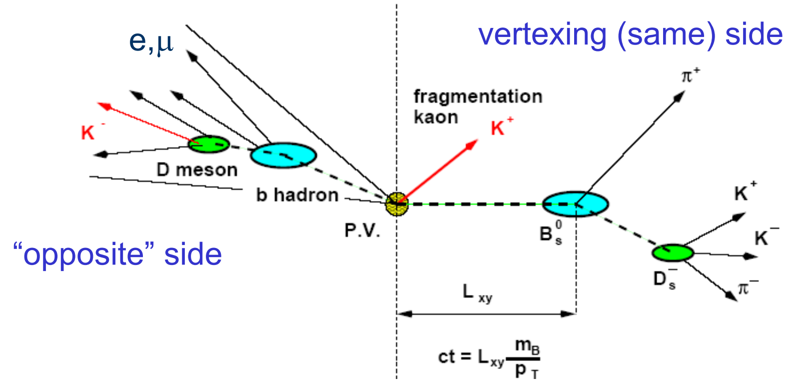
- utilize large prompt charm cross section
- construct "B^0-like" topologies of prompt D^- + prompt track
- calibrate ct resolution by fitting for "lifetime" of "B^0-like" objects

B_s Proper Time Resolution



- event by event determination of primary vertex position used
- average uncertainty ~ 26 μm
- this information is used per candidate in the likelihood fit

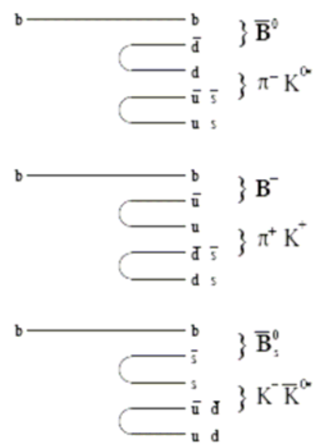
Tagging the B Production Flavor



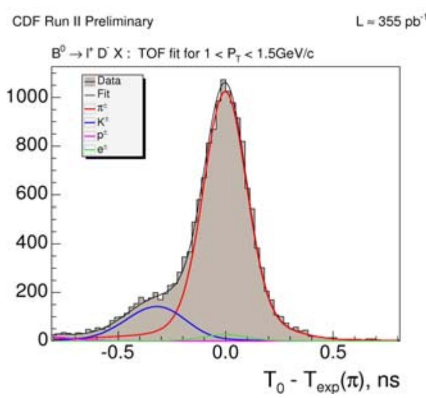
- use a combined same side and opposite side tag!
- use muon, electron tagging, jet charge on opposite side
- jet selection algorithms: vertex, jet probability and highest p_T
- particle ID based kaon tag on same side

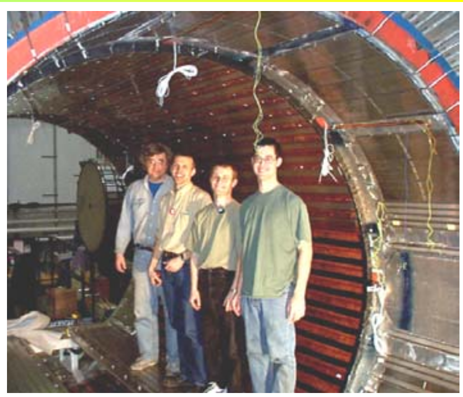
Same Side Kaon Tags

- exploit b quark fragmentation signatures in event
- B^0/B^+ likely to have a π^-/π nearby
- B_s^0 likely to have a K^+
- use TOF and COT dE/dX info. to separate pions from kaons
- problem: calibration using only B^0 mixing will not work
- tune Monte Carlo simulation to reproduce B^0, B^- distributions, then apply directly to B_s^0



Time Of Flight System





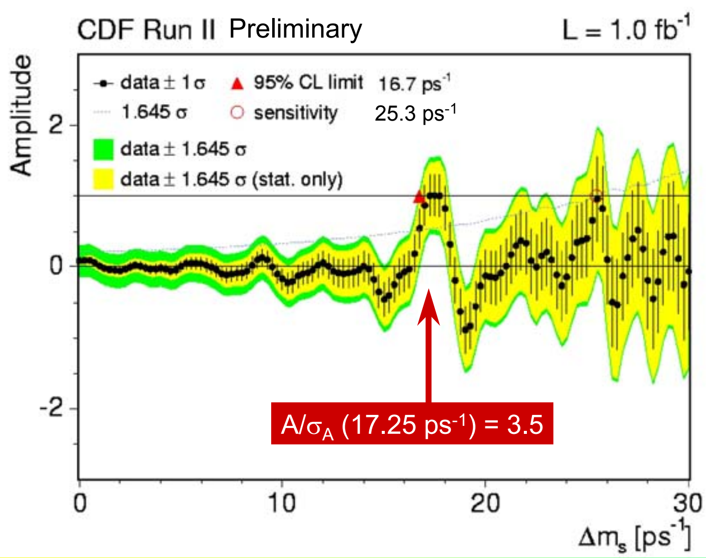
- timing resolution ~100 ps --> resolves kaons from pions up to p ~ 1.5 GeV/c
- TOF provides most of the Particle ID power for SSKT

Tagger Performance

	εD^2 Hadronic (%)	εD^2 Semileptonic (%)
Muon	0.48 +- 0.06 (stat)	0.62 +- 0.03 (stat)
Electron	0.09 +- 0.03 (stat)	0.10 +- 0.01 (stat)
JQ/Vertex	0.30 +- 0.04 (stat)	0.27 +- 0.02 (stat)
JQ/Prob.	0.46 +- 0.05 (stat)	0.34 +- 0.02 (stat)
JQ/High p_T	0.14 +- 0.03 (stat)	0.11 +- 0.01 (stat)
Total OST	1.47 +- 0.10 (stat)	1.44 +- 0.04 (stat)
SSKT	3.42 +- 0.98 (syst)	4.00 +- 1.02 (syst)

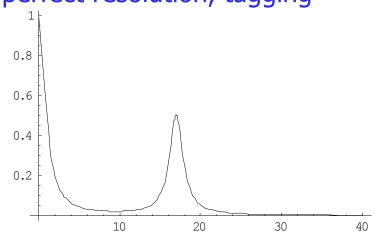
- use exclusive combination of tags on opposite side
- same side – opposite side combination assumes independent tagging information

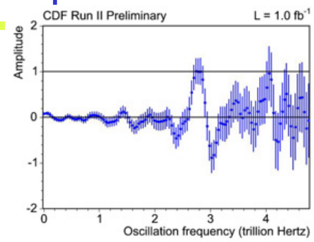
Combined Amplitude Scan



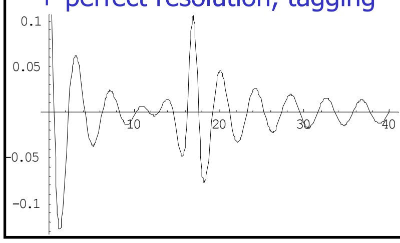
B_s Mixing: do we understand the Δm_s variation of the amplitude?

Fourier transform for t=0 -> inf.
+ perfect resolution, tagging

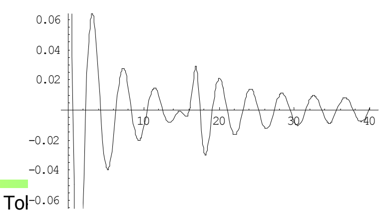




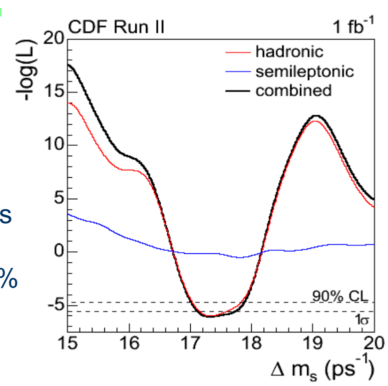
Fourier transform for t=1.5 -> inf.
+ perfect resolution, tagging



Fourier transform for t=1.5-> inf.
+ realistic resolution, tagging



Measurement of Δm_s



the measurement is already very precise--> (at 2.5% level)

$\Delta m_s = 17.33\ ^{+0.42}_{-0.21}$ (stat) +- 0.07 (syst) ps^{-1}

Δm_s in [17.00, 17.91] ps^{-1} at 90% CL

Δm_s in [16.94, 17.97] ps^{-1} at 95% CL

$|V_{td}| / |V_{ts}|$

$$\frac{\Delta m_s}{\Delta m_d} = \frac{m_{Bs}}{m_{Bd}} \xi^2 \frac{|V_{ts}|^2}{|V_{td}|^2}$$

- inputs:
  - → $m(B^0)/m(B_s) = 0.9830$ (PDG 2006)
  - → $\xi = 1.21\ ^{+0.047}_{-0.035}$ (M. Okamoto, hep-lat/0510113)
  - → $\Delta m_d = 0.507 \pm 0.005$ (PDG 2006)

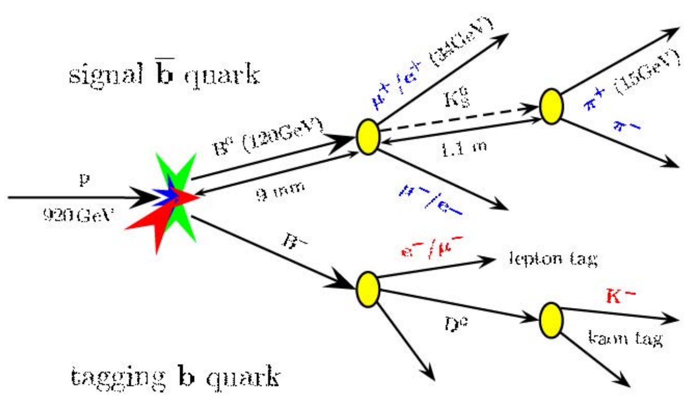
$|V_{td}| / |V_{ts}| = 0.208\ ^{+0.008}_{-0.007}$ (stat + syst)

- compare to Belle $b \to d\gamma$ (hep-ex/0506079):
  $|V_{td}| / |V_{ts}| = 0.199\ ^{+0.026}_{-0.025}$ (stat) $^{+0.018}_{-0.015}$ (syst)

HERA-B

Fixed target B - Factory at HERA (DESY)

Originally designed for measurement of CP violation in $B \to J/\psi K_S^0$



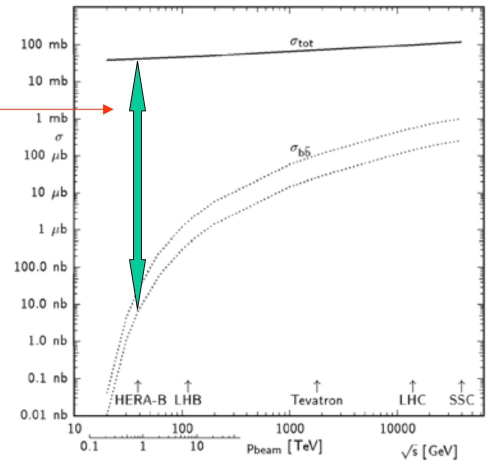
HERA-B

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

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 (=0.4 10^8 s^{-1})

→LHC like experiment several years before LHC

Parasitic running:

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

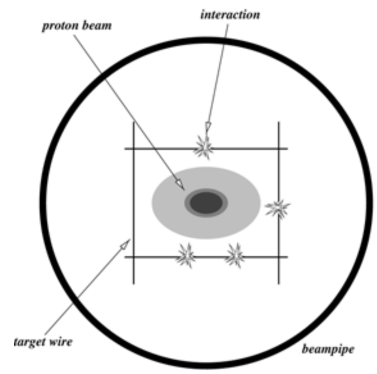
Needed:

•target in beam halo

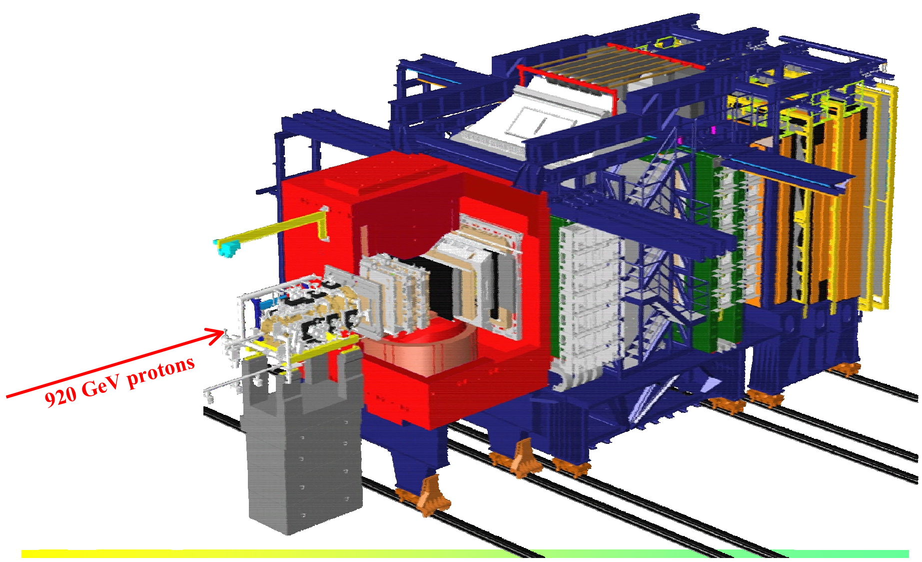
•efficient separation of primary vertices for high interaction rates.

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

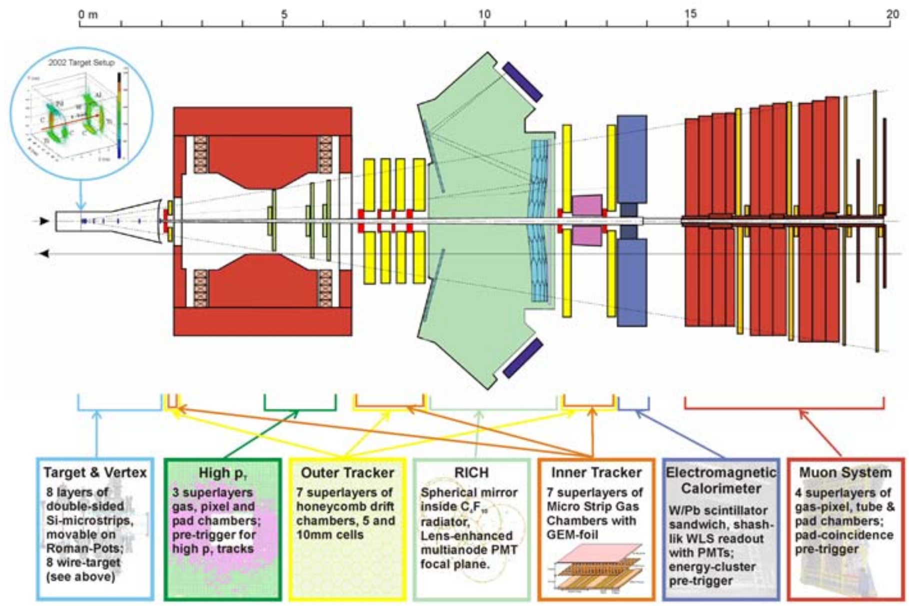
Operation of the wire target has been reliable for years, little interference with HERA ep operation



HERA-B spectrometer



HERA-B spectrometer



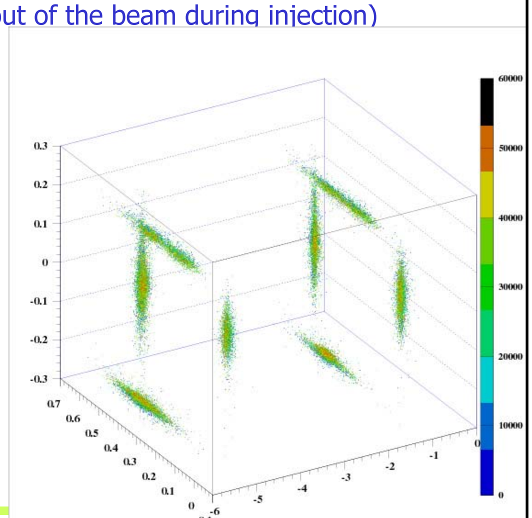
HERA-B: SVD

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

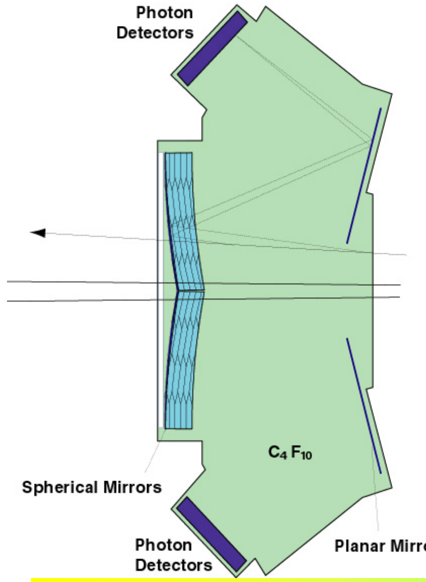
Excellent and reliable operation.

Reconstructed vertices

On eight target wires ->



HERA-B RICH



HERA-B RICH photon detector

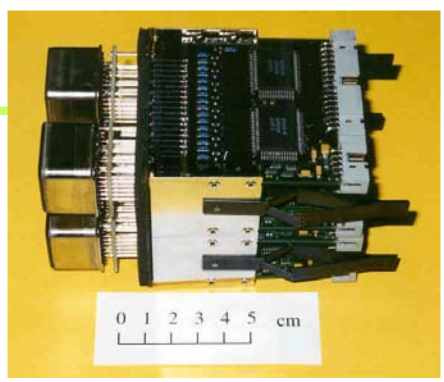
Requirements:

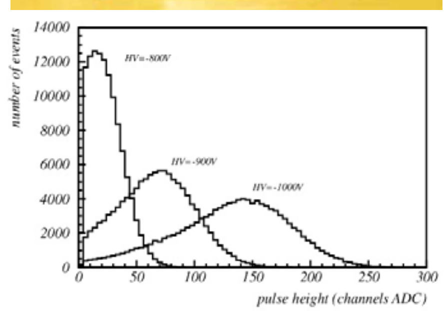
- High QE over ~3m^2
- Rates ~1MHz
- Long term stability

→Gas based detectors could not be used

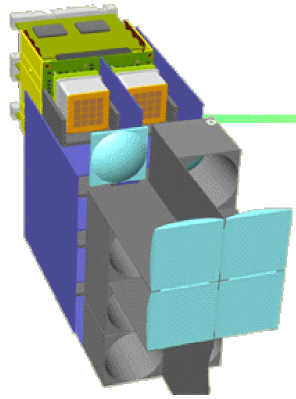
Multianode PMTs: Hamamatsu

R5900-M16 and R5900-M4



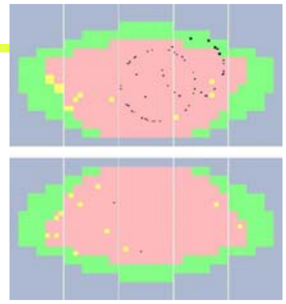


HERA-B RICH



Event display with two isolated rings

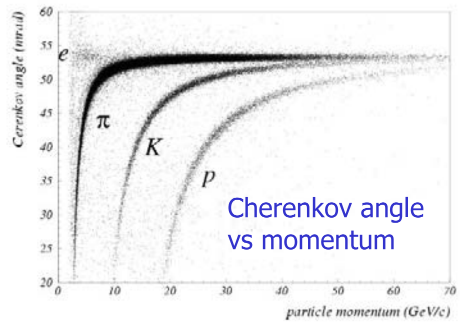
→ no noise



Light collection system (imaging!) to:

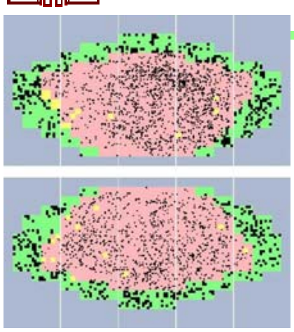
-Adapt the pad size

-Eliminate dead areas



Cherenkov angle vs momentum

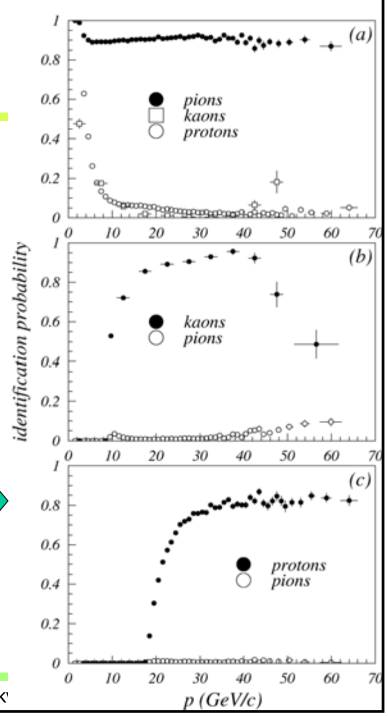
HERA-B RICH



Typical event

Still: it works actually very well!

pion, kaon and proton efficiency and probability



NIM A516 (2004) 445

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

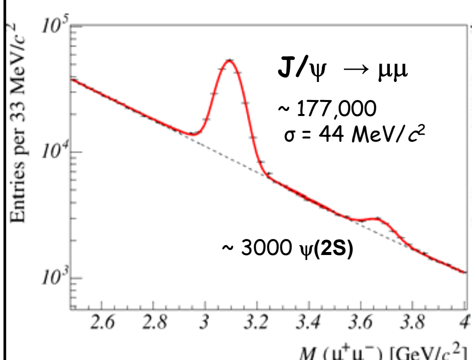
First Level Trigger (FLT): Track trigger in hardware using tracking detectors behind magnet, seeding by pretriggers

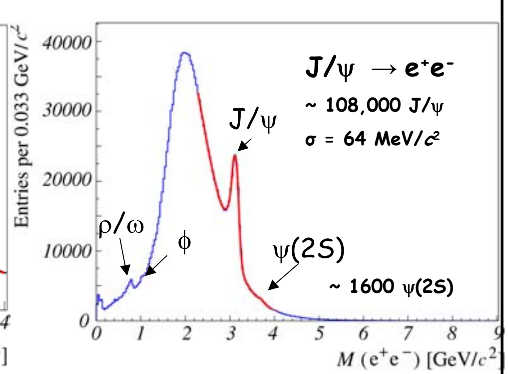
20 kHz

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

100 Hz

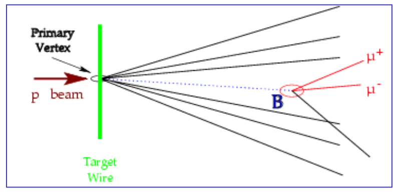
HERA-B: J/ψ Production





HERA-B: Open Beauty Production

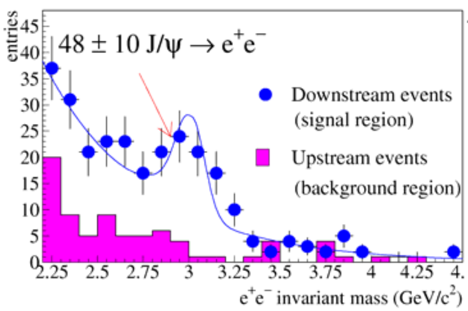
Detached vertex analysis

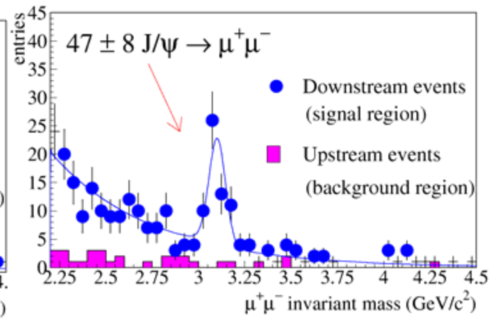


$pA \rightarrow b\ \bar{b} + X$

$\quad \hookrightarrow J/\psi + X'$

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





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->$\mu\mu$, pentaquark searches)
- HERA-B experience: An important input for LHC experiments

HERA-B Summary 2

First LHC like experiment before the LHC → messages for the LHC experiments

-do not use MSGCs

-large area trackers are not easy

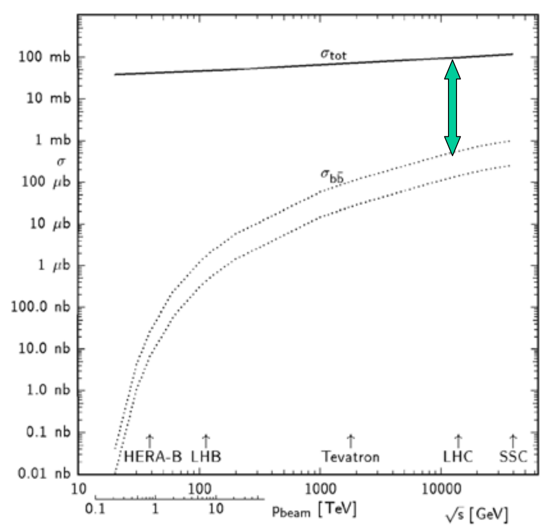
-trigger processors can get saturated by high occupancy events which are not necessarily interesting

-RICH counters are more robust than anticipated

-retractable SVD works reliably

b-production in pp collisions at LHC

Cross section for bb pair production much higher at the LHC



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

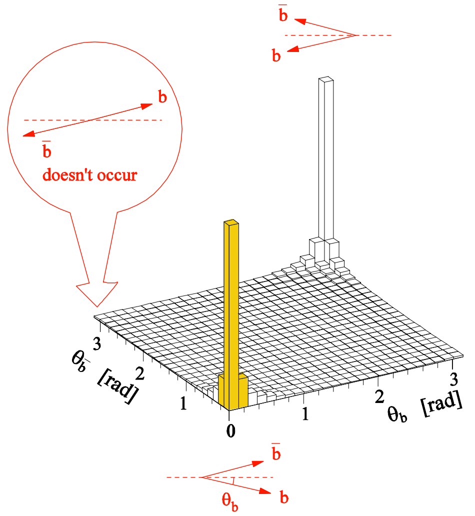
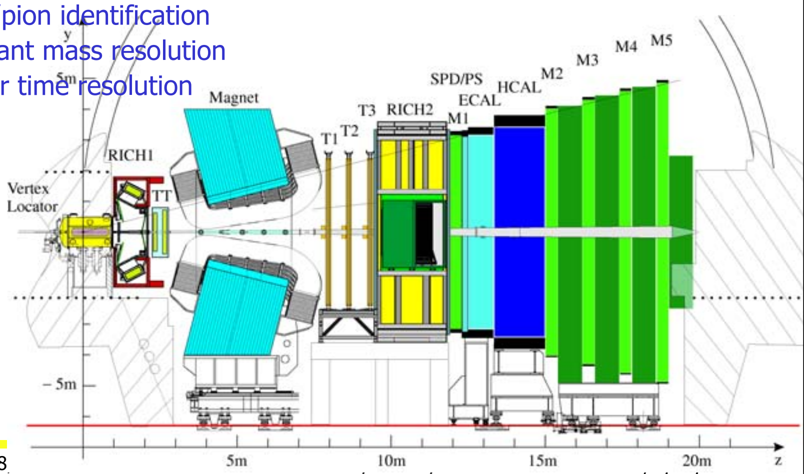
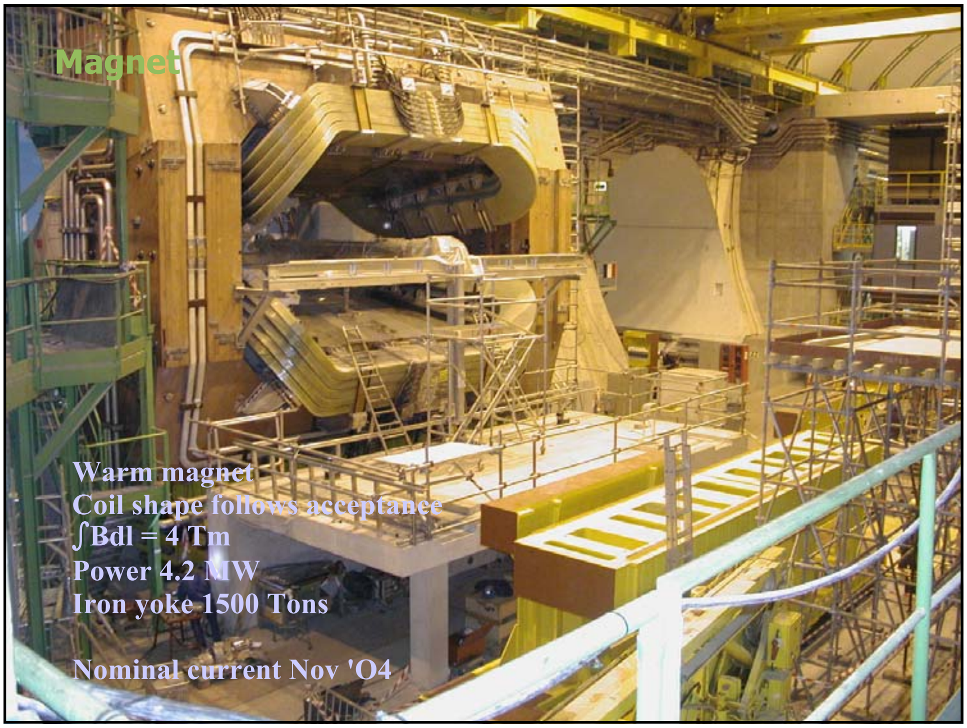


Figure 2.1: Polar angles of the b- and $\bar{b}$-hadrons calculated by the PYTHIA event generator.

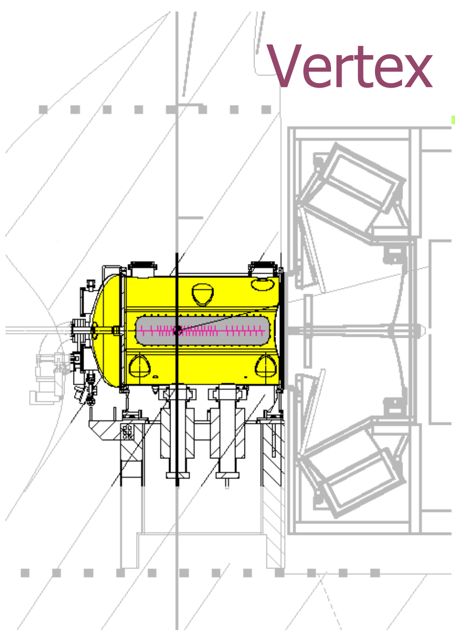
LHCb

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





Vertex locator...

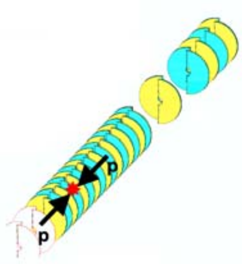


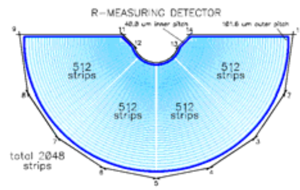
Key element surrounding the IP:

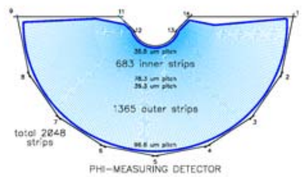
- Measure the position of the primary and the $B_{d,s}$ vertices
- Used in L1 trigger.

Vertex locator

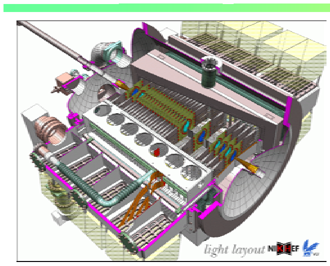
- 21 pairs of silicon strip detectors arrange in two retractable halves:
  - Strips with an R-φ geometry:
    - R strip pitch: 40-102 μm
    - φ strip pitch: 36-97 μm
  - 172k channels.
- Operated:
  - In vacuum, separated from beam vacuum by an Al foil
  - Close to the beam line (7 mm)
  - Radiation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







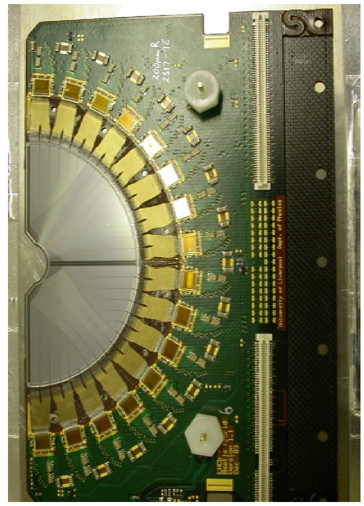
Vertex locator



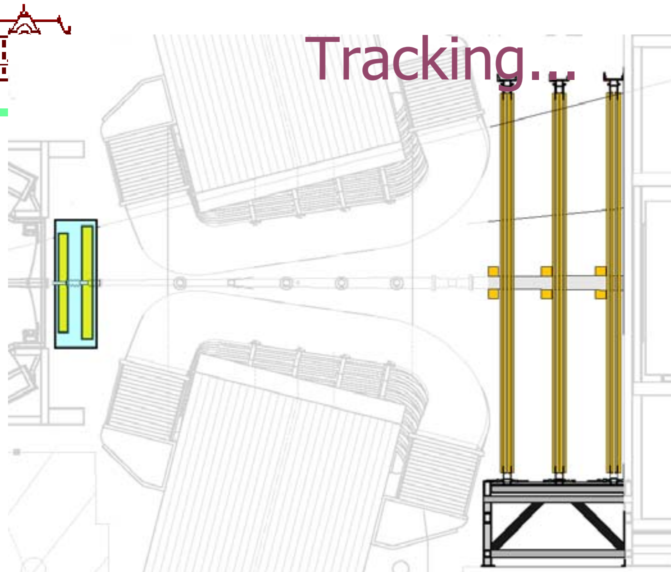
Installation in November '05

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

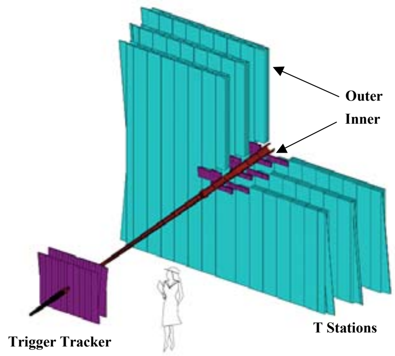


Tracking...



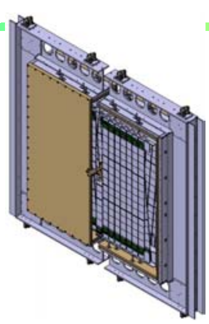
Key elements to find tracks and to measure their momentum.

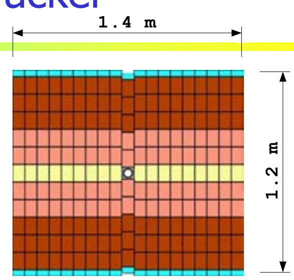
Overview of the tracking system



- 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

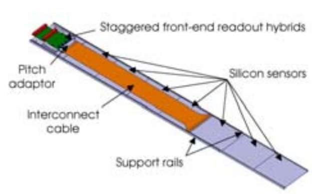
Trigger Tracker



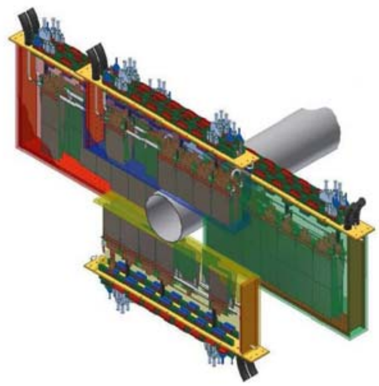


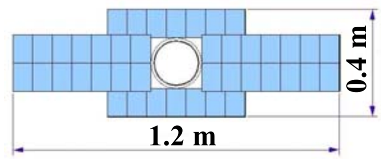
0° layer

- 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



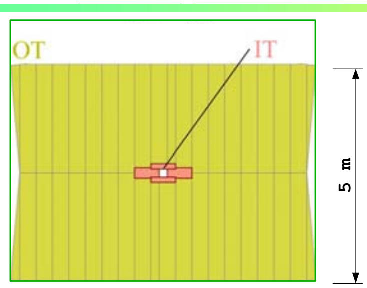
T Station: inner tracker part





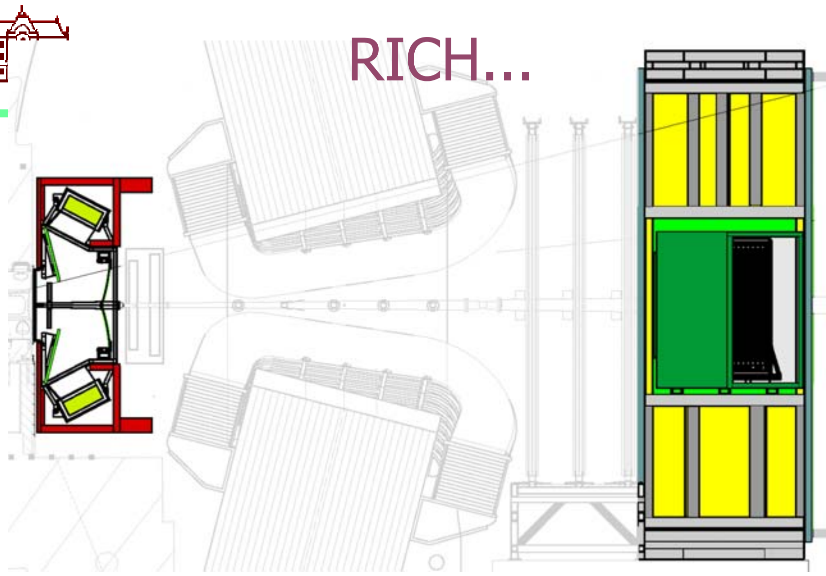
- Microstrips silicon detector:
  - Same sensors as Trigger Tracker
  - Four layers (0°, +5°, -5°, 0°)
  - Strip length 11, 22 cm
  - Radiation ≤ 9×10^{12} n_{eq}/cm^2 over 10 years
  - Cooled -5 °C

T station: outer tracker part



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

RICH...



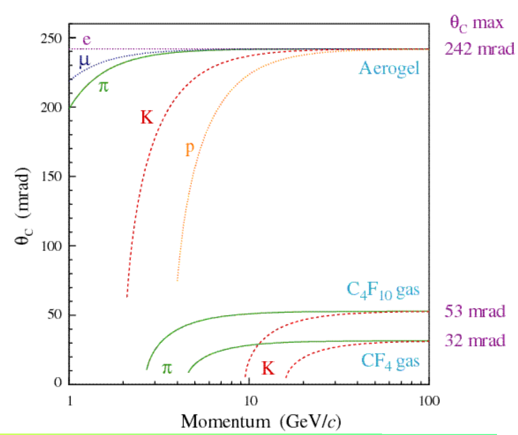
Key elements to identify pions and kaons in the momentum range $p \in [2, 100]\,\mathrm{GeV}/c$

Overview of the RICH

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

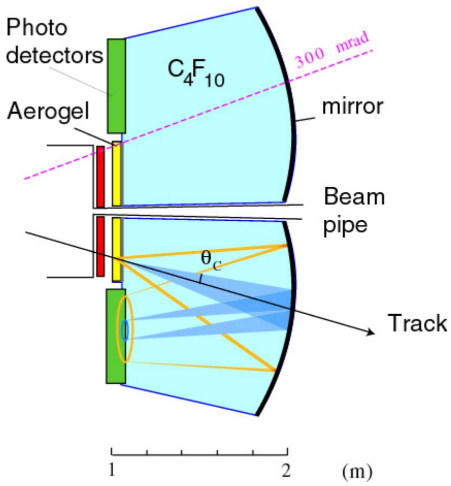
•from a few GeV (tagging kaons)

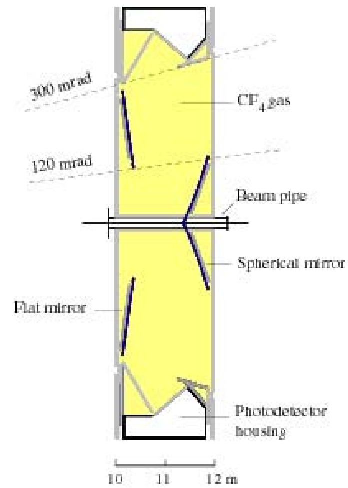
•up to 100 GeV: two body B decays



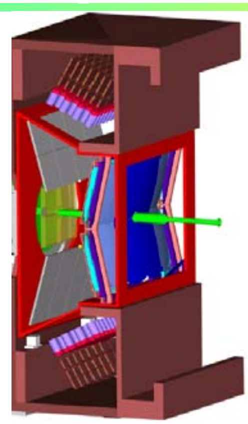
General rule: a RICH with a single radiator can cover a factor of 4-7 in momentum for 3σ from threshold to the max. p. Larger region → more radiators!

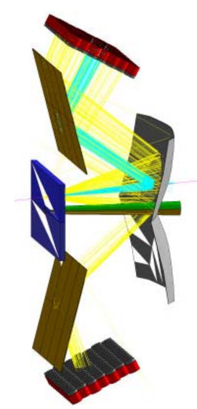
RICH with three radiators





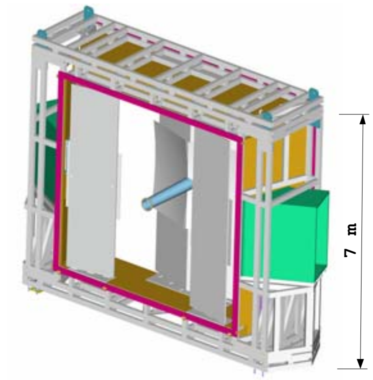
RICH1





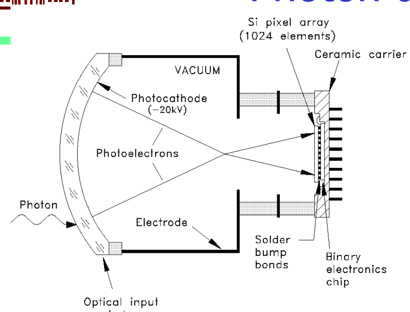
- RICH1 in production
  Installation in UX85 start end April '05

RICH2

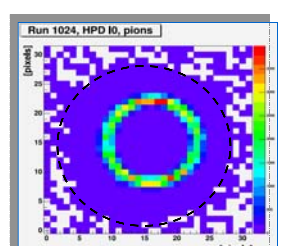


Installation in July '05

Photon detector HPD



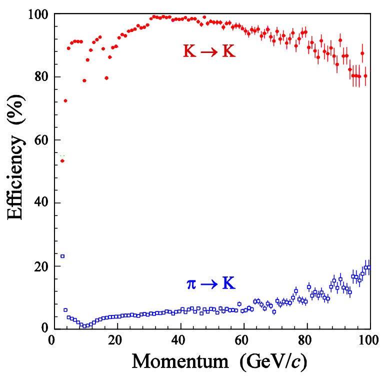
- Novel photodetector:
  - 32×32 pixel sensor array (500×500 μm²)
  - 20 kV operation voltage
  - Demagnification factor ~5

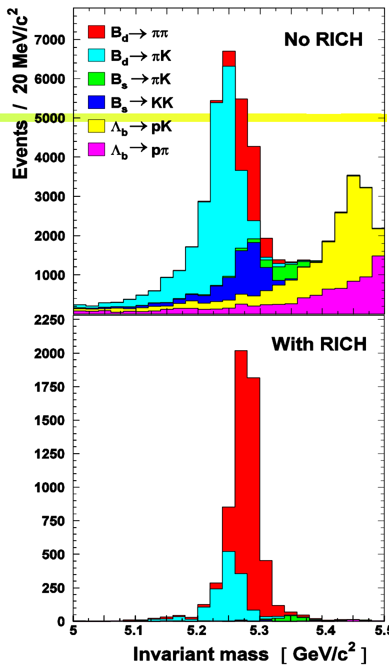


N_2 radiator

Particle Identification

Kaon identification efficiency:

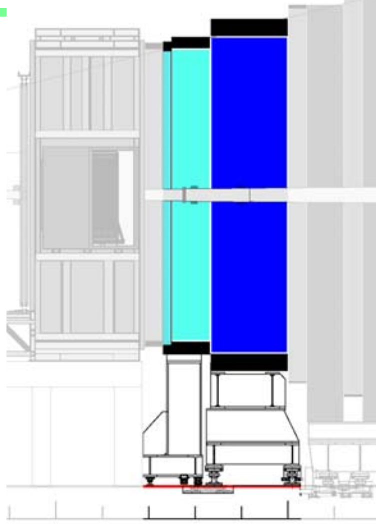




<K Efficiency>: 88%

<π misidentification> 3%

Calorimeters...



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

Used in L0 trigger.

Overview of the Calorimeters

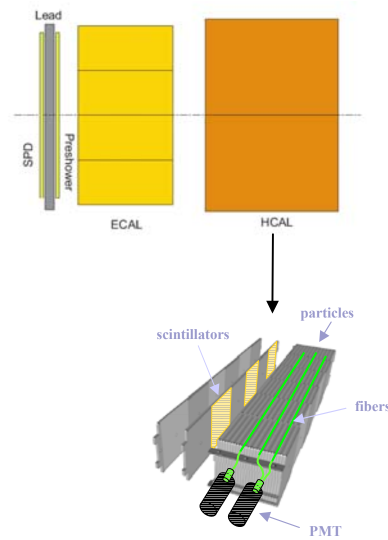
- System subdivided in 3 parts:

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

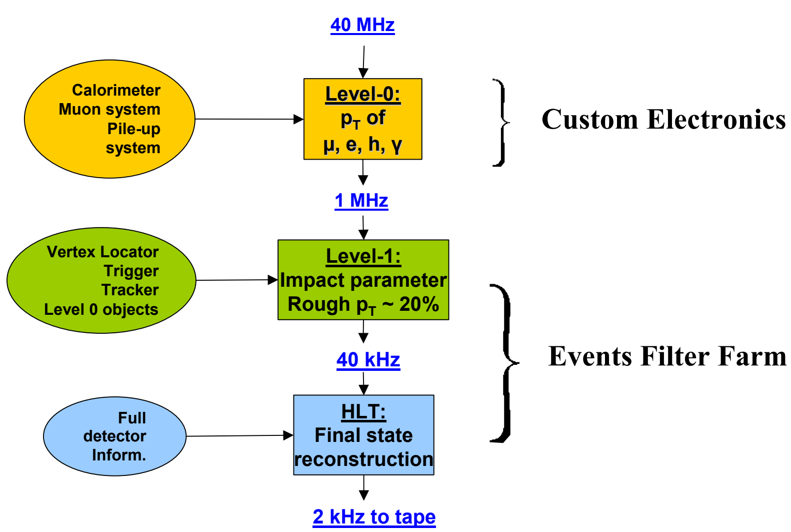
  Electromagnetic Calorimeter (ECAL):
  - Shashlik types,
  - Lead+ scintillator tiles
  - 25 X_0

- Hadronic calorimeter (HCAL):
  - Iron + scintillator tiles
  - 5.6 λ_I

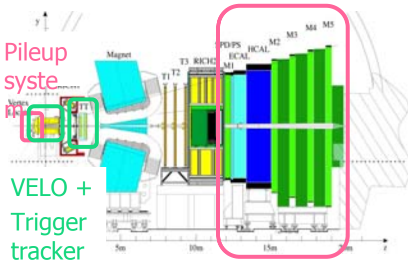
- A total of 19k channels readout by Wave Length Shifter fibres connected to PMs or MaPMTs.



Triggers...



Trigger overview



Pileup system

VELO + Trigger tracker

Calorimeters + Muon system

10 MHz

L0: hight p_T + not too busy
- Fully synchr. (40 MHz), 4μs latency
- On custom boards

1 MHz

L1: IP + high p_T
- Ave. latency: 1 ms (max 50 ms)
- Buffer: 58254 events

40 KHz

HLT + reconstruction
- Full detector: ~ 40 kb / evt

~ 200 Hz

Single PC farm ~1800 CPUs

June 5-8, 2006 Course at University of Tokyo Peter Križan, Ljubljana

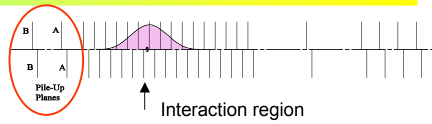
Level 0

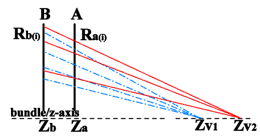
- **Fast search for 'high' p_T particles** (calorimeters, muon syst)
  - Charged **hadrons**: HCAL (~ 3 GeV)
  - Electrons, photons, π^0: ECAL (~ 3 GeV)
  - Muons: muon system (~ 1 GeV)
- **Cut on global variables:**
  - Require minimum total E_T in HCAL (calorimeters)
    - Reduces background from halo-muons
  - Rejection of multiple primary vertices and busy events (Pileup system, SPD) :
    - fake B signatures (IP)
    - Busy events spend trigger resources without being more signal-like
      - Better throw them early and use bandwidth to relax other cuts

June 5-8, 2006 Course at University of Tokyo Peter Križan, Ljubljana

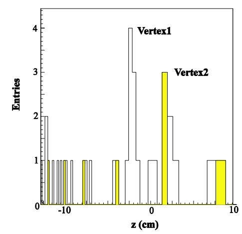
Level 0: Pile-up system

- **Pileup system:**
  - 2 silicon planes
  - Measure R coordinate
  - backwards from interaction point $\rightarrow$ no tracks from signal B





- **Trigger strategy:** veto multi-PV evts
  - From hits on two planes $\rightarrow$ produce a histogram of z on beam axis



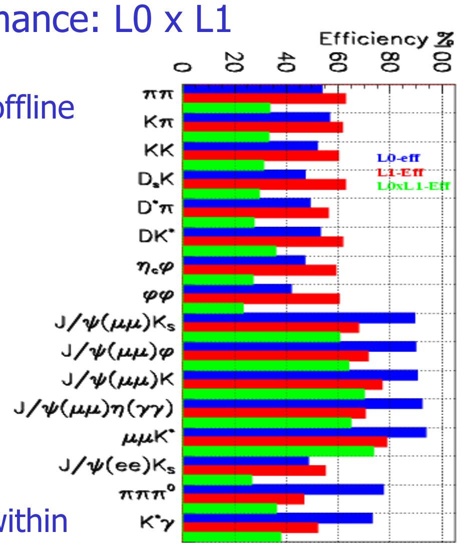
- **Sent to L0 Decision Unit:** height of two highest peaks + multiplicity

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)

Performance: L0 x L1

- Efficiencies computed on offline selected events
- Overall L0xL1 efficiency:
  - **30% for**
    - **hadronic channels**
    - **$e/\gamma/\pi^0$ channels**
  - **60-70% for di-muons**
- Software and hardware prototyped and working, within time budget
  - see Trigger TDR, Sept 2003

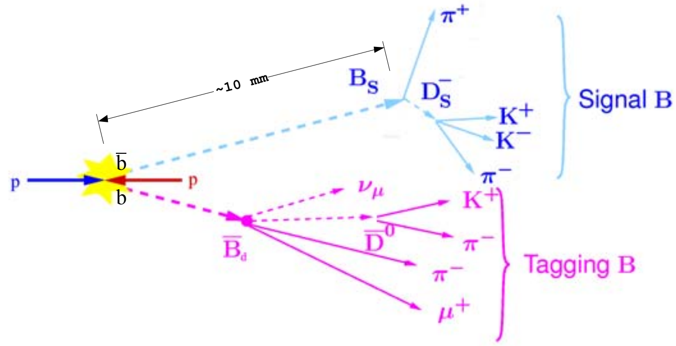


L0 efficiency
L1 efficiency
L0×L1 efficiency

LHCb physics program

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

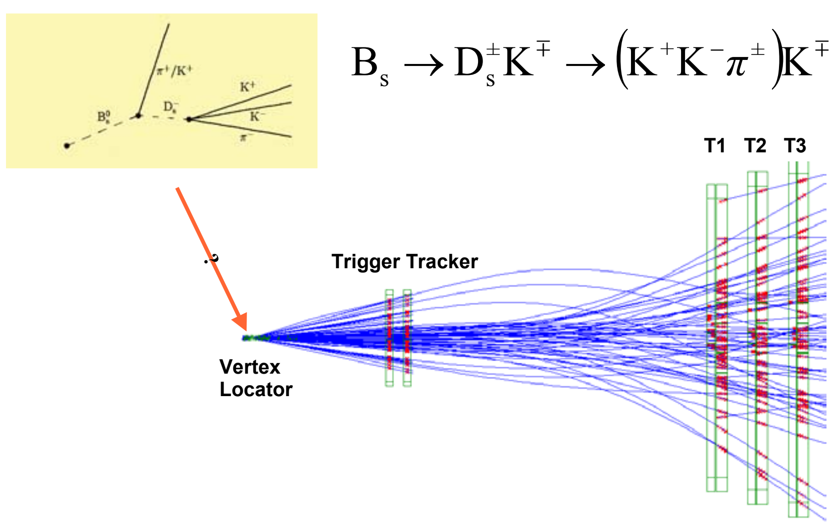
Time dependent asymmetry at LHCb



- 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)

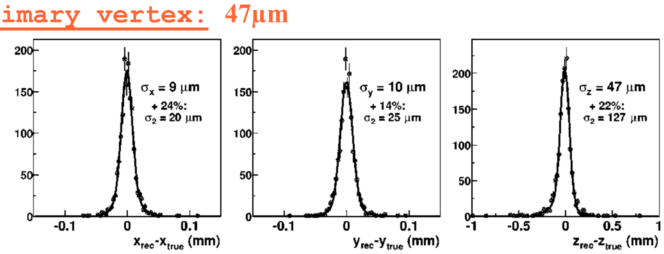
$$B_s \to D_s^{\pm} K^{\mp} \to \left(K^+ K^- \pi^{\pm}\right) K^{\mp}$$

1) Primary vertex.
2) D_s meson by using identified kaons and pions 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 $m_{B_s} \pm 50\,\mathrm{MeV}/c^2$

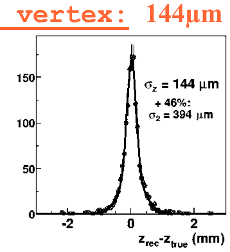
Resolution:

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

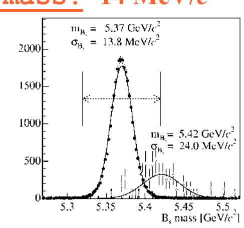
Primary vertex: 47µm



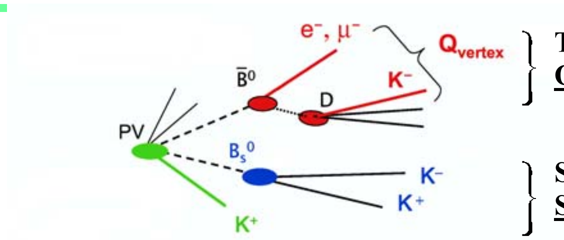
Bs vertex: 144µm



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.

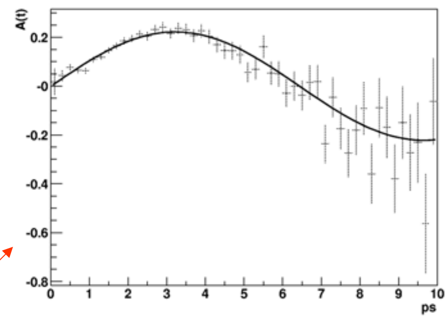
$$B_d \to J/\psi K^{*0} \text{ for } B_d \to J/\psi K_S$$

The angle β (ϕ_1) in $B_d \to J/\psi(\mu^+\mu^-)K_S(\pi^+\pi^-)$

- Decay is dominated by a tree amplitude with $Im(\lambda) = \sin 2\beta$
- 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…

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

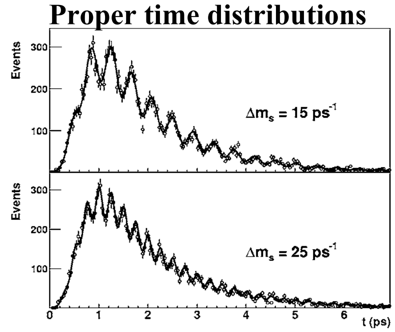
$$\Delta\Gamma_s \text{ and } \varphi_s \text{ in } B_s \to J/\psi\varphi$$

Oscillation frequency Δm_s

- Flavour-specific B decay:

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

Proper time distributions



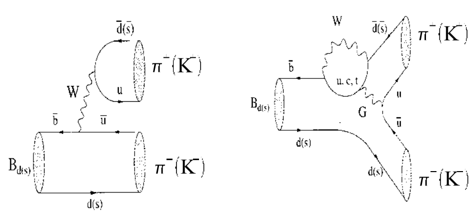
- Sensitivity for 2 fb^{-1}:

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 $B_s \to K^+K^-$

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

R. Fleischer, Phy. Lett. B 459 (1999) 306

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

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

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

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

R. Fleischer, Phy. Lett. B 459 (1999) 306

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

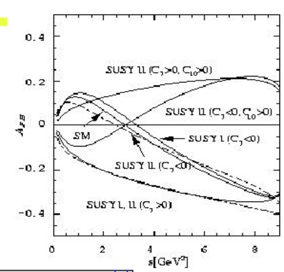
LHCb CP reach

	Channel	Yield	Precision*
β	$B_d \to J/\psi K_s$	119 k	$\sigma(\beta) \approx 0.6^o$
γ	$B_s \to D_s K$ $B_d \to \pi\pi$, $B_s \to KK$	8 k 27 k, 35 k	$\sigma(\gamma) \approx 10^o$ $\sigma(\gamma) \approx 3^o$
α	$B_d \to \pi^+\pi^-$	27 k	$\sigma(\alpha) \approx 5^o - 10^o$
$2\delta\gamma$	$B_s \to J/\psi\, \phi$	128 k	$\sigma(2\delta\gamma) \approx 2^o$
$\lvert V_{td}/V_{ts}\rvert$	$B_s \to D_s\pi$	72 k	Δm_s up to 58 ps^{-1}
rare decays	$B_d \to K^*\gamma$	20 k	

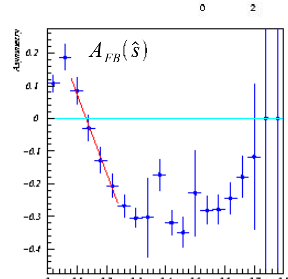
2003 status

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

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



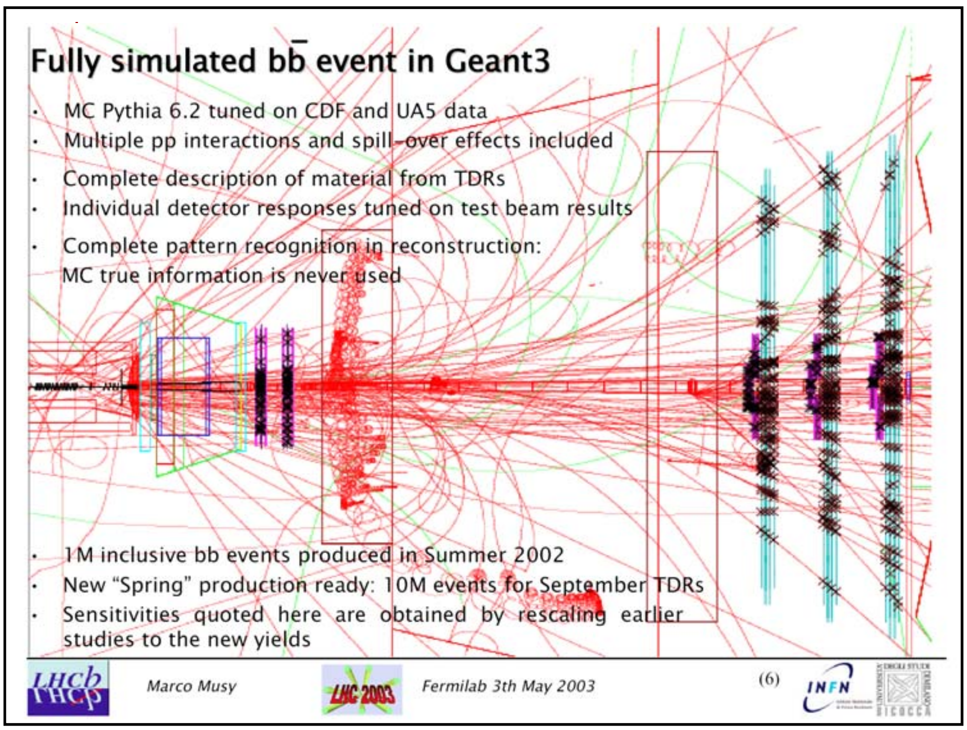
- Sensitivity for 2 fb^{-1}: zero point location to +-0.04 in $\hat{s} = (m_{\mu\mu}/m_B)^2$



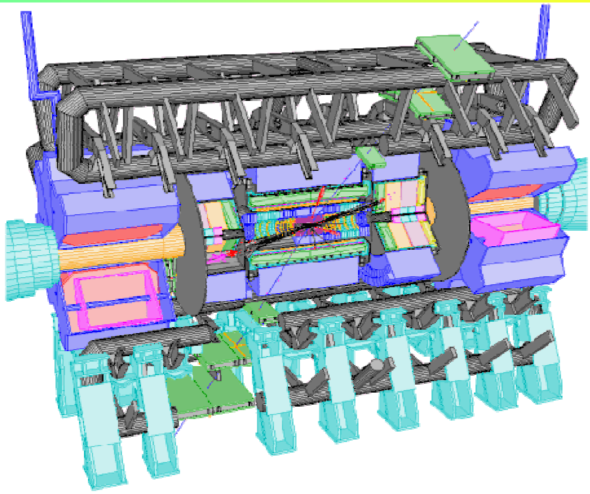
$\hat{s} = (m_{\mu\mu}/m_B)^2$

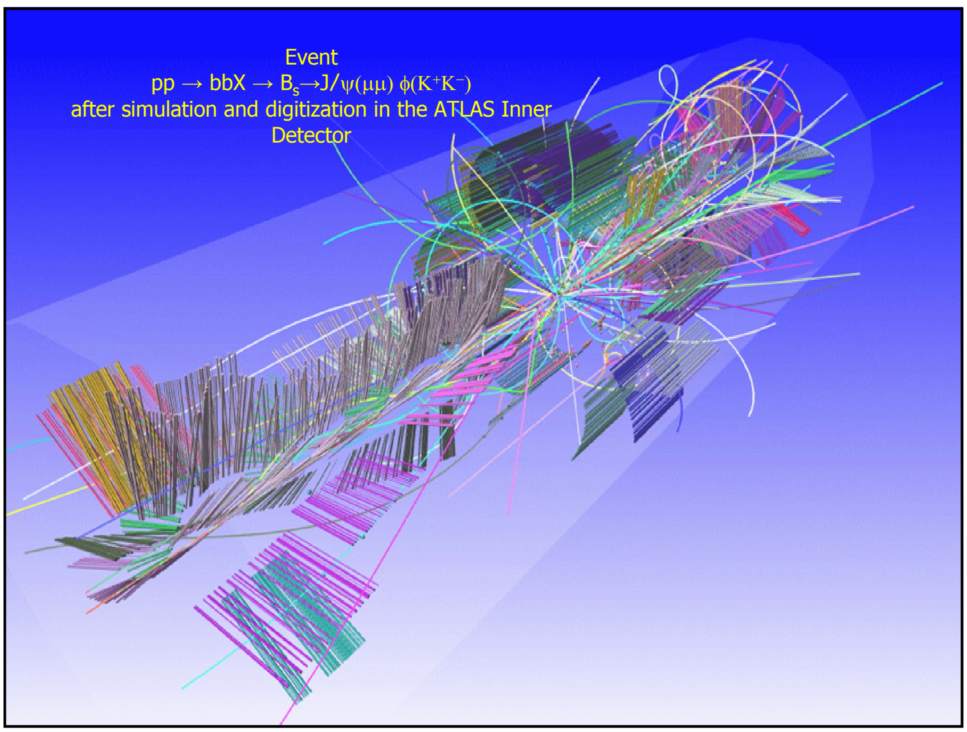
LHCb summary

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

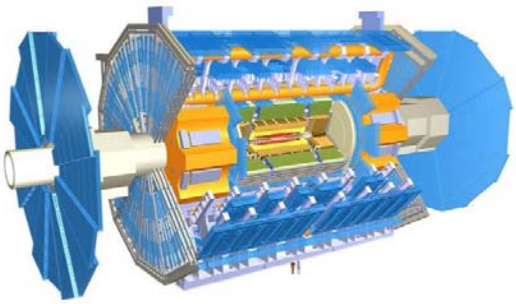


B physics at ATLAS



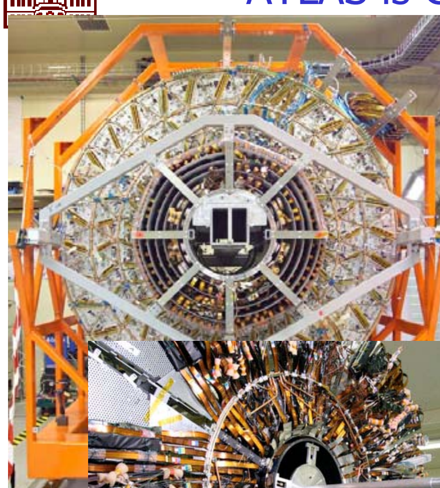


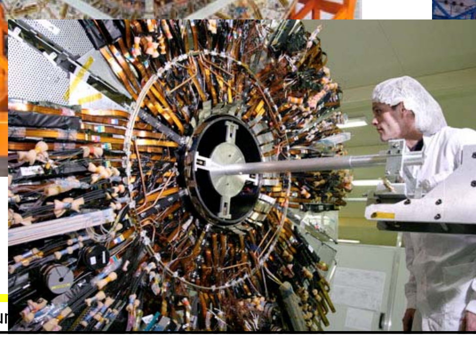
The ATLAS Detector



- Inner Detector (ID)
  - Semiconductor pixel and strip detector
  - Transition radiation tracker: straw-tubes interspersed with a radiator (e/π separation)
  - Inside solenoid of 2T magnetic field
- Calorimeter
  - Highly granular LAr EM calorimeter: $|\eta| < 3.2$
  - Hadron calorimeter: $|\eta| < 4.9$ (scintilator-tile in barrel and end-caps and forward)
- Muon spectrometer
  - Air-core toroid system on average ~ 0.5 T
  - MDTs & CSCs; RPCs & TGCs

ATLAS is Getting Ready



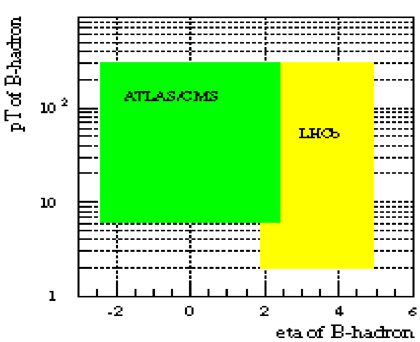


Beauty at LHC - experimental conditions

LHC pp	σ total = 100 mb σ inelastic = 80 mb σ bb = 500 μb	
	ATLAS/CMS Central detectors	LHCb Forward detector
$\eta - p_T$ one B-hadron 'in'	$\lvert\eta\rvert < 2.5$ $p_T > 10$ GeV $\sigma = 100\ \mu$b	$1.9 < \eta < 4.9$ $p_T > 2$ GeV $\sigma = 230\ \mu$b
Luminosity for B physics	$L = 2 \times 10^{33}$ cm^{-2} s^{-1} rare B 10^{34} cm^{-2} s^{-1}	$L = 2 \times 10^{32}$ cm^{-2} s^{-1}
Statistics exclusive B	1 y @ 10^{33} cm^{-2} s^{-1} 2.6×10^6 dominated by $B \to J/\psi(\mu\mu)$	1 y @ 2×10^{32} cm^{-2} s^{-1} 1.7×10^6 $B \to J/\psi$ 1.7×10^6 hadronic

LHC p-p experiments : kinematics for b-events

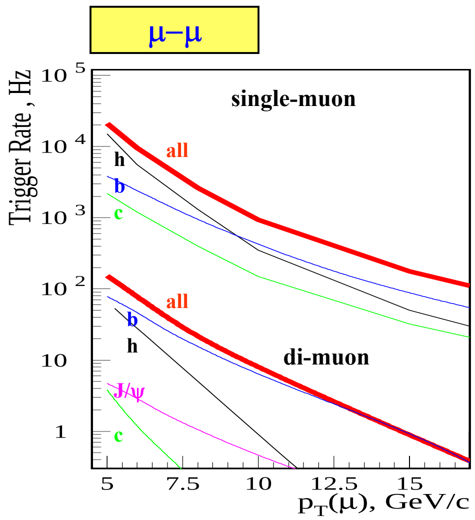
p_T- η range of B-hadrons after trigger and off-line reconstruction



Common parts of phase space: opportunity for normalization checks in absolute Beauty cross-section measurement at LHC.

η: pseudorapidity = -ln tan $\theta/2$

B-physics trigger strategies



- Di-muon triggers are most favorable – they reduce background contribution as well as rate.
- Muon – EM/jet trigger gives almost no reduction in rate. However it will serve to guide LVL2 search for B-jet or electron/gamma.

ATLAS B-physics trigger strategies

- **Flexible B trigger strategies, according to luminosity conditions:**
  - **At luminosity few times 10^{33} cm^{-2}s^{-1}**
    - **μ (p_T>6GeV) + μ(5GeV)** $B_s \to J/\psi\ \phi$, $B_d \to K^{0*}\mu\mu$, $B \to \mu\mu$
    - **μ (p_T>6GeV) + e/γ (E_T>6GeV)** $B_d \to K^{0*}\gamma$ $B_s \to \phi\gamma$ $B \to \mu\mu\gamma$
    - **μ (p_T>6GeV) + Jet (E_T>10GeV)** $B_s \to D_s\ \pi$
  - **At nominal luminosity 10^{34} cm^{-2}s^{-1}**
    - **2μ (p_T > 6 GeV)** $B \to \mu\mu$
  - **At low luminosity (end of spill) < ~10^{33} cm^{-2}s^{-1}**
    - **single μ (p_T > 6-8 GeV) leaving further selections for High Level triggers.**
- **Objects identified at LVL1 are further analysed at High-level triggers using full detector granularity. Inner detector is involved.**
- **B-events written to permanent storage → 10^8/year all passed criteria for specific exclusive B-decays modes.**

ATLAS sensitivity in B_s tree-level dominated decay channels with possible signatures BSM

Proper-time resolution for $B_s \to D_s \pi$: 89 fs

		Number of events after trigger + offline reconstruction 3y@$10^{33}cm^{-2}s^{-1}$		Models used in MC or to confront experimental sensitivities.
		Signal	Backgr	
$B_s \to J/\psi\,\phi$ $B_s \to J/\psi\,\eta$	$\phi_s\, \Delta\Gamma_s$,	300k 9000	30% <100%	SM: Fleisher CERN-TH-2000-101 NP: Ball,Khalil, Phys.Rev.D69:115011 ,2004
$B_s \to D_s\,\pi$ $B_s \to D_s a_1$	ΔM_s	6750 3620	<100% <100%	NP: Ball,Khalil, Phys.Rev.D69:115011 ,2004

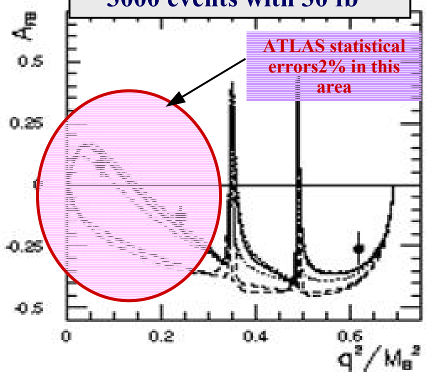
Semi-muonic exclusive rare B-decays in ATLAS

BR used in the MC			Signature after trigger +offline reconstruction 3y@$10^{33}cm^{-2}s^{-1}$		Models used in MC or to confront experimental sensitivities.
			Signal	Backgr	
1.3 10^{-6} 1.0 10^{-7} 1.0 10^{-6}	$B_d \to K^{0*}\mu\mu$ $B_d \to \rho\,\mu\mu$ $B_s \to \phi\,\mu\mu$	Br.frac. $\mu\mu$-mass A_{FB}	3000 300 900	<3000 1000 <3000	Melikhov, Nikitin, Simula, PRD57,98; Melikhov, Stech, PRD62, 2000 WC: SM Buras, Munz, PRD52, 95; MSSM Cho, Misiak,Wyller, PRD54,96.
2.0 10^{-6}	$\Lambda_b \to \Lambda\mu\mu$		1500		NP: Chen, Geng, PRD64,2001 Aliev NPB649,2003

Sensitivity to New Physics in $B_d \rightarrow \mu\mu K^{0*}$

$B \rightarrow K^{0*}\mu\mu$

3000 events with 30 fb^{-1}



— SM

- - MSSM C_{7geff}>0

······· MSSM C_{7geff}<0

A_{FB} (muon asymmetry) plotted versus $\mu\mu$–mass$^2/M_B^2$

In low values of di-muon masses

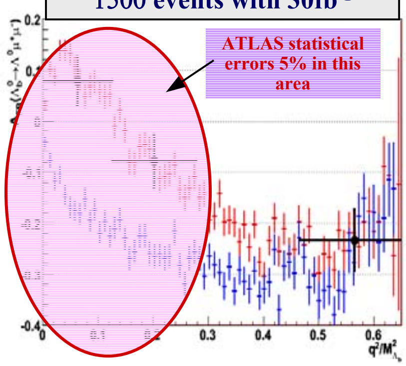
ATLAS can after 3 years @$10^{33}cm^{-2}s^{-1}$ = 30 fb^{-1} distinguish

MSSM C_{7geff}>0 from SM

Sensitivity to New Physics in $\Lambda_b \rightarrow \Lambda\mu\mu$

$\Lambda_b \rightarrow \Lambda\ \mu\mu$

1500 events with 30fb^{-1}



ATLAS statistics errors corresponding to 1500 events – expected after 3 years

ATLAS MC events generated with SM after trigger and reconstruction analysis

ATLAS MC events generated with MSSM C_{7geff}>0 after trigger and reconstruction analysis

ATLAS can already after 3 years @$10^{33}cm^{-2}s^{-1}$ = 30 fb^{-1} distinguish MSSM C_{7geff}>0 from SM in low values of di-muon mass

ATLAS sensitivity in Br($B^0_s \to \mu^+\mu^-$)

Integral LHC Luminosity	Expected Signal events after cuts	Expected BG events after cuts	ATLAS upper limit at 90% CL	CDF best upper limit at 95% CL
100 pb^{-1}	**~ 0**	**~ 0.2**	**6.4×10^{-8}**	**$1.\times10^{-7}$ 780 pb-1**
10 fb^{-1}	**~ 7**	**~ 20**	**7.0×10^{-9}**	
30 fb^{-1}	**~ 21**	**~ 60**	**6.6×10^{-9}**	

Full trigger and detector TDR study was made also for luminosity **$10^{34}cm^{-2}s^{-1}$** It proved that

- the **B** $\to \mu\mu$ program can be continued at nominal LHC luminosity.
- already after 1 year a signal of 92 $B_s \to \mu\mu$ events can be extracted over background of 900 events and a limit **3. 10^{-10} can be posed on $B_d \to \mu\mu$**

The study continues for Final detector layout. Values in table given for **$10^{33}cm^{-2}s^{-1}$ are already for Final detector.**

ATLAS summary

- ATLAS preparations for B channels potentially sensitive to New Physics are in progress both at trigger and off line.
- $B_s \to J/\psi\phi$: potential to reach NP values of weak phase ϕ_s, precision will depend on value of x_s. Rate $\Delta\Gamma_s$ will be measured in the same analysis with precision of 13%. Strong phases cannot be decoupled.
- Semi-muonic rare decays of all B-mesons species B_d, B_s Λ_b are under preparation and will allow to distinguish between SM and certain classes of MSSM.
- ATLAS can collect 10000 $B \to K^{0*}\gamma$ and 3400 $B_s \to \rho\gamma$ events in 3 years.
- In 3 years of $10^{33}cm^{-2}s^{-1}$ ATLAS can observe $B_s \to \mu\mu$ with stat. significance of 3.
- After 1 year of nominal LHC luminosity $10^{34}cm^{-2}s^{-1}$ ATLAS can achieve a limit of 3. 10^{-10} on branching fraction of $B_d \to \mu\mu$ with 95%CL.