B physics perspectives with the ATLAS detector

- Rates
- Detector and Trigger
- Detector Performance
- $B_s^0 \bar{B}_s^0$ mixing
- Rare decays
- For CP violation, see talk of D. Rousseau, this conference.

B physics topics

At low luminosity (planned for first 3 years), expect 10^{12} produced events $\mathrm{b\bar{b}}$ produced per year

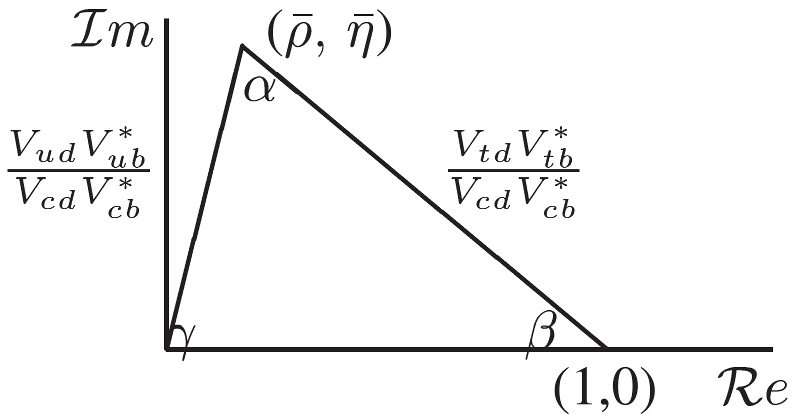
- CP violation through measurements of decay asymmetry (see talk of D Rousseau, this conference).
- CKM element (V_{td}, V_{ts}) determination: $\mathrm{B}_s^0\bar{\mathrm{B}}_s^0$ mixing and rare decays: Unitarity triangle from CP conserving processes.
- Searches for new physics through decay rates and angular distributions of rare decays.

$$\begin{pmatrix} ud^* & cd^* & td^* \\ us^* & cs^* & ts^* \\ ub^* & cb^* & tb^* \end{pmatrix} \begin{pmatrix} ud & us & ub \\ cd & cs & cb \\ td & ts & tb \end{pmatrix} = I$$

$$V_{ud}V_{ub}^* + V_{cd}V_{cb}^* + V_{td}V_{tb}^* = 0$$

$$\begin{pmatrix} 1-\frac{\lambda^2}{2} & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{\lambda^2}{2} & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

$$\lambda \approx 0.22$$



$\underline{V_{td} \text{ and } V_{ts}}$

V_{td} = A$\lambda^3(1-\rho-i\eta)$; V_{ts} = -Aλ^2 (UT relevance?)

V_{td}: $B^0_d\bar{B}^0_d$ mixing, B^0_d decays

V_{ts}: $B^0_s\bar{B}^0_s$ mixing, B^0_s decays.

Ratio removes common theoretical and experimental uncertainties.

eg:

$$\delta m_s = \frac{G_F^2}{6\pi^2}\eta_B m_{B_q} F^2_{B_q} M^2_W S_0(x_t)|V_{tq}|$$

$$\left|\frac{V_{td}}{V_{ts}}\right| = \frac{\delta m_d}{\delta m_s}\frac{F_{B_s}\sqrt{B_{B_s}}}{F_{B_d}\sqrt{B_{B_d}}}$$

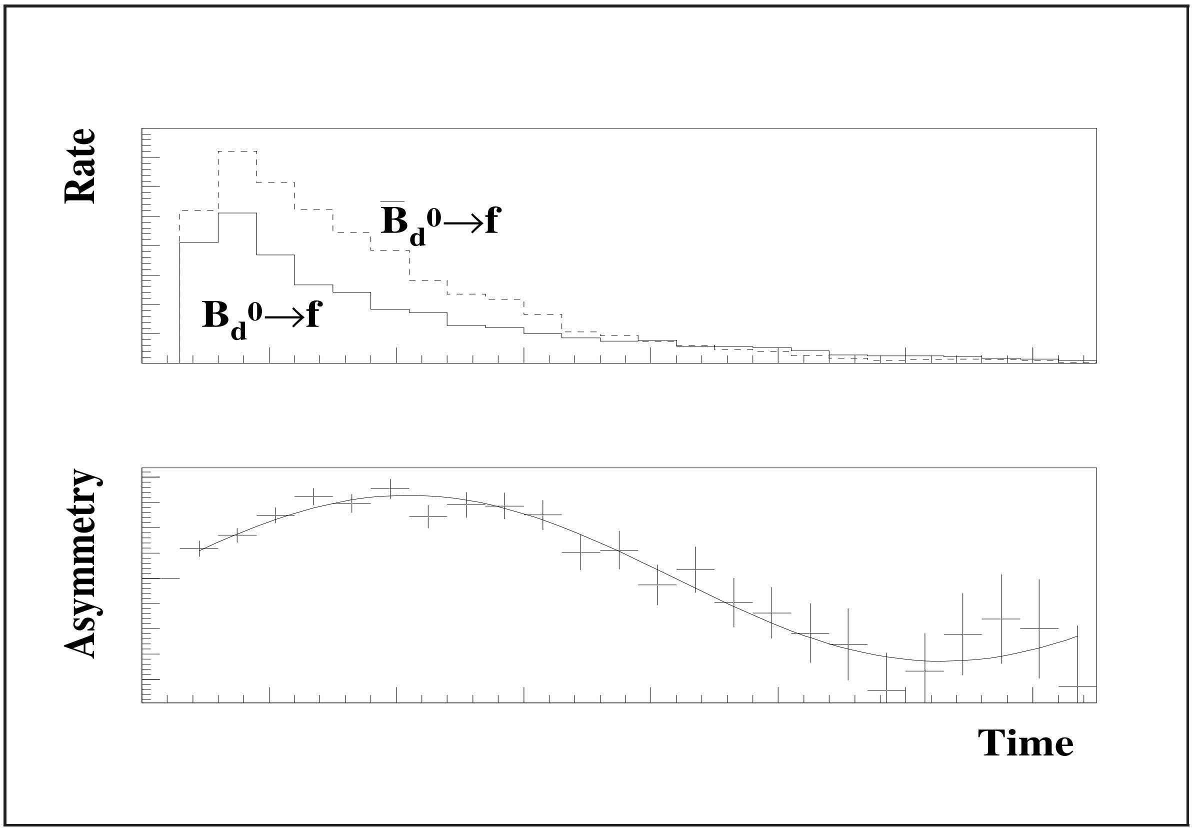
$$\frac{F_{B_s}\sqrt{B_{B_s}}}{F_{B_d}\sqrt{B_{B_d}}} = 1.15 \pm 0.05$$

(from QCD lattice calculations)

UT angles from Asymmetries

For $B^0 \to$CP e-state, $\overline{B}^0 \to$CP e-state

$$a(t) = \frac{\Gamma(B^0 \to \text{CP e-state;}t) - \Gamma(\overline{B}^0 \to \text{CP e-state;}t)}{\Gamma(B^0 \to \text{CP e-state;}t) + \Gamma(\overline{B}^0 \to \text{CP e-state;}t)}$$



$B_d^0 \to \psi K_s$: dominated by single amplitude:

$$\boxed{a(t) = \sin 2\beta \sin \delta m_d t}$$

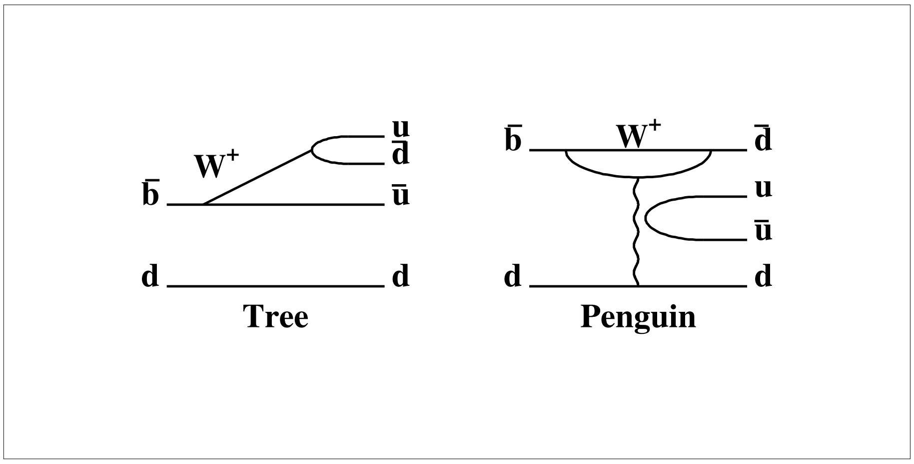
UT fits: $16^\circ \leq \beta \leq 26^\circ$

$B_d^0 \to \pi^+\pi^-$

Tree + Penguin amplitudes:

$$
\begin{aligned}
a(t) &= -2P\sin\delta\sin\alpha\cos\delta m t \\
&+ (\sin 2\alpha + 2P\cos\delta\cos 2\alpha\sin\alpha)\sin\delta m t
\end{aligned}
$$

UT fits: $77^\circ - 110^\circ$

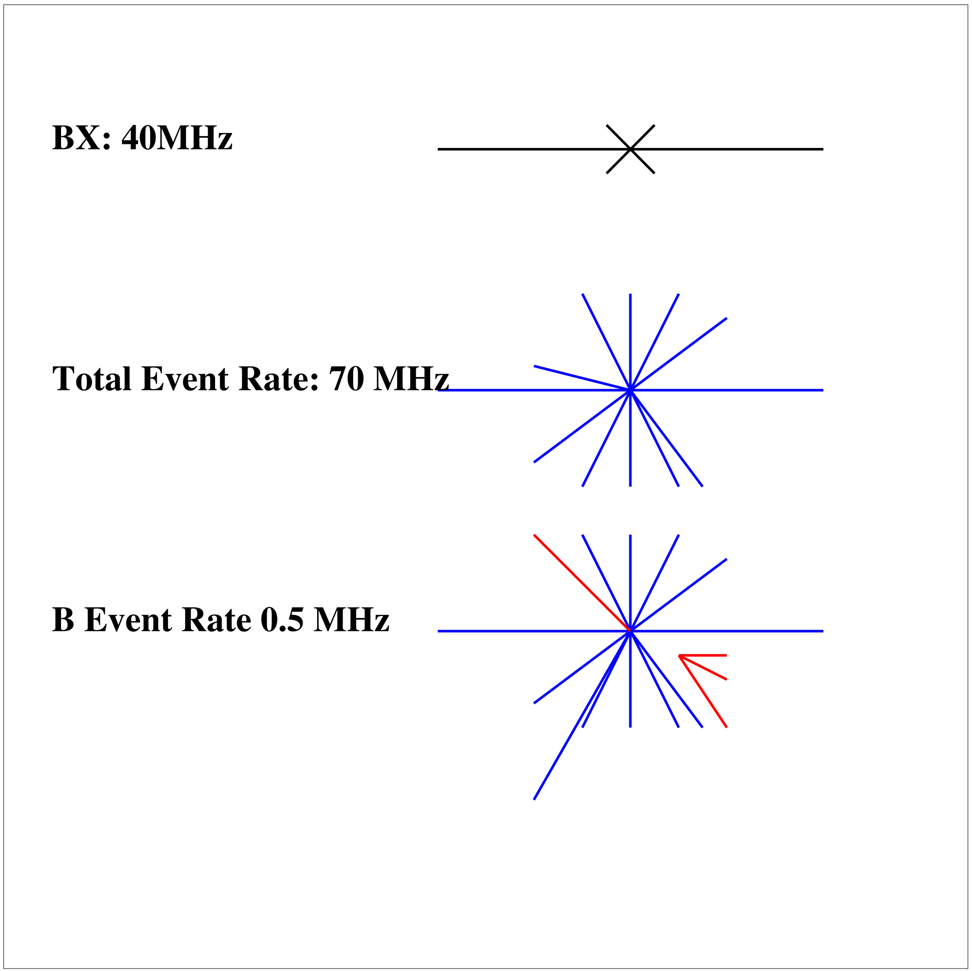


Penguin presence (measure from $B^+ \to K^0\pi^+$, $B^+ \to \pi^+\pi^0$, transform to $B_d^0 \to \pi^+\pi^-$ using SU3 + corrections to SU3 symmetry breaking (Fleischer,Mannel hep-ph 9610357))

Large asymmetries possible in dominant background $B_d^0 \to K^+\pi^-$ (Fleischer hep-ph 9802433)

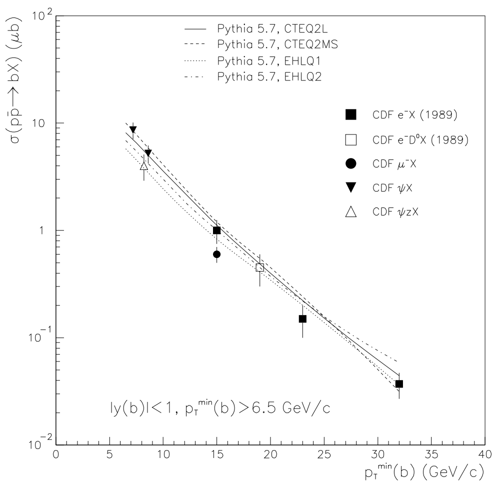
Setting the Scene: some rates

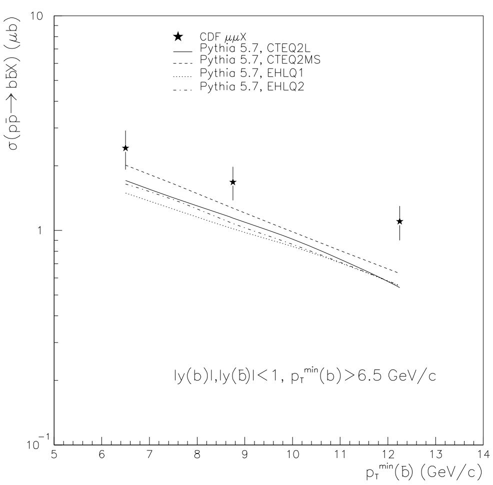
- Expected Luminosity in first 3 years
  $10^{33} \mathrm{cm}^{-2}\mathrm{s}^{-1}$ (=10^6 mb^{-1}Hz)
- $\sigma_{\mathrm{pp}\to X} = 70$ mb; $\sigma_{\mathrm{pp}\to\mathrm{b\bar{b}}} = 0.5$ mb
- pile up: ≈ 2.3 min bias on top of 'interesting' events



Checks on rate predictions

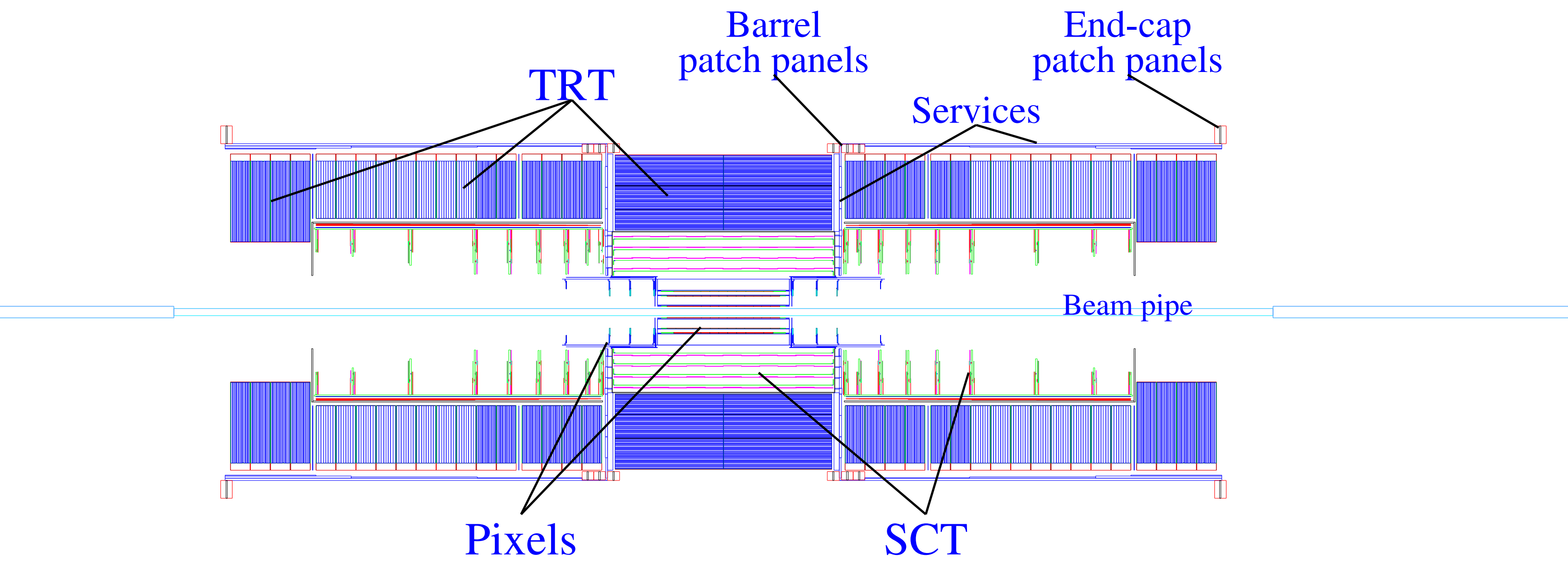
- Physics Simulations: Pythia 5.7, Jetset 7.4; Detector Simulation: Geant 3.2
- Flavor creation (q$\bar{\text{q}}$, gg$\rightarrow$ b$\bar{\text{b}}$),Flavor excitation (bg$\rightarrow$bg), gluon splitting in parton shower (g$\rightarrow$ b$\bar{\text{b}}$)
- p$\overline{\text{p}}$ $\rightarrow$bX $\sqrt{s}$=1.8 TeV,η p_t cuts on single b, agrees with Tevatron data.
- Discrepancy when cuts applied both b quarks
- QCD NLO calculations underestimate rates.





Detection Requirements for B Physics

- Vertex reconstruction : for background separation, and proper time measurements ($B_s^0\bar{B}_s^0$ oscillations)
- Good mass reconstruction (separation of different B mesons, background rejection)
- Particle identification (triggering, tagging, ($\psi \to e^+e^-$, $\psi \to \mu^+\mu^-$ decays...)
- V^0 Reconstruction (decays with K^0, Λ^0 in the final state, eg $B_d^0 \to \psi K_s$)


Barrel
patch panels
End-cap
patch panels
TRT
Services
Beam pipe
Pixels
SCT

Inner Detector

- Outer Radius = 115 cm, total length 700 cm. Barrel region ± 80 cm. Limited by EM calorimeter cryostat.
- Tracking for $|\eta| \leq 2.5$
- 7 high precision points/track from pixel and silicon strips within radius 56 cm of beam (R-ϕ-z).
- 36 points/track from straw detectors in transition radiation tracker (TRT). R-ϕ only. (lower cost, less material)
- 2T solenoidal field.

Pixel Detector

- Of particular use for b, τ vertex detection
- 3 barrel layers at 4, 11, and 14 cm, 4 disks/endcap
- 140×10^6 channels
- Replaceable innermost layer lifetime of a few years (radiation damage)
- $\sigma_{R\phi}$ = 12 μm, σ_z = 66 μm.

Silicon Strips

- 4 precision points/track. Contribute to p, d_0 and vertex measurements
- Barrel detectors at 20, 37, 45 and 52 cm.
- z from small angle stereo.
- 6.2×10^6 channels

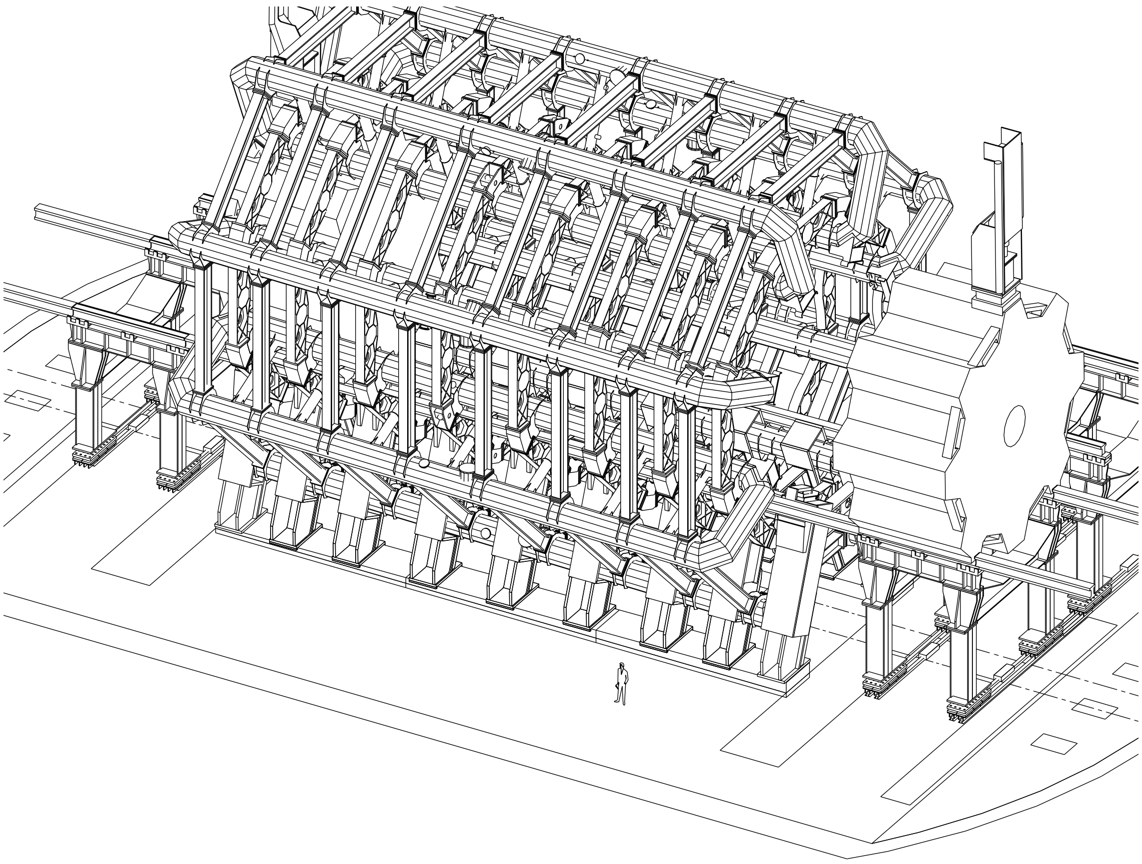
- $\sigma_{R\phi}$ = 16, σ_z = 580 μm.
- Two-track resolution $\sigma = 200\mu$m.

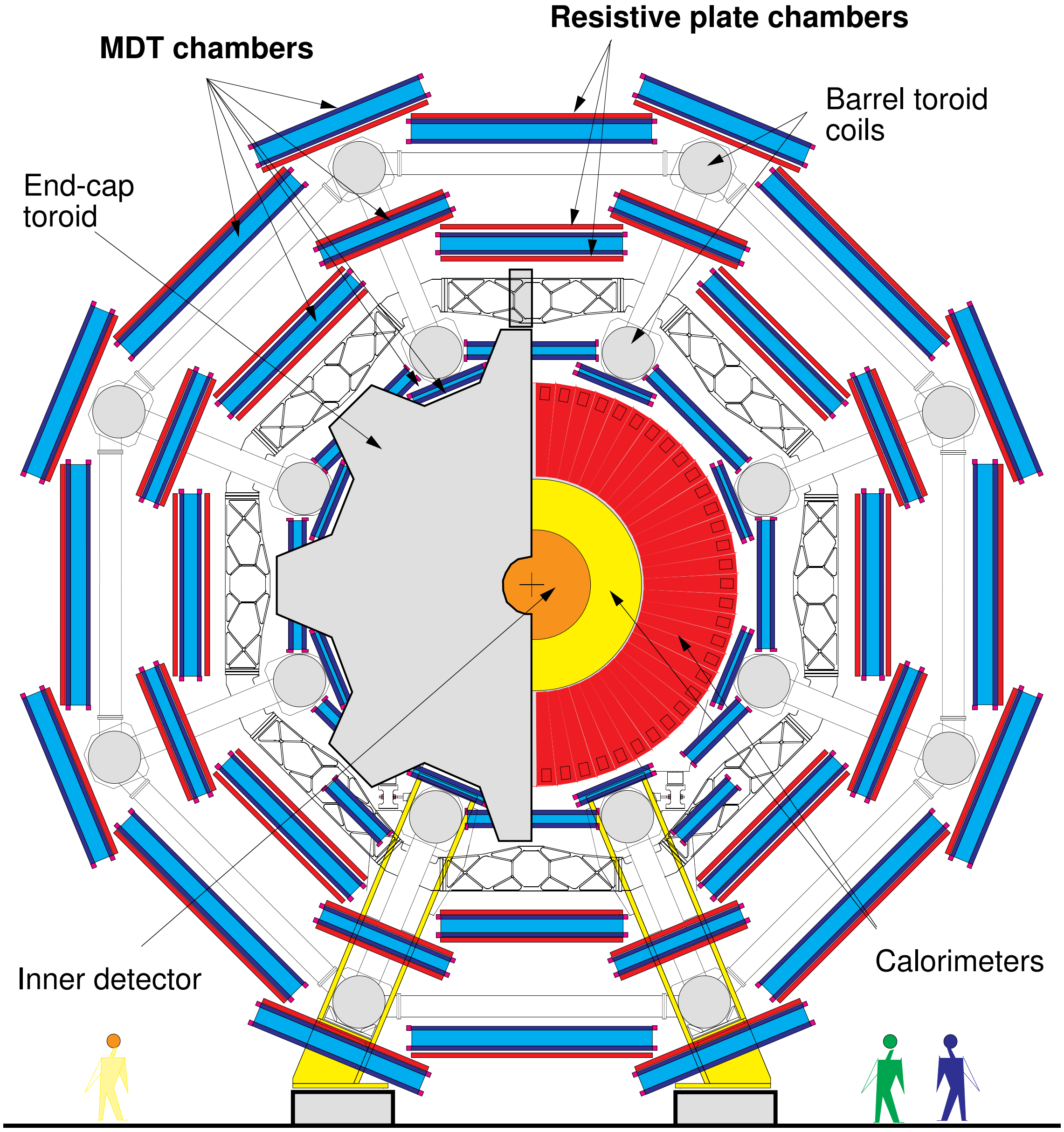
Transition Radiation Detector

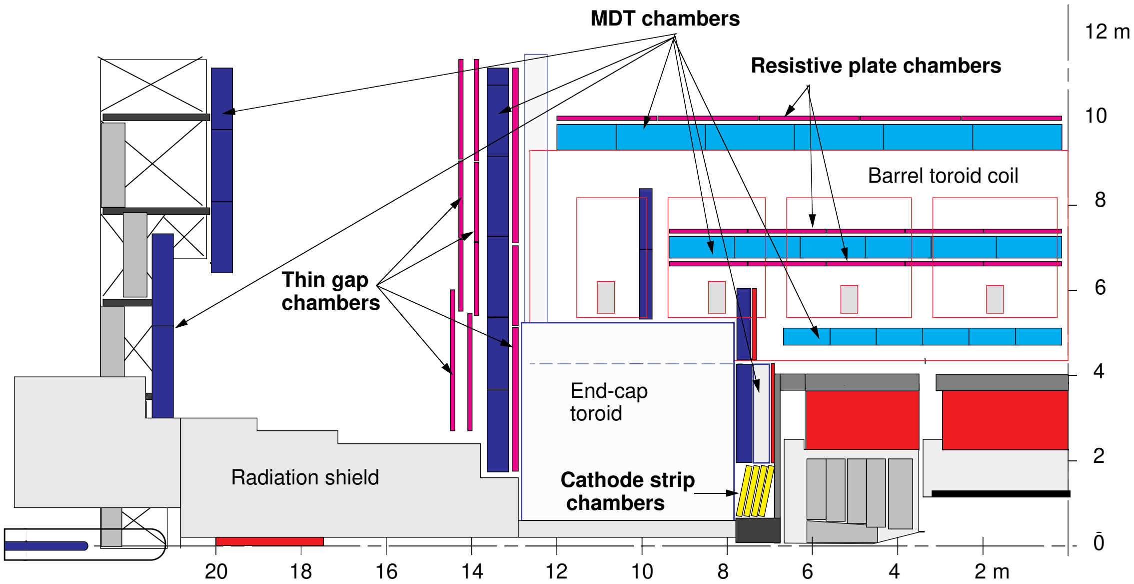
- information in r-ϕ plane only
- 50 000 tubes, length $\rightarrow$ 150 cm, radius 4mm.
- drift time gives spatial resolution 170 μm. 36 hits/track $\equiv$ single hit resolution 50μm.
- maximum drift time 40 ns (cf 25 ns between beam crossing): high occupancy
- xenon in tubes detects transition radiation γ from intertube radiator
- two signal threshold to allow hadron/electron separation
- hadron rejection 15-200 (η – dependent)

Muon Spectrometer

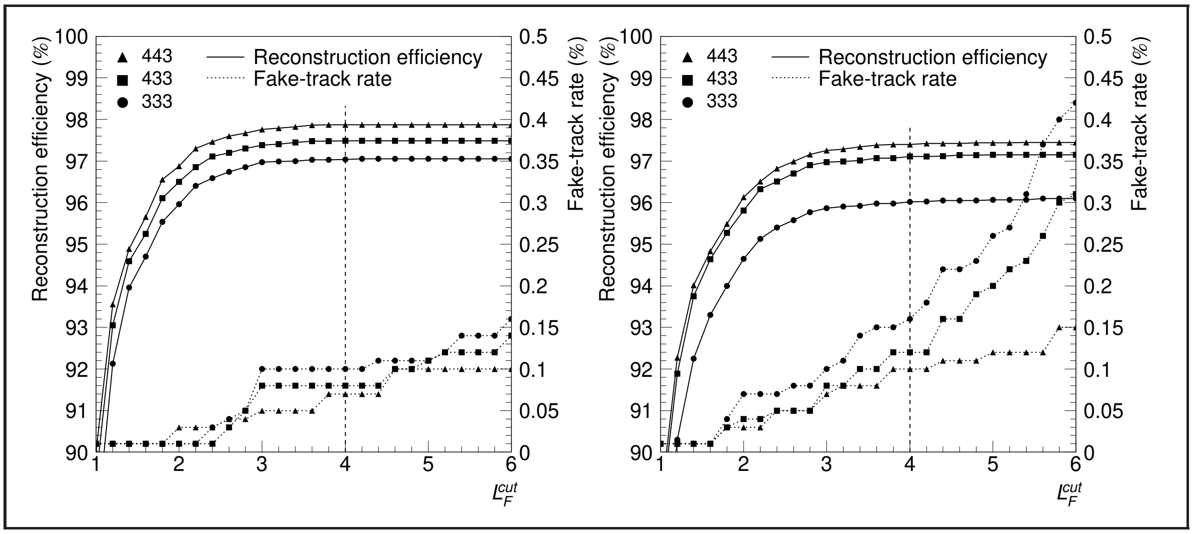
- Barrel Torroids
  - Length 25m $\times$ (9.4m$\times$20.1m)
  - $|\eta| \leq 1$
  - $\int B \cdot \ell$ = 2.5 Tm
- End Cap Toroids
  - length 5m $\times$ (1.7m$\times$10.7m)
  - 1.4$\leq |\eta| \leq 2.7$
  - $\int B \cdot \ell$ = 6 Tm
- Momentum cut-off 3 GeV
- Trigger and Precision chambers




Resistive plate chambers
MDT chambers
Barrel toroid coils
End-cap toroid
Inner detector
Calorimeters

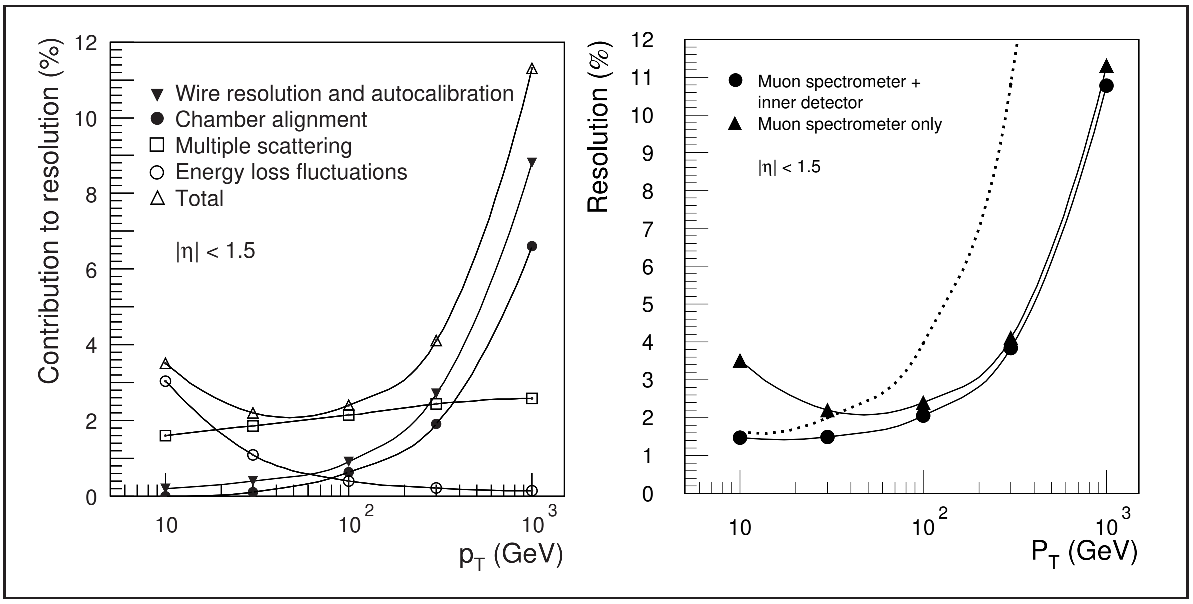

MDT chambers
Resistive plate chambers
Barrel toroid coil
Thin gap
chambers
End-cap
toroid
Radiation shield
Cathode strip
chambers
12 m
10
8
6
4
2
0
20
18
16
14
12
10
8
6
4
2 m

μ spectrometer: efficiency and fake rate



10% occupancy inner station

30% occupancy inner station

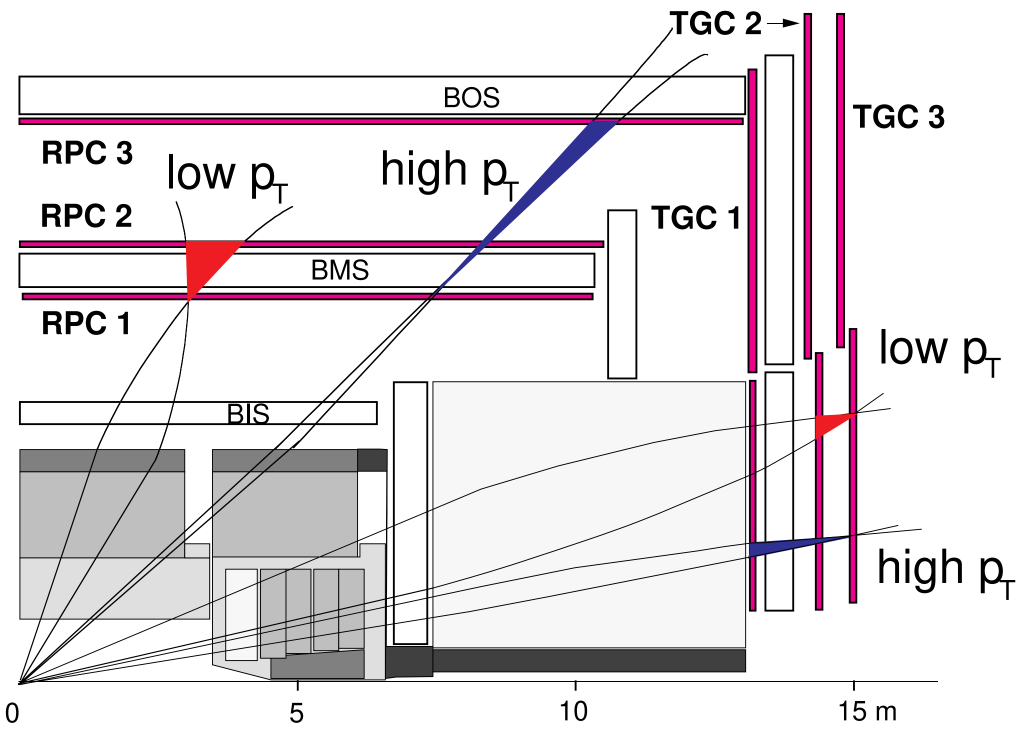


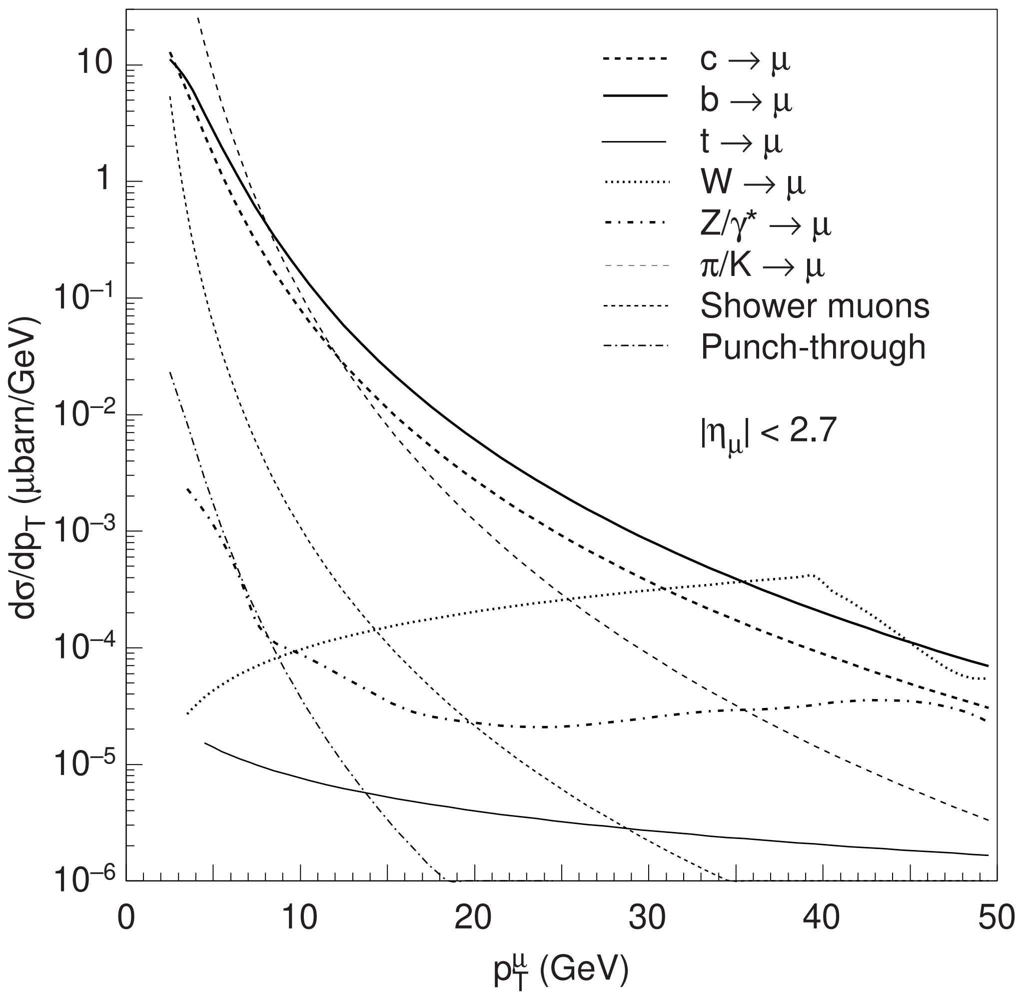
μ spect. alone σ_{p_t}

μ spect. + ID σ_{p_t}

L1 Trigger

Simple algorithms, programmable electronics, 2μs decision time μ with $p_t > 6$ GeV, $|\eta| < 2.4$





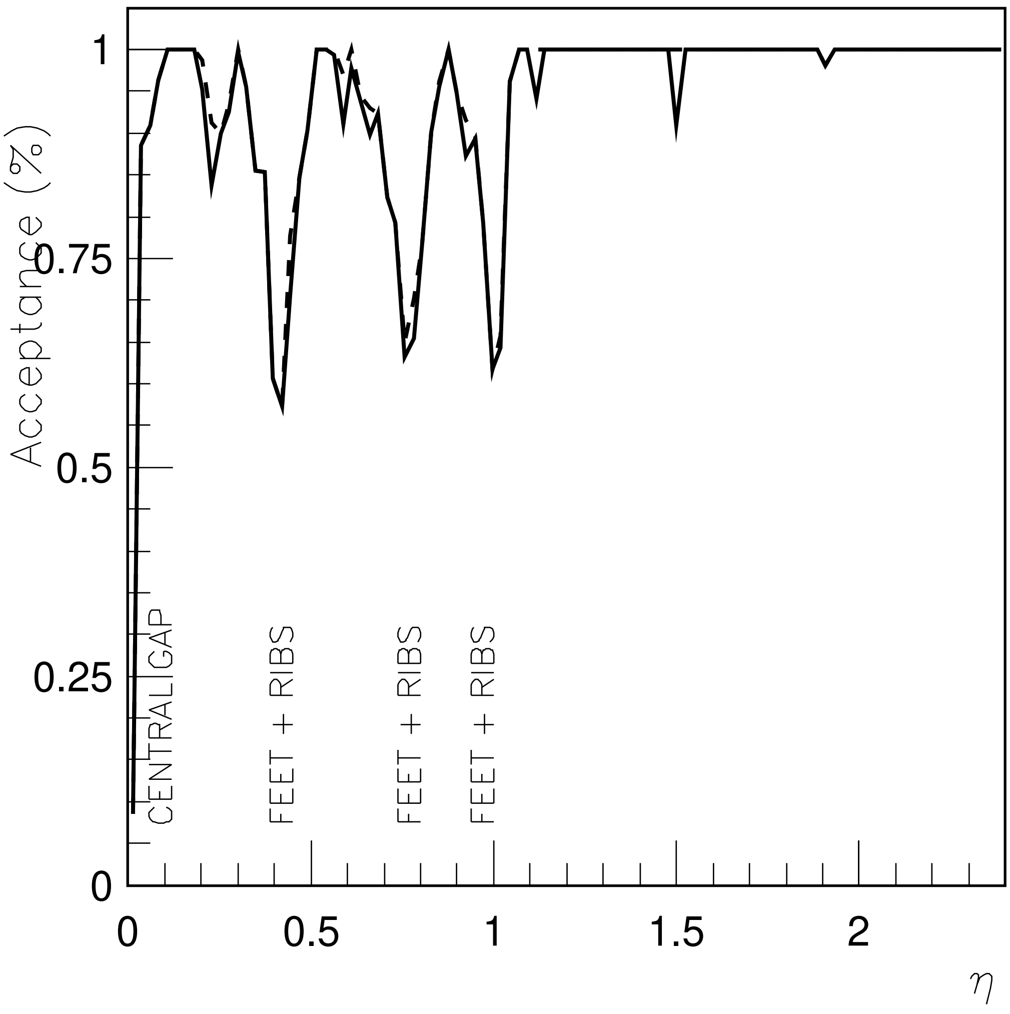
$c \to \mu$
$b \to \mu$
$t \to \mu$
$W \to \mu$
$Z/\gamma^* \to \mu$
$\pi/K \to \mu$
Shower muons
Punch-through
$|\eta_\mu| < 2.7$
$d\sigma/dp_T$ (μbarn/GeV)
p_T^μ (GeV)
10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
0
10
20
30
40
50

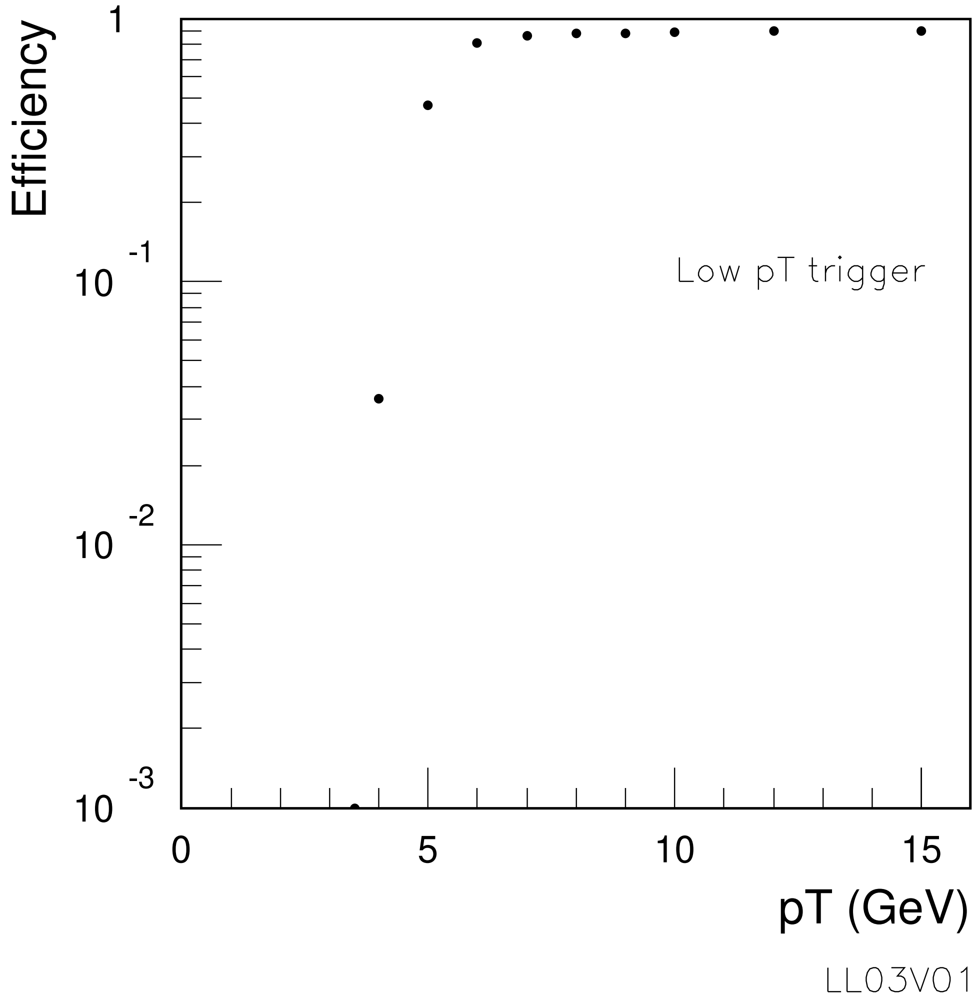
$\sigma(\mathrm{pp} \rightarrow \mathrm{b\bar{b}}) = 2.25\mu\mathrm{b}$ with these $\eta,\ p_t$ cuts

40MHz(BX) $\rightarrow$ 23KHz

- π/K decays: 16.8 KHz
- W,Z decays: 0.02 KHz
- c$\rightarrow$ μ: 2.4 KHz
- b$\rightarrow$ μ: 4.0 KHz

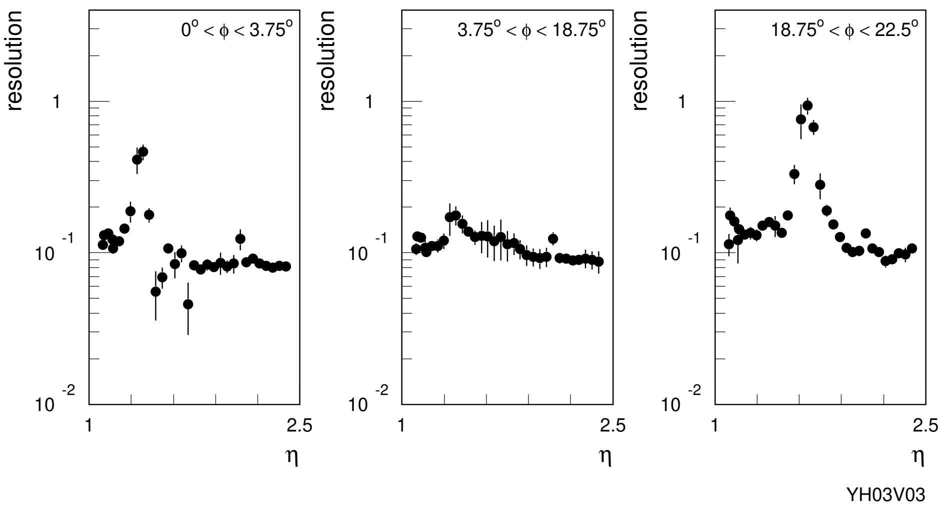
Efficiency = 0.909





Efficiency
1
10^-1
10^-2
10^-3
Low pT trigger
0
5
10
15
pT (GeV)
LL03V01

Low p_t resolution at barrel/endcap crossover: Big contribution to rate from π/K decays.



Masking? - under study.

L2 trigger

Uses data, requirements on track multiplicity + momentum, mass cuts, e/μ particle identification.

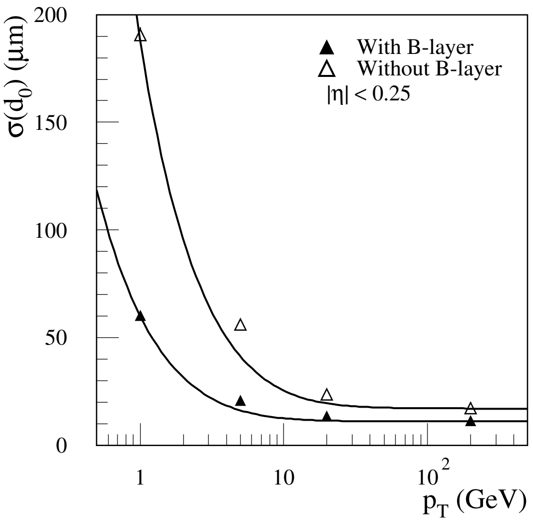
- μ verification with Inner Detector
  - 23KHz$\rightarrow$9 Khz
  - b $\rightarrow \mu$: 2.3 KHz
  - c $\rightarrow \mu$: 1.1 KHz
  - π, K $\rightarrow \mu$: 5.6 KHz
  - ψ, W, Drell Yan $\approx$0
- Selection of decay channels of interest: eg $B_d^0 \rightarrow \psi K_s$, $\psi \rightarrow e^+e^-$: require identified e^+e^-, $p_t > 0.5$ GeV/tk, $m_{ee} > 2.0$ GeV.
- Efficiency, according to channel, 0.6-0.8.
- 10ms decision time
- output rate 1 KHz

Event Filter

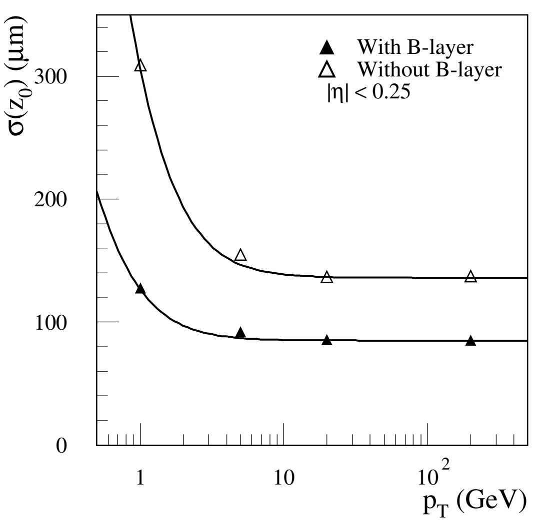
Full event data, complex algorithms (eg Vertex finding, γ-conversions)

- 1–10 s decision time

Detector Performance



d_0 resolution



z_0 resolution

Primary Vertex Measurement

- Beam spread: $\sigma_x = \sigma_y = 15\mu$m $\sigma_z = 6$ cm

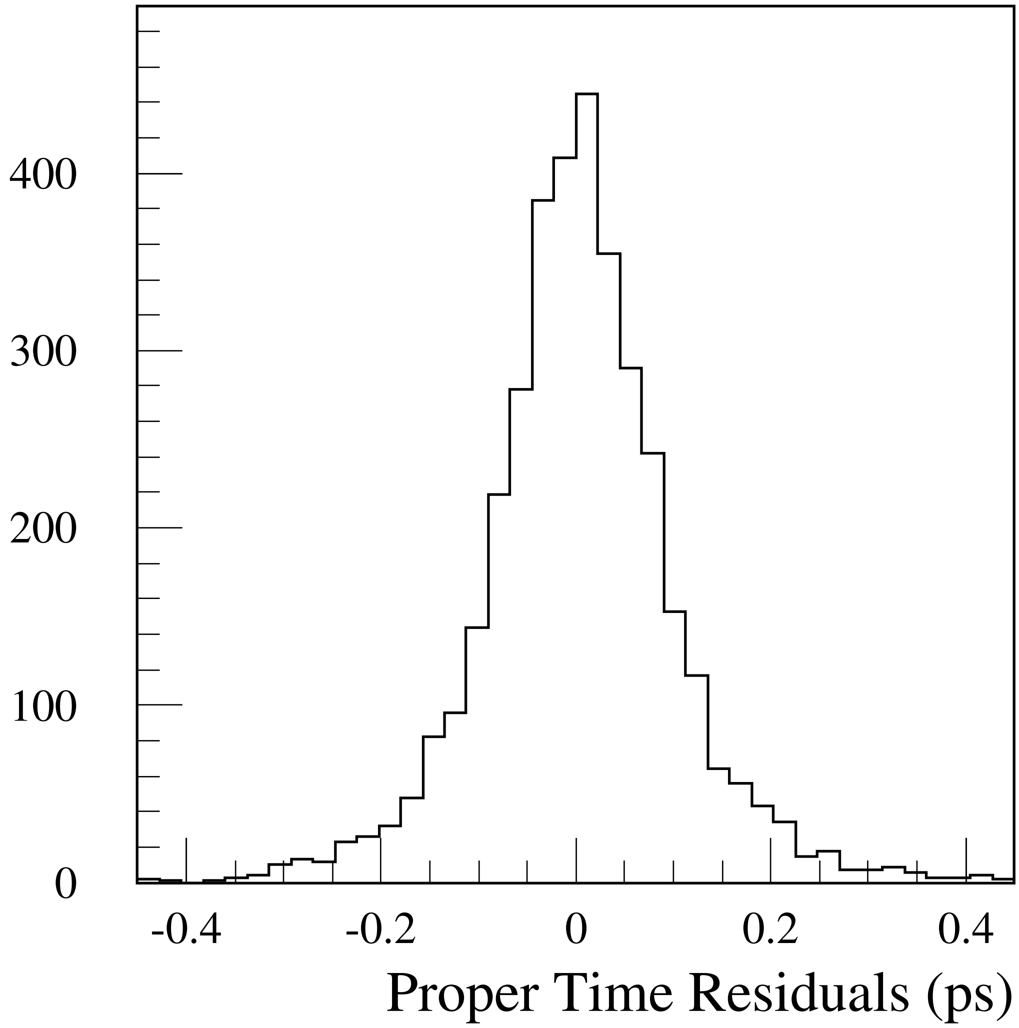
Channel	σ_x	σ_y	σ_z
$B_d^0 \to \psi K_s$	29	27	44
$B_s^0 \to D^-\pi^+$	29	29	47
Min. Bias	47	48	70

Secondary Vertex Measurement

After K^0, ψ recon, 3-D fit to $B_d^0 \to \psi K_s$, Mass cut at $\pm 3\sigma$:

Channel	$\sigma_{dec.\,length}$
$B_d^0 \to \psi K_s, \psi \to \mu^+\mu^-$	64
$B_d^0 \to \psi K_s, \psi \to$e$^+e^-$	64
$B_s^0 \to D^-\pi^+$	58

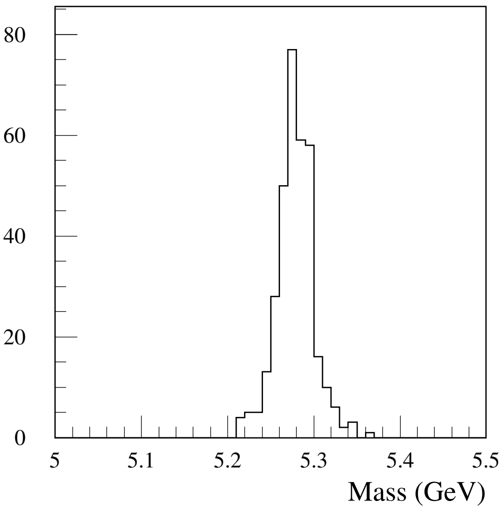
Proper time residuals for $B_s^0 \to D^- \pi^+$

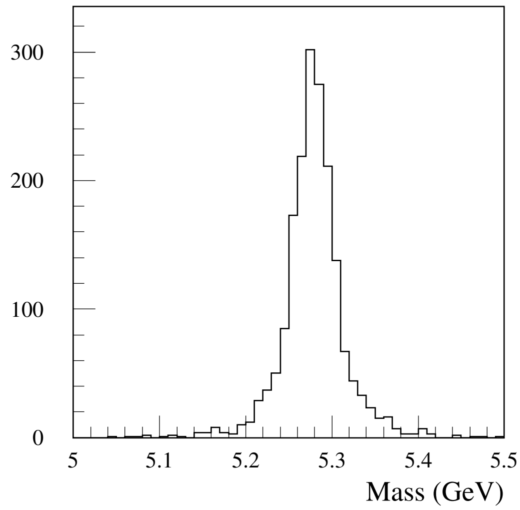


$\sigma = 0.073$ ps

(Mean lifetime B$_s$ = 1.54 ± 0.07 ps)

Mass resolution





$$B_d^0 \rightarrow \psi K_s$$

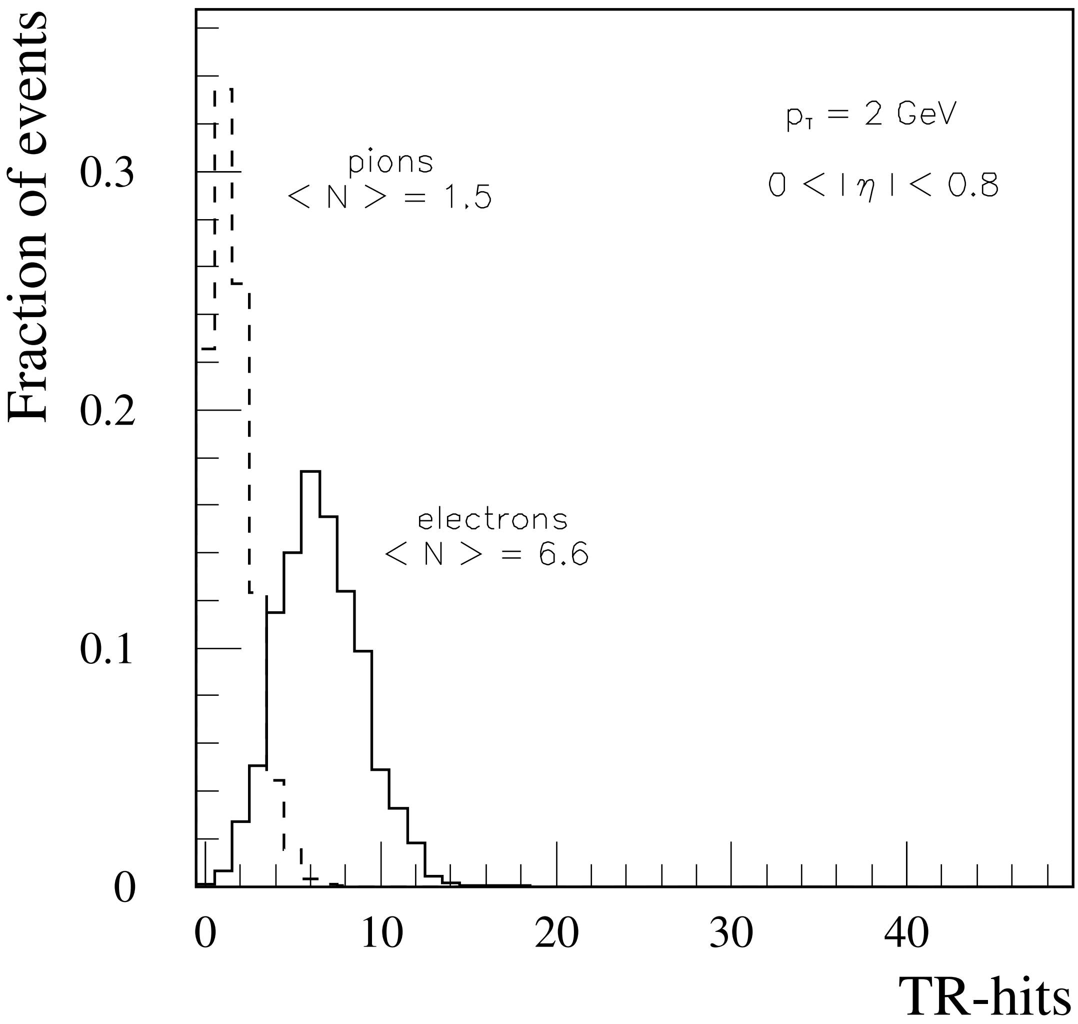
$\psi \rightarrow \mu^+\mu^-$ σ_{mass}=19 MeV

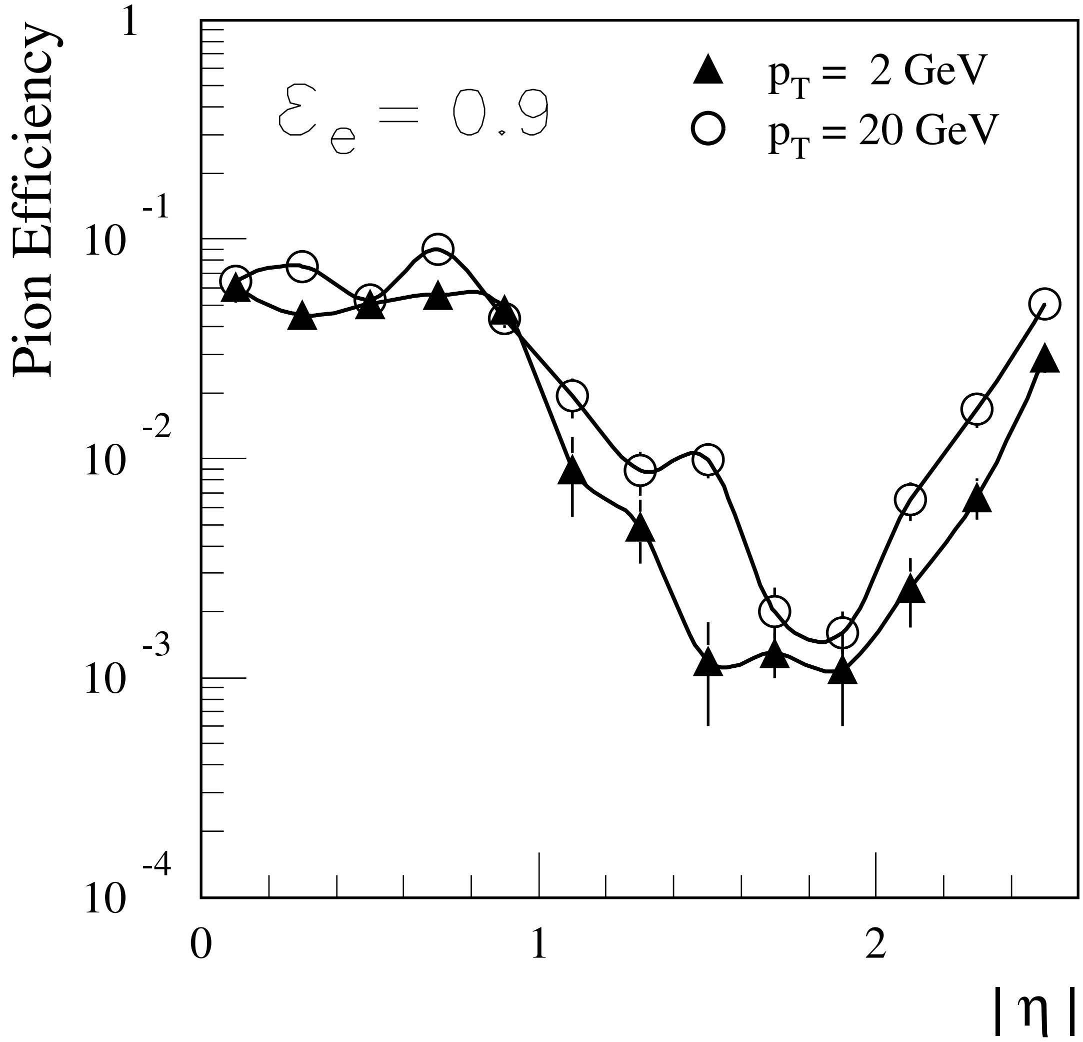
$\psi \rightarrow$e$^+$e$^-$ σ_{mass}=26 MeV

$B_d^0 \rightarrow \pi^+\pi^-$: σ_{mass}=70 MeV

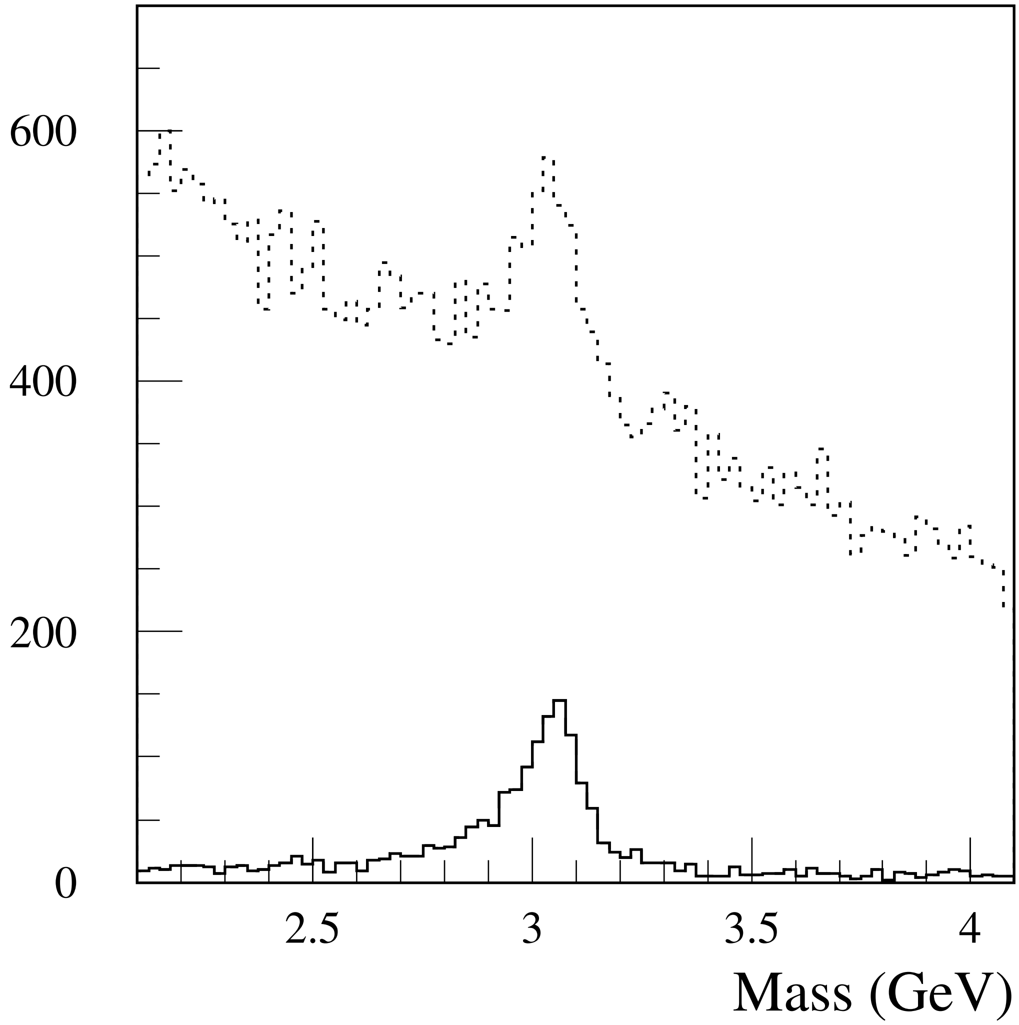
Decay	Tk Assign.	Recon-Nominal B$_d^0$ Mass
$B_d^0 \rightarrow K^+\pi^-$	$\pi\pi$	-40 MeV
$B_s^0 \rightarrow K^-\pi^+$	$\pi\pi$	+50 MeV
$B_s^0 \rightarrow K^+K^-$	$\pi\pi$	+10 MeV

Electron identification



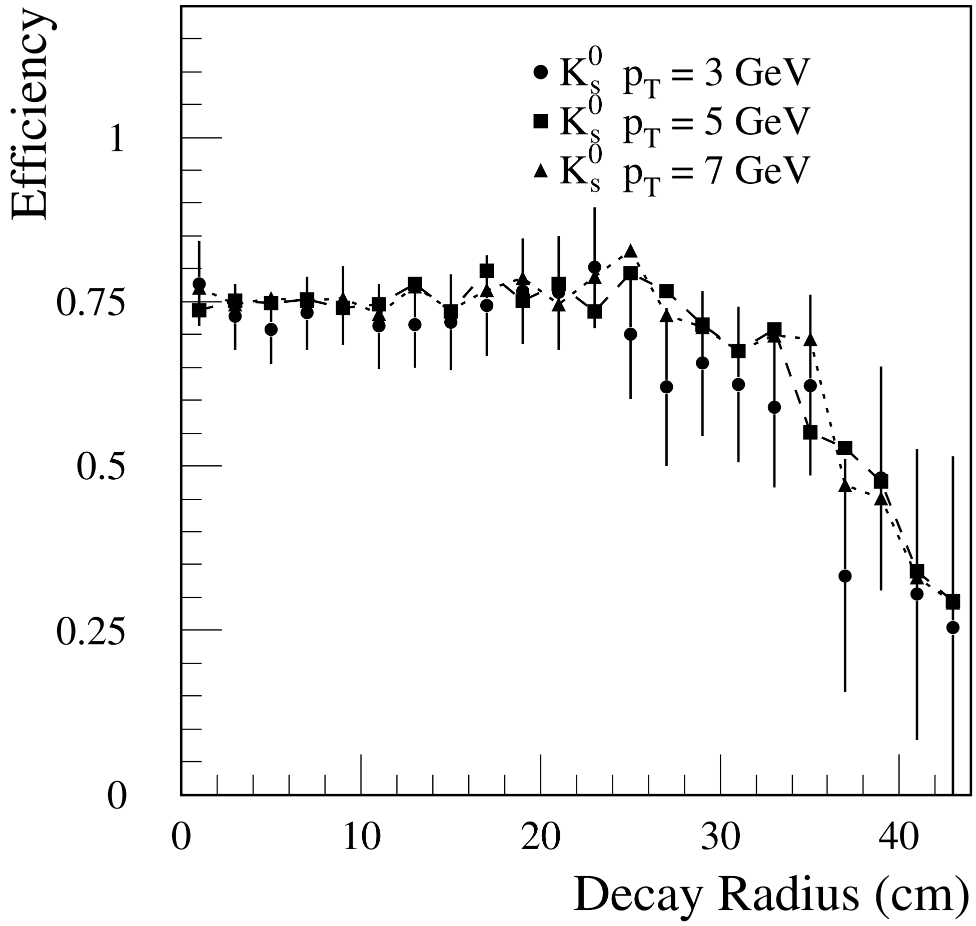


More radiator as η increases



$\psi \rightarrow e^+e^-$ in $B_d^0 \rightarrow \psi K_s$ events

K^0 reconstruction

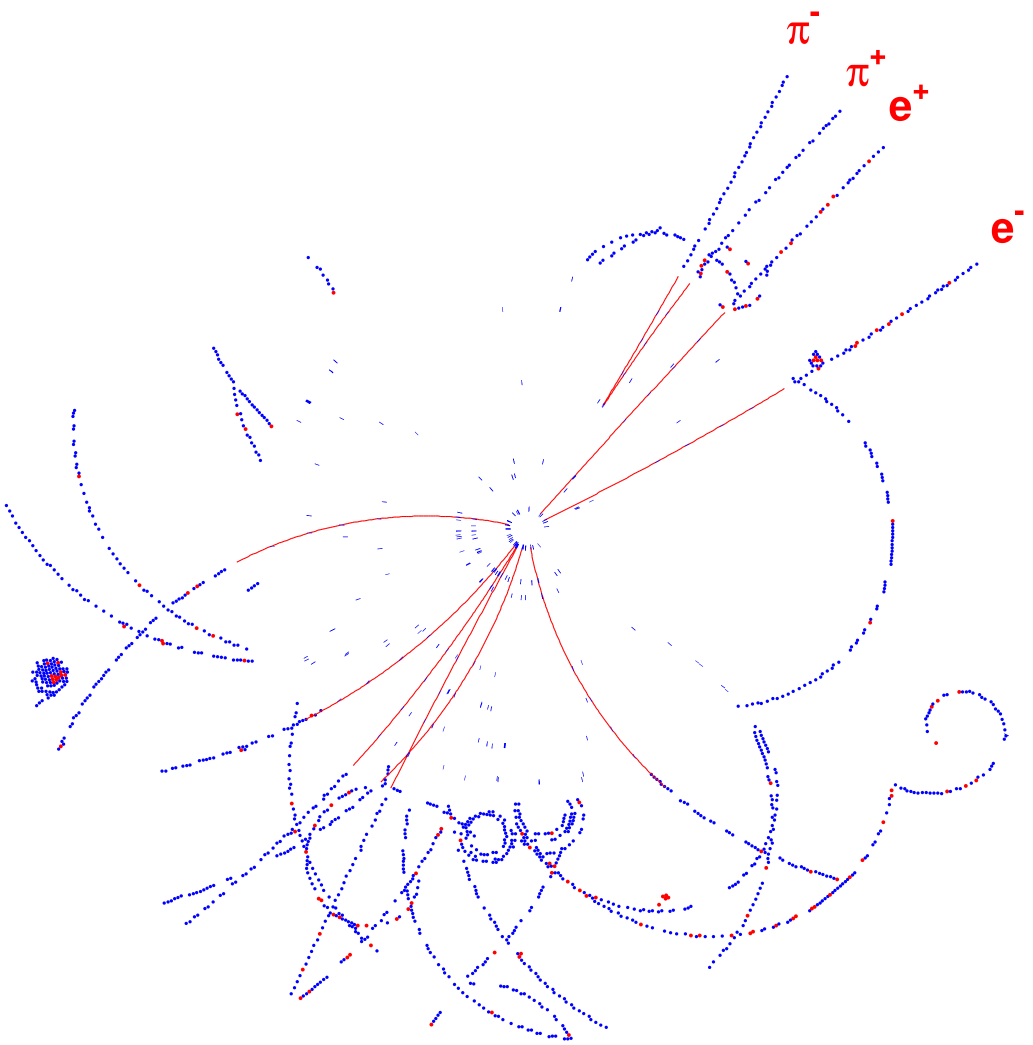


Tracks not constrained to pass through primary vertex.

$\geq$ 2 Si points required (Si layers at 20, 37, 35, 52 cms).

ATLAS Barrel Inner Detector

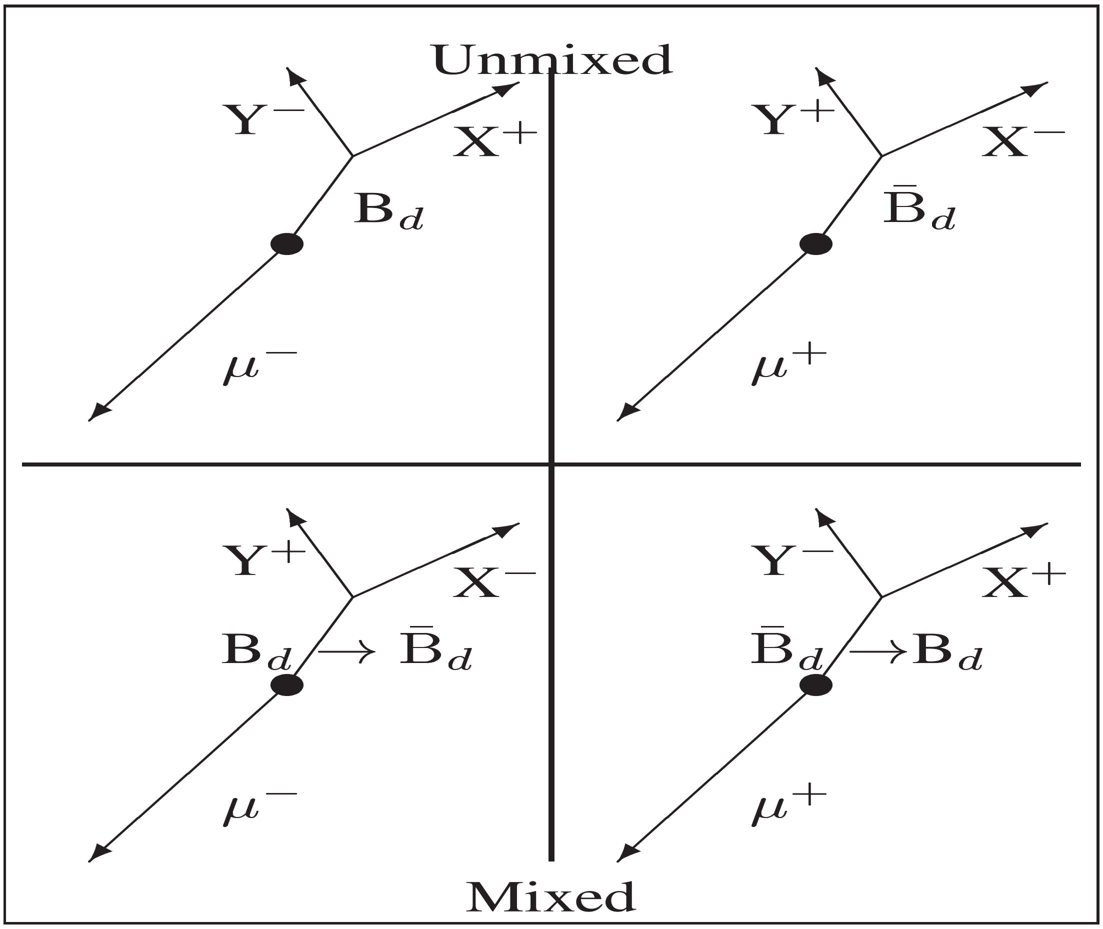
$B_d^o \rightarrow J/\psi\, K_s^o$



K^0 vertex

e hits in TRT (red)

$B_s^0\bar{B}_s^0$ Mixing



$$a(t) = \frac{n_{unmix} - n_{mix}}{n_{unmix} + n_{mix}} = D \cos \delta m_s t$$

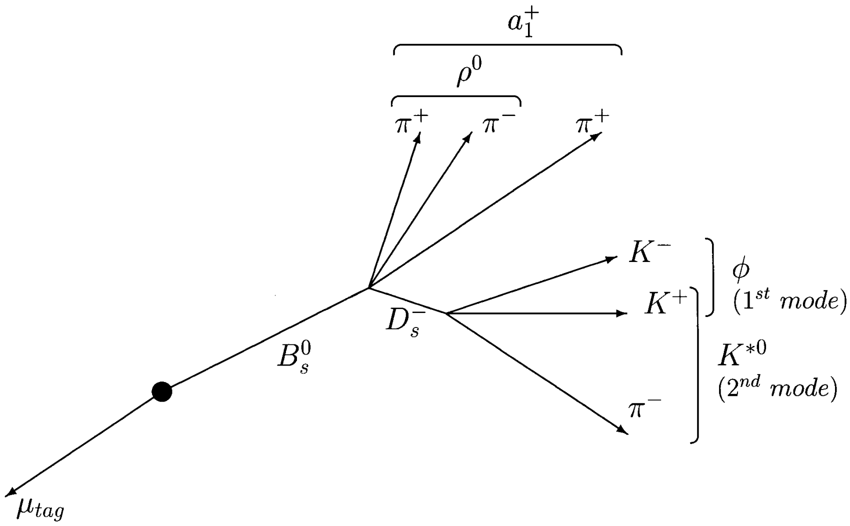
D Dilution: wrong sign tags, background, time resolution

δm_s mass difference between B_s^0 mass eigenstates.

$\delta m_s \approx \mathcal{O}(20)$ SM

$\delta m_s \geq 8.0\ \mathrm{ps}^{-1}$ (LEP)

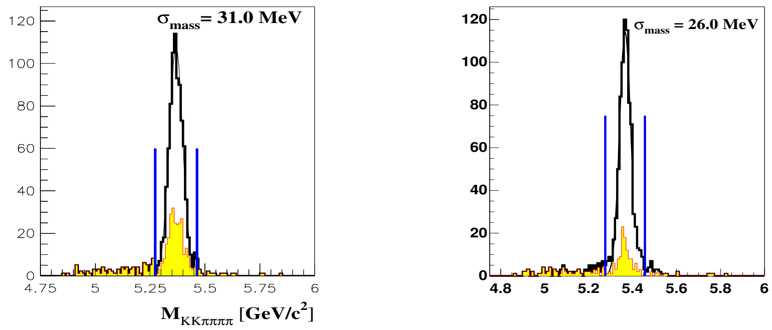
$B_s \to D_s\ a_1$



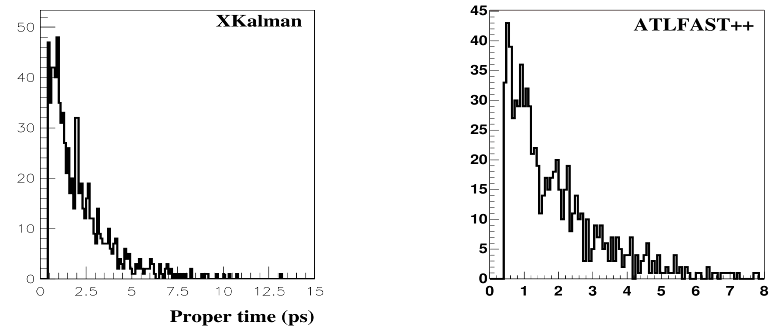
Level 1 trigger:	μ_{tag} ($p_T > 6$ GeV/c ; $\lvert\eta\rvert < 2.5$)
	semileptonic decay $b \to c l^- \nu_l$
Level 2 trigger:	loose ϕ, D_s mass cuts and p_T cuts
	(not applied)
Natural width:	$\Gamma_{\rho^0} \sim 150.7$ MeV
	$\Gamma_{a_1} \sim 400$ MeV

Reconstructed B_s

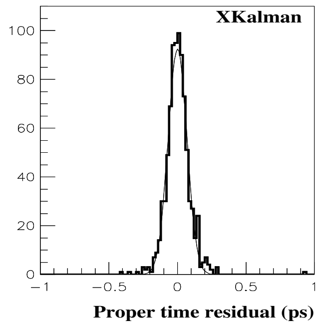
B_s fitted mass

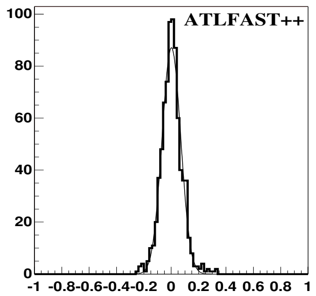


B_s proper time



B_s proper time residual

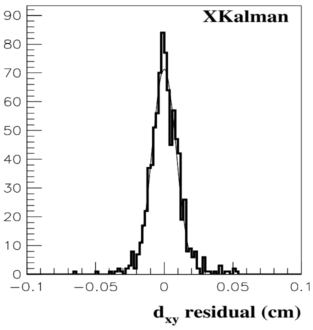


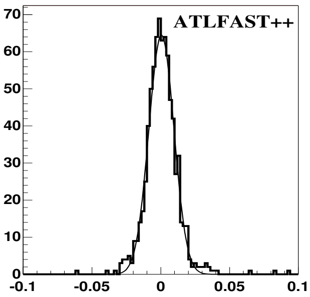


$\sigma_\tau^{full\ sim}$=0.069 ps

$\sigma_\tau^{fast\ sim}$=0.068 ps

B_s transverse decay radius residual





$\sigma_{dxy}^{full\ sim} = 88\ \mu$m

$\sigma_{dxy}^{fast\ sim} = 91\ \mu$m

Number of signal events

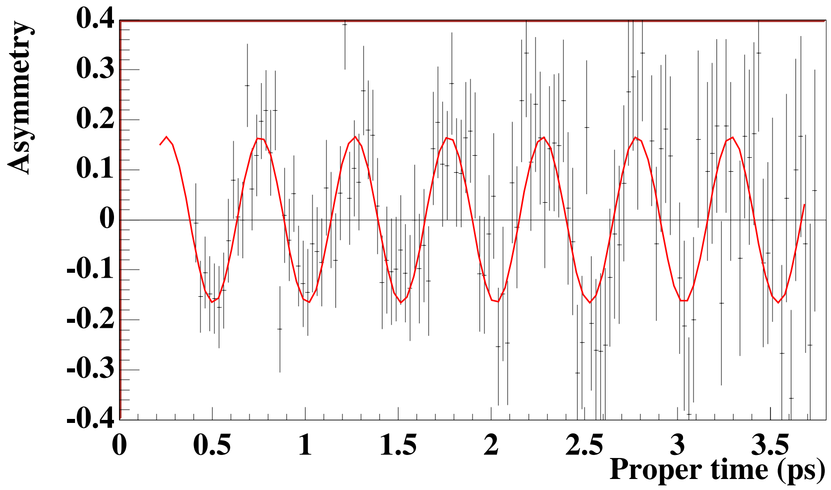
One year (10^7 s) of operation at $\mathcal{L} = 10^{33}$ cm^{-2}s^{-1}

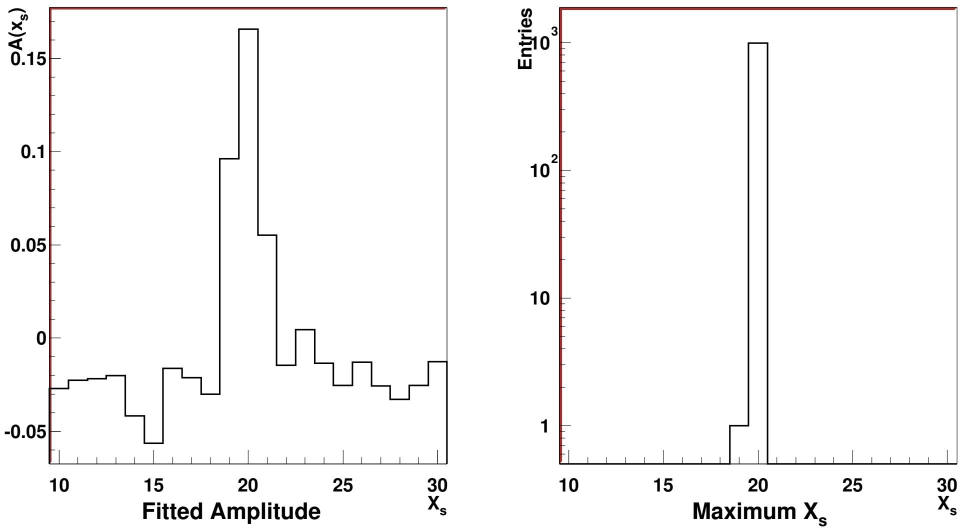
Parameter	Full sim	Fast sim
N($K^+K^-\pi^-\pi^+\pi^-\pi^+$)	136600	136600
Cut acceptance	133048	132092
Events with ϕ rec	81277	78135
Events with D_s rec	50591	49956
Events with ρ rec	43438	42073
Events with a_1 rec	32238	31145
Rec B_s ($\pm 3\sigma$) events	11474 (8.4%)	10518 (7.7%)
Trigger efficiency	0.50	
Muon efficiency	0.85	
Hadron efficiency	$(0.90)^6$	
	2592	2369
B_s mass cut $\pm 2\sigma$ (0.95)	2462	2250
B_s mass cut $\pm 1\sigma$ (0.68)	1762	1611

$\mathrm{B}_s^0\bar{\mathrm{B}}_s^0$ Mixing: $\mathrm{D}\pi$

- scan values of $\mathrm{x_s}$, and fit $A\cos\frac{\mathrm{x_s}t}{\tau_B}$: true $\mathrm{x_s}$ gives maximum amplitude. ($\rightarrow$)
- Repeat Monte Carlo experiment many times. Define reach as value of $\mathrm{x_s}$ where experiment is successful 95% of trials. ($\rightarrow$)

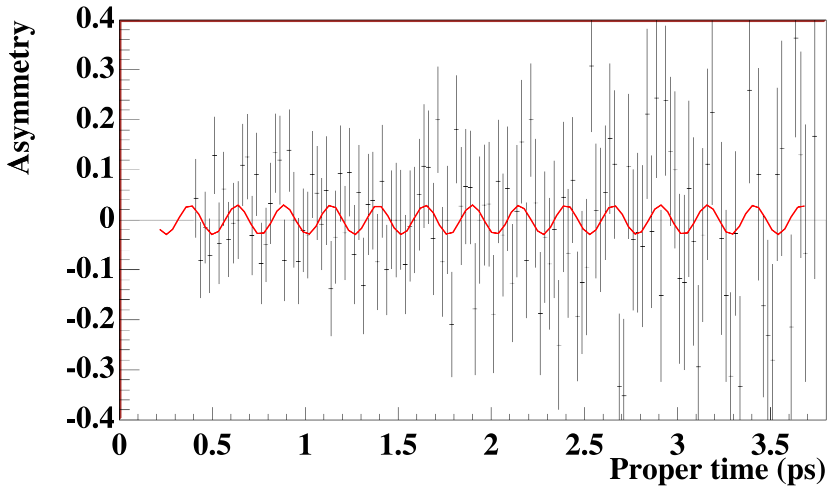
Time Dependent Asymmetry

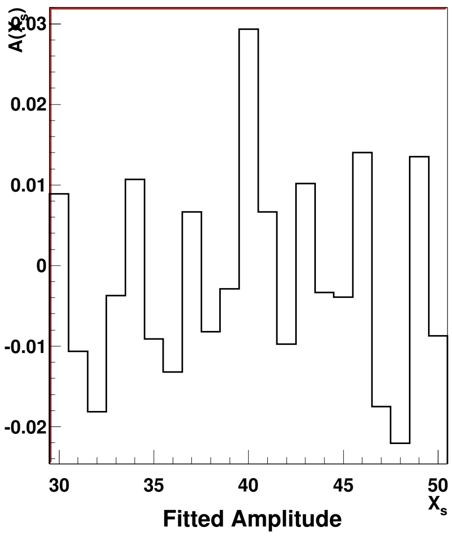


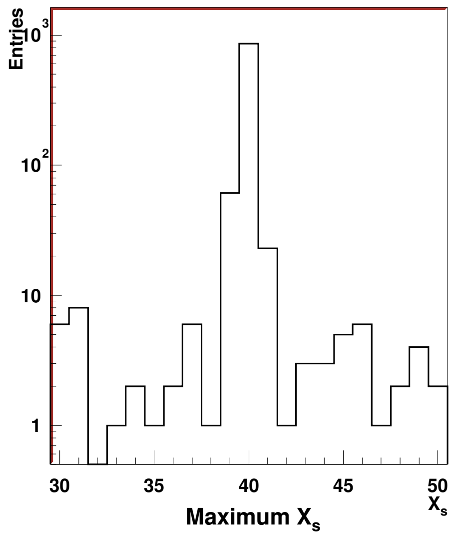


$\int L\,dt = 10^4\ pb^{-1}$, σ_t = 0.07 ps X_s = 20

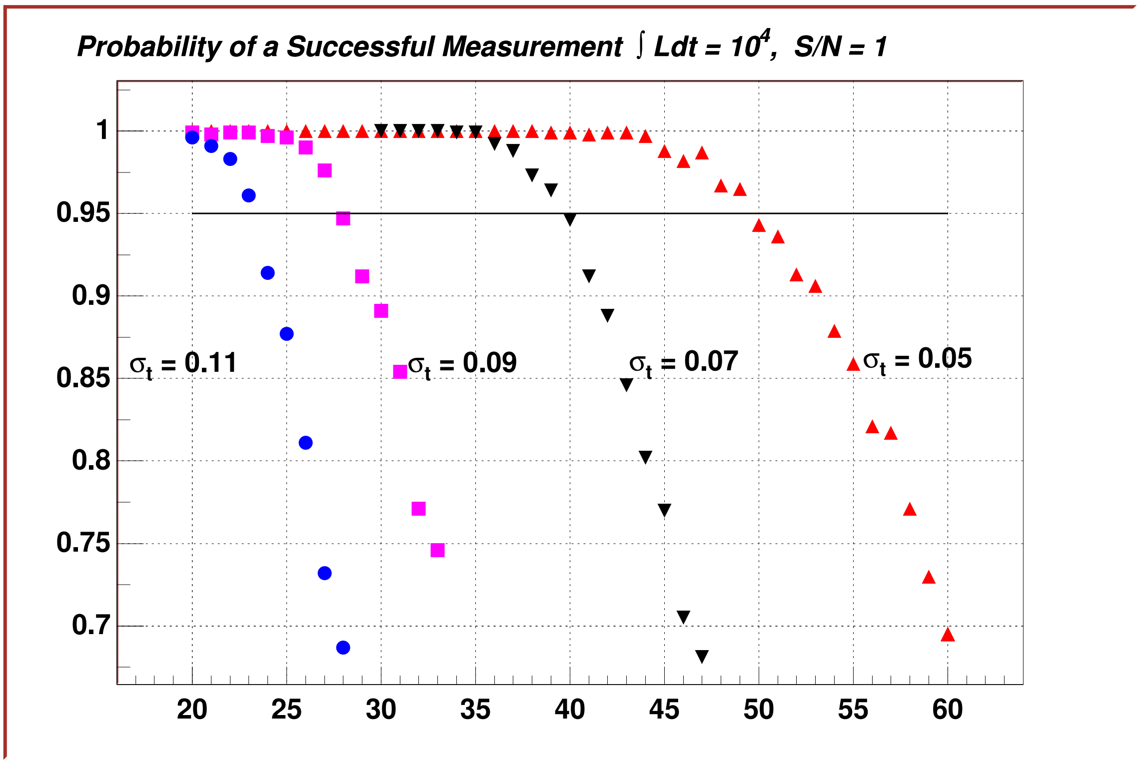
Time Dependent Asymmetry







$\int L\,dt = 10^4$ pb^{-1}, $\sigma_t = 0.07$ ps $X_s = 40$


Probability of a Successful Measurement ∫ Ldt = 10^4, S/N = 1
1
0.95
0.9
0.85
0.8
0.75
0.7
σt = 0.11
σt = 0.09
σt = 0.07
σt = 0.05
20
25
30
35
40
45
50
55
60

Rare decays: $B_d^0 \to \rho\mu^+\mu^-$, $B_d^0 \to K^*\mu^+\mu^-$

- BR $\approx 10^{-6}$
- $\frac{BR(B_d^0 \to \rho\mu^+\mu^-)}{BR(B_d^0 \to K^*\mu^+\mu^-)} = \kappa|\frac{V_{ts}}{V_{td}}|^2$
- Branching ratio, dilepton mass spectra and lepton angular asymmetry sensitive to new physics (more so than $B_d^0 \to X\gamma$)

Both μ: $p_t > 6$ GeV, $|\eta| < 2.5$.
Both hadrons: $p_t > 1$ GeV, $|\eta| < 2.5$.

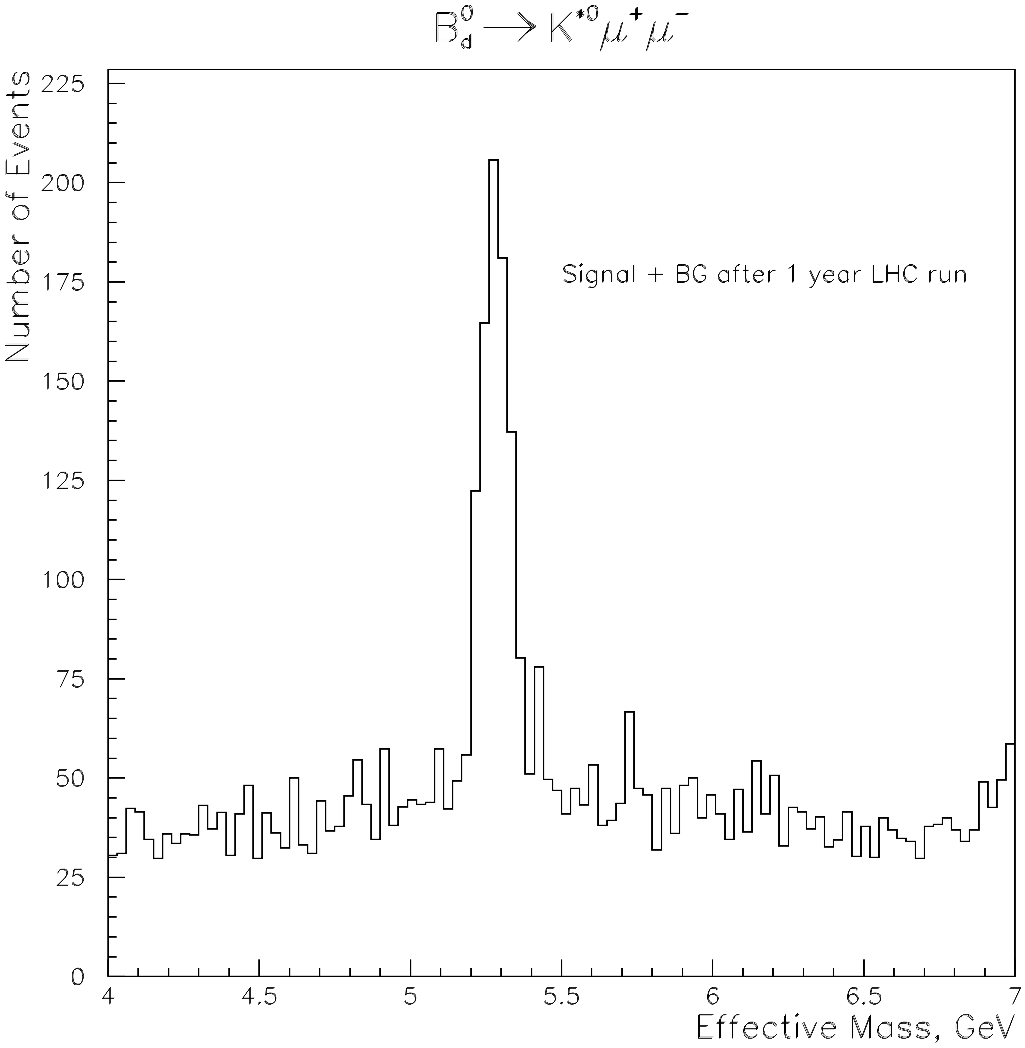
Main backgrounds: $B \to \psi X$, $B_s^0 \to K^*\mu^+\mu^-$, $B_s^0 \to \phi\mu^+\mu^-$, b$\to \mu$X. ($\to$)

After 1 year low luminosity:

	signal	background
$B_d^0 \to \rho\mu^+\mu^-$	97	370
$B_d^0 \to K^*\mu^+\mu^-$	680	185

κ (SU3-breaking) calculable to $\approx 10\%$

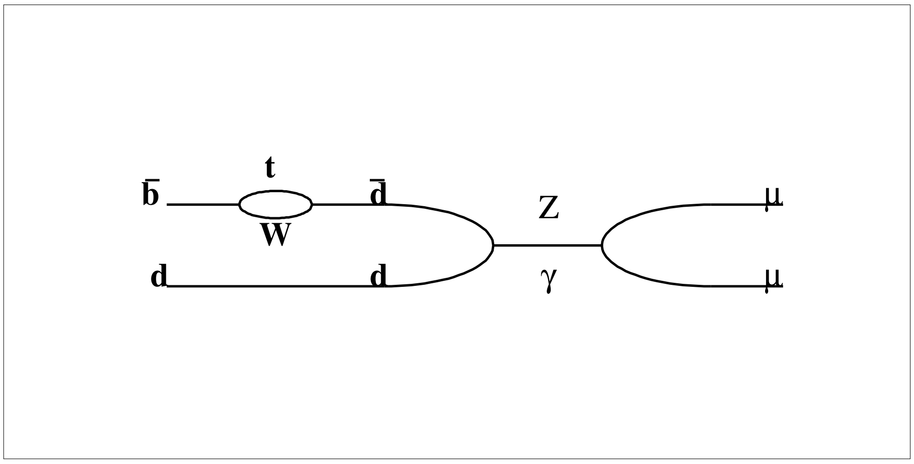
1 yr: statistical error $|\frac{V_{ts}}{V_{td}}|^2 \approx 10\%$, 3yrs: $\approx 6\%$



$B_d^0 \longrightarrow K^{*0}\mu^+\mu^-$
Number of Events
225
200
175
150
125
100
75
50
25
0
Signal + BG after 1 year LHC run
4
4.5
5
5.5
6
6.5
7
Effective Mass, GeV

Rare decays – $B_d^0 \to \mu^+\mu^-$, $B_s^0 \to \mu^+\mu^-$

- SM branching ratios:
  BR($B_d^0 \to \mu^+\mu^- = 1.5 \pm 0.9 \times 10^{-10}$
  BR($B_s^0 \to \mu^+\mu^- = 3.5 \pm 1.0 \times 10^{-9}$
  (Ali hep-ph/9610333)
- Clean place to look for new physics.



Other possibilities for loop:

Charged Higgs t,c,u
Charginos squarks
Gluinos squarks
Neutralinos squarks

- $\frac{Br(B_d^0 \to \mu^+\mu^-)}{Br(B_s^0 \to \mu^+\mu^-)} = \frac{\tau_{B_d} m_d F_{B_d}^2 |V_{td}|^2}{\tau_{B_s} m_s F_{B_s}^2 |V_{ts}|^2}$
- Remain sensitive at high $\mathcal{L}$ due to dimuon trigger

After 1 year:

	signal	background
$B_d^0 \to \mu^+\mu^-$	1.3	31
$B_s^0 \to \mu^+\mu^-$	9	31

SM gives 3σ signal after 3 years for $B_s^0 \to \mu^+\mu^-$.
BR($B_d^0 \to \mu^+\mu^-$) $\leq 8 \times 10^{-10}$ (95% CL).

Conclusions and Outlook

The ATLAS detector elements and performance of particular relevance to B physics have been summarised

Measurements will be made of $\mathrm{B}_s^0\bar{\mathrm{B}}_s^0$ mixing, with reach of x_s up to $\approx$40, whereas the SM expectation is $x_s \approx 20$. The proper time resolution is the dominant limiting factor for the reach. $\mathrm{B}_s^0\bar{\mathrm{B}}_s^0$ mixing will be studied in a number of channels: the Dπ and Da_1 are currently under study.

Mesurements of V_{td} and V_{ts} will be made in the (medium) rare processes $B_d^0 \to \rho\mu^+\mu^-$ and $B_s^0 \to K^*\mu^+\mu^-$, as well as from the (very) rare processes $B_d^0 \to \mu^+\mu^-$ and $B_d^0 \to \mu^+\mu^-$. The branching ratios for all these processes are sensitive to new physics. The dilepton mass spectrum and the asymetries of the positive lepton with respect to the b-jet are also sensitive to new physics - including the MSSM.

Other topics under study include the detection of charmed beauty hadrons, and Λ_B polarisation.

CP violation measurements via decay asymmetries are a major part of the ATLAS B physics program. They will be described in a following talk.