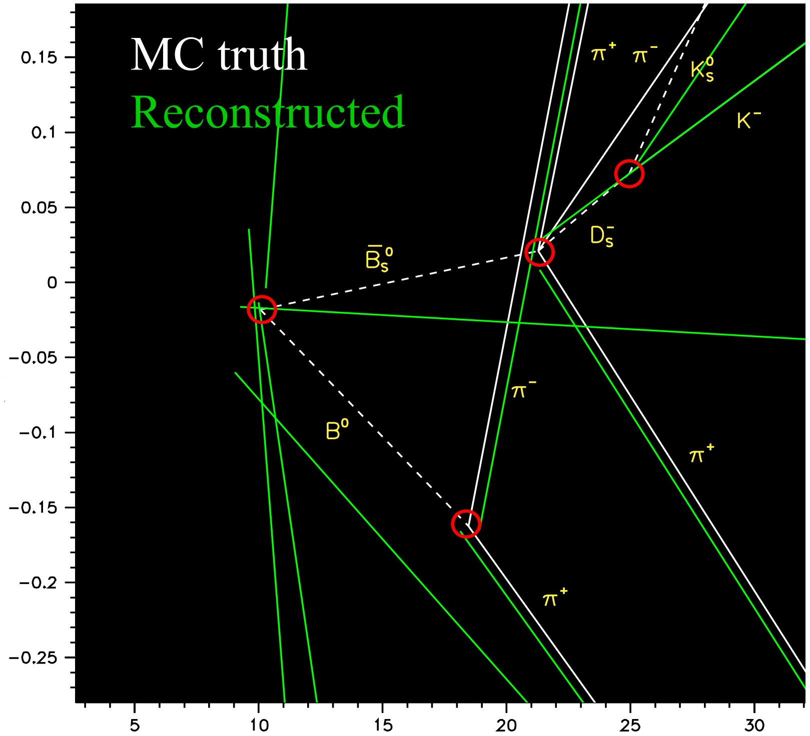
HCP2005, 4-9 July 2005, les Diablerets Switzerland



Event Reconstruction and Physics Performance of the LHCb Experiment

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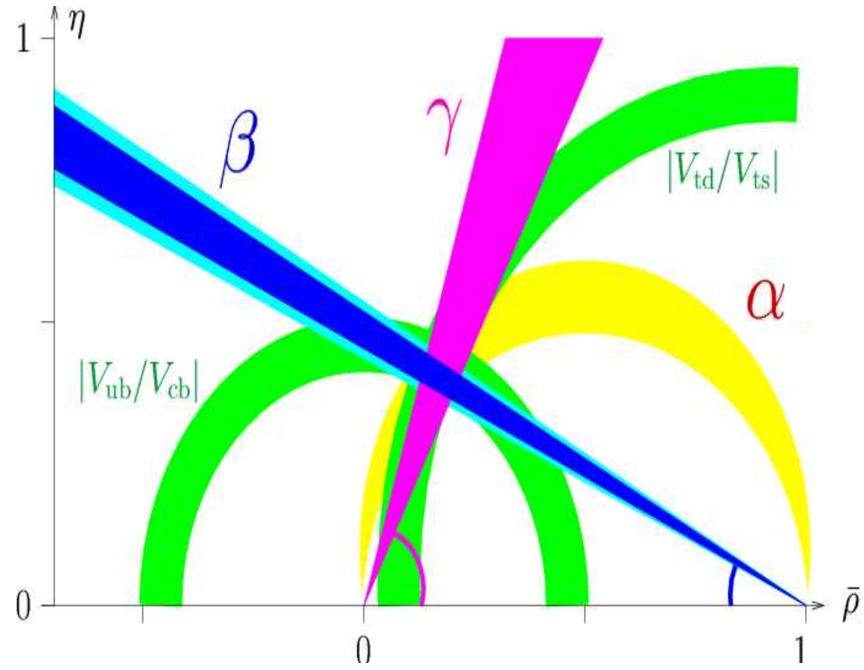
University of Edinburgh

representing the LHCb collaboration



Outline

- Introduction
- Event reconstruction capability
  - Tracking
  - Vertexing and proper time determination
  - Flavour tagging
  - Particle identification
- Physics potential
  - Physics programs
  - B_s Mixing
  - CKM angles
  - Rare B decays
- Conclusions

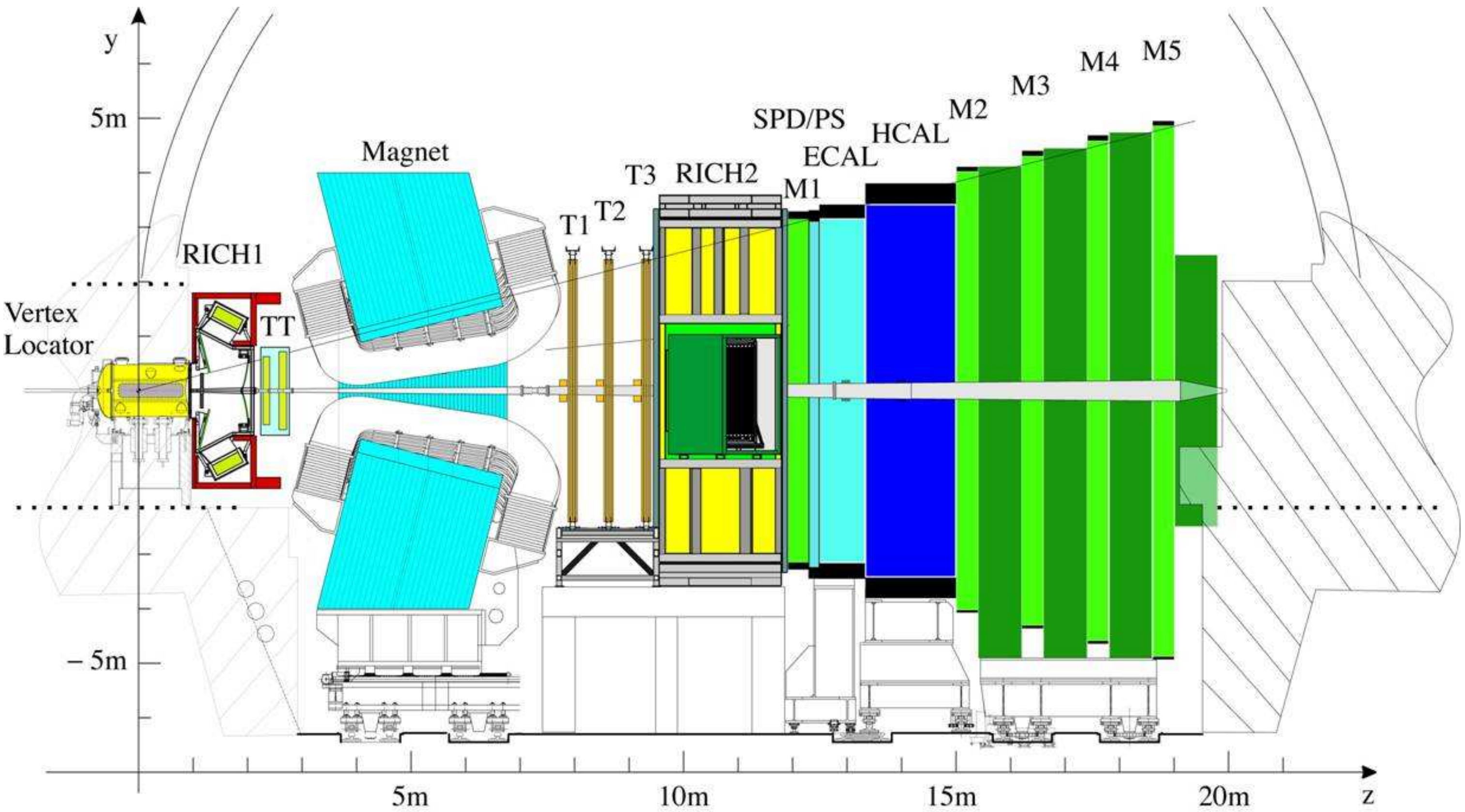
Introduction

- **Goal of LHCb: look for new physics in CP violation and rare B decays**
- **Time-dependant measurements: exclusive signal reconstruction, proper time determination and B flavour tagging**
- **Requirements to reconstruction:**
  - **Exclusive B reconstruction requires good mass resolution**
    → need precise momentum measurement up to 100 GeV
  - **Very fast B_s oscillation requires a good proper time resolution**
    → need high precision of primary and secondary vertex position
  - **Flavour tagging and background rejection require efficient particle identification for 2-100 GeV**

LHCb detector

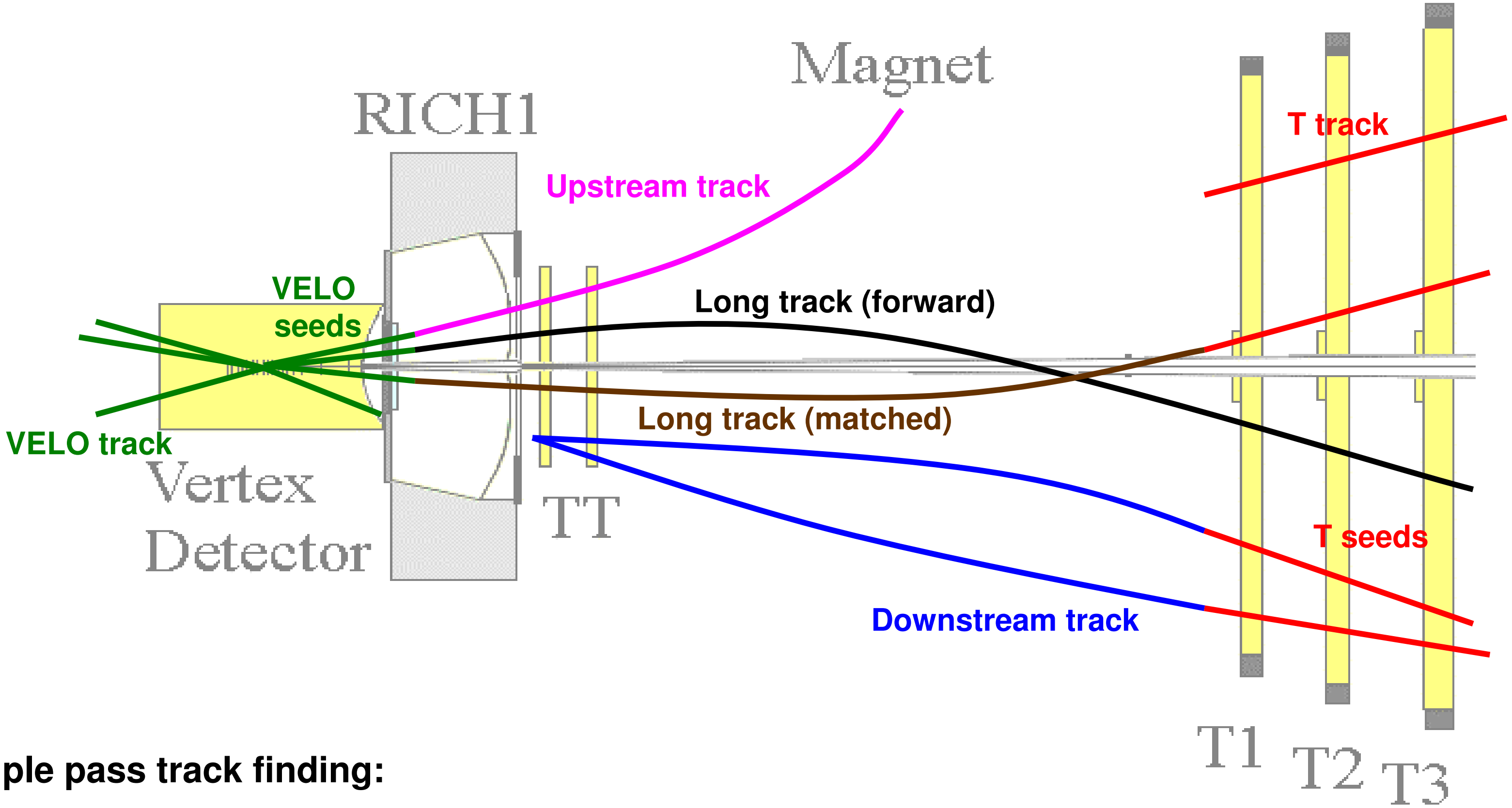
Tracking:
Vertex Locator
TT
T1-T3
Magnet

Related LHCb talks:
LHCb Status: Roger Forty
Particle Identification: Ann Van Lysebetten



PID:
RICH1/RICH2
SPD/PS
ECAL
HCAL
M1-M5

Track finding strategy



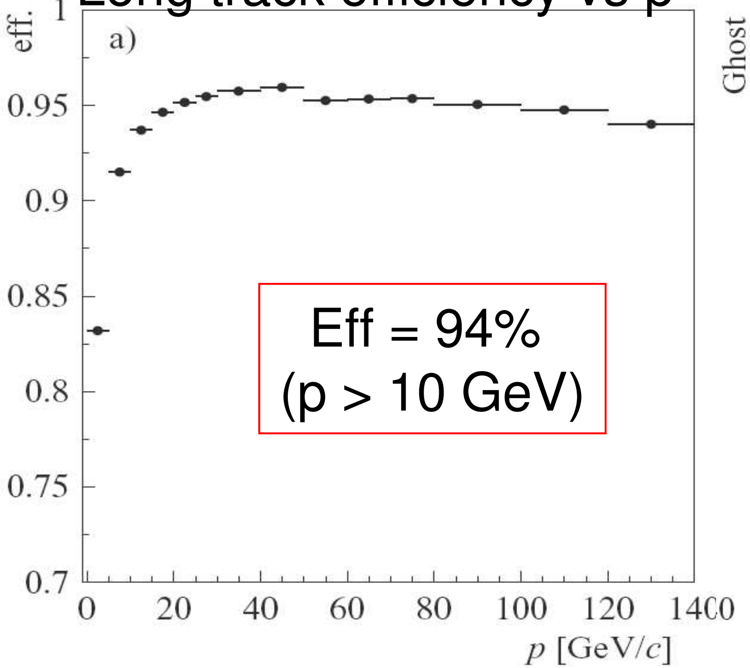
Multiple pass track finding:

Velo seeds
T seeds

Long tracks ⇒ highest quality for physics
Downstream tracks ⇒ needed for efficient K_S finding
Upstream tracks ⇒ lower p, worse p resolution, useful for RICH1 pattern recognition

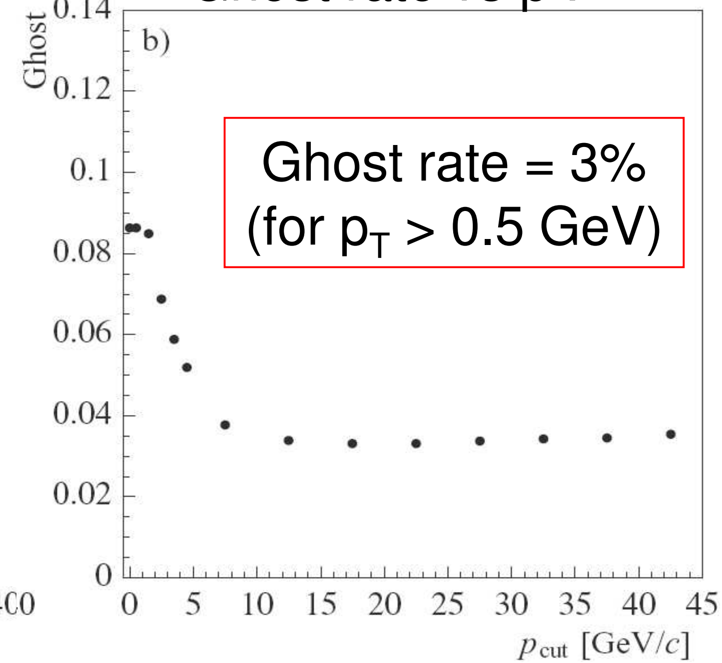
Tracking performance

Long track efficiency vs p



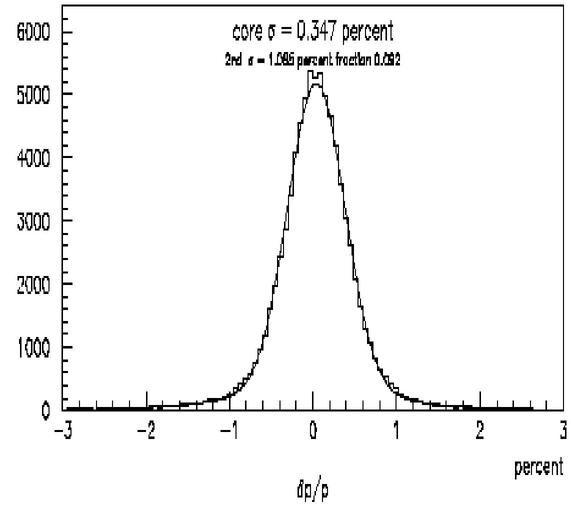
Eff = 94%
(p > 10 GeV)

Ghost rate vs p :



Ghost rate = 3%
(for p_T > 0.5 GeV)

δp/p ~ 0.37%

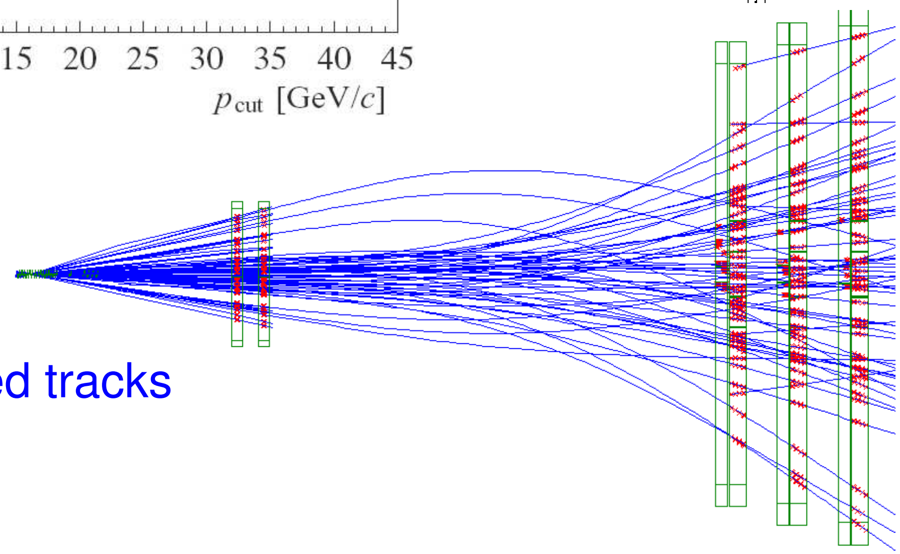


A typical reconstructed event:

On average:
26 long tracks
11 upstream tracks
4 downstream tracks
5 T tracks
26 VELO tracks

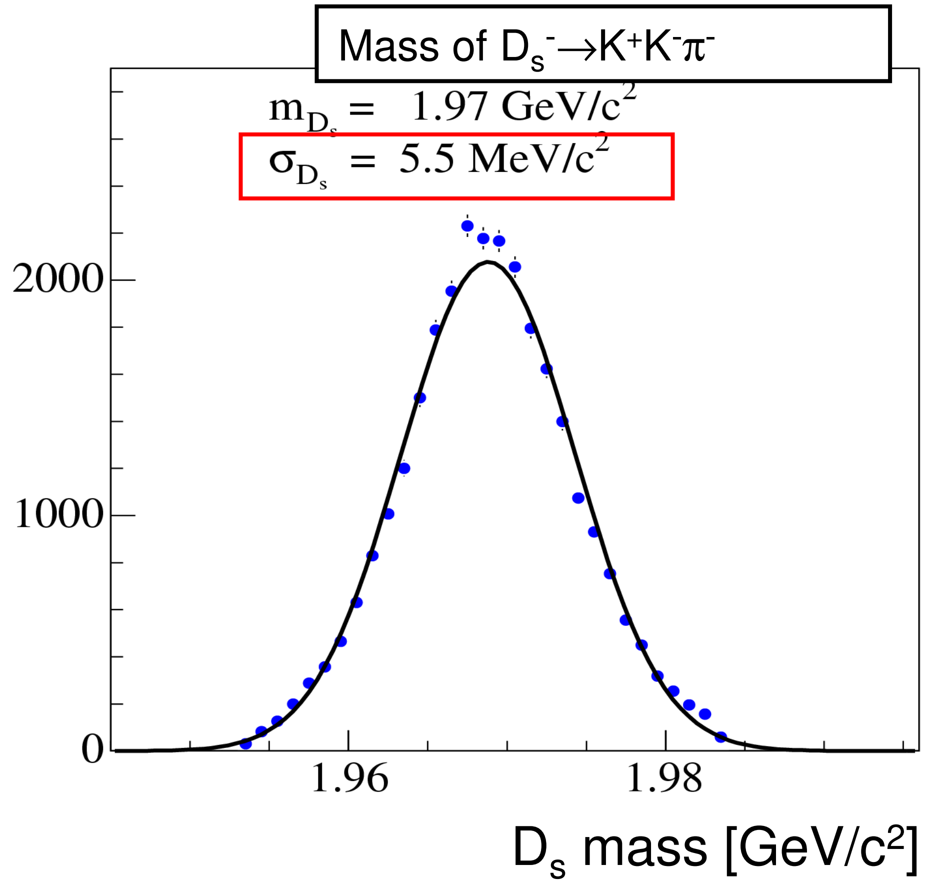
red = detected hits

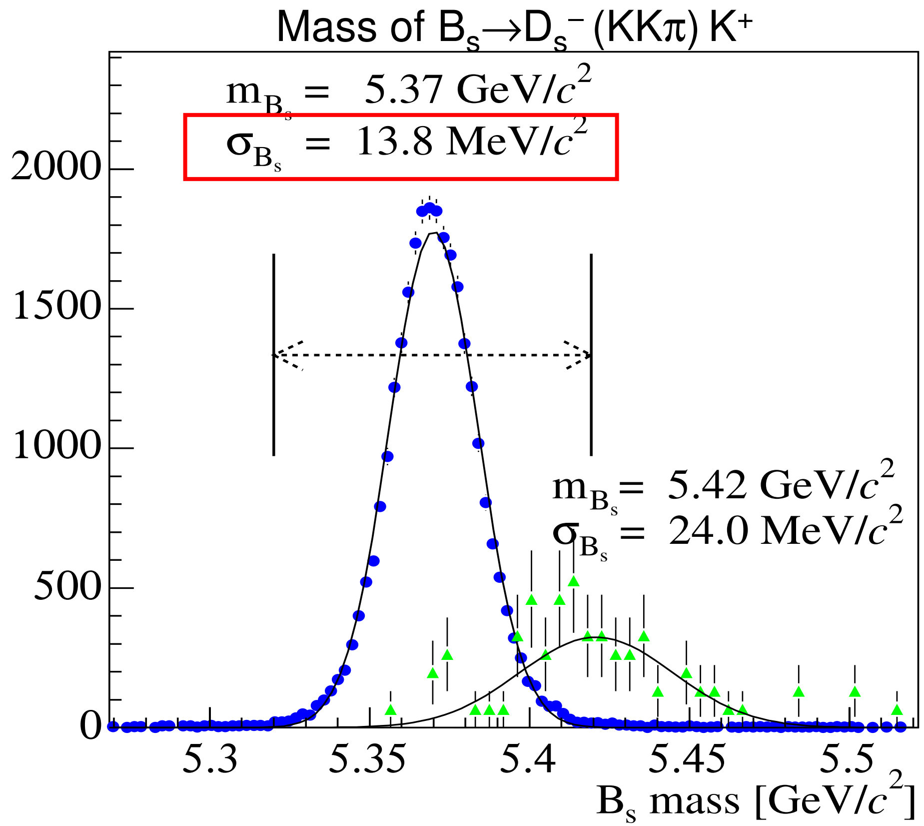
Blue = reconstructed tracks



Mass resolution

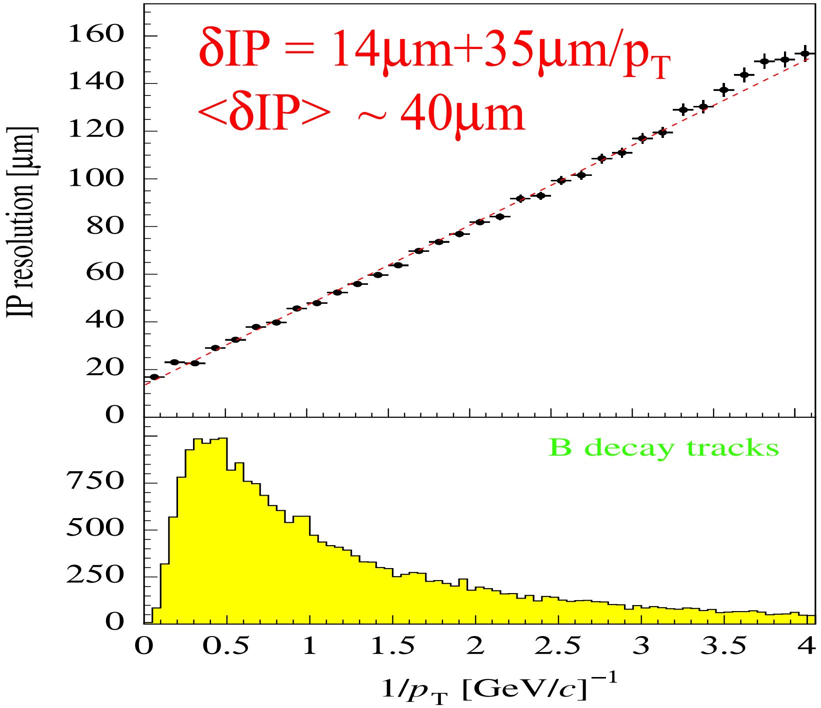
Mass resolution based on the δp/p ~ 0.37% momentum resolution

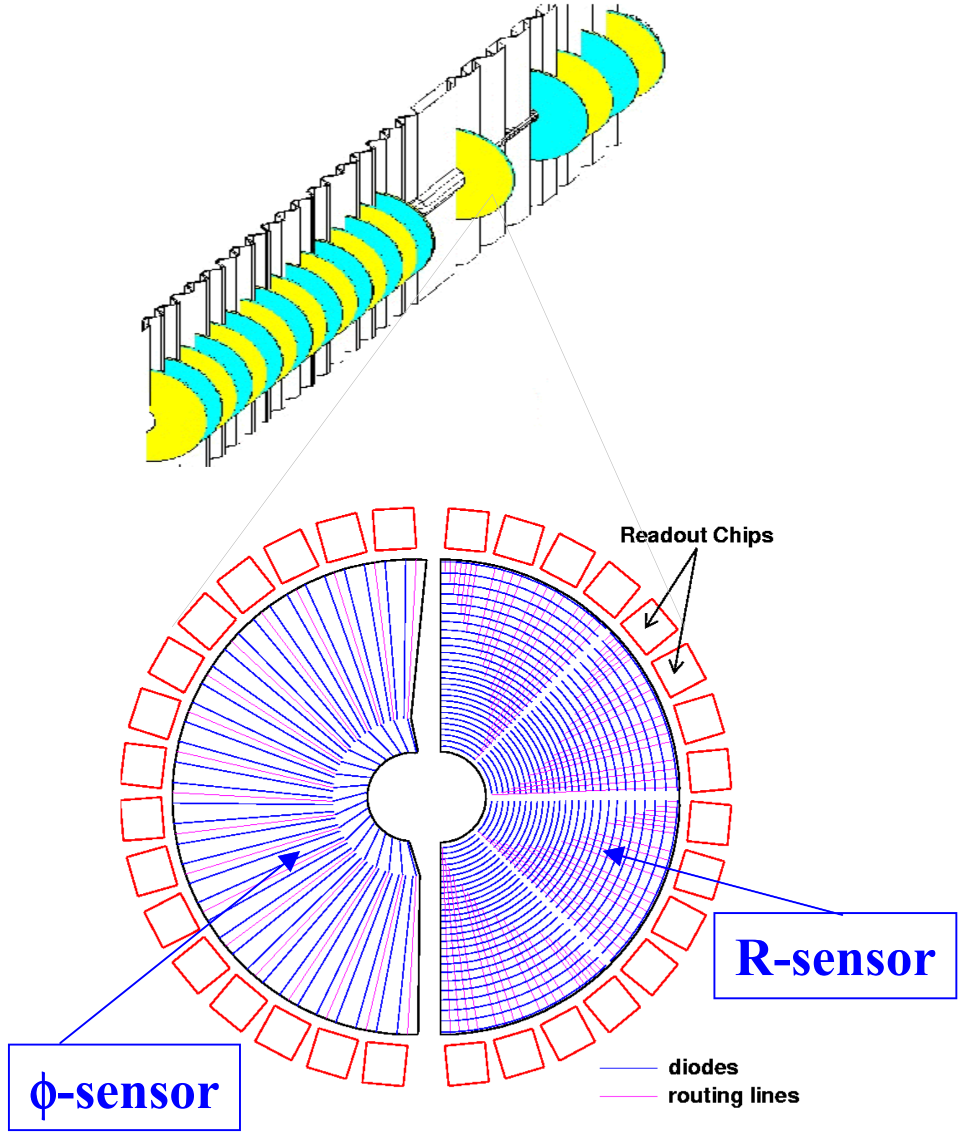




Vertex detection

- 21 silicon stations placed along the beam direction, 8mm to beam
- Two detector halves in each station
- Two sensor types to measure R and ϕ
- Track impact parameter precision to origin vertex:





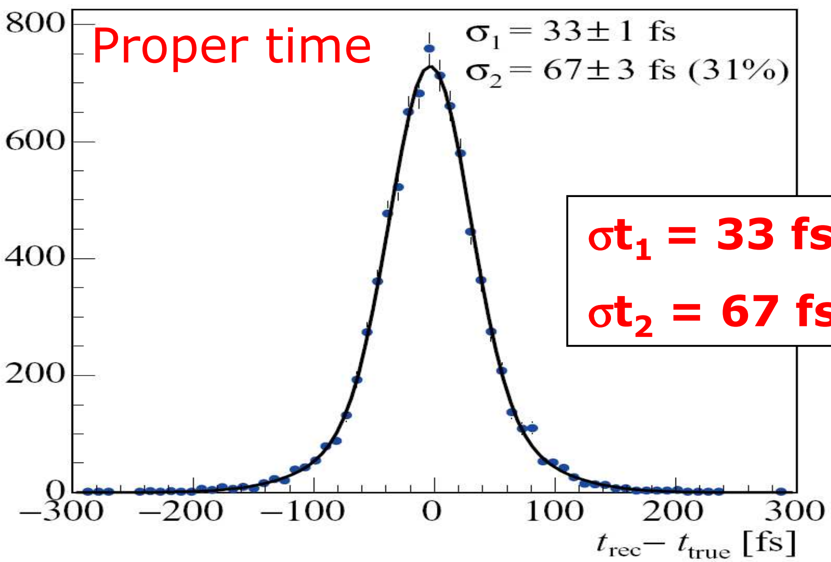
Vertex reconstruction

proper time $\tau = l \cdot m/(p \cdot c)$

- **Proper time resolution is dominated by B vertex resolution**

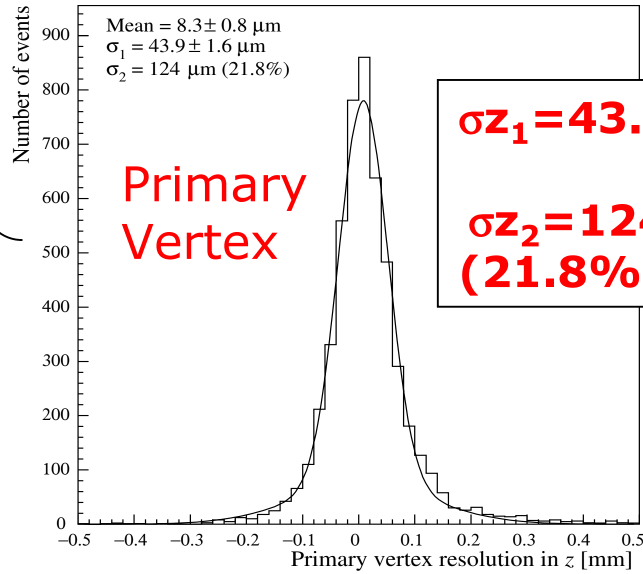
$B_s \rightarrow D_s \pi$

σz=168 μm



σt_1 = 33 fs

σt_2 = 67 fs (31%)



σz_1=43.9 μm

σz_2=124 μm (21.8%)

Particle identification performance

- K/π separation is provided by RICH
- Lepton identification is mainly provided by calorimeter and muon chambers

Typical event in the RICH1 photon detectors:

Hits from signal tracks and background tracks

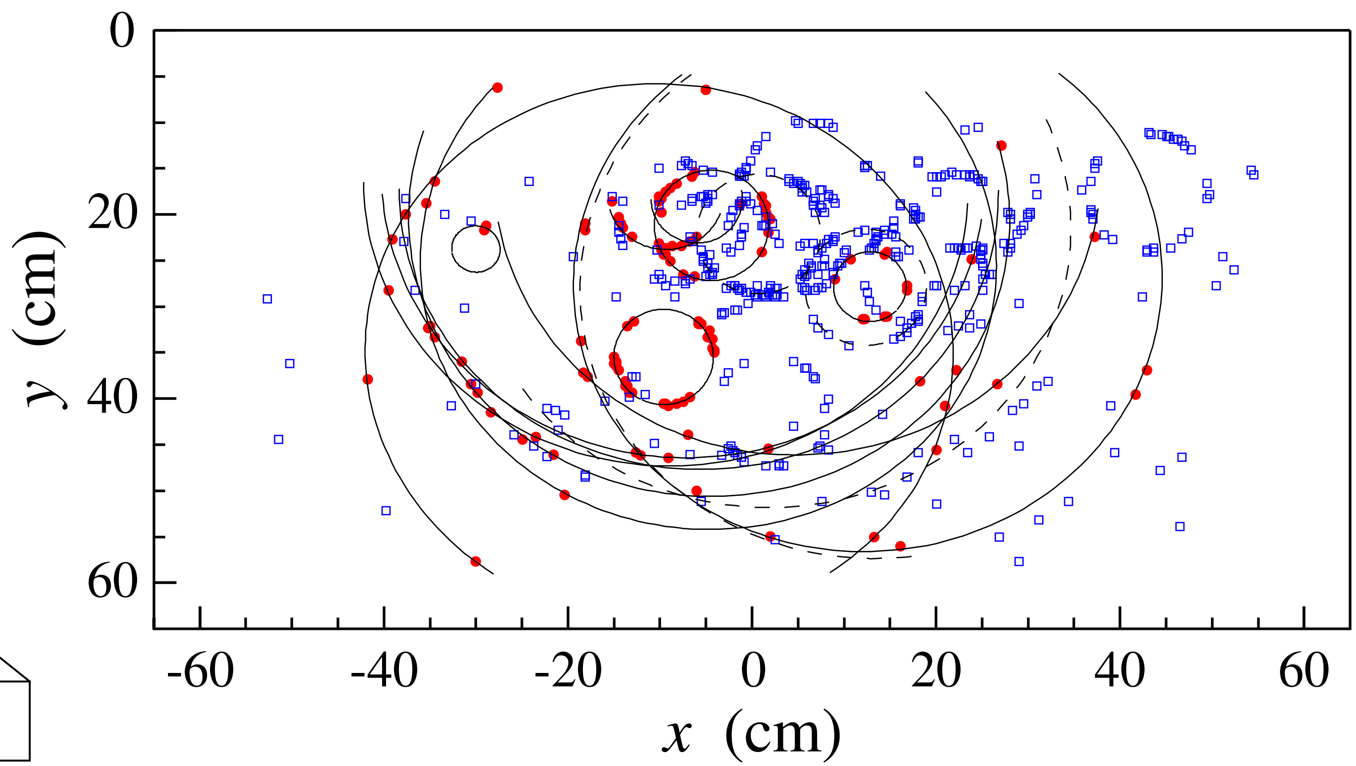
Reconstructed rings: large from aerogel, small from gas C_4F_{10}

RICH PID
2<p<100 GeV/c
<ε(K→K)> = 88%
<ε(π→K)> = 3%

Lepton ID
<ε(μ→μ)> = 94%
<ε(π→ μ)> = 1%

<ε(e→e)> = 81%
<ε(π→ e)> = 1%

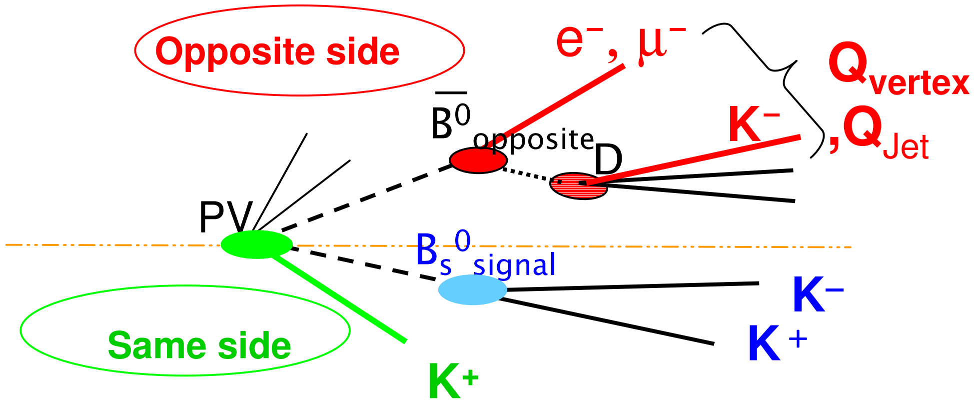
95% within calo acceptance



Flavour tagging

Opposite side

- High Pt leptons
- $K^\pm$ from $b \rightarrow c \rightarrow s$
- Vertex charge
- Jet charge



Same side

- Fragmentation $K^\pm$ accompanying B_s
- $\pi^\pm$ from $B^{**} \rightarrow B^{(*)}\pi^\pm$

Tagging power in %		
Tag	**B_d**	**B_s**
Muon	1.2	1.4
Electron	0.6	0.6
Kaon opp.side	2.1	2.4
Jet/ Vertex Charge	0.7	0.8
Same side π / K	0.7 (π)	3.1 (K)
Combined	~ 4.4	~7.5

(Same opposite side performance for B_d and B_s within errors)

Figure of merit:

$\varepsilon D^2 = \varepsilon(1-2\omega)^2$: tagging power

ε: tagging efficiency;

ω: wrong tagging fraction

Physics Programs

10^{12} $b\bar{b}$ pairs produced in a nominal year (10^7 s at $L=2\times10^{32}$ $cm^{-2}s^{-1}$)

$B_d : B_u : B_s : B_c$: b-baryons ~ 40 : 40 : 10 : 0.1 : 10

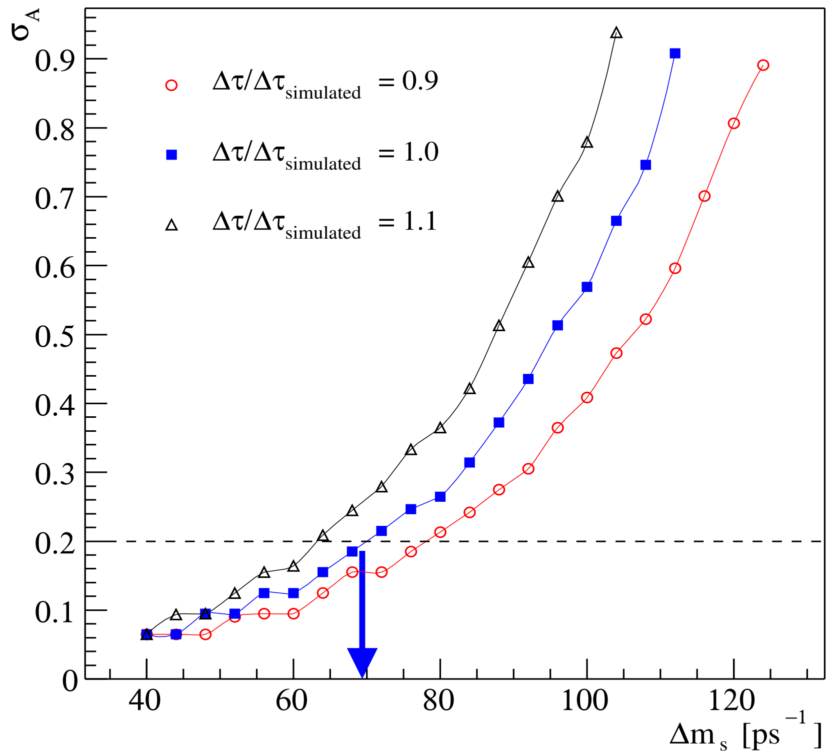
- **Measuring B_s mixing to look for new physics effect in box diagrams**
  - **Δm_s from $B_s \to D_s\pi$**
  - **ϕ_s and $\Delta\Gamma_s$ from $B_s \to J/\psi\phi$**
- **Measuring CKM angles from different processes to over-constrain unitary triangle**
  - **$\sin(2\beta)$ from $B_d \to J/\psi K_s$**
  - **γ from $B_s \to D_sK$, $B_d \to D^*\pi$**
  - **γ from $B_d \to D^0K^*$**
  - **γ from $B \to hh$**
  - **α from $B_d \to \rho\pi$**

Red: more details to come

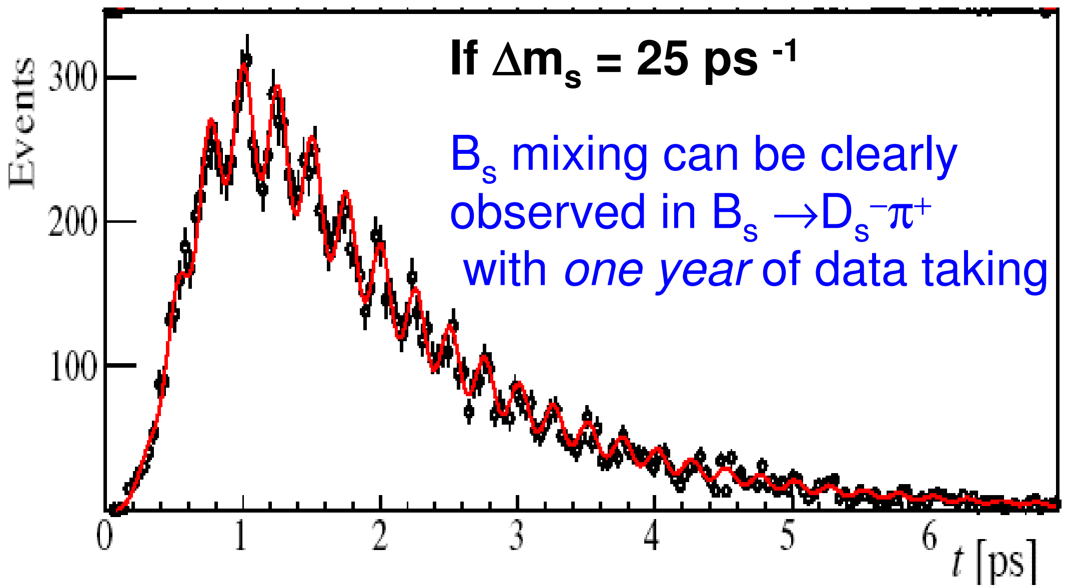
- **Looking for new physics effect in rare B decays**
  - **leptonic rare decays: $B_s \to \mu\mu$**
  - **Semileptonic rare decays: $B_d \to K^*\mu\mu$**
  - **Radiative penguin: $B_s \to \phi\gamma$, $B_d \to K^*\gamma$ and $B_d \to \rho/\omega\gamma$**
  - **Hadronic penguin: $B_s \to \phi\phi$ and $B_d \to \phi K_s$**
- **Other physics**
  - **CP violation in B_c decays**
  - **b hadron spectrum, lifetimes (ratio)**
  - **charm physics**
  - **…**

B_s mixing: Δm_s from $B_s \rightarrow D_s\pi$

Statistical uncertainty on B_s oscillation as a function of Δm_s



- New physics probe
- 80k events/year
- B/S = 0.32 ± 0.10
- $\sigma t \sim 40$ fs

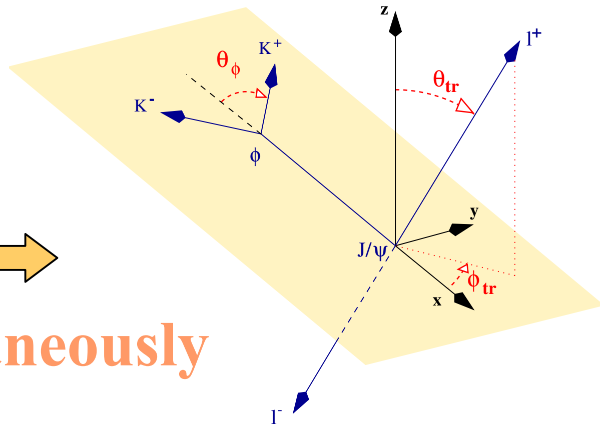


5σ sensitivity in one year $\Delta m_s < 68$ ps^{-1} is well beyond SM preferred value $\Delta m_s \sim 20$ ps^{-1}

Once oscillation observed, Δms can be measured with very high statistical precision $\sigma(\Delta m_s)=0.01$ ps^{-1}

B_s mixing: $\Delta\Gamma_s$ and ϕ_s from $B_s \rightarrow J/\psi\phi$

- SM ϕ_s = $-2\lambda^2\eta \sim -0.04$, sensitive to new weak phases in box process
- $\Delta\Gamma_s$: input to other measurements; test of HQET
- Gold-plated mode: 120k events/year, B/S<1
- Admixture of CP-even and CP-odd eigenstates
- Kinematic variables for angular analysis
- Fit proper time and angular distribution simultaneously
  - use Δm_s from $B_s \rightarrow D_s\pi$

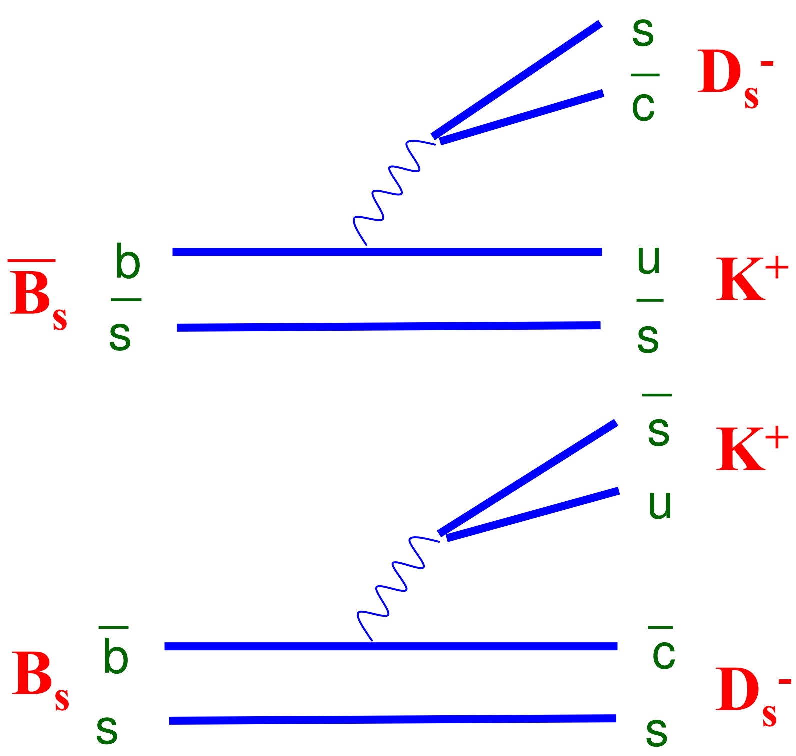


- Can be combined with CP eigenstate modes ($B_s \rightarrow J/\psi\eta$, $\eta_c\phi$) to improve precision
- Using untagged samples can achieve similar sensitivity of $\Delta\Gamma_s$

Sensitivity (1 year)	$\sigma(\Delta\Gamma_s/\Gamma_s)$	$\sigma(\phi_s)$ [rad]
$B^0_s \rightarrow J/\psi\,\phi$	0.018	0.06
$B^0_s \rightarrow J/\psi\,\eta$	~0.025	~0.1
$B^0_s \rightarrow \eta_c\phi$	~0.025	~0.1
Combined ϕ_s sensitivity		~0.05

γ from $B_s \to D_s K$

- **5.4k events/year, B/S<1**
- **Measure $\gamma+\phi_s$ in tree diagrams**
  - **fit four time dependant decay rates**
    B_s ($\overline{B}_s$) $\to D_s^- K^+$ + cc
  - **use ϕ_s measured in $B_s \to J/\psi\phi$**
- **Free of new physics contribution to penguin diagrams**
- **Measured γ is not affected by new physics effect in B_s mixing**
- **Discrepancy with indirect γ from CKM fit will signify new physics in mixing**
- **U-spin combination with $B_d \to D^{(*)}\pi$ to resolve discrete ambiguity**
  - **200k events/year**

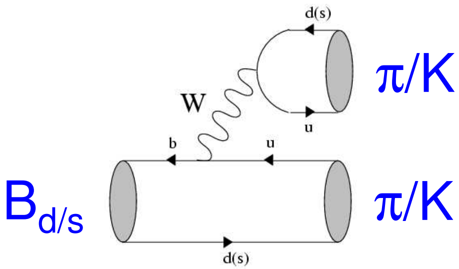


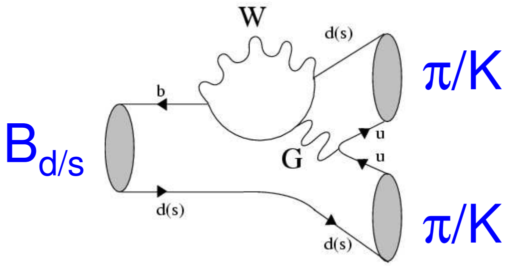
sensitivity in one year:

Δm_s	20ps^{-1}	25ps^{-1}	30ps^{-1}
$\sigma(\gamma)$	14.2°	16.2°	18.3°

(55° < γ <105°)

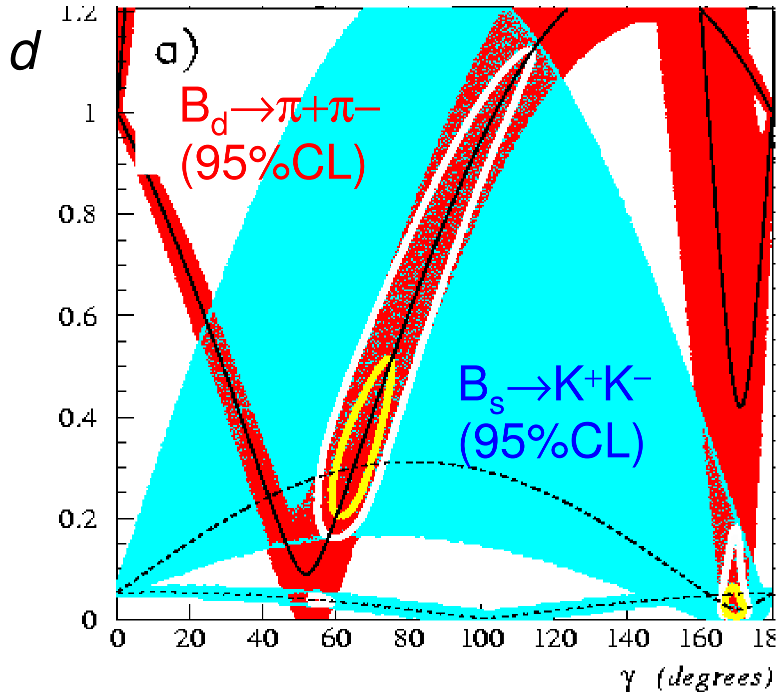
γ from $B \to hh$





- Measure time dependant asymmetries for $B_d \to \pi\pi$ and $B_s \to KK$ to determine A_{dir} and A_{mix}

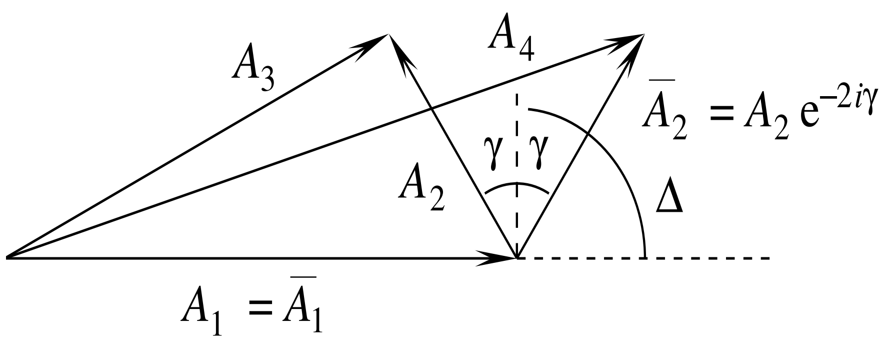
  $A_{CP}(t) = A_{dir} \cos(\Delta m\, t) + A_{mix} \sin(\Delta m\, t)$
- A_{dir} and A_{mix} depend on
  - γ
  - Mixing phases ϕ_d or ϕ_s
  - Penguin/Tree=$de^{i\theta}$
- Use ϕ_d and ϕ_s from J/ψϕ and J/ψKs
- U-spin symmetry: $d_{\pi\pi}=d_{KK}$, $\theta_{\pi\pi}=\theta_{KK}$
- 4 observables, 3 unknowns: solve for γ



- 26k $B_d \to \pi\pi$ events/year, B/S<0.7
- 37k $B_s \to KK$ events/year, B/S=0.31±0.1
- $\sigma(\gamma) \sim 5°$+ uncertainty from U-spin symmetry breaking
- Sensitive to new physics in penguin

γ from $B_d \to D^0 K^{*0}$

- ***Gronau-Wyler-Dunietz*** **method can be simply illustrated as**



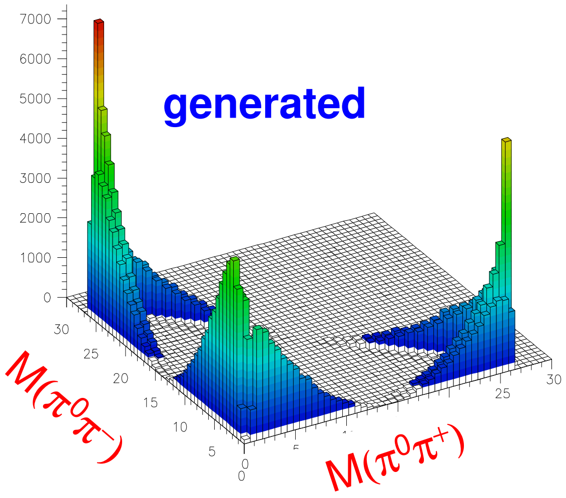
$$A_1 = A\left(B_d \to \overline{D^0} K^{*0}\right)$$
$$A_2 = A\left(B_d \to D^0 K^{*0}\right)$$
$$A_3 = A\left(B_d \to D^0_{CP} K^{*0}\right) = 1/\sqrt{2}\left(A_1 + A_2\right)$$
$$\overline{A_1} = A\left(\overline{B_d} \to D^0 \overline{K^{*0}}\right) = A_1$$
$$\overline{A_2} = A\left(\overline{B_d} \to \overline{D^0}\,\overline{K^{*0}}\right) = A_2 \cdot e^{-i2\gamma}$$
$$\overline{A_3} = A\left(\overline{B_d} \to D^0_{CP} \overline{K^{*0}}\right) = 1/\sqrt{2}\left(\overline{A_1} + \overline{A_2}\right)$$

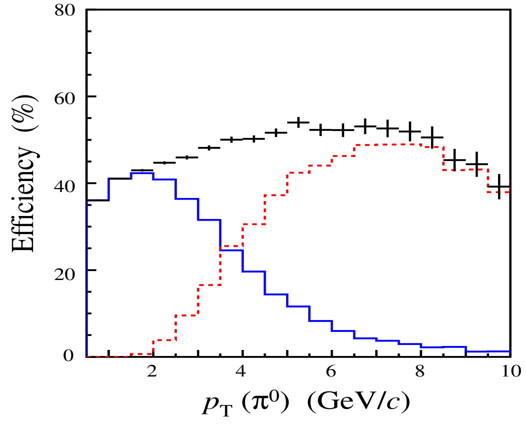
- **Measure 6 time-integrated tree level rates**
  - **Self-tagged through K^{*0} or $\overline{K}^{*0}$**
  - **Only relative rates needed**
  - **Big ratio: $|A_2/A_1| \sim 0.4$**
- **Need to resolve 8-fold ambiguity**
- **New physics in D^0-$\overline{D}^0$ mixing could affect this measurement**

Mode	Yield	S/B
$B_d \to \overline{D}^0\ (K^-\pi^+)\ K^{*0}$	3400	> 3.3
$B_d \to D^0\ (K^+\pi^-)\ K^{*0}$	500	> 0.6
$B_d \to D^0_{CP}\ (K^+K^-)\ K^{*0}$	600	> 0.7

$\sigma(\gamma) \sim 8°$ in a year
($55° < \gamma < 105°$, $-20° < \Delta < 20°$)

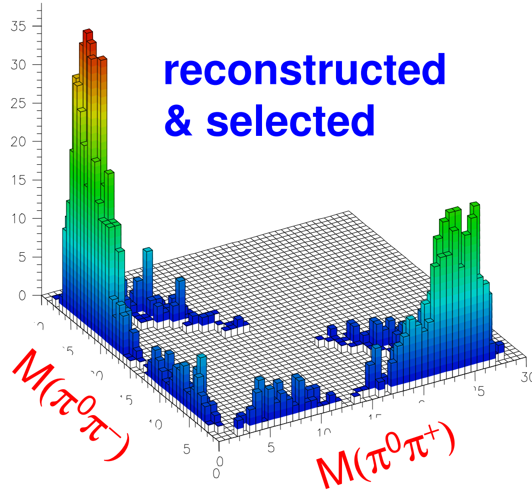
α from $B_d \rightarrow \rho\pi \rightarrow \pi^+\pi^-\pi^0$





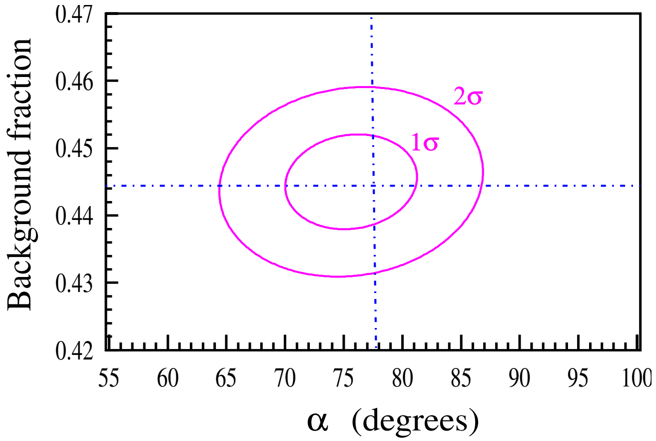
π^0 reconstruction efficiency

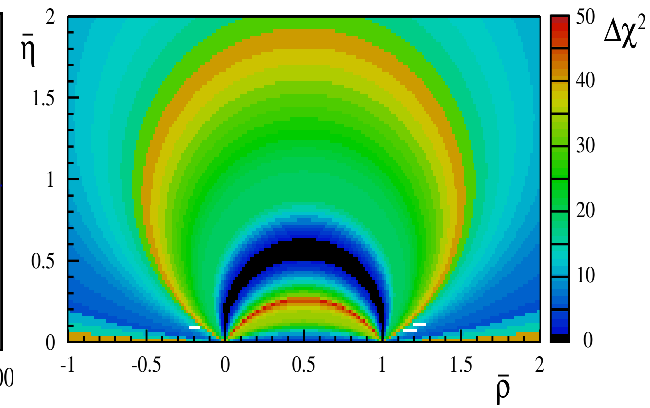
— merged π^0 — resolved π^0



- **14k event/year with B/S=0.80**
- **Time dependent Dalitz analysis**
- **Theoretically clean extraction of α from a 9-parameter fit, taking into account penguin contribution and resonant background**
- **Statistical precision in one year**

$\sigma(\alpha) < 10°$

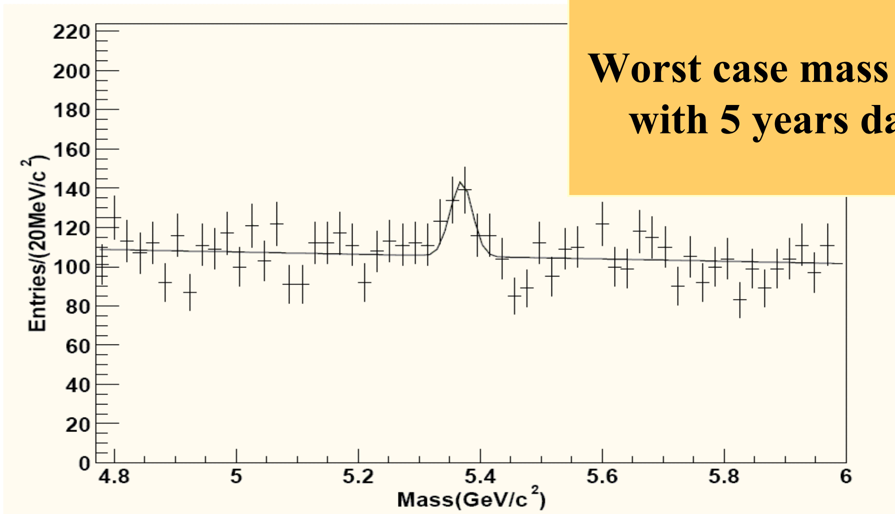




(Further work: systematics; α from $B \rightarrow \rho\rho$)

$B_s \to \mu^+\mu^-$

- **SM: Br = (3.5±1.0) x 10^{-9}**
- **Can be significantly enhanced in some SUSY models**
- **Ideal candidate for new physics**
- **17 events/year expected assuming SM Branching ratio**
- **Present limit B/S < 5.7 at 90% c.l. from** $b \to \mu x + cc$ *
- **Require more MC events to obtain precise estimate of B/S**
- **Challenges**
  - **Background suppression**
  - **trigger and selection efficiency determination**
  - **Normalization method**



Worst case mass plot with 5 years data

*** Events with μ from semi-leptonic b decays have been found to be dominating background**

Conclusions

- **The LHCb detector and software can efficiently reconstruct many different B decay channels with good performance in proper time resolution, particle identification and mass resolution**
- **This enables LHCb to**
  - **fully explore B_s mixing and decays**
  - **extract CKM parameters with high precision in different ways**
  - **perform study of rare B decays which are sensitive to new physics**
- **LHCb will have a great opportunity to make precision test of SM in flavour sector in order to find new physics or push possible new physics to a higher mass scale, from the first year of data taking.**

Thank you!

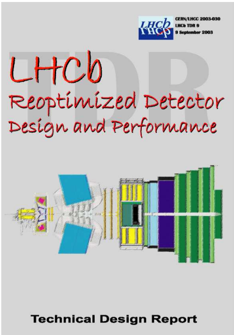
Back up slides

Systematics control

- **Some potential sources of experimental systematics:**
  - **$B/\bar{B}$ production asymmetry**
  - **Charge-dependent detection efficiencies**
  - **Background asymmetries**
  - **Lack of knowledge of proper time acceptance, proper time resolution and tagging performance**
- **Control strategy: use real data to determine wrong tagging efficiency, proper time resolution, proper time acceptance, charge dependant PID efficiencies. Examples:**
  - **Use buffer tampering to determinate tagging performance in separate trigger categories**
  - **Use D^* sample for PID**
  - **Use time-unbiased sample to study time resolution and acceptance**
  - **Fit signal and background simultaneously ($B_s \rightarrow D_s\pi$ and $B_s \rightarrow D_sK$)**

TDR event yields

Decay channel	Factors (in %) forming ε_{tot} (in %) $\varepsilon_{det} \times \varepsilon_{rec/det} \times \varepsilon_{sel/rec} \times \varepsilon_{trg/sel} = \varepsilon_{tot}$					Assumed visible BR (in 10^{-6})	Annual signal yield	B/S ratio from incl. $b\bar{b}$ back.
	ε_{det}	$\varepsilon_{rec/det}$	$\varepsilon_{sel/rec}$	$\varepsilon_{trg/sel}$	ε_{tot}			
$B^0 \to \pi^+\pi^-$	12.2	91.6	18.3	33.6	0.688	4.8	26. k	< 0.7
$B^0 \to K^+\pi^-$	12.2	92.0	25.2	33.2	0.94	18.5	135. k	0.16 ± 0.04
$B^0_s \to \pi^+K^-$	12.0	92.1	13.5	36.7	0.548	4.8	5.3 k	< 1.3
$B^0_s \to K^+K^-$	12.0	92.5	28.6	31.1	0.988	18.5	37. k	0.31 ± 0.10
* $B^0 \to \rho\pi$	6.0	65.5	2.0	36.0	0.028	20.	4.4 k	< 7.1
$B^0 \to D^{*-}\pi^+$	9.4	77.7	18.5	27.4	0.370	71.	206. k	< 0.3
$B^0 \to \overline{D}^0(K\pi)K^{*0}$	5.3	81.8	22.9	35.4	0.354	1.2	3.4 k	< 0.5
$B^0 \to D^0_{CP}(KK)K^{*0}$	5.2	81.4	29.4	31.2	0.390	0.19	0.59k	< 2.9
$B^0_s \to D_s^-\pi^+$	5.4	80.6	25.0	31.1	0.337	120.	80. k	0.32 ± 0.10
$B^0_s \to D_s^{\mp}K^{\pm}$	5.4	82.0	20.6	29.5	0.269	10.	5.4 k	< 1.0
$B^0 \to J/\psi(\mu\mu)K^0_S$	6.5	66.5	53.5	60.5	1.39	19.8	216. k	0.80 ± 0.10
$B^0 \to J/\psi(ee)K^0_S$	5.8	60.8	17.7	26.5	0.164	20.0	25.6 k	0.98 ± 0.21
$B^0 \to J/\psi(\mu\mu)K^{*0}$	7.2	82.7	35.1	69.9	1.462	59.	670. k	0.17 ± 0.03
$B^+ \to J/\psi(\mu\mu)K^+$	11.9	89.6	44.8	68.7	3.28	68.	1740. k	0.37 ± 0.02
$B^0_s \to J/\psi(\mu\mu)\phi$	7.6	82.5	41.6	64.0	1.672	31.	100. k	< 0.3
$B^0_s \to J/\psi(ee)\phi$	6.7	76.5	22.0	28.0	0.315	31.	20. k	0.7 ± 0.2
$B^0_s \to J/\psi(\mu\mu)\eta$	10.1	69.6	10.1	64.8	0.461	7.6	7.0 k	< 5.1
$B^0_s \to \eta_c\phi$	2.6	69.5	15.8	27.	0.078	21.	3.2 k	< 1.4
$B^0_s \to \phi\phi$	6.7	79.7	37.9	23.2	0.470	1.3	1.2 k	< 0.4
$B^0 \to \mu^+\mu^-K^{*0}$	7.2	82.4	16.1	73.5	0.704	0.8	4.4 k	< 2.0
$B^0 \to K^{*0}\gamma$	9.5	86.8	5.0	37.8	0.156	29.	35. k	< 0.7
$B^0_s \to \phi\gamma$	9.7	86.3	7.6	34.3	0.220	21.2	9.3 k	< 2.4
$B_c^+ \to J/\psi(\mu\mu)\pi^+$	11.5	89.3	20.7	60.8	1.30	680.	14.0 k	< 0.8



- Nominal year = 10^{12} bb pairs produced (10^7 s at L=2×10^{32} cm^{-2}s^{-1} with σ_{bb}=500 μb)

* The result for B→ρπ has been changed since TDR time.

Summary of sensitivities

- B_s mixing (1 year)
  - 5σ sensitivity $\Delta m_s < 68 ps^{-1}$, $\sigma(\Delta m_s) = 0.01 ps^{-1}$ from $B_s \rightarrow D_s \pi$
  - $\sigma(\Delta\Gamma_s/\Gamma_s)=0.018$, $\sigma(\phi_s)=0.06$ from $B_s \rightarrow J/\psi\phi$
- CKM angles (1 year)
  - $\sigma(\gamma) \sim 14°$ from $B_s \rightarrow D_s K$
  - $\sigma(\gamma) \sim 5°$ from $B \rightarrow hh$
  - $\sigma(\gamma) \sim 8°$ from $B_s \rightarrow D^0 K^{*0}$
  - $\sigma(\alpha) < 10°$ from $B_d \rightarrow \rho\pi$
  - $\sigma(\sin 2\beta) \sim 0.02$ from $B_d \rightarrow J/\psi K_s$
- Rare B decays
  - $\sigma(s_0/m_B^2)= 0.04$ from $B_d \rightarrow K^{*0} \mu^+\mu^-$ in 2 years
  - 17 $B_s \rightarrow \mu\mu$ events/year to be selected

$B_d \to K^{*0} \mu^+\mu^-$

- **SM: FCNC suppression, Br ~ 10^{-6}**
- **4.4k events/year, S/B > 0.4**

- **New physics probe $A_{FB}(s)$: forward-backward asymmetry in the μμ rest frame, sensitive to some SUSY models**
- **Experimentally measure $A_{FB}(s)$ and look for intersection point with y=0**
- **$A_{FB}(s/m_B^2)$ reconstructed using toy MC (two years data, background subtracted)**

$\sigma(s_0/m_B^2) = 0.04$