LHC-B:
A dedicated experiment on CP violation in B decays at LHC

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CKM matrix

Matrix elements of V_{CKM} determined by charged current coupling to the $W^{\pm}$ bosons

$$V_{CKM} \equiv \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix}$$

in Wolfenstein form ...

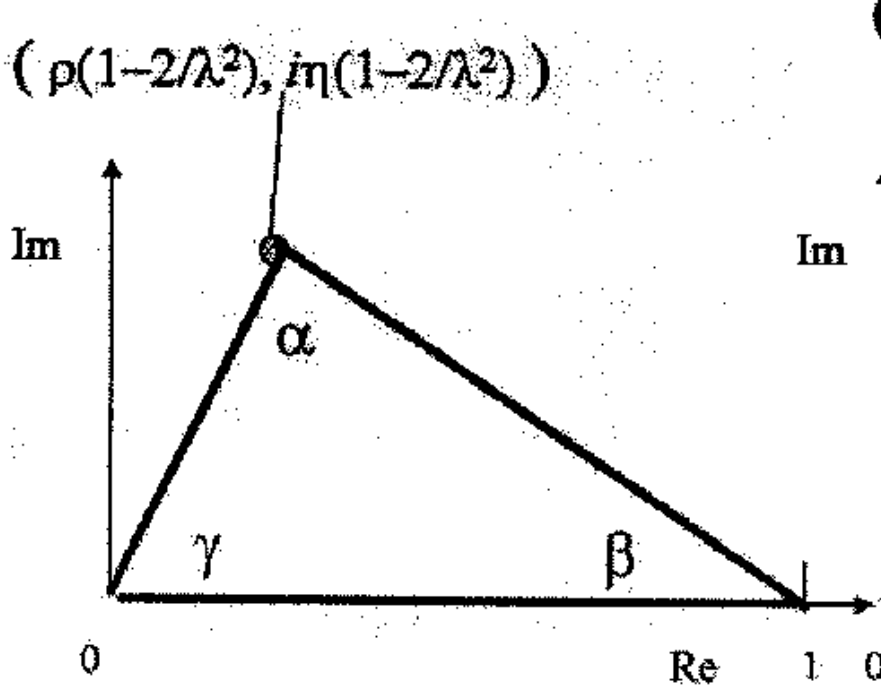
$$V_{\text{Wolfenstein}} = \begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & A\lambda^3(\rho - i\eta) \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ A\lambda^3(1-\rho-i\eta) & -A\lambda^2 & 1 \end{pmatrix}$$

where $\lambda \equiv \sin\theta_c$

Complex phase in V_{CKM} responsible for CP violation in the Standard Model

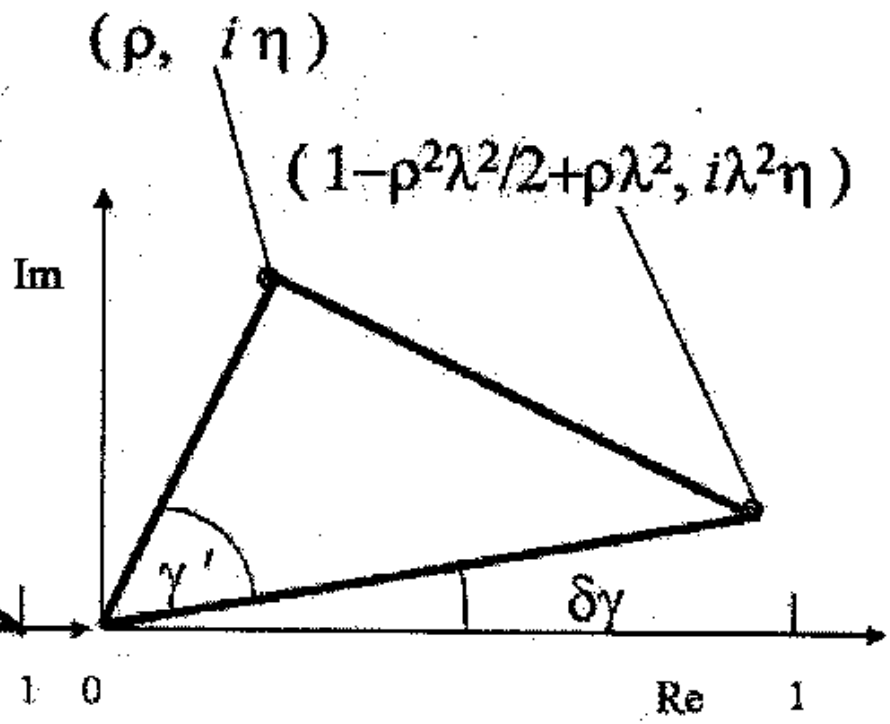
Unitarity Triangle

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



Unitarity Triangle

$(V_{ud}^{*} V_{td} + V_{us}^{*} V_{ts} + V_{ub}^{*} V_{tb} = 0)$



Re-write CKM matrix in terms of $\alpha, \beta, \gamma, \delta\gamma$:

$$\begin{pmatrix} 1-\frac{1}{2}\lambda^2 & \lambda & |V_{ub}|e^{-i\gamma} \\ -\lambda & 1-\frac{1}{2}\lambda^2 & A\lambda^2 \\ |V_{td}|e^{-i\beta} & -|V_{ts}|e^{-i\delta\gamma} & 1 \end{pmatrix}$$

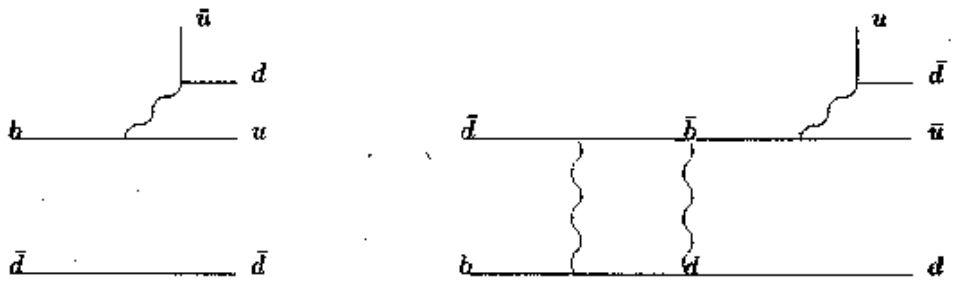
Measure $\alpha, \beta, \gamma, \gamma', \delta\gamma, x_s$
to overconstrain the Unitarity $\triangle$

$$\alpha + \beta + \gamma = \pi$$

$$\begin{array}{ccccc} 10^\circ & \leq & \alpha & \leq & 150^\circ \\ 5^\circ & \leq & \beta & \leq & 45^\circ \\ 20^\circ & \leq & \gamma & \leq & 165^\circ \end{array}$$

CP Violation in B Decays

Look at interference between $B^0 - \bar{B}^0$ mixing



$$V_{ub}V_{ud}^* \qquad V_{tb}V_{td}^*V_{td}^*V_{tb}V_{ub}^*V_{ud}$$
$$e^{-i\gamma} \qquad e^{+i(2\beta+\gamma)}$$

Interference term
$\sim \Im(e^{-i(2\beta+2\gamma)}) \rightarrow \sin 2\alpha$

By measuring B-decays can measure the angles & sides of Unitarity triangle

$\sin 2\alpha$	$B_d^0 \rightarrow \pi^+\pi^-$
$\sin 2\beta$	$B_d^0 \rightarrow J/\Psi K_s^0$

x_s	$B_s^0 \rightarrow D_s\pi$
γ'	$B_s^0 \rightarrow D_sK$
γ	$B_d^0 \rightarrow D^0K^{*0}$

Principle of Measurement

Pure B^0 beam: $n(t) \propto e^{-t}\,(1 + \sin 2\beta\ \sin xt)$

Pure $\overline{B^0}$ beam: $\bar{n}(t) \propto e^{-t}\,(1 - \sin 2\beta\ \sin xt)$

(mixing parameter $x = \Delta M/\Gamma \approx 0.67$)

$$a(t) = \frac{n(t) - \bar{n}(t)}{n(t) + \bar{n}(t)} = \sin 2\beta\ sinxt$$

Time integrated asymmetry:

$$A_{int} = \frac{\int n(t)\,\mathrm{d}t - \int \bar{n}(t)\,\mathrm{d}t}{\int n(t)\,\mathrm{d}t + \int \bar{n}(t)\,\mathrm{d}t} = \sin 2\beta\ \frac{x}{1+x^2} \approx 0.46$$

asymmetry proportional to $\sin 2\beta$

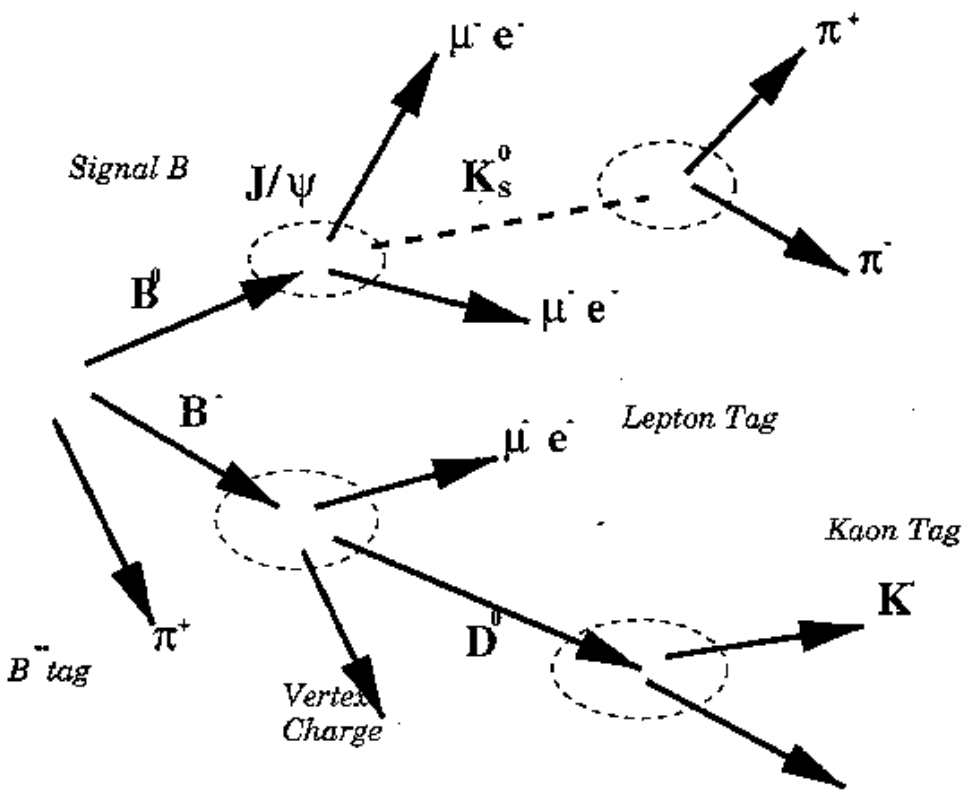
1. Count number of decays $B^0 \to J/\psi\, K^0_S$

2. Count number of decays $\overline{B^0} \to J/\psi\, K^0_S$

necessary:
tag of the initial flavour (b or $\bar{b}$)
with the second B meson

B Flavour Tagging

Tag initial flavour of B
Example: $B^0 \to J/\psi K_s^0$



Detector Requirements
τ_B, m_B resolution
particle ID

Dilution
Particles from b decays
Particles NOT from b decays
(π/K decays, $\gamma \to e^+e^-$)

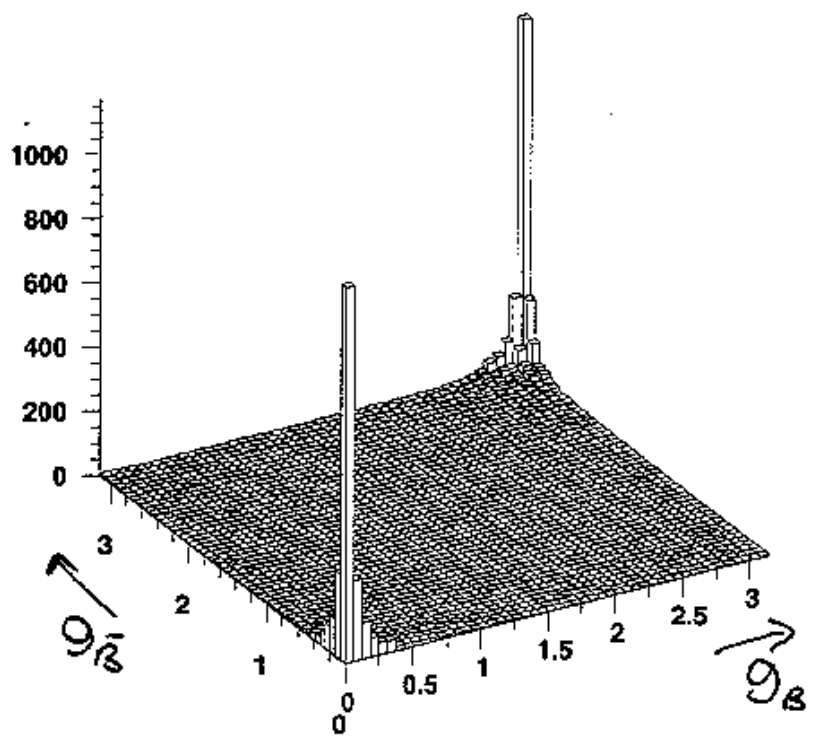
Need to know quality of tag

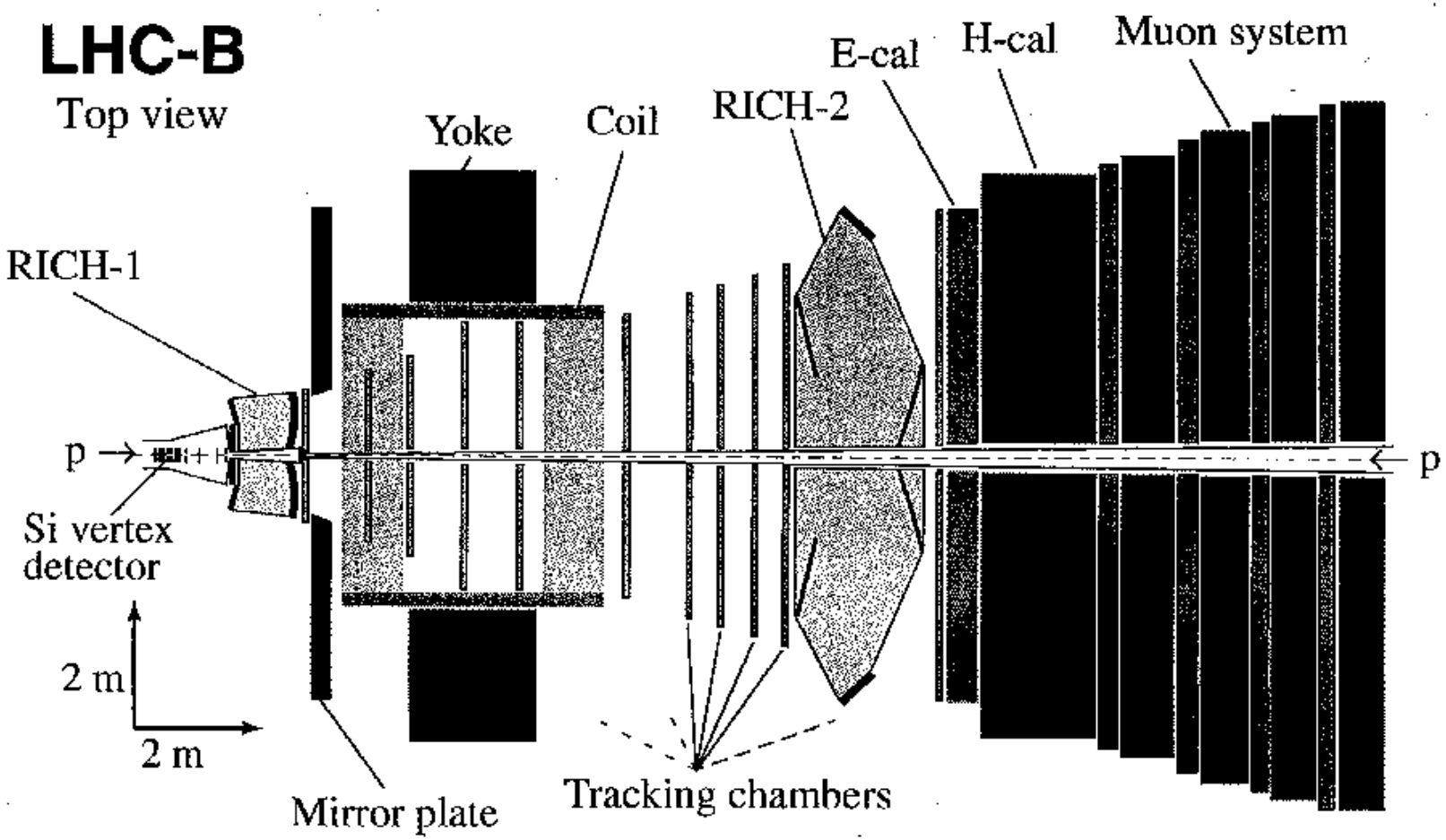
CP Violation at LHC

$\sigma_{\text{inel}} = 80$ mb $\quad \sigma_{b\bar{b}} = 500\mu$b

$\Longrightarrow$ **production rate** $\sim 10^5$ **Hz**

***b* quarks are produced forward**




LHC-B
Top view
Yoke
Coil
RICH-2
E-cal
H-cal
Muon system
RICH-1
p
p
Si vertex
detector
2 m
2 m
Mirror plate
Tracking chambers

LHC-B Trigger

Level-0: Reduction of rate to $\sim$ 1MHz
selecting minimum bias events by
high p_T muon, electron or hadron

Level-1: reduction of rate to $\sim$ 40kHz
rejecting minimum bias events by vertex detector
and tracking stations (separately)

Readout to data acquisition buffer

Level-2: reduction of rate to $\sim$ 5kHz
mainly rejecting minimum bias events by combining
several different detectors

Level-3: reduction of rate to $\sim$ 200Hz (16 MB/sec on tape)
rejecting uninteresting B events by
partial and full reconstruction of B final states

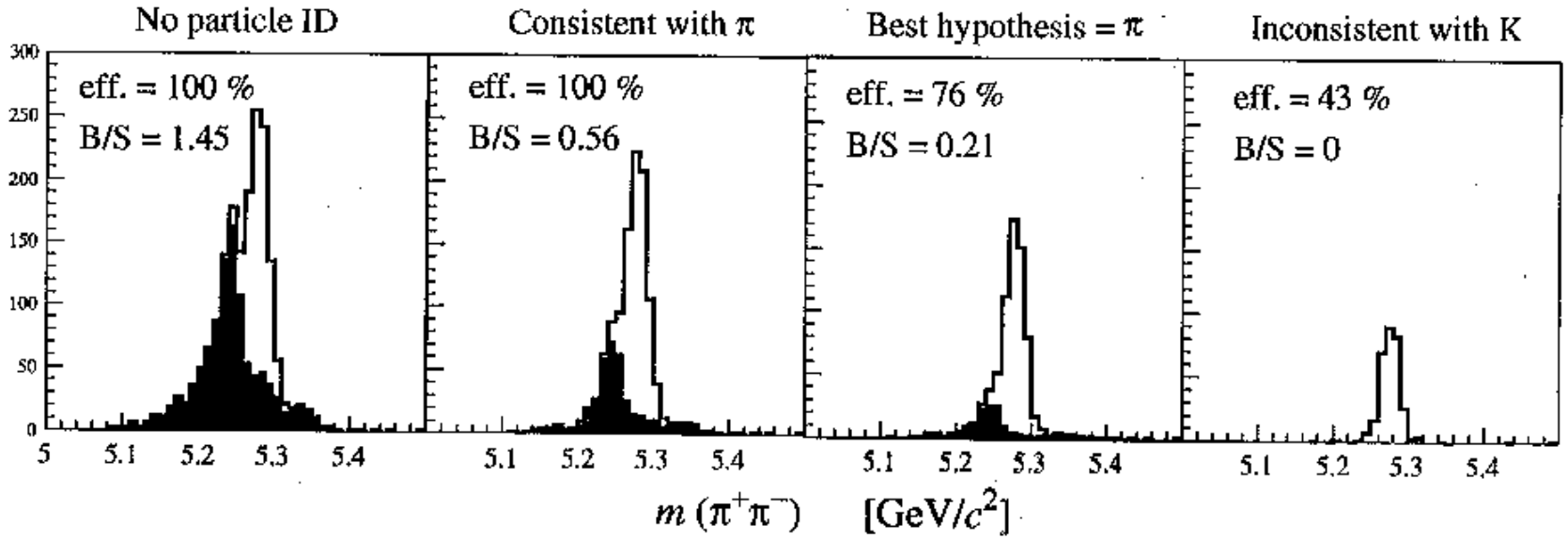
LHC-B

$(1+B/S)$

Particle identification and $B \to \pi^+\pi^-$ reconstruction

all combinations

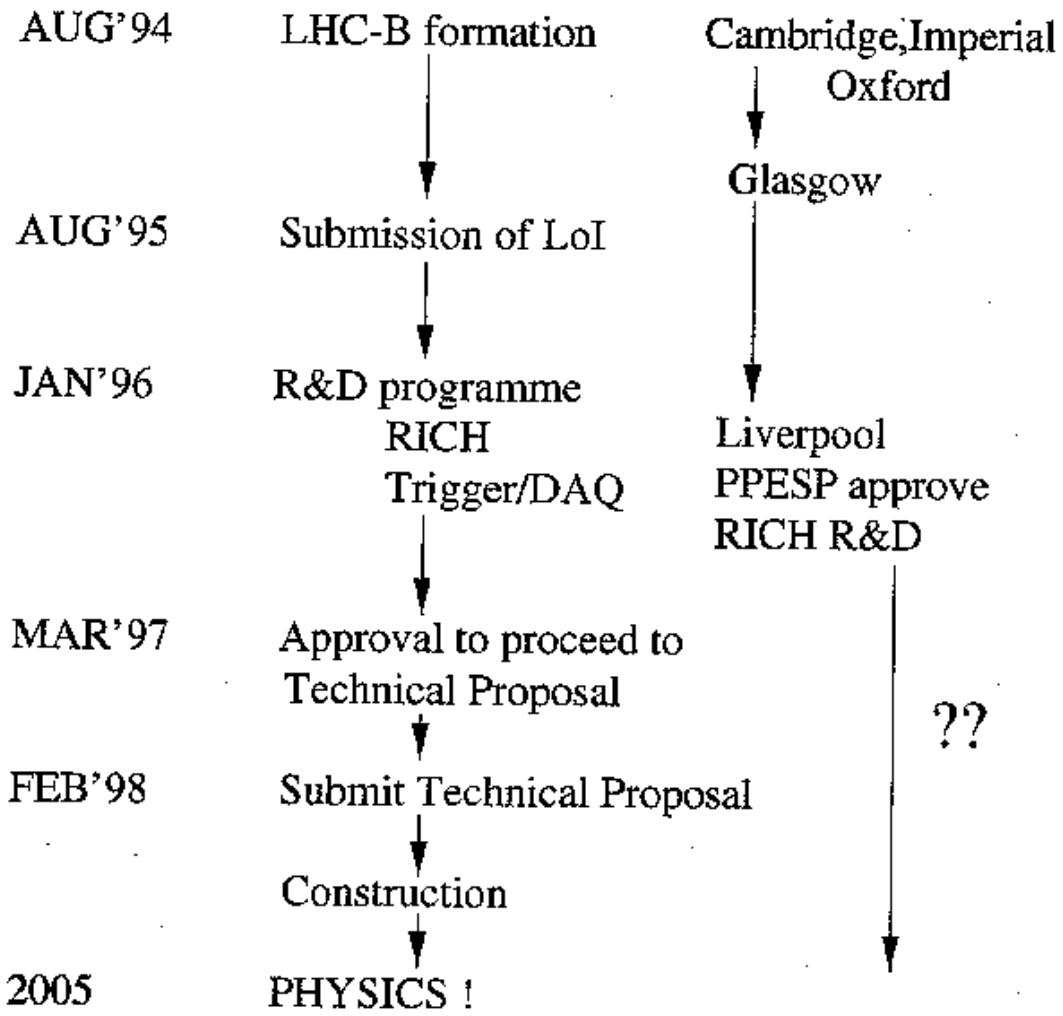
background ($B_d \to K\pi$; $B_s \to K\pi$, KK)



$\sin 2\beta$	$B_d \to J/\Psi K_S$	55k		
$\sin 2\alpha$	$B_d \to \pi^+\pi^-$	14k	(if no penguin)	
γ	$B_d \to DK^*$	0.9k		
γ'	$B_s \to D_s K$	3.3k		
$\sin 2\delta\gamma$	$B_s \to J/\Psi\phi$	44k		
x_s	$B_s \to D_s\pi$	35k		

Measurements not systematic limited

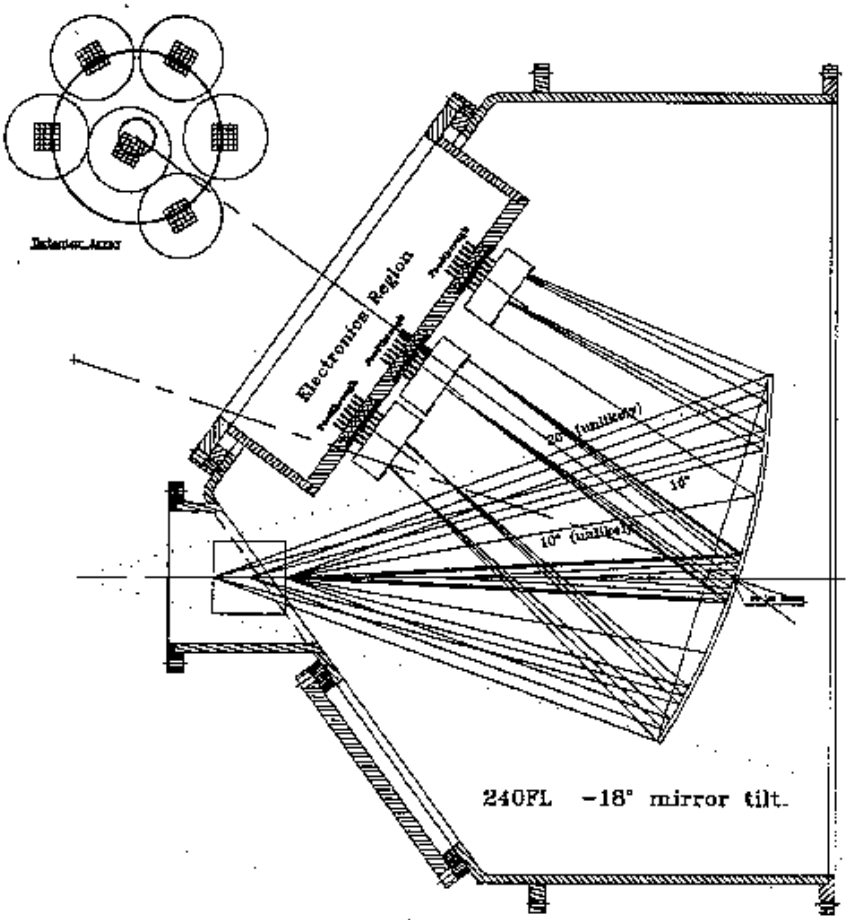
Status of LHC-B & UK Involvement



Testbeam RICH

RICH prototype

$\frac{1}{4}$ size final detector



Placed in testbeam at CERN

Aerogel and C_4H_{10} Radiators

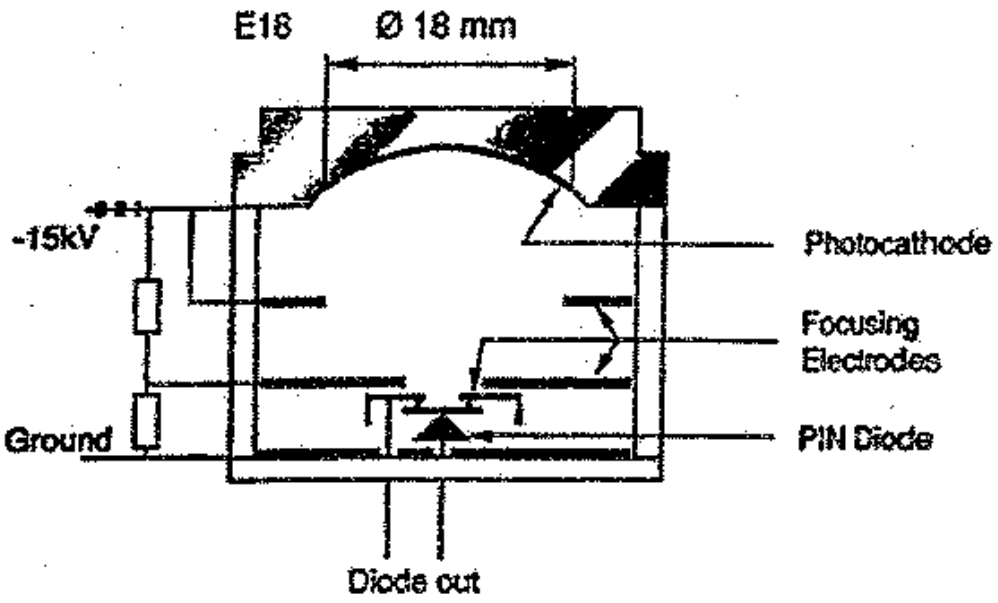
15 GeV $-$ ve beam

π^-

e^-

K^-

Hybrid PhotoDiode

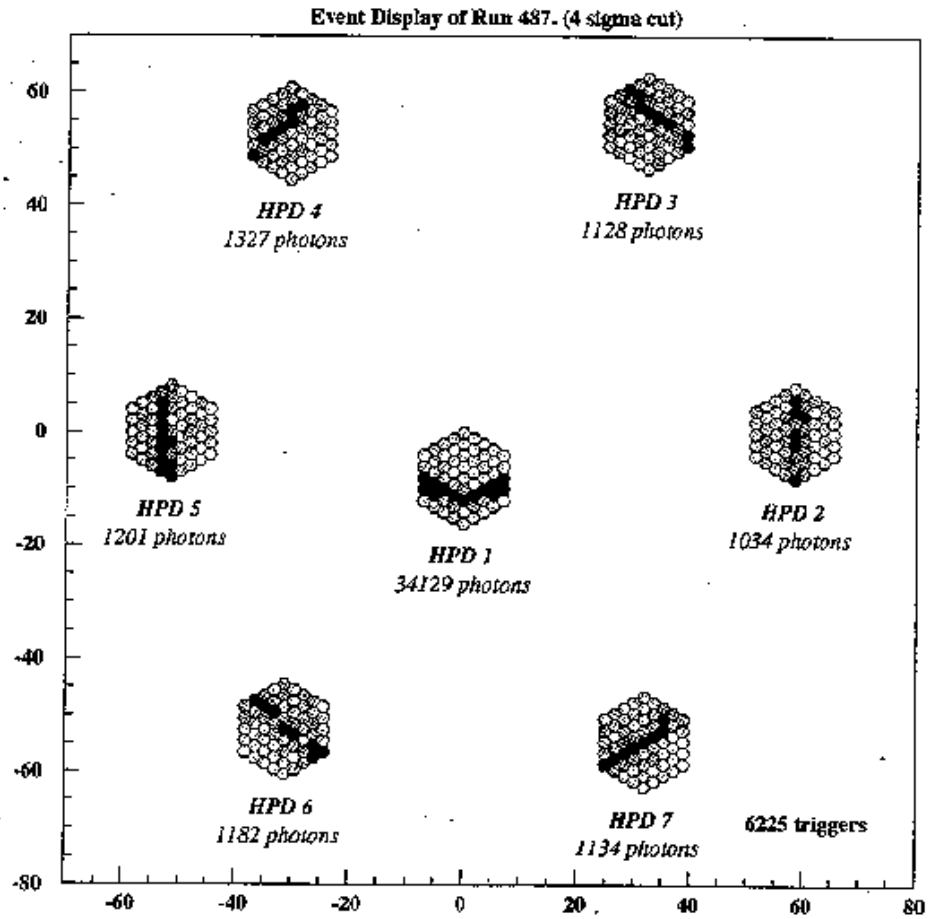


Large acceleration voltage for photoelectron (massive E-field ≈ 1 MVm^{-1})

Single electron accelerated and energy dissipated in silicon detector (as opposed to multiplicative technique of Photomultiplier tube)

Čerenkov Rings

First observation of Č rings with pixellated devices



Pixel hit if separated from 0th (pedestal) peak by 4σ
(Outer) aerogel ring
(Inner) C_4H_{10} ring

HERA-B vs. BaBar

10^7 sec. running at design luminosity

	BaBar	HERA-B
$J/\Psi K^0_s$ evts		
$\Delta \sin 2\beta$	± 0.10	0.13
All channels		
$\Delta \sin 2\beta$	± 0.06	0.13
$\pi^+\pi^-$		
$\Delta \sin 2\alpha$	± 0.20	$\pm 0.14\sqrt{1+B/S}$
$\rho^\pm\pi^\pm$		
$\Delta \sin 2\alpha$	± 0.11	
All channels		
$\Delta \sin 2\alpha$	± 0.085	$\pm 0.14\sqrt{1+B/S}$

B physics at Hadron Machines

results taken from "Beauty'96"

	CDF/D0	HERA-B	ATLAS/CMS	LHC-B
$\Delta \sin(2\alpha)$	~ 0.10	~ 0.14	0.10/0.07	0.039
$\Delta \sin(2\beta)$	~ 0.10	~ 0.13	0.02/0.07	0.023
$\Delta\gamma$				$6 - 16^\circ$
x_s		≤ 17	≤ 34	≤ 55