Tracking at BES-III

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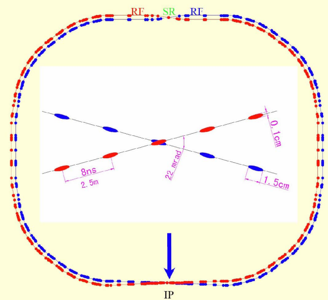
BEPC-II and BES-III

BEPC-II: a τ-charm factory



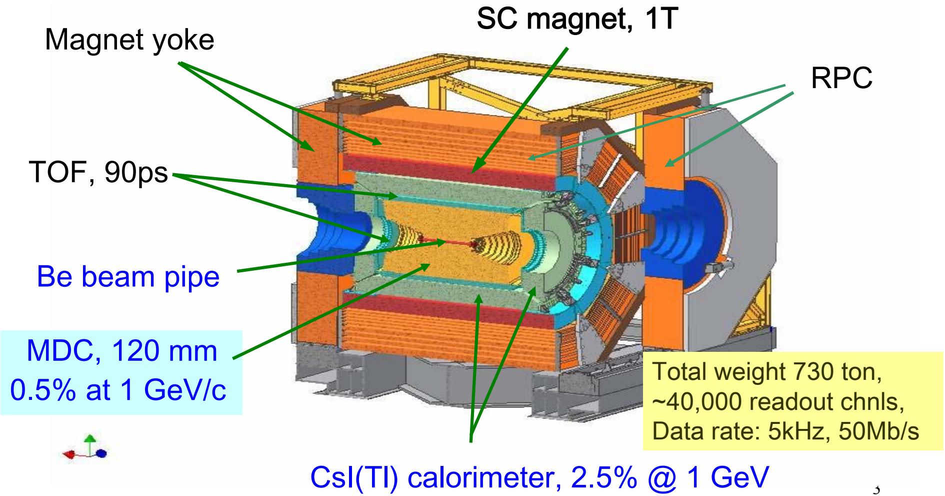
BEPC-II

Upgrade of BEPC (started 2004)
Beam energy 1 . . . 2.3 GeV
Optimum energy 1.89 GeV
Single beam current 0.91 A
Design luminosity $10^{33}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Current record: $6.5 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Crossing angle ± 11 mrad

Data samples

106 M + 400 M ψ' (Apr. 2009 + 2012)
225 M + 1,000 M J/ψ (Jul. 2009 + 2012)
3 fb^{-1} $\psi(3770)$ (2010–2011)
0.5 fb^{-1} near 4.010 GeV (2012)
Mass scan near $\tau\tau$ threshold
Scan for R

BES-III detector



Physics requirements

- τ-charm region, $\sqrt{s} = 2 \cdots 4.3\,\mathrm{GeV}$
- e^+e^- CMS almost at rest in lab frame
  crossing angle of $\pm 11\,\mathrm{mrad}$ creates small boost
- Typical hadronic final states:
  most probable momentum $\approx 0.3\,\mathrm{GeV}/c$,
  almost no tracks above $1\,\mathrm{GeV}/c$
- most probable photon energy $\approx 100\,\mathrm{MeV}$

➠ Need tracking . . . for rather low energetic particles:
minimise multiple scattering

- typical $\beta\gamma c\tau$ for D mesons $\sim 40\,\mu\mathrm{m}$:
  no vertex detector to minimise material

Multilayer Drift Chamber: Design goals

- Spatial (single-hit) resolution

$$\sigma_x \approx 130\,\mu\mathrm{m}$$

- Momentum resolution

$$\frac{\sigma(p_t)}{p_t} \approx 0.5\% \quad \text{at } 1\,\mathrm{GeV}/c$$

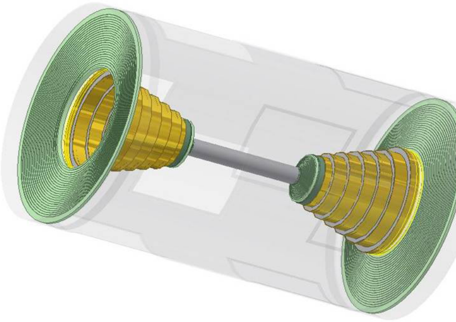
- Cell efficiency $> 98\%$
- Energy loss

$$\frac{\sigma_{\mathrm{d}E/\mathrm{d}x}}{\mathrm{d}E/\mathrm{d}x} \approx 6\%$$

  to provide π/K separation
- Reconstruct long-lived K_s^0 and Λ decaying in MDC, as well as short, low p_t tracks
- Contribute to L1 trigger

MDC design

- Design resembles CLEO-III drift chamber
- Outer chamber with stepped endplate to accommodate low-β SC quadrupole magnets
- Inner and outer chamber, sharing gas volume
  inner chamber can be replaced in case of radiation damage/ageing
- In 1 T axial field of superconducting solenoid

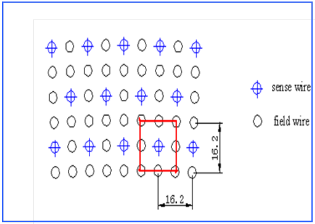


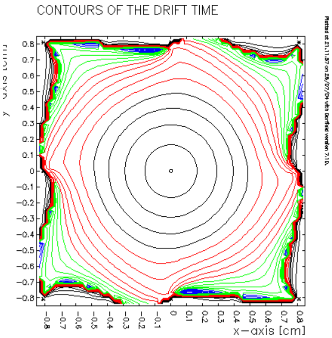
Mechanical parameters

$r_{\text{inner}} = 63\,\text{mm}$, 2 mm away from Be beam pipe
$r_{\text{outer}} = 810\,\text{mm}$
Length 2582 mm (outer)
Coverage: $|\cos\theta| \leq 0.93$ (innermost layer), ≤ 0.83 (outermost layer)

MDC: drift cells

- 6796 sense wires, 25 μm gold-plated tungsten
- 21884 Field wires, 110 μm gold-plated Aluminium
- Small, almost square drift cells:
  inner chamber 6 mm, outer chamber 8.1 mm
  fast; good spatial resolution; but needs careful $r - t$ calibration
  (known to work well: Belle, BABAR, CLEO-III)





MDC: gas mixture

Desired properties

- Low Z (low multiple scattering)
- Small Lorentz angle
- Large primary ionisation
- Small diffusion coefficient (large contribution to single-cell resolution)

Gas mixture: $He:C_3H_8$ 60:40
radiation length of gas mixture: 550 m
He-based counting gases used in BABAR, Belle, KLOE, CLEO-III

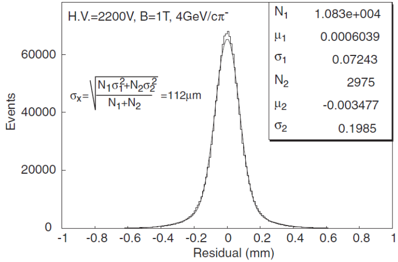
Ageing tests

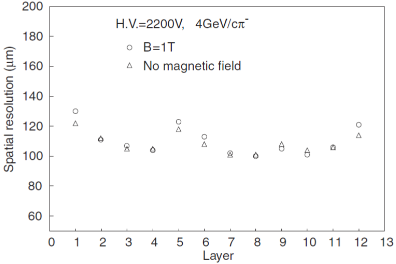
Collected charge 70 mC/cm $\widehat{=}$ 5 a BES-III operation
Drop in gas gain $\sim 10 - 13\%$
acceptable performance

Prototype Beam Test at KEK

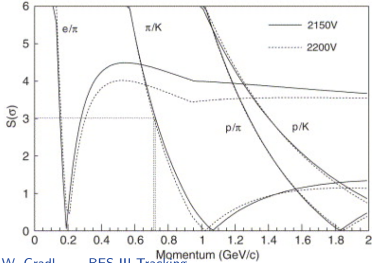
NIM A557, 436 (2006)

Single-hit resolution





PID via dE/dx



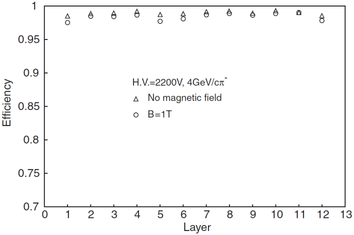
Resolution $< 130\,\mu\mathrm{m}$

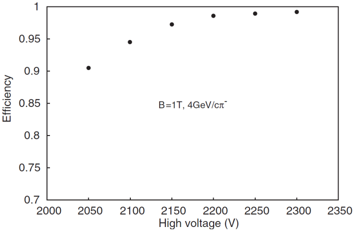
pi/*K* separation at 3σ up to 770 MeV/c momentum

performance as designed!

Single cell efficiency

Results from prototype test at KEK





Plateau of $\varepsilon > 98\%$ reached at operating voltages above 2200 V
High efficiency in 1 T magnetic field!

Momentum resolution

In uniform axial field, with n equally spaced measurements:

$$\frac{\sigma_{p_t}}{p_t} = \sqrt{\left(\frac{\sigma_{p_t}^{\text{wire}}}{p_t}\right)^2 + \left(\frac{\sigma_{p_t}^{\text{MS}}}{p_t}\right)^2}$$

$$\frac{\sigma_{p_t}^{\text{wire}}}{p_t} = \frac{330\sigma_x}{B\,L^2}\,p_t\sqrt{\frac{720}{n+5}}$$

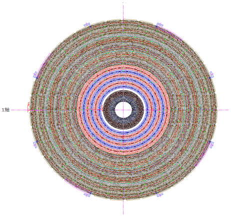
$$\frac{\sigma_{p_t}^{\text{MS}}}{p_t} = \frac{0.05}{B\,L}\sqrt{1.43\frac{L}{X_0}}\left(1+0.038\ln\frac{L}{X_0}\right)$$

For a $1\,\mathrm{GeV}/c$ track at 90°, with single-hit resolution as measured:
expect $\sigma_{p_t}/p_t \approx 0.47\%$

MDC spatial resolution

43 sense wire layers, arranged in 11 "superlayers"
6 superlayers with stereo angles $\pm 3^\circ$, 5 axial superlayers

Layer No.	Superlayer No.	Tilted angle
1–4	1	U: $-(3.0^\circ–3.3^\circ)$
5–8	2	V: $+(3.4^\circ–3.9^\circ)$
9–20	3–5	A: 0°
21–24	6	U: $-(2.4^\circ–2.8^\circ)$
25–28	7	V: $+(2.8^\circ–3.1^\circ)$
29–32	8	U: $-(3.1^\circ–3.4^\circ)$
33–36	9	V: $+(3.4^\circ–3.6^\circ)$
37–43	10–11	A: 0°



Resulting spatial resolution:

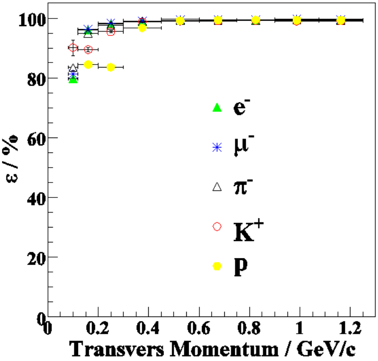
$$\sigma_{r\phi} = 130\,\mu\text{m}$$
$$\sigma_z \approx 2\,\text{mm} \qquad \text{at the interaction point}$$

Track finding

Initally using two approaches:

- MdcPatRec: BABAR, using template matching in each superlayer
- TrkReco: Belle, conformal transformation to find segments

TrkReco in conjunction with a track fitter using Kalman filter



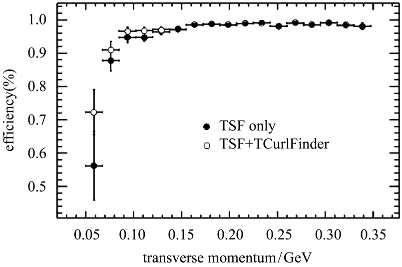
Simulated data, rather old study (2007)

Low p_t track reconstruction

Jia LK *et al.*, Chin.Phys.C 34, 1866 (2010)

- Tracks need at least $p_t = 122\,\mathrm{MeV}/c$ to traverse whole MDC
- Other tracks will loop in MDC

➡ Needs dedicated track finder algorithm for low-p_t tracks



Simulated data:
$\psi(2S) \to J/\psi\,\pi^+\pi^-$
π^+ tracking efficiency improved at very low p_t

Summary

- BES-III MDC provides reliable, efficient, and precise tracking for a high-luminosity experiment in the τ-charm region
- Low momentum of tracks requires specific design choices (materials, gas mixture, . . .)
- Good performance close to design