BEAM ENERGY SPECTROMETER

DESY – Dubna – TU Berlin

$\left\{ \begin{array}{c} \textbf{Machine physicists, engineers,} \\ \textbf{particle physicists} \end{array} \right\}$

Significant overlap with other efforts

Accelerator, Beam Delivery,

Detector Groups, Physics Groups

Goal

Technical Design Report

for Energy Spectrometer

$\Rightarrow$ **Spring 2004**

Energy Precision needed:

(dictated by Physics)

- Target $(1\text{-}2) \times 10^{-4}$ for $\Delta E_b/E_b$

  from $2\, m_{top} < \sqrt{s} \leq 1$ TeV

  $\rightarrow \Delta m_{top}, \Delta m_H \sim 50$ MeV

- Recognize 5×10^{-5} at $\sqrt{s} = 2\, m_W$

  $\rightarrow \Delta m_W \sim 6$ MeV

- New Z line shape scan

  $\Delta E_b/E_b \sim 10^{-5}$ (-10^{-6})

Questions / Comments

- Can basic requirements on precision be achieved?
- Extrapolation of existing devices
  or clever new ideas needed?
- Energy, energy width (after IP) needed?
- Redundant measurement(s) necessary?
  (cross-checks / different technique(s))
-
-
-
-
- Default energy: E_b = 250 GeV
  cover also extreme cases: 45 GeV
  400 GeV

Techniques proposed

- Beam Instrumentation

  - Magnet spectrometer (LEP)
  - Møller scattering (Bhabha scattering) (?)
  - Spin precession method (Telnov)

  } upstream of IP

  - Wire-imaged synchrotron radiation detector (SLAC)
    WISRD-style
  - \`Wire´ scanner at high dispersion point

  } downstream of IP

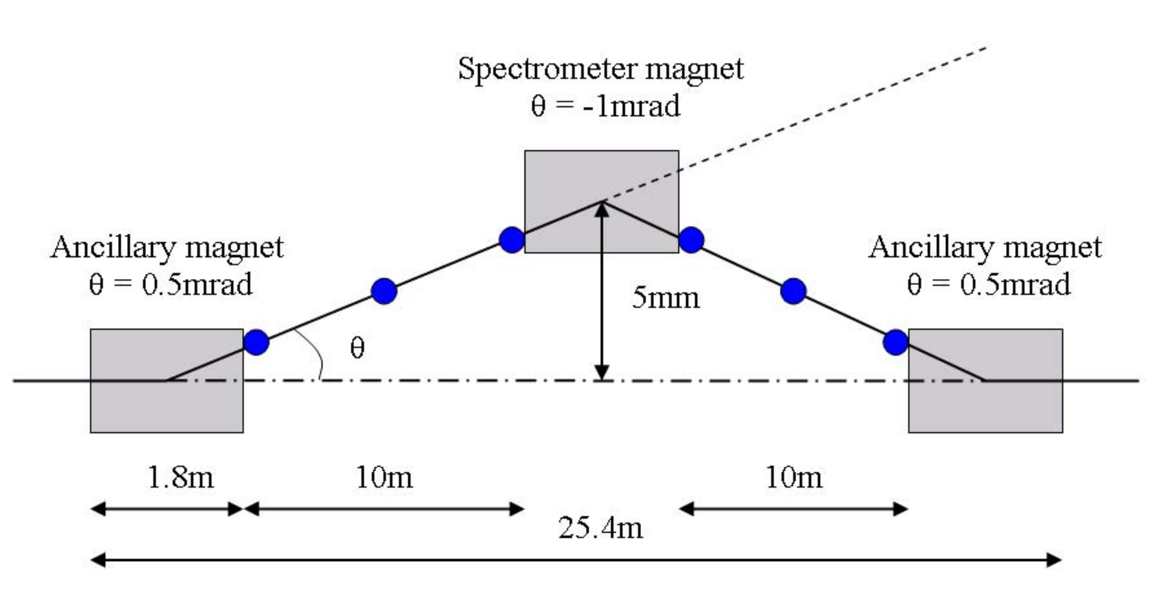
- ‚Physics' Techniques

  - Radiative returns using
    Z mass ($e^+e^- \to Z\gamma \to \mu^+\mu^-$ (γ)
    ‚gold-plated' channel
    [muon momentum measurements in forward direction (200-400 mrad]

  } event accumulation $\Downarrow$ <$\sqrt{s}$>

BPM – based Spectrometer

TDR:



- In-beam line spectrometer with fixed bending angle
- BPMs used to measure beam position ⇒ bending angle

$$E_b \propto \frac{1}{\theta} \int B dl$$

TESLA: large bunch spacing ~ 330 ns (~ 180 ns)

⊕

fast high-precision BPMs

⇒ E_b (e^+/e^-) for each bunch

- Questions related to BDS

- Magnets

- BPMs

- Alignment / Stability

Position of the spectrometer within the BDS:

- Diagnostic section
- Final Focus Section,

  but ~ 150 m upstream of IP

- Space required: 30 – 50 m
- also, aspect ratio σ_x/σ_y = 30 – 100

  since σ_y ~ few microns

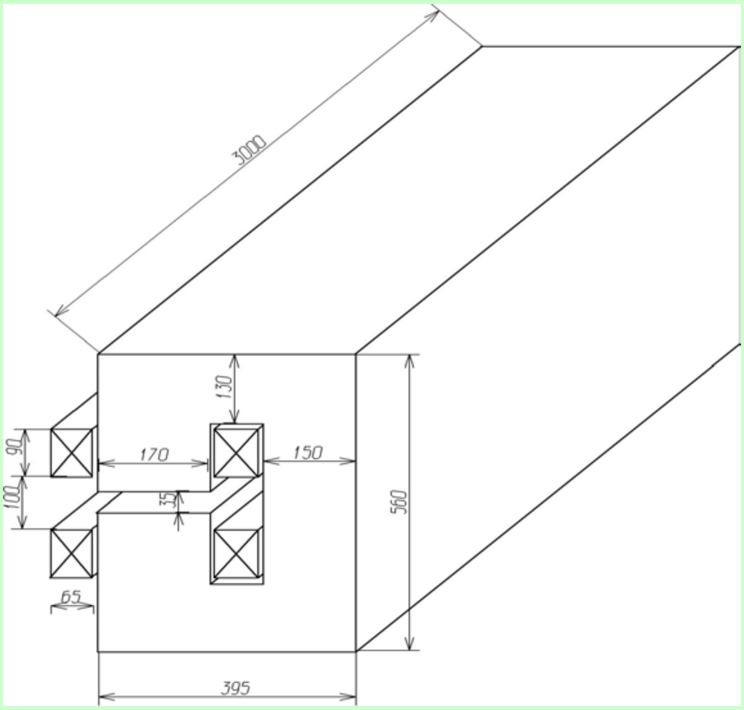
  $\Rightarrow \sigma_x \leq 40\ \mu m$

- account for the spectrometer during design phase of BDS!
- impact to the lattice design:

  $\Rightarrow$ negligible

Spectrometer Magnet

Basic design:



The 3D view of the spectrometer magnet (the sizes are in mm)

- C-shaped iron magnet
- length = 3 m; gap height = 35 mm; θ_{bend} = 1 mrad

Question: iron vs. superconducting?

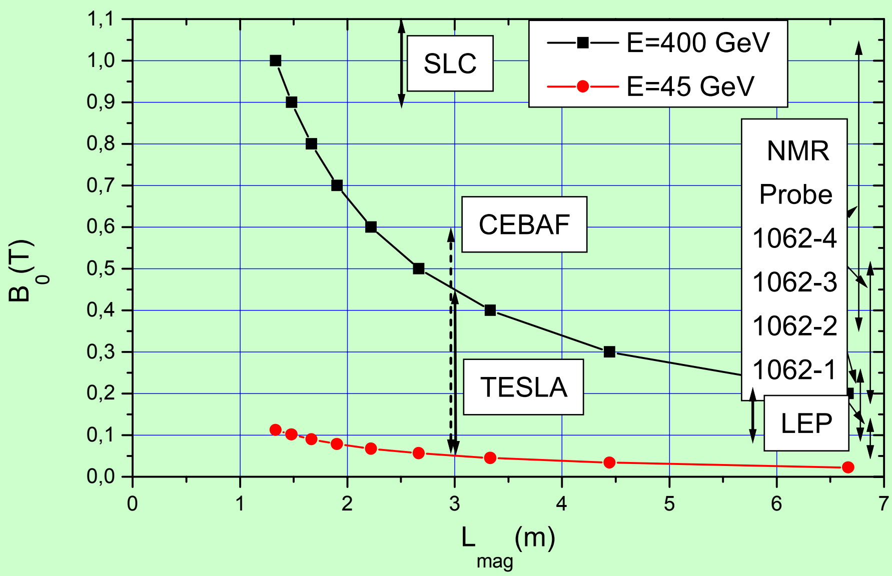
no expertise of ‚cold' magnets

\- volunteer -

$\Rightarrow$ Follow iron magnet concept

Table: Basic spectrometers magnet parameters

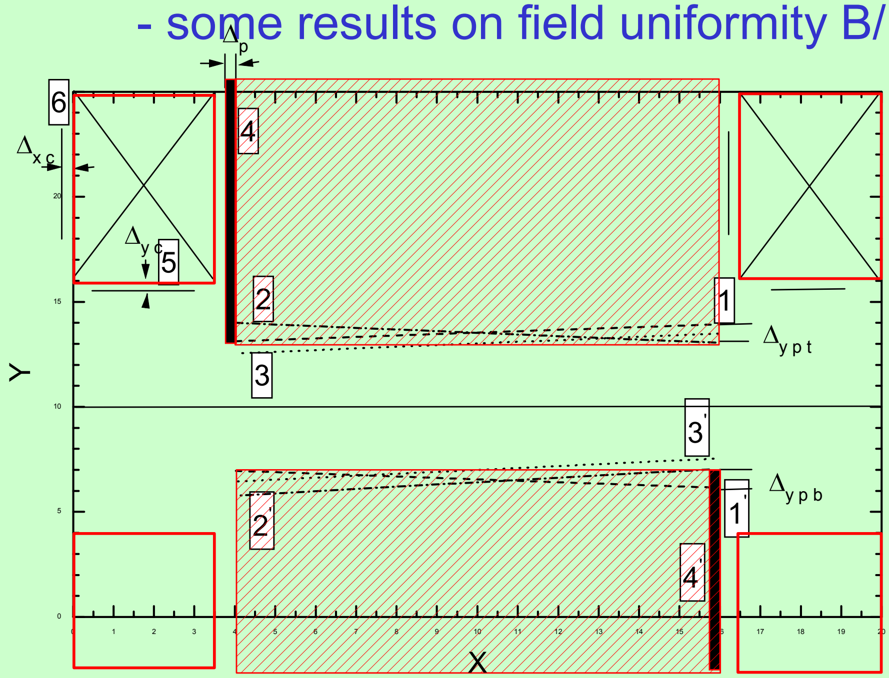
	SLC	LEP	CEBAF	TESLA (Proposal)
Energy E (GeV)	42 - 50	40 - 100	0.5 – 7	45 - 400
Absolute accuracy of energy measurement ΔE/E	5×10^{-4}	1×10^{-4}	1×10^{-4}	1×10^{-4} - 1×10^{-5}
Bending angle (mrad)	18.286	3.75		1
Magnetic field range (T)	0.88 – 1.1	0.086 – 0.216	0.04 – 0.6	0.05 – 0.44
Magnetic field integral (T•m)	2.56 – 3.05	0.5 – 1.242	0.12 – 1.8	0.15 – 1.33
Magnetic measurement error of the field integral (relative)	7×10^{-5}	3×10^{-5}	1×10^{-5}	3×10^{-5}
Magnet iron length (m)	2.5	5.75	3	3
Effective magnet length (m)				3.045
Gap height (mm)	31.7	100	25.4	35
Magnet type	H	C	C	C
Laboratory ∫B•dl measurement technique	Moving wire, moving probe (NMR, Hall)	Moving probe (NMR, Hall), search coil	NMR probe, 2 search coils	Should be estimated
Operational ∫B•dl measurement technique	Flip coil, fixed probes (NMR)	Fixed probes (NMR)		Should be estimated
Energy loss due to synchrotron radiation (max) (MeV)		3.55		120



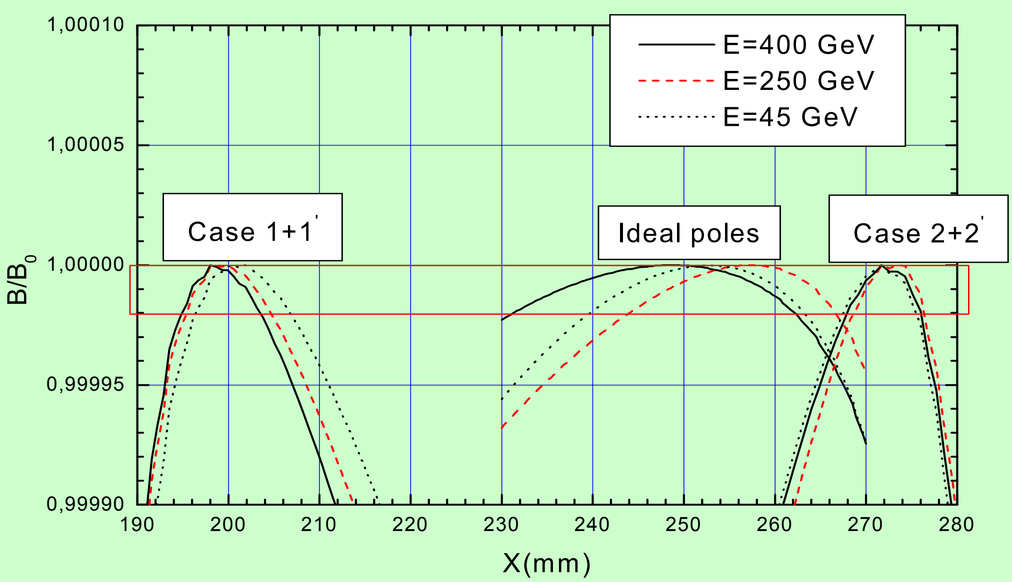
$B_0=f(L_{mag})$ relations for the TESLA spectrometer magnet

Now, geometrical distortions were inserted to the magnet geometry

- some results on field uniformity B/B_0:



The scheme of the magnet geometry distortions.



Normalized magnetic field of the spectrometer magnet (ideal geometry, cases with distortions)

⇒ most important

parallelism tolerance of the poles

≤ 0.02 mm

for $B/B_0 \leq 1\text{x}10^{-5}$

⇒ Requires careful design and manufacturing

Summary:

- Field uniformity $B/B_0 \leq 1\text{x}10^{-5}$ over a common range of few mm in x, for E_b = 45 ... 250 ... 400 GeV
- Error for the magnetic field integral $\Delta B/B \cong 1 \text{ x } 10^{-5}$
  (apply more than one measurement technique: NMR probes, search coils)
- Temperature stabilization $\Delta T \leq 1^o$
- Further activities:
  - 3 D calculations (MAFIA)
  - design for ancillary magnets
  - measurement techniques

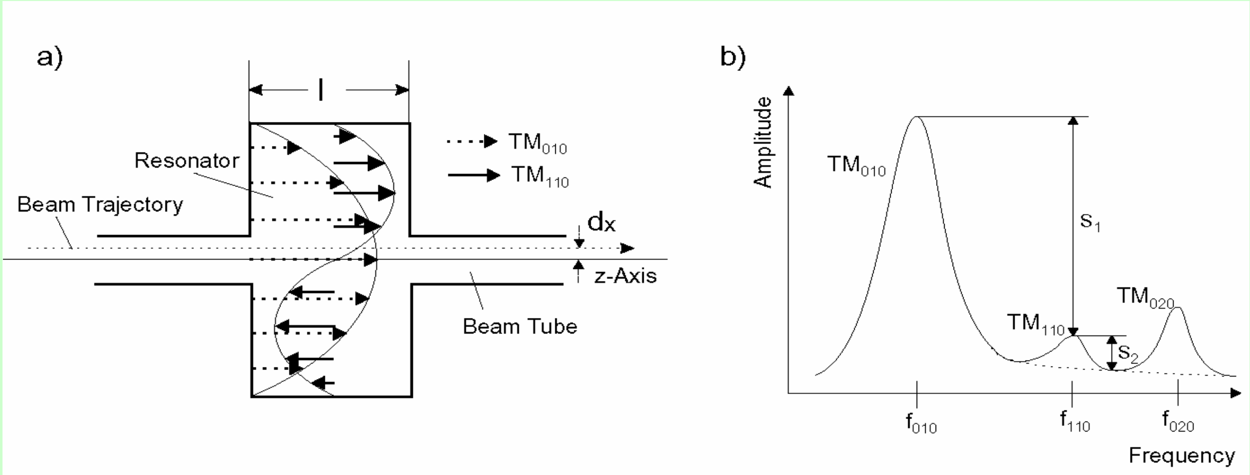
BPMs

Task: Design fast, high-resolution monitor based on pill-box cavity approach

position resolution ~ 100 nm

→ New type of cavity BPM

Typical for a cavity monitor:



a) Excitation of the TM_{010} and the TM_{110}-mode
b) Amplitudes of the TM_{010}, TM_{110} and TM_{020}-modes as a function of frequency

- Only the dipole mode (TM_{110}) involves information on beam displacement
- This mode is very small ($TM_{010}/TM_{110} > 10^3$)
- Leakage TM_{010} signal at the frequency of the dipole mode deteriorates the position resolution
- Our design: y with slot couplings to waveguides in which only the dipole mode exists

- Prototype I: dipole mode frequency 1.5 GHz
  - rf-behaviour confirmed
  - lab. measurements: σ_x = 200 nm
    over ± 1mm
    (σ_x = 40 nm
    over ± 150 μm)
- For several reasons,
  dipole mode frequency 1.5 GHz ⇒ 5.5 GHz
  ↳ Prototype II
  - lab. tests
  - in-beam tests
    beginning 2004
- Monitor calibration:
  - start with B-field off
    ⇒ extract constants for each monitor
  - B-field on
    move monitors (spectrometer magnet?)
    to right positions and measure energy

Do monitor constants change? (inclined beam trajectory!)

Needs careful understanding and solution

Besides the high-resolution BPMs we need reference monitor for two reasons:

- it provides LO frequency
- it provides the bunch charge

↳ charge-independent beam displacement possible

Reference Monitor

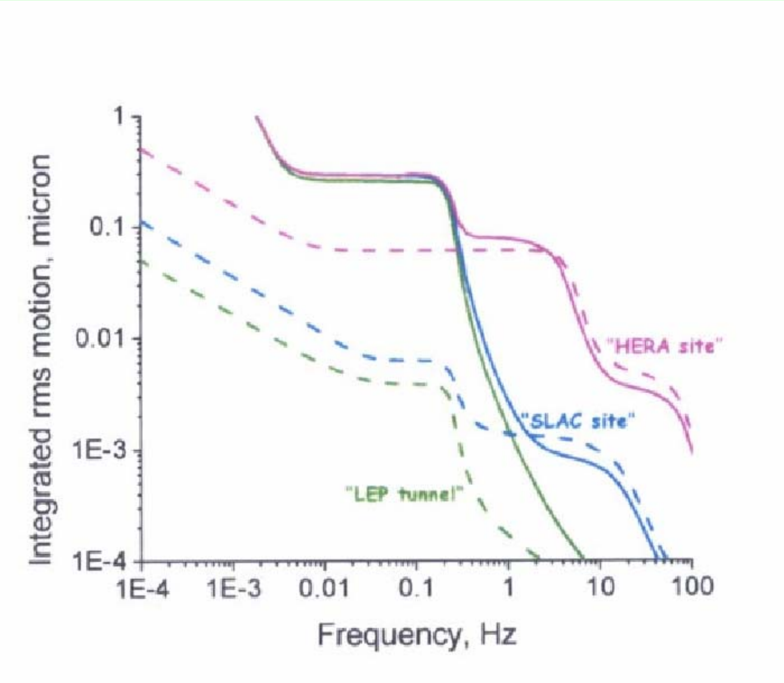
- simple pill-box cavity monitor with

Frequency (TM_{010}) = Frequency (TM_{110}) = 5.5 GHz

ref. mon — high-resol. mon

Alignment / Stabilization

- Fast fibrations



dashed curves: relative motion of two points separated by 50 m

Solution: position the BPMs and the magnets on a common rigid girder

- Slow ground motion

Schemes for alignment (global / local) including temperature stabilization for the spectrometer magnet have to be developed

Summary

- basic parameters of the spectrometer as indicated in the TDR o.k.

- dE_b/E_b = 1×10^{-4} feasible
  = few $\times 10^{-5}$ challenging
  = 1×10^{-5} (or better) (probably) excluded

  } for each e^+/e^- bunch

New Ideas

- Alexej Ljapine: new monitor
  which measures the angle
  and not the beam offset

- Igor Meshkov, Evgeny Syresin:
  Beam energy measurement by means
  of the synchrotron radiation from the
  spectrometer magnet $\Rightarrow \Delta E_b/E_b \cong 10^{-4}$