## PROGRESS OF THE TESLA MAGNETIC SPECTROMETER FOR BEAM ENERGY MEASUREMENT

DESY - Dubna - TU Berlin

- Magnets
- Beam Position Monitors
- Control System
- Complementary Methods
  - Synchrotron Radiation
  - Radiative Return Events
  - [Resonance Absorption Method]

# Magnets



### spectrometer magnet

- status given in Amsterdam based on 2D simulations
- now: 3D simulations (MAFIA code) added which support the 2D results on
  - uniformity  $(<2 \cdot 10^{-5})$
  - manufacturing tolerances
  - $\Delta \int B dl \leq 2 \cdot 10^{-5}$ over 11 millimeters (uniformity region shifts from 2D to 3D simulations)

#### 3D view of the main spectrometer magnet



## Number of meshpoints: 300 000

## **Distance of points:** ~ 1 cm





J. Schreiber, ECFA LC Workshop Montpellier, 13-16 Nov. 2003



Normalized magnetic field in the middle cross-section of the main magnet.



Longitudinal magnetic field integral (normalized) for main magnet.

# ancillary magnets

- start with 2D simulations for three possible versions:
  - transverse design identical to spectrometer magnet, but two times shorter in length (L=1.5 m)
  - transverse design more compact, but L=1.5 m
  - more compact in transverse direction and L < 1.5m</li>

- version 2 is favored due to less effort for detailed design; it has minimum of design optimization parameters
- > only this will be considered in future

## ➢ width uniformity (≤2 · 10<sup>-5</sup>) over 8 mm, but shift between 2D and 3D simulations



Longitudinal magnetic field integral (normalized) for the ancillary magnet

Also, simulations were performed of

- various elements for components connecting different parts of the magnets
- in dependence on
  - defects in the magnet core
  - magnet girder
  - chemical impurities of steel
  - position and geometry of end field screens
     (μ -metal)

- ➢ effects are visible → impact on longitudinal field integral <10<sup>-3</sup>
- requirements during magnet manufactoring derived
- careful mapping of field needed

# B-field masurements

- in lab (field mapping) two independent methods:
  - moving probes (NMR probes) in main field region, Hall probes in edge field region
  - two search coils
- in operation
  - NMR probes in two fixed points and
  - moving wire (magnetic field integral)

For accurate long. probe positions: laser interferometer for their accurate transverse positions: linear encoder

$$\Rightarrow \Delta B / B \approx 20 \, ppm$$

## In summary

Magnet designs quite far advanced (for 1 mrad spectrometer bending angle as proposed in TDR)

# **BEAM POSITION MONITORS**

# **Basic requirements:**

- position resolution  $\leq 100 nm$
- development of new monitor  $\implies$  cavity type BPM

## First approach:

⇒ large, heavy cavity BPM (Prototype I) with dipole mode frequency of 1.5 GHz (see Amsterdam talk)

### now:

new design (Prototype II) much more compact dipole mode frequency of 5.5 GHz

# **BPM Structure**

Coupling of the dipole mode, which involves the beam offset information, by means of special designed slots and rectangular waveguides.



Due to this configuration the strong monopole mode is not coupled

$$> \frac{S}{N}$$
 strongly enhanced

improves position resolution to  $\leq 100 nm$ 

# Prototype II



Its size is about 4 times smaller than Prototype I





The reference cavity (for LO frequency and bunch charge) is also implemented in the prototype.

## First measurements with 5.5 GHz-Prototype

Setup:



An antenna excites the dipole mode within the BPM. By moving the antenna transversally, beam offsets are simulated.



The two output signals from the electronics as a function of the "beam offset"



Sensitivity (estimated)	1.9 <i>mV</i> /100 <i>nm</i>
Common Mode (estimated)	4.3 mV (at $f_{010} = 3.8$ GHz with 100 $\mu$ m mechanical error)
Position Resolution	200 nm
Offset	few nm
Linear Range	$\pm 700\mu m$
Time Resolution	16 <i>n</i> sec

Resolution and linear range strongly limited by signal processing scheme (5.5 GHz)  $\Rightarrow$  improvements expected by factor 2-3

## Summary

- mechanical fabrication tolerances: few micrometers
- time resolution: 16 nsec (w.r.t. 115 nsec of Prototype I)

(TESLA bunch spacing: ~ 330 nsec)

- much less dependence on inclination angle of bunch trajectory
- resolution: 200 nm  $\Rightarrow$  70-100 nm - linear range:  $\pm$  0.7 mm  $\Rightarrow$   $\pm$  1.5 mm  $\}$  using improved electronics

At beginning 2004,

with an improved design of

Prototype II (UHV !)

and using proper electronics

# $\Rightarrow$ test with beam

## SLOW CONTROL

First suggestions

- a simple design for a control system
- by no means complete; indicates the direction of current design work and identifies areas for more thought

Informations from magnetic field measurements, BPM beam displacements, temperature sensors, aligment system



Use IEEE 488 network system

Transfer to external DAQ system: **IEEE 802 (Ethernet)** and related network using **TCP / IP protokol** 

# BEAM ENERGY MONITOR BASED ON SYNCHROTRON RADIATION



Relying on synchrotron radiation (SR) of the spechrometer magnets

⇒ absolute measurement of  $E_b$ with  $\Delta E_b / E_b \cong 10^{-4}$  for each bunch, by measuring the angle between the light cones.  $\Rightarrow$  a control of the relative beam energy down to few  $10^{-5}$  seems possible, by measuring the SR intensity.

## For the moment,

- only basic, rough estimates
- ideal assumptions
- no details on SR detector

# feasibility study needed, progress next meeting

# **RADIATIVE RETURN EVENTS**

Independent determination of beam energy resp.

cms\_energy  $\sqrt{s}$  on event-based method using kinematics of  $e^+e^- \rightarrow f \bar{f} \gamma$  radiative return events.

# Advantage

## Allows a direct measurement of the luminosity-weighted beam energy at the interaction point

## cross check of spectrometer beam energy measurements

# Radiative return events



For coplanar muons (3-body kinematics),



E<sub>beam</sub> is derived from the very precisely known Z mass gives an independent measure for each IP

or 
$$\sqrt{s} = 2E_b$$
 (by definition  $E_b^- \equiv E_b^+$ )  
In our example, we determine  $\sqrt{s}$ 

## **DEMONSTRATION of METHOD**

Ass:  $e^+e^- \rightarrow \mu^+\mu^-\gamma$  at  $\sqrt{s_{nom}} = 500 \, GeV$  and  $\int Ldt = 100 \, fb^{-1}$ 

long-term measurement (over weeks or even months)

Aim:  $\Delta E_b / E_b \le 1 \cdot 10^{-4}$ i.e.  $\Delta E_b \le 25 MeV$  for  $E_b = 250 GeV$ 

Generated 130 400 events  $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$ 



TESLA Detector Simulation Program (SIMDET)

<u>Aim</u> is to select coplanar  $\mu^+\mu^-\gamma$  events with <u>one and only one hard ISR photon</u>

and the muons are <u>back-to-back</u> in the plane transverse to the beam

# Requirements: $-only1\mu^+ and 1\mu^-$ (well measurement) $-|p_x^+ + p_x^-| < 4 \, GeV$ $-|p_y^+ + p_y^-| < 4 \, GeV$ $-|p_z^+ + p_z^- + p_z^{miss}| < 1 \, GeV$ $-|E^+ + E^- - \sqrt{s_{nom}}| < 2 \, GeV$ - no photon in detector

Apply 
$$\frac{M_Z}{\sqrt{1-x_{\gamma}}} \equiv \sqrt{s_{meas}}$$
  
with  $x_{\gamma} = fkt(\theta^+, \theta^-)$   
to extract  $\sqrt{s_{meas}}$ 





In our example: ~20% of the events selected:

 $\geq 2\gamma$ 's (with  $E_{\gamma} > 1 GeV$ )

b) events with 1 hard ISR photon but with  $\theta_{\gamma} \neq 0$  and not in detector acceptance:



 aim: improve selection procedure and / or correct by proper ISR simulation (⇒ uncertainties on ISR modelling)

## **BACKGROUND PROCESSES**

might mimic  $\mu^{+}\mu^{-}\gamma$  signal events:

 $e^+e^- 
ightarrow e^+e^-\mu^+\mu^-(\gamma)$   $ightarrow au^+ au^- V^x_s(\gamma)$  $ightarrow W^+W^- 
ightarrow \mu^+\mu^- V'_s(\gamma)$ 

(huge  $\sigma$ ) (large  $\sigma$ ) (large  $\sigma$ )

preliminary studies: almost all  $\tau^+ \tau^$ and  $W^+ W^-$  can be removed;  $e^+ e^- \mu^+ \mu^-$  background is substantial

## **Preliminary results from LEP experiments:**

Experiment	Channel	$\Delta E_{_{beam}}[MeV]$
ALEPH	$\mu^{+}\mu^{-}\gamma$	$-167 \pm 91 \pm 48$
DELPHI	$\mu^+\mu^-\gamma$	+113 ± 75± 27
DELPHI	$q\bar{q\gamma}$	- 55 $\pm$ 53 $\pm$ 65
L3	$\mu^{+}\mu^{-}\gamma$	$+10 \pm 115 \pm 22$
L3	$q \bar{q} \gamma$	- 46 $\pm$ 33 $\pm$ 51
OPAL	$e^+e^-\gamma$	+ 40 $\pm$ 136 $\pm$ 78
OPAL	$\mu^+\mu^-\gamma$	- 51 $\pm$ 84 $\pm$ 22
OPAL	$\tau^{+} au^{-}\gamma$	+ 301 ± 191 ± 148
OPAL	$q \bar{q} \gamma$	- 67 $\pm$ 34 $\pm$ 70
Combined	$l^+l^-\gamma$	- 5 $\pm$ 41 $\pm$ 16
Combined	$q\bar{q}\gamma$	- 52 $\pm$ 24 $\pm$ 43
Combined	$f \overline{f} \gamma$	- 20 ± 25 ± 22
		systematic error
		difference to LEP group measurements



statistical error might be reduced to 6 MeV

can the systematic error at LC reduced ?

## **ADDITIONAL POINTS TO BE DISCUSSED**

- Beamstrahlung
- Forward tracker needed to improve heta resolution ?

# (at higher $\sqrt{s} = 500 \text{ GeV}$ )

- Complications
  - beam energy spread
  - large discruption angle
  - correlations between luminosity spectrum and collision energy



$$\Delta E_b / E_b \cong 1.10^{-4}$$

with radiative return events