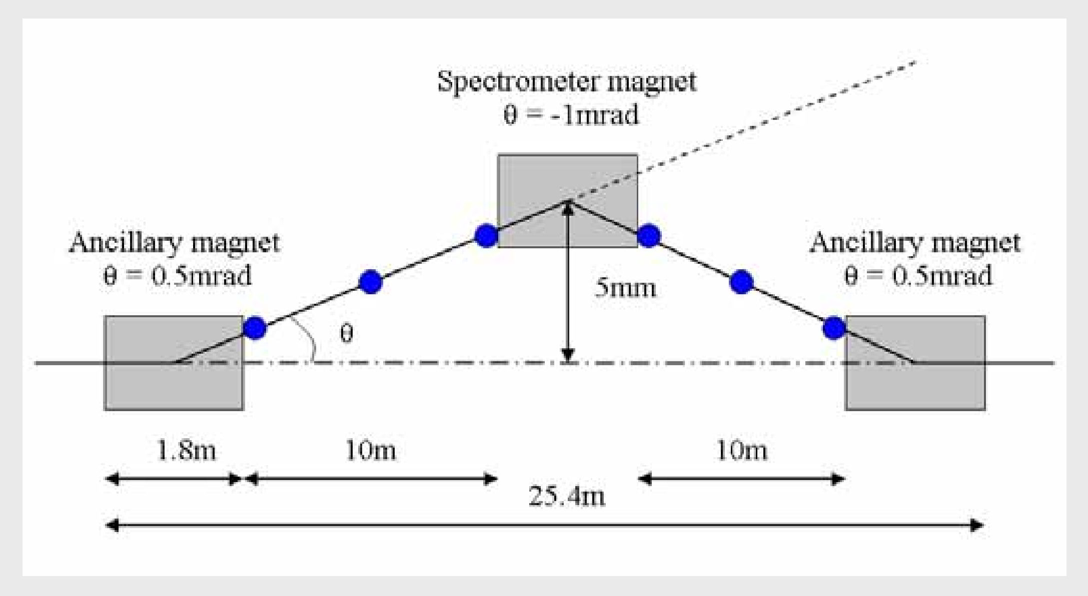
PROGRESS OF THE TESLA MAGNETIC SPECTROMETER FOR BEAM ENERGY MEASUREMENT

DESY - Dubna - TU Berlin

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

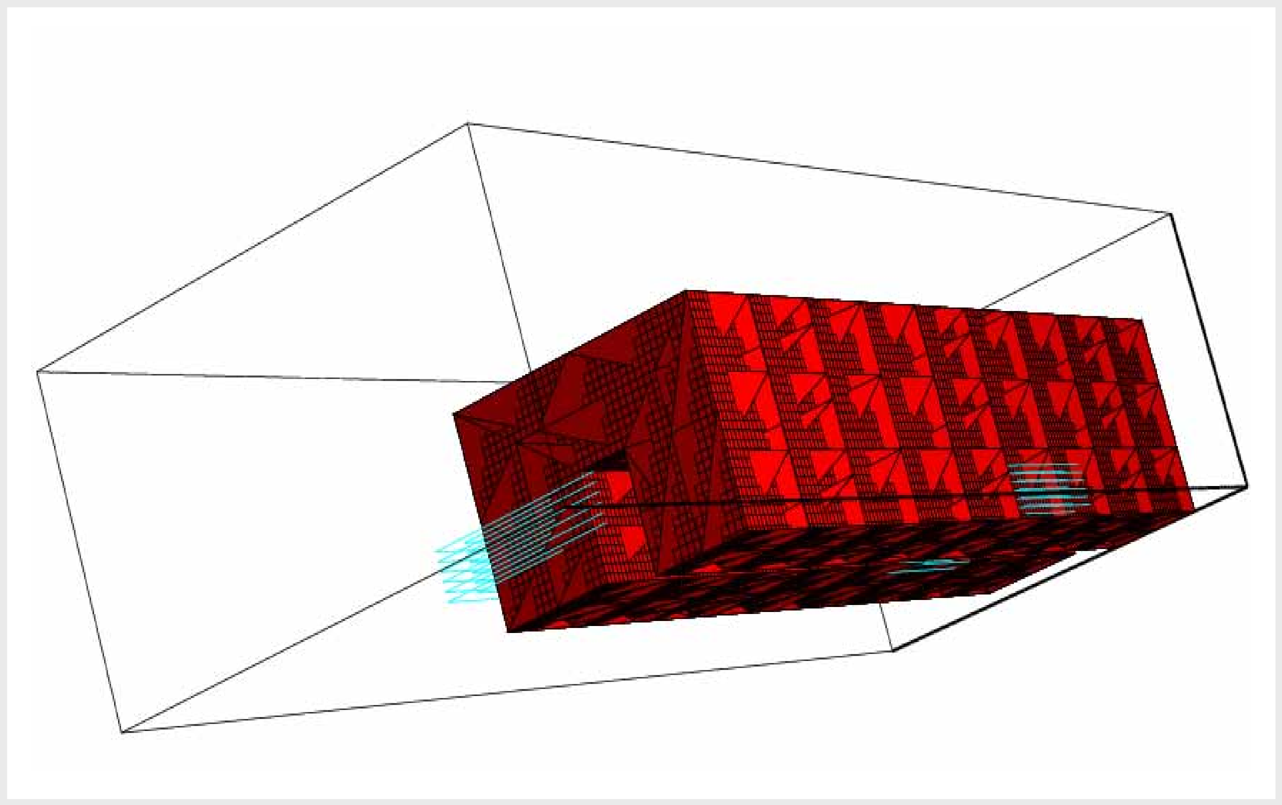
Magnets



spectrometer magnet

- status given in Amsterdam based on 2D simulations
- now: 3D simulations (MAFIA code) added which support the 2D results on
  - uniformity $(<2\cdot10^{-5})$
  - manufacturing tolerances
  - $\Delta\int Bdl \le 2\cdot10^{-5}$ over 11 millimeters (uniformity region shifts from 2D to 3D simulations)

3D view of the main spectrometer magnet

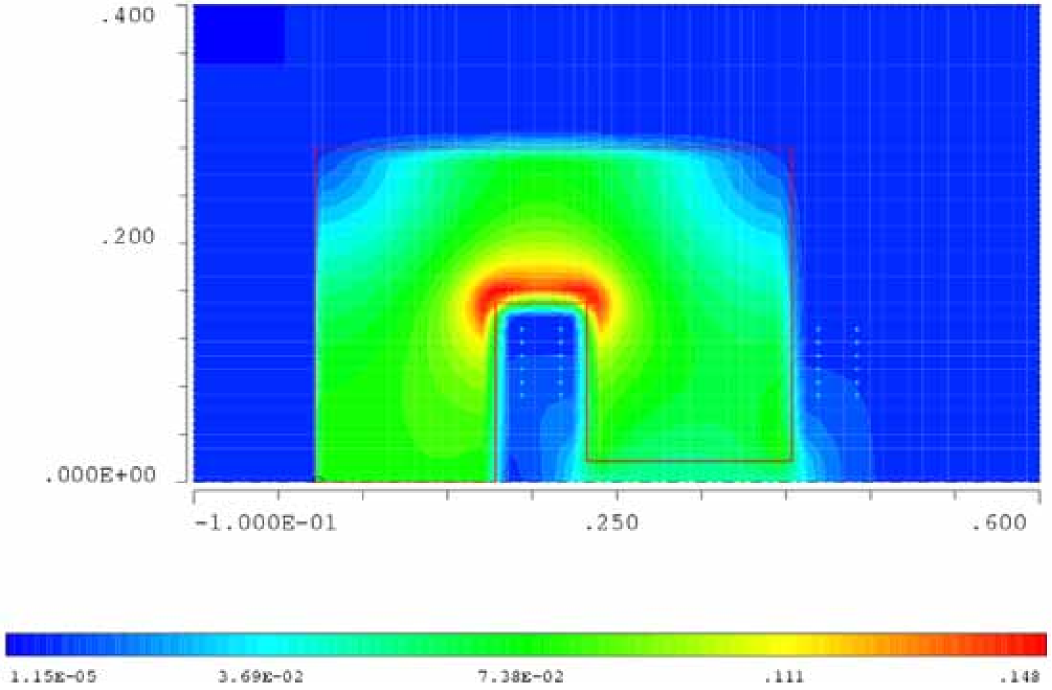


Number of meshpoints: 300 000

Distance of points: ~ 1 cm

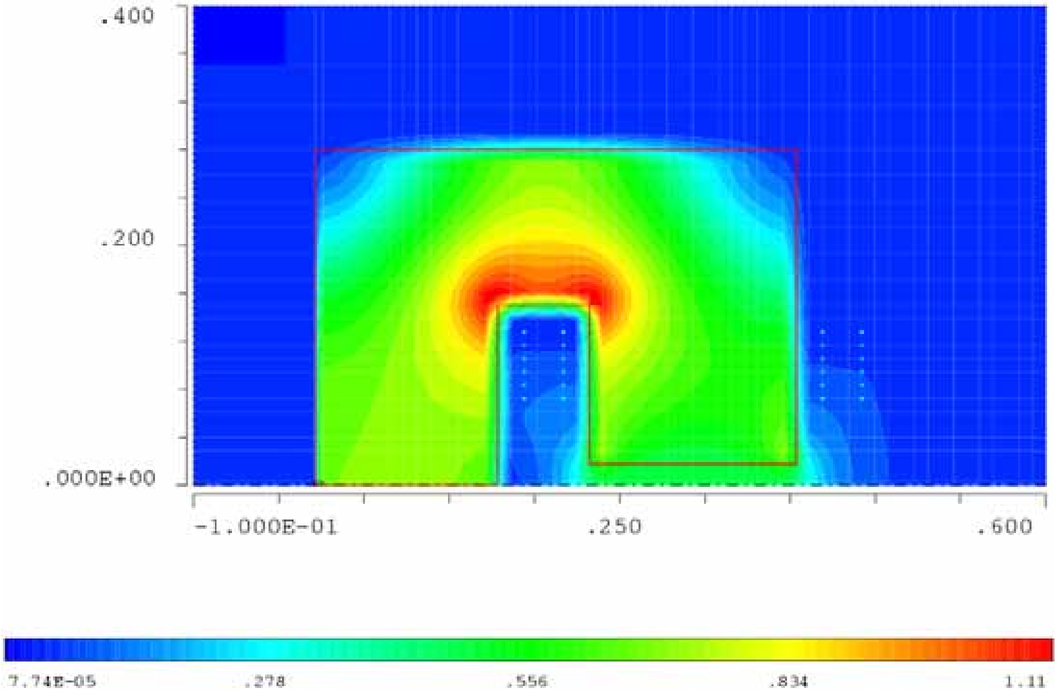
Magnetic field contour plot for the main magnet model (middle cross-section, Z=0)

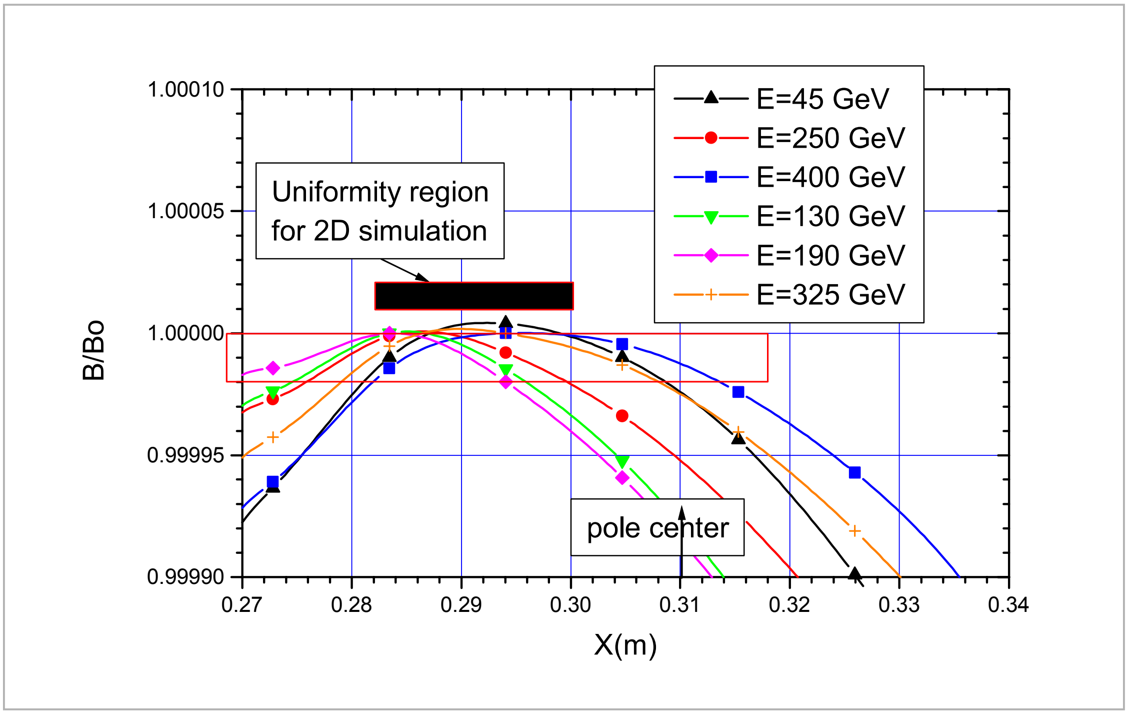
(B=0.05T)



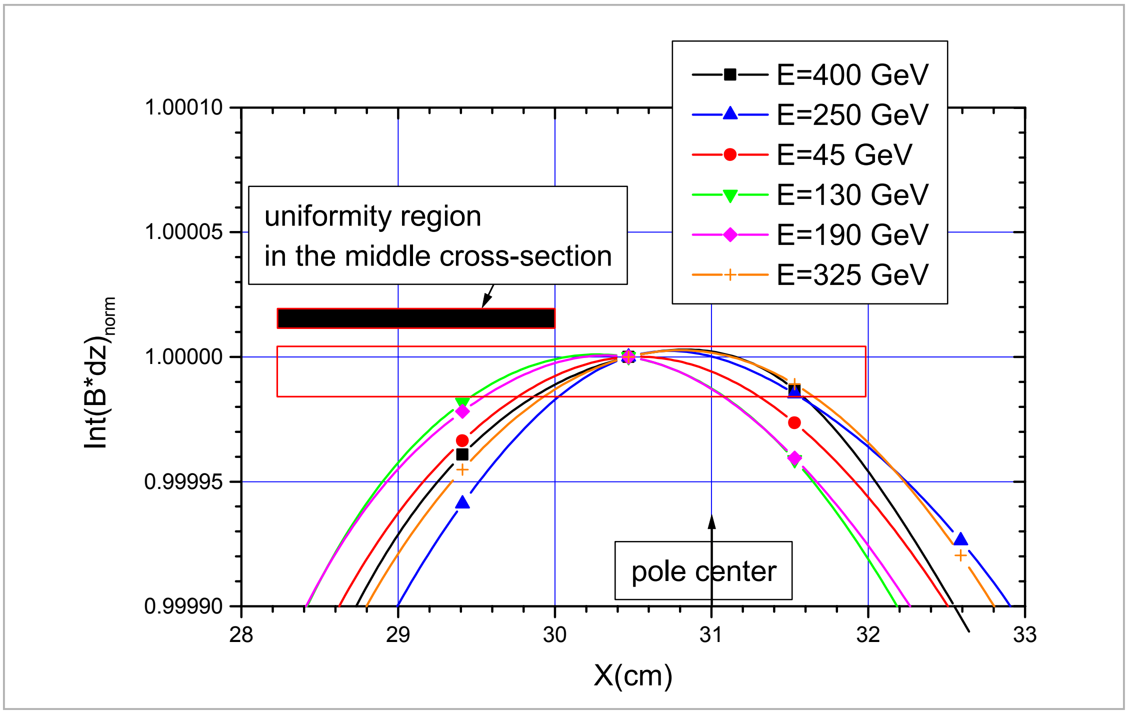
Magnetic field contour plot for the main magnet model (middle cross-section, Z=0)

(B=0.44T)





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



Longitudinal magnetic field integral (normalized) for main magnet.

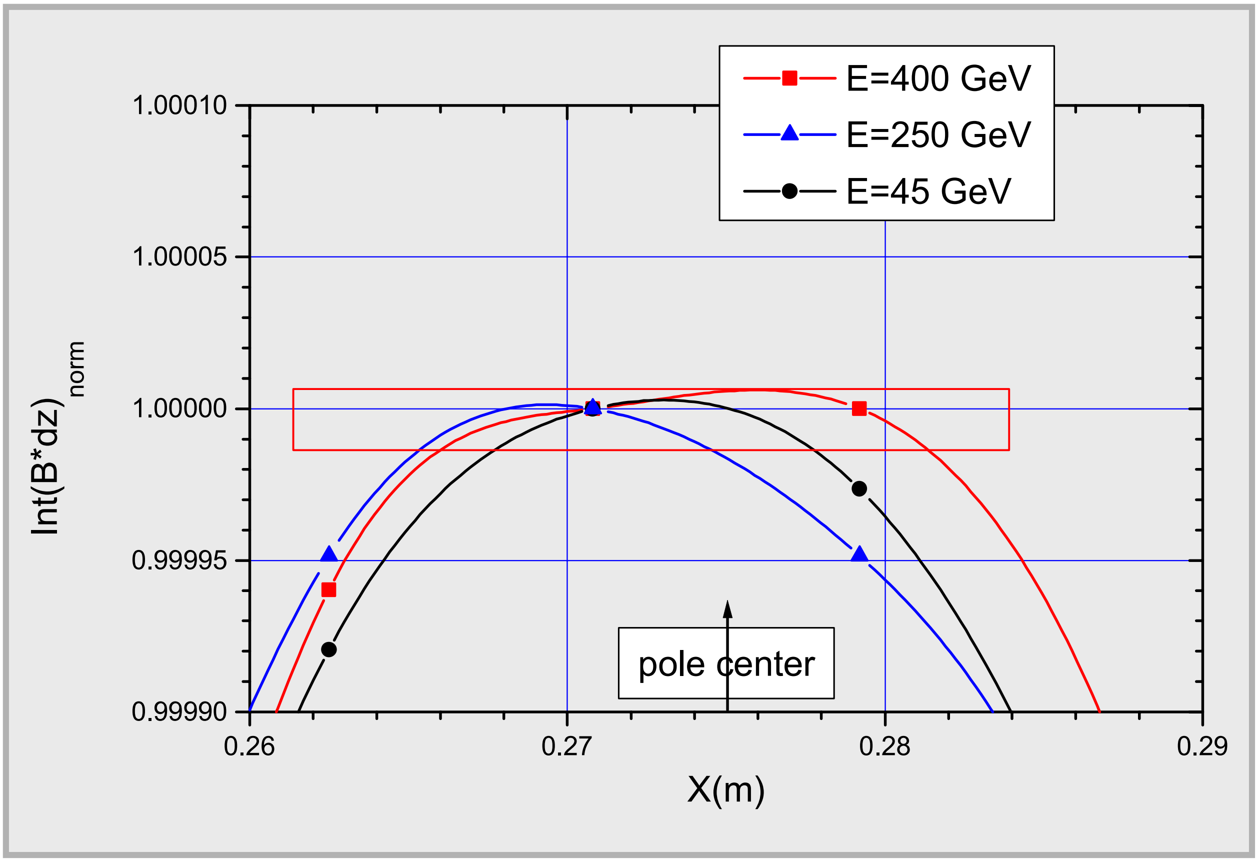
ancillary magnets

- 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

- **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 $\left(\leq 2\cdot 10^{-5}\right)$ 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 $<10^{-3}$

➢ 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

$$\Rightarrow \boxed{\Delta B / B \simeq 20\ ppm}$$

In summary

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

BEAM POSITION MONITORS

Basic requirements:

- position resolution $\leq 100\,nm$
- single-bunch measurement $\Longrightarrow$ fast BPM

$\Longrightarrow$ development of new monitor $\Longrightarrow$ cavity type BPM

First approach:

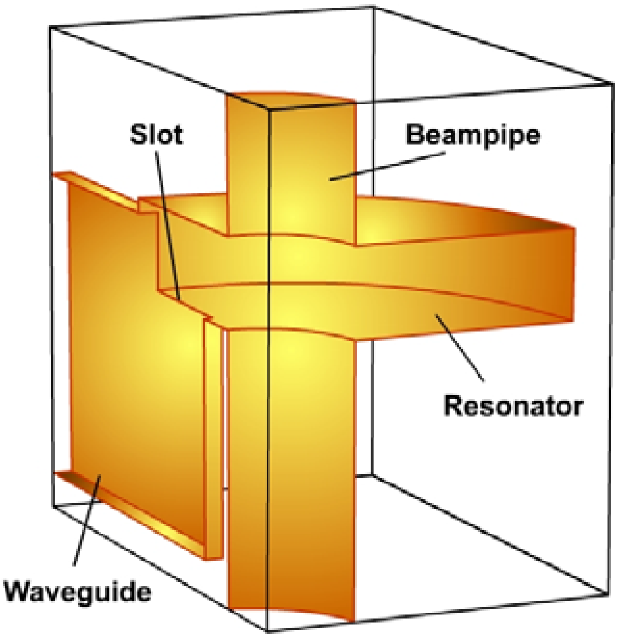
$\Longrightarrow$ large, heavy cavity BPM (Prototype I)
with dipole mode frequency of 1.5 GHz
(see Amsterdam talk)

now:

$\Longrightarrow$ 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

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

improves position resolution to $\leq 100\,nm$

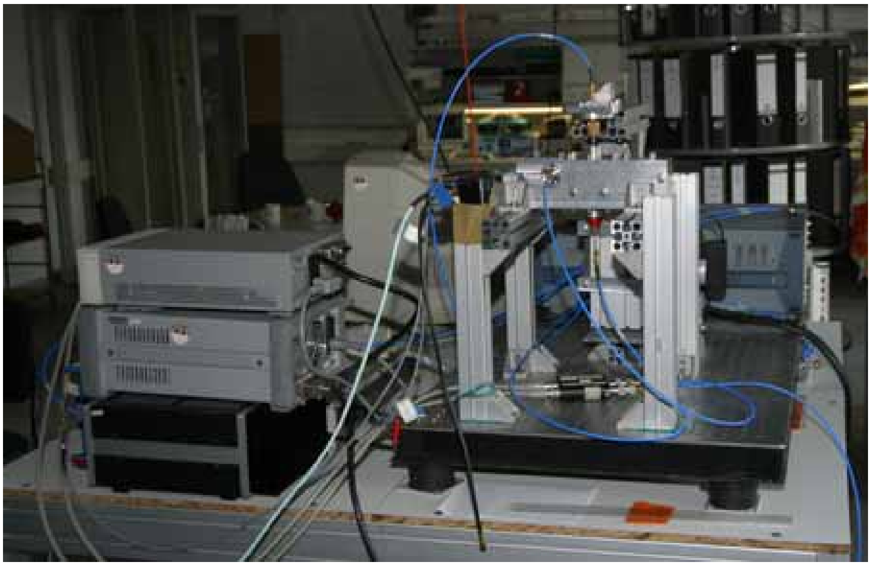
Prototype II

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.

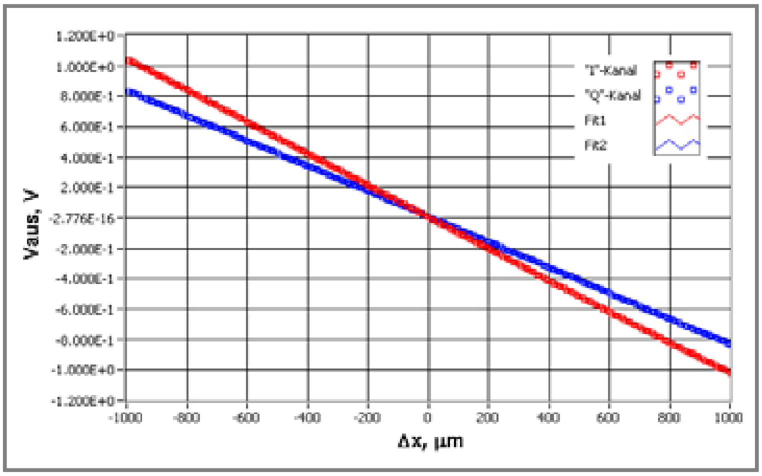
First measurements with 5.5 GHz-Prototype

Setup:



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

Results:



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

resolution and linear range

Sensitivity (estimated)	$1.9\,mV/100\,nm$
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	$16\,n\sec$

Resolution and linear range strongly limited by signal processing scheme (5.5 GHz) ⇒ 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 ⇒ 70-100 nm
- linear range: ± 0.7 mm ⇒ ± 1.5 mm

} using improved electronics

At beginning 2004,

with an improved design of

Prototype II (UHV !)

and using proper electronics

⇒ test with beam

SLOW CONTROL

First suggestions

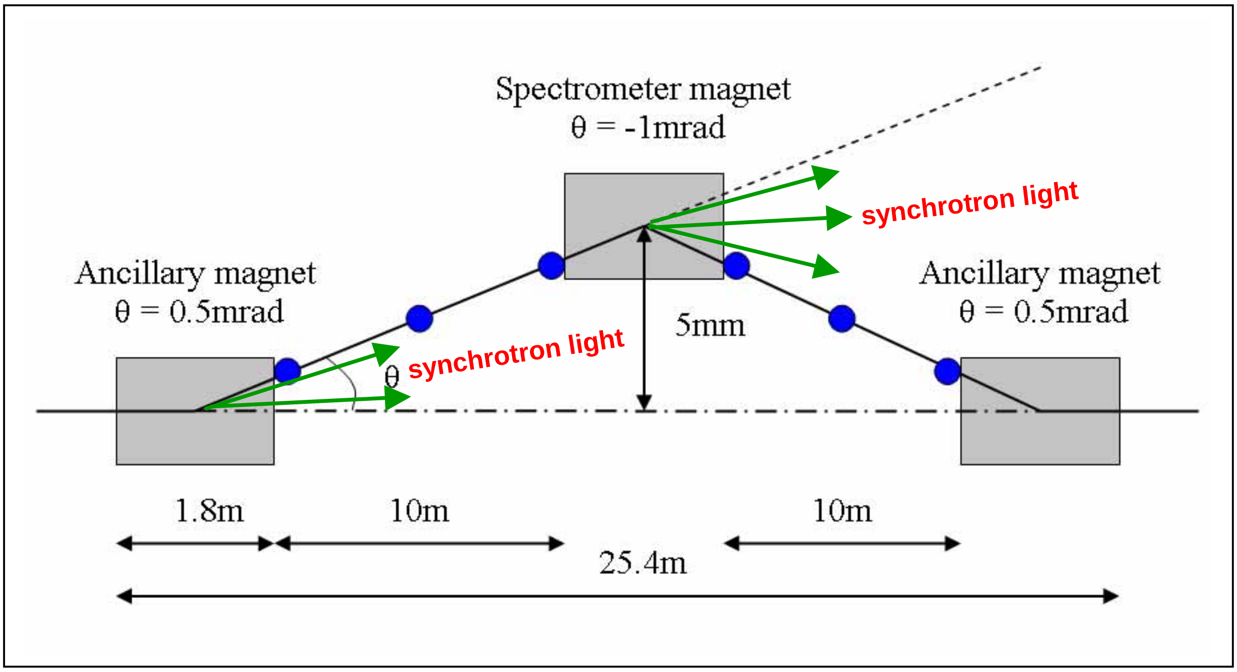
- a simple design for a control system
- by no means complete;
  indicates the direction of current design work and identifies areas for more thought

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

↳ monitored

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.

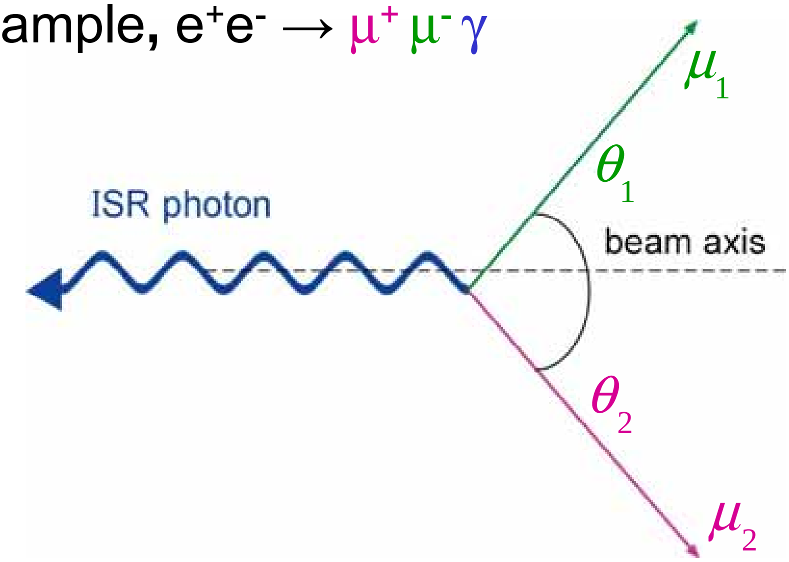
Advantage

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

cross check of spectrometer
beam energy measurements

Radiative return events

Example, $e^+e^- \to \mu^+\mu^-\gamma$



For coplanar muons (3-body kinematics),

$$\frac{E_\gamma}{E_{beam}} \equiv x_\gamma = \frac{2\sin(\theta_1+\theta_2)}{\sin(\theta_1+\theta_2)+\sin\theta_1+\sin\theta_2}$$

$$E_{beam} = \frac{M_z}{2\sqrt{1-x_\gamma}}$$

$E_{\mathbf{beam}}$ 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: $\Delta E_b / E_b \leq 1\cdot 10^{-4}$

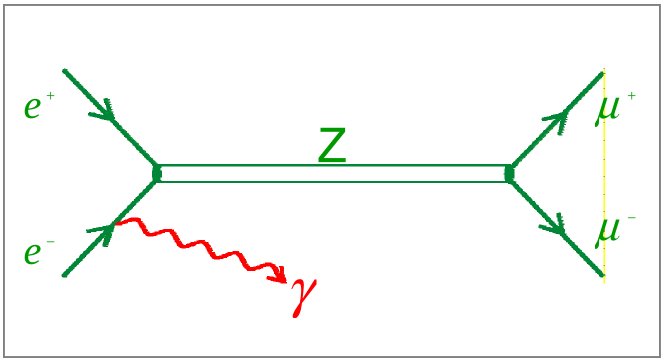
$i.e.\ \ \Delta E_b \leq 25 MeV\ \ for\ E_b = 250\,GeV$

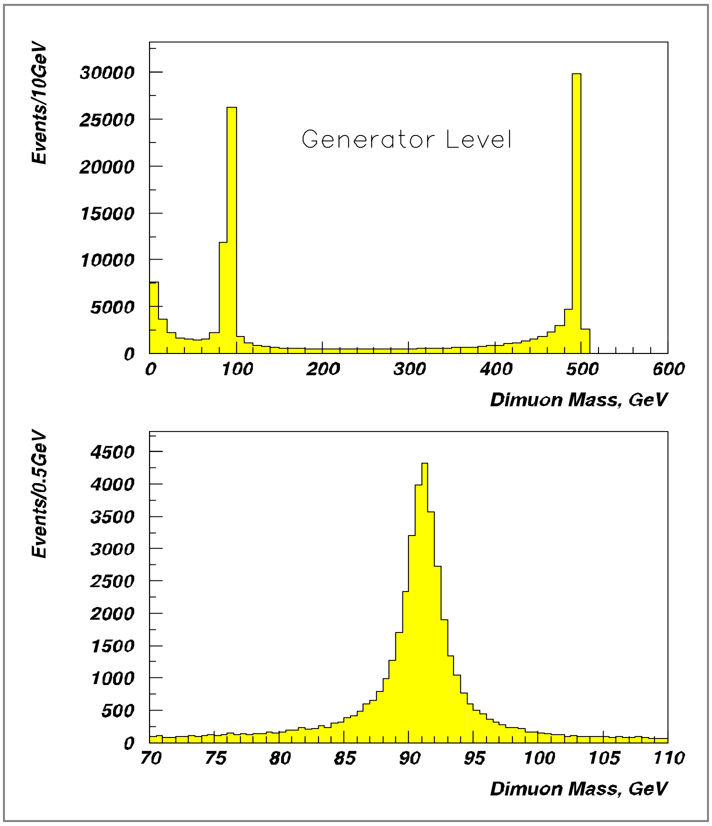
Generated 130 400 events $e^+e^- \rightarrow \mu^+\mu^-(\gamma)$

two prominent spikes:

$at\ \sqrt{s_{nom}} = 500\,GeV$

$at\ M_z = 91.2\,GeV$





➡ TESLA Detector Simulation Program (SIMDET)

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

(⟶ usually, it travels along the beam pipe)

and the muons are back-to-back in the plane transverse to the beam

Requirements:

$$-\, only\, 1\mu^+\ and\ 1\mu^- \quad (\text{well measurement})$$

$$-\left|p_x^+ + p_x^-\right| < 4\,GeV$$

$$-\left|p_y^+ + p_y^-\right| < 4\,GeV$$

$$-\left|p_z^+ + p_z^- + p_z^{miss}\right| < 1\,GeV$$

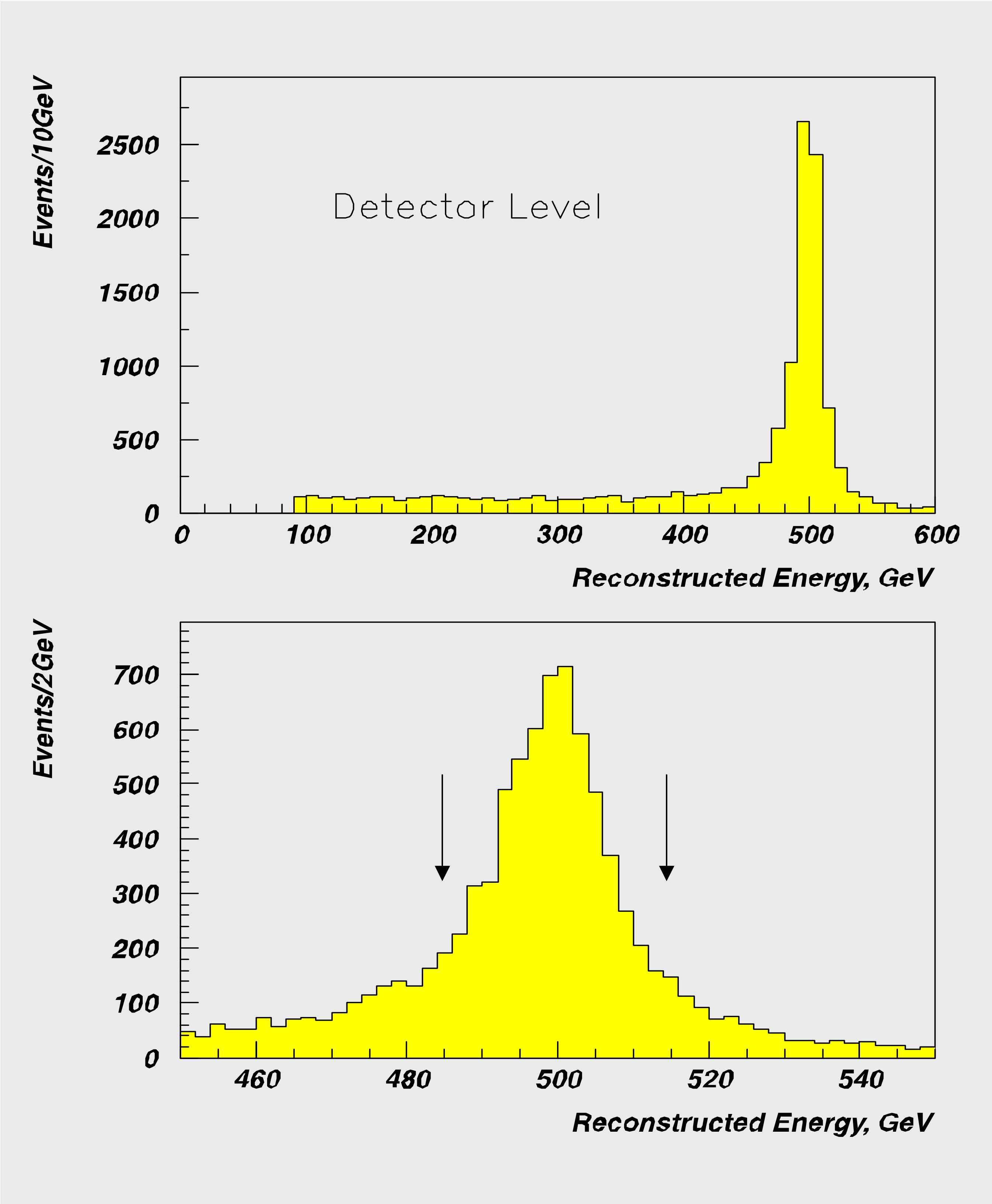
$$-\left|E^+ + E^- - \sqrt{s_{nom}}\right| < 2\,GeV$$

$$-\ \text{no photon in detector}$$

Apply $\dfrac{M_Z}{\sqrt{1-x_\gamma}} \equiv \sqrt{s_{meas}}$

$$with\ x_\gamma = fkt\left(\theta^+, \theta^-\right)$$

$$to\ extract\ \sqrt{s_{meas}}$$


Events/10GeV
2500
2000
1500
1000
500
0
Detector Level
0
100
200
300
400
500
600
Reconstructed Energy, GeV
Events/2GeV
700
600
500
400
300
200
100
0
460
480
500
520
540
Reconstructed Energy, GeV

From events close to $\sqrt{s_{nom}}$

determine cms-energy resp. E_{beam}

-In our case (for simplicity), all events within

$$\sqrt{s_{nom}} - 20\,GeV < \sqrt{s_{meas}} < \sqrt{s_{nom}} + 20\,GeV$$

$\longrightarrow$ average: $\sqrt{s_{meas}} = 499.216\,GeV$

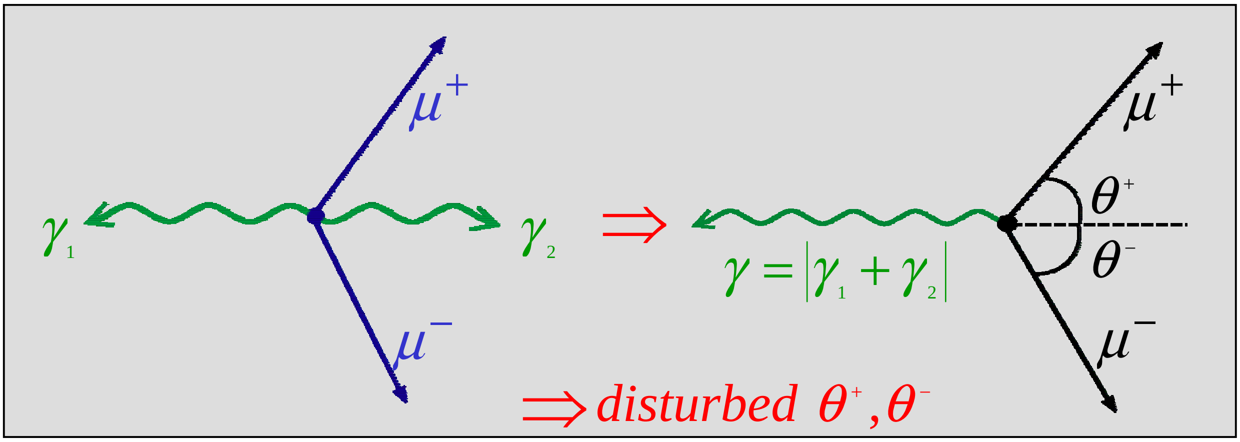
$$\Updownarrow$$

$$\sqrt{s_{nom}} = 500.000\,GeV$$

-better: apply fit $\longrightarrow$ peak position (LEP II)

Problems: which limit precision on $\sqrt{s_{meas}}$

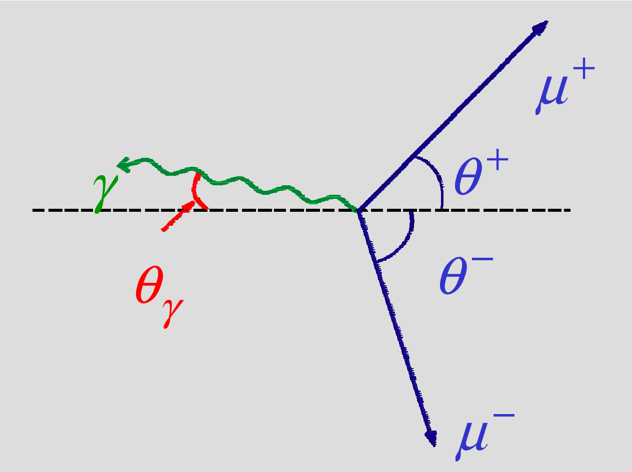
a) besides the (wanted) 1 ISR photon events



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

$$\geq 2\gamma's \quad \left(with\ \ E_\gamma > 1GeV\right)$$

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
($\Rightarrow$ uncertainties on ISR modelling)

BACKGROUND PROCESSES

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

$$e^+e^- \to e^+e^-\mu^+\mu^-(\gamma) \qquad (huge\ \sigma)$$

$$\to \tau^+\tau^- \to \mu^+\mu^-\nu^{x}_{s}(\gamma) \qquad (large\ \sigma)$$

$$\to W^+W^- \to \mu^+\mu^-\nu'_{,s}(\gamma) \qquad (large\ \sigma)$$

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 ± 91± 48
DELPHI	$\mu^+\mu^-\gamma$	+113 ± 75± 27
DELPHI	$q\bar{q}\gamma$	- 55 ± 53 ± 65
L3	$\mu^+\mu^-\gamma$	+10 ± 115 ± 22
L3	$q\bar{q}\gamma$	- 46 ± 33 ± 51
OPAL	$e^+e^-\gamma$	+ 40 ± 136 ± 78
OPAL	$\mu^+\mu^-\gamma$	- 51 ± 84 ± 22
OPAL	$\tau^+\tau^-\gamma$	+ 301 ± 191 ± 148
OPAL	$q\bar{q}\gamma$	- 67 ± 34 ± 70
Combined	$l^+l^-\gamma$	- 5 ± 41 ± 16
Combined	$q\bar{q}\gamma$	- 52 ± 24 ± 43
Combined	$f\bar{f}\gamma$	- 20 ± 25 ± 22

systematic error

statistical error

difference to LEP group measurements

$$\Rightarrow \int L\,dt = 100\ fb^{-1} at\ \sqrt{s} = 500\,GeV$$

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 θ resolution ?

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

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

Challenge to measure

$$\Delta E_b / E_b \cong 1 \cdot 10^{-4}$$

with radiative return events