Physics Requirements for Detectors in the Forward Region

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A personal, and not very comprehensive take on some of the issues.
Some angle “definitions”

TESLA TDR version.
LAT (FDET) design now more conducive to Bhabha lumi measurement a la LEP. Also L* evolving.

BARREL $\theta > 30\text{-}45^\circ$
ENDCAP $\theta > 100\text{ mrad}$
FDET $\theta > 30\text{ mrad}$
LUMICAL $\theta < 30\text{ mrad}$

FDET = TESLA_LAT = NLC “instrumented mask”
LUMICAL = TESLA LCAL = NLC Pair Lumi monitor

NLC Forward Masking, Calorimetry & Tracking 2003-04-01
Latest iteration – from Achim Stahl – last night.

Note this also includes Shintake monitor.
What should I really be discussing?

- **Forward region** (broadly defined) is critical for measuring initial beam parameters and providing feedback to the accelerator:

  - \( \frac{dL}{d\sqrt{s}} : \text{lumi spectrum} \): using Bhabhas in the endcap region (100 – 250 mrad). Optimize forward tracker for polar angle measurement and low material.

  - \( \downarrow L \ dt \): good measurement using Bhabhas in the FDET acceptance looks feasible with LEP-like precision.
    - Critical issue is polar angle acceptance definition.
    - (Even if FDET region difficult, I claim e\(^+\)e\(^-\) \( \bullet \) \( \gamma \gamma \) using ENDCAP acceptance only should be sufficient for all physics except Z-pole.)

  - \( < \delta s > \): using radiative Z events (particularly \( \mu\mu\gamma \) & \( ee\gamma \)). Critical issue (\( \theta \) acceptance at high \( \delta s \)), accurate \( \theta \) (few 10\(^{-5}\))

  - Incoming and extraction line **diagnostics** for accelerator feedback and fast lumi, E and P measurements – some of these may have more or less invasive effects on the “4\(\pi\)” physics program.

- Some of these issues require coordination between forward “special interests” and wide-angle general purpose calorimetry and tracking.
What design criteria were used for the “FDETs” at LEP?

• 1) Absolute integrated lumi. Measurement using Bhabhas
• 2) tagging of scattered electron(s) in two-photon collision events – principally in the context of measuring $\gamma \gamma$ kinematics

• BOTH of these design considerations are MUCH less important for LC physics
  – I) Difficult to improve on LEP lineshape given $E_{\text{beam}}$ issues in LC cf low energy storage ring.
  – II) $\gamma \gamma$ physicists will be busy colliding lasers
Main focus of this talk

- **HERMETICITY** – broadly defined as the ability to measure events with GENUINE missing transverse momentum with as broad an acceptance in $|\not\! p_T|$ as possible and with HIGH efficiency.
  - I believe this is the most important design consideration for the physics – and it has broad implications for the whole detector – and maybe the accelerator (crossing angle issue).

- I’ve decided not to focus on the afore-mentioned Lumi, Energy, Polarization type issues.
  - many physics channels are not that demanding.
    - Although I will stress that one of the real advantages of $e^+e^-$ cf hadron colliders is that we can measure these quantities (and really well hopefully if and when we need to)
What this talk is and is not

• NOT an exploration of the physics benefits of a crossing angle or no crossing angle. (See Achim Stahl’s talk – ECFA/DESY, Amsterdam)
  – Your work also on this would be welcome!
• NOT an attempt to compare physics reach for SUSY with/without crossing angle. (see Z. Zhang’s talk – Euro-GDR, Orsay)
  – Your work also on this would be welcome!
• It is an attempt to alert you to some of the issues and encourage the development of a coherent $4\pi$ detector design which will be a superb device for exploring whatever physics produces events with missing energy.
  – (even better than eg. OPAL which I know (too?)well)
Most sensitive slepton pair search at LEP

NB. Cross-sections are model independent

BUT detector $\theta_{\text{min}}$ of $\approx 25$ mrad leads to NO acceptance for small mass differences
Why is hermeticity important?

Only difference between supersymmetry and 2-photon event is the observation of an electron in the FDET balancing the di-muon $p_T$. 

$e^+ e^- \rightarrow smu^+ smu^-$

$e^+ e^- \rightarrow e^+ e^- \mu^+ \mu^-$

0.7 $E_{beam}$

FDET cluster
What is the limitation? Kinematics.

- Let’s look at the simplest case – massless visible system.
- Signal = $\gamma + \text{missing energy}$
- Background = $e^+ e^- \gamma$ where both $e^+$ and $e^-$ go undetected (easiest way is by escaping below the detector polar angle acceptance $\theta < \theta_{\text{min}}$)
- The highest total $p_T$ of the unobserved $e^+$ and $e^-$ is given by $(2E_{\text{beam}} - E_\gamma) \sin \theta_{\text{min}}$.
- So, if we require that the measured photon $p_T$ exceeds $(2E_{\text{beam}} - E_\gamma) \sin \theta_{\text{min}}$, this background is eliminated kinematically.
• In general, need to require:
  \[ p_T \text{ (visible system)} > (2E_{\text{beam}} - E_{\text{vis}}) \sin \theta_{\text{min}}. \]
• Often, this is simply stated as:
  \[ p_T/E_{\text{beam}} > 2 \theta_{\text{min}} \text{ or } > \theta_{\text{min}} \]
  (when prepared to gamble on only one of the electrons being scattered)
• I’ll now show some slides from studies that are summarized in Fig 9.5.1 in the TESLA TDR, using
  \[ p_T/E_{\text{beam}} \]
  (see http://home.cern.ch/g/graham/www/lc/hermeticity.html)
Comparison of 90 GeV smuon signals at $\sqrt{s} = 189$ GeV to gamma-gamma background.

$$e^+ e^- \rightarrow e^+ e^- \mu^+ \mu^-$$
(electron veto to $\theta_{\text{min}} = 83$ mrad)

$$\frac{(M_{\text{smu}} - M_{\text{LSP}})}{M_{\text{smu}}} = \begin{cases} 2.8\%, & 5.6\%, & 11\%, & 22\%, & 50\%, & 100\% \end{cases}$$
\( \frac{M_{\text{smu}} - M_{\text{LSP}}}{M_{\text{smu}}} = 2.8\%, 5.6\%, 11\% \)

Same plot – but now electron veto to \( \theta_{\text{min}} = 25 \text{ mrad} \)

No veto anywhere
(M_{smu} - M_{LSP})/M_{smu} = 2.8\%, 5.6\%, 11\%

Electron veto for \( \theta > 83 \) mrad and 25\( \leq \theta \leq 55 \) mrad

A “what if we don’t instrument the mask – but get some acceptance below it.

NOT MUCH USE!

Please keep this plot in mind when getting cute ideas with the crossing angle plots I’ll show.
Hermeticity in action

Generically, ANY missing energy signal will have this kind of background from “single nearly tagged” and “double nearly tagged” eeX events.

Add on to this resolution (red peak broadens).

Add on to this gamma-gamma overlay per crossing X detector resolving time (proportional to $\Delta N$)

Add on to this other possible sources of “noise” – cosmics, machine backgrounds
How to veto?

- Hermeticity requirements make the relevant metric $p_T$. So e.g., a 100 GeV photon at 45° is 70 times as important as one at 10 mrad.
  - Very important to take care of business at each step
  - Tracker, barrel, **barrel-endcap overlap**, endcap, endcap/FDET overlap, FDET, FDET/LumiCAL, LumiCAL IN THAT ORDER.

- For some channels it can be acceptable to just veto on detection of extra energy – even though the measurement of the $p_T$ is poor.

- It is better to aim for good measurement of vector $p_T$ and add all measured objects together.
  - We did this quite a lot for OPAL
  - Also many of the vetoes were confined azimuthally.
Electro-magnetic Hermeticity

Designed so that large missing $E_T$ cannot be faked by undetected electrons or photons

Continuous EM calorimetry to 24 mrad (99.97% of 4\(\square\)\(\bigcirc\)\(\bigotimes\))

A 100 GeV electron in the beam-pipe carries at most 2.4 GeV of pT
So detecting electrons and photons is all I need care about?

- NO, NO and NO.
- but basically yes, yes and yes ..(it is an electron collider – and the electron population is large)
- To be really sure you have genuine missing energy you need to care also about
  - Missing muons. (I think the FDET region needs to aim for MIP detection)
  - Missing taus
  - Missing jets
  - Missing neutral jets
  - Missing softer wider angle electrons and photons
  - Extraneous muons (cosmics, halo …)
  - Etc, etc.
Muon hermeticity

Scintillating tiles added to the endcap and low angle region

Endcap and barrel scintillators used for cosmic rejection

Low angle ones for vetoing muons at low angle

We also vetoed muons using MIP detection in Si-W luminometer!

A $\eta \phi$ data event with a missing muon

Low angle ones for vetoing muons at low angle

missing muon is detected in MIP-PLUG scintillator - and such events are vetoed
Electro-magnetic Hermeticity

Designed so that large missing $E_T$ cannot be faked by undetected electrons or photons

Continuous EM calorimetry to 24 mrad (99.97% of 4

A 100 GeV electron in the beam-pipe carries at most 2.4 GeV of $pT$
But aren’t such low pT signatures “niche physics”? 

NO!

I think you will hear lots of talks today that emphasise that the cosmological CDM results (e.g., WMAP) imply that if nature is supersymmetric, then it is quite likely that the lightest stau is nearly mass degenerate with the LSP. (stau co-annihilation)
Following slides are stolen from:

Achim Stahl (DESY-Zeuthen) (mostly accelerator specific material – presented at Amsterdam April 2003)
Z. Zhang, Richard, Berggren (Orsay, Paris) (mostly SUSY specific material. EuroGDR meeting, Orsay)
The Pair Lumi Monitor...

Old TESLA plot – No X-angle

Energy Deposition at z=2.60 m 2003/03/19 09.06

I think the scale is in GeV per cm² for one side.

IF the collisions are stable, the fluctuations in this kind of energy deposit per bunch crossing may be small – and at least for TESLA – it is claimed that the presence of meager 250 GeV electrons with a S/B of 1/100 can be ascertained.
The incoming beampipe can be smaller than the outgoing one!

For this study, we use Head-on mode:
- \( r = 1.2 \text{cm} \)
- @ \( z = 370 \text{cm} \)

Crossing-angle mode:
- \( r_{\text{in}} = 1.2 \text{cm} \)
- \( r_{\text{out}} = 2.1 \text{cm} \)
- @ \( z = 370 \text{cm} \)

as suggested by P. Bambade & K. Buesser

Slide from Zhang’s talk
LCAL Veto $\gamma \gamma \rightarrow e e \mu \mu$ for Head-on & Crossing-Angle Collisions

Head-on collisions

10 mrad half crossing-angle

Assuming $r=1.2\text{cm}$ for head-on and $r=1.2\text{cm (in)}$ $r=2.1\text{cm (out)} @ z=370\text{cm}$

$\gamma \gamma \rightarrow e e \mu \mu$ generated with BDKRC & simulated with SGV

Zhang, Richard, Berggren
With a ± 10 mrad crossing-angle

Integrating ONE bunch crossing!

Zone of high energy density extends to higher R wrt outgoing beam-line
Muon Transverse Momentum sum

Ideal Veto
head-on
10 mrad

Realistic Veto

$p_T(\mu^-) - p_T(\mu^+)$

Slide from Stahl.

Insufficient statistics to conclude regarding importance of effect.
Any Loss in Vetoing Power with Crossing-Angle?

Thus:
- Head-on:
  - LCAL @ z=370cm: 1.6GeV
  - LCAL @ z=350cm: 1.7GeV

- Crossing-Angle:
  - LCAL @ z=370cm: 6.6GeV
  - LCAL @ z=350cm: 6.7GeV

Prel. Plot from Zhang
Summary

Let’s not make our detector behave like this:

(ie. cover “in principle” to low angle – but miss substantial parts of pT acceptance at higher θ)