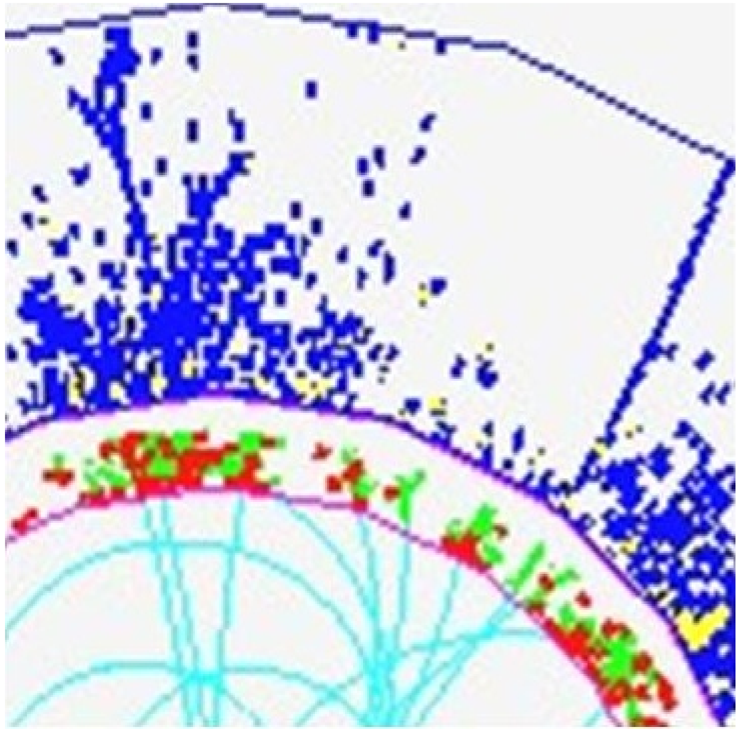
Experimental Issues

Ray Frey
University of Oregon
ICLC Paris, April 19, 2004

- Physics imperatives
  - detector implications
- The LC environment & implications
  - interaction region
  - initial state(s)
  - accelerator technology
- Revisiting detector design issues
  - major parameters
    - Session Thursday
  - implications
    - technology choices: H. Yamamoto
- Issues for the workshop



Timeline for Experimentalists

Time	DoE Time	Tasks
T – >10~11	Before 2005	Detector R&D
T – 10~11	2005~6	Test Beam I
T – 8~9	2006~7	•Detector Technology chosen. •Detector Development and design begins
T – 6	2009	Detector Construction begins
T	2015	LC and Detector ready

J. Yu, Jan 2004

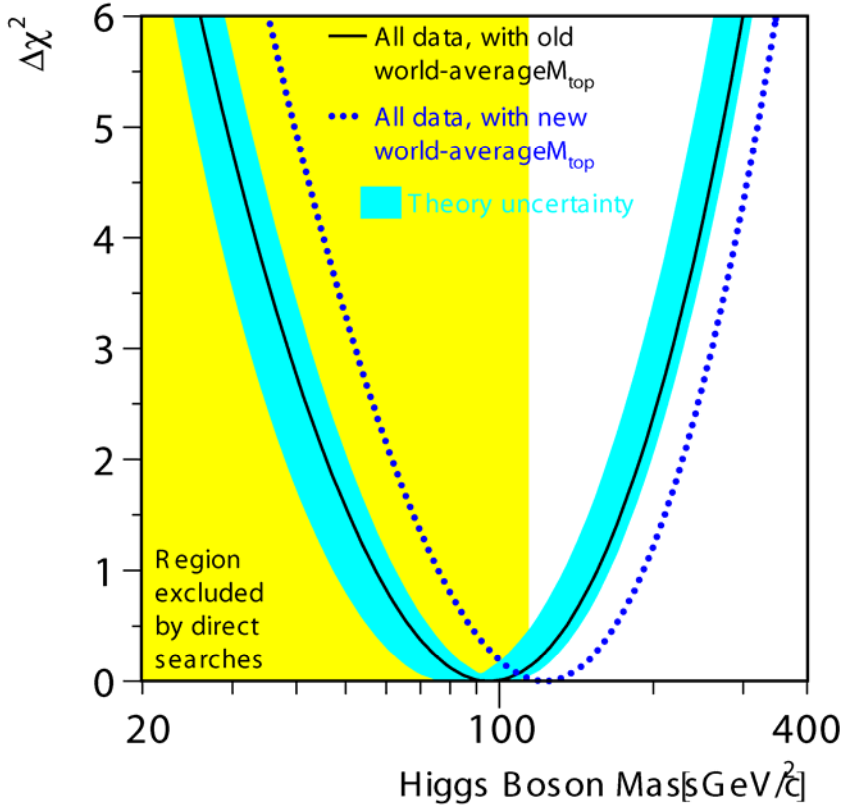
- Transfer of physicist-days from physics studies to detector R&D
  - Essential, since we are pushing frontiers in several areas
- Good: Experimental issues being addressed in more detail
  - This talk
- Bad: Many physics studies need (much) more work

Physics Imperatives

#1 A light Higgs boson

- SM, from precision EW
- SUSY

- Measure its properties
  - Mass
  - Width
  - Spin
  - Branching fractions
  - Couplings to gauge bosons
  - Self-couplings
  - Top Yukawa coupling
- Go after additional family members
  - H^o, $H^\pm$ (2HDMs, etc)
  - CP violation ($\gamma\gamma$ collider)

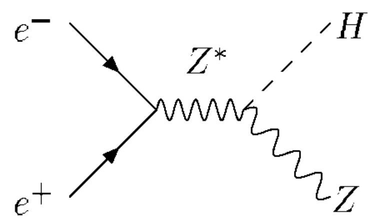


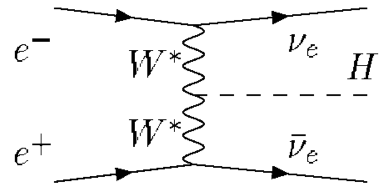
Physics Imperatives (contd)

#1 A light Higgs boson (contd)

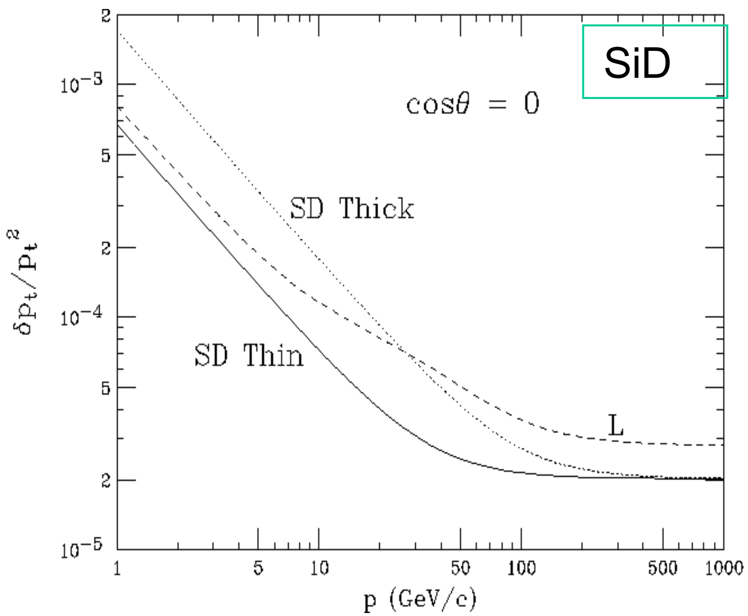
- The higgstrahlung process:

  $e^+e^- \rightarrow Zh$

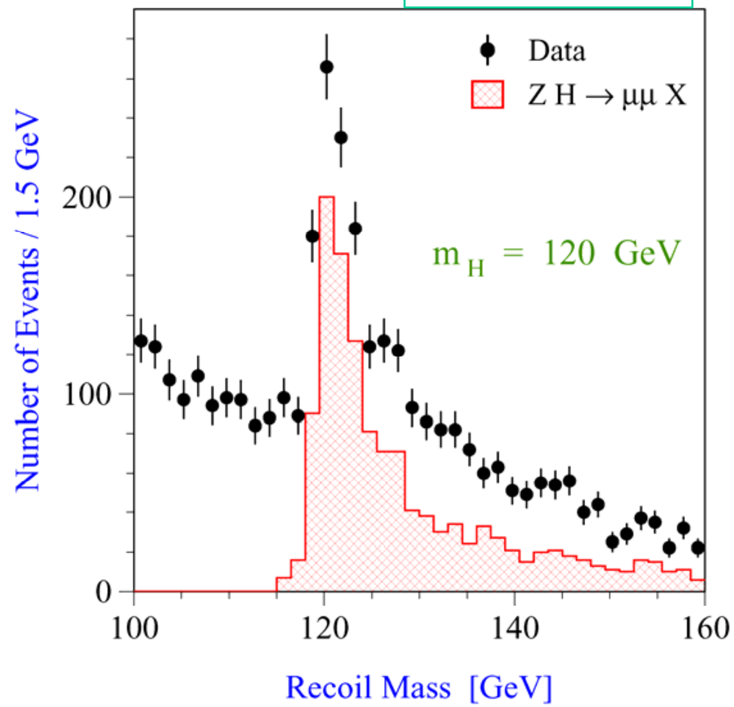




- ▪ Isolate Higgs sample independent of its decay modes
- ▪ Momentum resolution drives tracker design: $\Delta p/p^2 \approx$ few x 10^{-5} GeV^{-1}



TESLA TDR



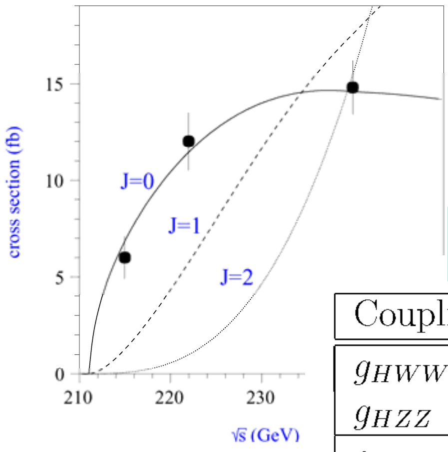
Physics Imperatives (contd)

#1 A light Higgs boson (contd)

- Measure its properties
  - Mass ✓
  - Width ✓
  - Spin ✓
  - Branching fractions ✓
    - Drives vertex det designs
  - Couplings to gauge bosons ✓
  - Self-couplings
  - Top Yukawa coupling

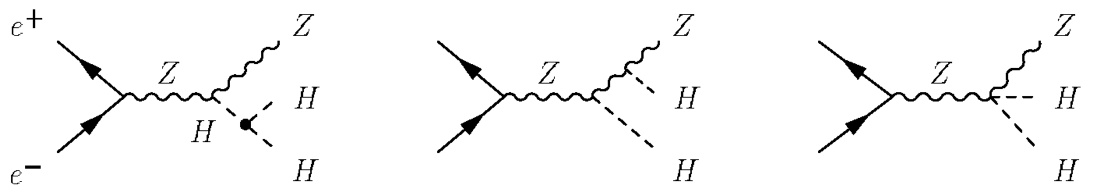
Challenging! Important!

Few x 10% sensitivity …
in general need more experimental scrutiny



TESLA TDR

Coupling	$M_H = 120\,\mathrm{GeV}$	140 GeV
g_{HWW}	$\pm$ 0.012	$\pm$ 0.020
g_{HZZ}	$\pm$ 0.012	$\pm$ 0.013
g_{Htt}	$\pm$ 0.030	$\pm$ 0.061
g_{Hbb}	$\pm$ 0.022	$\pm$ 0.022
g_{Hcc}	$\pm$ 0.037	$\pm$ 0.102
$g_{H\tau\tau}$	$\pm$ 0.033	$\pm$ 0.048
g_{HWW}/g_{HZZ}	$\pm$ 0.017	$\pm$ 0.024
g_{Htt}/g_{HWW}	$\pm$ 0.029	$\pm$ 0.052
g_{Hbb}/g_{HWW}	$\pm$ 0.012	$\pm$ 0.022
$g_{H\tau\tau}/g_{HWW}$	$\pm$ 0.033	$\pm$ 0.041
g_{Htt}/g_{Hbb}	$\pm$ 0.026	$\pm$ 0.057
g_{Hcc}/g_{Hbb}	$\pm$ 0.041	$\pm$ 0.100
$g_{H\tau\tau}/g_{Hbb}$	$\pm$ 0.027	$\pm$ 0.042



Physics Imperatives, contd.

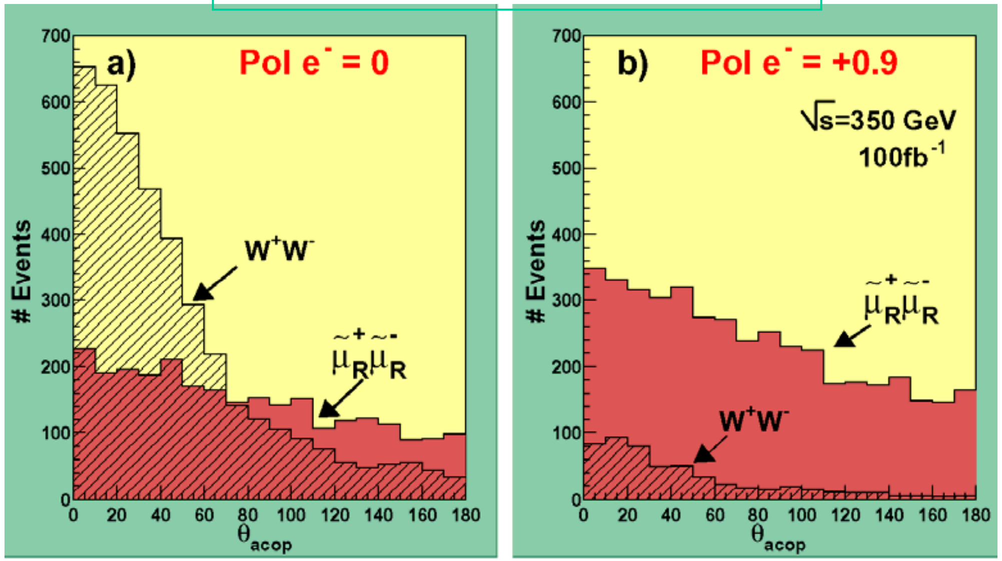
#2 Light SUSY ?

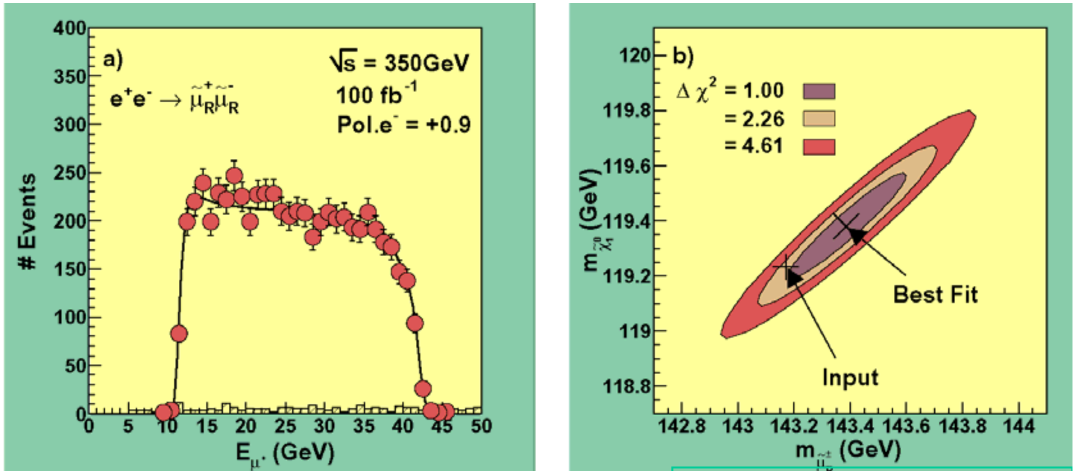
- Shows off LC capabilities
- Good example of LHC/LC complementarity

particle	m [GeV]	δm [GeV] LHC	δm [GeV] LHC+LC
h^0	109	0.2	0.05
A^0	259	3	1.5
χ_1^+	133	3	0.11
χ_1^0	72.6	3	0.15
$\tilde{\nu}_e$	233	3	0.1
$\tilde{e}_1$	217	3	0.15
$\tilde{\nu}_\tau$	214	3	0.8
$\tilde{\tau}_1$	154	3	0.7
$\tilde{u}_1$	466	10	3
$\tilde{t}_1$	377	10	3
$\tilde{g}$	470	10	10

TESLA TDR

$e^+e^- \rightarrow (s\mu)(s\mu) \rightarrow \chi\chi\mu\mu$





GLC project report

However….

Physics Imperatives, contd.

Possible experimentalist solution to the hierarchy problem…

- TONOTA (*theory of none-of-the-above*)
- Open-mindedness reinforced by recent theoretical creativity…

- •MSM
- •MSSM
- •Fat Higgs
- •Little Higgs
- •SUSY t-color models
- •Higgs-less (extra dims.)
- •Topcolor
- •TONOTA

H. Murayama

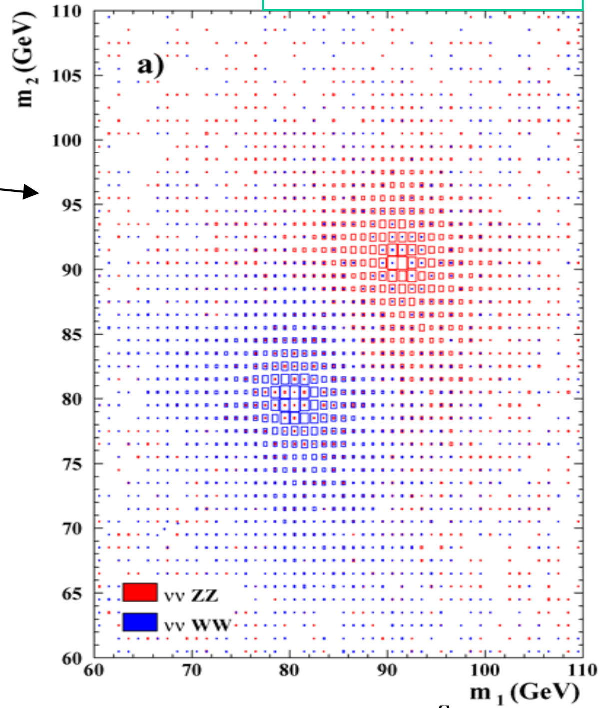
Physics Imperatives, contd.

#2 Well… um… hmmm

My view (still): This is a facility of ***exploration***, not specialization.

- Must be ready for ~~anything~~ many possibilities !
- However, we expect final states which include:
  - Multi-jet final states
    - With or without beam constraint
  - Leptons
    - *including* tau
  - Heavy quarks
  - Missing energy/mass
  - *Combinations of these*

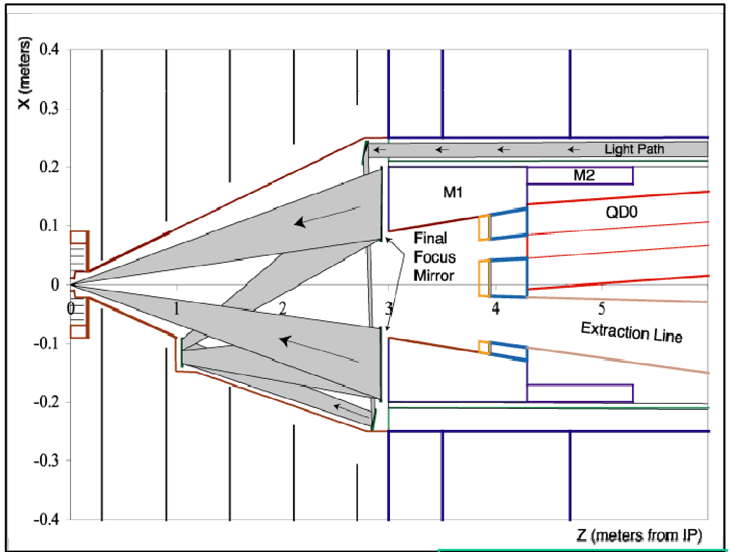
TESLA TDR



Physics Imperatives, contd.

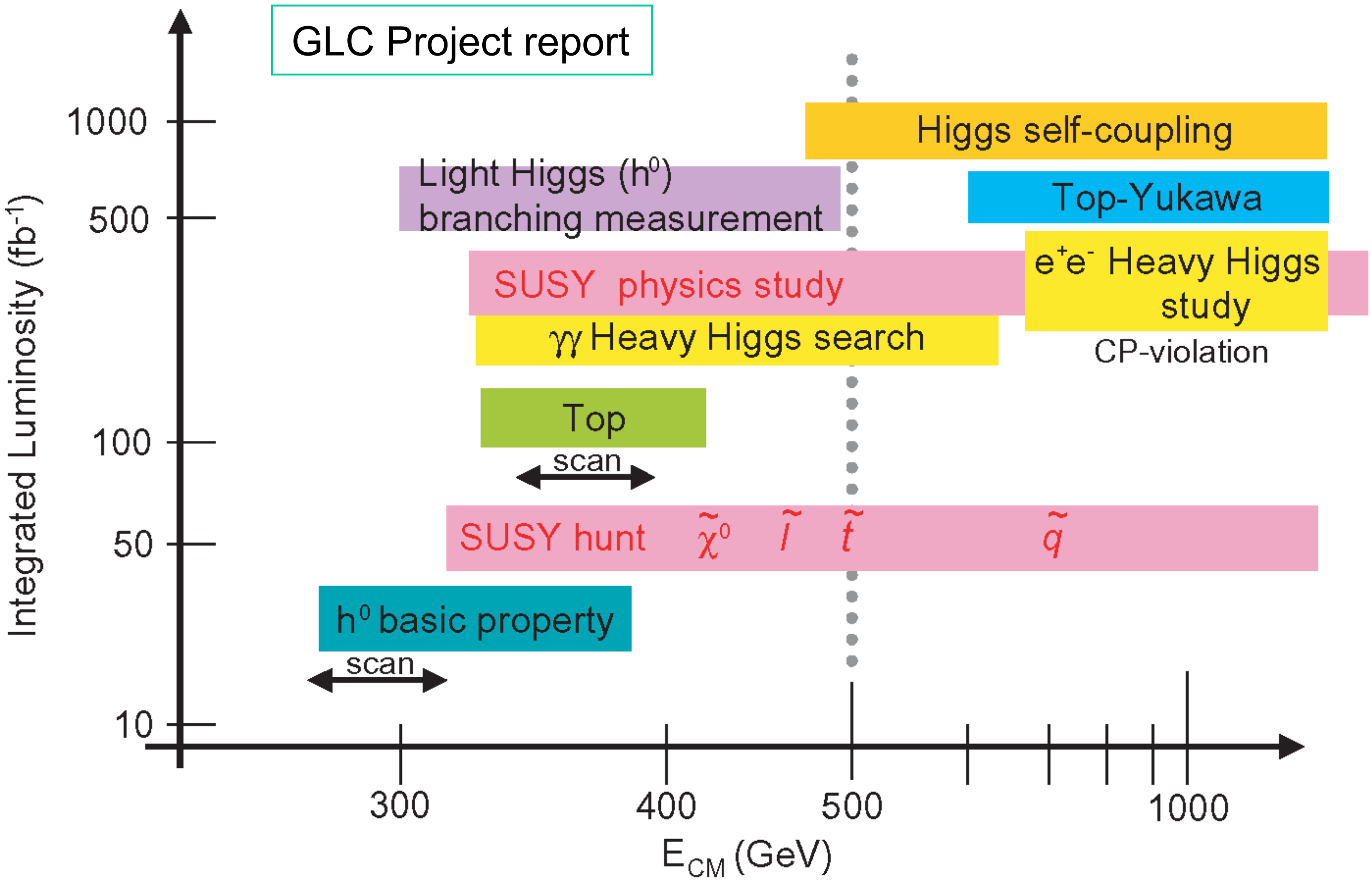
Be prepared to exploit the inherent power of LC

- Well-defined initial state
  - Energy, tunable
  - Momentum constraints
  - No gluons
  - Quantum numbers
  - Polarization: e^-, e^+, γ
  - Possibilities for $\gamma\gamma$, γe^-, $e^- e^-$
  - Tiny collision region
- Ability to reconstruct hadronic final states
- Ability to tag heavy (light) quarks
- Excellent missing energy/mass sensitivity
- Ability to choose energy, polarization of collisions
  - Threshold scans, Giga-Z
  - Modulation of signals *and* backgrounds



$\gamma\gamma$ IR, Large

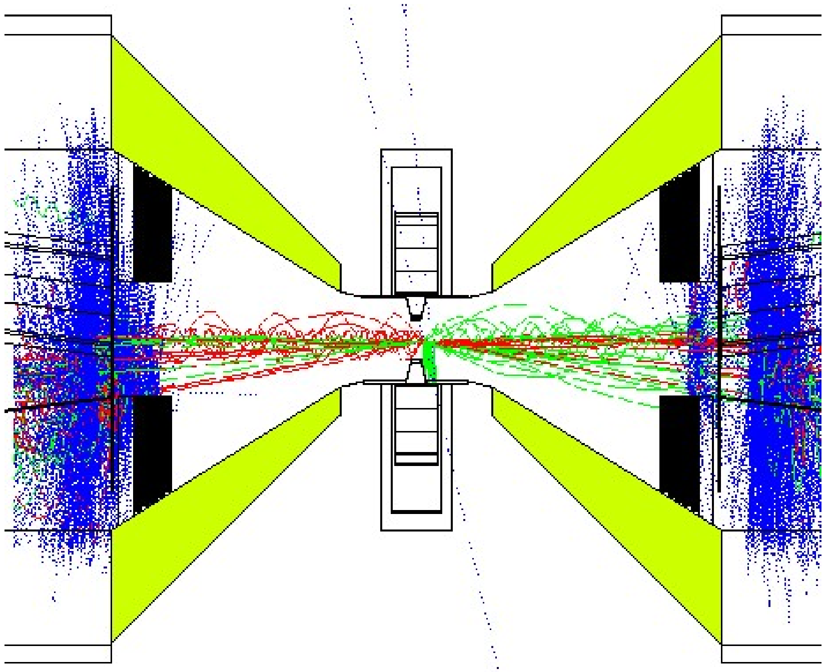
A typical physics roadmap

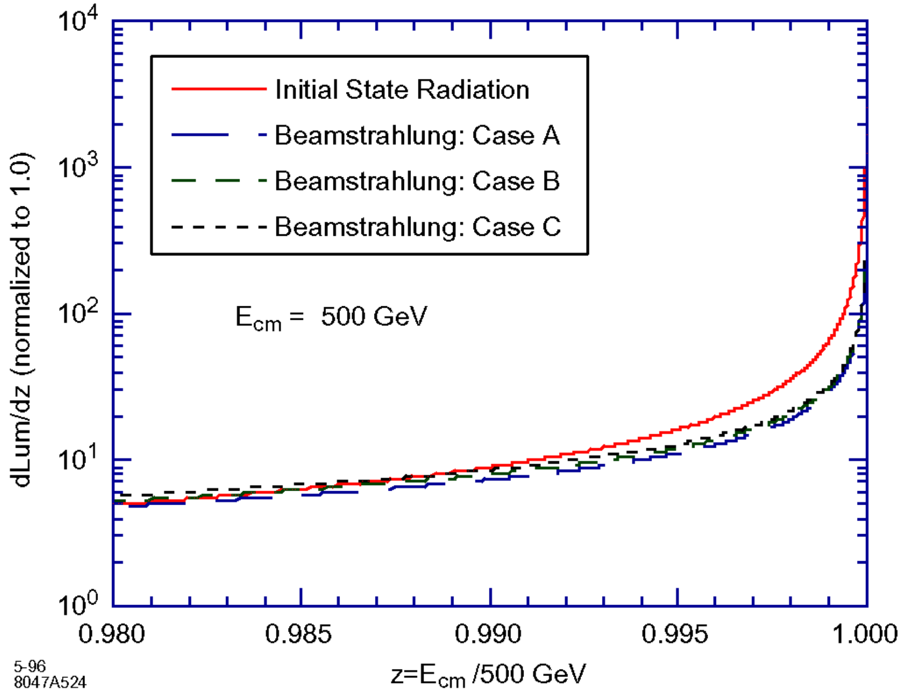


Sensible programs can be formulated to cover all of the (foreseen) physics within a luminosity and energy budget.

e.g. P. Grannis hep-ex/0211002 (LCWS2002)

“At the LC, the initial state is well defined”…





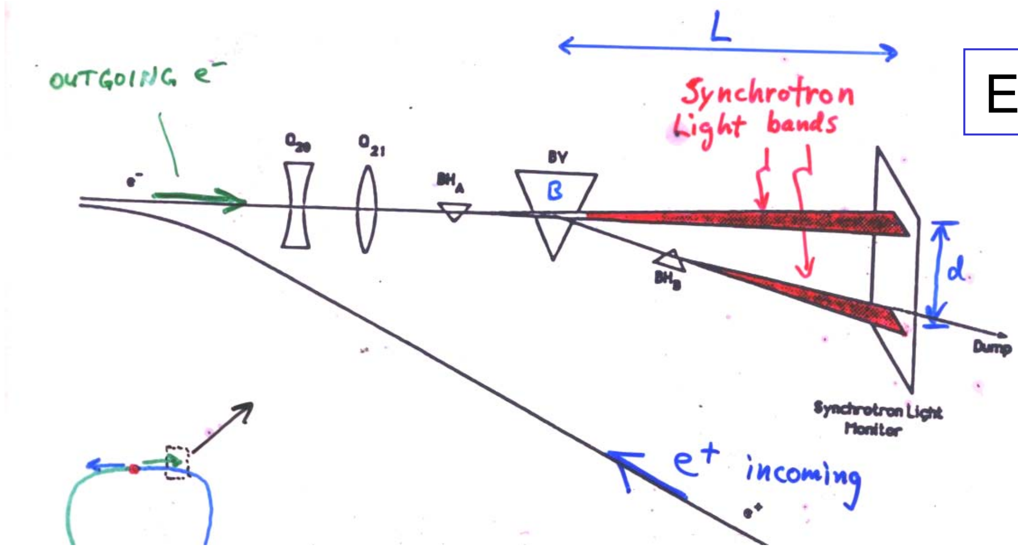
A Luminosity Spectrum dL/dE

- Contributions
  1. ISR
  2. Beamstrahlung } → “$\delta(E_o)$ + tail”
  3. Linac energy spread, $\Delta E/E$ → Broadening near E_o

- Measuring dL/dE

Mean beam-energy measurement

SLC extraction line spectrometer

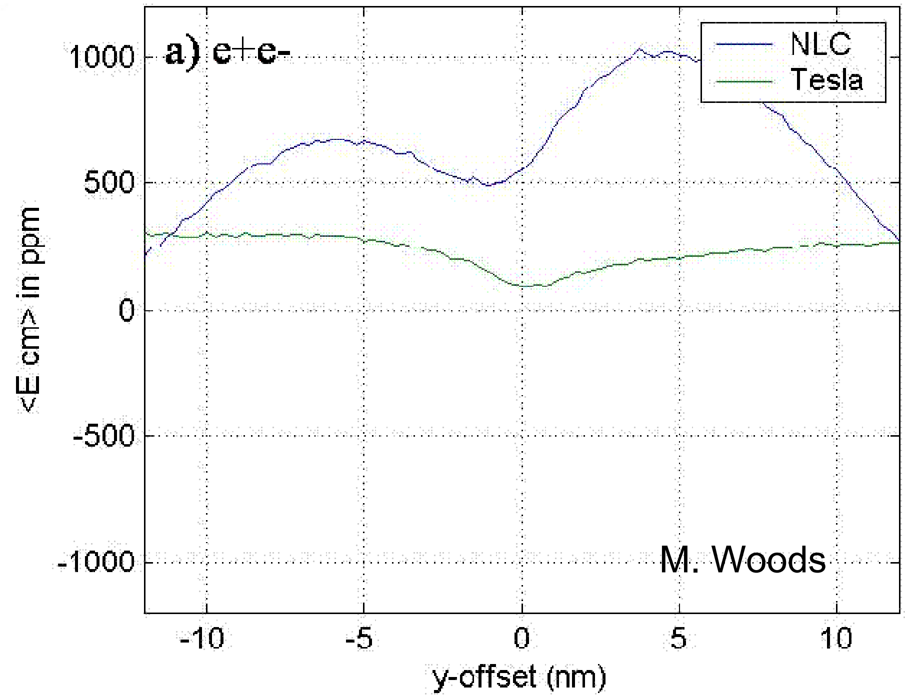


$E = (cL/d) \int B dl$

~few x10^{-4}

but…

Not so straightforward at fLC

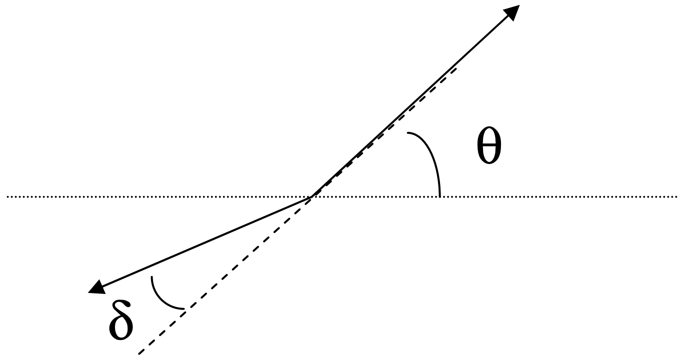


Requires calibration/crosscheck of energy scale ⇐

Using detector final states

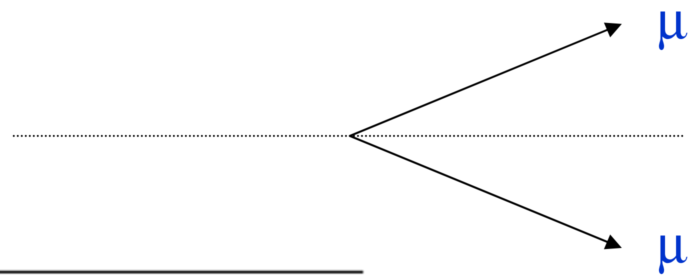
- Bhabha acollinearity

$$\delta \propto (E_+ - E_-) \sin\theta / E$$



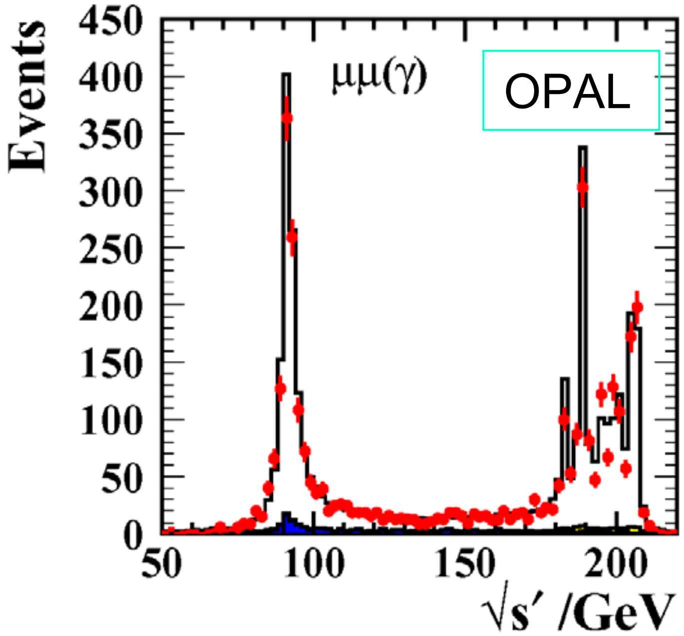
- Sum?
  - Several possibilities
    - Zγ, ZZ, WW?
  - Promising: radiative returns

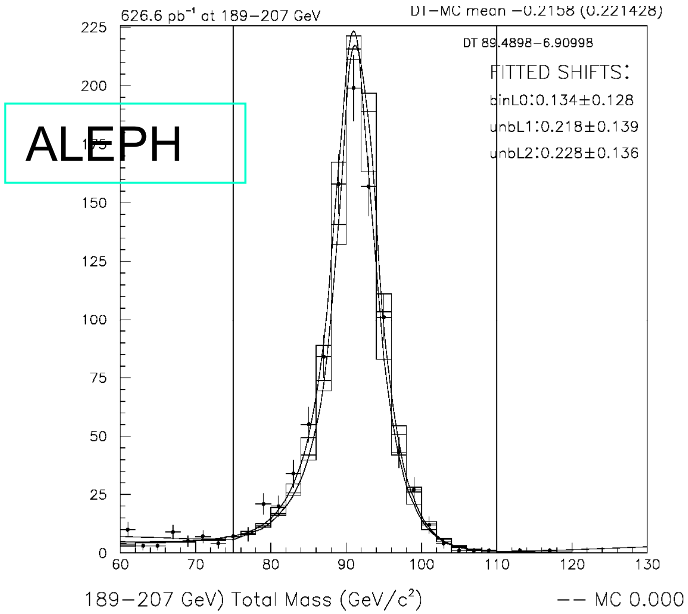
$$e^+e^- \rightarrow Z\gamma \rightarrow \mu\mu\gamma$$

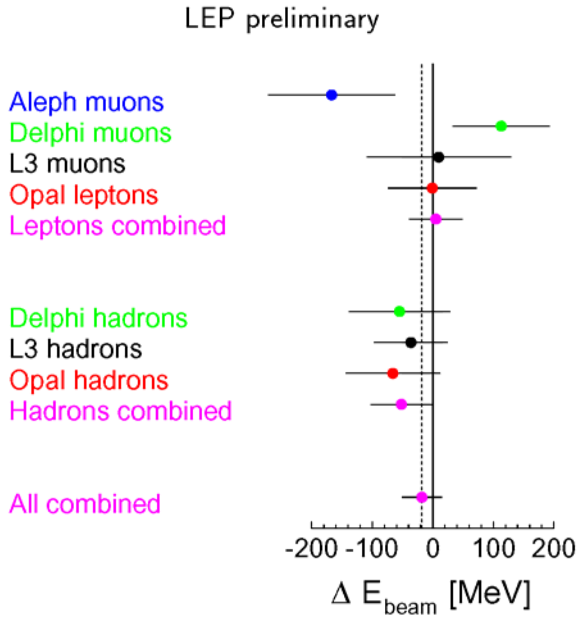


$$\sqrt{s'} = \sqrt{s} \cdot \sqrt{\frac{\sin(\theta_f) + \sin(\theta_{\bar{f}}) - |\sin(\theta_f + \theta_{\bar{f}})|}{\sin(\theta_f) + \sin(\theta_{\bar{f}}) + |\sin(\theta_f + \theta_{\bar{f}})|}}$$

energy constraints (contd)



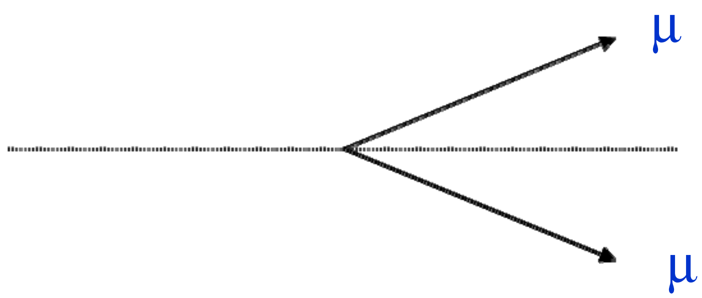




Experiment	Channel	ΔE_{beam} [MeV]
ALEPH	$\mu^+\mu^-\gamma$	$-167 \pm 91 \pm 48$
DELPHI	$\mu^+\mu^-\gamma$	$+113 \pm 75 \pm 27$
DELPHI	$q\bar{q}\gamma$	$-55 \pm 53 \pm 65$
L3	$\mu^+\mu^-\gamma$	$+10 \pm 115 \pm 22$
L3	$q\bar{q}\gamma$	$-46 \pm 33 \pm 51$
OPAL	$e^+e^-\gamma$	$+40 \pm 136 \pm 78$
OPAL	$\mu^+\mu^-\gamma$	$-51 \pm 84 \pm 22$
OPAL	$\tau^+\tau^-\gamma$	$+301 \pm 199 \pm 148$
OPAL	$q\bar{q}\gamma$	$-66 \pm 34 \pm 70$
Combined	$l^+l^-\gamma$	$+5 \pm 41 \pm 16$
Combined	$q\bar{q}\gamma$	$-52 \pm 24 \pm 43$
Combined	$f\bar{f}\gamma$	$-20 \pm 25 \pm 22$

energy constraints (contd)

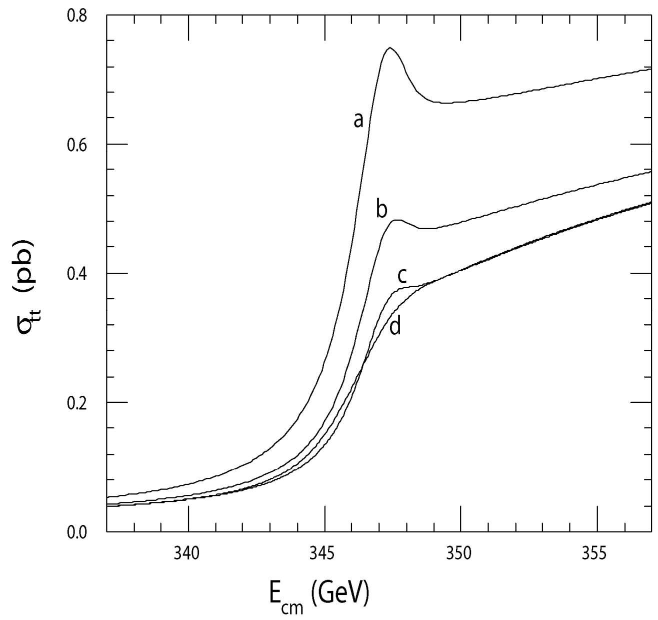
$ee \rightarrow Z\gamma \rightarrow \mu\mu\gamma$ $(ff\gamma)$



- Systematics?
  - Precise positions/angles in forward tracking system
  - or invariant mass recon. In forward system
  - $\theta \sim$ few degrees for high energy running

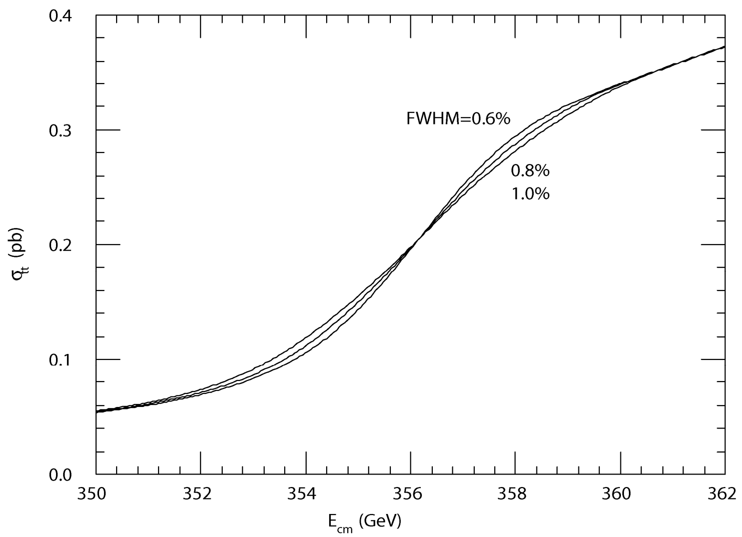
Energy spread effects on physics

- ISR + beamstrahlung
  - ~Lum. loss at nominal √s
  - Provide radiative returns



$e^+e^- \rightarrow t\,t$ at threshold

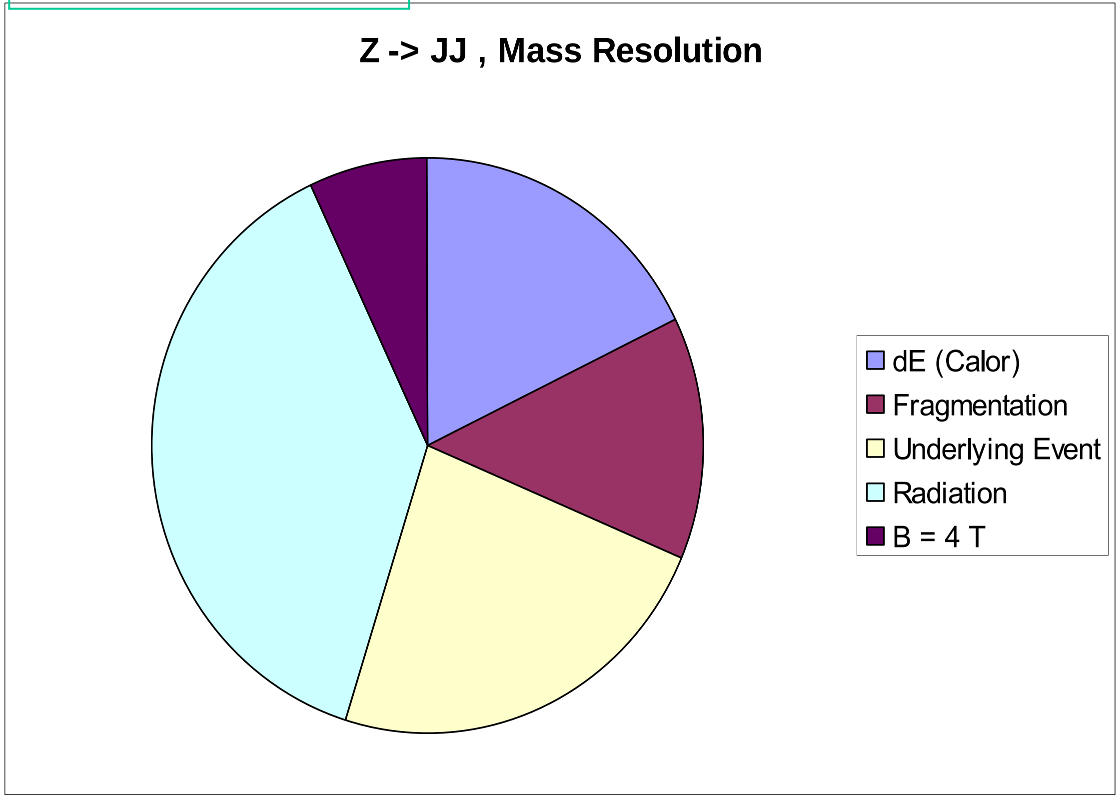
- Linac energy spread
  - Can smear out narrow structures



LC Calorimetry (global really)

D. Green, Calor2002

LHC Study: Z→ 2 jets



- **FSR is the biggest effect.**
- **The underlying event is the second largest error (if cone R ~ 0.7).**
- **Calorimeter resolution is a minor effect.**

σ_M / M ~ 13% without FSR

⇒ At the LC, the situation is reversed: Detection dominates.

⇒ Opportunity at the LC to significantly improve measurement of jets.

calorimetry (contd)

Complementarity with LHC:

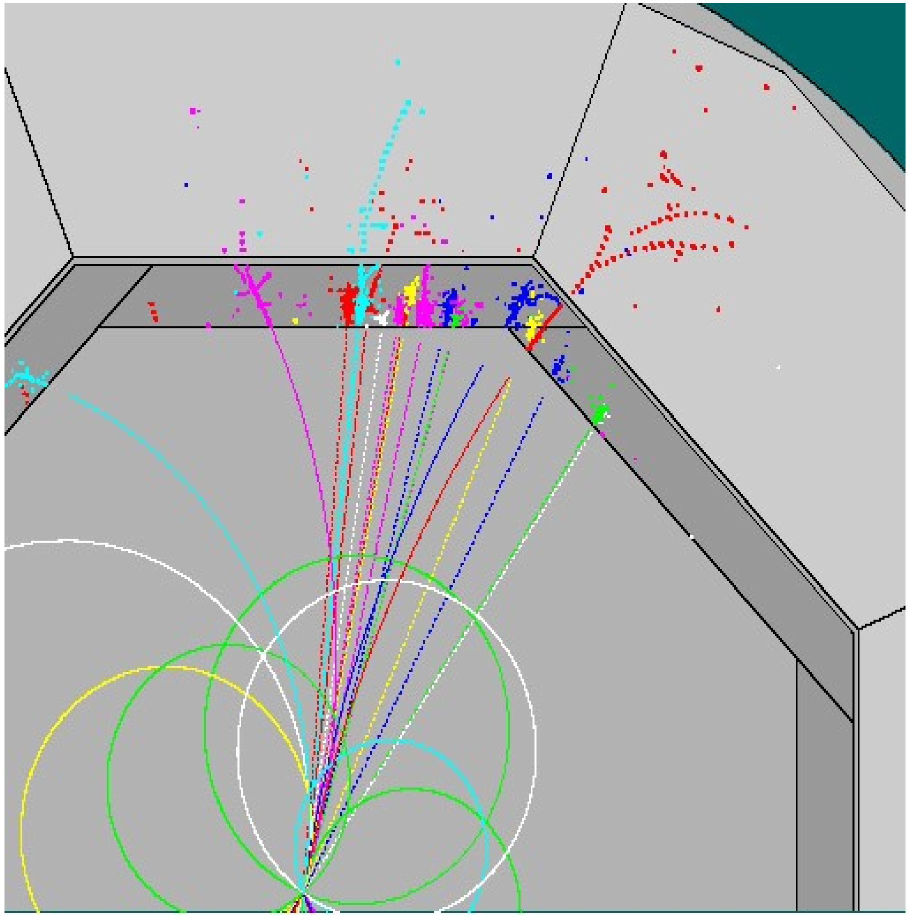
LC should strive to do physics with ***all*** final states.

1. Charged particles in jets more precisely measured in tracker
2. Jet energy 64% charged (typ.)

Separate charged/neutrals in calor.

⇒ The "Particle Flow" paradigm

- ECAL: dense, highly segmented
- HCAL: good pattern recognition



H. Videau

Energy Flow Algorithms

Dean Karlen, LCWS 2002

$$E_{\text{jet}} = E_{\text{charged}} + E_{\text{photons}} + E_{\text{neut. had.}}$$

$$\sigma^2_{E\text{jet}} = \sigma^2_{E\text{charged}} + \sigma^2_{E\text{photons}} + \sigma^2_{E\text{neut.had.}} + \sigma^2_{\text{confusion}}$$

- Ignoring the (typically) negligible tracking term:

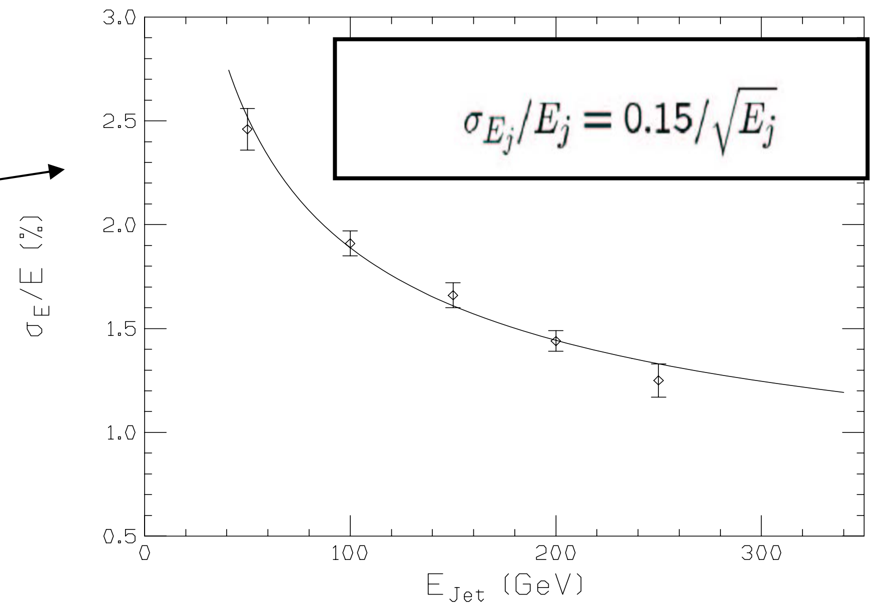
$$\sigma^2_{E\text{jet}} \approx (0.14)^2 \left(E_{\text{jet}} \cdot \text{GeV}\right) + \sigma^2_{\text{confusion}} \approx (0.3)^2 \left(E_{\text{jet}} \cdot \text{GeV}\right)$$

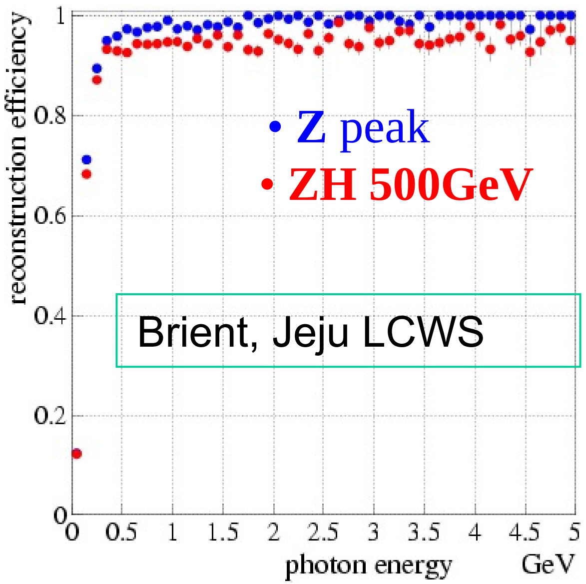
  - $\sigma^2_{\text{confusion}}$ is the largest term of all

calorimetry (contd)

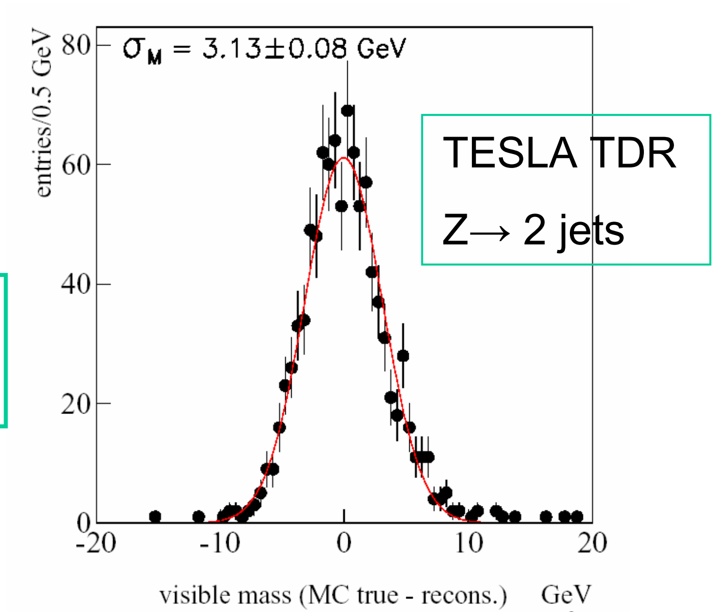
Expectations for jet resolution

- Let σ(confusion)=0 (QCD+res)
- What can we expect for σ(conf) ?
  - Requires full simulations with believable MC (Geant4?)
  - To be verified at test beams
  - Development of algorithms
- Studies to date: jet res ~ 0.3/ √ Ejet





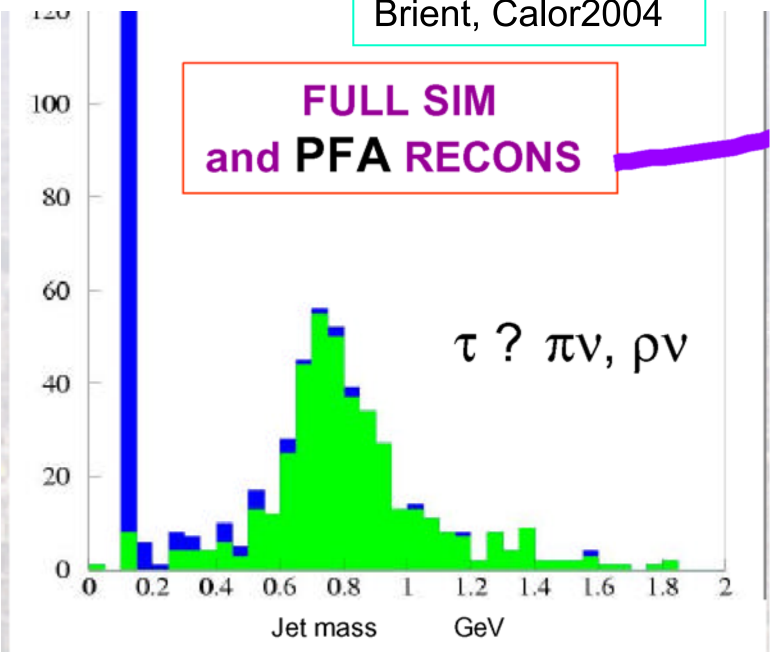
Hope to see more PFA results



calorimetry (contd)

- Such a calorimeter will also do very well for:
  - Photons, including non-pointing
  - Electrons and muons
- Tau id. and polarization
  - 3rd generation
  - Yukawa coupling
  - Separation of tau final states

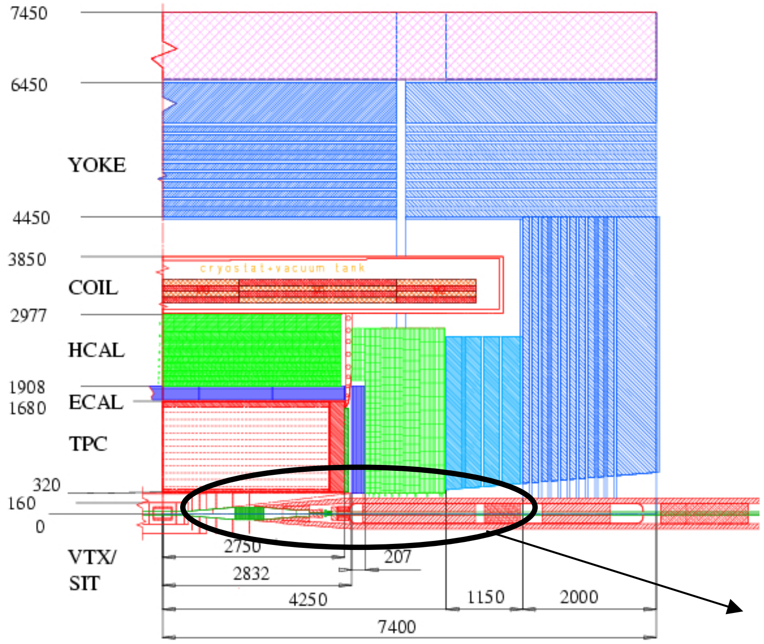
Brient, Calor2004



$\tau \rightarrow \rho\nu \rightarrow \pi^+\pi^o\nu$

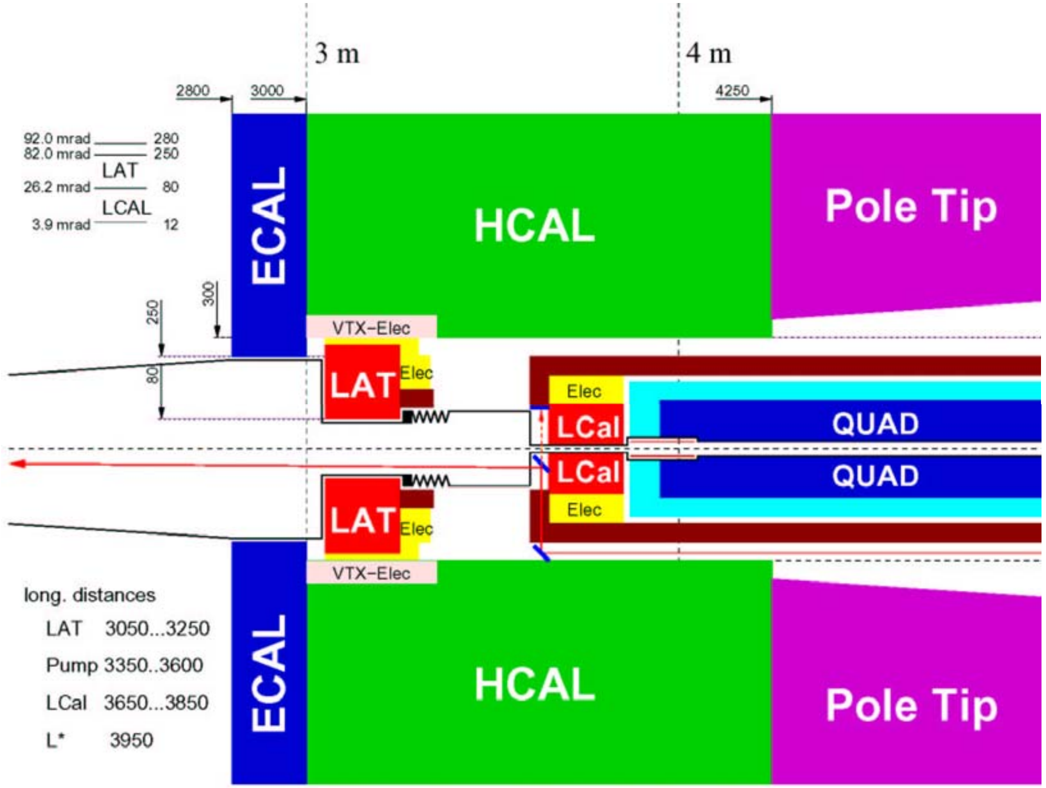
H. Videau

Hermiticity



TESLA

- This is a 4π issue, of course
- We focus on the forward region, which has been "under appreciated".



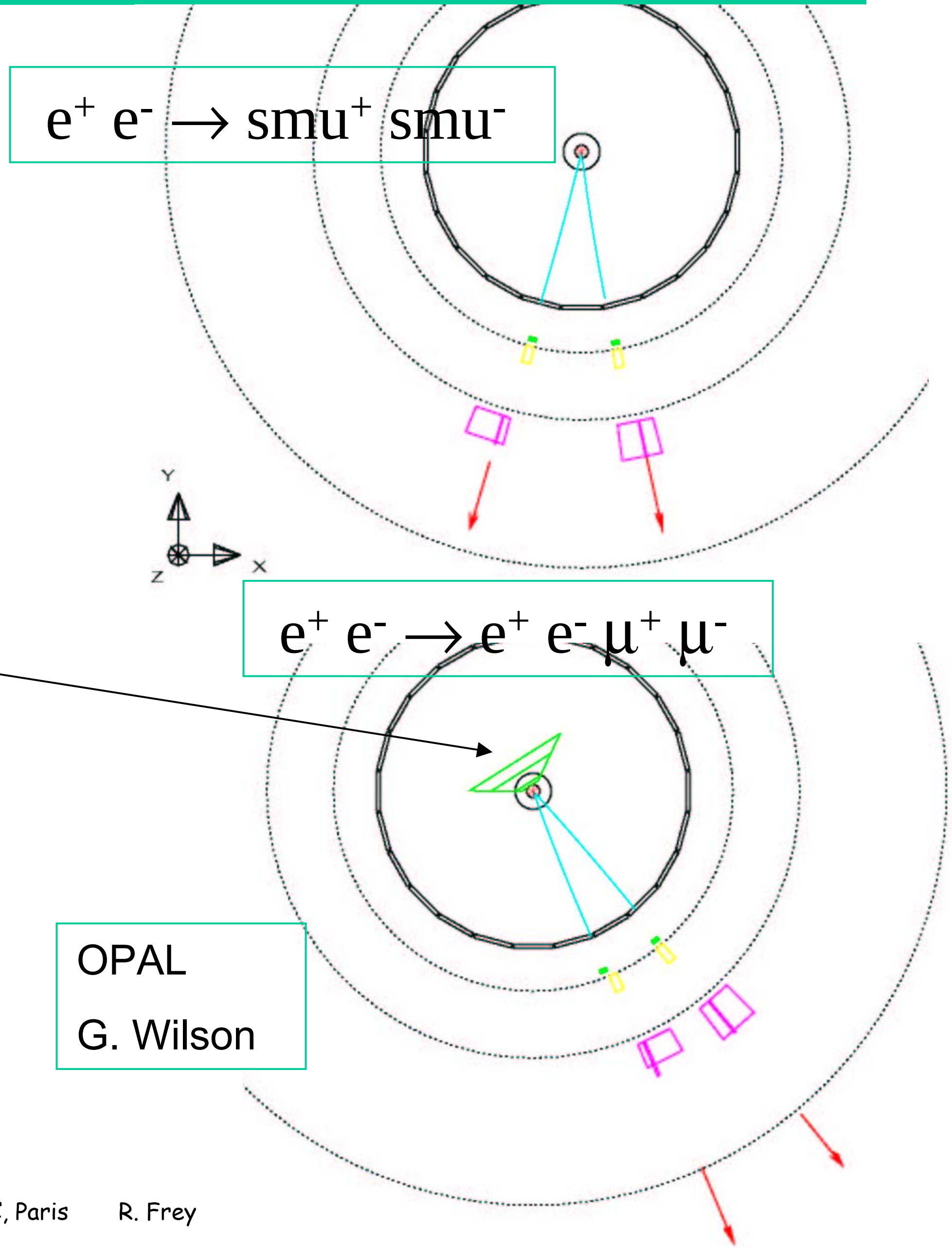
hermiticity (contd)

- Consider as an example: sleptons nearly mass-degenerate with neutralinos
  - Favored by SUSY-WIMP consistency with CDM

- The SUSY events will look like 2-photon events…

  unless the 2-photon electron is vetoed.

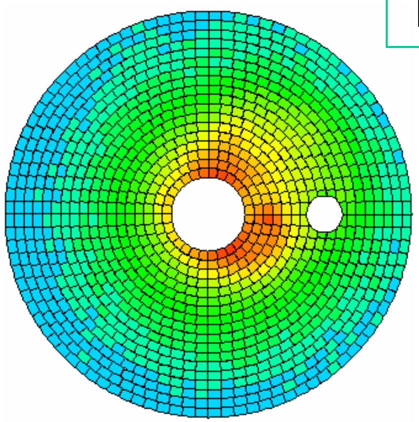
- Requires good forward veto coverage



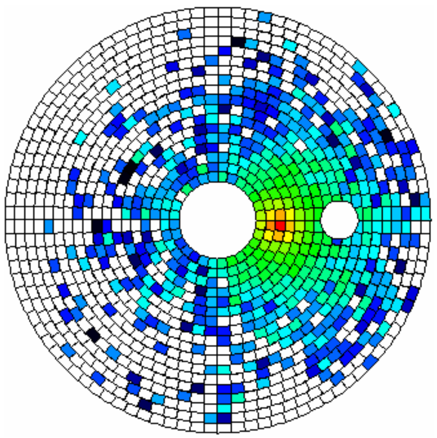
hermiticity (contd)

Veto < 25 mrad ?

T. Maruyama



← pairs

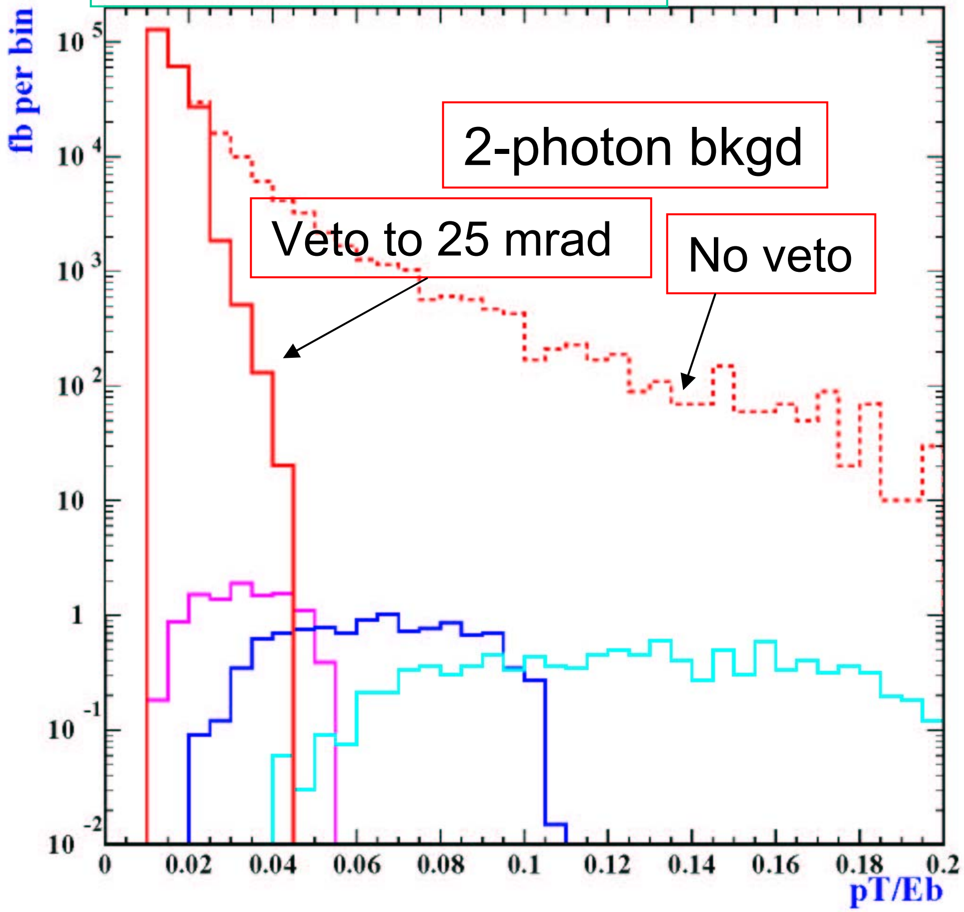


← 250 GeV e-

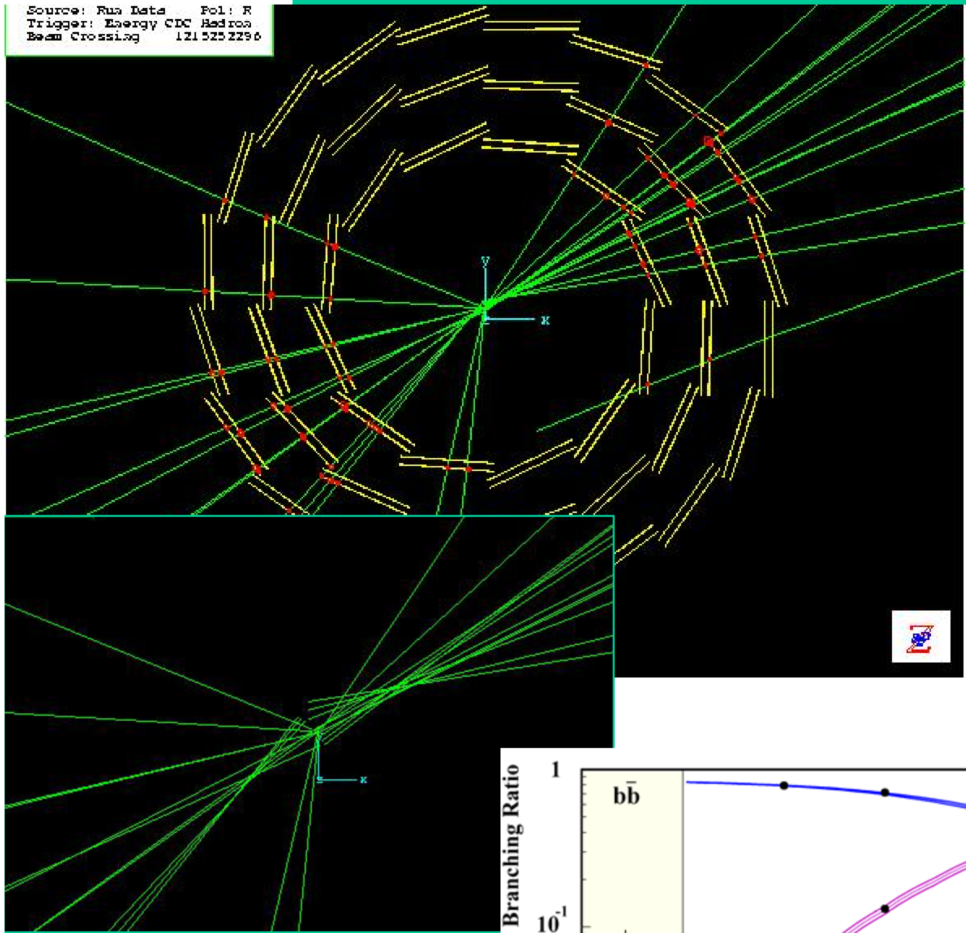
- requires few ns readout (warm)
- TESLA: veto to 6 mrad (Lohmann)

$(M_{smu}-M_{LSP})/M_{smu}$ = 2.8%, 5.6%, 11%

G. Wilson

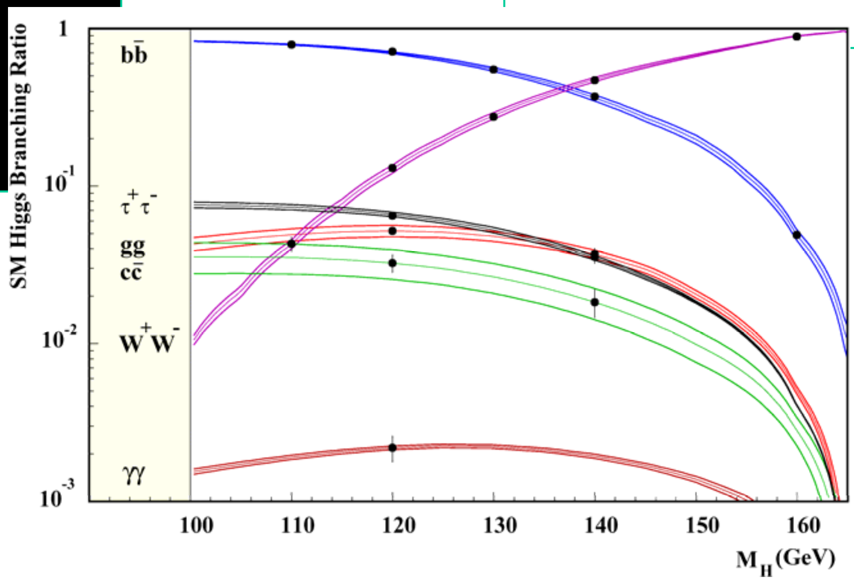


At the LC, vertexing is (nearly) ideal



- Tiny, stable interaction *point*
- Small inner radius ~1 cm
- Clean events allow *full* reconstruction of secondary vertices → mass, charge, …
- Beam duty cycle allows readout of even slow pixel detectors
- Pixels provide pileup immunity
- Moderate radiation

⇒ Superior b,c (u,d) flavor tagging, tau's



Accelerator Technology

Warm or Cold ??

Yes, *please* !

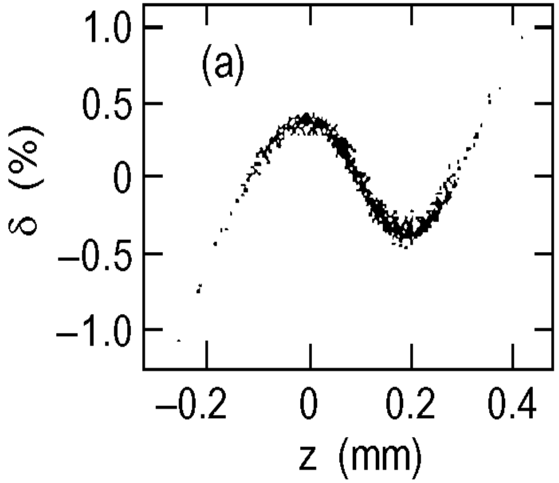
!!

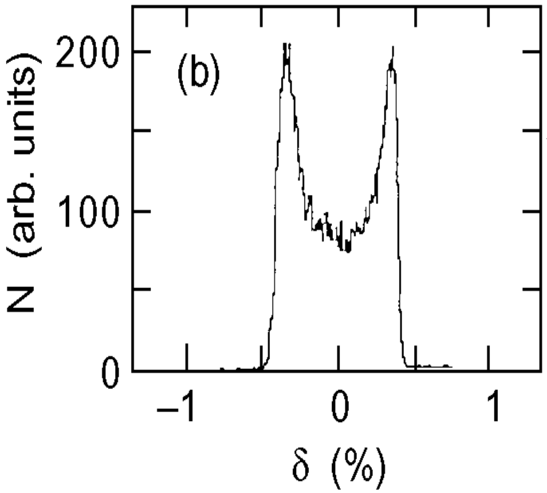
Implications on detector design

(my opinion: small effects)

- energy spread
- bunch timing structure
- crossing angle

Linac beam energy spread

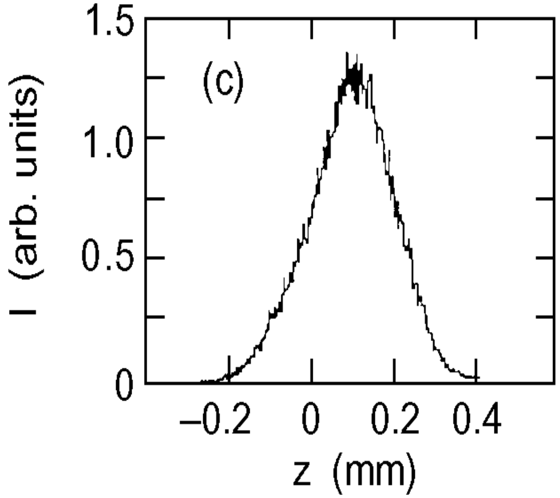


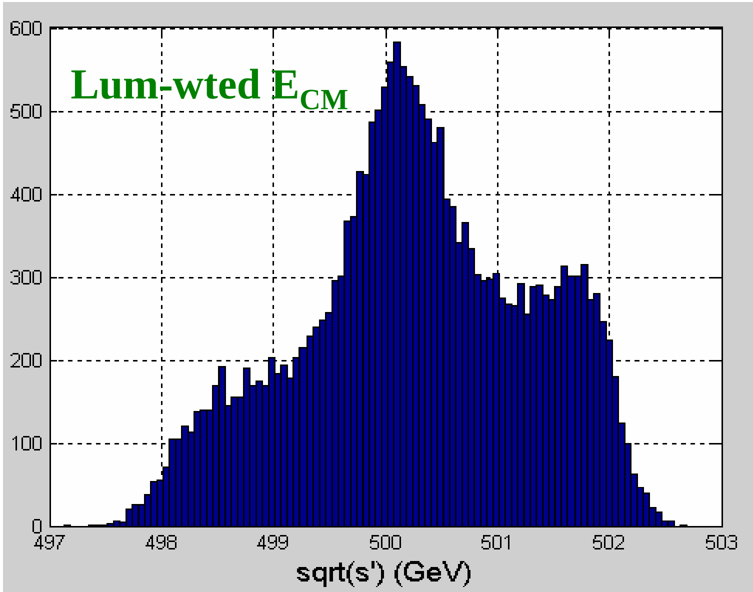


$\delta = \Delta E/E$, one beam,

X-band

$E_+ \oplus E_-$





Warm: $\delta \approx 0.3$ %

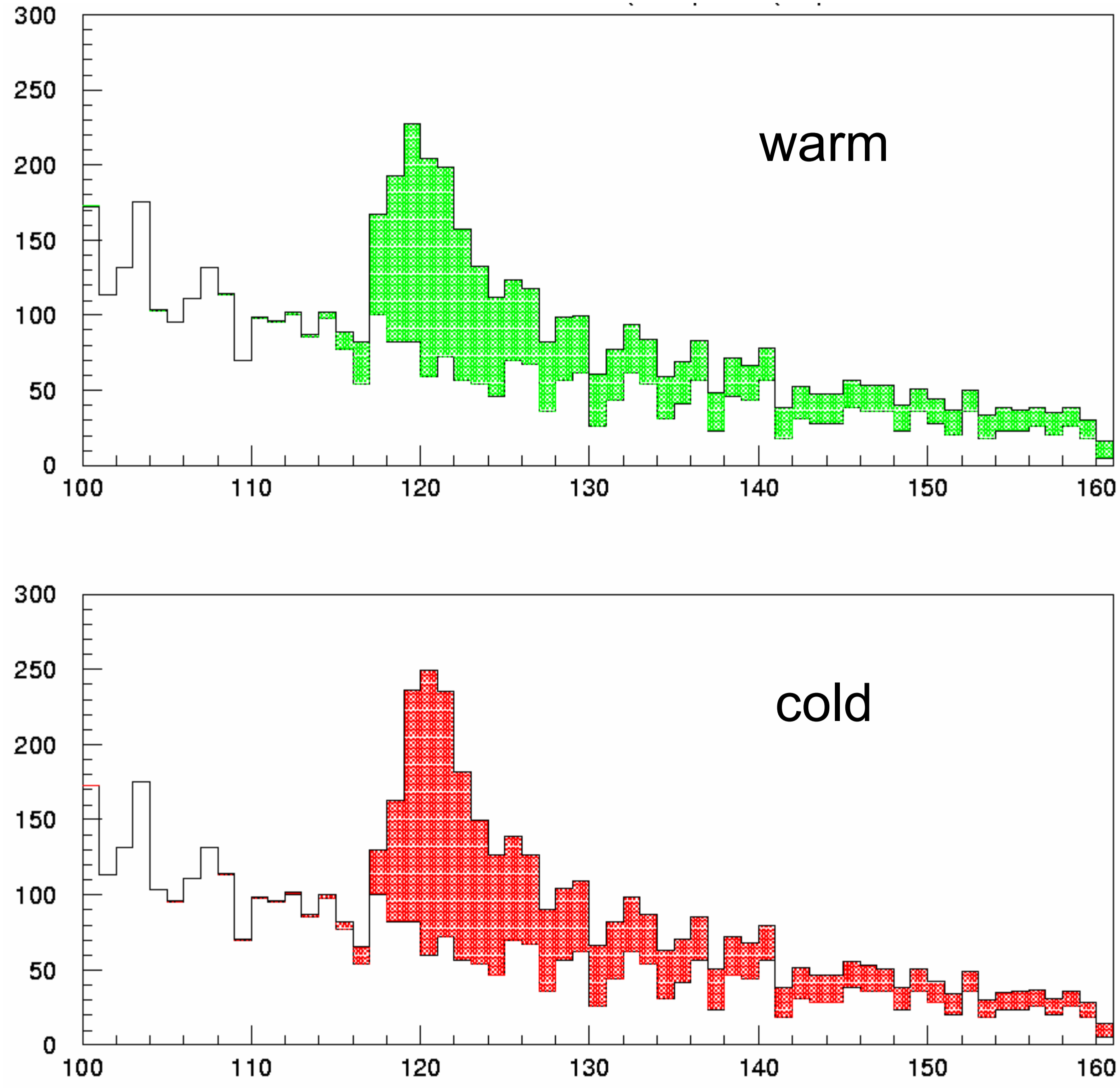
Cold: $\delta \approx 0.1$ %

Linac energy spread

$e^+e^- \rightarrow Zh$

T. Barklow

$Z \rightarrow e^+e^-, \mu^+\mu^- \quad \sqrt{s} = 350\ GeV\ L = 500\ fb^{-1}$

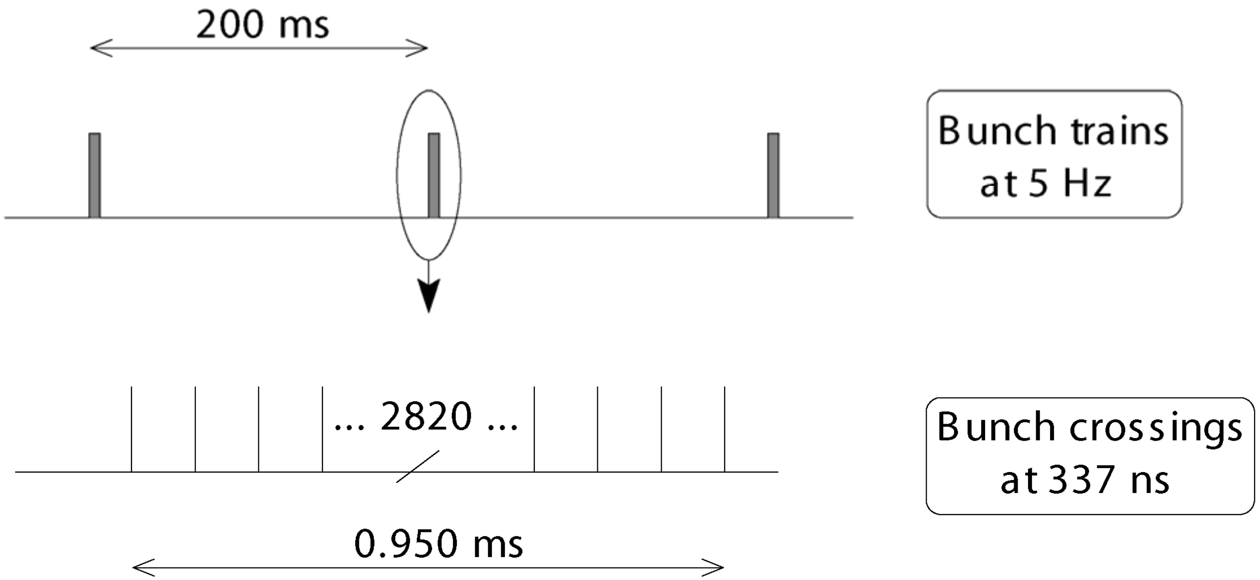


- Warm: ~0.3%
- Cold: ~0.1%

- Additional examples in *Machine-detector interface* sessions

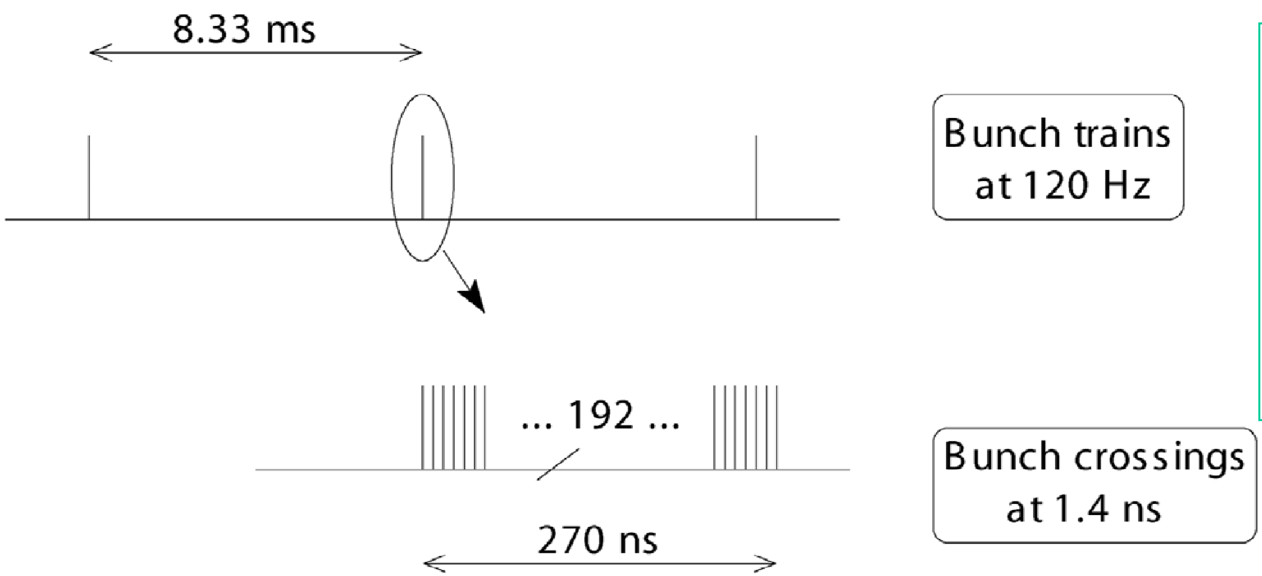
Beam crossing time structure

Cold



- •Fast readouts: OK, no pileup
- •Digital pipeline
- •bx live: 5×10^{-3}

Warm



- •Pileup over bunch train
- •Or fast timing
- •bx live: 3×10^{-5}

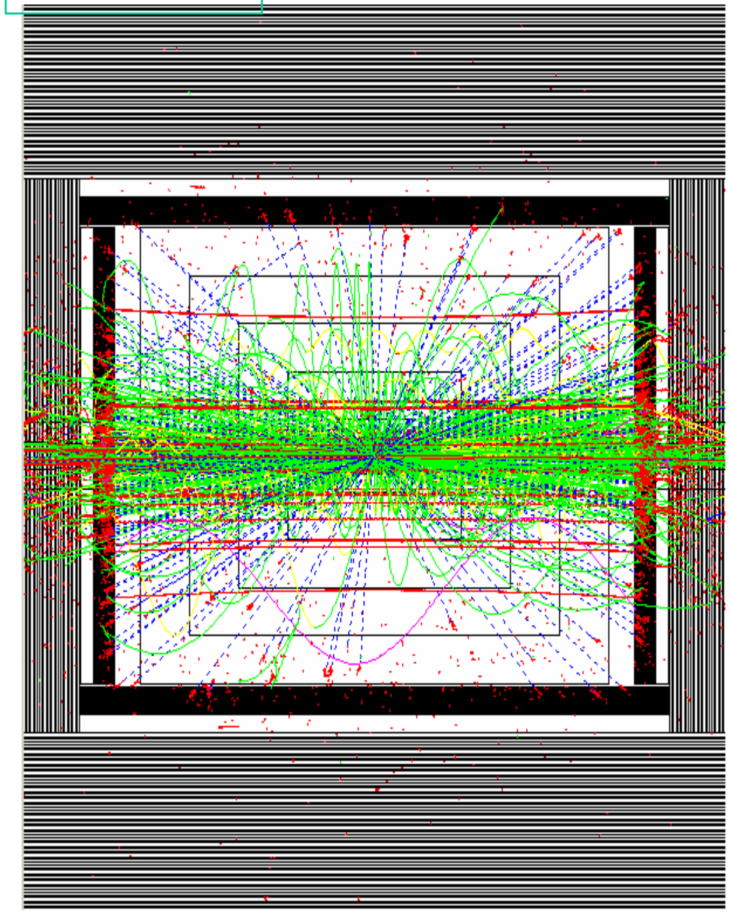
$\Rightarrow$ power pulse

Timing is good

Warm detector concern:

Pileup of $\gamma\gamma\rightarrow$ hadrons over bx train

T. Barklow

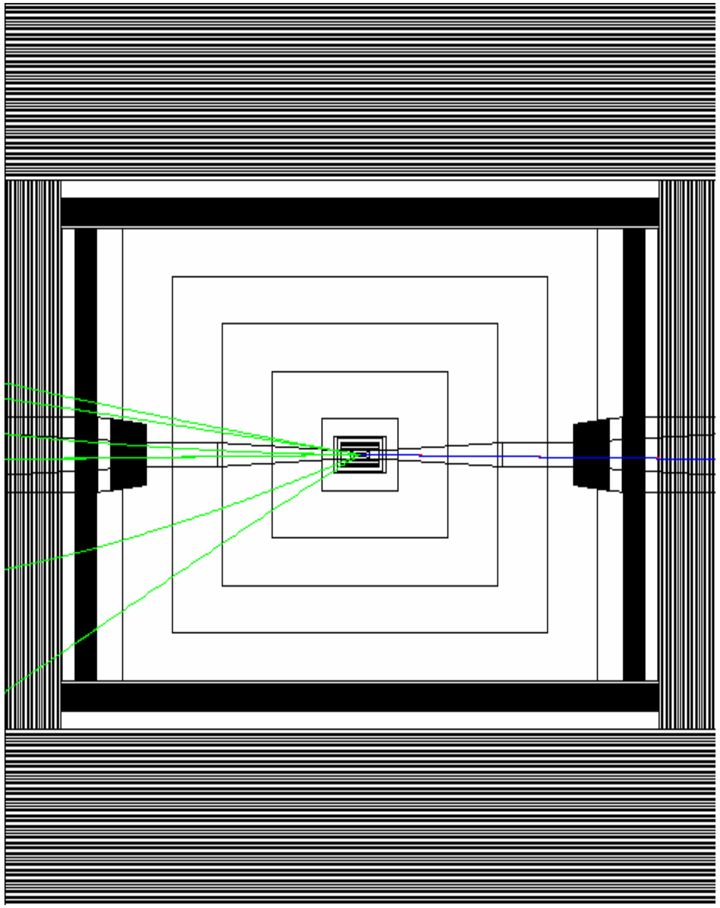


192 bx pileup

(56 Hadronic Events/Train)

Si/W ECal

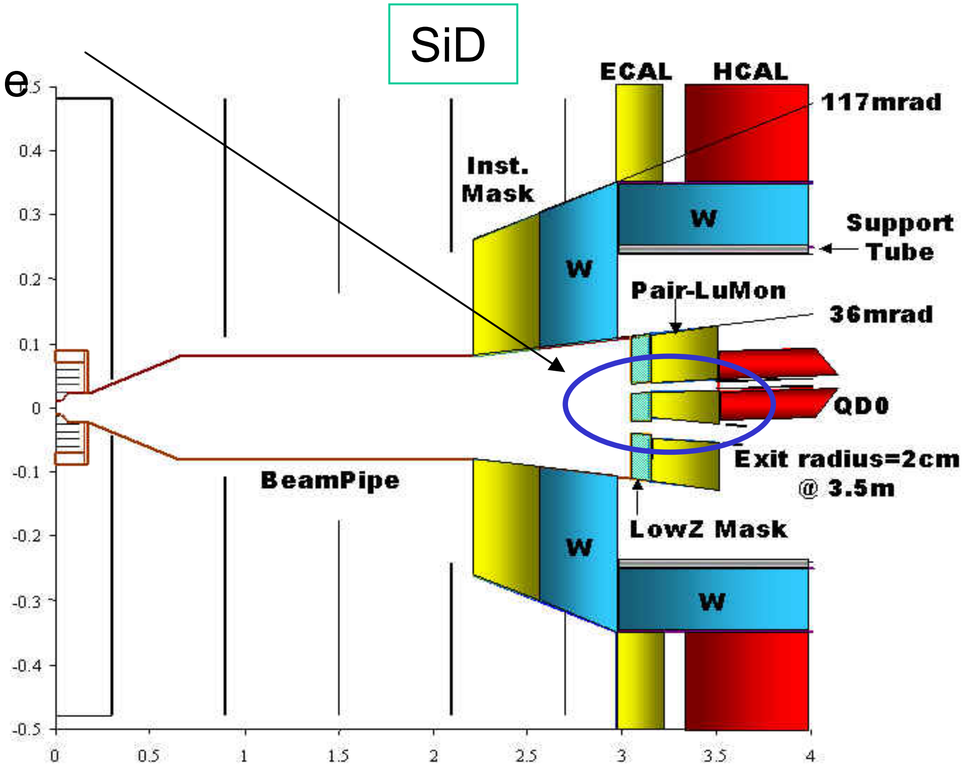
Timing ~ 1 ns



3 bx pileup (5ns)

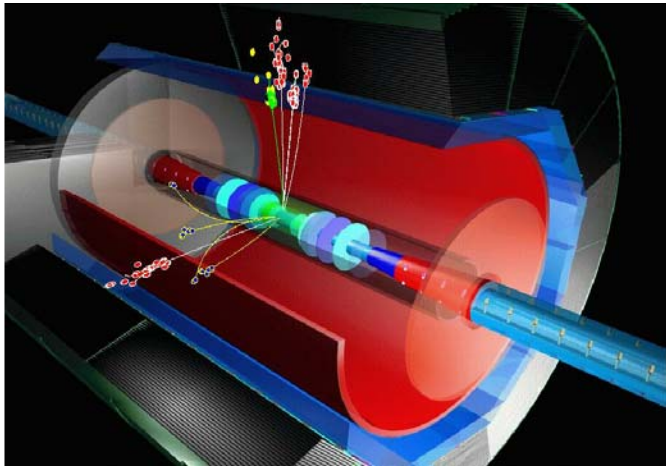
Beam crossing angle

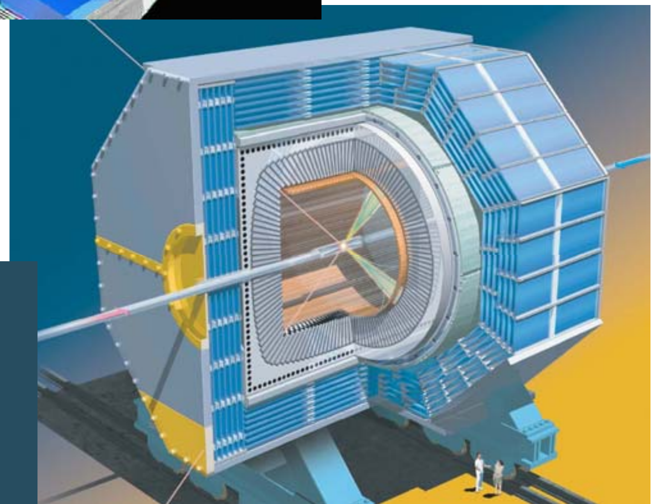
- Warm machine: required (1.4 ns bx)
  - 20 mrad
- Cold machine: optional
  - Advantage: comfortable beam diagnostics (energy, polarization measurements)
  - Disadvantage: small acceptance loss near beam line (1 cm)
    - the degenerate SUSY example
    - not easy to cover this,
      in any case
- Note:
  The Dugan committee used crossing angles for both warm and cold



summary of design issues discussed

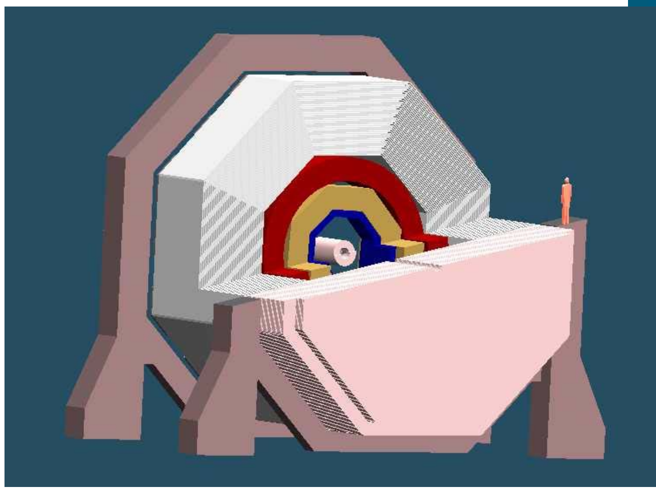
Technology choices: next talk





- Vertex detector
  - Inner radius
  - (material, readout speed)
- Central tracker
  - Momentum resolution
  - Efficiency: jets, decays,etc
  - Forward tracking
- Calorimeter
  - Segmentation
  - Timing
  - Hermiticity
- Muon det

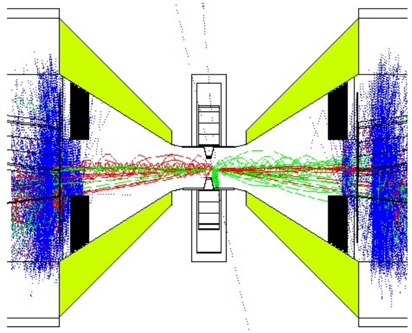
- Large or Small ?

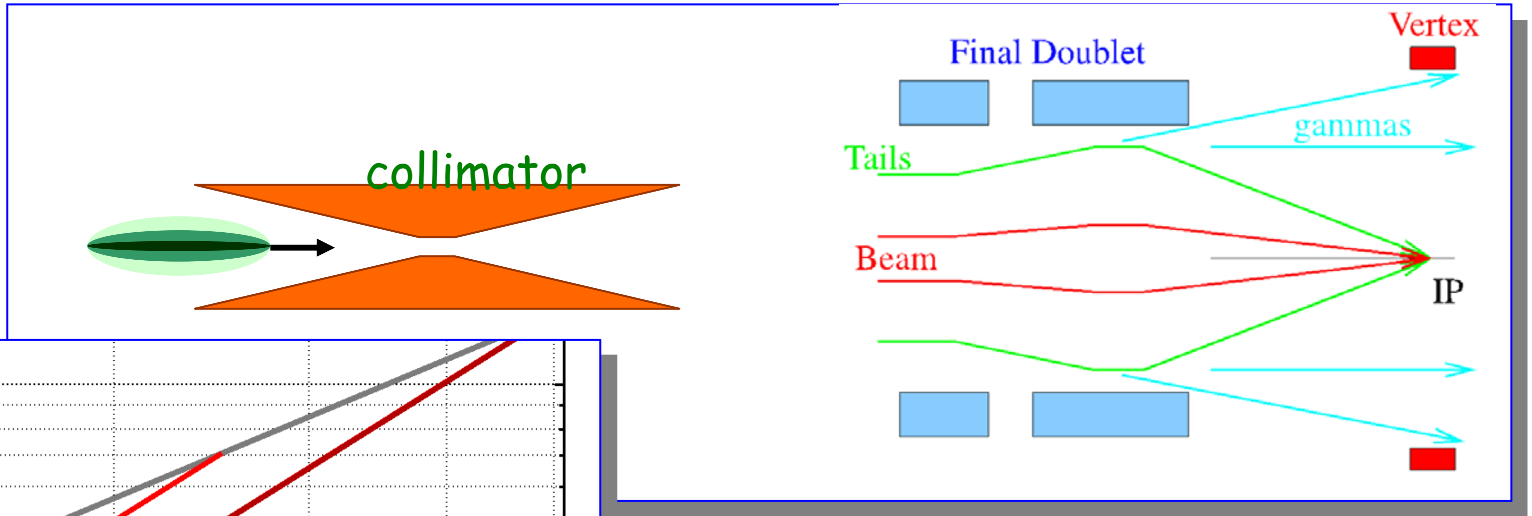


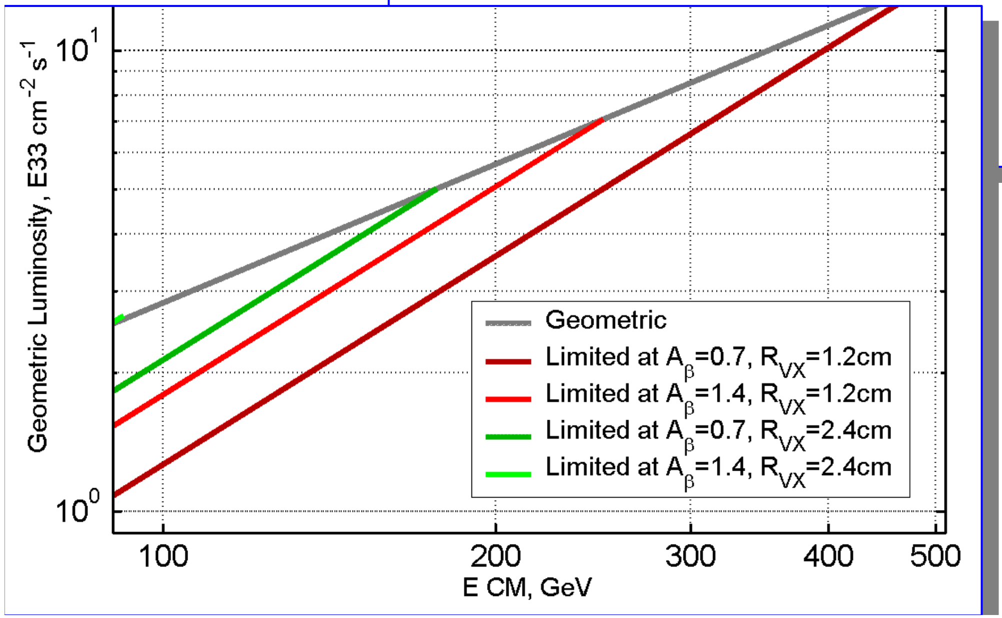
Vertex detector inner radius

<u>In favor of a larger radius</u>

- Backgrounds
  - Pairs, photons, tracks (2-photon)
- More comfortable extraction
- Collimation wakefields ⇒ Lum reduction





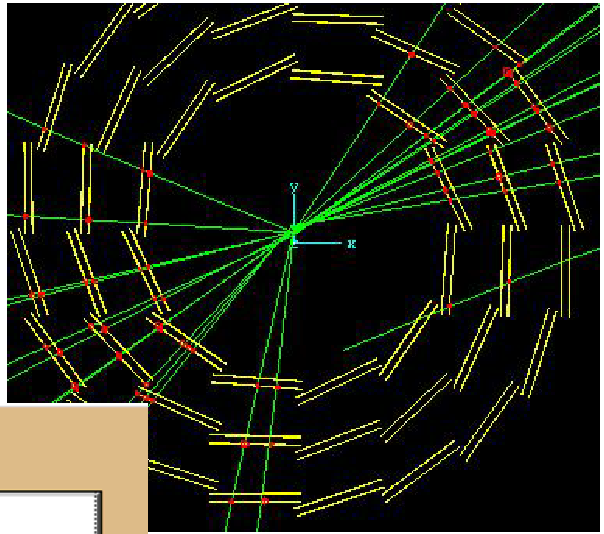


cold ≈ warm

A. Seryi

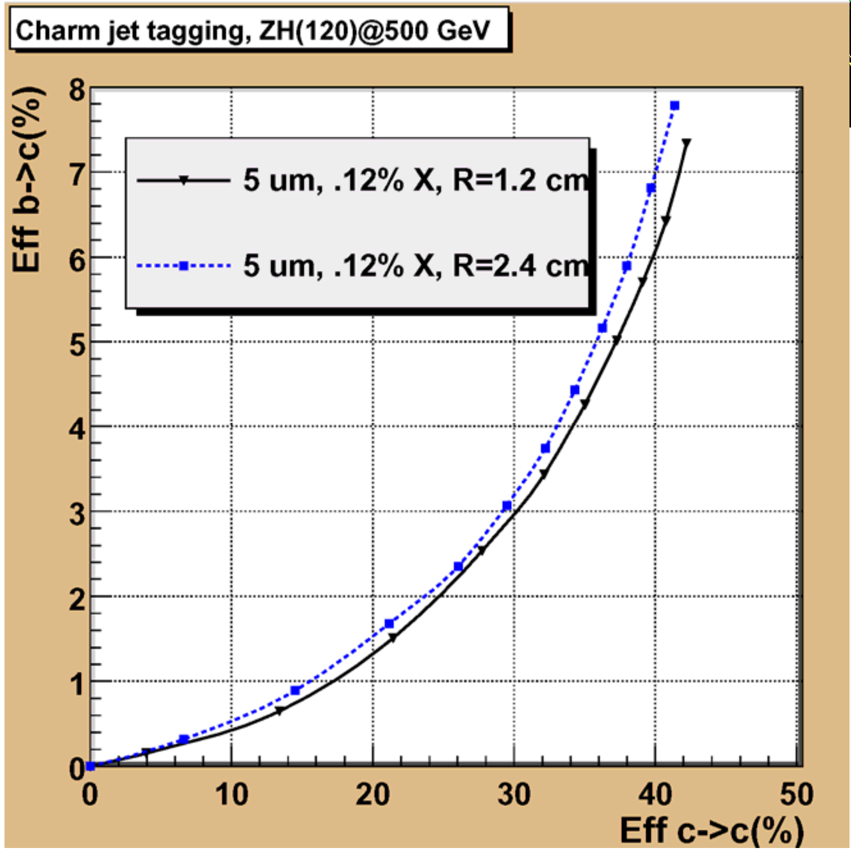
In favor of a smaller radius

- Physics sensitivity



A. Chou

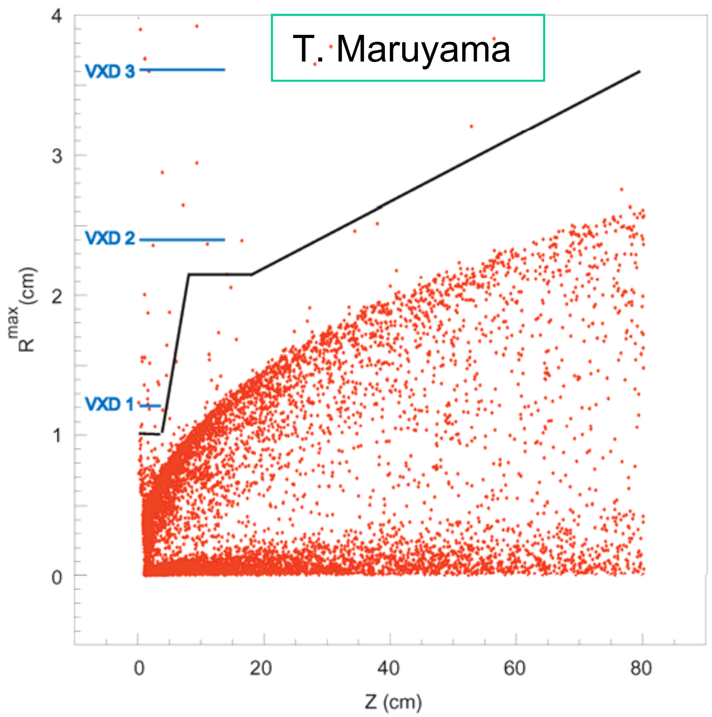
ZH, H→ cc



• significant improvement ?

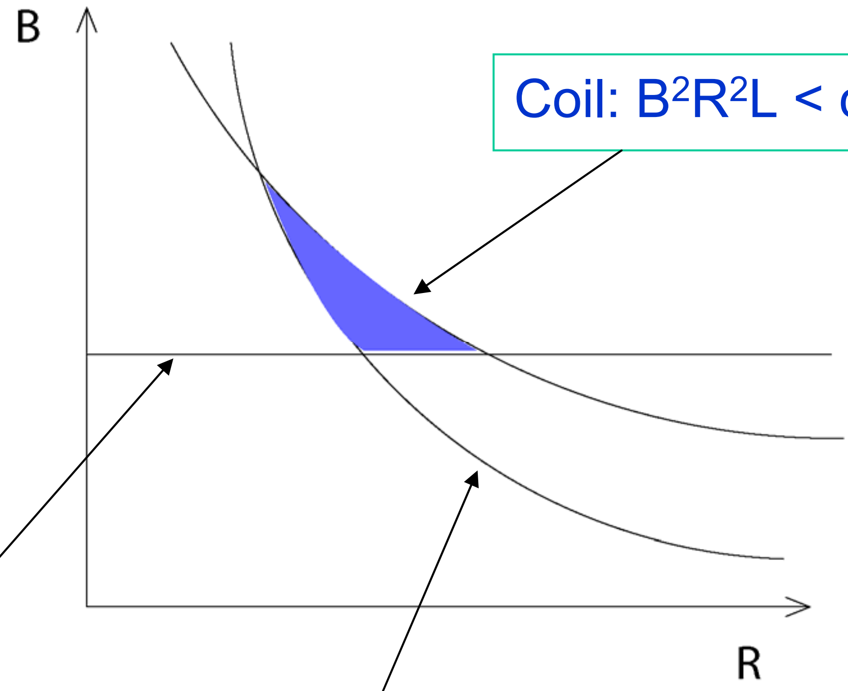
• more studies?

Large or small detector ?



The pairs background and the VXD inner radius
⇒ minimum B

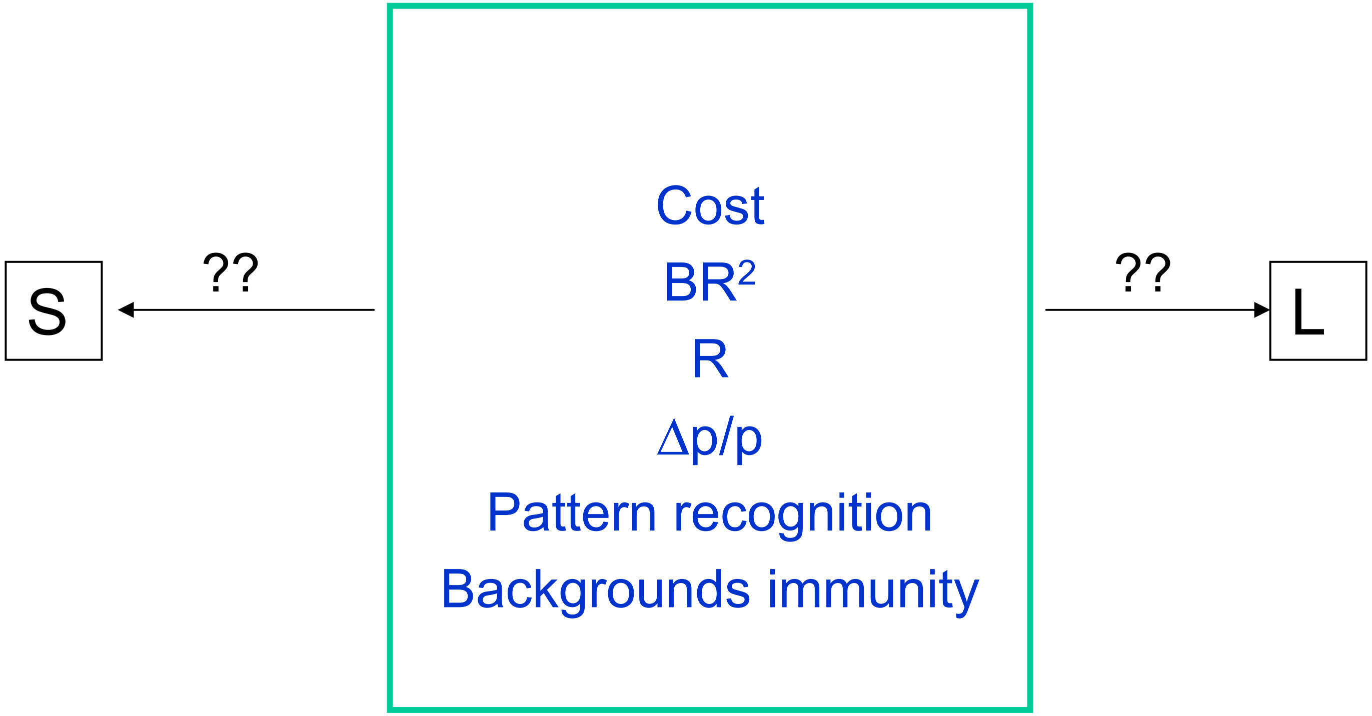
A naïve approach



Coil: $B^2R^2L < c_2$

Particle flow: $BR^2 > c_1$

S or L ? (contd)



- Warm vs. cold has technology correlations, not much (any?) for S vs L.
- Look forward to session on Thursday

Summary

- Goal: Push the envelope on measurement capabilities by exploiting the assets of the LC.
- LC a discovery facility – let's design our experimental program accordingly.
- Need to continue simulation efforts while we ramp up for an interesting period of detector R&D.
- Interplay of warm/cold and large/small issues has been healthy – has brought forward new issues… hopefully more this week!

- Apologies to those whose work was not mentioned !!