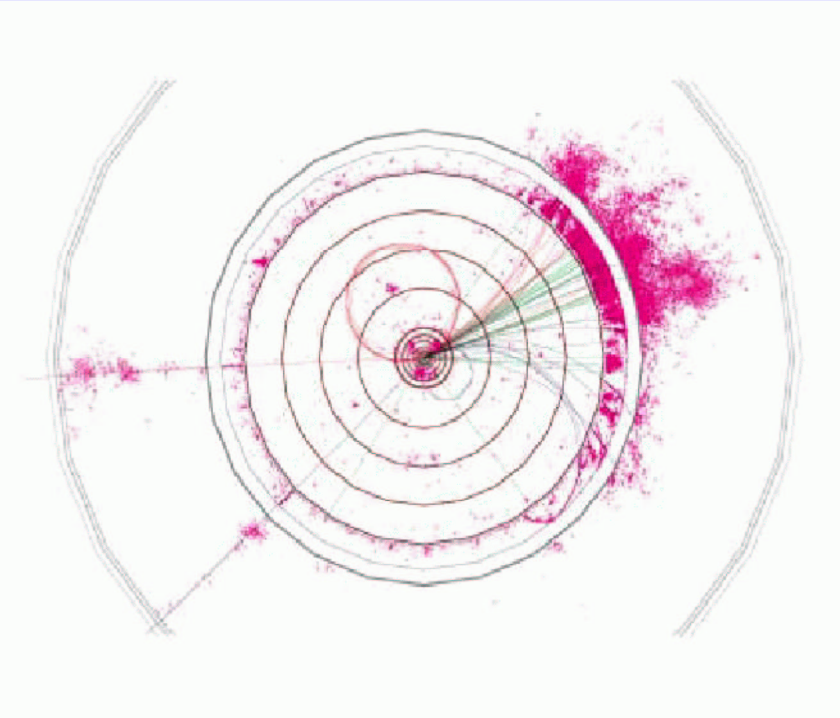
Physics and Detector R&D for the Linear Collider



David Gerdes
University of Michigan

FNAL Users Meeting
June 11, 2002

Machine Parameters

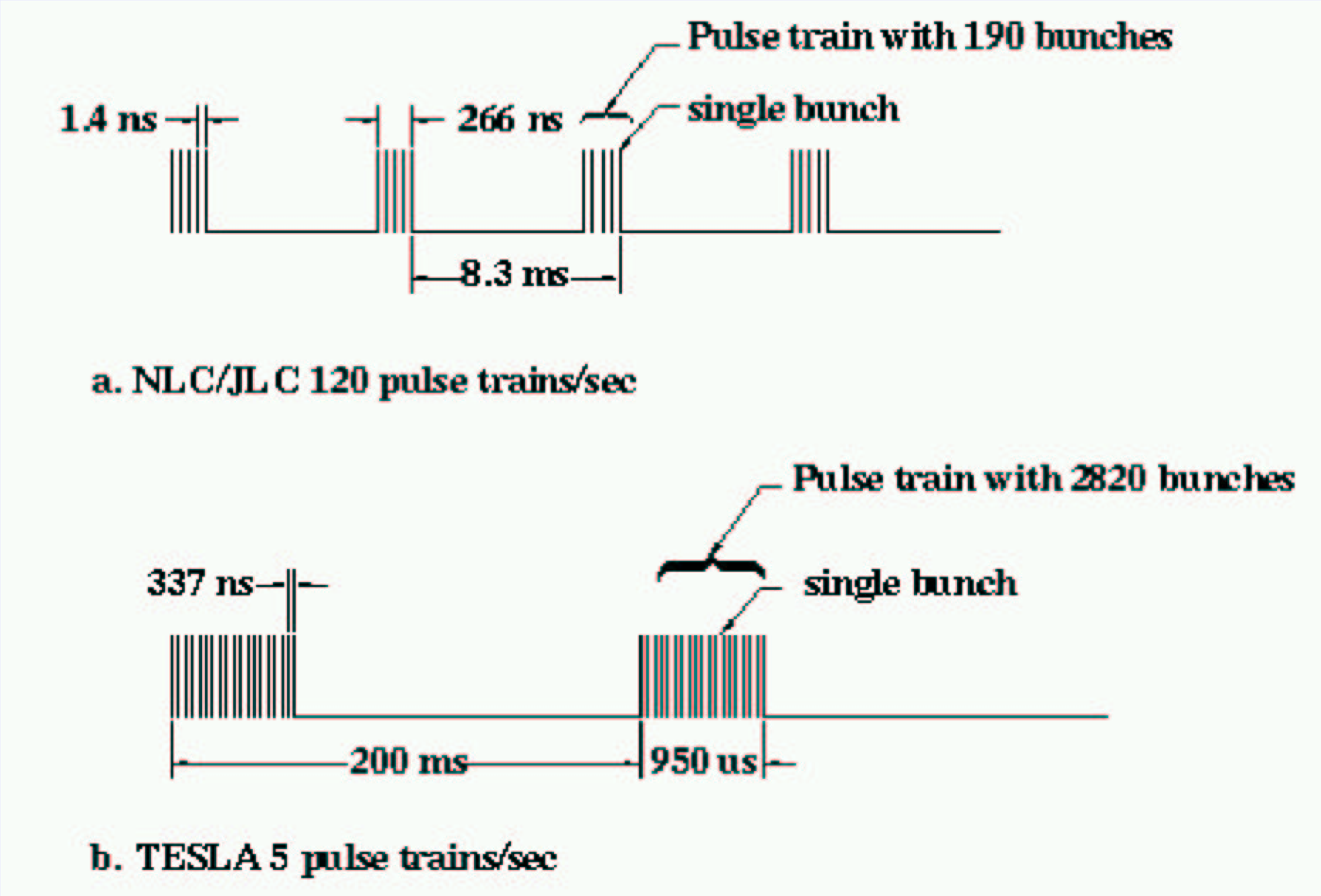
	TESLA(500)	TESLA(800)	NLC(500)	NLC(1000)	Tevatron
E (GeV)	500	800	500	1000	2000
Lum. x 1E33	31	5	20	34	0.1
Rep rate (Hz)	5	3	120	120	--
Bunches/pulse	2820	4500	190	190	--
Bunch sep (ns)	337	189	1.4	1.4	396
$\sigma(x)$ at i.p.	553 nm	391 nm	245 nm	190 nm	30 μm
$\sigma(y)$ at i.p.	5 nm	2 nm	2.7 nm	2.1	30 μm
$\sigma(z)$ at i.p.	0.4 mm	0.3 mm	110 nm	110 nm	30 cm
$\delta B(\%)$	3.3	4.7	4.7	10.2	0
P(e−) (%)	80−90	80−90	80−90	80−90	--
P(e+)(%)	60	60	--	--	--

NB:Total cross section: ~5 pb (e^+e^-, 500 GeV)
~50 mb (p−pbar, 2 TeV)

Bunch structure

NLC

TESLA



Low rates ⇒ Read out between crossings and "trigger" in software

The Challenge of LC detectors?

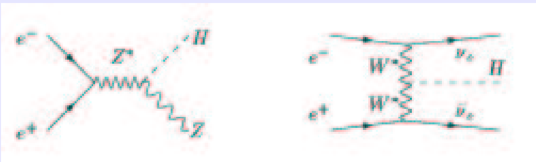
- Typical Tevatron experimentalist's view:
  - "It's trivial!"
  - "Just copy a LEP detector or SLD!"
- Sure, the issues of trigger/DAQ appear straightforward.
- But the challenge is to build a high−precision instrument capable of producing the "textbook data on the next energy scale" (M. Peskin)

Physics Unique to the LC

- Measurement of Higgs branching ratios, e.g. via $e^+e^- \rightarrow Zh$ followed by $Z \rightarrow ll$, $h \rightarrow X$
- Study of the top quark threshold, measurements of m_t, Γ_t, α_s, g_{tth}
- Precision SUSY spectroscopy
- ttH production; top−Higgs Yukawa coupling
- Trilinear Higgs coupling; reconstruction of the Higgs potential.

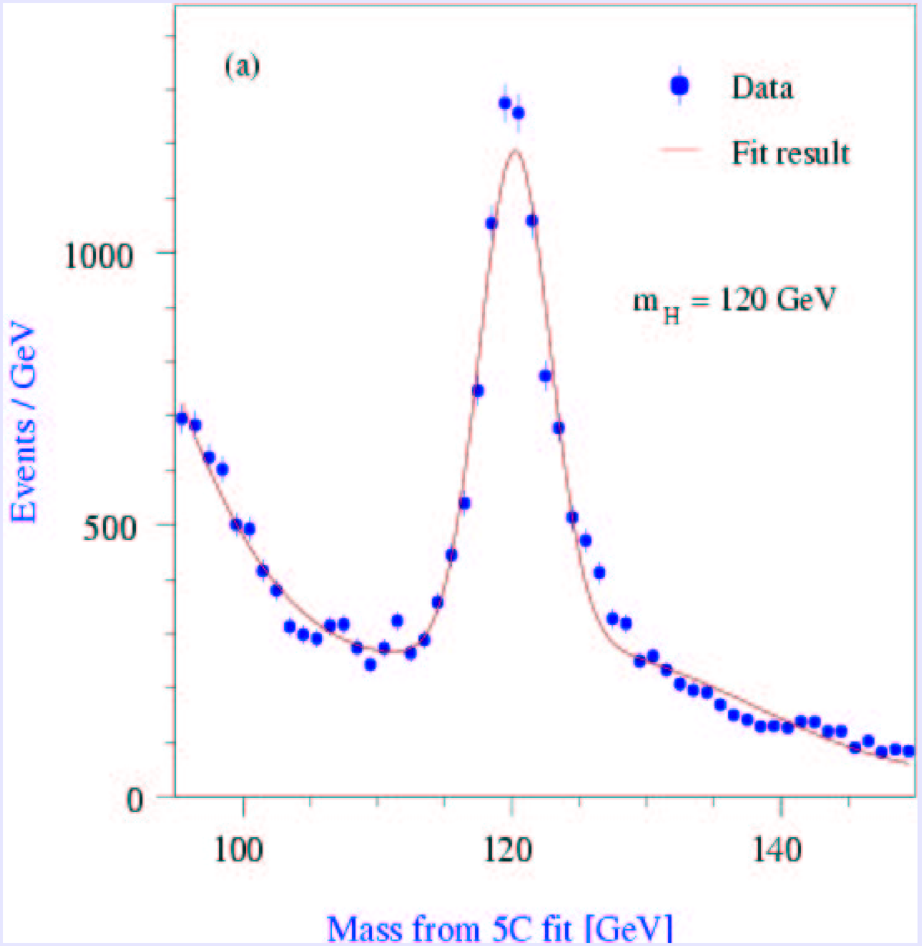
Higgs Reconstruction

- Current EWK fits favor a light Higgs, $m_h < 200$ GeV
- Produced at the LC in recoil off the Z



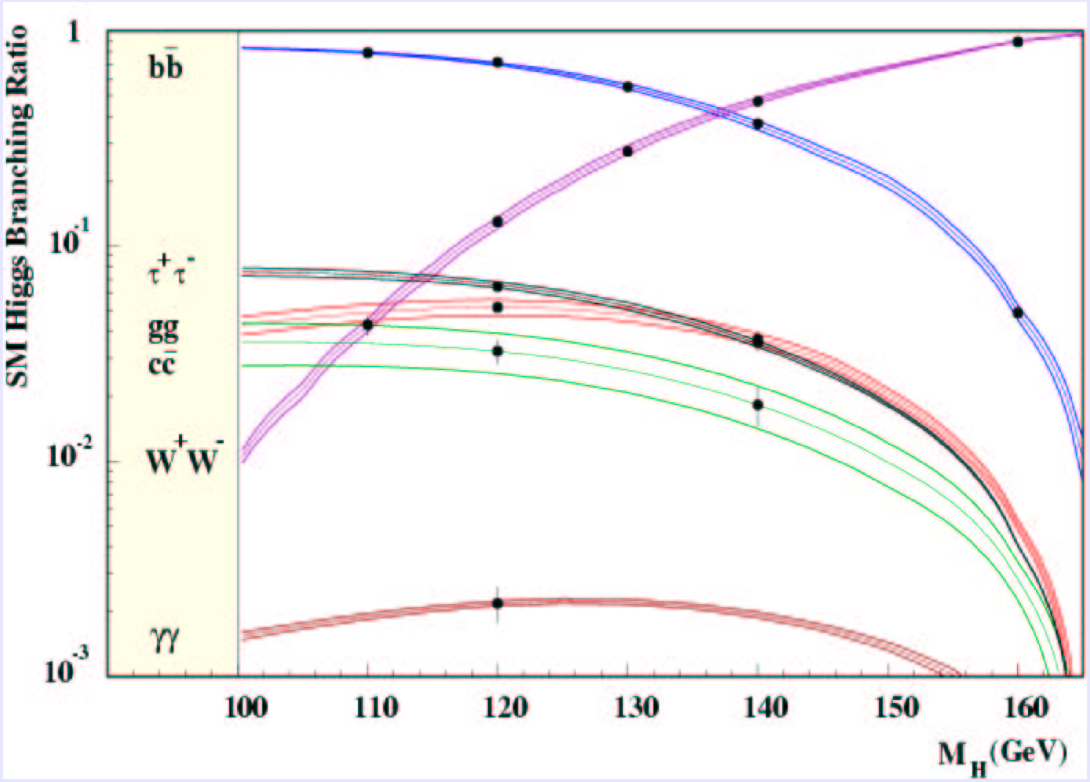
Detector requirement:

Excellent tracking resolution, $\sigma(1/p_T) \sim 5\times10^{-5}$ GeV^{-1}



Measurement of Higgs BR's

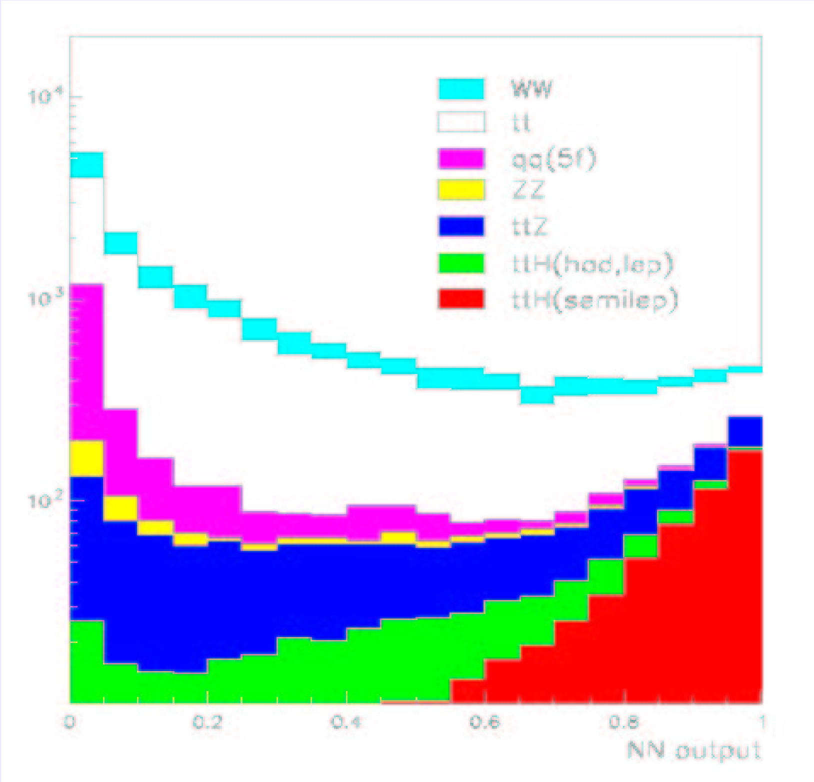
- Event selection is based on the Z, not the H, so the Higgs decays constitute an unbiased, inclusive sample.
- Key to determining that "the Higgs is the Higgs"−−or something else!
- Detector requirements: precision vertexing, flavor tagging.



M. Battaglia

$t\bar{t}H$ production and the Top Yukawa Coupling

- $e^+e^- \rightarrow t\bar{t}H \rightarrow WbW\bar{b}\ b\bar{b}$
- Very complicted final state:
  - Up to 8 jets
  - 4 b's
  - Many kinematic constraints
- Tiny cross section (~2 fb), with backgrounds ~3 orders of magnitude higher.
- Detector requirements:
  - Excellent jet resolution
  - Flavor tagging



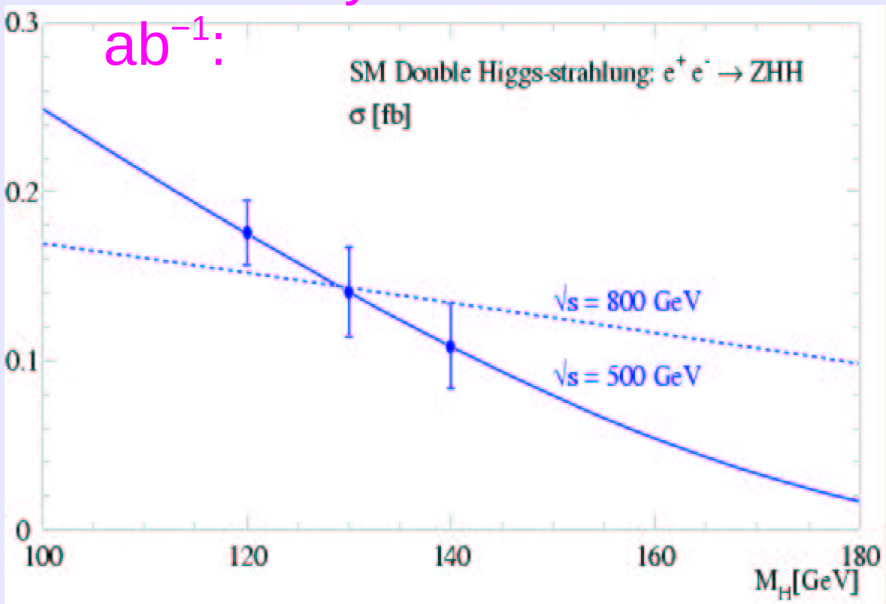
Juste, Merino: hep−ph/9910301

Note: ttH cross section maximized at $\sqrt{s}$~800 GeV

Reconstructing the Higgs Potential

Striking final state: 4 b jets, plus dileptons, jets, or missing energy from the Z decay.
But: Tiny cross section (~0.2 fb), huge 4−, 6−fermion backgrounds make this among the most challenging processes to study at the LC.

Sensitivity with 1 ab^{-1}:



Detector requirements:
- Excellent jet resolution
- Flavor tagging

Accelerator requirements:
- Lots and lots of luminosity

So to sum up the detector challenges, we need:

- Excellent hermeticity — multijet final states, forward−peaked cross sections
- Excellent calorimetry — W/Z separation
- Excellent tracking resolution — Precision mass measurements
- Excellent flavor−tagging — b/c/τ identification

•As opposed to a Tevatron or LHC detector where major design drivers include:

- Ability to handle very high rates
- Radiation tolerance

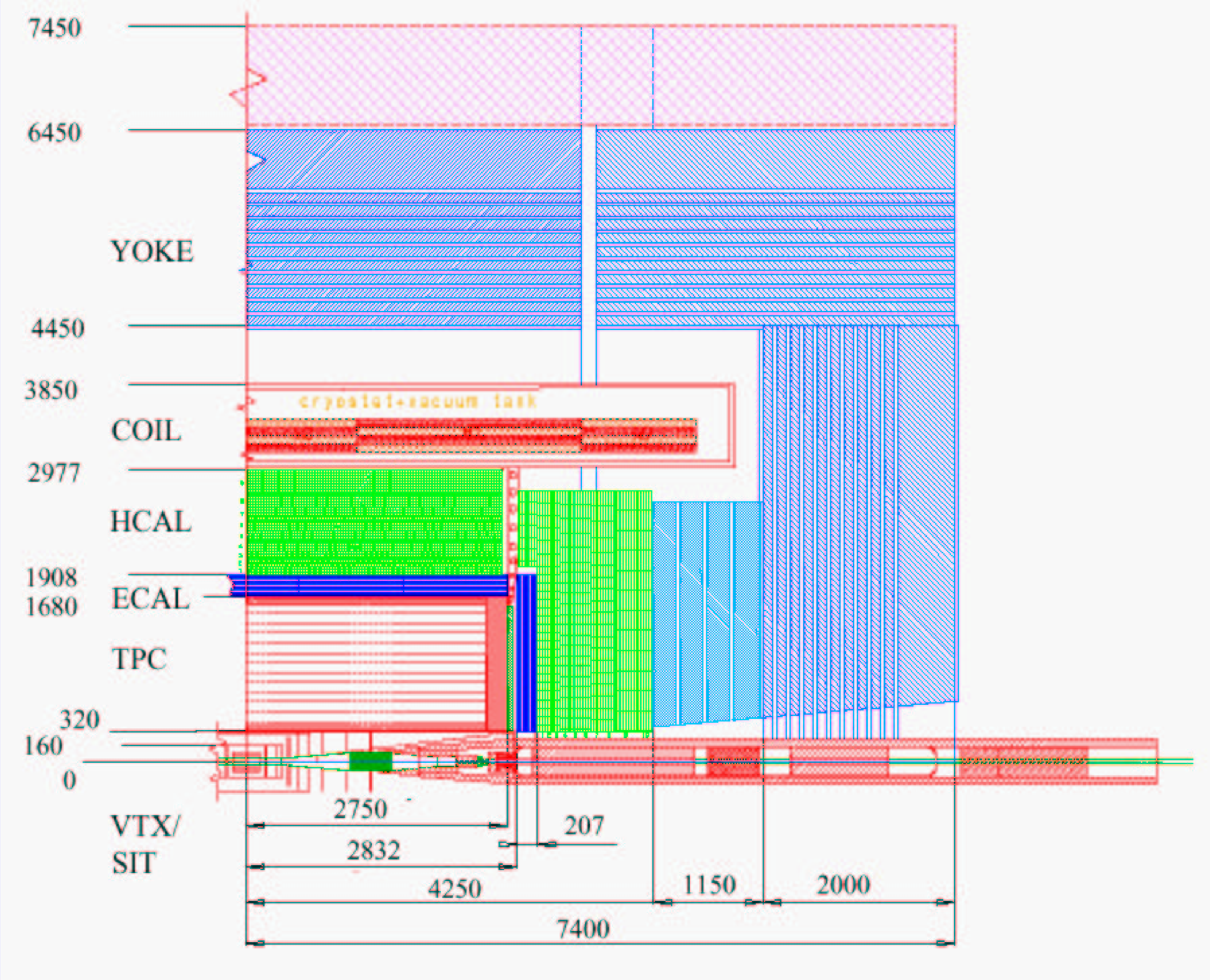
LC−LHC Detector Comparisons

	CMS	ATLAS	TESLA design
Tracker thickness (X0)	30%	28%	5%
Vertex layer thickness	1.7%	1.7%	0.06%
Vertex channel count (Mpixels)	39	100	800
ECAL granularity (det. elements)	76,000	120,000	32,000,000

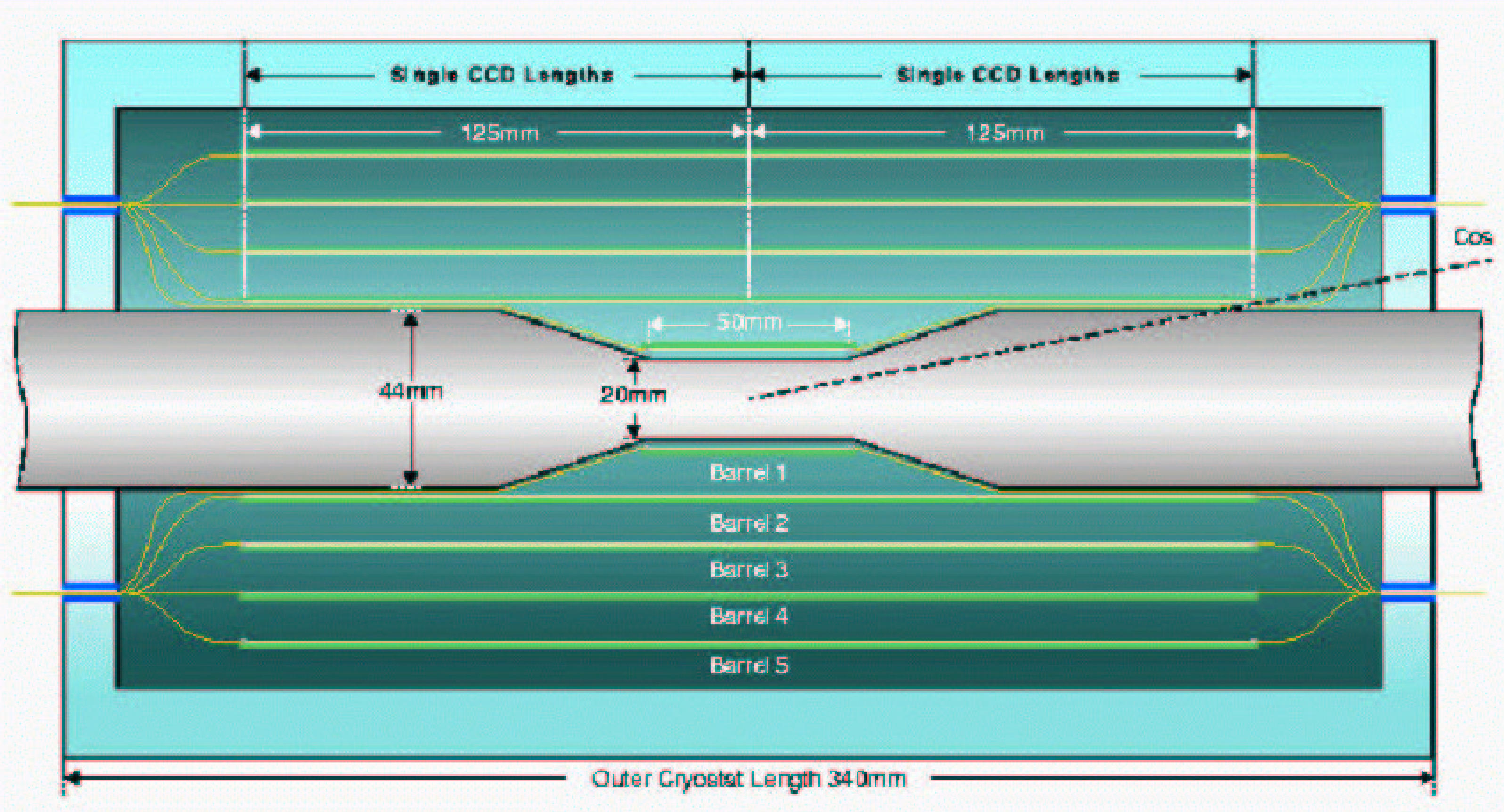
- 6x less material for photon conversions
- Vertex detector 3−6x closer to interaction point
- 35x smaller vertex detector pixel size
- 30x thinner vertex detector layers
- 10x better track momentum resolution
- >200x higher ECAL granularity *(expensive)*

"A Ferarri, as opposed to a state−of−the art Abrams battle tank." (C. Damerell)

TESLA Detector



CCD Vertex Detector



Standalone 5−layer tracking device
~800,000,000 pixels
Inner layer at r~1 cm

R&D Issues for the VXD

- Improve rad hardness of CCD’s. LC neutron backgrounds sufficiently uncertain to cause concern.
- Continued development of active pixel options.
- Better thinning of layers to reduce material
- Understand requirements for inner radius and other parameters
  - In context of global detector issues, like size and type of outer tracker, B−field strength...
- Better understanding of flavor tagging in real physics events with all backgrounds included.
- Resolve Higgs BR measurement discrepancies. (US/TESLA studies in some disagreement)

Central Tracking

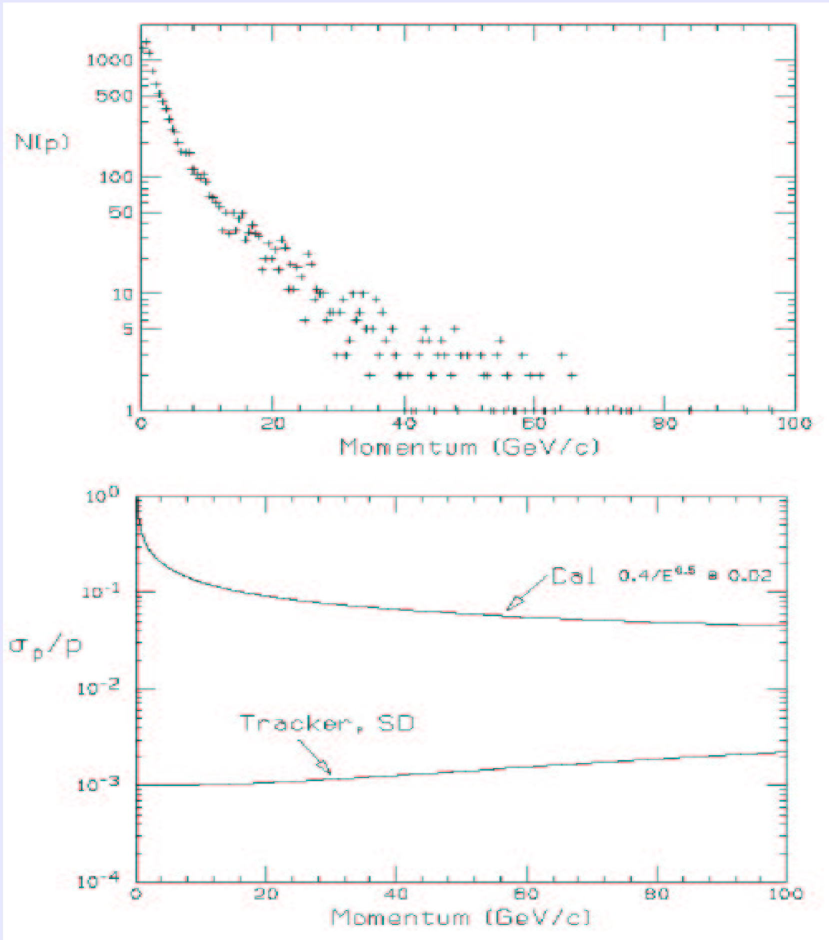
- Two major designs
  - "Large" detector (TESLA detector is similar)
    - TPC tracker (52 < R < 190 cm)
    - 3 T B−field (TESLA uses 4 T), compare 1.4 T @ CDF
    - Forward Si disks and intermediate Si strips
  - "Small" detector
    - 5−layer Si strip or drift tracker (20 < R < 125 cm)
    - 5 T B−field
    - Forward Si disks
    - Optimized for "energy flow" calorimetry
- Same 5−layer VXD in both designs

Tracking Design Issues

- Tradeoffs between a few precise hits (Si) vs. many coarse hits (gas)
  - 2−track separation, pointing accuracy
  - Robustness of pattern recognition against backgrounds
  - Get dE/dx in a gas tracker "for free". Is it necessary?
- 3D devices (TPC or Si drift) vs. 2D (drift chamber or Si strips)
- Need an intermediate tracker if a gas outer tracker is chosen?
  - Depends on R_{max} of VXD and R_{min} of outer tracker.
  - May improve momentum resolution by factor of 2.
  - Effect on pattern recognition unclear.
  - May provide a means to tag bunch−ID

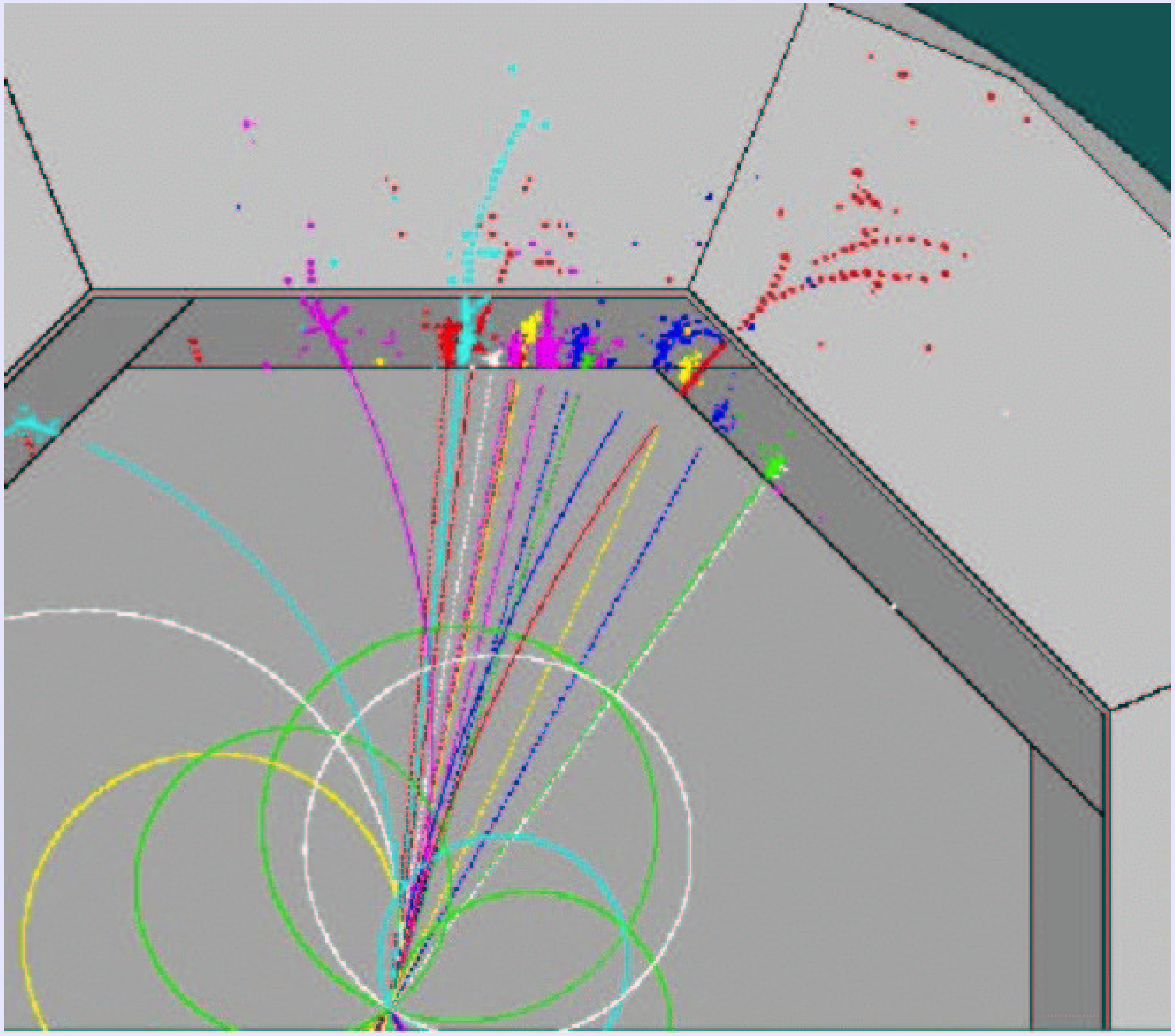
Calorimetry: The Energy−Flow Concept

- Typical jet contains:
  - 64% charged energy
  - 25% photons
  - 11% neutral hadrons
- Main idea: use tracker for charged particles, calorimeter for neutrals only:
  $E_{jet} = \Sigma p_{charged} + \Sigma E_{neut,ECAL} + \Sigma E_{neut,HCAL}$
- Requires a very finely segmented calorimeter so that one can extrapolate tracks to charged particle energy and remove it.
  - Figure of merit is BR^2/R_m
- Fine segmentation = high channel count = high cost. How good is good enough?

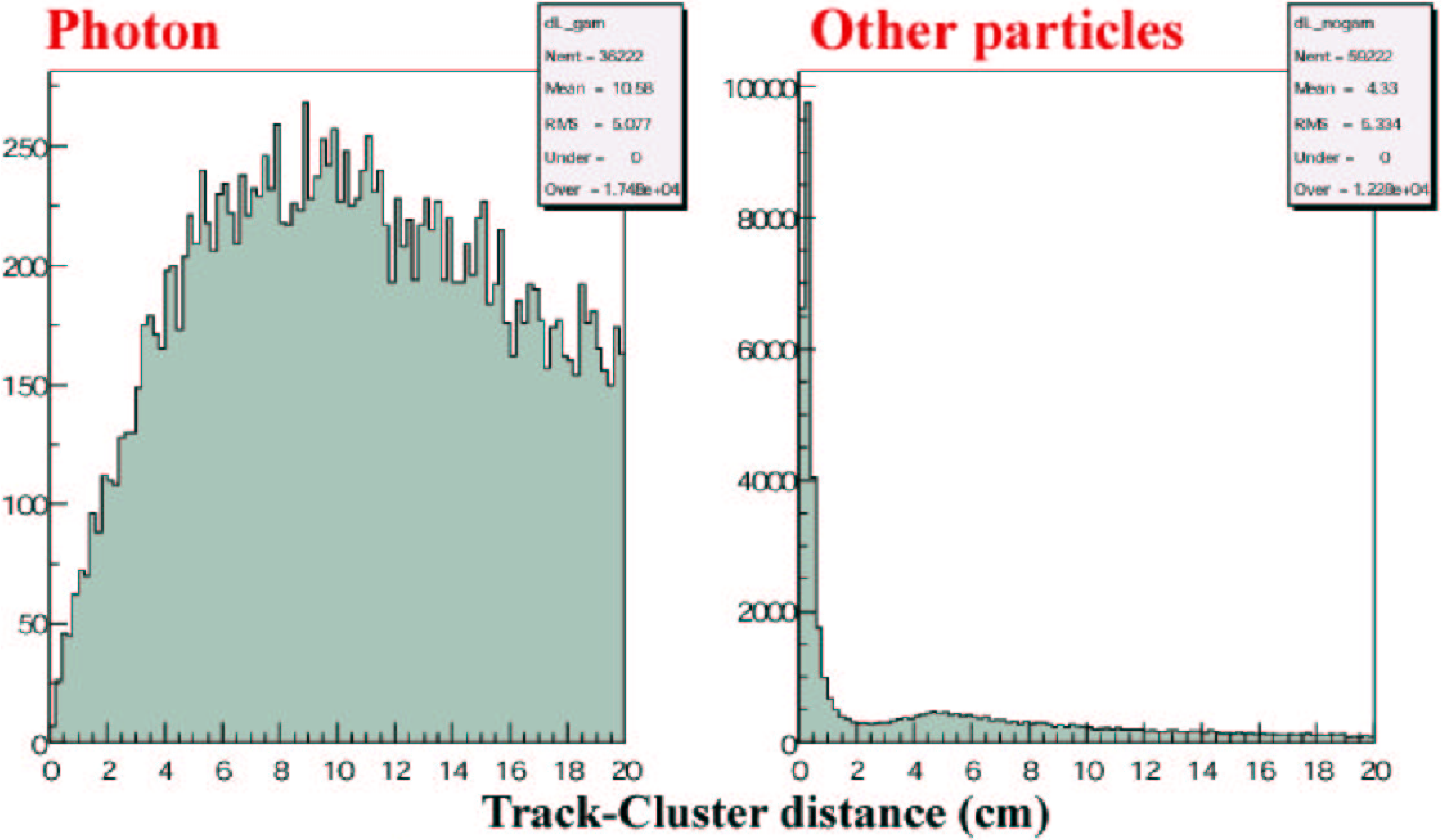


R. Frey, Chicago LCDW ’02

Energy Flow at TESLA



Perform photon ID by looking at distance between track and nearest EM cluster in "S" detector design



M. Iwasaki, Chicago LCDW '02

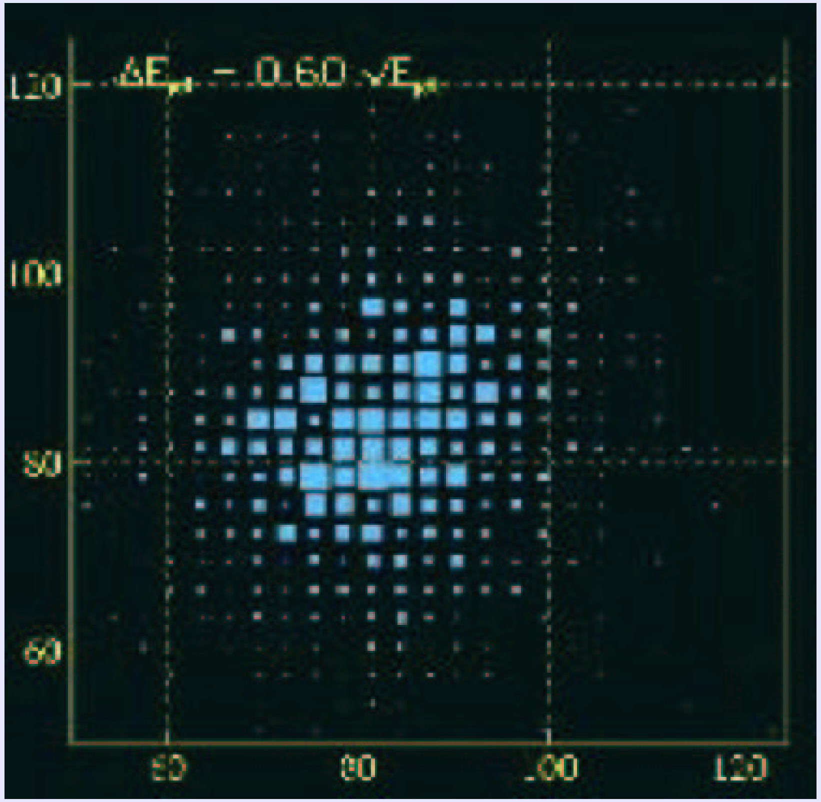
Benefits: Better Jet Resolution

Separation of $e^+e^- \rightarrow WW\nu\nu$ from $e^+e^- \rightarrow ZZ\nu\nu$:

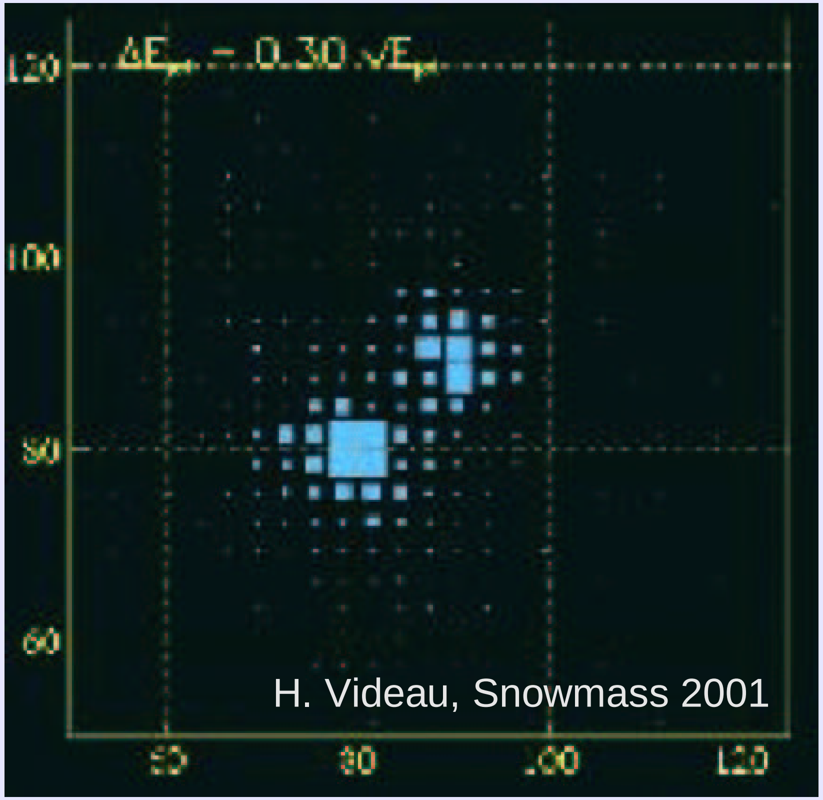
$\Delta E/E = 0.6/\sqrt{E}$

$\Delta E/E = 0.3/\sqrt{E}$

$M_{jj,2}$



$M_{jj,2}$



$M_{jj,1}$

$M_{jj,1}$

Calorimeter R&D Issues

- Further develop physics justification for excellent energy flow
  W/Z separation at high energy, ttH, Higgs self−coupling, SUSY, heavy Higgs?
- Detailed simulation of energy flow; integration with flavor tagging
- Parametrize for fast simulation / refine based on detailed simulation
- Can we use the calorimeter as a muon tracker?
- Physics case for non−pointing photons (SUSY...)
- Parameter tradeoffs: trans/long segmentation, B−field size, calorimeter radius, coil location.
- Less expensive alternatives to Si/W? (e.g. scint. tile?)
- What if we can achieve higher B−fields, i.e. 5 T in large detector?

R&D Next Steps

- Identify existing efforts worldwide
  - Avoid duplication of effort
  - Focus resources on most critical areas
    - Those that affect the choice of accelerator technology
    - Those that affect the ability to meet thephysics goals
  - Report of international R&D committee due later this month.
- In the US:
  - Efforts coalescing into "consortia" (see Blazey's talk), with Fall '02 goal for initial proposal submission.
  - Santa Cruz LC meeting, 6/27−30.
  - Biweekly meetings at FNAL, Thurs. 10−12 (ON this week), in IBC 2E (the Hermitage)