Detectors for the ILC and Photon Linear Collider

Jeff Gronberg / LLNL

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Workshop

CERN

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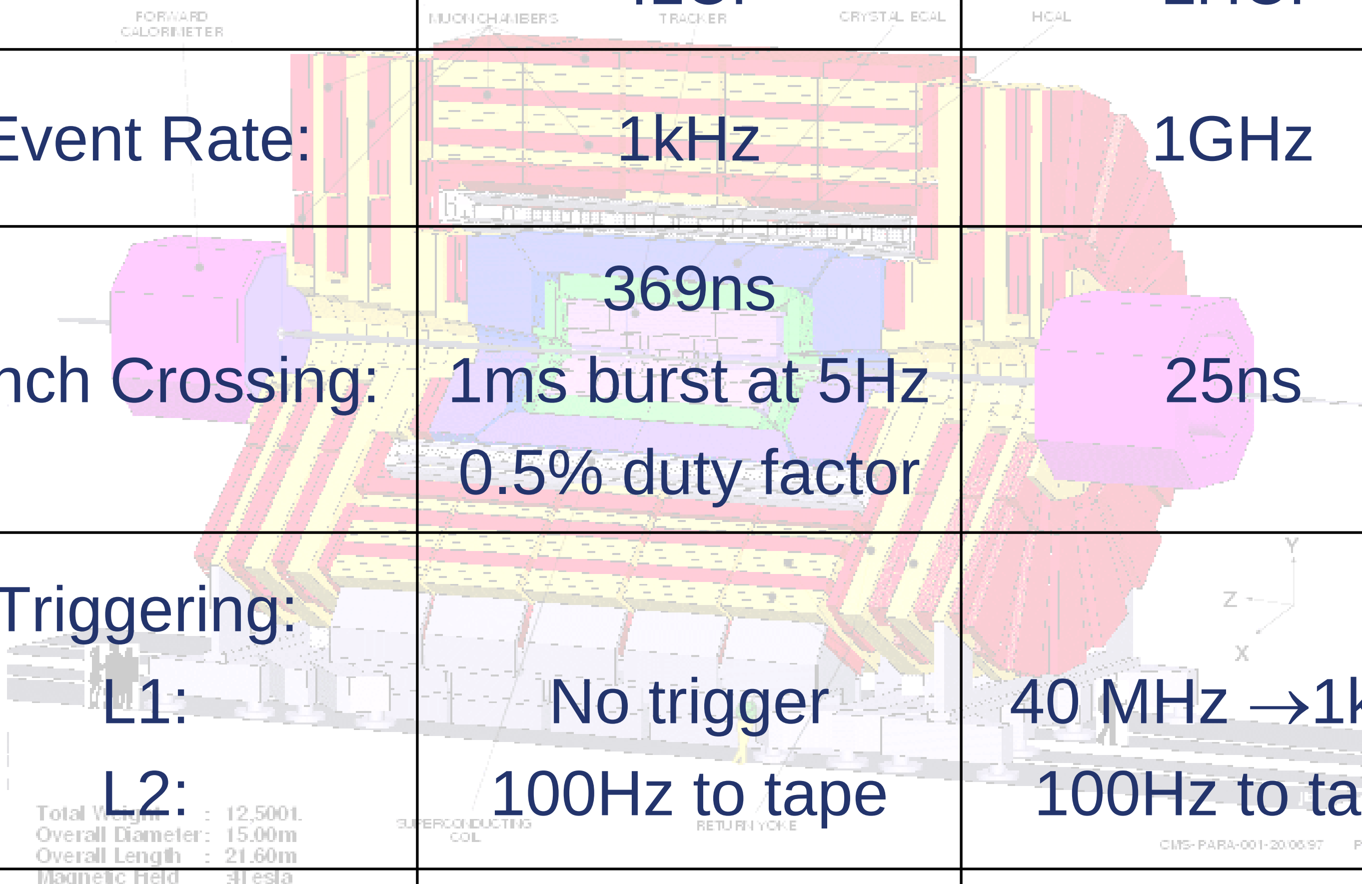
International Linear Collider

- Envisioned to be the next big project in HEP
  - **Linear collider at 500 GeV C.M. upgradable to 1TeV**
    - e+e-
    - e-e-
    - $\gamma\gamma$
- Precision studies of particles discovered at LHC
- R&D is a multiregional collaboration under the Global Design Effort (GDE)
- Multi-billion ICU (International Currency Unit) experiment
- A decade in the future

ILC vs LHC Detector Environment



	ILC:	LHC:
Event Rate:	1kHz	1GHz
Bunch Crossing:	369ns 1ms burst at 5Hz 0.5% duty factor	25ns
Triggering: L1: L2:	 No trigger 100Hz to tape	 40 MHz $\rightarrow$1kHz 100Hz to tape
Radiation:	<1kRad/yr	1-100MRad/yr

Detector Requirements are driven by the physics

- ILC-GDE has produced a Reference Design Report (RDR)
  - **Contains a Detector Concept Report (DCR)**
  - **Physics reach as a function of detector performance was studied for several key analyses**

Sub-Detector Performance Needed for Key ILC Physics Measurements.

Physics Process	Measured Quantity	Critical System	Critical Detector Characterstic	Required Performance
ZHH $HZ \to q\bar{q}b\bar{b}$ $ZH \to ZWW^*$ $\nu\bar{\nu}W^+W^-$	Triple Higgs Coupling Higgs Mass $\mathrm{B}(H \to WW^*)$ $\sigma(e^+e^- \to \nu\bar{\nu}W^+W^-)$	Tracker and Calorimeter	Jet Energy Resolution, $\Delta E/E$	3to4%
$ZH \to \ell^+\ell^- X$ $\mu^+\mu^-(\gamma)$ $ZH + H\nu\nu \to \mu^+\mu^- X$	Higgs Recoil Mass Luminosity Weighted Ecm $\mathrm{B}(H \to \mu^+\mu^-)$	Tracker	Charged Particle Momentum Res., $\Delta p_t/p_t^2$	5×10^{-5}
$HZ, H \to b\bar{b}, c\bar{c}, gg$ $b\bar{b}$	Higgs Branching Fractions b quark charge asymmetry	Vertex Detector	Impact Parameter, δ_b	$5\mu\mathrm{m} \oplus 10\mu\mathrm{m}/p(\mathrm{GeV/c})\sin^{3/2}\theta$
SUSY, eg. $\tilde{\mu}$ decay	$\tilde{\mu}$ mass	Tracker, Calorimeter	Momentum Res., hermeticity	

Most detector concepts are familiar 4π ideas

Calorimeter Resolution

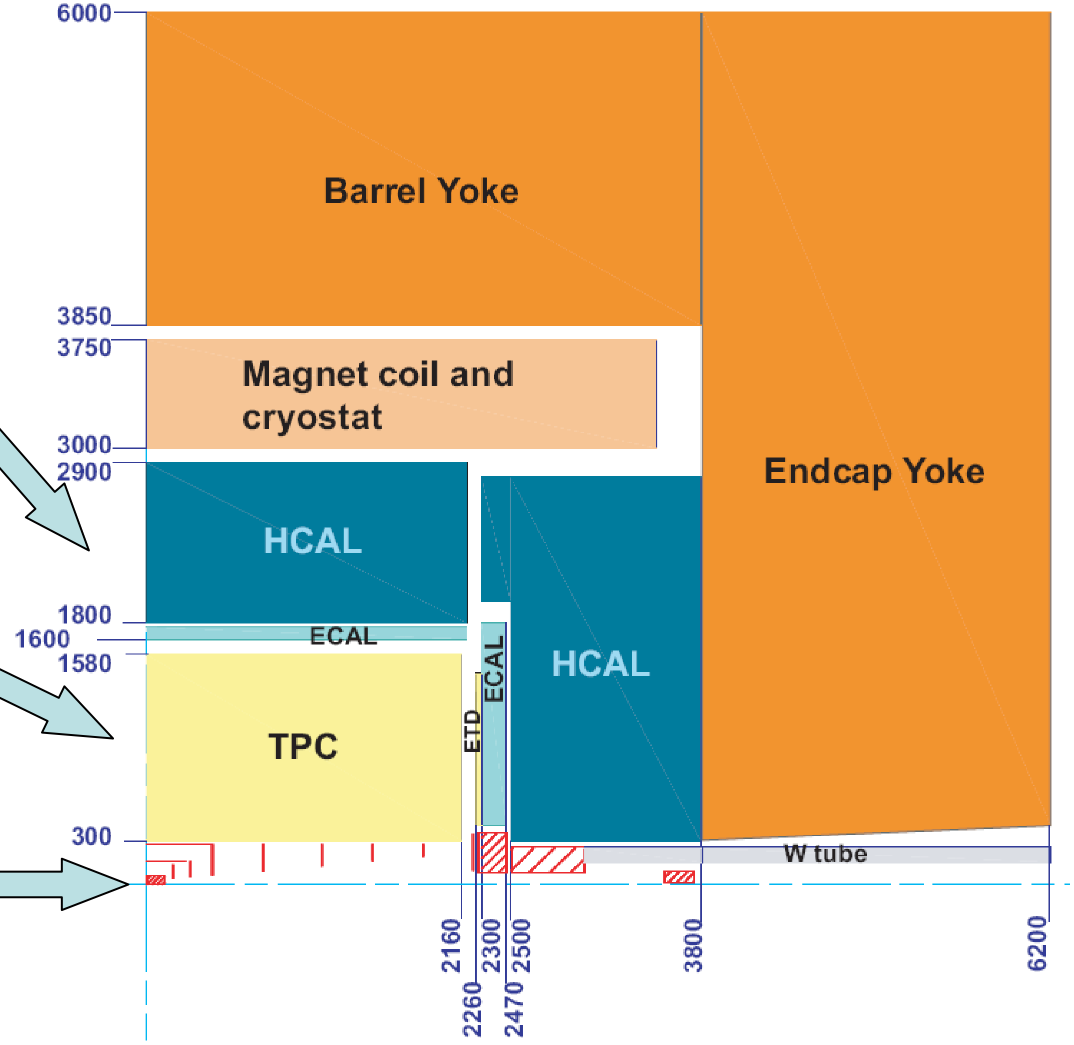
H → bb : Z → bb separation

Precision Tracking
Recoil mass resolution

e+e- → HZ

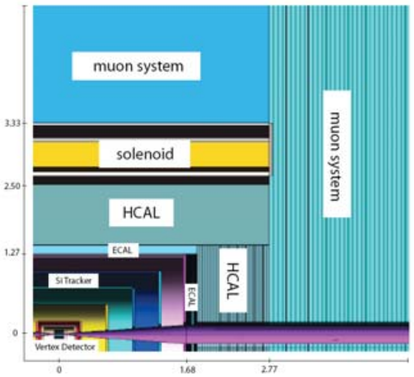
Vertexing for b-tagging

H → bb, cc

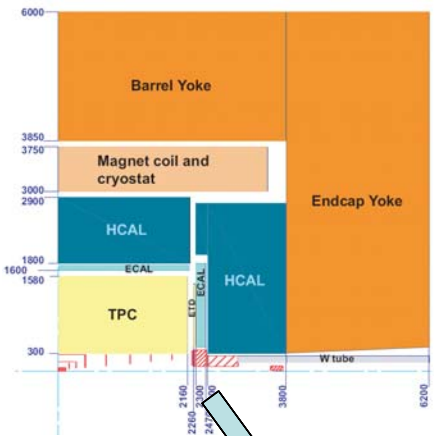


Current Detector Concepts

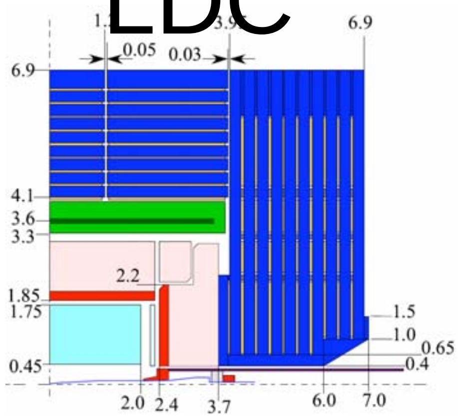
SiD



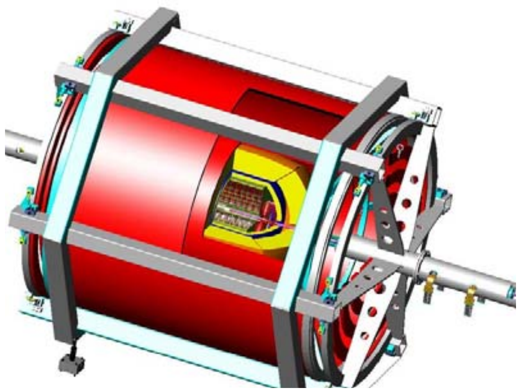
GLD

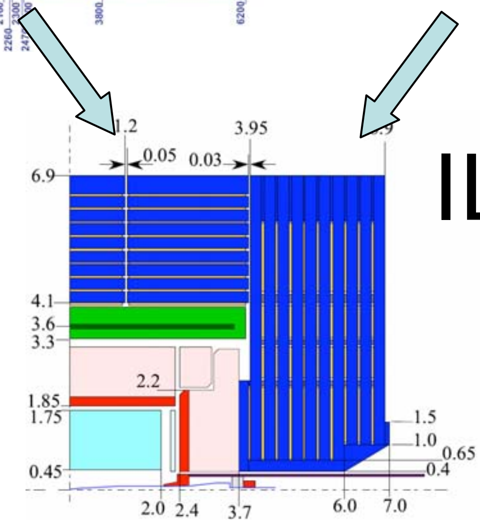


LDC



4th



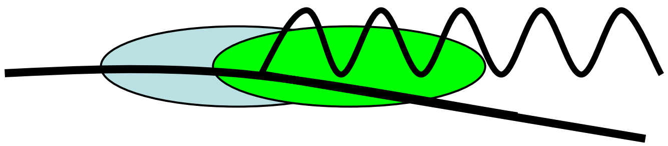


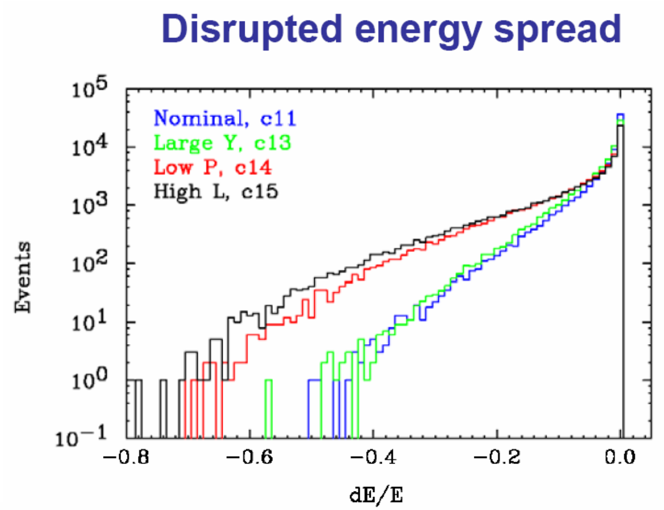
ILD

- 4π detectors
  - **Particle flow calorimetry**
  - **Tracking**
    - Si or TPC
  - **Magnetic field**
    - 3, 4 or 5

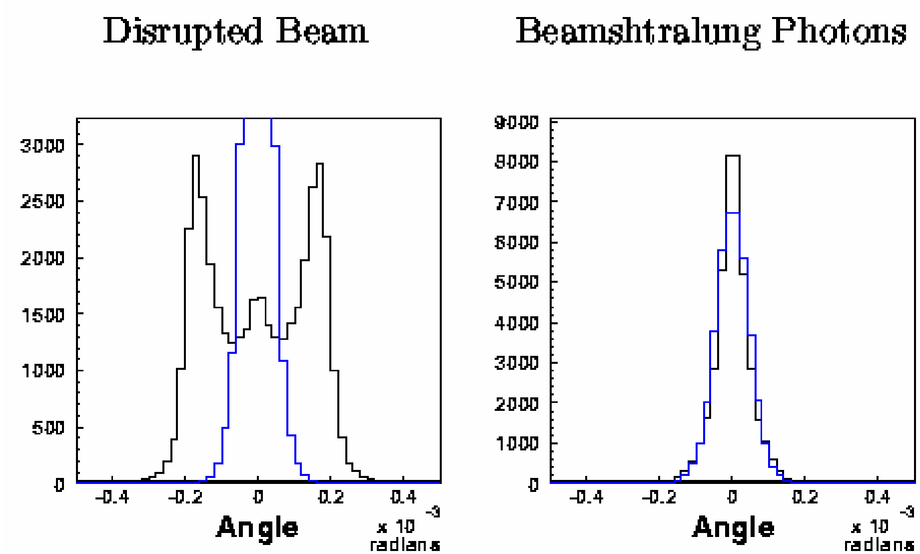
- 4th concept
  - **Dual solenoids**
    - No flux return iron
  - **Compensating calorimeter**
  - **Tracking: TPC**

“Beam”-strahlung is a new challenge at the ILC



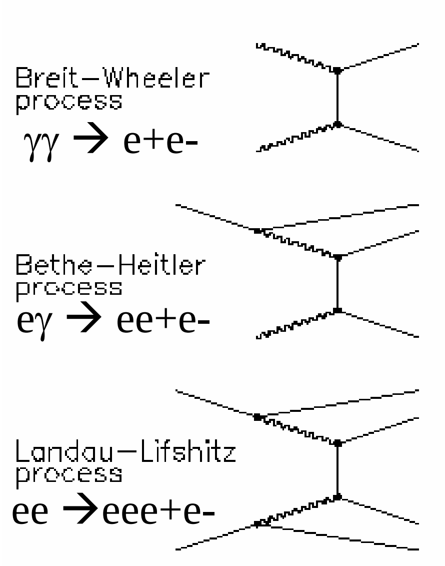


- Electron bunches are focused to 3nm width during collision
- One beam will see the electric field of the other
  - **“Beam”-strahlung photons will be emitted**
  - **Self-focusing changes the effective luminosity**
    - Enhances e+e-
    - Degrades e-e-
    - No effect $\gamma\gamma$
  - **Photon emission produces a tail in the C.M. energy distribution**
  - **Some depolarization effect**

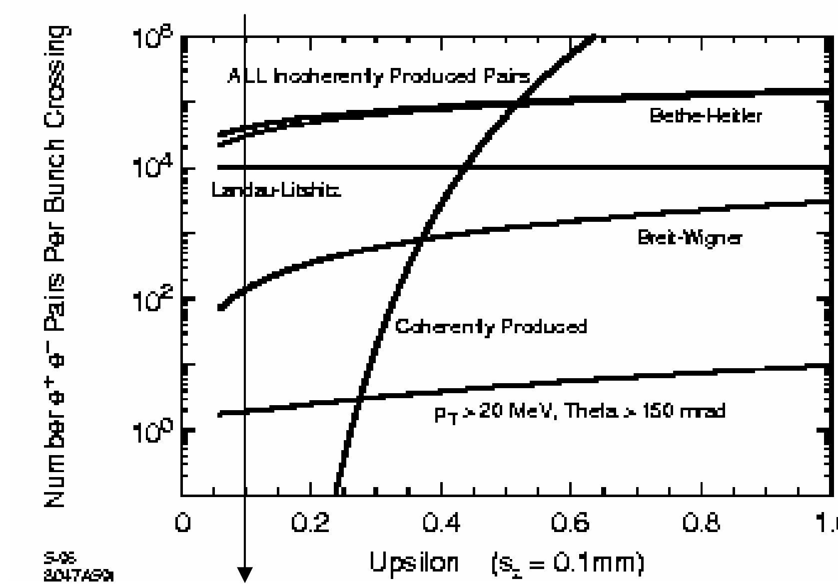


Pair Production

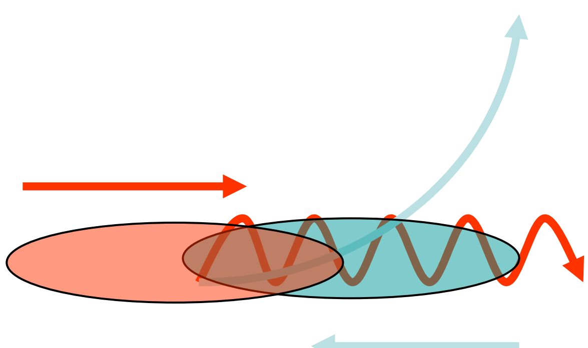
Photons interact with opposing e,g to produce e+,e- pairs and hadrons



γ → e+e- (Coherent Production)



500 GeV designs

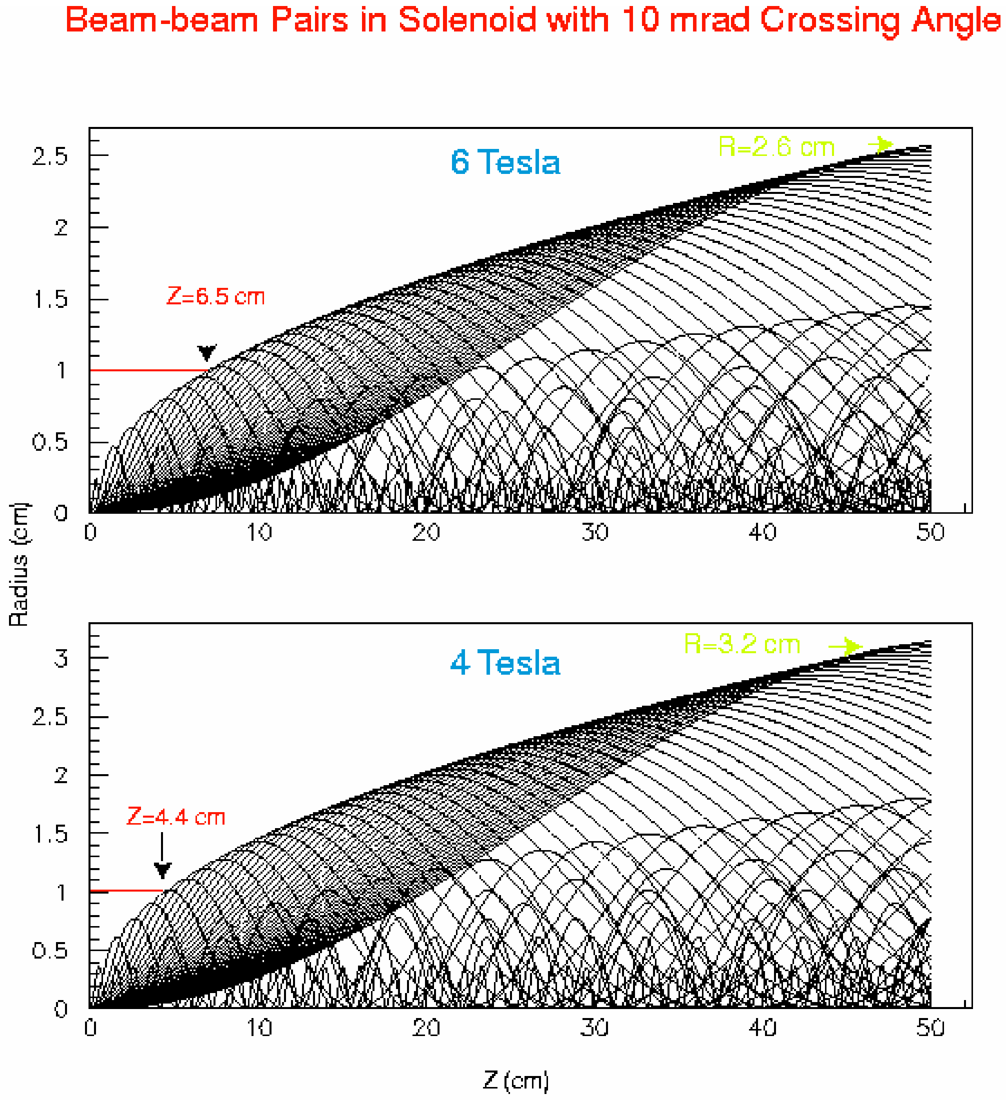


Pair P_T:

- SMALL Pt from individual pair creation process
- LARGE Pt from **collective field of opposing bunch**
  - limited by finite size of the bunch

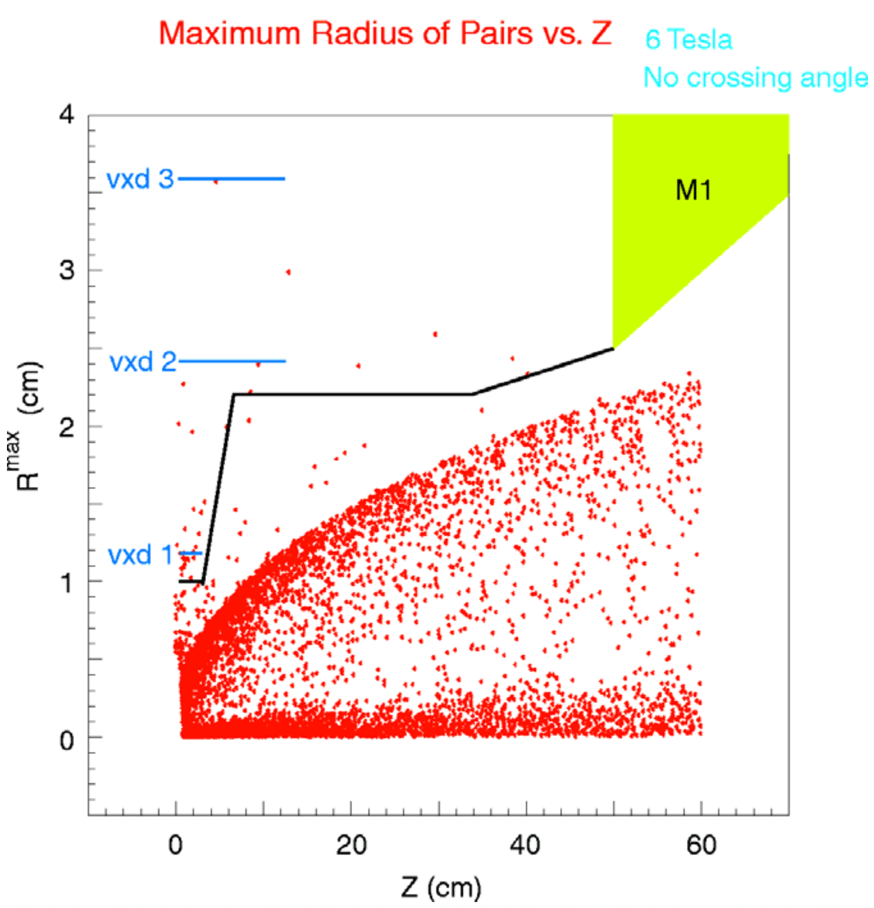
Low energy pairs spiral in the solenoidal field

- Pairs produce equal number of electrons and positrons
  - **One sign will be focused by the colliding bunch**
  - **The other sign will be deflected**
- The deflected particles have an energy-angle correlation
  - **The z-position of the point of maximum distance from the beam axis will trace out a curve**
  - **This curve will be a function of the solenoidal magnetic field and the crossing angle**
- We want to get the first layer of the silicon vertex detector as close to the IP as possible

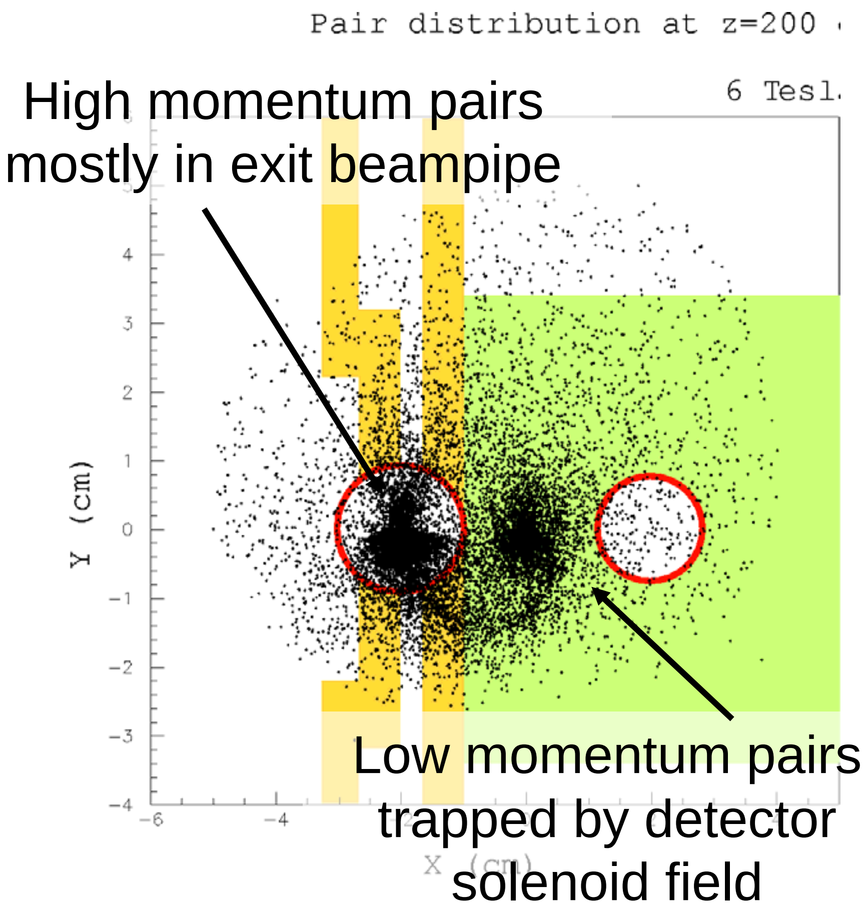


The pairs are a significant source of background

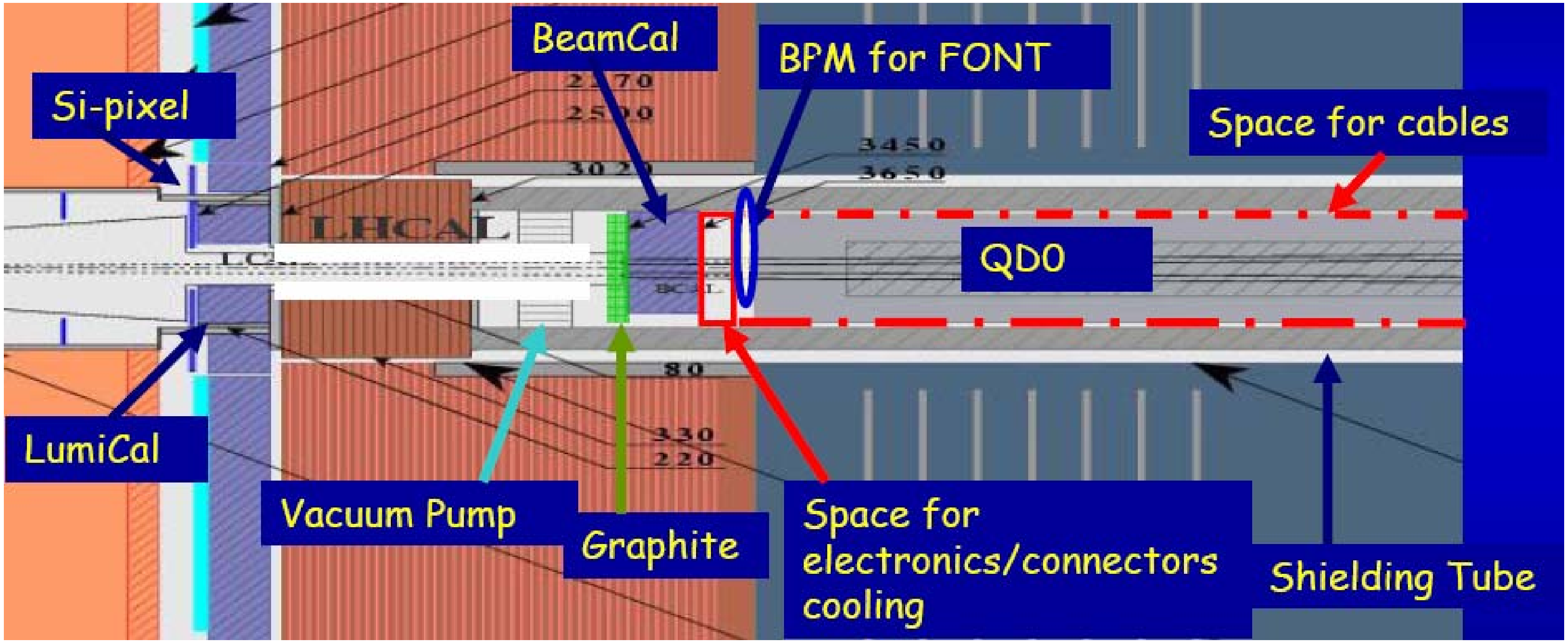
Beam pipe must respect the "stay clear" from pairs



e,γ,n secondaries made when pairs hit high Z surface of LUM or Q1



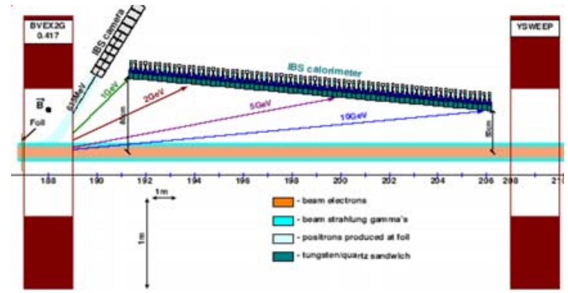
Forward Detectors

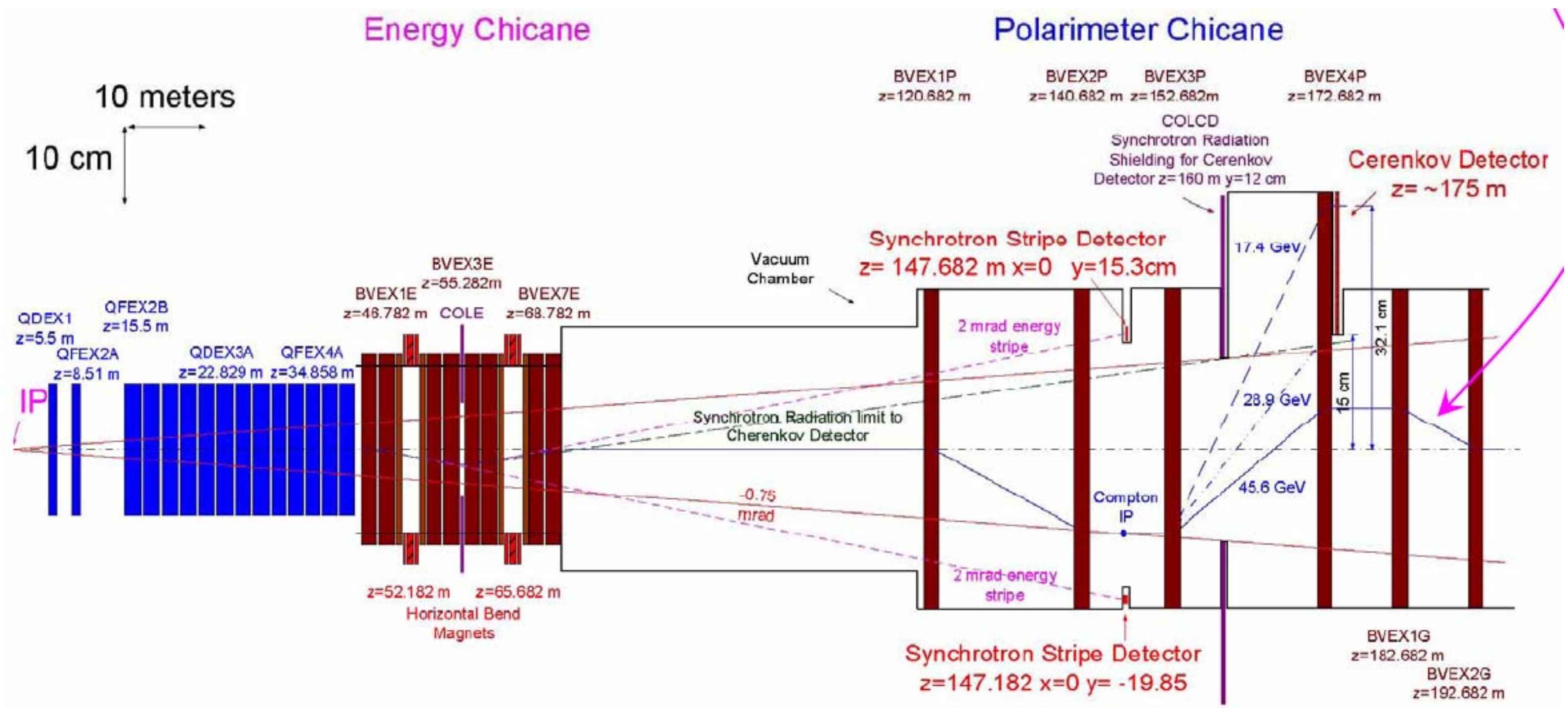


- Precise (Lumical) and Fast (BeamCal) luminosity measurement
- Hermeticity for electron tag (BeamCal)
- Masks for the inner detector
- Shielding for the accelerator components

Extraction Line Diagnostics

- Energy: SR spectrometer to measure energy and energy spread
- Polarization: Compton polarimeters before and after the IP
- Luminosity: Pair spectrum from lumical and beamstrahlung spectrum from gamcal monitors beam-beam interaction

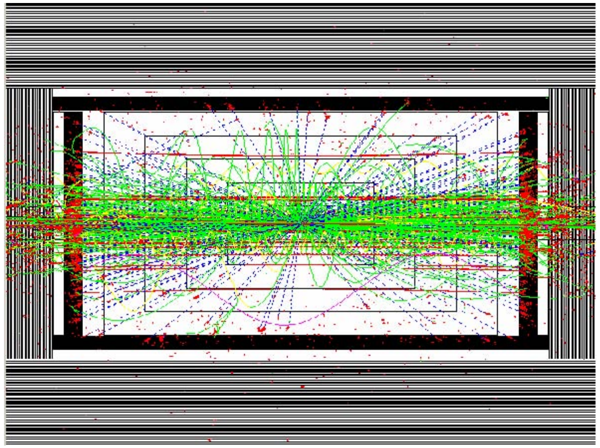




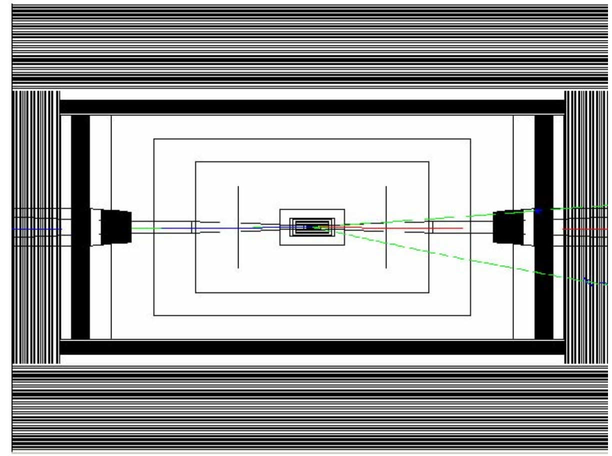
Y. Nosochkov, IRENG07

Occupancy of the Vertex Detector is a challenge

130 Beam crossings – 40μs



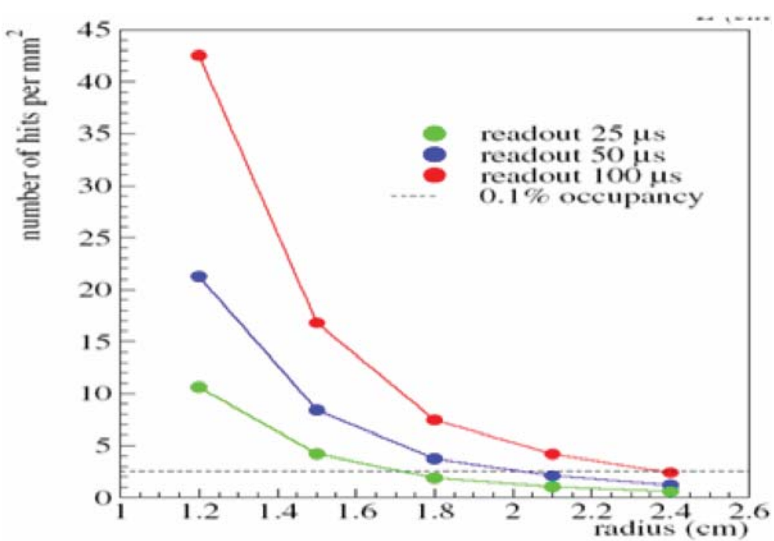
1 Beam crossing – 100ns



- Low occupancy is needed for pattern recognition
  - **0.1% occupancy desired**

- Occupancy in the VTX is dominated by pairs
  - **500 hits/mm2 for a full bunch train (2820 bunches)**
  - **Want that to be below 5 hits/mm2**

- Pixellated detectors and fast readout
  - **Faster readout, more energy dissipated**



J. Jaros, LCWS07

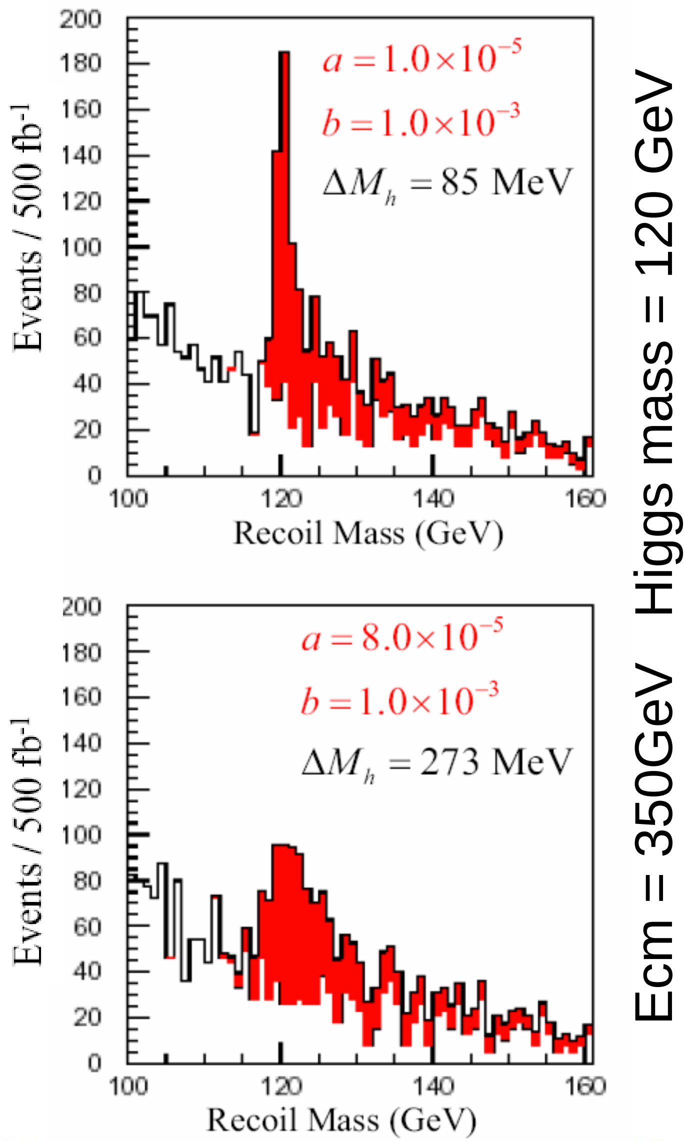
Higgs recoil benefits from precision tracking

- e+e- → ZH
  - **Z decays to lepton pair**
  - **H decay to anything (unreconstructed)**
  - **Initial state energy known**

- Parameterize tracking precision as:

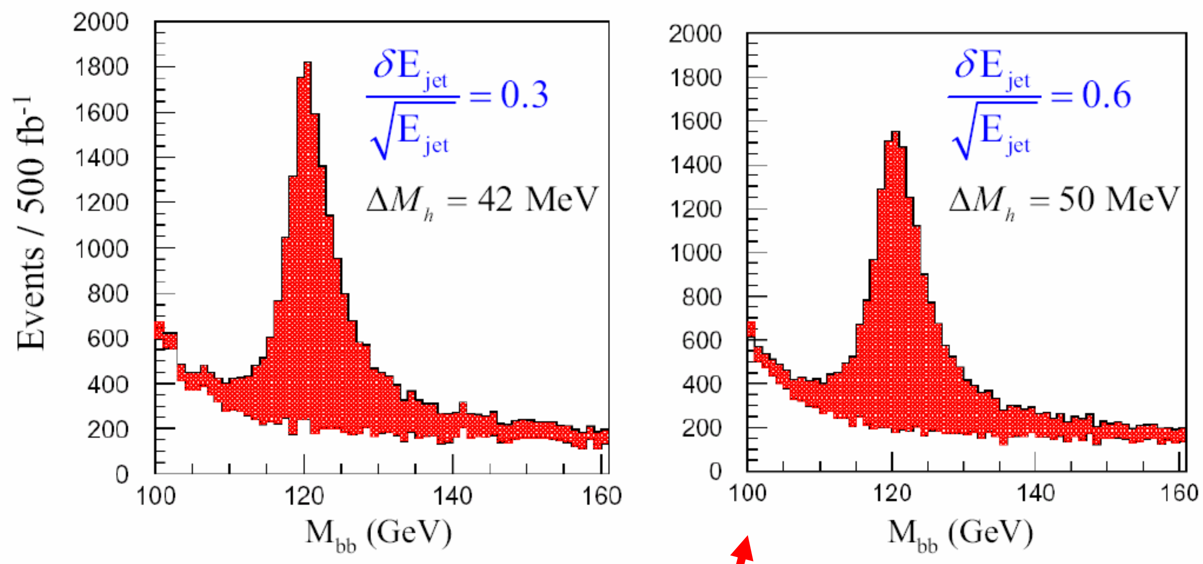
$$\delta p_t / p_t^2 = a \oplus b/(p_t \sin\theta)$$

- Current tracker concept have gotten partway



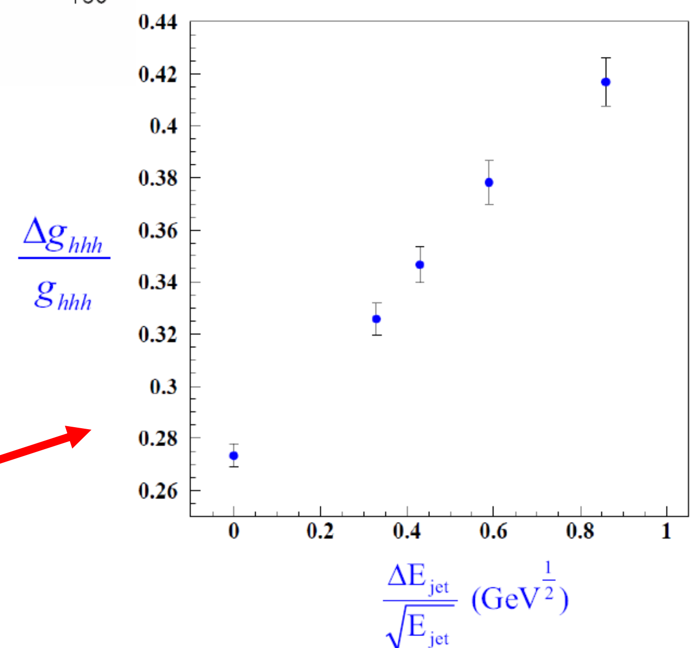
T. Barklow

Improved jet energy resolution requires advanced algorithms and detectors



Particle Flow Algorithms (PFA) will be critical to achieving this

- e+e- → HZ → bbqq
- Improved energy resolution is worth 40% of luminosity
- e+e- → HHZ → bbbbqq



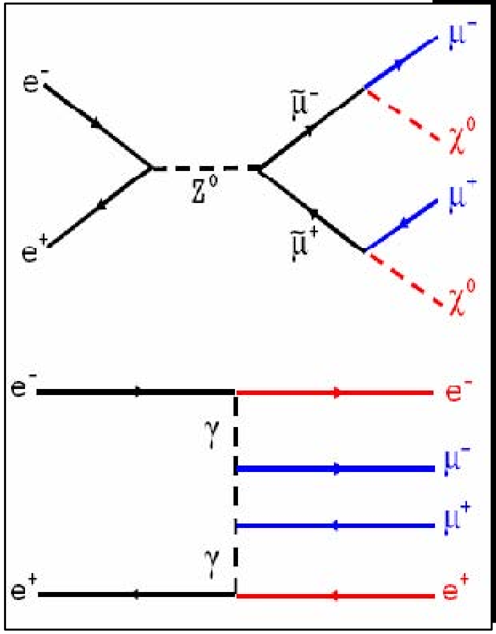
T. Barklow

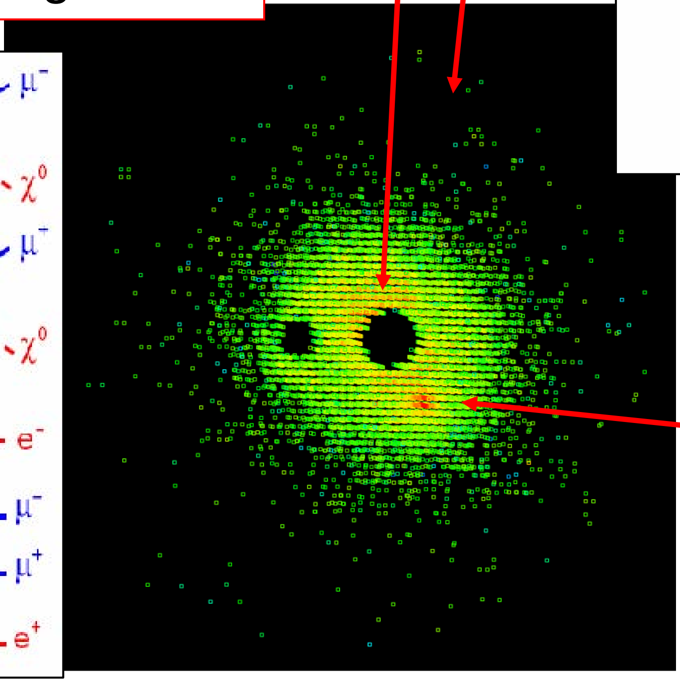
Beamcal: Luminosity and two-photon physics

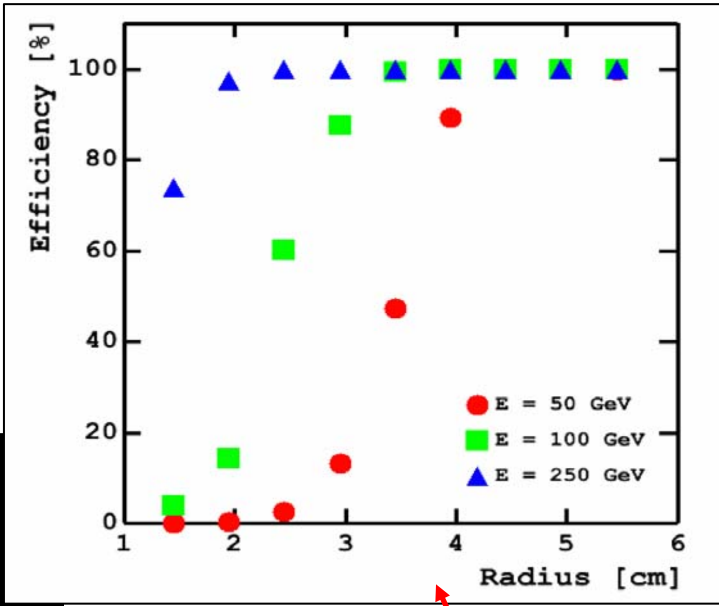
1 TeV of Beam-strahlung energy per bunch crossing

Centered on the extraction line

Anti-tag for slepton backgrounds





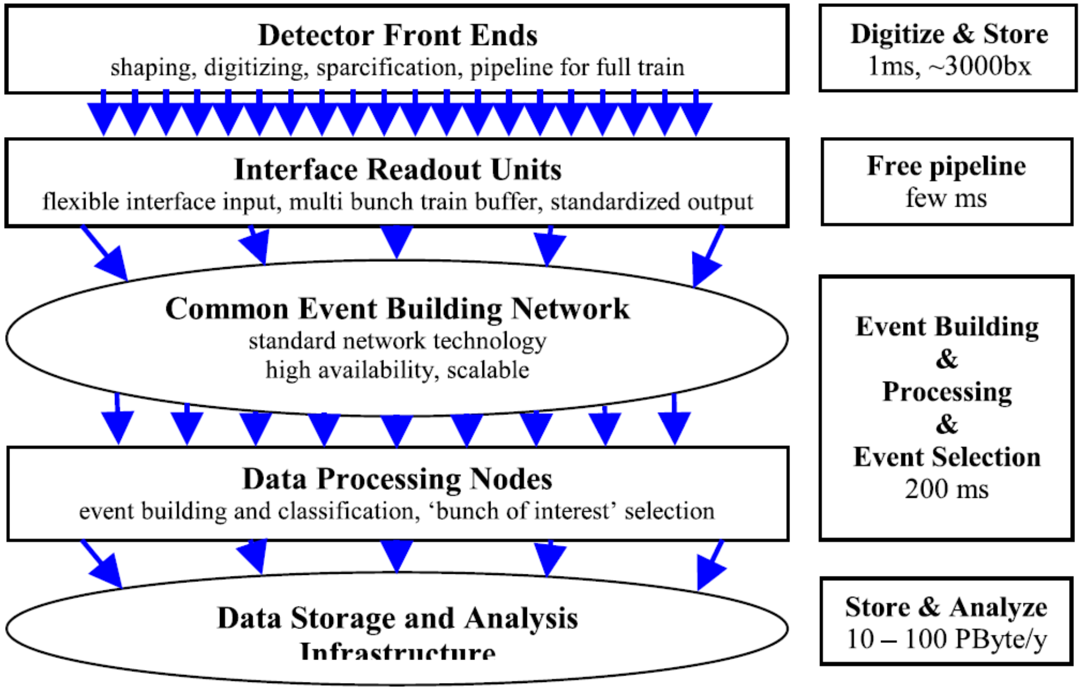


Detect very forward electrons

W. Lohman

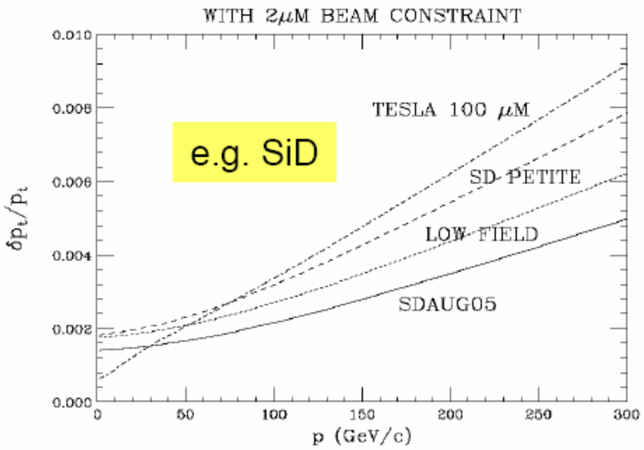
DAQ and Trigger

- Compared to LHC
  - **Lower data rate**
  - **10x higher channel count**
- No hardware trigger
  - **Software selection**
- ILC is burst mode machine
  - **1ms dead-time free pipeline**
  - **200ms event selection between trains**



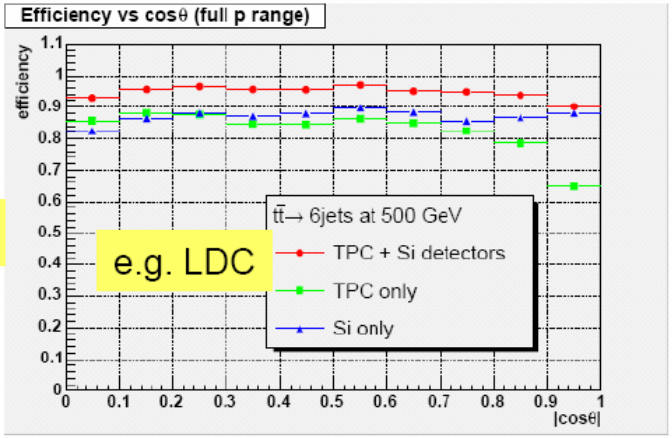
Current designs meet the detector performance goals

Momentum Resolution meets goal of $\Delta p/p^2 < 5 \times 10^{-5}$ (GeV^{-1})



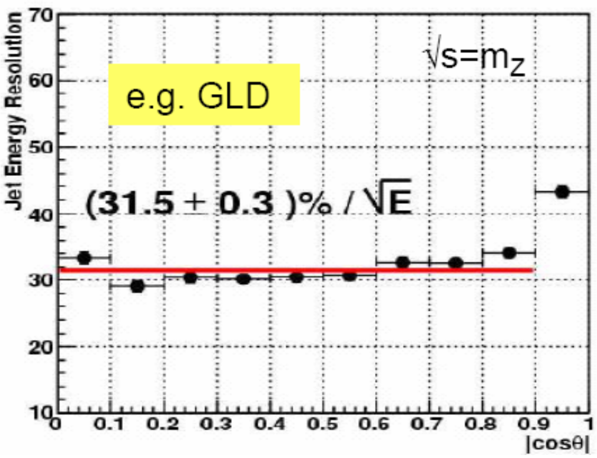
0.5%

Tracking Efficiency ~ 100%



Jet Energy Resolution α

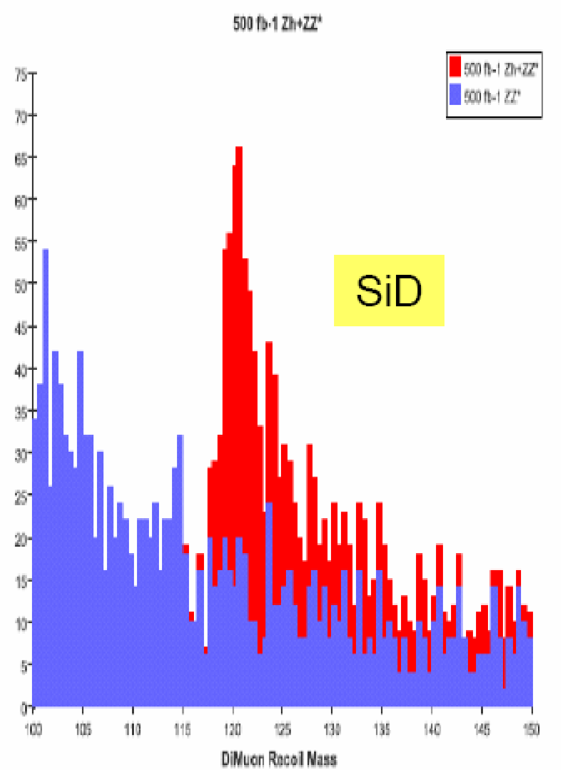
$\sigma_E/E = \alpha/\sqrt{E} \sim 30\,\%/\sqrt{E}$



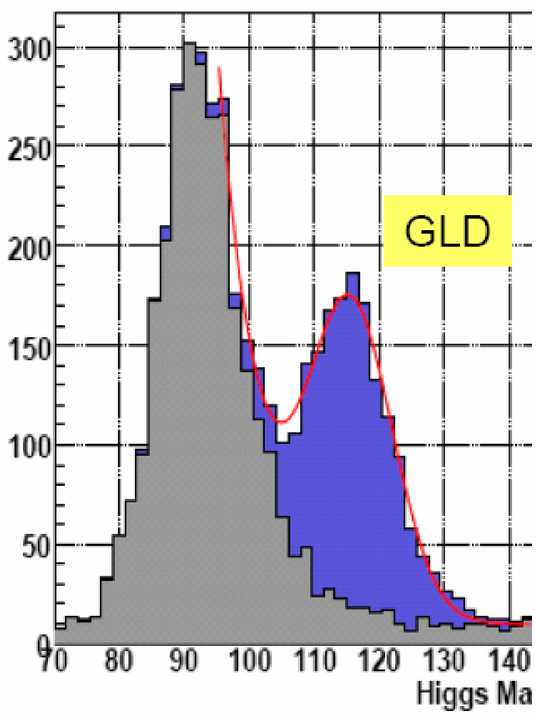
J. Jaros, LCWS07

Simulation results show the detectors can to the physics

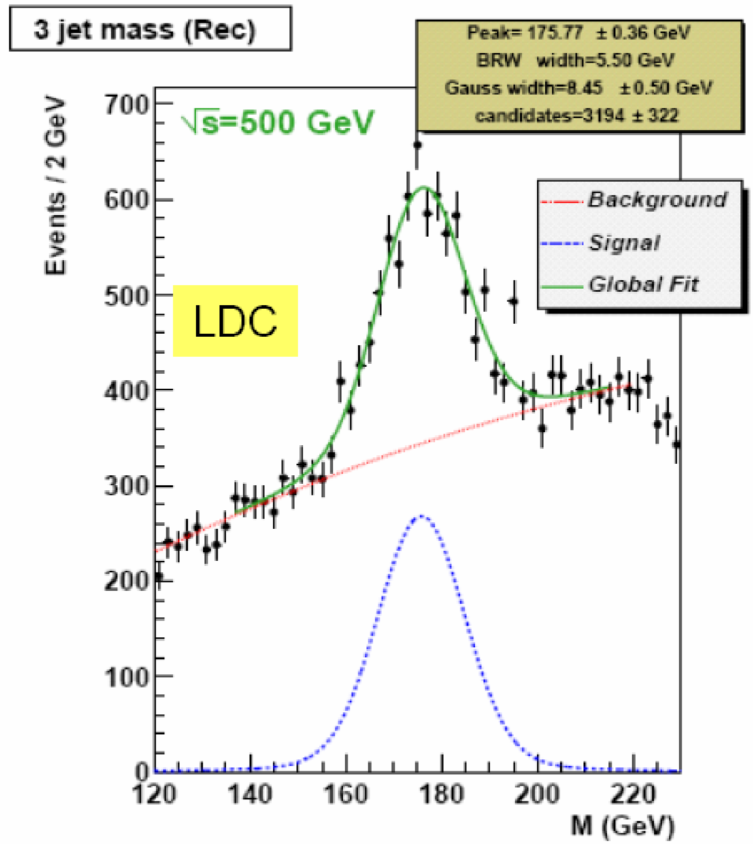
$e^+e^- \to ZH \to \mu\mu X$



$e+e- \to ZH \to \nu\nu bb$



$e+e- \to tt \to WbWb$



J. Jaros, LCWS07

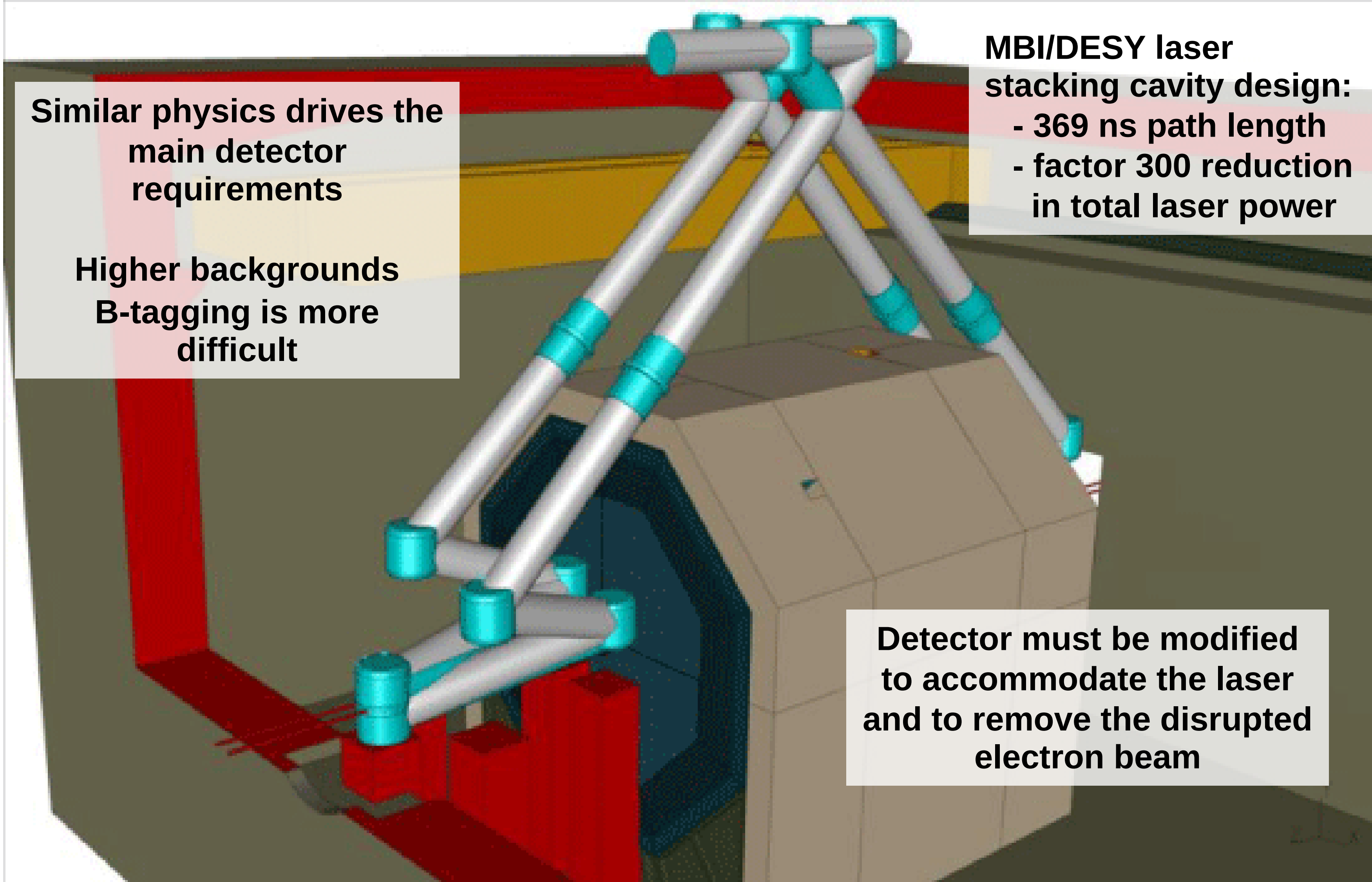
A world-wide effort is underway

- Linear Collider Workshops (LCWS) typically bring several hundred people together
  - **Week long workshops with 15-20 parallel sessions at once**

- Vigorous on-going efforts on:
  - **Simulations and reconstruction algorthims**
  - **Physics analysis modes**
  - **Detector technology design, prototyping, test beams**
  - **Machine-detector interface**

- Letters of Intent are being solicited for detector collaborations

Photon Linear Collider



MBI/DESY laser stacking cavity design:

- 369 ns path length
- factor 300 reduction in total laser power

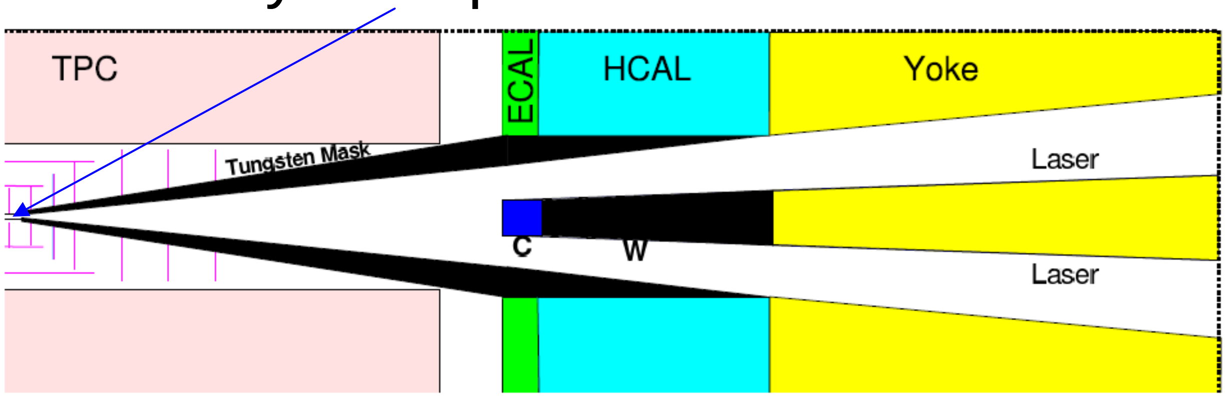
Similar physics drives the main detector requirements

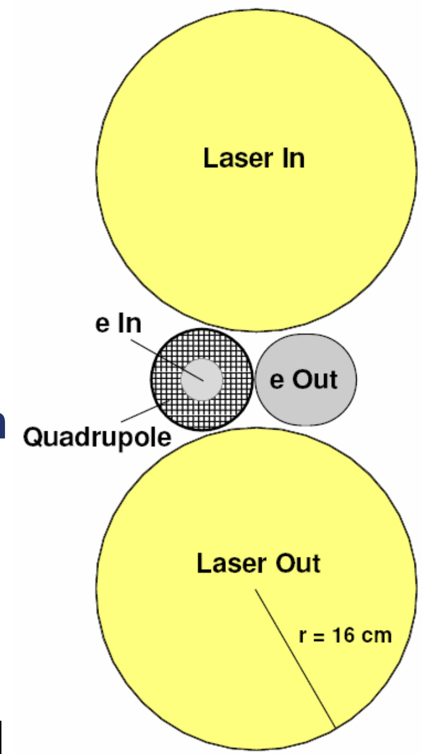
Higher backgrounds
B-tagging is more difficult

Detector must be modified to accommodate the laser and to remove the disrupted electron beam

Laser Cavity / Detector Integration

First: provide a line of sight to the laser cavity focal point 5mm from the IP



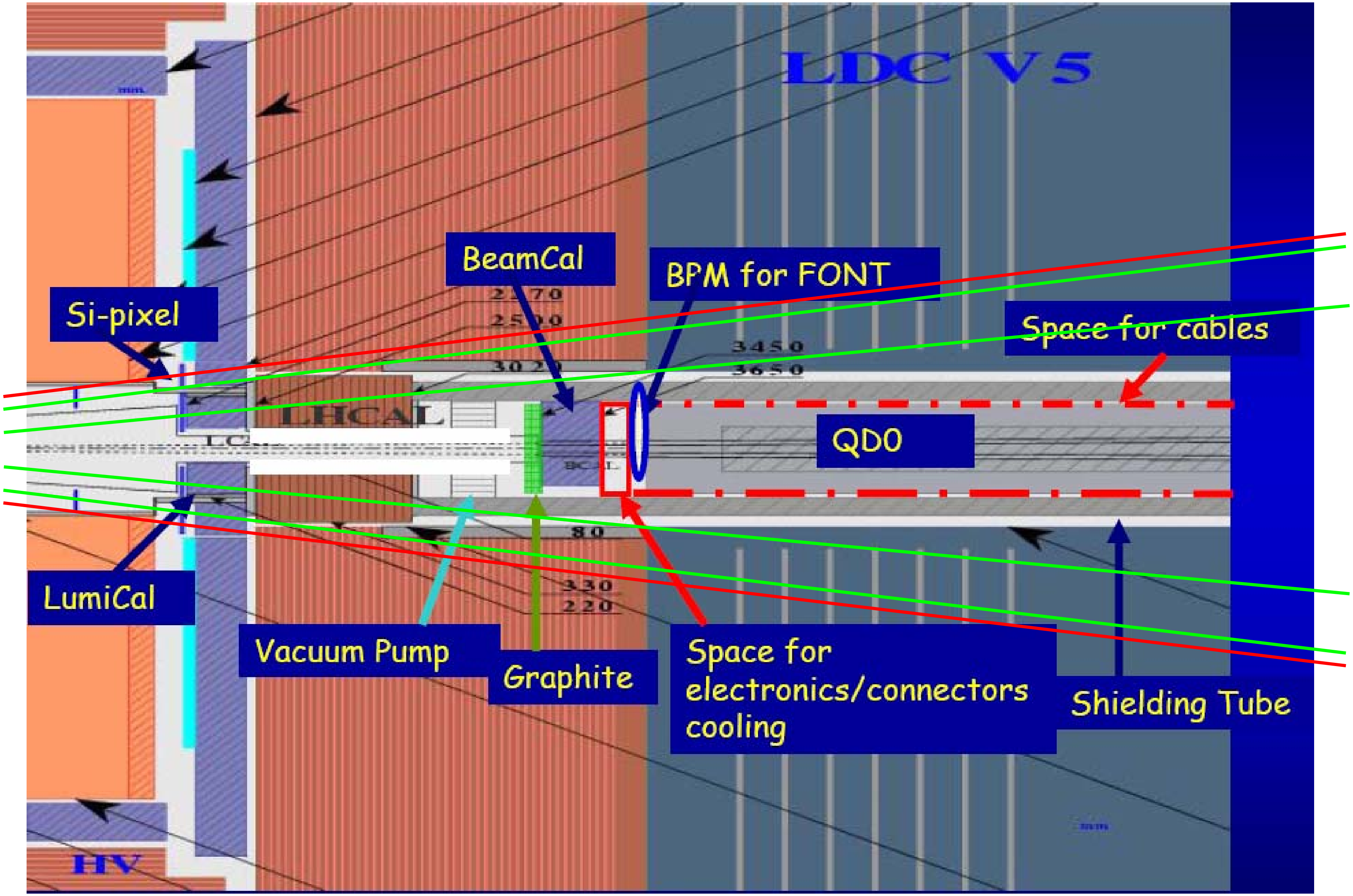


- Detector modifications:
  - **Unaffected: Barrel tracker, ecal, magnet, hcal, muon**
  - **Affected: endcaps, beam pipe, silicon**
    - Penetrations through the end cap yoke, hcal and ecal for the laser line of sight
    - Modification of the masks and forward silicon

It will be enormously cheaper to retro-fit a detector for photon collider operations if some attention is paid today

K. Moenig

The final focus is a crowded and complicated place laser beamlines increase the complexity

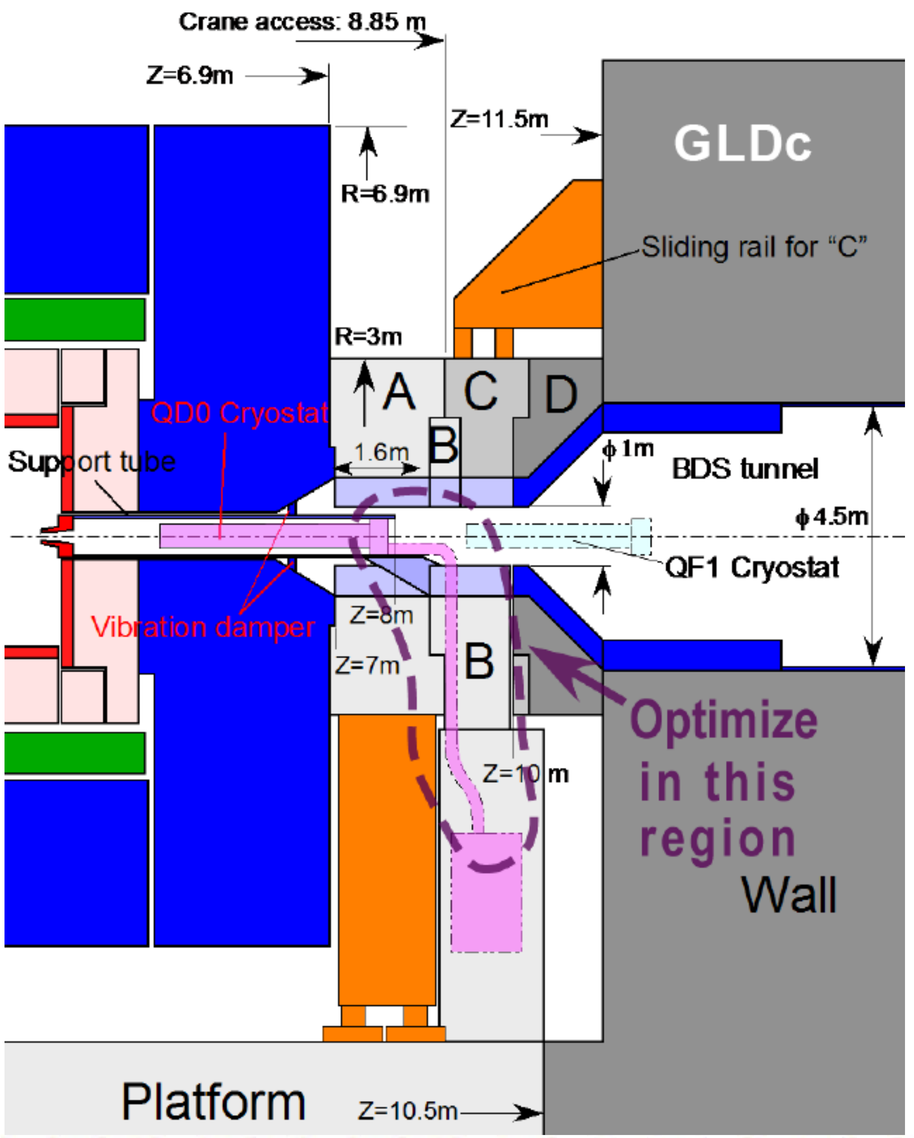


W. Lohman

Engineering space for the mirrors is a challenge

- The final focus mirror is about 1 meter diameter
  - **There are two mirrors on each side**
    - Space above and below the beamline must be provided for the optics in the BDS tunnel
    - “PACMAN” muon shield needs to be modified

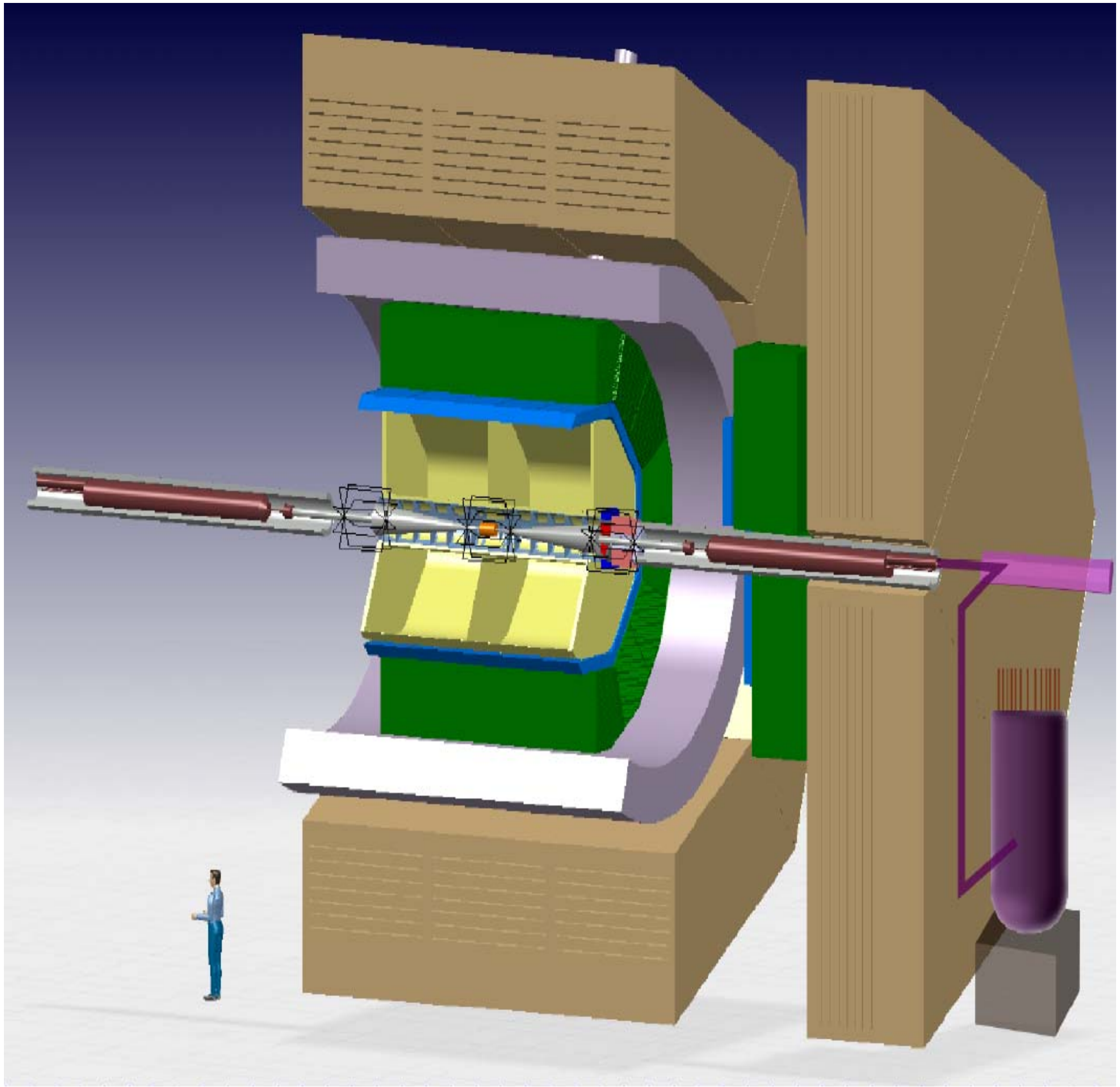
- The mirrors need to be stabilized against vibration
  - **This may have an impact on design of the support structure and stabilization**



T. Tauchi

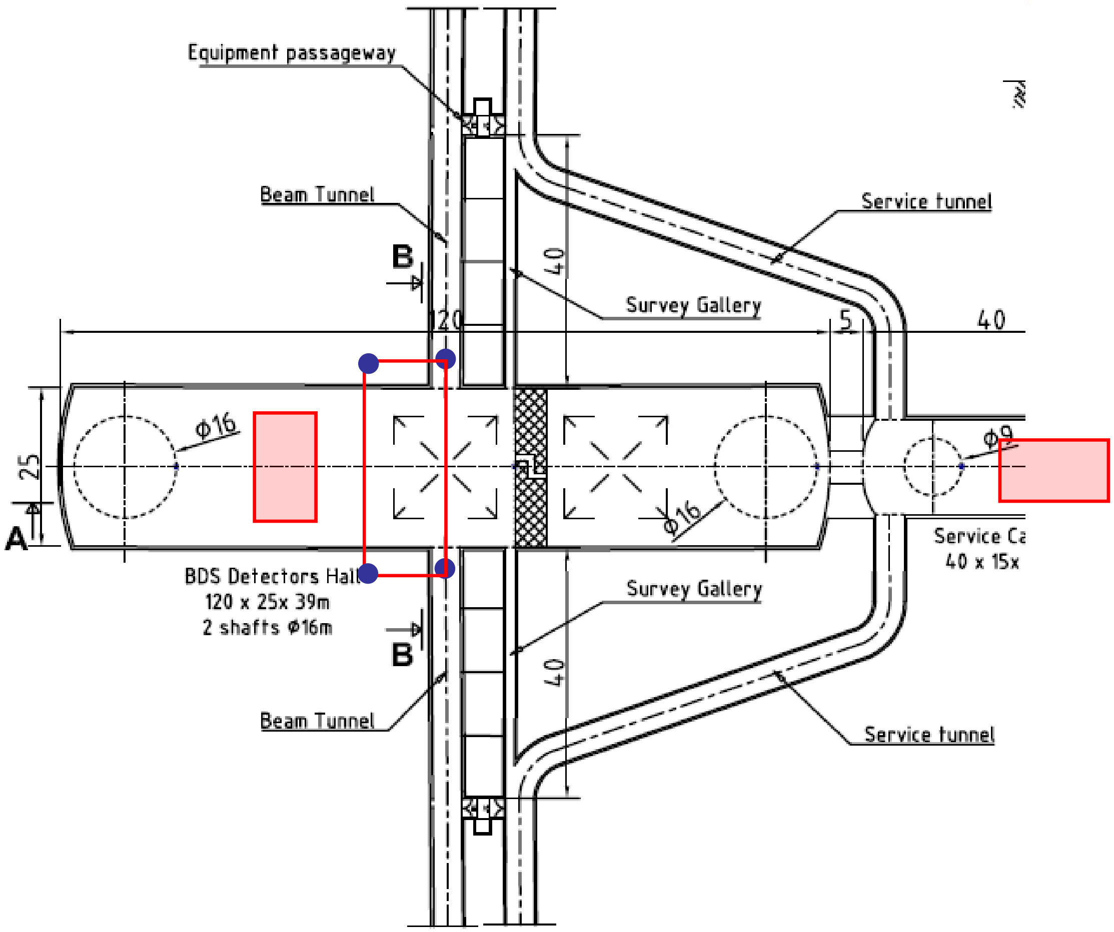
Installation and Servicing is also a challenge

- The detector must be taken apart like a puzzle for servicing
- Currently the beam tube allows the endcap to slide back
  - **PLC will need to expand the tube or engineer a way to handle a tapered tube**
  - **Loss of calorimeter coverage versus complicated support**



B. Parker

Space for the laser plant and cavity must be provided

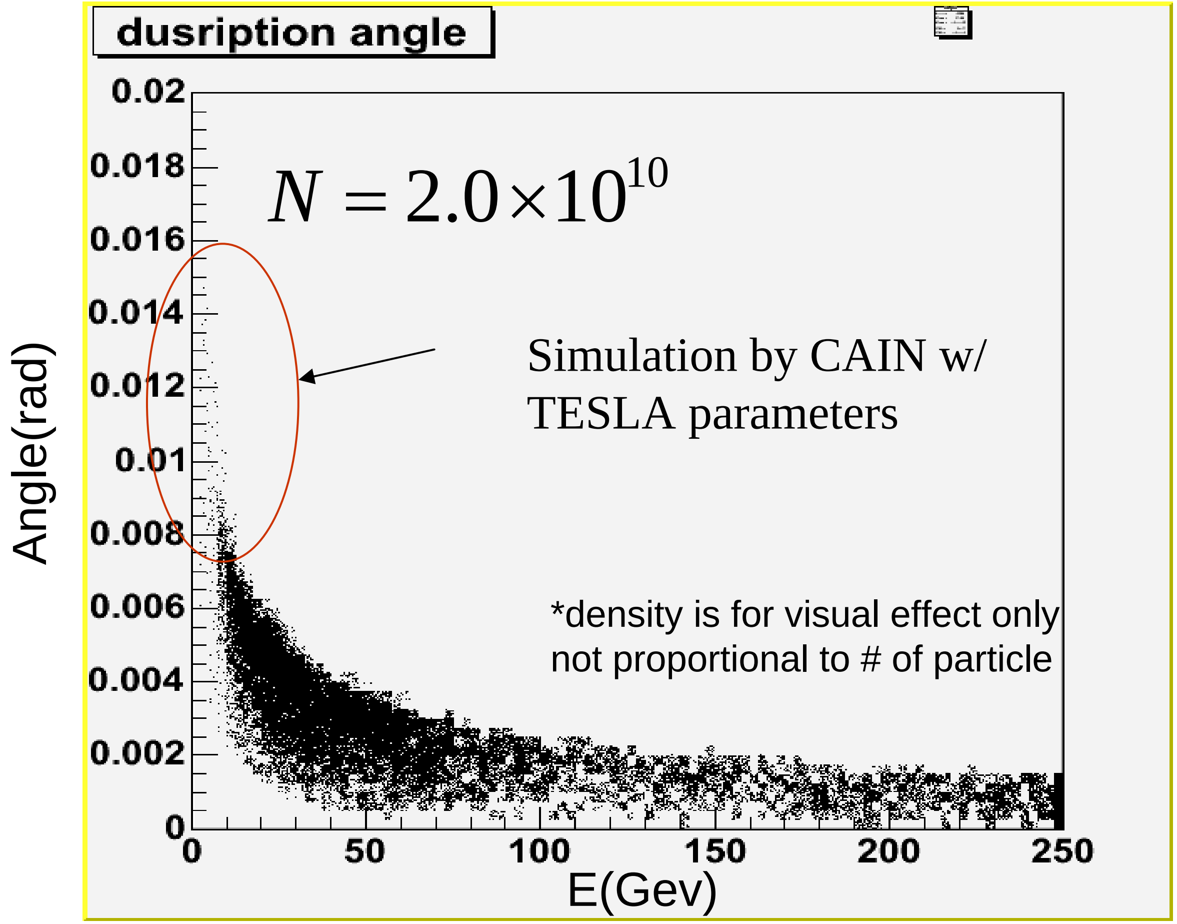


J. Osborne

- The cavity is driven by a short pulse laser which needs a clean room below ground
  - **Possible locations**
    - service cavern
    - Detector hall (temporary)
- A path for the laser light needs to be provided
  - **Locations for turning mirrors and diagnostics**
- Need to pursue least cost solution with CFS group

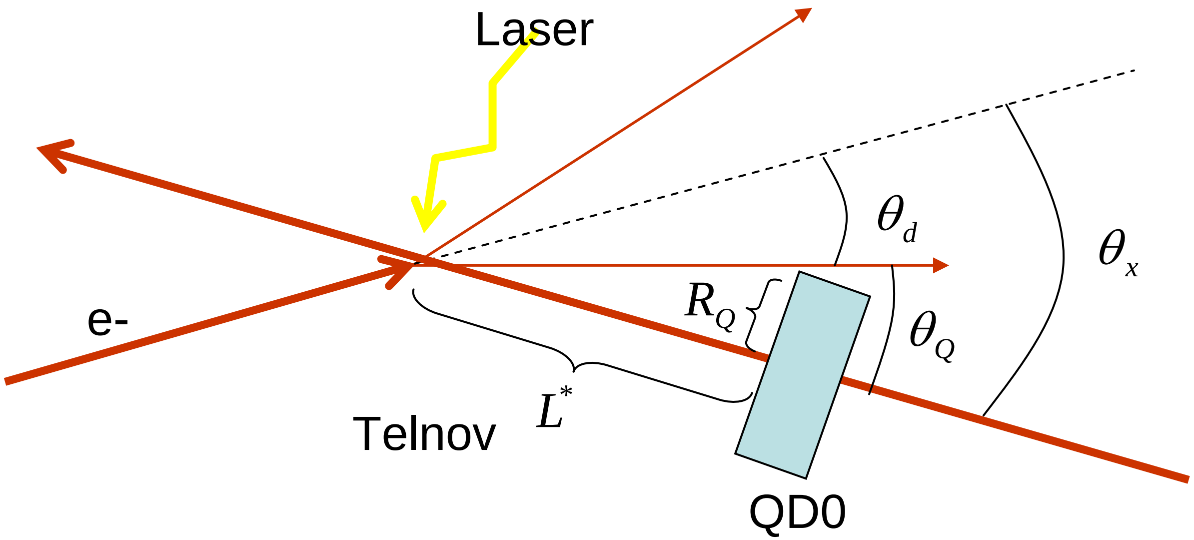
The crossing angle requirement has no flexibility

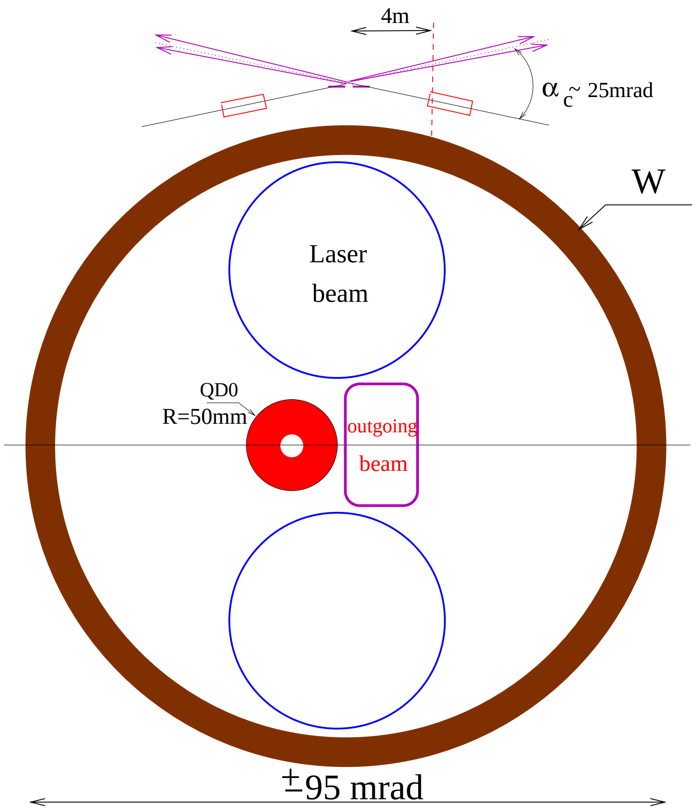
- A large crossing angle is required to remove the disrupted beam from the IP
- Compton backscattering leaves a large energy spread in the electron beam
- Beam-beam deflection at the IP gives an angular kick to the beams



T. Takahashi

The Photon Collider must have a 25 mr crossing angle





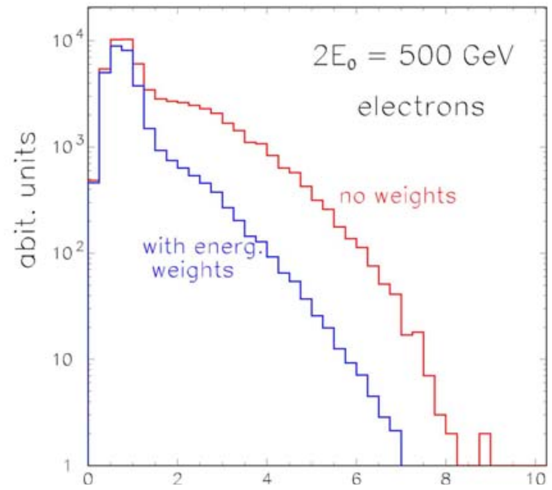
Telnov

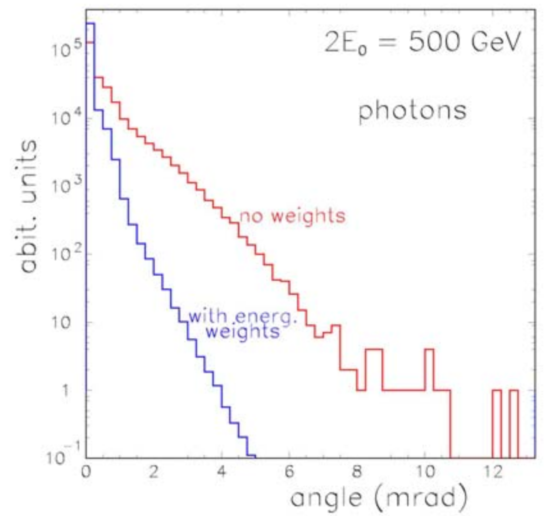
- Physical overlap between the extraction line and the final focus quad sets the minimum crossing angle

The outgoing beam sets unique requirements for the extraction line and dump

V.Telnov, physics/0512048, Snowmass2005

- The outgoing beam from the photon collider is a complicated object
- There are three main components
  - **Two with a large angular spread**
    - Disrupted electrons
    - Beamstrahlung photons
  - **One quite narrow**
    - Compton photons

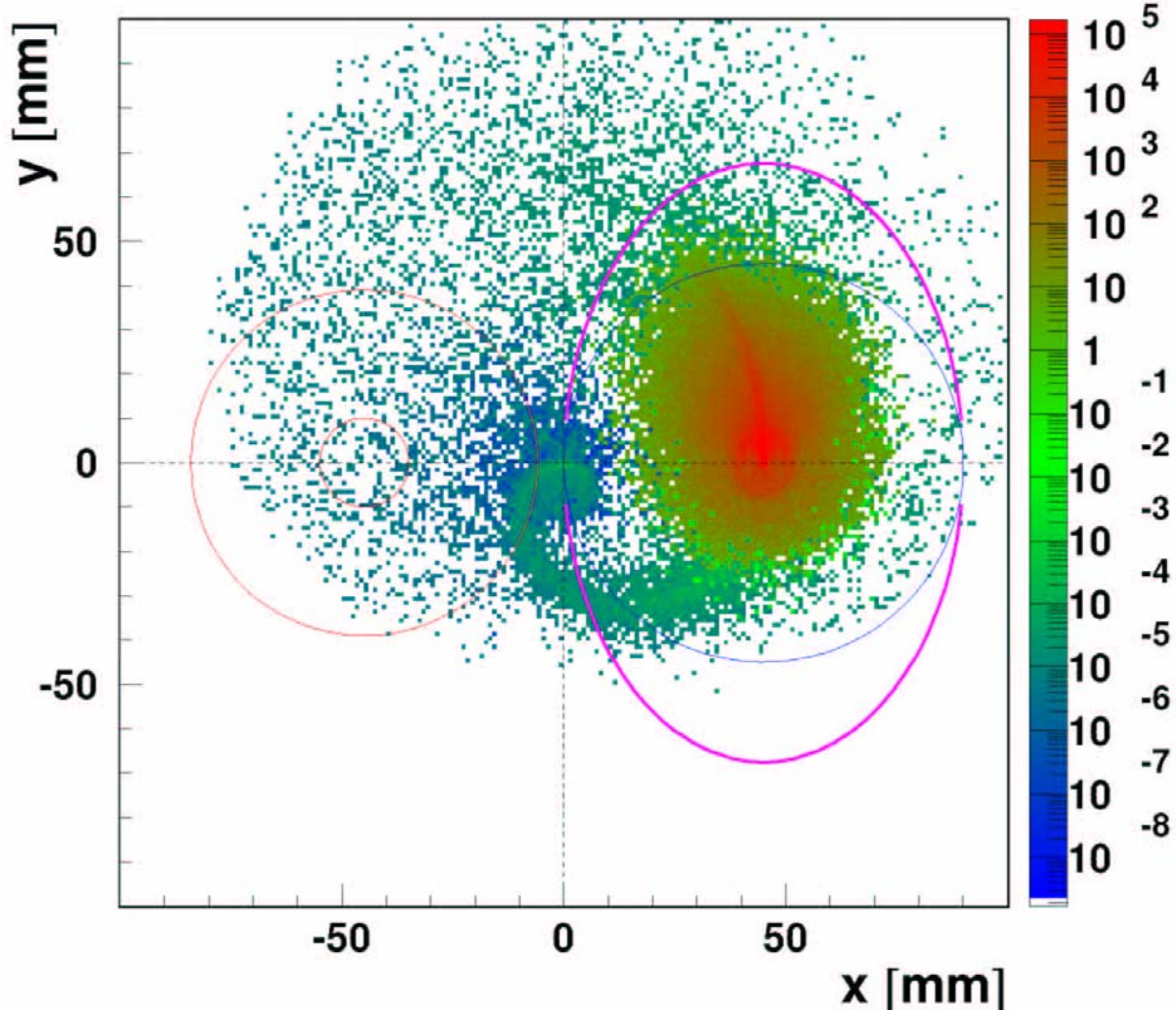




Component:	Angle	Size at 250m
Electrons	10 mrad	2.5 m
Beamstrahlung Photons	3-4 mrad	~1m
Compton Photons	(.04,.015) mrad	(1,0.35) cm

Spiraling of particles in the solenoidal field is again a design constraint

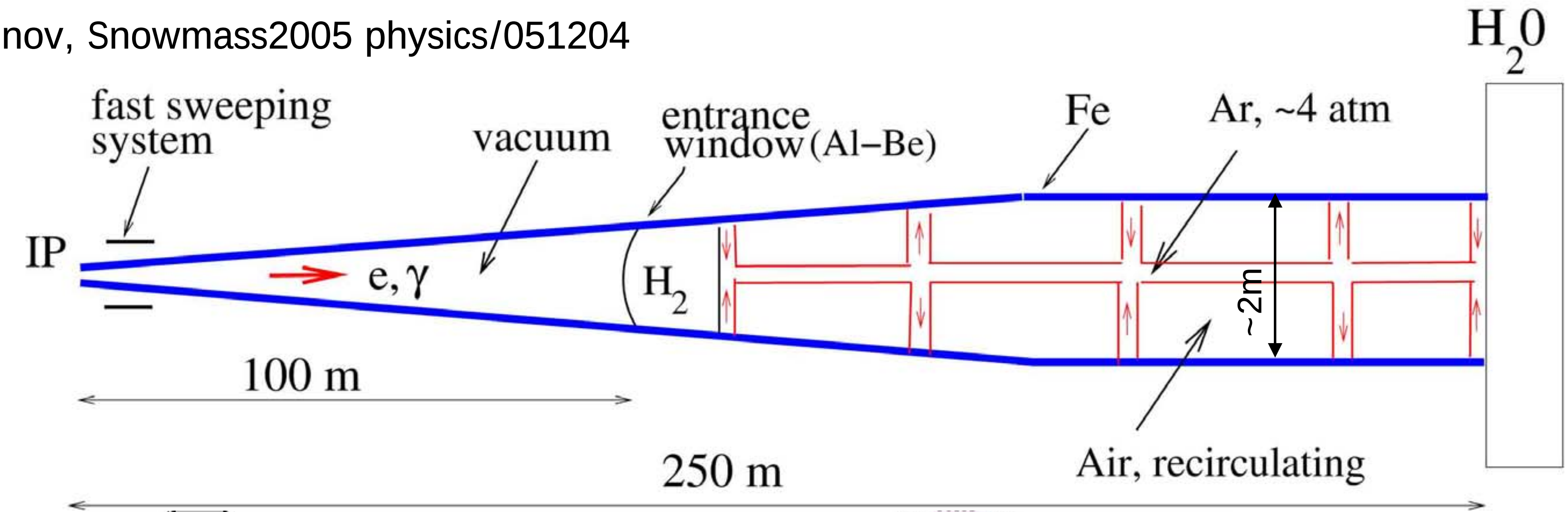
- Outgoing beam:
  - **Off-energy beam electrons**
  - **Pair background**
- The low energy cutoff in the disrupted beam sets the size of the exit aperture
- Low energy pairs impacting the superconducting solenoid is a concern
  - **< 1W**

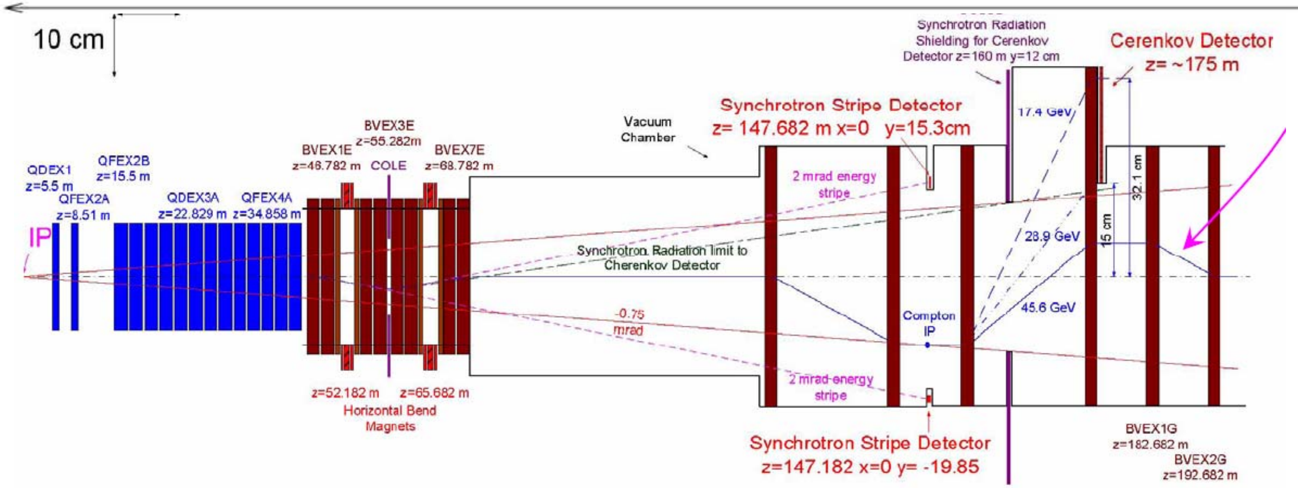


A.F. Zarnecki, LCWS06

PLC extraction line is incompatible with diagnostics

Telnov, Snowmass2005 physics/051204





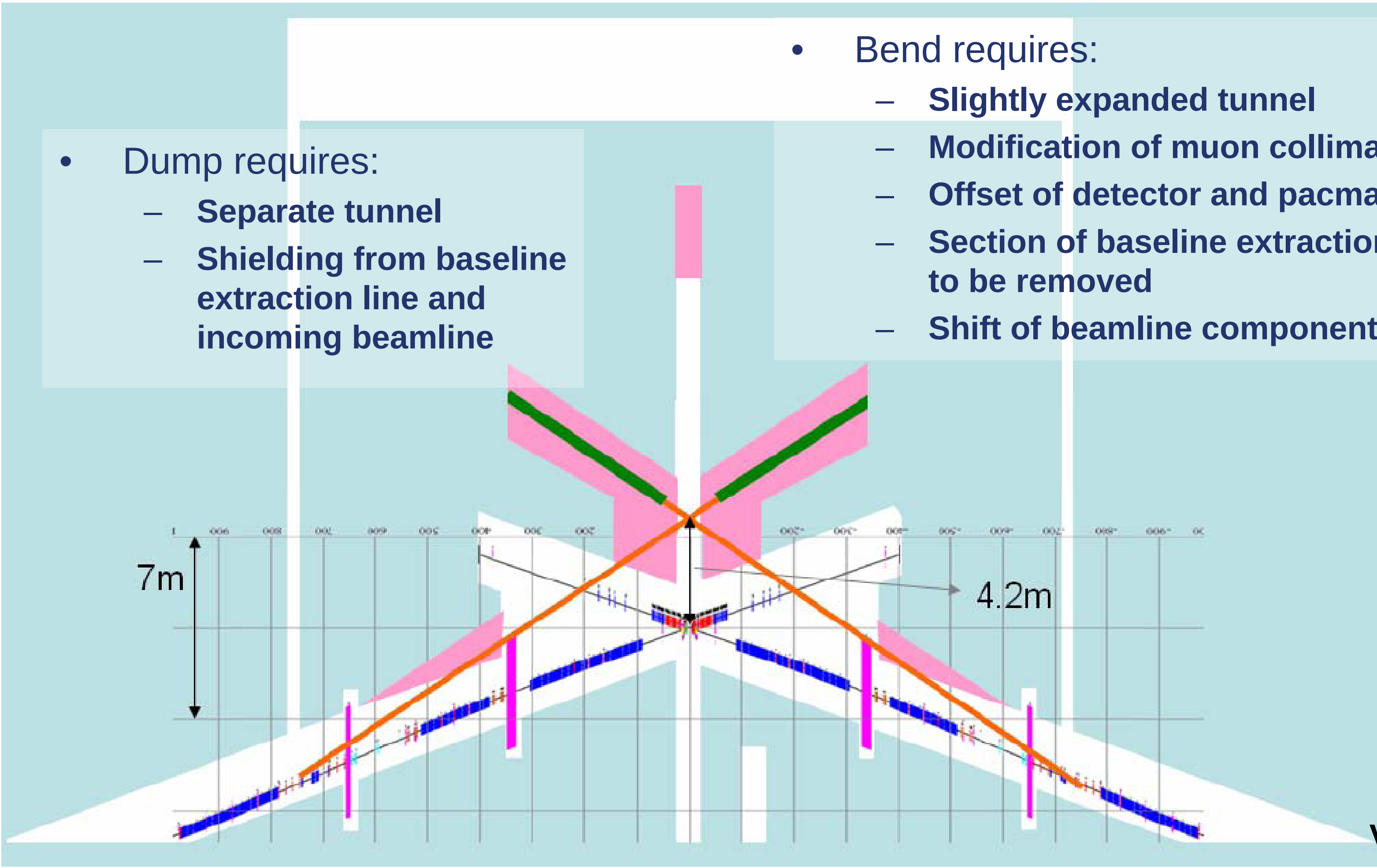
Proposed least cost solution for $\gamma\gamma$: Extra 5.5mr of bend at 700m

14mr => 25mr

A.Seryi, LCWS06

- Dump requires:
  - **Separate tunnel**
  - **Shielding from baseline extraction line and incoming beamline**

- Bend requires:
  - **Slightly expanded tunnel**
  - **Modification of muon collimators**
  - **Offset of detector and pacman**
  - **Section of baseline extraction line to be removed**
  - **Shift of beamline components**

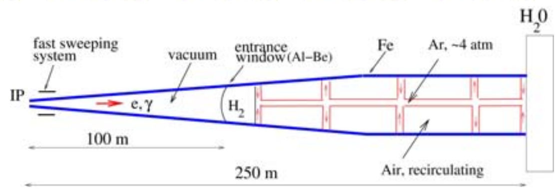


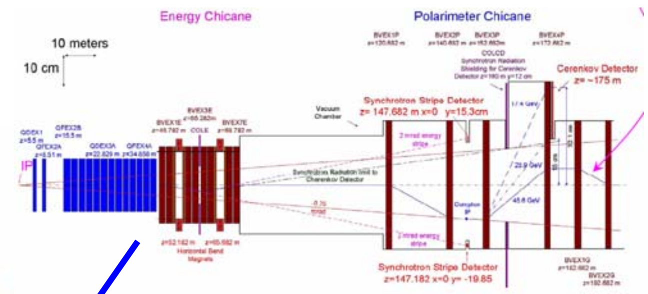
V. Telnov

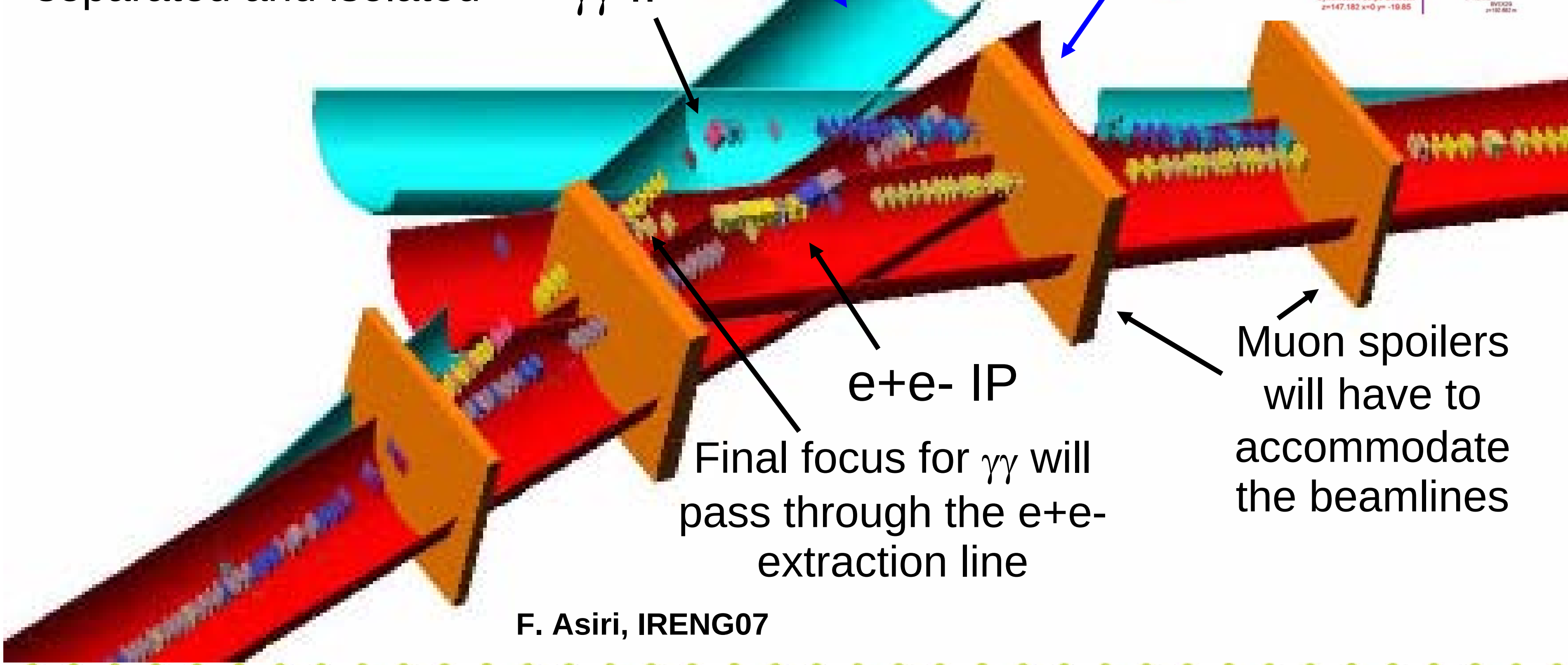
CF group asserts that further tunneling after baseline operations is unacceptable

Allowing both e+e- and $\gamma\gamma$ running has it's own engineering issues

Beam Dumps will be highly radioactive and the two systems must be separated and isolated







$\gamma\gamma$ IP

e+e- IP

Final focus for $\gamma\gamma$ will pass through the e+e- extraction line

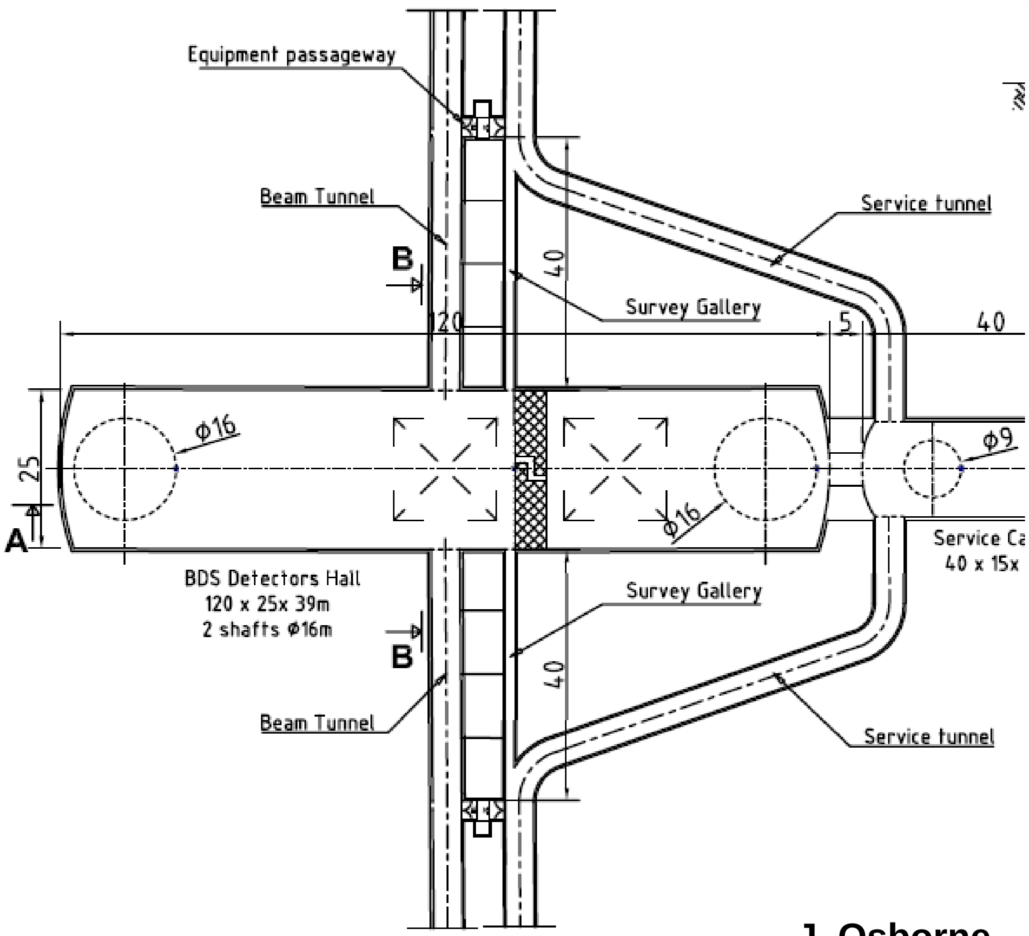
Muon spoilers will have to accommodate the beamlines

F. Asiri, IRENG07

Push-Pull makes the transition easier

- Detectors will be designed to move in and out of the beamline
  - **One experimental hall and beamline is a major cost savings**
  - **Detector will need to be shifted a few meters to move from e+e- to $\gamma\gamma$ beamline**

- However, PACMAN and shielding will also need to move



J. Osborne

Conclusion

- ILC Detector design is progressing
  - **Large simulation effort**
  - **Large detector technology R&D effort**
  - **It seems that the detectors will be able to do the physics**

- Photon Linear Collider Detector
  - **Basic detector can be reused for PLC physics**
  - **No show-stoppers**
  - **Enormous amount of work in detailed engineering to integrate the laser cavity with the equipment in the beamline**
  - **Understanding trade-offs and optimizations for integration of the laser with the detector in the forward region needs a significant effort**