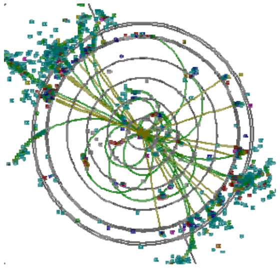
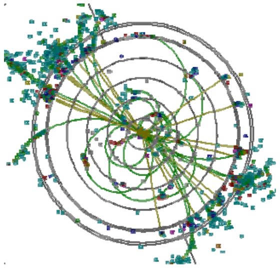


International Linear Collider: Machine Status and Physics

Jim Brau

University of Oregon

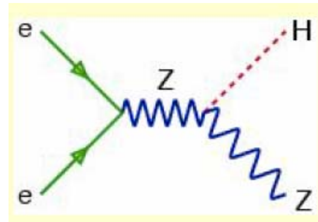
C2CR07 Conference **Granlibakken** **March 1, 2007**



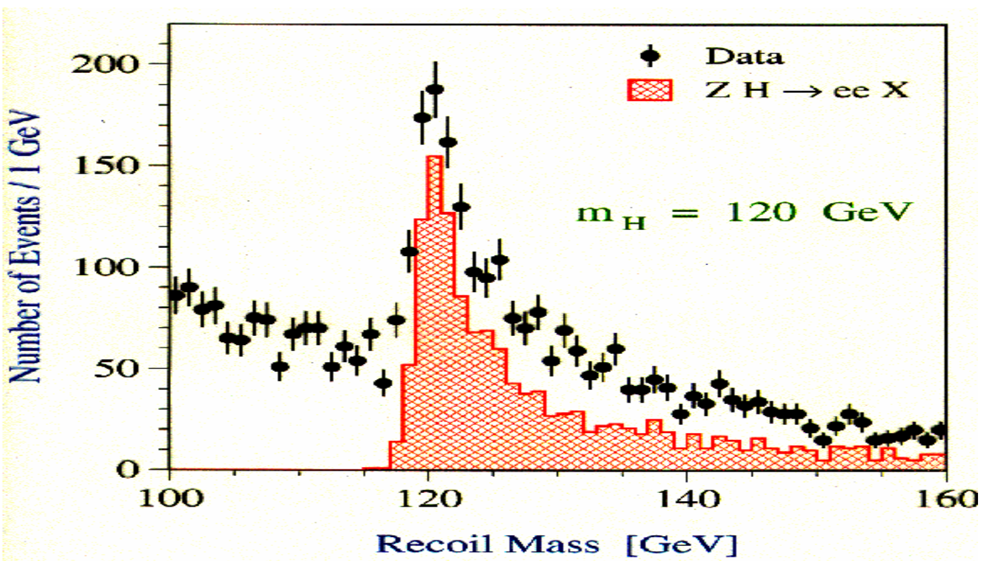
ILC Physics Goals

- EWSB
  - Higgs
    - Mass (~50 MeV at 120 GeV)
    - Width
    - BRs (at the few% level)
    - Quantum Numbers (spin/parity)
    - Self-coupling
  - Strong coupling (virtual sensitivity to several TeV)
- SUSY particles
  - Strong on sleptons and neutralinos/charginos
- Extra dimensions
  - Sensitivity through virtual graviton
- Top
  - Mass measured to ~ 100 MeV (threshold scan)
  - Yukawa coupling
- W pairs
  - W mass

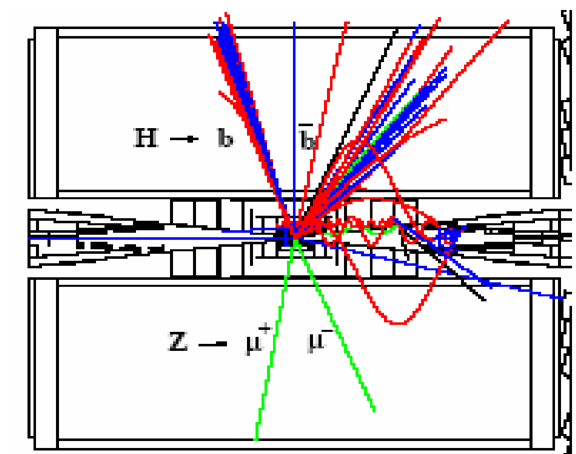
- Well defined initial state
- Democratic interactions



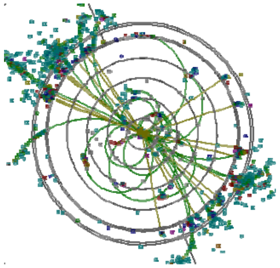
Higgs recoiling from a Z, with known CM energy⇓, provides a powerful channel for unbiassed tagging of Higgs events, allowing measurement of <u>even invisible decays</u> (⇓ - some beamstrahlung)



500 fb^{-1} @ 500 GeV, TESLA TDR, Fig 2.1.4



Demands Precise Tracking



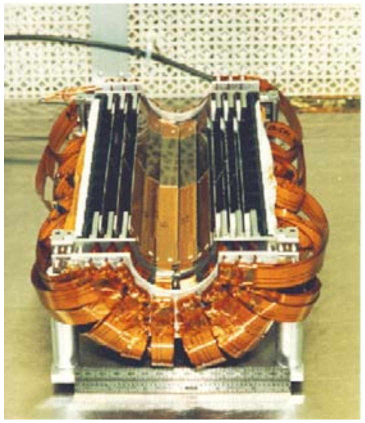
The Electroweak Precision Measurements Anticipate a Light Higgs – Then What?

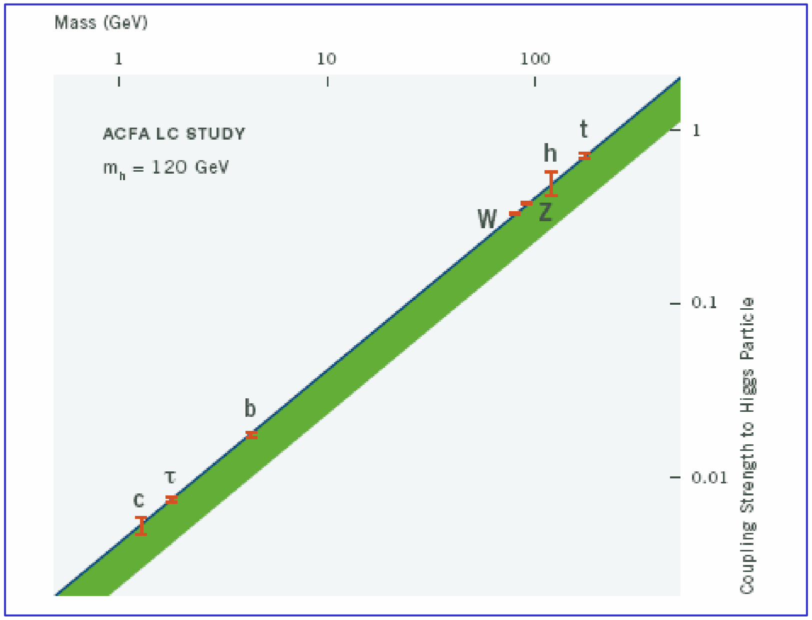
Measurement of BR's is powerful indicator of new physics

e.g. in MSSM, these differ from the SM in a characteristic way.

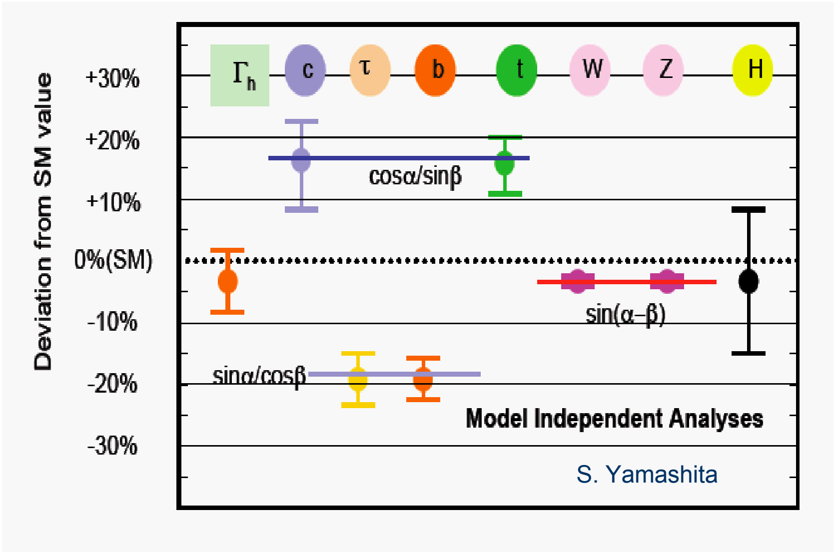
Higgs BR must agree with MSSM parameters from many other measurements.

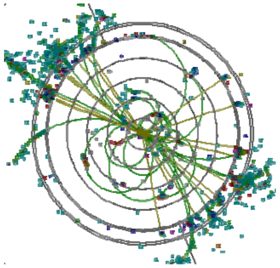
SLD comprised 307 Mpixels with < 4 μm point resolution over entire system





SUSY (2 Higgs Doublet Model)





Is This the Standard Model Higgs?

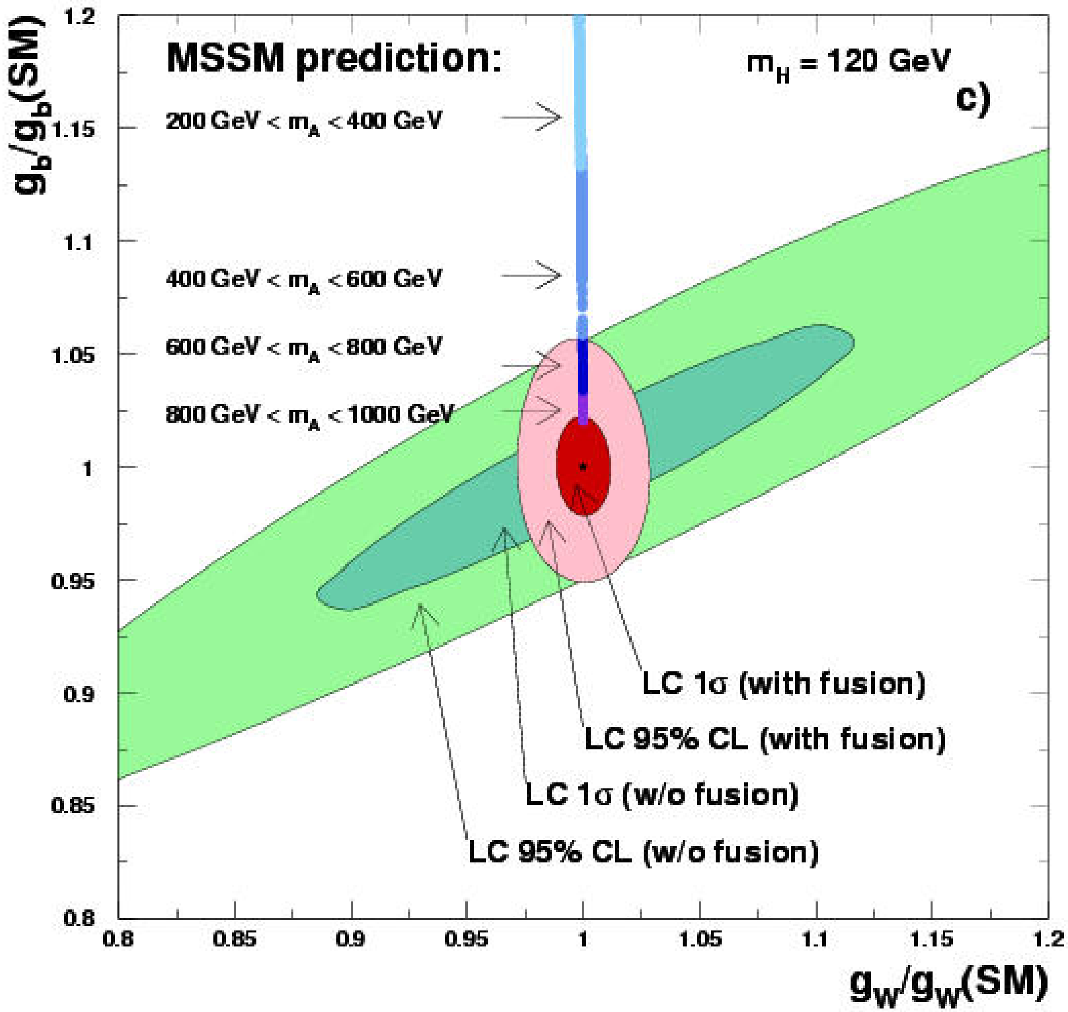
b vs. W

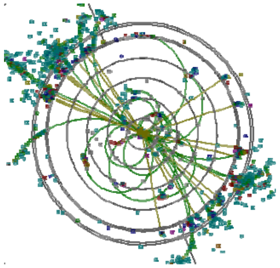
TESLA TDR, Fig 2.2.6

Arrows at:
- M_A = 200-400
- M_A = 400-600
- M_A = 600-800
- M_A = 800-1000

HFITTER output

conclusion:
for M_A < 600,
likely to distinguish





ILC Experimental Advantages

Elementary interactions at known E_{cm}* and ang. mom.

eg. $e^+e^- \rightarrow$ Z H * beamstrahlung manageable

Democratic Cross sections

eg. $\sigma(e^+e^- \rightarrow ZH) \sim 1/2\, \sigma(e^+e^- \rightarrow d\,\bar{d})$

Inclusive Trigger

total cross-section

Highly Polarized Electron Beam

~ 80% (+ positron polarization – R&D)

Exquisite vertex detection

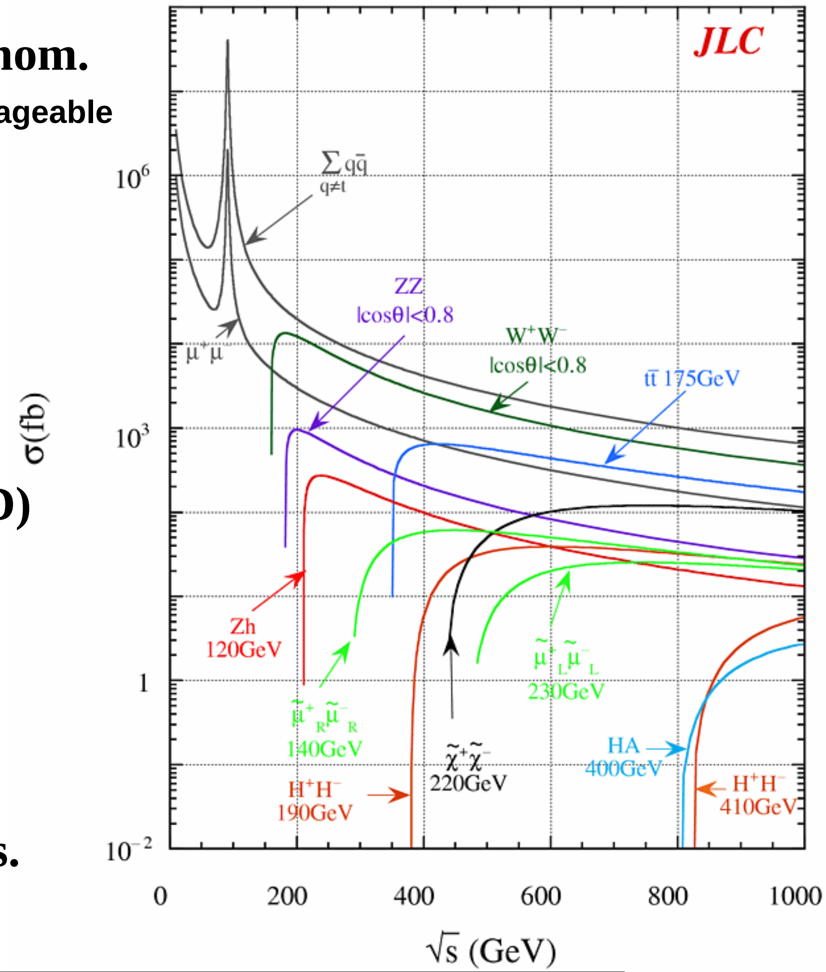
eg. $R_{beampipe} \sim 1$ cm and $\sigma_{hit} \sim 3\ \mu$m

Calorimetry with Particle Flow Precision

$\sigma_E/E \sim 30\text{-}40\%/\sqrt{E}$

Advantage over hadron collider on precision meas.

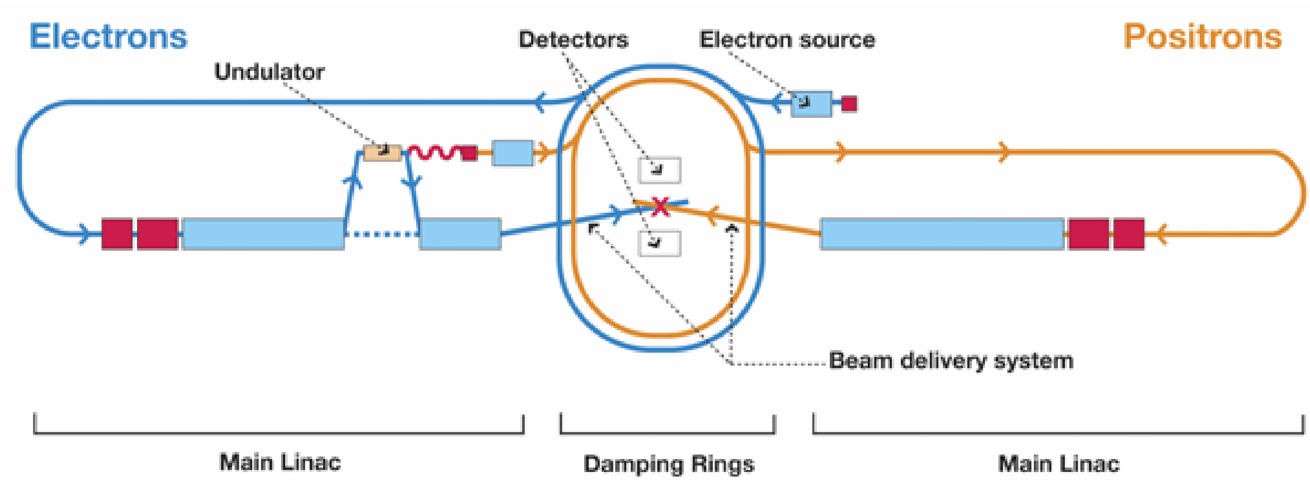
eg. $H \rightarrow c\,\bar{c}$



Detector performance translates directly into effective luminosity

ILC Milestones

- 2004 Aug. ICFA Decision of SC Technology (ICHEP at Beijing)
- 2005 Aug. Formation of GDE (Snowmass Workshop)
- 2005 Dec. BCD (Baseline Configulation Document) completed (Frascati Workshop)
- 2007 Feb. Draft of RDR (Reference Design Report) with Cost to be open to public (Beijing GDE Workshop)

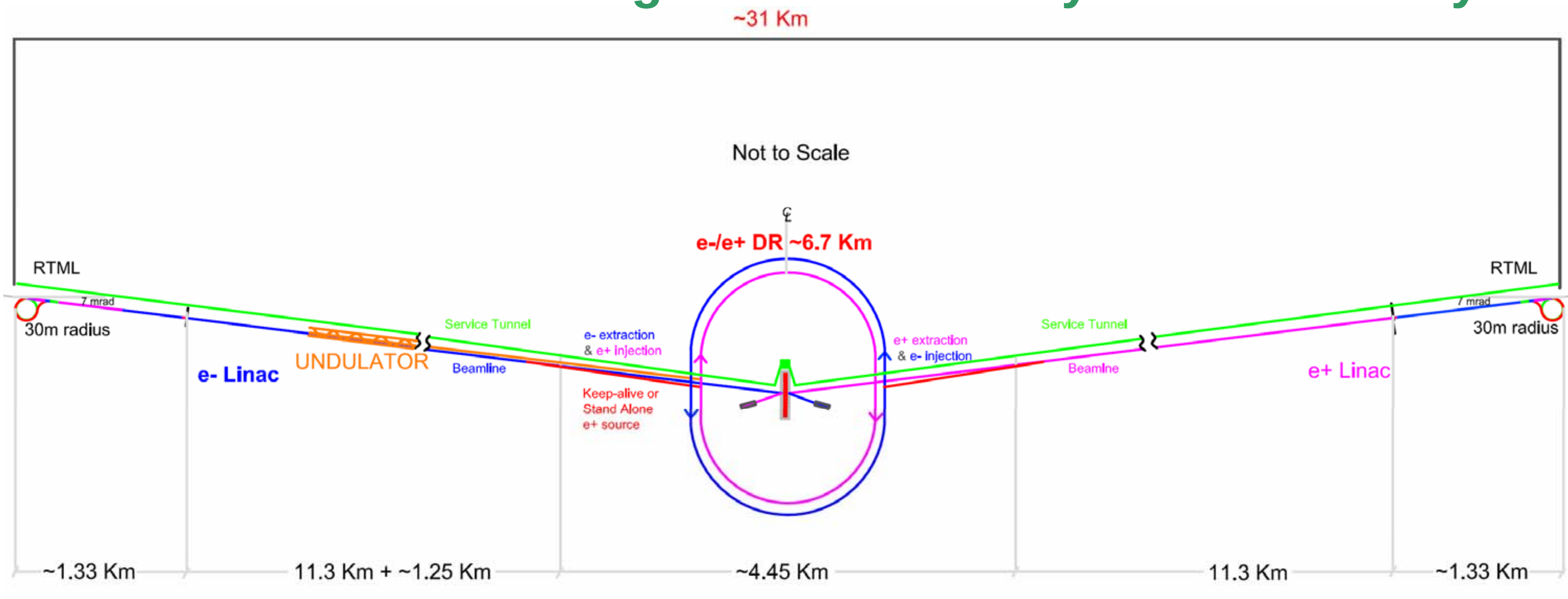


Then,

- EDR (Engineering Design Report), Site Selection, Approval, Construction...

ILC Schematic

- 11km SC linacs operating at 31.5 MV/m for 500 GeV
- Centralized injector
  - Circular damping rings for electrons and positrons
  - Undulator-based positron source
- Single IR with 14 mrad crossing angle
- Dual tunnel configuration for safety and availability

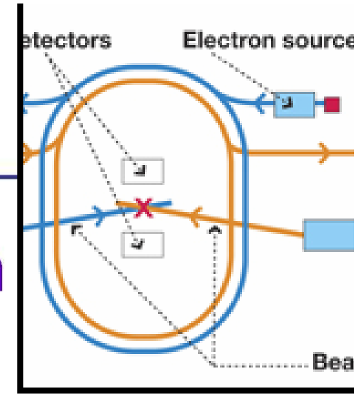


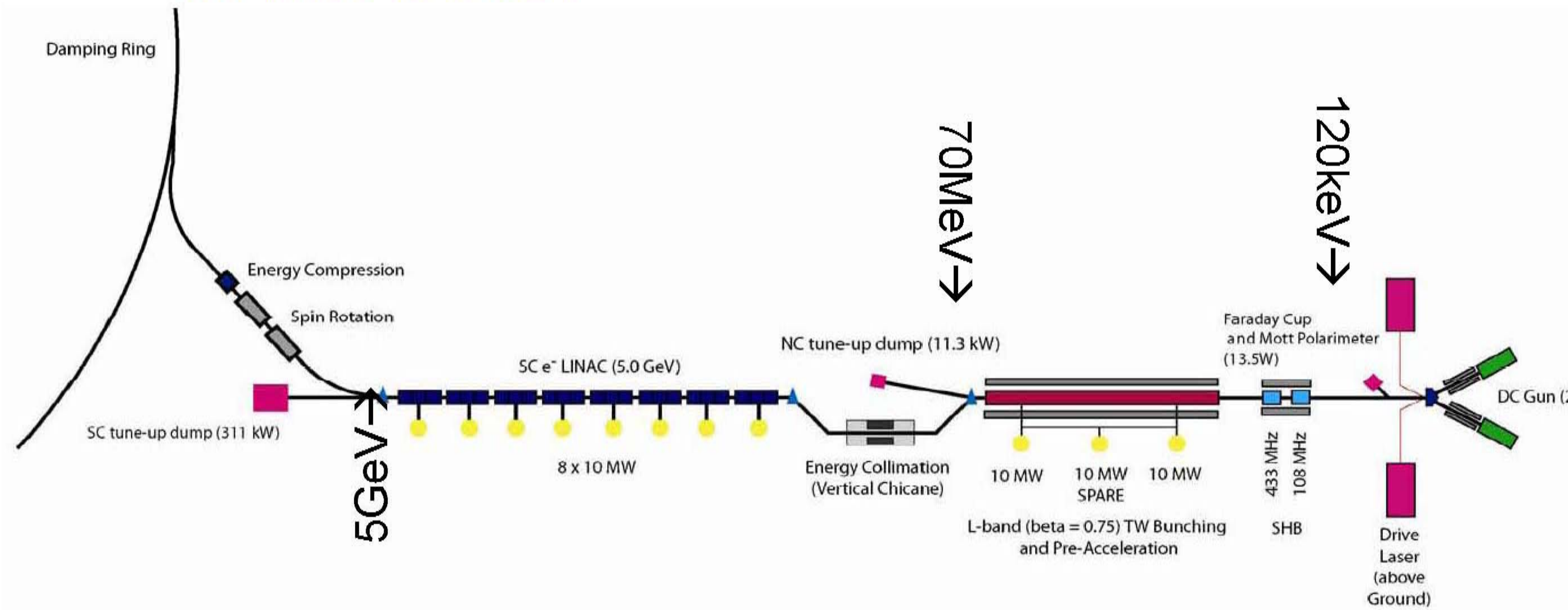
ILC Parameters

- Overall parameters
  - 2e34 peak luminosity
  - 80% collider availability → 500 fb^{-1} 1st four years
  - 9.0 mA average current during beam pulse
  - 0.95 ms beam pulse and 1.5 ms rf pulse length
  - 5 Hz operation and 230 MW power consumption
- Beam parameter ranges defined for operability
  - 1000 to 5400 bunches
  - 1e10 to 2e10 per bunch
  - Beam power between 5 and 11 MW
  - Bunch length: 200 to 500 um at IP
  - IP spots sizes: σ_x ~ 350 – 620 nm; σ_y ~ 3.5 – 9.0 nm

Electron Source

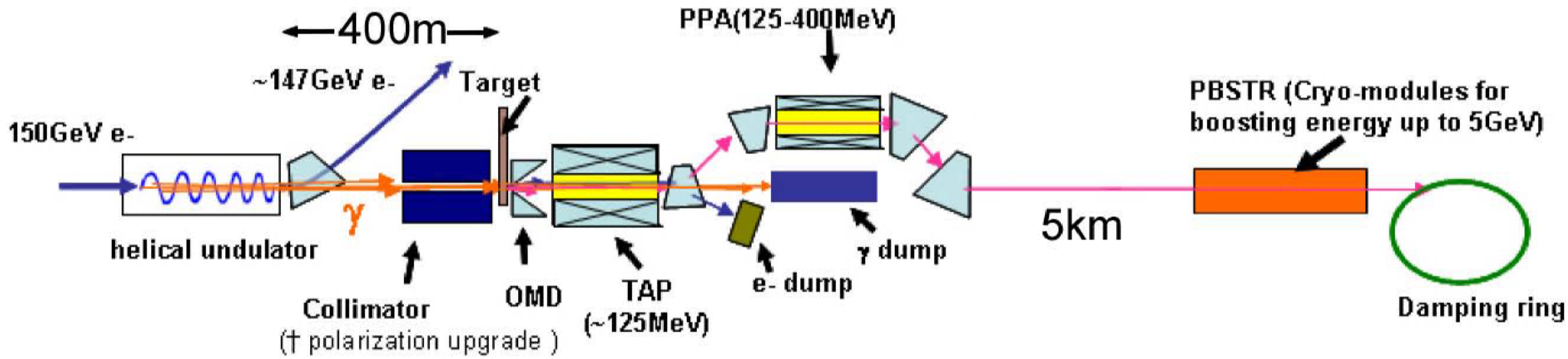
- Polarized gun (laser on surface) polarization > 80%
- SHB
- NC TW L-band tapered (β=0.75→1) buncher
- SC linac to 5GeV



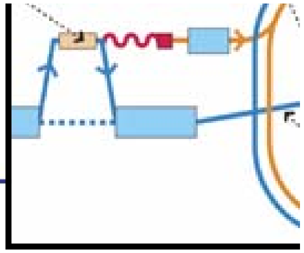


Positron Source

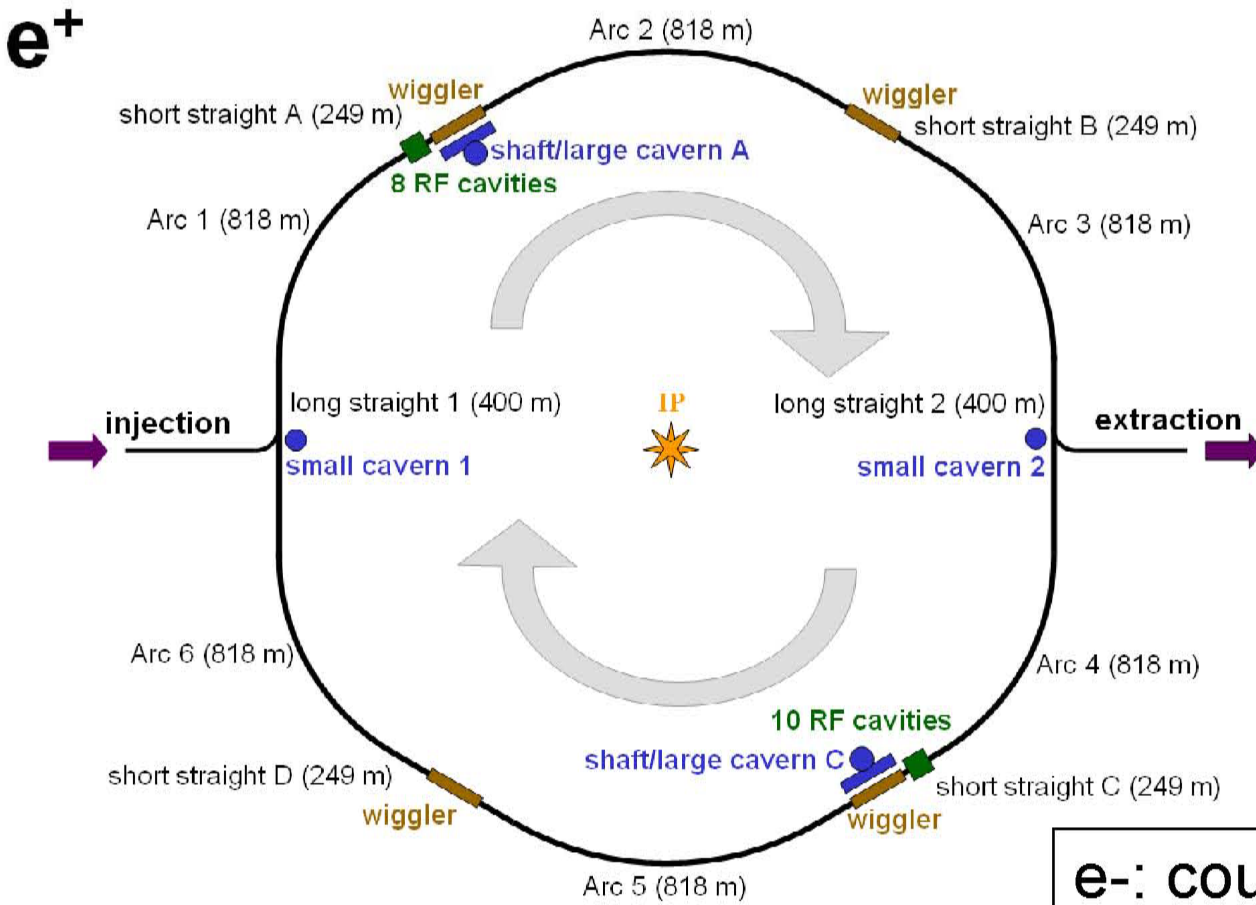
- Undulator scheme
  - **Electron beam at 150GeV**



  - **Undulator**
    - Helical, superconducting
    - length ~100m (~200m for polarized e+)
    - K=0.92, λ=1.15cm, (B=0.86T)
  - **Needs `keep-alive source'**
    - 10% intensity
    - Share 5GeV linac



Damping Ring Schematic Layout



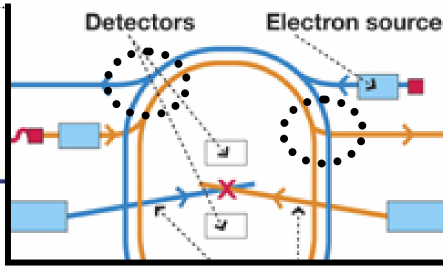
- 1e- and 1e+ ring in same tunnel
- Beam energy 5GeV
- Circumference 6.7km
- Requirements
  - **Bunch population 2×10^{10}**
  - **Number of bunches ~2600 (max ~5100)**
  - **Extracted beam**
    - Norm.emittance
      $\varepsilon\gamma x$= 8μm, $\varepsilon\gamma y$= 0.02μm
    - Bunch length 9mm
    - Energy spread 0.13%

e-: counter-clockwise

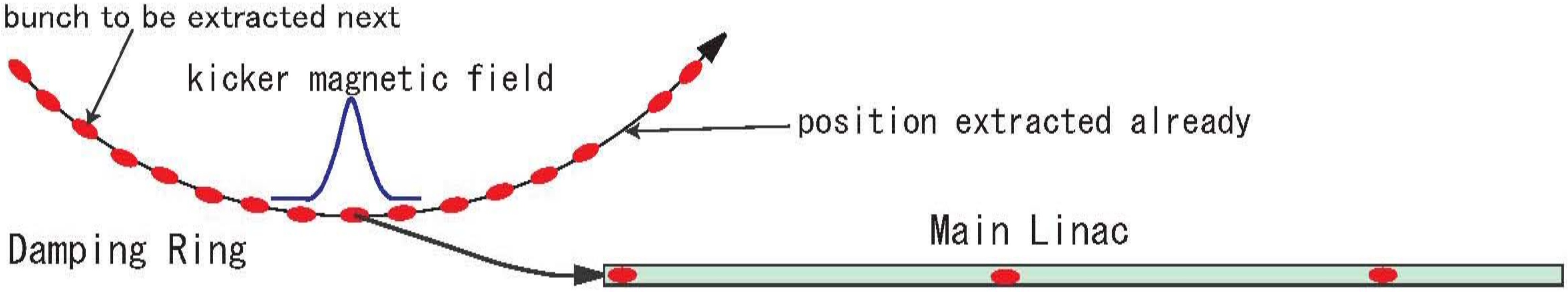
2 vertical shafts

A. Wolski

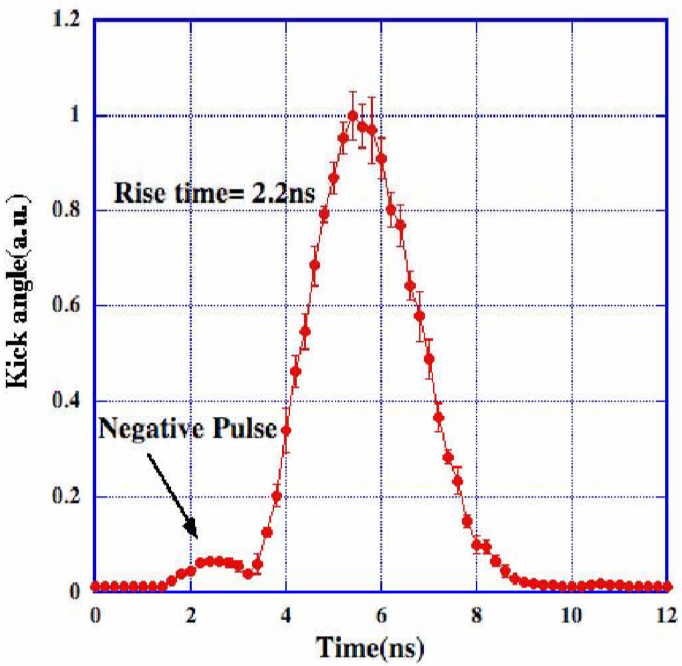
Kicker System



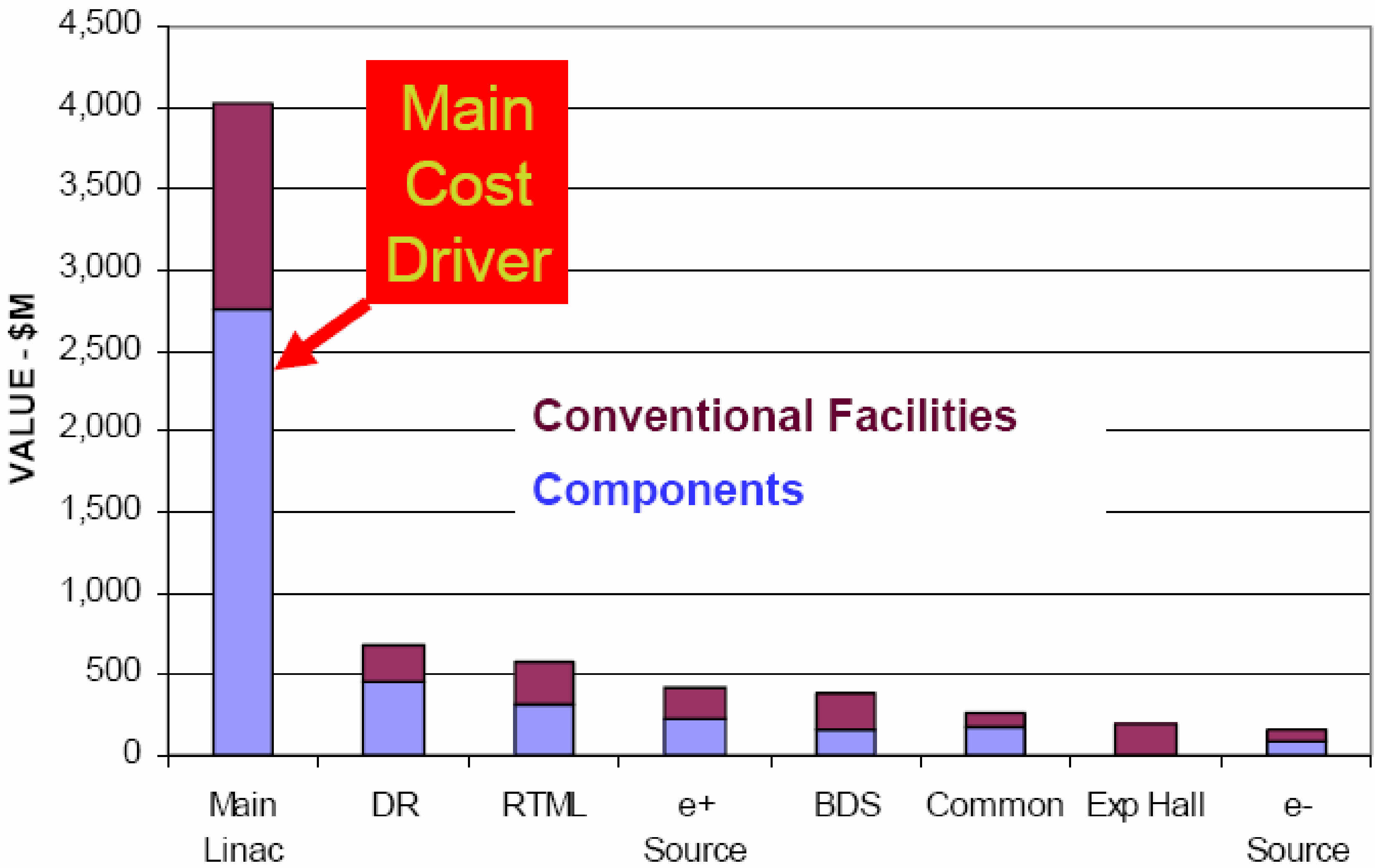
- Must extract bunches one-by-one



- Specification
  - rise, fall time < 3ns
  - rep.rate 5.5MHz
  - pulse length 1ms
  - stability < 0.1%
    (can be relaxed by feedforward)
- Fast kicker needed
  - A system with fast pulser and stripline developed at KEK. Unit test done.

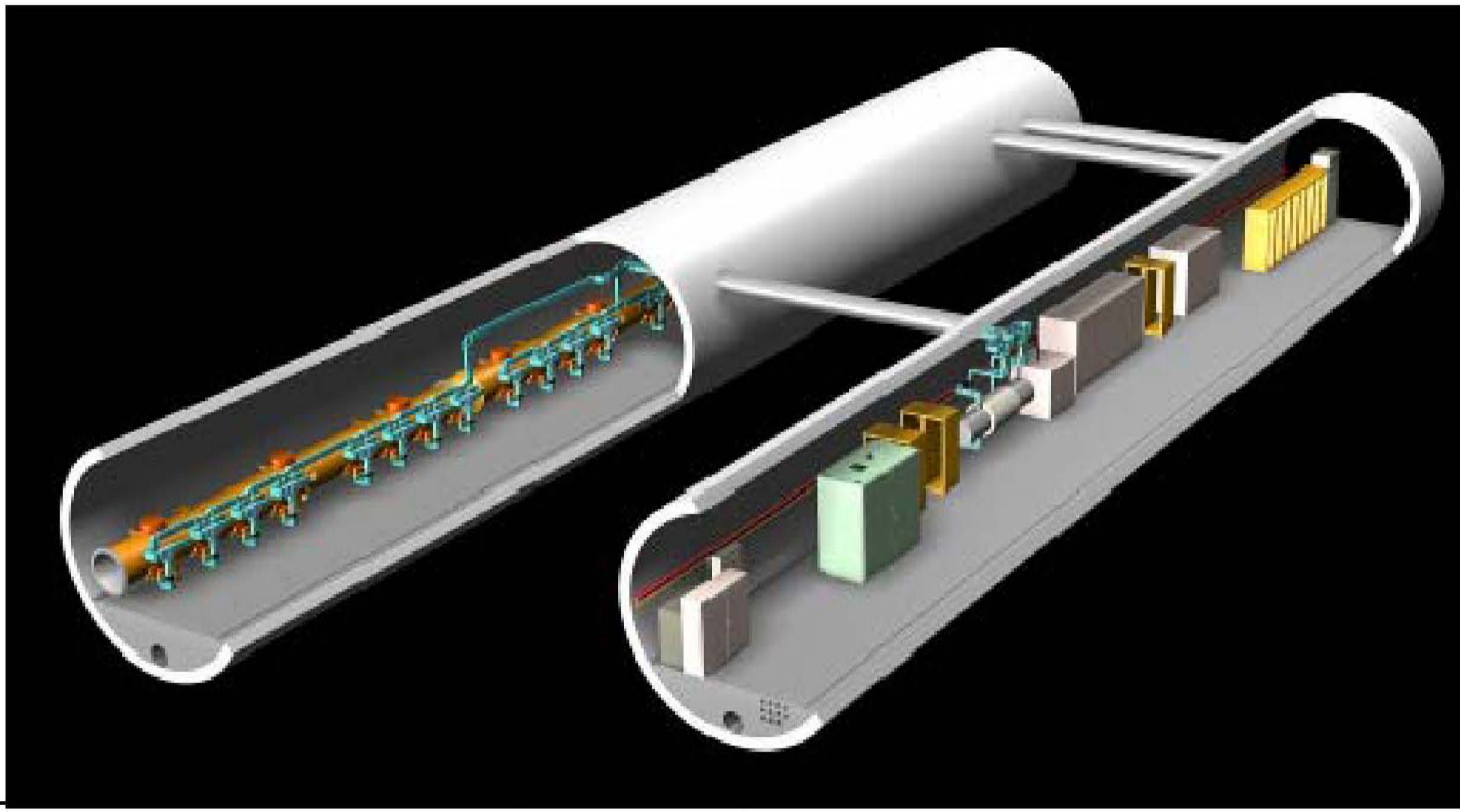


ILC Value – by Area Systems



Main Linac

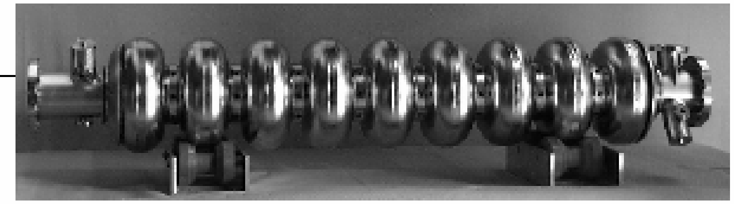
- Length ~11km x 2 (Average gradient 31.5MV/m)
- 2 tunnels (diameter 4.5m)

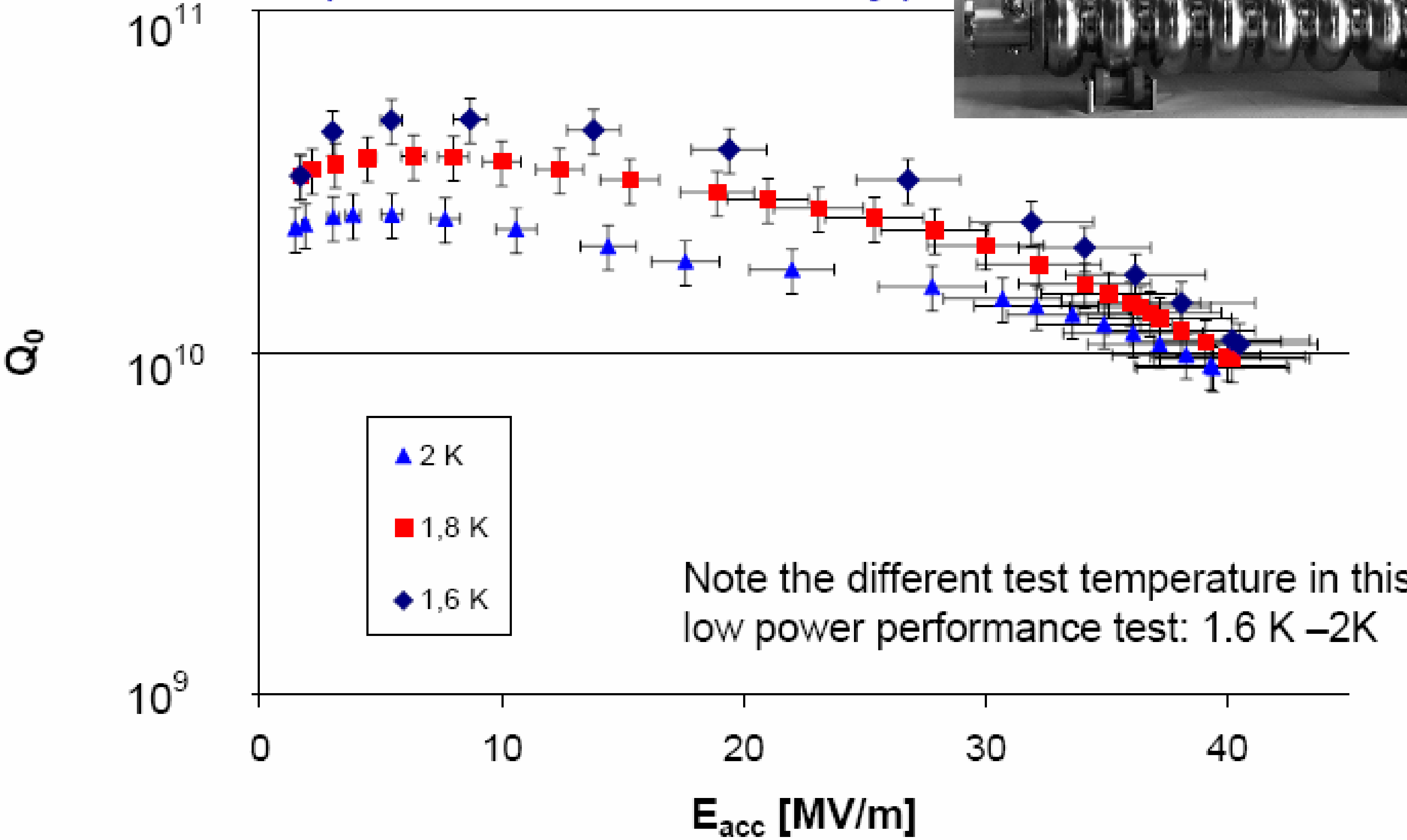


Cavities

- Several multi-cell cavities have met ILC specifications
  - In production mode yield of multi-cells is not yet sufficient
  - Single-cells have achieved much higher gradients
- Program to address this issue is being developed e.g.
  - Define goals
  - Make Results more comparable
  - Develop common set of parameters
  - Assess global capabilities
  - Synchronize efforts
- Outcome should give confidence for the technical design phase
  - Staging i.e. intermediate goals can help to account for progress
  - Overall cavity count and test capacity for R&D program is small compared to ILC numbers
- This should demonstrate an effective model of international coordination of R&D efforts

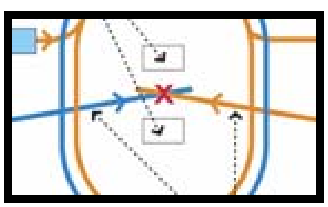
Proof-of-Principle: TESLA Nine-cell Test (ILC Baseline Cavity)

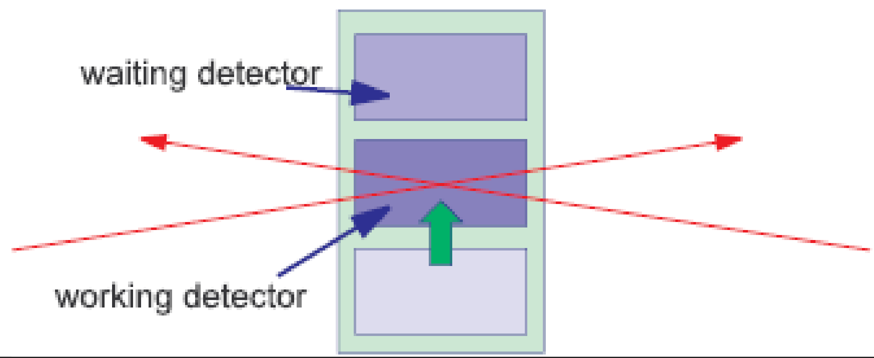




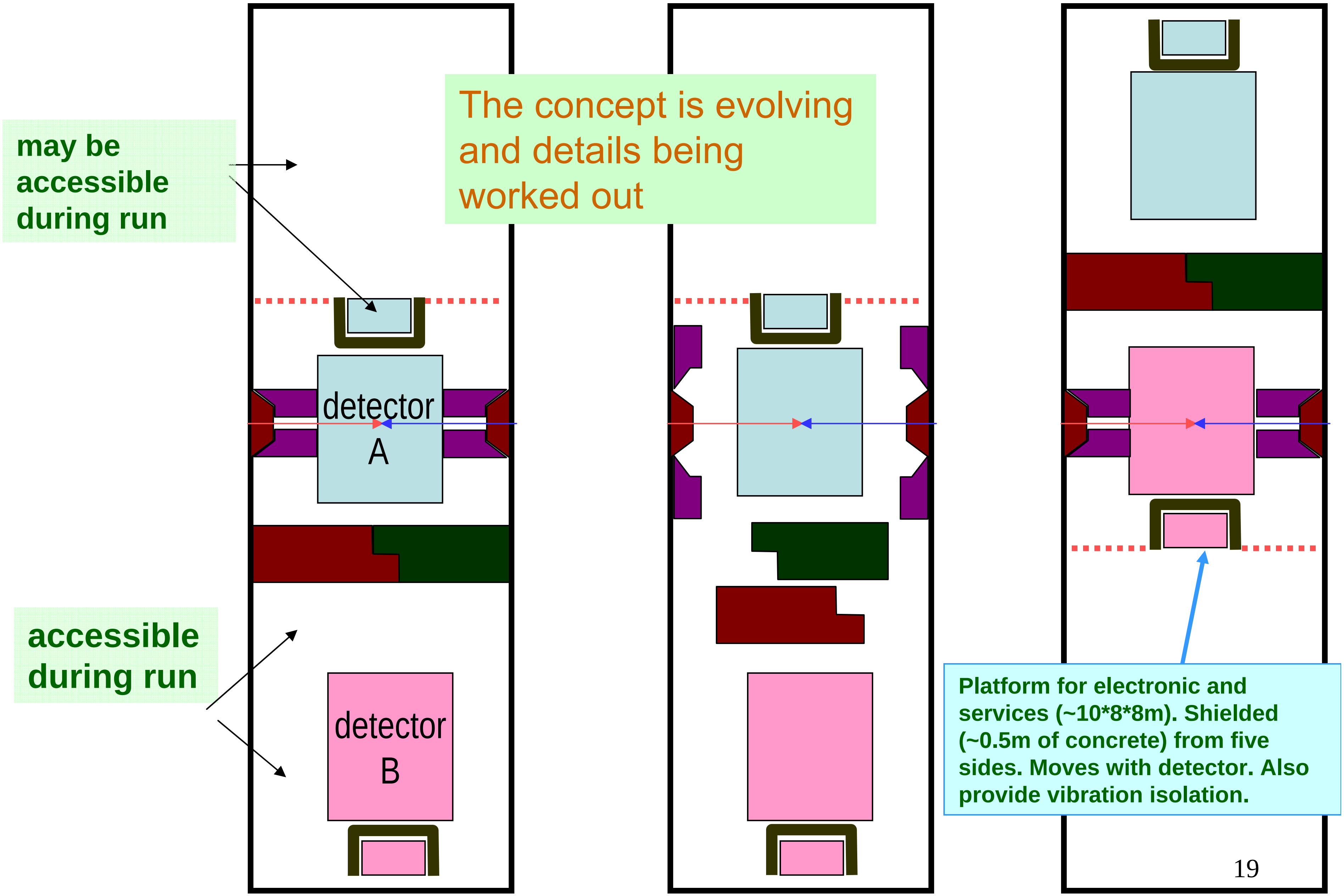
Single IR with Push-Pull Detectors

- Large cost savings compared with 2 IR
  - **~200M$ compared with 2IR with crossing angles 14+14mrad**
- Push-pull detectors
  - **Task force from WWS and GDE formed**
  - **Quick conclusion is**
    - No show-stoppers
    - But need careful design and R&D works
    - 2IR should be left as an `Alternative'





Concept of IR hall with two detectors



RDR Design & "Value" Costs

The reference design was "frozen" as of 1-Dec-06 for the purpose of producing the RDR, including costs.

It is important to recognize this is a snapshot and the design will continue to evolve, due to results of the R&D, accelerator studies and value engineering

The value costs have already been reviewed twice

- 3 day "internal review" in Dec
- ILCSC MAC review in Jan

Summary

RDR "Value" Costs

Total Value Cost (FY07)

$4.87B Shared

+

$1.78B Site Specific

+

13.0K person-years

("explicit" labor = 22.2 M person-hrs @ 1,700 hrs/yr)

Note – these costs are for the machine, and DO NOT include R&D, land, detectors, inflation, or contingency

Next Steps for the Global Design Effort

- Finalize RDR
  - Check inconsistencies
  - Possible final small changes
  - ILCSC-MAC review in ~April
  - Final form in summer
- Organization of GDE for the next step
  - Next milestone EDR (Engineering Design Report) around 2009.
  - Coordination of R&D essential
  - Engineering stage
  - To be decided in the next **couple of months**

Detectors for the ILC

Detector Requirements are defined by
- **ILC machine parameters**
- **physics goals**

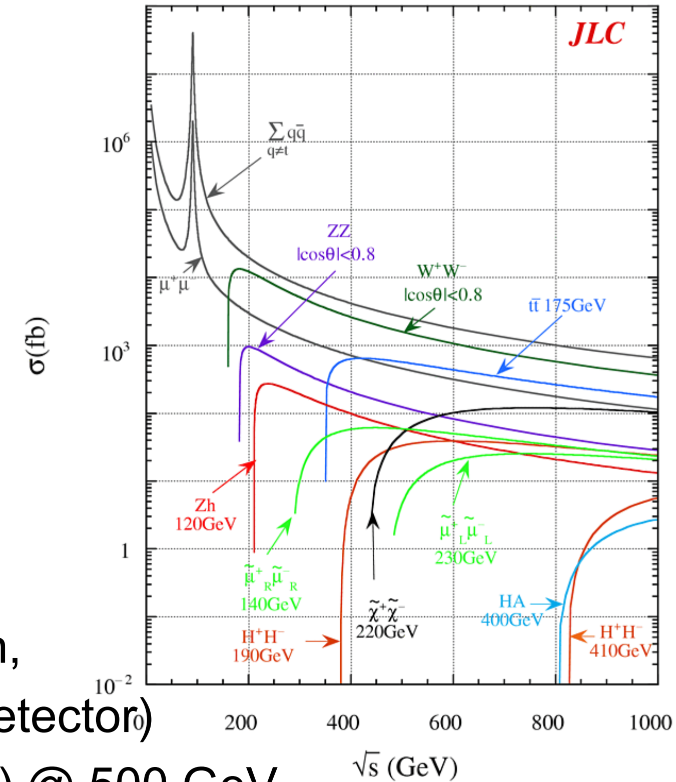
ILC creates new challenges and opportunities,
- **different in many respects from the challenges and opportunities of the LHC detectors**

Physics motivates
- Triggerless event collection (software event selection)
- Extremely precise vertexing
- Synergistic design of detectors components:
  - vertex detector, tracker, calorimeters integrated for optimal jet reconstruction
- Advanced technologies based on recent detector innovations

Detector R&D to optimize ILC opportunity is <u>critically</u> needed

Event Rates and Backgrounds

- **Event rates (Luminosity = 2 x 10^{34})**
  - $e^+e^- \to$ qq, WW, tt, HX
    - **~ 0.1 event / train**
  - $e^+e^- \to e^+e^- \gamma\gamma \to e^+e^-$ X
    - **~ 200 /train**

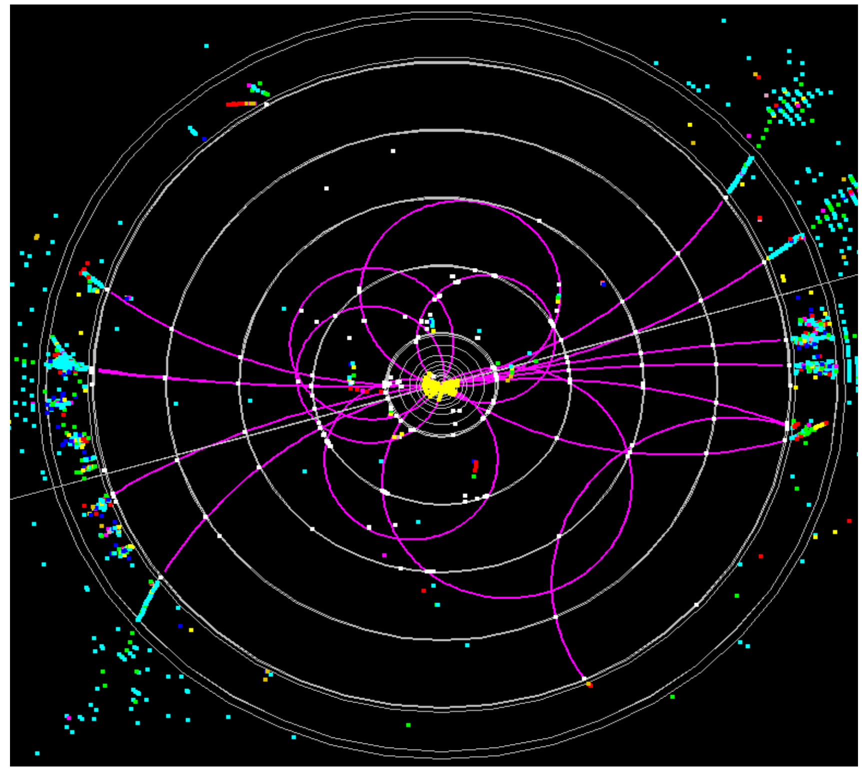


- **Background**
  - 6 x 10^{10} γ / BX (from synchrotron radiation, scatters into central detector)
  - 40,000-250,000 e^+e^- / BX (90-1000 TeV) @ 500 GeV
  - Muons: < 1 Hz/cm^2 (w/ beamline spoilers)
  - Neutrons: ~3 x 10^8 /cm^2/ yr @ 500 GeV

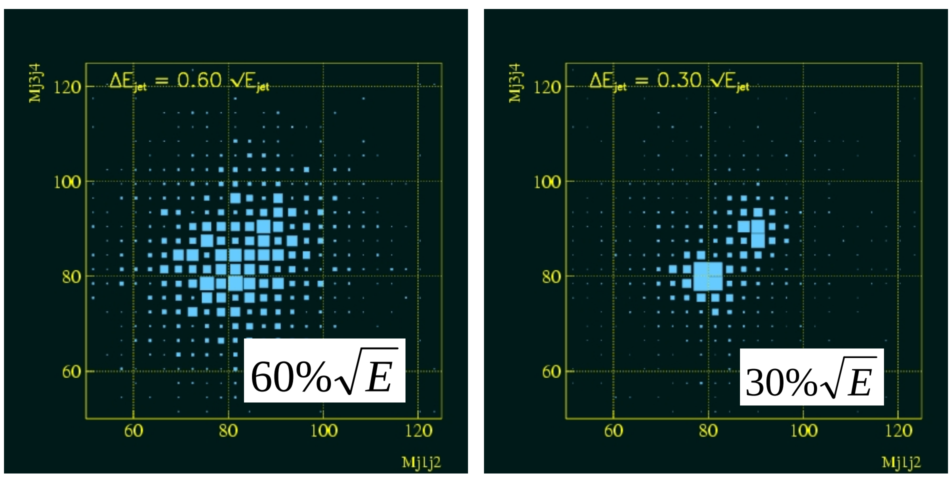
Ref: Maruyama, Snowmass 2005

Linear Collider Events

- Simple events (relative to Hadron collider) make particle level reconstruction feasible
- Heavy boson mass resolution requirement sets jet energy resolution goal

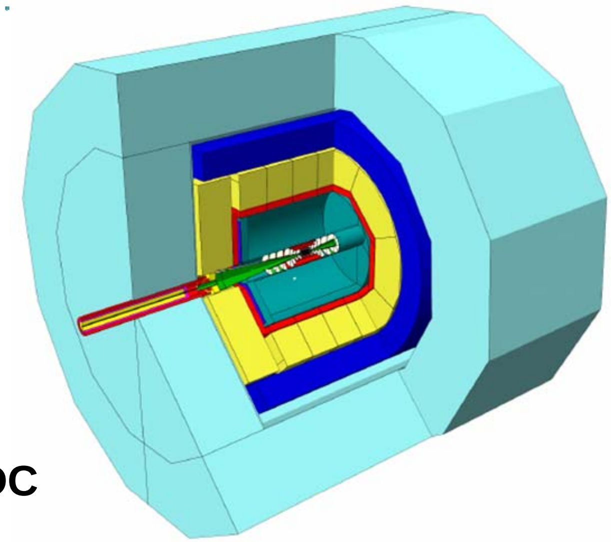


$e^+e^- \to WW\nu\bar{\nu}$, $e^+e^- \to ZZ\nu\bar{\nu}$

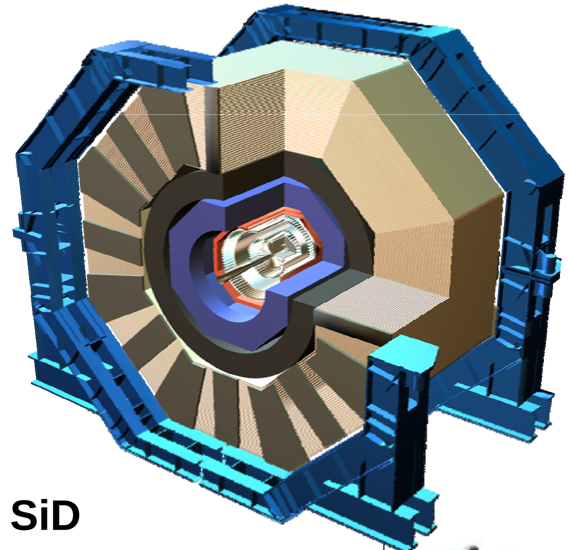


This event shows single bunch crossing in tracker, 150 bunches in the vertex detector

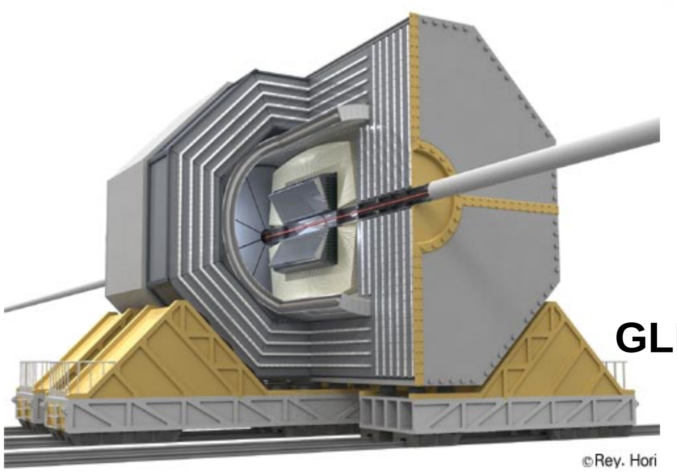
The Concepts



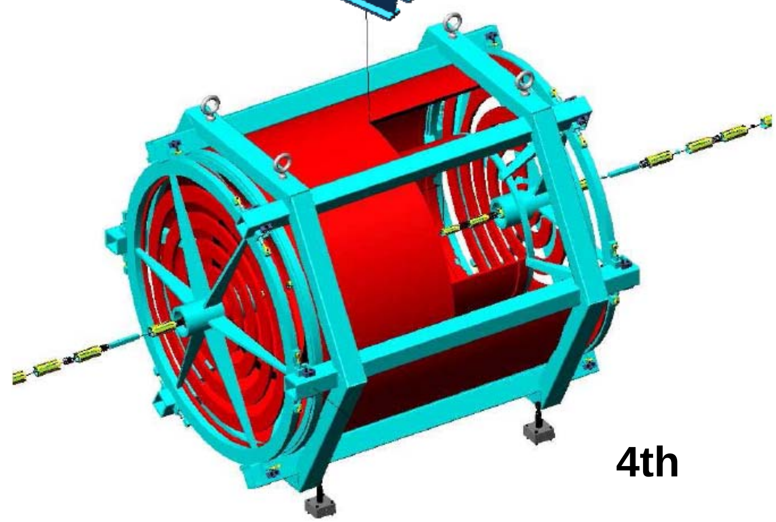
LDC



SiD

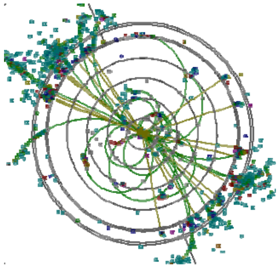


GLD



4th

See Detector Outline Documents for details - http://physics.uoregon.edu/~lc/wwstudy/concepts/

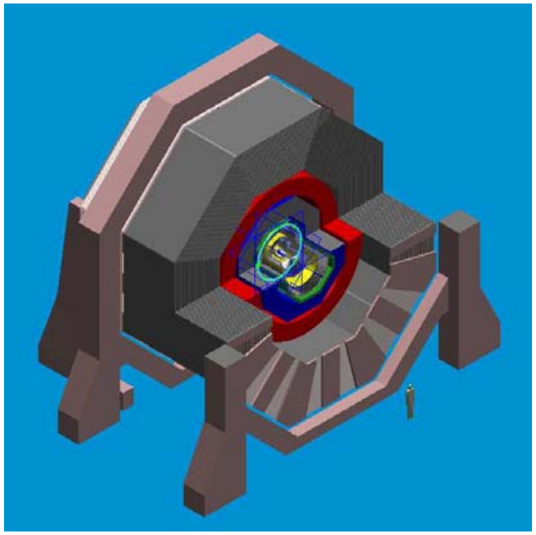


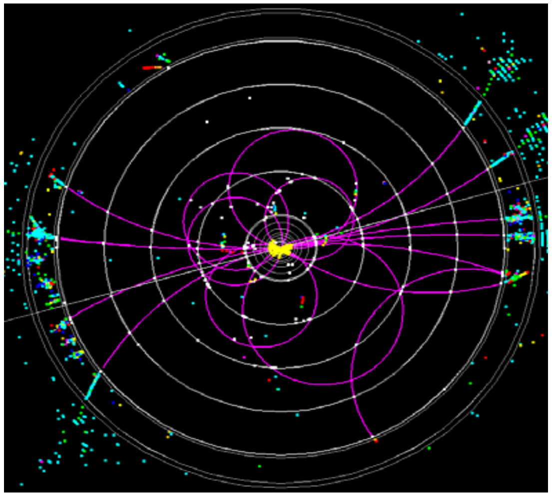
The Concepts

	Tracking	ECal Inner Radius	Solenoid	EM Cal	Hadron Cal	Other
SiD	silicon	1.27 m ↓	5 Tesla ↑	Si/W	Digital (RPC..)	Had cal inside coil
LCD	TPC gaseous	1.68 m ↓	4 Tesla ↑	Si/W	Digital or Analog	Had cal inside coil
GLD	TPC gaseous	2.1 m	3 Tesla	W/ Scin.	Pb/ Scin.	Had cal inside coil
4th	TPC gaseous			crystal	Compen-sating fiber	Double Solenoid (open mu)

SiD (the Silicon Detector)

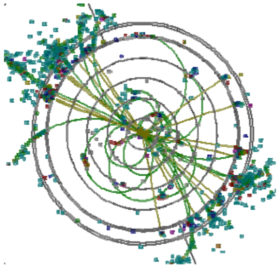
CALORIMETRY IS THE STARTING POINT IN THE SiD DESIGN





<u>assumptions</u>

- Particle Flow Calorimetry will result in the best possible performance
- Silicon/tungsten is the best approach for the EM calorimeter
- Silicon delivers robust tracking with excellent resolution in smaller volume
- Large B field desirable to contain electron-positron pairs in beamline
- Cost is constrained



Detector R&D Required

- Performance requirements for ILC Detector exceed state-of-the-art
  - Calorimeters with ~100 million cells
    - Jet resolution goal ~ 30%/ $\sqrt{E}$
  - Pixel Vertex Detector with ~10^9 $\leq$20 μm pixels
    - Impact parameter resolution 5μm $\oplus$ 10μm/(p $\sin^{3/2}\theta$)
    - Sensitivity to full 1 msec bunchtrain
  - Tracking resolution $\sigma(1/p) \leq 5\times10^{-5}$/GeV
    - TPC
    - Silicon microstrips
  - High Field Solenoid ~ 5 Tesla
  - High quality forward tracking systems
  - Triggerless readout

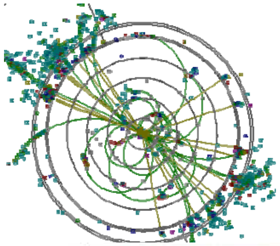
- R&D Essential

DISCOVERY OPPORTUNITY IS GREAT

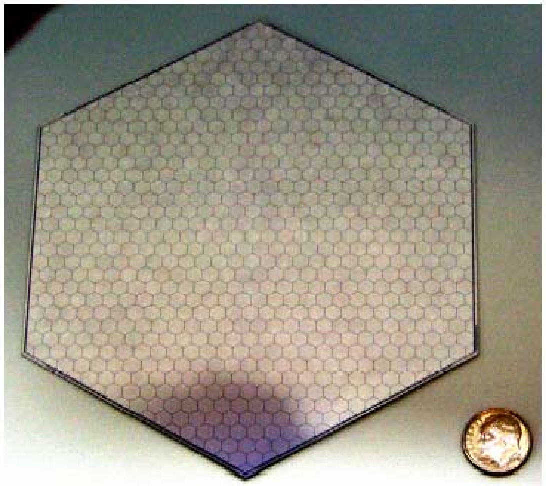
- limited by detector performance

small cross sections/significant backgrounds

- advances different from LHC required



Example of ILC Detector R&D: Silicon/Tungsten EM Calorimetry



SLAC/Oregon/BNL/Davis/Annecy

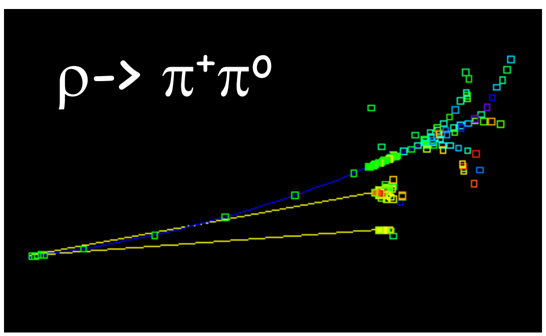
Dense, fine grained silicon tungsten calorimeter (builds on SLC/LEP experience)

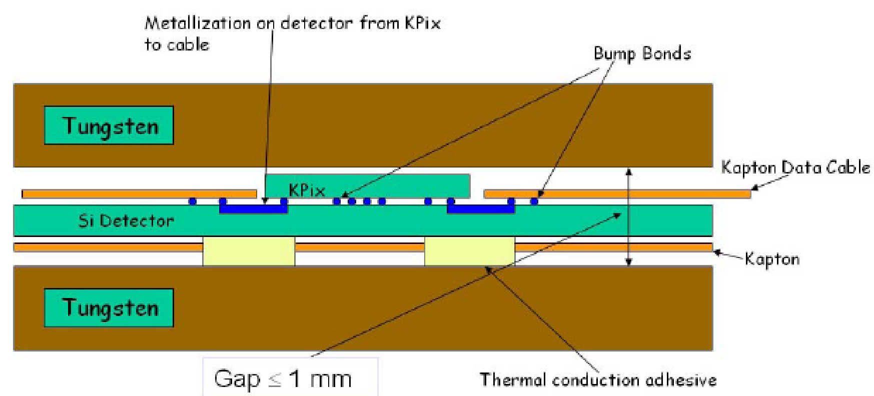
- **Pads: 12 mm^2 to match Moliere radius (~ R_m/4)**
- **Each six inch wafer read out by one chip**
- **< 1% crosstalk**

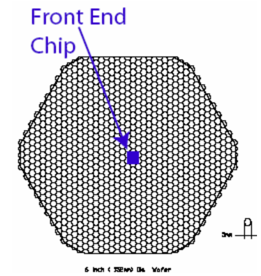
Electronics design

- **Noise < 2000 electrons**
- **Single MIP tagging (S/N ~ 7)**
- **Dynamically switchable feedback capacitor scheme achieves required dynamic range: 0.1-2500 MIPs – 4 deep storage/bunch train**

Passive cooling – conduction in W to edge



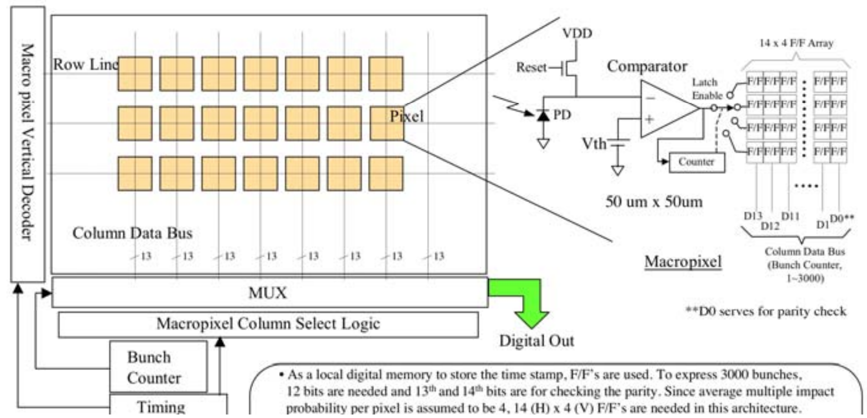


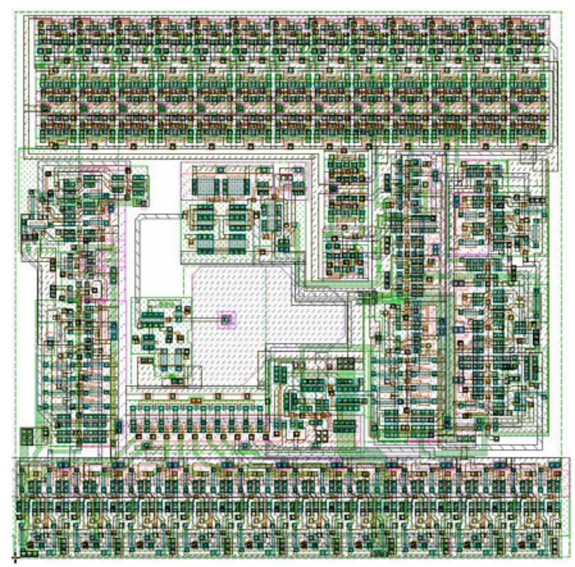


Example of ILC Detector R&D: Chronopixel (CMOS)

Yale/Oregon/Sarnoff

- Completed Macropixel design last year
  - ⇒ Key feature – stored hit times (4 deep)
  - 645 transistors
  - Spice simulation verified design
  - TSMC 0.18 μm ⇒ ~50 μm pixel
    - Epi-layer only 7 μm
    - Talking to JAZZ (15 μm epi-layer)
  - 90 nm ⇒ 20-25 μm pixel
- January, 2007
  - Completed design – Chronopixel
    - **2 buffers, with calibration**
  - Deliverable – tape for foundry
- Near Future (dependent on funding)
  - Fab 50 μm Chronopixel array
    - Demonstrate performance
  - Then, 10-15 μm pixel (45 nm tech.)

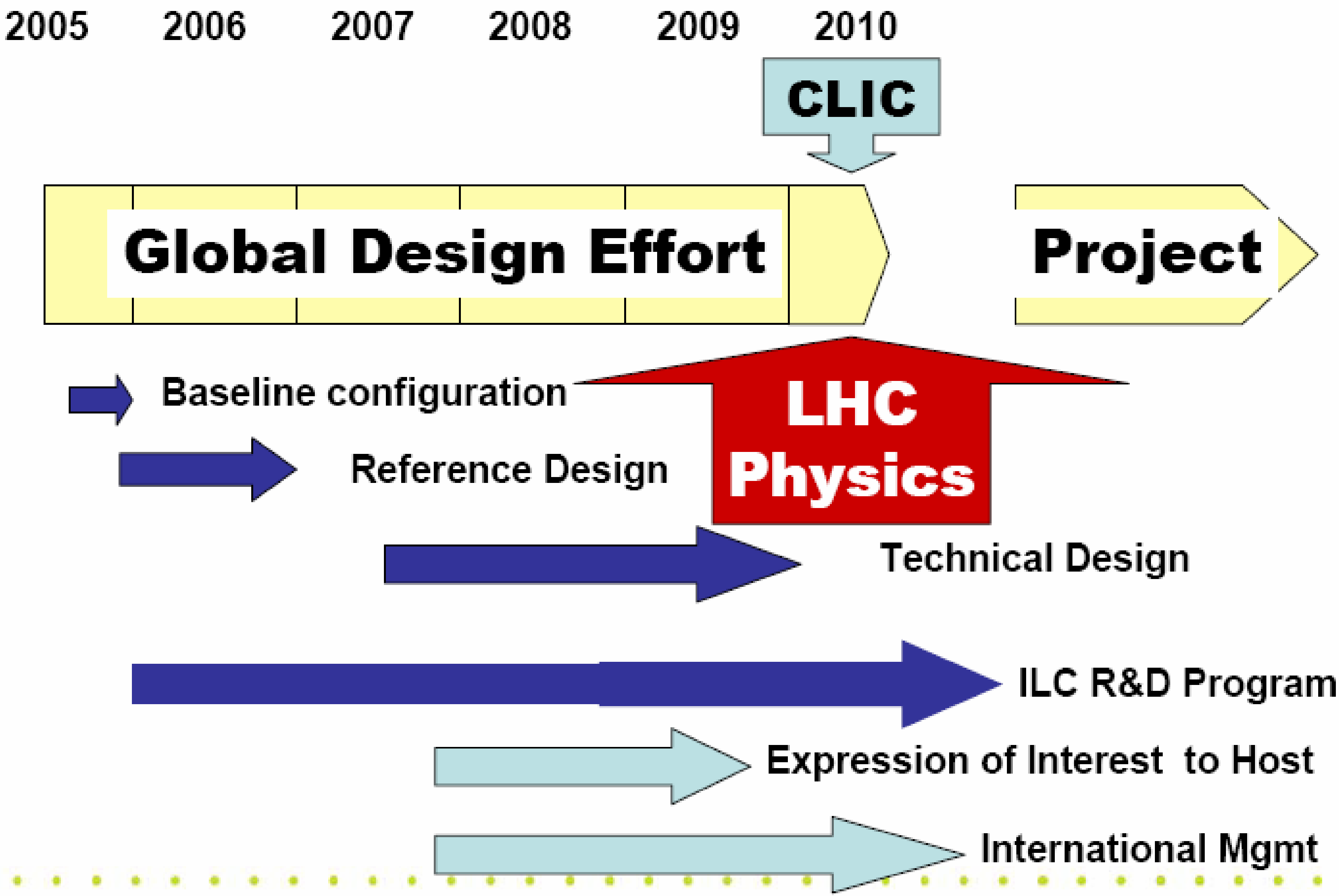


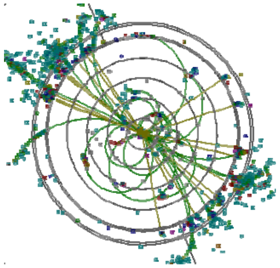


563 Transistors (2 buffers +calibration)

50 μm x 50 μm

The GDE Plan and Schedule



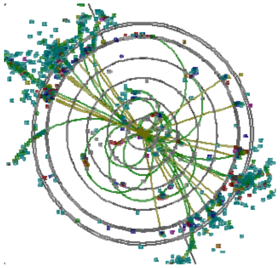


Detector Roadmap (the future)

<u>DETECTOR ROADMAP PROPOSAL</u>
<u>UNDER DISCUSSION</u> (not yet implemented)

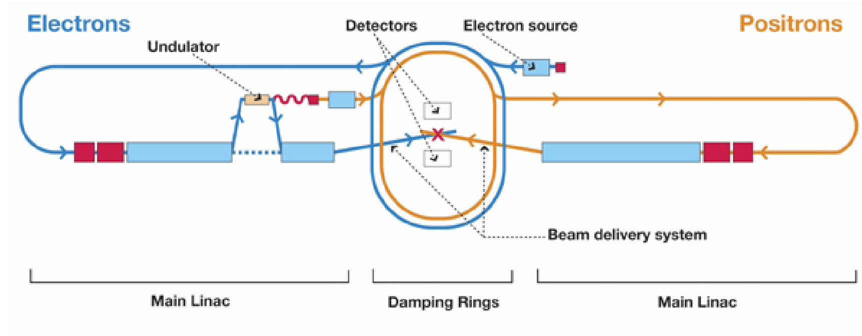
- **2008 – Two detector concepts selected to initiate engineering design effort**
- **2009-2011 – Development of two technical designs, produce first engineering design report for the overall detectors, which will be followed by additional volumes (detailed technical reports on subsystems)**
  Detector R&D continued

Presented by WWS at ILCSC meeting in Valencia, Nov 11, 2006
and again at Beijing ILCSC meeting February 8, 2007



CONCLUSIONS

- The last 2 years have produced a reference design with a cost estimate for the ILC

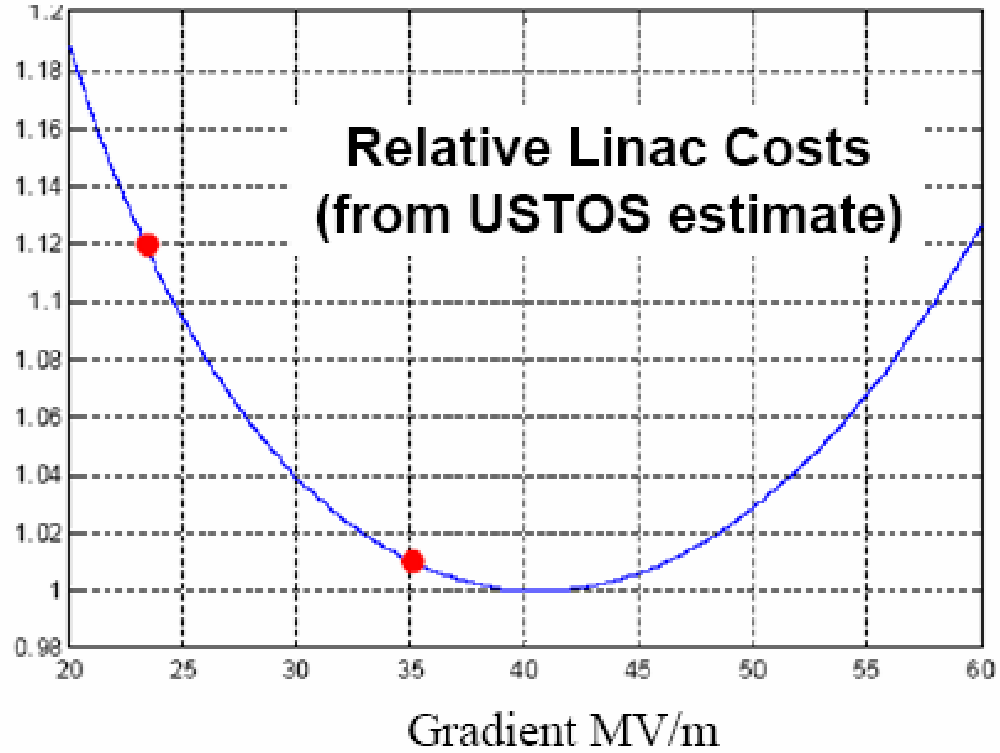


- Physics and Detector community prepares in parallel with the Global Design Effort for the experimental program
- Next steps for machine and detectors – Engineering Design completed in ~2010, and construction start soon after
- Thank you – K. Yokoya, T. Raubenheimer, A. Seryei, L. Lilje G. Dugan, B. Barish, and my colleagues in the World Wide Study

- **backup**

Main Linac Gradient Choice

- Balance between cost per unit length of linac, the available technology, and the cryogenic costs
- Optimum is fairly flat and depends on details of technology
- Current cavities have optimum around 25 MV/m



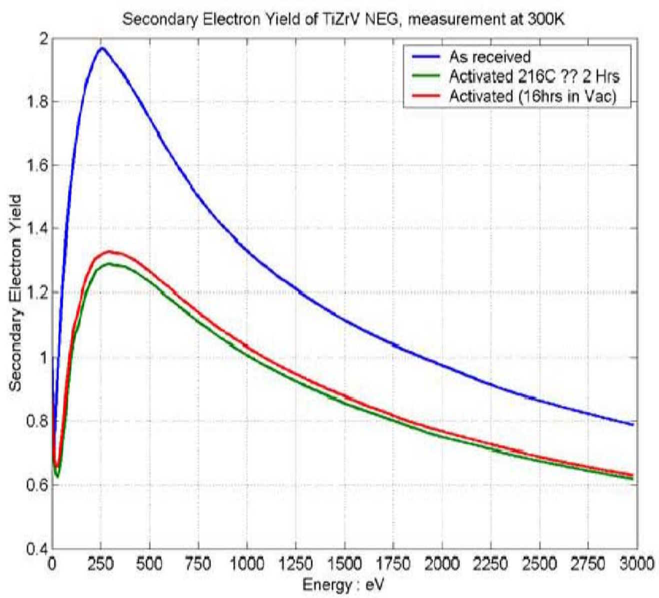
	Cavity type	Qualified gradient MV/m	Operational gradient MV/m	Length Km	Energy GeV
initial	TESLA	35	31.5	10.6	250
upgrade	LL	40	36.0	+9.3	500

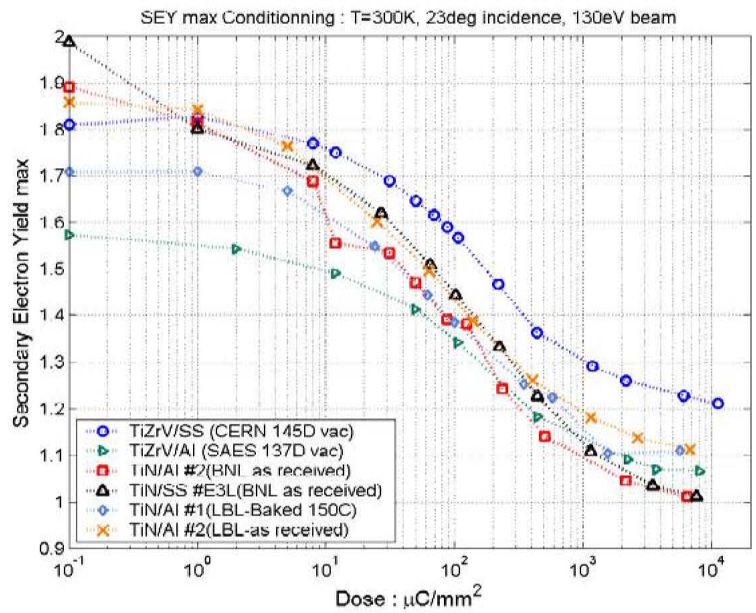
Design Parameters

Center-of-mass energy	500 GeV
Peak luminosity	2×10^{34} $\mathrm{cm}^{-2}\mathrm{s}^{-1}$
Availability	75%
Repetition rate	5 Hz
Duty cycle	0.005%
Main linacs	
Average accelerating gradient in cavities	31.5 MV/m
Length of each main linac	11 km
Beam pulse length	1 ms
Average beam current in pulse	9.0 mA
Damping rings	
Beam energy	5 GeV
Circumference	6.7 km
Length of beam delivery section (2 beams)	4.5 km
Total site length	31 km
Total site power consumption	230 MW
Total installed power	~300 MW

Electron Cloud

- Secondary electrons attracted by positron beam causes an instability
- Max of SEY (Secondary Electron Yield) should be < 1.1
- Possible cures
  - **Coating with NEG**
  - **Solenoids in free field region**
  - **Grooves on the chamber wall**
  - **Clearing electrode**



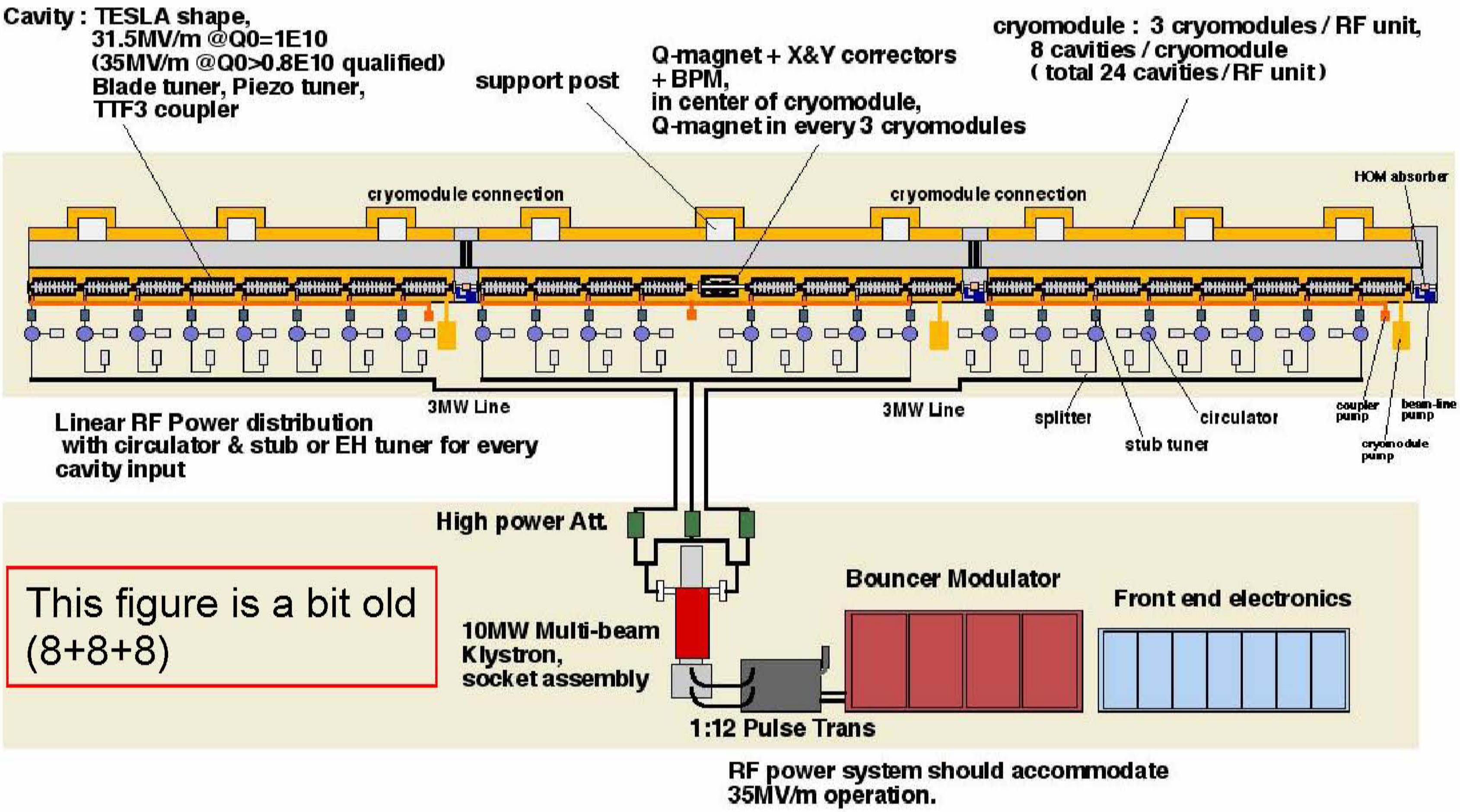


Fast Ion Instability

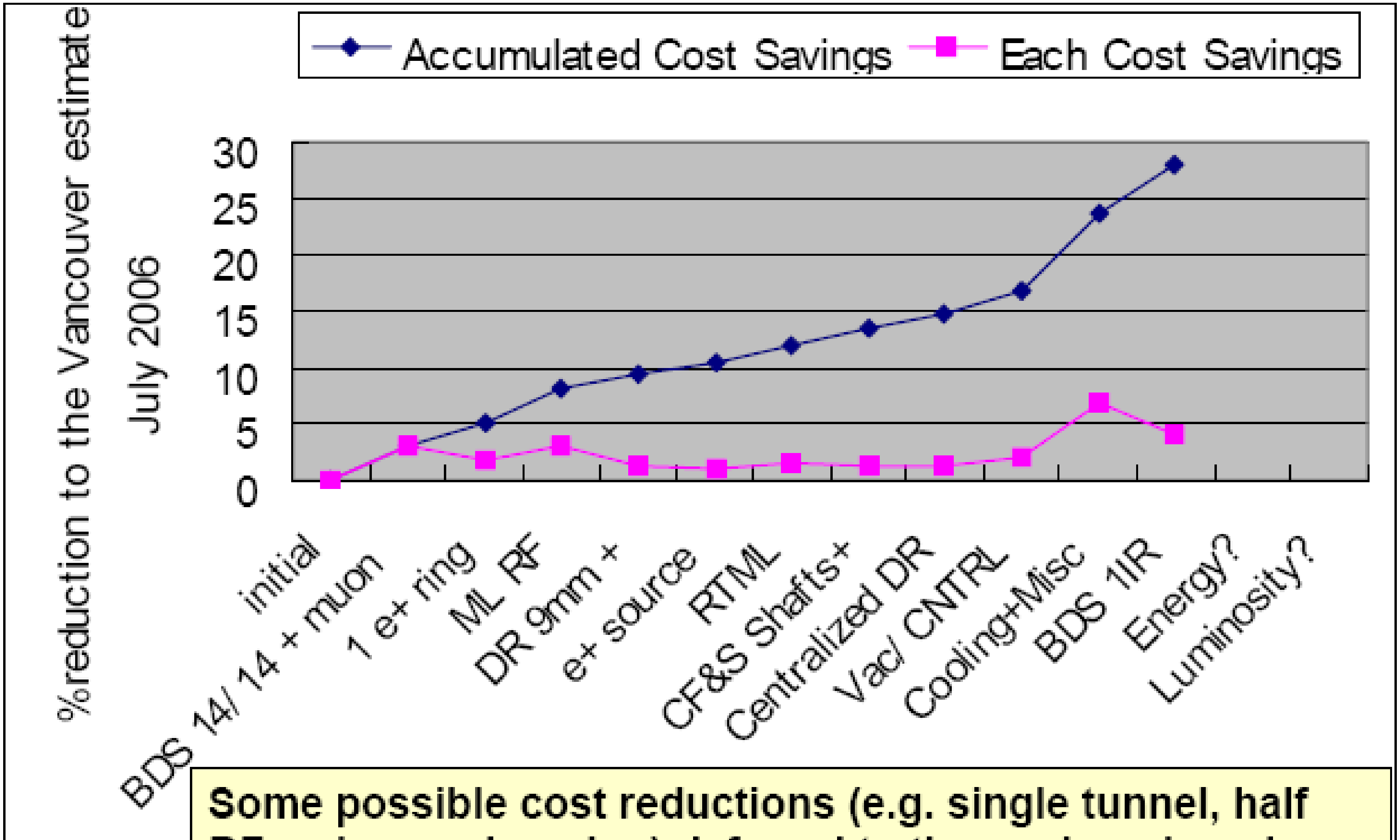
- Ions created from ionization by electrons are attracted by electrons and cause instability
- Cures
  - **Low vacuum pressure ~1nTor**
  - **Bunch-by-bunch feedback system**
  - **Gaps between bunch trains**

Linac Unit

- **Bouncer type modulator**
- **Multibeam klystron (10 MW 1.6 ms)**

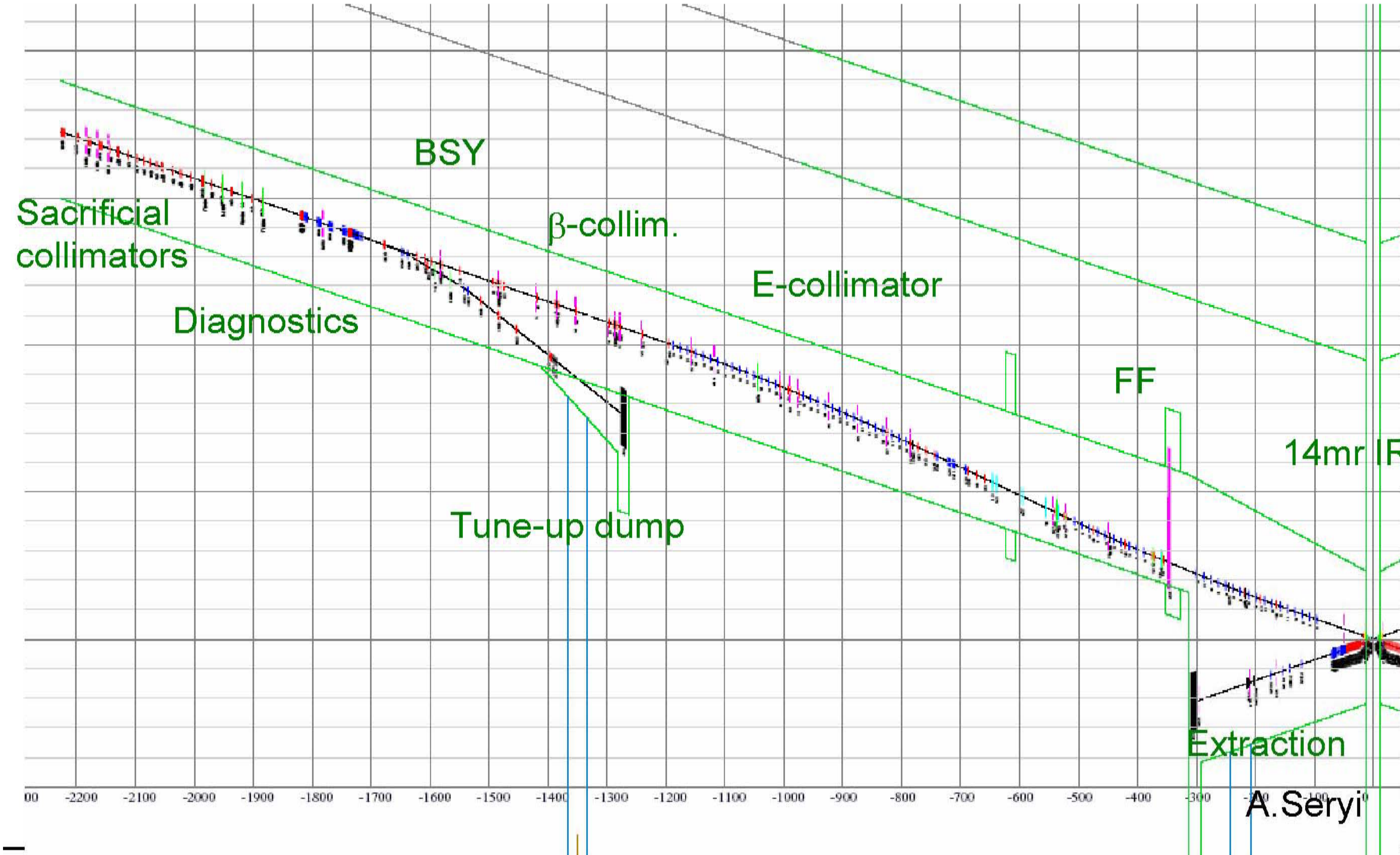


Evolving Design → Cost Reductions



Some possible cost reductions (e.g. single tunnel, half RF, value engineering) deferred to the engineering phase

BDS with single IR

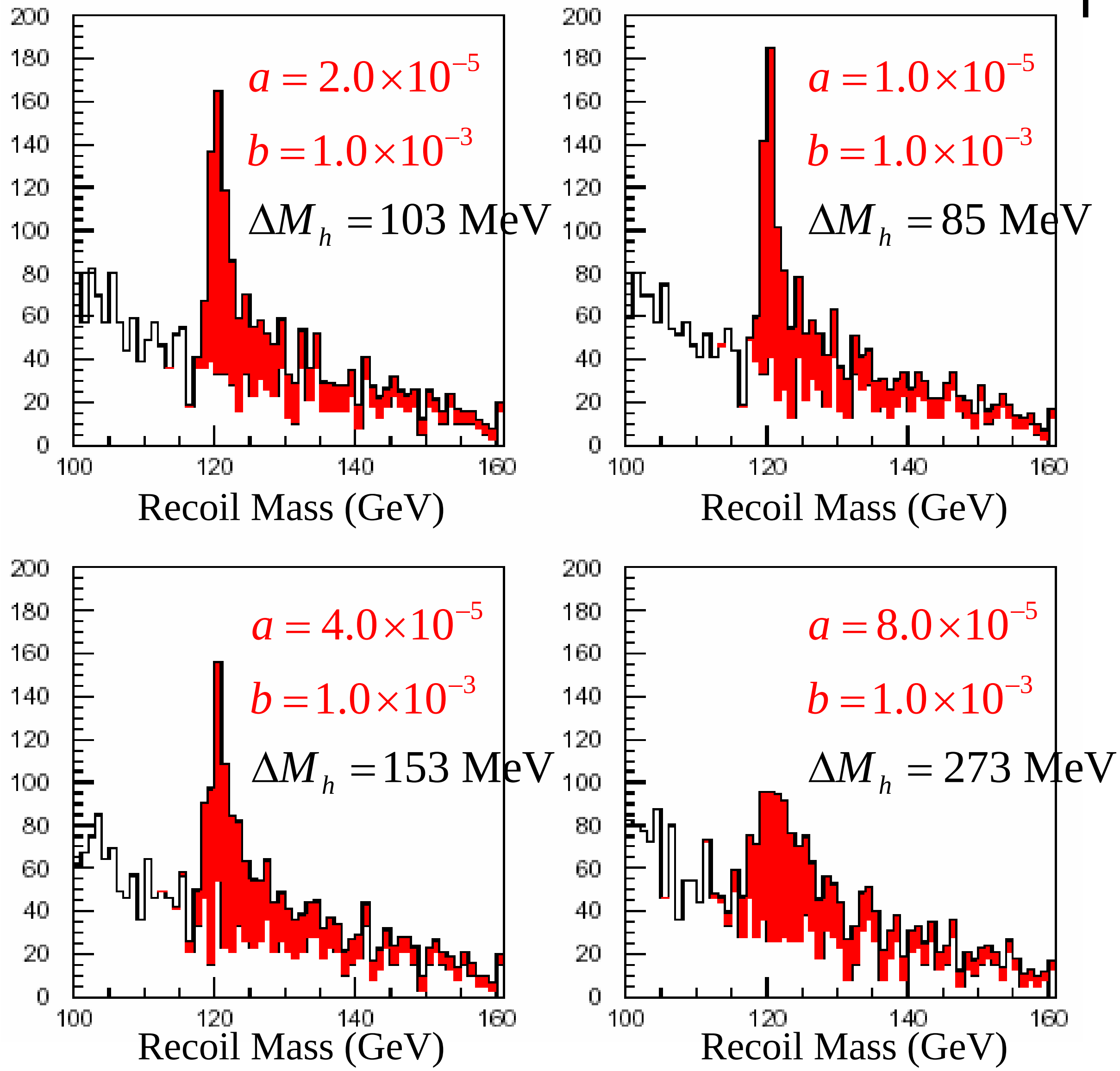


Effect of Tracking Resolution

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

$$\sqrt{s} = 350\, GeV$$
$$L = 500\ fb^{-1}$$

$$\frac{\delta p_t}{p_t^2} = a \oplus \frac{b}{p_t \sin\theta}$$



S0 Program

- Task Force S0 created a report for the R&D program to establish 35 MV/m (vert.test)
  - Tight-loop process
    repeated surface treatment with small number of cavities including exchange of cavities among Asia-US-Europe in 2007
  - Production-like process
    many cavities with the same recipe
- Time line
  - decide cavity type by ~mid 2008
  - Establish high yield by ~mid 2009
- Task Force S1 for establishing 31.5MV/m (average gradient)