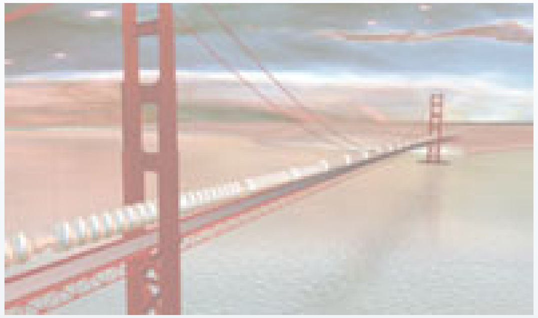
International Linear Collider Status and Prospects

Felix Sefkow
DESY – FLC –

DESY seminar, April 19, 2005

2005 INTERNATIONAL
LINEAR COLLIDER WORKSHOP

Stanford, California, USA 18-22 March, 2005



LCWS History

(Organized by WWS)

1. **Saariselka, Finland** - September 9 - 14, 1991
2. **Hawaii, USA** - April 26 - 30, 1993
3. **Morioka, Japan** - September 8 - 12, 1995
4. **Sitges, Spain** - April 28 - May 5, 1999
5. **Fermilab, USA** - October 24-28, 2000
6. **Jeju Island, Korea** - August 26-30, 2002
7. **Paris, France** - April 19-23, 2004
8. **Stanford, USA** - March 17-23, 2005 *~ 400 particpants*

Next: Feb /Mar 2006 in India

International activities on LC physics/detector are intensifying :

Every 2yrs → Every 1.5 yrs → Every <1 yr

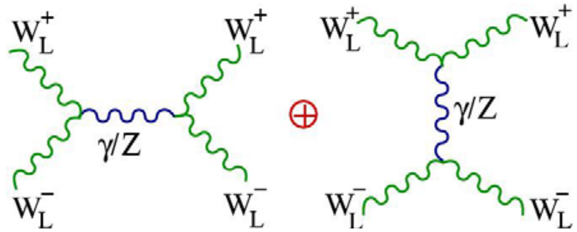
Plan

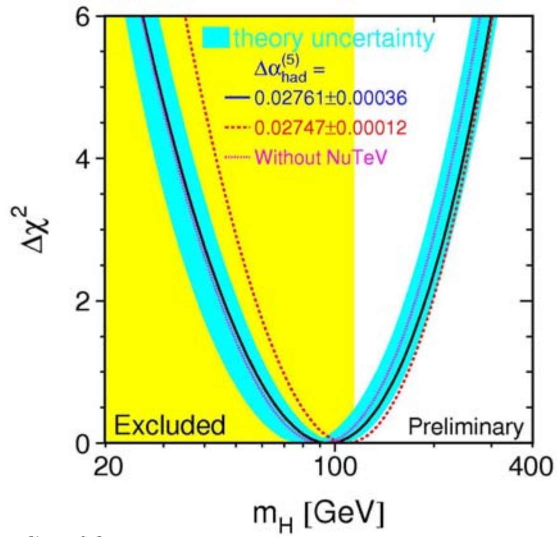
1. Physics directions
2. Organization and timelines
3. Machine issues
4. Detector concepts
5. Detector R&D

1. Physics

New physics nearby

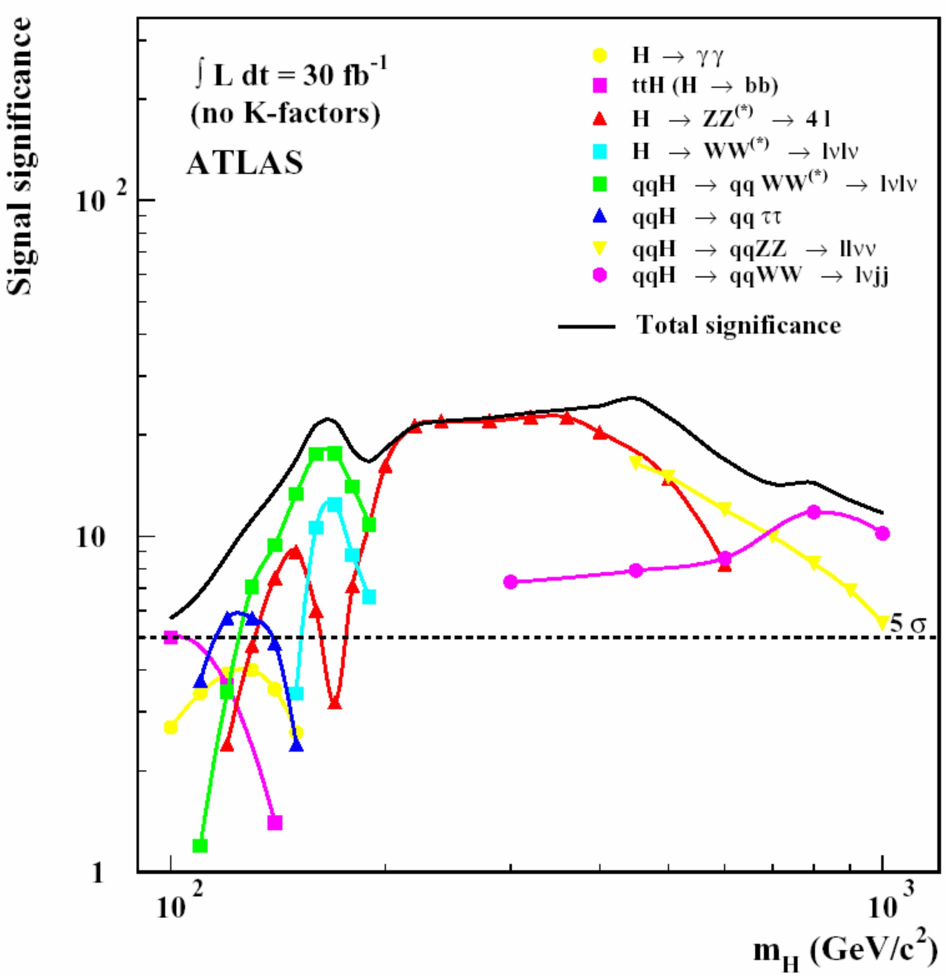
- We expect answers on fundamental questions at the TeV scale
  - Origin of particle masses, electro-weak symmetry breaking, grand unification, dark matter, …
- For theoretical reasons:
  - SM w/o Higgs is inconsistent above ~ 1.3 TeV
  - Fine-tuning problem if nothing between m_W and m_{Planck} – must be near m_W to be relevant
- For experimental reasons
  - Electroweak precision data want Higgs – or "something in the loops" - below 250 GeV
  - Astrophysics wants a dark matter particle with a few 100 GeV





Higgs discovery

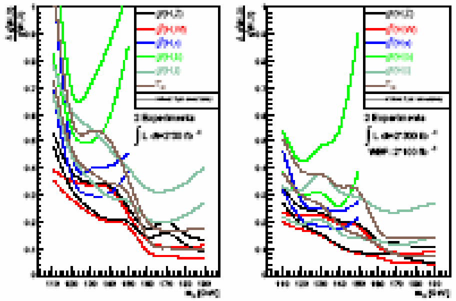
- At the LHC after about 1 year (2008+)
- Measure some properties
  - Mass
  - Ratios of couplings
- 1 year LHC = 1 day LC
  - LC can discover Higgs-like particle even if rate is 1/100 of SM



Higgs couplings: LHC reach

In principle, at LHC you can get only ratios of BRs — where do these results come from?

To exctract absolute coupling values from LHC data, you need assumptions.



Assumptions in these plots:

1. $g_{HWW} \leq 1.05 \times g_{HWW}^{\mathrm{SM}}$
2. The observed rates agree with SM predictions.

OK, but:

- $g_{HWW} \leq g_{HWW}^{\mathrm{SM}}$ valid only in weakly-interacting models (unitarity)
- The observed rate in WBF might turn out to be significantly below (or even above) SM
- The interesting physics is in exactly this $5\,\%$ margin (heavy vector bosons, Higgs triplets, . . .)

⇒ These assumptions need to be tested *before* we draw conclusions from measurements.

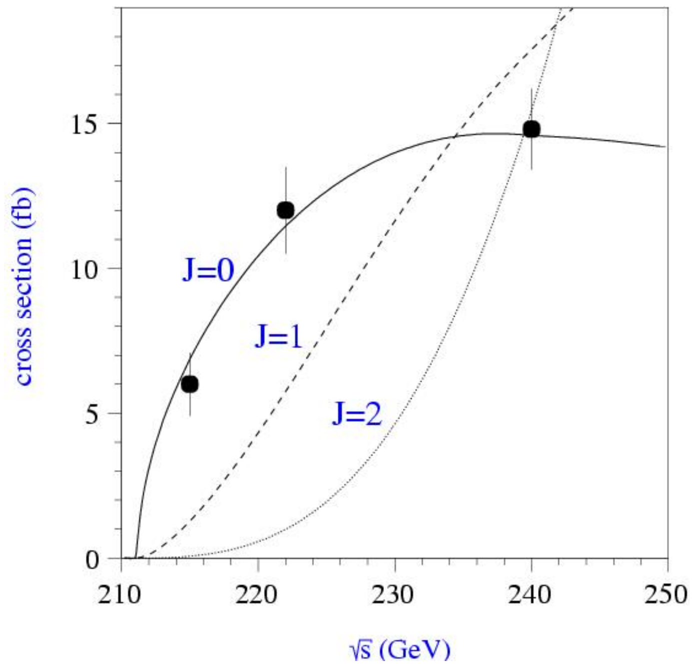
⇒ This precision is probably not sufficient if looking for new-physics signals in the Higgs sector

W. Kilian, LCWS 2005

Higgs at the ILC

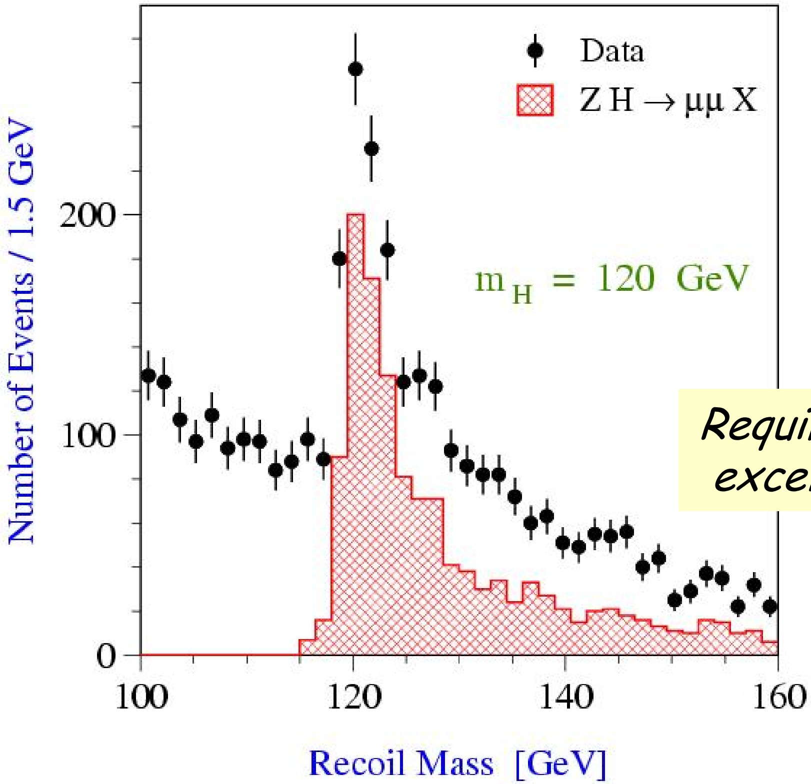
- Measure the Higgs profile
  - Mass and width
  - Quantum numbers
  - Couplings to fermions
  - Couplings to gauge bosons
  - Self coupling
- Prove that the Higgs **is** the Higgs
  - Establish the Higgs mechanism
- Do Higgs precision physics
  - Deviations from SM, admixtures, SUSY Higgs

e.g. spin

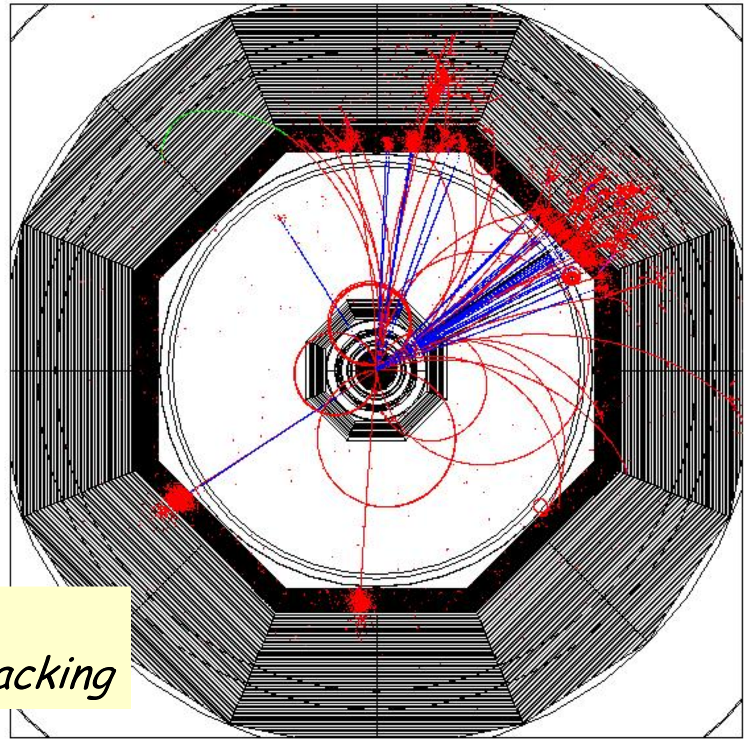


Higgs signature

- Model independent
- Independent of decay mode



Requires excellent tracking



- Provides absolute normalization for decay rates

Higgs trends

(from W.Kilian's summary)

- SM and MSSM Higgs are mature fields now
  - Beyond (MS)SM: many open issues under study
- Check anchor processes with full simulations (detector, background)
- Obtain higher order predictions

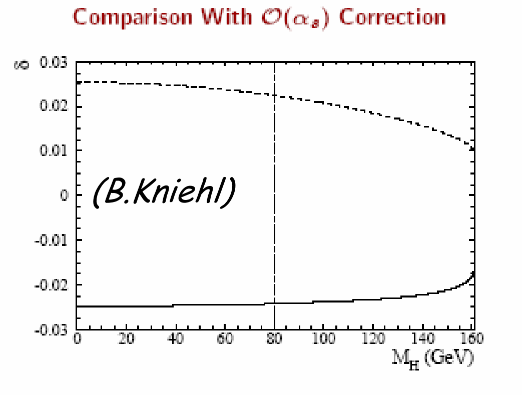
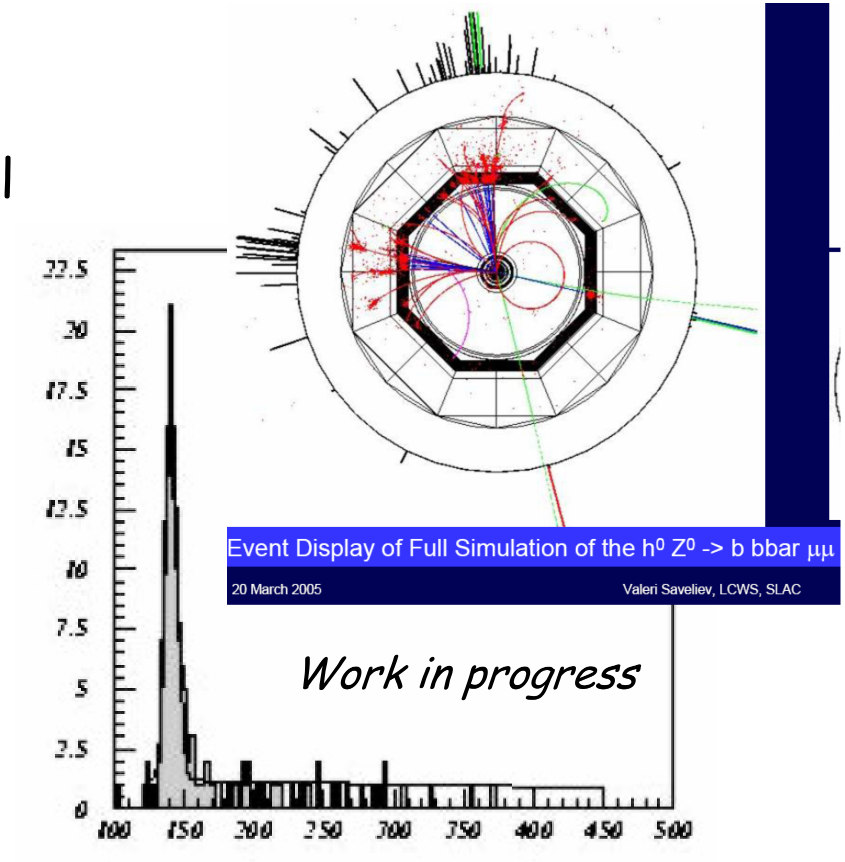


Figure 9: $\mathcal{O}(G_F M_t^2)$ (solid) and $\mathcal{O}(\alpha_s)$ (dashed) corrections to $\Gamma(H \to \gamma\gamma)$.



Independent physics case

- Whatever the discoveries at the LHC will be - an e+e- collider with 0.5 - 1TeV energy will be needed to study them
  - Light Higgs: verify the Higgs mechanism
  - Heavy Higgs: ditto, and find out what's wrong in EW precision data
  - New particles: precise spectroscopy
  - No Higgs, no nothing: This is BSM! find out what is wrong, and measure the indirect effects with max precision
- Case has been worked out and well documented (e.g. TESLA TDR)
- See also answers to ITRP questions: hep-ph/0411159

Physics studies

- No time to report on ongoing work on
  - SUSY – minimal and non-minimal extensions
  - New physics from electro-weak precision measurements
  - Top and QCD
  - Higher order calculations ("Loop Verein")

- Two relatively young working groups attract increasing attention:
  - LHC LC study group
  - Astrophysics and cosmology connections

LHC ⊕ LC synergy

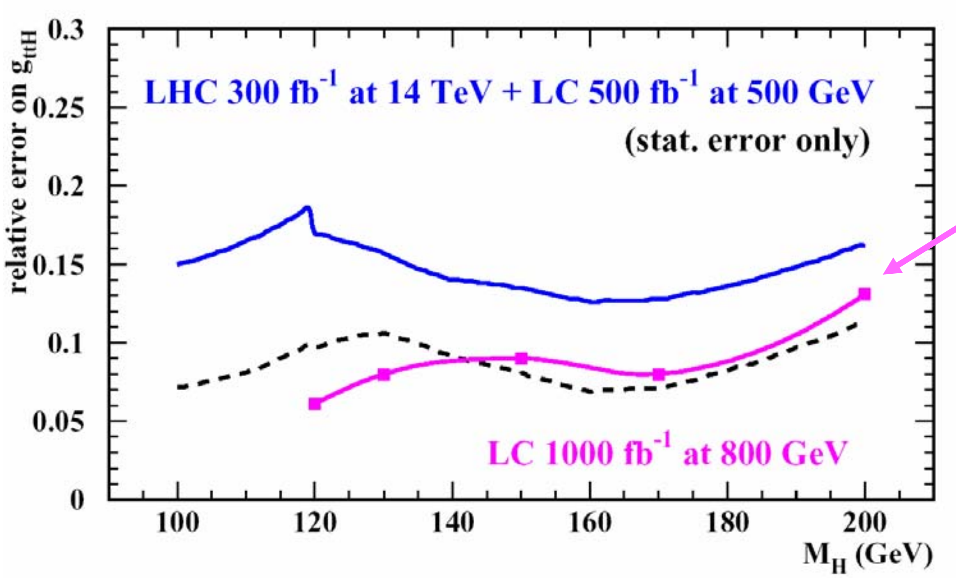
- Example for **combined interpretation**: Top Yukawa coupling

  absolute top Yukawa coupling from

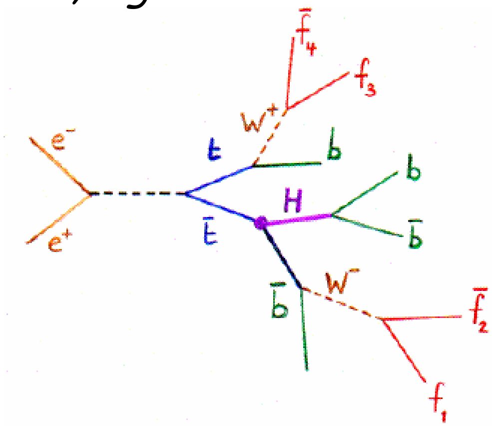
  gg,qq→ttH (H→bb,WW) (@LHC) (rate ~ $(g_t\, g_{b/W})^2$)

  and

  BR(H →bb,WW) (@LC) (absolute measurement of $g_{b/W}$)

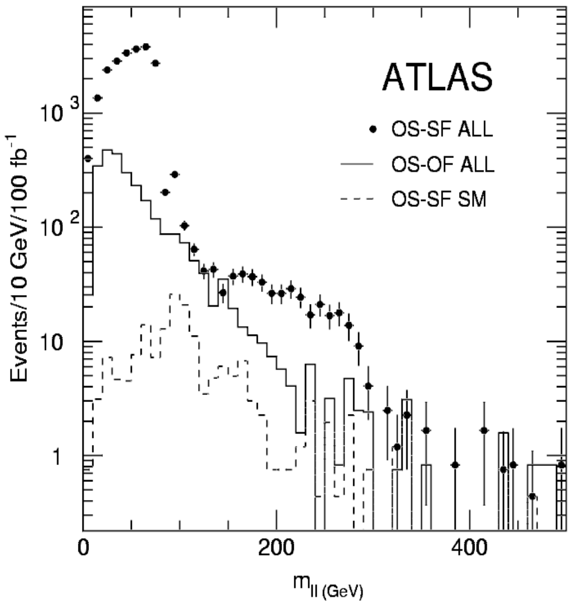


At the ILC (alone), need highest energy and combine many channels, e.g.:



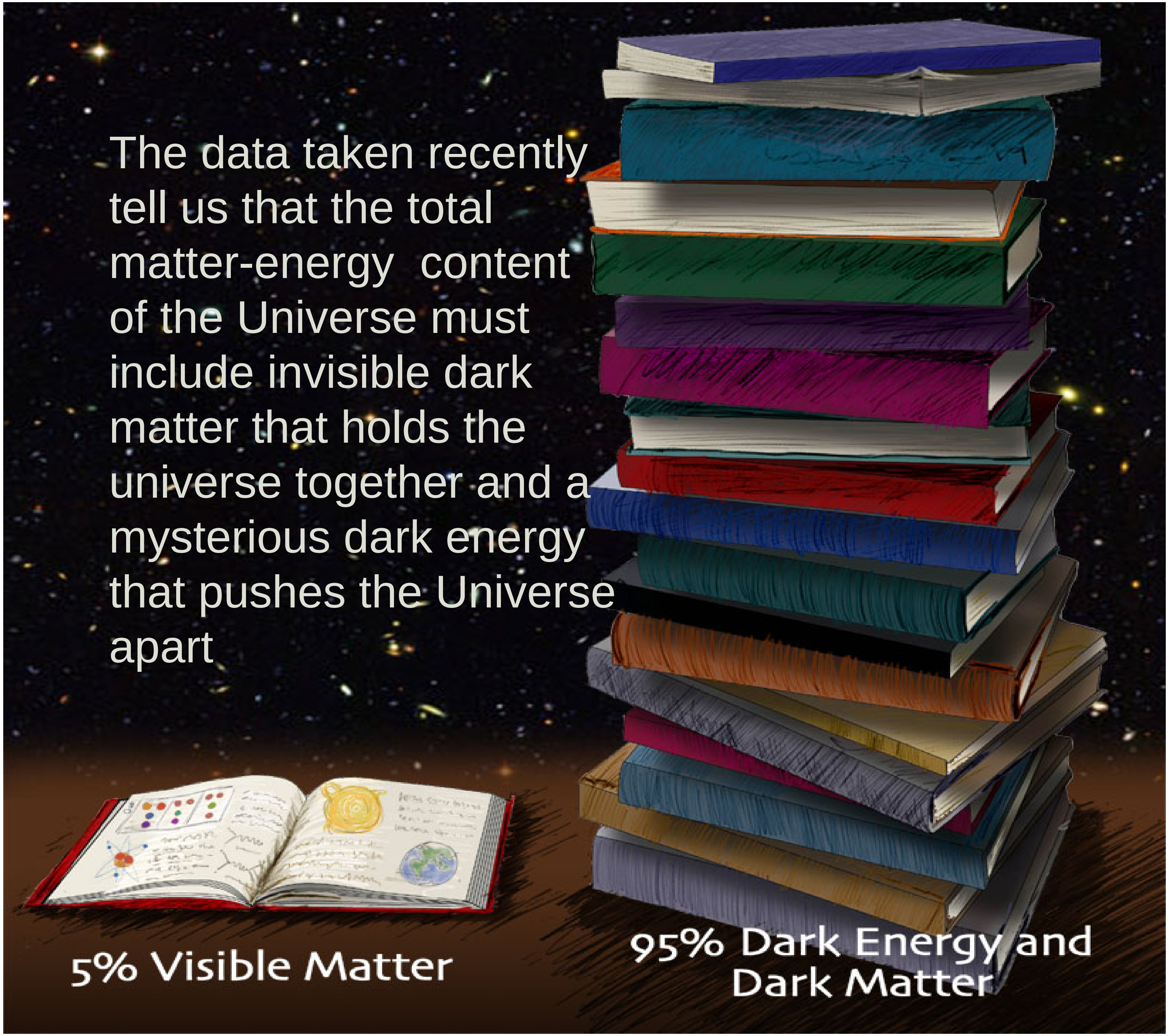
LHC ⊗ LC synergy

- Example for **combined analysis**: predict and discover heavy χ^0_4
- Predict χ^0_4 mass from SUSY parameters as determined from lowest chargino and neutralino states at LC
- Know where to look for the edge in the dilepton spectrum at LHC



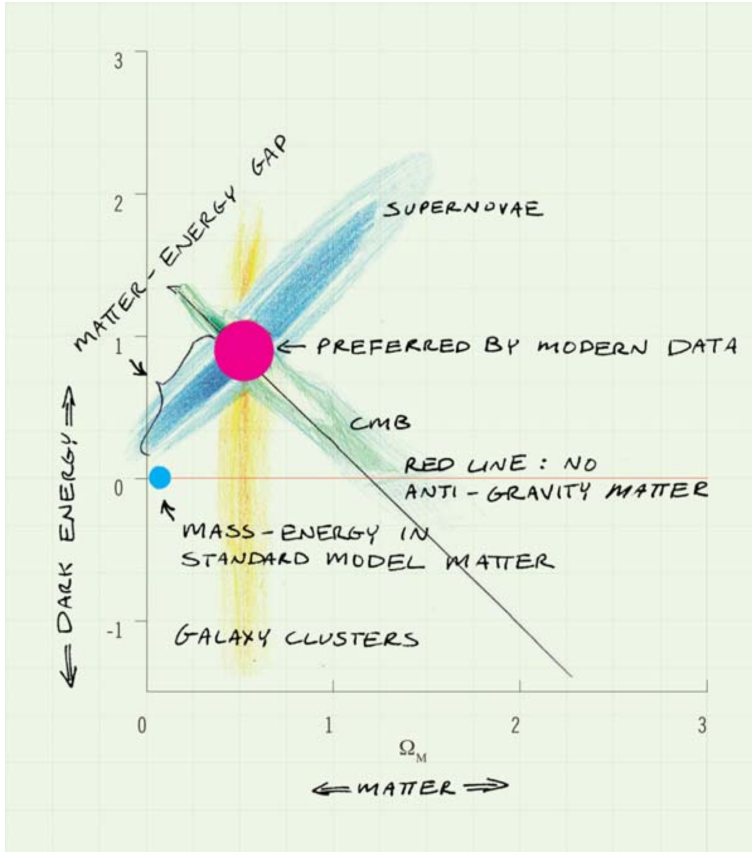
LHC ILC interplay has become one of the most active fields

See 1st study group report hep-ph/0410364 *(477pp)*


The data taken recently tell us that the total matter-energy content of the Universe must include invisible dark matter that holds the universe together and a mysterious dark energy that pushes the Universe apart
5% Visible Matter
95% Dark Energy and Dark Matter

Dark matter

- In many models dark matter is a “thermal relic” WIMP
- WIMPs are neutral, weakly interacting, massive particles
- Once in thermal equilibrium, then frozen out due to expansion of the universe
- Calculable density today
- Naturally appear in EW symmetry breaking models
  - Mass 100 GeV or so
  - Copiously produced at colliders

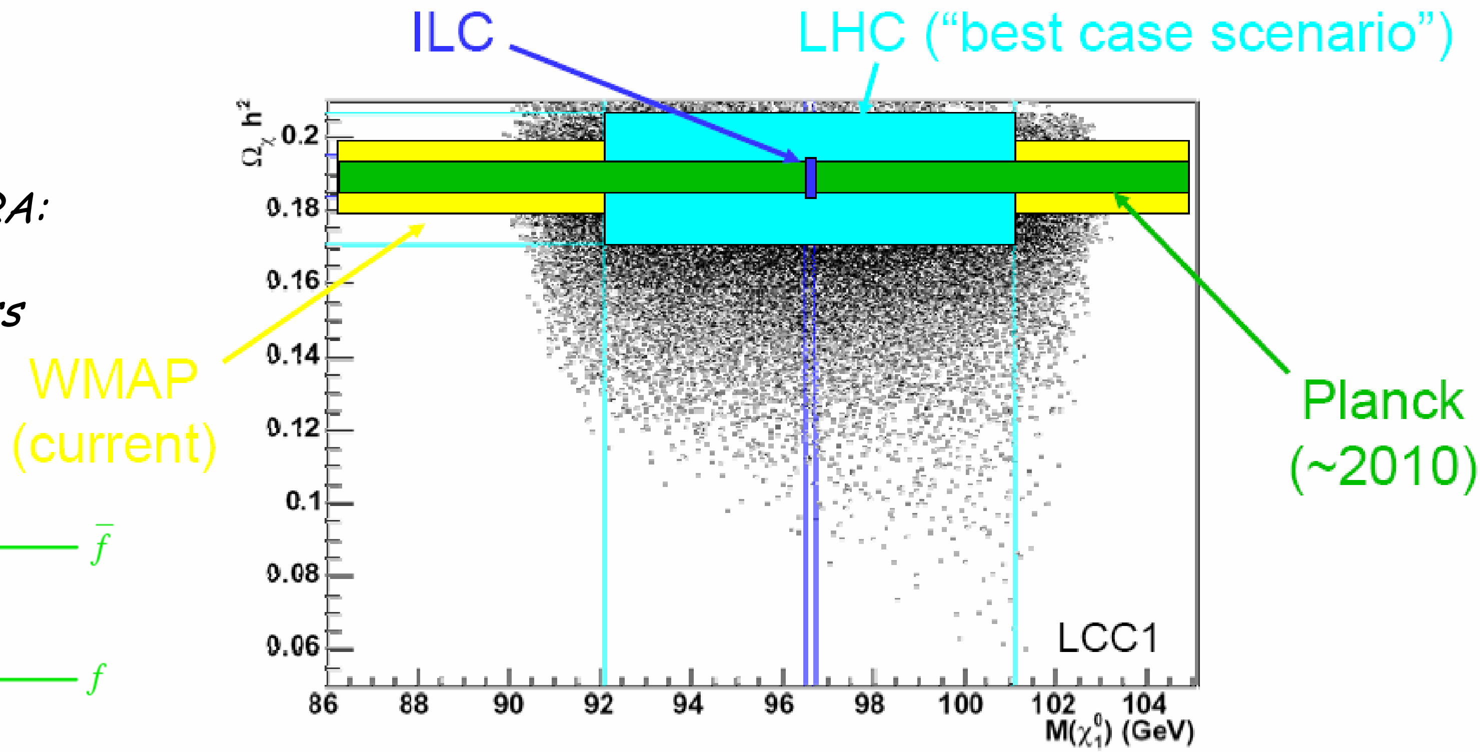


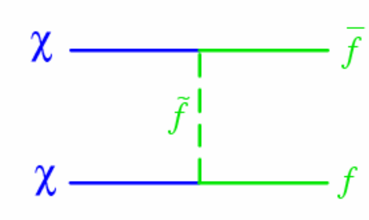
(from M.Peskin’s talk)

Dark matter interpretation

- LHC will see DM candidate as jets + missing energy, LSP = χ_1^0 ??
- To claim dark matter discovery, need to establish model; annihilation cross section to precisely calculate relic density, match with cosmology

E.g. mSUGRA: Depends on slepton mass





From J.Feng's talk

Cosmic connection

this is a special time in particle physics

- urgency: provocative discoveries lead to urgent questions
- connections: questions appear to be related in fundamental but mysterious ways -> big ideas are in play
- tools: we have the experimental tools, technologies and strategies needed to tackle these questions

conclusion:

we are seeing a scientific revolution in the making

J.Lykken, quoted from J.Dorfan

2. Organization & Timelines

ILC Parameters

"Scope document"
(http://www.fnal.gov/directorate/icfa/LC_parameters.pdf)

- **1st stage**
  - Energy 200→500 GeV, scannable
  - 500 fb^{-1} in first 4 years
    with option of x2 lum. in additional 2 years
- **2nd stage**
  - Energy upgrade to ~1TeV
  - ~1000 fb^{-1} in 3-4 years
- **Options**
  - $\gamma\gamma$, γe^-, e^-e^-, Giga-Z
- **2 IRs for 2 experiments**

- **Operating simultaneously with LHC**
  (to start ~2015 : not in the scope document)

International Consensus...

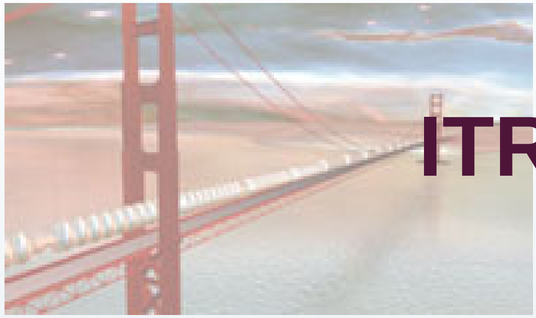
- Up to 2002, ACFA, ECFA, HEPAP reached the common conclusion that the next accelerator should be an electron-positron linear collider with an initial energy of 500 GeV, running in parallel with LHC, and later upgradeable to higher energies.
- 2003/11, US DOE Office of Science Future Facilities Plan: LC is first priority mid-term new facility for all US Office of Science
- 2004/1, ACFA, ECFA, HEPAP chairs reaffirmed their community's priorities for a 500 GeV linear collider operated in parallel with the LHC
- 2004/1, OECD Science Ministerial Statement endorsed the plan for global collaborative development of a linear collider.
- 2004/2, ICFA reaffirmed that the highest priority for a new machine for particle physics is a linear electron-positron collider with an initial energy of 500 GeV, extendible up to about 1 TeV, with a significant period of concurrent running with the LHC

...is overwhelming

Important development past year

ITRP
(International Technology Recommendation Panel)
Chair : Barry Barish

Set out to recomend LC technology between “warm” and “cold”.
After 6 months of intensive work...



ITRP Executive Summary

(excerpts)

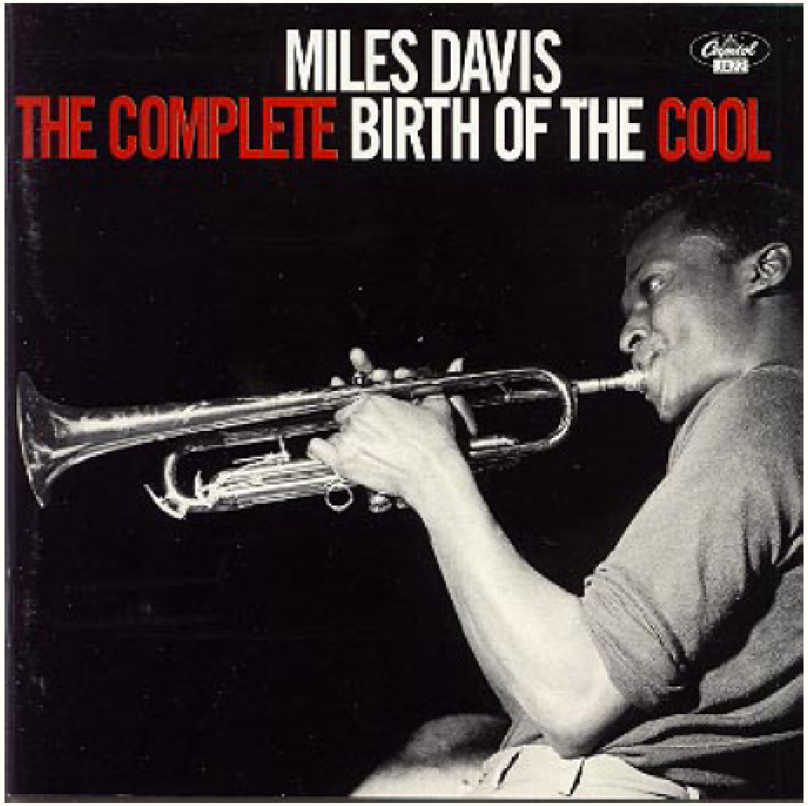
Aug 19, 2004

- **We recommend that LC be based on super-conducting RF technology.**
  - ... we are recommending a technology not a design. We expect that the final design be developed by a team drawn from the combined warm and cold linear collider communities...

Things are starting to roll

- The name is officially decided to be **ILC** (International Linear Collider)
- **GDE** (Global Design Effort) - the first stage of **GDI** (Global Design Initiative) - is being formed (see following talks)

The Birth of the GDE

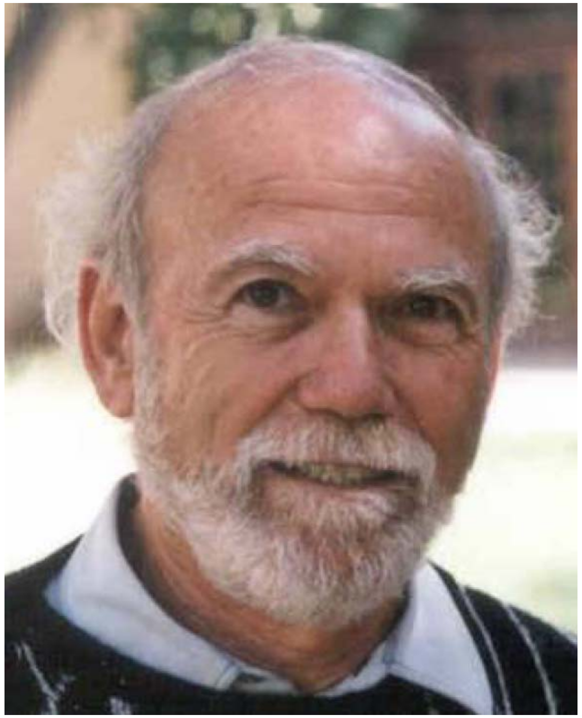


Barry Barish
TESLA Collab Mtg
31-March-05

Barry Barish GDE director

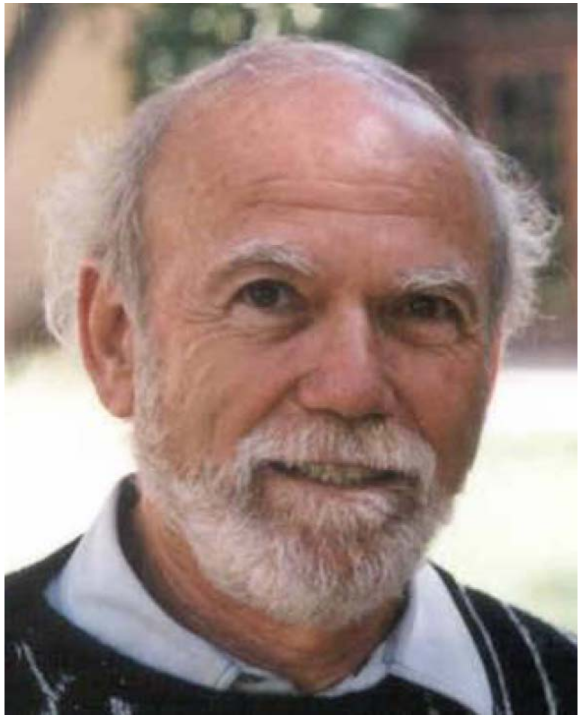
First statements on structure of GDE

- No host institute: GDE as virtual lab, truly international, **distributed effort**
- 3 regional directors to follow (Snowmass)
- 3 (regional) cost engineers
  - **Cost awareness** from the beginning
- 30 experts form distributed "core team"
  - Not regionally or politically balanced



Barry Barish: more on GDE

First statements on timeline of GDE



- Snowmass (2nd ILC meeting) is important
  - Fix ILC **baseline configuration**
  - Yet, keep open for improvements
- CDR target date: end of 2006
  - But: with **price tag**
  - Site dependent: **sample sites**
    - Understand geological / political constraints
- TDR in 2008

Tasks for LC Physics/Detector Studies

- **Inputs to Machine Design (GDE)**
  - Options ($\gamma\gamma$, γe^-, e^-e^-, Giga-Z...) (K. Hagiwara)
  - Number of IRs : A task force being formed
  - MDI issues including : (T. Tauchi)
    - Crossing angle
    - Constraints from detector designs
- **Design and Build Detectors**
  - Establish detector concepts (T. Behnke)
  - Perform necessary R&Ds (W. Lohman)
  - Study physics/detector bench marks (T. Barklow, M. Battaglia)
- **Sharpen LC Physics Cases**
  - New Physics Models (S. Dimopolous)
  - LHC and LC (G. Weiglein)
  - Cosmology and LC (J. Feng)
  - Outreach (K. Buesser)

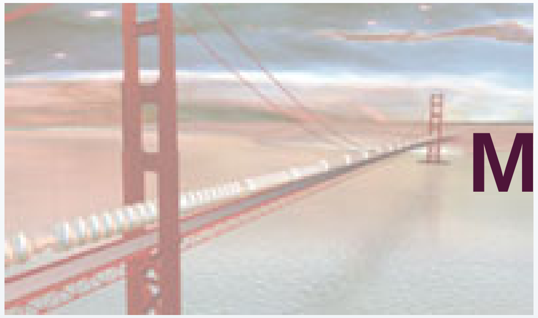
( ) : plenary talks this workshop.

Panels installed by WW Study

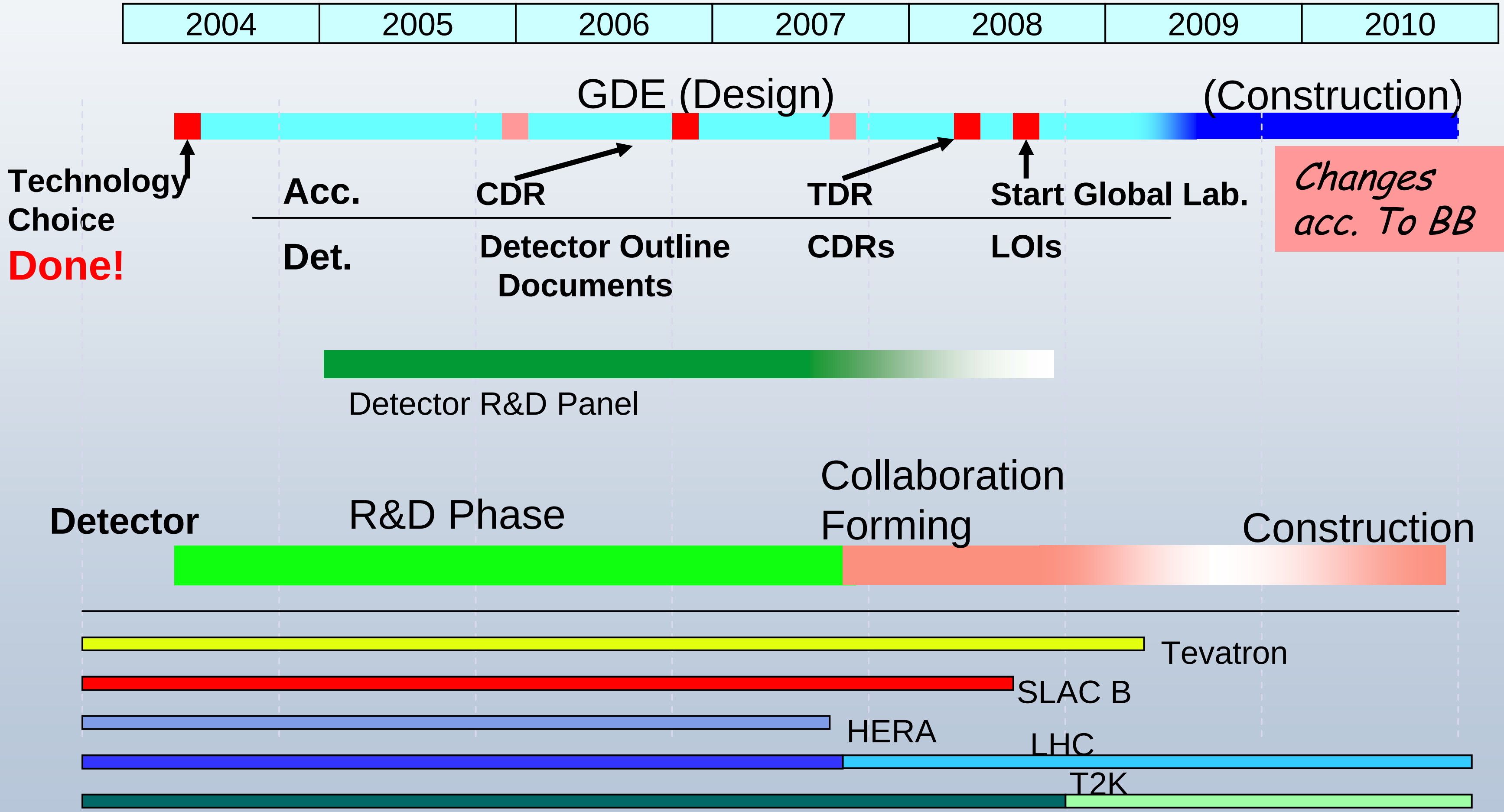
- **R&D panel**
  - 3 members from each region, balanced over expertice. Launched at this workshop.
    - C. Damerell, J.-C. Brient, W. Lohmann
    - H.J. Kim, T. Takeshita, Y. Sugimoto
    - D. Peterson, R. Frey, H. Weerts
  - Register the detector R&Ds (incl. MDI)
  - Evaluate them wrt detector concepts (document it ~Aug 2005)
  - Coordinate with regional review processes

- **MDI panel**
  - Liase with machine efforts (i.e. GDE)
  - Existing LCWS/WWS leadership of MDI acts as this panel for now
    - (P. Bambade, T. Tauchi , M. Woods)

- **Costing panel**
  - To be formed in time for serious work by this summer



Milestones of ILC (by sugimoto)



Statement of Funding Agency (FALC) Mtg

17-Sept-04 @ CERN

Attendees: Son (Korea); Yamauchi (Japan); Koepke (Germany); Aymar (CERN); Iarocci (CERN Council); Ogawa (Japan); Kim (Korea); Turner (NSF - US); Trischuk (Canada); Halliday (PPARC); Staffin (DoE – US); Gurtu (India)

Informal but regular meetings

Guests: Barish (ITRP); Witherell (Fermilab Director,)

"The Funding Agencies praise the clear choice by ICFA. This recommendation will lead to focusing of the global R&D effort for the linear collider and the Funding Agencies look forward to assisting in this process.

The Funding Agencies see this recommendation to use superconducting rf technology as a critical step in moving forward to the design of a linear collider."

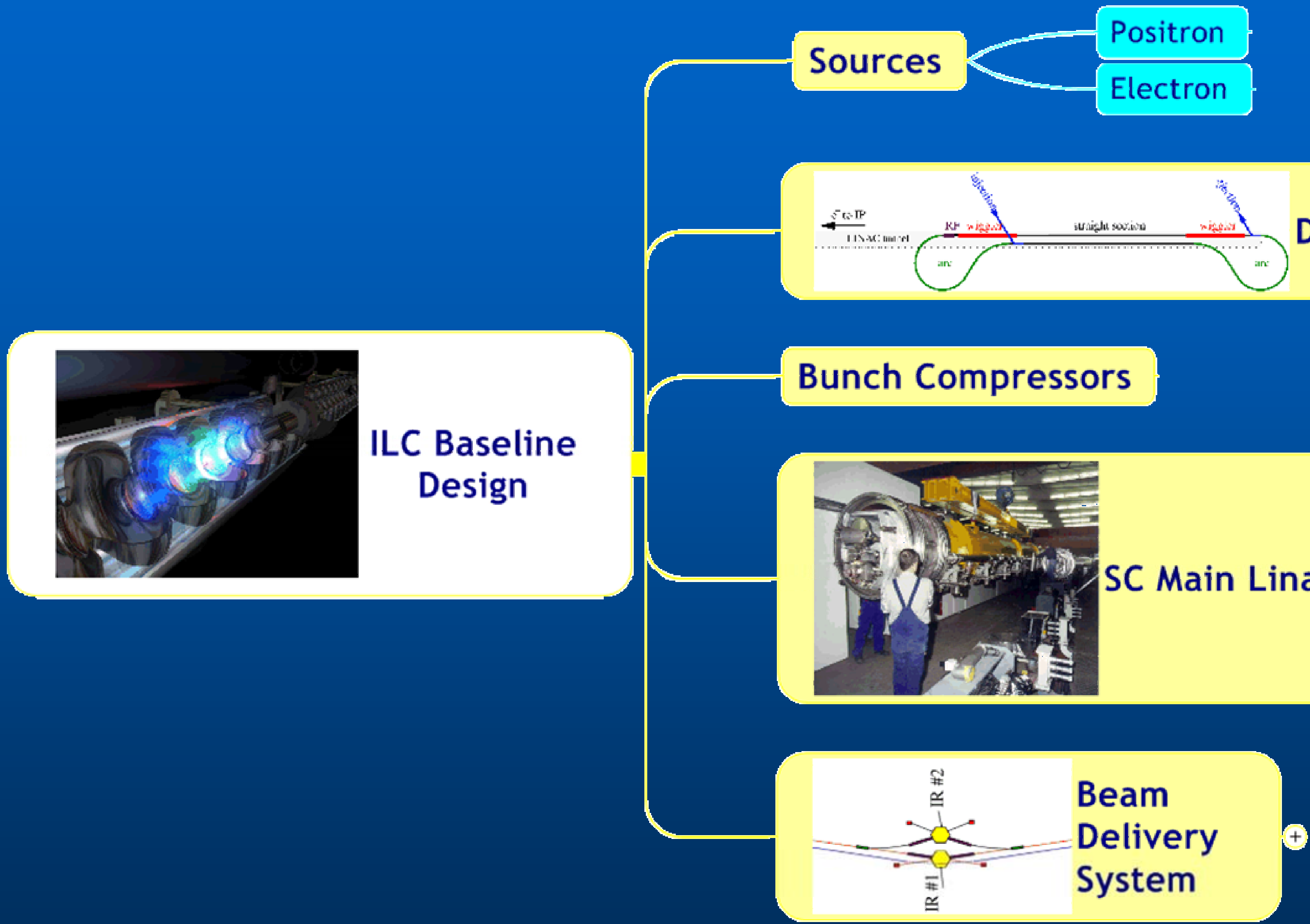
FALC is setting up a working group to keep a close liaison with the Global Design Initiative with regard to funding resources.

The cooperative engagement of the Funding Agencies on organization, technology choice, timetable is a very strong signal and encouragement.

B.Barish at TTC meeting

3. Machine

Towards the ILC Baseline Design



Decisions to be Made!

TESLA worldwide

DESY

DESY TELEGRAMM 4. April 2005

Zwei neue Mitglieder für die „TESLA Technology Collaboration“
KEK und SLAC jetzt mit dabei

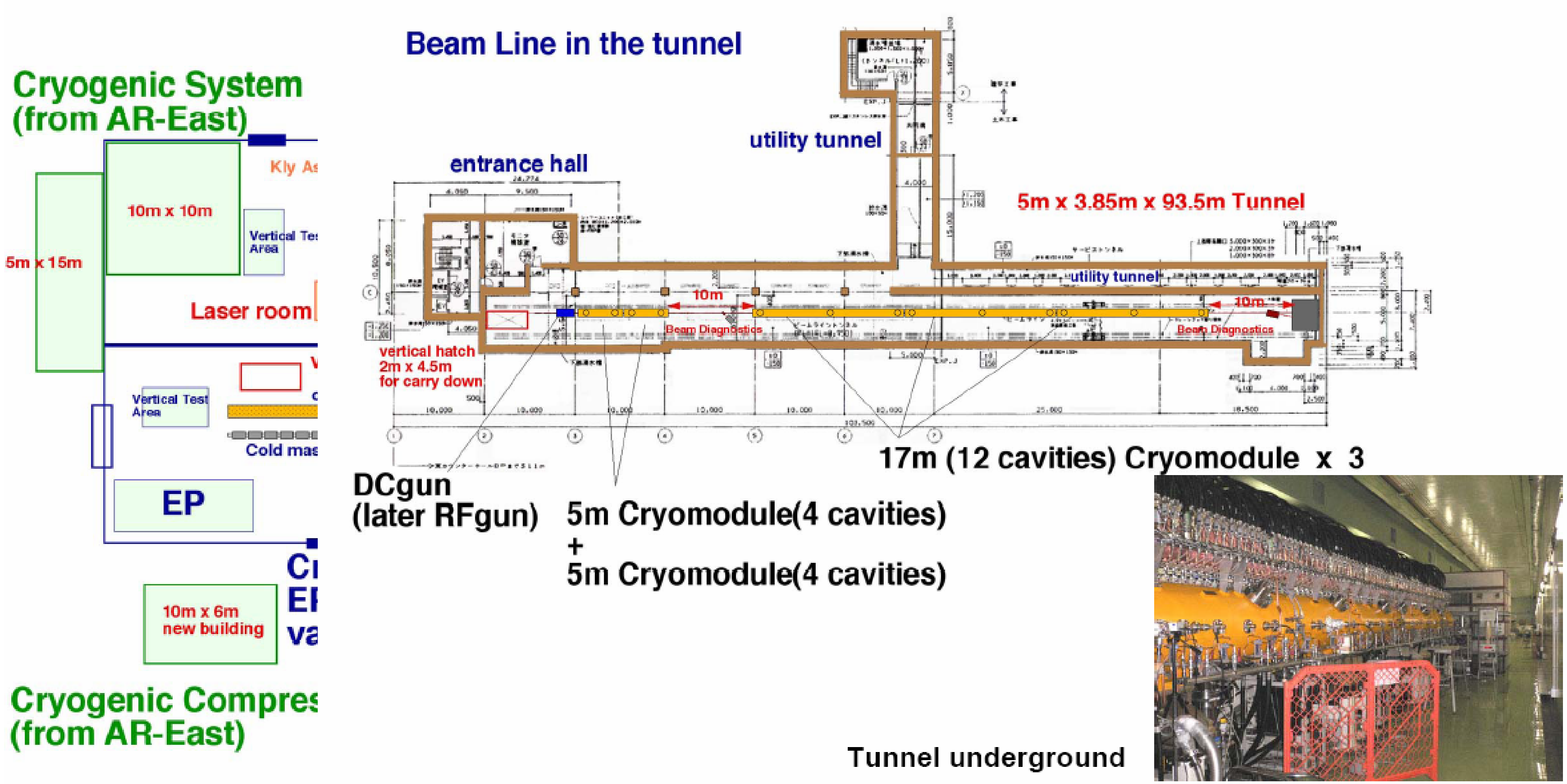
Two new members for the “TESLA Technology Collaboration”
KEK und SLAC now joined in

Auf ihrem Treffen bei DESY letzte Woche entschied die „TESLA Collaboration“, sich in „TESLA Technology Collaboration“ umzubenennen. Außerdem nahm sie zwei wichtige neue Mitglieder auf: Das japanische Forschungszentrum für Hochenergiephysik KEK und das „Stanford Linear Accelerator Center SLAC“ aus den USA.

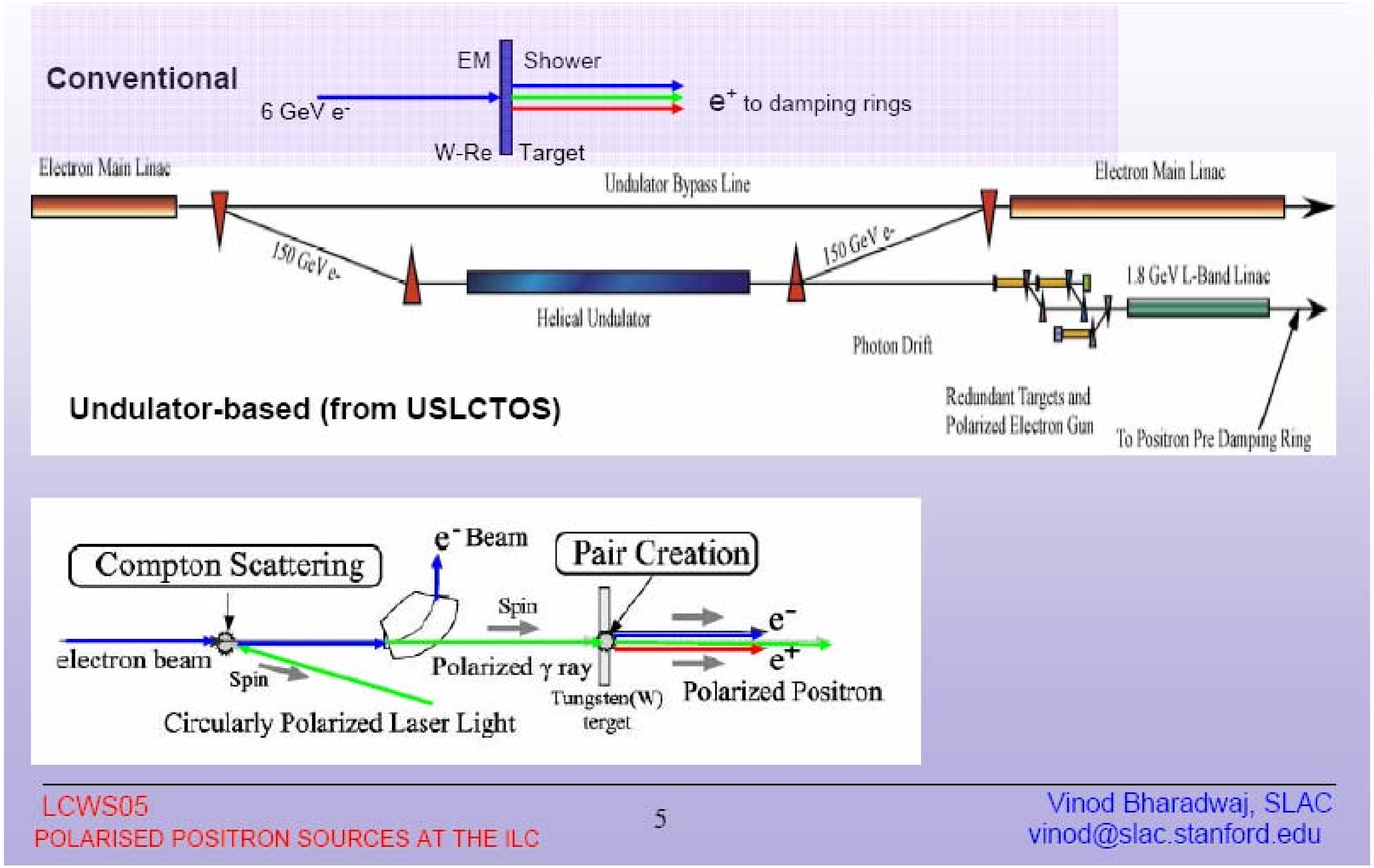
During its meeting last week at DESY the TESLA Collaboration decided to change its name into TESLA Technology Collaboration. At the same time two important new members joined the Collaboration: The Japanese Center for High Energy Physics KEK and the Stanford Linear Accelerator Center SLAC from the USA.

New TESLA test facilities

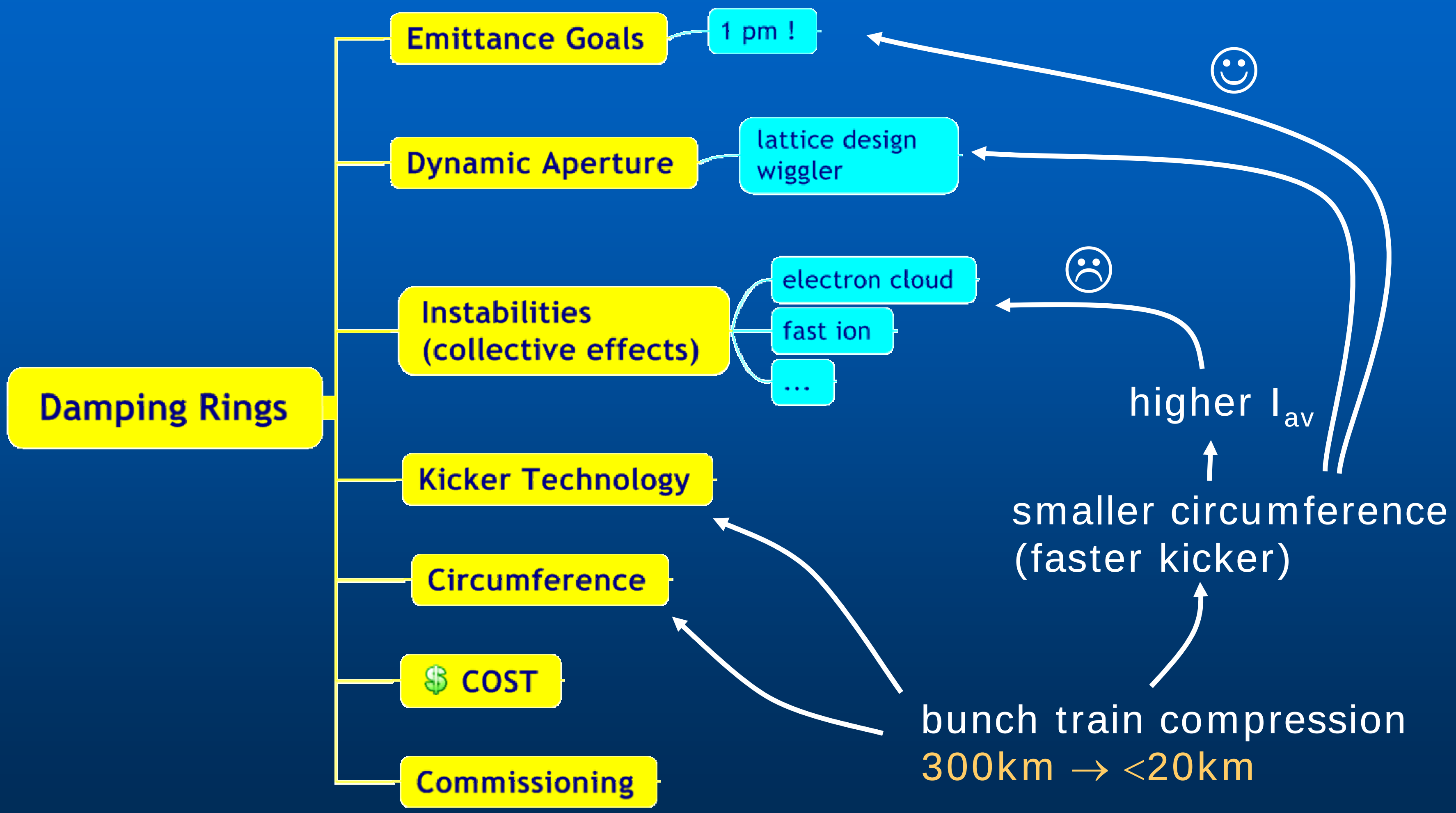
STF underground tunnel plane view



Positron production schemes



Damping Rings

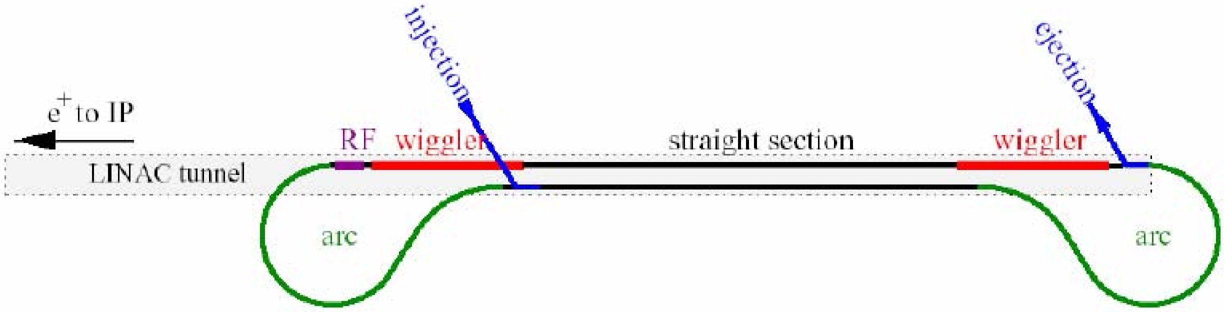


DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17 km lattice (arcs 1 km each, straights 15 km total).

Bunches spaced by 20 ns, injected and extracted individually.

Positron damping ring requires 440 m of wiggler to achieve damping time of 27 ms.



Schematic of Dogbone Damping Ring from TESLA TDR

Strengths:

- Relatively small amount of extra tunnel required.
- Large circumference reduces average current, and helps mitigate some instabilities.
- Flexibility in modes of operation (e.g. could double number of bunches)

Weaknesses:

- Large space-charge tune shift needs to be corrected using coupling-bumps.
- Sensitive to stray magnetic fields.

see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17

Bunches s

Positron d

Strengths

- Rela
- Larg
- Flexi

Weakness

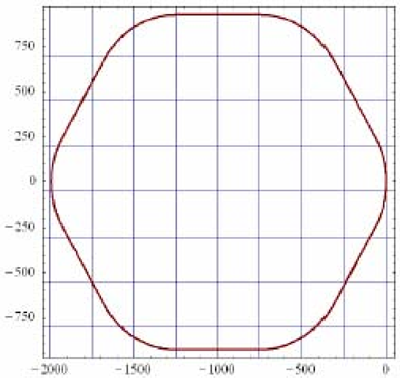
- Larg
- Sens

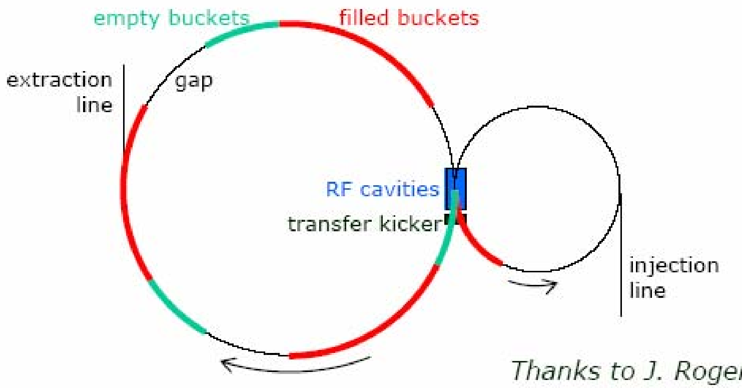
DR Design Approaches: Example #2, the FNAL 6 km lattice

5 GeV, 6 km lattice (six-fold symmetry).

Injection/extraction scheme uses 6 ns rise-time, 60 ns fall-time kicker.

Lattice documented in FERMILAB-TM-2272-AD-TD
http://www.hep.uiuc.edu/home/g-gollin/linear_collider/Fermilab_damping_ring_report.pdf





Thanks to J. Rogers and G. Dugan (Cornell)

Strengths:

- Relatively small circumference reduces space-charge effects.
- Reduced amount of wiggler needed to achieve required damping rate.
- Injection/extraction scheme allows use of slow fall-time kicker.

Weaknesses:

- Higher average current makes electron-cloud and ion effects more difficult.

see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

DR Design Approaches: Example #1, the TESLA TDR lattice

5 GeV, 17

Bunches s

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Strengths

- Relat
- Larg
- Flexi

Weakness

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DR Design Approaches: Example #2, the FNAL 6 km lattice

5 GeV, 6 k

Injection/e

Lattice doc

http://www.hep.

750
500
250
0
−250
−500
−750

Strengths:

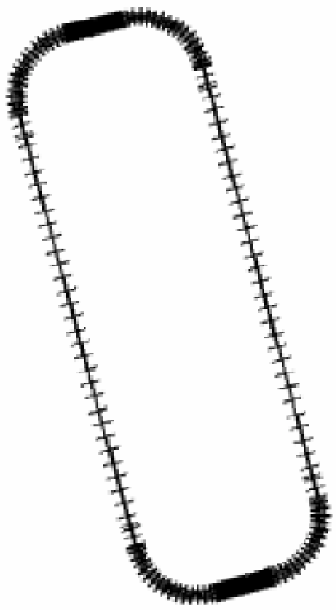
- Relati
- Redu
- Inject

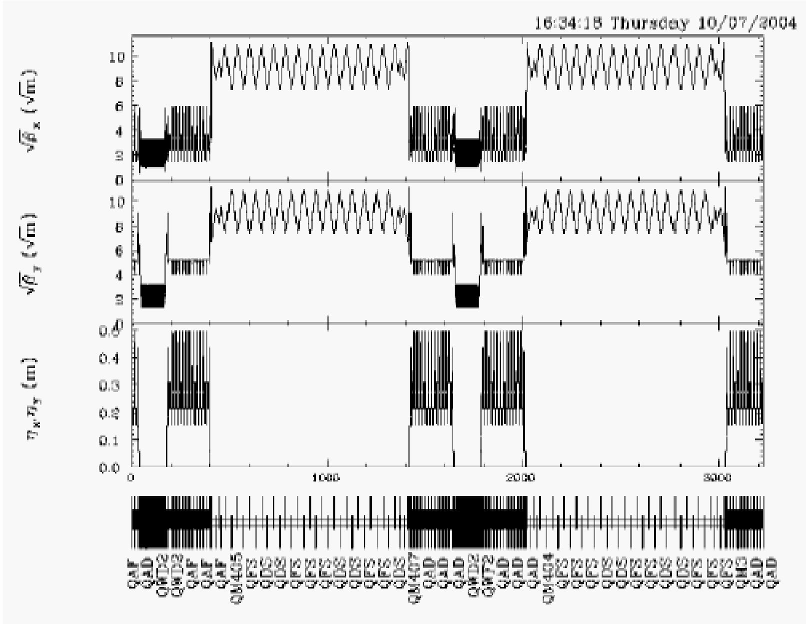
Weaknesse

- Highe

DR Design Approaches: Example #3, the KEK 3 km lattice

5 GeV, 3.2 km lattice (racetrack design).



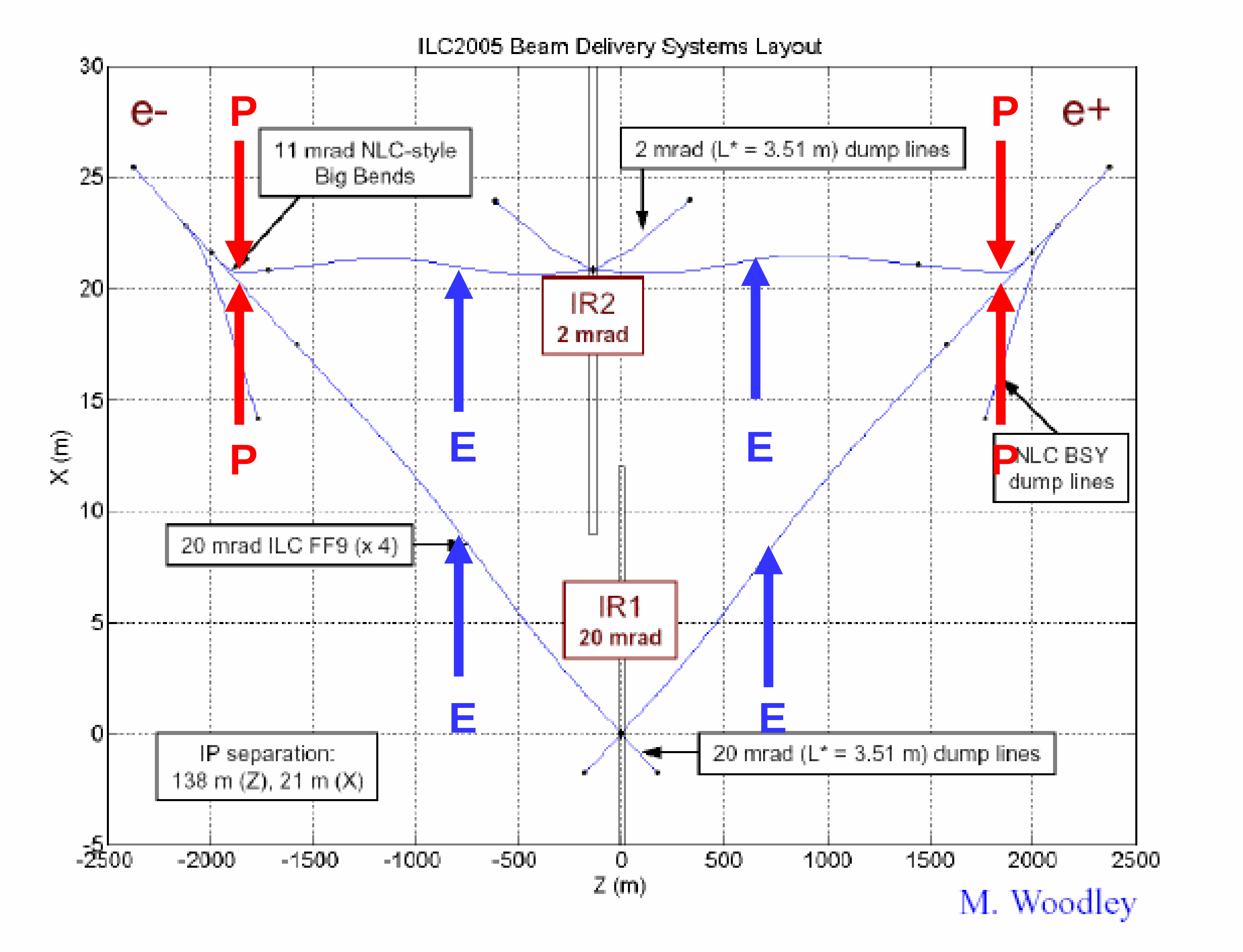


Lattice layout and optical functions in KEK 3 km damping ring.

S. Kuroda and J. Urakawa (KEK)

see A. Wolski's talk: http://lcdev.kek.jp/ILCWS/Talks/14wg3-10-WG3-10_DR_Wolski.pdf

ILC WG4 “Strawman” Layout of BDS with 20 mrad and 2 mrad IRs logically complete



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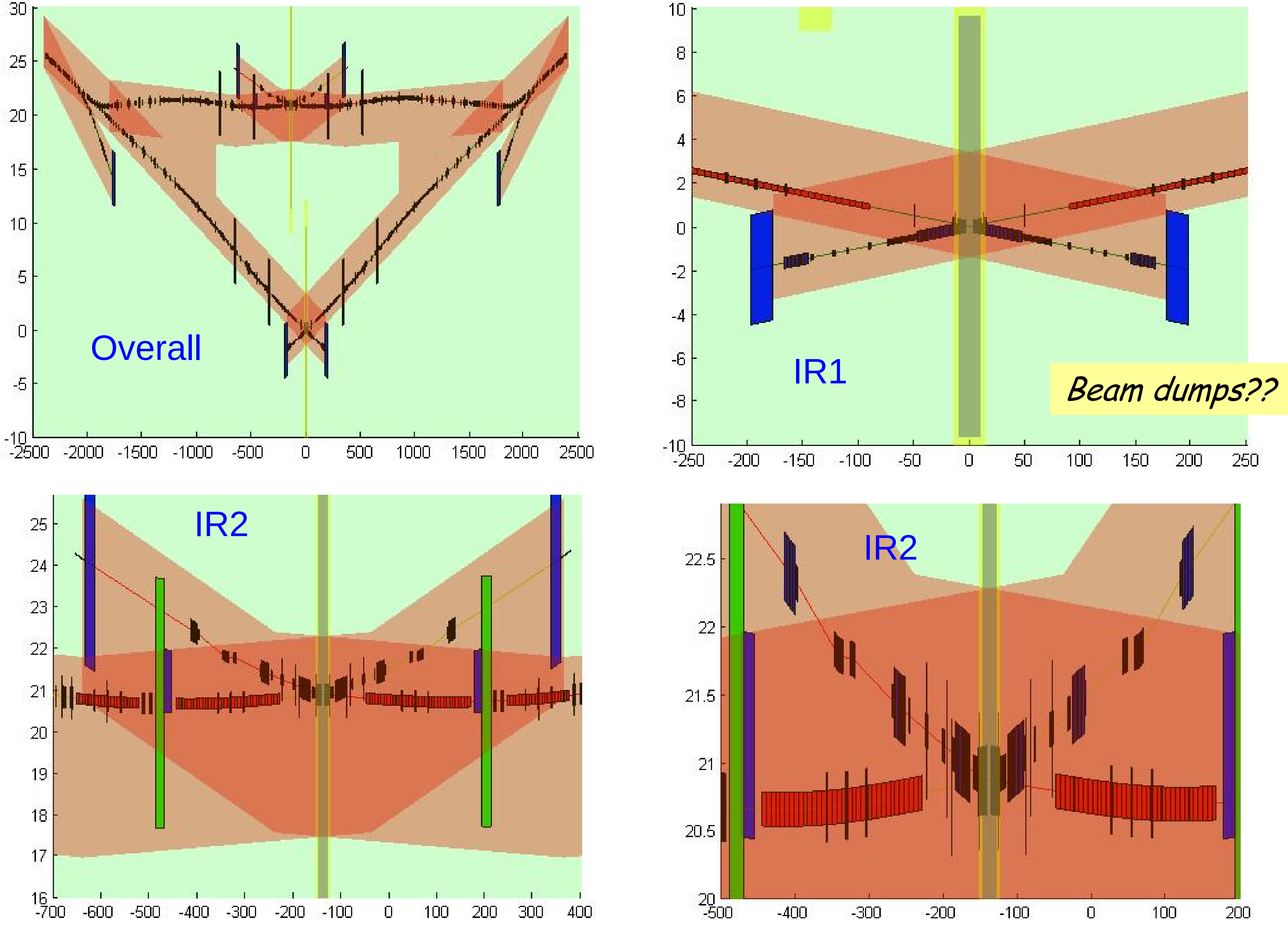
Interface to CF / Engineering Beginning



4. Detector Concepts

Detector challenge

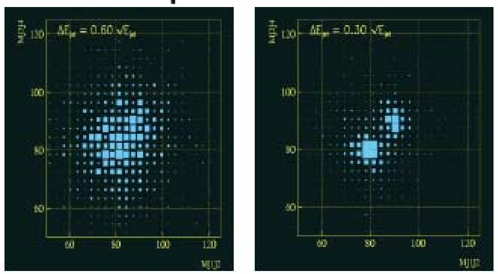
Ties Behnke: Detector concepts for the ILC

The starting points (well known by now)

- Precision tracking
- Precision vertexing
- Particle flow for overall event reconstruction

See talk by Tim Barklow this morning

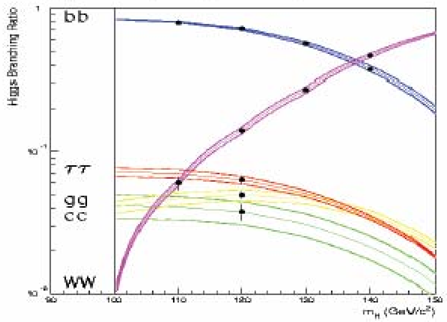
WW-ZZ separation



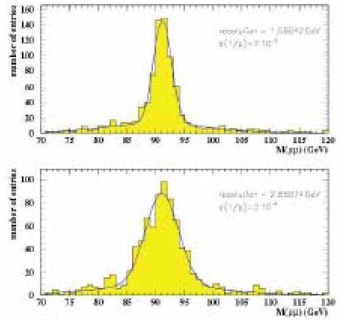
$30\%\sqrt{E}$

Charm tagging

Higgs Couplings to fermions:



Higgs recoil mass

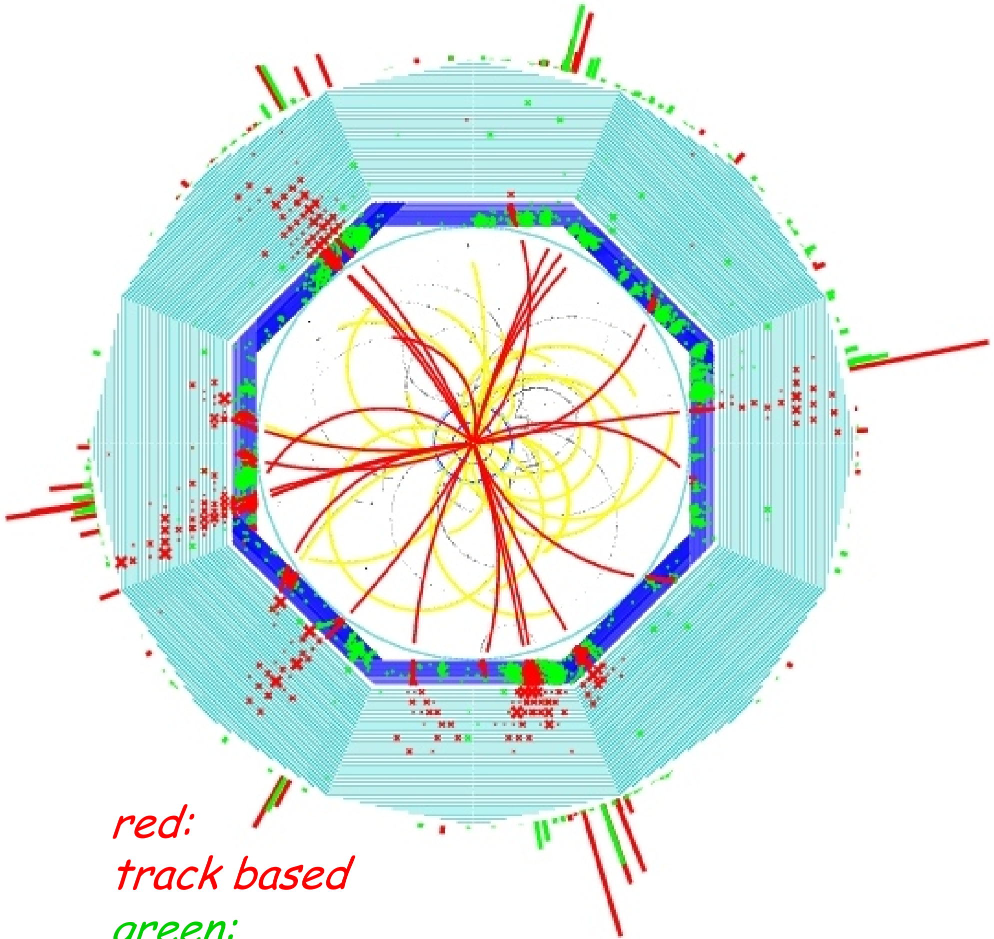


10x better than LEP

3

Particle flow detector

- Optimize overall detector resolution: reconstruct each particle individually
- Particle separation demands:
  - Large radius and length
  - Large magnetic field
  - High granularity
  - Compact calorimeter (R_M)

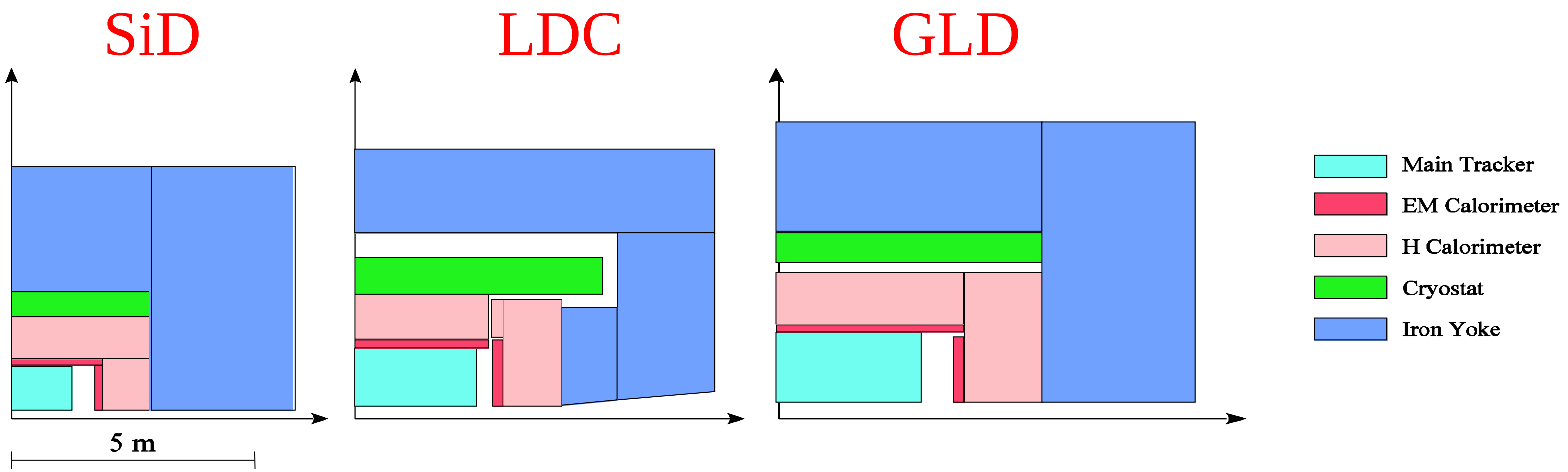


red: track based
green: calorimeter based

ZHH → qqbbbb

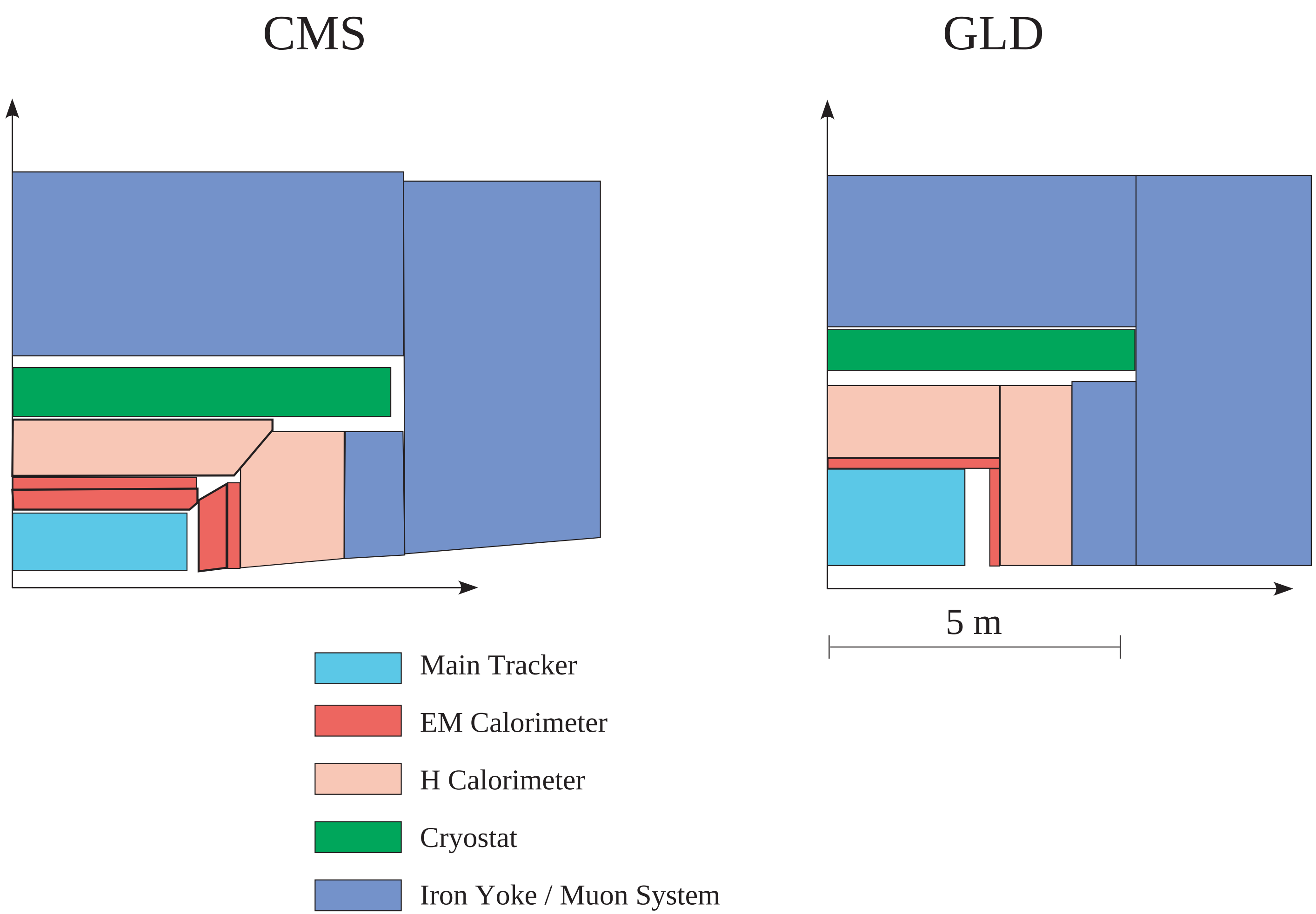
Detector concepts

- Sizes



	SiD	LDC	GLD
•	B= 5T	4T	3T
•	Si Tracker	Gasous Tracker (+Si?)	Gasous Tracker
•	SiW ECAL	SiW ECAL	Hybrid or Scint ECAL
•	…	Different HCAL options…	

Detector sizes



Open issues

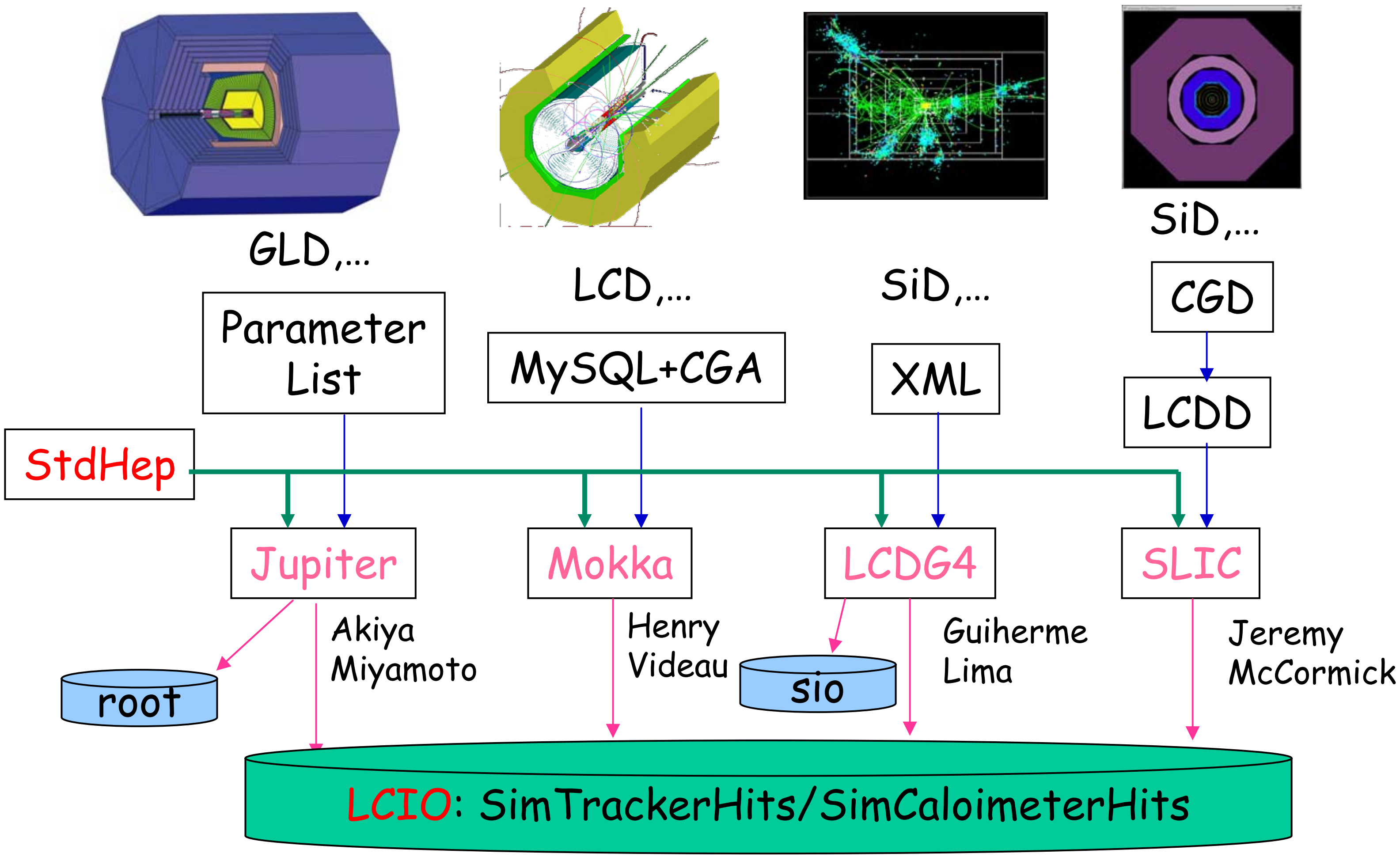
Randomly picking a few typical examples:

- Beam crossing angle
- Tracker: pattern recognition, robustness, calibration and alignment
- ECAL: size – compactness – granularity – B field
- ECAL – HCAL transition
- HCAL granularity (vs. resolution)

Full Simulation

*DESY

- Geant4, StdHep and LCIO* are common features
- Each trying to be generic with different approach
  → different ways to define geometries



Organization

Ties Behnke: Detector concepts for the ILC

Detector concept groups are forming

SiD: Weerts, Jaros, Aikara, Karyoakis

SiD meeting just before the LCWS05

LDC: Battaglia, Behnke, Karlen, Videau,
2 Asian contacts *Y.Sugimoto, NN*

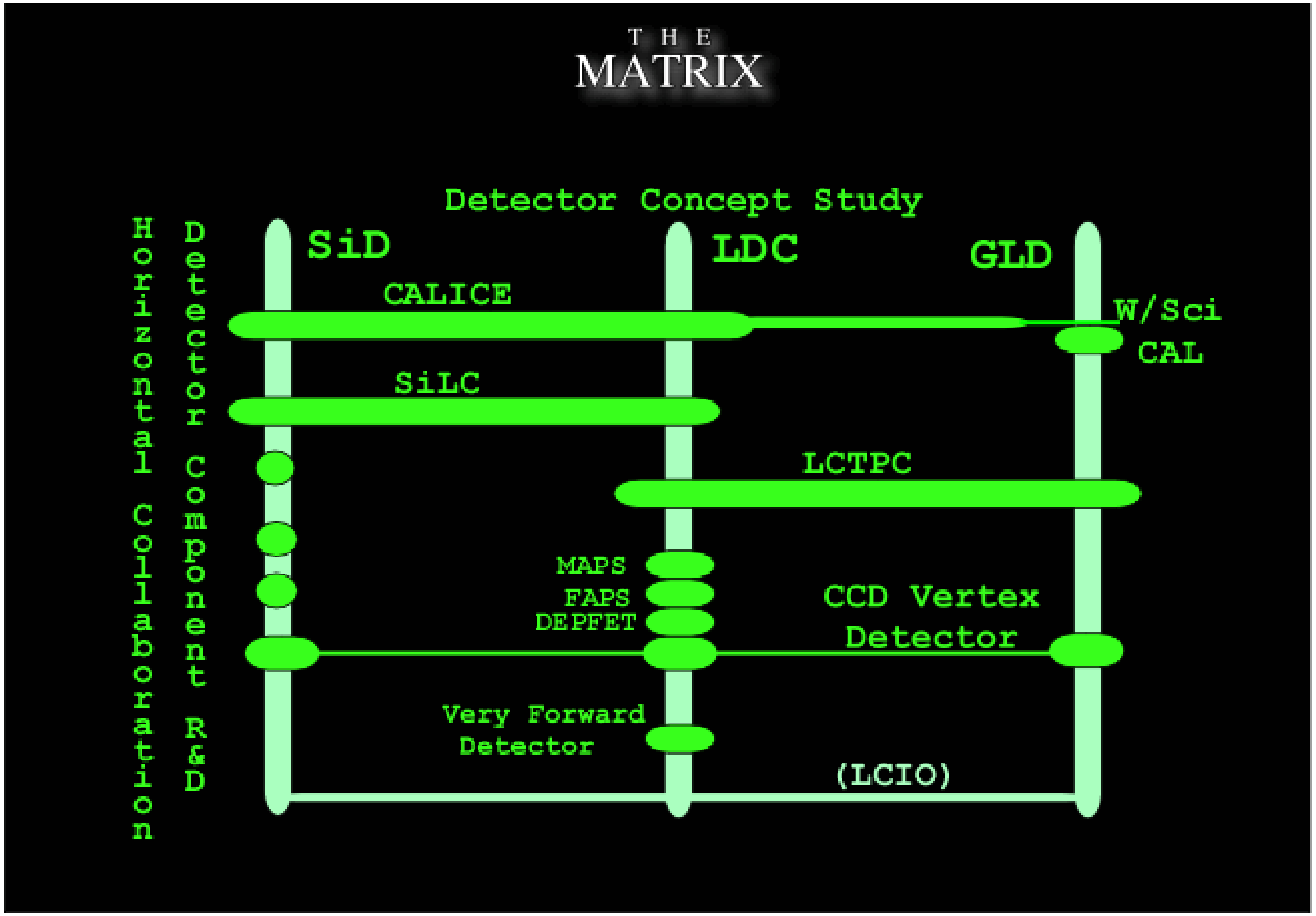
LDC discussion meeting Monday during lunch

GLD: Park, Yamamoto, EU contact, American contact

R.Settles, M.Thompson, G.Wilson, M.Ronan

All concept studies attempt to have an international convener-ship and base

Concepts and R&D



5. Detector R&D

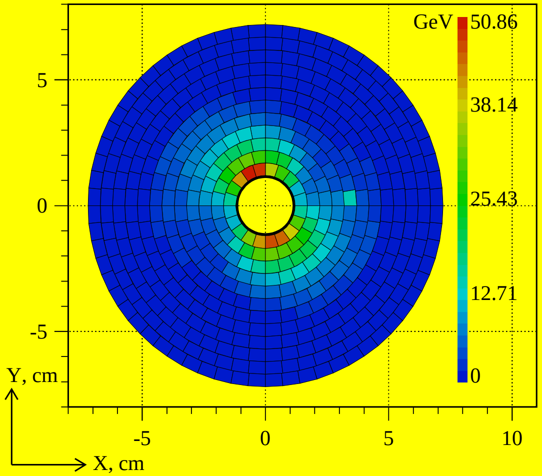
Packed agendas

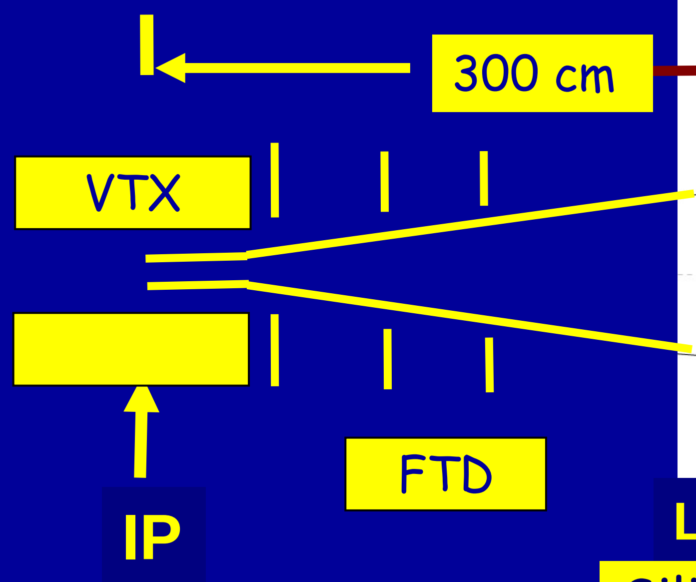
- 36 talks on calorimetry and muons (16 at LC99 Sitges)
- 32 talks on tracking and vertexing (13 at LC99 Sitges)
- 25 talks on simulation and reconstruction
- 20 talks on machine detector interface
- 15 talks on DAQ
- 7 talks on testbeam

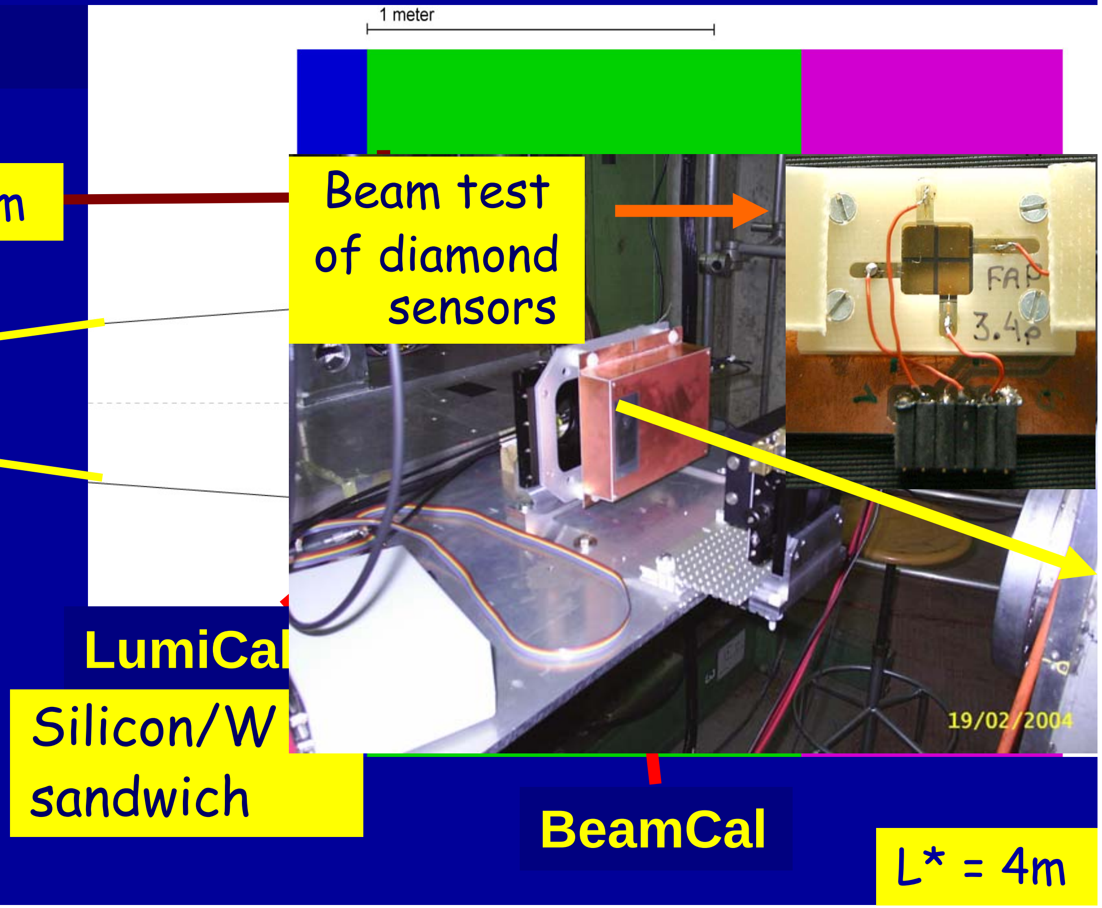
Very Forward Detectors

- Measurement of the Luminosity with precision (<10^{-3}) using Bhabha scattering
- Detection of Electrons and Photons at very low angle – extend hermeticity
- Fast Beam Diagnostics

Beamstrahlung Depositions:
20 MGy/year
Rad. hard sensors
e.g. Diamond/W
BeamCal







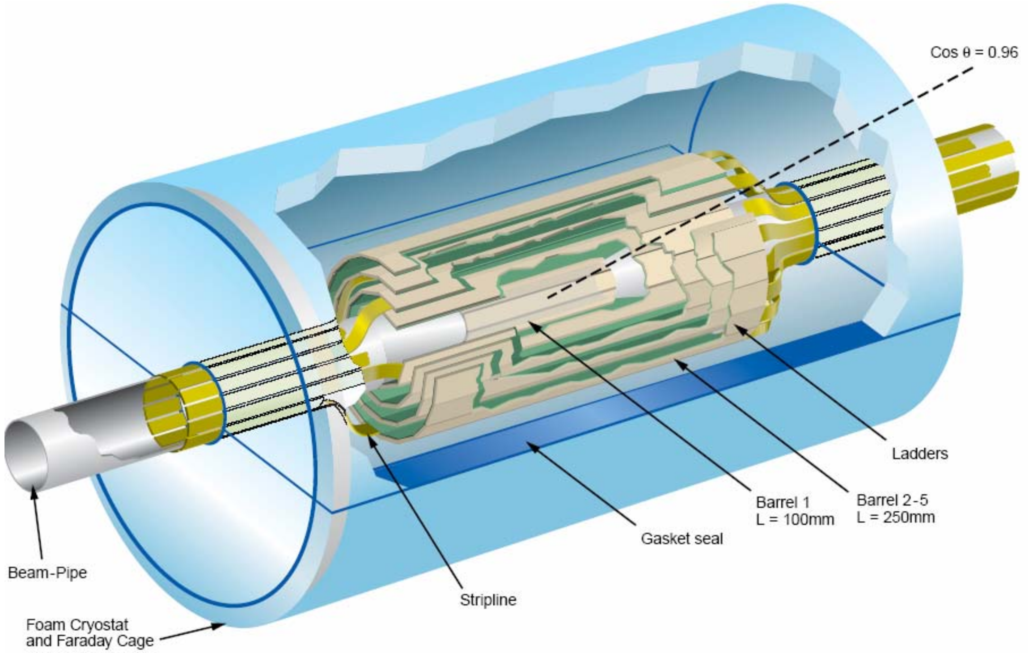
LumiCal: 26 < θ < 82 mrad
BeamCal: 4 < θ < 28 mrad
PhotoCal: 100 < θ < 400 μrad

Vertex detector

Technologies

CAP
CPCCD
DEPFET
FAPS
FPCCD
HAPS
ISIS – edge readout
ISIS – distributed readout
MAPS – transverse readout
MAPS-digital
SoI
Macro-pixel/Micro-pixel sandwich

(probably incomplete!)



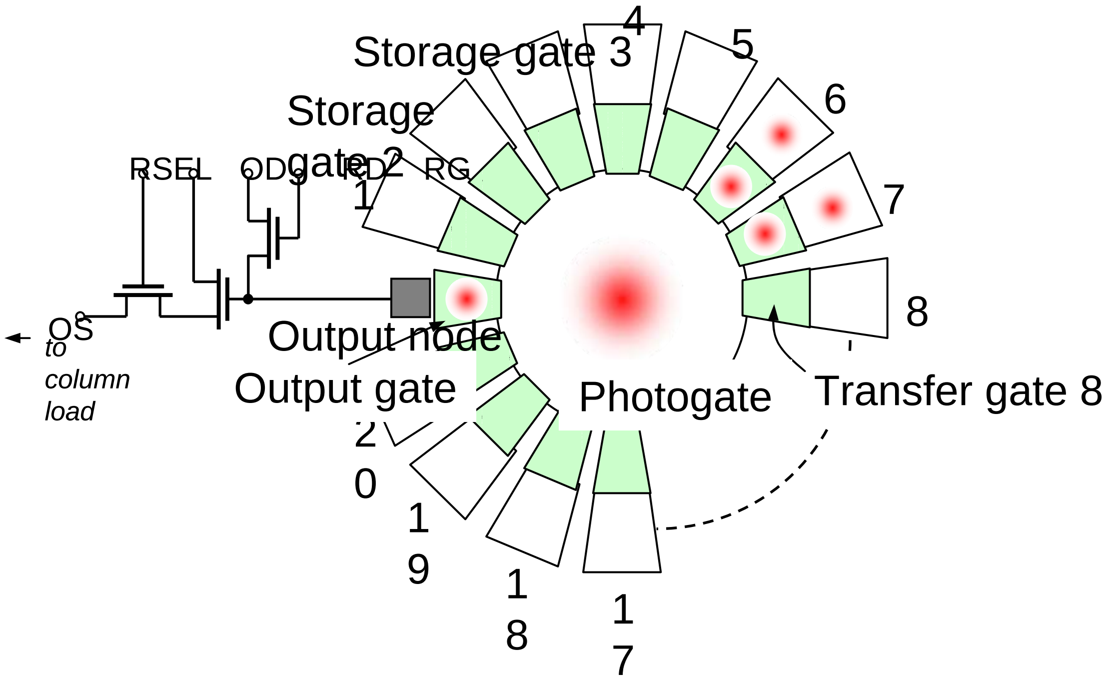
Giga pixel

- Thinner
- Faster
- Closer

than SLD

Revolver ISIS

- New idea: combine CCD and active pixel
- ISIS: In situ image storage
- 20 px in-situ storage CCD
- Read-out (charge to voltage) in quiet period between bunch trains
  - Reduced EMI sensitivity



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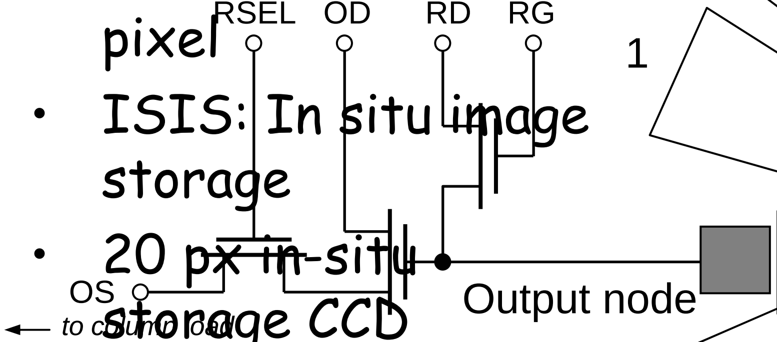
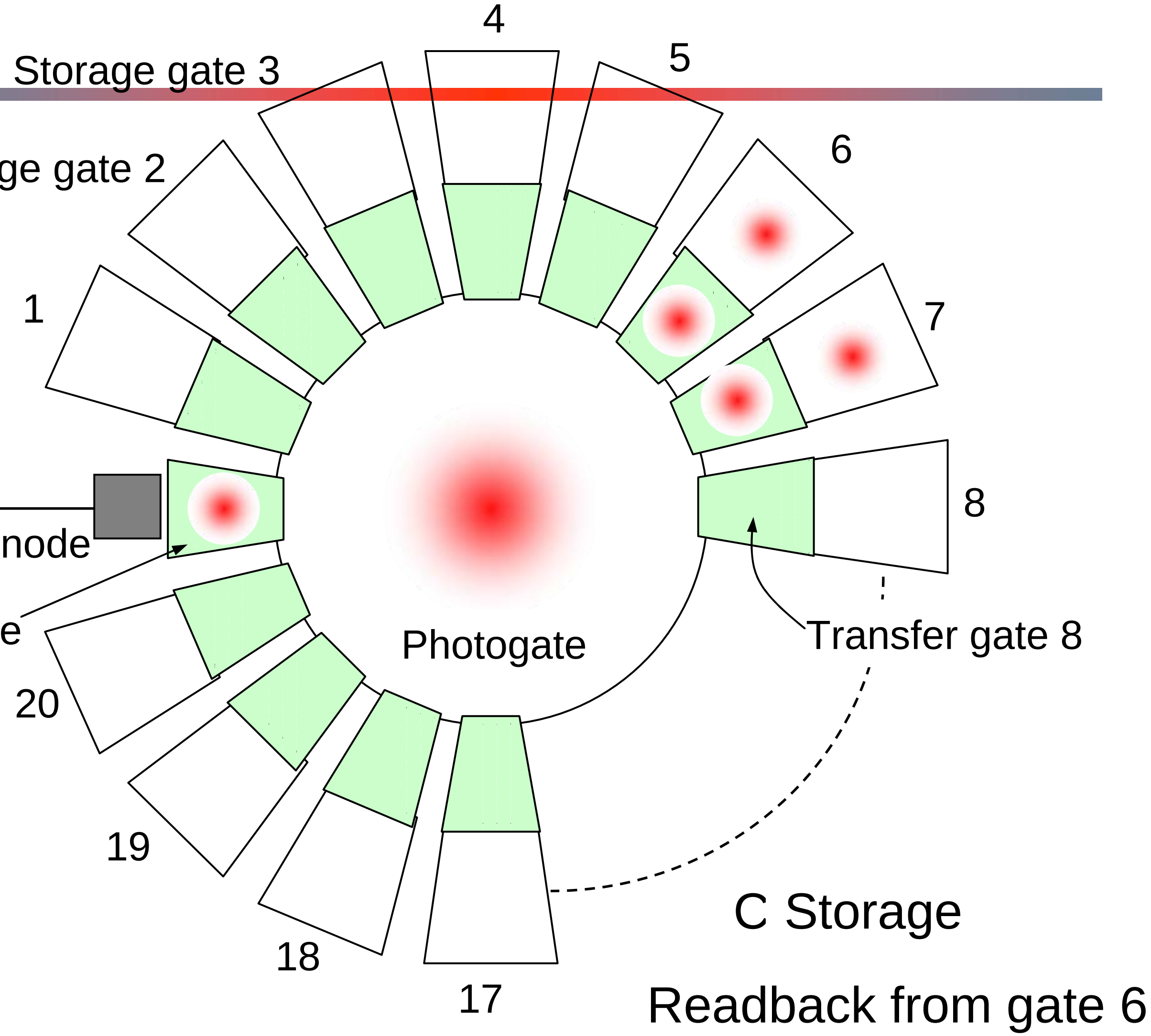
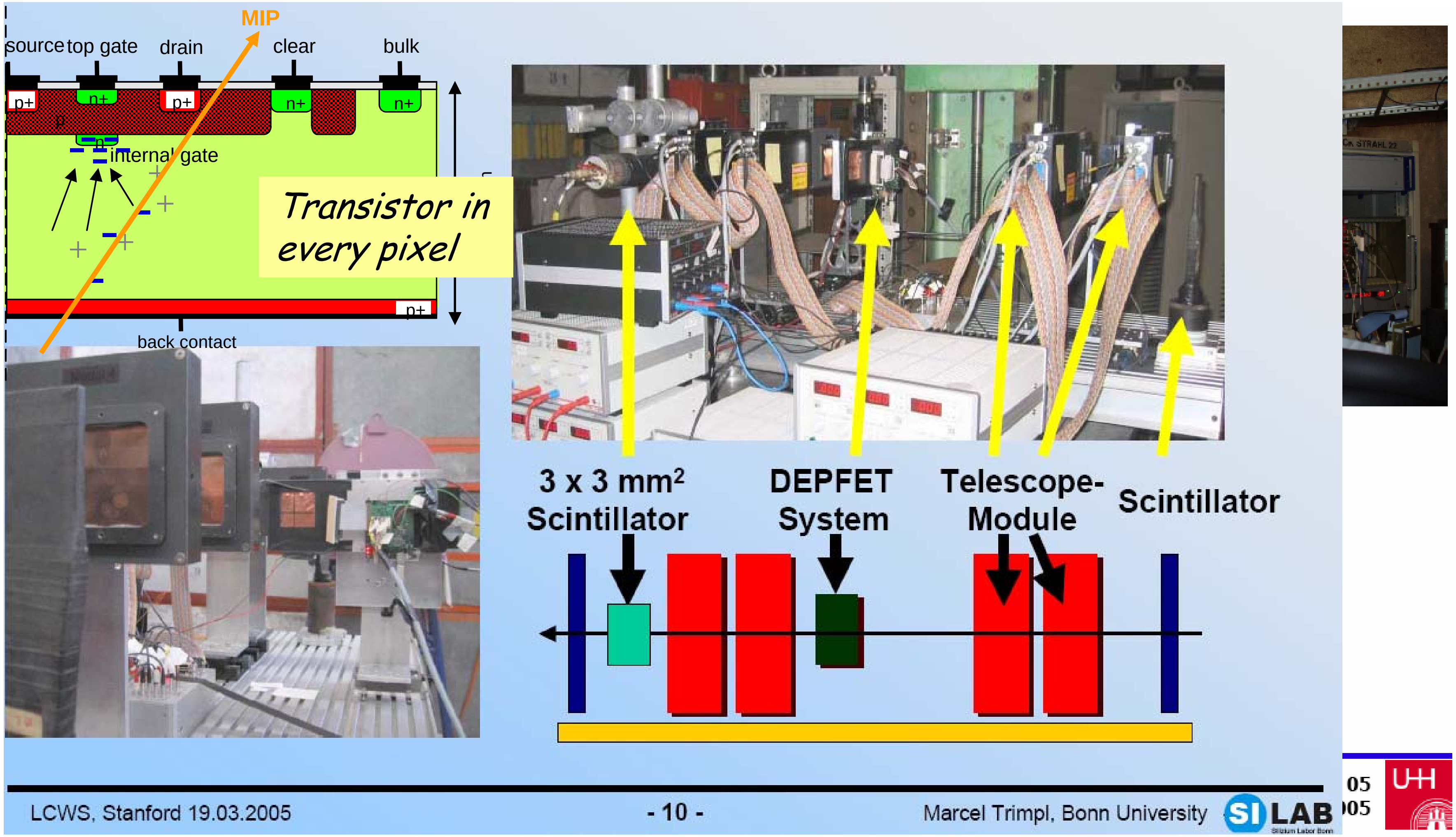


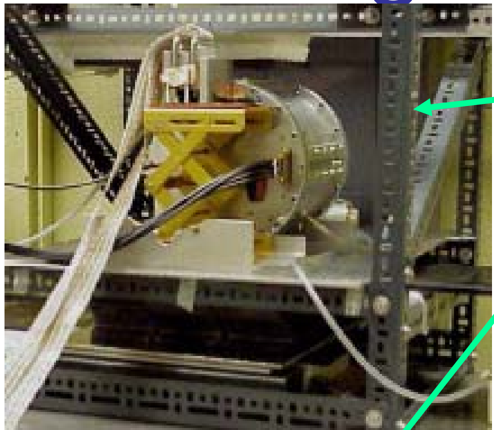


Idea by D. Burt and R. Bell (E2V)

Beam tests at DESY

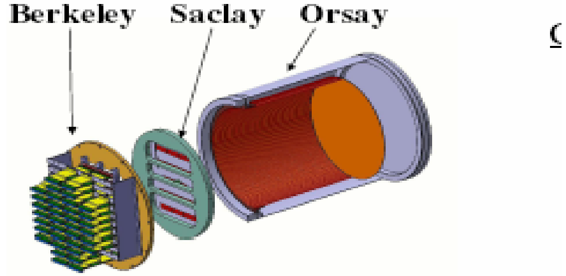


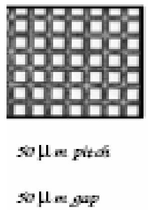
Tracking Detector: TPCs

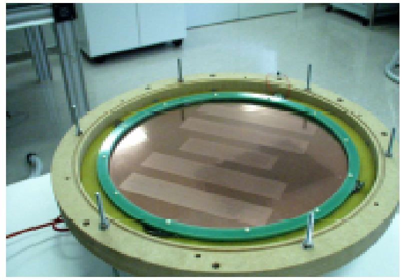


Carleton, Aachen, Desy(not shown) for B=0 studies with laser or cosmics

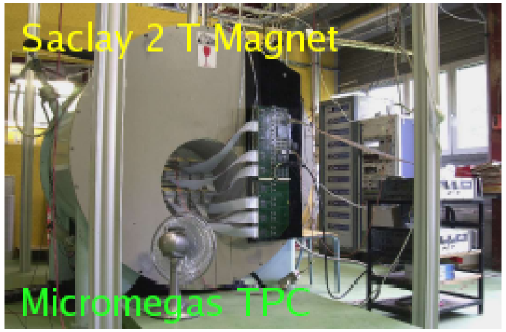
Desy, Victoria, Saclay (fit in 2-5T magnets)

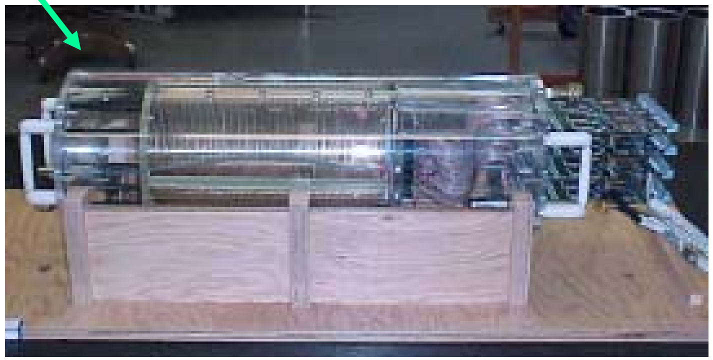




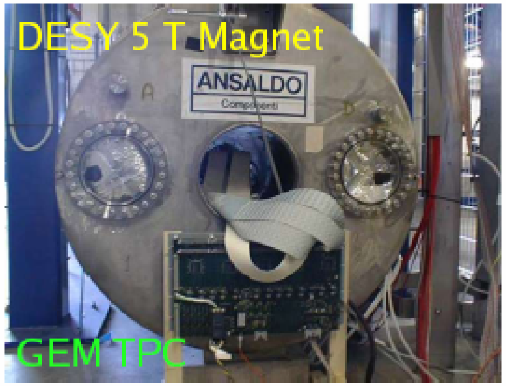


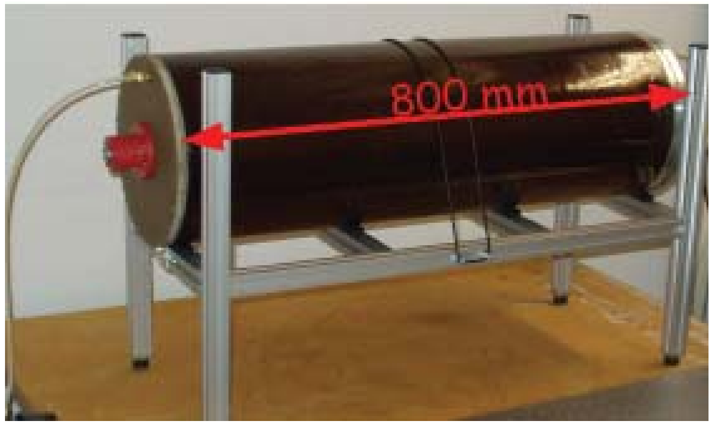
Saclay, Orsay, Berkeley





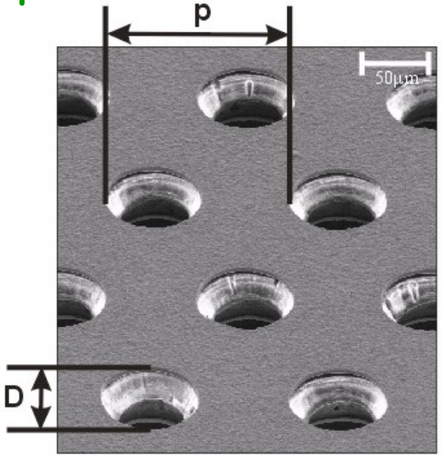
University of Victoria, DESY





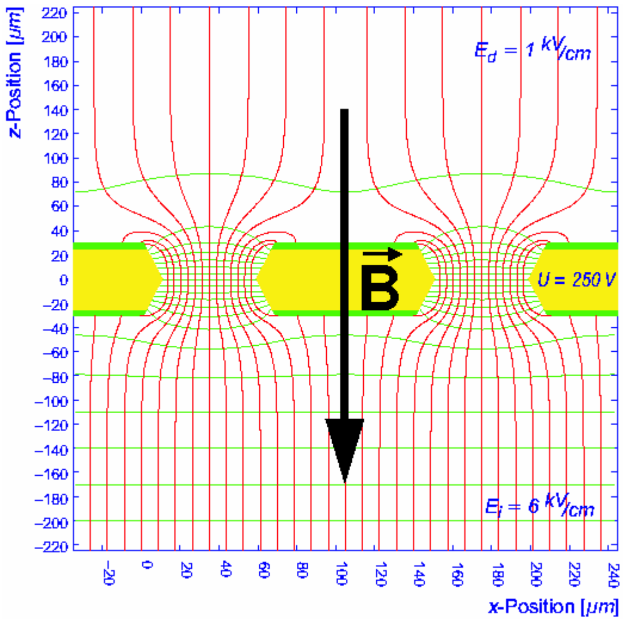
Gas-Amplification Systems: Wires & MPGDs→

GEM: Two copper foils separated by kapton, multiplication takes place in holes, uses 2 or 3 stages

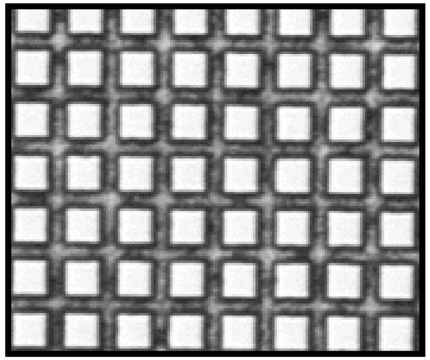


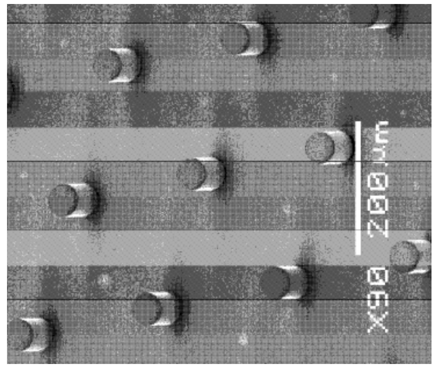
P~140 µm

D~60 µm

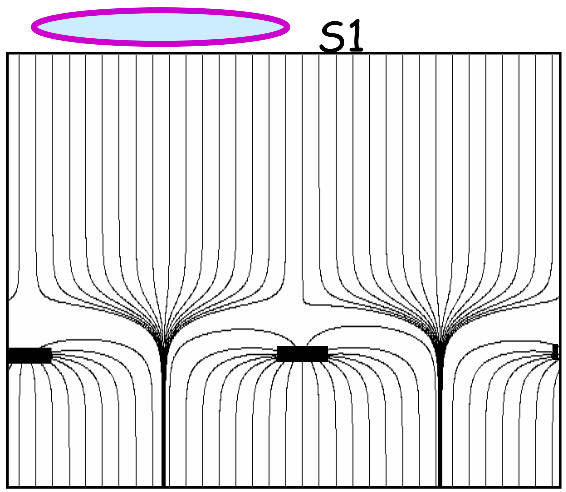


Micromegas: micromesh sustained by 50µm pillars, multiplication between anode and mesh, one stage



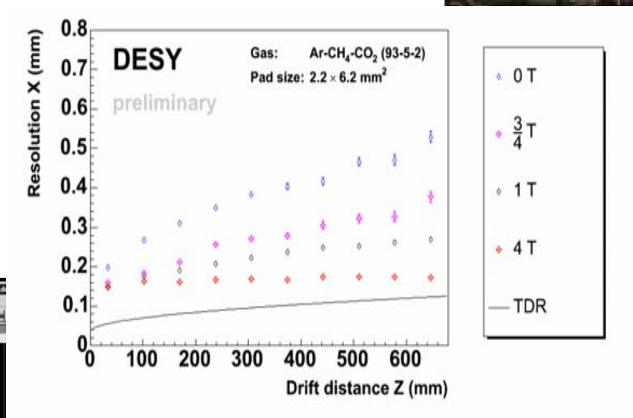


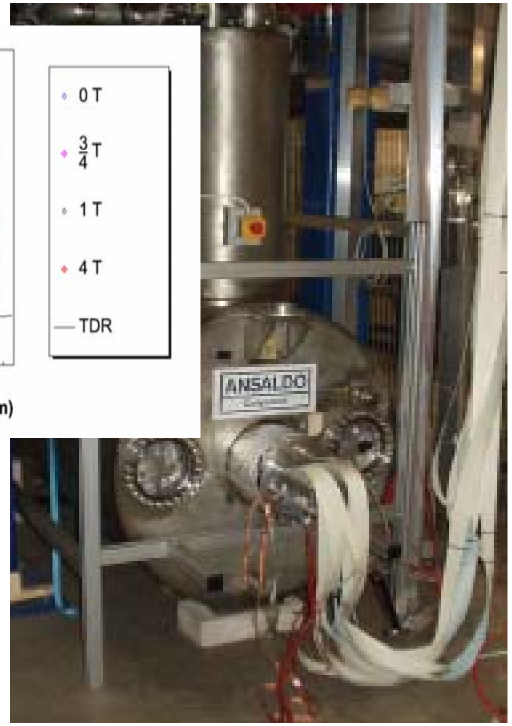
S1/S2 ~ Eamplif / Edrift

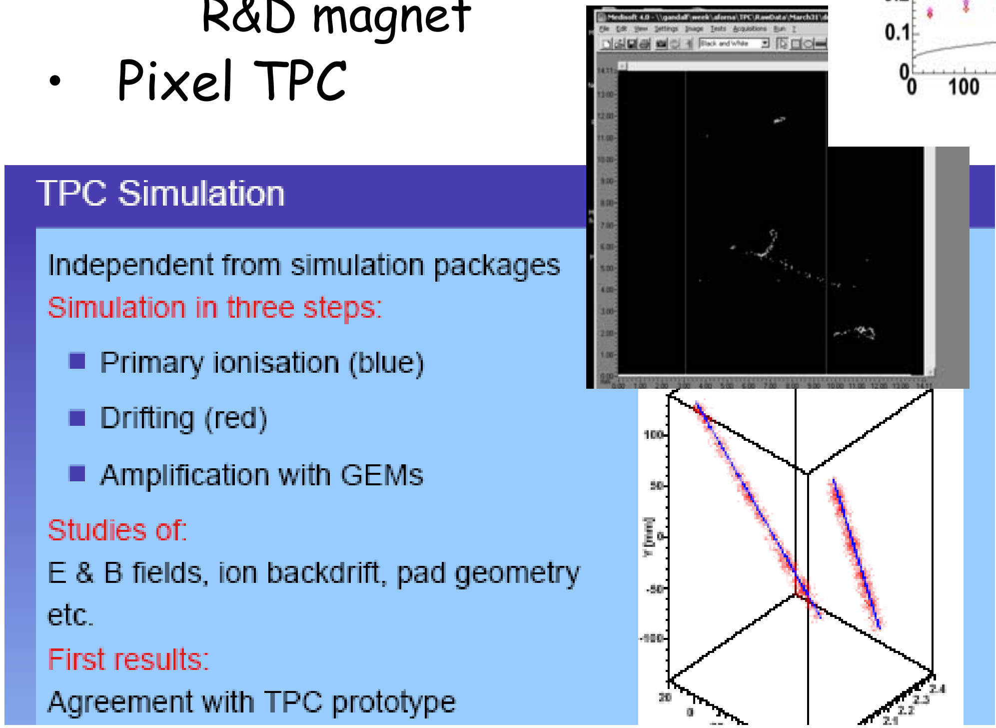


Understand GEM TPCs

- (and Micromegas)
- Tests in magnetic fields
  - Results from customers from all regions in DESY R&D magnet
- Pixel TPC



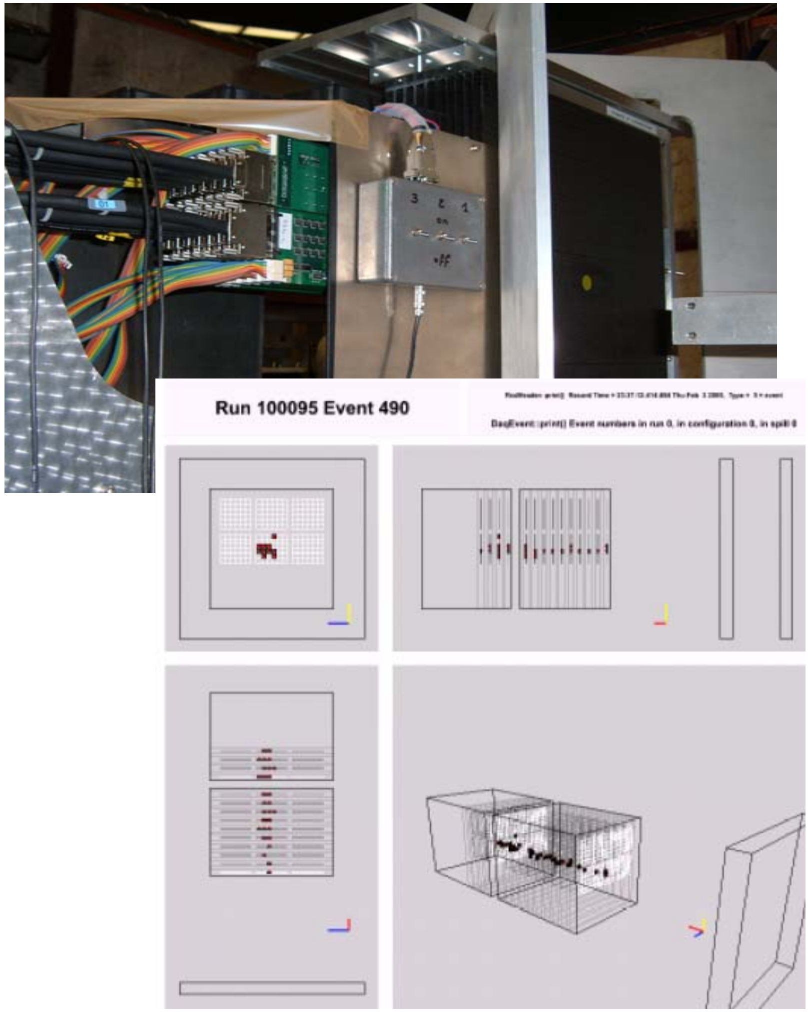




- Next: larger system(!)
- Electronics
  - DAQ kick-started since bunch structure known

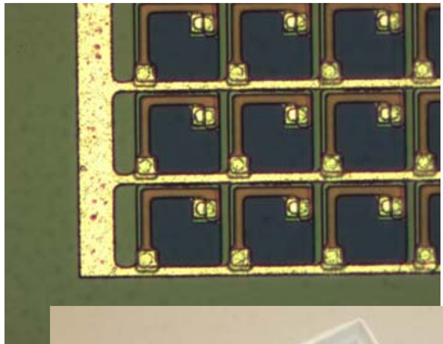
Calorimeter R&D

- ECAL: main option Si W
  - Demonstrate feasibility of ultra-compact systems
  - CALICE test beam at DESY
  - SLAC Oregon test wafers
  - Korean groups testbeam at CERN
- HCAL: gaseous or scintillator,
  - Understand hadron showers
  - Gaseous: RPC and GEM R&D
  - Scintillator: new possibilities with small Geiger mode photo-sensors ("SiPMs")
  - Prototype construction at DESY
- Photodector R&D
  - E.g. Hamamatsu SiPMs

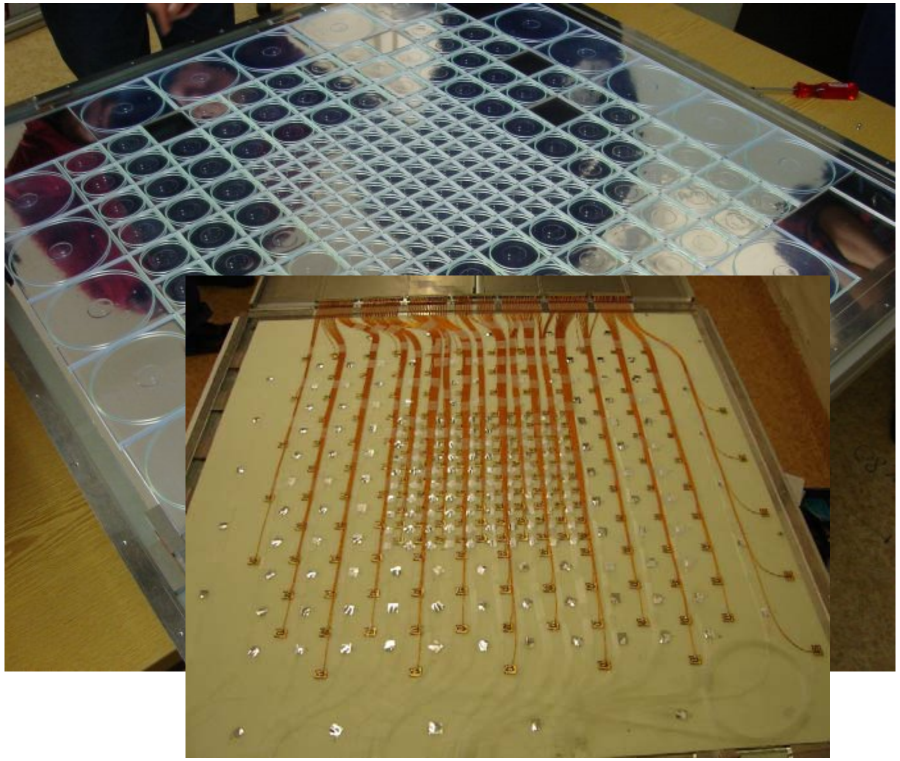


Scintillator HCAL

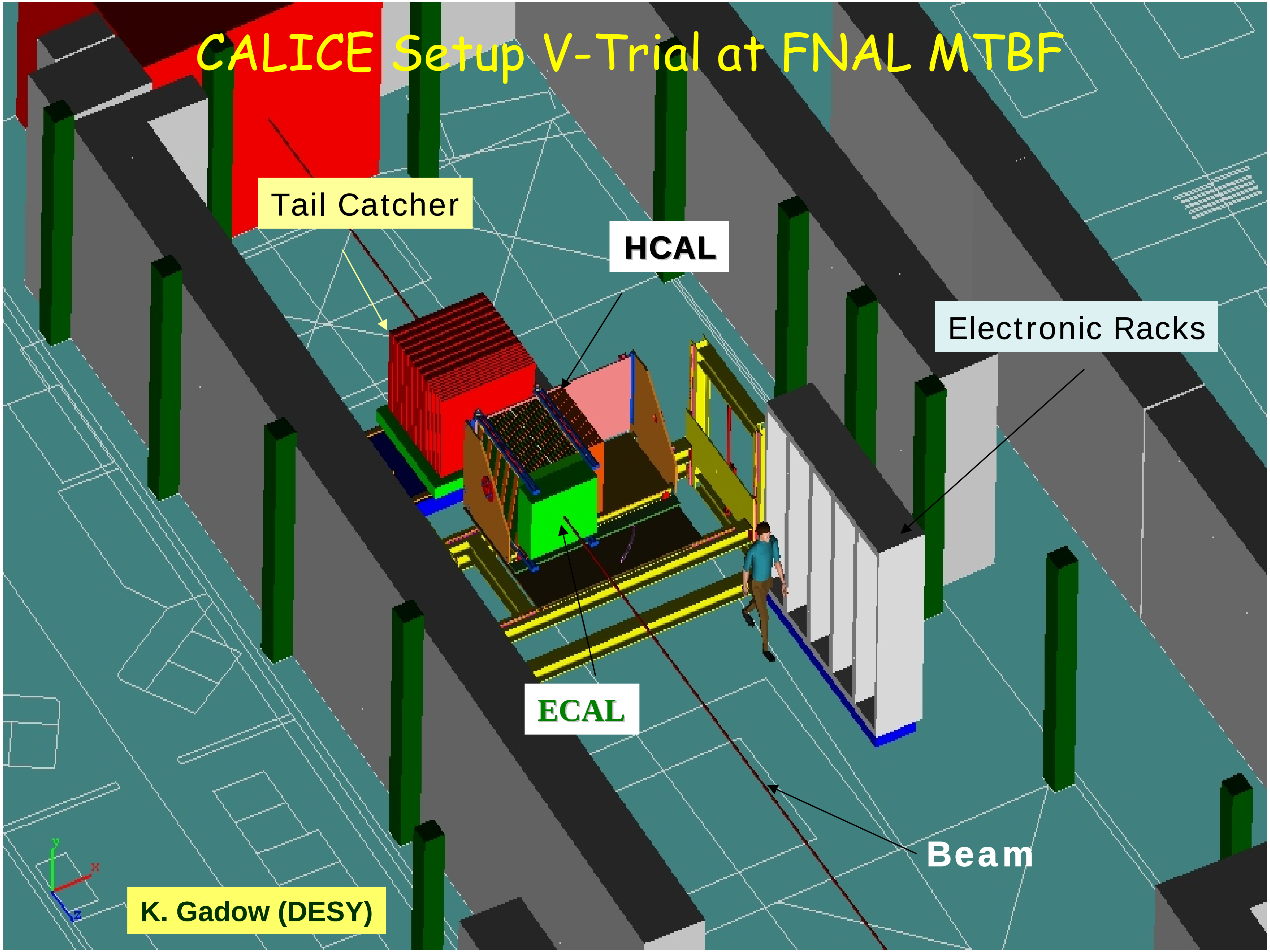
- Czech, France, Germany, Russia, UK, US
- Technical support from H1, ZEUS, FEB, ZE,...



SiPM:
1000 px on 1 mm^2



CALICE Setup V-Trial at FNAL MTBF



Summary

- Physics: “The scientific imperative is compelling.” (Dorfan)
- Organization and timelines: “Things start to roll.” (Yamamoto)
- Machine: “Working at furious pace towards CDR baseline configuration.” (Markiewicz)
- **Detector:** a challenge. Conceptual design choices to be made on “ambitious timescale” (Behnke). R&D on new technologies “critical” (White).
- DESY: a highly visible player in all ILC aspects.