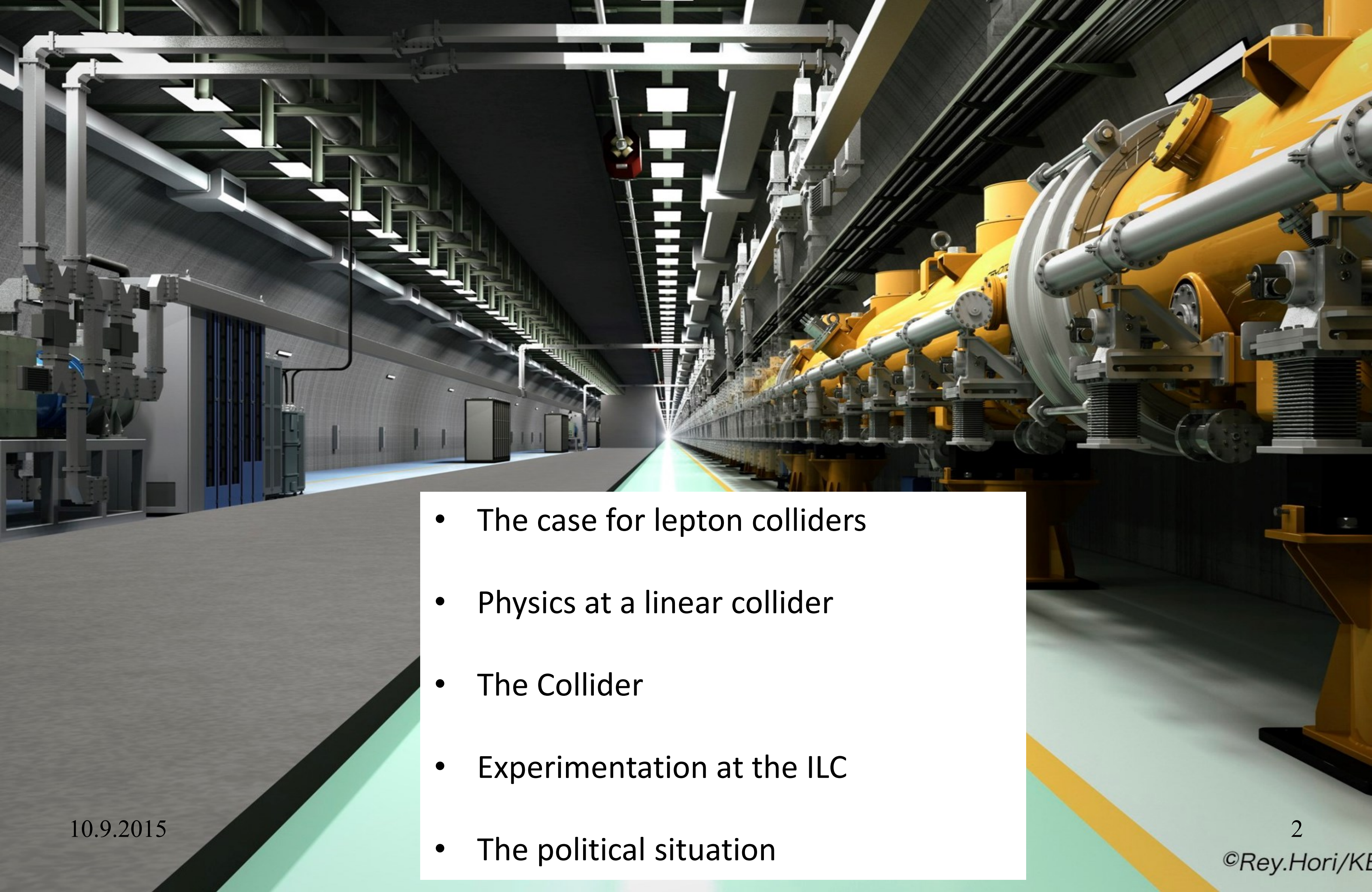
Linear Colliders: ILC

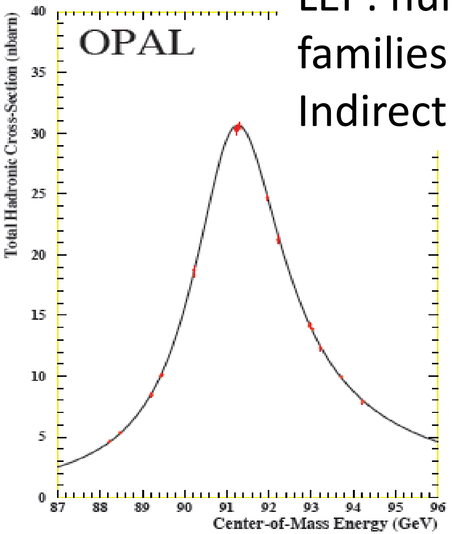
Corfu Summer Institute 2015

Ties Behnke, DESY



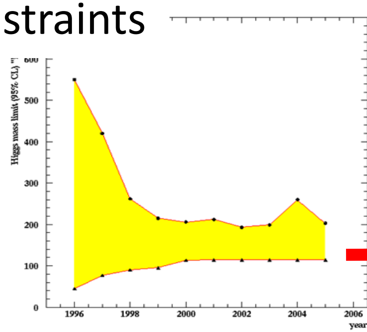
- The case for lepton colliders
- Physics at a linear collider
- The Collider
- Experimentation at the ILC
- The political situation

THE SUCCESS OF THE STANDARD MODEL

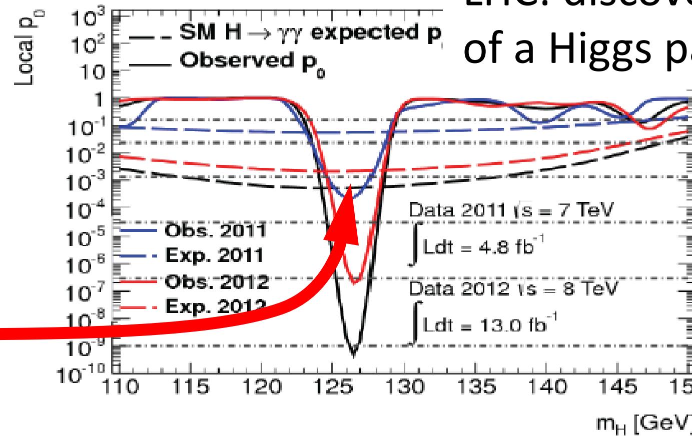


LEP: number of families

Indirect constraints



LHC: discovery of a Higgs particle



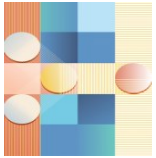
Theoretical ideas:

- Supersymmetry
- Extra Dimensions
- Compositness
- …

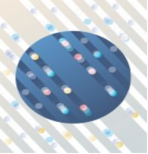
Many effects which are outside the scope of the Standard Model:

- dark matter
- baryogenesis
- quantum numbers of quarks and leptons
- neutrino mass
- dark energy and cosmic inflation
- …

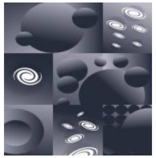
KEY CHALLENGES



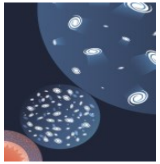
1. Use the Higgs Boson as a new tool for discovery



2. Pursue the physics associated with neutrino mass



3. Identify the new physics of dark matter



4. Understand cosmic acceleration: dark energy and inflation

5. Explore the unknown: new particles, interactions, and physical principles

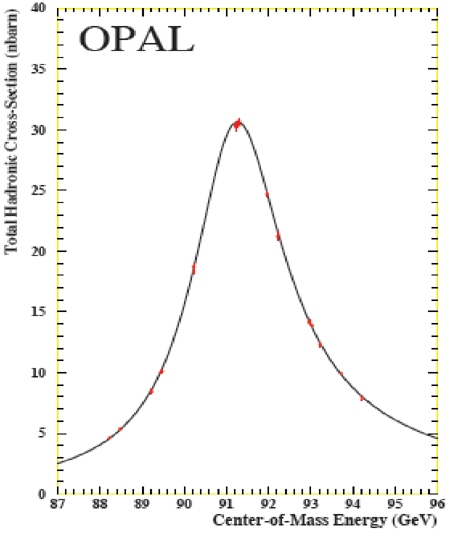
From the P5 report 2014

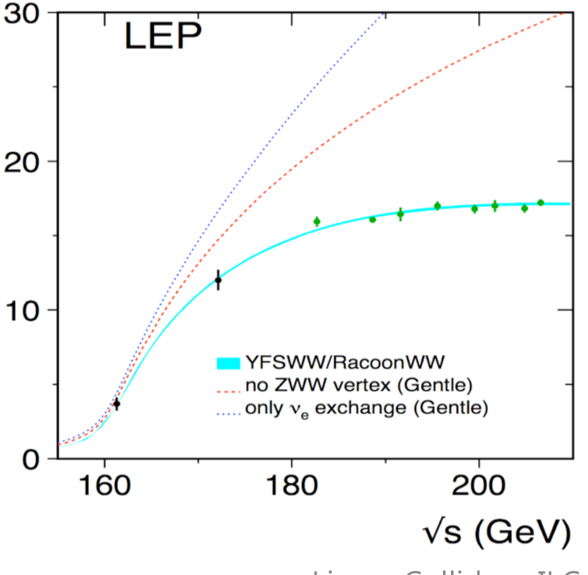
LEPTON COLLIDERS

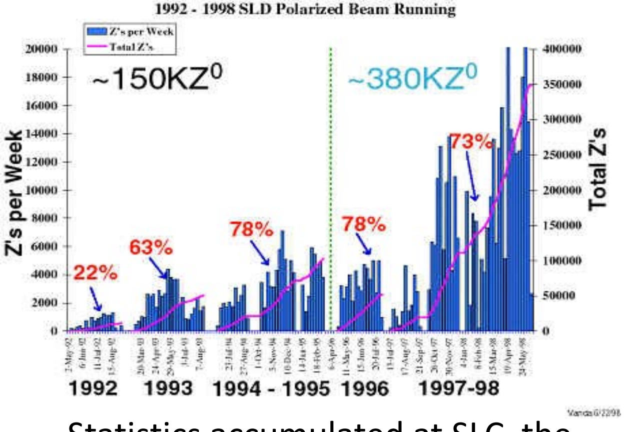
LEP tunnel

Long history of successful lepton colliders:

- Last high energy colliders: SLC at SLAC, until 1998, LEP at CERN, until 2000

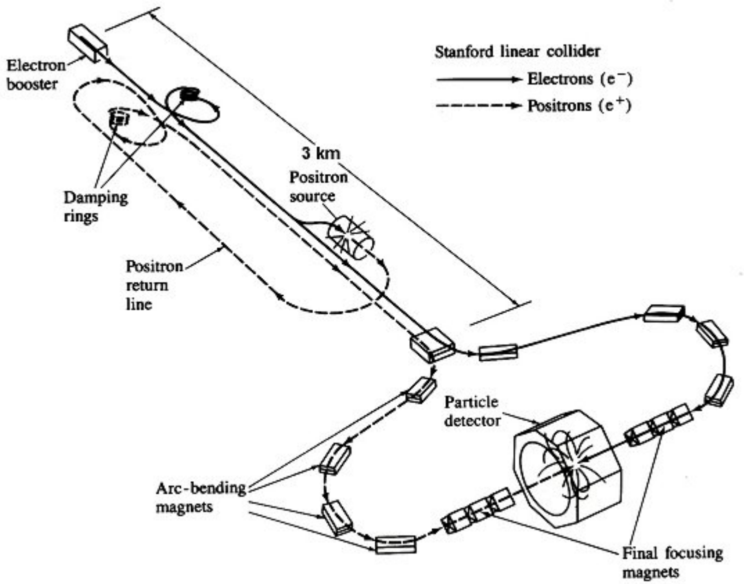


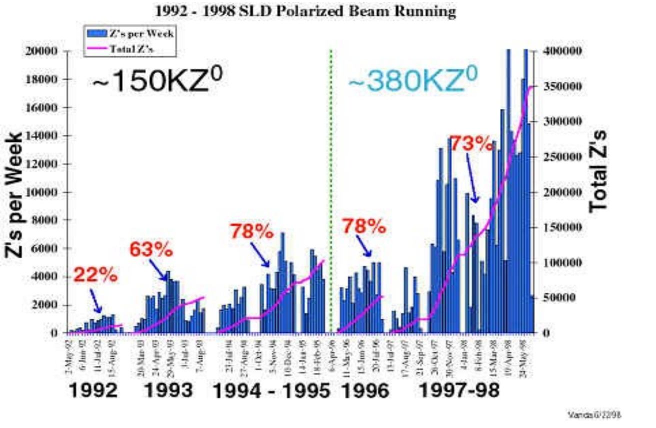




Statistics accumulated at SLC, the worlds only linear collider so far

SLC: THE WORLDS FIRST LC





A Possible Apparatus for Electron-Clashing Experiments (*).

M. Tigner

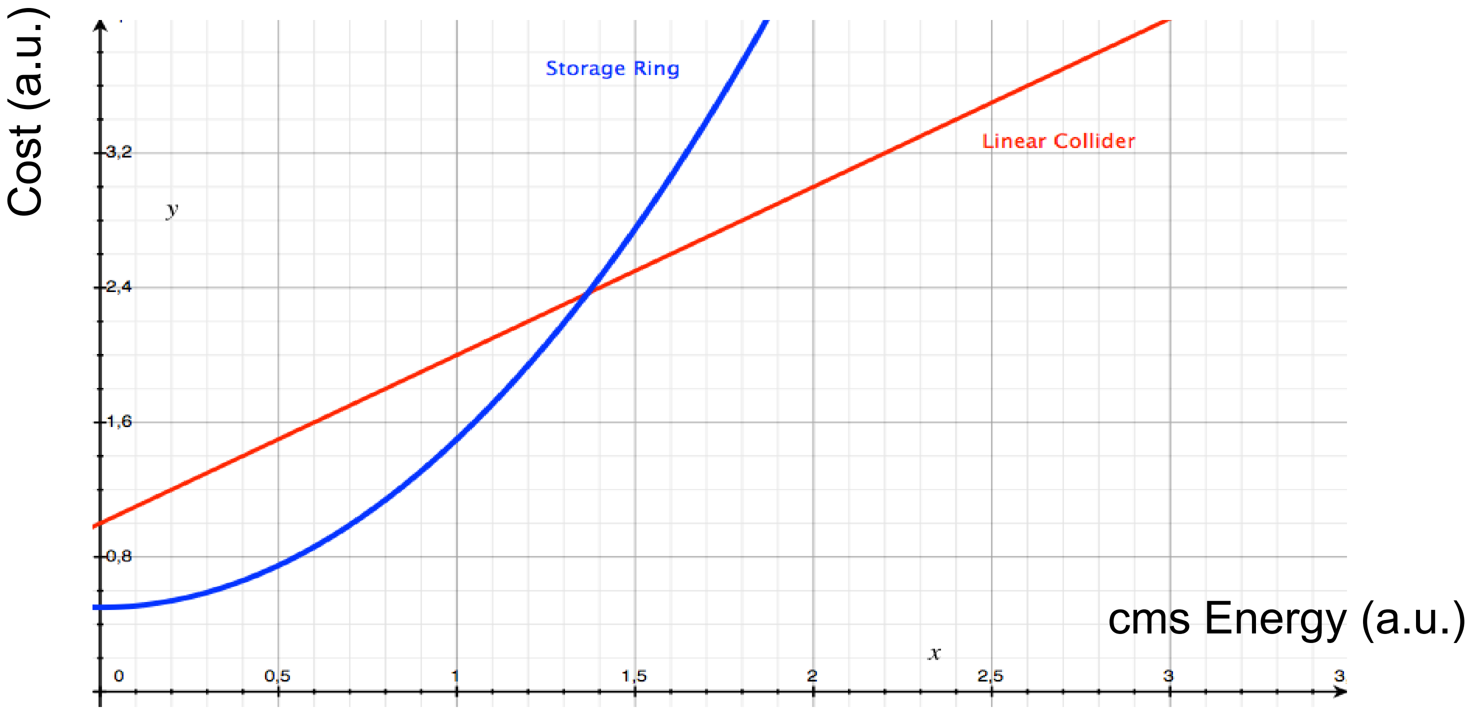
Laboratory of Nuclear Studies. Cornell University - Ithaca, N.Y.

Nuovo Cimento **37** (1965) 1228

"While the storage ring concept for providing clashing-beam experiments ([1]) is very elegant in concept it seems worth-while at the present juncture to investigate other methods which, while less elegant and superficially more complex may prove more tractable."

ACCELERATORS

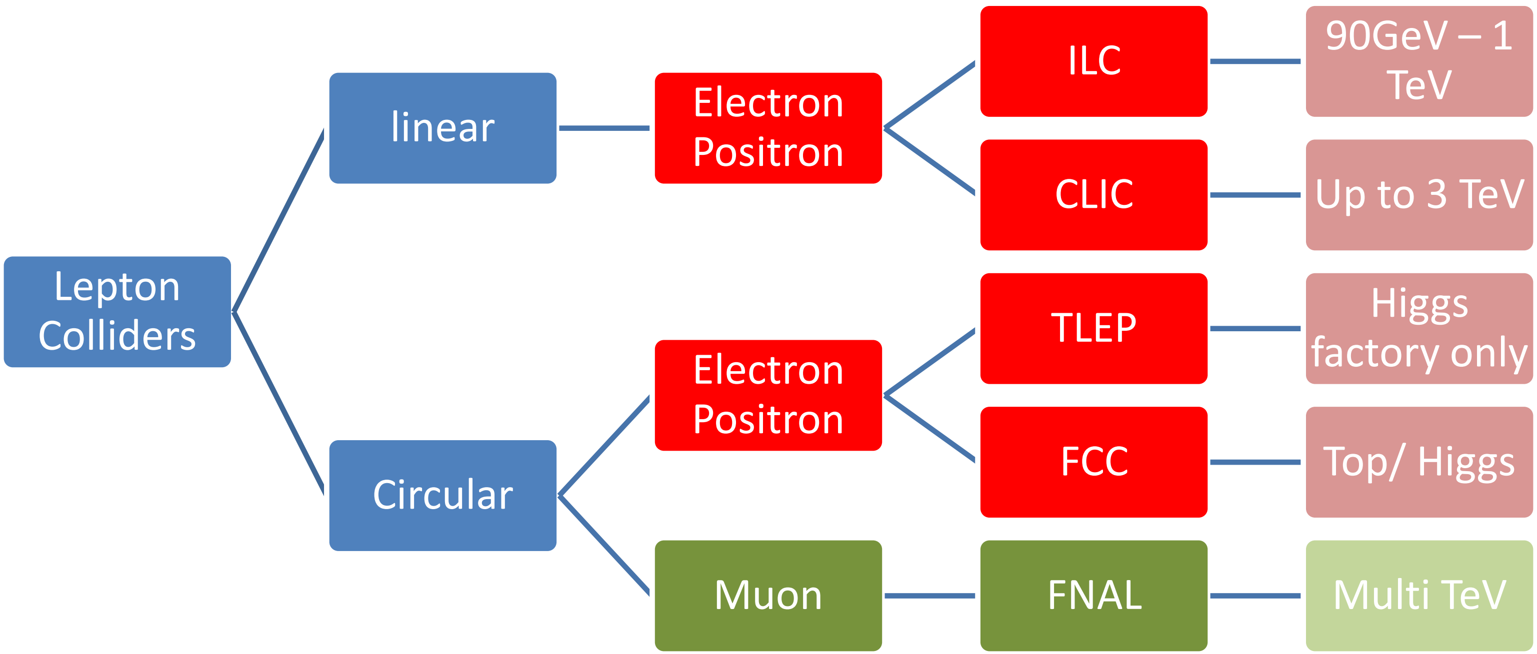
Cost Scaling



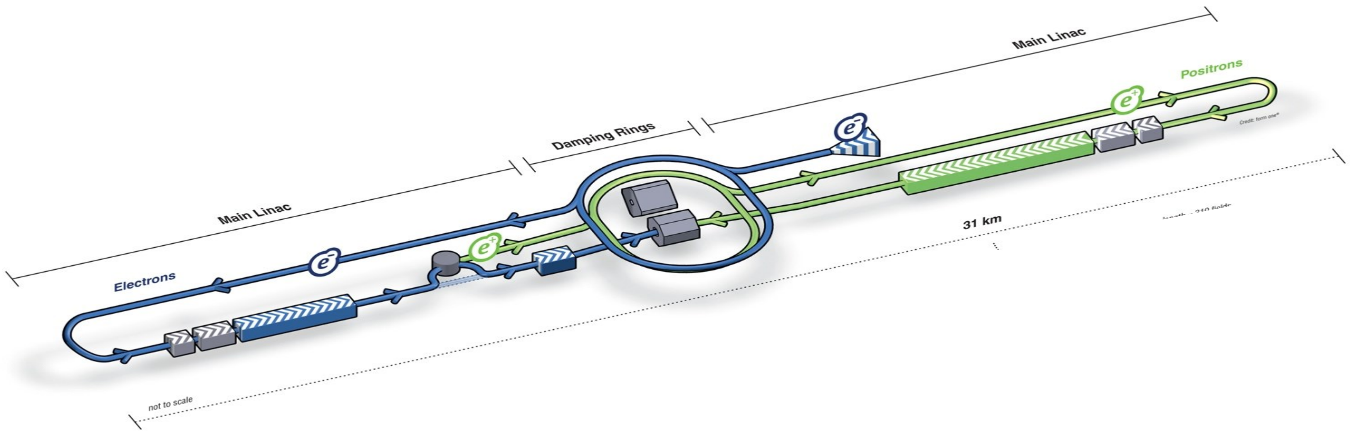
Linear colliders are the economical choice above ~220± GeV cms energy

Lepton Colliders

A number of options how to realize a HE lepton facility



CHALLENGES

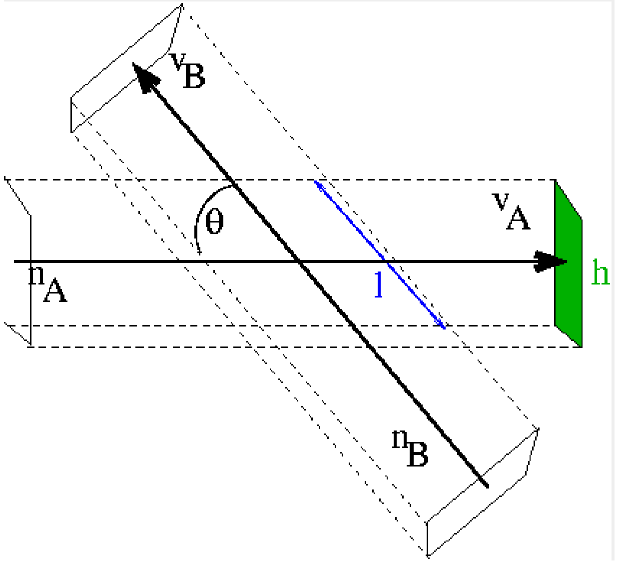


- One pass machines
- Need lots and lots of RF power
- Reaching high luminosity is a big challenge

THE LUMINOSITY CHALLENGE

- The luminosity ($cm^{-2}s^{-1}$) for a collider with Gaussian beams is given by:

$$L = \frac{n_b N^2 f_{rep}}{4\pi \sigma_x \sigma_y} H_D$$



- n_b = bunches per train
- N = particles per bunch
- f_{rep} = repetition frequency
- $4\pi\sigma_x\sigma_y$ = beam cross section at the interaction point
- H_D = beam-beam enhancement factor

The Luminosity Challenge

- Introducing the beam power:

$$n_b N f_{rep} E_{cm} = P_{beams}$$
$$= \eta_{RF \to beam} P_{RF}$$

- yields

$$L = \frac{\left(E_{cm} n_b N f_{rep}\right) N}{4\pi \sigma_x \sigma_y E_{cm}} H_D \longrightarrow L = \frac{\eta_{RF} P_{RF} N}{4\pi \sigma_x \sigma_y E_{cm}} H_D$$

- $\eta_{RF \to beam}$: conversion efficiency RF to beam

RF Power

- Some numbers:
  - E_{cm} = 500 GeV
  - N = 10^{10}
  - n_b = 1000
  - f_{rep} = 10 Hz
  - ⇒ P_{beams} = 8 MW
- adding efficiencies
  - Wall plug ⟶ RF ⟶ beam

    20-60% 30-60%
- yields AC power needs >100 MW just to accelerate beams and maintain luminosity!!!

$$L = \frac{\eta_{RF} P_{RF} N}{4\pi \sigma_x \sigma_y E_{cm}} H_D$$

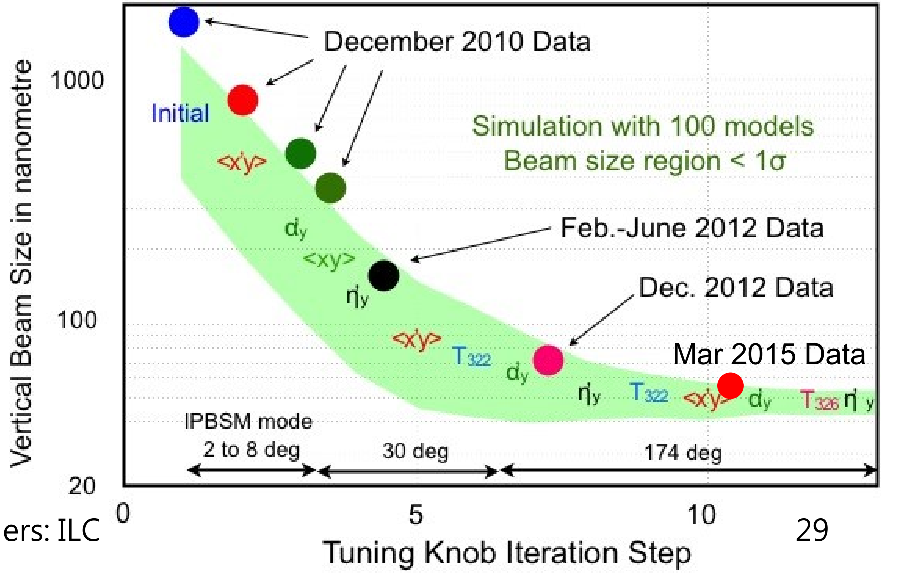
$$L = \frac{n_b N^2 f_{rep}}{4\pi \sigma_x \sigma_y} H_D$$

LUMINOSITY IN A LINEAR COLLIDER

- LEP f_{rep}: 44 kHz
- ILC f_{rep}: few to 100 Hz (power limited)

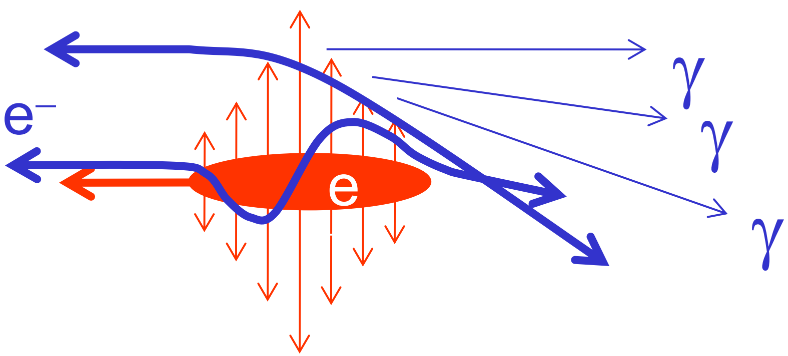
$$L = \frac{n_b N^2 f_{rep}}{4\pi \sigma_x \sigma_y} H_D$$

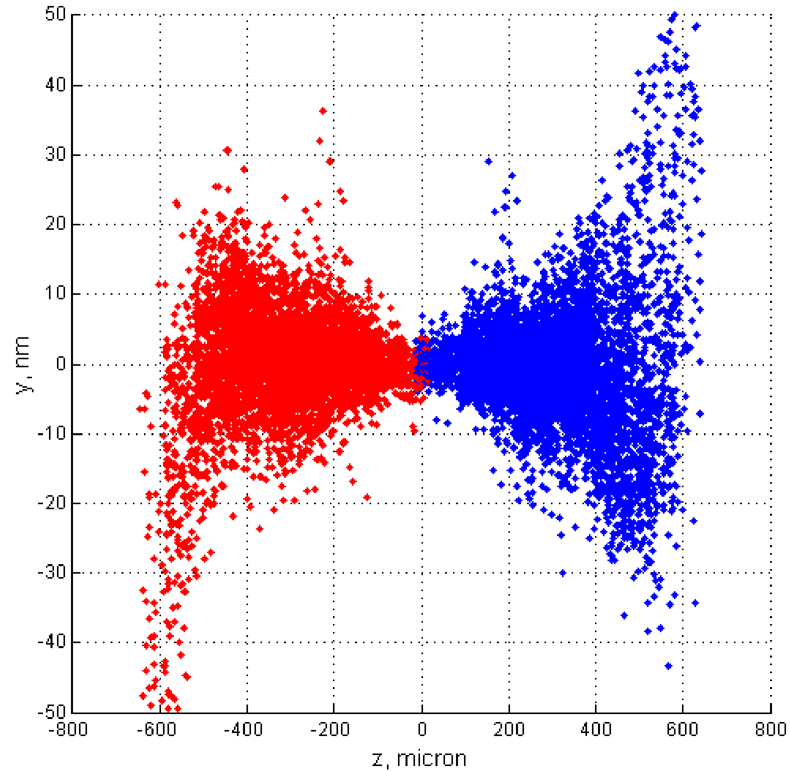
- Factor ~1000 in Luminosity already lost!
- Recover by pushing hard on the beam spot sizes at collision:
  - LEP: 130 x 6 μm^2
  - ILC: 500 x 5 nm^2
- Needed to achieve L=$\mathcal{O}$(10^{34} cm^{-2} s^{-1})



Beam Beam Interactions

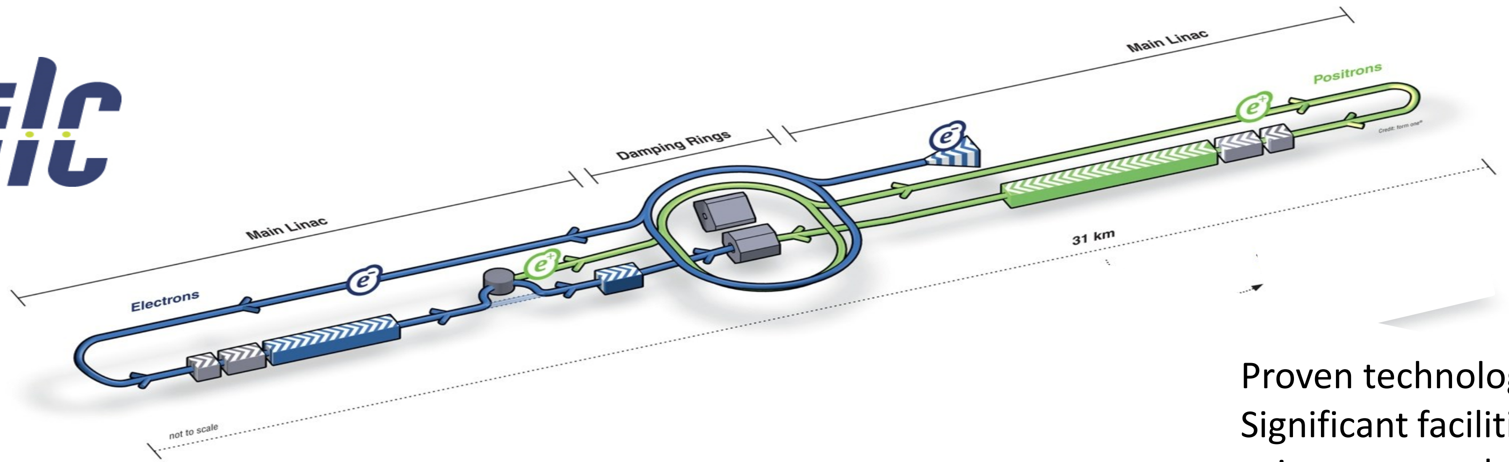
Simulation of two LC bunches as they meet each other





Andrei Sergey, SLAC

The International Linear Collider



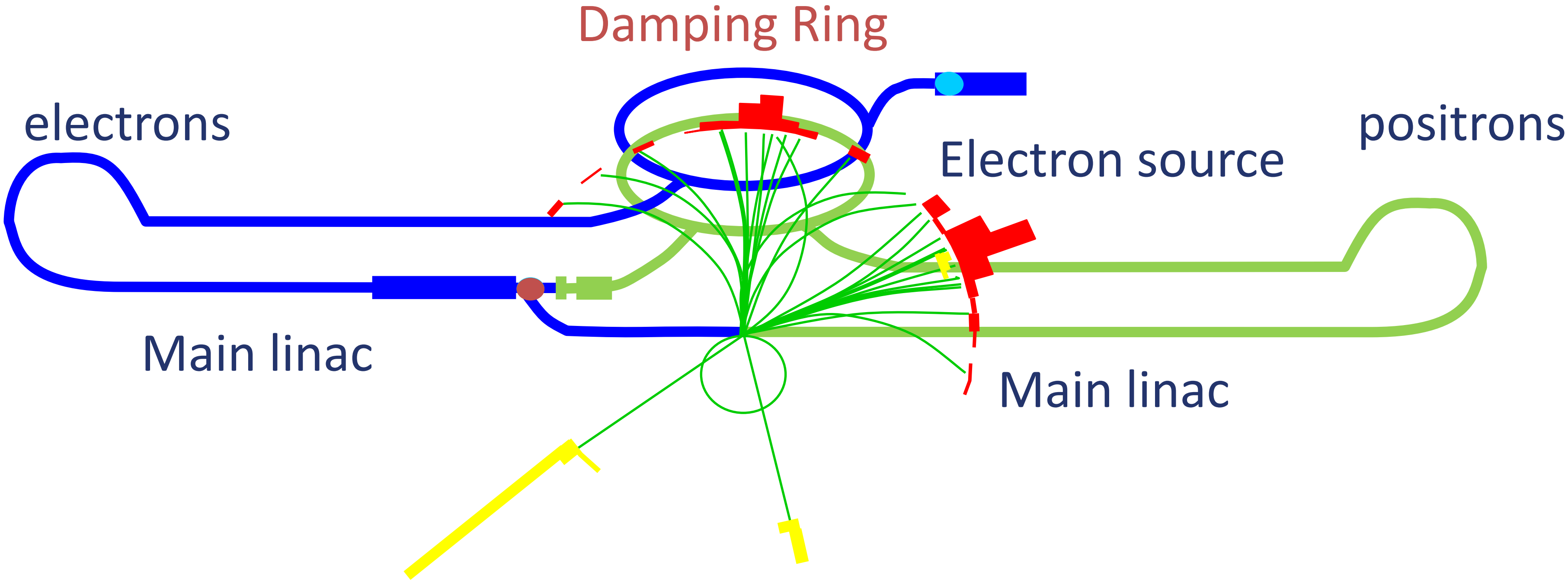
Proven technology
Significant facilities exist or are under construction (XFEL)

The international Linear Collider:

- Electron Positron Collisions
- Superconducting acceleration technology
- High Luminosity at E=500GeV to 1 TeV or lower energies
- About 31km site length
- Gradient of 32 MV/m needed

$$\mathrm{E} = 250\mathrm{GeV} \rightarrow 1\mathrm{TeV}$$
$$\mathrm{L} = 2 \times 10^{34}\mathrm{cm}^{-2}\mathrm{s}^{-1}$$
$500\mathrm{fb}^{-1}$ in 4 years

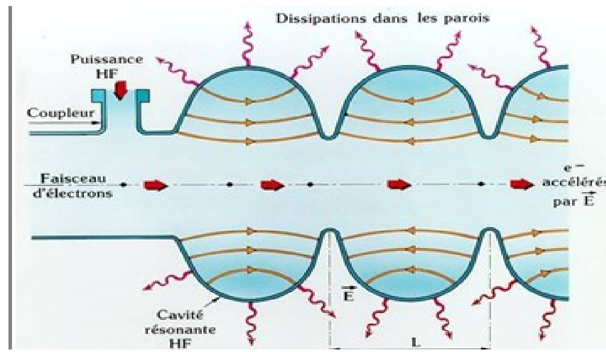
How Does it Work?



Animation by T. Takahashi (Hiroshima)

WHY SUPERCONDUCTING?

- Linear accelerator:
  Accelerate electrons in a
  long string of RF cavities
- Gradient: 31.5MV/m
  → need 15.8km for 500GeV!
- For given total power (electricity bill!),
  luminosity proportional to efficiency
- ILC: total site power
  ~160MW @ 500GeV
- Superconducting cavities
  maximise RF-to-beam efficiency



://www.supraconductivite.fr/media/
ges/Applications/image037.png

RF efficiency RF power

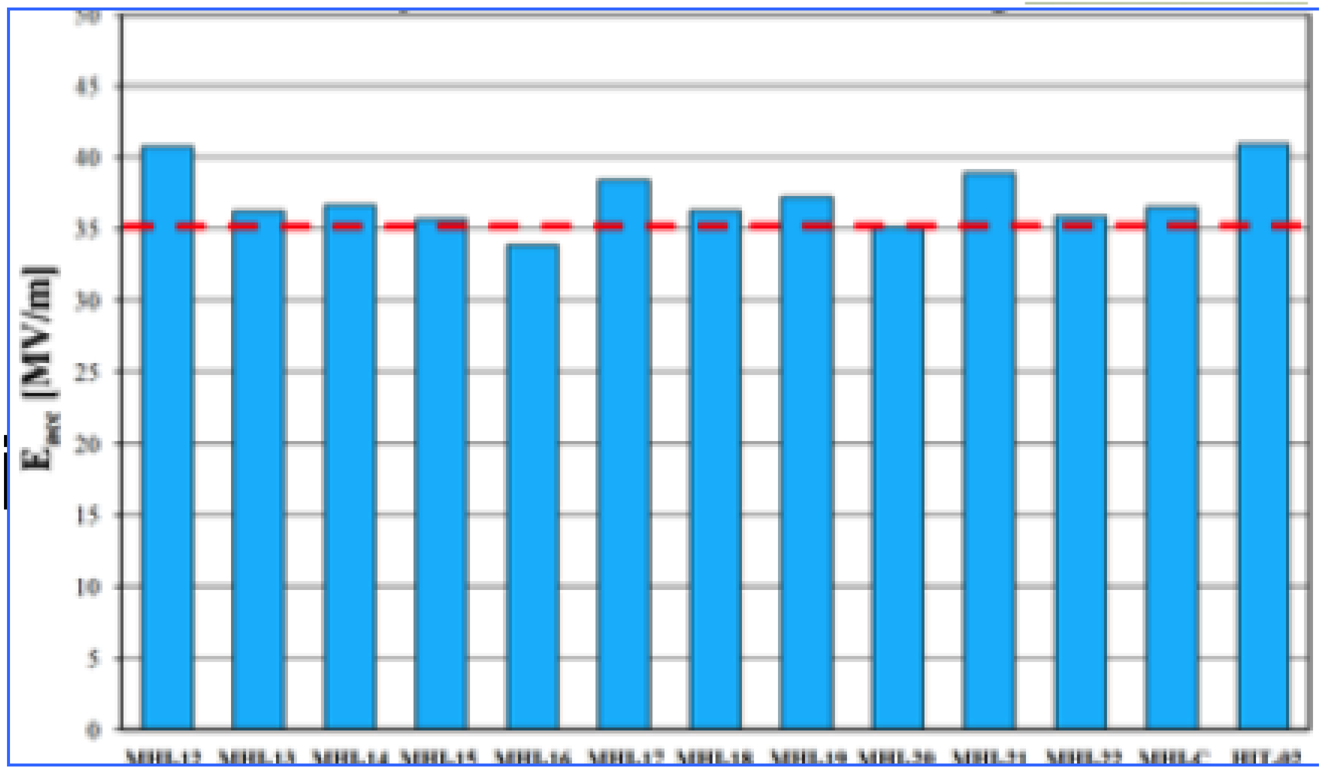
$$L \propto \frac{\eta P_{RF}}{E_{CM}} \sqrt{\frac{\delta_{BS}}{\varepsilon_y}}$$

ILC PERFORMANCE

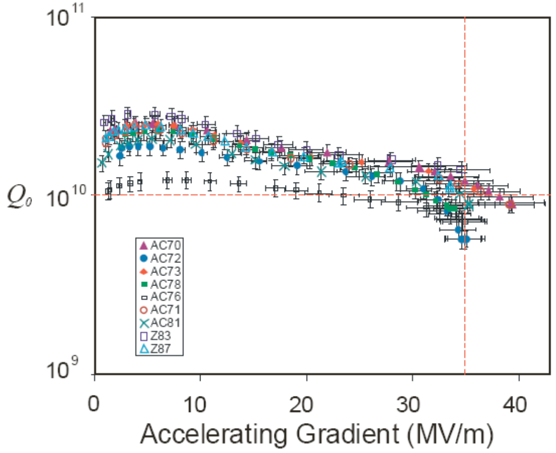
ILC baseline design

- Superconducting
- 31.5 MV/m gradie
- Well developed, t
  cryo modules, int
  accessible.

Proof of high gradient w/ single cells (2)



CAVITY QUALITY (Q VALUE)



- Superconducting cavity: $Q>10^{10}$

- A church bell (300 Hz) with

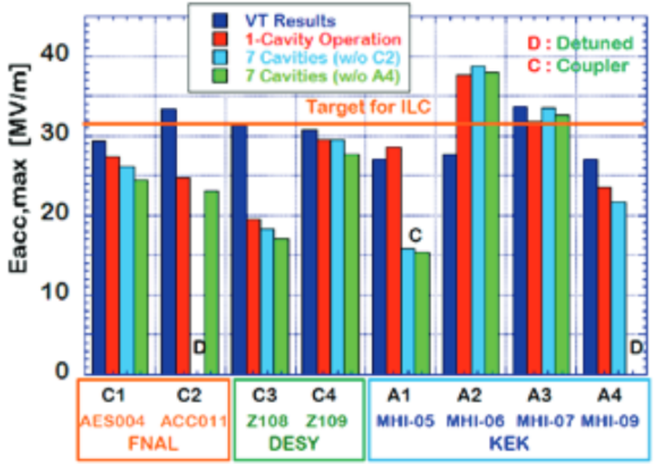
$Q=5 \times 10^{10}$ would ring – once excited – longer than one year!

ILC ACCELLARATOR MODULES

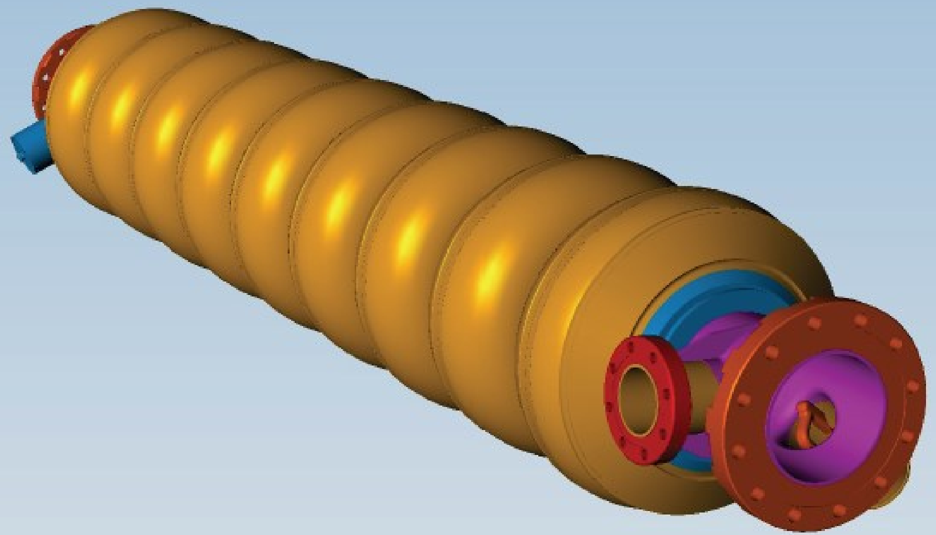
Mature design exists

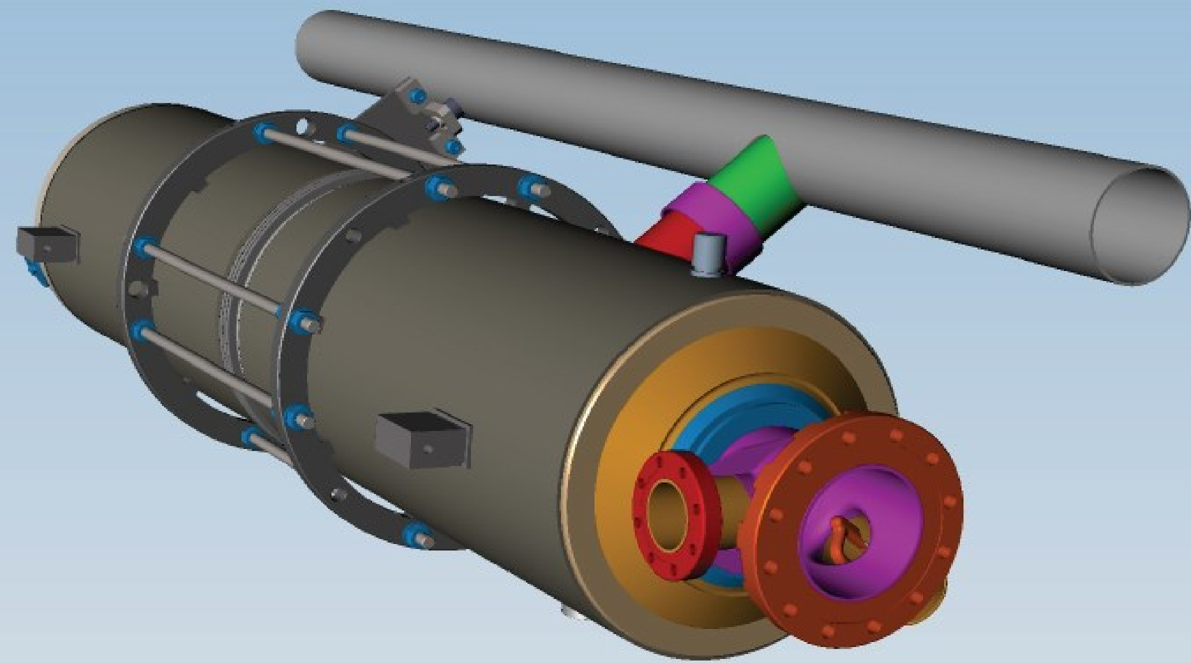
- Used by the XFEL
- Used by the LCLS II light-source at SLAC

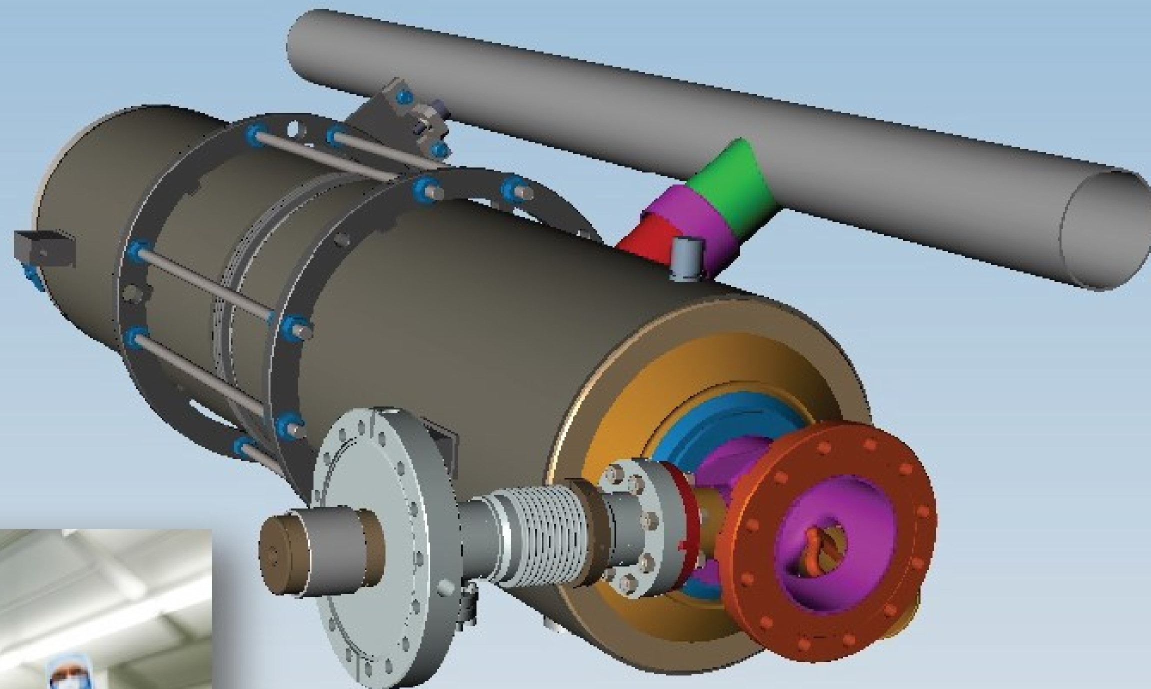
International effort to spread the knowledge

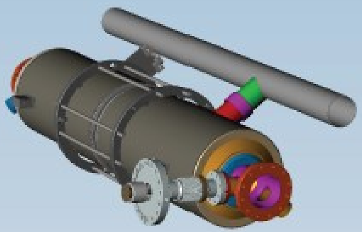


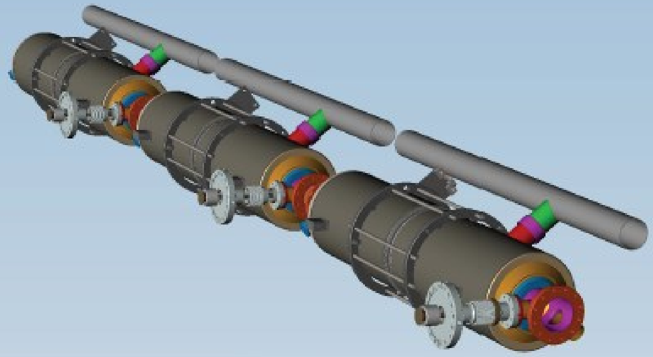
- Modules build in Americas, Asia, Europe
- Plug-compatibility has been achieved

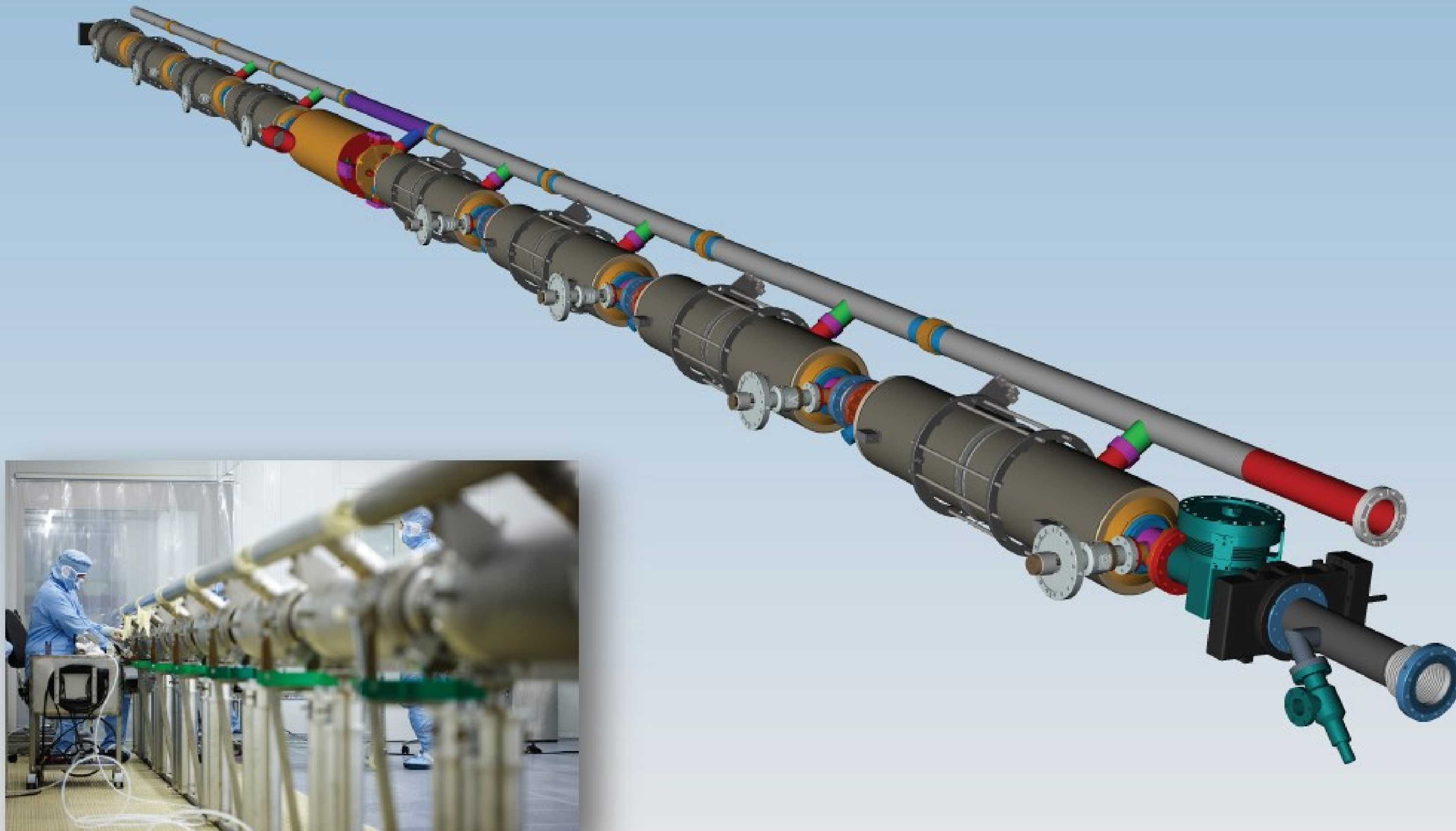


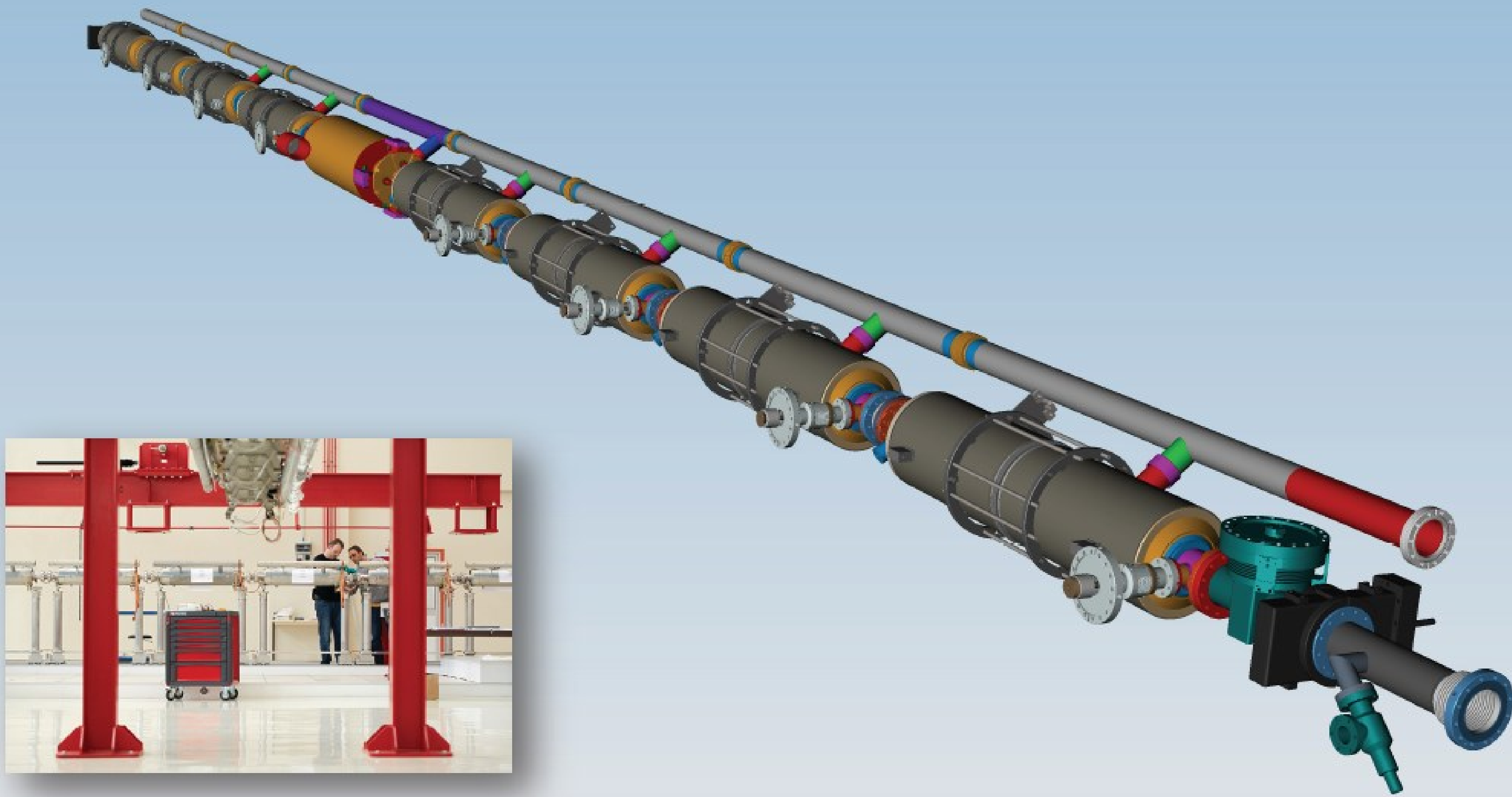


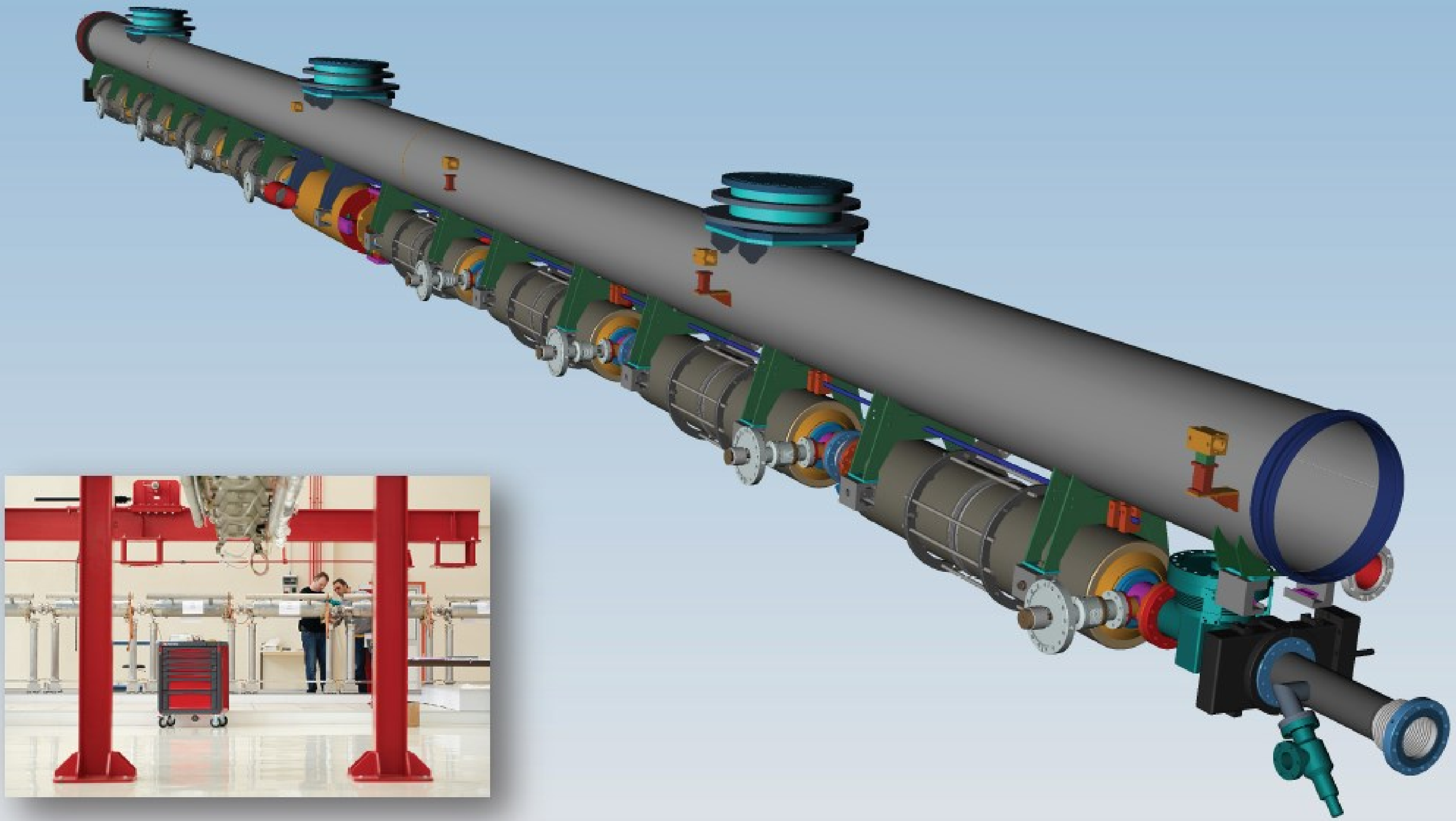


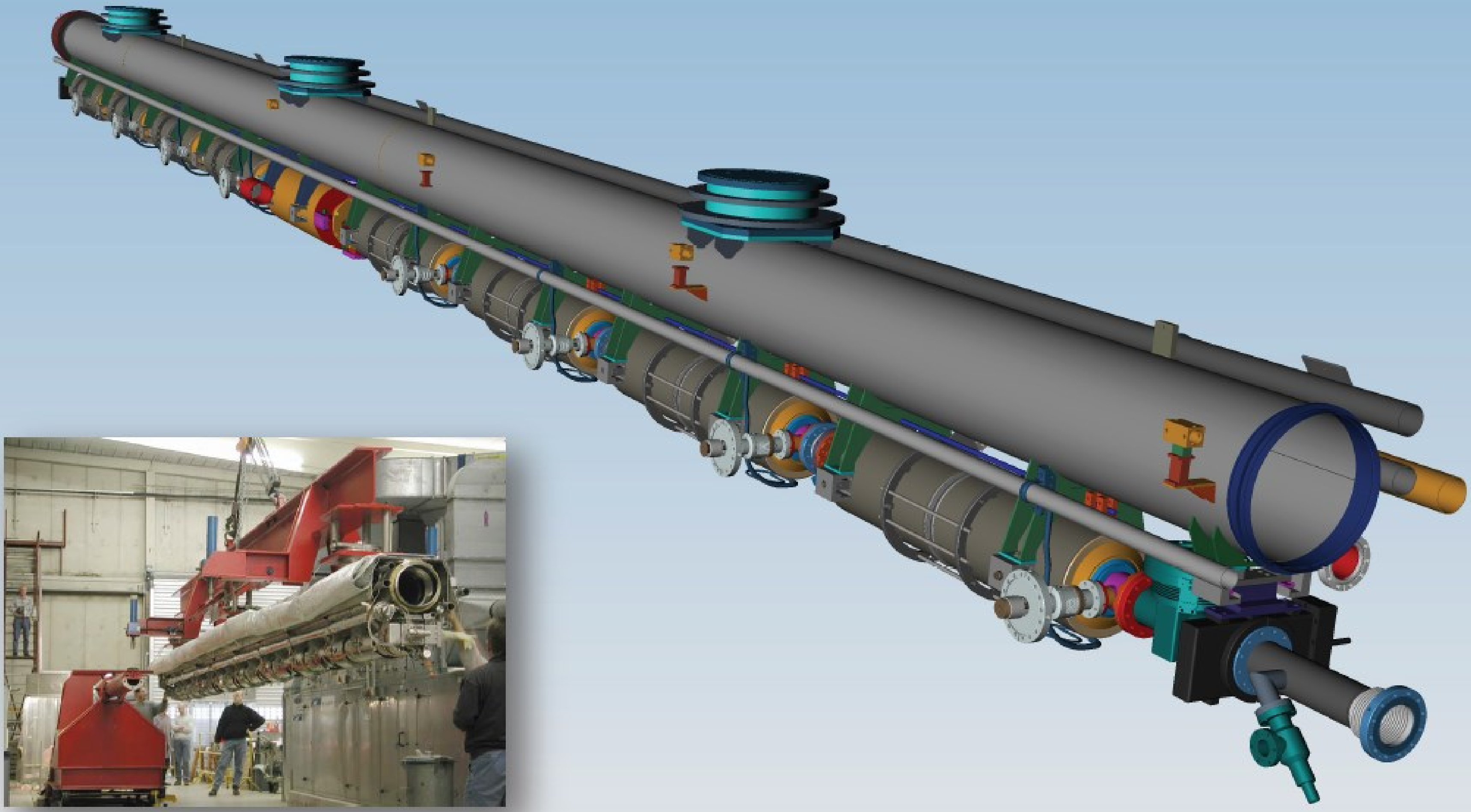


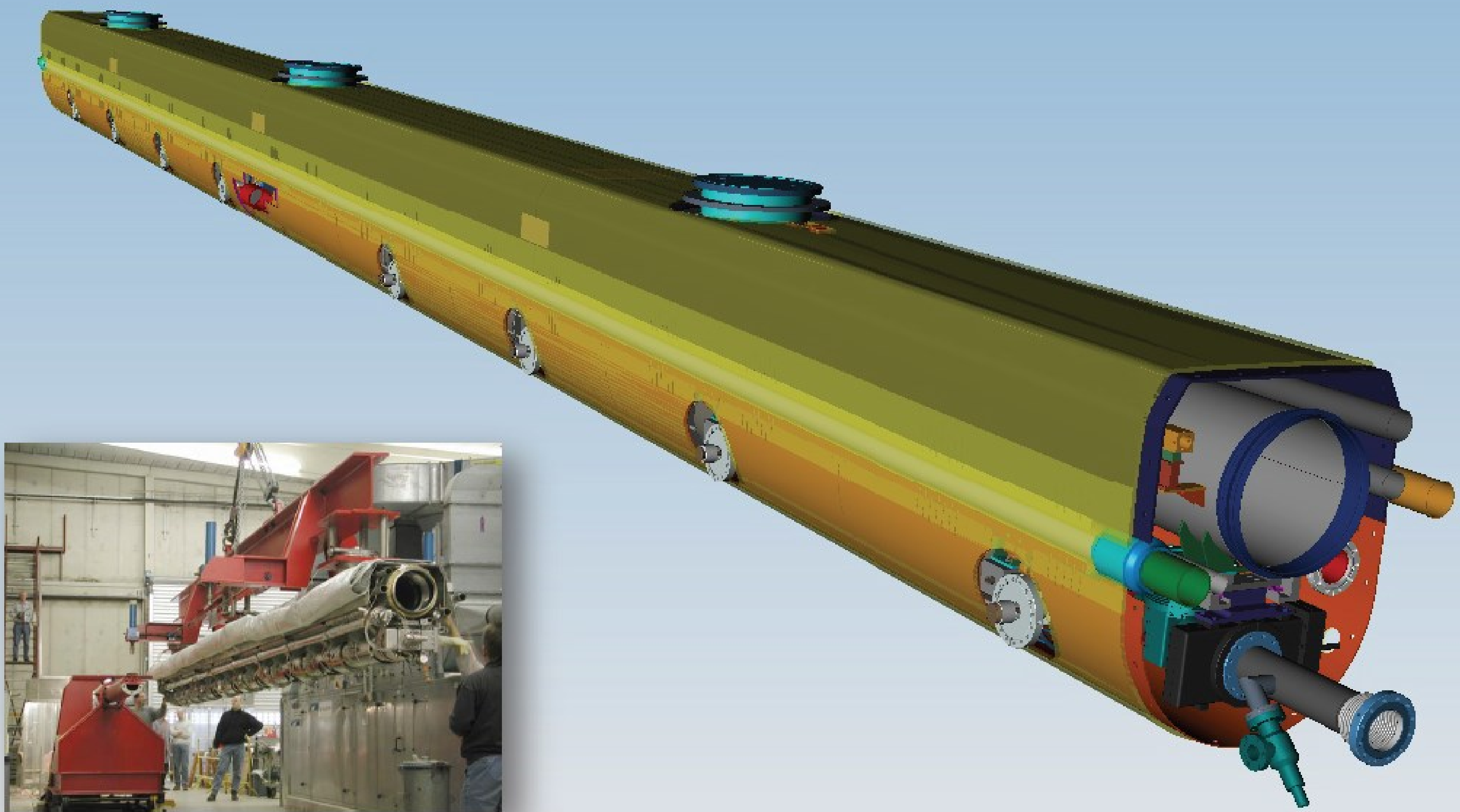


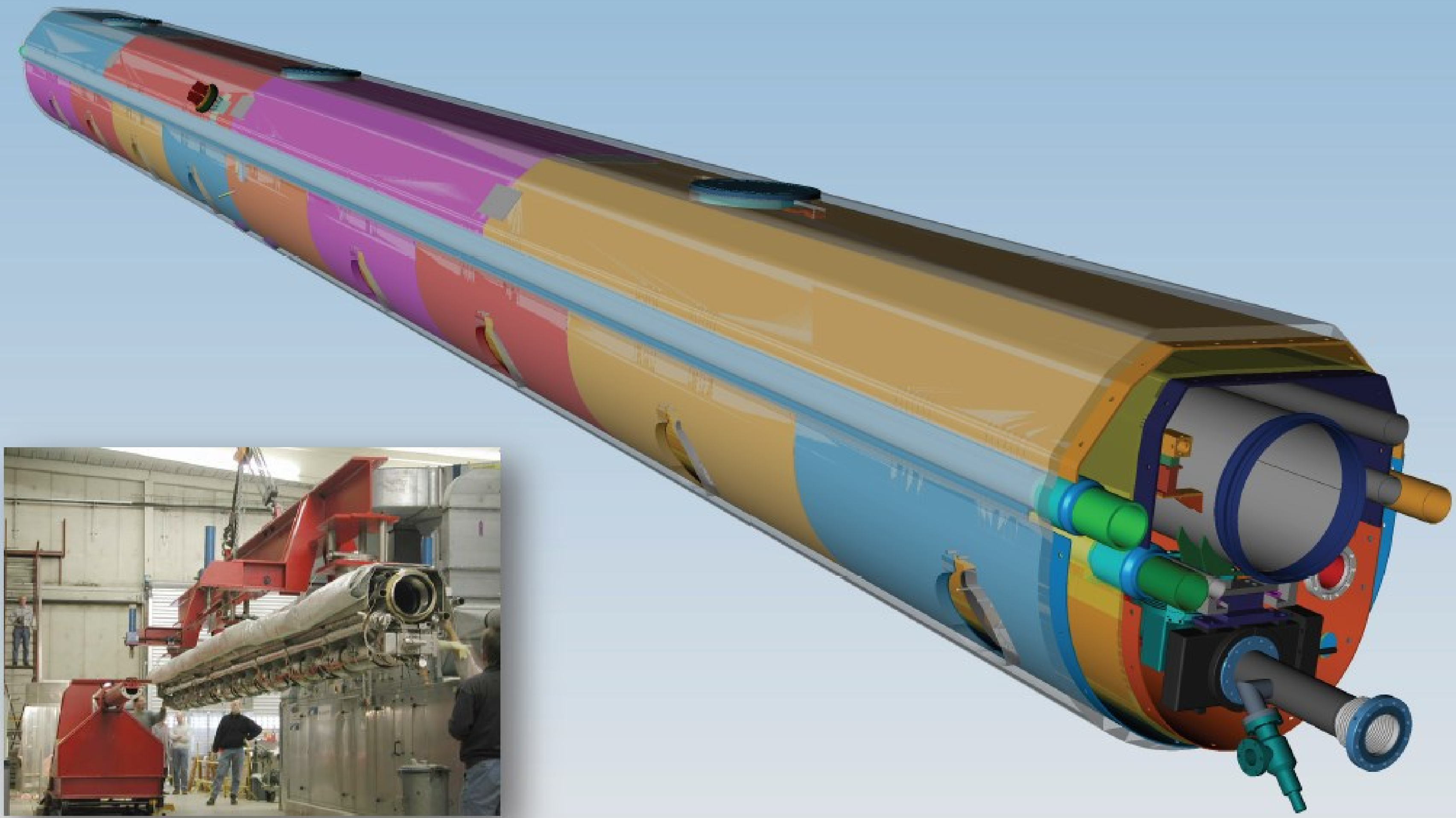


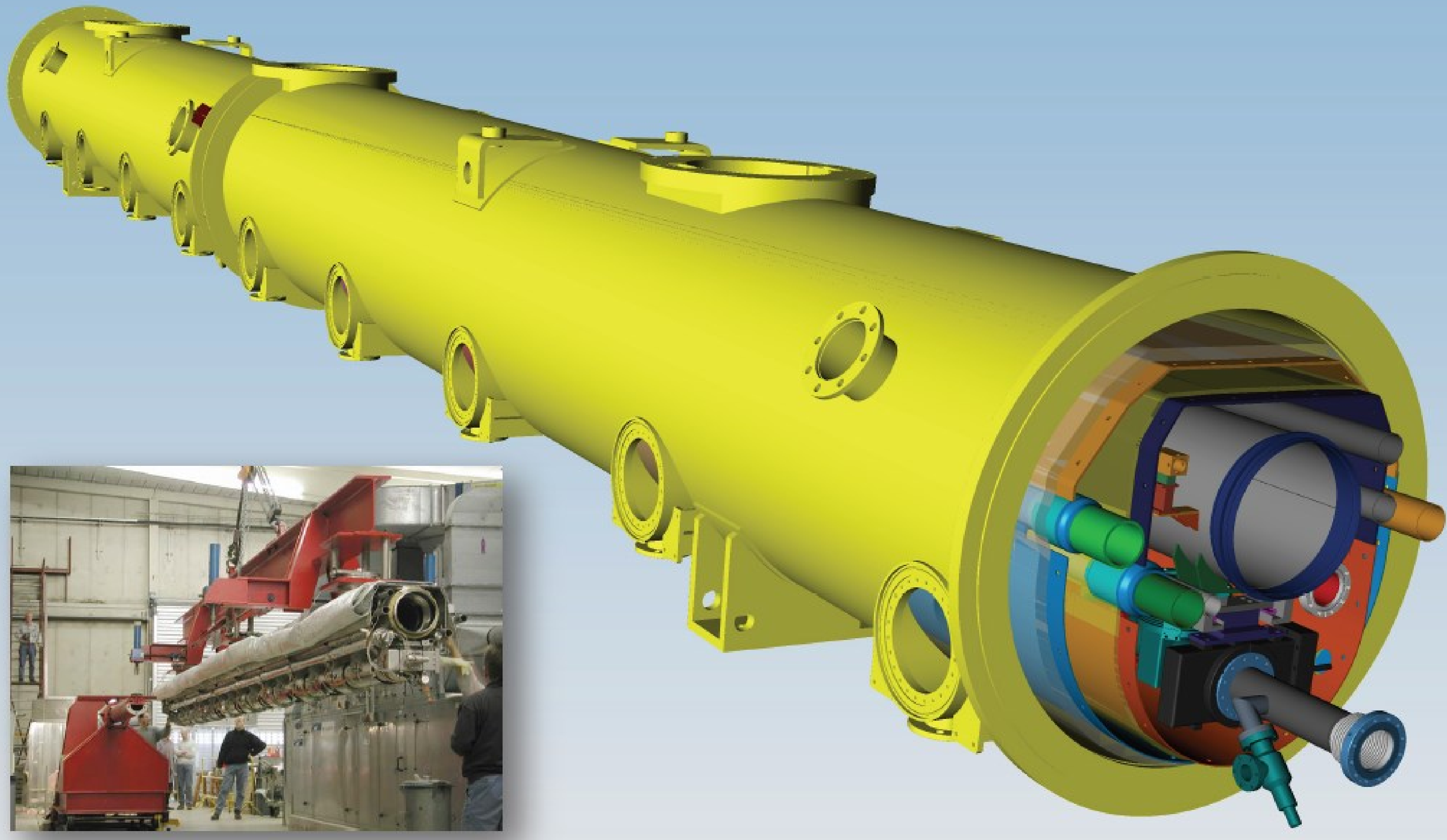


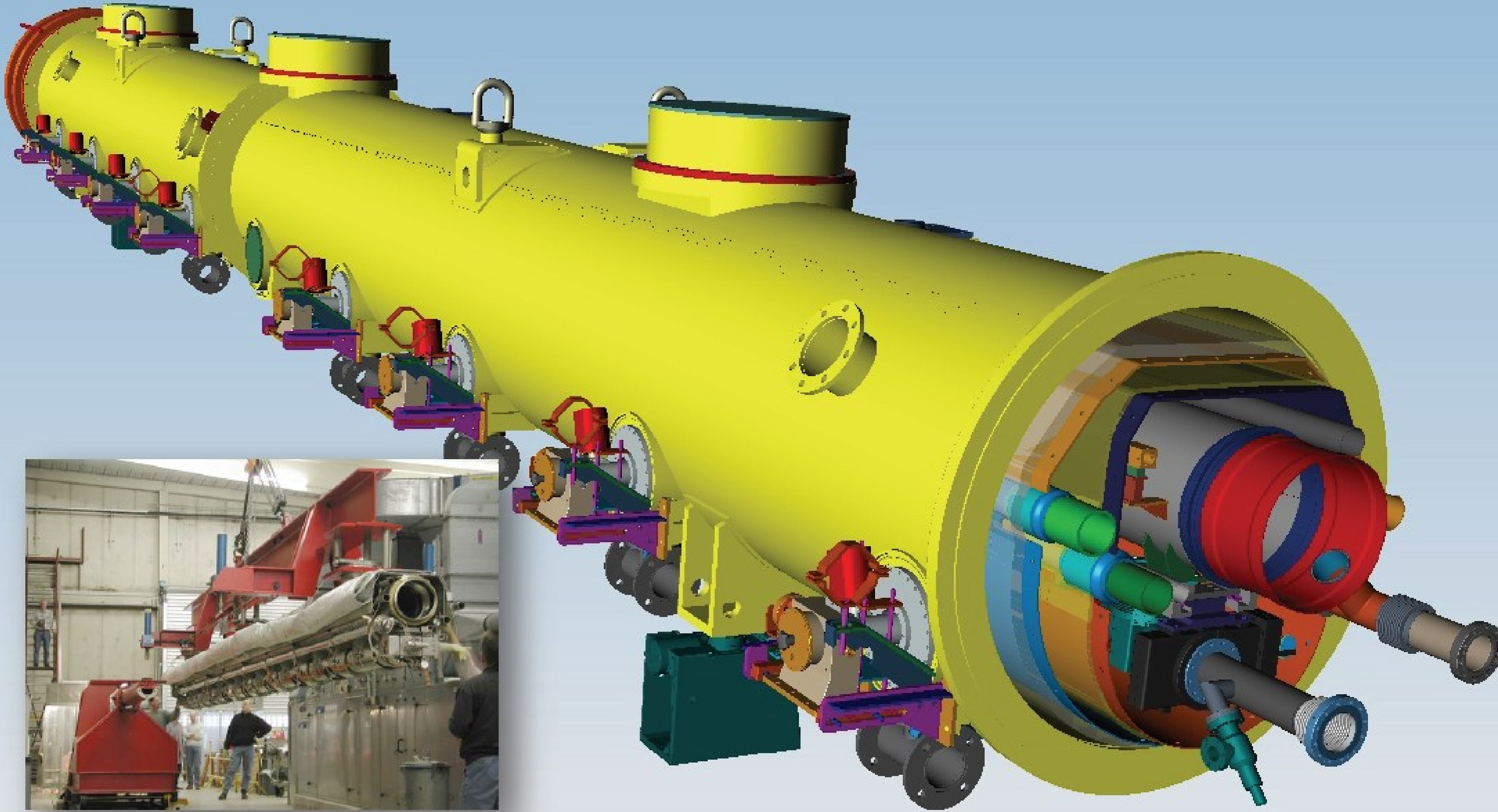


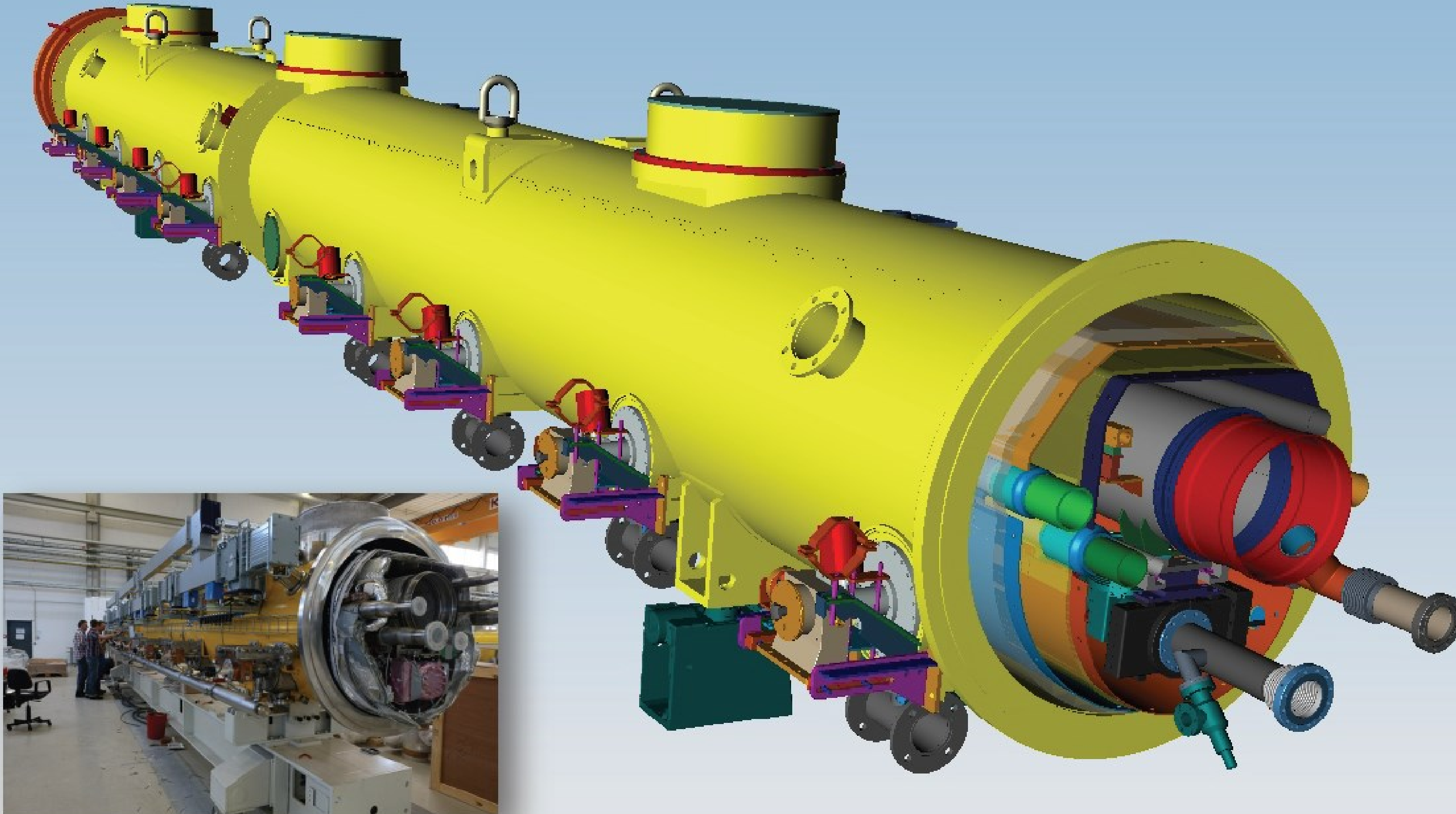












ILC PUBLISHED PARAMETERS

Centre-of-mass dependent:

Centre-of-mass energy	**GeV**	**200**	**230**	**250**	**350**	**500**
Positron RMS energy spread	%	0.19	0.16	0.15	0.10	0.07
IP vertical beta function	mm	0.48	0.48	0.48	0.48	0.48
IP RMS veritcal beam size	nm	9.3	8.6	8.3	7.0	5.9
Enhancement factor		1.83	1.83	1.91	1.84	1.95
Luminosity Upgrade	**$\times 10^{34}$ $cm^{-2}s^{-1}$**	**1.00**	**1.18**	**1.50**	**1.86**	**3.6**
Average energy loss		1%	1%	1%	2%	4%
Total pair energy / BX	TeV	24	34	51	108	344

http://ilc-edmsdirect.desy.de/ilc-edmsdirect/item.jsp?edmsid=D00000000925325

SUMMARY ACCELERATOR

- Mature design for the ILC exists
- The technology to build the accelerator has been developed and is at hand
- The costs of the accelerator are fairly well understood
- International Linear Collider
    - 500 (550) GeV collision energy
    - Few times 20^34 luminosity

PHYSICS AT THE LC

The LC Physics Agenda

Explore the physics at the scale of electroweak symmetry breaking

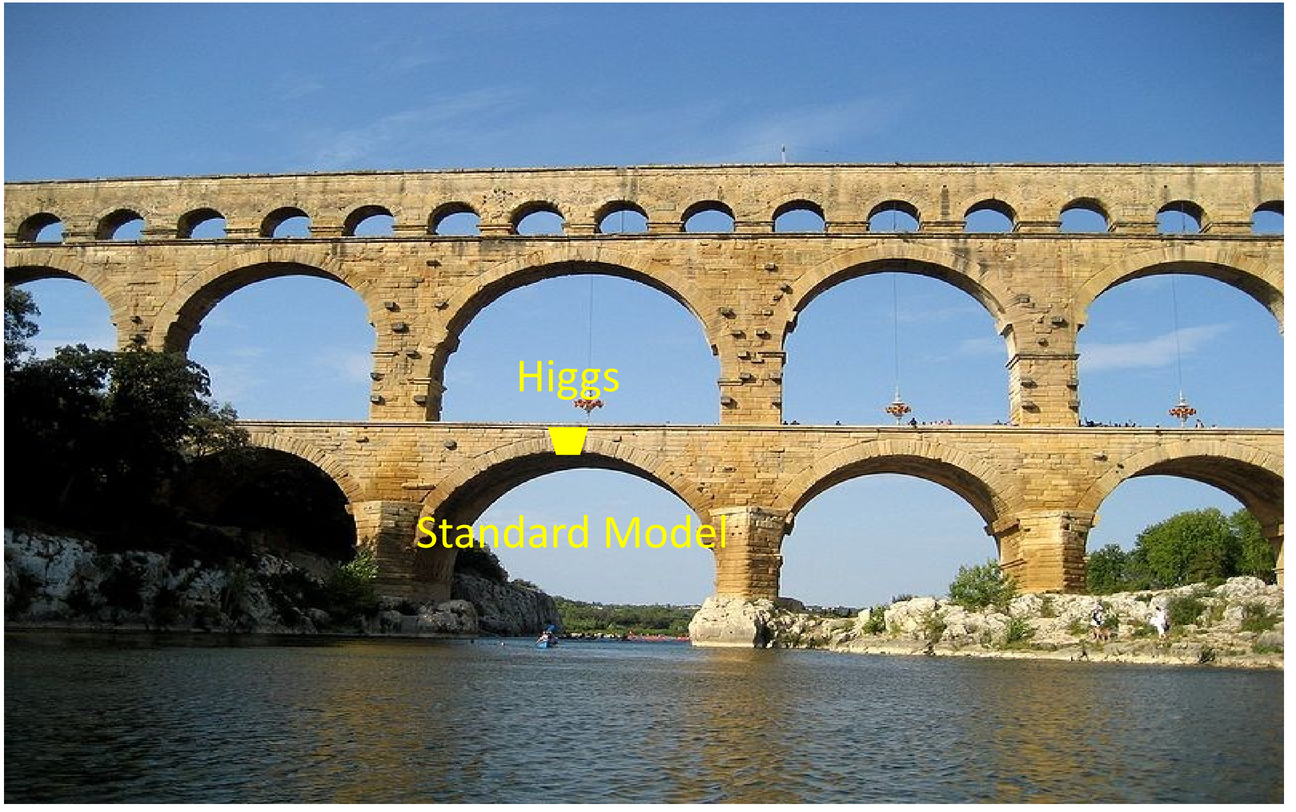
- Higgs Physics
- Standard Model Physics at "Terascale"

Physics beyond the Standard Model

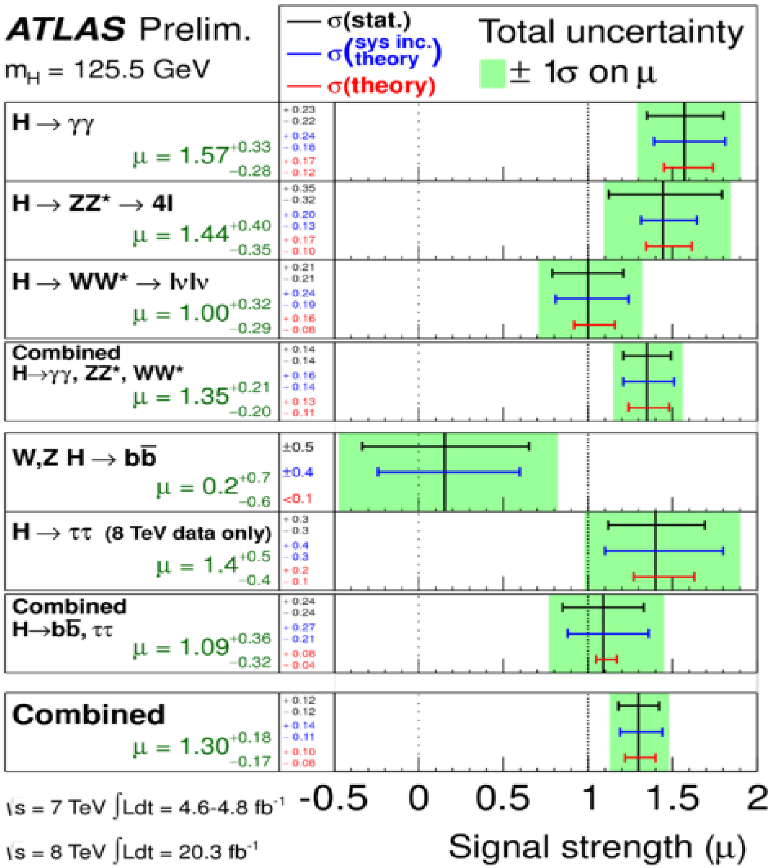
- Search for new physics (Supersymmety, ...)
- Explore the Terascale

Follow up on any discoveries the LHC might have made

Higgs: Keystone of Standard Model

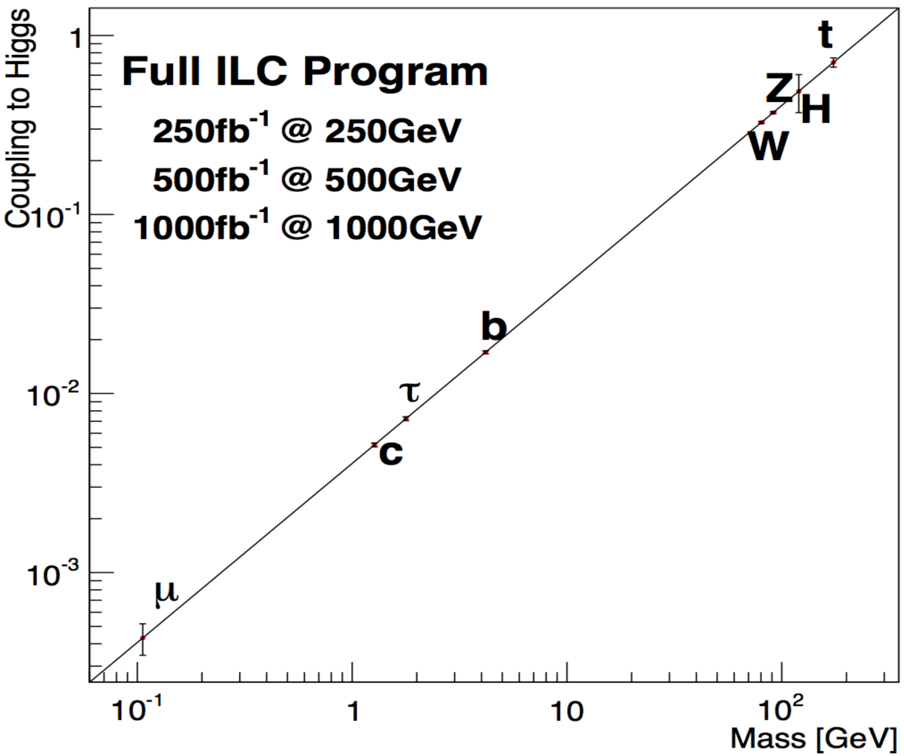


THE HIGGS: WHAT DO WE KNOW



- We have seen a Higgs like state
- Its known parameters so far are compatible with a SM Higgs
- We are sure to see this particle in pp and in electron positron (since it couples to WW, ZZ)

HIGGS PHYSICS: WHAT WE WANT

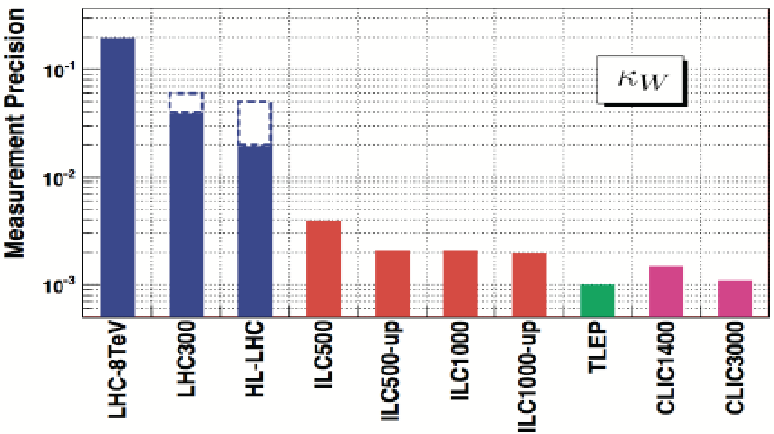


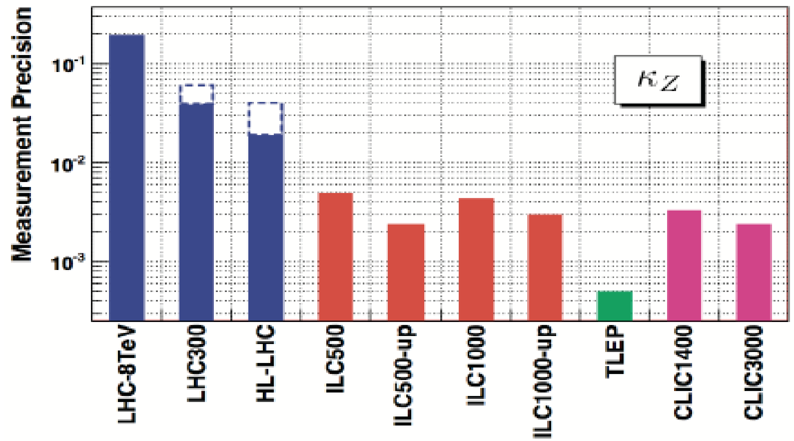
Goal of the LC program:

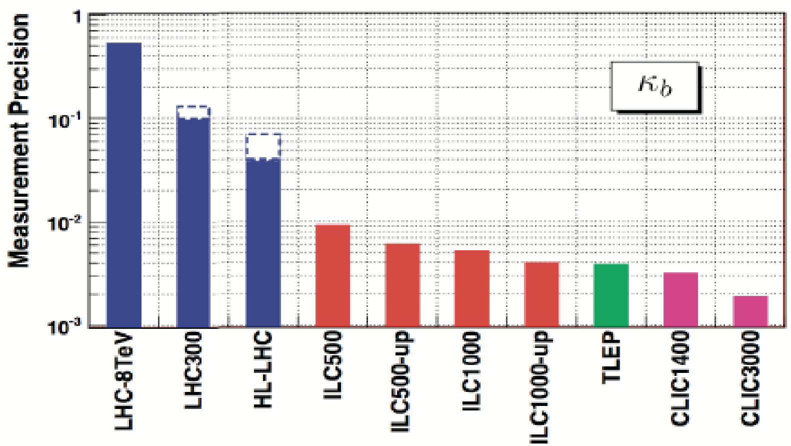
Comprehensive study of the Higgs Couplings

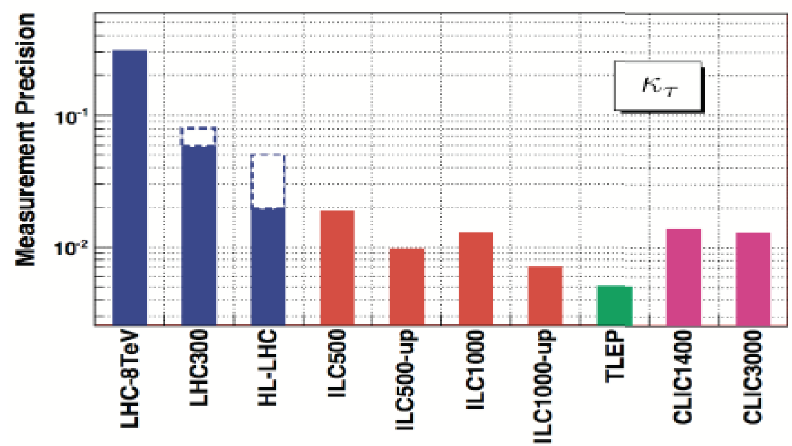
- Multi Jets in the final state
- need excellent jet-energy resolution to get decent measurement

RESULTS









Snowmass Higgs report

PRECISION NEEDED

Model	κ_V	κ_b	κ_γ
Singlet Mixing	$\sim 6\%$	$\sim 6\%$	$\sim 6\%$
2HDM	$\sim 1\%$	$\sim 10\%$	$\sim 1\%$
Decoupling MSSM	$\sim -0.0013\%$	$\sim 1.6\%$	$< 1.5\%$
Composite	$\sim -3\%$	$\sim -(3-9)\%$	$\sim -9\%$
Top Partner	$\sim -2\%$	$\sim -2\%$	$\sim +1\%$

2013 snowmass study, energy frontier report

Deviations from SM couplings are typically a few percent.

Discovery means 5σ, so need sub-percent accuracy

A WORD ON NUMBERS

When comparing results great care is needed to compare things on an equal footing.

The goal should be to be as model independent as necessary.

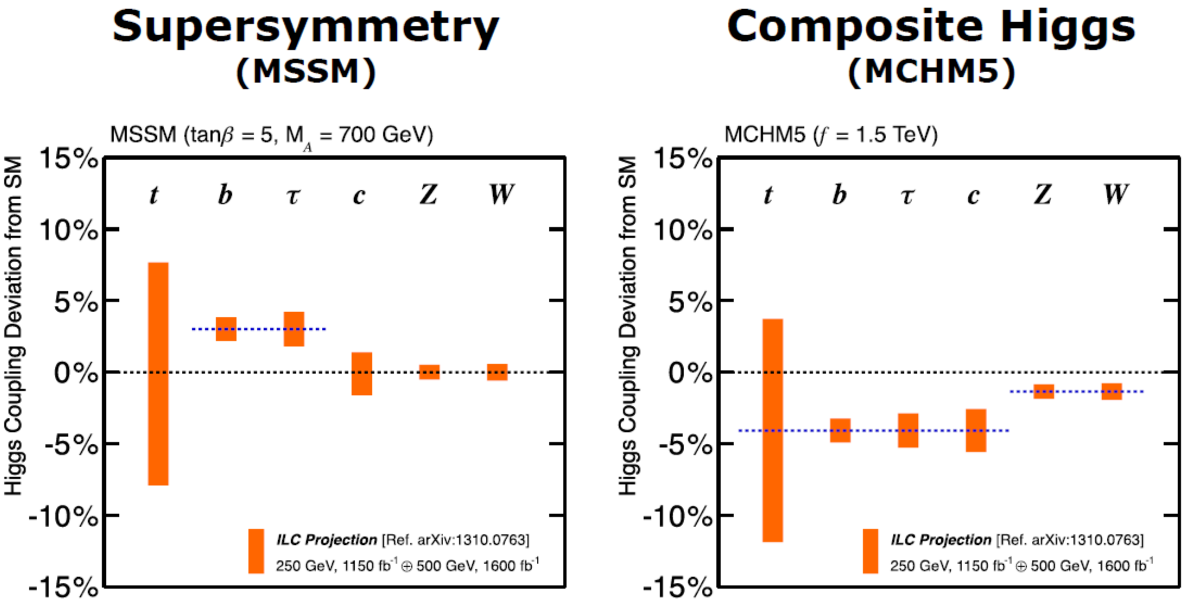
The impact on the results can be huge:

error in Γ_T	unconstrained	$\sum BR = 1$
ILC 500	5.0%	1.6%
ILC 500 up	2.8%	0.75%
ILC 1000	4.6%	1.2%

WHAT DOES THIS TELL US?

What is the underlying theory?

Supersymmetry like?
Composite Higgs?



ILC 250+500 LumiUp

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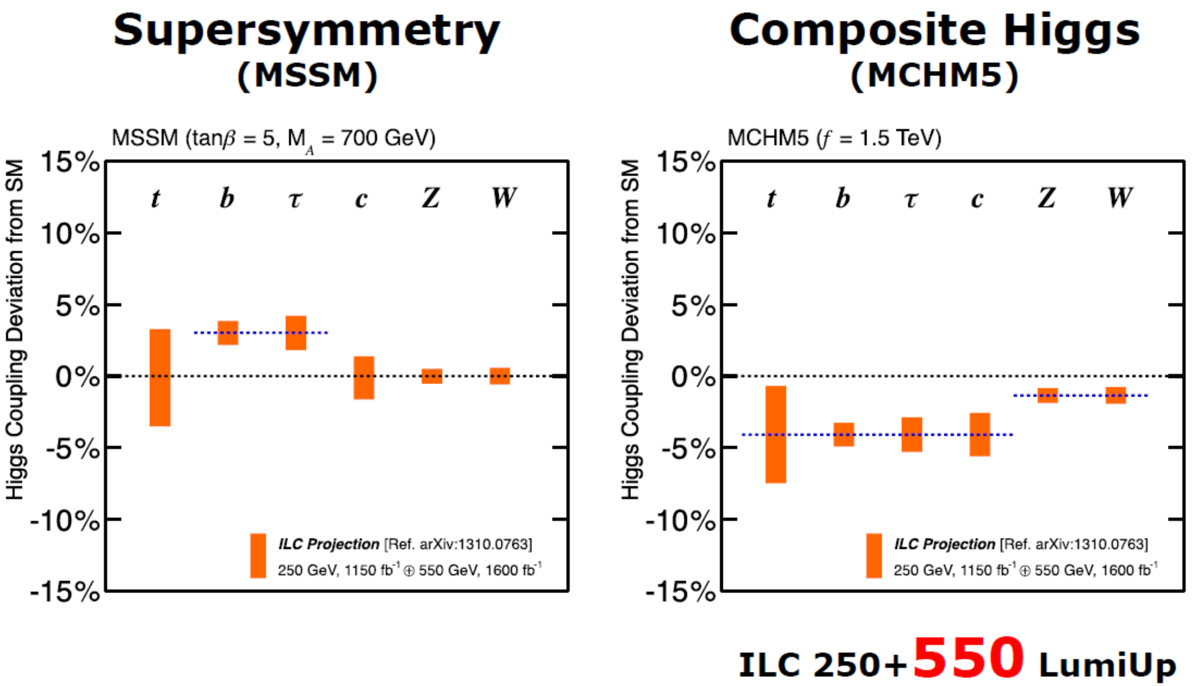
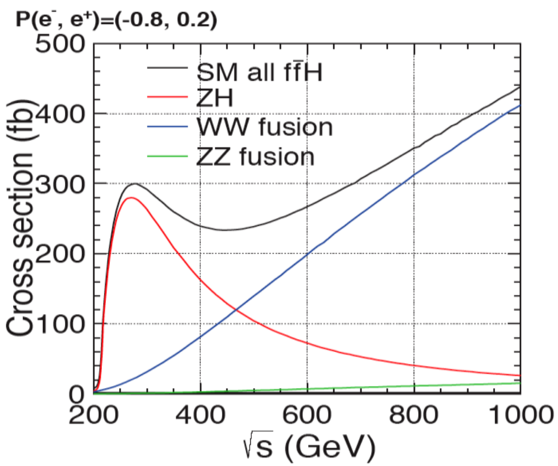
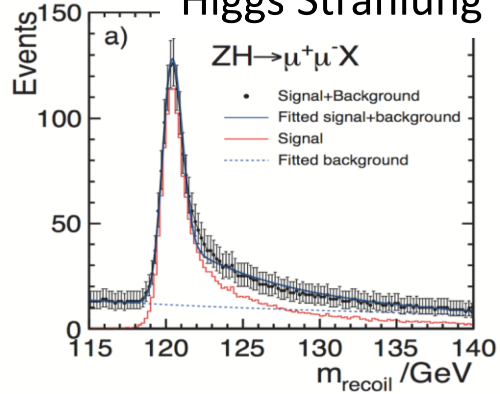


Higgs Physics

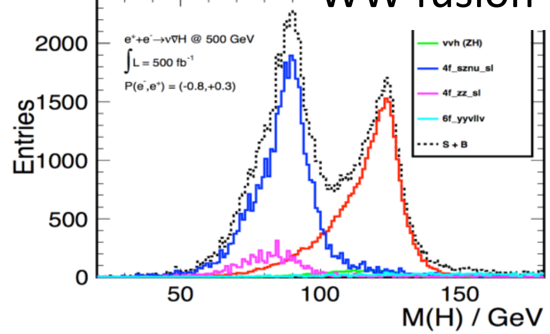
Higgs signals at ILC are very clean:



Higgs Strahlung



WW fusion



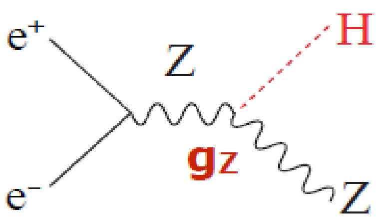
Higgs recoil measurement (absolute width):
~ **235-260 GeV**
(90+125+20 GeV)

Higgs branching ratios and tt threshold:
350 GeV = 2*175 GeV

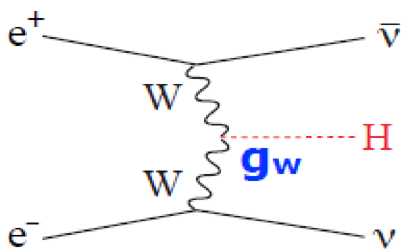
Htt coupling, top physics, Higgs self coupling:
≥ 500 GeV – 1000 GeV
(tth threshold:
2*175+125 = **475GeV**)

HIGGS PRODUCTION

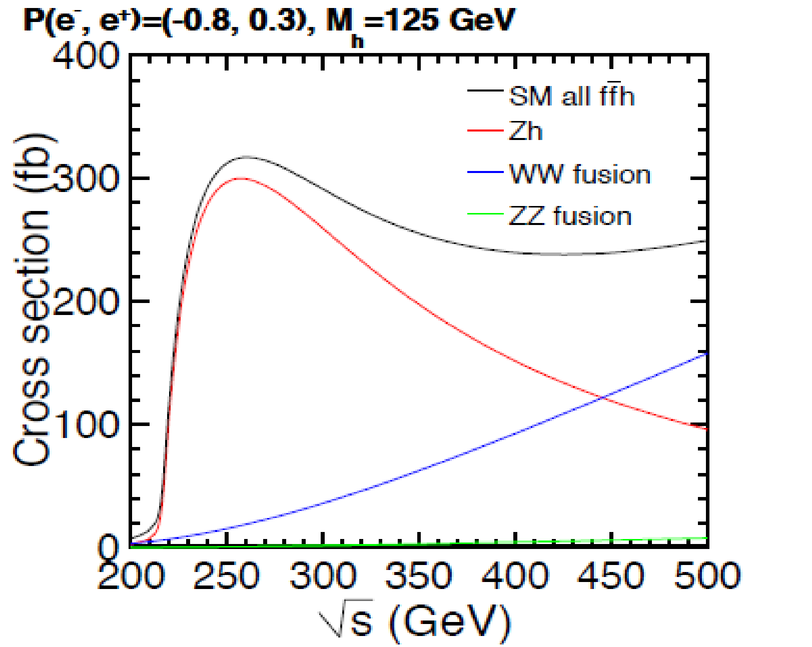
- Higgs strahlung



- W fusion



- Z fusion



- Use polarisation to enhance cross section
- Vary beam energy to select W or Z coupling

Slides F. Sefkow

HOW TO MEASURE THE HIGGS

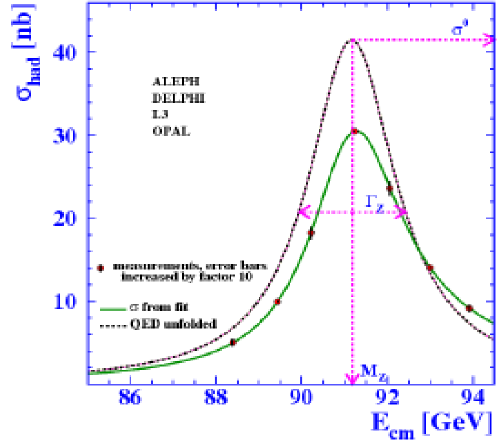
- We perform counting experiments:
- N events / integr. luminosity = cross section x branching ratio
- Branching ratio := partial width / total width

- **$\sigma \cdot BR = \sigma_i \cdot \Gamma_f / \Gamma_T \sim g_i^2 \, g_f^2 / \Gamma_T$**

- Need σ and total width to convert branching ratios into couplings
  - e.g. Z line shape at LEP
- $\Gamma_T\,(\text{Higgs})_{SM}$ = 4 MeV - unobservable

- At LHC, only poorly constraint
  - or SM value assumed

- At ILC, play the cards of e+e-…

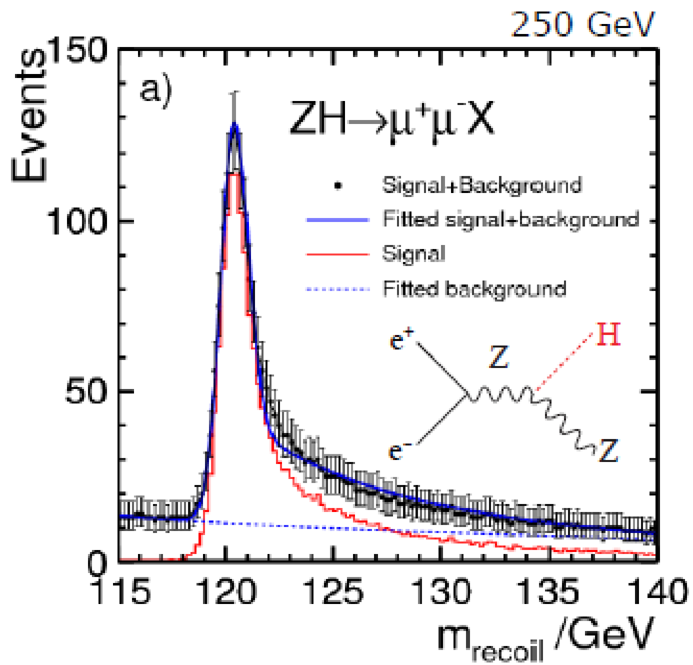


Slides F. Sefkow

HIGGS RECOIL

- In e+e-, use kinematic constraints
- recoil mass against Z
  - $M^2 = E^2 - p^2$
  - beam energy: $E = \sqrt{s} - E_Z$, $p = p_Z$
  - Z mass: $E_Z^2 = M_Z^2 + p_Z^2$

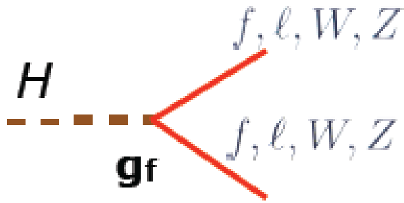
- No use of Higgs final state, can even be invisible
- **Model-independent** ZH cross section
- Absolute normalisation for BRs
  - sensitive to invisible decays
- **Direct extraction of g_Z**



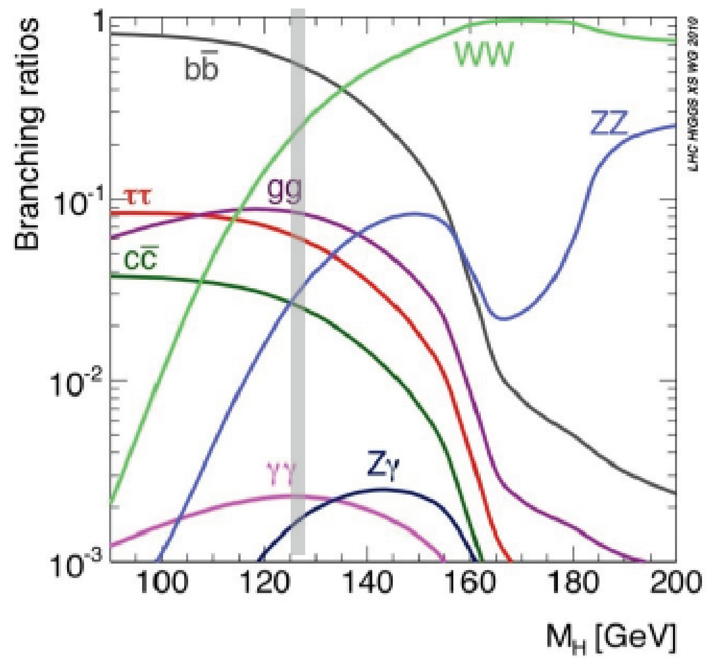
works best with muons,
also well with electrons
jets: not so easy

Slides F. Sefkow

HIGGS PRODUCTION



- M_H = 125 GeV
- ideal for ILC
  - but not for H → ZZ*
- BR (H→ZZ*) = $\Gamma_Z / \Gamma_T \sim g_Z^2 / \Gamma_T$
- $\Rightarrow \Gamma_T \sim g_Z^2$ / BR (H→ZZ*)
- in principle possible - but large error (20%)



Slides F. Sefkow

HIGGS TOTAL WIDTH

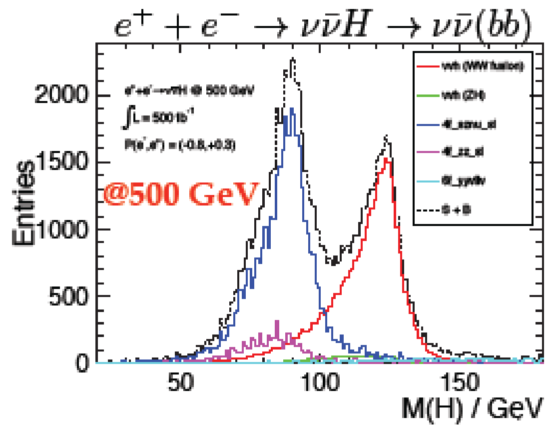
- Use **W fusion cross section** and H→WW* branching ratio
- $\Gamma_T \sim g_W^2$ / BR (H→WW*)

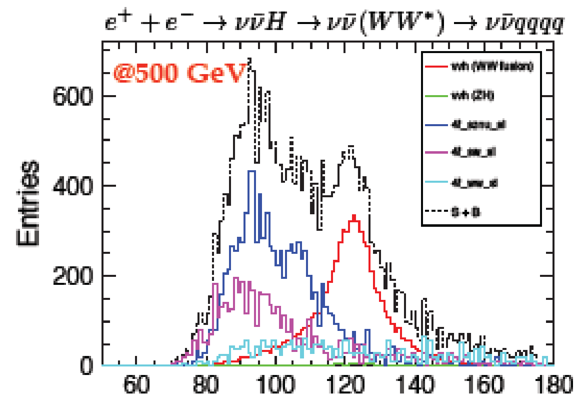
- W fusion σ is not model independent
  - ff = bb or WW* final state
  - measure same f.s. in ZH and scale

- $g_W^2/g_Z^2 \sim \sigma_{\nu\nu H}$ B(H→ff) / σ_{ZH} B(H→ff)
- g_Z^2 from Z recoil

- BR (H→WW*) in vvH or ZH prod

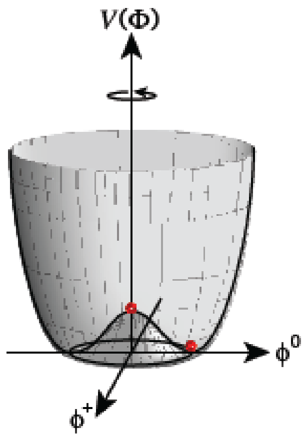
- Done!
  - self-contained set for absolute couplings

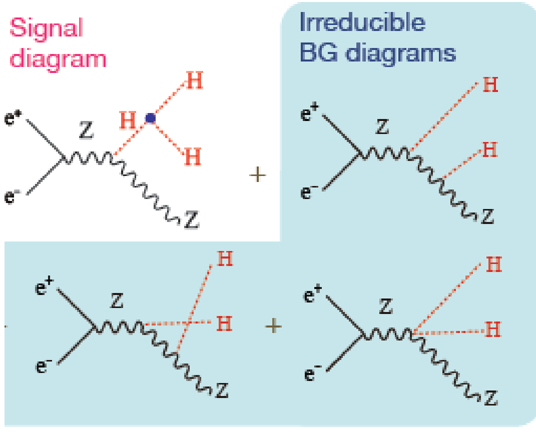


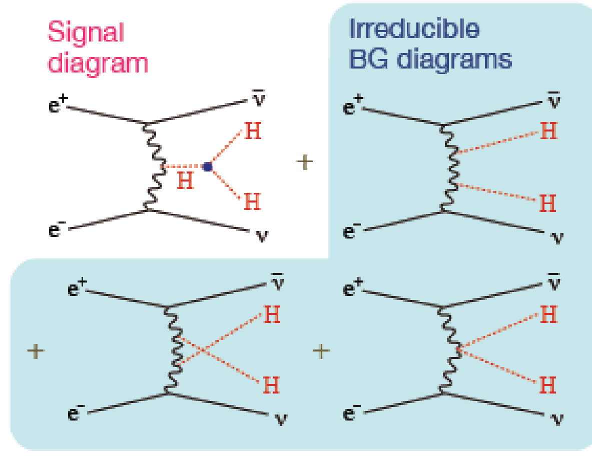


Slides F. Sefkow

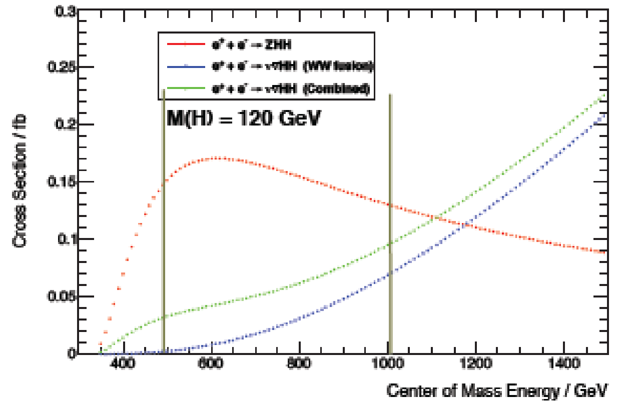
Higgs Self Coupling







- difficult even at ILC
- $\delta\lambda/\lambda > 0.5\ \delta\sigma/\sigma$
- W fusion offers better sensitivity
- possible at 500 GeV, best at 1 TeV



ILC HIGGS PROGRAM

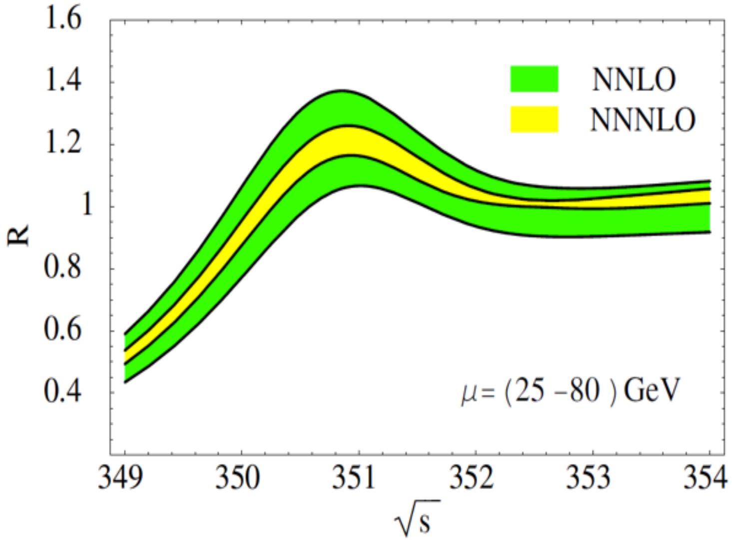
Energy	Reaction	Physics Goal
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak
160 GeV	$e^+e^- \to WW$	ultra-precision W mass
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings
350–400 GeV	$e^+e^- \to t\bar{t}$	top quark mass and couplings
	$e^+e^- \to WW$	precision W couplings
	$e^+e^- \to \nu\bar{\nu}h$	precision Higgs couplings
500 GeV	$e^+e^- \to f\bar{f}$	precision search for Z'
	$e^+e^- \to t\bar{t}h$	Higgs coupling to top
	$e^+e^- \to Zhh$	Higgs self-coupling
	$e^+e^- \to \tilde{\chi}\tilde{\chi}$	search for supersymmetry
	$e^+e^- \to AH, H^+H^-$	search for extended Higgs states
700–1000 GeV	$e^+e^- \to \nu\bar{\nu}hh$	Higgs self-coupling
	$e^+e^- \to \nu\bar{\nu}VV$	composite Higgs sector
	$e^+e^- \to \nu\bar{\nu}t\bar{t}$	composite Higgs and top
	$e^+e^- \to \tilde{t}\tilde{t}^*$	search for supersymmetry

Higgs Physics

coupling	250 GeV	250 GeV + 500 GeV	250 GeV + 500 GeV + 1 TeV
HZZ	1.3%	1%	1%
HWW	4.8%	1.1%	1.1%
Hbb	5.3%	1.6%	1.3%
Hcc	6.8%	2.8%	1.8%
Hgg	6.4%	2.3%	1.6%
Hττ	5.7%	2.3%	1.6%
Hγγ	18%	8.4%	4%
Hμμ	91%	91%	16%
Γ	12%	4.9%	4.5%
Htt	-	14%	3.1%
HHH	-	83%(*)	21%(*)

TOP AT THE LINEAR COLLIDER

- Top mass: Fundamental SM parameter, leading contribution to radiative corrections
- Threshold scan measures mass in a theoretically very clean way
  → gets rid of QCD uncertainties (~1 GeV) present in all measurements that sum up final state mass
- Important input for radiative correction measurements!
- Measure Z-tt vertex corrections -> tests new physics

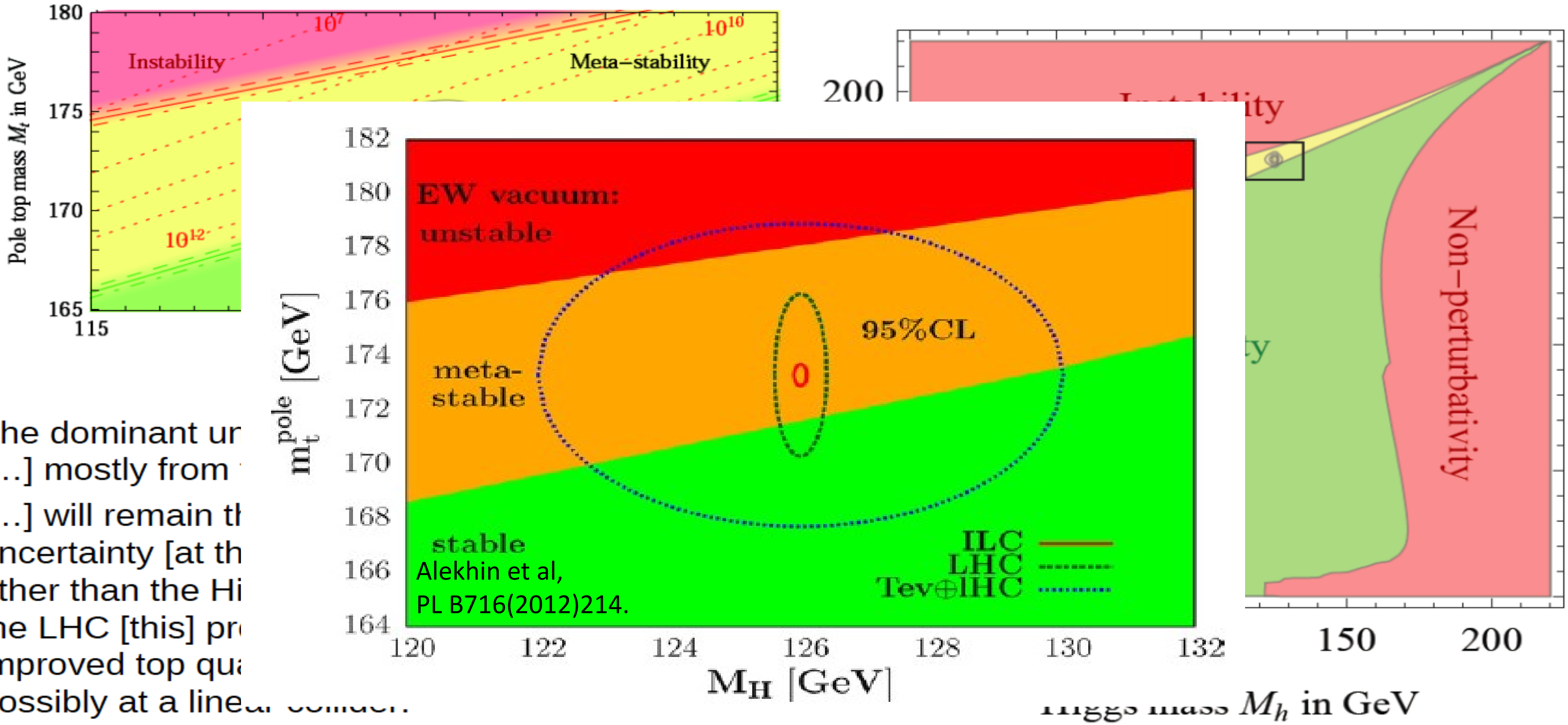


Top performance:
Mass*: 27MeV (0.019%)
Width: 22MeV (1.7%)

* Recent study (F. Simon, ALCPG'12)

How important is the top mass measurement?

[Degrassi, Di Vita, Elias-Miro,Spinosa,Giudici ’12,
Alekhin, Djouadi, Moch ’12]

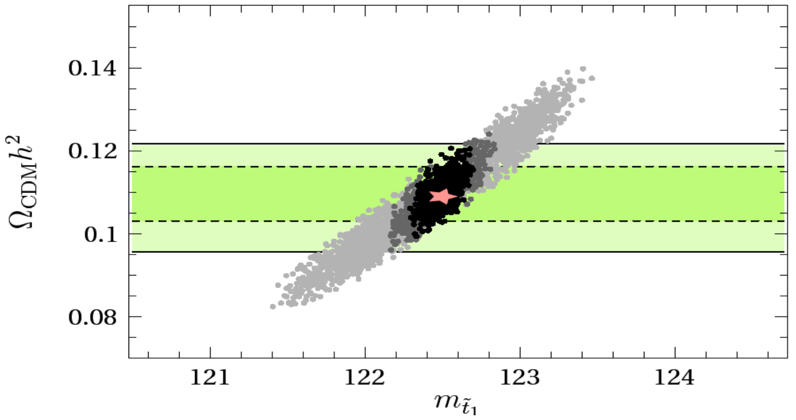


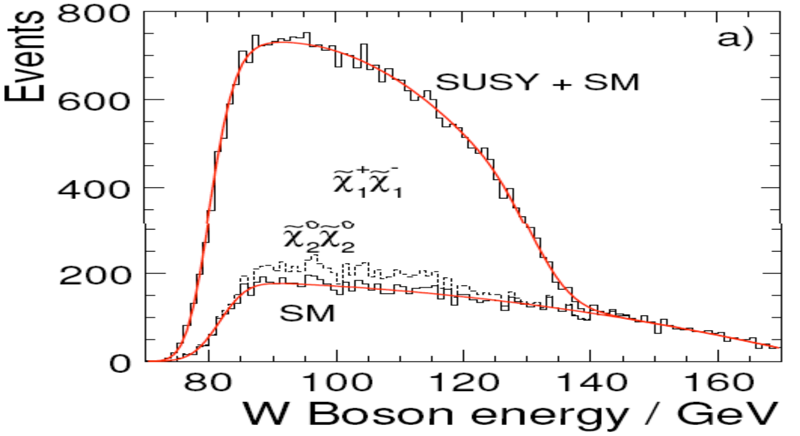
The dominant ur
[…] mostly from
[…] will remain tl
uncertainty [at th
other than the Hi
the LHC [this] pr
improved top qua
possibly at a linear collider.

Physics beyond the Higgs

A linear collider is

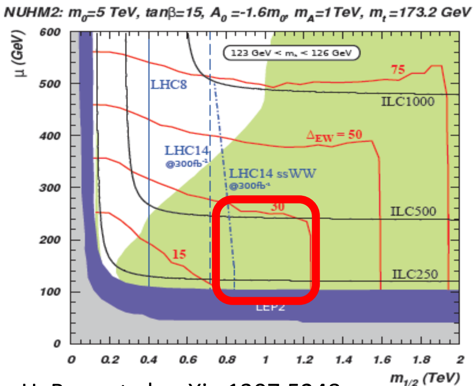
- A top factory (if E>threshold)
- A Standard Model physics center
- A discovery machine





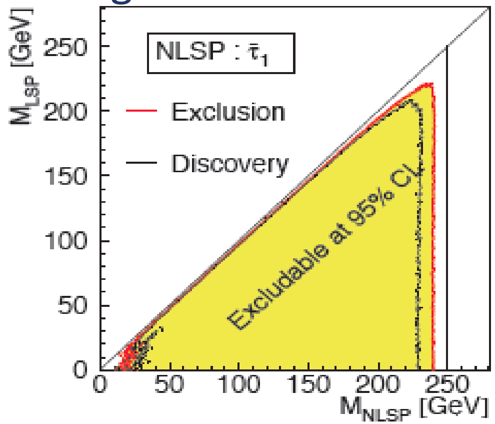
WHERE ILC WOULD HELP

Higgsino-like LSP



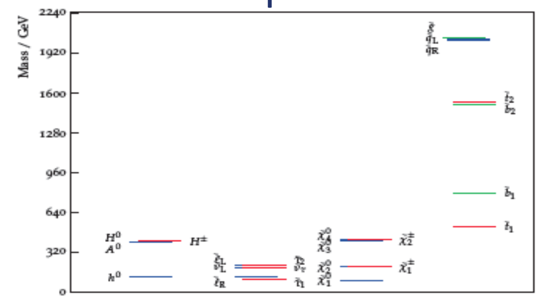
H. Baer et al, arXiv:1307.5248 and arXiv:1306.3148

Closing loopholes from near-degenerate masses



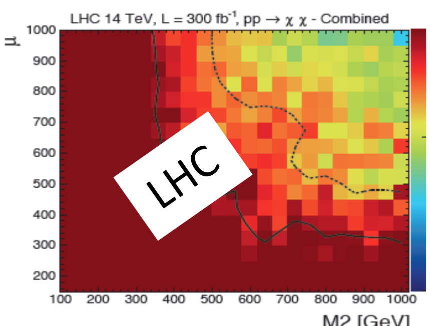
H. Baer et al, arXiv:1307.5248

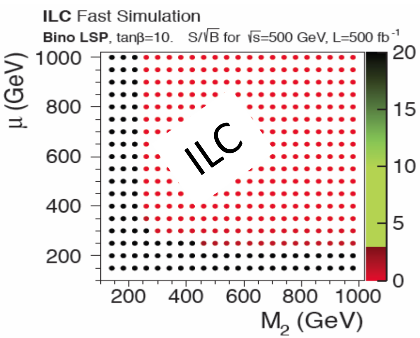
Understanding complex SUSY mass spectra



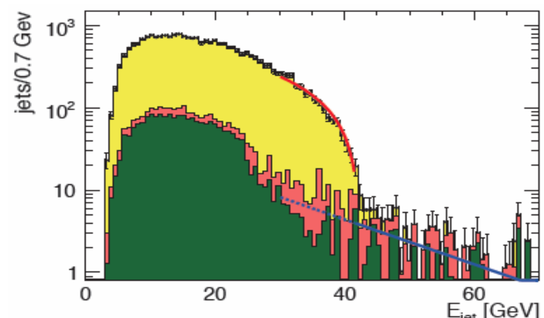
H. Baer, J. List, arXiv:1307.0782

Elektroweakino Sector

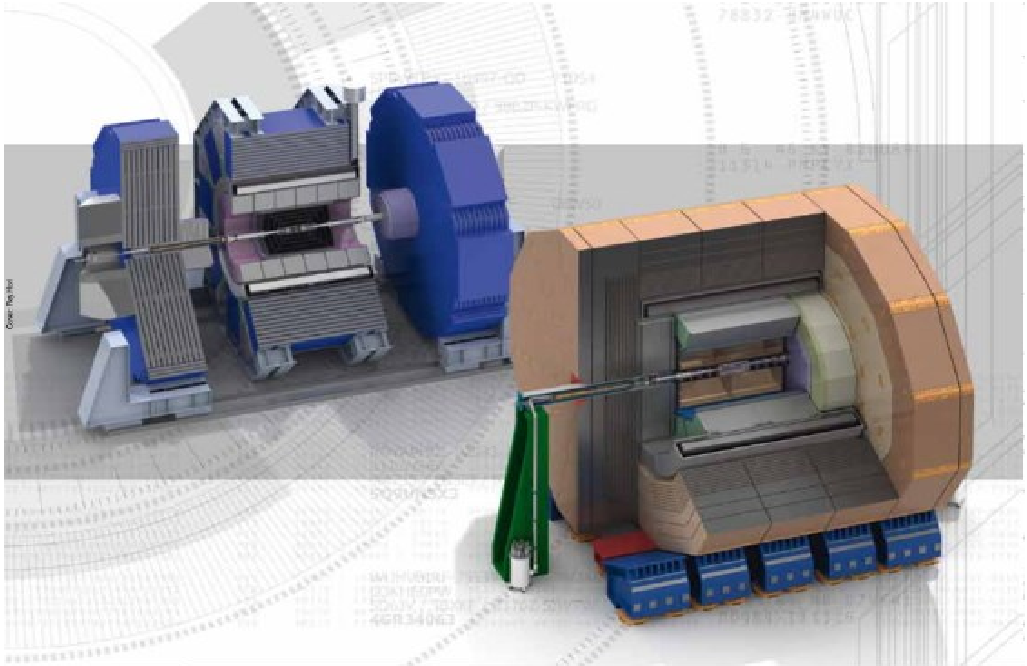




M. Berggren et al, arXiv:1309.7342



P. Bechtle et al., PR D82 (2010) 055016.



DETECTORS AT THE ILC

DESIGN PHILOSOPHY

Multi Purpose Detector,

Optimised for a broad range of final states, in

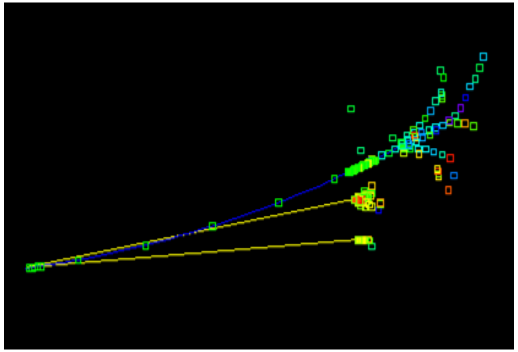
particular multi jet final statees

Particle flow as main reconstruction technique

Imaging Calorimeters

Extreme granularity wins over energy resolution,

in particular in the HCAL



High power tracking and vertexing

High efficiency, robust tracking in dense environments

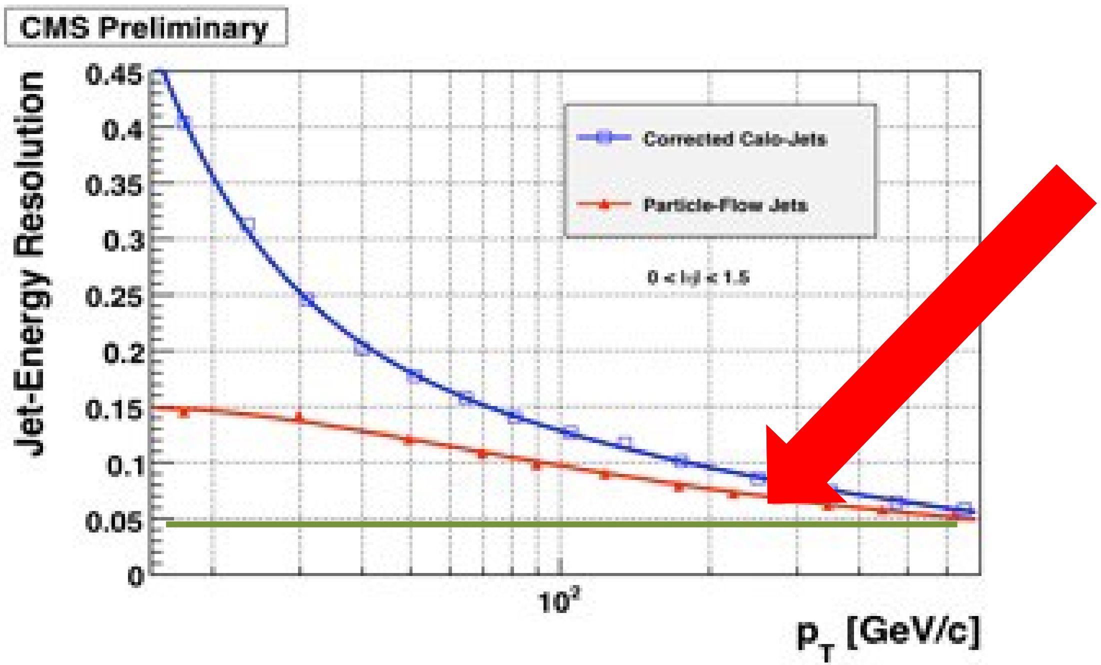
High precision vertexing for heavy flavour physics

The Particle Flow Paradigm

Particle flow is not new:
- LEP detectors (Aleph in particular)
- CDF
- CMS

Energy resolution is not the most important point

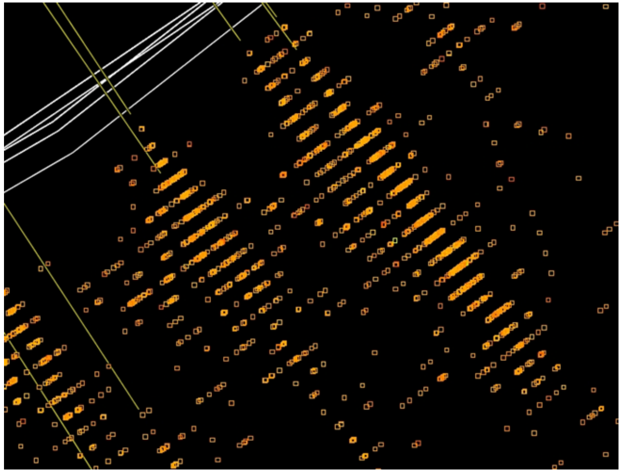
Pattern recognition in the Calorimeter



Linear Collider Goal: Significantly better than CMS performance

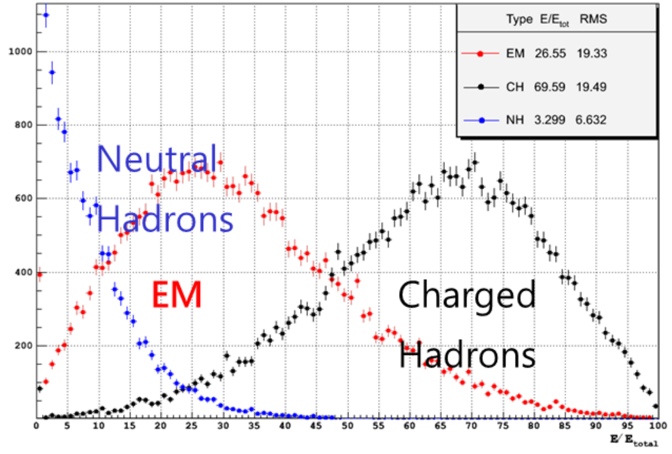
Particle Flow

Simulated shower in a highly granular calorimeter

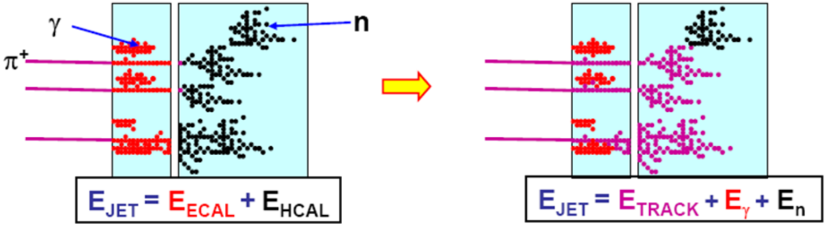


Particle flow:

A concept to reconstruct complex events (hadronic final states)
Relies on tracking and calorimetry



Particle Flow (PFA) is a way to handle fluctuations

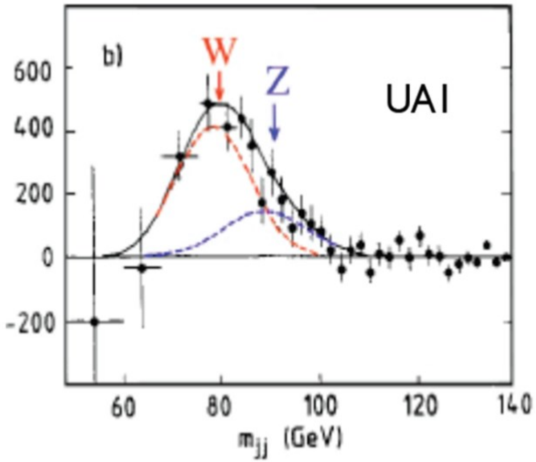


Granularity is stressed more than intrinsic energy resolution

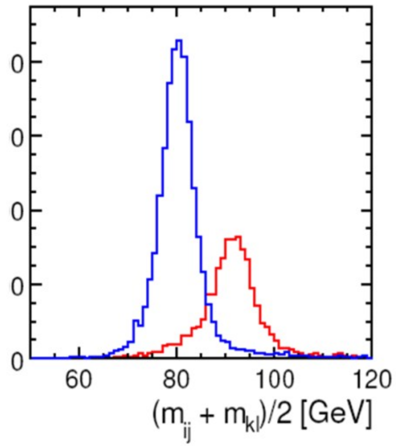
PARTICLE FLOW

Complex final states (e.g. W/ Z)

Traditional approach



Particle Flow approach

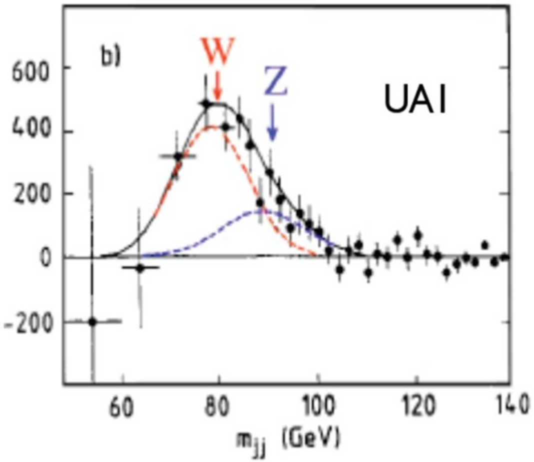


Jet-jet mass resolution

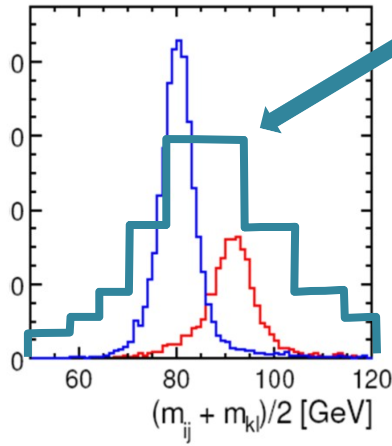
PARTICLE FLOW

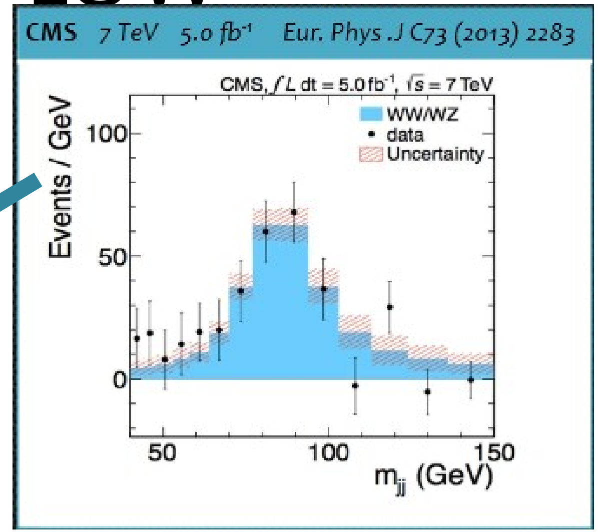
Complex final states (e.g. W/ Z)

Traditional approach



Particle Flow approach



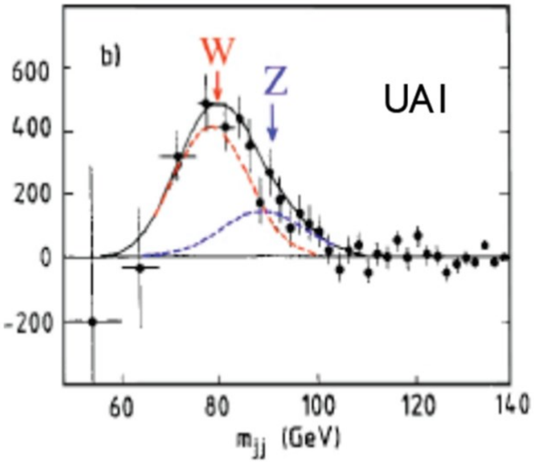


Jet-jet mass resolution

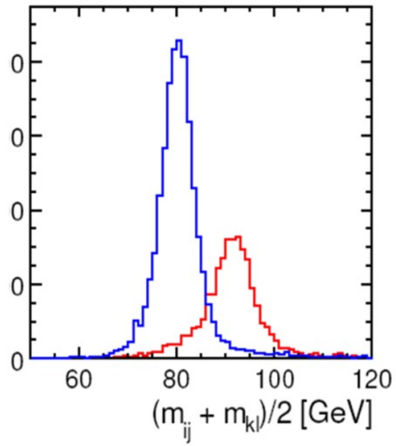
PARTICLE FLOW

Complex final states (e.g. W/ Z)

Traditional approach



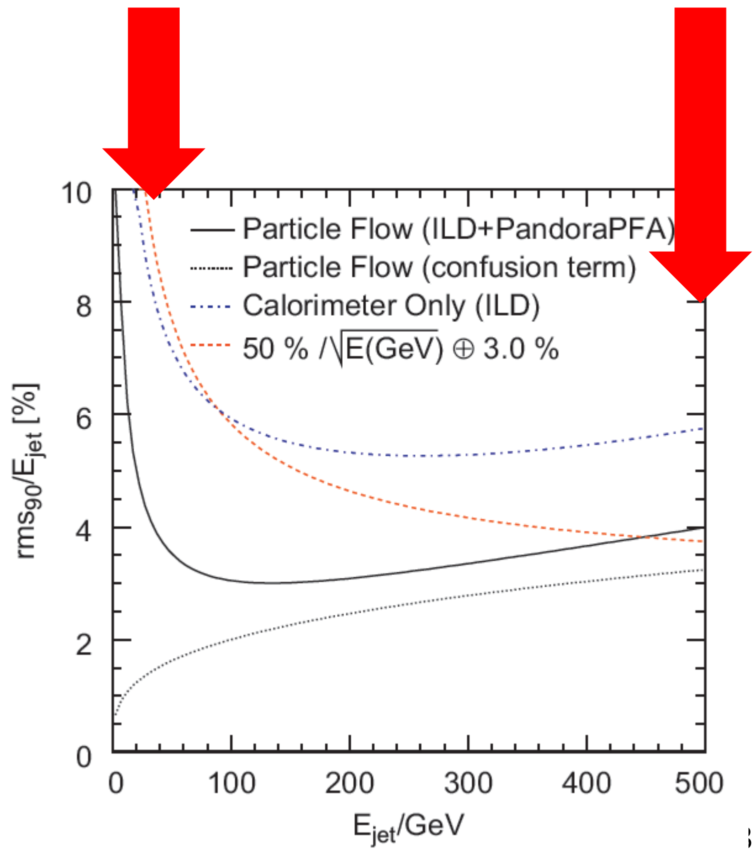
Particle Flow approach



Jet-jet mass resolution

Energy resolution

Confusion



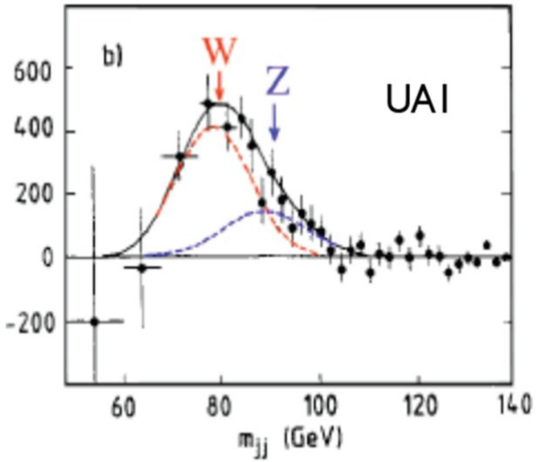
Particle flow is better than pure calorimetry

At high energies the advantage is less.

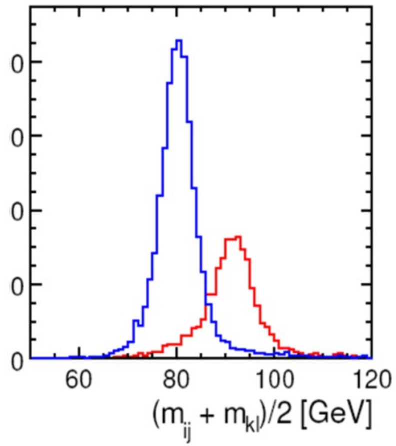
Particle Flow

Complex final states (e.g. W/ Z)

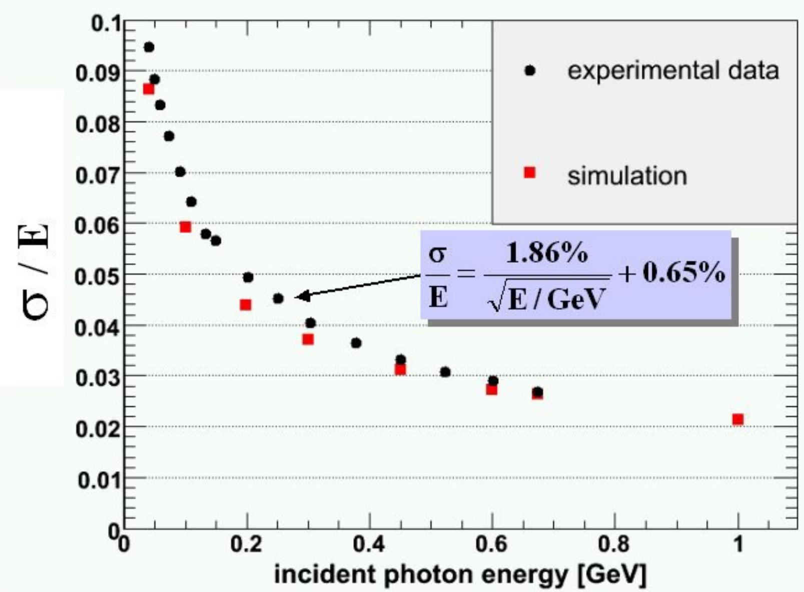
Traditional approach



Particle Flow approach

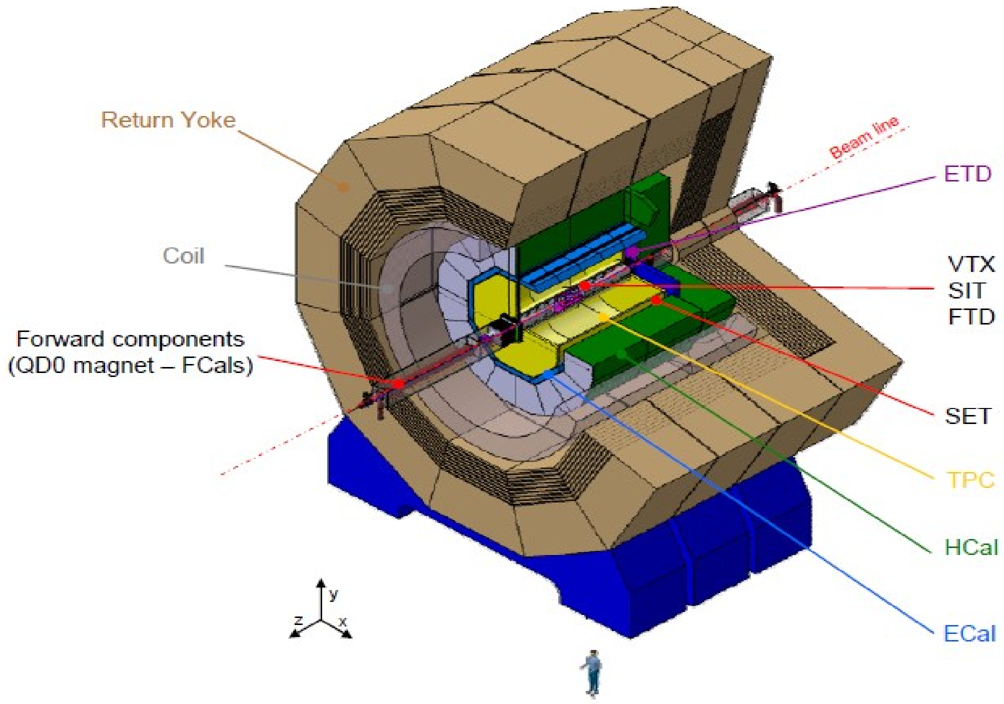


PANDA ECAL: Lead Tungstate crystals



Physics with exclusive final states
(e.g., PANDA with multiple photons in FS)
Focus on photon resolution rather than topological reconstruction

DETECTOR LAYOUT



Typical multi-purpose detector

precision tracking
precision calorimetry
precision muon system
hermetic

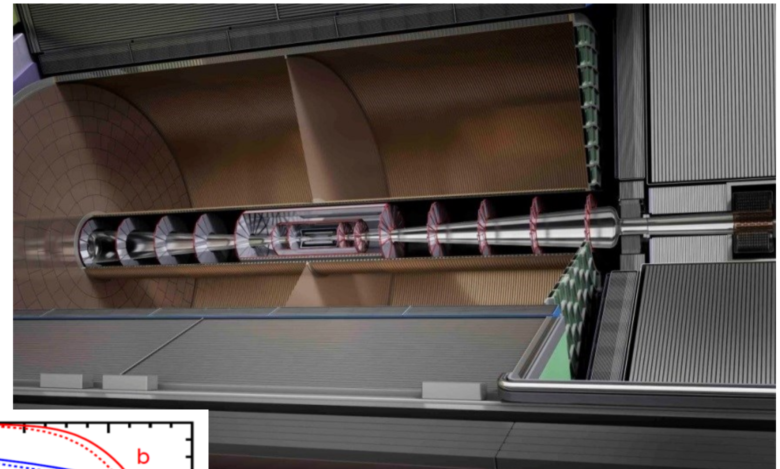
Two well developed concepts:
SiD ILD
I will concentrate on ILD

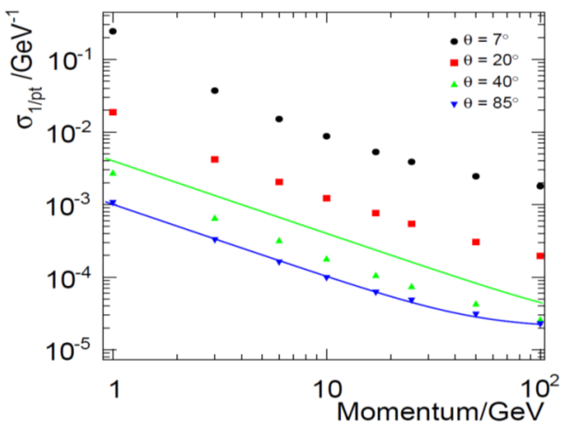
TRACKING DETECTOR

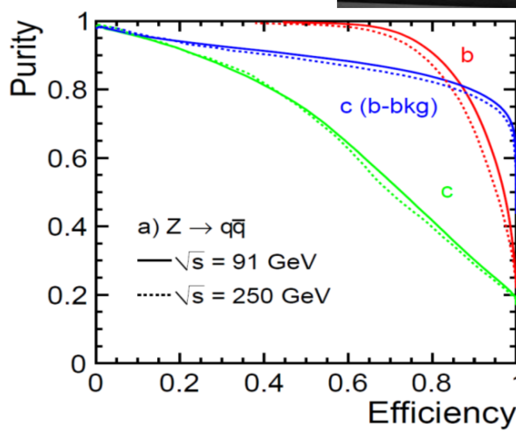
Pixel Vertex at small radii

Intermediate Silicon tracking

Large Volume TPC





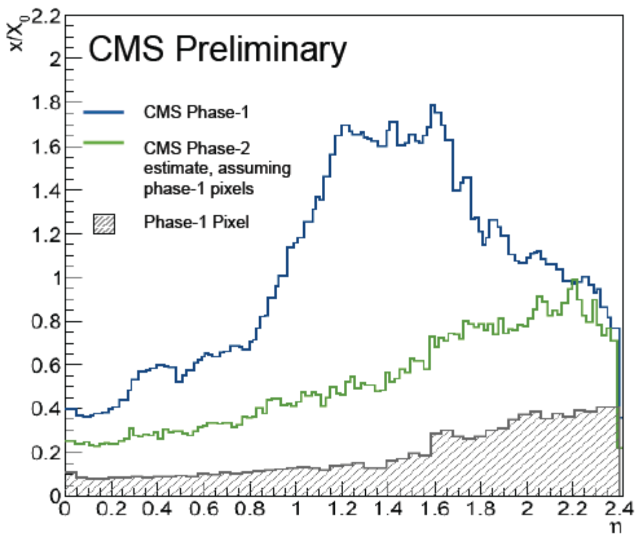


Intense R&D effort

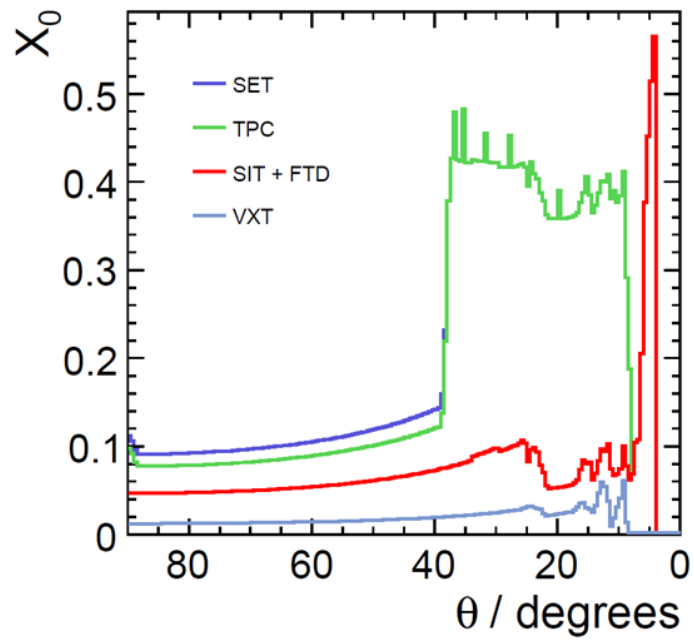
- Proof of concept done
- Performance reached
- Cost performance optimization ongoing

THE MATERIAL CHALLENGE

CMS tracker upgrade scenario:
reduce by factor 2

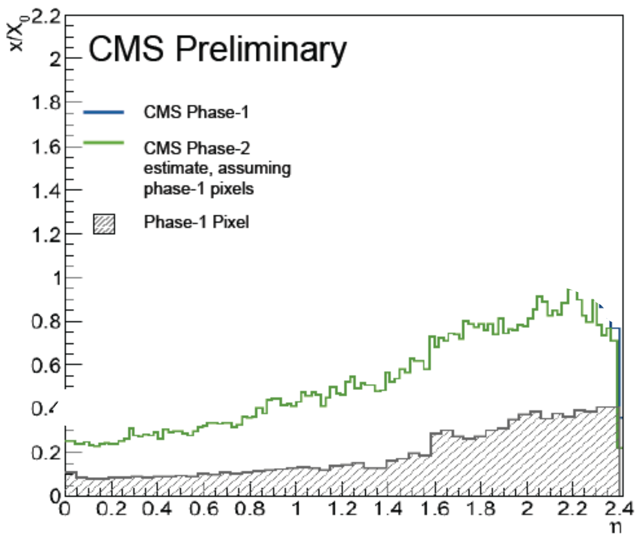


ILD estimate



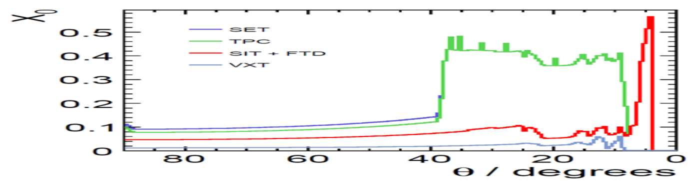
THE MATERIAL CHALLENGE

CMS tracker upgrade scenario:
reduce by factor 2



ILD estimate

Same scale as CMS plot:

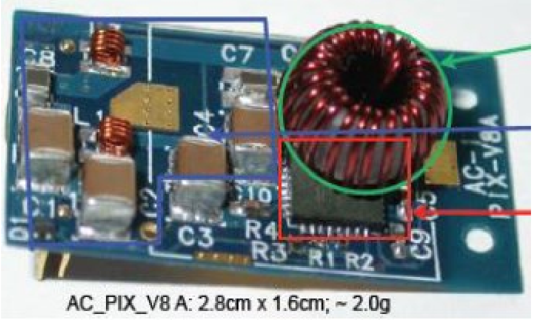


R&D done within LC and LHC communities has paved the way towards significantly thinner detectors.
But be aware of services…

POWER MANAGEMENT

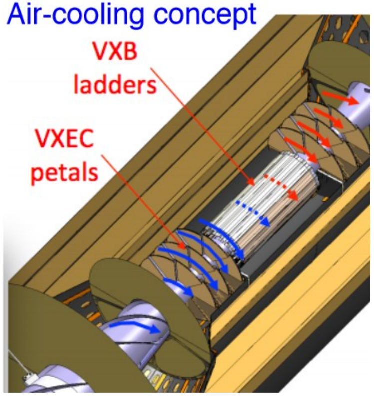
Powering:

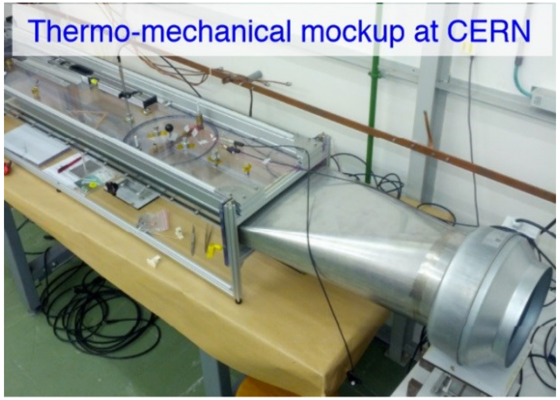
- Services are major part of material budget
- Advanced powering schemes can help:
  - DC-DC
  - Power capacitors…



Air cooling concept studies

- Low mass
- Sufficient for ILC/ CLIC conditions?

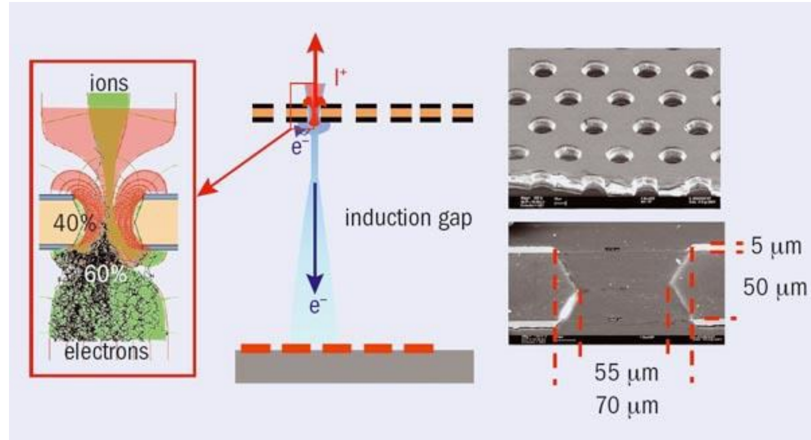




TIME PROJECTION CHAMBER

Time projection chamber as central tracker:

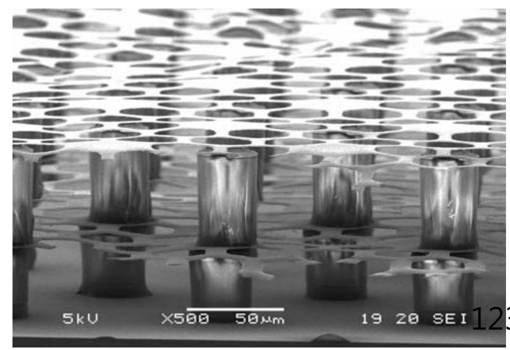
- Robust
- Redundant
- Particle ID



Focus of new developments:
Gas amplification systems based on Micro pattern gas detectors

Integration of
gas amplification
into Silicon technology:

INGRID and friends



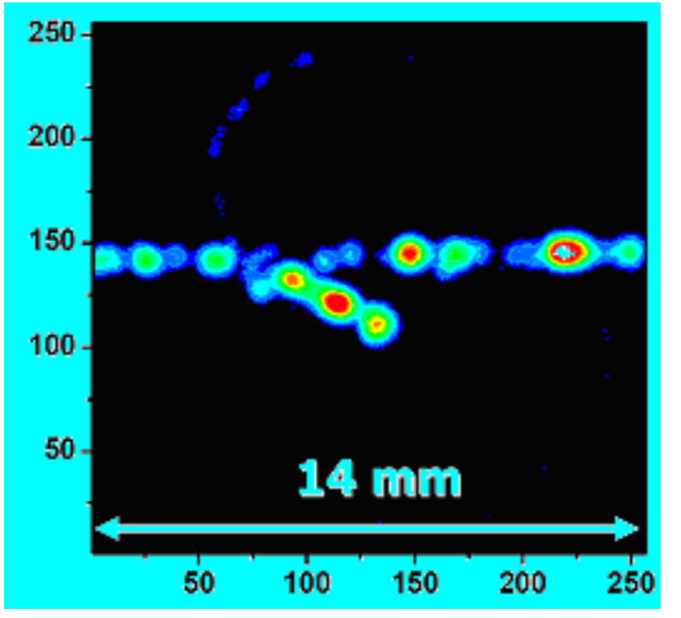
GASEOUS DETECTORS

Time projection chambers

- ALICE
- PANDA
- ILC (?)
- Rare events searches
- …

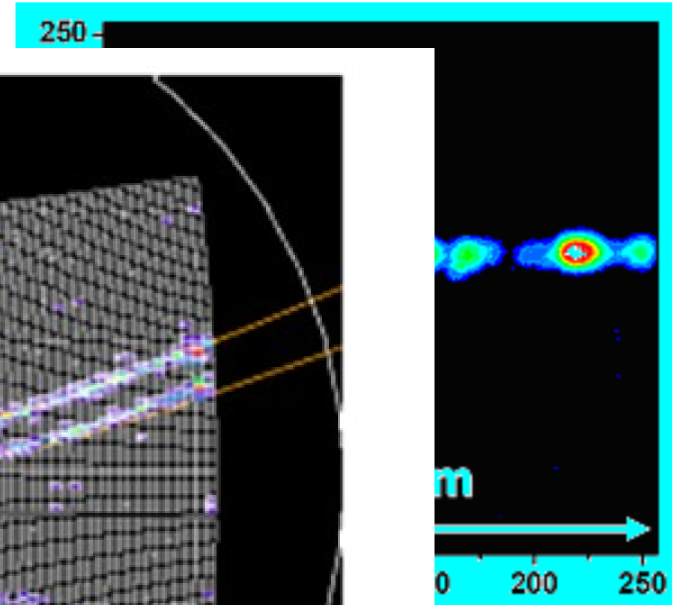
Established technology, broadly used

- Move to highly pixelated readout structures
- Merge the advantages of Si technology with gaseous technology



Picture of track in a TPC recorded with a TPC quipped with pixel readout (50 um pixel). Structure of ionization becomes visible.

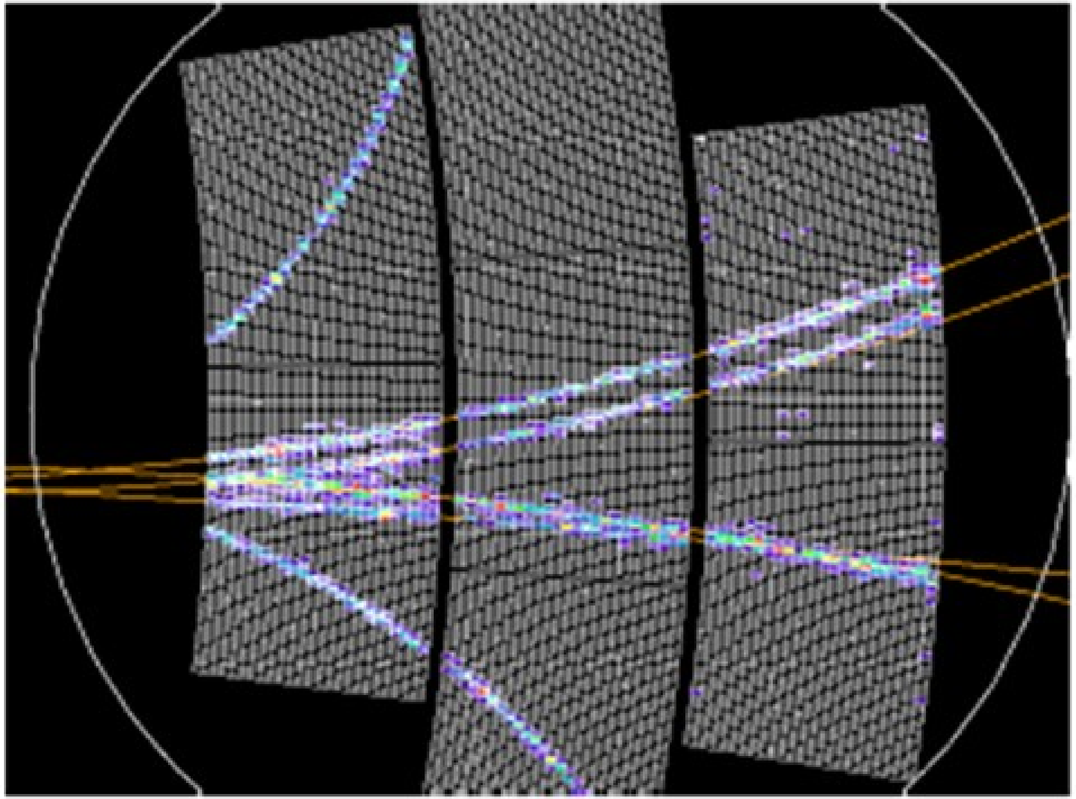
GASEOUS DETECTORS



Time projection cl
- ALICE
- PANDA
- ILC (?)
- Rare events se
- …

Established techn

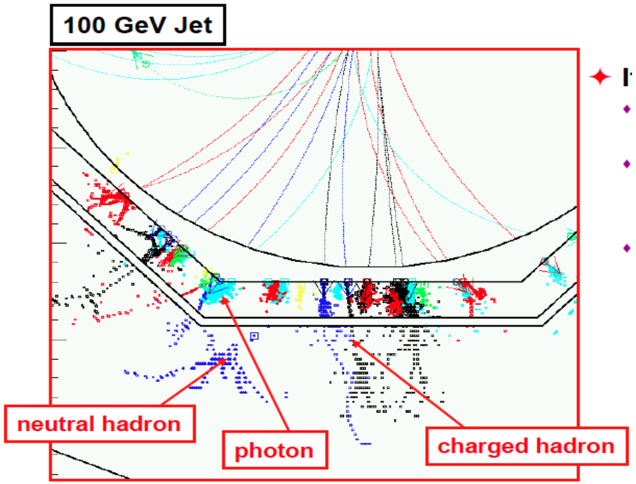
- Move to highly
- Merge the adv
  gaseous techn



TPC recorded
with
pixel).
on becomes
visible.

CALORIMETRY

Calorimetry is at the heart of any particle flow detector:



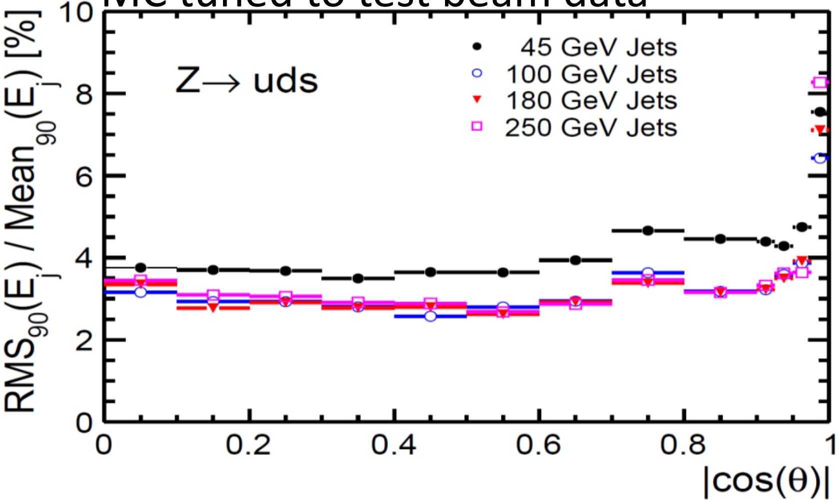
M. Thomson, Calor 2010

Highly granular, thick, calorimeters

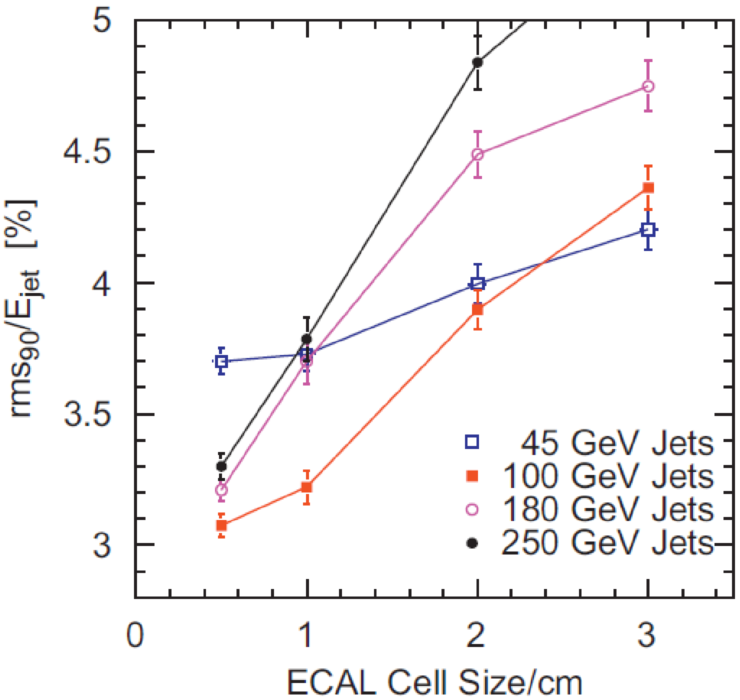
Several technologies studied

- Si-W
- Scintillator based
- RPC based

Performance simulations based on realistic detector models, background estimates, MC tuned to test beam data



SAMPLING CALORIMETERS

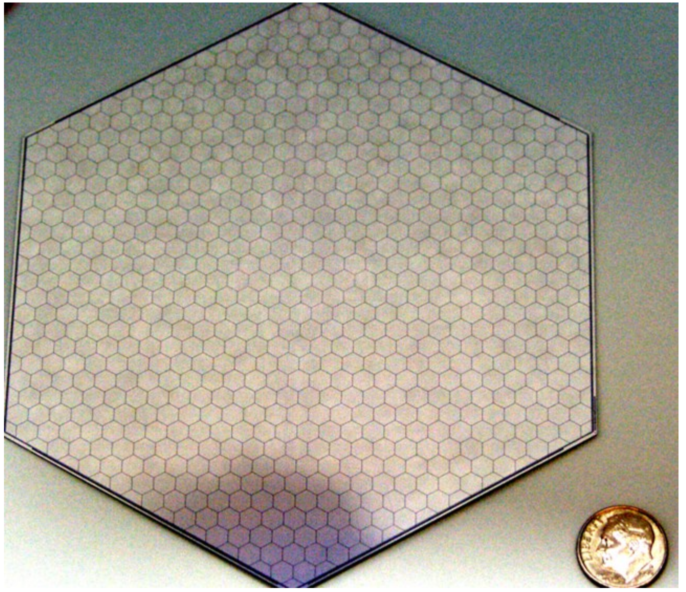


Cell sizes typically 5x5 mm^2

Integration of readout into the sensitive plane to save space and cabling

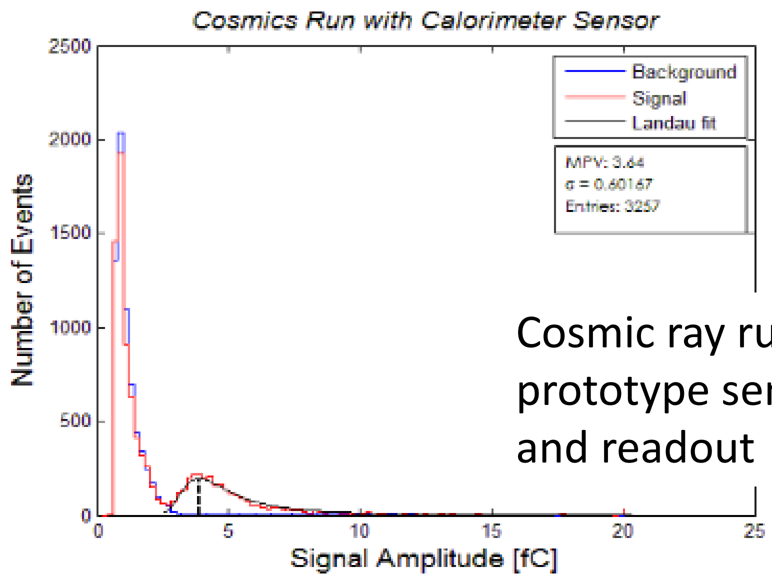
Particle flow = granularity

Optimize relative to particle flow performance

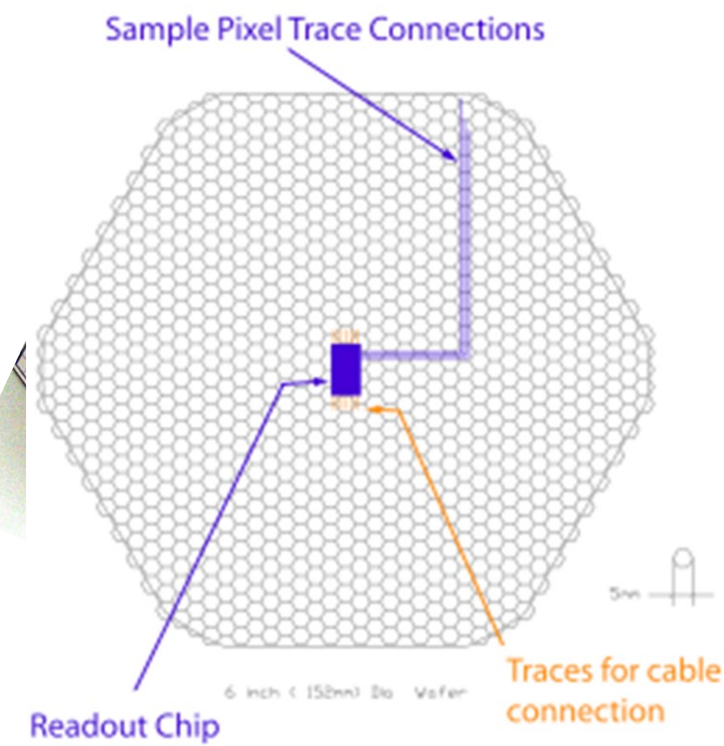


Proposal for a Si-ECAL (Breitenbach/ Strom/ Frey)

SAMPLING CALORIMETERS: SILICON



Cosmic ray run of prototype sensor and readout



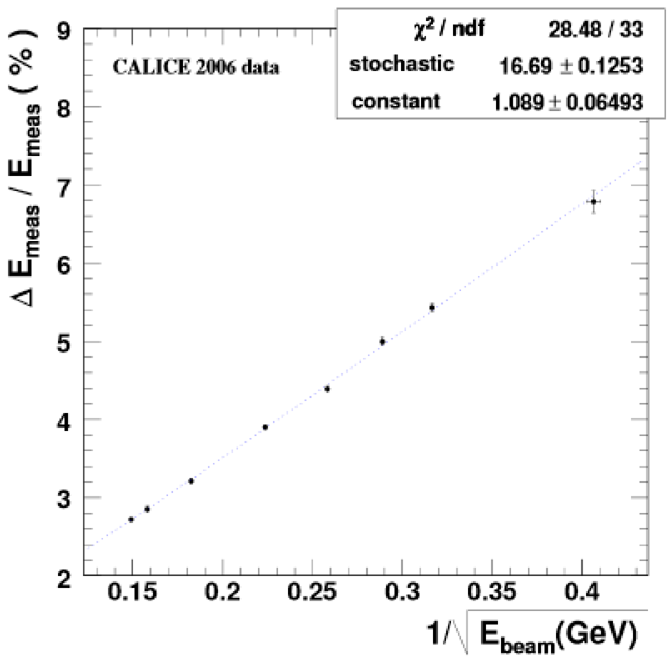
Cell sizes typically 5x5 mm^2

Integration of readout into the sensitive plane to save space and cabling

Similar proposal made in Europe by Brient/ Videau etal. (CALICE)

Silicon based Calorimetry

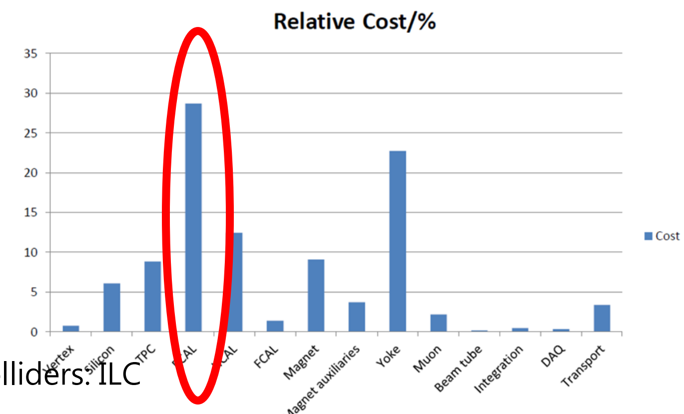
- Sampling calorimeters with silicon based sensitive planes are an attractive option.
- Large progress over the last years in hardware and in understanding
- CALICE: convincing test beam results to demonstrate the feasibility



Relative energy resolution of CALICE SI-ECAL

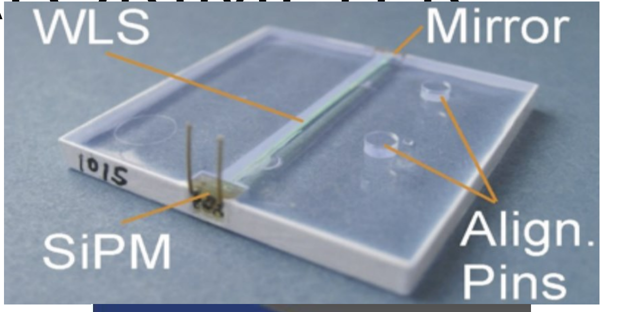
- Challenge:
  - Integration
  - Costs!

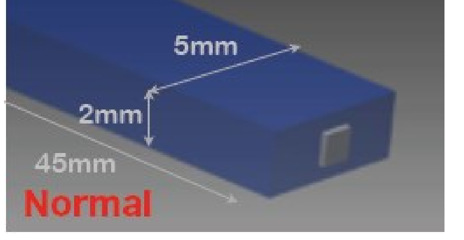
Example: ILD detector at the proposed ILC ECAL 100Mio channels

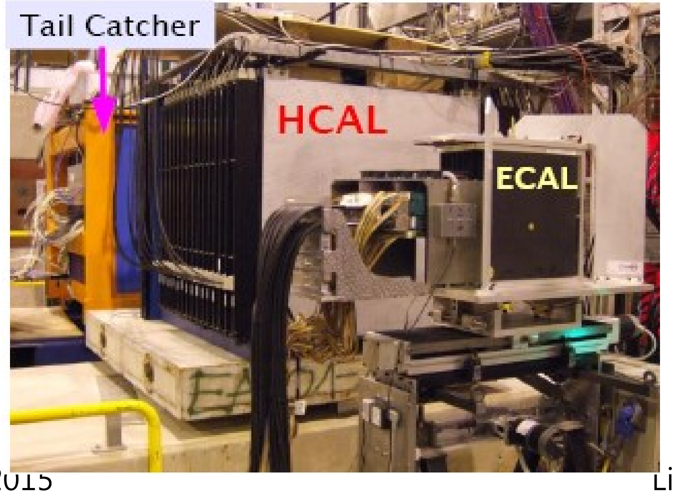


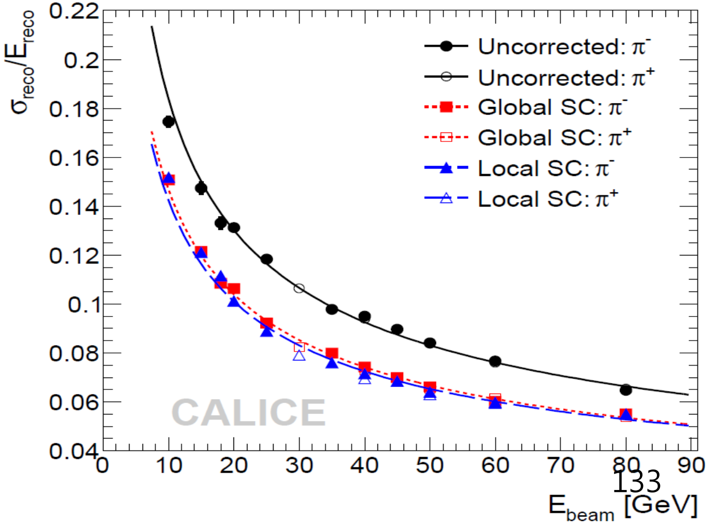
SCINTILLATOR BASED CALORIMETER

- Availablity of SiPM allows highly granular scintillator based designs
- HCAL: $3x3cm^2$ segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: $58\%/E^{1/2} \rightarrow 45\%/E^{1/2}$





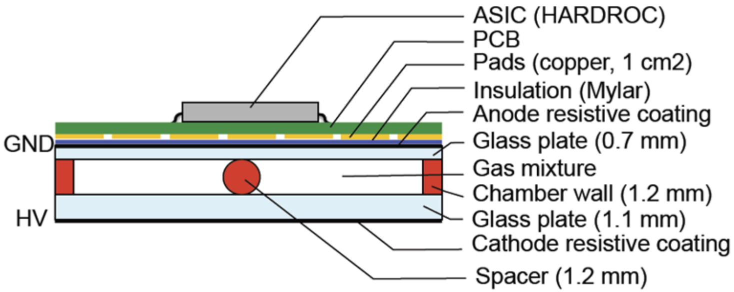




DIGITAL CALORIMETRY

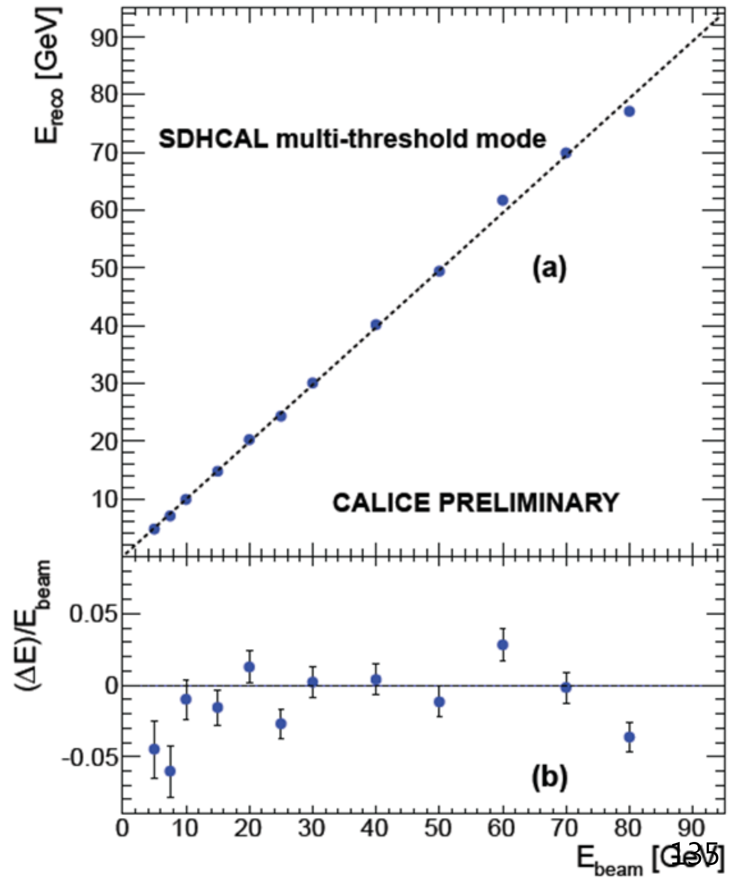
Digital calorimetry:

- Measure the energy of a particle through the number of cells hit
- Was tried already in the 80’ s (unsuccessfully) has seen a renaissance lately due to the availability of very granular systems.

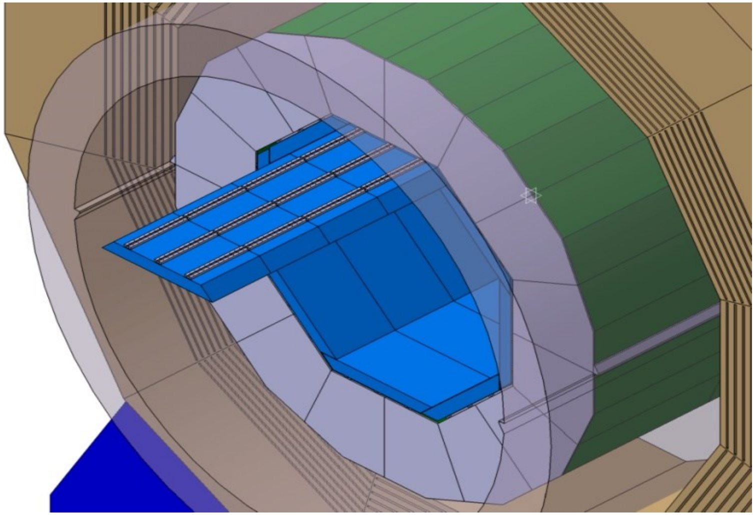


Active medium: gas RPCs

Test beam results from a large prototype detector

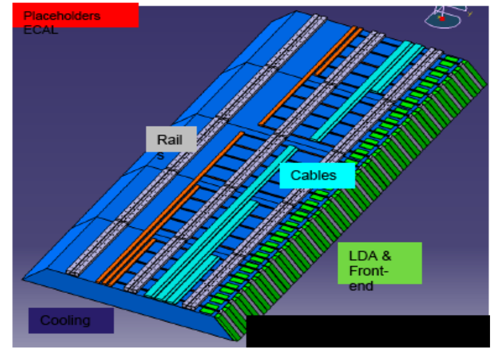


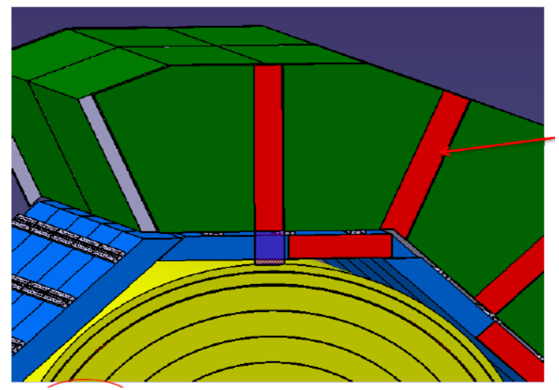
DETECTOR INTEGRATION



ILD integration study.

ILD simulation model





A detailed detector concept exists.
It has been simulated in detail.
Most technologies needed have been demonstrated.
A preliminary engineering has been done.

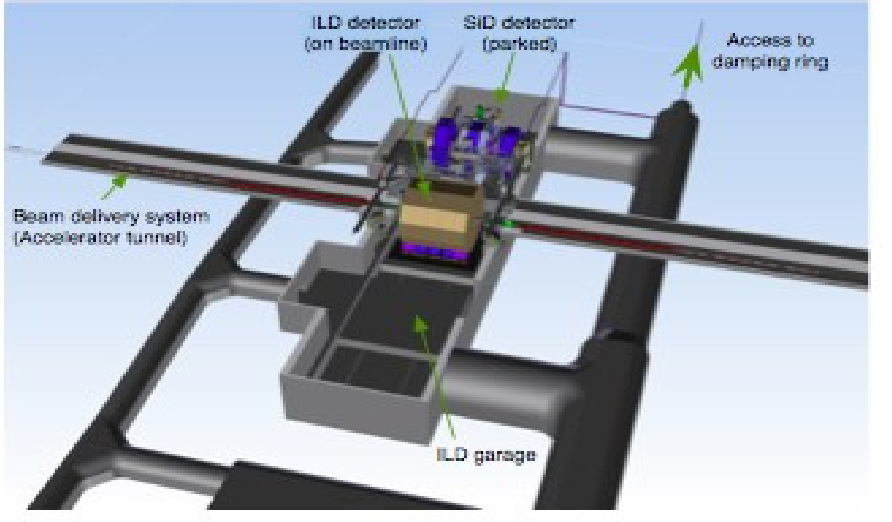
DETECTORS AND PUSH/PULL

- Integrated luminosity at linear colliders does not scale with the number of interaction regions

- ILC has just one interaction beam line (cost issue) but should have two detectors

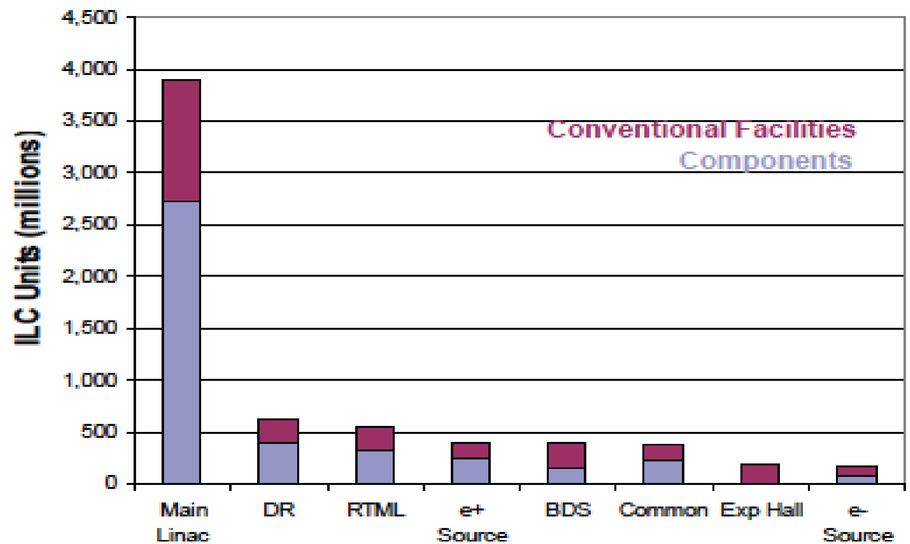
- Two detectors share one interaction region

  → Push/Pull System



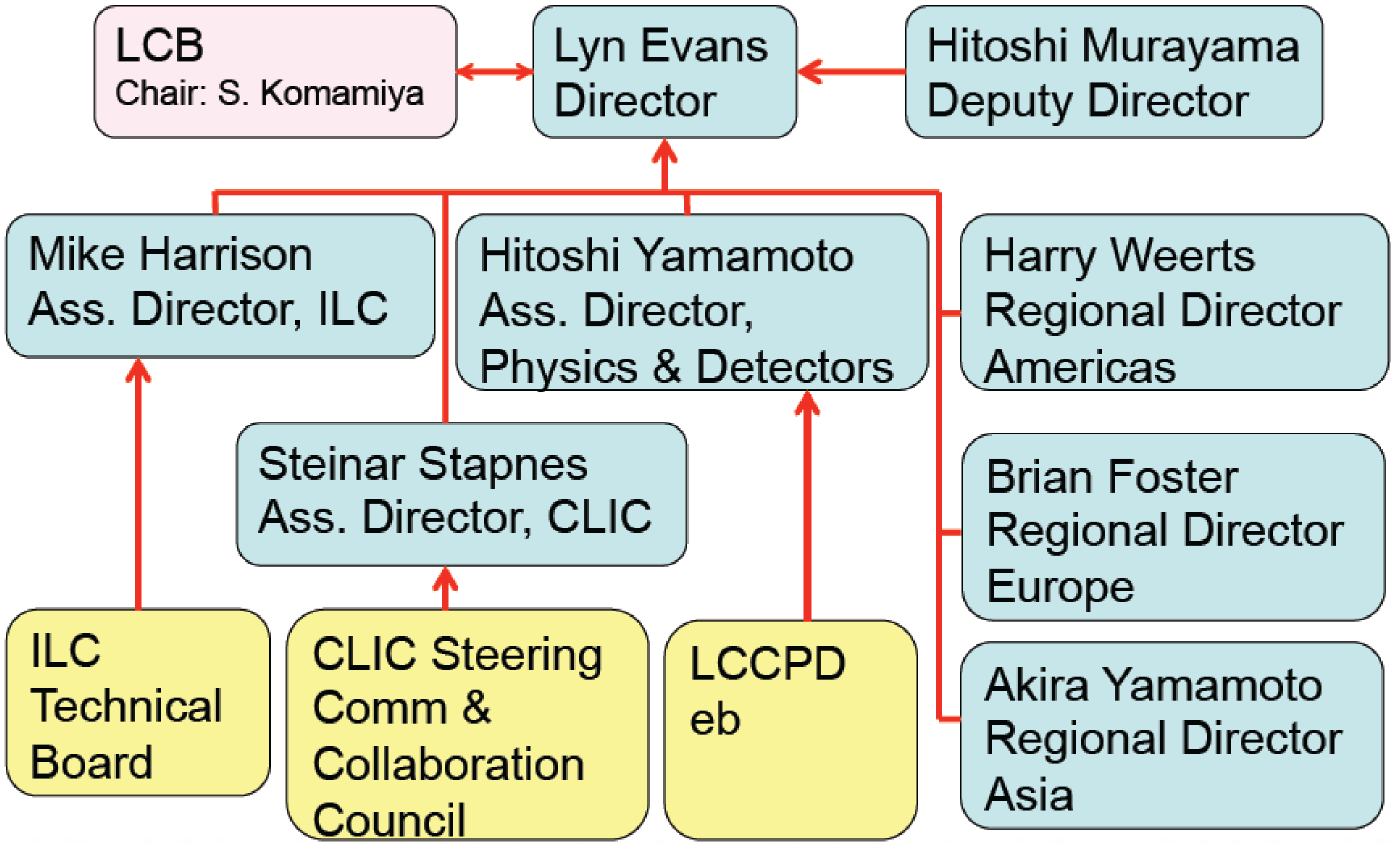
HOW MUCH DOES IT ALL COST?

- Estimate from 2007 Reference Design Report, escalated to 2012 prices:
  $7.3 \cdot 10^9$ \$ + 14k years labor
- New estimate in 2013 Technical Design Report:
  $7.8 \cdot 10^9$ \$ + 14k years labor (7% increase)
- Dominated by Main Linac

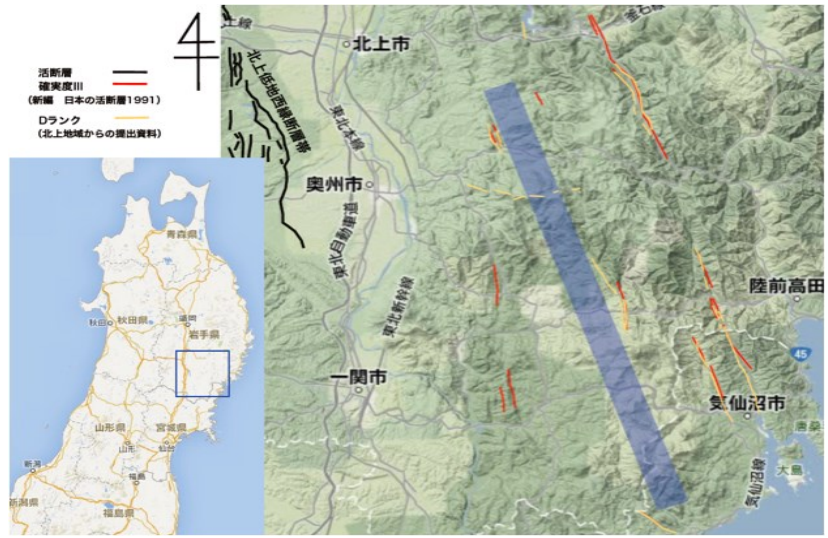


A LINEAR COLLIDER PROJECT

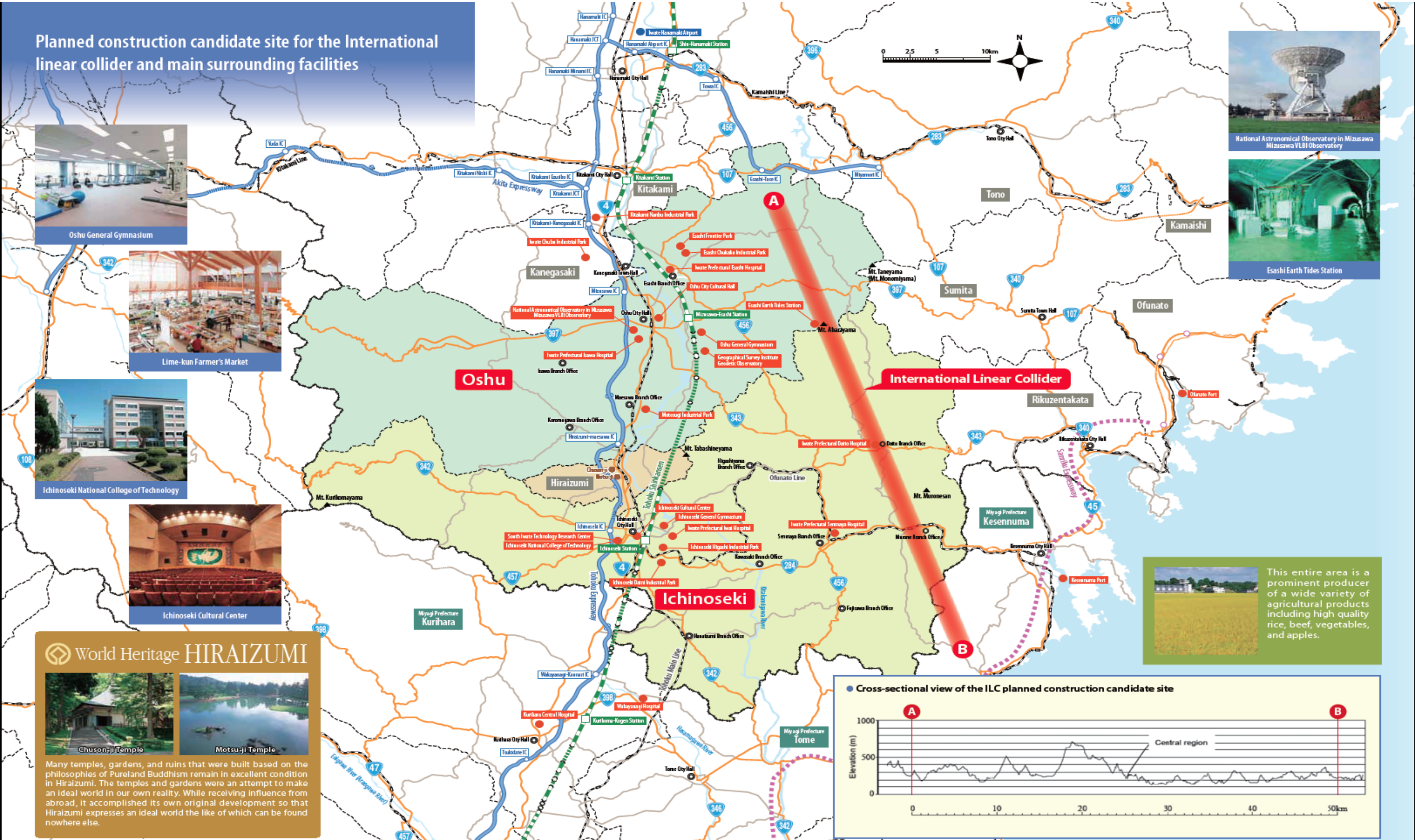
LINEAR COLLIDER ORGANISATION



NORTHERN JAPANESE SITE

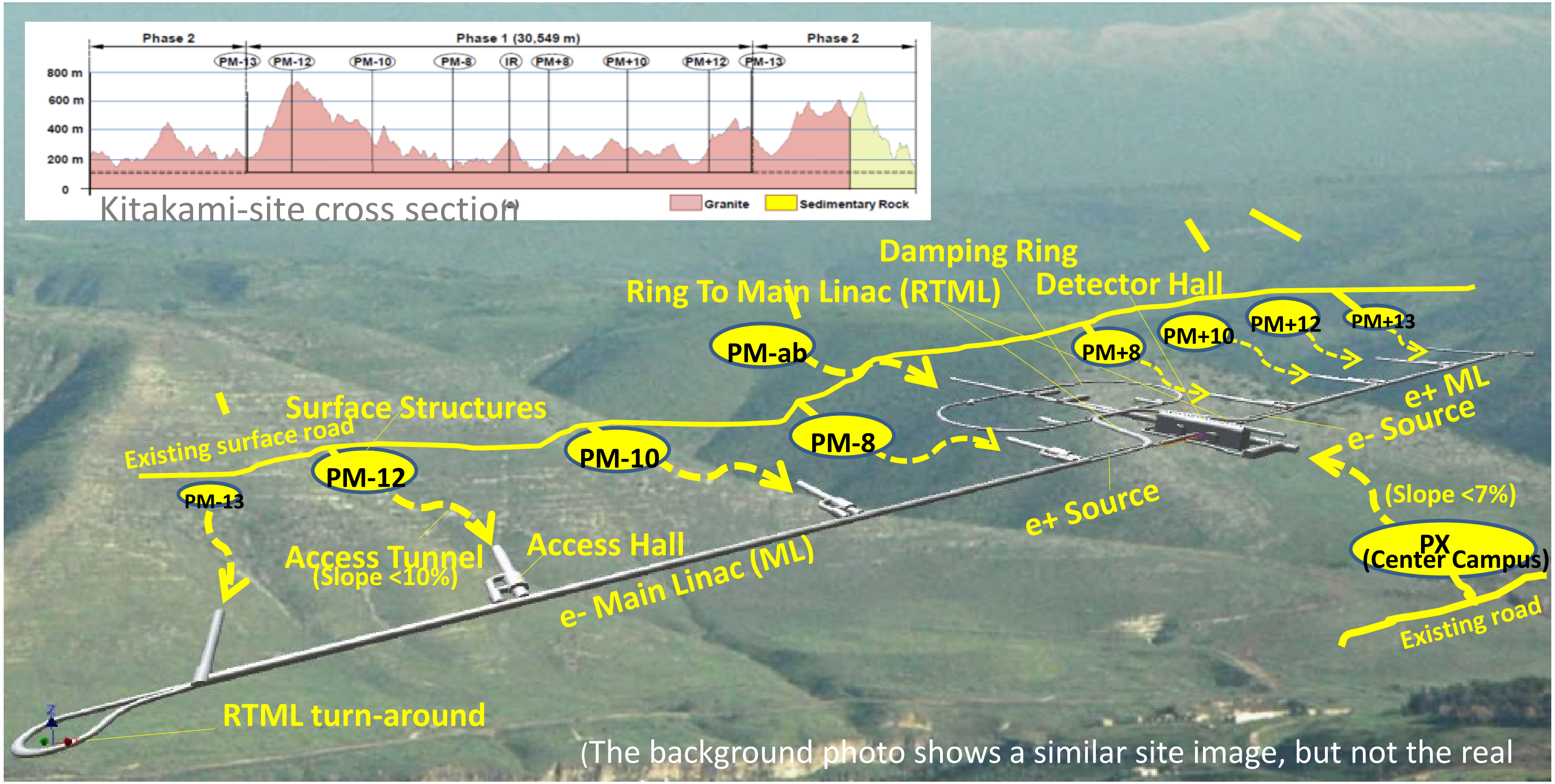


Geologically very stable area
Thinly populated, still well accessible through major roads and high speed rail roads
Closed big city: Sendai



http://www.city.oshu.iwate.jp/htm/ilc/archives/rayofhopee.pdf

ILC SITING



Need to establish the IP and linac orientation
Then the access points and IR infrastructure
Then linac length and timing

JAPAN AND THE ILC

- **Talk of Chair of Diet ILC Federation, Mr Kawamura@ LCWS Tokyo, Dec. 2013**

"The Technical Design Report of ILC was issued in December 2012 (sic)…I would again like to express my appreciation of this effort. I understand that it is now the turn of politicians to respond to this effort, and to construct a worldwide partnership to realize this project."

"I think that most Diet members' knowledge of physics is at high school students' level. If you allow me, let me take the liberty of pointing out that the understanding of political dynamics by most particle physicists is also at high school students' level. If physicists and politicians collaborate by using each other's area of expertise, it is certain that we can accelerate the realization of the ILC project."

HIGH LEVEL CONSULTATIONS

Lynn Evans (Director of Linear collider collaboration) meets with Japanese Prime minister Abe about a year ago

The next Steps

- MEXT in Japan has initiated an “wise man” review of the ILC and its merrits for Japan
- An interim summary of the work has just been published
- In parallel government level discussions have started
    - In US with the DOW
    - In Europe with the EU, CERN and with individual governments
- An official budget line for the ILC preparations has been approved by Japan parliament
- Japan has expressed an interest to host the ILC. The political process has begun. There is a lot of activity, though most of it behind the scenes.

- The next 2-3 years are decisive whether or not ILC will go forward
- International talks have begun, but are still at a very early stage

SUMMARY

A clear physics case exists for a lepton collider.

- Higgs physics
- Top physics
- BSM physics

If the 14TeV LHC finds nothing: we need to probe the Higgs boson and the top quark with ILC precision

If the 14TeV LHC finds new physics: this will make the case for an ILC even stronger, to explore the new physics and its implications

The ILC design is mature and ready to go.

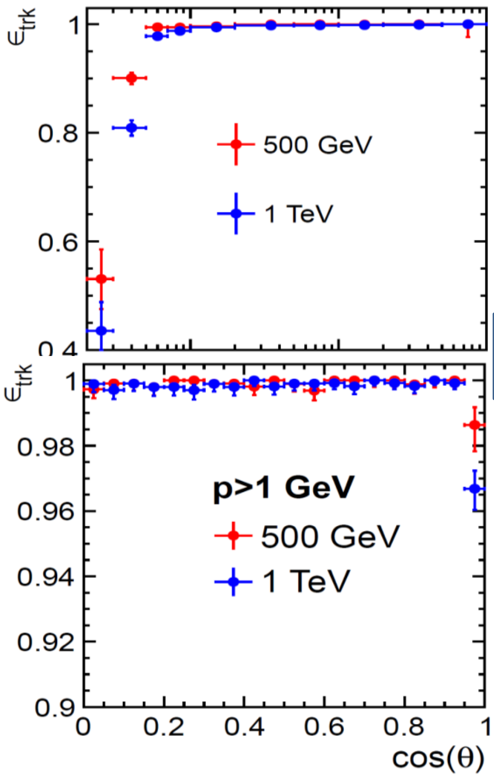
With the Japanese initiative we have a window of opportunity.


©Rey.Hori/KEK

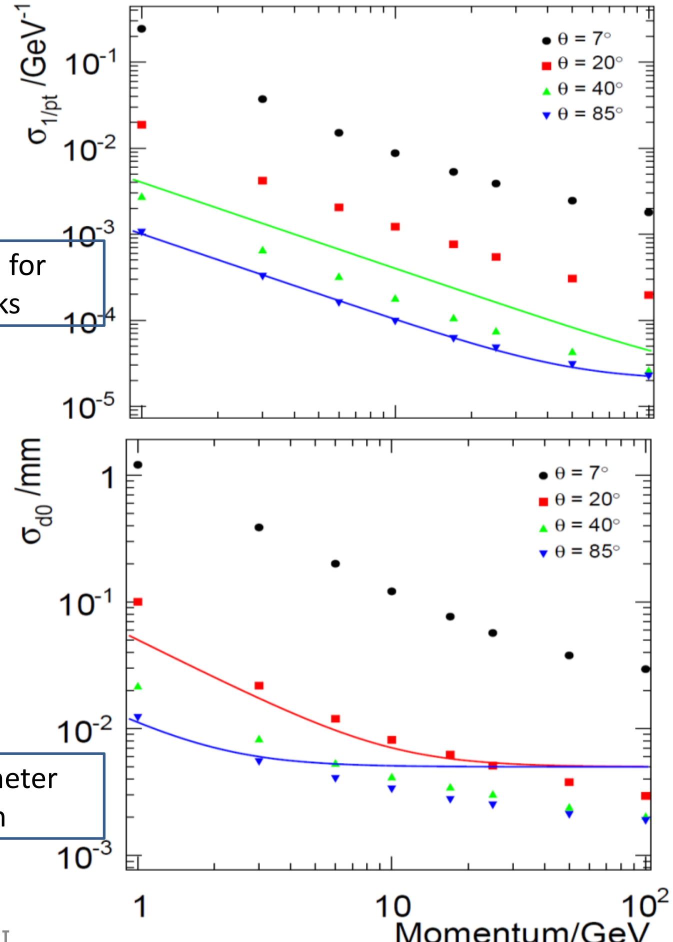
BACKUP

TRACKING PERFORMANCE

- Performance goal
  - $s_{1/pT} \sim 2x10^{-5} GeV^{-1}$
  - $s_{rf} = 5 \oplus 10/psin^{3/2}q$ [um]



Tracking efficiency for t t events

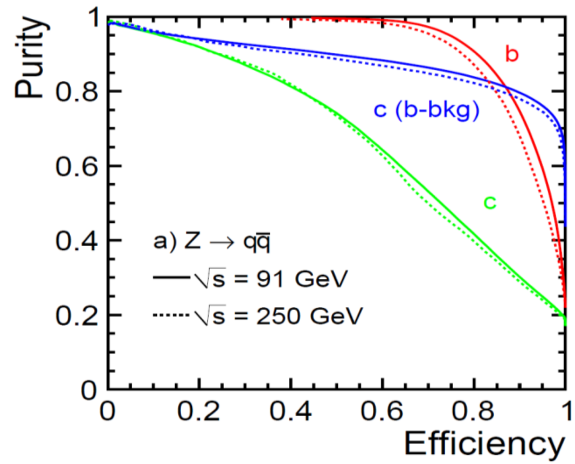


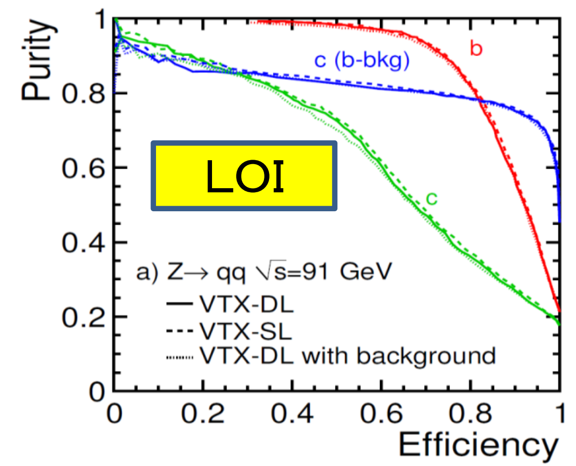
Pt resolution for muon tracks

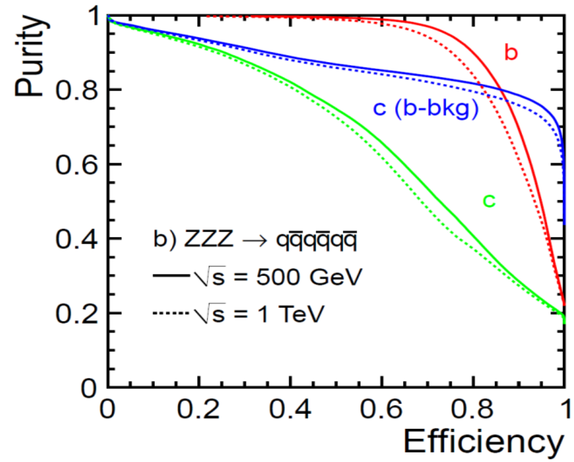
Impact parameter resolution

FLAVOR-TAG PERFORMANCE

- Sophisticated multi-variable tagging algorithm (LCFIplus)
- Continuous improvement
- Based on full simulation.





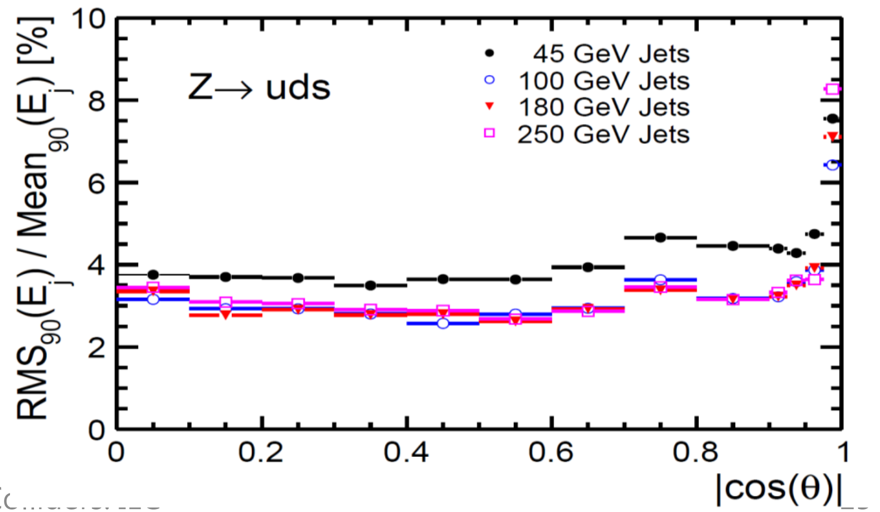


PFA PERFORMANCE

- Performance goal
  - Jet energy resolution < 3.5% for efficient separation of W, Z, and Higgs in hadronic mode
  - $s_E/E = a/\mathrm{sqrt}(E)$ is not applicable because particle density depends on Ejet
  - Jet energy resolution is slightly better than LOI due to improvement of reconstruction software

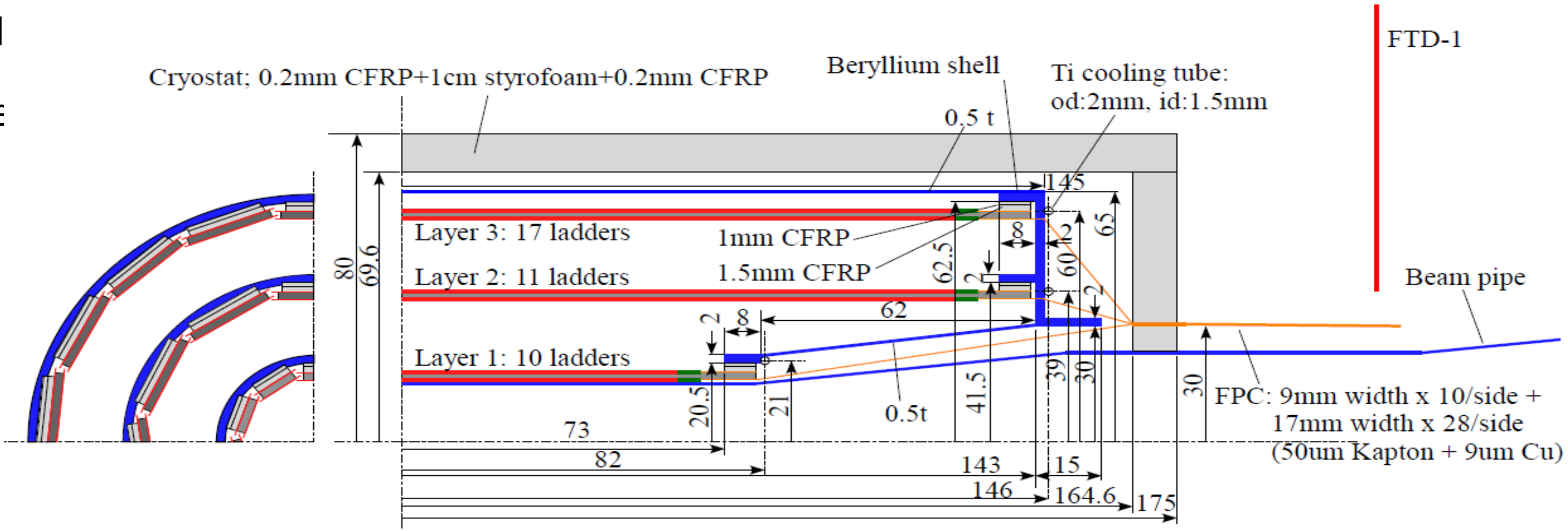
Jet energy	σ_E/E
45 GeV	3.66%
100 GeV	2.83%
180 GeV	2.86%
250 GeV	2.95%

Z→u,d,s events
|cosθ|<0.7



VERTEX DETECTOR

- Excellent impact parameter resolution better than 5⊕10/pbsin$^{3/2}$q is required for efficient flavor tagging
- 3 layers of double ladders (ca 100 um apart) (6 pixel layers)
  - Effect on pair-background rejection is expected, but not demonstrated yet
- Barrel only: |cosq|<0.97 for inner layer and |cosq|<0.9 for outer layer
- Point resolution <3um for innermost layer
- M
- Se



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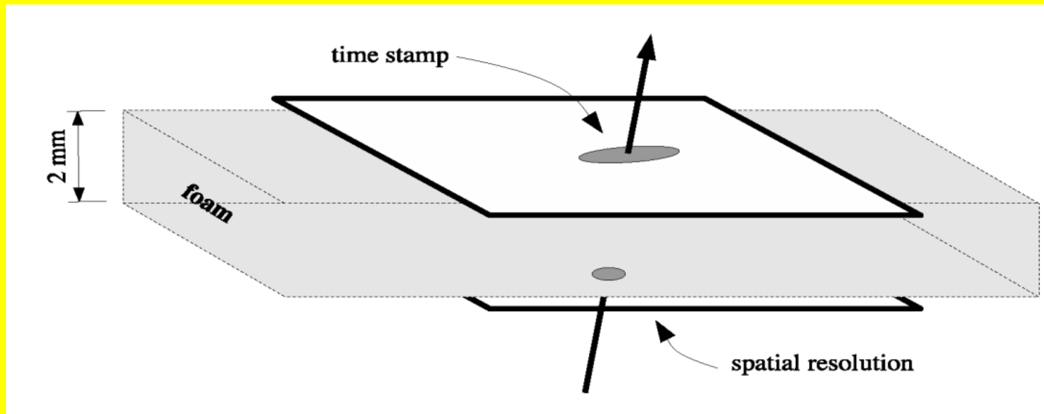
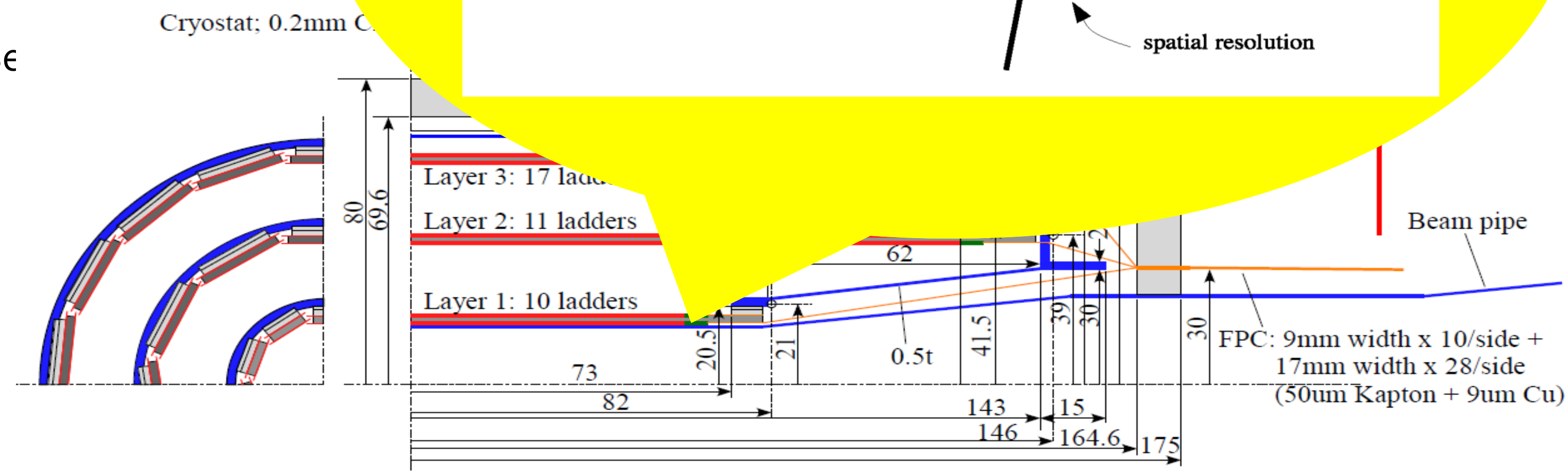
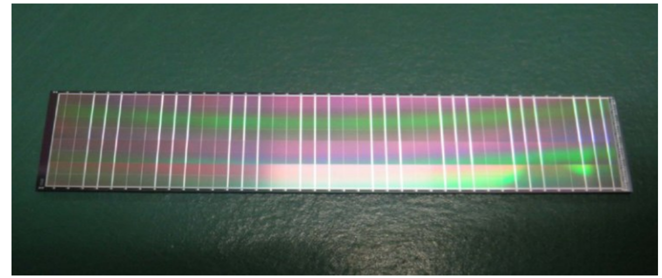
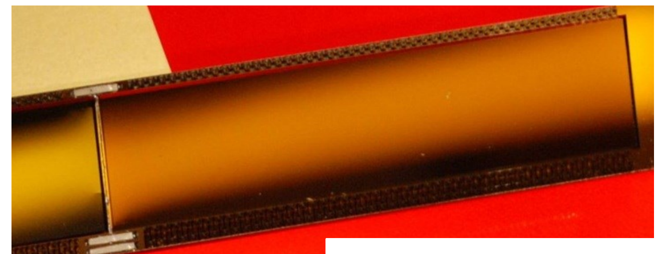




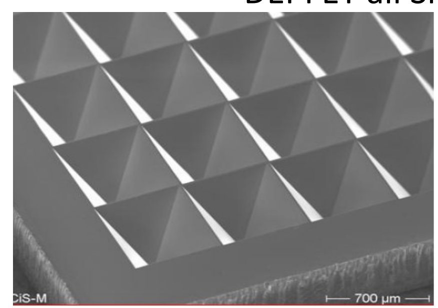
VERTEX DETECTOR

- CMOS option
  - Pixel size: 17x17(L1), 17x85(L2), 34x34(L3-6)
  - Frame readout time: 10us~100us
  - Power consumption: 600W → 10W by power pulsing
- FPCCD option
  - Pixel size: 5x5 (L1-2), 10x10(L3-6)
  - Readout between trains
  - Power consumption: ~40W (no power pulsing)
- DEPFET option
  - Experience at Belle-II
  - Frame readout time: 50us~100us
  - 5-single layer of all-Si ladder option
- Cooling
  - CO2 cooling for FPCCD
  - Additional material budget is small: 0.3%X0 in end-plate 0.1%X0 in cryostat



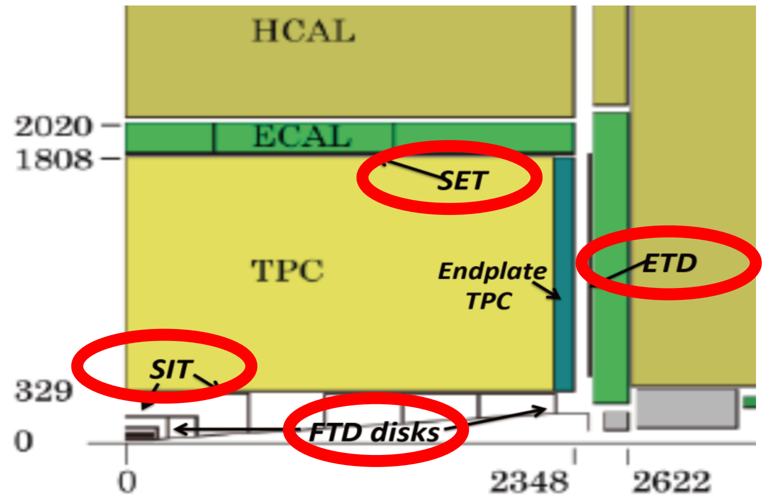


DEPFET all Si ladder



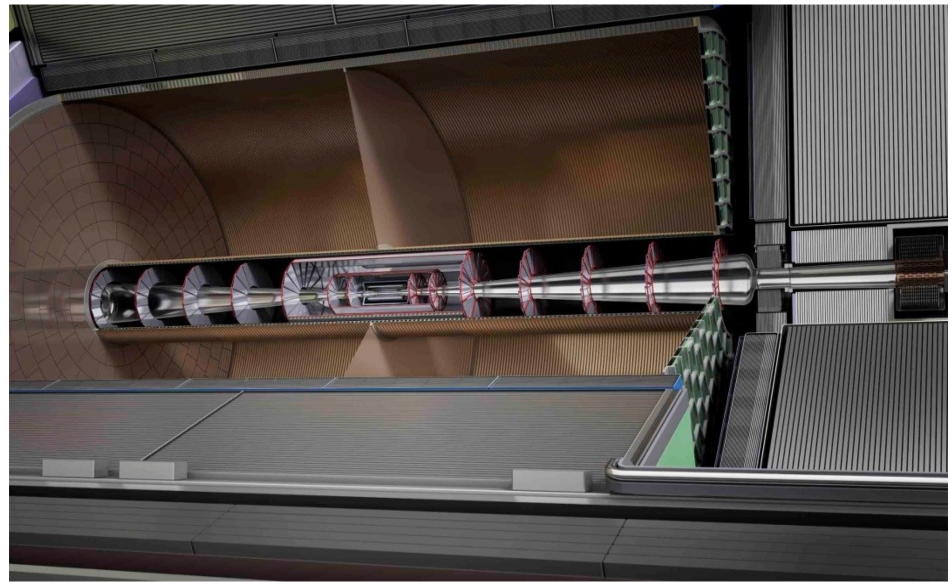
SILICON TRACKING SYSTEM

- Silicon tracking system
  - SIT (Silicon Inner Tracker)
  - SET (Silicon External Tracker)
  - ETD (Endcap Tracking Detector)
  - FTD (Forward Tracking Detector)
- Role of Silicon tracking system
  - Additional precise space points
  - Improvement of forward coverage
  - Alignment of overall tracking system
  - Time stamping
- SIT/SET/ETD
  - Two/one/one false double-sided layers of Si strip
  - Material budget: 0.65%X_0/layer
  - Same silicon strip tiles of 10cmx10cm with 50um pitch, 200um thick, edgeless sensors will be used
  - Point resolution of ~7um



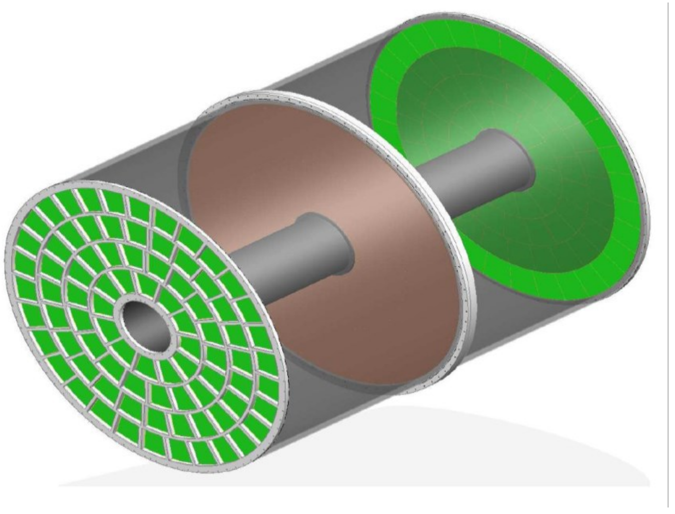
FORWARD SILICON TRACKING SYSTEM

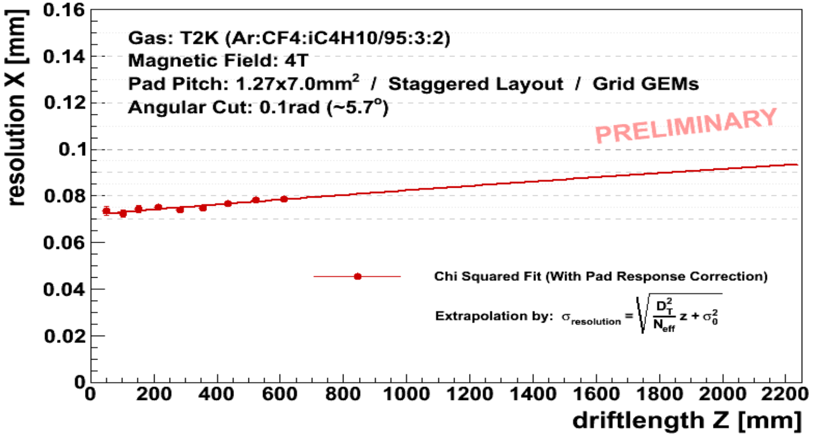
- FTD
  - Two pixel discs and five false double-sided strip disks
  - Pixel sensor options: CMOS, FPCCD, DEPFET
  - Power consumption: 2kW/disk → 100W/disk by power pulsing



TPC

- Time Projection Chamber: The central tracker of ILD
- Tracks can be measured with many (~200/track) 3-dimensional r-f-z space points
- s_{rf}<100um is expected
- dE/dx information for particle identification
- Two main options for gas amplification: GEM or Micromegas
- Readout pad size ~ 1x6mm^2 → 10^6 pads/side
- Pixel readout R&D as a future alternative
- Material budget: 5%X_0 in barrel region and <25%X_0 in endplate region
- Cooling by 2-phase CO2





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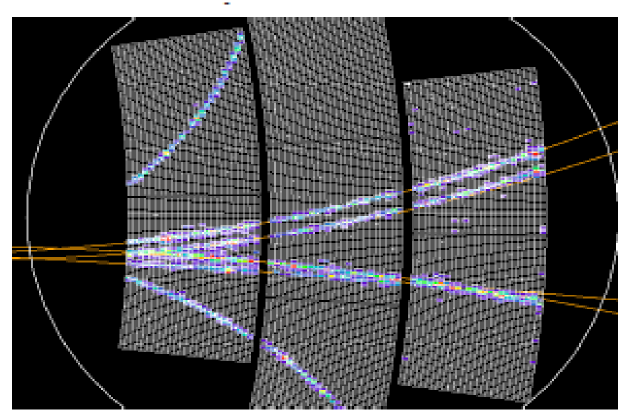
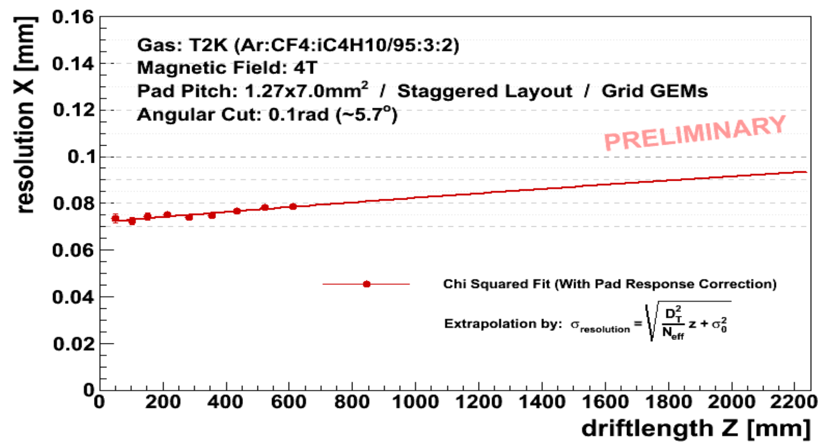
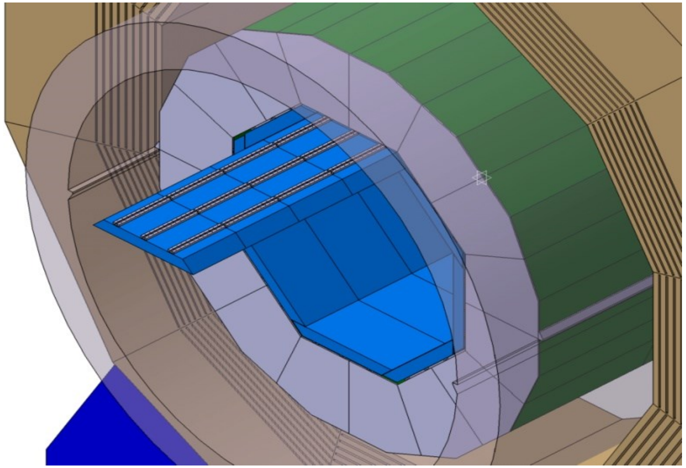
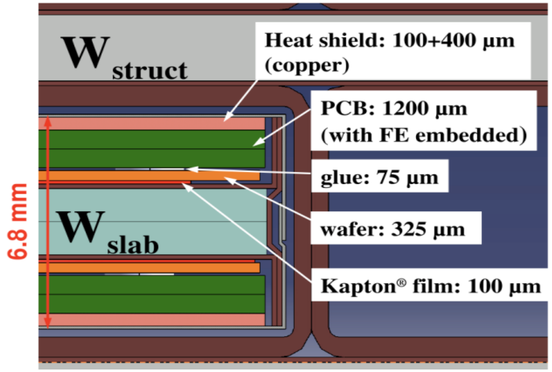


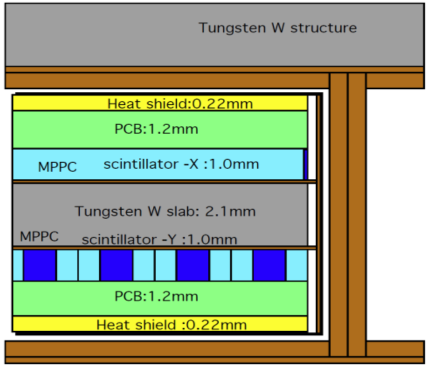


ECAL

- Sampling calorimeter of tungsten absorber / Si or scintillator-strip sensitive layer sandwich
- 30 layers / $24X_0$
- Si sensor: $5x5mm^2$ pixel size
- Scintillator strip: $5x45mm^2$, read out by MPPC
- Leak-less water cooling
- Detailed design exists, prototyped
- Discussions with industry are ongoing on production and costing.



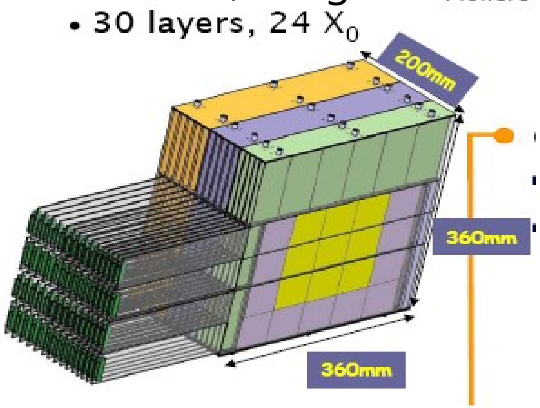




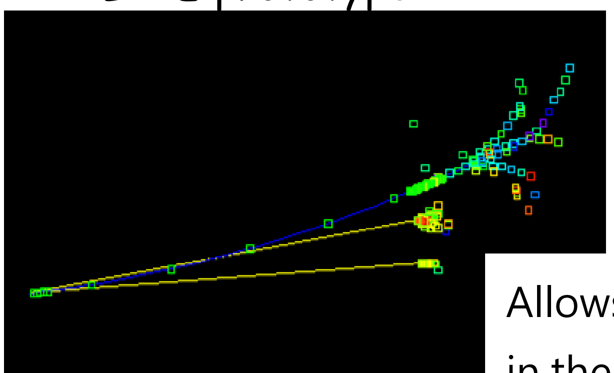
PFLOW ECAL

Typical granularity for ECAL: 0.5cmx0.5cm to 1cmx1cm,

SI detectors, Tungsten absorbers



CALICE prototype

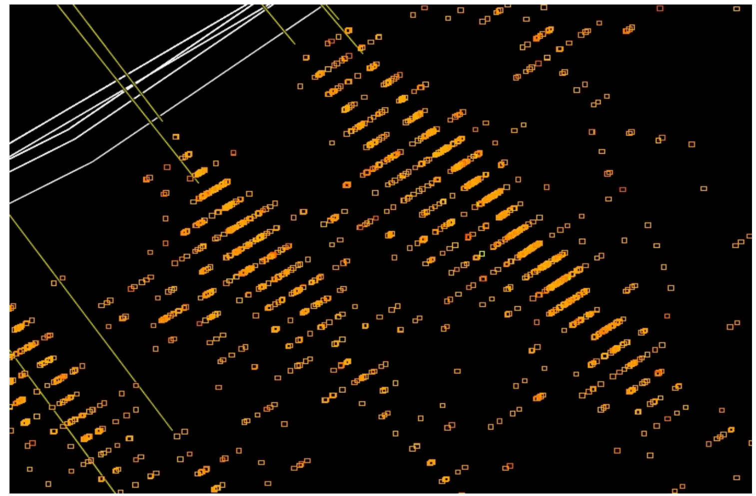


Allows "tracking"

in the calorimeter

Extreme segmentation:

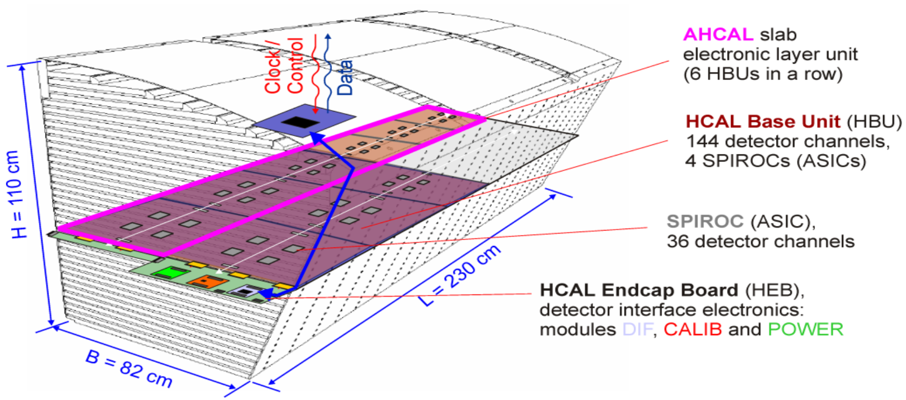
MAPS sensors in the ECAL



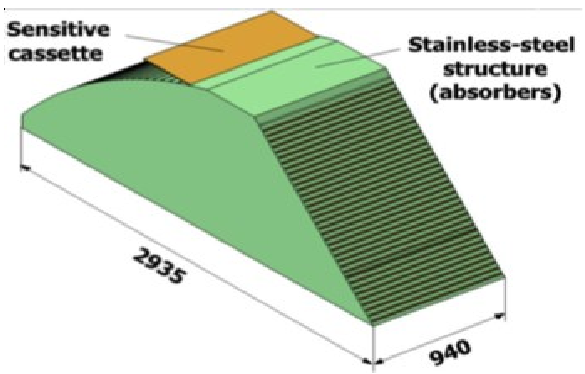
Very detailed shower images

HCAL

- Sampling calorimeter with steel absorber (48 layers, $6\lambda_I$)
- Two options for the active layer
  - Scintillator tiles with analog readout → AHCAL
  - Glass RPC with semi digital (2-bits) readout → SDHCAL



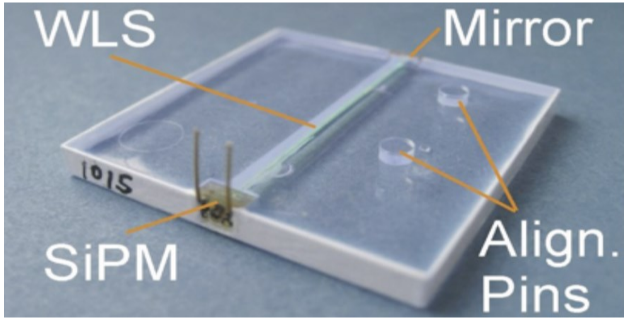
AHCAL module

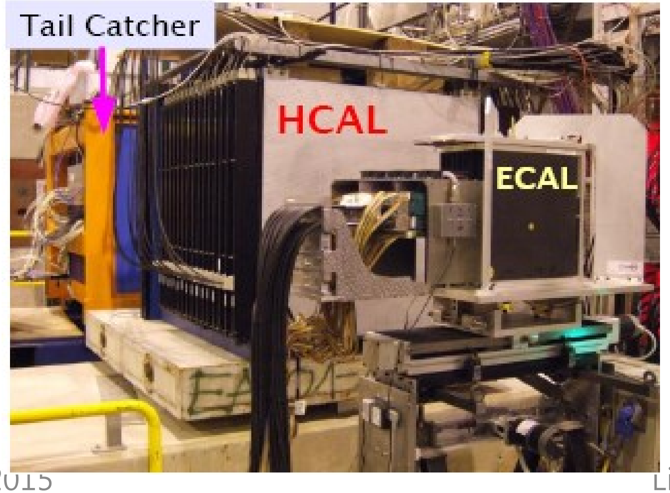


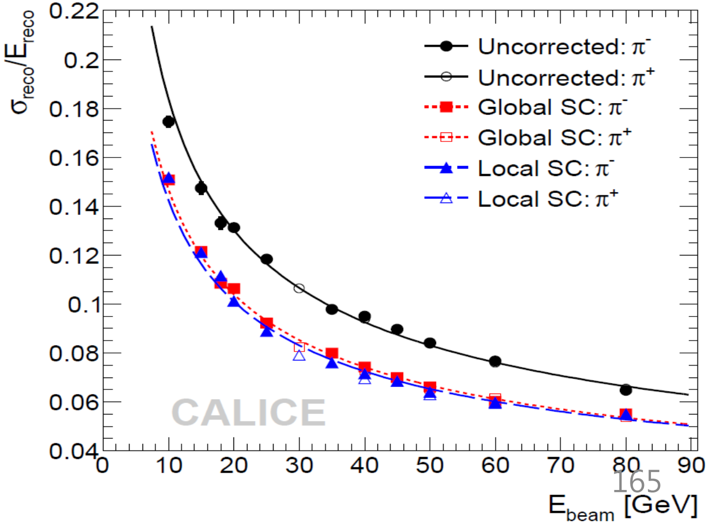
SDHCAL module

AHCAL

- $3x3cm^2$ segmentation of 3mm thick scintillator read out by SiPM through wavelength shifting fiber (Elimination of WLS under study)
- Software compensation (e/p ~1.2) technique was show to work well through beam tests: $58\%/E^{1/2}$ → $45\%/E^{1/2}$
- Test beam results are also used for evaluation of GEANT4 physics list

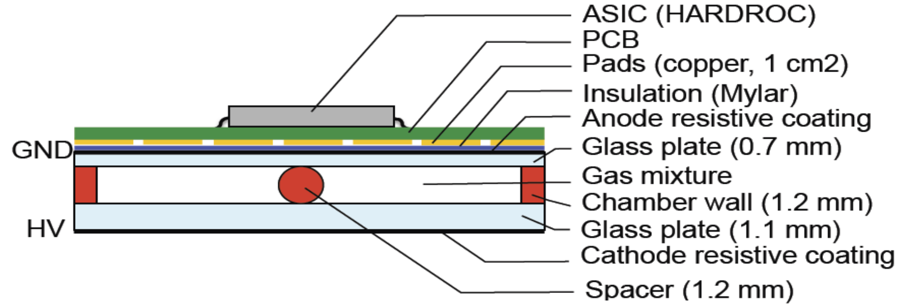


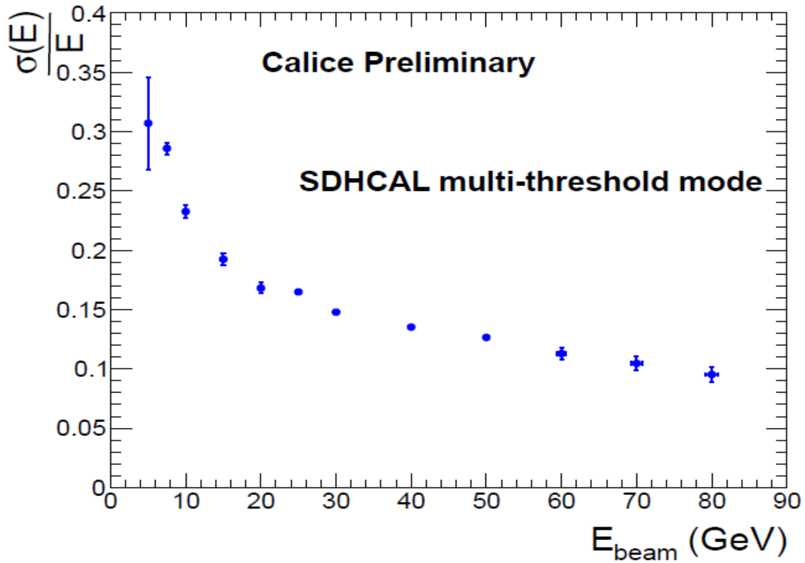


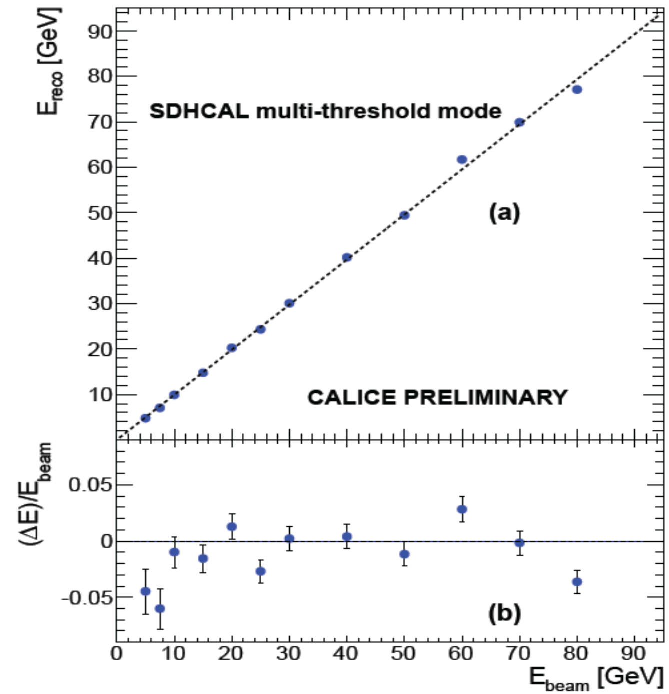


SDHCAL

- Active layer: GRPC with 1.2mm gap with $1x1cm^2$ signal pick-up pads
- Demonstrated to work with power-pulsing in 3T B-field
- Test beam at CERN PS and SPS

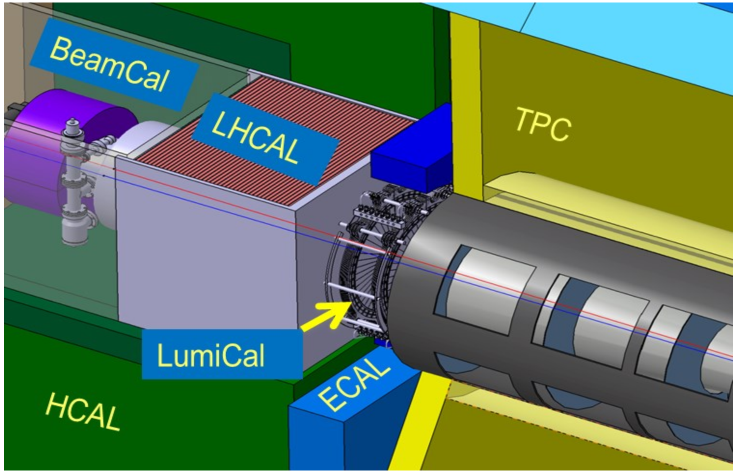






FORWARD CALORIMETERS

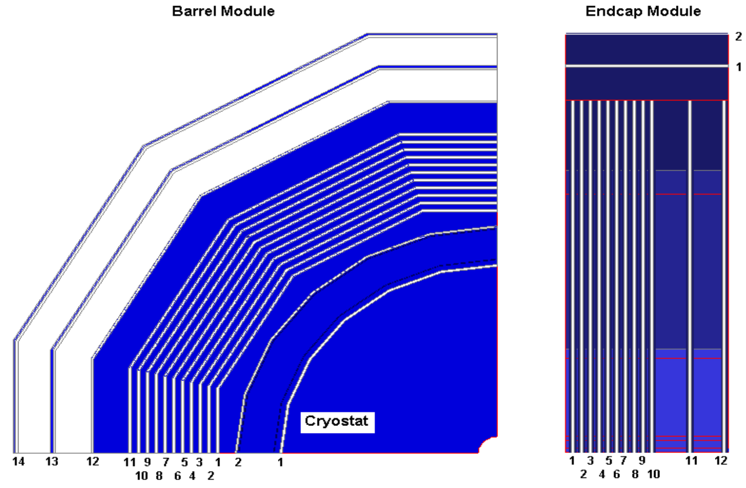
- LumiCal
  - Precise (<10^{-3}) luminosity measurement
- BeamCal
  - Better hermeticity
  - Bunch-by-bunch luminosity and other beam parameter measurements (~10%)
- LHCAL
  - Better hermeticity for hadrons

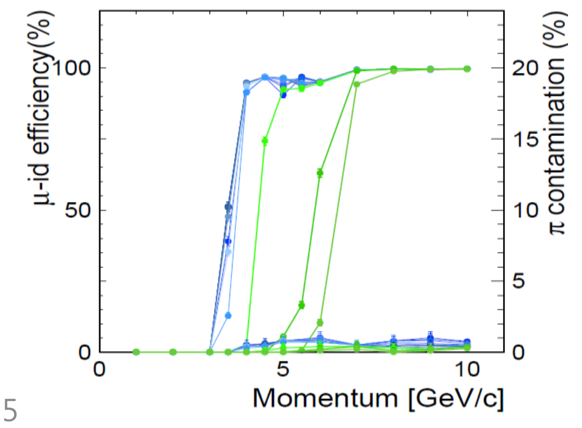


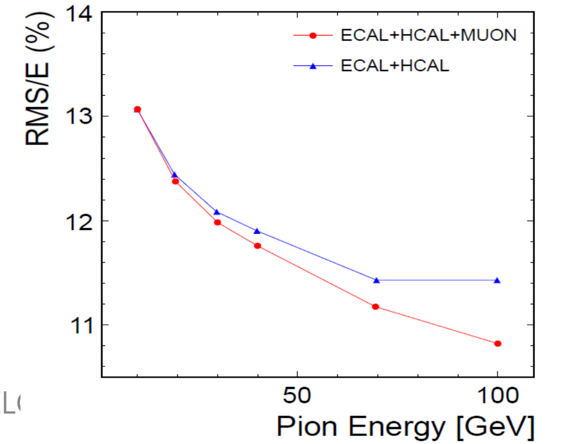
	Technology	Coverage
LumiCal	W-Si	31 – 77 mrad
LHCAL	W-Si	
BeamCal	W-GaAs / Diamond	5 – 40 mrad

Muon system

- Active layers (14 for barrel, 12 for endcap) interleaved with iron slabs of return yoke
- Baseline design adopts scintillator strips + WLS fiber + SiPM readout as the active layer
- RPC is considered as an alternative
- Used for muon identification and as a tail catcher of the HCAL

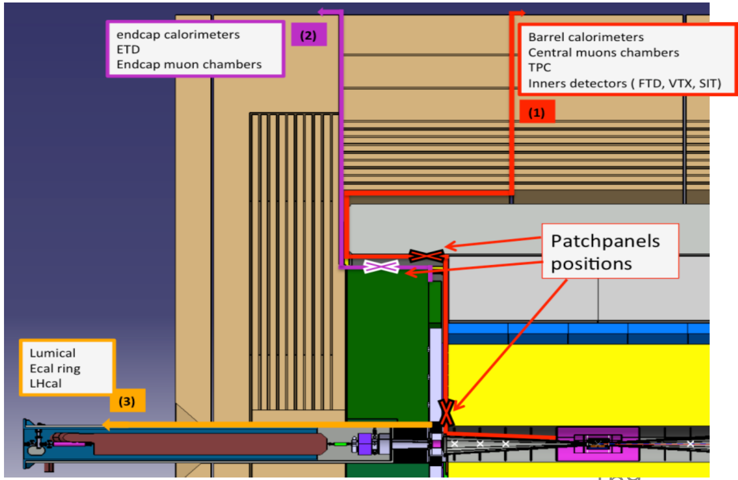






DETECTOR INTEGRATION

- Detector assembly
  - Non-mountain site: CMS style
    - Pre-assembled and tested on surface
    - Large pieces (3 barrel rings + 2 endcaps) are lowered through vertical shaft
    - 3500t crane for the vertical shaft
  - Mountain site: Access through horizontal tunnel
    - Yoke rings are assembled underground
    - 250t crane in the underground experimental hall
- Detector service path
  - Detector services (cables and tubes) are considered seriously for ILD
  - Barrel detectors
    - services go through gap of central yoke rings
  - Endcap detectors
    - gap between endcap yoke and barrel yoke
  - Forward detectors
    - along the QD0 support structure



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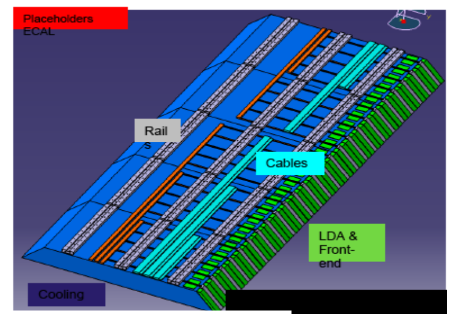

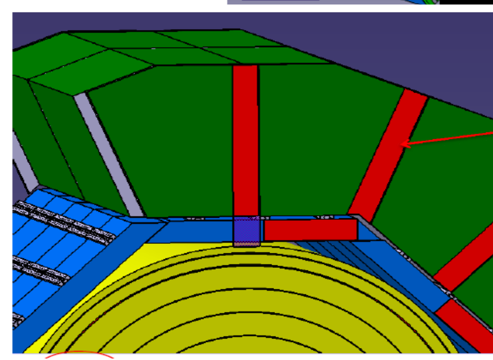

CALIBRATION/ALIGNMENT

- Alignment procedure
  - Accurate positioning during construction of sub-detectors by coordinate measuring machine
  - Alignment at the installation phase by standard survey technique
  - Hardware alignment system during operation
  - Ultimate micro-meter order alignment by "track-based alignment"
- Alignment techniques under R&D
  - IR laser alignment for Si strip detectors
  - Fiber Bragg Grating (FBG) sensors for mechanical structure alignment → Smart support structure
- Large Potential to profit from LHC upgrades!