And then there were two: a glimpse of the detectors for an experiment at the ILC

LC13

Trento, September 16, 2013

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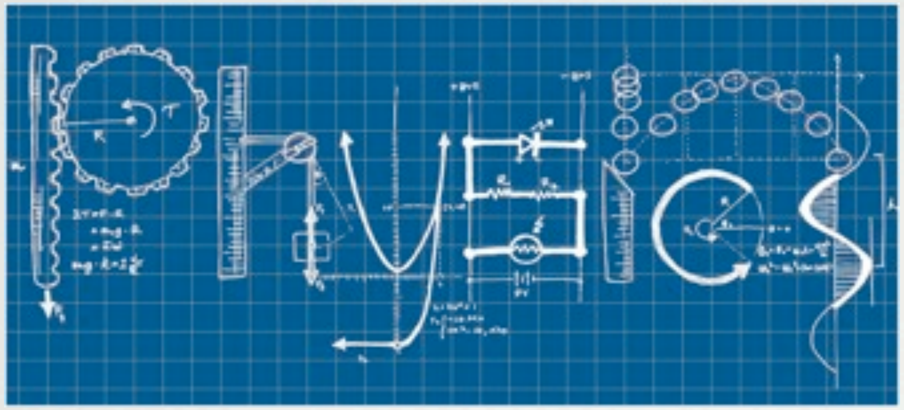


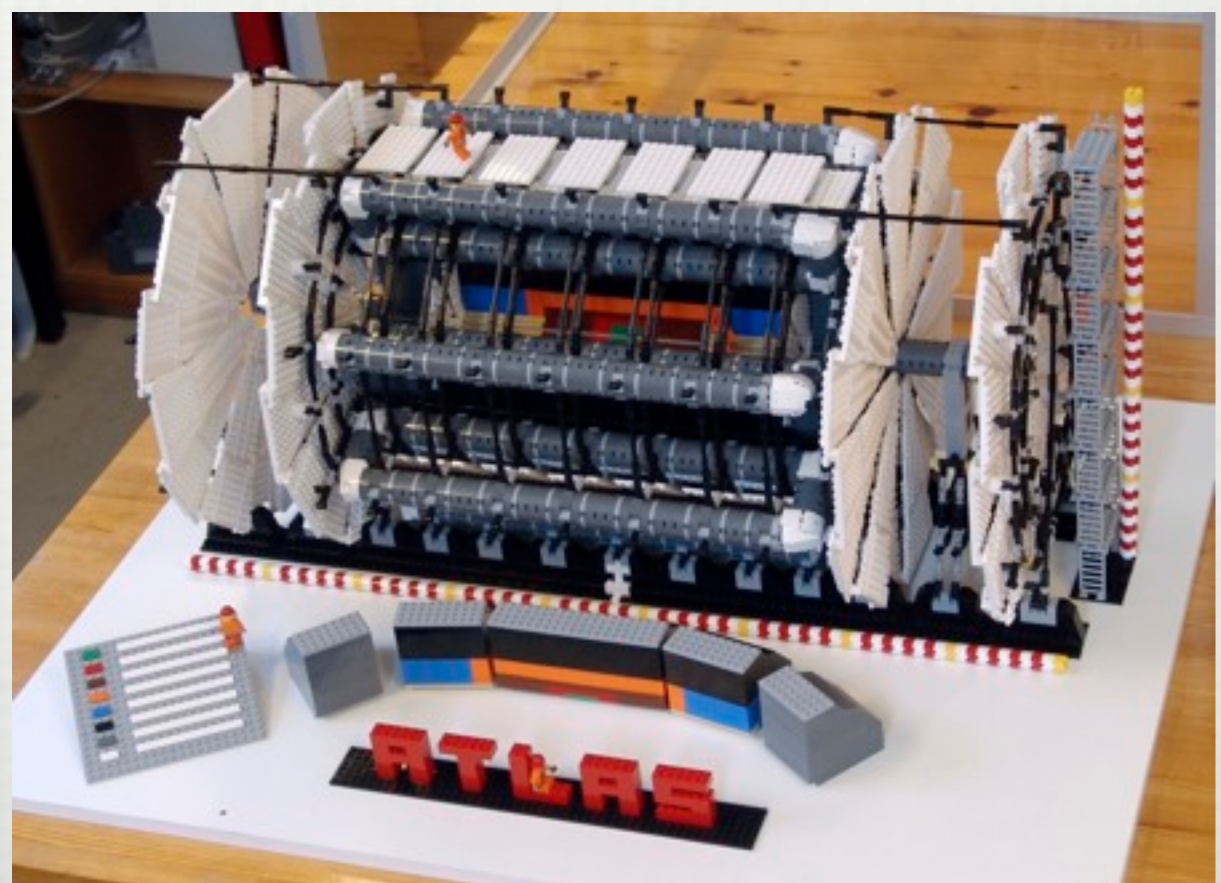
Machine

Physics

Detector Performance

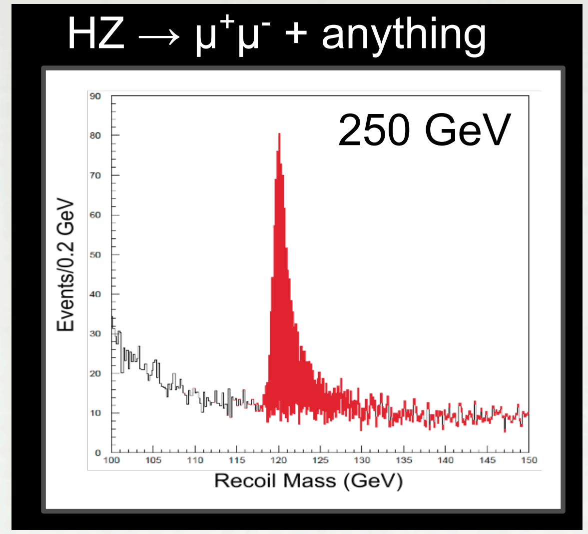
Design & Technology

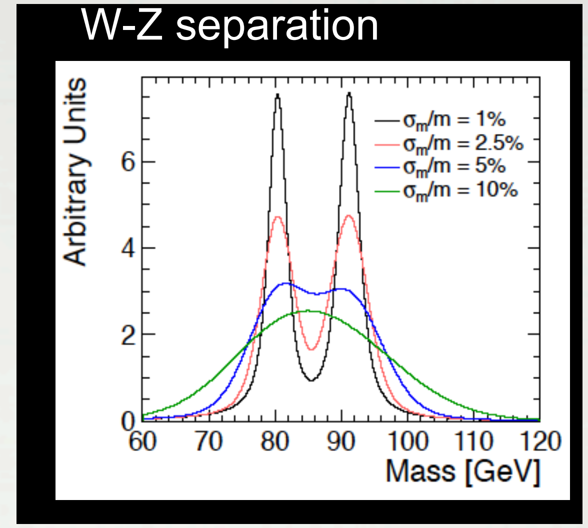
Engineering



...eventually done!

Detector Performance (1/2)





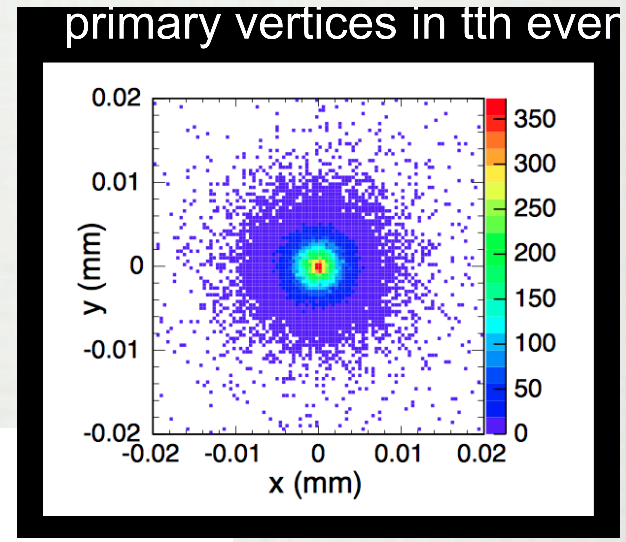


TABLE 2.1
Sub-Detector Performance Needed for Key ILC Physics Measurements.

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

A view at a generic, conceptual detector design:

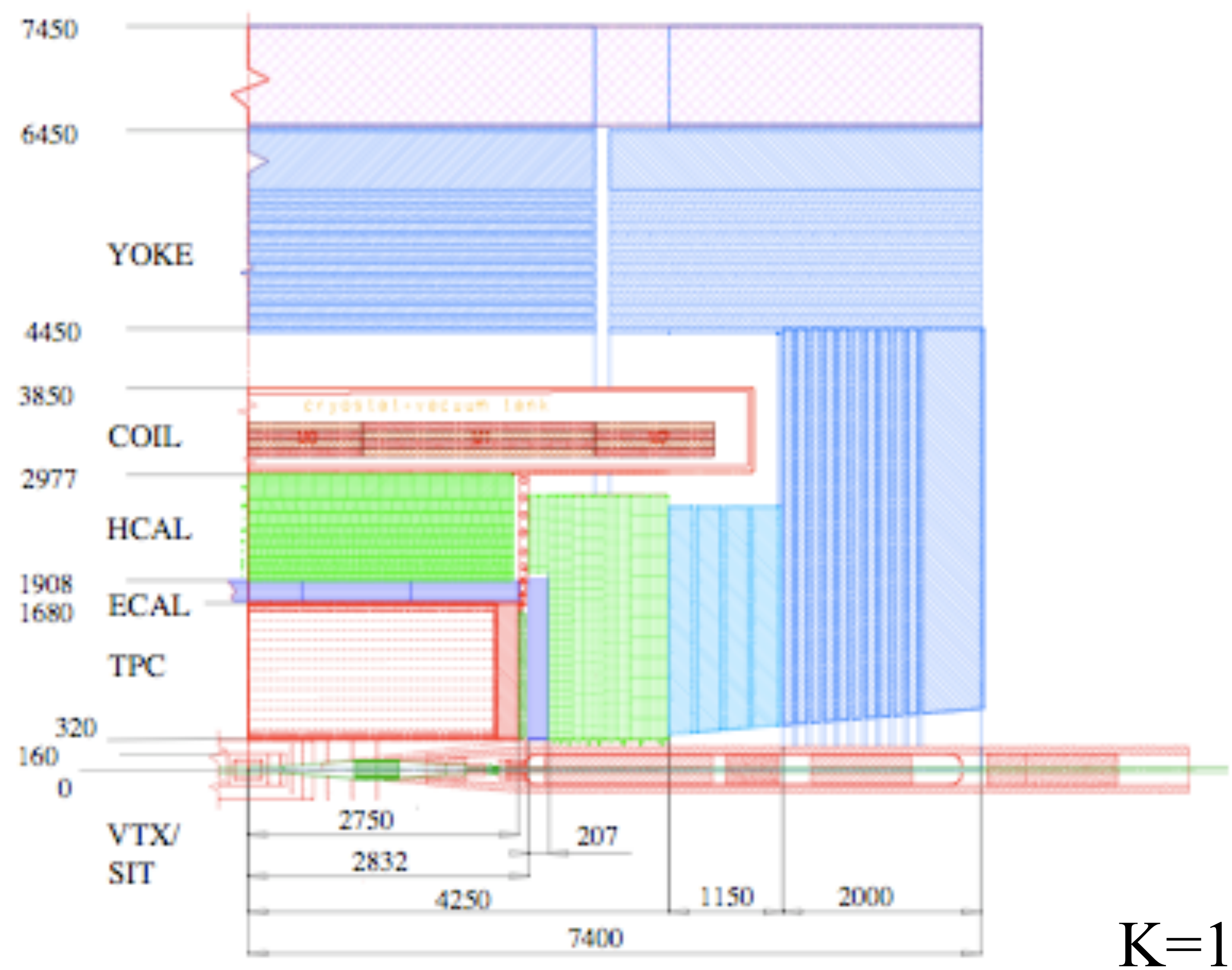


Figure 1.1.1: *View of one quadrant of the TESLA Detector. Dimensions are in mm.*

- rather compact (wrt ATLAS, where the fwd muon chambers are at z = ± 21 m and R = 13 m)
- the calorimetric system in inside the magnetic field
- the limited track length shall be compensated by a significant number of measured points, with a good precisions:

K=1/R

$$\delta k = \frac{\sigma}{L^2}\sqrt{\frac{320}{N+4}}$$

SubDetector Performance & Technologies

(yet from the TESLA TDR)

Subdetector	Goal	Technologies
Vertex Detector (VTX)	$\delta(IP_{r\phi,z}) \leq 5\,\mu\text{m} \oplus \frac{10\,\mu\text{m GeV}/c}{p \sin^{3/2}\theta}$	CCD, CMOS, APS
Forward Tracker (FTD)	$\frac{\delta p}{p} < 20\,\%, \delta_\theta < 50\,\mu\text{rad}$ for p=10-400 GeV/c down to $\theta \sim 100\,\text{mrad}$	Si-pixel/strip discs
Central Tracker (TPC)	$\delta(1/p_t)_{\text{TPC}} < 2\cdot 10^{-4}(\text{GeV/c})^{-1}$ $\sigma(dE/dx) \leq 5\%$	GEM, Micromegas or wire readout
Intermediate Tracker (SIT)	$\sigma_{point} = 10\,\mu\text{m}$ improves $\delta(1/p_t)$ by 30%	Si strips
Forward Chamber(FCH)	$\sigma_{point} = 100\,\mu\text{m}$	Straw tubes
Electromag. Calo. (ECAL)	$\frac{\delta E}{E} \leq 0.10 \frac{1}{\sqrt{E(\text{GeV})}} \oplus 0.01$ fine granularity in 3D	Si/W, Shashlik
Hadron Calo. (HCAL)	$\frac{\delta E}{E} \leq 0.50 \frac{1}{\sqrt{E(\text{GeV})}} \oplus 0.04$ fine granularity in 3D	Tiles, Digital
COIL	4 T, uniformity $\leq 10^{-3}$	NbTi technology
Fe Yoke (MUON)	Tail catcher and high efficiency muon tracker	Resistive plate chambers
Low Angle Tagger (LAT)	83.1–27.5 mrad calorimetric coverage	Si/W
Luminosity Calo. (LCAL)	Fast lumi feedback, veto at 4.6–27.5 mrad	Si/W, diamond/W
Tracking Overall	$\delta(\frac{1}{p_t}) \leq 5 \cdot 10^{-5}(\text{GeV/c})^{-1}$ systematics $\leq 10\,\mu\text{m}$	
Energy Flow	$\frac{\delta E}{E} \simeq 0.3 \frac{1}{\sqrt{E(\text{GeV})}}$	

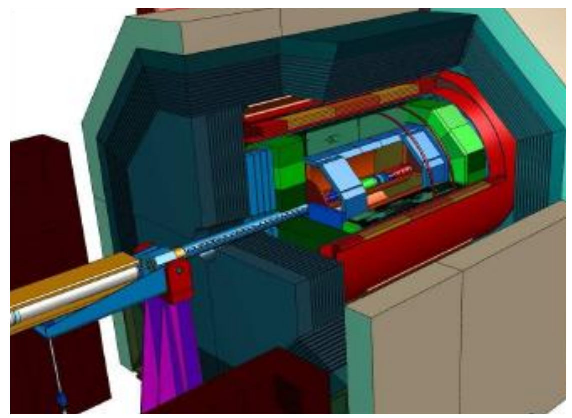
Table 1.3.1: *Detector performance goals for physics analyses for $\sqrt{s}$ up to $\sim$ 1 TeV.*

- there are problems with more than ONE solution
- there are many ways to draw a nice tree

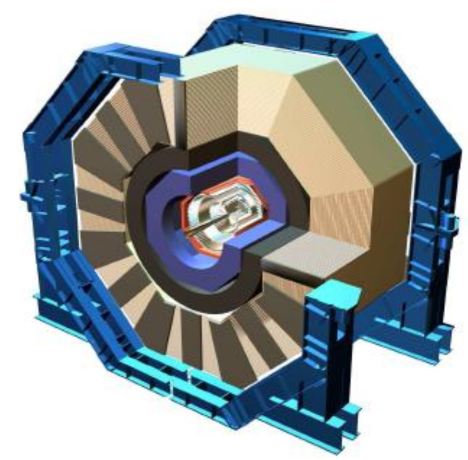
and there is certainly more than one way to design a fair detector compliant with the specified performance:

Large

LDC

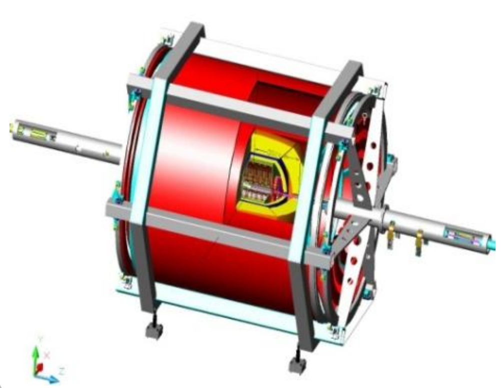


SiD

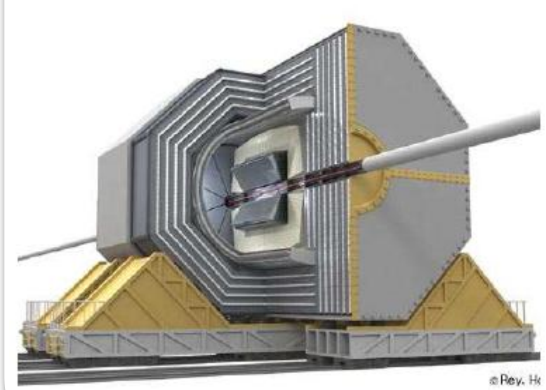


Small

4th



GLD



XXL

Vive la difference!

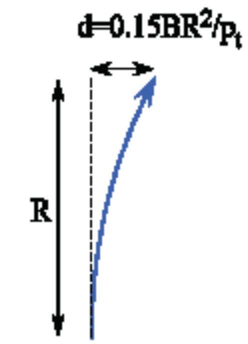
2007: and then there were four...

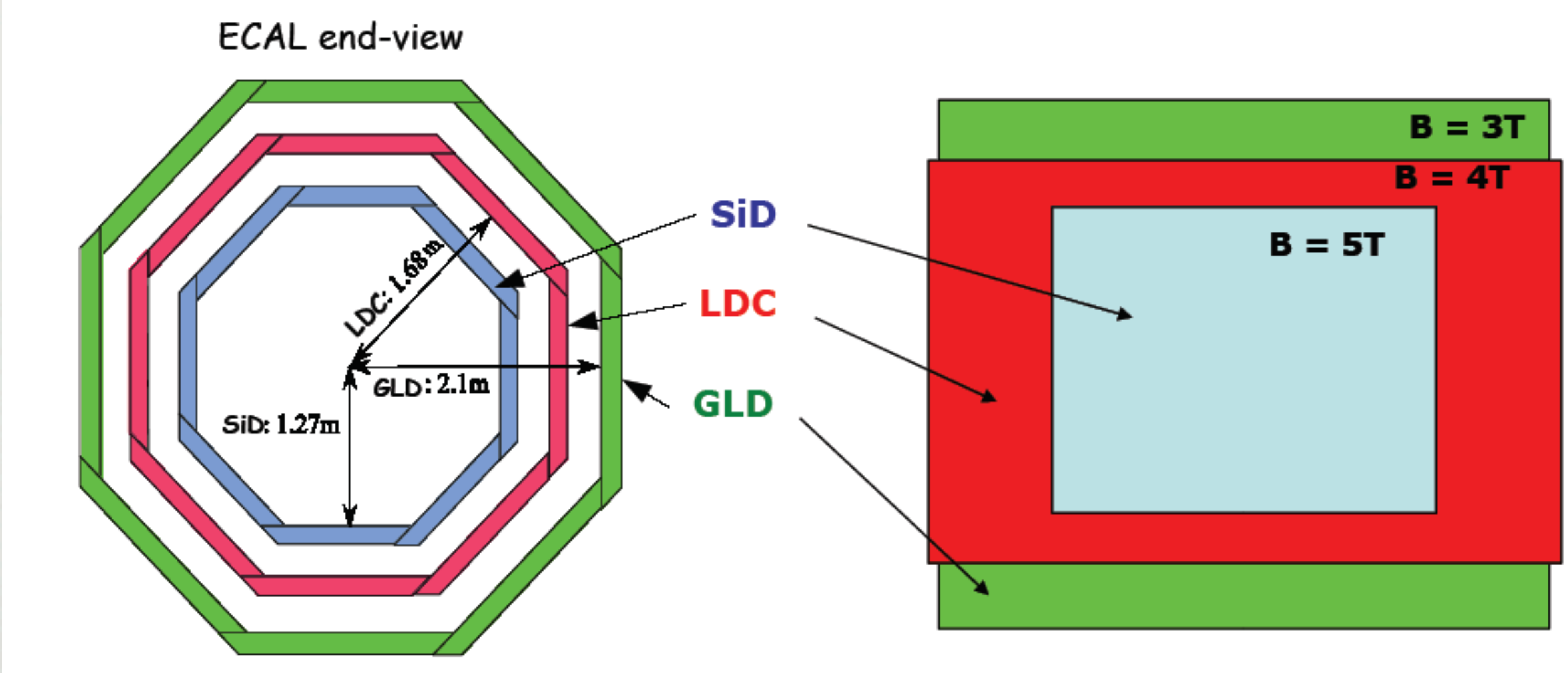
design guideline: maximize separation

(between showers associated to neutral and charged particles, among particles of different momentum...)

Different approaches

- $B R_{in}^2$: SiD
- $B R_{in}^2$: LDC
- $B R_{in}^2$: GLD





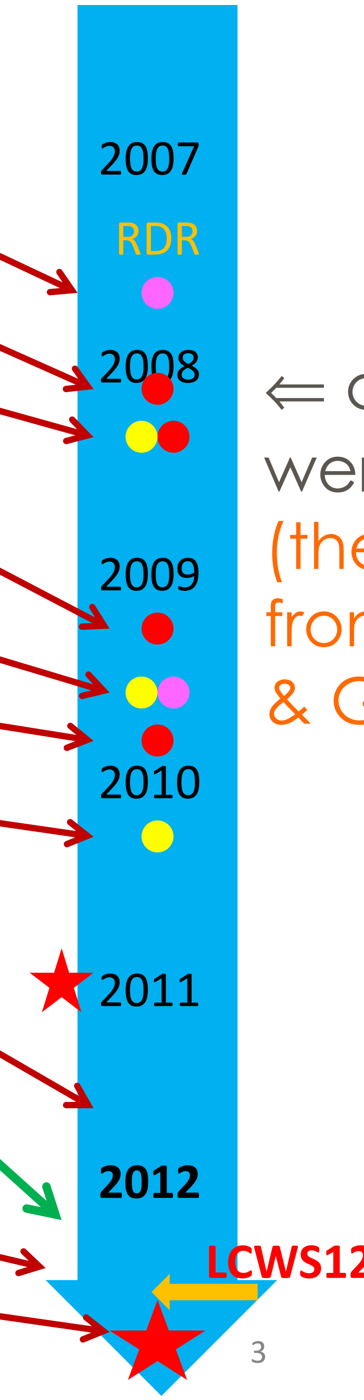
NB: assuming B = 4T, @R = 1.5m, separation is ~150 cm/p_t [GeV]

Decision making process within the Global Design Initiative

[Sakue Yamada, Research Director]:

The time line of the LOI process

- **Oct. 2007: Call for LOIs was made by ILCSC**
- Jan. 2008: Detector management was formed
- Mar.2008: IDAG formed, 3 LOI groups known
- **Mar.2009: 3 LOIs submitted**
- Summer 09: **IDAG recommendation for validation and ILCSC's approval**
- Oct 2009: Work plan of the validated groups
- **Mar:2009: IDAG began monitoring the progress**
- End 2010: Interim report completed
- ***Apr.2012 DBD outline monitored by IDAG***
- ***DBD Draft Review by IDAG***
- End 2012: **DBD to be completed**



⇐ and then there were two: SiD & ILD (the latter resulting from merging LDC & GLD)

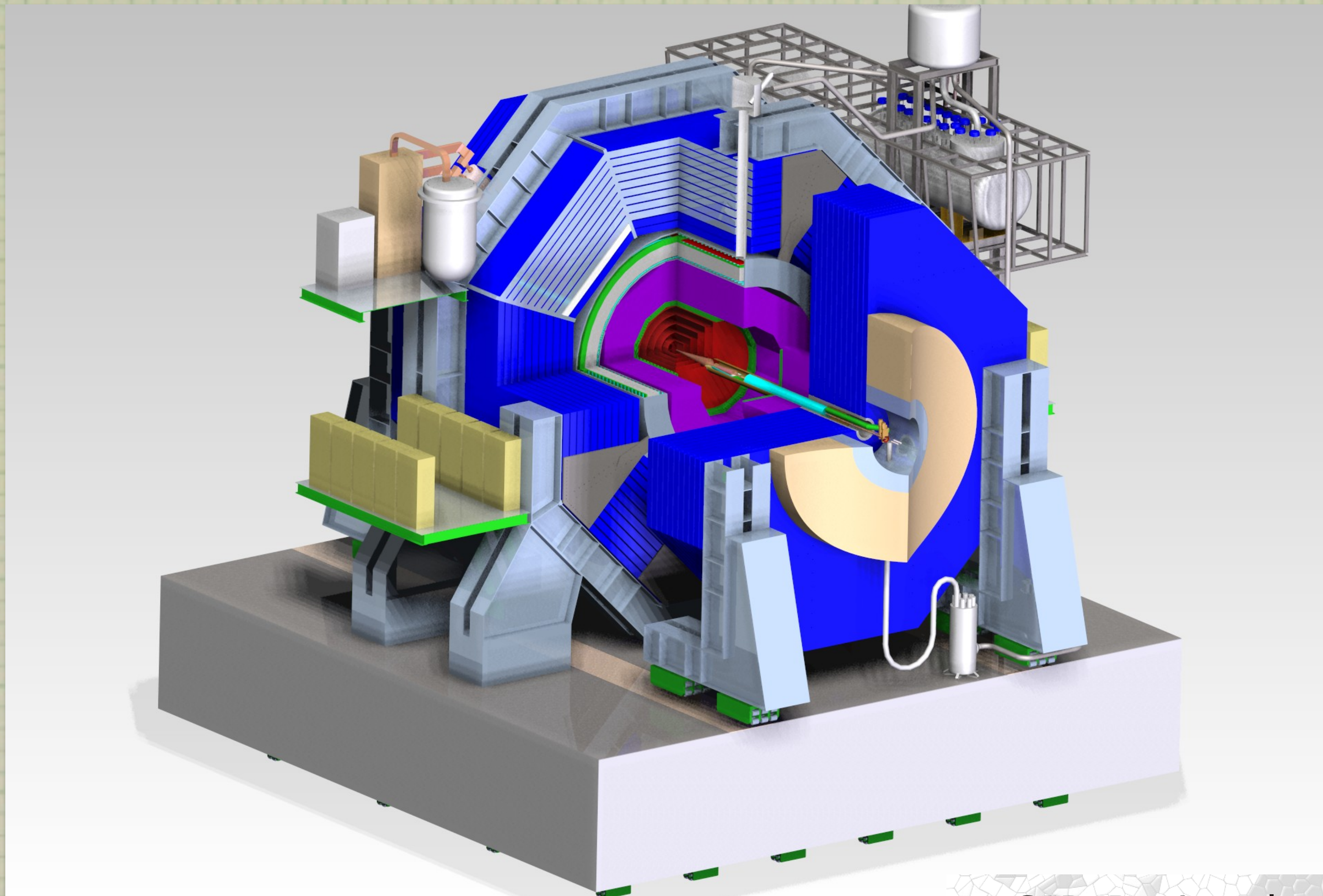
DONE!

2012/10/22 Sakue Yamada LCWS12 @Arlington 3

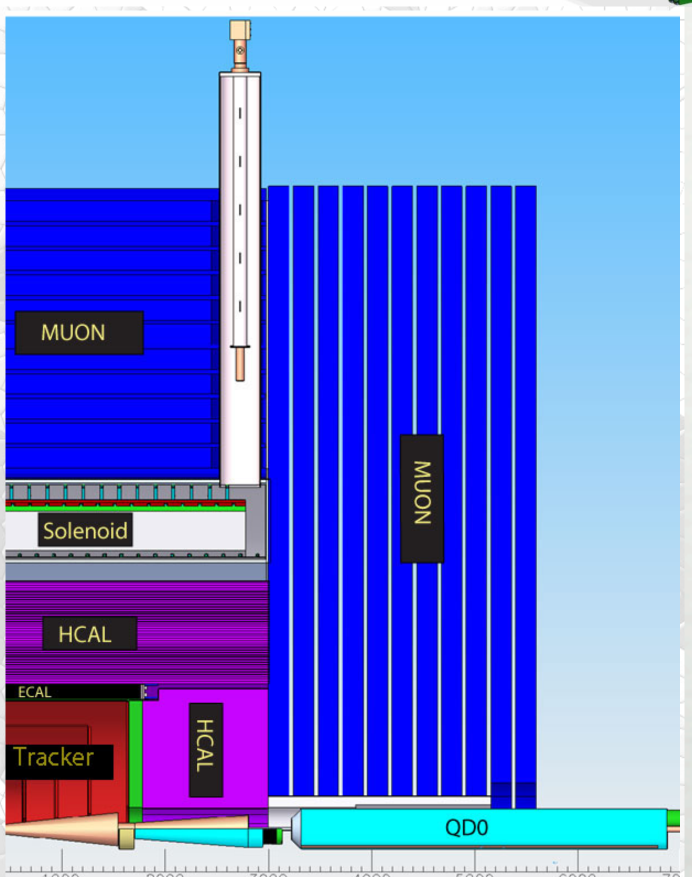
- IDAG: international detector advisory group
- DBD: Detector Baseline Design

Work plan after validation

1. Demonstrate proof of principle on critical components
   When there are options, at least one option for each subsystem will reach a level of maturity which verifies feasibility
2. Define a feasible baseline design
   While a baseline will be specified, options may also be considered
3. Complete basic mechanical integration of the baseline design accounting for insensitive zones such as the beam holes, support structure, cables, gaps, or inner detector material
4. Develop a realistic simulation model of the baseline design, including the identified faults and limitations
5. Develop a push-pull mechanism, working out the movement procedure, time scale, alignment and calibration schemes in corporation with relevant groups
6. Develop a realistic concept of integration with the accelerator including the IR design
7. Simulate and analyze updated benchmark reactions with the realistic detector model, including the impact of detector dead zones and updated background conditions
8. Simulate and study some reactions at 1TeV, including realistic higher energy backgrounds, demonstrating the detector performance
9. Develop an improved cost estimate



SiD [Marcel Stanitzki @ LCWS2012]:

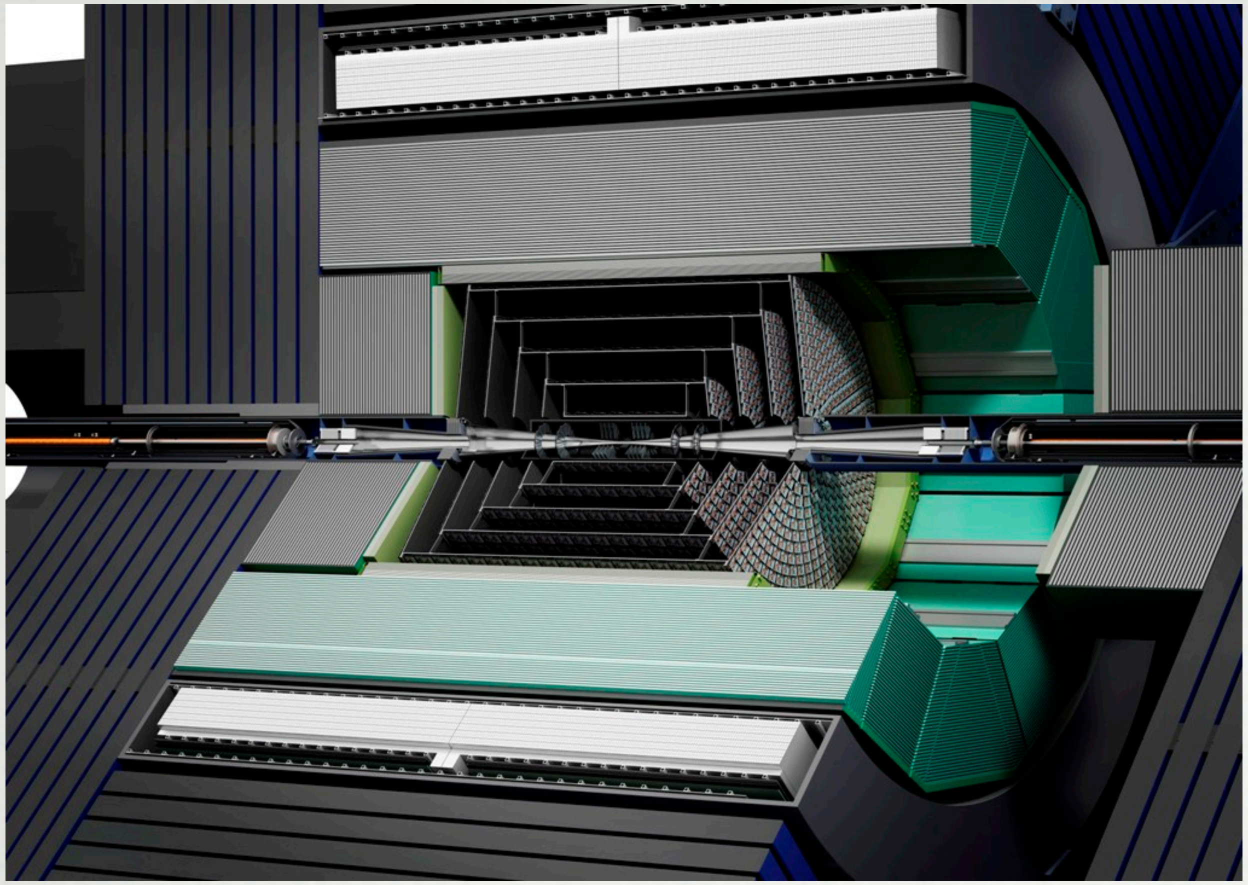


- SID Rationale
  - *A compact, cost-constrained detector designed to make precision measurements and be sensitive to a wide range of new phenomena*
- Design choices
  - Compact design with 5T field.
  - Robust silicon vertexing and tracking system with excellent momentum resolution
  - Time-stamping for single bunch crossings.
  - Highly granular Calorimetry optimized for Particle Flow
  - Iron flux return/muon identifier is part of the SiD self-shielding
  - Detector is designed for rapid push-pull operation

SiD: basic geometrical parameters & technology

SiD BARREL	Technology	Inner radius	Outer radius	z max
Vertex detector	Silicon pixels	1.4	6.0	$\pm$ 6.25
⇒ Tracker	Silicon strips	21.7	122.1	$\pm$ 152.2
ECAL	Silicon pixels-W	126.5	140.9	$\pm$ 176.5
HCAL	RPC-steel	141.7	249.3	$\pm$ 301.8
Solenoid	5 Tesla	259.1	339.2	$\pm$ 298.3
Flux return	Scintillator/steel	340.2	604.2	$\pm$ 303.3

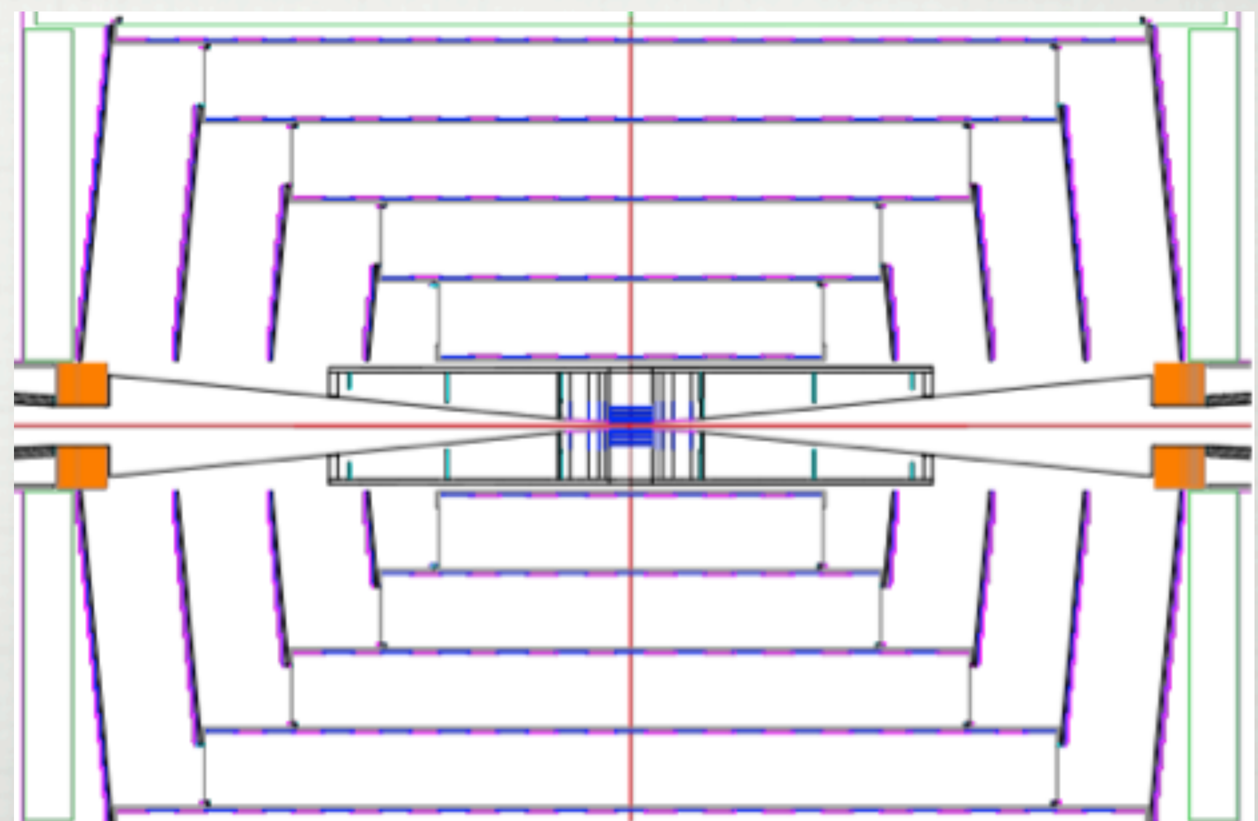
SiD ENDCAP	Technology	Inner z	Outer z	Outer radius
Vertex detector	Silicon pixels	7.3	83.4	16.6
Tracker	Silicon strips	77.0	164.3	125.5
ECAL	Silicon pixel-W	165.7	180.0	125.0
HCAL	RPC-steel	180.5	302.8	140.2
Flux return	Scintillator/steel	303.3	567.3	604.2
LumiCal	Silicon-W	155.7	170.0	20.0
BeamCal	Semiconductor-W	277.5	300.7	13.5



The SiD tracker layout

(a little toy with a weight of 7.8×10^3 ton

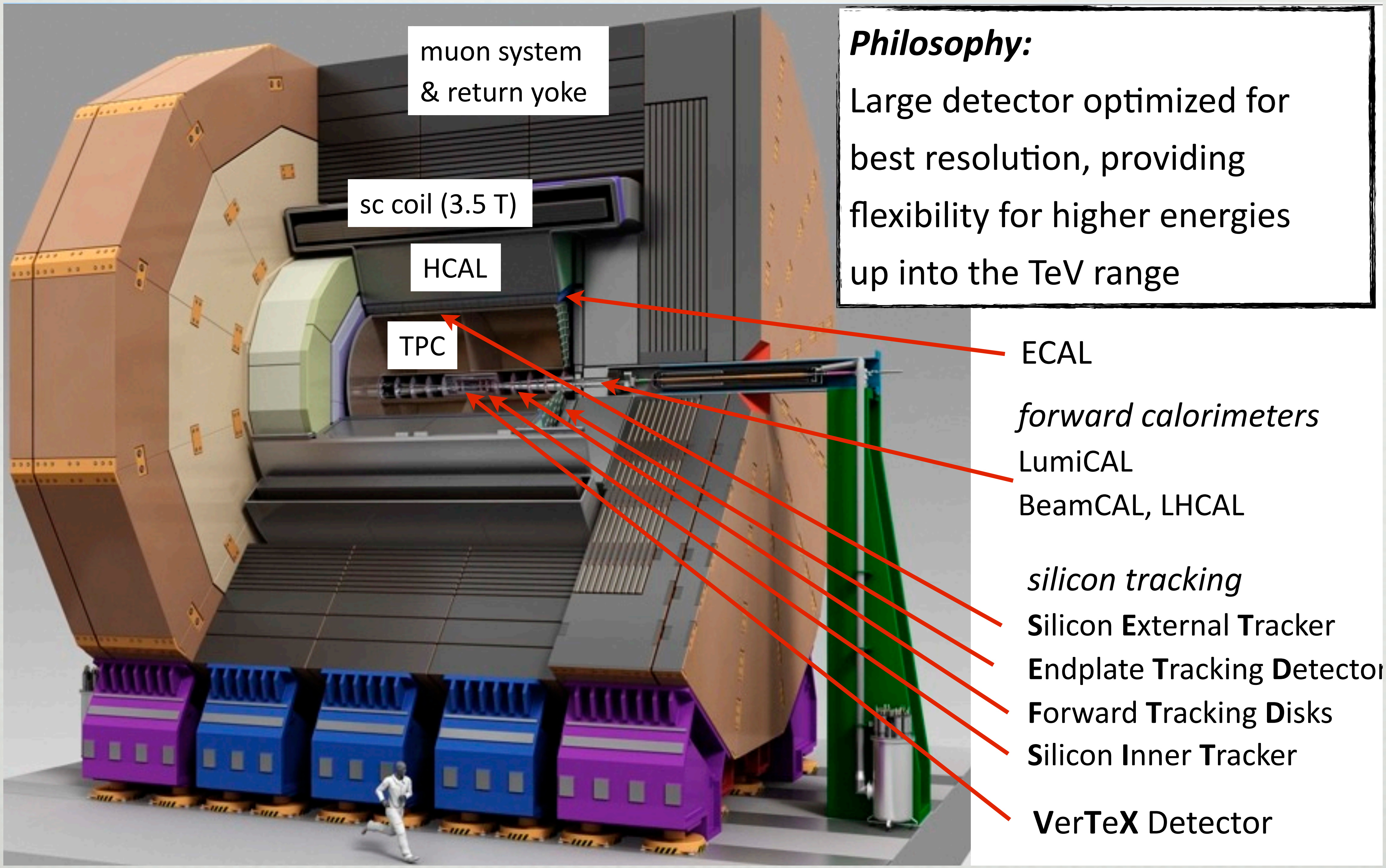
- 12 mm radius Be beam pipe
- 5 barrel lyrs/4 disks/3 forward disks pixel vertex detector (~1Gpixls)
- 5 barrel lyrs/4 disks Si strip tracker (Ro=1.25m)



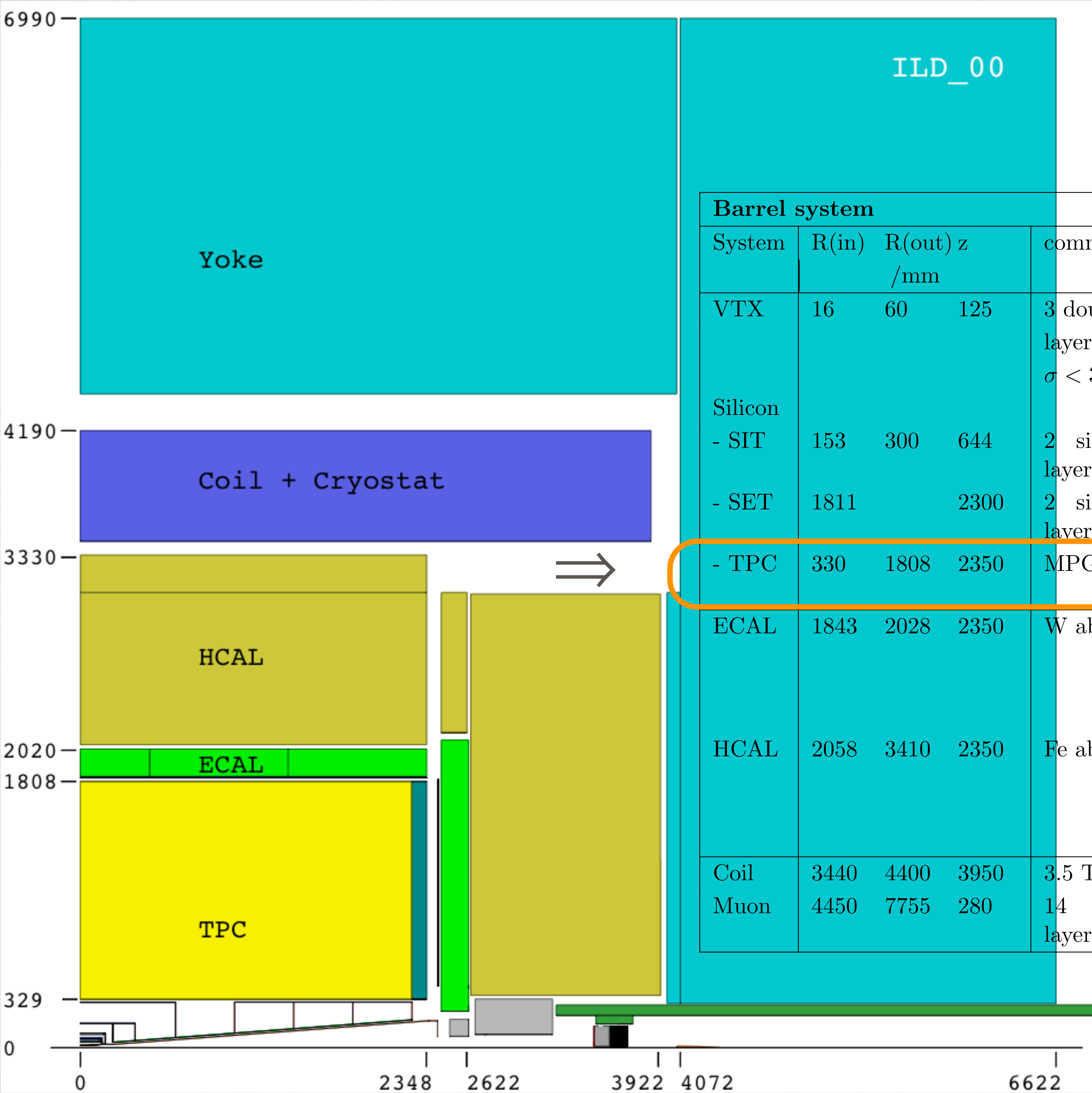
The ILD [International Large Detector] concept

[Frank Simon @ LCWS2012]:

Philosophy:
Large detector optimized for best resolution, providing flexibility for higher energies up into the TeV range

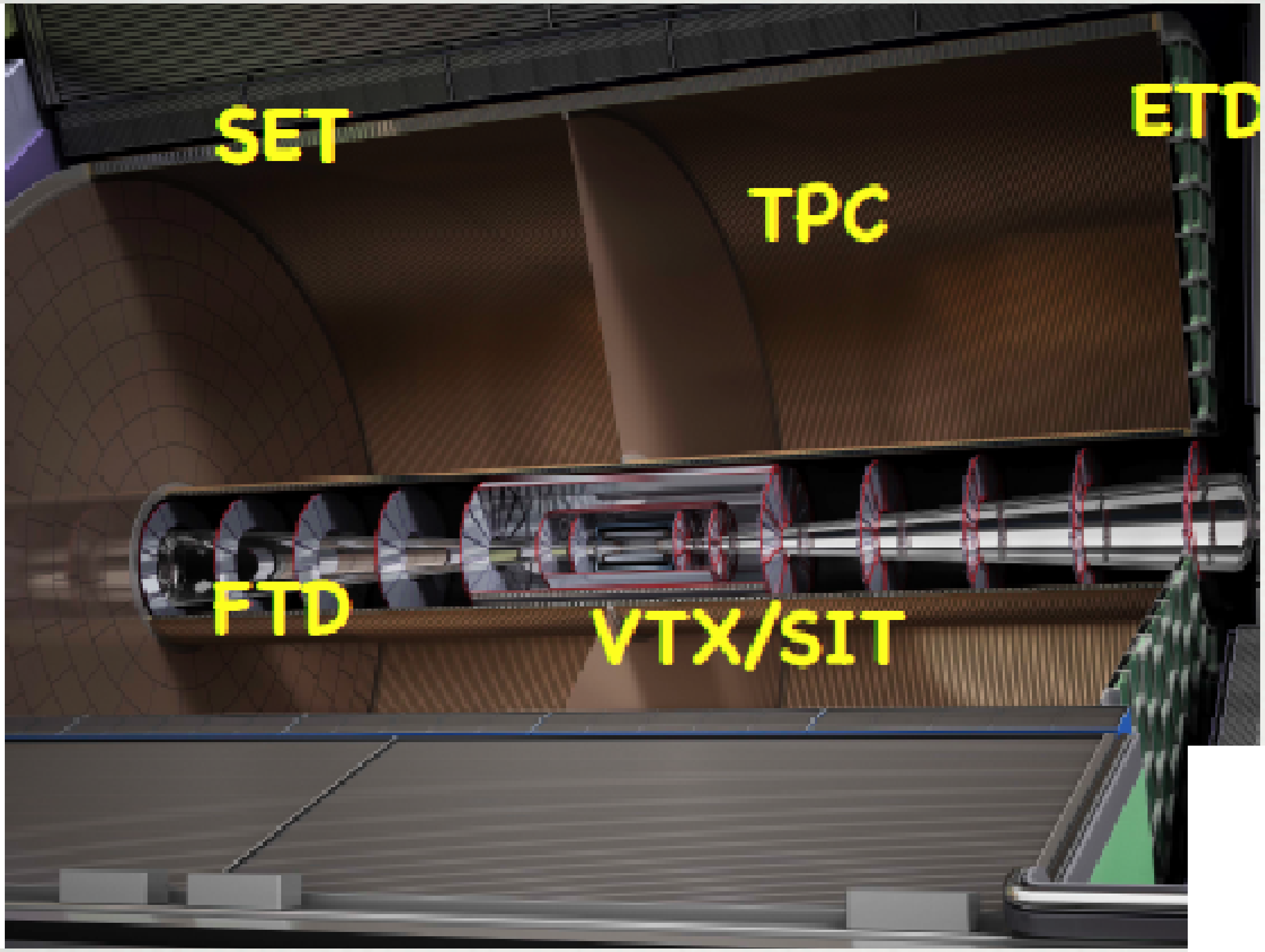


ILD parameters [draft DBD]:



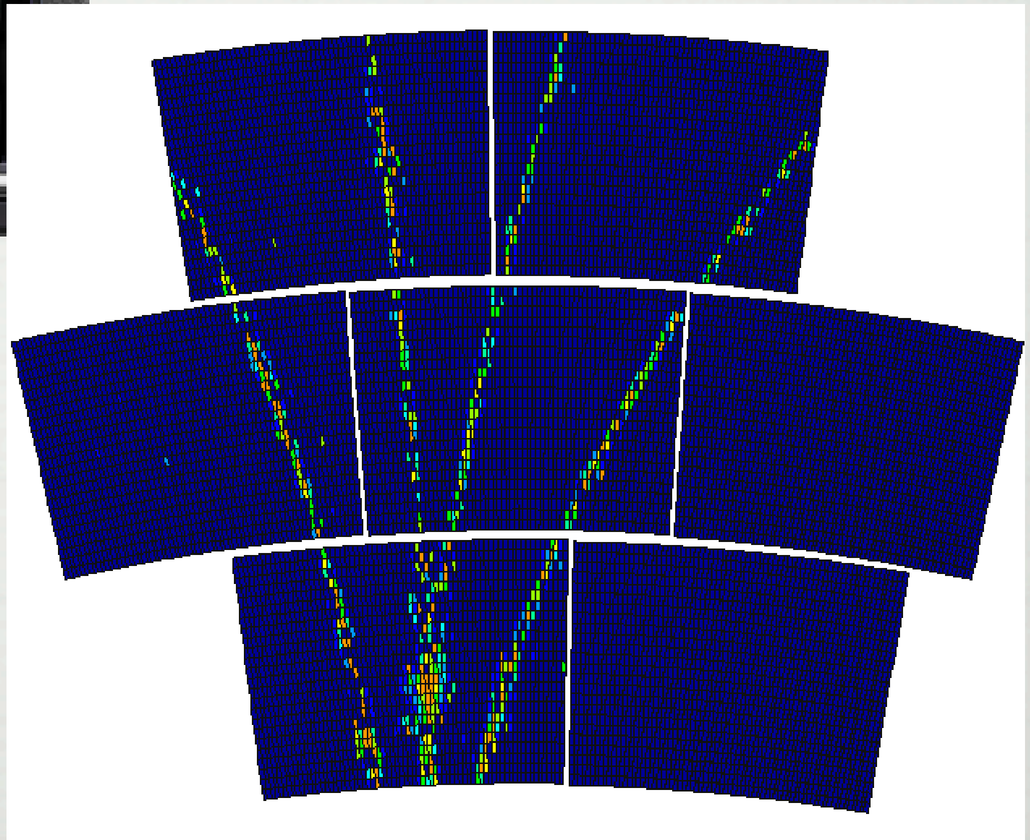
Barrel system

System	R(in)	R(out)	z /mm	comments		
VTX	16	60	125	3 double layers	Silicon pixel sensors,	
				layer 1:	layer 2:	layer 3-6
				$\sigma < 3\mu m$	$\sigma < 6\mu m$	$\sigma < 4\mu m$
Silicon						
- SIT	153	300	644	2 silicon strip layers	$\sigma = 7\mu m$	
- SET	1811		2300	2 silicon strip layers	$\sigma = 7\mu m$	
- TPC	330	1808	2350	MPGD readout	$1 \times 6\text{mm}^2$ pads	$\sigma = 60\mu m$ at zero drift
ECAL	1843	2028	2350	W absorber	SIECAL	30 Silicon sensor layers, 5×5 mm^2 cells
					EcECAL	30 Scintillator layers, 5×45 mm^2 strips
HCAL	2058	3410	2350	Fe absorber	AHCAL	48 Scintillator layers, $3 \times 3\text{cm}^2$ cells
					SDHCAL	48 Gas RPC layers, 1×1 cm^2 cells
Coil	3440	4400	3950	3.5 T field	2λ	
Muon	4450	7755	280	14 scintillator layers		



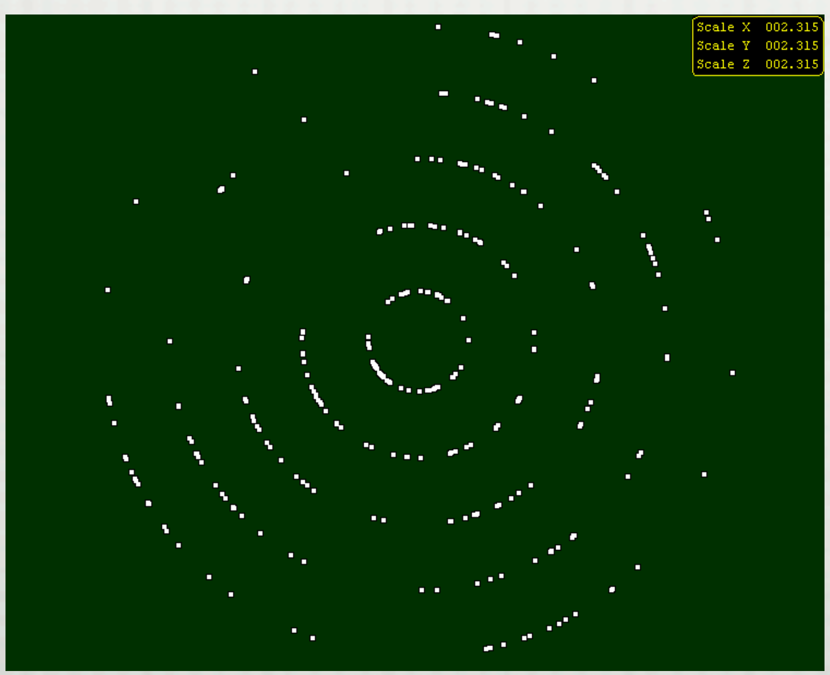
ILD-TPC basic

- $\approx$ 200 continuous position measurements along each track
- Single point resolution of $\sigma_{r\phi} <$ 100 µm
- Lever arm of around 1.2 m in the magnetic field of 3.5–4 T

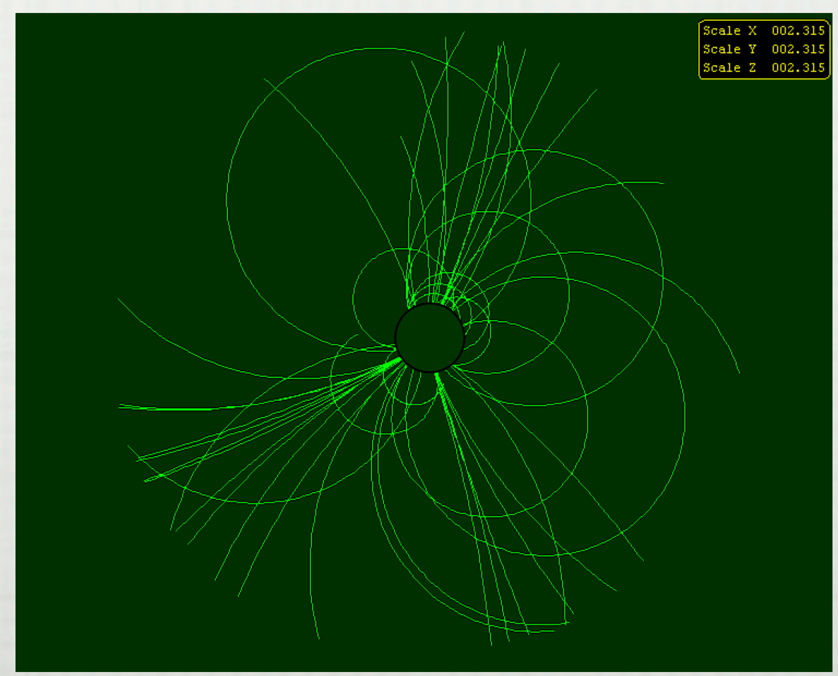


Any preference? You have anyway to *connect the dots....*

The SiD way



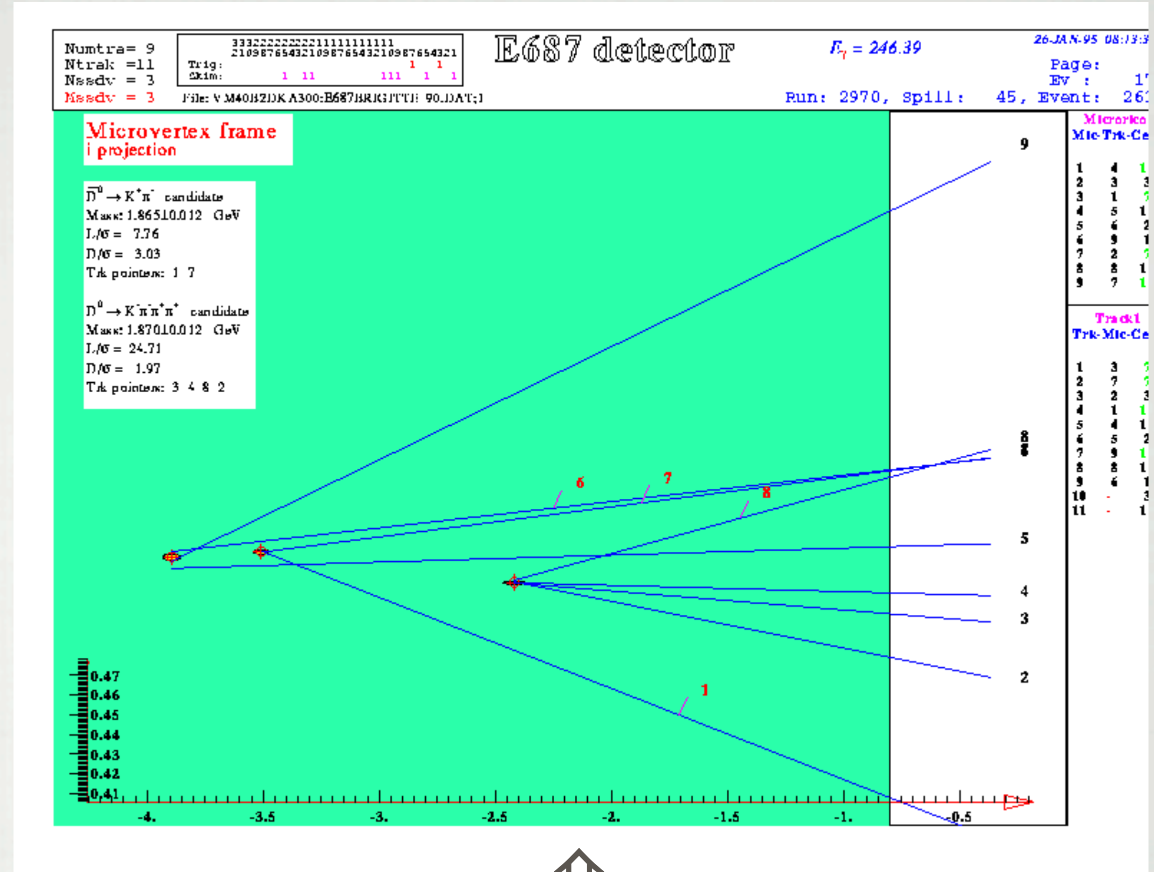
The ILD way



Signals in the tracker from the SAME event

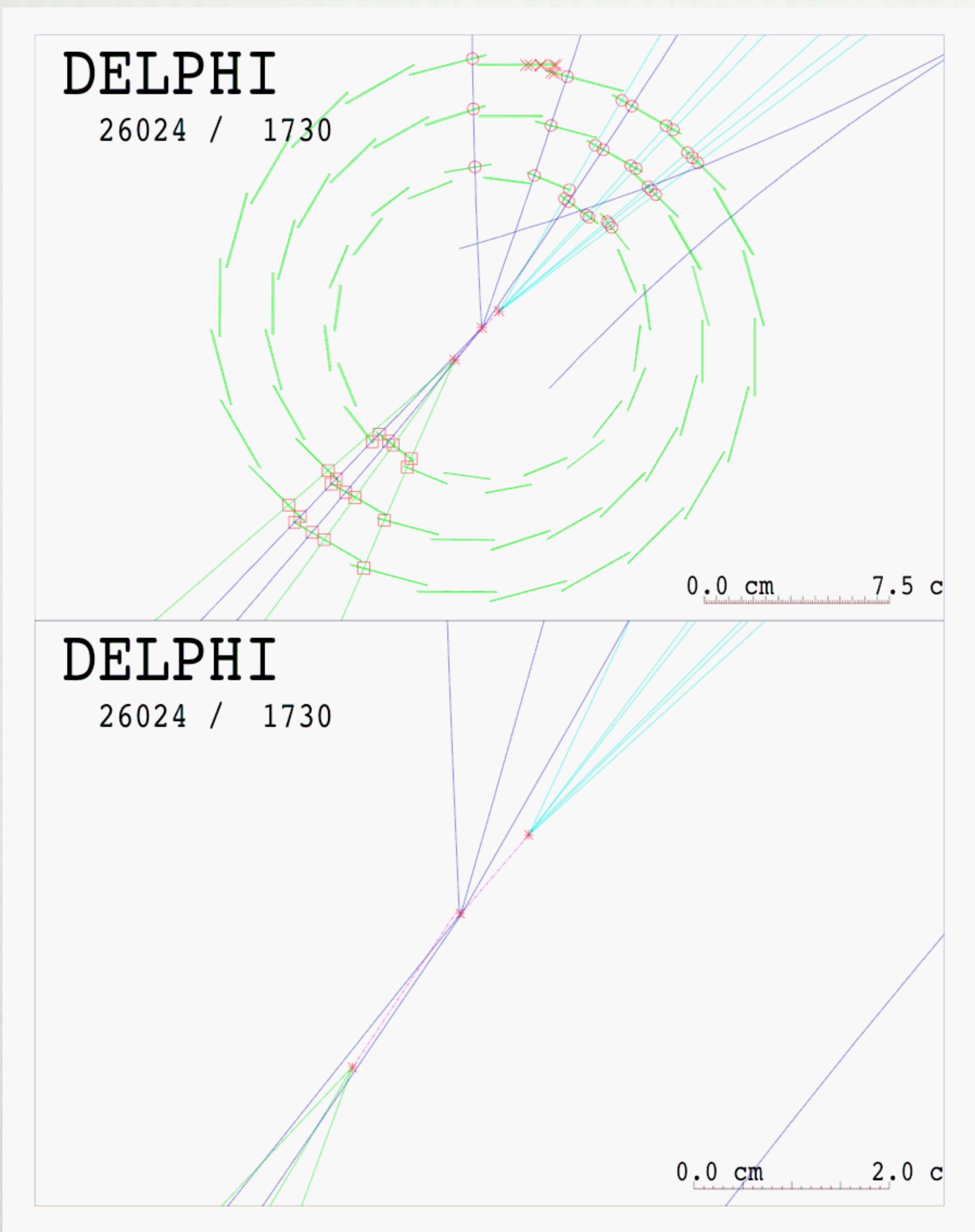
Graham Wilson, Como workshop 2013

The Silicon way:



⇑

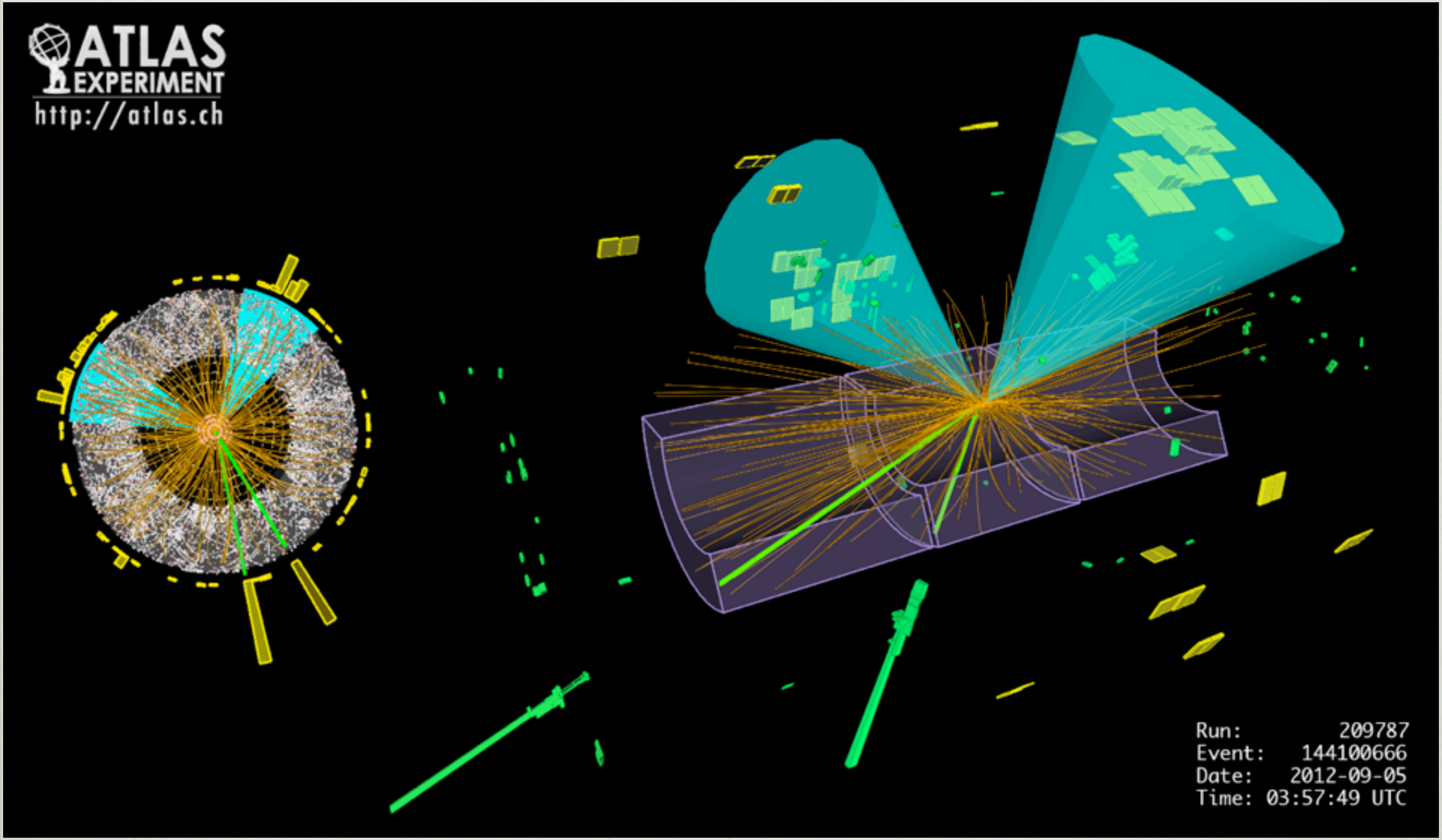
80's: μstrips & Charm physics @fixed target experiments



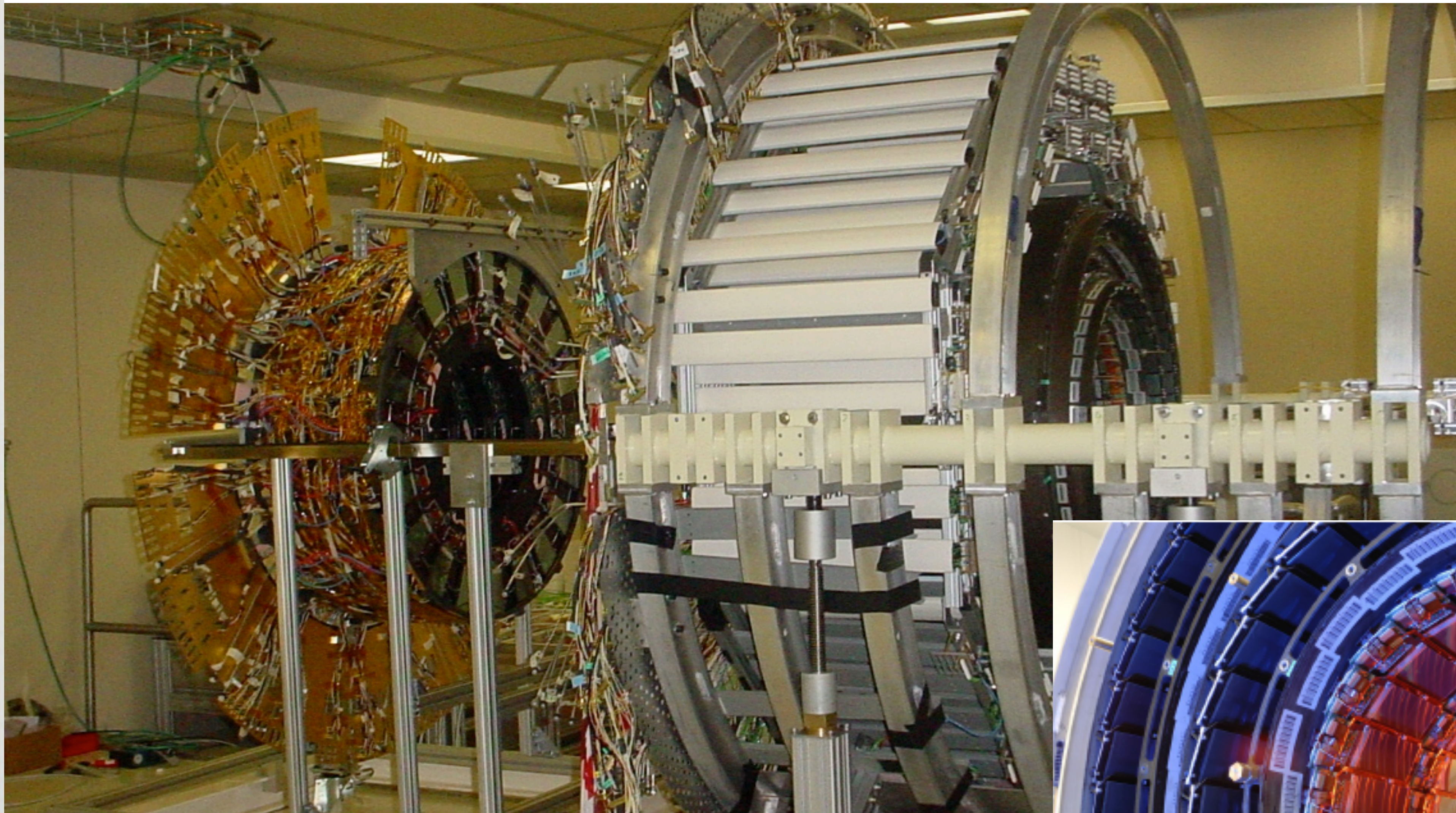
⇐

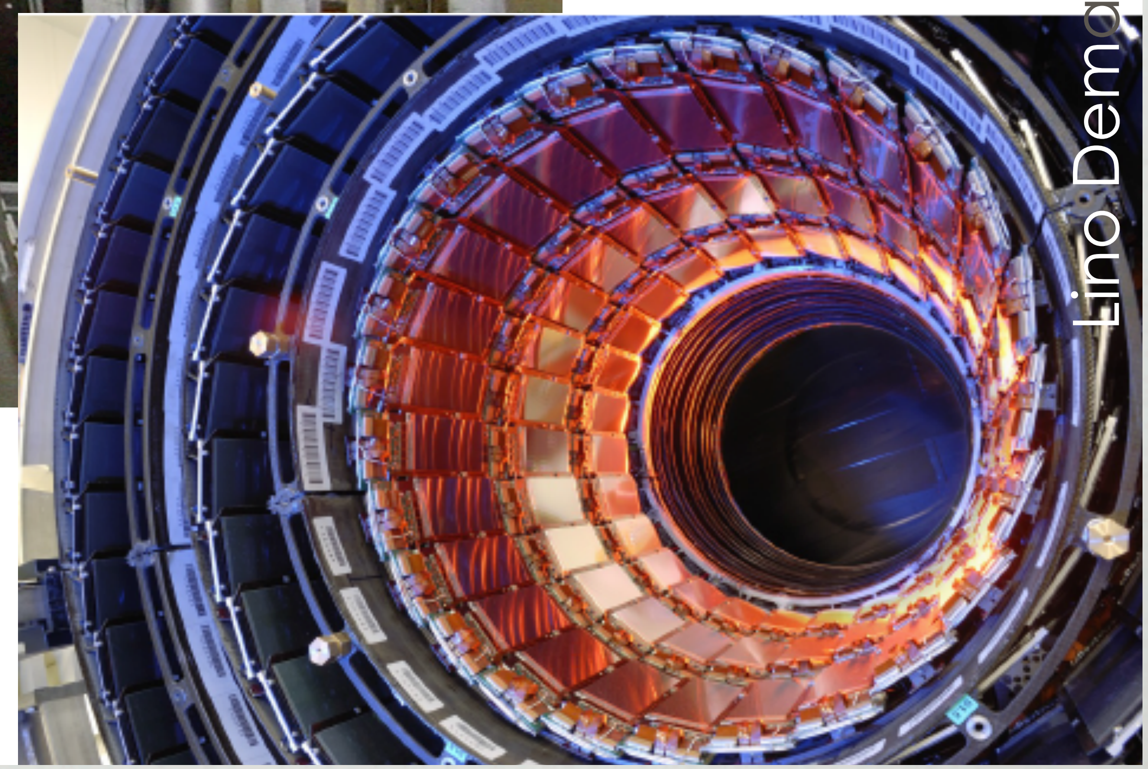
90's: μstrips & pixels, Charm & Beauty physics @e^+e^- colliders

Today @ATLAS:


ATLAS
EXPERIMENT
http://atlas.ch
Run: 209787
Event: 144100666
Date: 2012-09-05
Time: 03:57:49 UTC

Today @CMS:

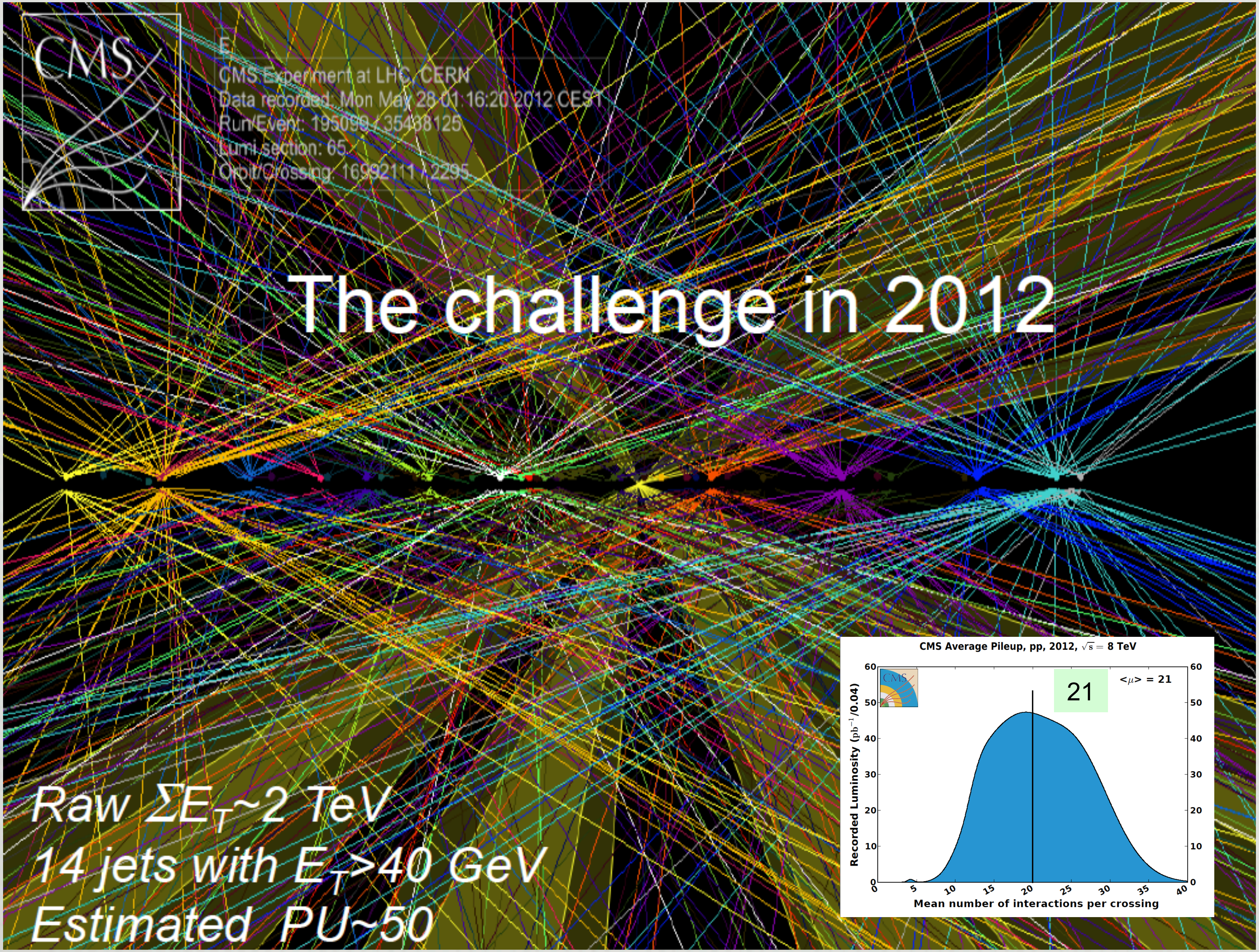




- ~198m^2 of strip detectors
- 66 MPixel in the vertex

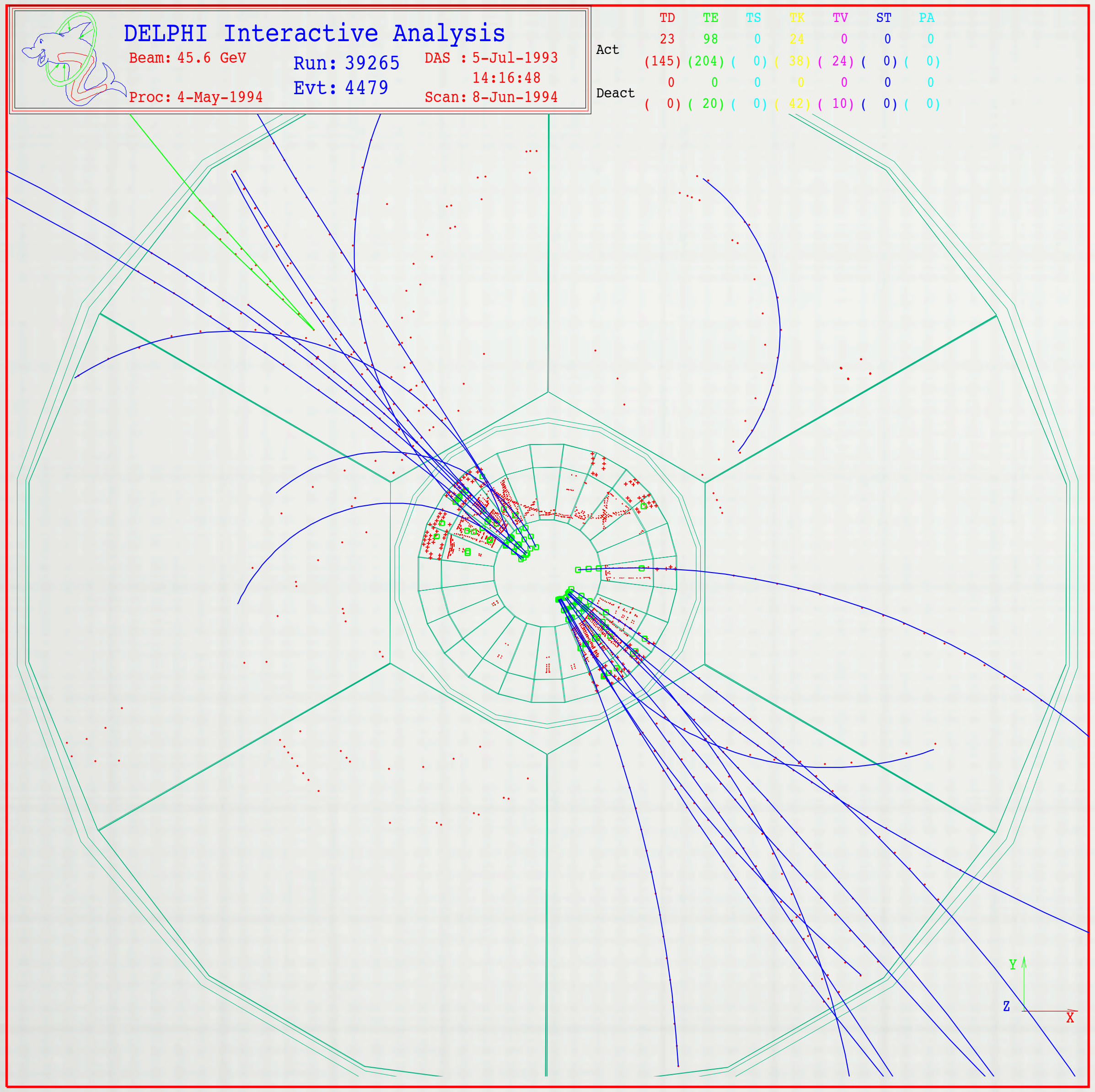
~ 10 years from the Technical Design Report to commissioning...

The challenge in 2012

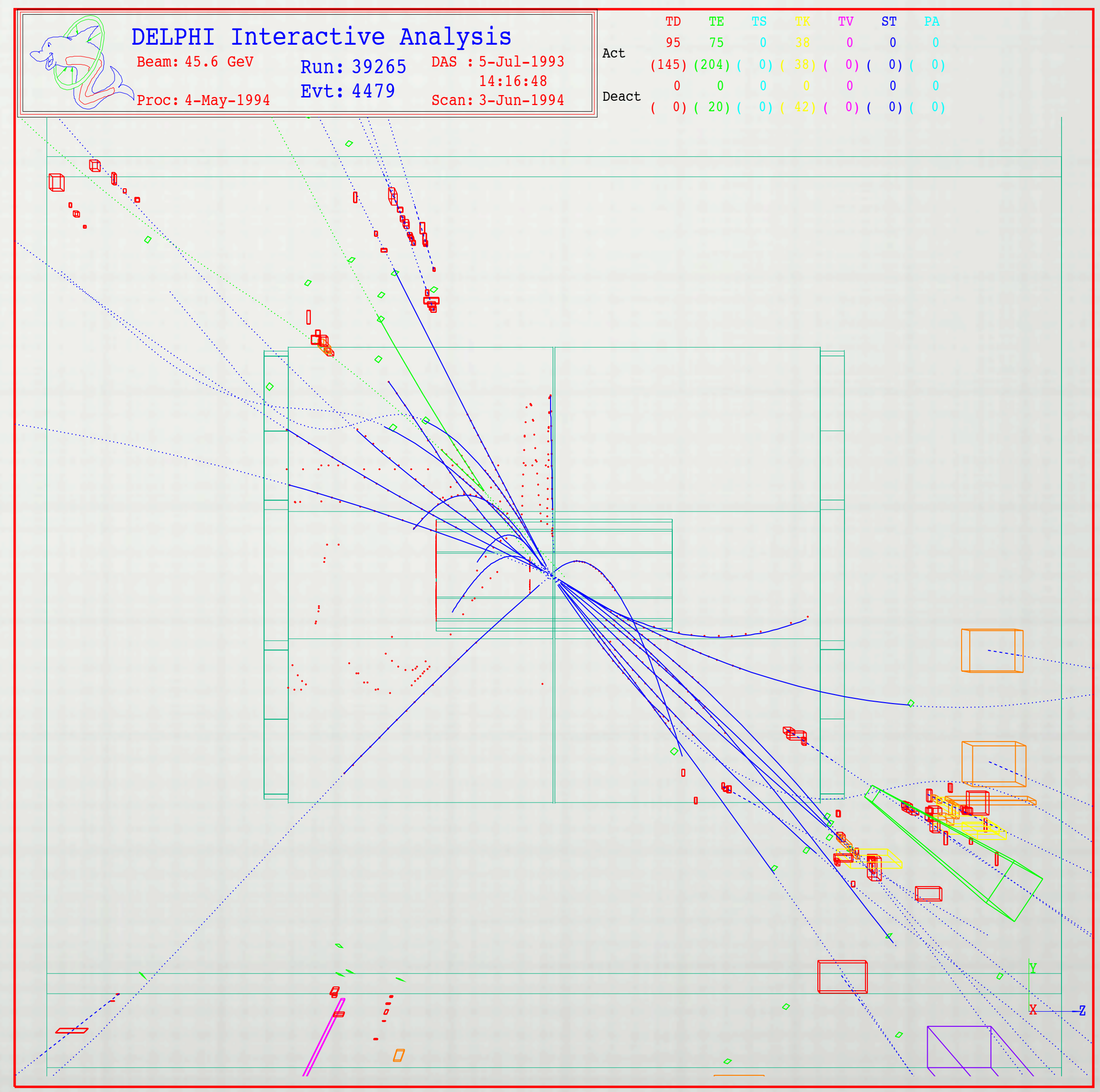


Raw ΣE_T~2 TeV
14 jets with E_T>40 GeV
Estimated PU~50

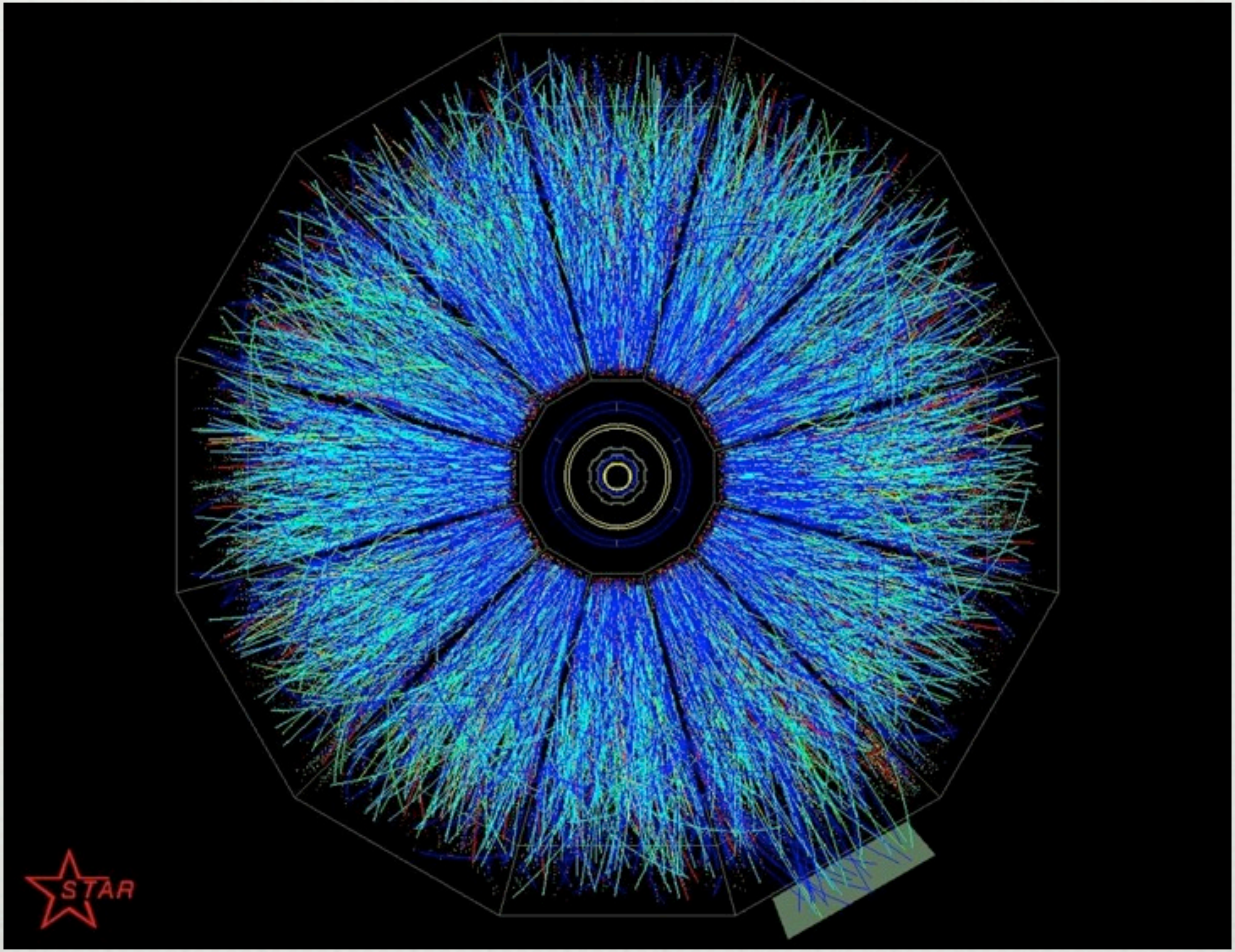
The Time Projecting 3D way:



90's: DELPHI & ALEPH at LEP

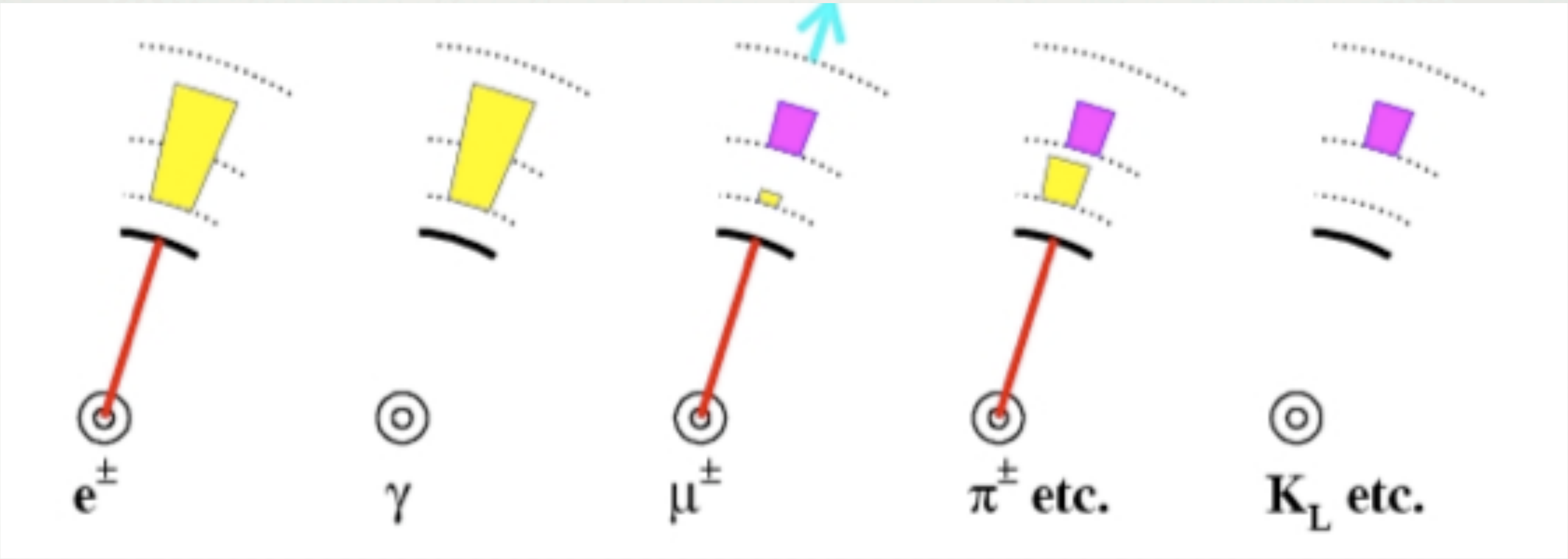


2001: Au-Au collision at 100 Gev/beam @STAR



2010: Pb-Pb collision in ALICE @$\sqrt{s}$ = 2.76 TeV

A bit about calorimetry, by now based on the shared paradigm of PARTICLE FLOW:



- measure charged particles in the tracker [60% jet nrj from charged hadrons]
- photons in the Electro-magnetic calorimeter [30% of the jet nrj]
- neutral hadrons in the Hadron Calorimeter [10% of the jet nrj; essentially n & K_L]
- separate (as much as you can) the energy deposition in the calorimeter system by the different particles

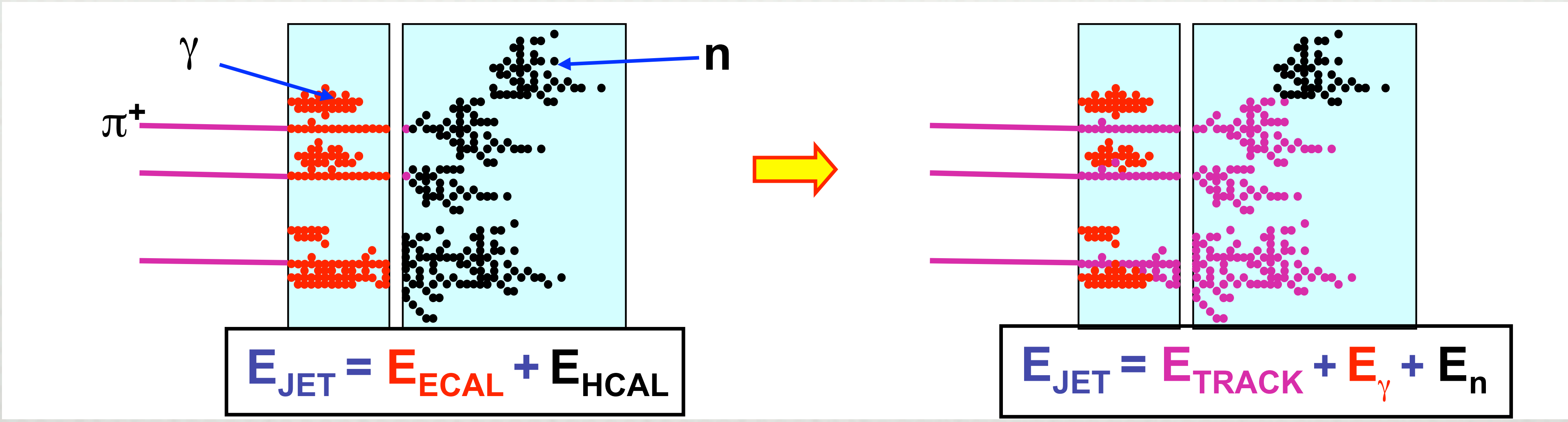
What is the main advantage of Particle Flow?

★ **Traditional calorimetric approach:**

- **Measure all components of jet energy in ECAL/HCAL !**
- **~70 % of energy measured in HCAL:** $\sigma_E/E \approx 60\,\%/\sqrt{E(GeV)}$
- **Intrinsically "poor" HCAL resolution limits jet energy resolution**

★ **Particle Flow Calorimetry paradigm:**

- **charged particles measured in tracker (essentially perfectly)**
- **Photons in ECAL:** $\sigma_E/E < 20\,\%/\sqrt{E(GeV)}$
- **Neutral hadrons (ONLY) in HCAL**
- **Only 10 % of jet energy from HCAL ⇨ much improved resolution**



Felix Sefkow, PF calorimetry Review at the Como ILC workshop, 2013

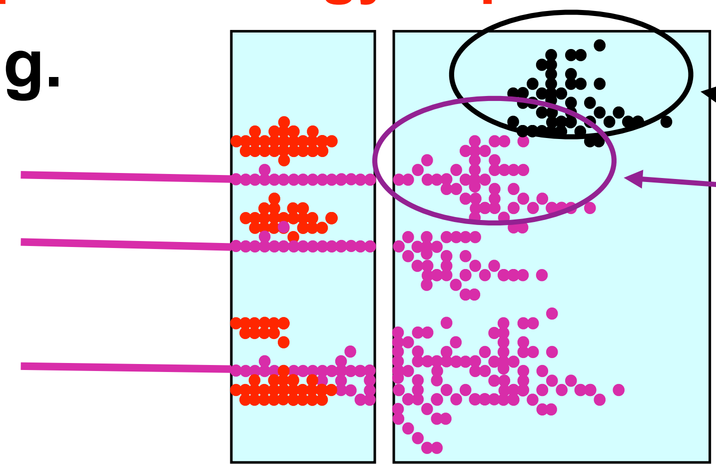
Why separation is a "must have":

Reconstruction of a Particle Flow Calorimeter:

★ **Avoid double counting of energy from same particle**

★ **Separate energy deposits from different particles**

e.g.

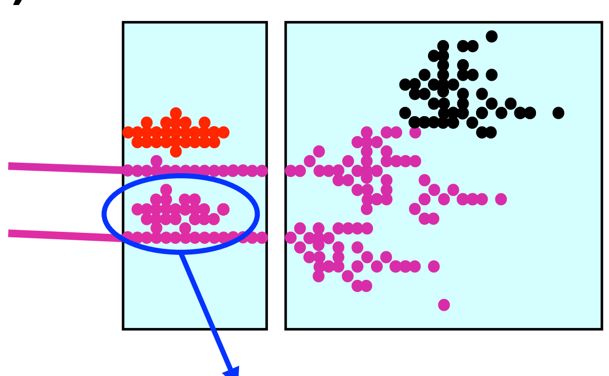


If these hits are clustered together with these, lose energy deposit from this neutral hadron (now part of track particle) and ruin energy measurement for this jet.

Level of mistakes, "confusion", determines jet energy resolution
not the intrinsic calorimetric performance of ECAL/HCAL

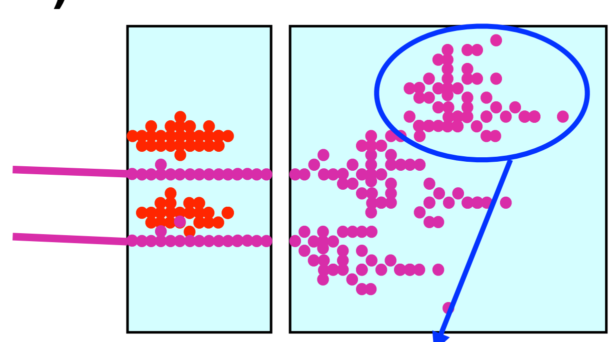
Three types of confusion:

i) Photons



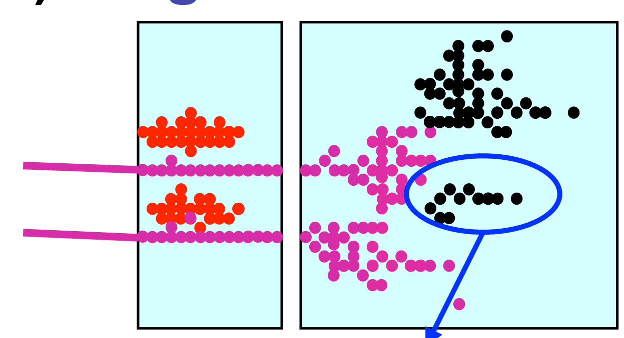
Failure to resolve photon

ii) Neutral Hadrons



Failure to resolve neutral hadron

iii) Fragments



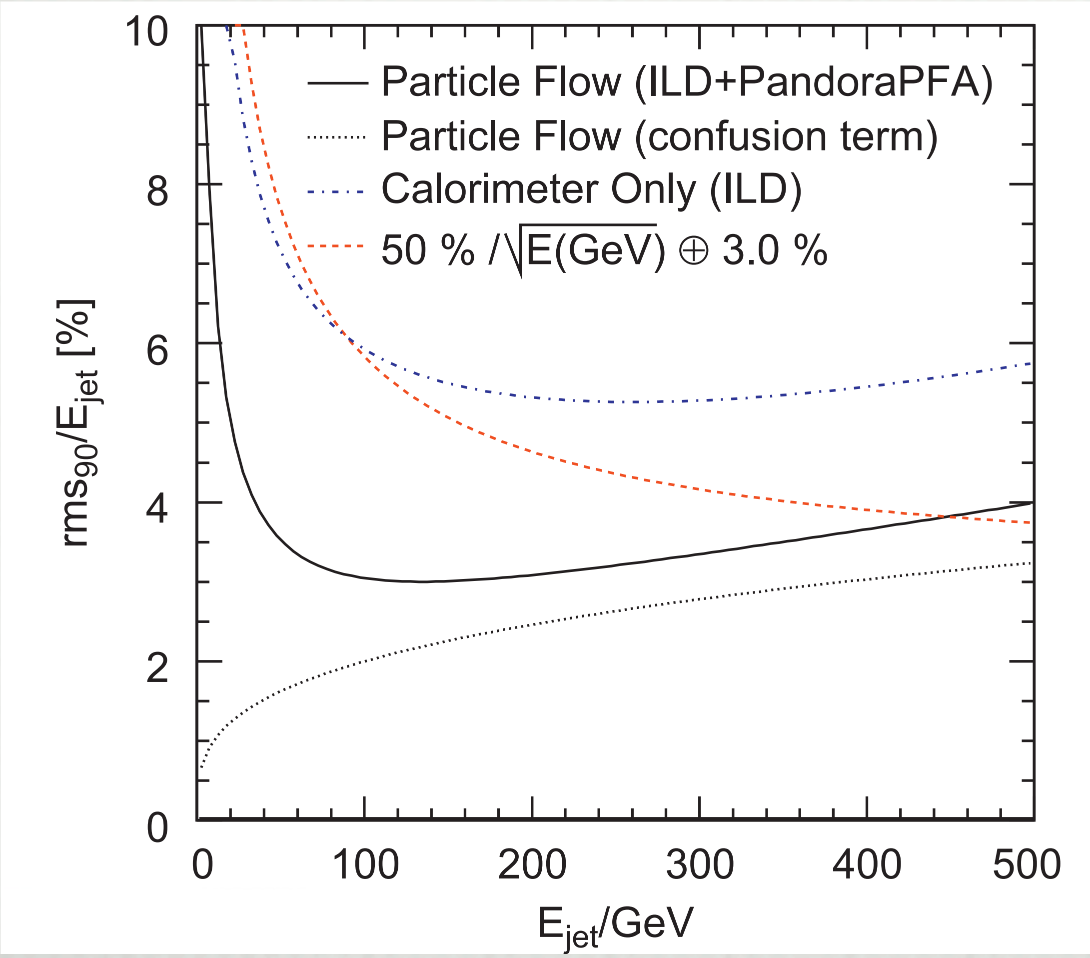
Reconstruct fragment as separate neutral hadron

credits: Mark Thomson

Talking about resolution:

$$\frac{\sigma_E}{E} = \frac{21}{\sqrt{E}} \oplus 0.7 \oplus 0.004E \oplus 2.1\left(\frac{E}{100}\right)^{+0.3} \%$$

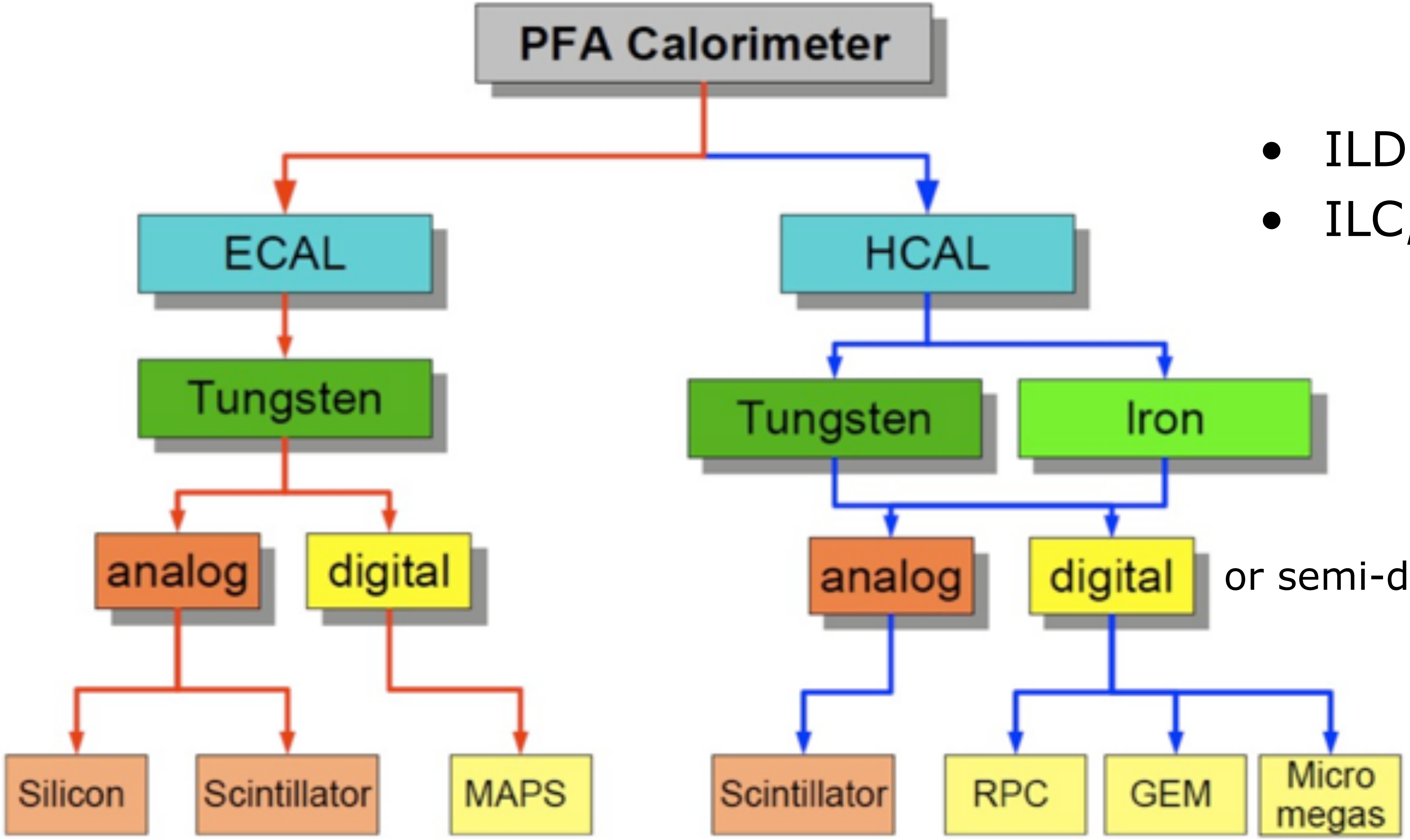
Resolution | Tracking | Leakage | Confusion



Total Resolution	3.1 %
Confusion	2.3 %
i) Photons	1.3 %
ii) Neutral hadrons	1.8 %
iii) Charged hadrons	0.2 %

N.B: rms_{90} = width containing 90% of events [~0.9σ of the central core gaussian]

Resolution comes at a price:

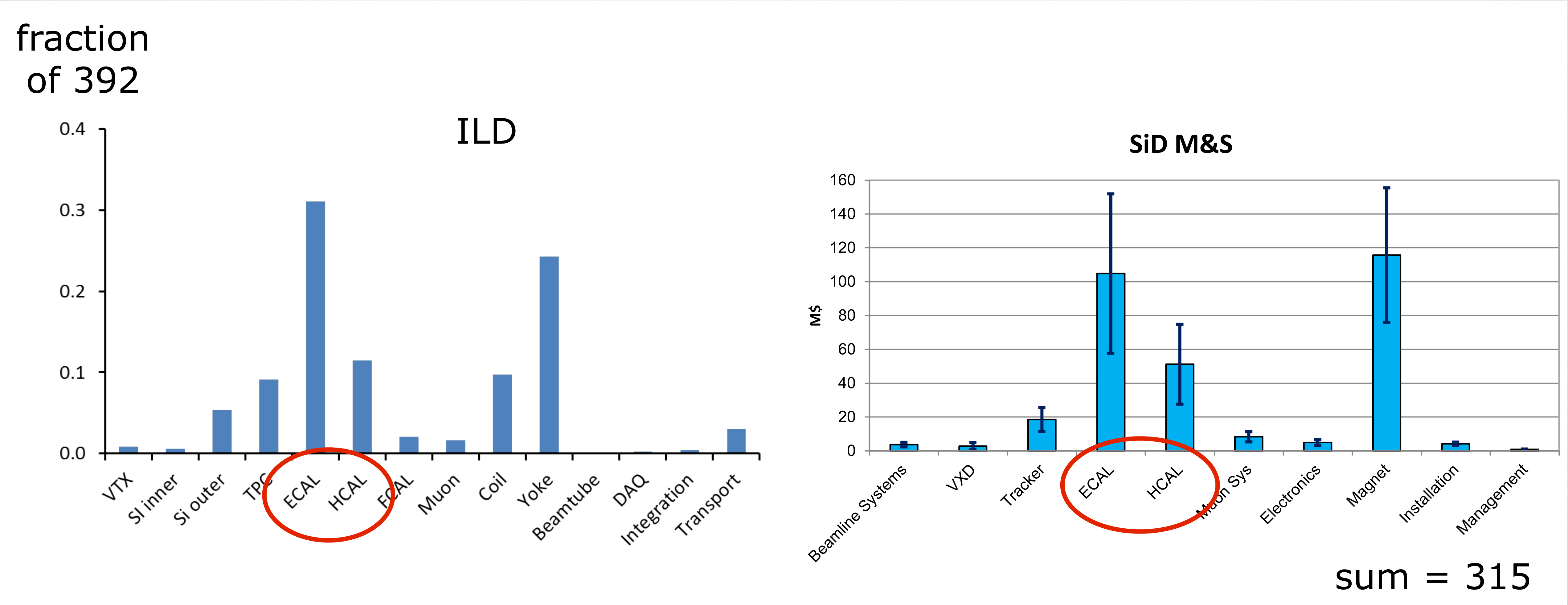


- ILD, SiD
- ILC, CLIC

or semi-digital

in terms of complexity...

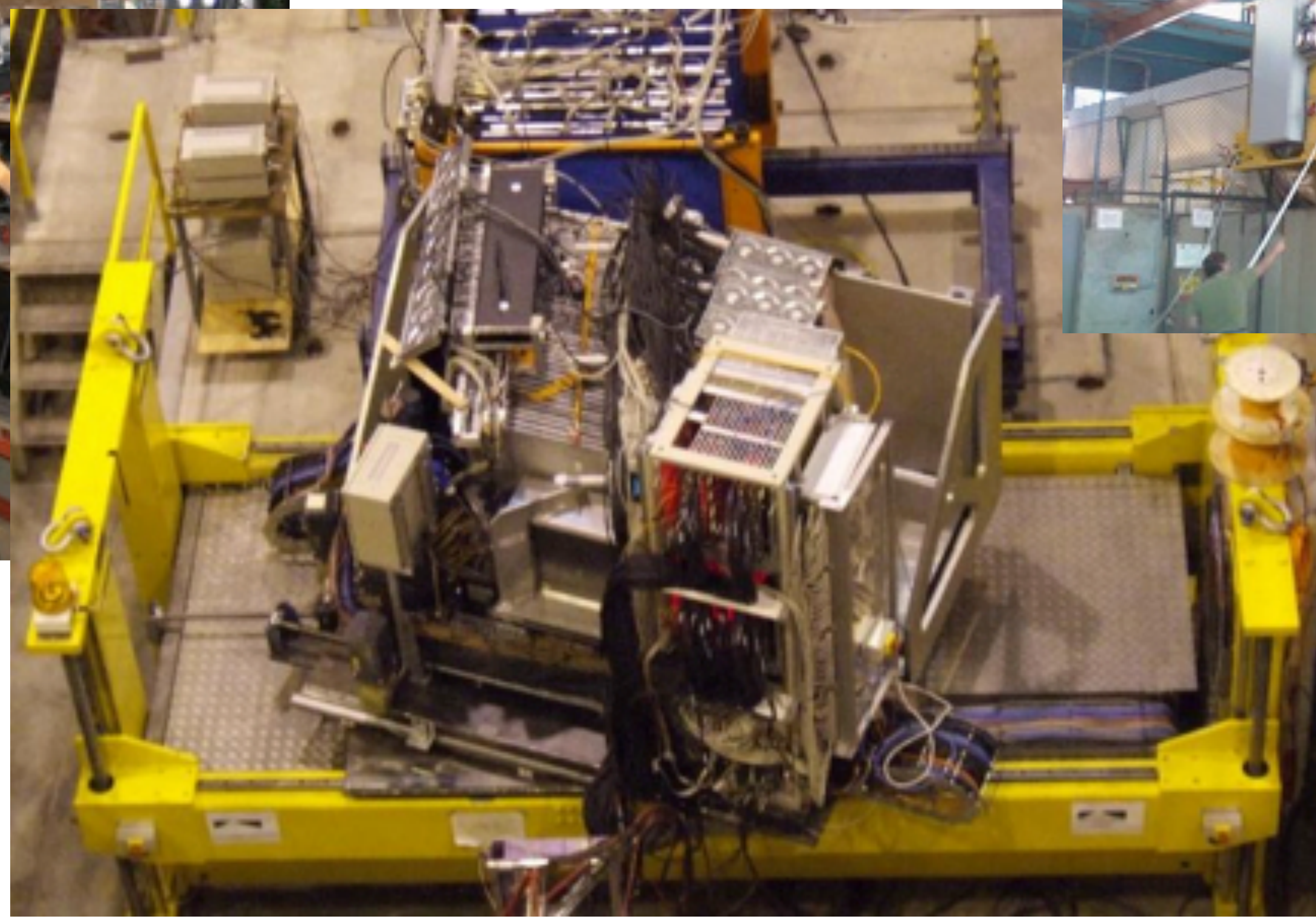
.... and in terms of costs:



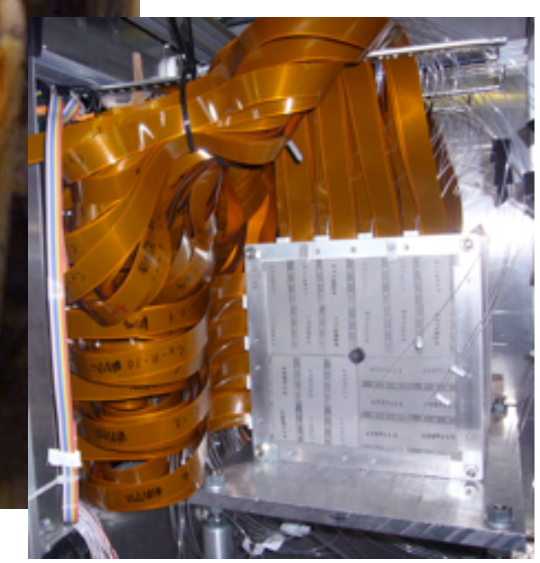
A lot was done, but there's still a long way to go...

DESY 2005
SiECAL

CERN 2006-2007
add Scint HCAL



FNAL 2008-09
Si -> Sci ECAL



an impressive series of test beam qualifications at DESY, CERN & FNAL

What's next, after the major effort that took the collaborations to the Baseline Design?

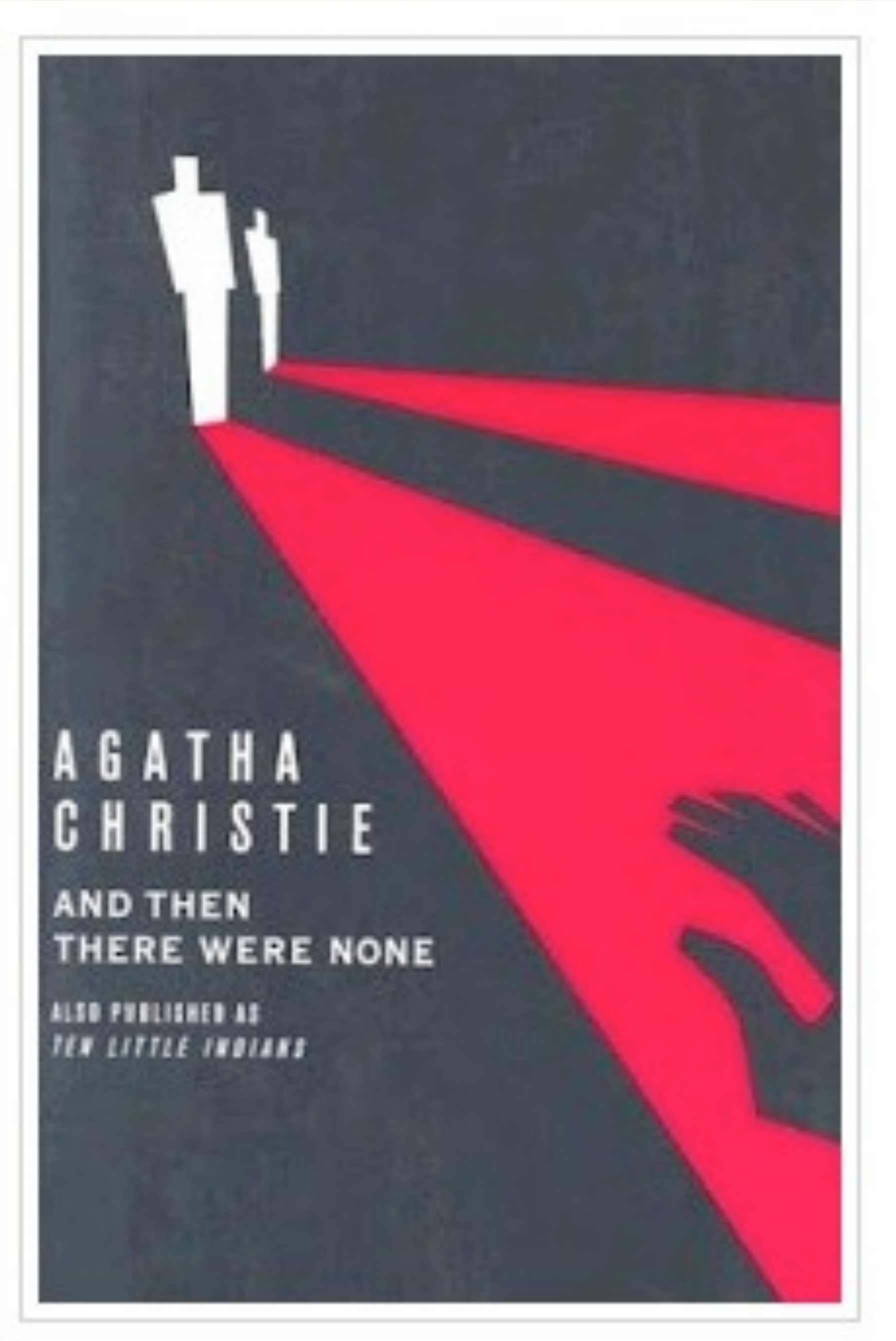
Jan Strube, SiD report at the ECFA-DESY workshop, May 2013

IID

SiD

... and time yet for 100 visions & revisions *[T.S. Eliot, The Love Song of J. Alfred Prufrock]*

... with a major goal: avoiding that, by the end of the day..


AGATHA
CHRISTIE
AND THEN
THERE WERE NONE
ALSO PUBLISHED AS
TEN LITTLE INDIANS