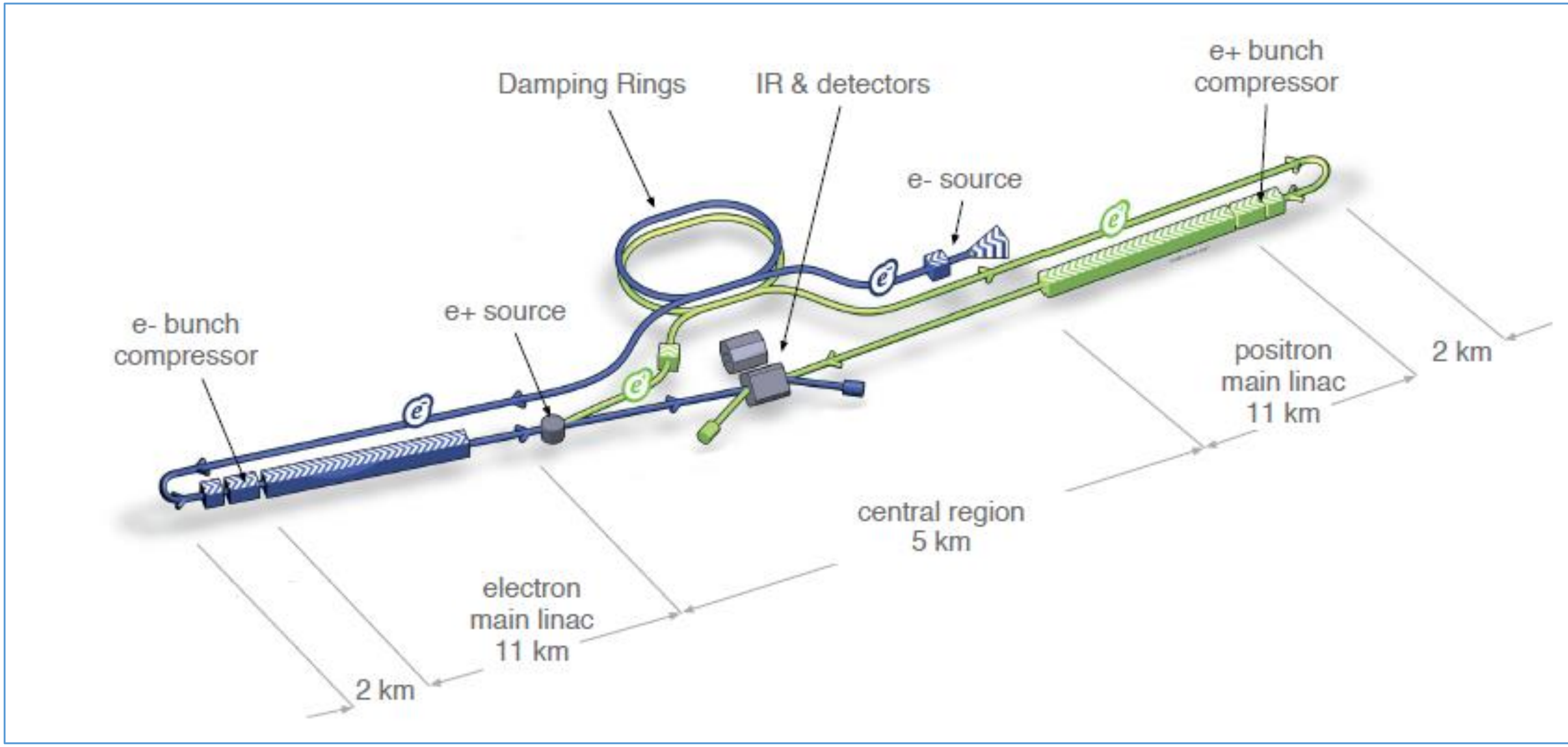
“Vertexing at the ILC”

From Marcel Stanitzki , POS VERTEX2015 (2015) 037

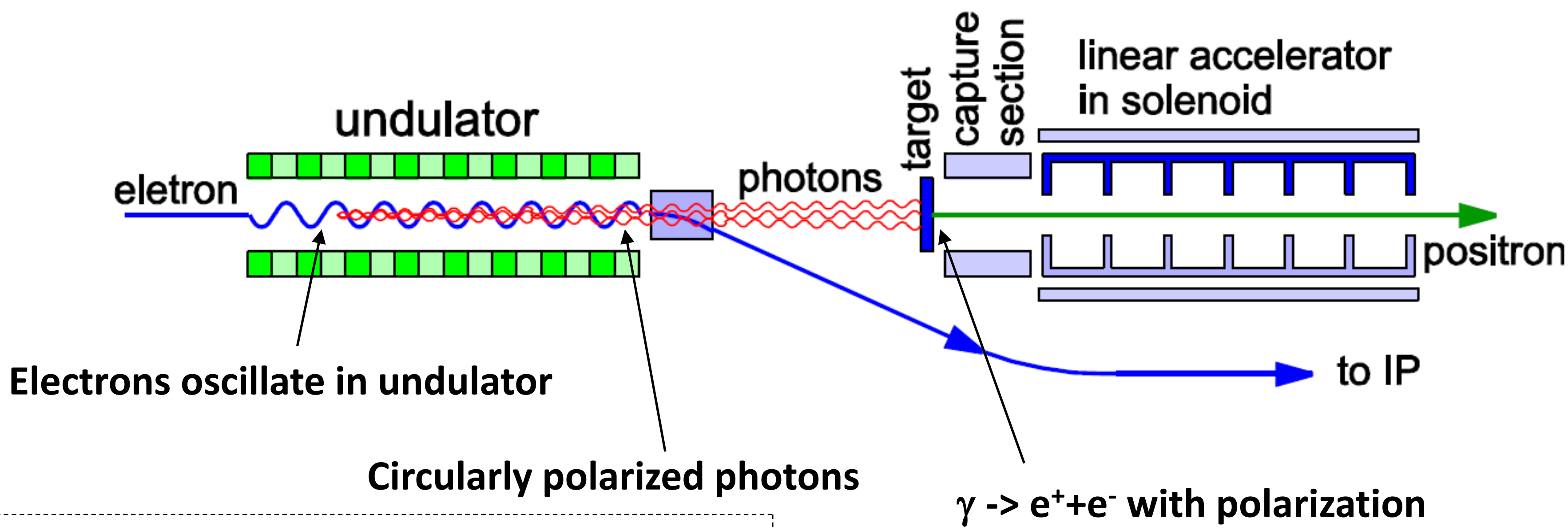
JC59, 04/13/2018

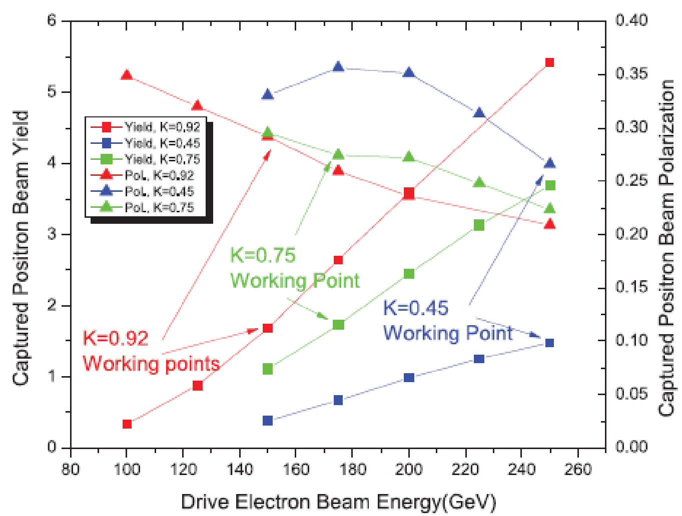
ILC (International Linear Collider)



Schematic layout of the ILC (not to scale)

Helical undulator and positron polarization





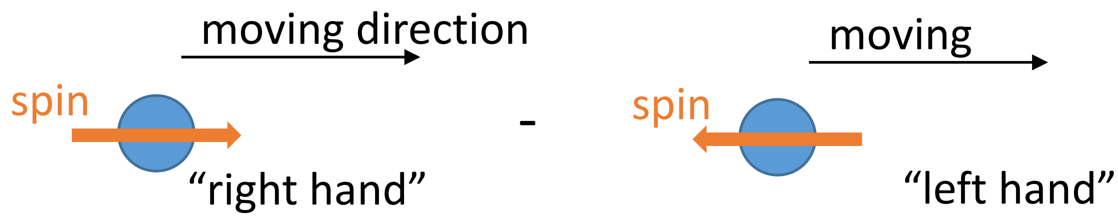
<u>simulation result : ▲ polarization ■ yield</u>

Polarization and yield depend on the electron beam energy as well as the length ? of undulator.

“Space for a ~220m undulator has been reserved for an eventual upgrade to 60& polarization” (TDR)

Q. (from Suyu) : What is the percentage of "polarized beams for both electrons (80%) and positrons (30%)" ? Why the number for positrons is small compared with electrons ?

Ratio $(P(-)_{electron})$ =



In explanations to follow, $P(-)$ and $P(+)$ are the polarizations for the e^- and e^+ beams, with, for example, $P(-) = -1$ corresponding to 100% left-handed polarization.

H- At the minimum, polarization can be used to enhance the event rate. In e^+e^- annihilation, an electron annihilates a positron of the opposite helicity. The ILC offers beam polarization both for electrons and for positrons. Thus, it is possible to tune the electron and positron polarization to be opposite ($e^-_L e^+_R$ or $e^-_R e^+_L$), enhancing the probability of an annihilation. The increase in the effective luminosity is

$$\mathcal{L}/\mathcal{L}_0 = 1 - P(-)P(+) \ , \qquad \text{(I-1.1)}$$

giving $\mathcal{L}/\mathcal{L}_0 = 1.24$ for $\mp 80\%$ e^-, $\pm 30\%$ e^+ polarisation.

ArXiv 1306.6329

Electron(e⁻) Source

A bunch train with 90% polarization is produced .

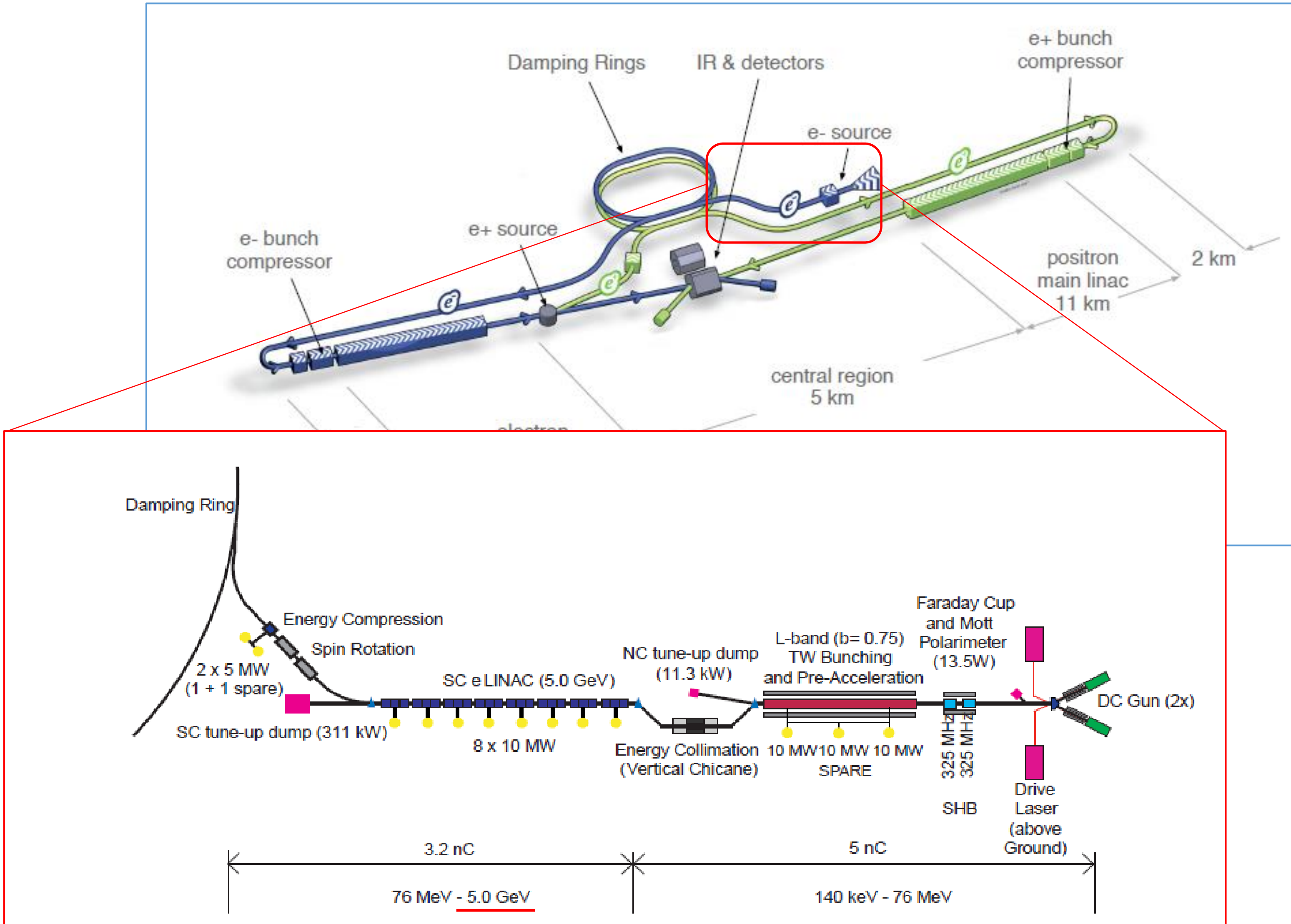
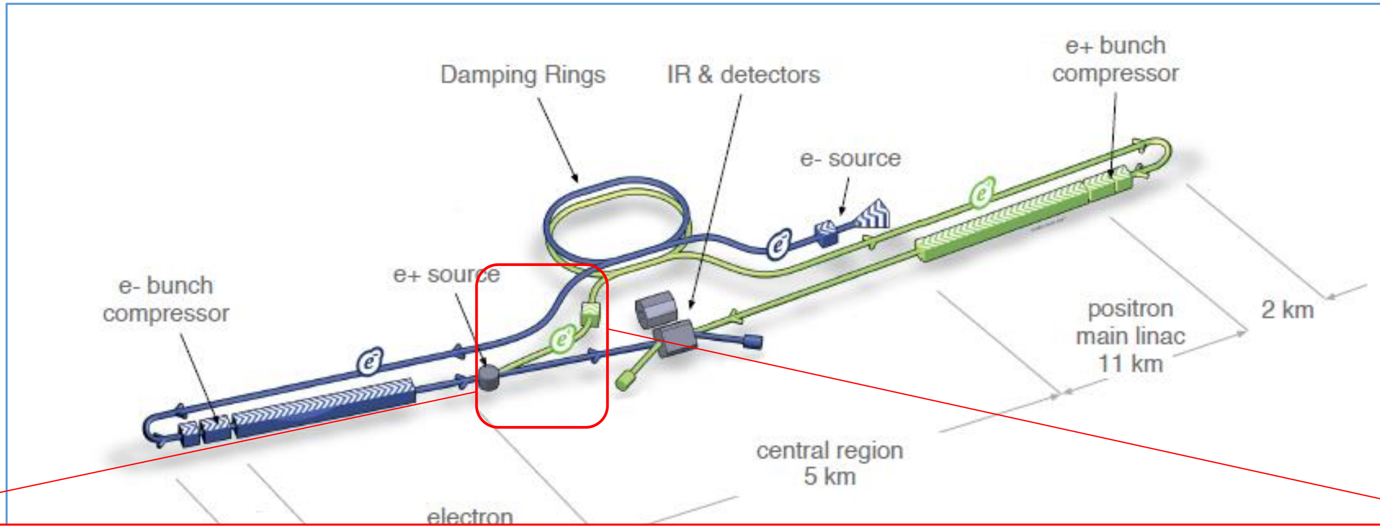


Figure 2.7. Schematic View of the Polarised Electron Source.

Positron(e^+) Source

Positrons are produced from (150-250) GeV e^- beam



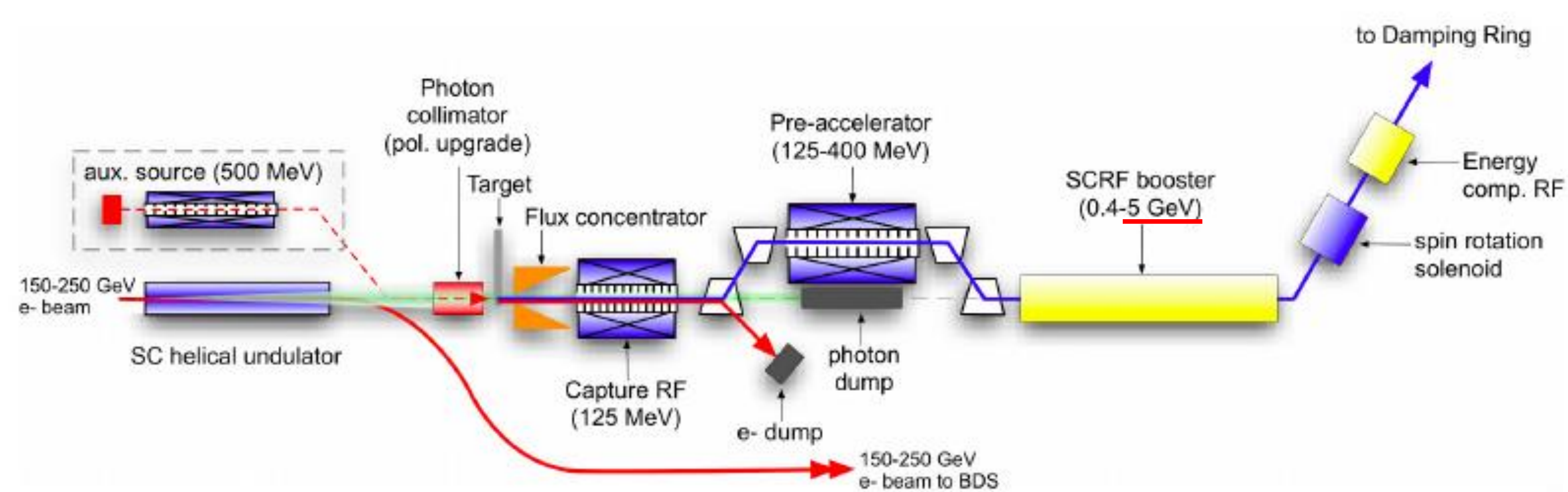


Figure 2.8. Overall Layout of the Positron Source.

Ring to Main Linac

Before reaching the main linac, there seems to be many functionality . . .

beam (particle) position correction, spin rotation , , ,

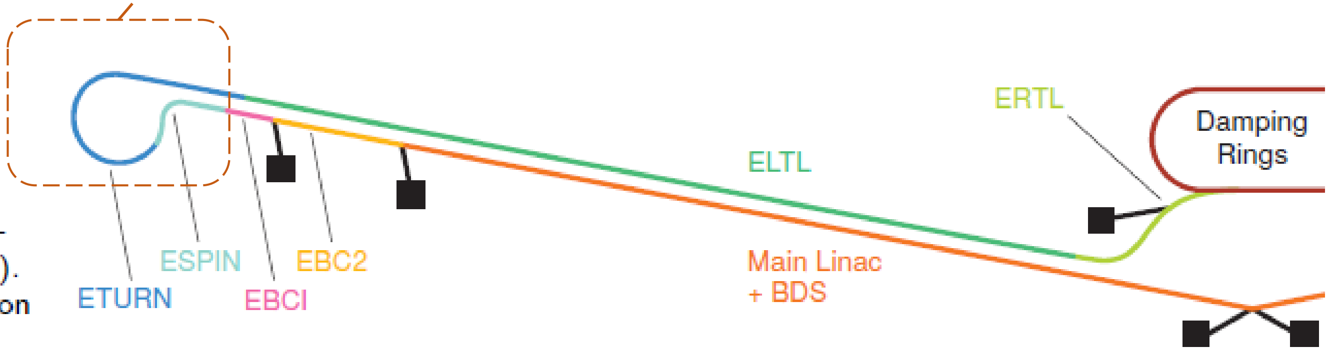


Figure 2.11 Schematic of the electron RTML (the positron system is a mirror image, with labels prefixed with 'P'). See text for explanation of the subsystems.

- a ~ 15 km long 5 GeV transport line (ELTL);
- betatron- and energy-collimation systems (in ERTL);
- a 180° turn-around, which enables feed-forward beam stabilisation (ETURN);
- spin rotators to orient the beam polarisation to the desired direction (ESPIN);
- a two-stage bunch compressor to compress the beam bunch length from several millimetres to a few hundred microns, as required at the IP (EBC1 and EBC2).

Synchrotron radiation @turn around ?

Q. (from Tao) : Would lots of energy be lost at the corner (turn around) ?
And how this effect would be compensated ?

Energy loss of e^-(e^+) by one circulation

$$U = 0.088 \frac{E^4[\text{GeV}]}{\rho[\text{m}]} \quad [\text{MeV}]$$

E=5 GeV is known, and I do not know of ρ , but if we assume ρ=10m,

→ U = 5.5 MeV → 5.5 MeV/5 GeV = 0.1 %

maybe acceptable ?

Super-conducting Cavity @ Linac

- One of technical challenges for ILC

- Super-conducting (low power consumption but w. cryostat) *vs* normal-conducting (high E-field)

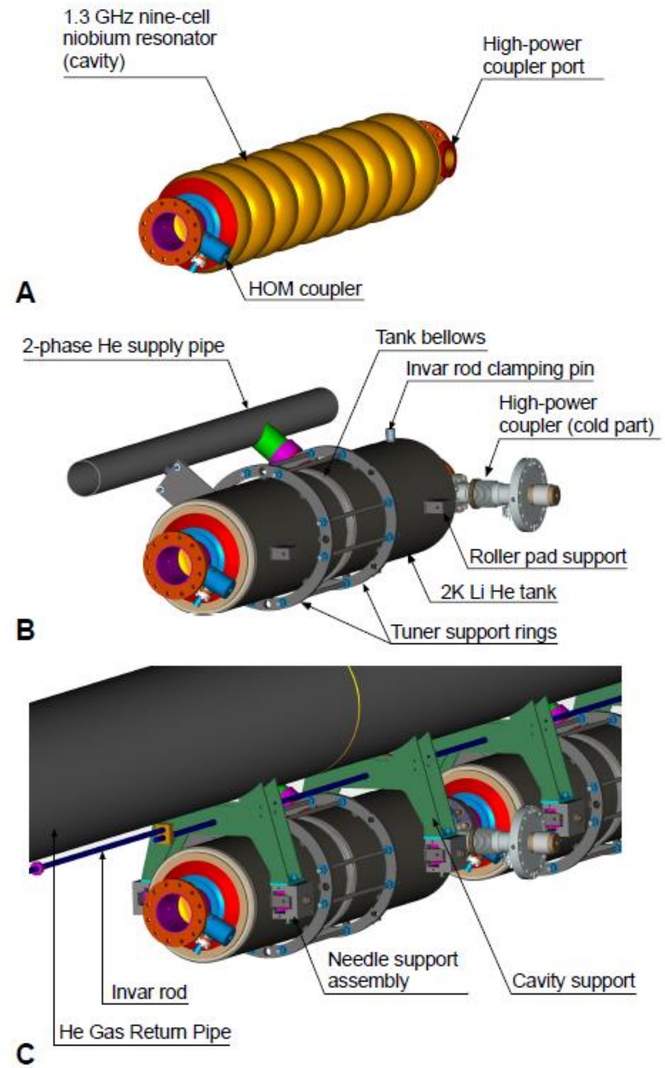
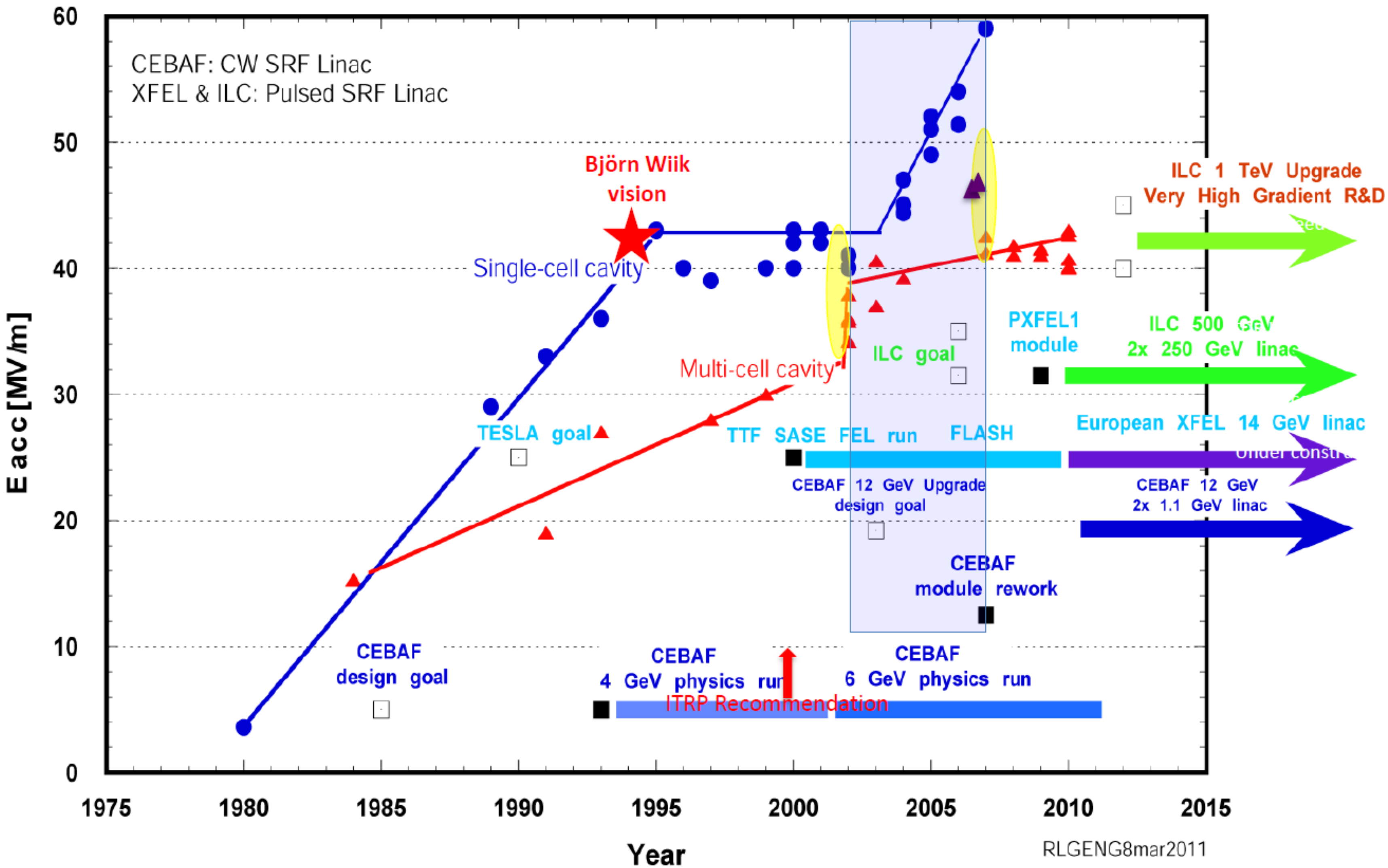


Figure 3.4
The baseline cavity package and string assembly: (A) the nine cell cavity (resonator); (B) the "dressed" cavity, showing the helium tank, 2-phase helium supply, high-power coupler (cold part) and the mount for the cavity tuner; (C) cavity package mounted into the cavity string and cryomodule. (Note the "blade" cavity tuner is not shown.)

History. Gradient (*E* MeV/m) of super-conducting magnet

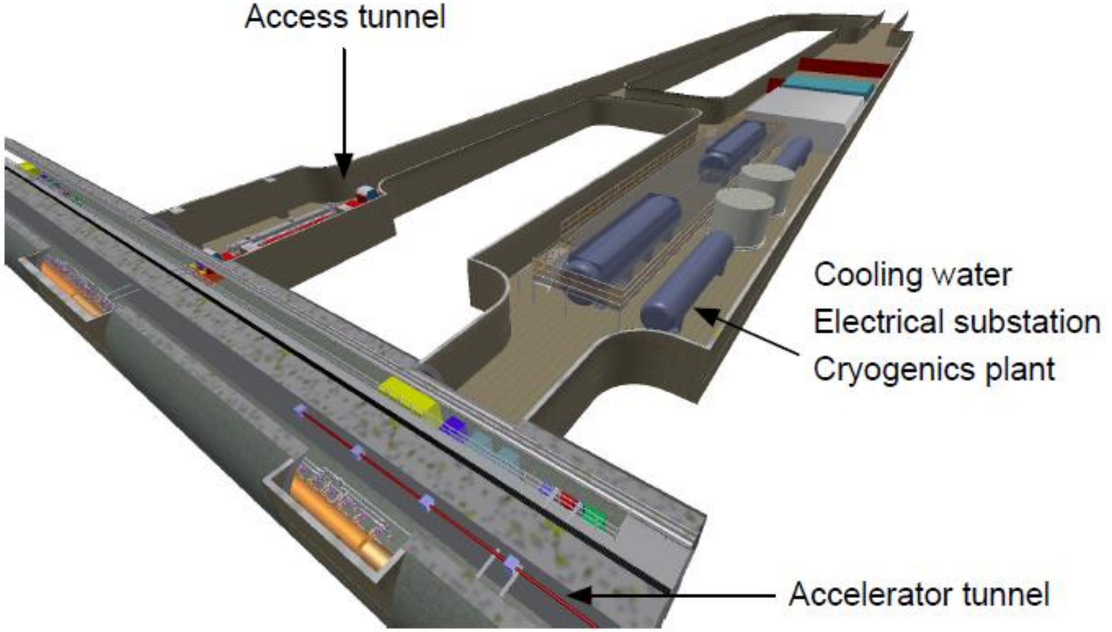


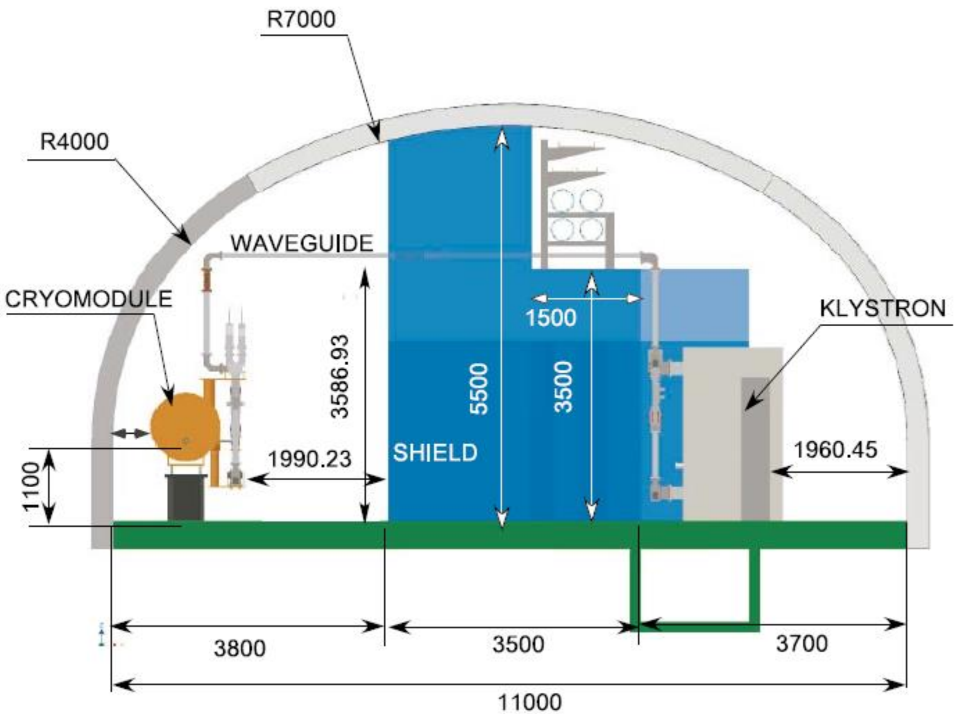
NishinaCenter 2014-1110
K.Yokoya

30 MeV/m x 11km = 300 GeV (in reality, the total length is not fully covered by the cavity, and the number is ~850 with ~1m length=> ~250 GeV)

Reference

Figure 3.39
3D rendering of a cryo cavern and horizontal access way. For more details see Section 11.4.2.





Combined result from ATLAS & CMS

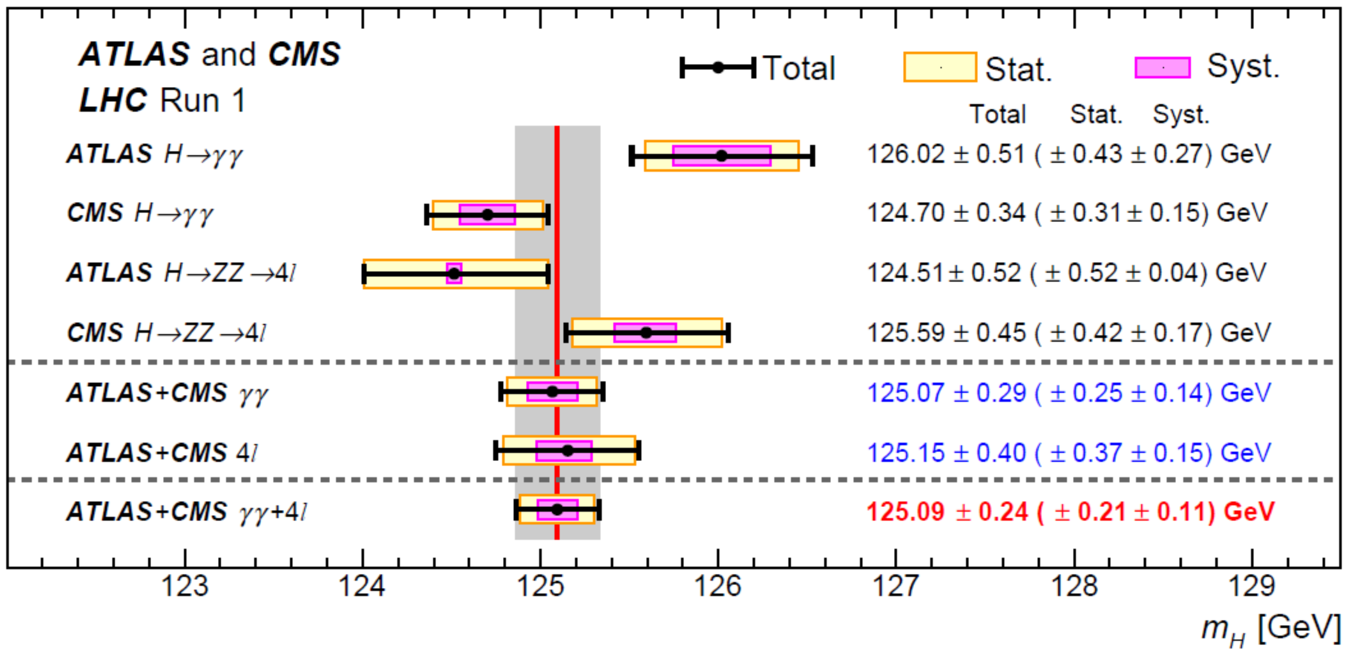


Figure 2: Higgs Bosons results from the LHC: The Higgs Boson mass measurements from both ATLAS and CMS and the combined analysis. The current average mass is m_H=125.09 ± 0.24 GeV/c^2 [8].

"Signal strength μ" (From G. Ada *et al.* Eur. Phys. J. C76 (2016) 6)

Q. (from Maoqiang) : What is the signal strength ?

Quite Impressive !

$$\mu = \frac{\sigma \times \mathrm{BR}}{(\sigma \times \mathrm{BR})_{\mathrm{SM}}} .$$

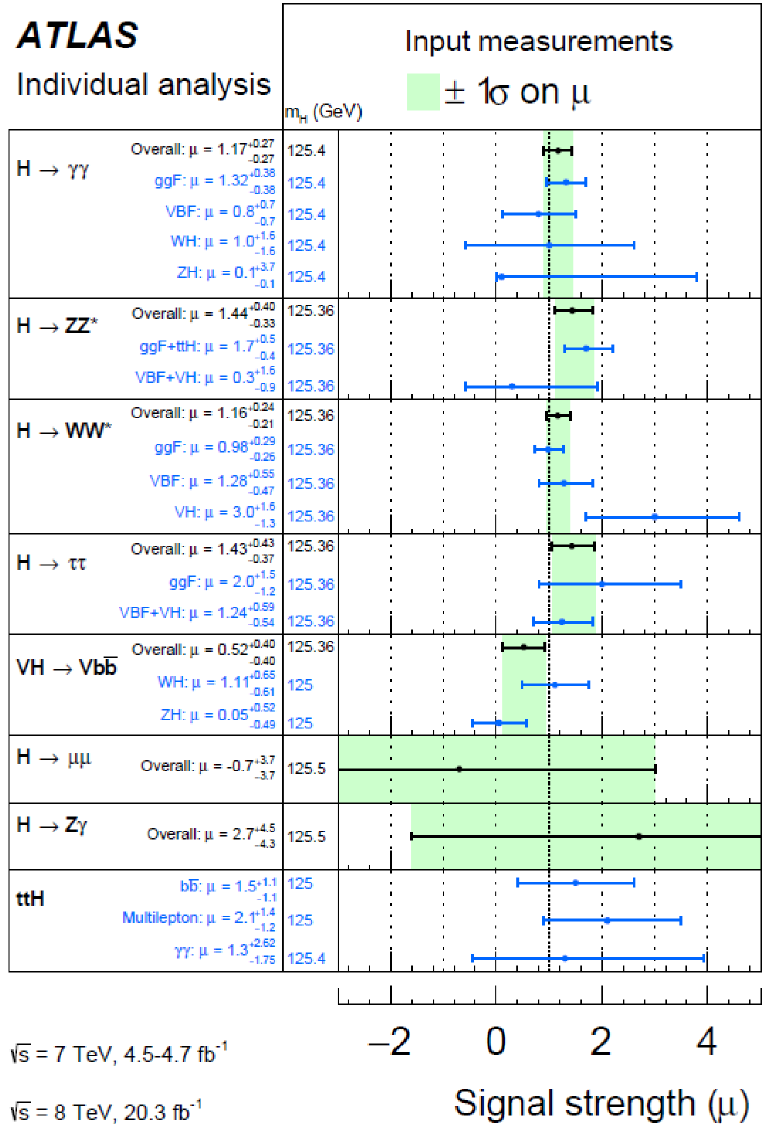
Prediction

Production process	Cross section [pb] $\sqrt{s} = 7$ TeV	Cross section [pb] $\sqrt{s} = 8$ TeV
ggF	15.0 ± 1.6	19.2 ± 2.0
VBF	1.22 ± 0.03	1.57 ± 0.04
WH	0.573 ± 0.016	0.698 ± 0.018
ZH	0.332 ± 0.013	0.412 ± 0.013
bbH	0.155 ± 0.021	0.202 ± 0.028
ttH	0.086 ± 0.009	0.128 ± 0.014
tH	0.012 ± 0.001	0.018 ± 0.001
Total	17.4 ± 1.6	22.3 ± 2.0

Decay channel	Branching ratio [%]
$H \to b\bar{b}$	57.1 ± 1.9
$H \to WW^*$	22.0 ± 0.9
$H \to gg$	8.53 ± 0.85
$H \to \tau\tau$	6.26 ± 0.35
$H \to c\bar{c}$	2.88 ± 0.35
$H \to ZZ^*$	2.73 ± 0.11
$H \to \gamma\gamma$	0.228 ± 0.011
$H \to Z\gamma$	0.157 ± 0.014
$H \to \mu\mu$	0.022 ± 0.001

$$n_s^c = \sum_i \sum_f \mu_i (\sigma_i)_{\mathrm{SM}} \times \mu_f (\mathrm{BR}_f)_{\mathrm{SM}} \times A_{if}^c \times \varepsilon_{if}^c \times \mathcal{L}^c$$

acceptance, efficiency, luminosity , ,



The deviation of Higgs boson branching ratios for different scenarios

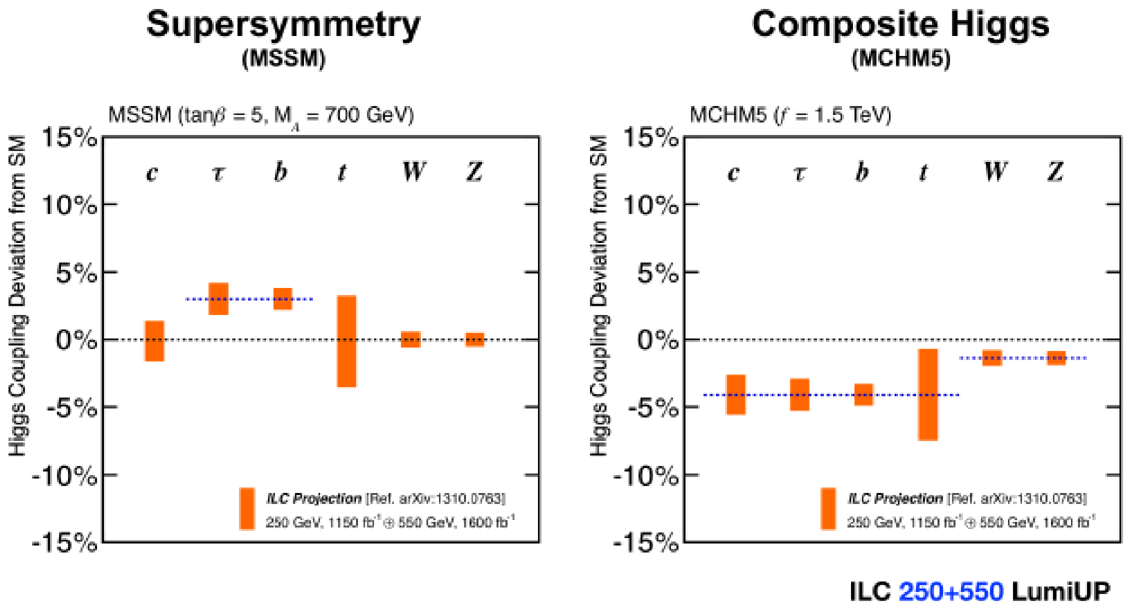


Figure 4: The deviation of the Higgs Boson branching ratios compared to the Standard Model for a Supersymmetric Model (left) and a model with composite Higgs Bosons (right) [10]. In both cases the expected deviations are only a few percent. The bars indicate the projected precision of the ILC using a specific running scenario.

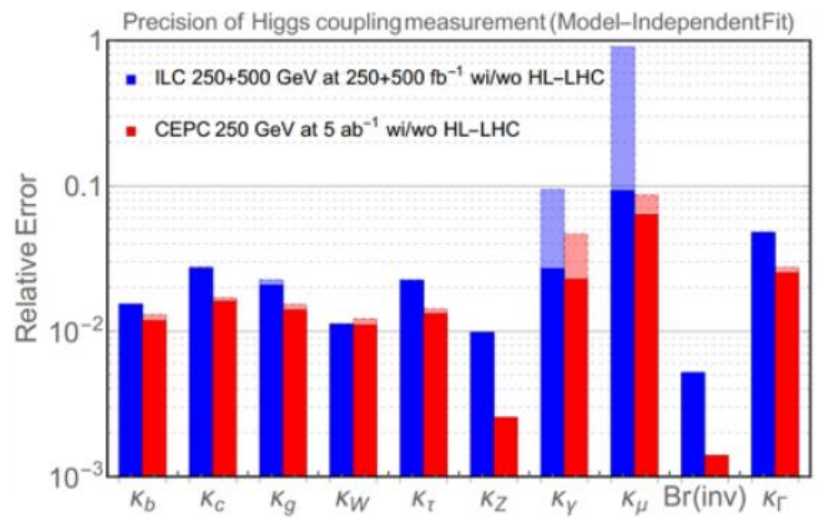
Q. (from Hao) : Compare to CEPC, what is the advantages and disadvantages of ILC ?

$\sqrt{s}$ and $\mathcal{L}$	CEPC: 5 ab^{-1}, 240 GeV	
	Zh	$\nu\bar{\nu}h$
$\Delta\sigma/\sigma$	0.70%	-
mode	$\Delta(\sigma \cdot \mathrm{Br})/(\sigma \cdot \mathrm{Br})$	
$h \to b\bar{b}$	0.32%	4.0%
$h \to c\bar{c}$	2.2 %	-
$h \to gg$	1.9%	-
$h \to WW^*$	1.7%	-
$h \to \tau^+\tau^-$	1.1%	-
$h \to ZZ^*$	4.8%	-
$h \to \gamma\gamma$	9.1%	-
$h \to \mu^+\mu^-$	27%	-

Coupling	CEPC (5 ab^{-1})	CEPC + HL-LHC
$\gamma\gamma$	4.8%	1.7%
gg	1.9%	1.8%
WW	1.6%	1.6%
ZZ	0.20%	0.20%
$t\bar{t}$	1.9%	1.9%
$b\bar{b}$	1.5%	1.5%
$\tau^+\tau^-$	1.7%	1.6%

Table 6. Estimated uncertainties in Higgs measurements at CEPC. At left: uncertainties in cross section and cross section times branching ratio measurements, analogous to Table 5.4 in the ILC Higgs White Paper [18]. At right: uncertainties on individual Higgs couplings from a profile likelihood in a seven parameter fit, analogous to Table 6.4 of ref. [18]. The third column includes a 3.6% constraint on the ratio $\mathrm{Br}(h \to \gamma\gamma)/\mathrm{Br}(h \to ZZ^*)$ from the high-luminosity LHC run [85].

arXiv : 1141.1054



CEPC

- Statistics (CEPC : circular <--> ILC: linac)

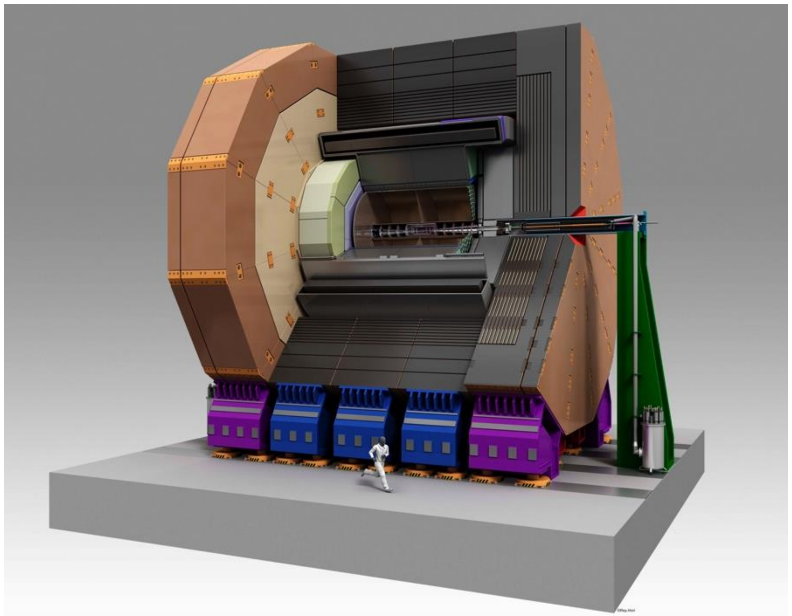
ILC

- Energy upgrade
- Using polarized beam

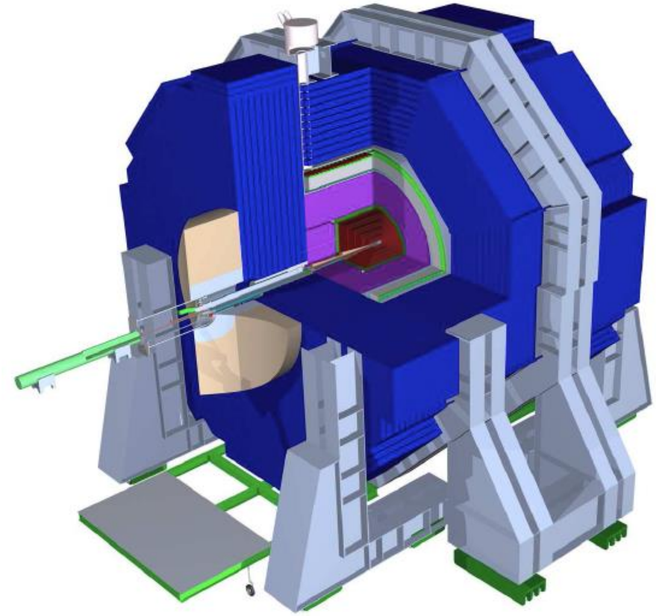
This is "my" current opinion/investigation and there would be something others

ILC Detectors -- SiD & ILD

ILD (International Large Detector)



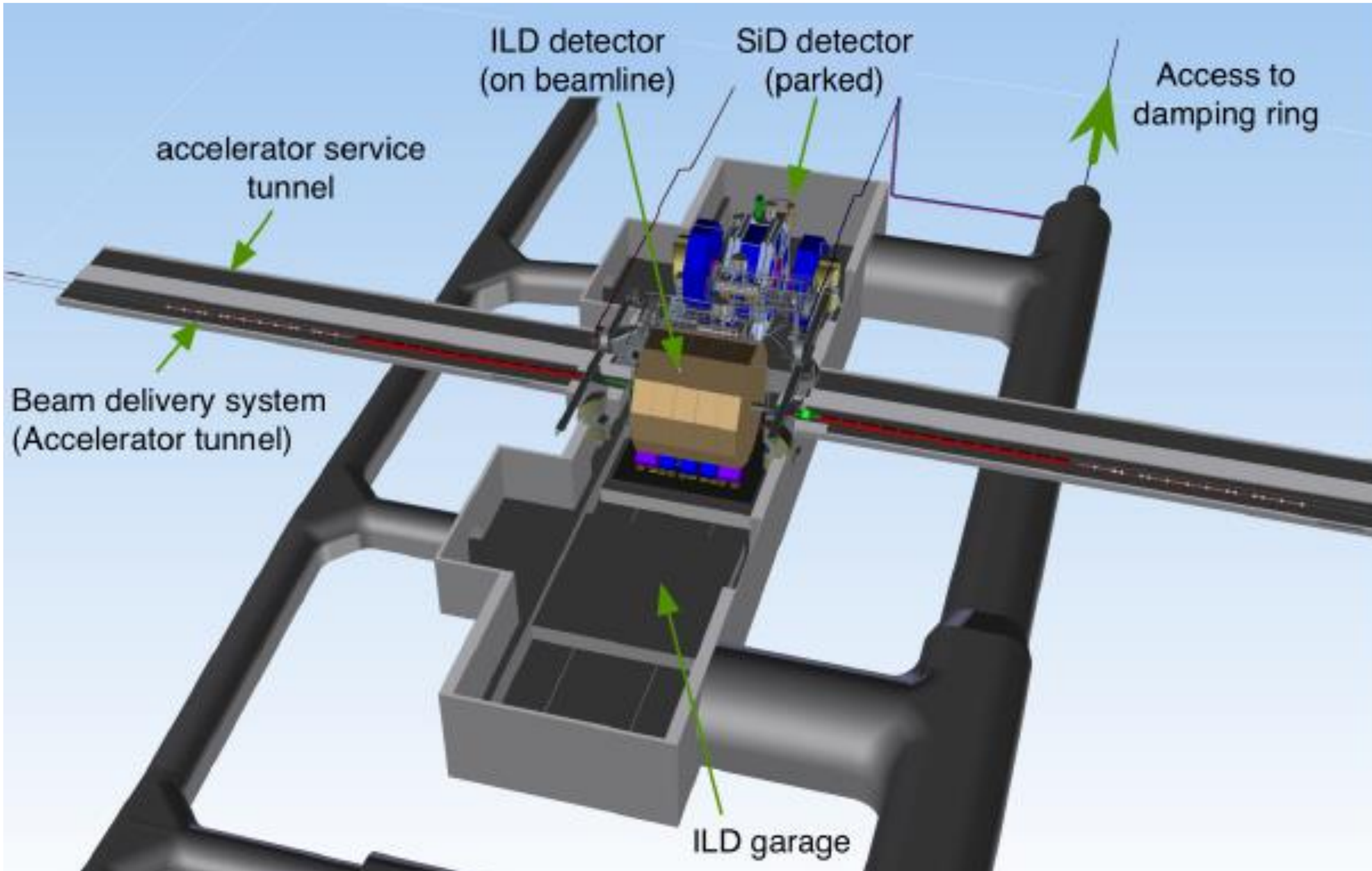
SiD (Sillicon Detector)



	ILD	SiD
Magnetic Field	3.5 T	5 T
Vertex pixel detectors	6 (3 pairs) or 5 layers (no disks) Technology open	5 barrel layers + 4 disks Technology open
Si strip trackers	2 barrel + 7 forward disks (3 of the disks are pixel), Outer and end of TPC	5 barrel layers + 4 forward disks/side
TPC	GEM or MicroMEGAS Pad (or Si-pixel) readout	None
ECAL	Si-W or Scint-W	Si-W 30 layers, pixel $(4\text{mm})^2$
HCAL	Scint-tile or Digital-HCAL + Fe	Digital HCAL with RPC readout with $(1\text{cm})^2$ cell

"Push-Pull" configuration

Q. (from Xin) : Why ILC has to run in push-pull mode ? what is the main difference on the tracker between SiD & ILD ?



So far, I only found statements such like "we need cross-check and compete " ...

Difference in tracker system

-- All silicon detectors

-- Few high precise hits

-- Low material budget

-- Silicon + TPC

-- High hit redundancy

-- Larger volume

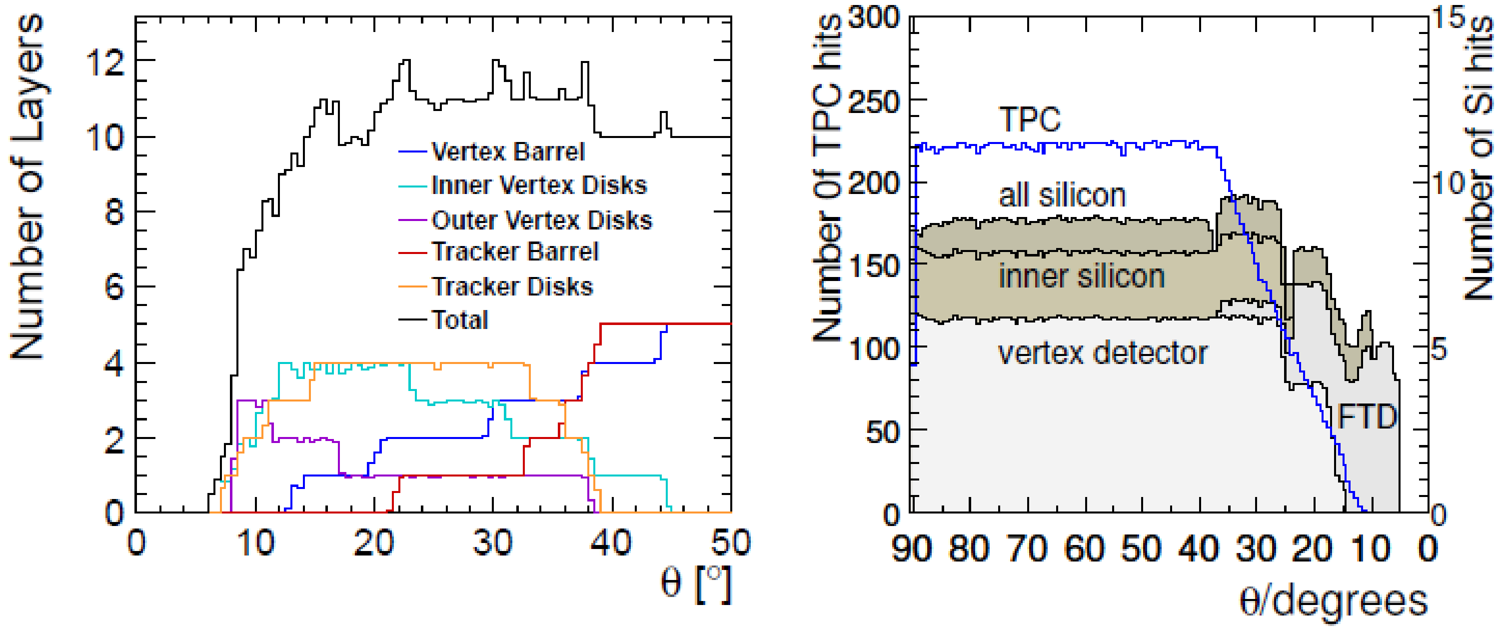


Figure 6: The available hits in both the vertex detector and the main tracker depending on the polar angle for SiD (left) and ILD (right). Both detectors have an excellent coverage down to very small angles.

Comparison of vertex detector

Q. (from Maoqiang) : What does “disk” means ?

SiD

“disk”

ILD

no“disk” (for vertex)

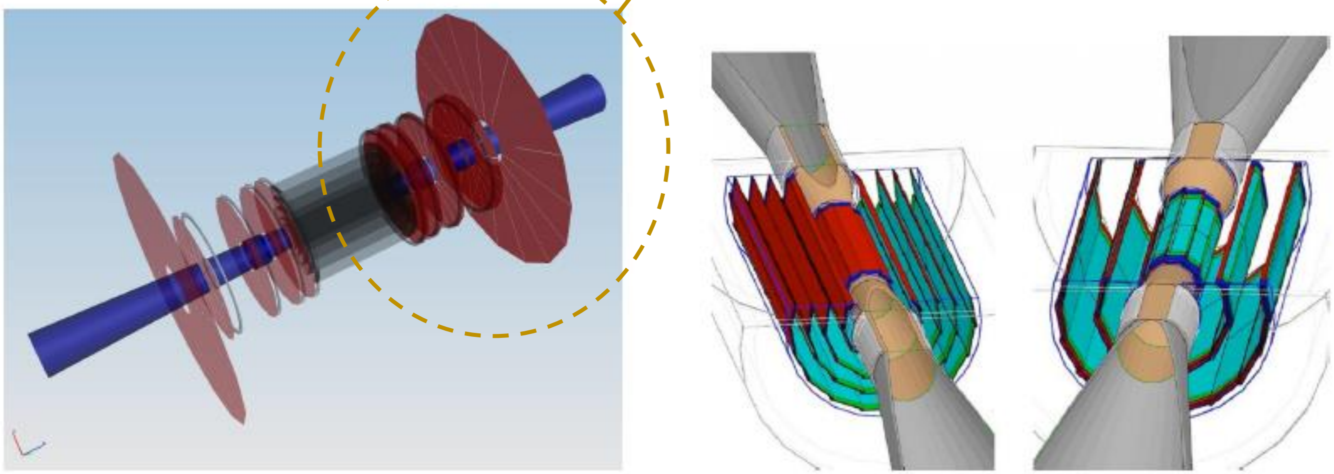
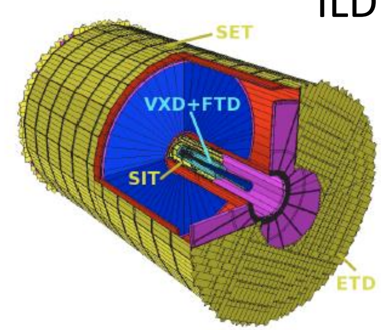


Figure 7: The vertex detector layouts of both SiD (left) an
the different approaches of both concepts

ILD



“disk” in the tracker of ILD

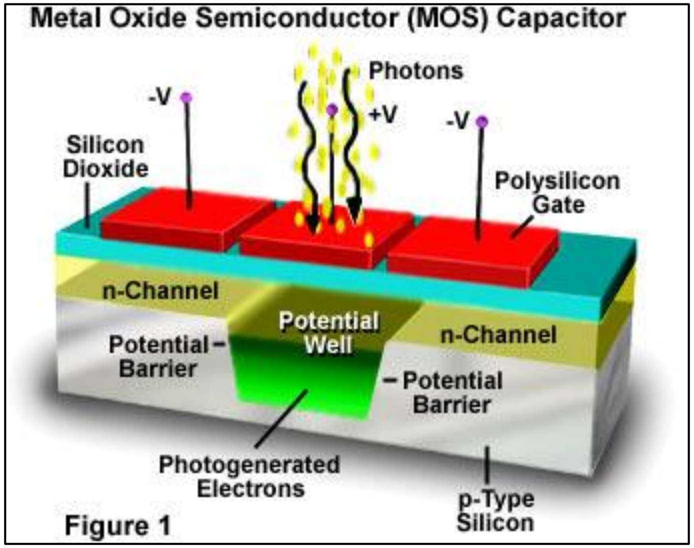
Physics target and the Energy reach

Table 2.1
Major physics processes to be studied by the ILC at various energies. The table indicates the various Standard Model reactions that will be accessed at increasing collider energies, and the major physics goals of the study of these reactions. A reaction listed at a given energy will of course be studied at all higher energies.

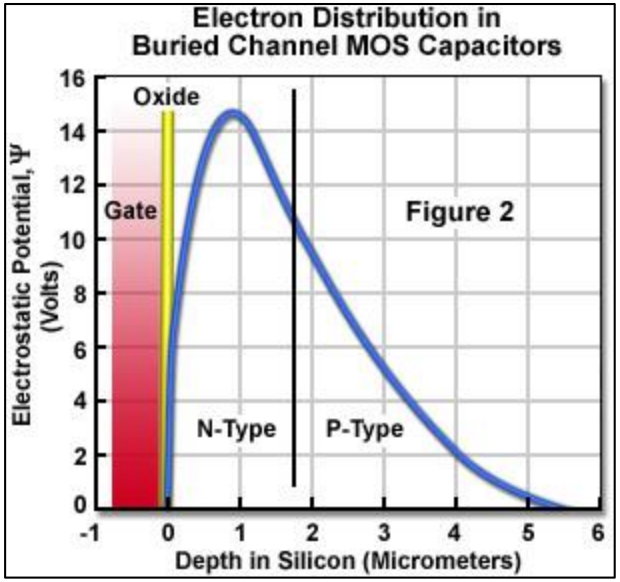
Energy	Reaction	Physics Goal
91 GeV	$e^+e^- \to Z$	ultra-precision electroweak
160 GeV	$e^+e^- \to WW$	ultra-precision W mass
250 GeV	$e^+e^- \to Zh$	precision Higgs couplings
350–400 GeV	$e^+e^- \to t\bar{t}$ $e^+e^- \to WW$ $e^+e^- \to \nu\bar{\nu}h$	top quark mass and couplings precision W couplings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

CCD (Charge Couple Device)

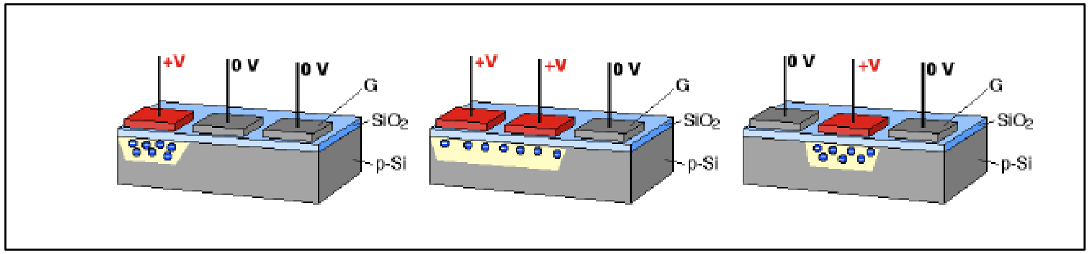
Q. (from Lingteng) : What is the multiple charge transfer and why FPCCD do better in handling it than CCD ?



Simple structure of CCD



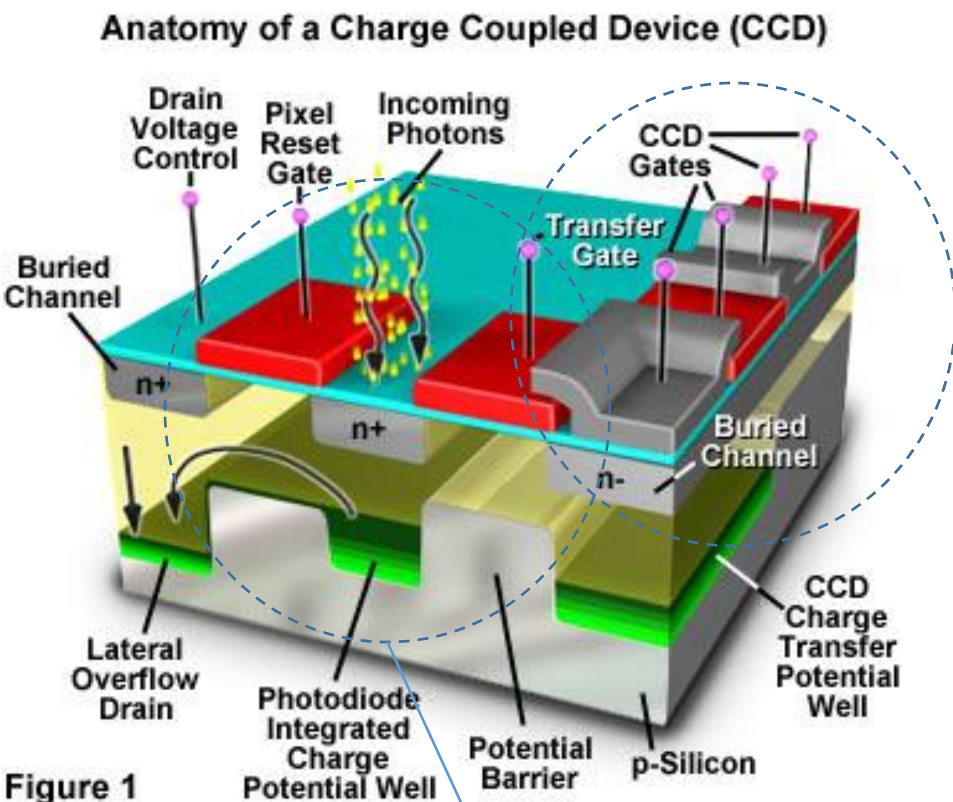
Potential well in CCD

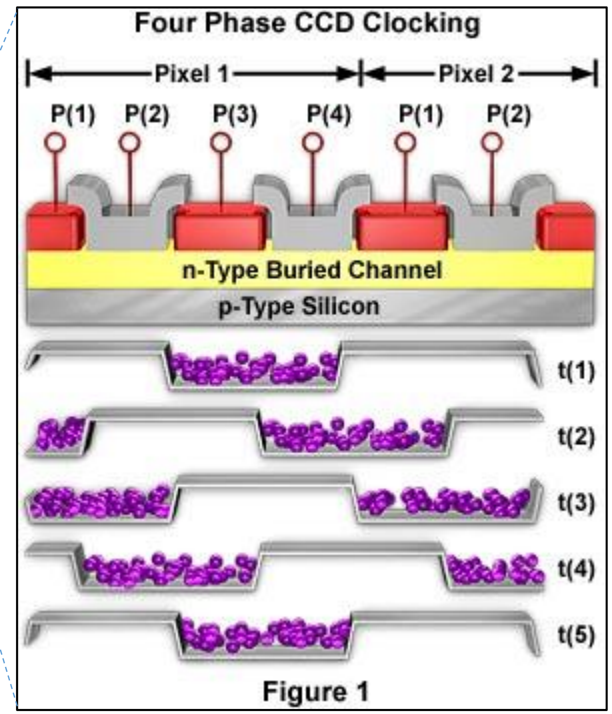


Charge transfer is performed by changing gate bias

From https://www.olympus-lifescience.com/en/microscope-resource/primer/digitalimaging/concepts/concepts/

The structure is not that simple, but to compare with the CMOS, the size of the circuit (or the needed area for that) is small.

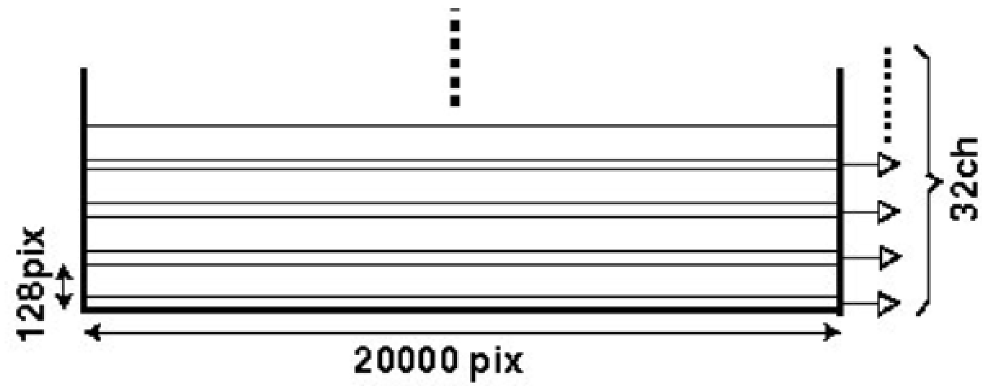




Charge Transfer

Charge potential

FPCCD (Fine Pixel CCD)



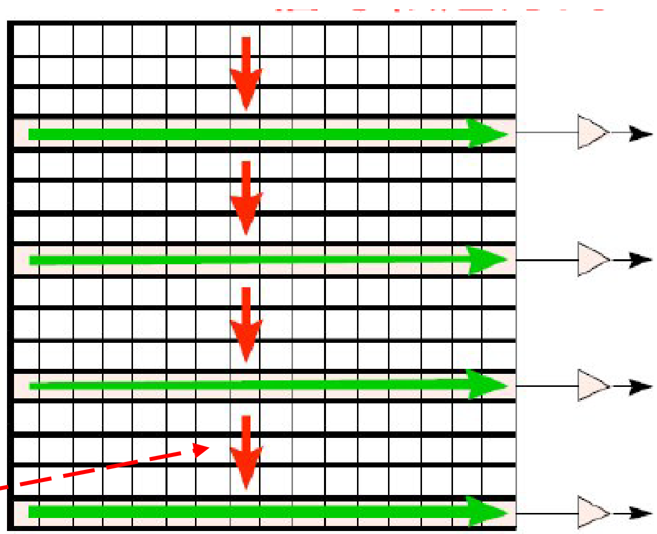
- Pixel size : 5 x 5μm^2
- Full Depletion type !

I do not know how they did

- Number of channel ~6000
  - -- 20,000 x 128 pixel/ch
  - -- Number of pixels ~10^{10}
  - -- Readout speed 10Mpixel/s

This seems underway

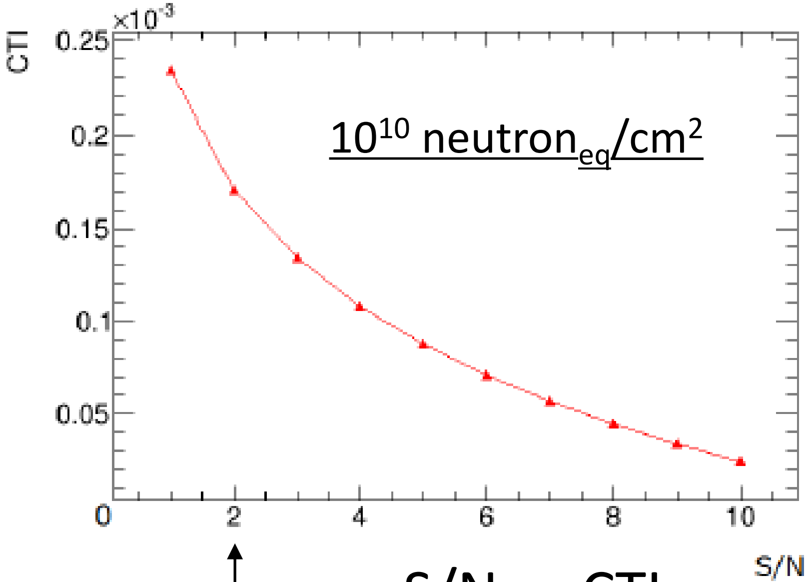
  - -- Read all of data during the beam interval



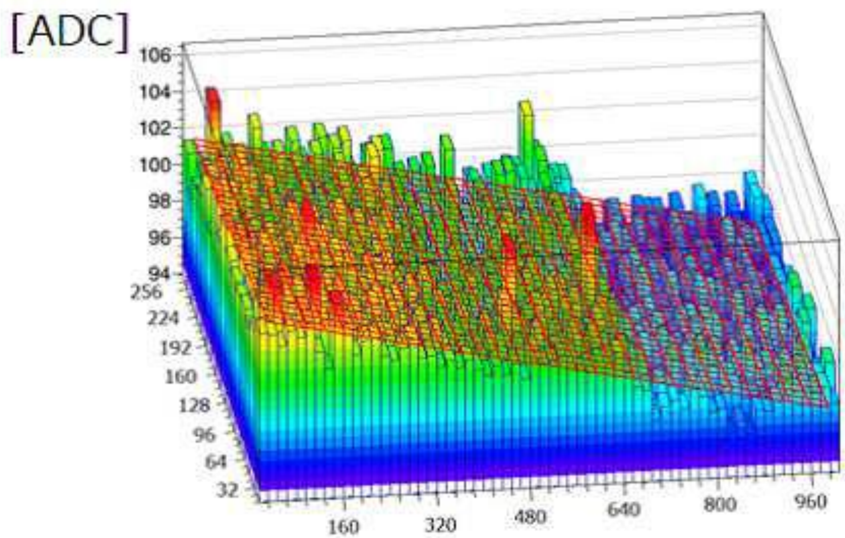
- Horizontal transfer register is embedded

Charge Transfer Inefficiency (CTI)

Due to radiation damage, the transfer efficiency drops !



S/N vs CTI



Two dimensional distribution of the peak ADC of 5.9 keV X-ray from ^{55}Fe .

One transfer(to next gate) efficiency loss is tiny ~ 10^{-4} but if it is 10,000 times , it is too big.

From arXiv : 1703.05603 “Radiation tolerance of FPCCD vertex detector for the ILC”

Possible improvement

- Notch channel

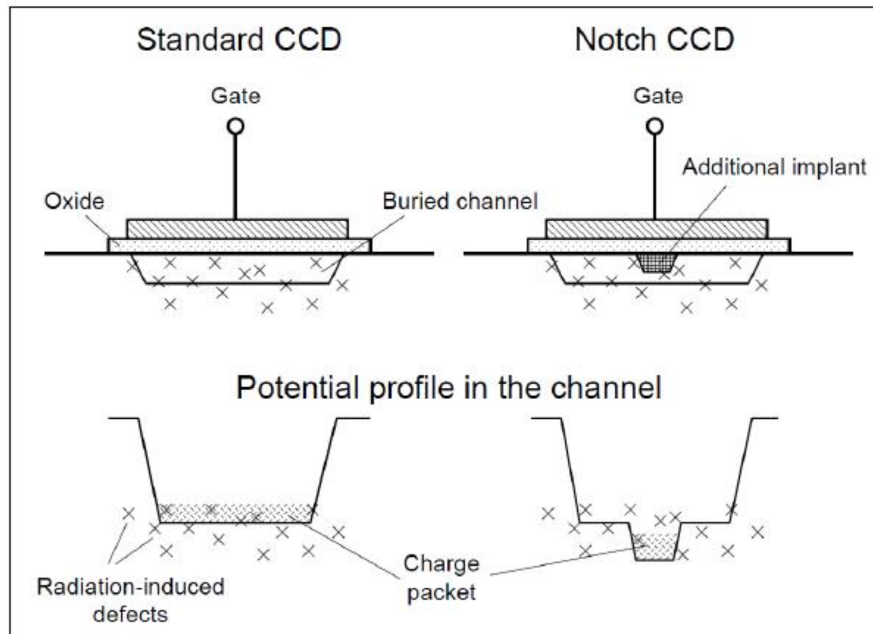
personally, I feel kinds of curiosity about this method

  - Signal charge encounters less traps if it is transferred through narrower channel
  - Narrower channel than pixel (shift register) width is called "notch channel"
  - Fat-zero charge injection is more effective

- Annealing
  - Annealing at ~100 deg is reported
  - CTI improvement by x2~3 after 168h 100℃ annealing

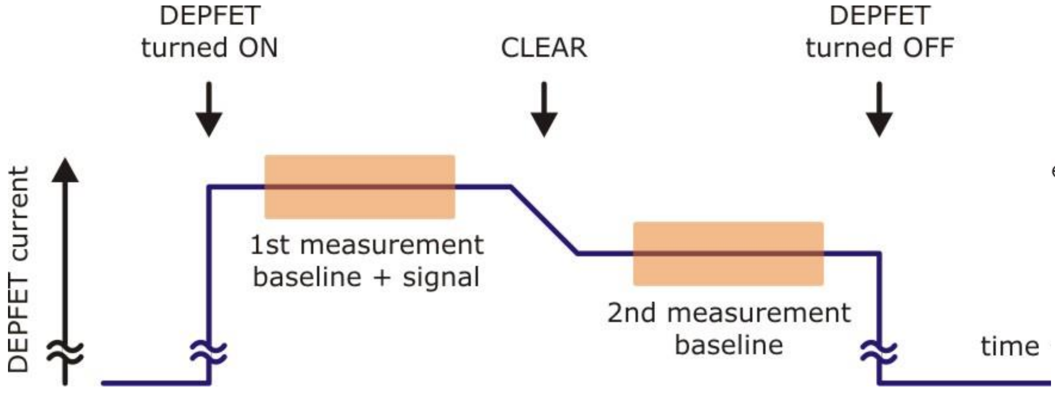
E. Martin, et al. IEEE Trans, Nucl. Sci. vol. 58, No.3, 2011

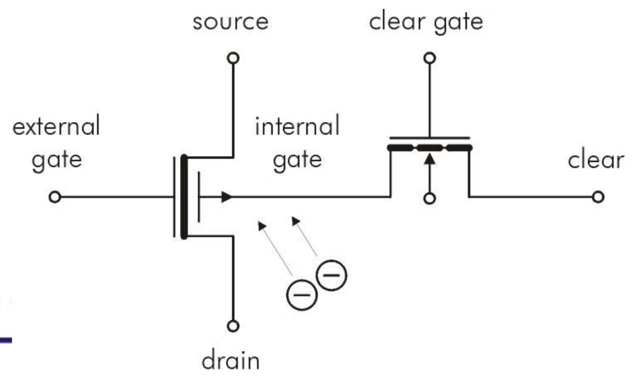
- Noise reduction
  - Requirement for CTI gets lax



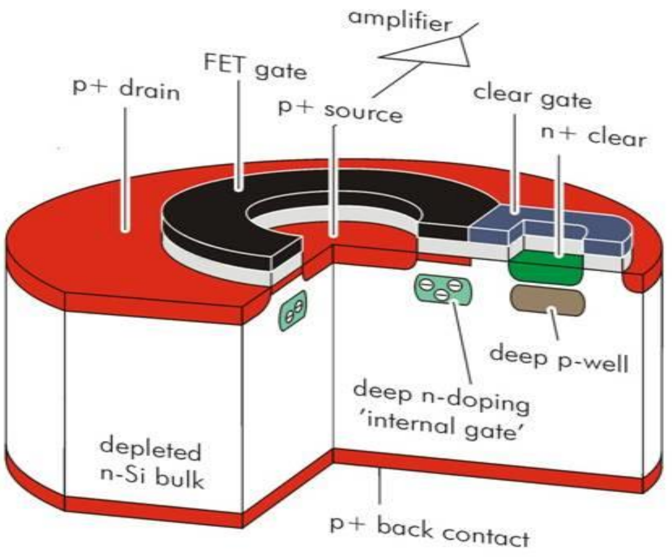
From 03/01/2017 Annual ILC meeting, presented by Murai

DEPFET Readout





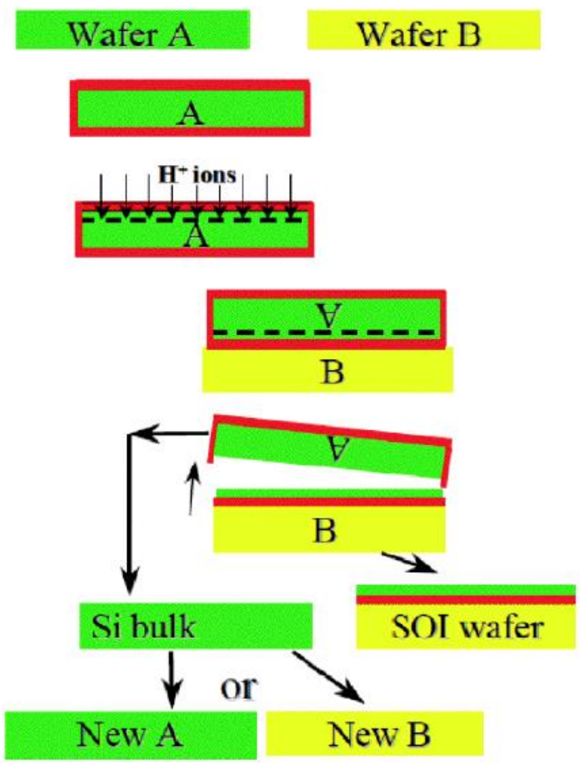
- ***Measurement of signal***
  - **Measure signal levels**
    - **source potential / drain current**
  - **Measure both before and after clear**
  - **Calculate the difference**
    - **correlated double sampling (CDS)**



From G. Luts et al. , VCI2016

CMOS sensor (MAPS)

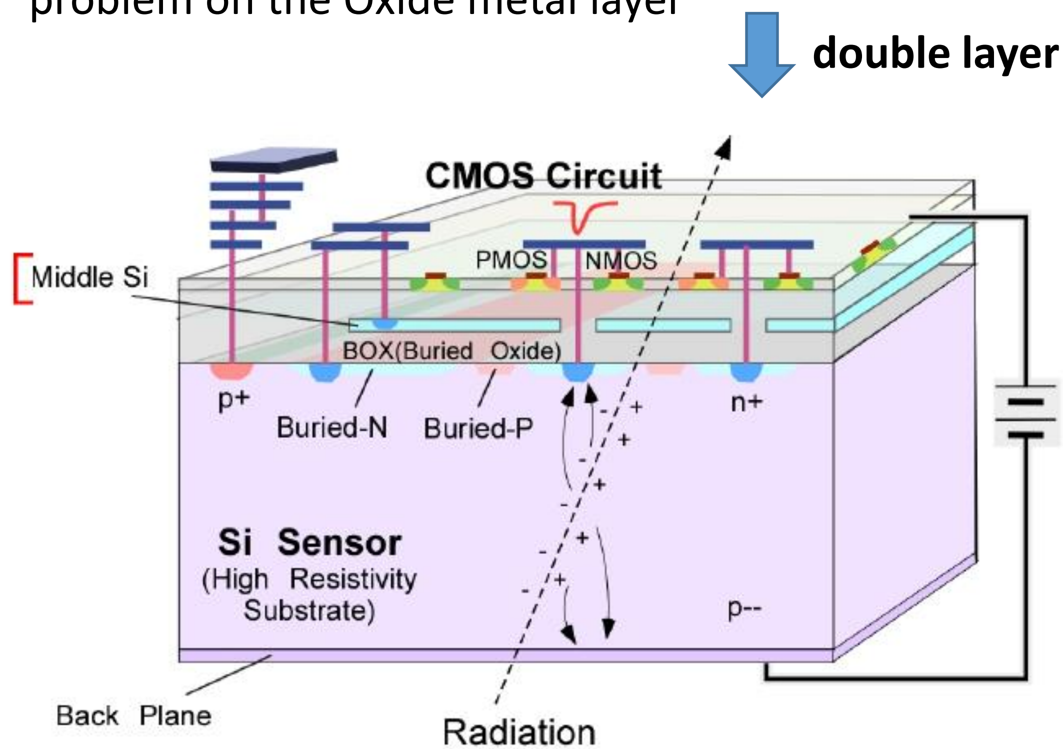
We can skip the detail or MAPS here



SOI technique

It was well known that radiation damage cause a problem on the Oxide metal layer

double layer

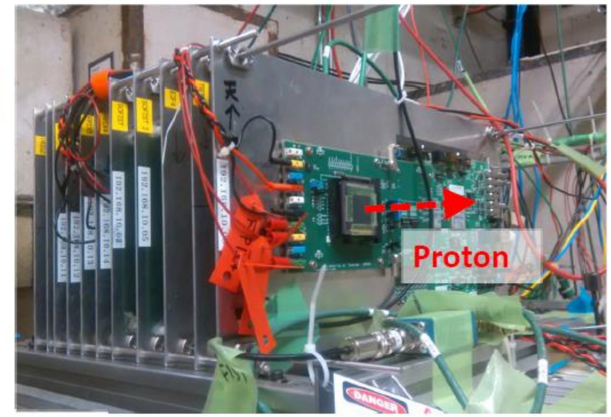


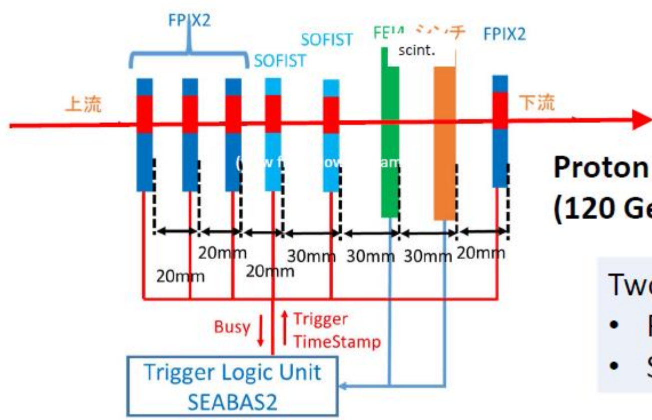
Merit of SOI is to utilize high resistivity wafer + ease of making CMOS circuit

From SOIPIX2017 @ OIST(Okinawa), presented by Arai

It seems the SOI technique is proving to work for fine pixel size !

Tracking Resolution:
High-Energy Beam test @Fermi National Accelerator Lab.





Proton Beam (120 GeV/c)

Two kinds of SOIPIX-DSOI detectors are used:

- FPIX2 x 4: 8 μm square pixel detector
- SOFIST1 x 2: 20 μm square pixel detector

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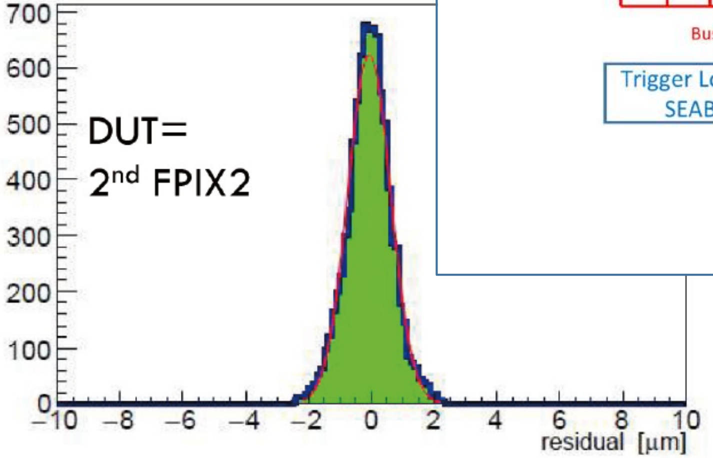
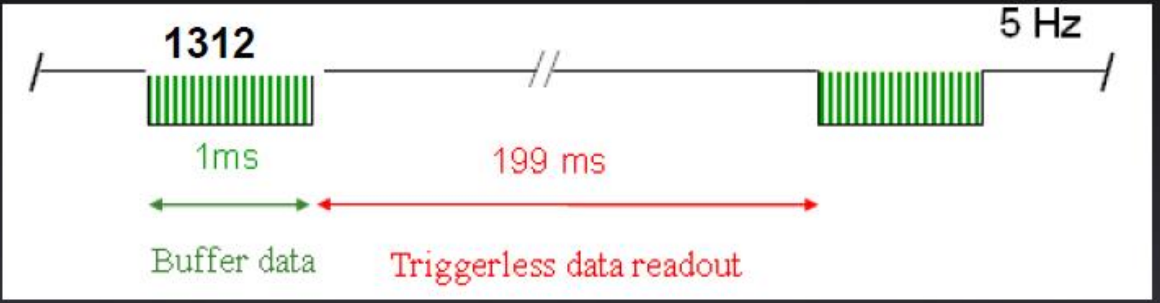


(K. Hara et al., Development of Silicon-on-Insulator Science, to be published)

Less than 1 μm Position Resolution for high-energy charged particle is achieved first in the world .

From SOIPIX2017 @ OIST(Okinawa), presented by Arai

ILC Environment



- ILC environment is very different compared to the LHC
  - Bunch spacing of ~ 554 ns (baseline)
  - 1312 bunches in 1 ms
  - 199 ms quiet time
- Occupancy dominated by beam background & noise
  - ~ 1 hadronic Z ($e^+e^- \rightarrow Z \rightarrow q\bar{q}$) per train ...
- Readout during quiet time is possible
- Big Impact on detector design