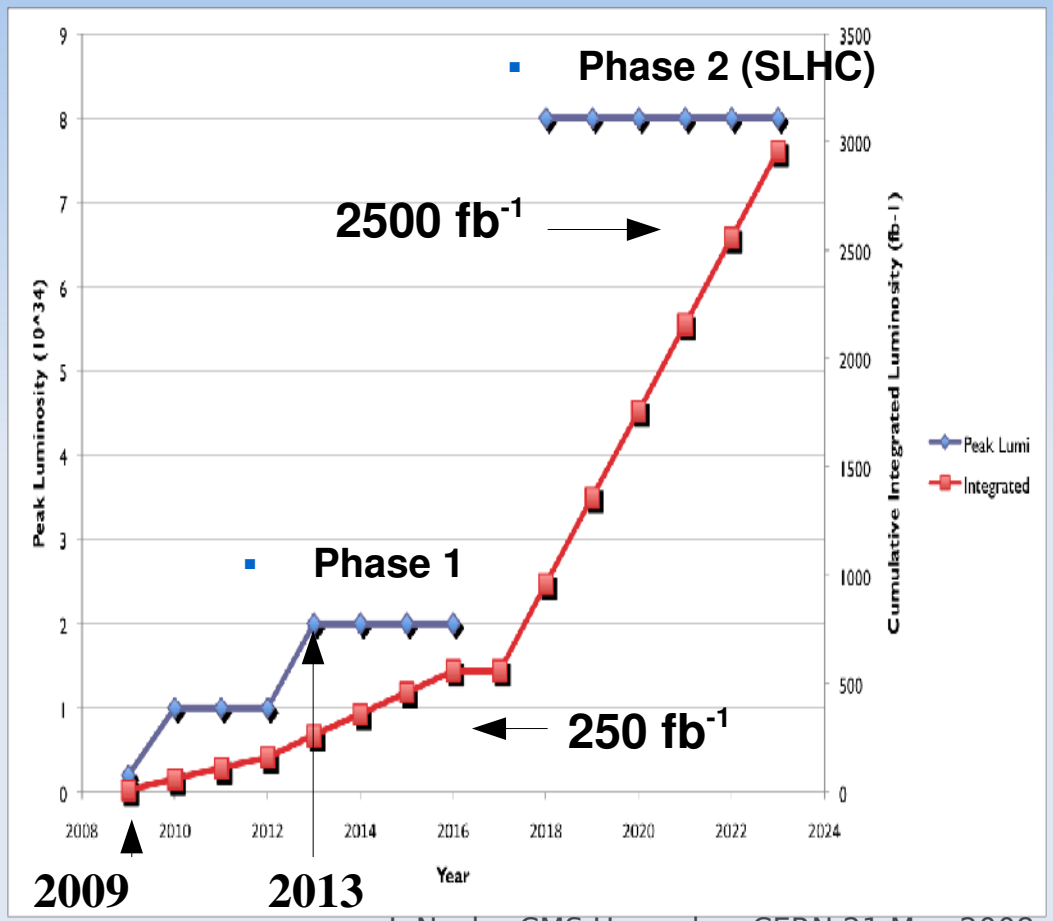
Pixel replacement/upgrade for Phase 1

- Implications of the LHC luminosity upgrade for the pixel system
- Inefficiencies of the present CMS pixel detector for LHC ugrade
- Status of the R&D activities at PSI
- Possible scenarios for the 2013 upgrade

Valeria Radicci
University of Kansas

LHC Luminosisty upgrade plan



J. Nash - CMS Upgrades CERN 21 May 2008

Nominal Peak Luminosity:

- **2009 → 2013**
  $L_{PEAK} = 1 \times 10^{34}\ cm^{-2}\ s^{-1}$
- **Phase 1 (Intermediate upgrade)**
  $L_{PEAK} = 2 \times 10^{34}\ cm^{-2}\ s^{-1}$
- **Phase 2 (SLHC)**
  $L_{PEAK} = 8 \times 10^{34}\ cm^{-2}\ s^{-1}$

Beam luminosity:

→ Radiation damage of the components
Inner pixel layer: needs replacement after 2-3 years @ full luminosity
→ Occupancy of the read out electronics
Inner pixel layer: already close to the limit (i.e. data loss ~4%)

Pixel replacement/upgrade plans for Phase 1

The intent is to mantain constant performance for the whole lifetime of CMS at LHC →

Option 0. Replace the sensors after the first years of running of LHC ~ 2013!

Option 1. (If $2x10^{34}$) upgrade the electronics to improve the inefficiencies at higher rates would be desireble (Phase 1: data loss → 10%)?

Option 2./3./4. Can we try to reduce the material budget of the pixel system?

Option 5. want to have 4 barrel pixel layers and 3 forward pixel disks but cannot provide low volage power and fibers.

Roland Horisberger, SLHC meeting at CERN 21/05/08:

0. Silicon sensor limitations

2009 → 2013 : Bpixel Radii : 4 / 7 / 11 cm layer

ϕ / year : 3 / 1.2 / 0.6 10^{14} neq/cm^2

Phase 1: Double the fluences!

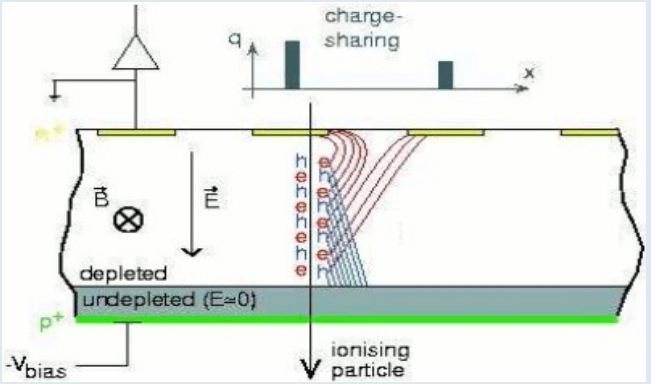
All the components of the present pixel detector remain operational up to **6 x10^{14}neq/cm^2 (TDR)**

- Radiation damage:
  - charge trapping → collect e- → **n+/n or n+/p**
  - space charge variation → benefit from **DOFZ or MCz**

BUT

- High field reduces mobility of charge carriers
- Lorentz angle is reduced
- no benefit from charge sharing (single pixel clusters)

Detector might become “useless” for impact parameter measurement although detection efficiency can be high (90%)

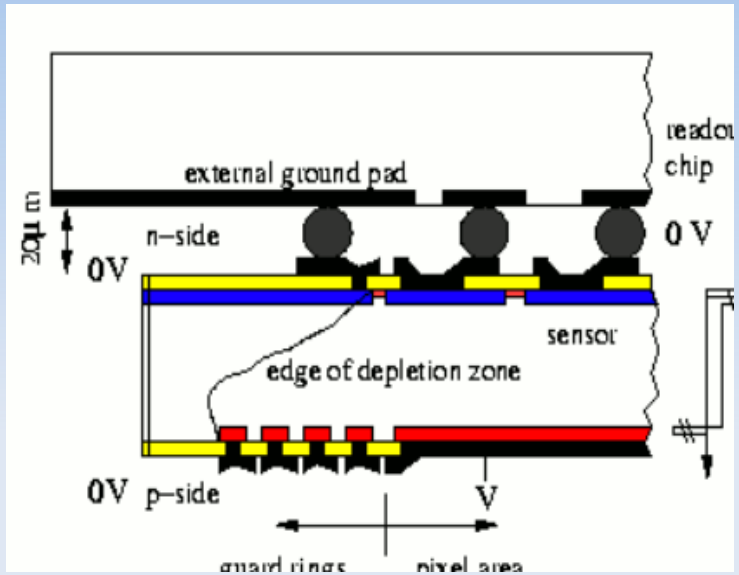


→ SENSORS & MODULES Session

Sensors for 2013 upgrade

Present CMS Barrel Pixel Sensor design:

- n+ on n substrate
- 150x100µm pixel
- distance between pixel implants 20µm (Gap)
- DOFZ (standard FZ material enriched with oxygen)
- inter-pixel isolation moderated p spray



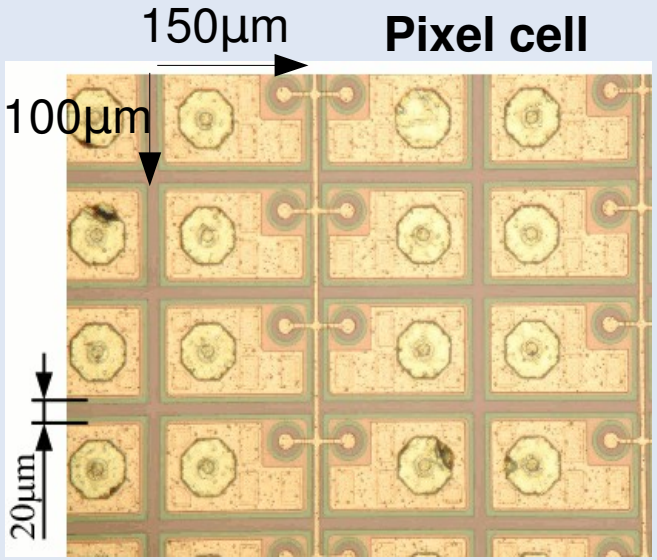
Use same design for Phase 1

R&D plan:

(I) try to determine the ultimate limit of the detection efficiency and loss of the signal charge by trapping.

(II) Investigate slightly modified sensor geometry (Gap = 30µm) and safer guard ring structures.

(III) Characterization of n+ on p, Mcz before and after irradiation. The samples are at PSI to be irradiated next year.

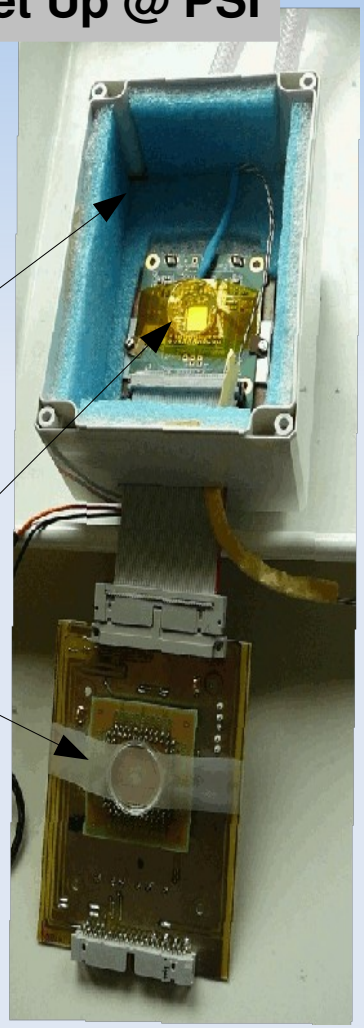


Sensors for 2013 upgrade

Last irradiation campaign of barrel pixel sensors during 2007:

- 24GeV protons at CERN
  - 4 fluences up to 5.1×10^{15} neq/cm^2
  - 33 samples (Gap20 and Gap30)
- 300MeV pions at PSI
  - 3 fluences up to 6.2×10^{14} neq/cm^2
  - 14 samples (Gap20 and Gap30)

CCE Set Up @ PSI



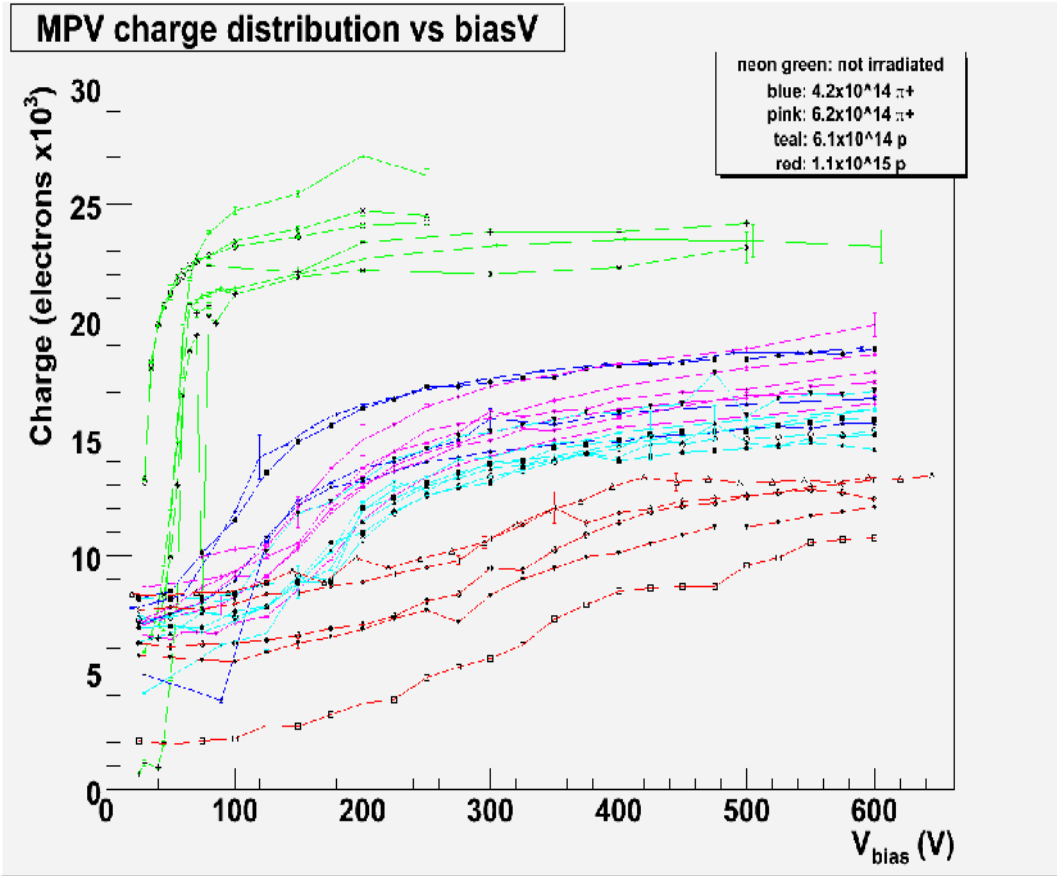
Charge Collection Efficiency Measurement:

Sr90 source
Cold box ~ -10^0C

Sensors for 2013 upgrade

Measurements performed by PIRE students: Jennifer, Jhon, Chris.

- ROC calibration and charge measurement without any problem **up to 1.1x10^{15} neq/cm^2**
- 1.1x10^{15} neq/cm^2
  - **Charge > 10000 e$^-$ (CCE~50%)**
  - **V_{dep} ~ 450V**
- @ the last two fluences the calibration of the ROC settings gave problems (standard procedure optimized for unirradiated chip): further investigation.



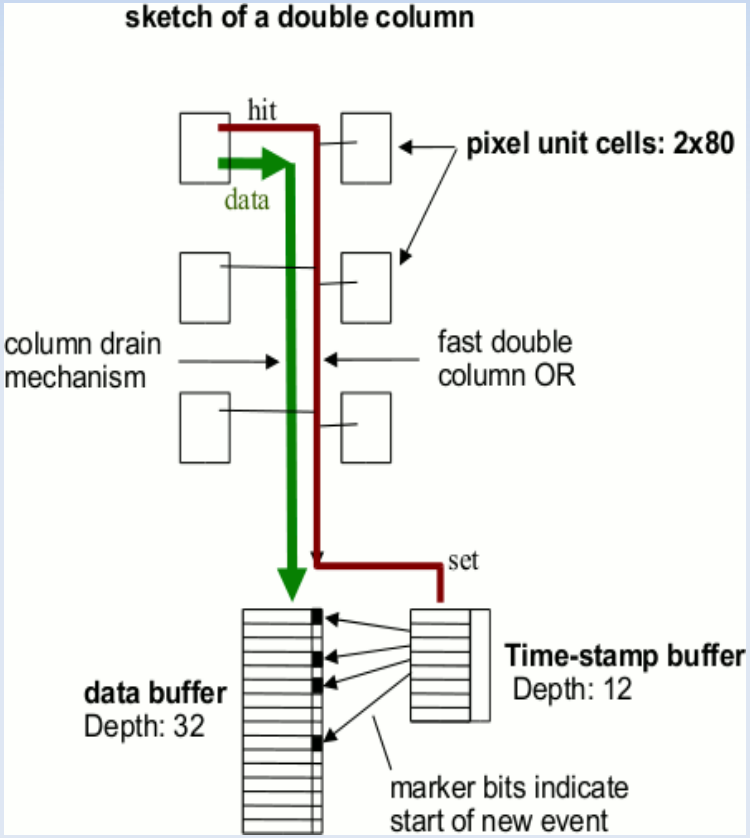
10000e- is still fine **but** operating with **V_{dep} =450V**

→ no benefit from charge sharing (single pixel clusters)

→ degradation in spatial resolution

1. Data loss mechanism

High rate tests and simulation of the Pixel ROC have shown inefficiency of the data transfer mainly due to the *buffer limitation* and the *dead time* of the ROC read out while transferring data to the TBM.



For Luminosity: 1 x 10^{34} $cm^{-2}sec^{-1}$

Radii = 11 cm / 7 cm / 4 cm layer

Total data loss @ L1A =100kHz

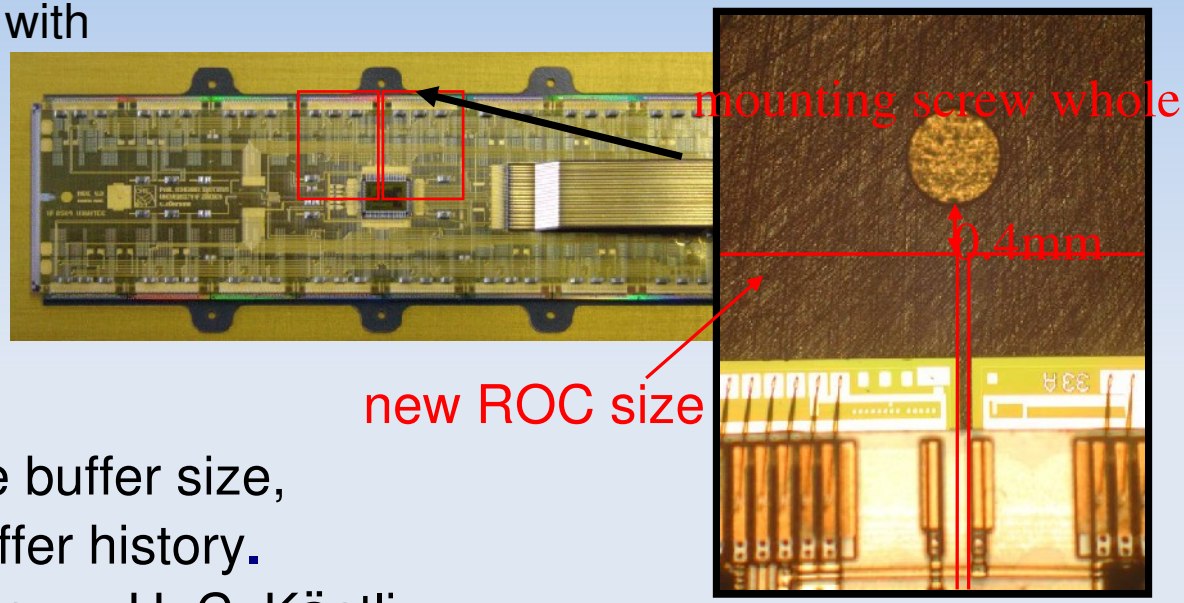
- **0.8%**
- **1.2%**
- **3.8%**

This is suitable for LHC luminosity BUT improvements are needed for inner layers for Phase 1 ---> **10%**!

→ READOUT Session

Data loss possible solutions

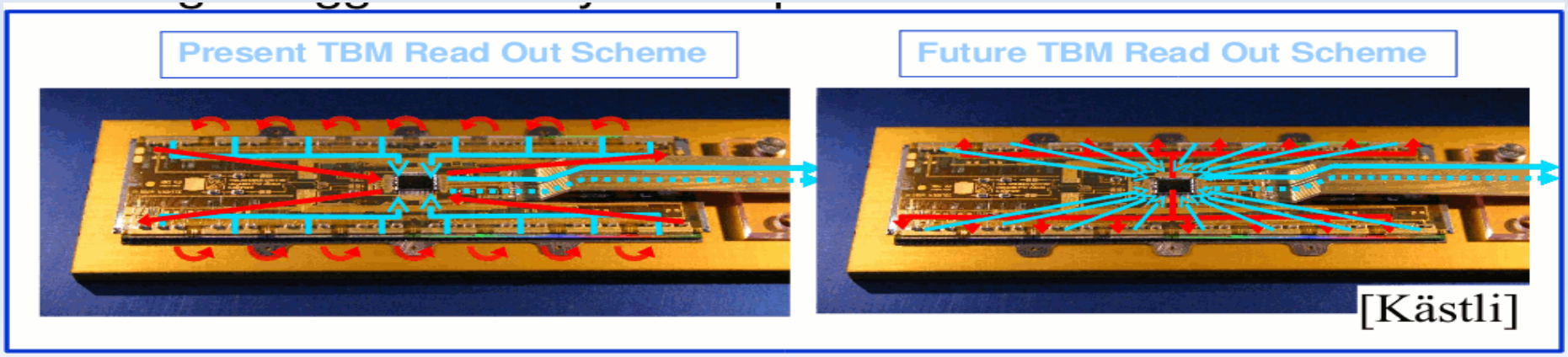
For 2013 upgrade: Improve rate capability and the module has to be fully compatible with present mechanics.



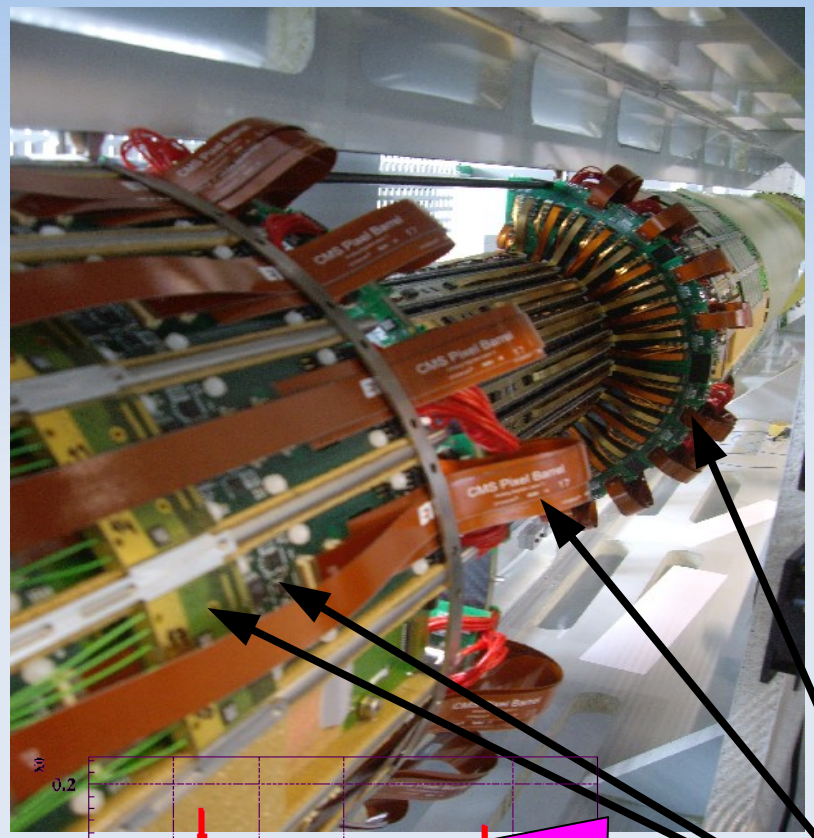
(1)**modify the ROC -->** doubling the buffer size, preserve buffer history.

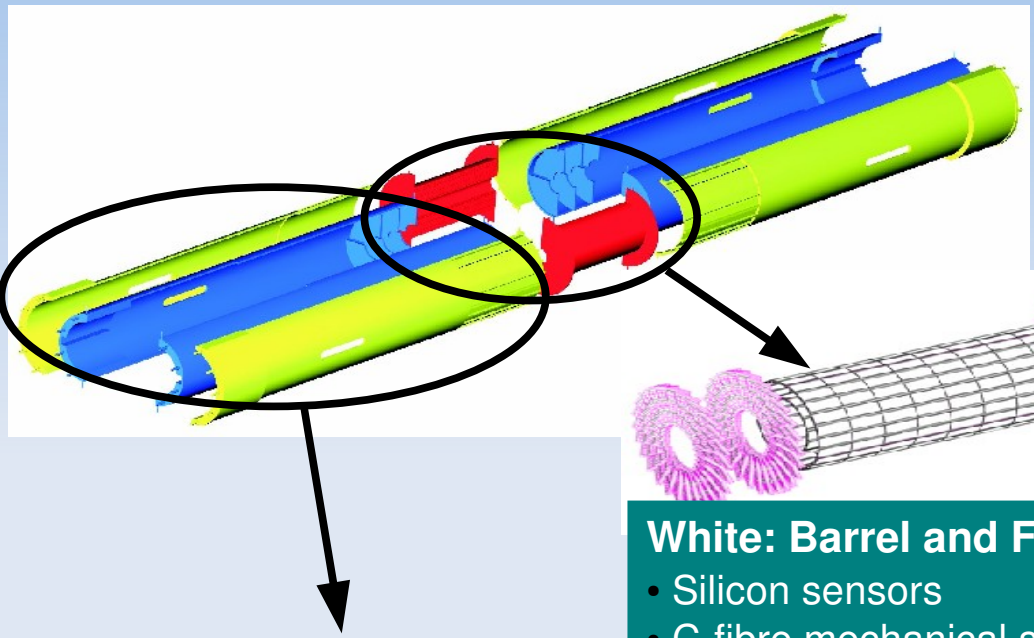
- 0.25µm technology just possible --> H. C. Kästli

(2) possibly new **TBM** with parallel ROC readout



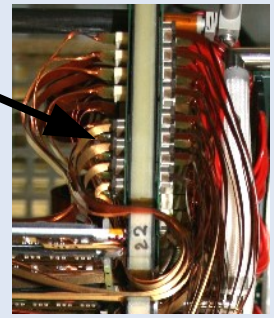
2. Material budget contributions

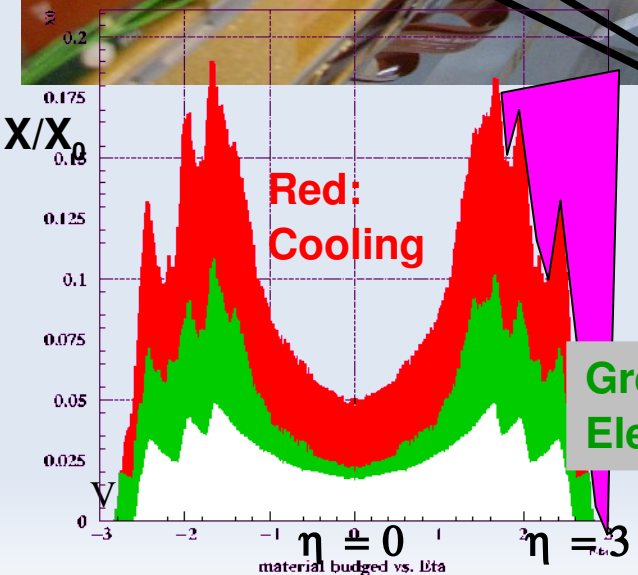




White: Barrel and Forward
- Silicon sensors
- C-fibre mechanical structure
- Cooling pipes

- **Magenta: Supply tube**
- Very complex, expensive PCB end flange prints with ~800 plugs!
- High density kapton signal cables
- DOH - AOH + PCB mother board

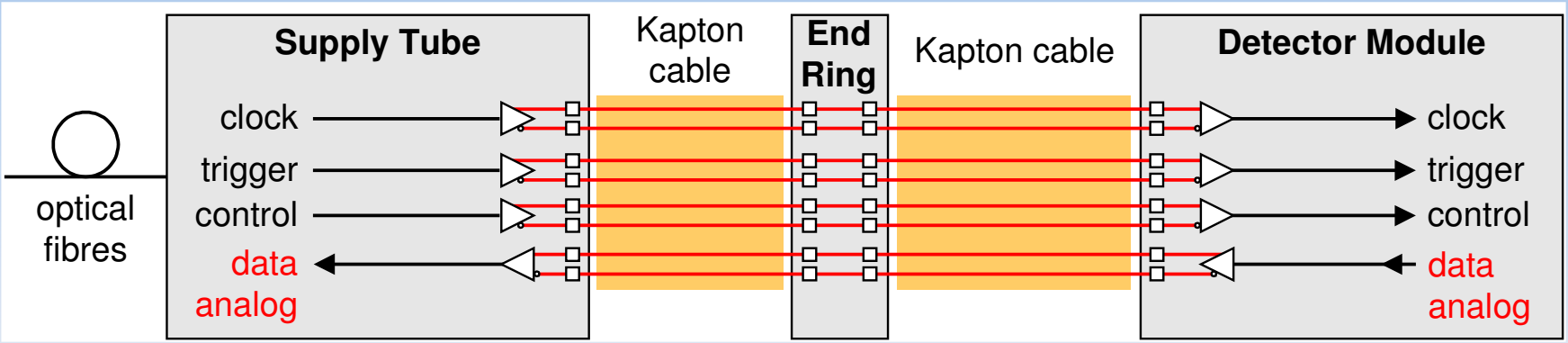




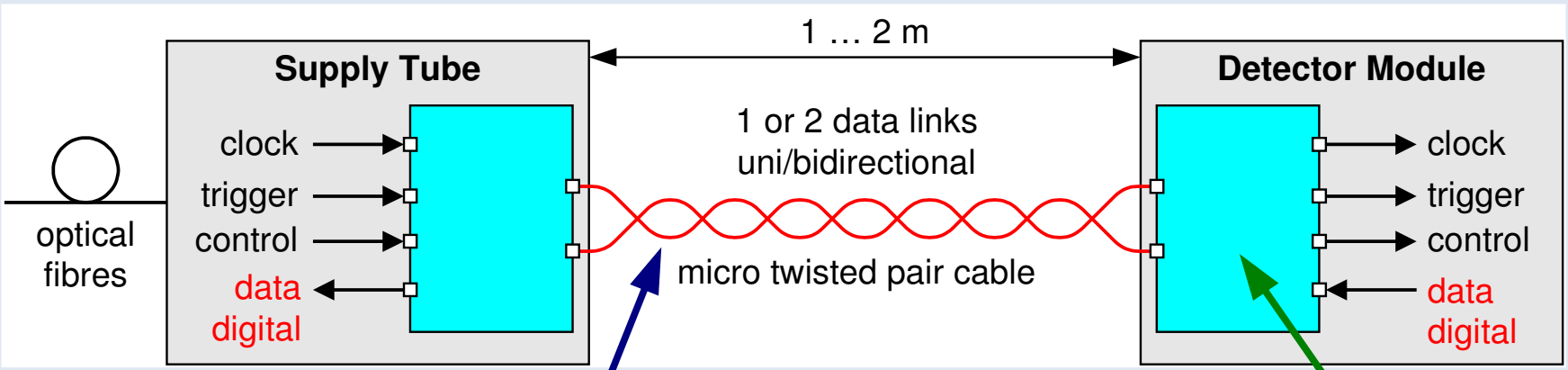
The material budget could be improved in eta region > 1.4

→ READOUT, COOLING, MECHANICS Sessions

Idea for saving the material budget at high eta: serial data link



Existing System



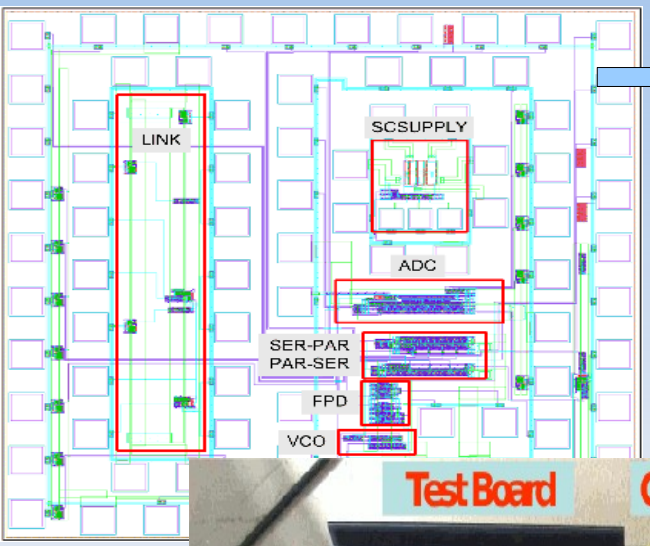
New Concept

(I) Study the electrical cable properties

(II) Expand the squared blocks

Beat Meier, PSI. TWEPP Conference September 2008

Test System

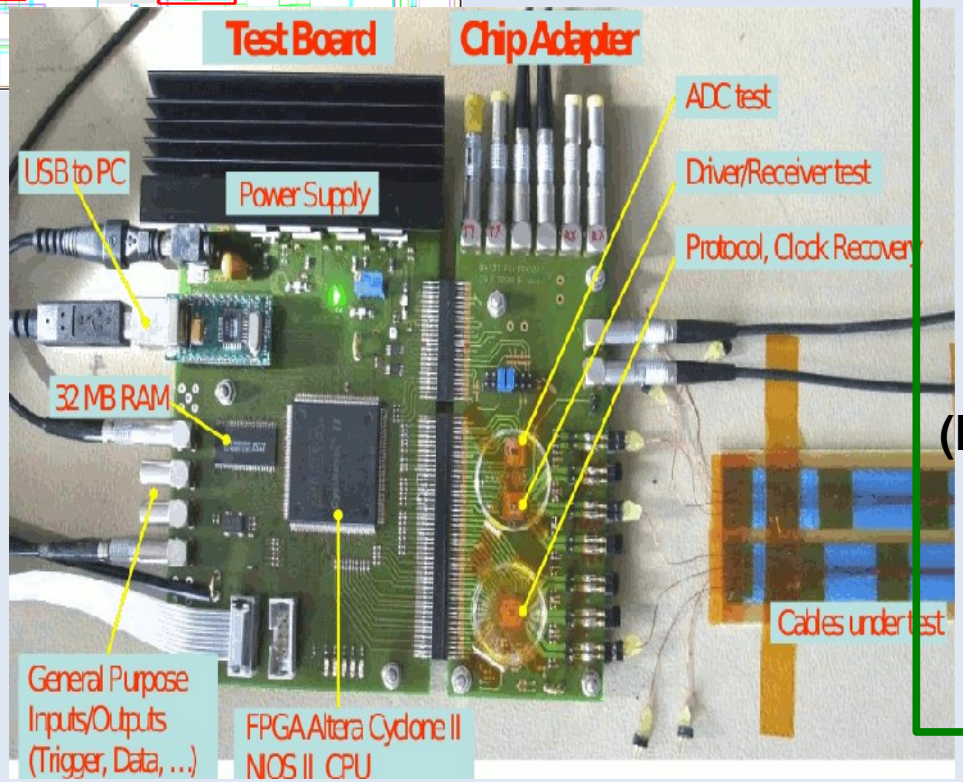


Test chip @ PSI

diff. drivers

diff. receivers

PLL, 4bit ADC...



R&D plan:

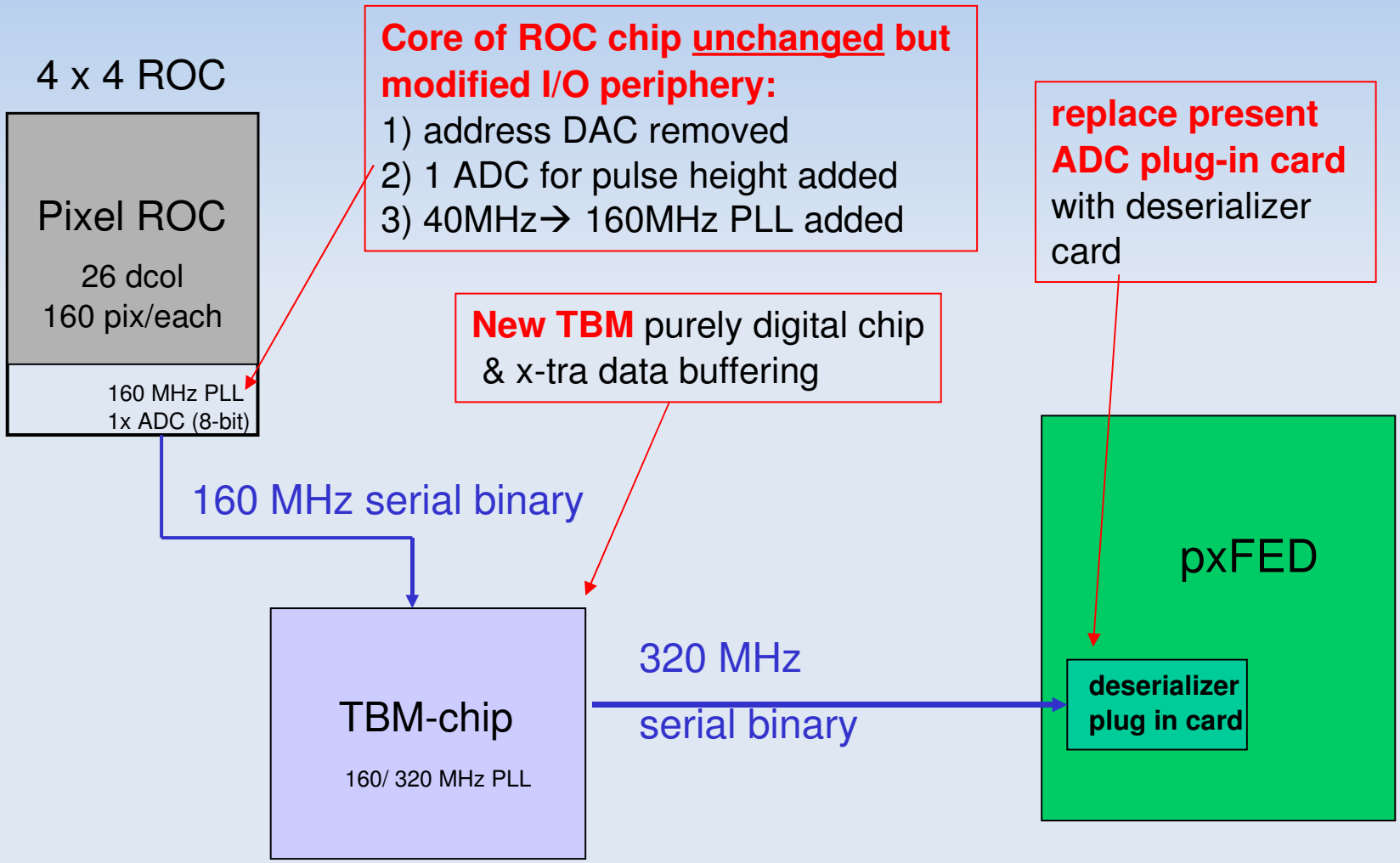
(I) Cable characterization, Beat and PIRE students: Sandra, Tony, David, Nick,

- impedance
- signal loss
- SPICE, ATLC simulations
- signal quality
- bit error rate
- cross talk
- high frequency transmission

(II) New digital protocol implementation:

- test PLL clock recovery
- test PLL clock multiplier
- test of the ADC (Irakli)
- implement the protocol (Samvel)

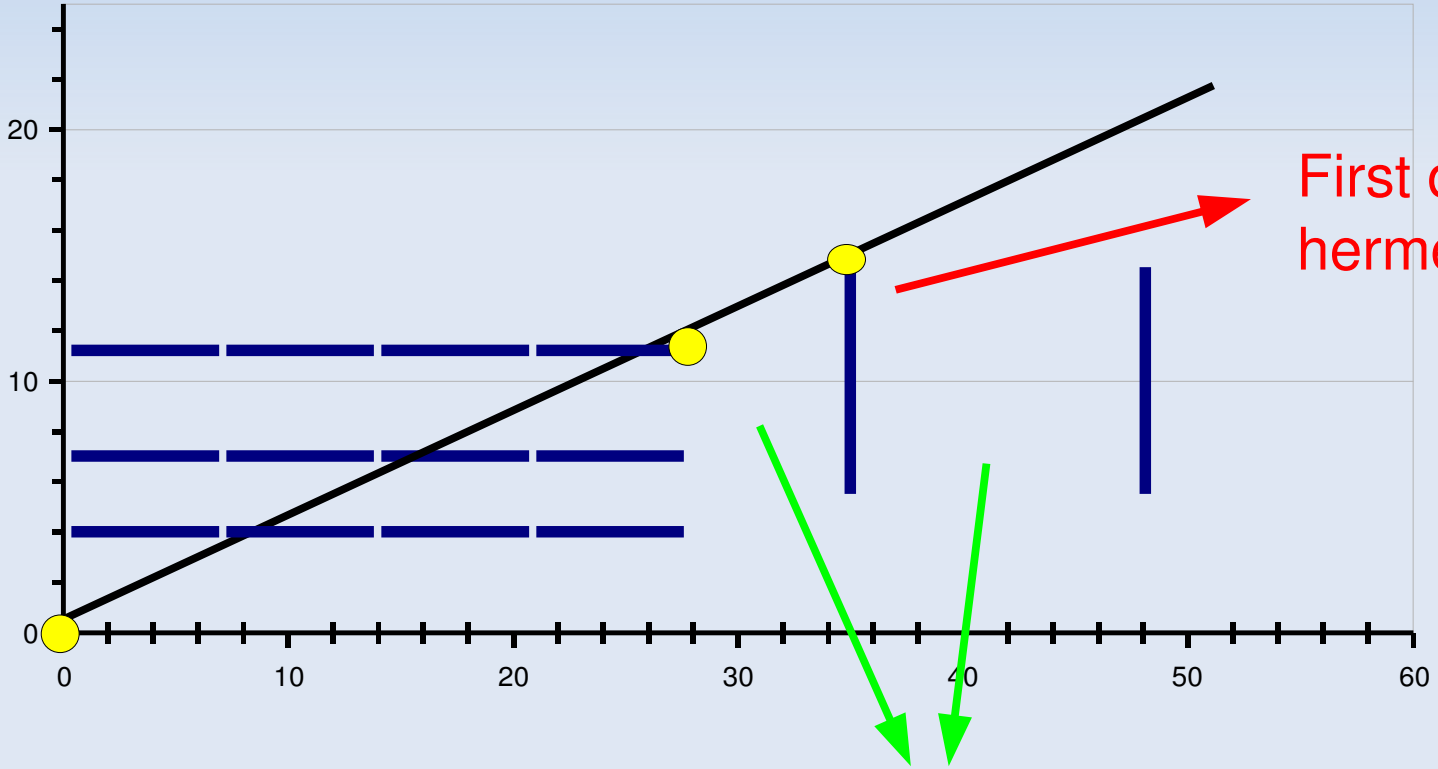
ROC and TBM changes for high speed digital read out



5. Increase the pixel Layers and/or Disks

Some geometrical considerations:

The **present** design: 3 barrel layers
2 disks



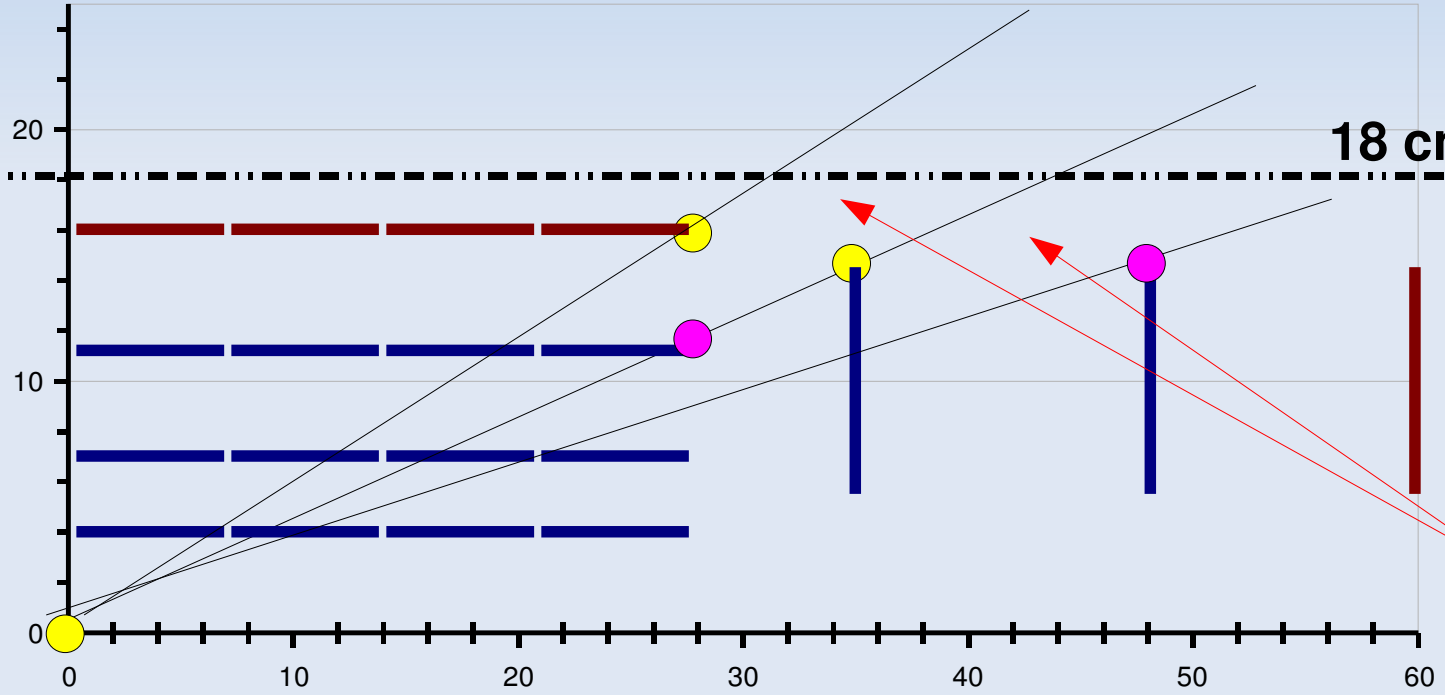
First disk position in z → hermetic 3 hit coverage

Portcards → minimum possible distance between barrel and first disk and between the disks

5. Increase the pixel Layers and/or Disks

Some geometrical considerations:

The **new** design: 4 barrel layers
3 disks



18 cm maximum distance

4^{th} layer @ 16 cm
3^{rd} disk @ z=59 cm

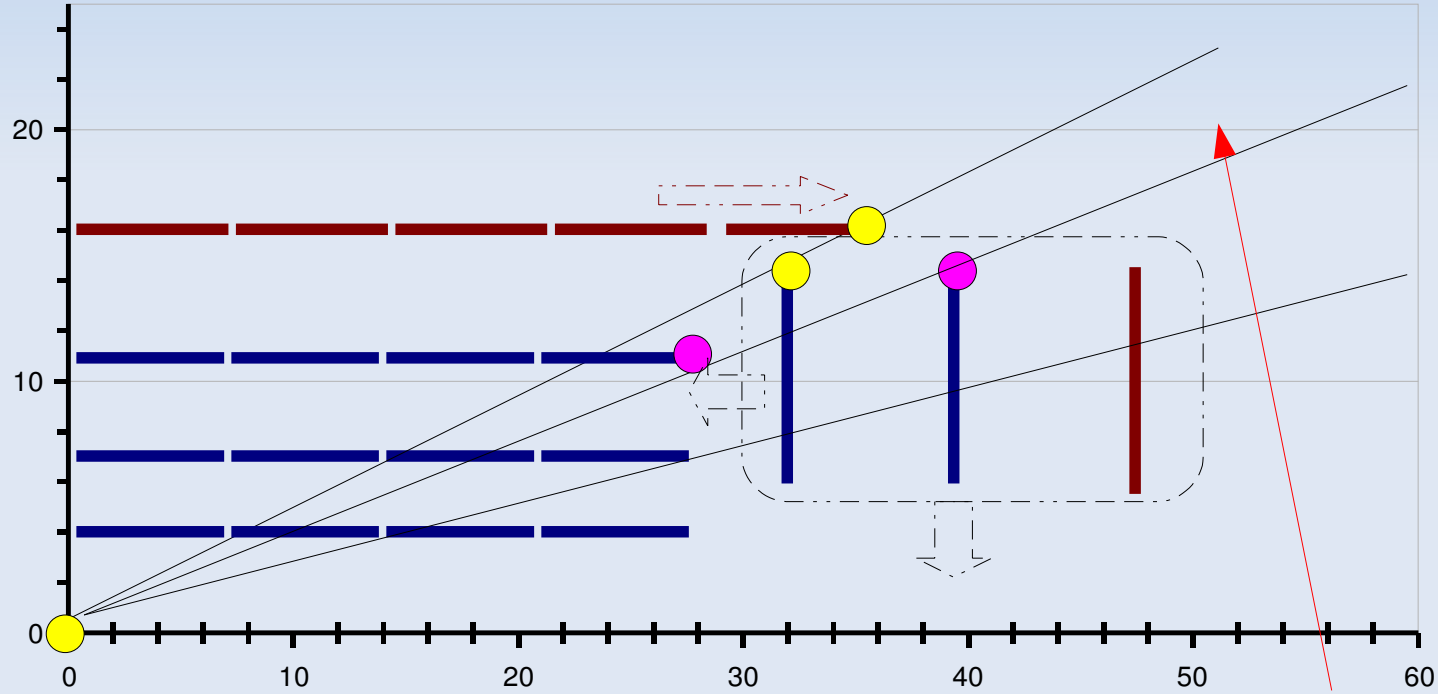
no hermetic 4 hit coverage!!!

How can we acheive hermetic 4 hit coverage?

5. Increase the pixel Layers and/or Disks

Some geometrical considerations:

The **new** design: 4 barrel layers
3 disks

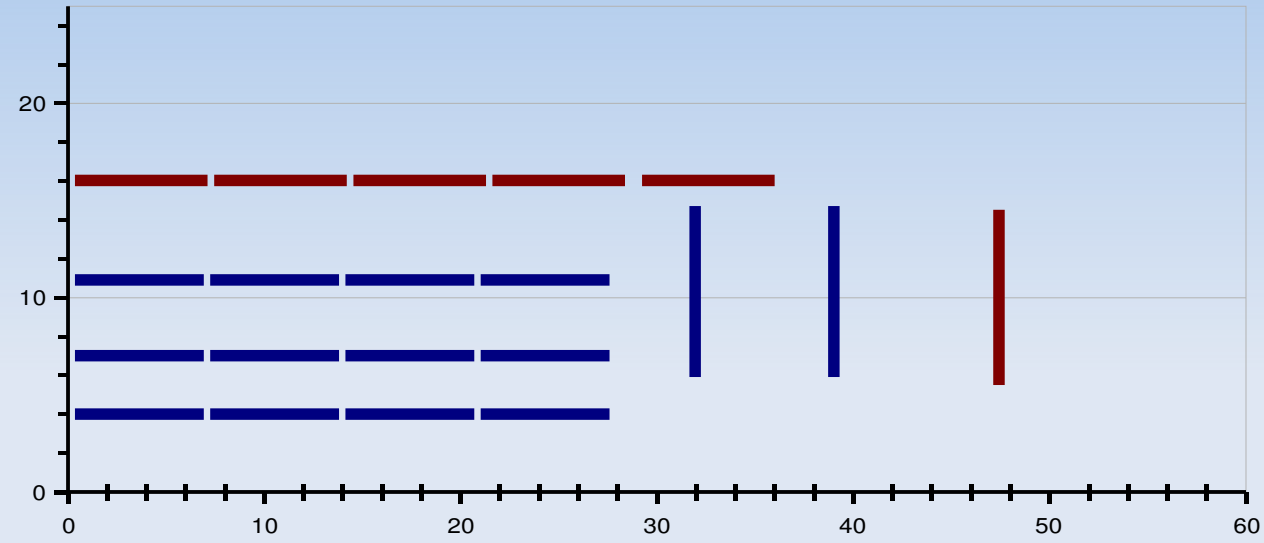


ALIGN the ●
1. Increase the 4th layer length by ~5cm
2. move the disks closer to beampipe
3. move the disks closer to barrel

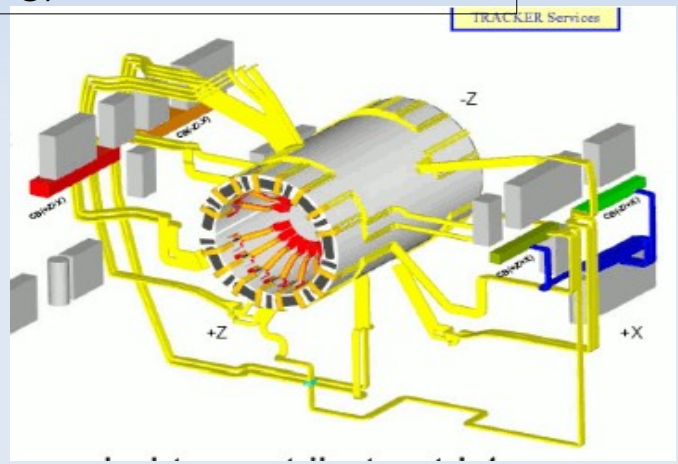
ALIGN the ●
1. move the 2nd disk closer to first

hermetic 4 hit coverage acheived!!!

5. Increase the pixel Layers and/or Disks



VERY IMPORTANT:
all existing services must be reused (cables, fibers, cooling)



- New 4 layer geometry & mechanical design!
- All the services for a 3rd disk are in place.
- To populate the 4th barrel layer only possible if:
  (1) have DC-DC step down converters to bring more power through cables
  (2) high speed links
  (3) have CO_2 cooling

→ MECHANICS & GEOMETRY,
→ POWER & CABLE
→ COOLING Sessions

Scenarios for 2013 replacement/upgrade

	Option	Layer/Radii	Modules	Cooling	Pixel ROC	Readout	Power
as 2008	0	4, 7, 11cm	768	C_6F_{14}	PS46 as now	analog 40MHz	as now
	1	4, 7, 11cm	768	C_6F_{14}	2x buffers	analog 40MHz	as now
	2	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz	as now
	3	4, 7, 11cm	768	CO_2	2x buffers	analog 40MHz μ -tw-pairs	as now
	4	4, 7, 11cm	768	CO_2	2xbuffer, ADC 160MHz serial	digital 320MHz μ -tw-pairs	as now
	5	4, 7, 11, 16cm	1428	CO_2	2xbuffer, ADC 160MHz serial	digital 640 MHz μ -tw-pairs	DC-DC new PS

R. Horisberger, SLHC meeting at CERN 21/05/08

Scenarios for 2013 replacement/upgrade

	Option	Weight	<X_0 gain>	Start Date	Costs	Comments
as 2008	0	3921 g	1	Aug 10	4.5 MCHF	ROC wafers exist
	1	3921 g	1	Nov 09	5.0 MCHF	new ROC wafers
	2	2274 g	1.7	Nov 09	5.4 MCHF	0.4 MCHF for CO_2 plant
	3	1624 g	2.4	Nov 09	5.4 MCHF	- - -
	4	1267 g	3.1	Dec 08	5.9 MCHF	new ROC & TBM & HDI mod. pxFED & pxFEC
	5	~ 2400 g estimate	~1.6	not possible for 2013	~9.8 MCHF +0.4 MCHF	DC-DC converters new LV Power Supplies

(R. Horisberger, SLHC meeting at CERN 21/05/08)

Questions:

- CABLES / MECHANICS / COOLING / MODULES:
  - CO_2 cooling possible with CMS piping ?
  - Can we define a long term 4 layer geometry for 2018?
  - Ultralight mechanics for 2013 already?
  - Are we able to rebuild first 3 layers of new mechanics and geometry for 2013?
- SENSOR:
  - n+/n or n+/p technology?
  - DOFZ or Mcz substrates?
  - different gaps for reducing the interpixel capacitance ?
  - safer guard ring structures?
- sensor order needs to be placed by August 2010

Questions

- READOUT_PART1:
  - When do we know how the machine develops?
  - Do we have time and manpower to upgrade the electronics to improve the inefficiencies at higher rates in case of $2x10^{34}$ luminosity?
  - Do we need to modify the ROC (buffer size, rebuffer)?
  - Ready with design for new ROC by Oct. 2009?
- READOUT_PART2:
  - Fabricate and connectorize 16 micro twisted pair, how is the crosstalk?
  - Can we use as a backup solution for an analog readout?
  - How can increase readout speed for 4 layer system?

    → 80MHz analog readout?

    → 160MHz/320MHz digital readout? Decision when?
  - AOH performance in digital transmission? Results when?
  - AOHs rebuilt for 2013 who? (No spares & I_{bias} increases with rad. damage)