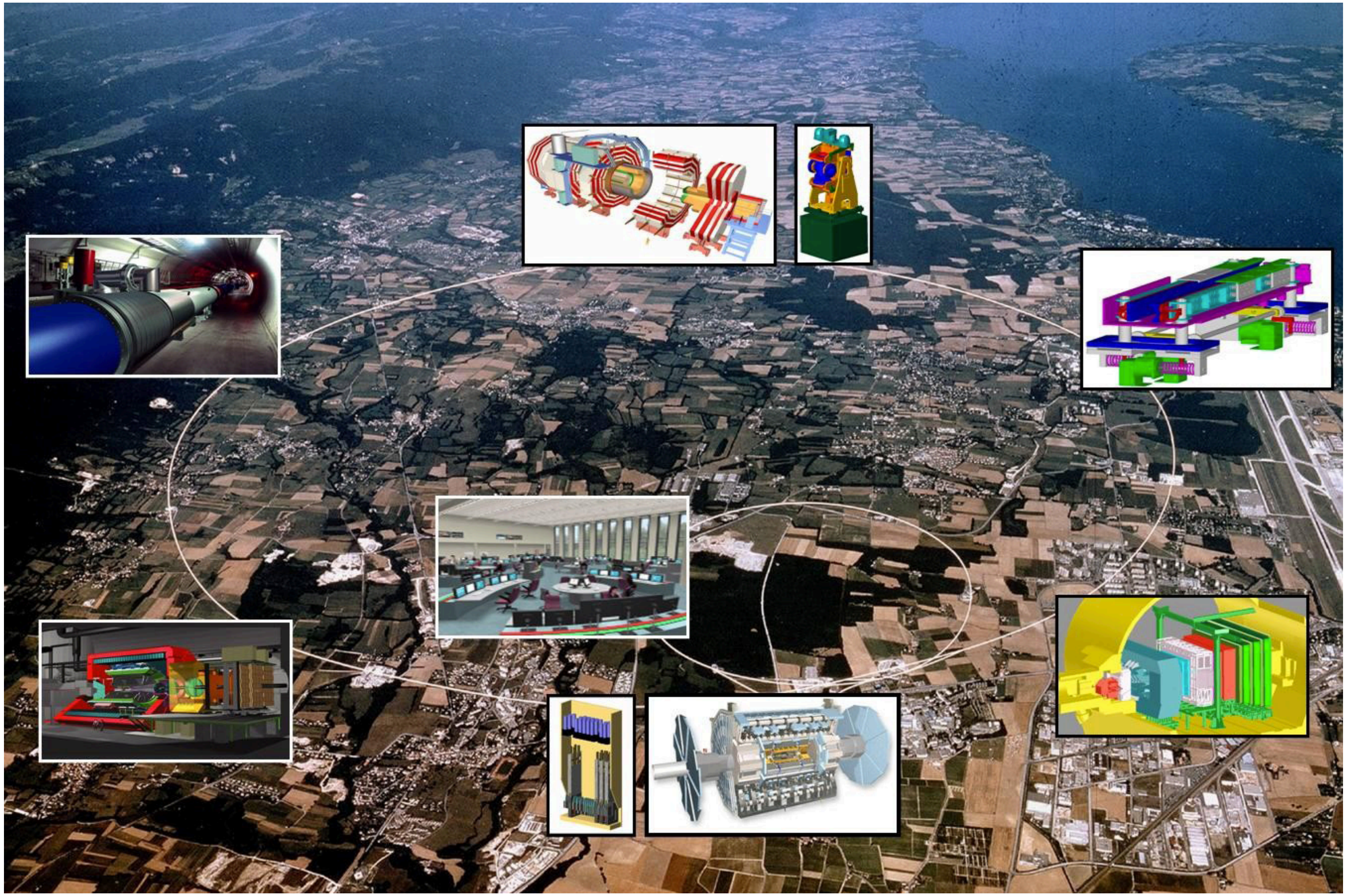
VELOPix and the LHCb Upgrade

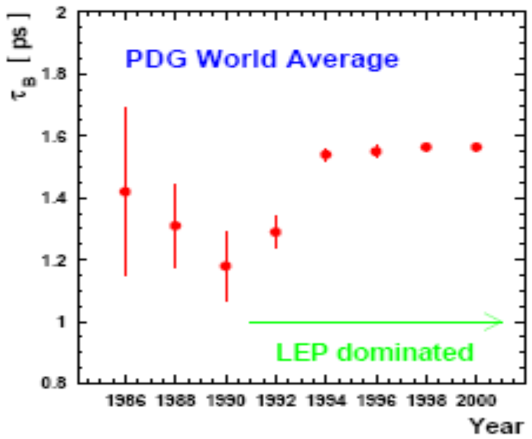
- Vertex Detectors at the LHC and LHC Upgrade
- The LHCb Upgrade and the VELO
- From Timepix to VELOpix
- VELO Upgrade outline
- The Timepix particle tracking telescope
- First results and future plans

Paula Collins
On behalf of the LHCb VELO Upgrade group

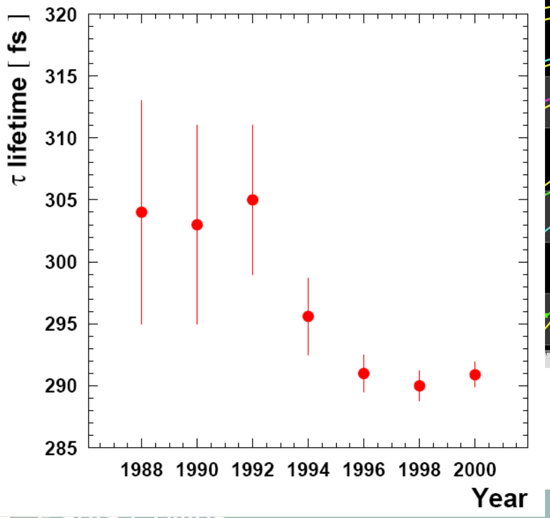
The LHC

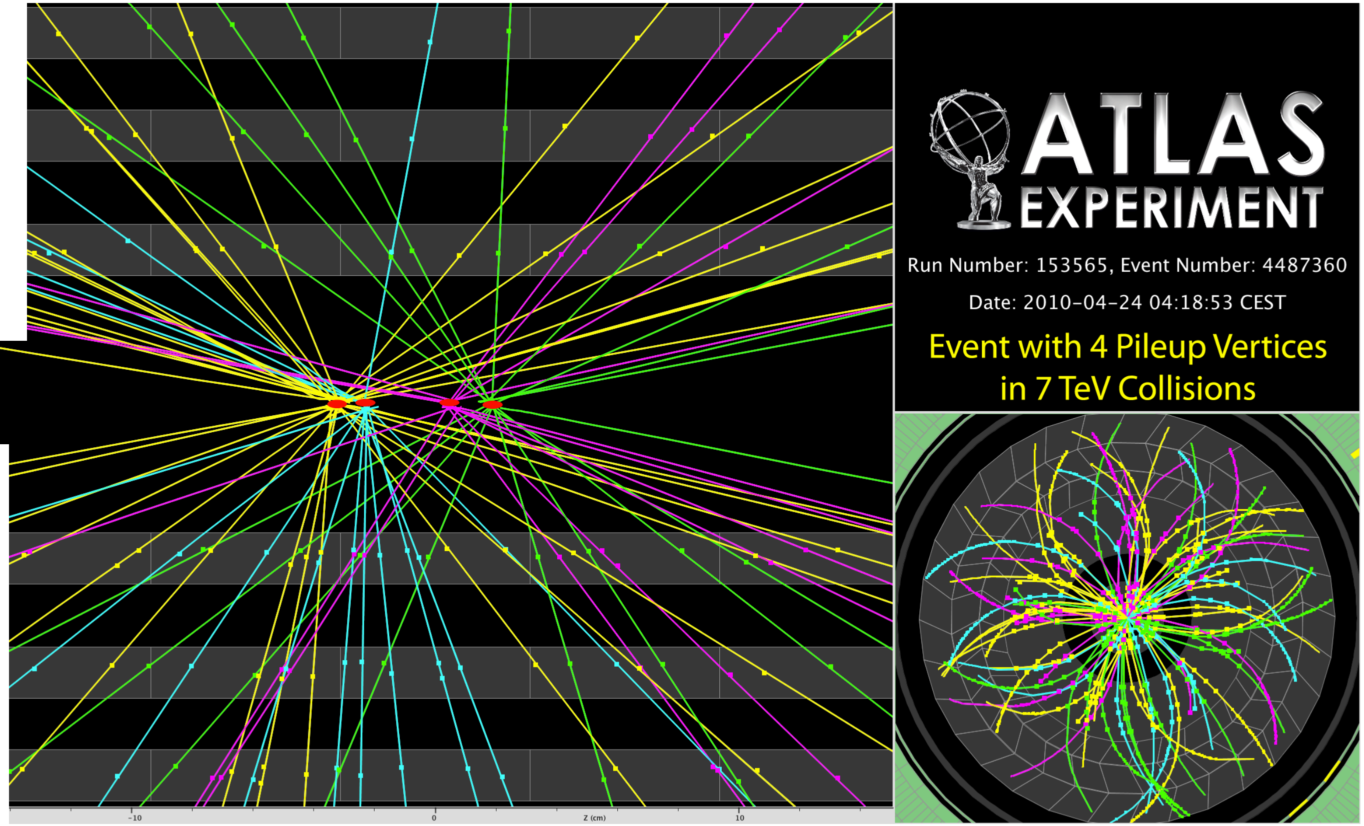


All 4 large experiments rely on silicon vertex detectors and silicon trackers



Historically….

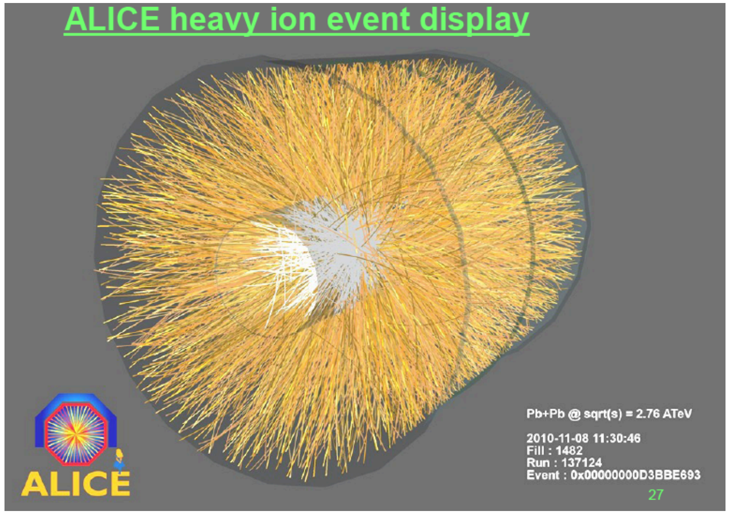


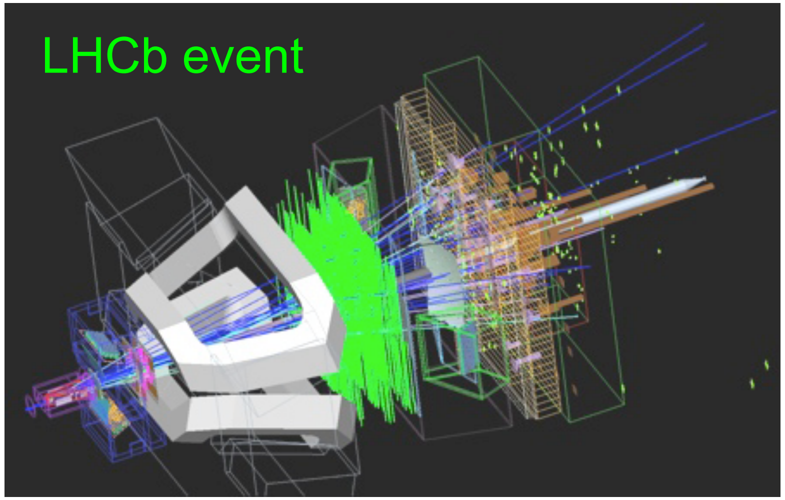


And now

Pixels and strips

- For the central detectors pixels are mandatory for the inner layers to keep the occupancy numbers reasonable
- ALICE pixel inner layer: max. occupancy for central
- Pb-Pb 2.1% (max. 8000 tracks/|η| at mid-rapidity)
- Silicon strips can be used at larger radii or (in the case of LHCb) to minimise material



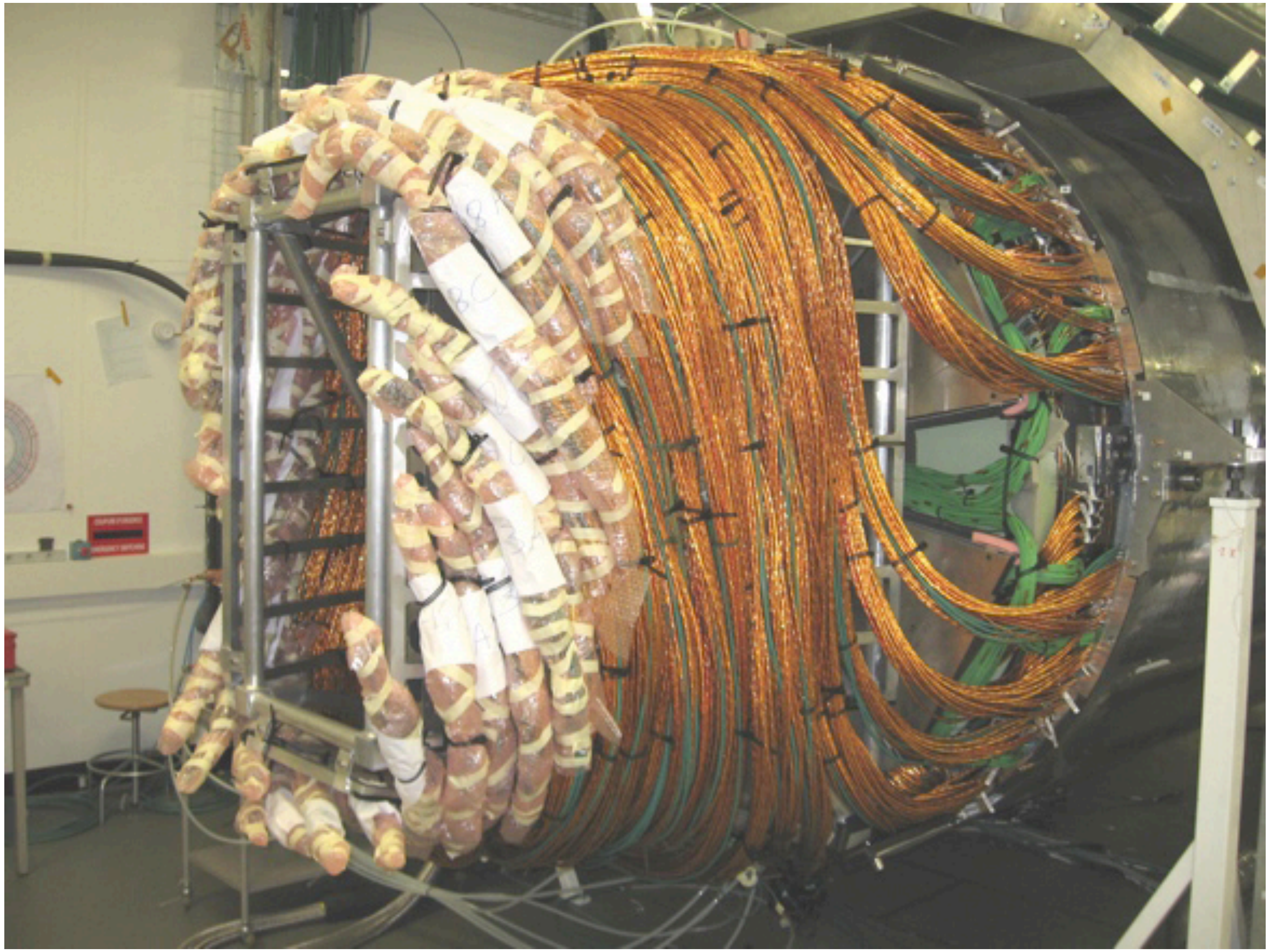


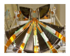
Huge variation in silicon parameters;

From the tiny

To the huge "industrial level"

CMS tracker

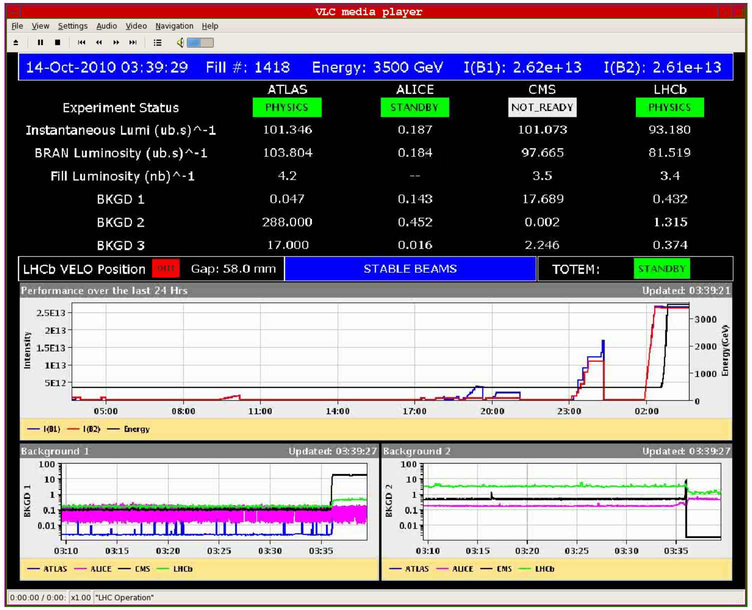




ALICE pixel

LHC had a bright startup in 2010

250 bunches with ca. 2.6 10^{13} ppb
Luminosity > 10^{32} cm^{-2} s^{-1}
➔ Emittance in collision < 3 μm

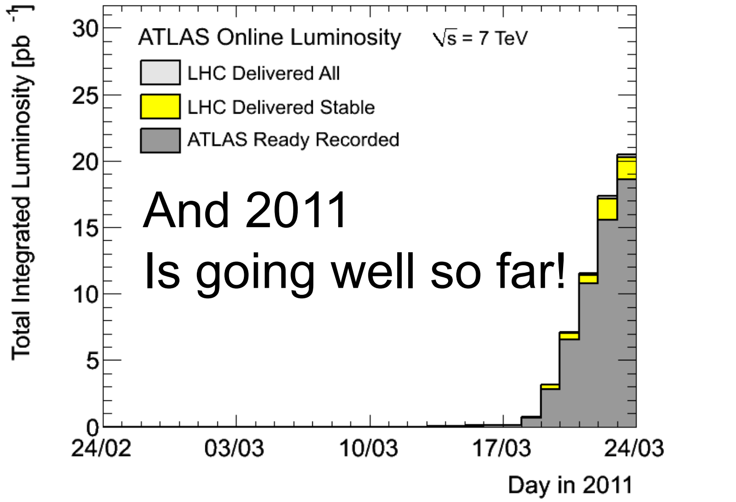


Potential to achieve > 5 fb-1 in 2 years

Plan to run at 7 TeV for 2011 and 2012

18 month shutdown in 2013-2014 to repair splices

Decision also driven by equally bright start for experiments – many channels and searches overtaking Tevatron after just 36 pb^{-1} of data



First phase of upgrades: 2010-2020

- This decade will see the initial operation of the LHC and the increase of energy and luminosity towards the design luminosities.
- Goal of extended running in the second half of the decade to collect ~100s/fb
  - 80% of this luminosity in the last three years of this decade
  - About half the luminosity would be delivered at luminosities above the original LHC design luminosity
- Motivation for upgrades during this phase
  - may be based on required performance for higher luminosity, better physics performance, better reliability of operation

2010-2012
Ramping up to fewx10^{33} @ 7TeV
Up to 5 fb-1 delievered

↓ Long shutdown
Splice repairs

2015-2016/7
Ramping up to 10^{34}
Up to 100 fb-1 delievered

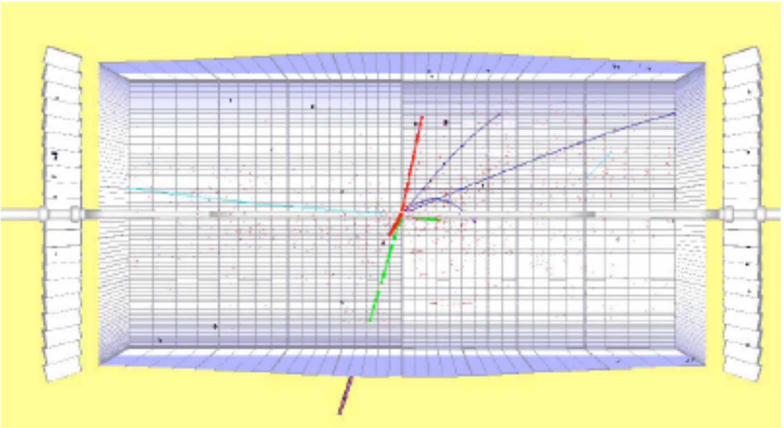
↓ Injector and LHC
Phase I upgrades

2018-2020/1
Ramping up to 10^{34}
Up to 100 fb-1 delievered per year

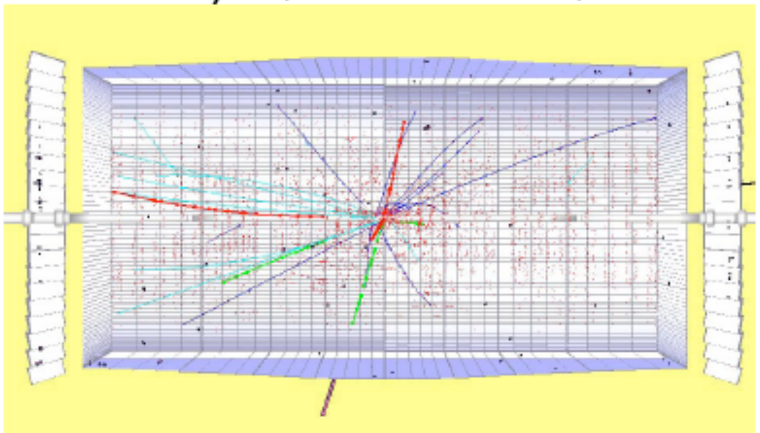
↓ Towards High
Luminosity LHC

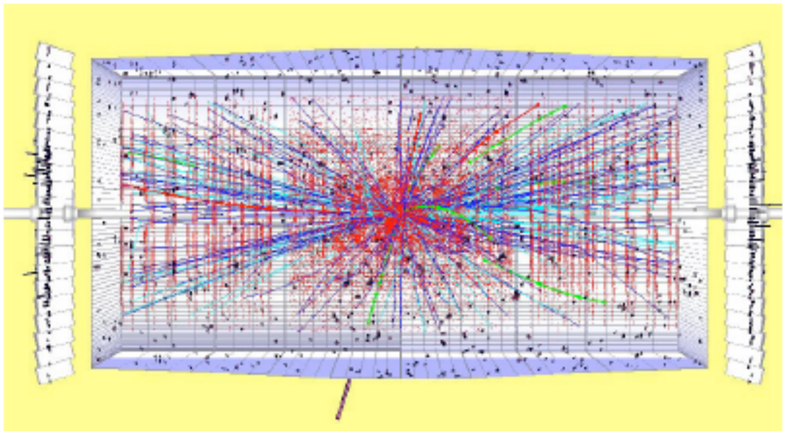
Detector Challenges – the problems pile up!
(This is a very old slide!)

LHC first month, $L = 10^{32}\ cm^{-2}s^{-1}$, 0 MBE

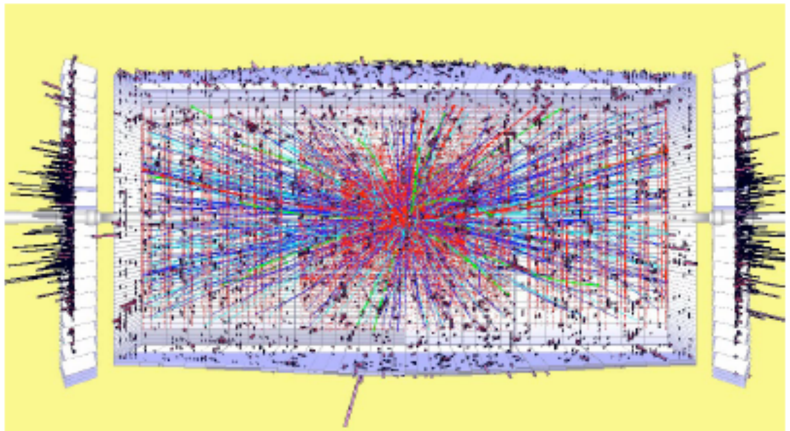


LHC first year, $L = 10^{33}\ cm^{-2}s^{-1}$, ~2 MBE



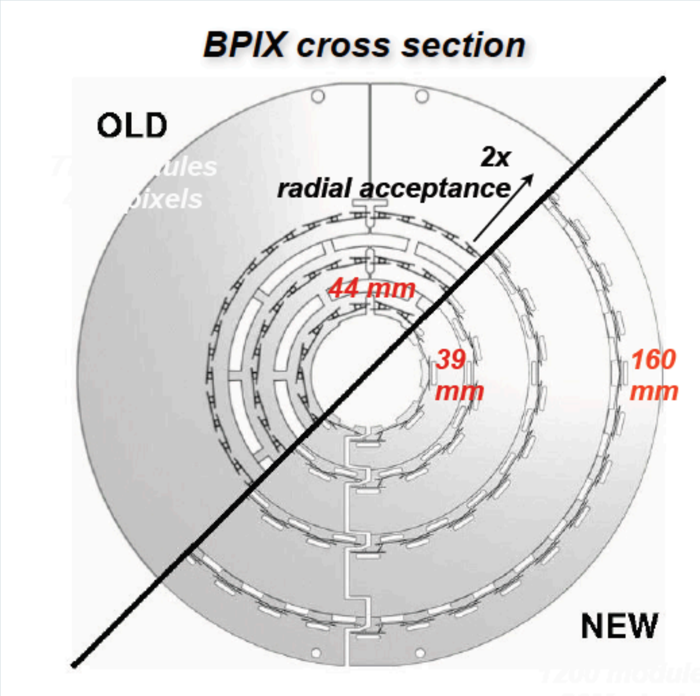


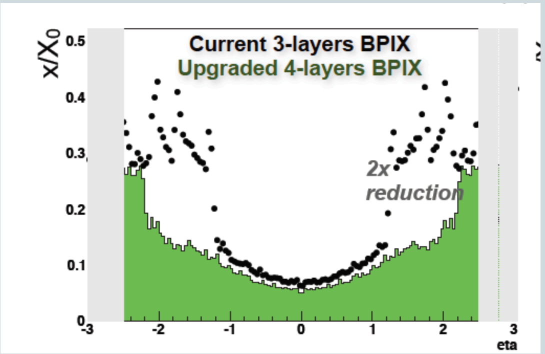
LHC, $L = 10^{34}\ cm^{-2}s^{-1}$, ~20 MBE



SLHC, $L = 10^{35}\ cm^{-2}s^{-1}$, ~200 MBE

CMS Snapshot

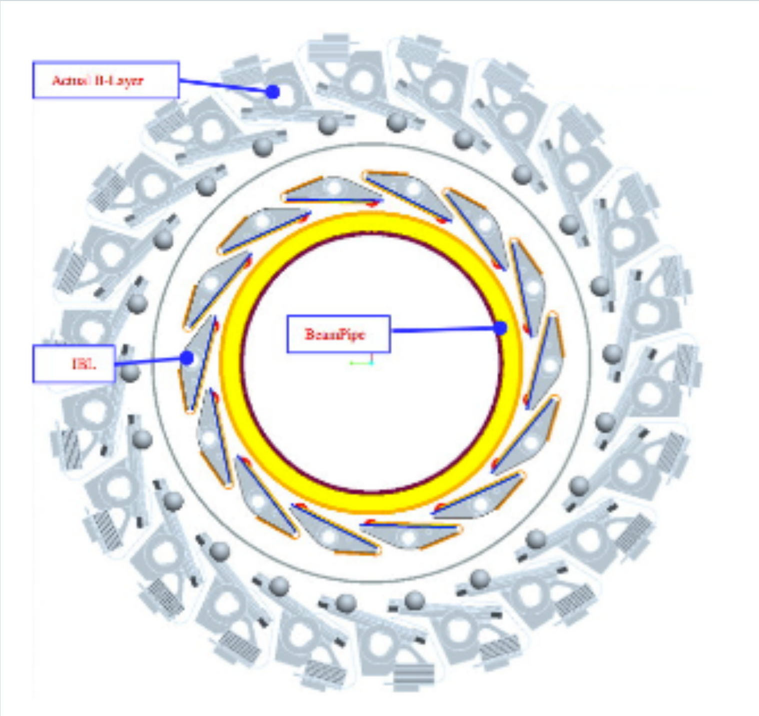


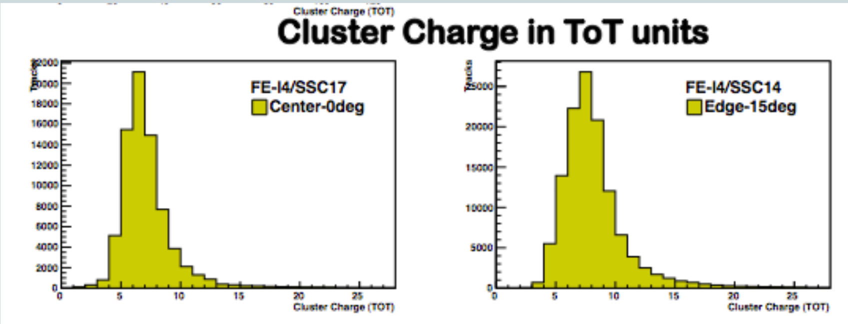


- Innermost layer with reduced radius
- Additional outermost layer at 160 mm
- ~2x radial acceptance
- ~65% more pixels
- CO2 cooling
- Reduced material for more layers!

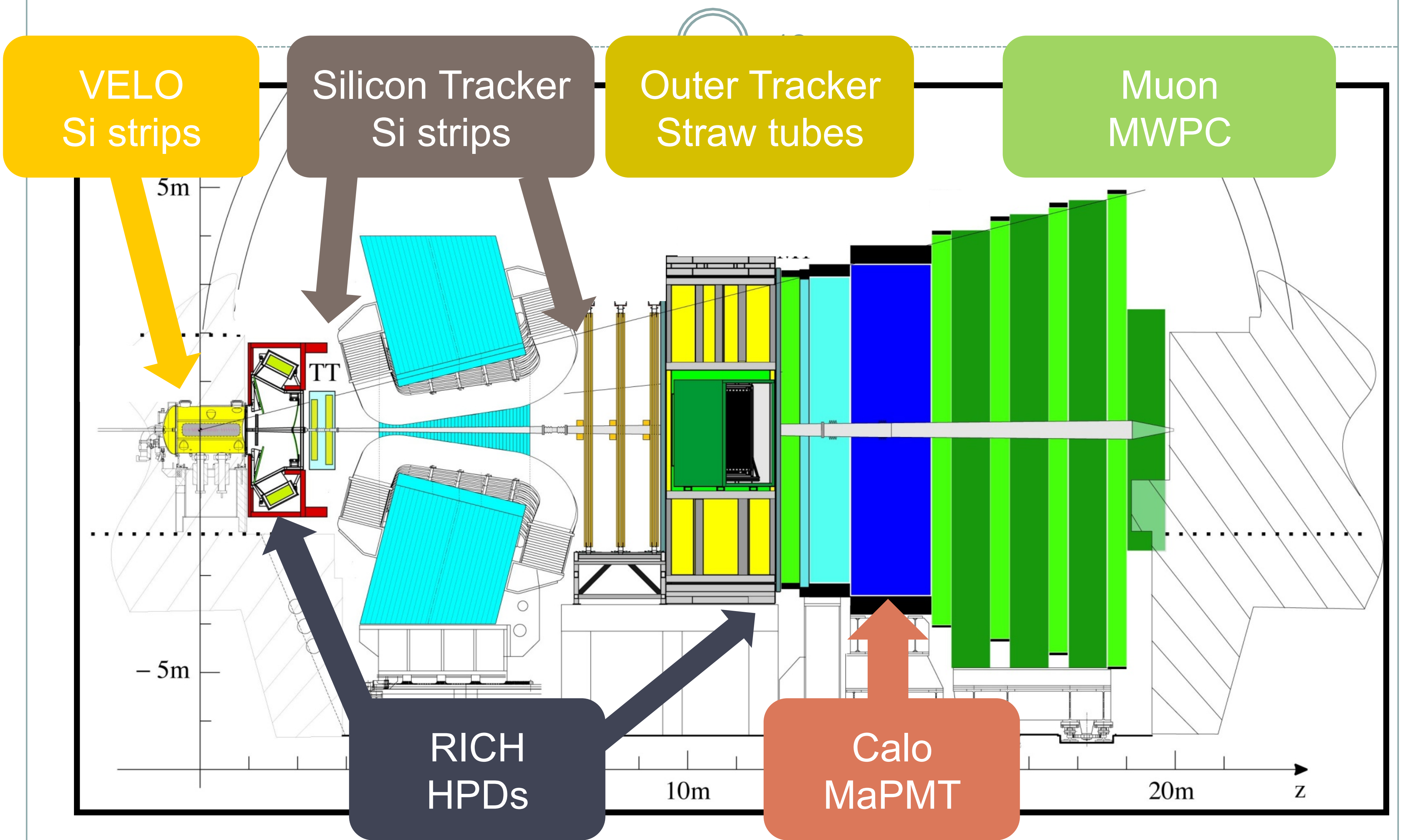
ATLAS Snapshot

- Insertable B-layer (IBL)
  - Addition to current B-layer inside the current ones
  - New FE-I4 ASIC in 130nm
    - 4 * area of FE-I3
    - 27k 50x250um pixels
    - 8b/10b on chip
  - Prototype successful – promising testbeam and irradiation results, irradiation of hybrid packages underway
  - Install in Phase 0 (Success driven)
  - Schedule recently accelerated by LHC timetable
- Move services to area with lower radiation
- Flat staves, and active/slim edges
- Replace entire inner detector in Phase II (1-2 10^{16} regime for innermost layer)





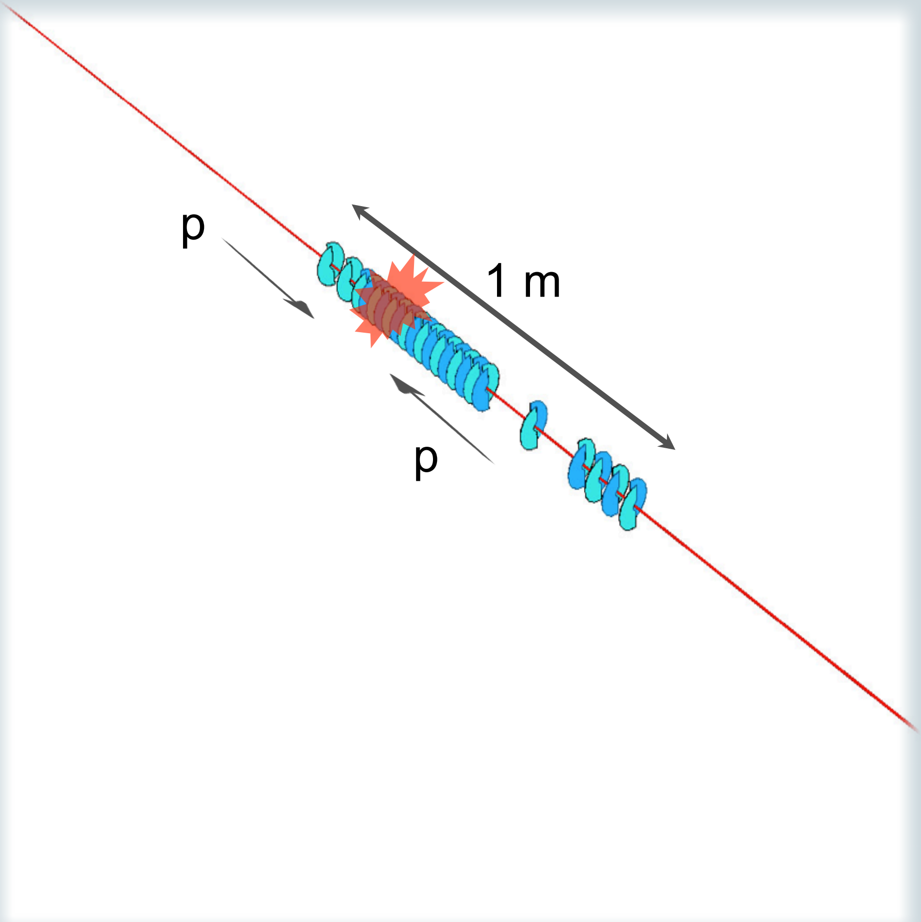
LHCb intro

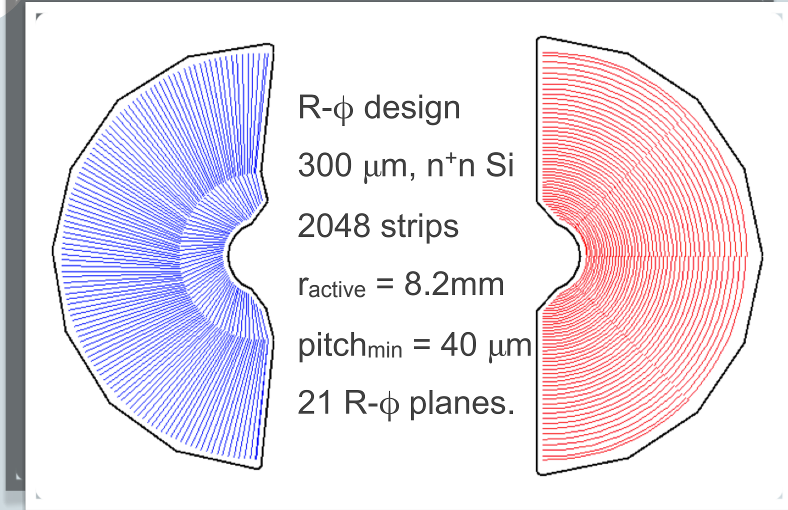


VELO
Si strips
Silicon Tracker
Si strips
Outer Tracker
Straw tubes
Muon
MWPC
5m
TT
– 5m
RICH
HPDs
10m
Calo
MaPMT
20m
z

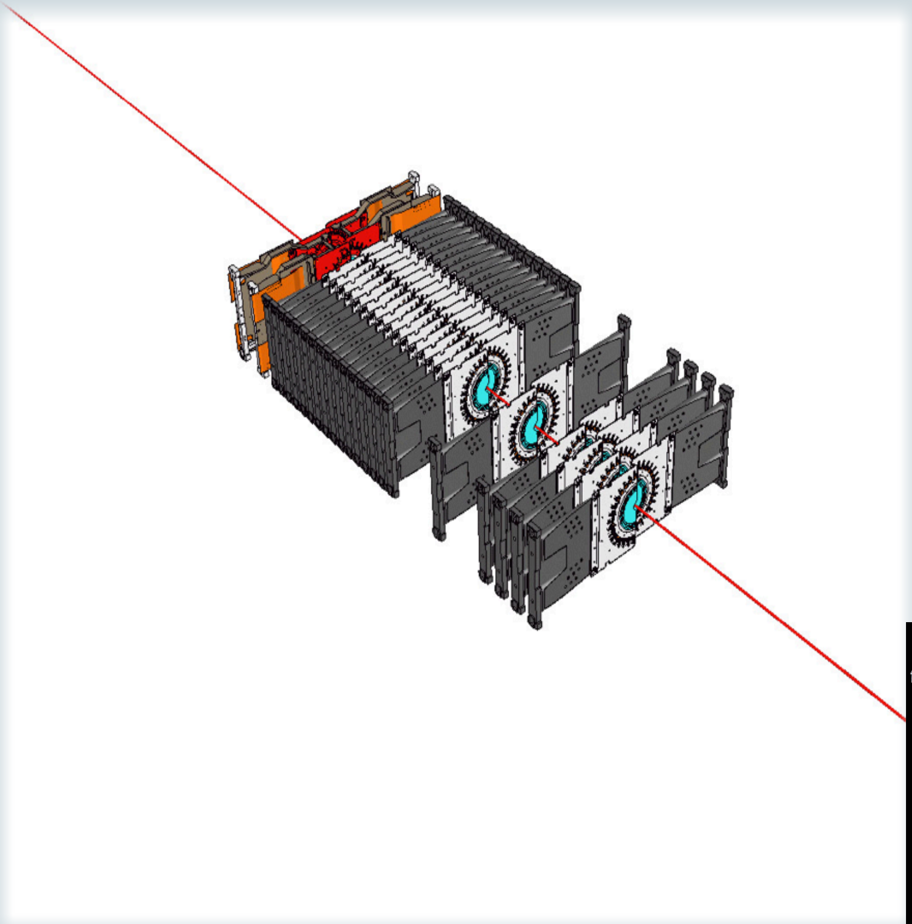
Zoom on the VELO

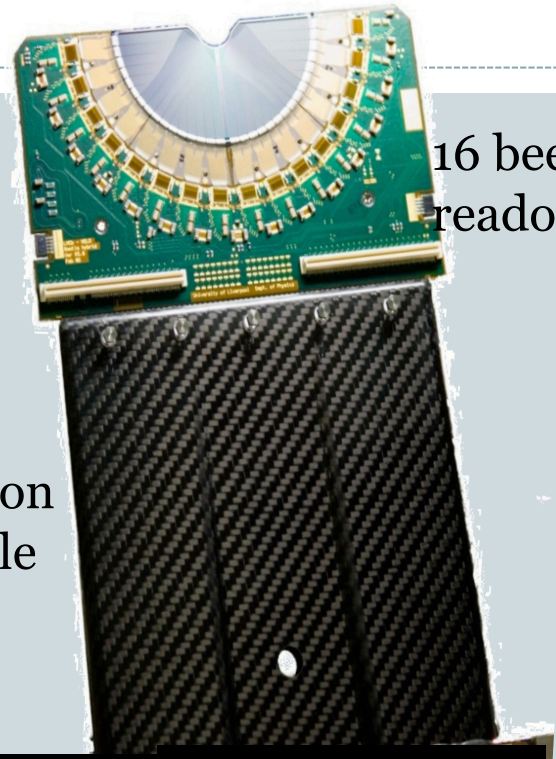
Semi-circular silicon detectors





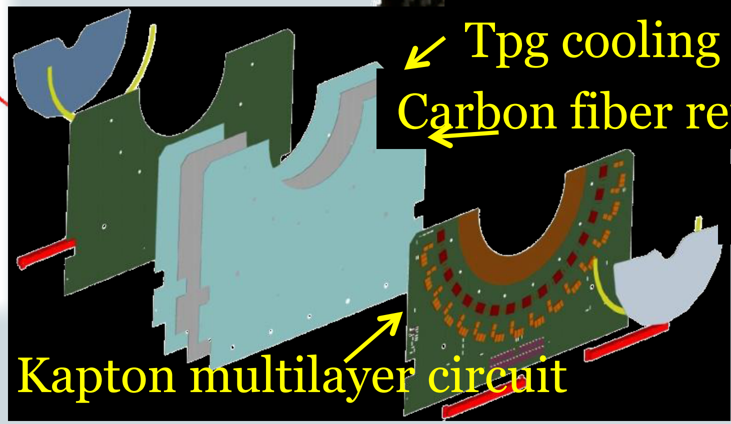
Hybrid circuit and rigid carbon paddle



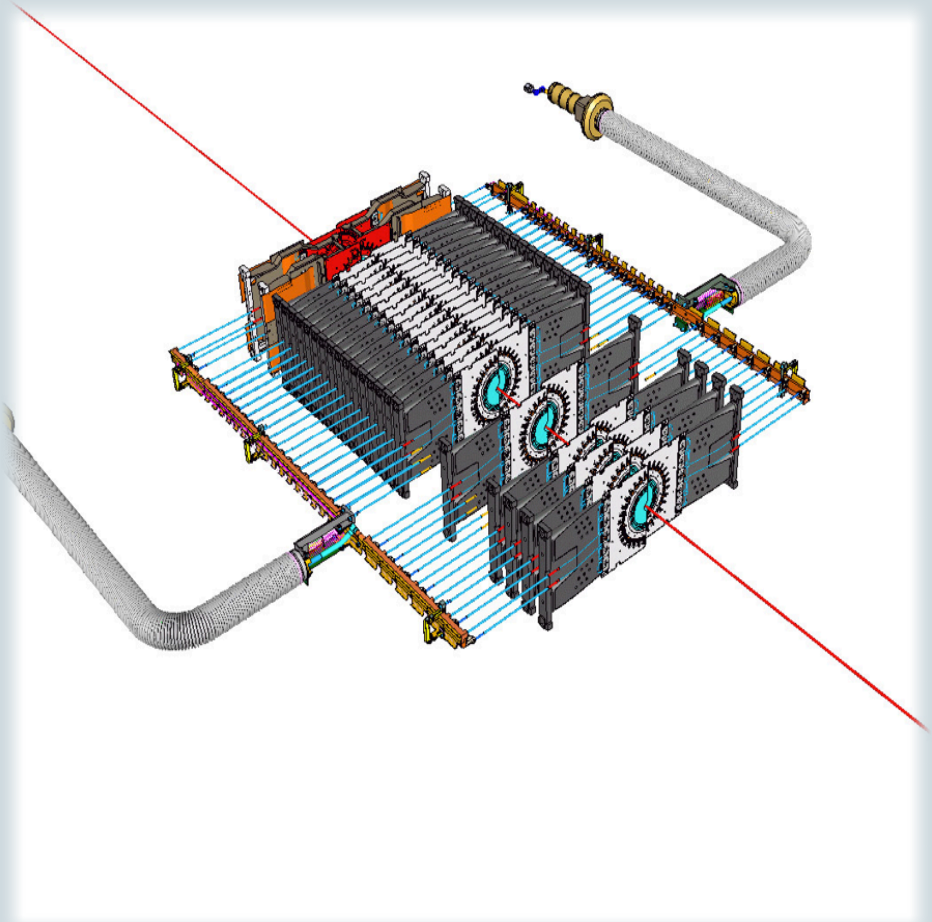


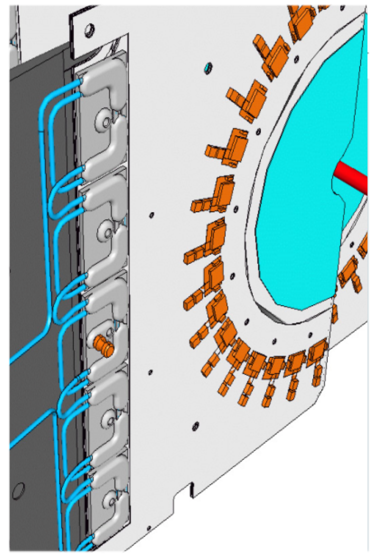
16 beetle readout asics

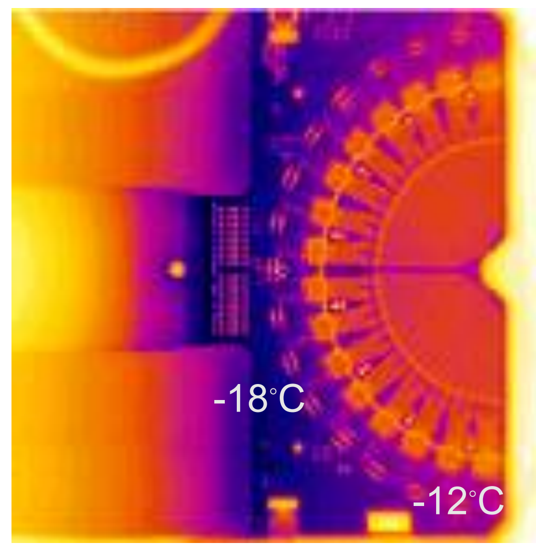
Rigid carbon fiber paddle



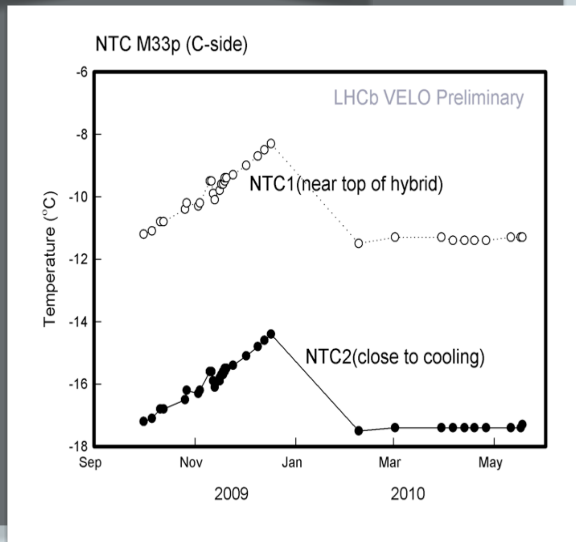
Cooling system : evaporative CO_2



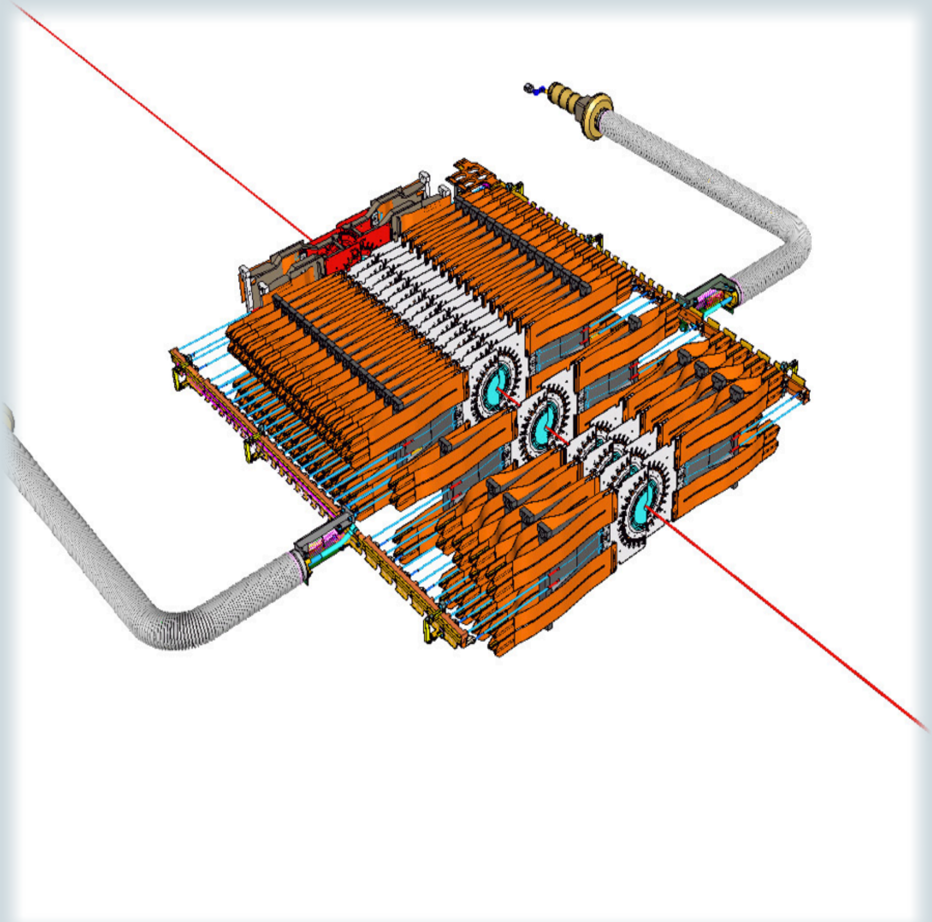




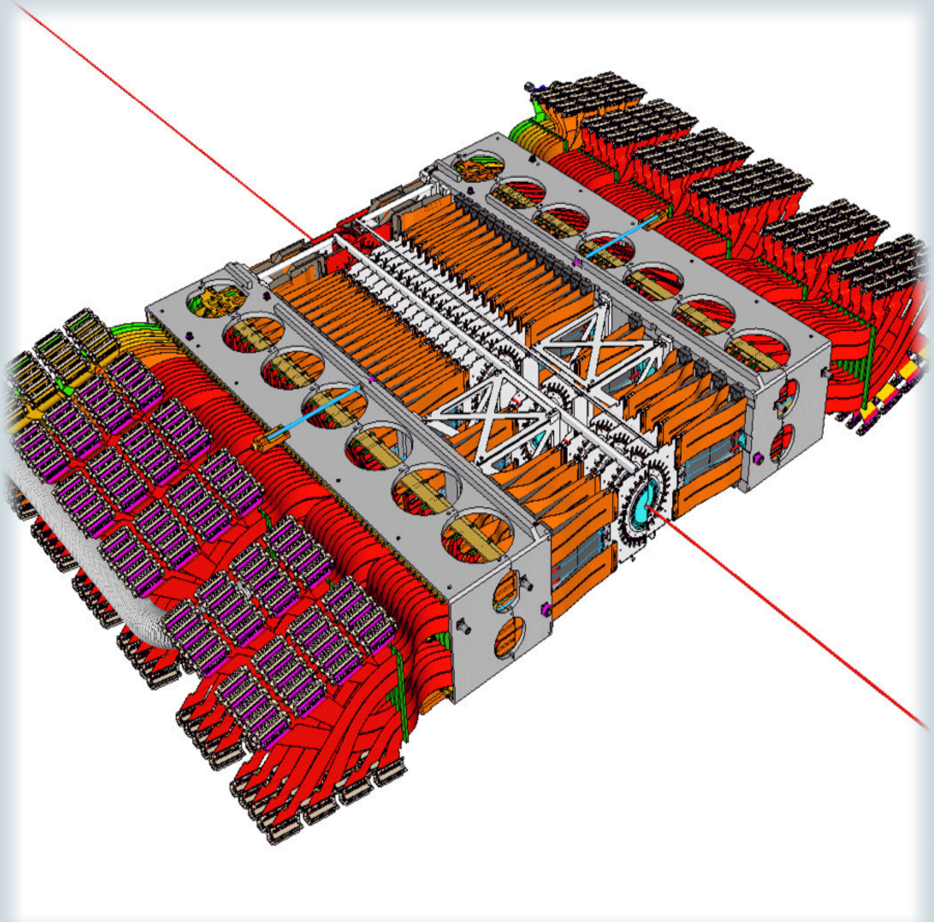
18 Watt power dissipation

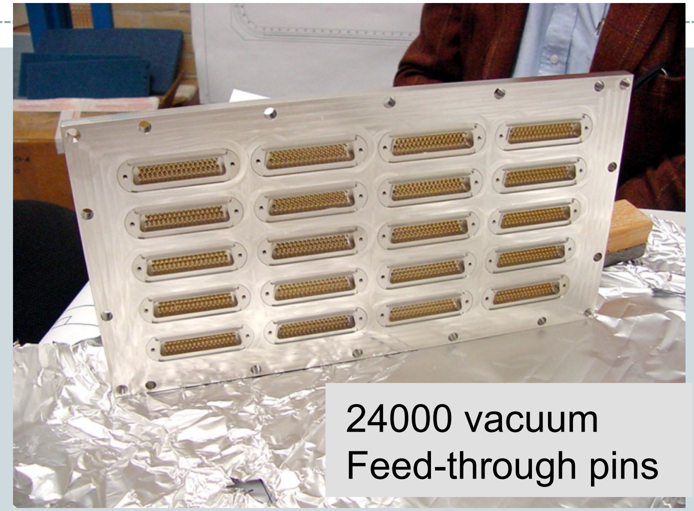


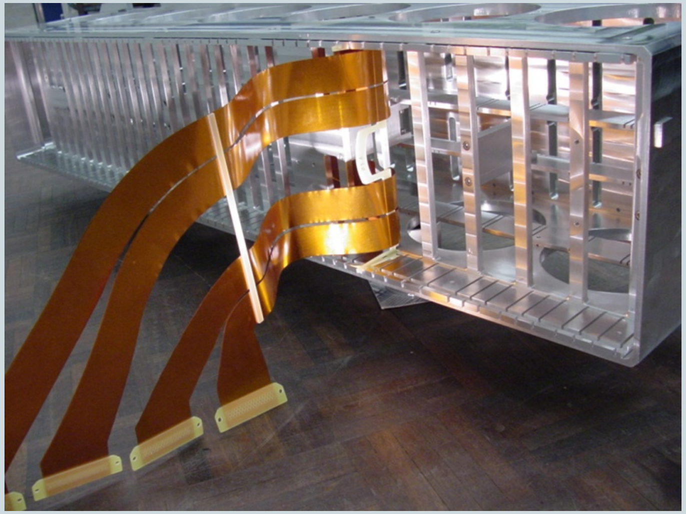
Short kapton cable: signal & power



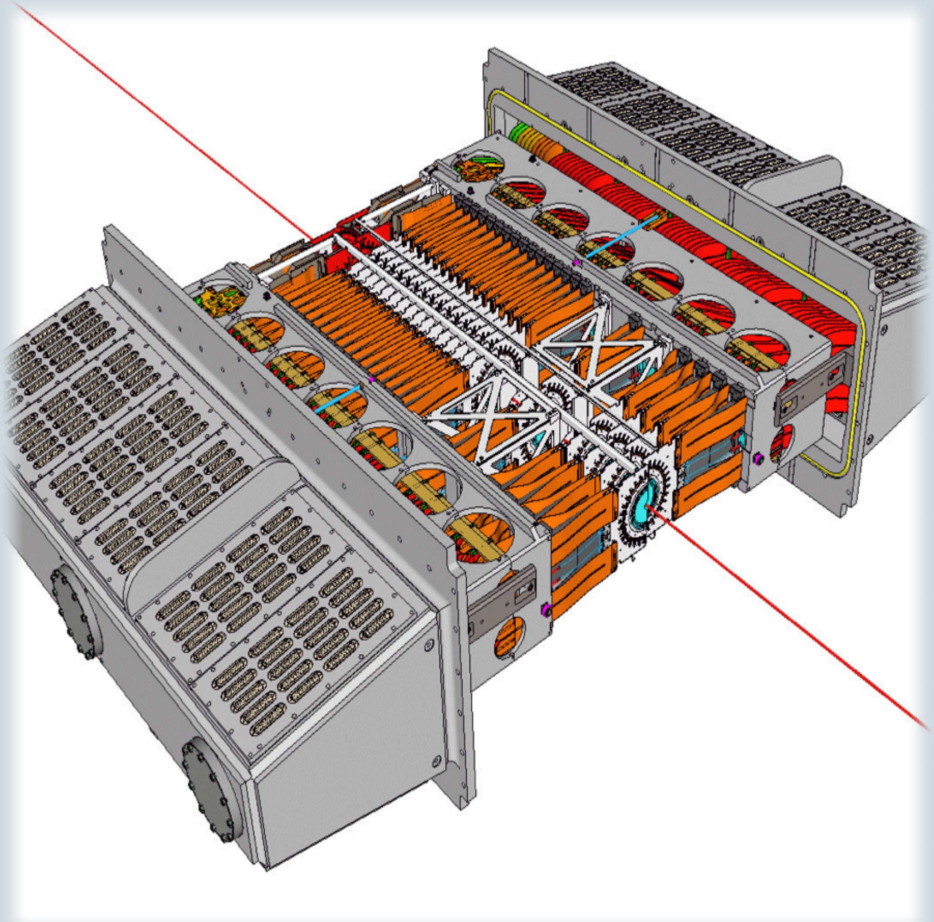
Module support and cabling to vacuum wall

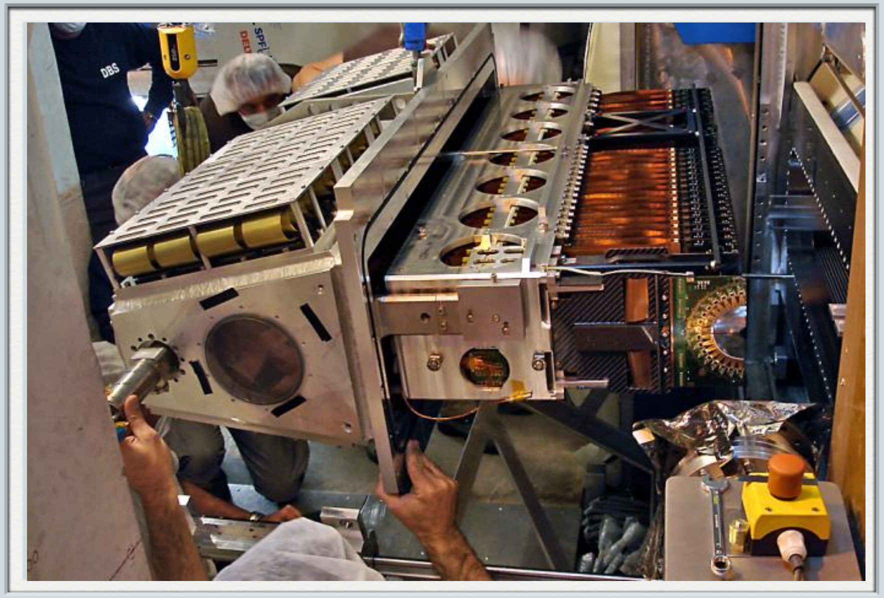




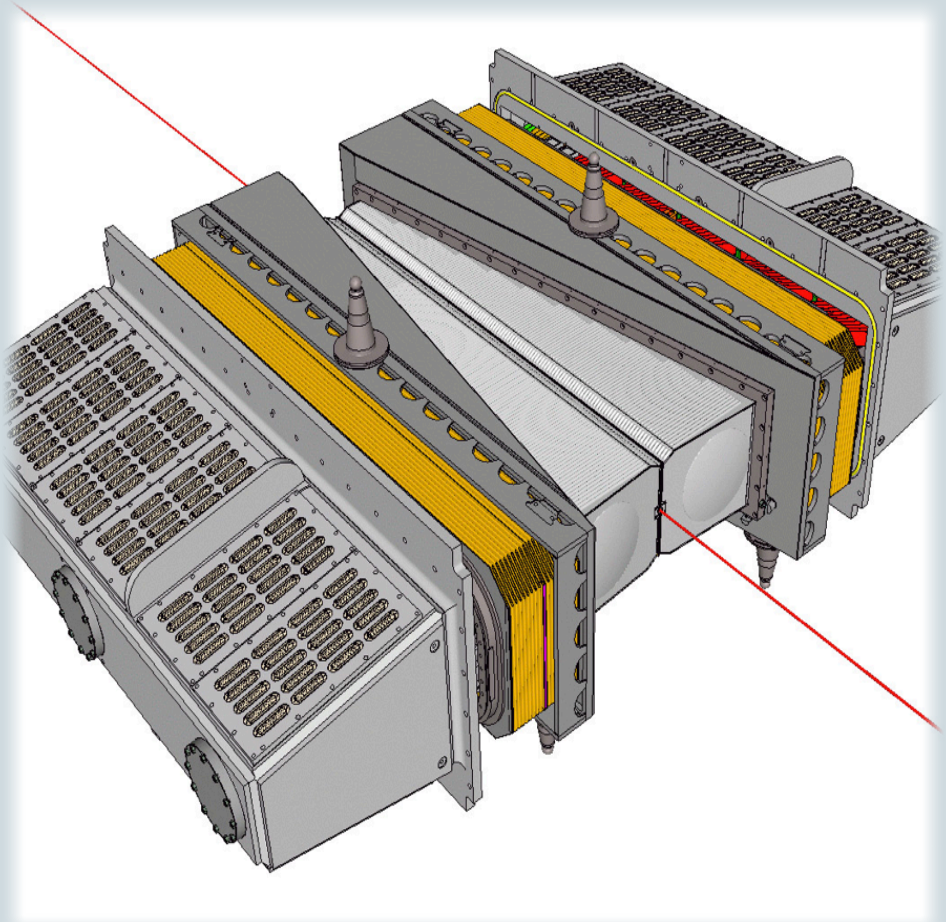


Vacuum-tight enclosure.

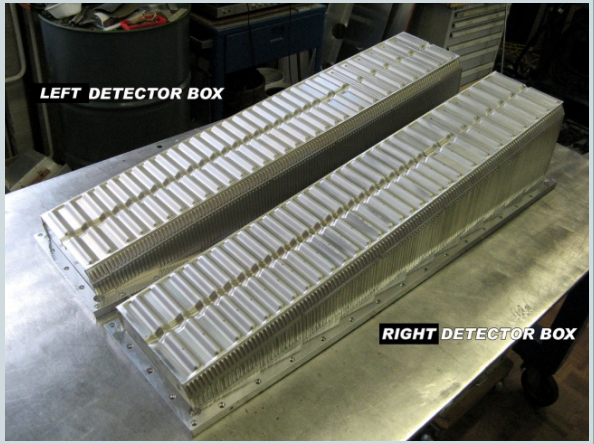




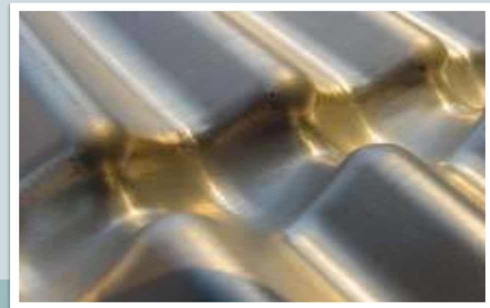
Detector box & RF foil



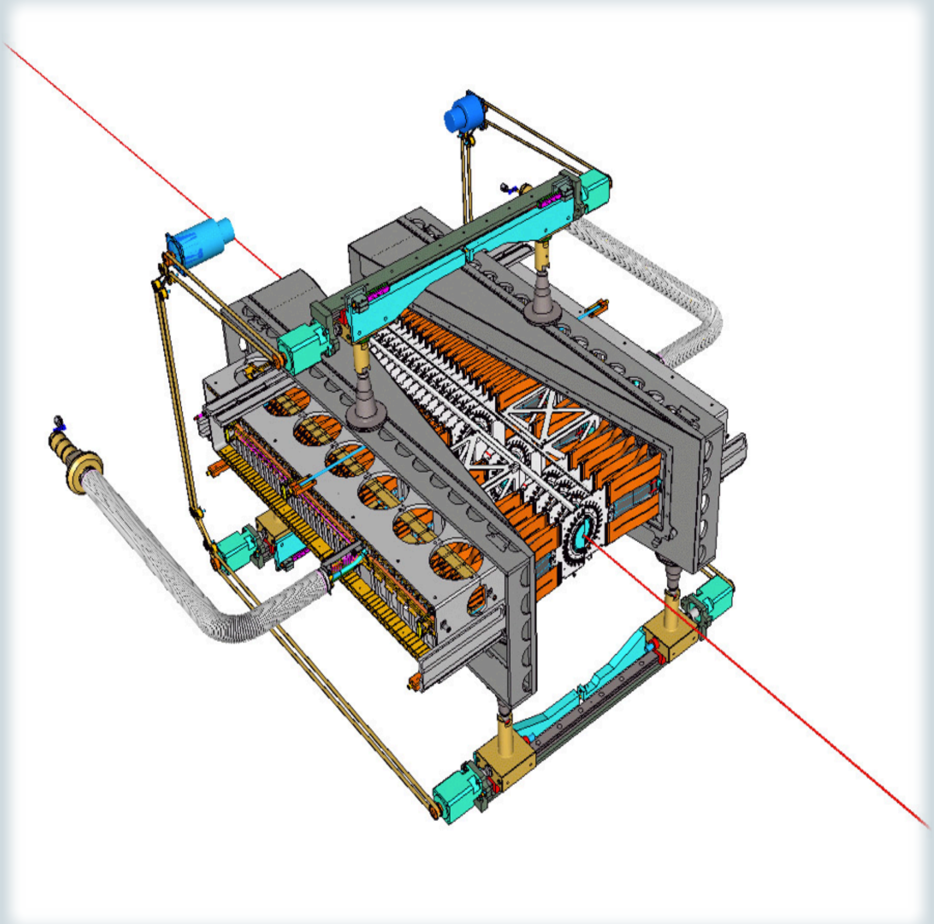
- Detectors are entirely contained within a secondary vacuum (~10^{-7} mbar) seperated from the primary beam vacuum (<10^{-9} mbar)



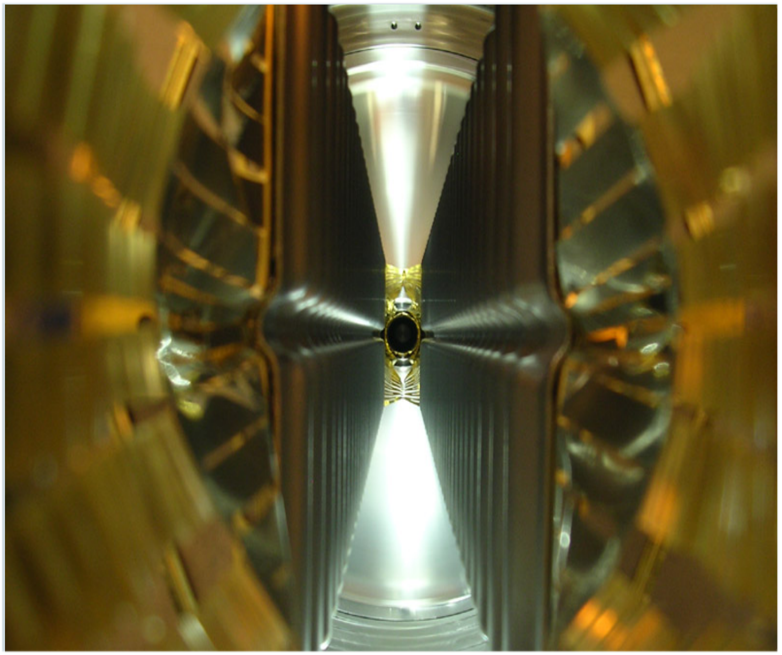
- RF pick-up from the passing beam is guarded against with a ~300µm-thick aluminium foil.



And the VELO moves …

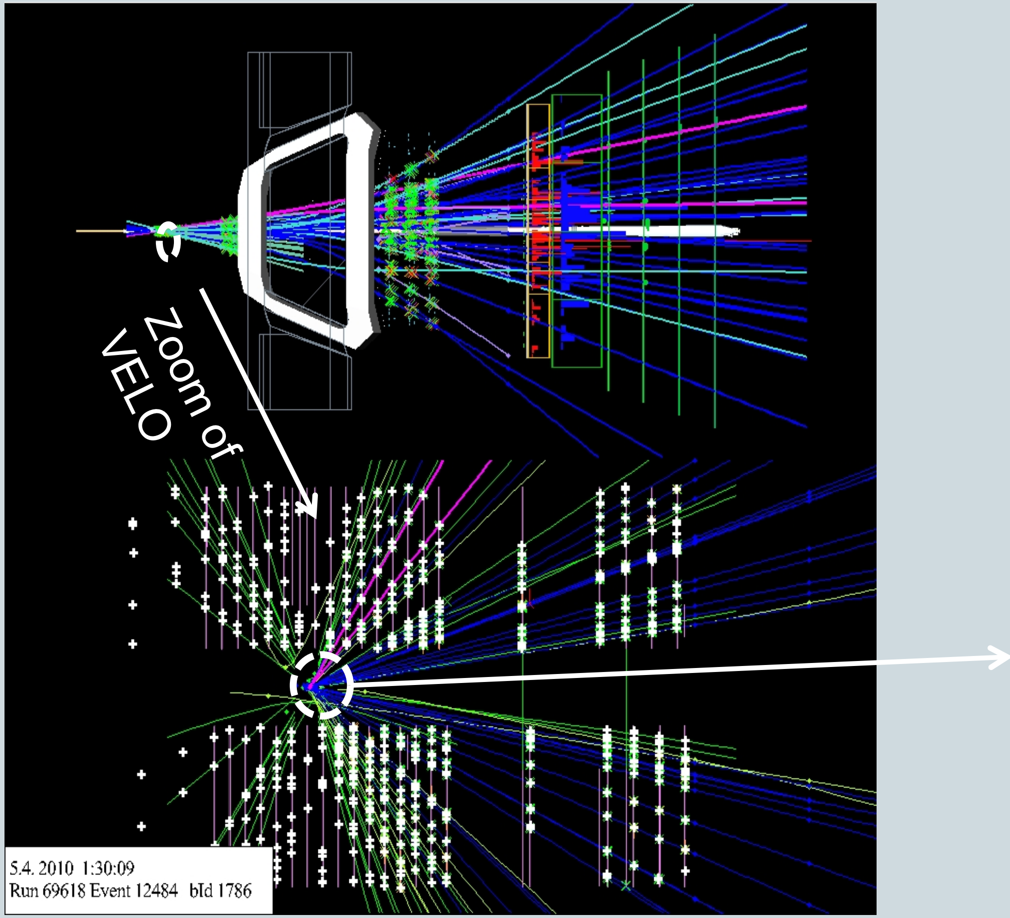


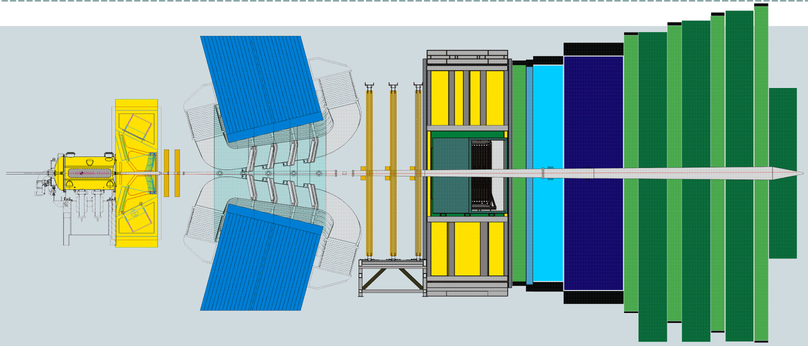
- At all times other than "STABLE BEAMS", the VELO sits back ~3 cm from beam-line.

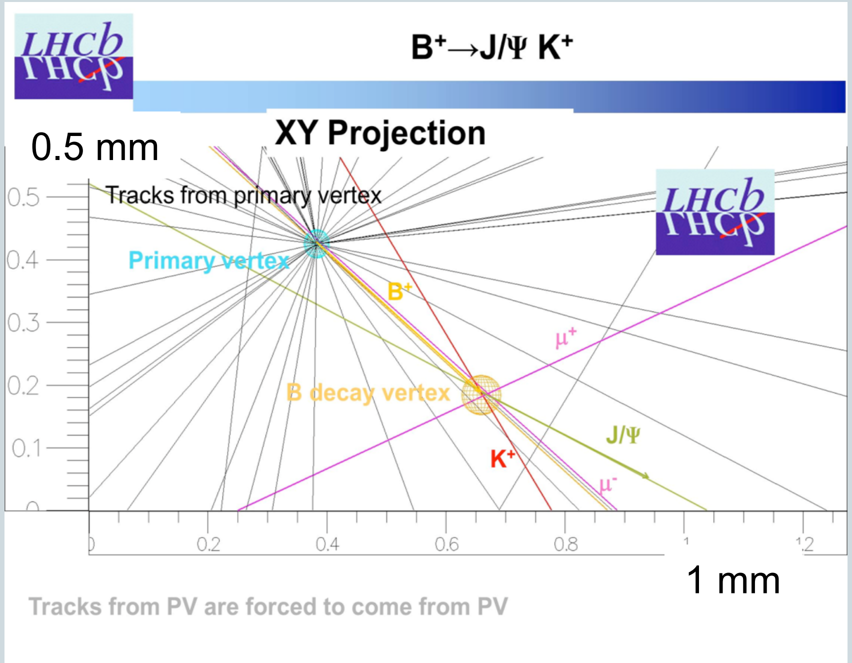


- Beam's eye view of the open VELO

Tracking and vertexing







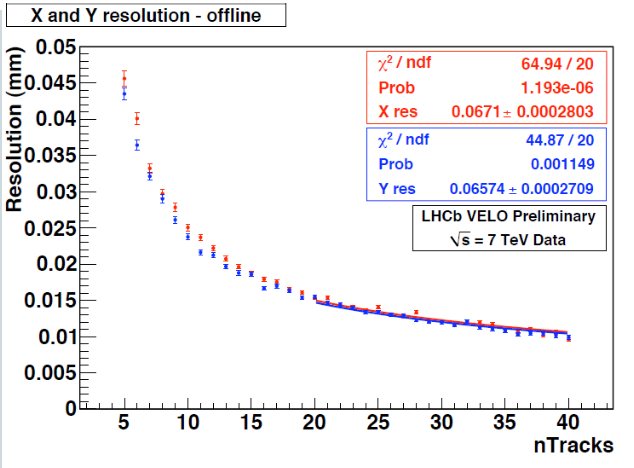
(Impact parameter of a track = distance to primary vertex)

Vertexing performance:

2 key 'figures of merit' :

- Primary vertex resolution: depends on the number of tracks in the event.

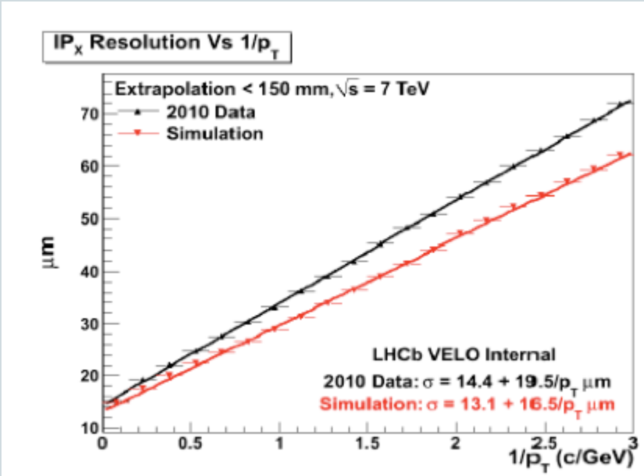
  For 25 tracks (typical) : 13 um (X and Y), 77 um (Z)



- Impact parameter resolution:
  - Depends on the transverse momentum p_T of the track.

    ~13 um + 26 um/p_T, in x,y

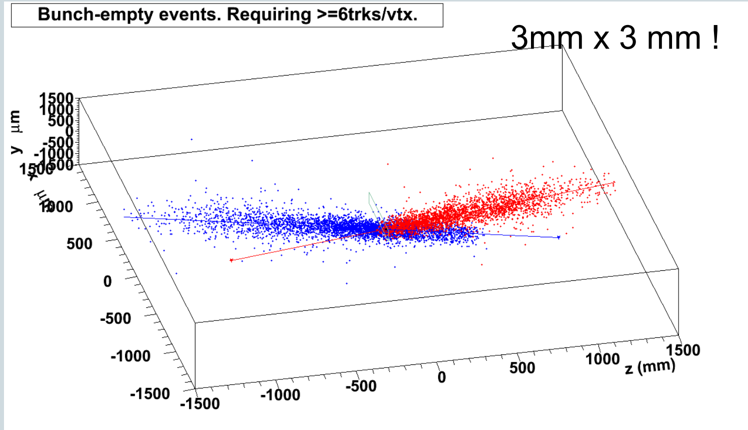
    ~16 um + 30 um/p_T in 3d



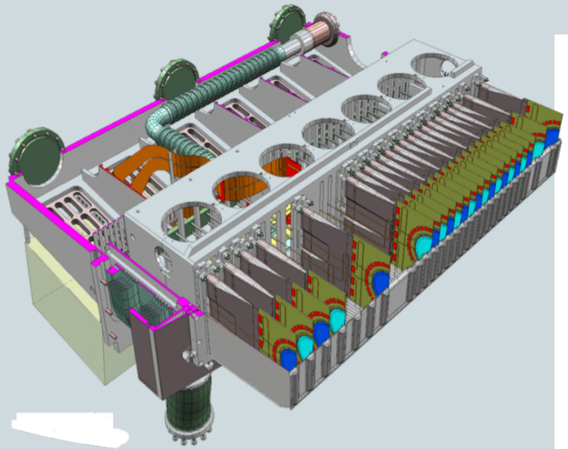
- The VELO is the main tracking and vertexing detector both for the online software trigger (HLT1) and the offline event reconstruction.

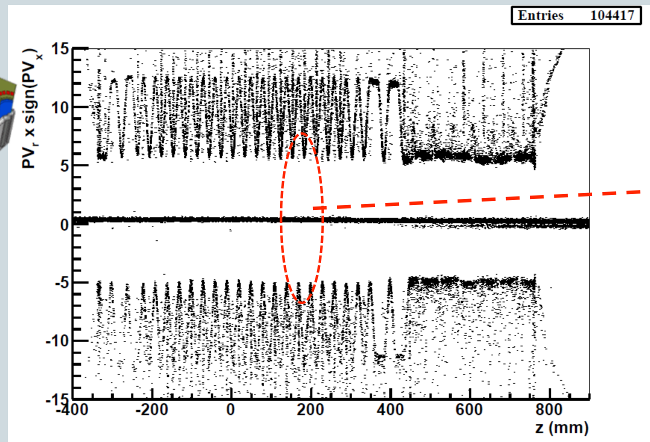
‘Other applications’ of excellent vertexing.

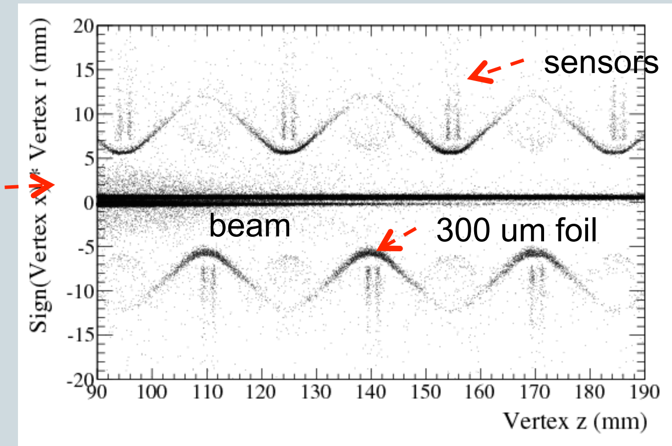
- Imaging of the beam bunches, by reconstructing proton - residual gas collisions.
    - Used for luminosity measurement. Unique to LHCb. Continuous and non disruptive.
    - ‘SMOG’ experiment will inject Xenon gas to enhance this effect.



- ‘Radiography’ or self- imaging of the VELO by reconstructing interactions in material :



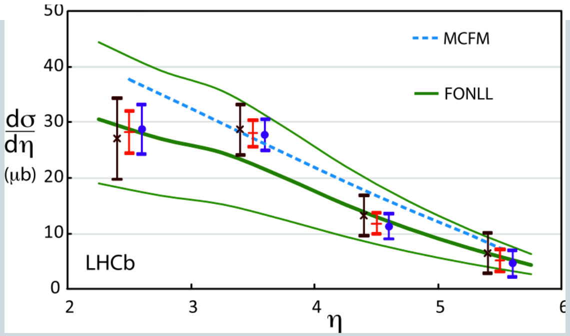


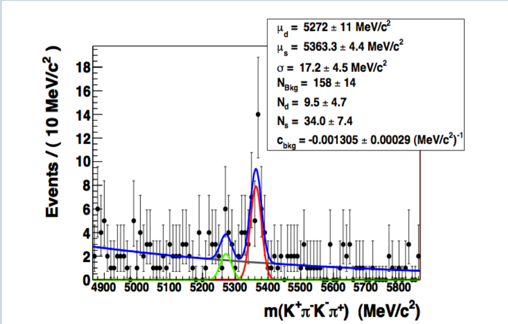


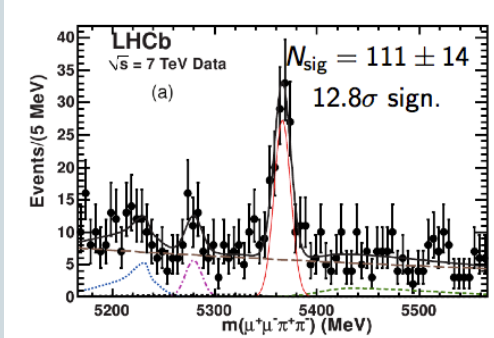
LHCb physics programme well underway

- In 2010 LHCb accumulated 37 pb^{-1} with luminosity close to design, but significantly higher pileup
- Excellent trigger and reconstruction performance
- Confidence in LHCb physics programme
- $B_s \to \mu^+\mu^- < 1.2 \times 10^{-8}$ 95% C.L.
- Clean Δm_s measurement at Tevatron precision and with 2x smaller systematic error
- Production cross sections in beauty and charm
- Ingredients in place for core CPV programme

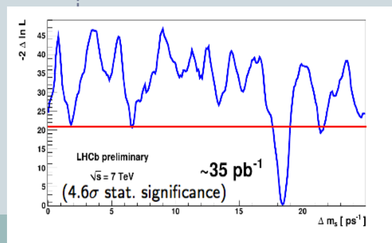
bb x sections with LHCb rapidity range

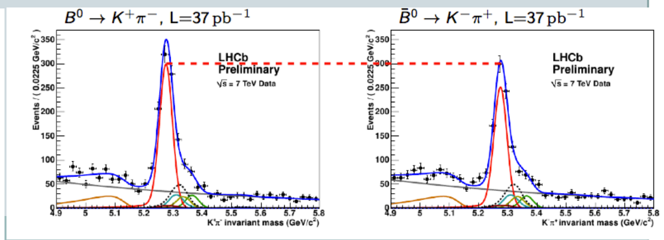






First observations: $B_s \to J/\psi f_0$, $B_s \to D_s K^{*0}$, $B_s \to K^{0*} K^{0*}$ …
Huge yields in critical channels





Direct CPV in $B \to K^{\pm}\pi^{\mp}$

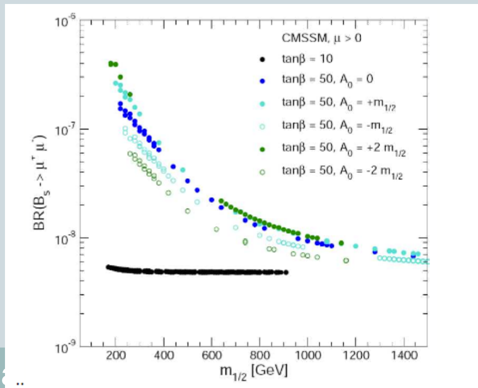
LHCb Upgrade Objectives

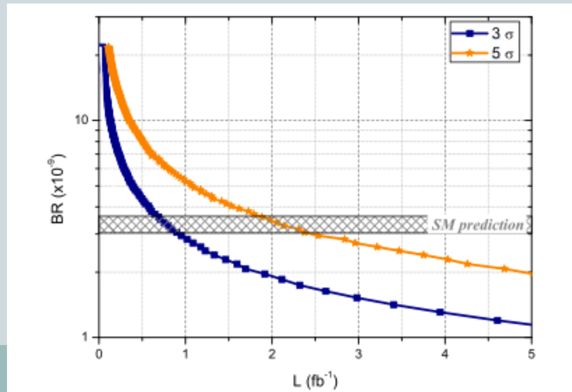
- Pursue core physics objectives with
  - Order of magnitude increase in integrated luminosity
  - Flexible software trigger able to focus on NP channels hinted at or measured in first phase – by LHCb or the GPDs

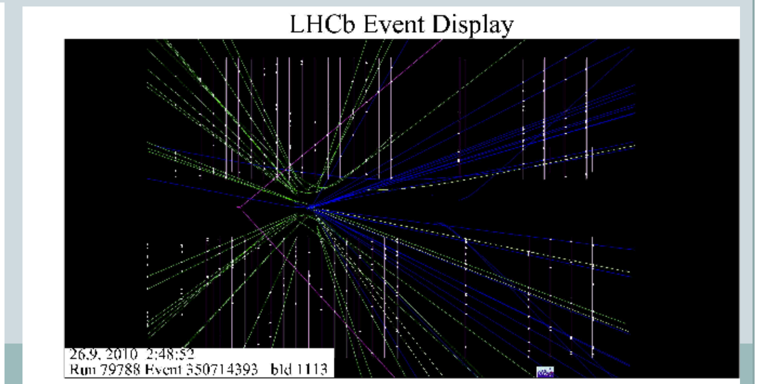
LHCb upgrade also accesses

- Lepton flavour physics, flavour violating t decays
- Charm physics
- Electroweak physics and exotics

	B_s->J/ψφ	Determination of γ	B_s -> $\mu^+\mu^-$	B_o->$K^*\mu^+\mu^-$
NOW	Find, or exclude large deviations from SM	Measure with 4° uncertainty	Measure SM value or large deviations	Measure zero crossing point of asymmetry
UPGRADE	Precise phase measurement	Achieve <1° precision and match (future) Lattice QCD	Make precision measurement and extend to B`->$\mu^+\mu^-$	Measure full kinematic distributions

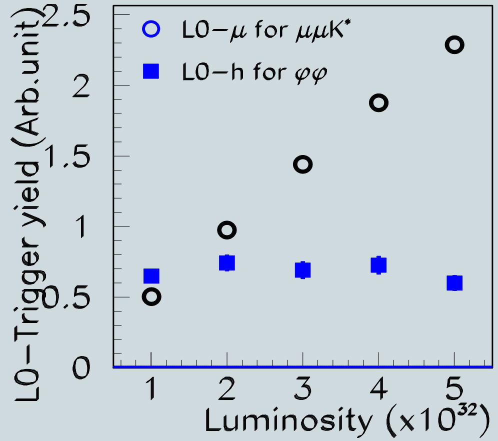


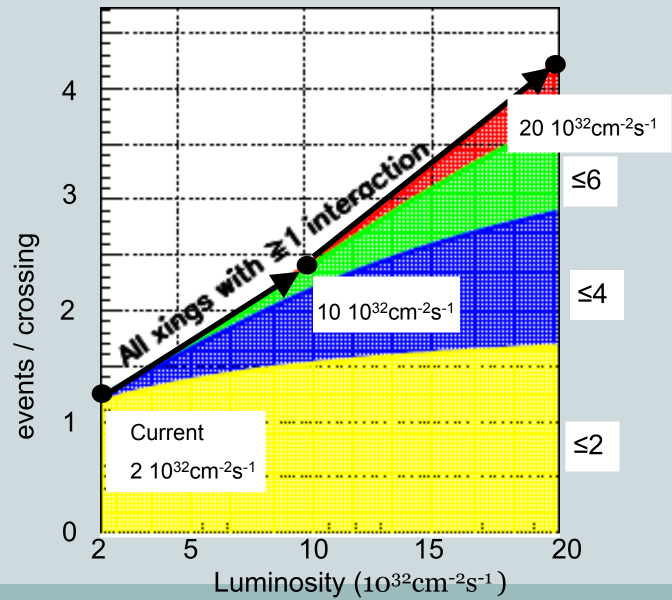




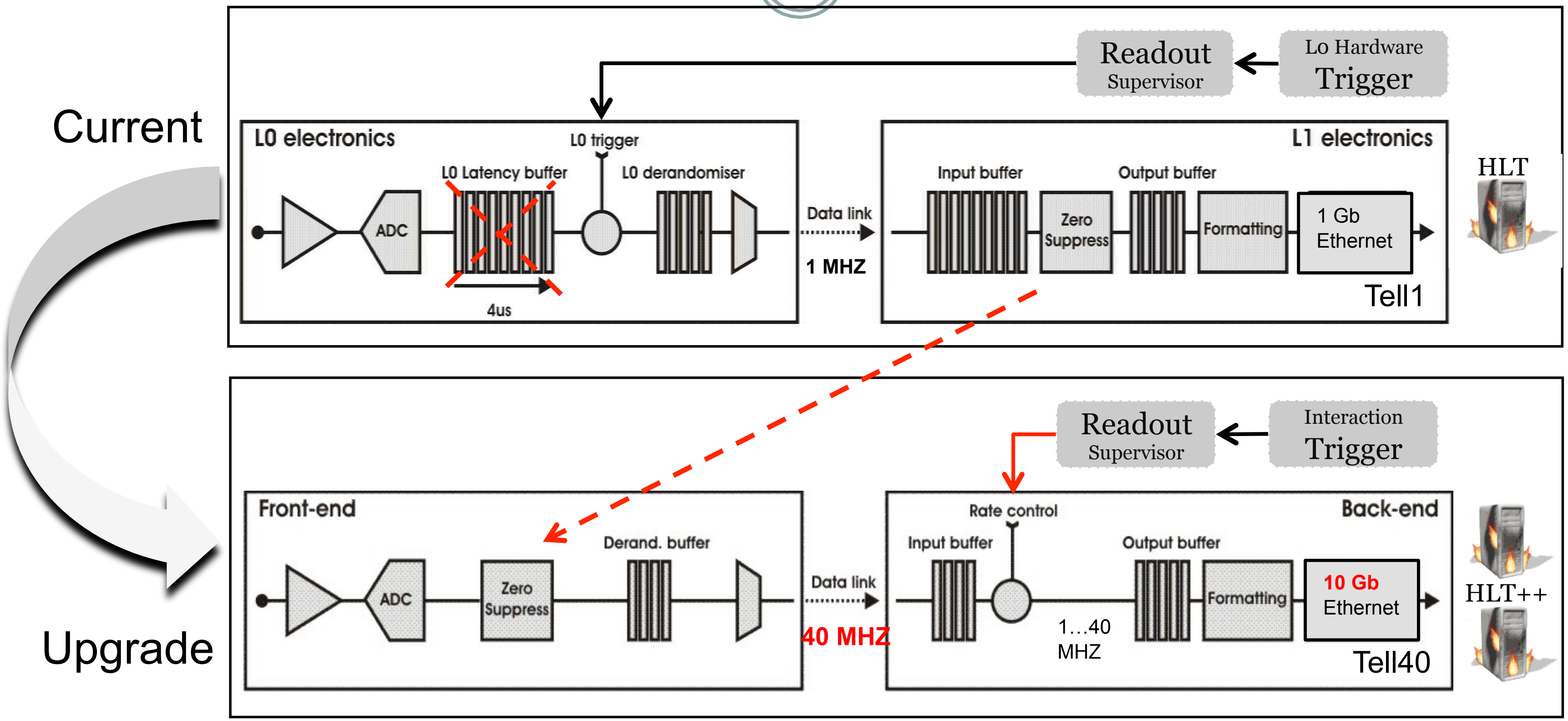
LHCb – upgrade

- Can confidently expect to run at nominal luminosity 2 x 10^{32} from 2011, after which time to double statistics is too low
- Aim of upgrade is to increase the event yield by a factor 10-20 by
  - Increasing luminosity by a factor 5 in the first phase and ultimately by a factor 10
  - Increasing the trigger efficiency in hadronic channels by a factor 2
- This can be done without serious increases in occupancies, so basic detector layout can remain
- Current experiment has bottle neck with reduction to 1 MHz imposed at the first level trigger, built into FE electronics of experiment





LHCb Upgrade Readout Scheme



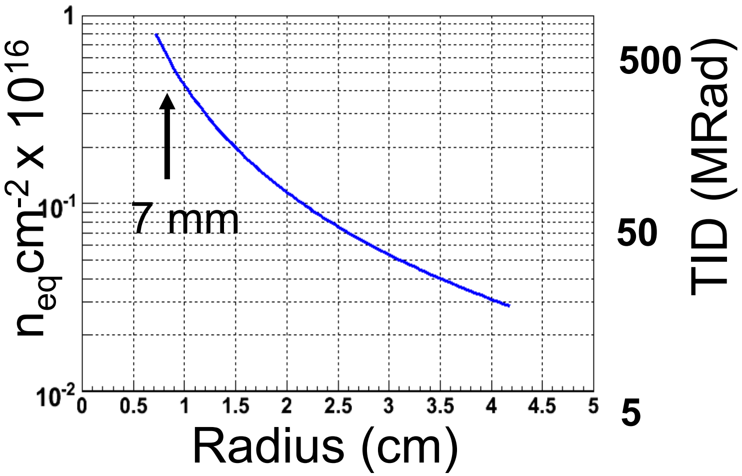
Solution: Execute trigger algorithms on ALL data in software -> more sophisticated trigger

A new **DAQ** system must transfer all, zero-suppressed front-end data straight into a large computer farm, through a huge optical network & router.
VELO to be completely replaced

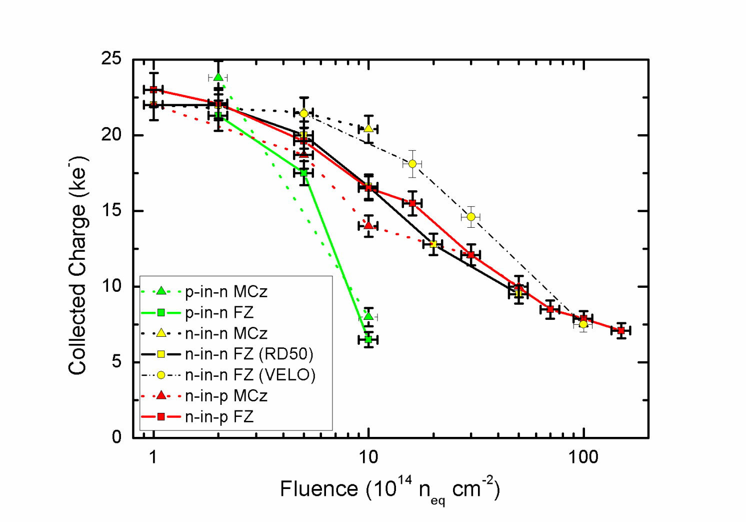
VELO Upgrade radiation challenge

At 7 mm from beam we accumulate 370 MRad or 8 x 10^{15} n_{eq}/cm^2.

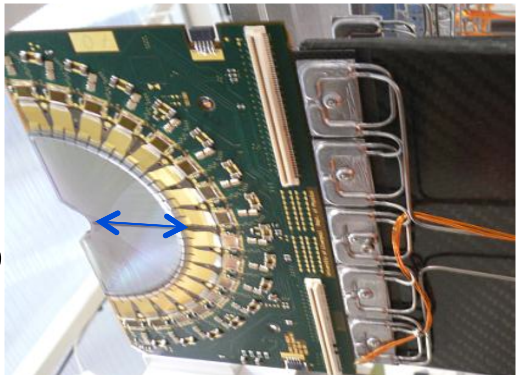
Dose after 100 fb^{-1}



Recent RD50 studies have shown that silicon irradiated at these levels still delivers a **signal** of ~ 8ke⁻ / MIP



Distance from silicon tip to thermal connection too great



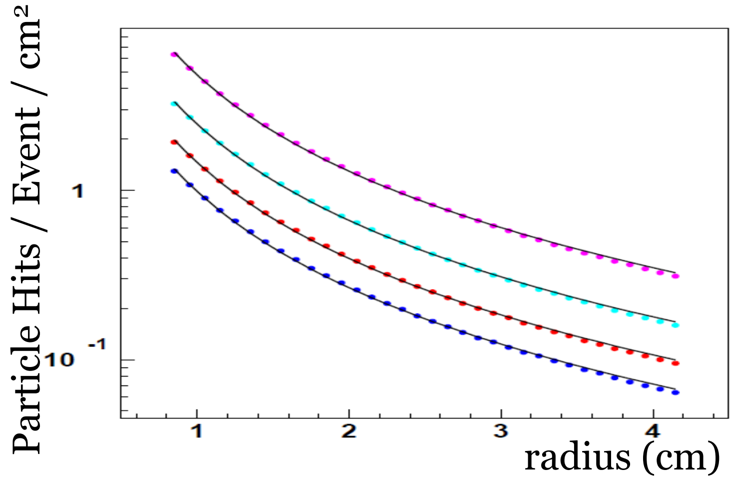
Efficient heat removal mandatory to avoid thermal runaway!

Diamond cooling substrate candidate solution

Electronics must be of sufficiently low noise to cope with reduced signal

VELO upgrade data rate challenge

- Electronics has to digitise, zero suppress and transmit event data at 40 MHz
- By pixel standards the occupancy of the VELO is miniscule, but the data rate is HUGE
- 1 chip has to transmit 10-20 Gbit / second
- Our current granularity, occupancies = ok but FE electronics and DAQ are not

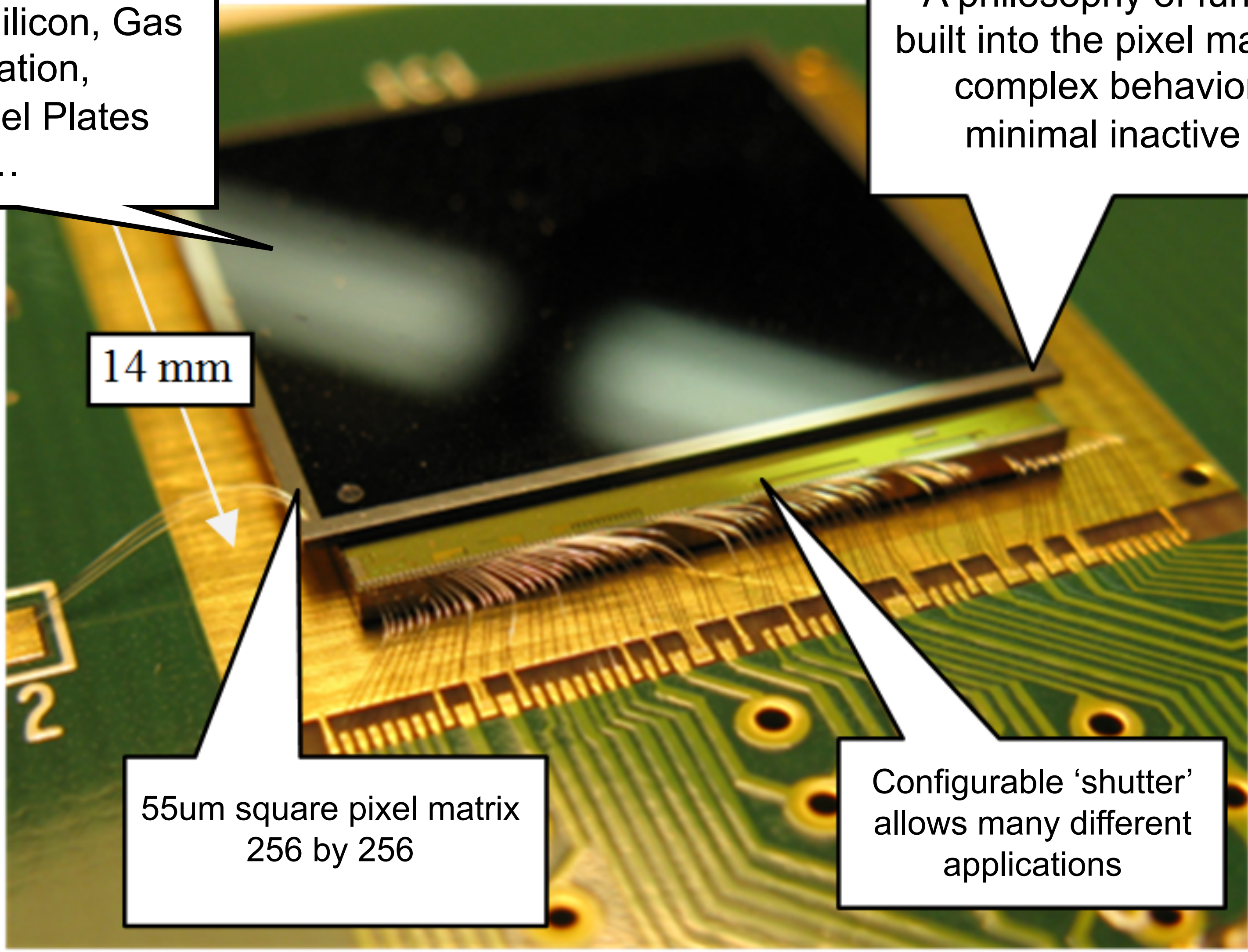


Luminosity (cm^{-2}s^{-1})	2.10^{32} Current	5.10^{32}	10.10^{32} Phase 1	20.10^{32} Phase 2
A=	0.98	1.46	2.46	4.80

The Medipix – from HEP to Medicine and back again

Silicon, 3D, CdTe, GaAs, Amorphous Silicon, Gas Amplification, Microchannel Plates etc…

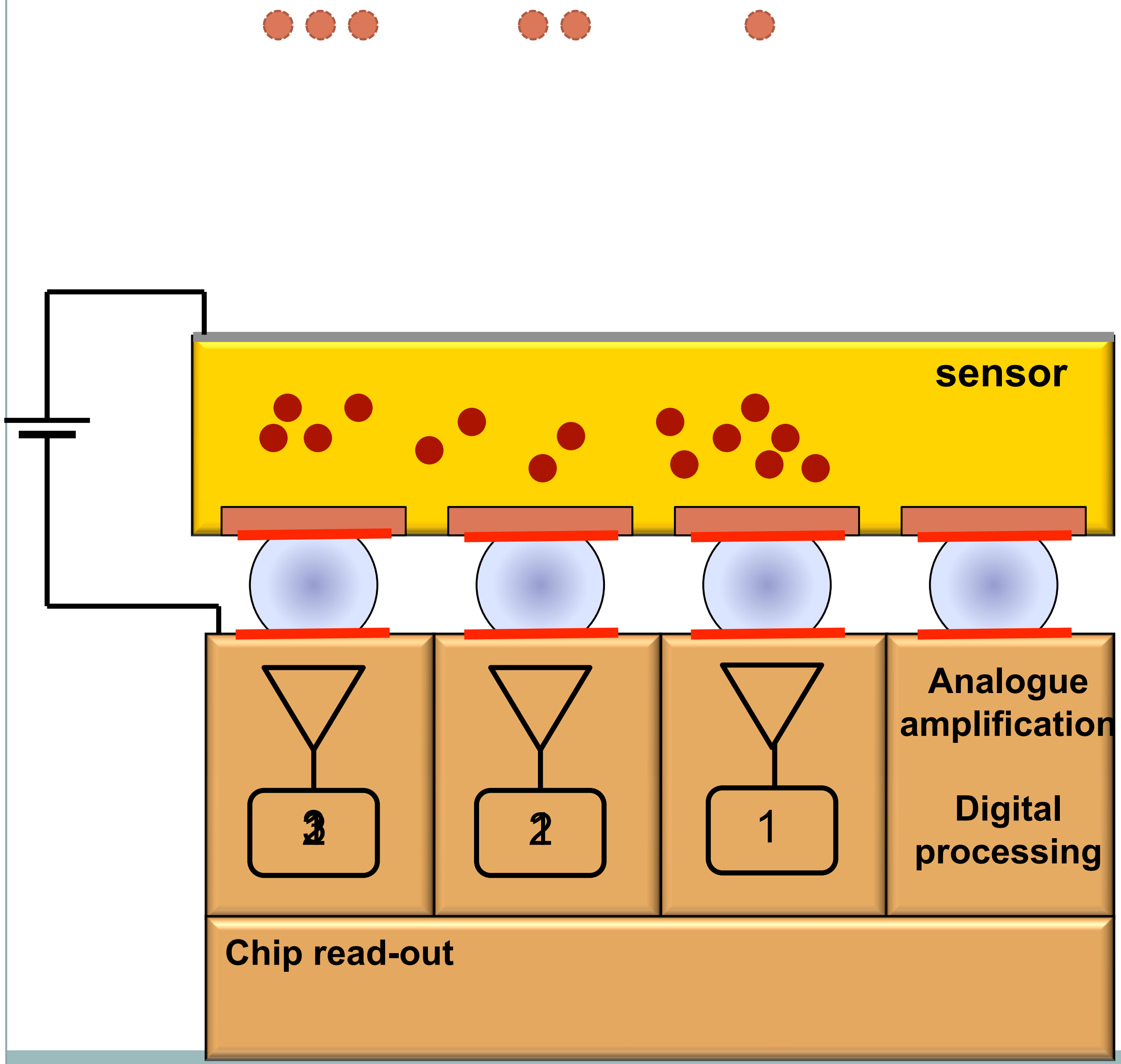
A philosophy of functionality built into the pixel matrix allows complex behavior with a minimal inactive region



55um square pixel matrix 256 by 256

Configurable ‘shutter’ allows many different applications

Medipix2 (2002) – Photon Counting



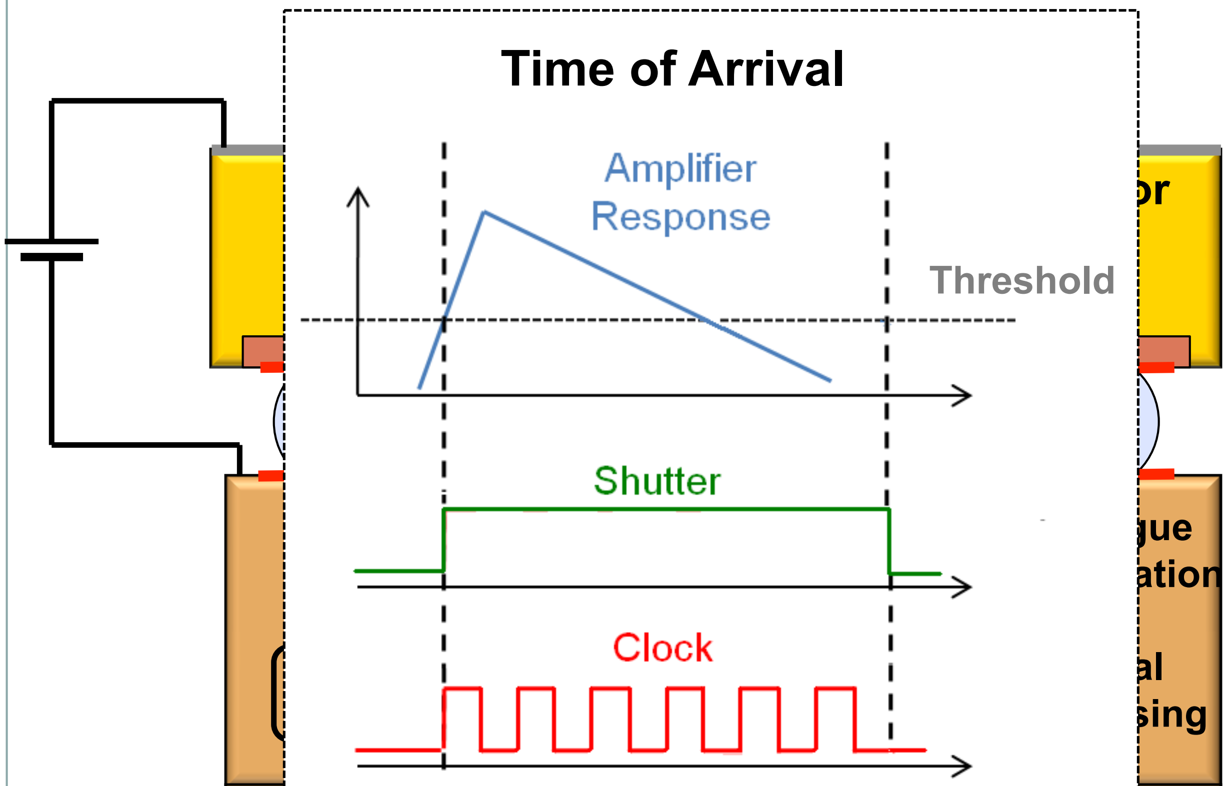
Each hit in the sensor is converted into a count in the 14 bit counter

Noise and below threshold events are not counted at all

1000 electron noise floor

The shutter closes and the data are shifted out

Timepix



Time of Arrival counts to the end of the Shutter

Timepix design requested and funded by EUDET collaboration

Conventional Medipix2 counting mode remains.

Addition of a clock up to 100MHz allows two new modes.

Time over Threshold

Time of Arrival

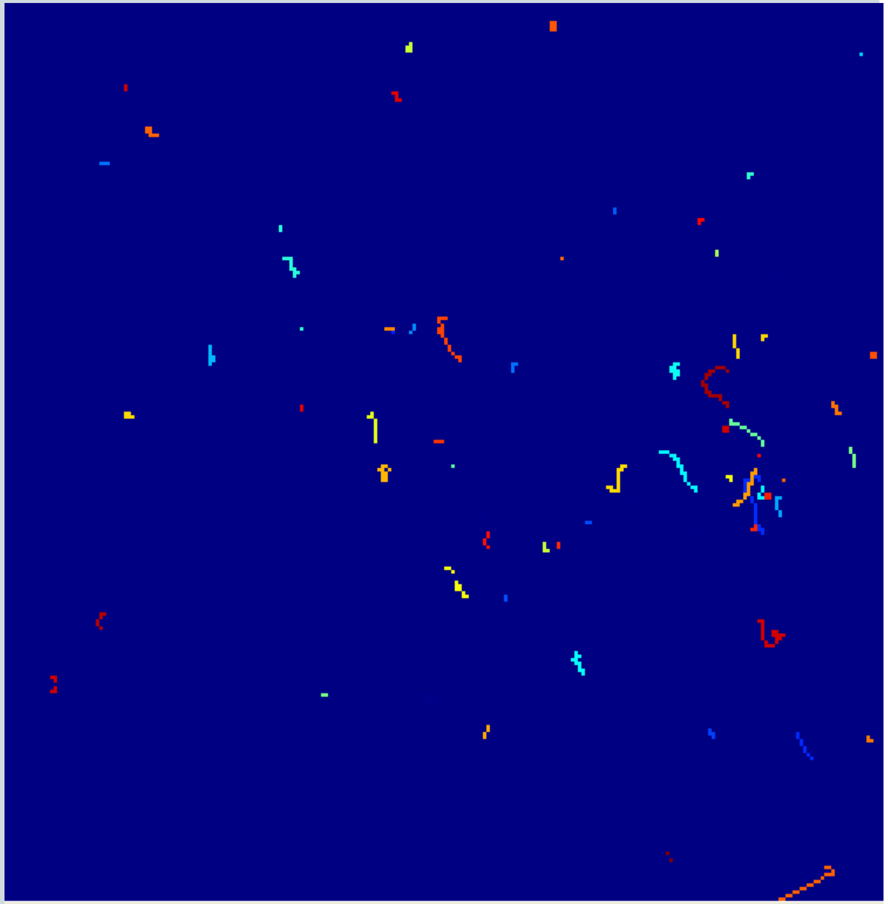
Pixels can be individually programmed into one of these three modes

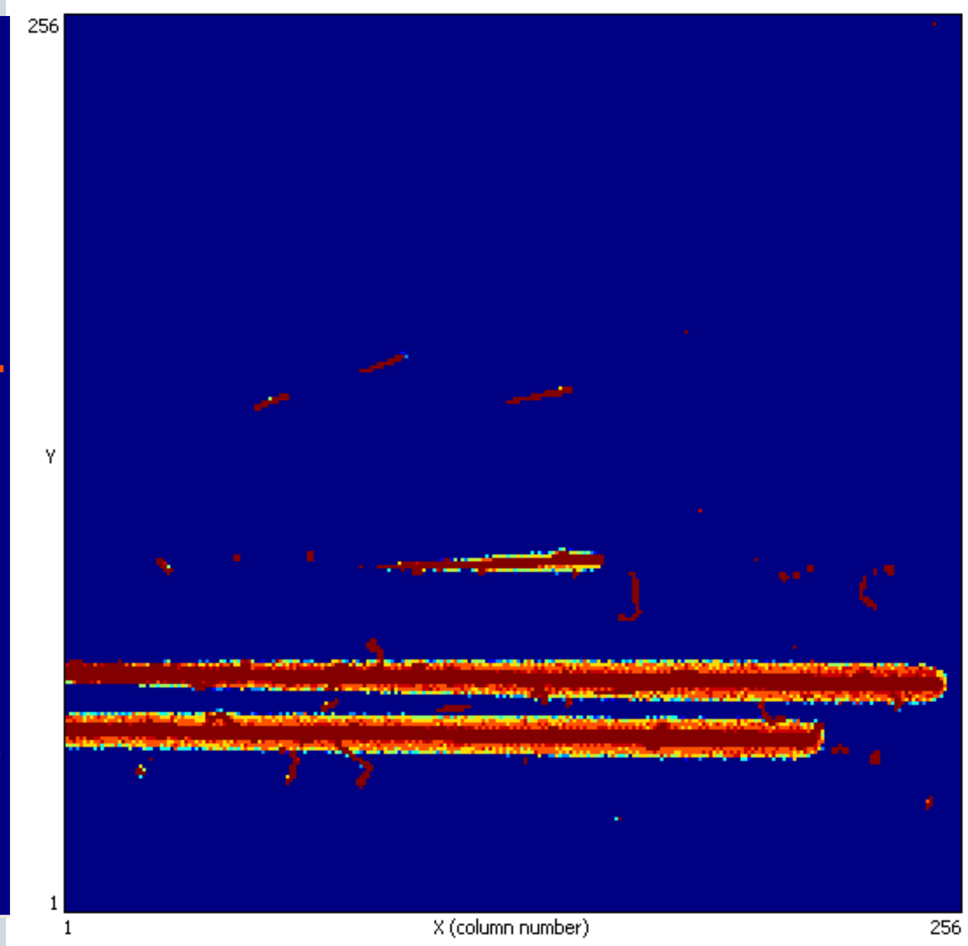
Time of Arrival

Strontium Source

Time over Threshold

Ion Beams at HIMAC





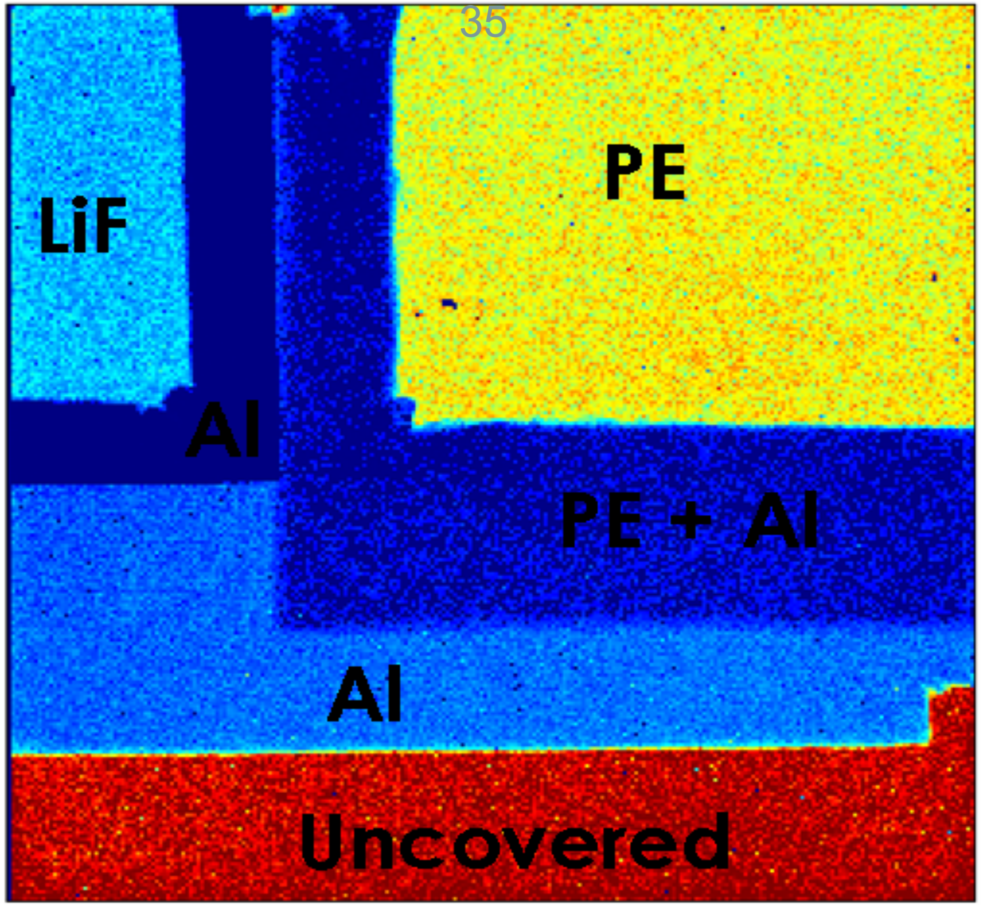
Charge deposition studies with various Isotopes
Space Dosimetry

Courtesy L. Pinsky, Univ. Houston

LiF (50 μm)
used for thermal
neutrons detection

Al (50 and 100 μm)
used to stop low
energy electrons
and photons

Uncovered
accepts all particles
low sensibility
to neutrons

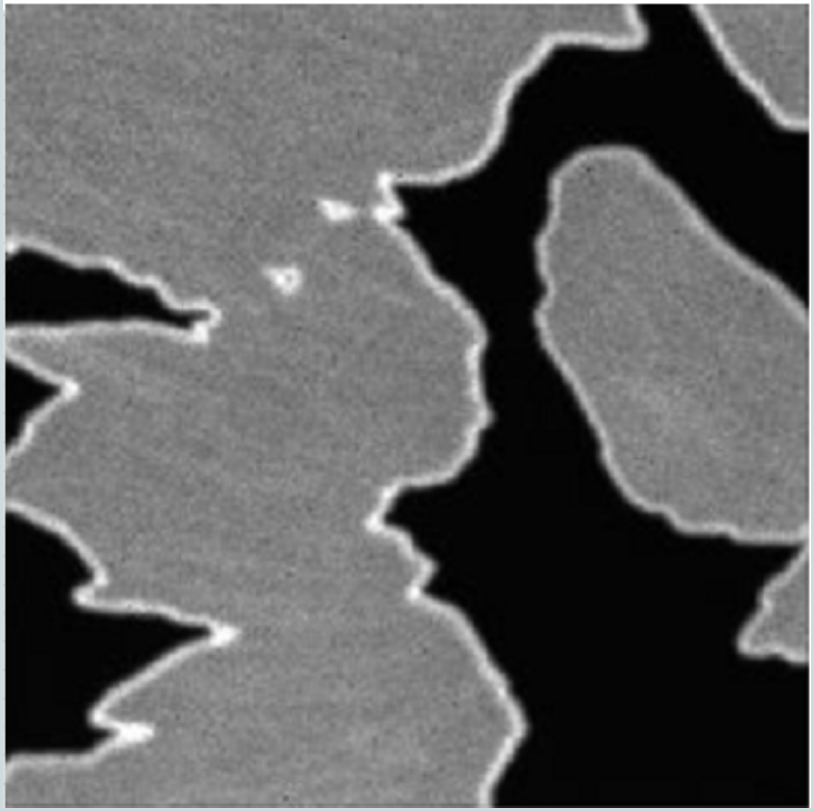


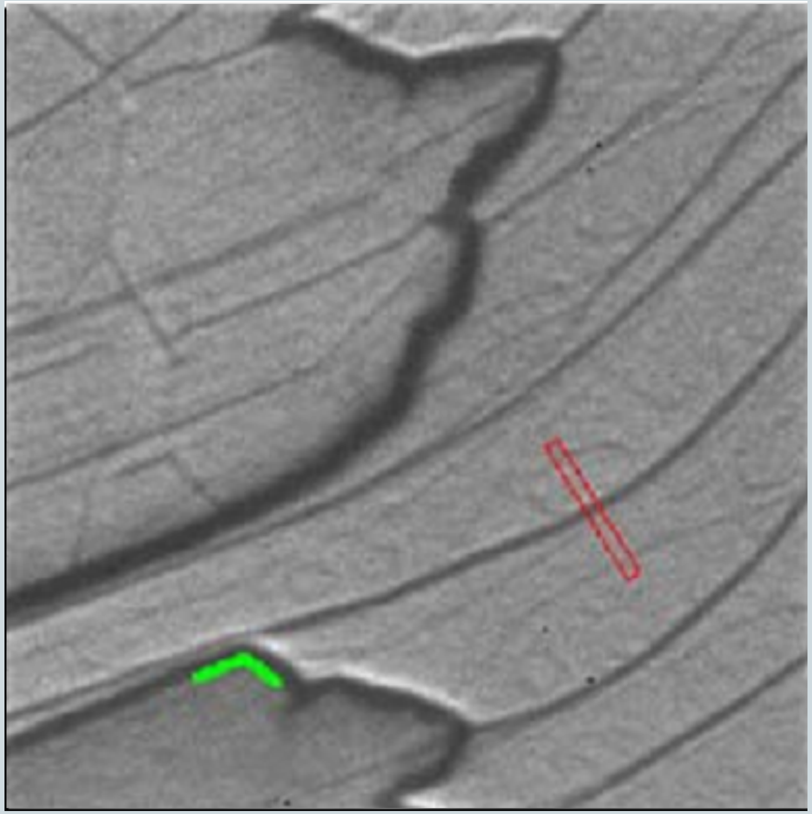
PE (1.3 mm)
used for
fast neutrons
detection

PE + Al
used for fast
neutrons detection
removing low
energy
electron photons
contributions

J. Jakubek, S. Pospisil, M. Suk, D. Turecek
and Z. Vykydal and the Group at Prague CTU

Low Energy Electron Microscopy





Images of Graphene Flakes presented to the Medipix2 collaboration by I. Sikharulidze, Leiden

‘Medipix2 applied to low energy electron microscopy’, Ultramicroscopy 110 (2009) 33 - 35

Timepix -> VELOPix (via Timepix2)

Why the Timepix decision

- Square Pixel size (55μm x 55 μm)gives equal spatial precision in both directions, removing the need for double sided modules and saving a factor 2 in material
- IBM 130 nm CMOS process
- Low occupancy is suited to ToT measurement, with no loss from 1 us deadtime

Changes needed

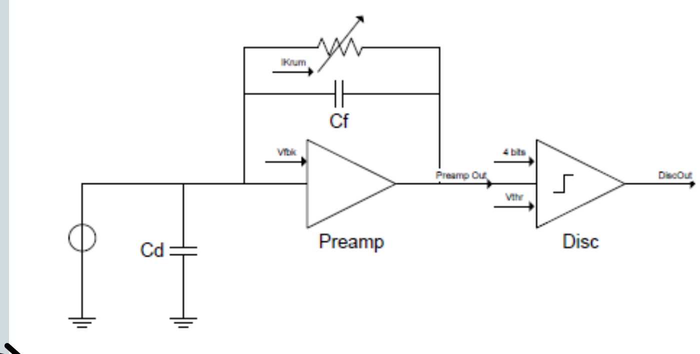
- Replace shutter based readout/acquisition scheme by continuous, deadtimeless operation
- Sustained readout of pixels with maximum flux 5 particles /cm²/25 ns
- Reduced ToT range and resolution
- Add bunchtime identification good within 25 ns

Timepix Evolution

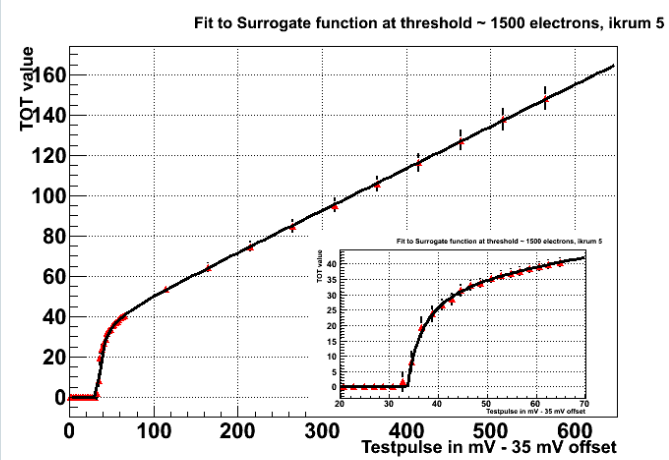
- Timepix2 is an important step towards Velopix
  - Similar front end
  - Fast column bus
  - Data Driven readout
  - Simultaneous Time Over Threshold and Time of Arrival measurements
- Timepix2 by end 2011
- Aim to have first Velopix by 2012

VELOPix: analog front-end requirements.

- Reduce timewalk: <25 ns @ 1ke$^-$ threshold.
  - Faster preamplifier and discriminator of Timepix2 covers and exceeds this requirement
- I_{krum} range 5 …40nA
  - ⇔ sensitivity 750 … 6000 e$^-$/25ns.
  - ⇔ 20 ke$^-$ signal returns to baseline in 660 … 83 ns



- Reduced non-linearity near threshold.
- Analog power consumption <10 uW/ pixel.
- Higher preamplifier gain (~50mV/ke$^-$).
  - reduced ENC, lower detectable charge (~500 e$^-$)
  - reduced linear range (30 ke$^-$) : better suited to Si -tracking
- Design by X.Llopart(CERN) and V.Gromov (NIKHEF) very advanced.



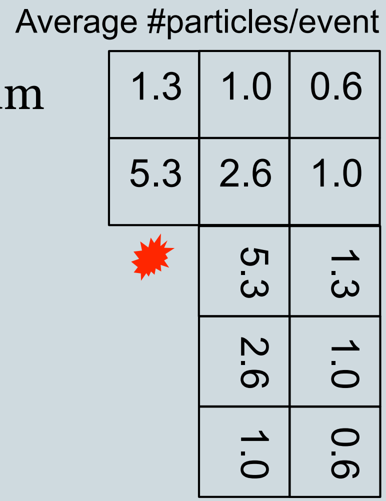
VELOPix:

- Digital :
  - Simultaneous 4 bit Time-over-threshold and time identification (12 bit).
  - Data loss must be kept < 0.5% in worst conditions (6kHz pixel hit-rate).
    - Limit ToT < 400ns.
    - Adequate buffering & bus speeds.
  - Data driven readout.
  - SEU protection of logic & registers.
  - multi-Gbit/s output links : 4 x 3.2Gb/s#
  - Design of superpixel, column bus and EOC logic very advanced (Tuomas Poikela).
- Total power budget <3W full chip.
- Radiation hardness TID 400Mrad.

Data rates

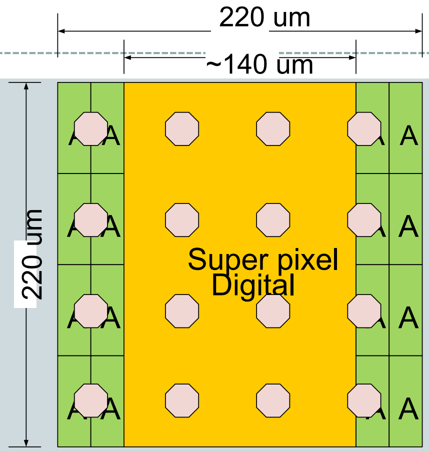
- Numbers at highest occupancies:
  - average particle rate per 'hottest' asic ~ 5 particles/25ns = 200MHz
  - average pixel cluster size ~2: (pessimistic assumption, 200um Si)
- Information bits per hit pixel : 32
  - 4 bit : Time over Threshold value.
  - 12 bit : bunch identification
  - 16 bit : pixel address.

  => Single asic data rate can reach 13 Gbit/s !

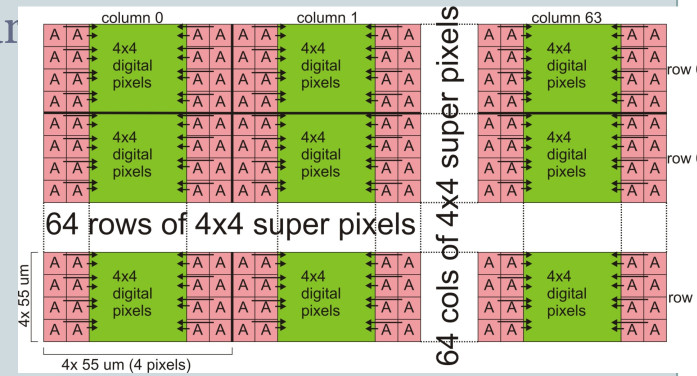


- 30% data reduction can be achieved by 'clustering' data:
  - share the bunch id (12bit) and address bits between neighbor pixels.
  - must be done before column readout, i.e. inside pixel array !
  - most efficiently done in units of 4x4 pixels = "Super pixel"

Super pixel



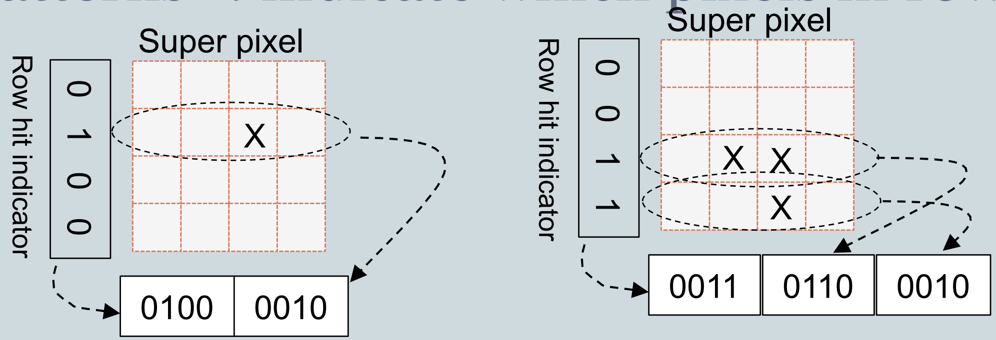
- Super pixel layout: group digital logic in a common area.
  - Advantages:
    - Space saving : some functional blocks can be shared (time-multiplexed).
    - More efficient routing of power rails and global signals.
    - Better analog/digital isolation.
    - Digital column logic is synthesized with standar library. Ease, reliability, yield …
  - Disadvantages:
    - bump pads on top of digital circuit:
      => digital feedback in analog frontend. Shielding ?
    - Non-uniform analog input capacitance:
      => Only small effect



- Status:
  - The verilog code for superpixel and digital column exists and has been laid out (Tuomas Poikela). Final simulations are done. Worst-case power estimate is ~840 mW, including clock distribution.
  - Use of a 'lower speed/lower power' library for IBM 130nm gives savings in space and power!

VELOPix. Address encoding

- Address encoding in 4x4 super pixel :
  - Super pixel address : 12 bit.
  - "Row hit indicator" : indicate which rows have hits (4 bit, always present).
  - 0 to 4 "row hit patterns" : indicate which pixels in row are hit (4bit).
  - Examples:

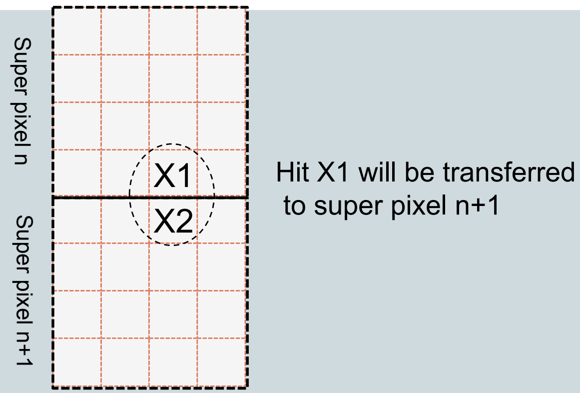


  - Gain compared to individual pixel address
  - Overall 20% data reduction

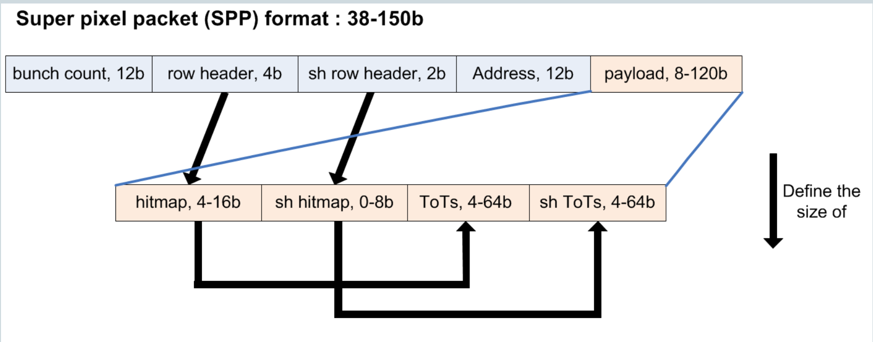
# hits	Individual address	Row hit encoding
1	16 bit	20 bit
2	32 bit	24 bit
3	48 bit	28 bit
4	64 bit	32 bit

ASIC design. Data reduction

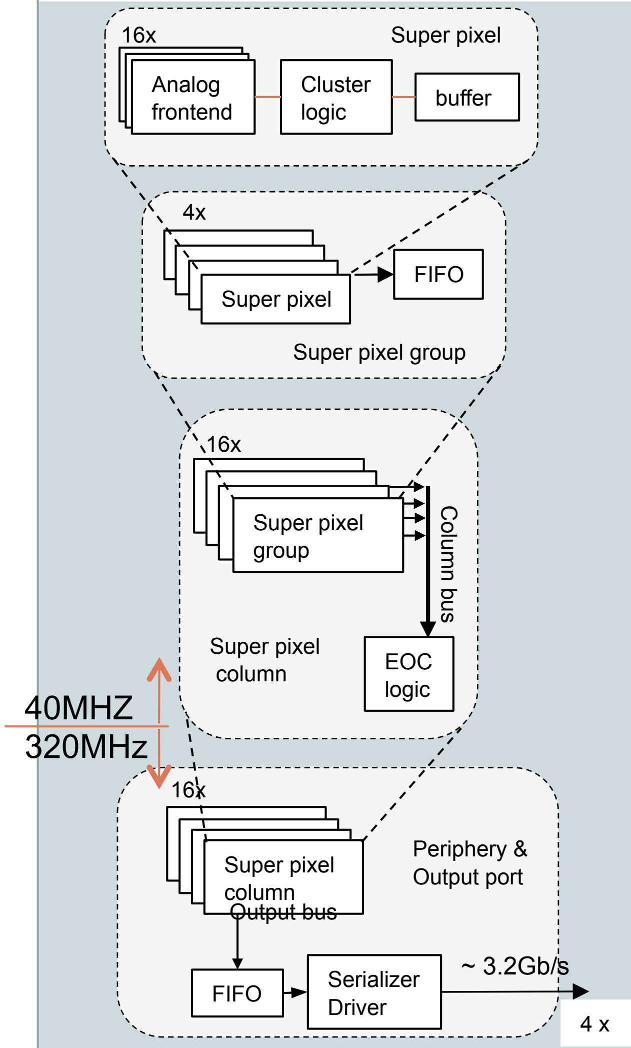
- Sharing across super pixel boundaries :
  - Only in 1 direction (column)
  - Results in additional 10% data reduction.



- Reject large multiplicity event :
  - If hit > N then no readout. (N is configurable and can be de-activated).
- Packet format:



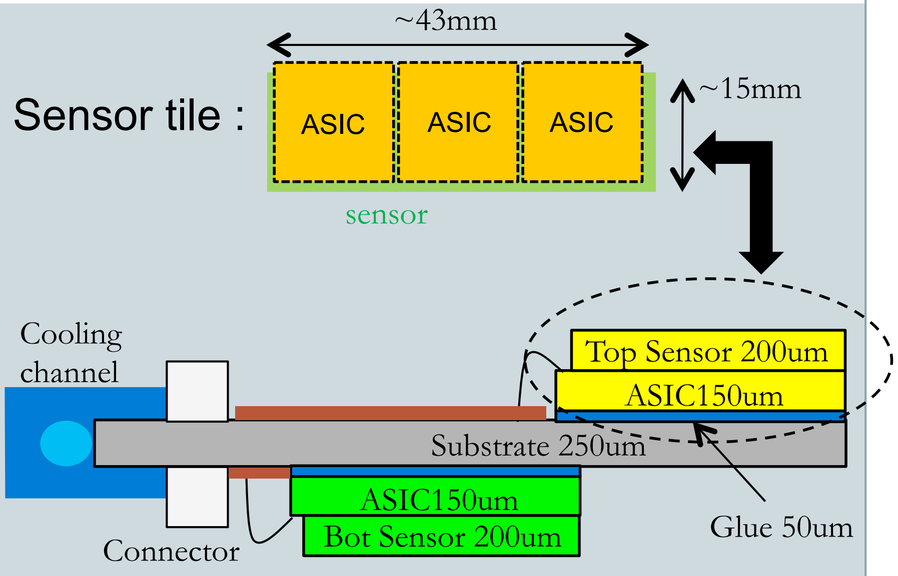
Pixel matrix readout architecture.

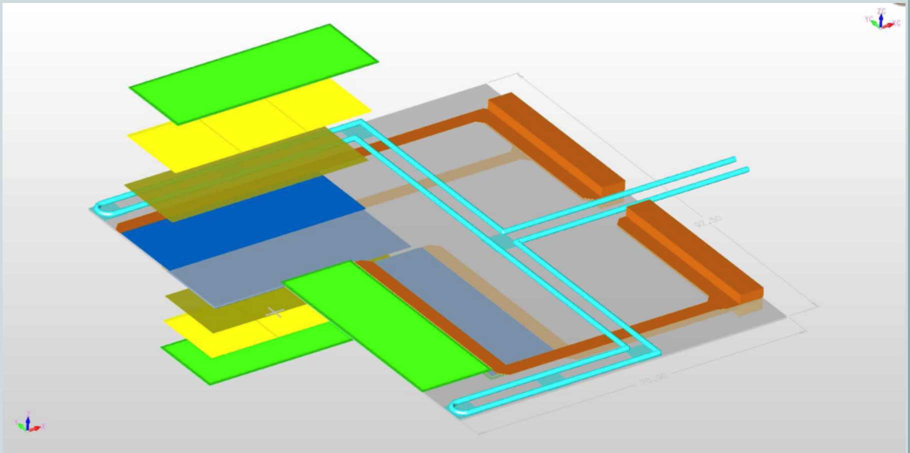


- Pixel matrix readout architecture
  - Internal bus speeds:
    - Column bus : 8bit@40MHz=320 Mbit/s
      - Token ring arbitration.
    - Output bus : 16bit@320MHz=5 Gbit/s
  - Total ASIC output : ~12.8 Gb/s.
  - Buffering in :
    - Super pixel : 2 clusters.
    - Super pixel group FIFO : 3 clusters.
    - Output FIFO: multi kbyte
- Simulation shows losses< 0.5% in highest occupancy conditions.
- Periphery & output links are under study.

VELO Pixel module.

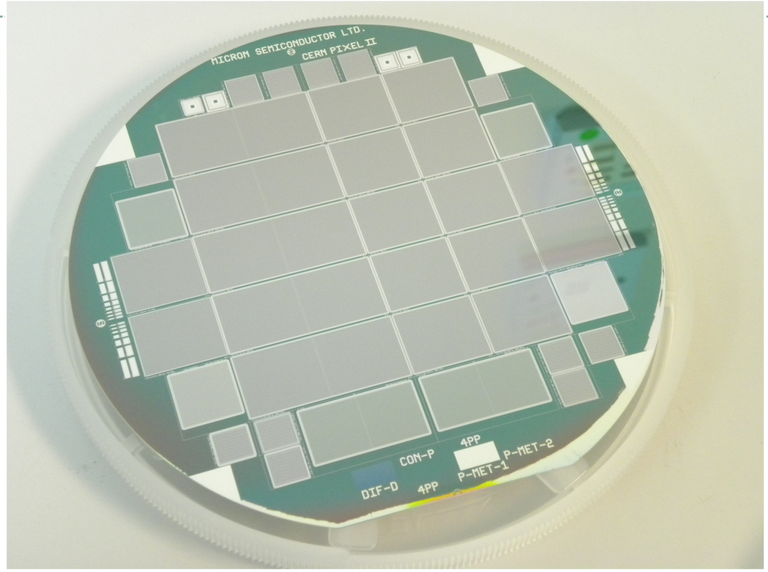
- Sensor tiles: made of 3 readout ASIC's on a single sensor, with a guard ring of 500 um.
- 2 sensor tiles are mounted on opposite sides of the substrate.
- Substrate choices:
  - Diamond : excellent mechanical and thermal properties: => low mass
  - Carbon fiber/TPG or Al/TPG.

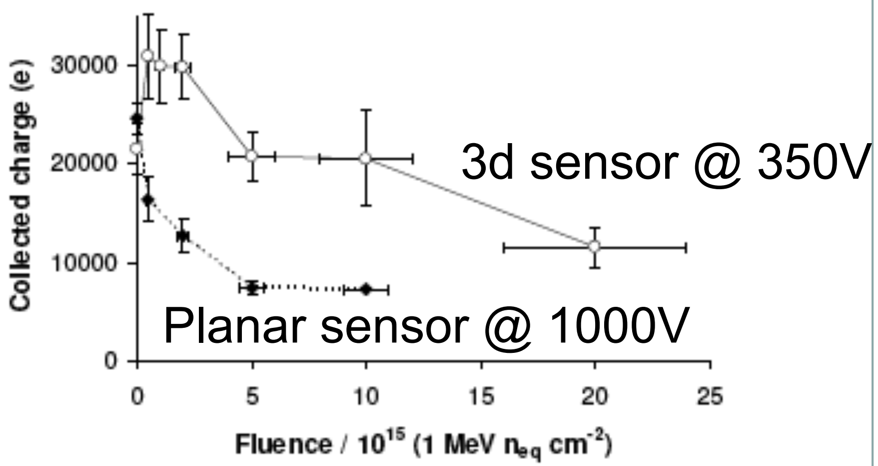




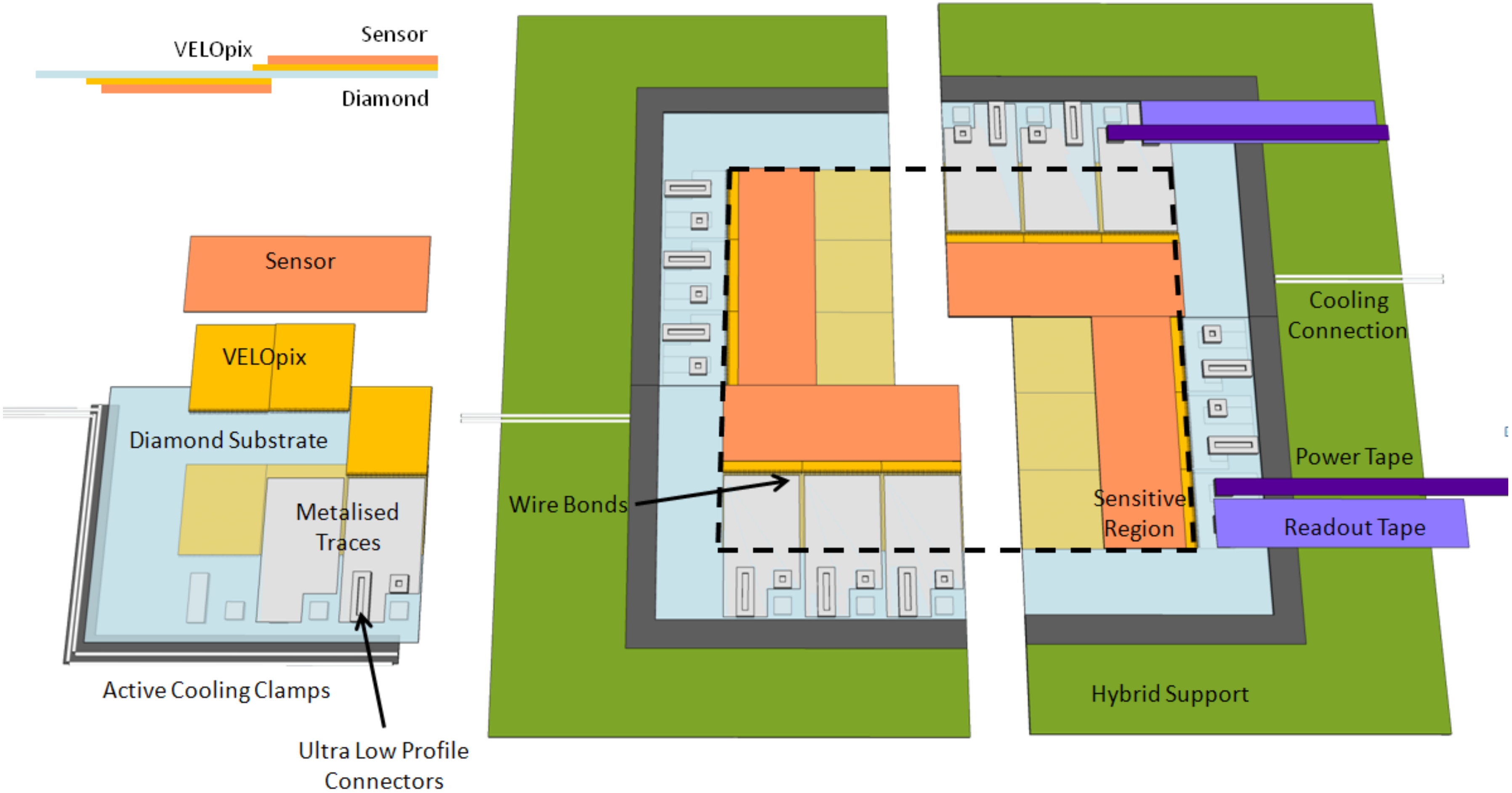
Sensor R&D

- Planar silicon
  - Thin sensors seem well suited to the high fluences
  - R&D focussing on guard rings
  - Several wafers in the pipeline with various manufacturers
  - Irradiation of planar silicon + Medipix3 assemblies starts in May
- Diamond
  - Exciting option for removing thermal runaway headache
  - Very radiation hard
  - Double act: sensor and thermal path
- 3d sensors
  - Potentially Super radiation hard
  - Many Medipix/Timepix assemblies available



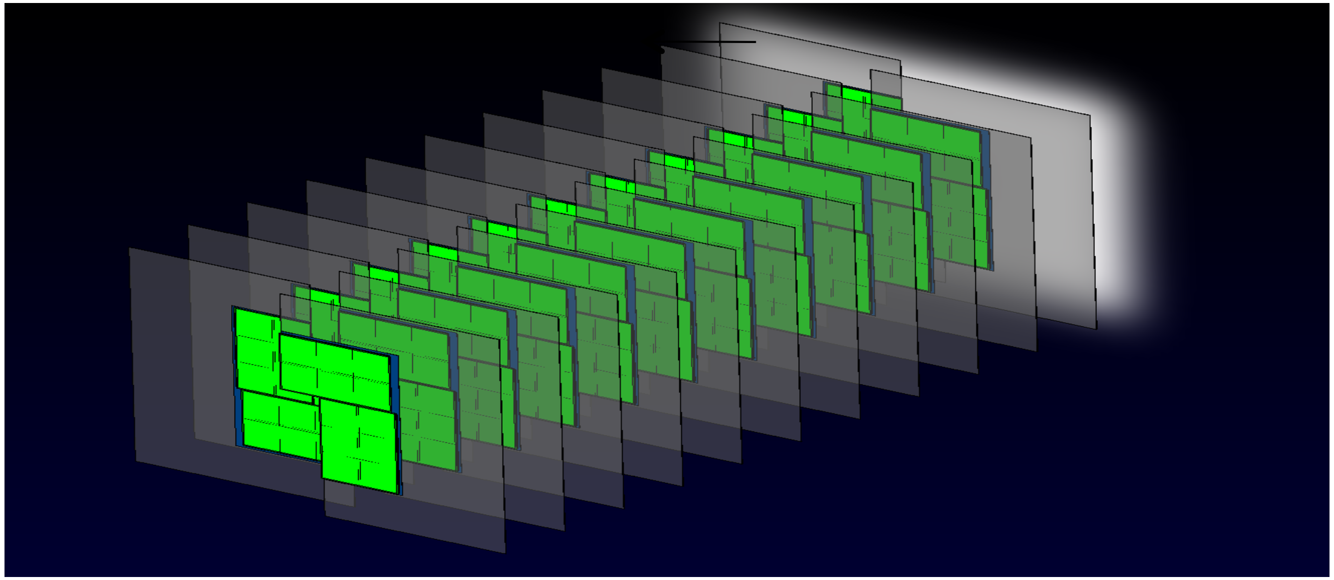


Module layout



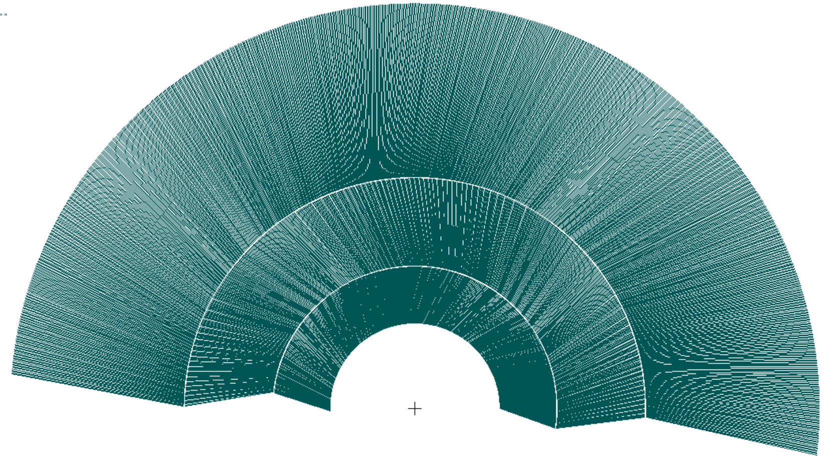
VELO Detector layout.

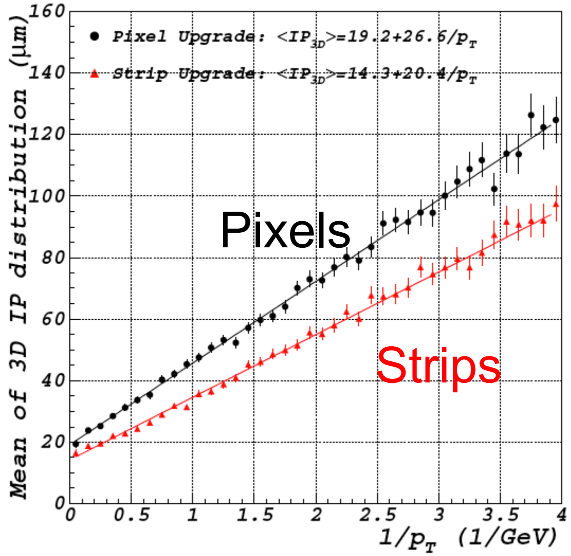
- The full detector is composed of 26 planes.
- The modules on either side of the beam are staggered to create overlap regions.
- This layout has been simulated to be fully efficient (4 hit per track) in the LHCb acceptance 250 x 300 mrad.



Strip Option

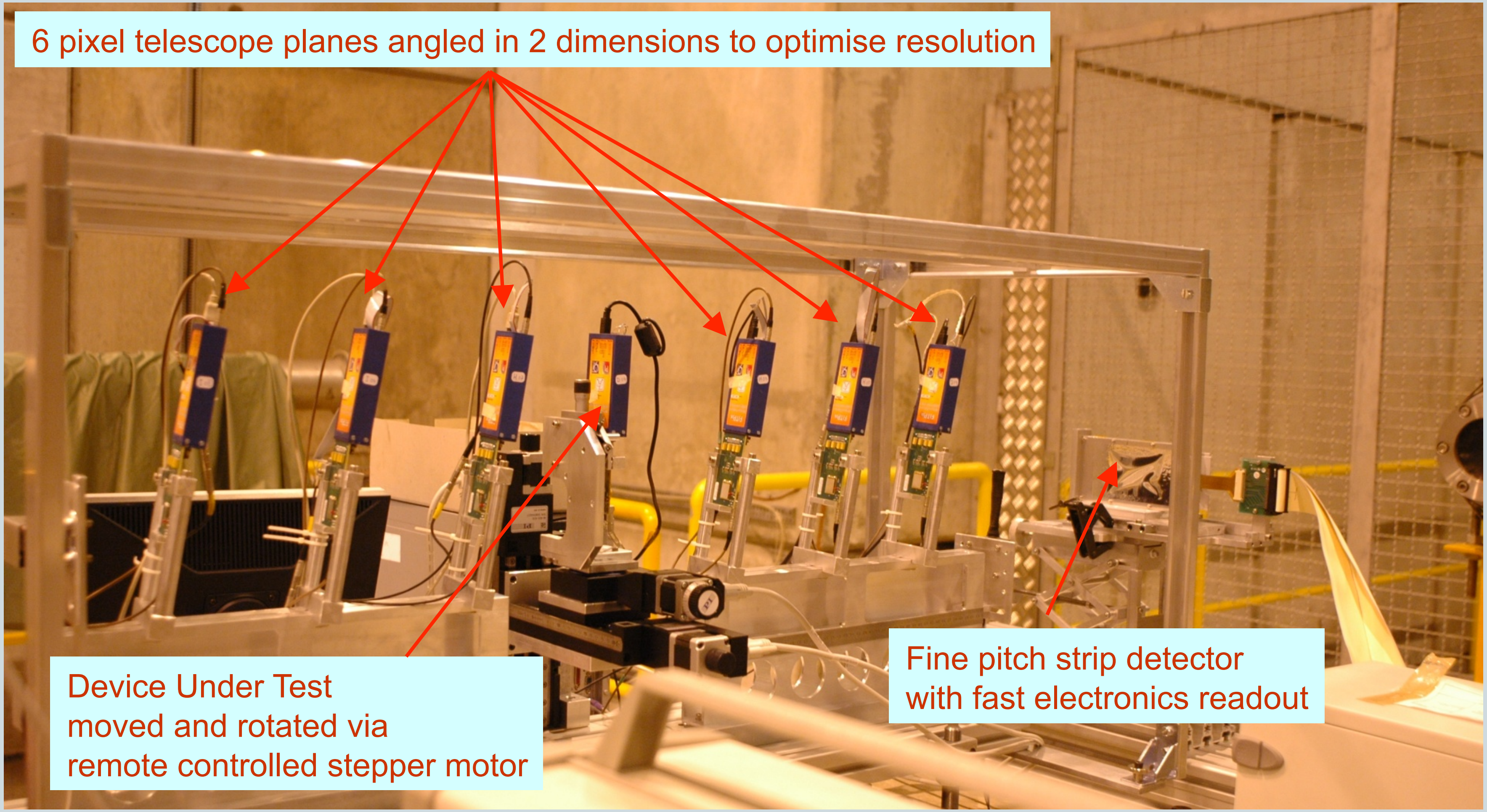
- In case the material budget/power consumption of the pixel option falls beyond specifications or time limits, a backup strip option is being prototyped.
- Key points:
  - Optimisation of strip capacitance to bring down noise
  - Possible move to “spider web”
  - Increase in number of strips and better layout – expected occupancy at upgrade will be 0.5% for first phase
  - New chip also needed (synergy with IT)
  - IP resolution superior to pixels





Timepix Telescope Arm Prototype early 2010

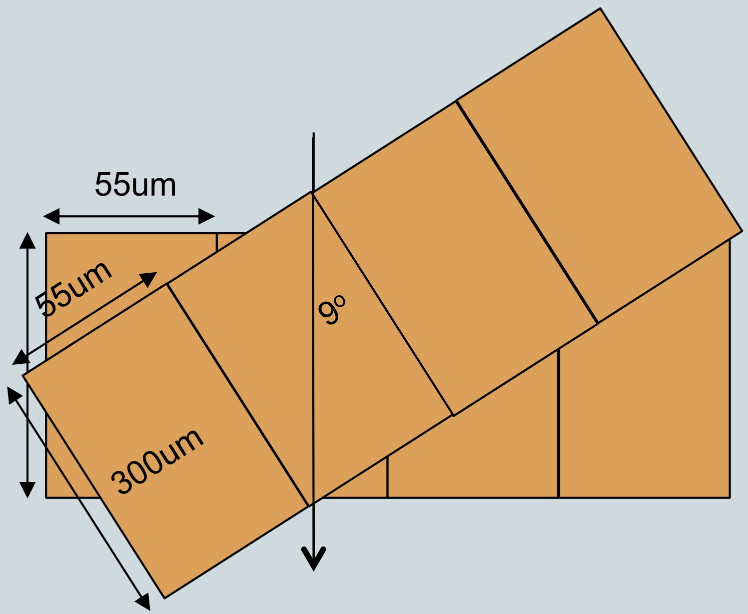
USB2 readout – 700 tracks per second

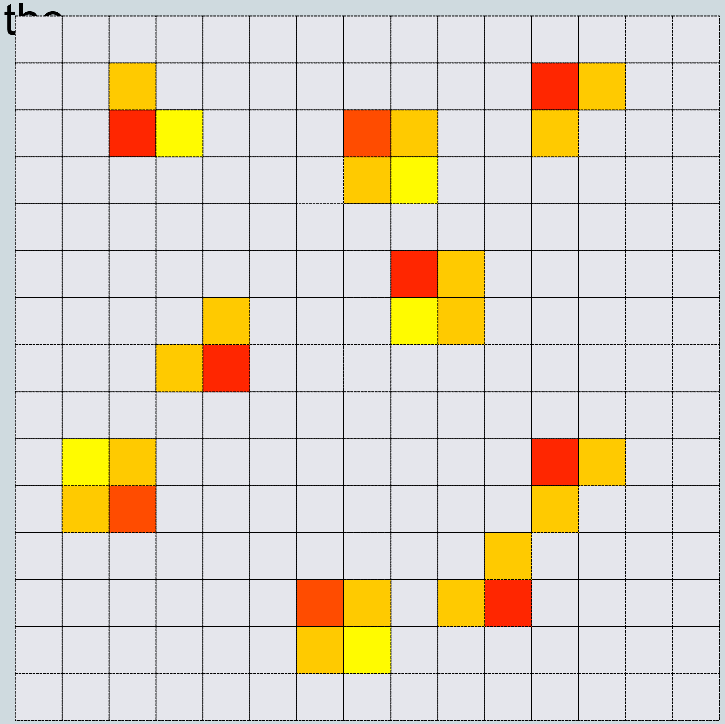


Angled Planes to Boost Resolution

Hits that only affect one pixel have limited resolution (30um region in 55um pixel)

Tilting the sensor means all tracks charge share and use the ToT information in centroid, CoG calculations

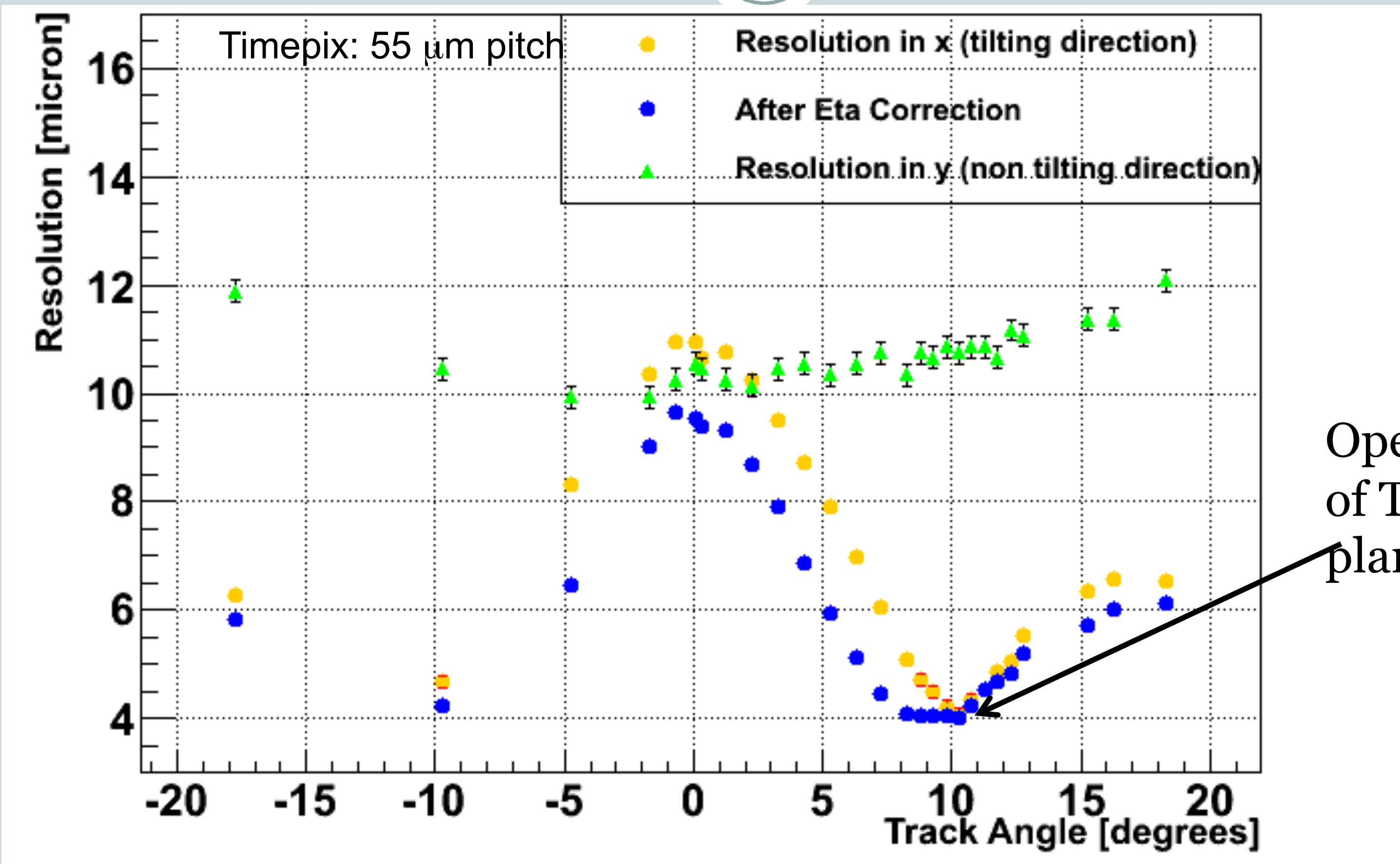




Indicative Timepix events

Perp ~10um resolution
9°   <4um resolution

Timepix Telescope – Resolution per Plane



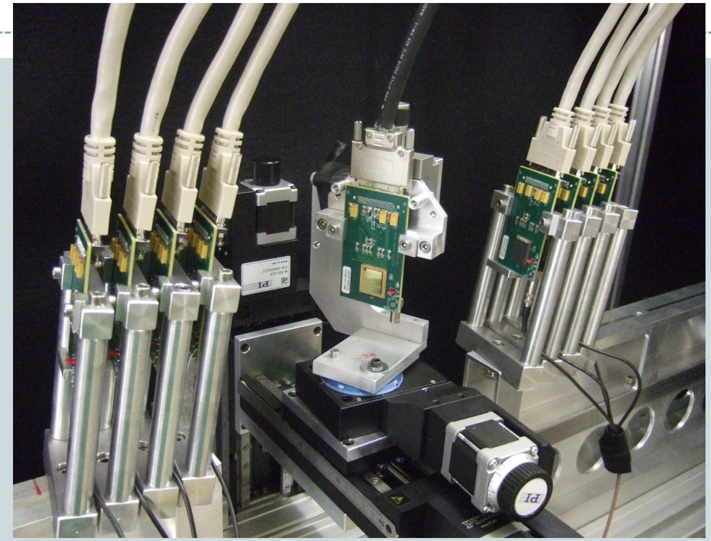
Operating point of Telescope planes

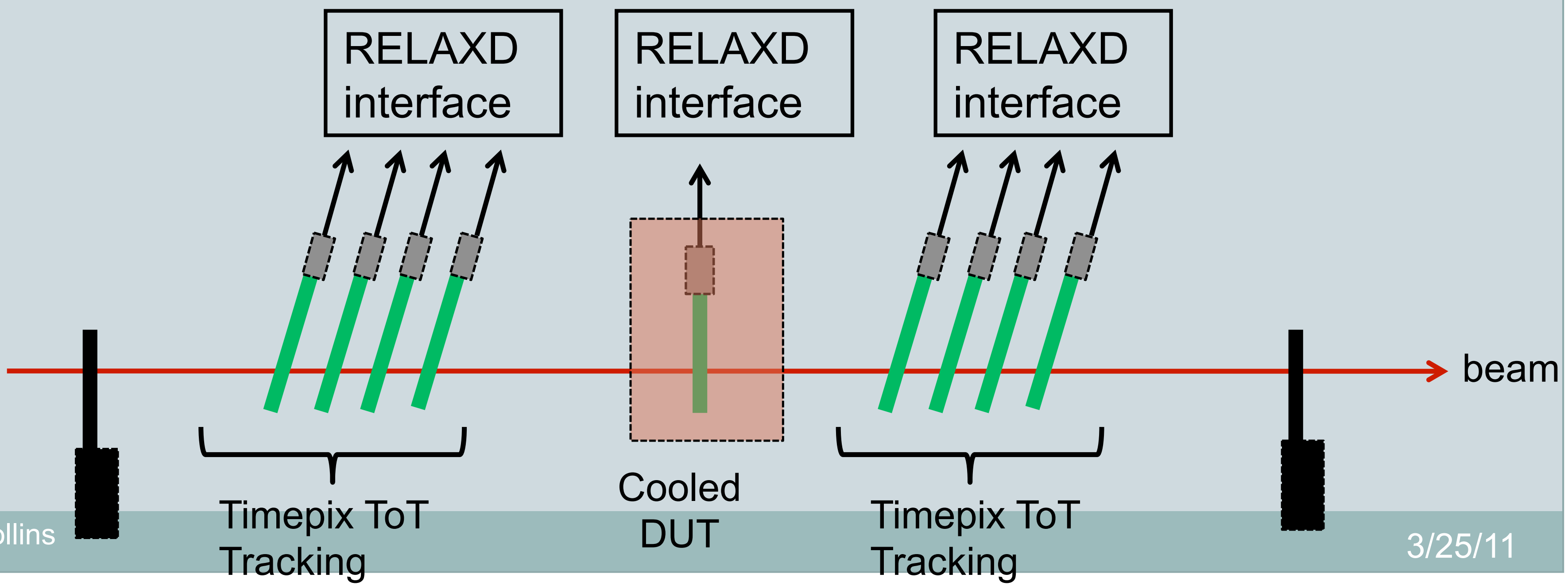
Resolution measured at Testbeam
Resolution per plane 4um
Resolution at Device Under Test (with 8 planes) 1.6um

Timepix Telescope Arm Prototype late 2010

- RELAXD readout from NIKHEF
- 55 frames per second over gigabit Ethernet
- 5,000k tracks per second readout

50,000,000 tracks recorded in 2 weeks
Eight different DUTs analysed

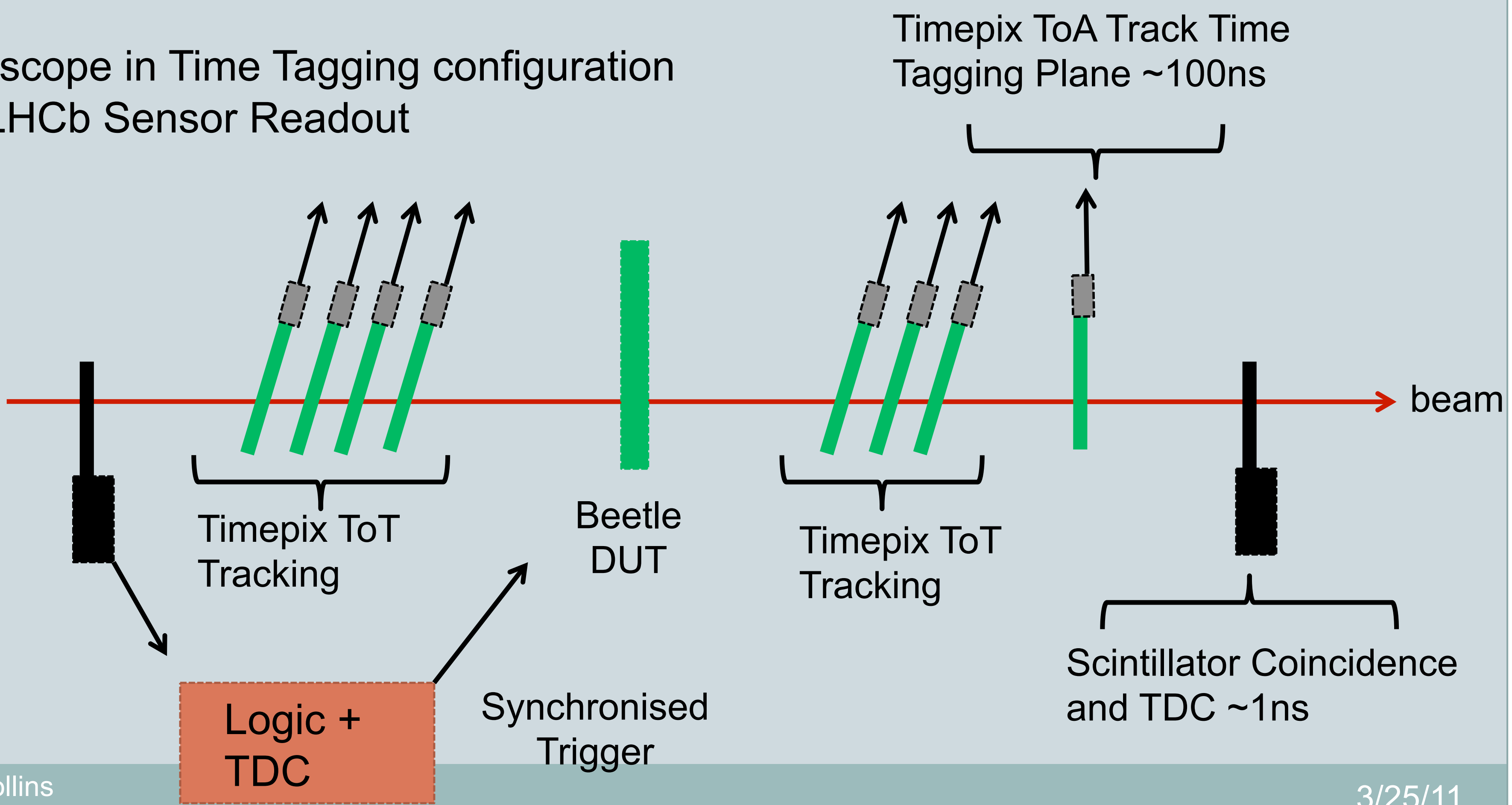




Added Time Tagging Capability to ~1ns

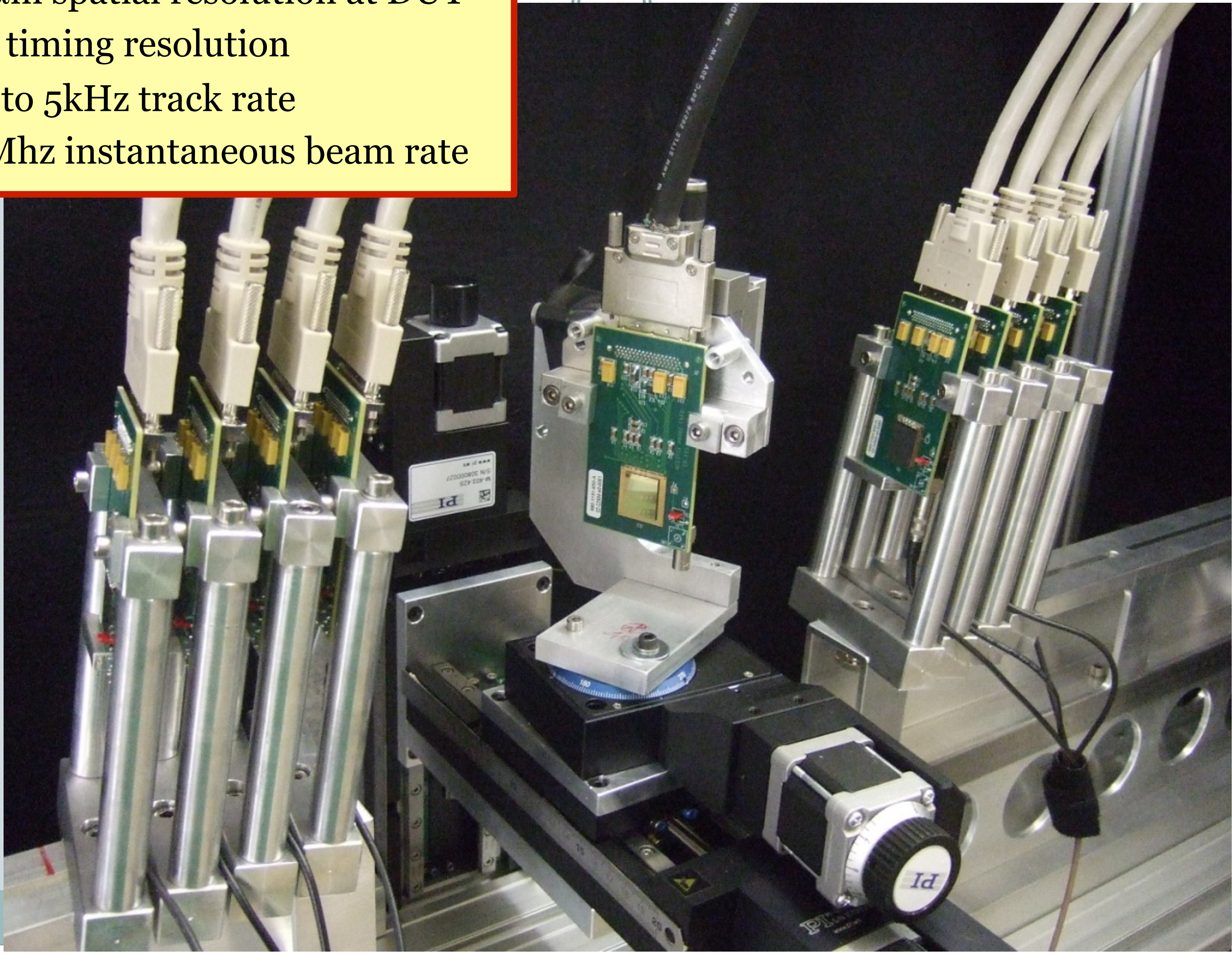
- Asynchronous SPS beam not suited to LHC systems designed for 25ns bunch structure
- Implemented a TDC which with Timepix ToA mode gives us ~1ns per track time stamping
- Able to provide and record synchronised triggers to 40MHz readout systems (TELL1

Telescope in Time Tagging configuration for LHCb Sensor Readout



Timepix Arm Performance Summary

- 1.5µm spatial resolution at DUT
- 1ns timing resolution
- Up to 5kHz track rate
- >1Mhz instantaneous beam rate



Links to AIDA Project

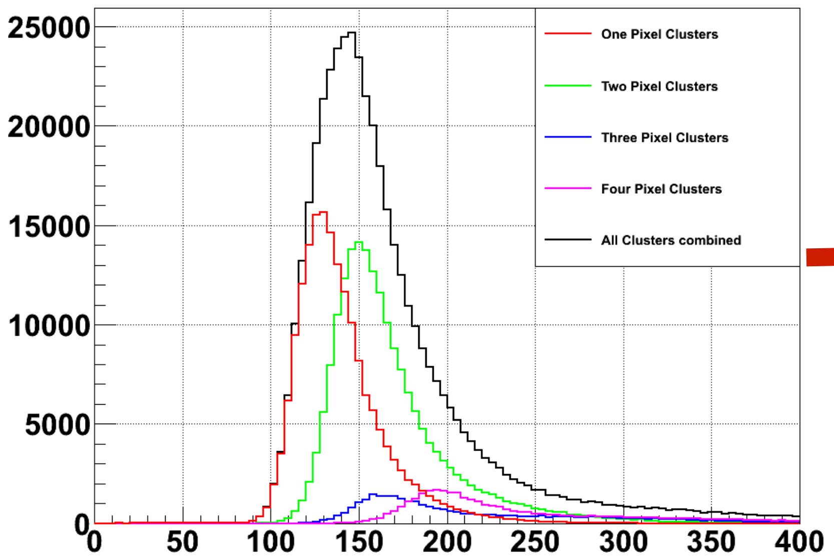
- Timepix Telescope arm is a AIDA Deliverable
- We have many exciting common areas of development

- Trigger Logic Unit: Currently we use 2 NIM crates and a VME TDC to perform timing tasks
  - Controlling the Shutter – eg selecting X particles per frame
  - Providing triggers to external systems
  - Measuring the phase between synchronised and unsynchronised triggers
  - Santiago University in collaboration with the AIDA team are developing a portable based TLU replacement
- Other areas of overlap under investigation

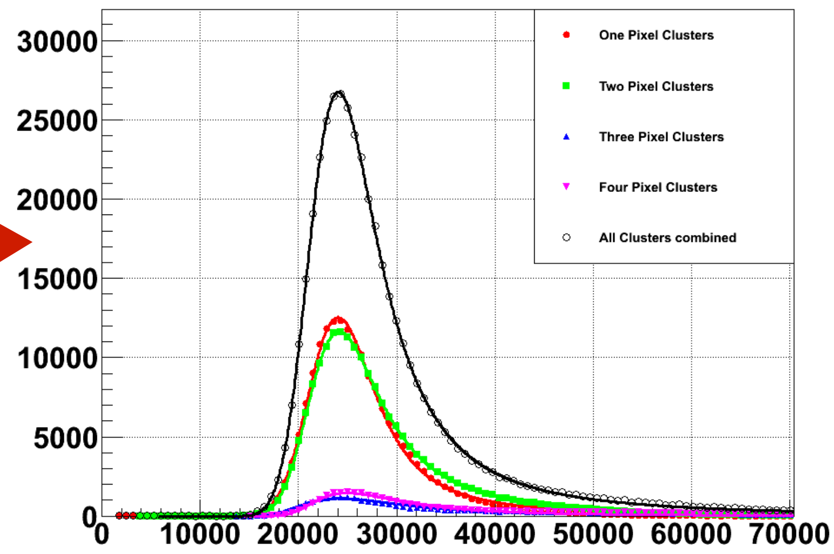
Timepix data analysis

- Calibration of chip under excellent control
- Many lessons learned for Timepix2 design and necessary useful features for calibrating final chip
- 1st paper submitted: http://arxiv.org/abs/1103.2739

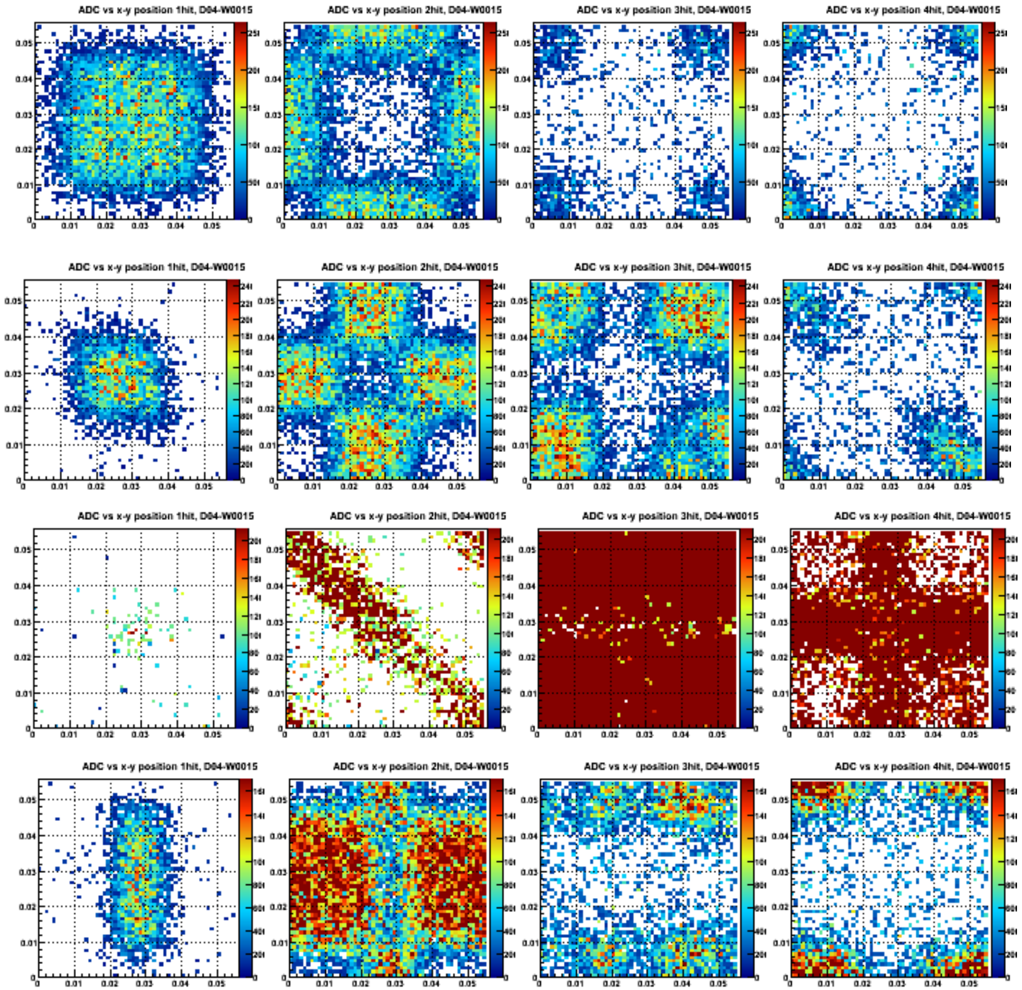
Before Calibration



After Calibration

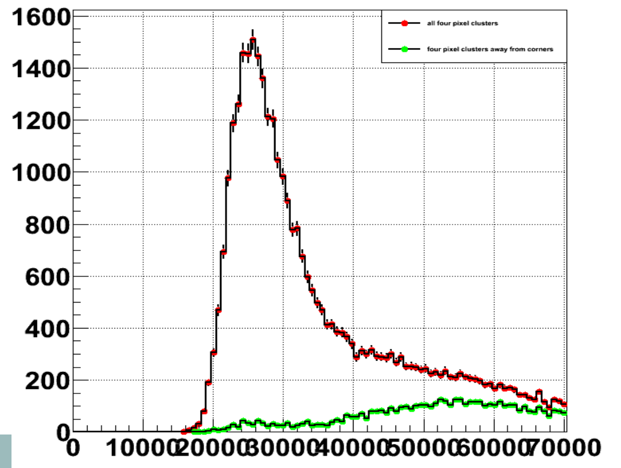


Scanning the pixel cells

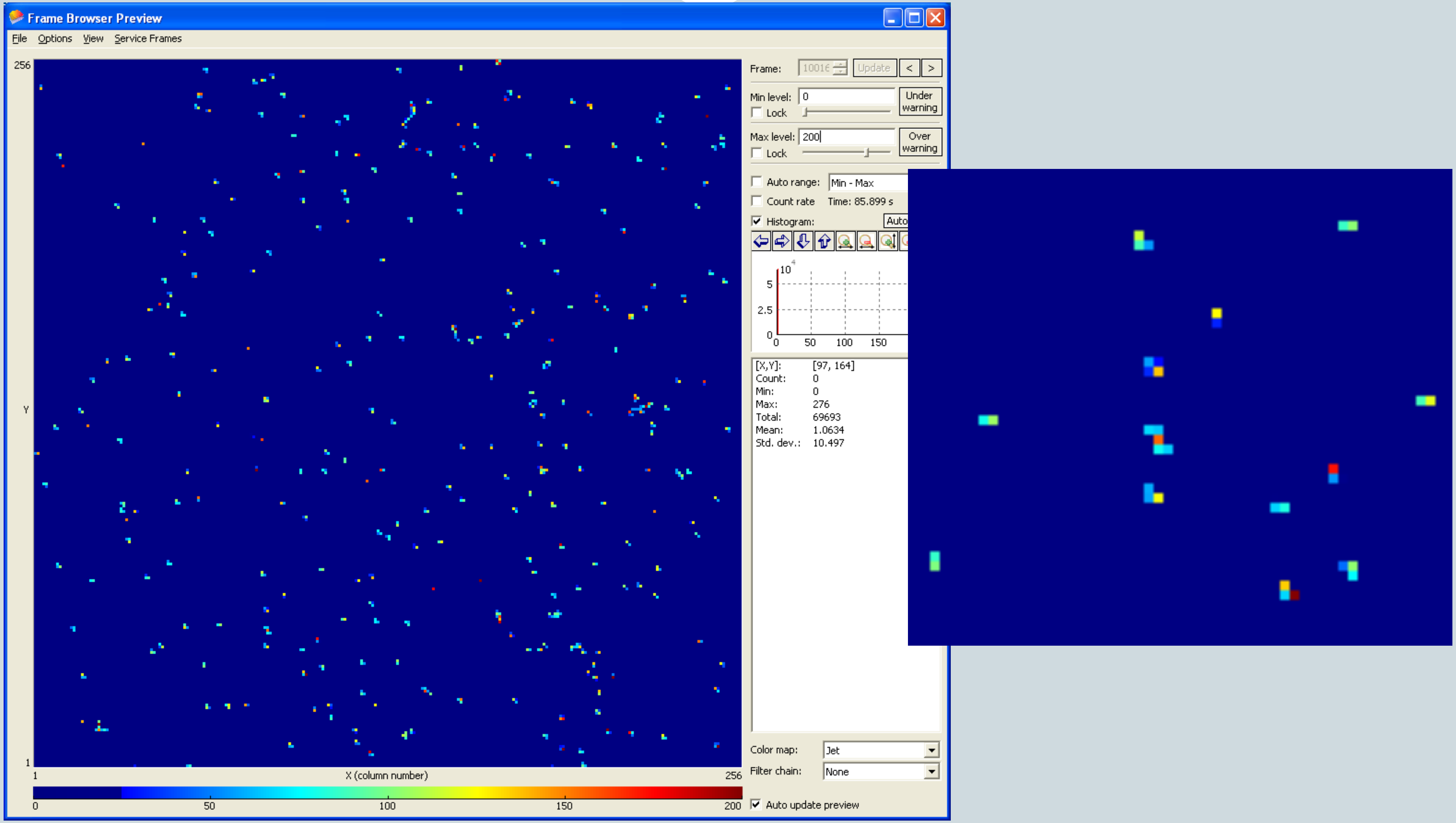


Very precise tracking allows us to probe all kinds of details within the pixel cells, allowing us to to

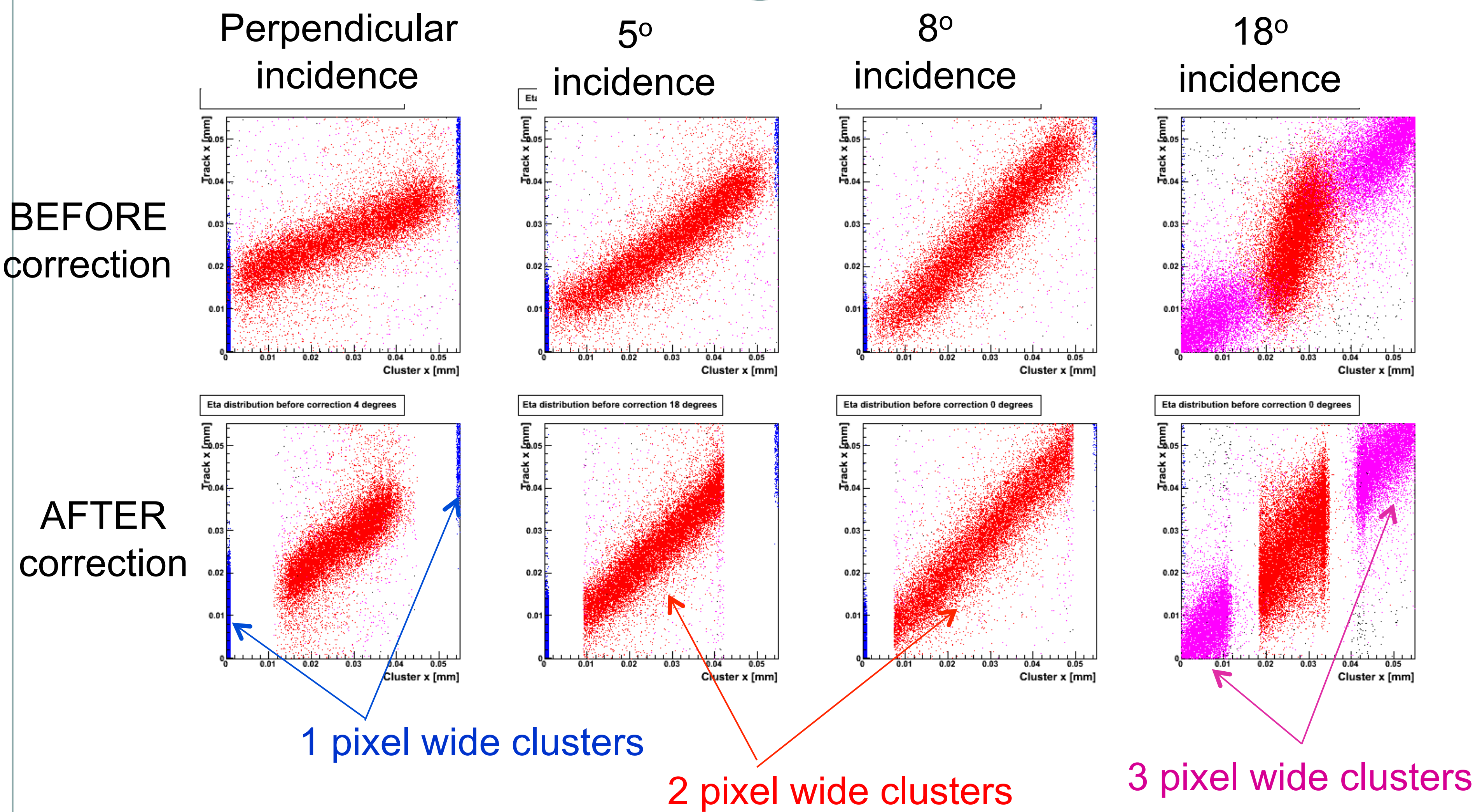
- Identify delta rays
- Investigate threshold effects
- Measure pixel diagonal resolution
- Measure timewalk
- Measure efficiency etc. etc.



Example Frame from 2010 Testbeam

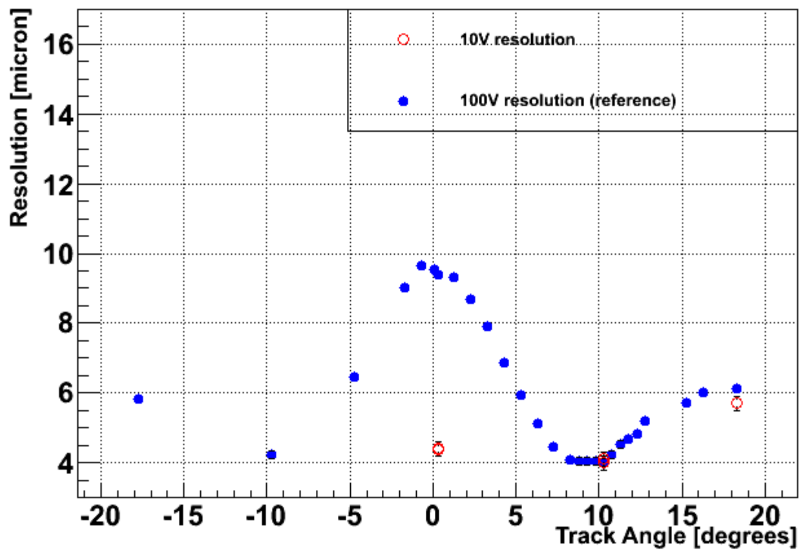


Very precise studies of eta distributions possible



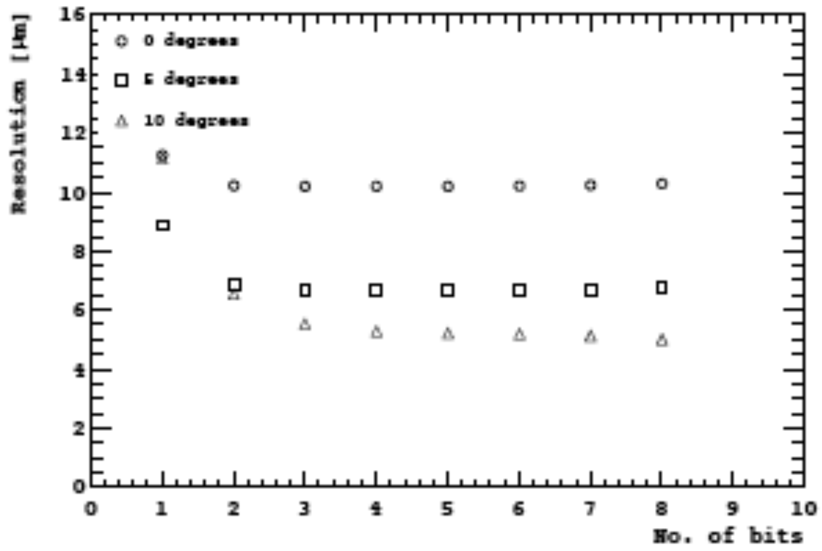
A few highlighted results:

Resolution as a function of angle



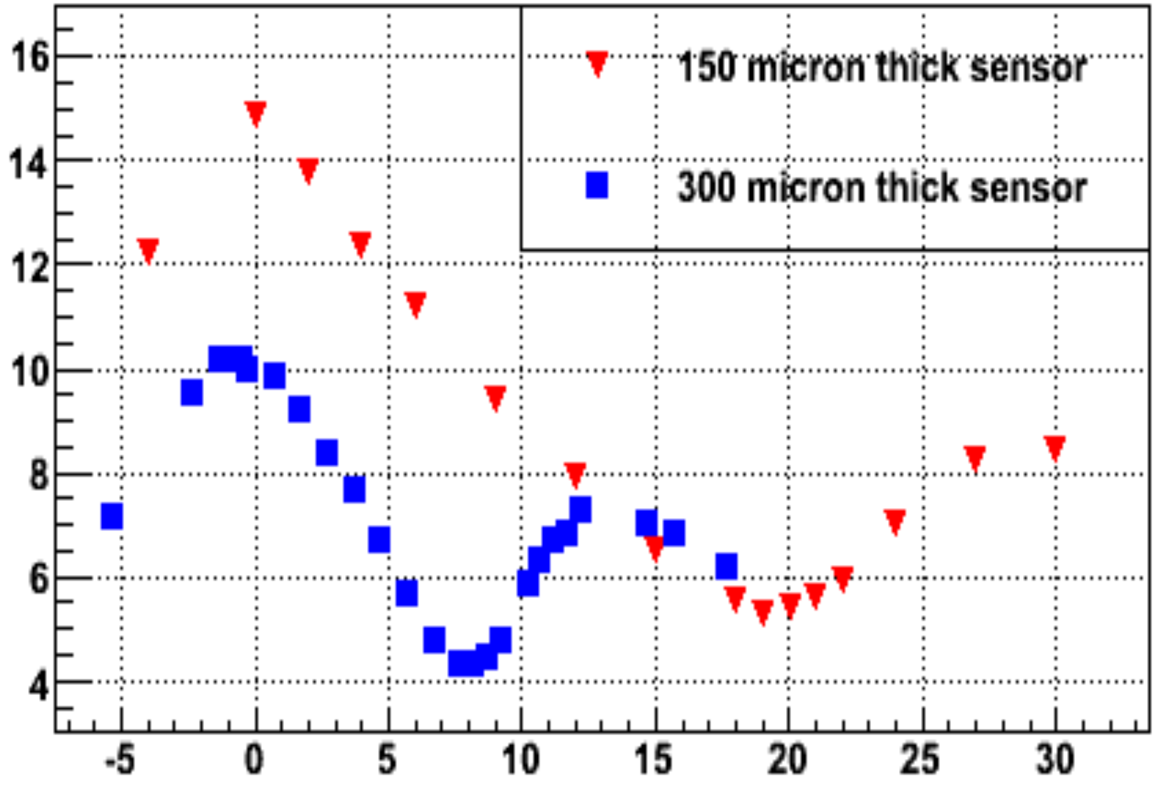
10V data (close to depletion)
100V data (overdepleted)
There is an enormous gain at lower voltage
Possible advantage for VELO under investigation

Resolution as a function of # bits



Resolution as a function of number of bits (shown for three different angles)
Input to Timepix2/Velopix design
4 bits and above are safe
3 bits is close to resolution degradation

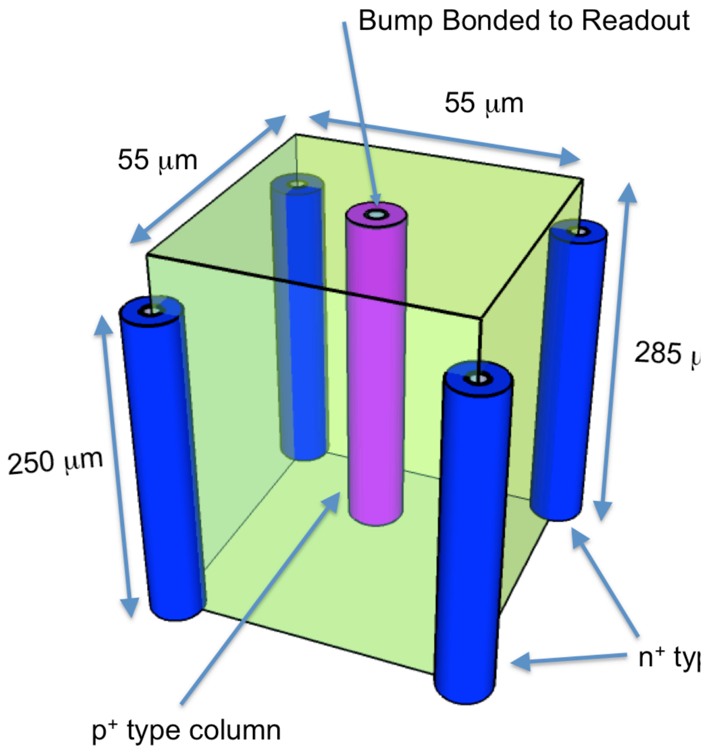
Thin vs Thick

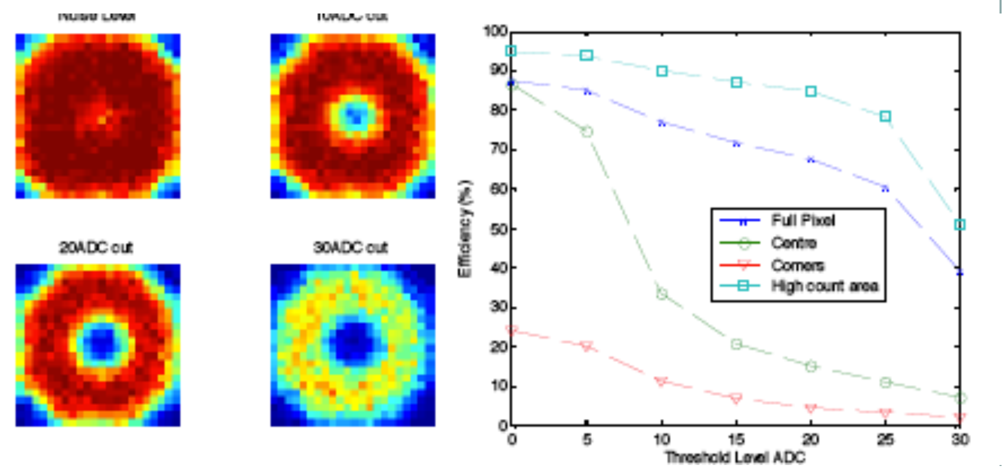


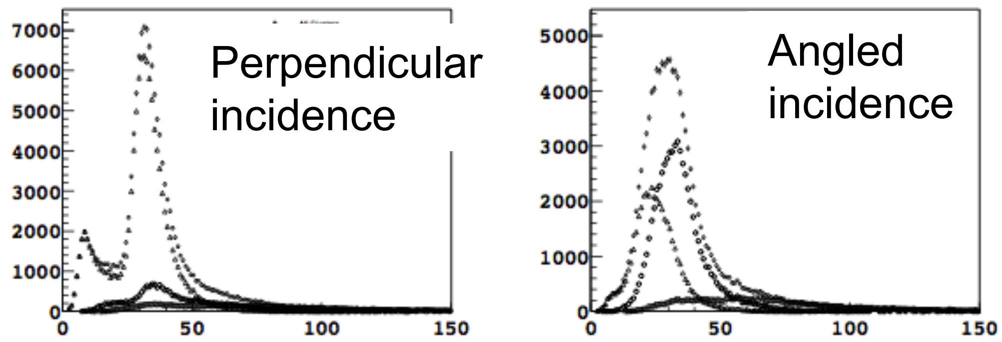
Thin sensors: Direct comparison of 300 and 150 μm thick sensors in identical conditions

3D sensors

3d device: Detailed characterisation of 3d device and direct comparison to planar sensor. Irradiated sensor also evaluated





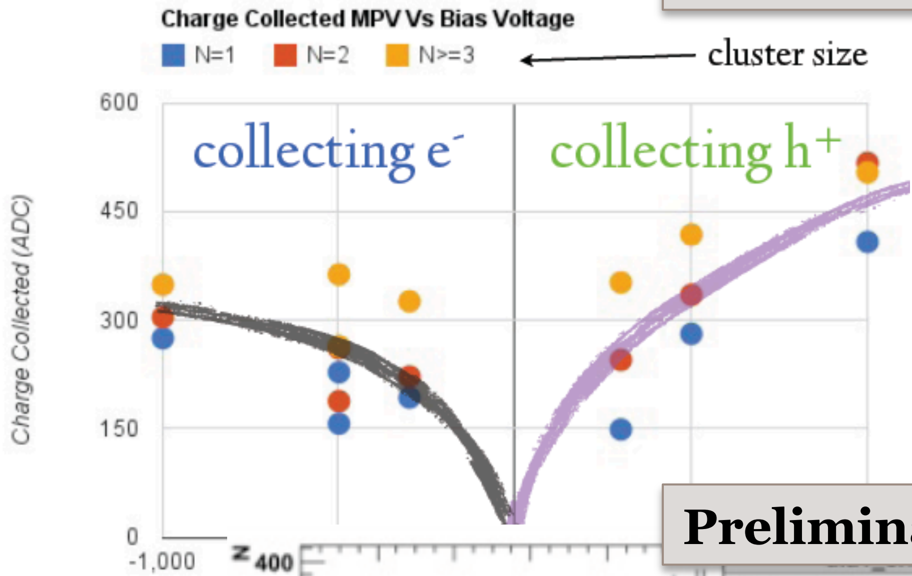


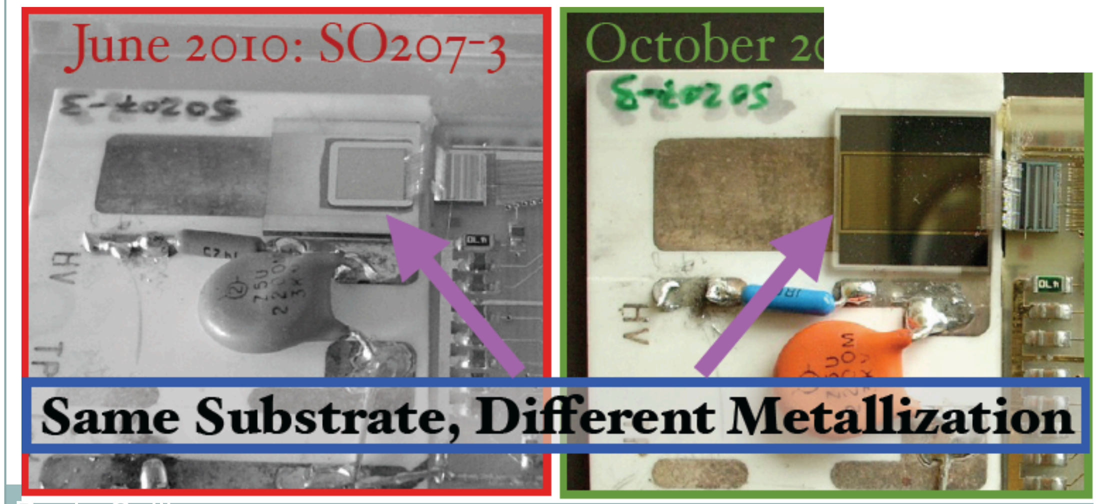
Landau distributions for different cluster sizes

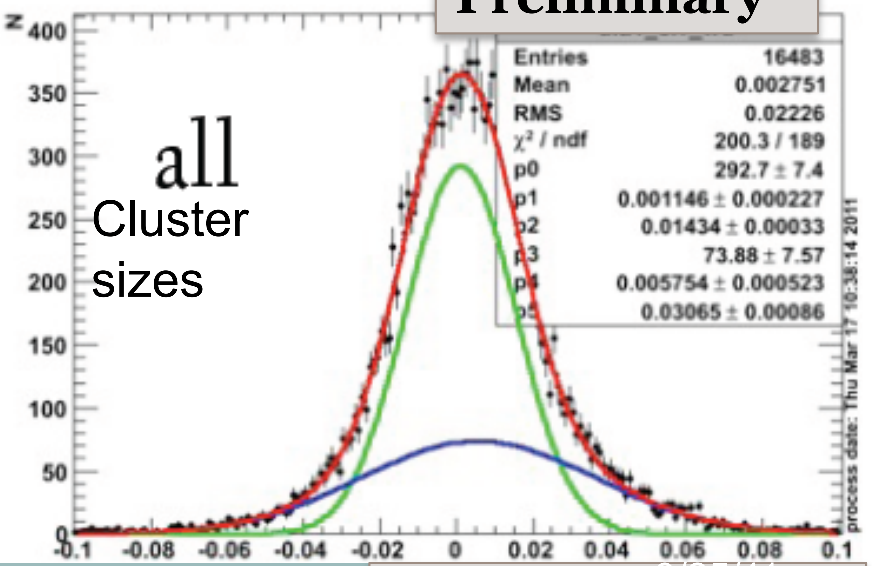
R&D on pvCVD diamond sensors Strasbourg telescope

Goal: produce 400 μm sensors and compare their performance with 150 μm Si at different level of irradiation

First step: laboratory and test bench studies of 750 μm sensors in a test beam (CERN RD42 test beam with Strasbourg telescope)





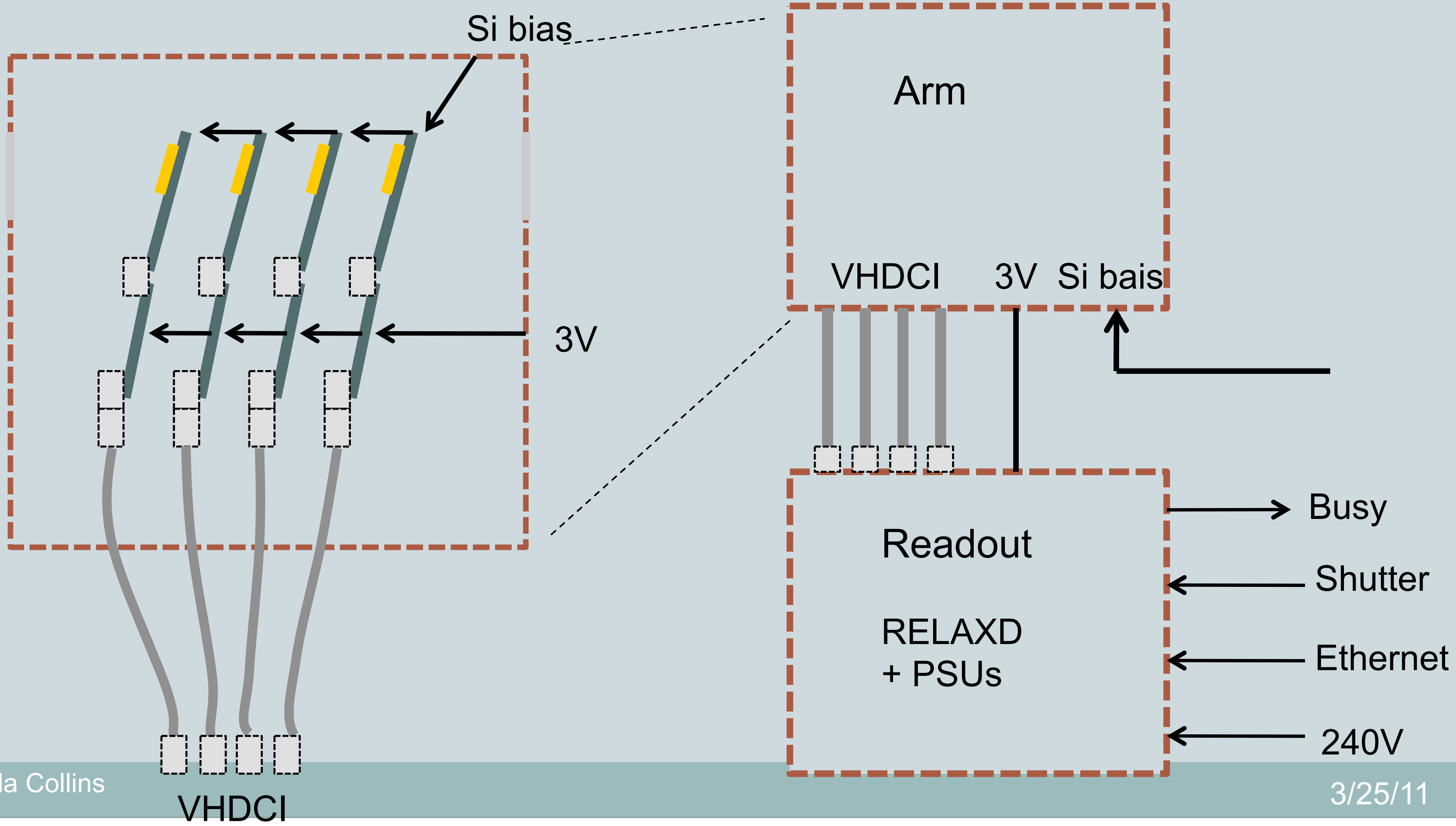


Conclusions

- The VELO upgrade is on course for 2017/2018 installation
- The VELOPix ASIC is an ambitious and performant chip on course to deliver the needed specifications for the VELO modules
- The LHCb physics programme is on course to deliver full results with the first phase of operation and looks forward to a great, upgraded future
- Hope I've been able to give you a "flavour" of what we are doing – Thanks for listening

Moving to Full Telescope Arms

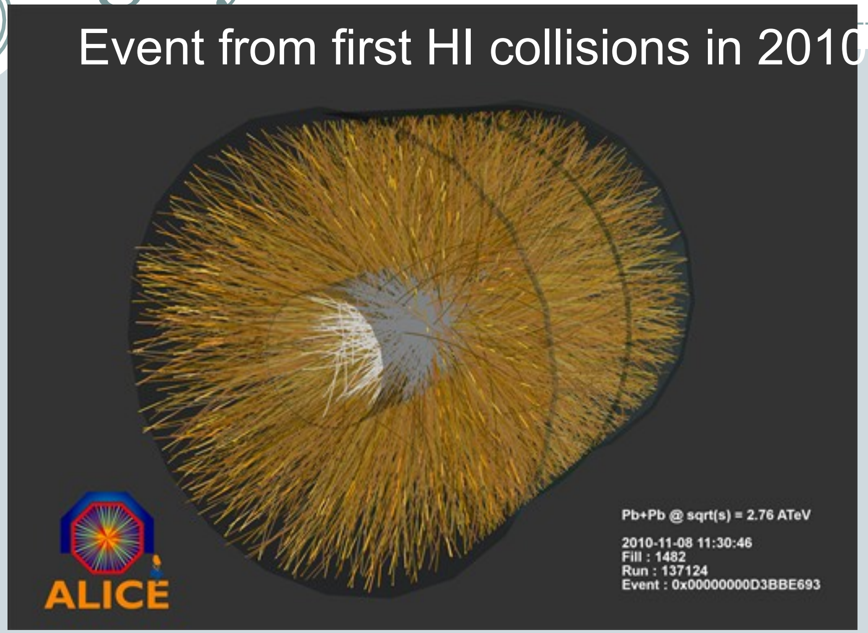
- Major hardware work remaining is to make the system easier to set up and use
- Very strong overlap with proposed AIDA work

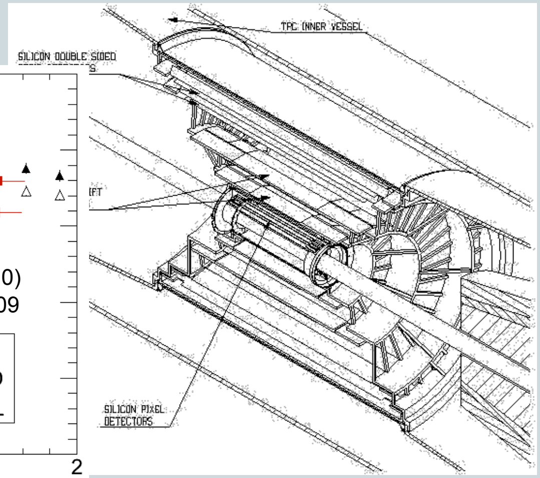


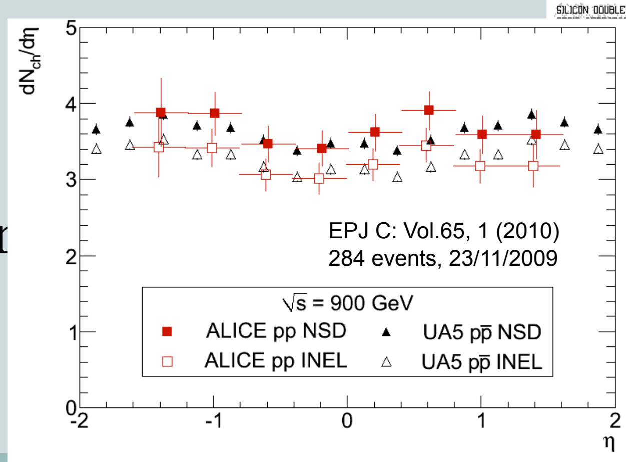
ALICE Inner Tracking System - ITS

ITS consists of 6 concentric barrels of silicon detectors (pixels, drift, double sided strips)

- Radial coverage from 3.9 cm to 43 cm)
- 2D devices (pixels and drift)
- PID with drift and strips
- Total material budget ITS <8% X_0, pixels 1.14 % X_0 per layer
- Pixel trigger: each pixel chip creates FastOr signal which is contributing via dedicated trigger system to the L0 trigger decision (bg-noise rejection in p-p, event selection in HI)







Medipix2 Applications

- The most commercialized of the current chips and being sold by PANalytical (NL) in X-Ray Diffractometers

- Also active applications in
  - Material Analysis
  - Medical Imaging
  - Synchrotron Light Source Instrumentation
  - Micro CT material analysis
  - Proton Beam Monitoring (at the SPS)
  - Electron microscopy
  - Mass spectrometry
  - Neutron Imaging
  - Charged Particle Dosimitry

PANalytical