A Silicon Vertex Tracker Upgrade for the PHENIX Experiment at RHIC

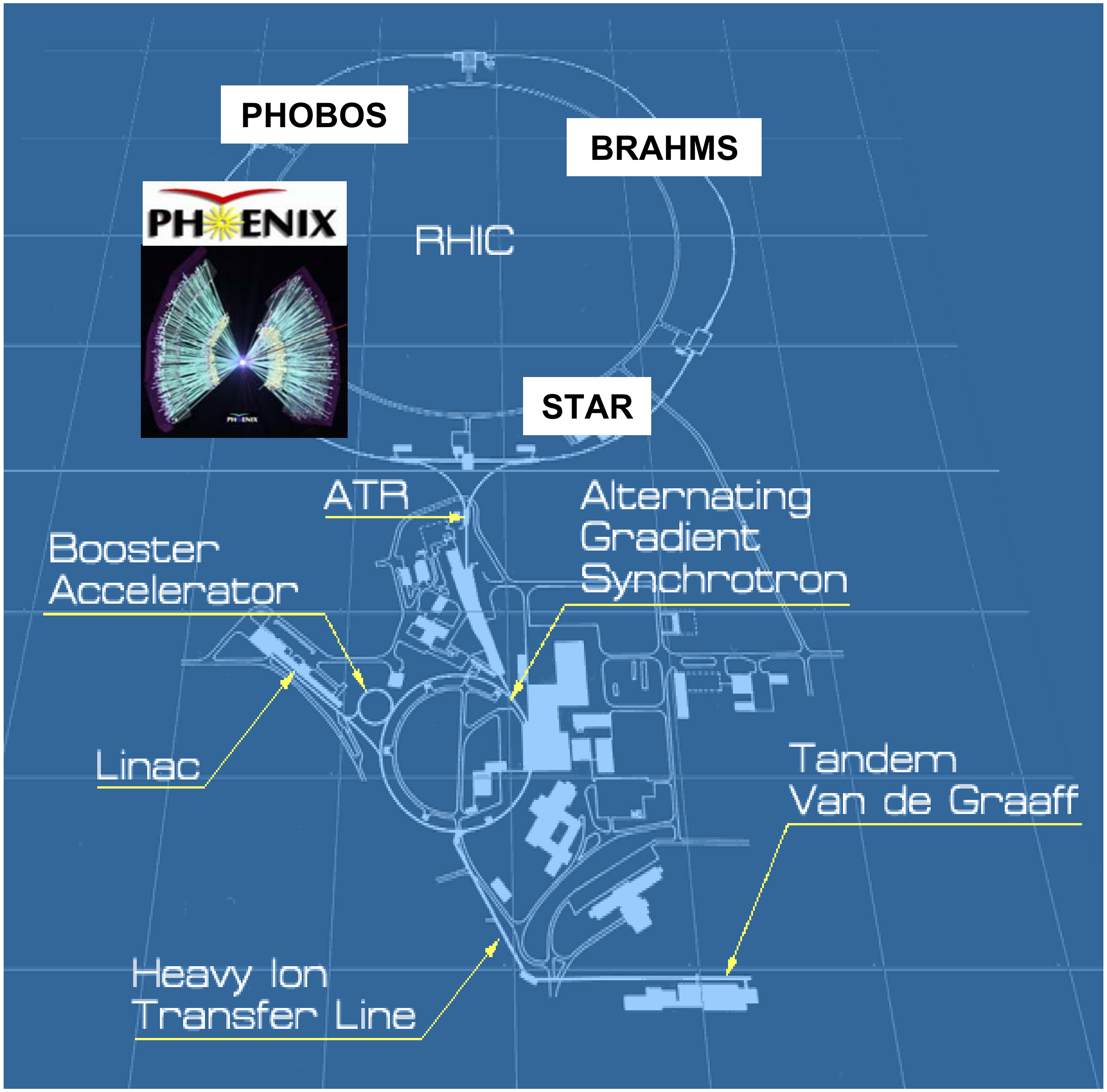
- RHIC and PHENIX in Brief
- Physics Goals & Detector Upgrades
- Silicon Vertex Tracker:
  Concept and Status of Preparations

Johann M. Heuser, RIKEN
for the PHENIX Collaboration

International Workshop on Radiation Imaging Detectors, Glasgow, July 25-29, 2004

PHENIX

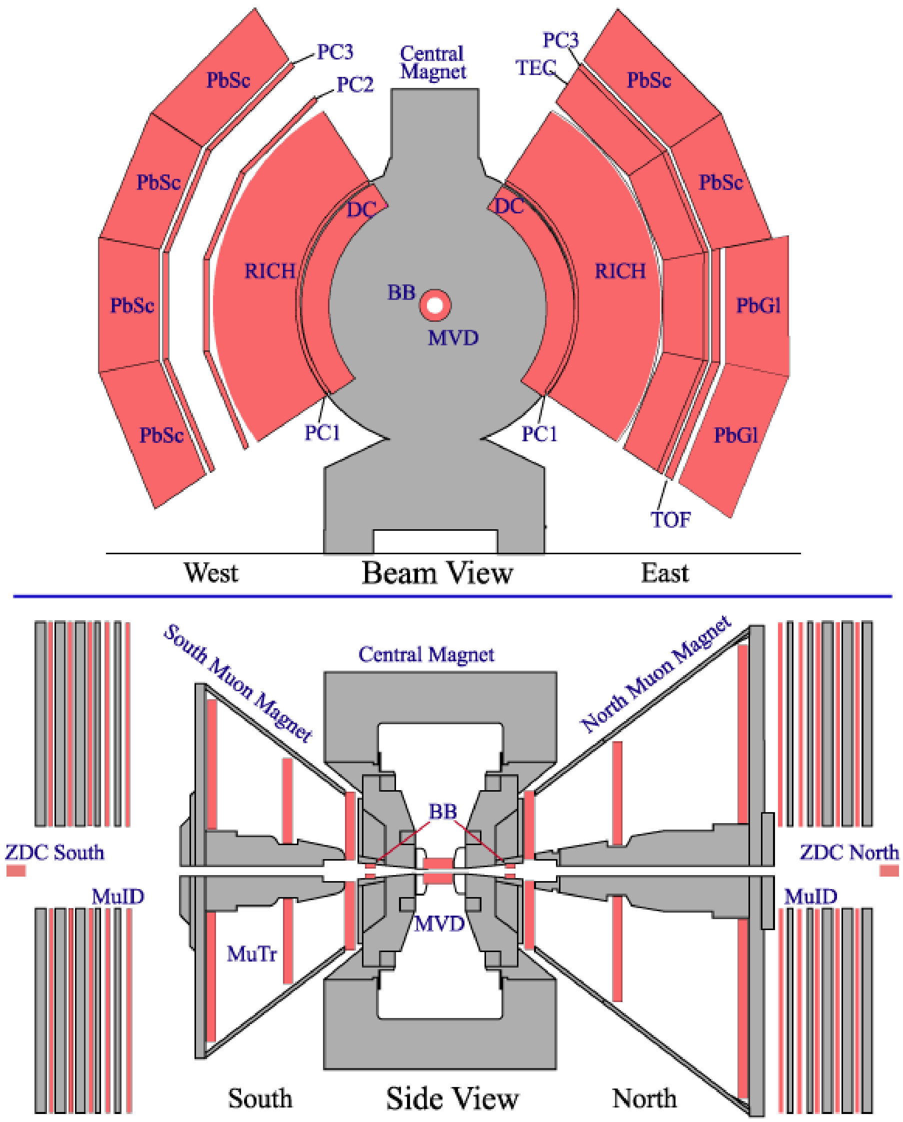
PHENIX at the Relativistic Heavy Ion Collider



PHENIX:
- large high-rate experiment, specifically designed to detect hadrons, leptons, photons & rare electromagnetic probes
- 4 spectrometer arms
- > 400 internat`l collaborators

RHIC:
- 3.83 km circumference
- two independent rings
  - up to 120 bunches/ring
  - 106 ns crossing time
- energy:
  - up to 200 GeV for Au-Au (per N-N collision)
  - up to 500 GeV for p-p
- luminosity:
  - Au-Au: 2×10^{26} cm^{-2} s^{-1}
  - p-p (pol.): 2×10^{32} cm^{-2} s^{-1}

The PHENIX Detector



Central Arm Tracking
- Drift Chamber
- Pad Chambers
- Time Expansion Chamber

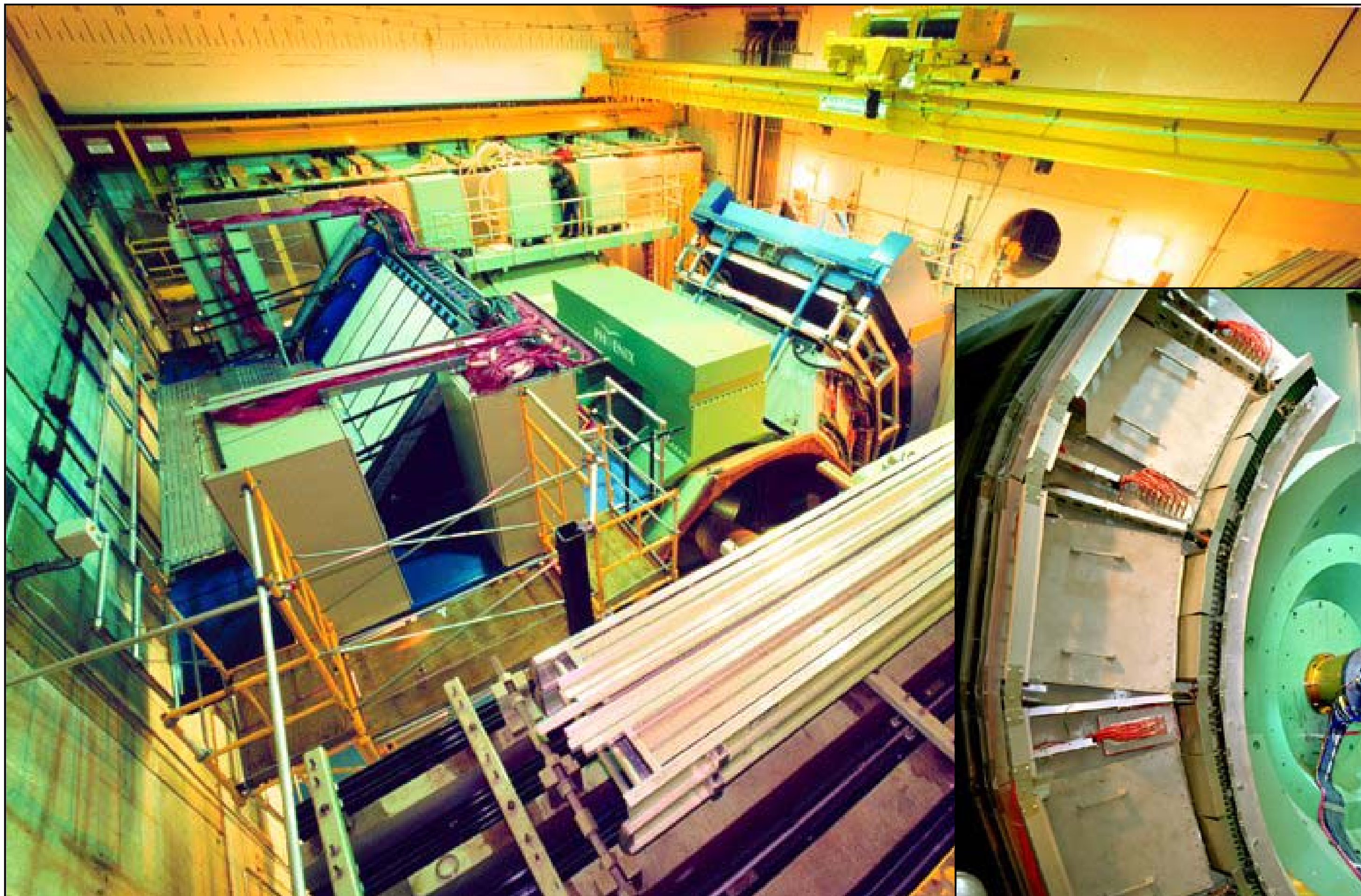
Muon Arm Tracking

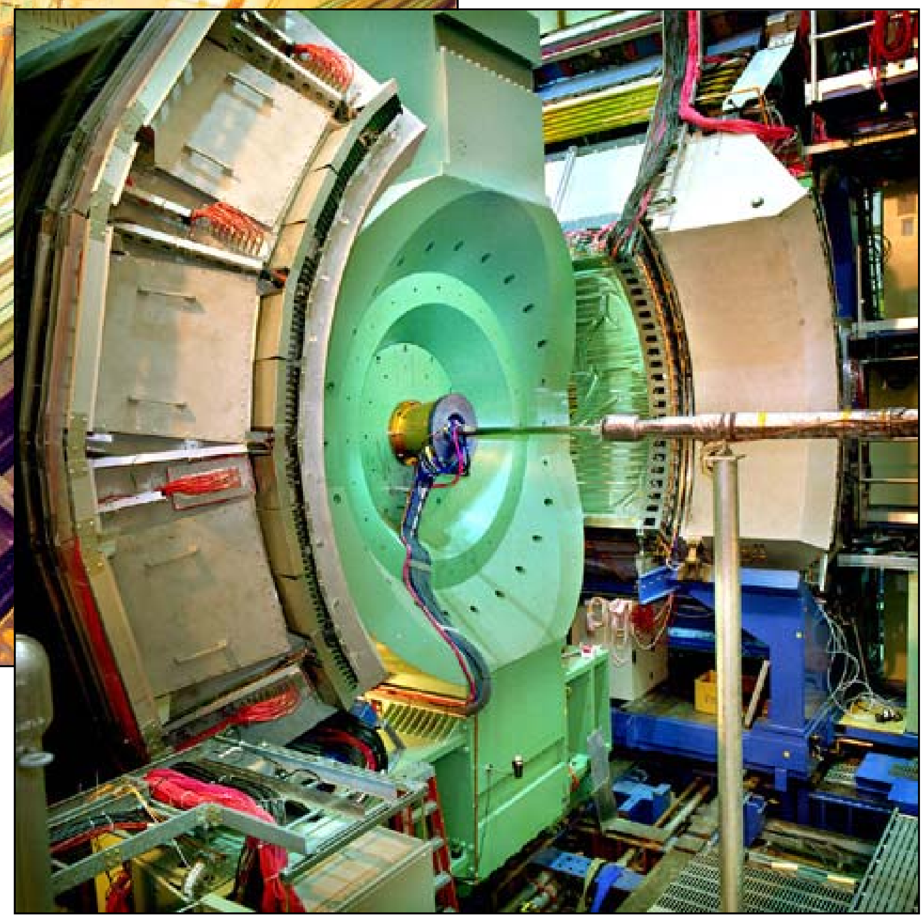
Calorimetry
- PbGl
- PbSc

Particle Id
- Muon Identifier
- RICH
- TOF
- TEC

Global Detectors
- BBC
- ZDC/SMD
- Local Polarimeter
- Forward Hadron Calorimeters
- NTC
- MVD

PHENIX - View in the Experimental Hall





Baseline detector completed since Run-III (2003).

PHENIX – Physics Program

Relativistic Heavy Ion Physics:

- Detection of Quark-Gluon-Plasma state of nuclear matter in Au-Au-collisions at $\sqrt{s_{NN}}$=200 GeV.
- Access leptonic, photonic, hadronic probes in the same experiment.

RHIC I: focus on confirmation of QGP.
→ **ongoing**

RHIC II: detailed study of its properties.
→ **2nd half of this decade**
!! detector upgrades !!

Spin Physics:

- Study spin composition of nucleon. Collisions of polarized proton beams at $\sqrt{s_{NN}}$=200-500 GeV.
- Main goal: gluon polarization.
- Probes: high-p_T photon production, jet and heavy flavor production.

→ **ongoing** **!! detector upgrades !!**

Run	Year	Collision System	$\sqrt{s_{NN}}$ [GeV]	
01	2000	Au-Au	130	commissioning
02	01/02	Au-Au	200	RHIC at full energy
		p-p	200	first p beams
03	02/03	d-Au	200	PHENIX baseline detector completed
		p-p (pol.)	200	first pol. p beams
04	03/04	Au-Au	200	RHIC at full luminosity
		Au-Au	62	
		p-p (pol.)	200	
05	04/05	lighter than Au-Au	200	
…	…			

List of published results:
http://www.phenix.bnl.gov/results.html

PHENIX – Detector Upgrades

- Enhanced particle ID

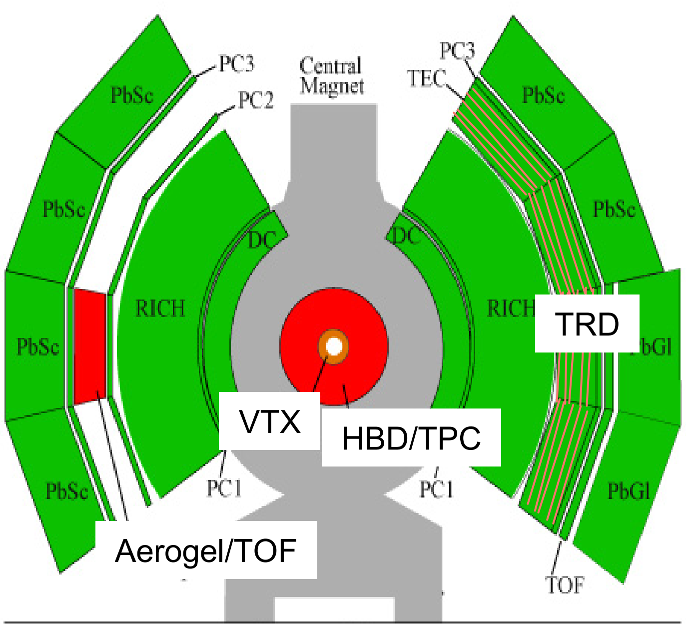
  TRD, Aerogel/TOF:

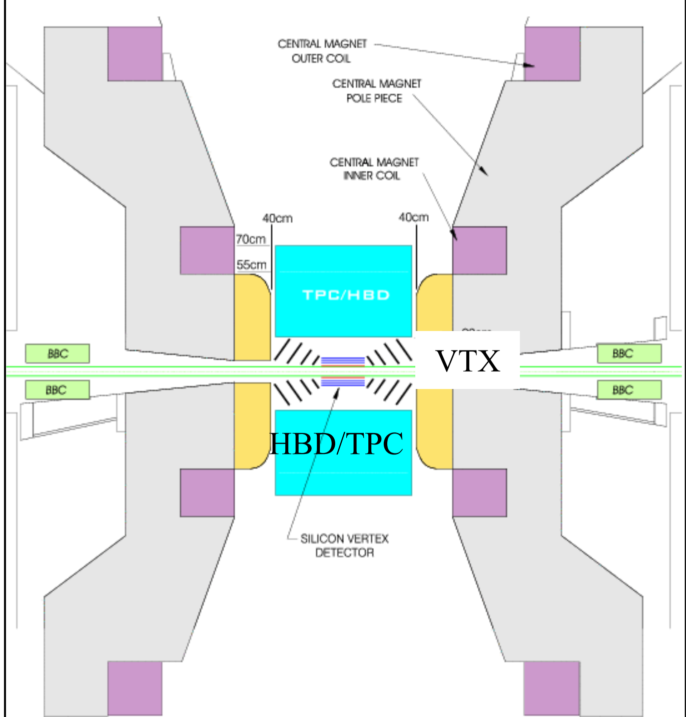
  e/π and π/K/p, separation for p_T up to10 GeV/c.

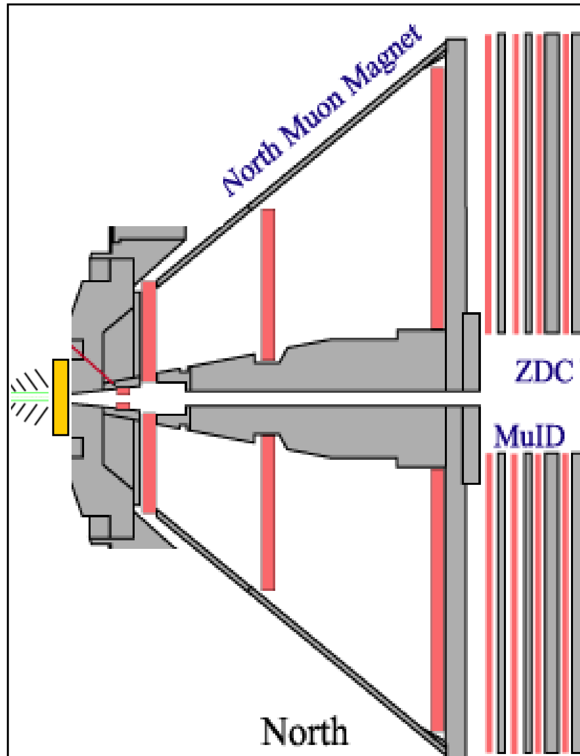
  (TRD, Aerogel already installed)

- **Silicon Vertex Tracker for new physics capabilities:**
  - ► **4-layer central barrel** ► **4-layer end-caps**
  - – **detect displaced vertices from charm/bottom decays.**
- Flexible magnetic field
- Hadron Blind Detector, TPC: $e^{\pm}$ continuum, Dalitz rejection.

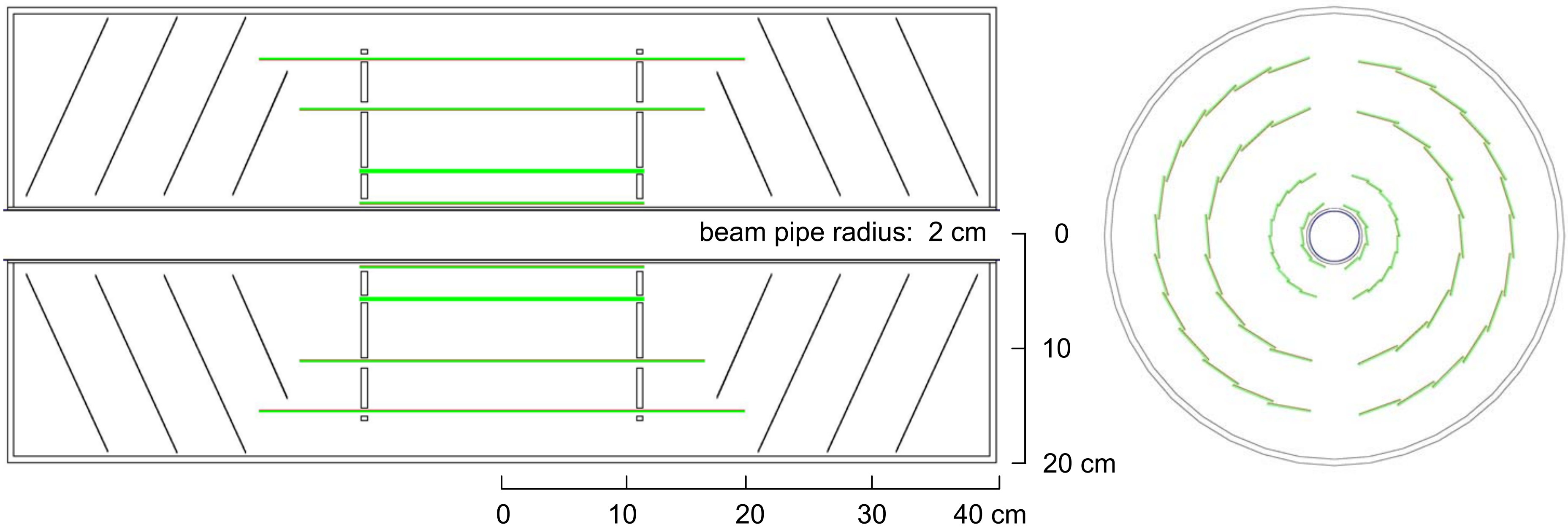
- Forward Si-W calorimeter
- Trigger capabilities.







The PHENIX Silicon Vertex Tracker



Mechanical Specifications:

4-layer Barrel at central rapidity:

layer radius	2.5, 5, 10,14 cm
layer length	24, 24, 30, 36 cm
pixels (layers 1+2)	10+20 modules, ~3.9 M pixels
pixel size	50 μm x 425 μm
strip-pixels (layers 3+4)	18+26 modules, ~378 K r/o ch.
strip-pixel size	80 μm x 1 mm (3 cm)
azimuthal coverage	~320 deg

4-layer Cones at forward rapidity:

inner radius	2.5 cm
outer radius	18 cm
z position (at r = 2.5cm)	20, 26, 32, 38 cm
mini strips	50 μm x 2.2-13 mm
total sensor elements	~2.0M
azimuthal coverage	360 deg

Vertex Tracker – System Integration Study

Physics with the Silicon Vertex Tracker

Detailed study of the hot, dense matter formed in **heavy ion collisions**:

- Potential enhancement of charm production.
- Open beauty production.
- Flavor dependence of jet quenching and QCD energy loss.
- Accurate charm reference for quarkonium.
- Thermal dilepton radiation.
- High-p_T phenomena with light flavors, p_T >10-15 GeV/c.
- Upsilon spectroscopy, e^+e^- decay channel.

Study of the gluon spin structure of the nucleon in **polarized p-p collisions**:

- Gluon polarization $\Delta G/G$ with charm, beauty.
- *x* dependence of $\Delta G/G$ with γ-jet correlations.
- Sea-quark polarization.
- Transverse spin structure distributions δq.

⇒ **Key issue: Precision track measurement on vertex level.**

Nucleon structure in nuclear environment:

- Nuclear dependence of PDFs.
- Saturation physics:
- Gluon shadowing over broad x-range.

Physics at **forward rapidity**:

- Open charm, bottom contribution to J/ψ production in $\mu^+\mu^-$ decay channel.
- Larger *x*-range for measurement of gluon spin structure function.
- Open charm, beauty in pol. p-p collisions.

Silicon Tracker - Simulated Performance

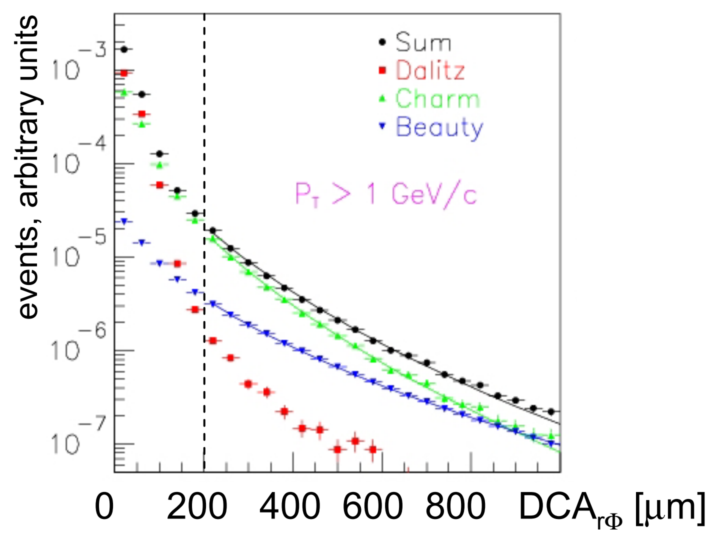
Assumptions: 1% X_0 total per layer; 500 µm Be beam pipe.
Single e-tracks / heavy ion events. No Magnetic Field.

Barrel at central rapidity:

occupancy: (in central Au-Au collisions)

- 1^{st} layer ~0.6% (pixels required!)
- 2^{nd} layer ~0.2% (pixels required!)
- 3^{rd} layer ~4.7% (strip-pixels)
- 4^{th} layer ~2.7% (strip-pixels)

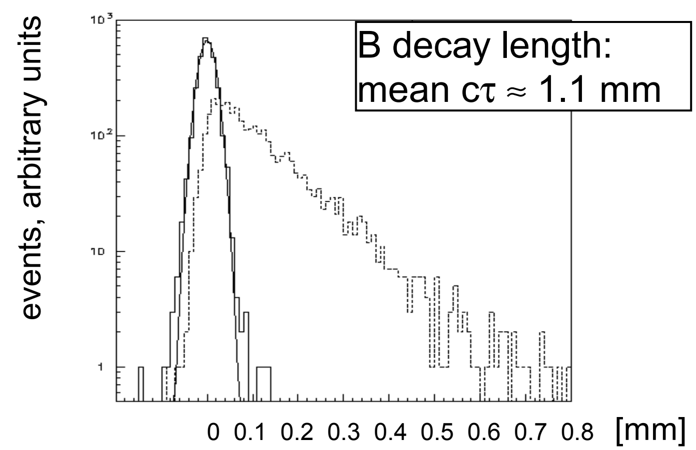
resolution: Semi-leptonic decays **B,D → e+X.**
A **200 µm cut** on the "**D**istance of **C**losest **A**pproach" between e-tracks + event vertex discriminates effectively **Dalitz background.**



End-caps at forward rapitidity:

occupancy: <1% (mini-strips)

resolution: **Δz_{vertex} (B→ J/Ψ→ $\mu^+\mu^-$) < 200 µm**



Silicon Pixel Detectors

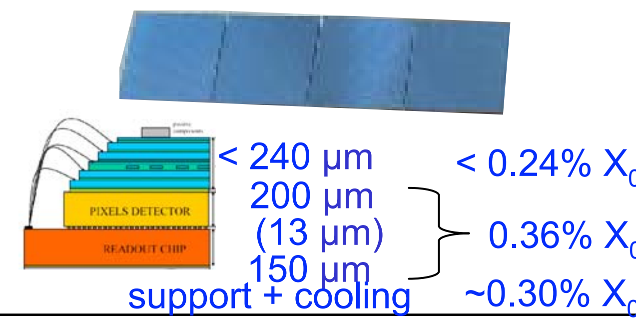
Development and production of PHENIX pixel sensor ladders and module readout electronics in collaboration of RIKEN with the ALICE experiment.

ALICE1LHCb readout chip:

- Pixel: 50 µm x 425 µm.
- Channels: 256 x 32, 10 MHz r/o clock.
- Output: binary, not zero-suppressed, in 25.6µs.

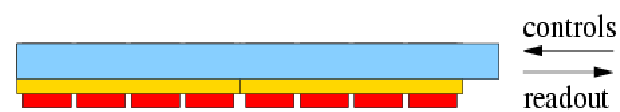
Sensor ladder:

- 4 ALICE1LHCb readout chips.
- Bump-bonded (VTT) to silicon sensor.
- Thickness: r/o chips 150 µm, bumps 13 µm, sensor 200 µm.



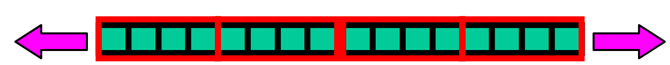
Half-module (2 sensor ladders, bus + Pilot module):

- 1.36 cm x 10.9 cm + bus extender to ~z = 40cm.
- Thickness bus: < 240 µm.



Module, two half-modules in z-direction:

- Δz = 24 cm.
- detector resolution in rΦ: ~14 µm r.m.s.



Silicon Pixel Detector - Ladder Production

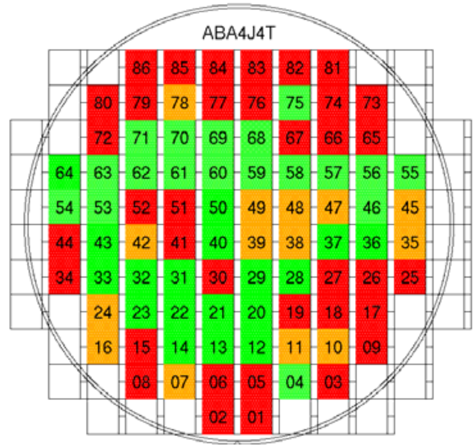
Production volume: 30 modules, 120 sensor ladders $\Rightarrow$ 480 ALICE1LHCb chips.

Ongoing comprehensive quality acceptance tests of readout chips prior to bump bonding:

RIKEN wafer probe station installed at CERN, equipped with a test system developed by ALICE.

Class-I chips passed all tests and go into ladder production.

Yield from 86 chips/ 8“ wafer

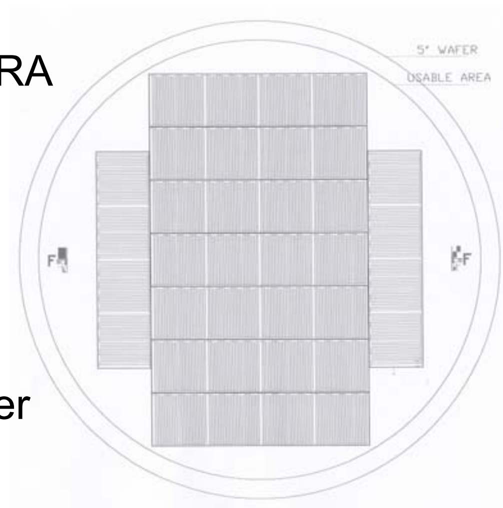


4 wafers tested out of 16+X

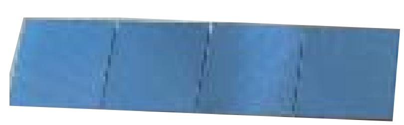
Wafer ID	Class-I	Class-II	Class-III
ABA4J4	36	14	36
AAA4J5	35	9	42
A9A4J6	25	13	48
AVA4LL	38	23	26
Total	134	59	152

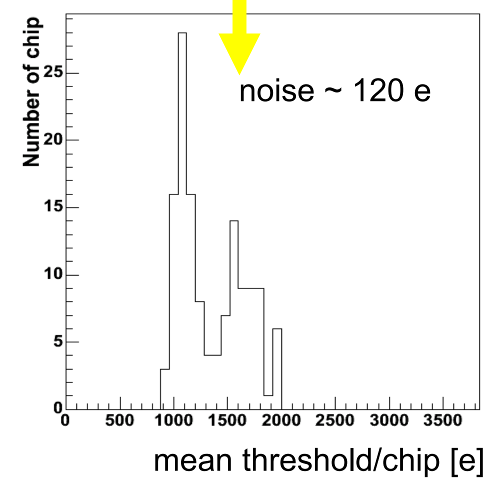
CANBERRA sensor wafers; delivery 7/2004.

9 sensor ladders per wafer.



First batch of ladder production at VTT in August 2004.

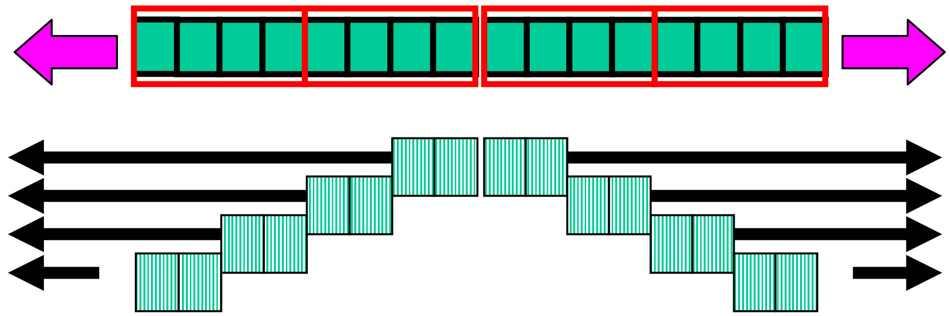




Silicon Pixel Detector: Readout

ALICE:
Pixel detector readout in **256 µs** per half-module (10 chips in series on bus).

PHENIX:
Min. bias trigger L1: rate ≤ 25 kHz, latency < 4.3 µs (40 BCOs).
⇒ PHENIX DAQ requirement:
Front-end module freeing in less than 1/ 25 kHz = **40 (80) µs**.

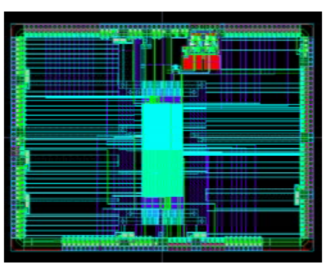


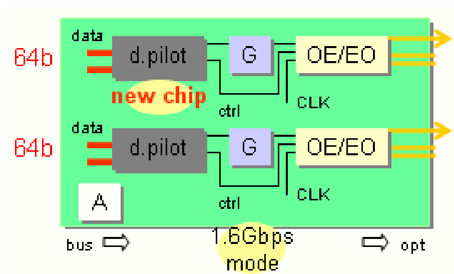
Development of a new 128 bit bus, parallel 4 × 32 bit readout, and a new parallel pilot chip:

⇒ 256 32-bit words × 2 chips × 10 MHz = **51.2 µs**.

New Pilot control chip + Pilot module:

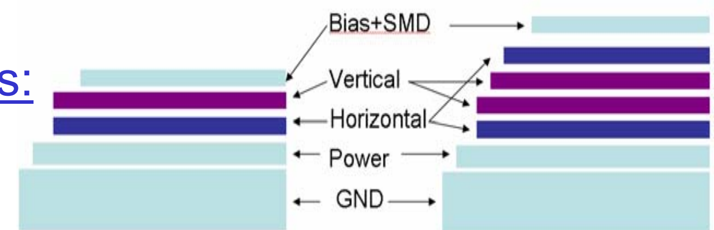
Modified ALICE design, 4 x parallel input, 2 x output, data serialized at 1.6 Gb/s.





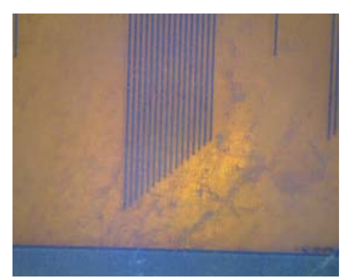
Pilot chip submitted for production.

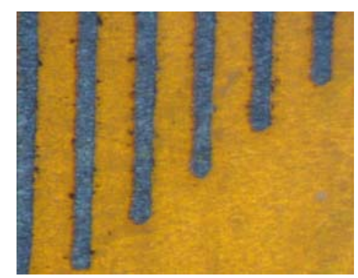
High-density Al-Kapton bus:



Two technical solutions with 70 µm and 140 µm line pitch.

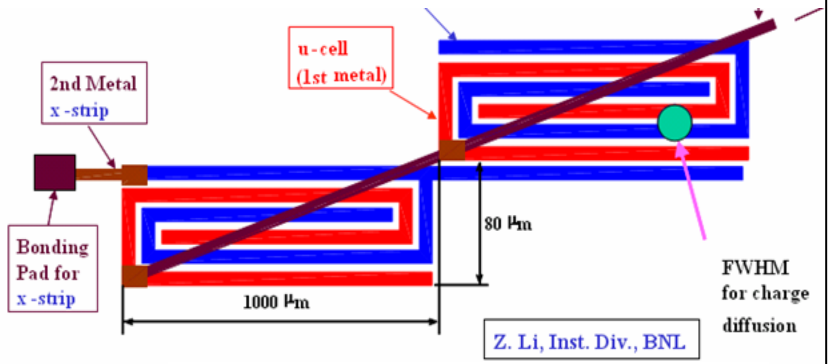
Prototyping in industry.





Strip-Pixel Detectors

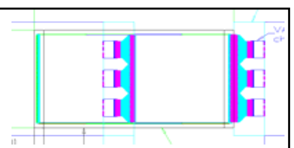
Sensor elements:



Pixels: 80 μm × 1 mm, projective readout via double metal XU/V "strips" of ~3 cm length.

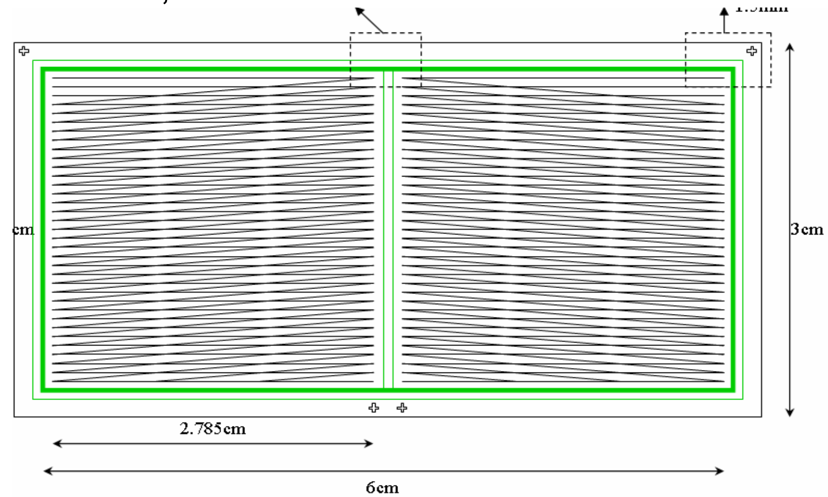
Prototype, 2002 (2004):

front-end chips: VA2 (SVX4)



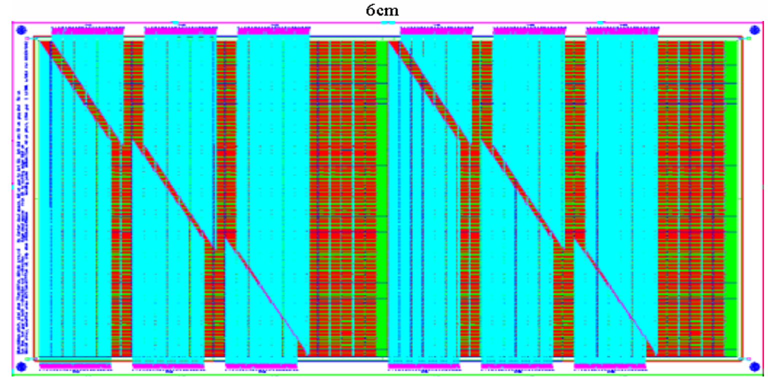
Test beam: track residuals σ_X=44μm , σ_U=38μm.

Two strip-pixel arrays on a single-sided wafer of 250 (400) μm thickness, with 384 + 384 channels on 3 x 3 cm² area.



initial design:

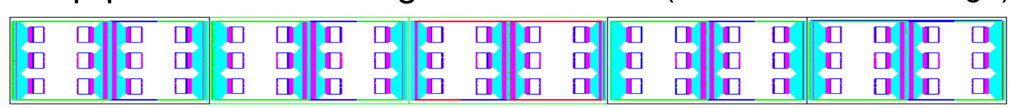
"longi-tudinal" readout.



new design:

"lateral" SVX4 readout.

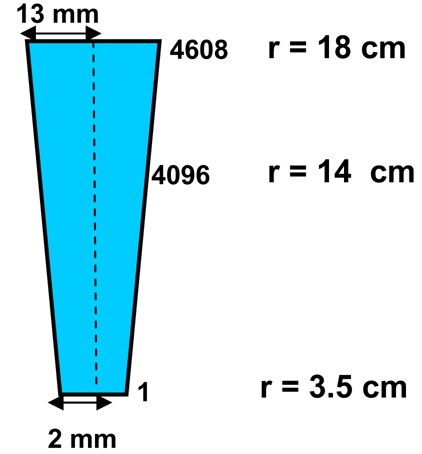
Strip-pixel module: Length 30 cm. (readout in initial design)



Silicon Tracker at Forward Rapidity

- Four umbrella stations on each side matching the muon spectrometer acceptace.
- Mini-strips of 50 μm * 2.2 -13 mm.
- Readout via new PHX chip from Fermilab.
- Data push via ~3 Gigabit optical links.
- Total channel count: 2 Million.
- Total chip count: 4000.

- 50 μm radial pitch (z vertex reconstruction).
- 4608 (4096) “mini-strips”.
- Two module sizes: 3.5 cm < r < 18 (14) cm.
- Occupancy < 1 %.
- 48 modules (“double towers”) in Φ direction.
- Mini-strips from 13.0 mm to 2.2 mm width.
- 2 rows of strips per “double tower”.
- Readout via one chip row.
- Connections sensor strips ↔ PHX via bump-bonds.



“double tower” module in two sizes.

⇒ **Conceptual design to be presented at the IEEE Nuclear Science Symposium 2004 in Rome.**

Summary

- Physics motivation, technical concept and beginning construction of the PHENIX Silicon Vertex Tracker was outlined.
- The Silicon Vertex Tracker is an important upgrade of the PHENIX detector and will extend its physics capabilities to new observables for the physics program at RHIC II and the polarized proton physics program.
- The technical proposal document for the barrel detector layers at central rapidity has been submitted. The prototyping and production of its detector components have started. The full detector in PHENIX is aimed at for the year 2007/8 (Run 8).
    - Pixel detectors: are essential in the inner two layers to achieve the spatial resolution for secondary vertex measurement.
      Due to short time scale until they are needed: Focus on the application of up-to-date established technology. Utilization of CERN-ALICE hybrid pixel detectors as the building block for PHENIX specific pixel detector modules.
    - Novel “Strip-pixel” detectors in the outer layers are essential for the track reconstruction and help with linking the tracks to the central spectrometers.
- A proposal for the end-cap vertex tracker at forward rapidity will be presented soon. The application of this device is aimed at for around the year 2008/9.