Summary of Discussion on Technology Choice For The Inner Tracker

Inner Tracker meeting at CERN, April 3, 2001

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1 Introduction

During the Inner Tracker meeting on February 13, five criteria had been identified on which the decision on the Inner Tracker baseline technology should be based[1]:

- price of silicon sensors (offers from companies)
- required Inner Tracker size for each tracking station (with Tracking Task Force)
- maximum length for silicon ladders (laboratory measurements)
- pitch requirements for momentum resolution and occupancy (simulation studies)
- demonstration that full-size 3GEM prototype "works" (laboratory measurements)

The status of these five topics was reviewed and a recommendation to the Technical Board was prepared. The decision on the baseline technology is planned to be finalized during the next LHCb week, May 7-11.

2 Cost Estimate For Silicon Sensors

Four companies were asked for informal offers for the production of silicon sensors, according to the specifications layed out in Inner Tracker Memo 2001-002. All four declared general interest in our project. By the time of the meeting, cost estimates had been received from SPA Detector and Hamamatsu. An offer from Sintef arrived late for the meeting but has been included in this summary.

For an order volume of 1800 sensors, SPA Detector quotes a cost of 1200 USD (about 2050 CHF) per sensor. According to private communications, this could be reduced by a factor of two if the specification on maximum leakage current was released. Hamamatsu quotes 1490 CHF per sensor for a production according to our specifications (they request small modifications to geometry and coupling capacitance), and 1380 CHF per sensor if GLAST specifications are used. Sintef quotes 7000 NOK (about 1318 CHF) per sensor. All companies point out that these are rough estimates.

These informal offers translate into the following total cost for 1800 sensors, cost per cm^2, and total cost for $12\,m^2$:

[1] See http://documents.cern.ch/cgi-bin/setlink?base=agenda&categ=a0147&id=a0147s3/transparencies for transparencies of the summary talk

Cost in CHF	per sensor	for 1800 sensors	per cm^2	for $12m^2$
SPA Detector	2050	3.69M	22.8	2.73M
Hamamatsu	1490	2.68M	16.6	1.99M
Hamamatsu/GLAST	1380	2.48M	15.3	1.84M
Sintef	1317	2.37M	14.6	1.75M
SPA Detector / 2	1025	1.85M	11.4	1.37M

As reminder, $12\,m^2$ is the sensitive surface that has to be covered by the Inner Tracker in the current layout of the tracking system. A realistic Silicon Inner Tracker layout must include overheads due to the finite size of the used sensors, about 1500 sensors were needed in the layout presented in LHCb note 2000-109. The quoted number of 1800 sensors takes into account in addition 20% spares.

For the silicon Inner Tracker cost estimate presented in Inner Tracker memo 2000-010, a cost per surface of $18\,CHF/cm^2$ and a surface of $12\,m^2$ were assumed, and a total amount of 2.16 MCF was allocated for silicon sensors.

Conclusion: the unit cost for silicon sensors is in the expected range. The overall cost could exceed the allocated resources if realistic layout and spare sensors are taken into account.

3 Maximum Length of Silicon Ladders

The limiting parameter for the length of silicon ladders is the noise performance of the front-end amplifier. The noise grows roughly linearly with the input load capacitance, and thus also with the silicon ladder length.

First signal-to-noise measurements were performed at MPI Heidelberg, using the 6.6 cm long prototype sensors produced at SPA Detector, and the Helix read-out chip.

For a single unirradiated sensor connected to a Helix chip, signal-to-noise ratios of 20.8, 19.3, and 18.6 were measured for the regions of strip-width over pitch of 0.20, 0.25, and 0.30, respectively. The measured deterioration with width over pitch agrees with expectation, but the overall values are worse than those expected from earlier estimates. The poorer performance can be only partially explained by the fact that these estimates assumed a too optimistic value of about 1 pF / cm for the total strip capacitance. Direct measurements have shown values around 1.5-1.6 pF / cm, see LHCb note 2001-036. Proper tuning of Helix settings could still improve the measured performance.

Measurements were also performed on a single sensor that had been irradiated to a peak fluence of 10^{14} protons / cm^2, as described in LHCb note 2001-035. The measurements were performed after the sensor had been annealed at room temperature for four days. At room temperature, leakage currents of about $200\mu A$ were measured at full depletion voltage, in good agreement with expectation for the integrated fluence seen by the sensor. Shot noise from these leakage currents dominated the signal-to-noise performance. At 7°C, a signal-to-noise ratio of about 15 was measured for the region of width-over-pitch of 0.3. The deteriorated performance as compared to the unirradiated sensor can be explained quantitavely if the measured increase of strip capacitance after irradiation, see LHCb note 2001-036, and the expected leakage currents of $50\mu A$ at this temperature are taken into account. At the meeting, a measurement was presented according to which the leakage current had dropped to a negligible level at 7°C. However, this result is inconsistent with the known behaviour of silicon and was after the meeting reported to be due to a measurement error.

Preliminary results were shown for a 20 cm long ladder, assembled from three unirradiated sensors connected to a Helix read-out chip. Signal-to-noise values of up to 13 were obtained.

A further improvement was expected from the optimization of Helix operational parameters for large input capacitances.

Conclusion: measured signal-to-noise values are generally worse than expected from earlier estimates. With proper tuning of Helix parameters, and an appropriate operating temperature for the sensors, acceptable signal-to-noise values for 20 cm long ladders can be expected also after irradiation. At this point of the investigation, it is not clear if it will be possible to operate ladders much longer than 20 cm with acceptable signal-to-noise performance.

4 Required Size of Inner Tracker

The required size of the Inner Tracker was discussed at a meeting of the Tracking Task Force, at NIKHEF on March 27/28[2].

Studies performed by the RICH group indicate that particle-identification performance would not suffer if station 11, as well as the "y"-views in stations 1 and 2, were removed. These results still needed be discussed within the RICH group and in the Technical Board. Removing these station and views would reduce the sensitive surface of the Inner Tracker by about $2\,\mathrm{m}^2$.

Within each tracking station, the size of the Inner Tracker has to be chosen such that acceptable occupancies are obtained in the innermost regions of the Outer Tracker. At the time of the meeting, it was felt that tracking studies were not advanced enough to define a well justified limit on acceptable occupancies. The "gut feeling" was that occupancies above 10-15% would be worrisome. To keep maximum occupancies below this limit, the height of the Inner Tracker would have to be increased by 2×10 cm in stations 2, 3, and 4, its width by 2×30 cm in all stations.

Discussions on acceptable occupancy levels in different tracking stations, and on possible measures to ensure that these occupancies are not exceeded in the innermost regions of the Outer Tracker, are still ongoing at the time of writing of this summary.

Another issue raised at the workshop was the necessity of overlaps between Inner and Outer Trackers, in order to avoid acceptance gaps. These overlaps were so far neglected in all studies. Overlaps at upper/lower edge of Inner Tracker will have siginificant impact on the sensor layout, if they have to be covered by the Inner Tracker. Slightly longer silicon ladders imply longer sensors. These would have to be narrower in order to still fit on the silicon wafer. Strip pitch would become smaller because number of strips is determined by the granularity of the read-out chip. Impact on number of read-out channels can be significant.

Conclusion: tracking studies and overall optimisation of the tracking system are not advanced enough to fix the size of the Inner Tracker.

5 Pitch Requirements, Occupancies and Resolution

Simulation studies were performed using a silicon digitization code. Charge sharing between neighbouring strips was simulated according to an η-function measured on the SPA-detector prototype sensors. A gaussian noise corresponding to a signal-to-noise value of 15 was added to each strip signal, and a threshold of 3σ of the noise was used to suppress noise hits.

With these settings, average cluster sizes are found to be 2 strips for non-electrons and 2.5 strips for electrons (mostly secondaries generated in the beam pipe and crossing the detector planes under large angles). The simulation gives a significantly larger fraction of

[2]See http://lhcbott.home.cern.ch/lhcbott/tracking/Meetings_Mar_27_2001.ps for a detailed summary of the meeting.

two-strip clusters and a smaller fraction of one-strip clusters than was measured on the prototype sensors. The discrepancy has to be understood, it may be related to a different choice of hit thresholds.

For luminosities of $2 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ ($5 \times 10^{32}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$), including pile-up and spill-over, average strip occcupancies below 2% (3%) and maximum strip occupancies below 4% (6%) were found for Inner Tracker stations 1-3. In stations 5-11, occupancies are more than a factor of two lower. Maximum strip occupancies in each station were determined as the highest average of all groups of 32 strips in that station.

Residual distributions of reconstructed cluster position vs. "true" GEANT hit show a spatial resolution of better than $80\,\mu$m r.m.s. for non-electrons and of up to $100\,\mu$m for electrons (secondaries from the beam pipe). Restricted to a window of $\pm 200\,\mu$m around the "true" impact point, the r.m.s. is $50\,\mu$m or better (depending on cluster size).

Distributions of momentum resolution as function of particle momentum were shown but suffered from lack of statistics for high-momentum tracks. A very restrictive definition of the track sample was made to select tracks that went through the Inner Tracker region in the full tracking system. The average momentum resolution was worse than $\delta p/p = 0.4\%$. No improvement was found decreasing the strip pitch by a factor of two. Increasing the pitch by a factor two caused a clear deterioration. Better statistics will be needed to investigate the momentum dependence.

Conclusion: Occupancies are acceptable in all stations, and low in stations 5-10. Spatial resolution is in the expected range. Momentum resolution needs to be studied with more statistics, and for "mixed" tracks going through Inner and Outer Trackers.

6 Status of Full-Size 3GEM Prototype

As reported in previous meetings, the first full-size prototype built by the Lausannne and Zürich groups had problems to hold high-voltage over the conversion gap. At the time of the meeting, a second prototype was still under cconstruction and had not yet been tested in the laboratory.

Conclusion: It has not yet been shown that the full-size 3GEM prototype works in the laboratory.

7 Conclusion

The performance of an all-silicon tracker is adequate for the needs of the LHCb Inner Tracker. Occupancies are low and alternative sensor geometries that would to allow to reduce the number of read-out channels, without compromising performance, will be investigated (larger read-out pitch with intermediate strips).

Efforts will also be made to minimize the per-channel cost of the read-out electronics. Cost estimates show that an all-silicon tracker should then be affordable for the current size of the Inner Tracker.

In view of the still missing decision on the size of the Inner Tracker, it was decided to submit the following recommendation to the Technical Board:

> "The Inner Tracker group recommends to adopt an all-silicon tracker as baseline technology for the Inner Tracker, provided that the size of the Inner Tracker does not have to increase (significantly)."

This recommendation will be presented to the Technical Board on April 20. The decision on the baseline technology is planned to be finalized during the next LHCb week, May 7-11.

8 Collaboration with GLAST

Another item discussed at the meeting was a possible collaboration with the GLAST silicon tracker group on sensor production. The GLAST silicon group thinks positive about such a collaboration and would be happy to let us profit from their experience. However, the general feeling was that the specific constraints of the Inner Tracker, although similar to theirs in many respects, will require the development of dedicated sensors. In addition, the offer from Hamamatsu indicated rather small cost savings. However, the option of a collaboration will be kept in mind.