Verification of CD-4 parameters

At the pre CD-1 review the HFT project presented a suggested list of CD-4 parameters. Following the reviews these were revisited several time in order to:
- Have parameters that can be verified w/o beam
- Have parameters from which it can be inferred that the physics goals can be achieved
- Have them relaxed so they are not overly strict, thus leading to a *failure* of the project in DOE terms.[1]

Due to the change in the parameters, and reluctance on the CD-1 review committee to actually acknowledge that we did a good job on the simulation, Helmut Marsiske has numerous times stressed that "we must demonstrate at CD-2 review that the high-level Key Performance Parameters (KPP) can be derived from the low-level KPP, and that the expected physics performance results from these".

Again at the BNL pre-review, the reviewers expressed concern over definitions and apparent lack of clarity. Therefore we have to address this. In addition some additional details came out from a discussion this afternoon between Tom L, Ed, Jamie and myself. In the committee discussion it was felt that parameters as defined was confusing, (not that I agree I think this can be clarified by in the text) and that some were too stringent and should be revisited. These in particular stability/alignment requirement, and to some degree the efficiencies of sensors layers. In particular Steve Vigdor was apparently adamant about this, The cd-4 should be guaranteed to be met. I suspect changing these would then propagate to the higher level KPPs. My concern about this approach is that this will influence the more vaguely defined physics performance, and might require some additional work.

One way of phrasing these are simply (HGR):

How is the pointing resolution of 50mum derived from the lower level parameters?
How is the single-track efficiency derived?

Secondary, we could iterate how the low-level KPP will be confirmed/determined. The PEP has a high-level description, but I think that documenting this in more details (quoting accuracies of CMM, cooling test, calculations) How is the radiation length determined precisely (material budget accounting, measurements). Addressing these up front could also help us in the planning of the project.
The physics response from April does not precisely address these two questions, but are clearly related. There may well be intermediate simulation results that confirm these.

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[1] The parameter limits are though not all equal in impact of the physics. Should e.g. the efficiency of a single layer by 94% rather than 95 it is only a 2% overall increase in running time needed to do the same physics.

Proposal:

Prepare a document that includes:
- Document derivations of pointing resolution and single track efficiency from the low level KPP in extreme case.
- Document how the all low level KPP will be determined, in more details, and document that these can be guaranteed.
- Prepare the text that should go into to PEP for tabular values, and for lower level documentation.

The relation to physics should be kept in the TDR, since we probably want to have this expanded in any case.

Relevant information from the Preliminary PEP:

1.1   TECHNICAL SCOPE

The HFT project scope comprises designing, building and assembling the three sub-detectors that constitutes the system. The technical scope is defined in Table 3-1: Key performance parameters for the HFT instrument to achieve Critical Decision (CD-4) and in Table 3-2: Deliverables for CD-4.

1.1.1   CD-4 KEY PERFORMANCE PARAMETERS

Although the high-level key performance parameters (KPPs) cannot be directly measured without beam, the capability to achieve these parameters can be demonstrated at CD-4 through the measurement of the low-level KPPs. The achievement of the low-level KPPs will be proven through bench tests, survey measurements and the meeting of design specifications. Appendix A provides further details on the KPPs.

High-level CD-4 key performance parameters: instrument must be capable of:

Pointing resolution of HFT system (750 MeV/c kaons)[2]	≤50 μm
Single-track efficiency for HFT system (1 GeV/c pions)	≥ 60%
Compatible with STAR DAQ-1000 system	

Low-level CD-4 key performance parameters: experimentally demonstrated at Project Completion:

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[2] Note that this is both r-phi, and z.

1	Thickness of first PXL layer	< 0.6% X_0
2	Internal alignment and stability PXL	< 30 μm
3	Internal alignment IST and SSD relative to PXL layer.	< 300 μm
4	PXL integration time	< 200 μs
5	Detector hit efficiency PXL	> 95% sensor efficiency and noise from all sources < 10^{-4}
6	Detector hit efficiency IST	> 96% with 98% purity
7	Live channels for PXL and IST	> 95%
8	PXL and IST Readout speed and dead time	<5% additional dead time @ 500 Hz average trigger rate and simulated occupancy
9	SSD dead time	< 9% at 500 Hz

Table 3-1 HFT Key Technical Performance Parameters

These were further justified in the appendix:

APPENDIX A - HFT CD-4 KEY PERFORMANCE PARAMETERS

This appendix describes in detail the CD-4 key performance parameters, justification and verification methods.

HIGH-LEVEL PARAMETERS
The instrument must be capable of a pointing resolution of better than 50 μm for kaons of 750 MeV/c. 750 MeV/c is the mean momentum of the decay kaons from D mesons of 1 GeV/c transverse momentum, the peak of the D meson distribution. The pointing resolution can be calculated from the design parameters and from the results of surveys of the sensor ladders.

The instrument must also be capable of a single-track efficiency of better than 60% for pions at 1 GeV/c in an Au+Au environment that are emitted from the center of the detector within a rapidity of ± 1. The 1 GeV/c pion is representative of the momentum distribution. This efficiency does not include the TPC tracking efficiency. The single-track efficiency can be calculated from the design parameters.

LOW-LEVEL PARAMETERS
Low-level parameters 1-9 in Table 3-1 support the high-level key performance parameters. It can be shown by detailed simulations that fulfilling these parameters

results in the anticipated performance given above.

The required pointing resolution can be achieved if performance requirements 1-3 in Table 3-1 are fulfilled.

The required single-track efficiency can be achieved if additionally performance requirements 4-7 are fulfilled.

The requirements 8-9 will allow the HFT system to acquire data in excess of 500M Au+Au collisions for a typical RHIC running period (10 weeks).

Specific justifications are given in the following with the requirement number given in the heading.

MULTIPLE SCATTERING IN THE INNER LAYERS (1)
The precision with which we can point to the interaction vertex is determined by the position resolution of the PXL detector layers and by the effects of multiple scattering in the material the particles have to traverse. The beam pipe and the first PXL layer are the two elements that have the most adverse effect on pointing resolution. We have chosen a radius of 2 cm for a new beam pipe with a wall thickness of 750 μm, equivalent to 0.21% of a radiation length. The two PXL layers will be at a radius of 2.5 cm and 8 cm, respectively. The total thickness of the first PXL layer must be smaller than 0.6% of a radiation length. The radiation lengths of the two innermost structures, the beam pipe and the first PXL layer, are verifiable design parameters.[3]

INTERNAL ALIGNMENT AND STABILITY (2, 3)
The PXL sensor positions need to be known and need to be stable over a long time period in order not to have a negative effect on the pointing resolution. The alignment and stability need to be better than 30 μm for the PXL .[4] The relative positions of the pixels will be measured with a coordinate measuring machine

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[3] Maybe stress that the thickness of the second layer do not contribute to the pointing resolution. There is an issue with the wall's between layer one and 2. That rad length do contribute in parts of phase-space. How to desl with this? Define pointing resolution (RMS of Gaussian part of distribution?)
[4] Must specify precisely what is meant by stability – refer to vibrations, thermal stability- reproducibility?
There is no stability requirements (the expected level of <20microns is too small to have as req. compared to the 300 micron resolution. (Alignement, mechanical tolerance /reproducibility of ladders, internal known much better Define thse as envelopes, ranges, not RMS. Q Have we really dealt with this properly ? Some how the 20*20 pixel size and 20micro vibration conspires to give 30micron?

(CMM). Stability against thermal expansion induced changes will be measured with TV holography and a capacitive probe. Stability against cooling air induced vibration will be measured in the final PXL assembly with a capacitive probe. The internal stability of IST and SSD relative to PXL should be determined to better than 300 μm. Those parameters can be determined from cosmic ray measurements. Relative alignment of IST to IST components and relative alignment of SSD to SSD components will be mapped with a CMM. Final alignment of detector system to detector system will be determined from cosmic ray measurements.

PXL INTEGRATION TIME (4)
The PXL is a "slow" device with a long integration time. All events that occur during the integration or lifetime of the PXL will be recorded and may contribute to pile-up. Pile-up will not limit the physics capability of the HFT if the integration time of the PXL detector is smaller than 200 μs. The PXL integration time is a verifiable design parameter.

PXL EFFICIENCY AND NOISE (5)
The hit efficiency of PXL detectors is essential for good detection efficiency. In the case of secondary decay reconstruction, the hit inefficiency of each detector layer enters with the power of the number of reconstructed decay particles into the total inefficiency.
The PXL detector sensors are designed to have an operating threshold point such that they will be more than 95% efficient for Minimum Ionizing Particles with a sensor noise hit rate of < 10-4. This can be verified by measurements of complete readout chain on bench and with test beam.

IST DETECTOR HIT EFFICIENCY (6)
The hit efficiency for the IST detector is essential for good detection efficiency for tracks. In order to keep inefficiency low, we require that each the detector layer has a hit efficiency of better than 96% with a purity of > 98%.[5] The hit efficiency of each detector layer can be measured on the bench before installation. A signal to noise ratio of 10:1 is known from experience with Si-sensors to ensure a hit purity of 97% or better with an efficiency of 99%. The IST is a triggered detector.

LIVE CHANNELS (7)
Dead channels in the PXL and IST will cause missing hits on tracks and thus lead to inefficiencies in the reconstruction of decay tracks. Therefore, the number of dead channels needs to be as low as possible. The impact of dead channels on the overall performance will be minimal if more than 95% of all channels are alive at any time.

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[5] Should be defined as efficiency for active/live channels. Is it really well defined ? The purity ie. true hit vs noise depends on signal rate vs noise.

The number of dead channels can be determined immediately after installation of the detectors on the mounting cone structures.[6]

READOUT SPEED AND DEAD TIME (8, 9)
In the absence of a good trigger for D mesons it is imperative for the measurement of rare processes to record as many events as possible and as required by the physics processes. In order not to add significant dead-time to DAQ, the PXL and IST readout speed needs to be compatible with that of DAQ-1000 and the dead-time such that at a readout rate with the Time Projection Chamber at 500 Hz additional dead time is no more than 5% for PXL, IST and 9% for SSD. The SSD dead time varies linear with rate constrained by the existing non-replaceable components on the detector ladders.
Readout speed and dead time are verifiable design parameters.

OTHER FUNCTIONAL REQUIREMENTS

A	Active sensor length of PXL layer 1 & 2	≥ 20 cm
B	Active sensor length for IST	≥ 46 cm
C	Pseudo-rapidity coverage for SSD	$|\eta| < 1.15$
D	PXL RDO data path integrity	BER $< 10^{-10}$

The active sensors length requirements for PXL and IST are to ensure rapidity coverage in $-1 < \eta < 1$ for all detector systems in the vertex range from -5 cm to +5 cm.

The total length of the PXL detector silicon sensors is designed to be 21.7 cm. The active tracking silicon in this length is 21.19 cm.

The total active silicon length of the IST should be 46 cm or greater at a maximum radius of 15cm to be able to cover $-1 < \eta < +1$.

The length of the SSD ladders is fixed. The requirement C is consistent with a radius of 22 cm and 2π azimuthal coverage.

The PXL readout data path is expected to have a data transfer rate of $\sim$ 200 MB/s (with a trigger rate of 1 kHz). In order to preserve the data integrity we will validate the data path to have a bit error rate (BER) of $< 10^{-10}$.

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[6] Are we setting us self up for failure if e.g a full ladders is not working when installed, and it is too late to pull out? I am also thinking of the ALICE IST experience.

Sub-system	Deliverable
PXL	
	PXL insertion structure
	PXL insertion tool
	10 sectors with each sector consisting of : One ladder at a radius of 2.5cm and 3 ladders at 8.0 cm. Each ladder contains: 10 silicon detector elements, one readout board 40 ladders total
	3 DAQ receiver Personnel Computers
	Two clam shells, with five sectors integrated and aligned on each clam shell, installed on pixel insertion tool.
	Forty tested ladders to serve as spares and replacement components to allow for any needed repairs to the existing sectors of the PXL detectors
	Low Voltage, Cabling, and Cooling
	A PC-based control and monitoring system
IST	
	27 (24+3 spares) ladders with six sensors per ladder
	24 IST ladders installed on the Middle Support Cylinder
	Silicon bias voltage system for 24 ladders
	Readout system for 24 ladders
	Cabling and Cooling Services
SSD	
	20 of the existing SSD ladders instrumented with new readout electronics compatible with the readout requirements for the Time Projection Chamber
	SSD installed on the Outer Support Cylinder (OSC)
	Cabling and cooling services compatible with the IDS structure and the Forward GEM Tracker (FGT)
IDS	
	The east support cone, and the middle support cylinders for the SSD, IST and the beam pipe support
Software	
	Online control software verification