# A Fast Track Trigger with High Resolution for H1

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Representing the H1 UK Groups

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- Introduction.
- Physics Motivation for a new Tracking Trigger.
- System Overview.
- Level 1 System.
- Simulated Performance.
- Requests from PPESP.

# Trigger Rates after the HERA Upgrade

- HERA upgrade 2000-1 ... factor $\sim 5$ increase in luminosity.

At $\mathcal{L}^{\max} \sim 70\ \mu\mathrm{b}^{-1}\mathrm{s}^{-1}$, rates of observable $ep$ interactions:

| Kinematic range | Rate [Hz] |
|---|---|
| $Q^2$ <1 GeV$^2$ | 1000 |
| 1< $Q^2$ <10 GeV$^2$ | 40 |
| 10 GeV$^2$< $Q^2$ | 4 |

- Max input rate to level 4 (filter farm) trigger $\sim 100\ \mathrm{Hz}$.

Without improved selectivity at earlier stages of trigger, prescaling will be necessary:

| $Q^2$ | Present Prescale | Prescale after Upgrade | Resulting Efficiency |
|---|---|---|---|
| 0 | $\infty$ | $\infty$ | 0% |
| 5 | 5 | 25 | 4% |
| 40 | 2 | 10 | 10% |
| 150 | 1 | 1 | 100% |

Most Exclusive Final States at low $Q^2$ subject to these prescales

# Example Physics Processes

Many measurements crucial to our understanding of QCD dynamics / proton structure . . .

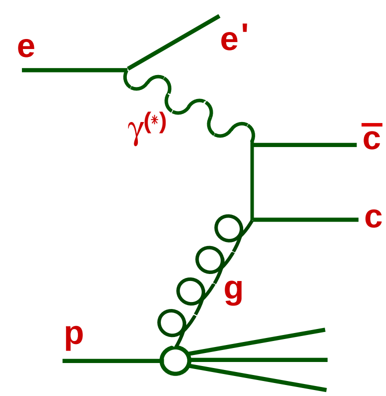
1) have low visible cross section.

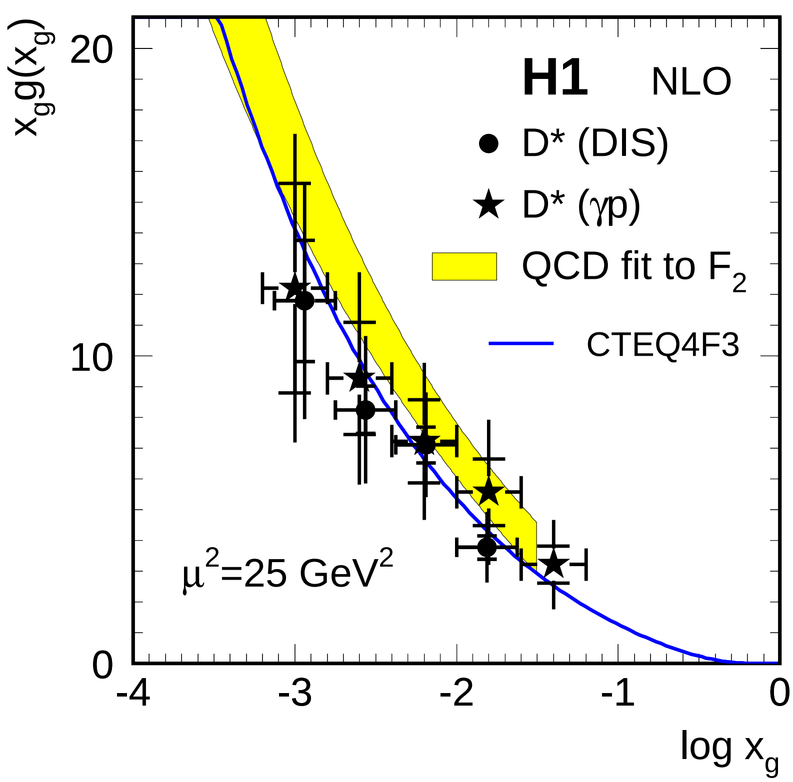
2) do not contain high $p_t$ final states for easy triggering.

3) display track based signatures.

**1) Open charm physics:** $(D^* \to D^0 \pi_{\rm slow} \to K\pi\pi_{\rm slow})$

- Direct $x_g g(x_g)$ via $\gamma^{(\star)} g \to c\bar{c}$
- Charm structure function $F_2^{c\bar{c}}$
- Gluon distribution of photon, pomeron . . .
- Open beauty physics through $b \to c$ decays.



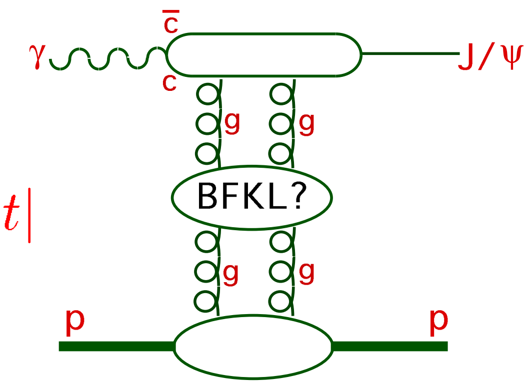

Proton gluon density

Stat. errors $\sim 25\%$ from $\leq$ 96 data.

Much better stats and high $p_T(D^*)$ data needed for detailed analysis!

# Example Physics Processes

## 2) Vector meson production:




- $\gamma p \rightarrow Vp$ calculable in pQCD?
- Novel parton dynamics?
- $\rho$, $J/\psi$ not well measured at high $Q^2$, $|t|$
- Little data so far for $\phi$, $\rho'$, $\psi'$, $\Upsilon$ . . .
- Inelastic $J/\psi$ poorly understood.

## 3) High $p_T$ Charged Particles

- High $p_t$ charged particles almost always interesting . . .

  e.g. $W$, $Z$ (semi)-leptonic decays.

  Heavy flavour semi-leptonic decays.

  Isolated muons with missing $p_t$.
- FTT accurately measures track $p_T$ at early stages of trigger.

## 4) Discovery Potential

- Exotic processes can show up as anomalous charged / neutral final state yields . . .

  QCD Instantons.

  Centauro / Anti-centauro events.

  Disoriented chiral condensate (Bjorken).
- FTT can be used in conjunction with calo jet trigger etc.

# Example Physics Processes

| PROCESS | 1996 DATA $13\,\mathrm{pb}^{-1}$ DELIVERED | ESTIMATED $97-00$ $92\,\mathrm{pb}^{-1}$ DELIVERED (OPTIMISTIC!) | ESTIMATED 2001++ $600\,\mathrm{pb}^{-1}$ DELIVERED |
|---|---|---|---|
| $D^*$ in DIS ($Q^2 > 2\,\mathrm{GeV}^2$) | 583 | 4100 | 27000 |
| $D^*$ in DIS FROM $b$ DECAY | (9) | (60) | (420) |
| $D^*$ in diffractive DIS ($Q^2 > 2\,\mathrm{GeV}^2$) | 11 | 80 | 510 |
| $D^*$ in $\gamma p$ | 788 | 5500 | 36000 |
| $D^*$ in $\gamma p$ FROM $b$ DECAY | (13) | (90) | (600) |
| Elastic $\rho^0 \to \pi^+\pi^-$ ($Q^2 > 30\,\mathrm{GeV}^2$) | 16 | 110 | 740 |
| Quasi-elastic $J/\psi \to \mu^+\mu^-$ ($Q^2 > 2\,\mathrm{GeV}^2$) | 156 | 1100 | 7200 |
| Quasi-elastic $J/\psi \to e^+e^-$ ($Q^2 > 2\,\mathrm{GeV}^2$) | 74 | 520 | 3400 |

# Track Triggering in H1

- Present H1 track triggering . . .

    Loose selection at L1 (DCr$\phi$) (Deadtime free $2.3\ \mu$s)

    L4 refinements based on full track rec'n ($800\ \mu$s)

- Proposed Fast Track Trigger (FTT) . . .

    Decisions at L1 ($2.3\ \mu$s), L2 ($25\ \mu$s) and L3 ($\lesssim 100\ \mu$s)

| | DCr$\phi$ | FTT |
|---|---|---|
| number of DC layers | 10 | 12 |
| hit resolution | 5 mm | 500 $\mu$m |
| $p_T$ range | $\gtrsim 400$ MeV | $> 100$ MeV |
| track multiplicity | $N_{\mathrm{DCr}\phi} \propto N_{\mathrm{tracks}}$ | precise |
| $p_t$ resolution | 2 loose thresholds 400, 800 MeV | $\sigma(1/p_T) \sim 0.05/\mathrm{GeV}$ |
| $z$-information | no | yes |
| topological info. | Limited, $r\phi$ only. | Detailed, 3D |
| invariant masses | no | yes |

The FTT will . . .

- Generally improve H1 track triggering capabilities.
- Identify exclusive final states early enough to avoid large prescales.

# Principle of the Fast Track Trigger

H1 Central Jet Chambers:

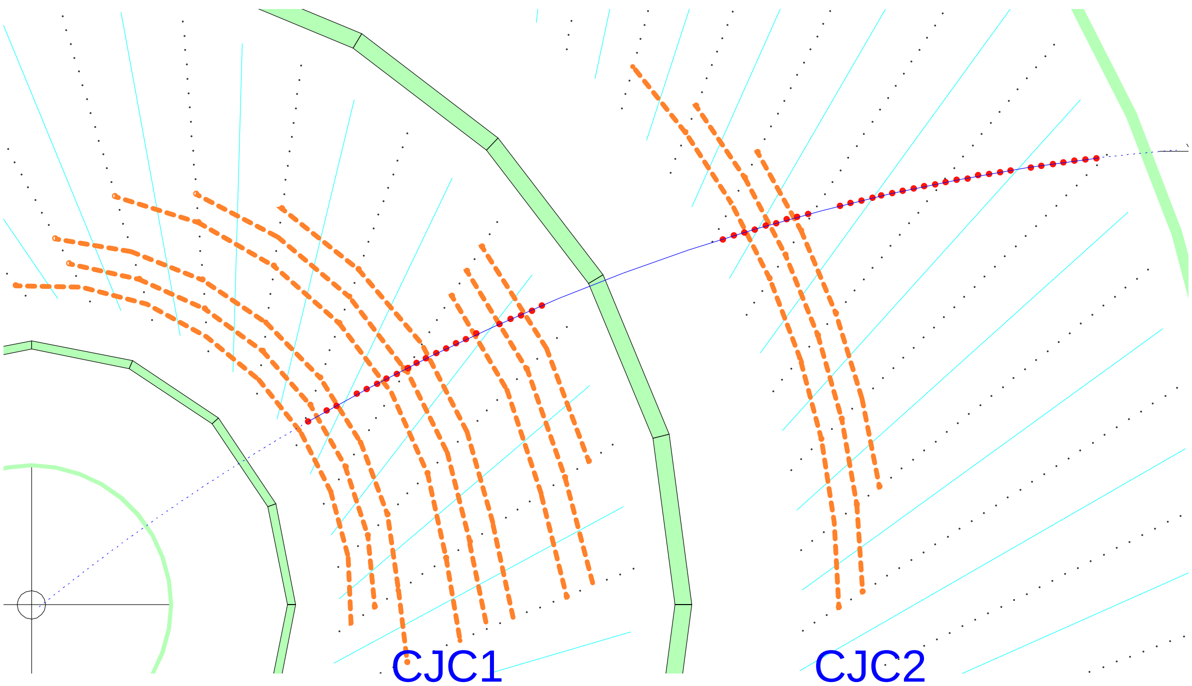
CJC1 - 30 cells in $\phi$, 24 layers of sense wires in $r$

CJC2 - 60 cells in $\phi$, 32 layers of sense wires in $r$

Take signals from four groups of three layers, all cells.

e.g. CJC1: (3,5,7), (10,12,14), (18,20,22), CJC2: (4,6,8).

**$r$-$\phi$ Projection**




Advances in integration and speed of electronics and rapidly reducing costs allow . . .

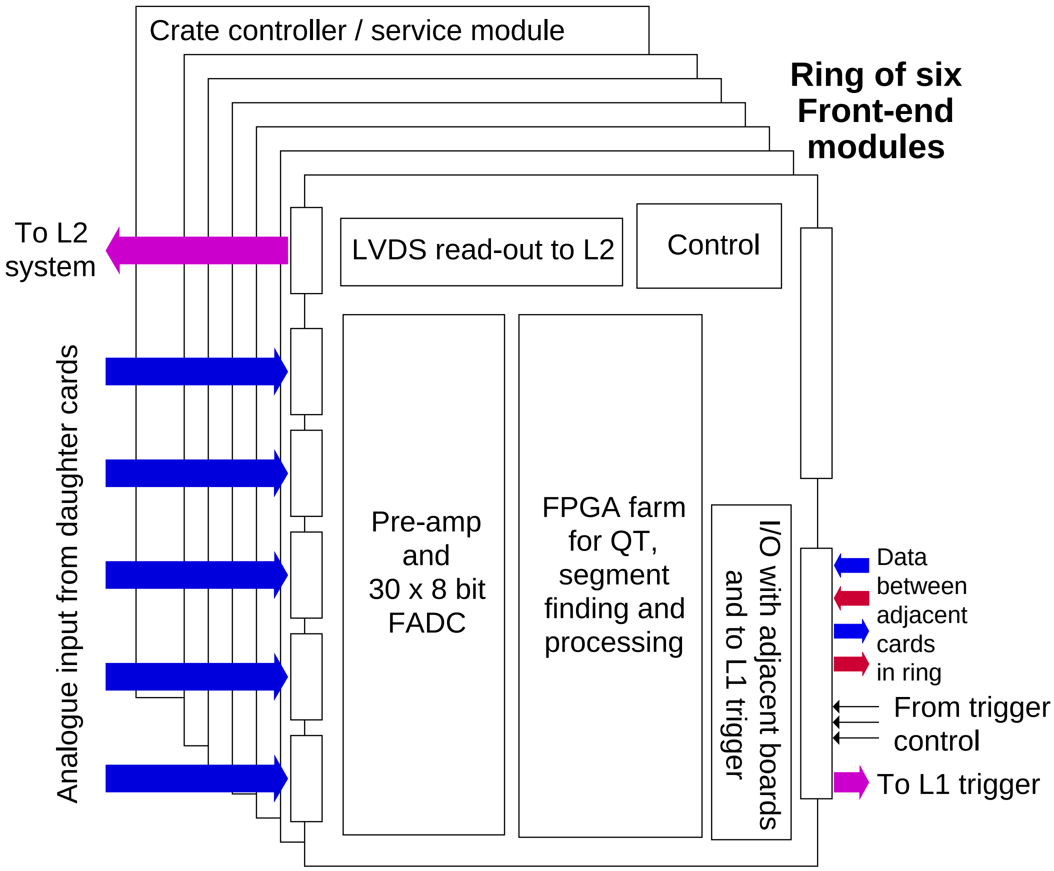
- Detailed drift chamber analysis on-line.
- Identification of complex signatures from track combinations at L1-3.

# Specifications at L1-L3

| | L1 | L2 | L3 |
|---|---|---|---|
| Latency | $2.3\ \mu s$ | $25\ \mu s$ | $\lesssim 100\ \mu s$ |
| Tasks | $Q - t$ analysis<br><br>Track segment finding | Track Segment linking. | Event rec'n. |
| Data for Trigger Decision | Coarsely linked track segments | Tracks with precisely determined 3-momenta | Combinations of Tracks |
| Basis of Trigger Decision | Tracks with variable $p_T$ thresholds, multiplicity, sign? | Track $p_T$ multiplicity, topology total $E_t$ ... | Invariant mass sums $D^*\ \Delta M$ ... |

H1-UK groups have taken responsibility for the L1 system.

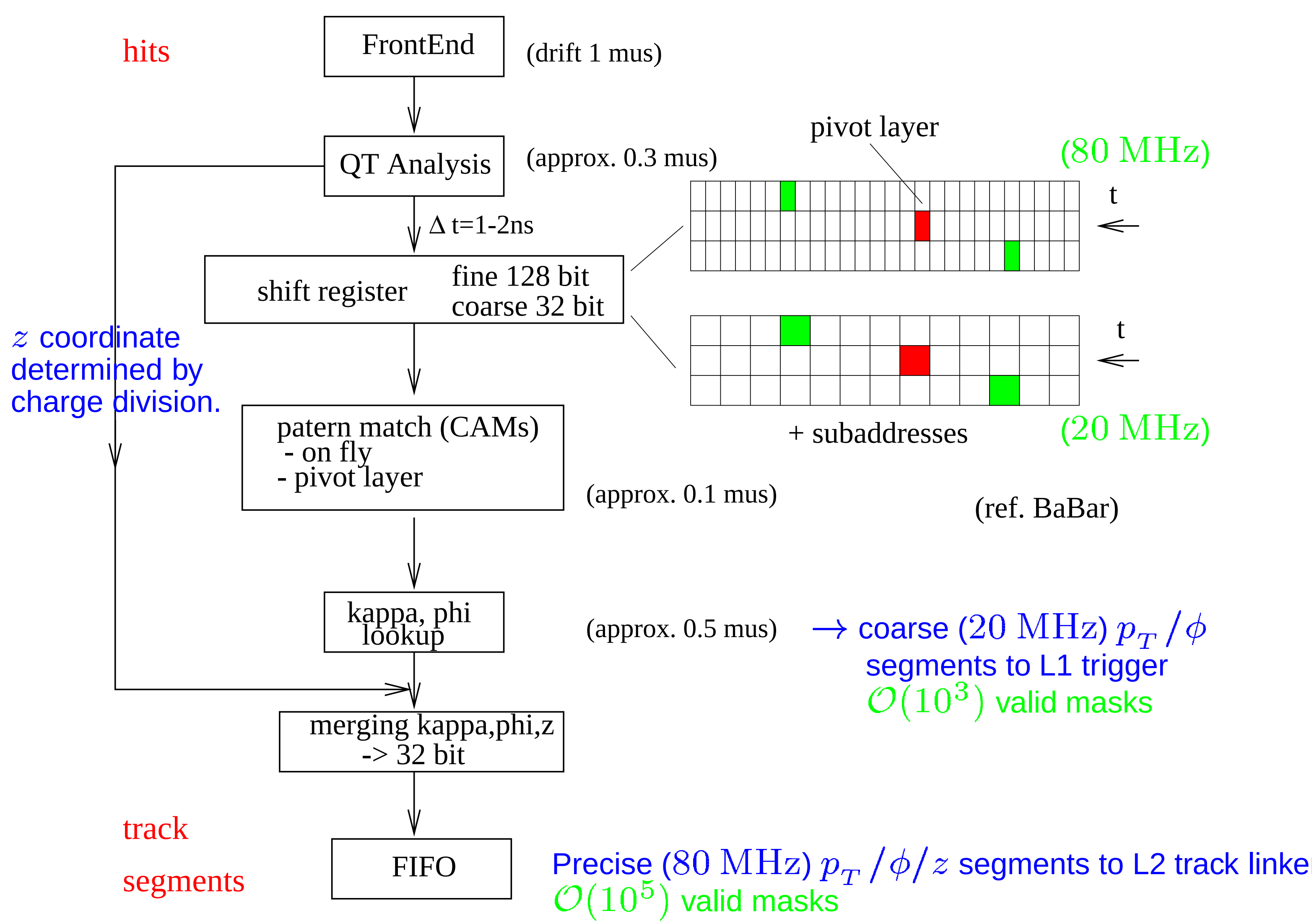
# Overview of L1 System




Functionality:

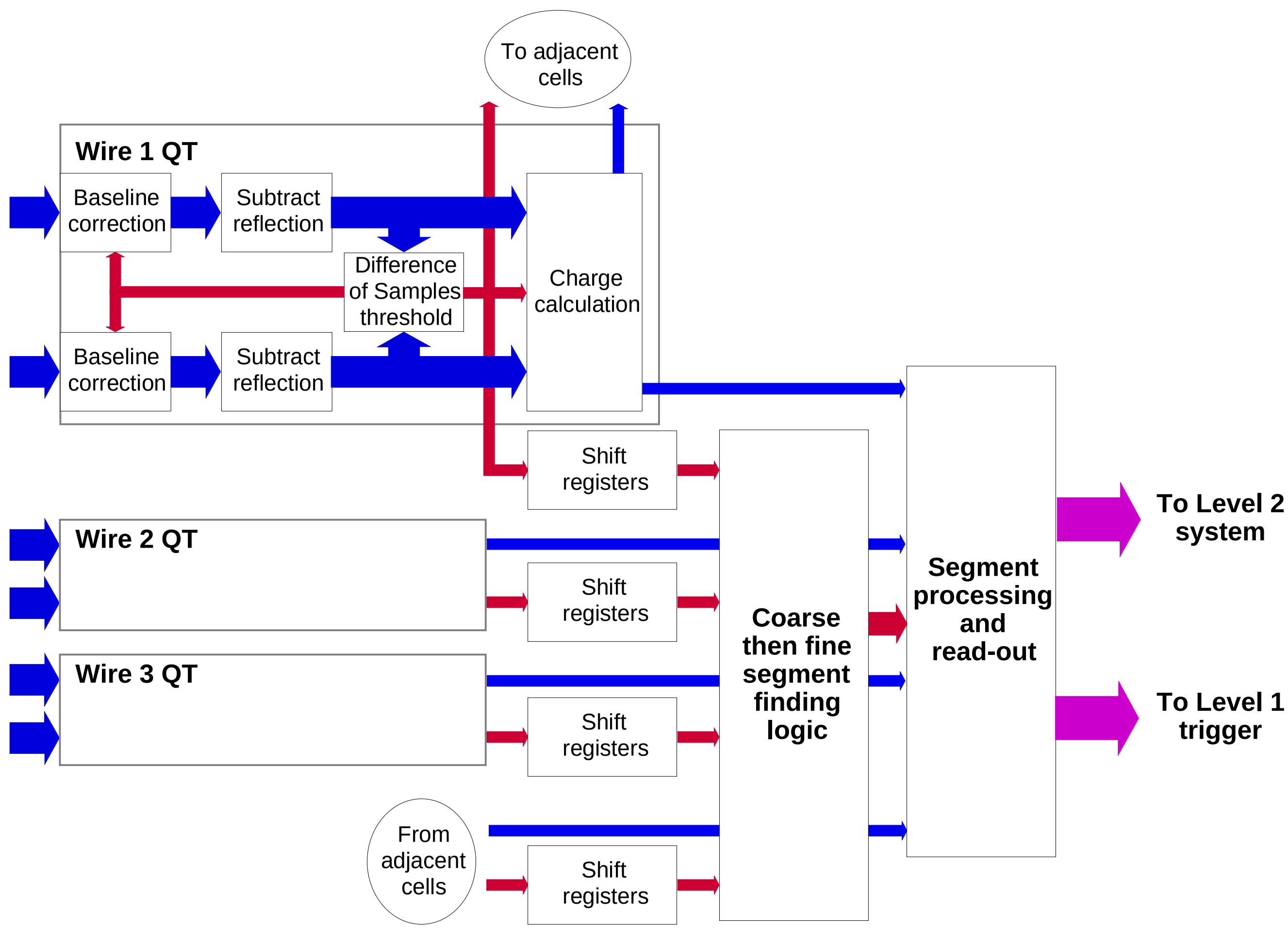
- Analogue CJC signals taken from front of FADC cards.
- Preamp. and 30 8-bit FADCs digitize signals at 80 MHz.
- $Q - t$ algorithm implemented on FPGAs
- Coarse/fine track segment finding done using CAM functionality of the ”FPGA farm”
- Track segment data processed $\rightarrow$ merged $p_T$, $\phi$, $z$-info.

# Data Flow Through L1 System



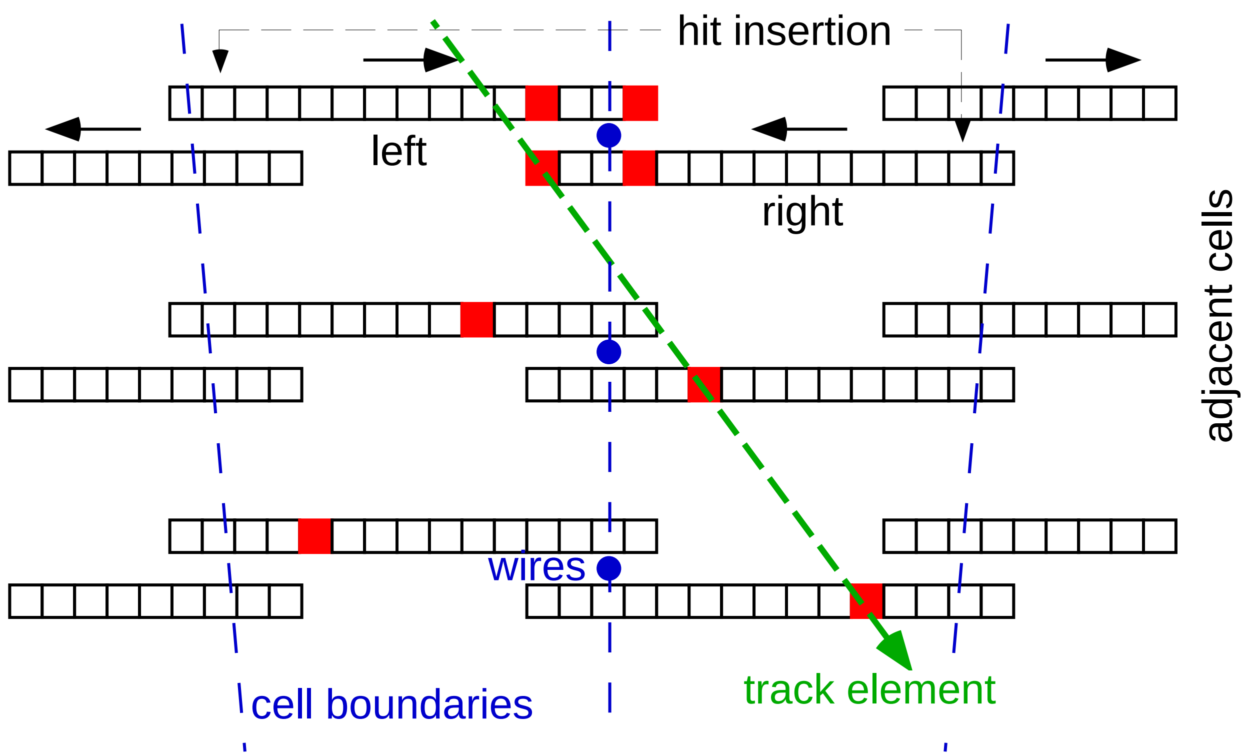
# Front End Digitisation and Segment Finding

Implemented in e.g. Altera Apex 20K1000 with $\sim 10^6$ gates.



# Finding Valid Masks for Trigger Groups

Track Segment Finding

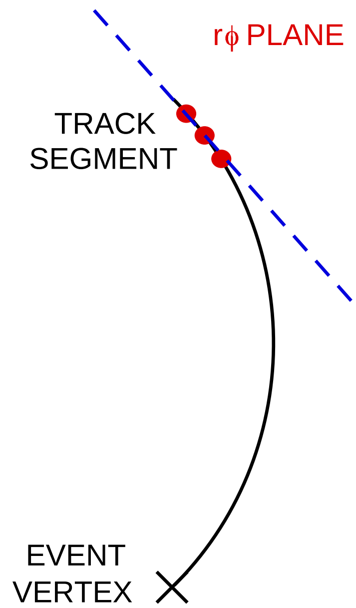



- Masks defined in shift registers, corresponding to valid track segments in 3 wires of a trigger layer.
- Entries in shift registers corresponding to left-right drift space ambiguity.
- Adjacent cells analysed together to deal with tracks crossing cell boundaries.
- Bunch crossing of origin can be identified where tracks pass on either side of wires or cross cell boundaries.

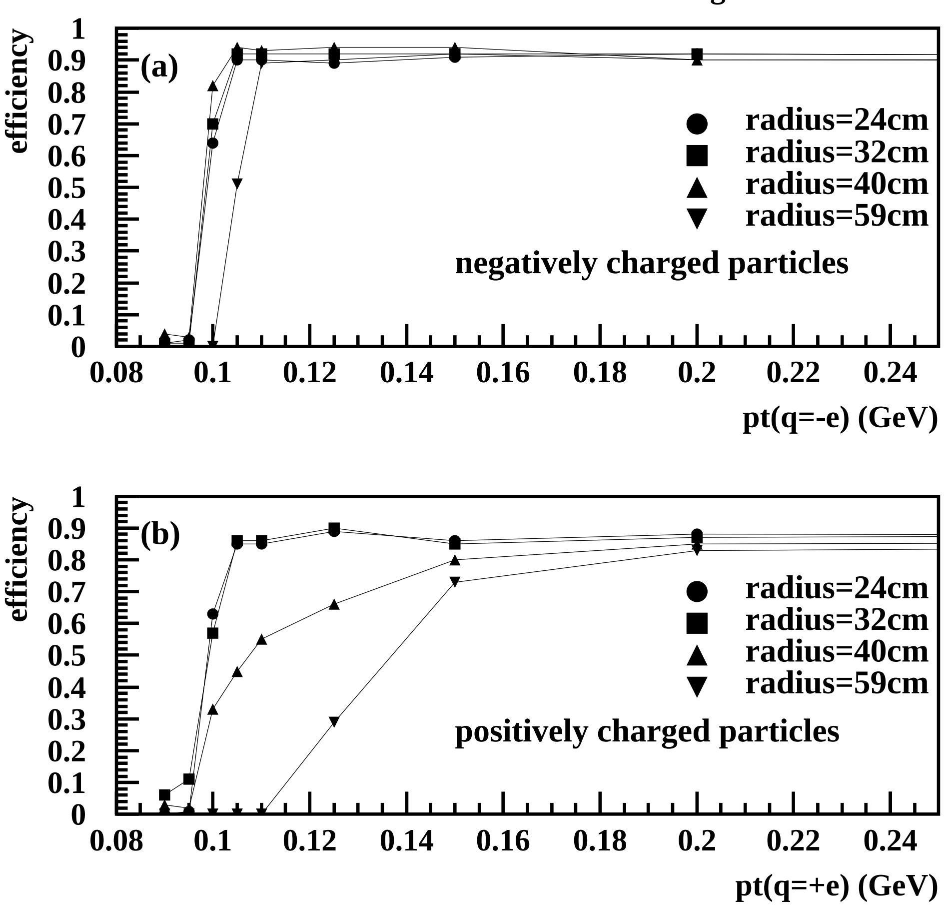
# Determination of $\phi$, $p_T$

Assumption of vertex in $r$-$\phi$ plane allows $\phi$ and $p_T$ determination.

Valid track segment masks converted to ($p_T$ , $\phi$) values using Look Up Tables




Trigger Group Efficiency ($\varepsilon_{single\ hit}$=0.95)




Each trigger group is 3 CJC wires.

High efficiency down to $p_T \sim 100$ MeV in most cases.

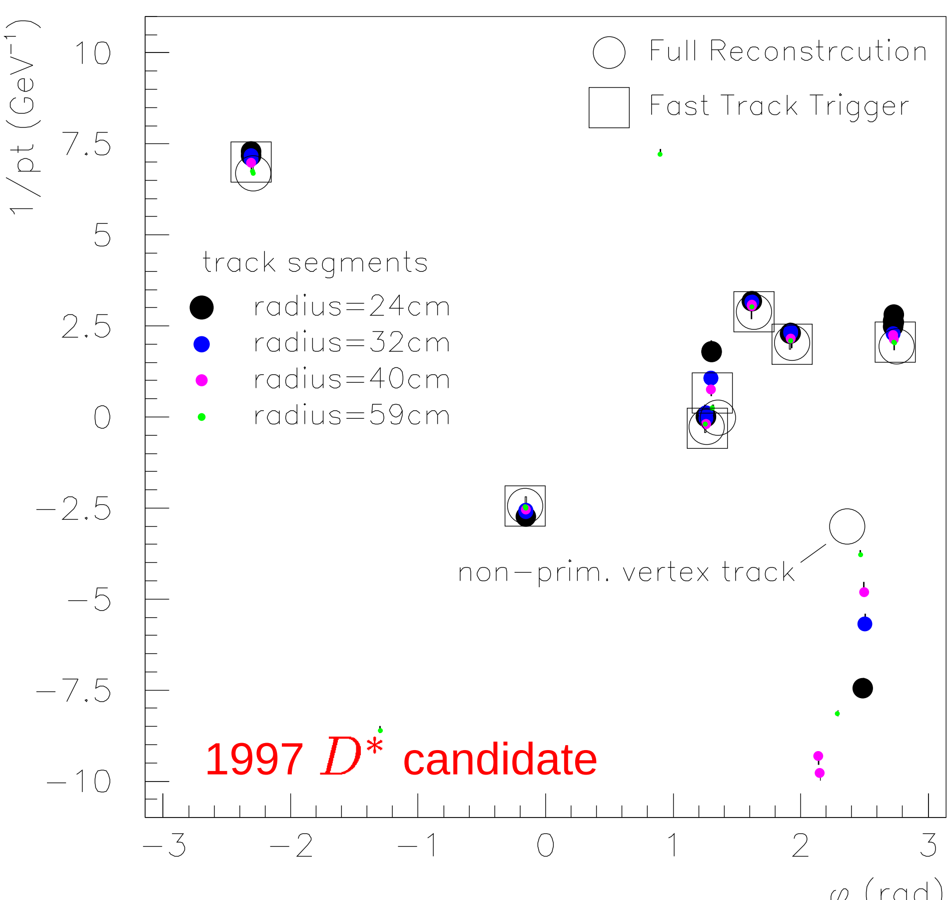
# Level 1 Trigger Decision

Feasibility study of level 1 trigger decisions in progress.

Several possible improvements over existing DCr$\phi$ trigger . . .

- Lower / sharper / more flexible $p_T$ thresholds.
- Improved determination of bunch crossing of origin.
- Better track multiplicity / topology information

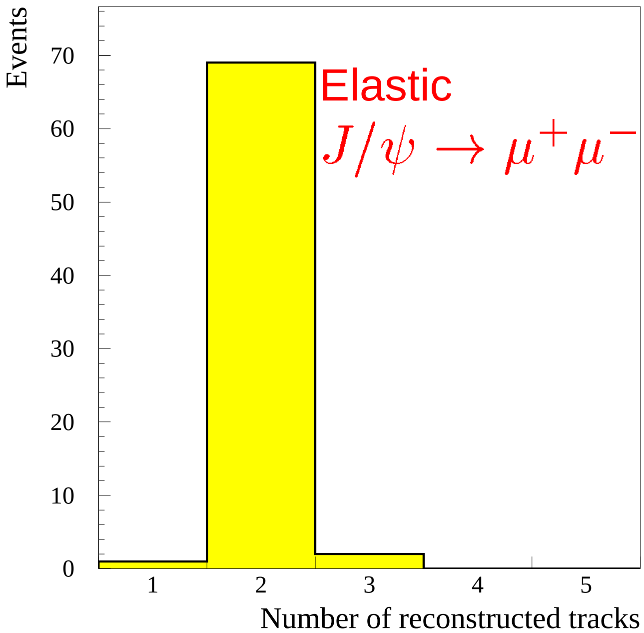
Pattern match track segments with the same $p_T$, $\phi$ from up to four radial groups at $20\ \mathrm{MHz}$.




Linking of track segments in 1/pt vs $\varphi$

e.g. 2 out of 4 segment coincidence could define a track.

# Level 1 Trigger Viability

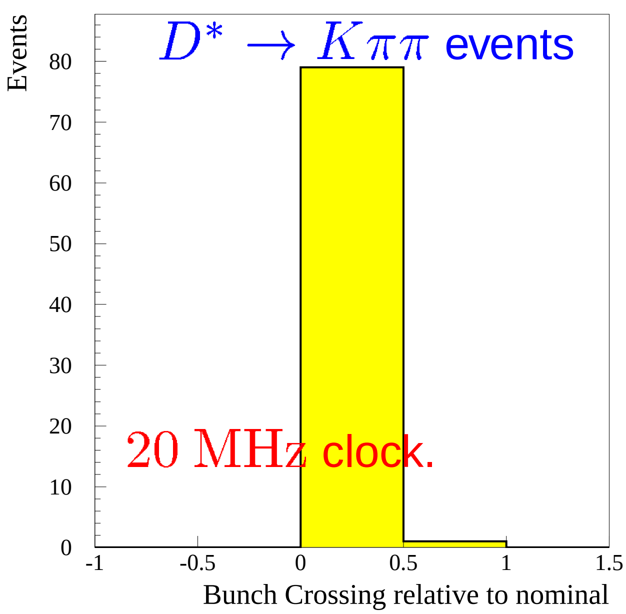


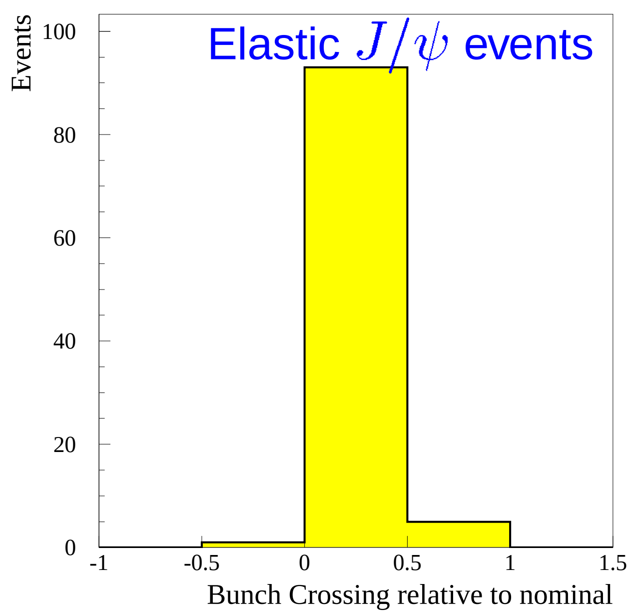

First simulation studies promising . . .

Correct number of tracks reconstructed by L1 trigger.

Significant improvement on DCr$\phi$

Bunch crossing of origin ($\times 96$ ns) determination . . .



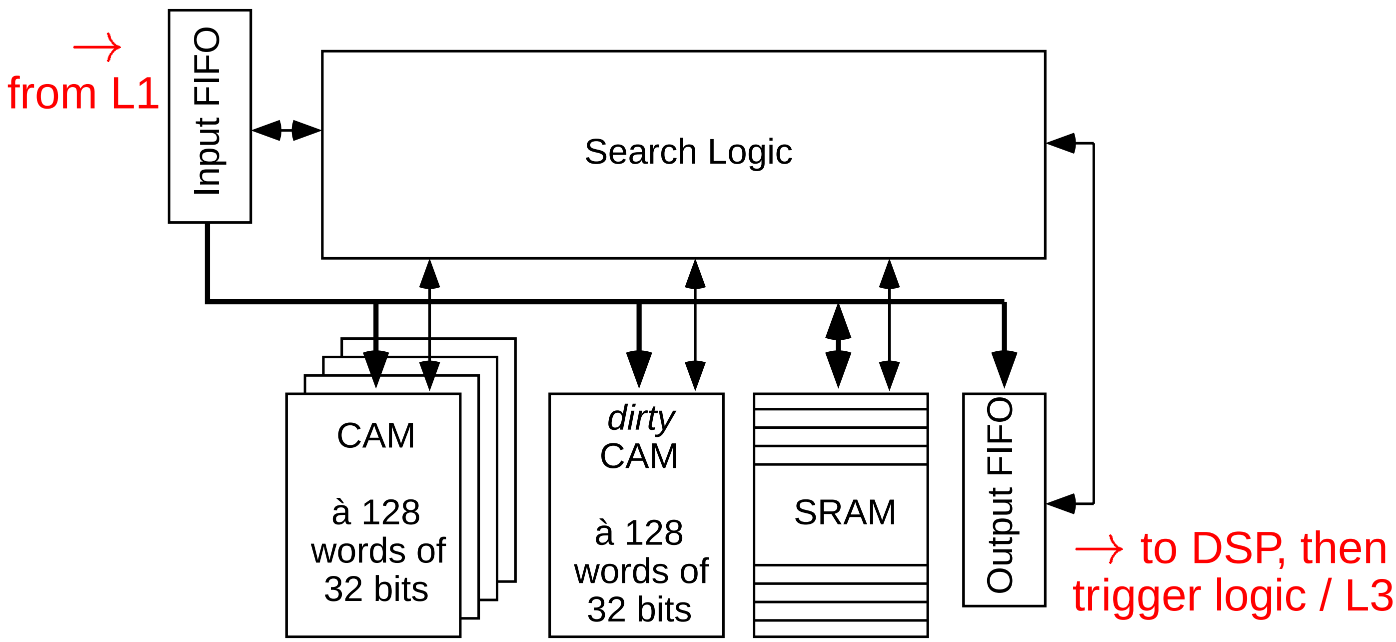

$p_T - \phi$ track segment pattern matching could be realised using CAMs at marginal hardware costs.

Crucial question will be time constraints

# Level 2 Track Segment Linking

Level 2 track linking is performed by pattern matching track segments with the same $p_T$, $\phi$ from all four radial groups.

Achieved using CAMs




1. ($p_T$, $\phi$) vectors loaded into 1 CAM per radial group.
2. All track segments loaded into SRAM.
3. SRAM contents matched in ($p_T$, $\phi$) with each CAM.
4. Best match with $\geq 2$ coincidences defines track.
5. 'Dirty' CAM containing already linked segments vetoes double counting.
6. Optimisation procedure in DSP.

Development at an advanced stage (DESY, ETH Zürich).

# Level 3 System

- Tracks combined to search for complex final state signatures ($D^*$, $J/\psi$, $\rho \ldots$)
- L3 reject can be made anytime during $\sim 800\ \mu\mathrm{s}$ detector readout time.
- Early decision reduces deadtime, allowing more events to be processed.
- With L3 decision after $100\ \mu\mathrm{s}$, $500\ \mathrm{Hz}$ processing costs $5\%$ deadtime.

Software selection to run on commercial processors . . .

- 2 PCs enough to trigger on wide range of processes.

Detailed work yet to begin.

# FTT Resolution in $p_T$, $\phi$, $\theta$

FTT level 1, 2 algorithms have been simulated . . .

Efficiencies, resolutions, robustness studied with real events.

## Track resolutions in $1/p_T$, $\phi$

(relative to full off-line reconstruction, using 1997 $D^*$ data) . . .

$$\sigma(1/p_T) \sim 0.05\ \mathrm{GeV}^{-1}$$
$$\sigma(\phi) \sim 5\ \mathrm{mrad}$$

## Reconstruction of Track $\theta$

$\theta$ calculated from . . .

- $z$ of hits from L1 FTT charge division $[\sigma(z_{\rm hit}) \sim 6\ \mathrm{cm}]$
- $z$ of vertex from L1 MWPC trigger $[\sigma(z_{\rm vtx}) \sim 2.5\ \mathrm{cm}]$

(relative to full off-line reconstruction, using 1997 $D^*$ data) . . .

$$\sigma(\theta) \sim 50\ \mathrm{mrad}$$

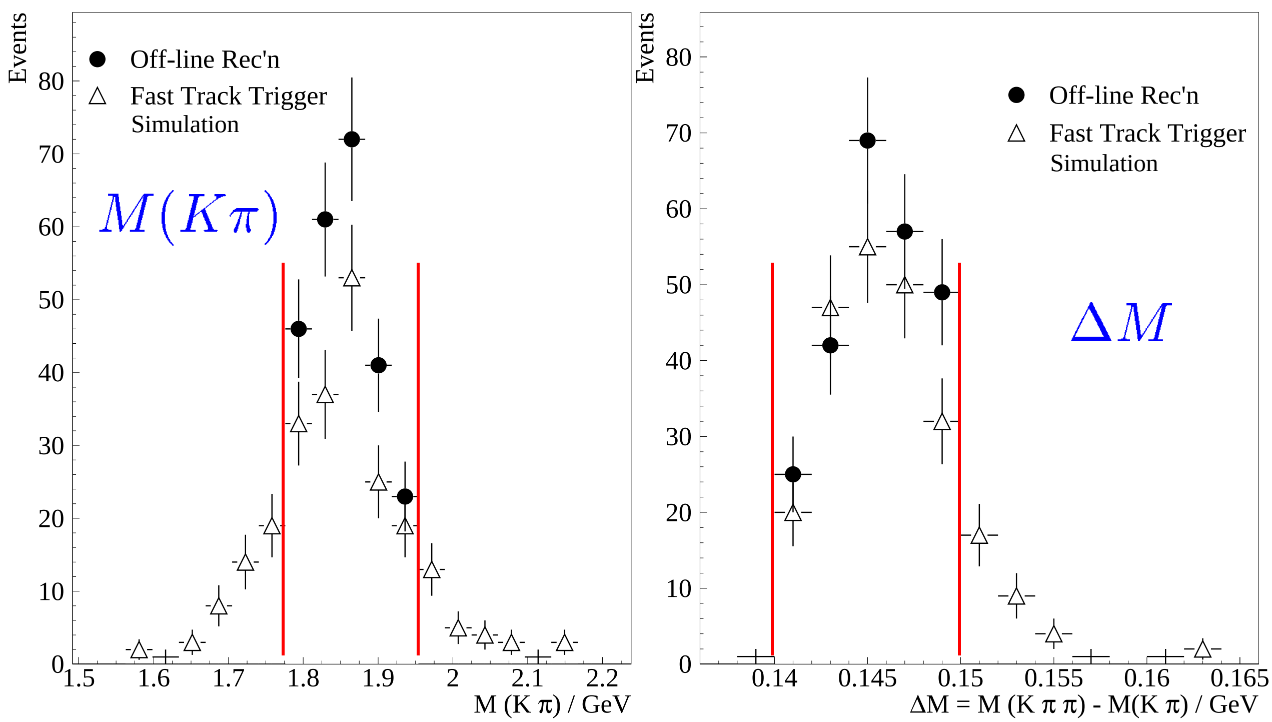
# Performance for $D^*$ Events

Open charm usually identified through 'golden' decay channel, $D^* \to D^0 \pi_{\rm slow} \to K\pi\pi_{\rm slow}$.

Selection through cuts on . . .

1. $M(K\pi) - M(D^0_{\rm nom})$
2. $\Delta M = M(K\pi\pi_{\rm slow}) - M(K\pi)$

Resolutions evaluated using sample of 1997 $D^*$ events.

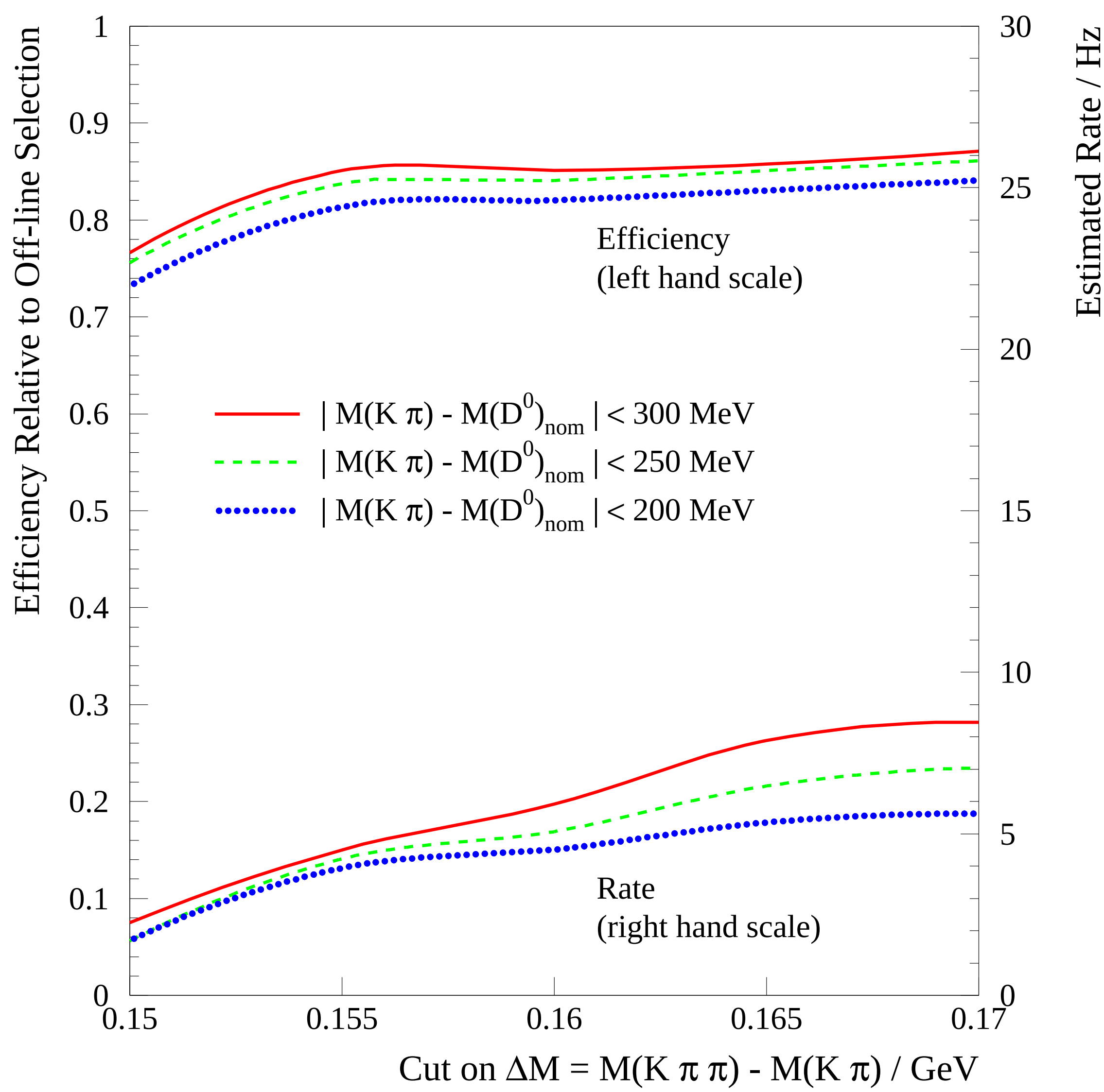



Standard Off-Line Selection

# Performance for $D^*$ Events

$D^*$ finding efficiency studied relative to off-line selection for various cuts on $D^0$ mass window and $\Delta M$.

Trigger rates estimated for *peak* post upgrade luminosities by extrapolation from current rates.




$80\%$ efficiency achievable with $\lesssim 5\ \mathrm{Hz}$ peak rate.

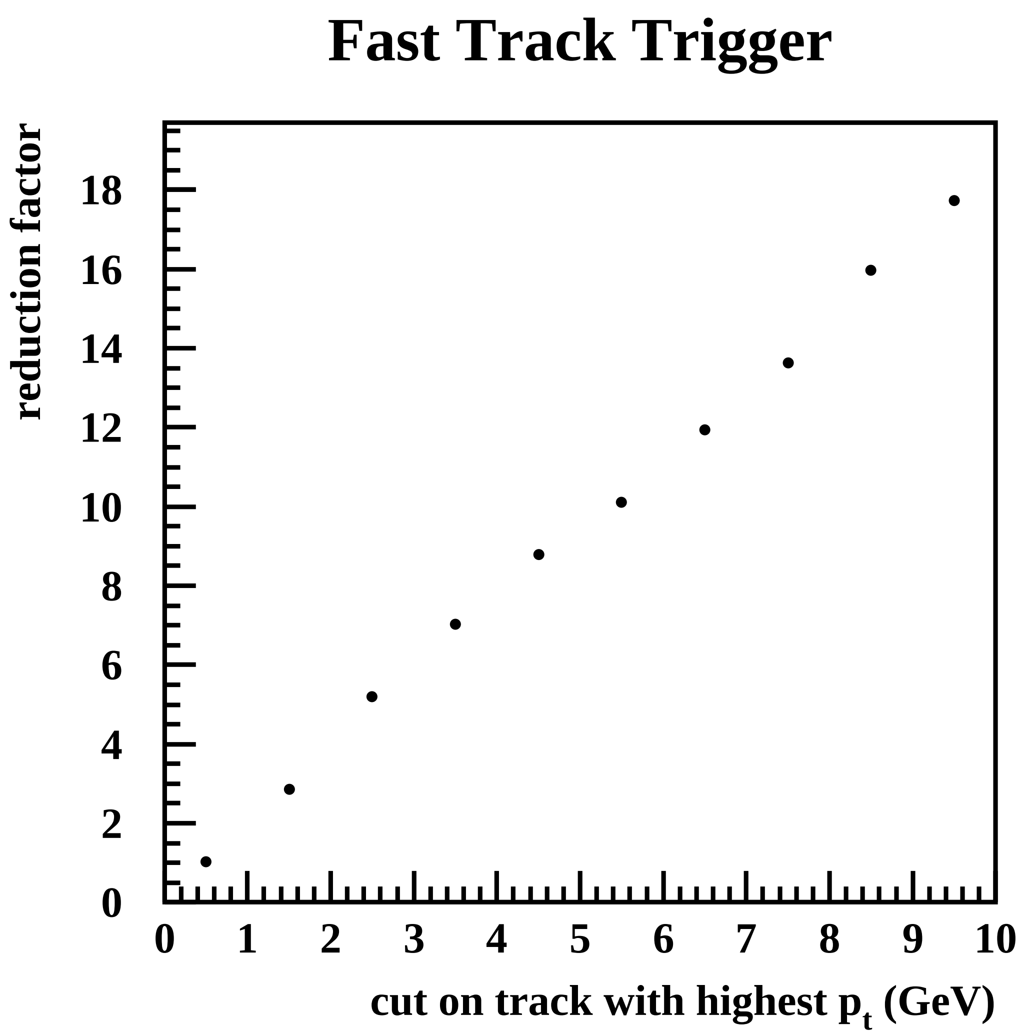
Efficiencies $\sim 5\%$ higher for $b \to c \to D^*$.

# Transverse Momentum Selectivity

Large rate reductions can be achieved for many physics channels with $p_T$ cuts at level 2.

e.g. $\Upsilon$, $J/\psi$, $Z \rightarrow l^+l^-, W \rightarrow \mu\nu \ldots$

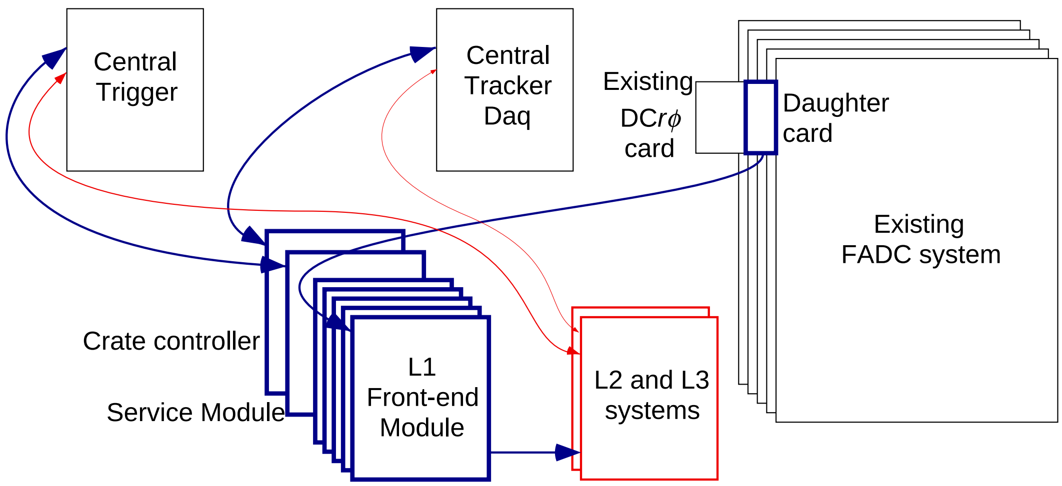
Resolution $\sigma\left(\frac{1}{p_T}\right) \sim 0.05\ \mathrm{GeV}^{-1}$.



# Estimated Trigger Efficiencies

| | trigger rates with FTT [Hz] | | | trigger efficiency [%] | |
|---|---|---|---|---|---|
| **Process** | **L1** | **L2** | **L3** | with FTT | without |
| D$^*$ decay (DIS) | 160 - 500 | 30 | 5 | 70 | 1 |
| D$^*$ decay ($e$-tagged $\gamma$ p) | 120 - 500 | 25 | 4 | 60 | 1 |
| $\rho \rightarrow \pi^+\pi^-$ (DIS) | 40 | 2.5 | 1 | 80 | 2 |
| J/$\Psi$ $\rightarrow$ ee,$\mu\mu$ | 50 | 20 | 1-3 | 12-60 | 1-3 |
| $\Upsilon$ $\rightarrow$ ee, $\mu\mu$ | 50 | 5 | 0.5-2 | 12-60 | 1-3 |

# UK Commitments to Level 1 System




- ‘Plug through’ analogue card from CJC FADCs
- Front End Module Design and Construction
- Control software / Interfaces
- L1 Service Module / trigger card
- L1 Trigger algorithm design / simulation
- Monitoring software to compare with CJC readout

# Costing of Level 1 System

| ITEM | COST (£) | EFFORT (Staff Years) | SOURCE OF EFFORT |
|---|---|---|---|
| Analogue Plug-through Card (150) | 30k | 0.25 + 0.5 | RAL + Manchester |
| Front End Modules (30) | 135k | 3 + 1 | RAL + RAL PPD |
| Coding segment finding algorithm | | 2 | DESY + Zürich |
| Crate control processor (2) | 10k | | |
| Control software and Interfaces | | 0.75 + 0.25 | RAL + Manchester |
| Service Module / trigger card (2) | 10k | 1 | Birmingham + Manchester |
| Compact PCI Crates (2) | 20k | | |
| Cabling | 10k | | |
| Workstation and Interfaces | 5k | | |
| Trigger algorithms / simulation | | 2.5 | Birmingham + Zürich |
| Monitoring Software | | 1.25 | UK Universities |
| Total (incl. VAT @ 17.5 %) | **260k** | **4 + 8.5** | |

Items in red are requests from PPESP.

# Funding Model

Total project (L1-3) costed at DM 1950

| EQUIPMENT COSTS | | |
| --- | --- | --- |
| DESY | 250k | Approved |
| Dortmund | 310k | Approved |
| ETH Zürich | 550k | Seeking approval |
| Cracow | 70k | Seeking approval |
| UK | 770k | This request |

4 Staff Years of effort are requested from RAL-ID.

Other physicist and technical effort . . .

| STAFF YEAR ALLOCATIONS | |
| --- | --- |
| DESY | 3 SY |
| Dortmund | 8 SY |
| ETH Zürich | 4 SY |
| Cracow | 2 SY |
| UK | 6 SY |

# Time Schedules for Level 1 System

Fully commissioned system by end 2001 gives $\geq 5$ years run-time.

| FRONT END MODULE | |
|---|---|
| Preliminary design report | now - 03/00 |
| First design | 03/00 - 06/00 |
| Board layout | 06/00 - 12/00 |
| Prototype manufacture | 12/00 - 01/01 |
| Debug / testing prototype | 01/01 - 03/01 |
| Installation of prototype at H1 | before 03/01 * |
| Redesign and layout | 04/01 - 06/01 |
| Main production | 06/01 - 12/01 |

* end of HERA shutdown is planned for 03/01

| OTHER MILESTONES | |
|---|---|
| Segment finding algorithm Finalised | before 04/00 |
| Segment finding programmed on FPGAs | before 03/01 * |
| L1 trigger viability studies | now - 03/00 |
| L1 trigger algorithm design | 03/00 - 11/00 |
| Service Module design, build, test | before 02/01 |
| Installation of Service Module | before 03/01 * |
| Installation of Analogue Plug through cards | before 03/01 * |
| First version of Control Software | before 03/01 * |
| Full System Operational | before 12/01 |

# Summary and Status

- HERA Upgrade presents unique opportunities in QCD / low $x$ Physics.
- FTT will allow H1 to exploit these possibilities in full.
- Trigger selectivity will be improved for many other processes.
- Simulations show that very high performance device is possible.

- Physics benefits recognised by DESY directorate $\rightarrow$ Approval from DESY PRC.
- L2-3 Resource approval obtained at DESY / German Universities, being sought in Switzerland, Poland.
- H1-UK groups request $\pounds 260k$ plus 4 staff years from RAL-ID for construction of L1 system.