A Fast Track Trigger with High Resolution for H1

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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 ~ 5 increase in luminosity.

At $\mathcal{L}^{\rm max} \sim 70\ \mu{\rm b}^{-1}{\rm s}^{-1}$, 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 ~ 100 Hz.

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

Q^2	Present Prescale	Prescale after Upgrade	Resulting Efficiency
0	∞	∞	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 . . .

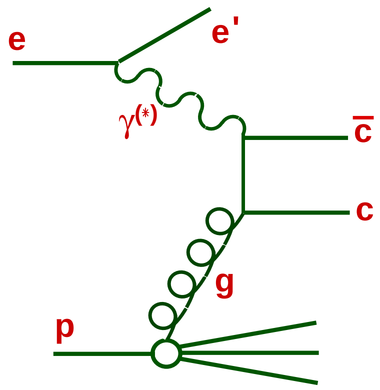
1) have low visible cross section.

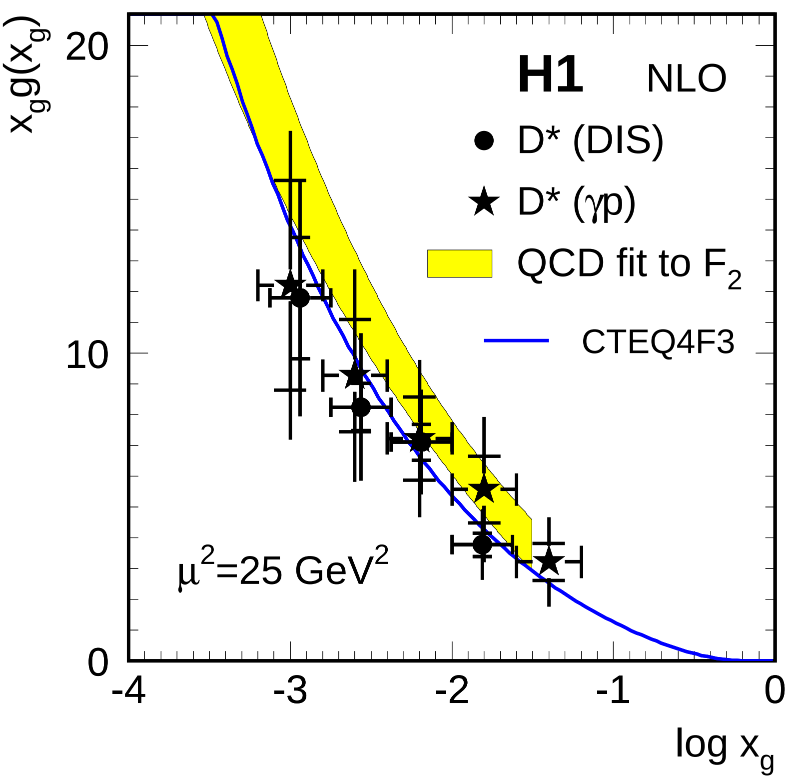
2) do not contain high p_t final states for easy triggering.

3) display track based signatures.

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

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





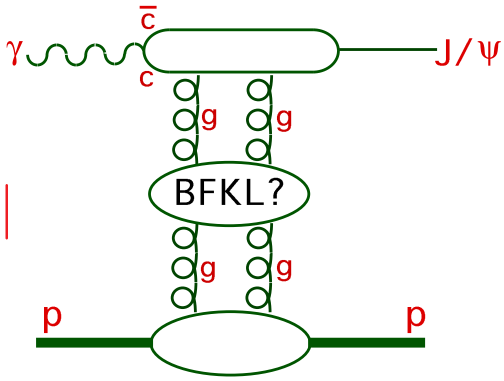
Proton gluon density

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:



- $\gamma p \rightarrow V p$ calculable in pQCD?
- Novel parton dynamics?
- ρ, J/ψ not well measured at high Q^2, $|t|$
- Little data so far for ϕ, ρ', ψ', Υ ...
- Inelastic J/ψ 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 γp	788	5500	36000
D^* in γp 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 (DCrϕ) (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)

	DCrϕ	FTT
number of DC layers	10	12
hit resolution	5 mm	500 μm
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:

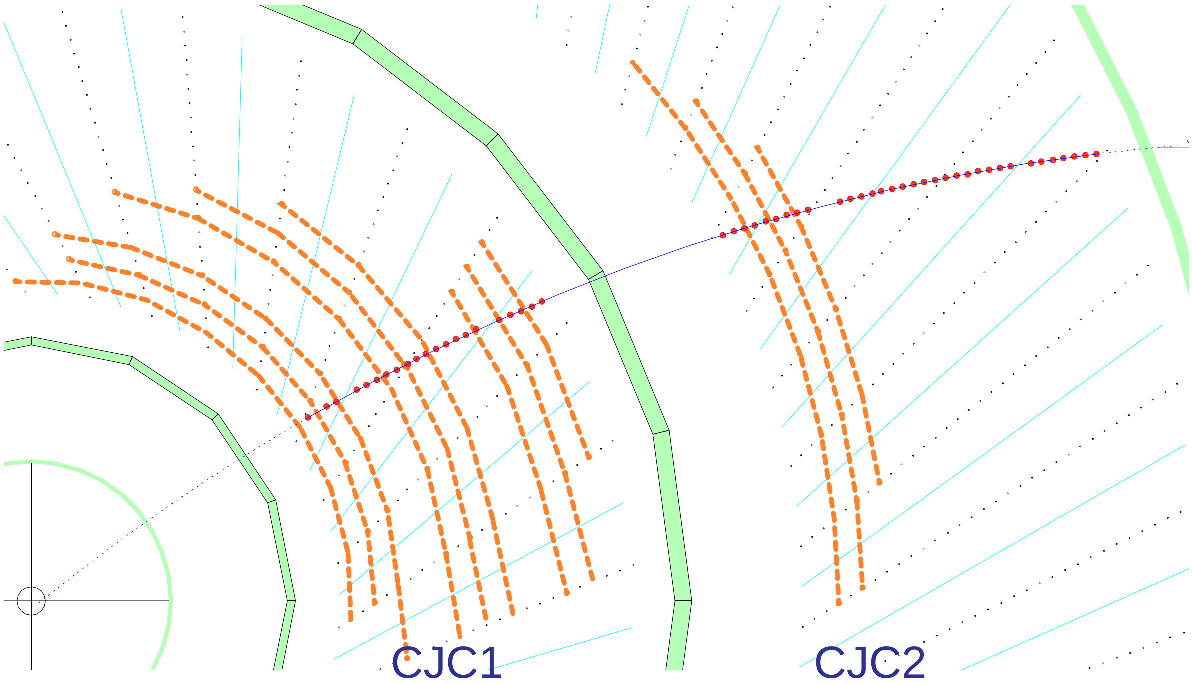
CJC1 - 30 cells in ϕ, 24 layers of sense wires in r

CJC2 - 60 cells in ϕ, 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-ϕ Projection



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

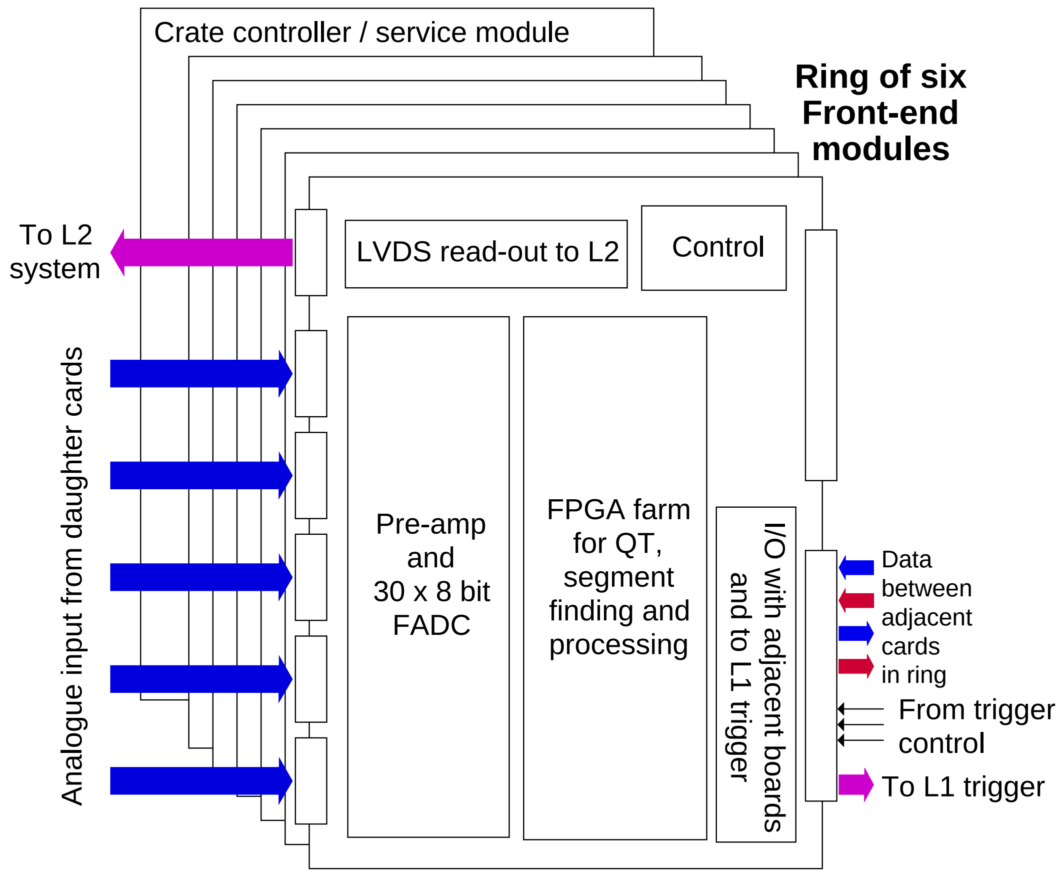
- Detailed drift chamber analysis on-line.
- Identification of complex signatures from track combinations at L1-3.

Specifications at L1-L3

	L1	L2	L3
Latency	$2.3\ \mu s$	$25\ \mu s$	$\lesssim 100\ \mu s$
Tasks	$Q - t$ analysis 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.

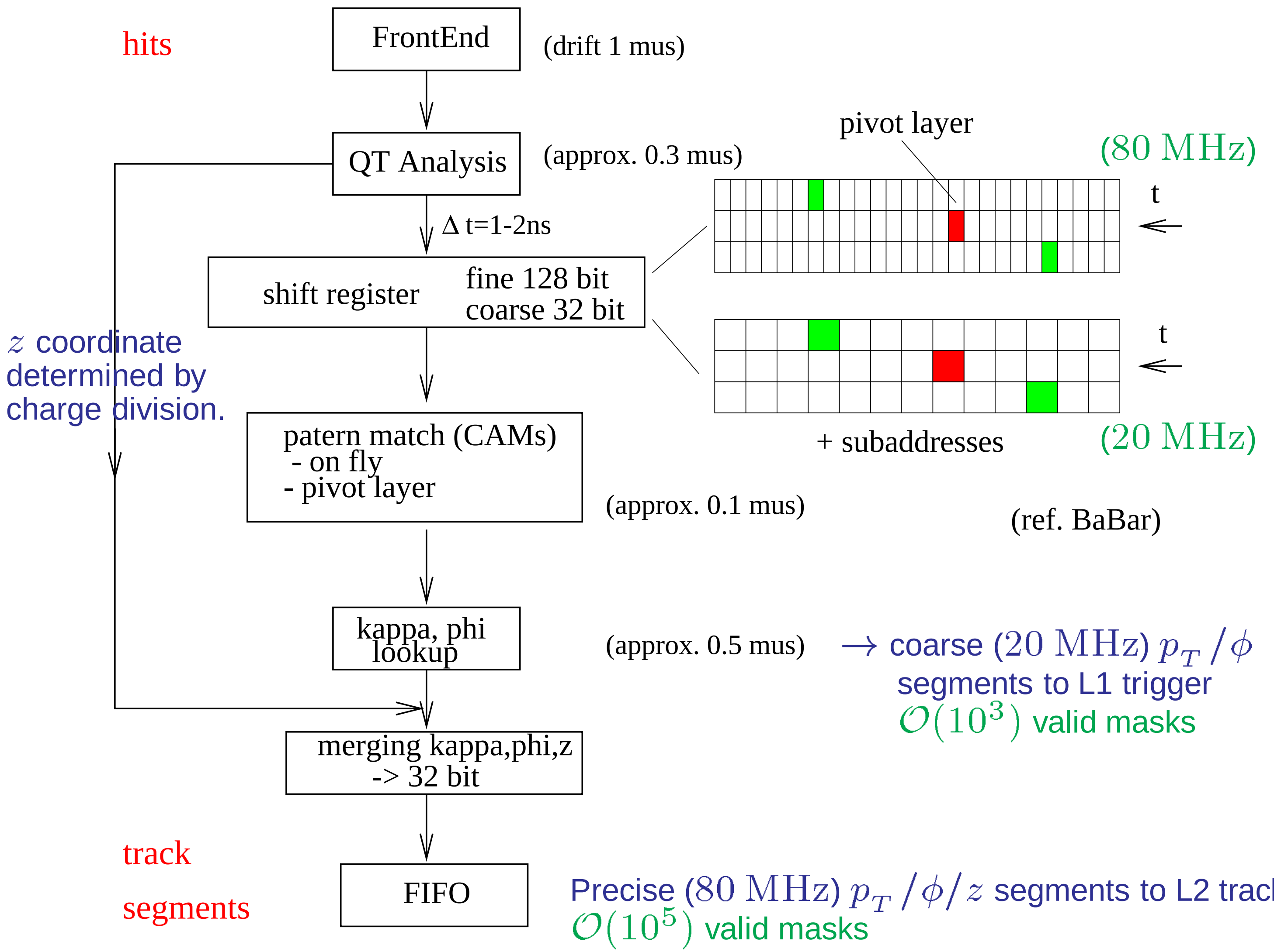
Overview of L1 System



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, ϕ, z-info.

Data Flow Through L1 System

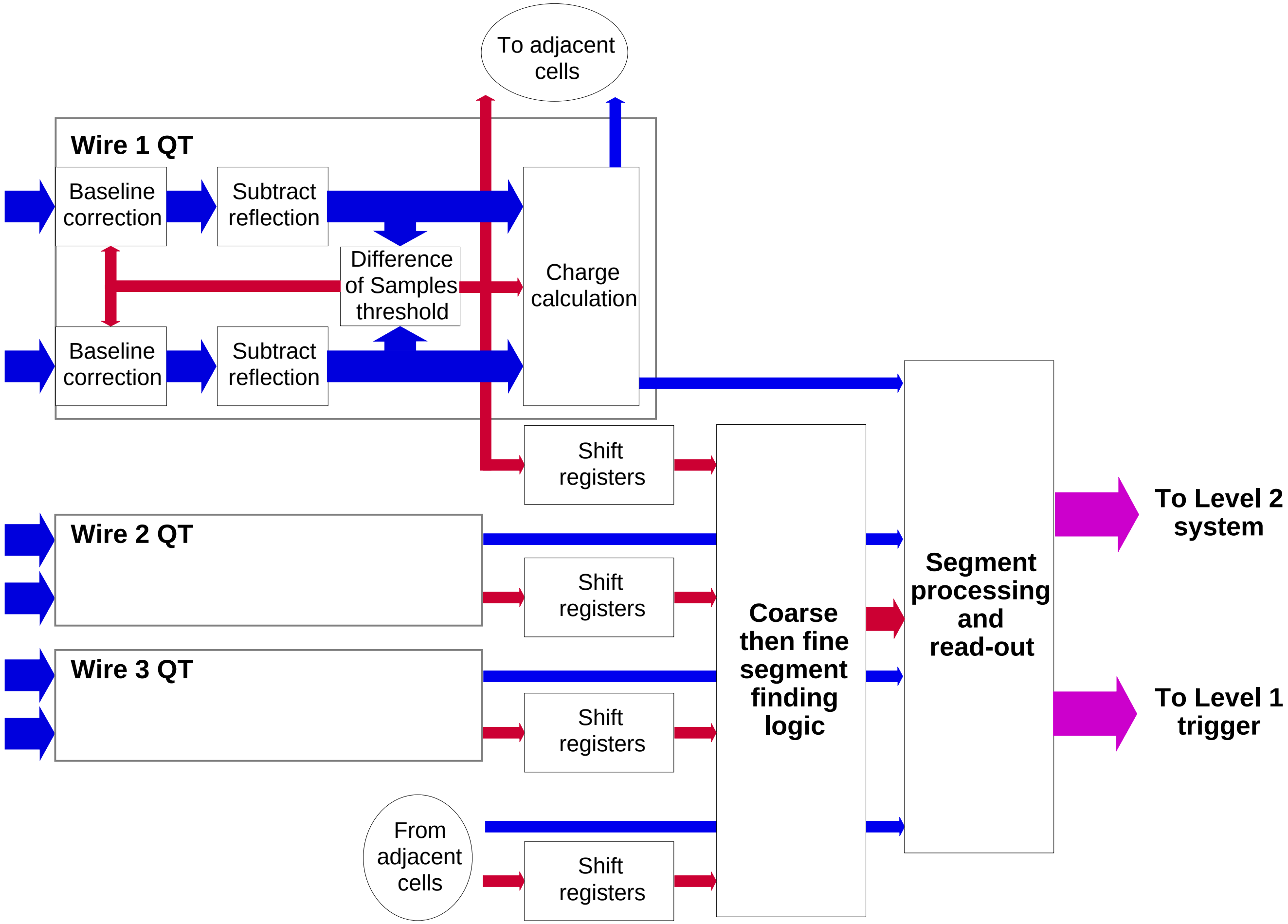


$\rightarrow$ coarse $(20\ \mathrm{MHz})$ p_T/ϕ
segments to L1 trigger
$\mathcal{O}(10^3)$ valid masks

Precise $(80\ \mathrm{MHz})$ $p_T/\phi/z$ segments to L2 track linker
$\mathcal{O}(10^5)$ valid masks

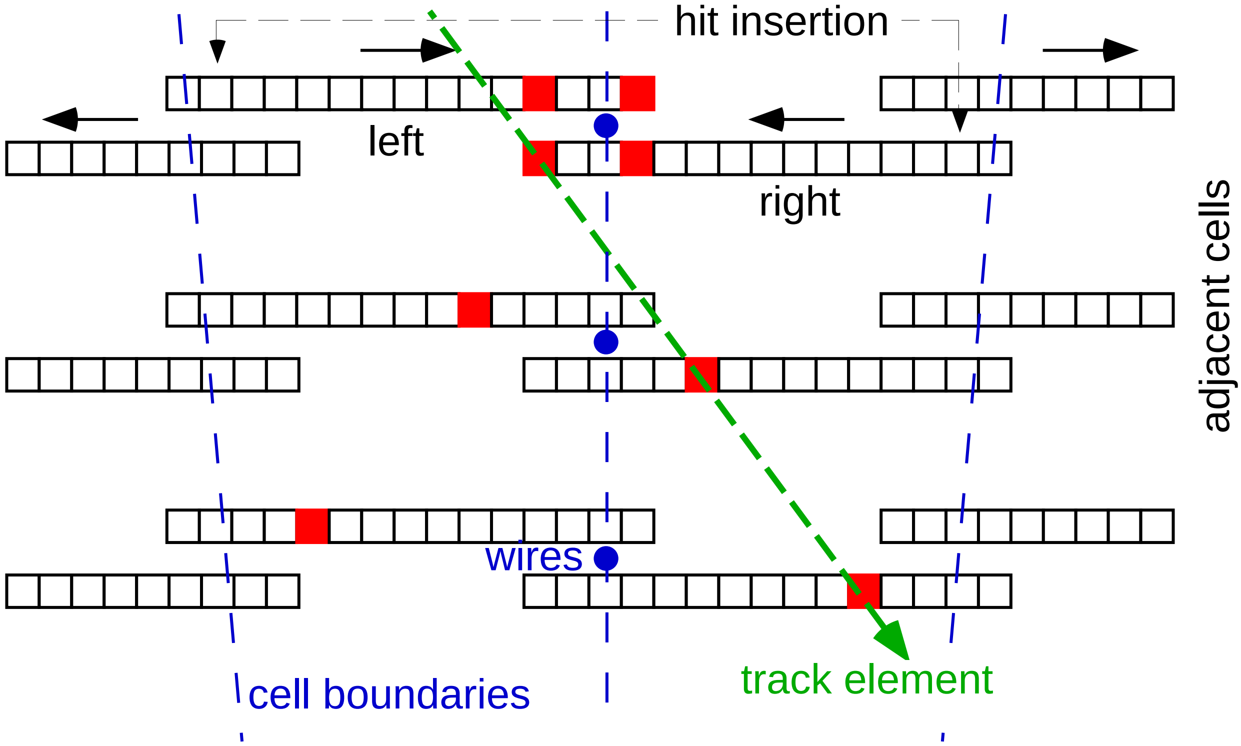
Front End Digitisation and Segment Finding

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



Finding Valid Masks for Trigger Groups

Track Segment Finding

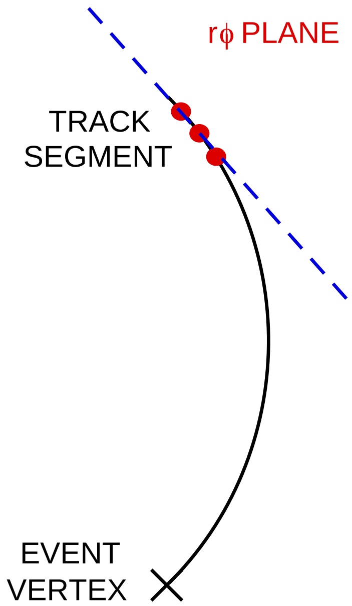


- Masks defined in shift registers, corresponding to valid track segments in 3 wires of a trigger layer.
- Entries in shift registers corresponding to left-right drift space ambiguity.
- Adjacent cells analysed together to deal with tracks crossing cell boundaries.
- Bunch crossing of origin can be identified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

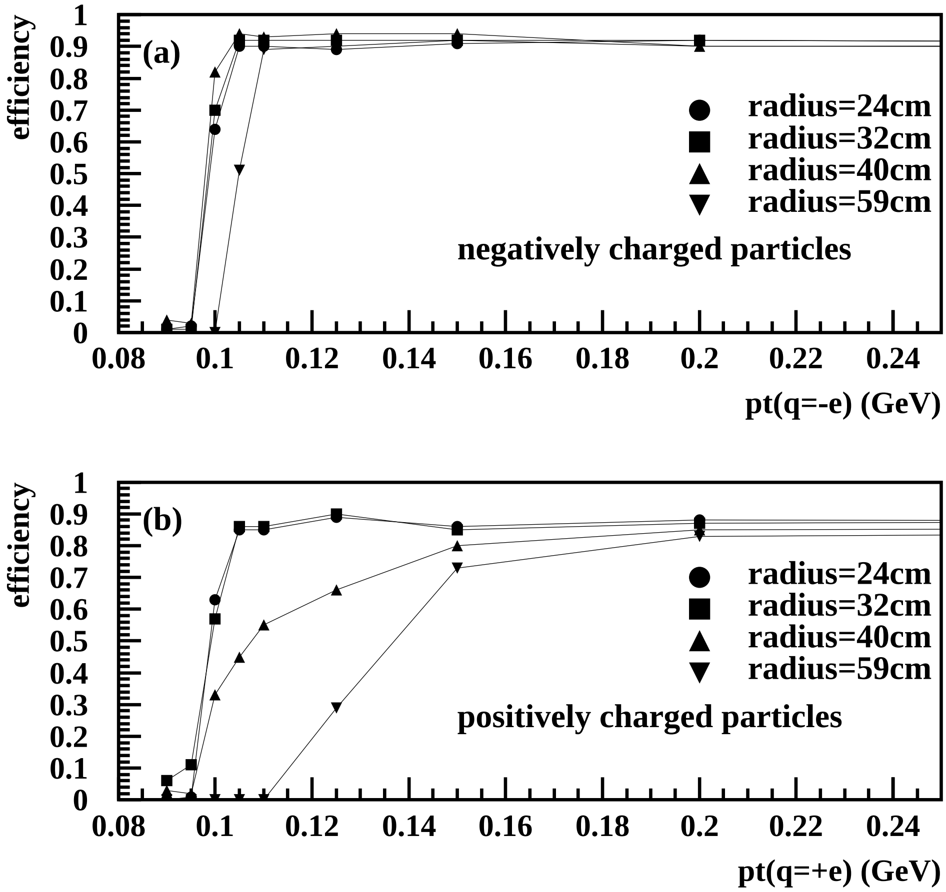
Determination of ϕ, p_T

Assumption of vertex in r-ϕ plane allows ϕ and p_T determination.

Valid track segment masks converted to (p_T , ϕ) values using Look Up Tables



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



Each trigger group is 3 CJC wires.

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

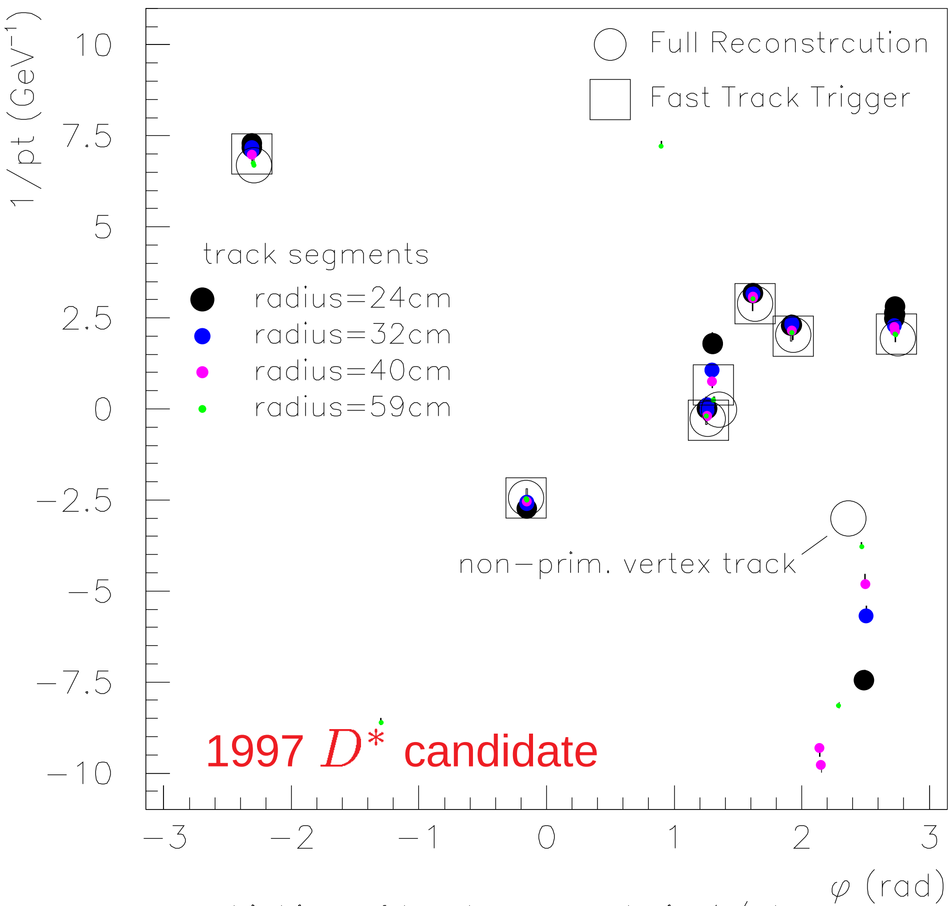
Level 1 Trigger Decision

Feasibility study of level 1 trigger decisions in progress.

Several possible improvements over existing DCrϕ trigger . . .

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

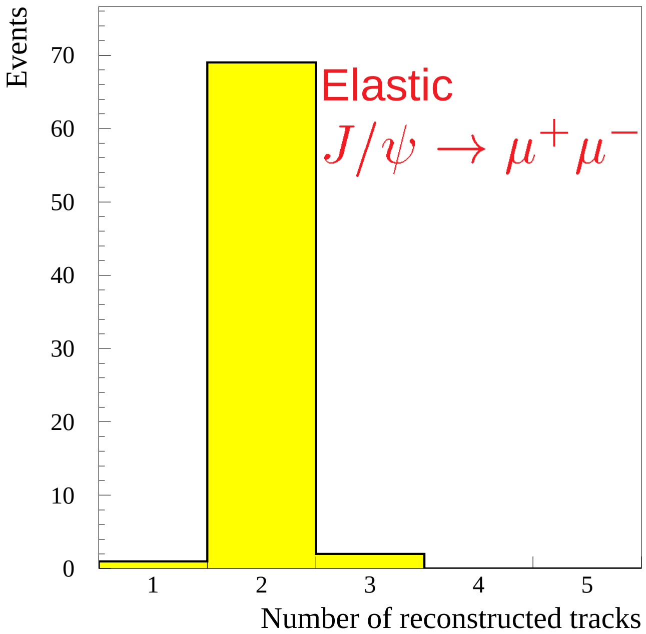
Pattern match track segments with the same p_T, ϕ from up to four radial groups at $20\ \mathrm{MHz}$.



Linking of track segments in 1/pt vs φ

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

Level 1 Trigger Viability

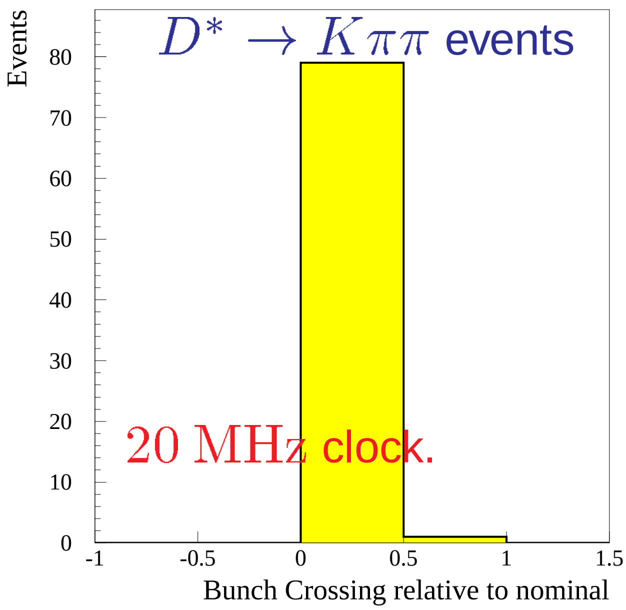


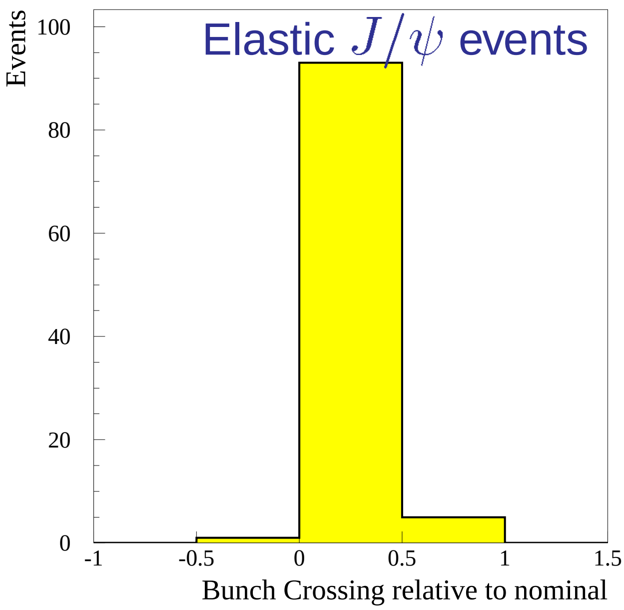
First simulation studies promising . . .

Correct number of tracks reconstructed by L1 trigger.

Significant improvement on DCrϕ

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





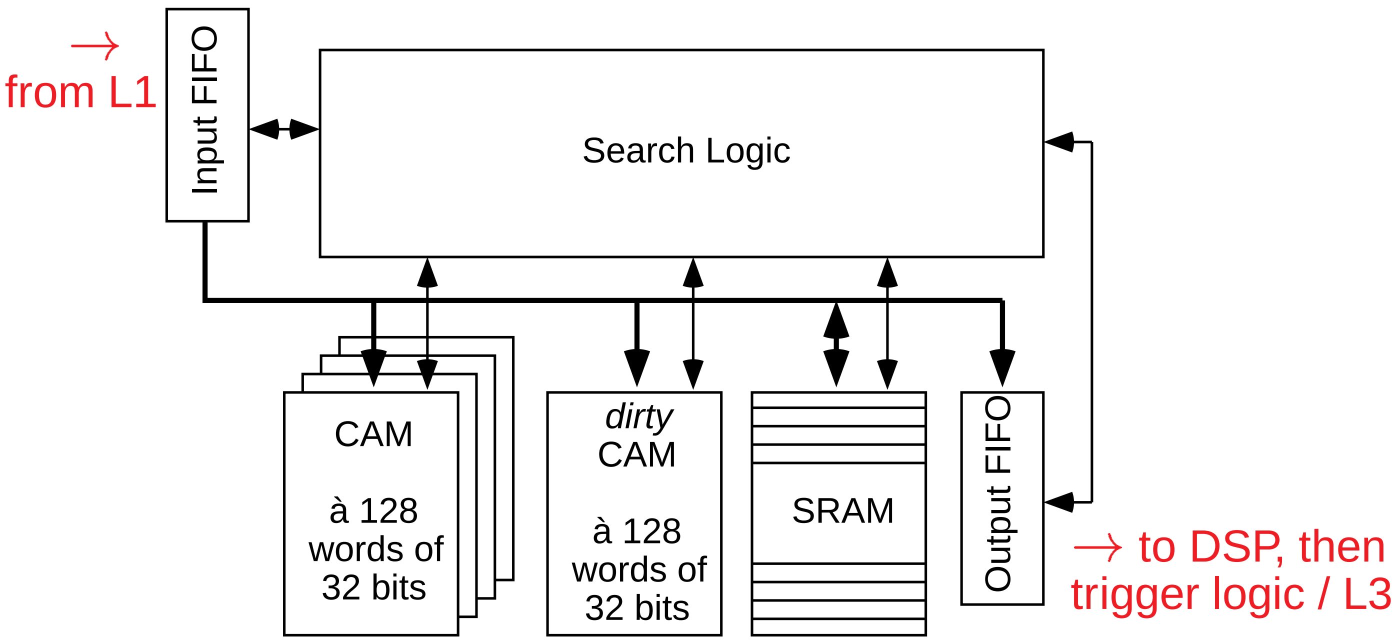
$p_T - \phi$ track segment pattern matching could be realised using CAMs at marginal hardware costs.

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, ϕ from all four radial groups.

Achieved using CAMs



1. (p_T, ϕ) vectors loaded into 1 CAM per radial group.
2. All track segments loaded into SRAM.
3. SRAM contents matched in (p_T, ϕ) with each CAM.
4. Best match with ≥ 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/ψ, $\rho \ldots$)
- 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, ϕ, θ

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

Efficiencies, resolutions, robustness studied with real events.

Track resolutions in $1/p_T$, ϕ

(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 θ

θ calculated from . . .

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

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

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

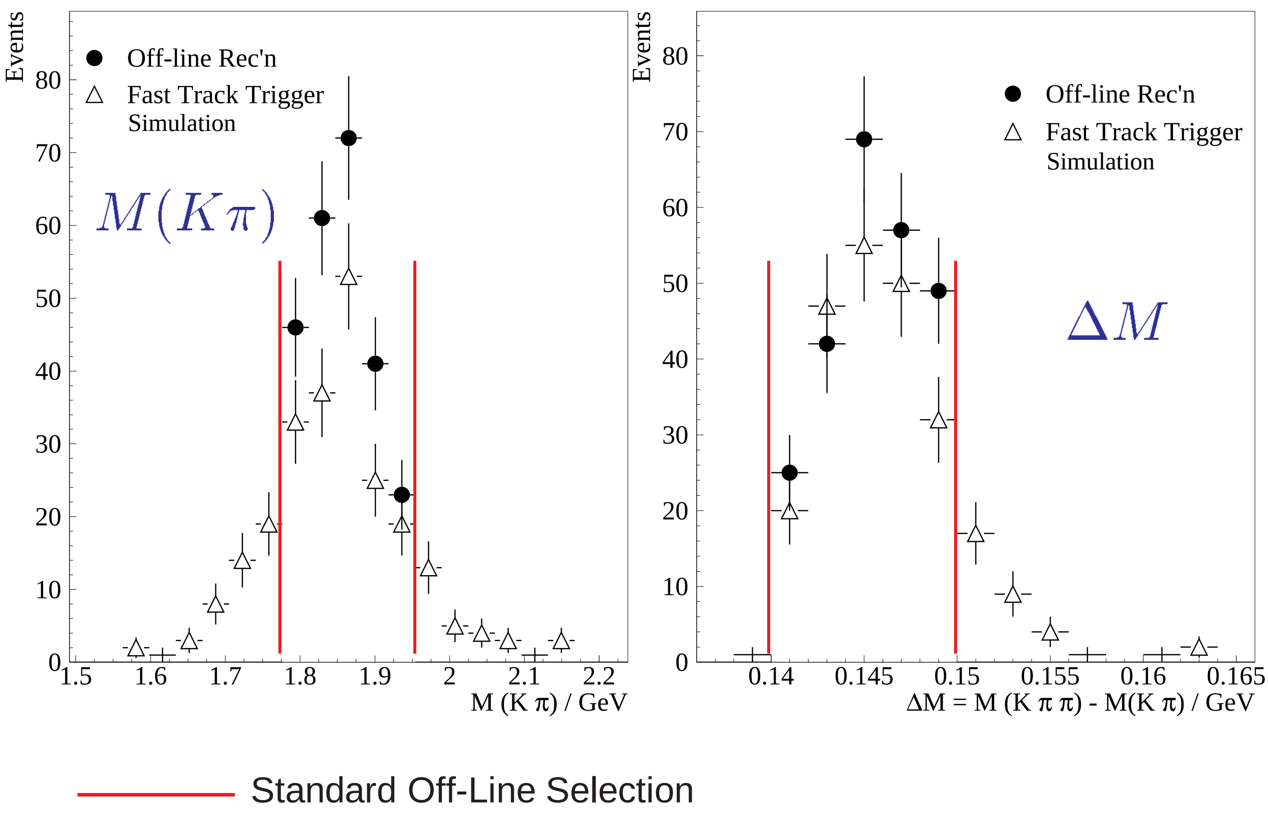
Performance for D^* Events

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

Selection through cuts on . . .

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

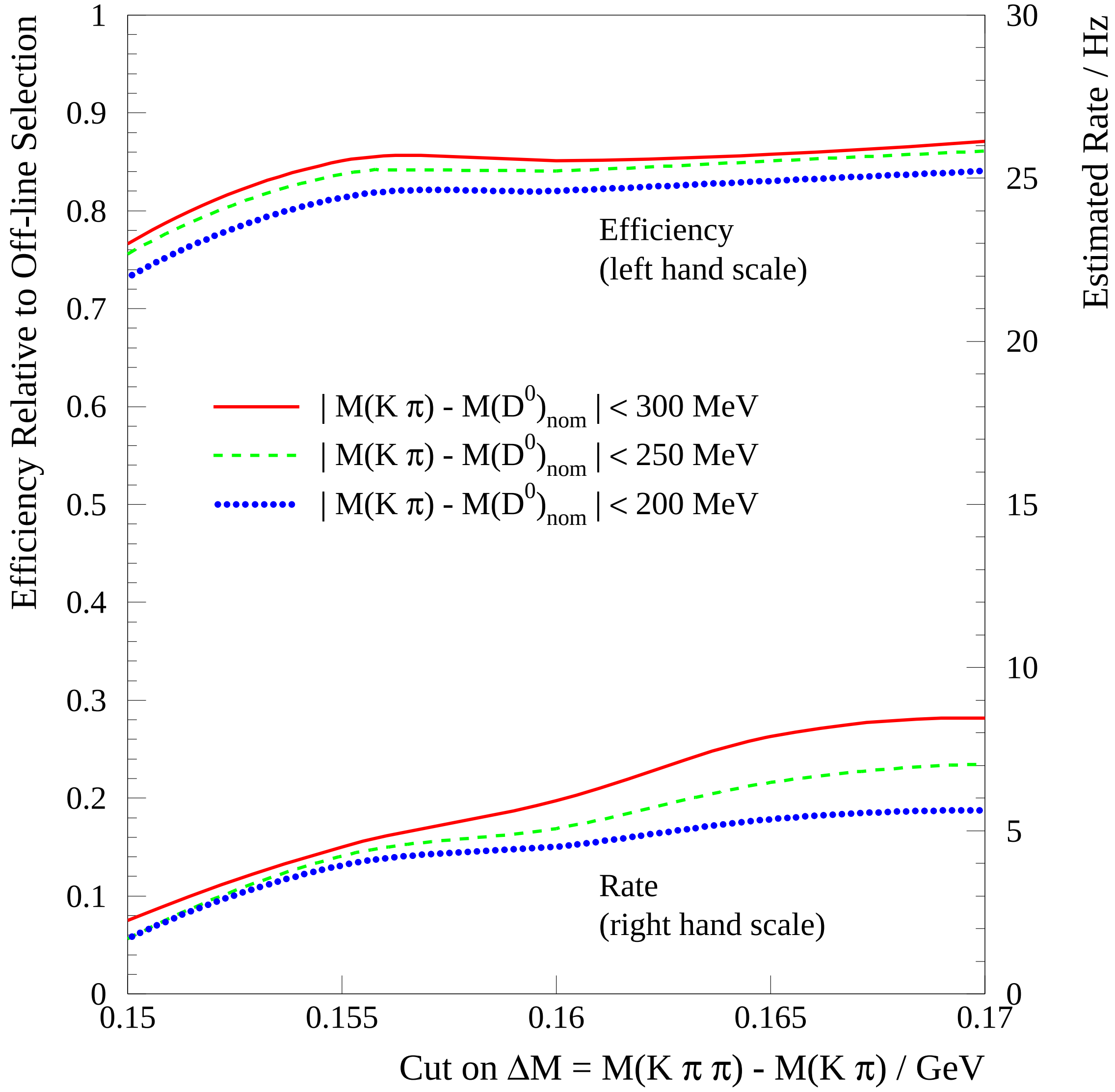
Resolutions evaluated using sample of 1997 D^* events.



Performance for D^* Events

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

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



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

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

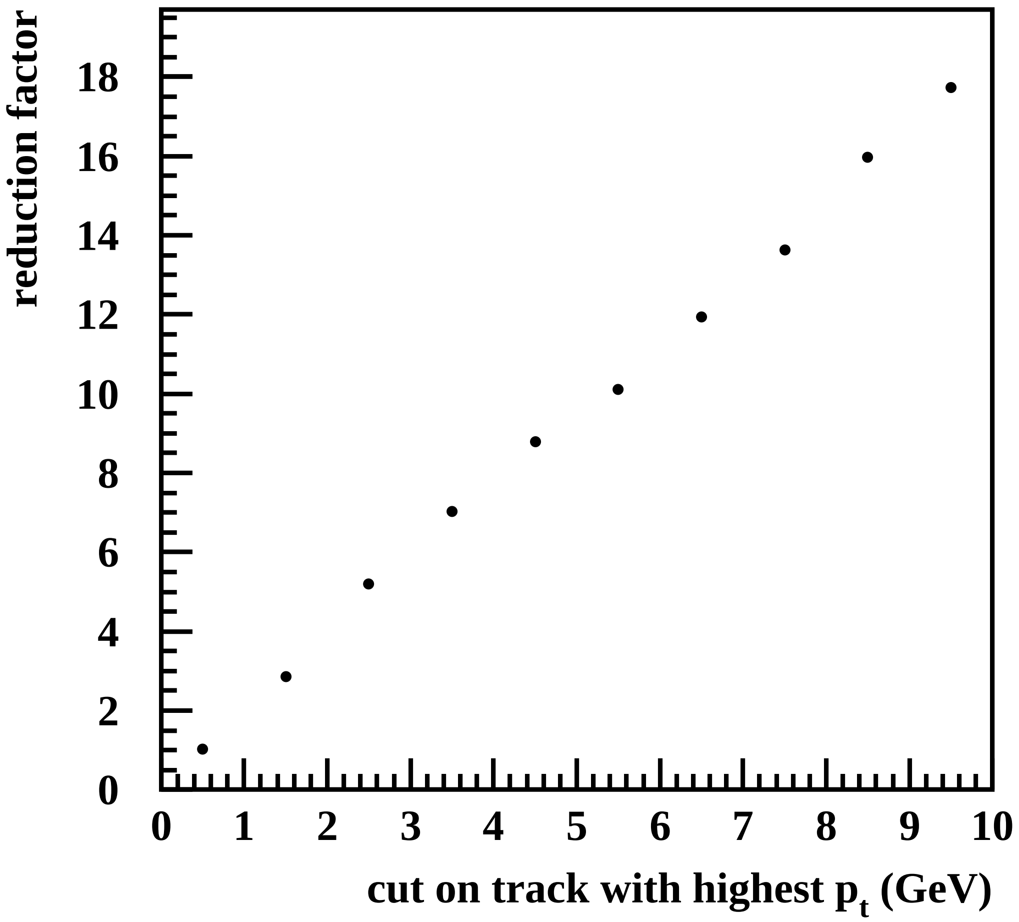
Transverse Momentum Selectivity

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

e.g. Υ, J/ψ, $Z \to l^+ l^-$, $W \to \mu\nu \ldots$

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

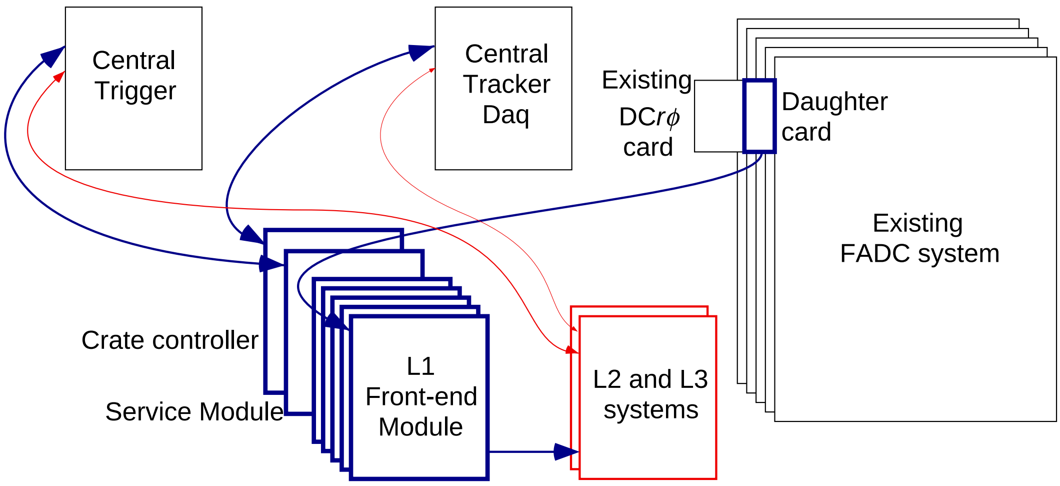
Fast Track Trigger



Estimated Trigger Efficiencies

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