The BTeV Trigger and $B^0 \rightarrow \pi^+\pi^-$

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Overview

After submitting a preliminary technical design report (PTDR) in May 1999, the BTeV collaboration has been working to simplify the design of the spectrometer and to reduce the amount of material in the detector.

A substantial part of the material is in the BTeV pixel system. By eliminating a total of 31 pixel planes and by simplifying the design of the pixel system, we now have a new design that has 60% of the material of the PTDR design.

- the new pixel system is easier to build
- fewer photon conversions and reinteractions in the pixel system
- less cooling required for the new system
- lower cost
- $^2/_3$ the number of pixels (less data per event)

… but what about the Level 1 trigger?

Overview (cont.)

The Level 1 vertex and impact parameter trigger is a key component of BTeV.

Events with *B* decays are found by using data from the pixel detector to reconstruct primary vertices, so that *B*-decay tracks can be identified using an impact parameter calculation. This analysis is performed by the Level 1 trigger for every beam crossing.

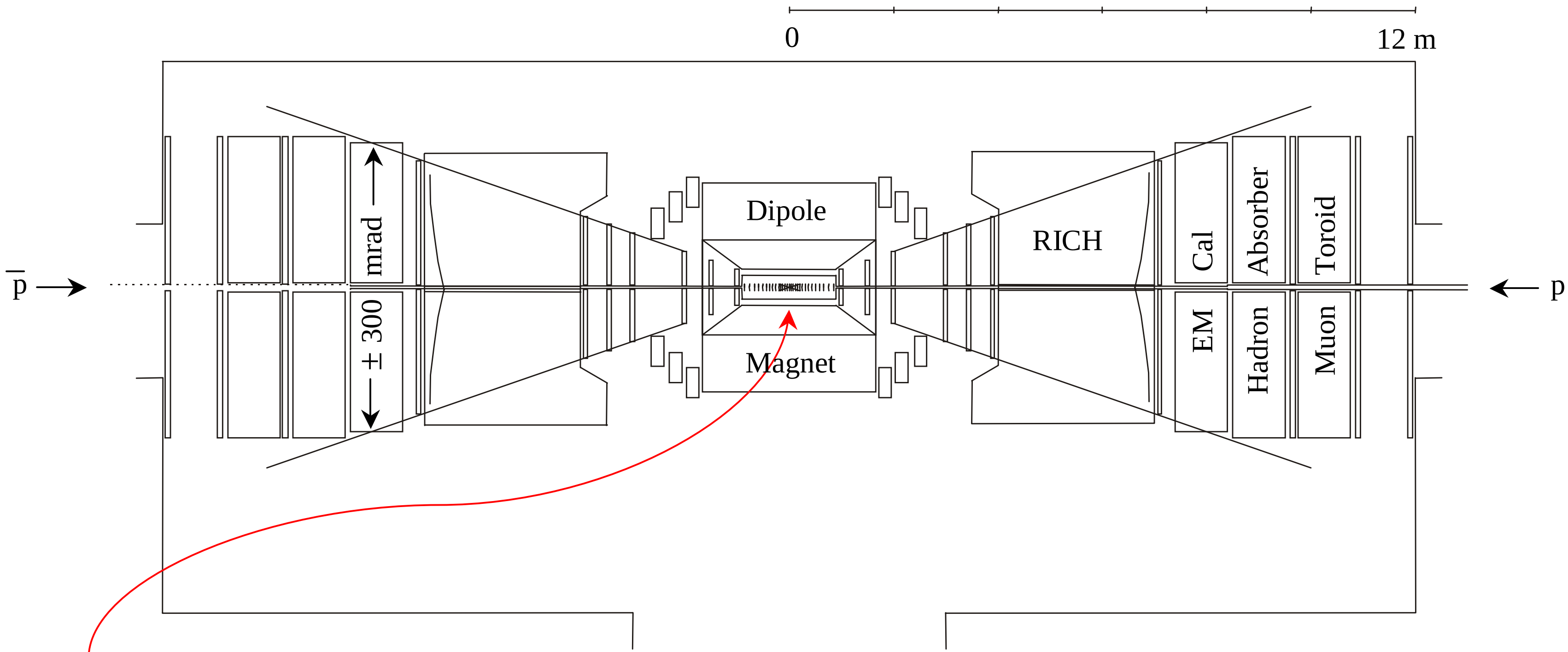
- the Level 1 trigger makes BTeV especially efficient for *B*'s decaying into hadrons
- the trigger design is tied closely to the design of the pixel tracking system
- physics analyses depend on the design of the Level 1 trigger, since the trigger represents the first step of the data analysis (especially for hadronic *B* decays)

➢ New geometry for the BTeV pixel detector (2 instead of 3 planes per tracking station)

➢ New baseline design for the Level 1 trigger

➢ Updated PTDR results for $B^0 \rightarrow \pi^+\pi^-$ physics simulations

Plan View of the BTeV Detector

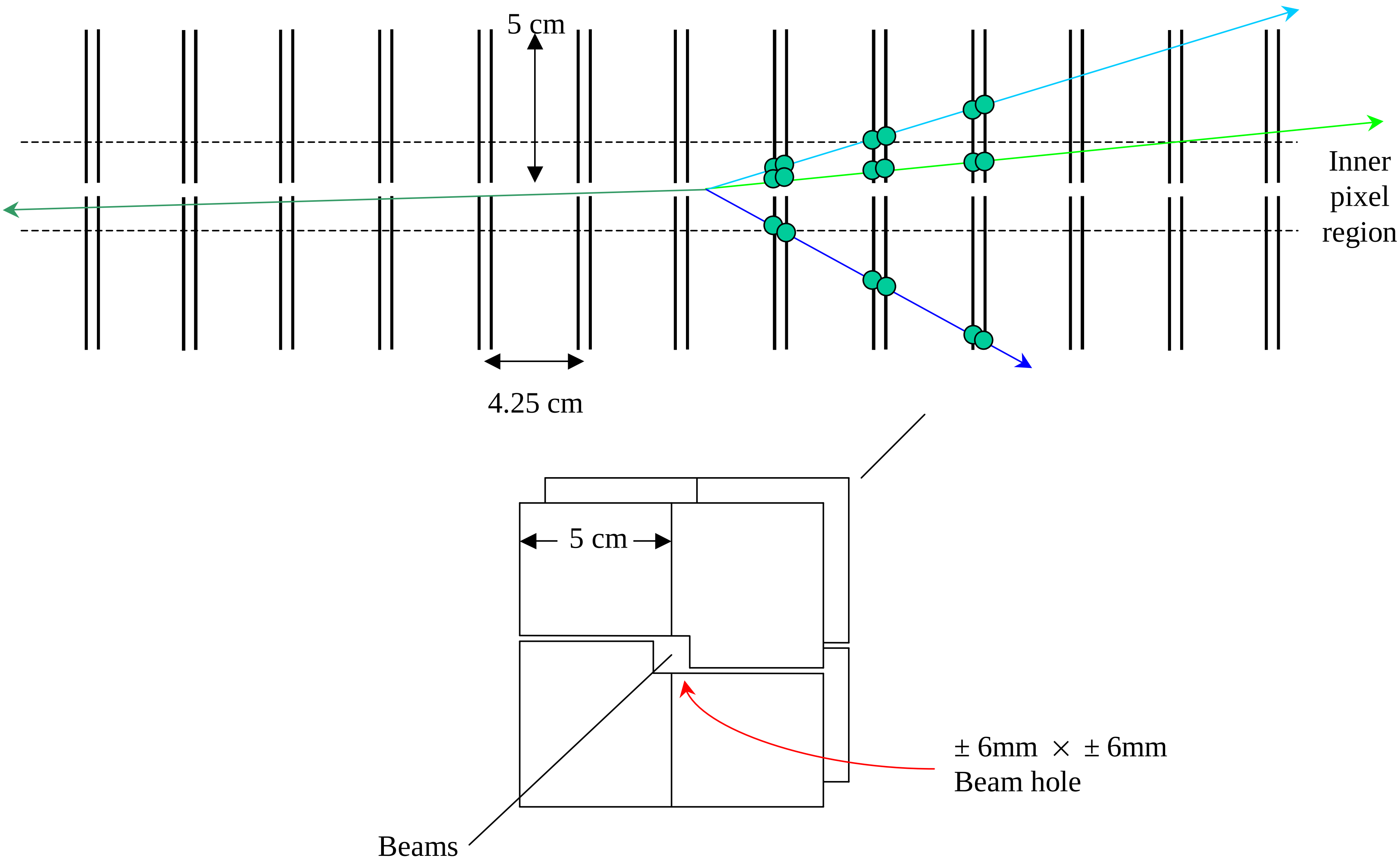


Pixel System (inside beam vacuum):

- 31 stations distributed over 128 cm (± 64 cm)
- Each station has 2 planes arranged in "views" (y,x)
- Each plane has over 500,000 pixels in a 10 x 10 cm area (square beam hole)
- Each pixel is 50 x 400 μ in size (pulse height measurement for each pixel)

NEW geometry!

Close-up View of the Pixel System



Overview of the Level 1 Trigger

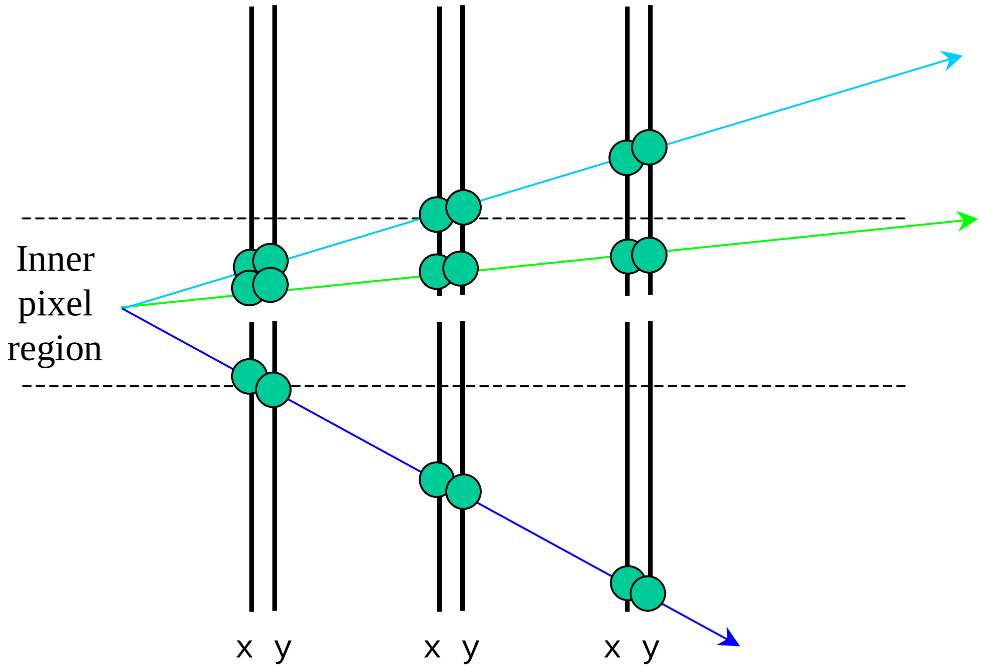
The Level 1 trigger performs 4 analysis steps:

- pattern recognition using pixel hits
- track reconstruction and extrapolation to the beam region
- primary vertex reconstruction and impact parameter calculation
- trigger decision based on the number of tracks with large impact parameter

Key features of our NEW baseline trigger:

- find tracks as they enter the pixel detector (tracks are called interior triplets)
- find tracks as they exit the pixel detector (tracks are called exterior triplets)
- the first hit on a track is required to be within the "inner pixel region"
- the last hit is required to be in the "outer pixel region"
- simple and draconian removal of fake tracks (kill tracks that share hits)

Pattern Recognition in the Level 1 Trigger



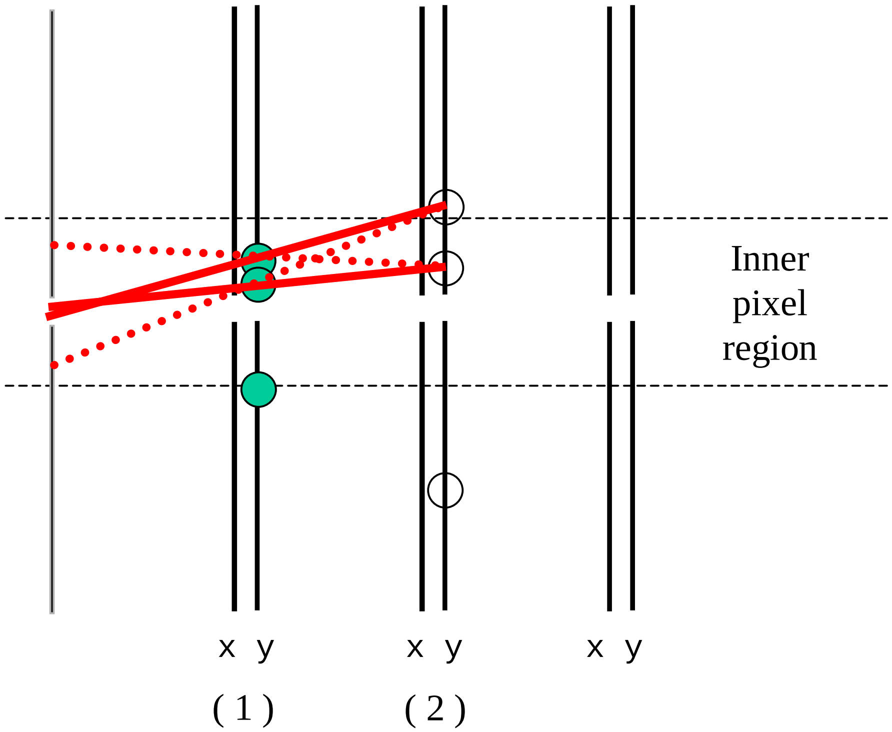
The pixel hits from three stations are sent to an FPGA tracker, for pattern recognition:

- interior and exterior track doublet finder (precision *y* hits)
- interior and exterior track triplet finder (precision *y* hits)
- interior *x*-hit matcher (requires 2 of 3 matching *x* hits)

Interior and exterior triplets are sent to a farm of digital signal processors to complete the pattern recognition:

- interior/exterior triplet matcher
- fake-track removal

Find interior "doublets" using precision y hits in pixel stations 1 & 2



The goal is to find the first two hits on a track:

• doublet finder considers pairs of hits from stations 1 and 2

• the hit in station 1 is required to be within a 3 cm x 3 cm region (inner pixel region) to reduce the number of doublets, and still be more than 99% efficient for finding tracks

• project to "upstream" station by calculating

$$x = 2 * x_1 - x_2$$
$$y = 2 * y_1 - y_2$$

• require that the calculated position (x,y) falls within the 1.2 cm x 1.2 cm beam region

Fortran:

$\text{abs}\,(2 * x_1 - x_2)\ .\text{LT.}\ 0.6$

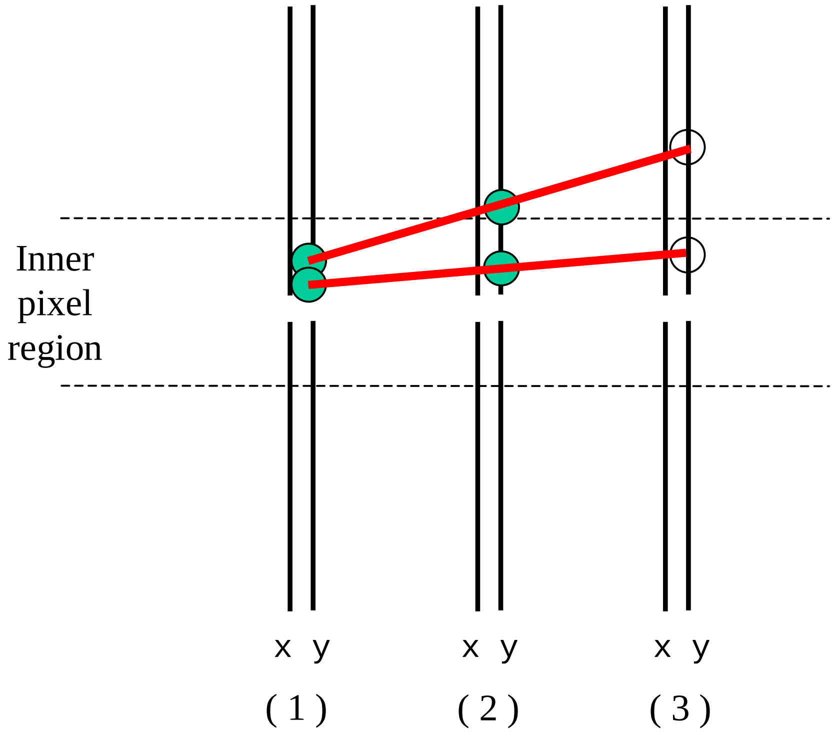
$\text{abs}\,(2 * y_1 - y_2)\ .\text{LT.}\ 0.6$

Associative Memory:

$x_2 < (2 * x_1 - 0.6)$ AND $x_2 > (2 * x_1 + 0.6)$

$y_2 < (2 * y_1 - 0.6)$ AND $y_2 > (2 * y_1 + 0.6)$

Find "triplets" using the doublets and precision y hits in station 3



Find the first three hits on a track:

- triplet finder looks for a confirming third hit in a 2mm x 1mm window in station 3 for each doublet found by the doublet finder

- the confirming third hit reduces the number of fake tracks found by the doublet finder

- project to "downstream" station by calculating

$$x = 2 * x_2 - x_1$$
$$y = 2 * y_2 - y_1$$

- hits that fall in the 2mm x 1mm window centered on the projected position produce a triplet, and the change in y slope ($\Delta m = m_{23} - m_{12}$) is used at a later stage to find matching exterior triplets

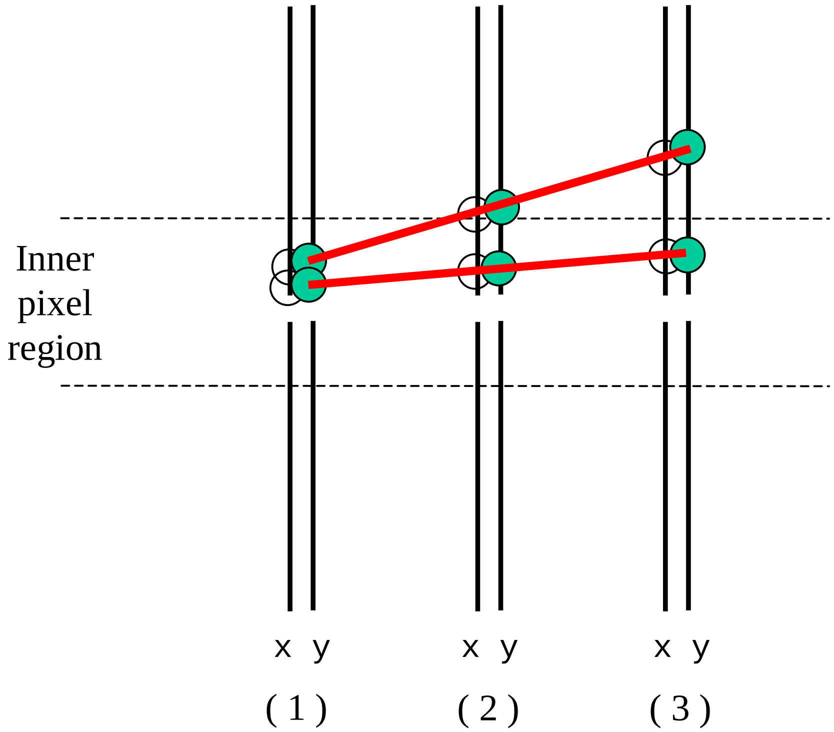
Fortran:

abs (x_3 - (2 * x_2 - x_1)) .LT. 0.1
abs (y_3 - (2 * y_2 - y_1)) .LT. 0.05

Associative Memory:

$x_3 < (2 * x_2 - x_1) - 0.10$ AND $x_3 > (2 * x_2 - x_1) + 0.10$
$y_3 < (2 * y_2 - y_1) - 0.05$ AND $y_3 > (2 * y_2 - y_1) + 0.05$

Find matching x hits for interior triplets for stations 1, 2 & 3

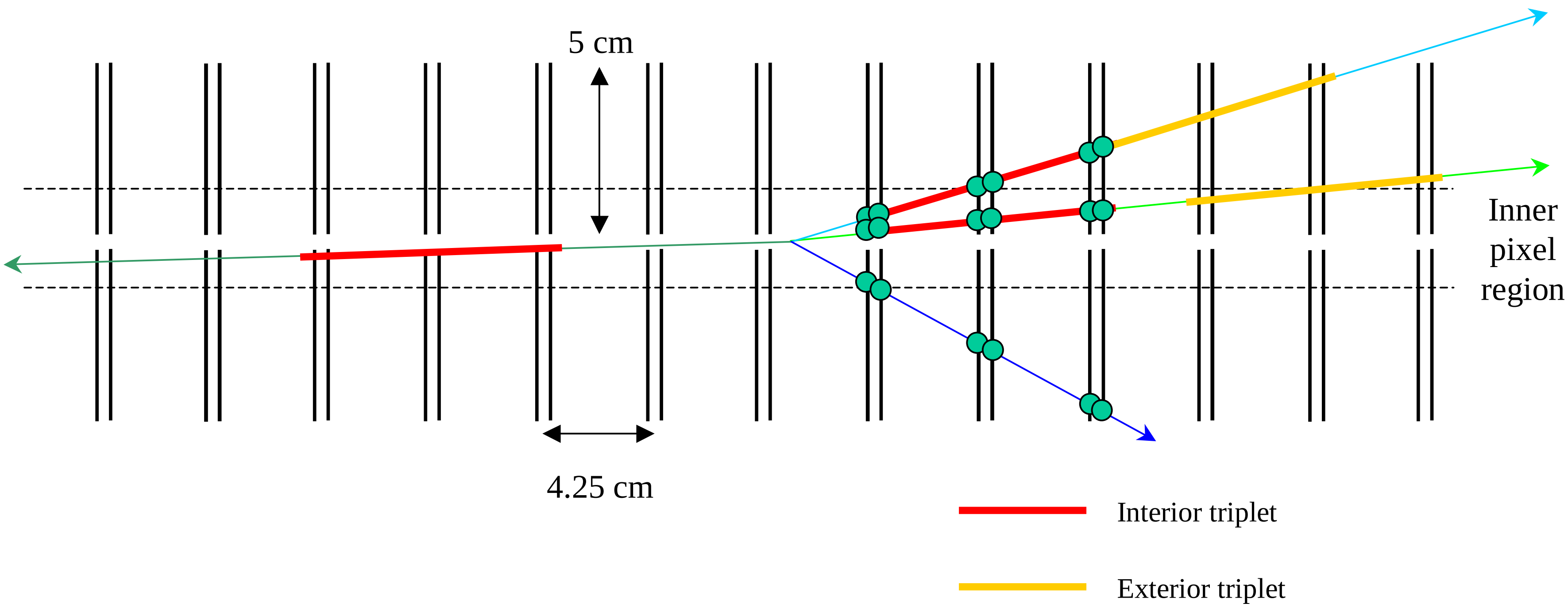


• x-hit matcher uses the track slope to find hits in a window (800μ x 1200μ) in precision x planes for interior triplets only

• tracks are required to have 2 out of 3 matching hits

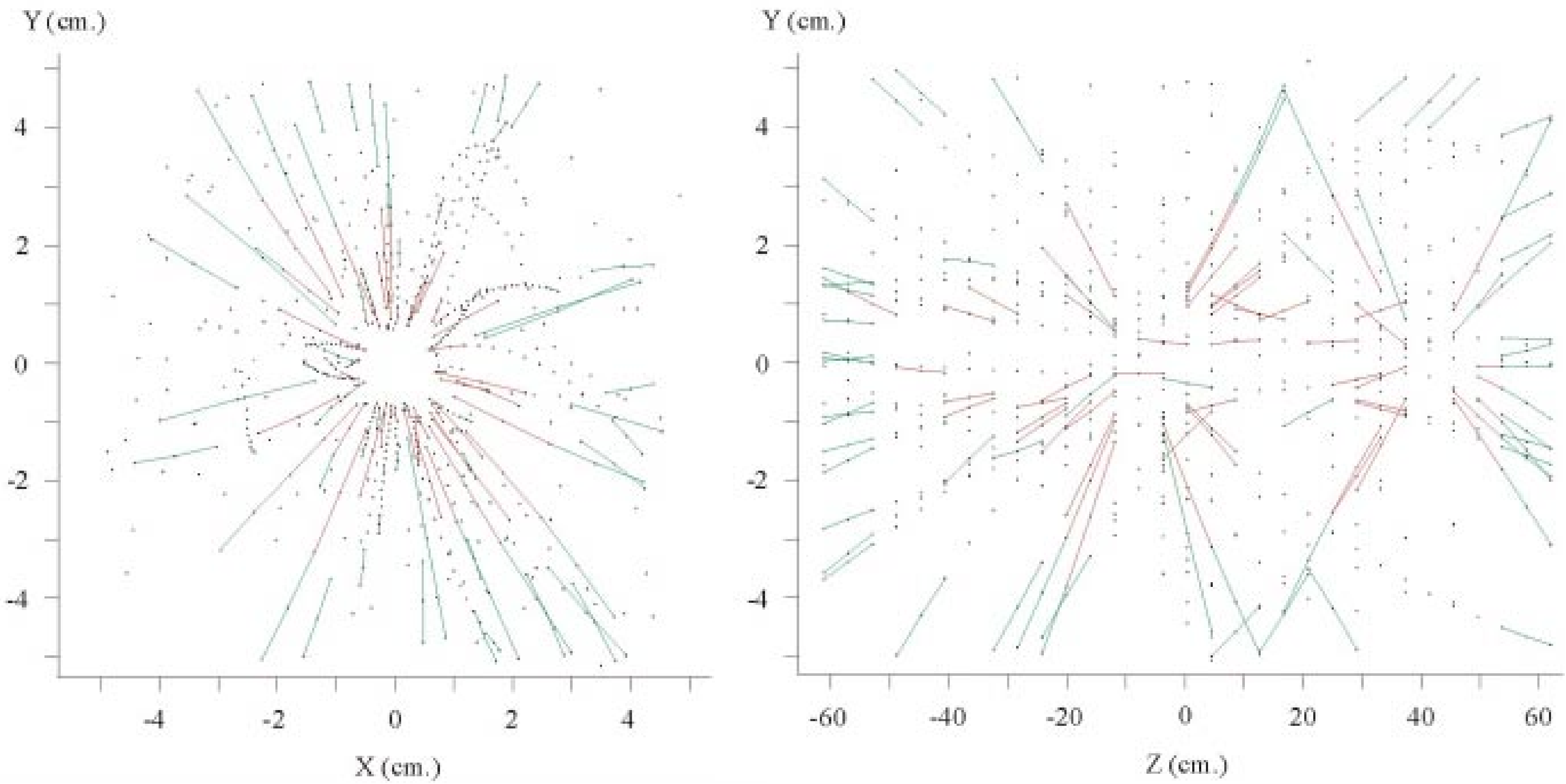
• x hits are used to find matching exterior triplets

Find matching exterior triplets for each interior triplet



• interior/exterior matcher links interior and exterior triplets
• current algorithm has a 2% loss in tracking efficiency (not understood)

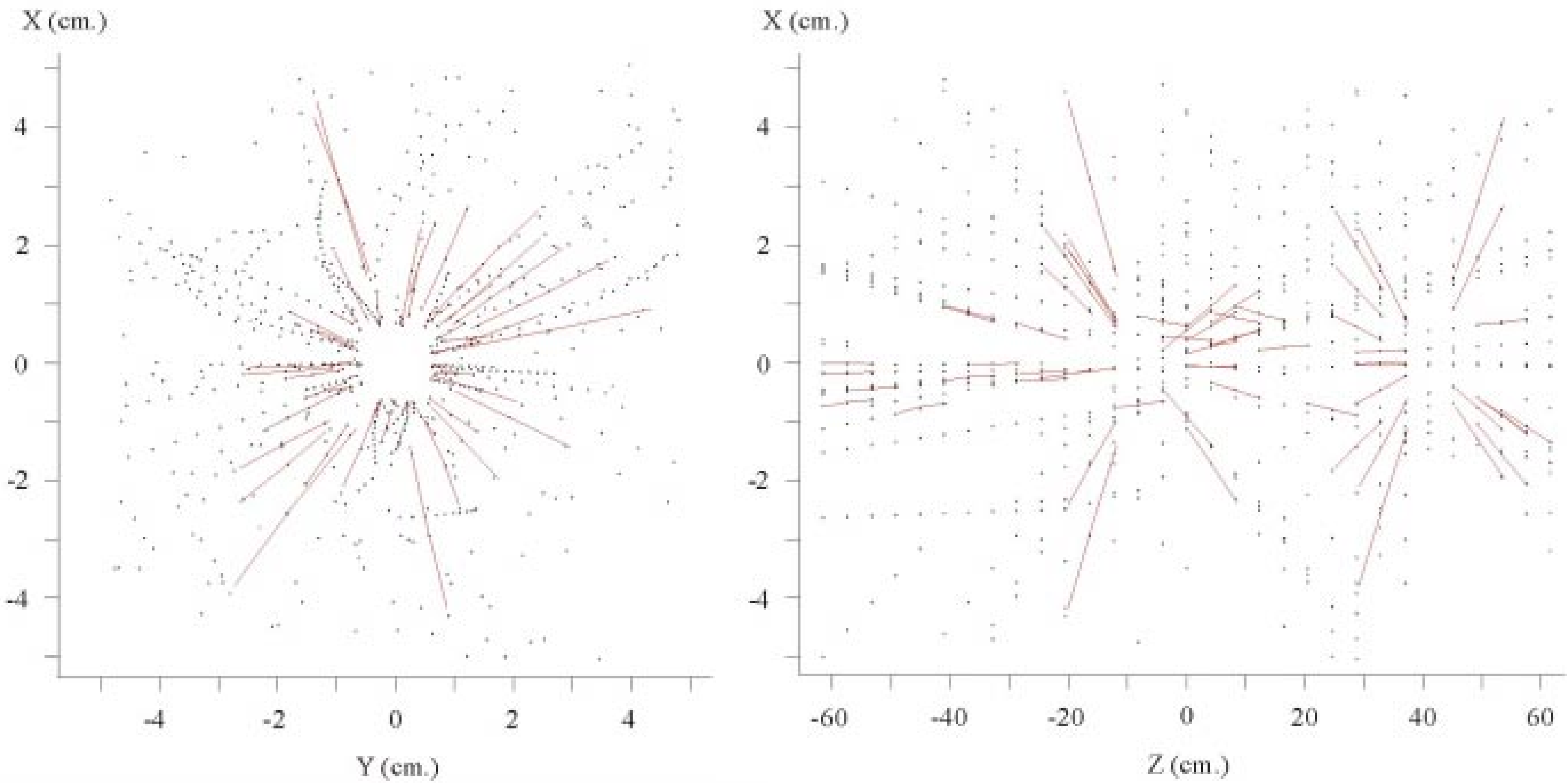
Pattern Recognition for “y-hits” in a Generic *B* Event



Interior triplet

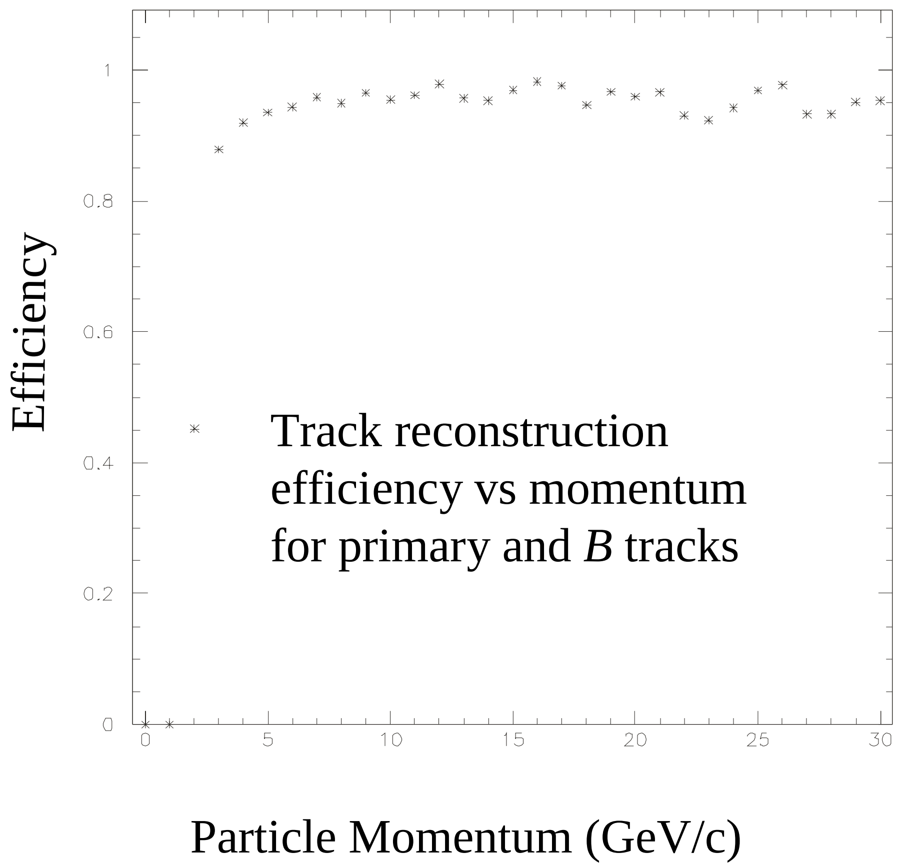
Exterior triplet

Precision x-hits used by the Level 1 Trigger



Interior triplet

Track Reconstruction Efficiency (for primary and *B* tracks)



Trigger Algorithm	Track Reconstruction Efficiency (p > 5 GeV)	
Track doublet finder (precision y hits)	Interior 99.5%	Exterior 99.8%
Track triplet finder (precision y hits)	Interior 99.4%	Exterior 99.6%
Hit matcher (precision x hits)	Interior 99.4%	
Int./Ext. matcher	95.9%	
Fake removal	95.3%	

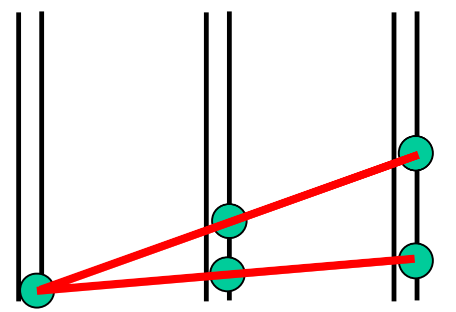
Fake Tracks at each Stage of the Level 1 Pattern Recognition

Trigger Algorithm	**Percentage of Tracks that are fake**	
Track doublet finder (precision y hits)	Interior 81.4%	Exterior 78.1%
Track triplet finder (precision y hits)	Interior 16.5%	Exterior 8.6%
Hit matcher (precision x hits)	Interior 14.5%	
Int./Ext. matcher	1.5%	
Fake removal	0.71%	

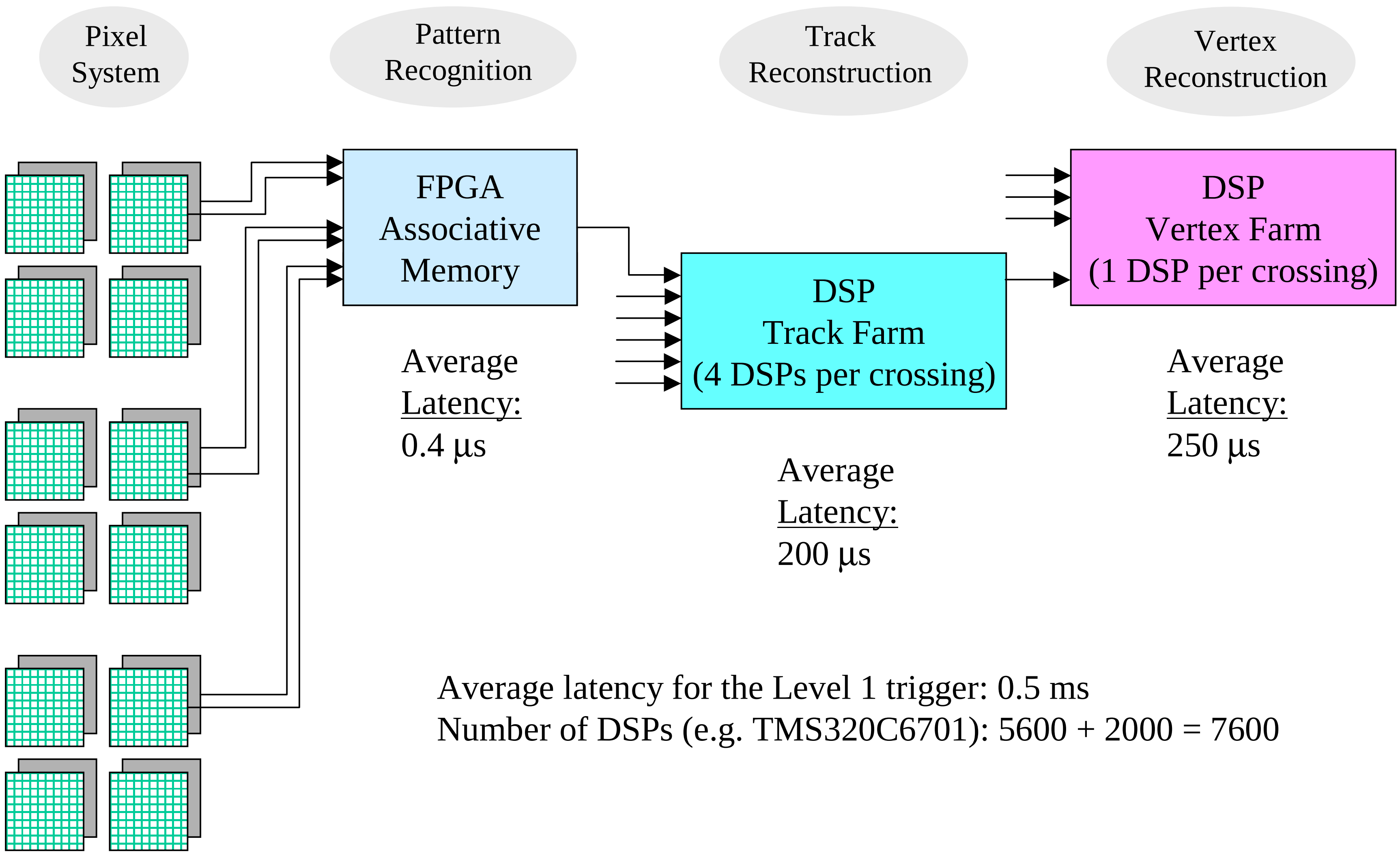
Of the fake tracks that remain:

- 53% have fake interiors
- 47% have fake exteriors

Note:
The last stage of the Level 1 pattern recognition removes fake tracks by removing all tracks that share hits with other tracks.



Block Diagram of the Level 1 Trigger



Average latency for the Level 1 trigger: 0.5 ms
Number of DSPs (e.g. TMS320C6701): 5600 + 2000 = 7600

Status of the Level 1 Trigger

New trigger results (2 interactions per beam crossing):

- 75% trigger efficiency for $B_s \rightarrow D_s K$ (the PTDR value is 70%)
- 62% trigger efficiency for $B^0 \rightarrow K\,\pi$ (the PTDR value is 54%)
- 1% of minimum bias (light quark) events produce a trigger
- good performance with "noise" hits exceeding 10^{-4}
- good performance with pixel efficiencies down to 98%
- hardware architecture that can be built with today's technology

Note: the trigger efficiency for $B^0 \rightarrow \pi\,\pi$ should be around 60%

Updated PTDR Results for $B^0 \to \pi^+ \pi^-$

Parameter	PTDR Value	New Value
Luminosity	2×10^{32} cm^{-2} s^{-1}	2×10^{32} cm^{-2} s^{-1}
B cross section	100 μb	100 μb
B events per 10^7 seconds	2×10^{11}	2×10^{11}
Number of B_d's	1.4×10^{11}	1.4×10^{11}
$B_d \to \pi^+\pi^-$ branching fraction	0.75×10^{-5}	0.43×10^{-5}
Reconstruction efficiency	0.06	0.06
Trigger efficiency	0.55	0.60
Reconstructed $B_d \to \pi^+\pi^-$	3.4×10^4	2.2×10^4
Tagging efficiency εD^2	0.10	0.10
S/B	0.6	0.6
δa_{CP}	0.023	0.023

Include factor from the time-dependent analysis

Conclusions

BTeV has a new design for the pixel system:

- significantly LESS material (60% of the material compared to the PTDR)
- new system is easier to build, requires less cooling, lower cost
- reduces the number of photon conversions and reinteractions

BTeV has a new design for the Level 1 trigger

- better performance compared to the PTDR trigger
- the hardware architecture can be implemented using today's technology
- we anticipate further improvements in the design for the BTeV Proposal

We expect improvements in all physics simulations compared to the results we presented in the PTDR.