Highly parallel algorithm for high-pT physics at FAIR-CBM

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Abstract

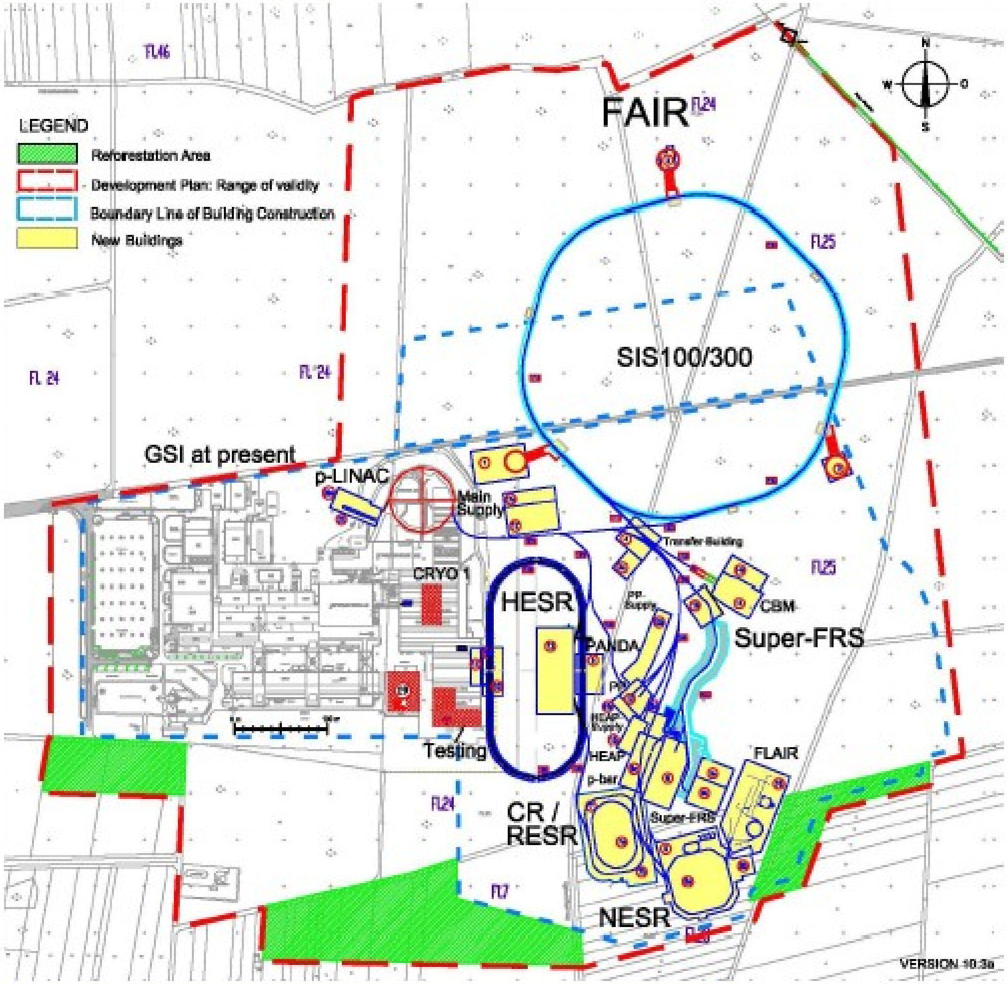
Unusually high intensity (10**11 proton/sec) beam is planned to be ejected for fixed targets at FAIR accelerator upto 90 GeV energy. Using this beam the FAIR-CBM experiment provides an unique high luminosity facility to measure high pT phenomena with unprecedented sensitivity exceeding by orders of magnitude that of previous experiments.

Applying 1% target the expected minimum bias event rate will be in the range of GHz. In order to get a selective trigger which reduces this rate to the kHz range one needs an extremely fast algorithm. Due to the fact that the minimal read-out time for pixel detectors is about 1 microsec, one could get even 1000-fold pile-up.

Proton-Carbon interactions in the STS detector of CBM were simulated assuming 4 pixel and 5 strip detector (x,y) planes, a highly parallel online algorithm is proposed which could select the high pTtracks with high efficiency.

The proposed mosaic-trigger system is data-driven. The recorded hits are directed toward the so called "double-cone" corridors consisting of the corresponding"mozaics" in the given Si-plane. Exhaustive search is performed on a limited set of track defining detector planes using the hit list from content addressable memories (CAM's) which are extended to the full detector collecting nearest hits from the appropriate mozaic CAMs.

The international Facility for Antiproton and Ion Research



primary beams

- 10^{12}/s; 1.5-2 GeV/u; $^{238}U^{28+}$
- factor 100-1000 increased intensity
- $4x10^{13}$/s 90 GeV protons
- 10^{10}/s ^{238}U 35 GeV/u (Ni 45 GeV/u)

secondary beams

- rare isotopes 1.5 - 2 GeV/u; factor 10 000 increased intensity
- antiprotons 3(0) - 30 GeV

storage and cooler rings

- beams of rare isotopes
- e – A Collider
- 10^{11} stored and cooled antiprotons 0.8 - 14.5 GeV

accelerator technical challenges

- Rapidly cycling superconducting magnets
- high energy electron cooling
- beam losses

Motivation for new measurements below $\sqrt{s} = 20$ GeV

Practically no high or medium P_t data between $E_{inc} = 24$ and 200 GeV

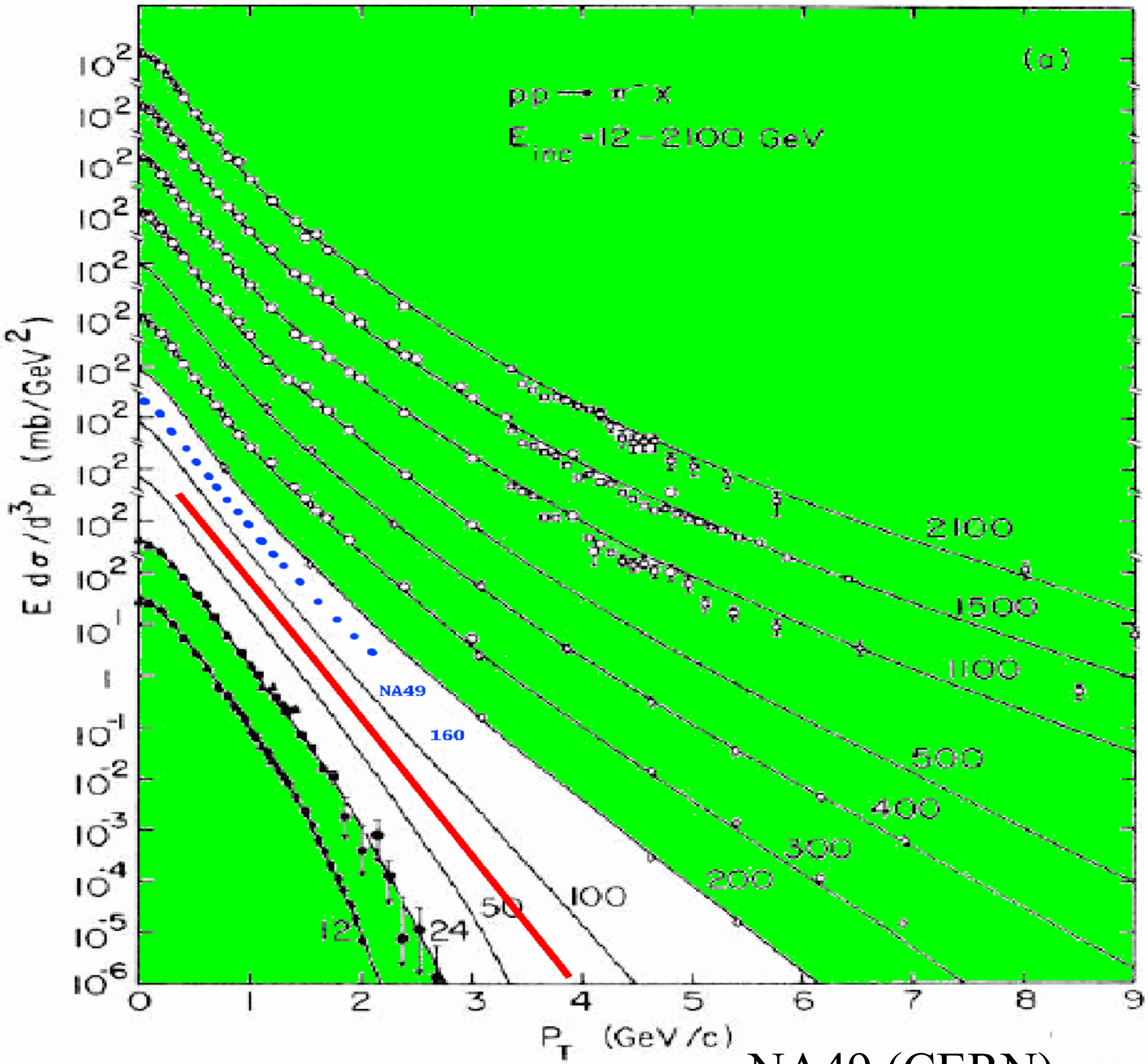
Mysterious transition around 80-90 GeV: convex versus concave spectra

Energy threshold for Jet-quenching?

Emergence of Cronin-effect in pA interactions is completely unknown

energy dependence
centrality dependence
particle type dependence
particle correlations

Production of Upsilon (9.5 GeV) particles near the threshold.



Beier (1978)

NA49 (CERN) results at 158
FODS (IHEP) at 70 GeV

Special requirements for Y-> e+e- and high pT

Extremely high intensity - Pile-up

Segmented multi-target - Relaxed vertex precision

Straight tracks - High momentum tracks

DREAM: 10 interactions/sec

In typical experiments the high-Pt trigger is generally based on **"local"** detector elements (calorimetric cells or specialized few planes trackers) covering only some limited phase space. This arrangement assures reasonable parallelism and simple selection algorithms.

The proposed **"mozaic trigger"** method is based on the information obtained by the standard large phase space tracking detector (in the concrete case the CBM-STS silicon detector) containing relatively large (8-10) number of planes. By this **"global"** scheme one can achieve extremely high parallelism and superfast speed relying on a data-driven algorithm based on strategically subdivided memory partitions ("mozaics") reducing the calculations to read-out of Content Addressable Memories (CAMs).

In reality the algorithm in this case also uses local detector elements, but they are virtual and created by data-driven online software.

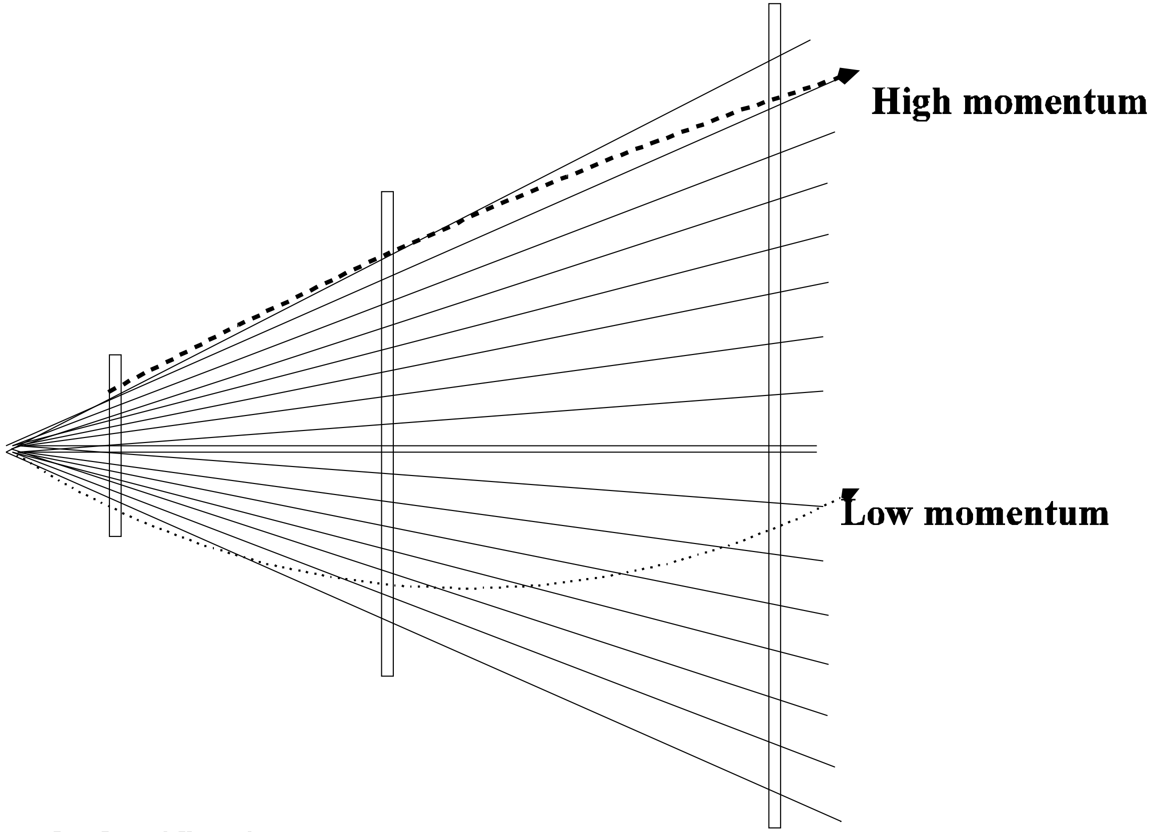
Basic features:

The yz projection of the tracks is almost exactly linear due to the nearly homogenous dipol magnetic field.

The xz projection of high Pt tracks is approximately linear because due to the Loretz-boost the particles have relatively large momentum perpendicular to the magnetic field.

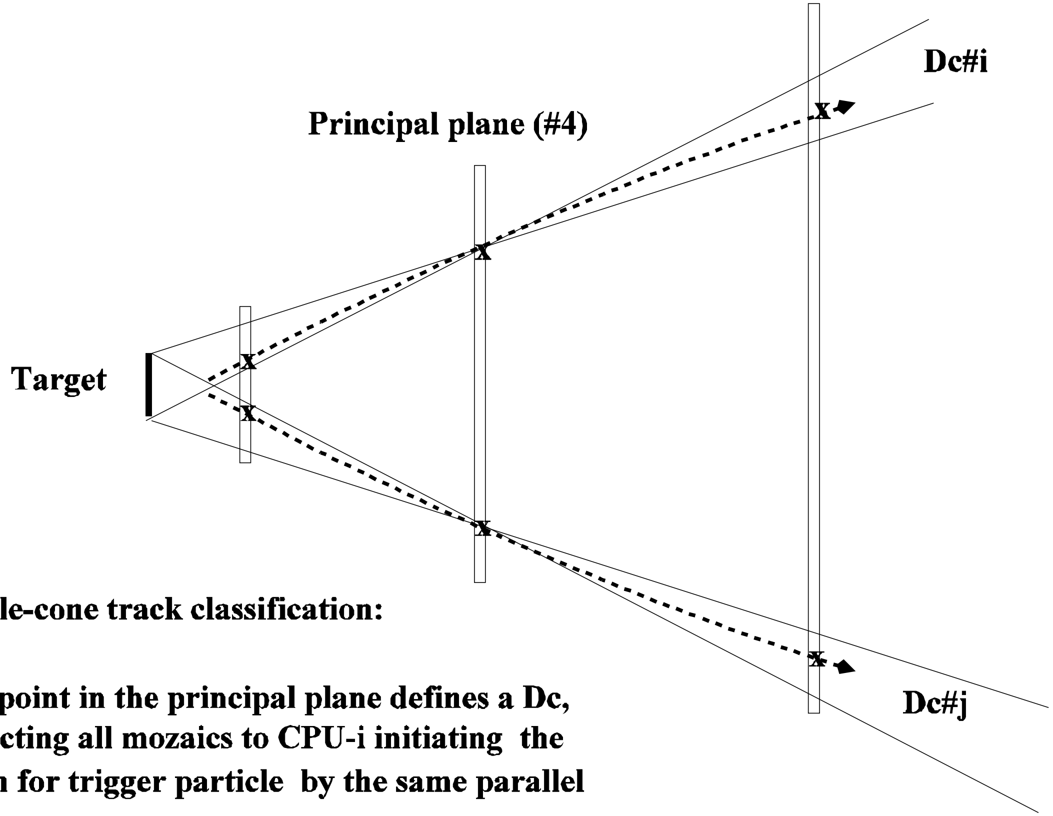
Due to the extended beam-spot size the vertex distribution in (x,y), there is no point source of particles. Instead of "single-cone" track classification one proposes to use a "double-cone" approach based on the "principal plane"

Point source of HIGH-Pt (almost straight) tracks



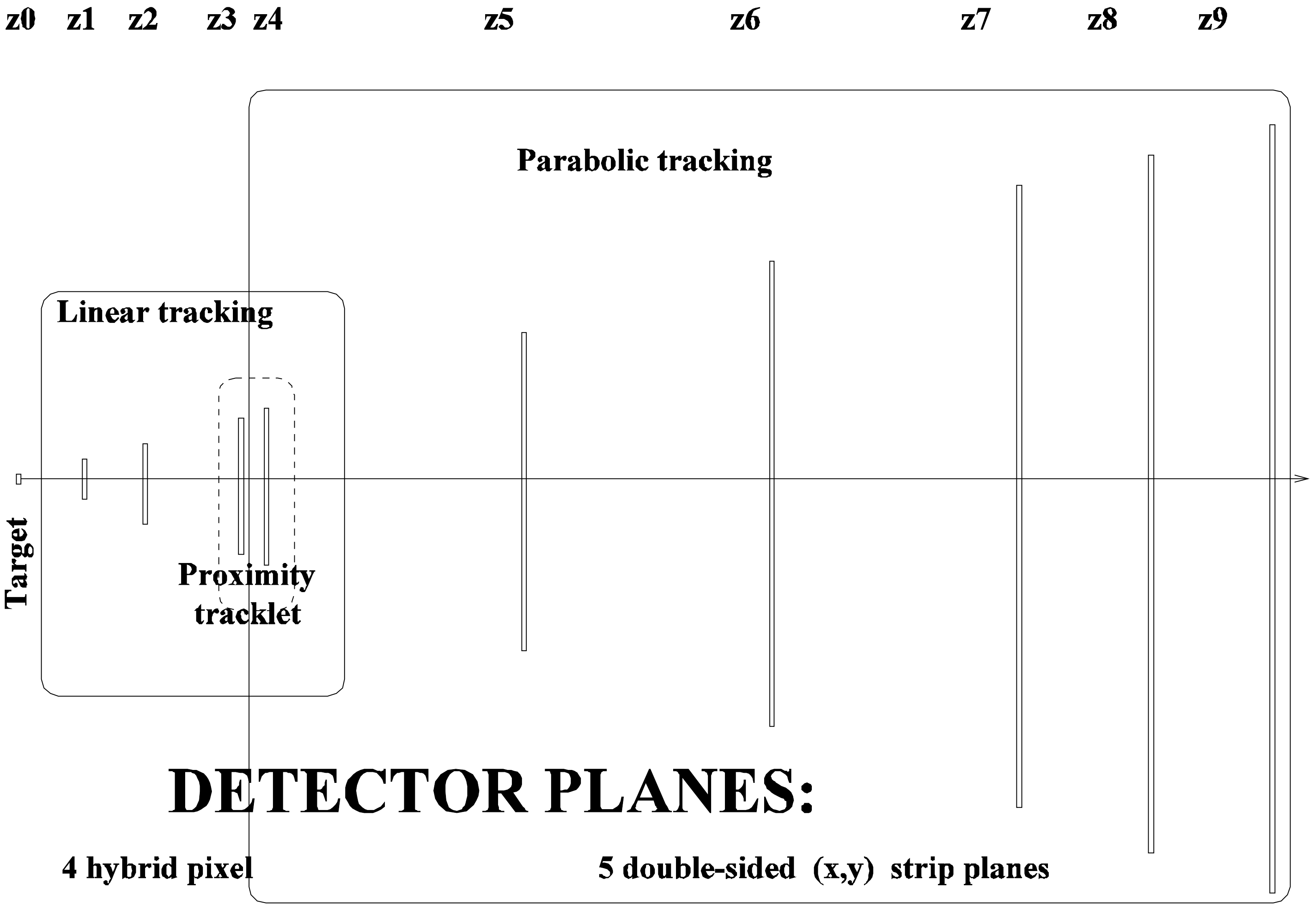
Single-cone track classification

Extended target of HIGH-Pt (almost straight) tracks



Double-cone track classification:

Each point in the principal plane defines a Dc, connecting all mozaics to CPU-i initiating the search for trigger particle by the same parallel SIMD process for all seed hits.



DETECTOR PLANES:

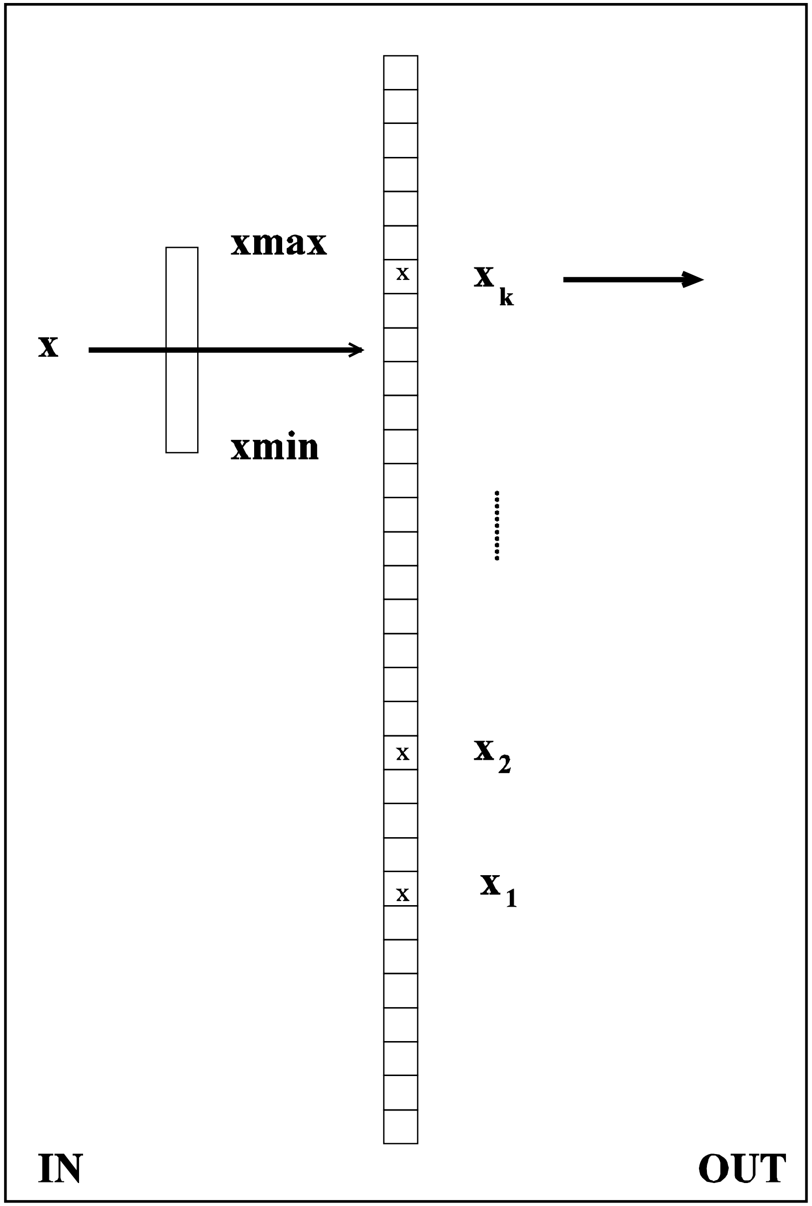
4 hybrid pixel

5 double-sided (x,y) strip planes

NEAREST HIT CAM

QUERY: X +/- Δ

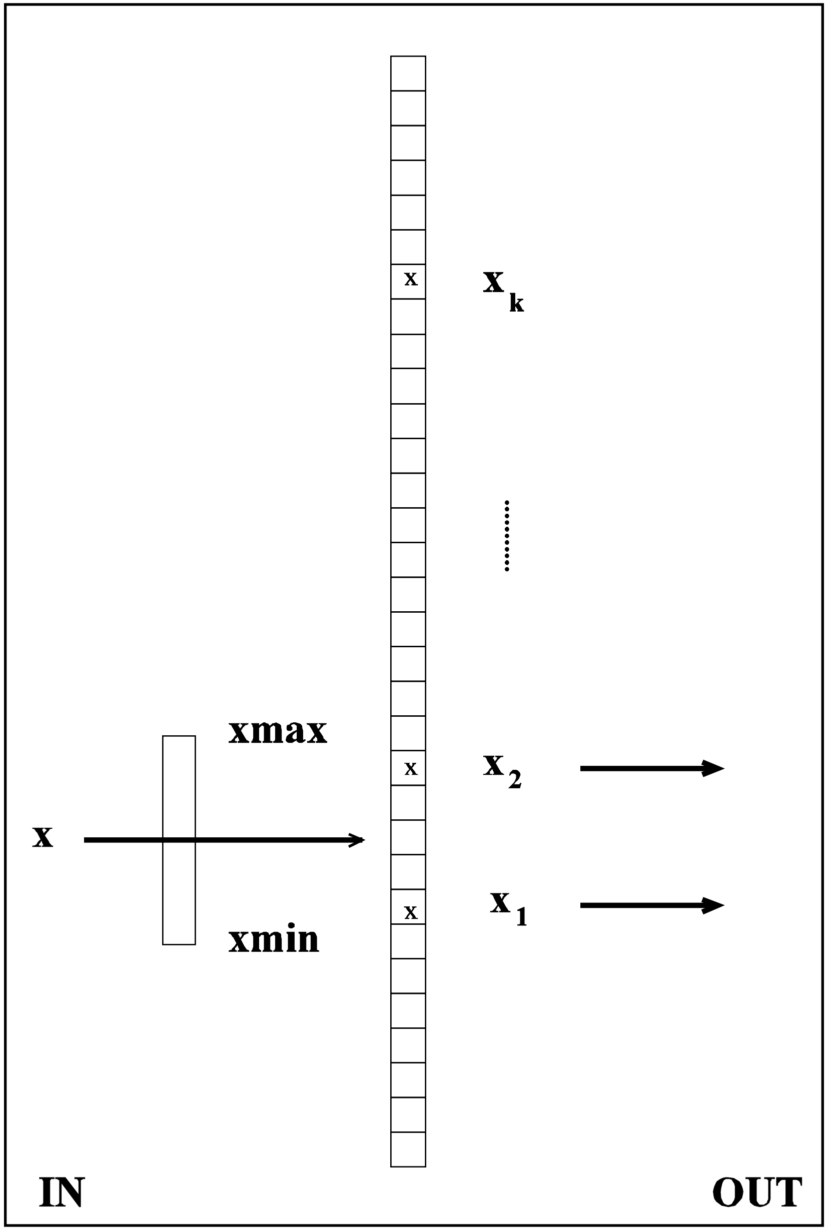
RESPONSE: X_k



x-coordinate = hit address

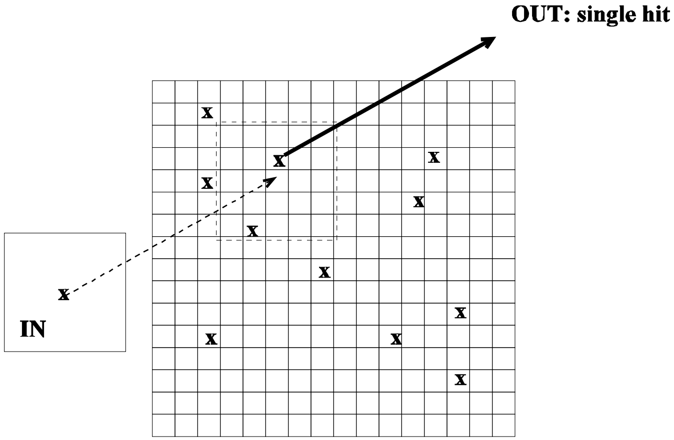
ALL HITS CAM

QUERY: $X \pm \Delta$



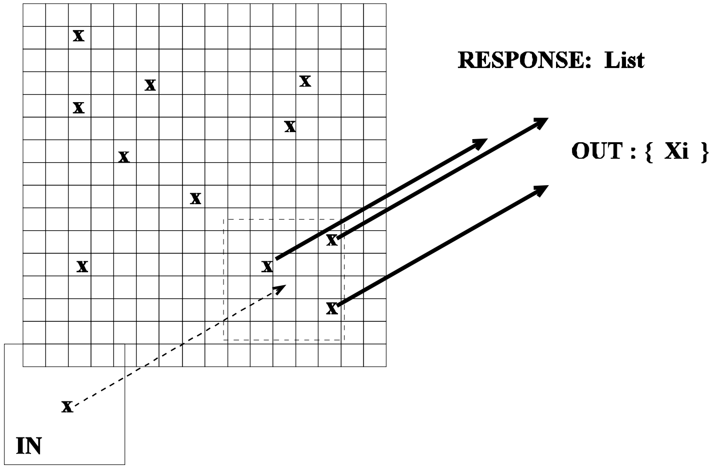
RESPONSE: $\{X_1, X_2\}$

NEAREST HIT CAM2



QUERY: { Xmin< x <Xmax; Ymin < y < Ymax }

ALL HITS CAM2



QUERY: { Xmin< x <Xmax; Ymin < y < Ymax }

3 phase programming scheme

PHASE-I: Proximity tracklets

The proposed high-Pt selection method is starting on the "principal plane„ #4. The required number of processors is equal to the number of mozaics in the principal plane. For each mozaic in plane #4 the list of mozaics in #3 plane is predetermined and in one single-step content addressing readout cycle one gets all the { (x3,y3) (x4,y4) } tracklets which arepotentially passing through the target. At the end of PHASE I each tracklet initiates a THREAD in its multi-core CPU. This procedure is very effective because z3 is so close ("proximity„ plane) to z4, that generally there is only 1 tracklet candidate per plane#4 mozaic even in case of high pileups. Important REMARK: mozaics of #3 and #4 planes are ListCAM-2 type. This assures exhaustive search for all tracks originating from the target.

PHASE-II: Linear tracking in pixel planes

The total z-difference between plane#1 and plane#4 is only 15 cm, therefore all the trakcs are almost exactly linear in xz-plane too. Mozaics belonging to planes #1 and #2 are HitCAM-1 type, providing the nearest hit for the query. All the threads are executing the same programming steps:

From planes #3 and #4 one predicts the (x,y) domain in plane#2 if there is no hit found the thread dies, otherwise (x2,y2) stored.

For survivig tracklets the procedure is repeated with prediction for plane#1.Due to the fact that very high momentum tracks frequently missing the first plane one doesn't kills tracklets with missing first point, but a flag stored instead of (x1,y1).

PHASE-III: Parabolic tracking in strip planes

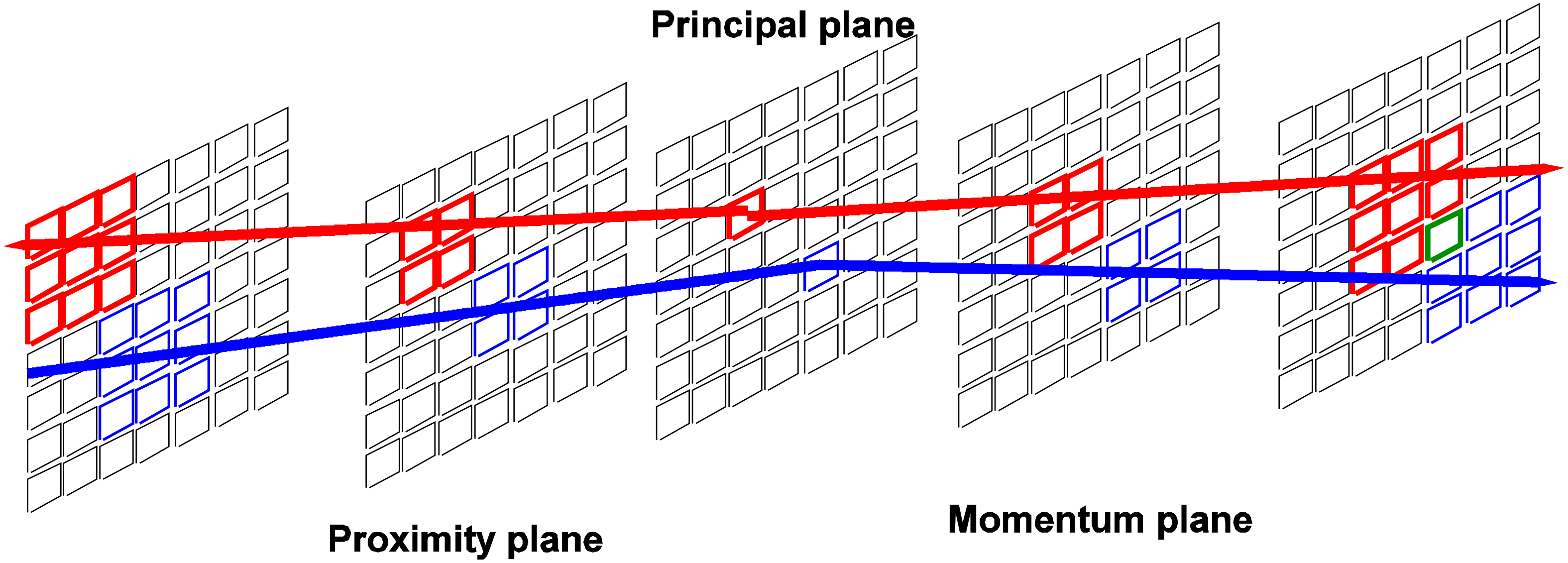
For parabolic tracking one need some curvature measurement. This is accomplished in plane#6, which again has ListCAM type mozaics but only in the xz-projection. All the other x and y strip planes have HitCAM-1 type mozaics.

Combining each linear tracklet from the previous phase with all the candidates from x-plane#6 list, one redifenes the new set of active threads.

The successive planes are searched for the corresponding hits using the parabolic approximation from the previous 3 planes.

At the end of the tracking one can calculate an approximate value of the transverse momentum, Pt and apply the TRIGGER threshold.

MOZAIC STRUCTURE of Double-cones



Detector planes are subdivided into MOZAICs, data from each mozaic stored in CAM .

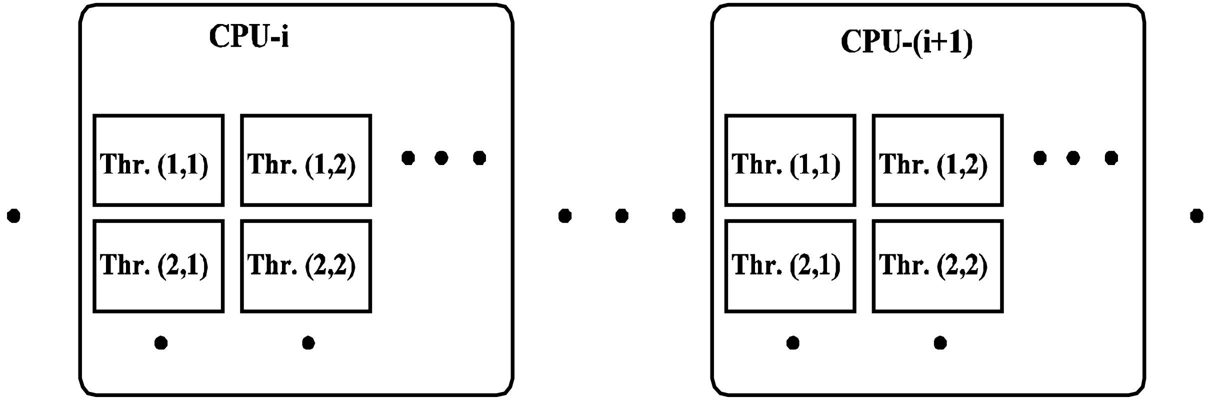
Principal, Proximity and X6-momentum planes have ListCAM.

Data from all other planes are stored in HitCAMs.

Mozaics belonging to red (blue) track double-cone are indicated.

The different cones can have common mozaic CAMs (see eg. green mozaic).

Multi-core CPUs with SIMD threads



Single Instruction on Multiple Data

Number of CPUs is equal to the number of mozaics in the principal plane.

The number Threads at start in given CPU is given by the number of proximity Tracklets. At the start of the parabolic tracking the Threads are reinitiated according to the number surviving linear tracks match with momentum candidates.

Corridor processors

STANDARD system: consecutive cycling on all „planes”

If only 2 points per plane: number of cycles = $2^{(4+2*5)} = 2^{14} = 16384$

NEW system: cycling only on 3 „planes” (for pixels x and y has common cycle)

If only 2 points per plane: number of cycles = $2^{(2+1)} = 2^{3} = 8$

The Linear and Parabolic Trackings are producing a list containing:

corNUM,   x1,x3,x5,x7,x8,x9,   y1,y3,y5,y6,y7,y8,y9

There is NO extra cycling TIME because the HitCAMs provides only YES/NO.

The gain in processing time (if only 2 points per plane): 2^{11} = 2048-fold

Simulation results

The algorithm is tested on pC interactions generated by the CBM Geant simulation program.

90 GeV beam energy was used at the event generation. At the simulation all the particle transport effects were included. For simplicty, it was assumed that the detector efficiency is equal to 100%. Particle hits were represented by single bit value, without using the analogue de/dx information.

The triggering efficiency is depending on the threshold value and the intensity of beam. Typical efficiency is greater than 60% and the fake trigger is less than 10% in case of moderate (below 100-fold) pileups .

Due to the practical exhaustive search there is no loss of good tracks even in case of 500-fold pileup, but the number of FAKE combination is increasing dramatically, which can be reduced very effectively using the fact that the coordinates measured in the STRIP planes can have ruther precise timing information too.