Fast Parallel Ring Recognition Algorithm in the RICH Detector of the CBM Experiment at FAIR

<u>Semen Lebedev</u>

GSI, Darmstadt, Germany and LIT JINR, Dubna, Russia

Claudia Höhne

GSI, Darmstadt, Germany

Ivan Kisel

GSI, Darmstadt, Germany

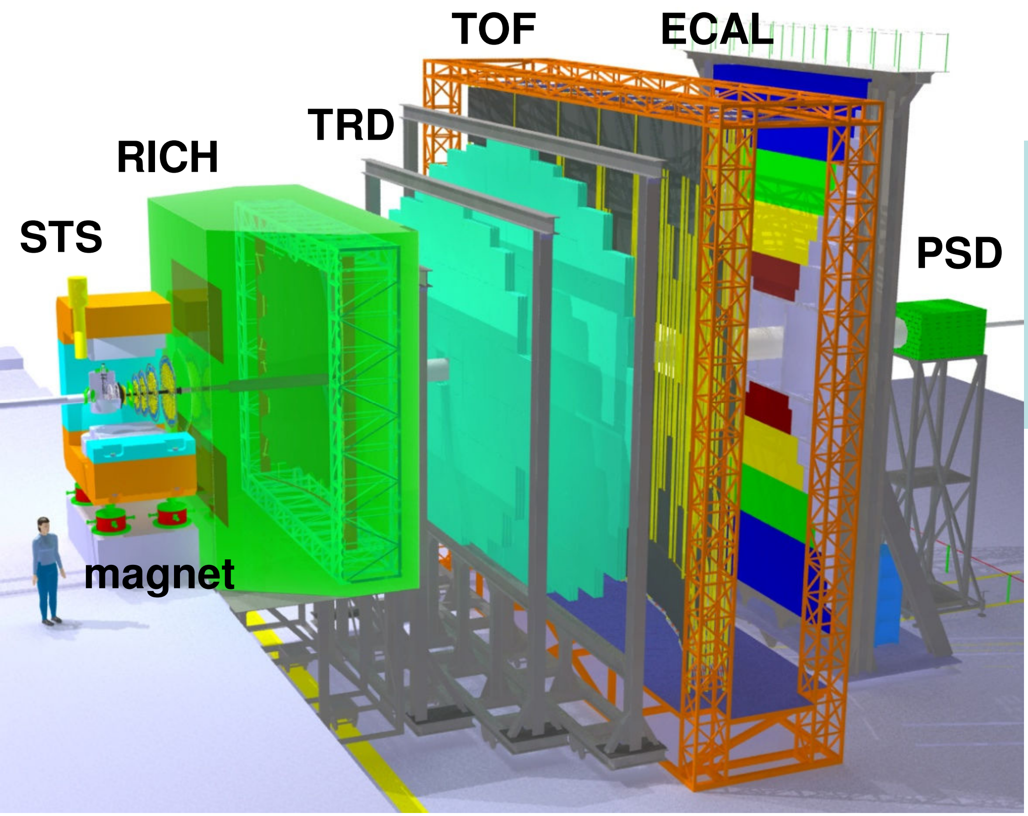
Gennady Ososkov

LIT JINR, Dubna, Russia

S.Lebedev@gsi.de

The CBM experiment

Aim: Investigation of the QCD phase diagram -> measurement of hadronic and leptonic probes in large acceptance



MVD+STS: tracking, momentum determination, vertex reconstruction

RICH & TRD:

electron identification

$\rightarrow$ pion suppression $\geq 10^4$

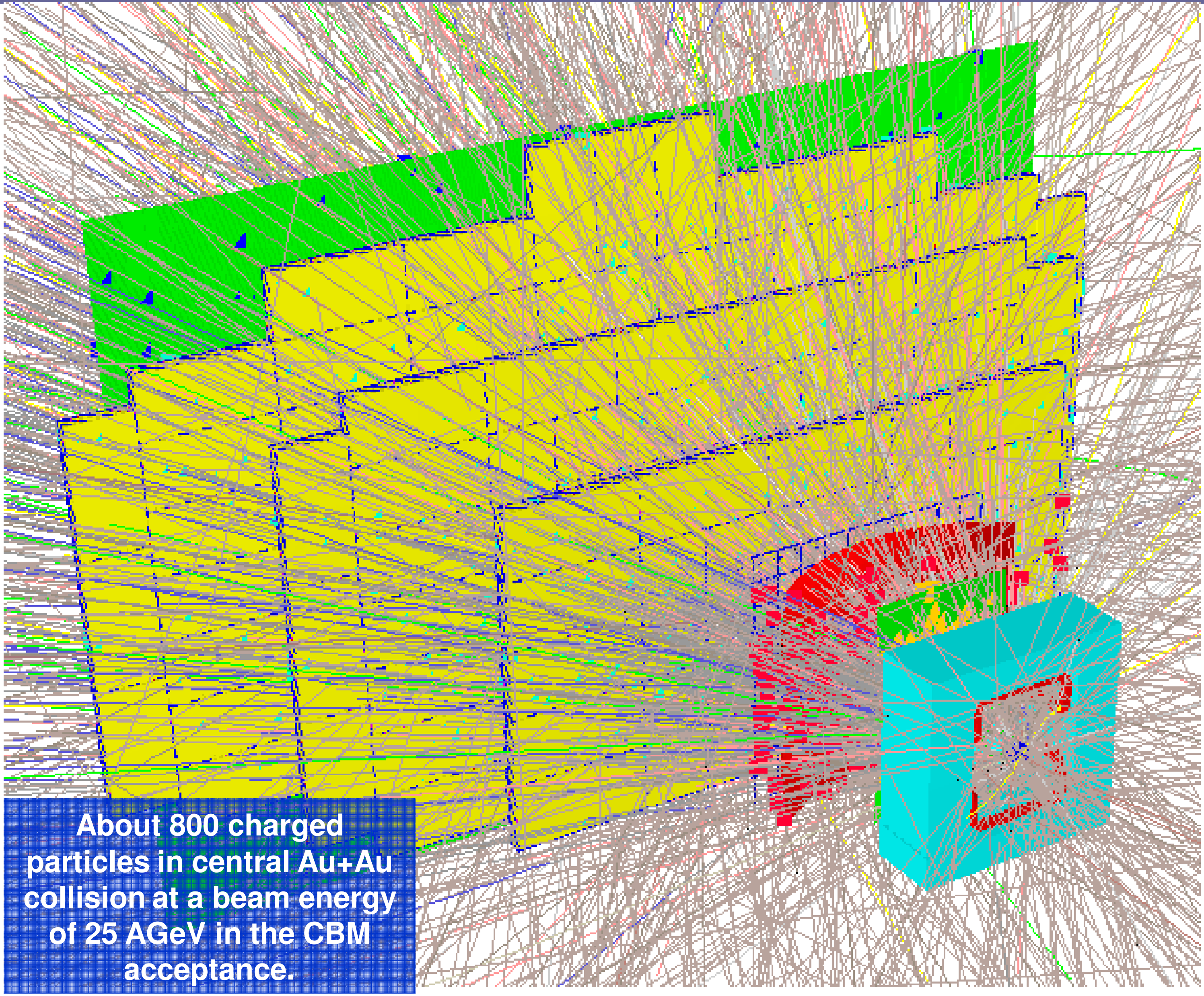
TOF: hadron identificaion

ECAL: photons, π^0, γ

PSD: event characterization

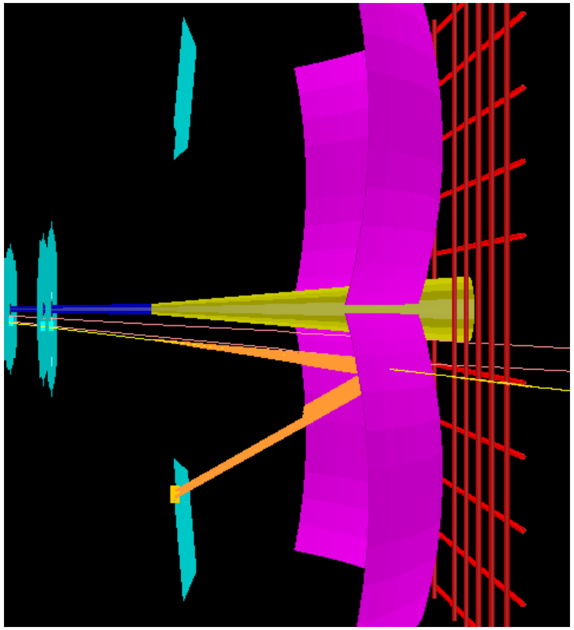
up to 10MHz interaction rate → <u>rare probes</u>
→ fast reconstruction algorithms are essential!

The CBM experiment



About 800 charged particles in central Au+Au collision at a beam energy of 25 AGeV in the CBM acceptance.

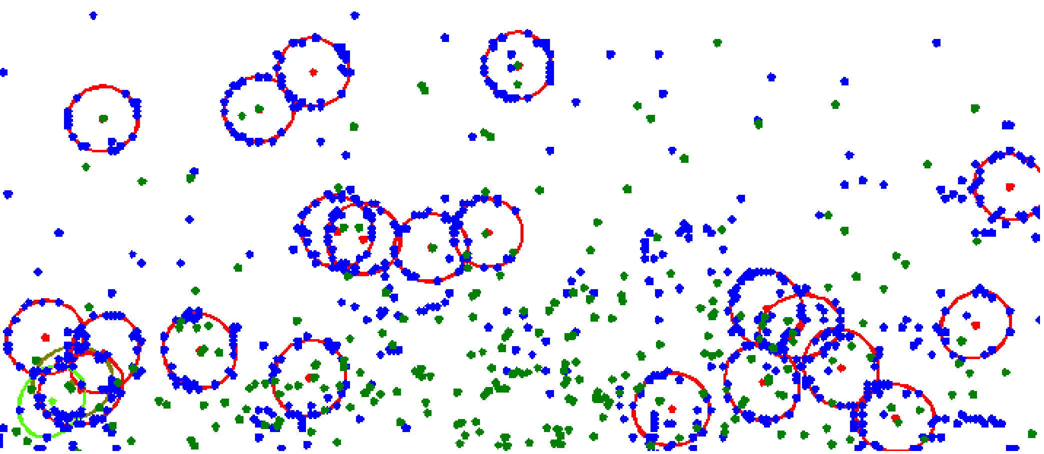
The CBM RICH detector



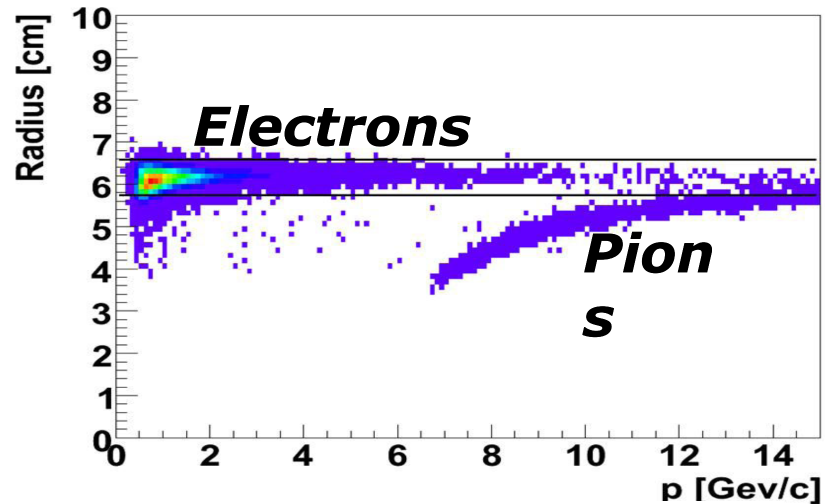
RICH characteristics:

- **radiator:** CO_2 length 1.5 m
- **glass mirror of 6 mm thickness:** radius-3m; size-11.8 m^2
- **photodetector Hamamatsu H8500 MAPMT:** 2.4 m^2 -> 55k channels

Mean number of hits per electron ring is 21



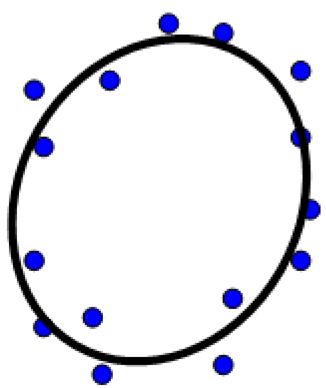
RICH hits (blue), found rings (red), track projections (green).

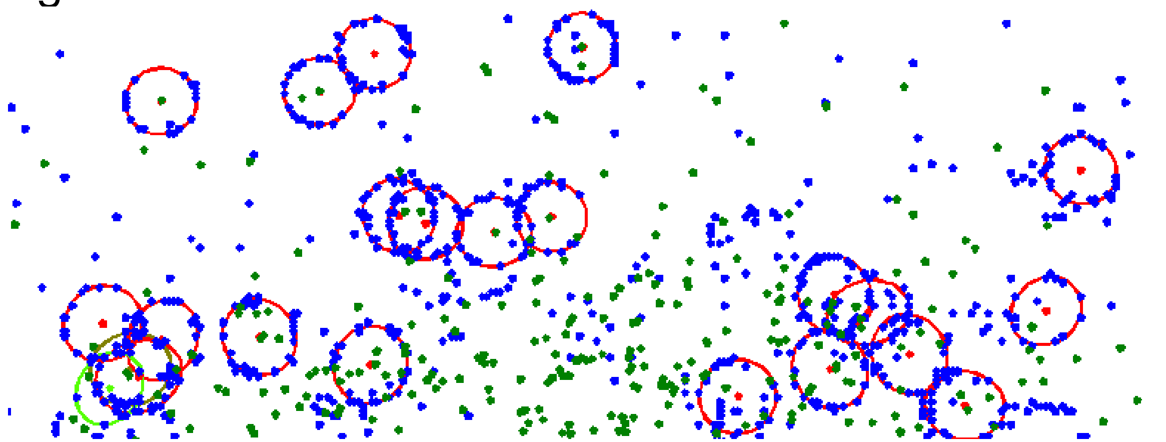


Radius versus momentum for reconstructed rings.

Challenges for ring recognition

- **Big number of hits in each event** including noise hits (around 1200 hits per event)
- **High ring density**, especially in the inner part of the photodetector
- **Different number of hits per ring** (from 5 to 50) -> hard to reconstruct rings with small number of hits
- **Elliptic shape of the rings** (mean B/A = 0.9)
- **Fuzzy ring shape** -> optical distortions, photodetector granularity ($0.58x0.58cm^2$ around 10% of ring radius), residue of magnetic field
- **High interaction rate** -> algorithm must be fast.





RICH hits (blue), found rings (red), track projections (green).

Ring recognition algorithm

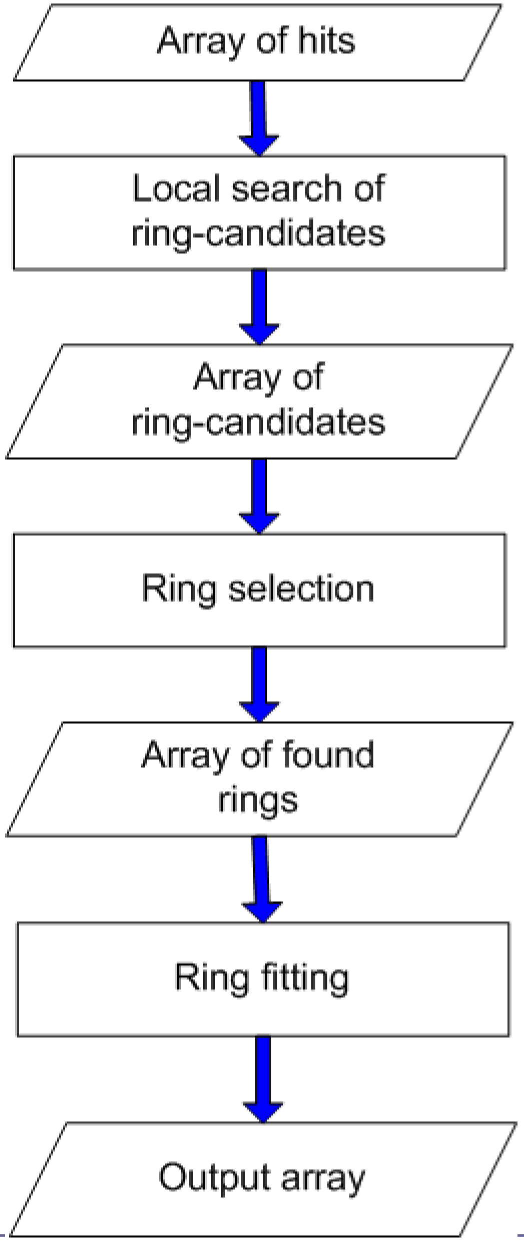
Standalone ring finder.

Three steps:

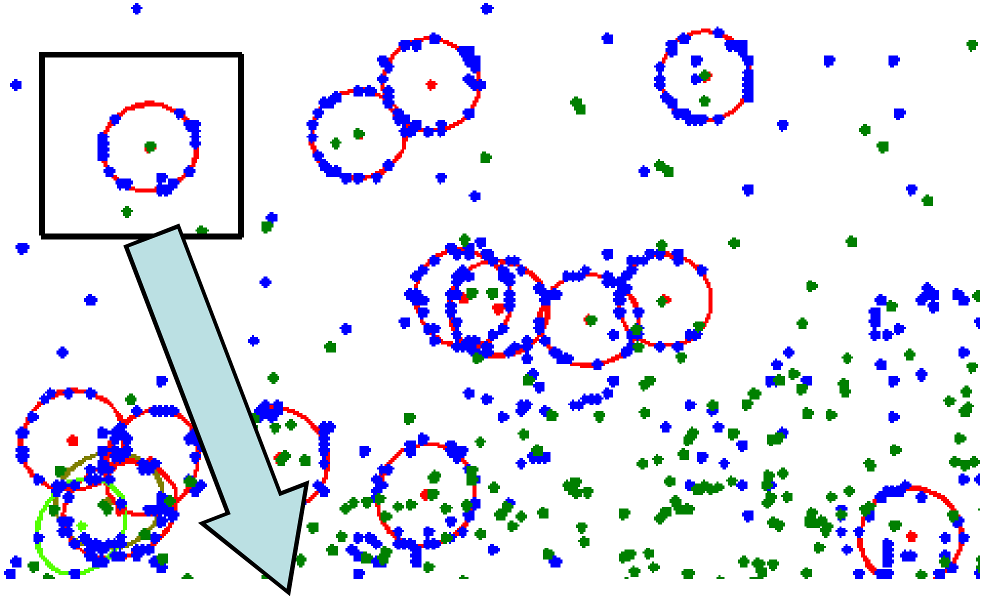
Ring-candidates finding:
Hough Transform.

Ring selection:
compares all ring-candidates and chooses only good rings, rejecting clone and fake rings.

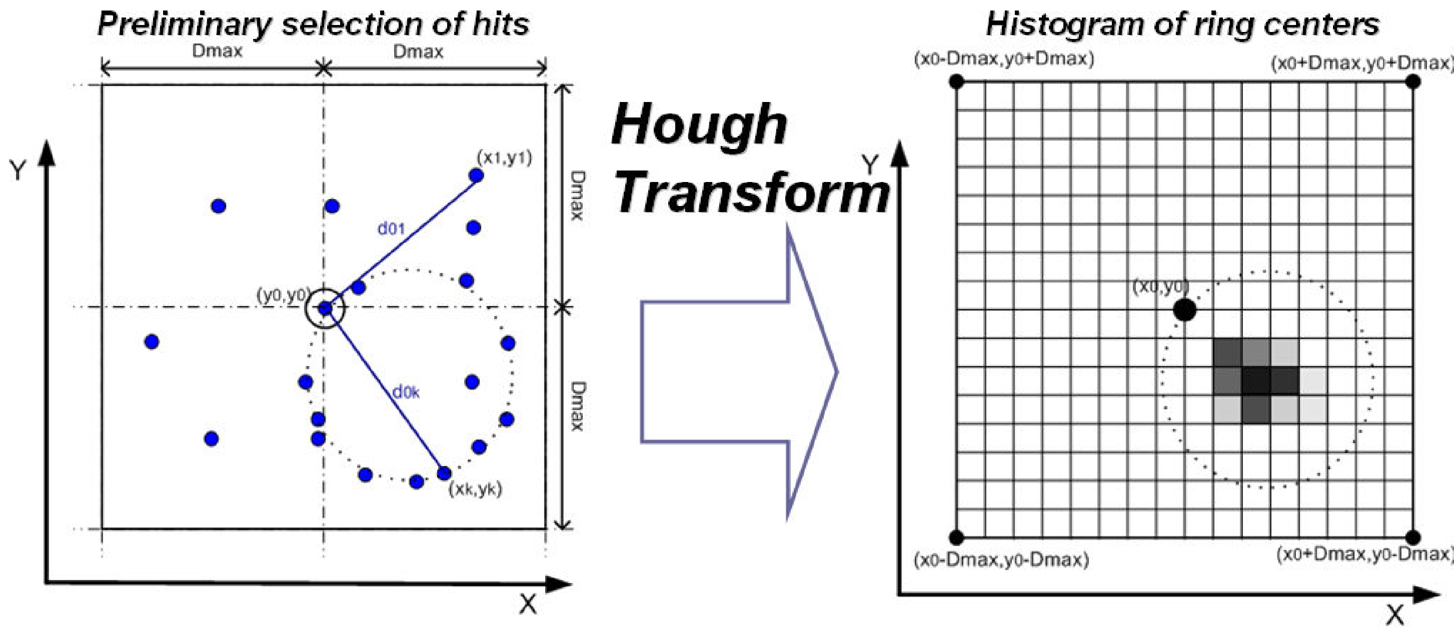
Ring fitting:
ellipse fitter based on Taubin method.



Find ring-candidates, Hough Transform



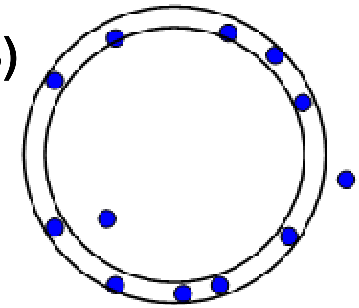
Hough Transform:
large combinatorics => slow
Localized Hough Transform:
much less combinatorics => fast



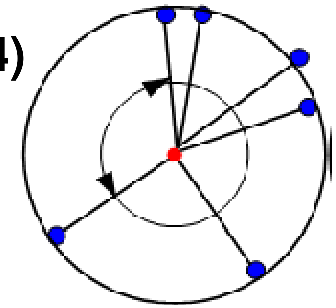
Ring quality

1. number of hits in ring;
2. chi-squared
3. number of hits in a small corridor around the ring;
4. biggest angle between neighboring hits;
5. position of ring on photodetector plane;
6. radius

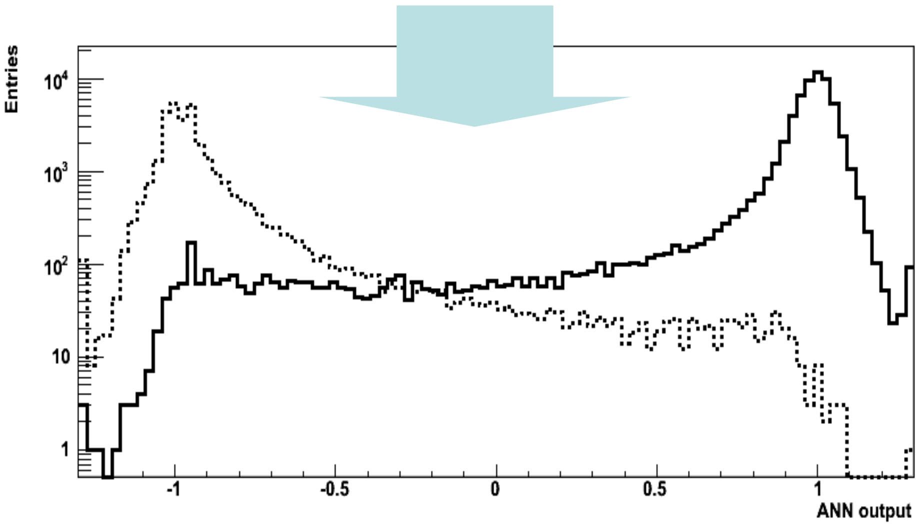
3)



4)



- ***Artificial Neural Network (ANN)*** derives ring quality from six parameters.
- The ANN output provides a ring quality parameter or probability, whether ring-candidate was found correctly or not.



ANN output value for correctly found (solid line) and fake (dashed line) rings

Reject candidate with worse quality if it shares more than 25% of hits with a ring candidate with better quality.

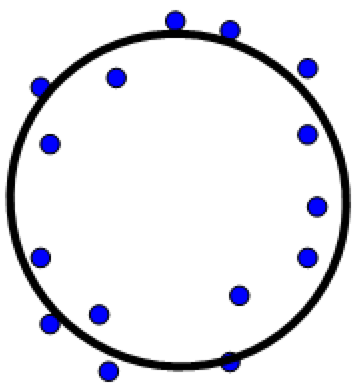
CBM RICH ring fitting

Circle fitting

- *usage in ring finding algorithm*
- *program realization of the COP (Chernov-Ososkov-Pratt), based on the minimization of the functional*

$$\bar{M}(a,b,R) = \sum_{i=1}^{n} \left[\left((x_i - a)^2 + (y_i - b)^2 - R^2 \right)^2 / 4 * R^2 \right]$$

- *Newton method for nonlinear equations with one variable is used*
- *3-4 iterations*
- *algorithm is very robust to the initial parameters*

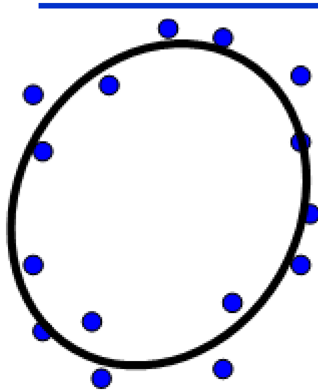


Ellipse fitting – final ring fitting

- *Rings in the photodetector plane have a slight elliptic shape*
- *general, as conic section*

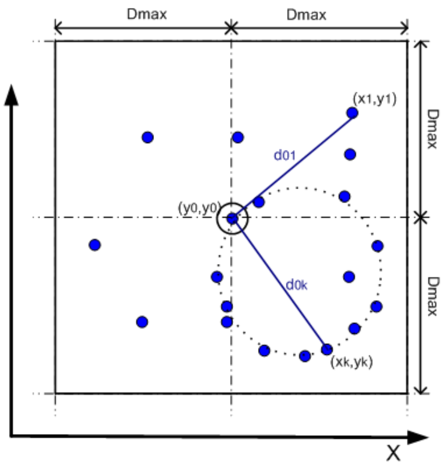
$$P(\mathbf{X}) = Ax^2 + Bxy + Cy^2 + Dx + Ey + F$$

- *Taubin method is used*
- *Minimize P(x) by A,B,C,D,E,F, but measuring deviations along normals to the curve.*
- *non-linearity is avoided by Tailor expansion*
- *non-iterative very fast direct algorithm*
- *no need of start values for parameters*



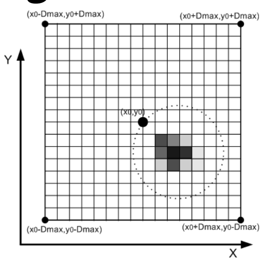
Mean B/A for CBM RICH rings **= 0.9**

- ***Optimization of the Hough Transform combinatorics***
  - ***Divide hits into several groups***
  - ***Run Hough Transform of each group <u>independently</u>***



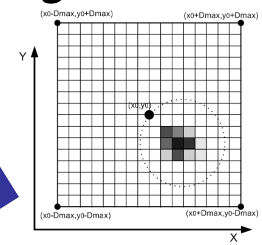
First group of hits

Hough Transform

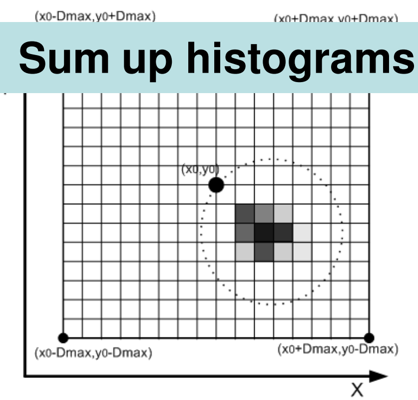


Second group of hits

Hough Transform

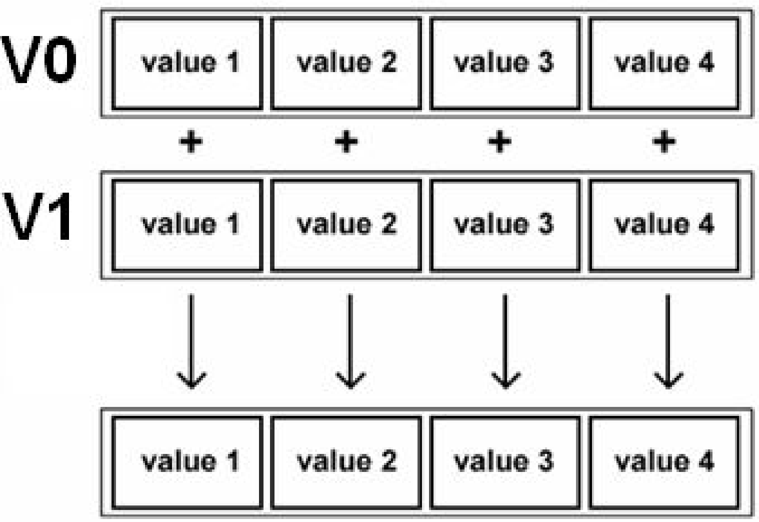


Sum up histograms



Other optimizations
- memory optimization
- math optimization
- double->float

SIMD and multithreading



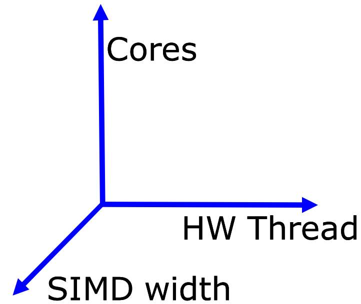
4 floats

4 floats

4 floats

Today CPUs have SSE 128 bit registers

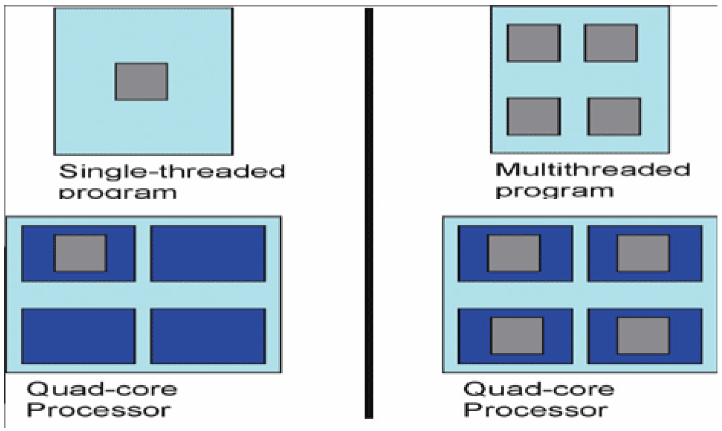
4 float operations concurrently



- The best candidate for SIMDization is a computing intensive procedure without branches (if, break, continue), which can work in parallel for multiple data.
- Rethink algorithm in a way of using SIMD.

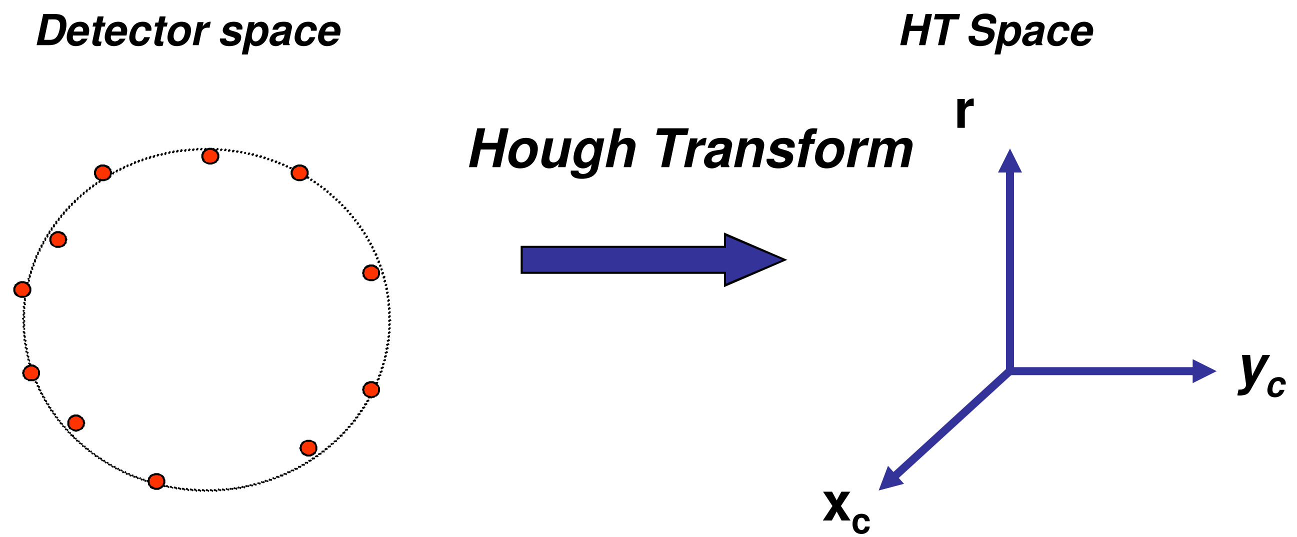
Multithreading:

- Many independent cores in one CPU
- Run independent tasks
- Tool for multithreading: Threading Building Blocks



Hough Transform and SIMD

- From Double to Float precision
  - HT works good with Float precision
- RICH data vectorization
  - Hit: Xv, Yv, where $Xv=(X_0,X_1,X_2,X_3)$; $Yv=(Y_0,Y_1,Y_2,Y_3)$
- SSE instructions were overwritten in a header file
- Calculate ring parameters (x, y, r) from triplets using SIMD: 4 parameters at a time.

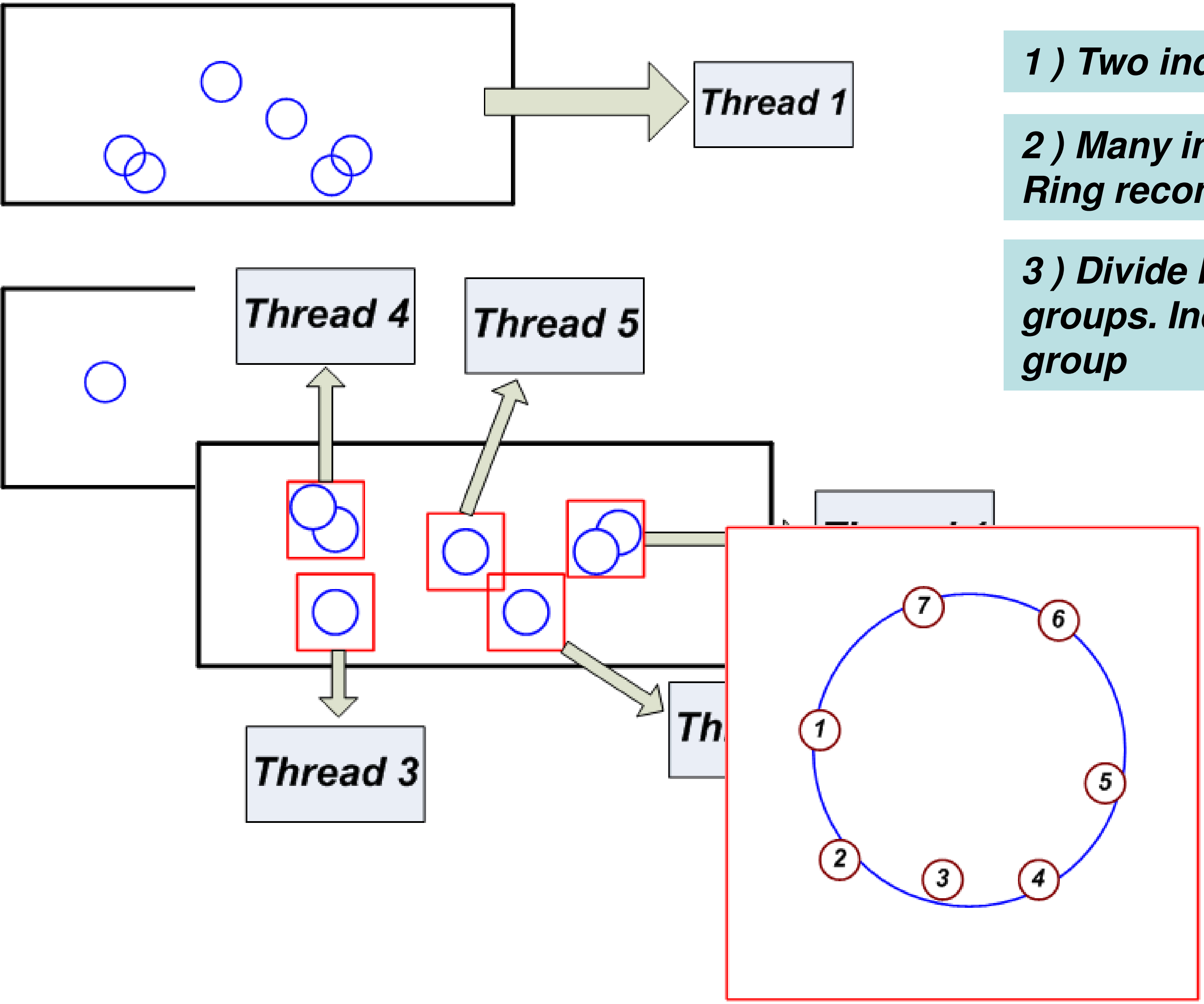


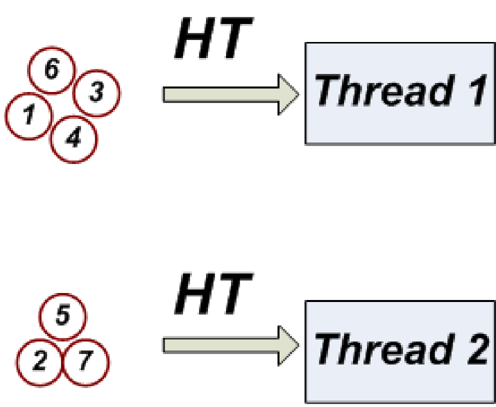
Multithreading parallelization of Hough Transform algorithm can be done on different levels.

1) Two independent photodetectors

2) Many independent local Ring reconstructions

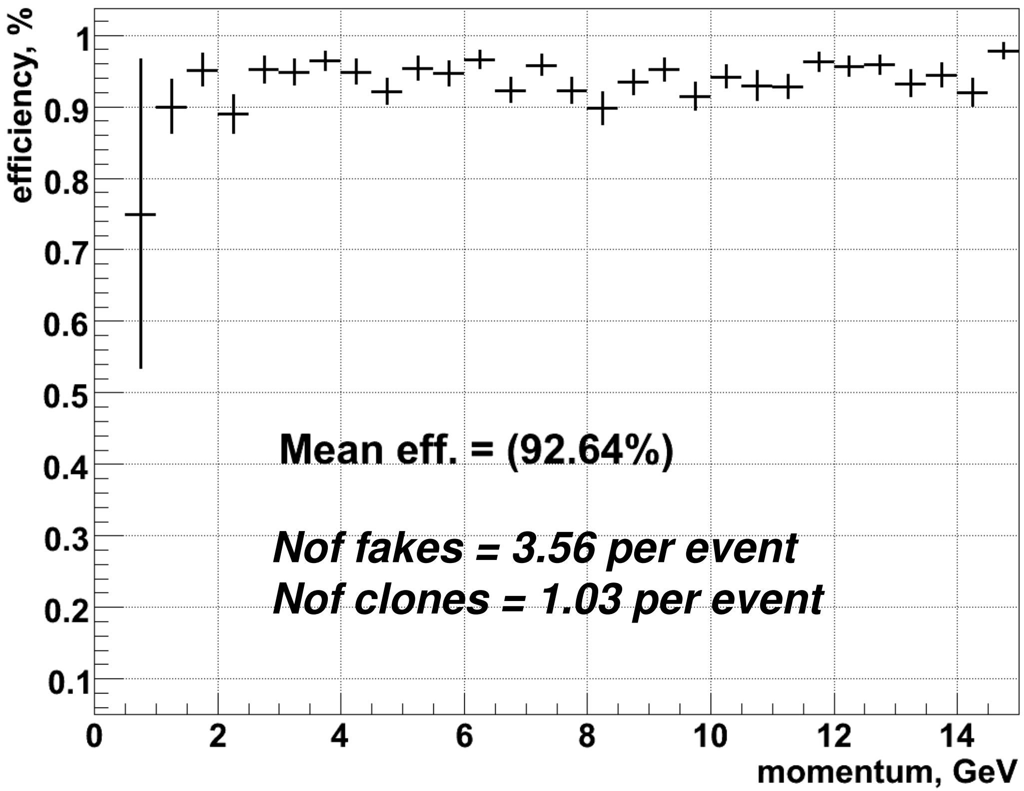
3) Divide hits into a several groups. Independent HT for each group





Ring finding results

Simulation: central Au+Au collisions at 25 AGeV beam energy (UrQMD)
5e+ and 5e- embedded to enhance statistics



Ring reconstruction efficiency for embedded e+ and e-.

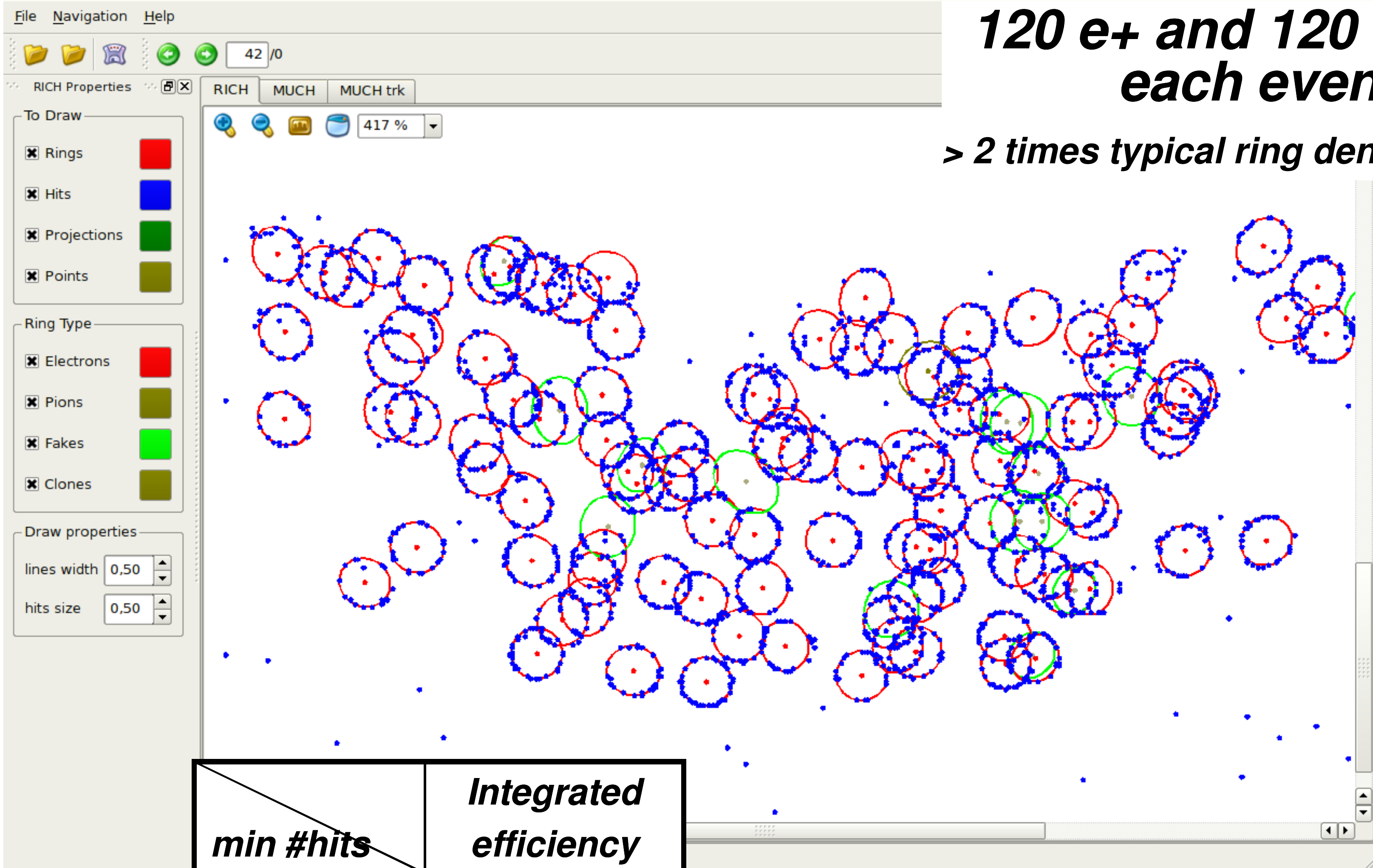
	Time, ms	Speedup
Initial	357	-
Optimization	5.8	62
Parallelization	3	2
Final	-	119

2x Intel Xeon X5550 processors at 2.67GHz (8 cores)

Not all parts of the algorithm are parallelized (to be studied in future)

Accepted rings = rings with >= 5 hits

Stability test for ring finder



120 e+ and 120 e- in each event

> 2 times typical ring density

min #hits	***Integrated efficiency***
5	***91.07***
10	***92.71***
15	***95.28***

Mean number of hits per ring is 21

Summary

- Fast event reconstruction algorithms are essential for the CBM experiment -> develop fast ring reconstruction routines for the RICH detector.
- Fast and efficient algorithm for ring recognition in CBM RICH was developed
  - based on the fast Hough Transform method with local selection of hits.
  - ellipse fitting algorithm was implemented for precise estimation of ring parameters.
  - a ring selection algorithm was developed to select good rings, while rejecting fake and clone rings.
- Parallel algorithm (SIMD and multithreading) was developed
- Time for reconstruction of one event in RICH (about 80 rings)
  - for optimized scalar version is 5.8 ms,
  - for parallel version is 3 ms.
- Further investigations of the parallel version is ongoing.