Development and application of the Kalman filter method in the CBM and ALICE experiments

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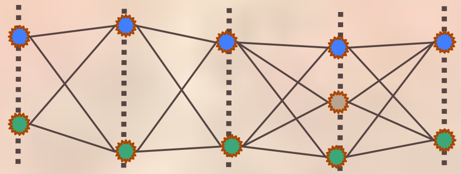
Outline

- Fit problem in event reconstruction in HEP
- The Kalman Filter method
- Kalman Filter for on-line event reconstruction in CBM
  - KF track fit in CBM
  - CA+KF tracker in CBM
  - Fast SIMDized Kalman Filter
- Kalman Filter for on-line event reconstruction in ALICE HLT
  - CA tracker for ALICE HLT
  - KF fit with 3D track model
- Reconstruction of vertices and decayed particles
- Summary

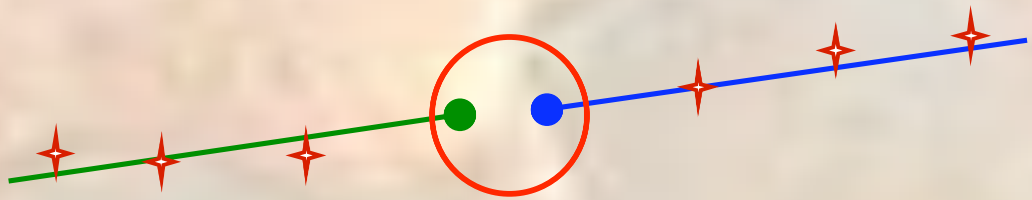
Fit problem in event reconstruction

- Track finding

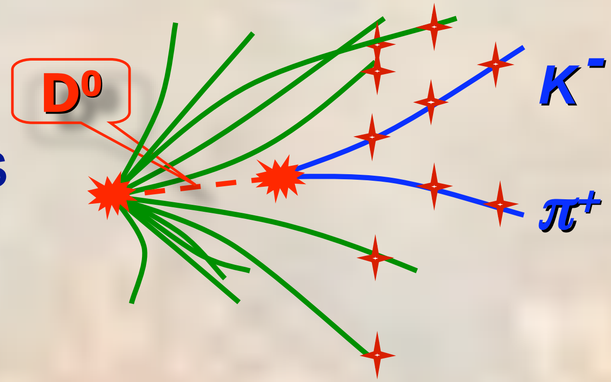


- Track fitting

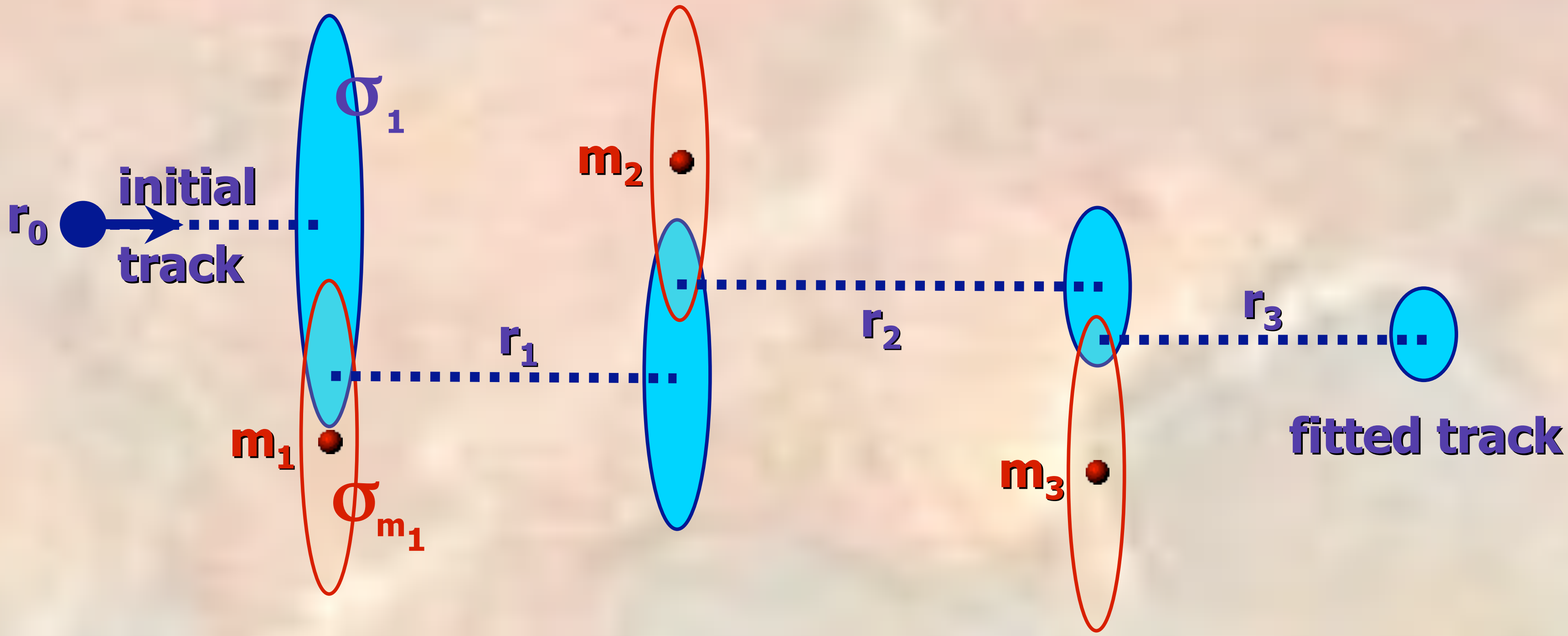
- Track merging



- Reconstruction of vertices and decayed particles

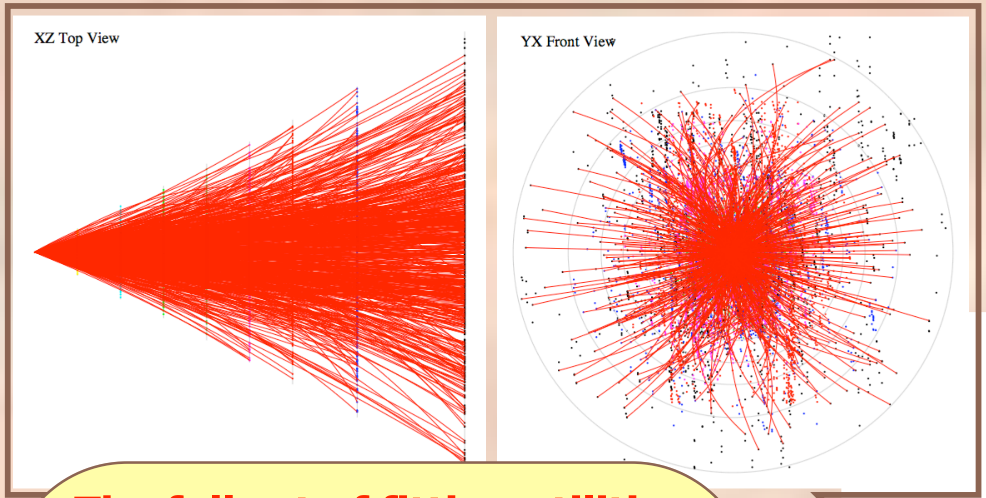


The Kalman filter method



The Kalman filter is the most used method for the fit problem.
The method is well known in HEP, but in modern experiments
the large amount of data and specific problems require development of new
Kalman filter-based algorithms as well as investigations of the basic method.

KF fit in the CBM experiment



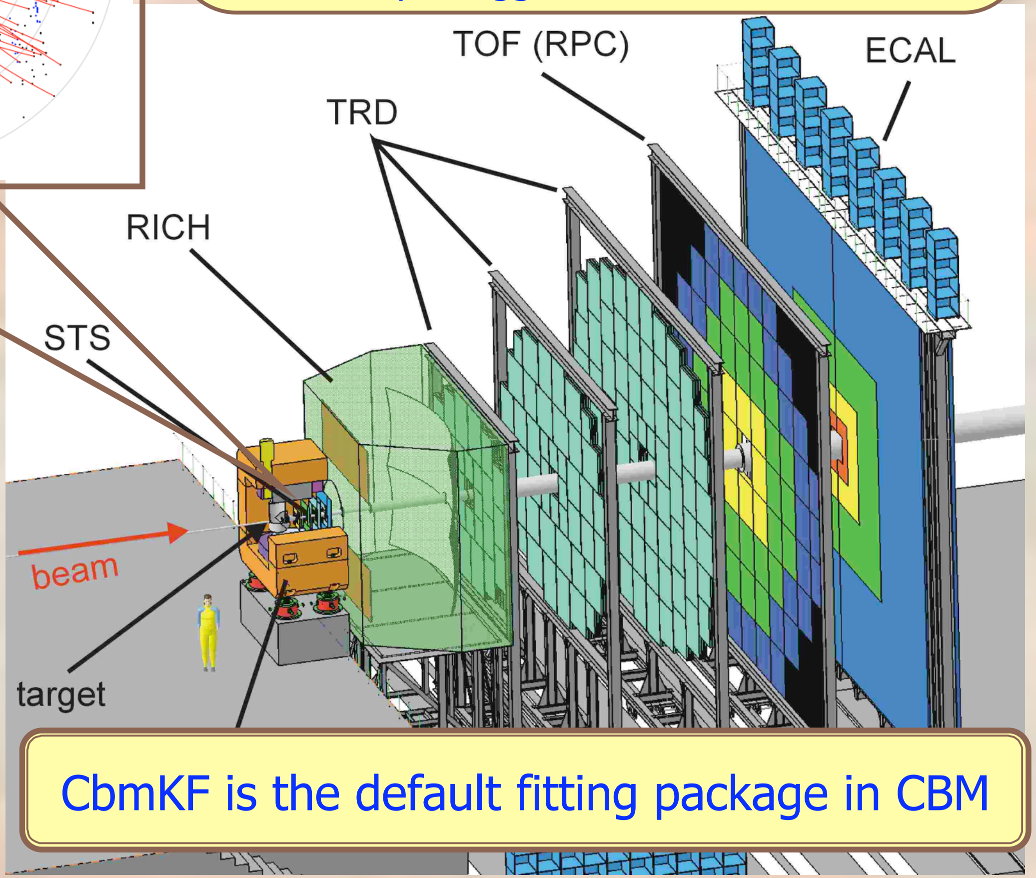
CBM reconstruction challenge

- ~ 1000 charged particles/collision
- 85% fake hits
- non-homogeneous magnetic field

- 10^7 Au+Au collisions/sec
- no simple trigger

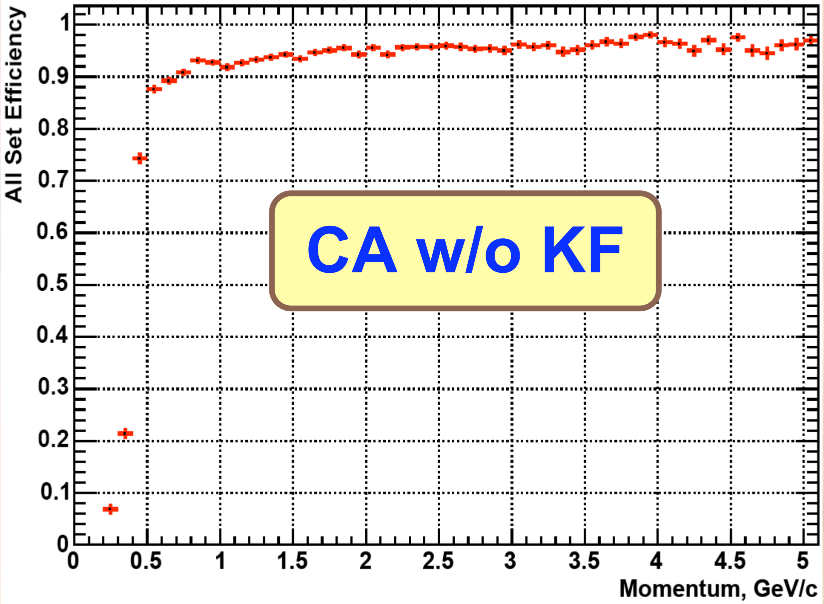
The full set of fitting utilities has been developed

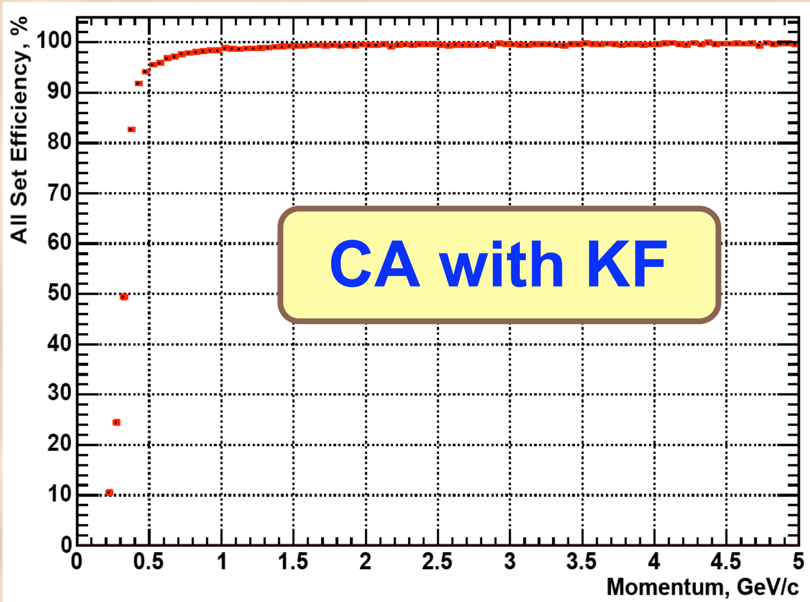
- Tracking in STS
- Tracking in muon chambers
- Tracking in TRD
- Track-ring match in RICH
- Hit gathering (MVD)
- Global tracking
- Reconstruction of vertices and decayed particles
- Smoother utility



CbmKF is the default fitting package in CBM

CA+KF tracker for CBM





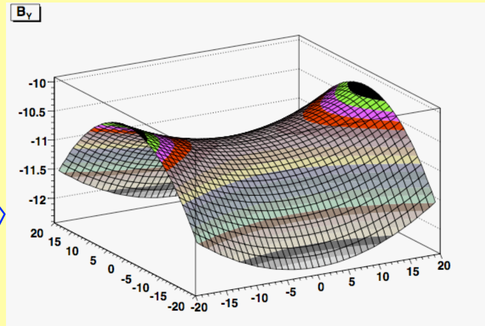
Efficiency, %	Track category	Efficiency, %
95.29	Reference set	99.45
90.52	All set	96.98
76.05	Extra set	89.46
0.00	Clone	0.01
2.18	Ghost	0.61

Speed up of the Kalman filter

Problem: Pixel geometry (1 sec) => double-sided strips (3 min)

Reco time = N combinations*fit time => speed up of KF fit utilities needed

Stage	Description	Time/track	Speedup
0	Initial scalar version	12 ms	-
1	Approximation of the magnetic field	240 μs	50
2	Optimization of the algorithm	7.2 μs	35
3	SIMDization	1.6 μs	4.5
4	Porting to SPE	1.1 μs	1.5
5	Parallelization on 16 SPE's	0.1 μs	10
	Final SIMDized version on Cell	0.1 μs	120000
6	FPGA	? ns	?



Dual Cell Blade at the IBM Laboratory, Böblingen, Germany

Future, but realistic

KF fit on different architectures

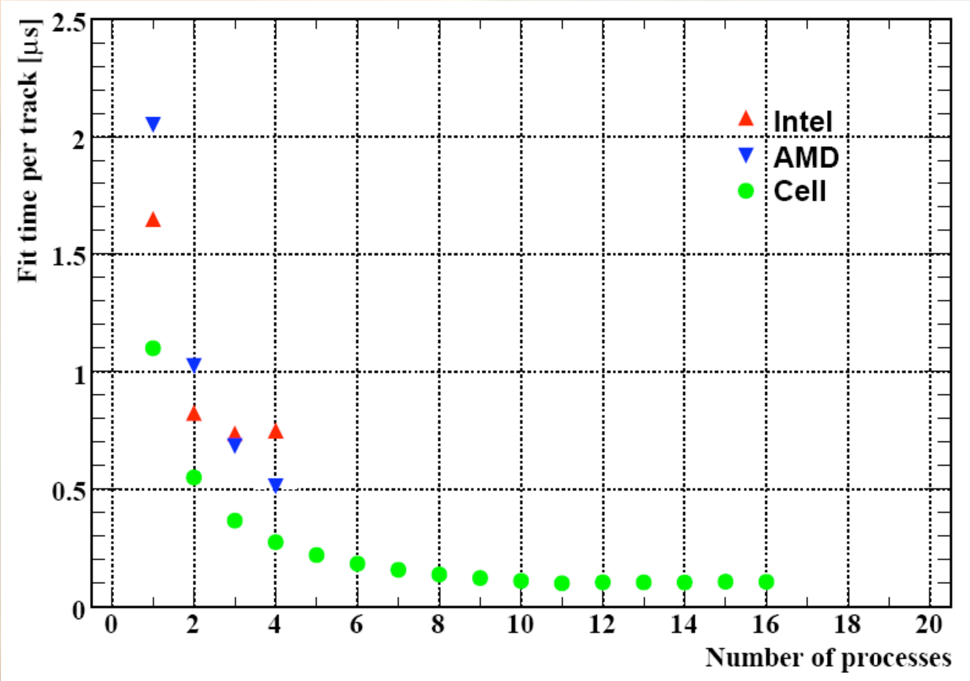
Fit of a single track:

lxg1411
eh102
blade11bc4

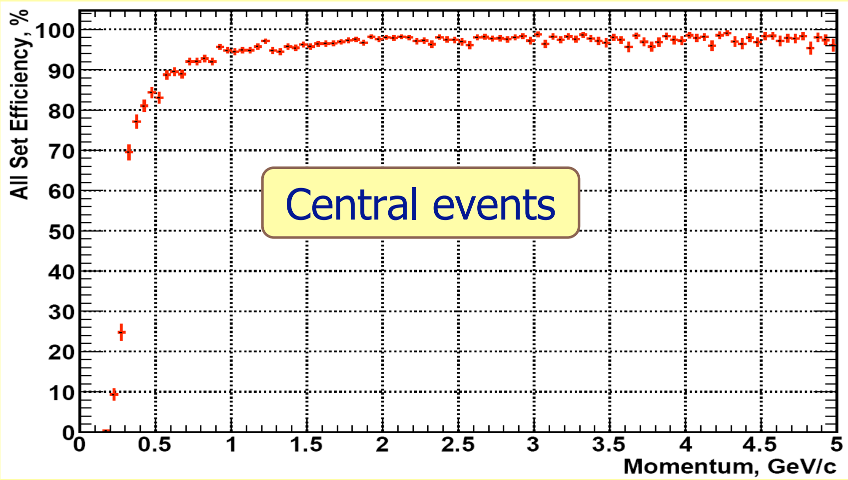
Processing Units	Cache/LS, kB	Clock, GHz	Time, μs	kCycle/Track
2 Intel Xeon with HT	512	2.66	1.47	3.91
2 Dual Core AMD Opteron	1024	1.8	1.86	3.35
2 Cell Broadband Engine	256	2.4	0.87	2.09

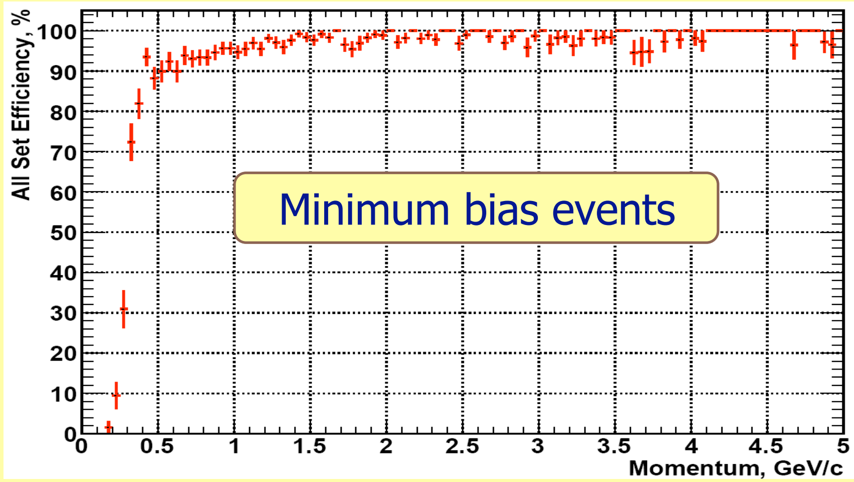
S.Gorbunov, U.Kebschull, I.Kisel, V.Lindenstruth, W.F.J.Müller, **Fast SIMDized Kalman filter based track fit**, acc. by CPC

Fit of thousands of tracks:



Speed up of CA+KF tracker





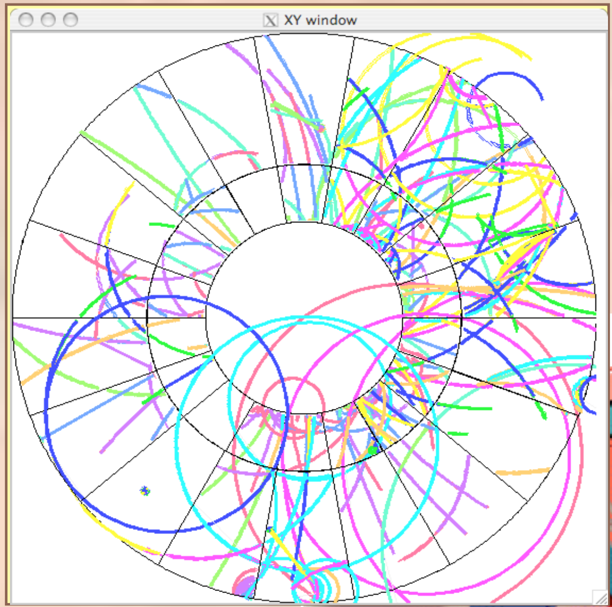
Efficiency, %	Track category	Efficiency, %
97.04	Reference set (>1 GeV/c)	98.21
93.26	All set	94.65
79.95	Extra set (<1 GeV/c)	82.02
1.15	Clone	1.07
2.28	Ghost	0.46
523	MC tracks/event found	93
78 ms	CA time/event	**5 ms**

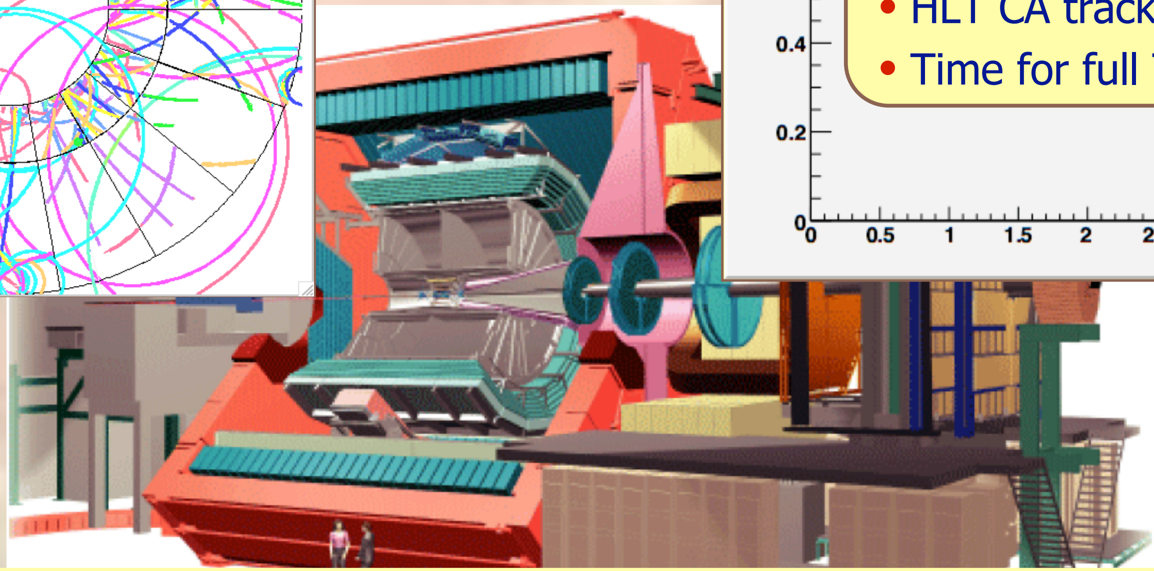
1000 times faster

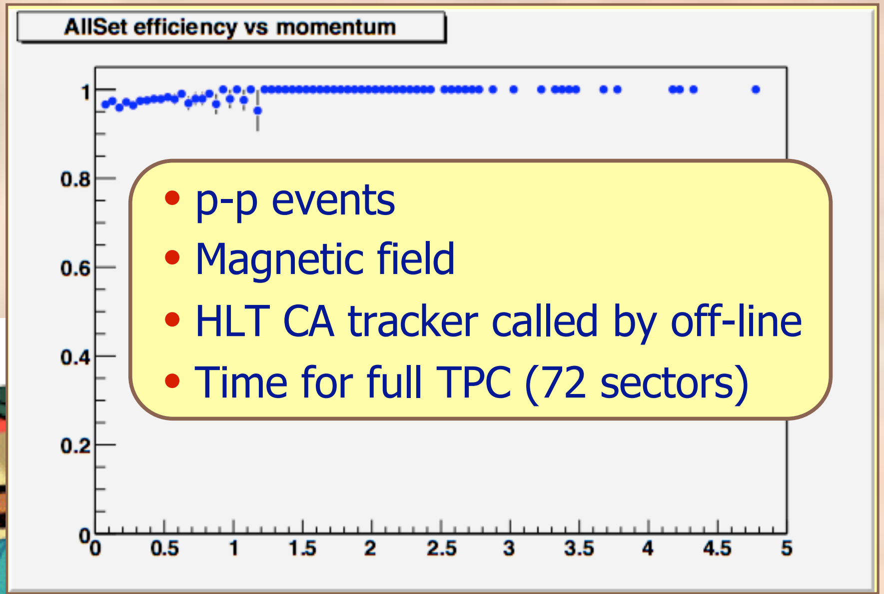
Event selection rate

S. Gorbunov and I. Kisel, **Fast SIMDized cellular automaton based track finder**, in progress

CA+KF tracker for ALICE HLT



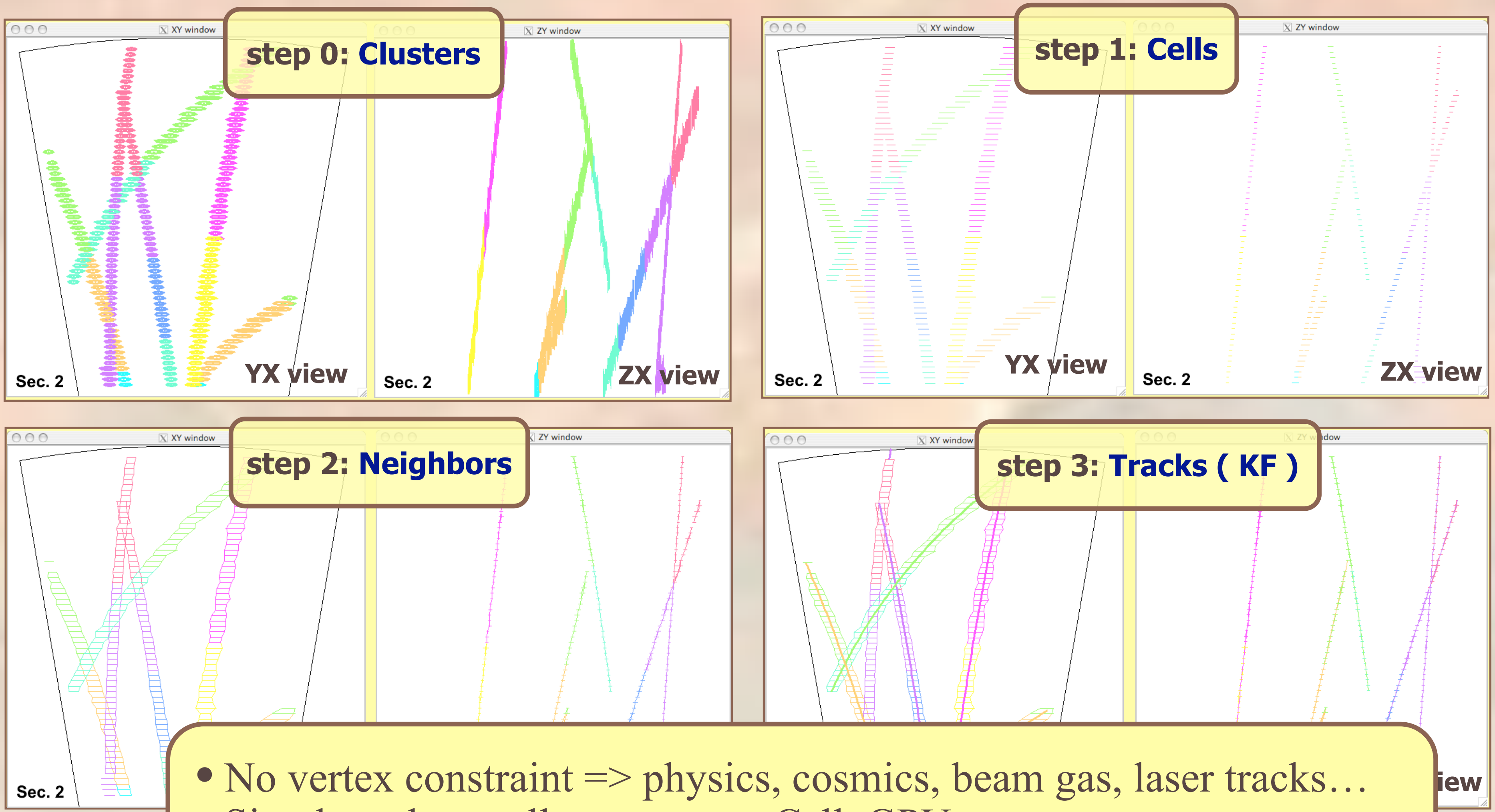




- p-p events
- Magnetic field
- HLT CA tracker called by off-line
- Time for full TPC (72 sectors)

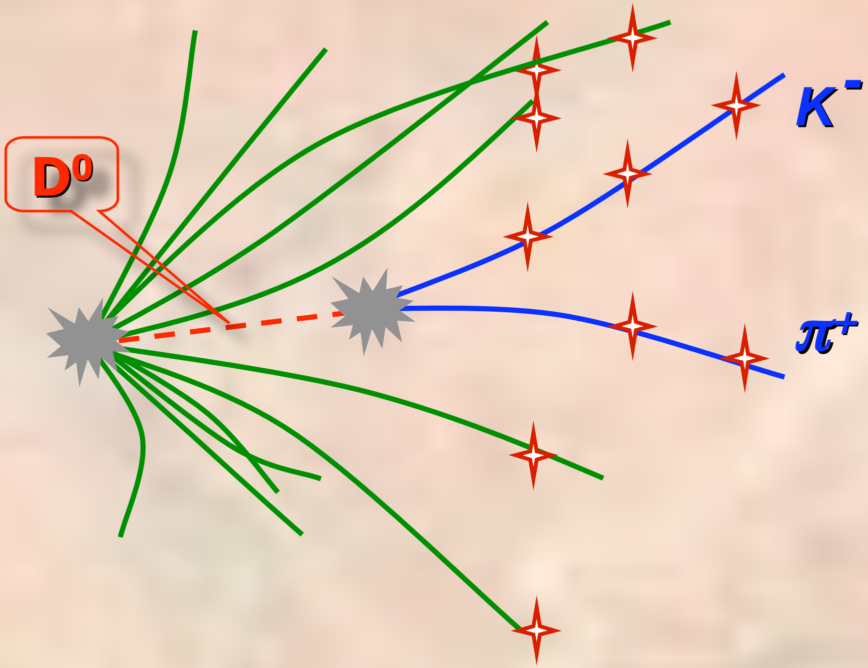
All Set (Hits >10, P > .05)		Reference Set (All Set + P>1.)		Extra Set (All Set + P<1.)		10^3 events	
Eff	Clone	Eff	Clone	Eff	Clone	Ghost	Time [s]
97.4	**14.2**	**99.5**	**0.00**	**97.17**	**15.3**	**6.8**	**0.1**

CA+KF algorithm (sector view)



- No vertex constraint => physics, cosmics, beam gas, laser tracks…
- Simple code, small memory => Cell, GPU,…
- 3D track model $r_{[8]} = (x, y, z, p_x, p_y, p_z, q/P)$

Reconstruction of vertices and decayed particles



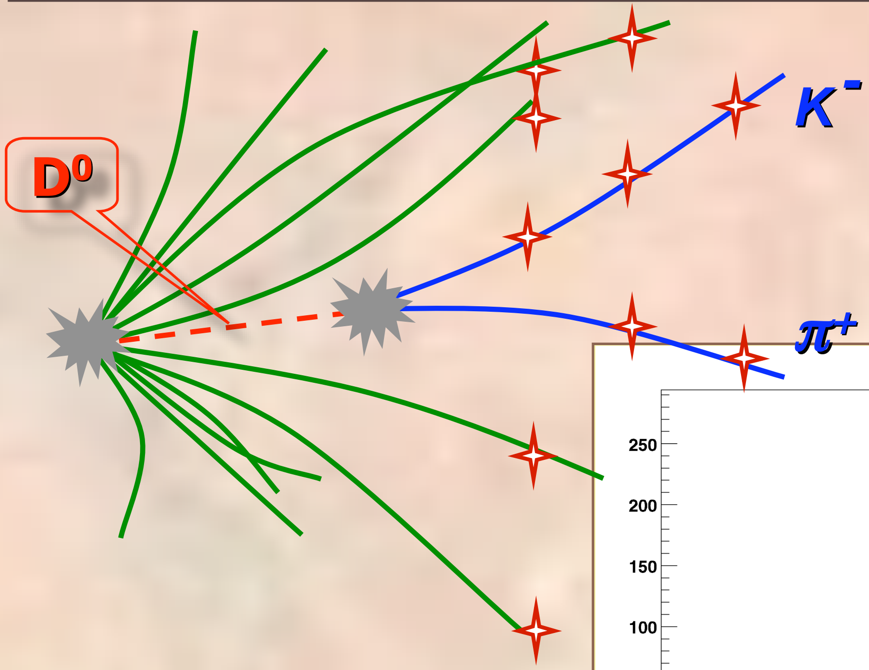
KFParticle: particle parameters

$$r_{[8]} = (x\ y\ z,\ p_x\ p_y\ p_z,\ E,\ S(=L/p))$$

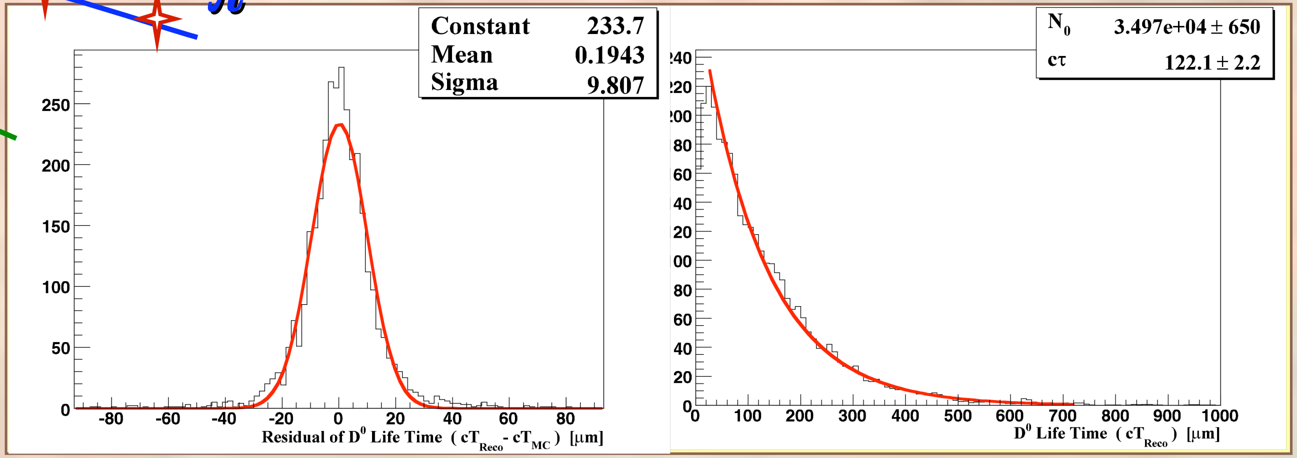
with full covariance matrix $C_{[8\times8]}$

- Physical track model for mother [D^0] and daughters [π^+, K^-]
- State vector contains all the particle parameters both at decay and production vertices
- Algorithm is suitable for vertex fit (including primary vertex fit)
- User friendly interface: *class* ***CbmKFParticle / AliKFParticle*** *;*

CbmKFParticle performance for D^0 fit in CBM

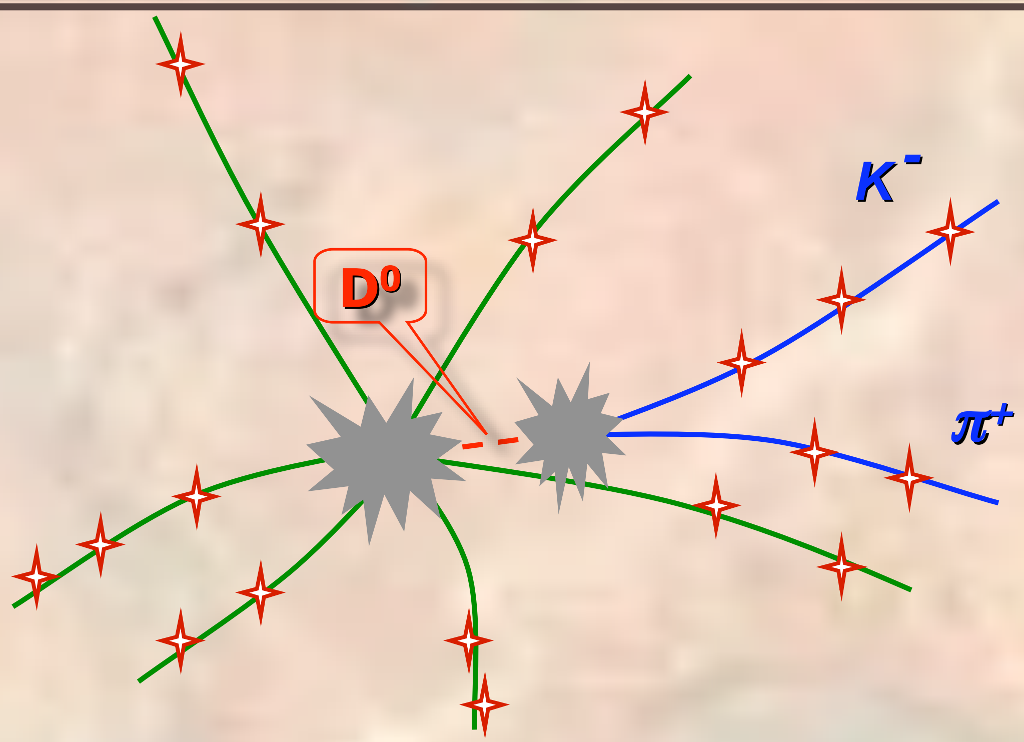


- Fixed target geometry
- Non-uniform magnetic field
- ~500 primary tracks



10^6 events	Production Vertex [μm]			Decay Vertex [μm]			Physical Parameters			
	x	y	z	x	y	z	P [%]	M [MeV/c]	L [μm]	cT [μm]
Accuracy	0.81	0.73	5.50	2.64	2.64	63.88	0.79	11.34	64.10	9.81
Pull	1.14	1.10	1.11	1.13	1.13	1.10	1.20	1.19	1.11	1.11

AliKFParticle performance for D^0 fit in ALICE



- Collider geometry
- Uniform magnetic field
- ~5 primary tracks

V^0 fit time: 50 μs => HLT

10^6 events	Production Vertex [μm]			Decay Vertex [μm]			Physical Parameters			
	x	y	z	x	y	z	P [%]	M [MeV/c]	L [μm]	cT [μm]
Accuracy	49.07	48.79	67.42	75.41	75.03	88.6	0.75	9.9	165.5	100.4
Pull	0.95	0.95	0.98	0.92	0.92	0.97	0.92	0.94	0.93	0.93

CbmKFParticle = AliKFParticle => same code!

Summary

- **Developed and implemented:**
  - ✓ The Kalman filter utilities for CBM reconstruction [σP = 1.2%]
  - ✓ Fast SIMDized Kalman filter for CBM on-line reconstruction [1.6 μs / 0.1 μs]
  - ✓ CA+KF tracker for CBM [Eff = 97%, 78 ms / 5 ms]
  - ✓ CA+KF tracker for ALICE HLT [Eff = 99%, 100 ms]
  - ✓ Reconstruction of decayed particles for CBM and ALICE [σcT= 9.8 μm/100 μm, 50 μs]

- **Related publications :**
  - S.Gorbunov, I.Kisel, Analytic formula for track extrapolation in non-homogeneous magnetic field, NIM A 559, (2006)
  - S.Gorbunov, U.Kebschull, I.Kisel, V.Lindenstruth, W.F.J.Müller, Fast SIMDized Kalman filter based track fit, CPC, (2007)
  - S.Gorbunov, I.Kisel, Primary vertex fit based on the Kalman filter, CBM-SOFT-note-2006-001, (2006)
  - S.Gorbunov, I.Kisel, Secondary vertex fit based on the Kalman filter, CBM-SOFT-note-2006-002, (2006)
  - S.Gorbunov, I.Kisel, Reconstruction of decayed particles based on the Kalman filter, CBM-SOFT-note-2007-003, (2007)
  - S.Gorbunov, I.Kisel, I.Vassiliev, Analysis of D0 detection in Au+Au collisions at 25 AGeV, CBM-PHYS-note-2005-001, (2005)
  - S.Gorbunov, I.Kisel, Elastic net for stand-alone RICH ring finding, NIM A 559, (2006)

- **Future plans (ALICE HLT):**
  - ➢ Track fit investigation
  - ➢ Speed up and SIMDization
  - ➢ Run the reconstruction core on the Cell processor and GPU
  - ➢ Test on heavy ion events