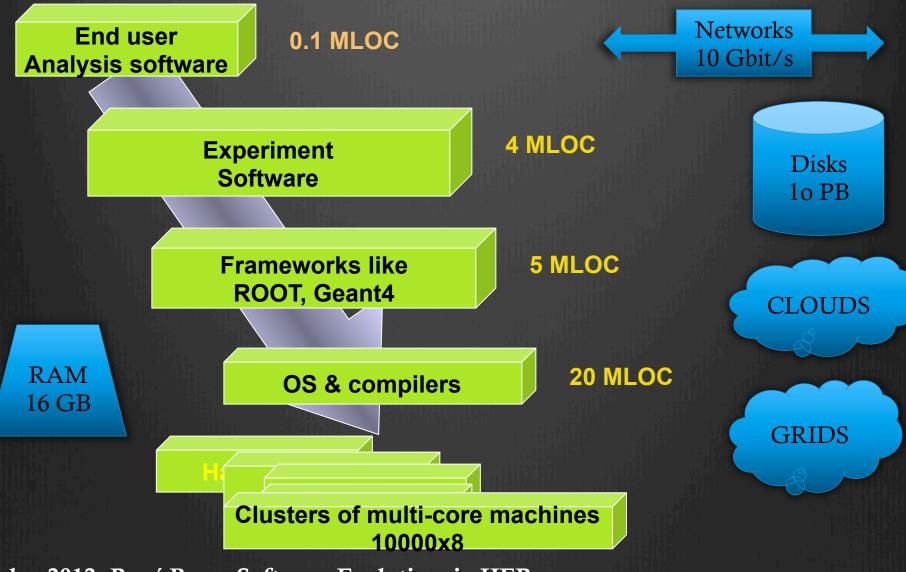
Simulation and reconstruction software for the CBM experiment

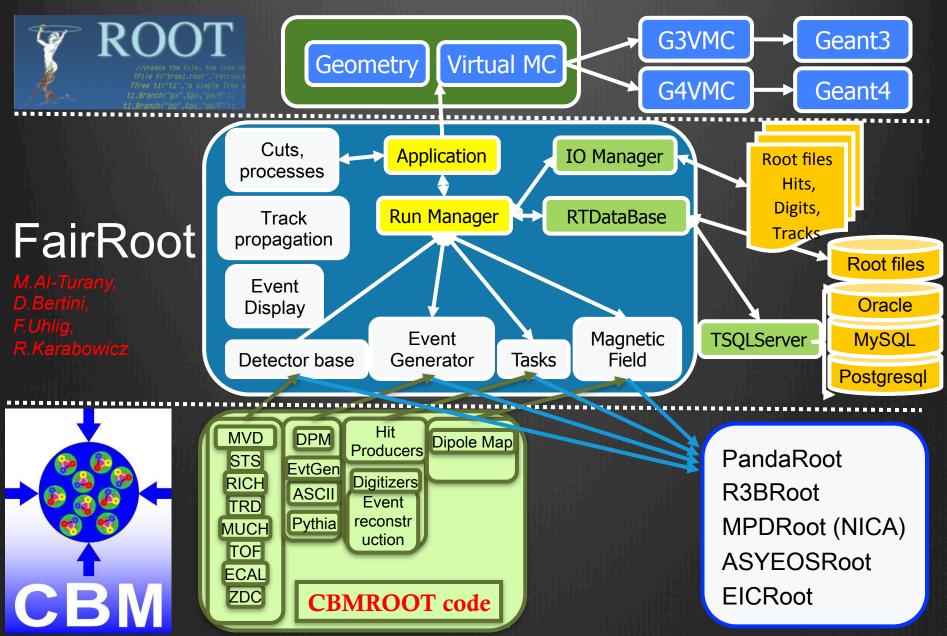
Andrey Lebedev for the CBM collaboration LIT JINR and IKF Frankfurt University

Systems today

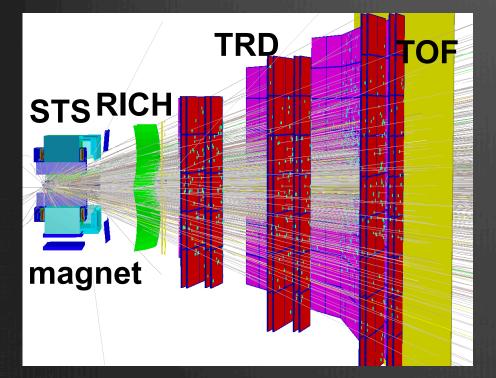


chep2012: René Brun: Software Evolution in HEP

FAIRROOT/CBMROOT



CBM experiment



Alternatively, muon measurements are foreseen by replacing RICH detector with muon detector MUCH.

Event reconstruction challenges:

 ✓ Large track and ring densities and multiplicities: up to 1000 charged particles per reaction in +/-25° of acceptance
 ✓ Reaction rate up to 10 MHz
 ✓ Fast reconstruction algorithms are essential: radical speedup, optimization and parallelism

Event Reconstruction in CBM

- Sevent reconstruction in CBM include the following tasks:
 - clustering and hit finding algorithms in MVD, STS, TRD, MUCH, TOF...
 - Itrack reconstruction and track fit in MVD, STS, TRD, MUCH, TOF, global tracking
 - RICH ring finding and fitting
 - electron identification in RICH, TRD...
 - Primary and secondary vertex finding and fitting
 - Calibration

 (\mathbf{x})

. . .

Global tracking

Global tracking: finding of tracks in downstream detectors – TRD, MUCH, TOF... and merging different track segments.

Track finding:

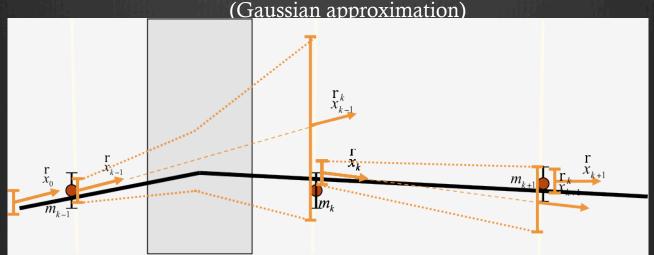
- ✓ Kalman Filter
- Track following method
- ✓ Validation gate calculation
- ✓ Hit-to-track association:
 - nearest neighbor: attaches the closest hit from validation gate
 - branching: creates
 branch for each hit in
 validation gate

rack propagation

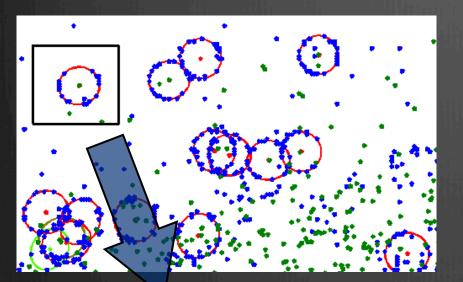
- Solution of equation of motion with 4th order Runge-Kutta method in inhomogeneous magnetic field OR straight line in field free regions
- Large material budget: Energy loss (ionization: Bethe- Bloch, bremsstrahlung: Bethe-Heitler); Multiple scattering (Gaussian approximation)

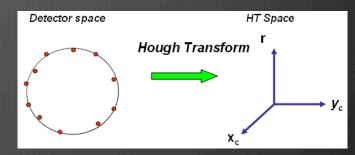
Frack selection

- ✓ aim: remove clone and ghost tracks
- tracks are sorted by their quality, obtained by chi-square and track length
- \checkmark check for shared hits

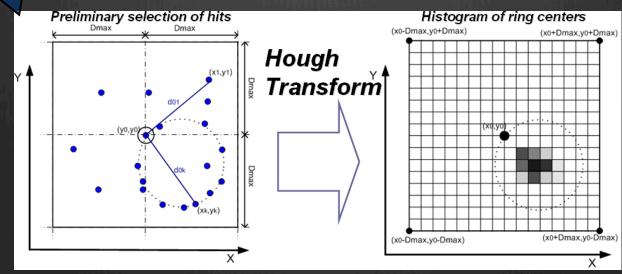


RICH reconstruction





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



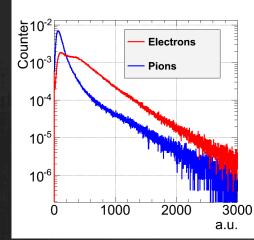
7

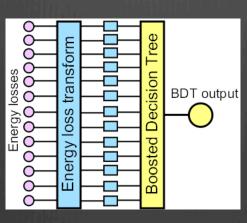
Electron identification in TRD

Problems:

• Long tail of Landau distribution for π .

✓ Using only standard cuts is not enough -> advanced methods were implemented, which allow to reach pion suppression 200-500 at 90% electron efficiency.





8

Methods

- ✓ Likelihood
- ✓ Artificial Neural Network (ANN)
- ✓ Ordered statistics (mediana)
- ✓ Boosted Decision Tree (BDT)

Method	π supp.
BDT	660
ANN	530
Likelihood	170
Mediana	140
Cut on ΣEi	5

Energy loss transform:

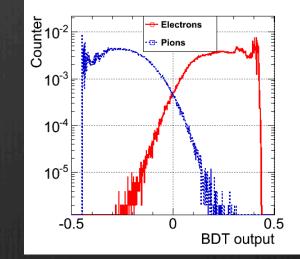
✓ Prepare PDF for ordered energy losses

✓ Sort energy losses

✓ Calculate likelihood ratio for each energy loss: $L = PDF\pi / PDF\pi + PDFe$

Evaluate probability using BDT:

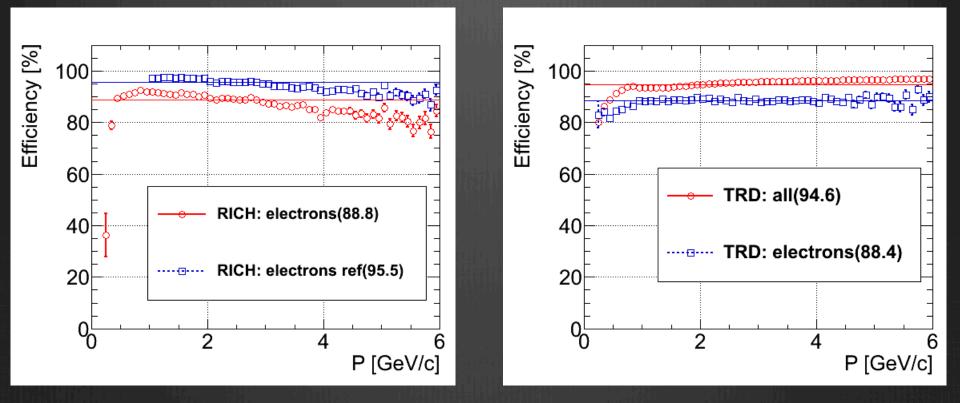
- \checkmark Boosted decision tree (BDT) classifier from TMVA
- ✓ Transformation is very important step for classifiers training



Tracking efficiency

RICH rings reconstruction efficiency

TRD tracks reconstruction efficiency



Simulation: 200k UrQMD events at 25 AGeV Au-Au collisions and ω meson decaying into e+e- embedded in each event.

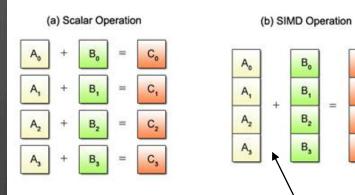
Parallel calculations

• SIMD – Single Instruction Multiple Data

- CPU's have it!
- o Today: SSE 128 bit registers
 - 4 x float
- Future: AVX
 - AVX: 8 x float
- Benefits:
 - X time more operations per cycle
 - X time more memory throughoutput

Multithreading

Many core era coming soon...
 Tool for CPU: Threading Building Blocks



4 concurrent add operations

C,

C,2

C.,

Optimization of the algorithms

• Minimize access to global memory by approximating magnetic field map: polynomial or grid

 Simplification of the detector geometry to reduce the number of detector nodes and improve the geometry navigation

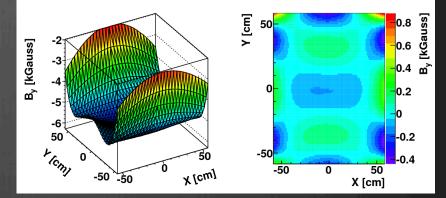
Computational optimization of the Kalman
 Filter

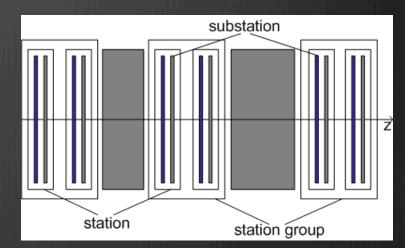
From double to float

 Implicit calculation on non-trivial matrix elements

○ Loop unrolling

 Branches (if then else ..) have been eliminated





All these steps are necessary to implement SIMD tracking

11

Speedup results

- Track fitting and track find performance is the same
- Significant speedup factor of the track fitting and finding algorithms is achieved

	Track fit	tting	Track finding			
	Time [µs/track]	Speedup	Time [ms/event]	Speedup		
Initial	1200		730			
Optimization	13	92	7.2	101		
SIMDization	4.4	3	4.8	1.5		
Multithreading	0.5	8.8	1.5	3.3		
Final	0.5	2400	1.5	487		

Automatization of SW testing

Motivation:

- More reliable software
- Reduce development cycles
- Continues integration and deployment
- High code coverage:
 - Ideally all code in the repository has to be tested
- Not only unit testing but also system test for simulation and reconstruction!
- Developing a good automatized test suite may be as much work as the development of the system itself or even more.
- Unified QA tool for event reconstruction:
 - Report generation: HTML, text, Latex;
 - Report generation for simulation studies;
 - Automatic check of output results based on predefined values;
 - Nightly monitoring of the simulation results;
 - Designed to be modular:
 - Easy to extend and add new histograms;

QA general structure

14

Histogram creator Performance calculator

Histogram manager

Drawer Feature extractor Report generator Result checker

Images JSON/XML Report in HTML, text, Latex

- Management of large number of histograms;
- Value object;
- Read/Write histograms from/to file;
- Get histograms using regular expressions;
- Lots of utility functions;
- Base classes for simulation and study report generation;
- Base functionality for histogram drawing;
- Base functionality for serializing/ deserializing to/from XML/JSON
 - Very useful and save a lot of time;
 Much less code, especially when histograms has to be created dynamically, for example, based on the detector setup;

QA report

One simulation trd v11c smearing branch

			Q		
	FAVORITES	Name	Date Modified	Size	Kind
	All My Files	clustering_qa_check.json	May 19, 2012 2:07 AM	593 bytes	Plain Text
		clustering_qa_much_hits_station.eps	May 19, 2012 2:07 AM	6 KB	EncaptScript
	P AirDrop	clustering_qa_much_hits_station.png	May 19, 2012 2:07 AM	7 KB	Portabimage
	Applications	clustering_qa_mvd_hits_station.eps	May 19, 2012 2:07 AM	6 KB	EncaptScript
	Desktop	clustering_qa_mvd_hits_station.png	May 19, 2012 2:07 AM	7 KB	Portabimage
	Documents	clustering_qa_sts_hits_station.eps	May 19, 2012 2:07 AM	7 KB	EncaptScript
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	😭 andrey	📄 clustering_qa.json	May 19, 2012 2:07 AM	616 bytes	Plain Text
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	SHARED	clustering_qa.txt	May 19, 2012 2:07 AM	1 KB	Plain Text
- -		📄 fit_qa_check.json	May 19, 2012 2:07 AM	8 KB	Plain Text
Latex	Alexander	fit_qa_sts_first_param.eps	May 19, 2012 2:07 AM	73 KB	EncaptScript
Latta	benbg009	fit_qa_sts_first_param.png	May 19, 2012 2:07 AM	45 KB	Portabimage
	Bengt's Mac	fit_qa_sts_last_param.eps	May 19, 2012 2:07 AM	73 KB	EncaptScript
	Carsten Pre	fit_qa_sts_last_param.png	May 19, 2012 2:07 AM	44 KB	Portabimage
Text		fit_qa_trd_first_param.eps	May 19, 2012 2:07 AM	73 KB	EncaptScript
ICAL	🔝 Denis Berti	fit_qa_trd_first_param.png	May 19, 2012 2:07 AM	45 KB	Portabimage
10	DViMac7	fit_qa_trd_last_param.eps	May 19, 2012 2:07 AM	76 KB	EncaptScript
ICON	Entfernter B	fit_qa_trd_last_param.png	May 19, 2012 2:07 AM	44 KB	Portabimage
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	au Au	🛅 fit_qa.json	May 19, 2012 2:07 AM	10 KB	Plain Text
	DEVICES	fit_qa.tex	May 19, 2012 2:07 AM	3 KB	Document
	📃 Andrey's iMac	fit_qa.txt	May 19, 2012 2:07 AM	8 KB	Plain Text
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			ue									
GlobalTrack	s.mean	610										
RichProjecti	ions.mea	n 610										
RichRings.m	nean	42										
StsTracks.n	nean	610										
IndTracks.n	nean	481										
Number o			d fake			ks and rin	gs					
Rich 19.32		4.31	0.789		211							
Sts 7.49	7.35		0.976		0238							
	10.54		0.945		0549							
racking												
		All			Prima	ary	Seconda	iry	Reference	e	Electron	

StsTrdTof (StsTrdTof)	77.7(286.6/368.9)	81.1(251.6/310)	59.5(35/58.8)	82.4(221/268.3)	73.9(10.1/13.7)
StsTrd (StsTrdTof)	86.6(319.3/368.9)	90(279.2/310)	68.3(40.2/58.8)	90.5(242.9/268.3)	87.1(11.9/13.7)
StsTrd (StsTrd)	85.5(355.9/416.3)	88.9(312/350.8)	67(43.9/65.5)	89.6(269.1/300.3)	86.9(12/13.8)
Sts (StsTrdTof)	92.7(342/368.9)	96.2(298.2/310)	74.6(43.9/58.8)	96.1(257.9/268.3)	98(13.4/13.7)
Sts (StsTrd)	92.7(386.1/416.3)	96.2(337.5/350.8)	74.1(48.5/65.5)	96.2(288.8/300.3)	98(13.5/13.8)
Sts (Sts)	87.5(601/687.2)	94.3(517.7/548.8)	60.2(83.4/138.4)	95.9(371/386.8)	97.6(14/14.4)
Tof (StsTrdTof)	89.7(286.6/319.3)	90.1(251.6/279.2)	87.1(35/40.2)	91(221/242.9)	84.8(10.1/11.9)
Trd (StsTrd)	92.2(355.9/386.1)	92.4(312/337.5)	90.4(43.9/48.5)	93.2(269.1/288.8)	88.7(12/13.5)

Tracking efficiency

00

		AllReference		ElectronReference		PionReference
Rich (Rich)	58.6(33/56.4)	83.8(12.3/14.6)	84.1(11.3/13.4)	90.6(10.9/12)	19.7(2.2/11.4)	53.3(1.5/2.8)
StsRichTrdTof (StsRichTrdTof)	42.3(13.4/31.8)	62.3(8.6/13.7)	61.3(7.9/12.8)	65.6(7.6/11.6)	16.7(1.4/8.3)	44.5(0.97/2.2)
StsRichTrd (StsRichTrdTof)	49.4(15.7/31.8)	72.5(10/13.7)	72.1(9.3/12.8)	77.1(9/11.6)	18(1.5/8.3)	47.3(1/2.2)
StsRichTrd (StsRichTrd)	48.4(15.9/32.8)	72(10.1/13.9)	71.9(9.3/12.9)	76.9(9/11.7)	17.6(1.6/9)	46.9(1.1/2.3)
StsRich (StsRichTrdTof)	54.5(17.3/31.8)	79.9(11/13.7)	80(10.3/12.8)	85.7(10/11.6)	18.3(1.5/8.3)	48.2(1/2.2)
StsRich (StsRichTrd)	53.6(17.6/32.8)	79.6(11.1/13.9)	80.1(10.3/12.9)	85.8(10/11.7)	18(1.6/9)	47.9(1.1/2.3)
StsRich (StsRich)	52.4(17.9/34.2)	79.2(11.3/14.3)	79.8(10.4/13)	85.8(10.1/11.7)	18.3(1.8/10)	48.6(1.3/2.6)
Sts (StsRichTrdTof)	89(28.3/31.8)	98.6(13.5/13.7)	98.7(12.7/12.8)	98.9(11.5/11.6)	95.3(7.9/8.3)	96(2.1/2.2)
Sts (StsRichTrd)	89(29.2/32.8)	98.6(13.7/13.9)	98.7(12.8/12.9)	98.9(11.6/11.7)	95.4(8.5/9)	96(2.2/2.3)
Sts (StsRich)	89(30.5/34.2)	98.6(14.1/14.3)	98.7(12.9/13)	98.9(11.6/11.7)	95.1(9.5/10)	96.1(2.5/2.6)

Number of ghosts per event

Name	
RichElId	0

	Many	simulation	ns	
00	🛅 res	ults-21-05-2012		
		Q		
FAVORITES	Name	 Date Modified 	Size	Kind
All My Files	trd_v10b_clustering_branch	Today 12:12 PM		Folder
	trd_v10b_clustering_nn	May 19, 2012 7:28 AM		Folder
P AirDrop	trd_v10b_smearing_branch	May 19, 2012 3:32 AM		Folder
Applications	trd_v10b_smearing_nn	May 18, 2012 11:39 PM		Folder
Desktop	trd_v11c_clustering_branch	May 19, 2012 10:23 AM		Folder
Documents	trd_v11c_clustering_nn	May 19, 2012 5:53 AM		Folder
	trd_v11c_smearing_branch	May 19, 2012 2:07 AM		Folder
🕛 Downloads	trd_v11c_smearing_nn	May 18, 2012 10:58 PM		Folder
Movies	trd_v11d_clustering_branch	May 19, 2012 11:16 AM		Folder
J Music	trd_v11d_clustering_nn	May 19, 2012 6:37 AM		Folder
Pictures	trd_v11d_smearing_branch	May 19, 2012 2:48 AM		Folder
	trd_v11d_smearing_nn	May 18, 2012 11:16 PM		Folder
😭 andrey	trd_v12a_clustering_branch	May 19, 2012 5:52 PM		Folder
iTunes	trd_v12a_clustering_nn	May 19, 2012 11:32 AM		Folder
	trd_v12a_smearing_branch	May 19, 2012 6:11 AM		Folder
SHARED	trd_v12a_smearing_nn	May 19, 2012 1:21 AM		Folder
💻 Alexander	trd_v12b_clustering_branch	May 19, 2012 6:40 PM		Folder
💻 benbg009	trd_v12b_clustering_nn	May 19, 2012 12:15 PM		Folder
Bengt's Mac	trd_v12b_smearing_branch	May 19, 2012 6:48 AM		Folder
	trd_v12b_smearing_nn	May 19, 2012 1:41 AM		Folder
Carsten Pre	Image: trd v12c clustering branch	May 19, 2012 2:36 PM		Folder

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ot/macro/littrack/test/tracking_ga_study.htm

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C Qr Google

Easy to

interpret

results of

simulations!

many

Directories with simulation results

28 items, 393.15 GB avail

+ Offle:///Users/andrey/Deve

Tracking QA

DViMac7

🖳 All..

Entfernter B...

Number of events

v10b v11c v11d v12a v12b v12c v12d EventNo 500 500 500 500 500 500 500

Carsten Pre... Find trd_v12c_clustering_branch

trd_v12c_smearing_branch

Image: Image:

trd_v12d_smearing_branch

trd_v12c_smearing_nn

trd v12d clustering nn

Denis Berti...) Trd_v12c_clustering_nn

Number of objects per event

GlobalTracks.mean	611	610.6	611	610.3	610.6	610.7	611.4
RichProjections.mean	611	610.6	611	610.3	610.6	610.7	611.4
RichRings.mean	43.1	43	42.4	43.1	43	42.8	43.1
StsTracks.mean	611	610.6	611	610.3	610.6	610.7	611.4
TrdTracks.mean	501.5	477.3	491	471.1	470.9	478.6	475.1

Number of all, true and fake hits in tracks and rings

Rich:All.mean	19.3	19.3	19.4	19.3	19.2	19.3	19.2
Rich:Fake.mean	4.2	4.3	4.2	4.3	4.3	4.2	4.2
Rich:FakeOverAll.mean	0.21	0.21	0.21	0.21	0.21	0.21	0.21
Rich:True.mean	15.5	15.5	15.7	15.5	15.5	15.6	15.4
Rich:TrueOverAll.mean	0.79	0.79	0.79	0.79	0.79	0.79	0.79
Sts:All.mean	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Sts:Fake.mean	0.65	0.65	0.65	0.65	0.64	0.65	0.65
Sts:FakeOverAll.mean	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Sts:True.mean	7.3	7.3	7.3	7.3	7.3	7.3	7.3
Sts:TrueOverAll.mean	0.98	0.98	0.98	0.98	0.98	0.98	0.98
Trd:All.mean	11	10.9	10.8	8.8	8.8	7.7	7.7
Trd:Fake.mean	0.92	0.91	0.9	1.6	1.6	1.2	1.1
Trd:FakeOverAll.mean	0.047	0.046	0.046	0.15	0.15	0.11	0.097
Trd:True.mean	10.6	10.5	10.4	7.8	7.8	7	7.1
Trd:TrueOverAll.mean	0.95	0.95	0.95	0.85	0.85	0.89	0.9

Number of ghosts

15

RichElId	0	0	0	0	0	0	0
RichStsMatching	2.2	2.2	2.2	2.3	2.1	2.2	2.1
Rich	8.5	8.7	8.3	8.7	8.5	8.4	8.6
StsRichMatching	0.11	0.092	0.092	0.1	0.078	0.086	0.054
Sts	8.4	8.3	8.7	8.2	8.4	8.3	8.7
Trd	21.7	19.5	19.7	57.6	57.1	37.1	31.9

Tracking efficiency with RICH

84.3(12.4/14.7) 83.8(12.3/14.6) 84.3(12.5/14.8) 83(12.3/14.8) 84.6(12.4/14.6) 84.2(12.6/14.9) 84.4(12.4/14.6)

QA monitoring

- Motivation:
 - Automatic testing of simulation, reconstruction and analysis
 - Automatic check of simulation results
- About 30 tests run nightly
 - Increase number of test: different collision systems, energies, detector geometries

Run simulation, reconstruction and QA as CDASH tests

Generate HTML report for each test and summary report

Copy resulting HTML reports to a web server

QA monitoring web server: http://www-linux.gsi.de/~andrey/wwwqa/

Summary

- Fast and efficient event reconstruction algorithms are essential for the CBM experiment
 - Optimization and parallelization of the algorithms in order to achieve the requirements
- Developing an automatized reliable testing suit is extremely important for software development
- CBM group in the Laboratory of Information Technologies plays significant role in the development of the event reconstruction algorithms and software for the CBM experiment