Simulation and reconstruction software for the CBM experiment

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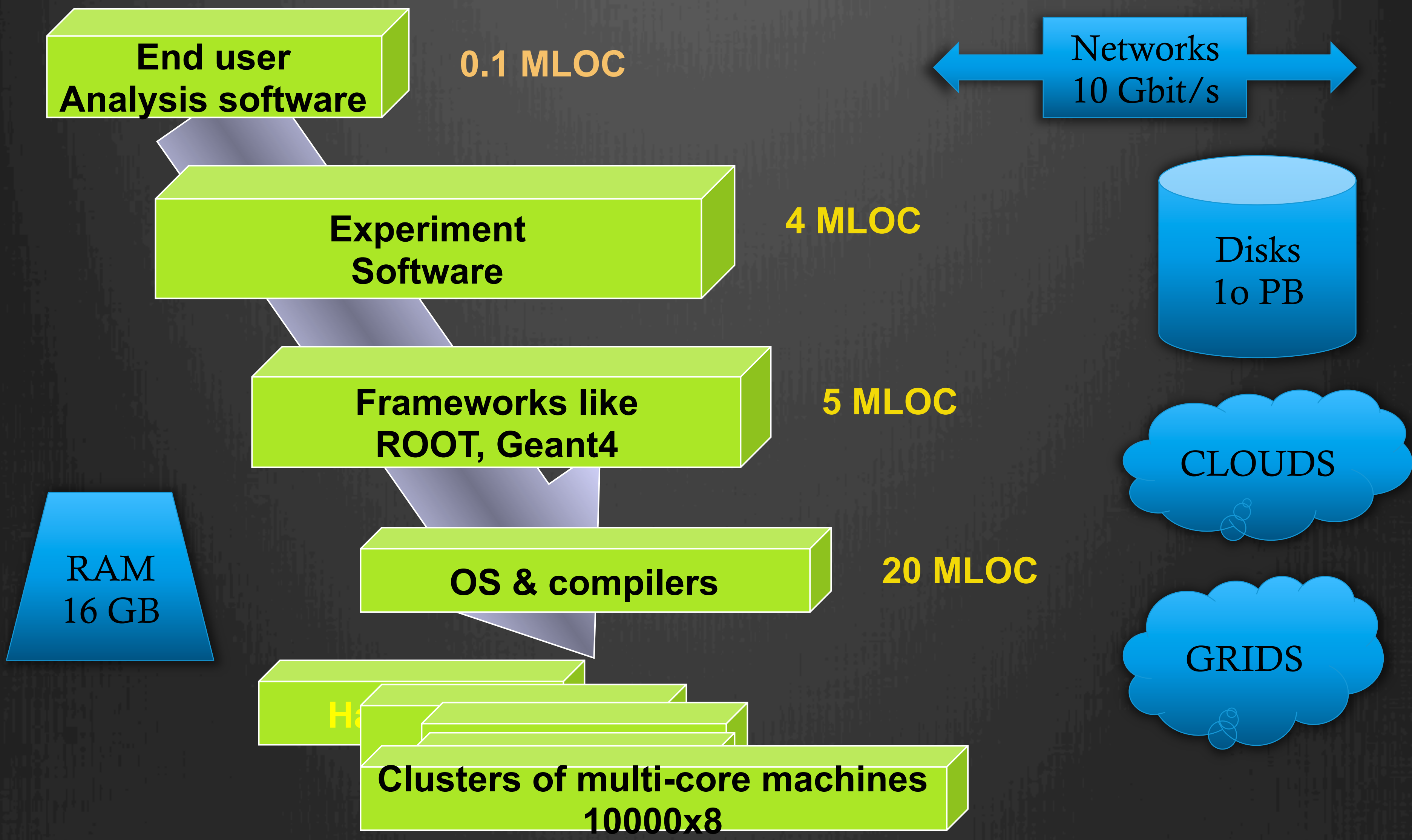
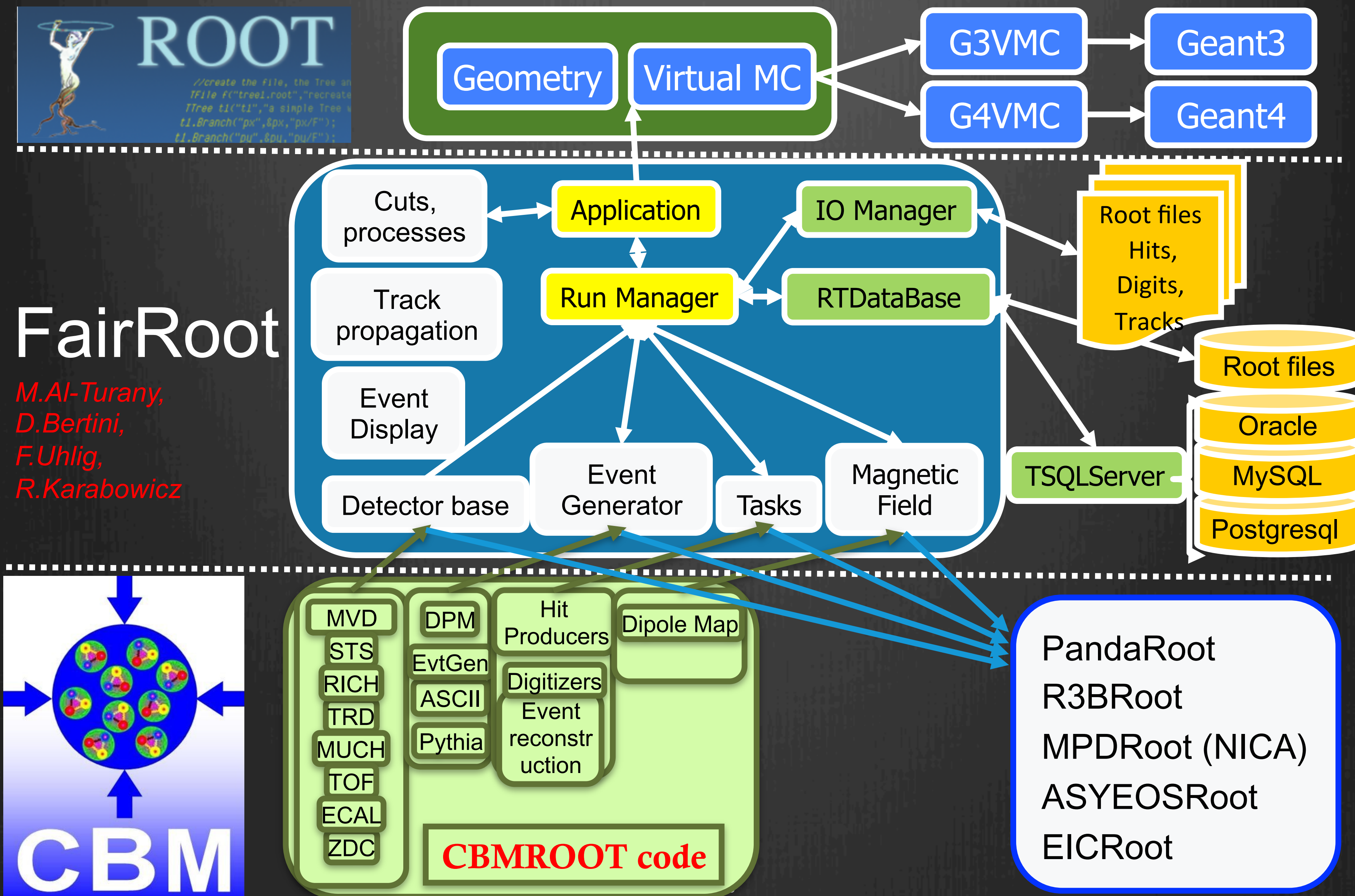
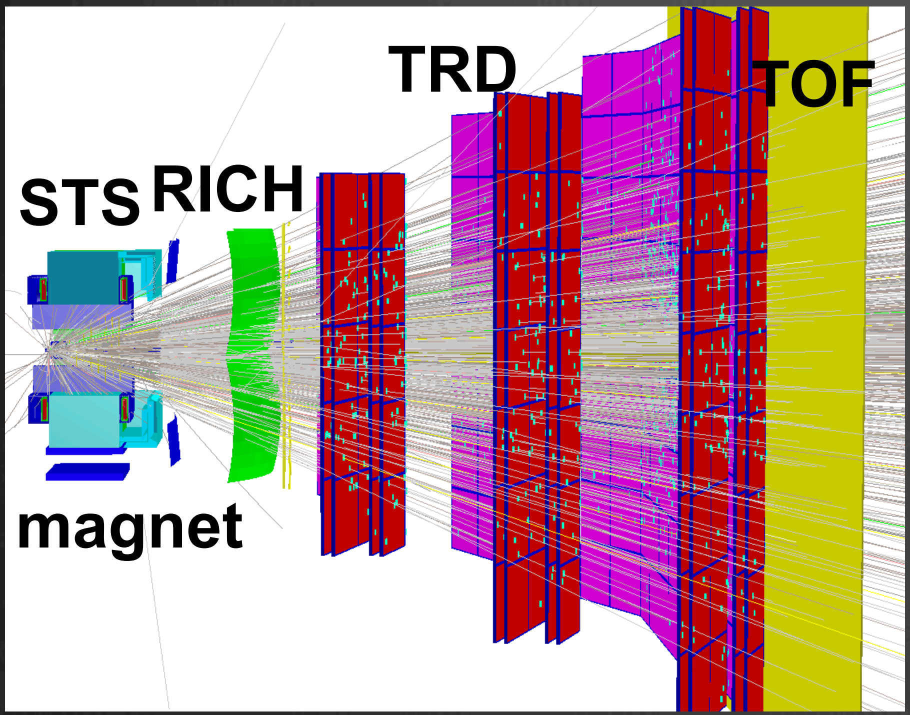
Systems today



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

- Event reconstruction in CBM include the following tasks:
  - clustering and hit finding algorithms in MVD, STS, TRD, MUCH, TOF…
  - track 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
  - …

Global tracking

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

Track finding:

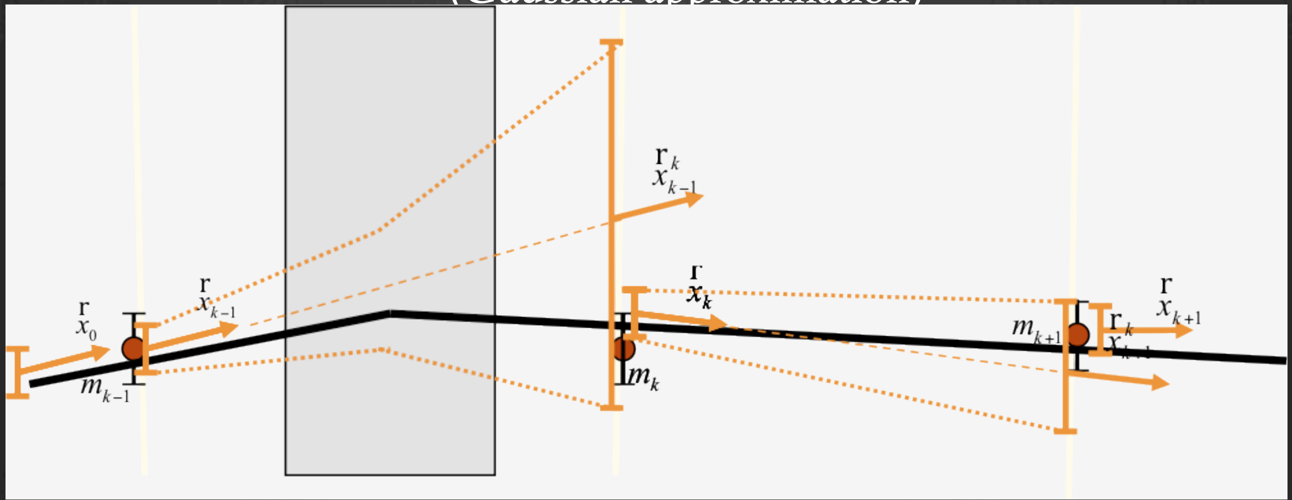
- ✓ Kalman Filter
- ✓ Track following method
- ✓ Validation gate calculation
- ✓ Hit-to-track association:
  - ➢ nearest neighbor: attaches the closest hit from validation gate
  - ➢ branching: creates branch for each hit in validation gate

Track propagation:

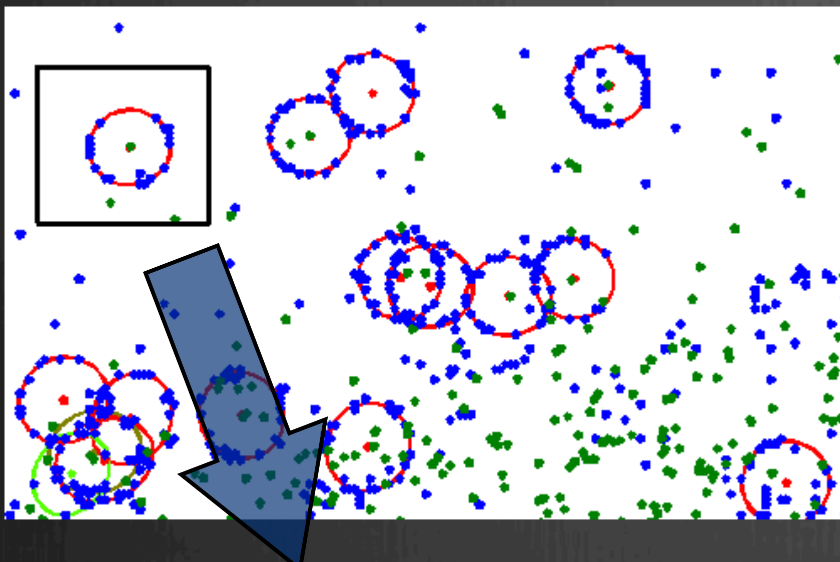
- ✓ Solution of equation of motion with 4th order Runge-Kutta method in inhomogeneous magnetic field OR straight line in field free regions
- ✓ Large material budget: Energy loss (ionization: Bethe- Bloch, bremsstrahlung: Bethe-Heitler); Multiple scattering (Gaussian approximation)

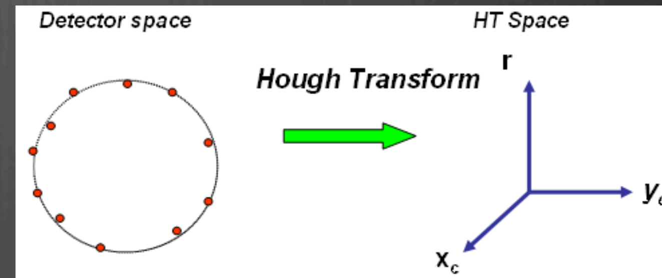
Track selection

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

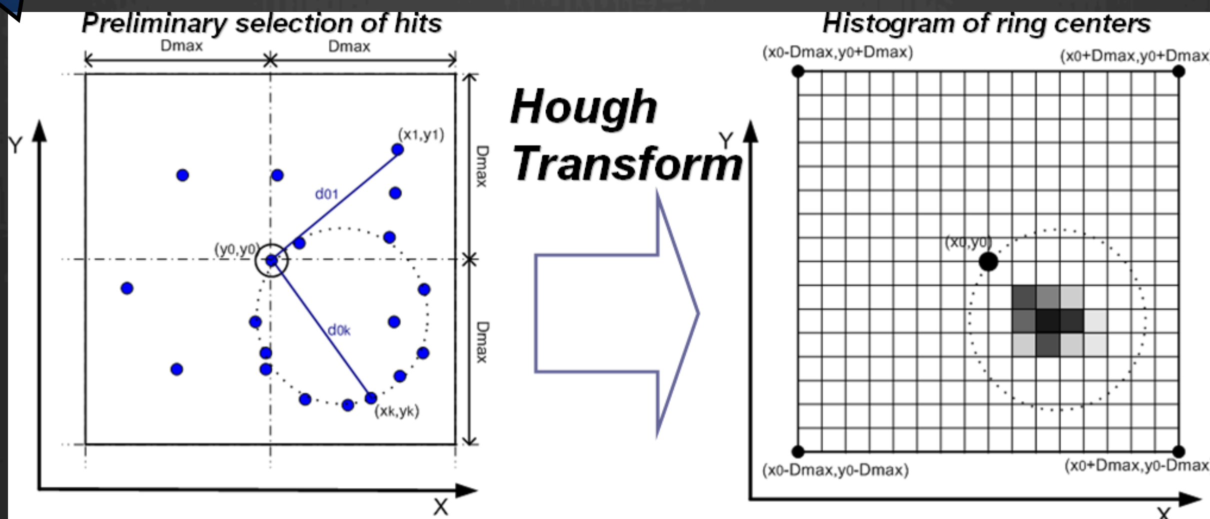


RICH reconstruction





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



Electron identification in TRD

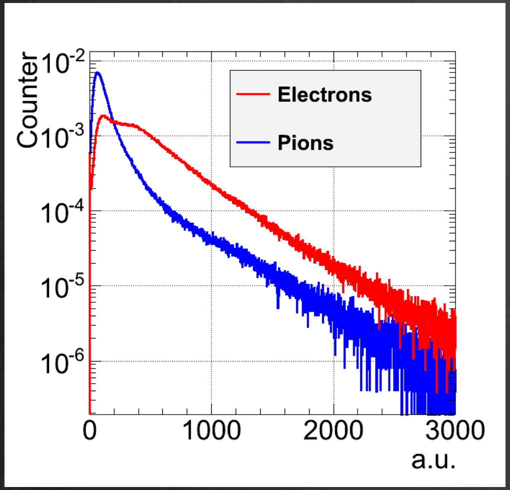
Problems:

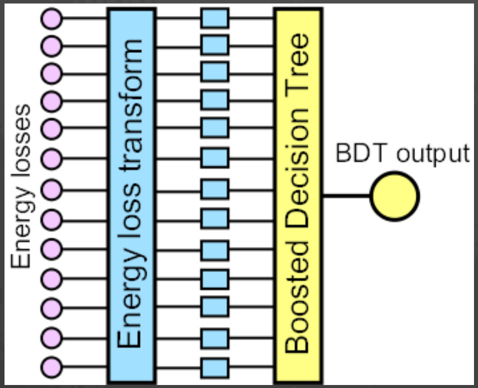
- ✓ Long tail of Landau distribution for π.
- ✓ Using only standard cuts is not enough -> advanced methods were implemented, which allow to reach pion suppression 200-500 at 90% electron efficiency.

Methods:

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

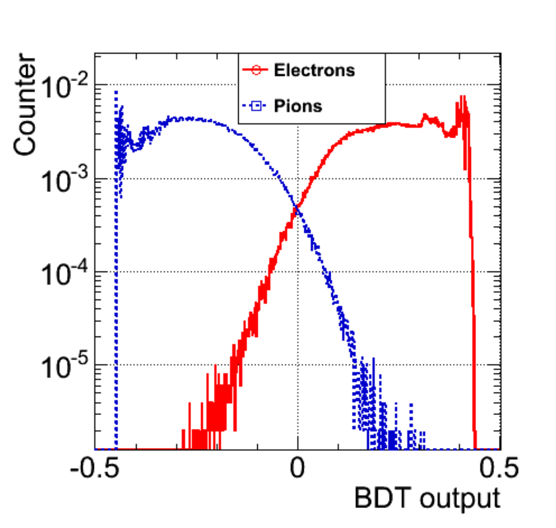
Method	π supp.
BDT	660
ANN	530
Likelihood	170
Mediana	140
Cut on Σ Ei	5





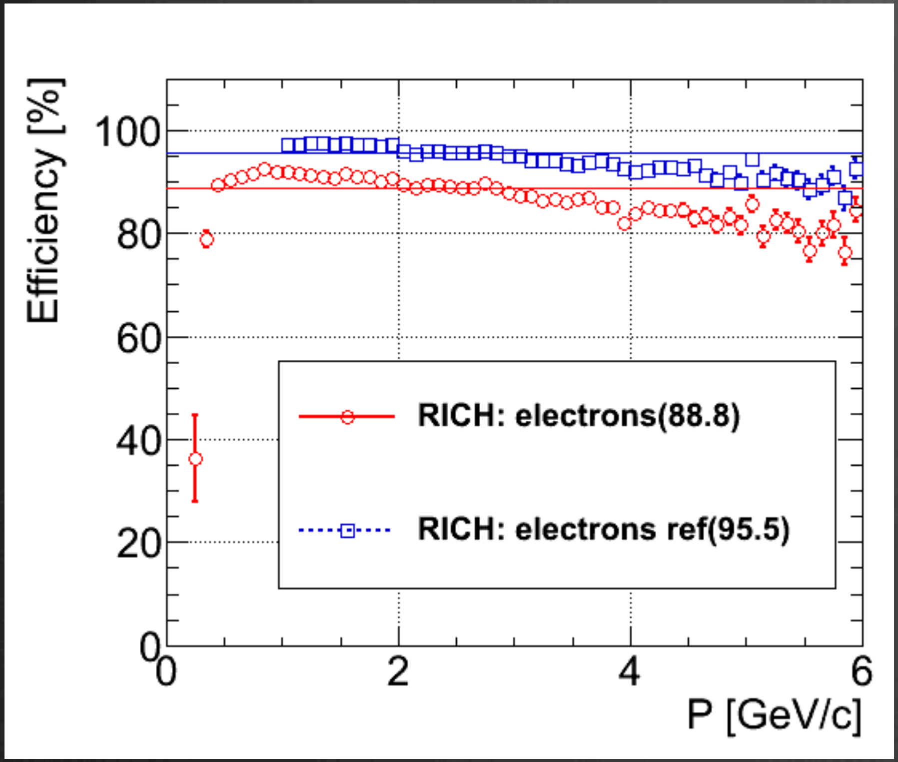
Energy loss transform:
- ✓Prepare PDF for ordered energy losses
- ✓Sort energy losses
- ✓Calculate likelihood ratio for each energy loss: L = PDFπ / PDFπ + PDFe

Evaluate probability using BDT:
- ✓ Boosted decision tree (BDT) classifier from TMVA
- ✓ Transformation is very important step for classifiers training

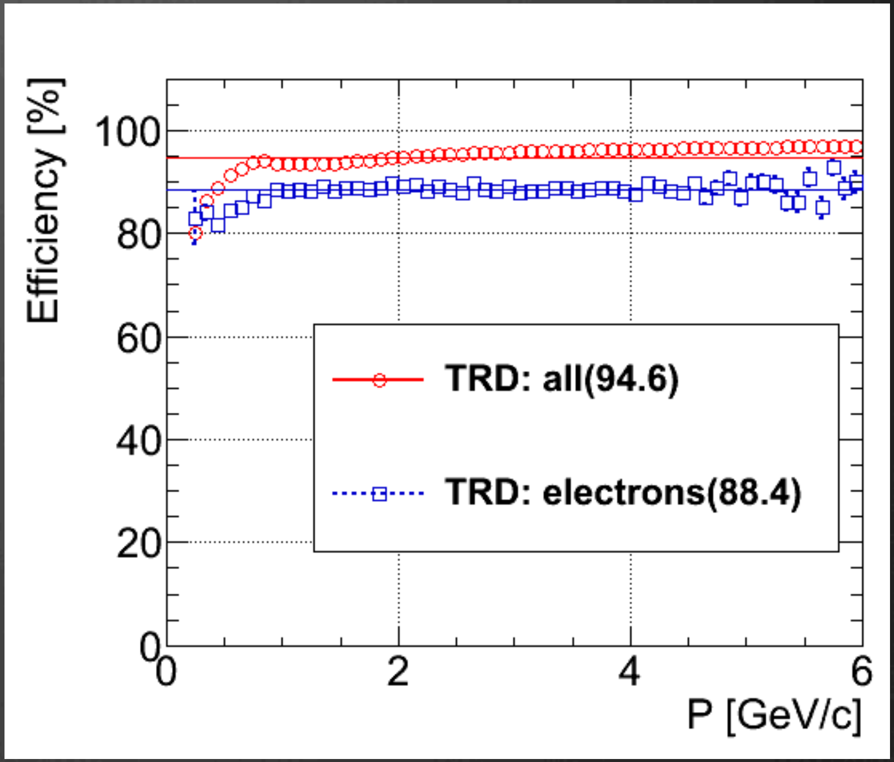


Tracking efficiency

RICH rings reconstruction efficiency



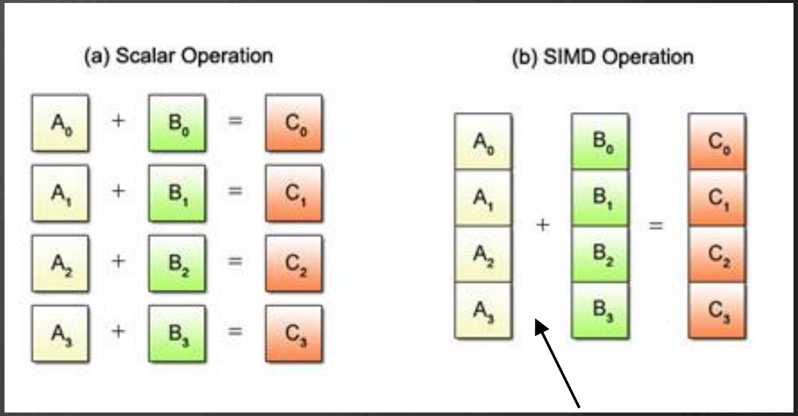
TRD tracks reconstruction efficiency



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

Parallel calculations

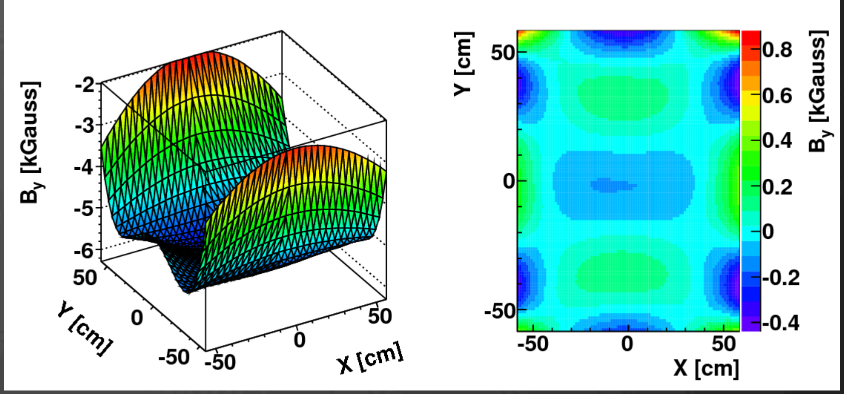
- SIMD – Single Instruction Multiple Data
  - CPU's have it!
  - **Today**: SSE - 128 bit registers
    - 4 x float
  - **Future**: AVX
    - AVX: 8 x float
  - Benefits:
    - X time more operations per cycle
    - X time more memory throughoutput
- Multithreading
  - Many core era coming soon…
  - Tool for CPU: Threading Building Blocks



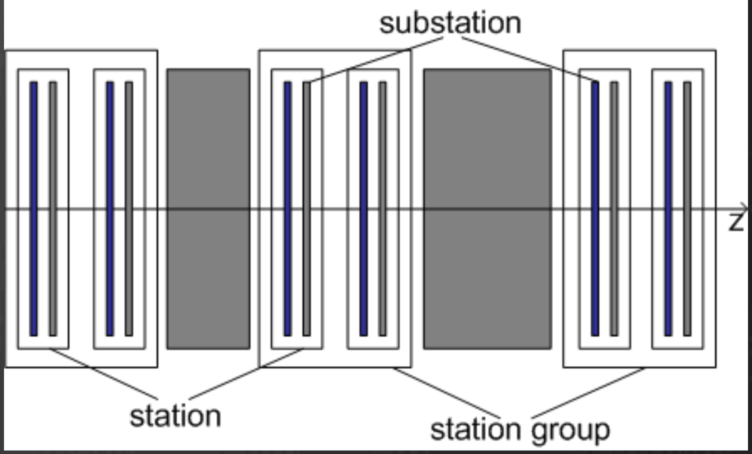
4 concurrent add operations

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

Speedup results

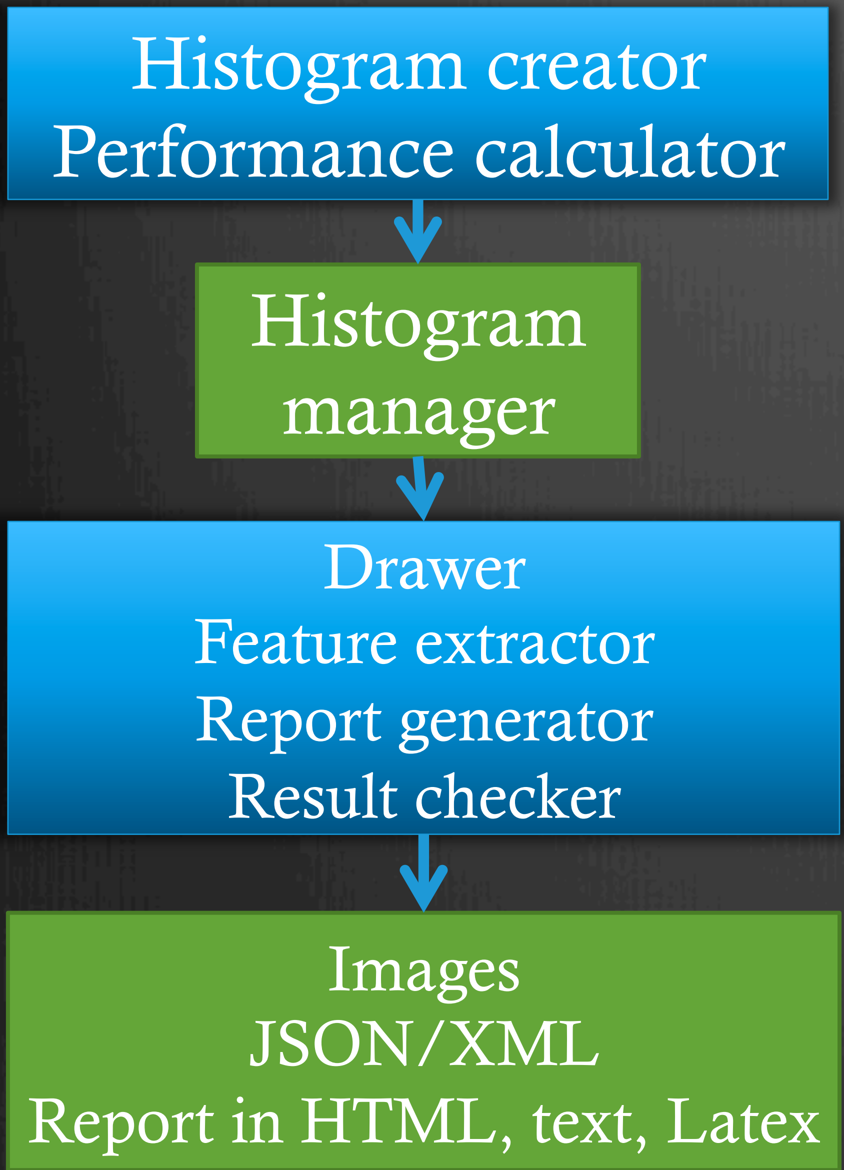
- Track fitting and track find performance is the same
- Significant speedup factor of the track fitting and finding algorithms is achieved

	Track fitting		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



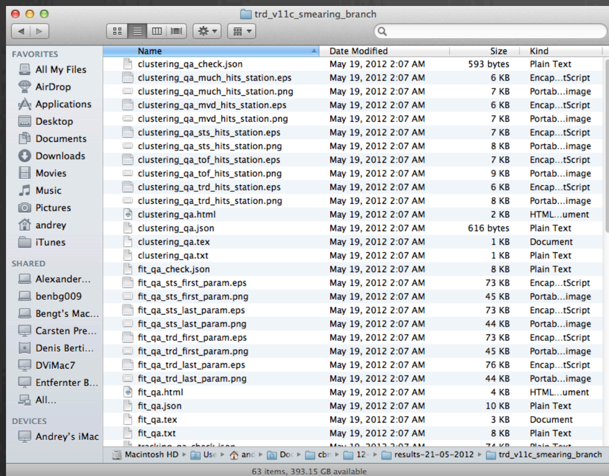
- Management of large number of histograms;
- Value object;
- Read/Write histograms from/to file;
- Get histograms using regular expressions;
- Lots of utility functions;

- 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;

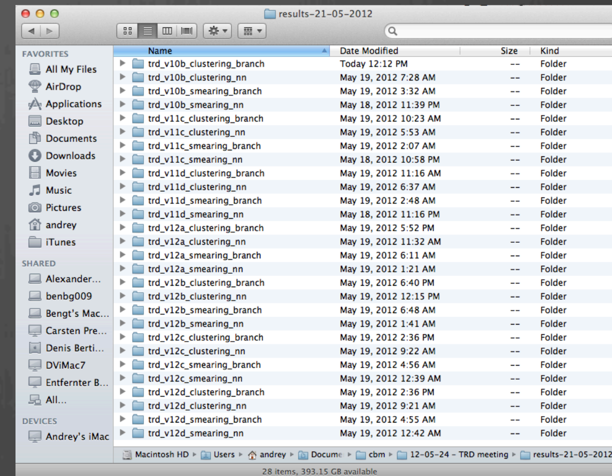
QA report

One simulation

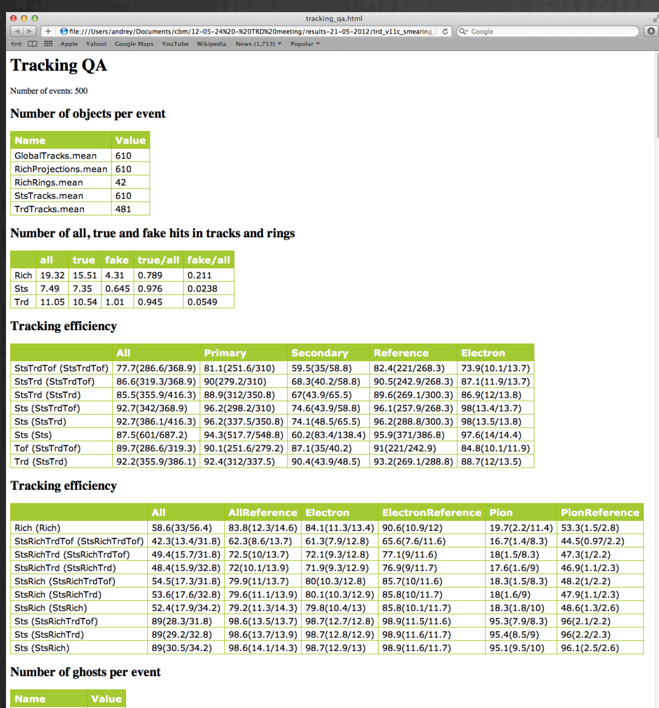


Images
HTML
Latex
Text
JSON
XML

Many simulations



Directories with simulation results



Tracking QA

Number of events: 500

Number of objects per event

Name	Value
GlobalTracks.mean	610
RichProjections.mean	610
RichRings.mean	42
StsTracks.mean	610
TrdTracks.mean	481

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

	all	true	fake	true/all	fake/all
Rich	19.32	15.51	4.31	0.789	0.211
Sts	7.49	7.35	0.645	0.976	0.0238
Trd	11.05	10.54	1.01	0.945	0.0549

Tracking efficiency

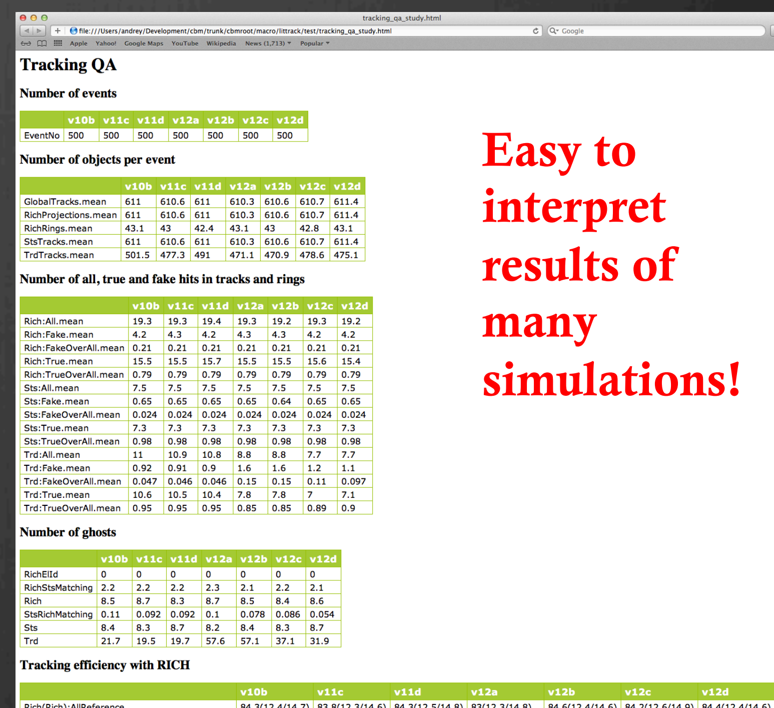
	All	Primary	Secondary	Reference	Electron
StsTrdTof (StsTrdTof)	77.7(286.6/368.9)	81.1(251.6/310)	59.5(35/58.8)	82.4(221/268.3)	73.9(10.1/13.7)
StsTrd (StsTrdTof)	86.6(319.3/368.9)	90(279.2/310)	68.3(40.2/58.8)	90.5(242.9/268.3)	87.1(11.9/13.7)
StsTrd (StsTrd)	85.5(355.9/416.3)	88.9(312/350.8)	67(43.9/65.5)	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

	All	AllReference	Electron	ElectronReference	Pion	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	Value
RichElId	0



Tracking QA

Number of events

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

Number of objects per event

	v10b	v11c	v11d	v12a	v12b	v12c	v12d
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

	v10b	v11c	v11d	v12a	v12b	v12c	v12d
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

	v10b	v11c	v11d	v12a	v12b	v12c	v12d
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

	v10b	v11c	v11d	v12a	v12b	v12c	v12d
Rich(Rich):AllReference	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)

Easy to interpret results of many simulations!

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