The optimisation of ALICE code

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January 19, 2012

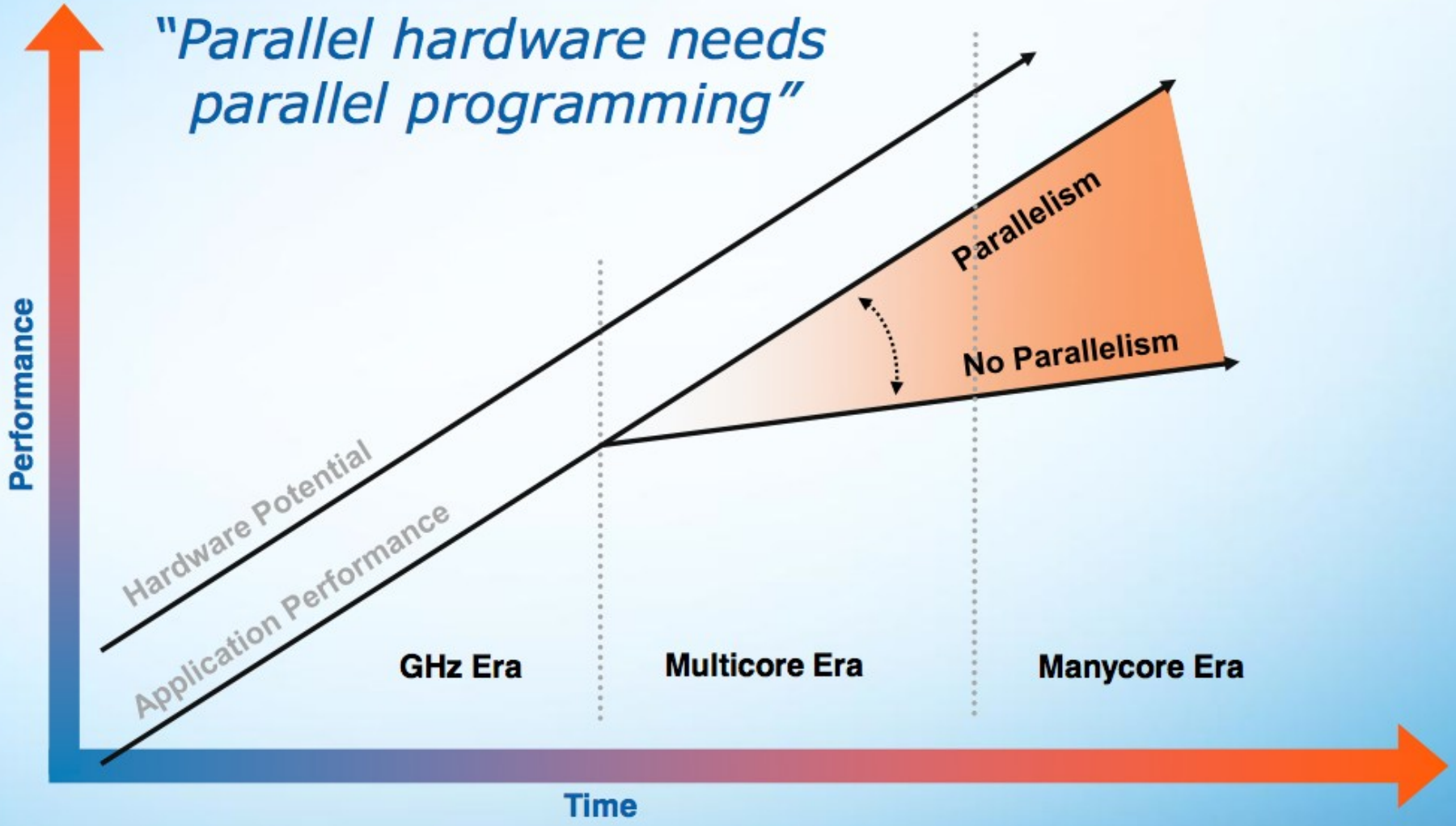
Rationale

- The HEP code
  - An embarrassing parallelism
  - An inextricable mix of branches / integer / float / double
  - A “flat” timing distribution – no “hot spots”
- We always got away with clock rate, now it is not possible any more
  - Parallelism is there to stay
- We cannot claim that we are resource-hungry and then exploit ~10%-50% of the hardware
  - Just think what it means in terms of money

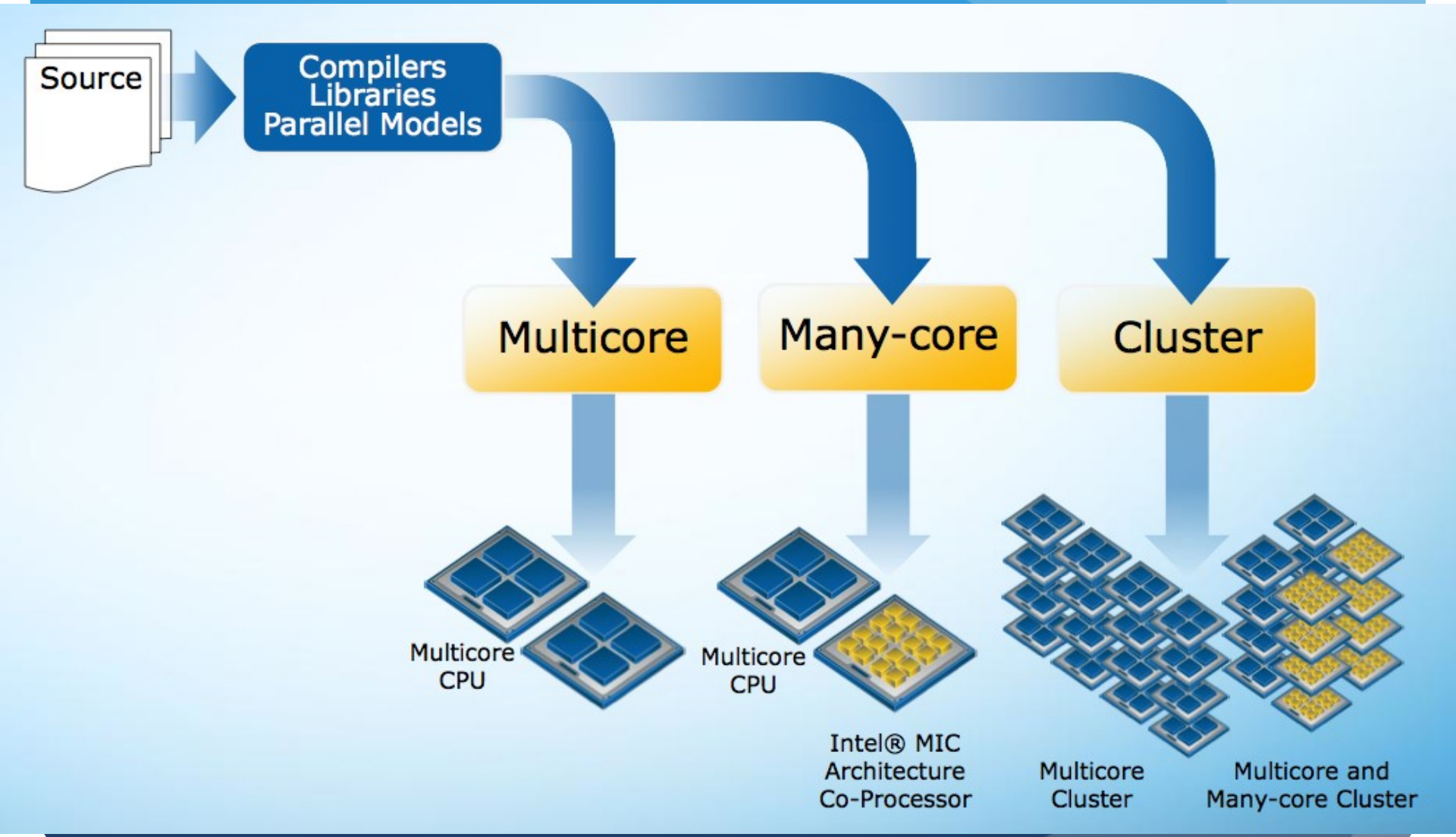
parallelism

Motivation: Performance

From a recent talk by Intel

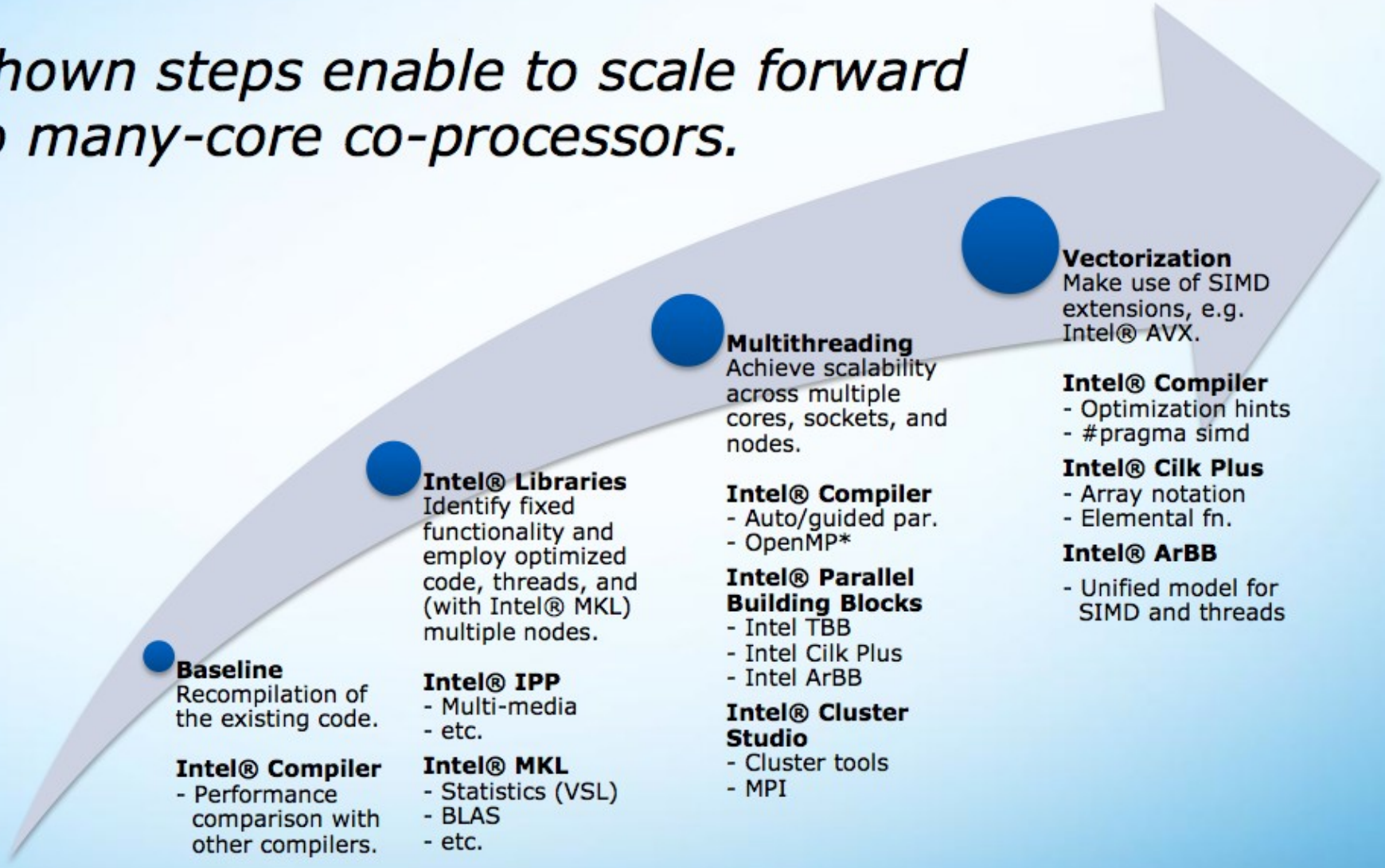


If you trust Intel



If you trust Intel 2

Shown steps enable to scale forward to many-core co-processors.

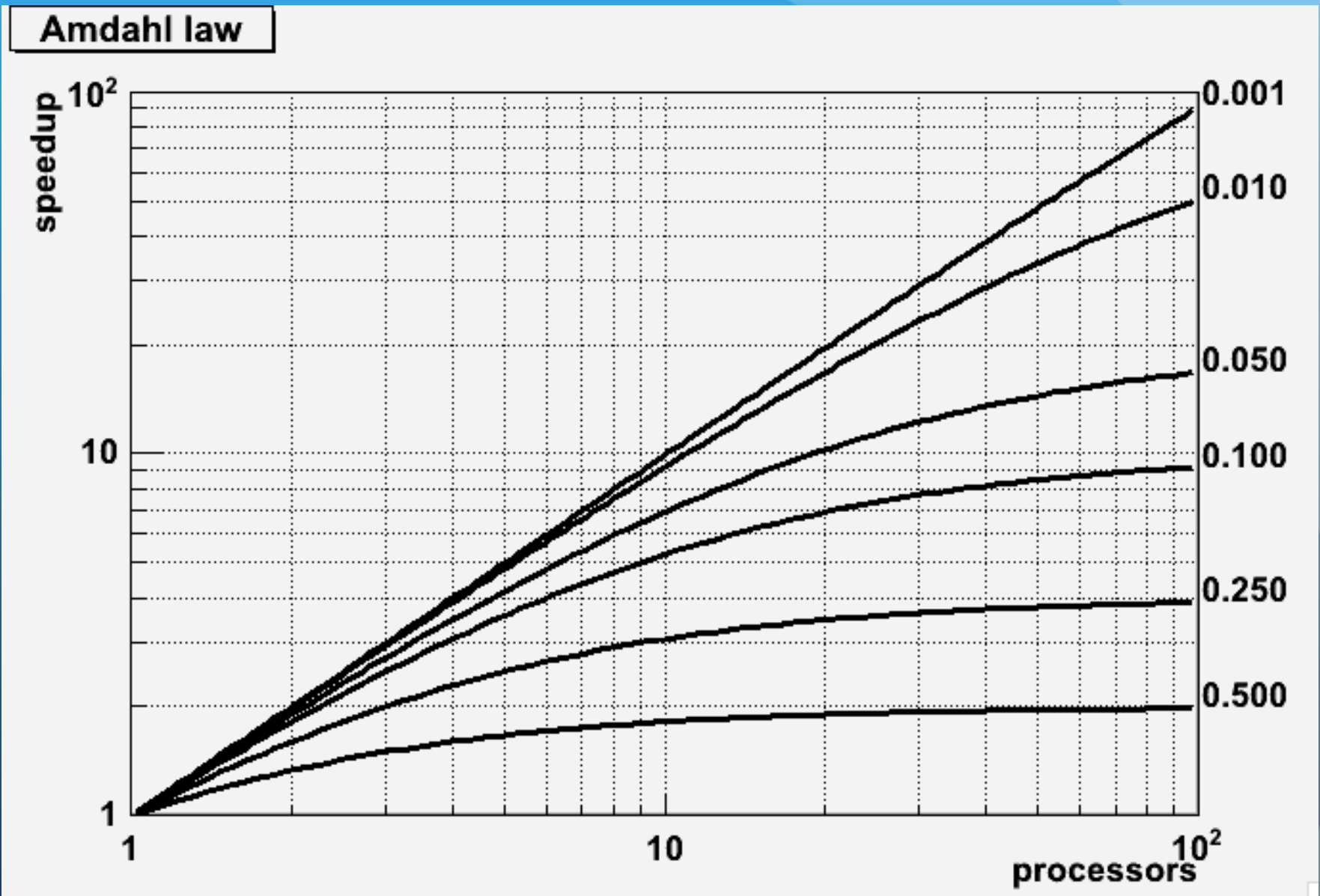


Why it is so difficult?

- No clear kernel
- C++ code generation / optimisation not well understood
- Most of the technology is coming out now
  - Lack of standards
  - Technological risk
- Non professional coders
- Fast evolving code
- No control on hardware acquisition

Why it is so difficult (cont)?

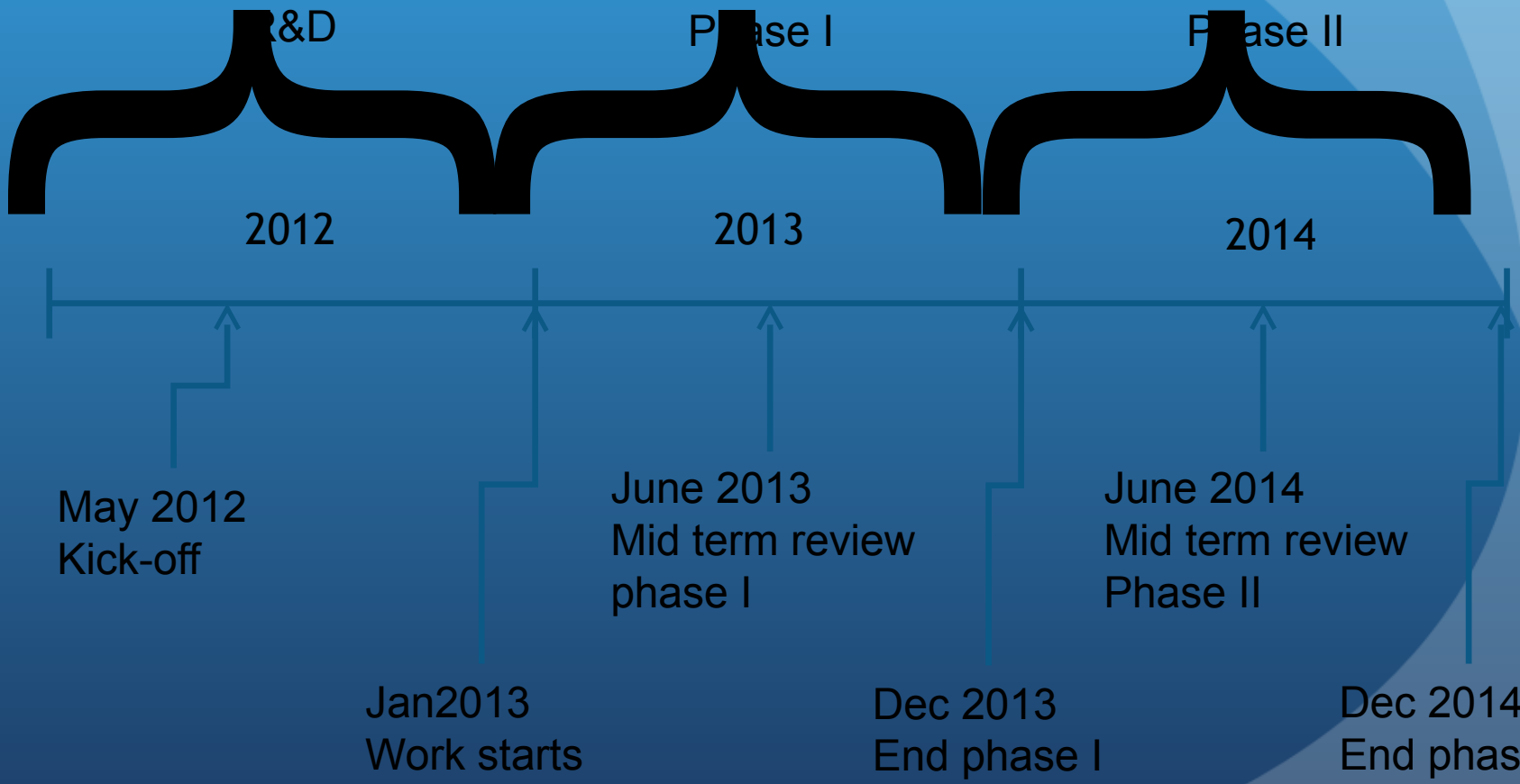
- Amdhal law sets stringent limits to the results that can be achieved
  - No “low level” optimisation alone will yield results
- Heterogeneous parallelism forces multi-level parallelisation
- Essentially the code (all of it!) will have to be re-written


Amdahl law
speedup
10^2
10
1
1
10
10^2
processors
0.001
0.010
0.050
0.100
0.250
0.500

ALICE strategy (unauthorised)

- Use the LSD-1 to essentially re-write AliRoot
- Use the LSD-2 to expand the parallelism to the Grid
  - Hopefully the major thrust will be on MiddleWare
- Refactor the code in order to expose the maximum of parallelism present at each level
- Keep the code in C++ (no CUDA, OpenCL etc.)
- Explore the possible use of #pragma's (OpenMP, OpenACC)
- Experiment on all hardware at hand (OpenLab, but not only)

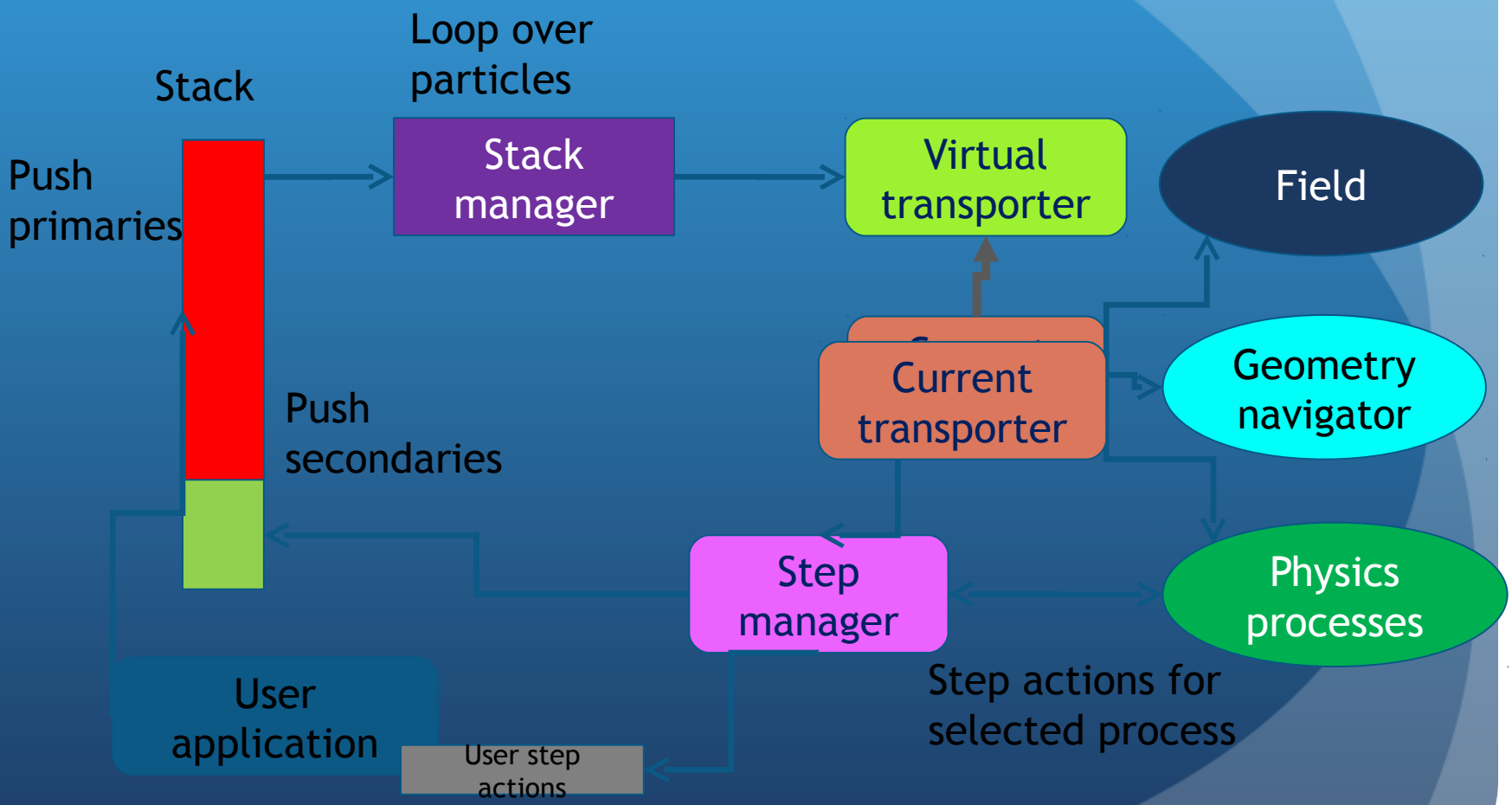
Timeline


&D
ase I
ase II
2012
2013
2014
May 2012
Kick-off
Jan2013
Work starts
June 2013
Mid term review
phase I
Dec 2013
End phase I
June 2014
Mid term review
Phase II
Dec 2014
End phase II

One example – Simulation

- The LHC experiments use extensively G4 as main simulation engine. They have invested in validation procedures. Any new project must be coherent with their framework.
- One of the reasons why the experiments develop their own fast MC solution is the fact that a full simulation is too slow for several physics analysis. These fast MCs are not in the G4 framework (different control, different geometries, etc), but becoming coherent with the experiments frameworks.
- Giving the amount of good work with the G4 physics, it is unthinkable to not capitalize on this work.

Event loop and stacking

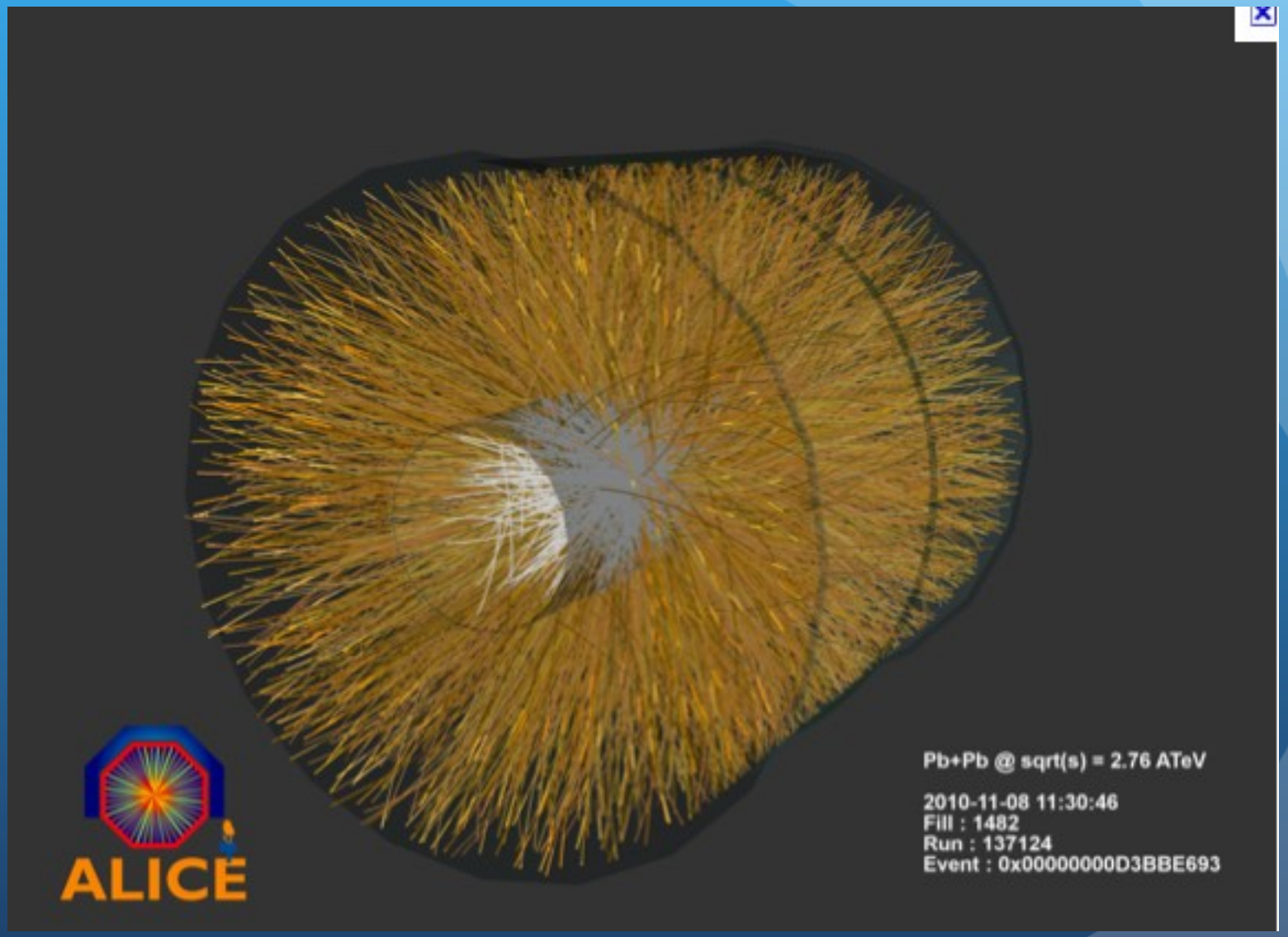


Fast and Full MonteCarlo

- We would like an architecture (via the abstract transporters) where fast and full MC can be run together.
- To make it possible one must have a separate particle stack.
- However, it was clear from the very beginning in January that the particle stack depends strongly on the constraints of parrallelism. Multiple threads cannot update efficiently a tree data structure.

Conventional Transport

- At each step, the navigator *nav has the state of the particle x,y,z,px,py,pz, the volume instance volume*, etc.
- We compute the distance to the next boundary with something like
  - Dist = nav->DistoOut(volume,x,y,z,px,py,pz)
- Or the distance to one physics process with, eg
  - Distp = nav->DistPhotoEffect(volume,x,y,z,px,py,pz)


ALICE
Pb+Pb @ sqrt(s) = 2.76 ATeV
2010-11-08 11:30:46
Fill : 1482
Run : 137124
Event : 0x00000000D3BBE693

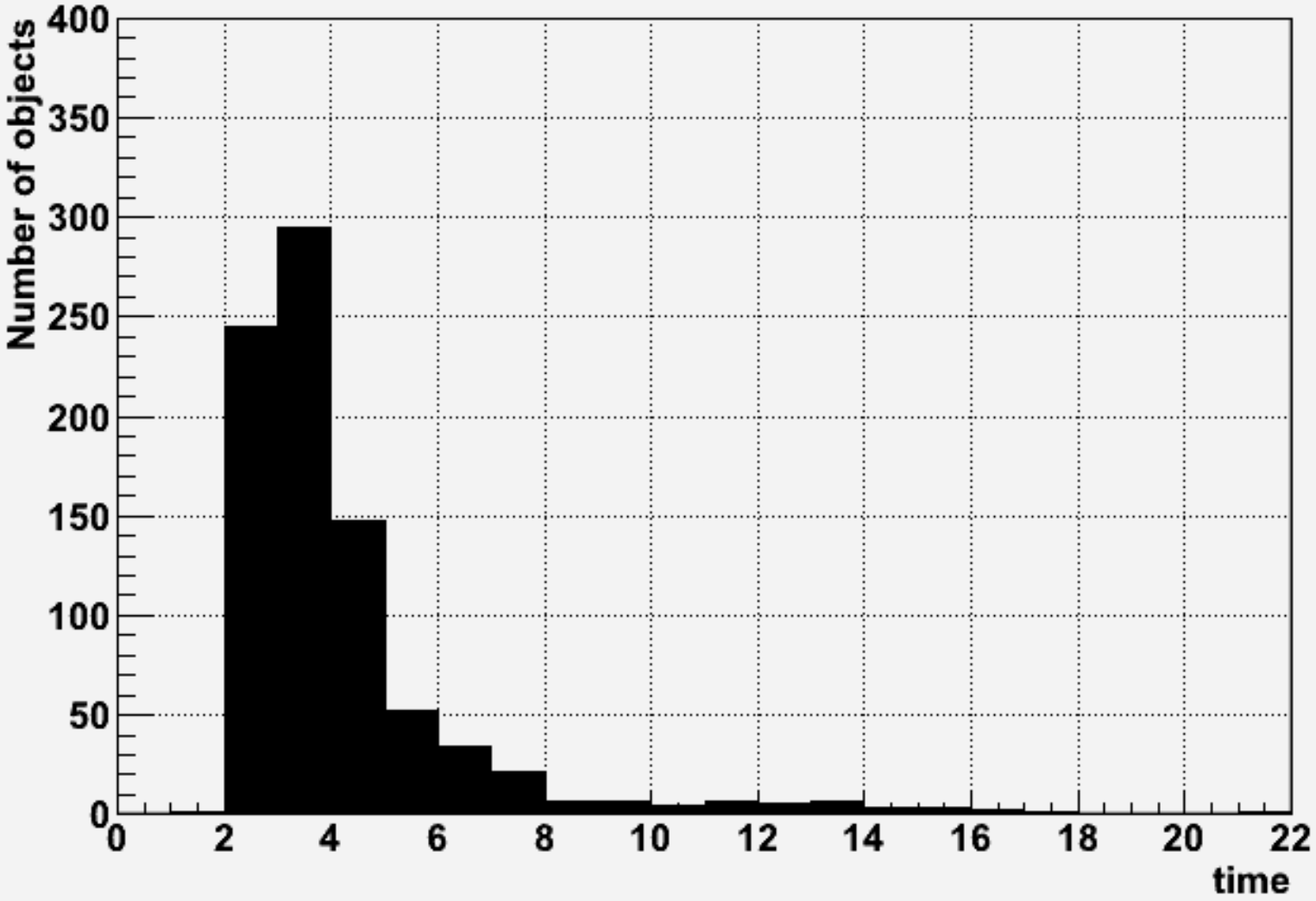
Current Situation

- We run jobs in parallel, one per core.
- Nothing wrong with that except that it does not scale in case of many cores because it requires too much memory.
- A multithreaded version may reduce (say by a factor 2 or 3) the amount of required memory, but also at the expense of performance.
- A multithreaded version does not fit well with a hierarchy of processors.
- So, we have a problem, in particular with the way we have designed some data structures, eg HepMC.

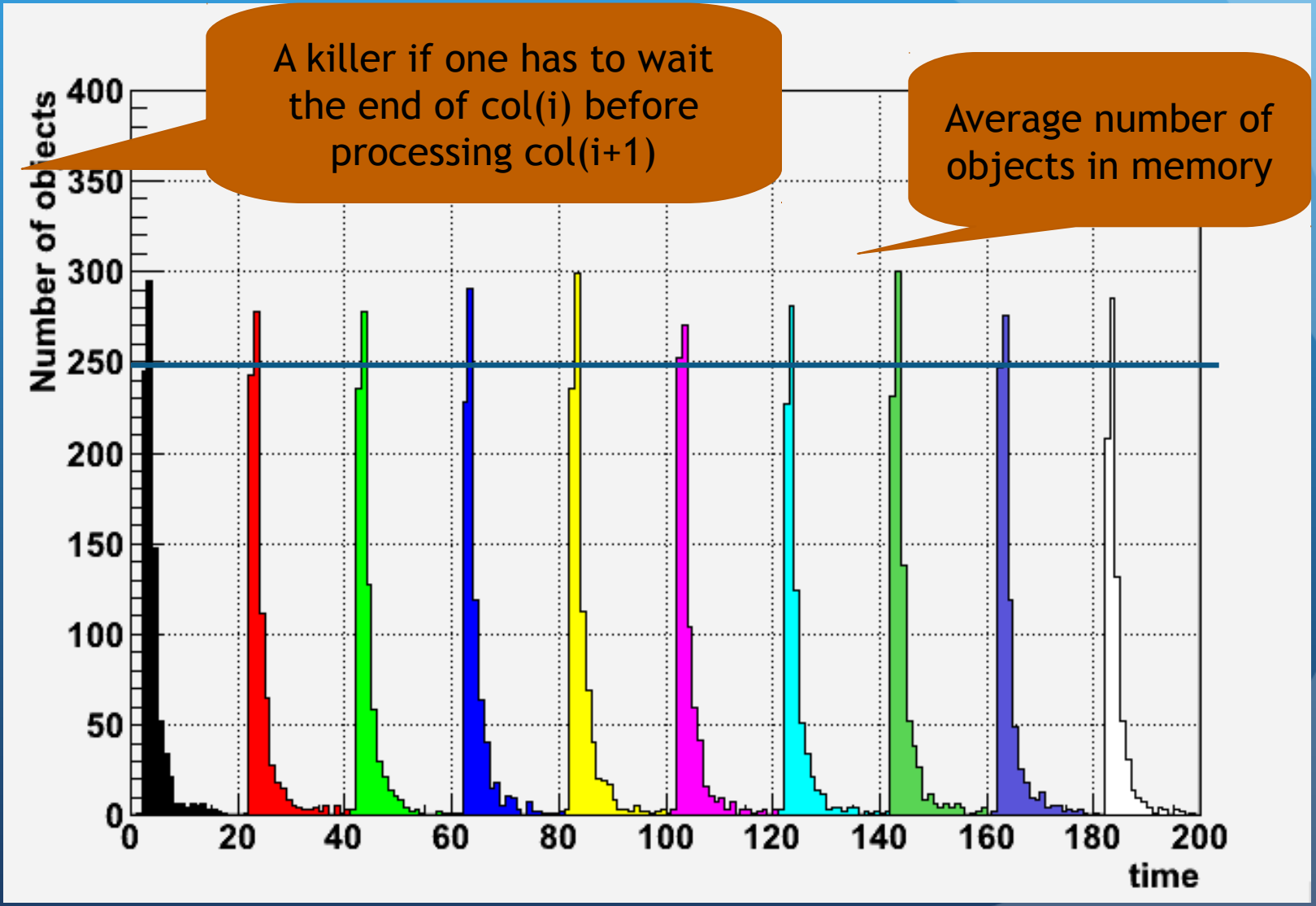
Can we make progress?

- We need data structures with internal relations only. This can be implemented by using pools and indices.
- When looping on collections, one must avoid the navigation in large memory areas killing the cache.
- We must generate vectors of reasonable size well matched to the degree of parallelism of the hardware and the amount of memory.
- We must find a system to avoid the tail effects

tails, tails, tails



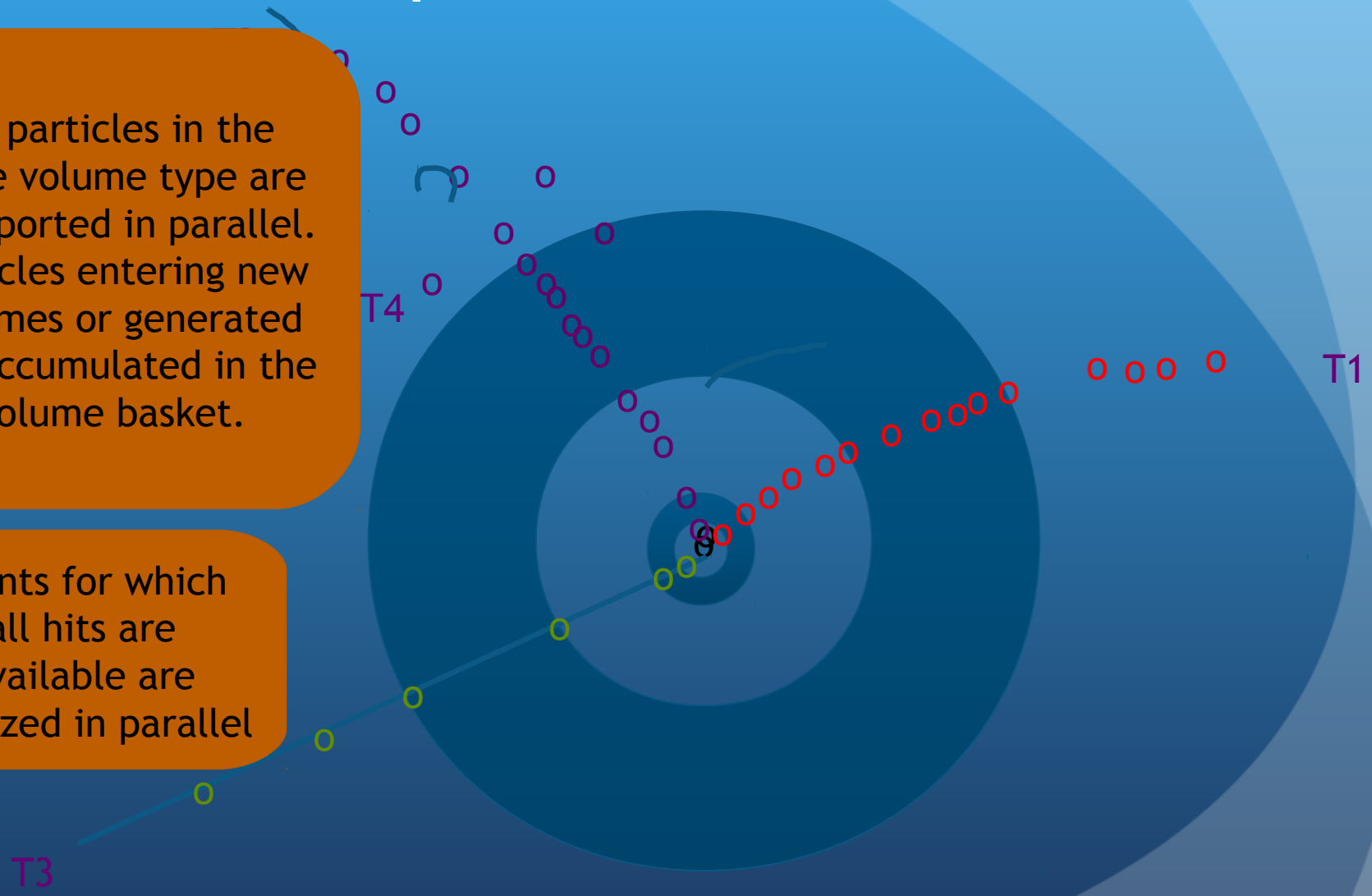
Tails again


A killer if one has to wait the end of col(i) before processing col(i+1)
Average number of objects in memory
Number of objects
400
350
300
250
200
150
100
50
0
0
20
40
60
80
100
120
140
160
180
200
time

New Transport Scheme

All particles in the same volume type are transported in parallel. Particles entering new volumes or generated are accumulated in the volume basket.

Events for which all hits are available are digitized in parallel



Generations of baskets

- When a particle enters a volume or is generated, it is added to the basket of particles for the volume type.
- The navigator selects the basket with the highest score (with a high and low water mark algorithm).
- The user has the control on the water marks, but the idea that this should be automatic in function of the number of processors and the total amount of memory available. (see interactive demo)

New Transport

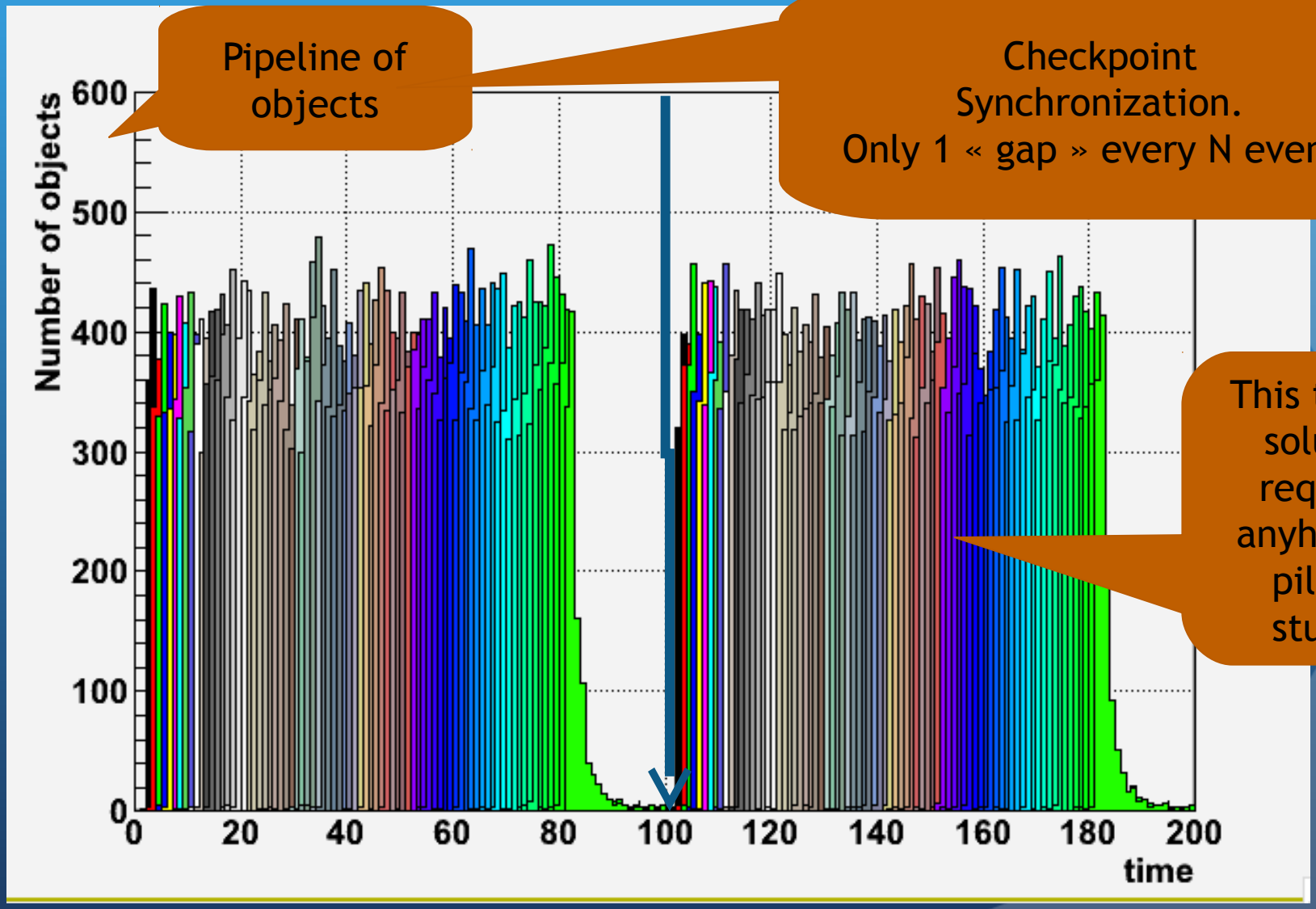
- At each step, the navigator *nav has the state of the particles *x,*y,*z,*px,*py,*pz, the volume instances volume**, etc.
- We compute the distances (array *Dist) to the next boundaries with something like
  - nav->DistoOut(volume,x,y,z,px,py,pz,Dist)
- Or the distances to one physics process with, eg
  - nav->DistPhotoEffect(volume,x,y,z,px,py,pz,DispP)

New Transport

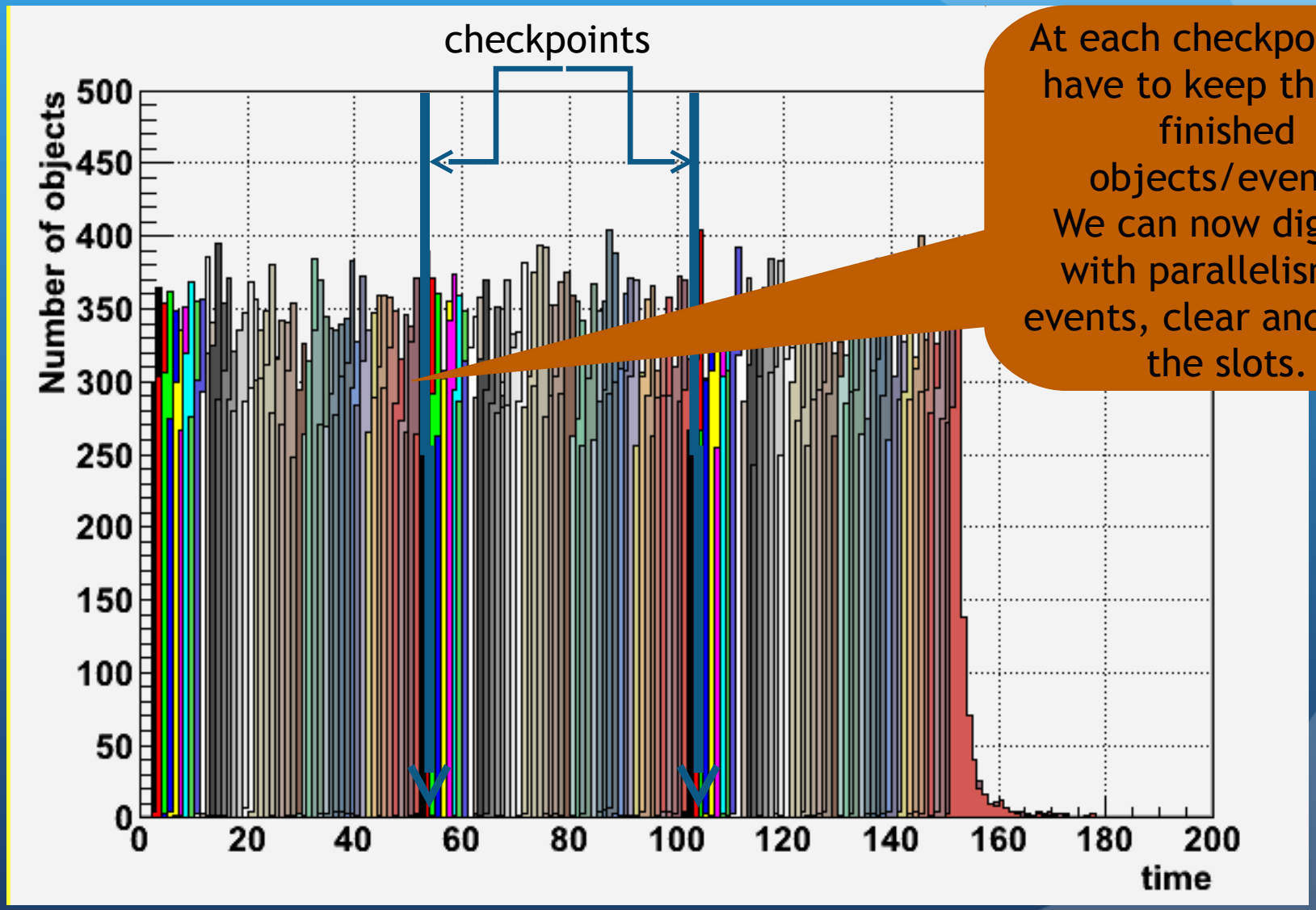
- The new transport system implies many changes in the geometry and physics classes. These classes must be vectorized (a lot of work!).
- Meanwhile we can survive and test the principle by implementing a bridge function like

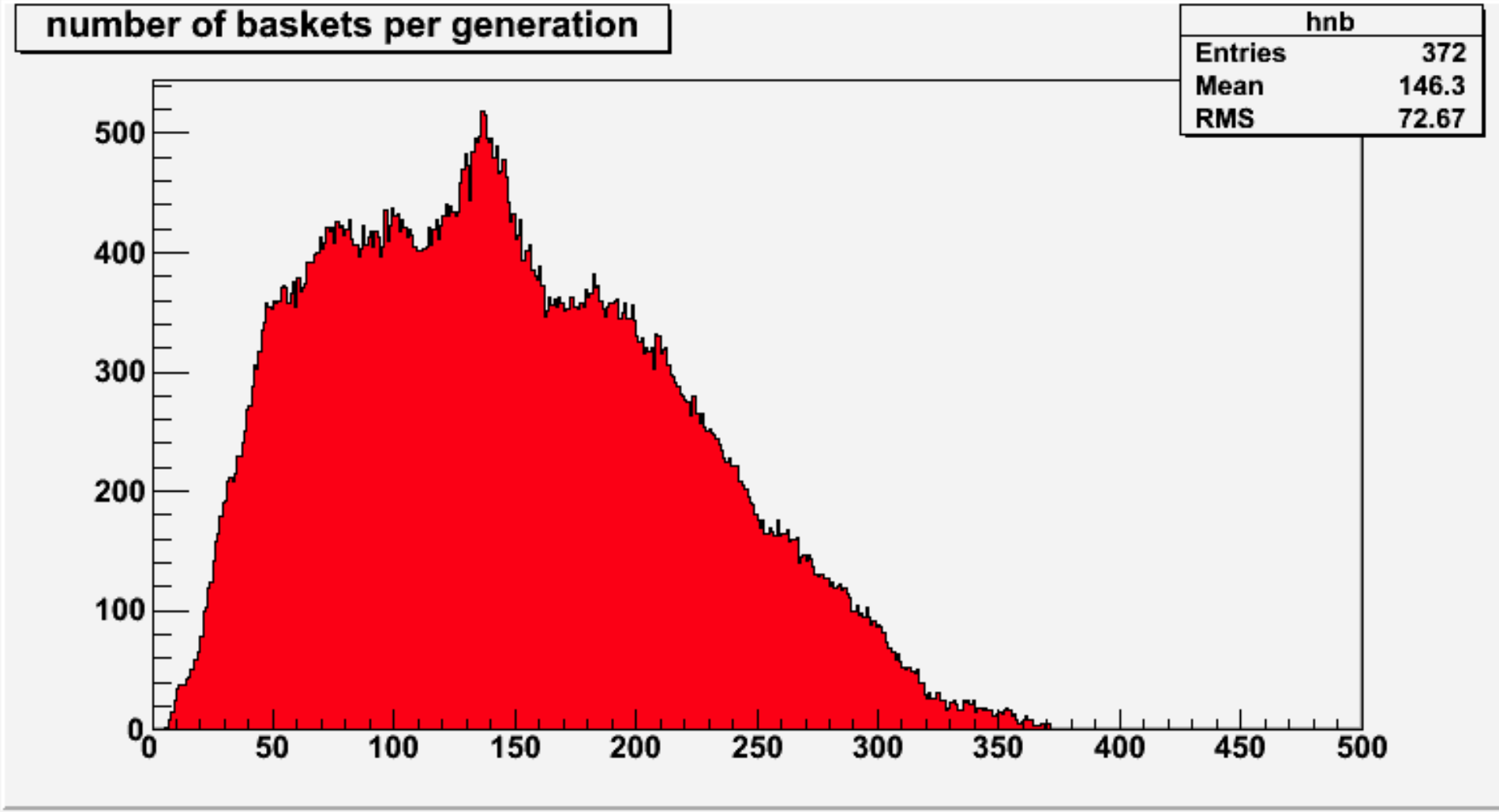
```
MyNavigator::DisttoOut(int n, TGeoVolume **vol, double *x,..)
{
   for int i=0;i<n;i++)  {
      Dist[i] = DisttoOutOld(vol[i],x[i],…);
   }
 }
```

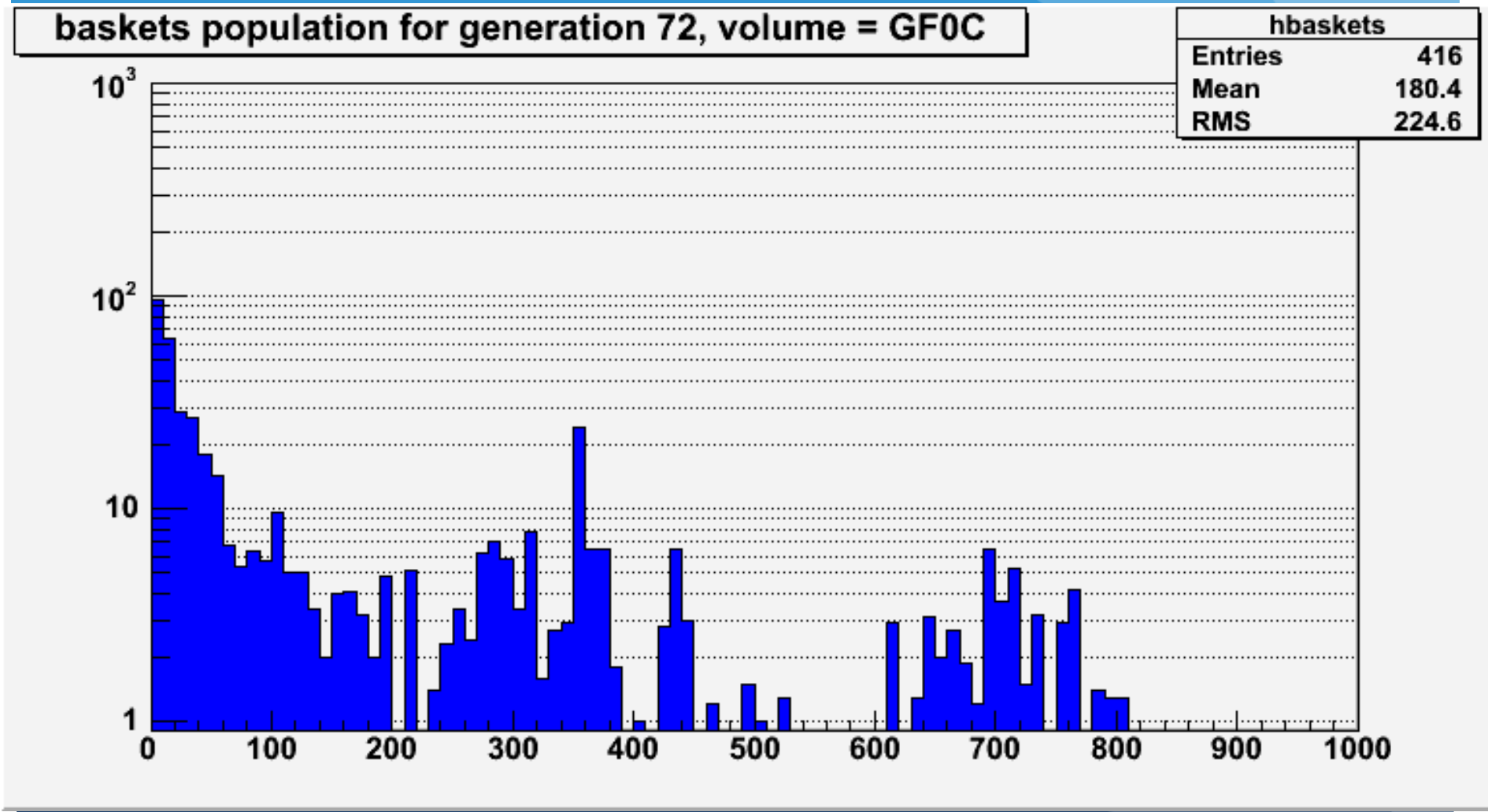
A better solution



A better better solution




number of baskets per generation
hnb
Entries 372
Mean 146.3
RMS 72.67
500
400
300
200
100
0
0
50
100
150
200
250
300
350
400
450
500


baskets population for generation 72, volume = GF0C
hbaskets
Entries 416
Mean 180.4
RMS 224.6
10^3
10^2
10
1
0
100
200
300
400
500
600
700
800
900
1000

Vectorizing the geometry (ex1)

```
Double_t TGeoPara::Safety(Double_t *point, Bool_t in) const
{
   // computes the closest distance from given point to this shape.
   Double_t saf[3];
   // distance from point to higher Z face
   saf[0] = fZ-TMath::Abs(point[2]); // Z

   Double_t yt = point[1]-fTyz*point[2];
   saf[1] = fY-TMath::Abs(yt);       // Y
   // cos of angle YZ
   Double_t cty = 1.0/TMath::Sqrt(1.0+fTyz*fTyz);

   Double_t xt = point[0]-fTxz*point[2]-fTxy*yt;
   saf[2] = fX-TMath::Abs(xt);       // X
   // cos of angle XZ
   Double_t ctx = 1.0/TMath::Sqrt(1.0+fTxy*fTxy+fTxz*fTxz);
   saf[2] *= ctx;
   saf[1] *= cty;
   if (in) return saf[TMath::LocMin(3,saf)];
   for (Int_t i=0; i<3; i++) saf[i]=-saf[i];
   return saf[TMath::LocMax(3,saf)];
}
```

Huge performance gain expected in this type of code where shape constants can be computed outside the loop

Vectorizing the geometry (ex2)

```
G4double G4Cons::DistanceToIn( const G4ThreeVector& p,
                               const G4ThreeVector& v  ) const
{
  G4double snxt = kInfinity ;      // snxt = default return value
  const G4double dRmax = 100*std::min(fRmax1,fRmax2);
  static const G4double halfCarTolerance=kCarTolerance*0.5;
  static const G4double halfRadTolerance=kRadTolerance*0.5;

  G4double tanRMax,secRMax,rMaxAv,rMaxOAv ;  // Data for cones
  G4double tanRMin,secRMin,rMinAv,rMinOAv ;
  G4double rout,rin ;

  G4double tolORMin,tolORMin2,tolIRMin,tolIRMin2 ; // `generous' radii squared
  G4double tolORMax2,tolIRMax,tolIRMax2 ;
  G4double tolODz,tolIDz ;

  G4double Dist,s,xi,yi,zi,ri=0.,risec,rhoi2,cosPsi ; // Intersection point vars

  G4double t1,t2,t3,b,c,d ;    // Quadratic solver variables
  G4double nt1,nt2,nt3 ;
  G4double Comp ;

  G4ThreeVector Normal;

  // Cone Precalcs

  tanRMin = (fRmin2 - fRmin1)*0.5/fDz ;
  secRMin = std::sqrt(1.0 + tanRMin*tanRMin) ;
  rMinAv  = (fRmin1 + fRmin2)*0.5 ;

  if (rMinAv > halfRadTolerance)
  {
    rMinOAv = rMinAv - halfRadTolerance ;
  }
  else
  {
    rMinOAv = 0.0 ;
  }
  tanRMax = (fRmax2 - fRmax1)*0.5/fDz ;
  secRMax = std::sqrt(1.0 + tanRMax*tanRMax) ;
  rMaxAv  = (fRmax1 + fRmax2)*0.5 ;
  rMaxOAv = rMaxAv + halfRadTolerance ;

  // Intersection with z-surfaces

  tolIDz = fDz - halfCarTolerance ;
  tolODz = fDz + halfCarTolerance ;

..... //here starts the real algorithm
```

All these statements are independent of the particle !!!

Huge performance gain expected in this type of code where shape constants can be computed outside the loop

Vectorizing the Physics

- This is going to be more difficult when extracting the physics classes from G4. However important gains are expected in the functions computing the distance to the next interaction point for each process.
- There is a diversity of interfaces and we have now sub-branches per particle type.

Plan ahead (no timing yet)

- Continue exploring all concurrency opportunities
- Develop “virtual transporter” to include a full and fast option
- Introduce embryonic physics processes (em) to simulate shower development
- Evaluate the prototype on parallel architectures
- Evaluate different “parallel” languages (OpenMP, CUDA, OpenCL…)
- Cooperate with experiments
  - For instance with ATLAS ISF (Integrated Simulation Framework) to put together the fast and full MC.

32