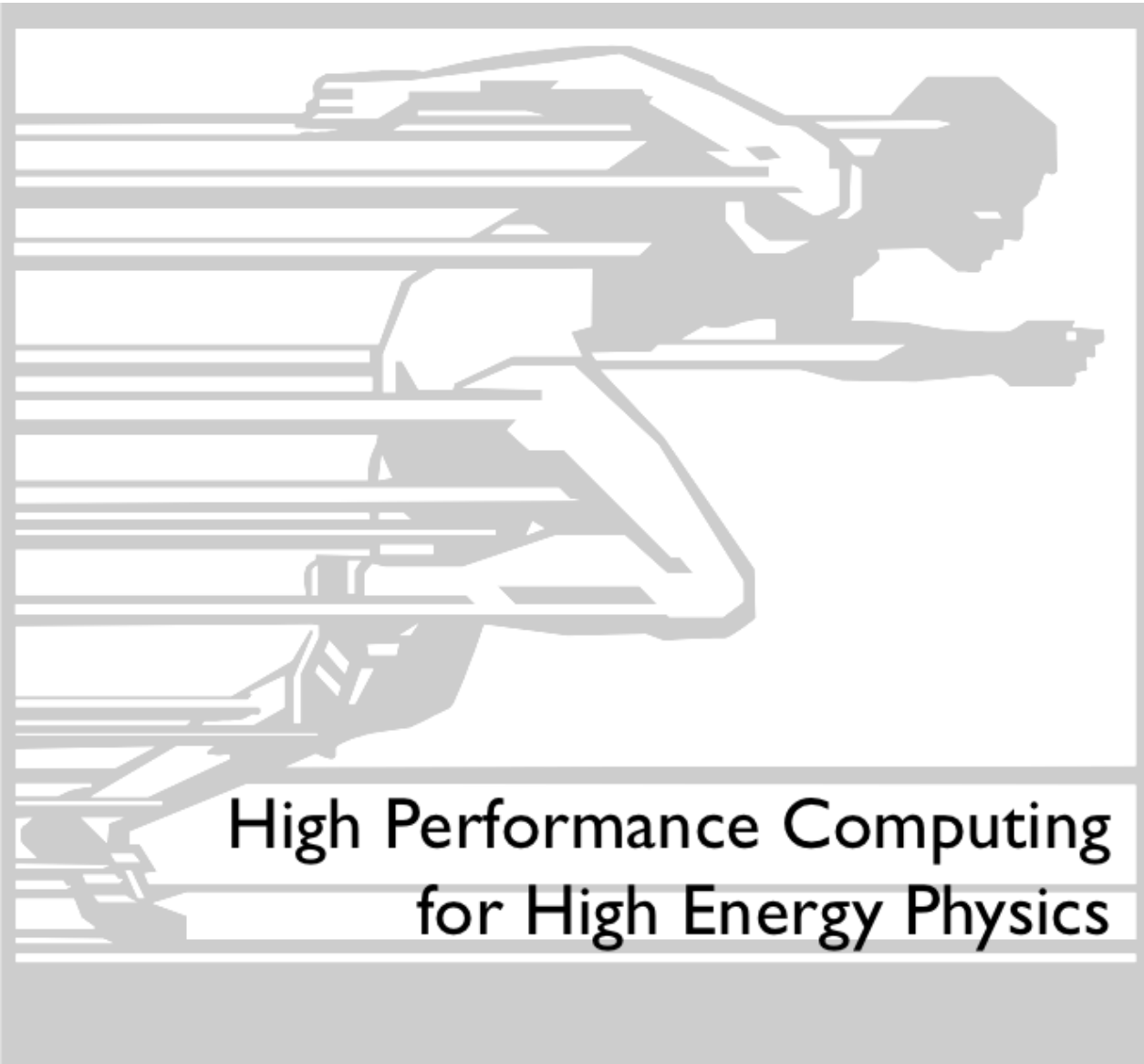


Yet another Malloc Profiler (this time based on `std::stacktrace`)

Vincenzo Innocente
CERN
CMS Experiment



High Performance Computing
for High Energy Physics

Motivations

- Replace igprof (unmaintained)
- Do not use external libraries (they need to be updated, and code ported)
- Keep code simple (easy maintenance)
- Keep output format simple (and possibly human readable)
- Use existing tools for analysis and display

std::stacktrace

- In C++23 standard
- “supported” in gcc since v12
- Need compiler to be specifically configured
 - --enable-libstdcxx-backtrace=yes
- Tool needs to be linked with a static library
 - -lstdc++_libbacktrace in gcc12, -lstdc++exp in gcc14
- Three bugs found: fixed in the main branches (last on Nov 15)

112348	gcc	libstdc+	unassigned@gcc.gnu.org	UNCO	---	[C++23] defect in struct hash<basic_stacktrace< Allocator>>
112263	gcc	libbackt	unassigned@gcc.gnu.org	RESO	FIXE	[C++23] std::stacktrace does not identify symbols in shared library
111936	gcc	libstdc+	redi@gcc.gnu.org	RESO	FIXE	std::stacktrace cannot be used in a shared library

Resources:

<https://stackoverflow.com/questions/3899870/how-to-print-a-stack-trace-whenever-a-certain-function-is-called/54365144>

Instrumentation

- As everybody else does
 - LD_PRELOAD
 - dlsym(RTLD_NEXT, "malloc"); etc
 - std::stacktrace objects kept in an unordered_map
 - One could try to use a Patricia Trie
 - Accumulation by thread (ncalls, memtot, memlive, max-memlive)
 - Final aggregation and symbol-name resolution at dump time
 - Filtering and “Remangling”: In process (dump-time) and post processing
 - Result is a file containing ;-separated-stacktraces with a value associated
- <https://github.com/VinInn/MallocProfiler/tree/main>

Visualization tools

- FlameGraph
 - <https://www.brendangregg.com/flamegraphs.html>
 - <https://github.com/brendangregg/FlameGraph>
 - `FlameGraph/flamegraph.pl --width 2400 step3_DumpDoEvent.md > /tmp/step3_DumpDoEvent.svg`
- Speedscope (thanks to Giulio Eulisse for pointing it out)
 - <https://github.com/jlfwong/speedscope>
 - Just open the web-app and drop the file
- Just try
 - `scp lxplus8.cern.ch:/afs/cern.ch/user/i/innocent/public/step3_DumpDoEvent.md.gz .`
- Screen shots in Backup

caveats

- Cling (via llvm) seems to “interact” with gcc backtrace data structures:
 - Hang deep in `gcc_src/libgcc/unwind-dw2-btree.h`
 - Solution: overload two functions and stop malloc-recording in there
- tls calls realloc
 - Not tracking realloc at the moment...
- Gcc unwind calls `dl_iterate_phdr` that seems to be protected by a mutex
 - Stacktrace recording the facto serializes
- Processing 100-event reco-relval takes ~2 hours (with recording threshold of 128 bytes)
- Dump (includes symbol name resolution) is very slow (several minutes)

Inline functions

- In absence of debug information inline functions are not reported
- In presence of debug information it is possible to obtain the full call chain
 - Currently not available in `std::stacktrace`
 - Available from the backend `libbacktrace`
 - gcc implementation actually reports the deepest callee
 - "easy" to clone the gcc-implementation and report the full call chain on demand

Remangling

- C++ symbol names can be long (boost::spirit? 30Kbytes!)
- Many stacktrace details are not of interest for the analysis in hand
 - Everything below TClass, TFormula, std::regex and boost::spirit for instance
 - Everything before tbb::detail::d1::function_task
- Many names can be shortened
 - string, vector, etc
 - , allocator<...> can be removed
- The whole signature is often not of interest (function name is enough)

Filtering

- The file is simple text: best post-processing filtering is grep and sed!

```
[innocent@patatrack01 11634.o_TTbar_14TeV+2021]$  
wc step3_DumpNew.mdr  
  1,114,944  117815162 3,354,955,155  
grep -ic cling step3_DumpNew.mdr  
163,652  
grep -ic TClass step3_DumpNew.mdr  
138,481  
grep -ic TFormula step3_DumpNew.mdr  
36,210  
grep -ic regex step3_DumpNew.mdr  
16,827  
grep -ic spirit step3_DumpNew.mdr  
322,480  
grep doEvent step3_DumpNew.mdr | wc  
  290,234  28882728 888,851,647  
# after symbol filtering (see next slide)  
wc step3_DumpDoEvent.md  
  290,194   580388 333,669,635
```

Example of post processing

```
# 3 is memtot, 4 is memlive
grep '_mpTrace_' $1.mdr | sed 's/\;{\1,\}/;/g' | sed 's/^;//' | cut -f1,4 -d'$' \
| sed 's/_mpTrace_;_start;__libc_start_main;main;main::{lambda()#1}::operator();tbb::detail::r1::task_arena_impl::execute;
tbb::detail::d1::task_arena_function<main::{lambda()#1}::operator>() const::{lambda()#1}, void>::operator();//' \
| sed 's/_mpTrace.*tbb::detail::d1::function_task/function_task/' \
| sed 's/std::__cxx11::basic_string<char, std::char_traits<char> >/string/g' \
| sed 's/std::basic_string_view<char, std::char_traits<char> >/string_view/g' \
| sed 's/operator new;malloc;//g' \
| sed 's/malloc;//g' \
| sed 's/unsigned /u/g' | sed 's/operator/op/g' | sed 's/std:://g' \
| sed 's/const//g' | sed 's/&//g' | sed 's/ //g' | sed 's/:::/g' | tr '$' ' ' > $1.md
```

Performance (and some results)

- 100 events, 4 threads, step3 (reco) wf 11634.0_TTbar_14TeV+2021
 - Threshold 128 Bytes (below threshold stacktrace is not recorded)
 - Elapsed time 6950 seconds: (~18 minutes before event 5 starts)
 - Total Number of malloc calls 579,980,716
 - Total MemTot 9.90328e+10 (100GB!)
 - Total Max Memlive 3,929,812,405
 - Raw dump: wc => 1,078,553 116,416,953 3,281,194,659 memdump_2003909_1.mdr
 - SmallAllocations: (<128 Bytes)
 - Number of malloc calls 474,512,716 (80% of tot!)
 - MemTot 1.80925e+10 (18GB)
 - Typical MemLive 524,182,207
 - Inverse Threshold (record stacktrace only for <128 Bytes allocations)
 - 55 events : 18,500 seconds (~2hours before event 5 starts)
 - Raw dump: wc => 2,528,393 213,268,892 6,504,541,718 memdump_99644_15.mdr
 - After filter: wc => 2,532,509 5,065,018 4,002,873,401 memdump_99644_16.md
 - Remove memlive=0 :
 - grep -v "; o" memdump_99644_16.md | wc => 469,045 938,090 753,865,549

Local Instrumentation

```
diff --git a/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc b/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc
index 852ff217c4b..1b423e2dc40 100644
--- a/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc
+++ b/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc
@@ -145,6 +145,7 @@ void ClusterShapeHitFilter::fillPixelData() {
 }
}

+#include "mallocProfiler.h"
void ClusterShapeHitFilter::fillStripData() {
    // copied from StripCPE (FIXME maybe we should move all this in LocalReco)
    auto const& geom_ = *theTracker;
@@ -158,19 +159,33 @@ void ClusterShapeHitFilter::fillStripData() {
 }
}

+ std::cout << "in ClusterShapeHitFilter::fillStripData " << dus.size()-offset << ' ' << sizeof(StripData) << ' ' << stripData.max_load_factor() << std::endl;
+ // need to active both
+ mallocProfiler::setThreshold(0);
+ mallocProfiler::activate(mallocProfiler::allThreads);
+ mallocProfiler::activate(mallocProfiler::currentThread);
+
+ stripData.reserve(dus.size()-offset);
for (auto i = offset; i != dus.size(); ++i) {
    const StripGeomDetUnit* stripdet = (const StripGeomDetUnit*)(dus[i]);
    assert(stripdet->index() == int(i));
    assert(stripdet->type().isTrackerStrip()); // not pixel
    auto const& bounds = stripdet->specificSurface().bounds();
    auto detid = stripdet->geographicalId();
-    auto& p = stripData[detid];
+    auto pp = stripData.emplace(std::make_pair(detid, StripData()));
+    auto & p = (*pp.first).second;
    p.det = stripdet;
    p.topology = (StripTopology*)(&stripdet->topology());
    p.drift = getDrift(stripdet);
    p.thickness = bounds.thickness();
    p.nstrips = p.topology->nstrips();
}

+ mallocProfiler::dump(std::cout, ' ', mallocProfiler::SortBy::none, mallocProfiler::currentThread);
+ mallocProfiler::deactivate(mallocProfiler::currentThread);
+ mallocProfiler::deactivate(mallocProfiler::allThreads);
+ std::cout << "in ClusterShapeHitFilter::fillStripData " << stripData.size() << ' ' << stripData.bucket_count() << ' ' << stripData.max_bucket_count() << ' ' << stripData.max_load_factor() << std::endl;
+ abort();
}
```

```
diff --git a/RecoTracker/PixelLowPtUtilities/BuildFile.xml b/RecoTracker/PixelLowPtUtilities/BuildFile.xml
index 3226f2c8d56..8350c10d381 100644
--- a/RecoTracker/PixelLowPtUtilities/BuildFile.xml
+++ b/RecoTracker/PixelLowPtUtilities/BuildFile.xml
@@ -14,6 +14,7 @@
<use name="TrackingTools/PatternTools"/>
<use name="TrackingTools/Records"/>
<use name="TrackingTools/TrajectoryFiltering"/>
+<use name="MallocDummy/MallocDummy"/>
<export>
  <lib name="1"/>
</export>
```

Raw dump.... (just two lines...)

```
in ClusterShapeHitFilter::fillStripData 15148 32
__mpTrace_._start;__libc_start_main;main;main::(lambda()#1)::operator()>tbb::detail::r1::task_arena_impl::execute;tbb::detail::d1::task_arena_function<main::(lambda()#1)::operator()> const::(lambda()#1),
void>::operator()>edm::EventProcessor::runToCompletion;edm::EventProcessor::processRuns;edm::FinalWaitingTask::wait;tbb::detail::d1::task* tbb::detail::r1::task_dispatcher::local_wait_for_all<false,
tbb::detail::r1::external_waiter>;tbb::detail::d1::function_task<edm::SerialTaskQueue::spawn(edm::SerialTaskQueue::TaskBase&):(lambda()#1)>::execute;edm::SerialTaskQueue::QueuedTask<edm::SerialTaskQueueChain::push<edm::eventsetup::CallbackBase<edm::ESProducer,
edm::ESProducer::setWhatProduced<ClusterShapeHitFilterESProducer, std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >>(ClusterShapeHitFilterESProducer*,
std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> > (ClusterShapeHitFilterESProducer::*)(CkfComponentsRecord const&), edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> const&, edm::es::Label const&):(lambda(CkfComponentsRecord
const&)#1), std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >::makeProduceTask<edm::eventsetup::Callback<edm::ESProducer,
edm::ESProducer::setWhatProduced<ClusterShapeHitFilterESProducer, std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >>(ClusterShapeHitFilterESProducer*,
std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> > (ClusterShapeHitFilterESProducer::*)(CkfComponentsRecord const&), edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> const&, edm::es::Label const&):(lambda(CkfComponentsRecord
const&)#1), std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >::prefetchAsync(edm::WaitingTaskHolder, edm::eventsetup::EventSetupRecordImpl const*,
edm::EventSetupImpl const*, edm::ServiceToken const&, edm::ESParentContext const&):(lambda(auto:1&&, auto:2&&, auto:3&&, auto:4&&)#1)::operator()<tbb::detail::d1::task_group*&, edm::ServiceWeakToken&, edm::eventsetup::EventSetupRecordImpl const*&, edm::EventSetupImpl
const*&>(tbb::detail::d1::task_group*&, edm::ServiceWeakToken&, edm::eventsetup::EventSetupRecordImpl const*&, edm::EventSetupImpl const*&, bool,
tbb::detail::d1::task_group*&):(lambda(std::_exception_ptr::exception_ptr const*)>#1)::operator()<(std::_exception_ptr::exception_ptr const*)>
const::(lambda()#2)::operator()>ClusterShapeHitFilterESProducer::produce;ClusterShapeHitFilter::ClusterShapeHitFilter;ClusterShapeHitFilter::fillStripData;operator new;get_stacktrace; 11 324840 166024 248208
__mpTrace_._start;__libc_start_main;main;main::(lambda()#1)::operator()>tbb::detail::r1::task_arena_impl::execute;tbb::detail::d1::task_arena_function<main::(lambda()#1)::operator()> const::(lambda()#1),
void>::operator()>edm::EventProcessor::runToCompletion;edm::EventProcessor::processRuns;edm::FinalWaitingTask::wait;tbb::detail::d1::task* tbb::detail::r1::task_dispatcher::local_wait_for_all<false,
tbb::detail::r1::external_waiter>;tbb::detail::d1::function_task<edm::SerialTaskQueue::spawn(edm::SerialTaskQueue::TaskBase&):(lambda()#1)>::execute;edm::SerialTaskQueue::QueuedTask<edm::SerialTaskQueueChain::push<edm::eventsetup::CallbackBase<edm::ESProducer,
edm::ESProducer::setWhatProduced<ClusterShapeHitFilterESProducer, std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >>(ClusterShapeHitFilterESProducer*,
std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> > (ClusterShapeHitFilterESProducer::*)(CkfComponentsRecord const&), edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> const&, edm::es::Label const&):(lambda(CkfComponentsRecord
const&)#1), std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >::makeProduceTask<edm::eventsetup::Callback<edm::ESProducer,
edm::ESProducer::setWhatProduced<ClusterShapeHitFilterESProducer, std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >>(ClusterShapeHitFilterESProducer*,
std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> > (ClusterShapeHitFilterESProducer::*)(CkfComponentsRecord const&), edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> const&, edm::es::Label const&):(lambda(CkfComponentsRecord
const&)#1), std::unique_ptr<ClusterShapeHitFilter, std::default_delete<ClusterShapeHitFilter> >, CkfComponentsRecord, edm::eventsetup::CallbackSimpleDecorator<CkfComponentsRecord> >::prefetchAsync(edm::WaitingTaskHolder, edm::eventsetup::EventSetupRecordImpl const*,
edm::EventSetupImpl const*, edm::ServiceToken const&, edm::ESParentContext const&):(lambda(auto:1&&, auto:2&&, auto:3&&, auto:4&&)#1)::operator()<tbb::detail::d1::task_group*&, edm::ServiceWeakToken&, edm::eventsetup::EventSetupRecordImpl const*&, edm::EventSetupImpl
const*&>(tbb::detail::d1::task_group*&, edm::ServiceWeakToken&, edm::eventsetup::EventSetupRecordImpl const*&, edm::EventSetupImpl const*&, bool,
tbb::detail::d1::task_group*&):(lambda(std::_exception_ptr::exception_ptr const*)>#1)::operator()<(std::_exception_ptr::exception_ptr const*)>
const::(lambda()#2)::operator()>ClusterShapeHitFilterESProducer::produce;ClusterShapeHitFilter::ClusterShapeHitFilter;ClusterShapeHitFilter::fillStripData;operator new;get_stacktrace; 15148 727104 727104 727104
```

Local Instrumentation

- `setenv LD_PRELOAD /data/user/innocent/MallocProfiler/mallocProfilerOFF.so`
- `cmsRunGlibc reco1.py`
 - in `ClusterShapeHitFilter::fillStripData 15148 32 1`
 - `ClusterShapeHitFilter::fillStripData;operator new;malloc; 11 324840 166024 248208`
 - `ClusterShapeHitFilter::fillStripData;operator new;malloc; 15148 727104 727104 727104`
- `Add stripData.reserve(dus.size()-offset);`
 - `ClusterShapeHitFilter;ClusterShapeHitFilter::fillStripData;std::_Hashtable<unsigned int, std::pair<unsigned int const, ClusterShapeHitFilter::StripData>, std::__detail::_Select1st, std::equal_to<unsigned int>, std::hash<unsigned int>, std::__detail::_Mod_range_hashing, std::__detail::_Default_ranged_hash, std::__detail::_Prime_rehash_policy, std::__detail::_Hashtable_traits<false, false, true> >::_M_rehash;operator new;get_stacktrace; 1 121384 121384 121384`
 - `ClusterShapeHitFilter::fillStripData;operator new;malloc; 15148 727104 727104 727104`
- $727104/15148 = 48 = 32+8 + 8$ (bucket?)
- $121384/15173 = 8$ (pointer to bucket?)

Experimenting with friendly “detailed” dump

```
In ClusterShapeHitFilter::FillStripData 15148 32 40 1
Stat 1 121384 121384 121384 at
#0 malloc :0
#1 operator new(unsigned long) ../../../../gcc_src/libstdc++-v3/libsupc++/new_op.cc:50
#2 std::__detail::_Hashtable_alloc<std::allocator<std::__detail::_Hash_node<std::pair<unsigned int const, ClusterShapeHitFilter::StripData>, false> > >::_M_allocate_buckets(unsigned long) /cvmfs/cms.cern.ch/el8_amd64_gcc12/external/gcc/12.3.1-40d504be6370b5a30e3947a6e575ca28/include/c++/12.3.1/bits/new_allocator.h:137
#3 std::_Hashtable<unsigned int, std::pair<unsigned int const, ClusterShapeHitFilter::StripData>, std::allocator<std::pair<unsigned int const, ClusterShapeHitFilter::StripData> >, std::__detail::_Select1st, std::equal_to<unsigned int>, std::hash<unsigned int>, std::__detail::_Mod_range_hashing, std::__detail::_Default_ranged_hash, std::__detail::_Prime_rehash_policy, std::__detail::_Hashtable_traits<false, false, true> >::_rehash(unsigned long) /cvmfs/cms.cern.ch/el8_amd64_gcc12/external/gcc/12.3.1-40d504be6370b5a30e3947a6e575ca28/include/c++/12.3.1/bits/hashtable.h:2523
#4 ClusterShapeHitFilter::ClusterShapeHitFilter(TrackerGeometry const*, TrackerTopology const*, MagneticField const*, SiPixelLorentzAngle const*, SiStripLorentzAngle const*, std::__cxx11::basic_string<char, std::char_traits<char>, std::allocator<char> > const&, std::__cxx11::basic_string<char, std::char_traits<char>, std::allocator<char> > const&) /data/user/innocent/CMSSW_13_3_0_pre4/src/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc:54
Stat 15148 727104 727104 727104 at
#0 malloc :0
#1 operator new(unsigned long) ../../../../gcc_src/libstdc++-v3/libsupc++/new_op.cc:50
#2 std::__new_allocator<std::__detail::_Hash_node<std::pair<unsigned int const, ClusterShapeHitFilter::StripData>, false> >::allocate(unsigned long, void const*) /cvmfs/cms.cern.ch/el8_amd64_gcc12/external/gcc/12.3.1-40d504be6370b5a30e3947a6e575ca28/include/c++/12.3.1/bits/new_allocator.h:137
#3 ClusterShapeHitFilter::ClusterShapeHitFilter(TrackerGeometry const*, TrackerTopology const*, MagneticField const*, SiPixelLorentzAngle const*, SiStripLorentzAngle const*, std::__cxx11::basic_string<char, std::char_traits<char>, std::allocator<char> > const&, std::__cxx11::basic_string<char, std::char_traits<char>, std::allocator<char> > const&) /data/user/innocent/CMSSW_13_3_0_pre4/src/RecoTracker/PixelLowPtUtilities/src/ClusterShapeHitFilter.cc:54
```

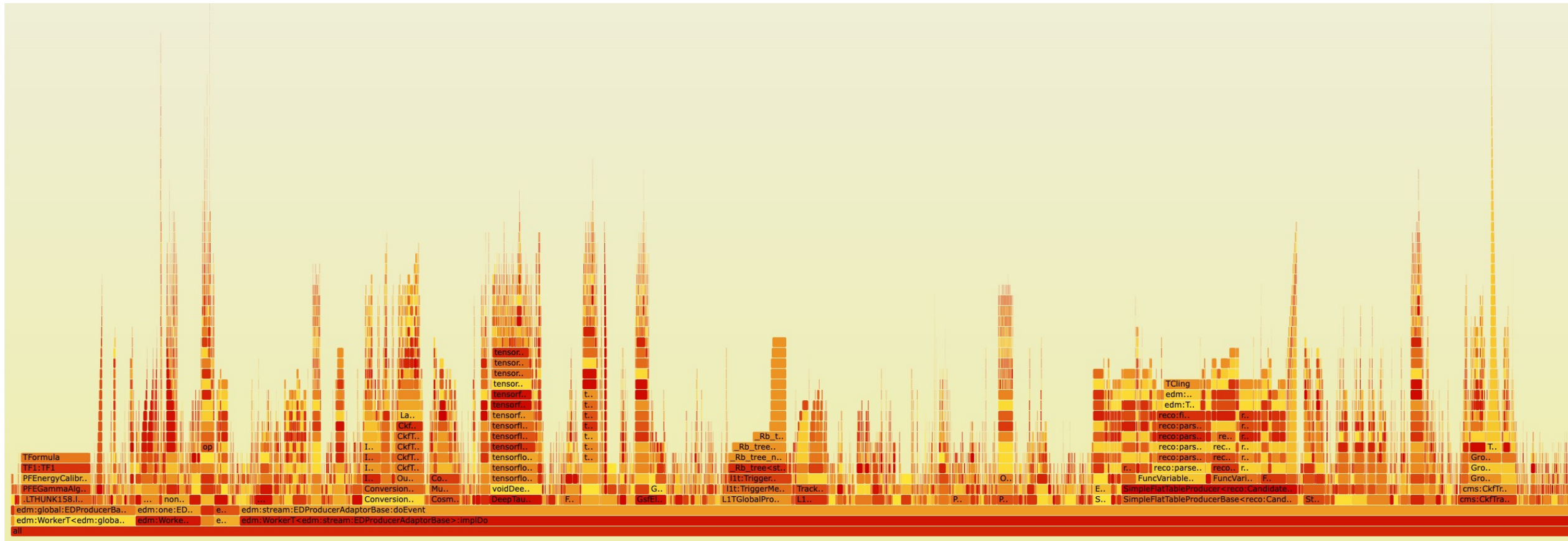
Current status and future developments

- What is provided:
 - *mallocProfiler.so*: the instrumentation library to preload
 - *mallocProfilerOFF.so*: as above with all tracing deactivated
 - *dummyMallocProfiler.so*: a dummy version of the API to link unconditionally
 - *tracingThread.so*: threads dumping summary and stacktraces at regular intervals (to preload)
- What could be provided
 - A wrapping script compiling options in a middleman library
 - A filtering hook
 - CMSSW specific instrumentations
 - More global statistics (mem-tot and mem-live histograms for instance)
- What will not be provided
 - The possibility to use a configuration file or env-var instead of the API

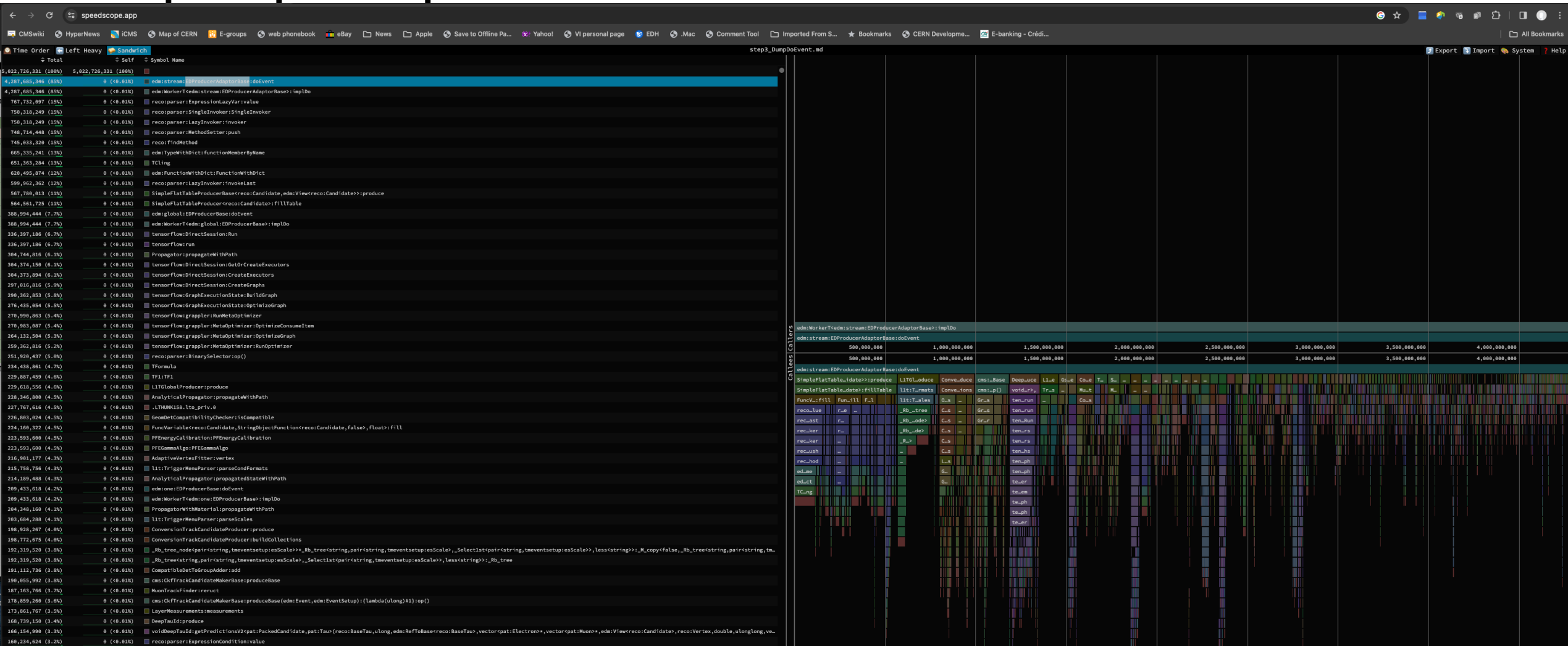
BACKUP

*In the following screenshots
a small defect made Self to be reported as 0*

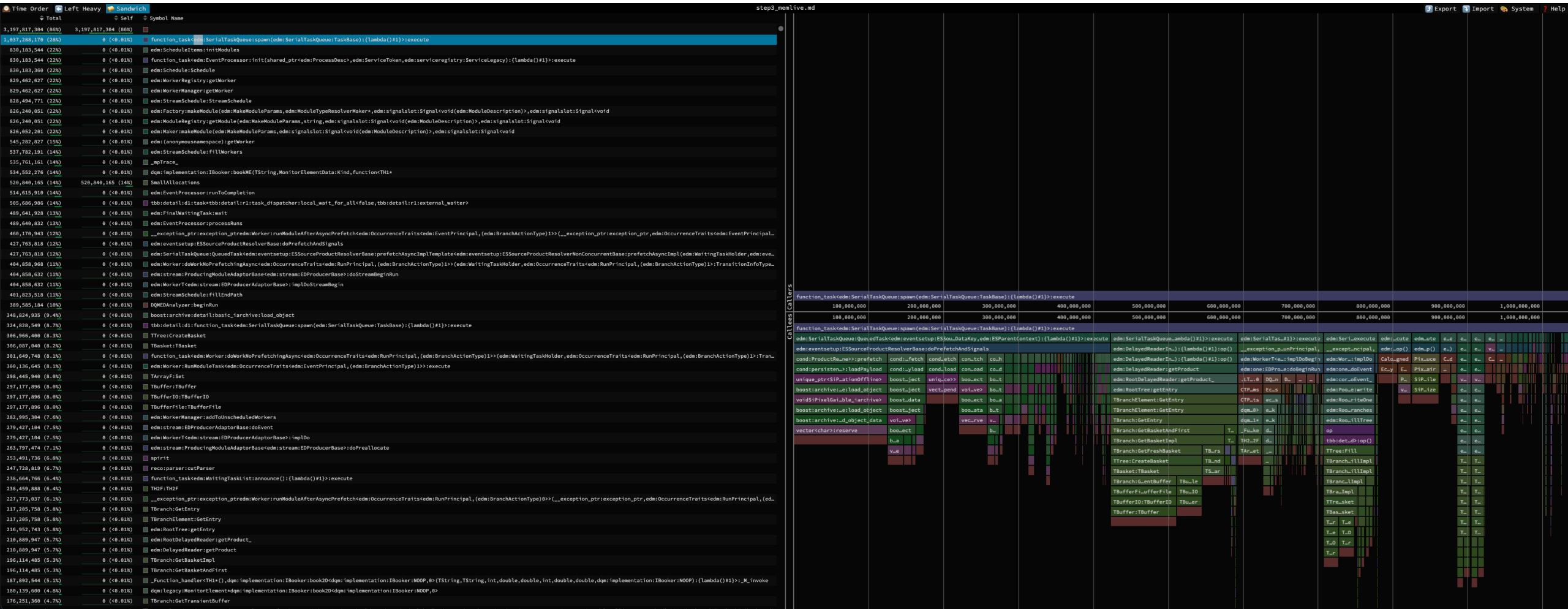
Flamegraph (memtot in "doEvent")



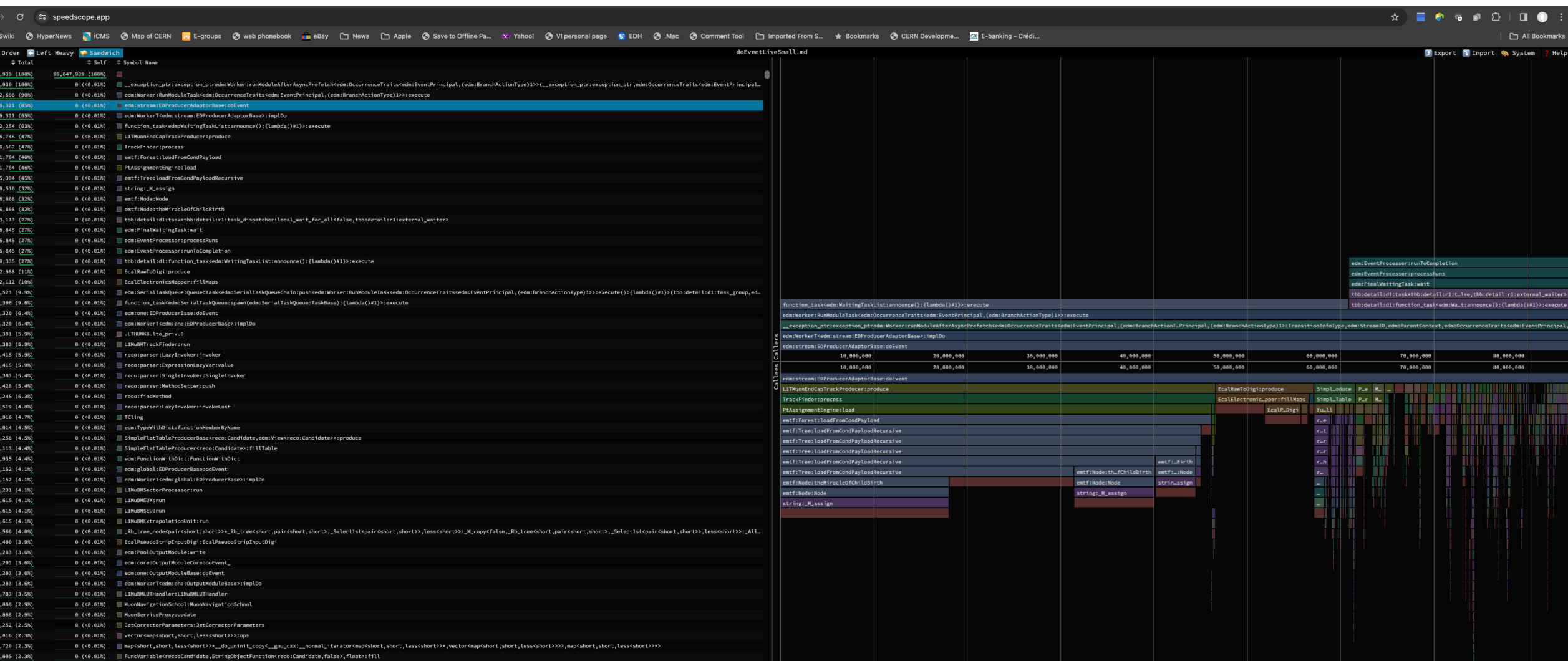
SpeepScope: MemTot >128B in doEvent



Speedscope (memlive >128B full)

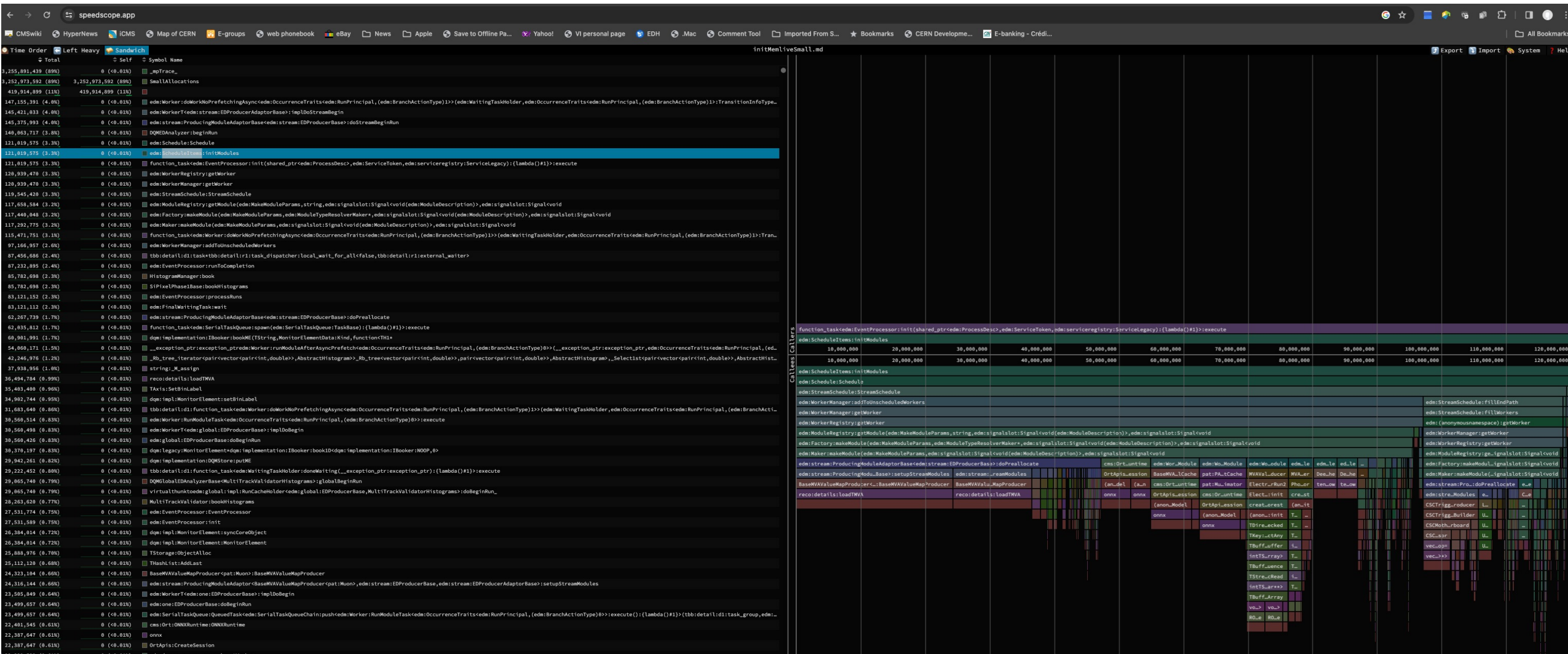


Speedscope: memlive SmallAlloc in doEvent




```
grep -v doEvent memliveSmall.md | grep -v spirit | sed 's/onnx.*\;/onnx\;/g' | sed 's/tensorflow.*\;/tensorflow\;/g' | sed 's/TMVA.*\;/TMVA\;/g' | sed 's/Hashtable.*\;/Hashtable\;/g' | grep -v "TClass;"
```

```
grep -v doEvent memliveSmall.md | grep -v spirit | sed 's/onnx.*\;/onnx\;/g' | sed 's/tensorflow.*\;/tensorflow\;/g' | sed 's/TMVA.*\;/TMVA\;/g' | sed 's/Hashtable.*\;/Hashtable\;/g' | grep -v "TClass;"
```



tail -n 11 memliveSmall.md

[illegible]