

Allen: LHCb GPU-based trigger

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GPU

- Each GPU core is slower than that of a CPU, but they outnumber CPU cores by a large amount (thousands vs tens or hundreds)

- For tasks that are paralelizable, GPU's are usually way better in computing power per euro than CPU's are

- eg, for a ML fit in Bs →J/ $\psi\Phi$ decays we find that a GPU 3090 (~2k euro) is ~3-4 times faster than a 7k euro Ryzen.

- Typically computing power per euro is $>\sim 10x$ better in GPU than in CPU.





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GPU

- GPU's are programmed using CUDA (NVIDIA models) or OpenCL (any model). They are very similar to C/C++

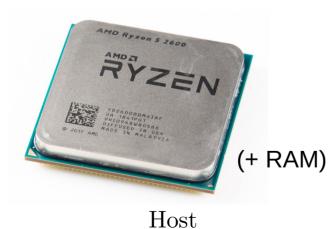
- Can also be managed in python via pycuda/pyOpenCL
- Some useful models

Model	Memory (GB)	F32 speed (TFLOPS)	Price (NA, USD)
RTX 2080 Ti	11	12	~1000 (2018)
RTX 3080	10	25-30	700
RTX 3080 Ti	12	34	1200
RTX 3090	24	36	1500
PS4 (c. AMD)	8	1.8	~400 (2013)
PS5 (c. AMD)	16	10	~400



Host and device

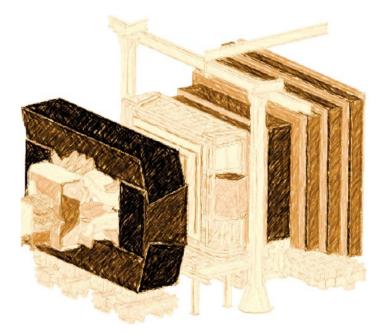
- In CUDA world, 'host' refers to the CPU and 'device' to the GPU
- Functions that run on the GPU are defined as _device_ bla
- Functions that run on the CPU are defined as _host_ bla
- Functions that run on both are defined as _global_ bla





LHCb

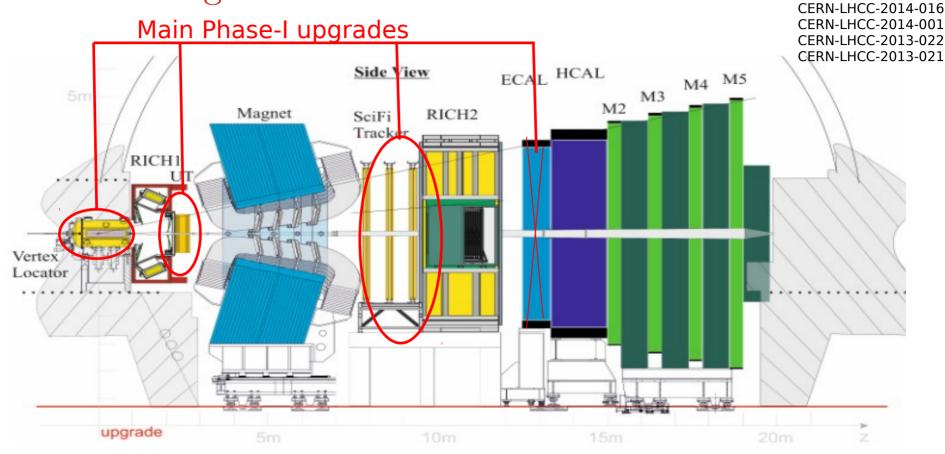
- Experiment at the LHC
- Studies **b** and **c** decays
- LHC produces bunch crossings at a rate of 40 M per second
- ${\sim}25\%$ are empty, so the "real" input rate is 30 M events per second (30 MHz)







LHCb tracking

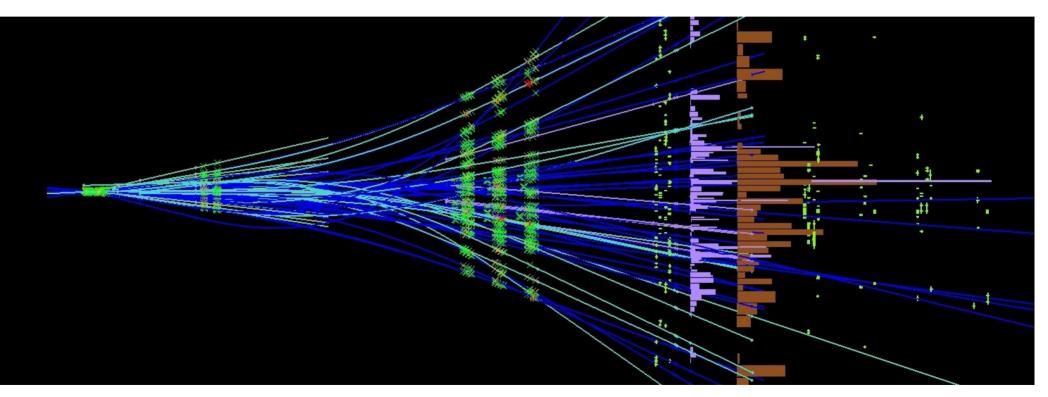


Long Track: hits in Vertex Locator & UT & SciFi



CERN-LHCC-2014-016 CERN-LHCC-2014-001 CERN-LHCC-2013-022 CERN-LHCC-2013-021

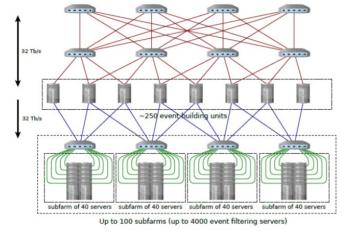
LHCb tracking

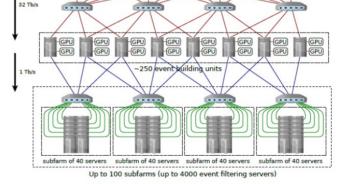


Long Track: hits in Vertex Locator & UT & SciFi



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CPU paradigm (baseline):

* The CPU farm processes both HLT1 & HLT2

GPU paradigm:

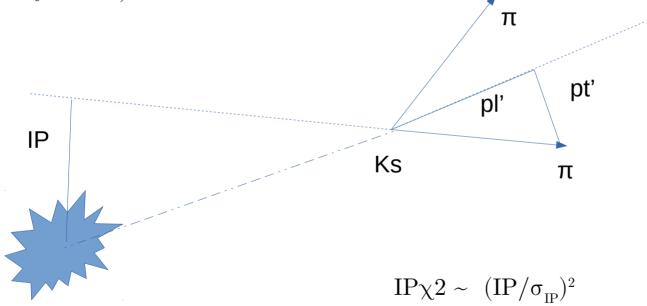
....

- * The GPU's replace the event building units, and run HLT1
- * CPU farm has to process only HLT2
- * Mind also the cheaper network system \rightarrow the cost reduction in network is already enough to pay the GPU farm!



V0 decays

V0 decays are neutral particles decay to two charged particles (Ks $\rightarrow \pi\pi$, $\Lambda \rightarrow p\pi$ but also many others)



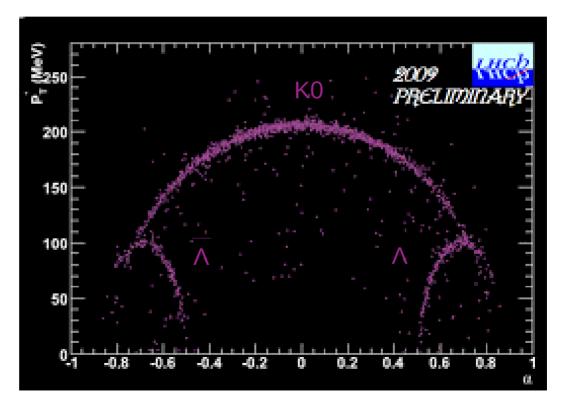


Armenteros-Podolanski plot

Y axis: pt'

X axis: α

$$\alpha = (pl'^{+} - pl'^{-})/(pl'^{+} + pl'^{-})$$





Allen lab, part I

- Optimize threads/memory for your card:
- + Find which is your card: nvidia-smi -a (or -q)
- + Compile w/o ROOT (should be done already)

+ ./Allen -
n500-r1000-m1000-t10--device
 0--mdf `ls -d.././DATA/*mdf | xargs echo sed 's
/ /,/g'`

-m : memory per thread
-t :number of threads
--device: GPU ID (details later)
-n : number of events, -r: repetitions

+ Note that $\mathbf{m} \mathbf{x} \mathbf{t}$ should be smaller or equal than the card memory



Allen lab, part I: throughput

Number of seconds between writes of the monitoring histograms (0: off) (--monitoring-sav Ignore signals to update non-event data with each run change (--disable-run-changes): 1

Opened ../../DATA/upgrade_mc_minbias_scifi_v5_000.mdf Starting timer for throughput measurement

Processing complete This is the throughp

108395.883213 events/s

Ran test for 46.127213 seconds

••• [diego.santos@pi057109_build]\$

This is NOT the throughput. Though you can also look at how does it change



Allen lab, part II

- + Edit the filter (LambdaFilter.cu) and the monitoring line (LambdasLine.cu)
- <bla>AllenSt1(2)/device/LAMBDAS/lambda_filter/src/LambdaFilter.cu
<bla>AllenSt1(2)/device/selections/lines/inclusive_hadron/src/LambdasLine.cu
- + in build: rm -rf *, then Compile w/ ROOT
- + ./Allen -m 1000 -t 10 --device 0 --mdf `ls -d ../../DATA/*mdf | xargs echo | sed 's/ /,/g'`
- + Don't run repetitions here, just the full dataset
- + Inspect the output (build/output/*root)

Quick look at LambdaFilter.cu

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		> associate			{//output arrays, mf means nothing, just historical				
-		> calo		12	<pre>set size<dev event="" list="" mf="" t="">(arguments, first<host events="" number="" of="" t="">(arguments));</host></dev></pre>				
•		> event_model		13	<pre>set_size<dev_mask_mf_t>(arguments, first<host_numbeof_events_t>(arguments)); //another event list, copy of the 1 a</host_numbeof_events_t></dev_mask_mf_t></pre>	above			
- 2		> example			<pre>set_size<host_event_list_mf_t>(arguments, first<host_number_of_events_t>(arguments)); //event list declared in host</host_number_of_events_t></host_event_list_mf_t></pre>				
		> kalman			<pre>set_size<dev_selected_events_mf_t>(arguments, 1); //counter (size is 1)</dev_selected_events_mf_t></pre>				
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		> SciFi			initialize <dev event="" list="" mf="" t="">(arguments, 0, context);</dev>				
		> selections			initialize <dev_selected_events_mf_t>(arguments, 0, context);</dev_selected_events_mf_t>				
2					initialize <dev_mf_decisions_t>(arguments, 0, context);</dev_mf_decisions_t>				
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		.gaudi_project_ignore	e		<pre>global_function(lambda_filter)(dim3(size<dev_input_event_list_t>(arguments)), property<block_dim_t>(), context)(</block_dim_t></dev_input_event_list_t></pre>				
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		> doc			Allen::copy <host_event_list_mf_t, dev_event_list_mf_t="">(arguments, context);</host_event_list_mf_t,>				
		> Dumpers							
		> external			Allen::copy <dev_mask_mf_t, dev_event_list_mf_t="">(arguments, context);</dev_mask_mf_t,>				
: 🛒		> host		40					
		> input		41	Allen::synchronize(context); reduce size <host event="" list="" mf="" t="">(arguments, first<host events="" mf="" selected="" t="">(arguments)); //free memory</host></host>				
		> integration		42 43	reduce size <dev event="" list="" mf="" t="">(arguments, first<host events="" mf="" selected="" t="">(arguments)); //ree memory</host></dev>	A Unable to watch for file changes in this	large wor	kspace	@ ×
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	^o	> output			assign_to_host_buffer <dev_event_list_mf_t>(host_buffers.host_event_list_mf, arguments, context);</dev_event_list_mf_t>				
	snz	> OUTLINE		47	unsigned* host_number_of_selected_events = &host_buffers.host_number_of_selected_events;			Instru	uctions
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		> checker	55 56	<pre>const unsigned number_of_events = parameters.dev_number_of_events[0]; const unsigned event number = parameters.dev input event list[blockIdx.x];</pre>		THE SAME AS A
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		> example	64	number of events};		
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		v src 70 const unsigned sv offset = parameters.dev sv offsets[event number];				
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A		> PV		construction for the secondary vertices - parameters accurate accu		
		> SciFi		for (unsigned i_sv = threadIdx.x; i_sv < n_svs; i_sv += blockDim.x) {		
		> selections		<pre>auto vertex = event_secondary_vertices[i_sv];</pre>		
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		> velo	82 83	<pre>bool alpha_sign = alpha < 0; if (parameters.alpha positive==1) alpha sign = alpha > 0; // config the filter if u want lambdas or anti-lambdas</pre>		
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		> main	94	if (threadIdx.x == 0 & & event mf_decision[0]) {	folder. Please follow the instructions link to	resolve this
	8	> mdf	95 96	<pre>const auto selected_event = atomicAdd(dev_selected_events_mf, 1); parameters.dev_event_list_mf[selected_event] = event_number;</pre>	issue.	
		> output	90	}		Instructions
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A		> PV	76 77	<pre>const VertexFit::TrackMVAVertex* event_secondary_vertices = parameters.dev_consolidated_svs + sv_offset; //Two Prong</pre>	vertices	
		> SciFi	78	for (unsigned i sv = threadIdx.x; i sv < n svs; i sv += blockDim.x) {		
		> selections •		auto vertex = event_secondary_vertices[i_sv];		
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		> doc	87 88	atomicOr(event_mf_decision, dec);		
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		> selections •	79 auto vertex = event_secondary_vertices[i_sv]; Your V0 candidates	
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		> utils	81 float alpha = -1;	
		> velo	<pre>82 bool alpha_sign = alpha < 0; 83 if (parameters.alpha positive==1) alpha sign = alpha > 0; // config the filter if u want lambdas or anti-lambdas</pre>	_
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Q	G	✓ ALLEN_INFIERI_21 [SSH: 17 [] □	() 日 AllenSt1 > device	e > LAMBDAS > lambda_filter > src > C · LambdaFilter.cu				
		> AllenBackup	• 51 }			2010 1970	generation	
		✓ AllenSt1	• 52					
►	90	> backend		<pre>>al_ void LambdaFilter::lambda_filter(LambdaFilter::Parameters parameters)</pre>				
	ð 4 7		54 { 55 cons	st unsigned number of events = parameters.dev number of events[0];		100	AND CARGONIC ME	
		> checker		st unsigned event number = parameters.dev input event list[blockIdx.x];				Ē
•	£	> cmake						
	-0	> configuration		Fi::Consolidated::ConstTracks scifi_tracks {parameters.dev_atomics_scifi, //number of tracks. Consolidated SciFiTracks == (pre) LongTracks here				
. =	₿	✓ device	• 59 60	parameters.dev_scifi_track_hit_number, parameters.dev scifi qop,			0.000 Anno 2000 Anno 2000 Anno 2000 Anno 2000 Anno 2000 Anno 2000	
• 🔛		> associate	61	parameters.dev scifi gop, parameters.dev scifi states, //state in scifi		100	MACONERCYMENT -	
	Ē	> calo	62	parameters.dev scifi_track_ut_indices,				
•		> event_model		event_number,				
1		> example	64	<pre> </pre>				
		> kalman ~ LAMBDAS	65 66 cons	st unsigned event offset = scifi tracks.tracks offset(event number);				
•		✓ LAMBDAS ✓ lambda_filter		t unsigned number of tracks event = scifi tracks.number of tracks(event number);				
		> include	68 unsi	igned* event_mf_decision = parameters.dev_mf_decisions.get() + event_number; //not a bool cs u can't do atomic OR w/ Bools.				
			69					
0		G- LambdaFilter.cu		st unsigned sv_offset = parameters.dev_sv_offsets[event_number]; st unsigned n svs = parameters.dev sv offsets[event number + 1] - sv offset;				
		E LambdaFilter.cu~	72	A missing i parameters det or sets terent_number (+ 1) = 31_or 13et,				
٤		M CMakeLists.txt		itted tracks				
9		⊑ CMakeLists.txt~		st ParKalmanFilter::FittedTrack* event_tracks = parameters.dev_kf_tracks + event_offset; //Kalman Filter				
-0-		> muon		Secondary vertices. st VertexFit::TrackMVAVertex* event secondary vertices = parameters.dev consolidated svs + sv offset; //Two Prong vertices				
A		> PV	76 Cons	vertexite				
		> SciFi		(unsigned i_sv = threadIdx.x; i_sv < n_svs; i_sv += blockDim.x) {				
		> selections		ito vertex = event_secondary_vertices[i_sv]; Your selection criteria	, go	C		
			80		0			
		> utils		toat alpha = -1; pol alpha sign = alpha < 0;				
		> velo		f (parameters.alpha positive==1) alpha sign = alpha > 0; // config the filter if u want lambdas or anti-lambdas	_			
		> vertex_fit		bol dec = 0;)				
		gaudi_project_ignore M CMakeLists.txt	85 M 95 jf					
\sim		> doc	00 1	f (dec) { atomicOr(event mf decision, dec);				
		> Dumpers	88 }					
		> external						
		> host						
-		> input		/ncthreads(); igned* dev selected events mf = parameters.dev selected events mf.get();				
		> integration		cgned+ dev_selected_events_mit = parameters.dev_selected_events_mit.get();	nis large	workspace	e 😳 🔅	
• 🙋		> main		(threadIdx.x == 0 && event_mf_decision[0]) { folder. Please follow the instructions	link to r	esolve thi	s	
	8	> mdf		<pre>onst auto selected_event = atomicAdd(dev_selected_events_mf, 1);</pre>				
		> output		arameters.dev_event_list_mf[selected_event] = event_number;			Instructions	
•••	203	> OUTLINE	97 } 98 }				inscruceions	
:::	1.0011	> TIMELINE I: 172.16.57.91 🐉 master* 🕂 🛞		Ln 1, Col 1 Spaces: 2		15 - 649		

Quick look at LambdasLine.cu

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LambdasLine.cu - ALLEN_INFIERI_21 [SSH: 172.16.57.91] - Visual Studio Code

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dit Selection View Go Run Termin	nal Help		
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Allen_INFIER_21 [SSH:17 [1]; F.; U) P > AllenBackup > AllenSt1 > AllenSt2 > DATA < INITS C LambdaFilter.cu C LambdaSLine.cu > SOLS rebootclass.csh E usefulcommands.crap	<pre>/************************************</pre>	The arrays in which you will add information from the event, to be sent later to the ROOT ntuple	
> TIMELINE	48 #ifdef WITH_ROOT		

🗴 SSH: 172.16.57.91 💡 master* 🕂 🛞 0 🔬 0 👷 0

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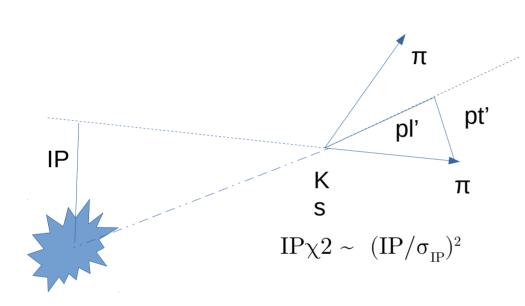
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		LambdasLine.cu -	ALLEN_	INFIERI_21 [SSH: 172.16.57.91] - Visual Studio Code	
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0	C	→ ALLEN_INFIERI 21 [SSH: 172.16.57.91]		INITS > C LambdasLine.cu	
	0	✓ ALLEN_INFIEKE_21 [35H: 172.16.57.91] > AllenBackup		57 }	
		> AllenSt1			The second
>_		> AllenSt2		59 device void lambda line::lambda line t::monitor(
	550	> DATA		60 const Parameters& parameters,	
		✓ INITS		61 std::tuple <const vertexfit::trackmvavertex&=""> input,</const>	in a second s
3)	æ>	G LambdaFilter.cu		62 unsigned index, 63 bool sel)	
		€- LambdasLine.cu		64 {	Carlo and a second
	ß	≣ LambdasLine.cu~		<pre>65 const unsigned event_number = parameters.dev_event_list[blockIdx.x];</pre>	plitition p
		✓ SOLS		<pre>66 const unsigned number_of_events = parameters.dev_number_of_events[θ];</pre>	I THE DOWN
	<u>G</u>	€ LambdaFilter.cu		67 68	the R and a second
		€- LambdasLine.cu		<pre>69 const auto& vertex = std::get<0>(input);</pre>	4. (MIGTORNAL) A and A and A a
		🗐 rebootclass.csh			
		≣ usefulcommands.crap		71 if (sel) {	
-				72 // Consolidated SciFi tracks. 73 SciFi::Consolidated::ConstTracks scifi tracks {parameters.dev atomics scifi.	
				73 SciFi::Consolidated::ConstTracks scifi_tracks {parameters.dev_atomics_scifi, 74 parameters.dev scifi track hit number,	
				75 parameters.dev_scifi_qop,	
0				<pre>76 parameters.dev_scifi_states,</pre>	
_		Make sure you feed here the		77 parameters.dev_scifi_track_ut_indices, 78 event number,	
E				79 number of events};	
S		arrays w/ the information			
				81 float pti = 0.;	
Δ		you'll want to add later to		82 parameters.dev_pt[index] = pti; 83 }	
				84 }	
		the ROOT file		85	
(?)		(Dight many inst adds some og)		86 void lambda line::lambda line t::output_monitor(
		(Right now just adds zeroes)		87 const ArgumentReferences <parameters>& arguments,</parameters>	
				88 const RuntimeOptions& runtime_options, 89 const Allen::Context& context) const	
				92 auto name_str = name();	
Į				<pre>93 std::string name_ttree = "monitor_tree" + name_str; 94 Allen::copy<host dev="" masses="" sv="" t="" t,="">(arguments, context);</host></pre>	
				95 Allen::copy <host dev="" pt="" t="" t,="">(arguments, context);</host>	
				<pre>96 Allen::synchronize(context);</pre>	
				<pre>98 auto handler = runtime_options.root_service->handle(); 99 handler.file("monitorLambda.root");</pre>	nges in this large workspace 🛛 🐯 🗡
				100 folder. Please follow the inst	cructions link to resolve this
	8			<pre>101 auto tree = handler.ttree(name_ttree.c_str()); issue.</pre>	
				102 floot at	Instructions
•••	503	> OUTLINE		103 float pt; 104	instructions
:::	C CCL	> TIMELINE :172.16.57.91			paces: 2 UTF-8 LF CUDA C++ 🔗 🕻
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		> AllenBackup • > AllenSt1 •			
• >_	20	> AllenSt2 •	82 } 83 }		
	0 47	> DATA			
:(())	a ₿	✓ INITS C LambdaFilter.cu	85 void lambda_line::lambda_line_t::output_monitor(86 const ArgumentReferences <parameters>& arguments,</parameters>		Mancers Mineses
	-0	G- LambdasLine.cu	87 const RuntimeOptions& runtime_options,		
• 🔤	₿	> SOLS rebootclass.csh	<pre>88 const Allen::Context& context) const 89 {</pre>		
	G	■ rebootclass.csn ≡ usefulcommands.crap			
			<pre>91 auto name_str = name(); 92 std::string name ttree = "monitor_tree" + name str;</pre>		Villationani . Martini
- 2			<pre>93 Allen::copy<host_sv_masses_t, dev_sv_masses_t="">(arguments, context); 94 Allen::copy<host_pt_t, dev_pt_t="">(arguments, context);</host_pt_t,></host_sv_masses_t,></pre>		
			95 Allen::synchronize(context);		
			96 97 auto handler = runtime options.root service->handle();		
0			98 handler.file("monitorLambda.root"); Ien Anen Wildt to Save to		
			auto tree = handler.ttree(name_ttree.c_str()); ROOT file		
0			101 102 float pt;		
E			102 Hoat pt, 103		
			104 105 handler.branch("pt", pt);		
A					
			<pre>107 108 unsigned n svs = size<host masses="" sv="" t="">(arguments);</host></pre>		
?			109 float* sv pt;		
			<pre>110 int i0 = tree->GetEntries(); 111 for (unsigned i = 0; i < n_svs; i++) {</pre>		
			<pre>112 sv_pt = data<host_pt_t>(arguments) + i; 113</host_pt_t></pre>		
			1/4 pt = sv_pt[0]; Loop over the candidates		
			and save info to the TTree		
			117 tree->Write(0, TObject::kOverwrite);		
			118) 119 #endif		
			120		
. 7					
	0				
	Ø				
:::	503	> OUTLINE > TIMELINE			



Allen lab, part II



Some useful variables for selecting V0's (and/or to monitor in your ROOT file)

* Minimum IP $\chi 2$ of the pions * $\chi 2$ of the decay vertex fit * Armenteros variables : (these you have to compute from the Kalman tracks)

Some examples implementing a filter and/or instantiating vertices:

https://gitlab.cern.ch/lhcb/Allen/-/blob/master/device/muon/muon_filter/src/MuonFilter.cu https://gitlab.cern.ch/lhcb/Allen/-/blob/master/device/vertex_fit/vertex_fitter/src/VertexFitter.cu#L66 https://gitlab.cern.ch/lhcb/Allen/-/blob/master/device/selections/lines/muon/src/DiMuonSoftLine.cu

Backup



Setup your session

Usernames are infieri1, infieri2, and infieri3. To connect to the machines:

ssh -X infieri1(2,3)@mastercr1.igfae.usc.es ssh -X infieri1(2)@172.16.57.91 (or ssh -X infieri3@172.16.57.223)

(for MAC users is ssh - Y)

source /cvmfs/sft.cern.ch/lcg/views/setup
Views.sh LCG_99 x86_64-centos7-clang10-opt source /cvmfs/sft.cern.ch/lcg/contrib/cuda/11.2/x86_64-centos7/setup.sh

You have these lines (plus other useful commands) in the file 'useful commands' just under ALLEN_INFIERI_21. For copypasting purposes



Paths and devices

- + infieri1: /ALLEN_INFIERI_21/AllenSt1/ uses --device 0
- + infieri2: /ALLEN_INFIERI_21/AllenSt2/ uses --device 1
- + infieri3: /scratch/ALLEN_INFIERI_21/AllenSt1/ uses --device 0 (or 1, doesn't matter)



Allen lab, part I compilation flags

```
Inside <bla>/build/ directory:
```

```
cmake -DSTANDALONE=ON -DTARGET_DEVICE=CUDA -
DCMAKE_BUILD_TYPE=Release -DSEQUENCE=hlt1_pp_default -DUSE_ROOT=OFF ..
&& make -j50
Students 1 and 2: -j50 or -j60 or so
Switch OFF ROOT
```

Student 3 : -j20 or so (CPU is worse in this machine)



Allen lab, part II compilation flags

```
cmake -DSTANDALONE=ON -DTARGET_DEVICE=CUDA -
DCMAKE_BUILD_TYPE=Release -DSEQUENCE=hlt1_pp_default -DUSE_ROOT=ON ..
&& make -j50
Students 1 and 2: -j50 or -j60 or so
```

Student 3 : -j20 or so (CPU is worse in this machine)



A look at Allen printout

configurable algorithm constants (--configuration): Sequence.json

number of events to process (-n, --number-of-events): 500 number of input slices to allocate (-s, --number-of-slices): 0 number of events per slice (--events-per-slice): 1000 number of threads / streams (-t, --threads): 16 number of repetitions per thread / stream (-r, --repetitions): 1000 memory to reserve on the device per thread / stream (megabytes) (-m, --memory): 500 memory to reserve on the host per thread / stream (megabytes) (-host-memory): 200 verbosity [0-5] (-v, --verbosity): 3 offload part of the computation to CPU (--cpu-offload): 1 Write selected event to output file (--output-file): select device to use (--device): 0, NVIDIA GeForce RTX 3090