Study of Dark Matter at e+ e- collider using KISTI-5 supercomputer

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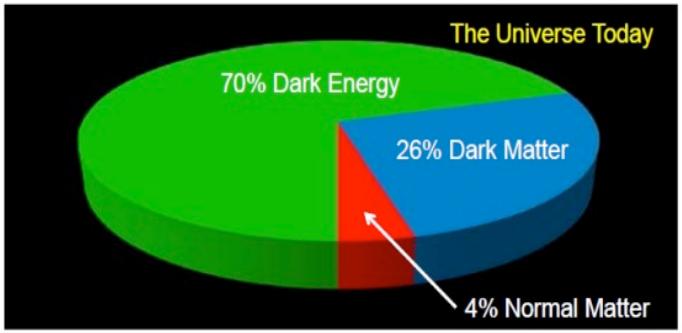
Contents

1. Introduction

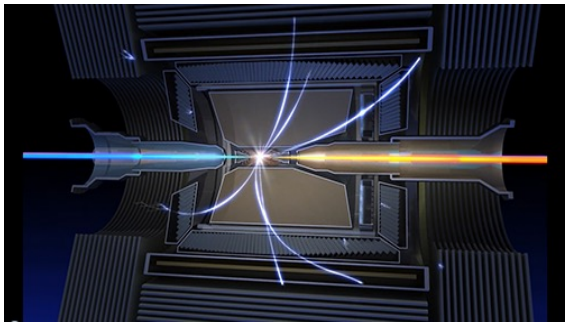
What is dark matter?

- Dark Matter (DM) is invisible matter.
- DM occupy 26 % of the density of the universe.
- We have sufficient evidence of existence of DM.
- But, DM is not detected yet.
- We can search for DM at collider experiments.



Ref. PDG

Courtesy NASA



Courtesy Belle II

Motivation

- Cross section of dark matter is very small.
  $\Longrightarrow$ Huge amount of simulation data is required.

- Hence, parallel processing is important to increase the efficiency of research in High Energy Physics (HEP).

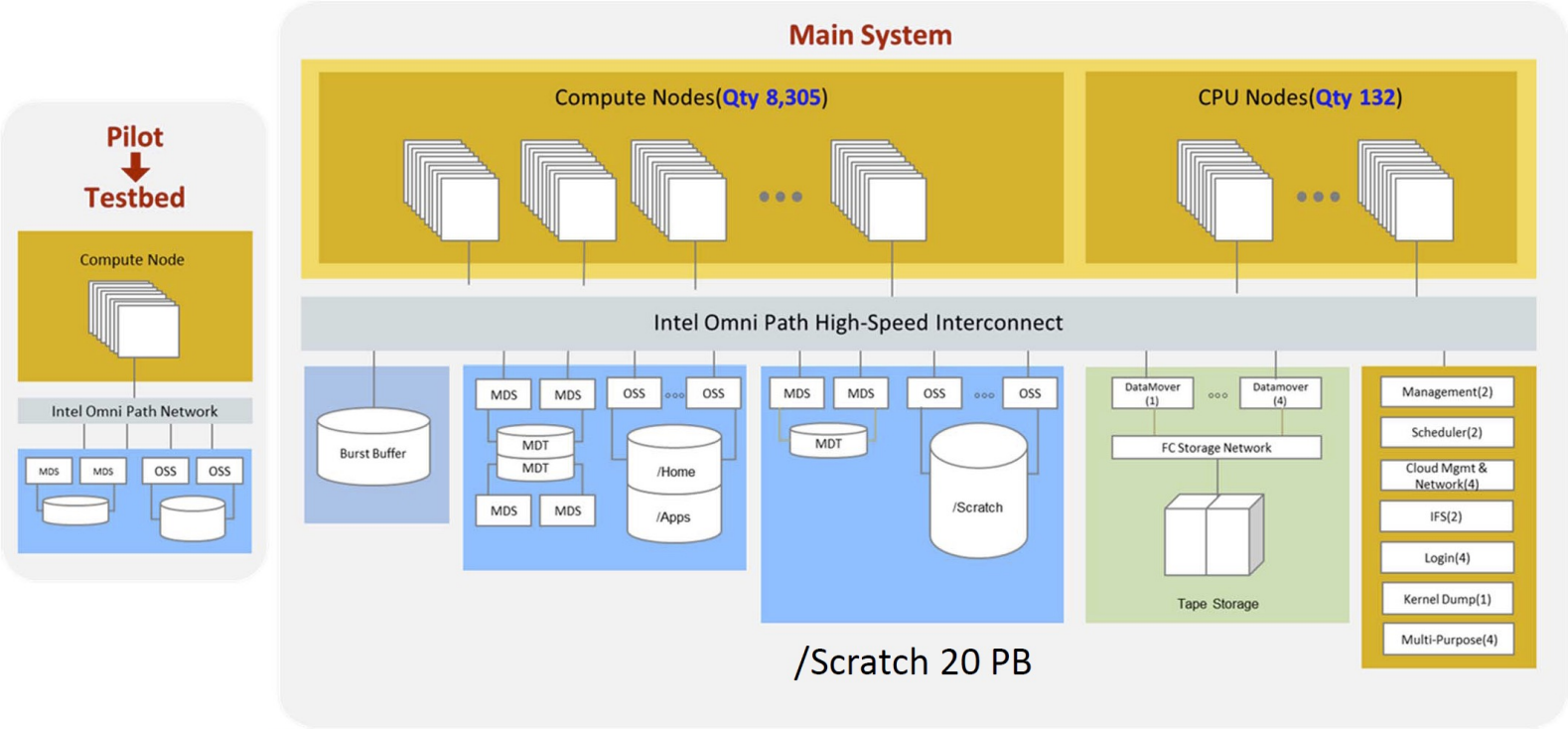
- To study parallel processing, we have compared the KISTI-5 supercomputer (Nurion KNL and SKL) and the local Linux machine.

2. Methods

Specification of used machines

Specification	KISTI-5 KNL	KISTI-5 SKL	Local Linux machine
OS	CentOS 7.4	CentOS 7.4	Scientific Linux 6.5
Processor	Intel Xeon Phi 7250 1.4 GHz	Intel Xeon Skylake (Gold 6148) 2.4 GHz	Intel Xeon CPU X5560 2.8 GHz
Architecture	Many-core	Multicore	Multicore
Number of cores/CPU	68	20	4
Number of CPUs/node	1	2	8
Number of cores/node	68	40	32
Number of total nodes	8,305	132	1
Number of total cores	564,740	5,280	32

Architecture of KISTI-5 supercomputer



/Home 0.5 PB /Apps 0.5 PB

Burst Buffer 0.8 PB (SSD)

Tape Storage 10 PB

@ Available KNL CORE Time = Available SRU Time x 4,352
@ Available SKL CORE Time = Available SRU Time x 1,280
1 account: 20,000 CPU*hour

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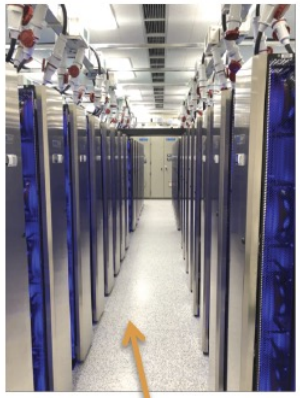
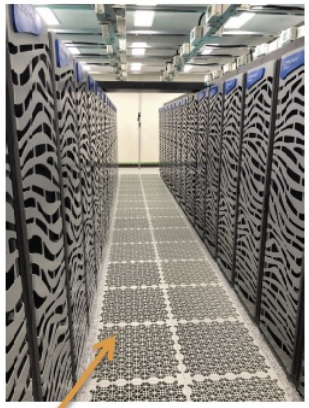
Rack Front Door

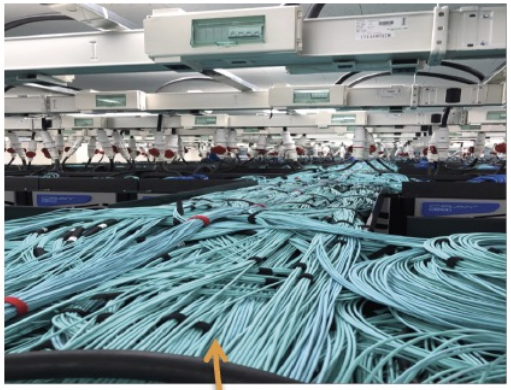
Rack Rear Door



Hot Aisle

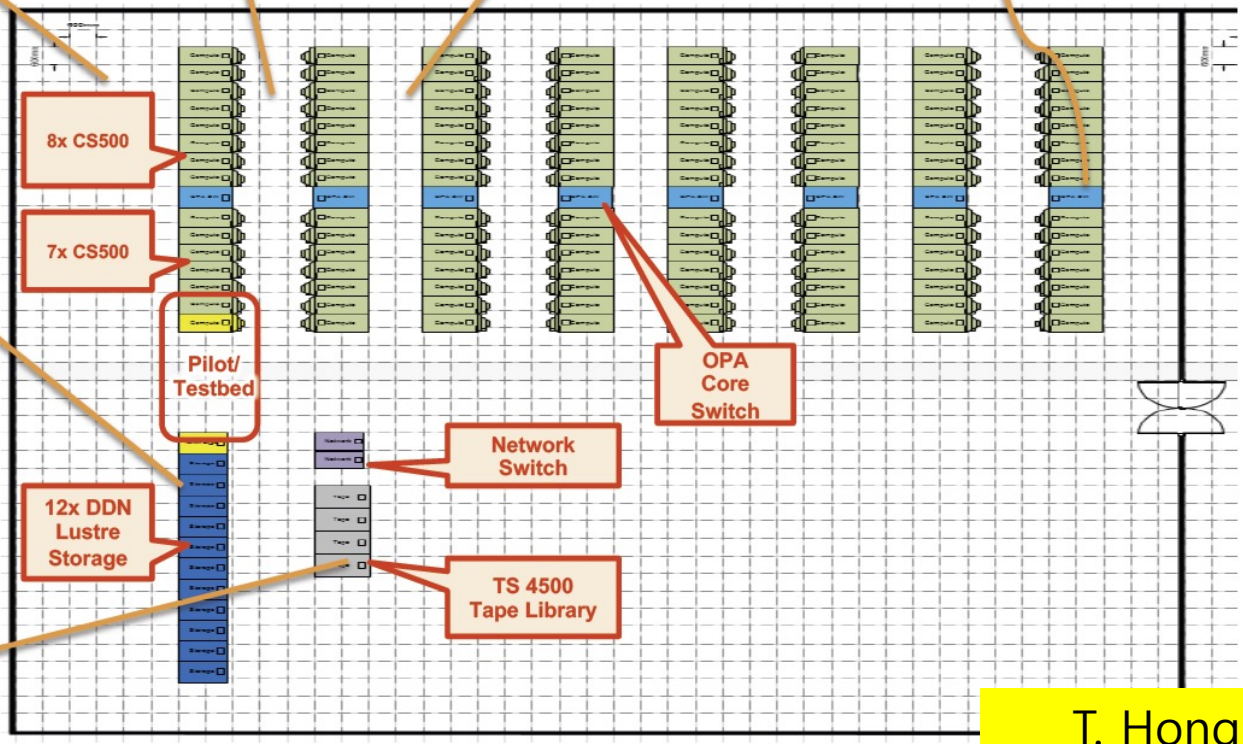


OPA Optic Cables



Disk Storage (21PB)

Tape Storage (10PB)



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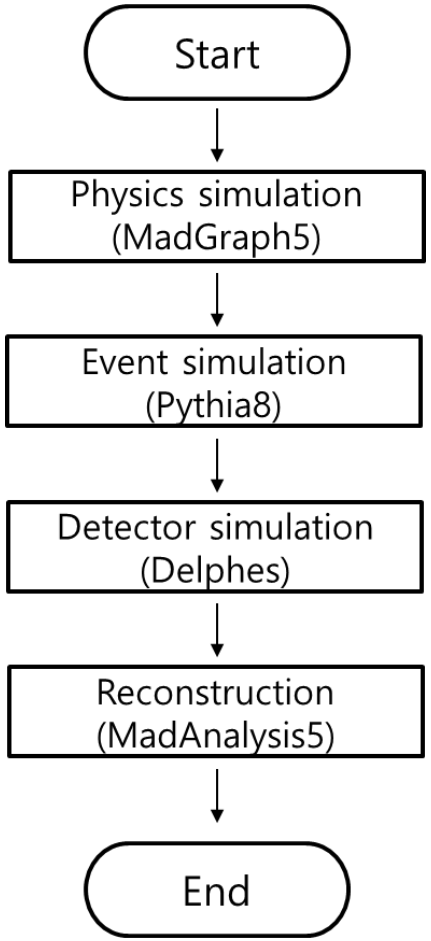
DataDirect
Networks

Flow chart of physics simulation



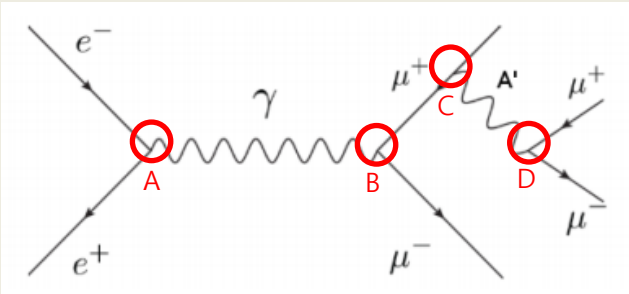
Proccesing	Software		Remark	
			Physics simulation only	Full simulation
I. Physics generation	MadGraph5	MadGraph5	↓	↓
		Pythia8		
II. Detector Simulation		Delphes		
III. Reconstruction		MadAnalysis5		

3. Study of Dark Matter at e+e- collider

Signal Mode

$$e^+ e^- \rightarrow \mu^+ \mu^- A'$$
$$\hookrightarrow \mu^+ \mu^-$$

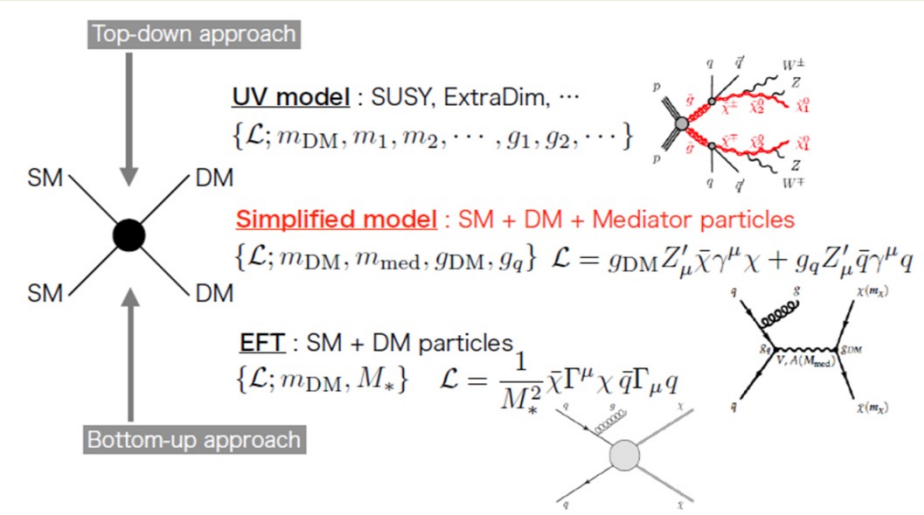
- **Feynman diagram of signal process [1, 2]**



[1] Insung Yeo and Kihyeon Cho, *J. Astron. Space Sci.* 35 (2018) 67-74.
[2] Shuve Brian and Itay Yavin, *Physical Review D* 89.11 (2014) 113004.

	Symbol (paper)	Symbol (MadGraph 5)	Default value	Description
A	α_{EW}^{-1}	aEWM1	1.325070e+02	Inverse of the electromagnetic coupling
B	α_{EW}^{-1}	aEWM1	1.325070e+02	Inverse of the electromagnetic coupling
C	$g_{l_{22}}^{v}$	gvl22	1	Muon-Y1 vector coupling
D	$g_{l_{22}}^{v}$	gvl22	1	Muon-Y1 vector coupling

- **Simplified model [3, 4]**



- The Standard Model particles + Dark Matter + Mediator particles (dark photon)
- A′: dark photon with spin1
- Imported in MadGraph5

[3] Daniele, et al., Alves, *Journal of Physics G*: Nuclear and Particle Physics, 39(10) (2012) 105005.
[4] Kentarou Mawatari's ppt (KAIST-KAIX workshop 07/15/19).

All Feynman diagrams of signal process

(a) $e^+ e^- \to \gamma \to \mu^+ \mu^- A'$

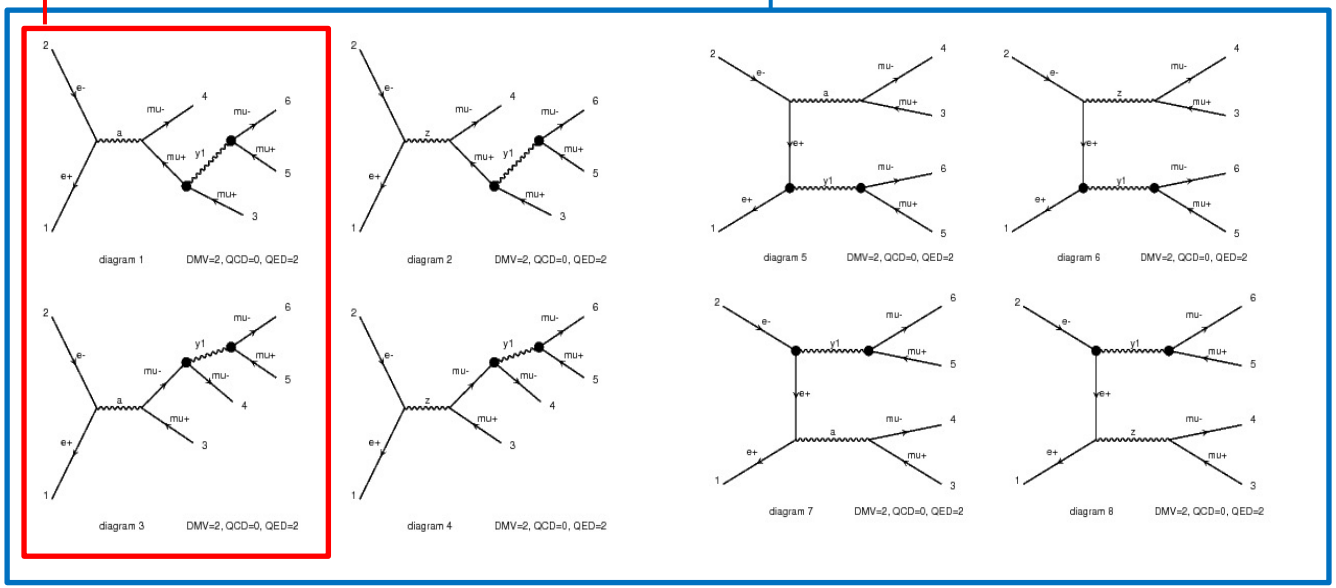
↳ $\mu^+\mu^-$

CM energy $<$ 30 GeV

(b) $e^+ e^- \to \mu^+ \mu^- A'$

↳ $\mu^+\mu^-$

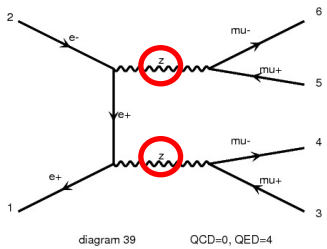
CM energy $\geq$ 30 GeV



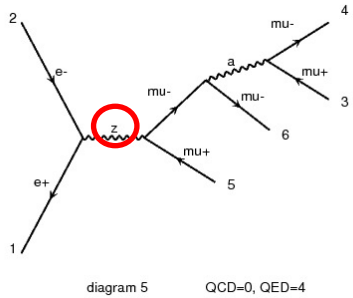
Background (SM) at generation level

$$e^+ e^- \rightarrow \mu^+ \mu^- \mu^+ \mu^-$$

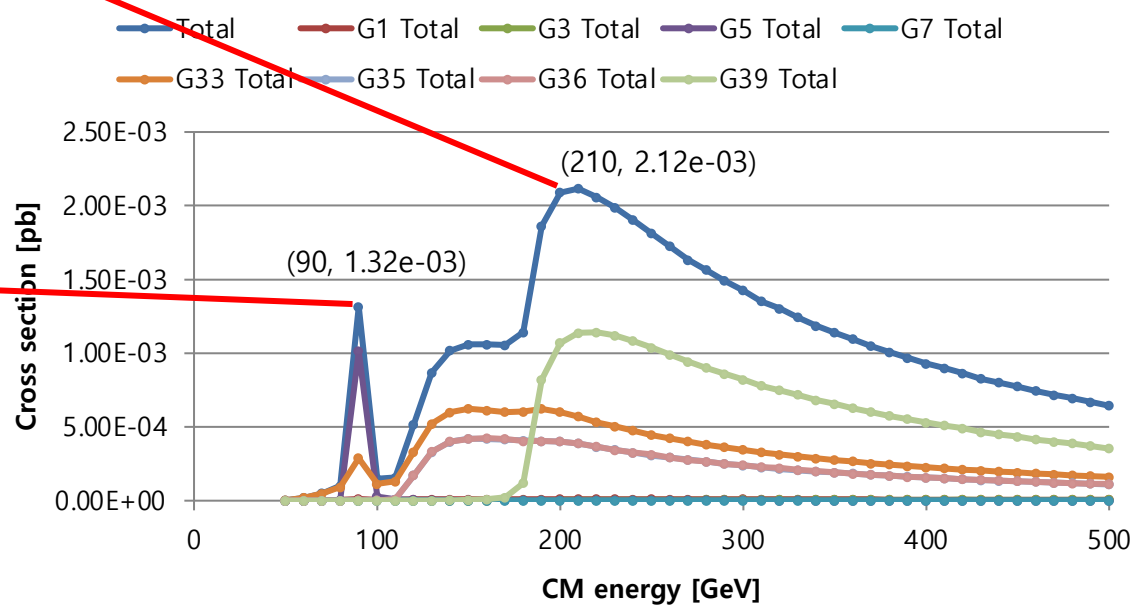
Maximum at 210 GeV (G39)



The First peak at 90 GeV (G5)



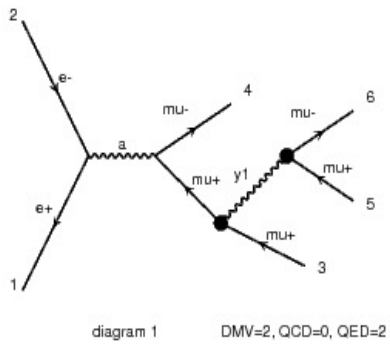
Cross section depending on **CM energy**



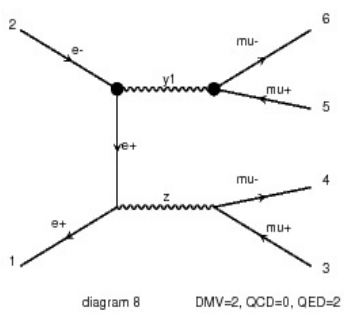
Signal at generation level with parameters(1)

$$e^+ e^- \rightarrow \mu^+ \mu^- A'$$
$$\hookrightarrow \mu^+ \mu^-$$

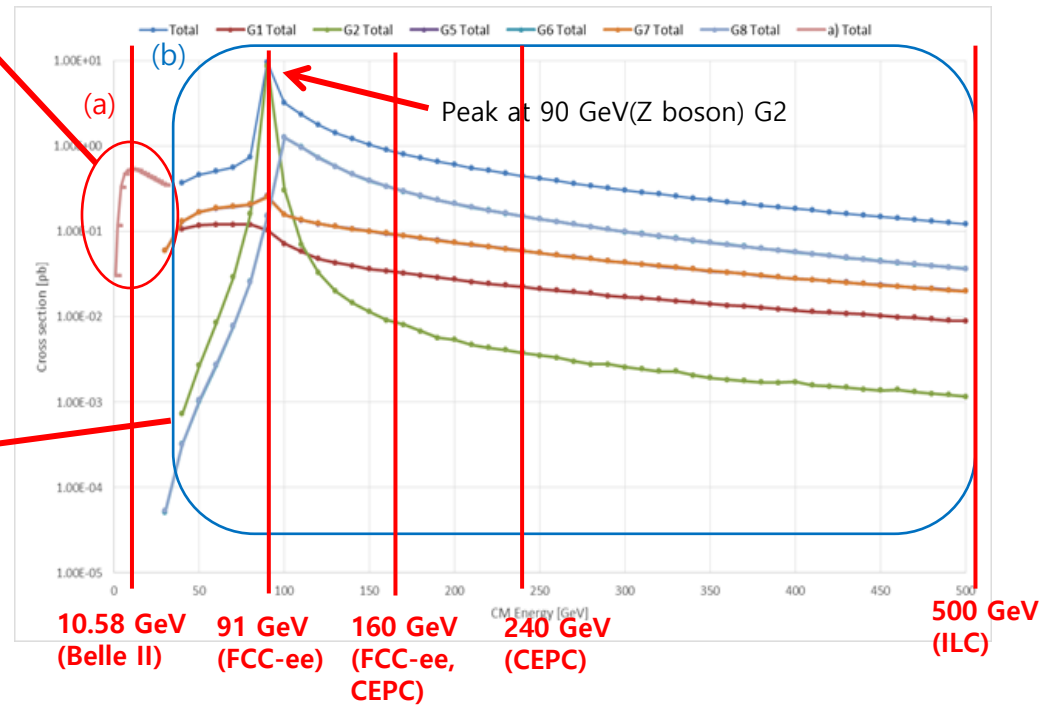
Most dominant mode(G1) in process (a)



Most dominant mode(G8) in process (b)



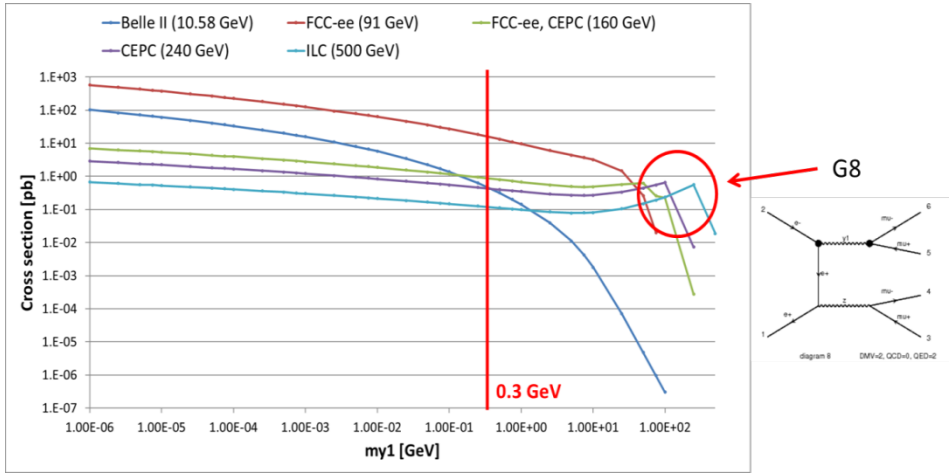
Cross section depending on **CM energy**



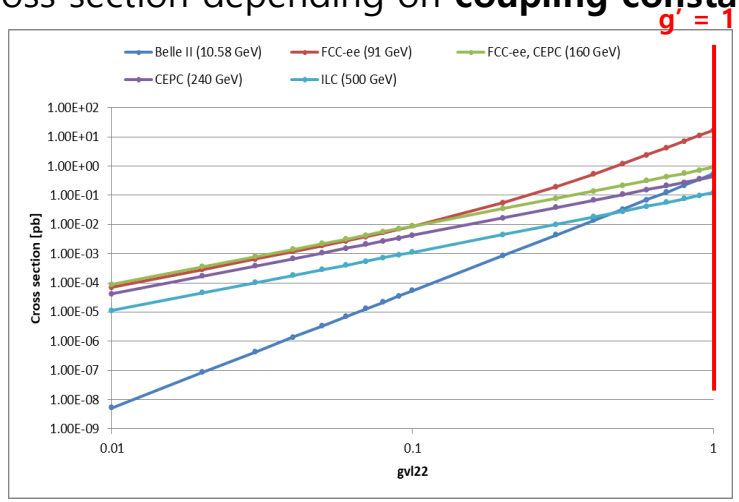
- Dark photon mass: 0.3 GeV
- Coupling constant: 1

Signal at generation level with parameters(2)

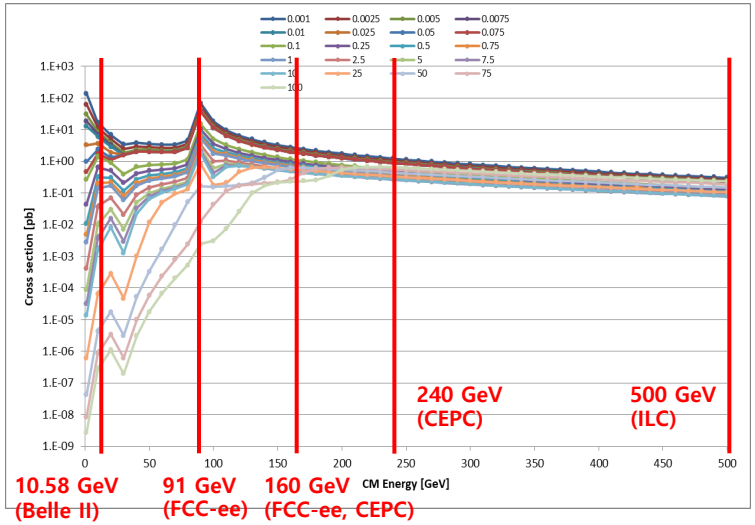
Cross section depending on **dark photon mass**



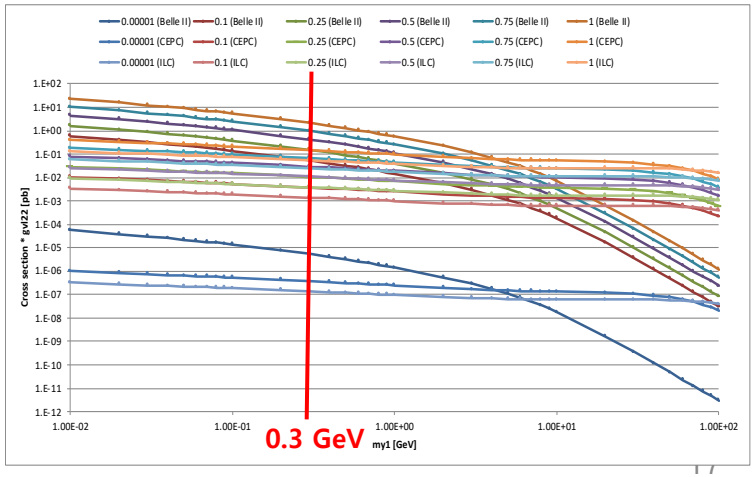
Cross section depending on **coupling constant**



Cross section depending on **both CM energy and dark photon mass**



Cross section depending on **both dark photon mass and coupling constant**



4. Results

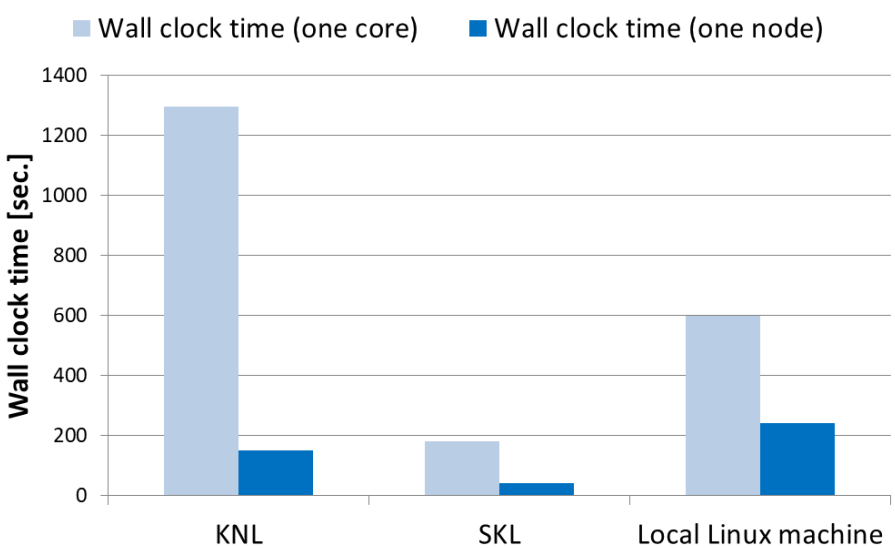
Study of CPU times on machines

Process	e+ e- -> mu+ mu- A', A' -> mu+ mu-
Number of events	10,000
CM Energy	10.58 GeV
Dark photon mass	0.01 GeV
Coupling constant	0.1
Number of jobs	15

Specification	KNL	SKL	local Linux machine
Processor	Intel Xeon Phi 7250 3.0464 TFLOPS/CPU	Intel Xeon 6148 1.536 TFLOPS/CPU	Intel(R) Xeon(R) CPU X5560 2.80GHz
Number of cores/node	68	40	32

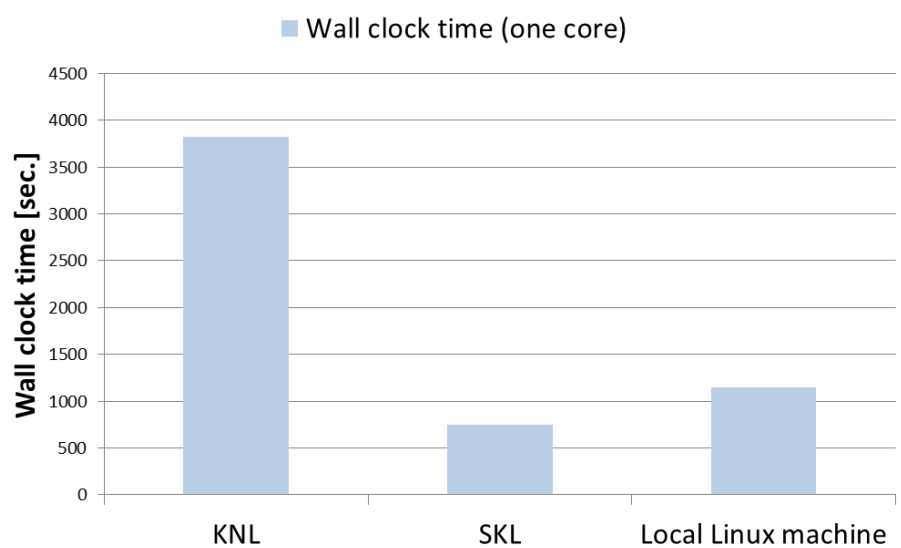
Physics simulation only

Madgraph	on
Pythia8, delphes(CMS), madanalysis5	off



Full simulation

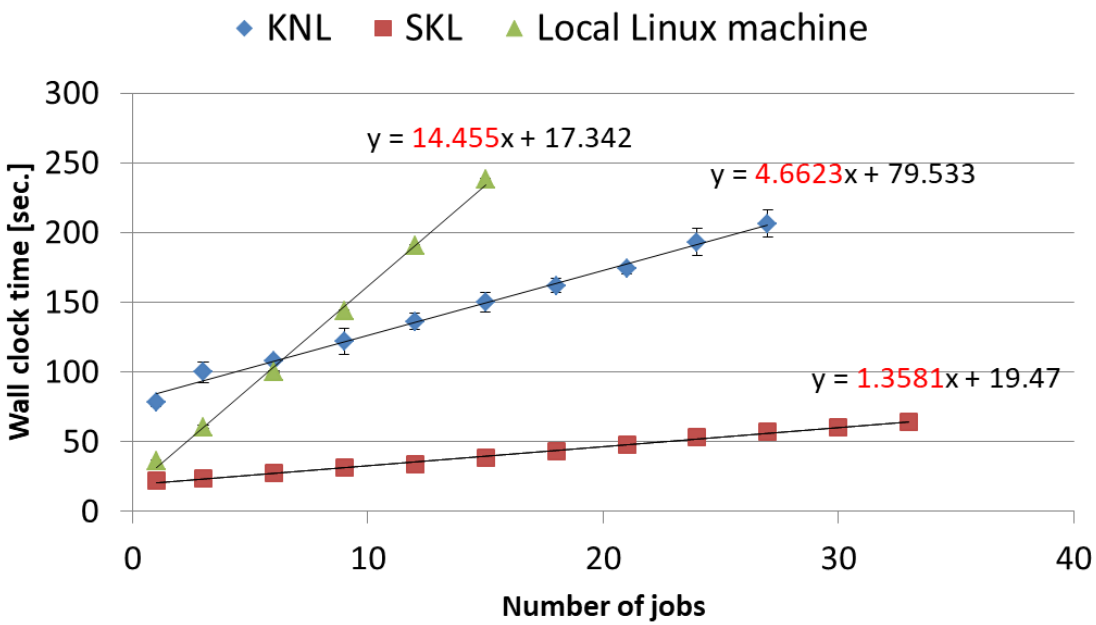
Madgraph	on
Pythia8, delphes(CMS), madanalysis5	on



Study of CPU times on number of jobs

Process	e+ e- -> mu+ mu- A', A' -> mu+ mu-
Number of events	10,000
CM Energy	10.58 GeV
Dark photon mass	0.01 GeV
Coupling constant	0.1
Comment	Physics simulation only
Number of jobs	1, 3, 6, ..., 60, 63, 27 for KNL 1, 3, 6, ..., 27, 30, 33 for SKL 1, 3, 6, 9, 12, 15 for local machine

Specification	KNL	SKL	local Linux machine
Processor	Intel Xeon Phi 7250 3.0464 TFLOPS/CPU	Intel Xeon 6148 1.536 TFLOPS/CPU	Intel(R) Xeon(R) CPU X5560 2.80GHz
Number of cores/node	68	40	32



The smaller the slope,
the better the parallel processing efficiency.

Parallel processing efficiency of the SKL is much better than that of the local Linux machine.

5. Summary

Summary

- We use dark photon that couples only to heavy lepton for signal process.
- At the generation level, we have studied the cross section depending on various parameters.
- We have compared KISTI-5 supercomputer(KNL and SKL) with local Linux machine to study efficiency of parallel processing.
- The results will help to optimize HEP software using HPC.

References

[1] Insung Yeo and Kihyeon Cho, J. Astron. Space Sci. 35 (2018) 67-74.

[2] Shuve Brian and Itay Yavin, Physical Review D 89.11 (2014) 113004.

[3] Daniele, et al., Alves, Journal of Physics G: Nuclear and Particle Physics, 39(10) (2012) 105005.

[4] Kentarou Mawatari's ppt (KAIST-KAIX workshop 07/15/19).

[5] Kihong Park and Kihyeon Cho , J. Astron. Space Sci. 35, (2021) 55-63.

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Thank you for your attention.

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