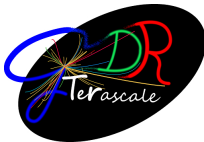


# BSM with muons @COMET

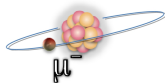
W. da Silva and F. Kapusta  
LPNHE Paris



IPhT Saclay,  
30 mars-1<sup>er</sup> avril 2015

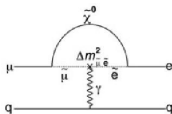
# Physics Motivation : Beyond the Standard Model with muons

- ▶ Direct search (Energy Frontier) LHC, ILC : higher energy for heavier new particle(s).
- ▶ Indirect search (Intensity Frontier): "slight" difference from SM prediction.



## Charged LFV

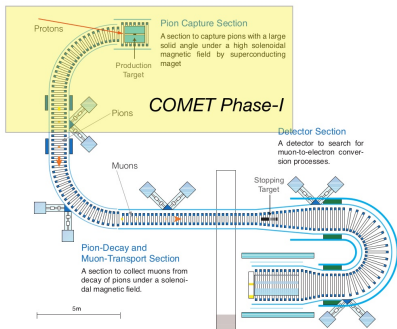
- ▶  $\mu \rightarrow e\gamma$  search from MEG@PSI :  $Br(\mu \rightarrow e\gamma) < 5.4 \cdot 10^{-13}$  (90%CL)
- ▶  $\mu - e$  conversion search : SINDRUMII@PSI  $7 \cdot 10^{-13}$   
COMET@J-PARC  $3 \cdot 10^{-15}$  ( PHASE I) &  $2.6 \cdot 10^{-17}$  ( PHASE II)  
Mu2e@FNAL  $2.4 \cdot 10^{-17}$



# COMET

$\mu \rightarrow e$  conversion

- ▶ Staging approach
- ▶ Phase I to achieve  $10^{-14}$  sensitivity and then Phase II



- ▶ Funding approved in JFY 2012 supplementary budget
- ▶ Annex of the current existing hall
- ▶ 8 GeV, pulsed proton beam to produce high-intensity muon beam
- ▶ J-PARC Hadron Experimental Hall completed by end of JFY2015



# COMET Collaboration



164 collaborators  
37 institutes, 12 countries

## The COMET Collaboration

R. Akhmetshin<sup>6,28</sup>, V. Anishchik<sup>4</sup>, M. Aoki<sup>29</sup>, R. B. Appleby<sup>8,22</sup>, Y. Arimoto<sup>15</sup>, Y. Bagaturia<sup>33</sup>, Y. Bai<sup>3</sup>, W. Bertche<sup>22</sup>, A. Bondar<sup>6,28</sup>, S. Canfer<sup>30</sup>, S. Chen<sup>25</sup>, Y. E. Cheung<sup>25</sup>, B. Chladze<sup>32</sup>, D. Clarke<sup>30</sup>, M. Danilov<sup>13,23</sup>, P. D. Dumbojia<sup>11</sup>, J. David<sup>20</sup>, W. Da Silva<sup>20</sup>, C. Densham<sup>30</sup>, G. Devidze<sup>29</sup>, P. Dornan<sup>11</sup>, A. Drutskoy<sup>13,29</sup>, V. Dugimov<sup>14</sup>, A. Edmonds<sup>25</sup>, L. Epshteyn<sup>6,27</sup>, P. Evtoukhovich<sup>14</sup>, G. Fedotov<sup>6,28</sup>, M. Finger<sup>7</sup>, M. Finger Jr<sup>7</sup>, Y. Fujii<sup>2</sup>, Y. Fukao<sup>15</sup>, J.-F. Genat<sup>20</sup>, M. Gensabeck<sup>22</sup>, E. Gillies<sup>11</sup>, D. Grigoriev<sup>6,27,28</sup>, K. Gritsay<sup>14</sup>, R. Han<sup>1</sup>, K. Hasegawa<sup>15</sup>, I. H. Hasin<sup>29</sup>, O. Hayashi<sup>29</sup>, M. I. Hossain<sup>16</sup>, Z. A. Ibrahim<sup>21</sup>, Y. Igarashi<sup>15</sup>, F. Ignatov<sup>6,28</sup>, M. Iio<sup>15</sup>, M. Ikeno<sup>15</sup>, K. Ishibashi<sup>19</sup>, S. Ishimoto<sup>15</sup>, T. Itahashi<sup>29</sup>, S. Ito<sup>29</sup>, T. Iwami<sup>29</sup>, Y. Iwashita<sup>17</sup>, X. S. Jiang<sup>2</sup>, P. Jonsson<sup>11</sup>, V. Kalinnikov<sup>14</sup>, F. Kapusta<sup>20</sup>, H. Katayama<sup>29</sup>, K. Kawagoe<sup>19</sup>, V. Kazanin<sup>6,28</sup>, B. Khazin<sup>16,28</sup>, A. Khvedelidze<sup>14</sup>, M. Koike<sup>36</sup>, G. A. Kozlov<sup>14</sup>, B. Krielder<sup>11</sup>, A. Kulikov<sup>14</sup>, E. Kulish<sup>14</sup>, Y. Kuno<sup>29</sup>, Y. Kuriyama<sup>18</sup>, Y. Kurochkin<sup>5</sup>, A. Kurup<sup>11</sup>, B. Lagrange<sup>11,18</sup>, M. Lancaster<sup>25</sup>, H. B. Li<sup>2</sup>, W. G. Li<sup>2</sup>, A. Liparteliani<sup>32</sup>, R. P. Litchfield<sup>35</sup>, P. Loveridge<sup>30</sup>, G. Macharashvili<sup>14</sup>, Y. Makida<sup>15</sup>, Y. Mao<sup>3</sup>, O. Markin<sup>13</sup>, Y. Matsumoto<sup>29</sup>, T. Mibe<sup>15</sup>, S. Mihara<sup>15</sup>, F. Mohamad Idris<sup>21</sup>, K. A. Mohamed Kamal Azmi<sup>21</sup>, A. Moiseenko<sup>14</sup>, Y. Mori<sup>18</sup>, N. Mosulishvili<sup>32</sup>, E. Motuk<sup>35</sup>, Y. Nakai<sup>19</sup>, T. Nakamoto<sup>15</sup>, Y. Nakazawa<sup>29</sup>, J. Nash<sup>11</sup>, M. Nioradze<sup>32</sup>, H. Nishiguchi<sup>15</sup>, T. Numao<sup>34</sup>, J. O'Dell<sup>30</sup>, T. Ogitsu<sup>15</sup>, K. Oishi<sup>19</sup>, K. Okamoto<sup>29</sup>, C. Omori<sup>15</sup>, T. Ota<sup>33</sup>, H. Owen<sup>22</sup>, C. Parkes<sup>22</sup>, J. Pasternak<sup>11</sup>, C. Plossnar<sup>30</sup>, V. Pomaradov<sup>4</sup>, A. Popov<sup>6,28</sup>, V. Rusinov<sup>13,23</sup>, A. Ryzhenkov<sup>6,28</sup>, B. Sabirov<sup>14</sup>, N. Saito<sup>15</sup>, H. Sakamoto<sup>29</sup>, P. Sarin<sup>10</sup>, K. Sasaki<sup>15</sup>, A. Sato<sup>29</sup>, J. Sato<sup>31</sup>, D. Shemyakin<sup>6,28</sup>, N. Shigvo<sup>19</sup>, D. Shoukavy<sup>5</sup>, M. Shmeckel<sup>3</sup>, M. Sugano<sup>5</sup>, Y. Takubo<sup>15</sup>, M. Tanaka<sup>15</sup>, C. V. Thao<sup>26</sup>, E. Tarkovsky<sup>13,23</sup>, Y. Tevzadze<sup>32</sup>, N. D. Thong<sup>29</sup>, V. Thuan<sup>12</sup>, J. Tojo<sup>19</sup>, M. Tomasek<sup>3</sup>, M. Tomizawa<sup>13</sup>, N. H. Tran<sup>19</sup>, I. Trek<sup>23</sup>, N. M. Truong<sup>29</sup>, Z. Tsamalaidze<sup>14</sup>, N. Tsvetava<sup>14</sup>, S. Tytgier<sup>22</sup>, T. Uchida<sup>15</sup>, Y. Uchida<sup>11</sup>, K. Ueno<sup>15</sup>, S. Umasankar<sup>19</sup>, E. Velicheva<sup>14</sup>, A. Volkov<sup>14</sup>, V. Vrba<sup>3</sup>, W. A. T. Wan Abdullah<sup>21</sup>, M. Warren<sup>26</sup>, M. Wing<sup>35</sup>, T. S. Wong<sup>29</sup>, C. Wu<sup>25</sup>, G. Xia<sup>22</sup>, H. Yamaguchi<sup>19</sup>, A. Yamamoto<sup>15</sup>, M. Yamataka<sup>24</sup>, Y. Yang<sup>19</sup>, H. Yoshida<sup>29</sup>, M. Yoshida<sup>15</sup>, Y. Yoshii<sup>15</sup>, T. Yoshioka<sup>19</sup>, Y. Yuan<sup>2</sup>, Y. Yudin<sup>6,28</sup>, J. Zhang<sup>2</sup>, Y. Zhang<sup>2</sup>

<sup>1</sup>North China Electric Power University, Beijing, People's Republic of China

<sup>2</sup>Institute of High Energy Physics (IHEP), Beijing, People's Republic of China

<sup>3</sup>Peking University, Beijing, People's Republic of China

<sup>4</sup>Belarusian State University (BSU), Minsk, Belarus

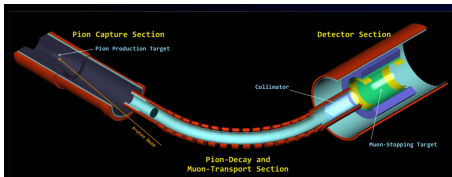
<sup>5</sup>B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus



## COMET (E21)

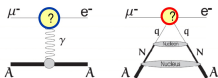
### COMET Phase I (2016)

- ▶ Beam background study and achieve S.E.S.  $\simeq 3.10^{-15}$  with 8 GeV - 3.2 kW proton beam,  $\sim 3$  months DAQ



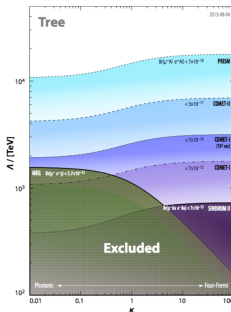
### COMET Phase II (2020)

- ▶ 8 GeV - 56 kW proton beam,  $\sim 1$  year DAQ to achieve the COMET final goal of S.E.S  $\simeq 3.10^{-17}$



For searches at colliders

- ▶  $|A_{SM} + \epsilon_{NP}|^2 \simeq |A_{SM}|^2 + 2\text{Re}(A_{SM}\epsilon_{NP})$
- CLFV sensitive to NP at high energy scale  $\Lambda$
- ▶  $|A_{SM} + \epsilon_{NP}|^2 \simeq |\epsilon_{NP}|^2 \Rightarrow \text{Rate} \simeq \frac{1}{\Lambda^4}$

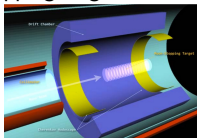


$\mu^- N \rightarrow e^- N$  low energy effective lagrangian

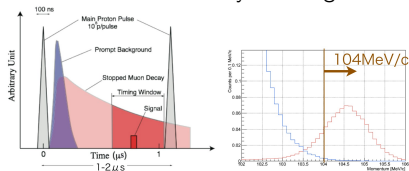
$$\mathcal{L} = \frac{1}{1+\kappa} \frac{m_\mu}{\Lambda^2} \bar{\mu}_R \sigma^{\mu\nu} e_L \mathcal{F}_{\mu\nu} + \frac{\kappa}{1+\kappa} \frac{1}{\Lambda^2} (\bar{\mu}_L \gamma^\mu e_L) (\bar{q}_L \gamma_\mu q_L) + h.c.$$

# France-Japan collaboration in COMET

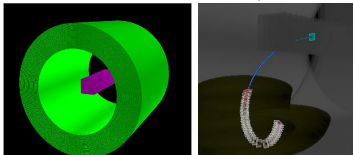
- ▶ COMET Phase I  
Construction of the muon transport solenoid down to the 1<sup>st</sup> 90° bend
- ▶ CDC and Triggering counter surrounding a muon stopping target



$\mu \rightarrow e$  conversion signal identified with an energetic electron of 105MeV emitted from a muonic atom with delayed timing.



- ▶ LPNHE R&D for an active muon stopping target in order to get an additional point for the electron trajectory (CM11 - 2013)

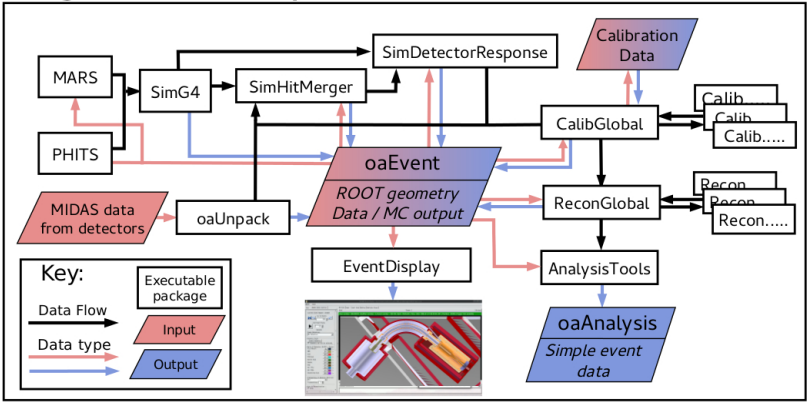


- ▶ Simulation and reconstruction with GENFIT within ICEDUST(Integrated Comet Experiment Data User Software Toolkit), the new COMET Software Framework rooted in T2K ND280.
- ▶ Discussion on the possibility of a beam test of ATLAS pixels at J-PARC with Kyushu University.
- ▶ MARS and ICEDUST installed at CCIN2P3 (thanks to Yonny Cardenas).

# ICEDUST

## Overview

### Integrated Comet Experiment Data User Software Toolkit



## Recent history

- ▶ COMET Software Framework: from ND280 to ICEDUST.  
Imperial College London lead : Ajit Kurup, Ben Krikler
- ▶ Common COMET g-2/EDM FJPLP Workshop (Paris, 20-21 february 2014)



Workshop on silicon detectors for g-2/EDM/COMET experiments

20-21 février 2014  
L'PHE, Paris  
Démare/Fernandez

Overview  
Agenda  
Timetable  
Registration  
1. Registration Form  
List of registrants  
Access to L'PHE

The g-2/EDM and COMET experiments will detect positrons and electrons with silicon microstrips and pixels detectors.  
The current status and the future needs will be reviewed and discussed.

Démare 20 fév. 2014 09:00  
Févr 21 fév. 2014 19:00  
Europe/Paris

L'PHE Paris  
1213-PCSB-11

- ▶ 3rd Workshop on Muon g-2, EDM and Flavour Violation in the LHC Era in december 2014



- ▶ It was the right time for a decision from CCIN2P3 director and IN2P3 Particle Scientific Deputy Director to create a comet group to allow "foreign collaborators" to register and use CCIN2P3 machines.



# Software Activity

## Software group structure, january 2014

- Software group involves 13+ people

Sub-group coordinator: <b>Ajit Kurup</b>	
<b>Sam Tygier:</b> Fluka	<b>Andy Edmonds</b> MARS, SimG4
<b>Ben Krikler:</b> SimG4, overall framework	<b>Chen Wu</b> Build system, repository, CyDet
<b>Per Johnsson:</b> Unit tests, ND280 support	<b>Phill Litchfield</b> Offline databases, ND280 support
<b>Kazuki Ueno:</b> Straw tracker	<b>Fedor Ignatov</b> Reconstruction
<b>Wilfrid da Silva, Frederic Kapusta:</b> GENFIT, Active Target	<b>Vladimir Kalinnikov, Elena Velicheva</b> ECAL

## GitLAB members, march 2015

The screenshot shows the GitLab interface for the 'conet' group. The 'Members' tab is selected, displaying a list of 15 members. Each member's entry includes their name, a role (such as Owner, Student, Developer, or Maintainer), and a status icon (a checkmark in a red box). The members listed are:

- Ajit Kurup (Owner)
- Benjamin Köber (Owner)
- KAPUSTA Frederic (Owner)
- Kou Okada (Student)
- Yuki Fujii (Student)
- Ben Thak (Developer)
- Wilfrid da Silva (Developer)
- Wingda Lee (Developer)
- Jordan Nash (Developer)
- Chen Wu (Developer)
- Griffith Steadley (Developer)
- Hossein Faragipour (Developer)
- Wong Ting Sun (Developer)
- Phill Litchfield (Developer)
- Yoshi Uchida (Developer)
- Per Johnsson (Developer)
- Kazuki Ueno (Developer)
- Ewan L Gibbs (Developer)

## Recent events

- ▶ Accepted proposal from the french group to use the CCIN2P3 computing power and support in order to prepare a Grid computing at the COMET Collaboration level.
- ▶ Accepted proposal to have gitlab.in2p3.fr hosting the COMET software in order to ease the collaborative work.
- ▶ ICEDUST is running with MARS using a common 1 TB of semi-permanent space on /sps/hep/comet.
- ▶ SimMARS still under test and optimization at CCIN2P3.
- ▶ A MySQL database is available for parameters storage.
- ▶ muon.in2p3.fr is a french website under construction to unify  $\mu^+$  ( g-2/EDM ) and  $\mu^-$  ( COMET ) experiments for BSM physics, the official COMET website being comet.kek.jp

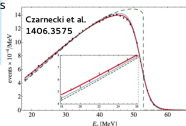
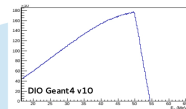
# Questions and a proposal

- ▶ From the "3rd Workshop on Muon g-2, EDM and Flavour Violation ...":
  - new idea of cLFV search  $\mu^- e^- \rightarrow e^- e^-$  in muonic atom.
  - upgrade of the DIO spectrum using Czarnecki last computation...

## Simulation: Intrinsic BG

ICEDUST  
Simulation

- ▶ Switch to Geant4 v10
  - ▶ Muon stopping on all Z:
    - ▶ Capture rates: Suzuki, Measday, Roalsvig, Phys.Rev. C35 (1987)
    - ▶ Decay rates: Mukhopadhyay Phys. Rep. 30 (1977)
- ▶ Include muon and pion capture processes as extended physics models
  - ▶ Radiative  $\mu$  and  $\pi$  capture
  - ▶ Charged particle emission after  $\mu$  capture
  - ▶ Neutron emission after  $\mu$  capture
  - ▶  $\mu$  decay in orbit using most recent calculations
  - ▶ Czarnecki et al. Phys. Rev. D 9 (2014)



December 2014

27

Ben Krüker

What else ?

- ▶ Expected contribution from french theorists : model predictions and "advertising plots".
- ▶ You are invited to give a talk at CM17 beginning of september in Paris and ... join COMET.