Search for charged lepton flavor violation with the COMET experiment at J-PARC

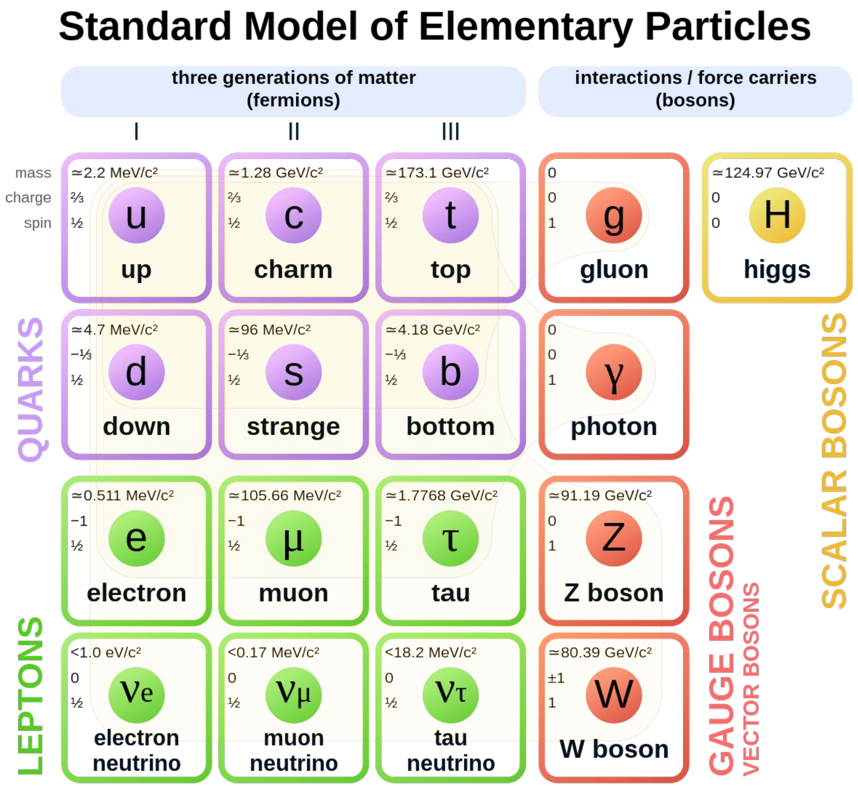
JRJC flavor physics session - 2024/11/26

Standard Model of particle physics

- Describes the elementary constituents of the Universe and the interactions between them.

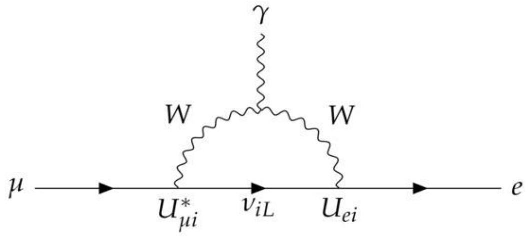
- Flavor violation has been observed for quarks and neutrinos.

→ What about charged leptons ?



Charged Lepton Flavor Violation (cLFV)

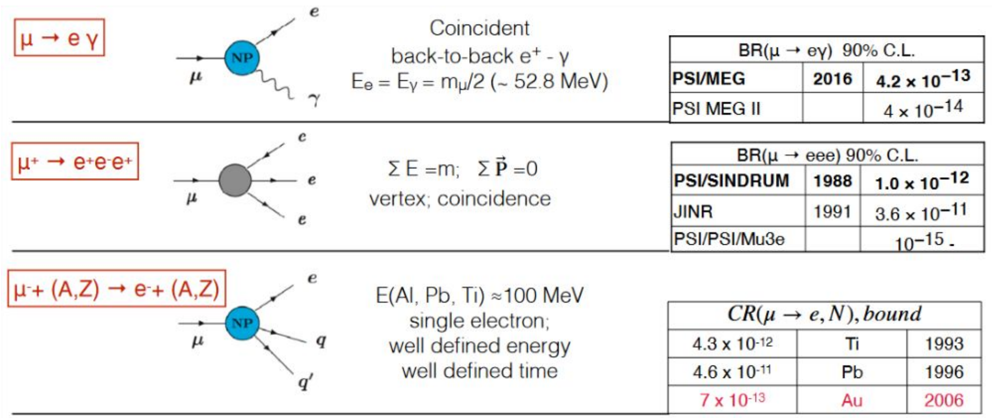
SM with $m_\nu > 0$:



$$B(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{j=1}^{3} U_{ej}U^*_{\mu j}\frac{m^2_{\nu j}}{M^2_W}\right|^2 \sim O(10^{-54})$$

!!!

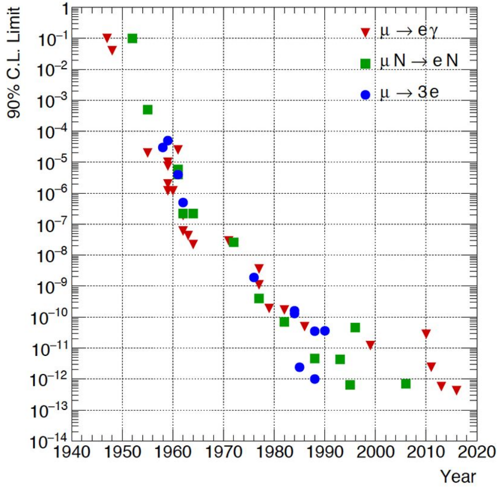
Observation of cLFV would be a clear sign for BSM physics.



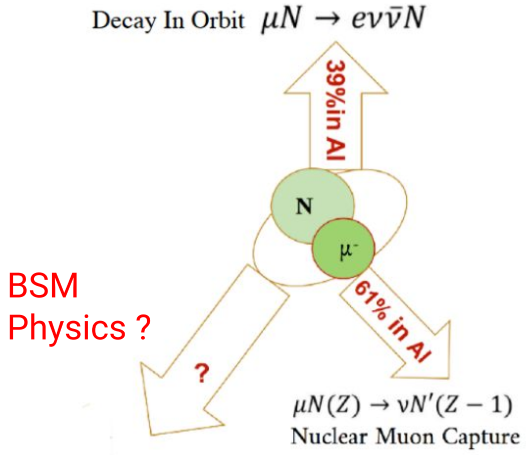
BR($\mu \to e\gamma$) 90% C.L.		
PSI/MEG	**2016**	**4.2×10^{-13}**
PSI MEG II		4×10^{-14}

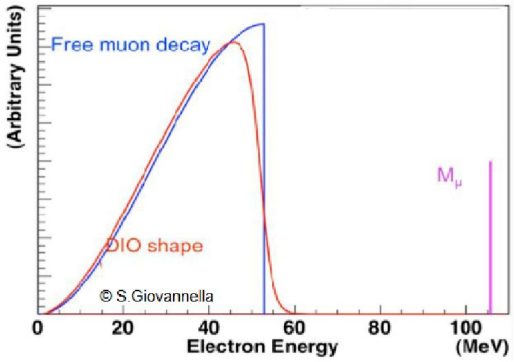
BR($\mu \to eee$) 90% C.L.		
PSI/SINDRUM	**1988**	**1.0×10^{-12}**
JINR	1991	3.6×10^{-11}
PSI/PSI/Mu3e		10^{-15}

$CR(\mu \to e, N)$, bound		
4.3×10^{-12}	Ti	1993
4.6×10^{-11}	Pb	1996
7×10^{-13}	Au	2006



Coherent neutrinoless conversion of a muon to an electron in a muonic atom





- A muon is captured in an outer shell of an atom (forming a "muonic atom"). The muon goes down energy levels emitting X-rays.

- Two possible processes according to SM:
  - Decay in Orbit (DIO),
  - Nuclear muon capture.

- BSM process with well defined signature: a single mono-energetic electron, emitted from the muonic atom at a well defined time after its creation.

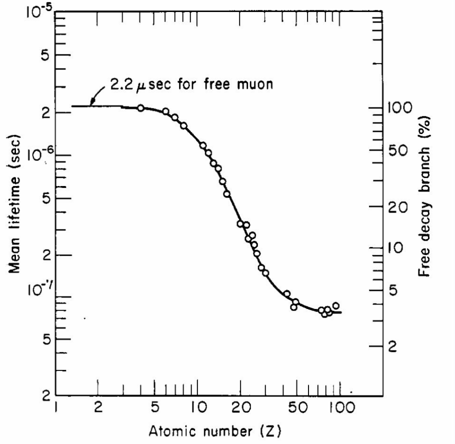
$$E_{\mu e} = m_\mu - B_\mu - E_{recoil}.$$

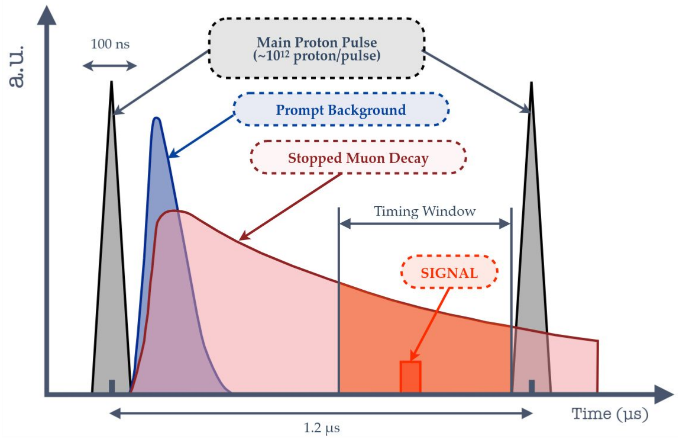
104.97 MeV for Al

COMET Experiment at J-PARC

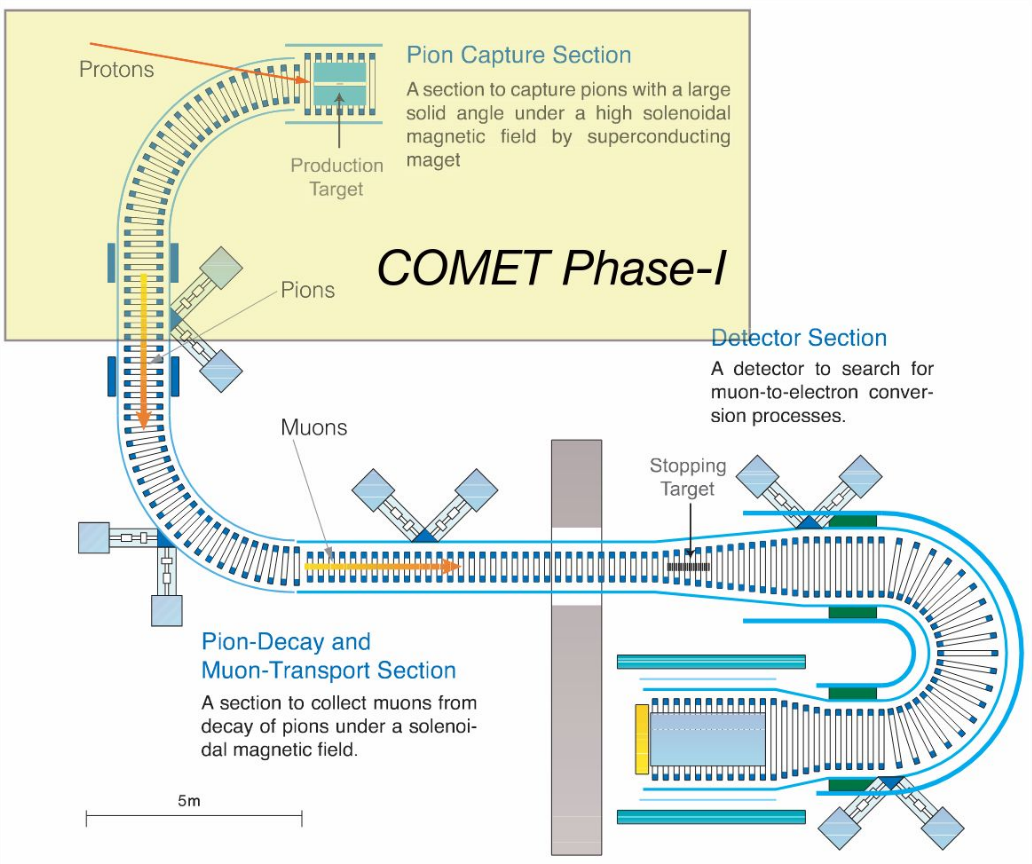
→ Model independent

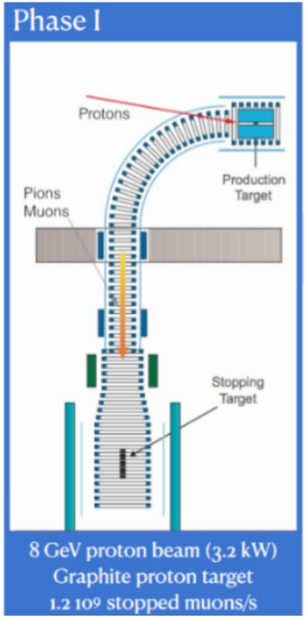
- pulsed proton beam on a fixed target;
- selection of low momenta pions, that decays into low momenta muons;
- the muon beam is focused on an aluminium target to produce muonic atoms. COMET will produce the most intense muon beam in the world.





COMET Phases





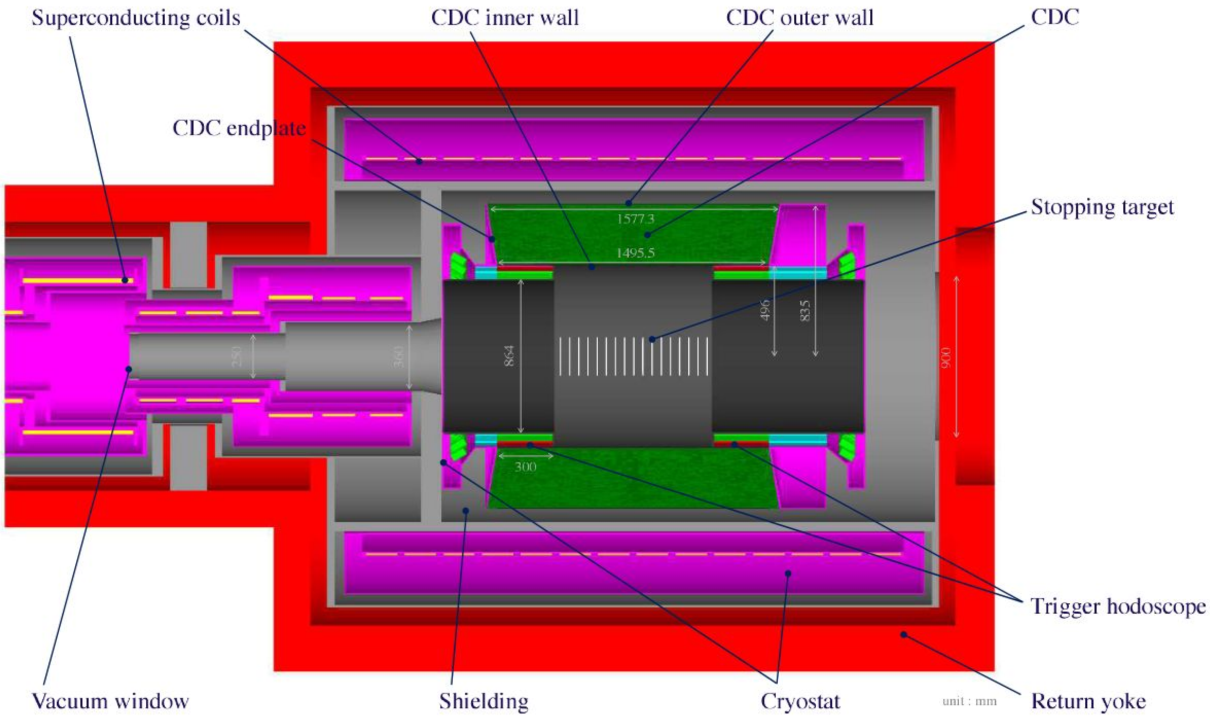
Aimed limits:

Phase-I → 10^-15

Phase-II → 10^-17

Very high precision measurement to constrain theoretical models!

Phase-I Cylindrical detector (CyDet)



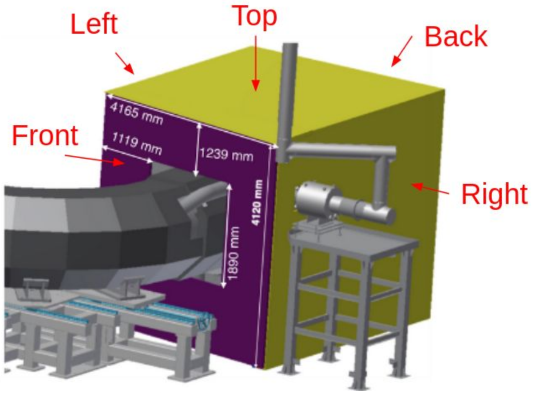
- *Cylindrical Drift Chamber (CDC)*
  ↪ to reconstruct the track of the signal electron.

- *Cylindrical Trigger Hodoscope (CTH)*
  ↪ provides the trigger.

Cosmic Ray Veto (CRV)

Type	Background	Estimated events
Physics	Muon decay in orbit	0.01
	Radiative muon capture	0.0019
	Neutron emission after muon capture	< 0.001
	Charged particle emission after muon capture	< 0.001
Prompt Beam	* Beam electrons	
	* Muon decay in flight	
	* Pion decay in flight	
	* Other beam particles	
	All (*) Combined	≤ 0.0038
	Radiative pion capture	0.0028
	Neutrons	$\sim 10^{-9}$
Delayed Beam	Beam electrons	~ 0
	Muon decay in flight	~ 0
	Pion decay in flight	~ 0
	Radiative pion capture	~ 0
	Antiproton-induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

† This estimate is currently limited by computing resources.



(old design)

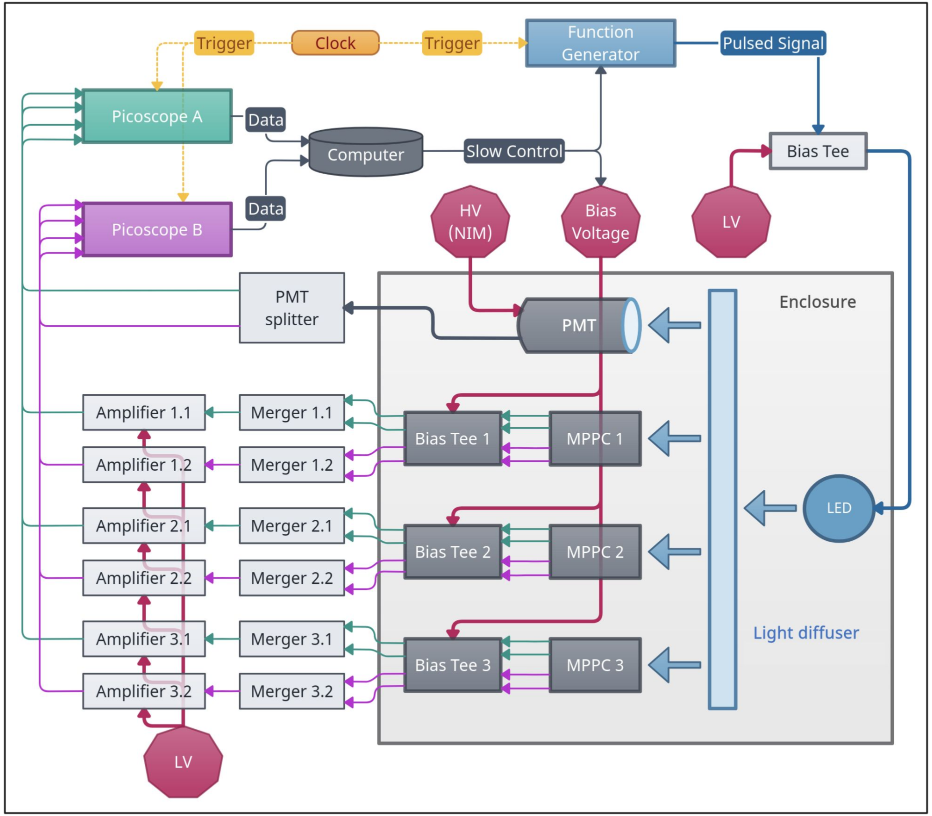
- Main background source for Phase-I: atmospheric muons.
  → High energy muon can interact with matter producing a signal-like electron.
  → A positive muon can misidentified as an electron.

- Cosmic rays veto system (~anti-trigger).

- Scintillators on the top, left and right surfaces of the CRV.

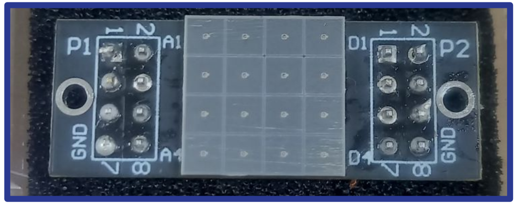
- In the very high radiation sectors (Front & Back): Resistive plate Chambers (RPCs)

CTH MPPCs Quality Control



<u>Goal:</u> Ensure a good light collection of photomultipliers used for CTH.

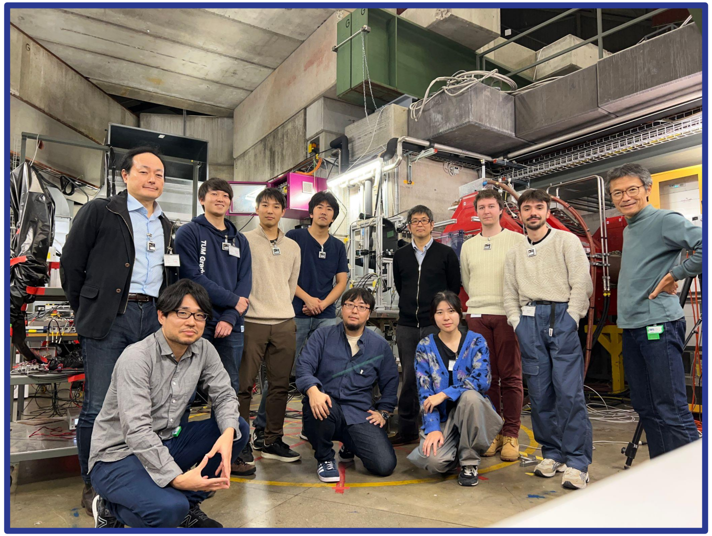
Worked in Japan on a quality control study of CTH Multi-Pixel Photon Counters (MPPCs or SiPM).



Especially worked on the Data Acquisition (DAQ) system.

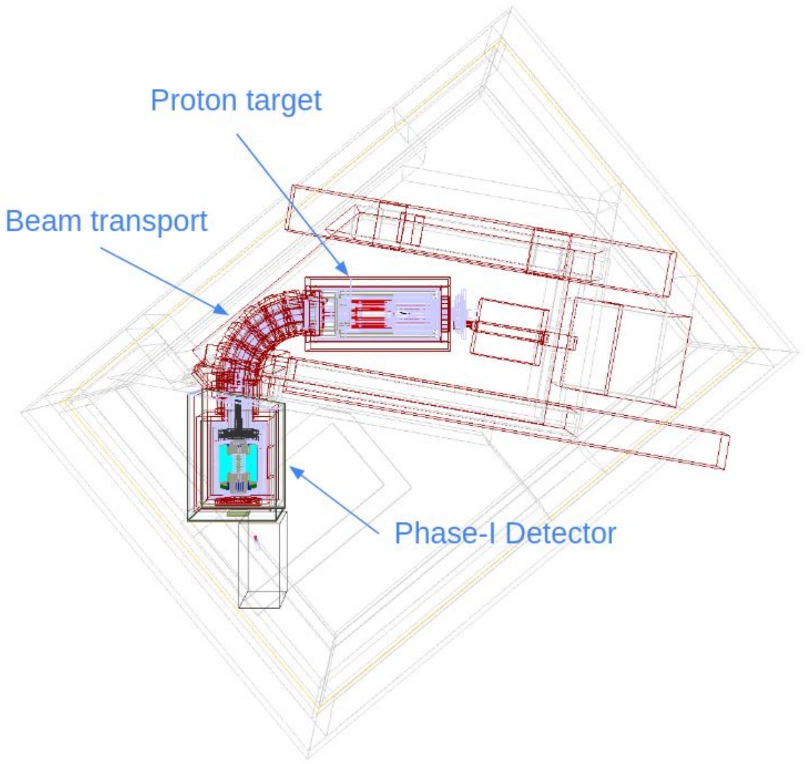
Beam test at Paul Scherrer Institut

PAUL SCHERRER INSTITUT



- Efficiencies & detectors response measurements were performed for the CTH.
- Showed that CTH can be used to distinguish μ+ from e- under low multiplicity.
  - Reducing multiplicity ↳better discrimination.

Study of radiation levels on detectors - Software

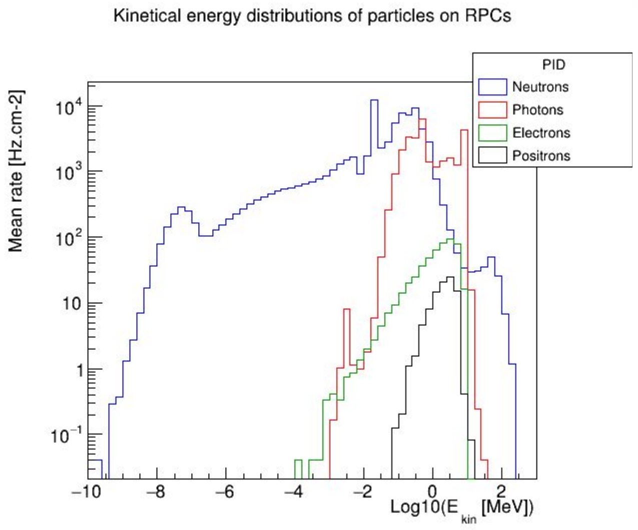


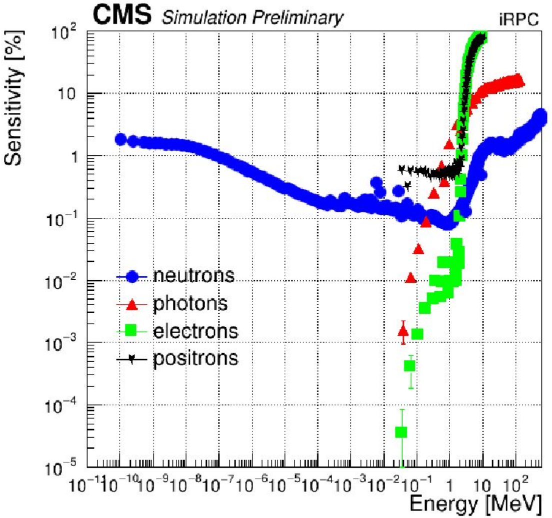
Goal: Estimate radiation levels on detectors.

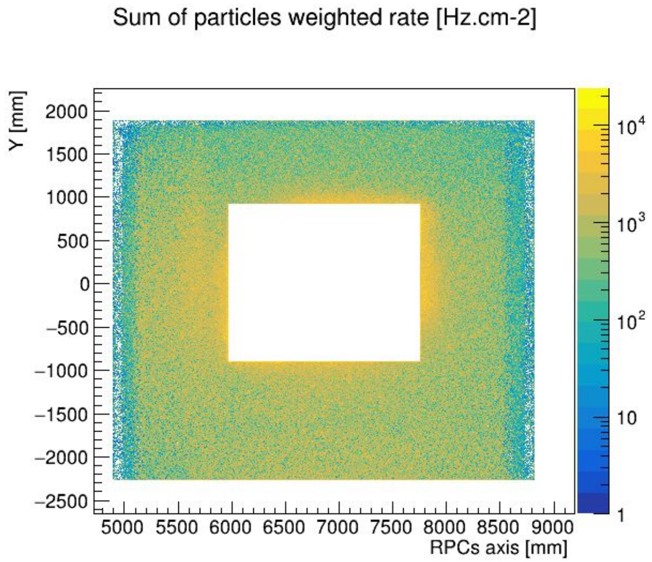
- Simulation framework called ICEDUST, based on GEANT4 and ROOT.
- Simulations include:
  → proton on target interaction,
  → beam transport to the detector,
  → detector simulation.
- A script architecture was developed to produce the simulations in an efficient way at CC-IN2P3. This include an automated bookkeeping system.

Study of radiation levels on detectors - Results

(working group with CMS researchers)







Most intense muon beam → High rates are expected on Front CRV and CTH.

Goal: Reduce radiation levels to ensure sensitivity to new physics!

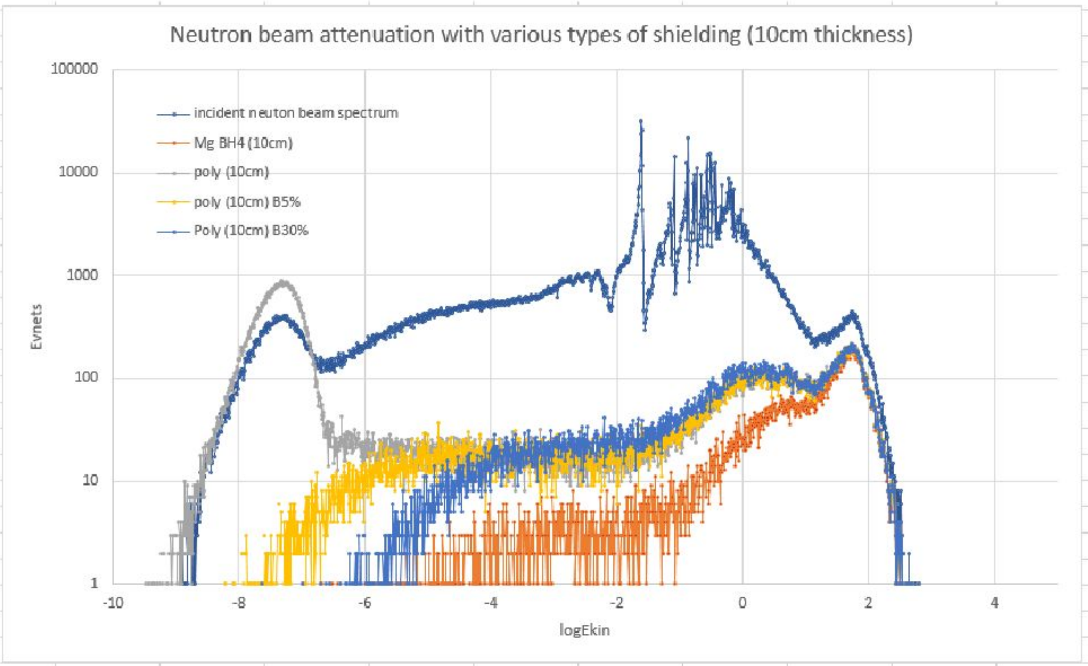
Neutron shielding materials

Working group : JC Angélique-JL Gabriel - LPC Caen T. Clouvel – C. Carlaganu - LPC Clermont

Neutron rate has an important effect on the efficiency of the detector (and its durability). Several neutron shielding materials were tested:

- Polyethylene
- Polyethylene 5% Boron
- Polyethylene 30% Boron
- Magnesium Borohydride

All spectra on the same figure for comparison.

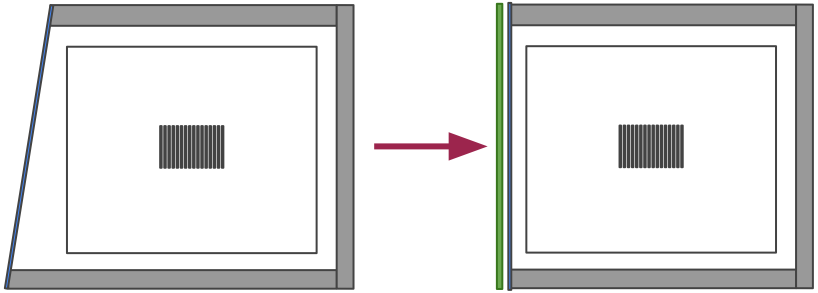


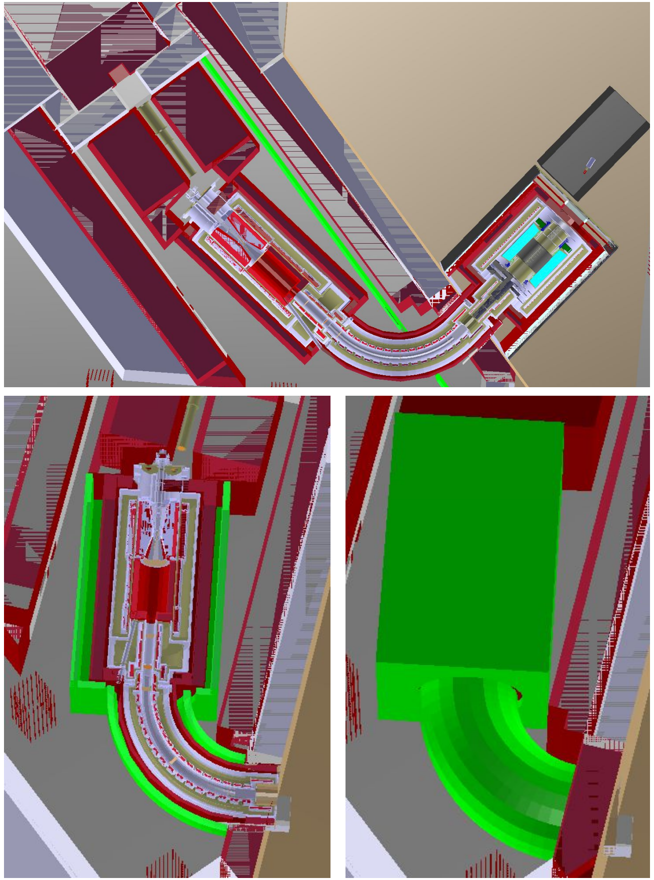
Geometry and shielding optimization to reduce multiplicity in detectors

- Not a lot of space in downstream area.

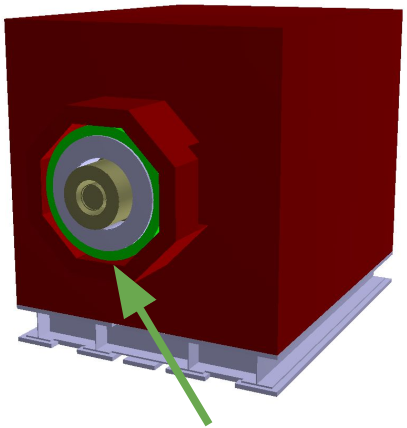
- Some shielding hypothesis in upstream area.
  - positive effects but cost/efficiency ratio not good enough.

- Changed the shape of the Front CRV
  - good for front CRV but bad for CTH

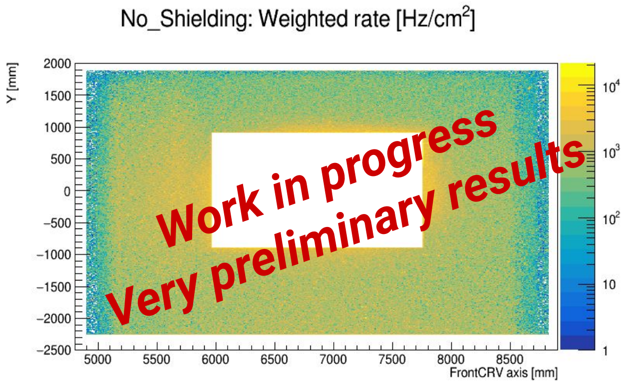


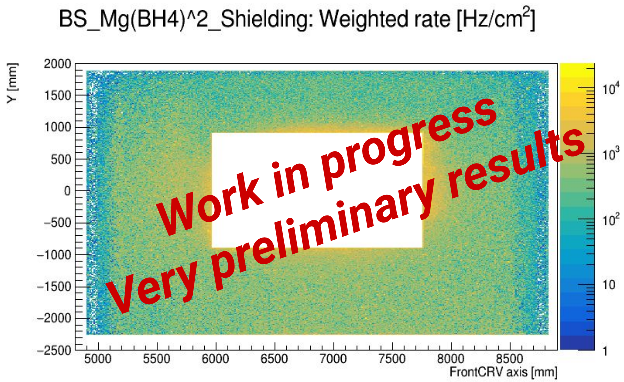


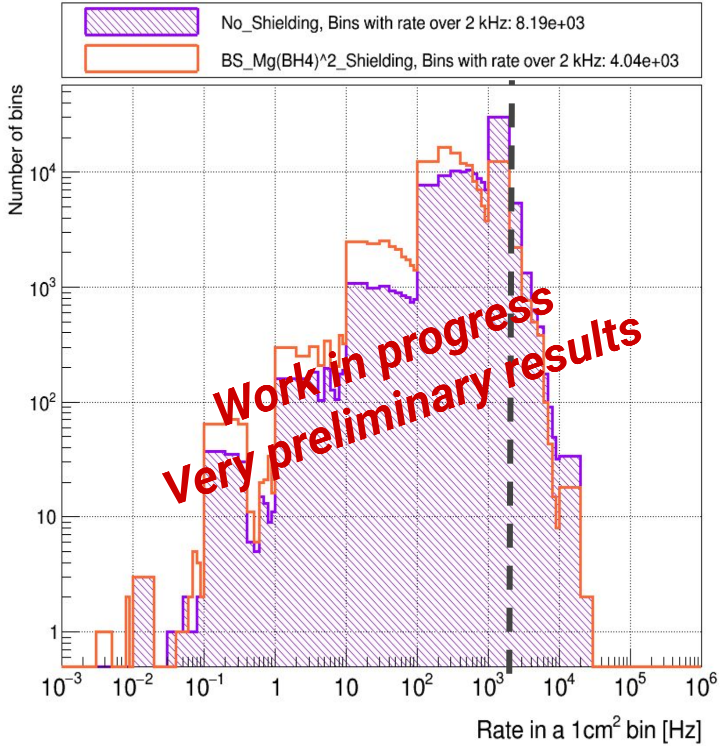
Very preliminary results for detector Solenoid shielding hypothesis



10cm thick $Mg(BH4)^2$ neutron shielding







Study still ongoing, some shielding hypothesis could lead to positive results for both CRV and CTH.

Conclusion

- COMET experiment is searching for cLVF:
  - A signal would be a clear sign of BSM physics,
  - No signal with an improvement of the current limit would help to constrain theoretical models.

- A really good precision is required to be sensitive to new physics.

- Some studies are being performed to ensure that detectors will reach the required efficiency to push current limits.