Search for Muon to Electron Conversion at J-PARC

COMET Experiment

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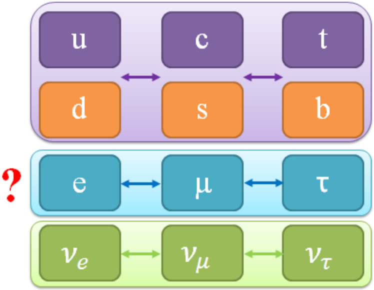
Charged Lepton Flavor Violation

Why do we search for charged lepton flavor violation (CLFV)?

1. It's a simple generalization of quark mixing and neutrino mixing.

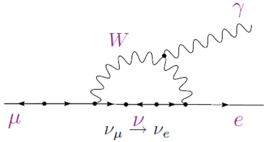


1. Quark Sector
   Mixed by CKM mechanism.
   Observed.
2. Neutral Lepton Sector
   Neutrino oscillation observed.
3. Charged Lepton Sector
   Mixing? $\rightarrow$ CLFV

Charged Lepton Flavor Violation

2. CLFV is a good probe to physics beyond the Standard Model (SM). Taking $\mu^+ \to e^+\gamma$ process as an examle:

In Standard Model, it's possible through neutrino oscillation:

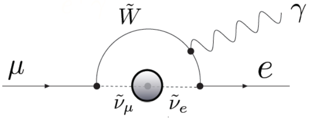


$Br(\mu \to e\gamma) =$

$\frac{3\alpha}{32\pi}|\Sigma_l (V_{MNS})^*_{\mu l}(V_{MNS})_{el}\frac{m^2_{\nu l}}{M^2_W}| \sim O(10^{-54})$

negligible!

In SUSY-GUT Model, for loop diagram:



$Br(\mu \to e\gamma) = 10^{-11} \times (\frac{2TeV}{\Lambda})^4(\frac{\theta_{\mu e}}{10^{-2}})^2$

Might be observable near 10^{-15}!

* Define branching ratio $Br = N_{CLFV}/N_{nuclear_capture}$

If CLFV process is observed, it will be a direct proof to new physics.

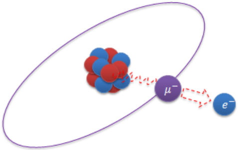
CLFV and Muon to Electron Conversion

Candidate CLFV processes:

1. CLFV processes in τ leptons: $\tau \to l\gamma$, $\tau \to lll$, $\tau \to lh^0$, ...
   Studied at B factories. (LHCb, BaBar, Belle)
   Big improvements expected in super B factories. (Belle II)
2. CLFV processes in μ leptons: $\mu \to e\gamma$, $\mu \to eee$, $\mu N \to eN$, ...
   Studied with muon source. (PSI)
   The new generation of muon sources can take us for a giant leap. (FermiLab, J-PARC)

Among them, $\mu N \to eN$ is our focus:

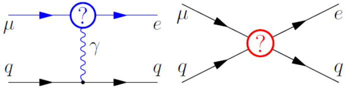
1. The muon to electron conversion ($\mu N \to eN$) is a process of a muon in a muonic atom converting into an electron w/o neutrino emission.
   $\mu^- + (A, Z) \to e^- + (A, Z)$
2. Event signature: a single mono-energetic electron of around 105 MeV (for Aluminium).
   $E_{sig} = m_\mu - m_e - E_{binding} - E_{recoil}$
3. Backgrounds: intrinsic (muon decay in orbit) and beam related backgrounds.



Muon to Electron Conversion

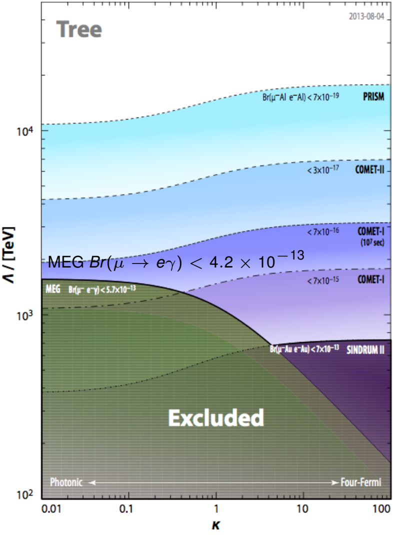
Why $\mu N \to eN$?

1. From the theoretical point of view:
   1. Both photonic process and four-fermion process can contribute to it.

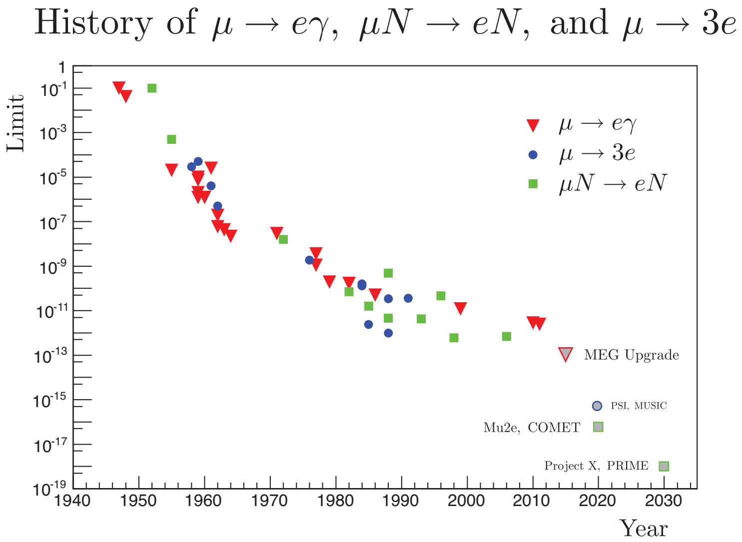


2. From the experimental point of view:
   1. The measurement for $\mu N \to eN$ measurement was restricted by beam related background.
   2. Now we have much better muon beam: pulsed, pure, and intense!

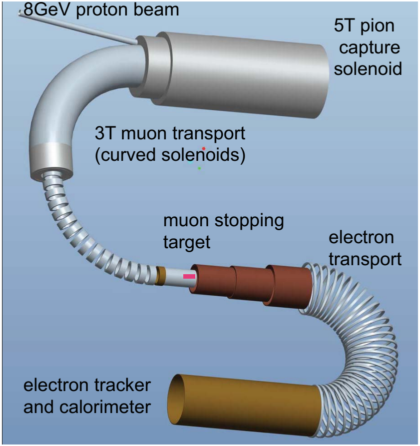
With the current detector technology and available beamline in near future we can improve the signal sensitivity by 4~6 orders of magnitude.



History of CLFV Experiment



COherent Muon Electron Transition (COMET)



The COMET experiment aims at searching for $\mu N \to eN$ conversion with a single event sensitivity $S.E.S. = 2.6 \times 10^{-17}$ in one year running time.

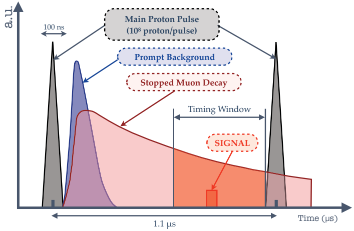
1. 8 GeV pulsed protons beam (56 kW) shooting onto a pion production target (Tungsten).
2. Pions will be captured by 5T capture solenoid and transported by 3 T C-shape transportation solenoid.
3. After 180° transportation, muons from pion decay will arrive at the stopping target (Aluminum or Titanium).
4. Charged tracks from the stopping target will be transported by another C-shape electron transportation solenoid and will finnally reach the detector.

10,000 times better than current result from SINDRUMII.

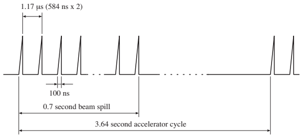
Location of the COMET Experiment

The Proton Beam at J-PARC

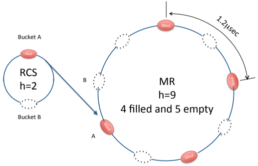
1. A pulsed proton beam is needed to reject beam related background.



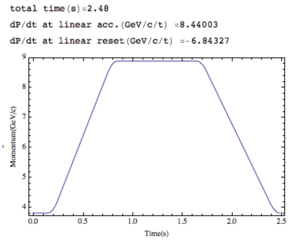
2. In J-PARC, the separation time is 1.17 μs and the pulse width is 100 ns.



3. Fill every other bucket. Use slow extracion with pulse structure kept.

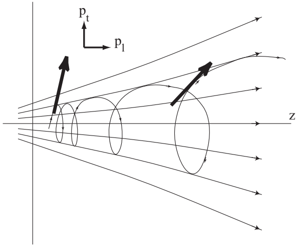


4. Spill length is 0.8 sec while accelerator cycle is 2.48 sec, thus the duty factor is $0.8/2.48 = 0.32$.

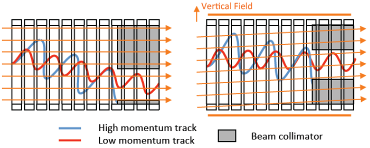


The Muon Beam at J-PARC

1. In the capture solenoid the pions from the production target will be captured by 5 T magnetic field.
2. After being captured, the momentum direction has a broad dsitribution. To make the beam more parallel to the beam axis, the magnetic field is decreased adiabatically.

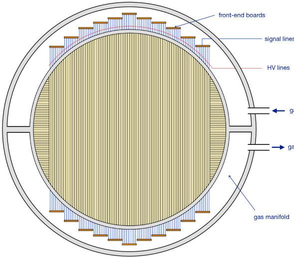


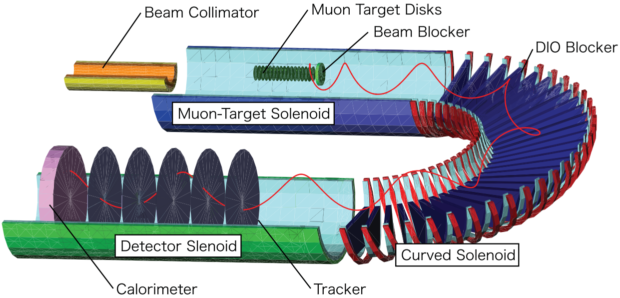
1. In the C-shape muon beam line, the curved solenoid will make charged particles drift along verticle direction
   1. The drift distance is proportional to the momentum amplitude.
   2. The drift direction is decided by the charged of the particle.
2. With the help of a dipole field and collimator, we can select the beam by charge and momentum.
   1. Muon with momentum smaller than 75MeV/c is preferable.



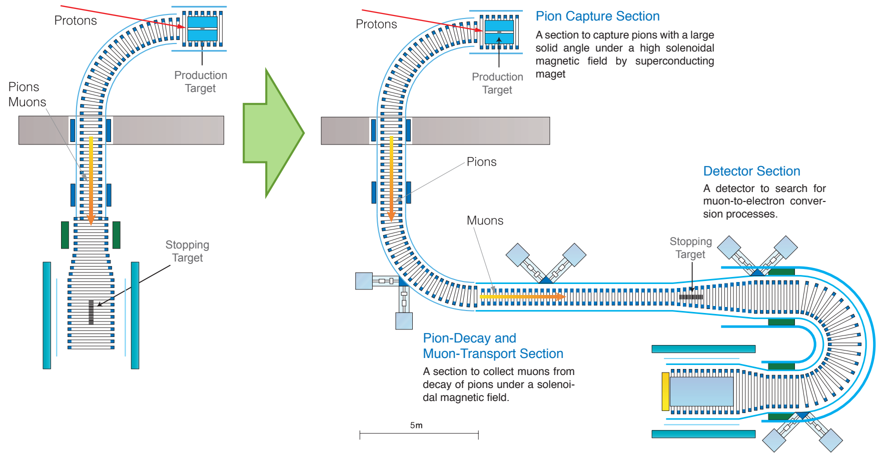
COMET Detectors

1. Signal tracks from the stopping target will be transported by the curve solenoid to the detector solenoid.
2. In the detector solenoid sit straw tracker and energy calorimeter.
   1. The straw tracker consits of (could be more than) 5 stations Each station has 4 layers of straw tubes.
   2. The energy calorimeter is a plane of crystals.





Staged Plan of COMET



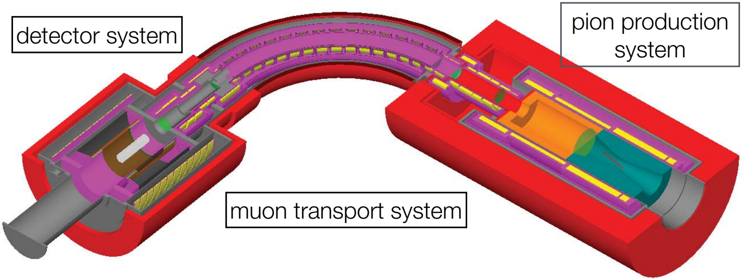
COMET Phase-I
Start from 2018

COMET Phase-I
Start from 2021

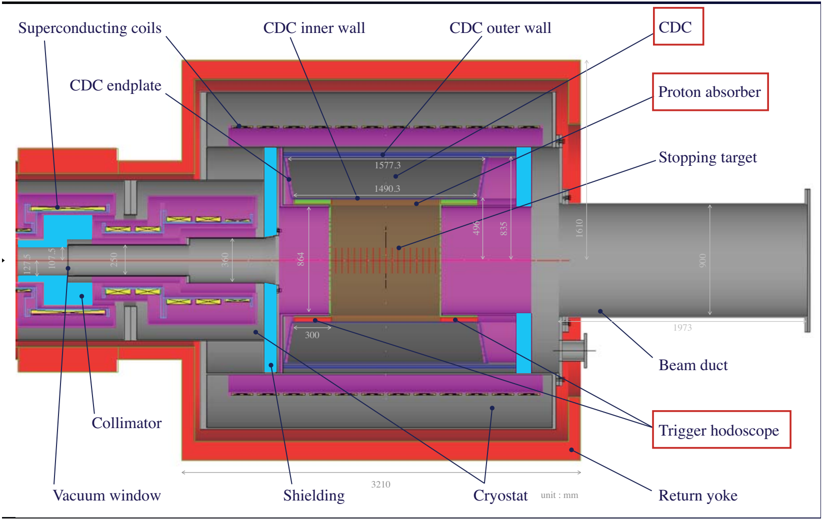
COMET Phase-I

The COMET Phase-I is designated to conduct the following tasks:

1. Background Study for COMET Phase-II:
   A direct measurement of potential background sources for the full COMET experiment by using the actual COMET beamline constructed at Phase-I.
   Using Phaes-II detectors: straw tube tracker and energy calorimeter (ECal).
2. Search for mu-e conversion:
   A search for mu-e conversion at intermediate sensitivity which would be more than 100 times better than the SINDRUM-II limit.
   Using new detector dedicated for Phase-I: cylindrical detector.



Cylindrical Detector for COMET Phase-I



Signal Sensitivity and Background in COMET Phase-I

1. The fact of COMET beam witin about $1.26 \times 10^{7} sec$ (146 days).

total protons	3.2×10^{19}
muon efficiency	0.00047
Number of stopped muons	1.5×10^{16}

2. Considering that the capture ratio in Al is 0.61 and the detector acceptance is 0.041, the fraction of $\mu - e$ conversion to the ground state in the final state of $f_{gnd} = 0.9$, we can achieve:

$S.E.S. = 3.1 \times 10^{-15}$

$B(\mu^{-} + Al \rightarrow e^{-} + Al) < 7 \times 10^{-15} (90\% C.L.)$

100 times better than the current limit!

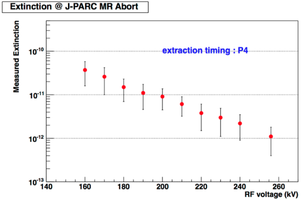
Expected background events are about 0.032

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
	Anti-proton induced backgrounds	0.0012
Others	Cosmic rays†	< 0.01
Total		0.032

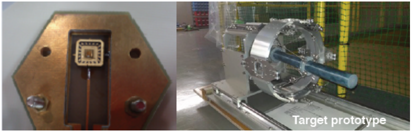
† This estimate is currently limited by computing resources.

Status of COMET Beamline

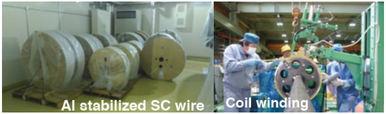
1. Proton extinction factor measured to be $\sim O(10^{-11})$.



2. Diamond detector has been studied to measure the beam profile/extinction in front of the capture solenoid.
3. Prototype of graphite target for Phase-I has been developed.



4. The coil winding for capture solenoid is almost done.



5. Muon transportation solenoid has been constructed.
6. 14 coils of the detector solenoid has been assembled.

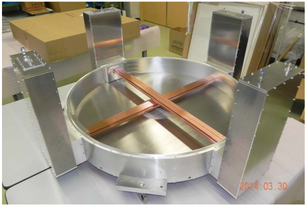
Status of COMET Facility

COMET Hall construction has been completed last year.

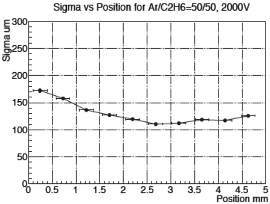
Status of COMET Phase-I Detectors

Straw Tube and Ecal

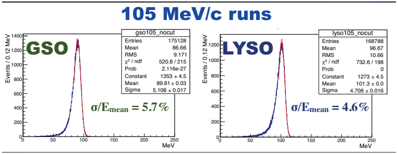
1. Straw assembly prototype with 20 micron straws.



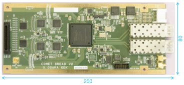
2. Operation in vacuum performed in success
3. Beam test with 105MeV/c electron was done: σ_x 150um

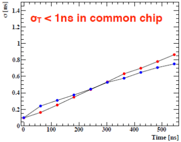


4. GSO and LYSO crystal test has been conducted and LYSO was chosen for higher yield and faster time response.



5. The front end board (ROESTI/EROS) has been developed. ROESTI V3 tests show good time resolution (<1ns).

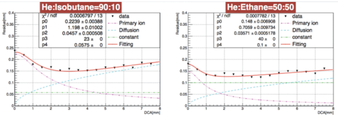




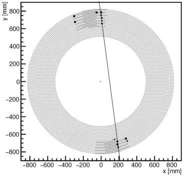
Status of COMET Phase-I Detectors

Cylindrical Detector

1. Beam tests and cosmic ray tests with prototypes have been conducted. Good spatial resolution and efficiency (150 um, 99%) have been achieved.

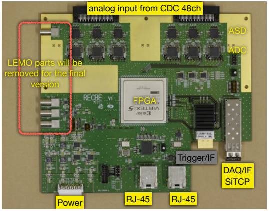


2. CDC construction completed in June 2016. Cosmic ray test is on going.



3. Beam tests for CTH prototype has been conducted. 1ns time resolution obtained.

4. Front end boards have been produced and mass test finished last year.



5. Trigger scheme using FC7-FCT with frontend trigger system has been studied.

6. Software framework (ICEDUST) finished last year. Full MC study indicates that the pre-trigger rate estimated as $\sim O(10)kHz$, and momentum resolution is appreciated ($\sim 170keV/c$).

The COMET Collaboration

176 collaborators
33 institutes, 15 countries

The COMET Collaboration

R. Abramishvili[11], G. Adamov[11], R. Akhmetshin[6,31], V. Anishchik[4], M. Aoki[32], Y. Arimoto[18], I. Bagaturia[11], Y. Ban[3], D. Bauer[14], A. Bondar[6,31], Y. Calas[7], S. Canfer[33], Y. Cardenas[7], S. Chen[28], Y. E. Cheung[28], B. Chiladze[35], D. Clarke[33], M. Danilov[15,26], W. Da Silva[23], P. D. Dauncey[14], C. Densham[33], G. Devidze[35], P. Dornan[14], A. Drutskoy[15,26], V. Duginov[16], L. Epshteyn[6,30,31], P. Evtoukhovich[16], S. Fayer[14], G. Fedotovich[6,31], M. Finger[8], M. Finger Jr[8], Y. Fujii[18], Y. Fukao[18], E. Gillies[14], D. Grigoriev[6,30,31], K. Gritsay[16], E. Hamada[18], R. Han[1], K. Hasegawa[18], I. H. Hasim[32], O. Hayashi[32], Z. A. Ibrahim[24], Y. Igarashi[18], F. Ignatov[6,31], M. Iio[18], M. Ikeno[18], K. Ishibashi[22], S. Ishimoto[18], T. Itahashi[32], S. Ito[32], T. Iwami[32], X. S. Jiang[2], P. Jonsson[14], T. Kachelhoffer[7], V. Kalinnikov[16], F. Kapusta[23], H. Katayama[32], K. Kawagoe[22], N. Kazak[5], V. Kazanin[6,31], B. Khazin[6,31], A. Khvedelidze[16,11], T. K. Ki[18], M. Koike[39], G. A. Kozlov[16], B. Krikler[14], A. Kulikov[16], E. Kulish[16], Y. Kuno[32], Y. Kuriyama[21], Y. Kurochkin[5], A. Kurup[14], B. Lagrange[14,21], M. Lancaster[38], M. J. Lee[12], H. B. Li[2], W. G. Li[2], R. P. Litchfield[14,38], T. Loan[29], D. Lomidze[11], I. Lomidze[11], P. Loveridge[33], G. Macharashvili[35], Y. Makida[18], Y. Mao[3], O. Markin[15], Y. Matsumoto[32], A. Melnik[5], T. Mibe[18], S. Mihara[18], F. Mohamad Idris[24], K. A. Mohamed Kamal Azmi[24], A. Moiseenko[16], Y. Mori[21], M. Moritsu[32], E. Motuk[38], Y. Nakai[22], T. Nakamoto[18], Y. Nakazawa[32], J. Nash[14], J. -Y. Nief[7], M. Nioradze[35], H. Nishiguchi[18], T. Numao[36], J. O'Dell[33], T. Ogitsu[18], K. Oishi[22], K. Okamoto[32], T. Okamura[18], C. Omori[18], T. Ota[34], J. Pasternak[14], C. Plostinar[33], V. Ponariadov[45], A. Popov[6,31], V. Rusinov[15,26], B. Sabirov[16], N. Saito[18], H. Sakamoto[32], P. Sarin[13], K. Sasaki[18], A. Sato[32], J. Sato[34], Y. K. Semertzidis[12,17], N. Shigyo[22], D. Shoukavy[5], M. Slunecka[8], D. Stöckinger[37], A. Straessner[37], M. Sugano[18], Y. Takubo[18], M. Tanaka[18], S. Tanaka[22], C. V. Tao[29], E. Tarkovsky[15,26], Y. Tevzadze[35], T. Thanh[29], N. D. Thong[32], J. Tojo[22], M. Tomasek[10], M. Tomizawa[18], N. H. Tran[32], H. Trang[29], I. Trekov[35], N. M. Truong[32], Z. Tsamalaidze[16,11], N. Tsverava[16,35], T. Uchida[18], Y. Uchida[14,32], K. Ueno[18], E. Velicheva[16], A. Volkov[16], V. Vrba[10], W. A. T. Wan Abdullah[24], M. Warren[38], M. Wing[38], M. L. Wong[32], T. S. Wong[32], C. Wu[2,28], H. Yamaguchi[22], A. Yamamoto[18], T. Yamane[32], Y. Yang[22], W. Yao[2], B. K. Yeo[12], H. Yoshida[32], M. Yoshida[18], Y. Yoshii[18], T. Yoshioka[22], Y. Yuan[2], Yu. Yudin[6,31], J. Zhang[2], Y. Zhang[2], K. Zuber[37]

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Summary

1. The CLFV process is a good probe to new phsycis beyond the Standard Model.
2. With a new generation of muon beam being available soon, the prospect of searching for muon to electron conversion is very atractive.
3. COMET at J-PARC aims at a search for muon to electron conversion with signal sensitivity $S.E.S = 2.6 \times 10^{-17}$ (10,000 times better than current limit) from 2021 with 1 year beam time.
4. Staged plan for COMET has been approved and COMET Phase-I is expected to take data from 2018 with 146 days beam time. It will carry out a background study for Phase-II together with a direct search for muon to electron conversion with signal sensitivity $S.E.S = 3.1 \times 10^{-15}$ (100 times better than current limit).
5. R&D and construction are in good shape.

Thank you!