The Quest for Muon-to-Electron Conversion:

Searching for New Physics with Charged Lepton Flavor Violation

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EPD seminar, IHEP, 19 July, 2023.

Outline

- Introduction
- mu-e conversion experiments
- Future prospects
- Summary

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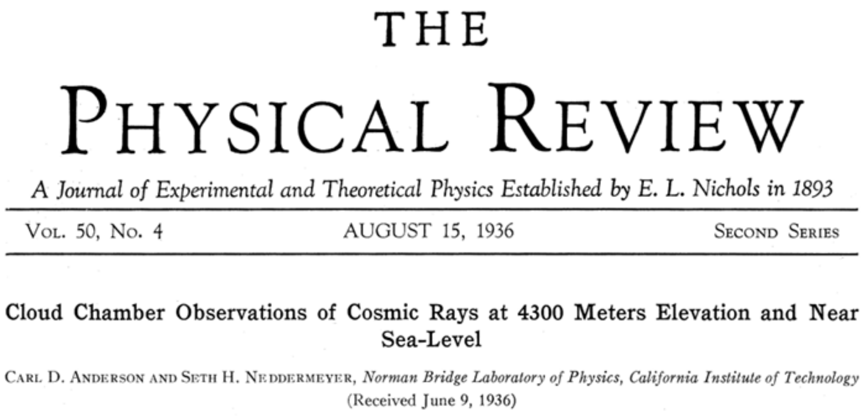
Charged Lepton Flavor Violation (CLFV)

- Processes that violate the conservation of individual lepton number⁎ in the charged lepton row
  - Not necessarily violating the total lepton number.
- Among all CLFV processes, 3 muonic channels are particularly popular:
  - $\mu \to e\gamma, Br = \frac{\Gamma(\mu\to e\gamma)}{\Gamma(\mu\to e\upsilon\upsilon)}$
  - $\mu \to eee\,, Br = \frac{\Gamma(\mu\to eee)}{\Gamma(\mu\to e\upsilon\upsilon)}$
  - $\mu N \to eN\,, Cr = \frac{\Gamma(\mu N\to eN)}{\Gamma(\mu N\to \nu N)}$**

⁎ In the lepton sector, family, generation, and flavor are somewhat used interchangeably. It was originally called "muon number violation". The name "lepton family violation" was also used in the past.
⁎⁎This is the original format of definition. In the recent years, some experimentalists use inclusive Γ as denominator, so that they simply stopped muons. This is causing confusions.

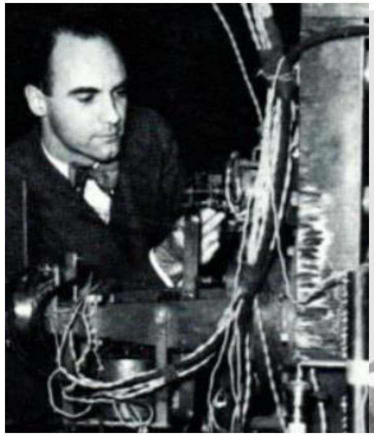
The discovery of muon

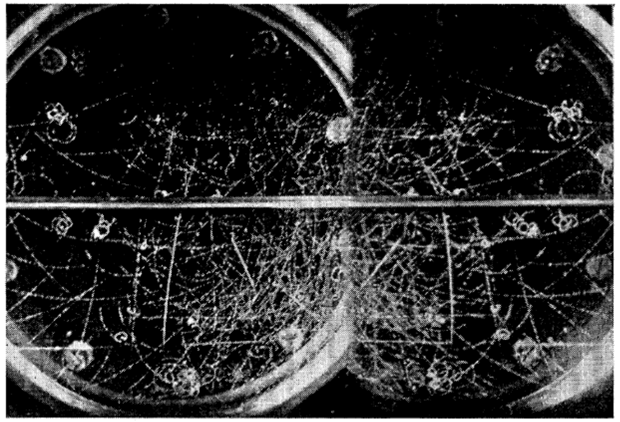
- Muon was first discovered in 1936 from the cosmic ray using cloud chamber
  - A particle with mass between electron and proton: named mesotron
- Naturally considered as Yukawa's meson which carries nuclear force
  - Postulated one year earlier
  - The actual Yukawa's meson, pion, was discovered one year later in 1937.
- Decay mode conceived as $\mu \rightarrow e + \nu$

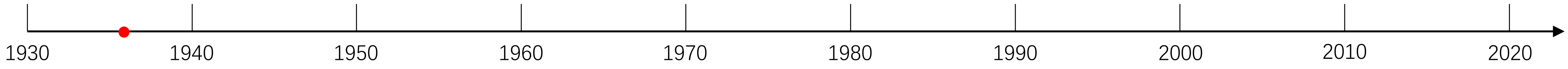

THE
PHYSICAL REVIEW
A Journal of Experimental and Theoretical Physics Established by E. L. Nichols in 1893
VOL. 50, No. 4 AUGUST 15, 1936 SECOND SERIES

Cloud Chamber Observations of Cosmic Rays at 4300 Meters Elevation and Near Sea-Level

CARL D. ANDERSON AND SETH H. NEDDERMEYER, *Norman Bridge Laboratory of Physics, California Institute of Technology*
(Received June 9, 1936)

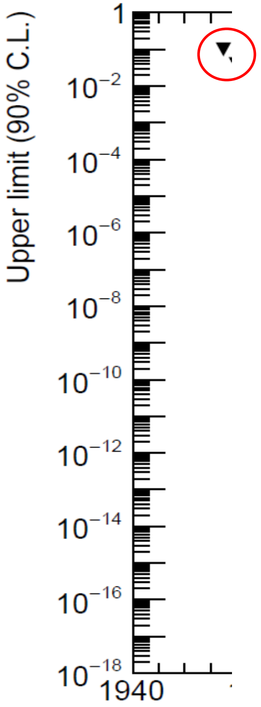






Muon is a lepton

- After a series of experiments, it's eventually clear that muon doesn't interact via strong force.
- Natural to take it as an exited electron: $\mu \to e + \gamma$
- Pontecorvo's experiment was the start of the CLFV search.



On the Disintegration of Negative Mesons

M. Conversi, E. Pancini, and O. Piccioni*

Centro di Fisica Nucleare del C. N. R. Istituto di Fisica dell'Università di Roma, Italia

December 21, 1946

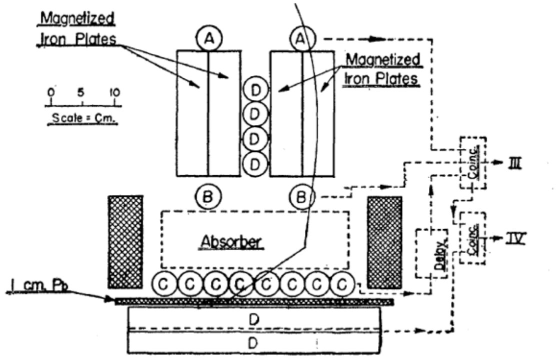


Fig. 1. Disposition of counters, absorber, and magnetized iron plates. All counters "D" are connected in parallel.

Search for Gamma-Radiation in the 2.2-Microsecond Meson Decay Process

E. P. Hincks and B. Pontecorvo

National Research Council, Chalk River Laboratory, Chalk River, Ontario, Canada

December 9, 1947

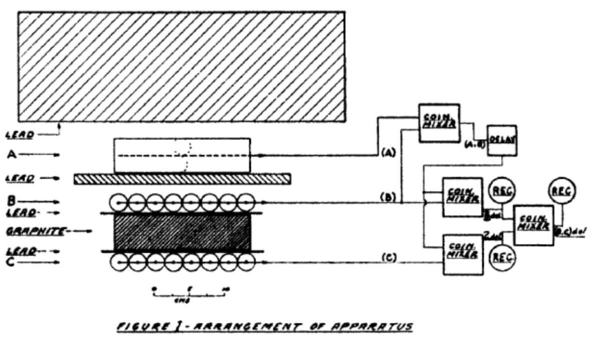
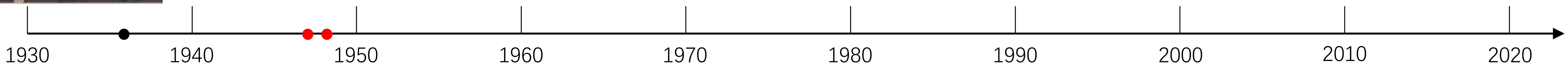


Fig. 1. Arrangement of apparatus.



The “muon puzzle”

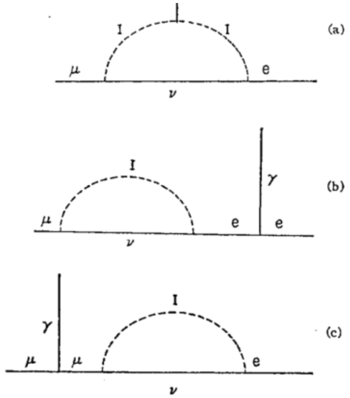
- Feinberg calculated $\mu \rightarrow e + \gamma$ Br up to 10^{-4}
- BNL’s accelerator was used to search for $\mu \rightarrow e + \gamma$ but not found
  - Start of accelerator CLFV
- Nishijima and Schwinger proposed “two neutrino theory”

Decays of the μ Meson in the Intermediate-Meson Theory*

G. Feinberg

Brookhaven National Laboratory, Upton, New York

(Received May 8, 1958)



Vanishing of the Neutrino Rest Mass*

K. Nishijima†

Brookhaven National Laboratory, Upton, New York

(Received September 12, 1957)

A Theory of the Fundamental Interactions

Julian Schwinger

Harvard University, Cambridge, Massachusetts

Search for Improbable Muon Decays

S. Lokanathan, J. Steinberger

Phys.Rev. 98 (1955) 240

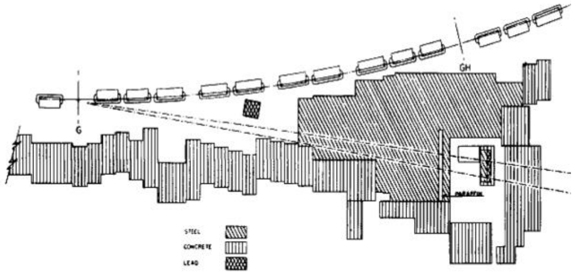
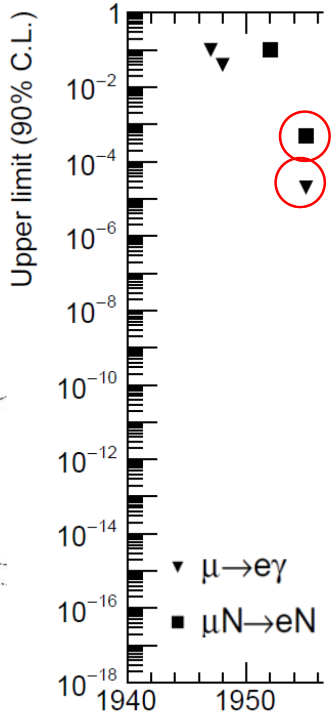
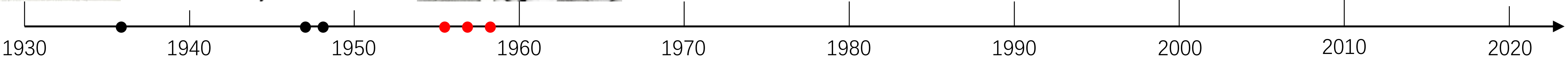


Fig. 3: Plan view of AGS neutrino beam experiment





Muonic neutrino

- Pontecorvo proposed to search for the different neutrino.
- Again in BNL, a group verified $\upsilon_\mu \neq \upsilon_e$
  - Two generations of leptons! Muon number accepted as a new quantum number.
  - A series of experiments carried out to test the conservation law of muon number.

Electron and Muon Neutrinos

B. Pontecorvo (Dubna, JINR)
1959

7 pages
Published in: *Sov.Phys.JETP* 10 (1960) 1236-1240, *Zh.Eksp.Teor.Fiz.* 37 (1959) 1751-1757

OBSERVATION OF HIGH-ENERGY NEUTRINO REACTIONS AND THE EXISTENCE OF TWO KINDS OF NEUTRINOS*

G. Danby, J-M. Gaillard, K. Goulianos, L. M. Lederman, N. Mistry, M. Schwartz,† and J. Steinberger†

Columbia University, New York, New York and Brookhaven National Laboratory, Upton, New York
(Received June 15, 1962)

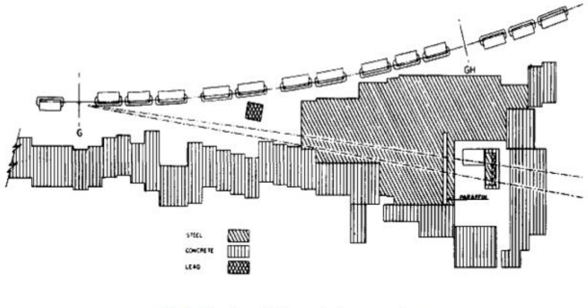
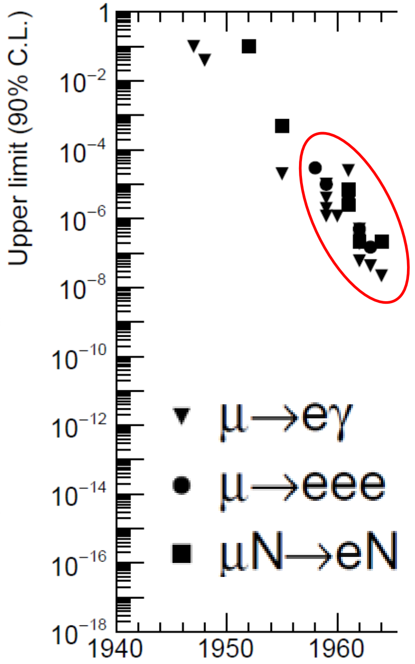


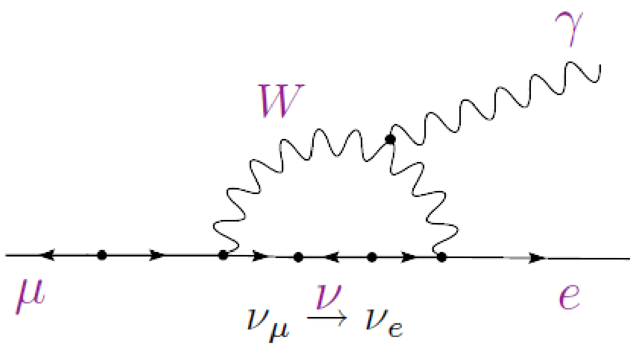
Fig. 3: Plan view of AGS neutrino beam experiment



The standard model (SM)

- The standard model was founded during 1960s and 1970s
  - Renormalizable quantum field theory with $SU(3)_C \times SU(2)_L \times U(1)_Y$ gauge symmetry.
  - Initially on 2, then extended to 3 generations of fermions (quarks & leptons)
- CLFV strictly forbidden, but
  - Neutrinos have tiny masses: allowed with negligible branching ratio.
  - A very clean place to test the SM!

$\mu \to e + \gamma$ in the SM+ m_ν



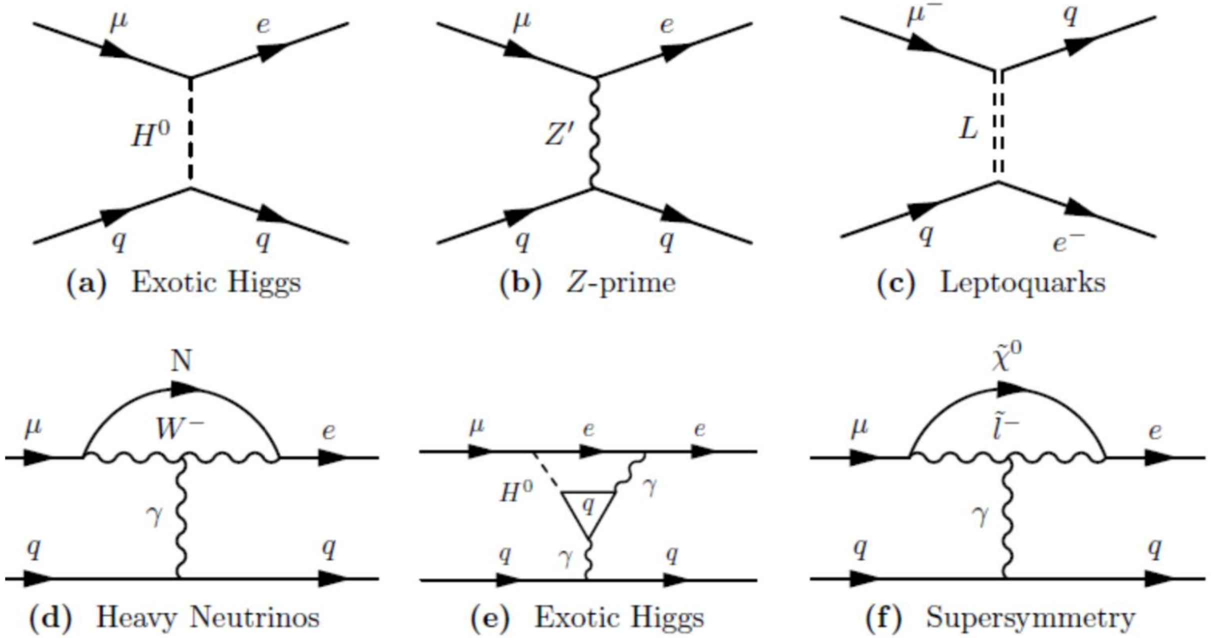
$$\mathcal{B}(\mu \to e\gamma) = \frac{3\alpha}{32\pi}\left|\sum_{i=2,3} U^*_{\mu i} U_{ei} \frac{\Delta m^2_{i1}}{M^2_W}\right|^2 \sim 10^{-54}$$

S.T. Petcov, Sov.J. Nucl. Phys. 25 (1977) 340

Highly suppressed by GIM due to the smallness of m_ν

New physics models beyond SM

- SM is a huge success. However it's definitely not the end.
  - Flavor puzzle.
  - Hierarchy problem.
  - Neutrino mass term.
  - Cosmological phenomena.
- New physics models proposed
  - CLFV naturally introduced.

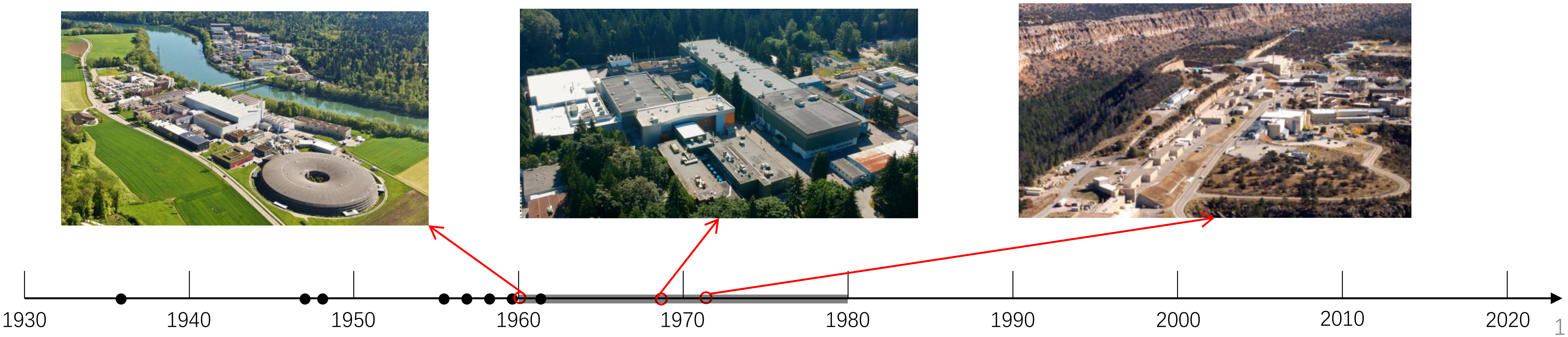


(a) Exotic Higgs (b) Z-prime (c) Leptoquarks

(d) Heavy Neutrinos (e) Exotic Higgs (f) Supersymmetry

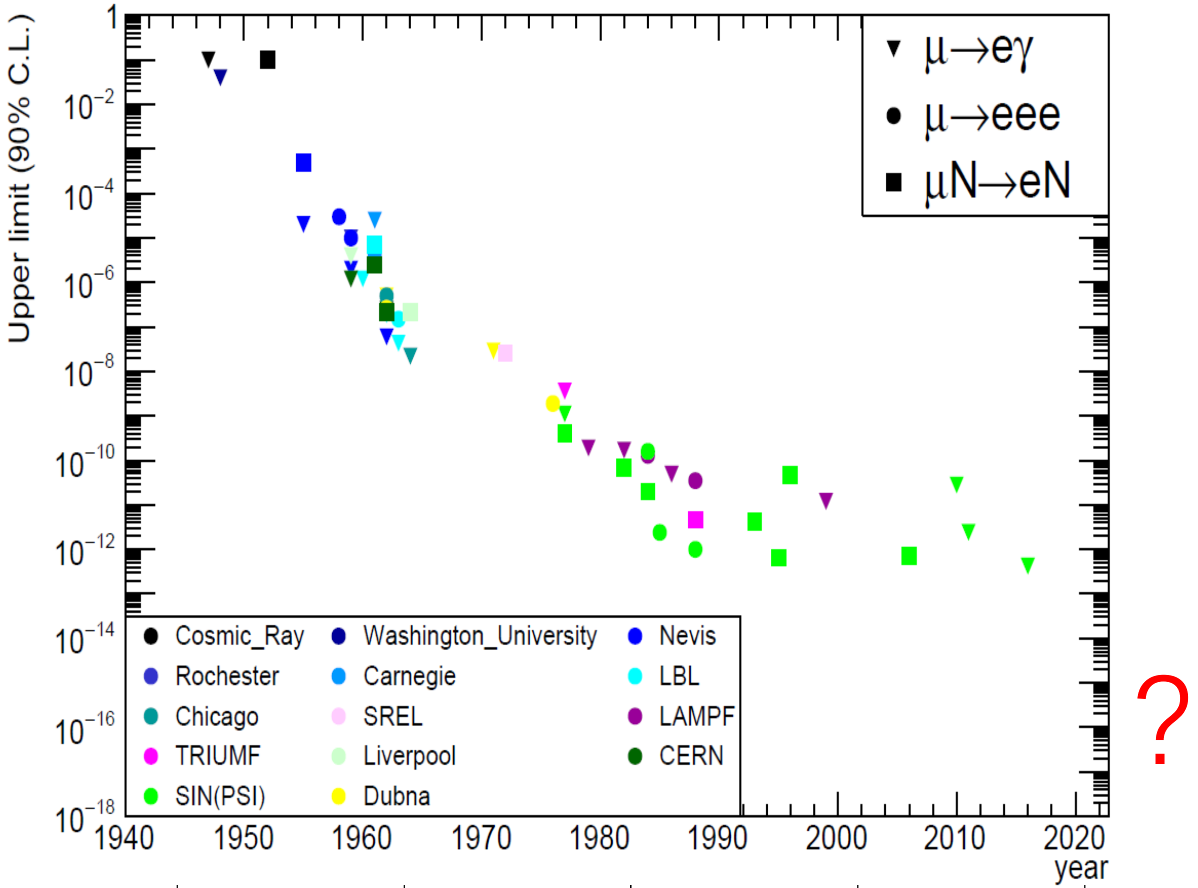
Meson factories

- In the same period of time, meson factories were built
  - SIN (PSI) 1960, TRIUMF 1968, LAMPF 1972
  - All with muon facilities to search for new physics on the precision frontier
  - All with $> 10^6$ muons (stopped) per second.
  - SIN (PSI) continued to upgrade to $10^7 \sim 10^8$ muons (stopped) per second
    - The world most powerful DC muon beam.



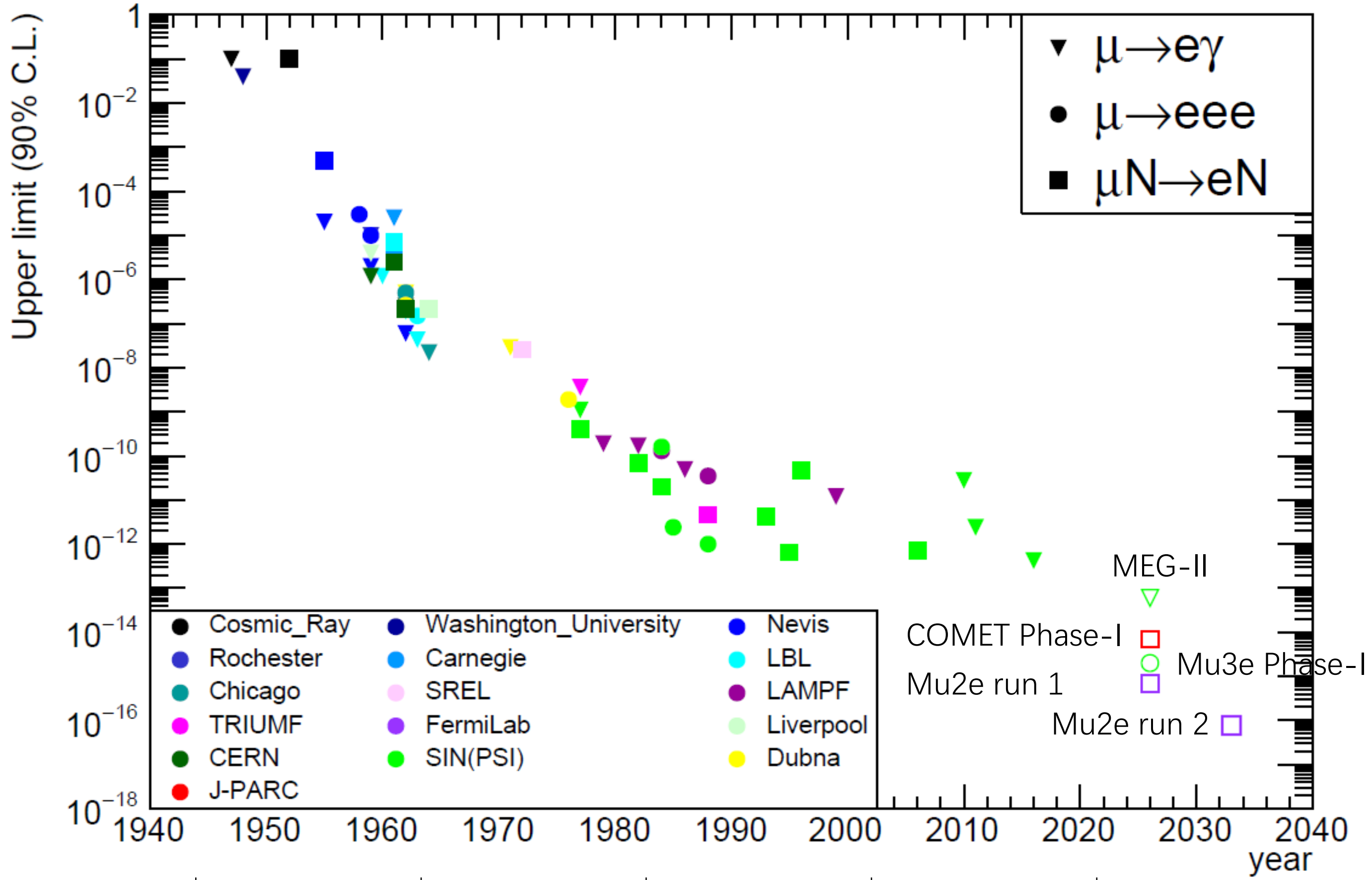
CLFV in meson factories

- The improvement was significant in 1980s
  - Brought the sensitivity down by ~4 orders of magnitude
- Slowed down afterward
  - Met challenge on the detector side
  - Gradually learning how to deal with the intensity frontier
- What will happen in the future?



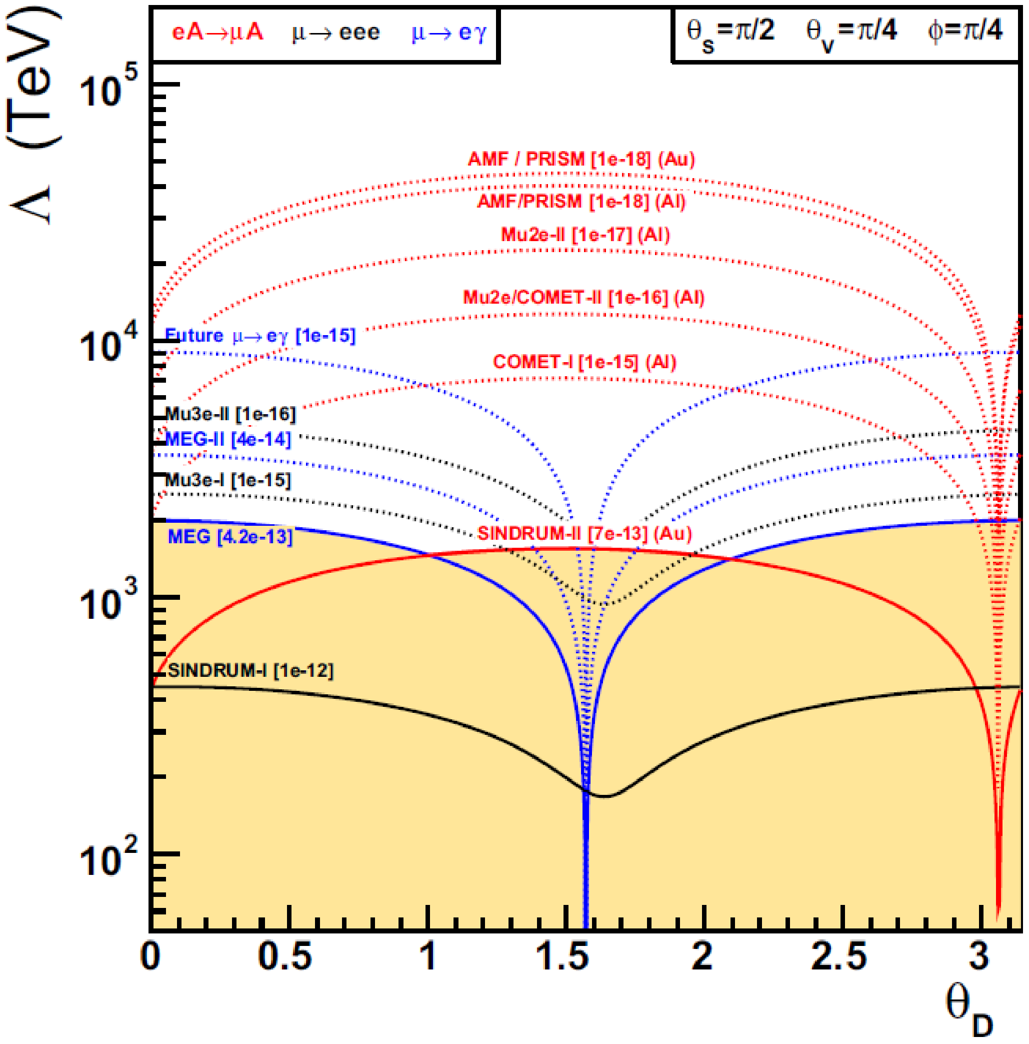
CLFV in the future?

- More experiments!
  - Already data taking: MEG-II
  - Under construction: COMET Phase-I, Mu2e, Mu3e
- Even more in the future
  - PSI muon facility upgrade plan (HiMB) will make Mu3e Phase-II and next stage $\mu \to e\gamma$ possible to improve by x10.
  - COMET Phase-II and Mu2e-II are seeking to be approved: aiming at 10^{-18}, an improvement by x10 .
  - In the far future, AMF/PRISM may bring the sensitivity to $< 10^{-19}$



Model independent approach: EFT

- Extend SM in effective field theory with higher dimension operators:
  $\mathcal{L} = \mathcal{L}_{SM} + \sum_{n\geq 1} \frac{{c_{ij}}^{4+n}}{\Lambda^n} \mathcal{O}^{4+n}$
- CLFV can be introduced from dim-6: $Br \sim \frac{1}{\Lambda^4}$
- Λ can reach $\mathcal{O}(10^3 \sim 10^4)$ TeV!
  - Good complementation to direct searches for new physics.



θ_D parameterizes the relative magnitude of dipole and four-fermion coefficients

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$\mu \to e\gamma$ and $\mu \to eee$

- Both processes have accidental backgrounds proportional to muon beam intensity
  - Needs to improve detectors constantly

$$B_{acc} \propto \Gamma_\mu^2 \cdot \delta E_e \cdot (\delta E_\gamma)^2 \cdot \delta T_{e\gamma} \cdot (\delta\Theta_{e\gamma})^2$$

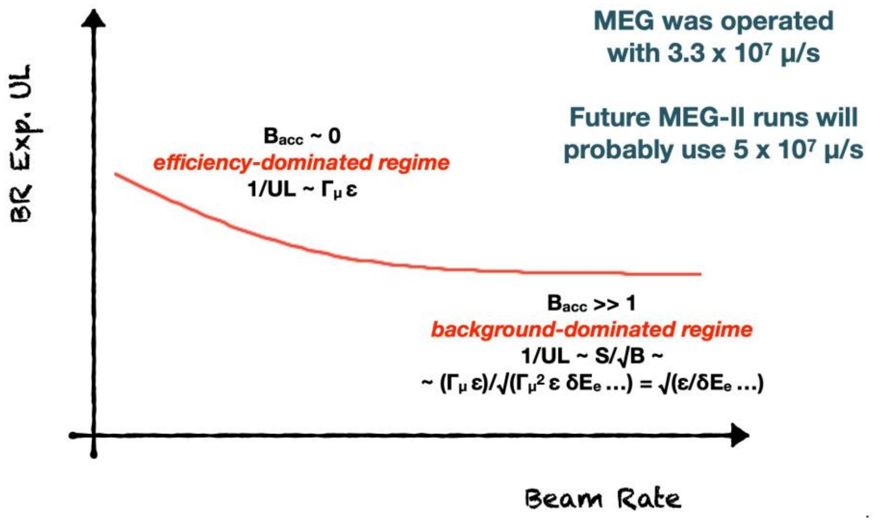
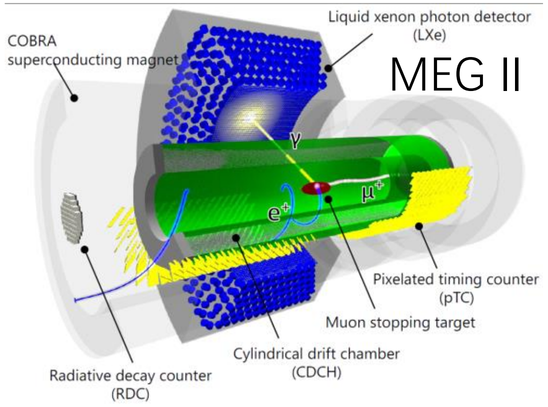


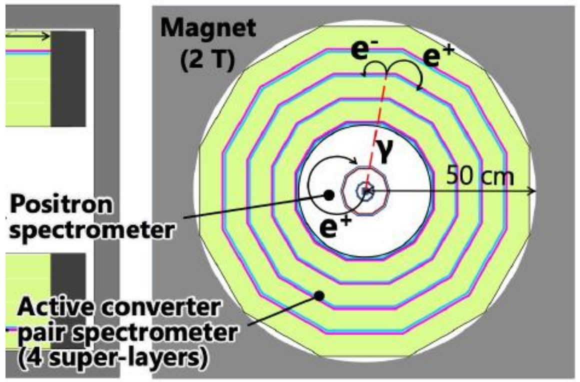
Illustration for accidental background limit to $\mu \to e\gamma$ sensitivity.

History of detector upgrades for $\mu \to e\gamma$

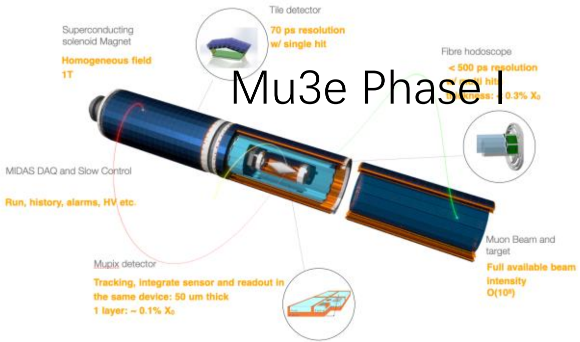
Experiment (year)	Rate (Hz)	Duty f.	ΔE_e	ΔE_γ	$\Delta t_{e\gamma}$	$\Delta\Theta_{e\gamma}$	Upper limit
TRIUMF (1977) [265]	2×10^5	100%	10.3%	8.7%	6.7 ns	80 mrad	3.6×10^{-9}
SIN (1980) [266]	5×10^5	100%	8.7%	9.3%	1.4 ns	–	1×10^{-9}
E328 (1982) [267]	2.4×10^6	6.4%	8.8%	8%	1.9 ns	37 mrad	1.7×10^{-10}
Crystal Box (1988) [269]	4×10^5	6.6%	8%	8%	1.8 ns	87 mrad	4.9×10^{-11}
MEGA (1999) [260]	2.5×10^8	6.5%	1.2%	4.5%	1.6 ns	17 mrad	1.2×10^{-11}
MEG (2016) [49]	3×10^7	100%	1.5%	4.7%	0.28 ns	30 mrad	4.2×10^{-13}
MEG II (2020) [313]	7×10^7	100%	0.6%	2.3%	0.19 ns	20 mrad	$5 \times 10^{-14 (a)}$

(a) Expected.





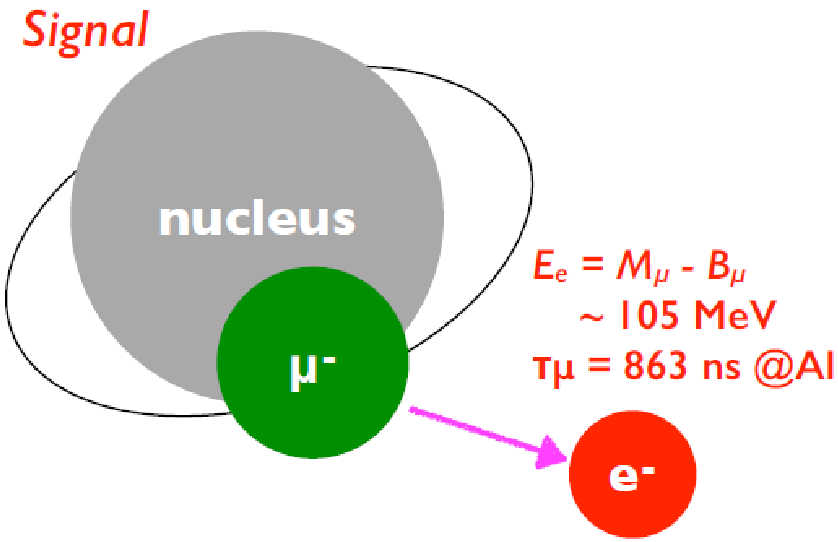
*One conceptual design for next step

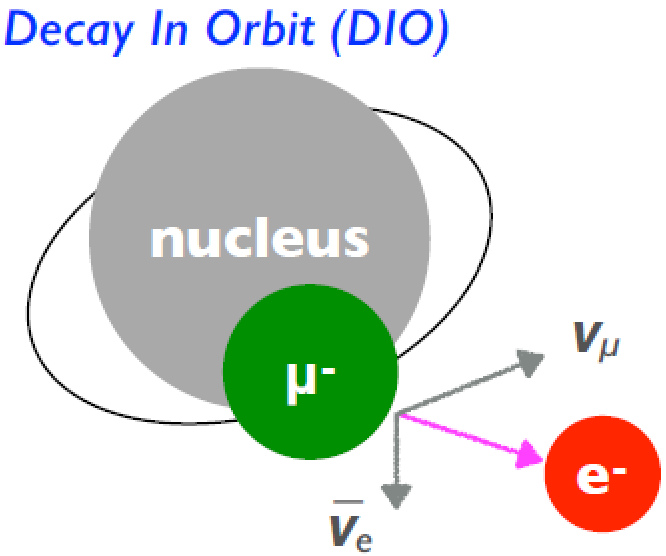


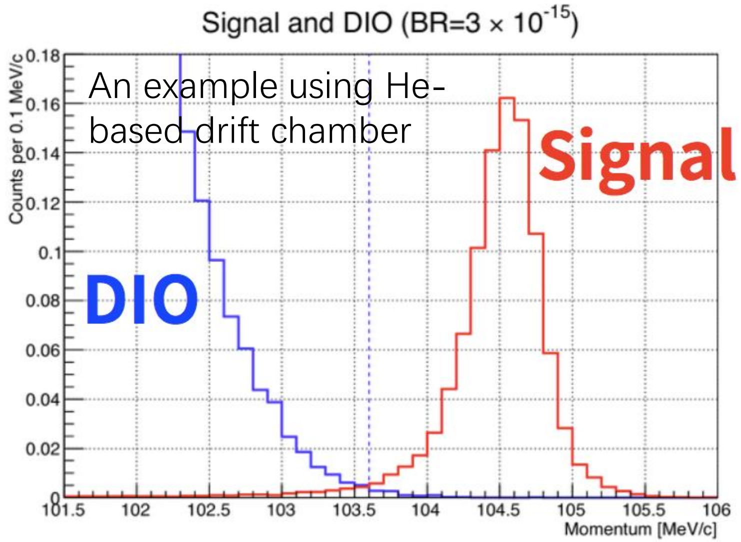
Mu3e Phase II
Even thinner silicon detector?

Muon-to-electron conversion ($\mu N \to eN$)

- Muon nuclear capture
  - Coherent process enhanced: the nucleus stays at ground state
- Signal: 1 mono-energetic electron: $E_e = M_\mu - B_\mu - E_{recoil} \sim 105\ MeV$
- Background: intrinsic, beam related, cosmic ray
  - The intrinsic background, from muon Michel decay in orbit, has an end point energy near half muon mass, but







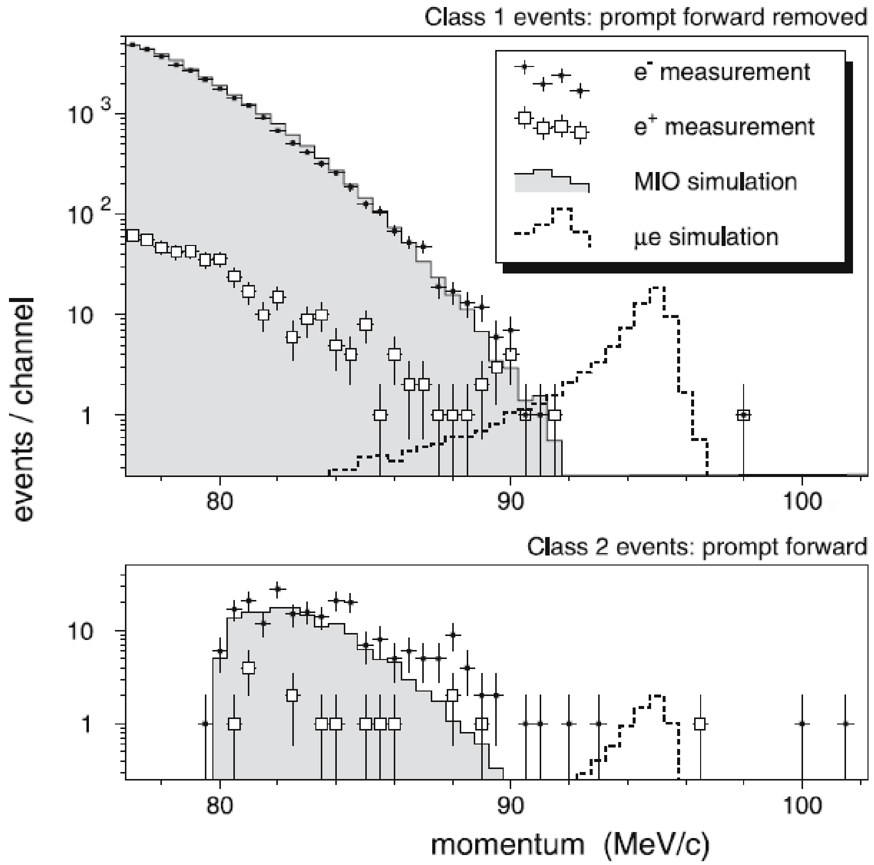
Lesson from SINDRUM-II

PSI proton beam repetition rate: 50.6 MHz. Pion lifetime: 26 ns: Pions can survive between pulses

- Original strategy: use scintillators to veto.
  - No longer feasible with
- SINDRUM-II strategy:
  - Use narrow momentum window and time window to select the beam.
  - Highly relying on the understanding of the beam
- Found unexpected events and had to stop.

To move forward, pion induced background must be solved!

- Need a better design about the beam structure.



Eur. Phys. J., 2006, C47:337-346

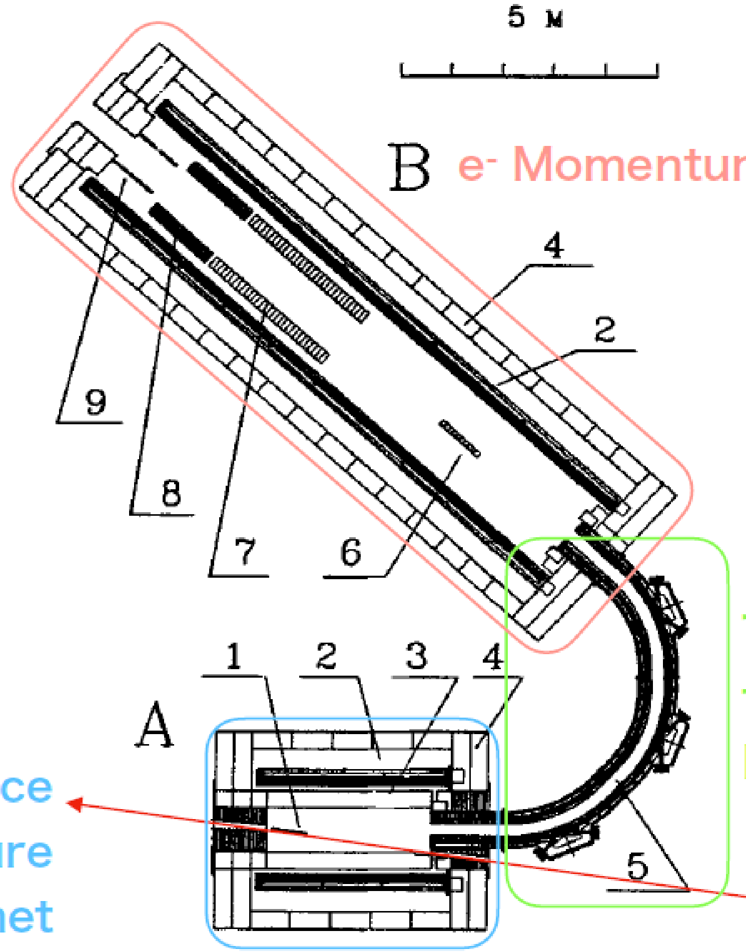
MELC @INR

The Lobashev scheme:

V.M. Lobashev:

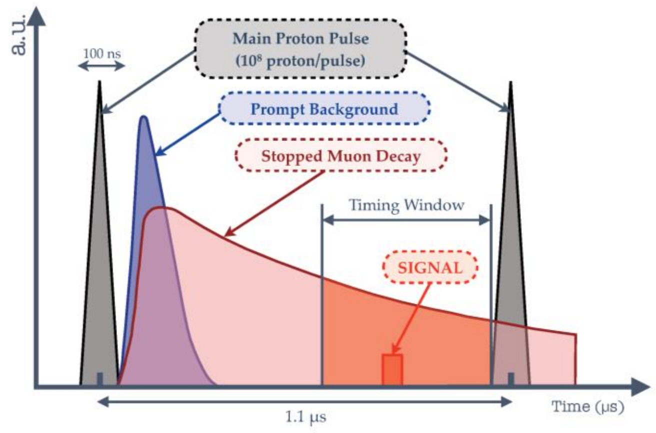
A brilliant idea that can drastically increase the μ^- yield by using a single solenoidal magnetic field connecting from the head to the tail.

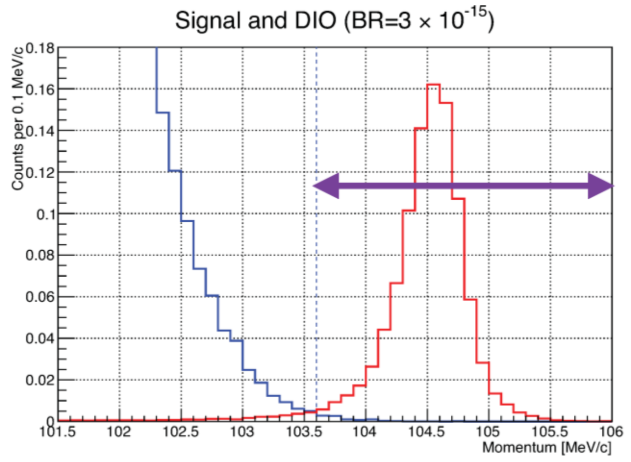
R.M. Djilkibaev and V.M. Lobashev, AIP Conf. Proc. 372 (1996) 53
R.M. Djilkibaev and V.M. Lobashev, Sov. J. Nucl. Phys. 49 (1989) 384
V.S. Abadjev et al., Preprint No. 786/92, INR



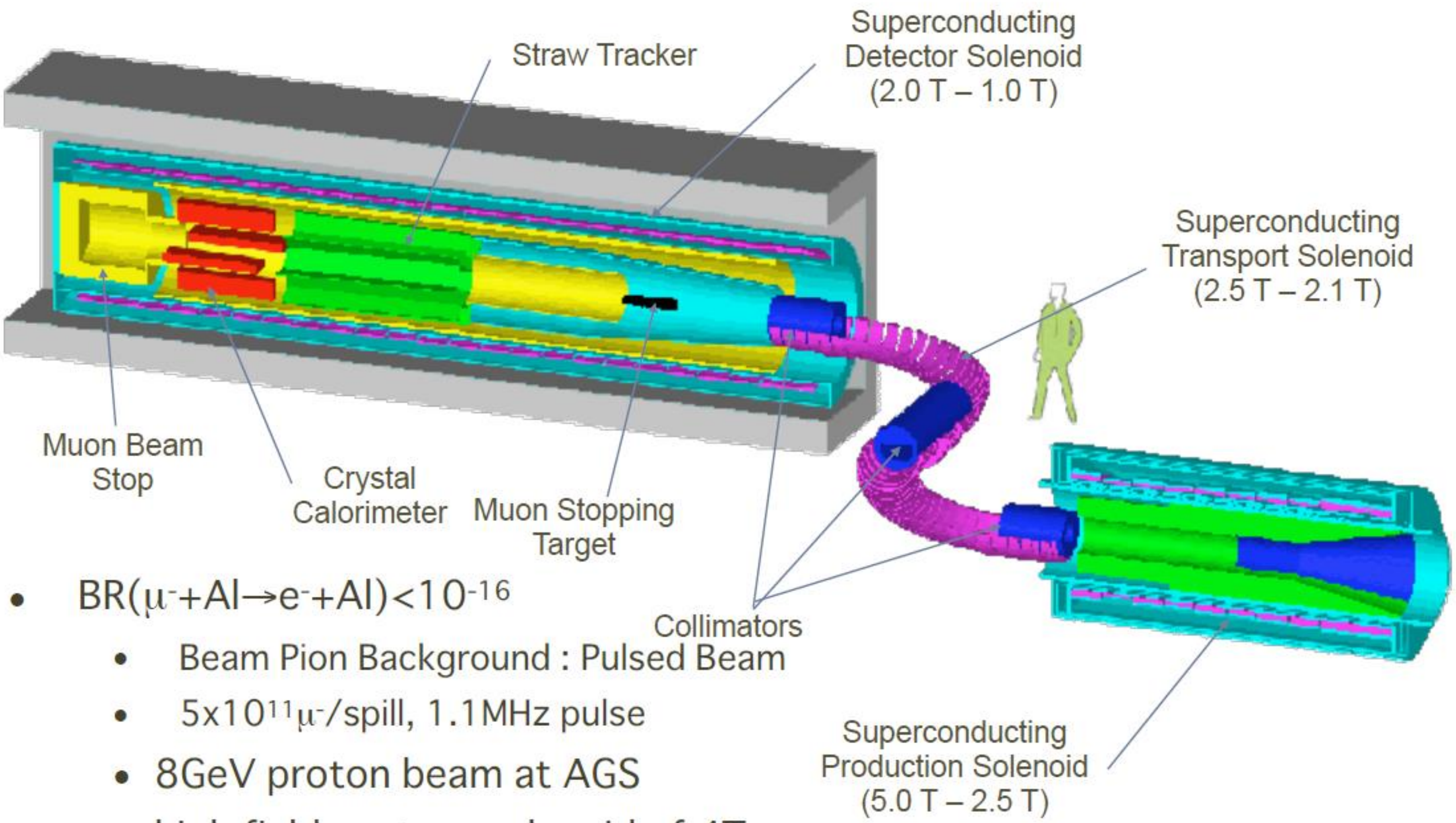
Toward $< 10^{-16}$ sensitivity

- Need much more muons
  - Thick target: ~1 hadron interaction length.
  - Powerful capture magnetic field. ~5 T
- Need to suppress pion induced background
  - Pulsed beam. Wait for pions decay.
- Need to suppress other beam particles
  - Curved solenoid: select low momentum.
  - Pulse beam also helps: wait for fast particles fly though.
- Need to control moun decay in orbit (DIO) background
  - A few 100 keV/c resolution can work: drift chamber, straw tracker, etc.
  - Mind the non-gaussian tail: fitting quality check.
- Need to suppress cosmic ray induced background.
  - Passive shielding will no longer be enough!
  - Pave scintillators on top to veto cosmic ray event.
  - Reduce live time: higher beam intensity.



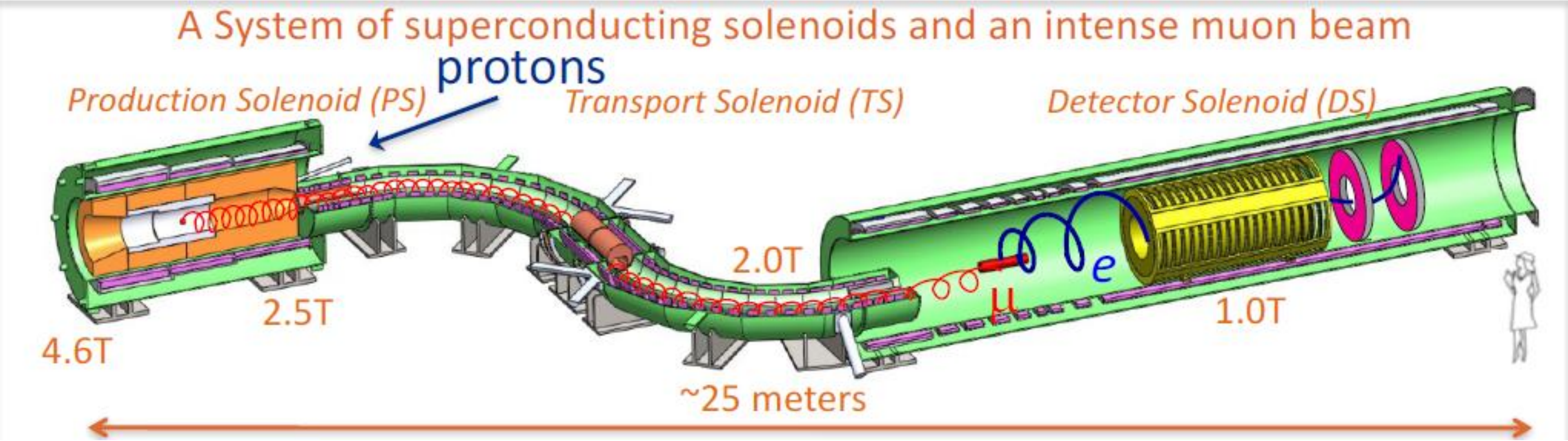


MECO @BNL/AGS

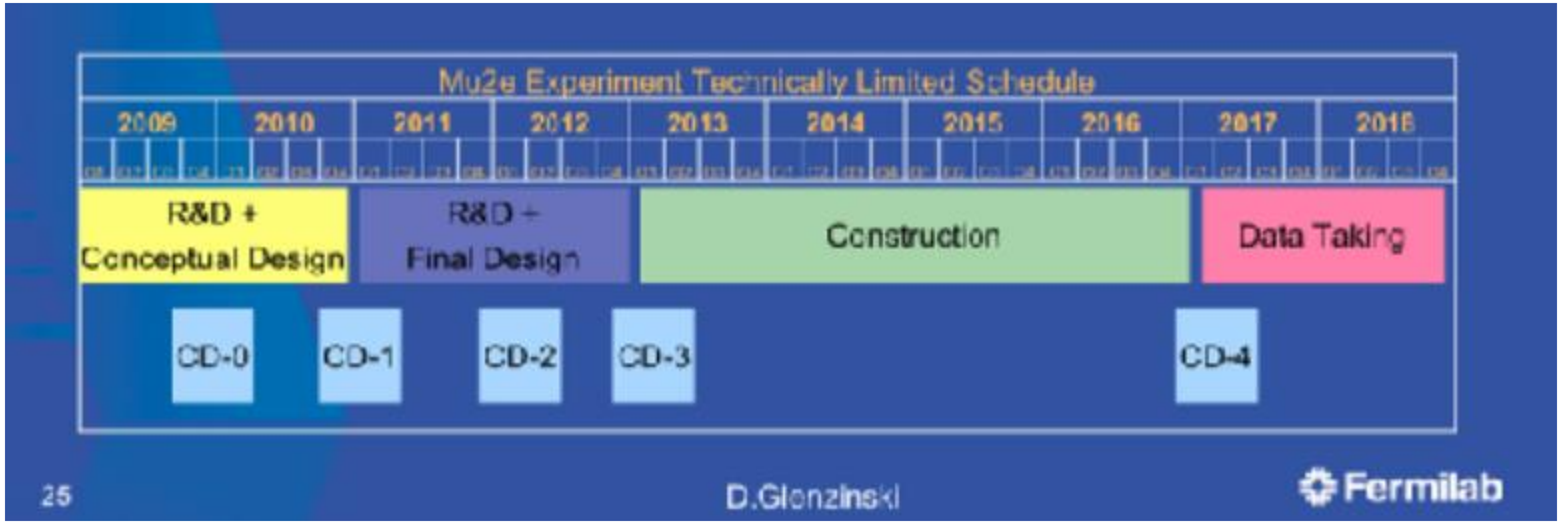


- $BR(\mu^- + Al \to e^- + Al) < 10^{-16}$
  - Beam Pion Background : Pulsed Beam
  - $5 \times 10^{11} \mu^-$/spill, 1.1MHz pulse
  - 8GeV proton beam at AGS
  - high field capture solenoid of 4T
- ~ 2005, and cancelled

Mu2e @ Fermilab



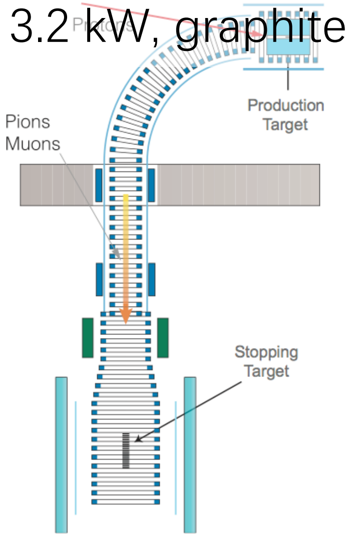
Prospect in the summer of 2009



COMET @ J-PARC

COMET Phase-I

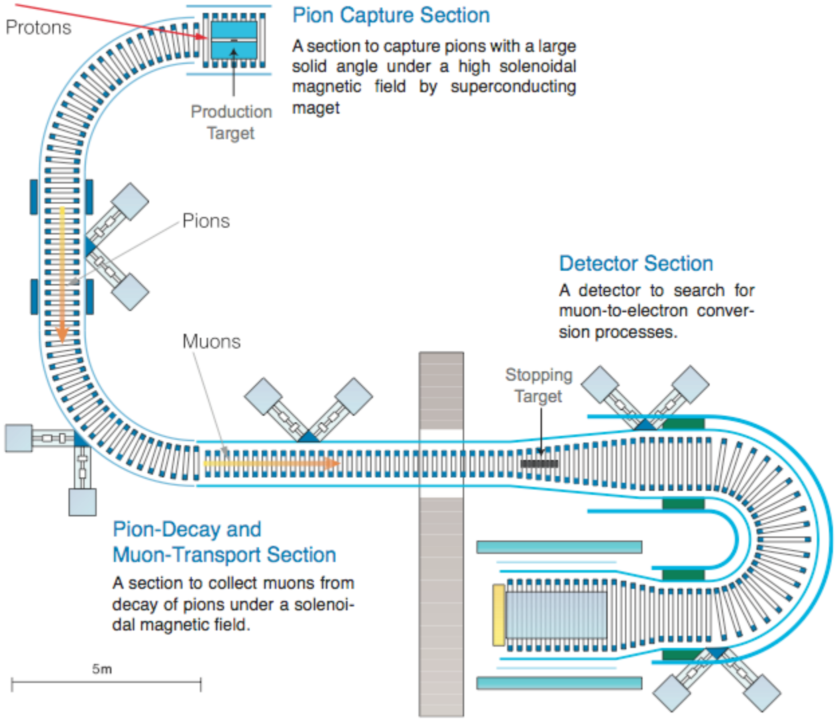
- Directly measure the muon beam with prototypes of Phase-II detector.
- Search for $\mu - e$ conversion with factor of 100 improvement
- LOI submitted in 2011: E21
- 8 GeV, 3.2 kW, graphite target



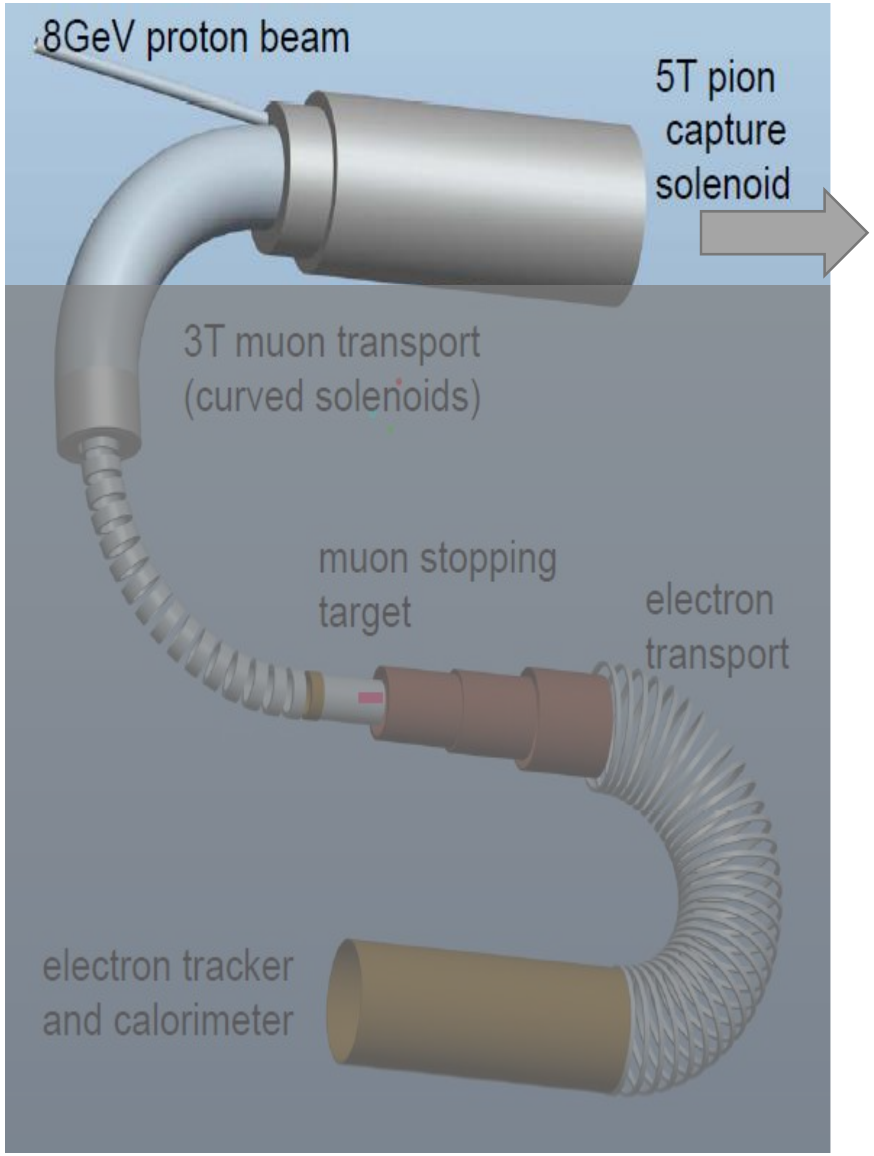
- Upstream part same as Phase-II
  - Except production target and part of shielding
- Detector is different.

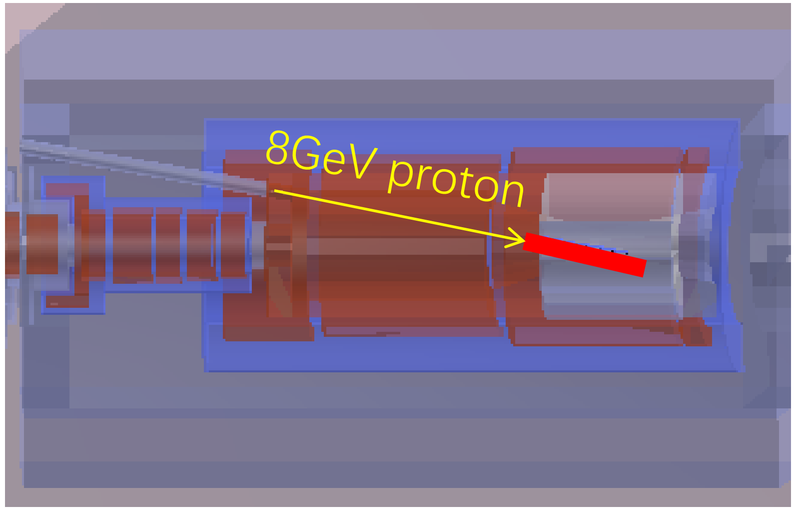
COMET Phase-II

- Search for $\mu - e$ conversion with full sensitivity: factor of 10,000 improvement
- CDR submitted in 2009
- 8 GeV, 56 kW, tungsten target



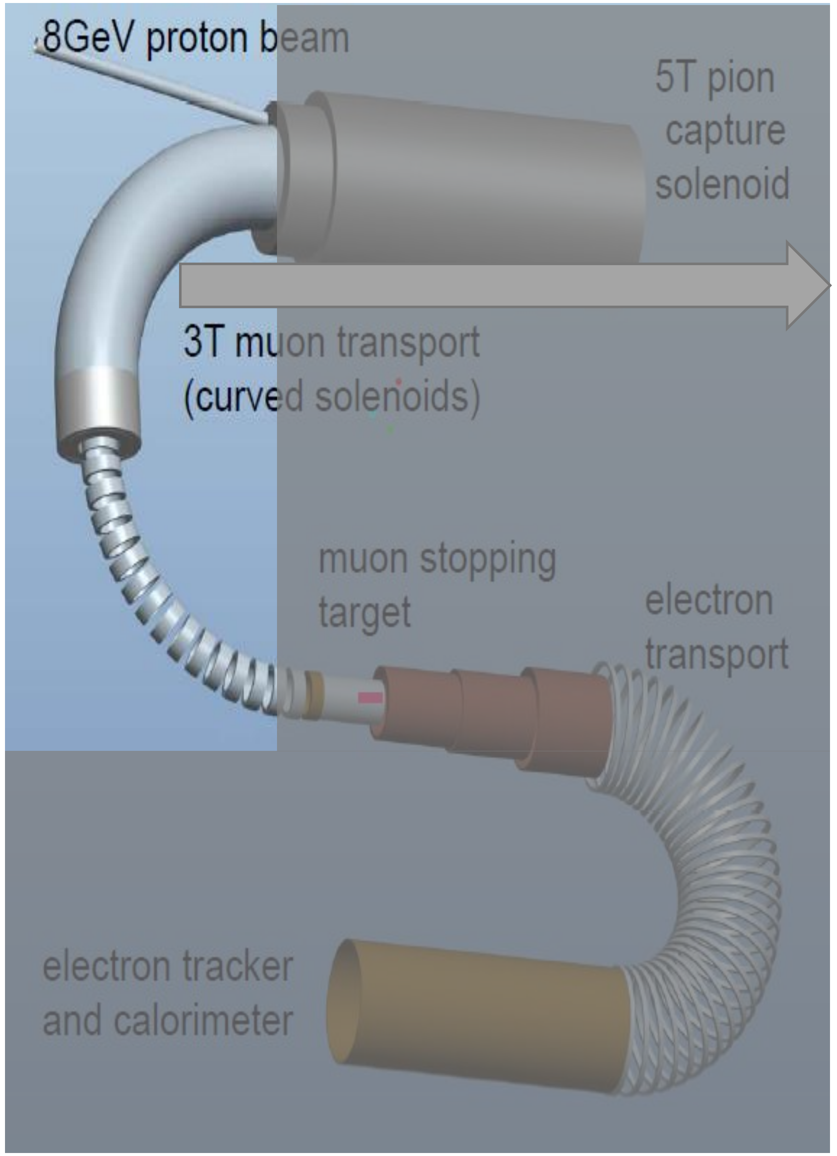
Production target and the capture magnet





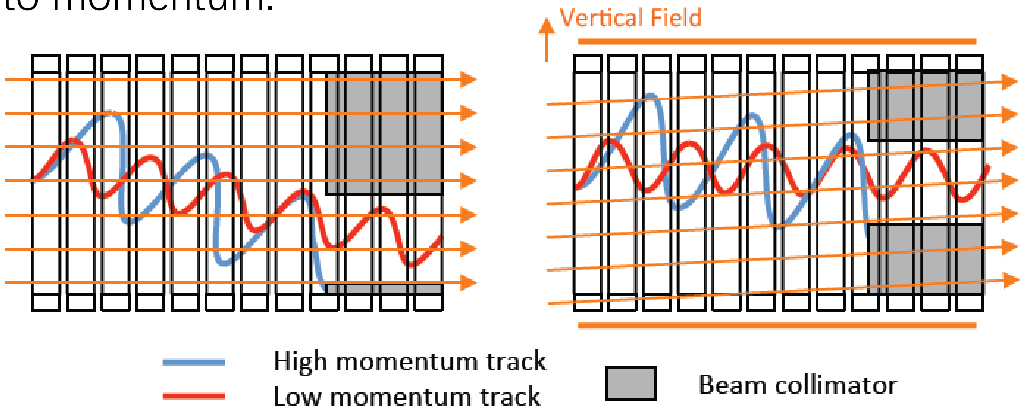
- 8 GeV 56 kW proton beam
- Thick target with 1~2 hadron interaction length
- Powerful capture magnet: 5 T
  - Large inner bore to fit in the shielding
  - Adiabatic decreasing field: focusing and mirroring
- Expected muon yield: 10^{11} muon/sec! $(10^{8}\ @\ PSI)$

Transportation solenoid



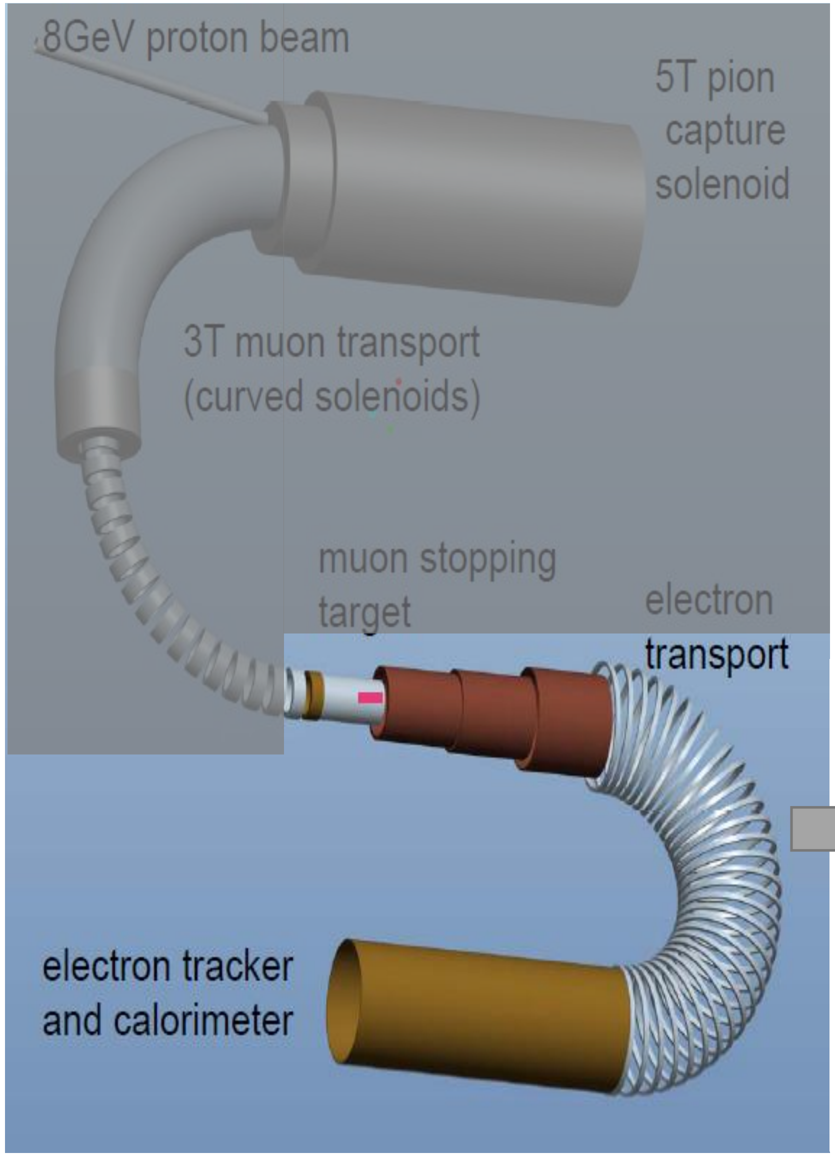
Drift vertically, proportional to momentum.

Vertical field as “correction”

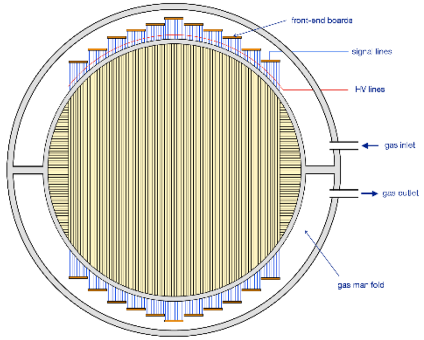


- Use C shape curved solenoid
  - Beam gradually disperses
    - Charge & momentum
  - Dipole field to pull back muon beam
    - Can be used to tune the beam
  - Collimator placed in the end
    - Utilize the dispersion in 180 degrees

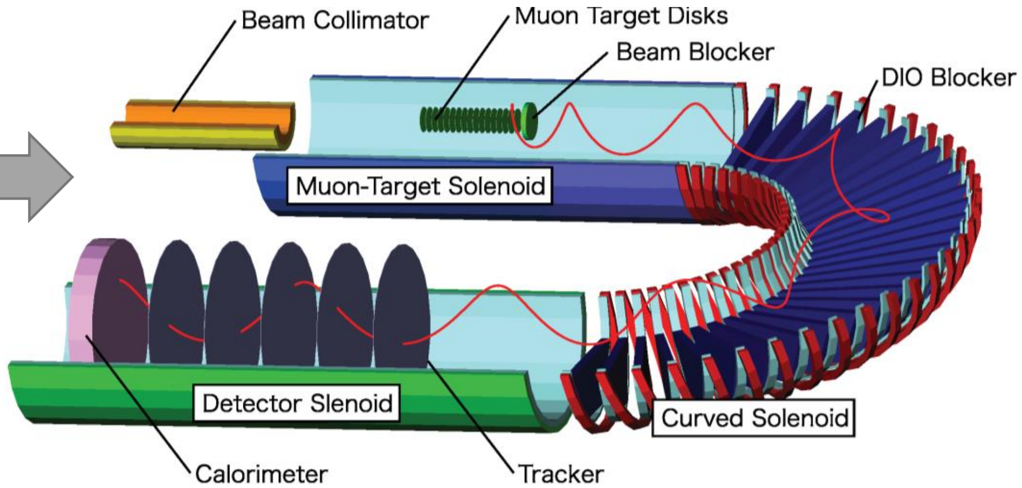
Stopping target and detector system



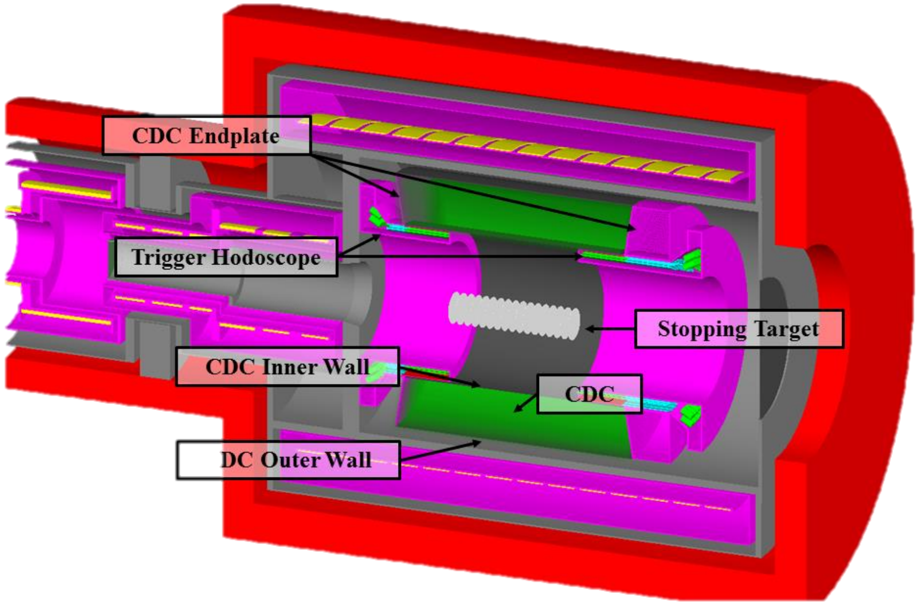
- Use straw tracker to measure the momentum
  - Really light: put in vacuum, 12 micro meter thin straw



- Electromagnetic calorimeter
  - Providing trigger, TOF and PID

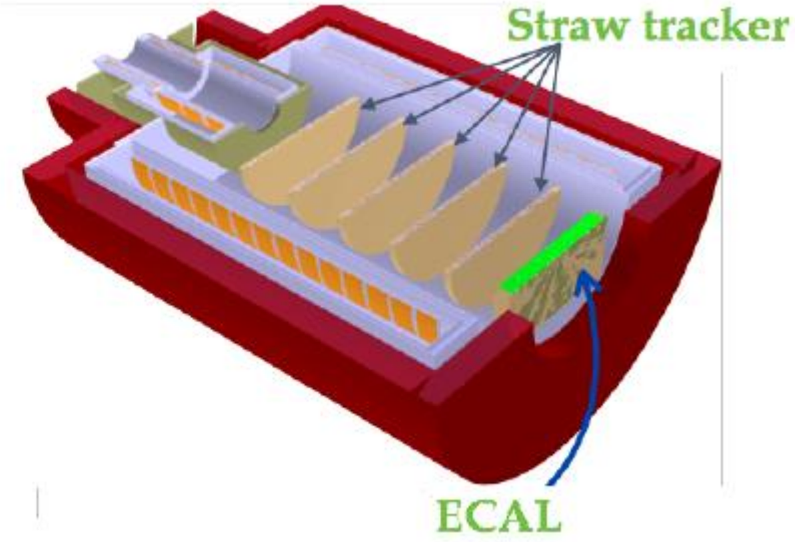


Phase-I detector: Cylindrical detector (CyDet)



- Specially designed for Phase-I. Consists of:
  - Cylindrical trigger hodoscope:
    - Two layers: plastic scintillator for t0 and Cerenkov counter for PID.
  - Cylindrical drift chamber:
    - All stereo layers: z information for tracks with few layers' hits.
    - Helium based gas: minimize multiple scattering.
    - Large inner bore: to avoid beam flash and DIO electrons.

Phase-I detector: Straw Tracker & Energy Calorimeter (StrEcal)



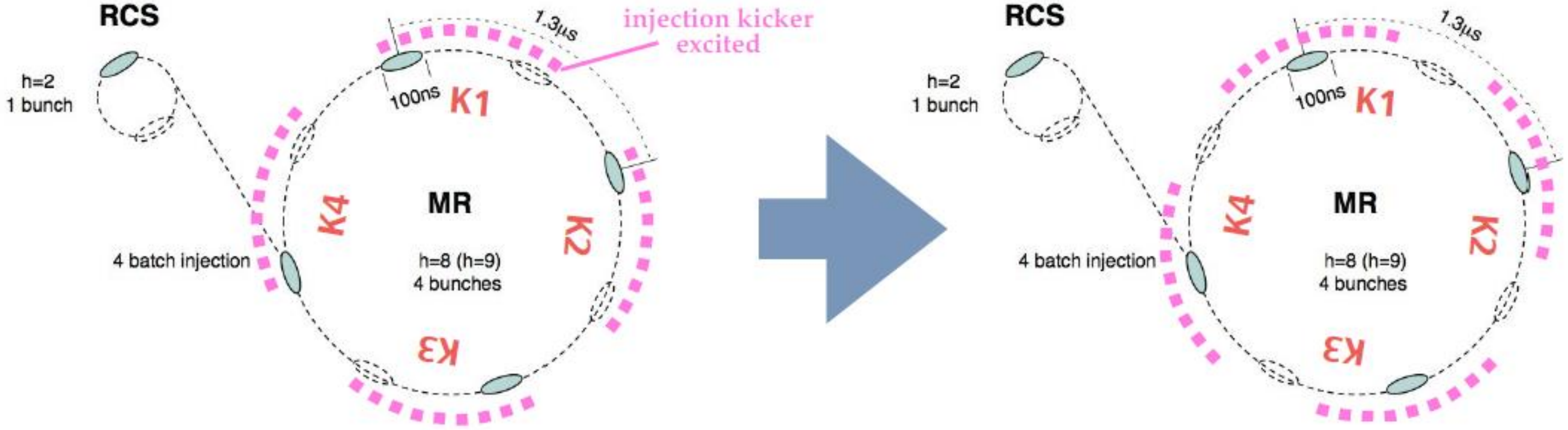
- To measure all delivered beam incl BG, vacuum-compatible tracker and calorimeter is employed
- Straw = Planer/Low-mass, LYSO crystal ECAL = High resolution / High density
- Same concept as Phase-II detector = Prototype of Phase-II Final Detector

Design is good, but actual work is not just copy paste in reality…

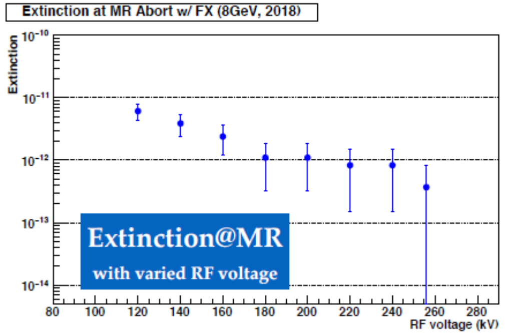
- Proton beam
  - Extinction, spill duty factor
- Full simulation of the muon beam: radiation issue
- Geant4 physics model validation
- Tracking quality control

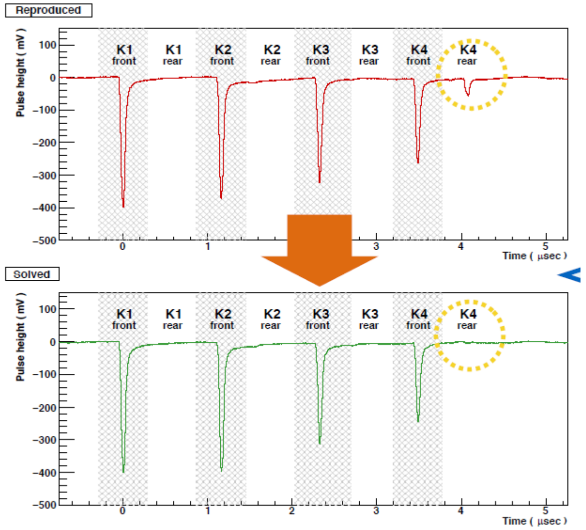
Proton beam from J-PARC

- To make the proton extinction factor: R $(N_{leak}/N_{pulse}) < 10^{-10}$
  - Shift the kicker phase by half period to avoid residual protons in the empty bucket.



Measurement at main ring:
proton leak < 10^{-12}

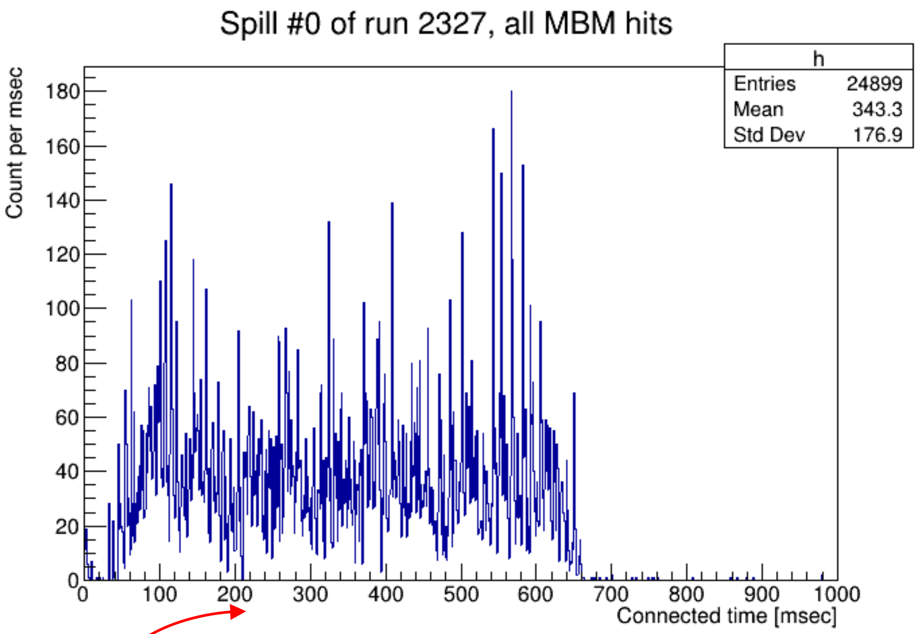


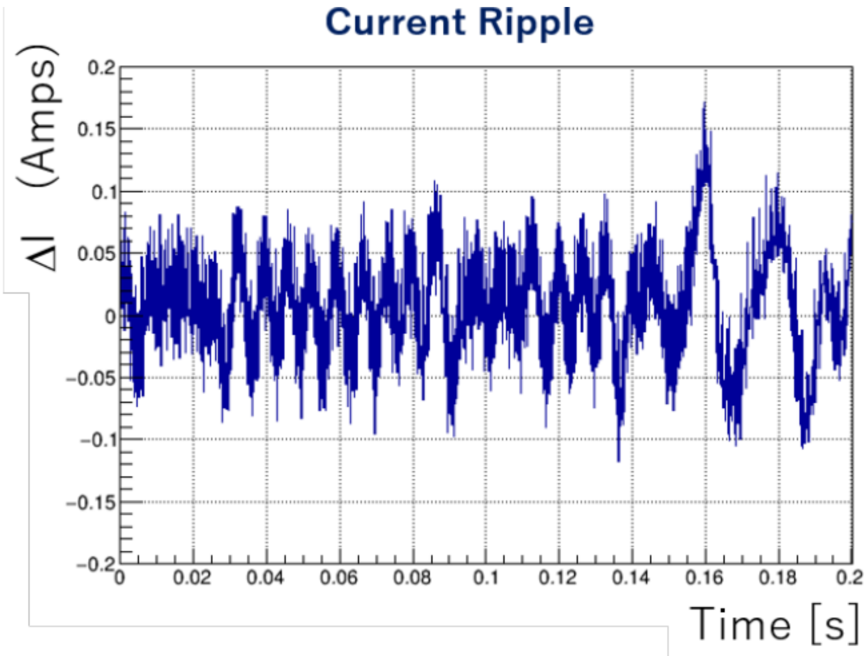


2018: Observed K4 rear leak.
2021: T78 at hadron hall, solved the leak by shifting the kicker further: $< 3.2 \times 10^{-12}$
2023: Confirmed same performance after the power upgrade in the J-PARC main ring.

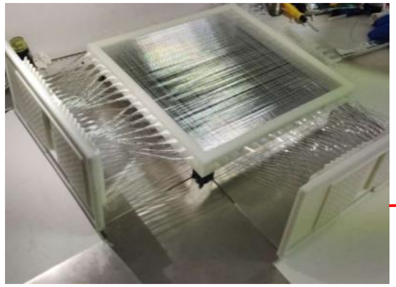
Proton beam intensity stability

- Measured the time structure of the secondary beam using COMET proton beamline.
- First look gave an impression that stability is not great.
  - Maybe caused by the current ripple shown below.
  - Can be canceled if precise fluctuation function can be give: next plan!





Muon beam monitor (MBM)



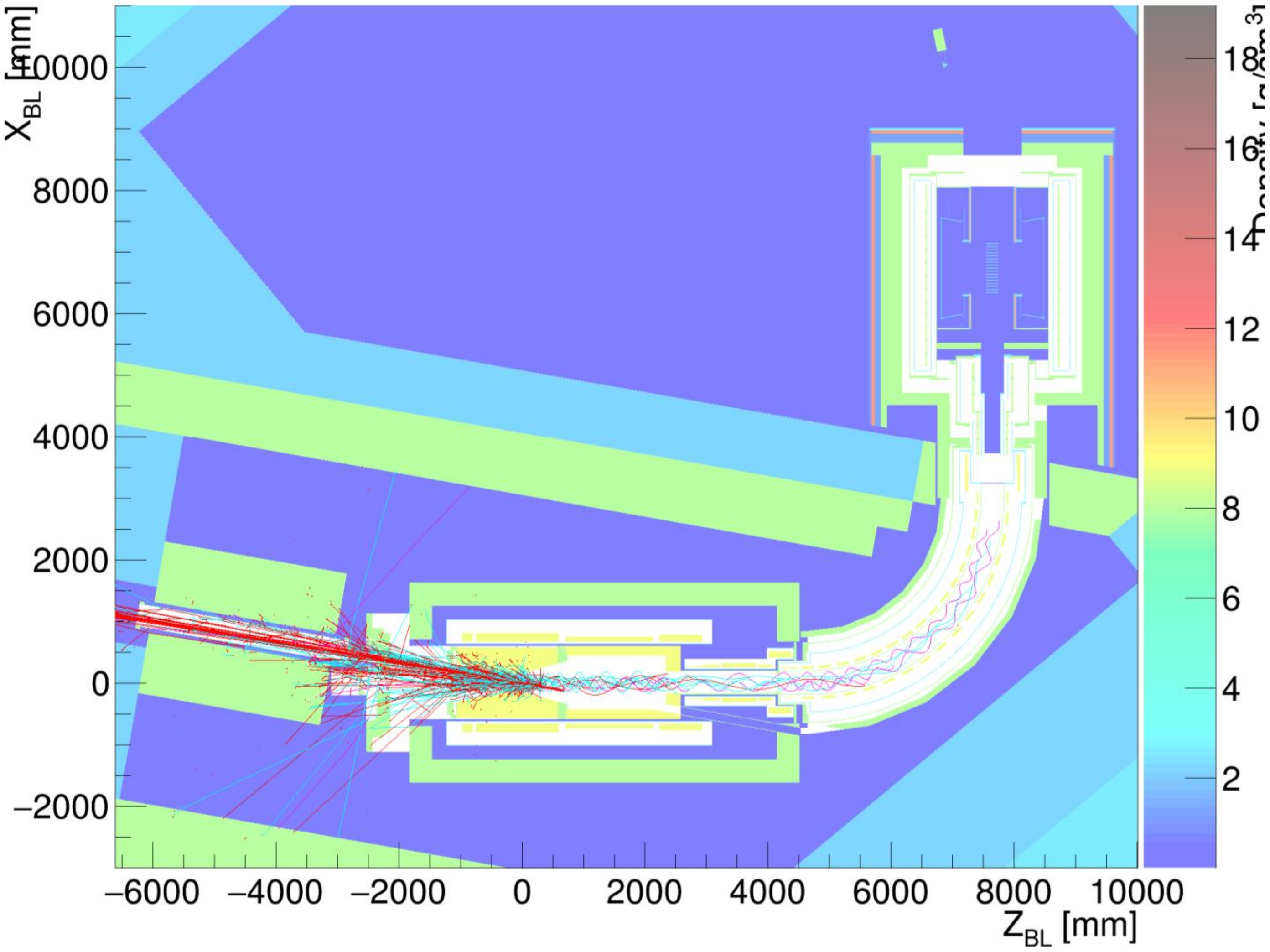
Data taken from MBM during Phase-alpha, March 2023.

* Current ripple in beamline magnet. From Ryotaro Muto, Slow Extraction Workshop 2019

Full simulation of the muon beam

From 100 proton hitting the target

Trajectory colors
Blue: e-
Green: e+
Magenta: mu±
Cyan: pi±
Yellow: photon
Gray: neutron
Red: proton
Black: ion



$\frac{1}{160000}$bunch
Or 0.00625 ns

It would be great if we only have muon/pion…

Full simulation of the muon beam

From 100 proton hitting the target

Trajectory colors
Blue: e-
Green: e+
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Cyan: pi±
Yellow: photon
Gray: neutron
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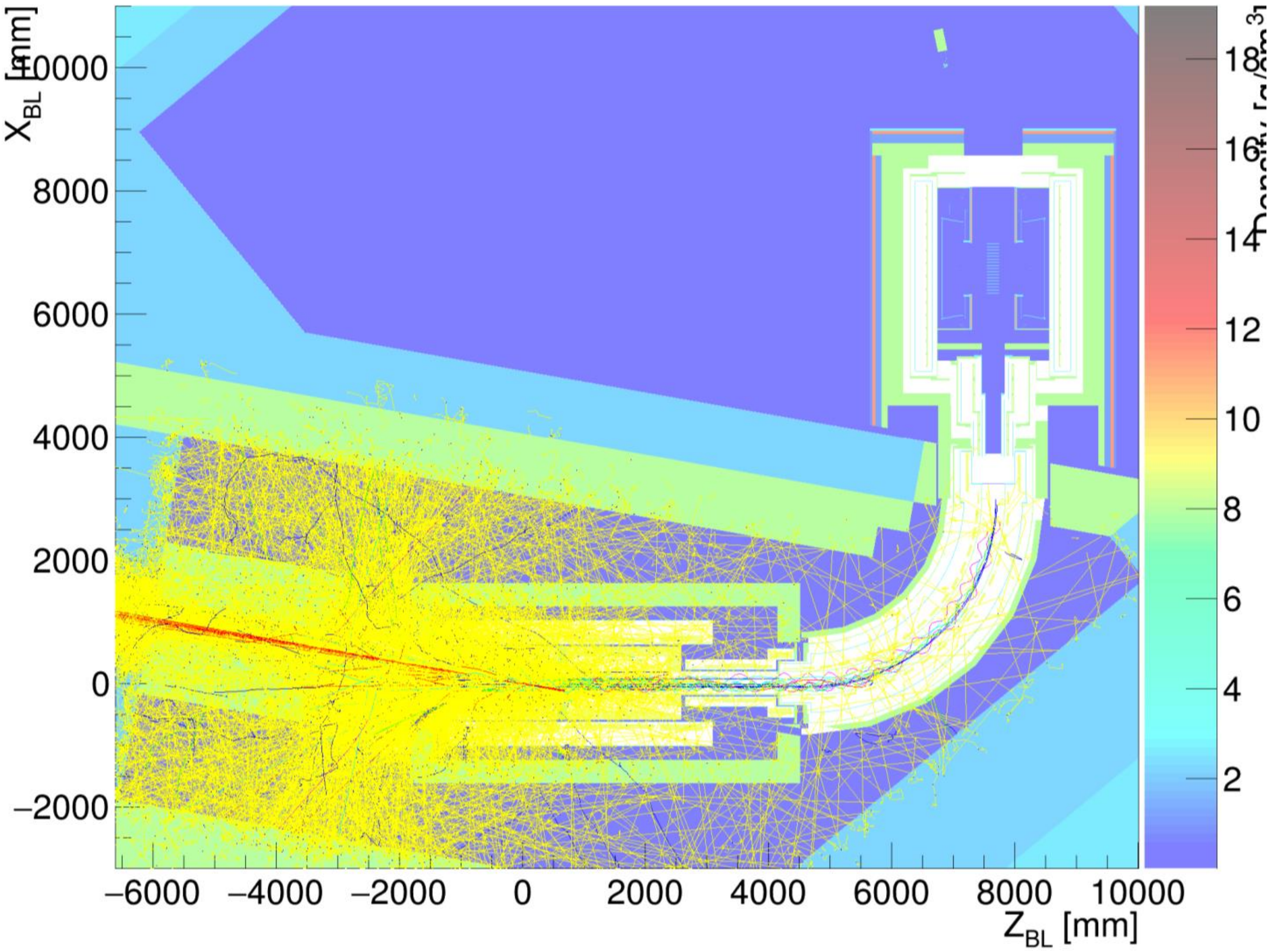


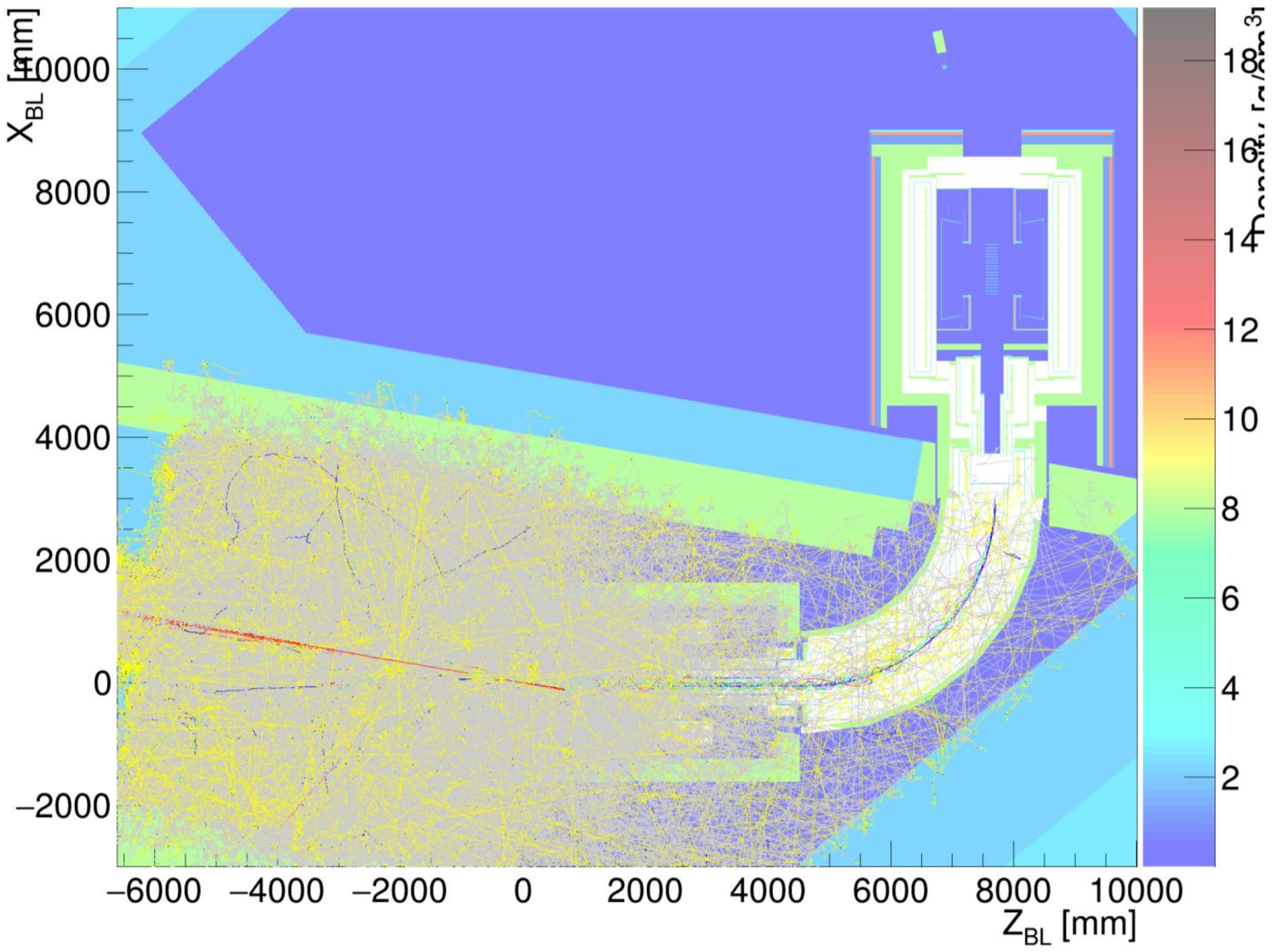
$\frac{1}{160000}$bunch
Or 0.00625 ns

But we also have photon/electron/positron…

Full simulation of the muon beam

From 100 proton hitting the target

Trajectory colors
Blue: e-
Green: e+
Magenta: mu±
Cyan: pi±
Yellow: photon
Gray: neutron
Red: proton
Black: ion

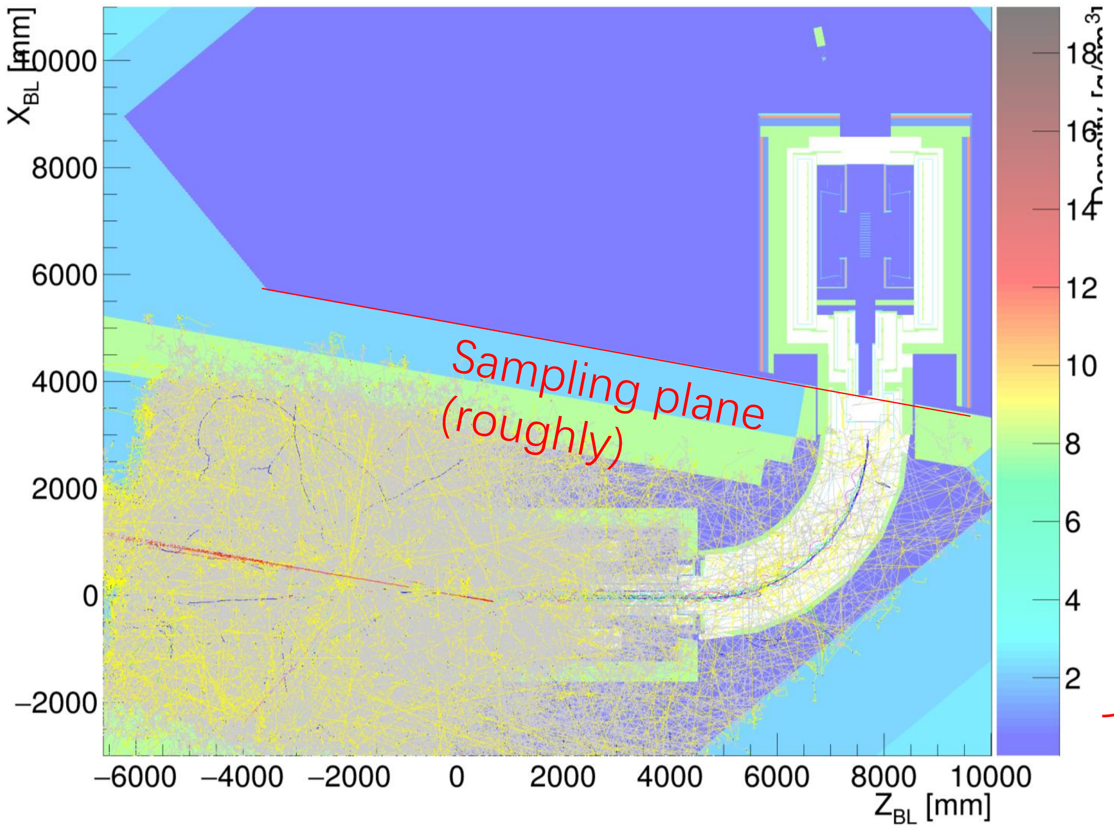


$\frac{1}{160000}$bunch
Or 0.00625 ns

And neutron…

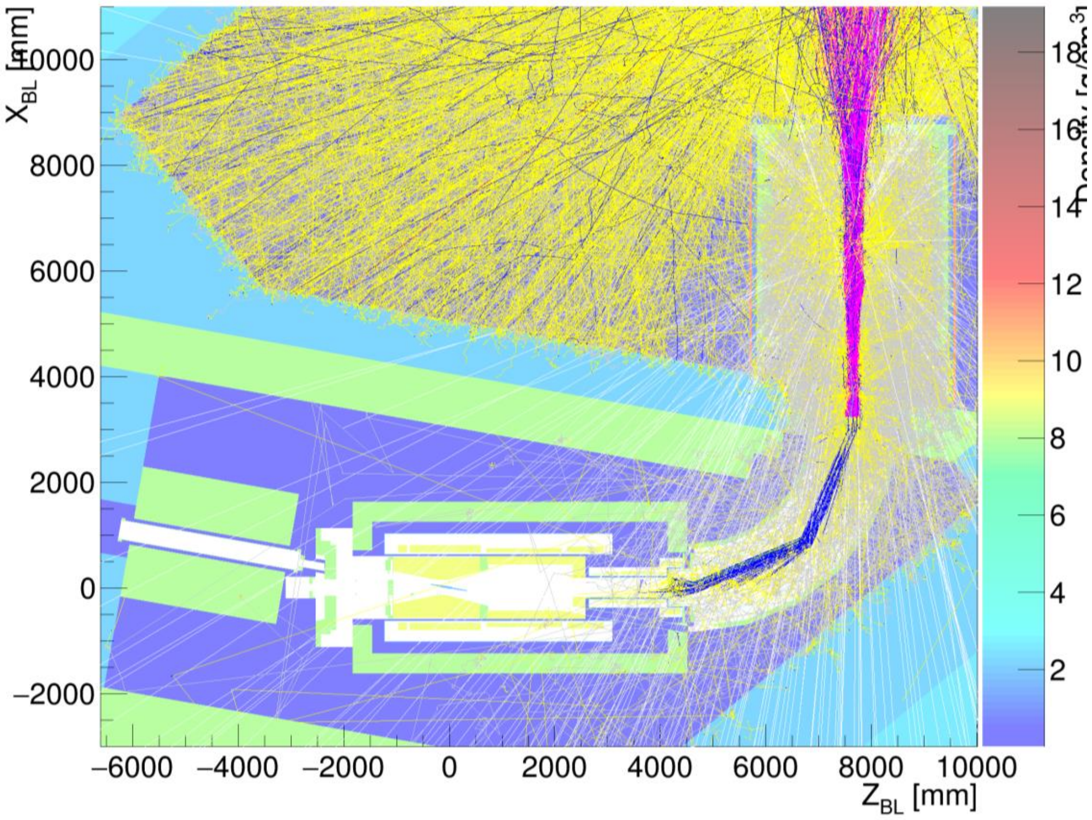
To study the radiation in the detector

From 100 proton hitting the target



$\frac{1}{160000}$bunch, Or 0.00625 ns

Accumulate x10000, record on sampling plane, and simulate part-II

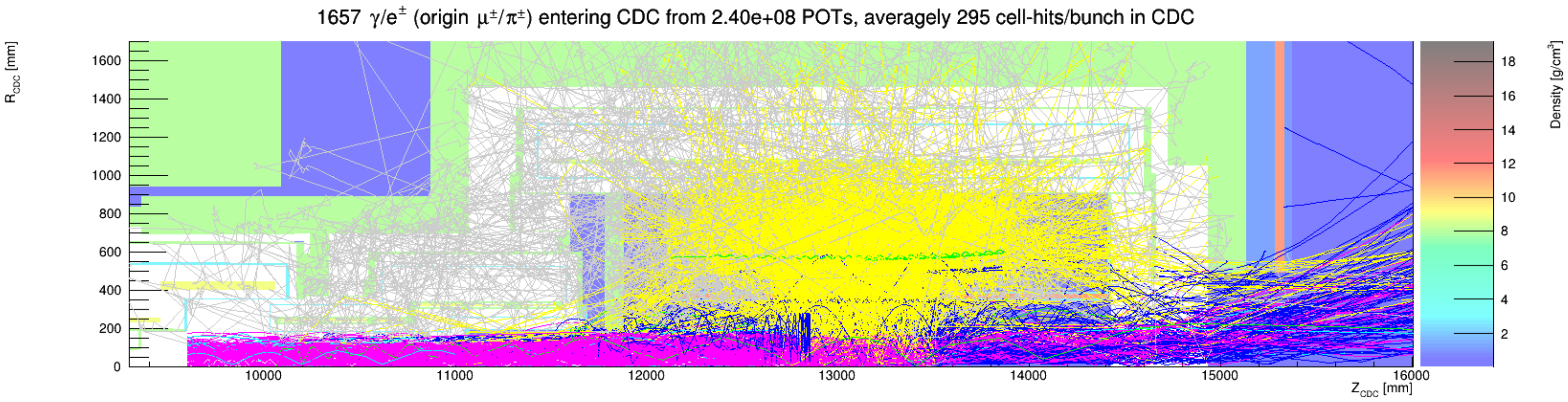


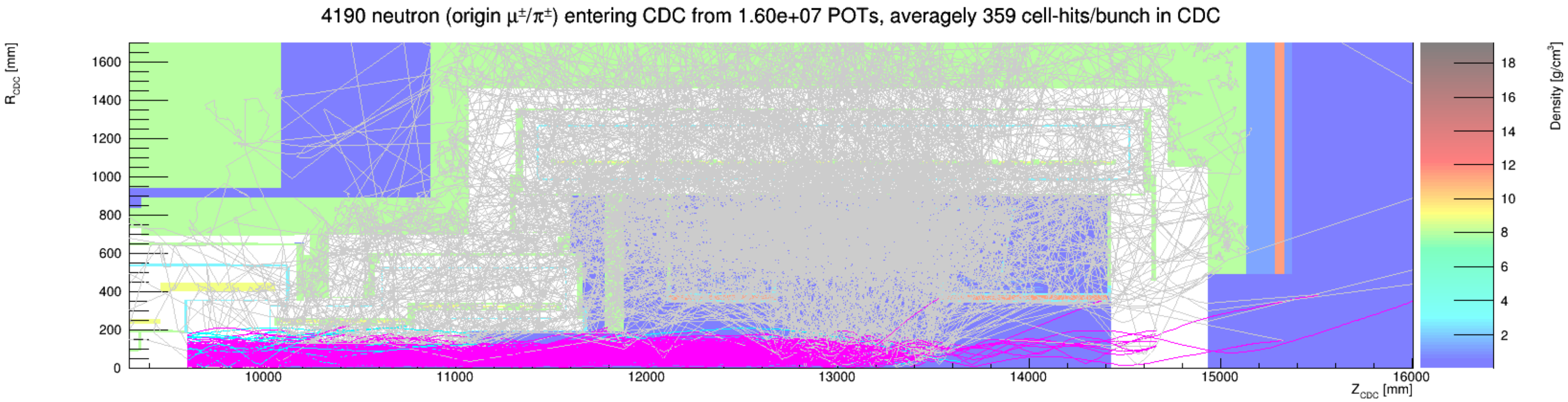
$\frac{1}{16}$bunch, Or 62.5 ns

* Statistics here are chosen for visualization. Actual study utilized $\mathcal{O}(100)$ bunches by mass production

Events that have hits in detectors

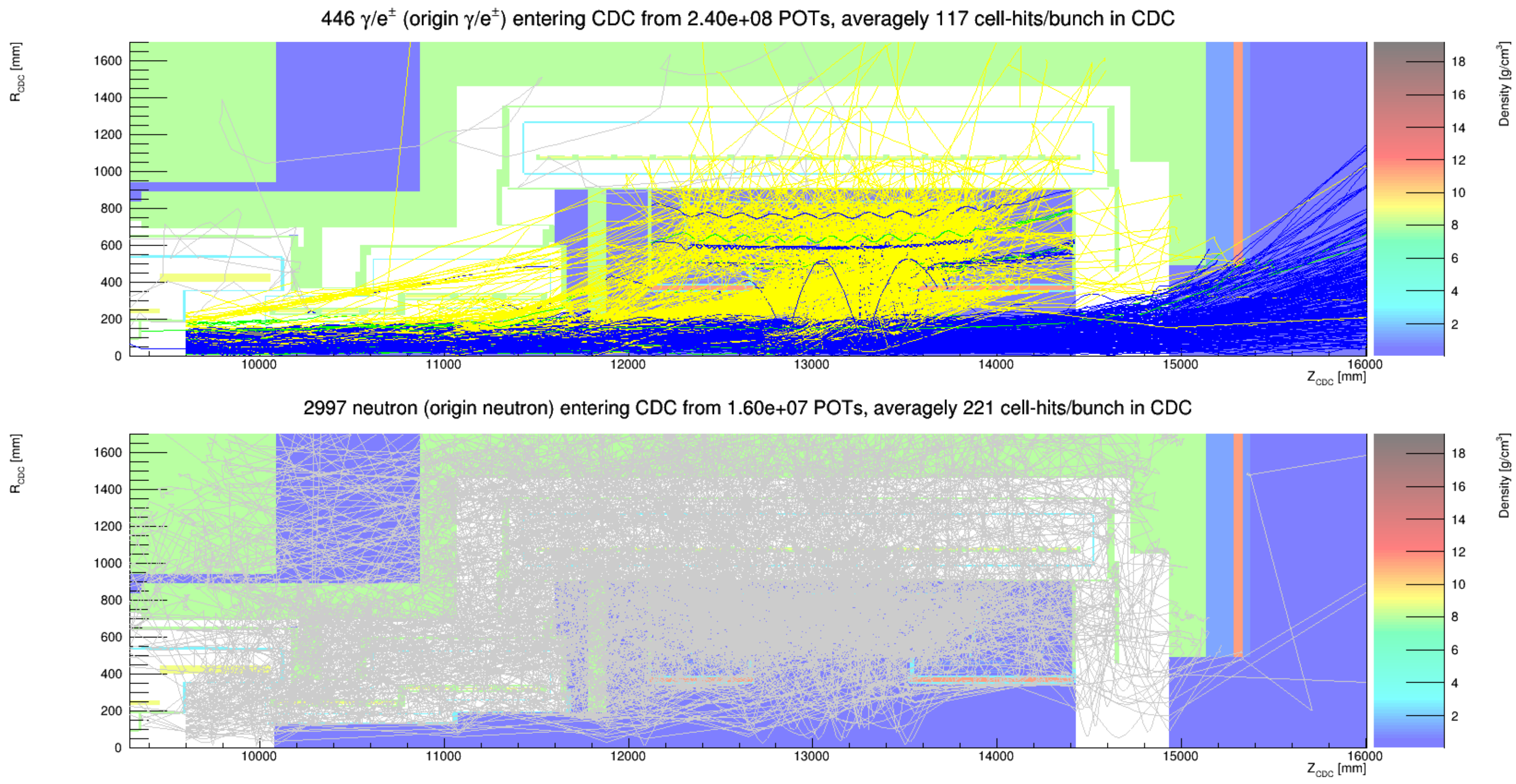
- The part from muon/pion in the beam is very difficult to be shielded.
  - Can work on improving the collimator design.



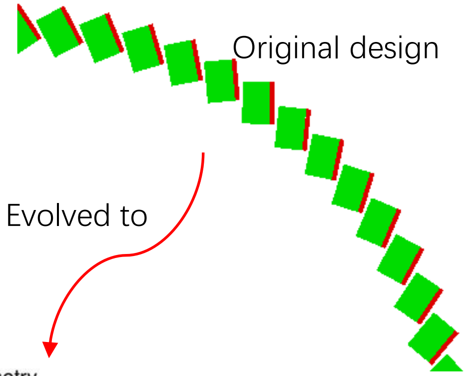


Events that have hits in detectors

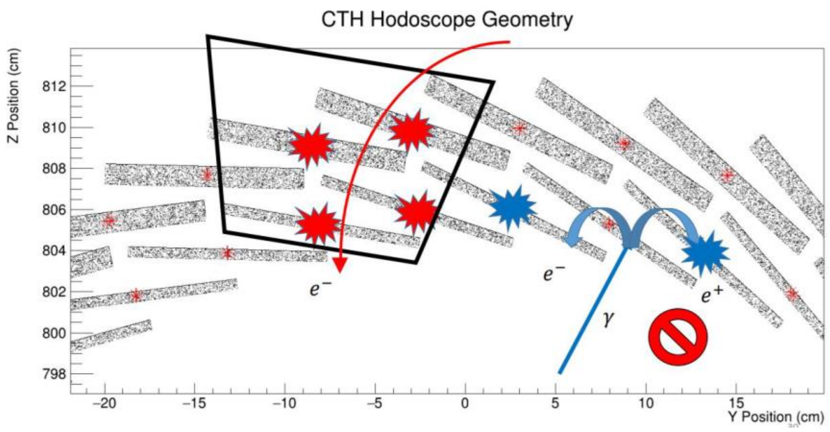
- The part from electron/positron /photon/neutron in the beam can be shielded
  - Shielding has been carefully optimized to reduce the hit rate in detector.

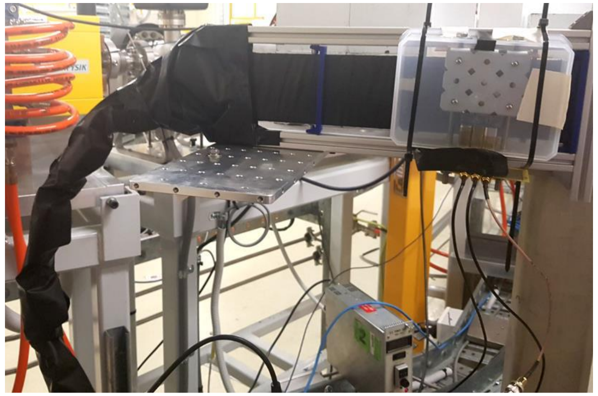


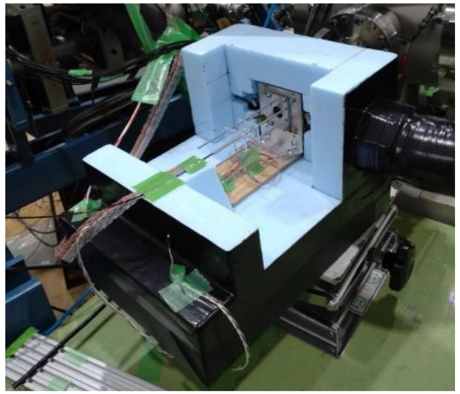
Radiation challenge to the CTH



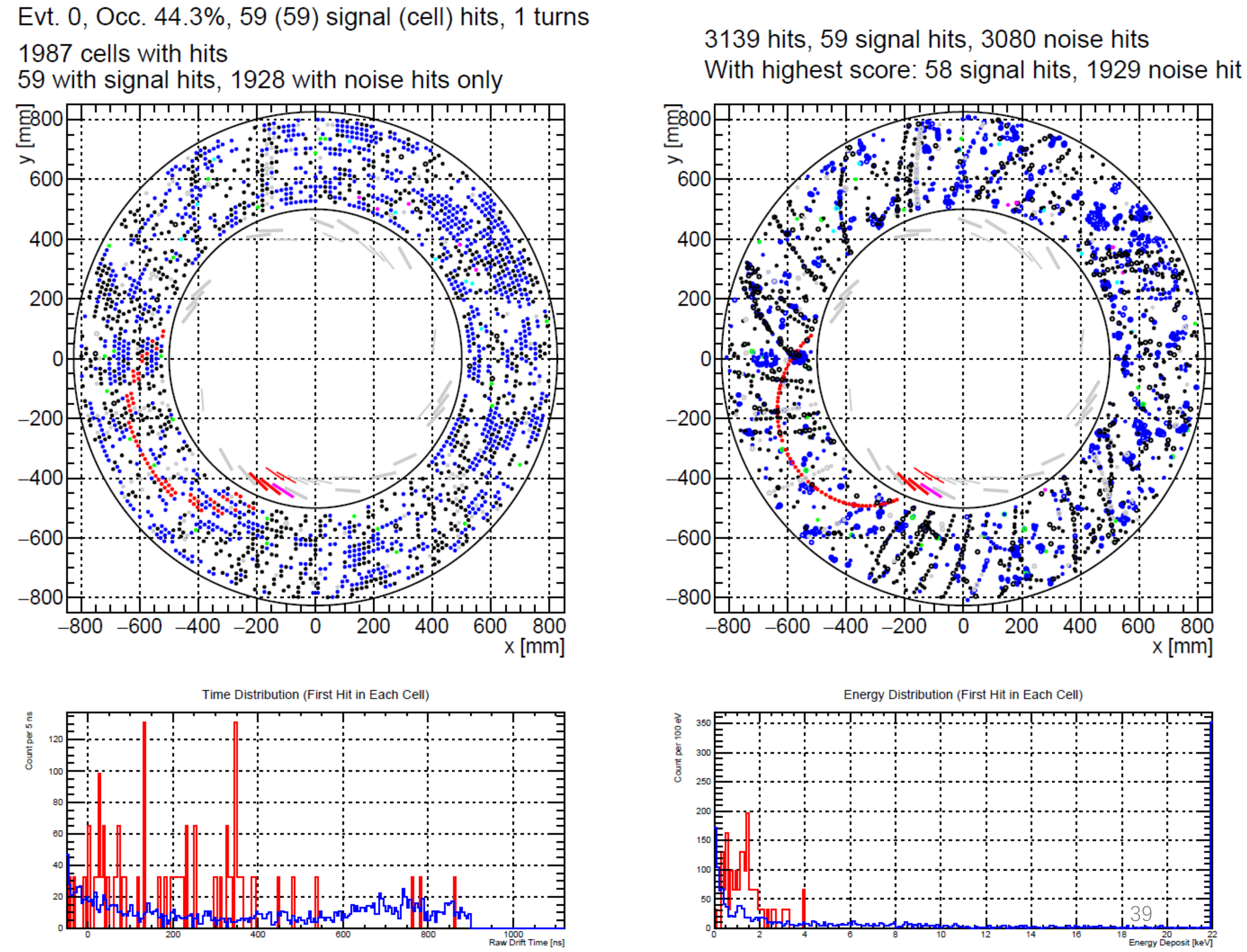
- The original design no longer work under the radiation
  - New design requires 4-fold coincidence to reduce the trigger rate.
  - Complicated optimization to an additional shielding (around CTH) was carried out.
- The neutron radiation level was found to be too high for MPPC
  - Had to use long fibers to reach out to low radiation level area.
  - Had to give up Cherenkov counter (for now) due to low yield.
  - Still cooling is found to be needed.







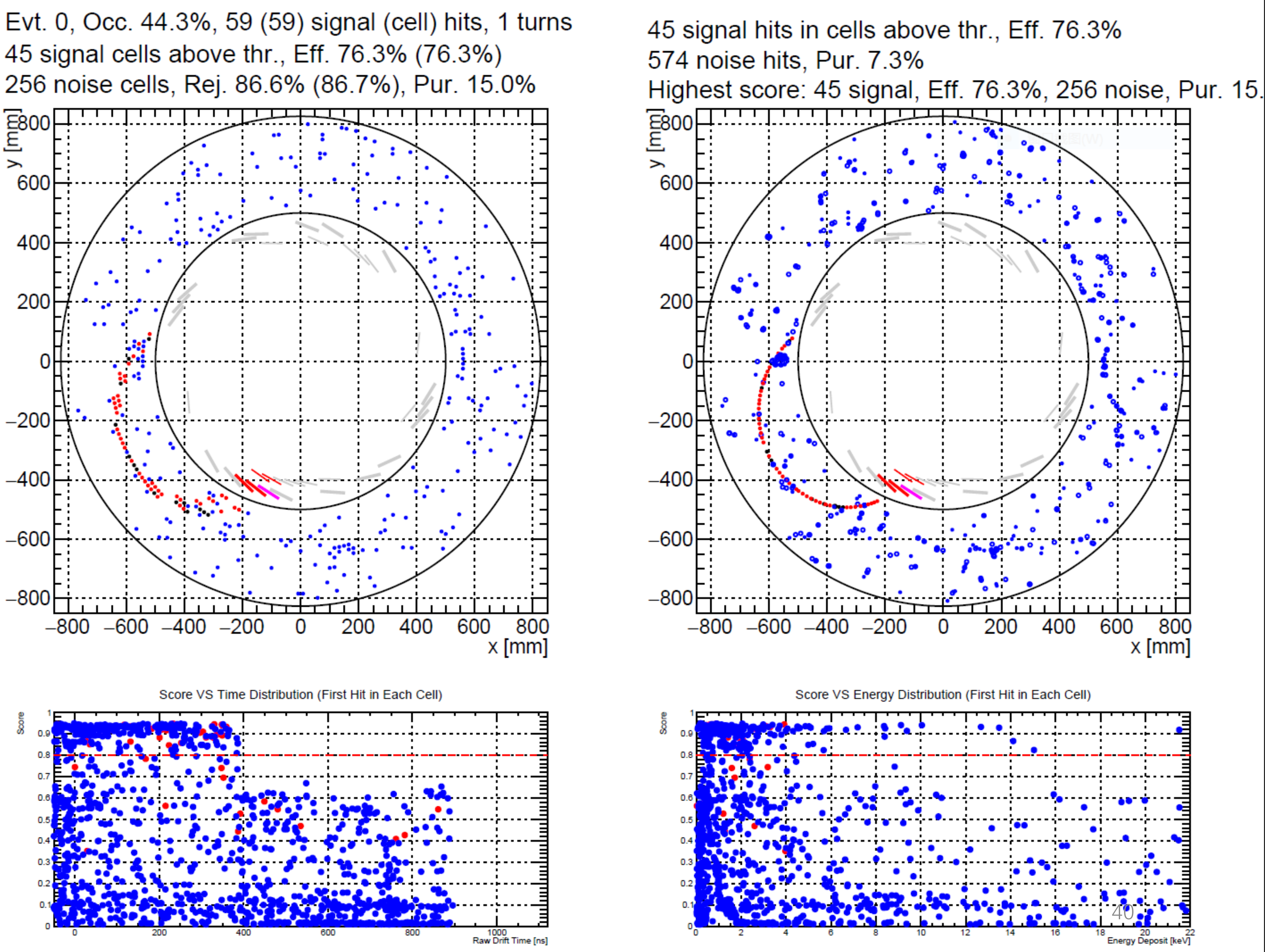
One typical event:
About 44% occupancy if counted in a 1 usec long time window.
Top left panel: hits drawn by endplate wire positions.
Top right panel: hits drawn by MC truth positions.



Hit colors
Blue: e-
Green: e+
Magenta: mu±
Cyan: pi±
Yellow: photon
Gray: neutron
Red: proton
Black: ion

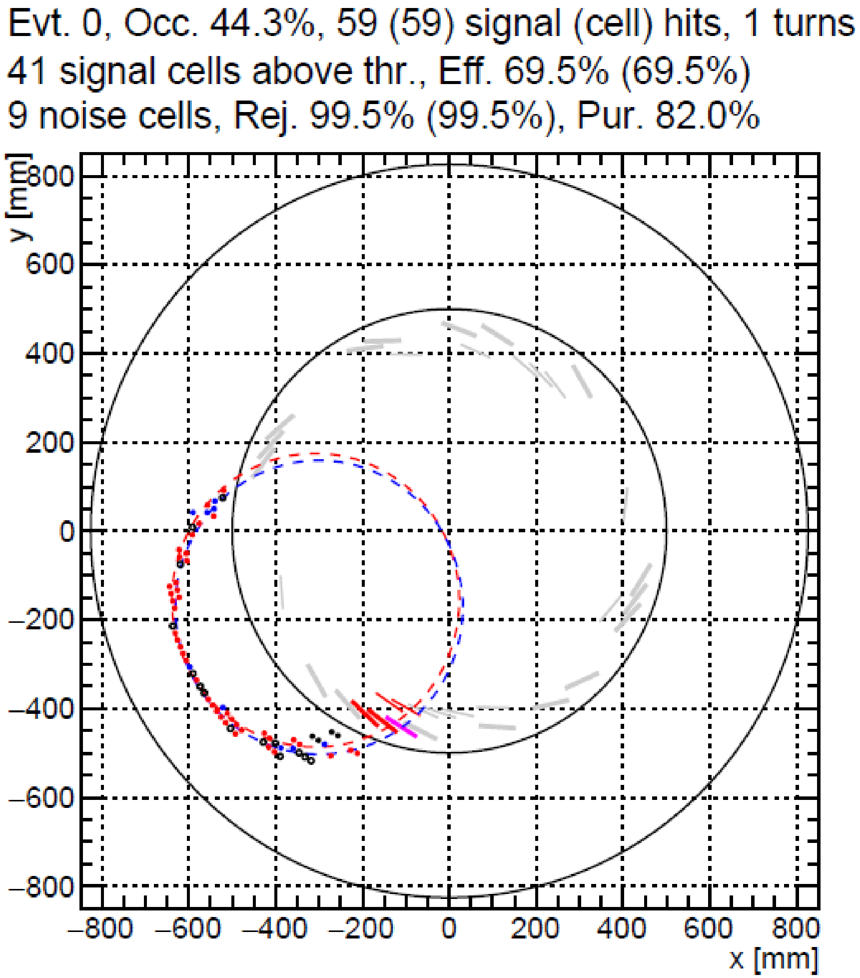
After hit selection using GBDT

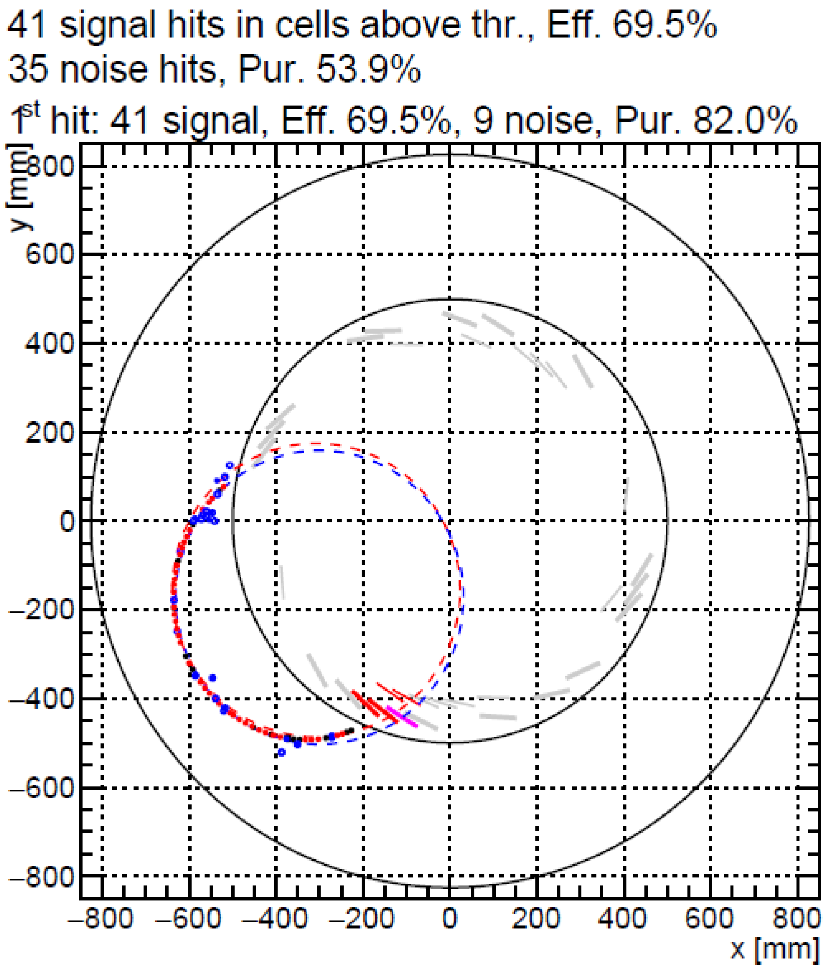
- It is known that neural networks can provide much better selection quality. However that takes larger training samples to study.
- This GBDT method was tentatively used for illustration.

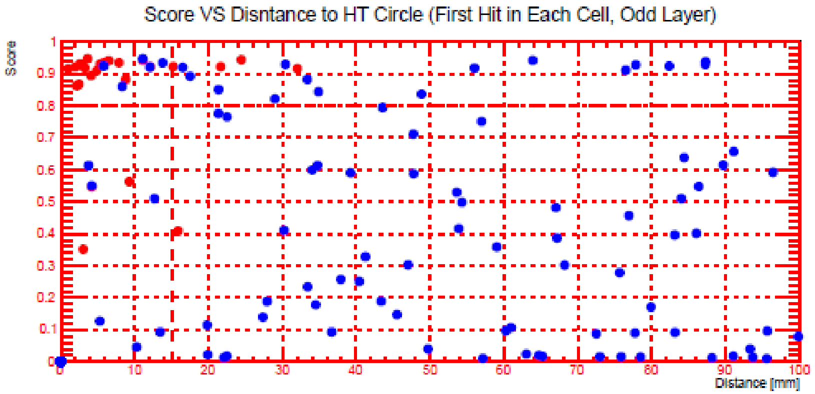


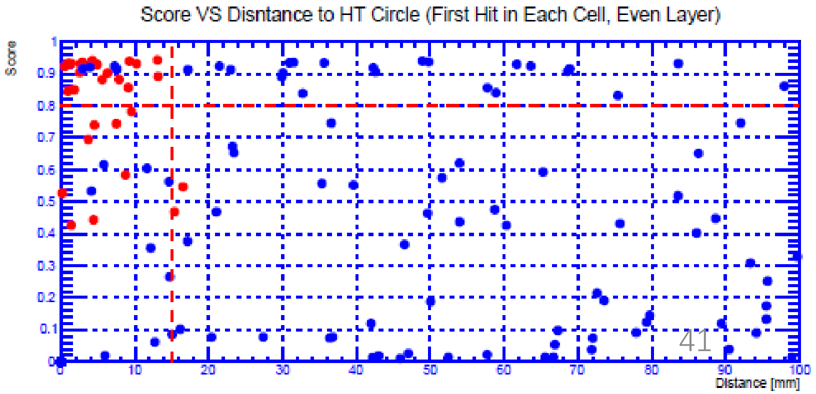
Further selection based on Hough transform can provide further rejection to noise hits

- Final performance is (on average) ~85% sample purity VS 85% signal efficiency after the selection



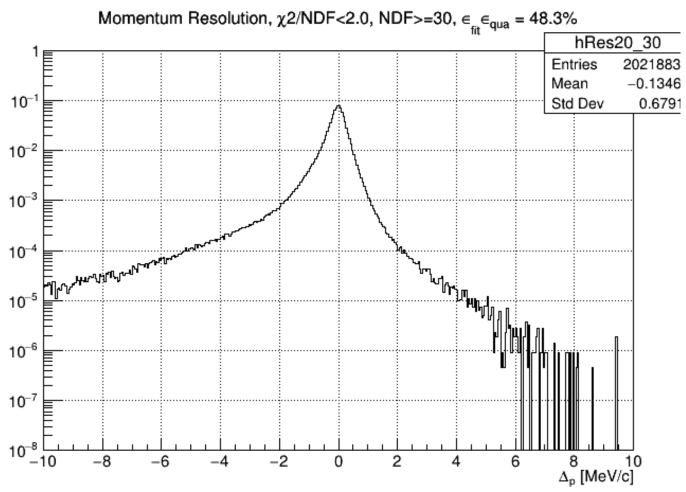


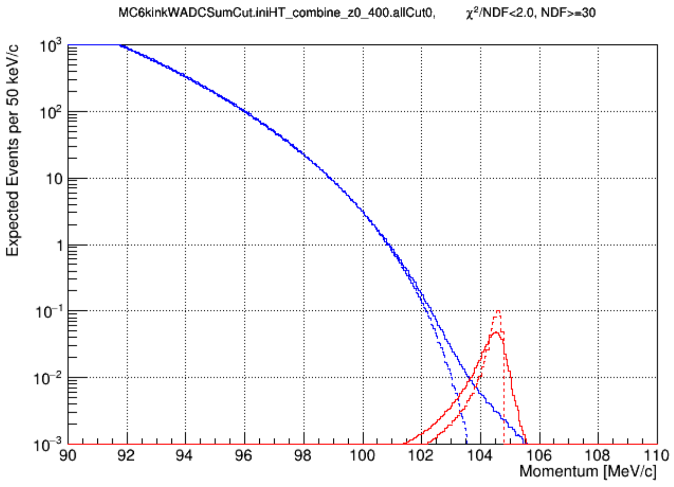


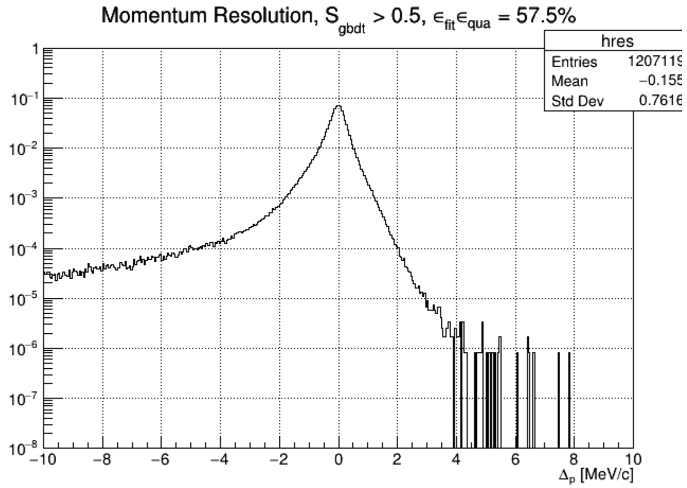


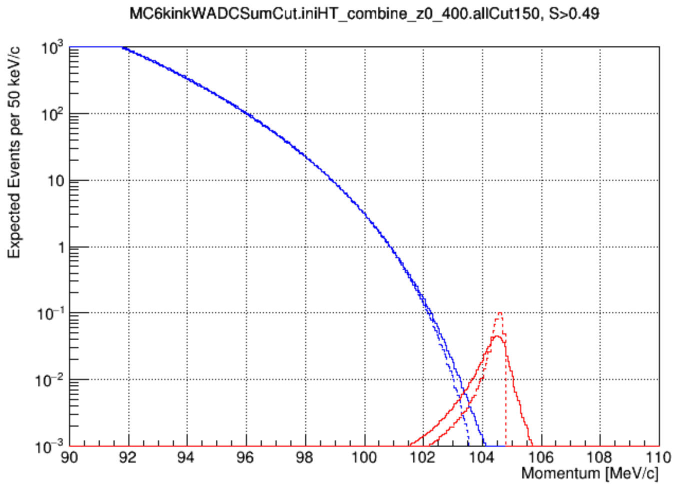
The above-like sample was used for a Mock data challenge

- Usually the impurity of input sample will cause a tail in momentum resolution, which is dangerous, and very difficult to be removed by a traditional box cut.
- Recent study shows that GBDT can help to control the fitting quality: significantly better than a box cut.



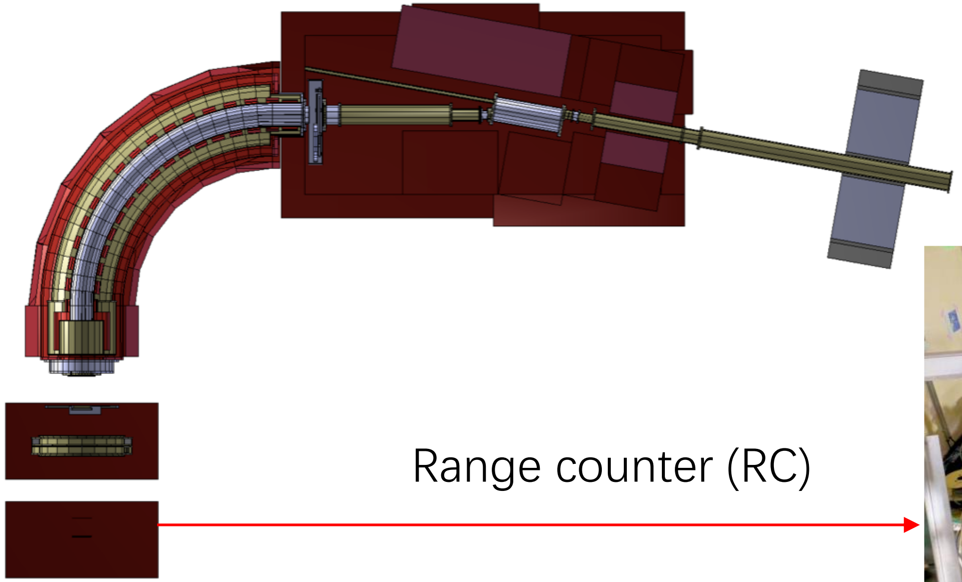




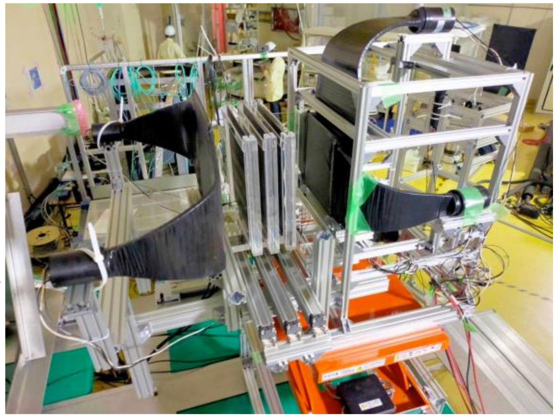


The biggest validation task is in the production target: hadron physics @ 8 GeV

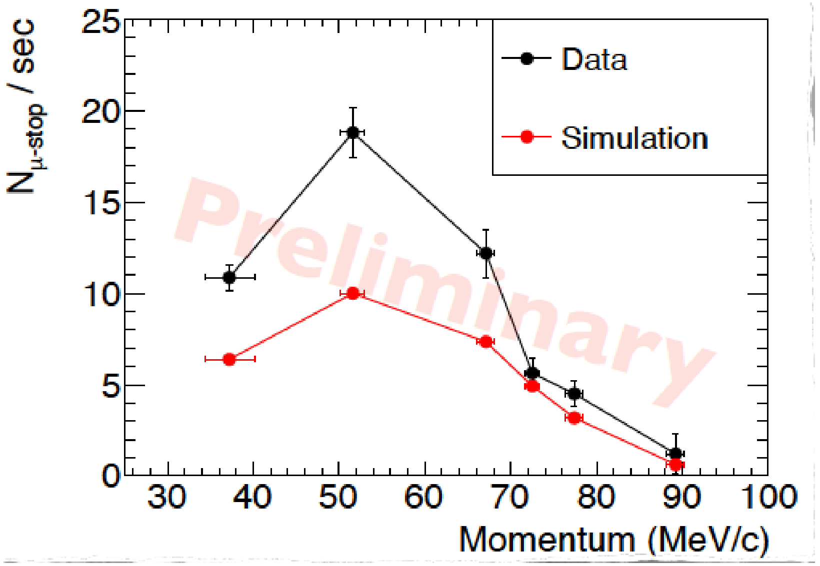
- The Phase-alpha experiment measured muons from 8 GeV proton beam on graphite target.
- The comparison with MC (a randomly chosen model) has already shown some discrepancy.
  - Further investigations are needed to better validate the hadron physics models.



Range counter (RC)



Muon spectrum by RC



The biggest validation task is in the production target: hadron physics @ 8 GeV

- For anti-proton production, which is a source to background, we don't have any data near the threshold. Had to implement theoretical model into Geant4
  - Can be improved by comparing with a larger set of data, present or in future.

$$(E \cdot \frac{d^3\sigma}{d^3p})_{RS} = f(x_R)\exp[-(A(x_R)p_t + B(x_R)p_t^2)] \ (\text{mb GeV}^{-2}\ c^3)$$

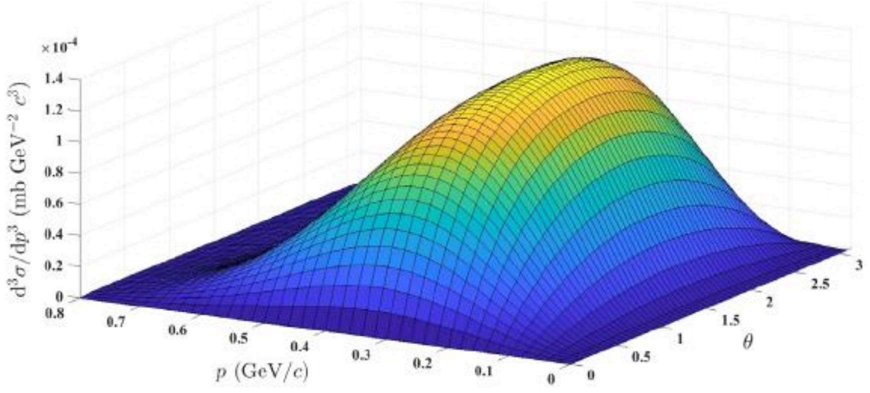
$$f = a_1\exp(-a_2 x_R)\theta(a_3 - x_R) + (\sigma_{00} - a_1)(1 - x_R)^{a_4}$$

$$A = a_1\exp(-a_6 x_R) + a_7 exp(a_8 x_R)$$

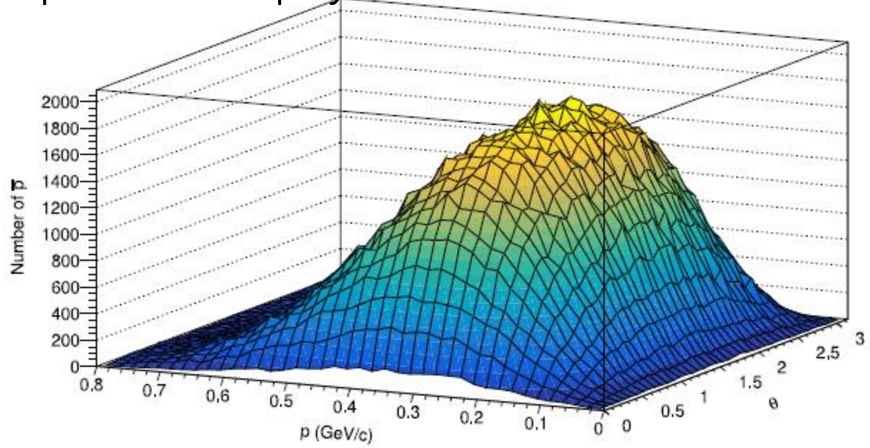
$$B = a_9\exp[-a_{10}(x_R + a_1 1)](x_R + a_1 1)^{a_{12}}$$

$$\theta(u) = \begin{cases} 0 & for\ u < 0 \\ 1 & for\ u \geq 0 \end{cases}$$

Differential cross section in model

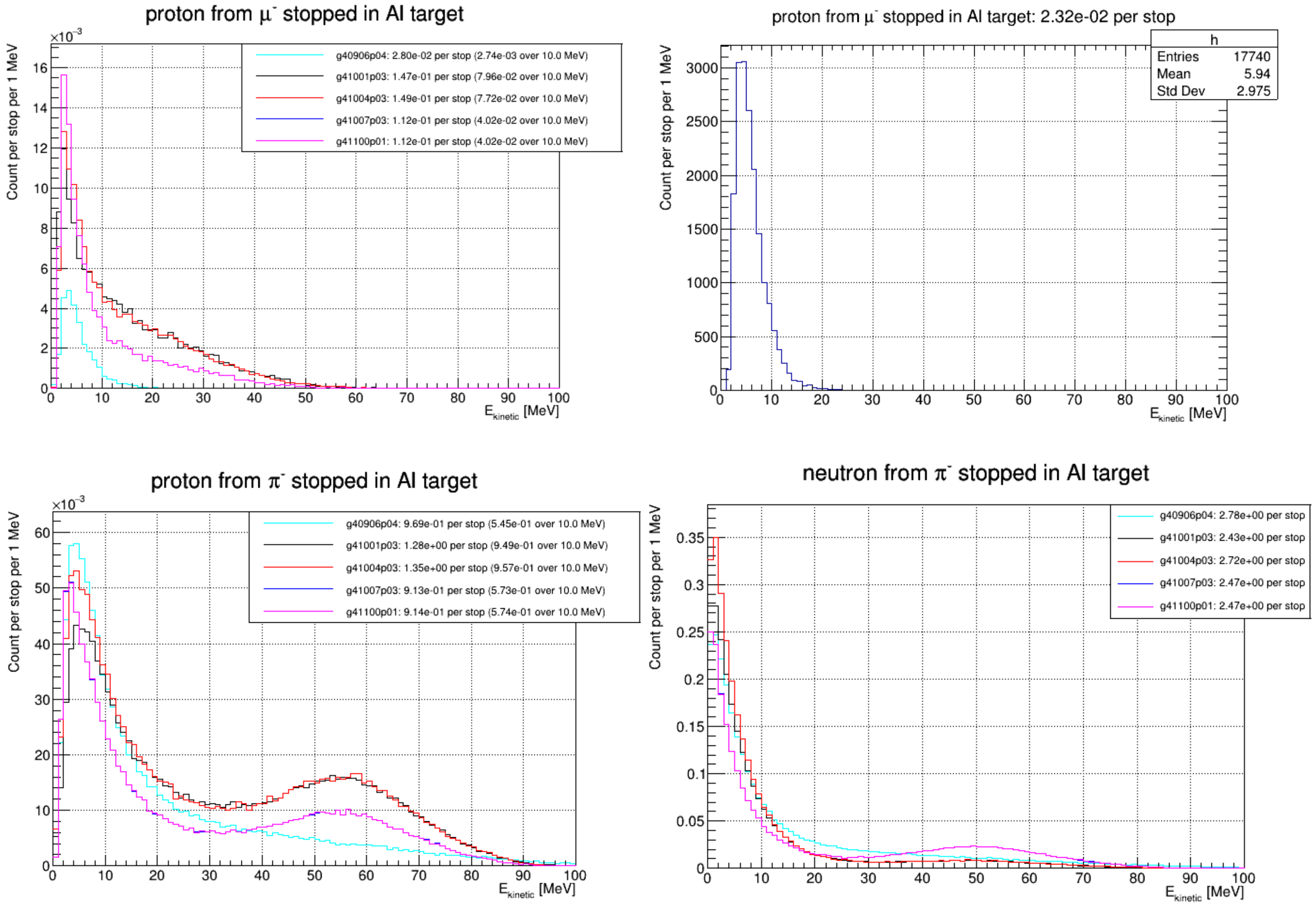


Distribution from Geant4 simulation using the implemented physics list



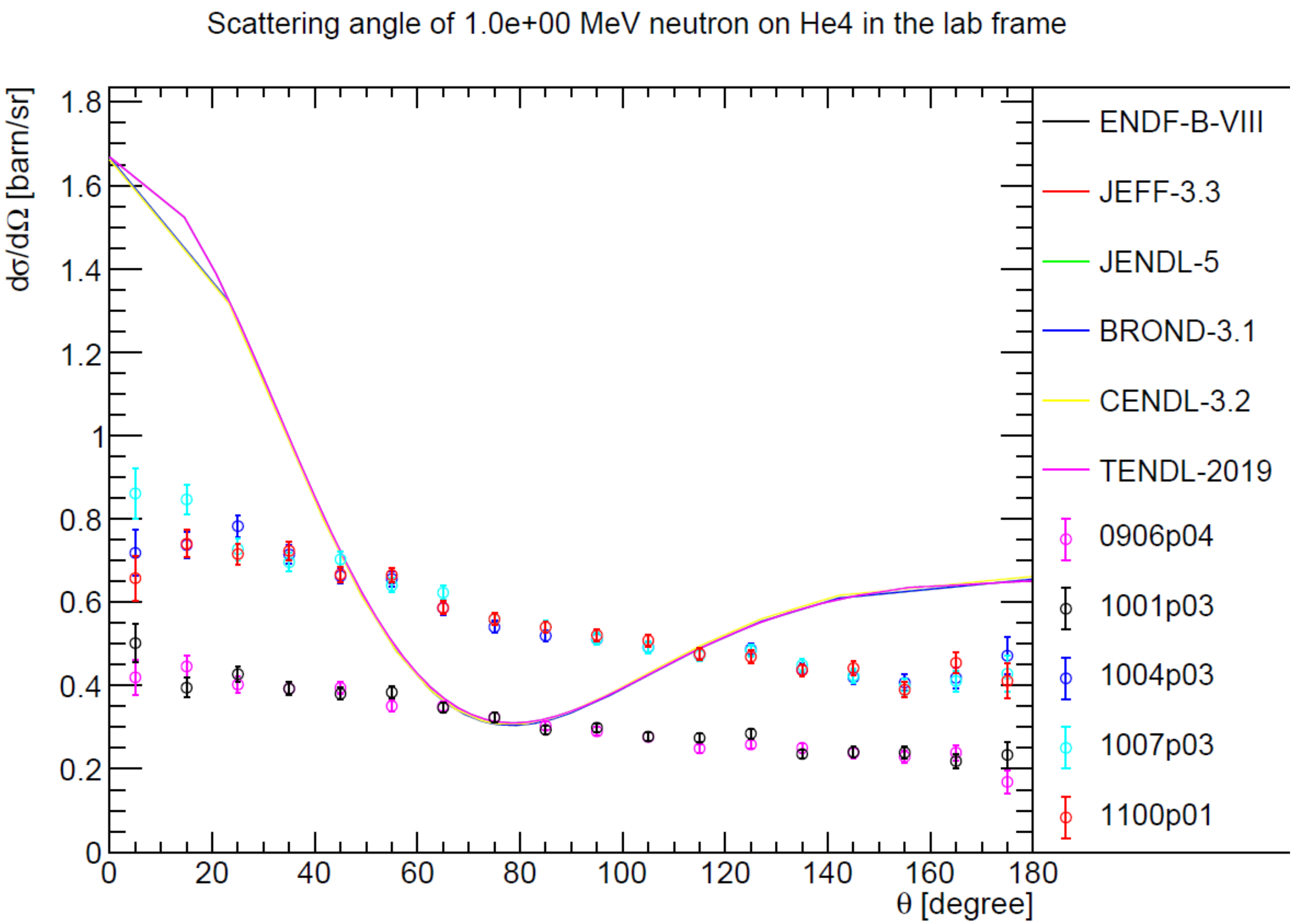
The nuclear capture models in Geant4 are mostly questionable

- For muon capture, we performed direct measurement at PSI (AlCap, with Mu2e group). The measured spectra were implemented as new physics models.
- For pion capture, recent updates caused concerns.
  - Further investigations needed.



The neutron scattering model

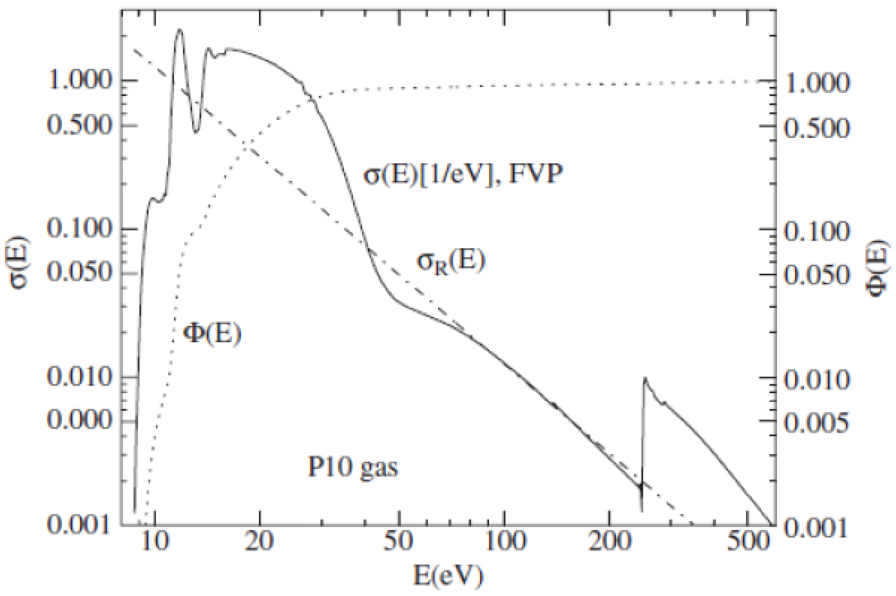
- The neutron radiation level is very important to guide the design.
- Some part of the scattering model in Geant4 doesn't seem correct.
- Comparisons with other simulations tools are under investigation.



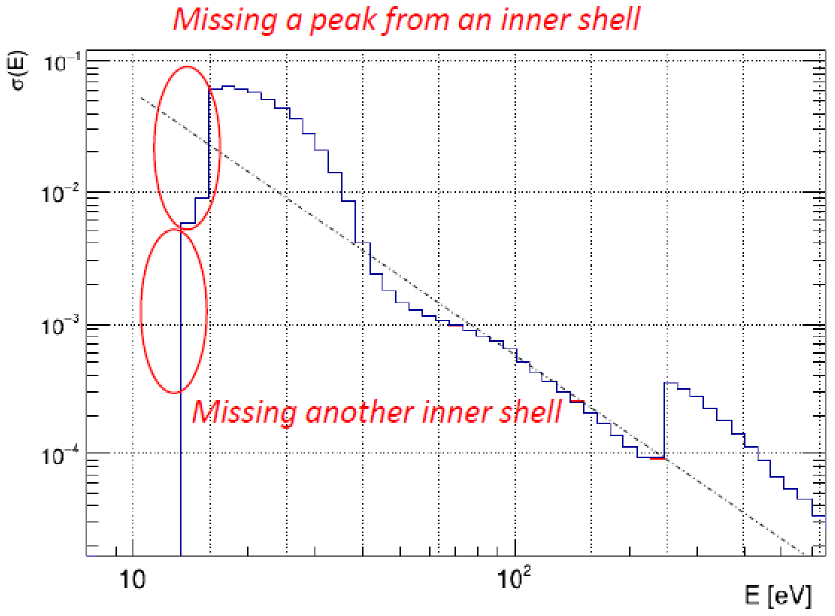
The electron scattering model

The energy straggling model in Geant4 (PAI model) is now under investigation. Certain discrepancies with literature was found.

CCS for particles with $\beta\gamma = 3.6$ in P10 gas
* Dash-dotted lines in both figures are Rutherford cross-section



*from Bichsel's paper: NIM A 562 (2006) 154-197



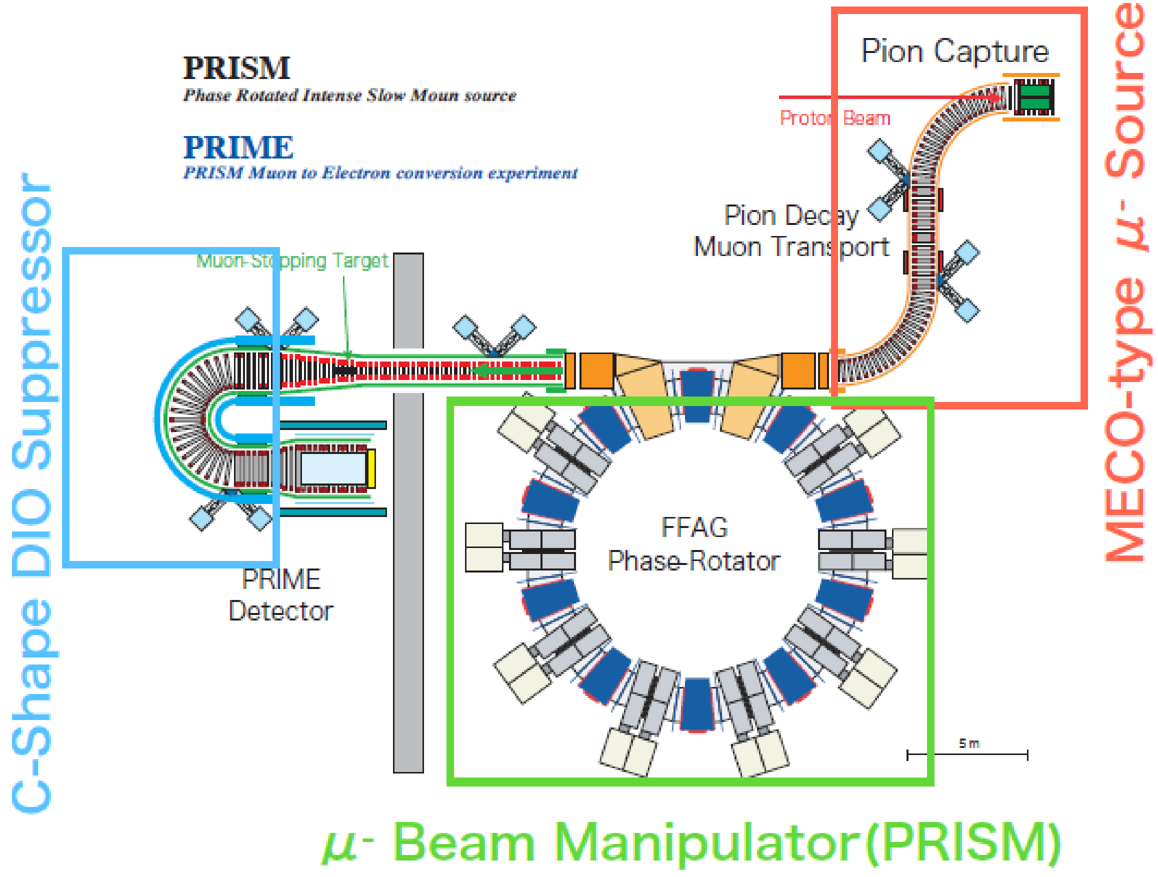
Geant4 simulation with EmLivermore+PAI

Outline

- Introduction
- mu-e conversion experiments
- Future prospects
- Summary

PRISM-PRIME experiment

Design started before 2005. An ultimate dream.



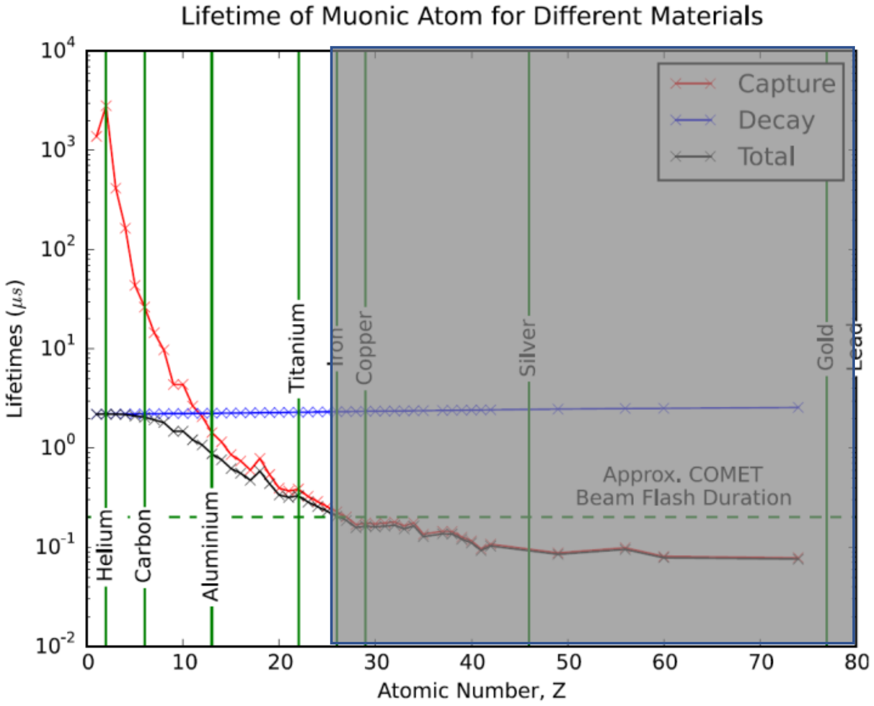
Aiming to achieve an ultimate sensitivity: BR<10^{-18}

17

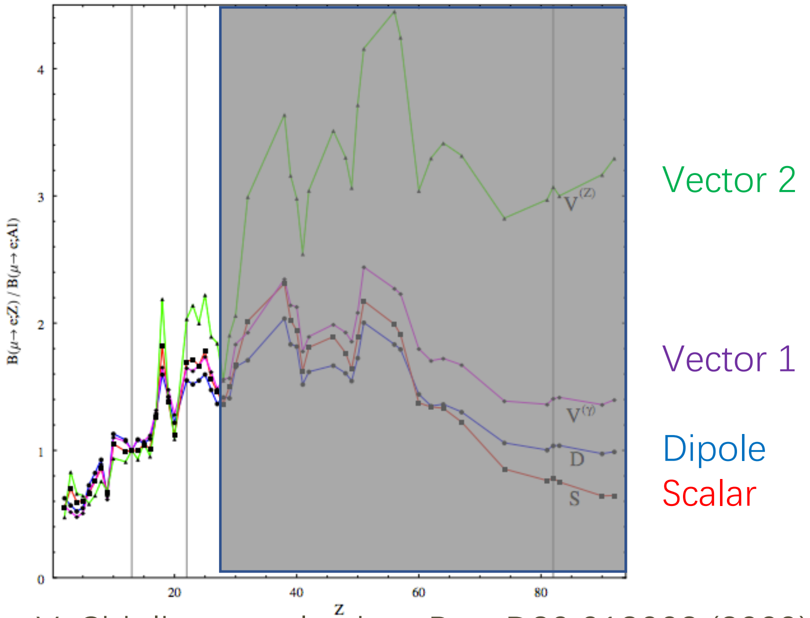
- Use FFAG to store muon
  - Clean muon beam.
  - No need to wait for a few 100 ns: can perform search on high-Z materials.
  - Narrow momentum bite: can use very thin stopping target to avoid energy straggling in the target which undermines the sensitivity.
- Use an additional curved solenoid to suppress DIO
  - At this sensitivity, DIO electrons will be too intense for the detector.
  - Curved solenoid can be used to select ~105 MeV electrons.

Trade off in Lobashev scheme can be recovered in PRISM scheme

- In high-Z target, muons immediately got absorbed by the nuclear
  - The muonic atom's lifetime can be shorter than the beam flash duration itself.
  - There is no way to wait for the beam flash to vanish…
- High-Z target is of particular interests:
  - Higher capture ratio means larger Cr and smaller DIO background.
  - Z scanning can tell apart new physics model.



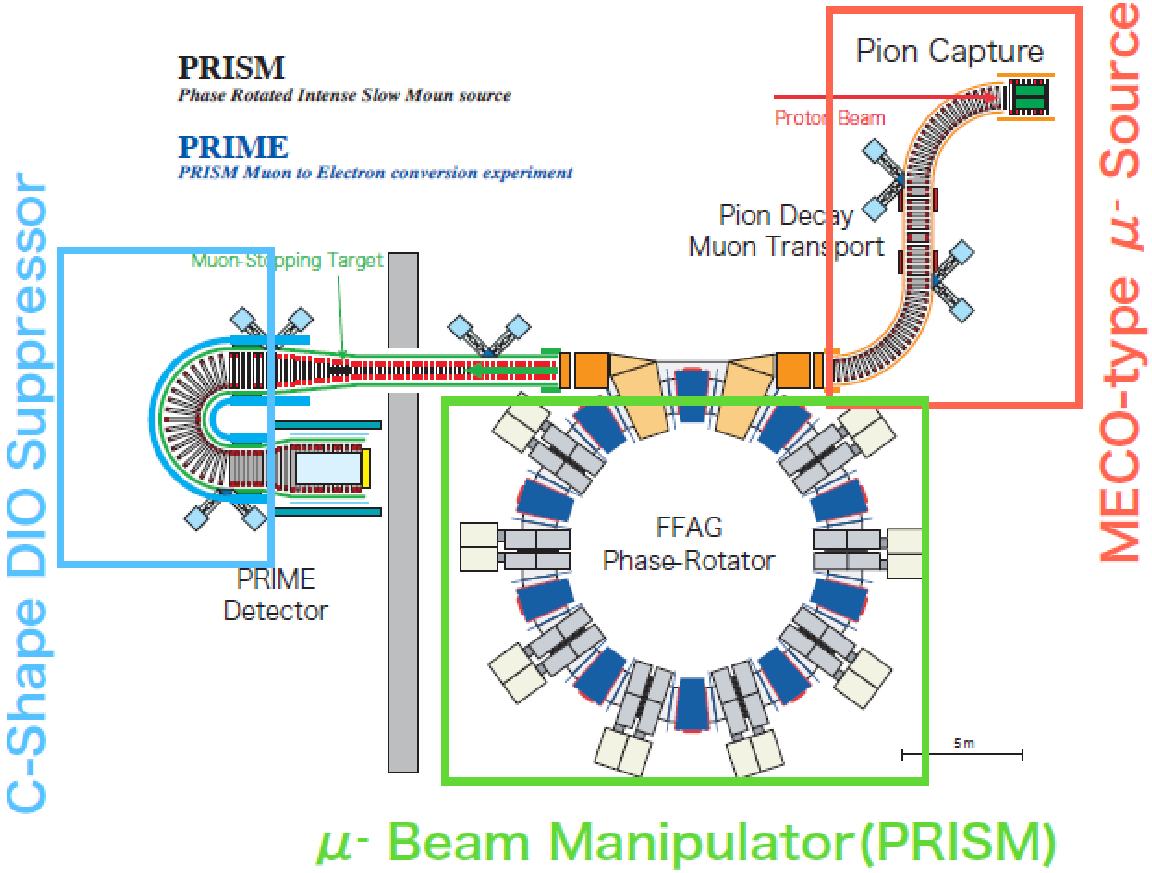
Area in gray: Impossible in Lobashev's scheme, but possible in PRISM



V. Cirigliano et al., phys. Rev. D80 013002 (2009)

PRISM-PRIME experiment

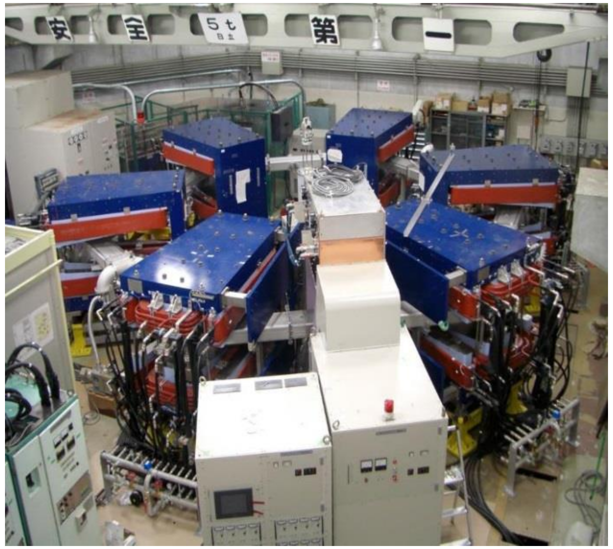
Design started before 2005. An ultimate dream.



Aiming to achieve an ultimate sensitivity: BR<10^{-18}

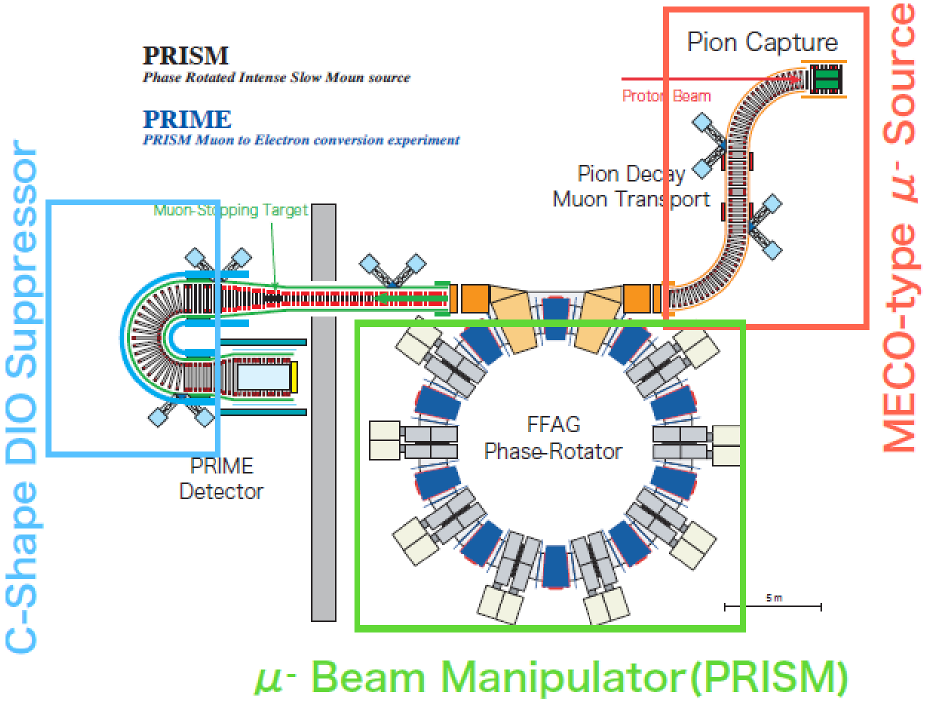
17

Demonstration of pion capture and FFAG in RCNP, Osaka Univ.



$\mu N \rightarrow eN$: Next generation

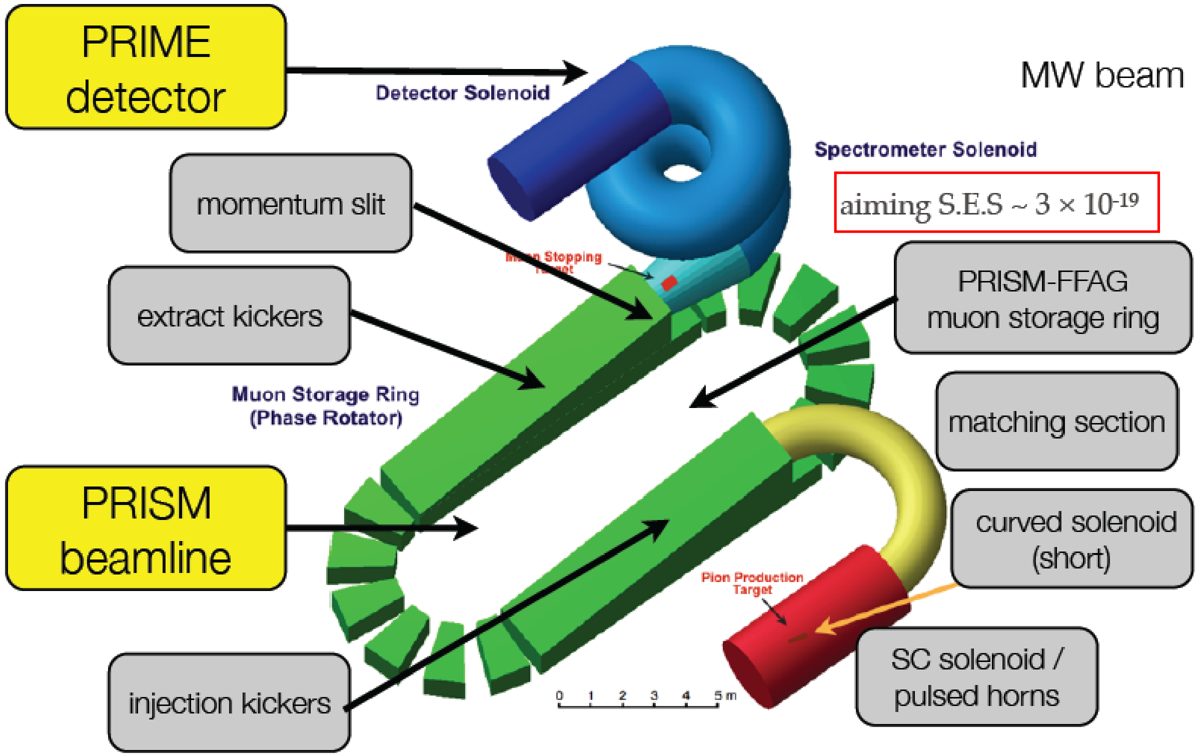
The original design before COMET
Started from 2005.



Aiming to achieve an ultimate sensitivity: BR<10^{-18}

17

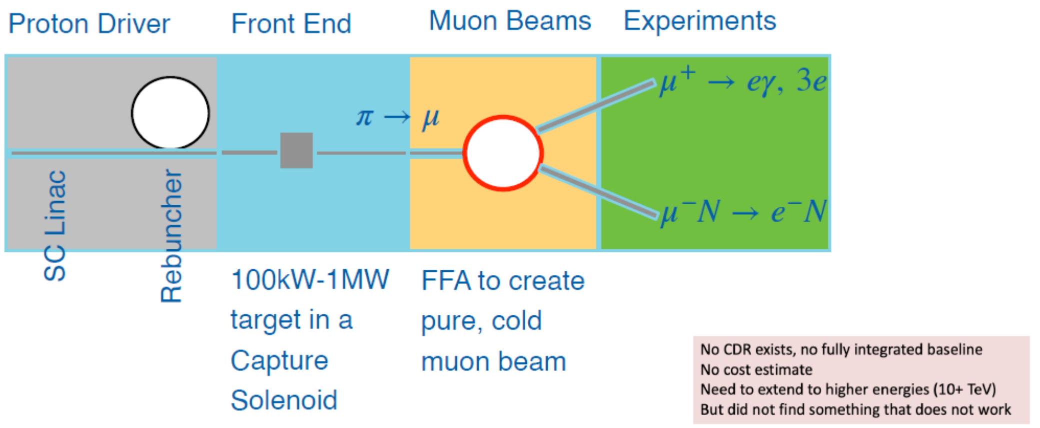
The PRISM group is still updating the design to achieve an ultimate search for $\mu N \rightarrow eN$



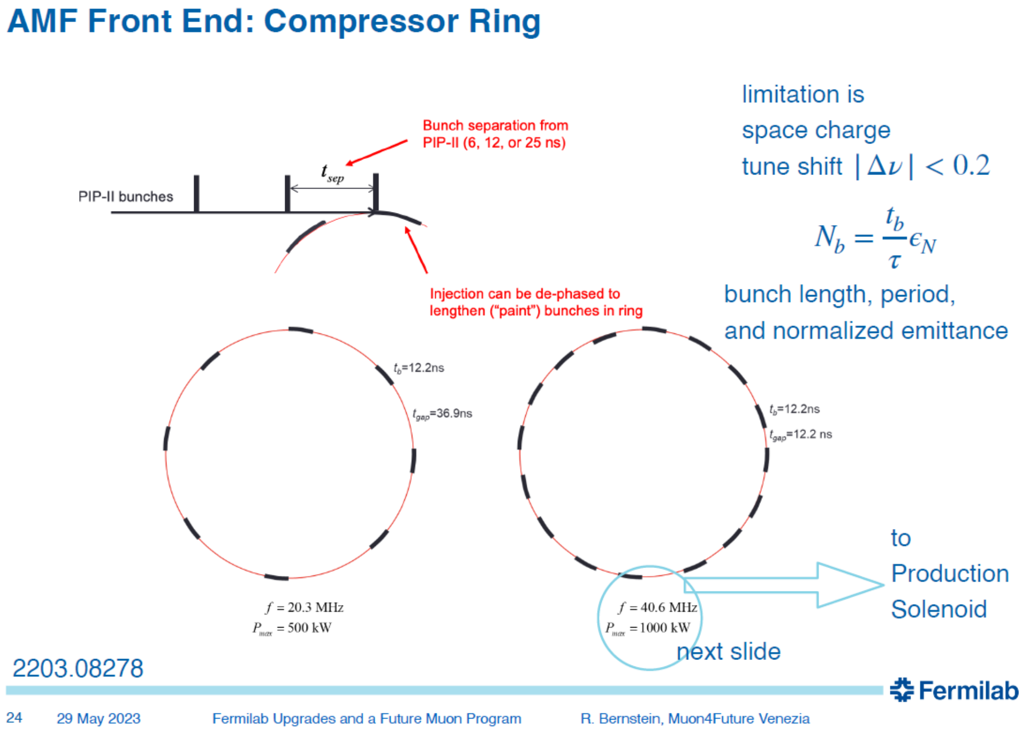
In synergy with muon collider: target, capture, and storage ring. Might be the most intense muon beam before muon collider.

$\mu N \to eN$: Next generation

- FermiLab will have its accelerator upgraded: PIP-II, 8kW -> 100 kW
- Advanced Muon Facility (AMF) was proposed to make use of PIP-II for next generation muon physics
- $\mu N \to eN$ plan in AMF took the idea from PRISM: in cooperation.
- AMF proposed to use compressor ring to make beam structure for FFA
  - 10 ns bunches at 100-1000 Hz
- Pile-up effect will be too much
  - Need PRISM type detector: select electrons.
  - $\mu^- N \to e^+ N$ needs separate run in this case.



D. Schulte, https://indico.cern.ch/event/930508/



AMF: hep-ex 2203.08278

Challenges in detector system

- Better resolution needed.
  - The thickness of the straw trackers can possible be reduced further
- Absolute momentum calibration
  - Current designs are using pion decays to calibrate the absolute value.
  - Extrapolation will cause an issue in higher sensitivity.
    - People even considered to build small LINAC to provide calibration source.
- Potential high radiation level
  - The duty factor of the beam from FFAG is small: Instantaneous radiation level might be very high.
  - Full simulations/radiation tests needed to make sure the shielding is enough. Also providing challenges to detectors and electronics.

Outline

- Introduction
- mu-e conversion experiments
- Future prospects
- Summary

Summary

- CLFV processes provide a clean test field for new physics models.
- Out of all CLFV channels, the muonic channels, especially the muon-electron conversion channel, remain in the leading position.
- The Lobashev's scheme aims to bring the sensitivity of muon-electron conversion from 10^{-13} to 10^{-17}, or even 10^{-18}
  - The scheme has already been waiting for 34 years…
  - Mu2e @ FermiLab & COMET at J-PARC are the current experiments aiming to achieve the goal by early 2030s.
    - Both have been delayed by > 10 years…
- The PRISM scheme aims to bring the sensitivity below 10^{-19}
  - Challenges are bigger, but so are the interests.
  - Now sure when will it be realized, but the quest will surely continue!

Thank You!

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