MEG II実験背景事象抑制に向けた DLC-RPC検出器の開発 –実機で期待される性能–

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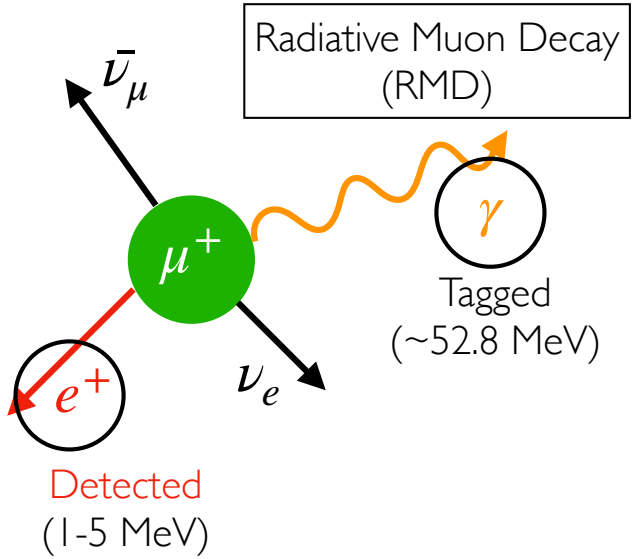
Outline

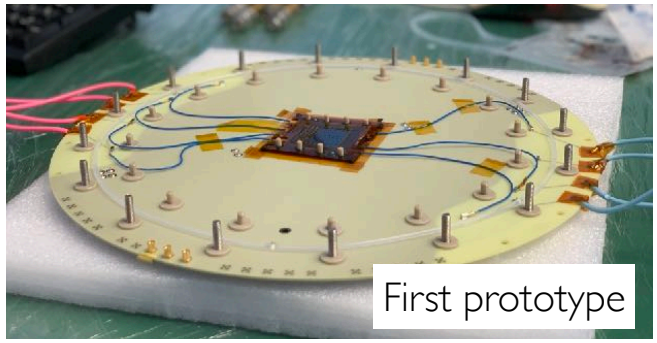
- Introduction
  - Upstream Radiative Decay Counter in MEG II
  - Motivation
- Sensitivity improvement estimation
  - Overview
  - Probability Density Functions for RDC
  - Sensitivity improvement estimation
- Conclusion & prospects

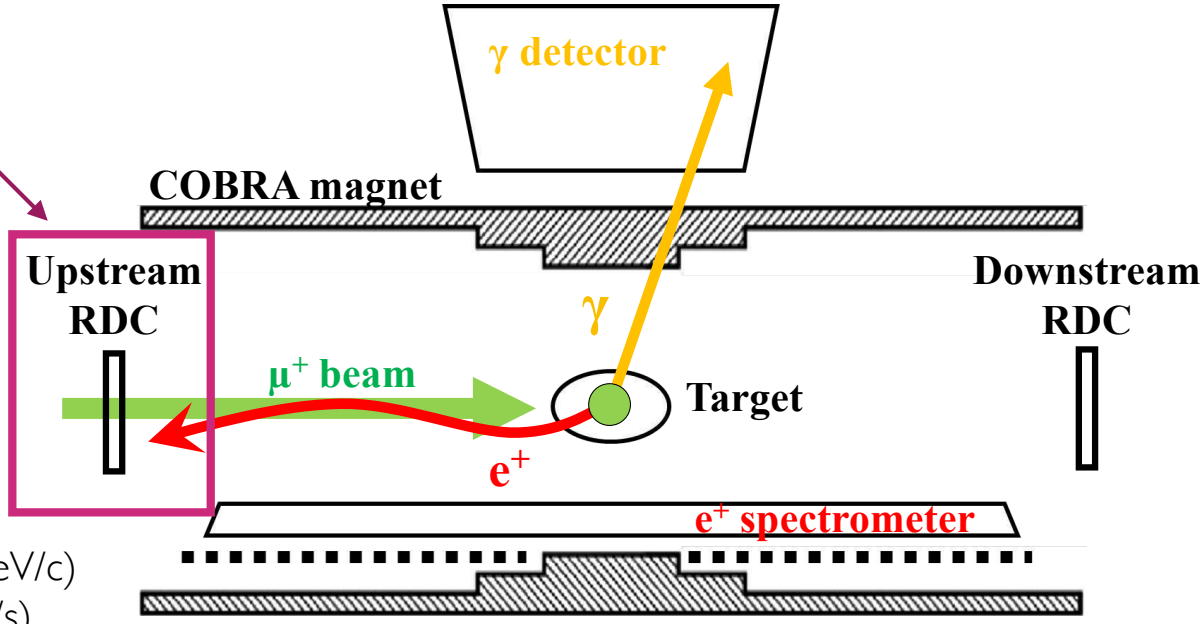
Upstream RDC in MEG II

- MEG II searches for $\mu \to e\gamma$ at Paul Scherrer Institut (PSI)
  - Most intense DC μ beam available
- Radiative Decay Counters: Detectors to tag BG-γ from RMD



Resistive Plate Chamber with Diamond-Like Carbon (DLC-RPC)
being developed as upstream RDC



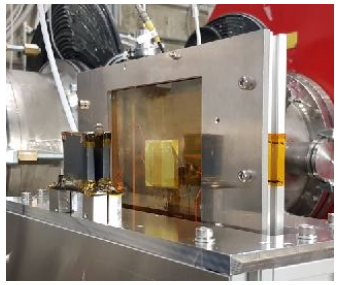


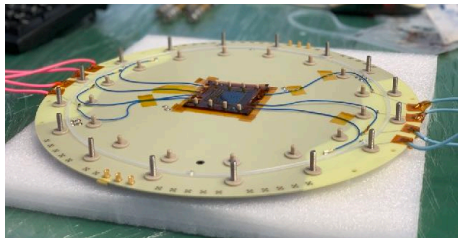
μ^+ beam
- Low momentum (28 MeV/c)
- High intensity (1×10^8 /s)

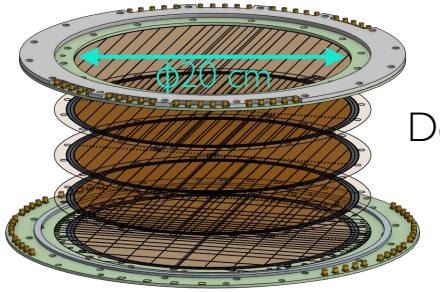
Motivation

DLC-RPC R&D

How much can upstream RDC improve MEG II sensitivity?







Design draft

μ beam test of testbench

Study with prototype
(Previous talks)

Aim at installation

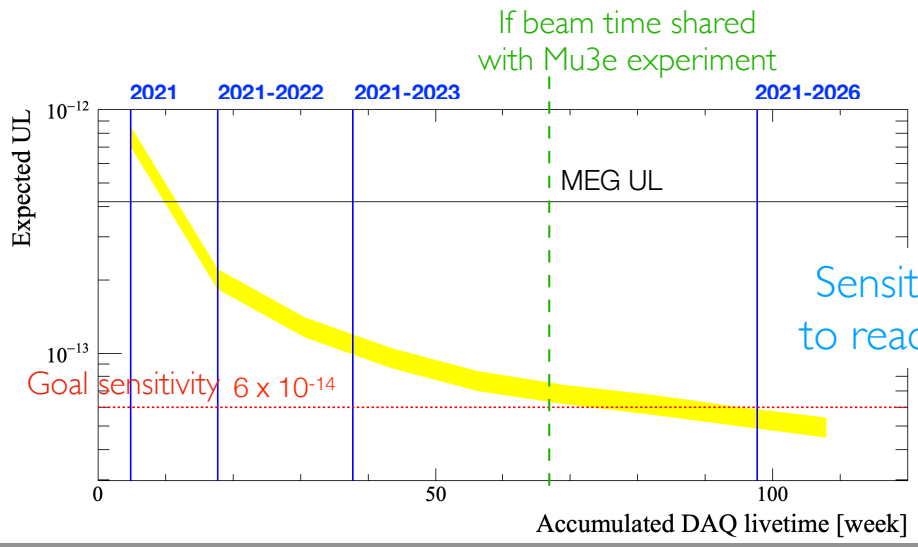
2021 2022 2023 2024 2025 2026 2027

We are here!

Physics data taking started

μ beam not available
due to beam upgrade at PSI

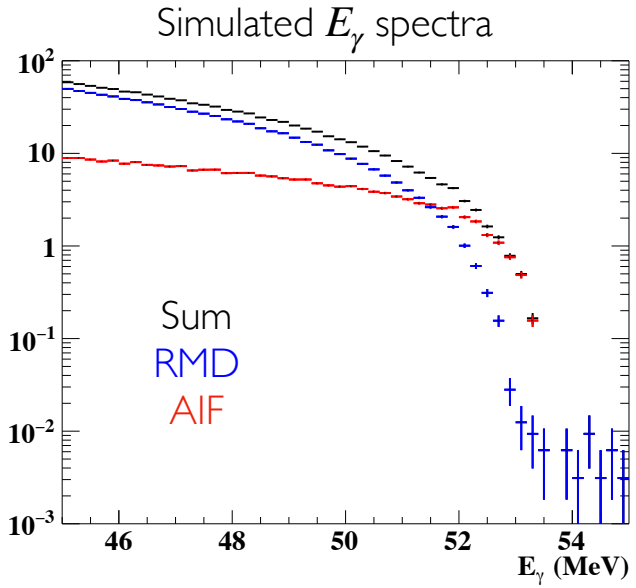
Situation of MEG II experiment



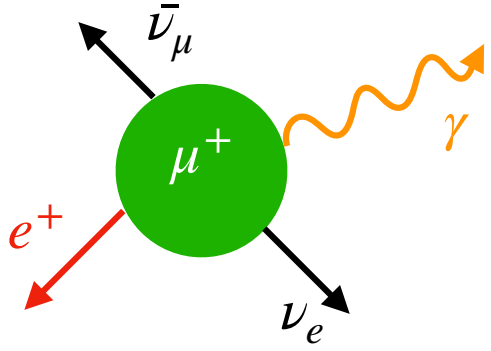
Sensitivity improvement required
to reach goal sensitivity in any case

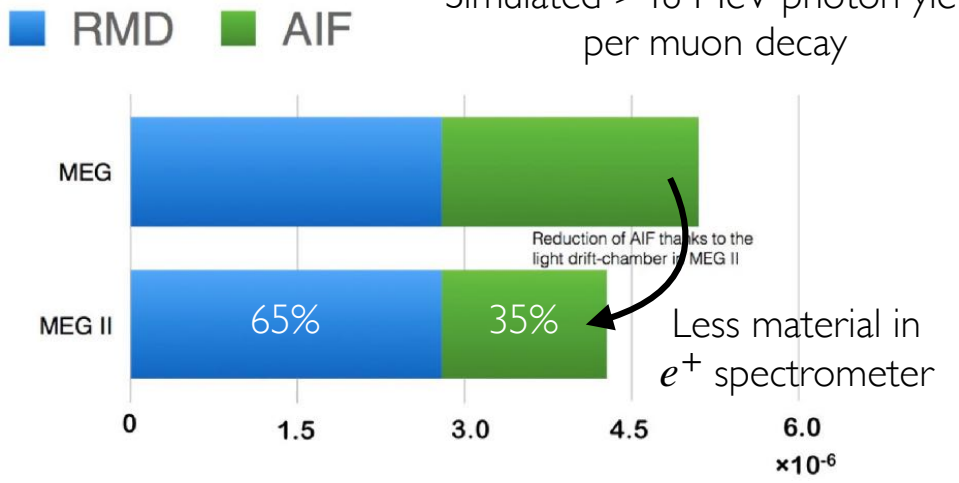
Background γ

- Background γ source: RMD & AIF
  - RMD/AIF = 65/35 for γ with >48 MeV
- **<65% of BG-γ can be suppressed by RDC**
  - Depending on detection efficiency

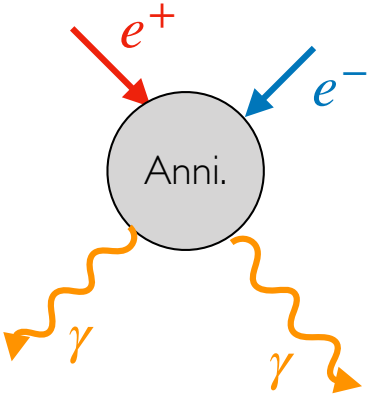


Radiative Muon Decay



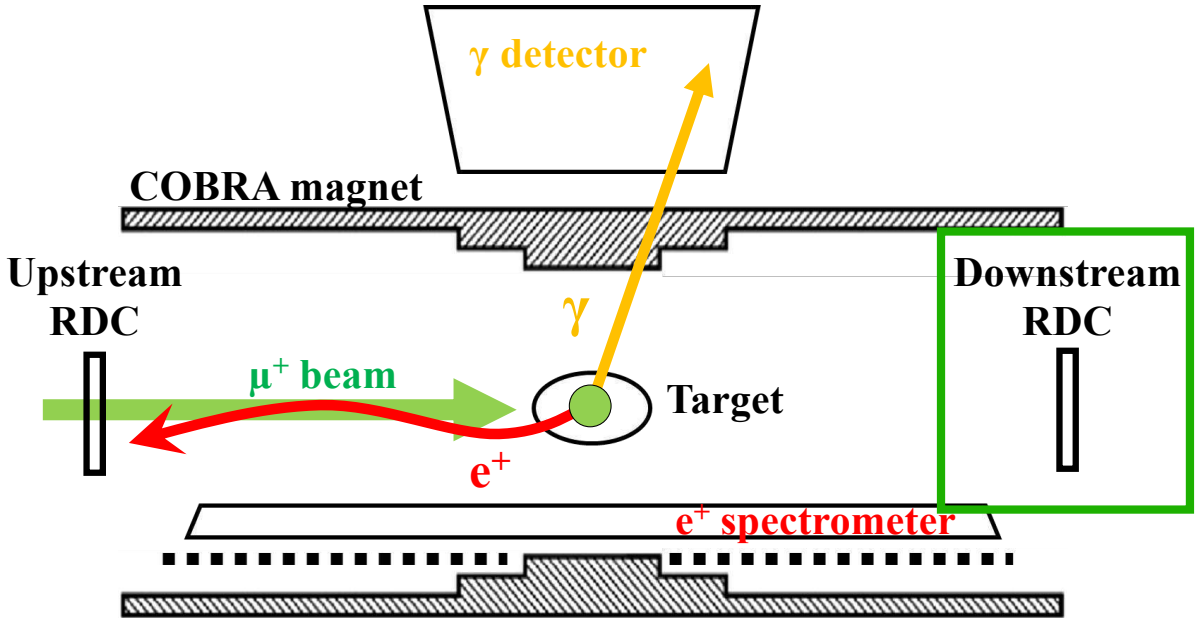


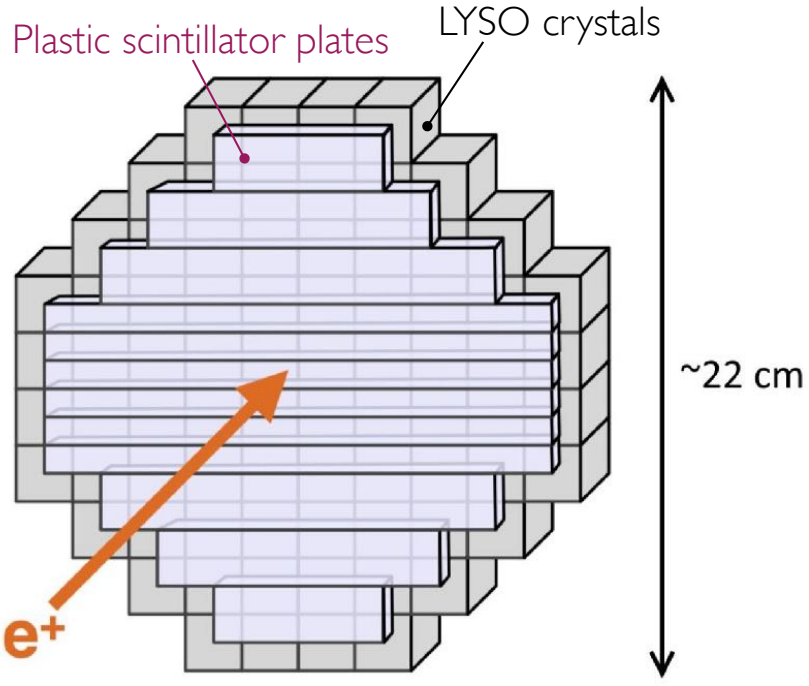
Annihilation In Flight



Downstream RDC

- Downstream RDC consists of
  - 12 plastic scintillators (timing measurement)
    - Readout from MPPCs at both ends
  - 76 LYSO crystals (energy measurement)
    - Readout from MPPC at each crystal
- Already installed, and operated in 2021, 22 physics runs



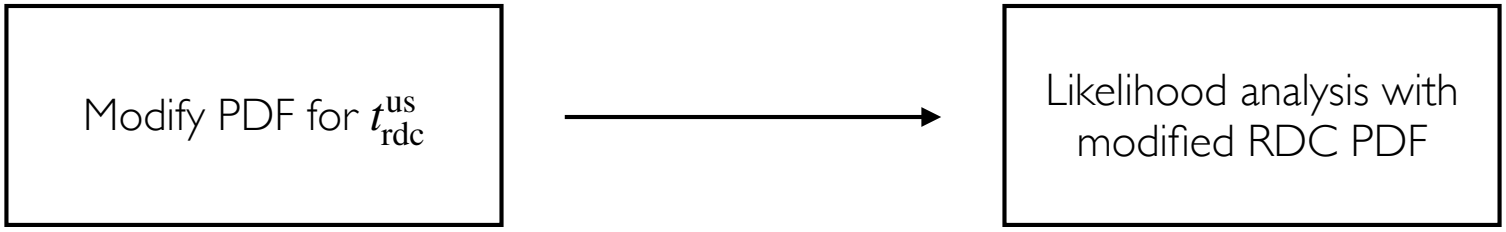


Sensitivity improvement overview

- Upper limit sensitivity estimated with maximum likelihood analysis
  - Expected number of signal events N_{sig} estimated by likelihood fit with probability density functions (PDFs)
    - **RDC PDFs contain RDC observables $t_{\mathrm{rdc}}^{\mathrm{us}}$, $t_{\mathrm{rdc}}^{\mathrm{ds}}$, $E_{\mathrm{rdc}}^{\mathrm{ds}}$**
  - Upper limit of N_{sig} at 90% confidence level calculated with pseudo experiments

- **8% sensitivity improvement by downstream RDC evaluated with MC**
  * R.Onda, Doctoral thesis, The University of Tokyo (2021)

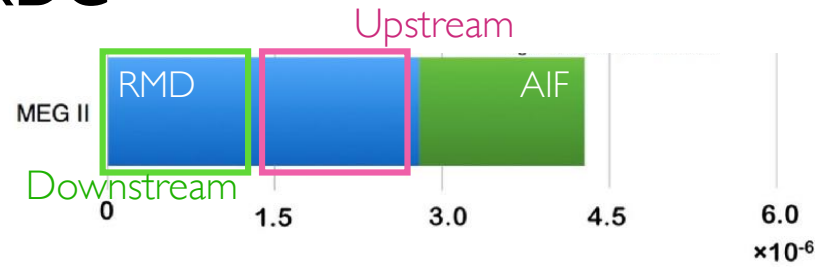
- Sensitivity improvement to be estimated with
  - Data ($t_{\mathrm{rdc}}^{\mathrm{ds}}$, $E_{\mathrm{rdc}}^{\mathrm{ds}}$) for downstream RDC
  - Estimation of $t_{\mathrm{rdc}}^{\mathrm{us}}$ distribution from previous studies for upstream RDC

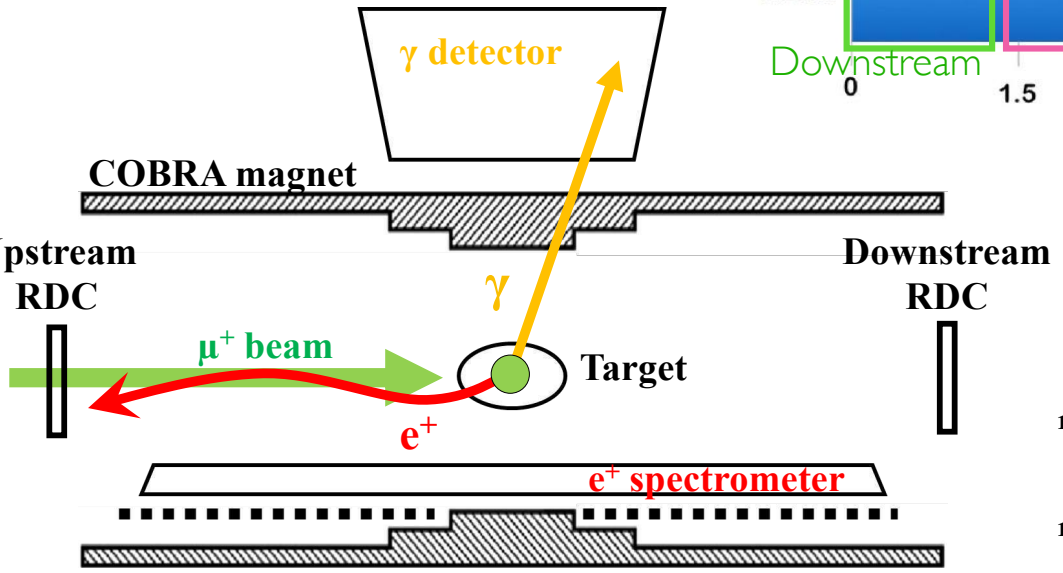


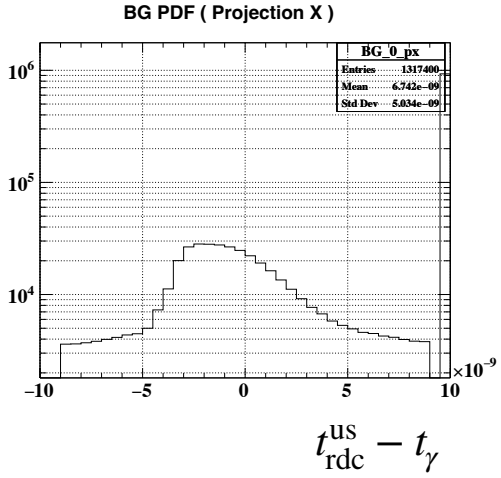
BG-γ suppression by full RDCs

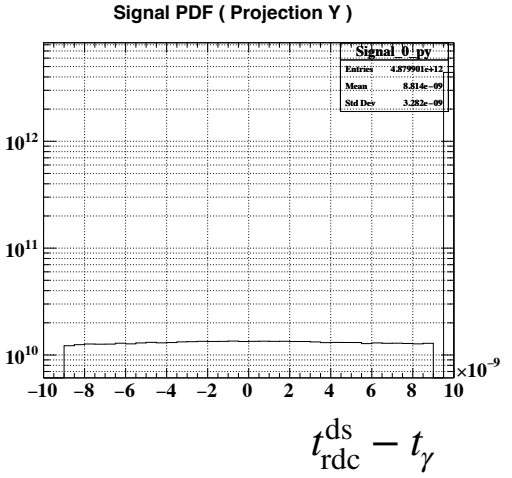
- **Upstream RDC can suppress the rest of BG-γ from RMD**
- RMD γ detected by γ detector
- RMD e^+ detected by either upstream or downstream RDC

➡ **e^+ must not be detected by the other RDC**



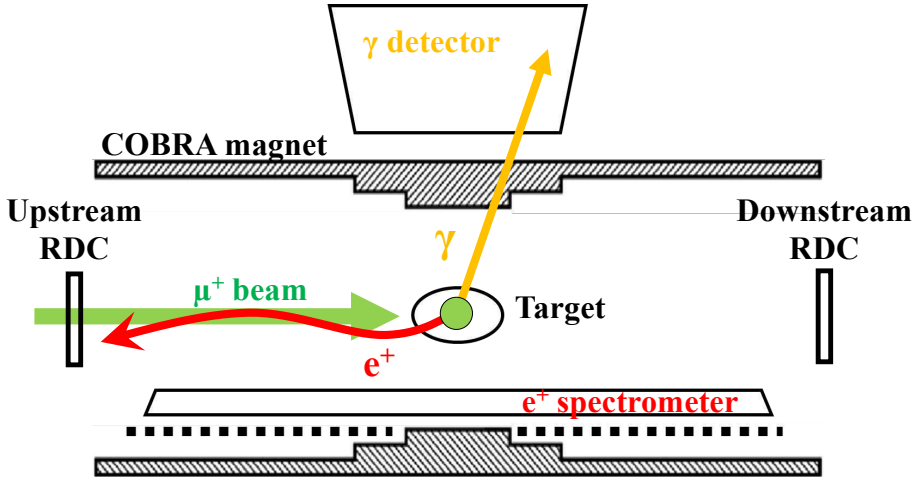




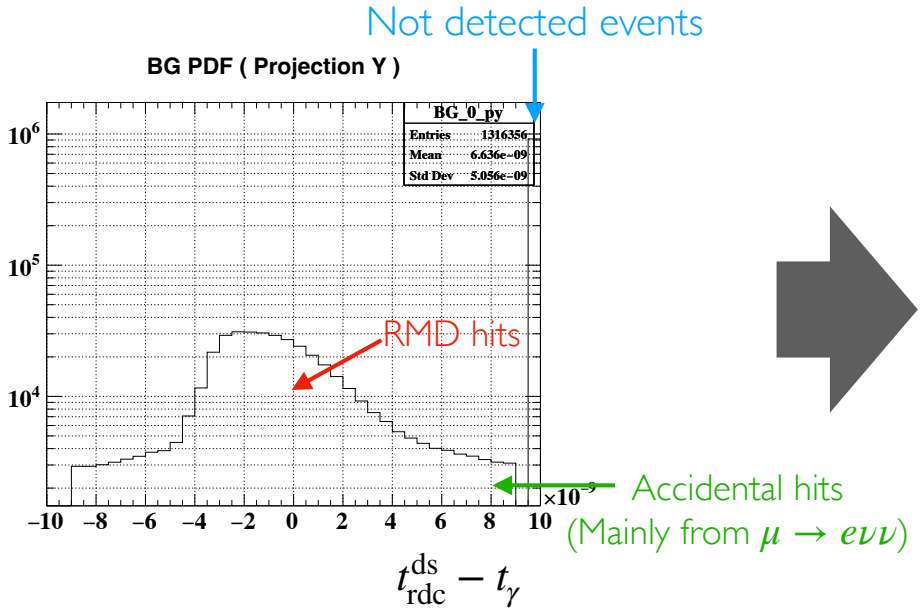


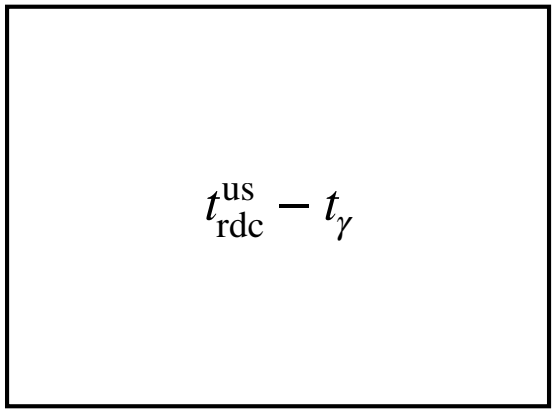
t^{us}_{rdc} estimation from t^{ds}_{rdc}

- t^{us}_{rdc} estimated from t^{ds}_{rdc}
  - Time resolution
  - Detection efficiency
  - Hit probability of RMD e^+, accidental e^+, and μ^+



Upstream RDC detects RMD e^+ in μ^+ beam

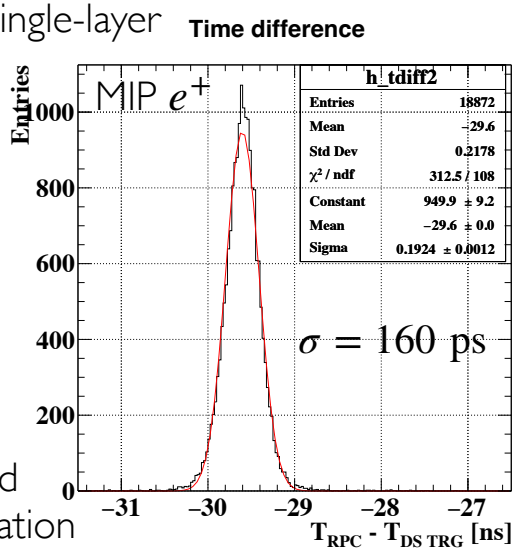




Time resolution

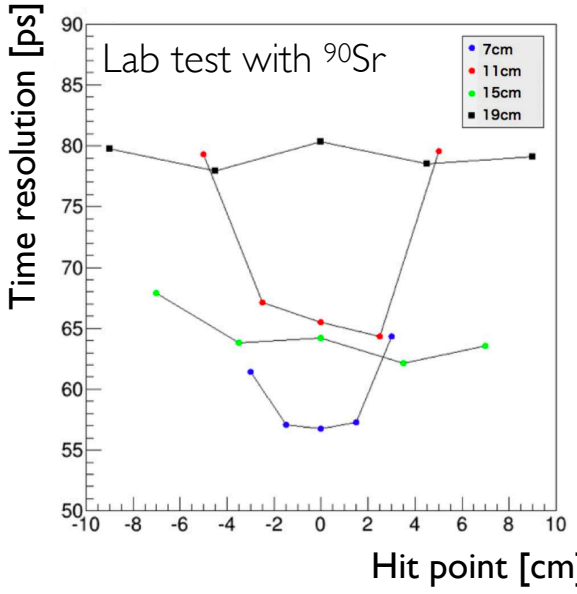
Upstream RDC : **~100 ps**

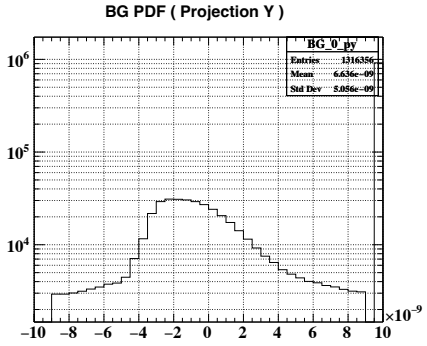
Single-layer

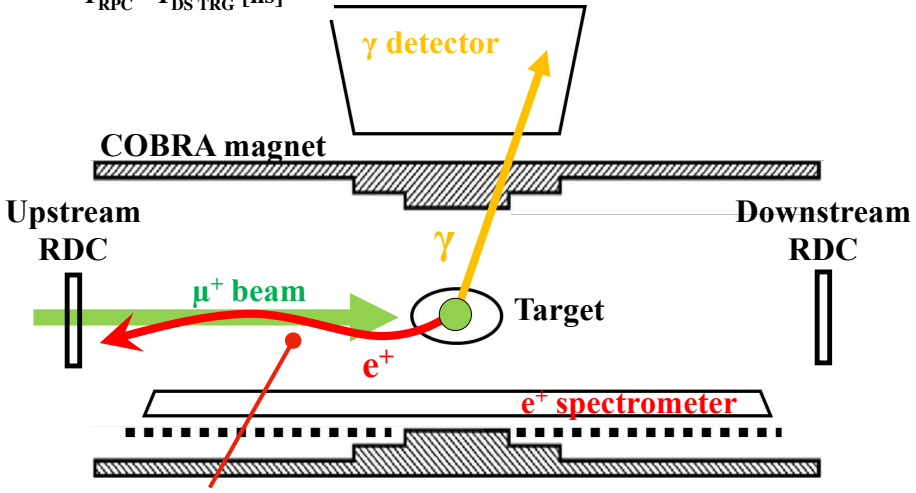


~100 ps expected
with 4-layer configuration

Downstream RDC : **<90 ps**







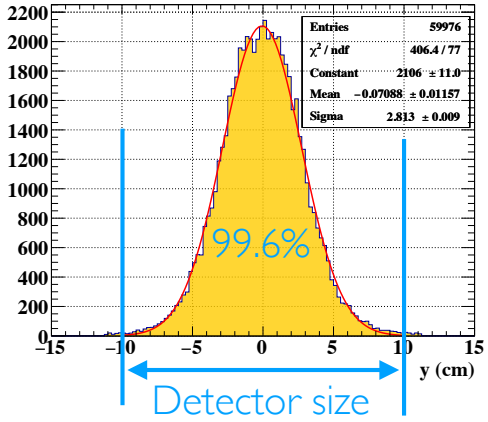
Main contribution to $t_{\mathrm{rdc}} - t_\gamma$: TOF of RMD e^+

Time resolution can be negligible

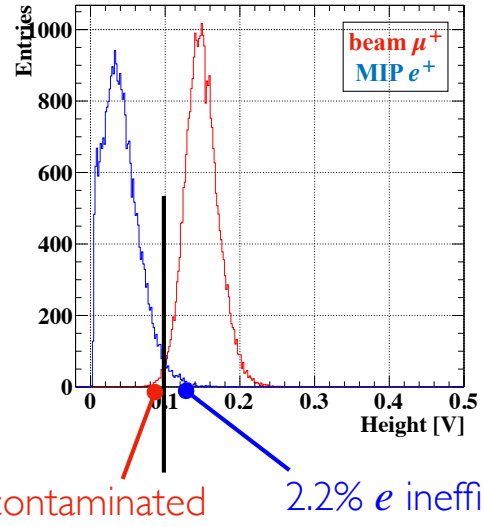
Detection efficiency

Upstream RDC : **88%** (assumption)

RMD e^+ distribution at upstream RDC

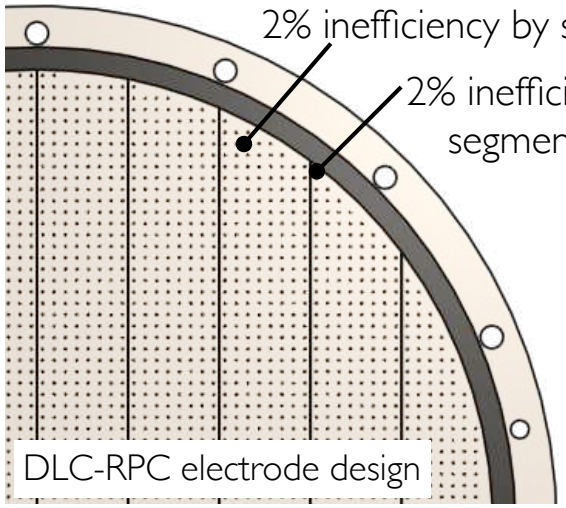


Expected pulse height spectra



0.1% μ contaminated

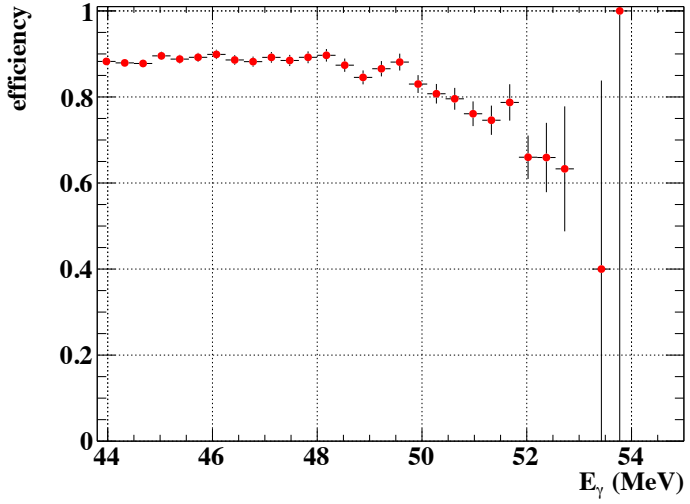
2.2% e inefficient



Other assumptions (to be improved)

- 1% inefficiency by pileup
- 5% inefficiency for MIP

Downstream RDC : **~88%**



Inefficiency comes from geometrical acceptance

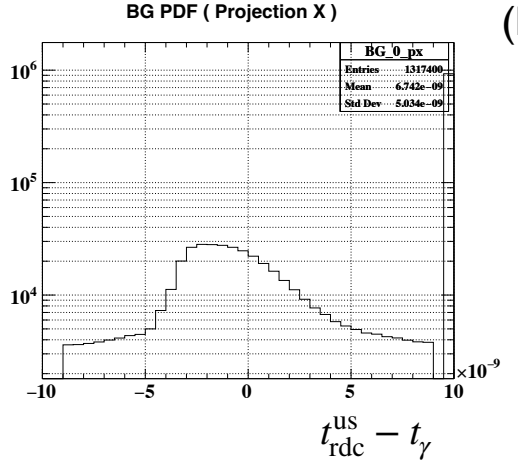
Detection efficiency of upstream RDC is consistent with that of downstream RDC

Hit probability

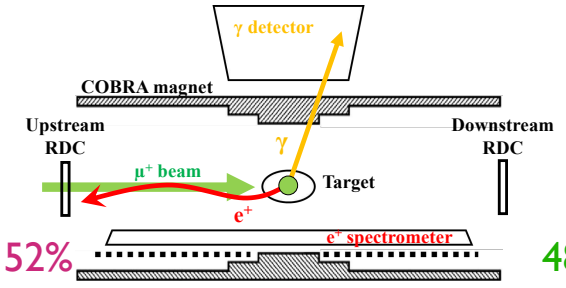
Upstream RDC
RMD e^+ ~ 30% / Accidental ~ 16%

Downstream RDC
RMD e^+ ~ 27% / Accidental ~ 13%

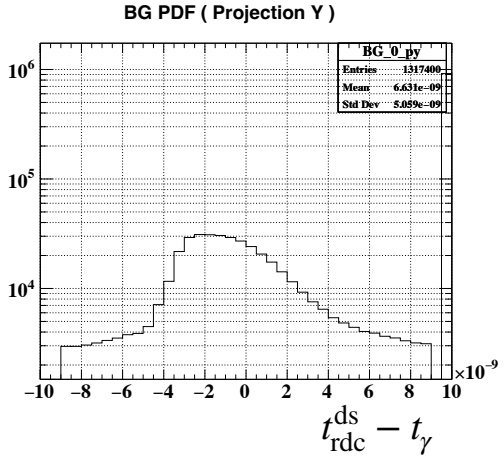
RMD e^+



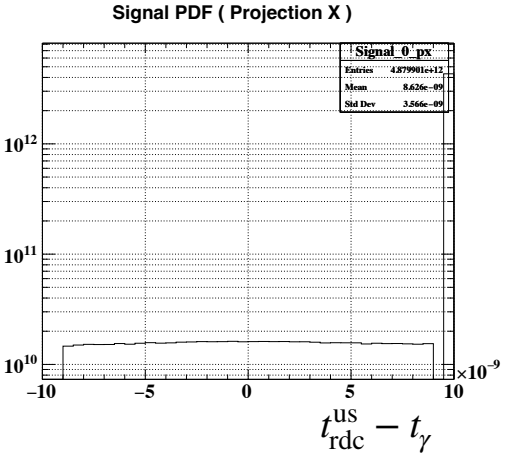
(RMD e^+ direction) x (Detection efficiency)



x 1.08 due to μ polarization



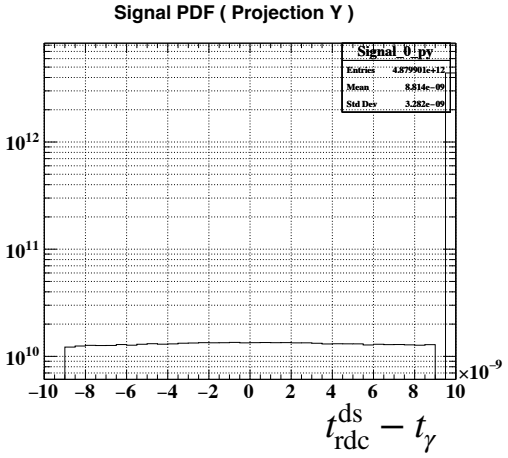
Accidental



Beam μ^+
- 0.1% μ^+ contaminated
- Ignorable

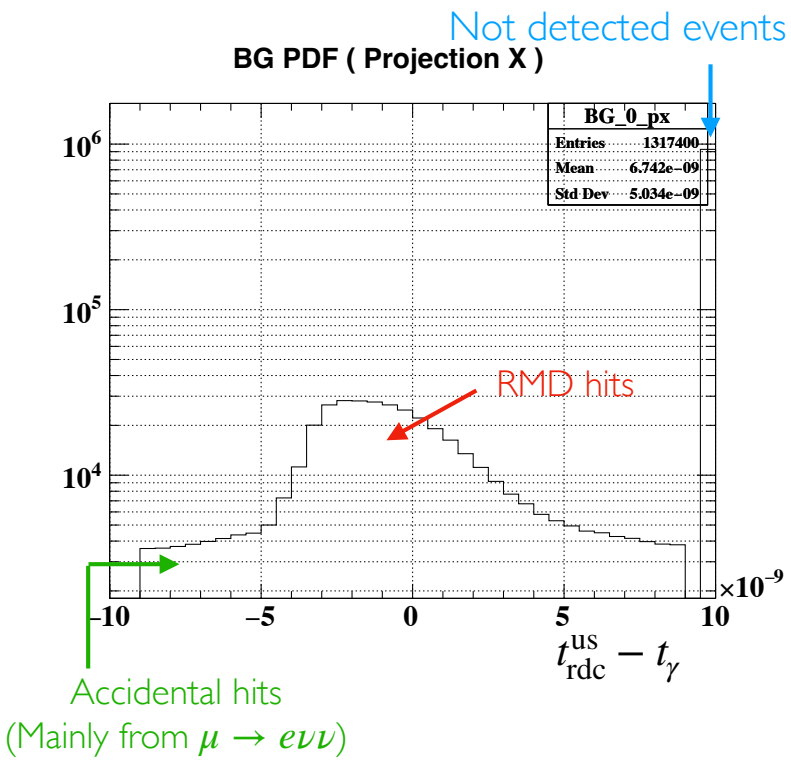
Accidental e^+
- 2% of μ^+ decays in spacer in DLC-RPC

x 1.2 due to spacers in detector

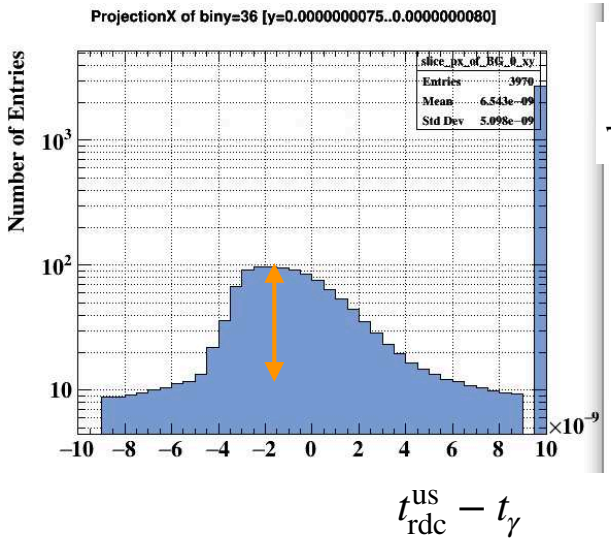


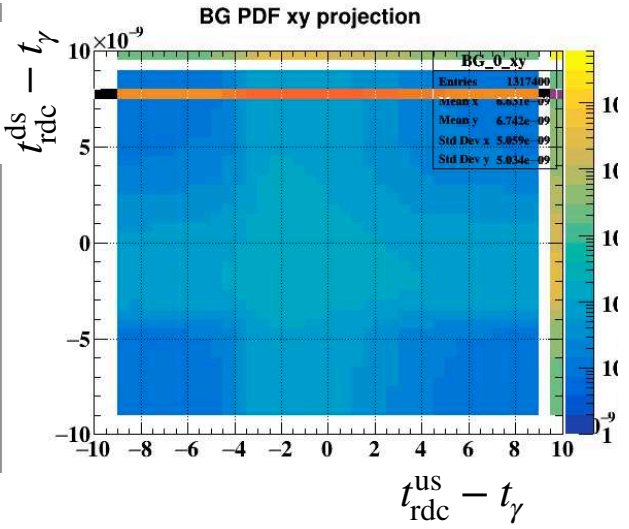
Hit probabilities estimated reasonably

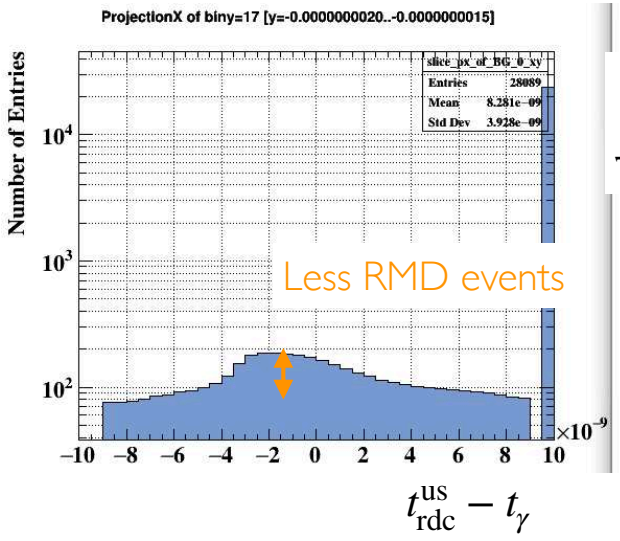
BG RDC PDF

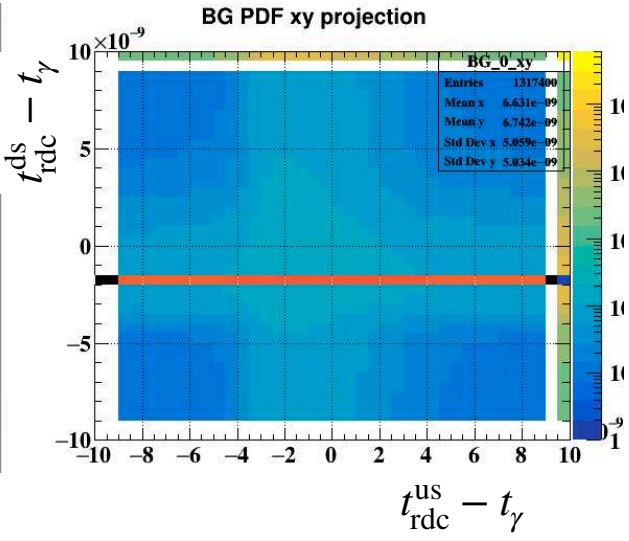


Correlation included in PDF









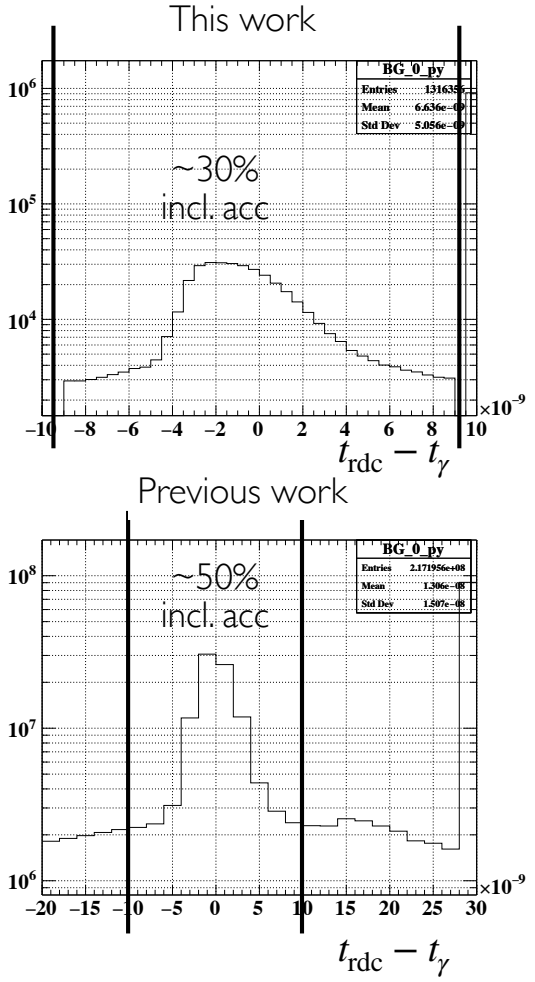
Reasonable RDC PDFs created

Sensitivity improvement

- **2% sensitivity improvement compared with only downstream RDC**
  - Assuming installation in 2024
- 2% lower improvement in only downstream RDC case
  - Detection efficiency seemed to be overestimated
  - Study on higher detection efficiency to be done
- DLC-RPC performance should be understood

Sensitivity improvement compared with no RDC case

	This work	Previous work
Only downstream RDC	6%	8%
Full RDCs	**8%**	Preliminary



Conclusion

- Upstream RDC is promising for further sensitivity improvement
  - DLC-RPC is under development as upstream RDC

- Sensitivity improvement estimated with
  - Data for downstream RDC observables ($t_{\mathrm{rdc}}^{\mathrm{ds}}, E_{\mathrm{rdc}}^{\mathrm{ds}}$)
  - Reasonable estimation for upstream RDC observable ($t_{\mathrm{rdc}}^{\mathrm{ds}}$)

- **2% sensitivity improvement estimated**
  - Assuming installation in 2024
  - Most uncertain part is performance of DLC-RPC

Prospects

- **DLC-RPC performance must be studied for further understanding of sensitivity improvement**

- DLC-RPC development
  - Detector design
    - System to secure uniform gap thickness
    - HV supply pattern to improve high-rate capability and scalability

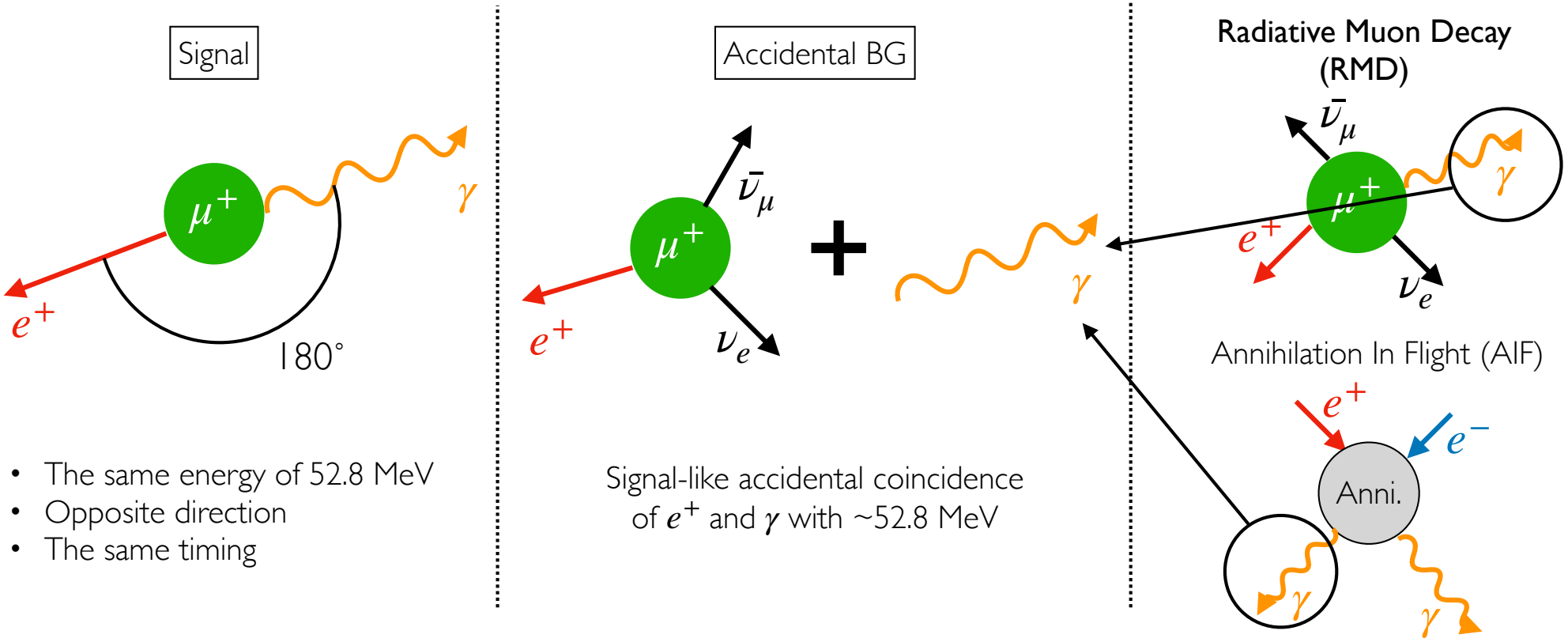
  ➡ **Goal of detection efficiency: 90% at 4 MHz/cm^2**

- **Aim at installation in 2024**

Backup

MEG II signal & background

- Dominant background is accidental coincidence of e^+ and γ from different μ^+
  - BG-γ source: RMD/AIF = 65/35 for detected γ with >48 MeV

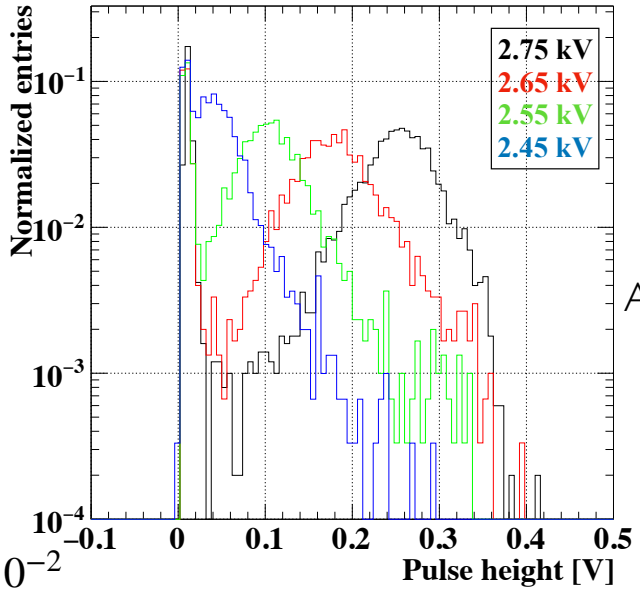


- The same energy of 52.8 MeV
- Opposite direction
- The same timing

Signal-like accidental coincidence of e^+ and γ with ~52.8 MeV

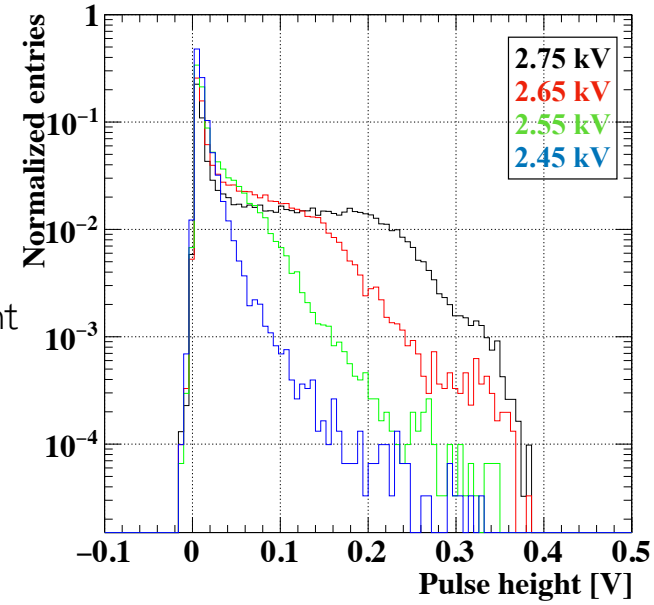
DLC-RPC response

Low-momentum μ



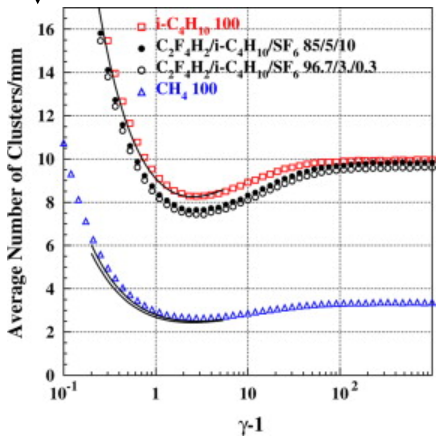
Average different by factor 3

MIP e



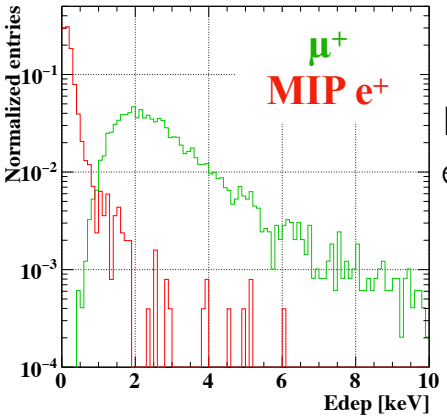
$\gamma - 1 = 3.4 \times 10^{-2}$

Simulated average number of clusters



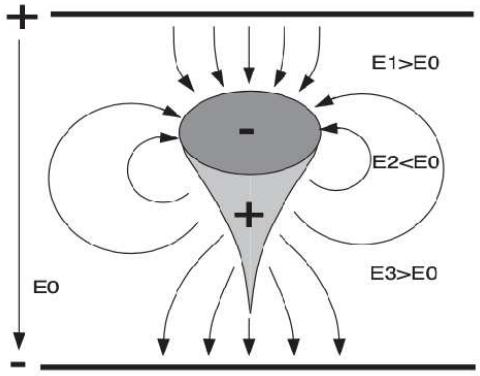
Riegler, W. and Lippmann, C., "The physics of Resistive Plate Chambers", NIM A, 518 (2004)

Energy deposit (MC)



Factor 10 difference

More clusters grow enough in case of μ



Amplification saturated due to space charge effect

$(p/E = \beta = 0.26)$

Hit probability

	Upstream RDC **RMD e^+ ~ 30% / Accidental ~ 16%**	Downstream RDC **RMD e^+ ~ 27% / Accidental ~ 13%**
RMD e^+	(RMD γ fraction out of BG-γ) x **(RMD e^+ direction)** x (Detection efficiency) 52% of RMD e^+ goes upstream	48% of RMD e^+ goes upstream
	x 1.08 due to μ polarization	
Accidental e^+	A few % increase due to polarization 2% of μ decays in spacers in DLC-RPC Assuming 1 x 10^8 μ/s, 2 MHz increase expected	~4 MHz @3 x 10^7 stopping μ/s observed Accidental hit probability: 13% ~10 MHz @7 x 10^7 stopping μ/s expected
	x 1.2 due to spacers in detector	
Beam μ^+	0.1% μ contaminated Assuming 1 x 10^8 μ/s, 0.1 MHz which is negligible	

Hit probabilities estimated reasonably

Discussion on sensitivity improvement

- Less sensitivity improvement than expected
- Possible causes
  1. Less # of RMD-γ detected ← Study on RDC detection efficiency
  2. More AIF-γ generated
- AIF-γ reduction is important for larger RDC contribution