Upgrade of MEG experiment

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@Stockholm

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THE UNIVERSITY OF TOKYO

ICEPP, The University of Tokyo
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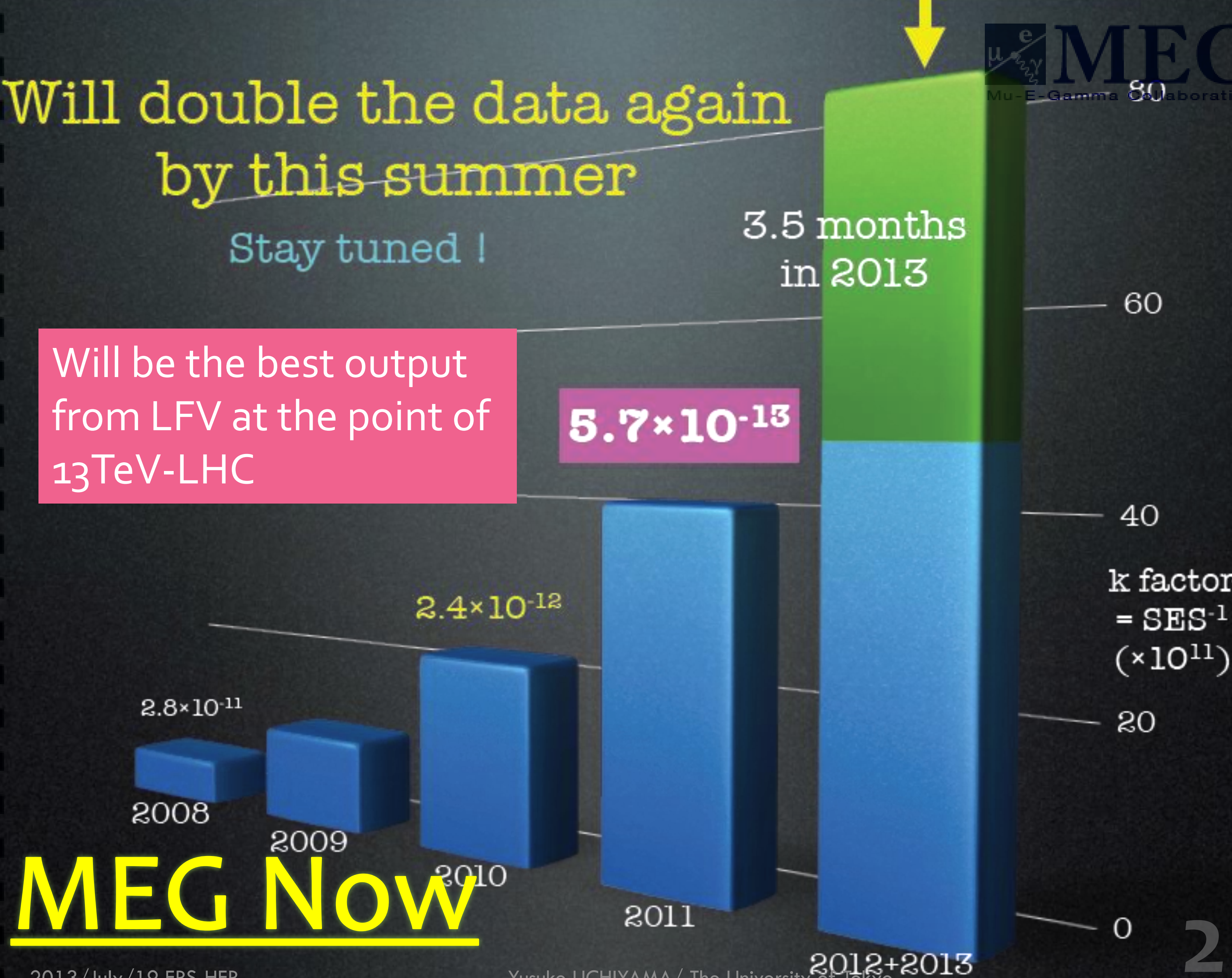
for the MEG collaboration

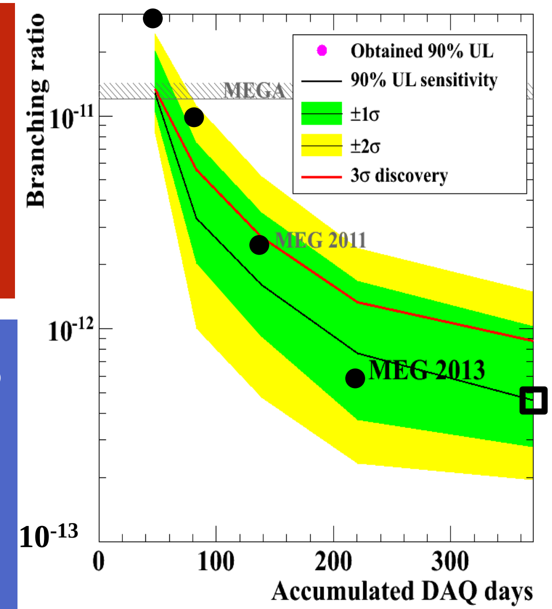
Will be the best output from LFV at the point of 13TeV-LHC



MEG Now

Why upgrade?

- **Sensitivity of MEG starts saturation due to finite BGs**
  Not possible to go down to $O(10^{-14})$



- **Physics viewpoint & the other programs**
  Pushing down to $O(10^{-14})$ is extremely interesting
  - No BSM signal from LHC so far
  - Start of 13–14 TeV run
  - Next generation LFV experiments take more time

- **Experimentally**
  1. Not using full beam intensity available to date
  2. Detector performance is not at the level of design

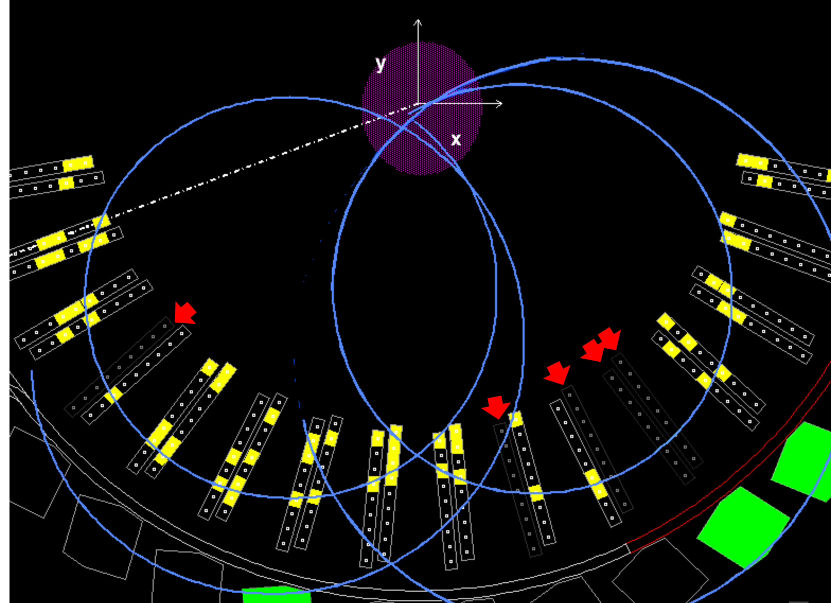
We can do better now

In reality → points of upgrade

- **Worse performance on e⁺ side than designed**
  - Half efficiency due to scattering on extra material
  - Instability, aging → loss of beam time as well as performance deterioration
  - Poorer hit resolution due to noise
- **Poor γ-energy resolution at shallow and edge part**

Variable	Foreseen	Obtained
ΔE_γ (%)	1.2	1.7
Δt_γ (psec)	43	67
γ position (mm)	4(u,v),6(w)	5(u,v),6(w)
γ efficiency (%)	> 40	63
ΔP_e (KeV)	200	306
e^+ angle (mrad)	$5(\phi_e),5(\theta_e)$	$8.7(\phi_e),9.4(\theta_e)$
Δt_{e^+} (psec)	50	107
e^+ efficiency (%)	90	40
$\Delta t_{e\gamma}$ (ps)	65	122

Drift chamber condition in worst period



Upgrade strategy

Mu-E-Gamma Collaboration

Goal	**Another order of magnitude ⇒ target sensitivity** ~5×10^{-14} ☐ Interesting from SUSY-GUT *etc*. ☐ Can be competitive with next generation experiments
Time	**On a time scale of ~5 years** ☐ Not lag behind the coming LHC-innovation ☐ Earlier than the next generation experiments
Steady going	☐ Keep the MEG concept ☐ Long time experience of MEG ☐ Introduce new technologies into conventional detector technique
Low cost, early realization	☐ Exploit existing apparatus ✓ beamline, magnet, LXe, calibration devices, *etc*. ☐ Established cooperative team with experts

How?

Mu-E-Gamma Collaboration

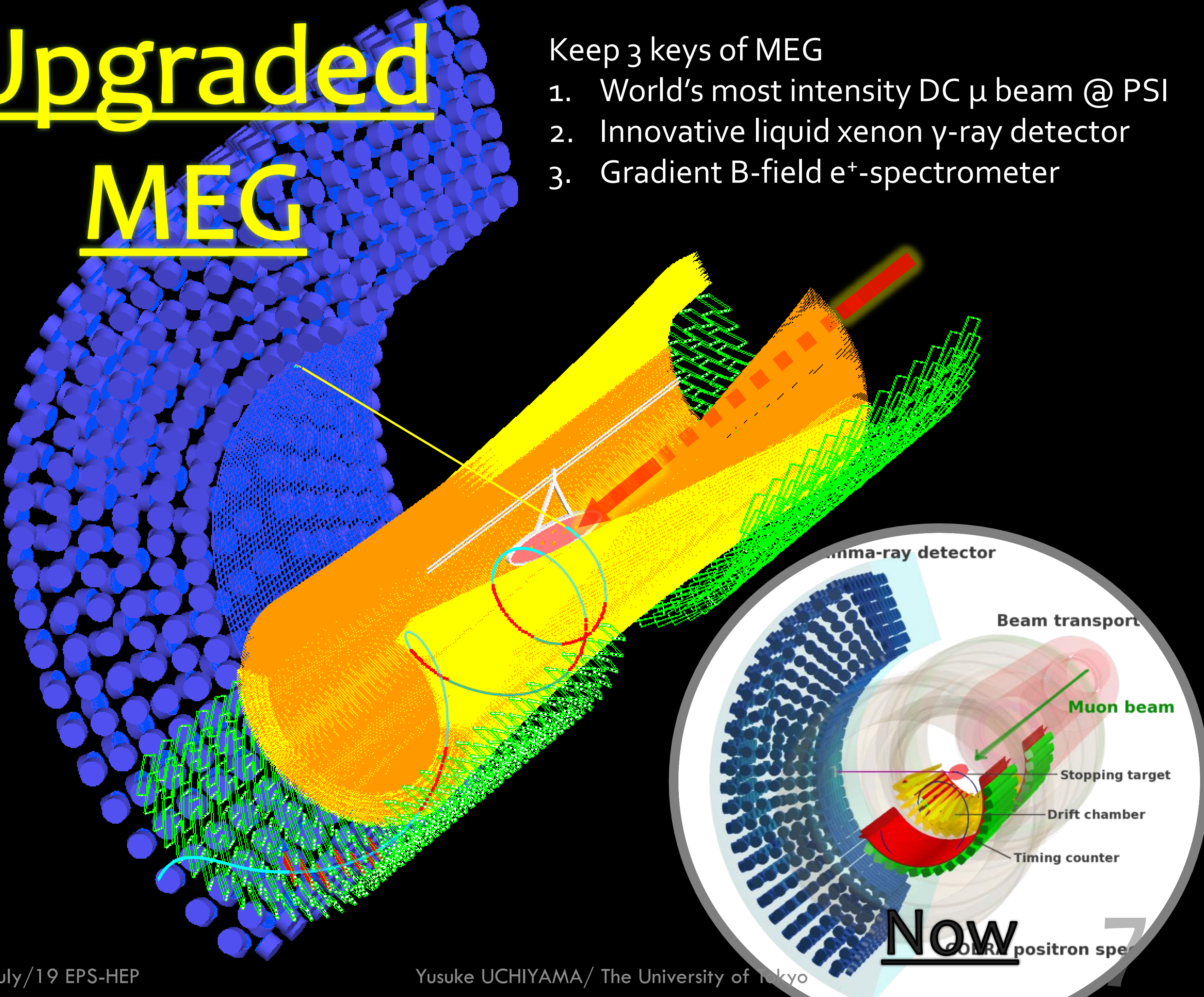
Statistics ×10	☐ Beam intensity ×2–3 ✓ Possible at present beamline πE5 ☐ Detector efficiency ×2 ✓ Recover the loss in current detector (especially on e^+ side) ☐ Efficient usage of beam time ✓ Little maintenance, short calibration, *etc.* with stable detector possible
requirements	☐ Stably operational detector under high rate beam
	☐ BG suppression 10 stats. × 3 rate = 30 BG ◆ Improve resolutions ● (2 in e^+ mom)x(2 in γ energy)x(2 in angle)²x(2 in time) = 32 ◆ Reduce BG yield ● Thinner target, lighter tracker ◆ Introduce BG veto or tag challenge

Our solution is ⇨

Upgraded MEG

Keep 3 keys of MEG

1. World's most intensity DC μ beam @ PSI
2. Innovative liquid xenon γ-ray detector
3. Gradient B-field e^+-spectrometer

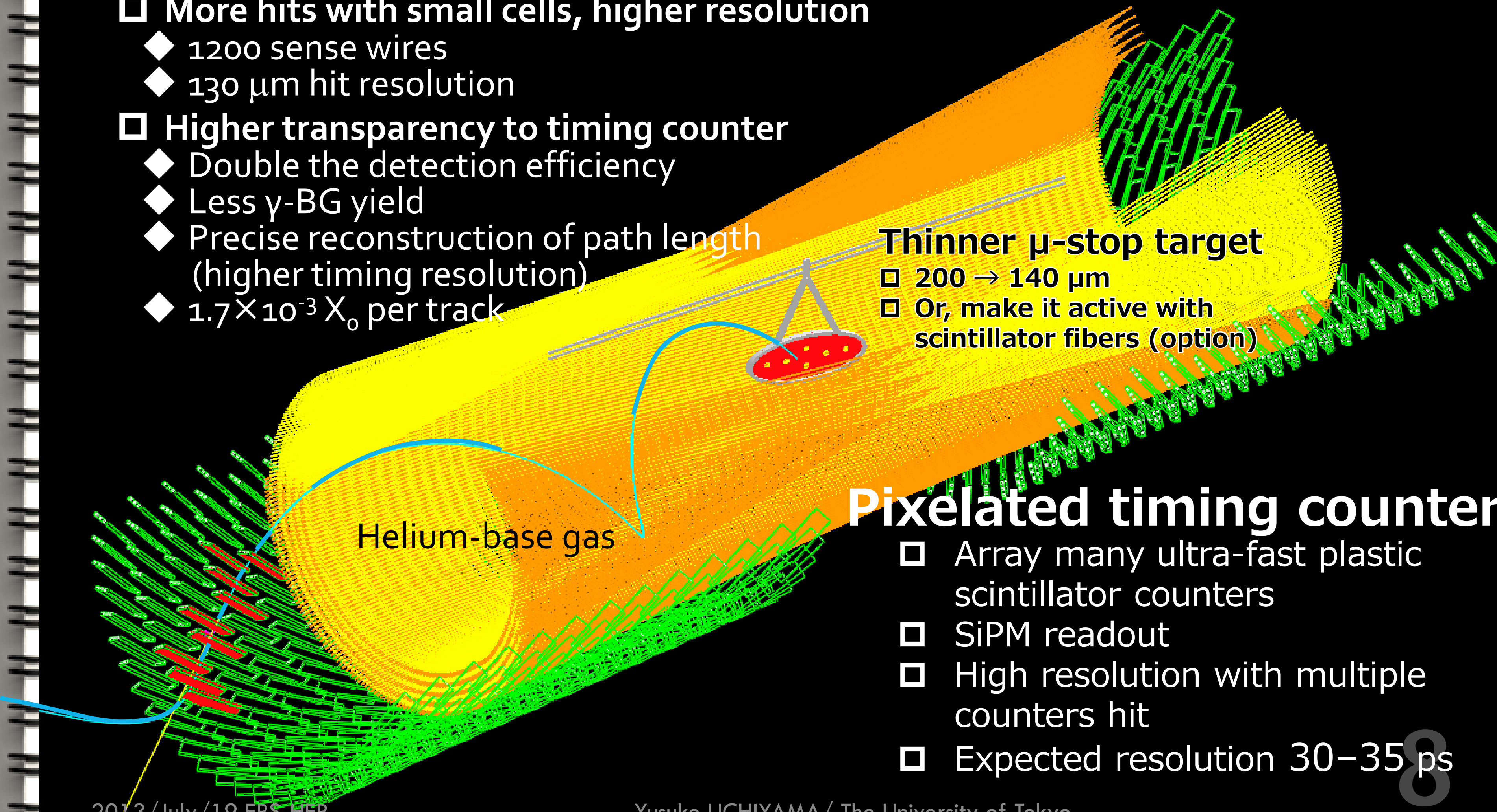


Now

New e^+ Tracker

Single-volume stereo-wire drift chamber

- High rate tolerable, long stability
- More hits with small cells, higher resolution
  - 1200 sense wires
  - 130 μm hit resolution
- Higher transparency to timing counter
  - Double the detection efficiency
  - Less γ-BG yield
  - Precise reconstruction of path length (higher timing resolution)
  - $1.7\times10^{-3}\ X_0$ per track



Thinner μ-stop target

- 200 → 140 μm
- Or, make it active with scintillator fibers (option)

Pixelated timing counter

- Array many ultra-fast plastic scintillator counters
- SiPM readout
- High resolution with multiple counters hit
- Expected resolution 30−35 ps

New e^+ Tracker

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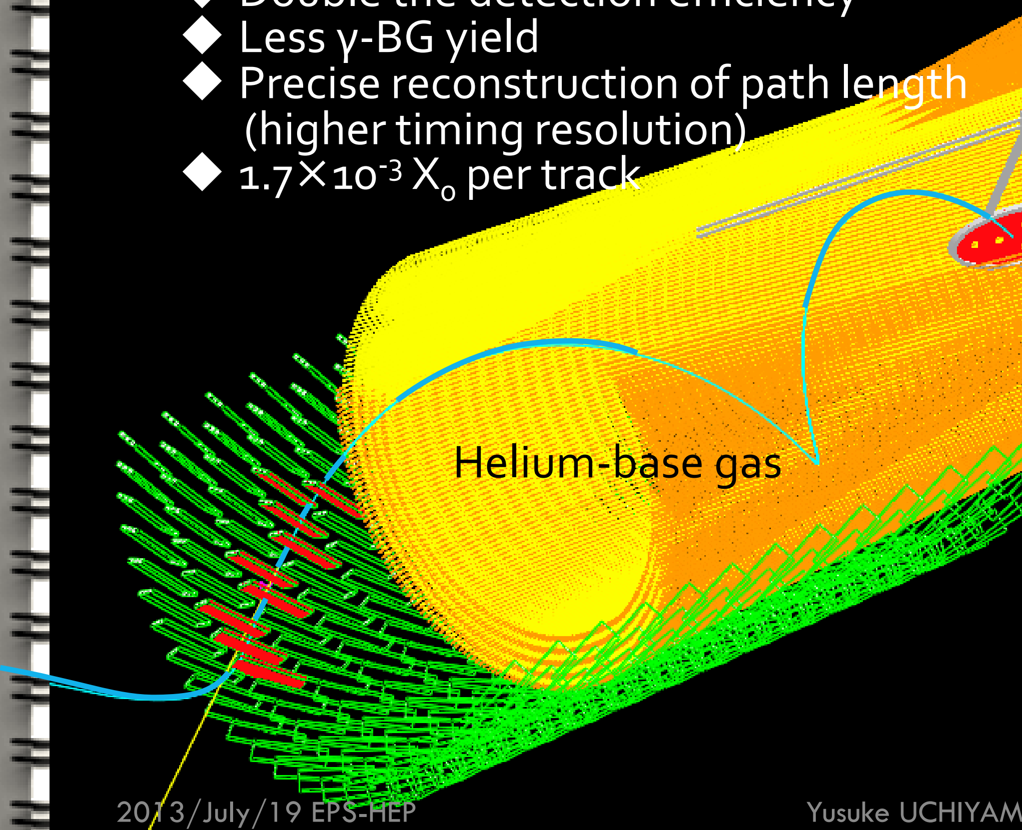
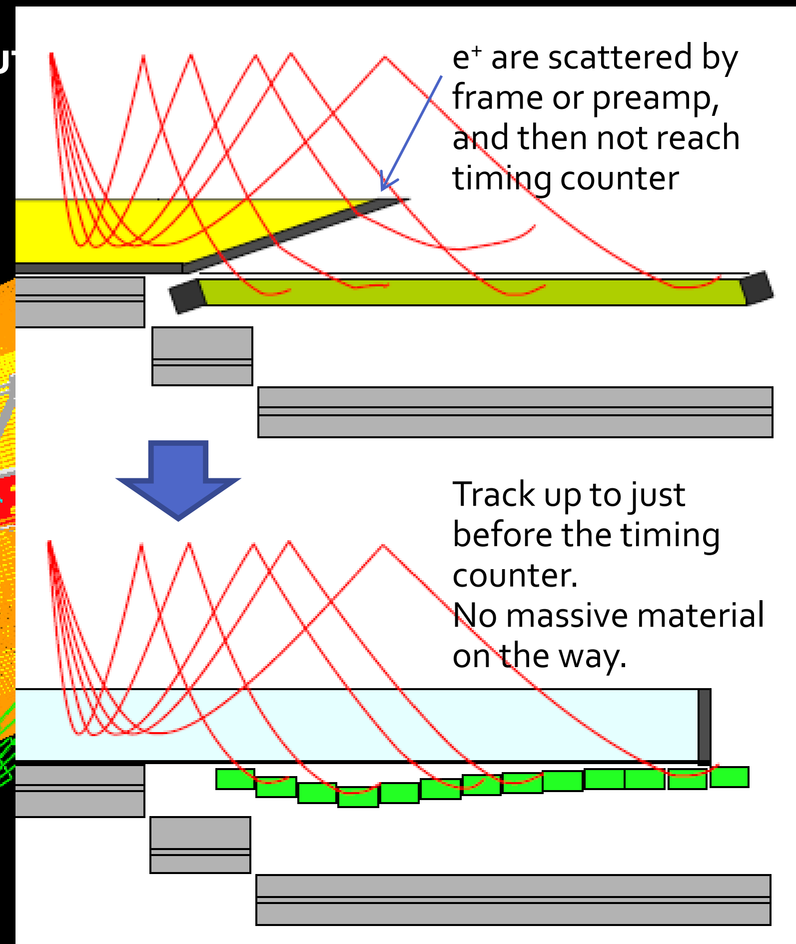




ter

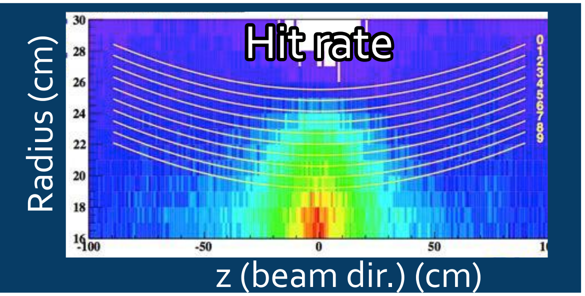
counters hit

- Expected resolution 30–35 ps

Missions to the tracker

① Build stable detector

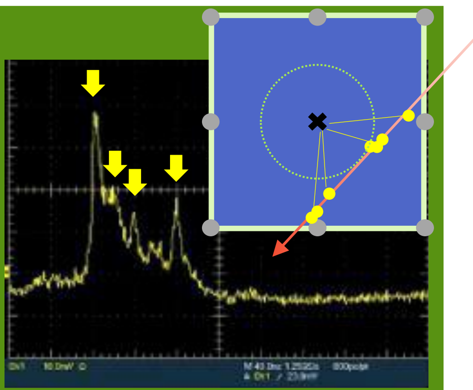
- >30 kHz/cm² on the innermost wire **@ 7×10⁷ μ/s**
- **0.32 C/cm** for 3 years DAQ ($He:iC_4H_{10}=90:10$)



② Improve resolution

- Large # of hits by single-volume with fine cells (7 mm): 15 → **~60**
- **<140 μm** for drift distance
- For longitudinal direction,
  - Charge division, time difference, and stereo angle
  - Redundant measurements enable pattern recognition for tracking

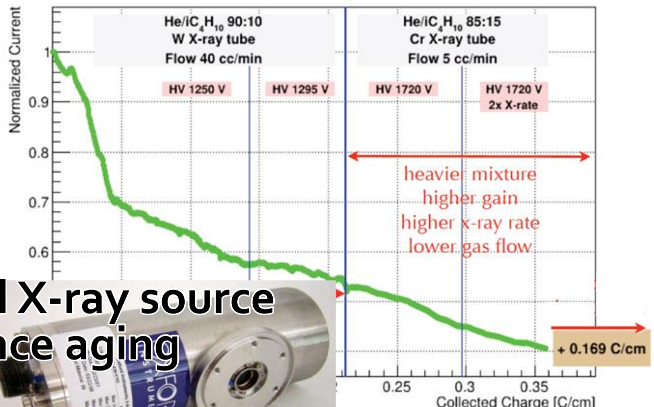
- Further improvement with **'cluster counting'** technique under study
  - Use full information of ionization clusters
  - Require high-bandwidth electronics



	Present chamber	Expected
Momentum (keV)	350	**~130**
Angular (mrad)	9, 11	**~5, ~5**
Vertex (mm)	1.8, 1.1	**1.2, 0.8**
Efficiency to TC (%)	40	**>80**

To accomplish these missions…

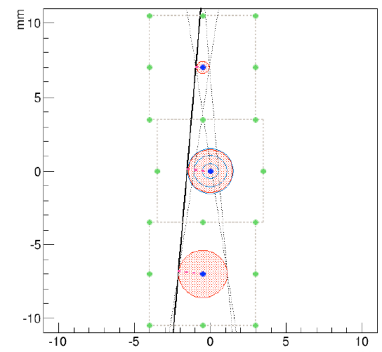
Aging prototype

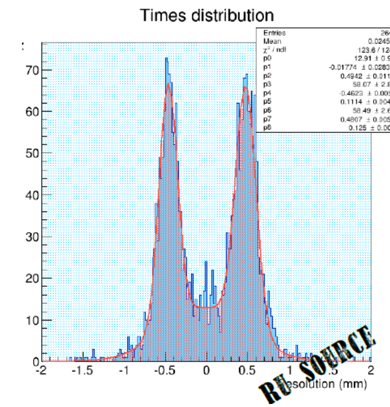


Test up to **0.5**C/cm, no severe problem

- Gain decreased ~50% , covered by HV

3-cell prototype



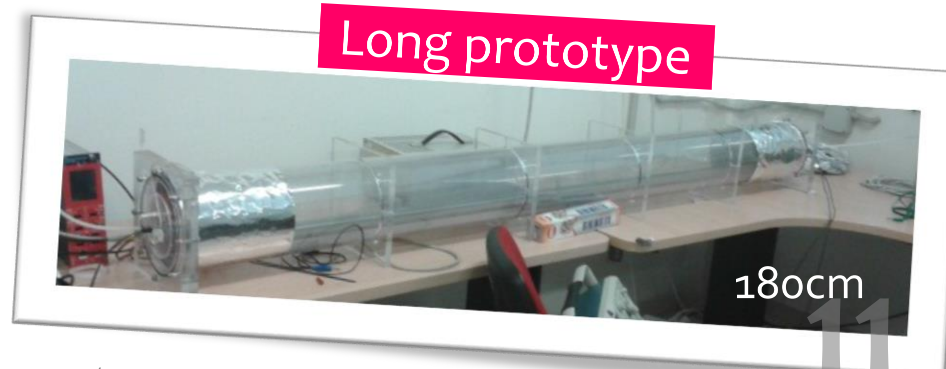


Test hit resolution $\mathcal{S} = \frac{d_1 + d_3}{2} - d_2 = \pm\Delta$

- Single hit resolution ~100μm achieved

Wiring prototype

Long prototype

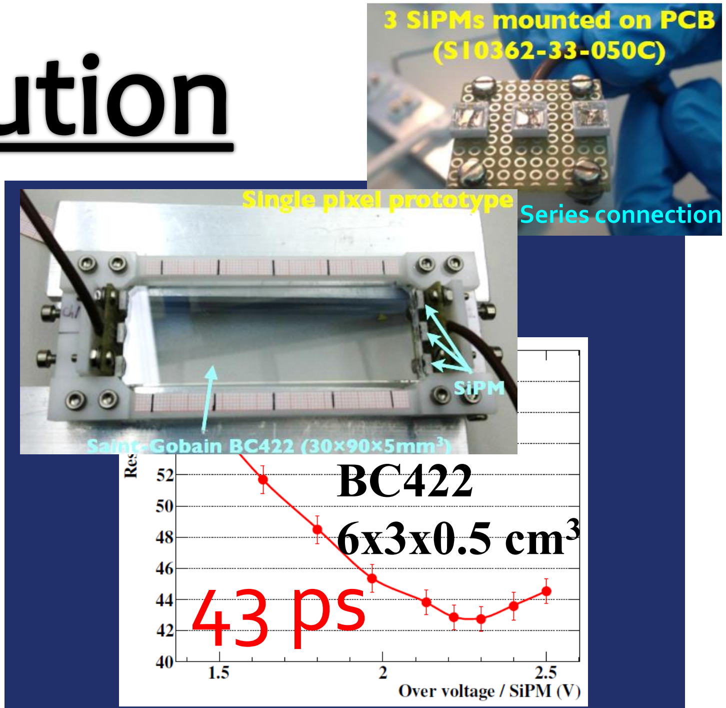


Down to 30 ps resolution

① High resolution with ultra-fast scintillator + SiPM readout

- Already achieved excellent single-counter resolution using prototype counters

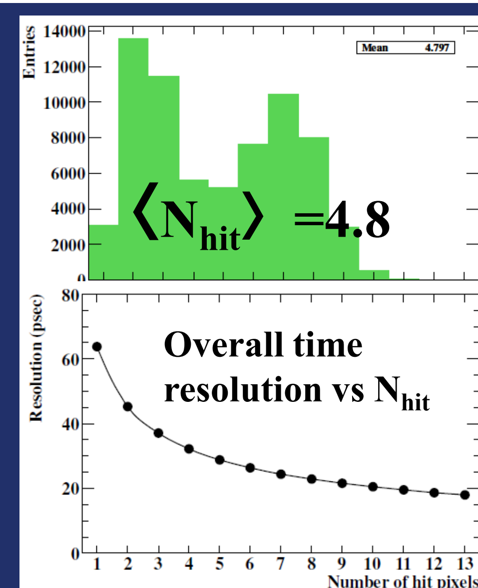
Proven technology



② Ultimate resolution with multi-counter hit

- Reduce electronics & calibration contribution as well as counter resolution
- Plan to verify in beam test
- Optimal layout under study

σ_{t_e}=76 ps → 30–35 ps



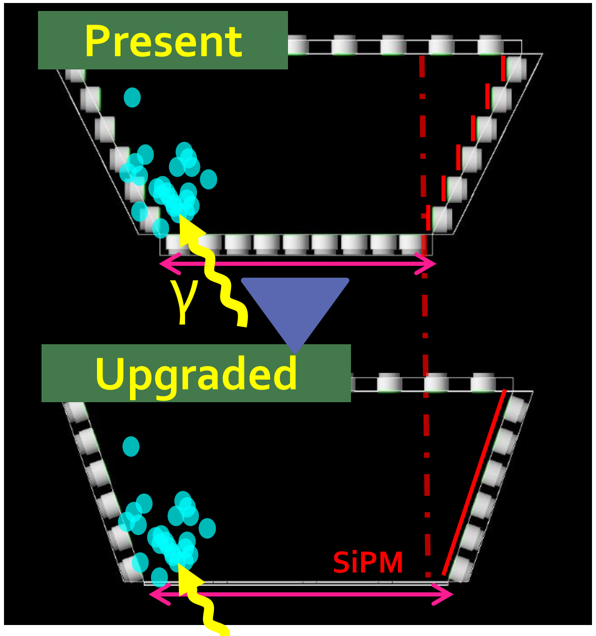
Gamma-ray detector

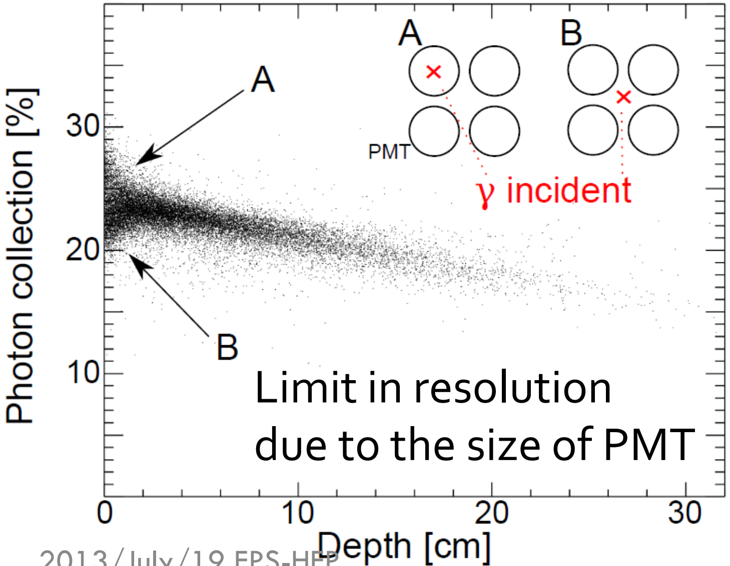
① **Replace important part PMTs with smaller device, SiPMs**

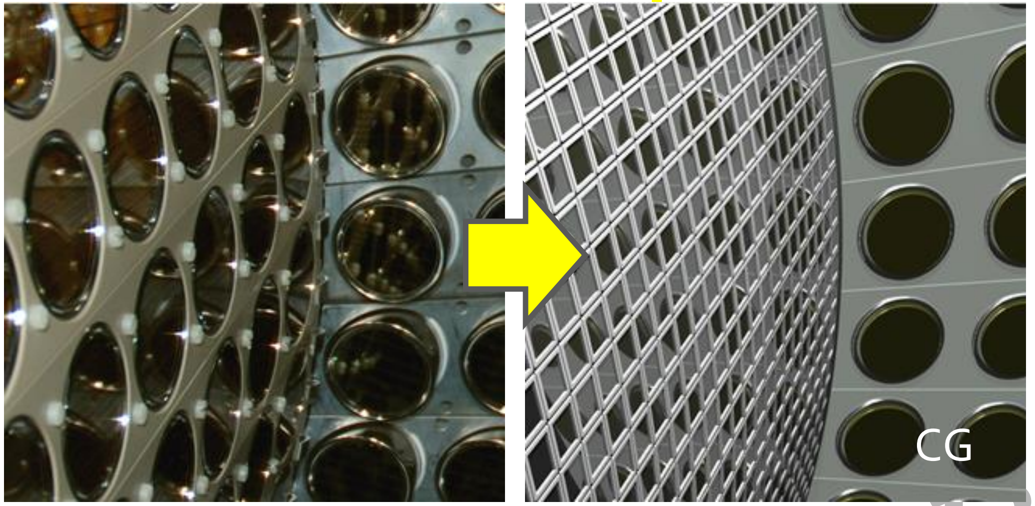
- For better uniformity of scinti. light collection
- Improve position & energy resolutions
- Improve power of pileup identification
- Improve the detection efficiency

② **Broaden LXe volume & modify PMT arrangement**

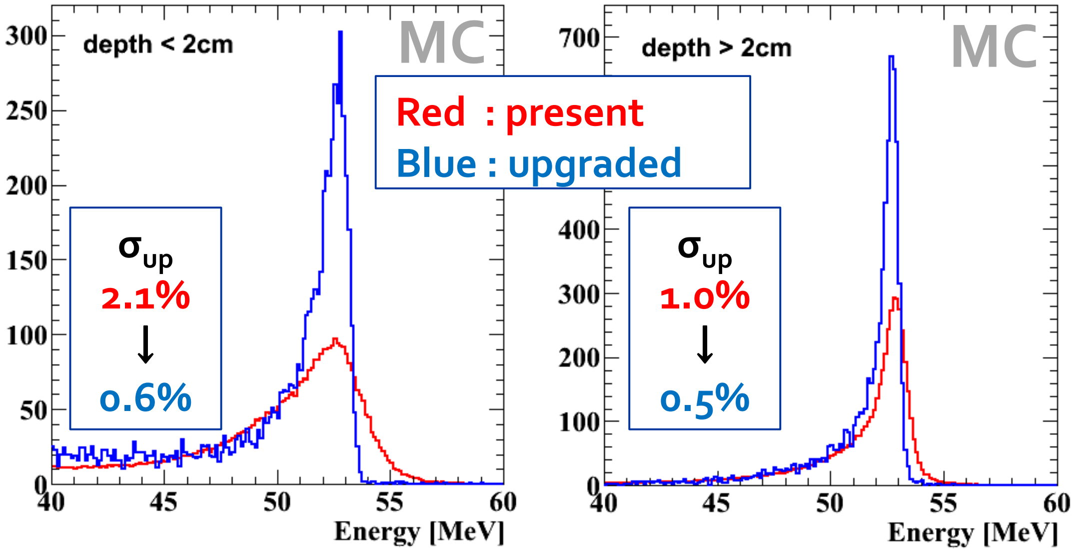
- To fully contain shower for edge events





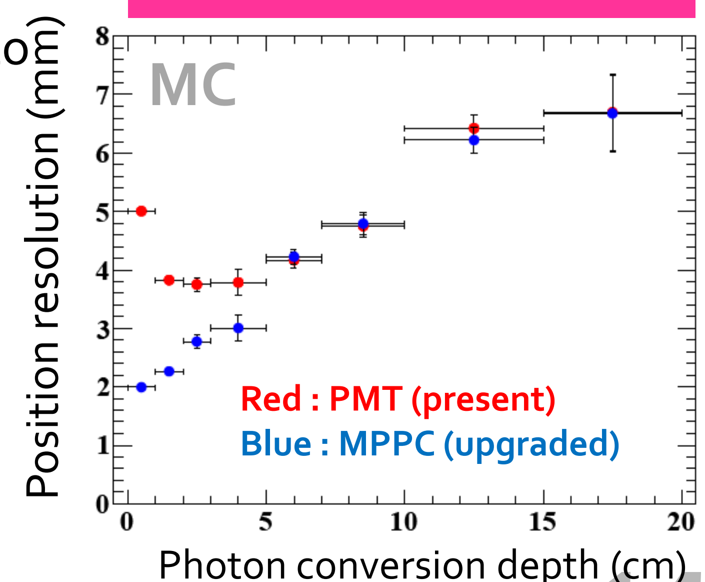


Energy Resolution

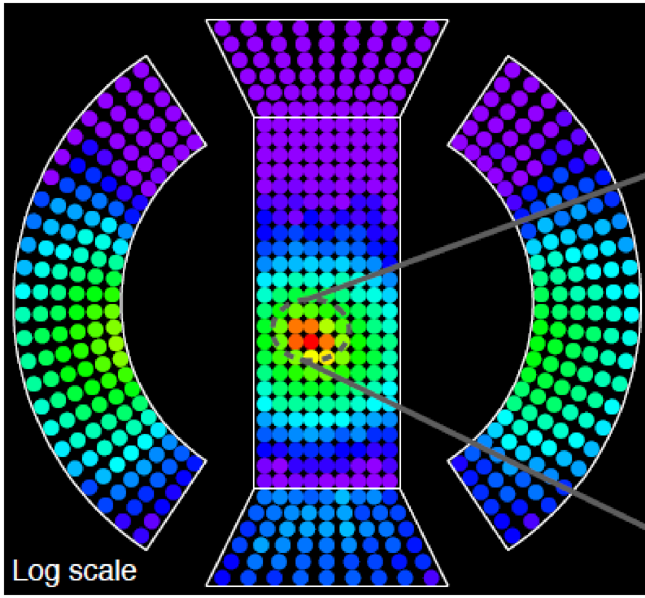


Signal γ-ray spectra, left and right correspond to shallow and deep part respectively.

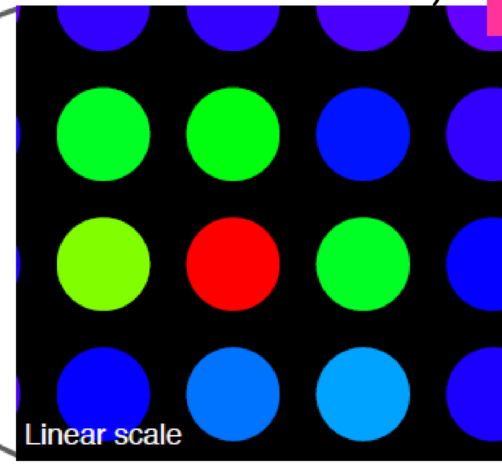
Position Resolution

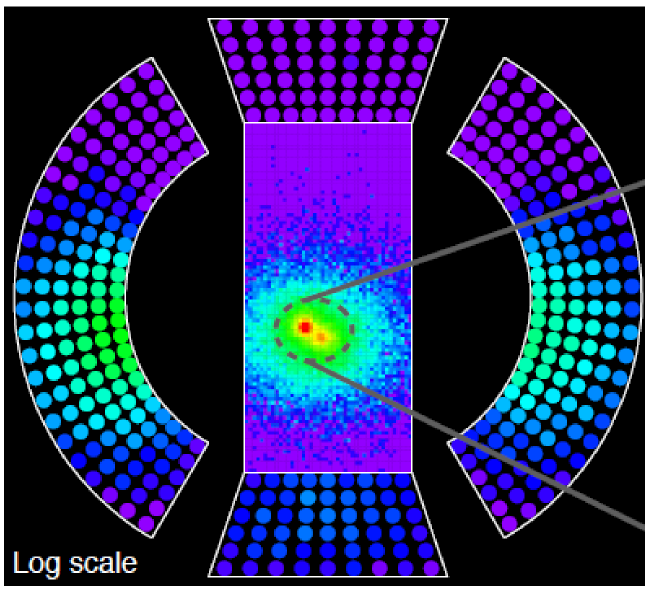


Pileup event
(28 + 25 MeV)

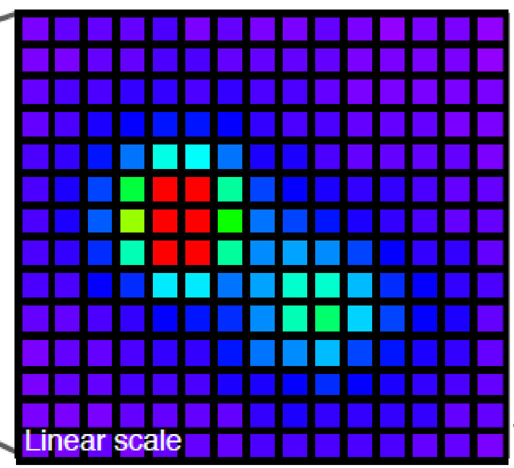


2-inch PMT
(216 ch
on the incident face)





12x12 mm² SiPM
(~4000 ch)



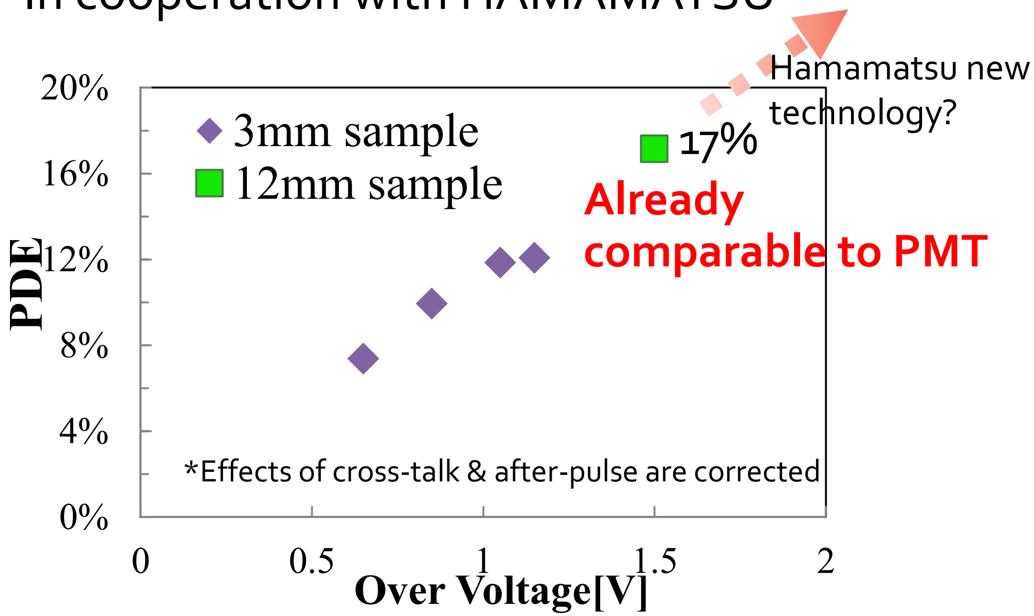
High imaging power
for the shower

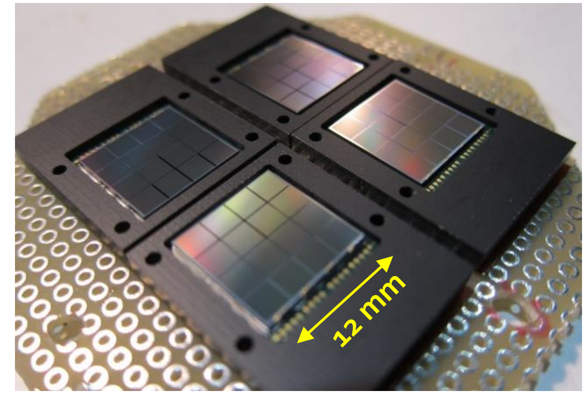
A view with a 'high-resolution camera'

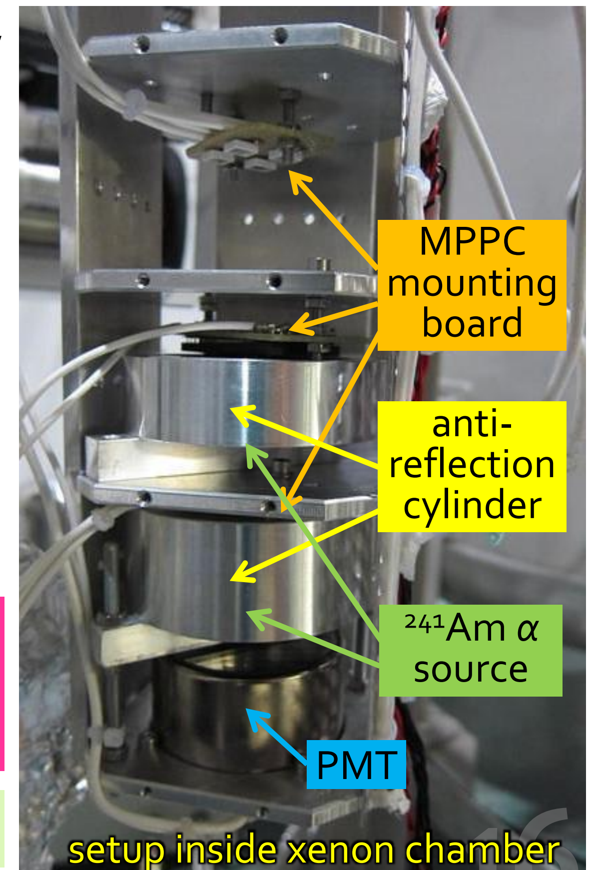
UV-sensitive SiPM

Developing UV-sensitive MPPC

- No commercial SiPMs are sensitive to LXe scintillation light (175 nm)
- In cooperation with HAMAMATSU





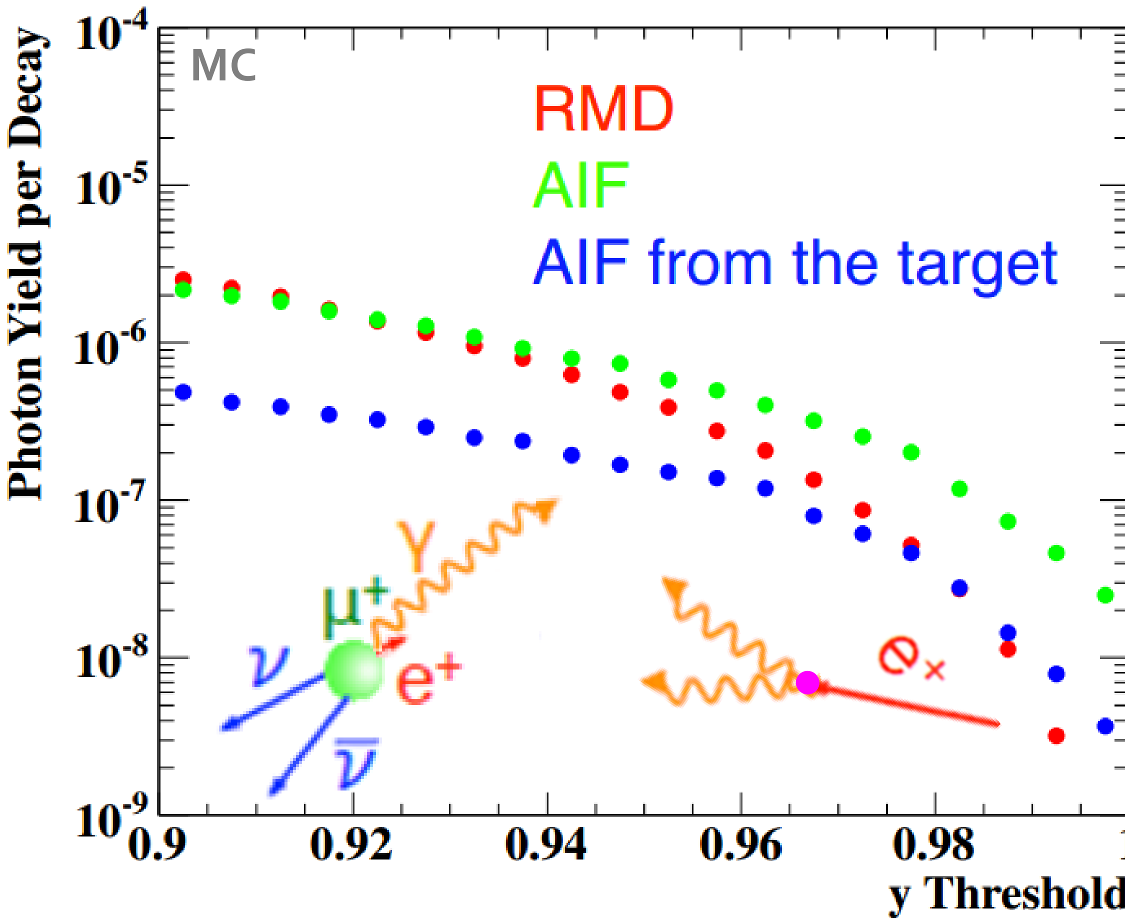


Succeed in the world's largest UV-sensitive SiPM with 1p.e. counting, >15% PDE

Next step: prototype with ~600 sensors, and beam test

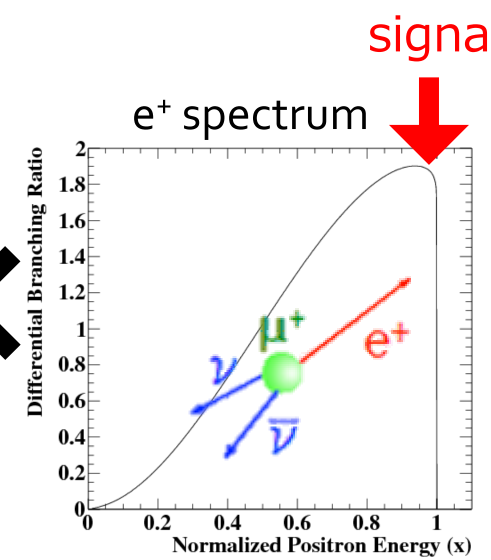
BG source

γ-BG spectrum in present detector



Accidental overlap is the dominant BG source

×



Improving γ-energy resolution can effectively suppress BG.

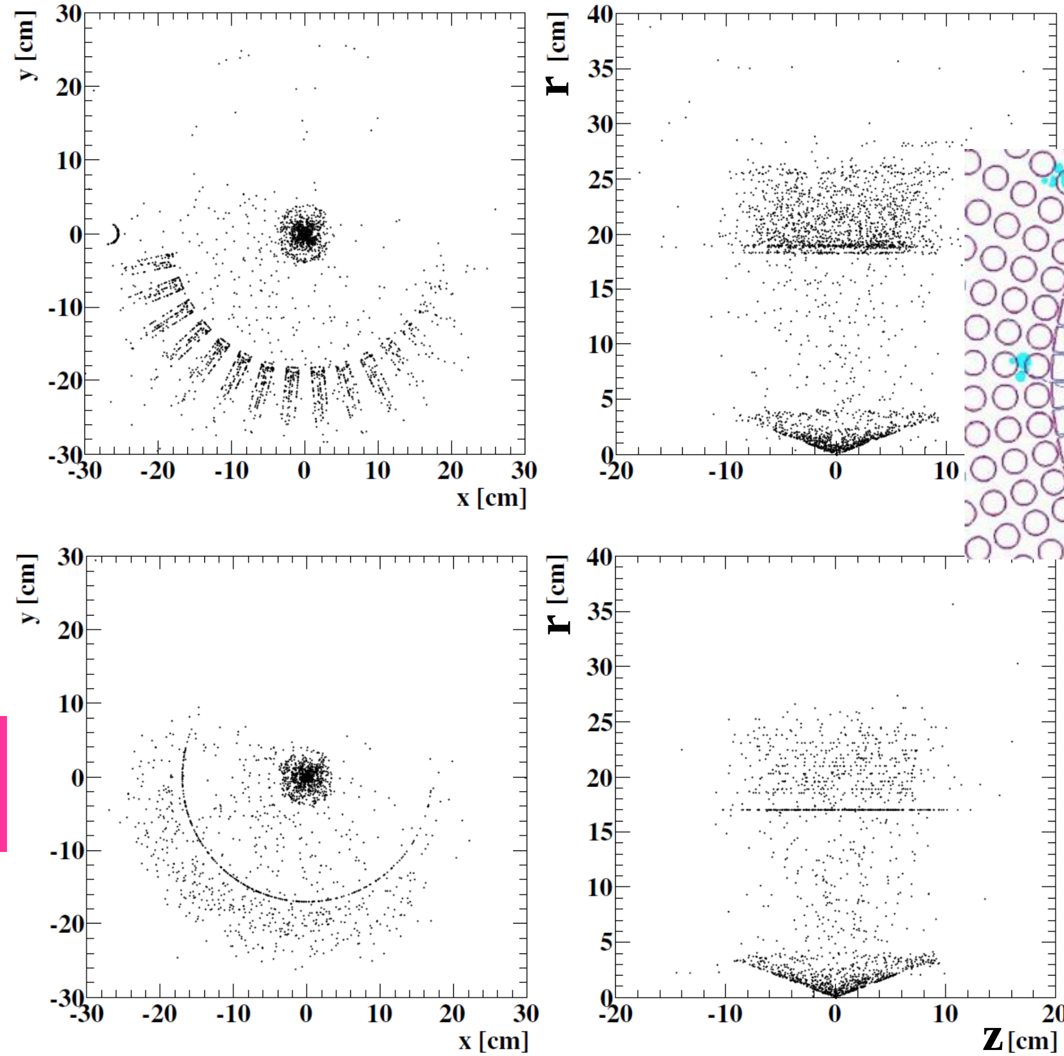
In addition ...

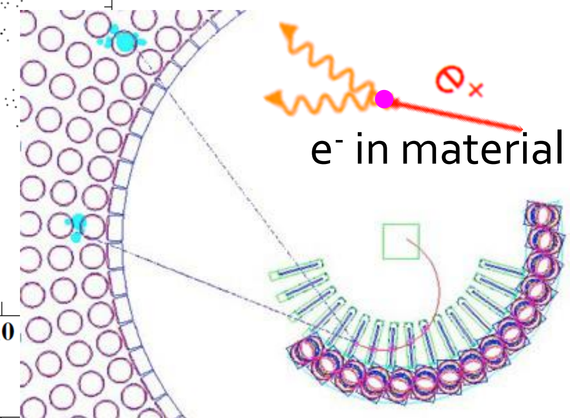
Reduce tracker-origin γ-BG to half!!

Generation point of gamma ray depositing >20 MeV in LXe

Present detector

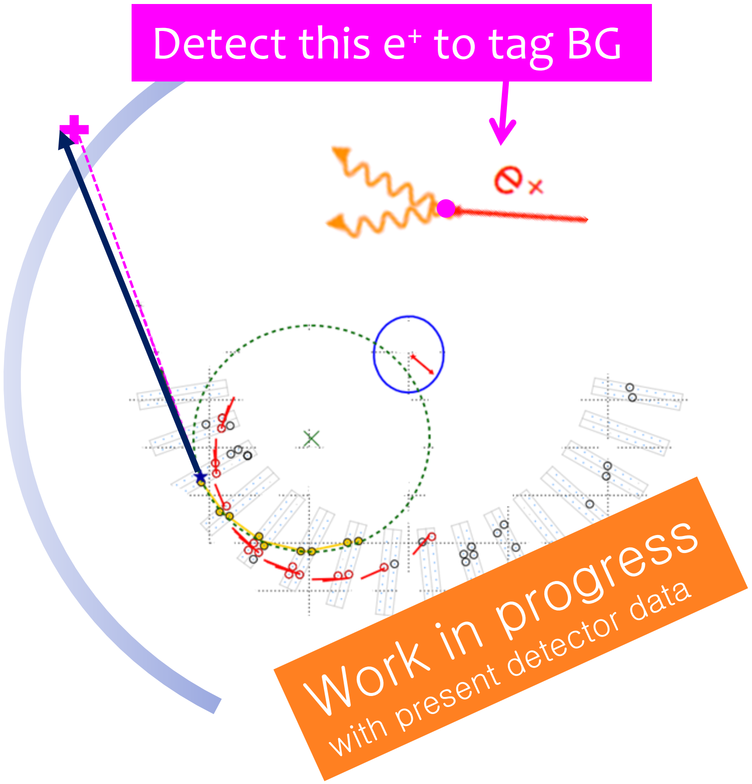
Upgraded detector

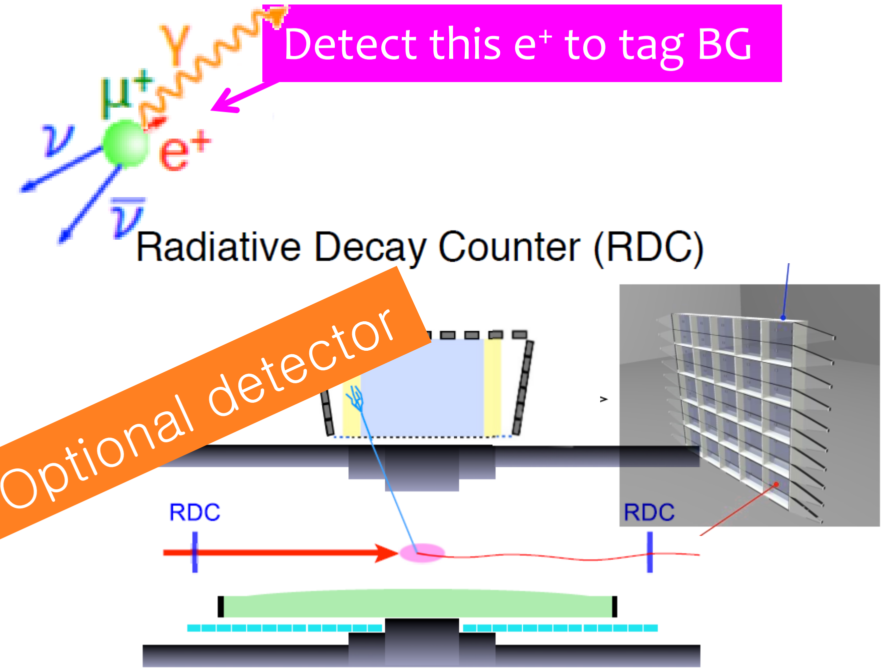




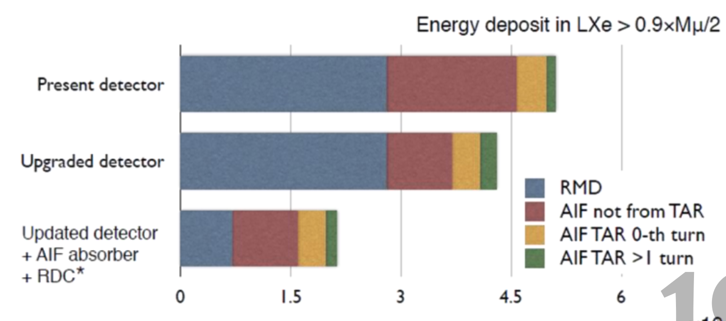
Less material in tracking volume

Further BG suppression





- Two counters at both ends of the detector
- Detect low energy e^+ coinciding with a high energy γ
- Typical e^+ bending radius is smaller than 4-9 cm depending on *z*-position.



Identify AIF-BG by

1. Detect e^+ trajectory before annihilation
2. Test correlation with γ

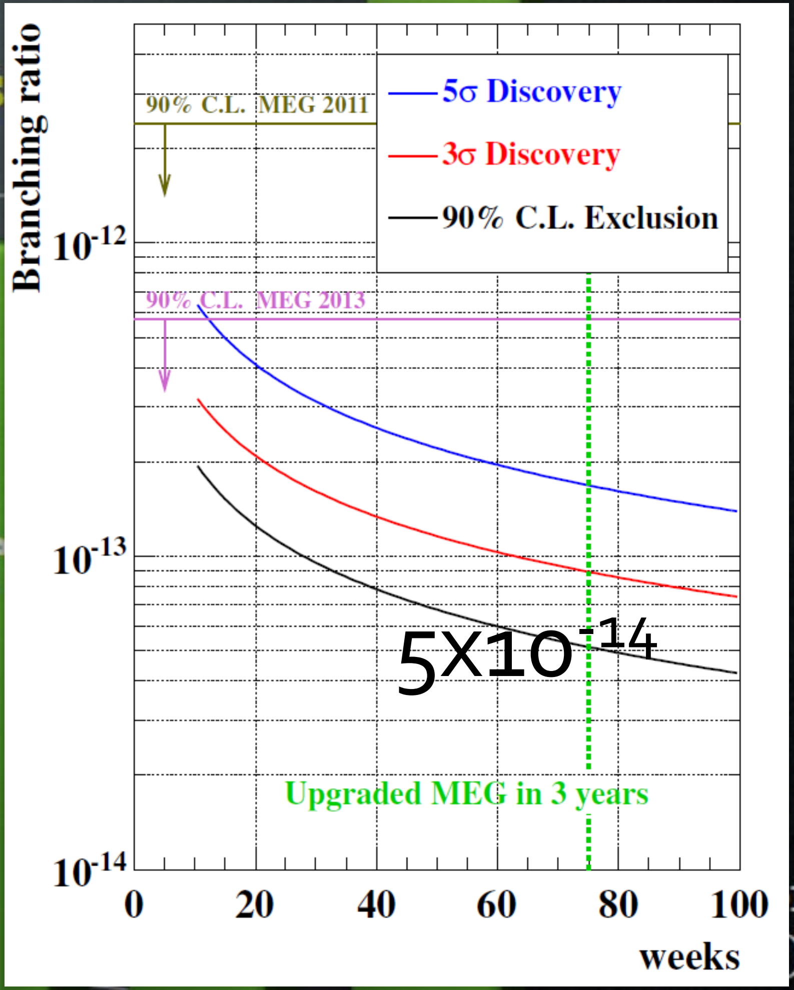
This algorithm will work better with upgraded tracker

Where We Will Be

Where We Will Be

TABLE XI: Resolution (Gaussian σ) and efficiencies for MEG up

PDF parameters	Present MEG	Upgrade sce
e^+ energy (keV)	306 (core)	130
e^+ θ (mrad)	9.4	5.3
e^+ ϕ (mrad)	8.7	3.7
e^+ vertex (mm) Z/Y(core)	2.4 / 1.2	1.6 / 0.7
γ energy (%) (w <2 cm)/(w >2 cm)	2.4 / 1.7	1.1 / 1.0
γ position (mm) $u/v/w$	5 / 5 / 6	2.6 / 2.2 / 5
γ-e^+ timing (ps)	122	84
Efficiency (%)		
trigger	≈ 99	≈ 99
γ	63	69
e^+	40	88
muon rate	3.3×10^7/sec	7×10^7/sec



Halve every resolution,
Double efficiency & intensity

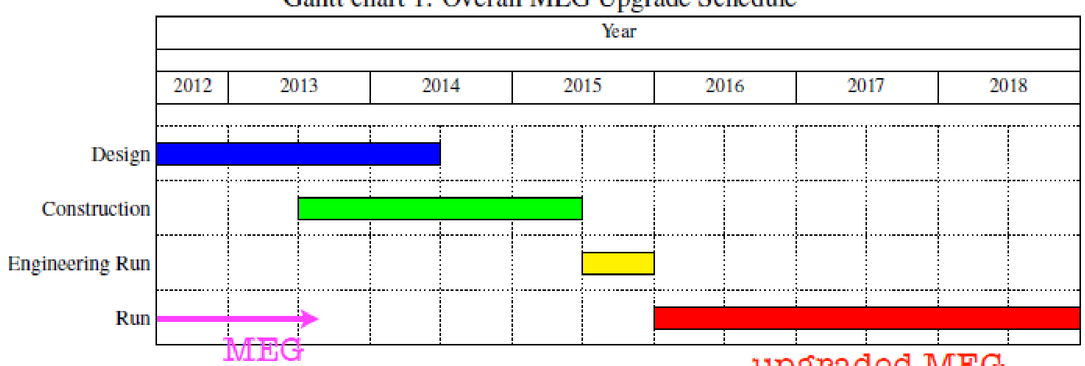
MEG upgrade status

- **Submitted proposal to PSI at the end of 2012** (http://arxiv.org/abs/arXiv:1301.7225)
- **Approved by PSI committee Jan. 2013**

> will ensure that PSI keeps its world leadership in the study of this process. The Committee approves the upgrade proposal and expects that, after the upgrade is successfully completed, MEG will be given the highest priority in πE5.

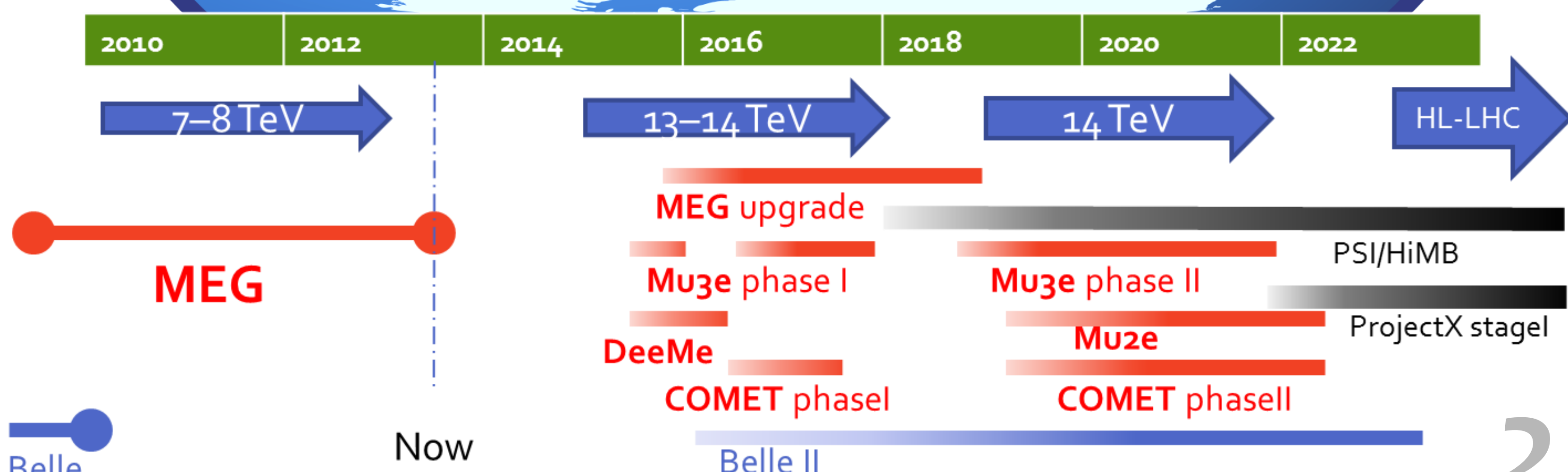
- **R&D and optimization have been intensively progressing since 2011**

Gantt chart 1: Overall MEG Upgrade Schedule

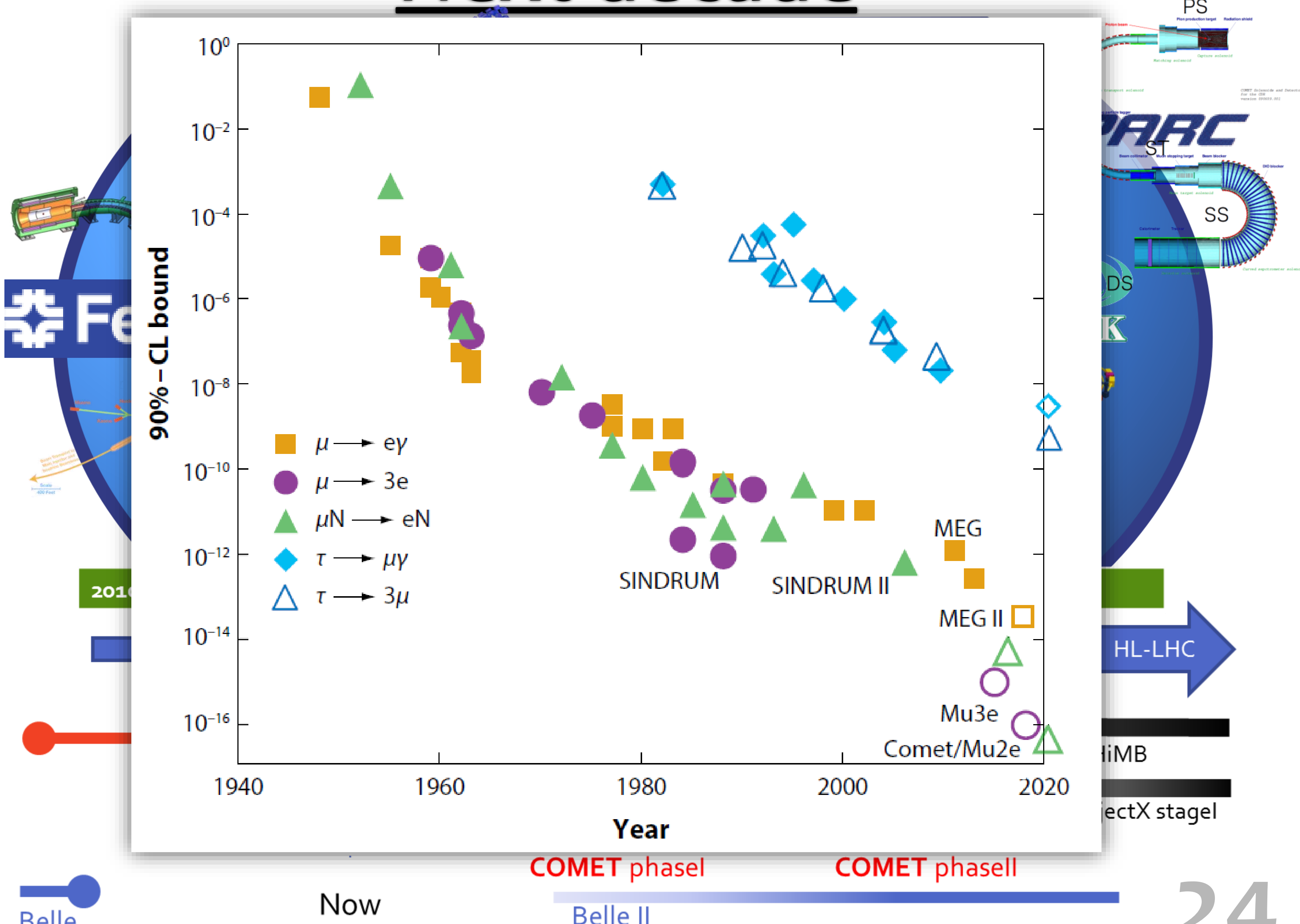


Next decade


PS
SS
DS
J-PARC
Electron Spectrometer
Tracker
Hodoscope
Secondary Beamline
Pulsed Proton
SiC Primary Target
KEK
SuperKEKB
PAUL SCHERRER INSTITUT
PSI
Fermilab
Mu2e
Project X
LHCb
CERN


2010
2012
2014
2016
2018
2020
2022
7–8 TeV
13–14 TeV
14 TeV
HL-LHC
MEG
MEG upgrade
PSI/HiMB
Mu3e phase I
Mu3e phase II
ProjectX stageI
DeeMe
Mu2e
COMET phaseI
COMET phaseII
Belle
Now
Belle II

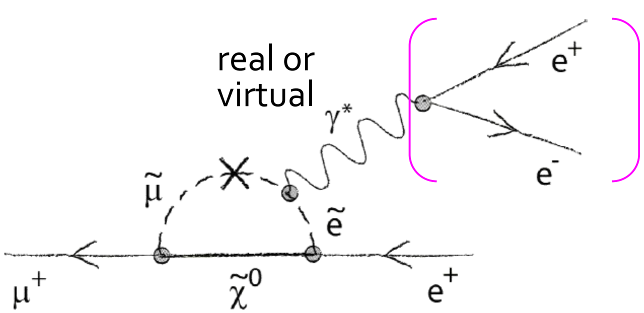
Next decade

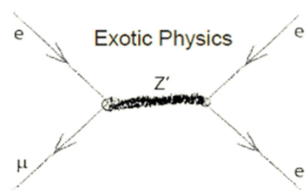


PS
SS
DS
ST
90% – CL bound
Year
1940
1960
1980
2000
2020
μ → eγ
μ → 3e
μN → eN
τ → μγ
τ → 3μ
SINDRUM
SINDRUM II
MEG
MEG II
Mu3e
Comet/Mu2e
HL-LHC
COMET phaseI
COMET phaseII
Now
Belle
Belle II

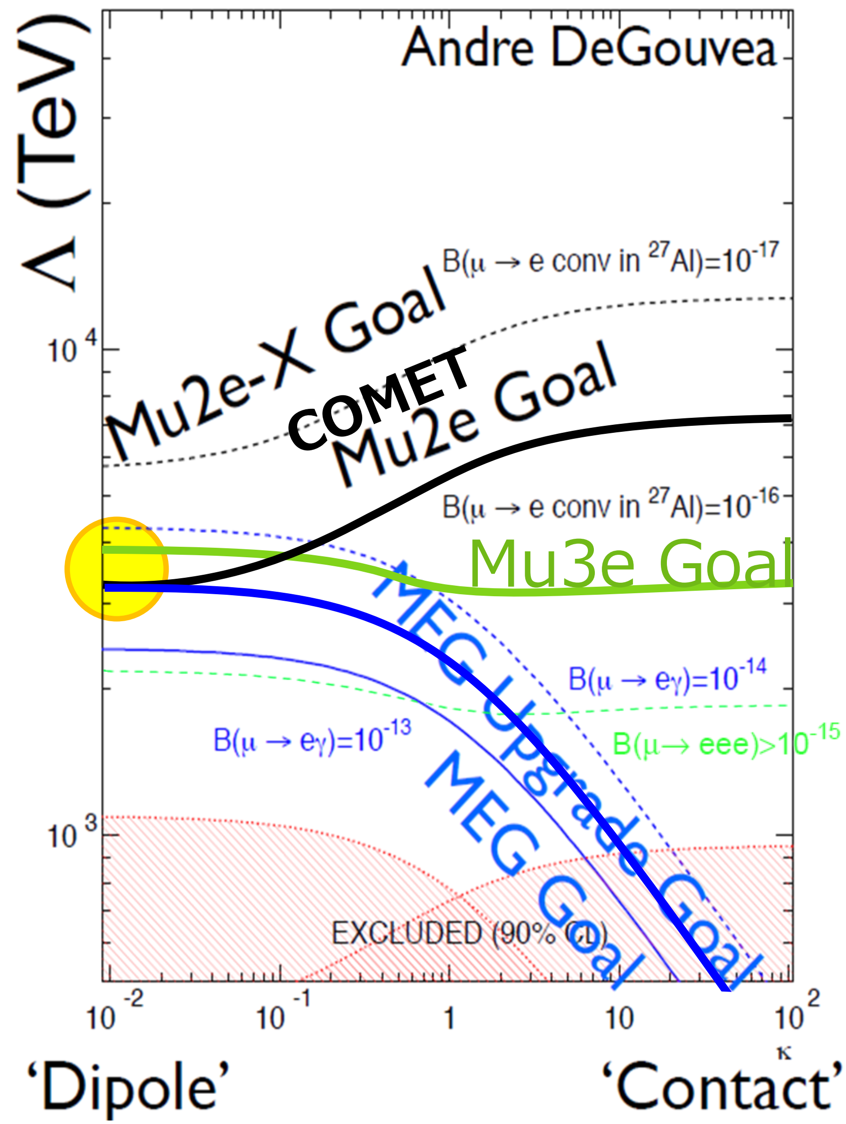
Synergy in physics

- For 'dipole-type', like SUSY, μ→eγ has O(α) higher sensitivity
  - MEG upgrade is competitive to next generation experiments
- Sensitivity to wide physics by μ→eee & μ-e conversion
- Once we find one of them, the other measurements provide discrimination of physics models.





Model independent analysis

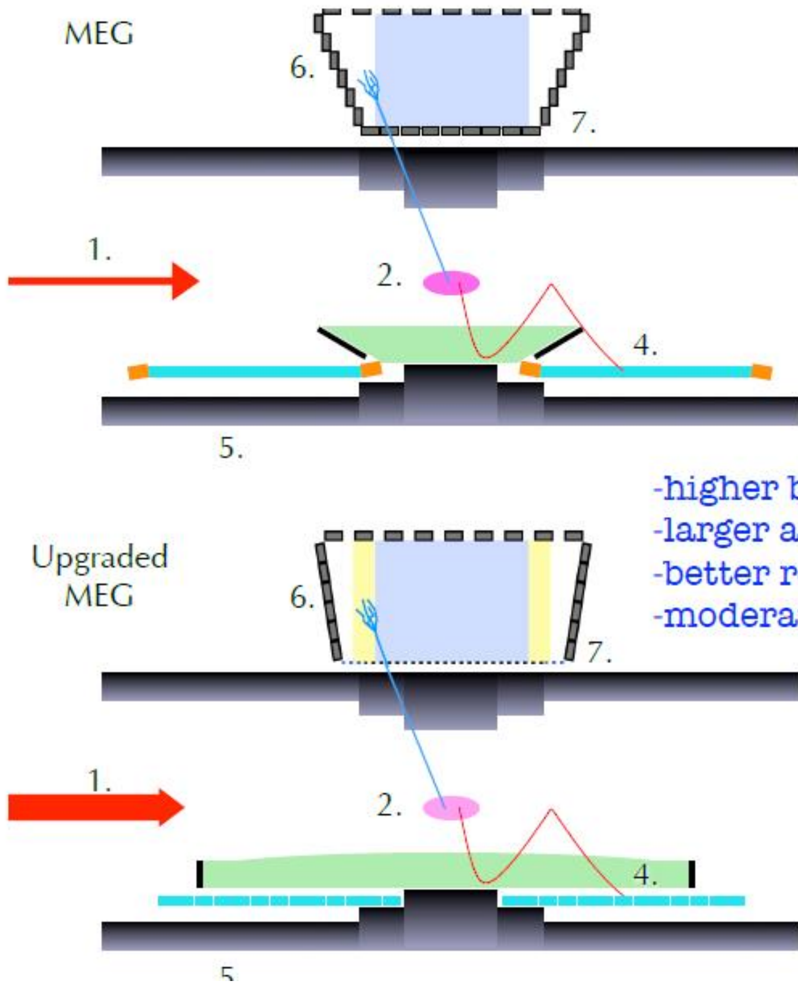


Conclusion

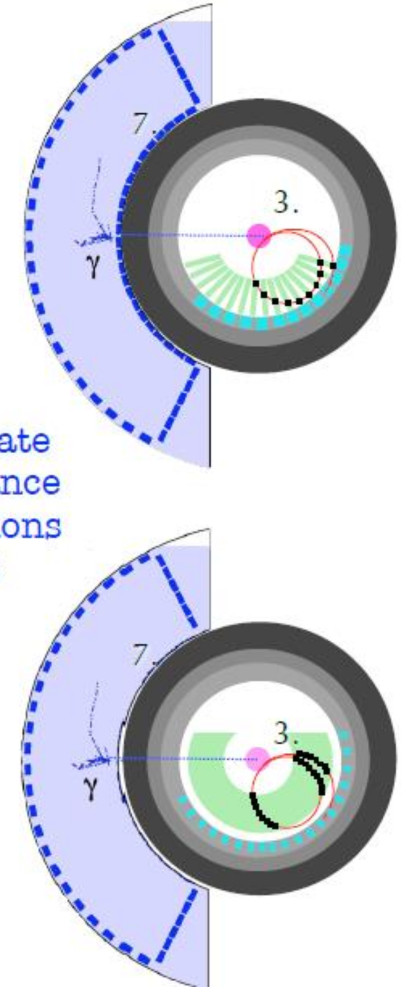
MEG upgrade	**We plan an upgrade of MEG** ☐ One order of magnitude improve ☐ Complement to 14 TeV LHC Target sensitivity: $\mathcal{B}(\mu\rightarrow e\gamma) < 5\times10^{-14}$ @90%CL
	☐ Higher beam intensity (max. available to date) ☐ Major modification of detectors
Now	**Intensive R&D is on-going** ☐ To start physics run in 2016
Future LFV	**Next decade, rich in LFV experimental programs** ☐ Preparation period for a few years ☐ New insights into physics will be brought in 5 years ☐ MEG keeps leading experiment in this field for the next ~5 years, followed by wider experiments Listen "Charged lepton flavor and dipole moments" by Prof. Klaus Kirch, 24/July

The MEG upgrade

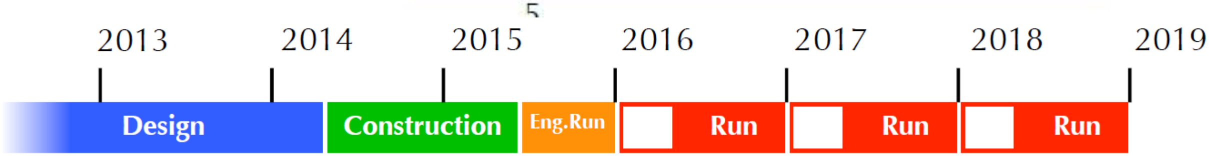
Overview



upgrade design based on our long time experience



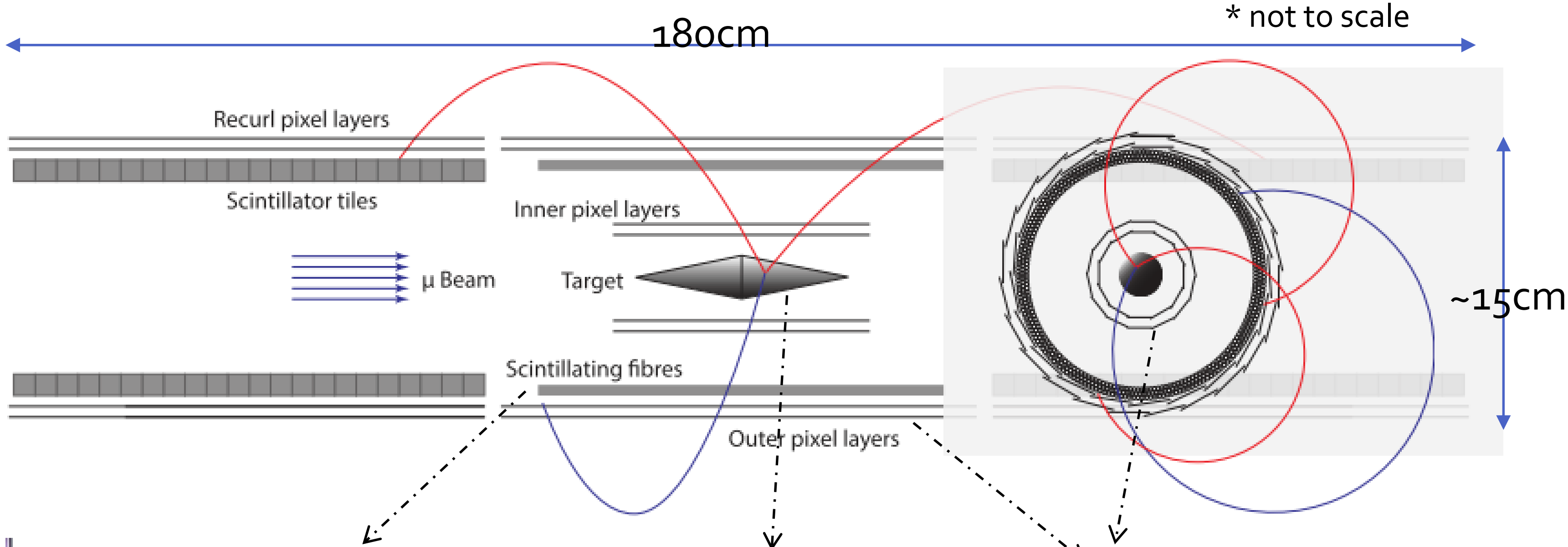
- higher beam rate
- larger acceptance
- better resolutions
- moderate cost

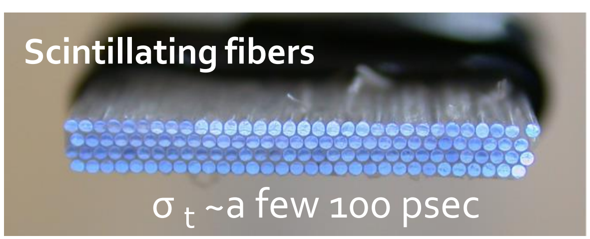


MEG Upgrade Proposal
(http://arxiv.org/abs/arXiv:1301.7225)

Mu3e experiment

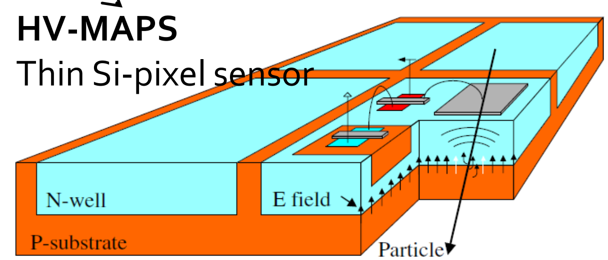
Stand with new technologies





Double-cone shape target
Large surface area to disperse decay vertices

HV-MAPS
Thin Si-pixel sensor



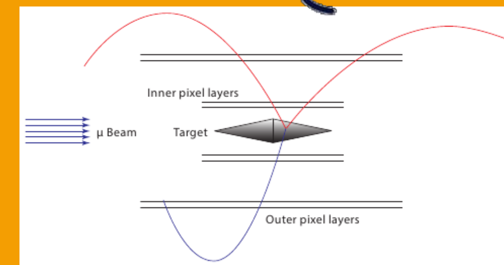
- Geometrical acceptance ~70%

Staging approach

Phase IA — 2015

Early realization with central Si

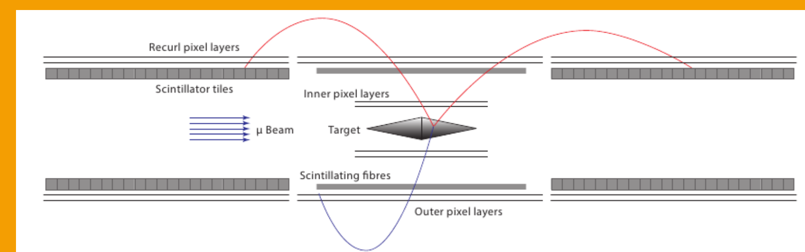
- ≦$10^7 \mu/s$ @πE5
- Experience for the new tech. Verify principal
- O(10^{-14})



Phase IB — 2016~

Introduce 1st side-station & ToF

- ~$10^8 \mu/s$ max. @πE5
- O(10^{-15})
  - ✓ Limited by statistics

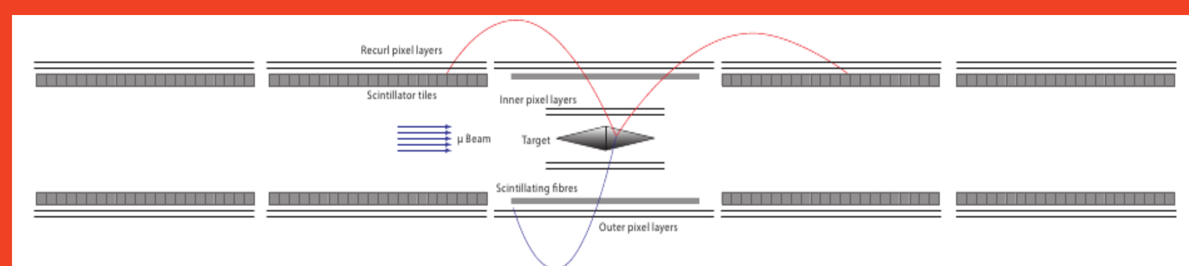


Phase II — Later than 2017

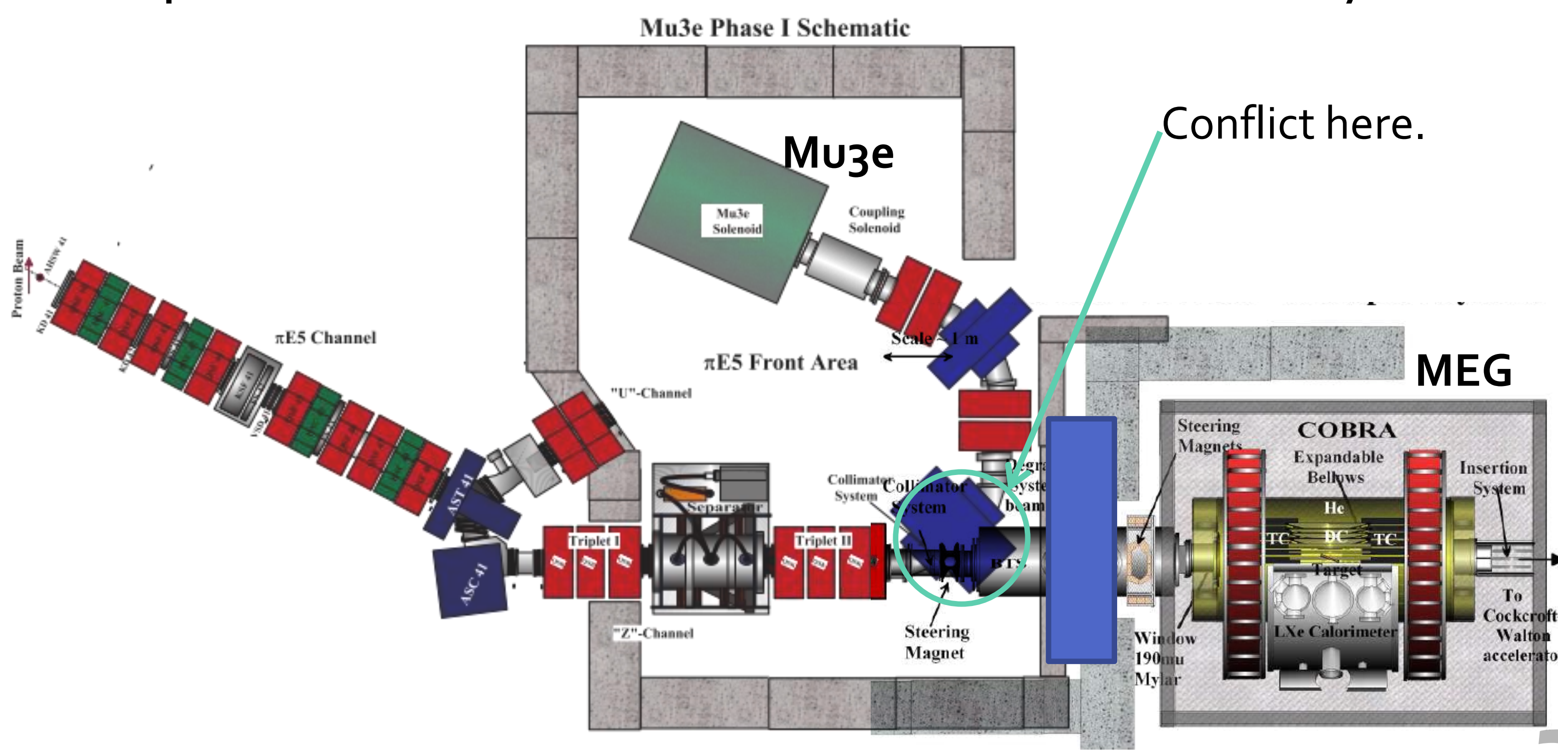
Full configuration

- **~$2\times10^9 \mu/s$ @new beamline**
- Goal

  O(10^{-16})



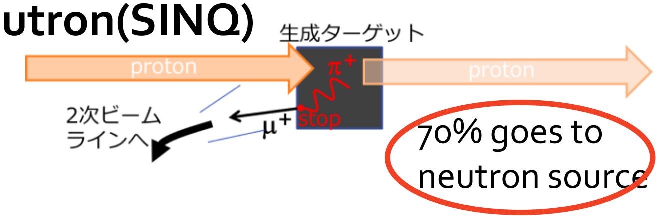
- **Share πE5 area**
- **to prepare experiments in parallel.**
- **Share the upstream elements in the beamline**
- **Switch beam**
  - Not possible to share the beam simultaneously



HiMB@PSI

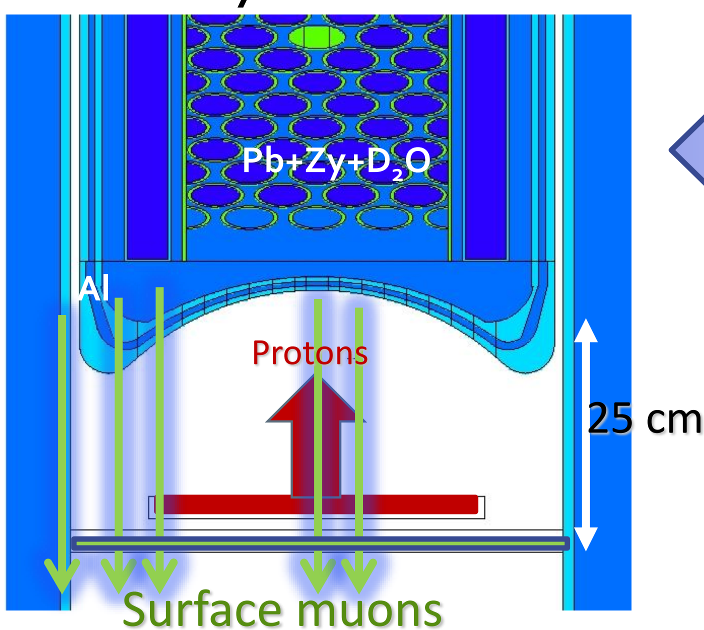
PAUL SCHERRER INSTITUT

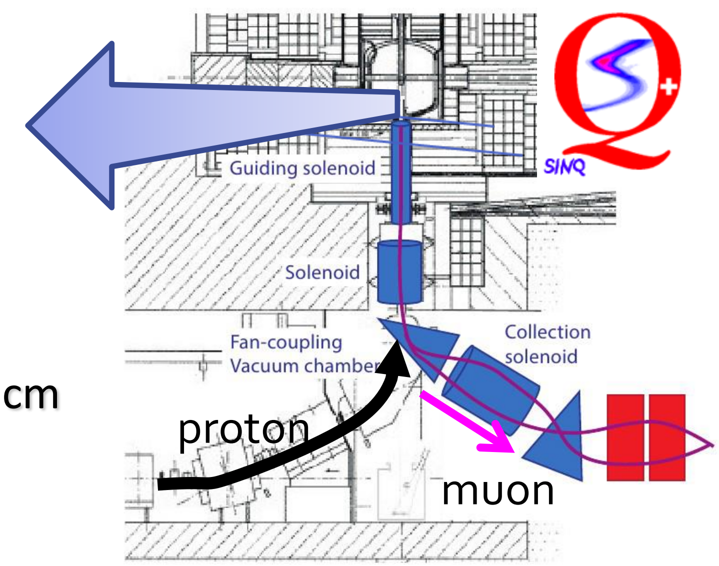
- **PSI next generation High intensity Muon Beam project**
- **Extract surface muon generated at the Spallation neutron(SINQ) target window**
  - High power proton (70% of primary beam stops here)
  - Large pion momentum range(<150MeV)
  - Huge volume (×9000)
  - Largecross-section



- **~3×10^{10} surface μ$^+$/sec (estimated)**
- **Started serious study this year**
  - Investigate the feasibility by next year
- **Construct 2016–2017 in time with the SINQ stop**

Sufficient for Mu3e phase II
Search for other usages

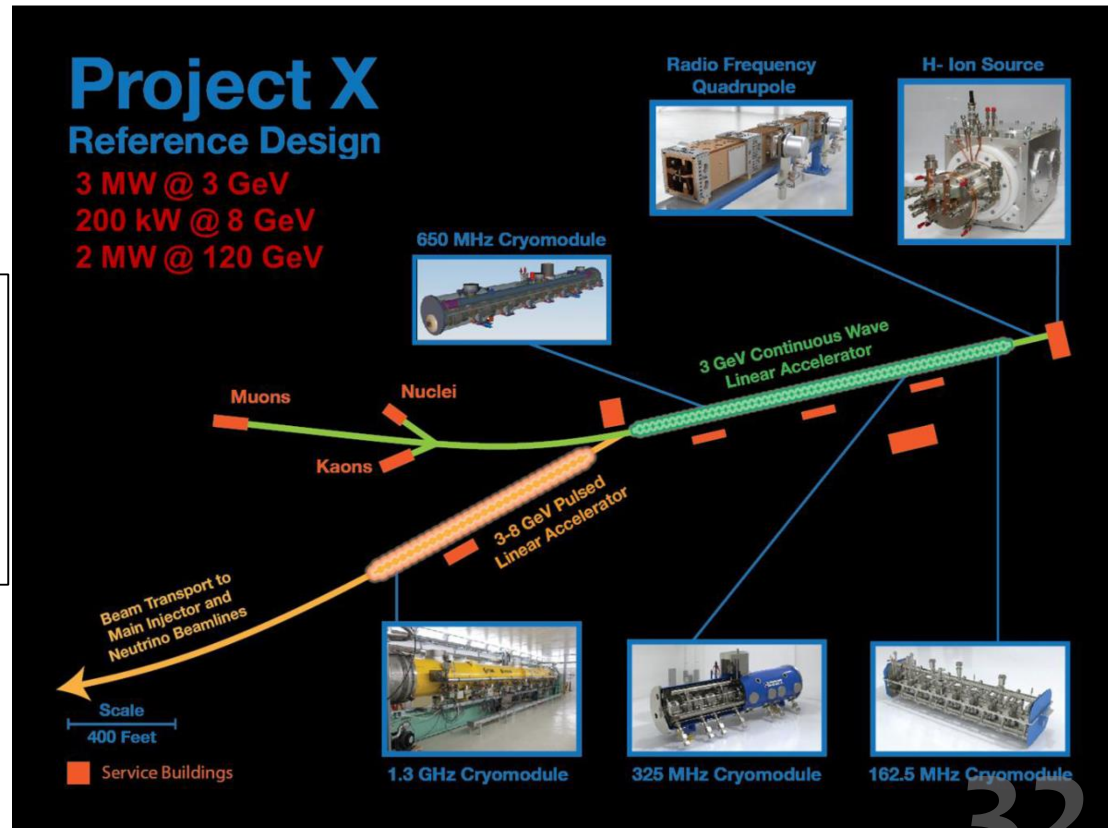




Fermilab

Project X

- **Next generation MW proton accelerator facility**
  @Fermilab
  - 3MW@3GeV, continuous wave linac
  - Able to flexibly tune the pulse structure (1–160MHz)
    - Pulse mode → μ–e conversion
    - High freq mode → new μ→eγ,eee



Towards Snowmass 2013, reviewing physics programs possible at PX, including next generation μ→eγ,eee

At earliest, start construction from 2017 for 5 years

Table 3.8: List of the top-ten important flavour-changing measurements chosen by G. Isidori, with wished for sensitivity (not listed in order of importance); SES stands for single-event sensitivity, and σ is the uncertainty.

Process	Sensitivity
$B(\mu \to e\gamma)$	SES$< 10^{-13}$
$B(\mu N \to eN)$	SES$< 10^{-16}$
$B(\tau \to \mu\gamma)$	SES $< 10^{-9}$
$B(B_s \to \mu^+\mu^-)$	$\sigma_{\rm rel} < 5$ %
ϕ_s	$\sigma < 0.01$
$B(K \to \pi\nu\overline{\nu})$ $(K^+\&K_{\rm L})$	$\sigma_{\rm rel} < 5$ %
$B(B^+ \to \ell\nu)$	$\sigma_{\rm rel} < 5$ %
$a_{\rm CP}(D \to \pi\pi\gamma)$	$\sigma < 0.005$
$\|V_{ub}\|$	$\sigma_{\rm rel} < 5$ %
CKM angle γ	$\sigma < 1°$

From Physics Briefing Book