MEG実験の全データを用いた μ → e γ 探索

The analysis of μ → e γ search in MEG experiment with all statistics

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$\mu^+ \to e^+ + \gamma$ search in MEG experiment

$\mu^+ \to e^+ + \gamma$

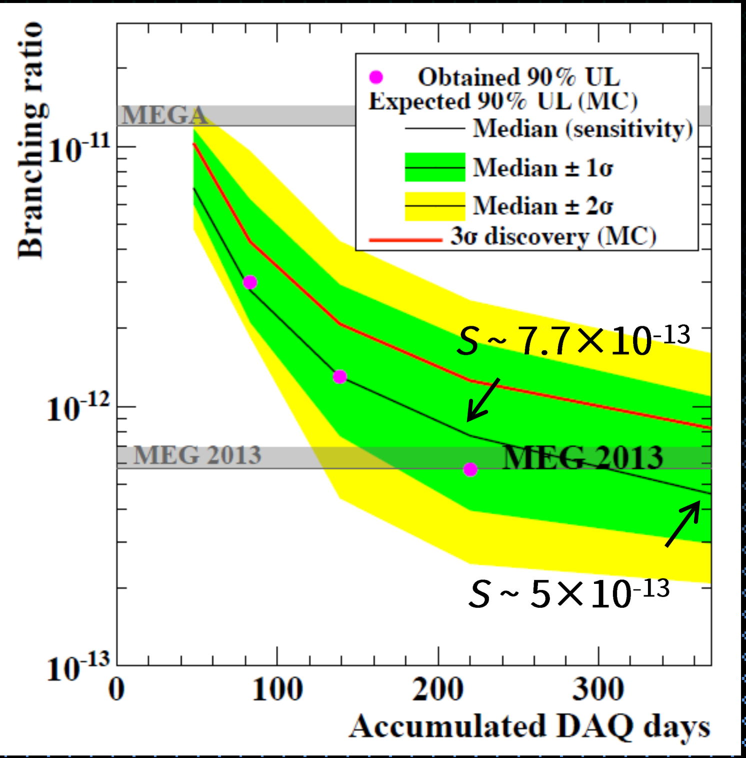
Forbidden decay in the Standard Model
Extremely low probability even with ν oscillation

Well motivated new theories (SUSY etc.) predict sizable probability ($10^{-12} \sim 10^{-14}$).

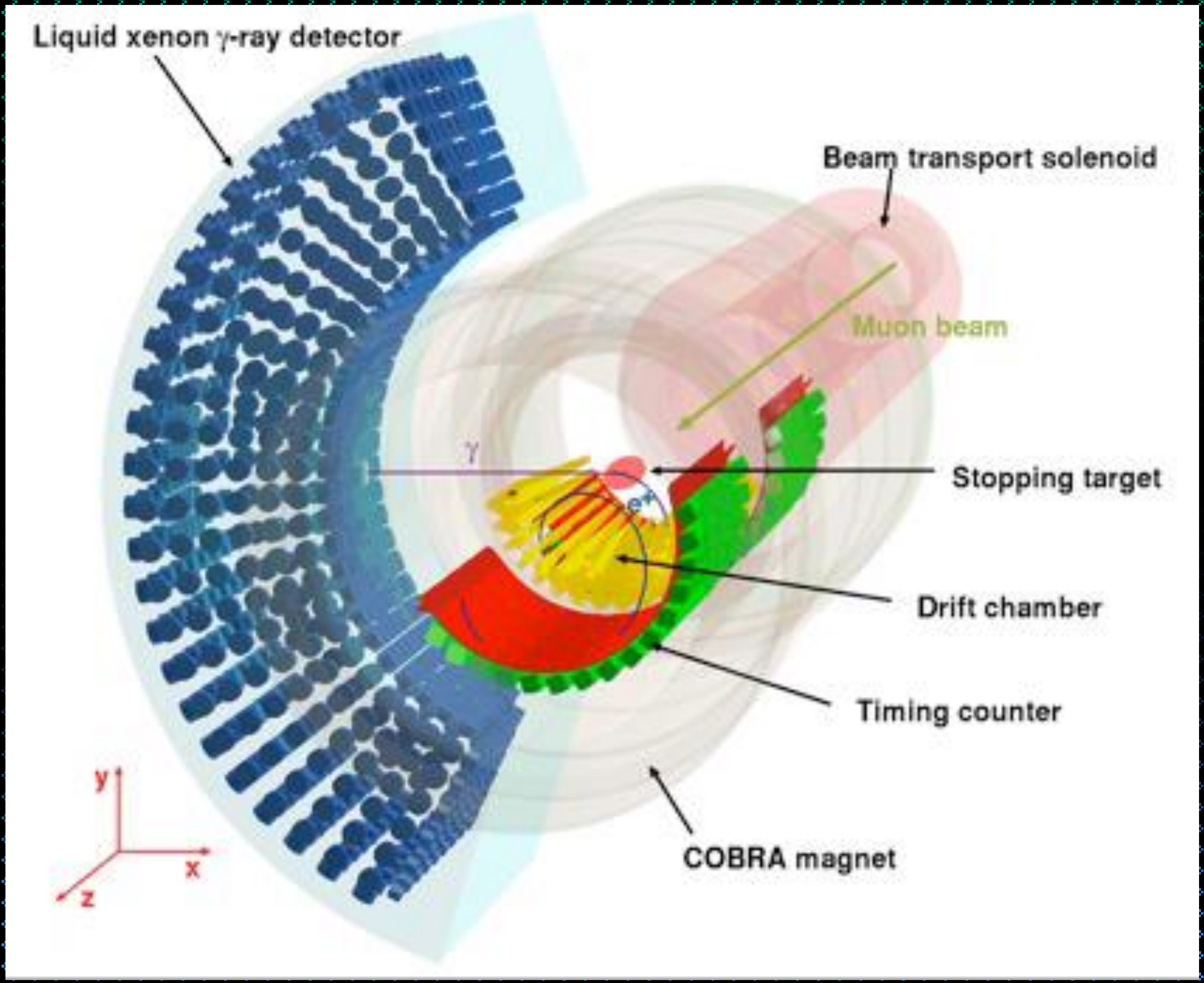
Latest result
Phys. Rev. Lett. 110, 201801 (2013)

2009 – 2011 data
$B(\mu^+ \to e^+ + \gamma) < 5.7\times10^{-13}$ (90%CL)

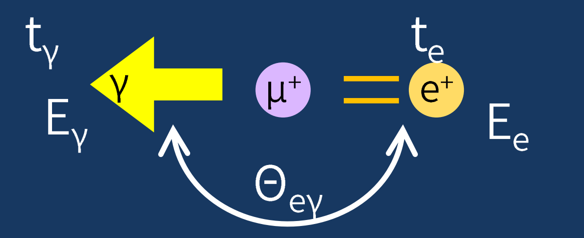
We finished data taking 2013, and analyze all data in this study with doubled amount of statistics.



MEG experiment

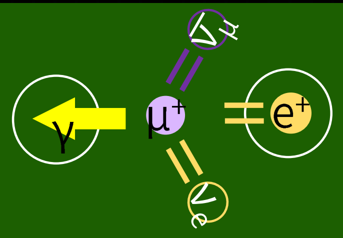


Signal Event

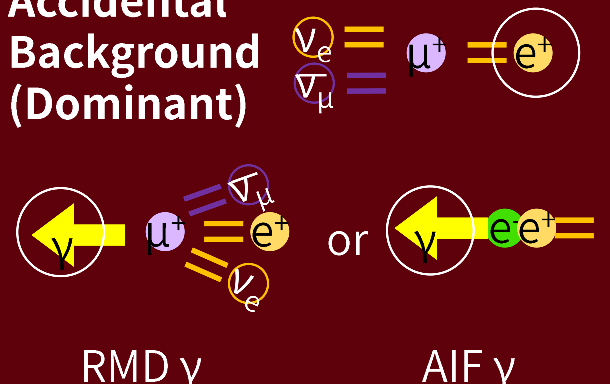


$$E_\gamma = E_e = m_\mu / 2$$
$$t_\gamma = t_e \,,\ \Theta_{e\gamma} = \pi$$

Radiative Muon Decay



Accidental Background (Dominant)



Status of physics analysis

It is taking longer time than expectation

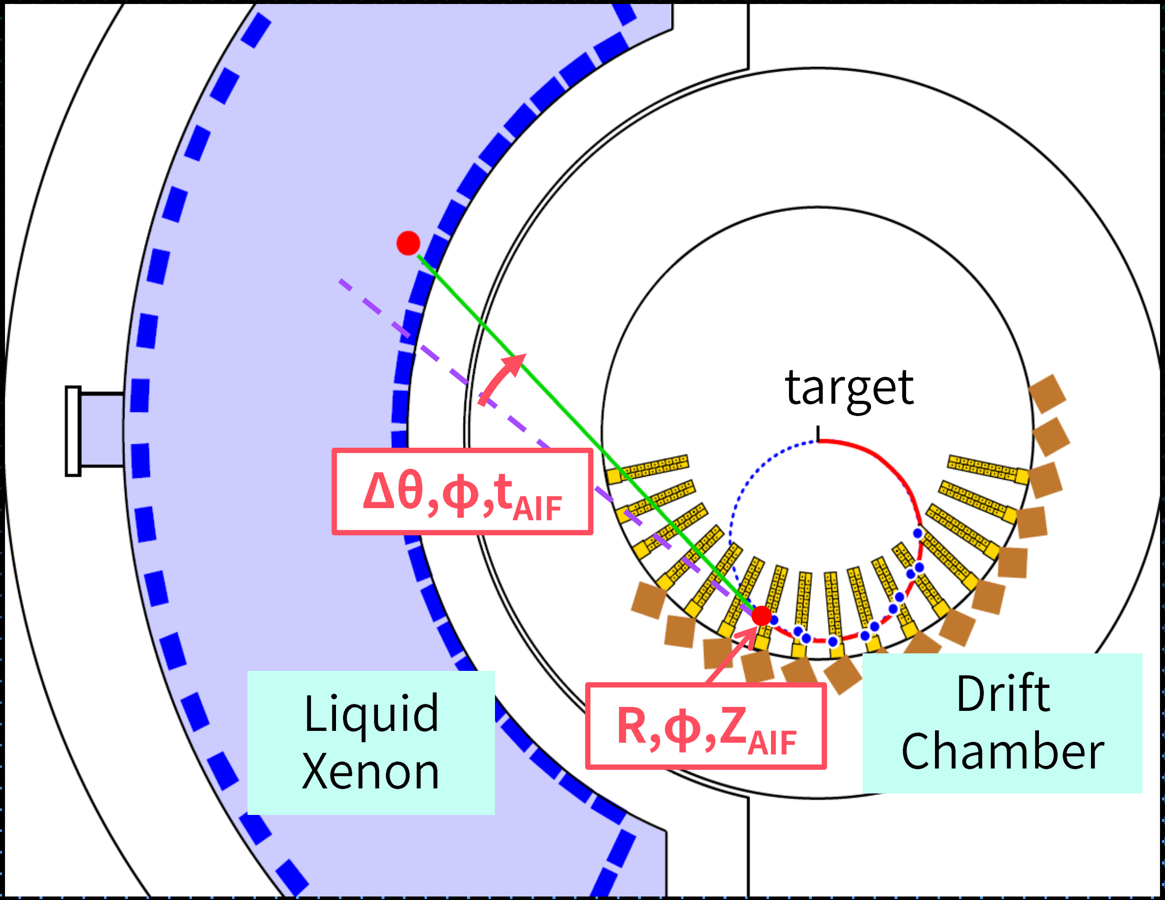
- Refinement of improved analysis
  - e^+ annihilation in flight
  - Missing turn identification

- Target alignment issue
  μ^+ stopping target turned out to be slightly deformed

Strategy is decided.

BG event by Annihilation in Flight (AIF)

Accidental coincidence of γ from AIF and e^+ from normal μ^+ decay. About 1/3 of all γ are from AIF which have possibility to detect by our tracker. The fraction of AIF γ is higher than RMD γ near signal region.



AIF Observables

$\Delta\theta_{AIF}$, $\Delta\phi_{AIF}$, Δt_{AIF} :
Comparison of e^+ & γ

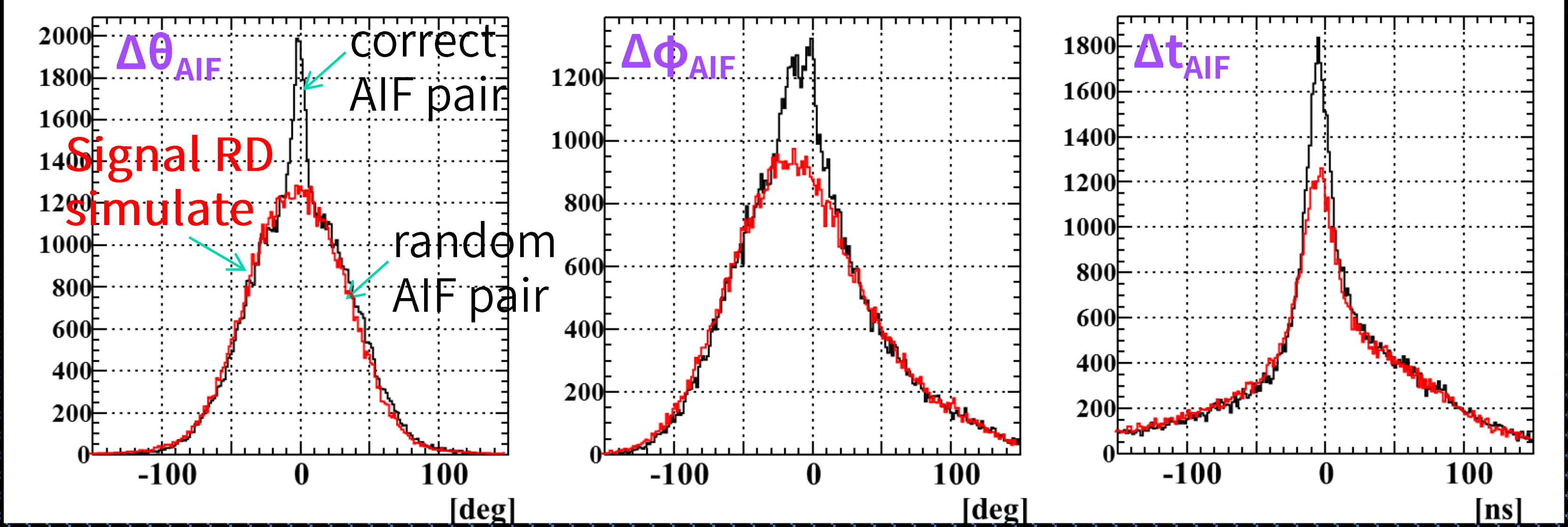
R_{AIF}, Z_{AIF}, ϕ_{AIF} :
Where AIF occurred

Inclusion of AIF observables

$$\mathcal{L}(N_{sig}, N_{RD}, N_{BG}) = \frac{e^{-N}}{N_{obs}!} e^{-\frac{(N_{RD}-\langle N_{RD}\rangle)^2}{2\sigma_{RD}^2}} e^{-\frac{(N_{BG}-\langle N_{BG}\rangle)^2}{2\sigma_{BG}^2}} \times \text{ PDFs for AIF observables}$$

$$\prod_{i=1}^{N_{obs}} (N_{sig} S(\vec{x_i}) S_{AIF}(\vec{y_i}) + N_{RD} R(\vec{x_i}) R_{AIF}(\vec{y_i}) + N_{BG} B(\vec{x_i}) B_{AIF}(\vec{y_i}))$$

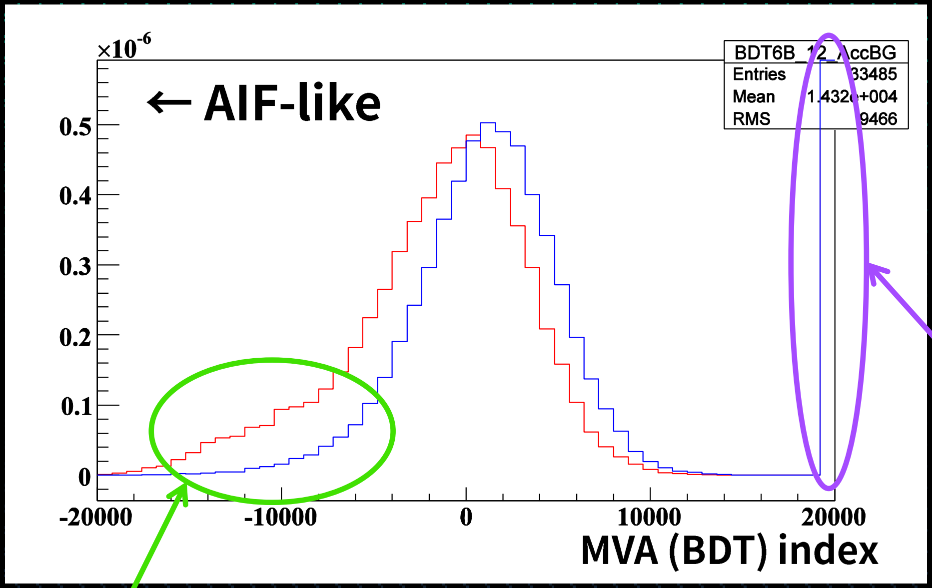
B_{AIF} : Use sideband data directly



S_{AIF}, R_{AIF} : Only “wrong AIF pair”, but pure data cannot be obtained.
How to make ? → Simulate by shuffling γ and e^+ combination

Multi-Variate Analysis (MVA)

AIF observables are implemented to the likelihood function via MVA.



Red : B_{AIF}

Blue : S_{AIF} & R_{AIF}

No-AIF-events are stored in the exceptional bin

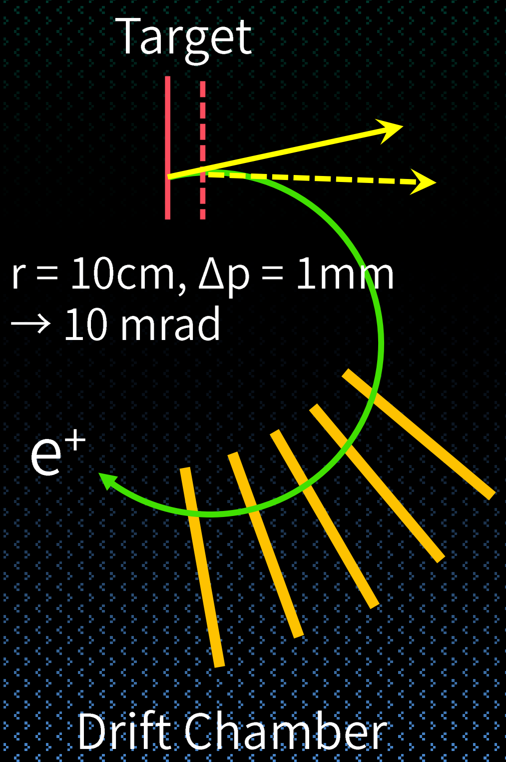
Correct AIF pair

Expected improvement in sensitivity is 5 – 10%.

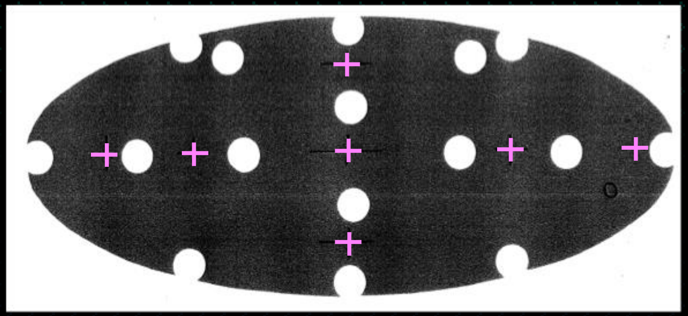
Target alignment

We get initial e+ information by extrapolating track to target

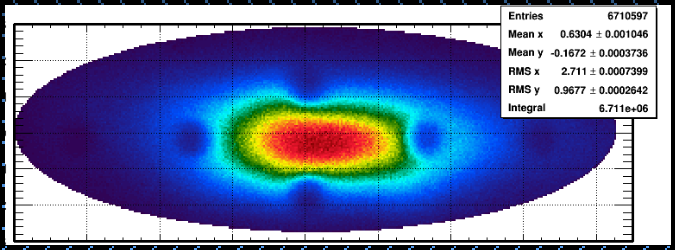
→ The relative position of target and tracker is very important



MEG muon stopping target



Alignment is done by
Target hole : by positron track data
Cross mark : by theodolite survey

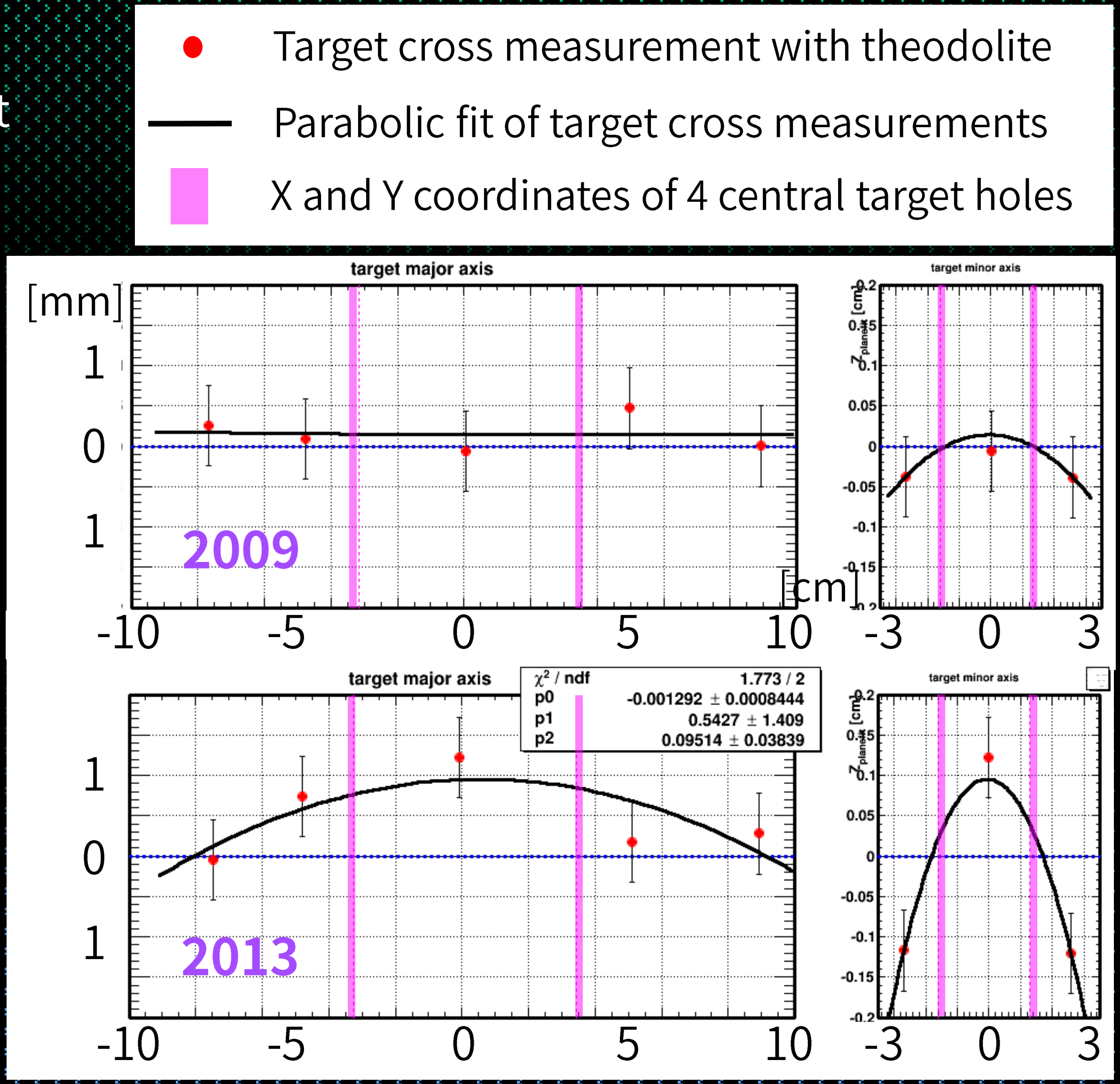


Hit distribution

Target bowing

In 2012 and 2013 data, target found to be deformed.
In 2009 and 2010 it was consistent with flat. In 2011, deformation was small.

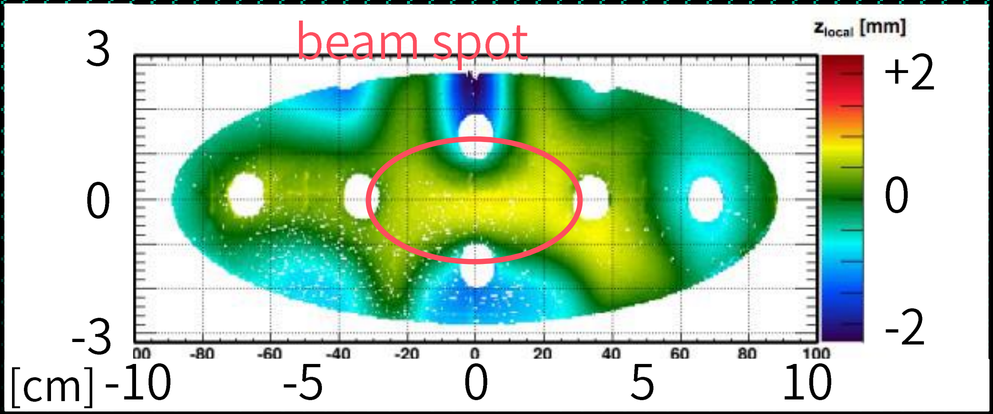
Survey by theodolite and hole analysis are in good agreement.



Countermeasure to target issue

We measured the target with 3D scanner in 2014 (after DAQ finished)

Result is basically consistent with survey, but found to be more complex shape.



Target shift and bowing is corrected

$$\Delta\phi_{e\gamma} = \phi_{e\gamma}^{\mathrm{raw}} + \Delta_{p0}\phi_{e\gamma} + \Delta_{\mathrm{para}}\phi_{e\gamma}$$

We introduced two new nuisance parameters, and profile with the parameters.

$$\mu_{\phi} = \Delta_{p}\phi_{e\gamma} + \left(\Delta_{\mathrm{3D}}\phi_{e\gamma} - \Delta_{\mathrm{para}}\phi_{e\gamma}\right) \cdot s$$

$$\mu_{\theta} = \Delta_{p}\theta_{e\gamma} + \left(\Delta_{\mathrm{3D}}\theta_{e\gamma} - \Delta_{\mathrm{para}}\theta_{e\gamma}\right) \cdot s$$

Expected deterioration of sensitivity by target issue is a few percents.

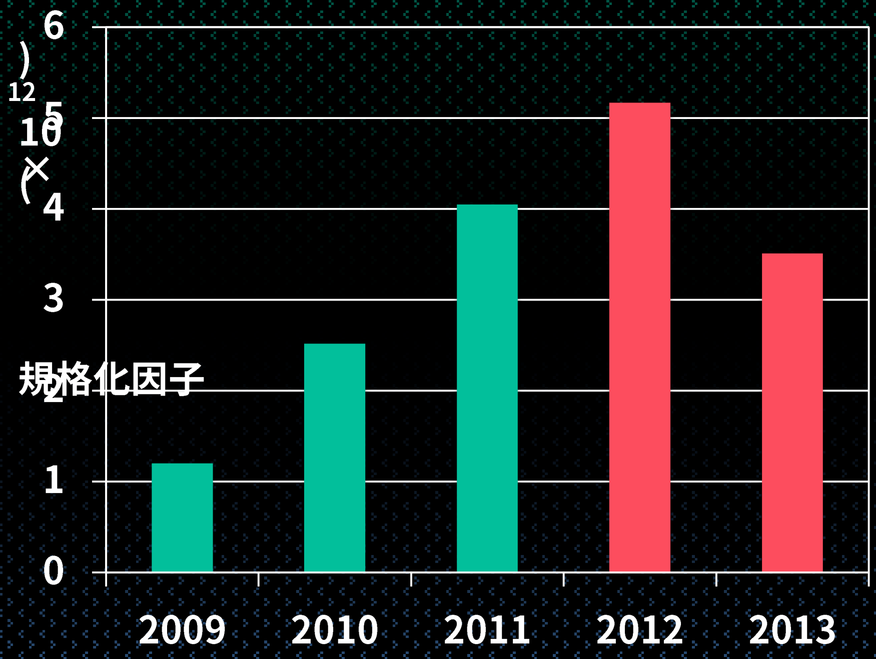
Summary

We are analyzing data for final physics result with all data amount.

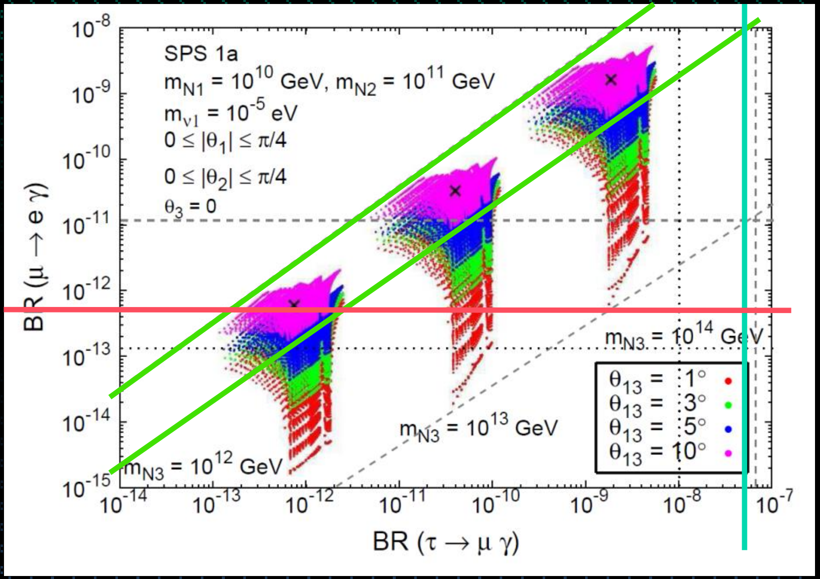
Expected sensitivity is 5×10^{-13} (last result 7.7×10^{-13})

Newly developed items and problems are being finalized.
 2-3 months before unblinding

We would like to present our result by summer of this year.
 ~1 month to calculate confidence region, etc.

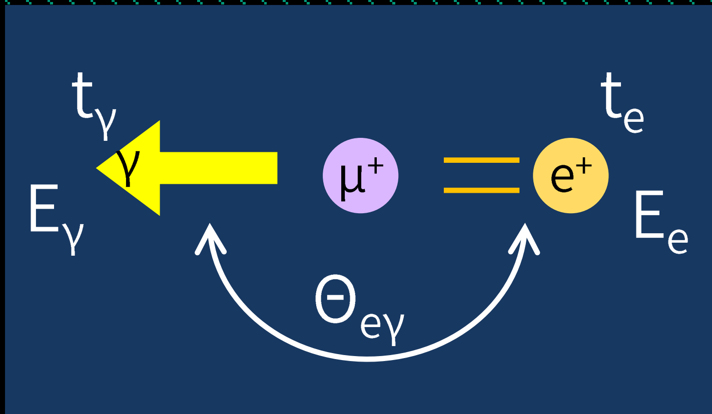


An example of SUSY seesaw
S. Antusch, et.al. JHEP 0611 (2006) 090



Signal & BG

Signal Event



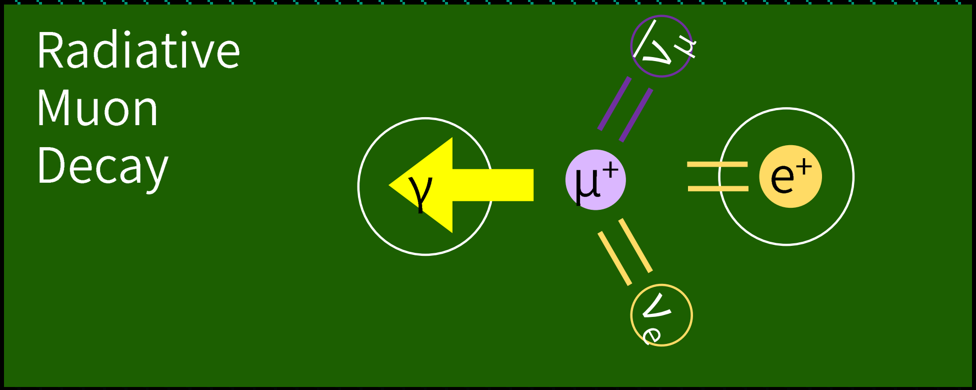
True $\mu \to e^+ \gamma$ event

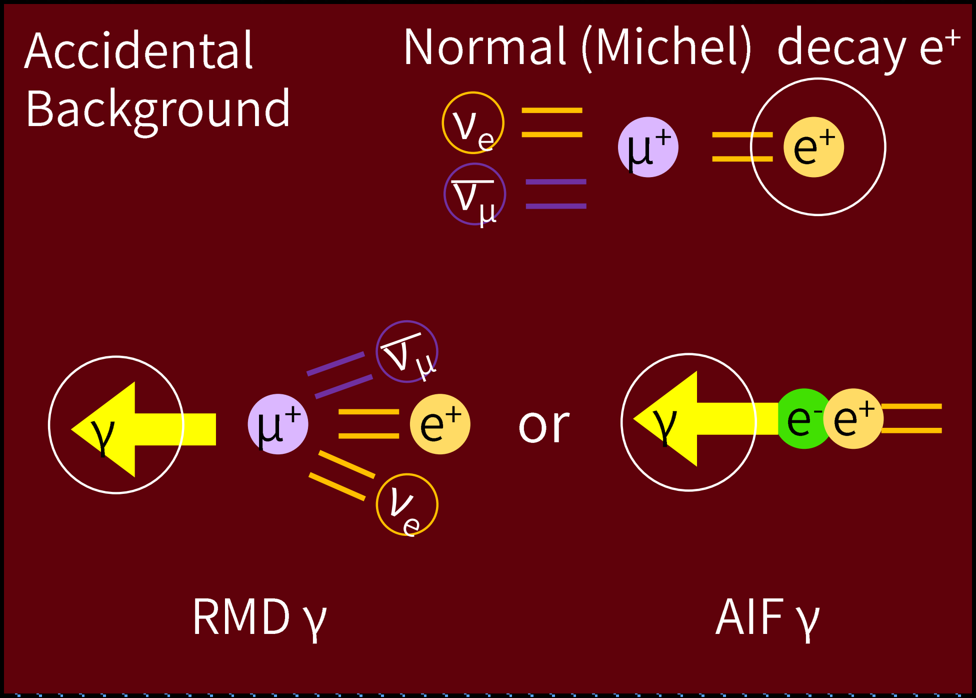
$$E_\gamma = E_e = m_\mu / 2$$

$$t_\gamma = t_e$$

$$\Theta_{e\gamma} = \pi$$

BackGround Event





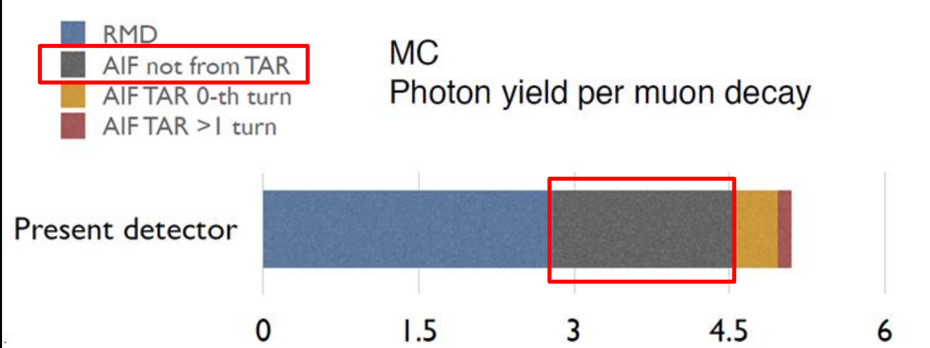
Strategy of physics analysis

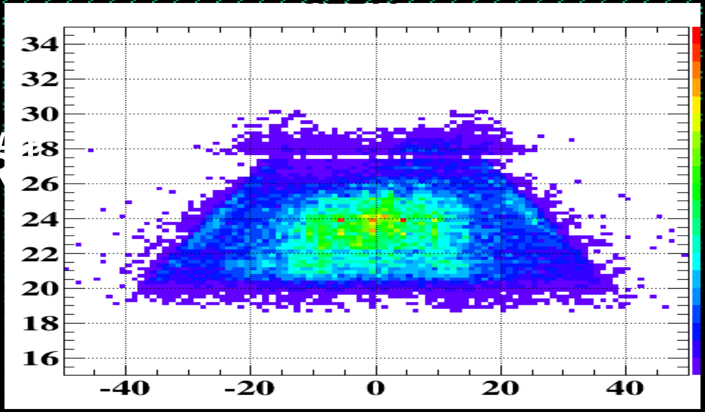
Calculate number of signal (Nsig) by most likelihood fitting, from observables (Eγ, Ee ···) which is obtained in experiment.

$$\mathcal{L}(N_{\mathrm{sig}}, N_{\mathrm{RD}}, N_{\mathrm{BG}}) = \frac{e^{-N}}{N_{\mathrm{obs}}!} e^{-\frac{(N_{\mathrm{RD}} - \langle N_{\mathrm{RD}} \rangle)^2}{2\sigma_{\mathrm{RD}}^2}} e^{-\frac{(N_{\mathrm{BG}} - \langle N_{\mathrm{BG}} \rangle)^2}{2\sigma_{\mathrm{BG}}^2}} \times \prod_{i=1}^{N_{\mathrm{obs}}} \left(N_{\mathrm{sig}} S(\vec{x_i}) + N_{\mathrm{RD}} R(\vec{x_i}) + N_{\mathrm{BG}} B(\vec{x_i}) \right)$$

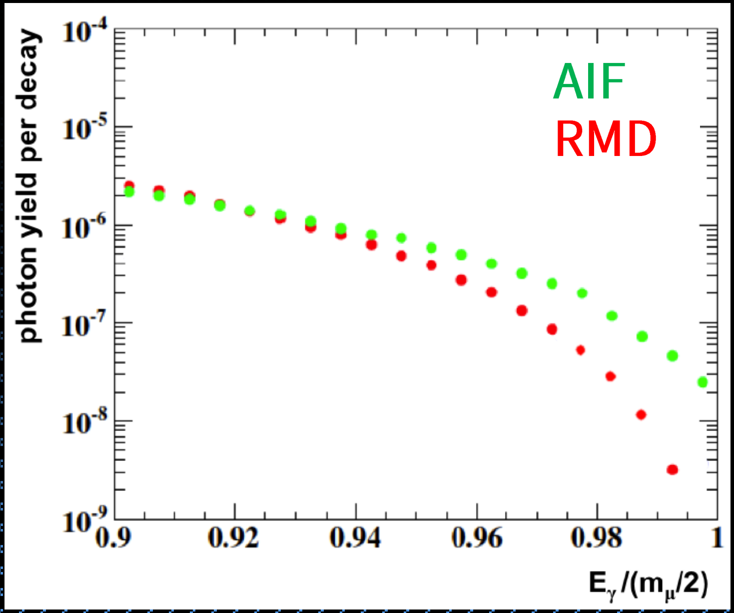
Branching ratio $\mathcal{B} = \frac{N_{\mathrm{sig}}}{k}$ k : Normalization factor, calculate from data

Set confidence interval (upper limit) from many Toy-MC experiment with Feldman-Cousin approach.


RMD
AIF not from TAR
AIF TAR 0-th turn
AIF TAR >1 turn
MC
Photon yield per muon decay
Present detector
0
1.5
3
4.5
6


34
32
30
28
26
24
22
20
18
16
-40
-20
0
20
40

Z_{AIF}

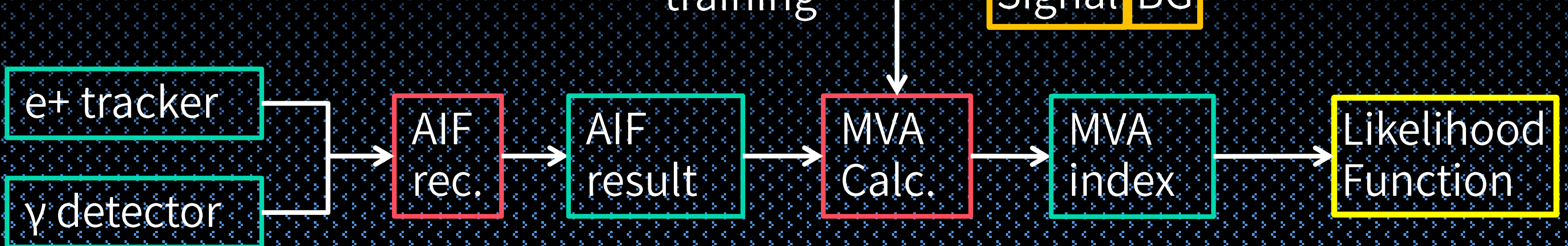

photon yield per decay
10^{-4}
10^{-5}
10^{-6}
10^{-7}
10^{-8}
10^{-9}
0.9
0.92
0.94
0.96
0.98
1
$E_\gamma/(m_\mu/2)$
AIF
RMD

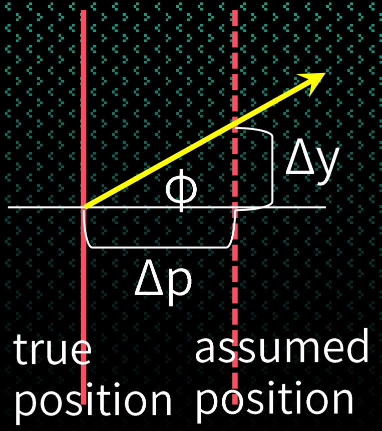
Implementation to analysis

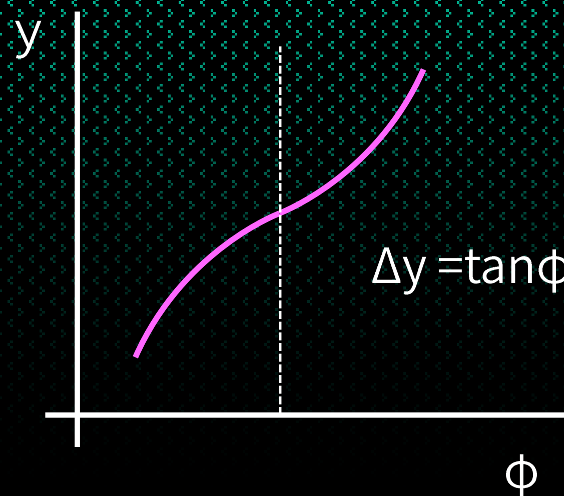
We developed the way to implement AIF to MEG physics analysis

PDF type	value	entry	comment
Projection	3×1D	Binning	▲Cannot treat correlation between AIF observables
3D Binning	1×3D	Binning	▲Much statistics needed for multi dimension
3D Fit	1×3D	Fitting	▲It is difficult to model distribution is whole analysis area
MVA	1×1D	Binning	● Correlation can be considered ● Less statistics needed because 1D

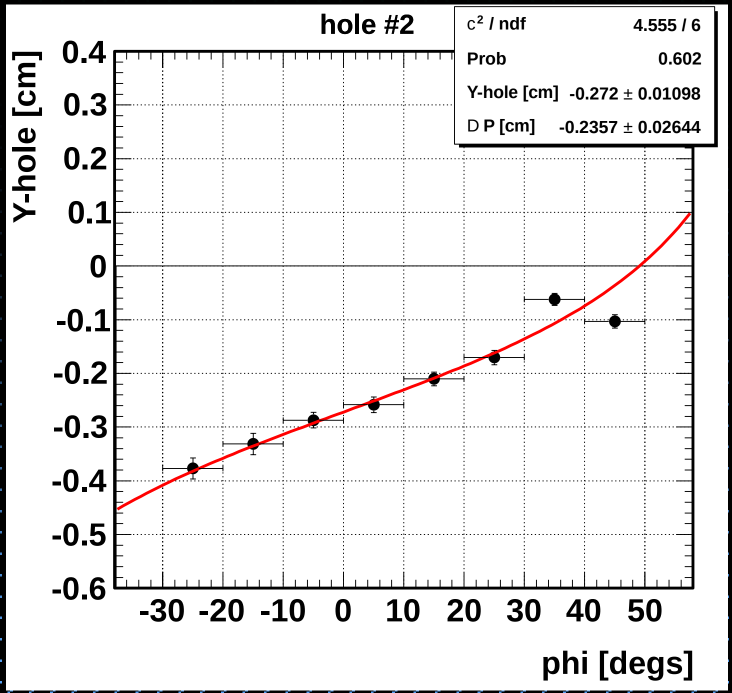
Data flow







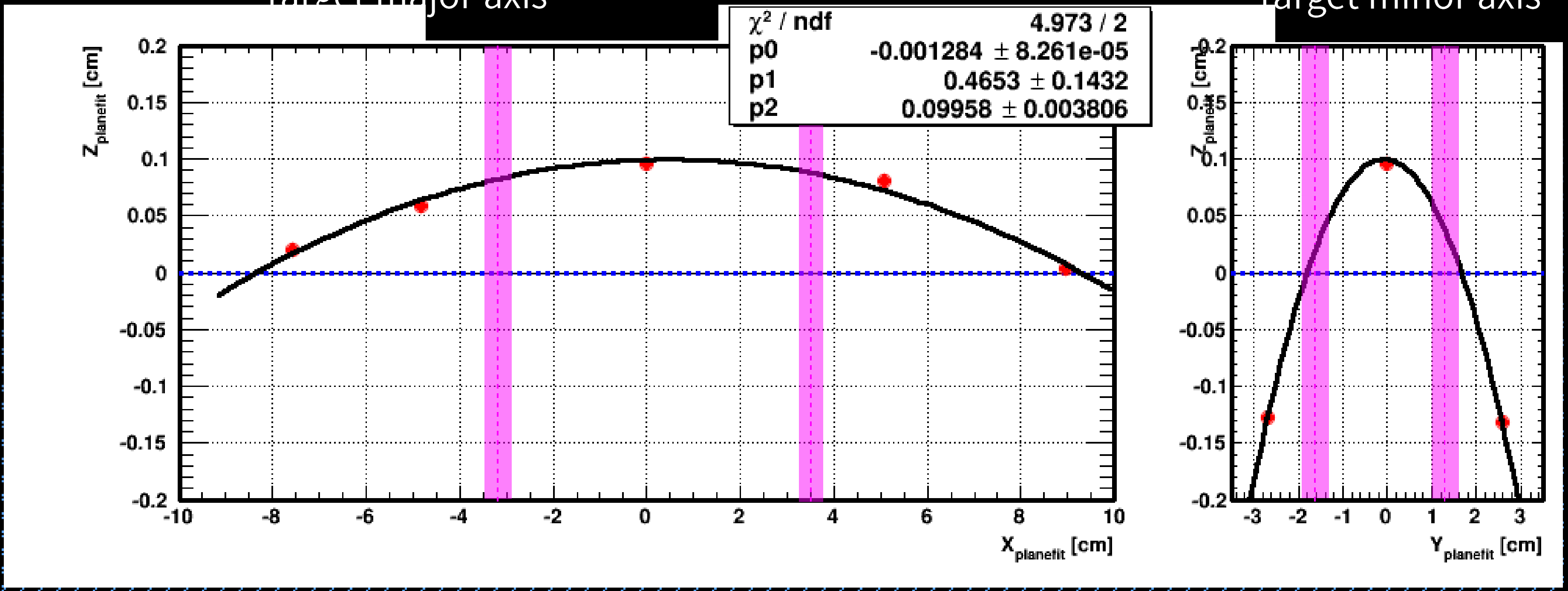
$$\Delta y = \tan\phi \times \Delta p$$



Using 50 μm errors!

Target major axis

Target minor axis



Schedule from now

- AIF (1.5- 2.5 months)
  - Finalize AIF
  - Decide MVA
  - PDF preparation
- Target (3weeks)
  - Review PDF parameters
  - Test modified fitting

3 months
2

- Missing turn (2 weeks)

— Re-process data (2-6 weeks)

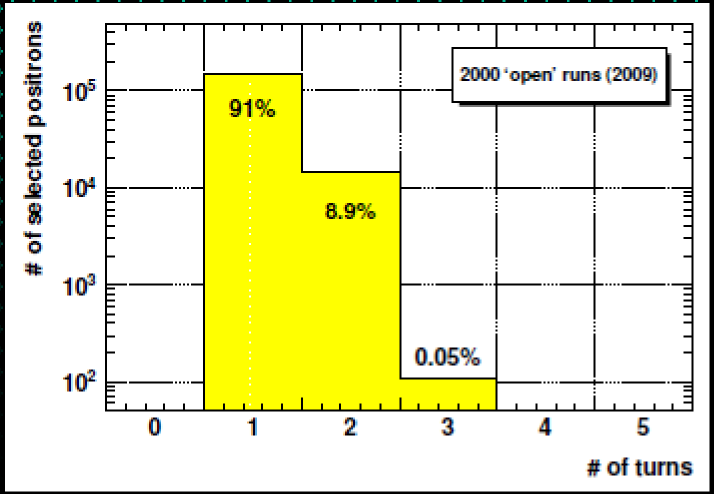
- Check before Unblind (1-2 weeks)

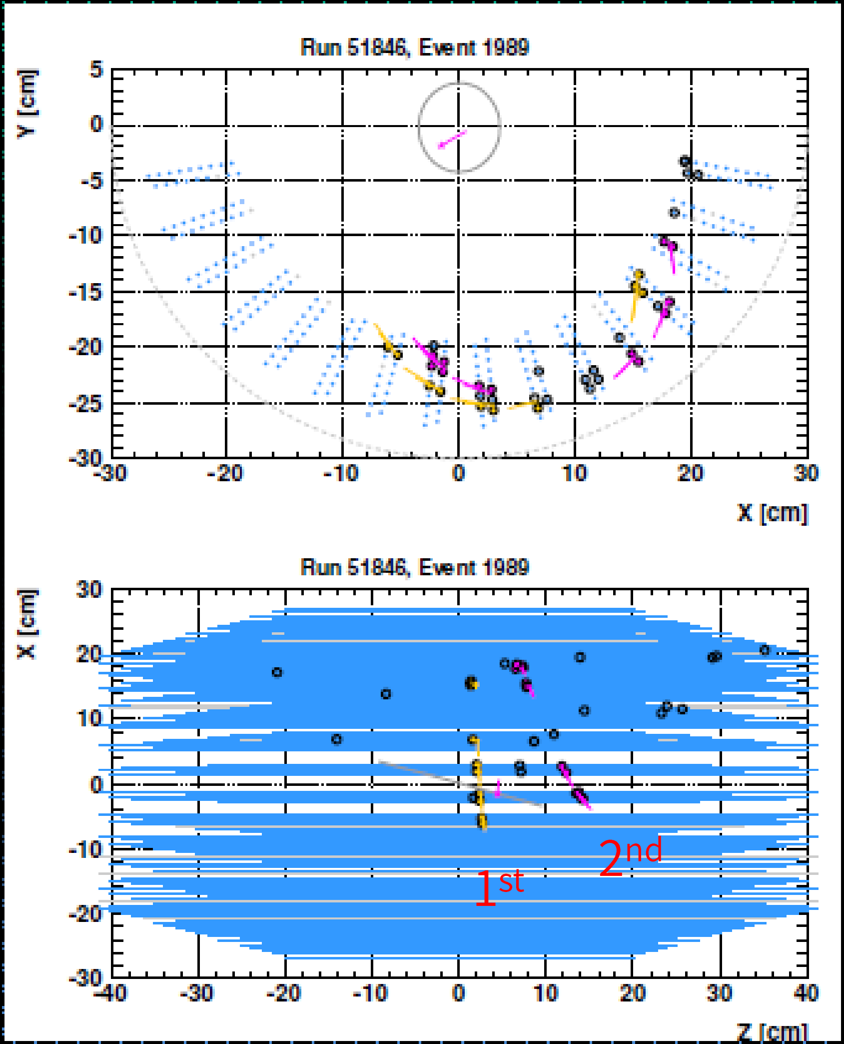
— Unblind data

- After unblind
  - Likelihood fit, event check
  - Sensitivity, Confidence interval calculation

1 month

missing turn





Sometimes positron runs more than 1 turns before exit drift chamber.

If 1st and 2nd turn are reconstructed as individual e^+, the initial vector of the 2nd turn makes wrong vertex.