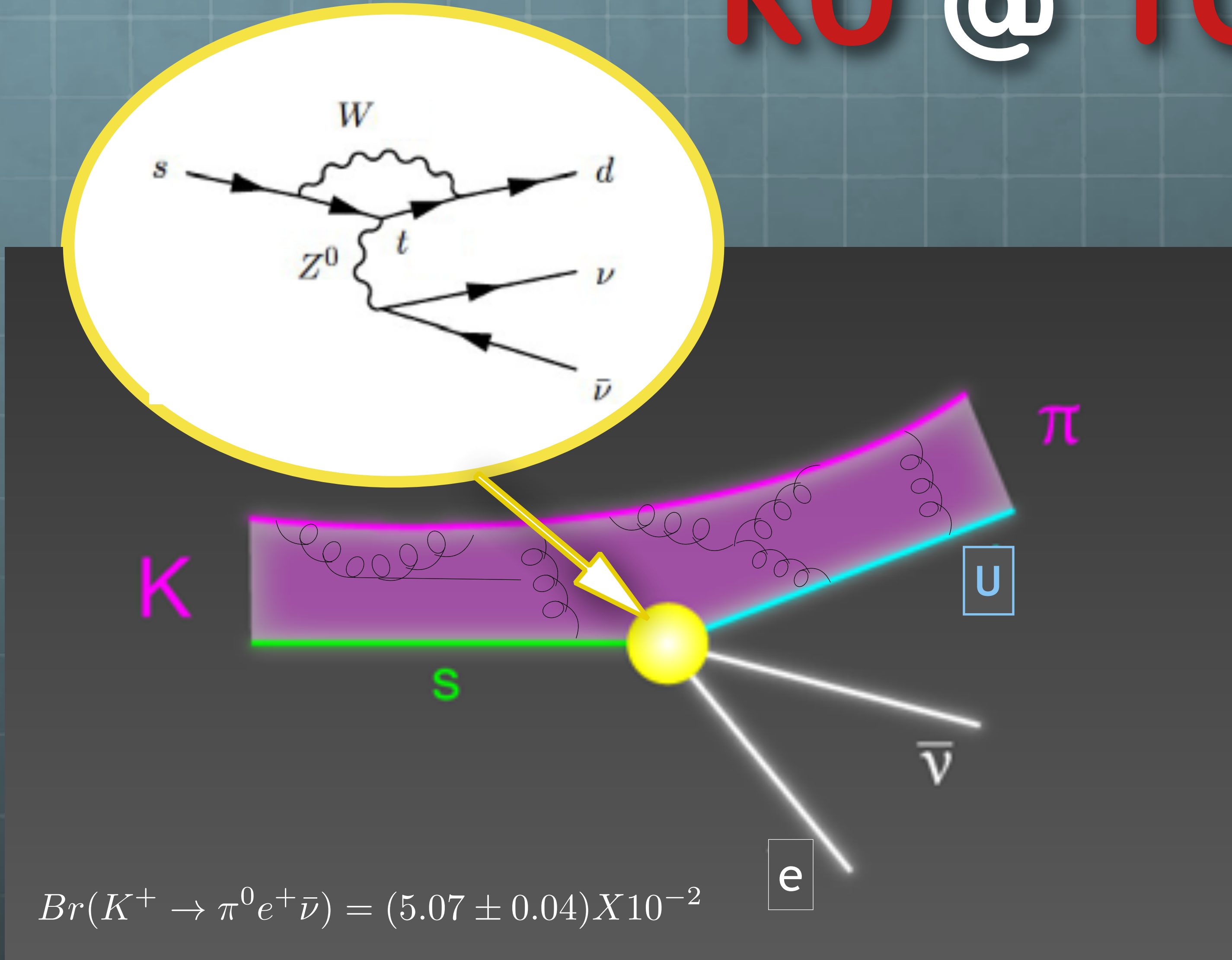
New charged veto for KOTO

G.Y.Lim
IPNS/KEK

CBNU @ 17th Sep., 2018

K0 @ TOkai



$$Br(K^+ \rightarrow \pi^0 e^+ \bar{\nu}) = (5.07 \pm 0.04) X 10^{-2}$$

The cleanest mode in theory

$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = \kappa_+(1+\Delta_{\mathrm{EM}})\cdot\left[\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X(x_t)\right)^2 + \left(\frac{\mathrm{Re}\lambda_c}{\lambda}P_c(X) + \frac{\mathrm{Re}\lambda_t}{\lambda^5}X(x_t)\right)^2\right]$$

$$\kappa_+ = r_{K^+}\frac{3\alpha^2 B(K^+ \to \pi^0 e^+\nu)}{2\pi^2\sin^4\Theta_W}\lambda^8 = 4.11\cdot 10^{-11}$$

$$\longrightarrow \quad (7.83 \pm 0.82)\times 10^{-11}$$

$$B(K_L \to \pi^0\nu\bar{\nu}) = \kappa_L\cdot\left(\frac{\mathrm{Im}\lambda_t}{\lambda^5}X(x_t)\right)^2$$

$$\kappa_L = \kappa_+\frac{r_{K_L}}{r_{K^+}}\frac{\tau(K_L)}{\tau(K^+)} = 1.80\cdot 10^{-10}$$

$$\longrightarrow \quad (2.49 \pm 0.39)\times 10^{-11}$$

F. Mercia & C. Smith, arXiv:0705.2025v2

The most suppressed FCNC

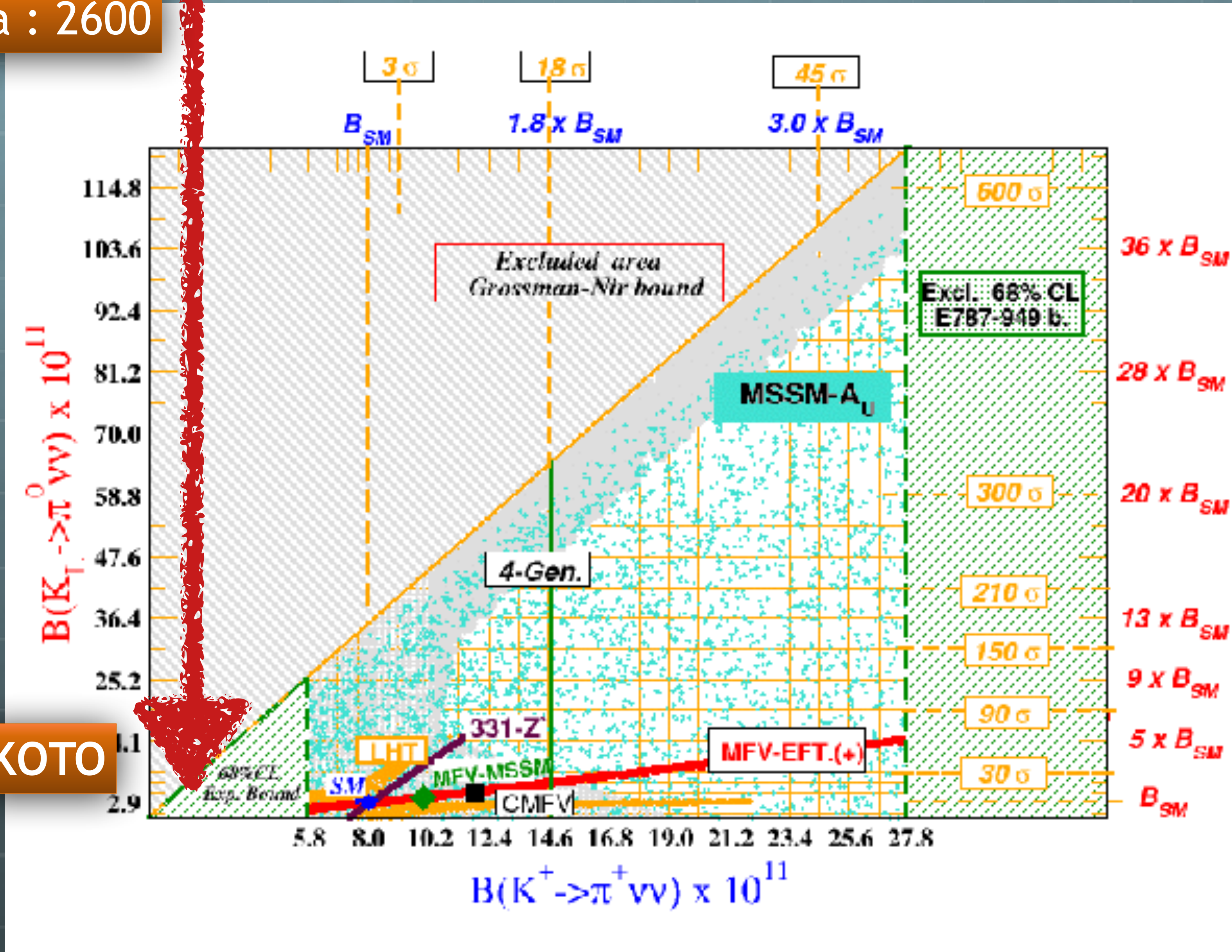
$$\underbrace{|V_{ts}^* V_{td}|}_{K \text{ system}} \sim 5 \cdot 10^{-4} \ll \underbrace{|V_{tb}^* V_{td}|}_{B_d \text{ system}} \sim 10^{-2} < \underbrace{|V_{tb}^* V_{ts}|}_{B_s \text{ system}} \sim 4 \cdot 10^{-2},$$

The largest deviations from the SM prediction in Kaon sector.

LHT : Littlest Higgs model with T-parity
RCs : Randall-Sundrum model
LR : General left-right model

M. Blanke, arXiv:1305.5671v1

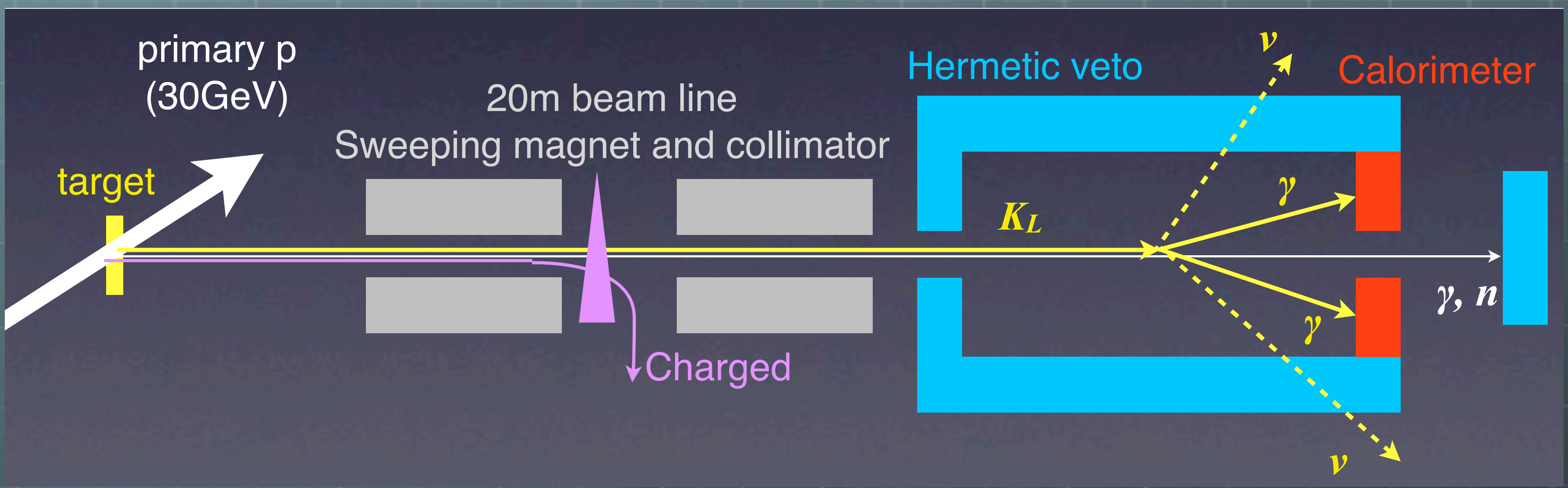
E391a : 2600



KOTO

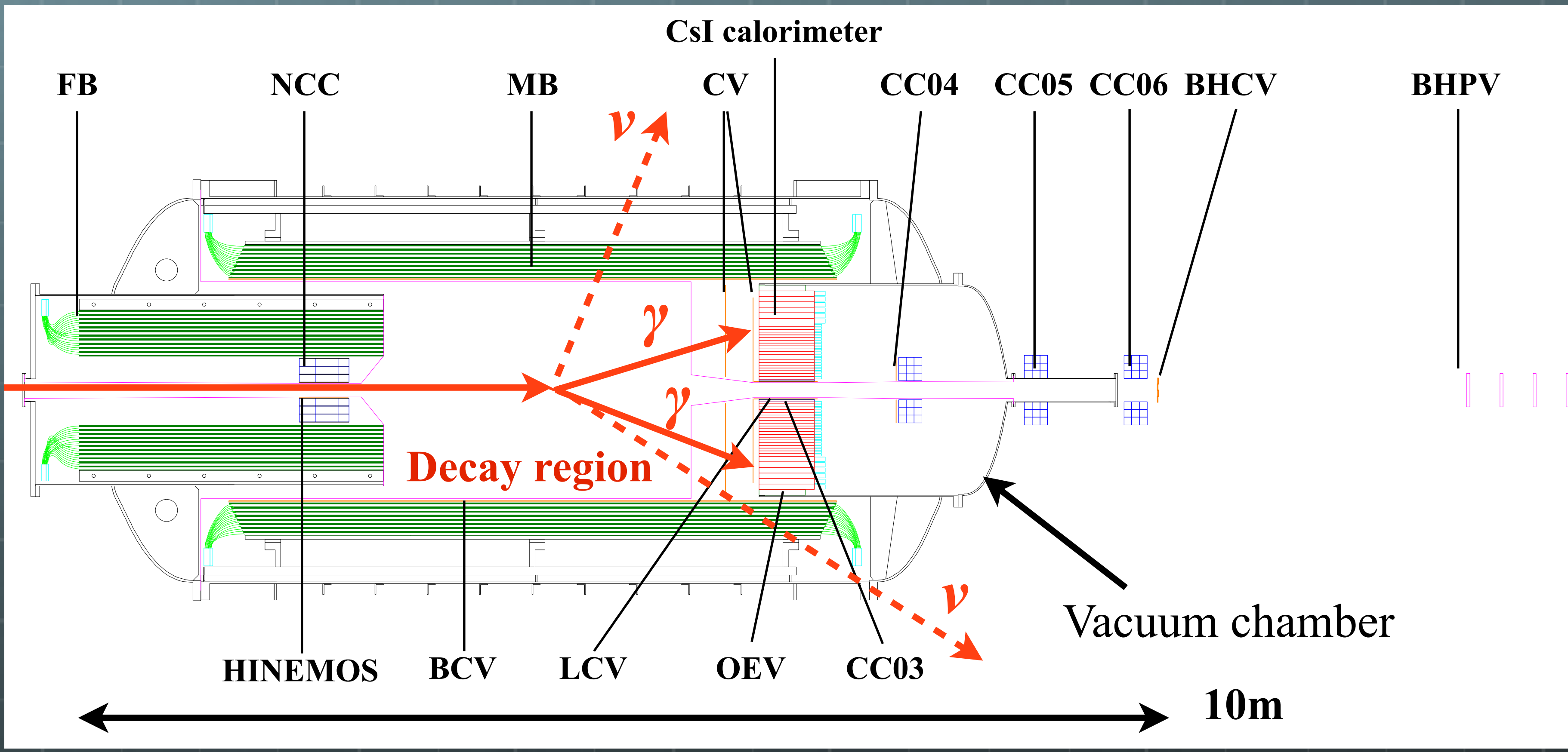
http://www.lnf.infn.it/wg/vus/content/Krare.html

Experimental Method



2γ+ Nothing

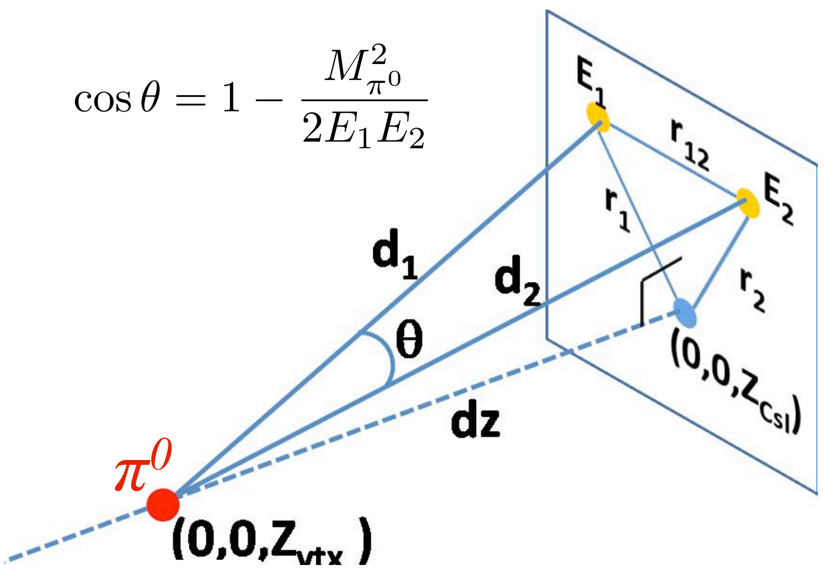
Detector

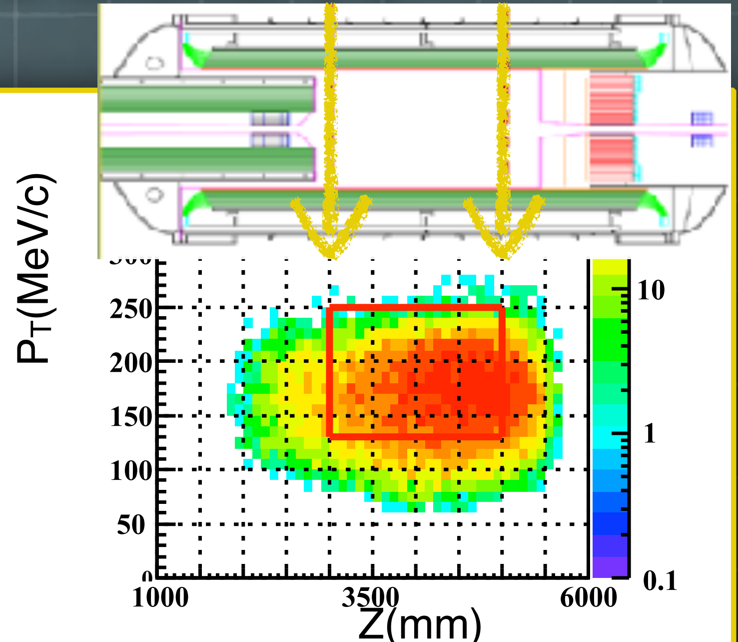

CsI calorimeter
FB
NCC
MB
CV
CC04
CC05
CC06
BHCV
BHPV
ν
γ
γ
ν
Decay region
Vacuum chamber
HINEMOS
BCV
LCV
OEV
CC03
10m

π^0 reconstruction

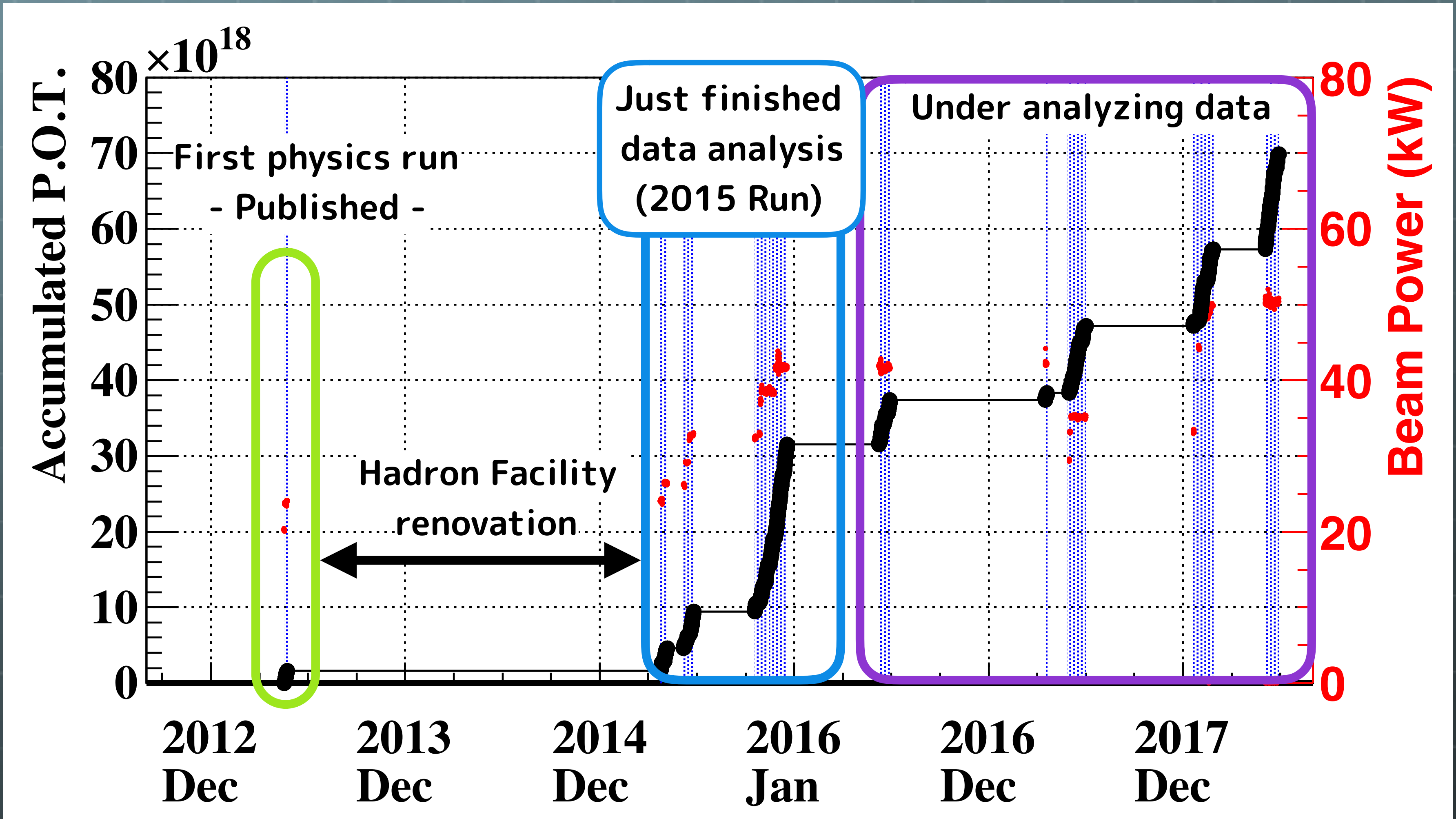
- EM calorimeter provides energies and incident positions of two photons
- With an assumption that π^0 decays at beam center and π^0 rest mass, we can obtain a distance between calorimeter and decaying vertex.
- Pair of neutrinos take away transverse momentum (P_T)

$$\cos\theta = 1 - \frac{M_{\pi^0}^2}{2E_1E_2}$$



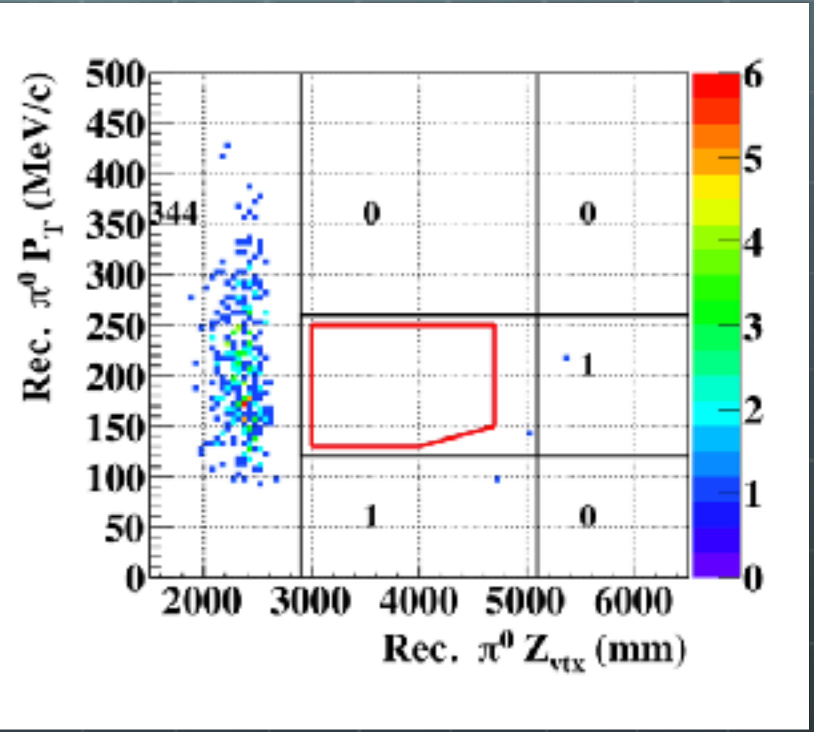


History of data taking



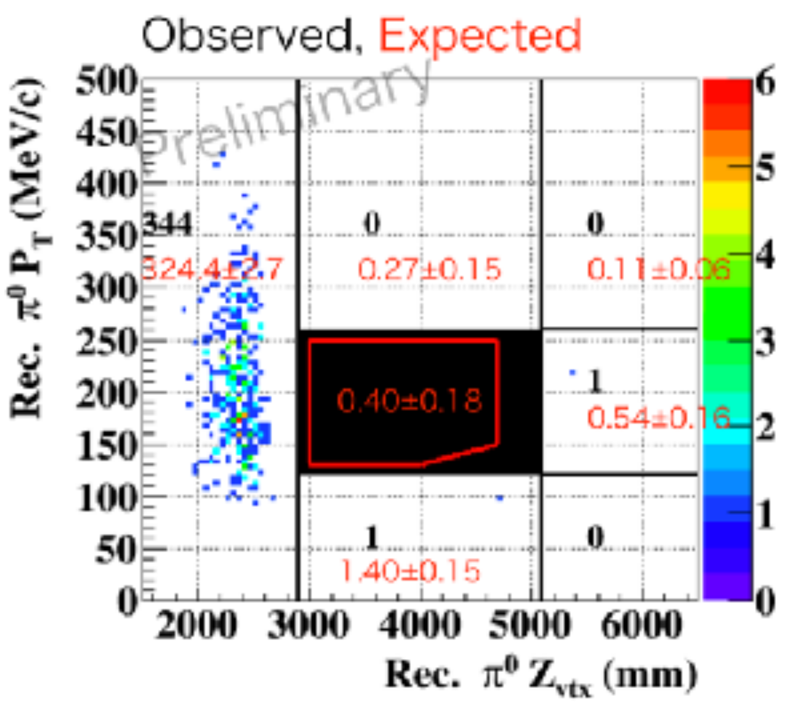
Result of 2015 Run

- Several detector upgrades to reject background events observed the first physics run
- Background estimation with blinded signal region
- Opened Box in June 2018
- No signal candidate
- BR<3.0×10-9 @90%C.L.

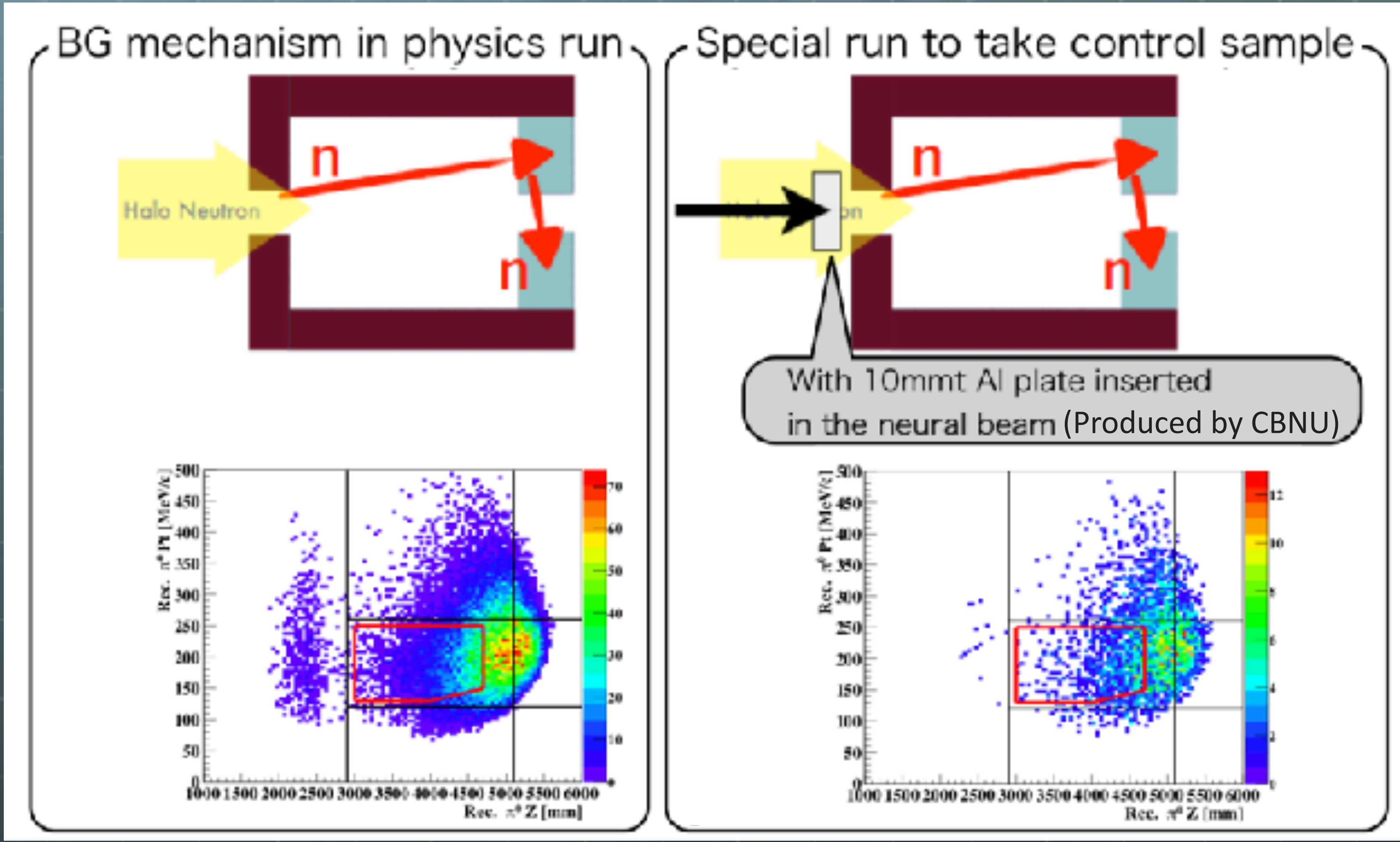


Background budget

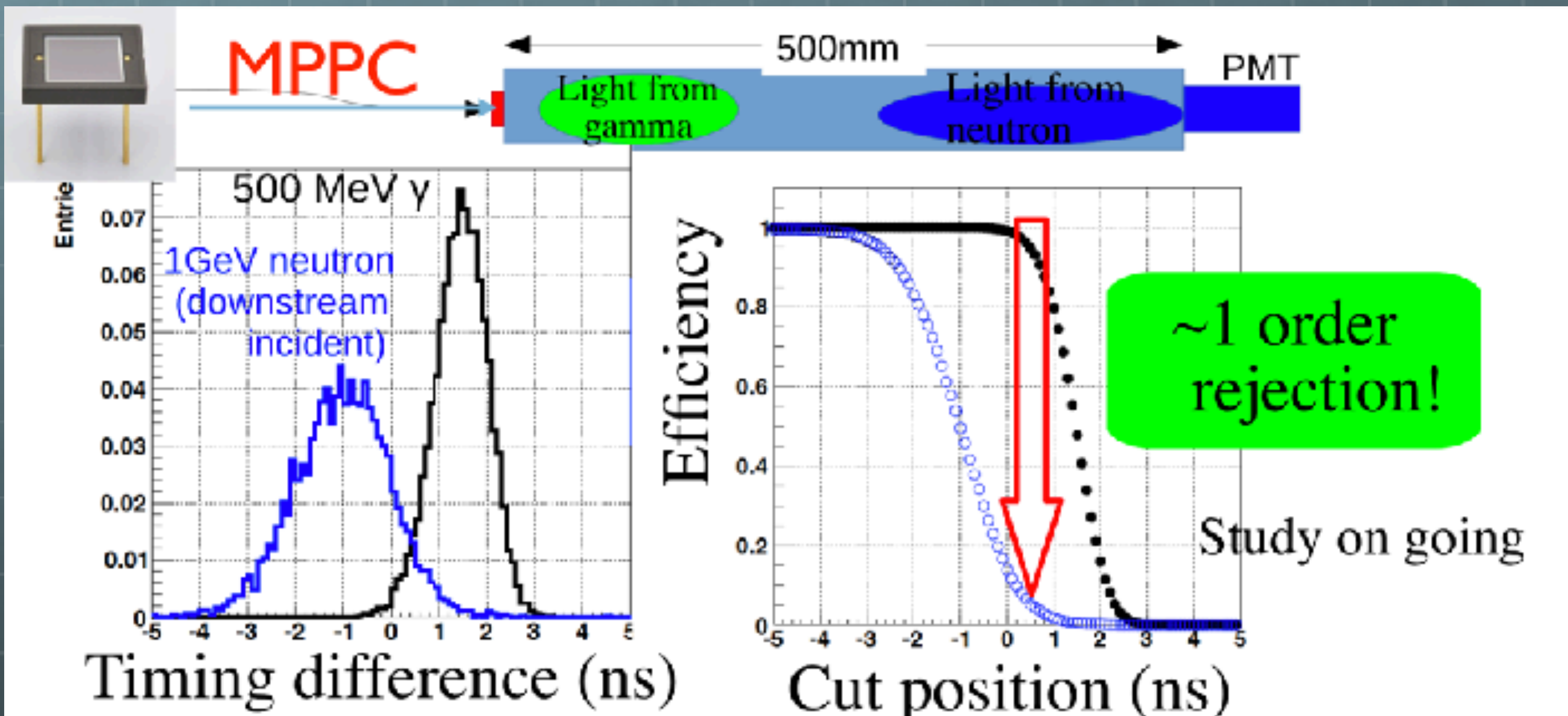
background source	#BG
Halo neutron hitting CSI	0.24±0.17
Halo neutron hitting upstream detectors	0.04±0.03
η background	0.03±0.02
KL->$\pi+\pi-\pi 0$	0.05±0.02
KL->$2\pi 0$	0.02±0.02
other BG sources	0.02±0.02
Sum	0.40±0.18



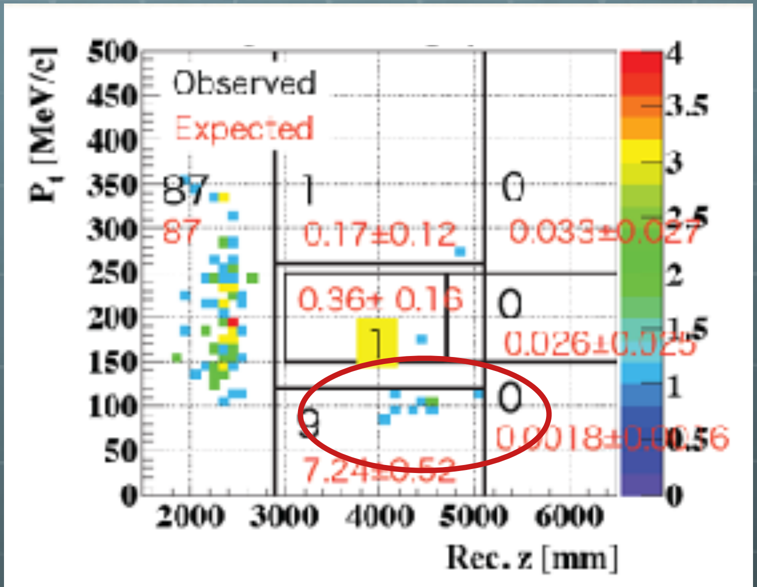
Halo neutron hitting CsI

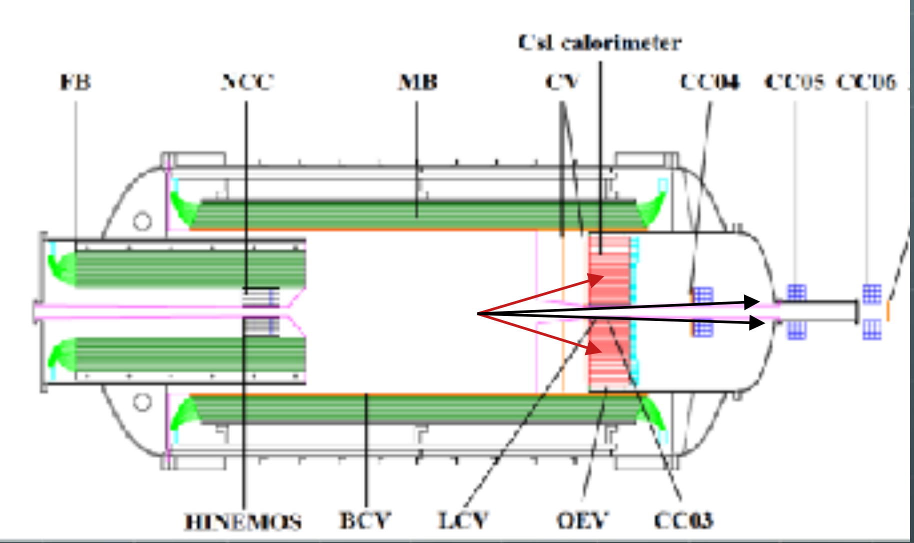


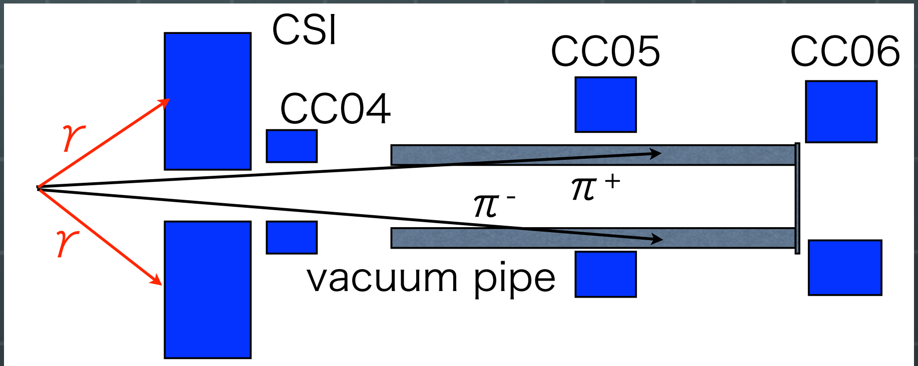
Further suppression



$K_L \rightarrow \pi^+\pi^-\pi^0$

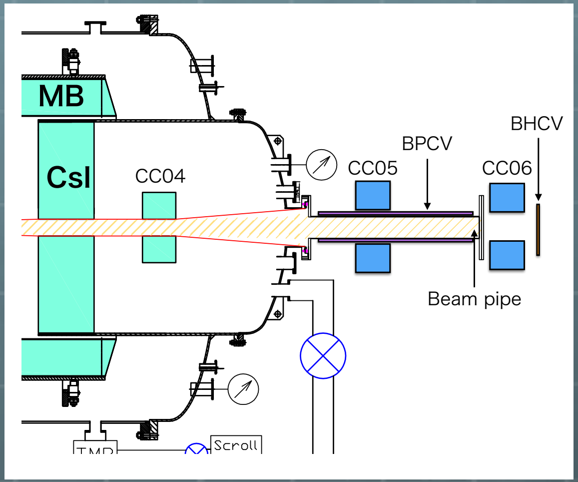


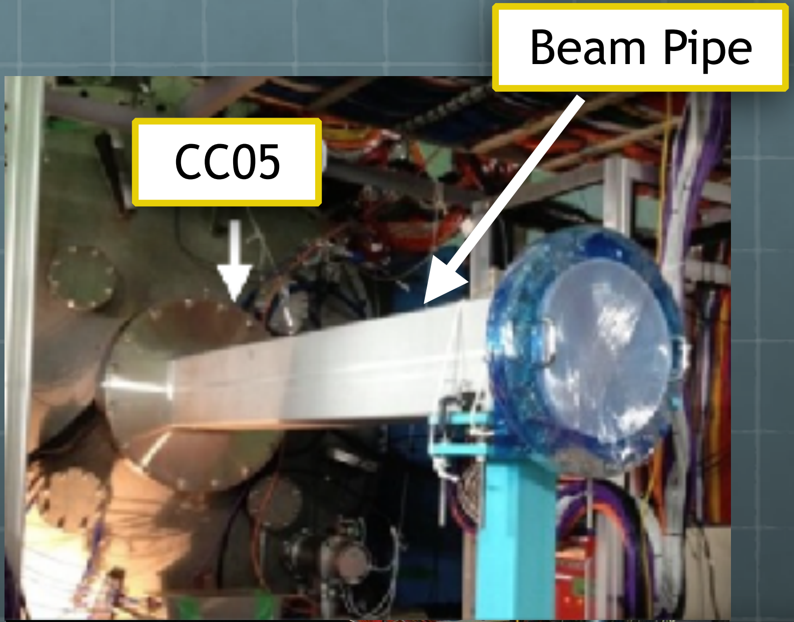


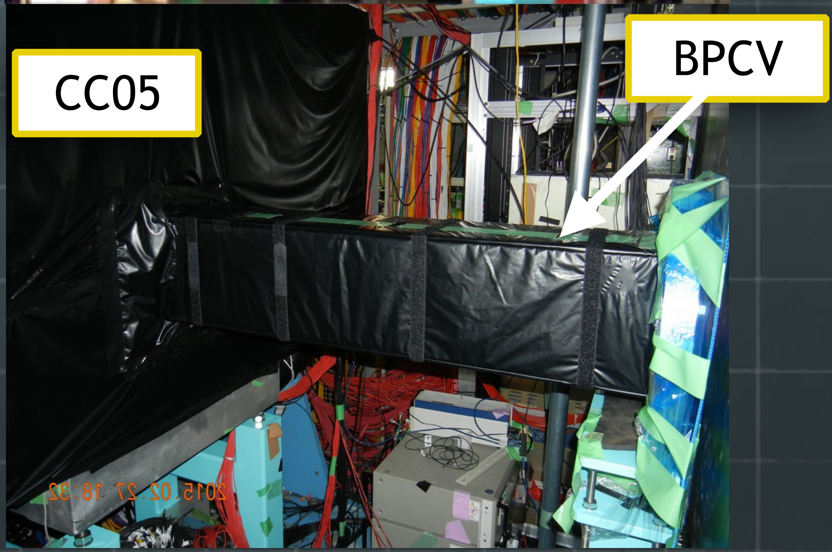


π^+ and/or π^- were not detected due to interaction with vacuum pipe

$K_L \rightarrow \pi^+\pi^-\pi^0$

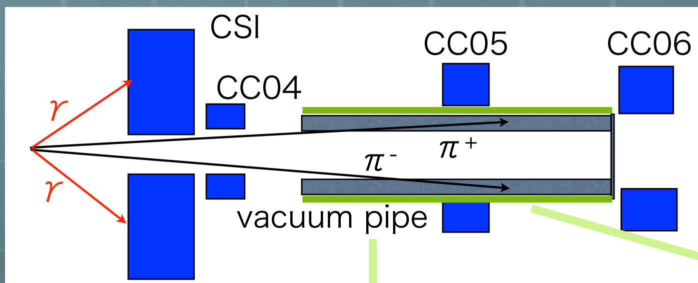




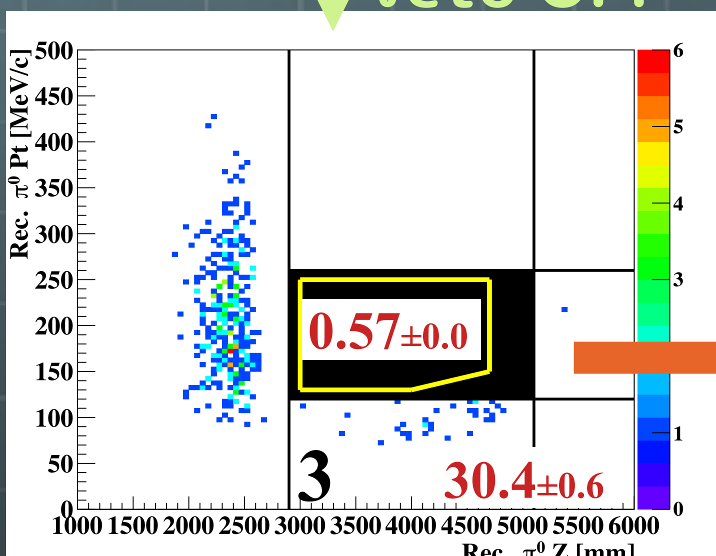


- Beam pipe with lighter material
  - Stainless Steel -> Aluminum
- Beam Pipe Charged Veto
  - 5mm-thick Plastic Scintillator
  - Wavelength shifting fiber readout

$K_L \rightarrow \pi^+\pi^-\pi^0$ (Cont.)

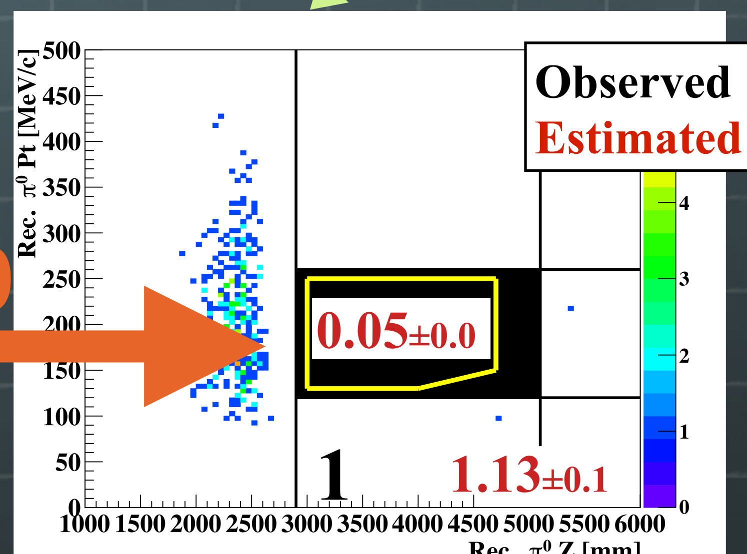


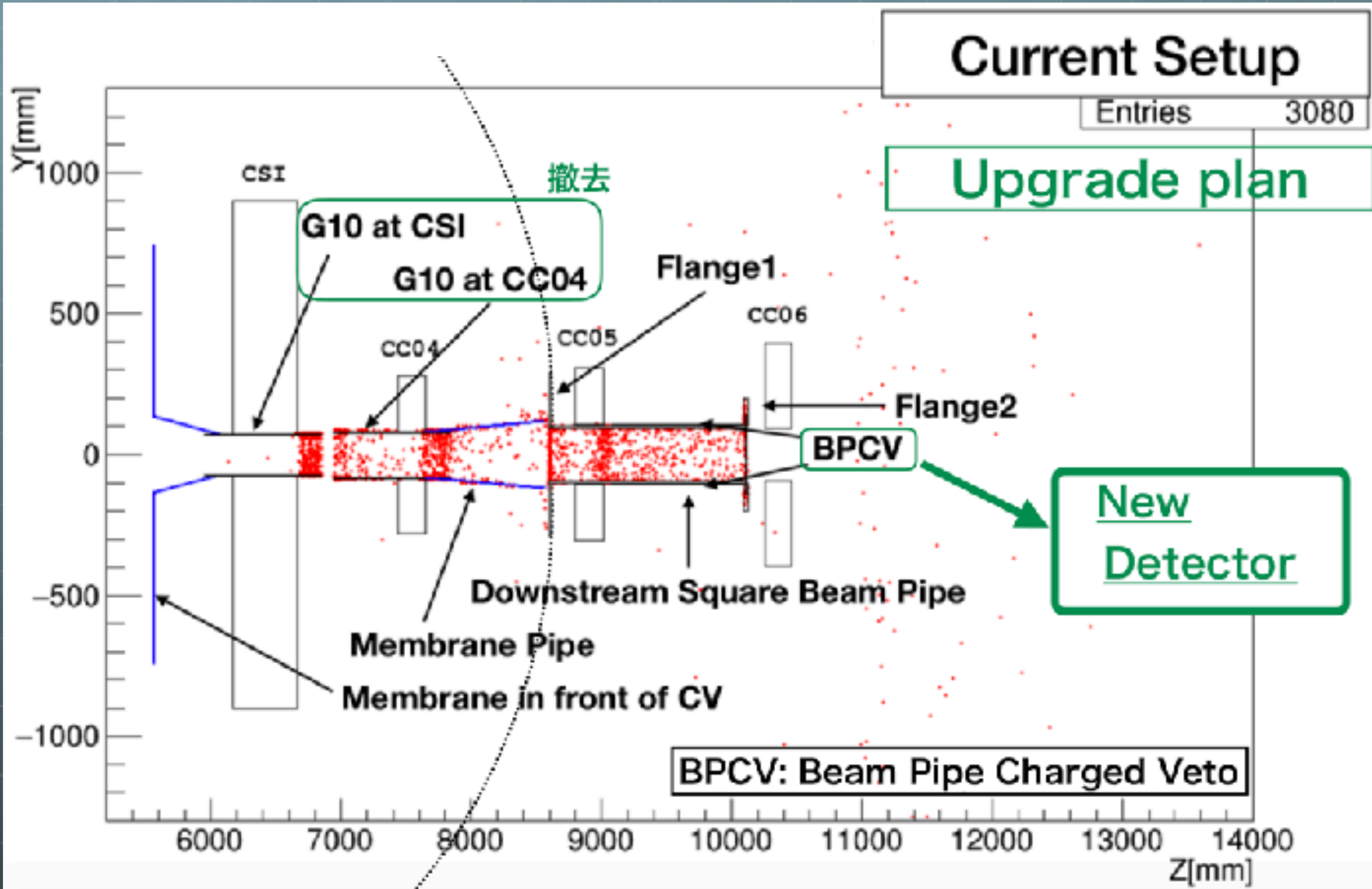
veto OFF



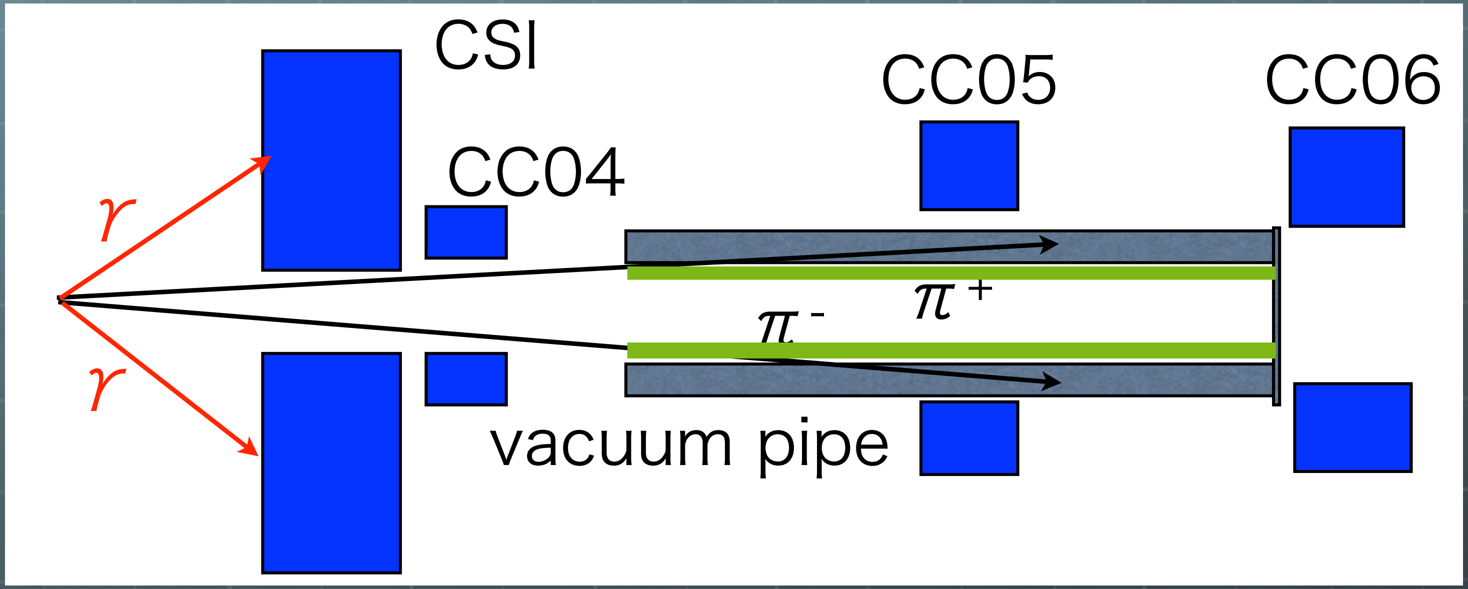
1/10

veto ON



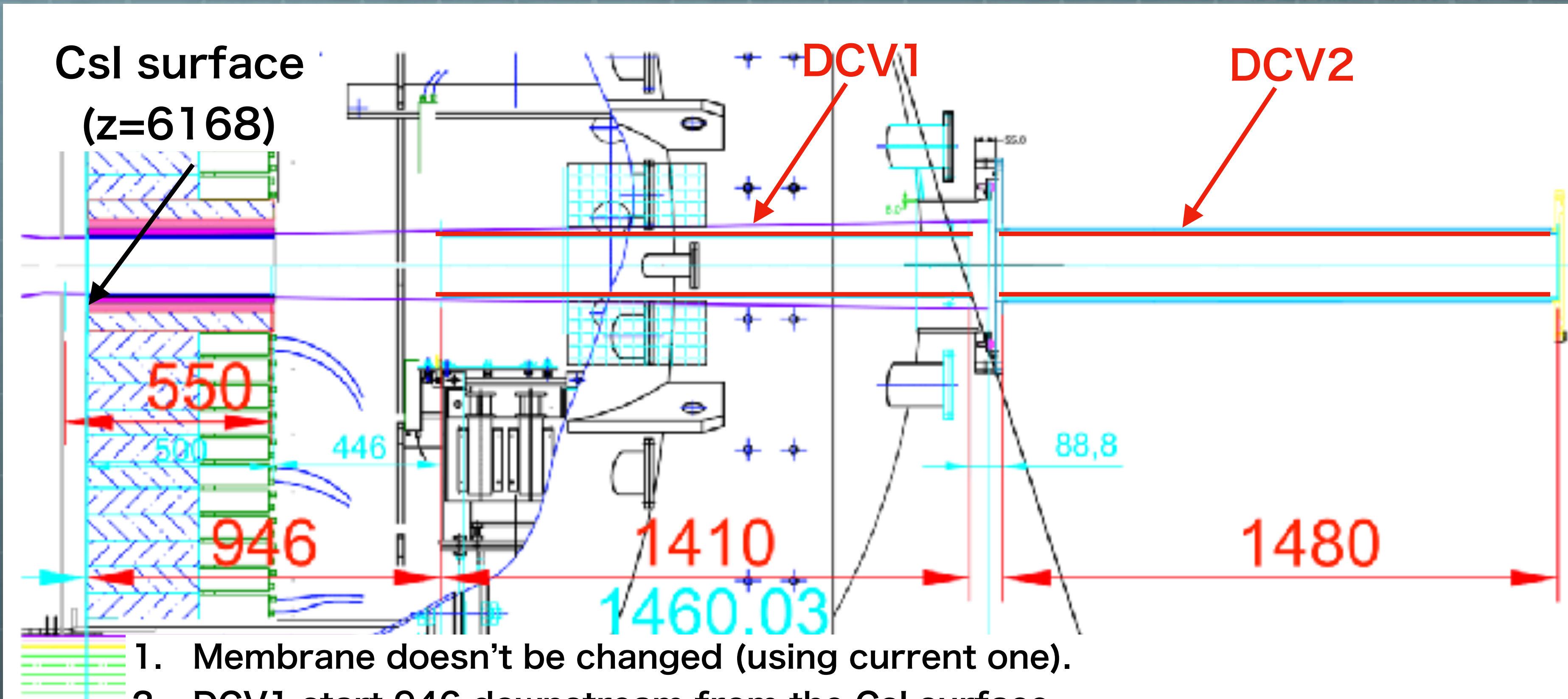

Current Setup
Entries 3080
Upgrade plan
撤去
G10 at CSI
G10 at CC04
Flange1
CSI
CC04
CC05
CC06
Flange2
BPCV
New Detector
Downstream Square Beam Pipe
Membrane Pipe
Membrane in front of CV
BPCV: Beam Pipe Charged Veto
Y[mm]
Z[mm]

Further suppression



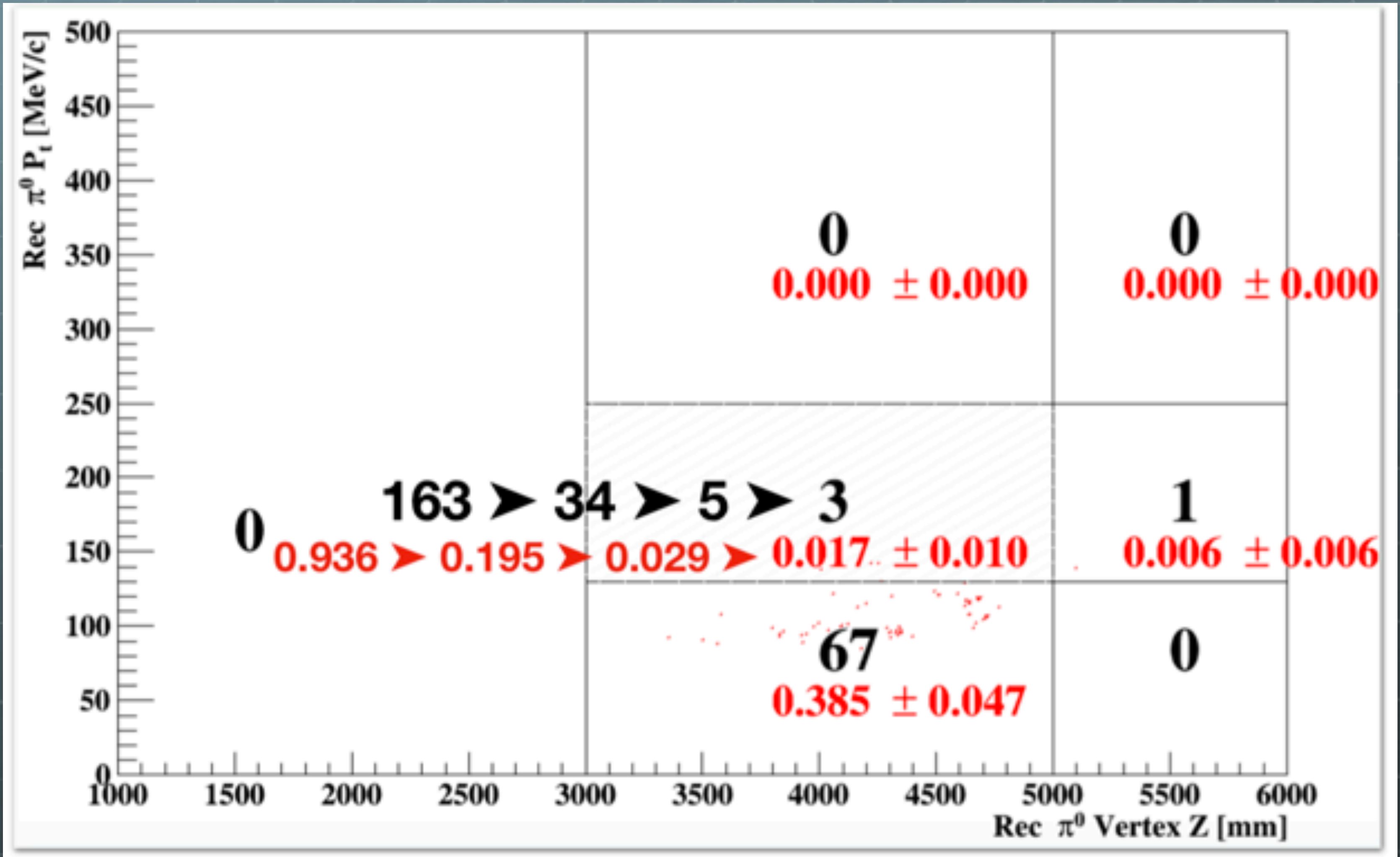
To detect π^+, π^- before interaction by installation detector inside vacuum pipe.

Downstream Charged Veto



1. Membrane doesn't be changed (using current one).
2. DCV1 start 946 downstream from the CsI surface.
    1. Cross section is 166mmX166mm and length of 1410mm
3. DCV2 start 89mm downstream from the DCV1 rare edge.
    1. Cross section is 176mmX176mm and length of 1480mm
4. Thickness of DCV1 and DCV2 is 5mm
5. CsI G-10 : change length 900 ->550
    1. start 50mm in front of the CsI

Factor of 50 additional reduction



R&D items

Outgassing

- Chamber Evacuation

$$P(t) = P_0 \exp\left(\frac{-St}{V}\right) + \frac{Q}{S}$$

P(t) : Chamber pressure at time t

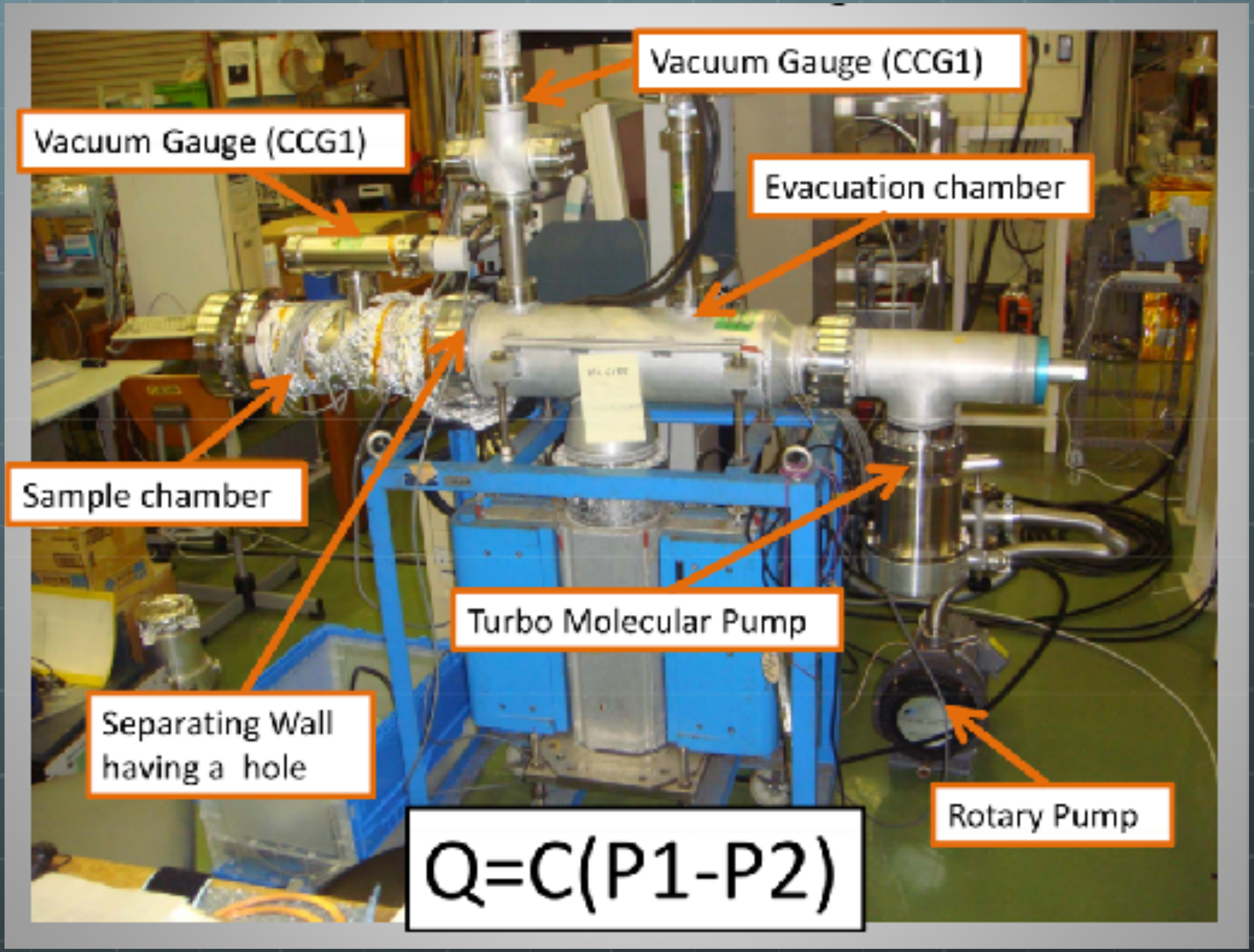
P0 : Initial Pressure

S : Pumping speed

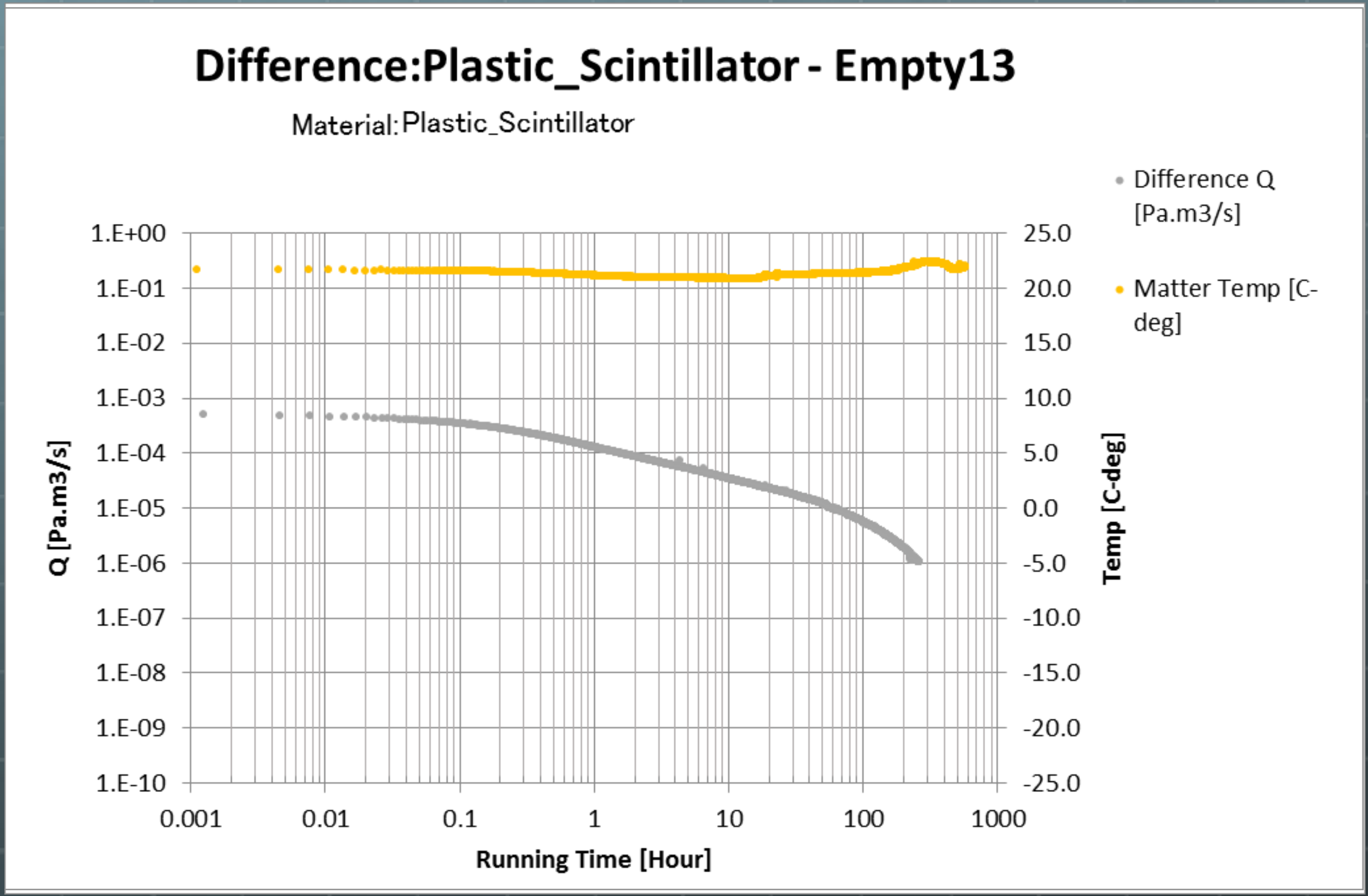
Q : Rate of outgassing

V : Volume of chamber

Measurement on outgassing rate



Outgassing rate of plastic scin.



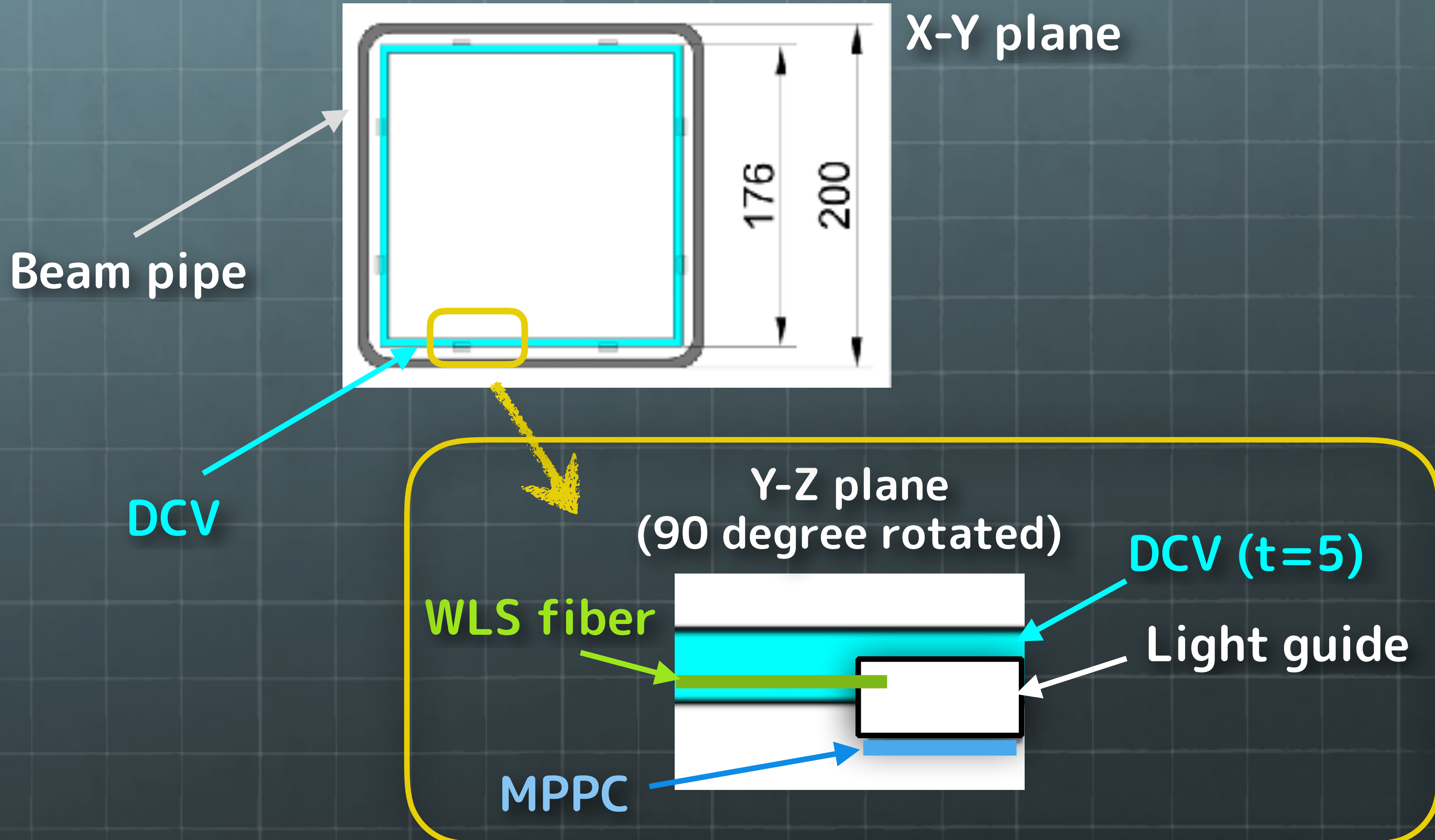
$Q = 1.0 \times 10^{-6}$ Pa・m^3 / s for $2 \times 10^{-5} m^2$

DCV contribution

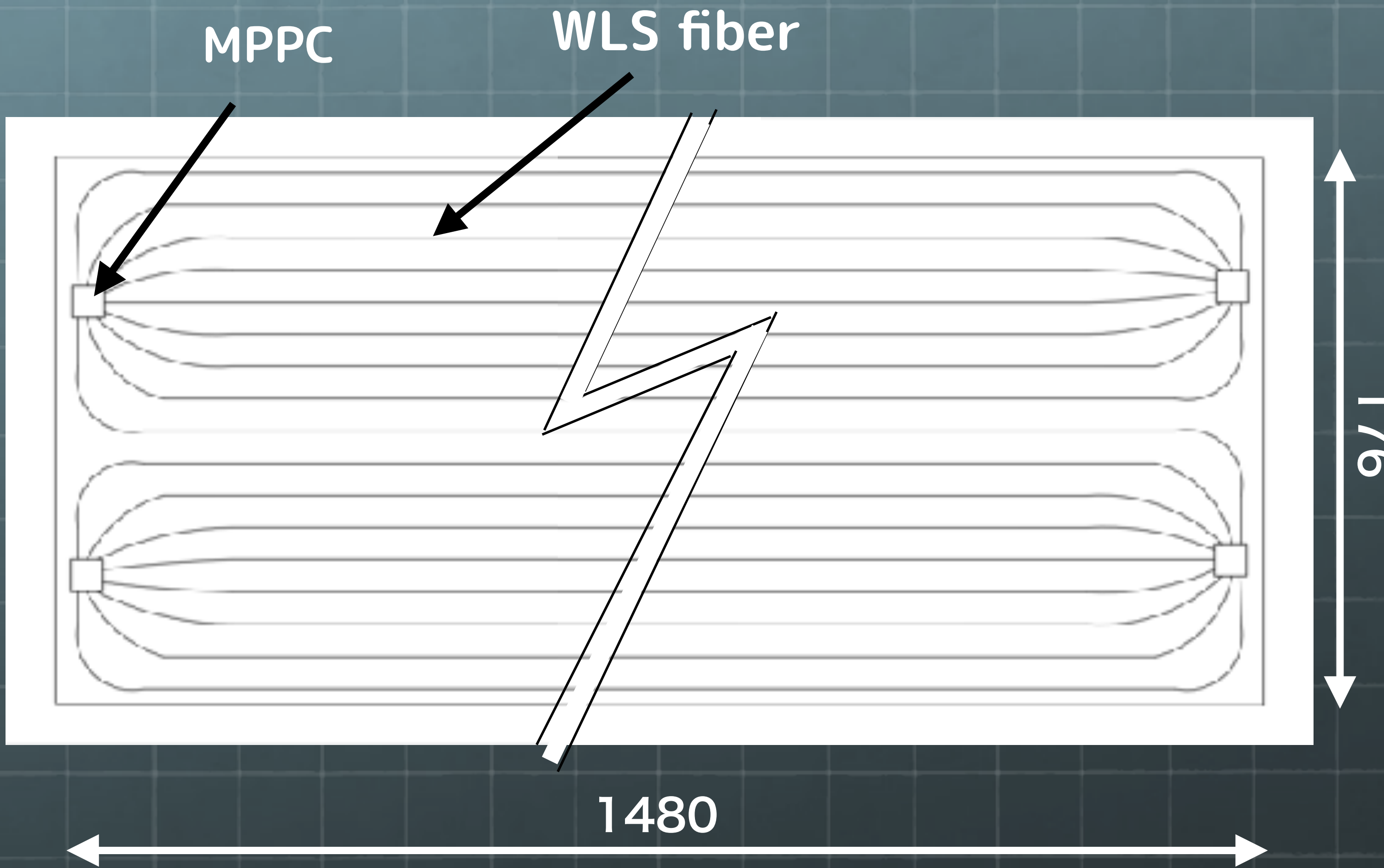
- Total surface of DCV : 2×10^{-3} m^2
  - 90.1 times larger than test sample
- Pumping speed of TMP : (800 m^3/s)X4
- Outgassing rate :1.0×10^{-6} Pa・m^3／s
  - Total outgassing rate:9.0×10^{-5} Pa・m^3／s
- Reaching Pressure $P = 2.8 \times 10^{-8}$ Pa
- We need large safety factor by considering conductance of detector system

Vertical Read-out

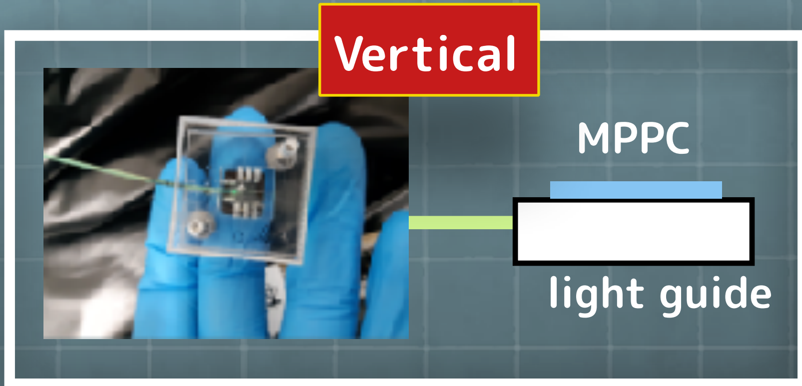
- Very limited space

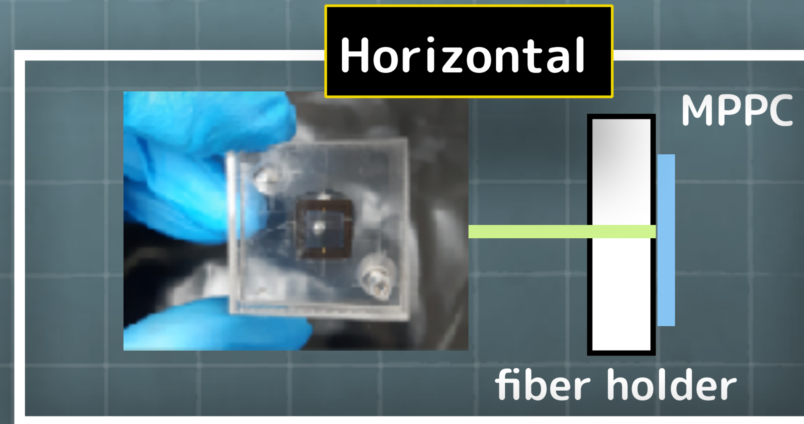


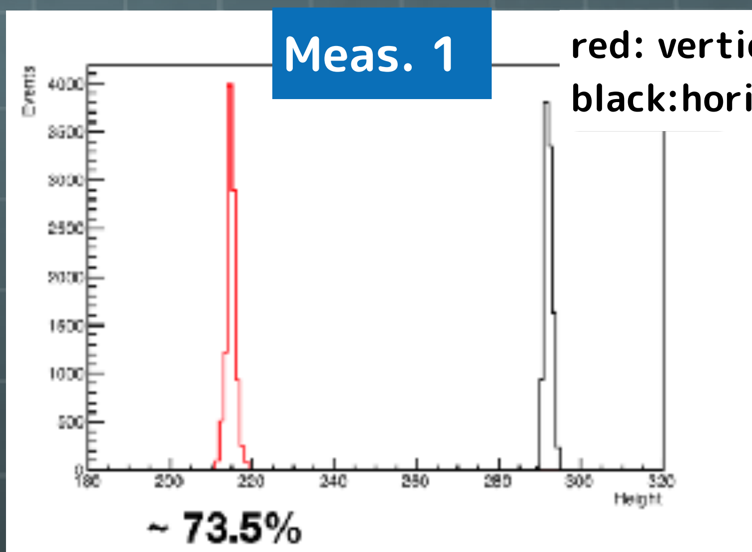
WLS embedded Scintillator



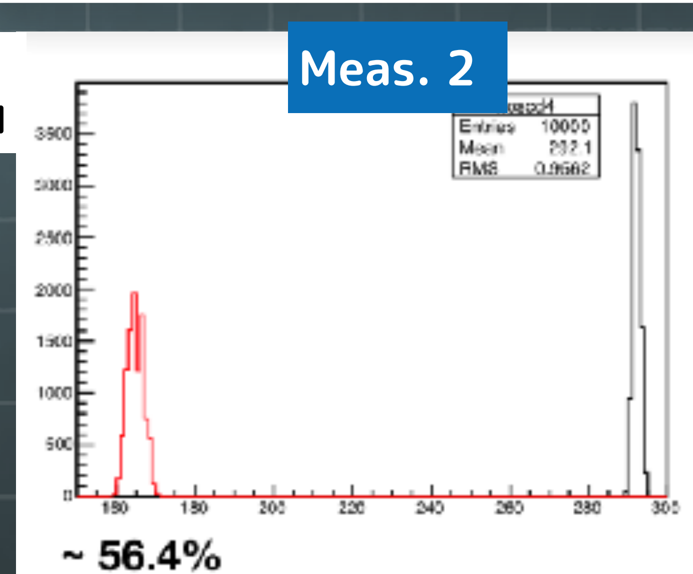
Light Yield : Vertical V.S. Horizontal







red: vertical
black:horizontal



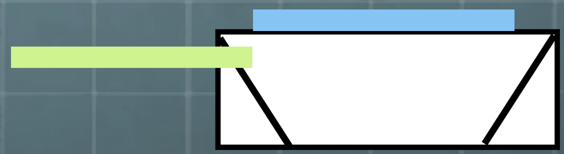
Finalize this results!
Measurement with scintillator in terms of photoelectron

R&D for light guide

Simple transparent light guide

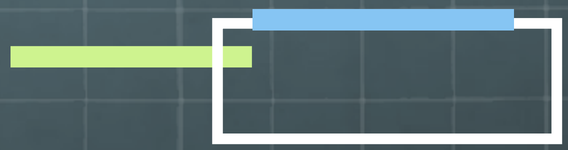
Matter of material selection

refection sheet



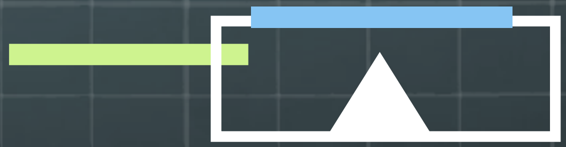
Variation of light guide

To change shape of light guide for better light collection



No light guide

Insert fiber into reflecting box

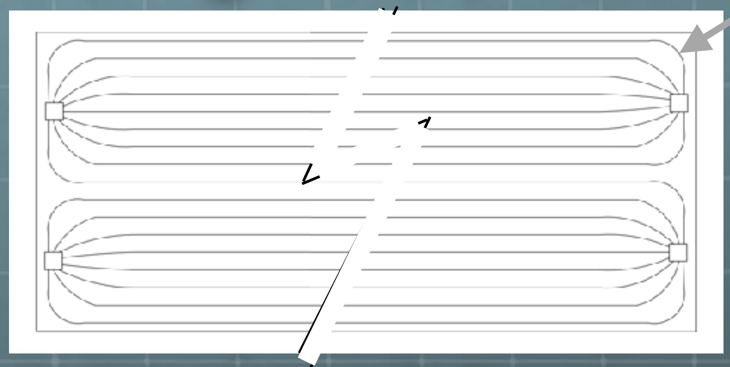


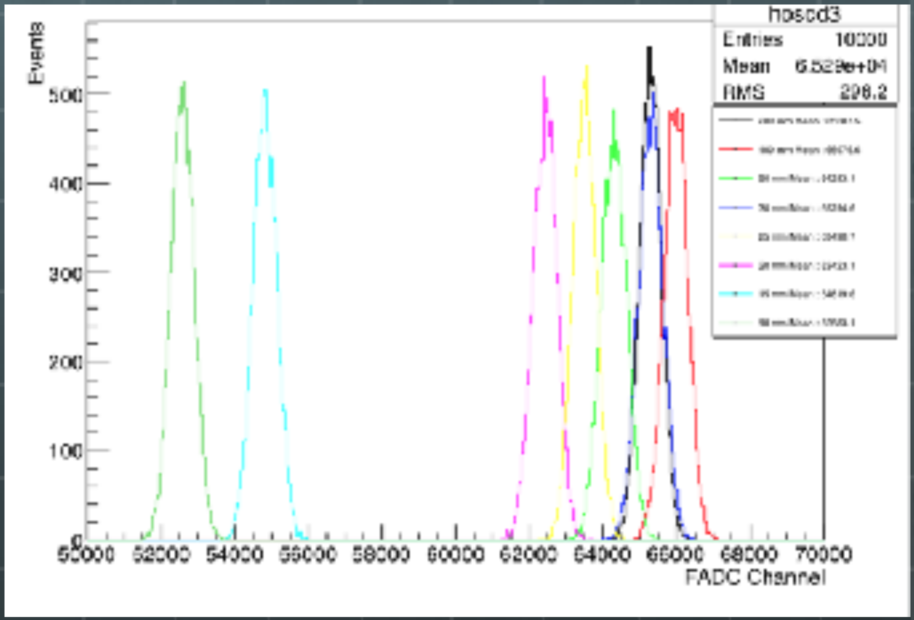
Variation of reflecting box

Insert a reflecting cone in the box

Bending Loss

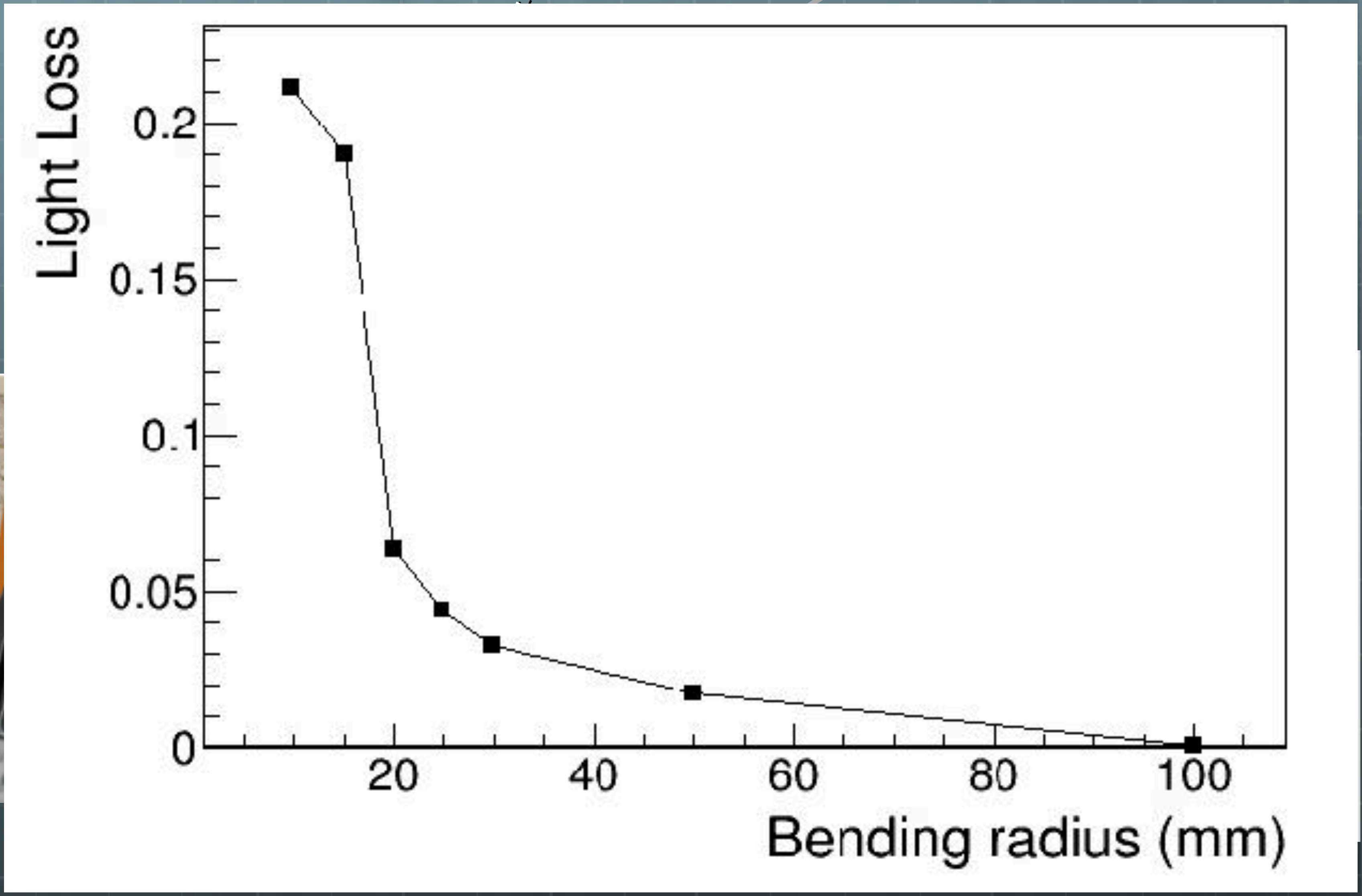
How to determine R ?





Bending Loss

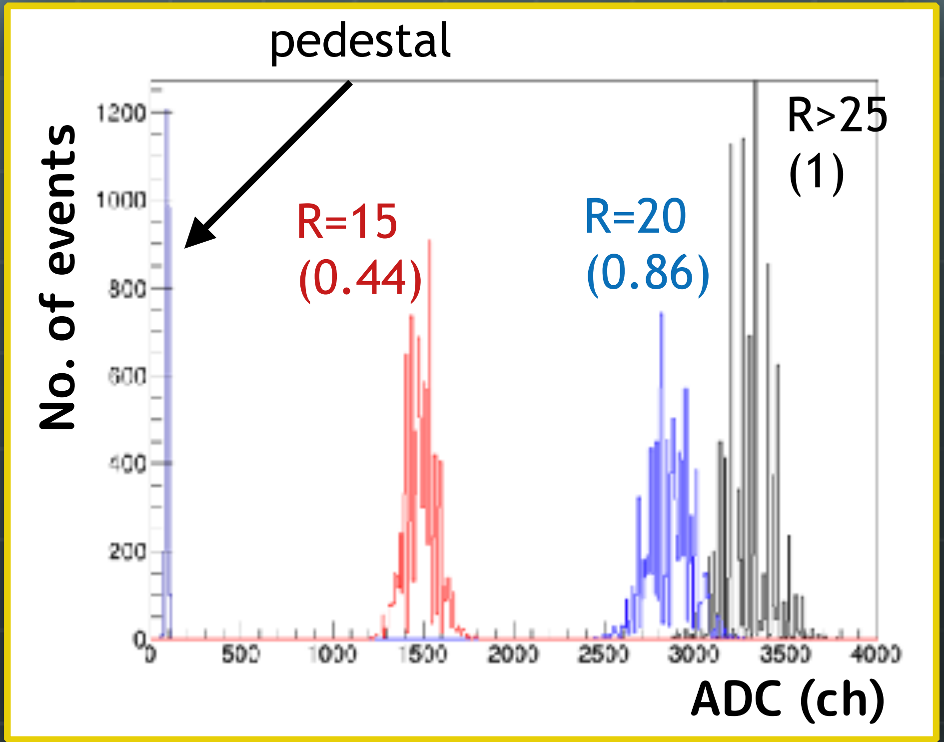
How to determine R ?



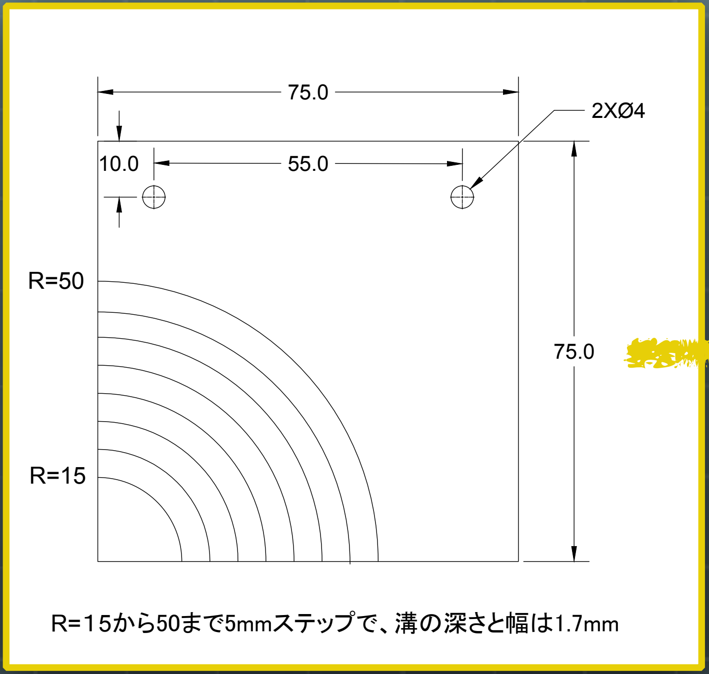
Consistency Check

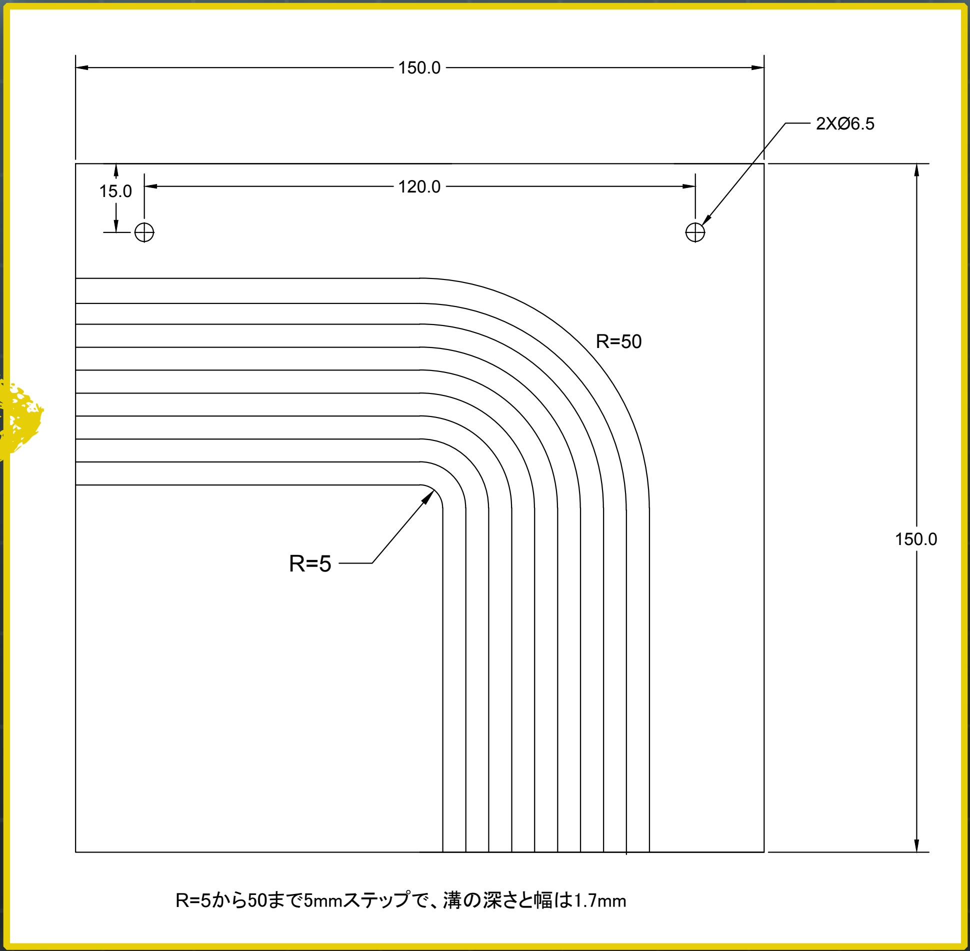
PMT

LED source



For better measurement





Pitch dependency ?

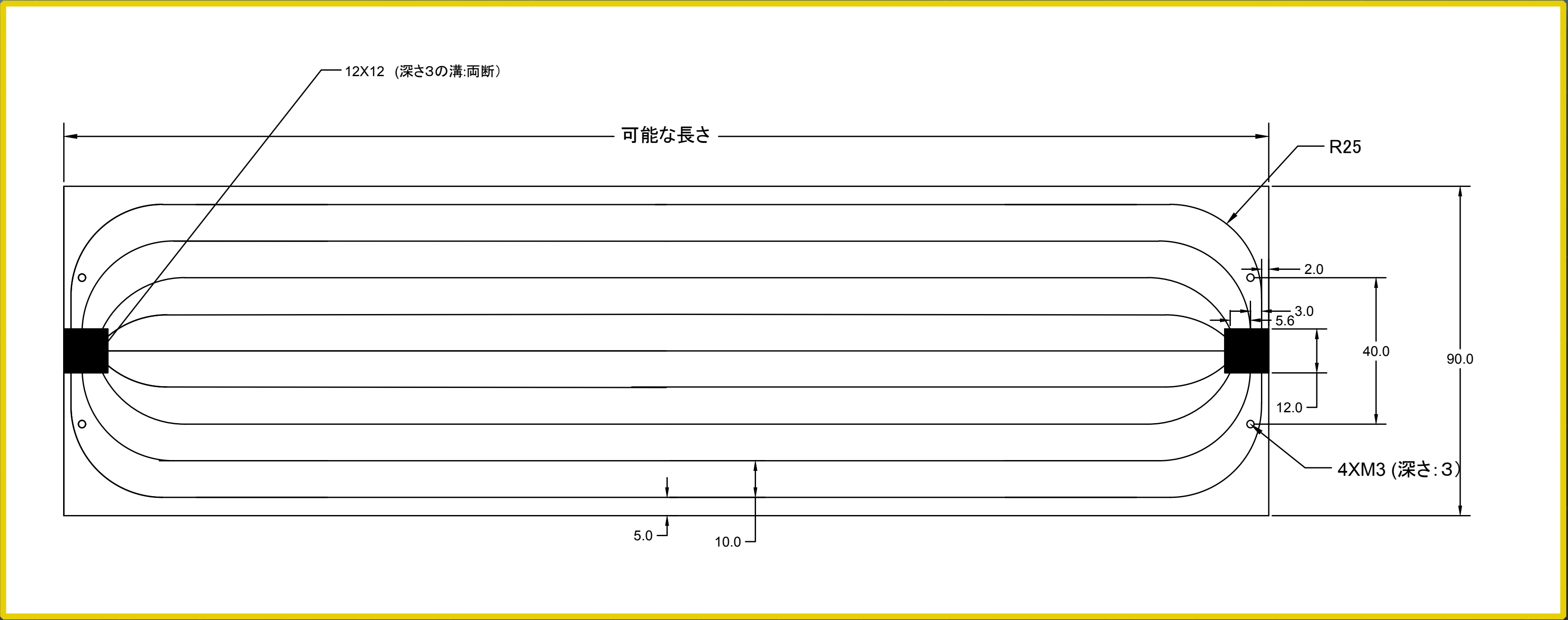
3 different pitches of groove

10mm 6.6mm, 5mm

2 different WLS fiber

- Best light yield !

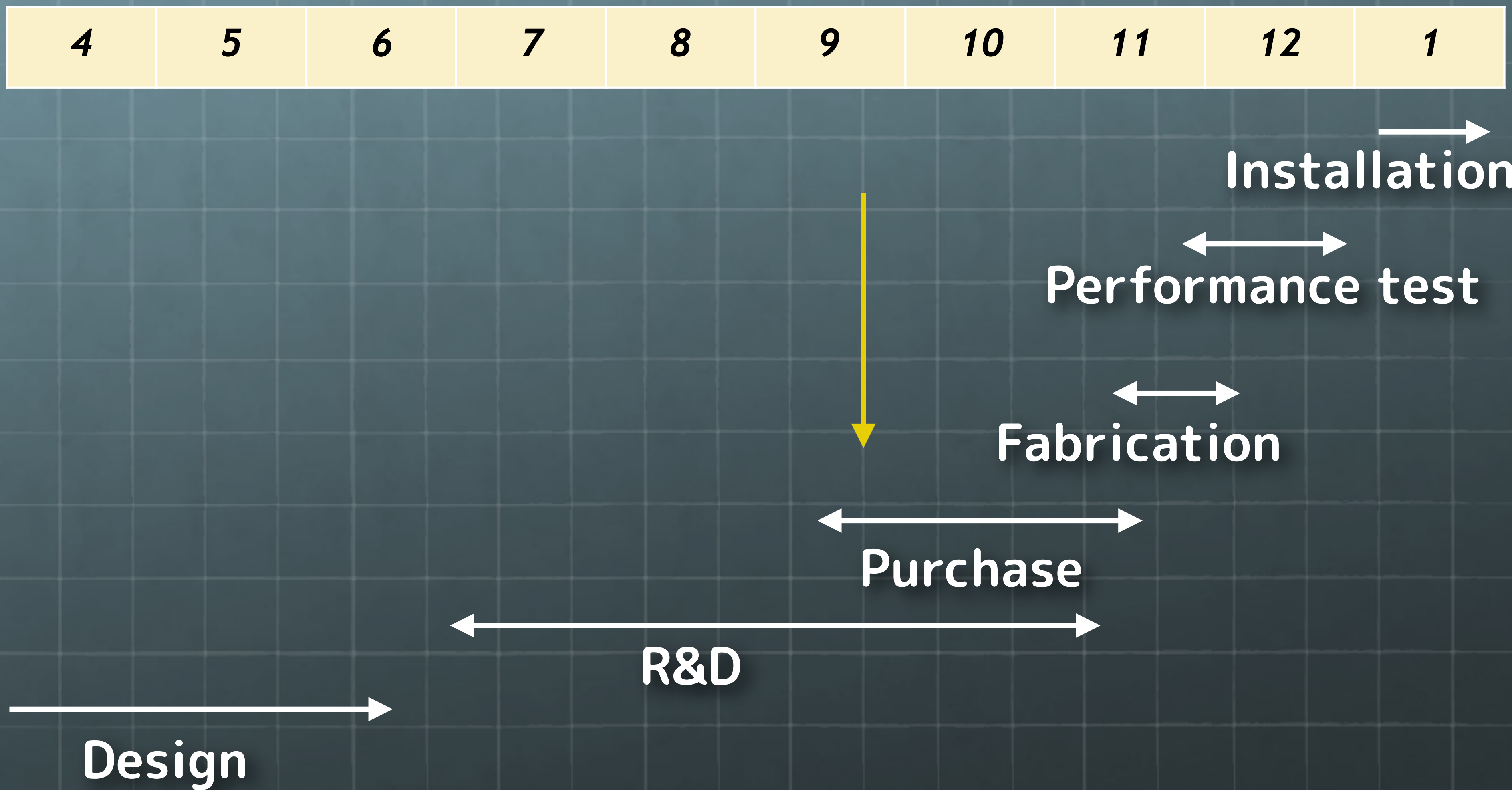
First trial



Will be delivered by the end of this month

Overall configuration will be tested

Schedule



4
5
6
7
8
9
10
11
12
1
Installation
Performance test
Fabrication
Purchase
R&D
Design

Things to do

- Decision on pitch of groove
- Selection of Reflector
- Design of fiber attachment (lightguide)
- Establishing gluing process
- Read-out circuit
- Feed-through

Decision on pitch of groove

- Select one of the 6 different configuration.
- Best light yield.
- Position dependency
  - Kye is the measurement on number of photo-electorns

    - By the end of this week ?
  - Repeat same measurement with EJ-200

    - By the end of this month

Selection of Reflector

- Large light yield
- As light as possible (~tens of micron ?)
- Operation inside vacuum
- No falling down into the beam line
- Alumilized myler
- 1st week on October (including wrapping method)

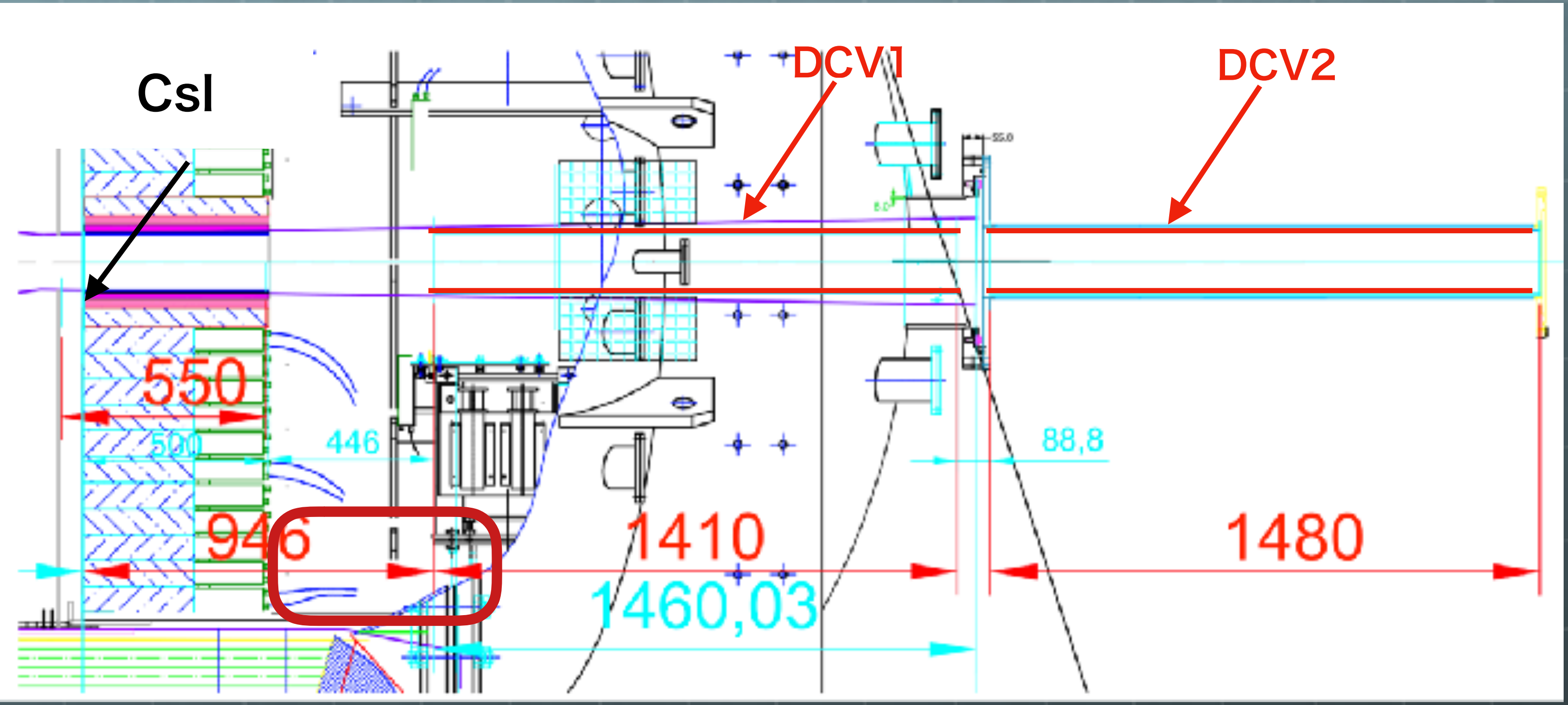
Design of fiber attachment (lightguide)

- Design & prototype making - by the end of Sep.
- Test & selection by the middle of Oct.
- Gluing process will be related.

Read-out circuit & Feed-through

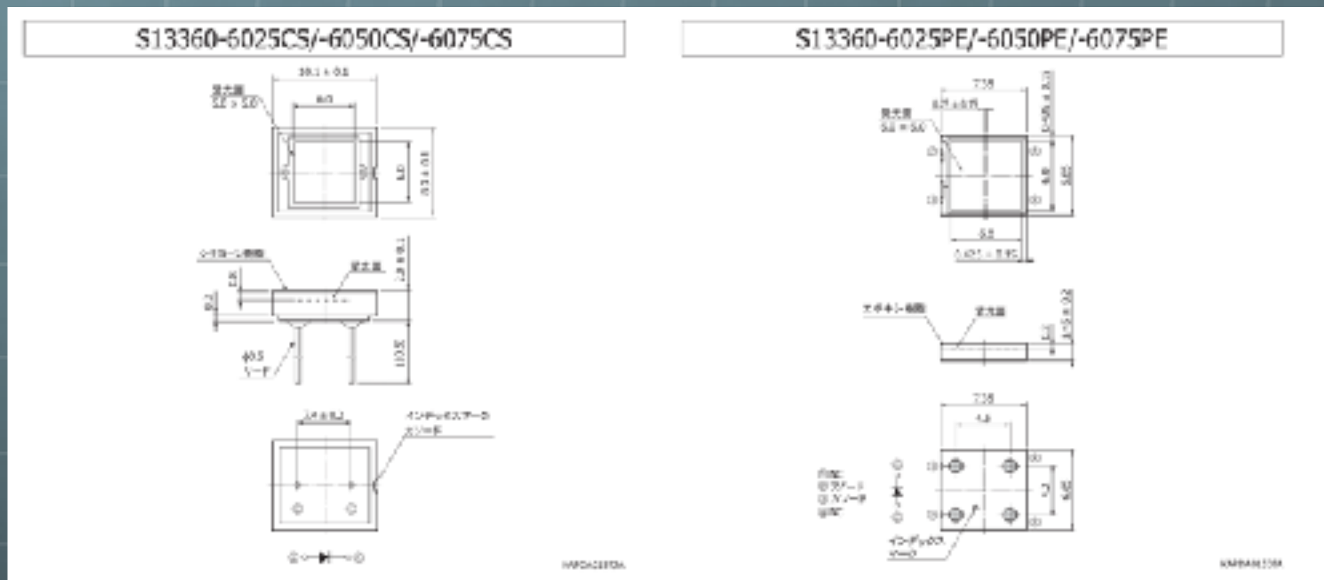
- Study at KEK
- 1st prototype by middle of Oct.
- Final design by the end of Oct.
- Production by the end of Nov.

Order Scintillator



- Not final design : just order scintillator only (no groove)
- DCV1 has a possibility to extend upstream
- How about order 8 sheets of 5mmX180mmX1500mm ?

MPPC selection



S13360-1350CS	50	1.3 × 1.3	667	セラミック	74
S13360-1350PE				表面実装型	
S13360-3050CS		3.0 × 3.0	3600	セラミック	
S13360-3050PE				表面実装型	
S13360-6050CS		6.0 × 6.0	14400	セラミック	
S13360-6050PE				表面実装型	
S13360-1375CS	75	1.3 × 1.3	285	セラミック	82
S13360-1375PE				表面実装型	
S13360-3075CS		3.0 × 3.0	1600	セラミック	
S13360-3075PE				表面実装型	
S13360-6075CS		6.0 × 6.0	6400	セラミック	
S13360-6075PE				表面実装型	

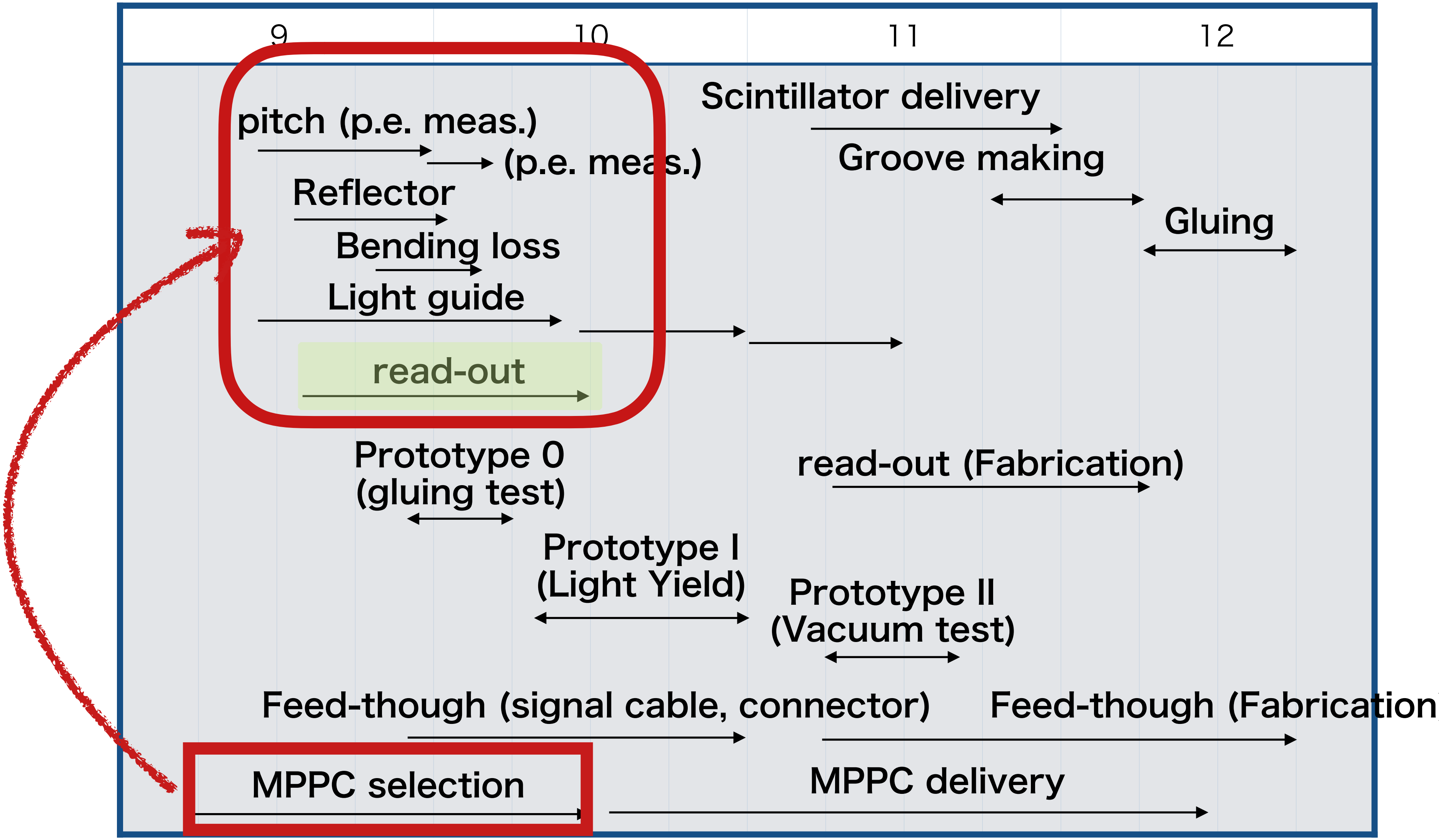
MPPC selection

電気的および光学的特性 (指定のない場合はTyp. Ta=25 ℃)

型名	測定条件	感度波長範囲 λ (nm)	最大感度波長 λp (nm)	検出効率 PDE*1 λ=λp (%)	ダークカウント*2 Typ. (kcps)	ダークカウント*2 Max. (kcps)	端子間容量 Ct (pF)	増倍率 M	降伏電圧 VBR (V)	クロストーク確率 (%)	推奨動作電圧 Vop (V)	推奨動作電圧の温度係数 ΔTVop (mV/℃)
S13360-1325CS	Vover =5 V	270 ~ 900	450	25	70	210	60	7.0×10^5	53 ± 5	1	VBR + 5	54
S13360-1325PE		320 ~ 900										
S13360-3025CS		270 ~ 900			400	1200	320					
S13360-3025PE		320 ~ 900										
S13360-6025CS		270 ~ 900			1600	5000	1280					
S13360-6025PE		320 ~ 900										
S13360-1350CS	Vover =3 V	270 ~ 900		40	90	270	60	1.7×10^6		3	VBR + 3	
S13360-1350PE		320 ~ 900										
S13360-3050CS		270 ~ 900			500	1500	320					
S13360-3050PE		320 ~ 900										
S13360-6050CS		270 ~ 900			2000	6000	1280					
S13360-6050PE		320 ~ 900										
S13360-1375CS	Vover −3 V	270 ~ 900		50	90	270	60	4.0×10^6		7	VBR + 3	
S13360-1375PE		320 ~ 900										
S13360-3075CS		270 ~ 900			500	1500	320					
S13360-3075PE		320 ~ 900										
S13360-6075CS		270 ~ 900			2000	6000	1280					
S13360-6075PE		320 ~ 900										

*1: 検出効率は、クロストークとアフターパルスを含んでいません。
*2: 閾値=0.5 p.e.
注) 上記特性値は、表中の増倍率が得られる動作電圧における値です (製品に添付されるデータを参照してください)。

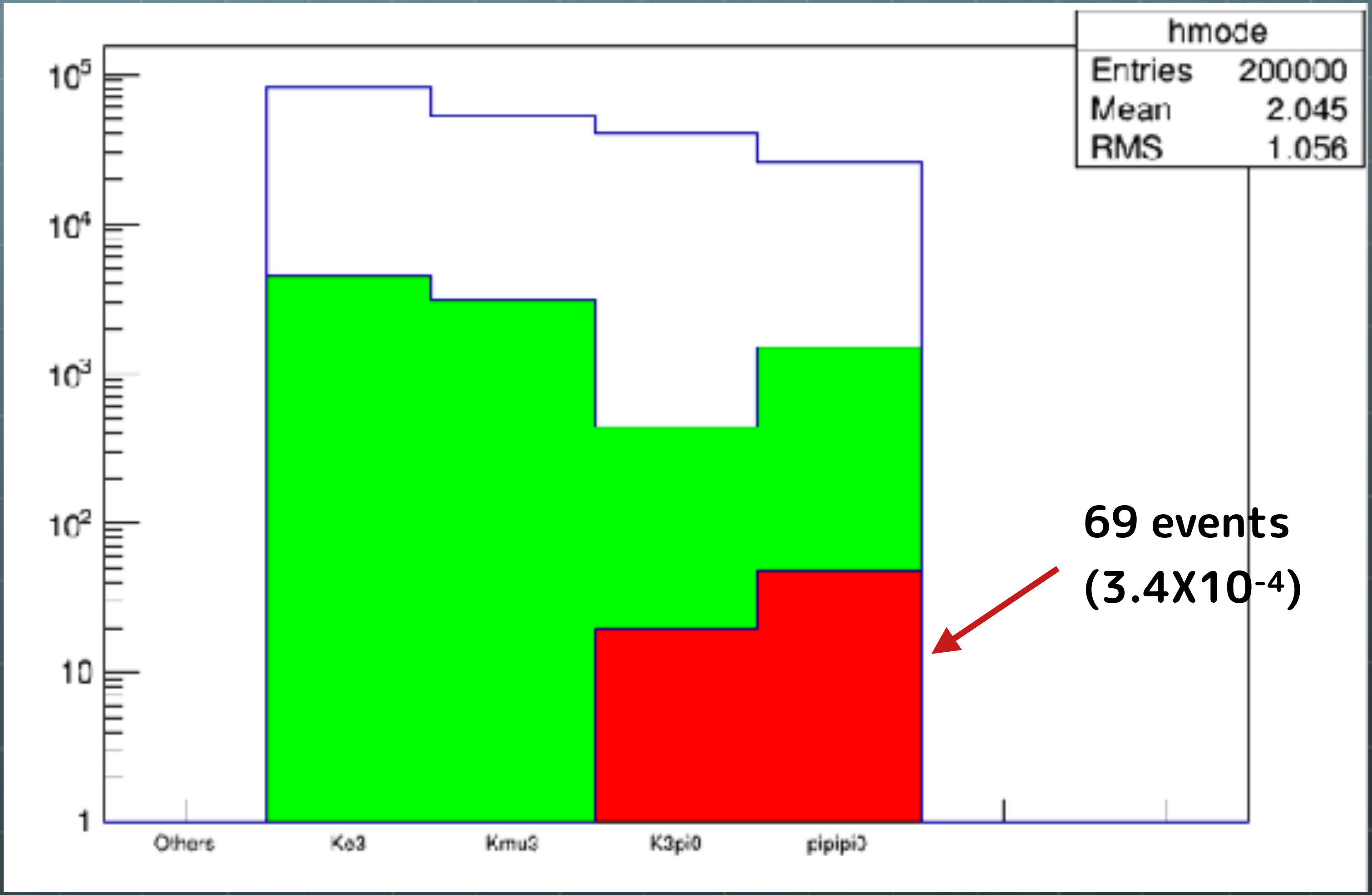
Schedule



No contingency plan. Keep schedule

Simple M.C.

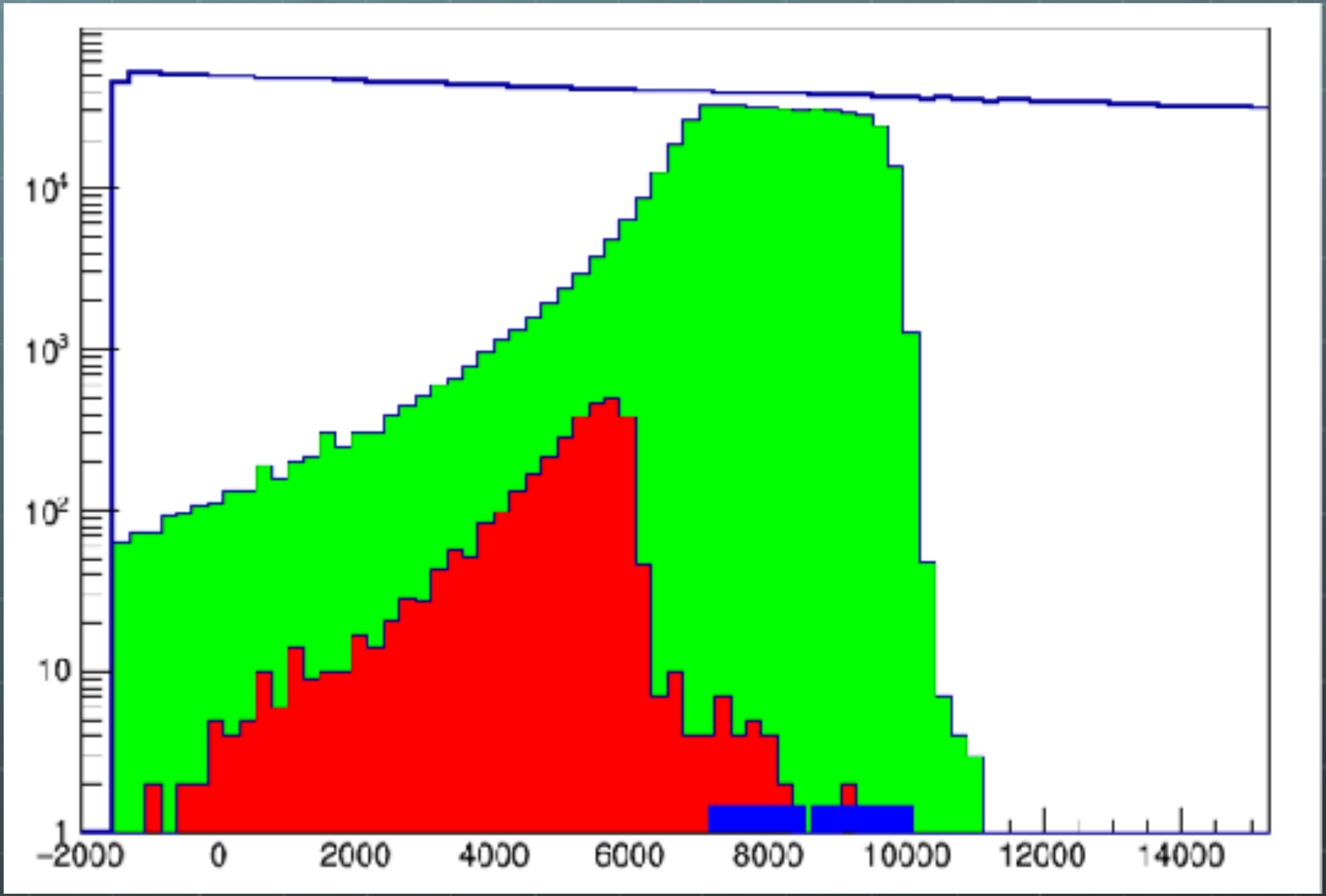
Decay Mode



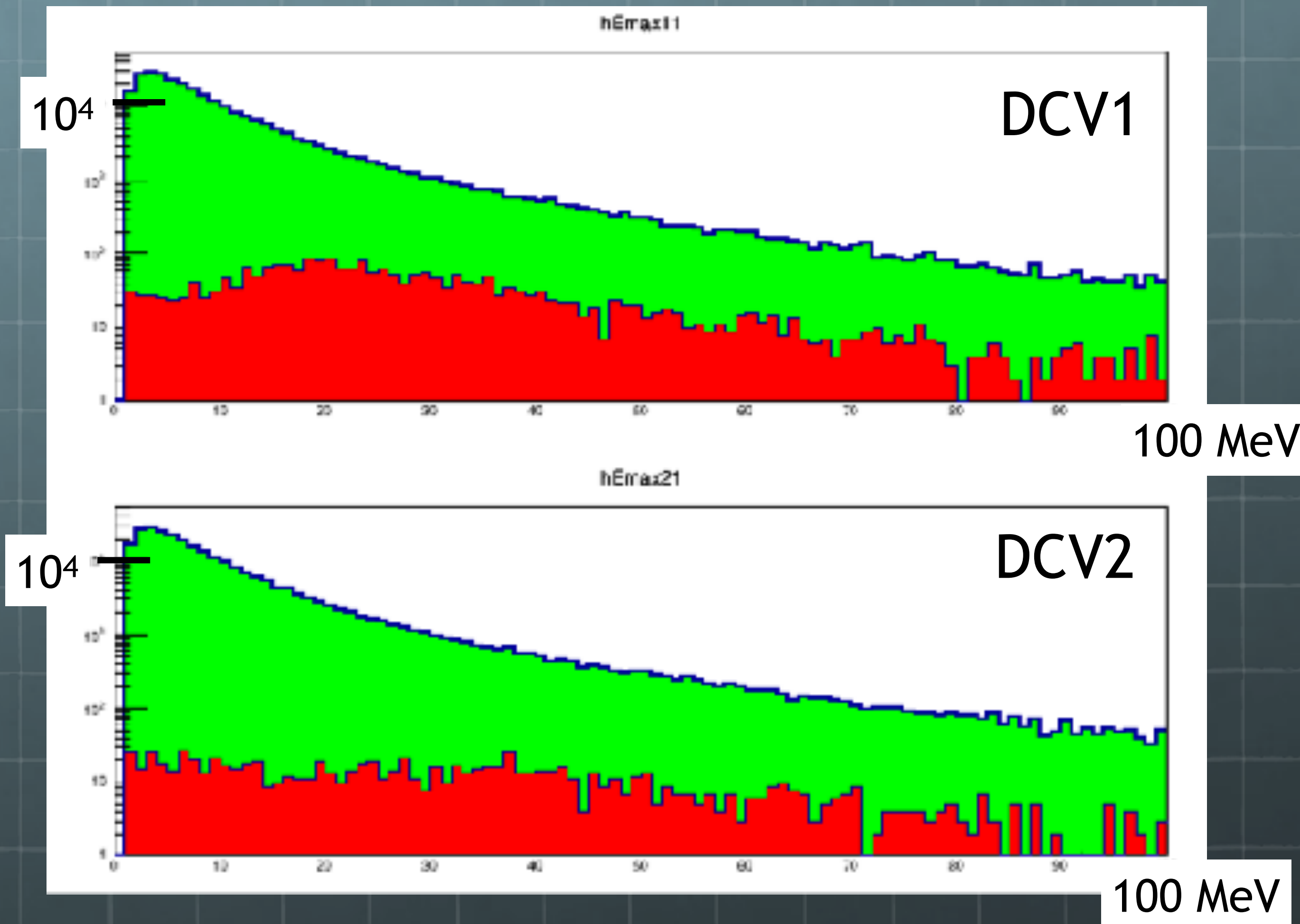
69 events

$(3.4X10^{-4})$

Vertex (for 10^7 KL)



Energy Deposit (for 10^7 KL)



20 Ch./MeV -> 2000 Ch./100MeV (12 bits)