E391a Run3 Analysis

Workshop "New Developments of Flavor Physics" 2009 (2009 Mar 9)

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- Run3 Analysis
  - Confirmation
    - Run stability
    - KL flux estimation
  - Optimization
    - Acceptance study
    - modified halo-n MC

Introduction

E391a Experiment

- Measures $K_L \to \pi^0 \nu \bar{\nu}$ @ KEK 12GeV PS
  - first dedicated experiment
  - pilot experiment for K^OTO (J-PARC E14)

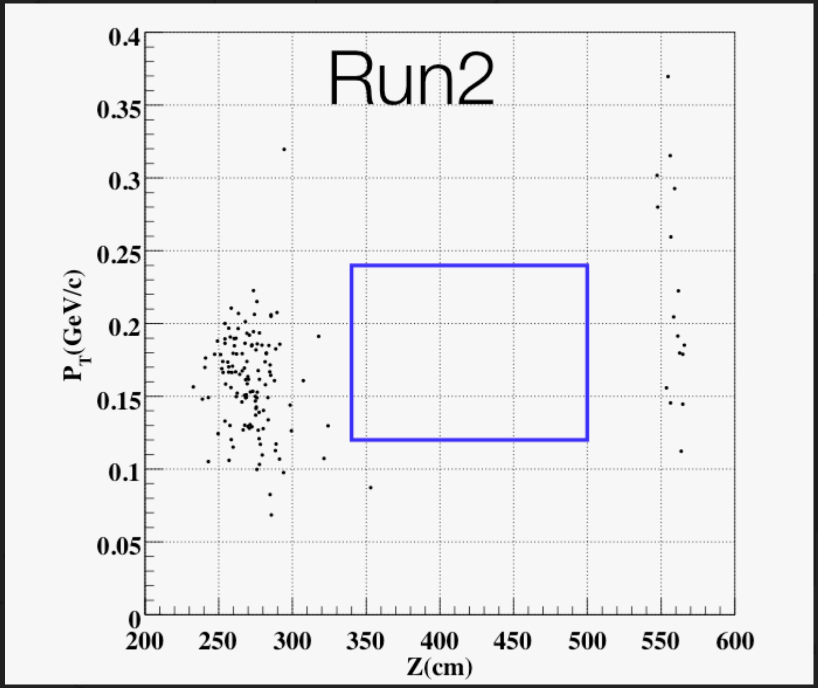
- Three Physics Runs
  - Run1 (2004 Feb-Jul)
  - Run2 (2005 Feb-Apr)
  - Run3 (2005 Nov-Dec)

- Run2 Result

  blind analysis

  No event observed in the signal box

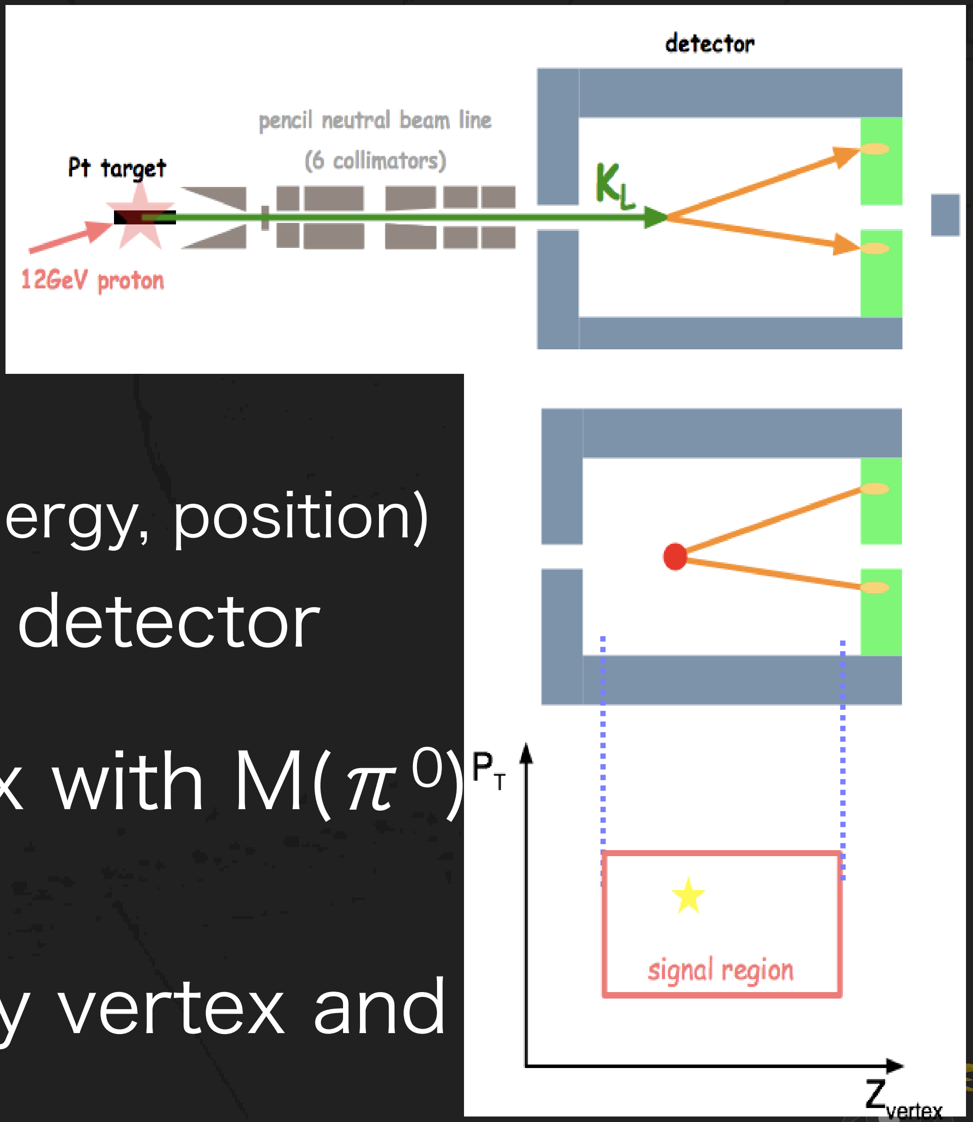
  Upper limit 6.7 x 10^{-8} (90% C.L.) (Phys. Rev. Lett. 100 201802, 2008)



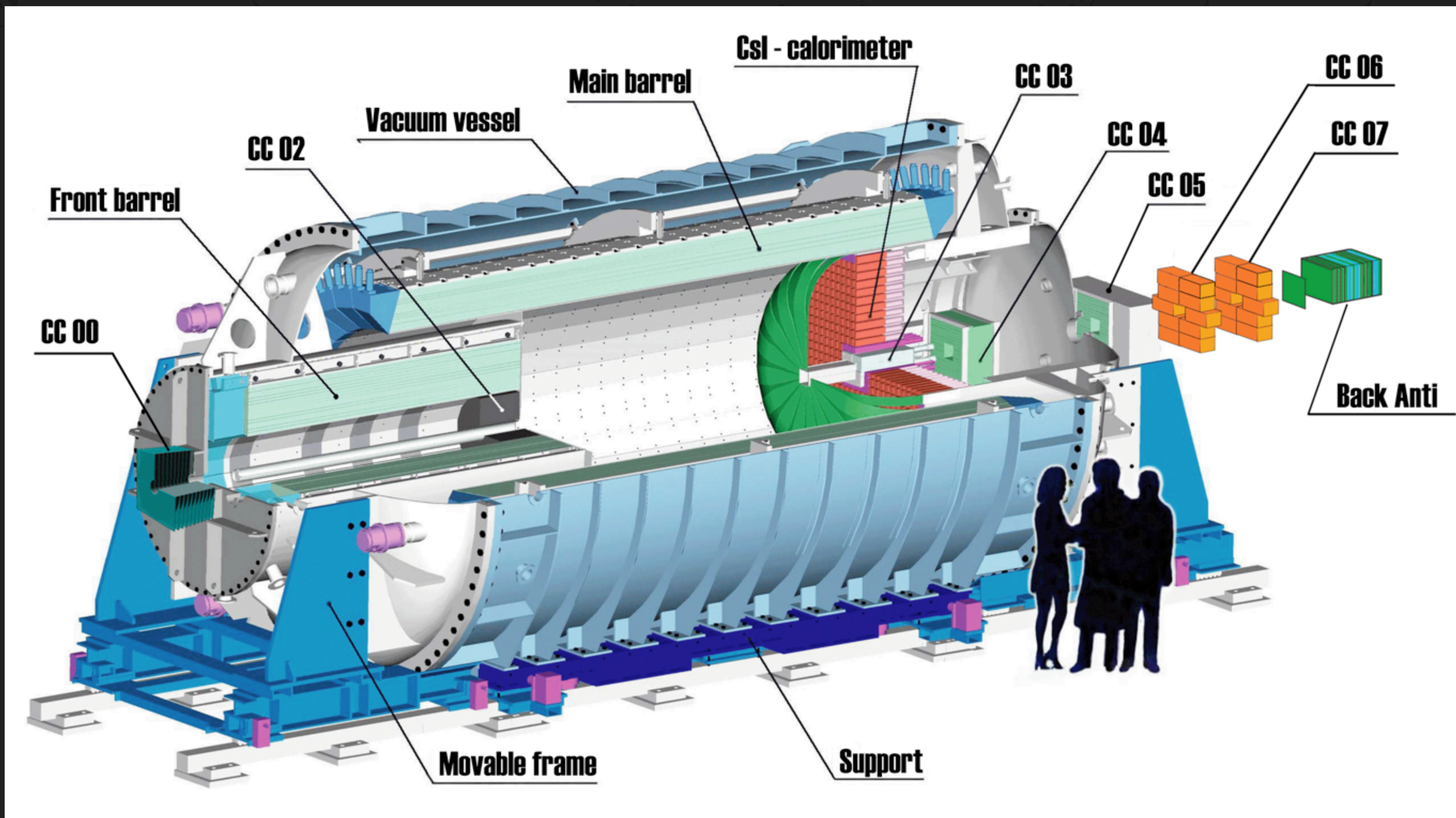
Experimental Principles

- How to identify $K_L \to \pi^0 \nu \overline{\nu}$ state?
  - π^0 └→ 2γ; $\nu \overline{\nu}$ → cannot detect
- "2γ + nothing"
  - 2γ → CsI calorimeter (energy, position)
  - nothing → hermetic veto detector
- Reconstruct decay vertex with $M(\pi^0)$

  $M(\pi^0) = E_1E_2(1\text{-}\cos\theta)$
  - select signal using decay vertex and transverse momentum

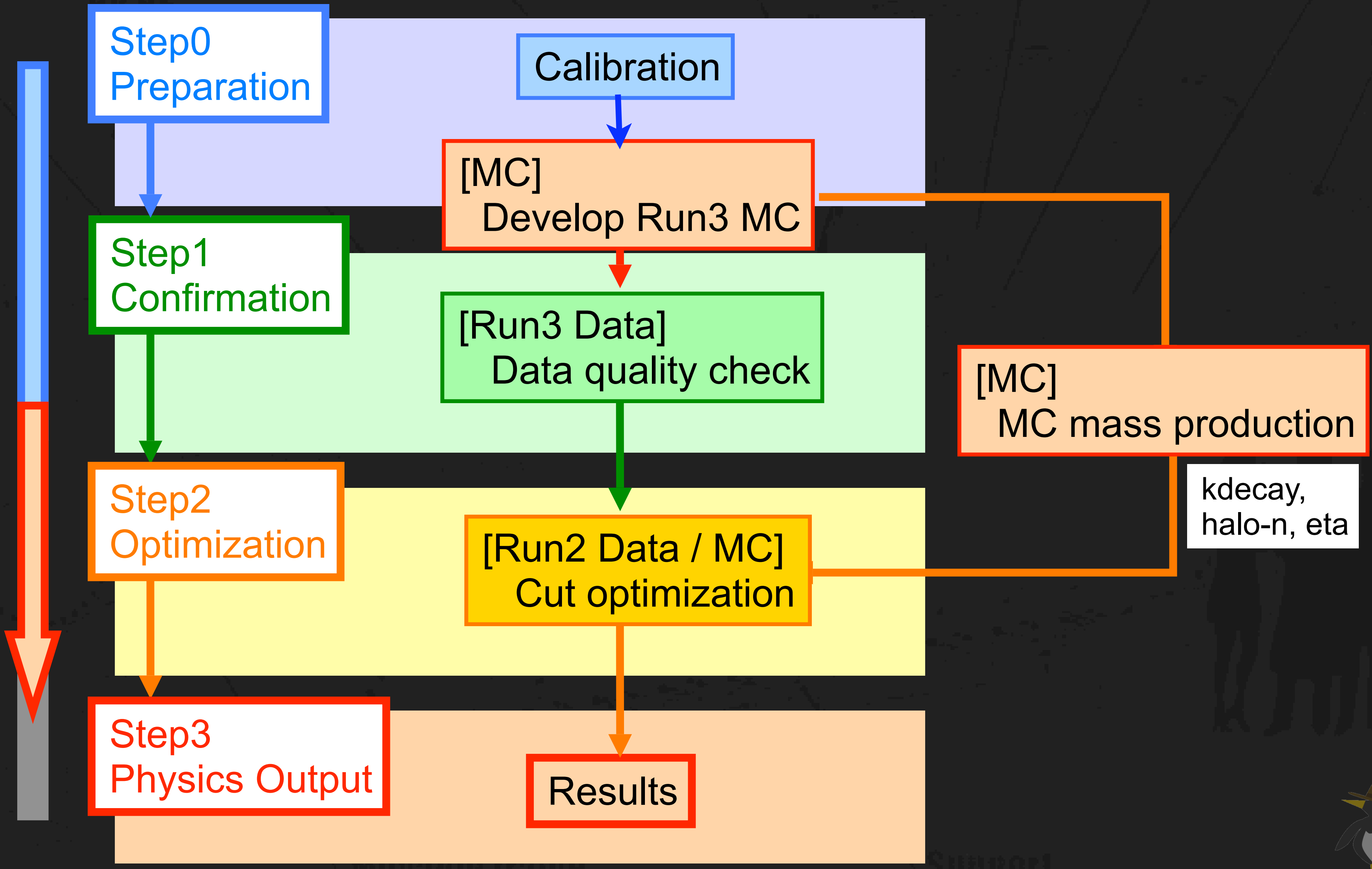


E391a Detector



Run3 Analysis Overview

Strategy for Run3 Analysis

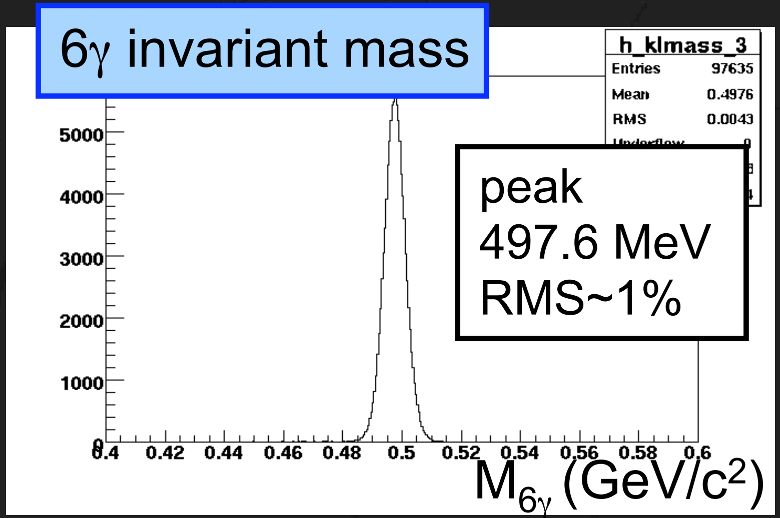


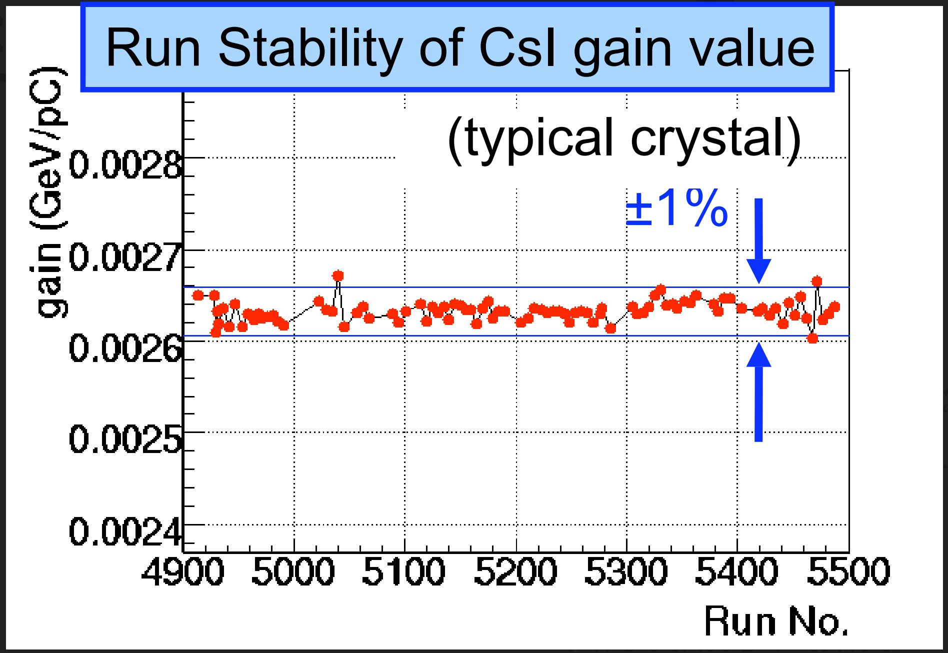
Step1 : Confirmation

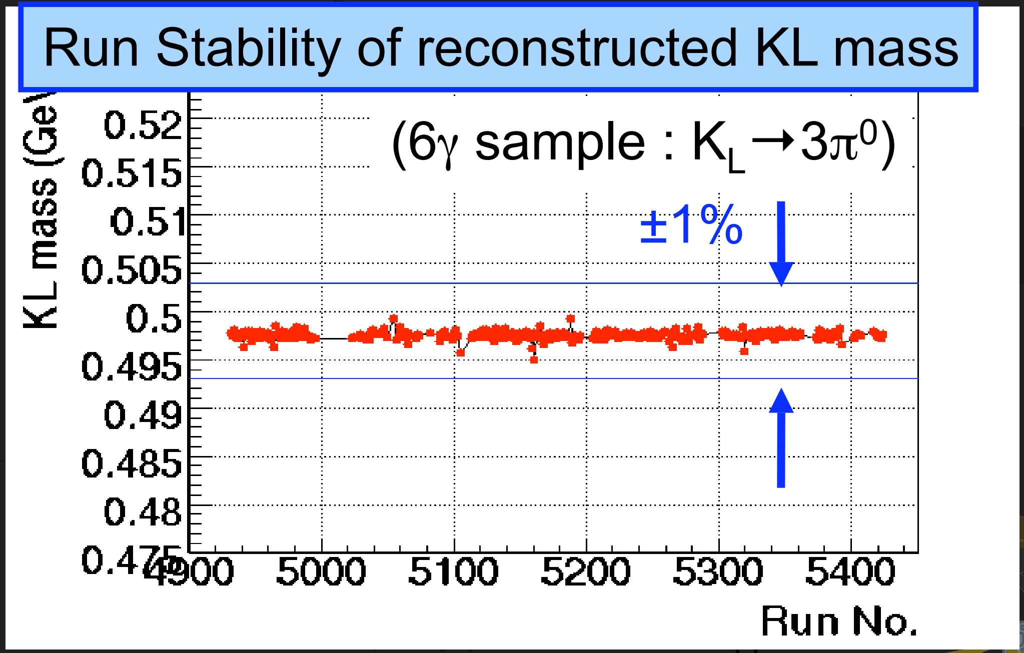
Run stability
KL flux estimation

Calibration & Run Stability

- Calibration & Run Stability completed / confirmed







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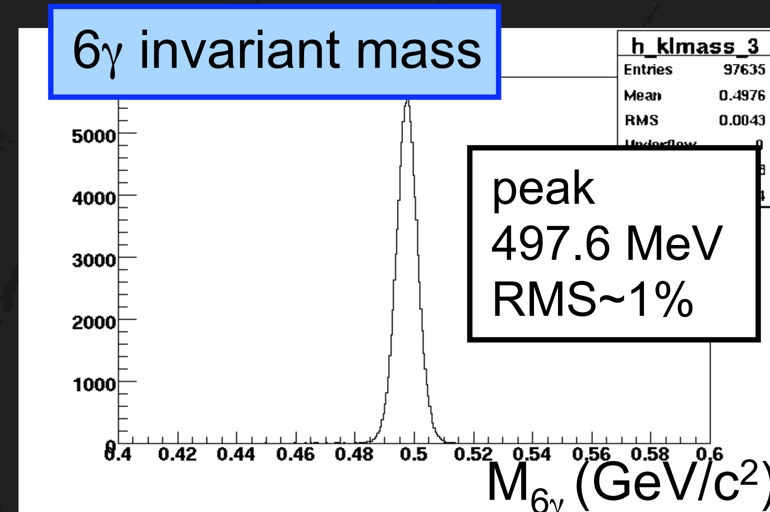
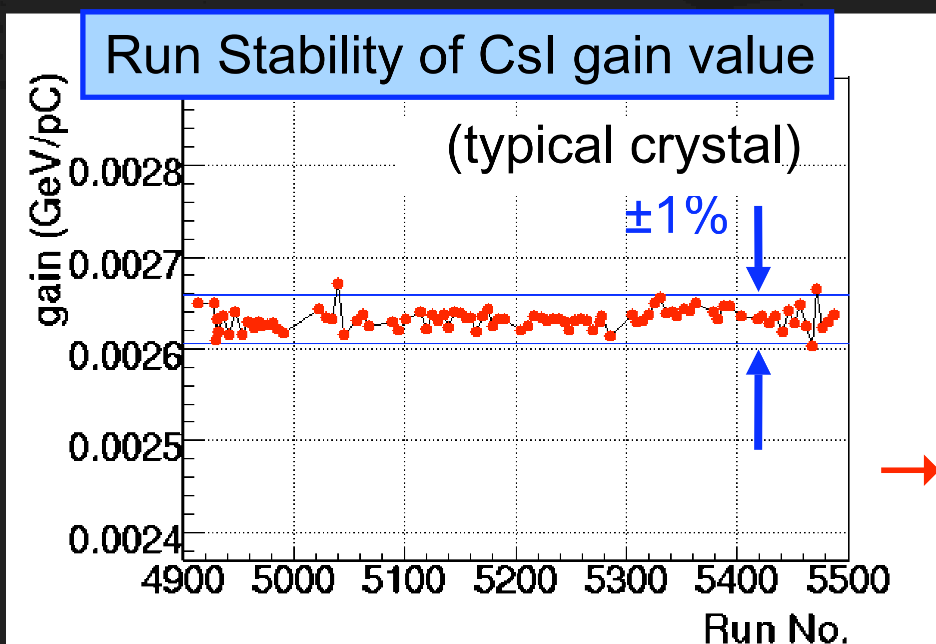
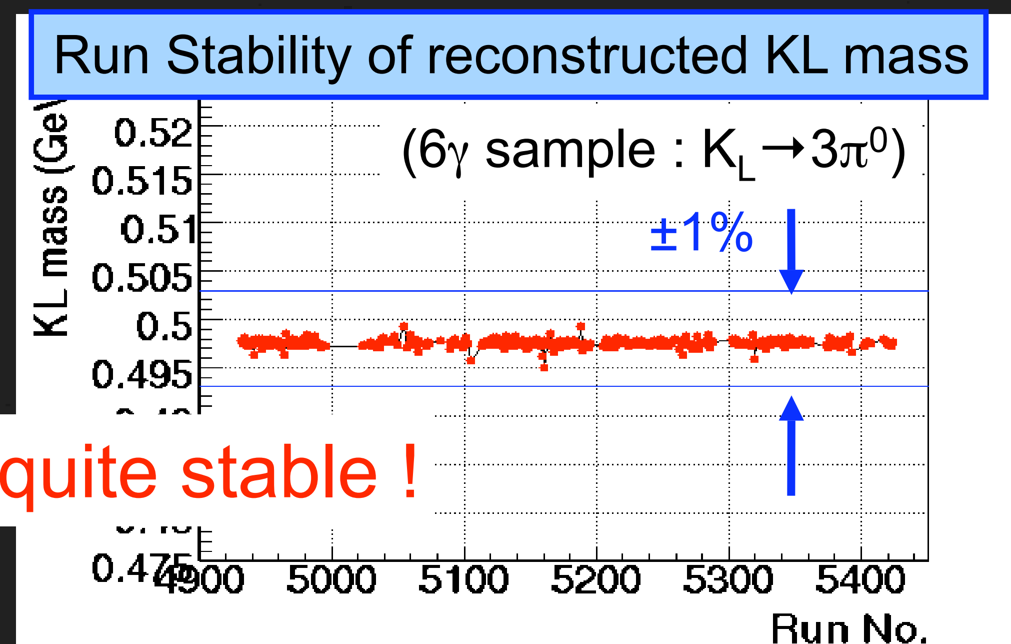


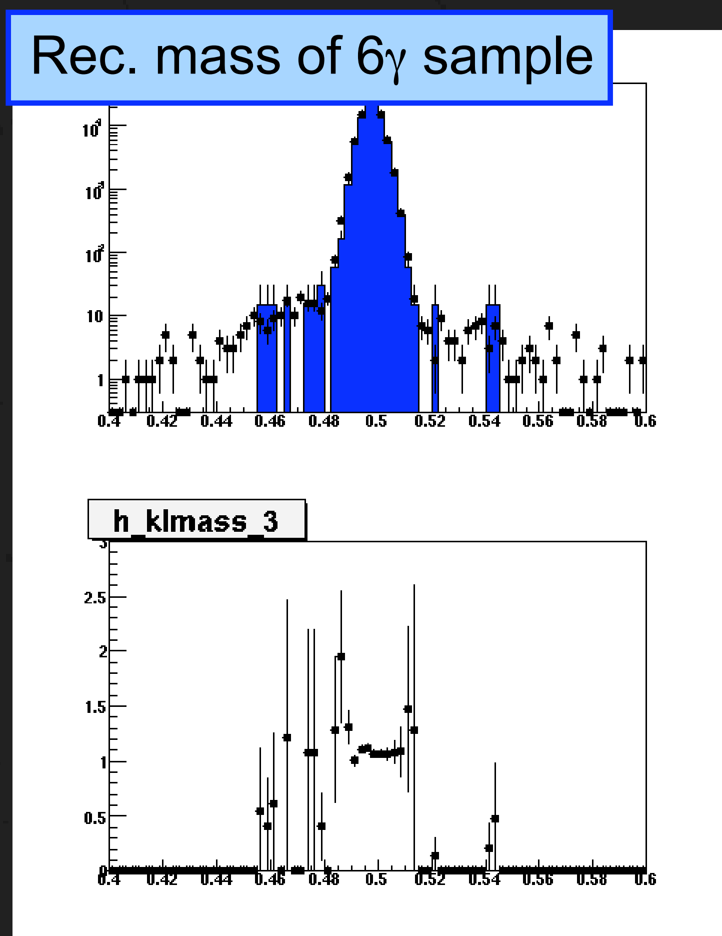


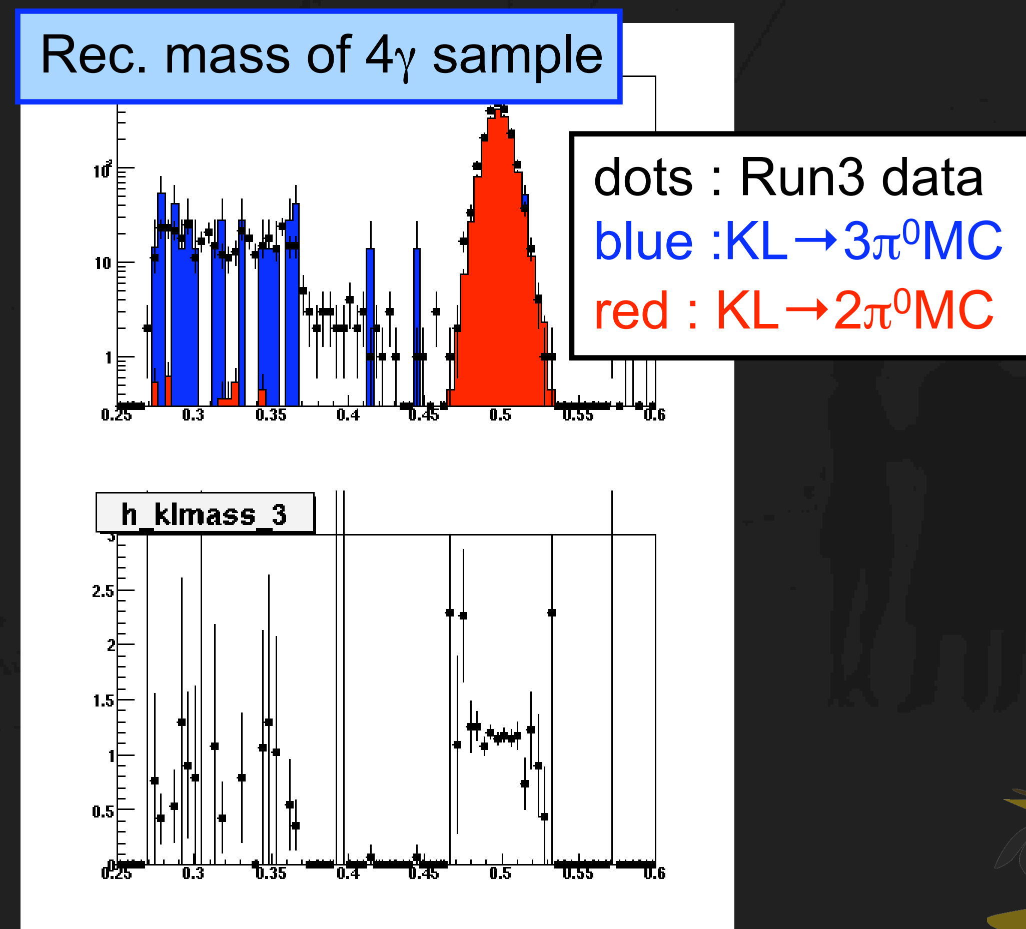


→ quite stable !

Reconstructed Mass Distriburtion

- Reconstructed mass distribution checked for KL→3π^0 and KL→2π^0 modes





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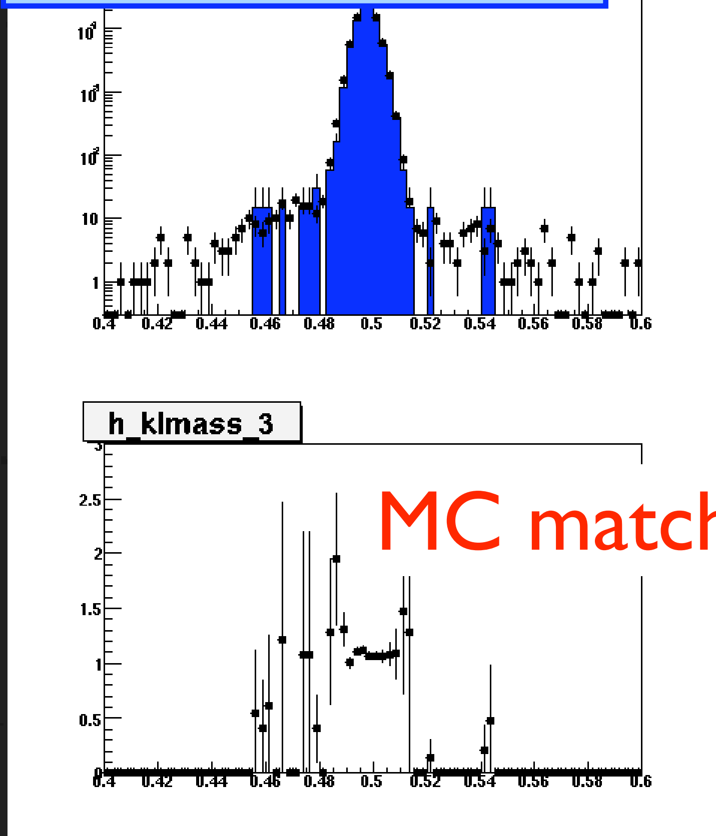
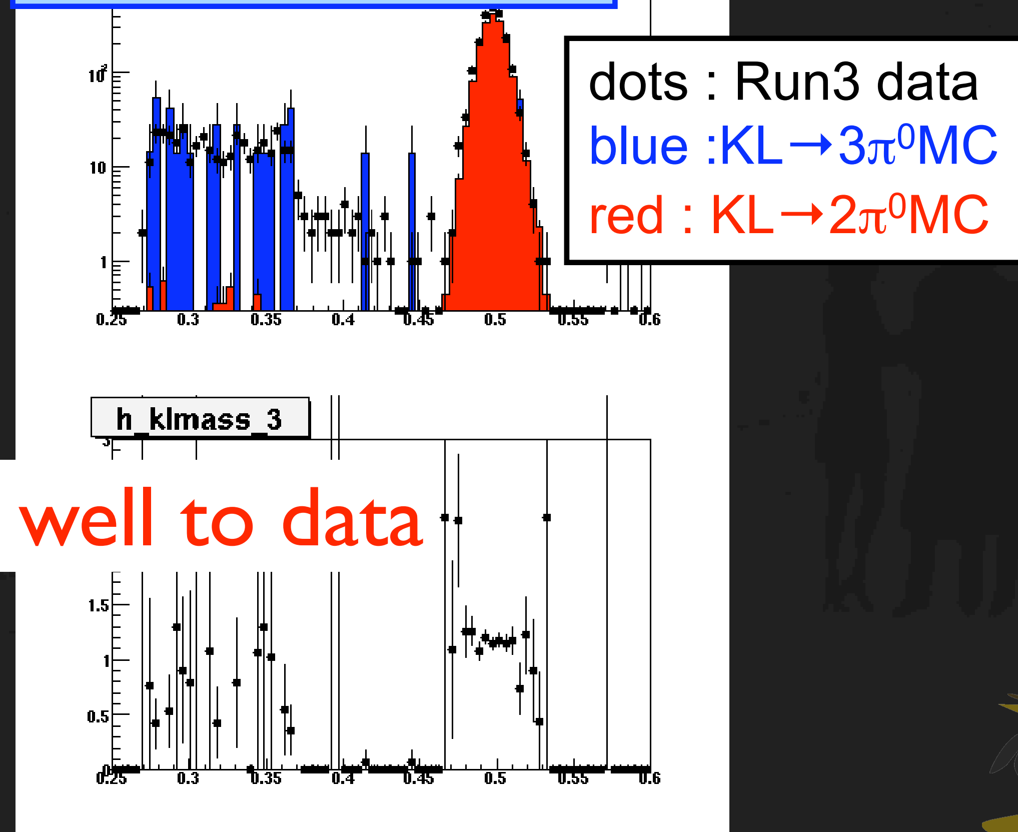
Rec. mass of 6γ sample



Rec. mass of 4γ sample



MC matches well to data

K_L Flux Estimation

- \# of K_L is estimated via 3 decay modes
  : $K_L \to 3\pi^0$, $2\pi^0$, 2γ

mode	# of events in data	# of events in MC(addbg)	acceptance	flux
$3\pi^0$	48229	8149 (stat. 5.0e9)	7.62×10^{-5}	3.24×10^{9} (-5.0%)
$2\pi^0$	1072	11620 (stat. 1.5e9)	3.62×10^{-4}	3.41×10^{9} (---)
$\gamma\gamma$	14278	30148 (stat. 2.0e8)	7.04×10^{-3}	3.70×10^{9} (+8.5%)

cf.) Run2 $3\pi^0$: 5.02×10^{9} (-2.1%)
$2\pi^0$: 5.13×10^{9} (---)
$\gamma\gamma$: 5.45×10^{9} (+6.2%)

Run3 statistics : ~70% of Run2

Step2 : Optimization

Optimization for event selection
Modified halo-n MC

Analysis Effort on Run3

- Modification from Run2 analysis
  - wanting more acceptance
  - better understanding to background

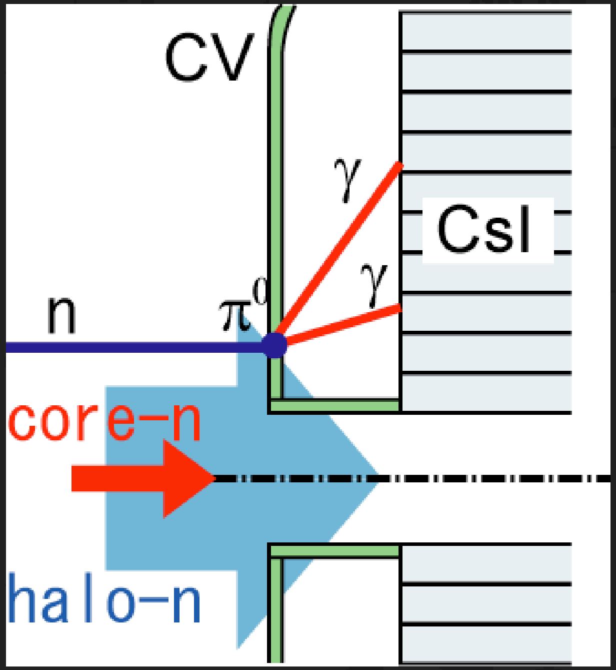
- Study for increasing acceptance
  - optimize event selection
- Better understanding to BG events
  - modify halo-n MC

Study for Getting More Acceptance

- Largest acceptance loss in Run2

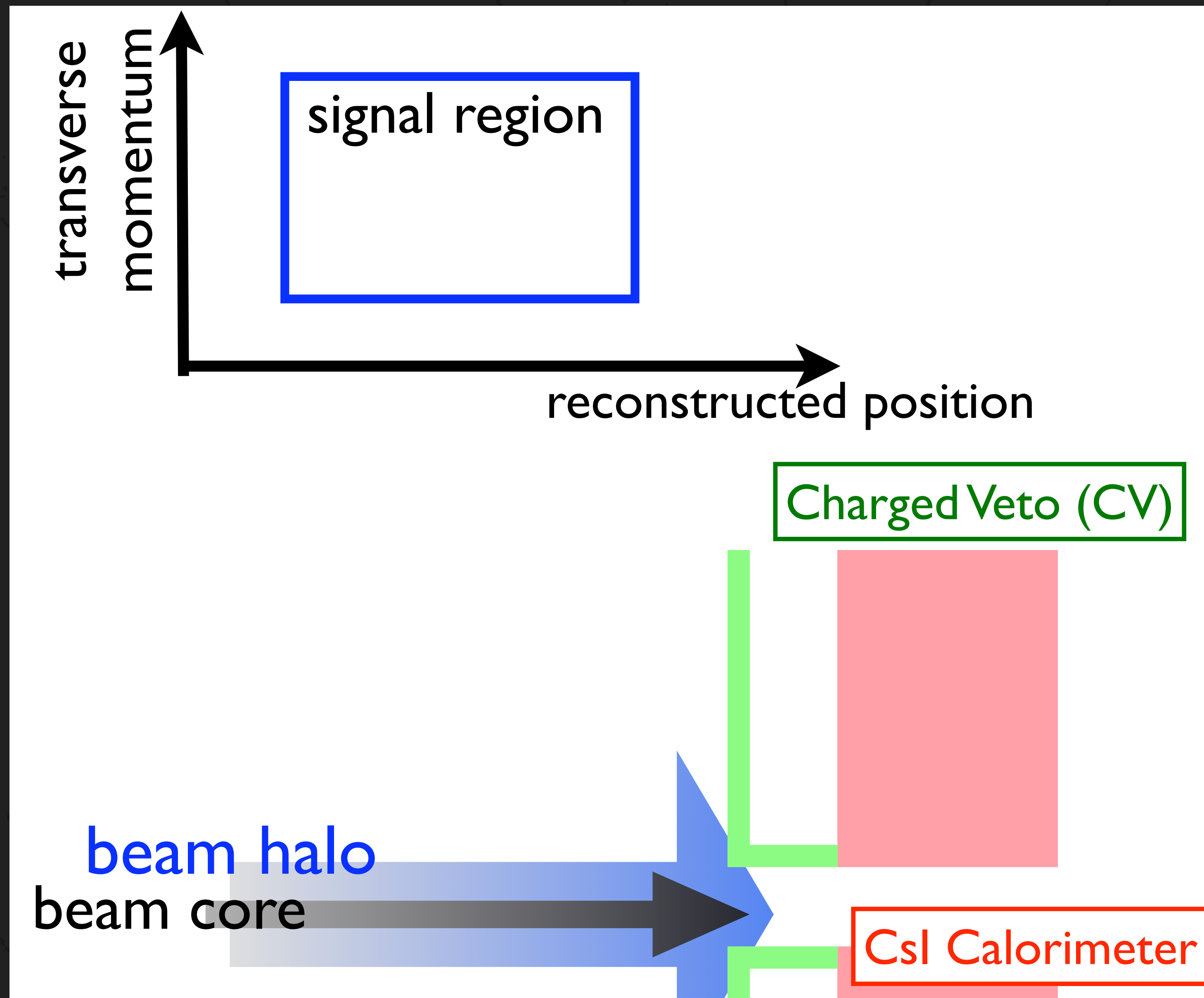
  “γ-RMS cut” (~42%)

  to reject “CV halo-neutron” background

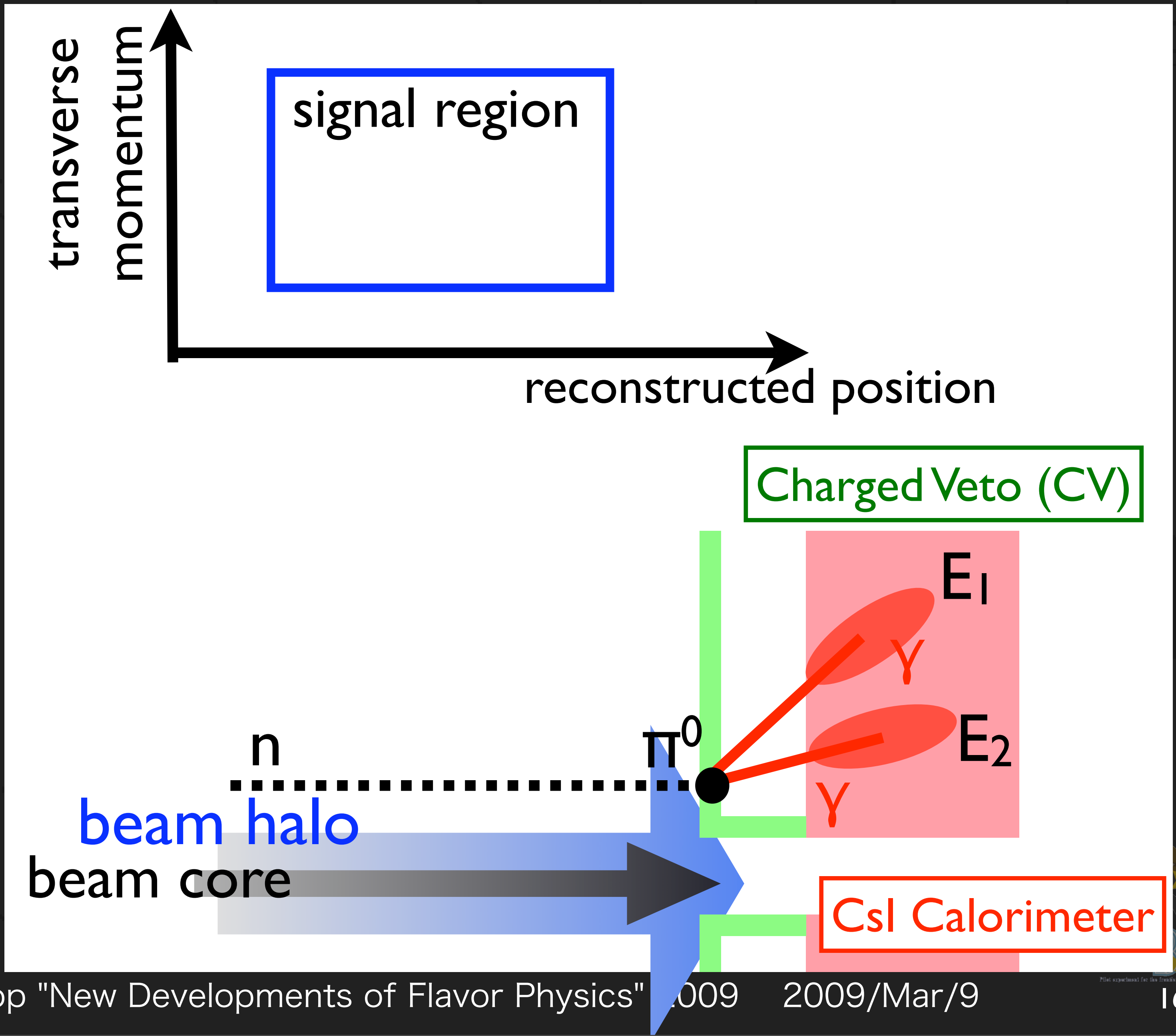


- How does CV halo-n events makes background?

Mechanism of halo-n CV background



Mechanism of halo-n CV background



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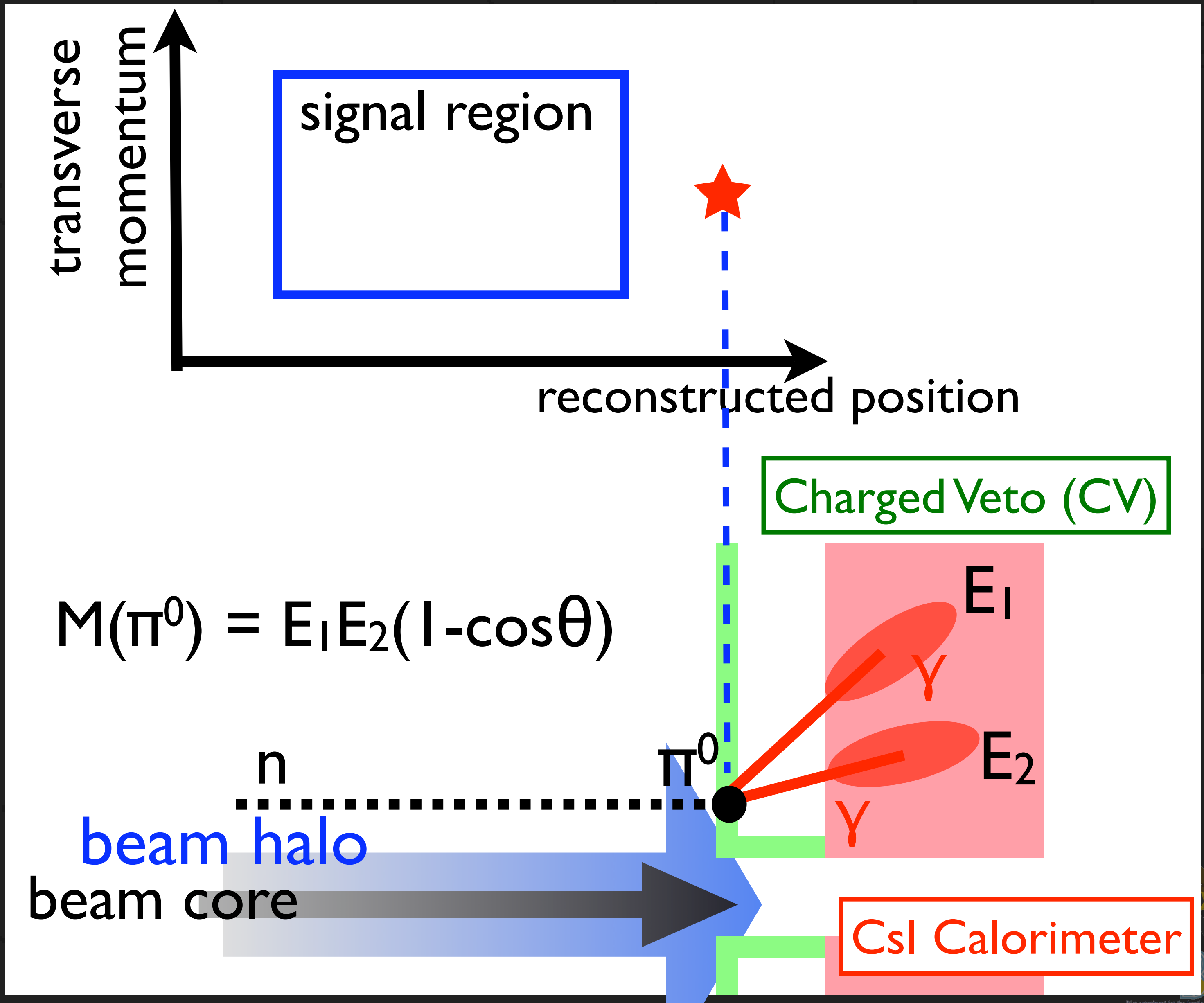

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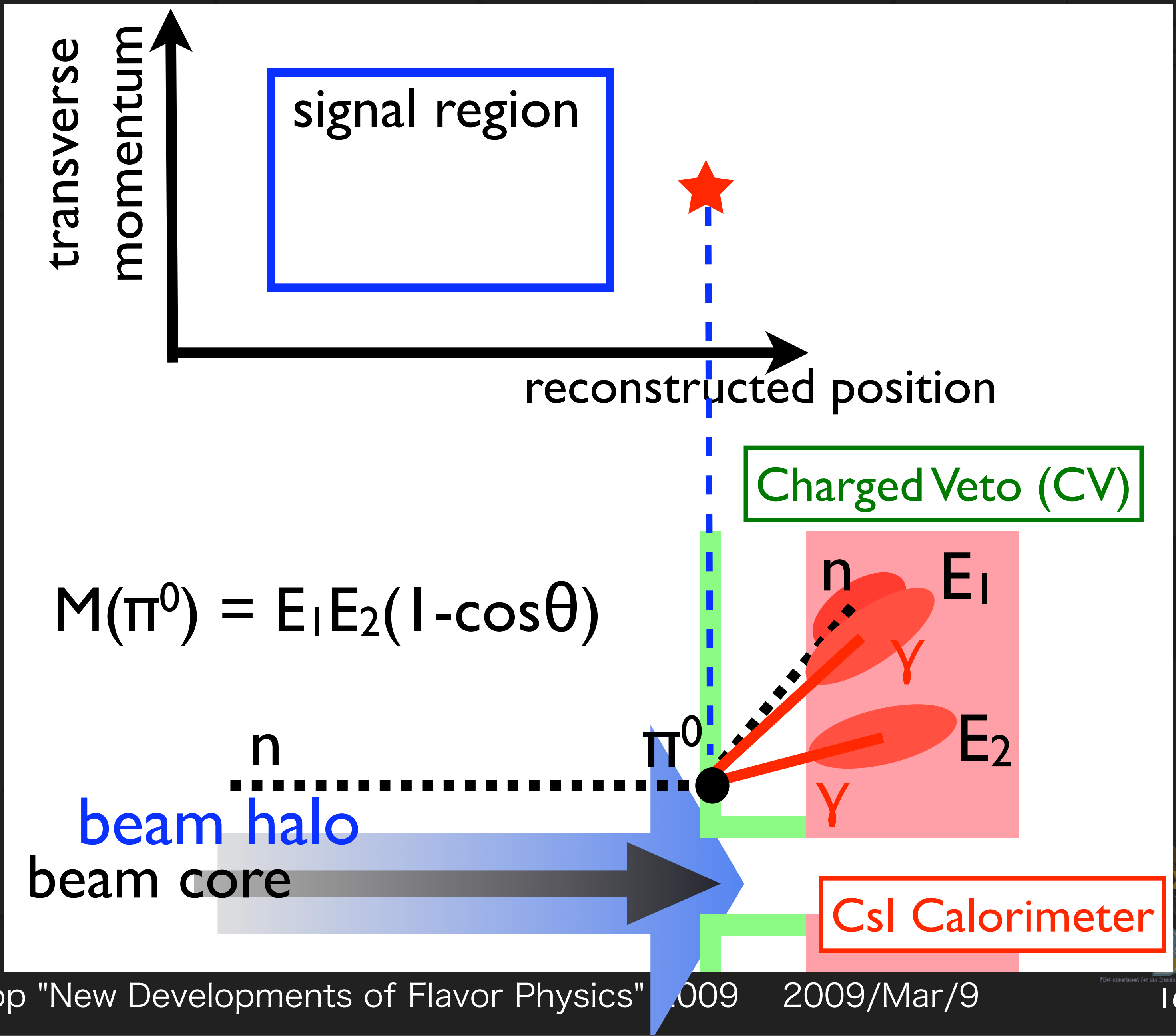

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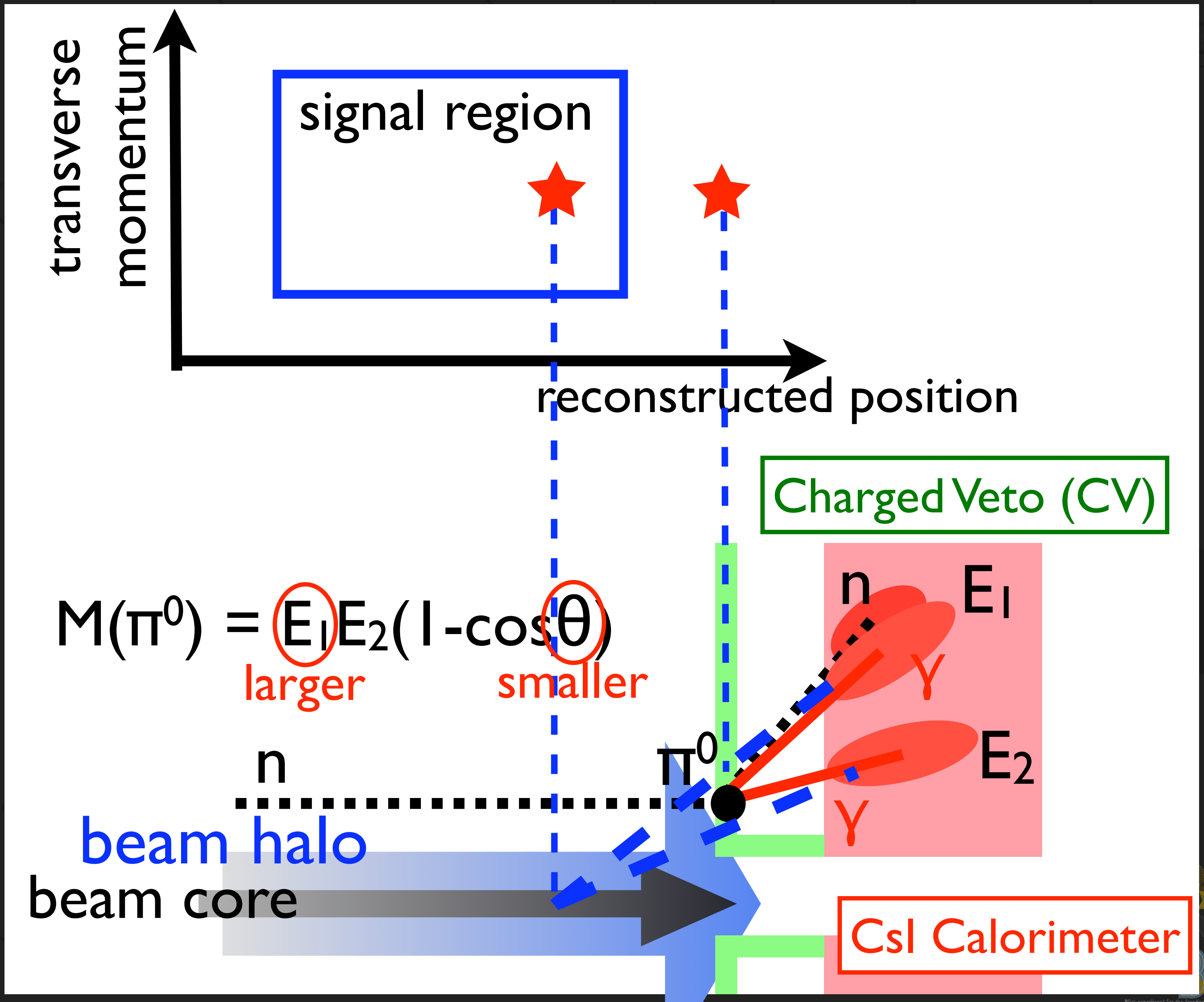

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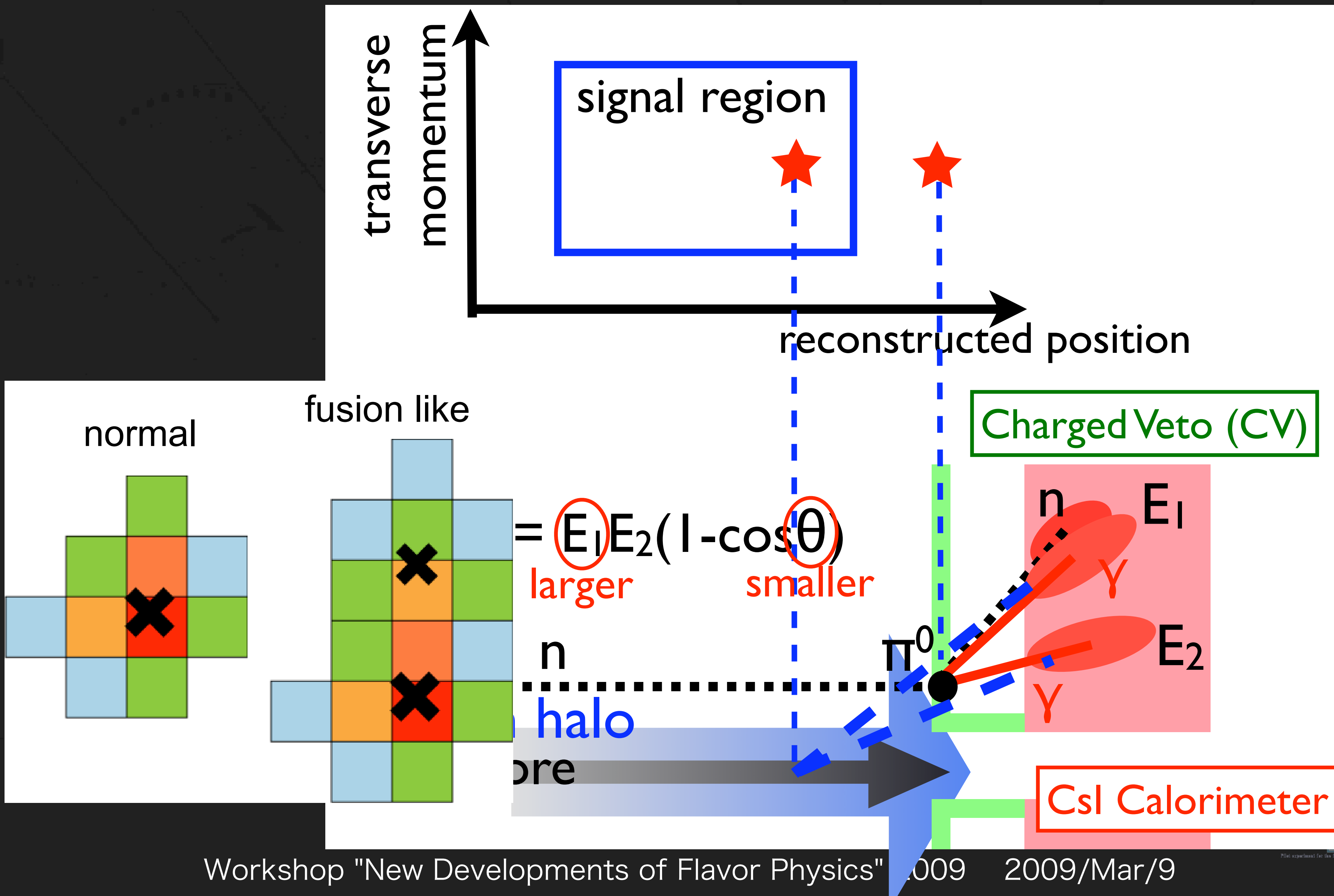
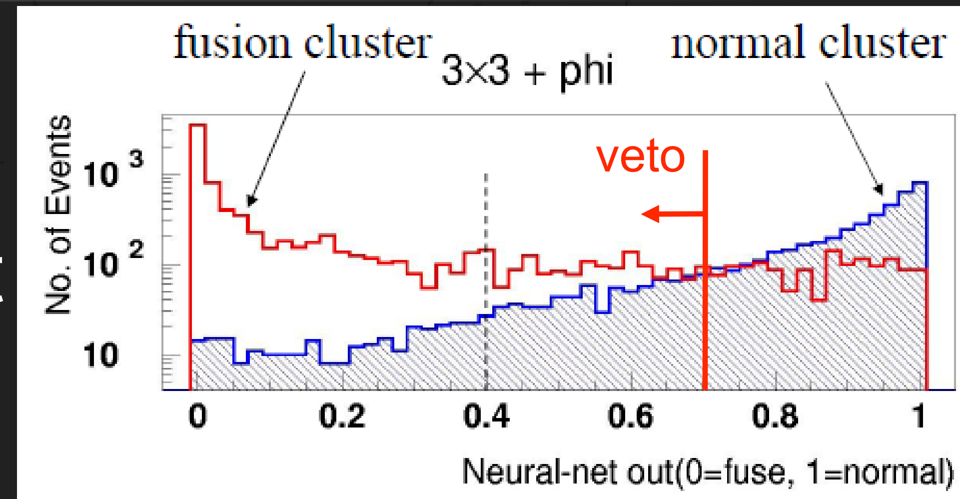


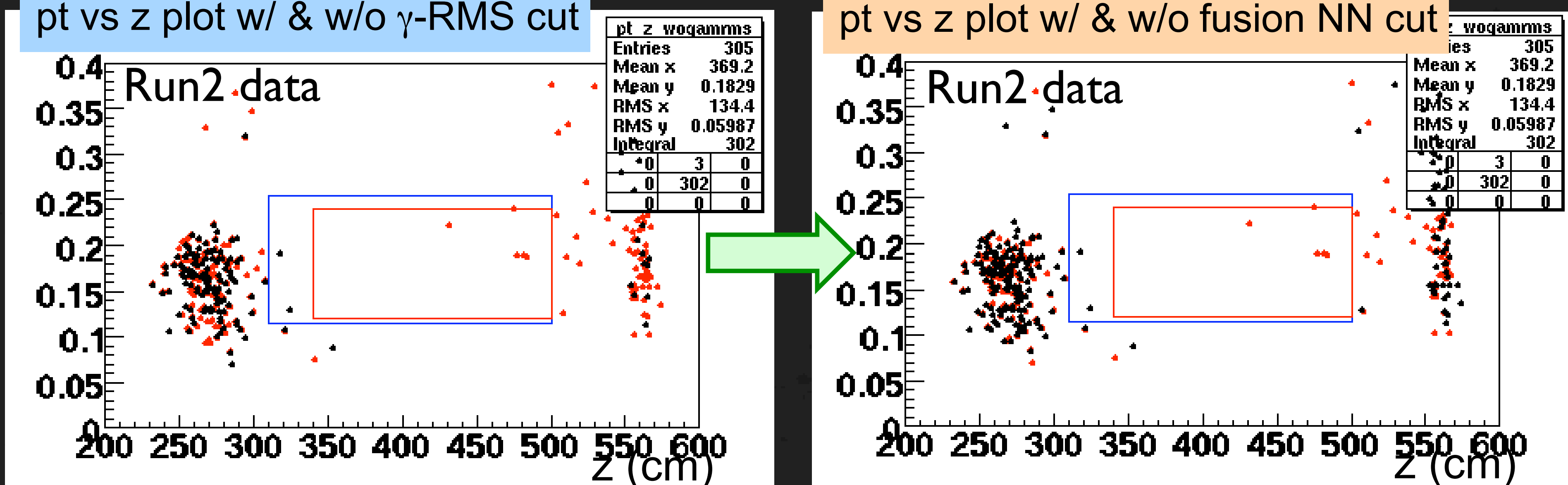
Fusion Neural Network Cut

- Utilize neural network cut instead of RMS cut



pt vs z plot w/ & w/o γ-RMS cut

pt vs z plot w/ & w/o fusion NN cut

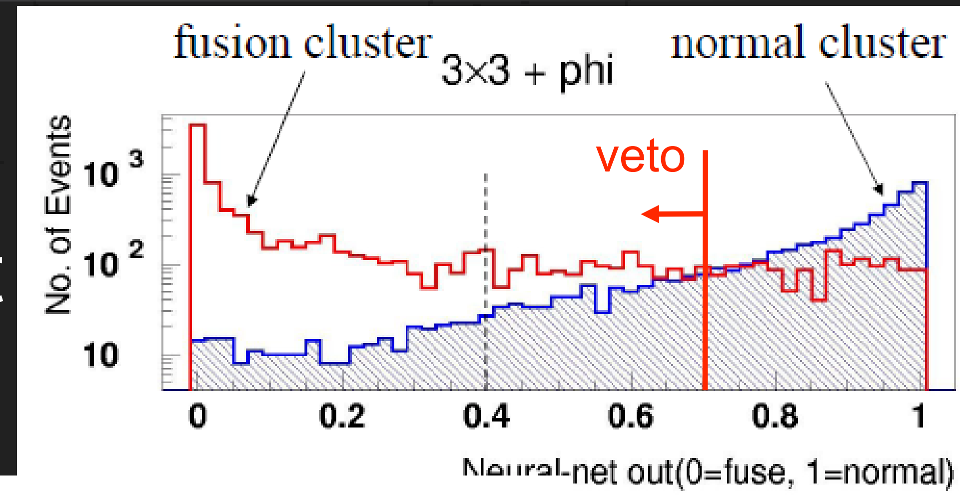


black : w/ γ-RMS cut
red : w/o γ-RMS cut

black : w/ fusionNN cut
red : w/o fusionNN cut

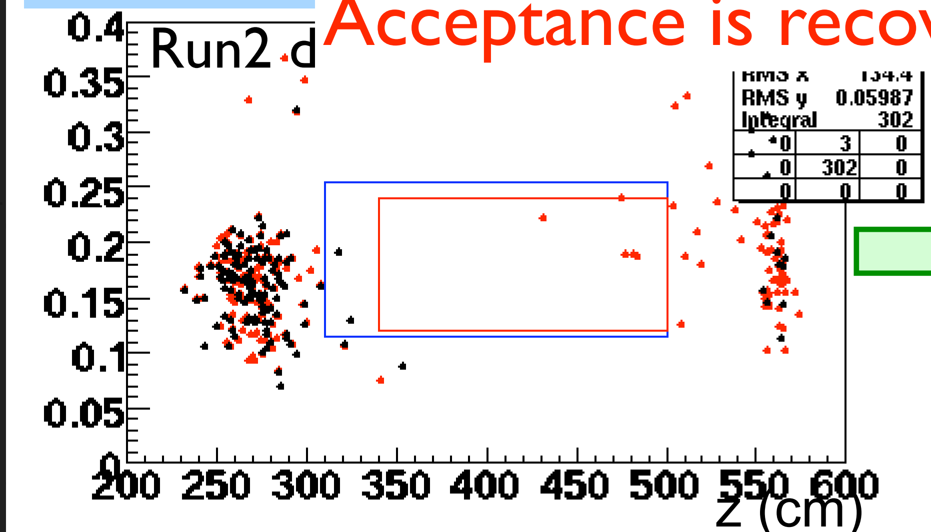
Fusion Neural Network Cut

- Utilize neural network cut instead of RMS cut

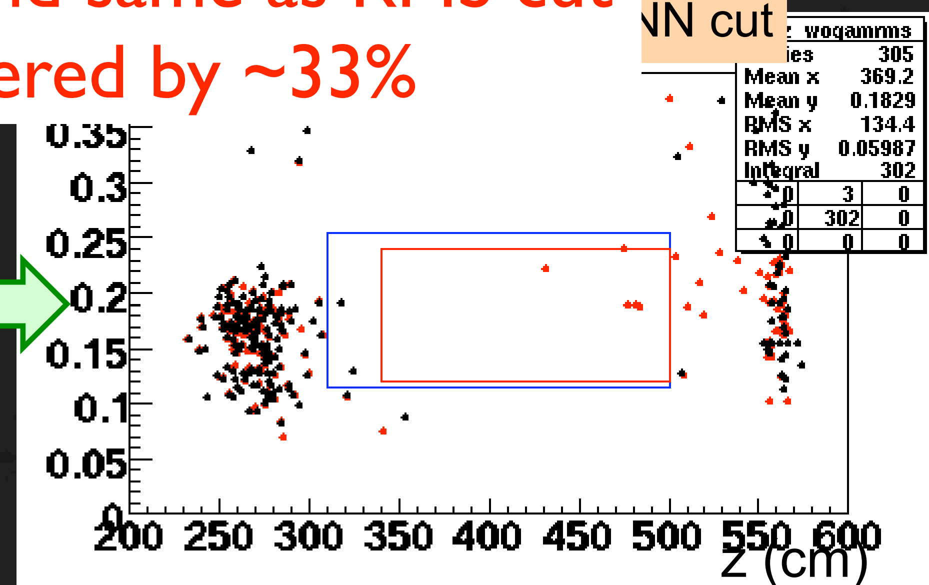


pt vs z plot w... NN cut

Reject CV background same as RMS cut
Acceptance is recovered by ~33%



black : w/ γ-RMS cut
red : w/o γ-RMS cut



black : w/ fusionNN cut
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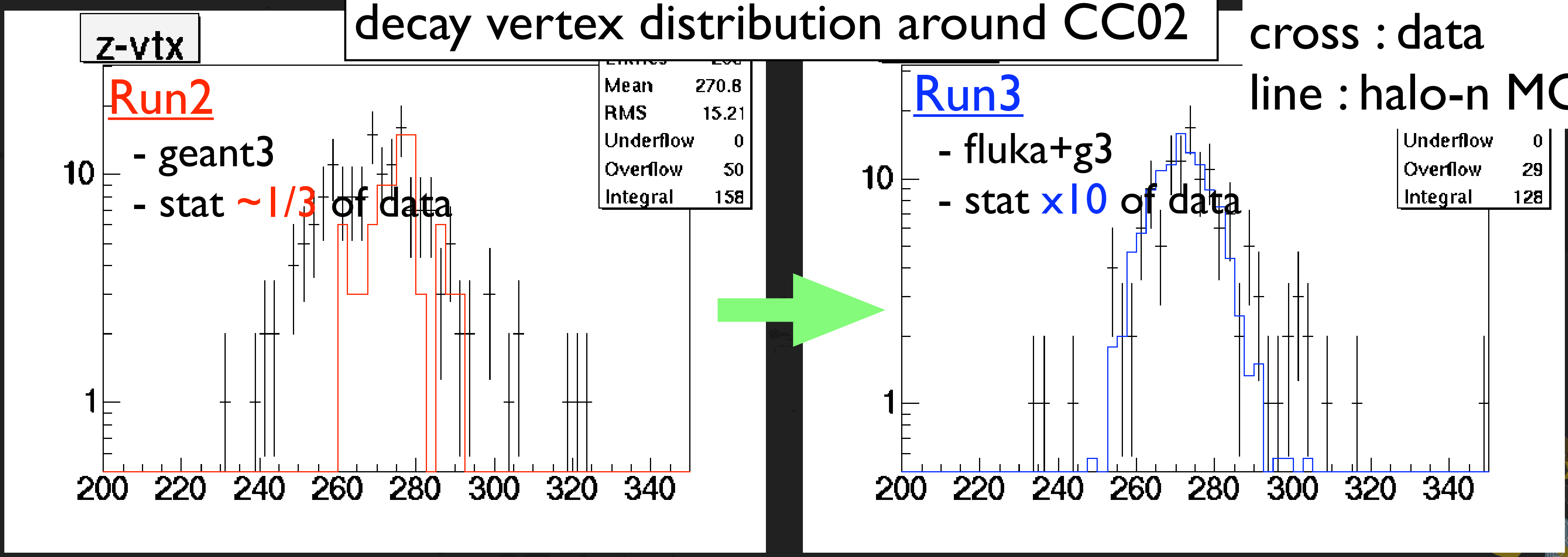
Modified Halo-n Monte Carlo

- Wanting better estimation for halo-n BG
  - utilize fluka package → better reproductivity
  - Recycling method

    recycle the event seed which could be background

decay vertex distribution around CC02



cross : data
line : halo-n MC

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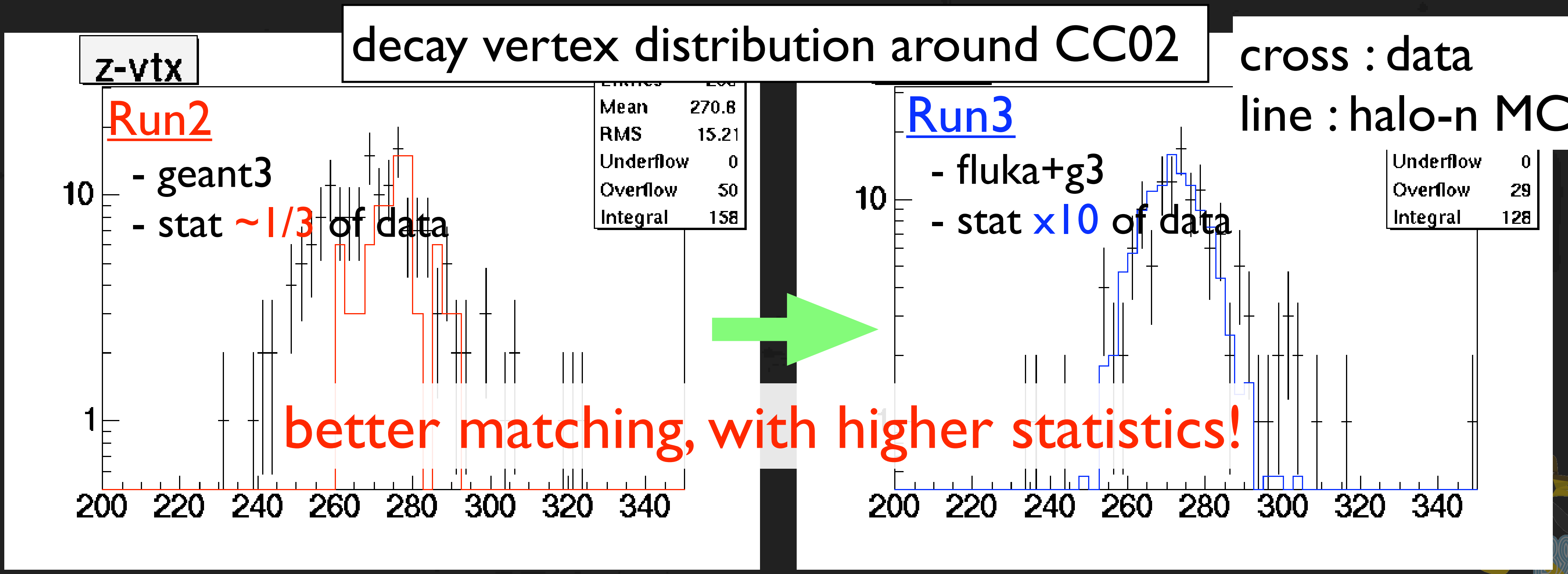


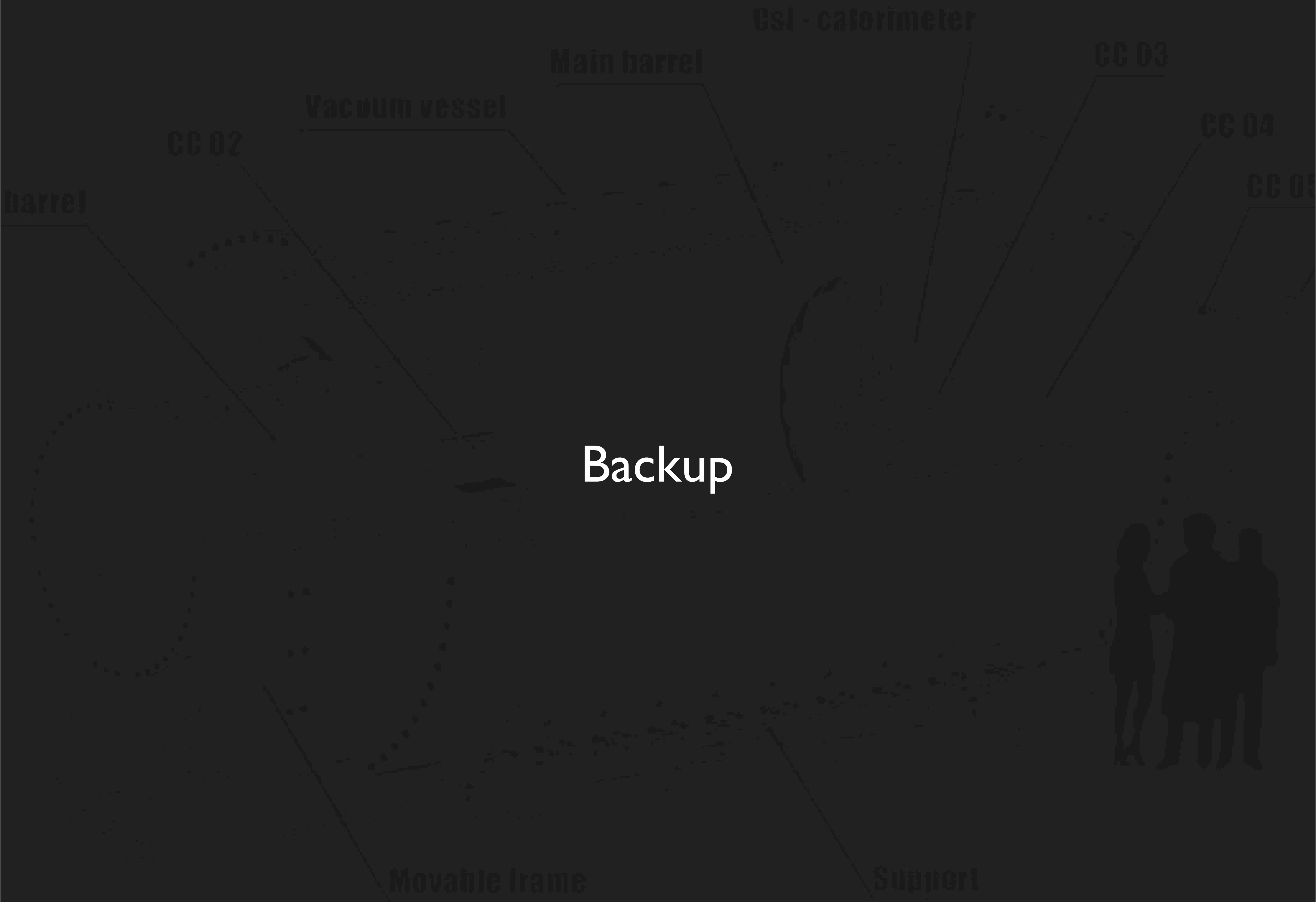
Summary

- E391a experiment @ KEK 12GeV PS
  - fist dedicated for $K_L \to \pi^0 \nu \bar{\nu}$
- Run3 analysis
- Confirmation
  - data taking : stable
  - KL flux : ~70% of Run2
- Optimization
  - Optimize event selection
  - Modify halo-neutron MC

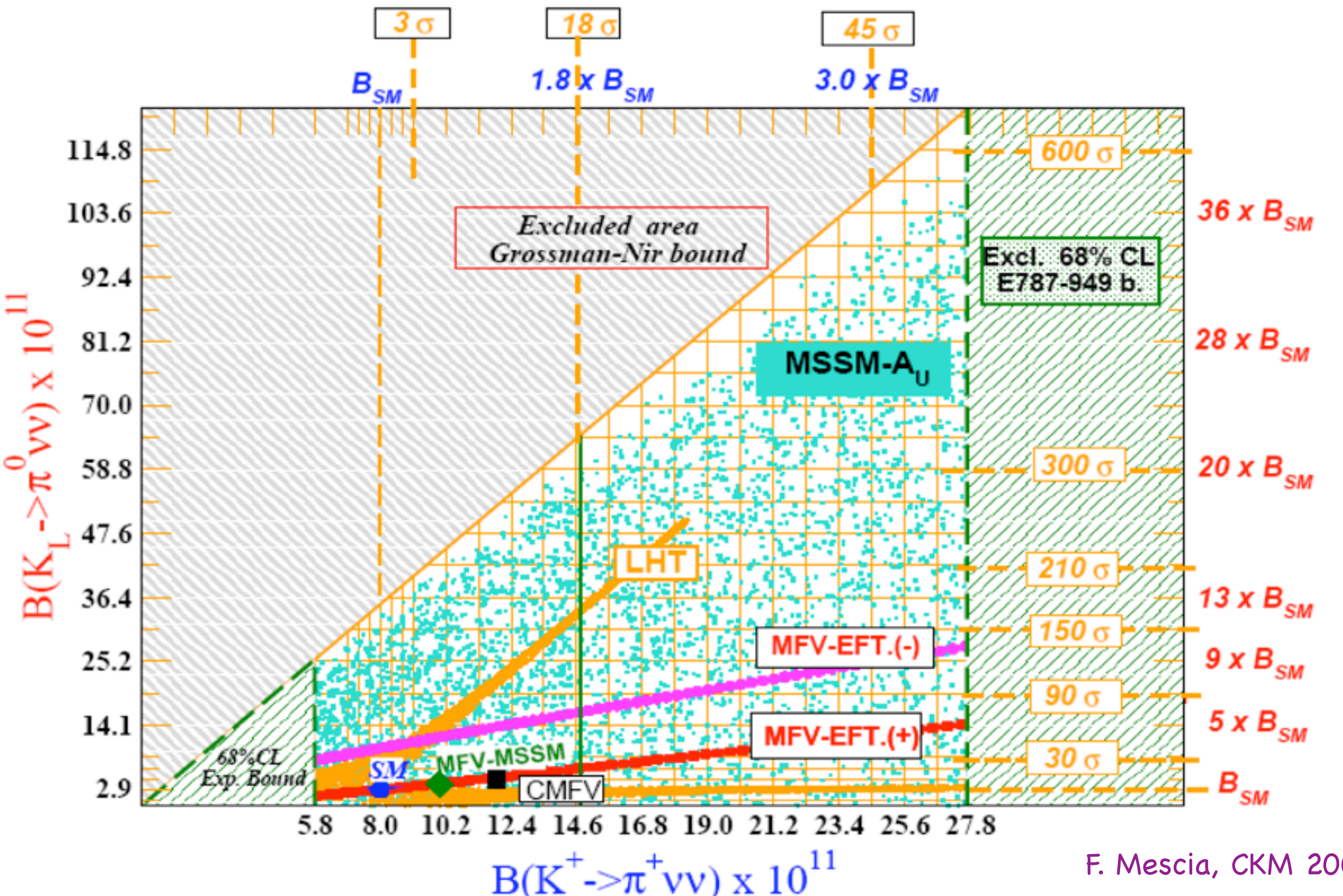
E391a

Pilot experiment for the frontier of CP asymmetry

Backup


CsI - calorimeter
Main barrel
CC 03
Vacuum vessel
CC 04
CC 02
barrel
Movable frame
Support

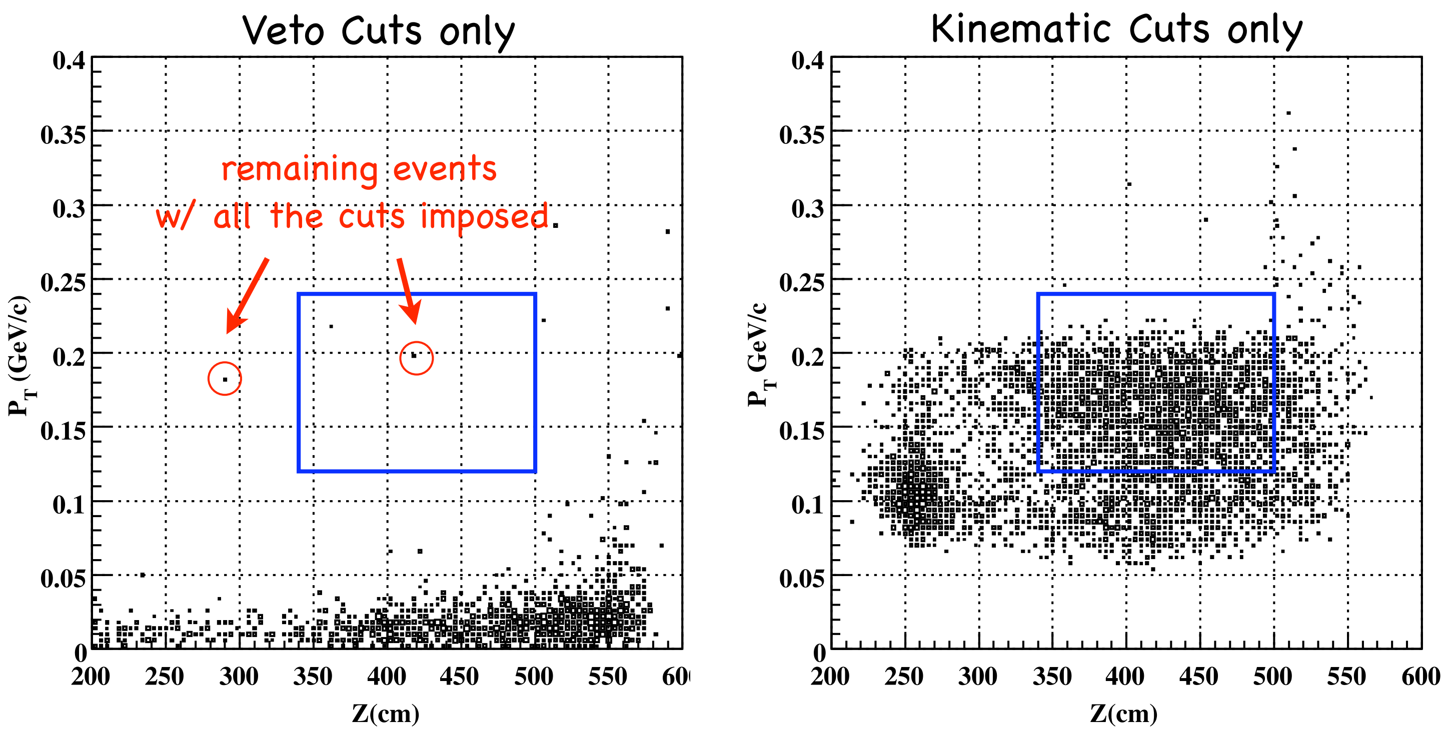
Beyond the Standard Model



F. Mescia, CKM 2006

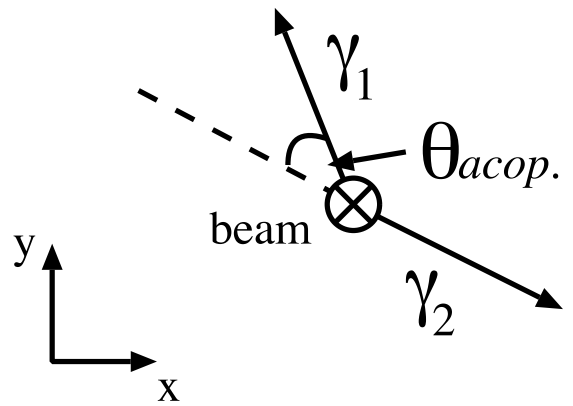
$K^0_L \to \pi^0\pi^0$ Background

- 1 event remaining w/ x9.6 statistics
  - weight: 1.16
  - BG: 0.12±0.12 events

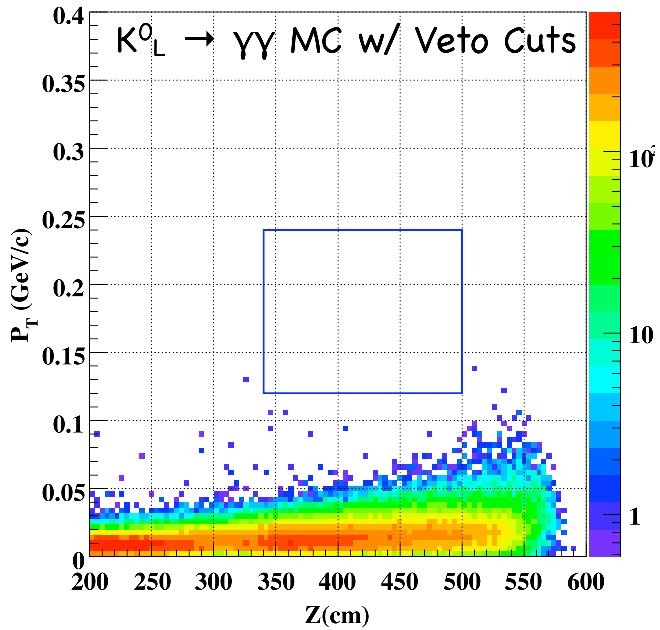


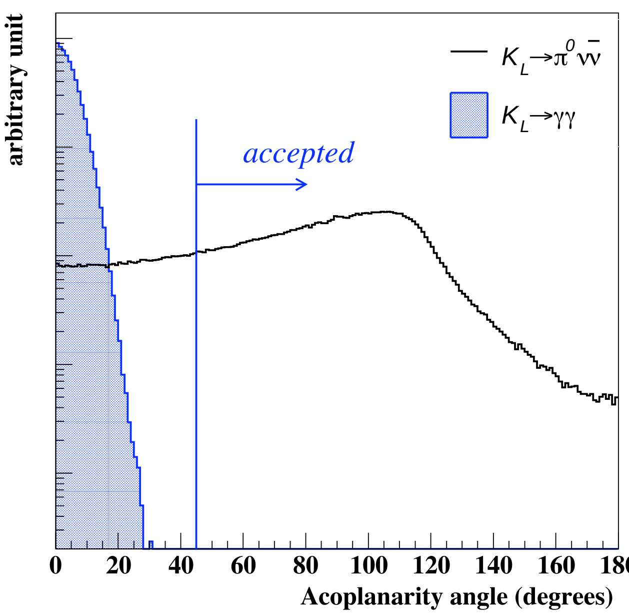
$K^0_L \to \gamma\gamma$ BG

- "Acoplanarity" angle cut for P_T mis-measurement
  - Rejection: ~1×10^5



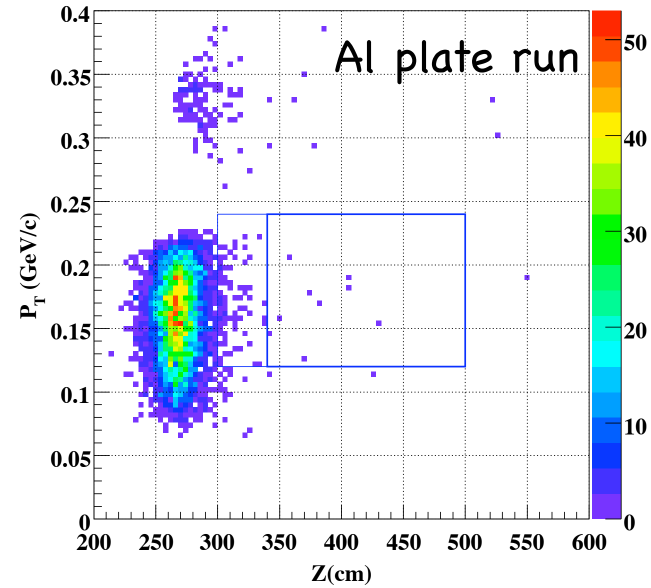
- Result
  - $N_{BG} < 3.9\times10^{-6}$
    - negligible

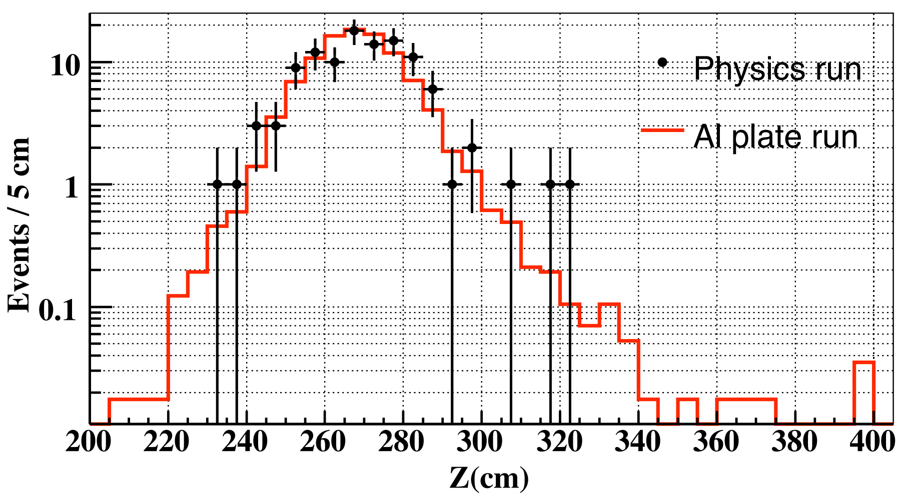


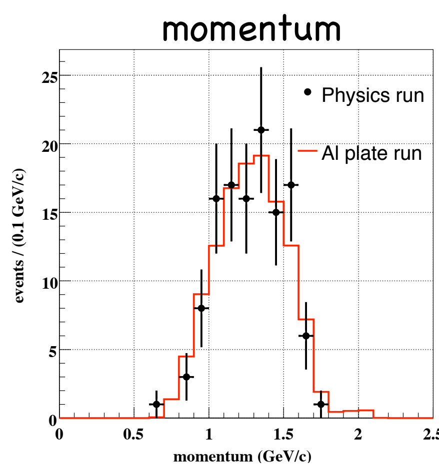


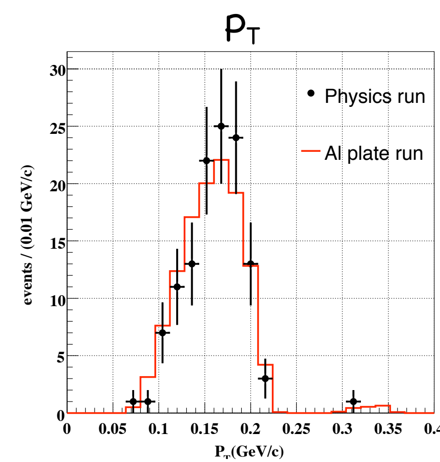
CC02 Events

- CC02/Al events in 200-300cm
  - Normalization by the number of events
  - Smearing using the distribution by MC
- Events in the Control Region
  - 300-340cm: 1.9±0.2 events
    - observed: 3 events
- Result of BG at 340-500cm
  - Signal in the Al plate run: 9
  - 9*(120/6824) = 0.16 ± 0.05 event





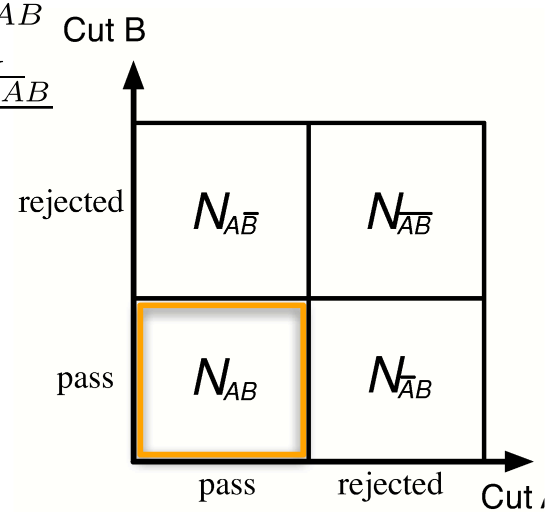




CV-π^0 Background

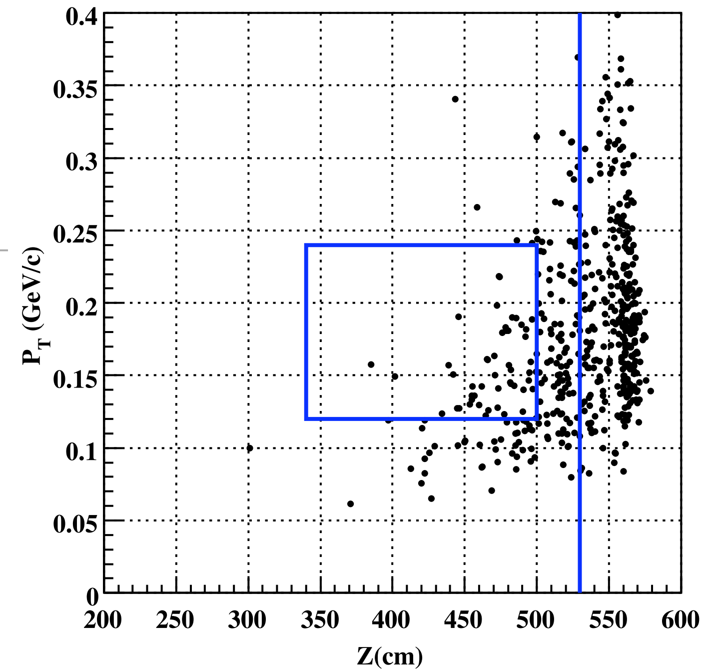
- π^0 productions at CV
  - data: 17 events, MC: 18.2±6.1 events
- BG sources: multi π^0 production,
  π^0 + neutron hit
  - bifurcation method
    - experience in Run-I
      - worked well at the downstream
      - BG estimation w/ MC
    - $N_{AB}/N_{A\overline{B}} = N_{\overline{A}B}/N_{\overline{A}\overline{B}}$

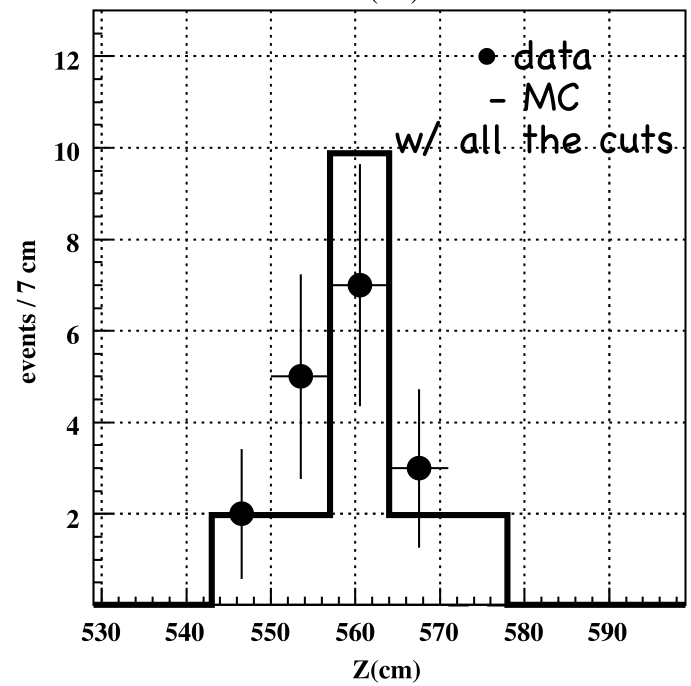
$$\Leftrightarrow N_{bg} = N_{AB} = \frac{N_{A\overline{B}} \cdot N_{\overline{A}B}}{N_{\overline{A}\overline{B}}}$$



- Cut sets
  - set-up cuts
    - π^0 cuts
  - set A
    - veto cuts
  - set B
    - photon cuts

- Result
  - 0.08±0.04 events





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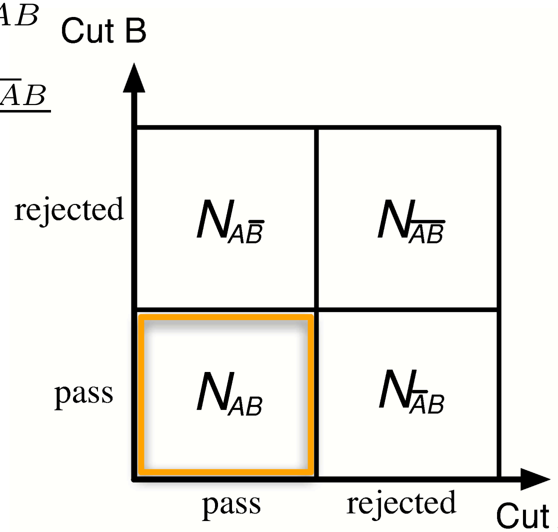

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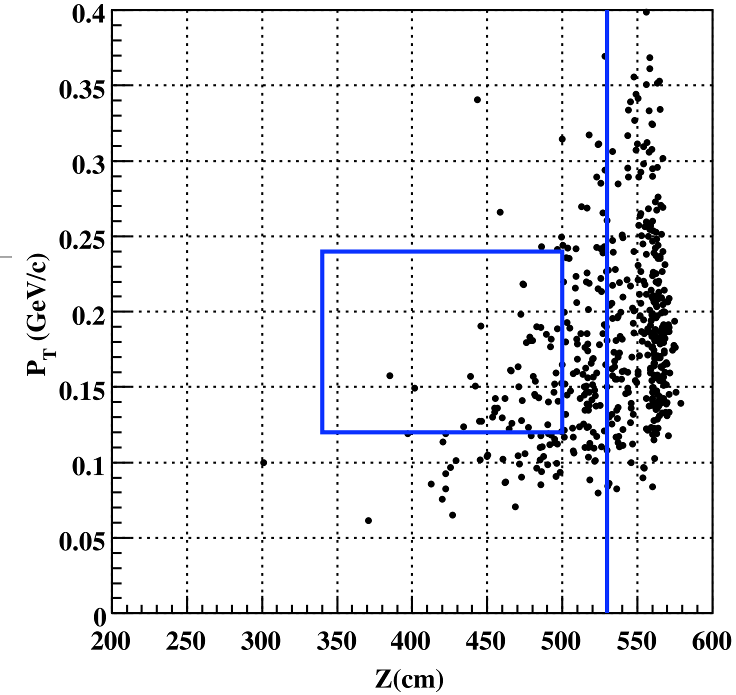
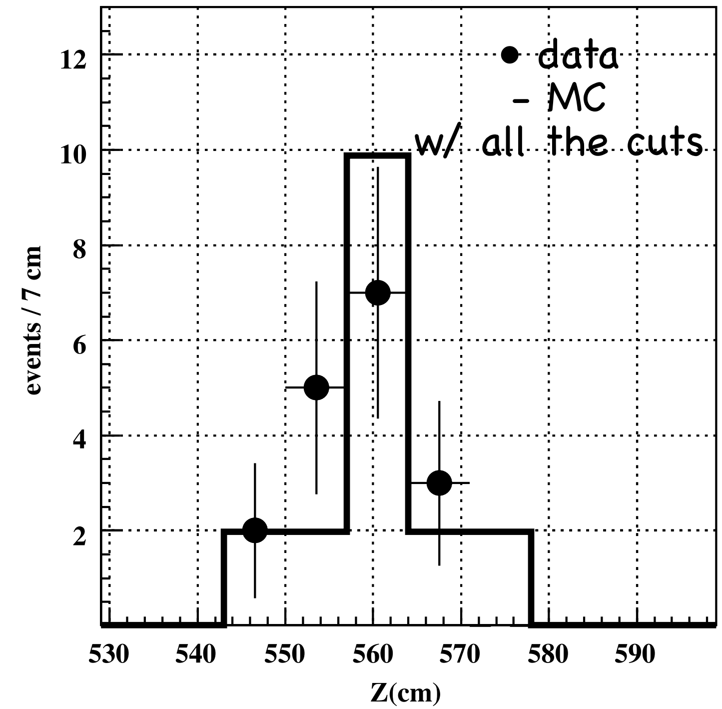
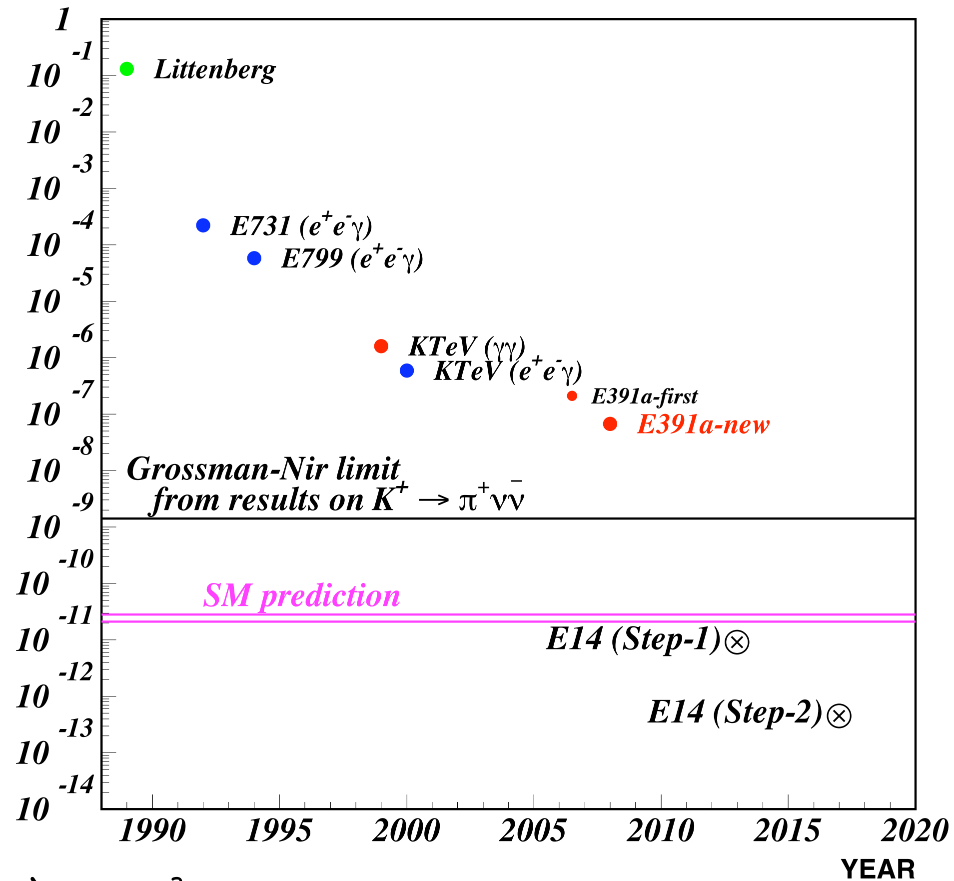




Improvement in the Upper Limit

- Upper limit
  - New result by E391a Run-II
    - $Br(K^0_L \to \pi^0 \nu \bar{\nu}) < 6.7 \times 10^{-8}$
  - KTeV
    - $\pi^0 \to \gamma\gamma$
      - $Br < 1.6 \times 10^{-6}$: x 24
    - $\pi^0 \to e^+ e^- \gamma$
      - $Br < 5.9 \times 10^{-7}$: x 8.8
  - Run-I 1week
    - $Br < 2.1 \times 10^{-7}$: x 3.1



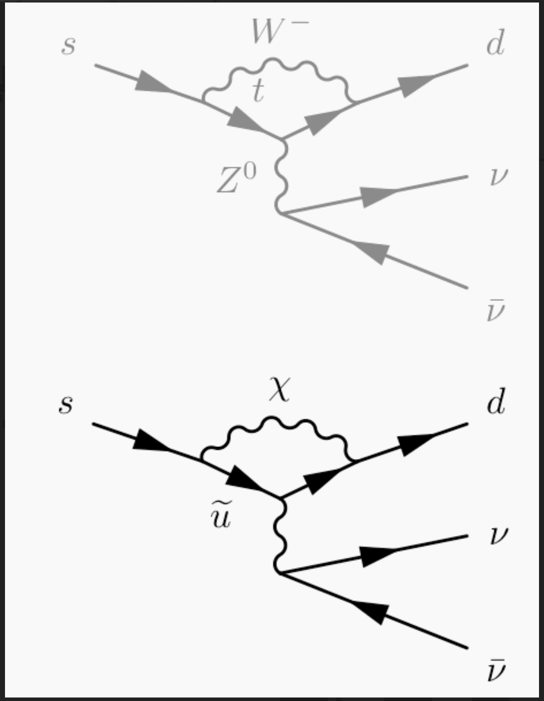
- Future Plans
  - E391a Data Analysis
    - Run I : remaining data sample (x9 of 1week)
    - Run III: ~70% K^0_L of Run II
      - Further optimization
        - Final result combining all runs
  - K^OTO (J-Parc E14) R&D
    - E391a detector + many upgrades
      - CsI : $7 \times 7 \times 30 cm^3 \to 2.5 \times 2.5 (5.0 \times 5.0) \times 50 cm^3$
      - CC02 : full active, fine segment

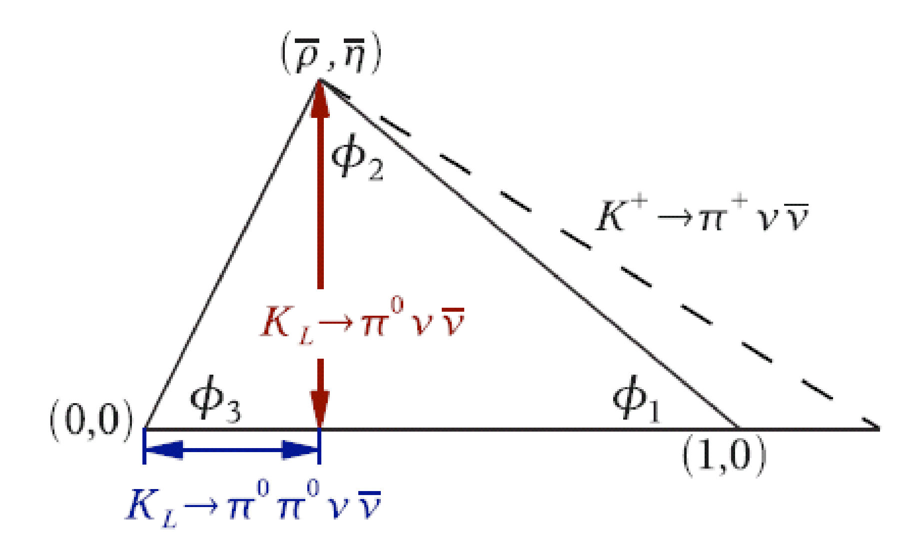
general


CsI - calorimeter
Main barrel
CC 03
Vacuum vessel
CC 04
CC 02
barrel
Movable frame
Support

Physics of $K_L \to \pi^0 \nu \nu$

- なぜ$K_L \to \pi^0 \nu \overline{\nu}$を測るのか？
  - 理論的不定性が小さい (~数%)
    "gold-plated" mode
  - CKM matrixの複素成分ηを直接測定
    分岐比 $Br(\pi^0 \nu \overline{\nu}) \propto \eta^2$: CPの物理
    - New Physicsへのプローブ
      B中間子系との比較
- 標準模型では
  - 分岐比 = 2.5×10^{-11}

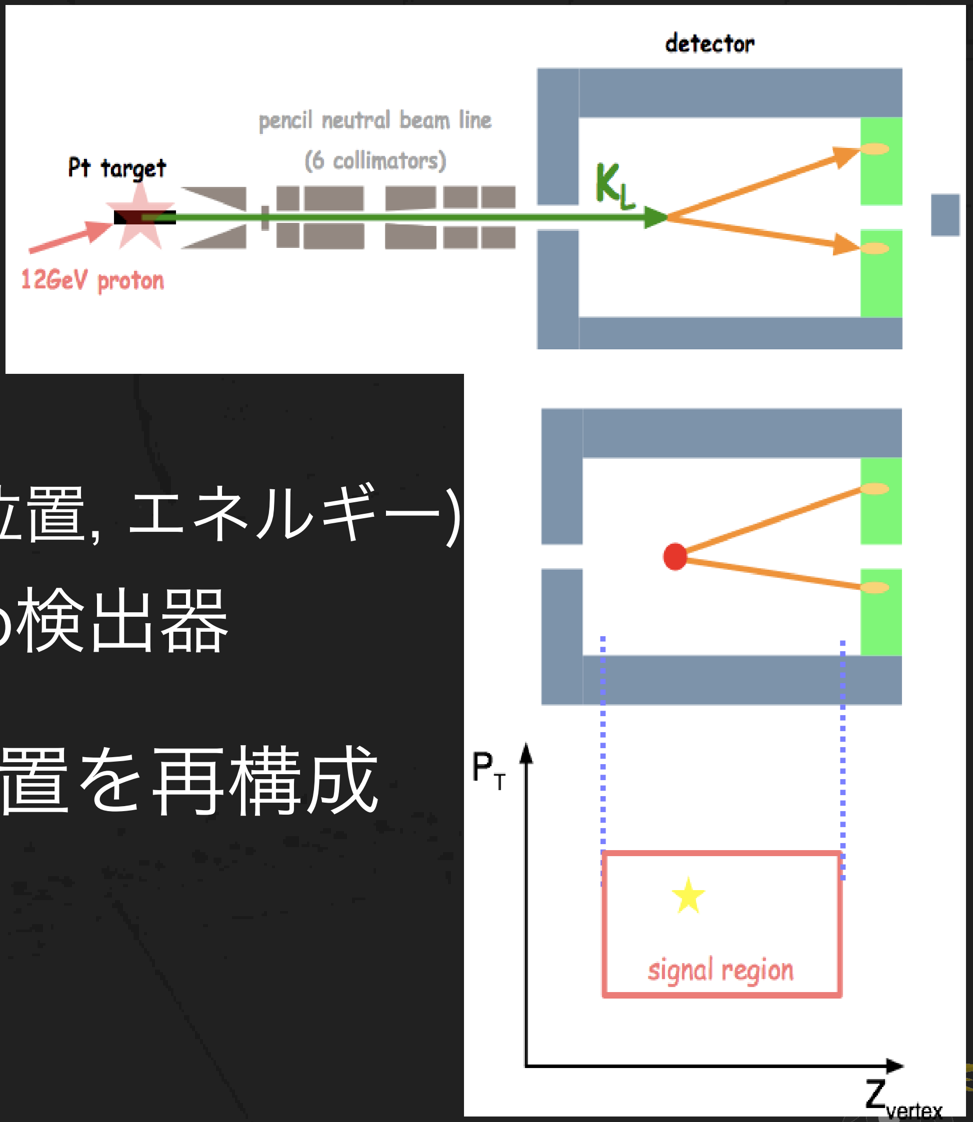




Experimental Principles

- どうやって終状態 $K_L \to \pi^0 \nu \bar{\nu}$ をIDするのか？
- “2γ + nothing”
  - 2γ → CsI カロリメータ (位置, エネルギー)
  - nothing → 全域を覆うveto検出器
- π^0の質量を仮定して崩壊位置を再構成

  $M(\pi^0) = E_1E_2(1-\cos\theta)$
  - 崩壊点と縦運動量によって signal regionを選択する



Experimental Principles

- どうやって終状態 $K_L \to \pi^0 \nu \bar{\nu}$ をIDするのか？
  └→2γ　→見えない
- “2γ + nothing”
  - 2γ → CsI カロリメータ (位置, エネルギー)
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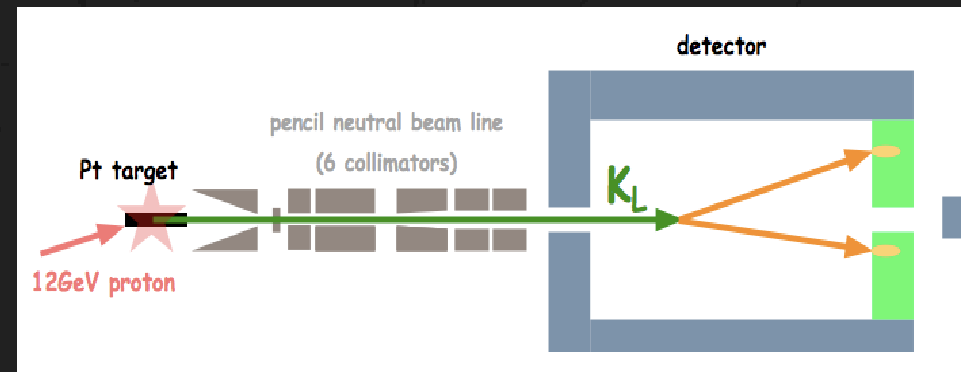
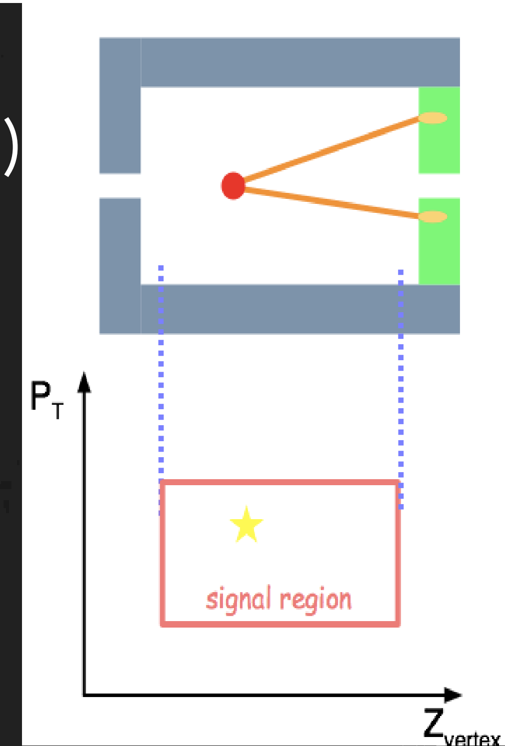
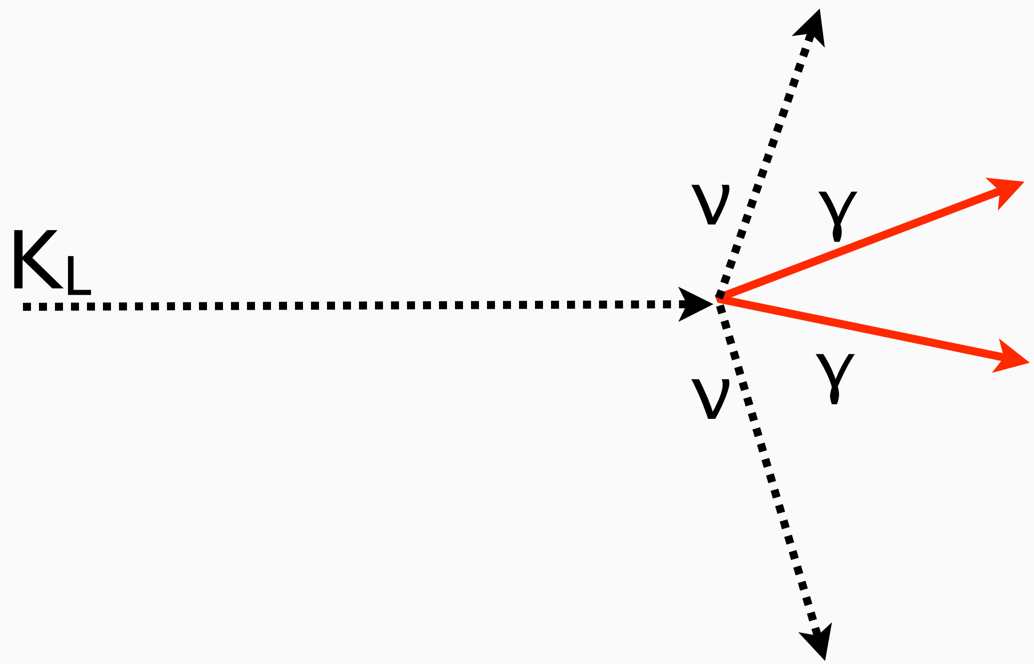
$$M(\pi^0) = E_1 E_2 (1-\cos\theta)$$

  - 崩壊点と縦運動量によって signal regionを選択する

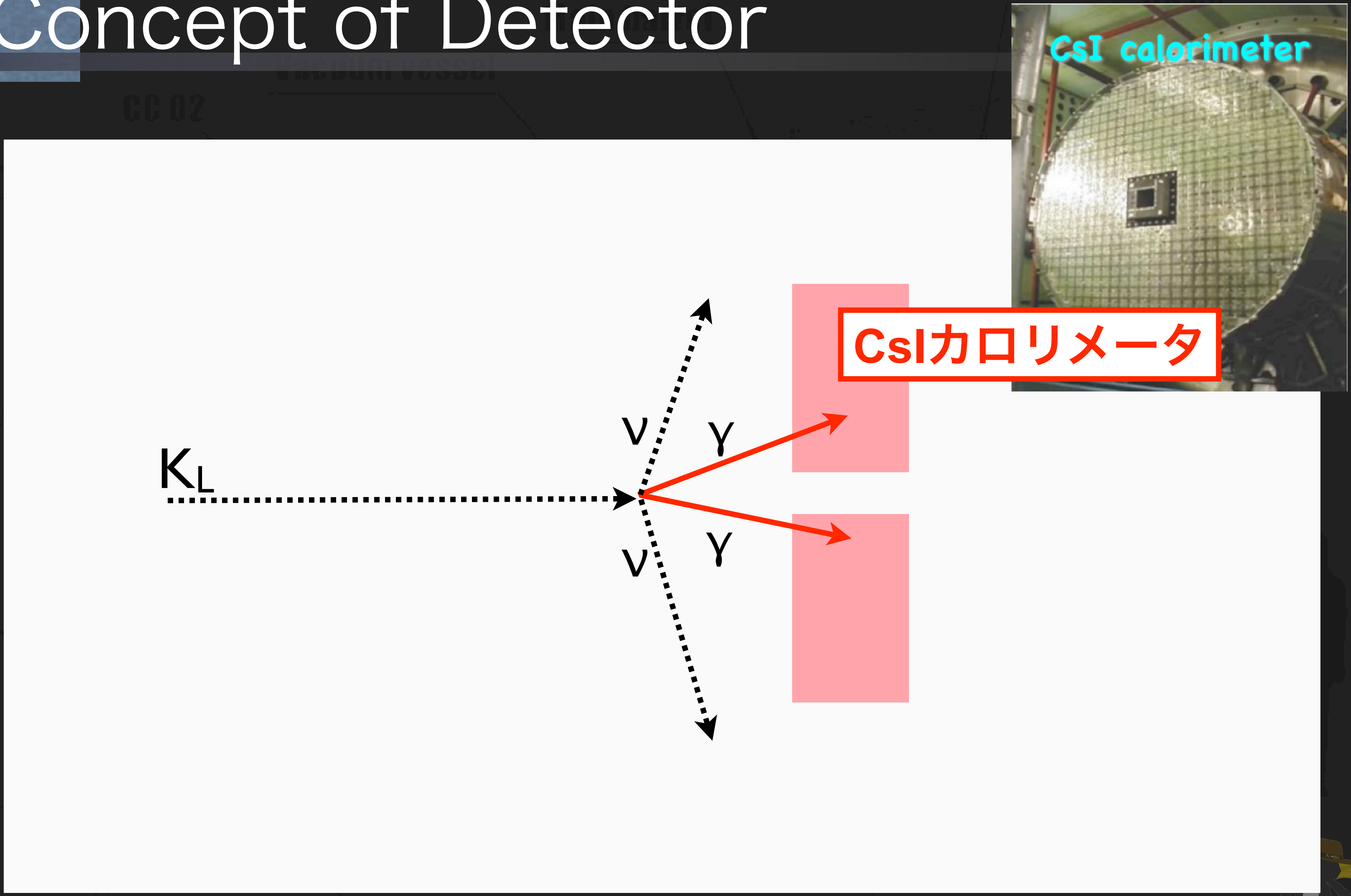




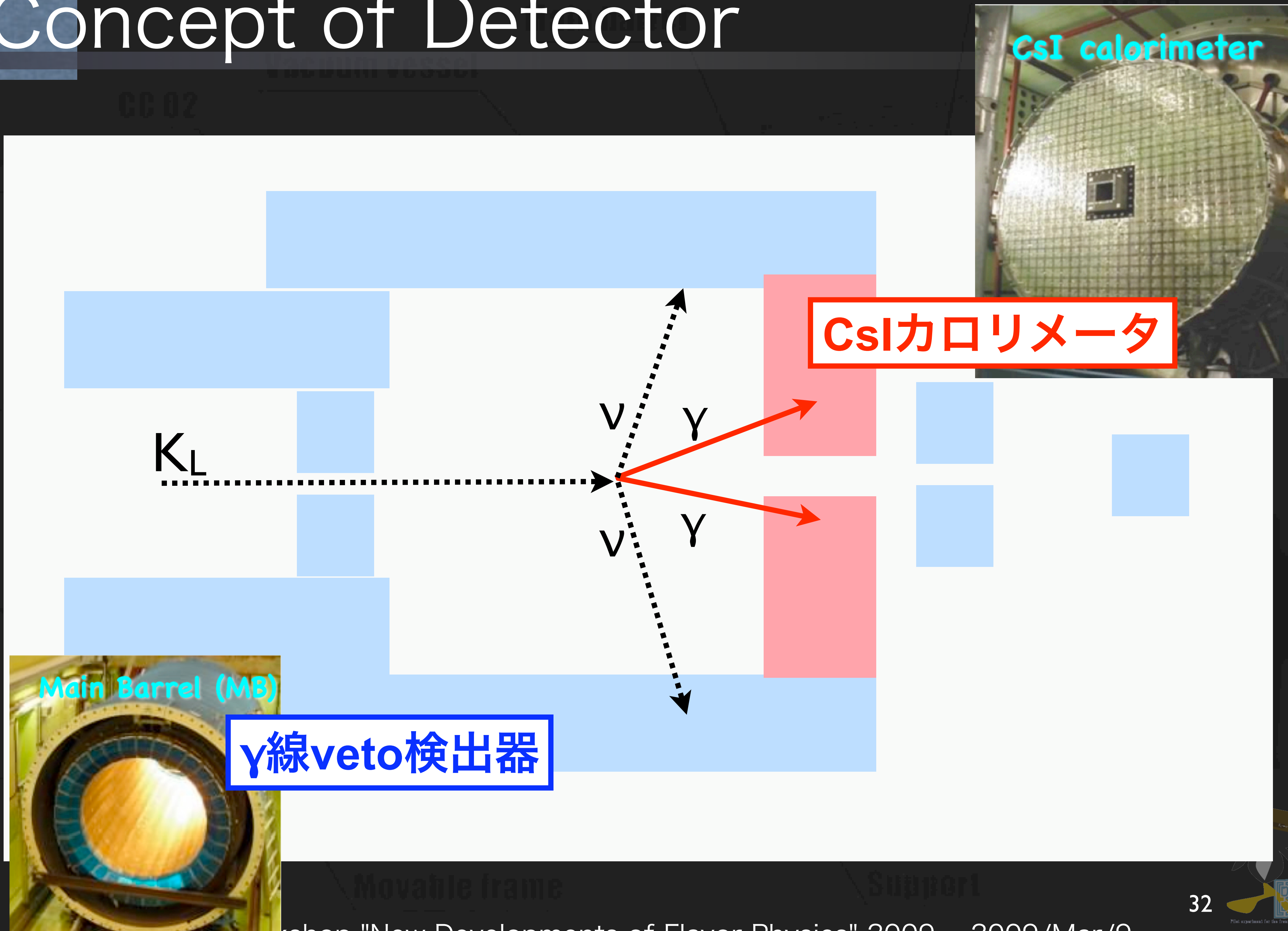
Concept of Detector



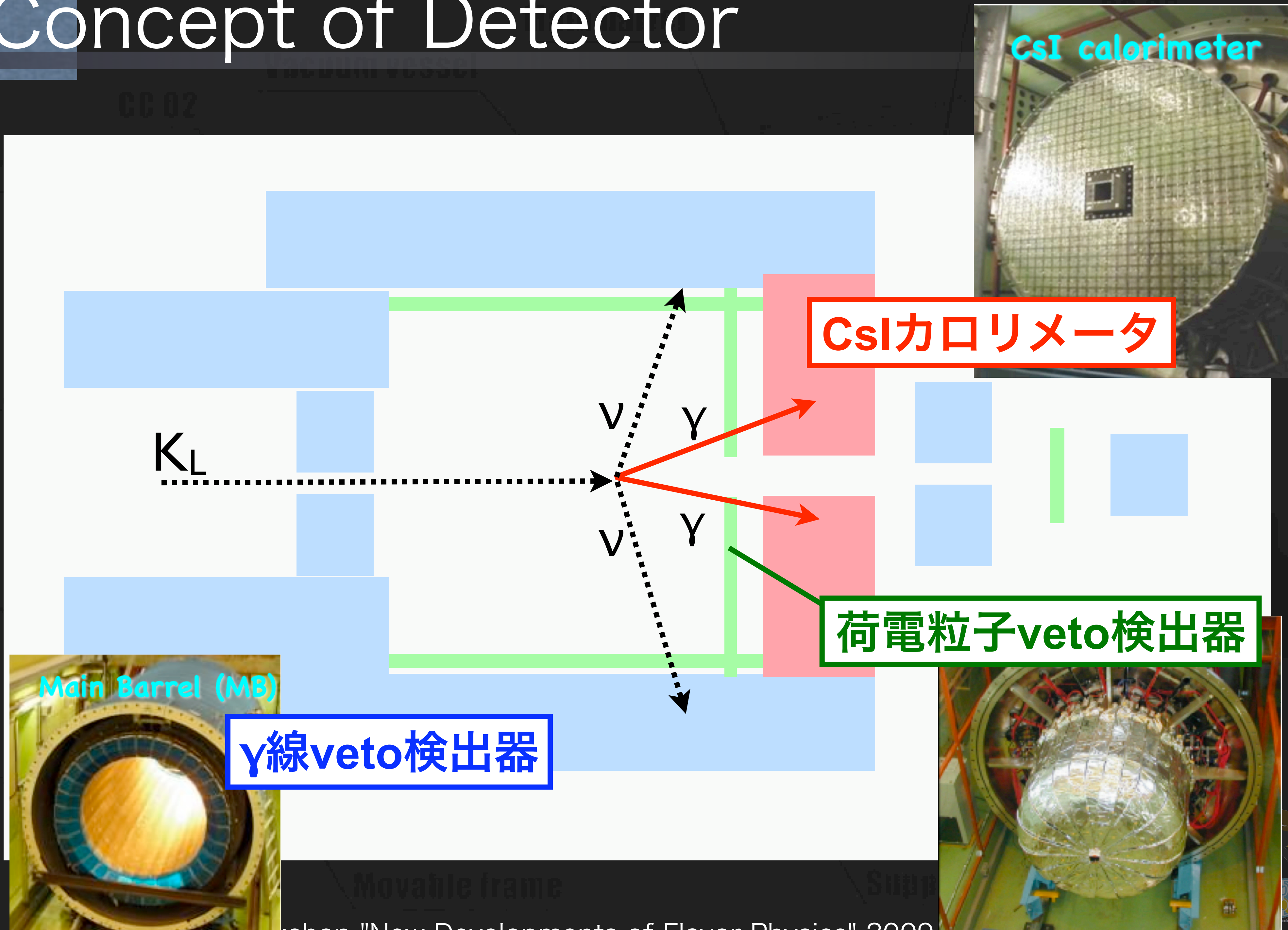
Concept of Detector



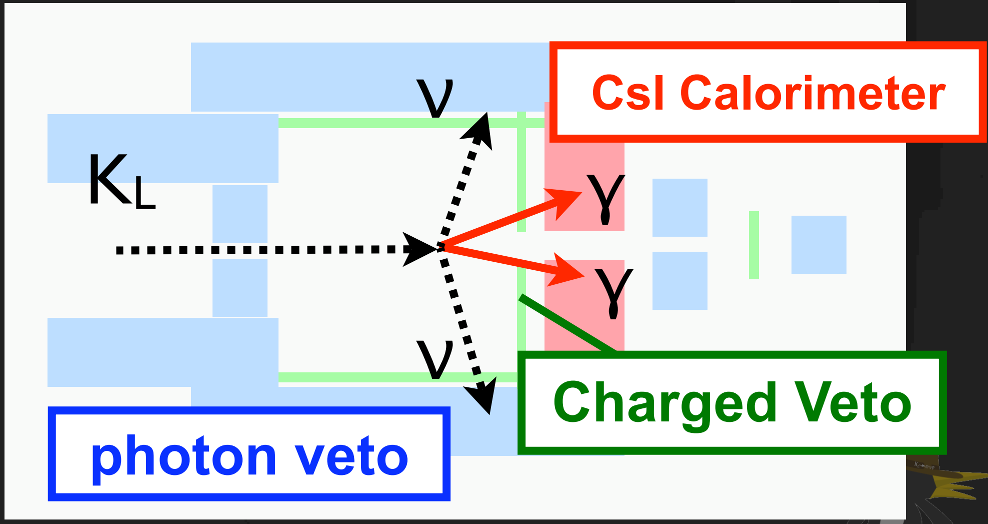
Concept of Detector



Concept of Detector



Concept of Detector

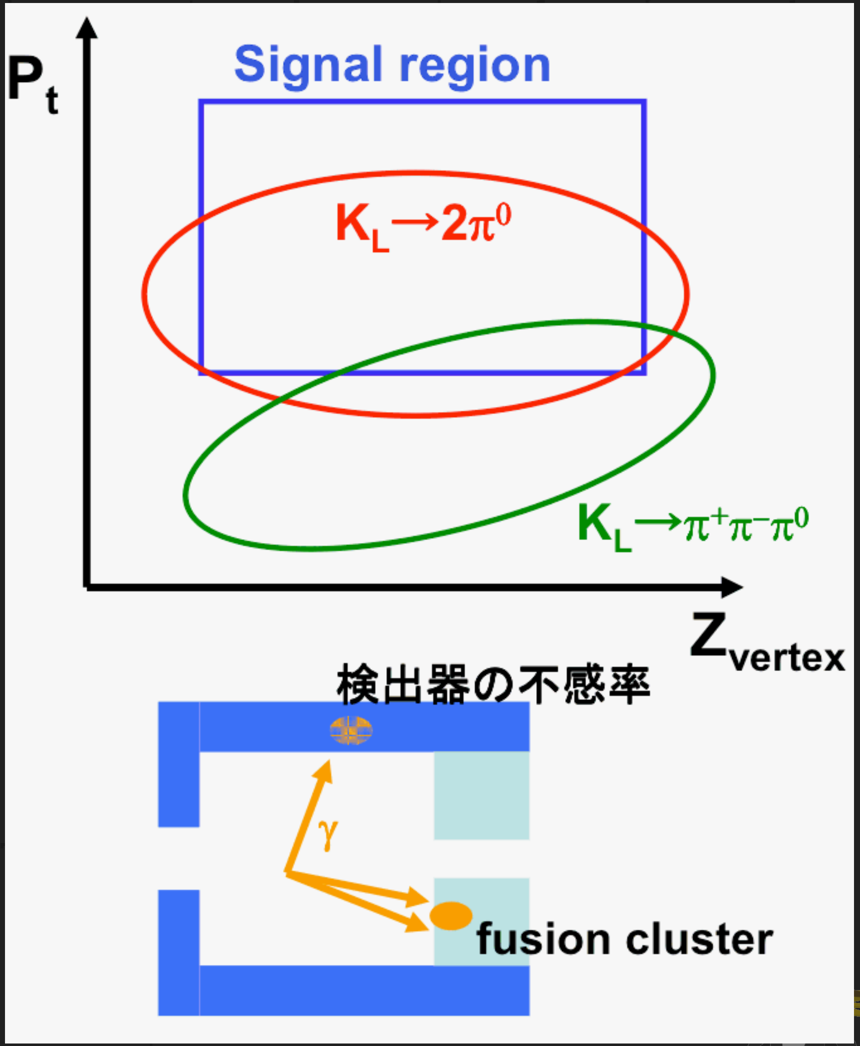


Background Events - K中間子起源

- K_L崩壊由来のバックグラウンド

1. $K_L \to 2\pi^0$ $(\to 4\gamma)$
 4つのγ線のうち2つをmiss

2. $K_L \to \pi^+\pi^-\pi^0$
 2つの荷電粒子をmiss

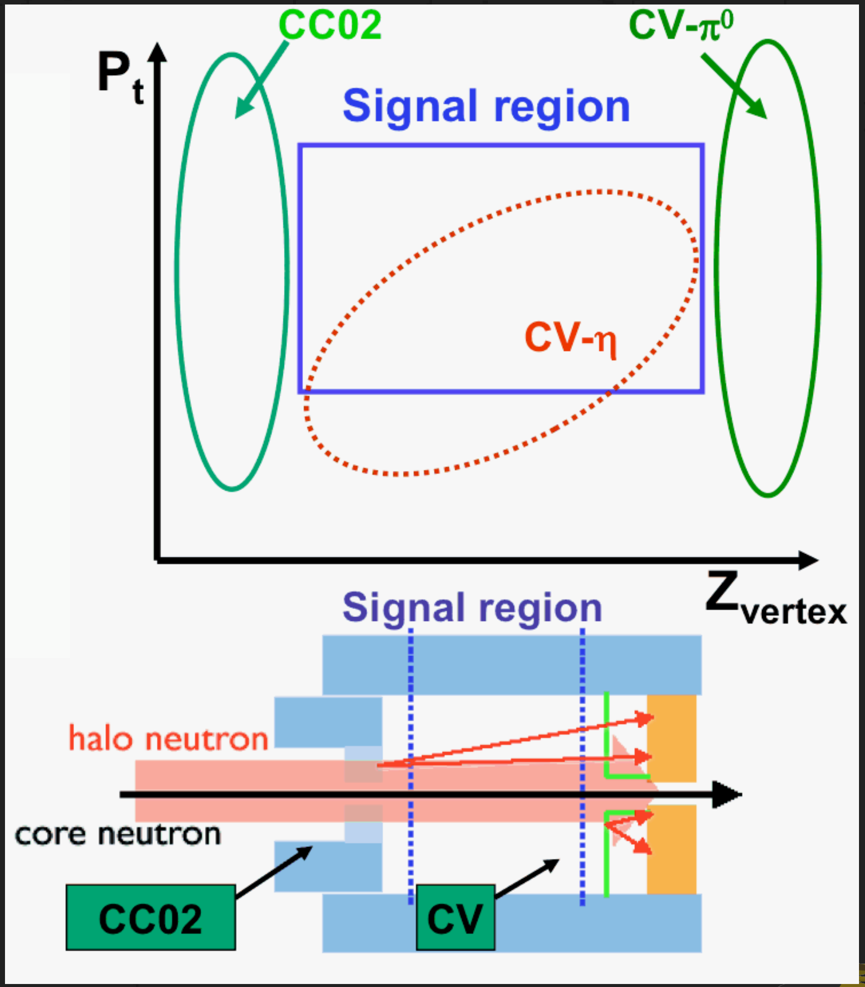


Background Events - ハロー中性子起源

- ハロー中性子
  ビームの周辺に中性子が残る
  →検出器と反応してπ^0を生成

- CC02バックグラウンド
  γ線のエネルギーを低く間違える
- CV バックグラウンド
  γ線のエネルギーを高く間違える

- CV-ηバックグラウンド



E391a Experiment

Signal/back ground summary

		# of event
Signal	$K_L \to \pi^0 \nu\nu$	2.7±0.05
KL BG	$K_L \to \pi^0 \pi^0$	1.7±0.1
	$K_L \to \pi^+ \pi^- \pi^0$	0.08±0.04
	$K_L \to \pi^- e^+ \nu$	0.02±0.001
Halon BG	CV-π^0	0.08
	CV-η	0.3

- 評価方法
  - Kaon BG
    - fast simulation　各検出器の応答はresponse functionで評価
  - Halon BG
    - full simulationによる評価