$K_L \to \pi^0 \nu \overline{\nu}$
実験の物理と展望

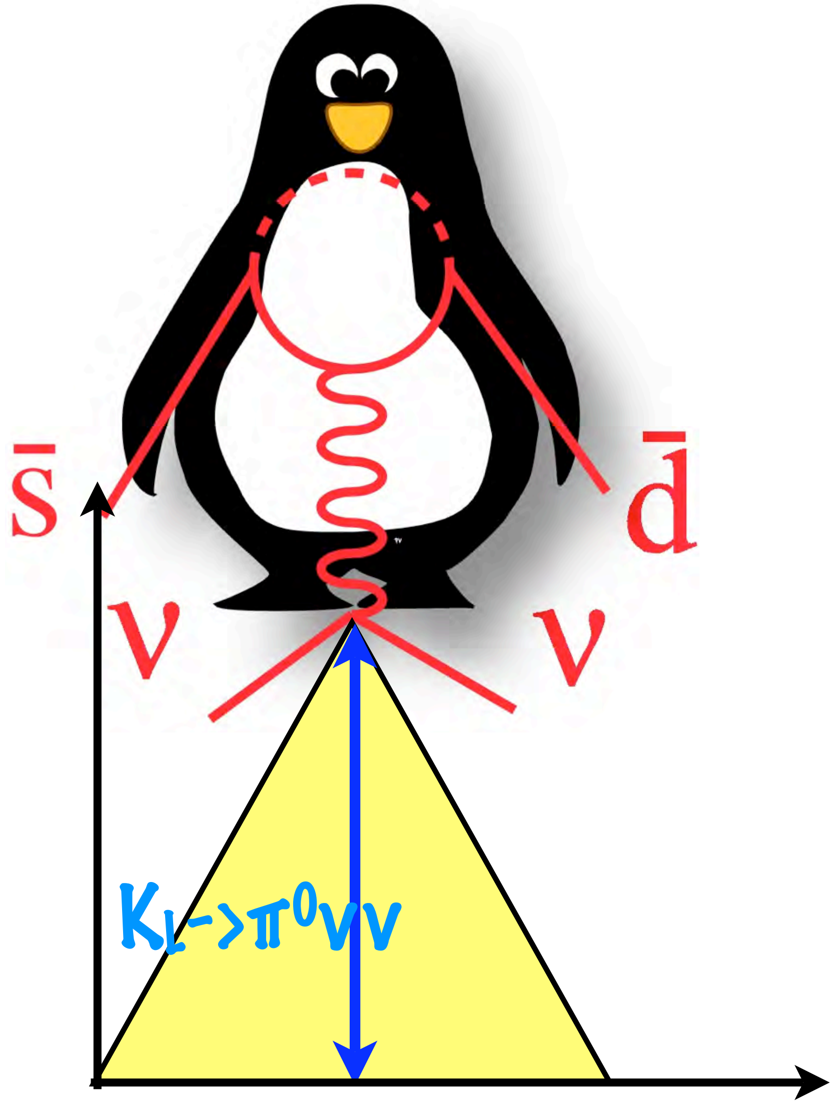
小松原　健　（KEK 素粒子原子核研究所）

特定領域「フレーバー物理の新展開」研究会

2007年3月16日　　京都・関西セミナーハウス

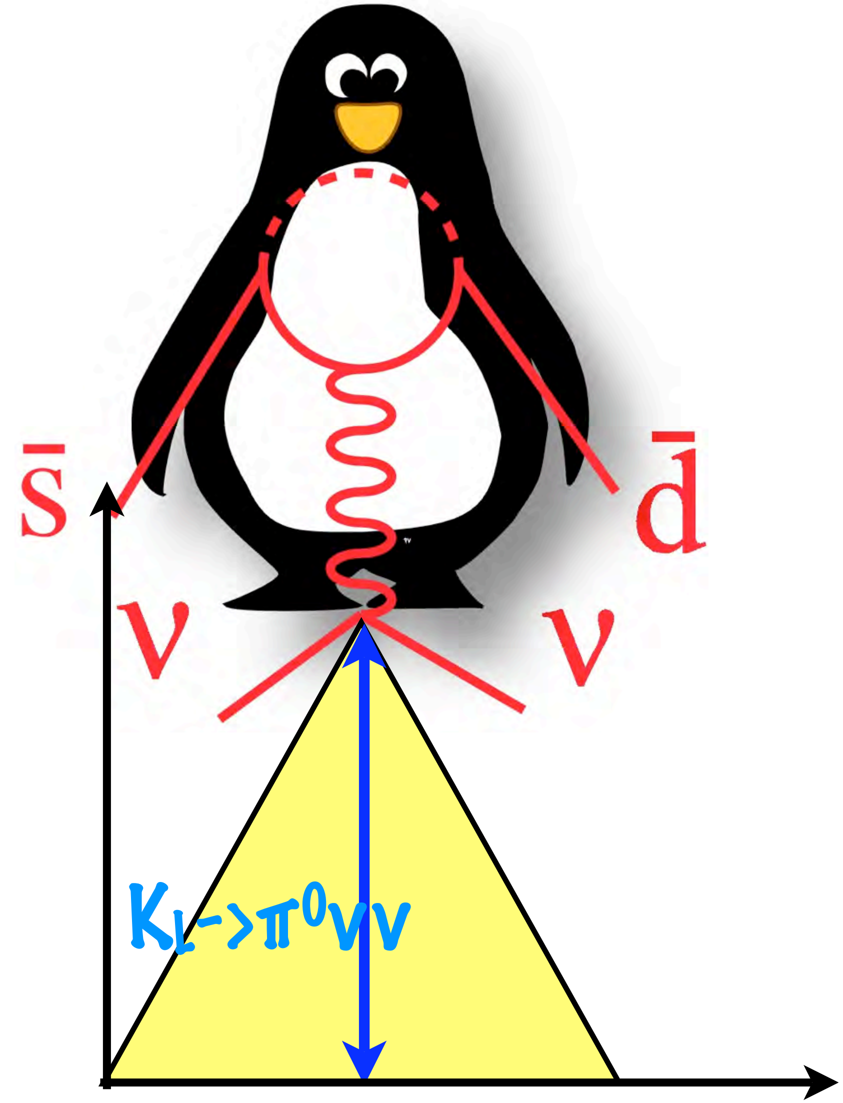
outline: $K_L \to \pi^0 \nu\overline{\nu}$ 実験の

- What　何を
- Why　なぜ
- Who　誰が
- Where　どこで
- When　いつ
- How　どのようにして



outline: $K_L \to \pi^0 \nu\overline{\nu}$ 実験の

- What　何を
- Why　なぜ　- 物理の目的
- Who　誰が
- Where　どこで
- When　いつ
- How　どのようにして　- 実験の手法



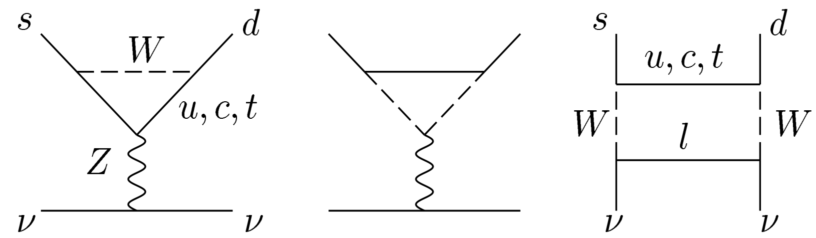
(30 slides in total)

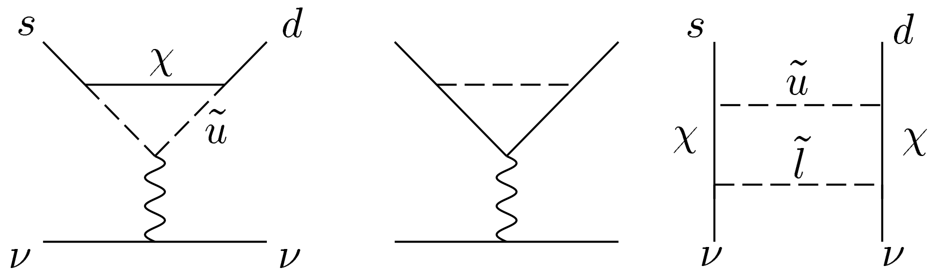
何を、なぜ

- $K_L \to \pi^0 \nu \overline{\nu}$ 崩壊の 分岐比 を測定して

3×10^{-11} in the SM

標準模型を越える物理の フレーバー構造 を探索する。





- Direct CP violation - クォークフレーバー混合の 複素位相

標準模型での $K \to \pi\nu\bar{\nu}$

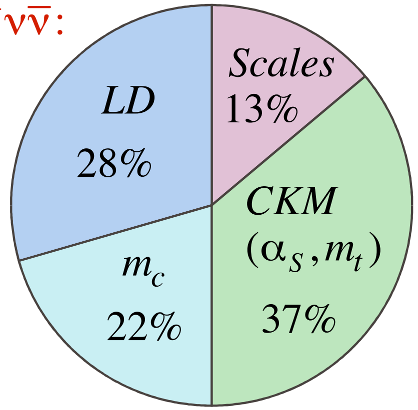
$$\mathcal{B}(K^+ \to \pi^+\nu\bar{\nu}) = (5.30 \times 10^{-11}) \cdot C_{\pi\nu\bar{\nu}} \times [(\rho_0 - \rho)^2 + \eta^2]$$

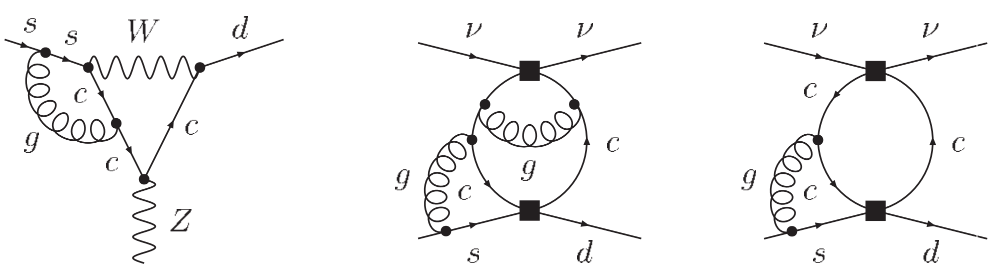
$$\mathcal{B}(K_L^0 \to \pi^0\nu\bar{\nu}) = (23.2 \times 10^{-11}) \cdot C_{\pi\nu\bar{\nu}} \times [\eta^2]$$

$$C_{\pi\nu\bar{\nu}} \equiv \left[\frac{\mathcal{B}(K^+ \to \pi^0 e^+\nu)}{4.87 \times 10^{-2}}\right] \times \left[\frac{|V_{cb}|}{0.0415}\right]^4 \times \left[\frac{X(x_t)}{1.529}\right]^2$$

	short-distance (e.w.) contrib. to the total rate $(\Gamma - \Gamma_{\text{no s.d.}})/\Gamma$	present irreducible th. error on the s.d. amplitude extracted from BR only	total BR within SM (central value)
$K_L \to \pi^0 \nu\nu$	> 99%	1%	3×10^{-11}
$K^+ \to \pi^+ \nu\nu$	88%	3%	8×10^{-11}

Theory errors for $K^+ \to \pi^+\nu\bar{\nu}$:





Haisch, FlavLHC ('06)
Buras, Gorbahn, Haisch, Nierste ('05, '06)

NNLO QCD

Grossman-Nir bound   PLB **398**, 163 (1997)

$$r_{is} \times \frac{\Gamma(K_L \to \pi^0 \nu\bar{\nu})}{\Gamma(K^+ \to \pi^+ \nu\bar{\nu})} = sin^2\theta$$

isospin breaking correction

$$\frac{BR(K_L \to \pi^0 \nu\bar{\nu})}{BR(K^+ \to \pi^+ \nu\bar{\nu})} < \frac{\tau_{K_L}}{\tau_{K^+}} \times \frac{1}{r_{is}} = 4.371\ldots \simeq 4.4$$

$$BR(K_L \to \pi^0 \nu\bar{\nu}) < 4.4 \times UL_{90\%}(K^+ \to \pi^+ \nu\bar{\nu})$$

$$\underline{1.4 \times 10^{-9}}$$

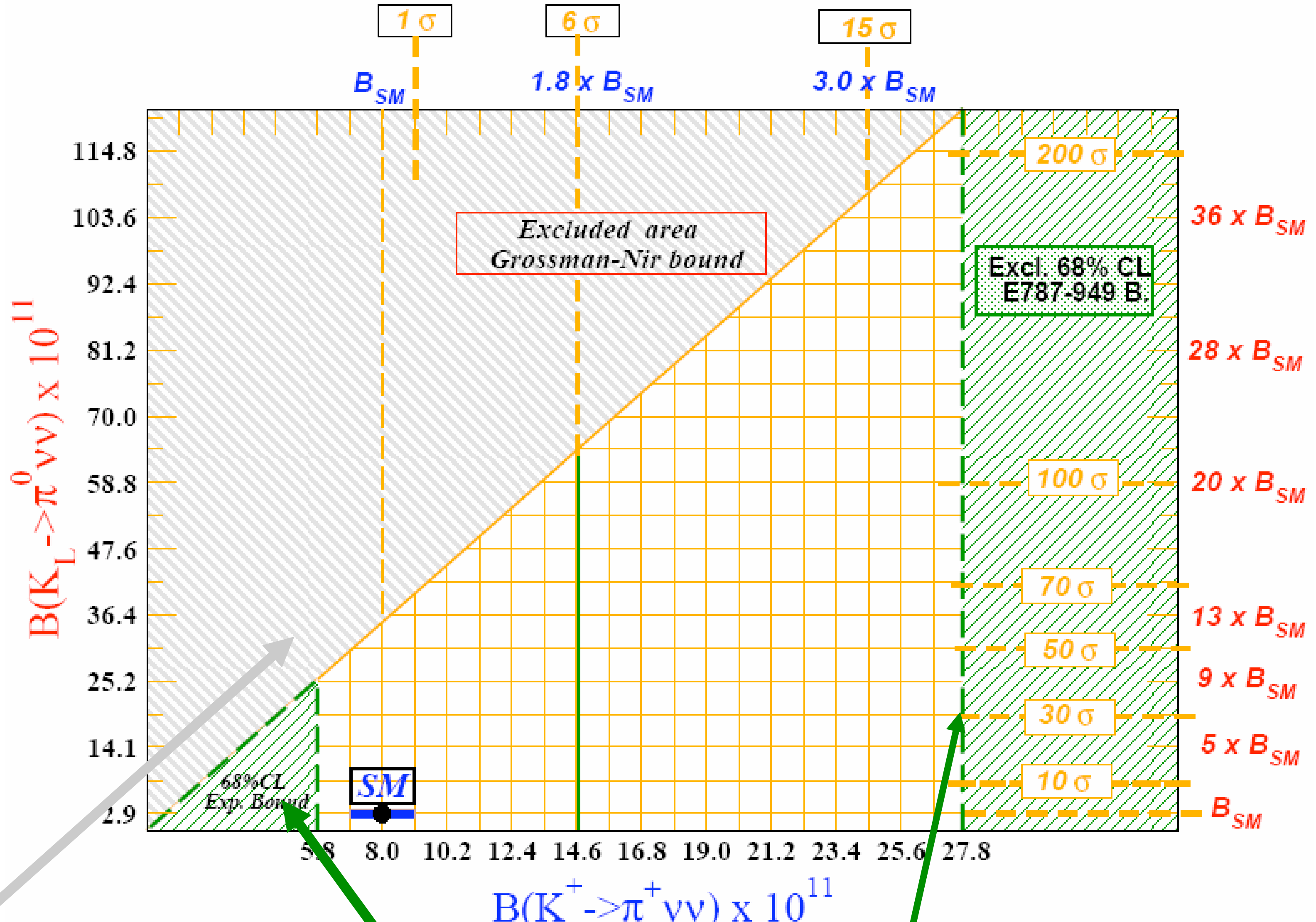
↑

$< 32.2 \times 10^{-11}$

15% due to present CKM accuracy

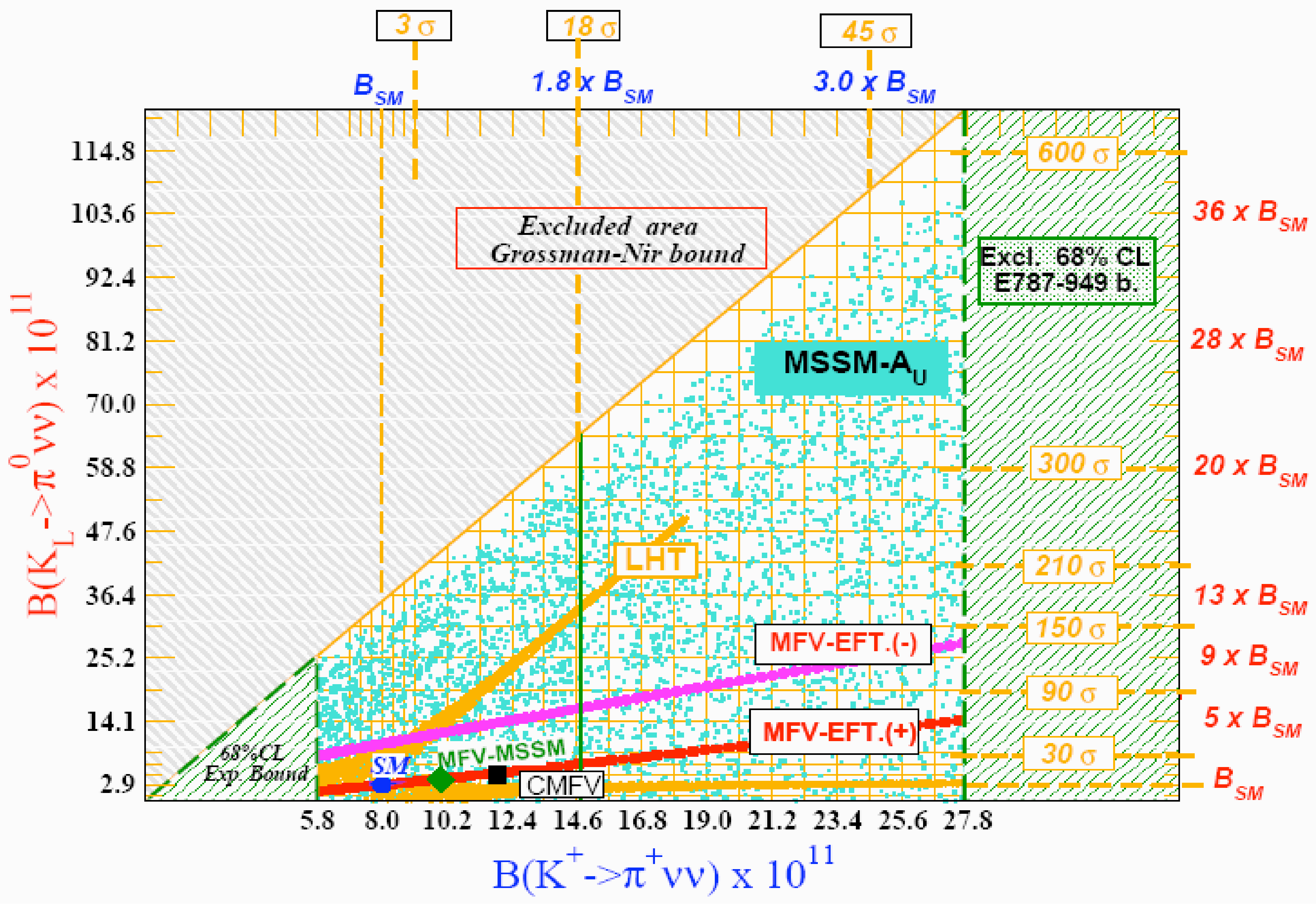
Golden Modes	Standard Model	Experiment
$K^+ \to \pi^+ \nu\bar{\nu}$	$8.0^{+1.1}_{-1.1} \times 10^{-11}$	$14.7^{+13.0}_{-8.9} \times 10^{-11}$ E787 E949
$K_L \to \pi^0 \nu\bar{\nu}$	$2.9^{+0.4}_{-0.4} \times 10^{-11}$	$< 2.1 \times 10^{-7}$ E391a

F. Mescia @CKM2006



$B(K^+ \to \pi^+ \nu\bar{\nu}) = 14.7^{+13.0}_{-8.9} \times 10^{-11}$ [E787-E949]

$B(K_L \to \pi^0 \nu\bar{\nu}) \leq 4.4 B(K^+ \to \pi^+ \nu\bar{\nu})$ [Grosmann - Nir Bound]



3 σ
18 σ
45 σ
B_SM
1.8 x B_SM
3.0 x B_SM
114.8
103.6
92.4
81.2
70.0
58.8
47.6
36.4
25.2
14.1
2.9
Excluded area
Grossman-Nir bound
Excl. 68% CL
E787-949 b.
MSSM-A_U
600 σ
300 σ
210 σ
150 σ
90 σ
30 σ
36 x B_SM
28 x B_SM
20 x B_SM
13 x B_SM
9 x B_SM
5 x B_SM
B_SM
LHT
MFV-EFT.(-)
MFV-EFT.(+)
MFV-MSSM
SM
CMFV
68%CL
Exp. Bound
5.8
8.0
10.2
12.4
14.6
16.8
19.0
21.2
23.4
25.6
27.8
B(K_L->π^0 νν) x 10^11
B(K^+->π^+ νν) x 10^11

Rare and CP-Violating K and B Decays in the Littlest Higgs Model with T-Parity

hep-ph/0610298
JHEP 0701 (2007) 066

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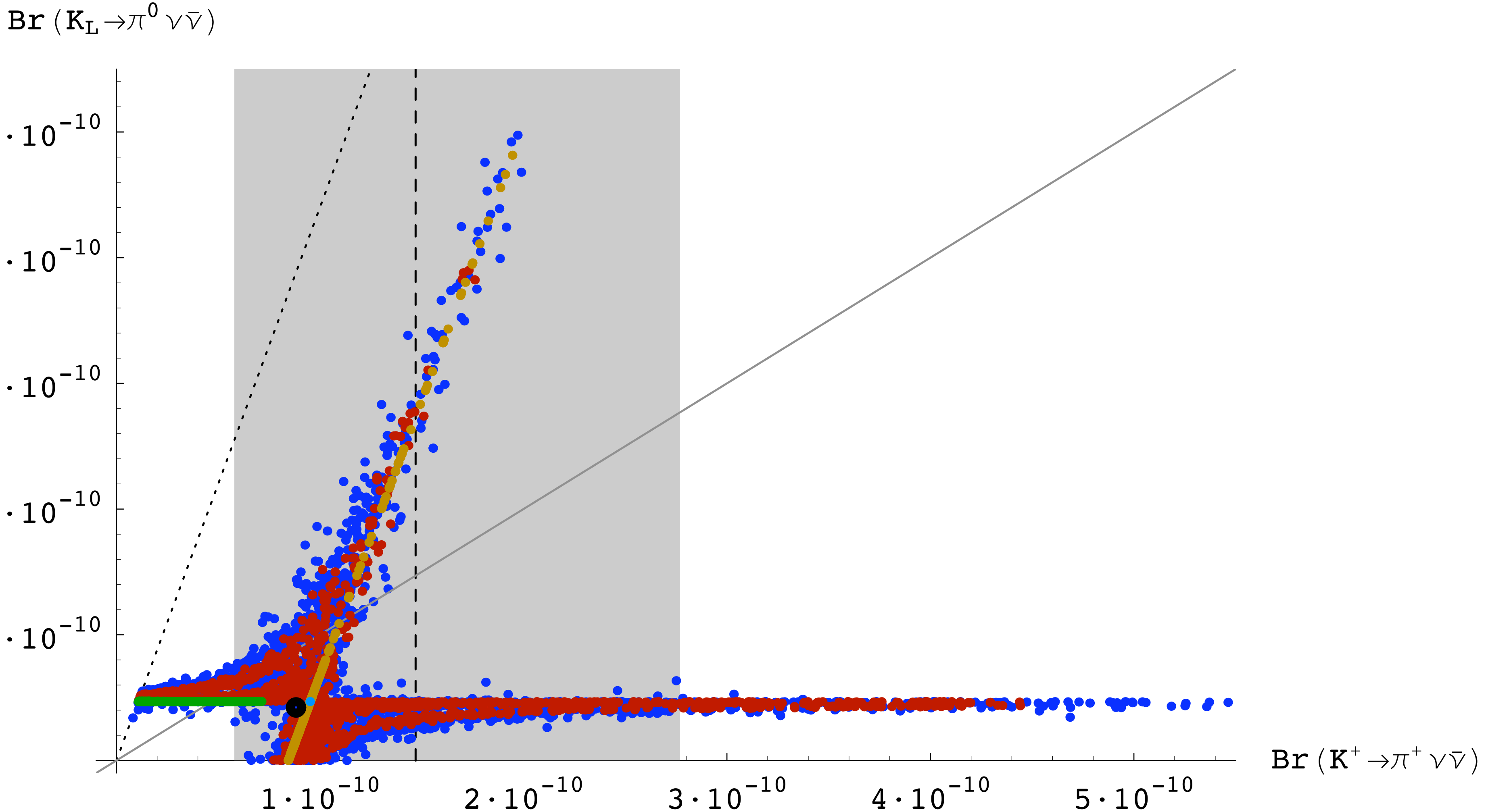
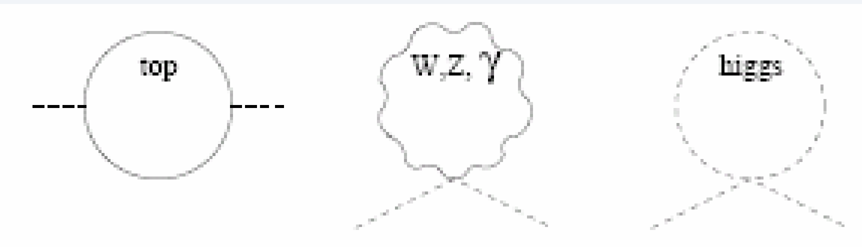
[a]*Physik Department, Technische Universität München, D-85748 Garching, Germany*
[b]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), D-80805 München, Germany*



A.J.Buras & C.Tarantino @CKM2006

SUSY vs Little Higgs

Problematic quadratic divergences in m_H^2



R-parity

T-parity

mirror fermion

	SUSY	Little Higgs
Quadratic divergences canceled by:	(different statistics) super-partners	(same statistics) heavy partners
Coupling relationships due to:	boson-fermion symmetry	global symmetry

- SUSY has a lot of virtues (required at M_{Pl},computable up to M_{Pl},helps GUT) but also …a lot of parameters (~120 in MSSM)
- Lack of SUSY signals at LEP constrains the MSSM parameters to be ~fine-tuned

- Little Higgs models are low-energy effective theories computable up to Λ~10 TeV
- Little Higgs can have less parameters(~20 in LH with T-parity) but some UV-sensitivity
- T-parity makes LH well compatible with ew precision tests, without fine-tuning

Stage-1 (scientific) approved by PAC in 2006

誰が - J-PARC E14 collaboration

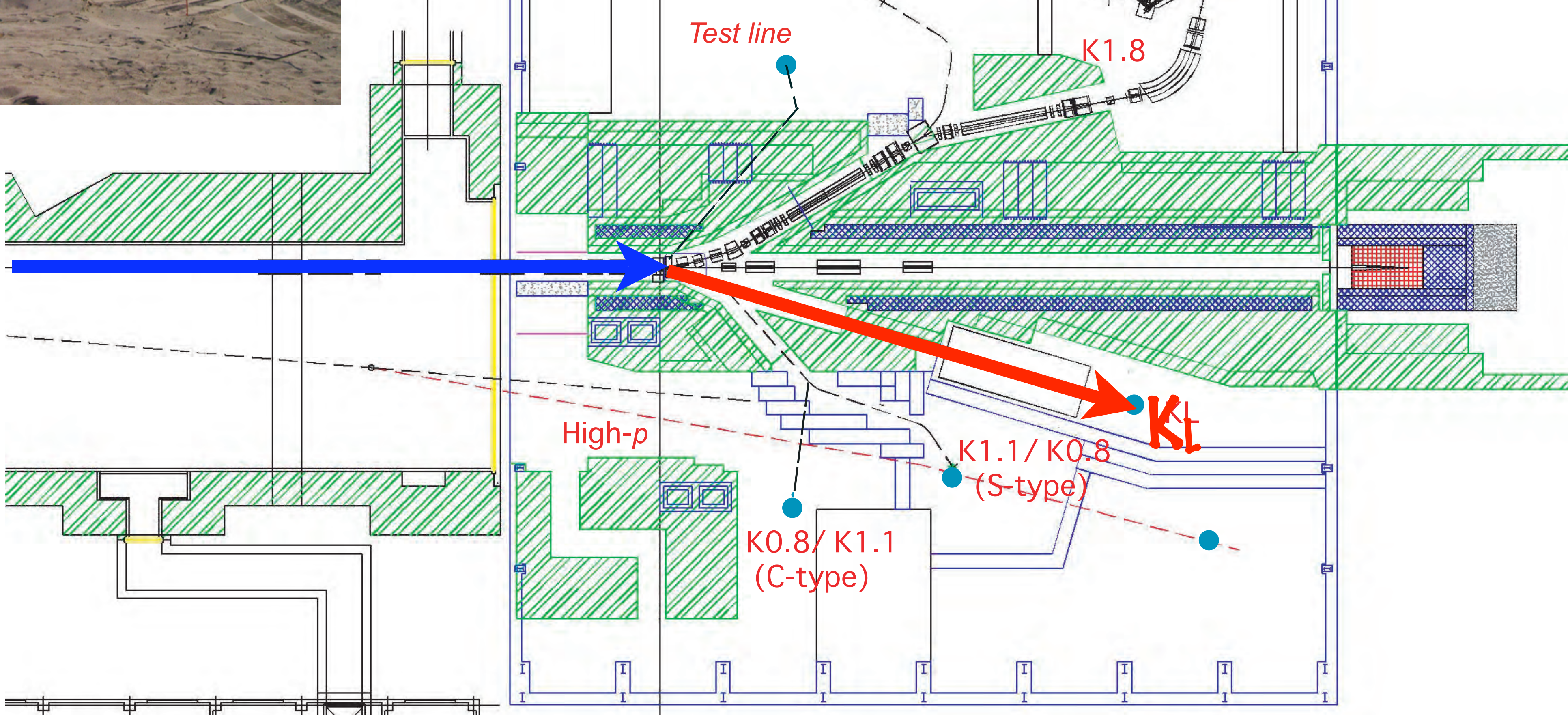
- 日本
  - KEK
    - Inagaki, Komatsubara, Lim, Watanabe, ...
  - 京都大学
    - Nanjo, Nomura, Sasao, ...
  - NDA
    - Matsumura, Shinkawa, ...
  - 大阪大学
    - Yamaga, Yamanaka, ...
  - 佐賀大学
    - Suzuki, Kobayashi, ...
  - 山形大学
    - Iwata, Tajima, Yoshida, ...
- 米国
  - Arizona State Univ
  - Univ of Chicago
  - Univ. of Michigan, Ann Arbor
- ロシア
  - JINR
- 台湾
  - National Taiwan Univ
- 韓国
  - Pusan National Univ
  - Univ of Seoul
  - CheonBuk National Univ

[new to the J-PARC experiment]

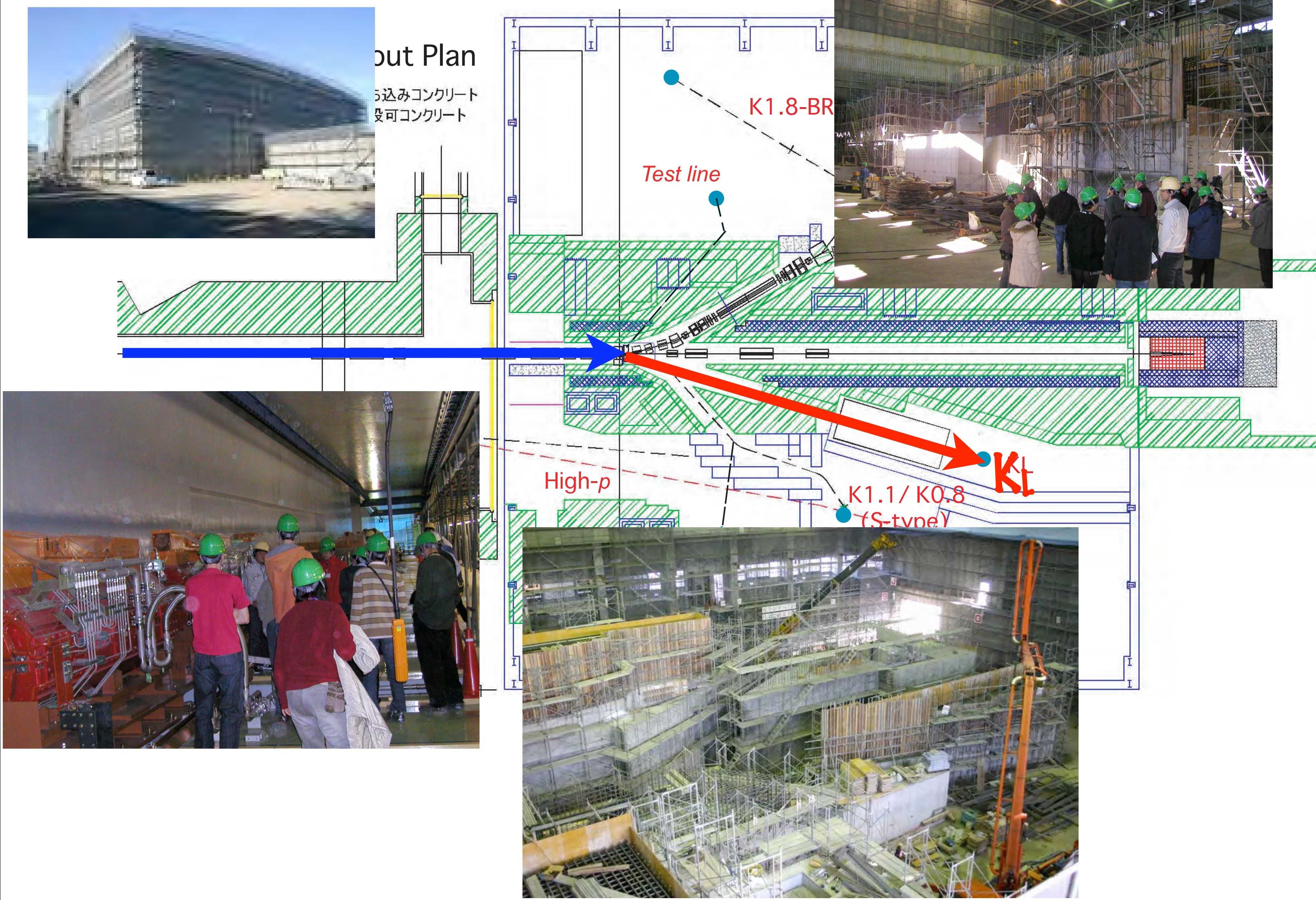
どこで - J-PARC

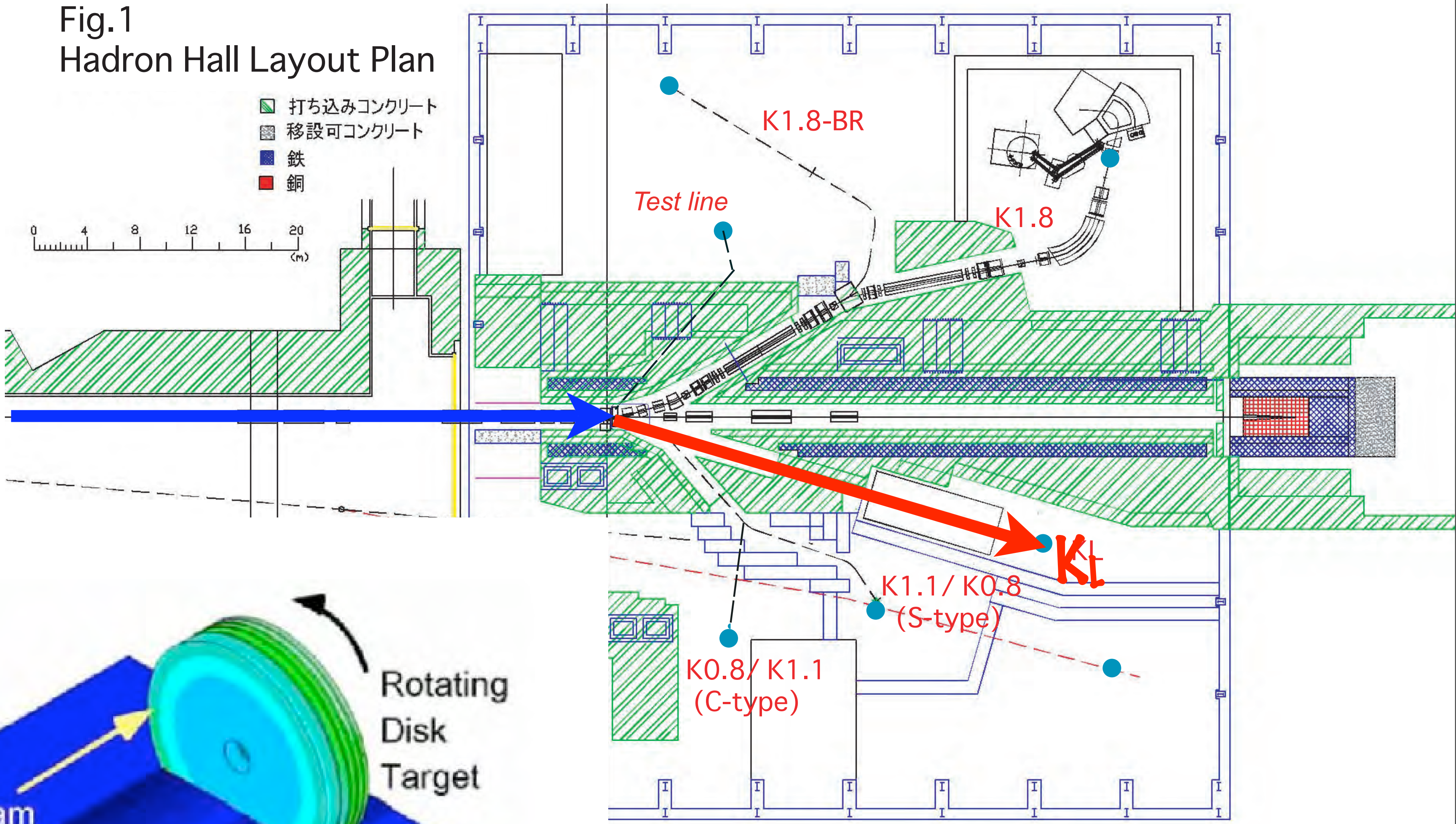
２００６年１２月撮影

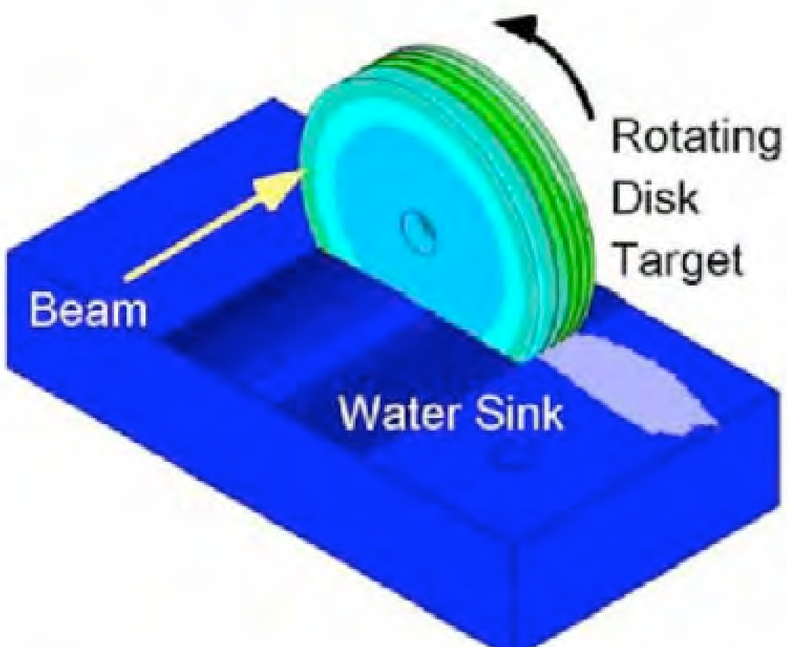

April 2004


K1.8-BR
Test line
K1.8
High-p
K1.1/ K0.8
(S-type)
K0.8/ K1.1
(C-type)
KL

http://j-parc.jp/ja/construction-j.html







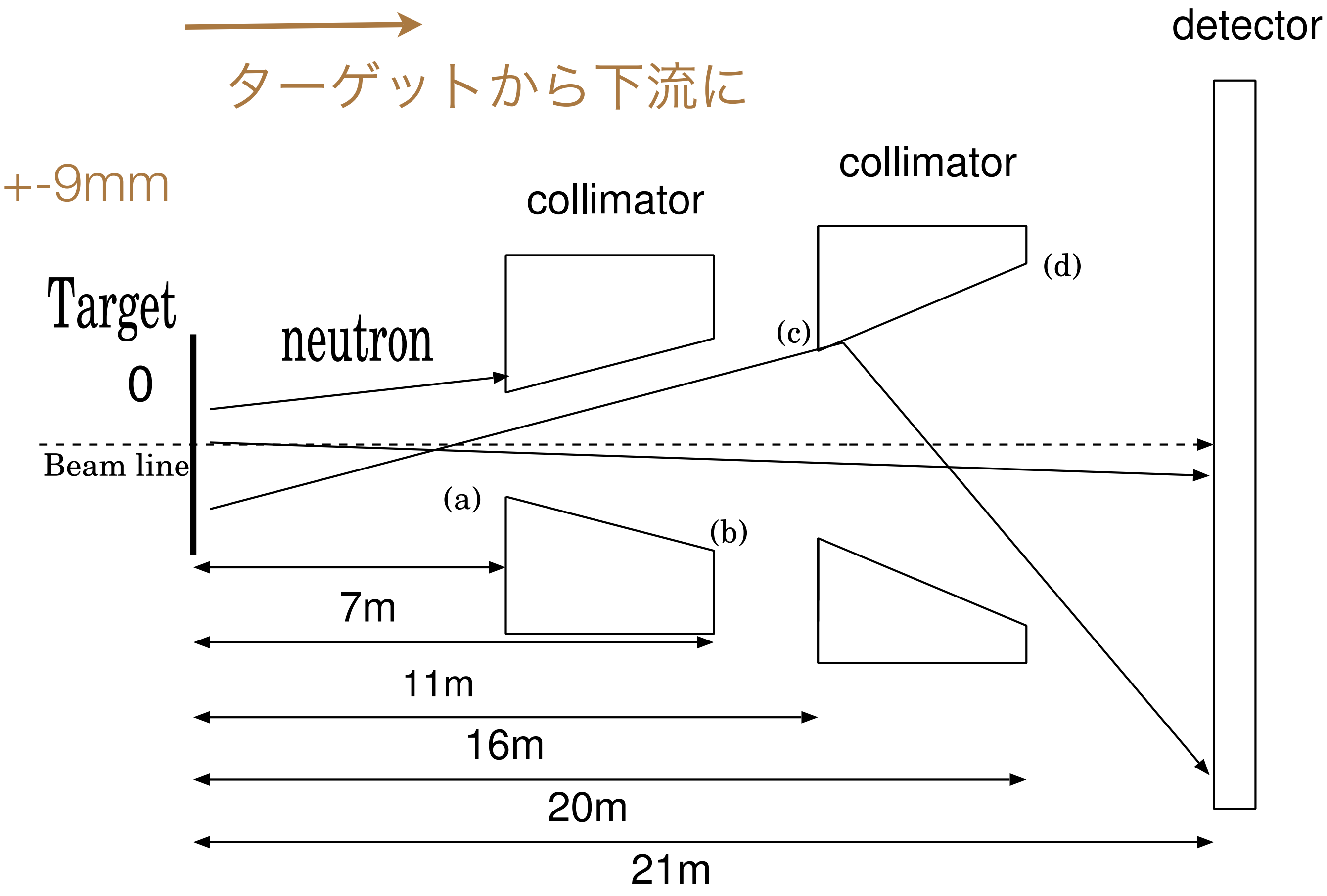
J-PARC開始初期（Phase I）に

first observation を目指す = "Step I"

どのようにして -

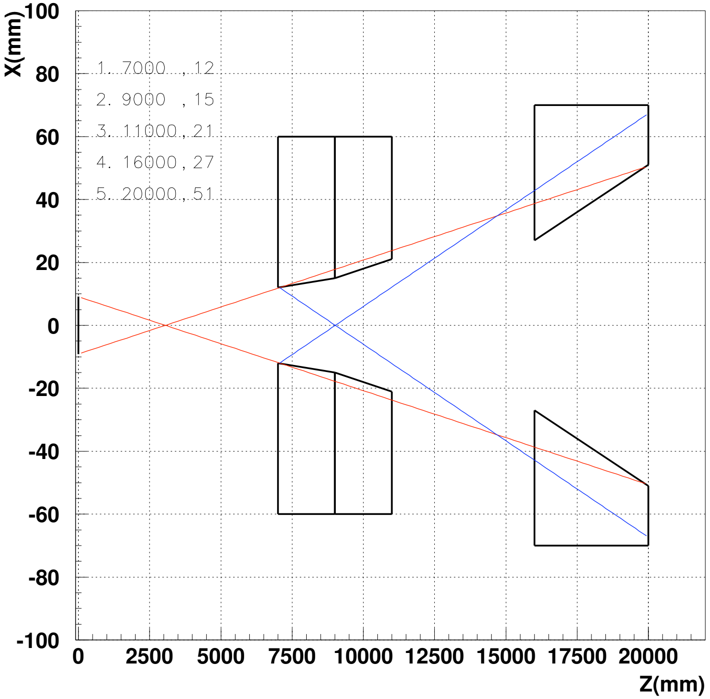
1. 中性ビームライン のデザイン（Monte Carlo）

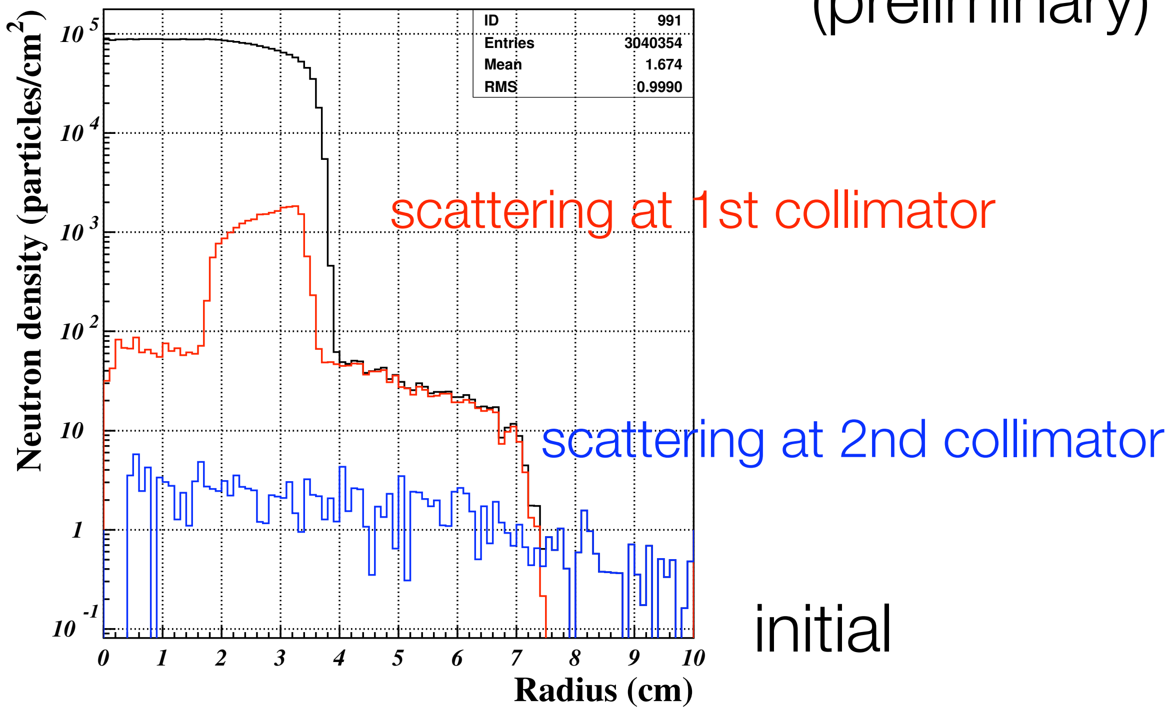
- Fast Geant4-MC to try various collimator configuration



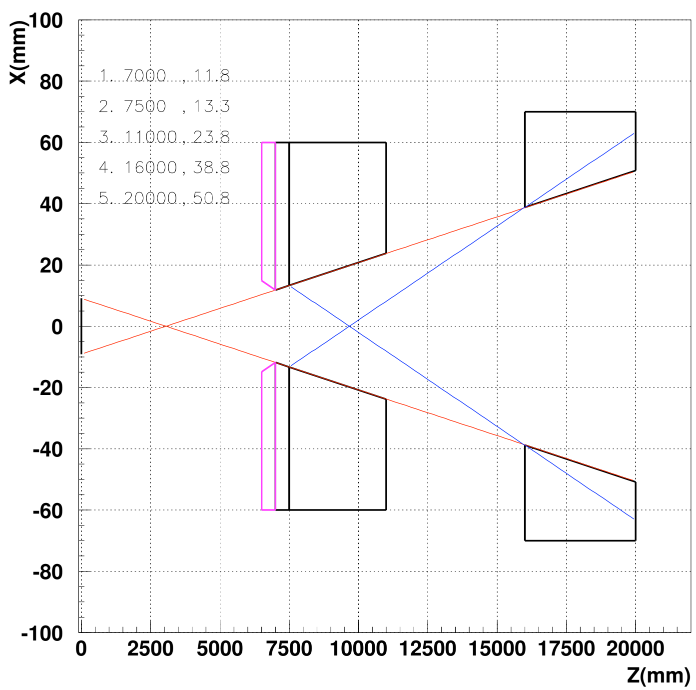
野村卓美（山形大）et al.

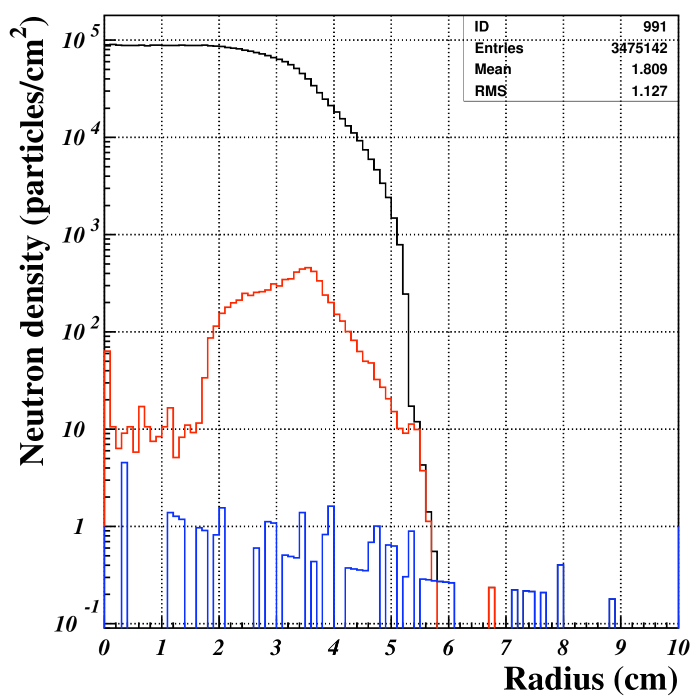
(preliminary)





initial

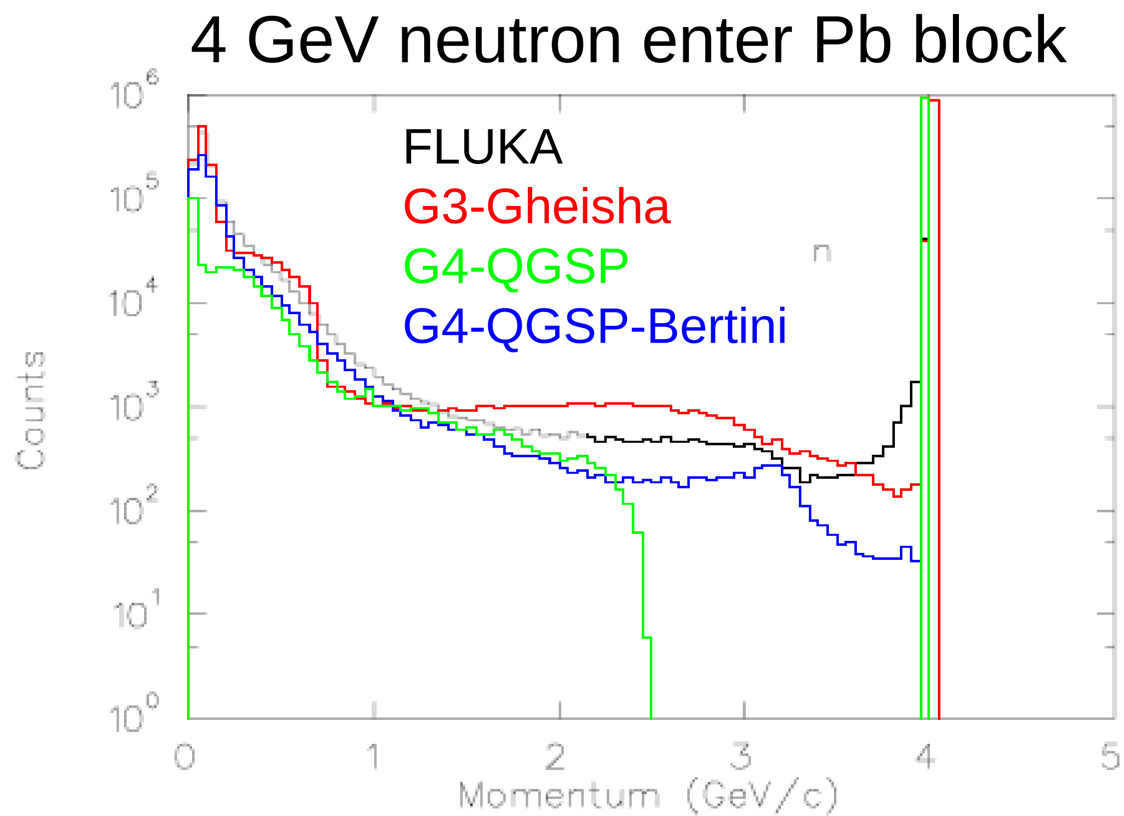




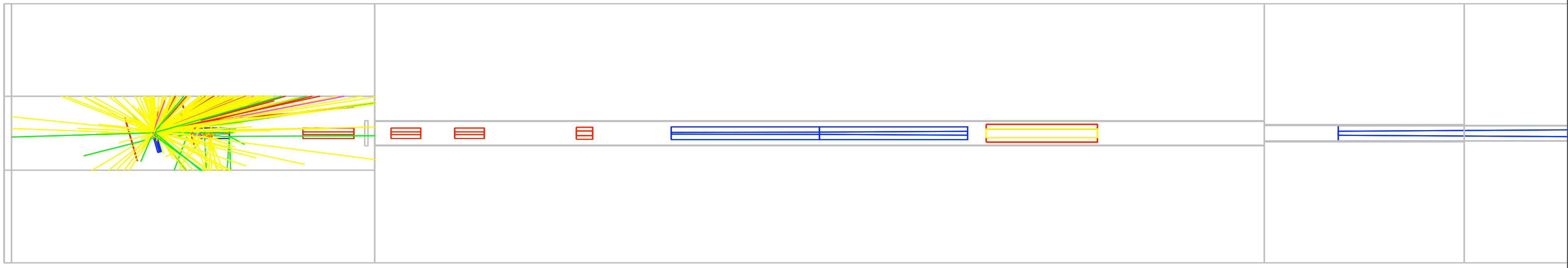
#33

- Comparing
  - Geant 3 with G-FLUKA (E391a)
  - Geant4
  - genuine FLUKA

  for target/beamline simulation



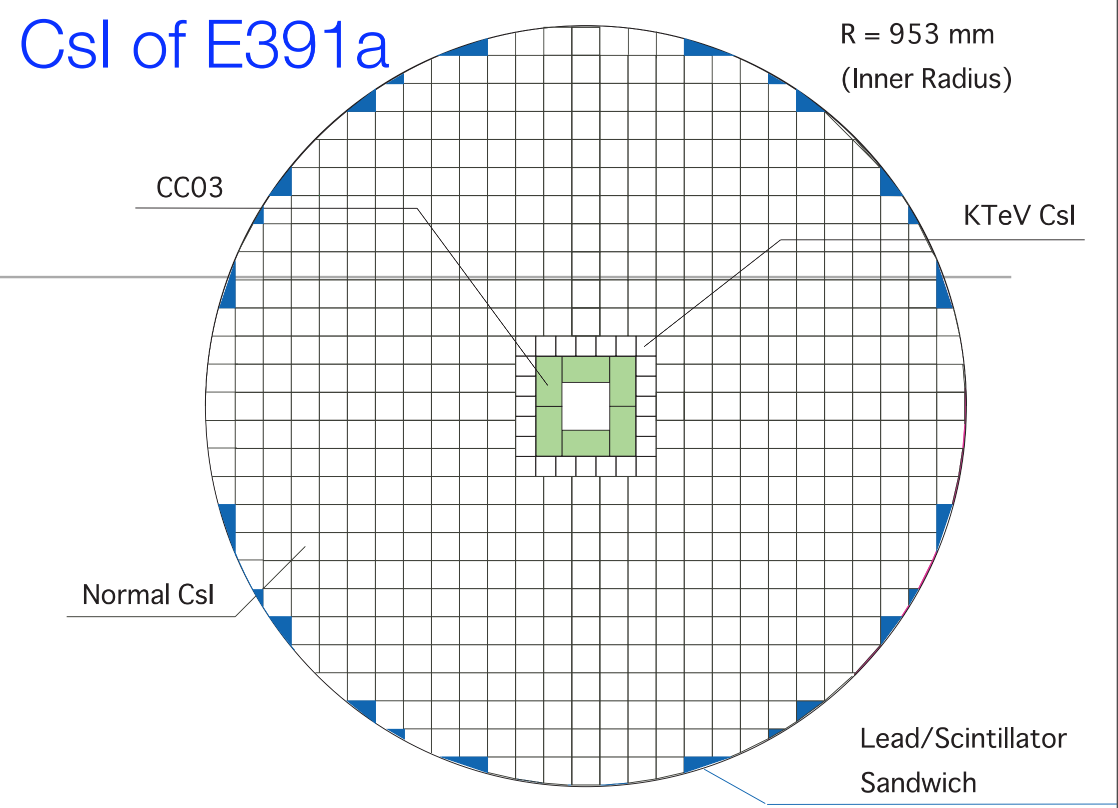
- G4 full-blown simulator is ready.

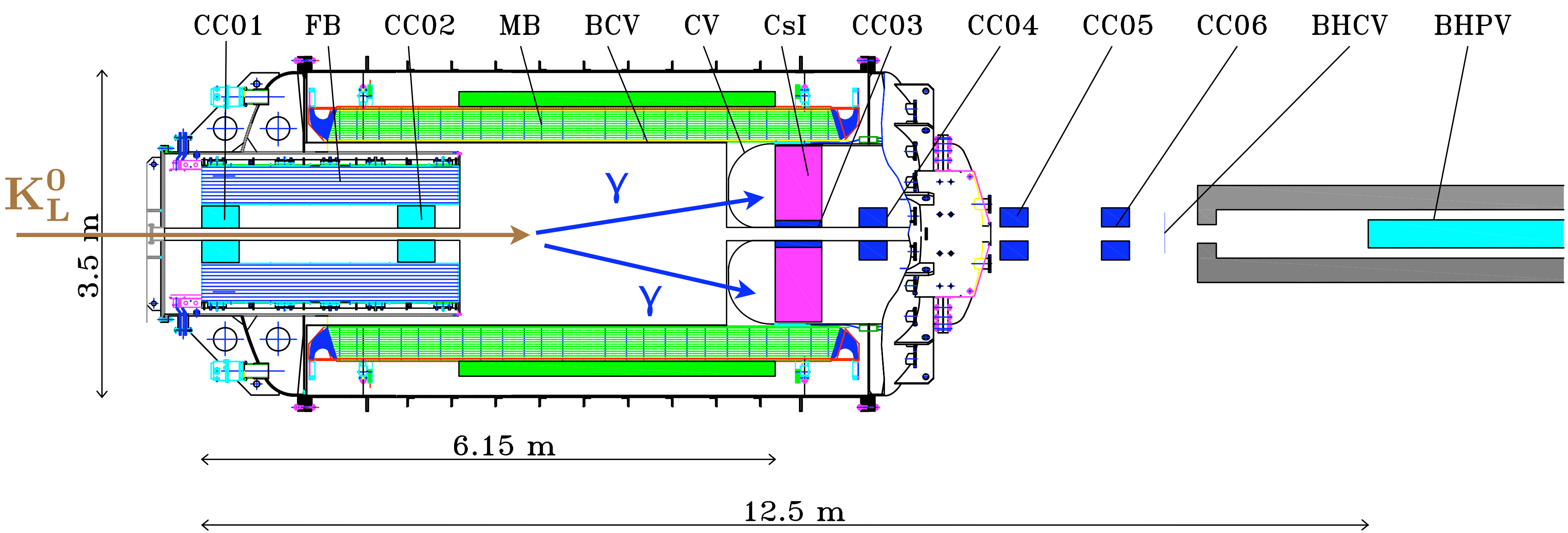


どのようにして -

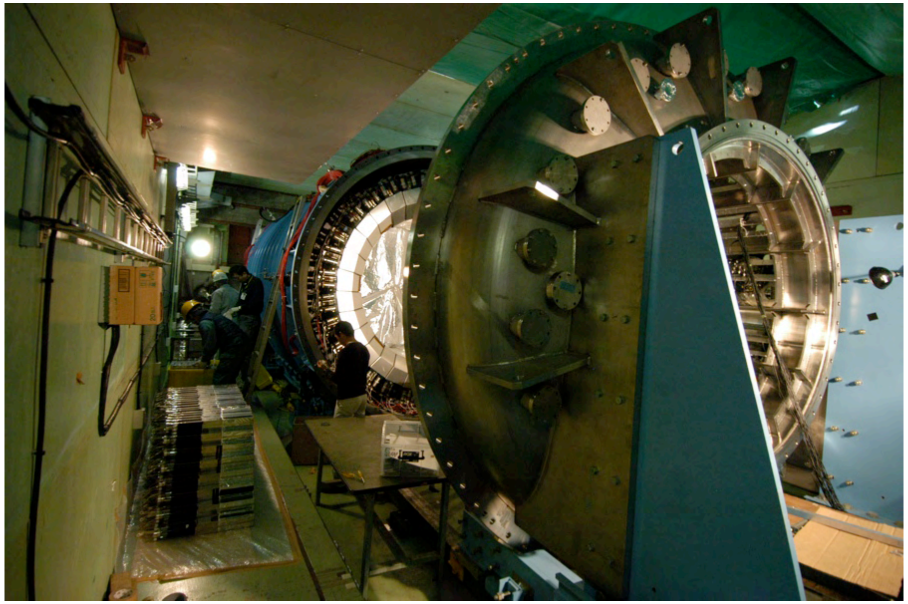
2. 測定器システム

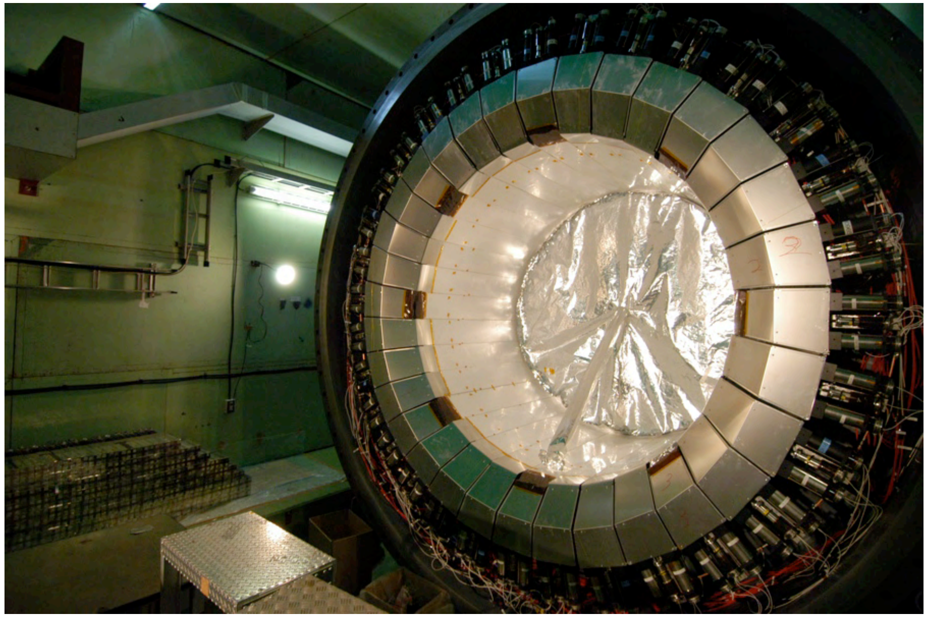
- E391a 測定器を移設／改造
  - CsI calorimeter
  - 読み出し: waveform digitization
  - photon veto in the beam



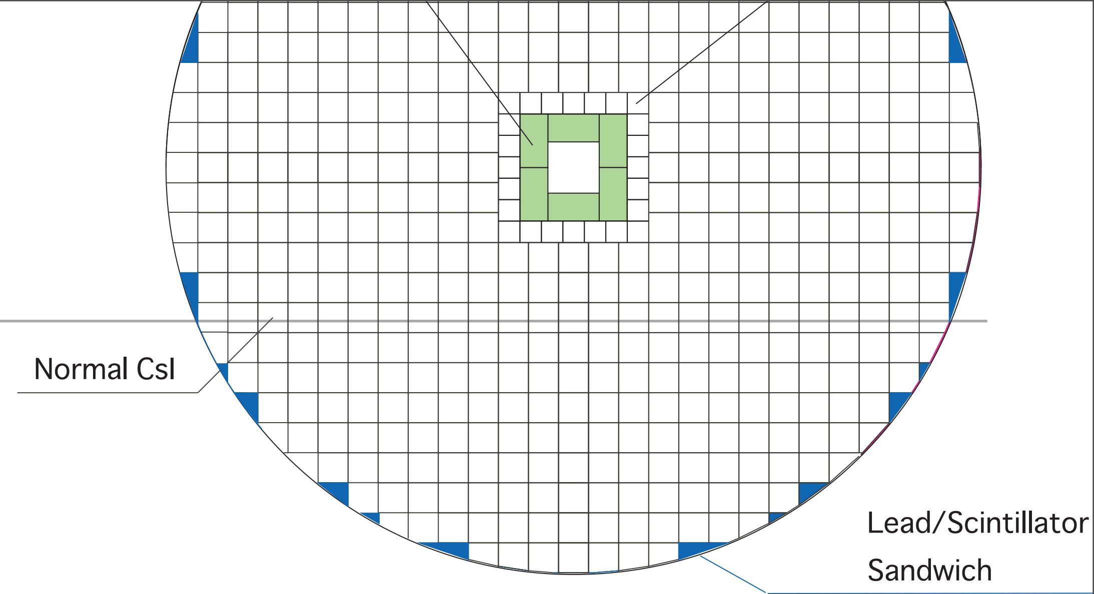


E391a 測定器 の解体作業 @東カウンターホール



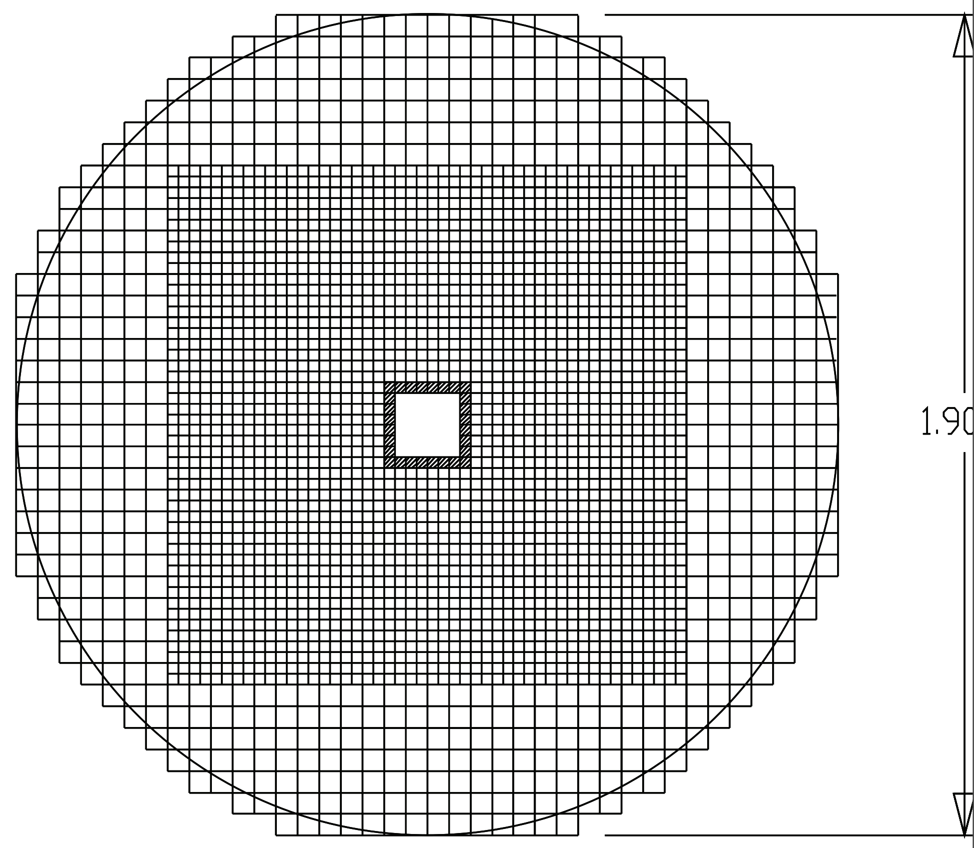


Calorimeter

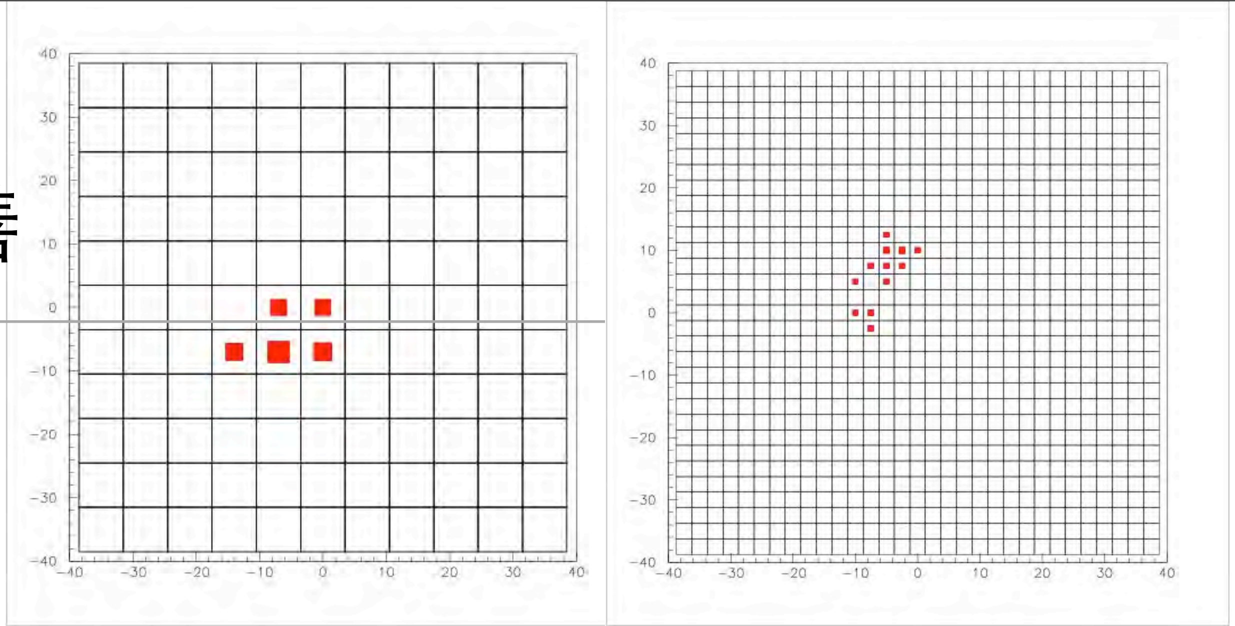


- 7cm x 7cm x 30cm (16 r.l.)
  CsI blocks for E391a (576 ch)

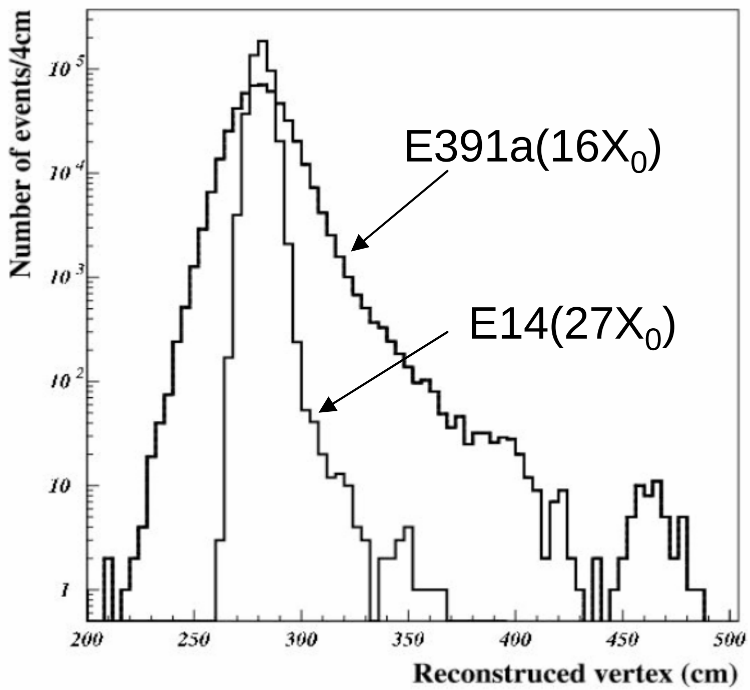
- 2.5cm x 2.5cm x 50cm (27 r.l.)
  or 5cm x 5cm x 50cm
  CsI blocks from KTeV (2816 ch)

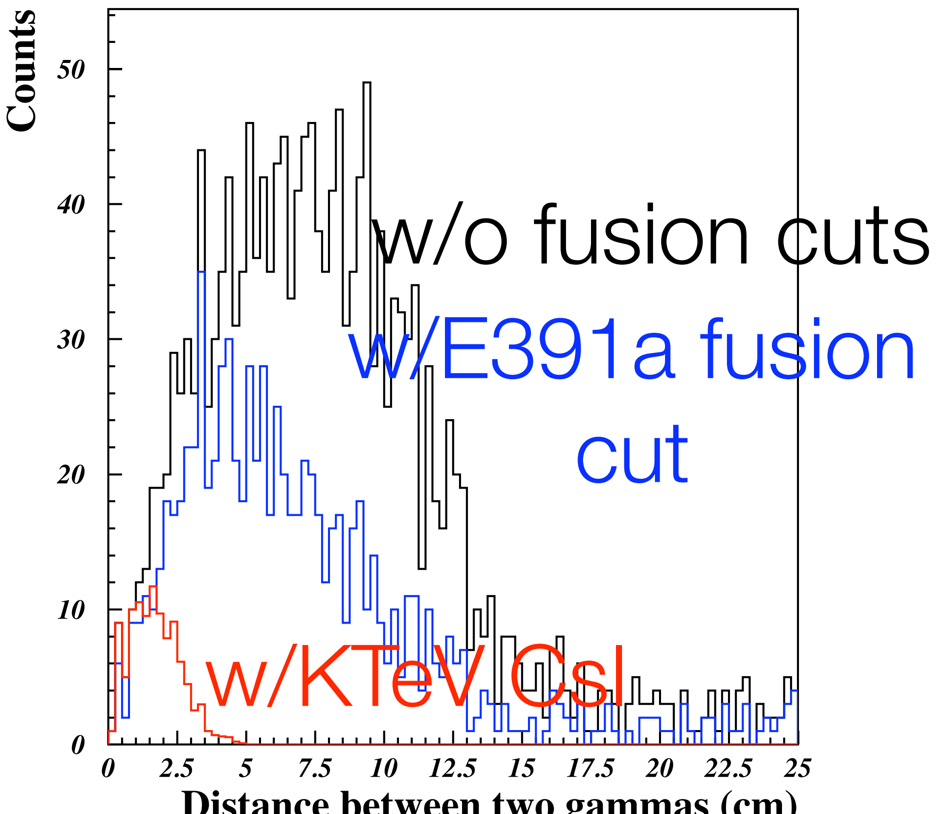


KTeV CsI による改善



- photon isolation
  - x8 bkg reduction
- energy resolution (punchthrough)
  - suppress n bkg





KTeV CsI を
Fermilab から借り受ける

- Fermilab Director, Dr. Oddone,
  visitd KEK and
  had a tour of E391a experiment
  on November 21, 2006.

- We were being told on December 1
  by Dr. Oddone that
  “There is no reason why we can’t have
  the KTeV CsI for E14”
  and he urged us to work with KEK/Fermilab
  to initiate the proper transfer.

進行中

Fermilab Today

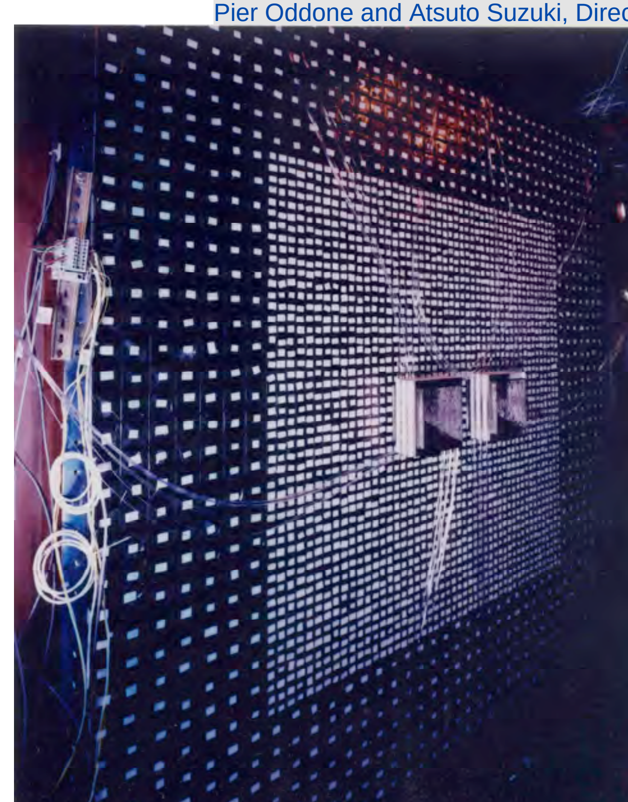
Tuesday, November 28, 2006

Search GO

Director's Corner

Future collaborations II

Pier Oddone and Atsuto Suzuki, Director of KEK.



出力波形　を記録する

waveform digitization of detectors

- for <u>high performance in high rate environment</u>

- 要求される事項：

  - Triggerable pipeline DAQ

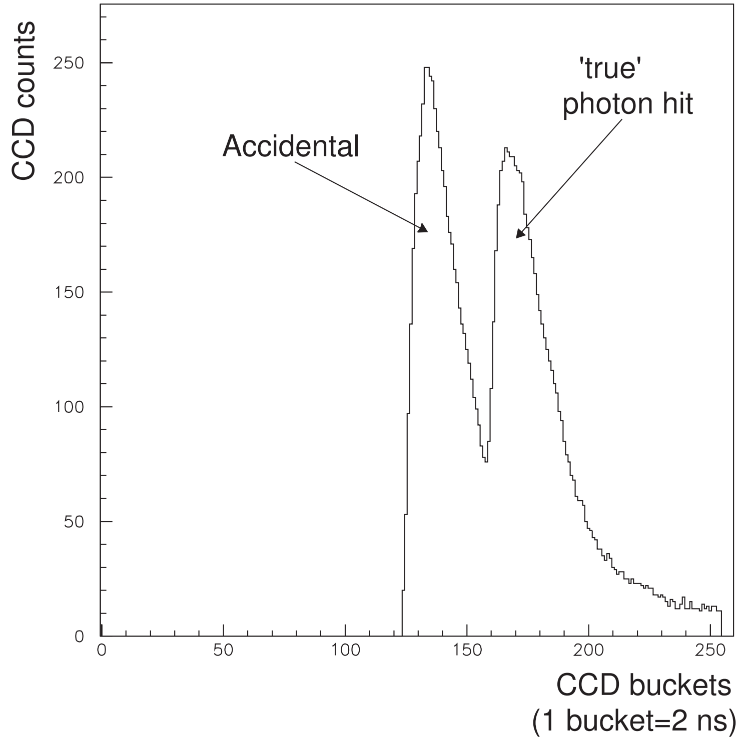
  - Wide dynamic range: 0.1MeV - 2GeV
    (>4 orders of magnitude)

  - <1ns time measurement

  - for ~4000 channels
    (2576 ch for the CsI calorimeter)

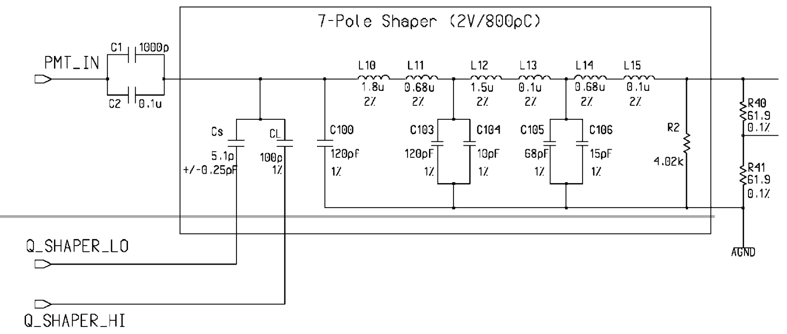
  - at high performance/cost

500MHz digitization
(BNL-E787 CsI endcap)



Waveform digitization design

passive (in vacuum)

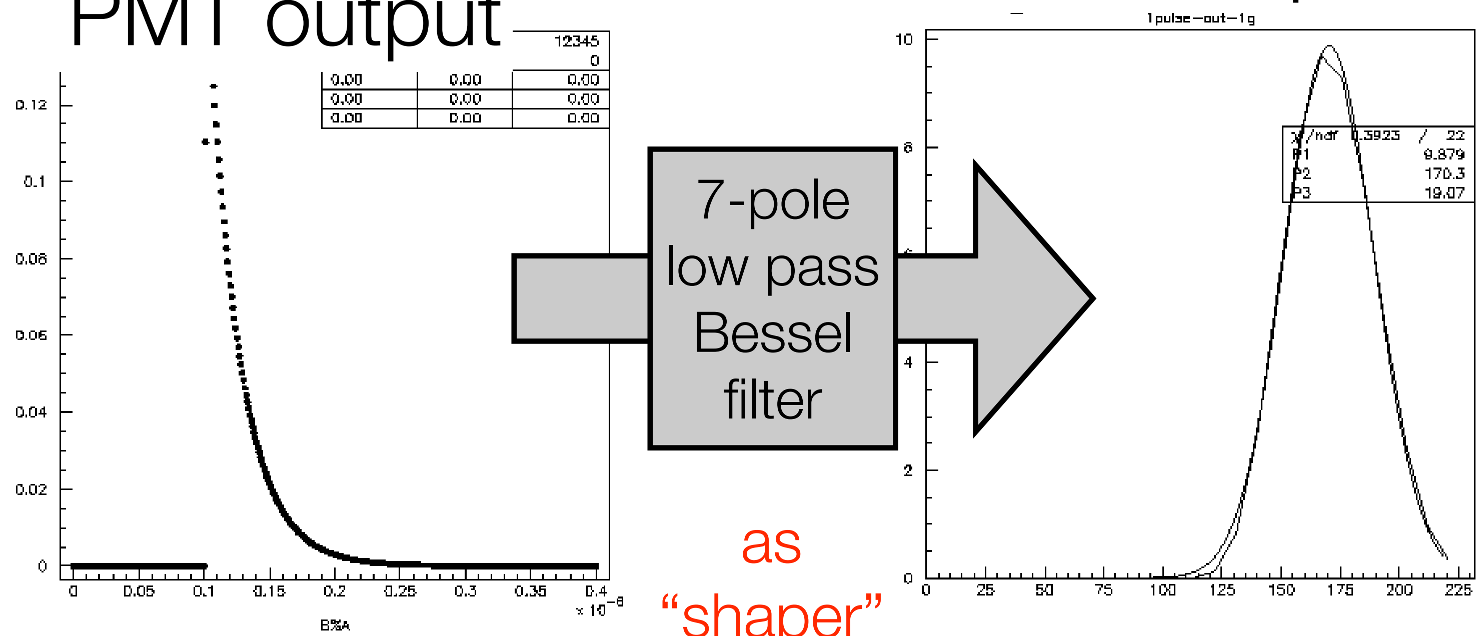


- Designed by Univ of Chicago Electronics Shop
- Basic idea:

originally for
ATLAS
tile calorimeter

PMT output

Gaussian pulse



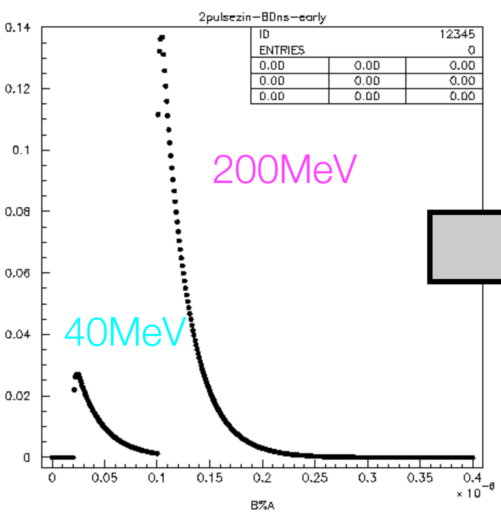
as
“shaper”

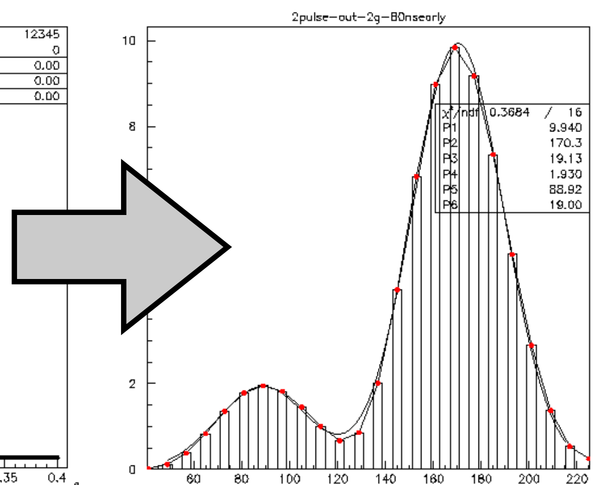
Digitize by 14bit
125MHz FADC

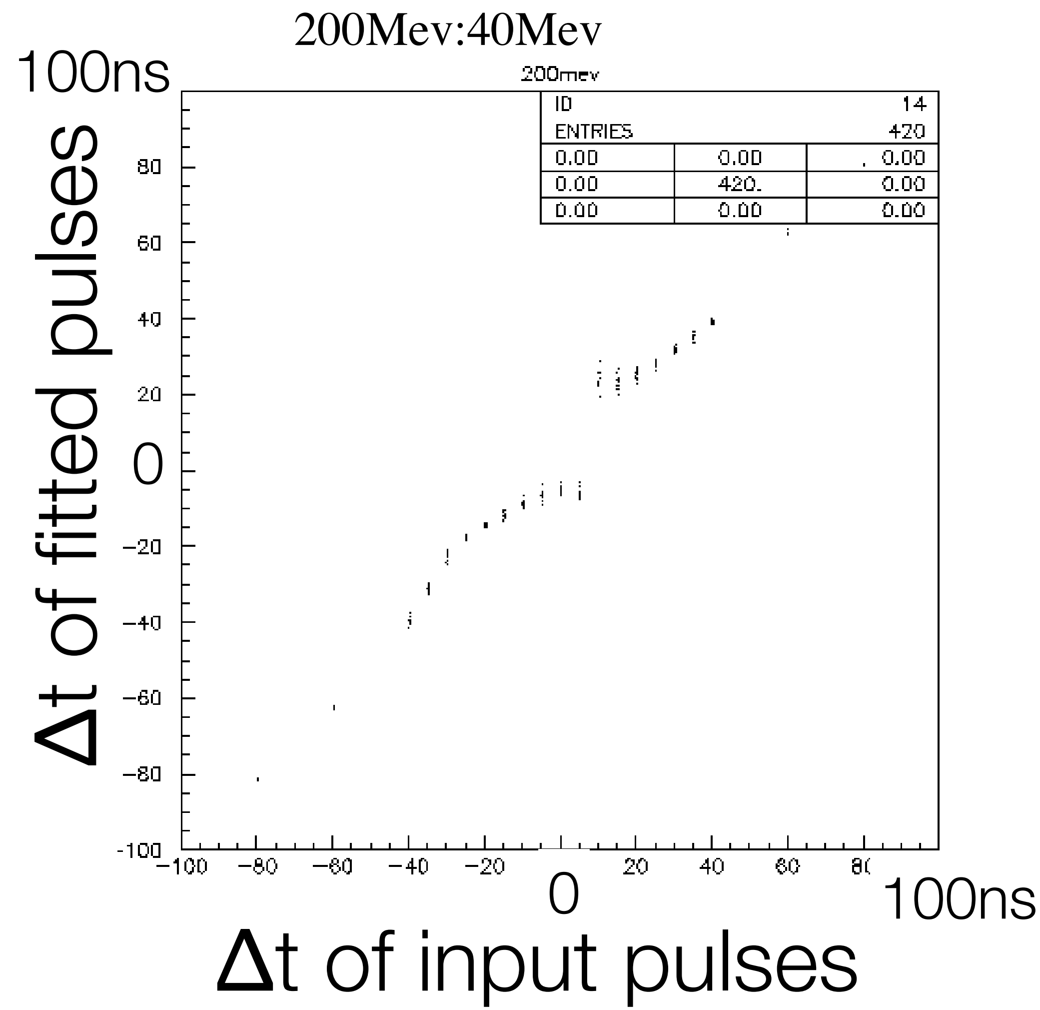
- Good E and t resolution with lower frequency

Double pulse resolution

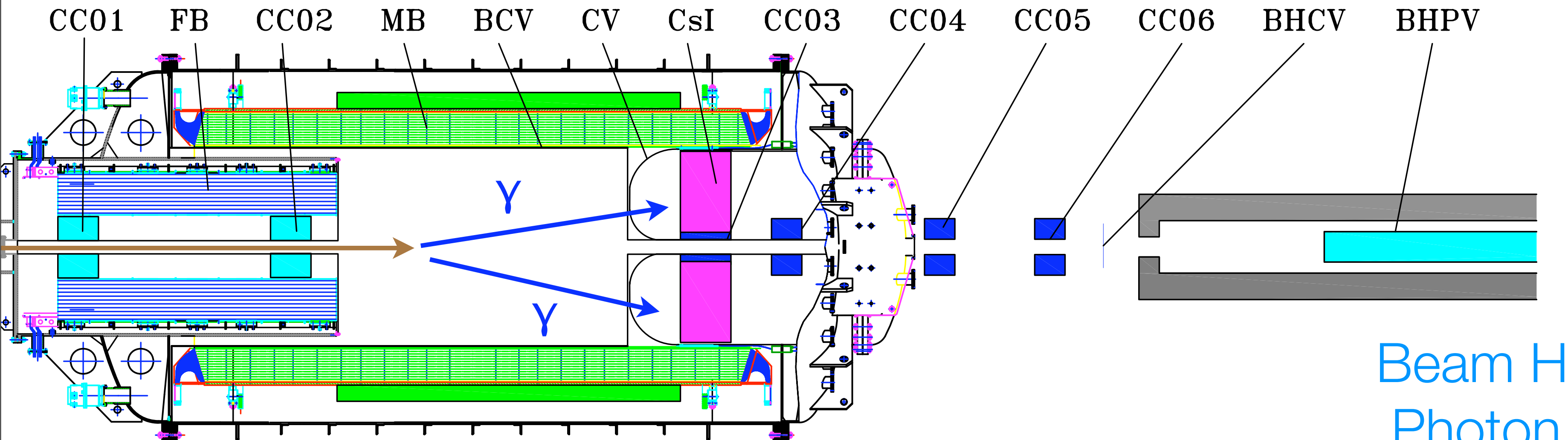
- Can resolve 200MeV and 40MeV pulses with >20ns apart



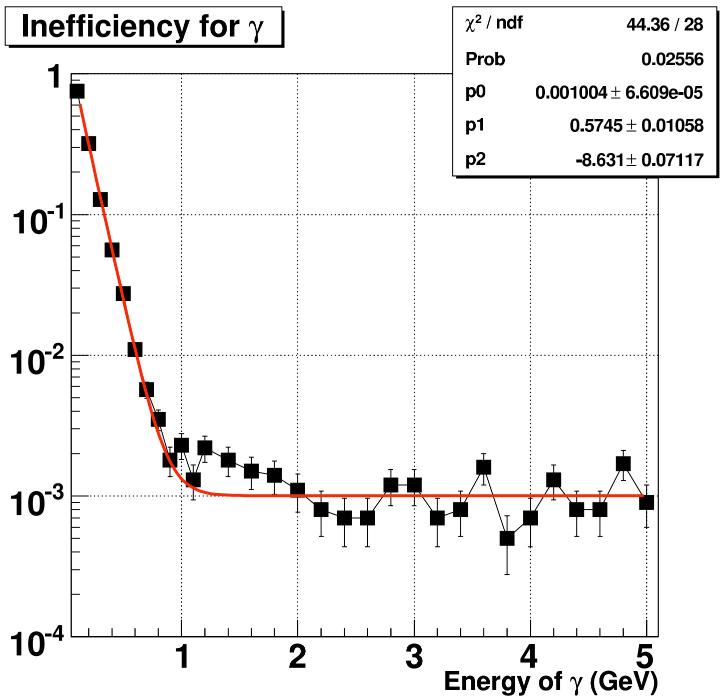


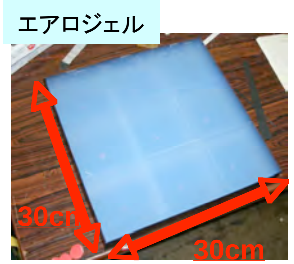


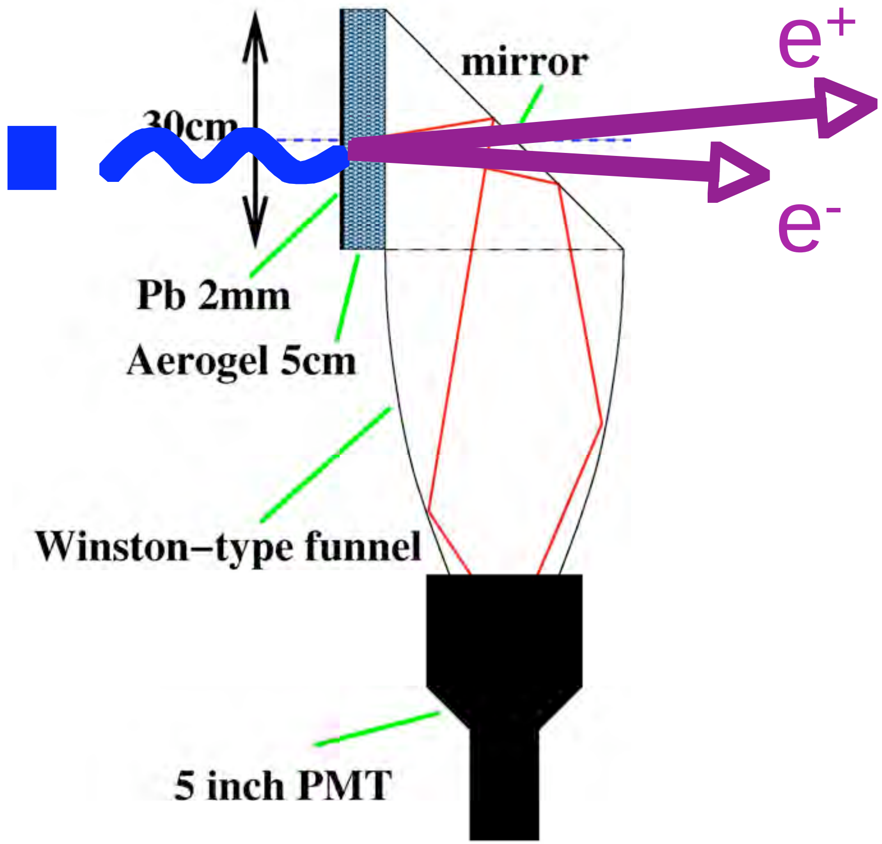
In-beam photon detection



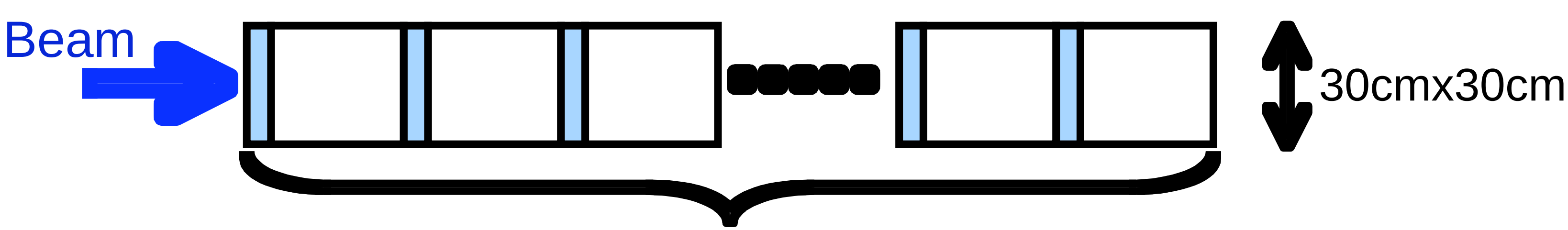
Beam Hole
Photon Veto







@E391a



25 modules(8.3X_0), 35cm pitch → ~9m long

いつ - スケジュール　(Step1 にむけて)

- JFY 2007
  - <u>preparation of the beam line and detector upgrade</u>
  - Design and make 100 channel system for CsI readout
  - --> Beam test at Fermilab test-beam facility
  - Test shipment of CsI crystals to Japan

- JFY 2008
  - Ship rest of the CsI crystals to Japan
  - Make rest of the boards for CsI and photon veto detectors
  - <u>Beam survey at the end of JFY2008</u>
- JFY 2009
  - Assemble detector
- JFY2010
  - Start experiment

まとめ:

- What　稀崩壊　$K_L \to \pi^0 \nu \overline{\nu}$
- Why　標準模型を越える物理の フレーバー構造 を探索
- Who　J-PARC E14 collaboration
- Where　J-PARC
- When　初期に、初めての観測を目指す = Step 1
- How

ペンシルビーム + CsIカロリメータ + waveform digitization + photon veto