Simulations for super rare-decay experiments

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MC Simulation

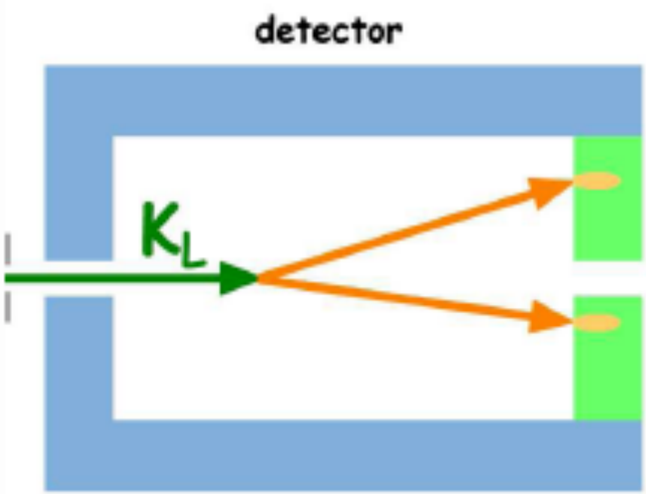
- Estimate environment
  - KL/neutron momentum, flux
- Design and evaluate beamline
  - KL, core / halo neutron momeutum, flux
- Design detector
  - Detector hit rate
  - Requirements for detector inefficiency
- Quantitative evaluation of Signal/ Backgrounds
- Analysis stage

Current E14 simulation status

- Target simulation
  - FLUKA/G3/G4
- Beamline simulation
  - FLUKA/G3/G4
- Detector (G4 base framework)
  - Kπνν signal
  - K background
    - Kp2
    - chKp3
    - Ke3
  - Halo neutron background
    - CC02
    - CV-π0

$\pi^0\nu\nu$ experiments

- 2 gammas from π^0→ Calorimeter
  - (In E14, π^0→eeγ is not used due to small Br)
- No other activities→ Veto detectors
- → Two types of detectors

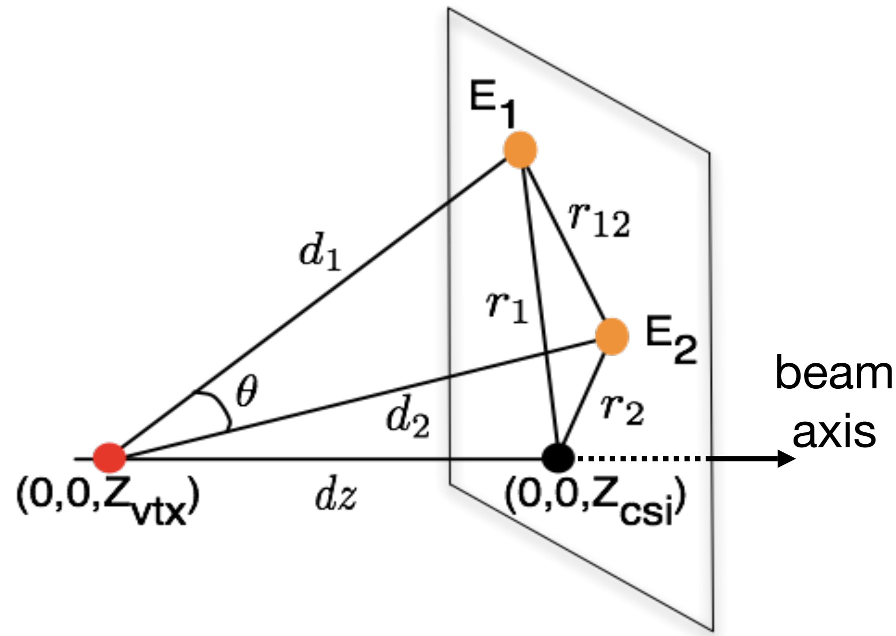


MHz/cm^2 core neutron flux

E14 approach

- Pencil beam method
  - Reconstruct p0 assuming its vertex is on the z axis

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

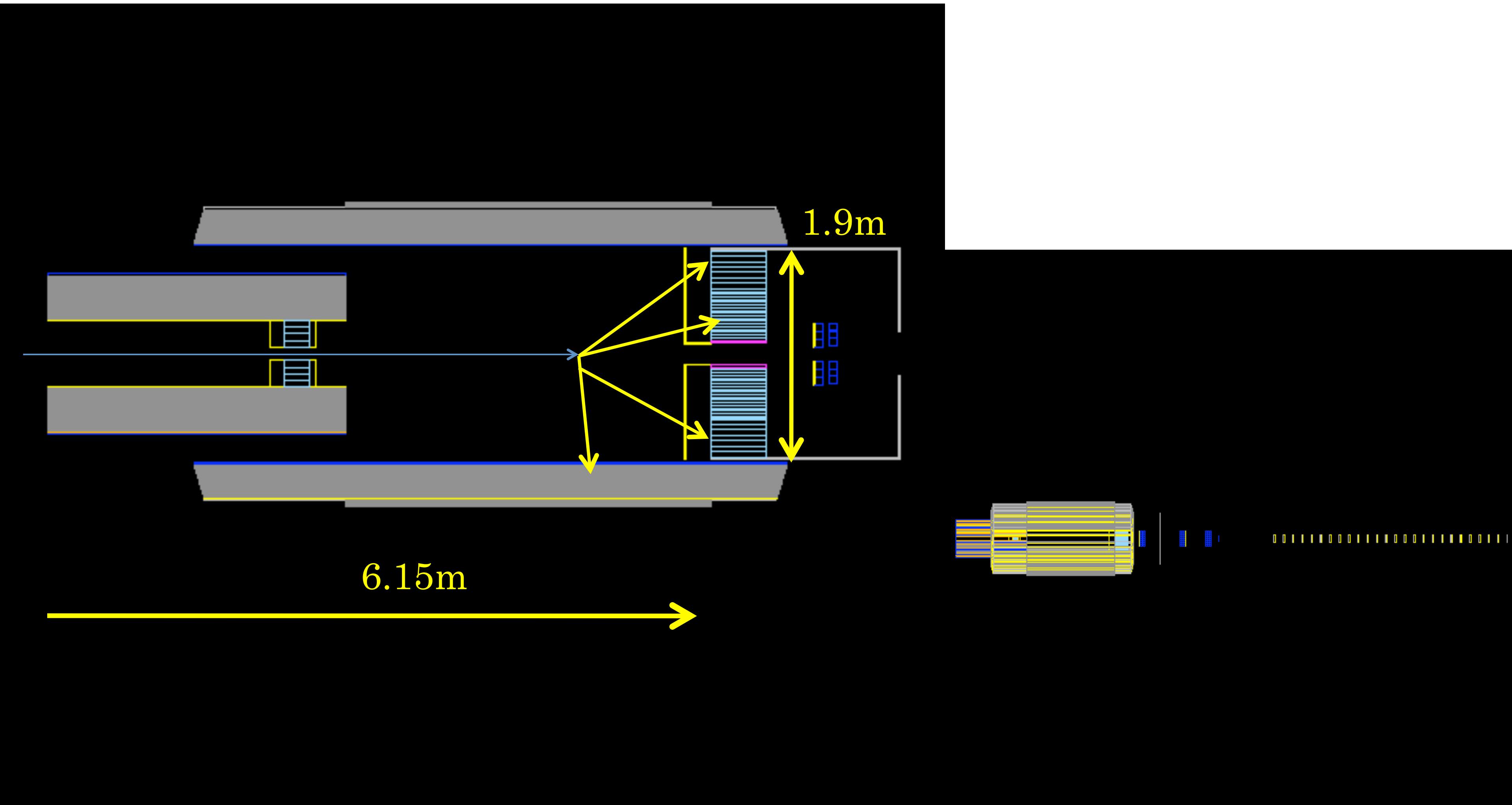


  - Calo:
    - Energy leak
      - Shower leakage
      - Photonuclear effect
    - Energy addition
      - Extra particles in π^0 or η production by halo neutron

E14 Detector

CsI :

Calorimeter and Veto function



Items to simulate

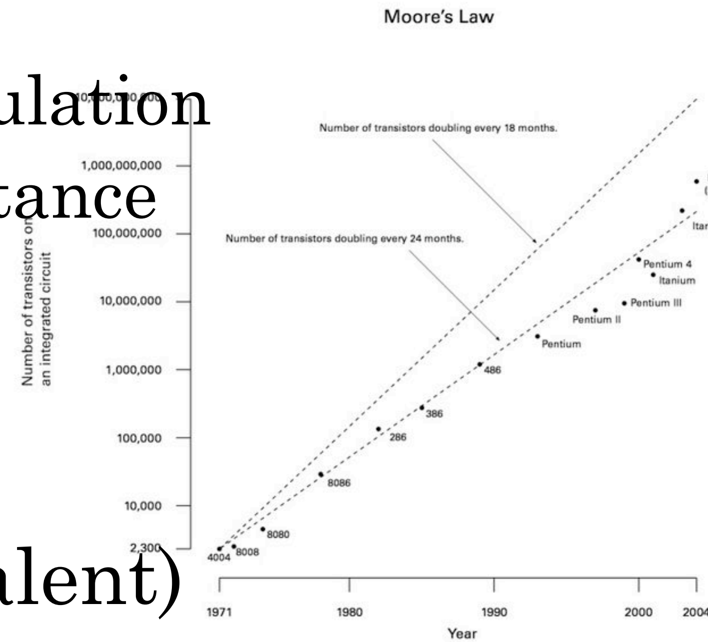
- CsI as Calo
  - Gamma energy reconstruction
    - Energy leak (Shower leakage and Photonuclear)
    - Energy addition by extra particles π^0 or η from neutron interaction
  - Cluster shape
- CsI as Veto
  - Inefficiency (incl. fusion) down to 1 MeV
- Other Veto detectors
  - Gamma inefficiency
    - Inefficiency down to 1MeV
    - Punch through, Sampling, Photonuclear effect
  - Charged inefficiency
    - $\pi^- + A \rightarrow \pi^0 + X$
    - $e^+ + e^- \rightarrow \gamma + \gamma$
- Neutron interactions
  - π^0, η production

E14 Simulation method

- Full simulation
  - Some speed-up methods
- Fast simulation
  - Inefficiency/fusion weight, smearing for CsI
- Recycling events of interest
- Fast-Full simulation
  - Use full simulation at CsI response and at halo-neutron interaction

Full Simulation

- Signal
  - Produce easily with full simulation
  - Already used to study acceptance



- Kπ2 : 7×10^{10} (S.E.S equivalent)
  - Now 3 months with 300 CPUs (2.8GHz)
  - CPU power will be 10 times higher at 2012.
    - Doubled every 18 months by Moore's law.

Speed up of MC production

Time [sec] for $10^4\ K_L \to 2\pi^0$	Conditions
120	FastSimLevel==5 for PhotonVetos
229	FastSimLevel==3 for PhotonVetos
1029	FastSimLevel==3 for BHPV
1099	FullShower
526	OnlineThresholdFastVeto
491	OnlineThresholdFastVeto, DetectorOrder
345	OnlineThresholdFastVeto, DetectorOrder, VtxFastTrigger
	$\to$9.2 months with 100 CPUs for $6.9 \times 10^{10}\ K_L \to 2\pi^0$

FastSimuLevel==5	:	Stop at the surface of the volume.
FastSimuLevel==4	:	Stop after the first step inside the volume.
FastSimuLevel==3	:	Stop 2ndary-creation from the processes, eBrem, annihil, and, conv.
OnlineThresholdFastVeto	:	Kill the event immediately if Edep>Threshold. CC00 0.05 GeV, CC01 0.05 GeV, CC02 0.05 GeV, CC03 0.05 GeV, CC04 0.05 GeV, CC05 0.05 GeV, CC06 0.05 GeV, FBAR 0.05 GeV, CBAR 0.05 GeV, CV 0.002 GeV
DetectorOrder	:	Decide from which detector shower simulation start. BHCV CV BCV CC04 CC05 CC06 BHPV CC00 CC01 CC02 FBAR CBAR CSI
VtxFastTrigger	:	Trigger with the end z-position of the primary. /GsimStackingAction/triggerPrimaryEndZ -10*m 10*m

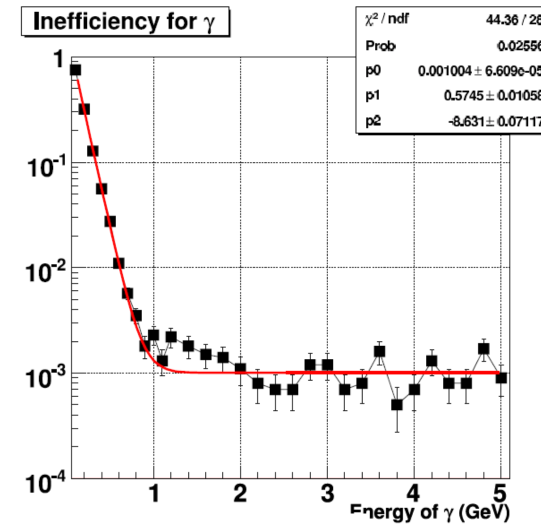
Fast Simulation

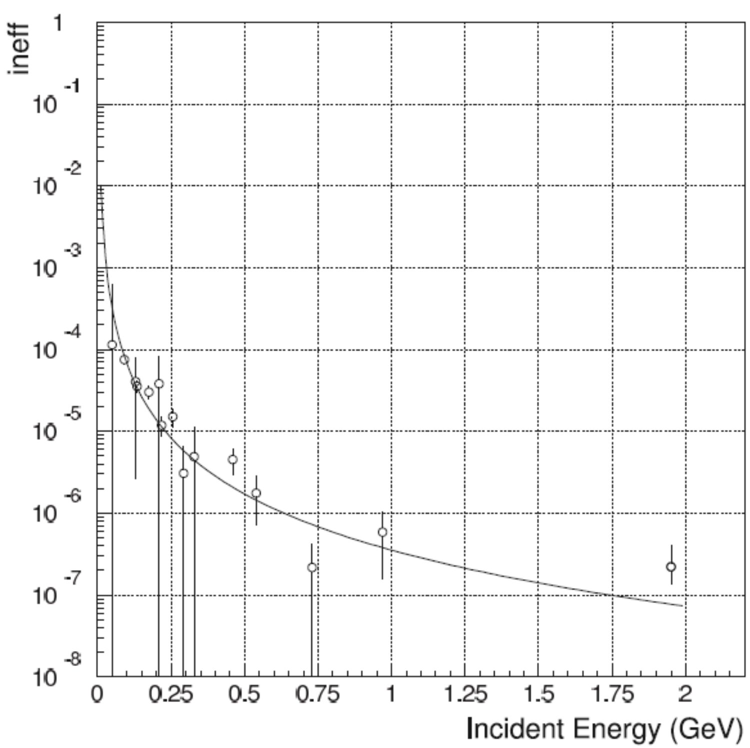
- Stop particles on the surface of detectors
- Use inefficiency, fusion weights
  - It enables to evaluate S/N with smaller MC statistics
    - Rare event topologies can be treated as event weights.
    - BG evaluation with ~10^7 events / 1day for K backgrounds.

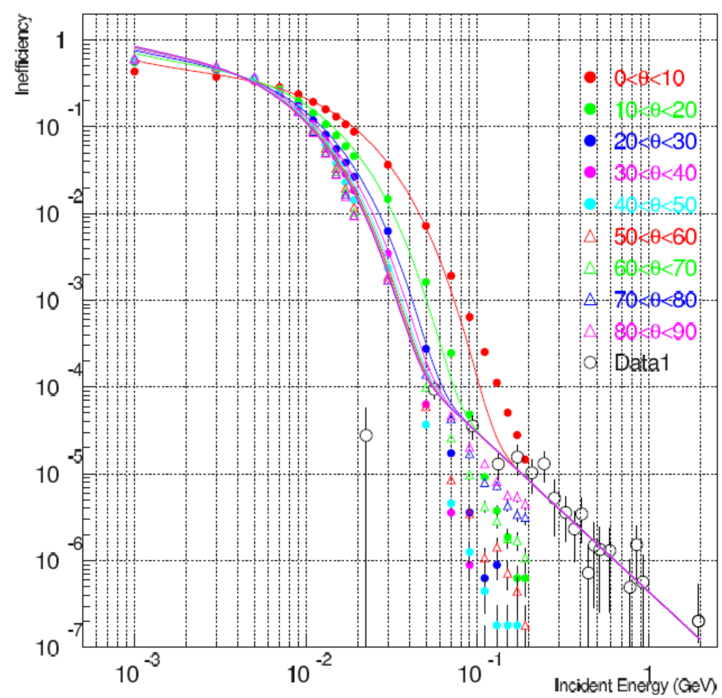
		standard cuts	CsI cluster shape cut	acceptance loss (50%)
Signal	$K_L \to \pi^0\nu\overline{\nu}$	6.0 ± 0.1	5.4 ± 0.1	2.70 ± 0.05
K_L BG	$K_L \to \pi^0\pi^0$	3.7 ± 0.2	3.3 ± 0.2	1.7 ± 0.1
	$K_L \to \pi^+\pi^-\pi^0$	0.18 ± 0.08	0.16 ± 0.07	0.08 ± 0.04
	$K_L \to \pi^-e^+\nu_e$	0.13 ± 0.01	0.03 ± 0.003	0.02 ± 0.001
halo n BG	CV	—	—	0.08
	η	8.1	0.6	0.3

Gamma Inefficiency Function

- CsI, Veto, BHPV
  - Photonuclear from Exp.Data
  - Veto : sampling calo. MC simu.
  - BHPV: beam test and MC

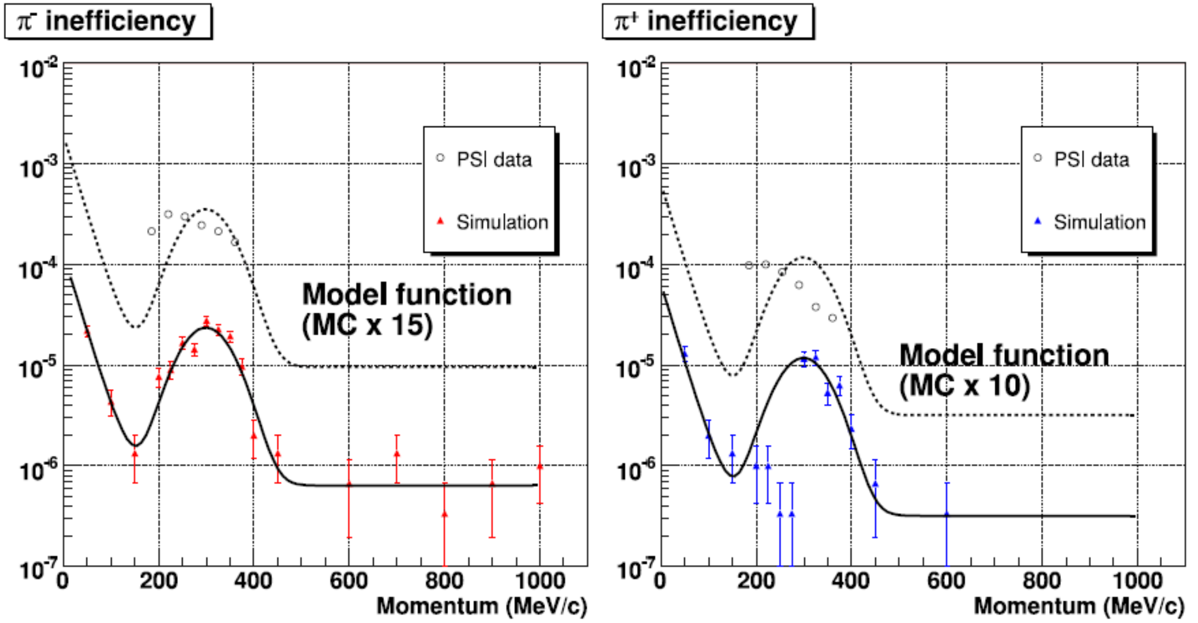






Charged Inefficiency Function

- CV: PSI measurements with a photon calorimeter behind.
  - Inconsistency due to the small size of a calorimeter used in the PSI measurements.
- BHCV : 0.5% by masking effect due to high counting rate



Recycle events of interest

- Multi-stage MC production for halo-neutron backgrounds and Ke3 (conversion type)
- For example, CC02 backgrounds

Halo n→Hit at CC02 Produce π0 Veto→2γ in CsI→π0 reconstruction

CC02 hitCC02 x pi0pord x veto

50% 10^{-3} 10^{-5} → 10^{8} gain

CV-eta hitCV x eta prod x 2γbranch x veto

10% 10^{-6} 0.4 1% → 10^{9} gain

CV-π0: hitCV x π0prod x veto

10% 10^{-4} 1% → 10^{7} gain

Ke3 : hitCV x π^- ineff. x e+ ineff. x reconstruction

4% x 10^{-4} x 10^{-4} x 30% → 10^{10} gain

→2-3 days to treat 10 times E14 halo neutrons

Fast-Full Simulation

- Use full simulation at CsI response and at halo-neutron interaction
- Merit:
  - Shower can be treated easily.
    - Cluster shape cut
    - Inefficiency v.s. Collateral cluster
    - Backsplash loss (They are not independent.)
  - Extra particles at neutron interactions
- Demerit:
  - Weight can't used→ Need large statistics to treat rate event topologies.
- Anyway, we are getting more realistic information around cluster shape cut

Future plan

- Speed up
  - Shower library for inefficient gammas in CsI → It enables weight method to treat rare event topologies.

- Complete detector design and construct detector.
- Calibration method for inefficiency function in data acquisition.
- Step2: 100 times higher statistics
  - Still affordable if these methods are validated.

  →~1 month for generation incl. Moor's law.