Search for invisible decay of ortho-Positronium

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1.1 Positronium

- Positronium
  - Simple bound state of e^+e^-

    (clean lepton system described by QED)
  - Aka, e^+e^- collider of $\sqrt{s} = 1.02\,\mathrm{MeV}$
  - CM energy is much smaller than LEP (5 orders!), but,

    we can use completely hermetic detector

    ⇓

    High sensitivity for invisible mode

    Our goal: $\Gamma_{\mathrm{invisible}} = 10^{-8}\Gamma_{3\gamma}$

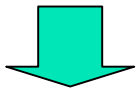
    (previous our limit (1993): 2.8×10^{-6})

1.2 ortho-Positronium (o-Ps)

- o-Ps
  - Spin triplet state ($^3S_1$)
  - Due to its characteristics for *C* conjugation, decaying to 2 γ is inhibited

Long lifetime: τ=142ns

(cf. p-Ps: 125ps)



Advantage to find small couplings

2. New physics from o-Ps invisible decays

- TeV scale extra dimension
  - R-S brane world with a big compacitification radius

    ⇒ Natural solution to the gauge hierarchy problem
  - Any massive particle can decay into bulk modes (invisible decay!)
  - In the case of (4+2+1)-dimensional space-time (n=2),

$$\Gamma\left(\text{o-Ps} \to \gamma^* \to \text{add dim}\right) \approx 1.2\times10^{5}\left(\frac{m_{\text{o-Ps}}}{k}\right)^{2}\Gamma_{3\gamma}$$

Compactification scale

$$\approx 1.2\times10^{-7}\left(\frac{1\,\text{TeV}}{k}\right)^{2}\Gamma_{3\gamma}$$

2. New physics from o-Ps invisible decays (cont.)

- Other exotic particles
  - Mirror world

    Search for $\varepsilon \sim 10^{-8}$ region

    Same level of BBN limit

    Photon-paraphoton mixing

  - Millicharged particle

    Search for $Q/e \sim 10^{-5}$ particles

    Most sensitive experimental search in m<511keV region

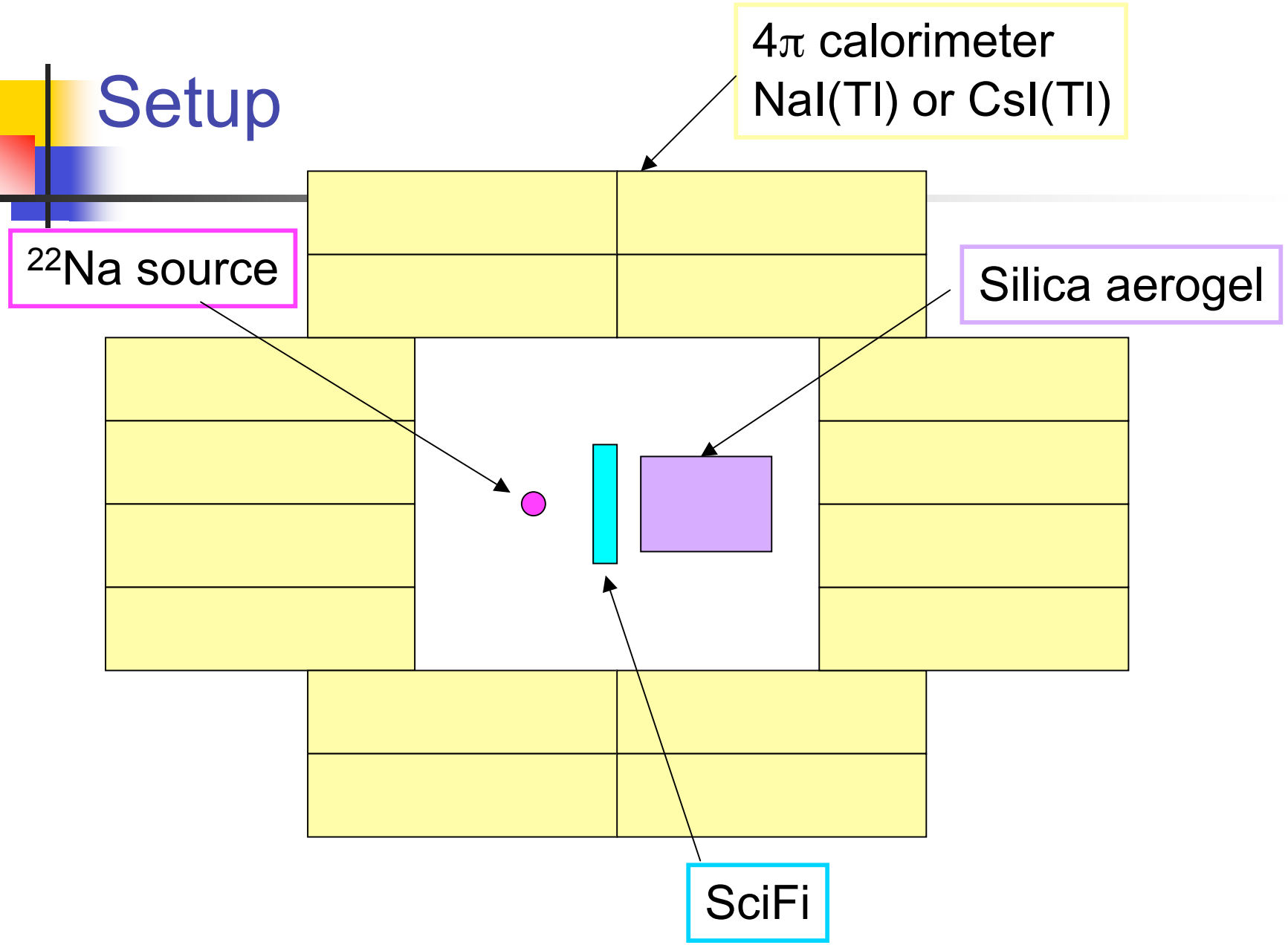
3. Detector design and setup

- Search for

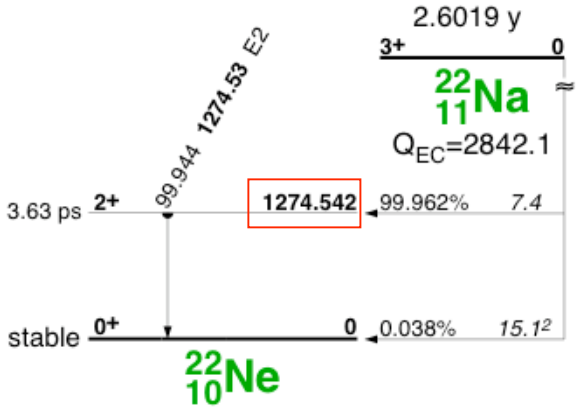
  ``^{22}Na source emits β^+, but no γ-rays related to β^+ are found''

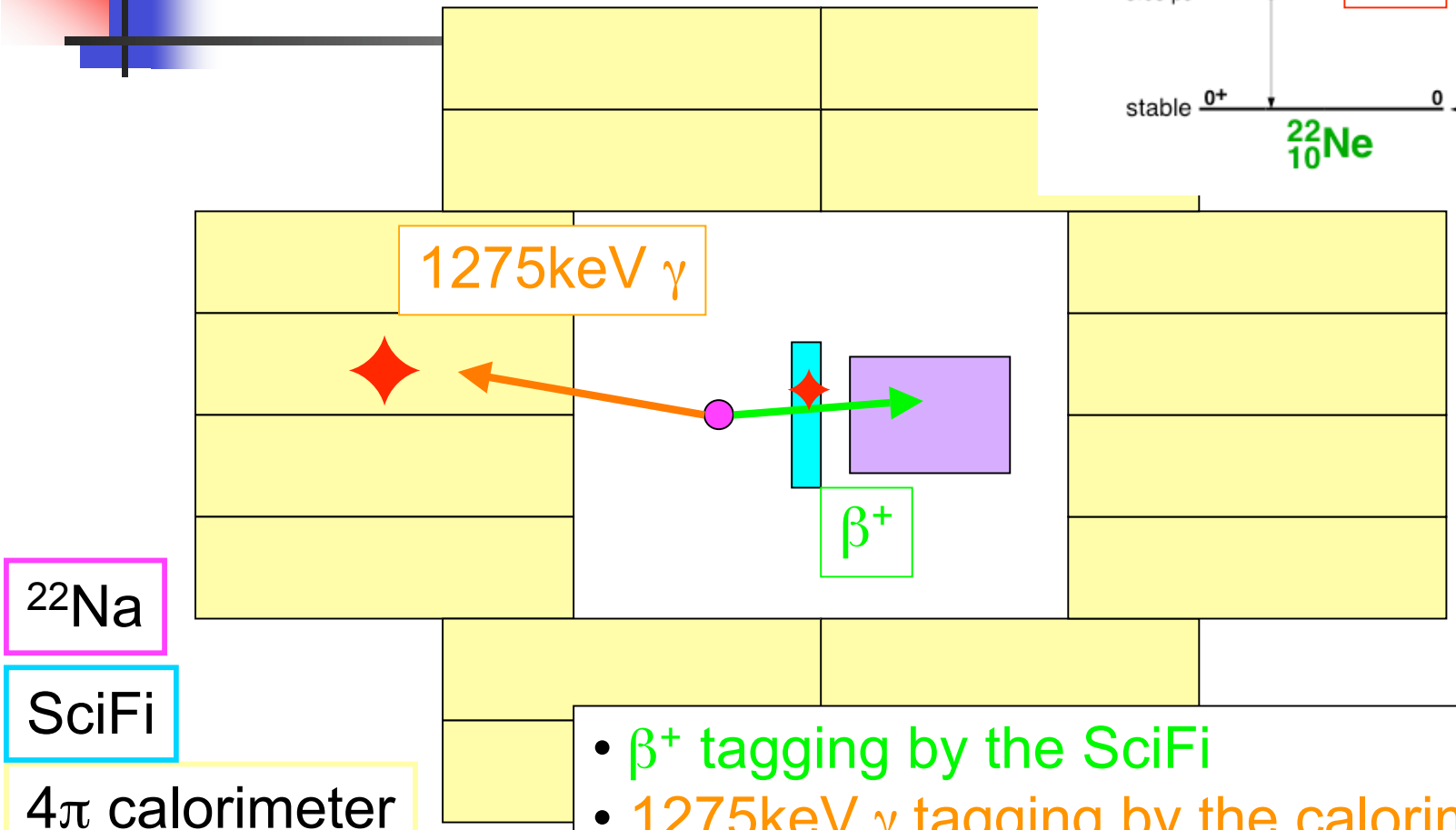
- Detector setup:
  - ^{22}Na β^+ source ($T_{1/2}$=2.6y, E_{end}=546keV)
  - SciFi (β^+ tag)
  - Silica aerogel (β^+ stopper & o-Ps production)
  - NaI(Tl) & CsI(Tl) hermetic calorimeter (γ-ray detection)

Setup


4π calorimeter
NaI(Tl) or CsI(Tl)
22Na source
Silica aerogel
SciFi

β^+ tagging from ^{22}Na





^{22}Na

SciFi

4π calorimeter

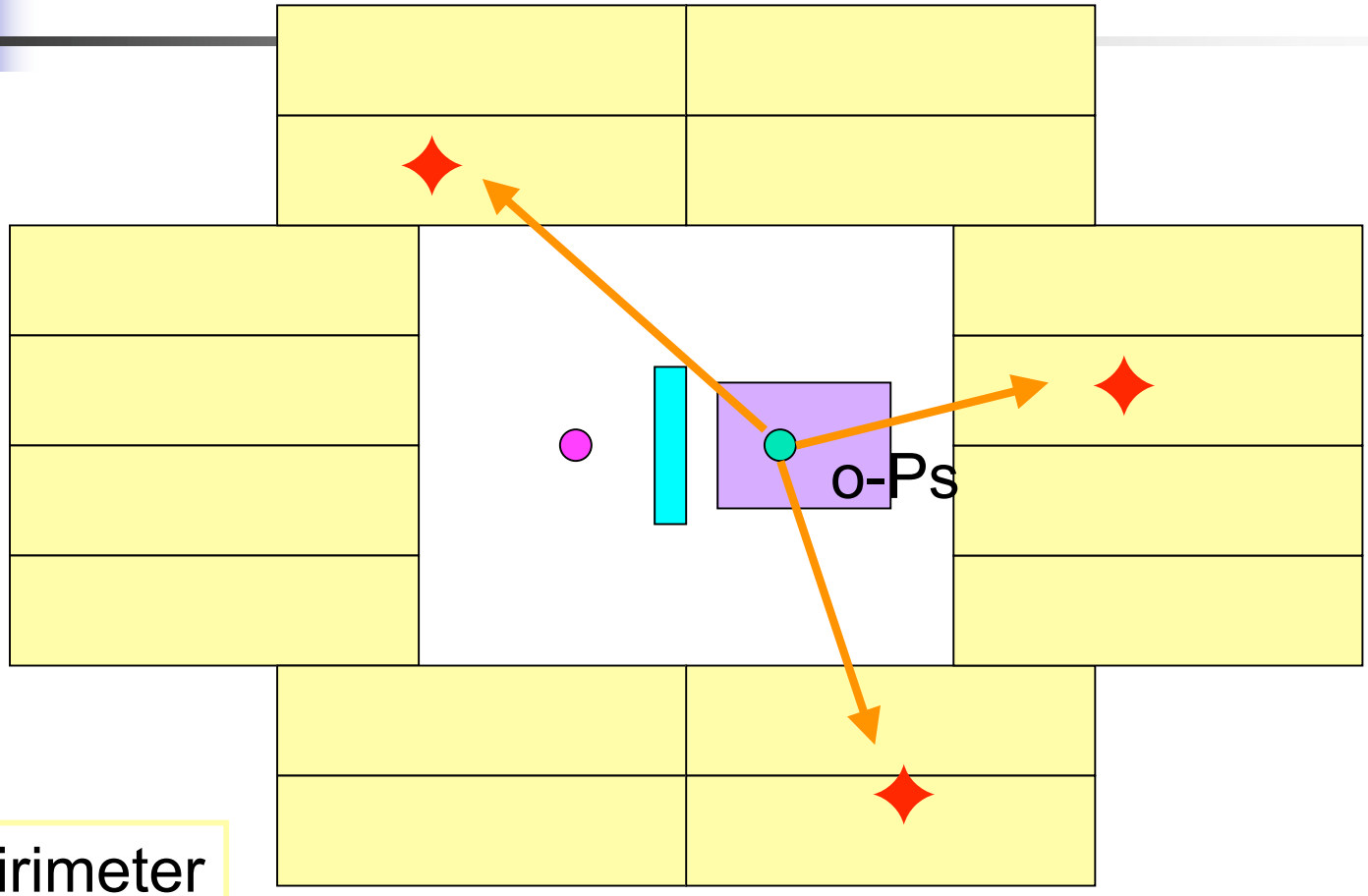
Silica aerogel

- β^+ tagging by the SciFi
- 1275keV γ tagging by the calorimeter

→ Reliable β^+ tagging by coincidence

o-Ps created, and usually decays to 3γ

(o-Ps creation probability: ~55%×3/4=41%)



^{22}Na

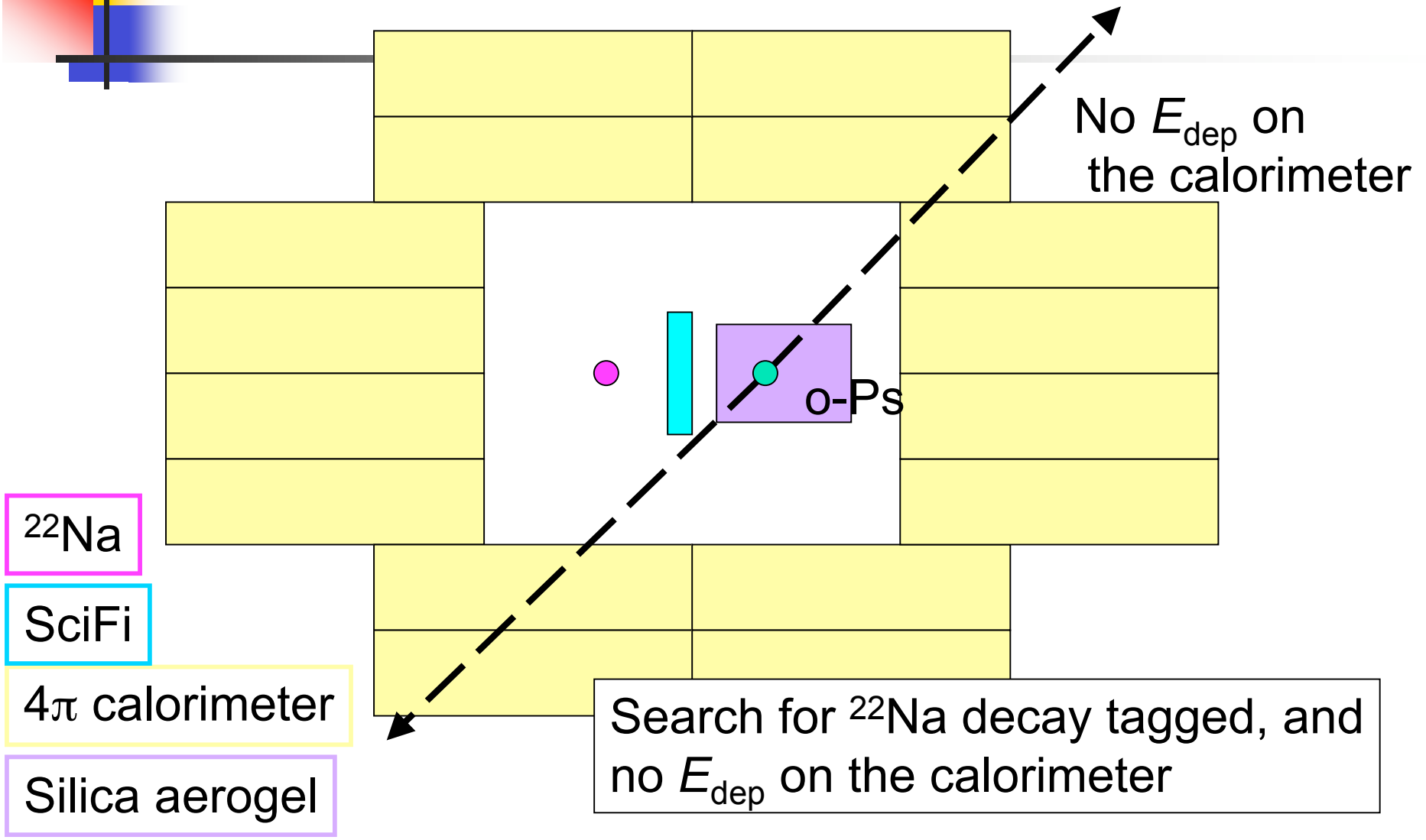
SciFi

4π calirimeter

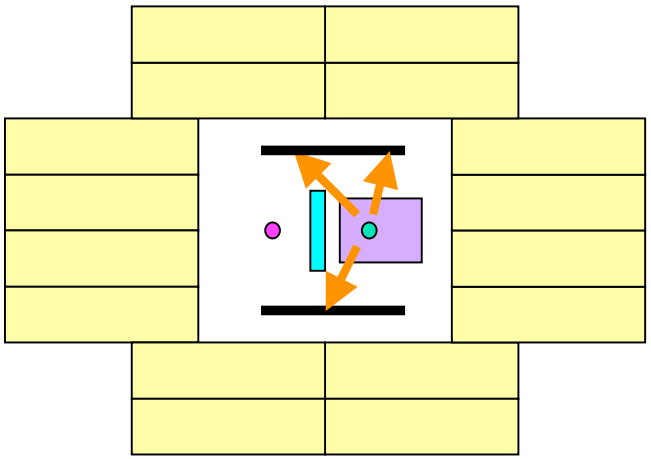
Silica aerogel

Energy deposition to the calorimeter

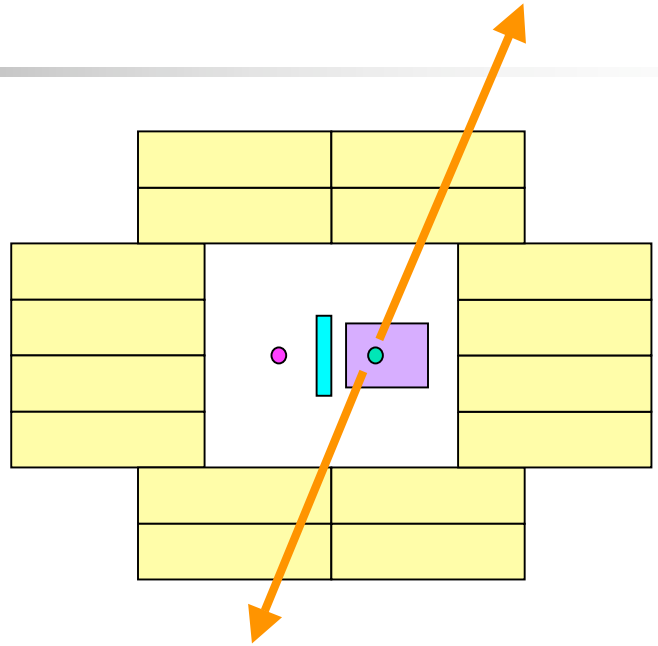
In the case of invisible decay,



Possible background



case 1) γ-ray absorption



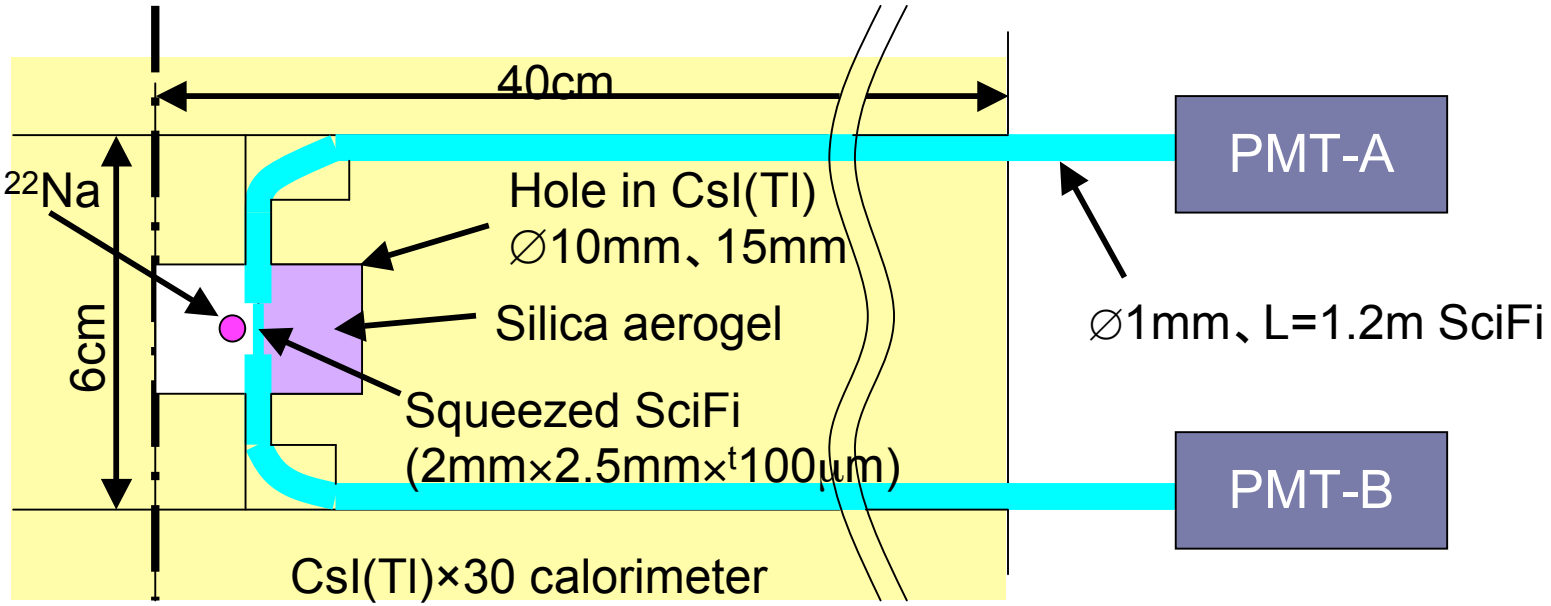
case 2: γ-ray escape
(especially 2γ's from annihilation)

Important things

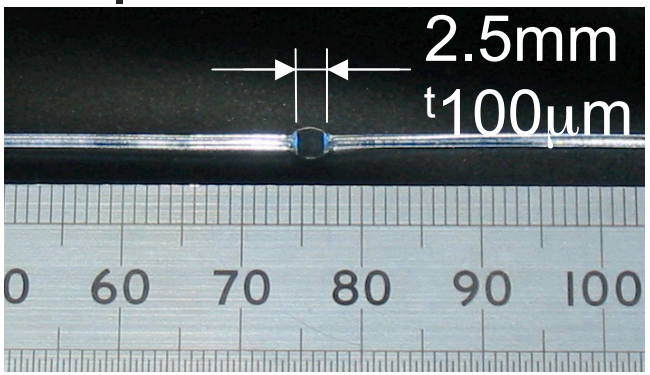
``No dead material inside'' & ``thick hermetic calorimeter''

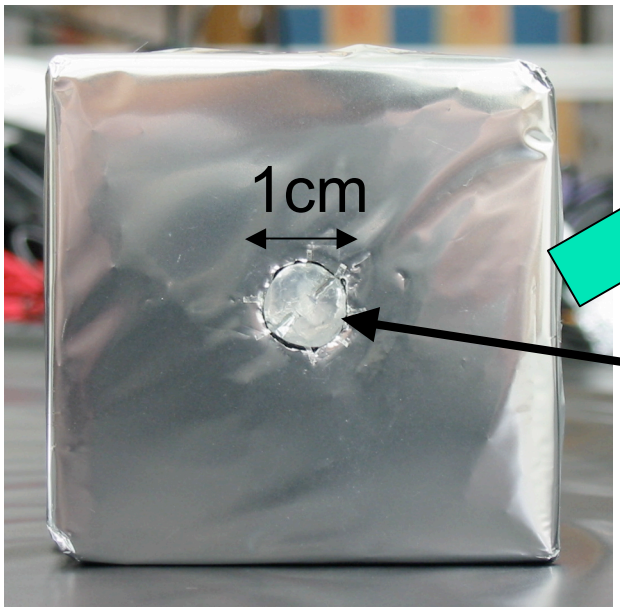
4.1 Detector (β^+ trigger)

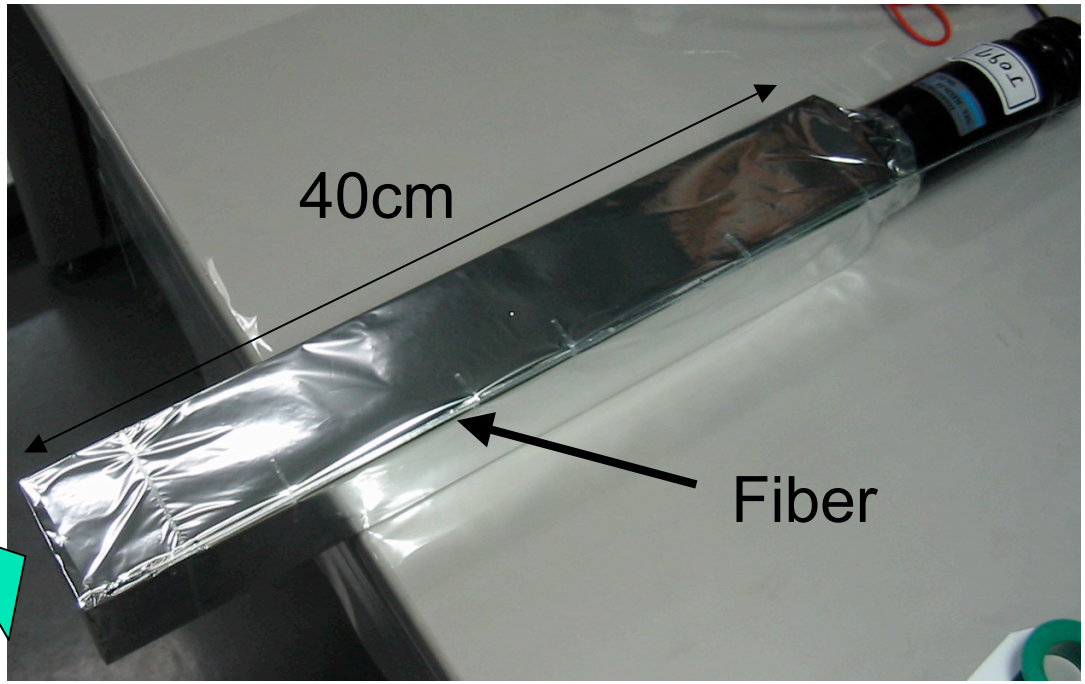
- ^{22}Na, silica aerogel, and SciFi are set in a hole of CsI(Tl) calorimeter
- SciFi is squeezed at the source (100μm)
- SciFi guides photons to the outside of the calorimeter
- Two PMTs are attached at the both ends



SciFi & core CsI(Tl) scintillator







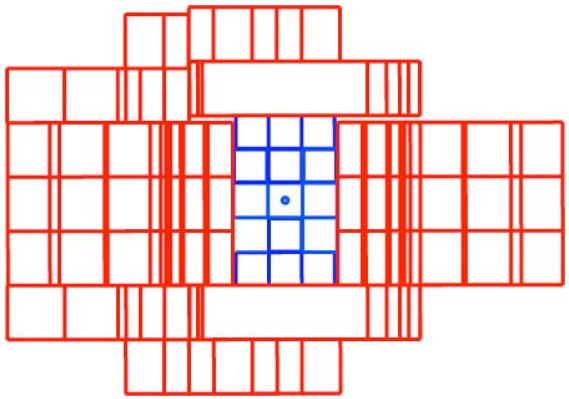
Squeezed fiber &
silica aerogel stopper

4.2 Detector (Hermetic calorimeter)

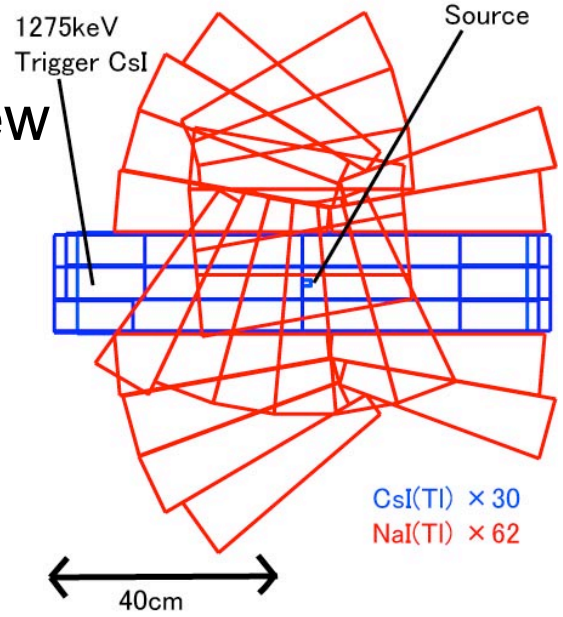
- Total 800kg of scintillators
  - 30 CsI(Tl) crystals: 60mm×60mm×400mm
  - 62 NaI(Tl) crystals: 94mm×110mm×375mm
    (Previously used in E68 experiment)
- Their layout is optimized by MC

➡ No escape of 511keV back-to-back γ's at the level of 10^{10} events

Side view



Top view

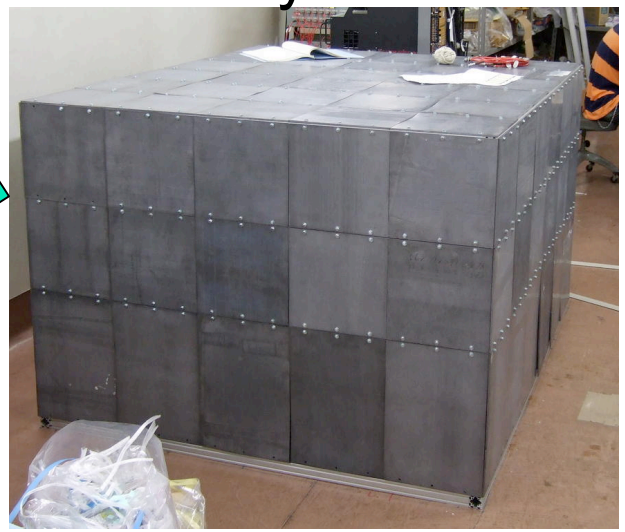


Detector overview

Bottom half

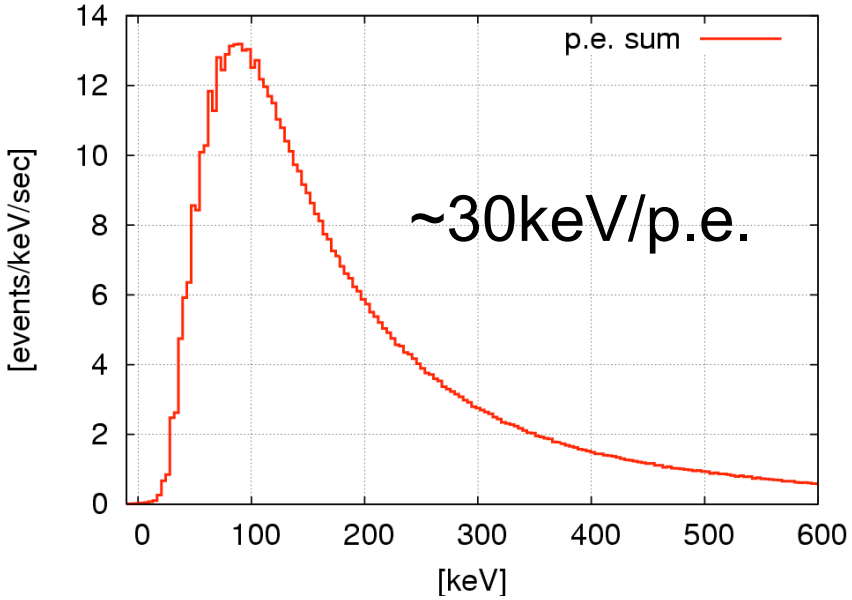
All scintillators arranged

Covered by 5mm lead

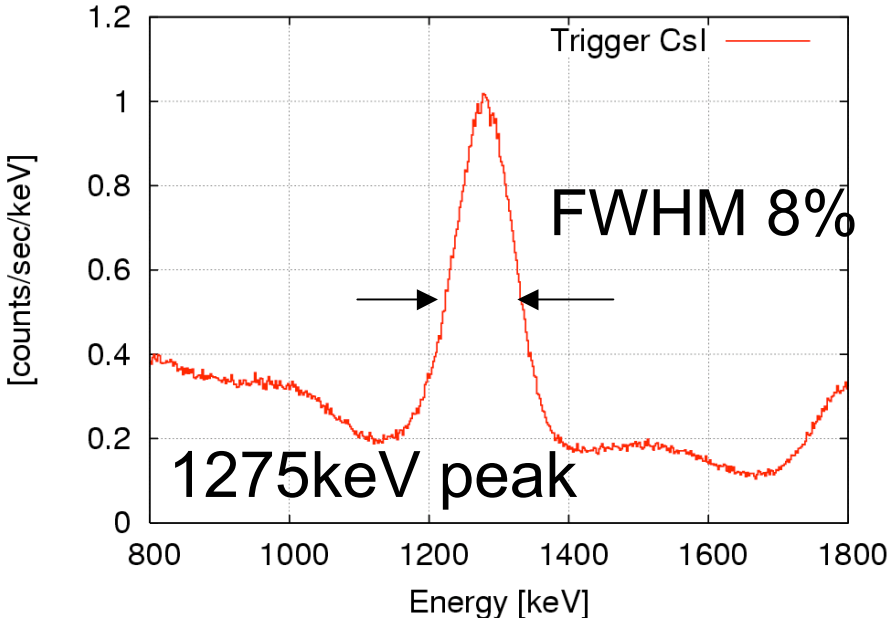


5. Detector performance

SciFi spectrum



Trigger CsI spectrum



^{22}Na 10kBq

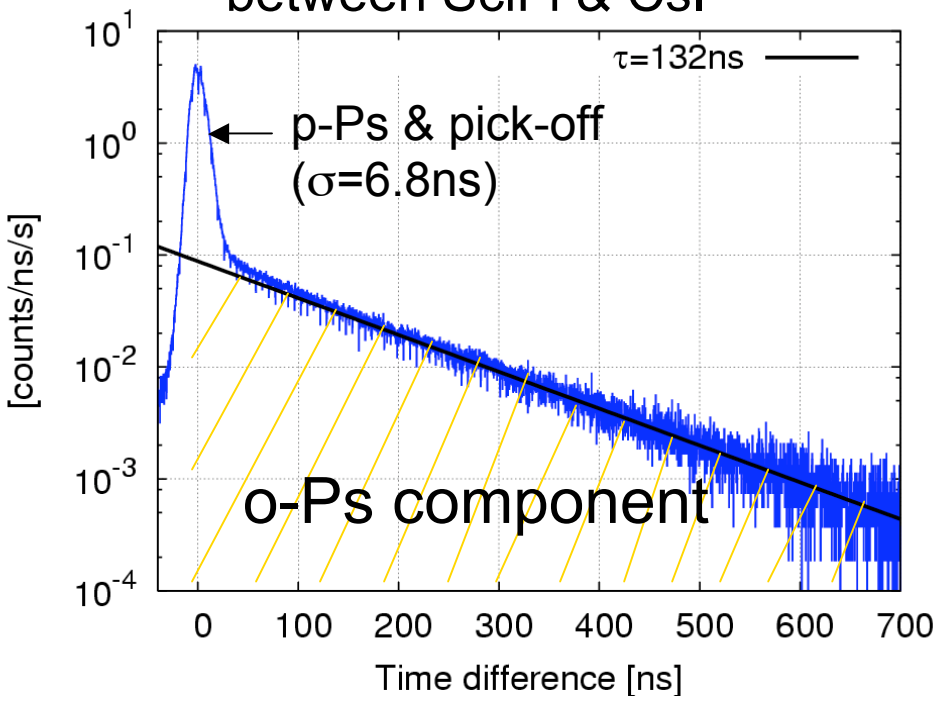
Trigger rate: 2.6kHz

1275keV

detection efficiency: 3.3%

5. Detector performance (2)

Timing difference
between SciFi & CsI

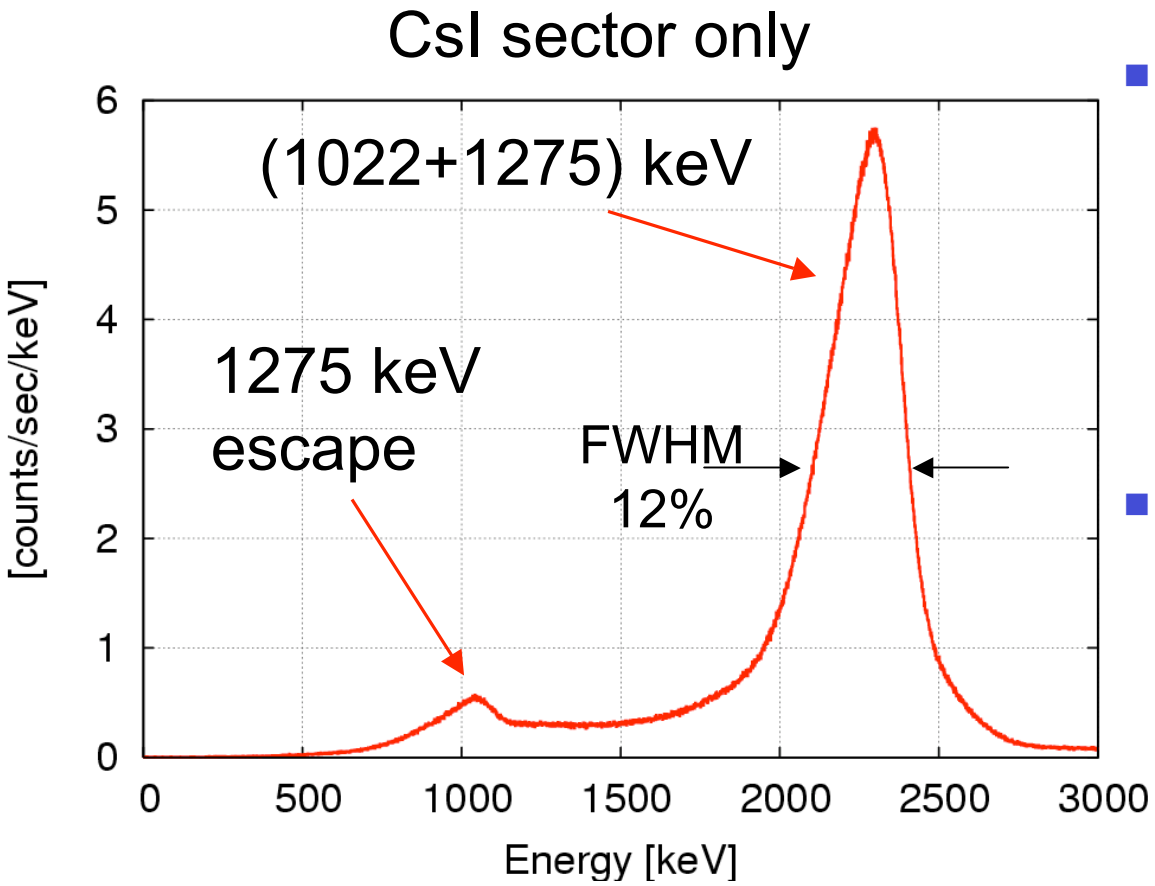


- We can observe
  10 events/s of o-Ps decay

- 10^8 o-Ps decays
  in 4 months

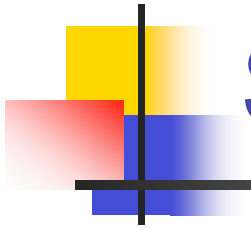
o-Ps creation probability:
13% of SciFi triggered events

5. Detector performance (3)



- Energy sum of CsI sector shows clear peak of ^{22}Na decay

- Now we're almost ready for the data taking



Summary

- Search for invisible decay of o-Ps
- Designed and constructed a new detector whose sensitivity is 10^{-8}
- Now we are almost ready for the data taking, and some basic plots show the detector design is OK
- All data taking will be finished in 4 months, and its result will be reported in the next JPS meeting

  (sorry for APS people)