

# *Liquid*



## **Blaise Pascal Chair & Liquido**

**Anatael Cabrera**

CNRS / IN2P3 @ LAL (Orsay) / APC (Paris)

# Blaise Pascal Chair...



international **Blaise Pascal Chair** (BCP)...

- funded by the **Région Ile-de-France**
- managed by the **Fondation de l'Ecole Normale Supérieure**

one of the most prestigious fellowships in France

# Prof. Suekane (laureate) ...

distinguished  
neutrino physicist



# Liquid

**LiquidO neutrino detection project**

**LiquidO & BPC $\rightarrow$  developed together**

# our agenda today...

09:00	
10:00	<b>LiquidO Introduction</b> <i>Anatael Cabrera</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 09:40 - 10:00
10:00	<b>LiquidO Project &amp; New Detection Principle</b> <i>Marco Grassi</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 10:00 - 10:30
10:00	<b>LiquidO Detection First Experimental Demonstration</b> <i>Emmanuel CHAUVEAU</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 10:30 - 10:50
11:00	<b>Coffee</b> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 10:50 - 11:10
11:00	<b>LiquidO Reactor Neutrino Detection</b> <i>Dr Thiago Junqueira</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 11:10 - 11:45
11:00	<b>LiquidO <math>\beta\beta</math> Detection</b> <i>Mathieu Bongrand</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 11:45 - 12:20
12:00	<b>LiquidO CP-Violation Method</b> <i>Fumihiko Suekane</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 12:20 - 13:05
13:00	<b>LiquidO-BPC Summary</b> <i>Anatael Cabrera</i> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 13:05 - 13:30
14:00	<b>Lunch</b> Amphitheatre Pierre-Gilles de Gennes, Laboratoire APC (Paris, France) 13:30 - 15:00
15:00	

most speakers trained by Suekane-san

Suekane-san direct impact to neutrino science in France

apologies...



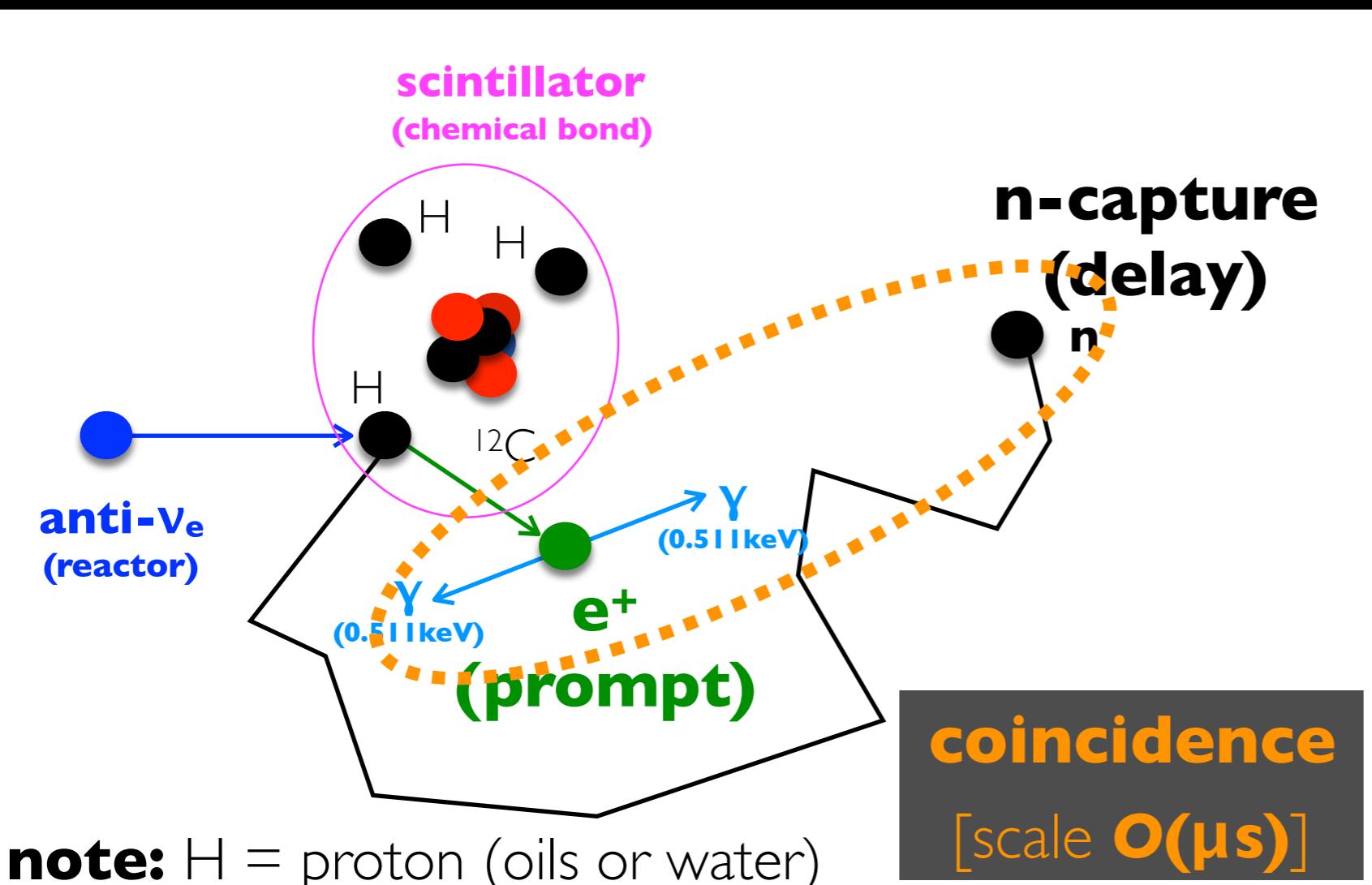
**early December → very bad timing!**  
(end year & XMAS)



the V discovery (1956)...

# inverse- $\beta$ decay (IBD) interaction...

**IBD: anti- $\nu_e$  +  $p \rightarrow e^+ + n$**



## IBD detection art...

- n-H (native)**
- n-C (native oil)**
- n-O? (native water)**
- n-Cd** (non-native)
- n-Li** (non-native)
- n-Gd** (non-native)
- $^3\text{He}$**  (non-native)

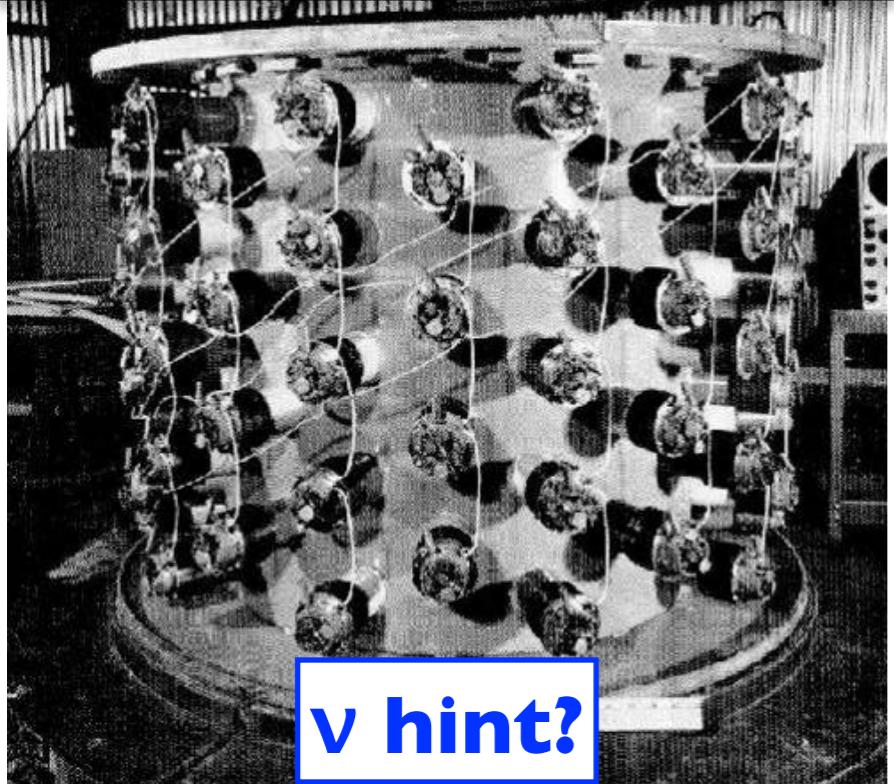
how to catch the n?

**no  $e^+$  PID** implies

$\gamma \approx e^- \approx e^+ \approx \alpha \approx p\text{-recoil (fast-n)}$

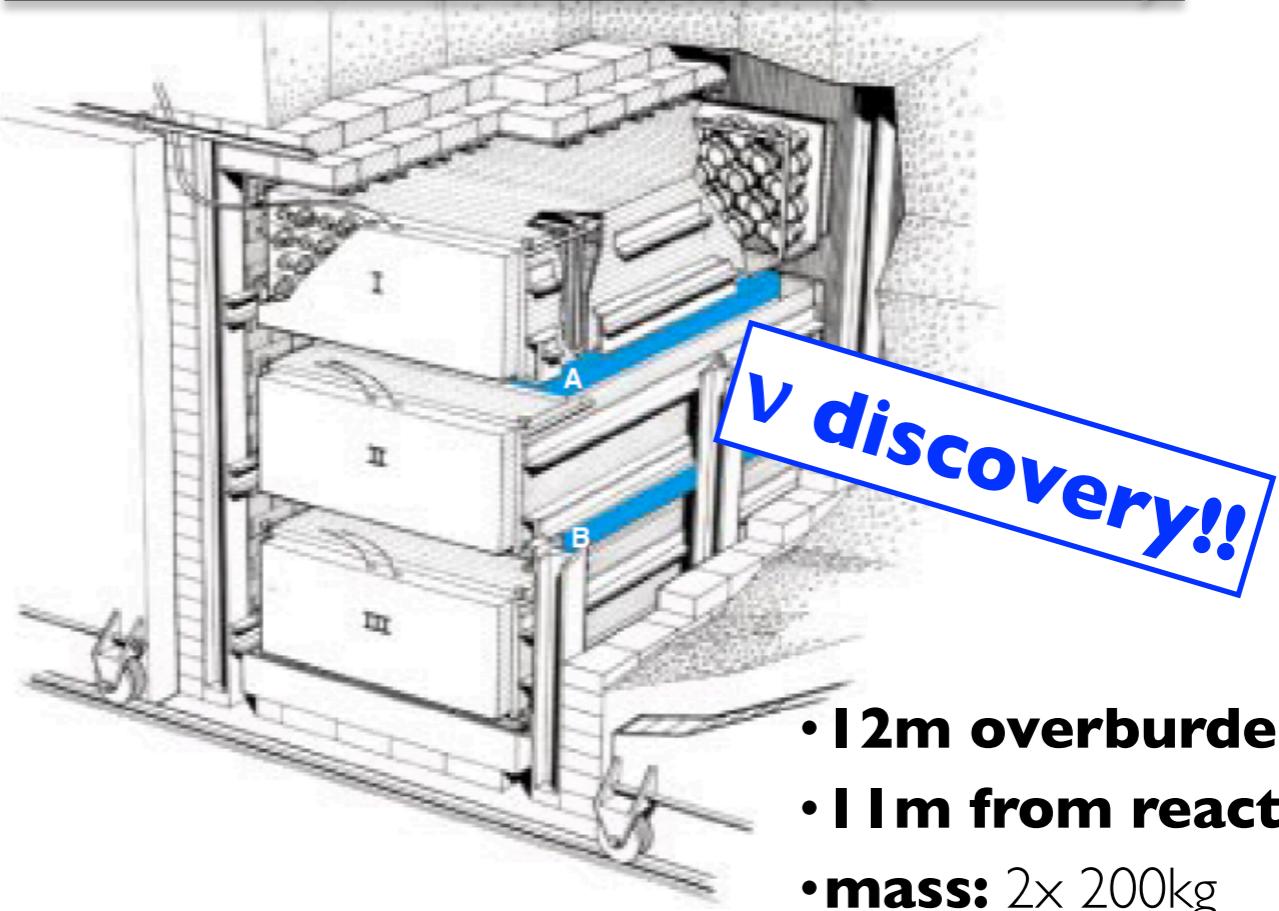
# Reines&Cowan pioneering detection...

Handford (1953)



- **surface** (inside a truck)
- > 15??m from reactor
- **mass:** ~300kg
- **target:** scintillator + Cd (loading?) **today's inspiration!**

Savannah River (1956)



- **12m overburden**
- **11m from reactor**
- **mass:** 2x 200kg
- **target:** water + Cd
- **I+II+III:** scintillator
- **rough segmentation**

THE REVIEW OF SCIENTIFIC INSTRUMENTS

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Liquid Scintillators for Free Neutrino Detection\*

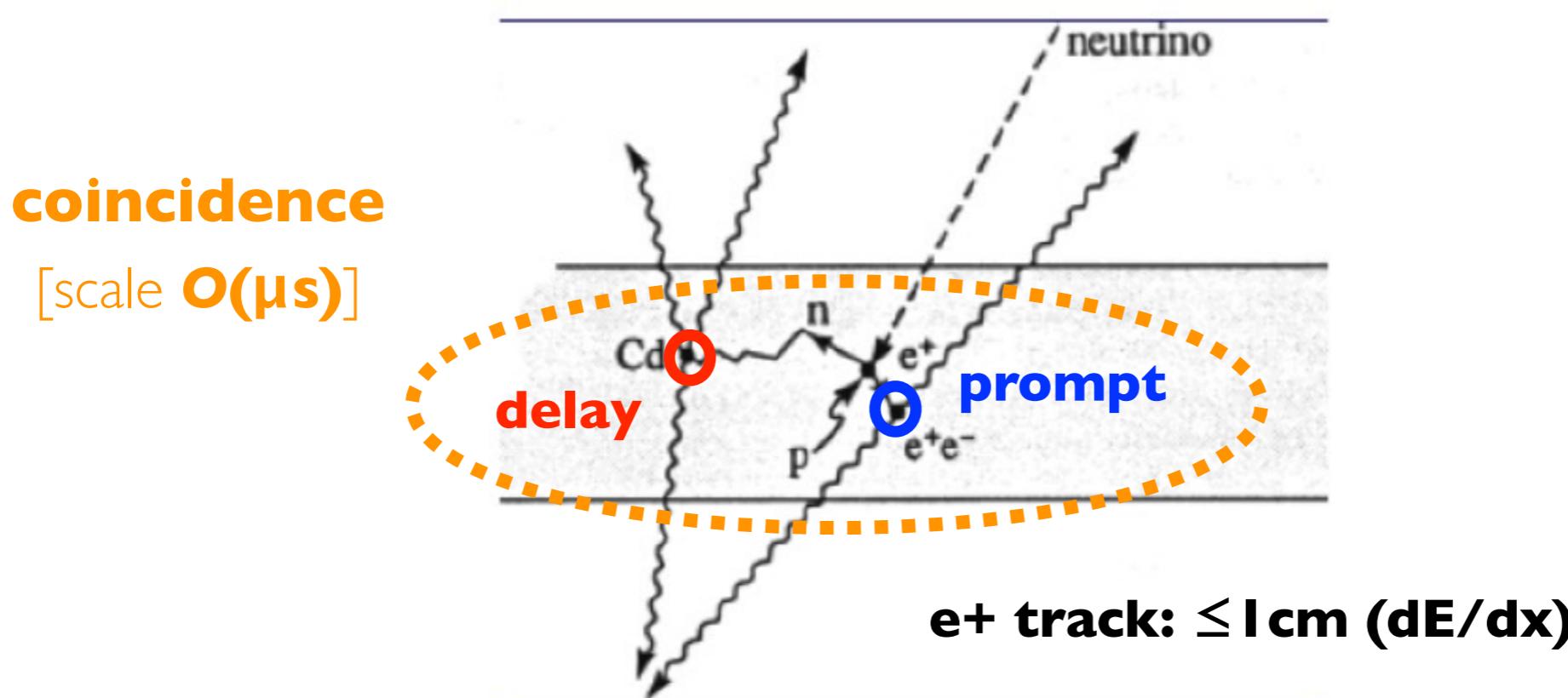
A. R. RONZIO,† C. L. COWAN, JR.,‡ AND F. REINES  
Los Alamos Scientific Laboratory, University of California, Los Alamos, New Mexico  
(Received October 28, 1957; and in final form, December 9, 1957)

The criteria by which liquid scintillators have been selected and developed for free neutrino detection experiments are described and a discussion is given of the preparation of the solutions. Triethylbenzene is a superior solvent and cadmium octoate is found to be the best cadmium compound known for these purposes.

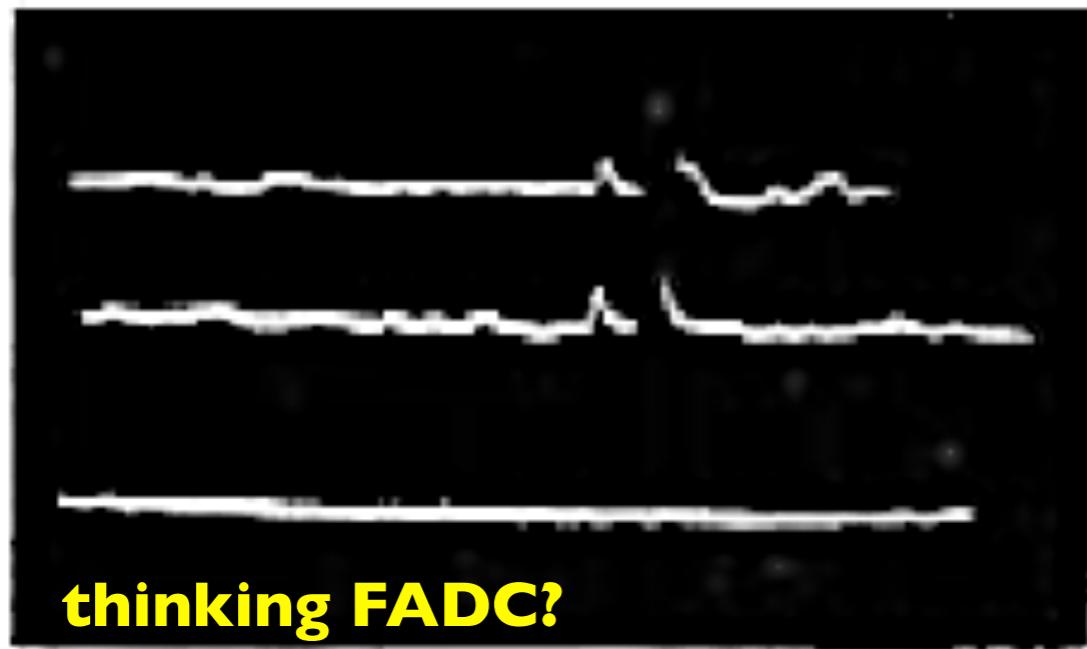
Cd loading on liquid scintillator

Anatael Cabrera (CNRS-IN2P3 & APC)

# Reines& Cowan powerful coincidence (IBD)...

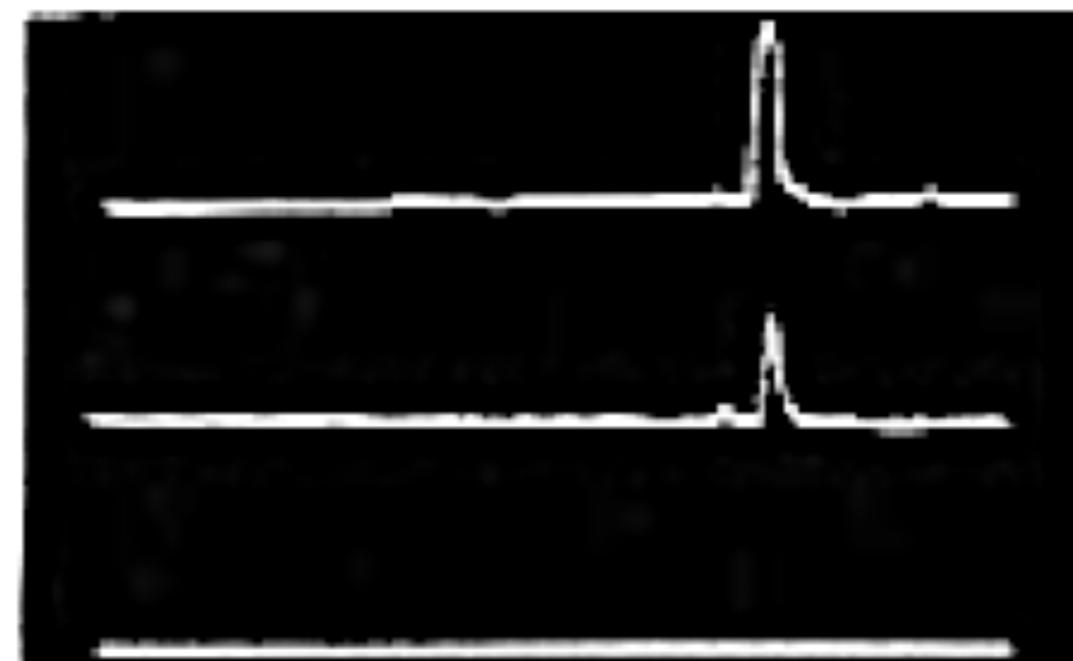


**e<sup>+</sup> annihilation** ( $2 \times 0.511\text{ MeV}$ )



(a) Position scope

**n-Cd capture** ( $\sim 9\text{ MeV}$ )



Neutron scope

**PMT  $\Leftrightarrow$  transparent medium**

**overburden** ( $\mu$ -cosmic shielding)

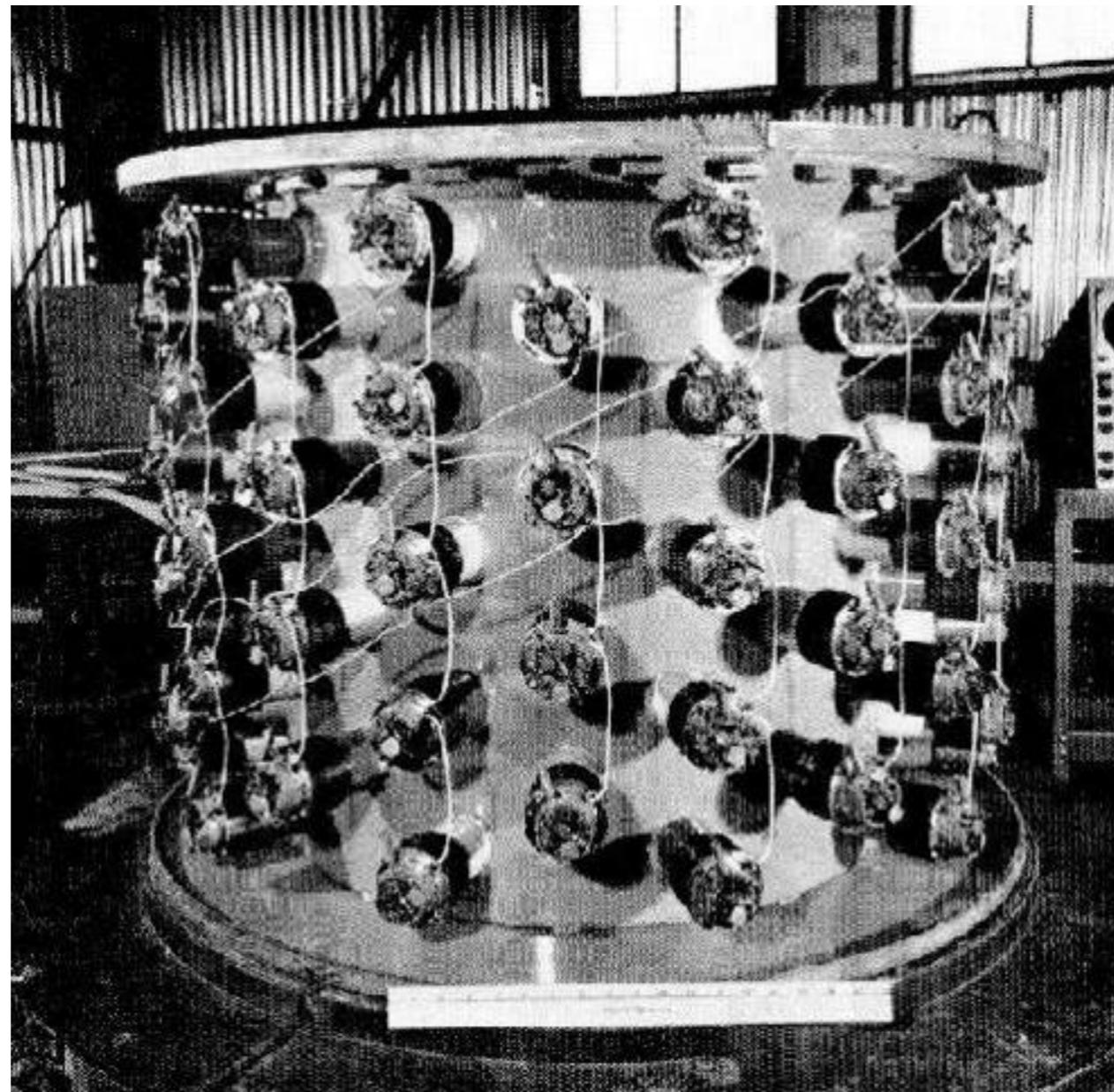
**external shielding** (radioactivity shielding)

**loaded medium ( $^{113}\text{Cd}$ )  $\rightarrow$  non-native detection!**

(reactor source) **modulation ON vs OFF**

**~70years ago similar to today!**

# Reines & Cowan detector (300kg)...



**today's inspiration!**

Handford (1953)

today's version of similar technology...

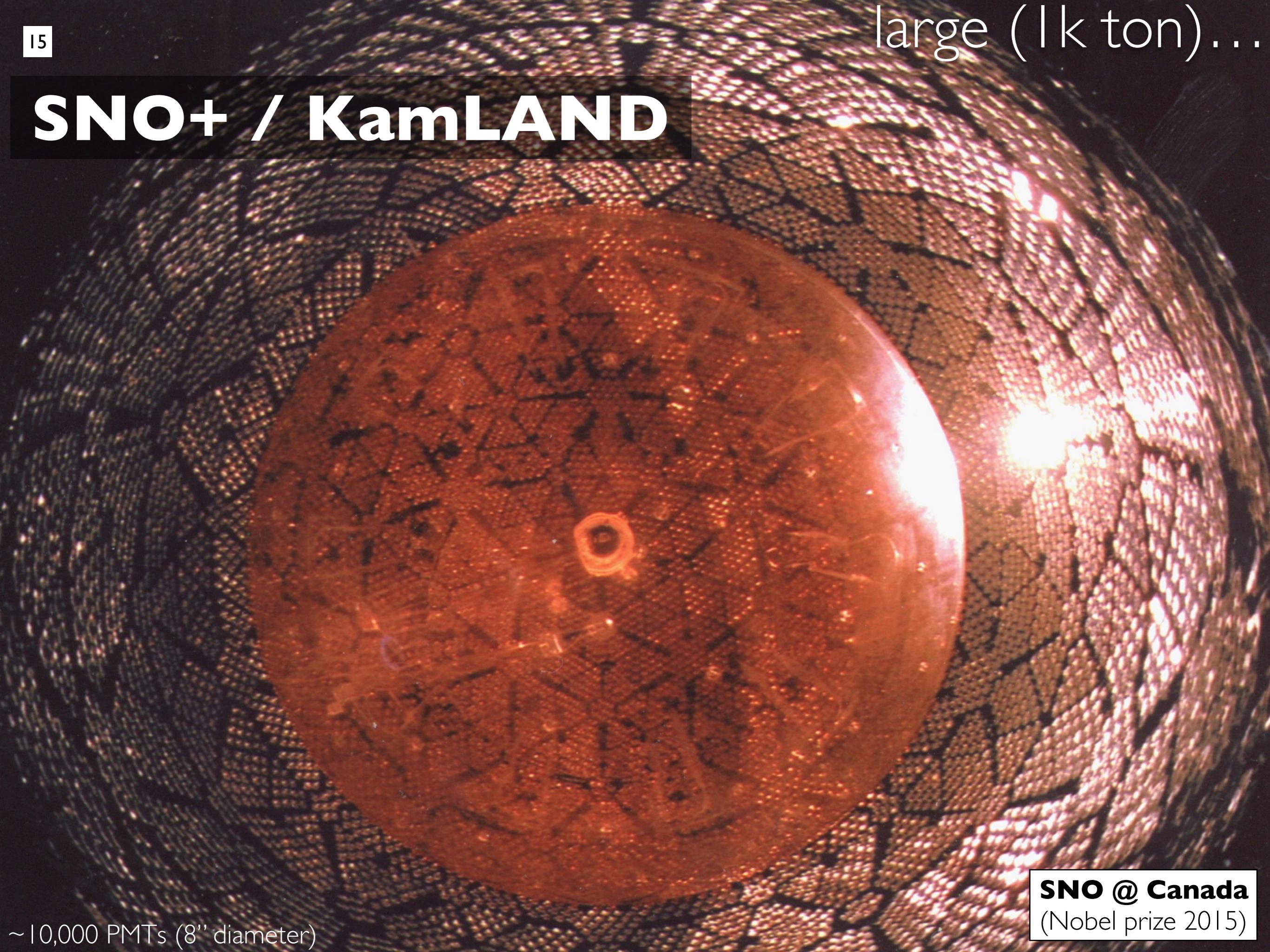
**PMT ( $\sim 1\text{ ns}$ )  $\Rightarrow$  transparency**

(most) exquisite radio-purity...

Borexino (GS)

large (1k ton)...

# SNO+ / KamLAND

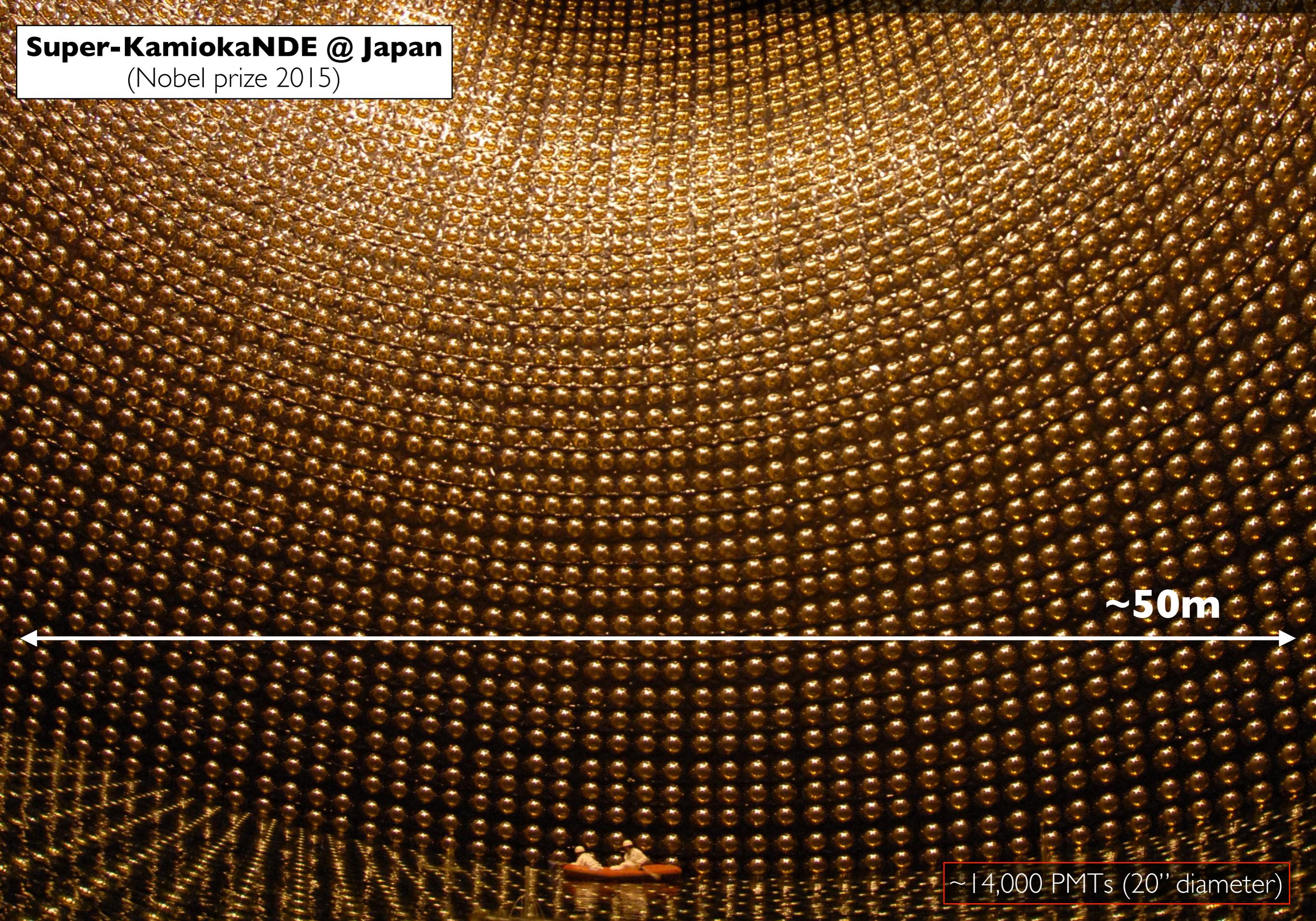


~10,000 PMTs (8" diameter)

**SNO @ Canada**  
(Nobel prize 2015)

very large (50k ton)...

**Super-KamiokaNDE @ Japan**  
(Nobel prize 2015)



**~70years challenge → no solution!**

any **limitations?** [poor PID]

liquid scintillator state of the art...

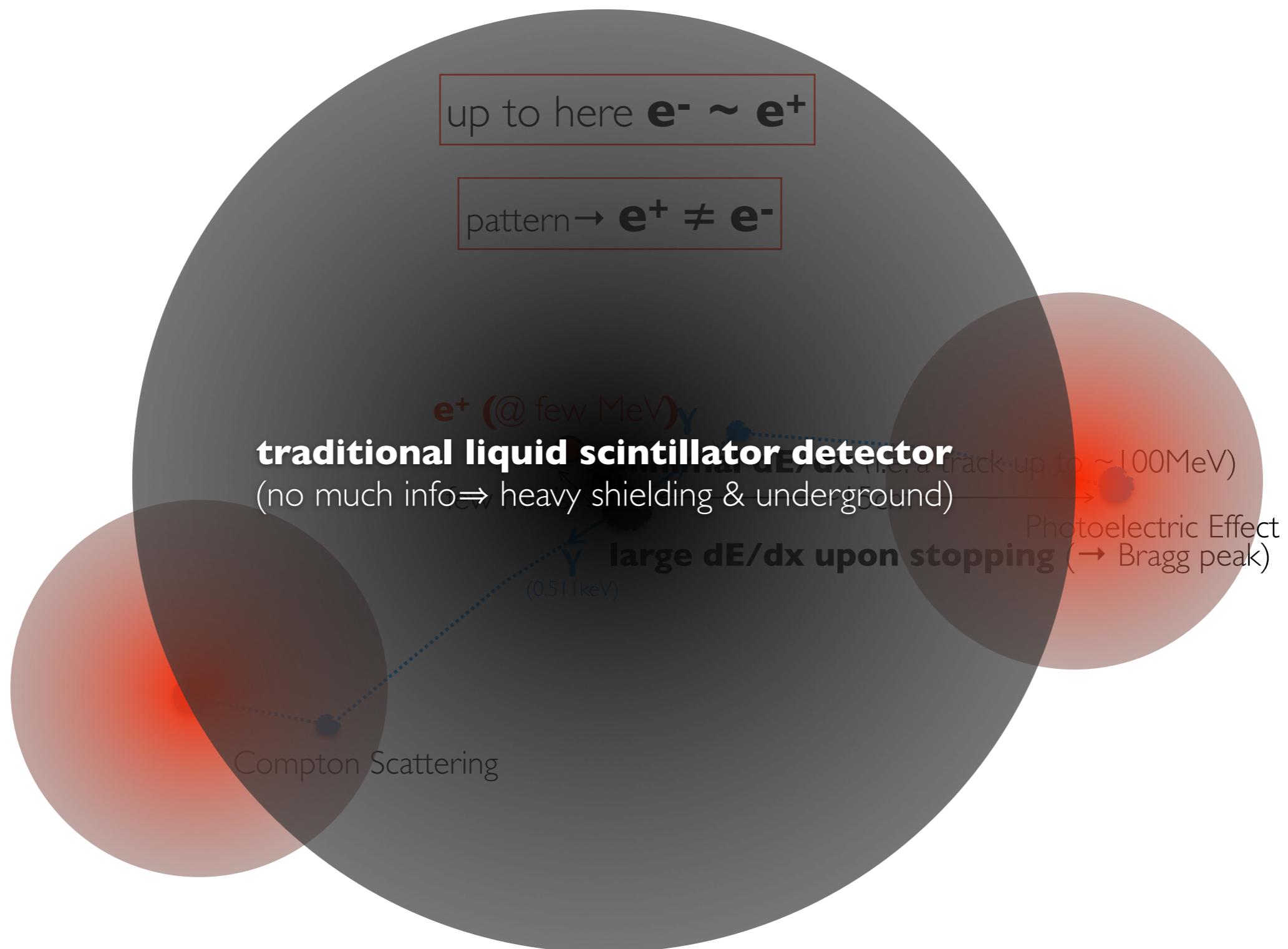
**“perfection” since Reines&Cowan...**

- exquisite **radio-purity**
- **scintillation PSD** (“some” **PID**)  
**at the expense...**
- **buffer volume** (PMT’s poor radio-purity)
- **PID loss?** **[this talk]**

**PMT**(~1ns)  $\leftrightarrow$  **Transparency**  $\Rightarrow$  **PID?**

an **Opaque** solution to PID...?

# e+ PID limitation (illustration)...



**powerful event pattern washed out  $\Rightarrow$  hardly any ID!**

why such a “poor” PID?

**no PID** (beyond PSD) implies

$\gamma \approx e^- \approx e^+ \approx \alpha \approx p\text{-recoil (fast-n)}$

**PMT**  $\leftrightarrow$  medium **transparency**  $\rightarrow$  **little PID**



$\sigma(\text{time}) \gtrsim 1\text{ ns} \Leftrightarrow \sigma(\text{space}) \gtrsim 20\text{ cm}$  [**unresolvable**]



$\sigma(\text{vertex}) \approx 10\text{ cm}$  [**individual vertex**]



**liquid**  $\rightarrow$  **(easy) loading BUT breaks transparency**

if **PID** implies

$\gamma \neq e^- \neq e^+ \& e^+ \neq (\alpha \& p\text{-recoil})$

$\implies$  **no need for coincidence?**

# naive $O(1\text{ cm})$ spatial resolution...

**important:** scintillator/water very low-Z material + a lot of “stable” H

$e^- \approx \alpha \approx p$ -recoil (fast-n)

$dE/dx \rightarrow$  Bragg peak

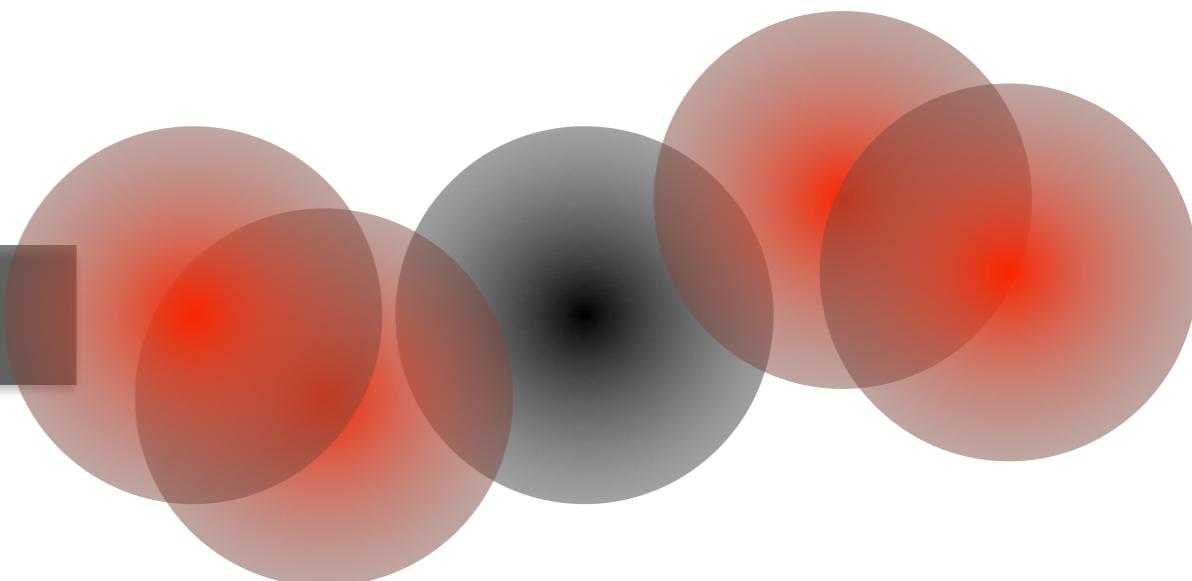
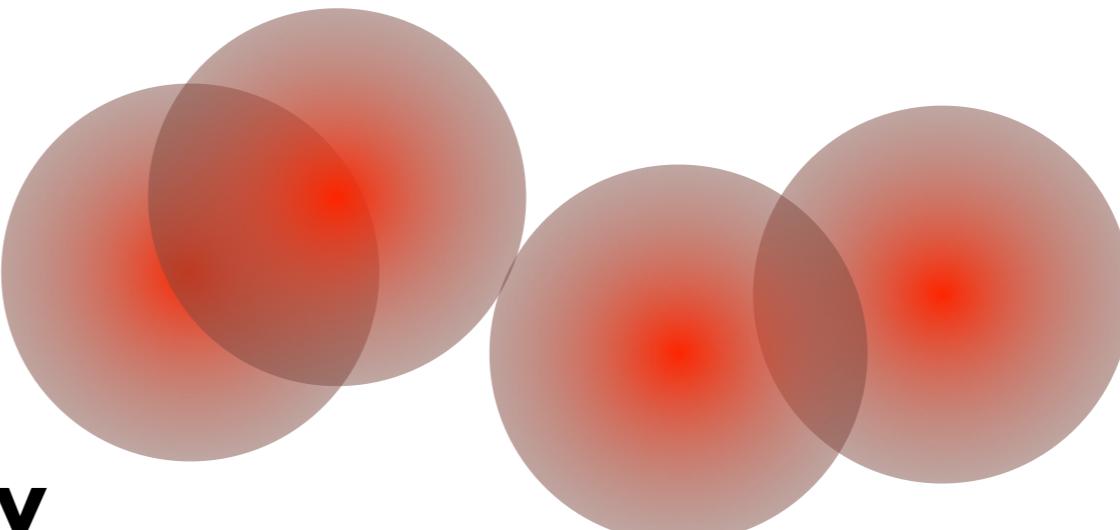
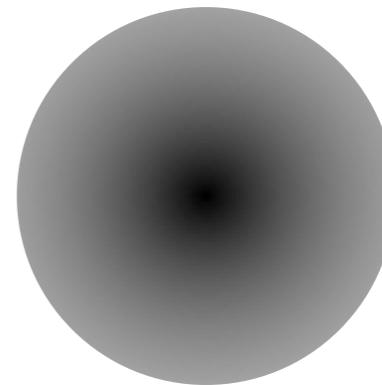
( $e^-$  starts as MIP)

$\gamma$

Compton scattering  $\leq 3\text{ MeV}$

$e^+ \approx e^- + 2 \times \gamma(0.5 \text{ l} \text{ l} \text{ MeV})$

hybrid-like event



can this be done **Opaque**?