A detector design for the Daya Bay reactor neutrino experiment

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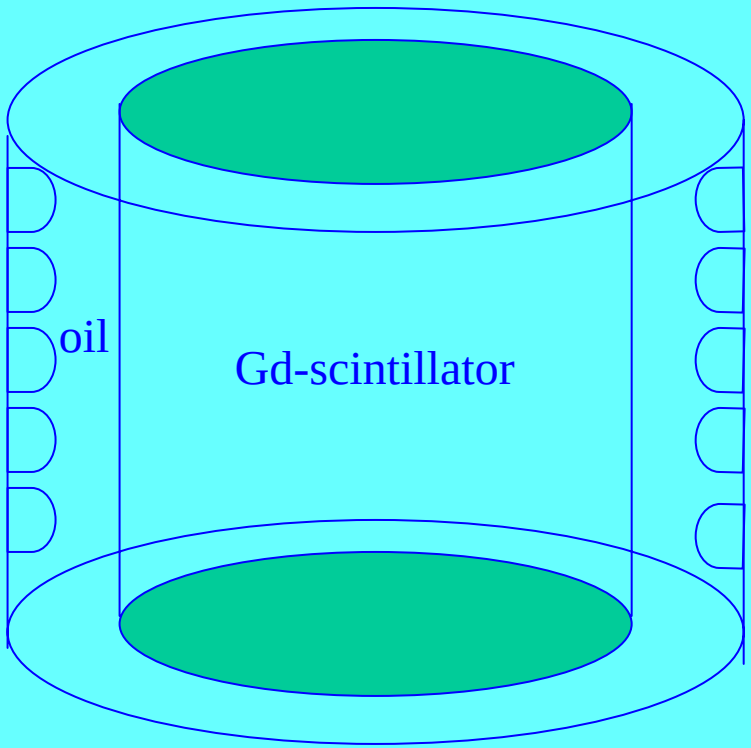
Important point to have small systematic error

- Energy threshold less than 0.9 MeV
- Homogeneous detector
- No position cut
- Use Gd-loaded scintillator
- Scintillator mass well determined
- Target scintillator all from one batch, mixing procedures well controlled
- Not too large detector
- Background well controlled ➔ good shielding
- Be able to measure everything(Veto ineff., background, energy/position bias, …)

Multiple modules

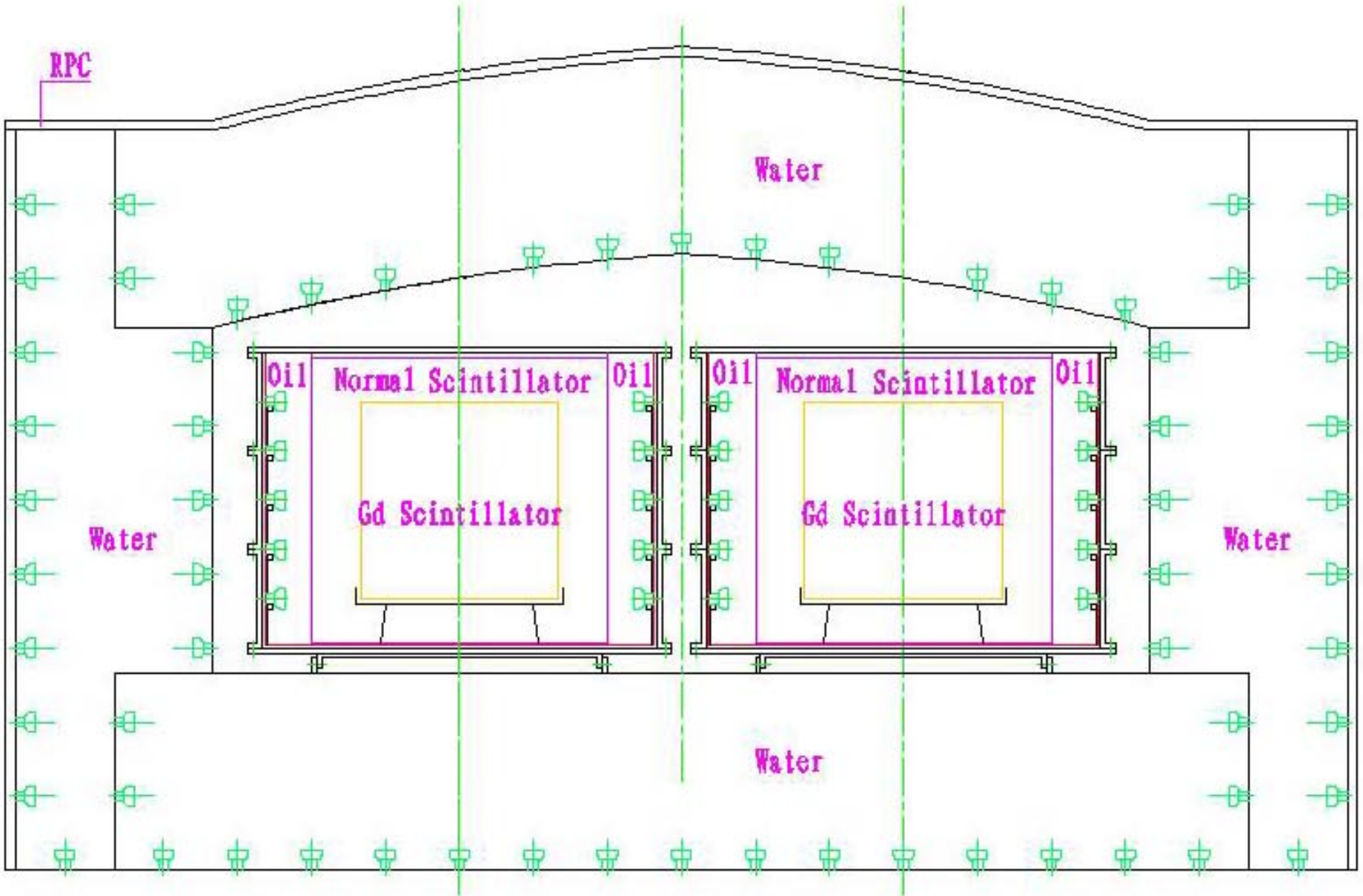
- **Many modules, 8t each, 100-200 8”PMT/module**
- **1-2 at near, 4-8 at far, small enough for movable calibration**
- **Correlated error cancelled by far/near**
- **Uncorrelated error can be reduced**
- **Event rate:**
  near: ~500-2000/day/module
  Far: ~40/day/module
- **100 days calibration at the near pit**
  → 0.2-0.5% statistical error
- **Two reference modules 100 days, others ~ 10 days calibration**



Advantages with multiple modules

- **Smaller modules have less unknowns**
- **Multiple handling to control systematic error**
- **Easy construction**
- **Easy movable detector**
- **Scalable**
- **Easy to correct mistakes**

Schematics of a multi-module detector



Detector issues:

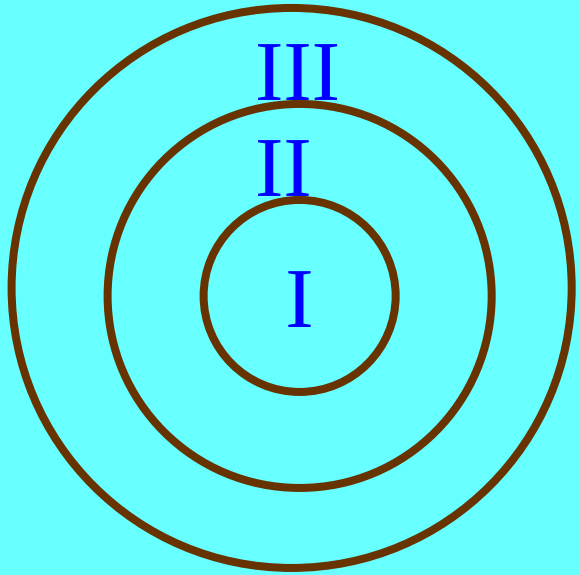
- Structure of the module
- PMT's
- scintillators
- Inner module: size,structure and materials
- Outer module: size,structure and materials
- Buffer
- Veto
- Calibration

For MC, See J. Cao's talk

For R&D, see C.G. Yang's talk

Structure of the module

- Three layers module structure
  I. target: Gd-loaded scintillator
  II. γ-ray catcher: normal scintillator
  III. Buffer shielding: oil



- Advantages:
  – Well defined fiducial volume
  – No cut on position → small systematics
- Disadvantages:
  – Complicated mechanical structure
  – Light yield matching/energy bias ?

See J. Cao’s talk

PMT

- 8” PMT, 150/module
- Hamamatzu R5912

40K: 2.5 Bq

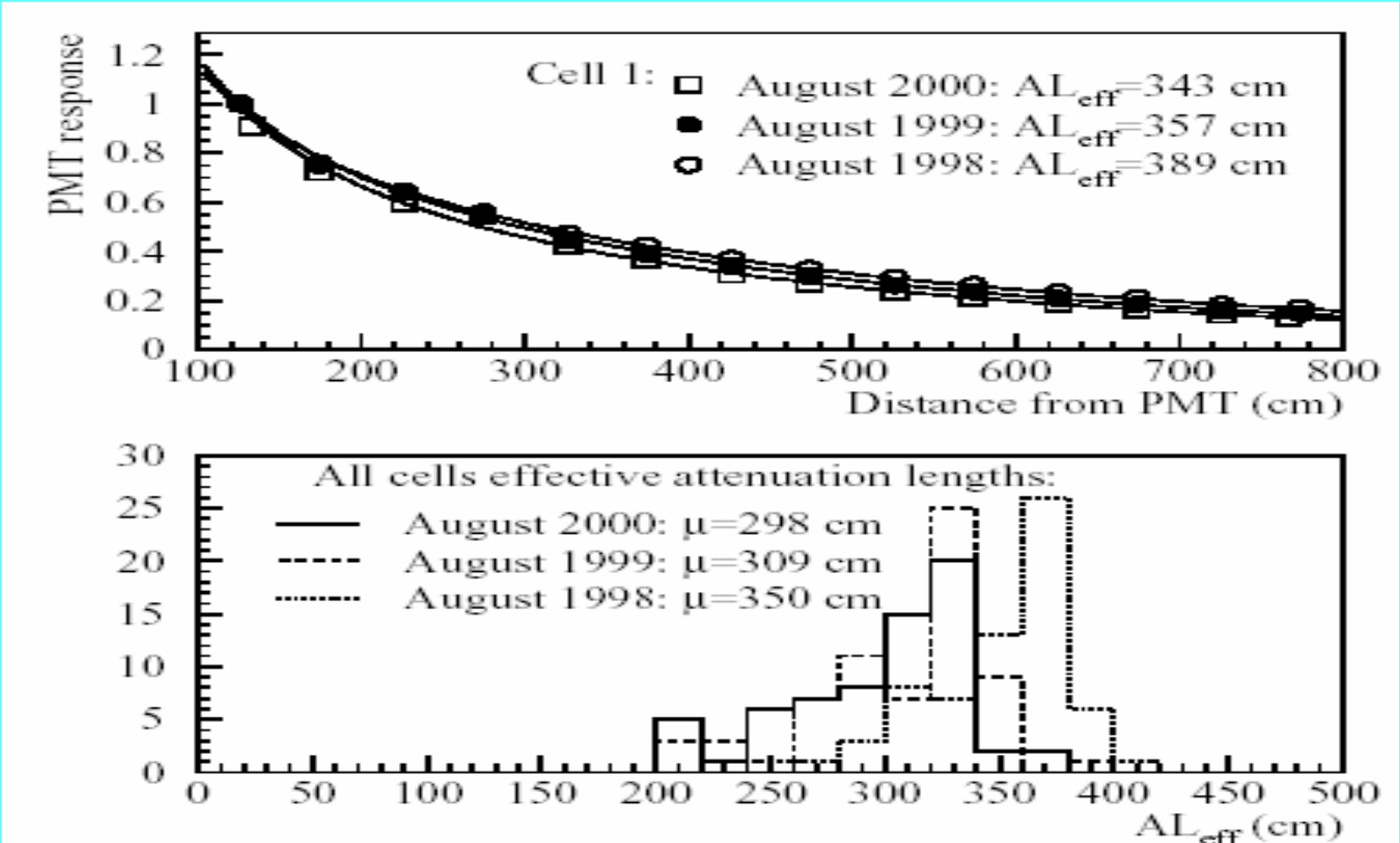
U: 2.5 Bq

Th: 1.0 Bq

PMT with schott glass for SNO, R1408: 20 Bq

Scintillator

- Gd-loaded scintillator is desirable,
- PV scintillator: 11m, 55% antracene
- PV aging: 0.03%/day, Chooz aging: 0.4%/day



Scintillator

- PV scintillator: $Gd(CH_3(CH_2)_3CH(C_2H_5)CO_2)_3$
  4% 2-ethoxyethanole, 36% pseudocumene, 60% mineral oil plus PPO, BisMSb, BHT, and Gd compounds
- More pseudocumene, more stable, 50% ?
- But
  - Compatibility with acrylic
  - Flush point
  - Cost

Compatibility issues: Inner tank

- Acrylic is OK for both Chooz and PV, but 40% seems the limit
- Epoxy based solid scintillator as the inner tank,
  - No compatibility problem with the liquid scintillator
  - Sensitive detector between target and γ-catcher → better energy resolution
  - Simple, easy and cheap
  - Check: transparency

Outer tank

- PE or steel
- Rotomolding or assembly pieces
- PMT fixture
- Mechanical strength (movable, assembly)
- Aging ?

see C.G. Yang's talk

Buffer

- 2m water buffer to shield backgrounds from neutrons and γ's from lab walls
- Active buffer is even better
- 800 8" PMT from Macro available

Background

- **Cosmic-muon-induced neutrons:**
  - **B/S < 0.005 → 1/day @ ~1km**

	100 MWE	300 MWE	1000 MWE
muon rate/m^2 (Hz)	4	0.4	0.02
n rate in rock/m^3 (/day)	11000	1600	160
reduction required (10^6)	9.2	1.4	0.14
Shielding (water equivalent) (m)	2.5m	2.1m	1.5m

- **Uncorrelated backgrounds:**
  - **B/S < 0.05 → < 8/day @ far site**
  - **single rate @ 0.9MeV < 50Hz**

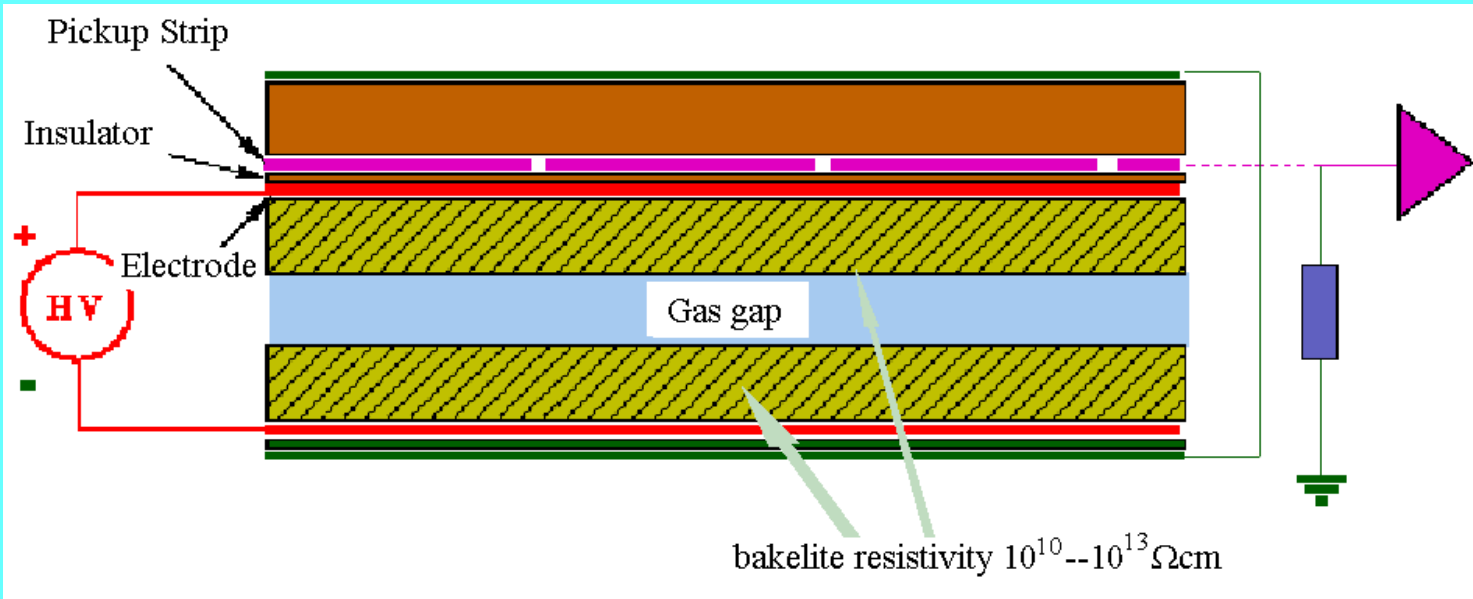
$$2 \cdot R_\gamma \cdot R_n \cdot \tau < 0.04/\text{day/module}$$

2m water shielding is enough → see J. Cao's talk

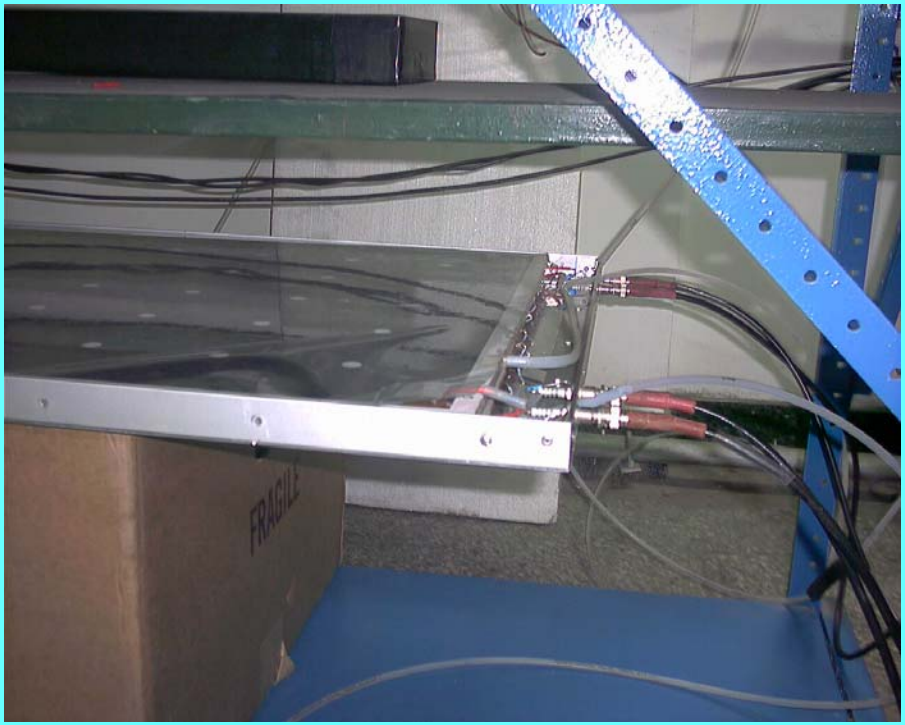
VETO

- Inefficiency less than 0.5%, known to 0.25%
- Need multiple handling
- RPC(>90%) + active water buffer(>95%) ➔

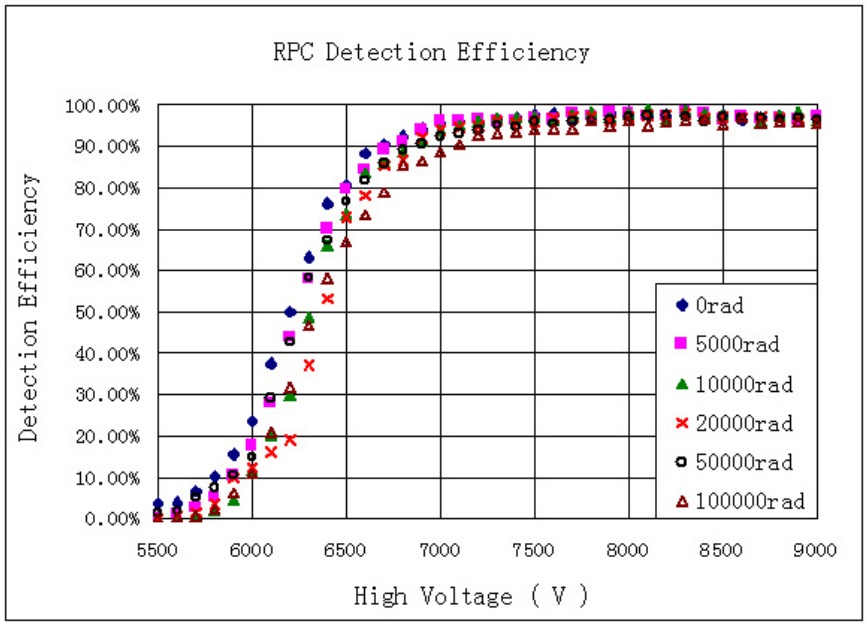
  total ineff. = 10%*5% = 0.5%
- 2 layers RPC, each layer with XY strips of 4cm in width

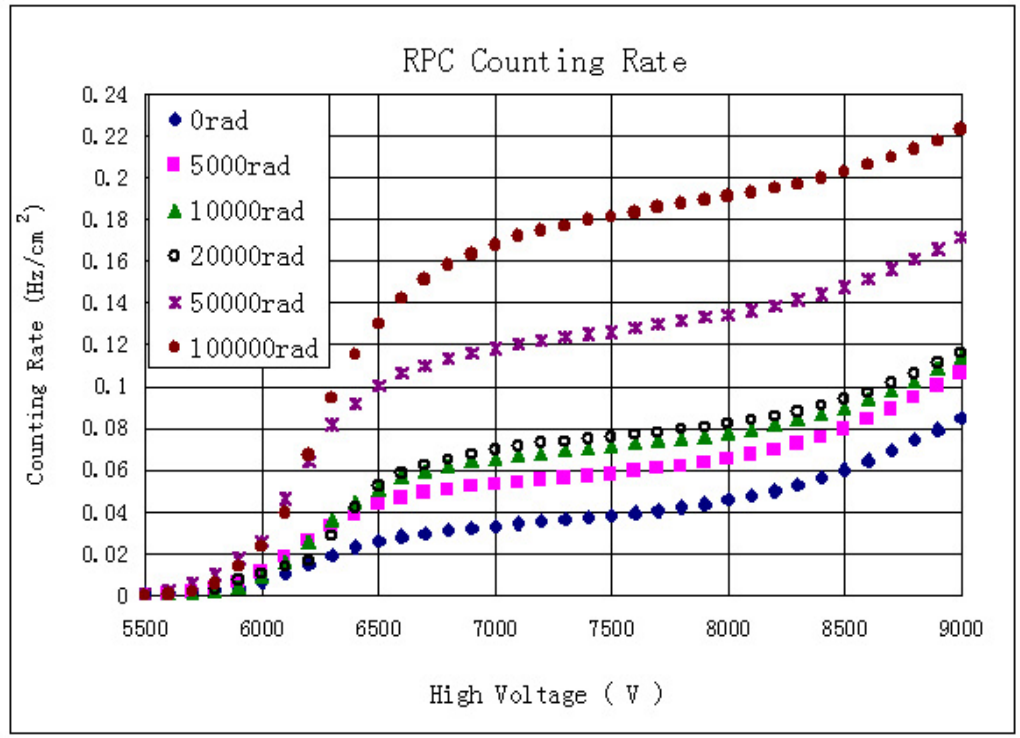


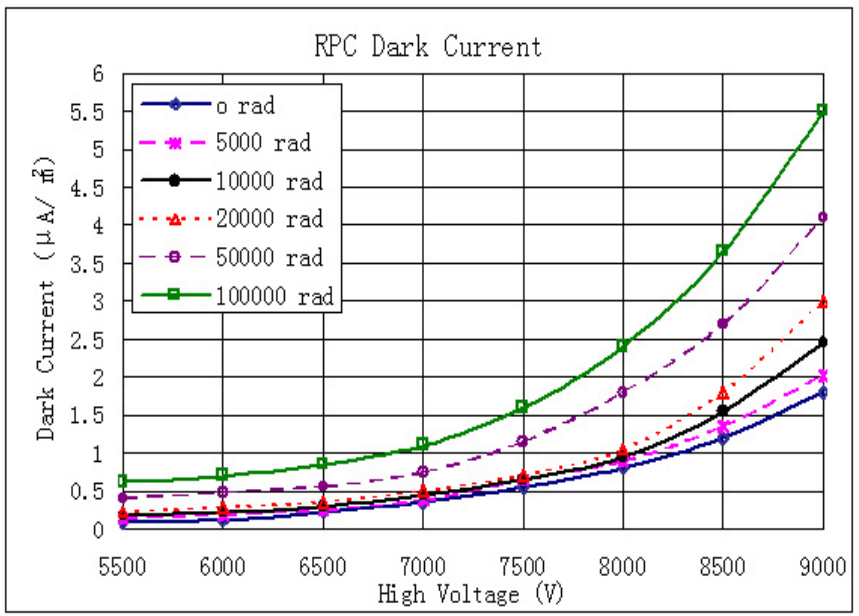
RPC prototypes



RPC under neutron radiation







After some time for recovery, all properties back to the level almost the same as that before radiation.

Calibration

- PMT response calibrated by light sources
- Multiple radiative sources at various position of the detector
- Goal: detector response to n/γ at different energies/locations
- Deploy system: a key to success

Budget for detector(8 module)

	Unit price($)	Quantity	Total ($)
PMT	1000	150*8	1200K
Scintillator	10/kg	8000*8	640K
Buffer oil/scintillator	2/kg	20000*8	320K
Outer Tank	10000	8	80K
Inner Tank	10000	8	80K
Electronics/HV	400	150*8	480K
RPC	150/m^2	3000 m2	450K
RPC electronics	30/ch	30000 ch	900K
Mechanics+shielding	300K	3	900K
Triger + Online	100K	3	300K
Contingency	500K	1	500K
Total			5750K