Liquid scintillator R&D in Europe

Christian Buck, MPIK Heidelberg

NNN08

Paris, September, 2008

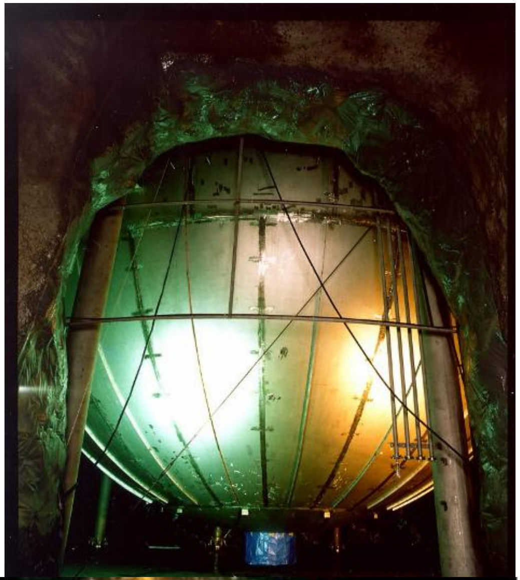
Overview

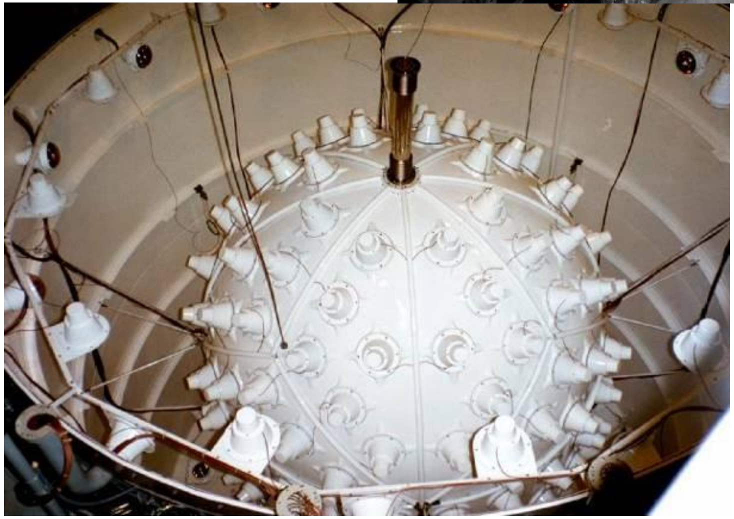
- Introduction
- Scintillator components
- Energy transfers
- Metal loaded scintillators
- Conclusions

Liquid scintillator past and present

Metal loaded:

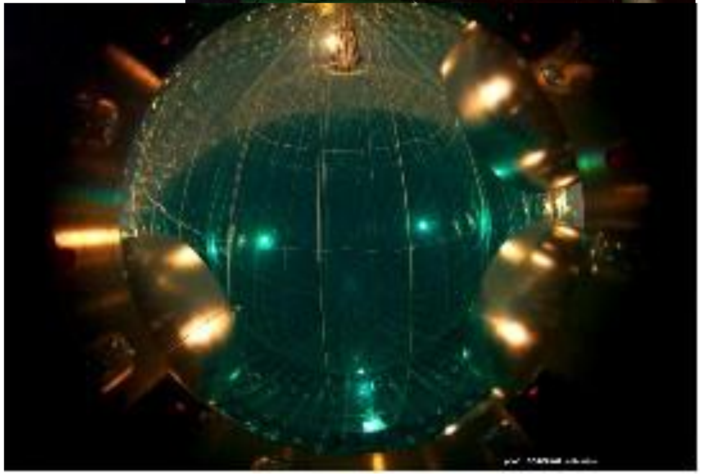
- Reines
- Bugey
- Chooz
- Palo Verde





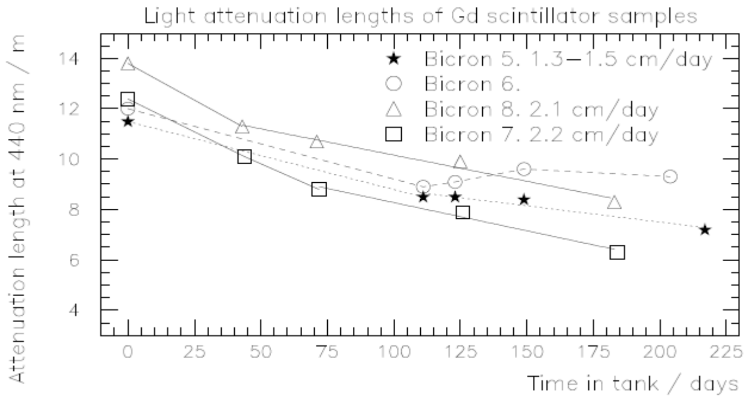
Unloaded:

- KamLand
- Borexino



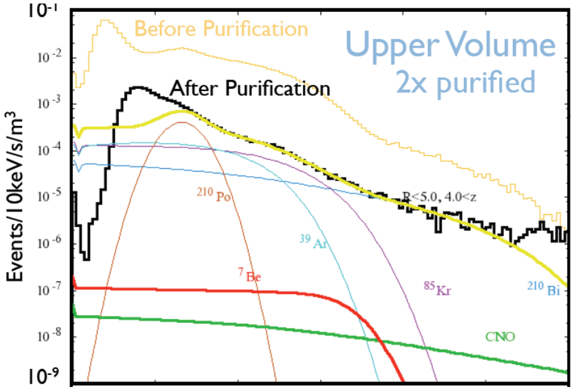
Challenges: Stability and purity

Palo Verde:



A.G.Piepke, S.W.Moser, V.M.Novikov; NIM A 342 (1999) 392-398

KamLAND Background:



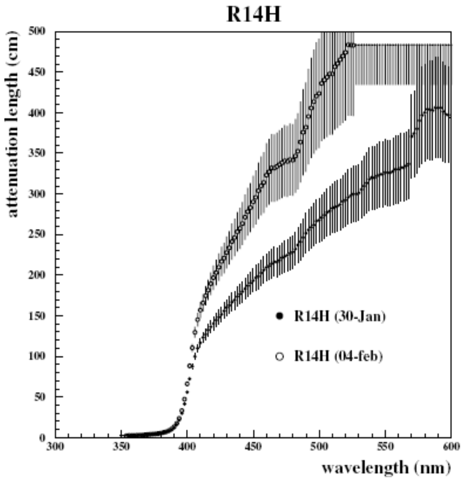
KamLAND Collaboration, Neutrino 2008, Christchurch, NZ

Chooz:

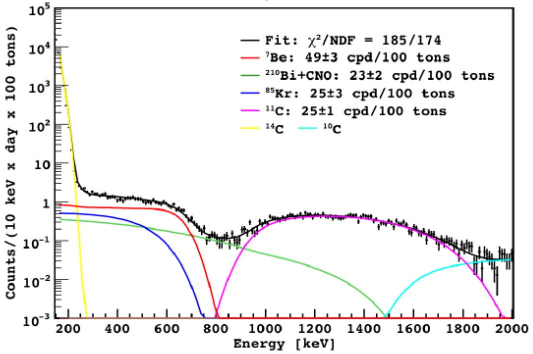
Gd(NO$_3$)$_3$

τ ~ 240 days

Chooz Coll.; Eur.Phys.C27, 331-374 (2003)



Borexino Background:

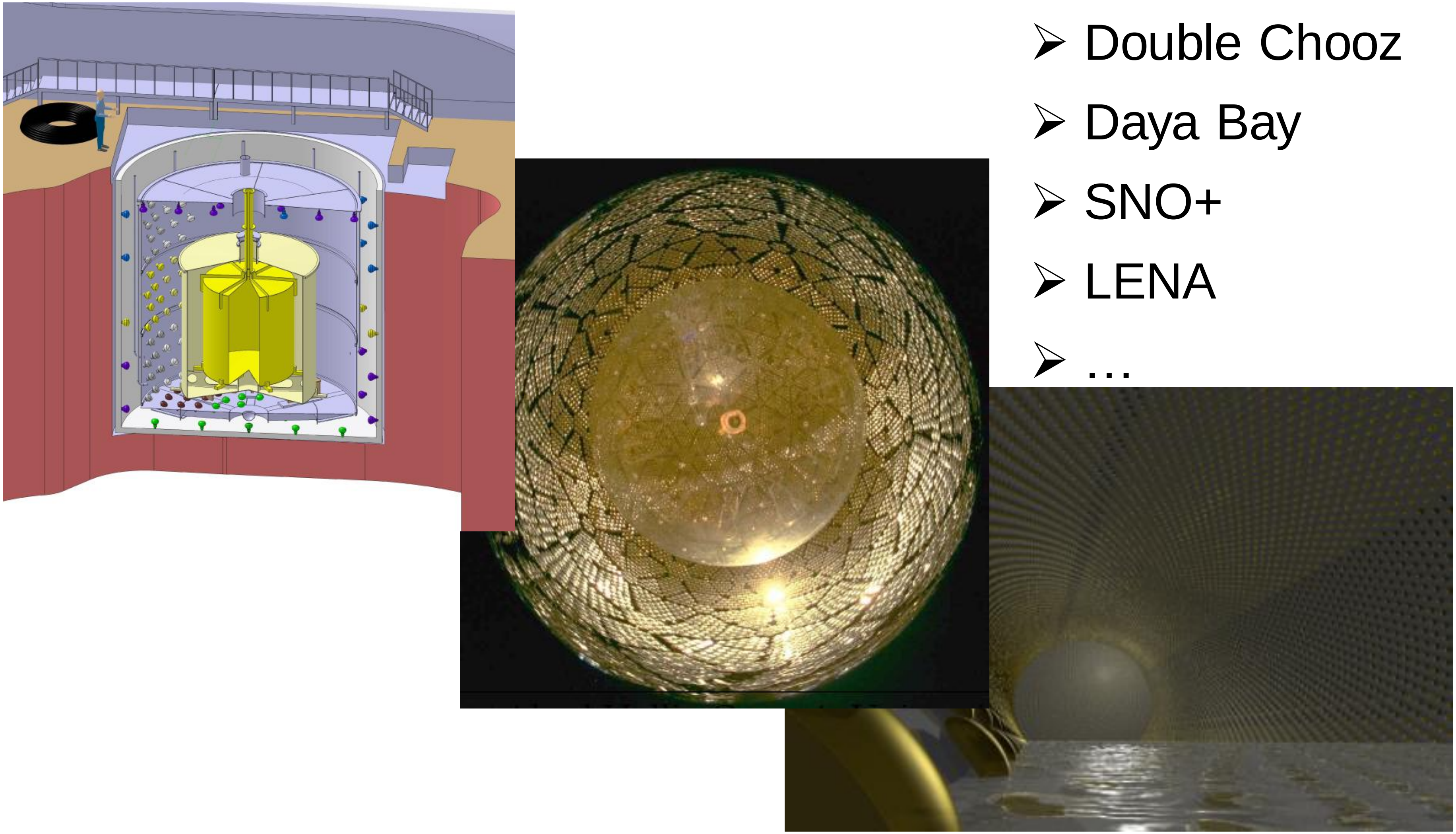


Borexino Collaboration, arXiv:0805.3843v2 [astro-ph], Jun 2008

Liquid scintillator properties

- High energy resolution
- Low energy detection threshold
- high purity (Borexino)
- fast signals (better understanding of timing properties)
- moderate cost
- Improved stability of metal loaded scintillators

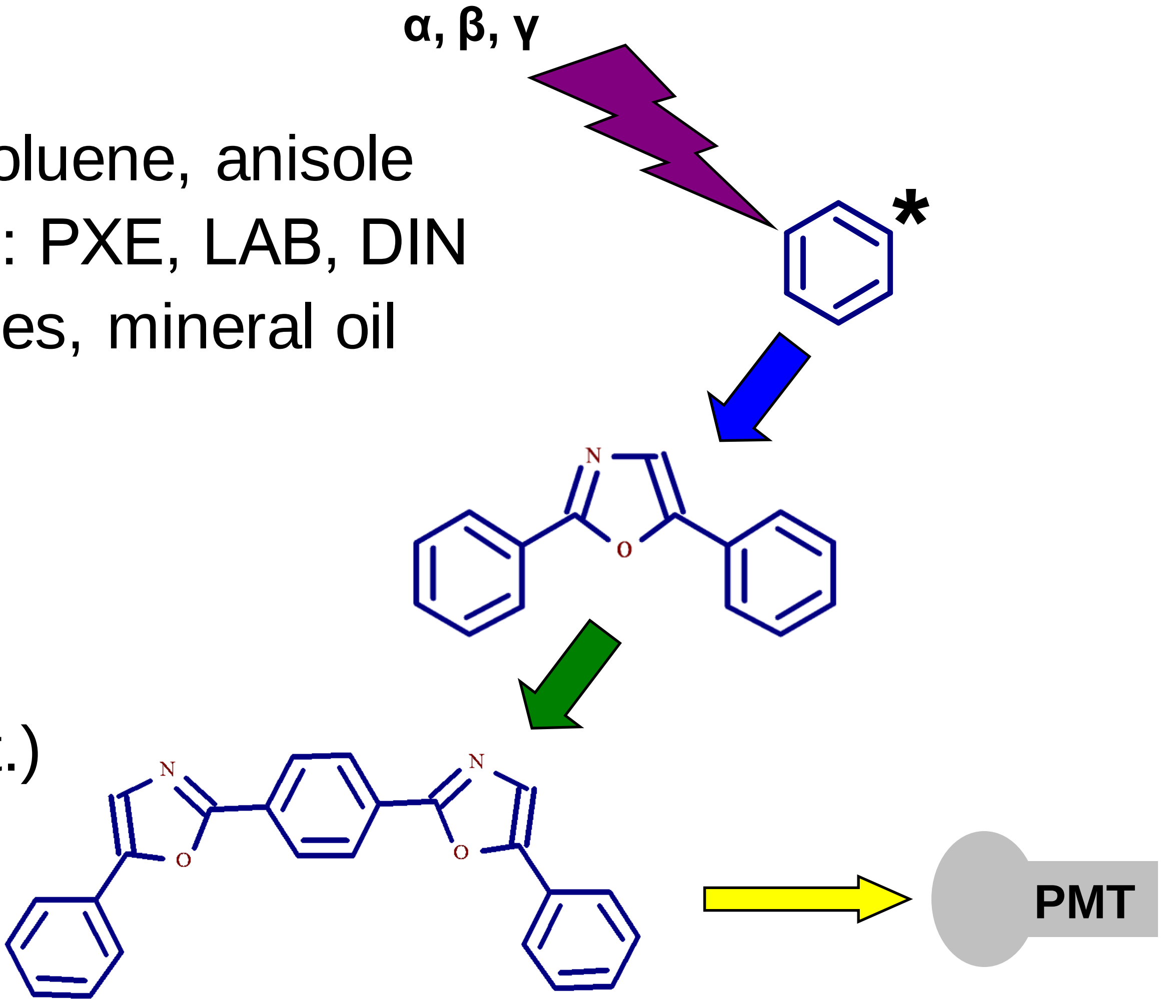
Liquid scintillator future



- ➢ Double Chooz
- ➢ Daya Bay
- ➢ SNO+
- ➢ LENA
- ➢ …

Liquid scintillator components

- Solvent
  - pseudocumene, toluene, anisole
  - „Safe scintillators“: PXE, LAB, DIN
  - Admixtures: alkanes, mineral oil
- Primary fluor
  - PPO
  - BPO
  - Butyl-PBD,…
- Secondary fluor (opt.)
  - Bis-MSB
  - POPOP



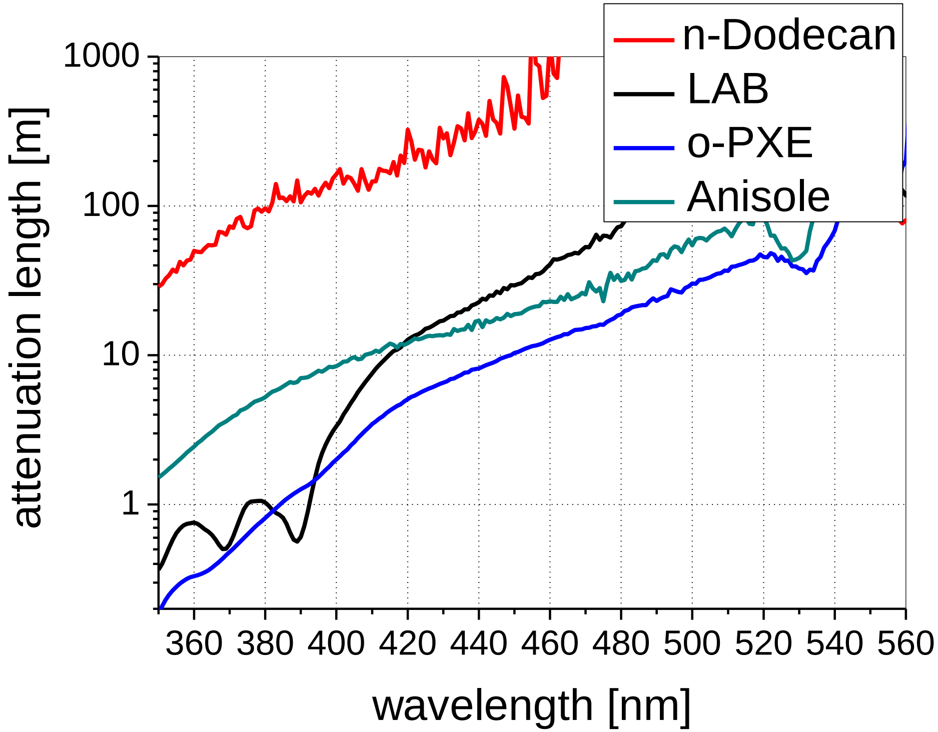
Comparison solvents

Scintillation yield

solvent	Yield
PC	1.00
Anisole	0.81
PXE	0.88
LAB	0.74
n-Dodecan	0.40
Oil	0.33

MPIK measurements (6 g/l PPO)

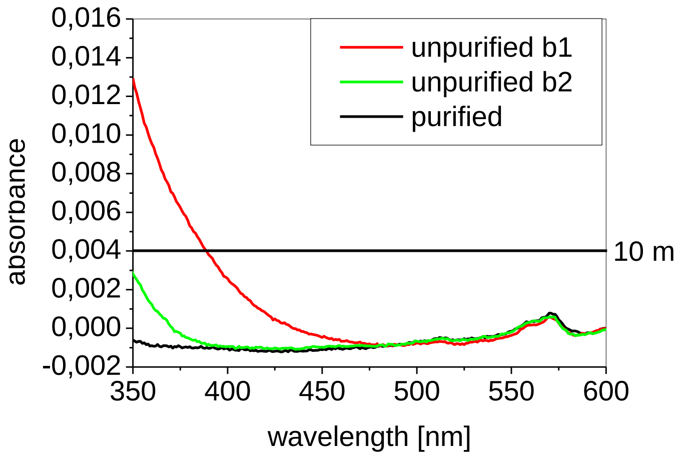
Attenuation length

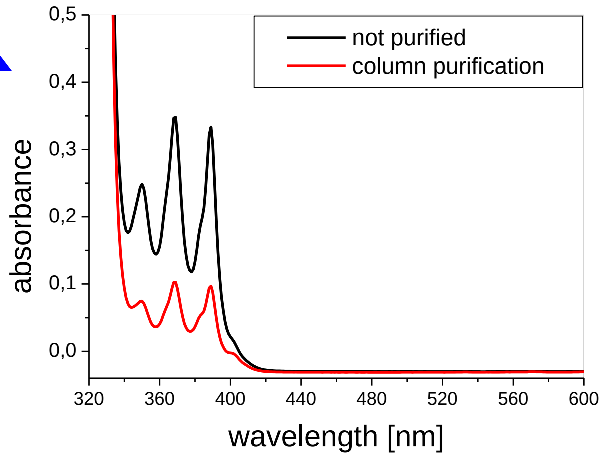


- UV/Vis (MPIK): (absorbance + scattering)
- Single contributions determined at TU Munich

Purification methods

- Column purification
  - Radioimpurities
  - Optics
- N_2 purging
  - Radon, ^{85}Kr
  - Light yield (oxygen)
- Water extraction
  - Radioimpurities (e.g. ^{40}K)
- Distillation
  - Radioimpurities
  - Optics





Purification methods

- Column purification
  - Radioimpurities
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- N_2 purging
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  - Light yield (oxygen)
- Water extraction
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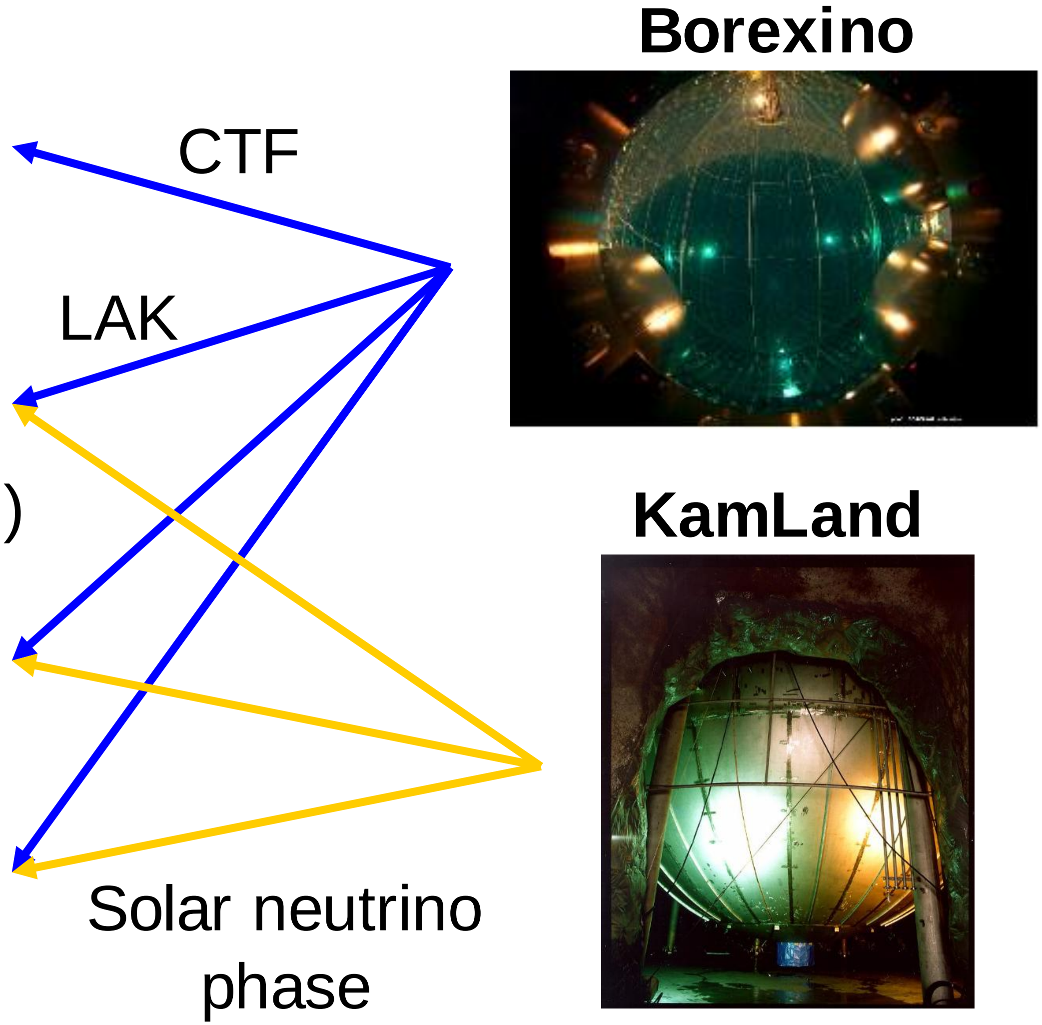
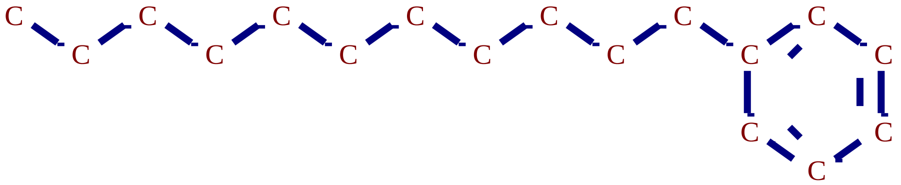
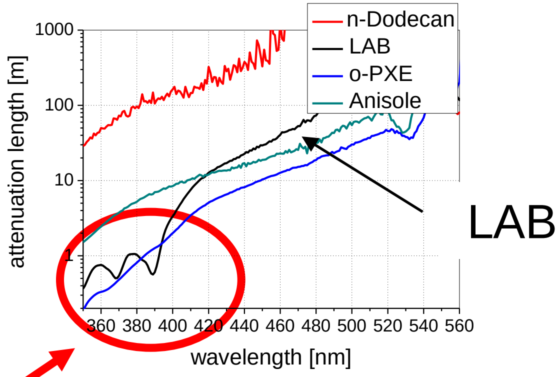


LAB

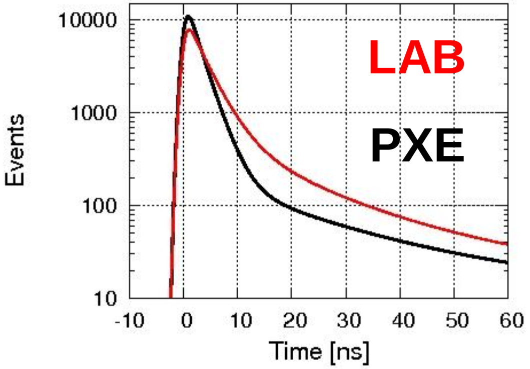


- Is LAB a new high light yield, transparent solvent?

  Not really.
  - Used since decades
  - Average light yield
  - Average transparency



- It is a high flash point, low toxicity solvent at moderate cost and reasonable optics,
- …but:
  - Mixture
  - Biphenyls (absorption/emission!)
  - Timing properties



Solvent mixtures

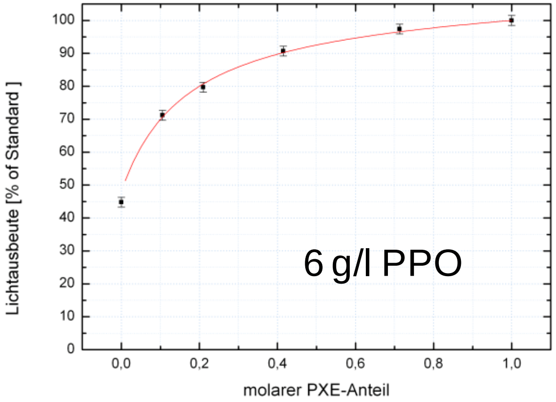
Advantage: Parameters tuneable

- ➢ optimize material compatibility
- ➢ change timing properties
- ➢ match density
- ➢ adjust light yield

Light production in alkanes

➢ Radiation creates e^{-} - hole pairs

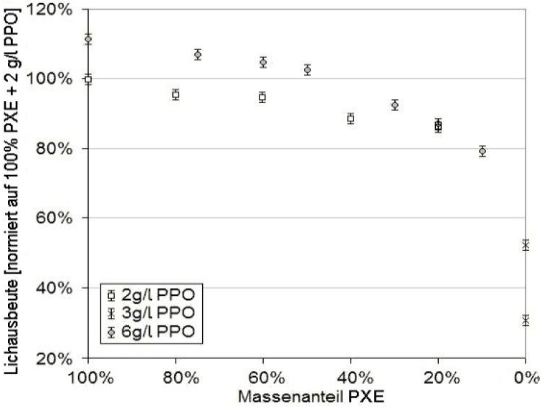
➢ Recombination, fragmentation, radicals, reactions ➔ excited molecules ➔ energy transfer to fluors



6 g/l PPO

C.Buck, dissertation, MPIK (2004)

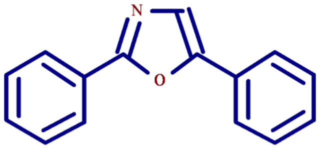
C.Aberle, diploma thesis, MPIK (2008)



M.Wurm, diploma thesis, TUM(2005)

Comparison fluors

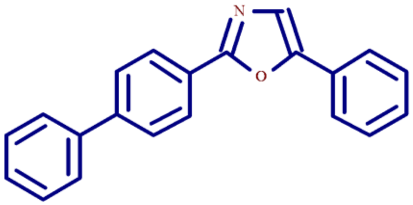
PPO



☺
- transparent
- well established
- high quantum yield

☹

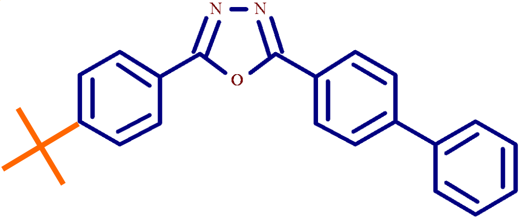
BPO



☺
- high(est) light yield
- emission around 400 nm

☹
- absorption properties
- limited availibility

(Butyl-)PBD



☺
- high light yield

☹
- poor quantum yield
- costs

pTP

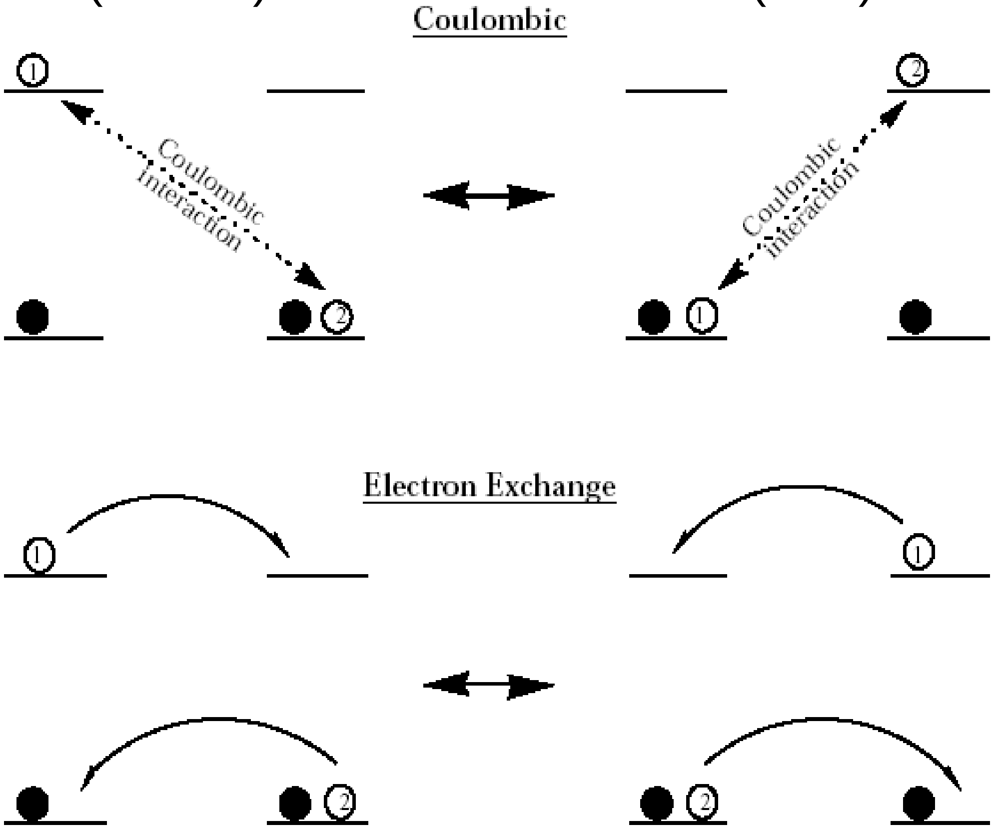
☺
- fast
- overlap with bis-MSB

☹
- low solubility
- poor quantum yield

Energy transfer (non-radiative)

Donor D
(solvent)

Acceptor A
(fluor)



$$k_{FRET} \propto \left(\frac{R_0}{R}\right)^6 \cdot J$$

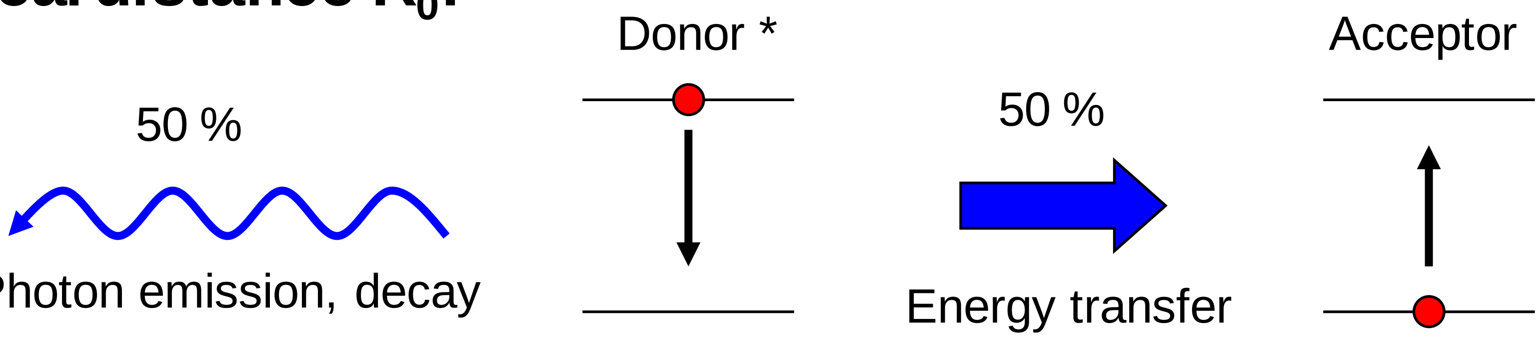
$$J = \int \frac{\varepsilon_A(\nu) \cdot f_D(\nu)}{\nu^4} d\nu$$

$$k_{exchange} \propto J \cdot e^{-2R/L}$$

T. Förster: Annalen der Physik 2 (1948) 55.
D.L. Dexter: J. of Chem.Lett. 21 (1952) 836.

Critical concentration

Critical distance R_0:



Donor *

Acceptor

50 %

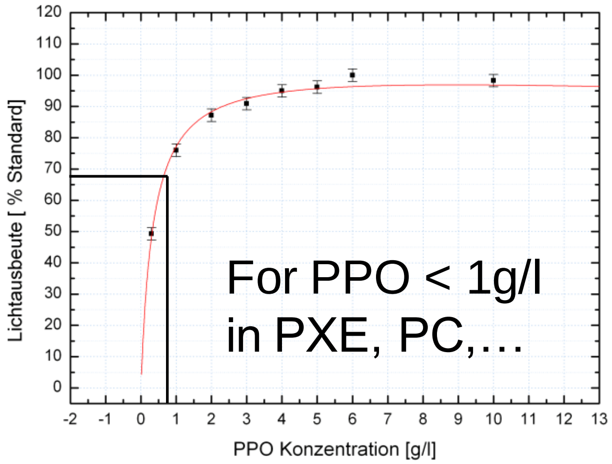
Photon emission, decay

50 %

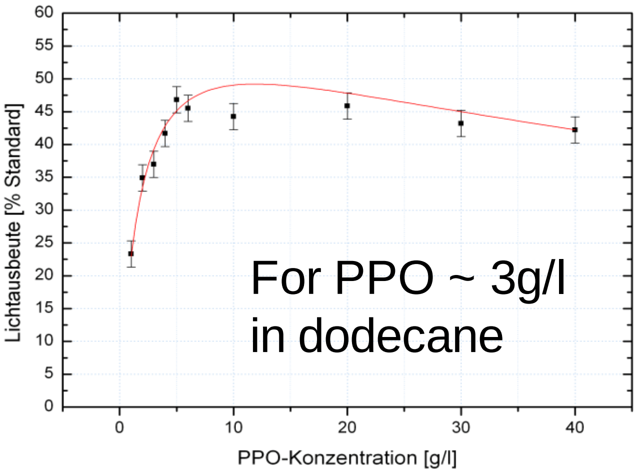
Energy transfer

Critical conc.:

$$c_0 \propto \frac{1}{R_0^3}$$

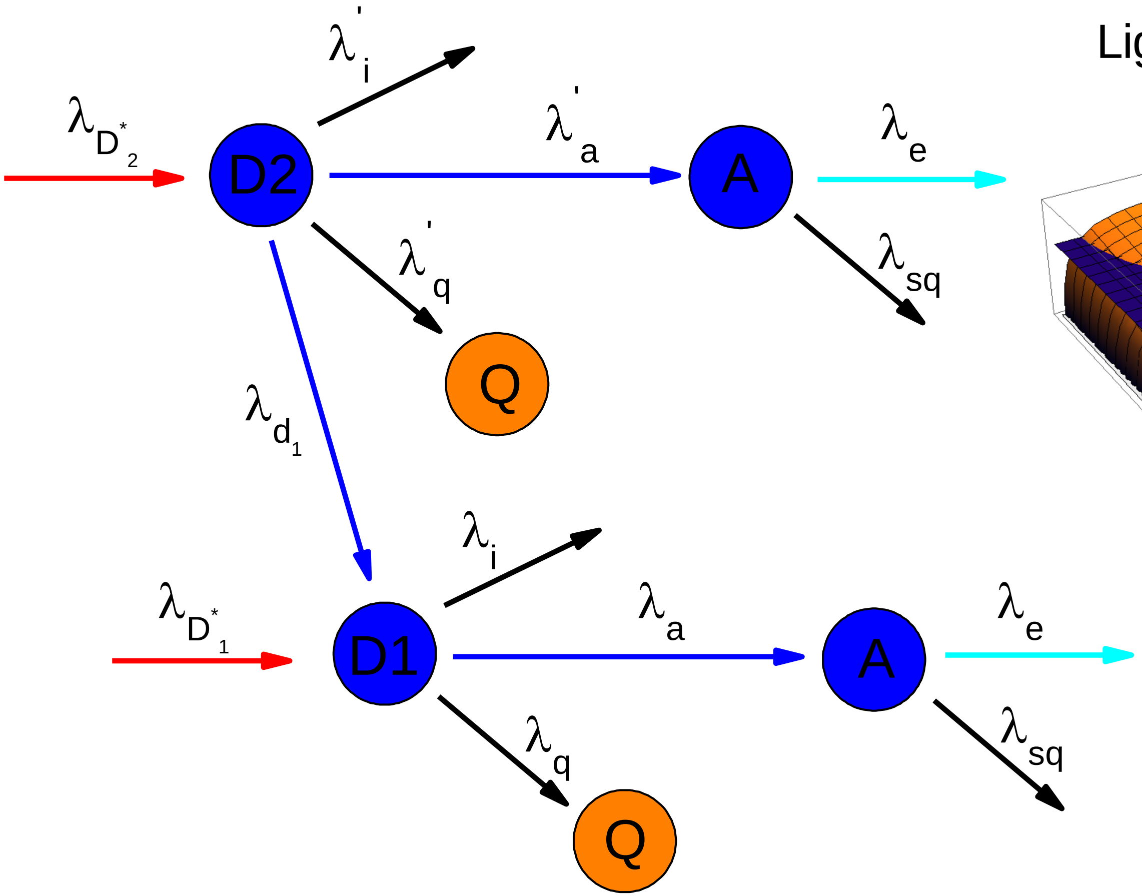


For PPO < 1g/l in PXE, PC,…

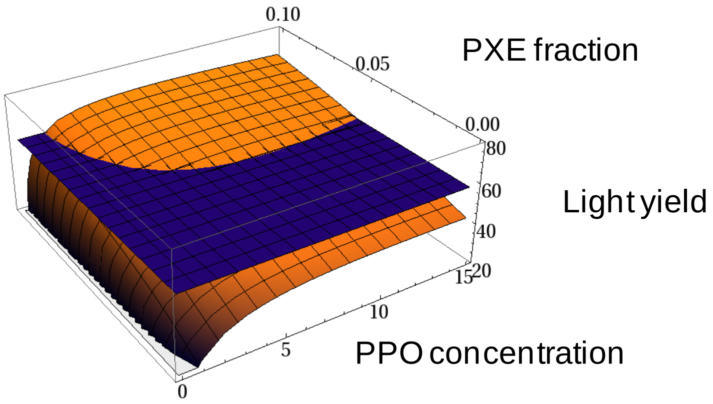


For PPO ~ 3g/l in dodecane

Light yield model



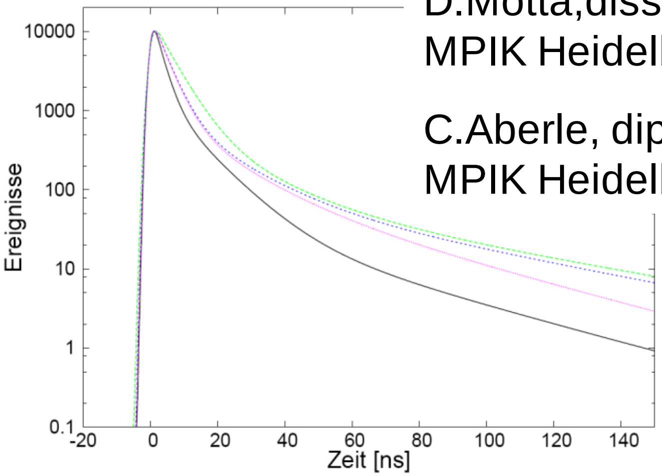
Light yield predictions



C.Buck, F.X. Hartmann, D.Motta. S.Schönert, CPL, 435 (2007) 252 - 256

C.Aberle, diploma thesis, MPIK Heidelberg (2008)

Timing properties



D.Motta,dissertation, MPIK Heidelberg (2004)

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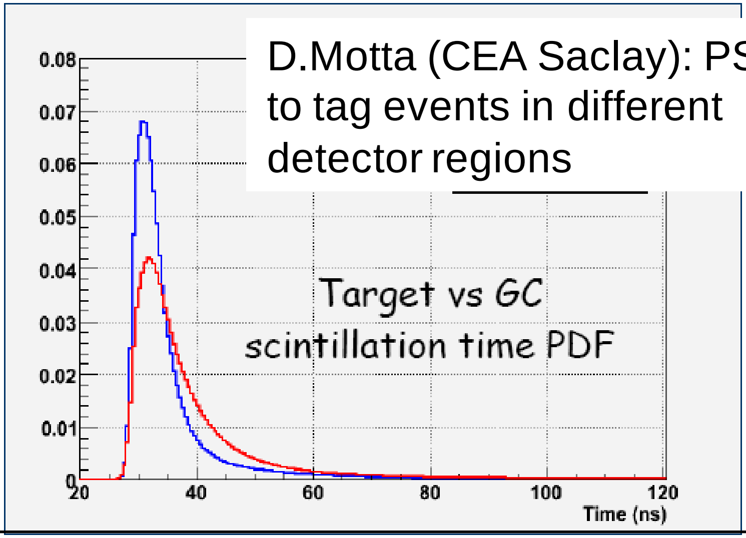
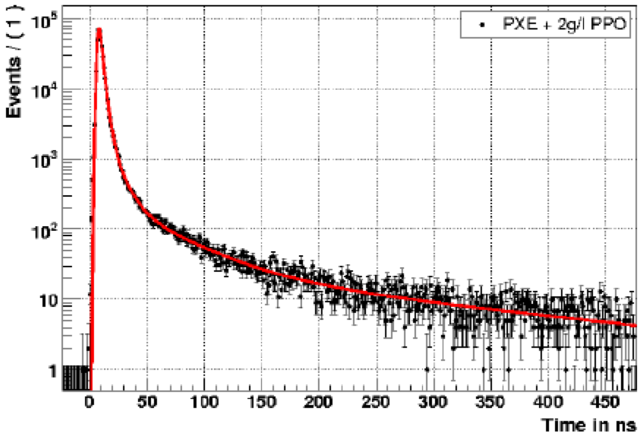
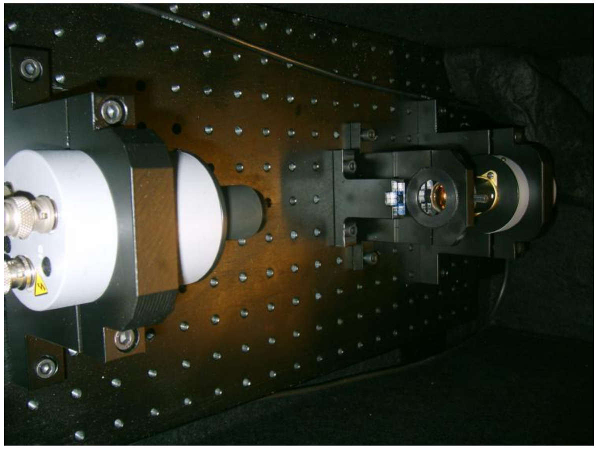


D.Motta (CEA Saclay): PS to tag events in different detector regions

T.Marrodan Undagoitia, dissertation, TU München (2008)





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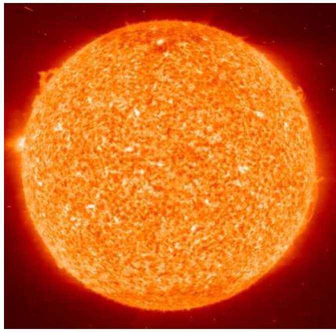
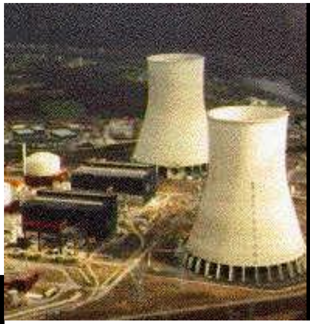
MPIK Heidelberg

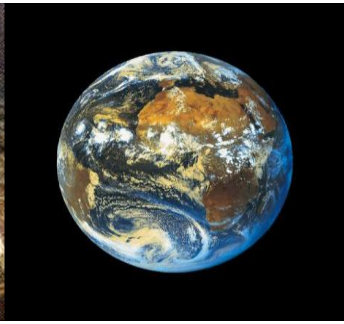
Paris, NNN08

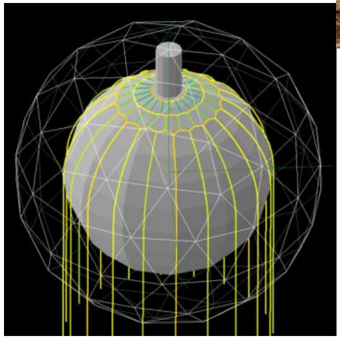
Metal loaded scintillators



- Solar neutrinos (LENS, SIREN):
  - Metal: Ytterbium, Indium, Gadolinium
  - Challenge: High loadings
- Reactor (Double Chooz, Daya Bay)
  - Metal: Gadolinium
  - Challenge: Stability
- ββ-decay (SNO+)
  - Metal: Neodymium
  - Challenges: transparency; purity





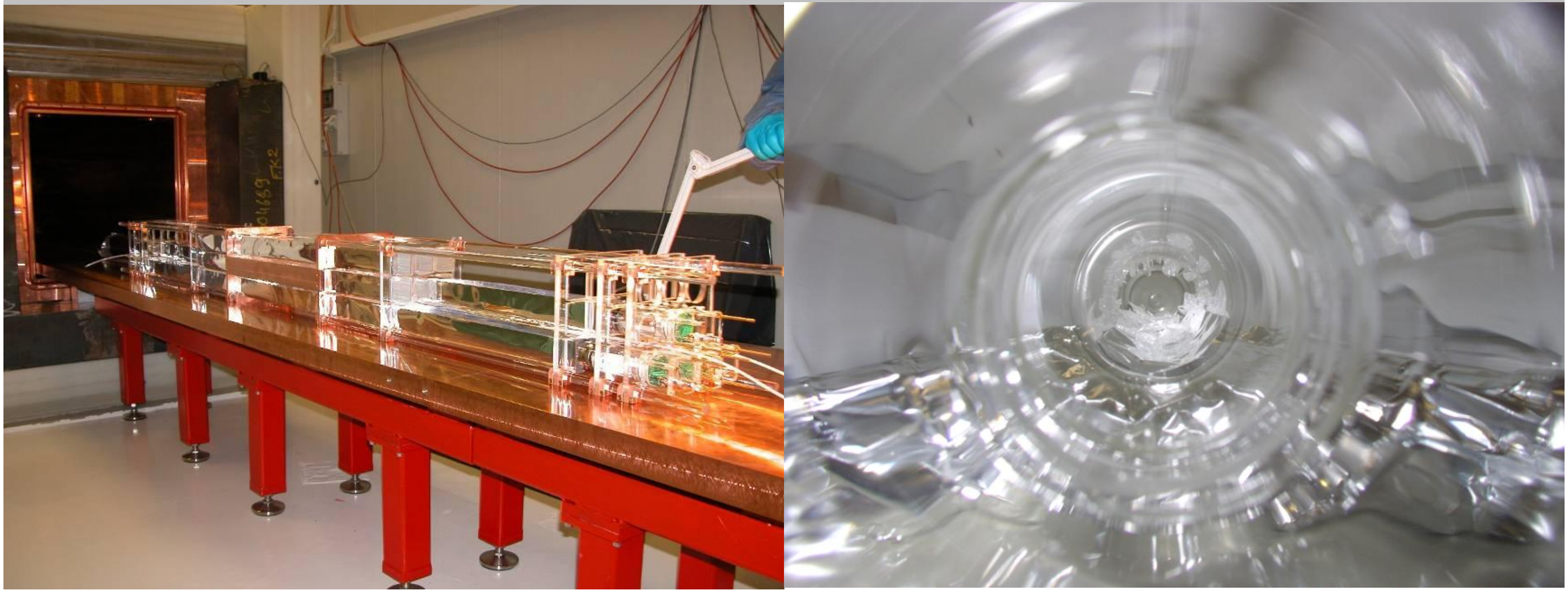


Indium

Indium-loaded scintillators at LLBF > 1 year

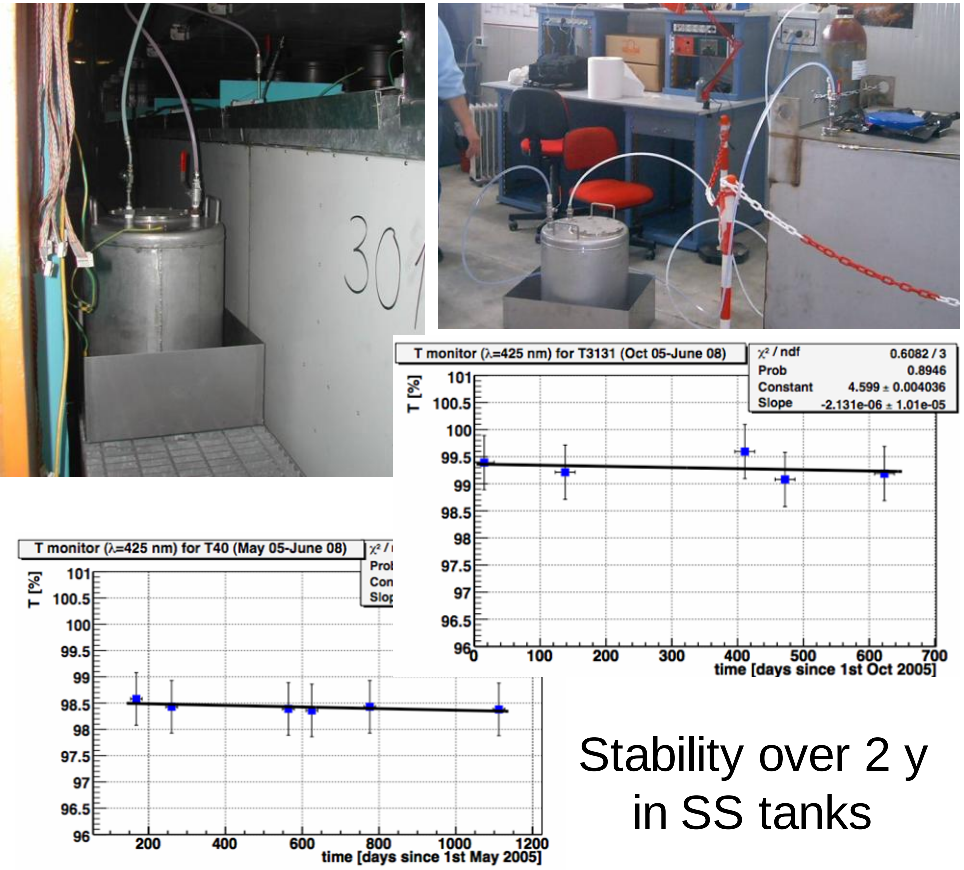
- MPIK: In(acac)$_3$ (F.X.Hartmann et al.)
- INR/LNGS: Carboxylic acid version

} > 50 g/l Indium



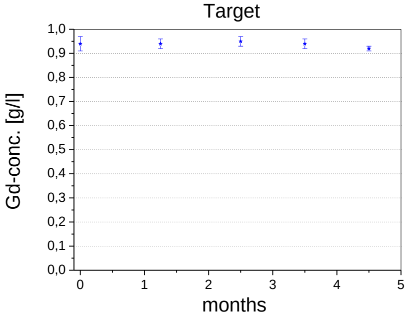
Gadolinium (Carboxylates)

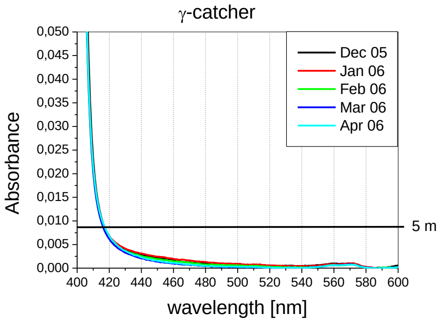
INR/LNGS: 2 x 1.2 t Gd-LS (0.1%) in frame of LVD

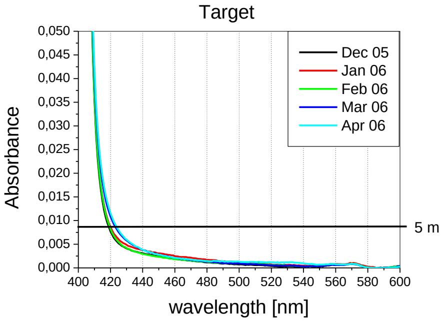


Stability over 2 y
in SS tanks

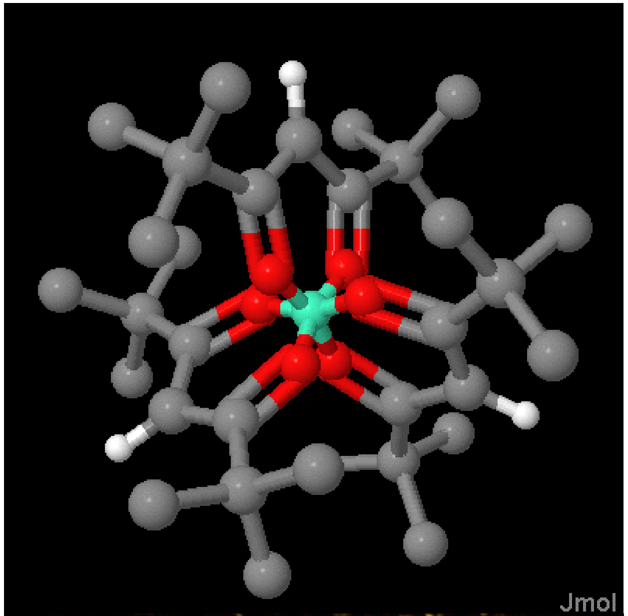
Double Chooz mockup (TMHA, MPIK Hd 2003):





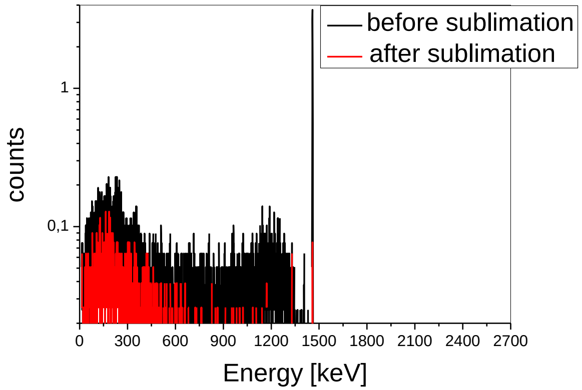


Gadolinium (β-diketones)

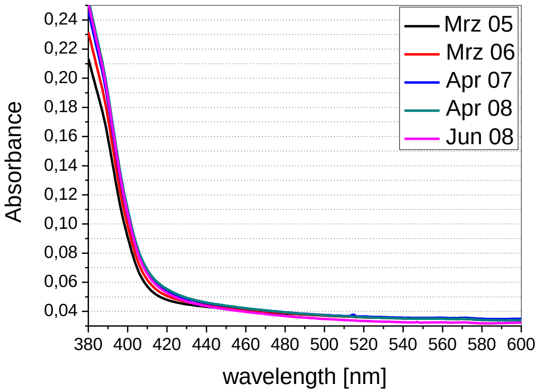


- Purified by sublimation
- stability tests at MPIK since > 3 years
- att. length (1 g/l) > 50 m above 420 nm
- 100 kg produced (2 DC detectors)
- stability/compatibility at CEA Saclay

Ge spectrum Gd(BDK)$_3$

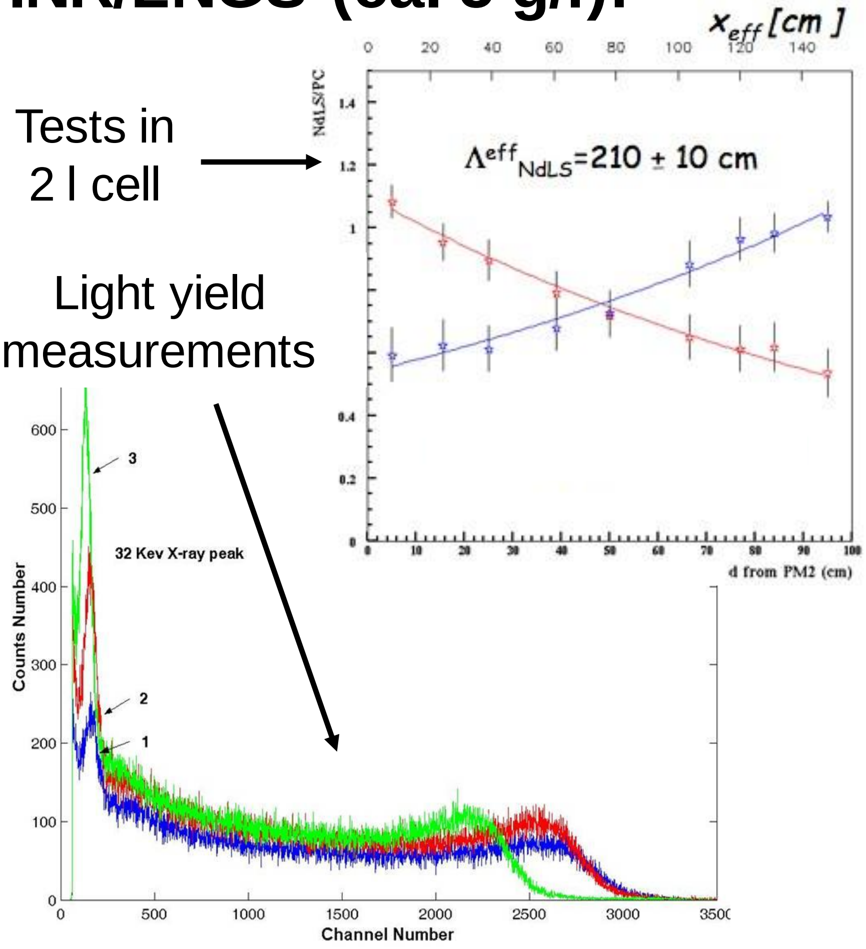


Gd not sublimed, Jan 05, no fluors, PXE isomers mixed



Neodymium

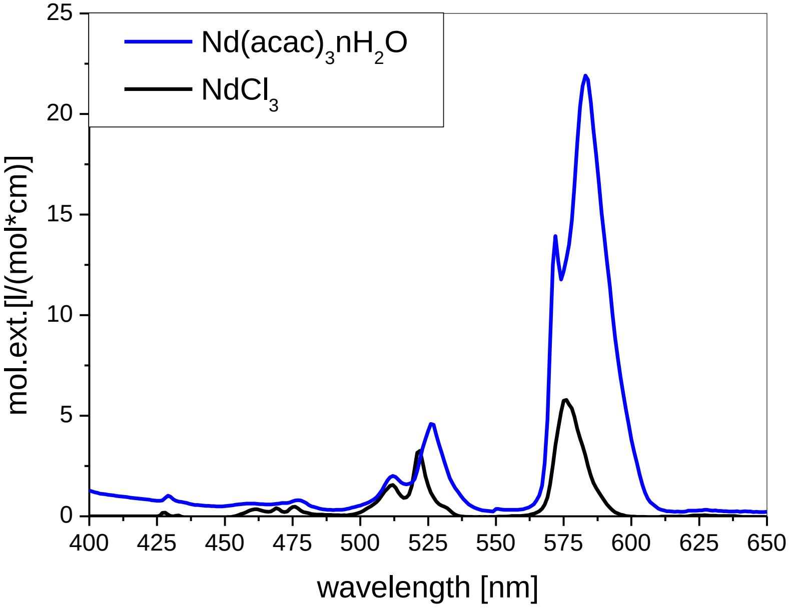
INR/LNGS (ca. 5 g/l):



Tests in
2 l cell

Light yield
measurements

MPIK (2003): Tests on BDK and carboxylate versions (F.X.Hartmann et al.)



R&D in US for SNO+

Summary

- Many solvent and fluor candidates
  - Choice depends on application and detector characteristics
  - Requirement for „safe“ scintillators (PXE, LAB,…)
- Energy transfer models allow light yield predictions
- Several applications for metal loaded scintillators
- Liquid scintillators were / will be key technology for large scale neutrino detectors
- Significant improvement in last years (stability etc.)