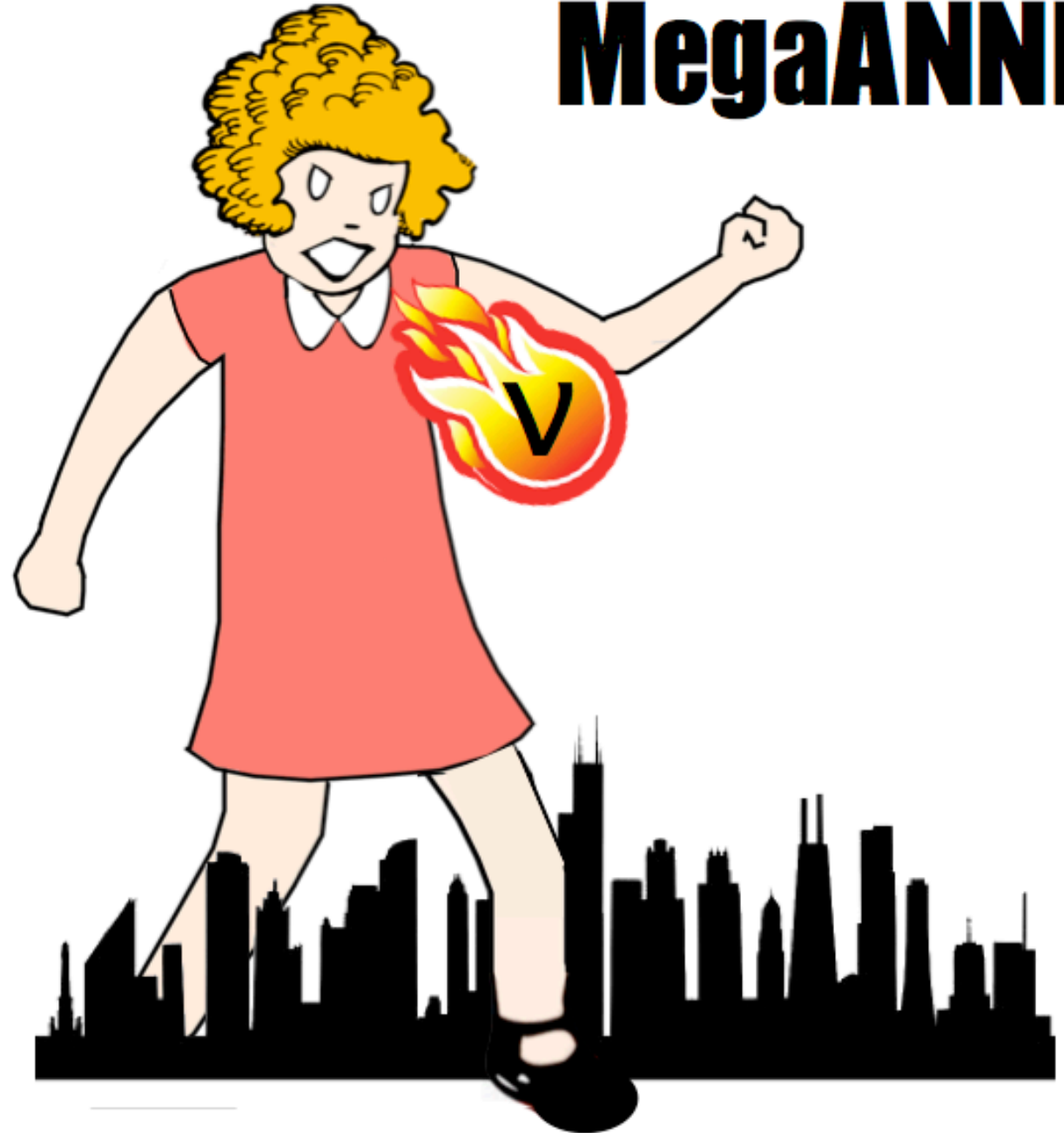


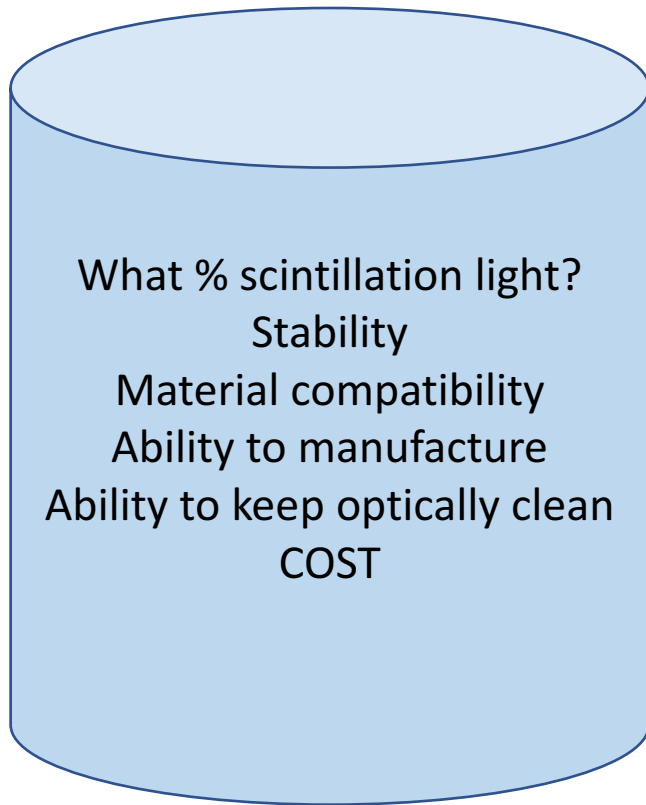
Opportunities for an ANNIE Run 3

R.Svoboda, DESY, March 27-29 2017

MegaANNIE



THEIA Long Baseline Physics Options



**Water based
Liquid Scintillator**

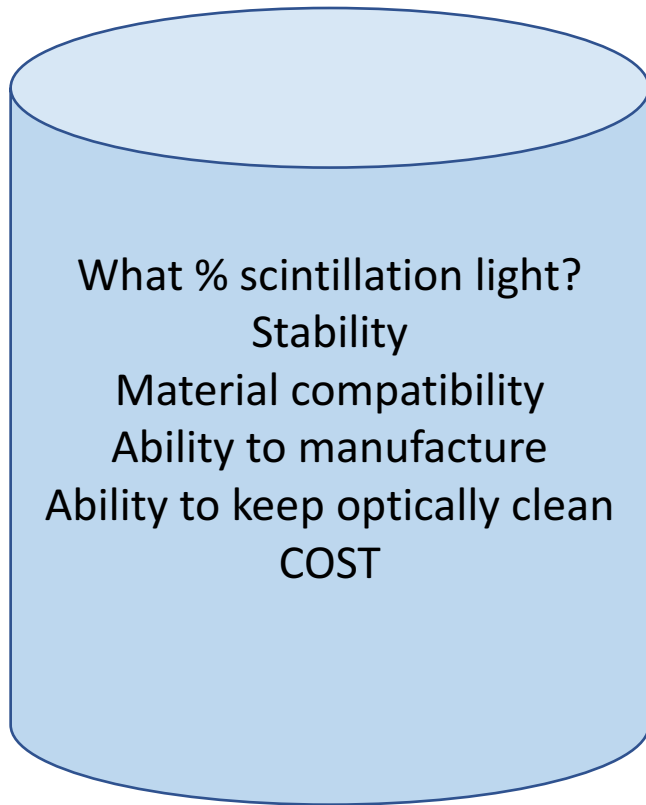


**Oil based
Liquid Scintillator**

Common R&D

- LAPPDs
- Fast, inexpensive PMTs
- New analysis techniques and reconstruction
- Understanding of the role of measuring neutron yield and spectrum could play
- Understanding of the role of hadronic activity could play

ANNIE Run 2



**Water based
Liquid Scintillator**



**Oil based
Liquid Scintillator**

Common R&D

- **LAPPDs**
- Fast, inexpensive PMTs
- **New analysis techniques and reconstruction**
- **Understanding of the role of measuring neutron yield and spectrum could play**
- Understanding of the role of hadronic activity could play

ANNIE Run 3



Water based
Liquid Scintillator



Oil based
Liquid Scintillator

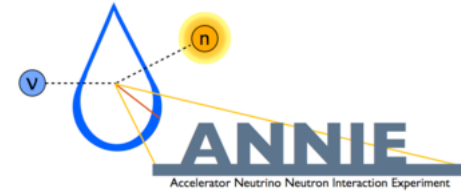
Common R&D

- LAPPDs (more)
- Fast, inexpensive PMTs
- New analysis techniques and reconstruction (more)
- Understanding of the role of measuring neutron yield and spectrum could play
- Understanding of the role of hadronic activity could play

ANNIE Hall next to SBND Hall

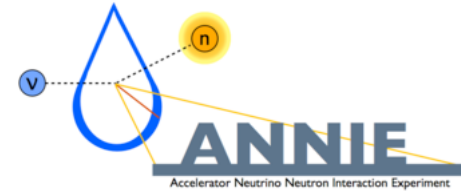


ANNIE Run 2 Proposal



- Refurbish and install PMT's from LUX (20 10" Hamamatsu), WATCHBOY (50 10" Hamamatsu), and LBNE (27 11" ETEL HQE) to allow detection of neutron capture on Gadolinium
- 60 (40) additional 8" (10") PMTs may also be needed
- Electronics and HV for the additional PMTs
- Muon Range Detector refurbishment (need plastic scintillator and small PMTs)
- New electronics for MRD and FACC highly desirable
- **Presentation to FNAL Program Advisory Committee July 2017**

ANNIE Run 2 and THEIA

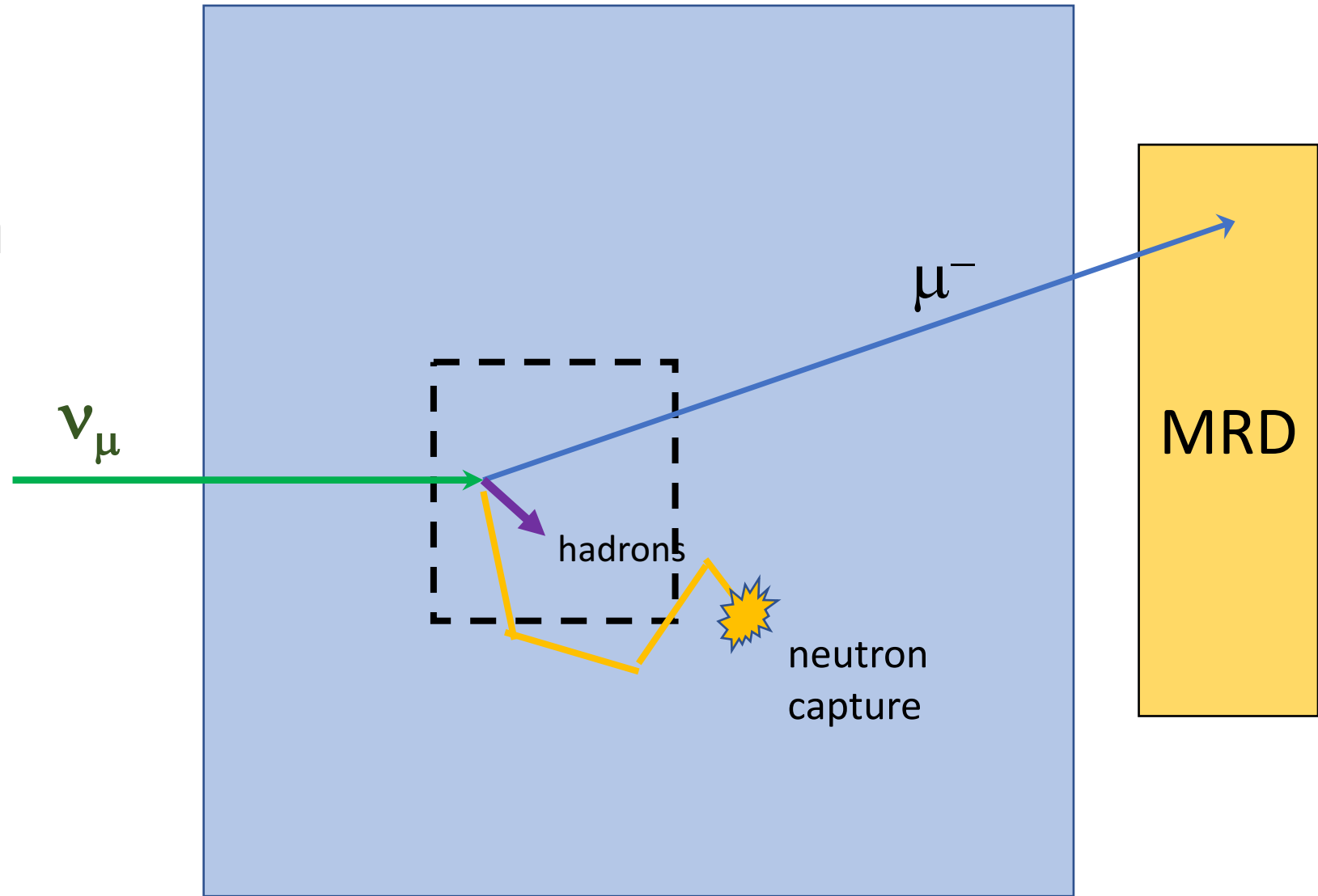


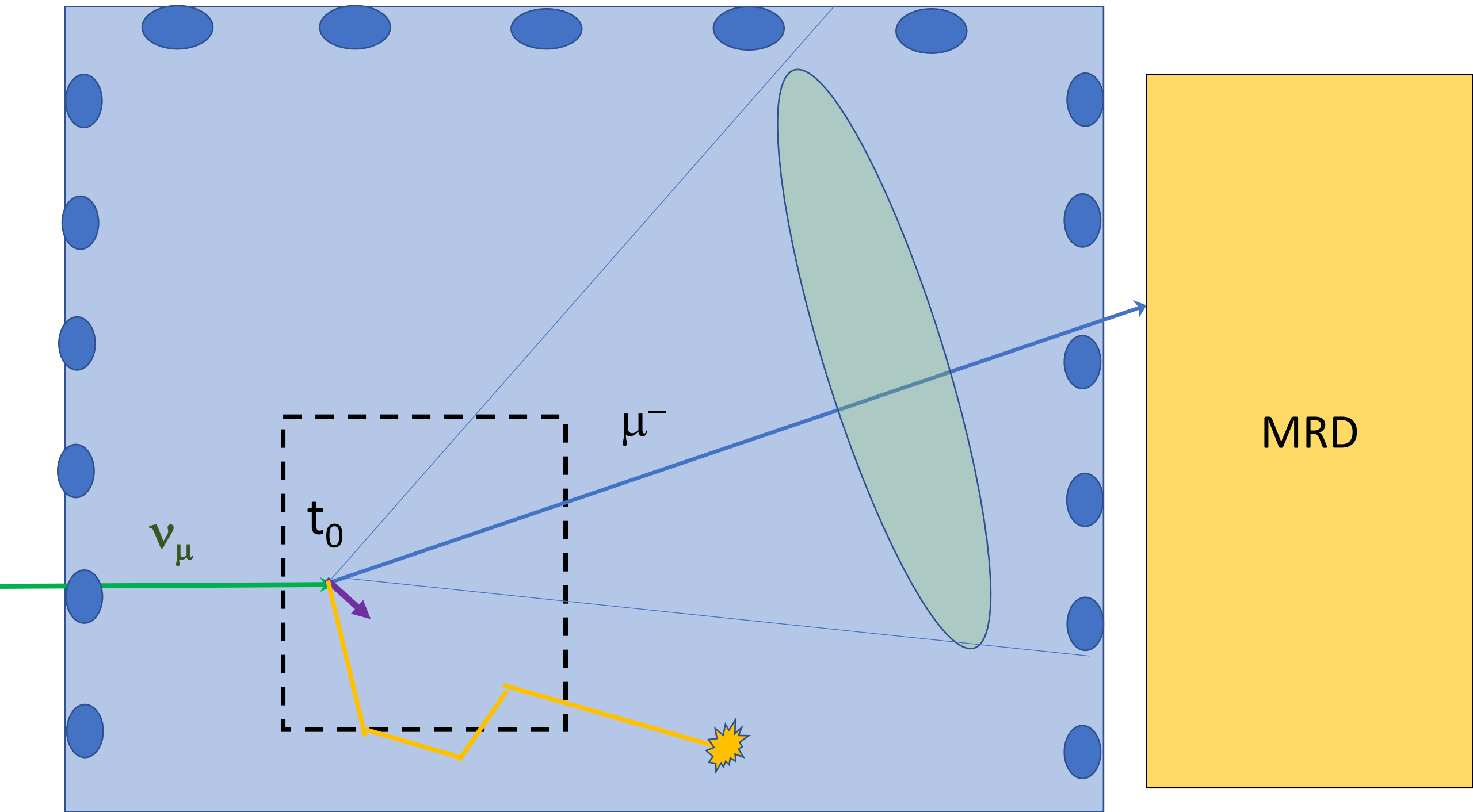
- Gadolinium loaded water target allows measuring neutron yield as a function of Q^2 This is critical to rejection of proton decay and Diffuse SN neutrino backgrounds
- First test of reconstruction techniques using a small number of LAPPD's
- Booster Neutrino Beam provides source of 1 GeV muon neutrinos and anti-neutrinos, allowing development of neutrino sign discrimination techniques using neutron yield
- ANNIE is a “sandbox” for the LBNF part of the THEIA program
- **If you are thinking about THEIA R&D for LBNF this is an optimal time to participate in the Run 2 proposal, as nothing is yet set in stone, and the chances of success with the FNAL PAC are very good**

ANNIE Run 2

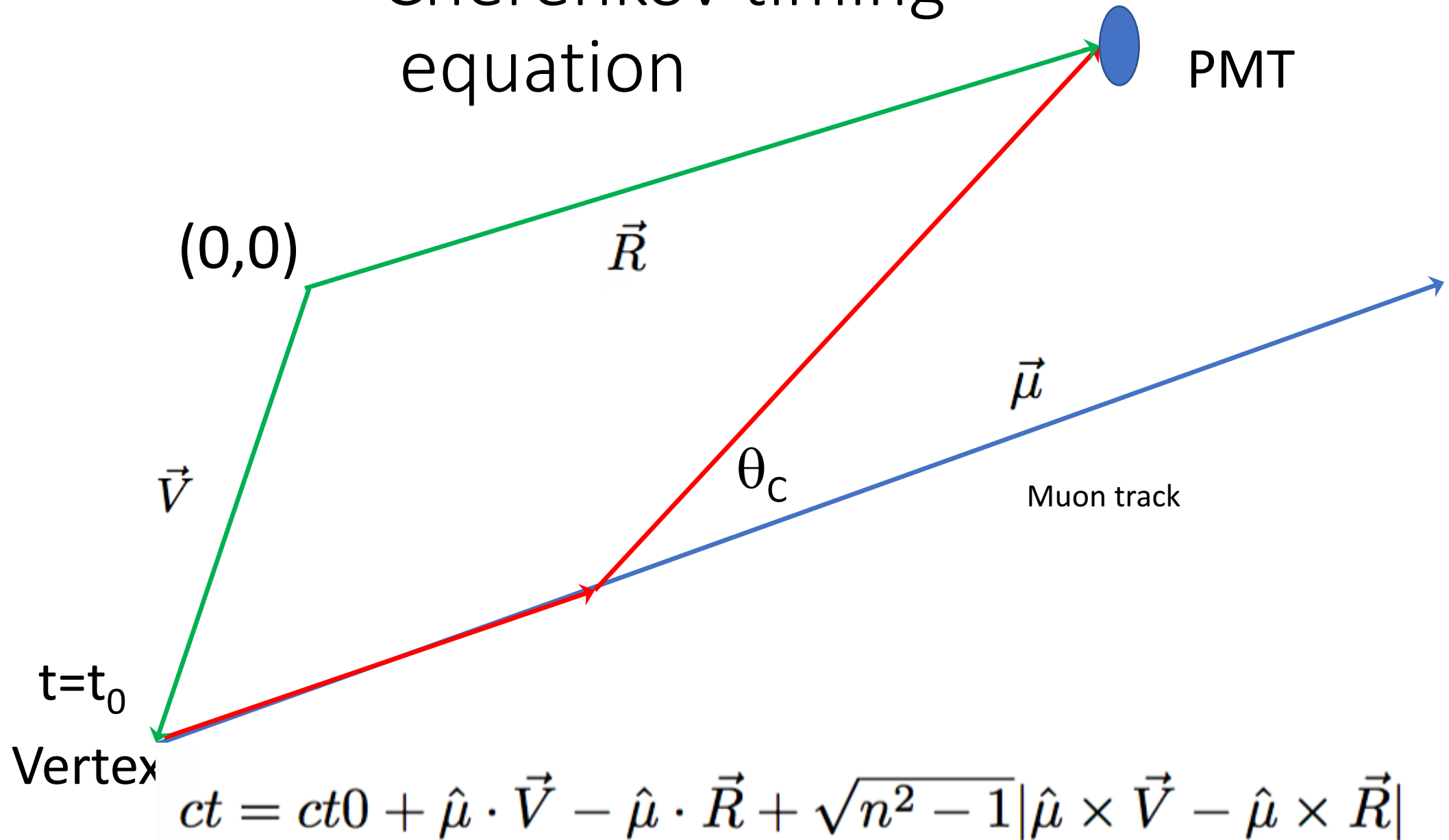
Importance of Vertex Resolution

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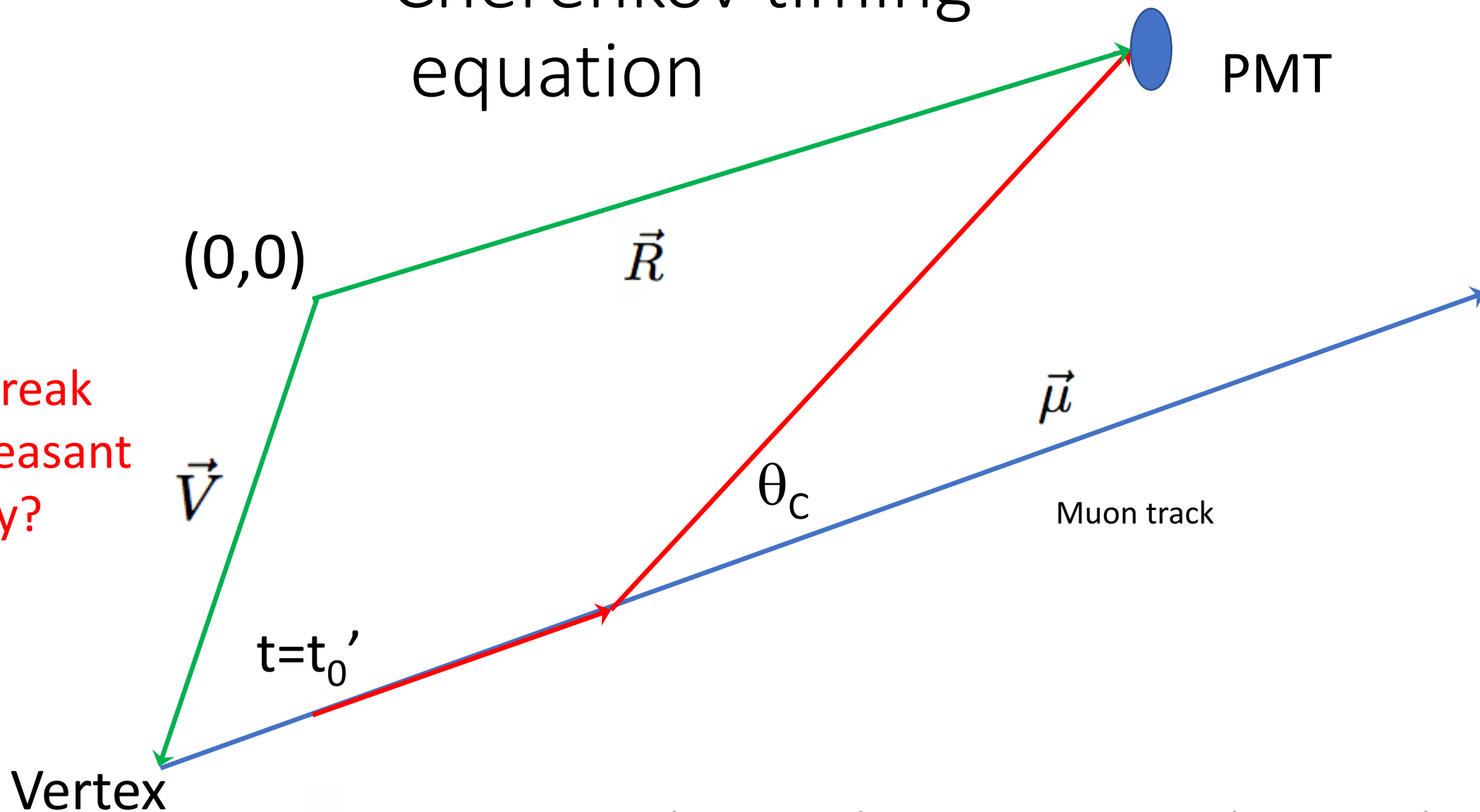


Cherenkov timing equation



Cherenkov timing equation

How to break this unpleasant symmetry?

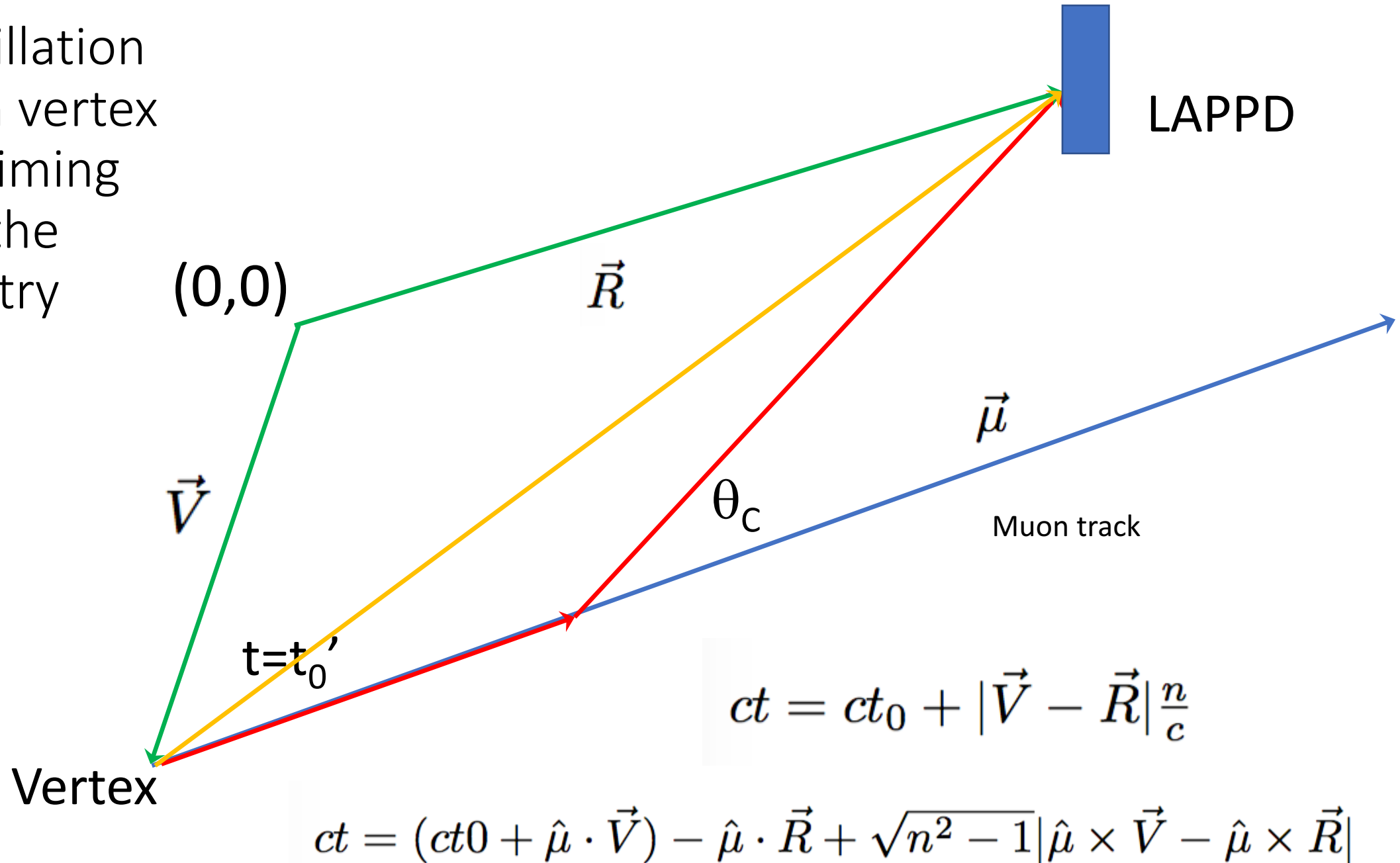


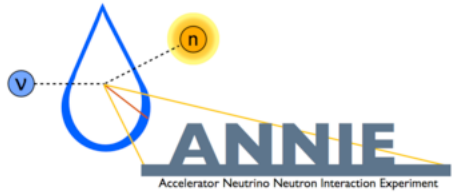
$$ct = (ct_0 + \hat{\mu} \cdot \vec{V}) - \hat{\mu} \cdot \vec{R} + \sqrt{n^2 - 1} |\hat{\mu} \times \vec{V} - \hat{\mu} \times \vec{R}|$$

Issues for vertex resolution

- If Cherenkov light only, then **must image the ring edge** to determine correct t_0 for timing. Need many pixels to do this precisely, as in Super-K.
- For ANNIE with LAPPD's the lateral timing will constrain the direction and perpendicular vertex uncertainty very well, but the uncertainty parallel to the track will still be an issue
- **One possibility is to have a Water-based Liquid Scintillator target**

Add scintillation
light from vertex
and fast timing
to break the
 t_0 symmetry

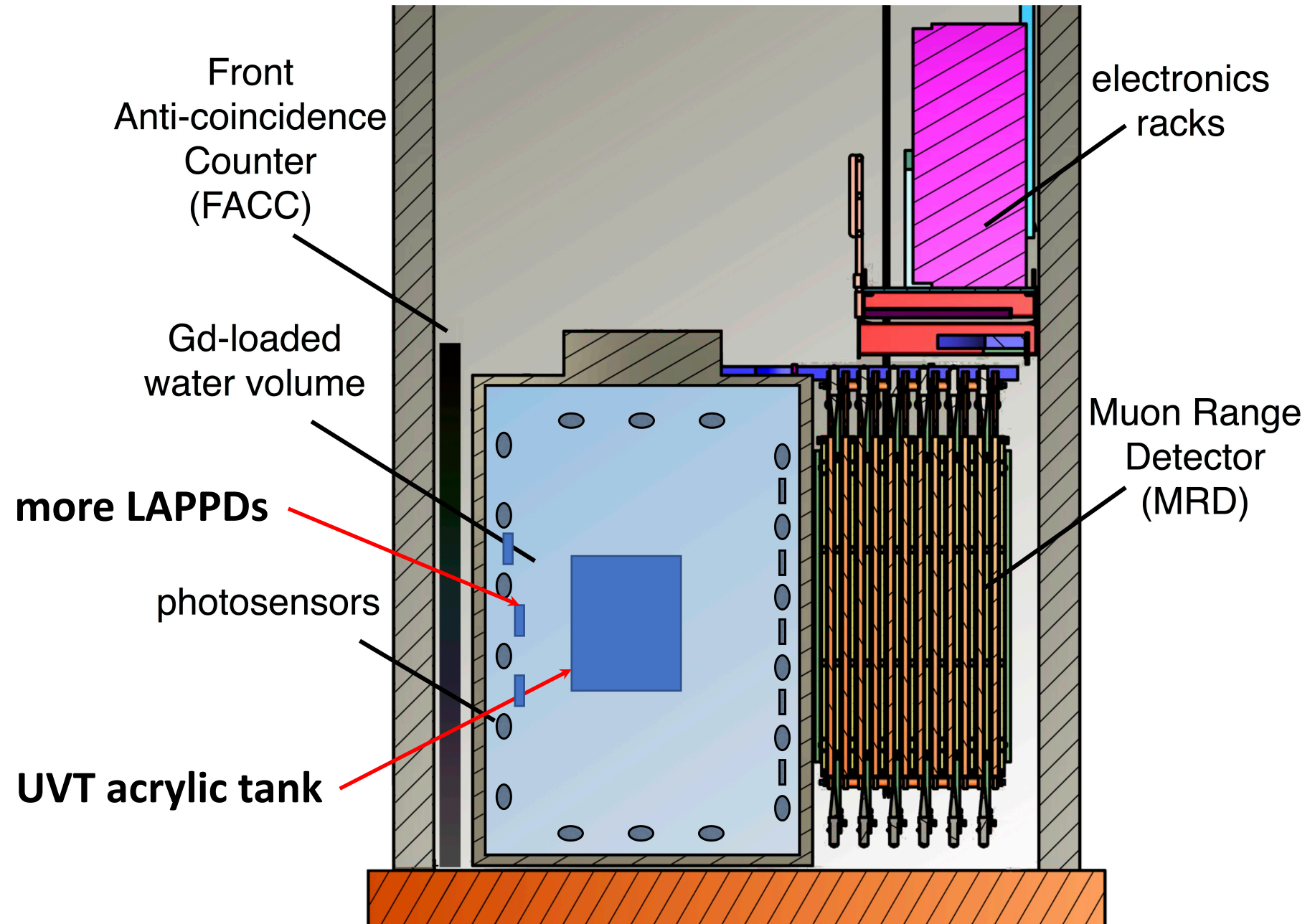


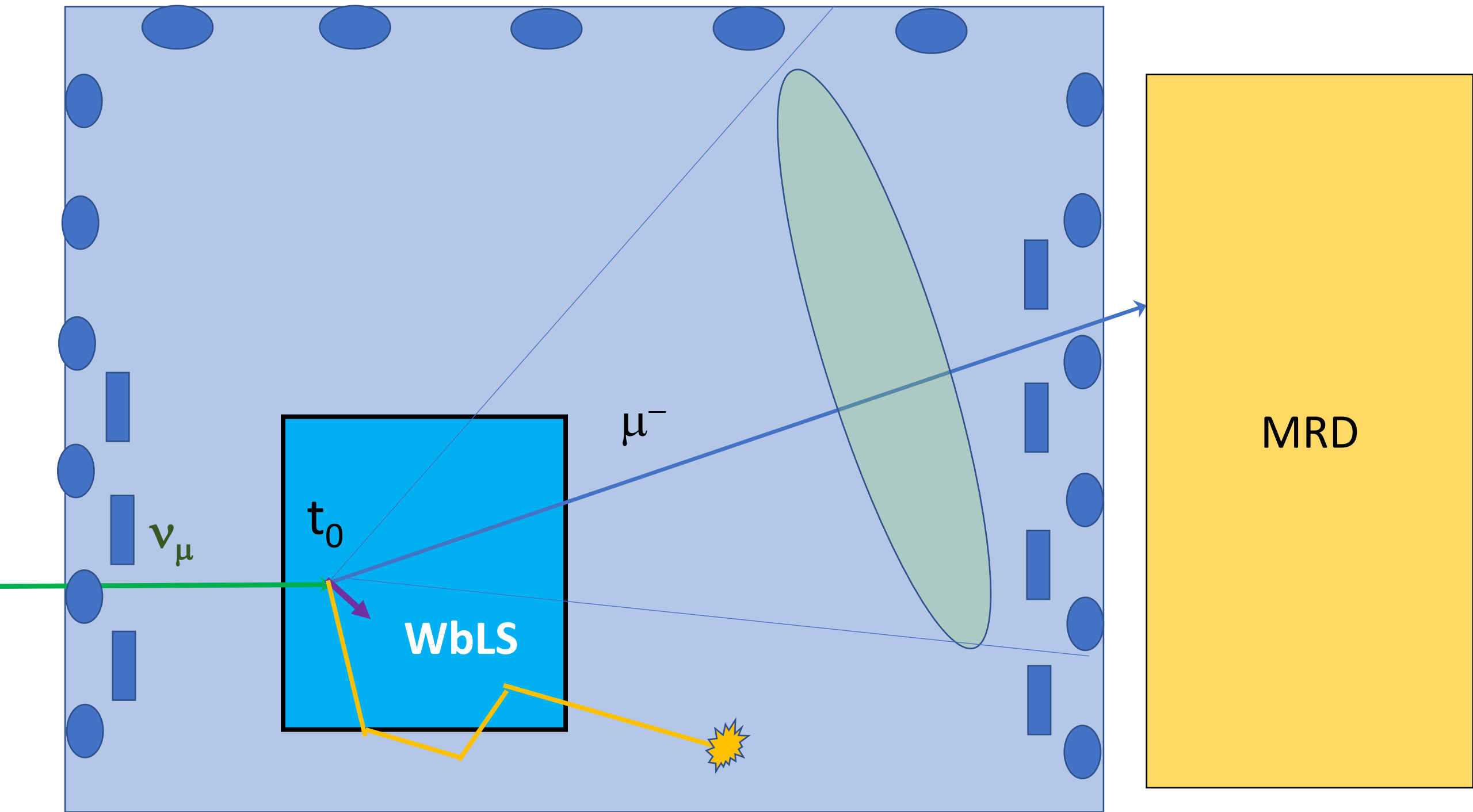


RUN 3A:

The addition of a WbLS target to ANNIE plus more LAPPD's would greatly extend usefulness to THEIA

Cost would be low and time scale would be quick





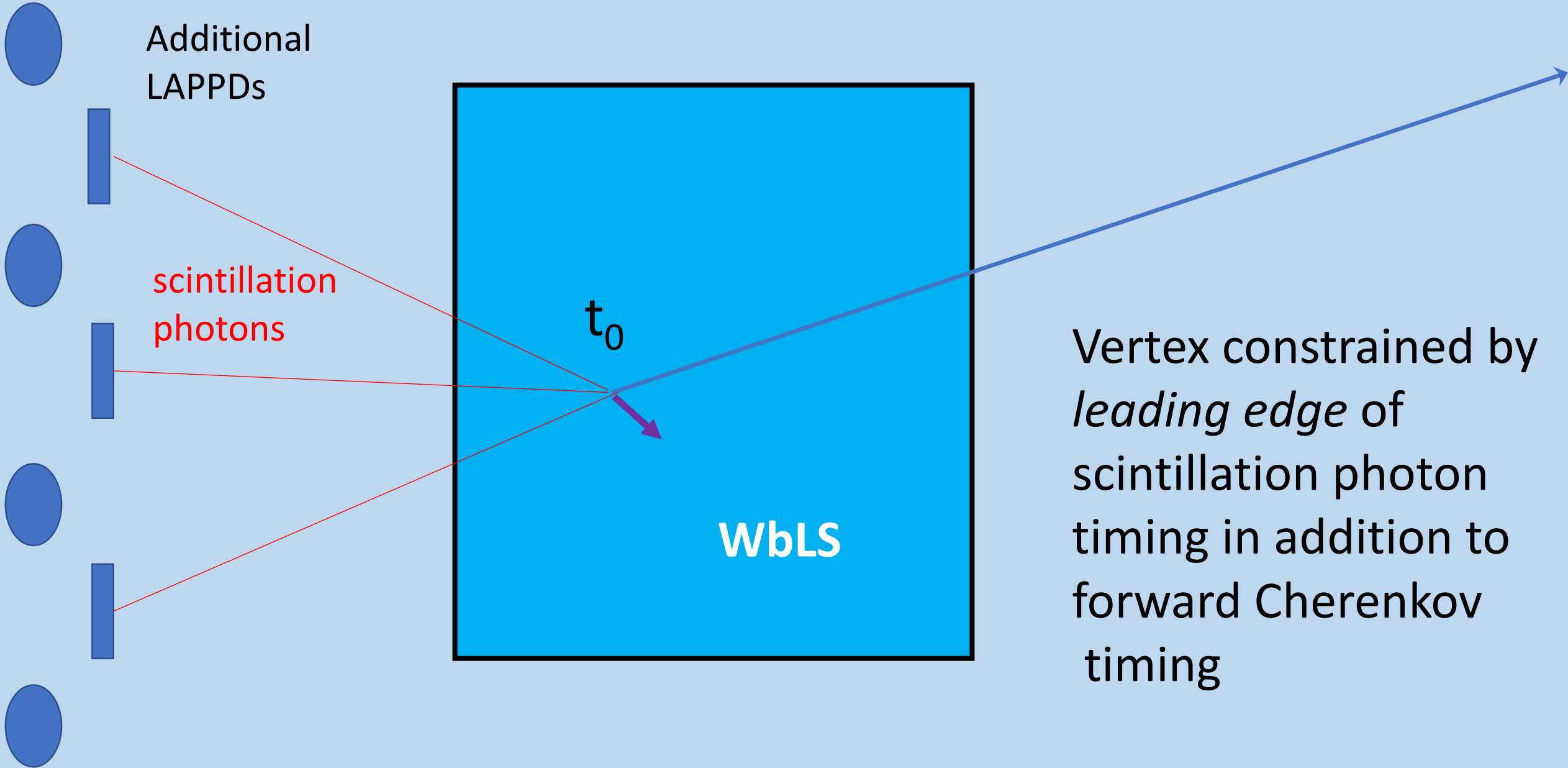
Additional
LAPPDs

scintillation
photons

t_0

WbLS

Vertex constrained by
leading edge of
scintillation photon
timing in addition to
forward Cherenkov
timing



Additional
LAPPDs



t_0

Vertex downstream of
the target has no WbLS
signal – only Cherenkov

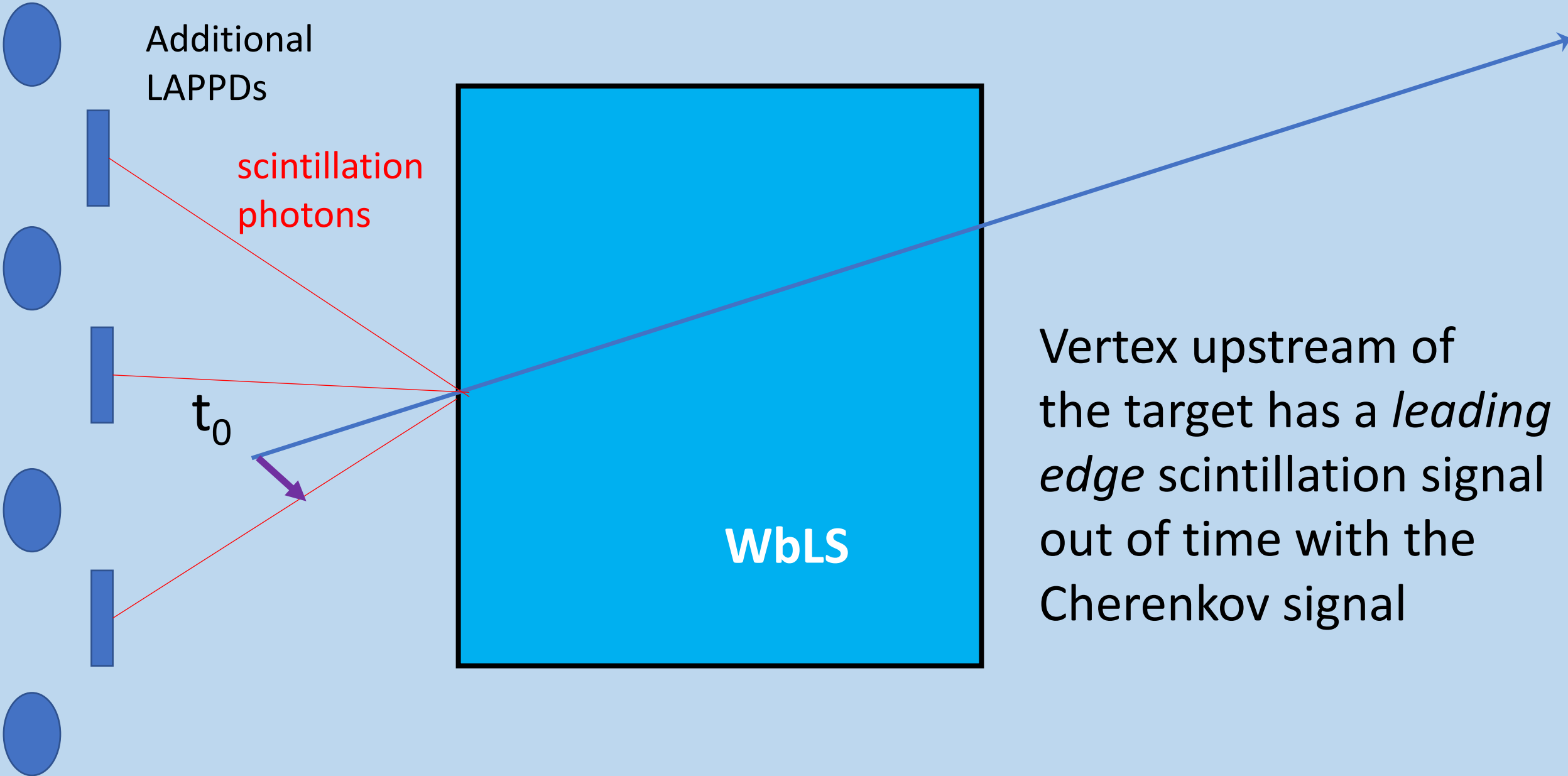
Additional
LAPPDs

scintillation
photons

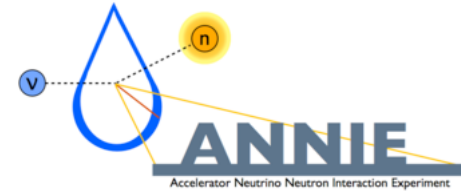
t_0

WbLS

Vertex upstream of
the target has a *leading
edge* scintillation signal
out of time with the
Cherenkov signal



ANNIE RUN 3A



- costs are only additional LAPPD's and holder, UVT acrylic vessel, and WbLS (about one ton) – perhaps less than \$200k?
- ANNIE Run 1 already set to handle 100 liter NCV, this would be about a factor of two larger target in linear dimensions
- Only need additional electronics for the additional LAPPD's
- Time to implement driven by LAPPD deployment and WbLS manufacturing time
- I would suggest a separate proposal to FNAL PAC and DOE following Run 2 proposal submission – but maybe good to mention in Run 2 proposal? TBD
- After this one can think of other possibilities if needed...

ANNIE RUN 3B?

- Perhaps fill ANNIE completely with WbLS or ObLS?
- material compatibility
- recirculation design and prototyping
- carbon target studies if ObLS
- test a small balloon?
- fast PMTs?
- Advanced LAPPD housing
- Once the “sandbox” is in place, very inexpensive to operate and available to THEIA R&D

