Proposed ^

Dark Photon Search in e+e- Annihilation

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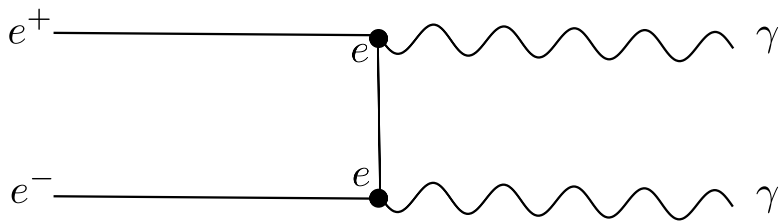
New Frontiers in Dark Matter and Dark Force Experiments

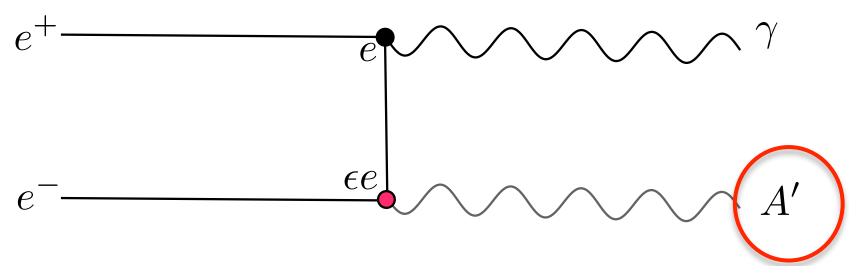
APEX Collaboration Mtg, April 19, 2015

Searching in the annihilation channel

Standard Model



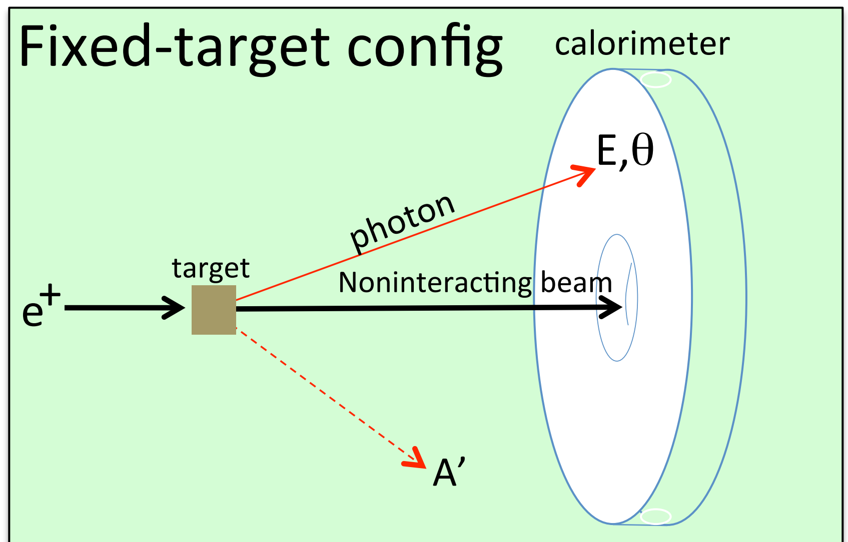
Dark Model



- *Missing mass* search:
  - Independent of A' decay mechanism
  - Bump hunt
  - Limited by sqrt(s)

$$M'_A < \frac{1}{2}\sqrt{s} \approx \sqrt{m_e E_{beam}/2}$$

  - 5 GeV beam: $M_{A'} <$ 71 MeV
- Need positrons
- *This is the basic idea for the A' search at Cornell.*

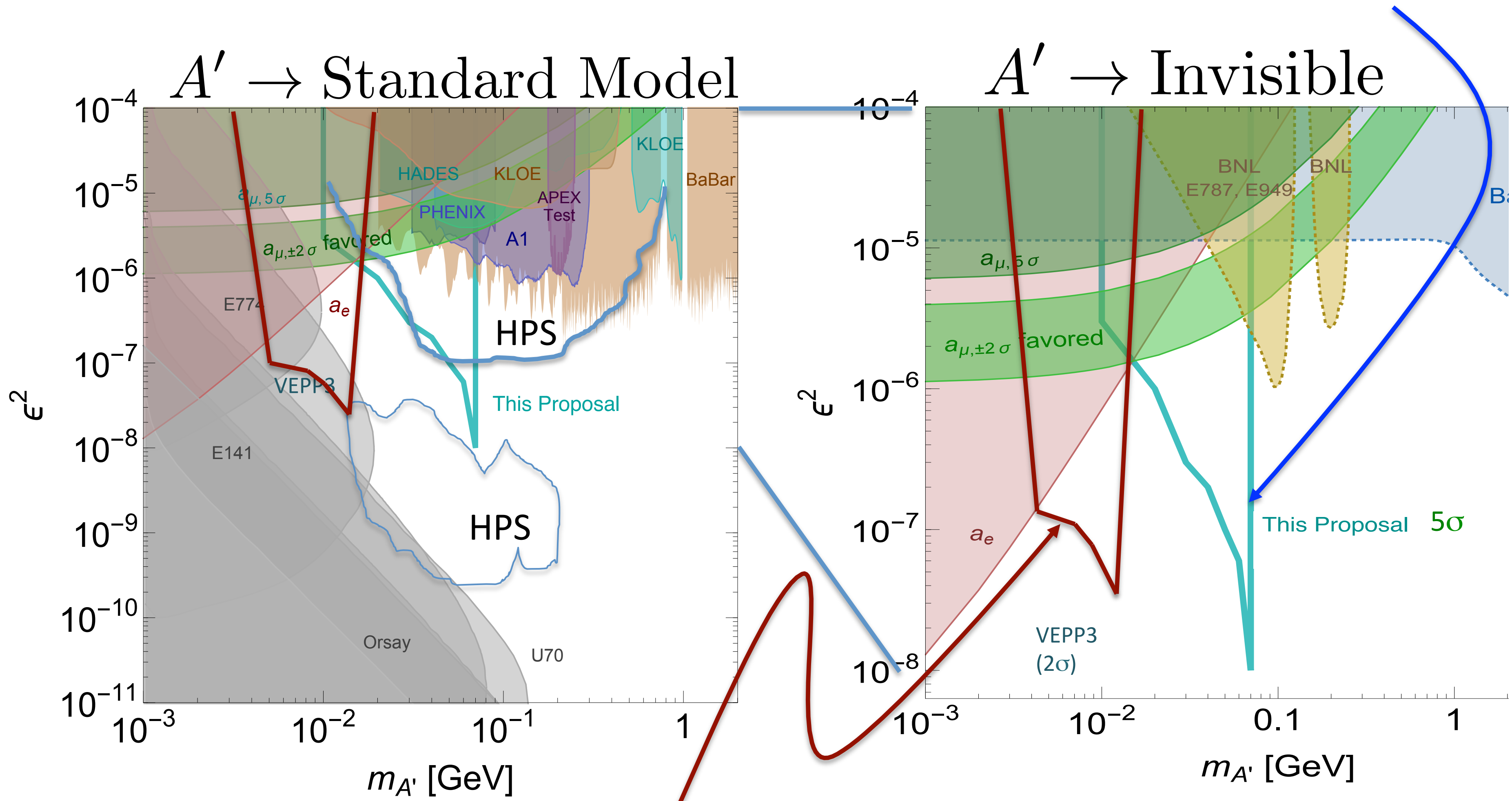


In this proposal:
E > 15 MeV
$2^o < \theta < 5^o$

Estimated reach for expt at Cornell

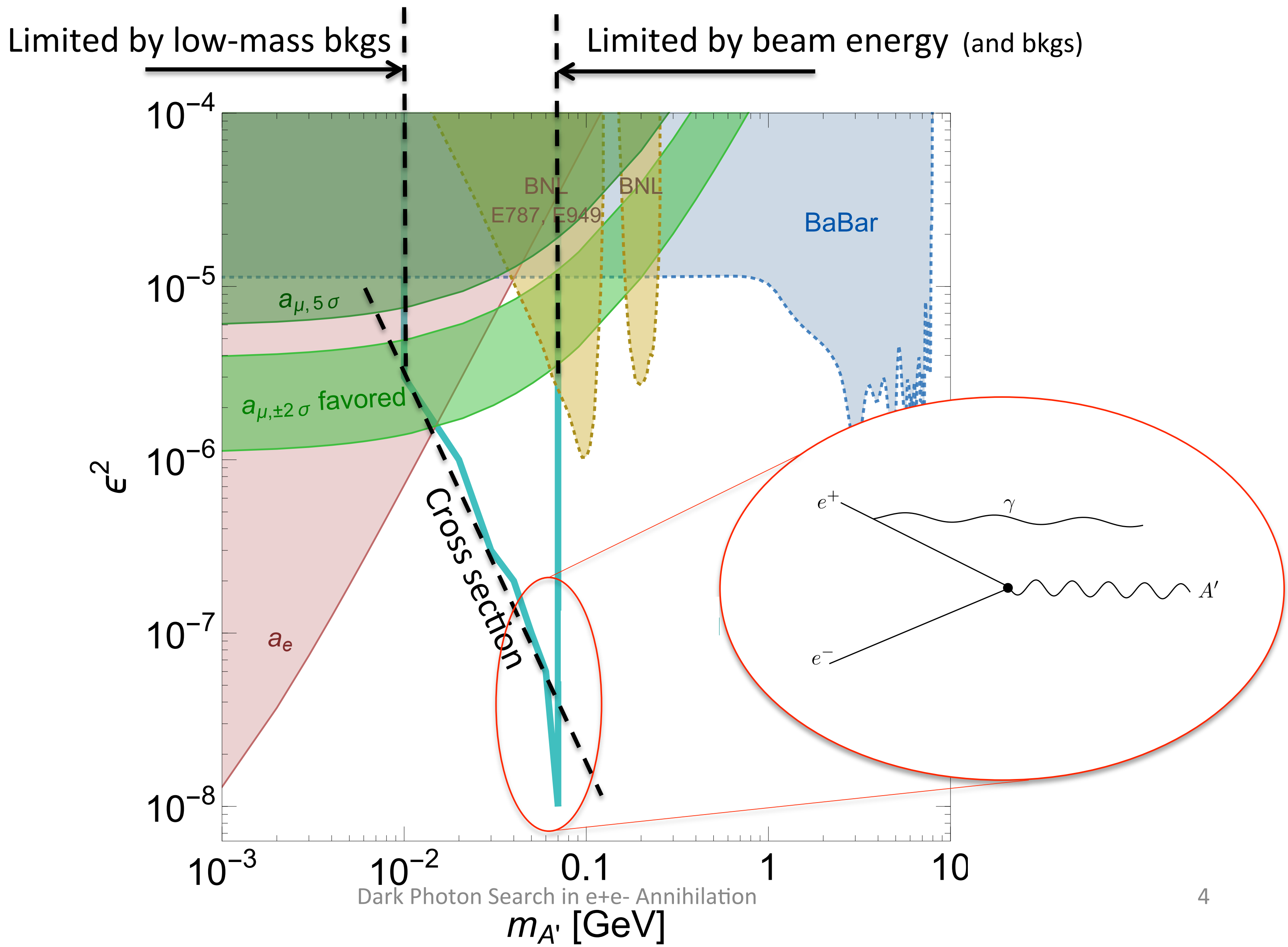
Based on GEANT4 simulation with all bkgs and pileup included

E_{beam}=5.3GeV, I^{avg}_{beam}=2.3nA, Lumi = $1.0\text{x}10^{34}$, T = 10^7sec, 5-sigma excl



“Sister experiment” at Novosibirsk (proposed)

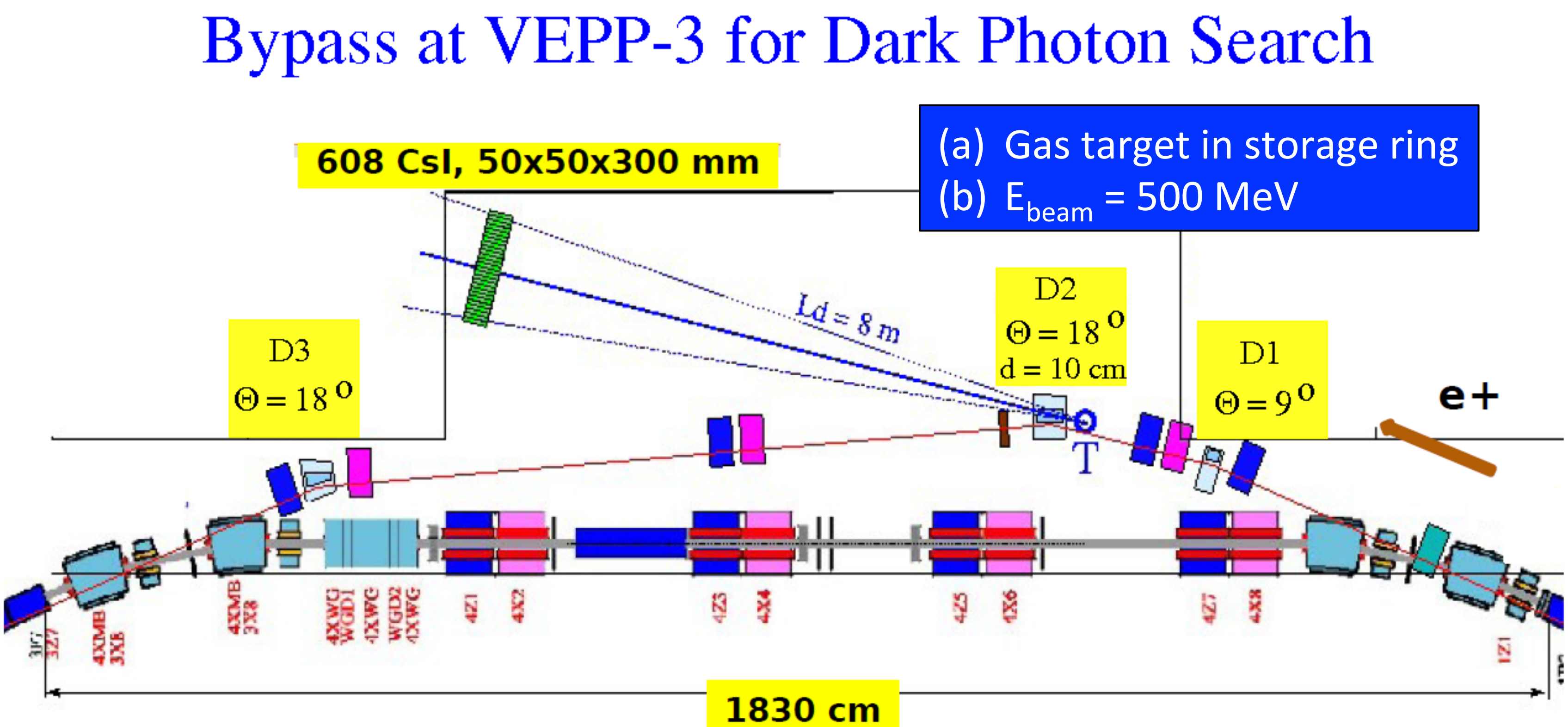
Estimated reach - Interpreted



Cornell plan inspired by VEPP-3 Proposal

Internal target in e+ storage ring

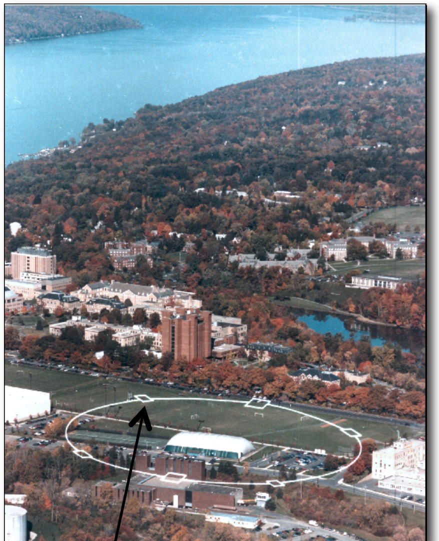
arXiv:1207.5089
Wojtsekhowski,Nikolenko,Rachek



(a) Gas target in storage ring
(b) E_{beam} = 500 MeV

Discussions with Bogdan Wojtsekhowski led to the design of related expt at Cornell

(a) Fixed target in extracted beamline
(b) E_{beam} = 5300 MeV

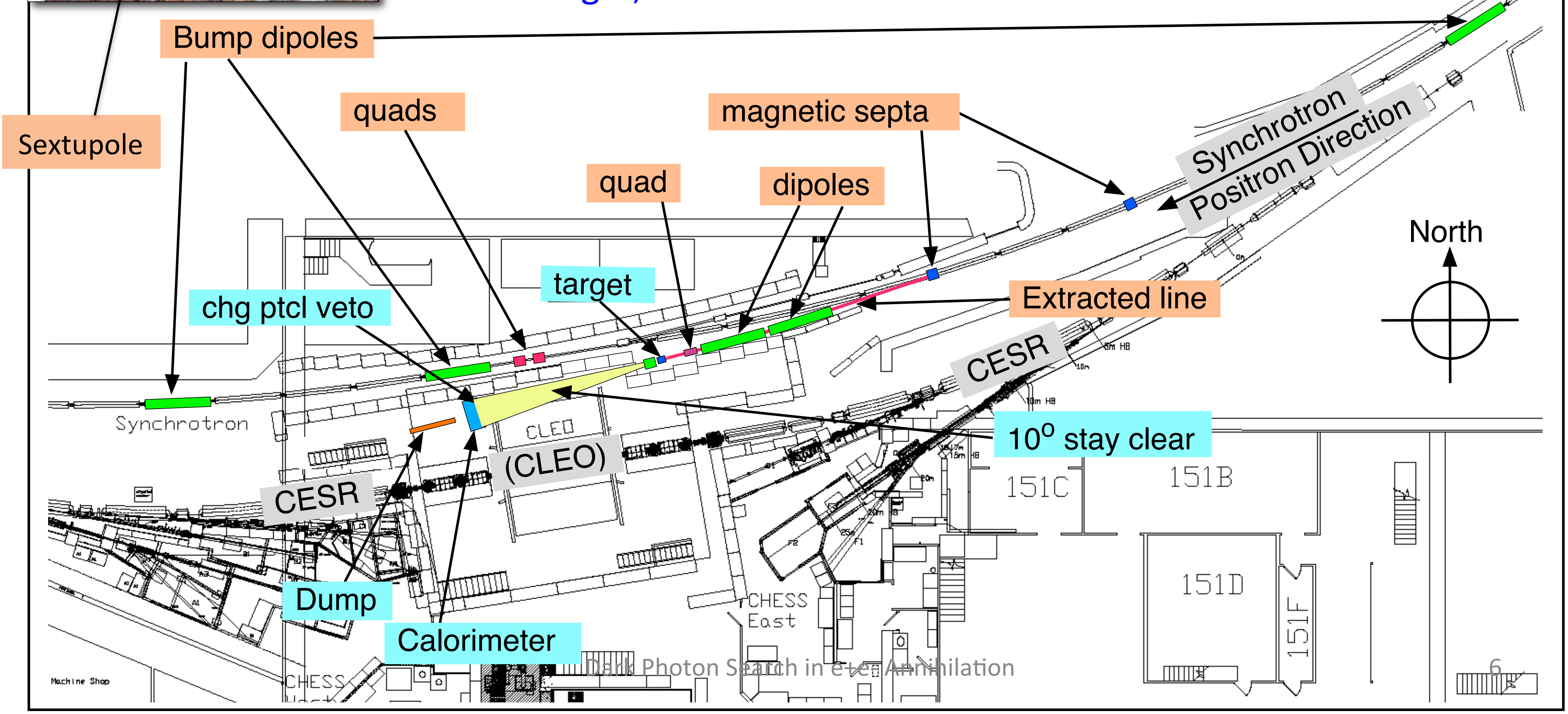


Cornell Proposal (e+e- → γA')

Extract positron beam from synchrotron (between CESR fills for xray program)

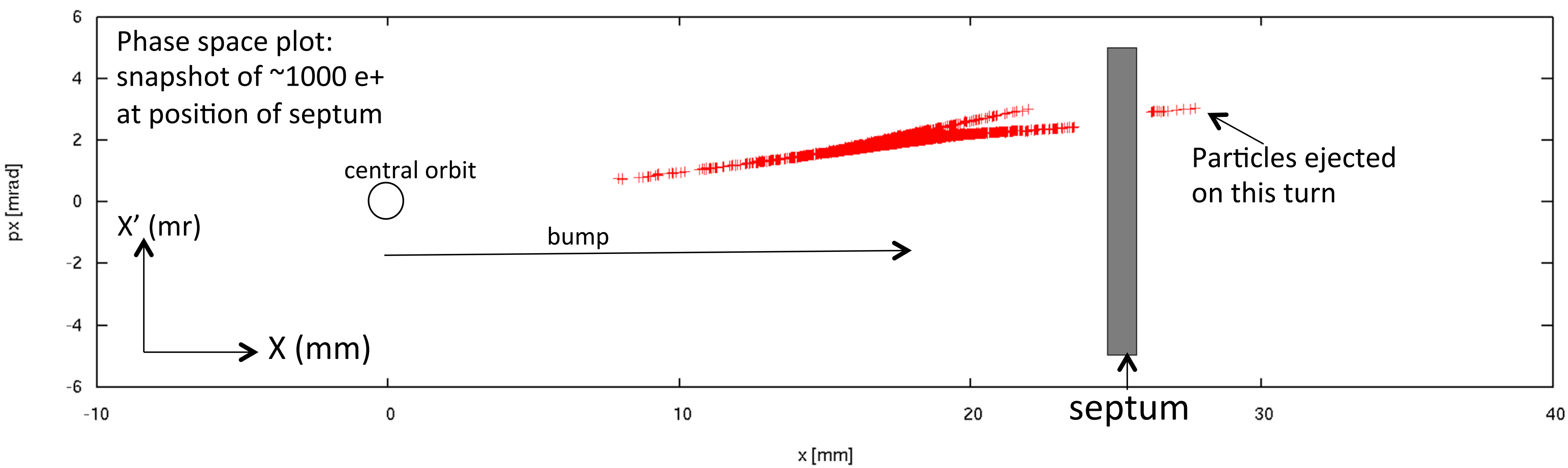
- E_{beam} = 5.3 GeV
- I_{beam} ~ 2.3 nA at target
- quasi-CW during ~millisecond spills @ 60Hz
- pulse structure: ~160ns

Fixed target, calorimeter 10m downstream.



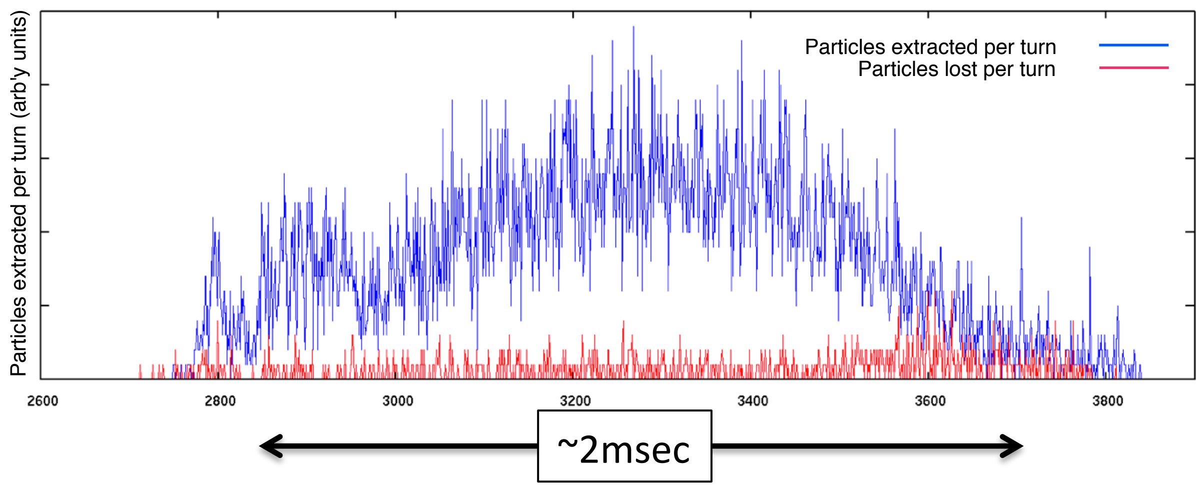
Resonant extraction from synchrotron

- Synchrotron: 60 Hz acceleration cycle:
  1. Linac loads the synchr with ~16 bunches of e+ (~10^9 e+)
  2. Accelerate to 5.3 GeV
  3. Gradually "dribble out" over ~2milliseconds
- The dribble:
  - Pulse quads: 10.65 tune → 10 $^2/_3$ ➔ resonance
  - Pulse sextupole: reduce stable phase space
  - particles spiral outwards, septum picks them off gradually
- Similar scheme used in 1970s for fixed target work at Cornell (pre-CESR/CLEO)
- BMAD simulations shown below:



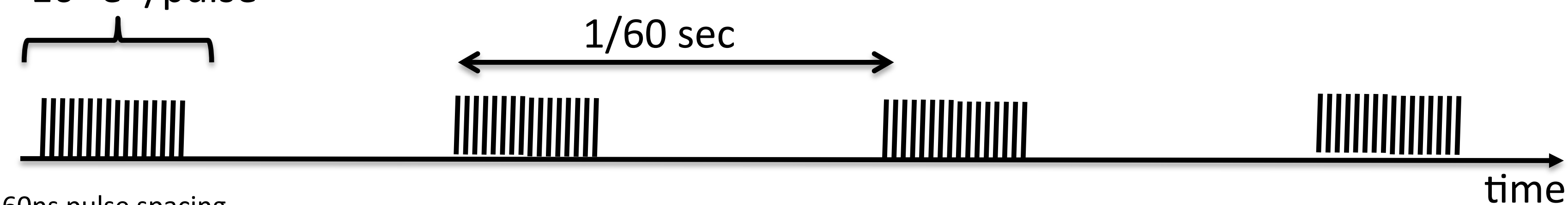
Characteristics of extracted beam

Extracted Yield vs time (single spill)



Beam structure:

~10^4 pulses extracted,
~10^5 e+/pulse



~160ns pulse spacing

Target: LH2

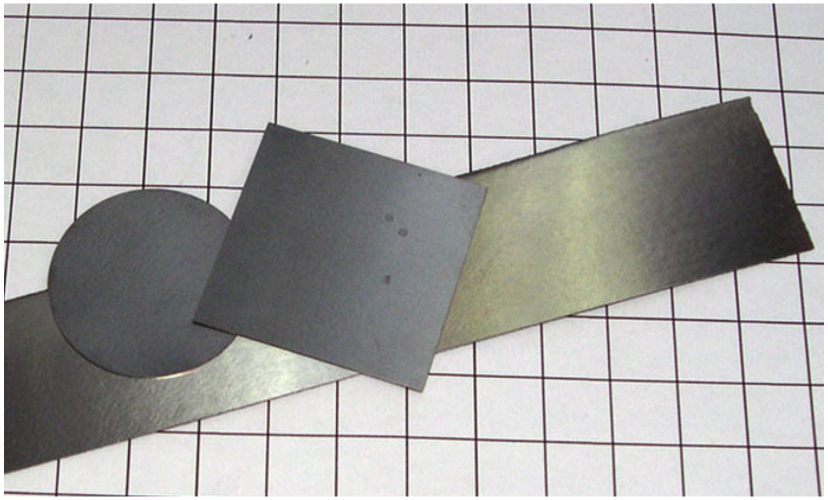
- LH2 target
  - on loan from University of Lund
- Length: 15cm
  - Volume 0.5 liter
  - Heat load from 2.3nA beam = 0.7W << cooling capacity
- Compact
- For beam characteristics on previous slides, we expect:

$$\mathcal{L}_{avg} \approx 10^{34}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

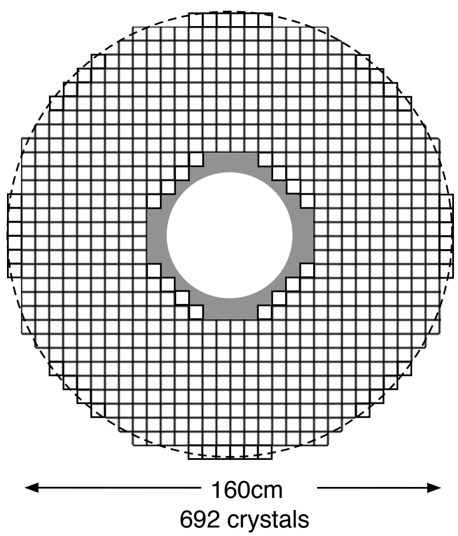
$$\mathcal{L}_{pk} \approx 10^{35}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

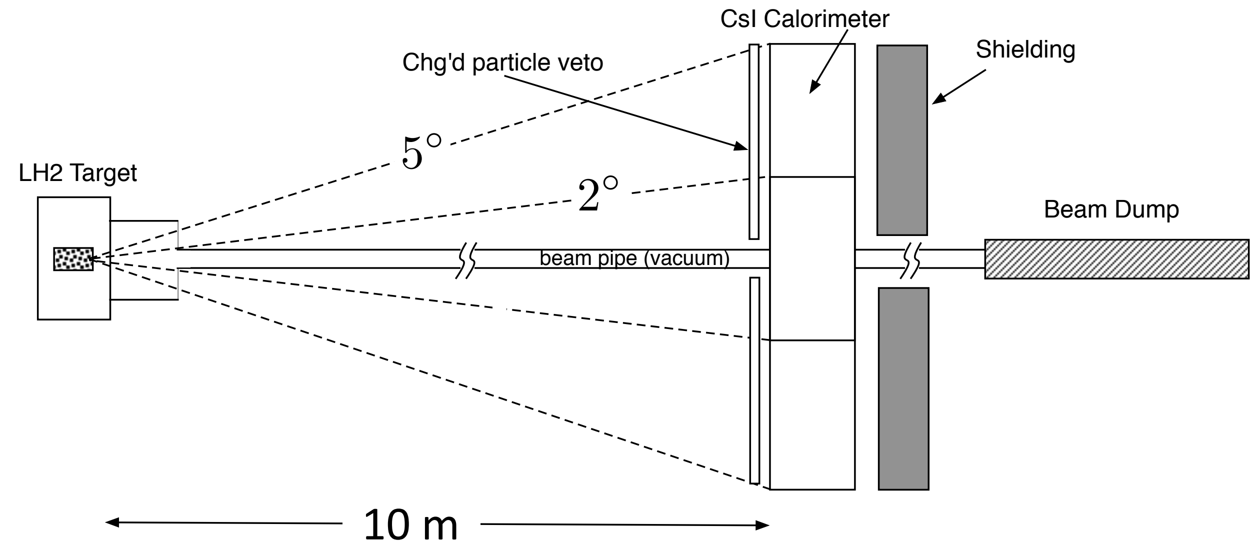
Alternative Target: solid Be sheet

- LH2 motivated by Z^2 dependence of bremsstrahlung cross section
- But simulation → bremsstrahlung is a small component of bkg.
- Dominant components
  ($e^+e^-\gamma,\gamma\gamma,\gamma\gamma\gamma$) scale with Z
- Simplicity & convenience
- Cooling? Needs study/ design



The detector ("baseline" design)



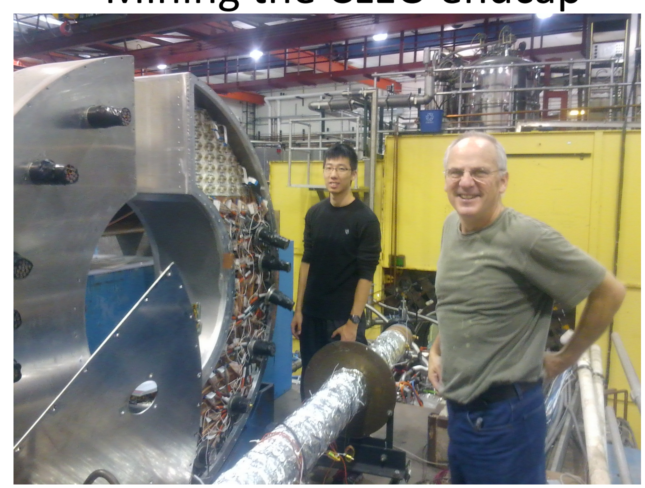


- CsI(Tl) crystals salvaged from CLEO, reconfigured
- Photodiodes and preamps also salvaged from CLEO*
- Dipole sweep magnet after target (not shown)
- Charged particle veto (scintillator)

Typical photon energy: 50-500 MeV

(Missing mass)^2 resolution depends mainly on E_{photon} resolution

Mining the CLEO endcap



* alternatives under consideration

Simulations

Focus on evaluating bkg rates

From largest to smallest:

Cross section X detector acceptance (2°-5°) $2\pi \int_{2^\circ}^{5^\circ} \frac{d\sigma}{d\Omega} \mathcal{A}(\theta)\, d\theta$

1.	Radiative Bhabha	160μb	$e^+e^- \to e^+e^-\gamma$	MadGraph
2.	2-photon	44μb	$e^+e^- \to \gamma\gamma$	GEANT4
3.	3-photon	12μb	$e^+e^- \to \gamma\gamma\gamma$	MadGraph
4.	Bremsstrahlung	3μb	$e^+p \to e^+p\gamma$	GEANT4 (mod)
5.	Inelastic	~1μb	$e^+N \to e^+N' + \text{hadrons}$	GEANT4

Signal cross sectionXAccept = 156μb x ε^2

Each of these bkgs can put a single photon in the detector, with the extra particles lost down the central beam hole

Many cross-checks on generators (MG vs theory, GEANT4 vs MG, GEANT4 vs data…)

Detector simulated with GEANT4

Lab-frame Kinematics

We observe: E,θ of one photon.

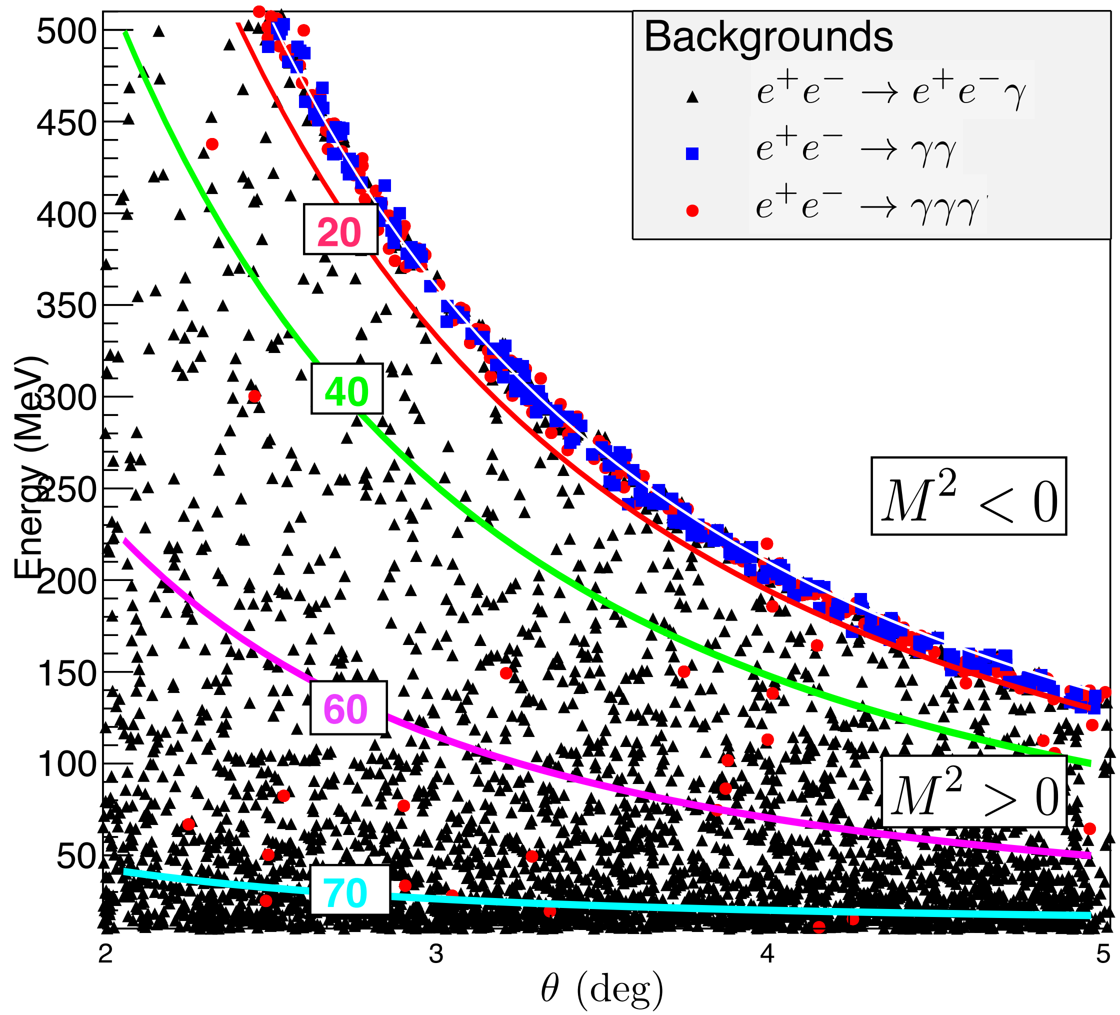
For 2-body processes ($\gamma\gamma$, $\gamma A'$) only one free parameter: θ_{CM}

➔ E,θ correlated in lab:

For other non-2body bkgs, E,θ not correlated

Interpreting each photon as γX, lines of constant M_X are shown:

Photon Energy (E_{Lab}, MeV) versus angle (θ_{Lab}, degrees)



The next-to-bottom line in one plot

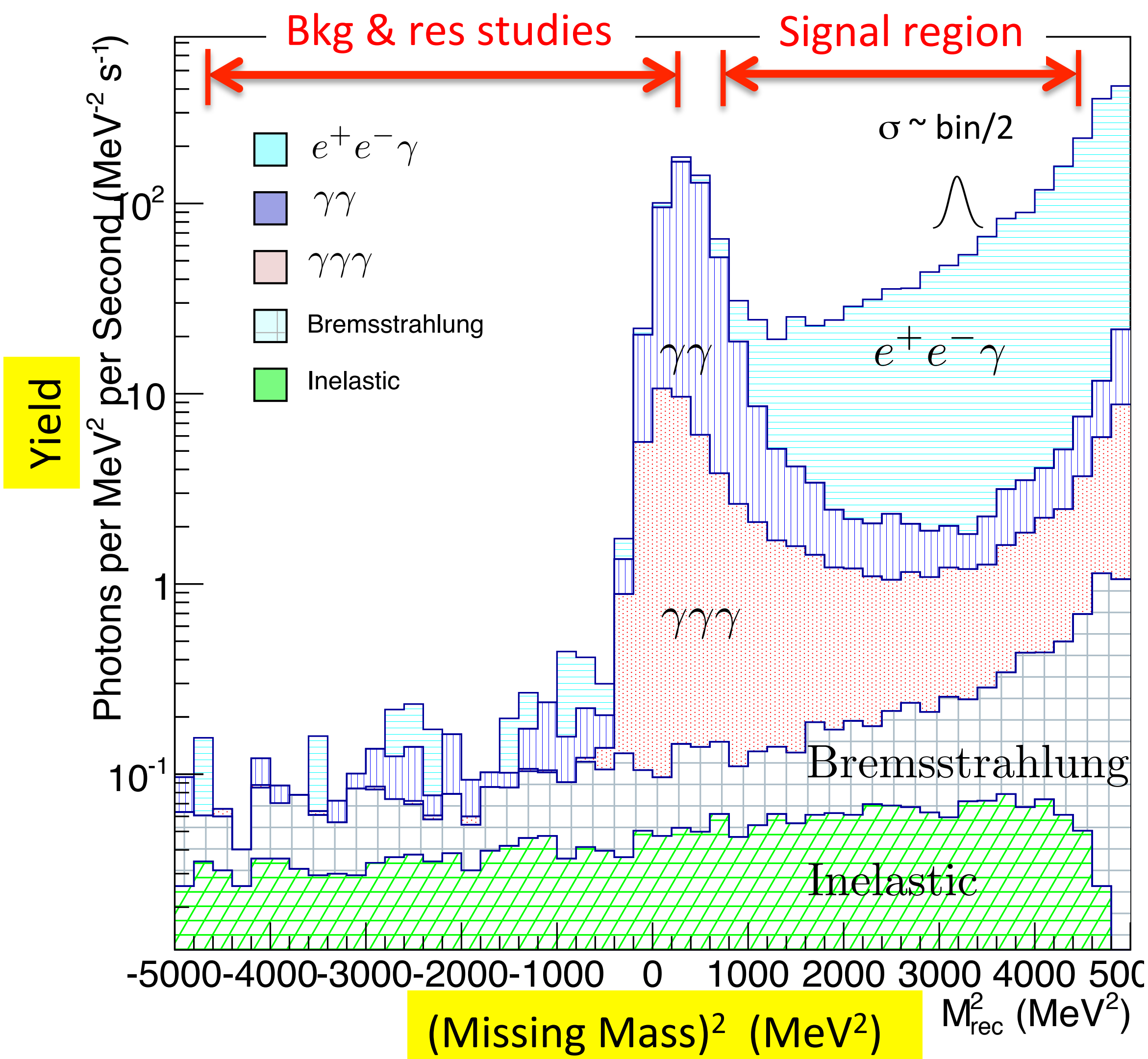
Mass resolution is critical:

(a) Maximize significance of peak in bump hunt

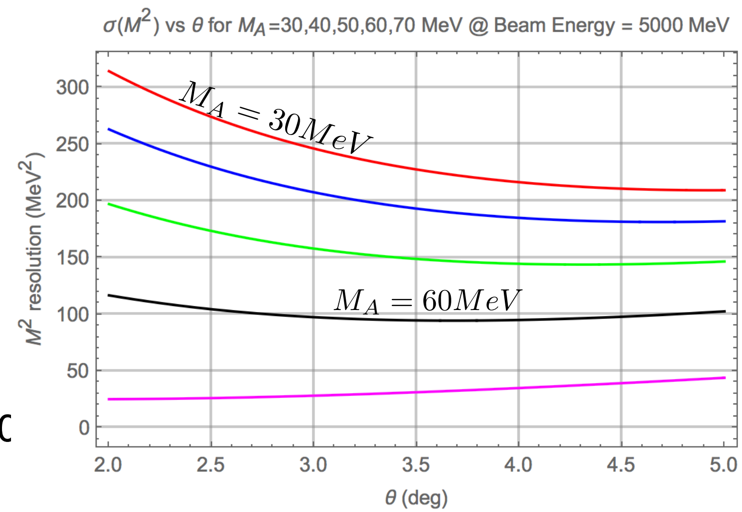
(b) Minimize background leakage into signal region

$$\text{F.O.M.} = \frac{S}{\sqrt{B}} \propto \frac{\sqrt{\mathcal{L}\,T\,\mathcal{A}}}{\sigma_{M^2}}$$

Luminosity (L)
Length of run (T)
Acceptance (A)
(Missing mass)^2 resolution



(missing mass)^2 resol. vs θ.



Photon Energy Resolution

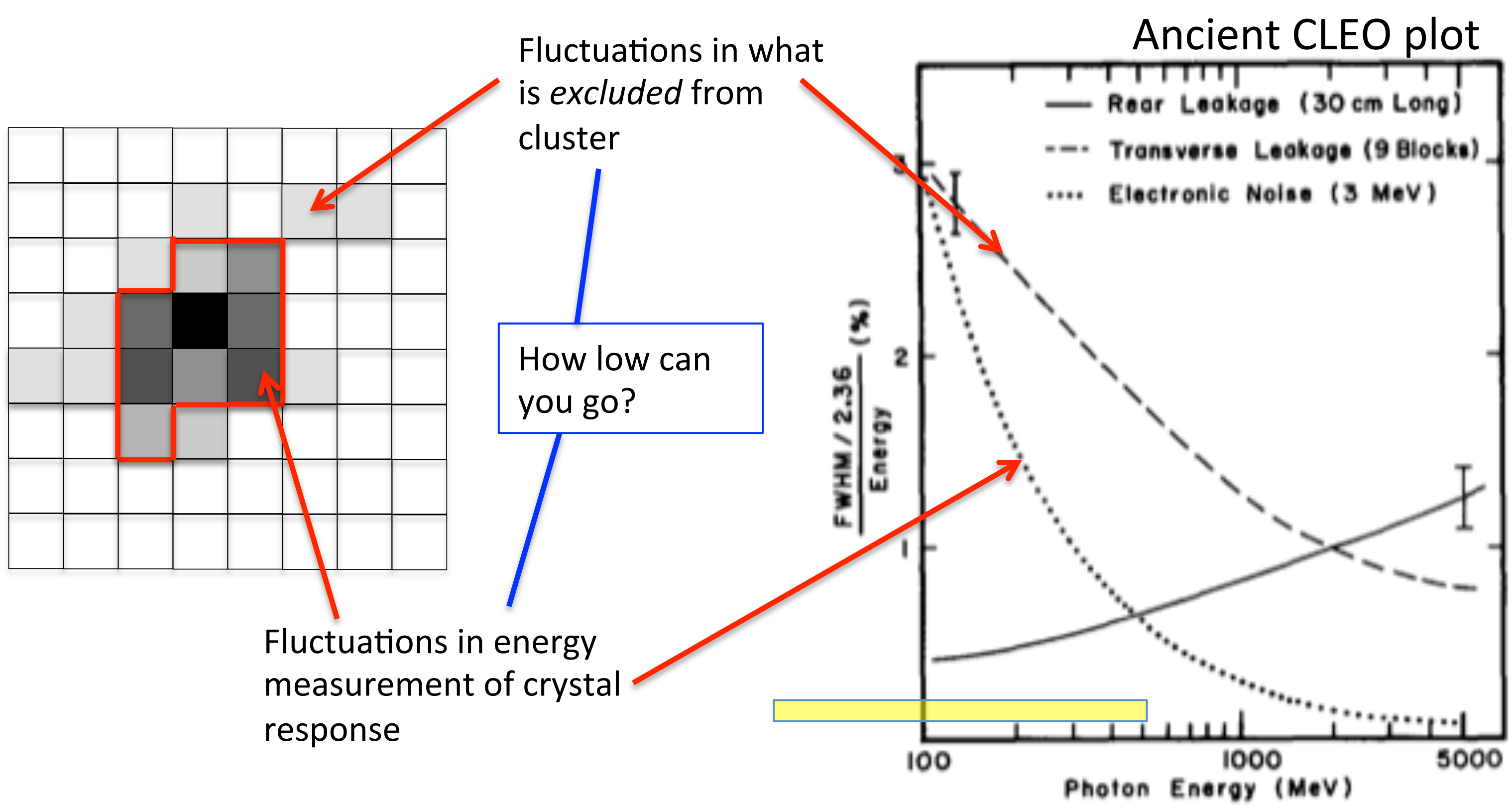
Crucial: determines (missing mass)^2 resolution

Two main contributions:

(a) fluctuations in how much energy is recovered

(b) electronics noise

These are further correlated by clustering algorithms



Photodiode Issues

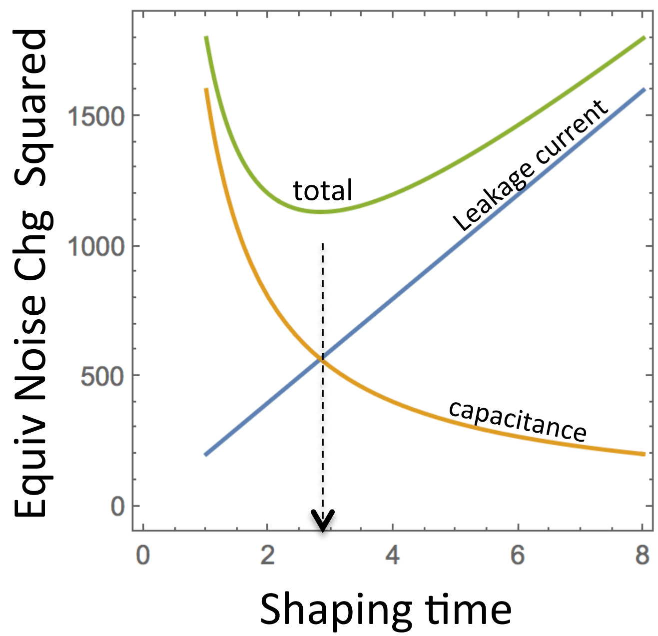
CsI(Tl) in CLEO: used photodiodes to detect scintillation; still attached to xtls

- photodiodes have large capacitance and non-trivial dark current
- Implies shaping times ~ 3us. *Very long for high rate expt.*

Also- CsI(Tl): 1us tail

Now investigating phototubes

$$ENC^2 = \alpha\, I_d\, \tau \;+\; \beta\, C_d^2\, \frac{1}{\tau}$$



Ancient CLEO plot

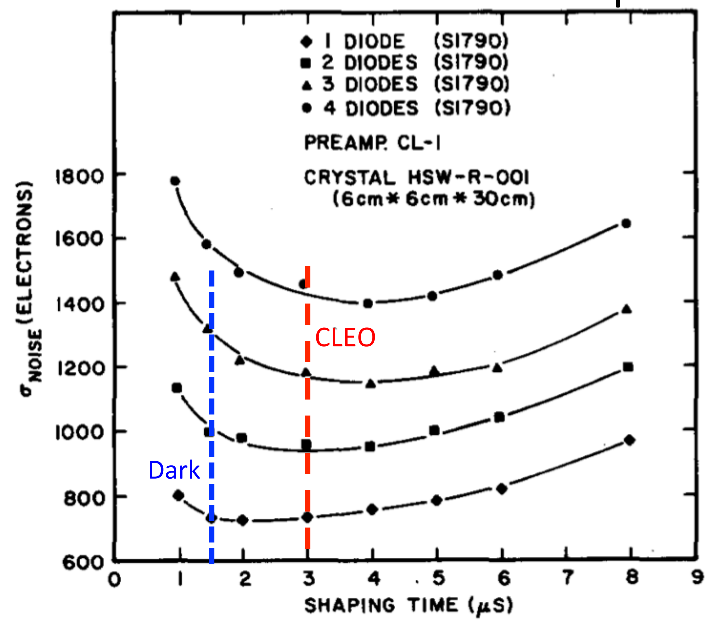
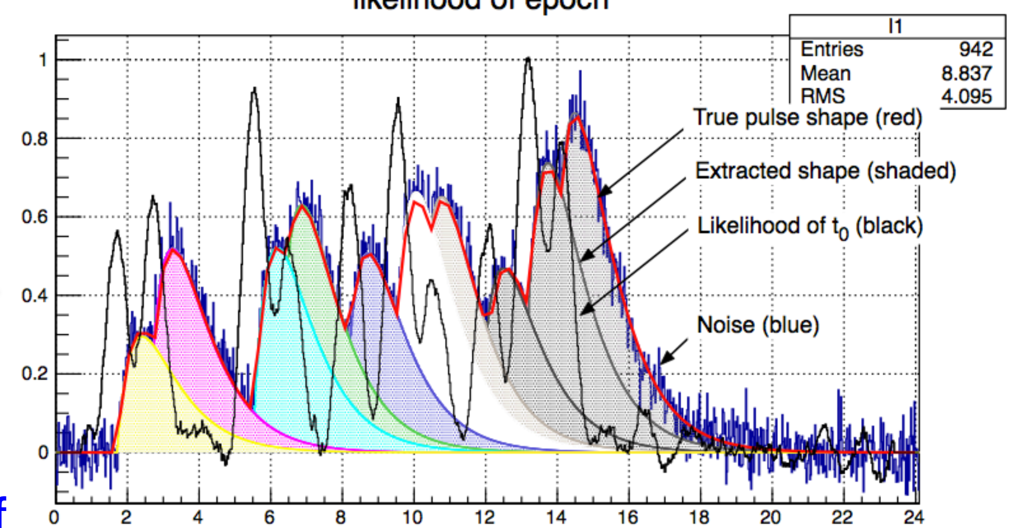


Fig. 15. Rms equivalent noise charge as a function of the shaping time for 1, 2, 3 or 4 photodiodes at the input of the preamplifier CL-1.

Pileup

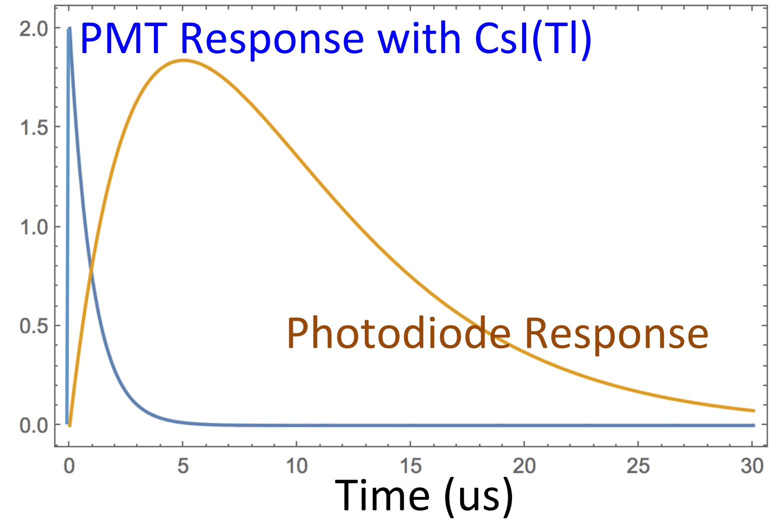
- Pileup == # photons in detector "at same time"
- "at same time" == $\tau \sim 2\mu s$ (CLEO photodiodes, CLEO shaping time/2 + 0.5us)
- At max luminosity: pileup~26 photons $\propto \mathcal{L}\tau\,(\Sigma\sigma_{bkg}\mathcal{A})$
- Scary! But:
  - Most of these are soft <30MeV ➔ 1,2-xtl clusters: minimizes overlap prob
  - Pileup algorithm: depends mainly on rise time
  - PMTs: fast rise=> small τ (x0.1)
  - Can dial down beam intensity if necessary…

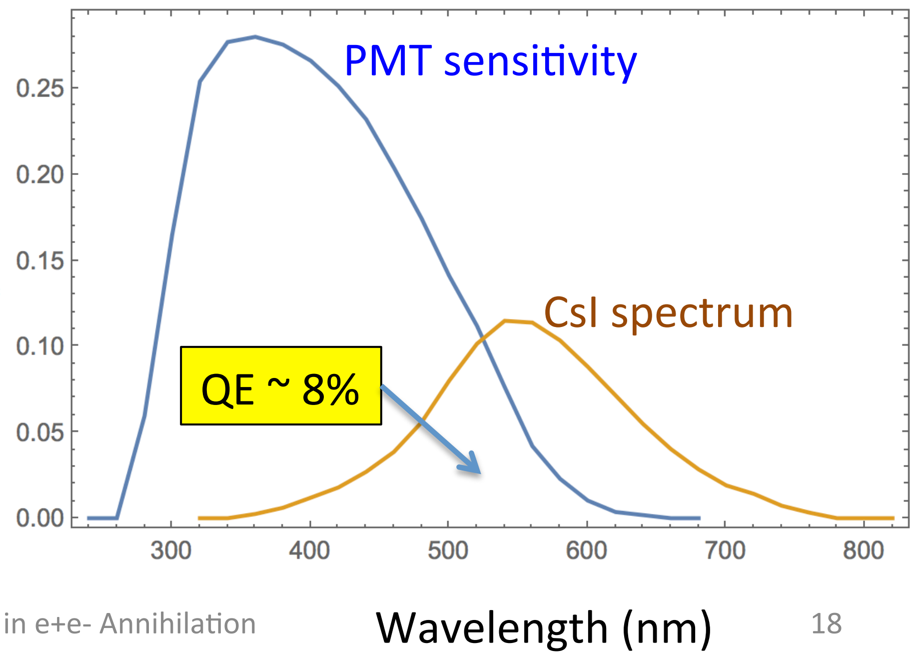
Photon signals piling up;
Disentangled by algorithm



Phototube Issues

- Advantages of PMT readout:
  - Fast rise time: ameliorate pile-up issues
  - Low-noise amplification
- Bogdan has large supply of PMTs from Babar DIRC
- ET-9125B
- Disadvantages:
  - Low QE → statistics of photoelectron production become significant
- Empirical studies needed; choice not made yet





Thinking beyond the baseline

- Are PMTs a better choice than photodiodes?
  - Naively, yes…
    - Faster rise time → mitigates pileup problems (x10??) max
  - Babar DIRC PMTs in storage at JLab. ~~Now~~ Soon! testing at Cornell.
- Solid target (Be instead of LH2)?
  - Largest bkgs scale with Z; only bremsstrahlung scales with Z^2.
  - Easier, cheaper
  - Higher lumi with fewer e+ needed
- Beam energy scan?
  - Objective: smooth out the exclusion reach versus $M_{A'}$ curve
  - Synchrotron has routinely run at 1.8 GeV (ILC studies): $M_{A'} < 40$MeV
  - Details not studied yet
  - Natural beam energy scan

- Many issues to study (while we wait to hear about funding)