Dark Photon Search in e+e- Annihilation

MMAPS = Missing Mass A-Prime Search

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Bad news first:

Bad news first:

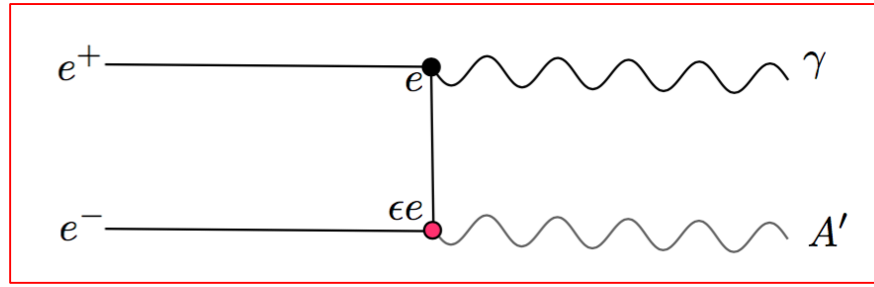
We learned last week that the NSF decided not to fund this experiment.

The Cornell Lab management is supportive, however. The experiment could go ahead if alternative funding arrangements were found.

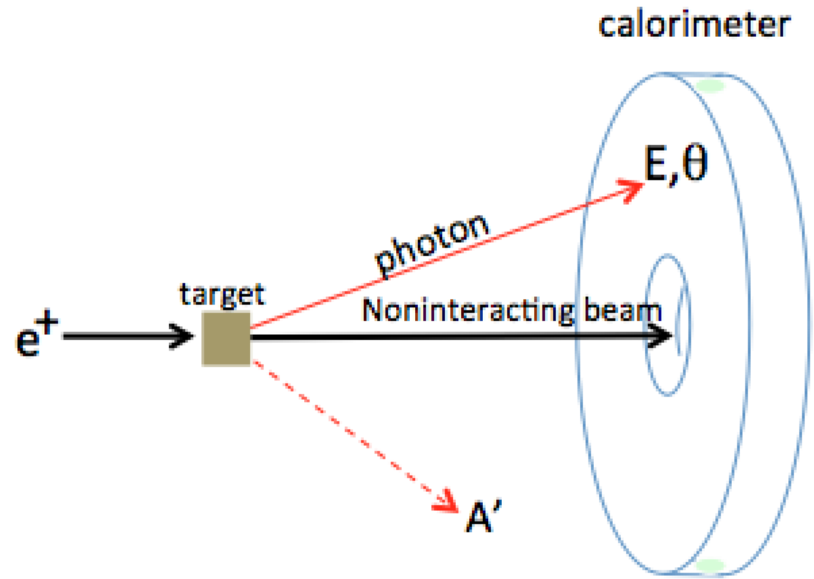
More discussion of this on the last slide.

Experimental concept in one slide

Process of interest:



Hardware:



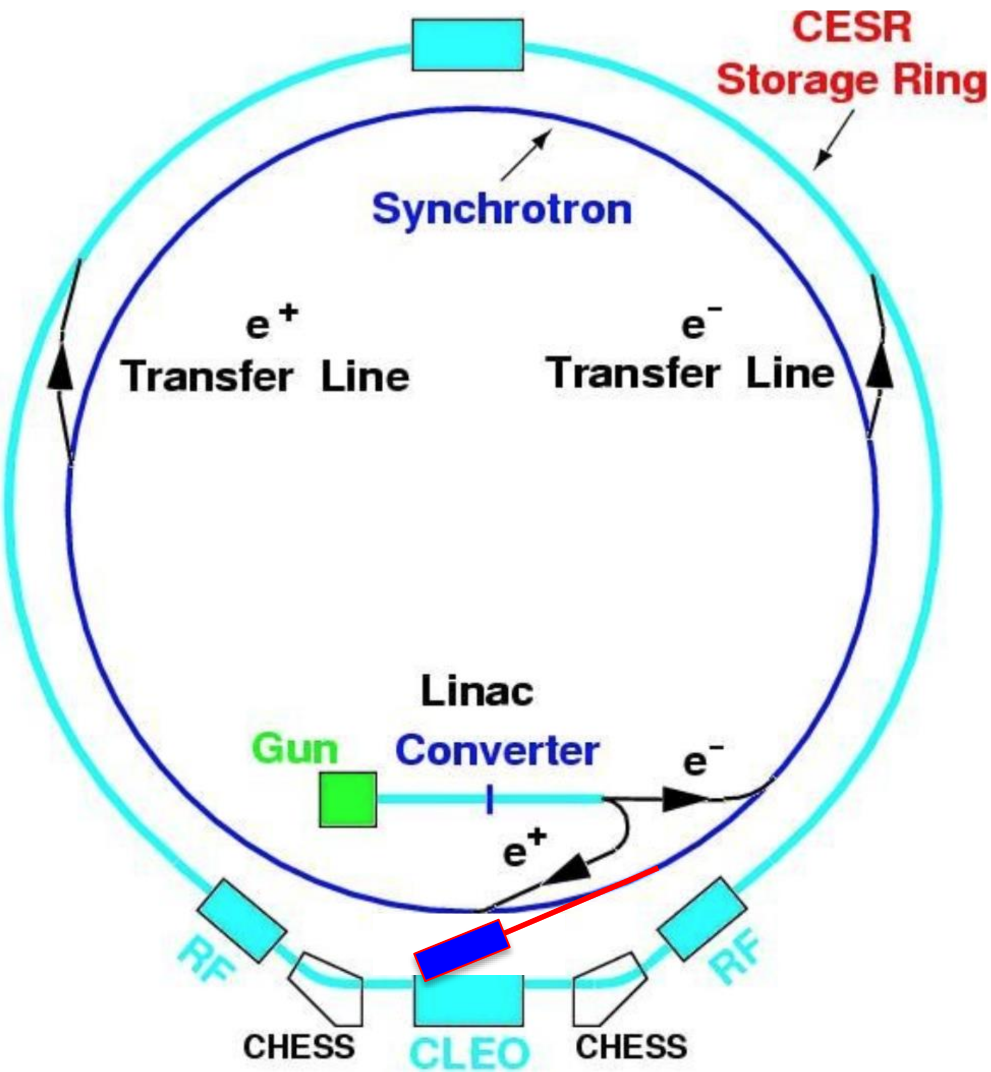
Data Analysis:

$$M^2_{\mathrm{rec}} = 2m_e\left(E_+ - E_\gamma(1 + \frac{E_+}{2m_e}\theta^2_\gamma)\right)$$

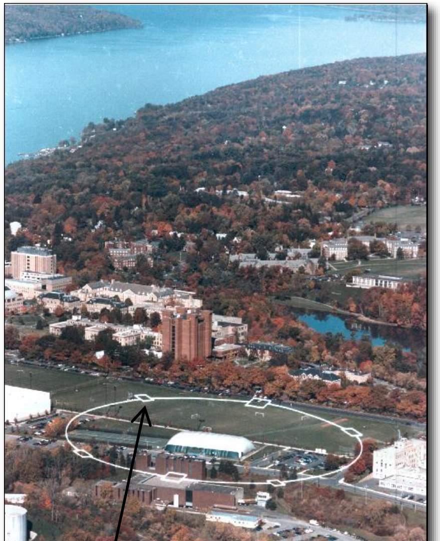
Positron source

Positron Source:

- Linac: e- on W target -> e+
- Enter synchr@150MeV
- Synchrotron: 60 Hz acceleration cycle
- Typical energy at extraction to CESR ~ 5300 MeV
- Avg Current ~ 10nA



Dark Photon Expt

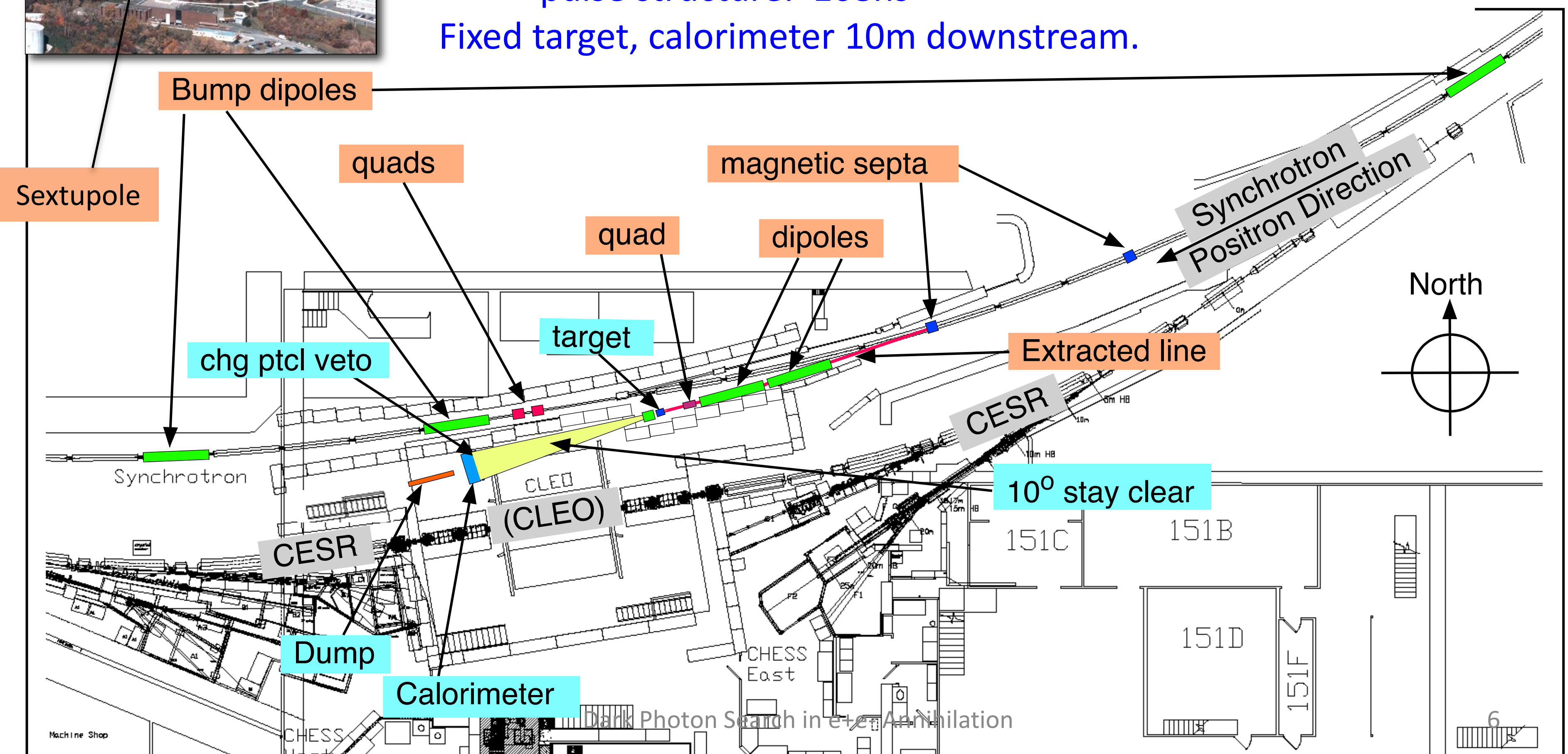


MMAPS in Wilson Lab

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

- E_{beam} = 1.8 -- 5.3 GeV
- I_{beam} ~ 2.3 nA at target
- quasi-CW during ~millisecond spills @ 60Hz
- pulse structure: 168ns

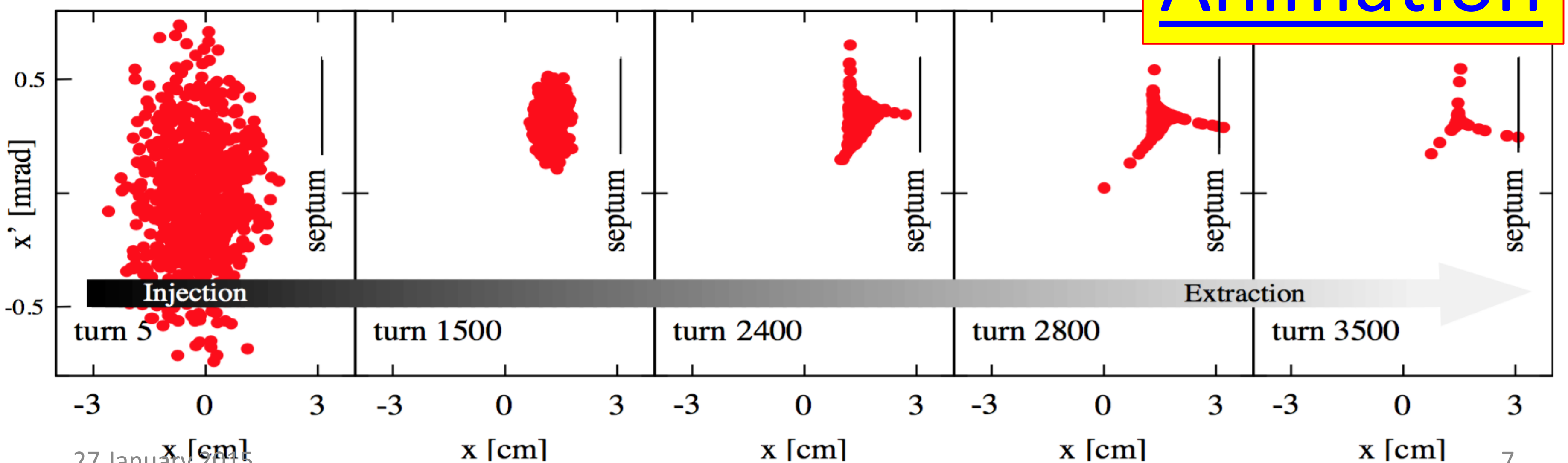
Fixed target, calorimeter 10m downstream.



Resonant extraction from synchrotron

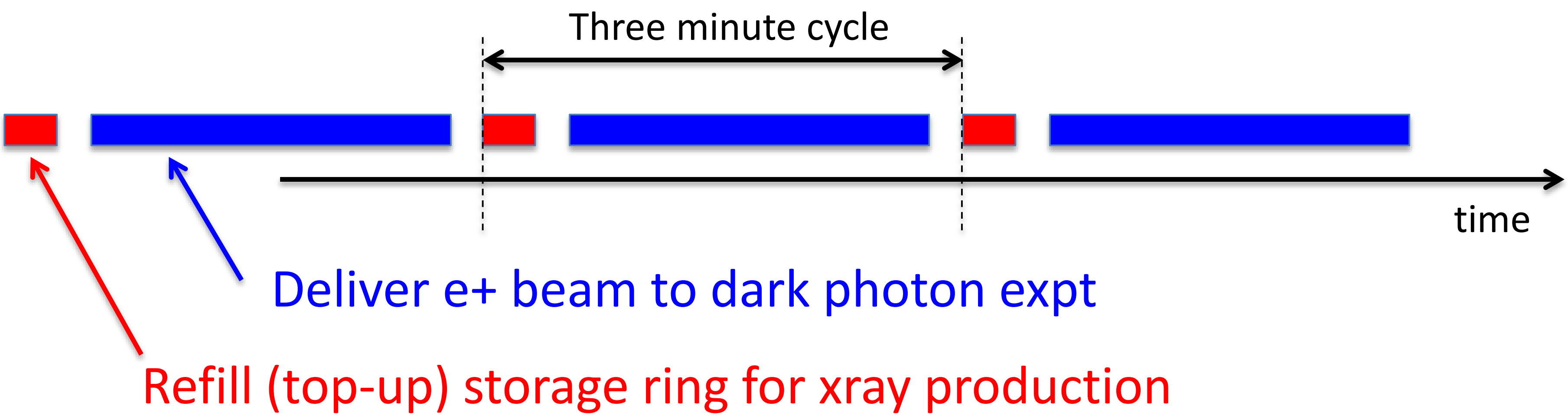
- Synchrotron: 60 Hz acceleration cycle:
  1. Linac loads the synchr with ~16 bunches of e+ (~10^9 e+)
  2. Accelerate to 5.3 GeV
  3. Gradually "dribble out" over ~2milliseconds
- The dribble:
  - Pulse quads: 10.65 tune → 10 $^2/_3$ ➔ *resonance*
  - Pulse sextupole: reduce stable phase space ➔ *particles leave stable orbit*
  - 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:

Animation



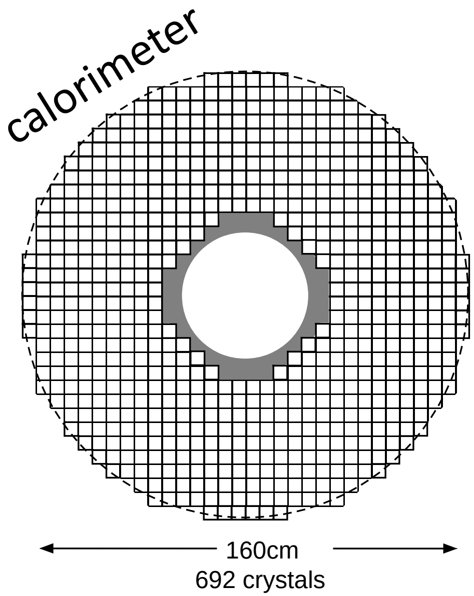
Dark Photons and Xray Operations

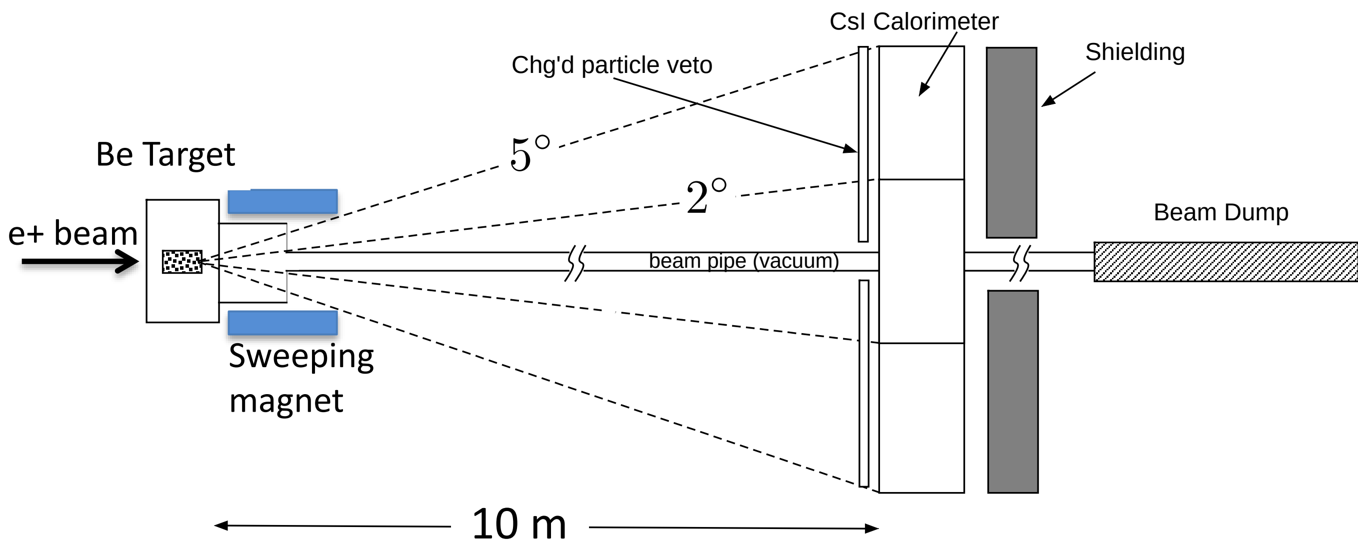
Sharing the Synchrotron



1. Duty cycle ~ 65% (?)
2. No additional operational $
3. No flexibility
4. Parasitic

Detector sketch

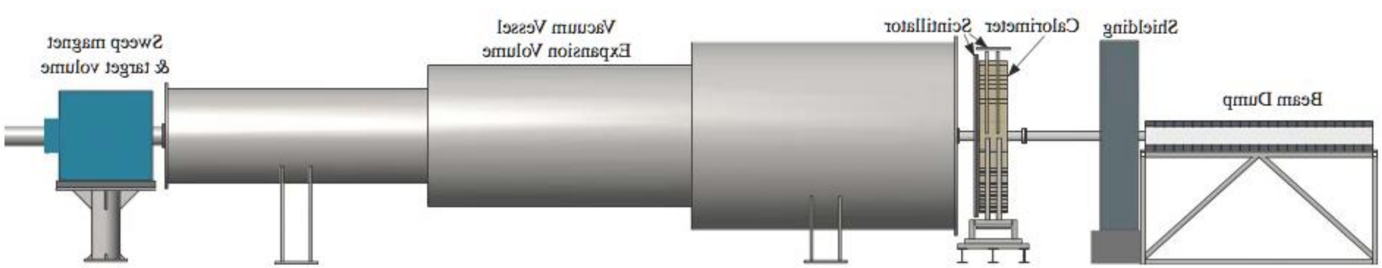




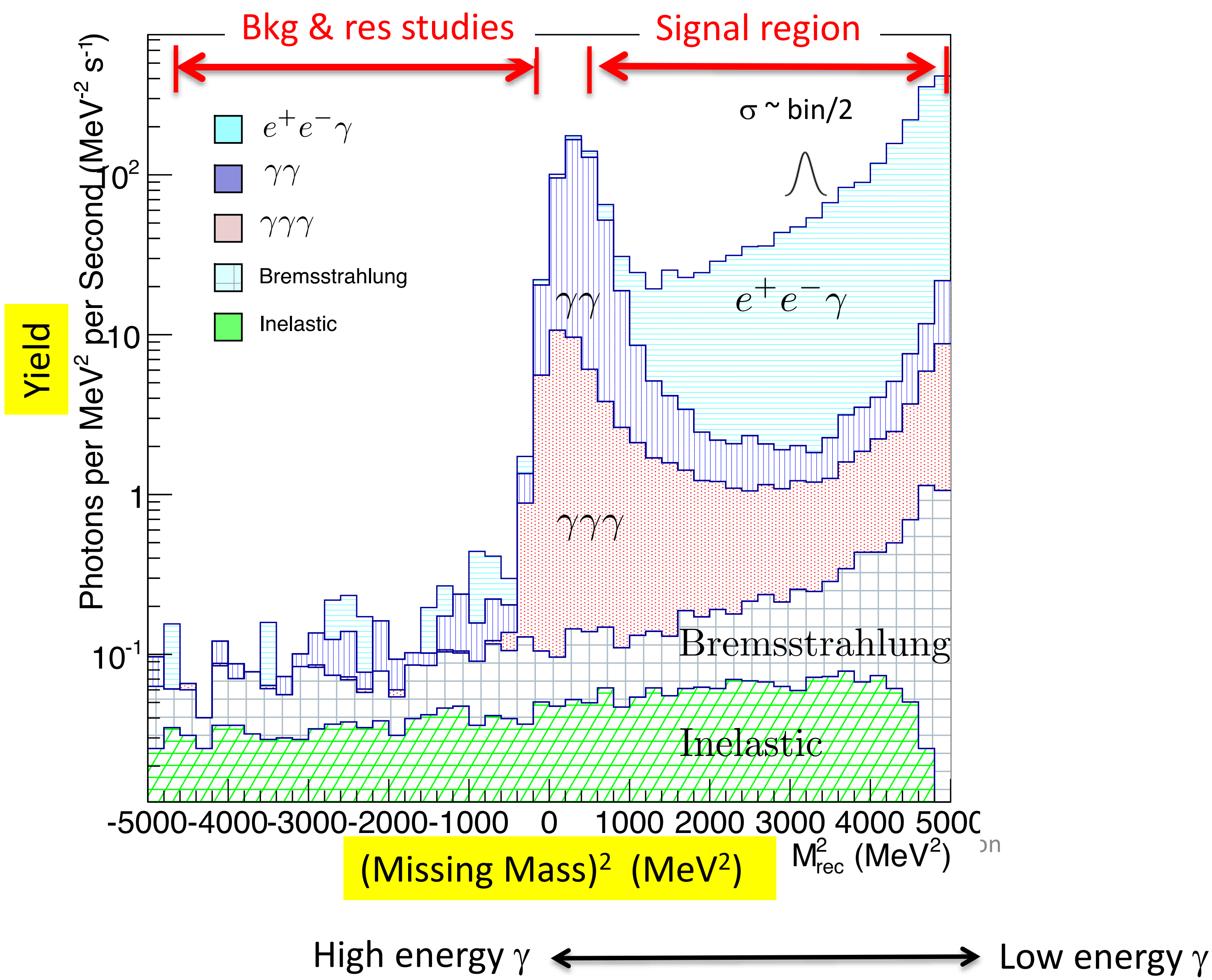
- CsI(Tl) crystals salvaged from CLEO, reconfigured
- Photodiodes swapped for PMTs salvaged from Babar
- Dipole sweep magnet after target: sweep Bhabhas out
- Charged particle veto (scintillator)

Typical photon energy: 5-500 MeV

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

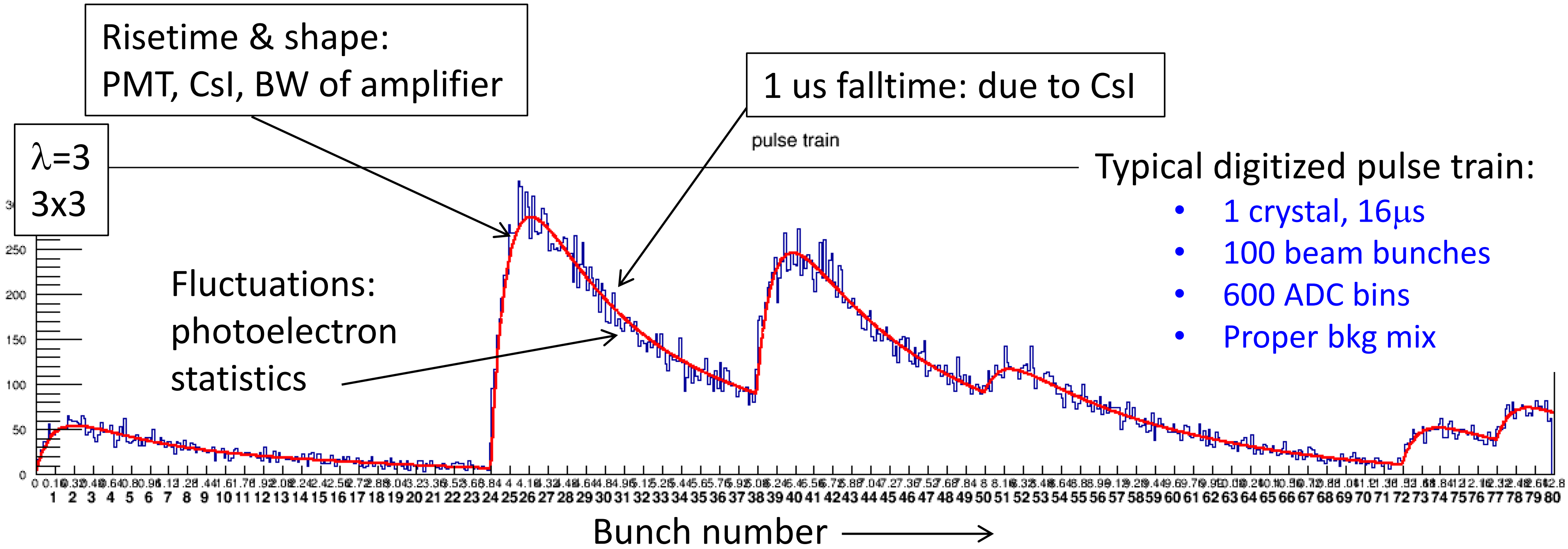


The (Missing-Mass)^2 plot



Pileup

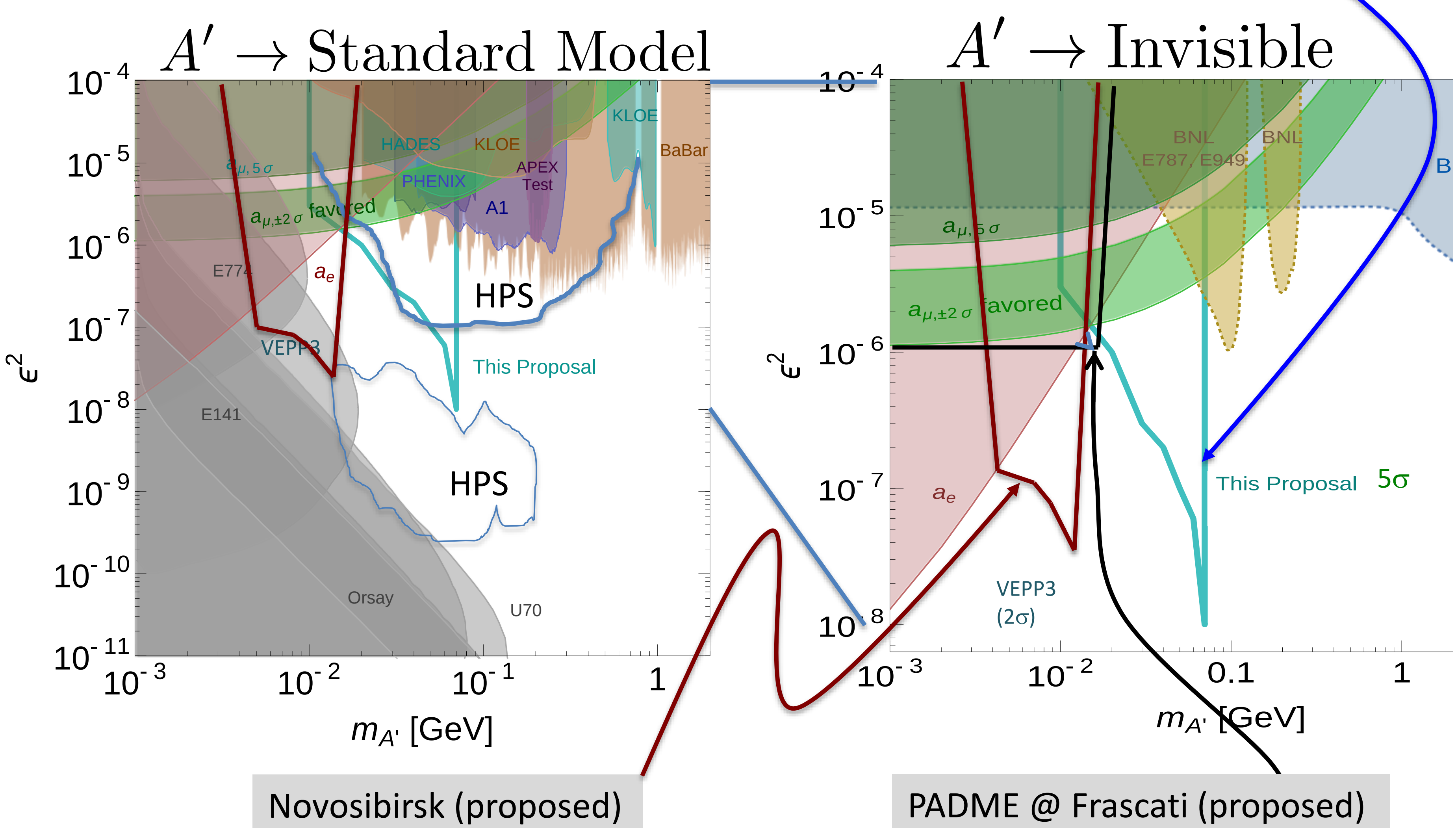
- At max luminosity: ⟨pileup⟩ ≡ $\lambda \simeq 3 \pm 1$ photons/beam bunch
- Most of these are soft < 30MeV ➔ 1,2-crystal clusters: minimizes *spatial overlap* probability → clustering algorithm
- *Temporal overlap* → pileup algorithm:
  - -- Effectiveness depends mainly on rise time – favors PMT choice
  - – Typical pulsetrain for PMT readout shown below:



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 = 1.0x10^{34}, T = 10^{7}sec, 5-sigma excl



Concluding remarks (1)

What *we* think about this expt:

- Elegant concept (thank you, Bogdan!)
- Good reach into unexplored parameter space
- Unique positron source (energy => mass range)
- Most of the components are free
- Cornell Lab is supportive, prepared to go ahead.

What NSF & reviewers said:

- Proponents are over-committed (CMS…)
- Despite savings, its expensive: accelerator mods

Both views are reasonable.

Concluding remarks (2)

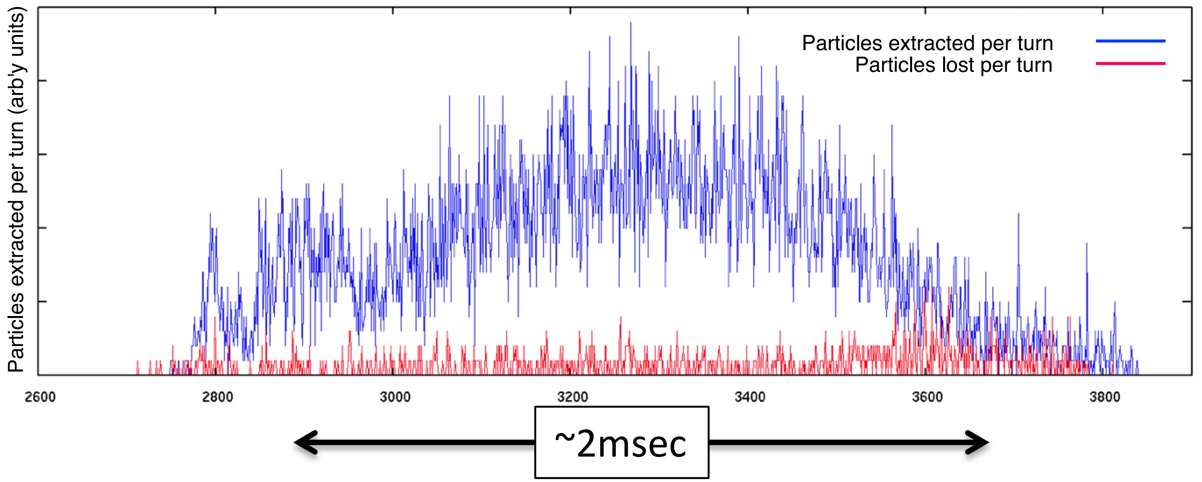
Possible ways forward:

- Abandon the whole plan. (not very satisfying)
- Divide the project into 2 pieces:
  - Accelerator modifications (Cornell)
  - Dark photon experiment (outside collaborators)
- How does this help?
  - Accel mods might be funded by NSF's MRI channel (new $)
  - Outside collaborators expand manpower base
  - Potential to tap into different funding sources
- What else is needed?
  - Have to convince oneself that the parameter space won't be already explored by the time this could launch
  - MRI chances would be best if there were a physics program (more than one experiment) associated with the e+ beam.

Back up slides

Characteristics of extracted beam

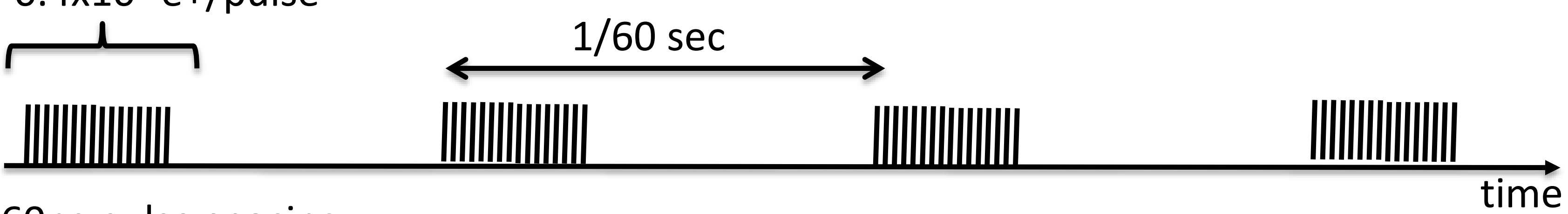
Extracted Yield vs time (single spill)



Beam structure:

~1.2x10^4 pulses extracted,
~0.4x10^5 e+/pulse

$\langle i^+ \rangle \approx 1 \sim 2 \times 10^{10}\, e^+/\mathrm{sec}$ at target



~160ns pulse spacing

Lab-frame Kinematics

We observe: E,θ of one photon.

For 2-body processes (γγ, γA') only one free parameter: θ_{CM}

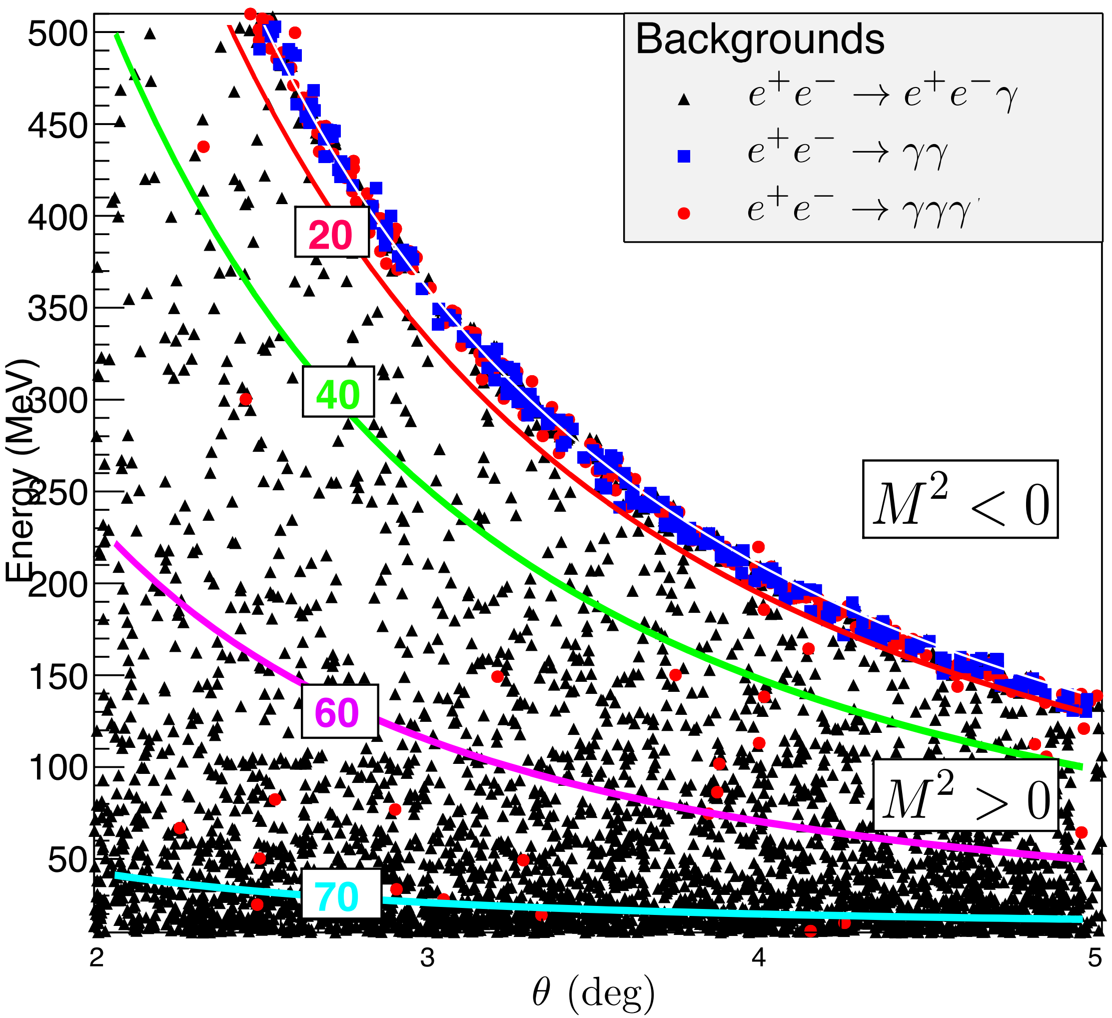
➔ E,θ correlated in lab:

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

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

Most photons (outside γγ peak) are low energy!

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



Data Acquisition

- Full waveform digitization on all crystals (to disentangle pileup) @50MS/sec
- Mu2e straw chamber daq board well suited; 2 ADCs + FPGA.
- Currently studying prototype version
- Data rates:
  - Avg Lumi = 10^{34}
  - Total sum of bkg cross sections X acceptance: 220 μb
  - Implies average event rate ~ 2MHz
- Expect to impose minimum energy cut in FPGA
  - Read out all crystals in clusters passing cut; plus some buffer zone.
  - "Read out" is not defined yet (how many samples? Integrate in FPGA?...)

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	$e^+N \to e^+N' + \mathrm{hadrons}$	GEANT4

$$\sum_{\mathrm{bkgs}} \sigma_i \mathcal{A}_i = 220\mu b$$

(Signal cross section) X (Acceptance) = 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