Dark Photon Search in e+e- Annihilation:

A short update on MMAPS

Cornell University — *J. Alexander, M. Perelstein, D. Rubin, P. Wittich*

University of Minnesota — *Y. Kubota,*

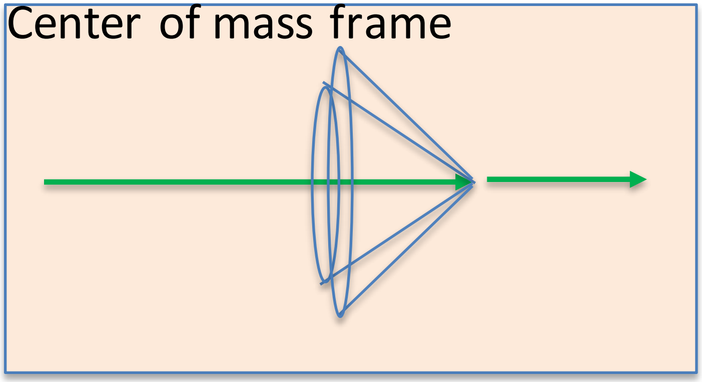
Carnegie Mellon University — *B. Wojtsekhowski*

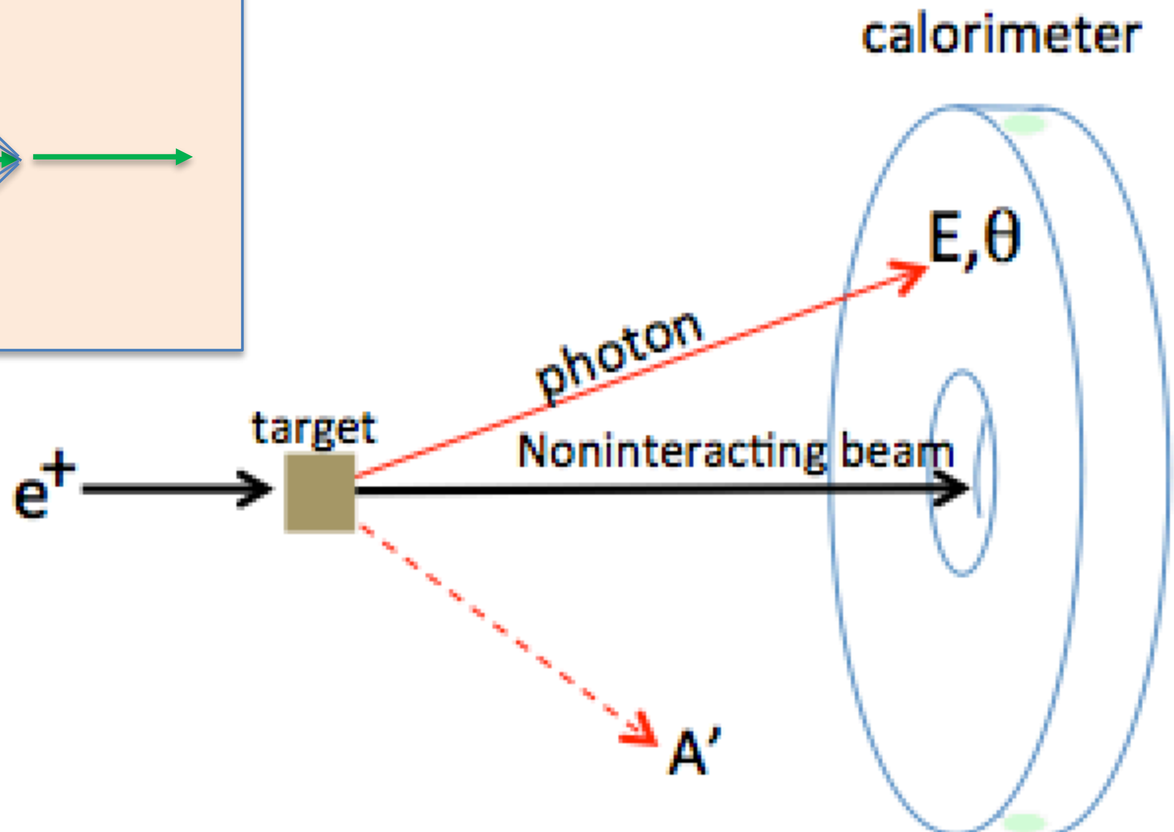
C. Cesarotti, E. Niklasson, B. Shin, Y. Wang
Katherine Ding, Josh Kurisko, Akshay
Sawhney, Saquib Hassan, J. Perrin, Andre
Frankenthal, J. Park

Cornell undergraduate students
Cornell graduate students
Northwestern University undergrad

***Advances in Dark Matter and Particle Physics* 2016**
October 24-27
Messina, Italy

Fixed-target configuration





(Missing Mass)^2 reconstructed from E, θ.

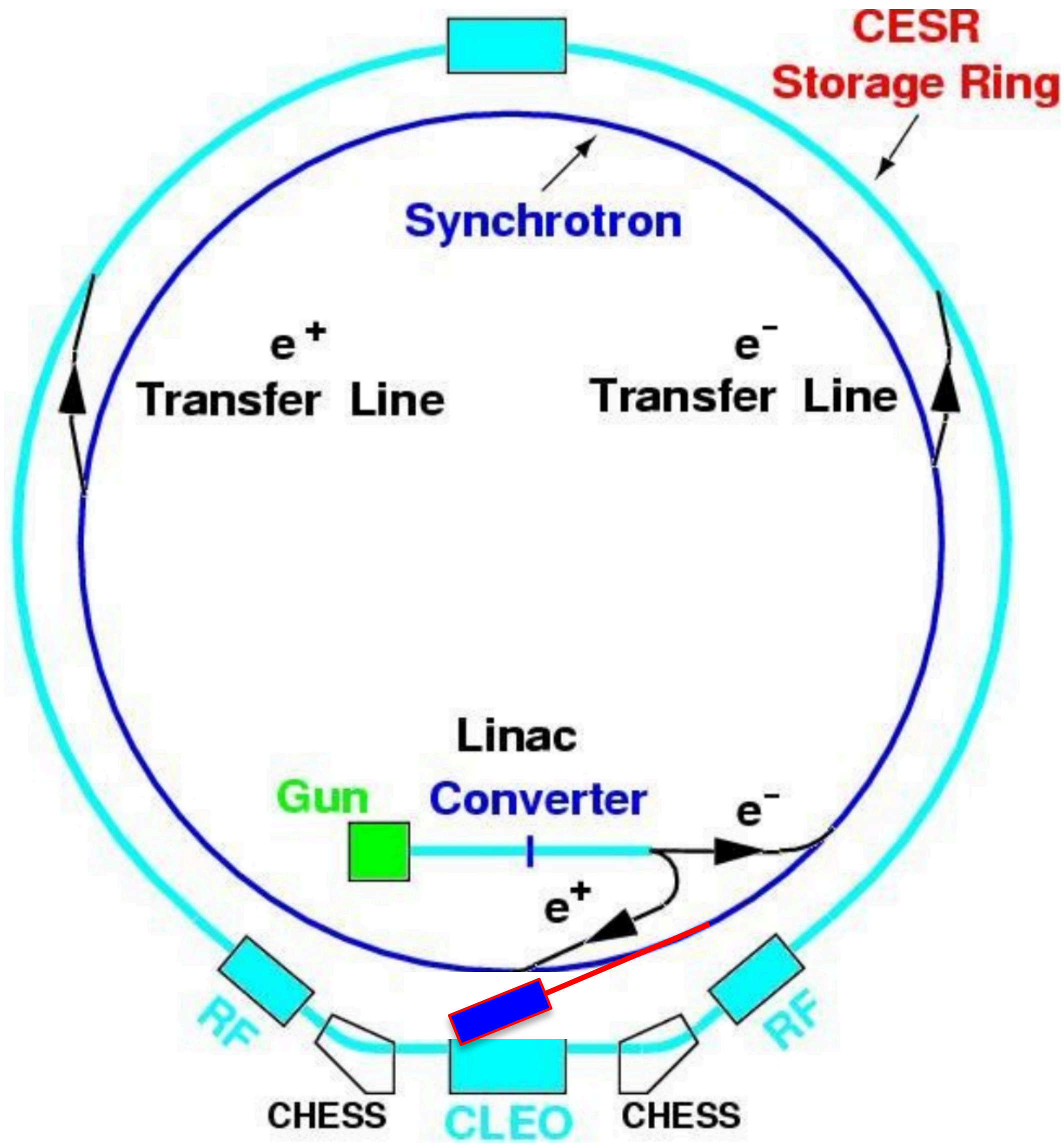
$$M_{\mathrm{rec}}^2 = 2m_e\left(E_+ - E_\gamma\left(1 + \frac{E_+}{2m_e}\theta_\gamma^2\right)\right)$$

In MMAPS proposal:
E_γ > ~20 MeV
$2^o < \theta_\gamma < 5^o$
Calorimeter: reuse CLEO CsI crystals

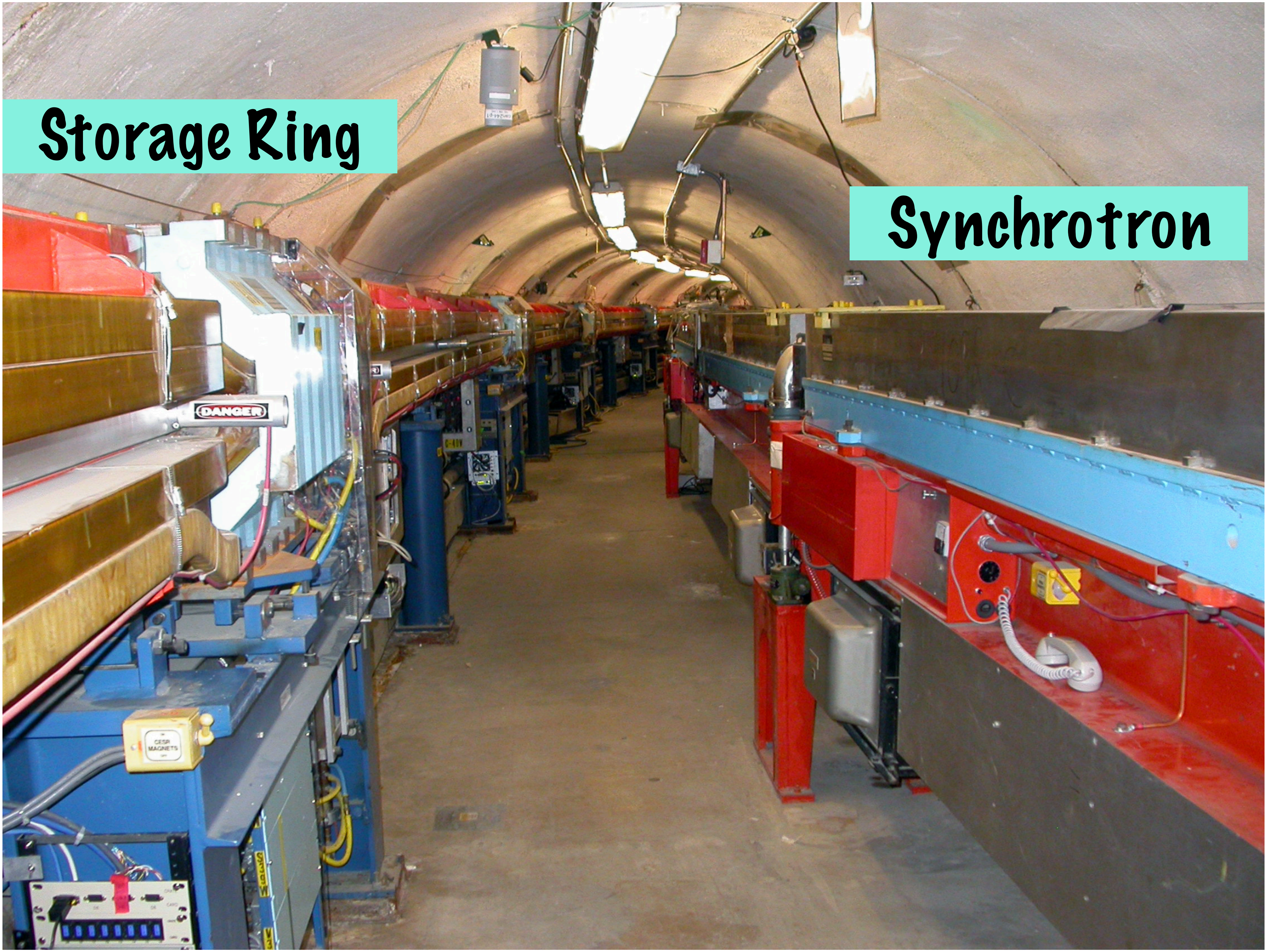
The Wilson Lab Accelerator Complex

Positron Source:

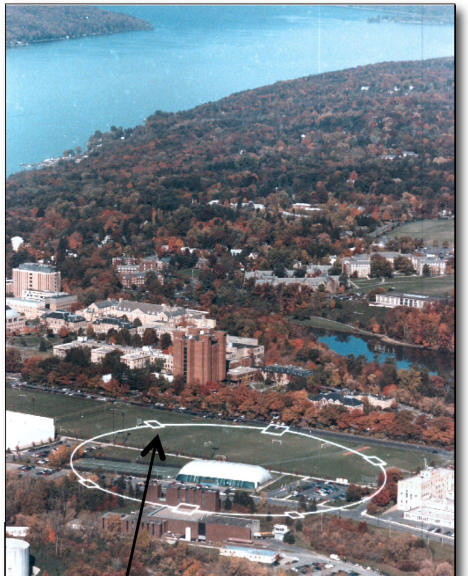
- Linac: e- on W target -> e+
- Enter synchr@150MeV
- Synchrotron: 60 Hz acceleration cycle
- Typical energy at extraction to CESR ~ 5300 MeV → 6000 MeV
- Avg Current ~ 10nA



Dark Photon Expt


Storage Ring
Synchrotron
DANGER
CESR MAGNETS

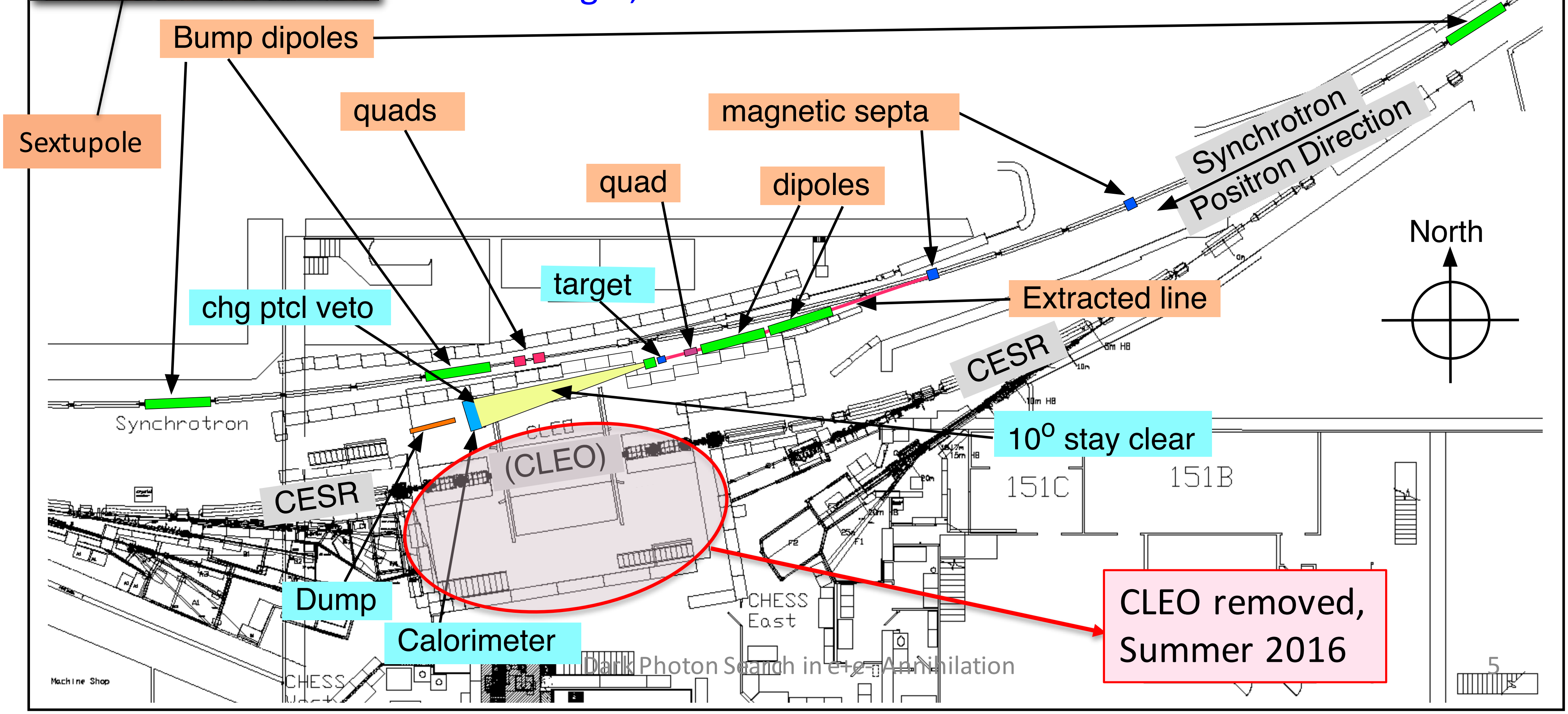
An Opportunity at Cornell



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

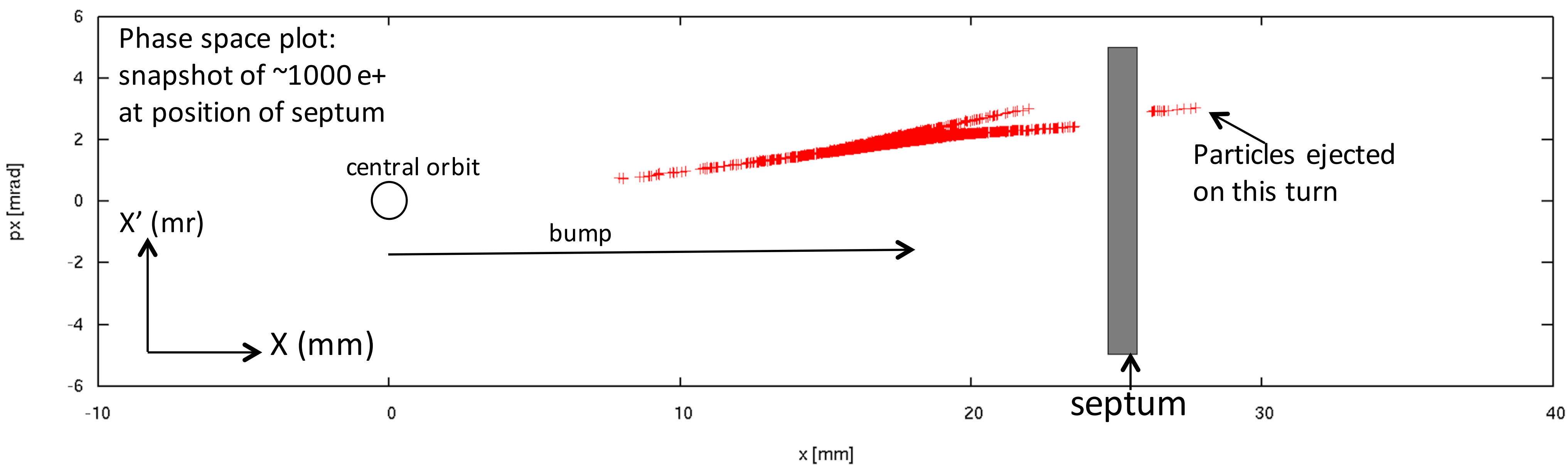
- E_{beam} = 1.8 – 6.0 GeV
- I_{beam} ~ 2.3 nA at target
- quasi-CW during ~millisecond spills @ 60Hz
- pulse structure: ~160ns

Fixed target, calorimeter 10m downstream.

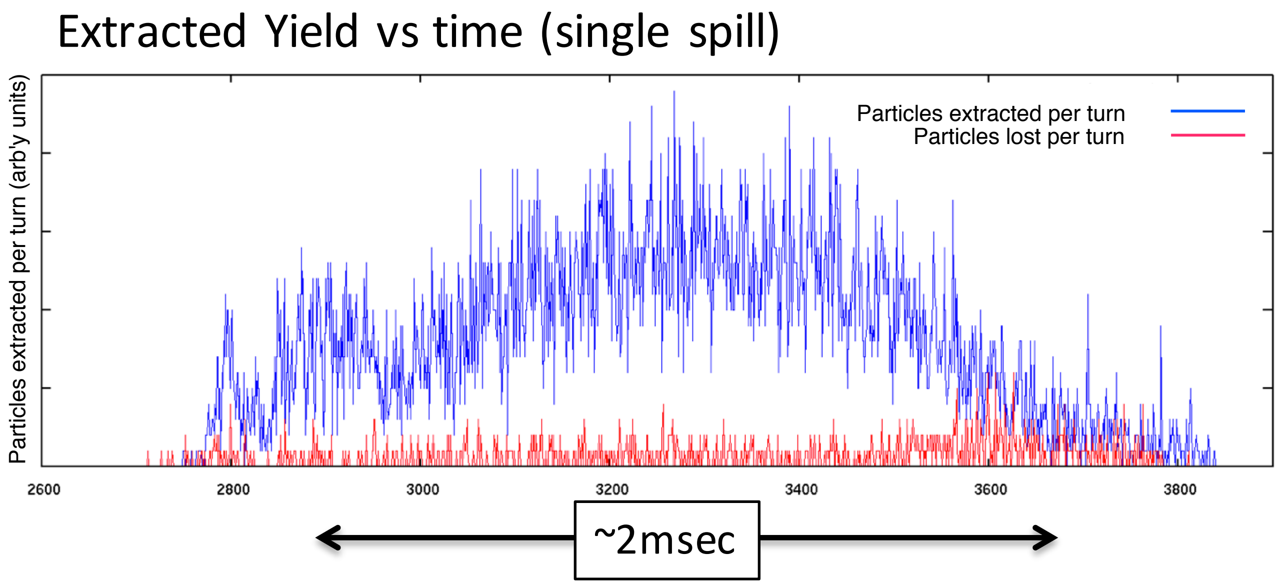


Resonant extraction from synchrotron

- 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 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:



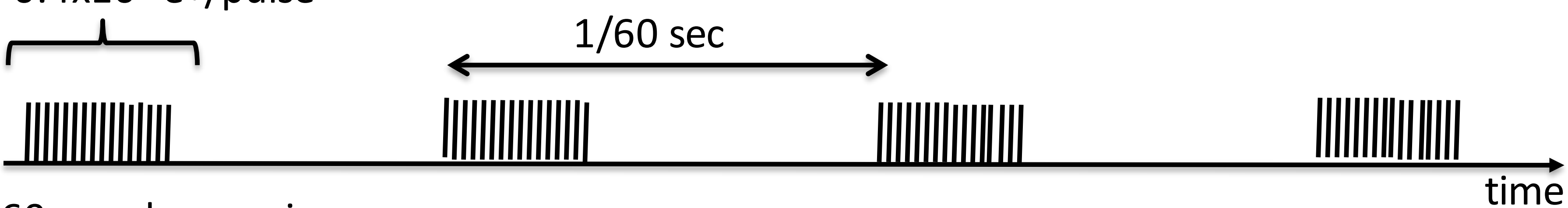
Characteristics of extracted beam



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

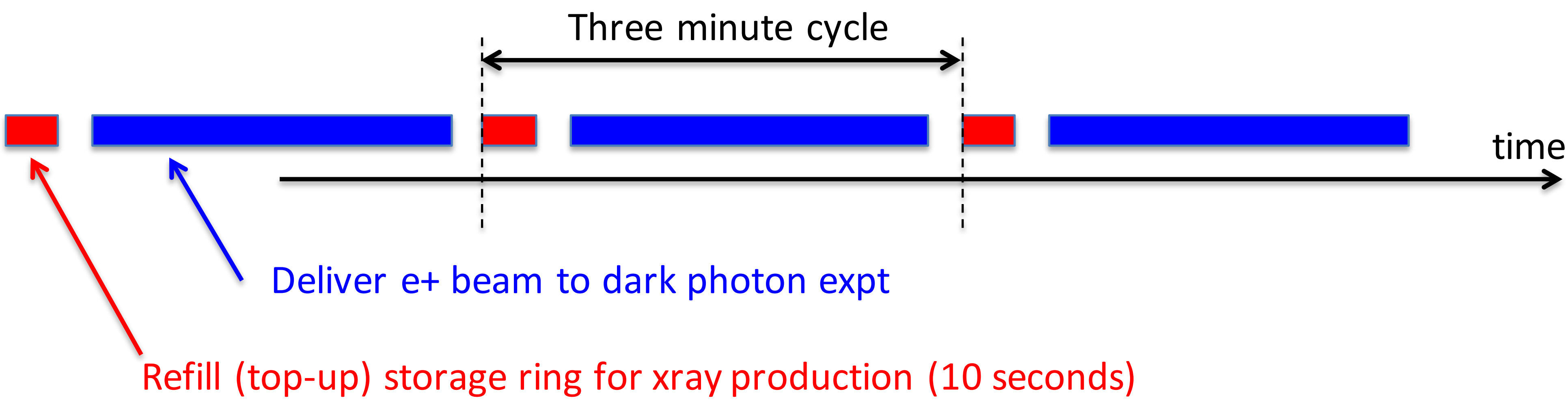


~160ns pulse spacing

Dark Photons and Xray Operations

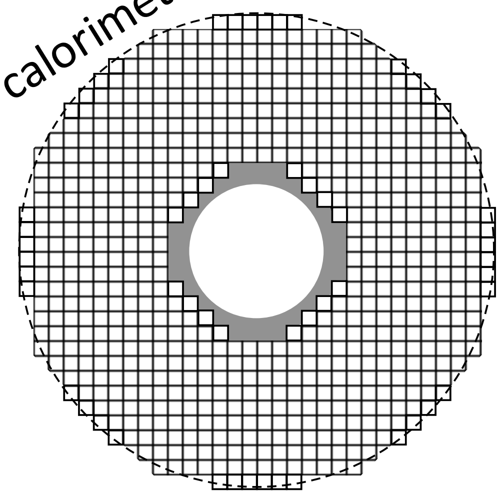
The CHESS x-ray program is the dominant activity in the laboratory

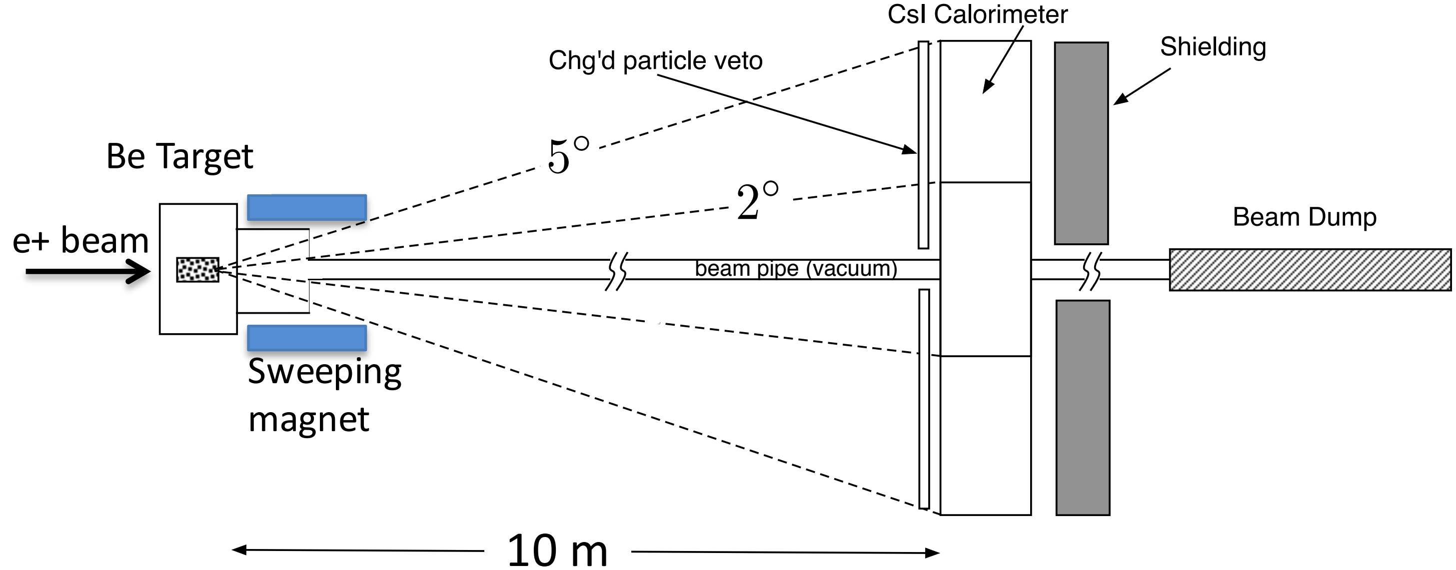
Adroit use of synchrotron cycles will satisfy CHESS and provide positrons for a dark photon experiment:



1. Duty cycle ~ 80% (?)
2. No flexibility
3. Parasitic

The MMAPS detector



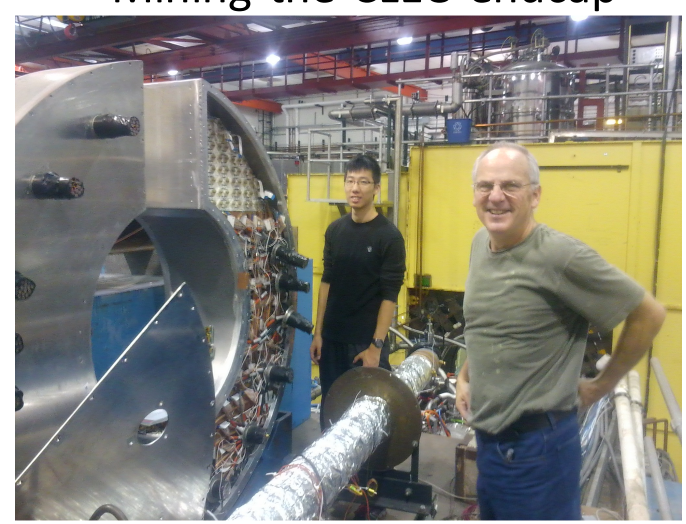


- CsI(Tl) crystals salvaged from CLEO, reconfigured
- Photodiodes and preamps also salvaged from CLEO*
- Dipole sweep magnet after target: sweep Bhabhas out
- Charged particle veto (scintillator)

Typical photon energy: 5-500 MeV

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

Mining the CLEO endcap



* Phototubes are under consideration

MMAPS 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

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

(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

Lab-frame Kinematics

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

We observe: E,θ of one photon.

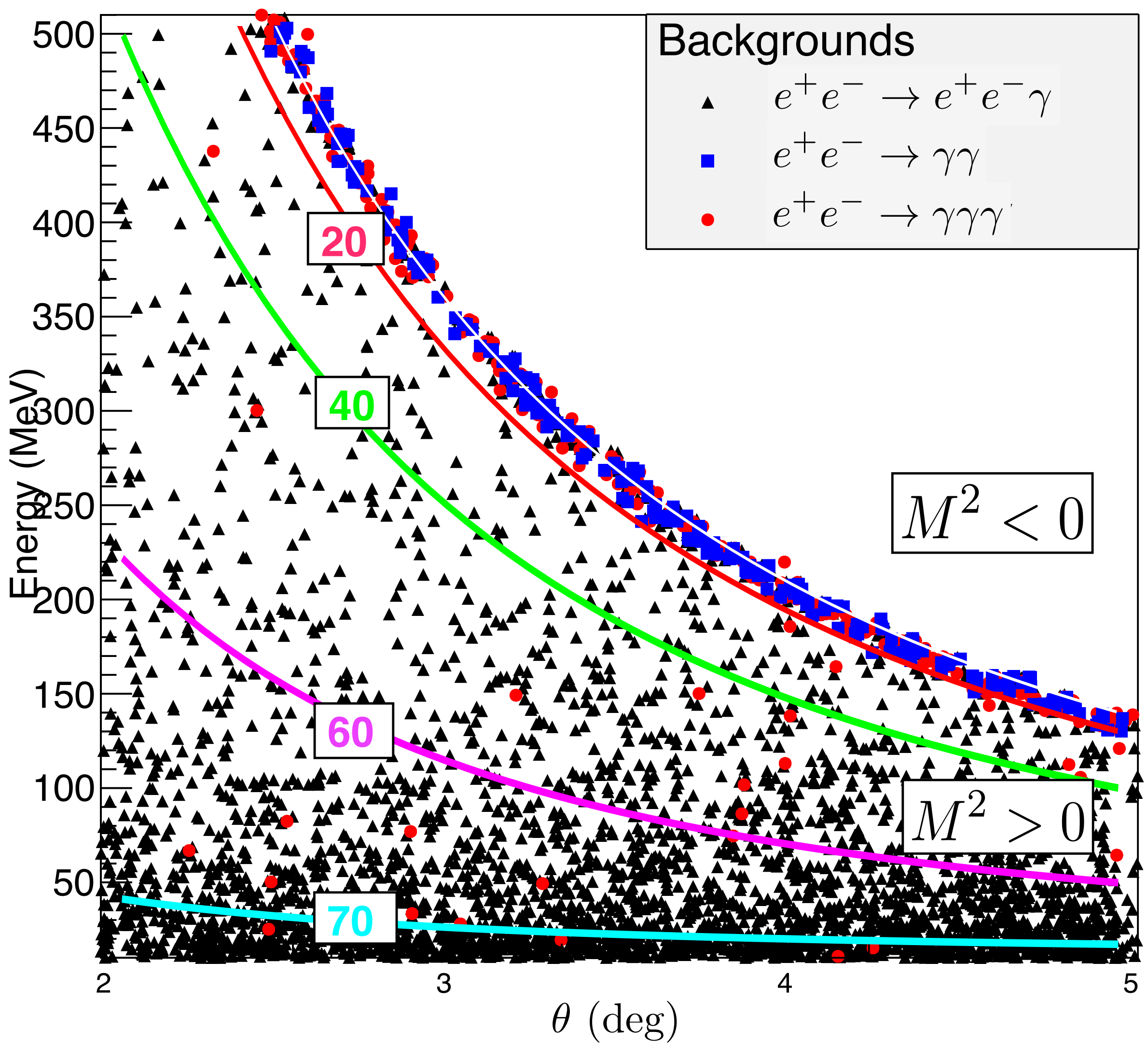
For 2-body processes (γγ, γA') only one free parameter: θ_{CM}

➔ E,θ correlated in lab:

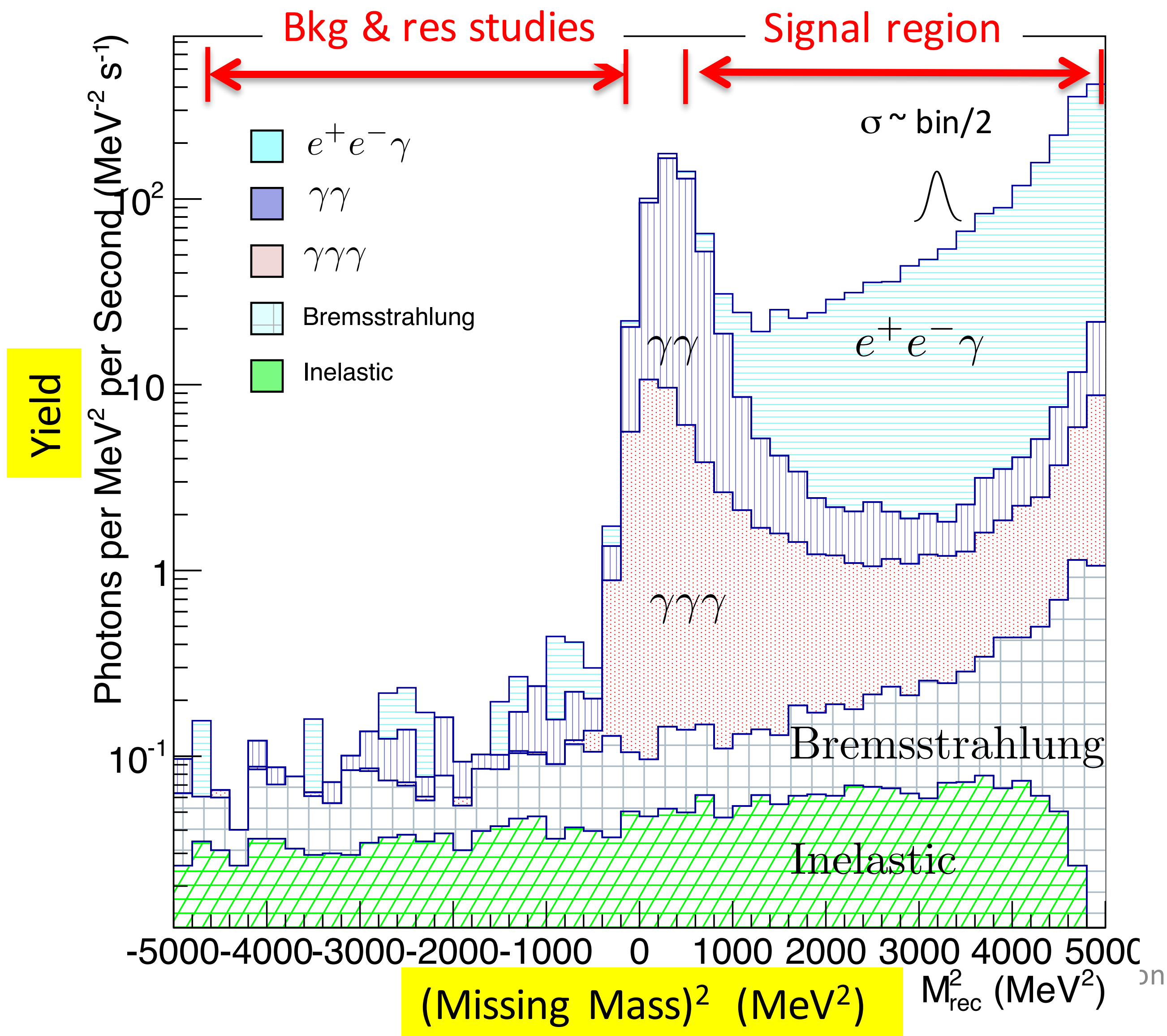
For other non-2body bkgs, E,θ not correlated

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

Most photons (outside γγ peak) are low energy!



The (Missing-Mass)^2 plot



High energy γ ⟷ Low energy γ

Mass resolution & optimization

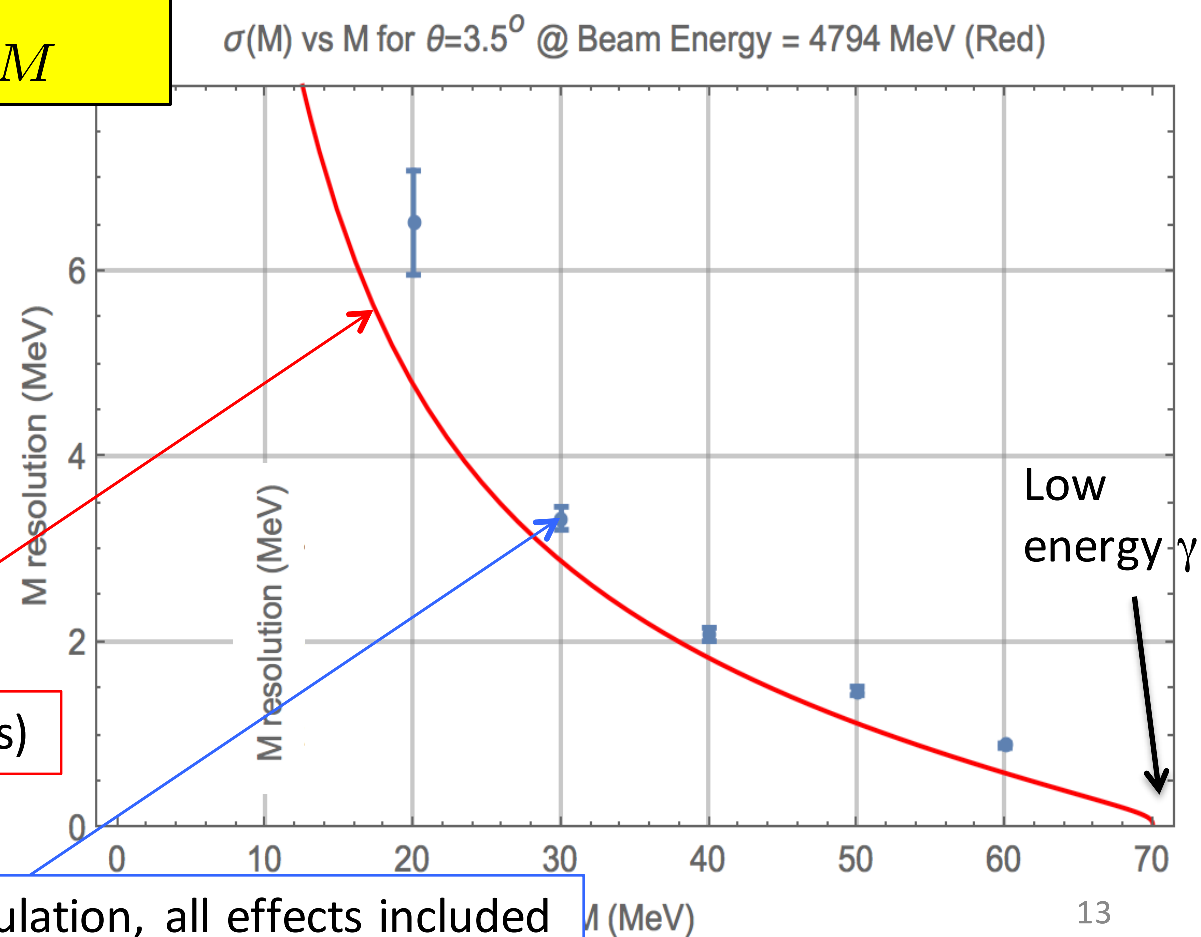
Mass resolution is critical:

(a) Maximize significance of peak in bump hunt
(b) Minimize background leakage into signal region

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

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

Missing Mass resolution vs M.

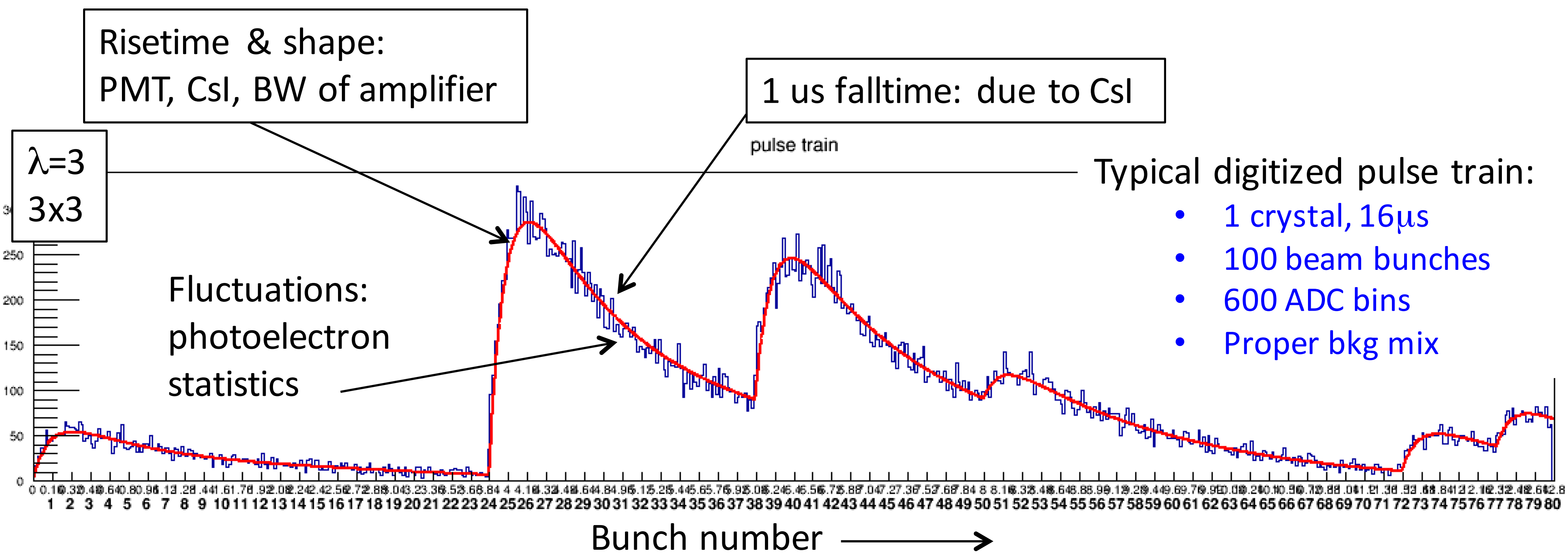


Analytic formula (CLEO params)

Full simulation, all effects included

Pileup

- At max luminosity: ⟨pileup⟩ $\equiv \lambda \simeq 3 \pm 1$ 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:



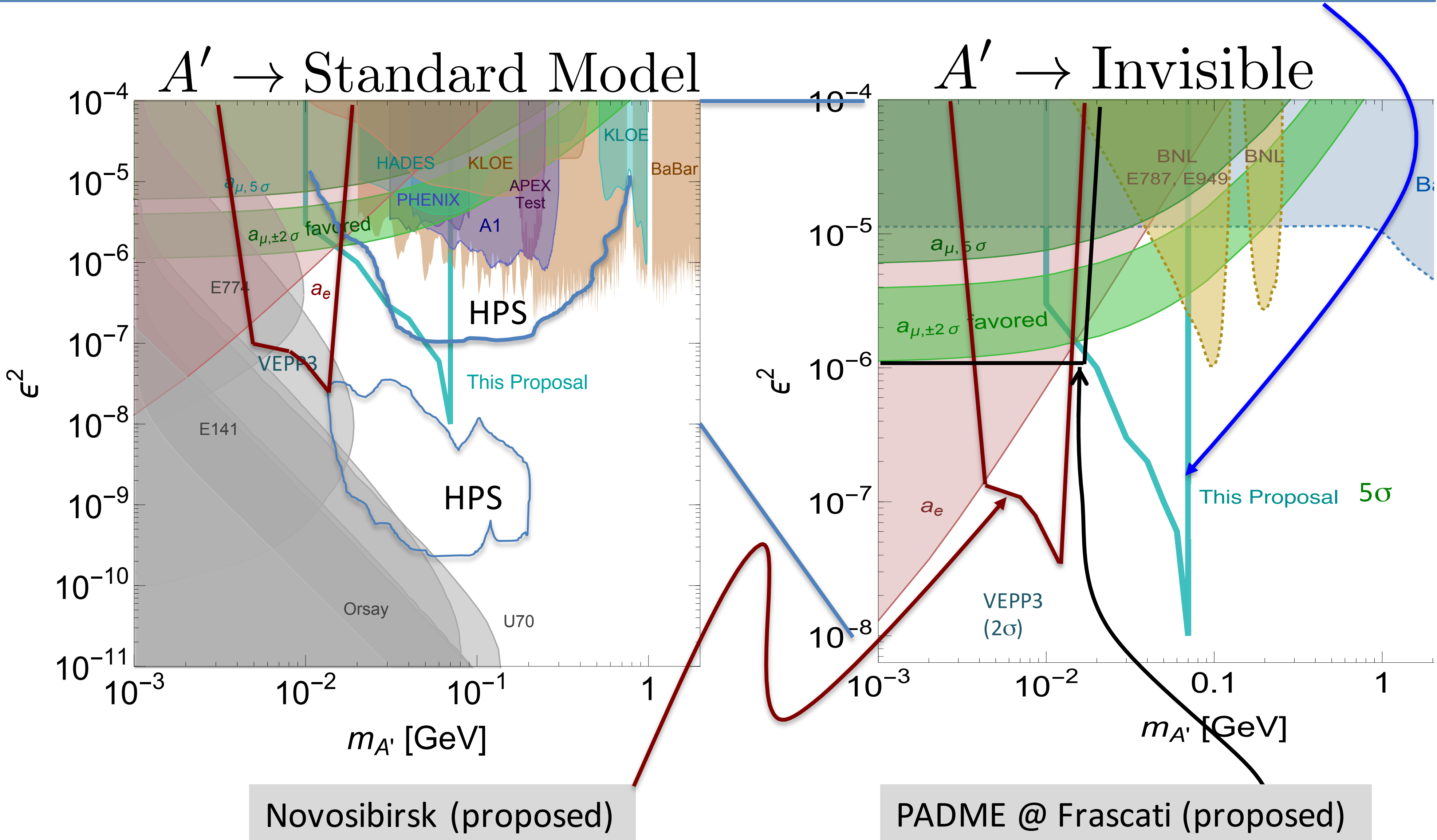
Data Acquisition

- 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?...)

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 = 10^7sec, 5-sigma excl

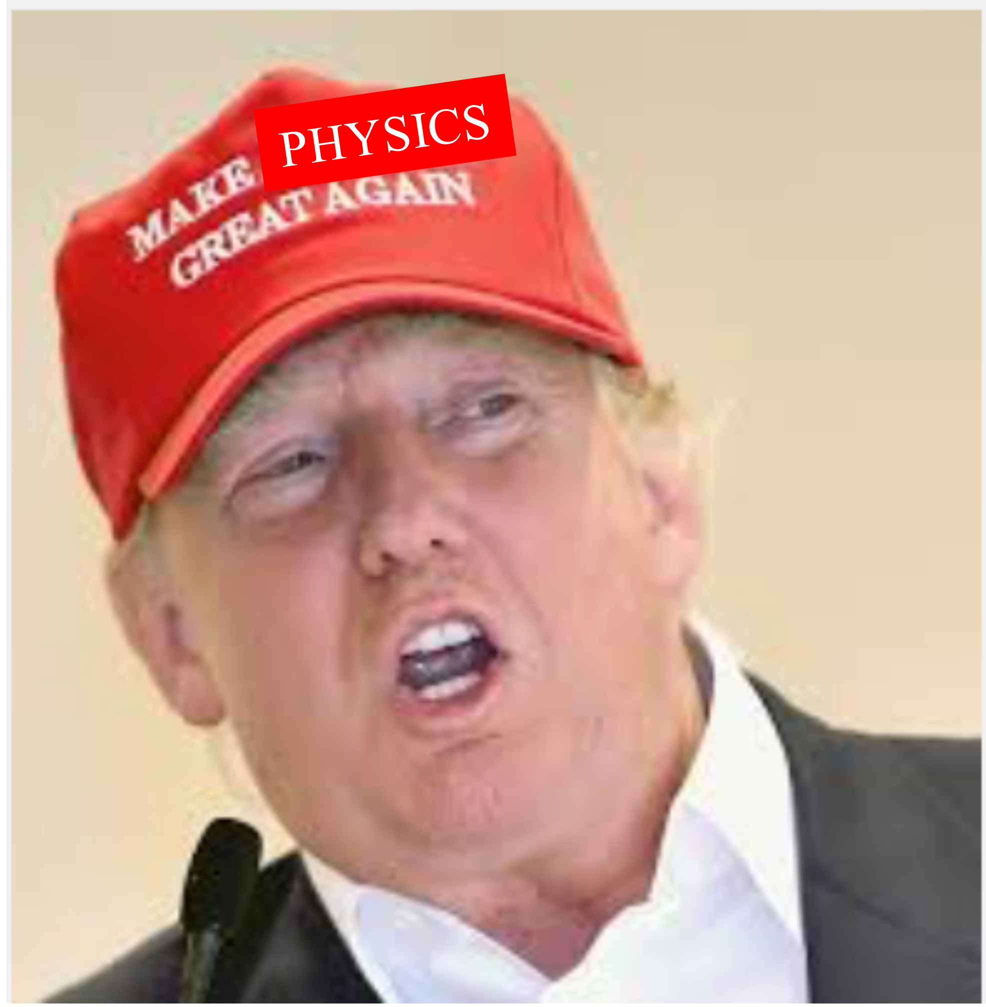


Looking for a path - without MMAPS

- MMAPS proposal was not funded.
- But the concept is widely appreciated, and the experiment could be done by others... (Note the close similarity to VEPP3 and Padme.)
- Cornell's *crucial contribution has to be the extracted positron beamline* – the opportunity is unique… and the responsibility is clear.
- We have submitted a new proposal to just build the beamline. If approved and funded, this will open an opportunity for outside groups to propose the experiment.
- With a broad-based collaboration we can find the person-power and the funding needed to make this a success and push forward into Dark Sectors…

A catchy slogan might help...

We're gonna build a beamline – and make our funding agency pay for it!



Vote for the Dark Sector [Physics] on November 8th!

Context of the positron beamline proposal

- Many big projects are afoot at Cornell. (CHESS upgrade, ERL accelerator loop, CMS Upgrade…) Resources must be carefully managed.
- Significant 3-year upgrade to the x-ray program ("CHESS") is underway. CLEO has been removed and CESR is being reconfigured.
- There is a window to build the positron beamline in 2018-2019, as the CHESS upgrade is finishing.
- This plan has the support of the two lab directors.
- The positron line would provide avg current of 2~3 nA with ~80% duty cycle. At 6.0 GeV. Beam structure as shown in slide 8. (Pileup is an issue.)

Concluding remarks

- Missing mass approach is very attractive and relatively(!) simple, with lots of unexplored parameter space
- We would like very much to host a dark photon experiment. This is beautiful physics. It addresses extremely profound questions about the universe we live in.
- No proposal is a slam-dunk. For the positron beamline proposal there are two major hurdles:
  - Internal Cornell competition
  - NSF Review – MRI proposals are Foundation-wide
- The proposal being crafted presents a plan to do dark photon physics while *also offering significant benefits* to all the lab's programs.
  - Has already led to acceptance within the lab
  - Hopefully will yield good reviews in the Cornell pre-competition and the subsequent NSF-wide review process
- If we build it, we hope you will come!