Heavy Photon Search Run and Results Update

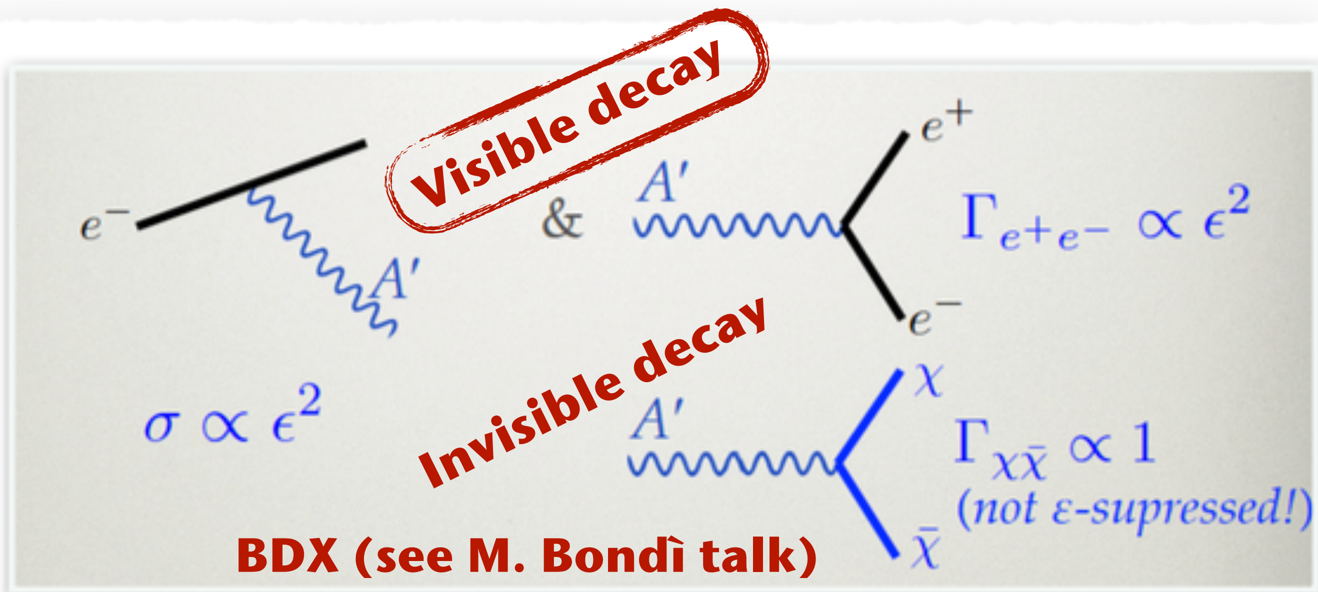
Marzio De Napoli
INFN Sezione di Catania

On behalf of the Heavy Photon Search Collaboration

- **Motivation and Proposed Reach**
- **Experimental Setup**
- **2016 Run: Ecal performance**
- **2016 Run: SVT performance**
- **Preliminary results**
- **Summary**

International Symposium
Advances in Dark Matter and Particle Physics
Messina (Italy) - October 24-27, 2016

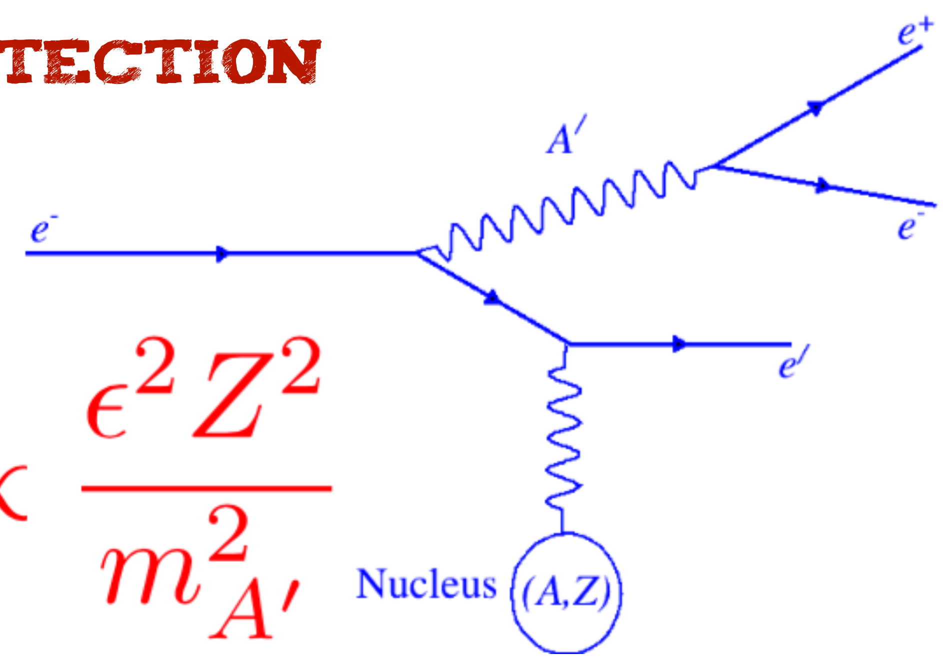
Fixed target experiments



HPS : A' PRODUCTION AND DETECTION

Since A' could couple to electric charge it could be produced in a bremsstrahlung process and decay into an e+-e- pair

$$\sigma \propto \frac{\epsilon^2 Z^2}{m^2_{A'}}$$



HPS Proposed Reach

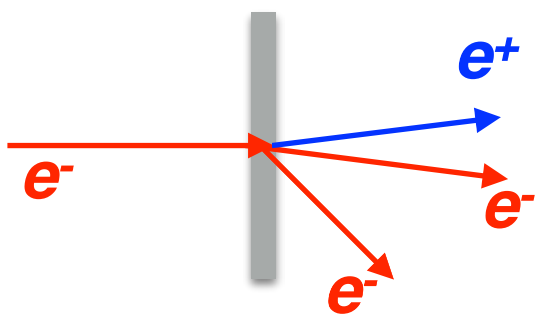
$\epsilon^2 \sim 10^{-5} - 10^{-10}$

$M_{A'} \sim 10$ MeV/c^2 - 1 GeV/c^2

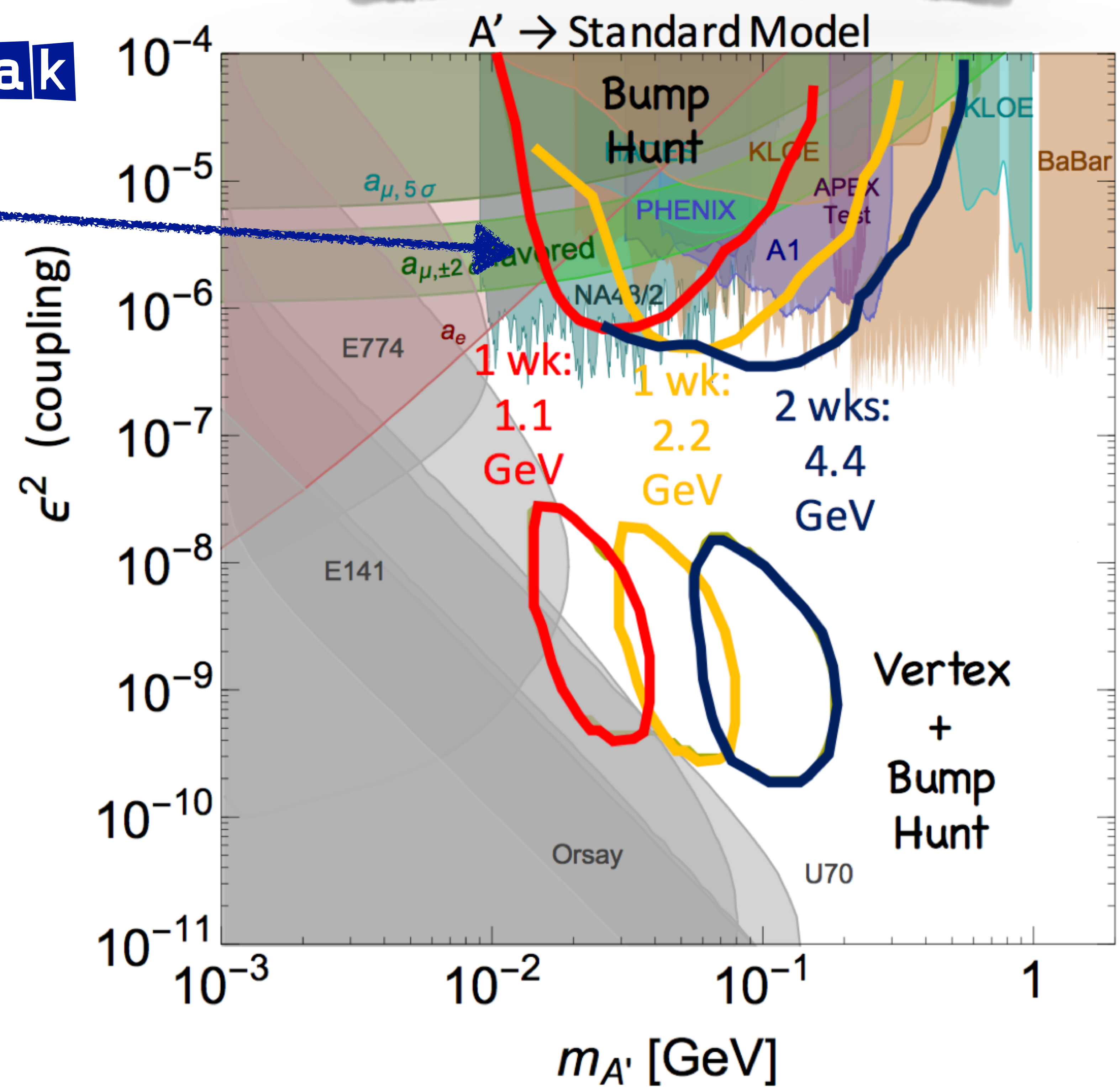
Two Signatures:

invariant mass peak

Large ϵ coupling - Prompt decay



Peak on large SM background

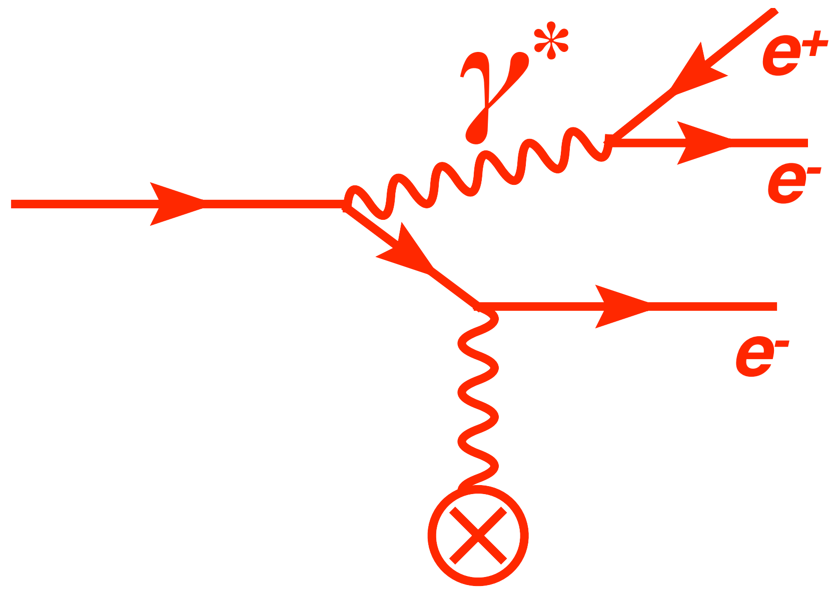


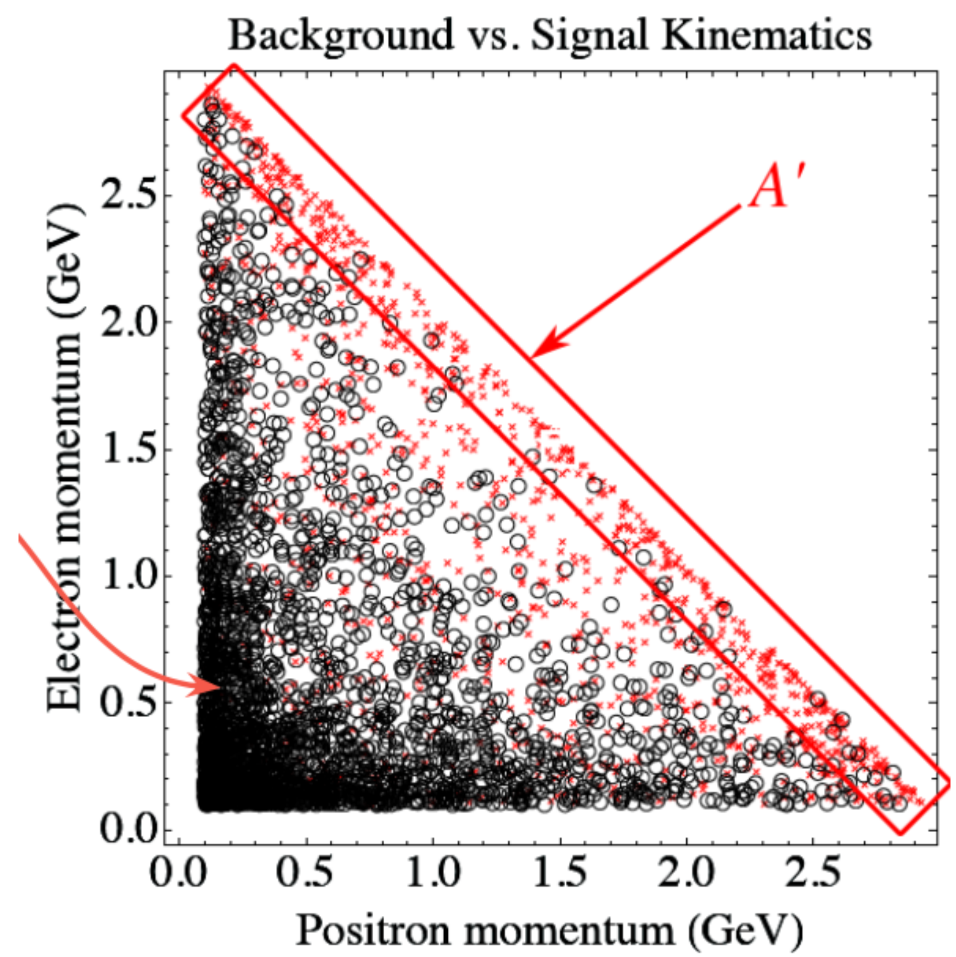
Physics Background

Two physics backgrounds known as "tridents"

Radiative

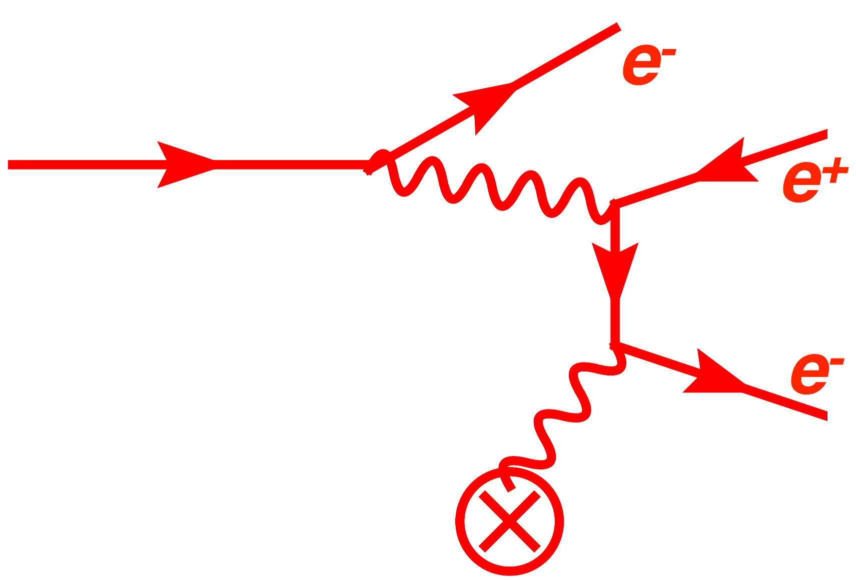
similar kinematics as A' decay, irreducible

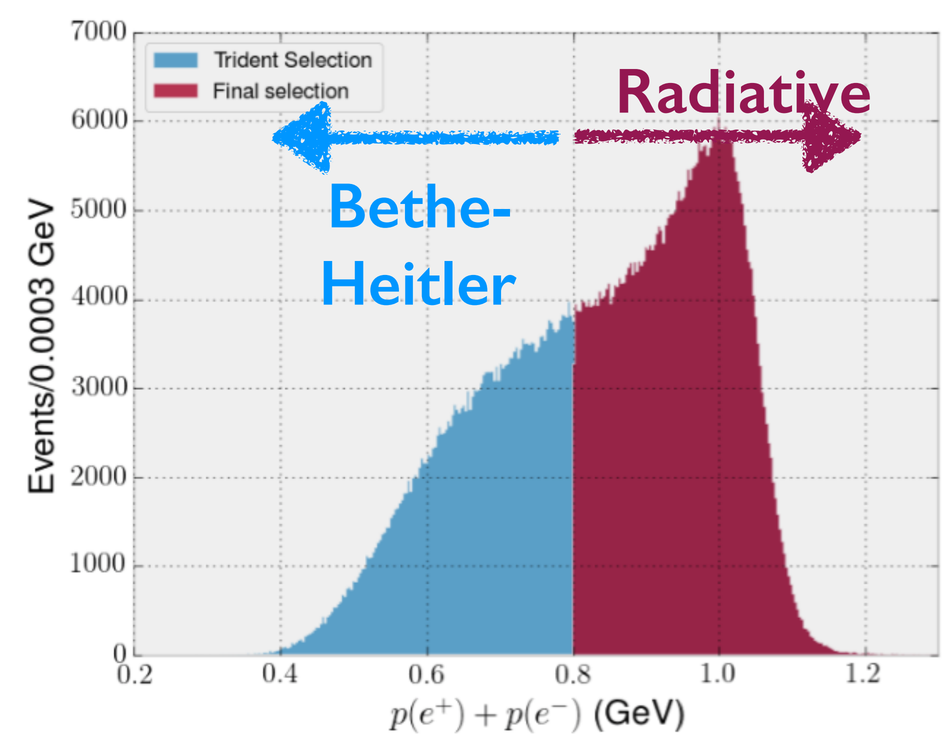




Bethe-Heitler

different kinematics, cross section >> radiative, dominant





HPS Proposed Reach

HEAVY PHOTON SEARCH

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invariant mass peak

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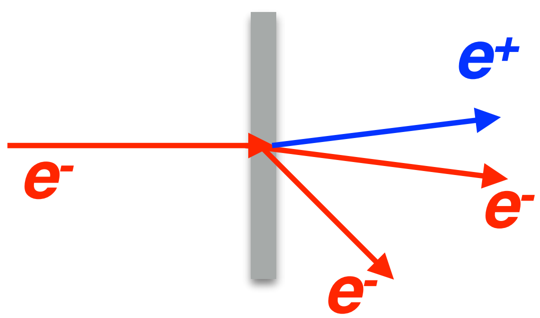
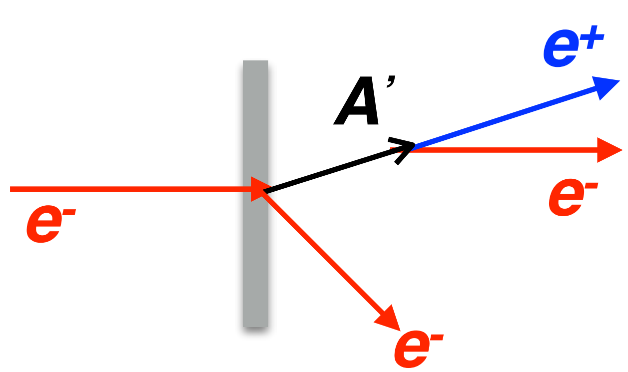


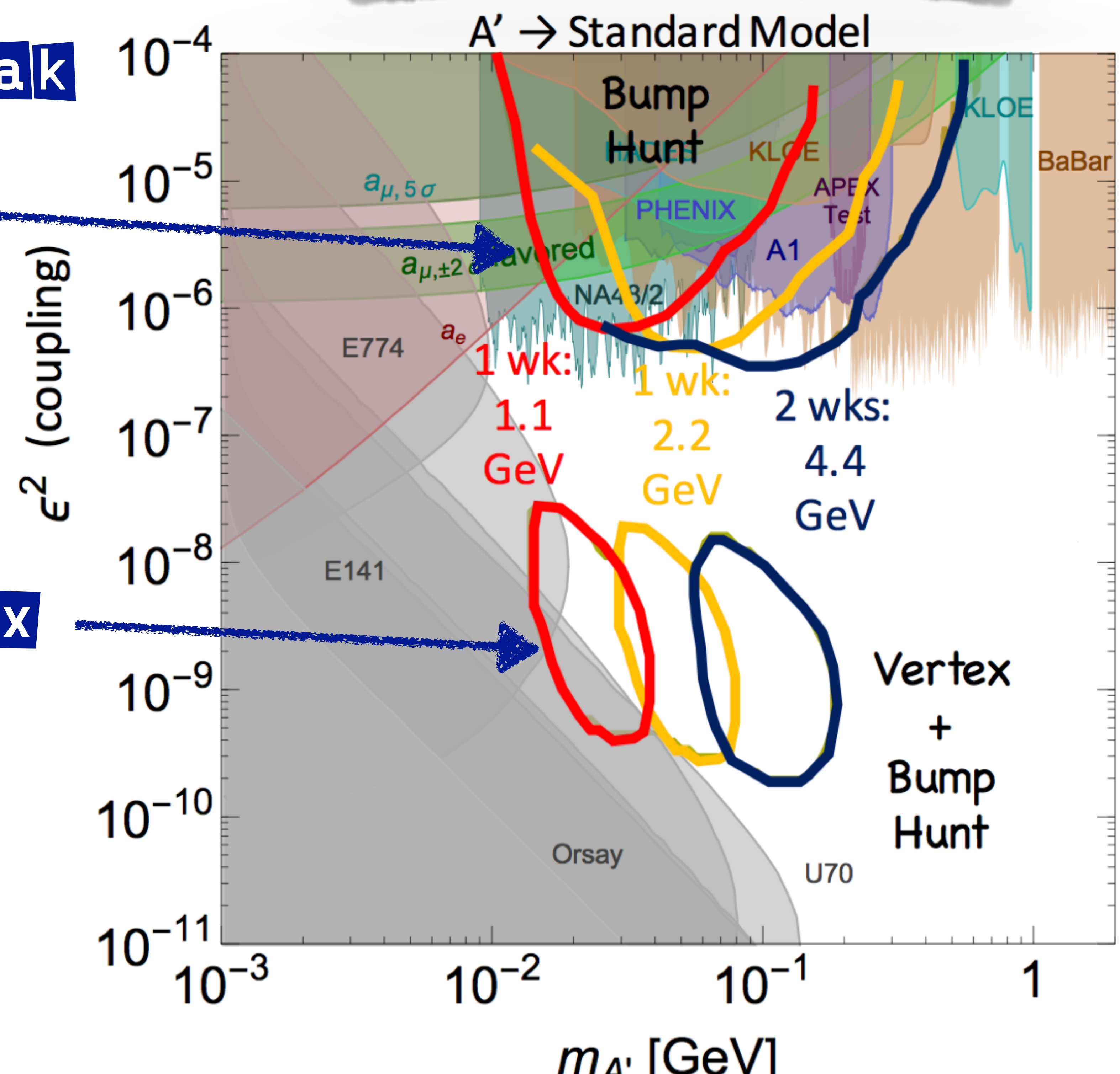
Peak on large SM background

Displaced Vertex

Small ϵ coupling - A' long-lived



Few events, no-background, displaced decay vertex



HPS Proposed Reach

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Run Status to date:

<u>Spring 2015: Engineering Run</u>

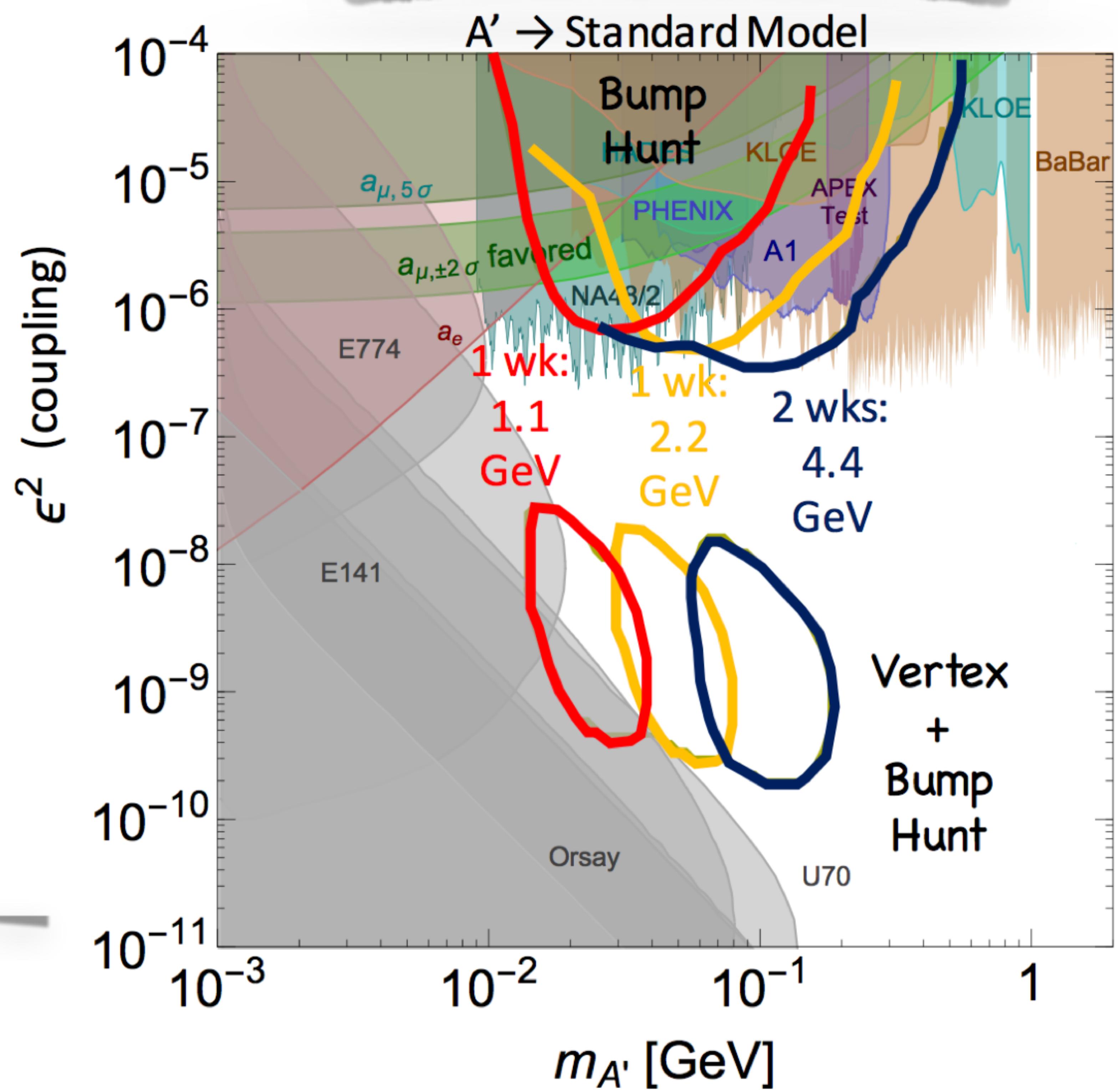
1.05 GeV, 50 nA

Achieved 30% of proposed production data

<u>Spring 2016: Physics Run</u>

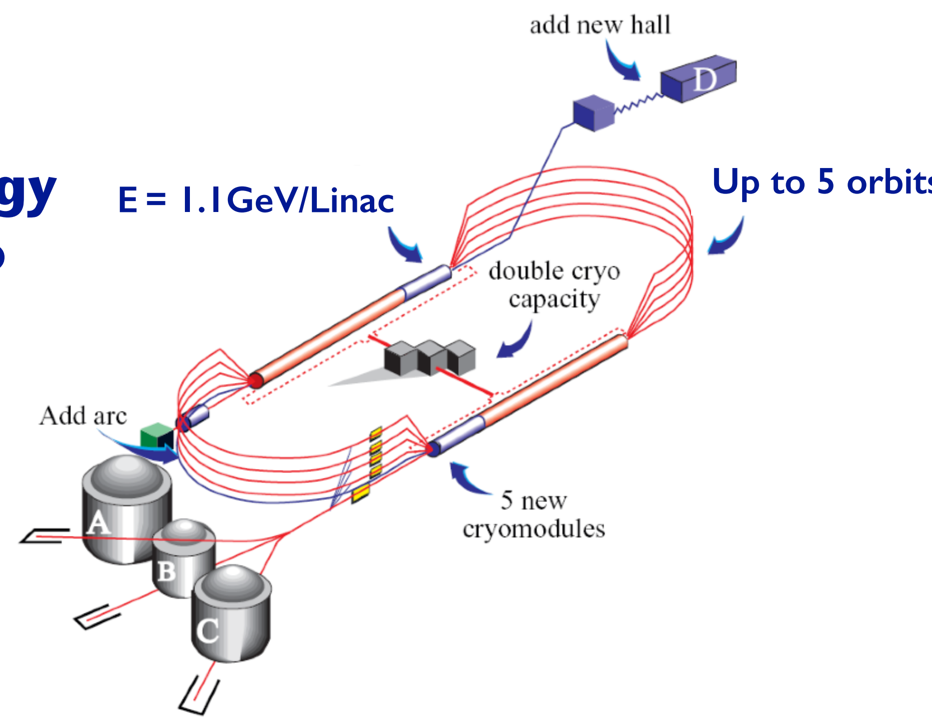
2.3 GeV, 200 nA

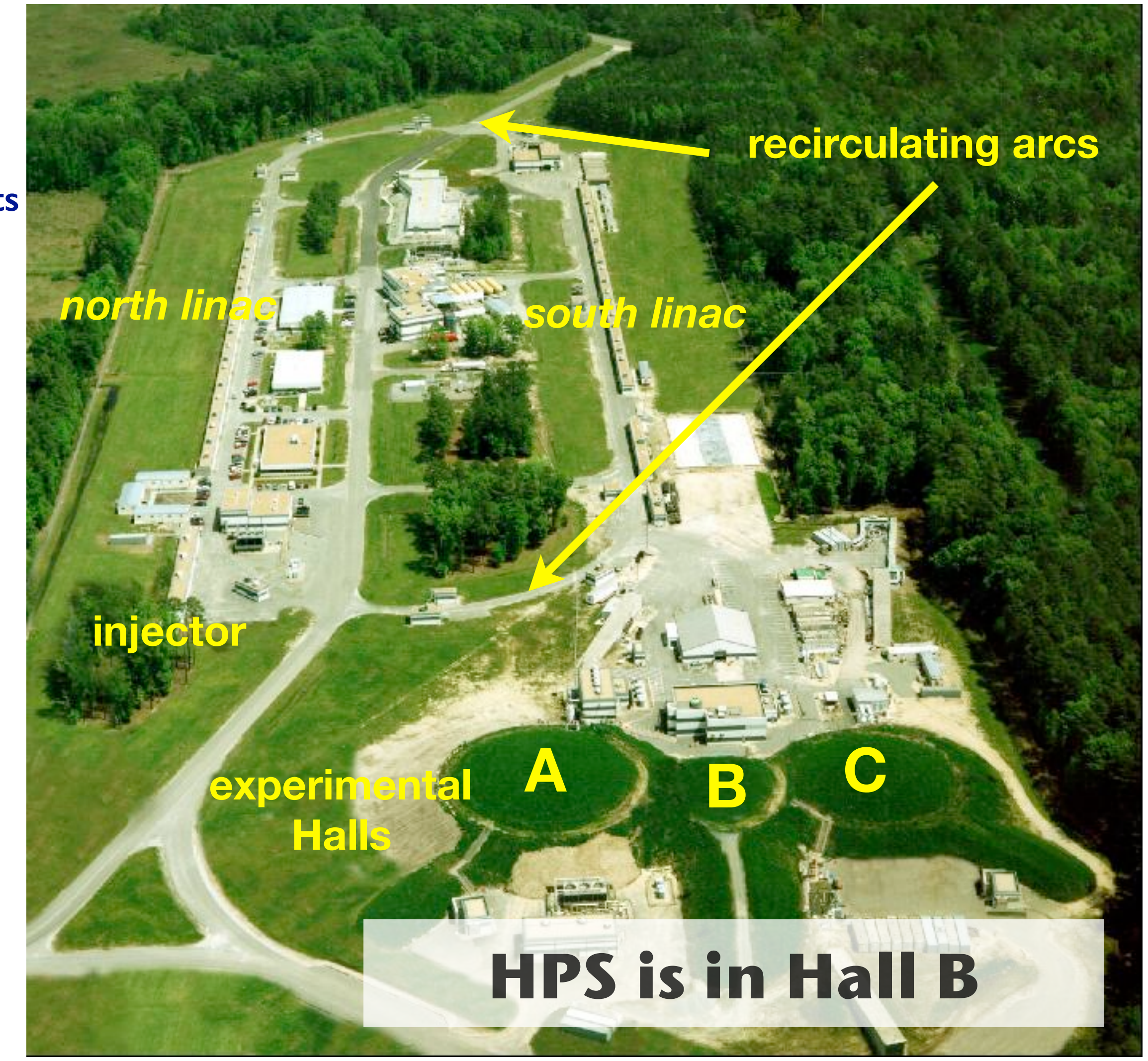
Achieved 77% of proposed production data



Continuous Electron Beam Accelerator Facility

JLab recently completed the energy upgrade from 6 to E_{max} =12 GeV





HIGH

Intensity

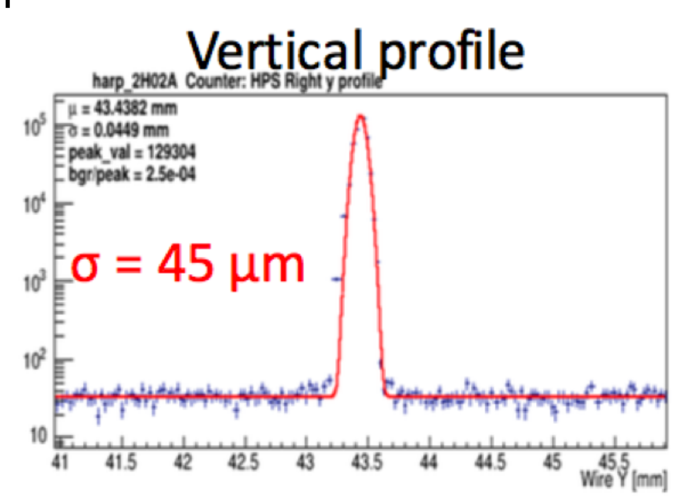
I_{beam} < 100 μA Hall A, C - < 800 nA - **Hall B (HPS: 50 - 400 nA)**

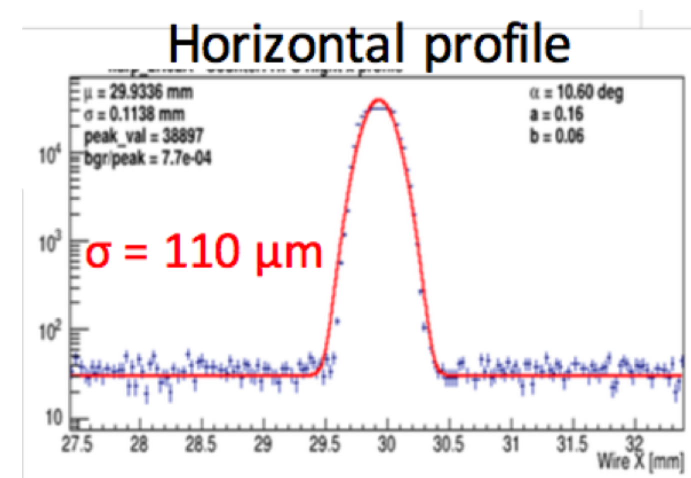
Frequency

~ DC beam, **2 ns bunch separation** (1 bunch ~ 10000 e^-)
Spread out beam background over time for manageable occupancies

Quality

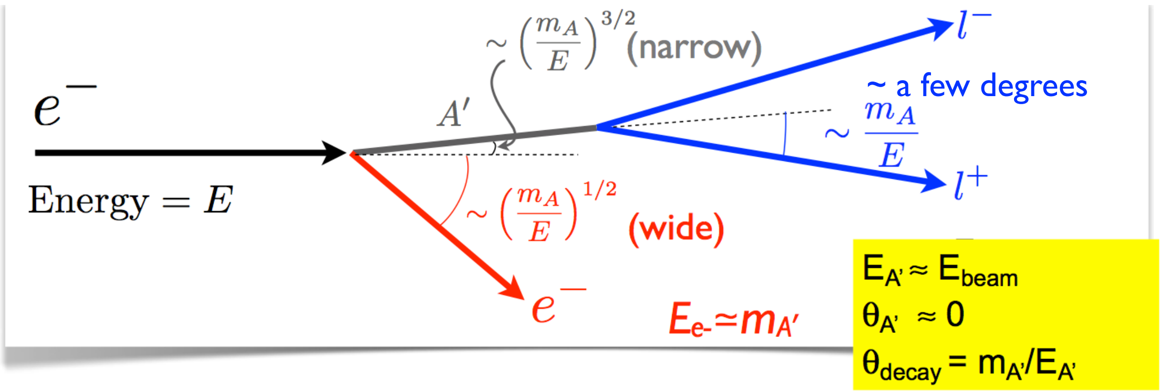
Tight beam spot in y helps tracking & vertexing
Very low halo = low background
Stable over time



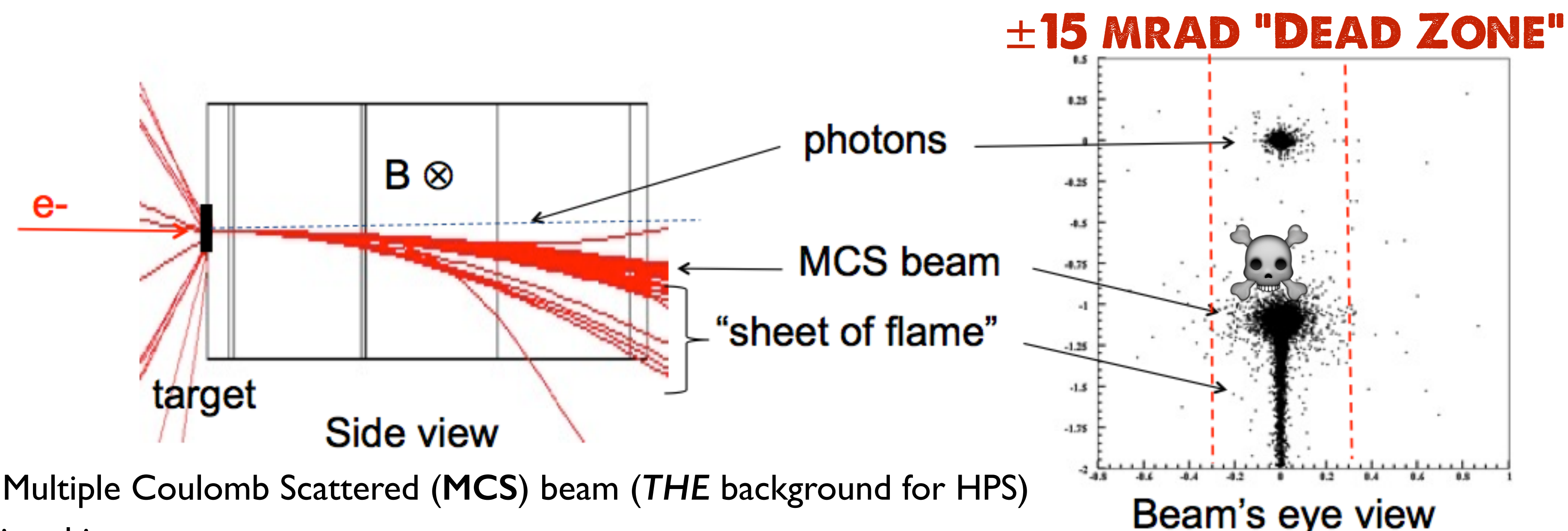


Controlling Beam Background

A' decay products highly boosted -> very forward acceptance detectors close to the target and the beam (just 0.5 mm for the first Si sensor)



BACKGROUNDS MATTER !



- Avoid most of the Multiple Coulomb Scattered (**MCS**) beam (*THE* background for HPS)
- Avoid photons radiated in target
- Avoid the electrons which have radiated photons, lost energy and been deflected in the horizontal plane by the magnet ("sheet of flame")
- Avoid beam gas interactions
- Avoid errant beam motions

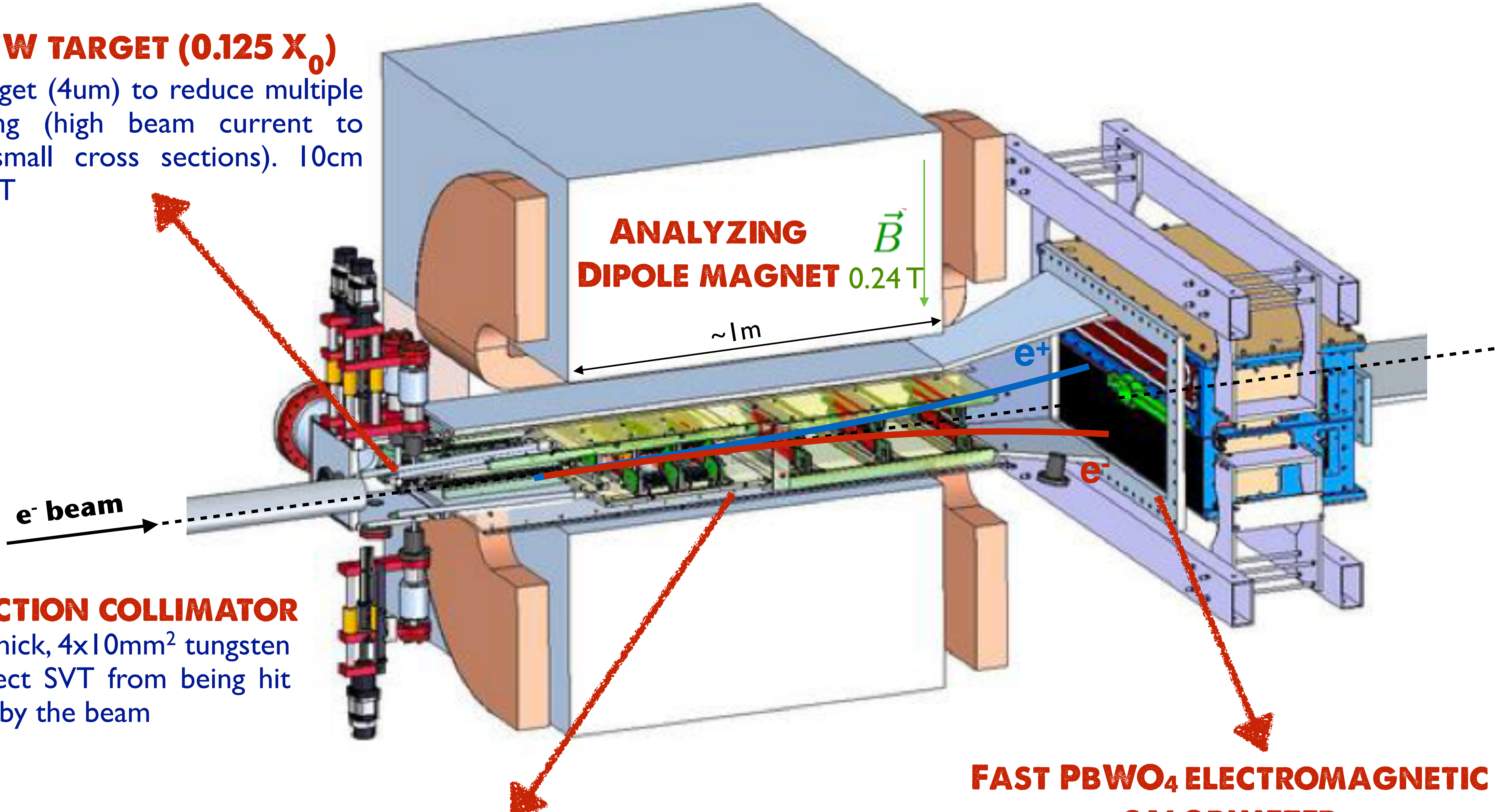
HPS design solutions

✓ Both SVT and Ecal are split vertically to avoid the "Dead Zone"
✓ SVT in vacuum to eliminate beam gas interactions
✓ Tightly collimate the incident beam
✓ A Fast Shut-Down stops the beam in <10 ms, if halo counters register above threshold counts.

HPS setup

THIN W TARGET (0.125 X_0)

Thin target (4um) to reduce multiple scattering (high beam current to probe small cross sections). 10cm from SVT



PROTECTION COLLIMATOR

10mm thick, 4x10mm^2 tungsten to protect SVT from being hit directly by the beam

COMPACT SI MICROSTIP TRACKER

- ✓ Determine invariant mass of A′ decay products (estimate momentum vectors)
- ✓ Distinguish A′ decay vertexes as non-prompt (extrapolate tracks to their origins)

FAST $PbWO_4$ ELECTROMAGNETIC CALORIMETER

- ✓ electron identification
- ✓ Triggering on e+e- pairs

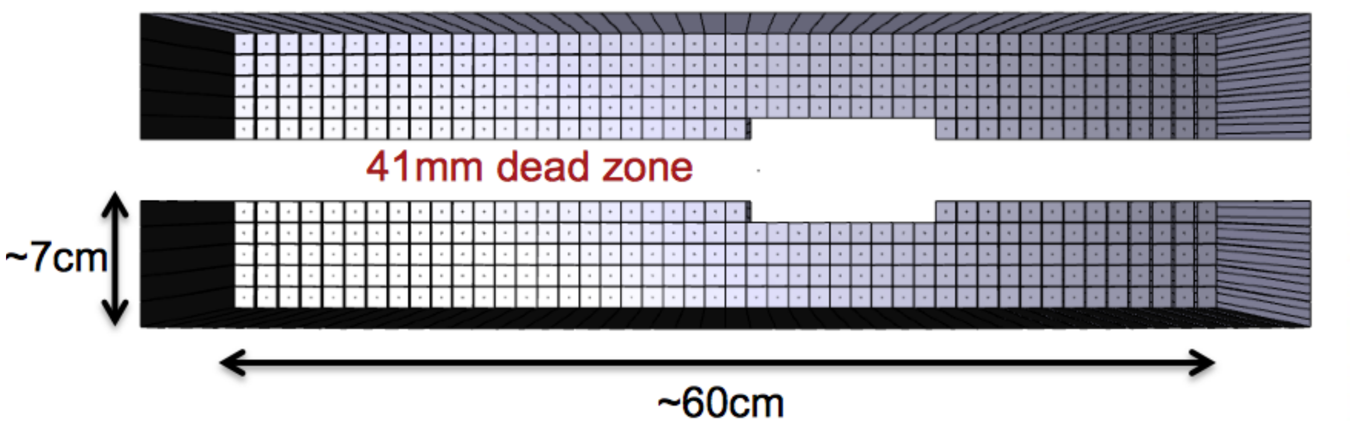
DAQ TRIGGER RATE UP TO 50 KHZ

Ecal

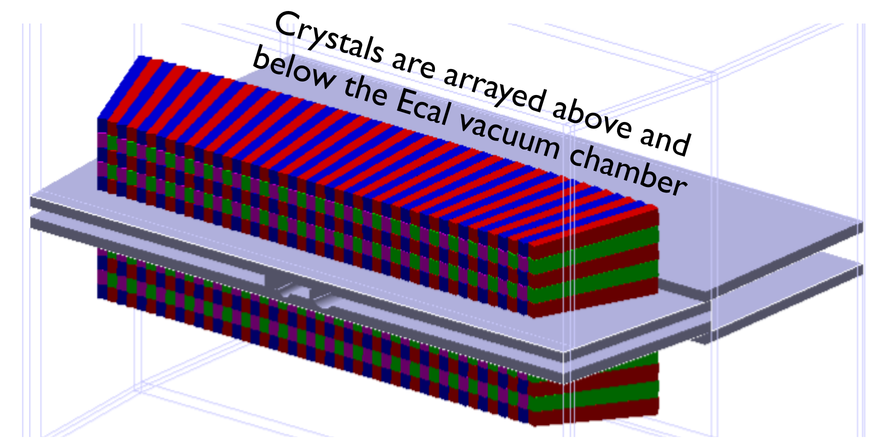
DESIGN

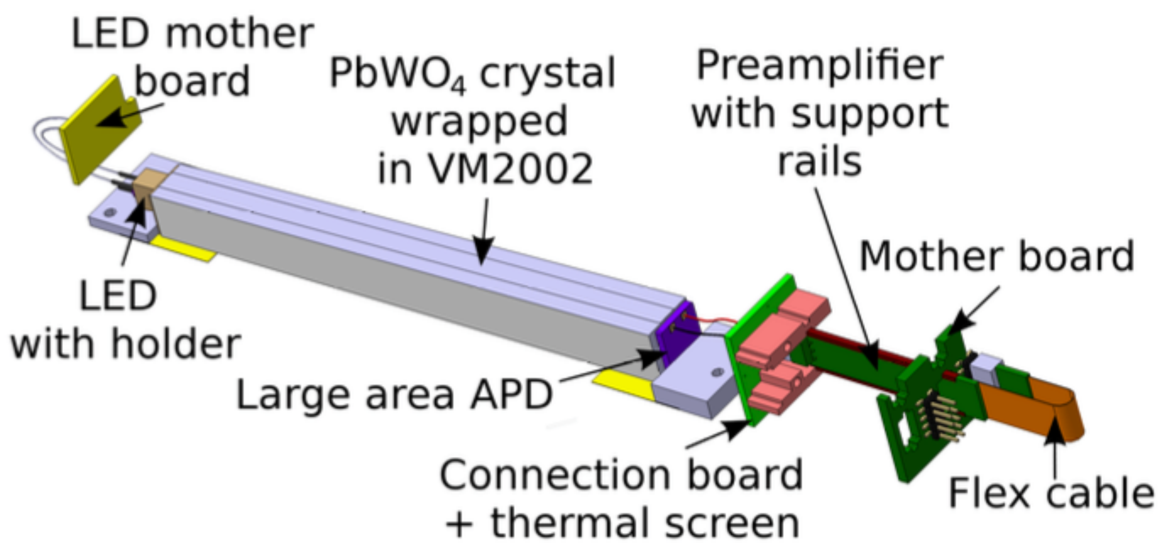
Fully absorb electrons with energies 0.5–6.5 GeV

442 $PbWO_4$ crystals: 13×13mm² (R_M~10mm), 160mm long ($4.5X_0$)

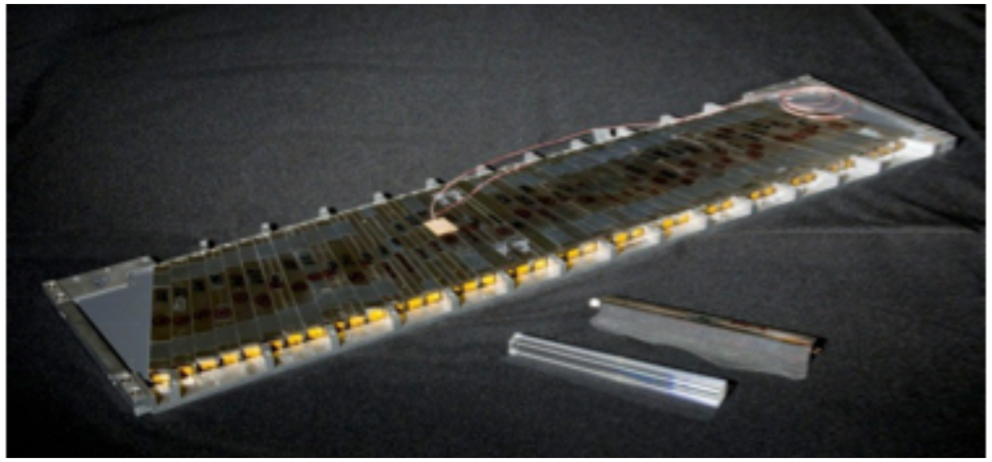


~ 137 cm from the upstream edge of the analyzing magnet





Modules are assembled inside temperature controlled enclosure to stabilize gains

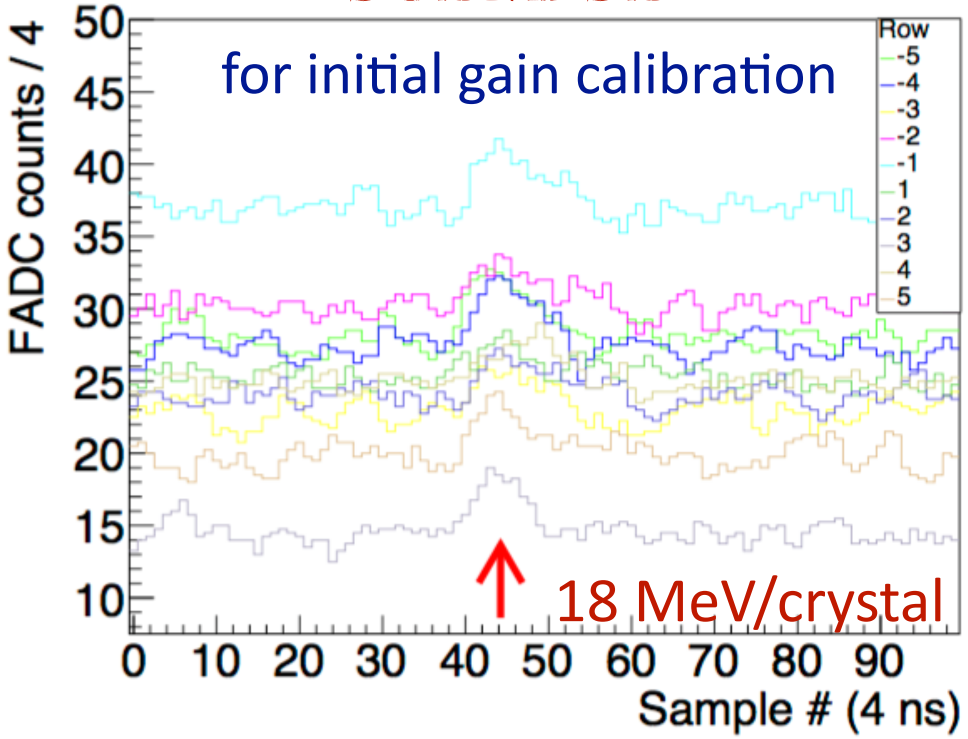


READOUT AND TRIGGER

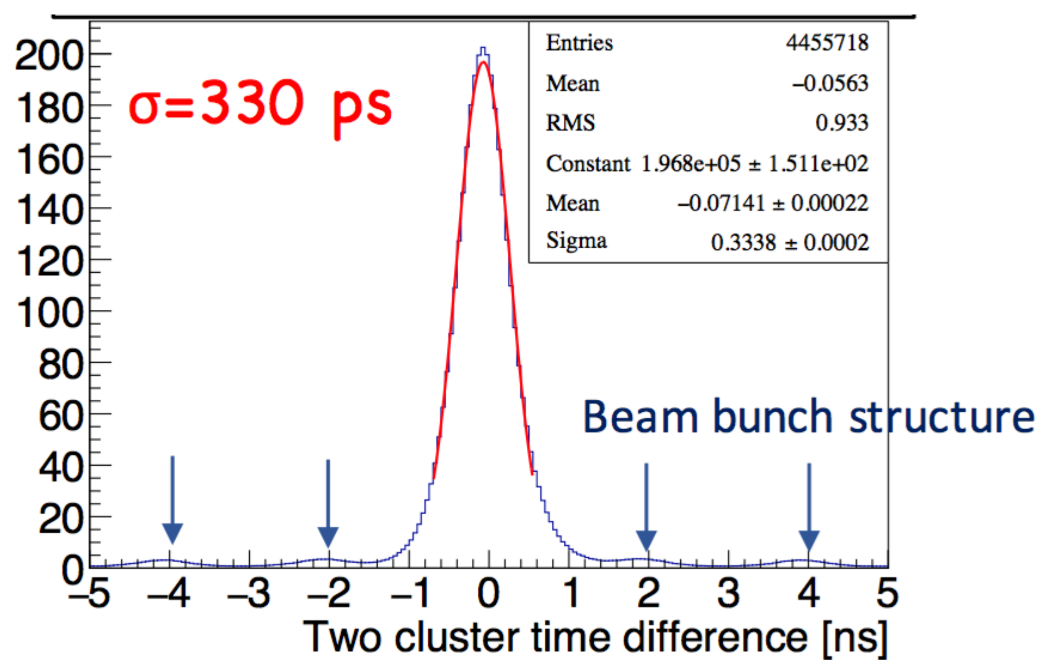
- Light readout by 10x10 mm² LA-APD (Hamamatsu S8664-1010) connected to custom pre-amp
- Data recorded with Jlab FADC250 VXS module, 250 MHz (4nsec) 12 bit, 8 usec time window
- Energy and time transferred every 16 ns to Trigger Processor FPGA for cluster finding
- Main Trigger (Pair1) : pair of clusters from top and bottom half in a 12 ns coincidence time window && cuts on cluster energies, coplanarity , …

2016 Run: Ecal Performance

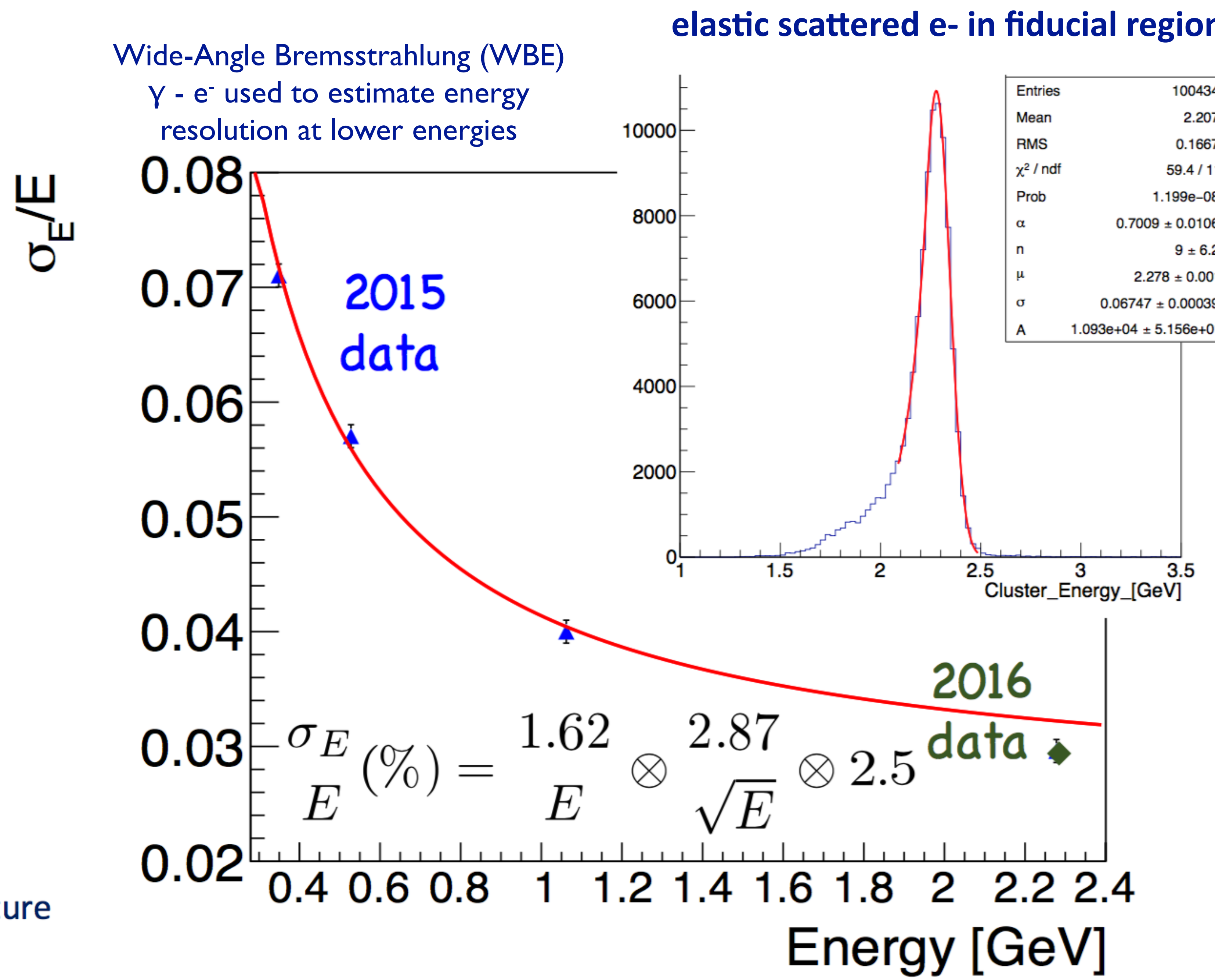
COSMICS



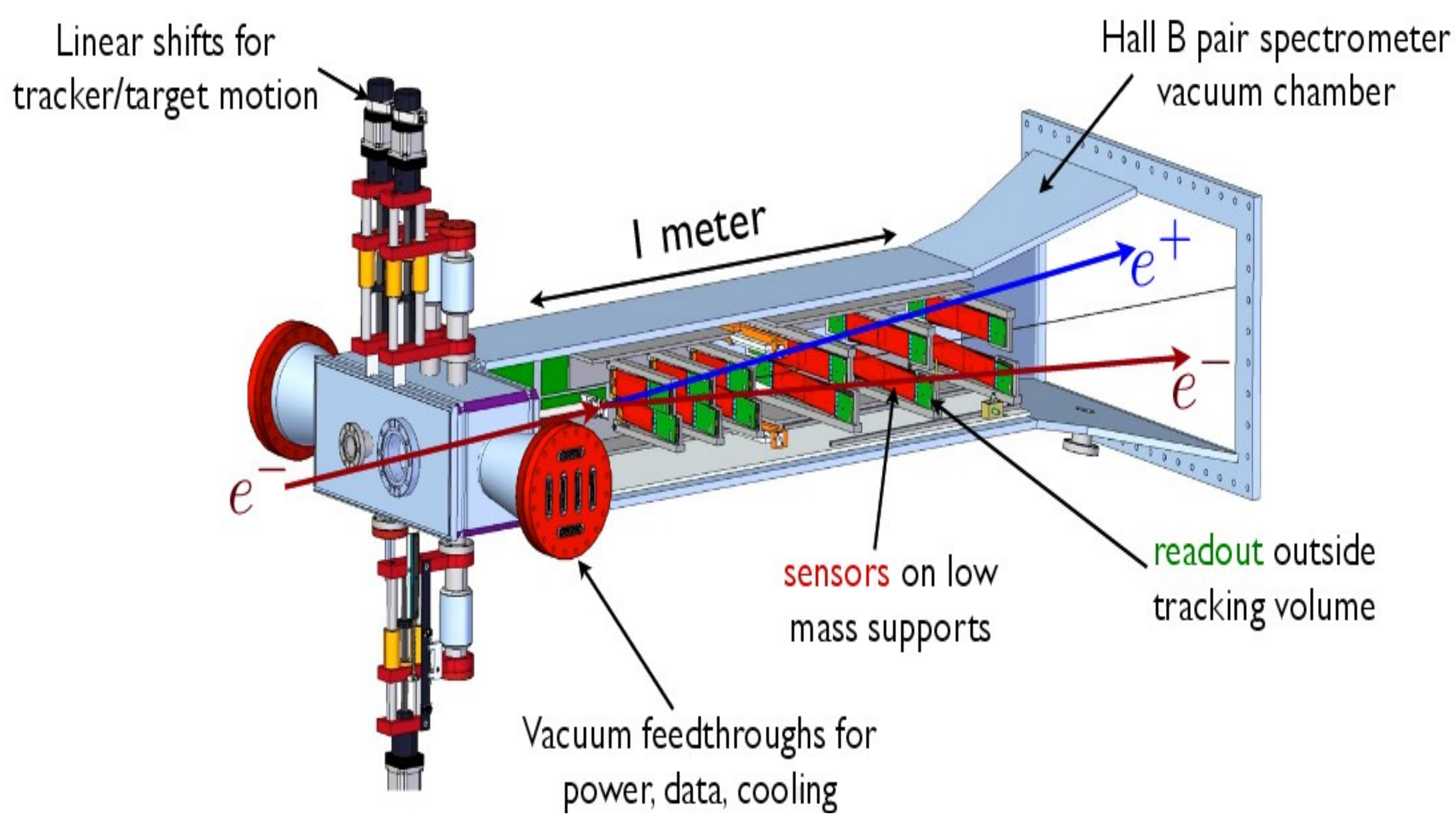
TIME DIFFERENCE BETWEEN TWO CLUSTERS

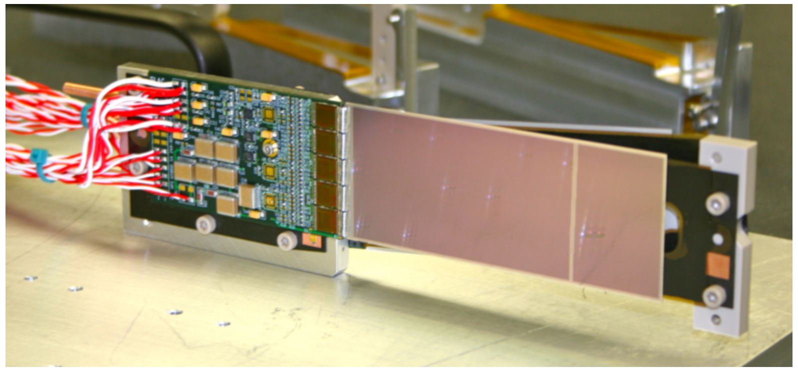


ENERGY RESOLUTION



SVT





Layer	1	2	3	4	5	6
z position from target (cm)	10	20	30	50	70	90
Stereo angle (mrad)	100	100	100	50	50	50
Bend plane resolution (μm)	≈6	≈6	≈6	≈6	≈6	≈6
Non-bend plane resolution (μm)	≈ 60	≈ 60	≈ 60	≈ 120	≈ 120	≈ 120
Nominal dead zone in y (mm)	± 1.5	± 3.0	± 4.5	± 7.5	± 10.5	± 13.5
Material budget ($\%X_0$)	.7	.7	.7	.7	.7	.7

DESIGN

- **6 layers** of detectors, split top-bottom, extending from 10 cm to 90 cm downstream of the target
- **Si microstrip** detectors single-sided 320 um thick, with 60 µm readout pitch over a 4x10 cm^2 surface.
  Tot: 36 sensors -> 23004 ch. Cooled to -14°C.
- (x,y) coordinates of a hit: two sensors per layer, one axial and the other at small stereo angle (100 or 50 mrad)
- **Thin layers** (0.7% X_0 per layer) to minimize Multiple Coulomb Scatt. dominating mass and vertexing uncertainties

READOUT

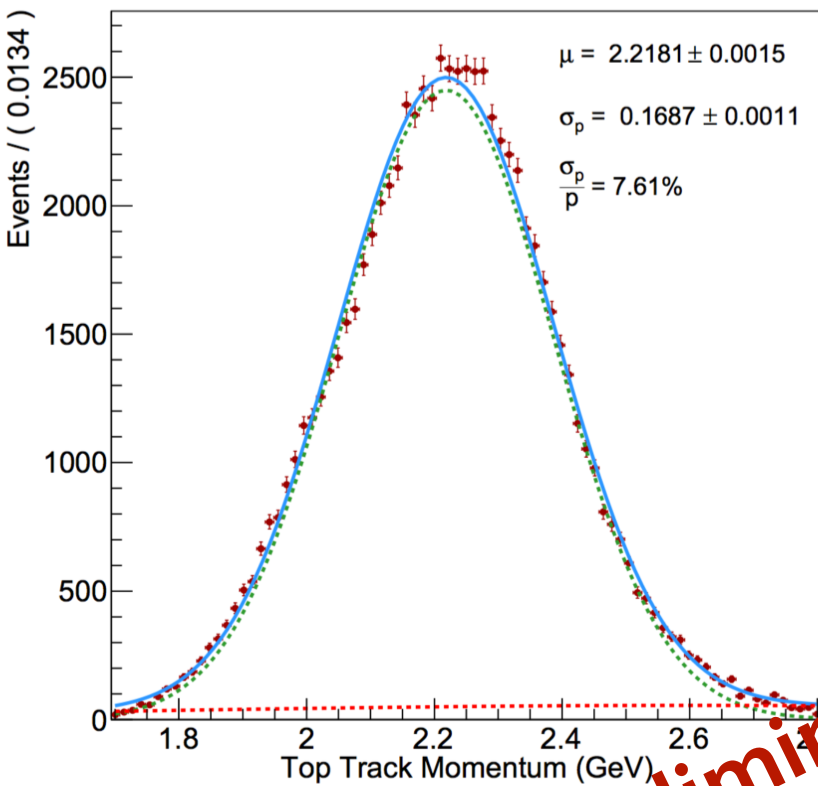
- CMS **APV25 ASIC chips** (128 ch), **40 MHz** continuous sampling (25 nsec).
- **Six-sample readout (2 before the trigger).** Short shaping time (50 ns -> shaper output evolution 250 nsec) to best distinguish overlapping hits
- Fit CR-RC shaping curve to determine the amplitude and the time of the hit
- Position and time of the cluster: amplitude-weighted mean of position and t_0 of individual hits

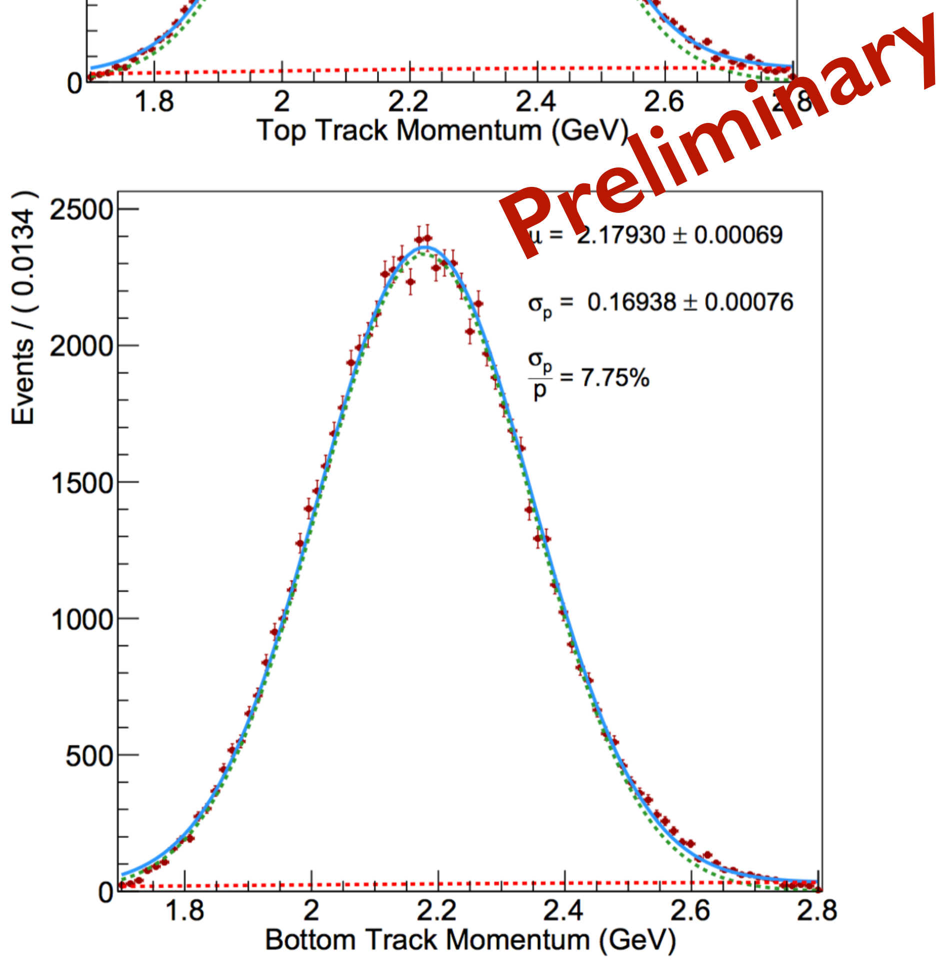
2016 Run: SVT Performance

- Calibration in progress
- Initial data, prior to alignment, already consistent with the proposal

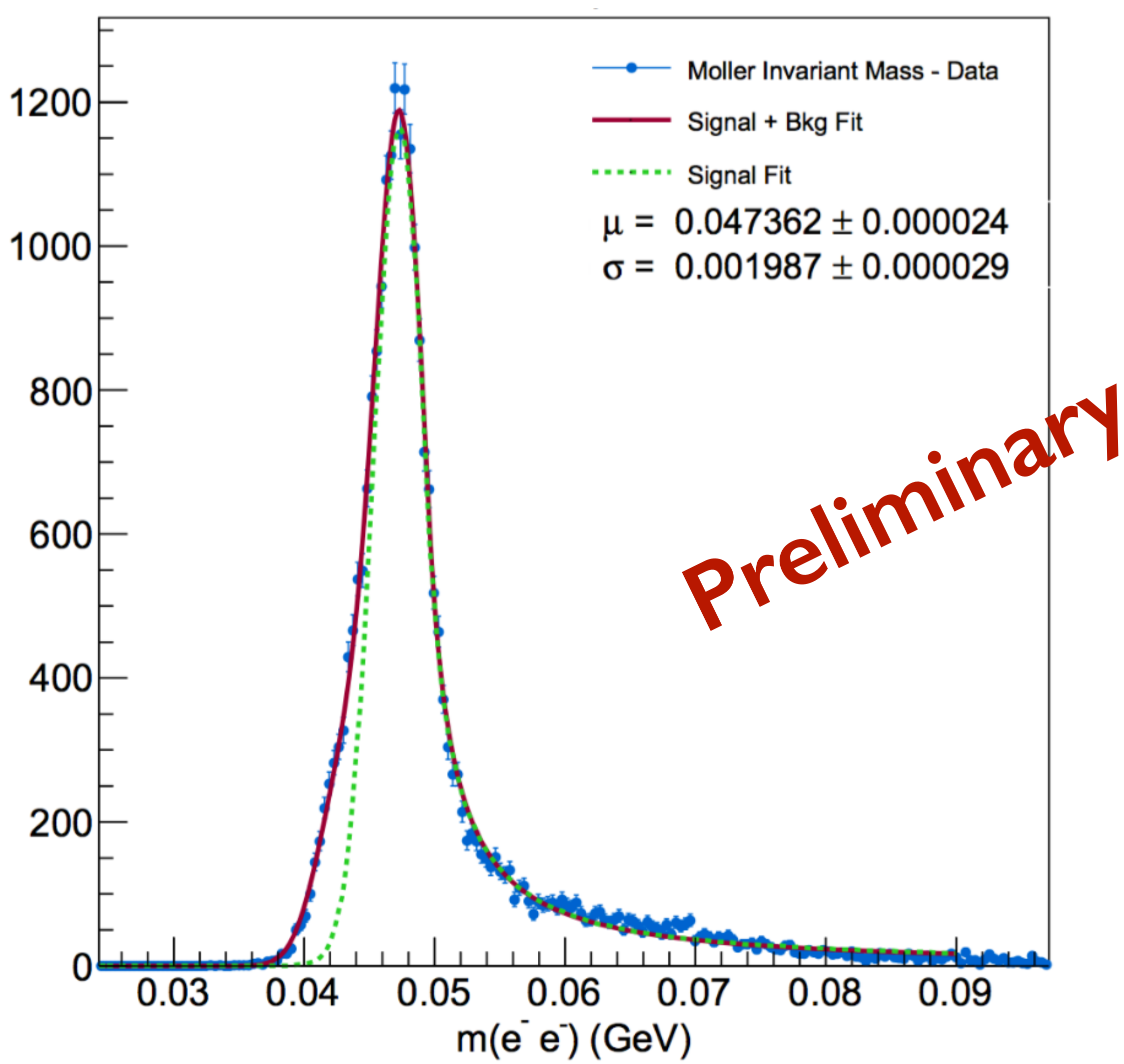
MOMENTUM RESOLUTION

Elastically scattered e-, initial data



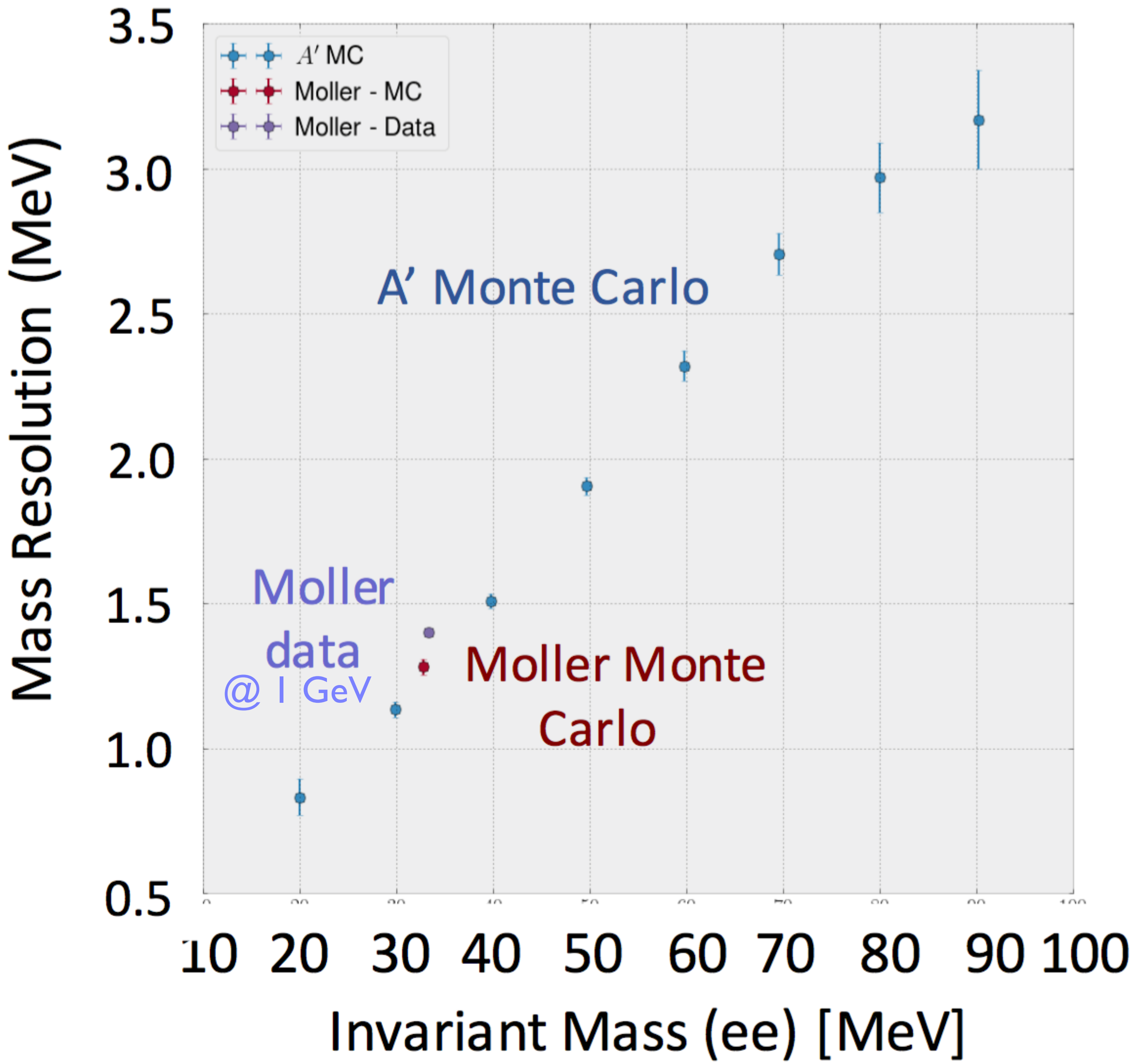


MOLLER MASS



Mass Resolution

A' is expected as a Gaussian peak over the QED trident background with the width corresponding to the mass resolution -> Crucial component of the resonance search.

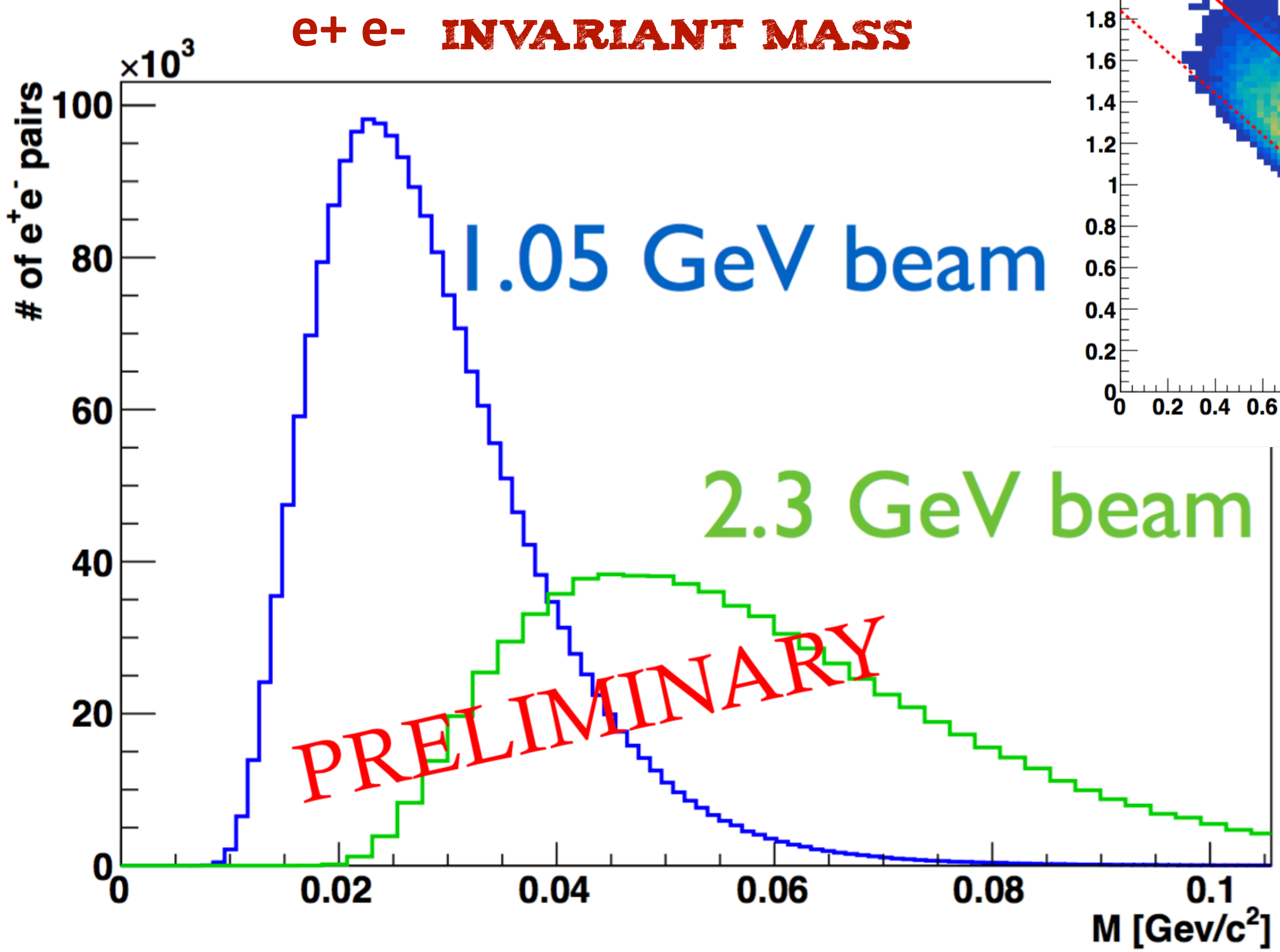


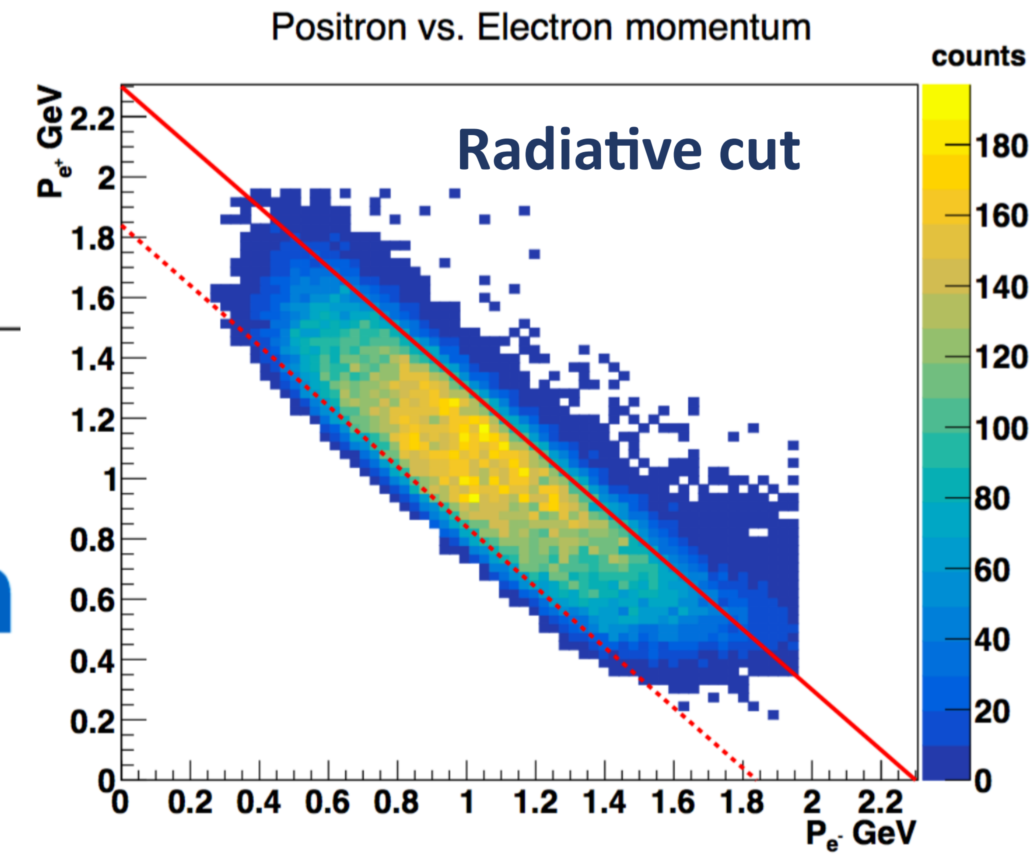
Pair mass resolution @ 33.2 MeV is **1.4 MeV (~4%)**,

Determining the mass resolution as a function of mass done by using A' signal and Moller Monte Carlo

Invariant Mass

Searching for the Heavy Photon using a
blinded analysis (10% of the data)



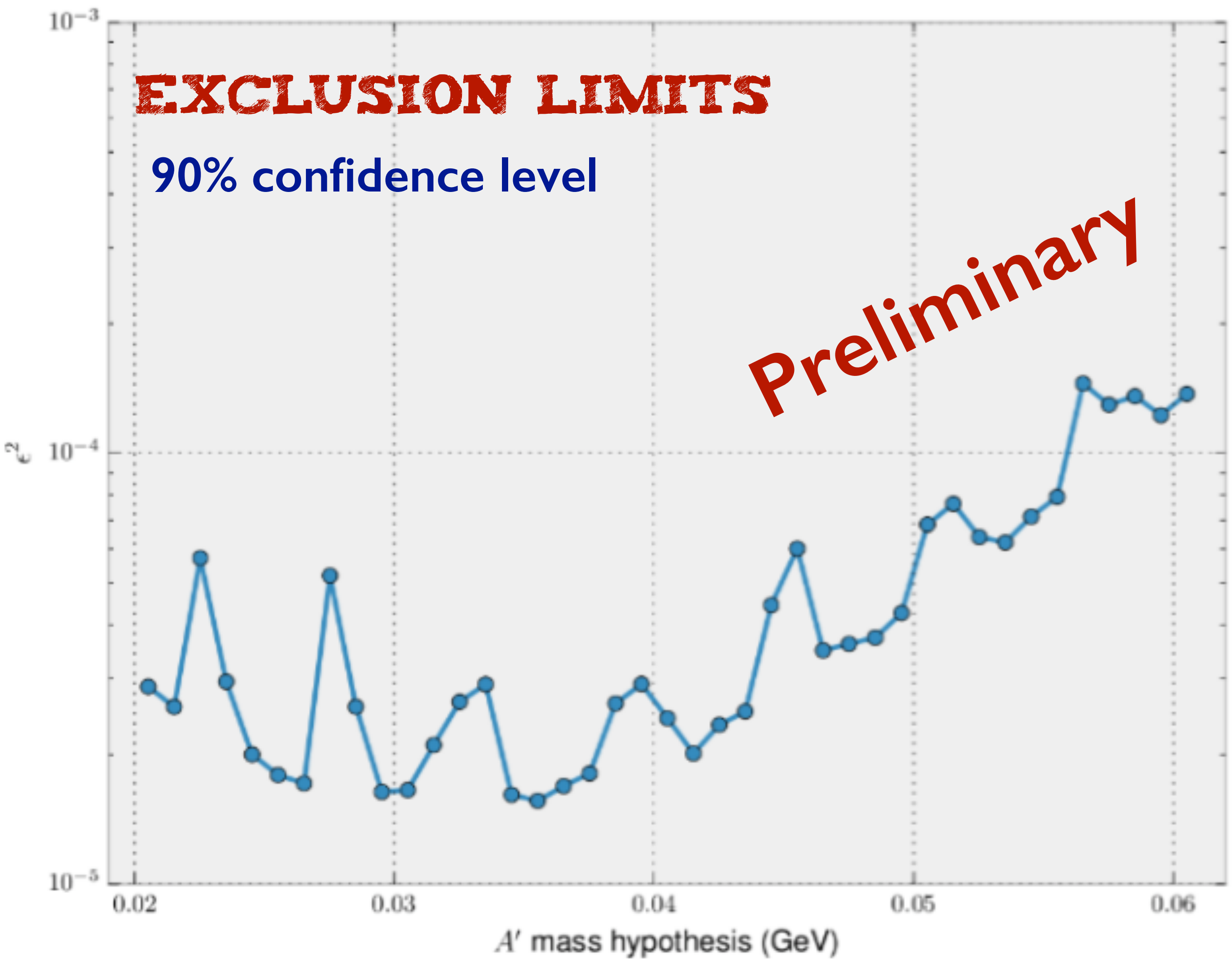


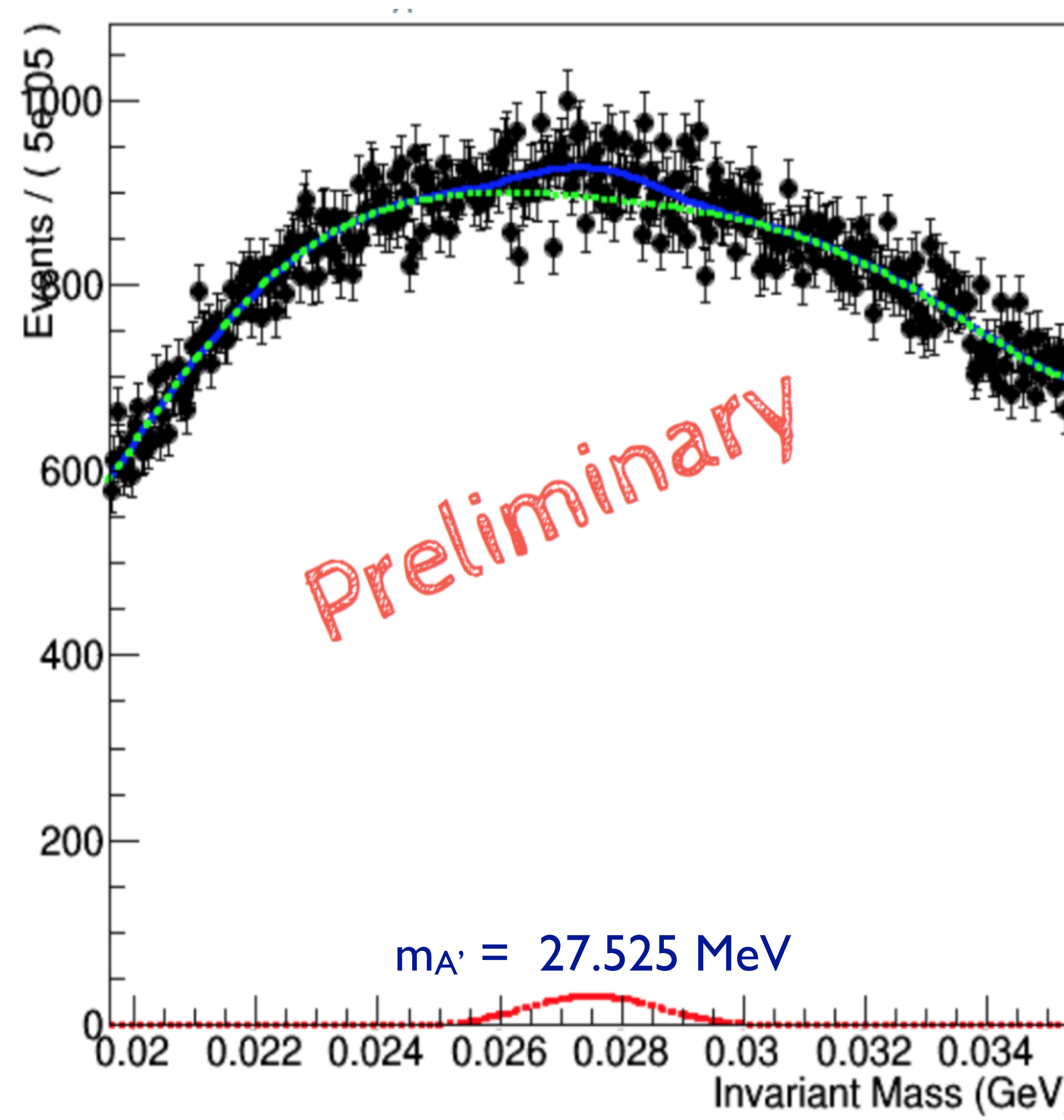
1 GeV Analysis: Bump Hunt

Search for a peak above the trident QED invariant mass spectrum

Maximum Likelihood method to test two hypothesis:

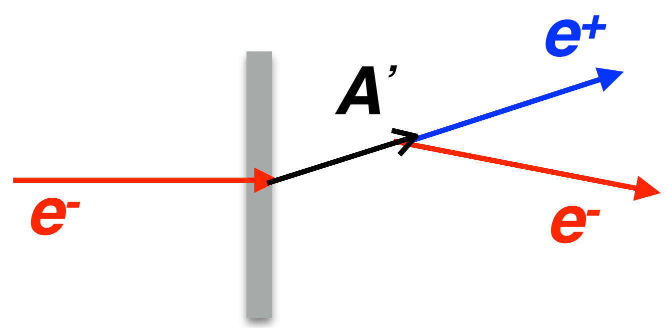
- background only (7th order polynomial)
- background + signal (Gaussian width given by exp. resolution)

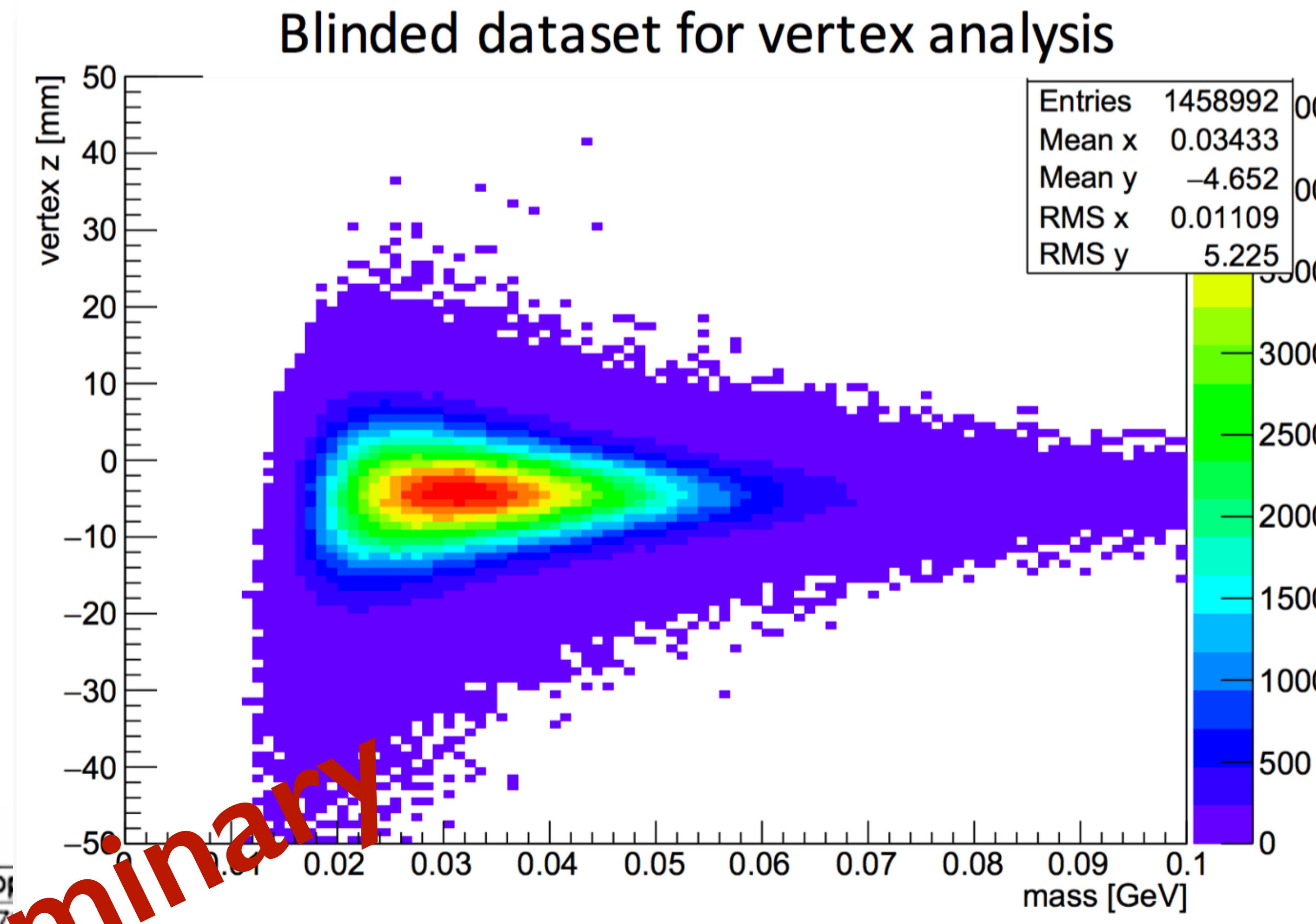


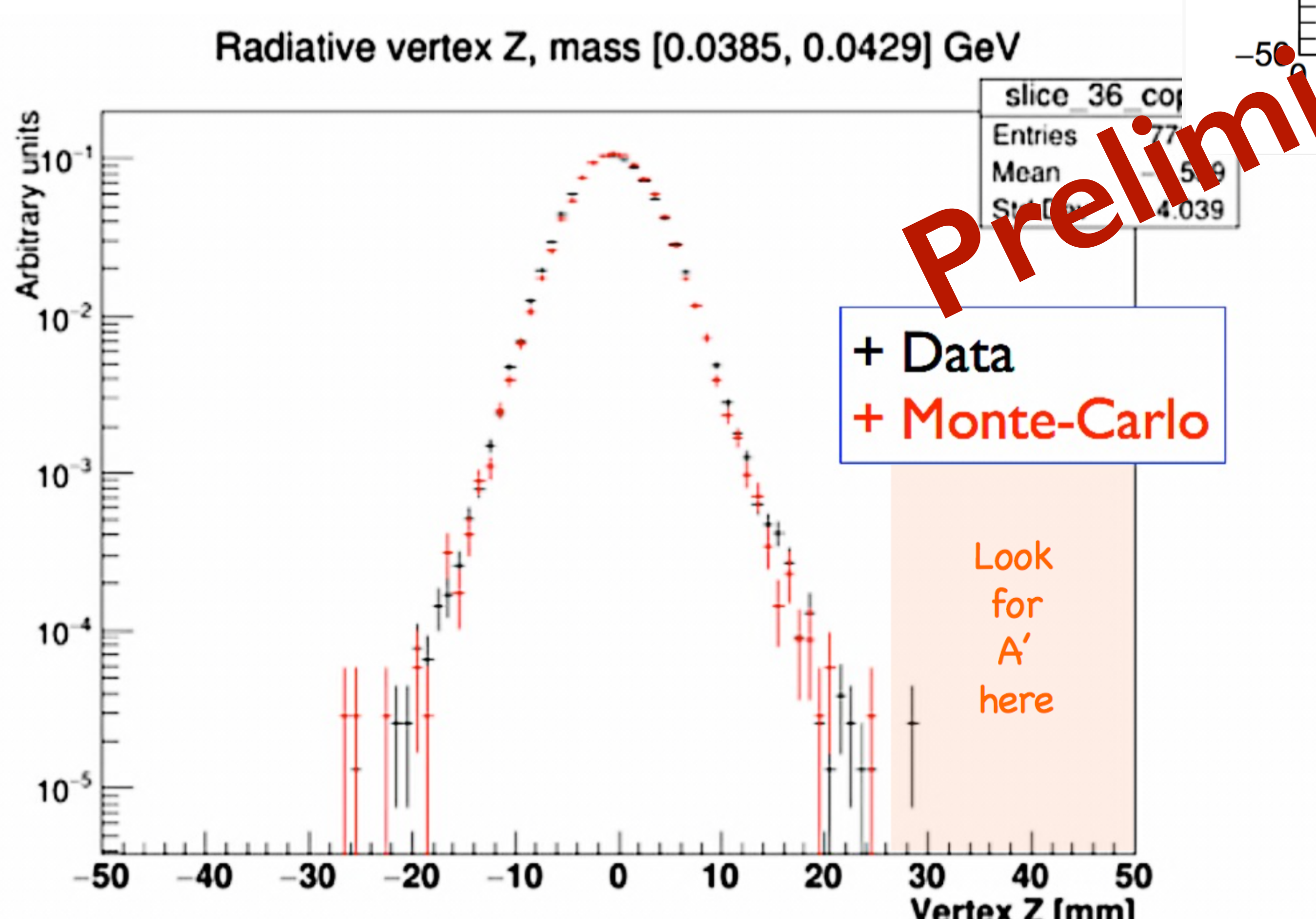


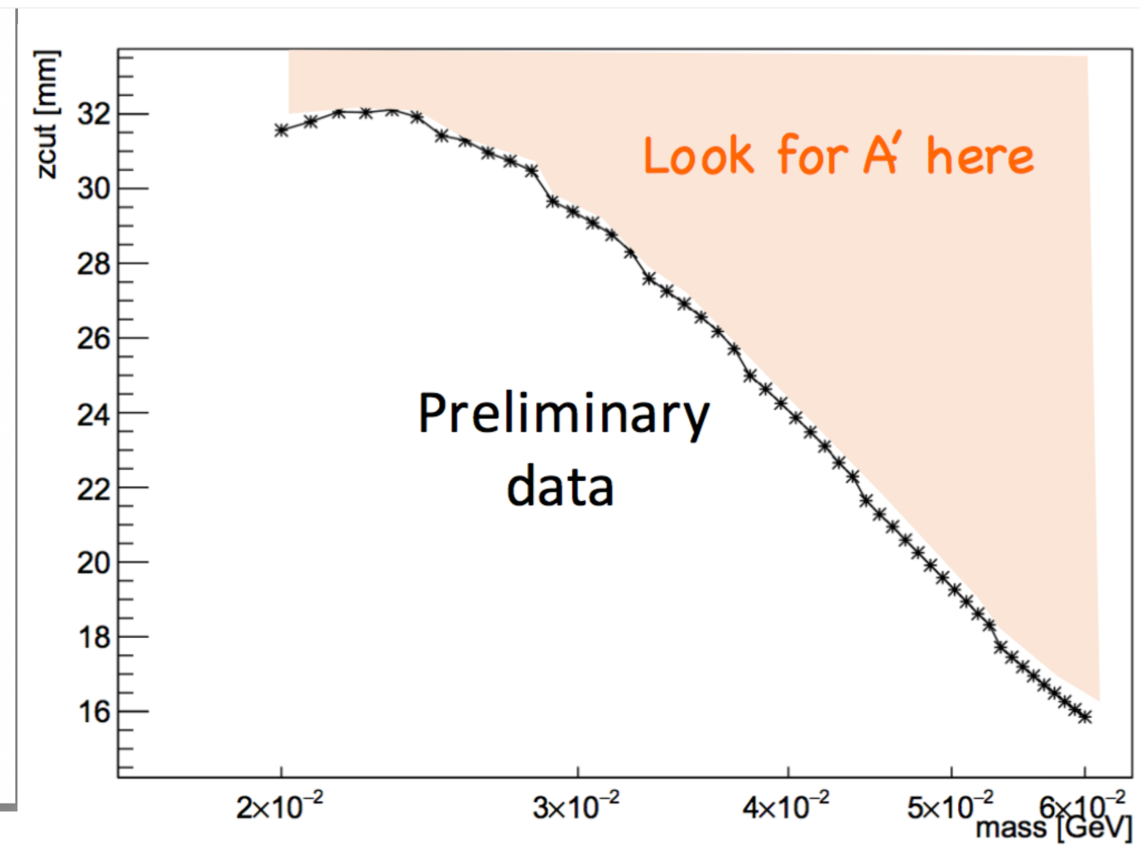
1 GeV Analysis: Vertex search

Search for long-lived A' with separated vertex









Summary

Successful short runs in 2015 and 2016 with data taken for both bump hunt and vertex search for Heavy Photons

Data analysis demonstrated good ECal and SVT performance during these runs

Instrumentation papers are in preparation for the beamline, SVT. Ecal NIM recently submitted arXiv:1610.04319

Finalizing analysis and expecting results in early 2017

165 days still remain: we expect next physics runs in 2018 and later

Trigger

$$E_{\text{min}} \leq E_i \leq E_{\text{max}},$$

$$E_{\text{sum min}} \leq E_1 + E_2 \leq E_{\text{sum max}},$$

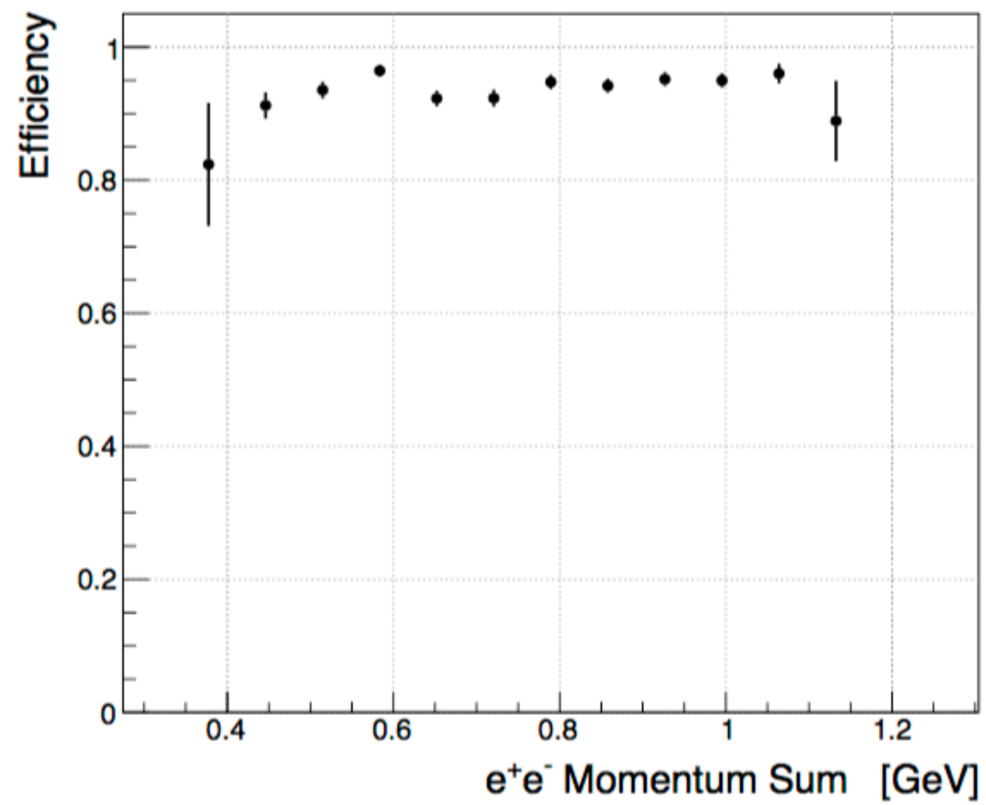
$$N_i \geq N_{\text{threshold}},$$

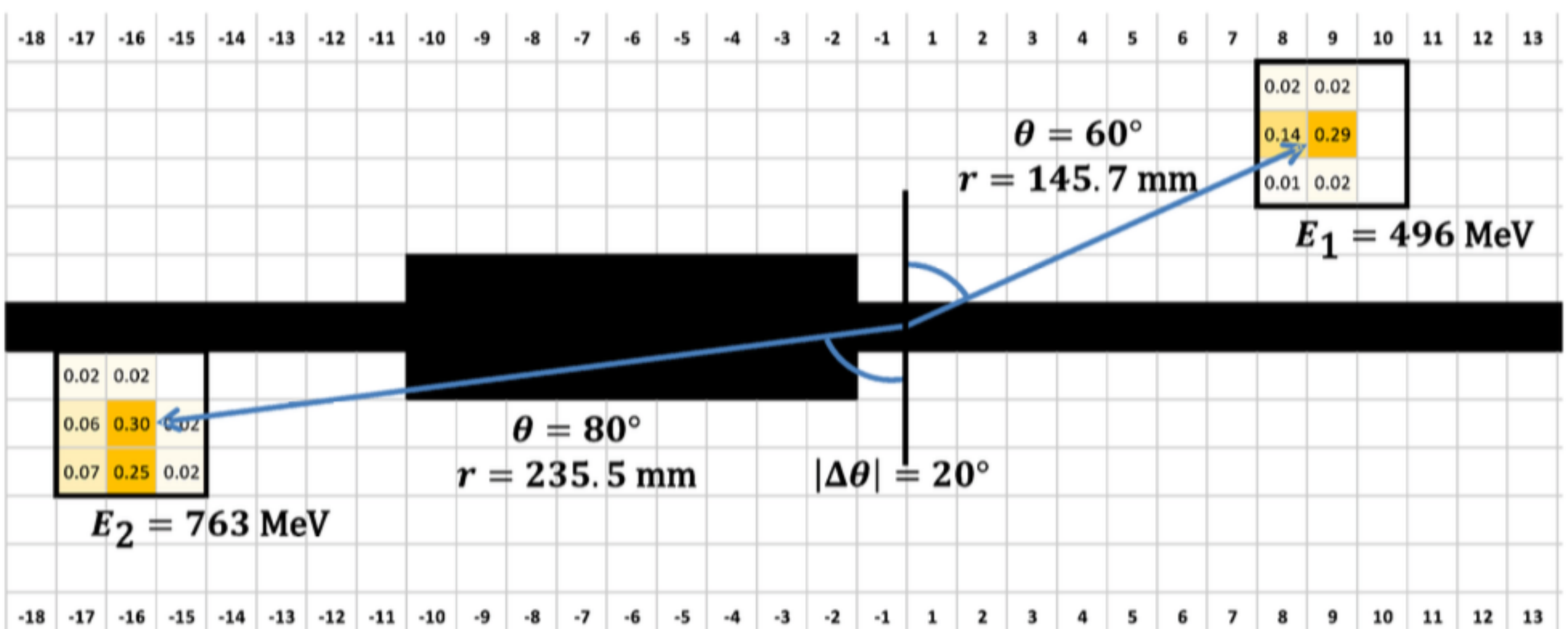
$$E_2 - E_1 \leq E_{\text{difference}},$$

$$E_1 + r_1 F \geq E_{\text{slope}},$$

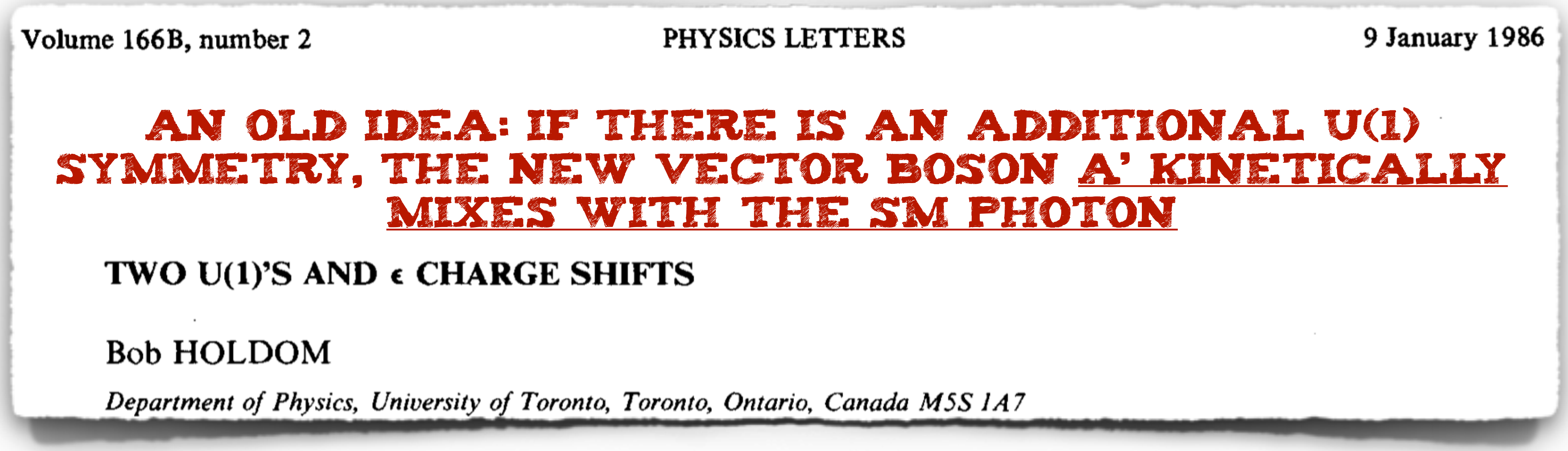
$$|\arctan \frac{x_1}{y_1} - \arctan \frac{x_2}{y_2}| \leq \theta_{\text{coplanarity}},$$

$$|t_1 - t_2| \leq t_{\text{coincidence}}.$$





Motivation


Volume 166B, number 2 PHYSICS LETTERS 9 January 1986

TWO U(1)'S AND ϵ CHARGE SHIFTS

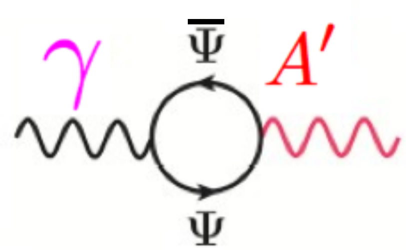
Bob HOLDOM

Department of Physics, University of Toronto, Toronto, Ontario, Canada M5S 1A7

$$\Delta\mathcal{L} = \frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}$$

"Kinetic mixing"

Loops of heavy particles charged under photon and A'



A' acts as a "portal" between the SM and the new sector