Status update for the Heavy Photon Search experiment

Rafayel Paremuzyan, on behalf of HPS collaboration

University of New Hampshire

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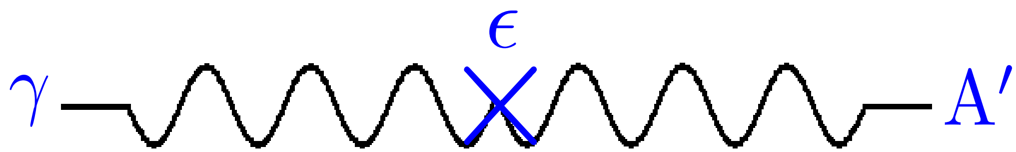
Introduction

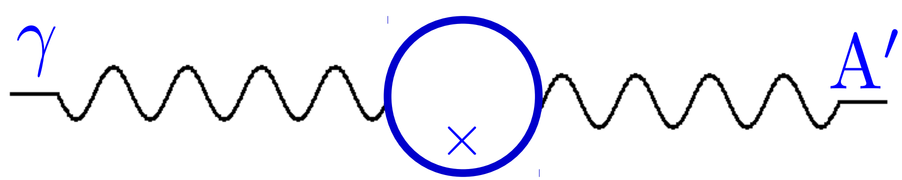
What, if Nature contains an additional broken U(1) (Abelian) force mediated by a massive vector boson, A'? Bob Holdom, Phys.Lett.,B166, 2, (1986)

$$\mathcal{L} = \mathcal{L}_{SM} + \underbrace{\frac{\epsilon}{2} F^{Y,\mu\nu} F'_{\mu\nu}}_{\text{Kinetic Mixing}} + \frac{1}{4} F'^{\mu\nu} F'_{\mu\nu} + m_{A'^2} A'^{\mu} A'_{\mu}$$



ϵ is the mixing strength

generated by heavy particles
$\times$ interacting with γ and A'

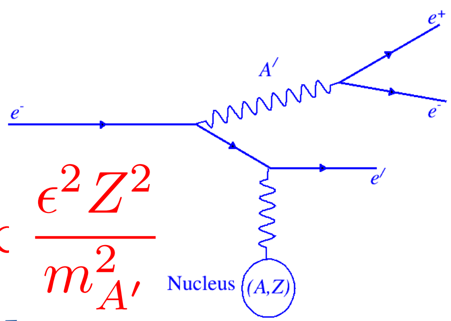


Many Dark Matter searches are based on this hypothesis

Producing A' in fixed target experiments

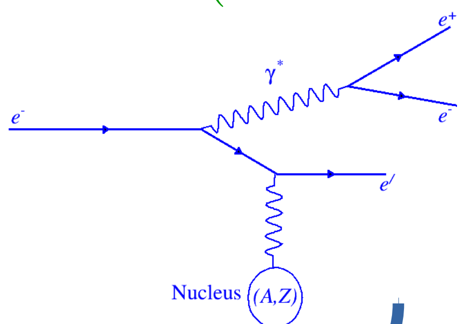
Since A' "can" couple to electric charge, then it is possible to expect it to be produced in a Bremsstrahlung process

A' production

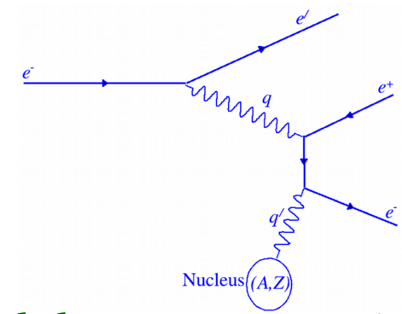


$$\sigma \propto \frac{\epsilon^2 Z^2}{m_{A'}^2}$$

Prodution of Timelike photon (radiative Tridents)

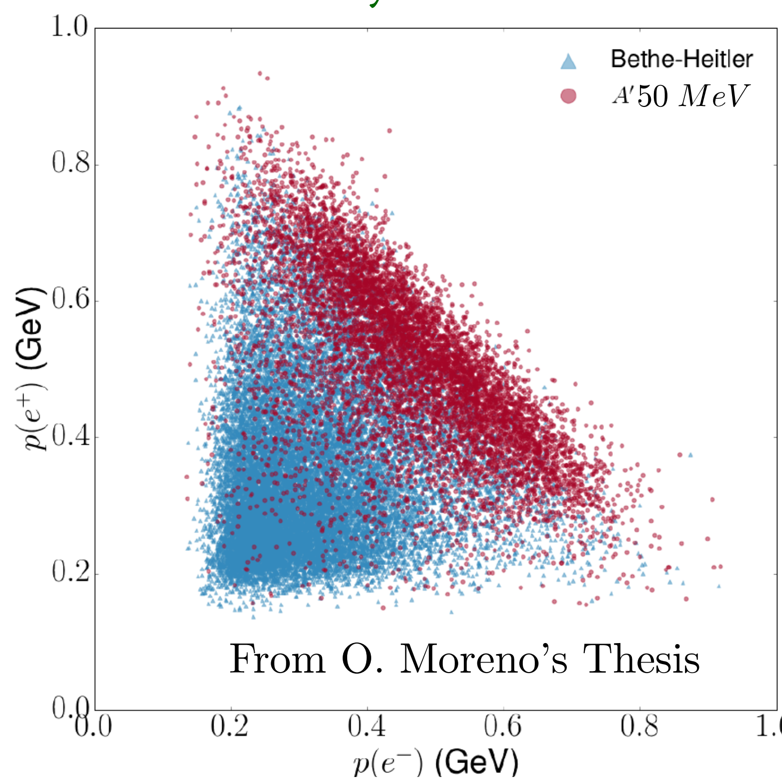


Bethe Heitler



Indistinguishable kinematics

Much larger cross section,
But very different kinematic



From O. Moreno's Thesis

Angle: Forward

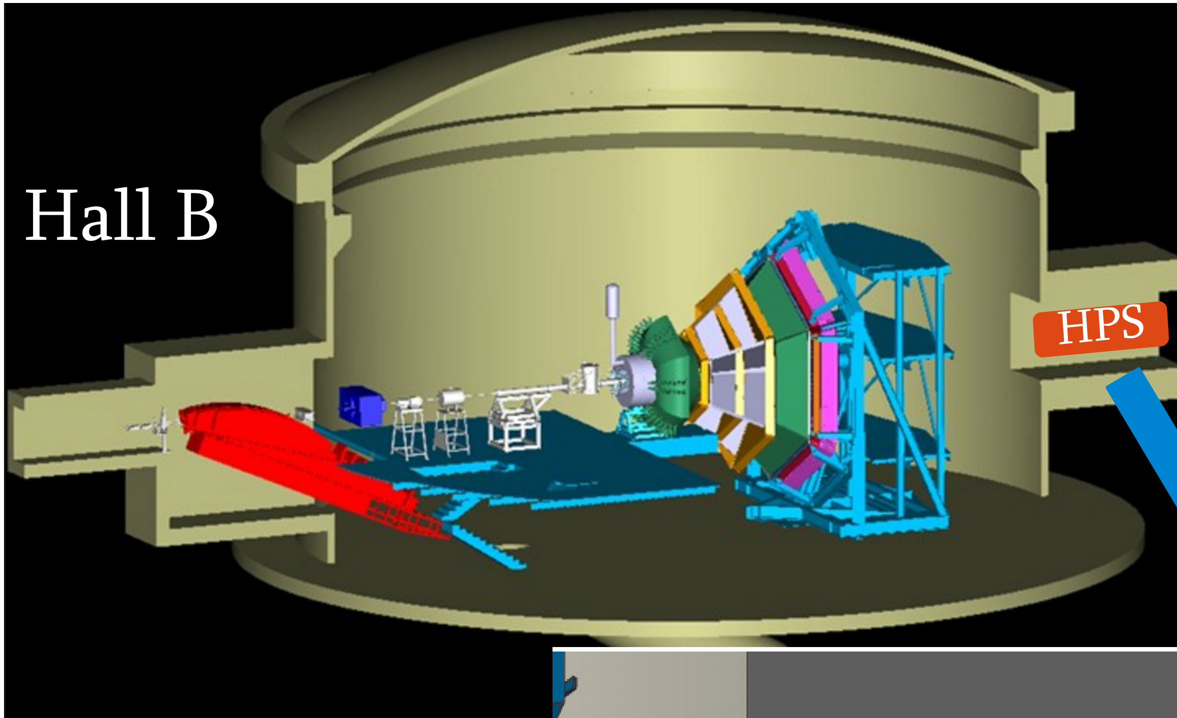
$$\theta_{A'\,\max} \sim \max\left(\frac{\sqrt{m_{A'} m_e}}{E_0}, \frac{m_{A'}^{3/2}}{E_0^{3/2}}\right)$$

Energy: takes almost all the beam energy

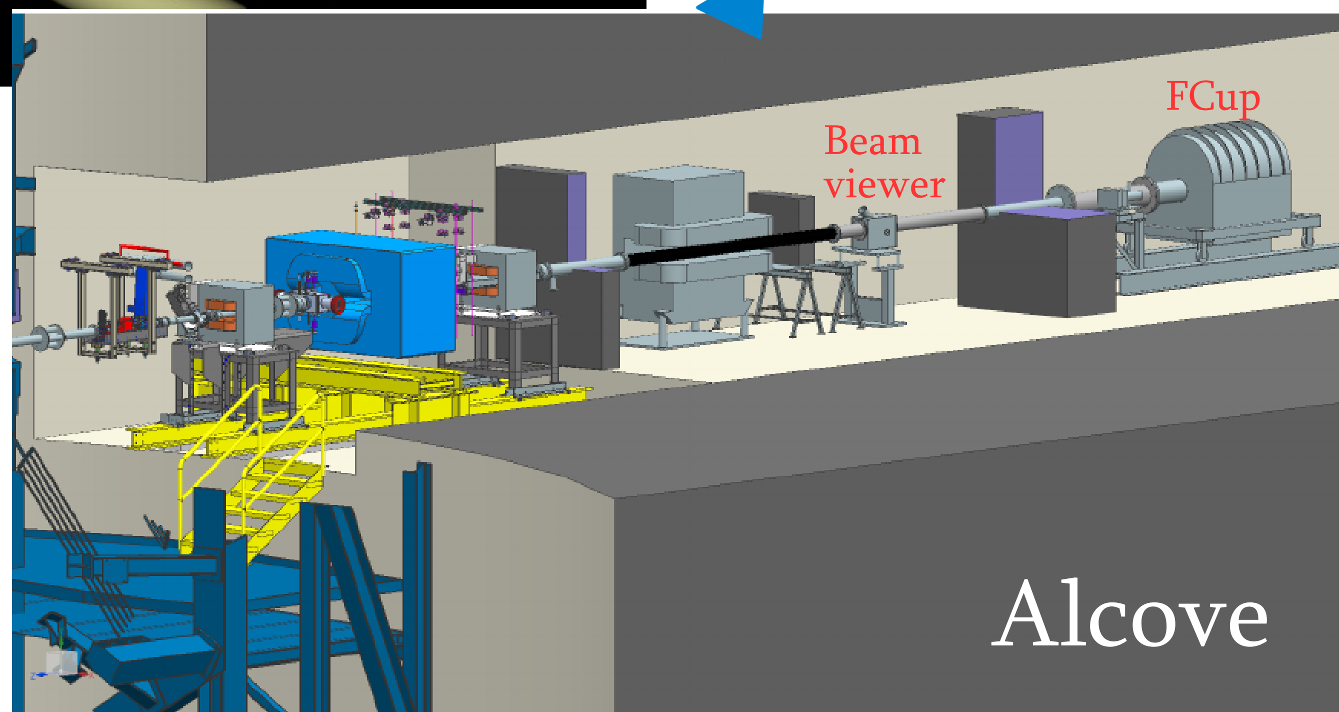
$$\frac{E_{A'}}{E_{beam}} \sim 1 - max\left(\frac{m_e}{m_{A'}}, \frac{m_{A'}}{E_0}\right)$$

$$\frac{\sigma(eA \to e' A'(\to e^- e^+))}{\sigma(eA \to e' \gamma^*(\to e^- e^+))} = \left(\frac{3\pi\epsilon^2}{2N_f \alpha}\right) \frac{m_{A'}}{\delta m}$$

HPS setup in the Hall B



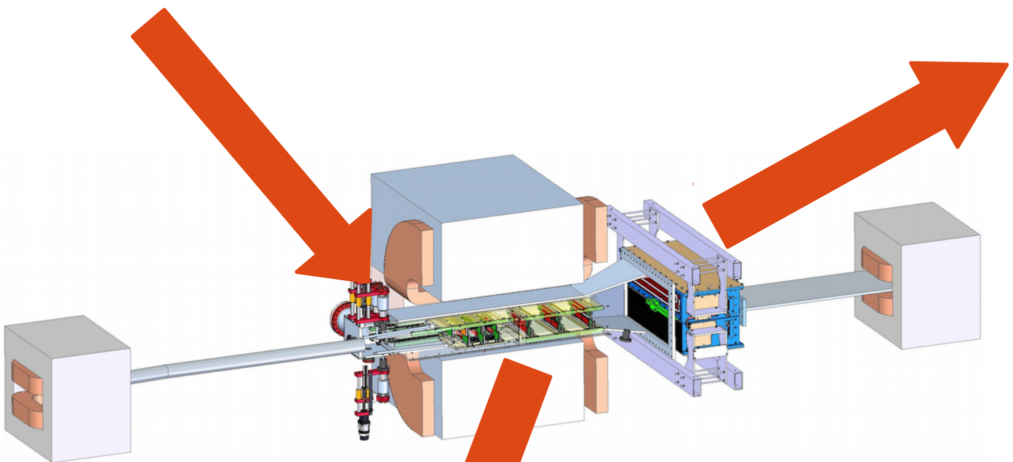
HPS is located in the downstream alcove

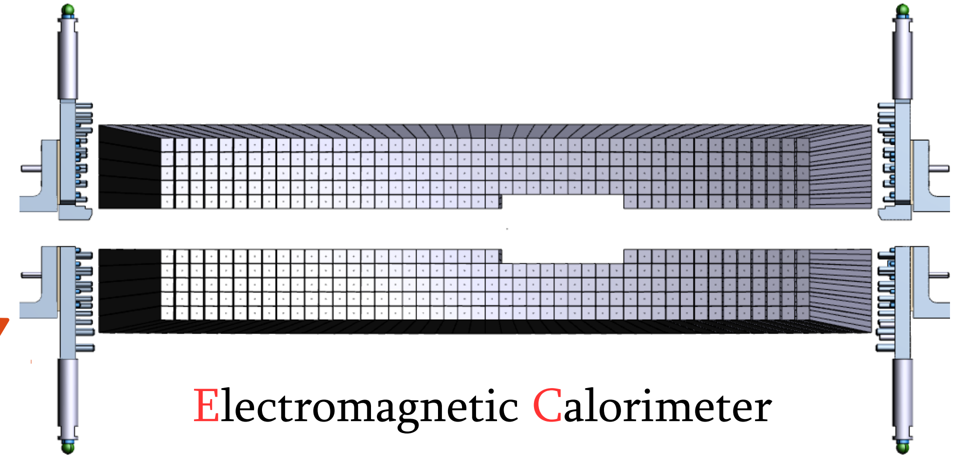


HPS experimental setup

Chicane system with 3 dipole magnets

4 μm tungsten target





Electromagnetic Calorimeter

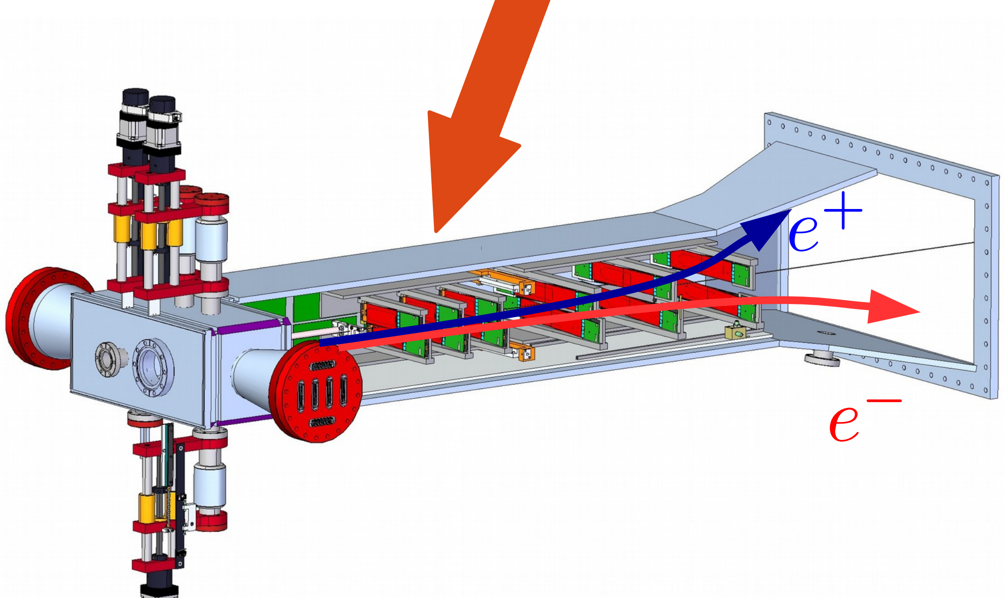
442 $PbW0_4$ Crystals

Initiates the trigger (Main, and 3 diagnostic)

Measures particle's energy

Resolution $\frac{4\%}{\sqrt{E}}$ at 1 GeV

Silicon Vertex Tracker



6 layers of silicon

1^{st} layer of silicon is at 0.5 mm from the beam

Measures charged particle's momentum

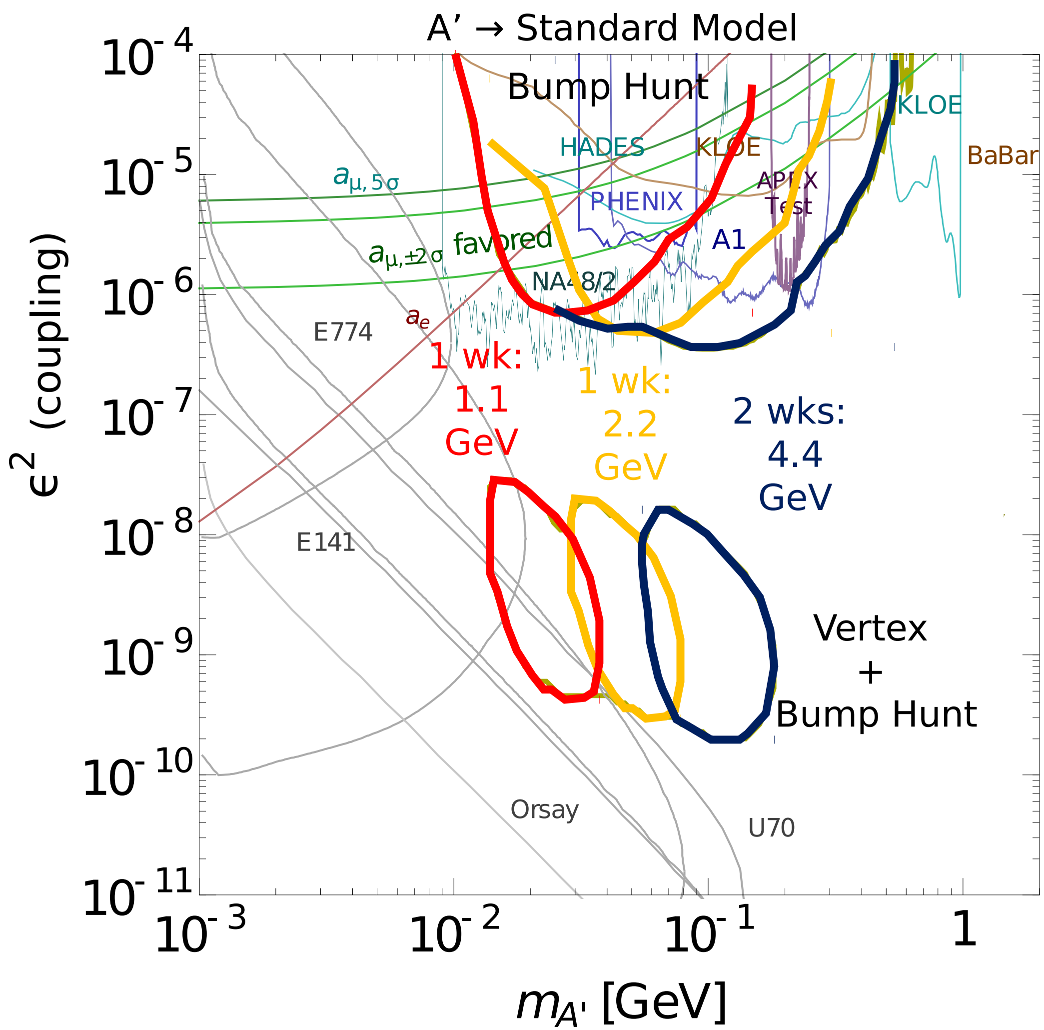
Vertical hit resolution $\approx 6\ \mu m$

Horizontal hit resolution $\approx 60\ \mu m$ (1st 3) and $\approx 120\ \mu m$ (3 other layers)

HPS proposed reach

180 approved days

Opportunistic runs:
Run only after work hours (2015)
And only on weekends (2016)



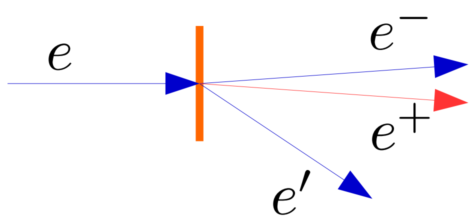
2015 Spring:

Beam current: 50 nA
Beam energy: 1.05 GeV
24% of proposed amount of production data

2016 Spring:

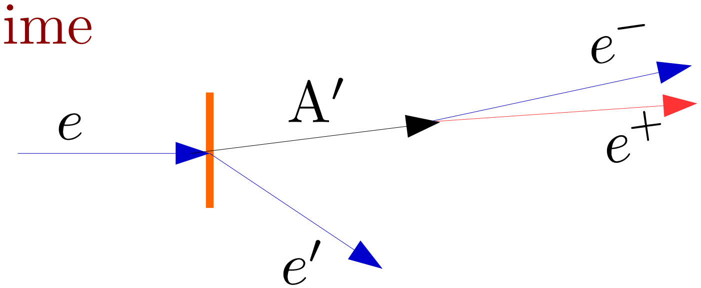
Beam current: 200 nA
Beam energy: 2.3 GeV
77% of proposed amount of production data

Prompt decay, but large coupling



Find a peak over a large background

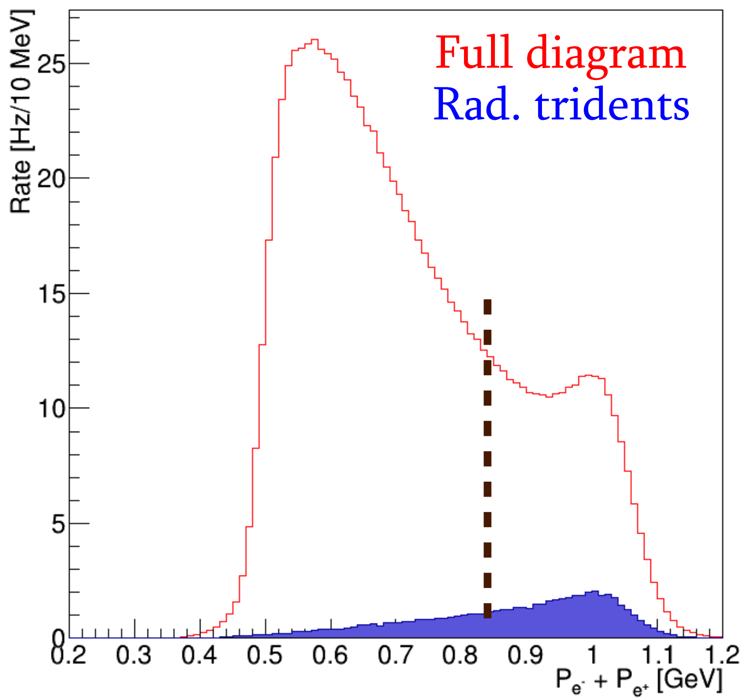
Small coupling, but longer decay time



No background, few events are enough

Tridents: Data vs MC

Expectations from MC

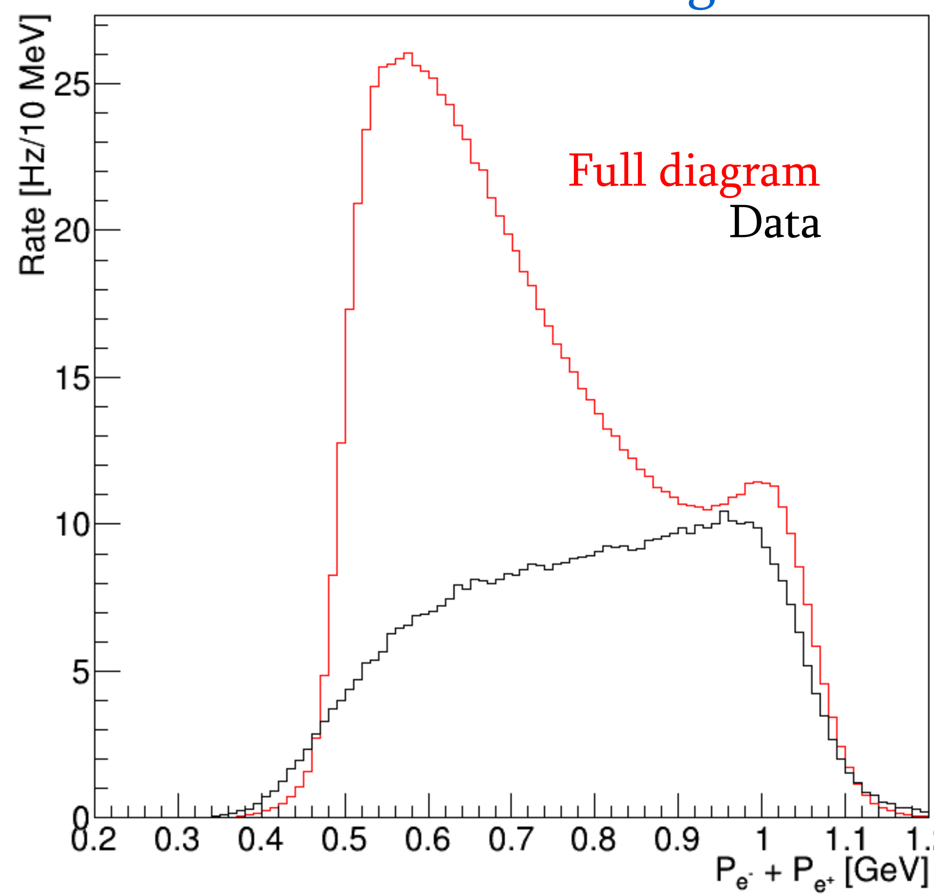


Note: The ratio $f_{rad} = \frac{N_{Rad}}{N_{Full}}$ is important for the calculation of ϵ

$$\frac{\sigma(eA \to e'A'(\to e^- e^+))}{\sigma(eA \to e'\gamma^*(\to e^- e^+))} = \left(\frac{3\pi\epsilon^2}{2N_f \alpha}\right) \frac{m_{A'}}{\delta m}$$

To get the the f_{Rad}, it is important to understand the P_{sum} distribution

However, the agreement between data and MC is not good



Trigger has been checked quite thoroughly

Trigger eff. > 95%

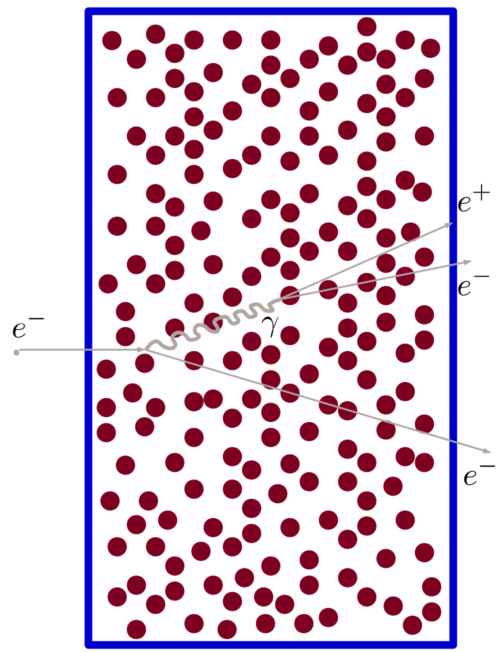
Calorimeter detection efficiency ≈ 100%

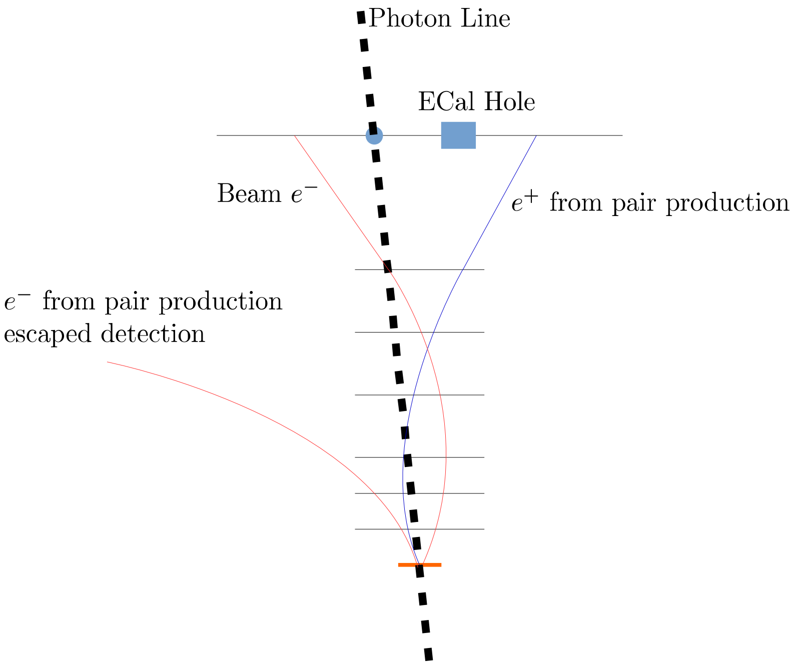
Lifetime >85%

No efficiency related factor found that could explain such discrepancy

Wide Angle Bremsstrahlung (WAB)

Two step process:
WAB then photon conversion





Photon conversions from the target, 1st and 2nd SVT layers can mimic trident signal

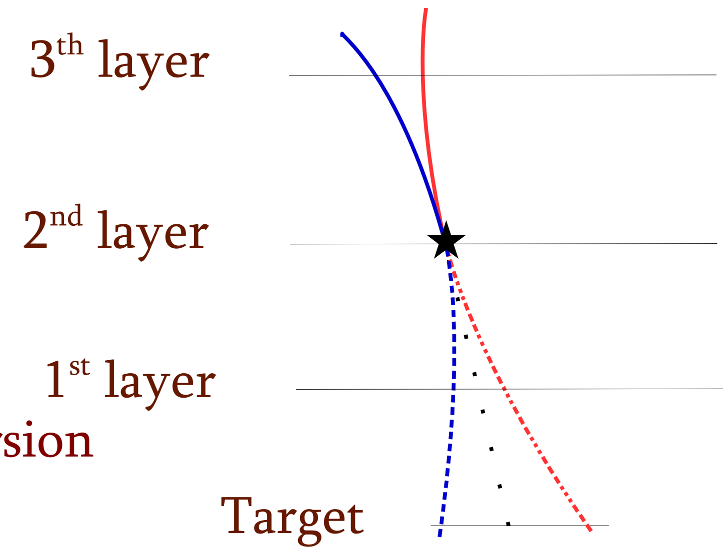
Both: WAB and photon conversion have large cross sections, so we have revised WAB contribution in the MC and data

The EGS5 program, that we are using for transport of the beam in the target, treats WABs incorrectly, resulting the the scattered electron escaping detection

Evidence of WABs in data

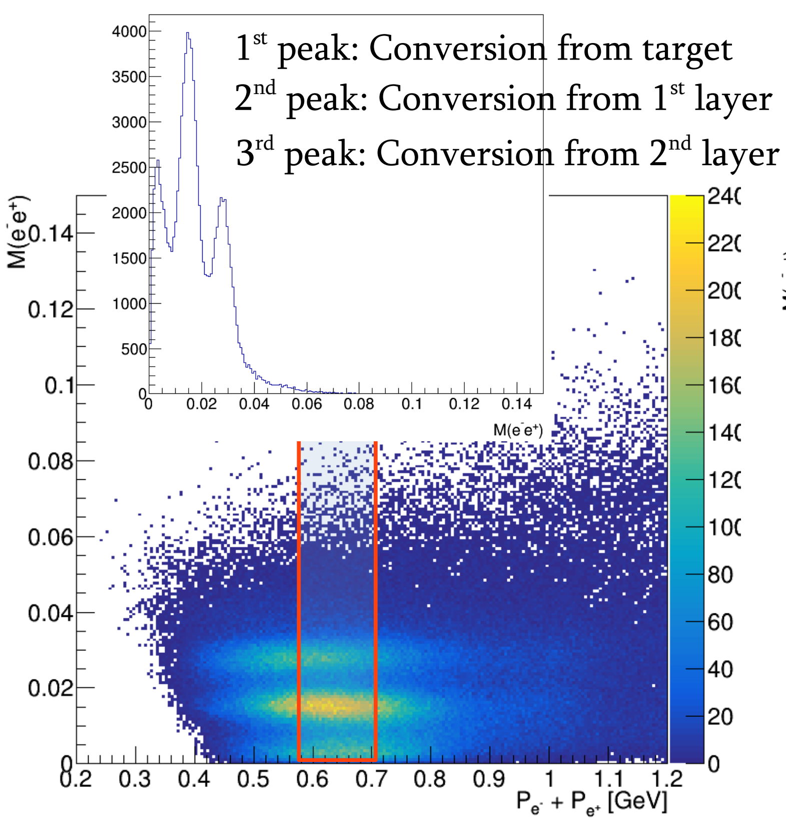
e^-e^+ pairs from WAB photon conversion have ~ 0 openning angle

- consequently ~ 0 invariant mass,
- and should be on the same detector half

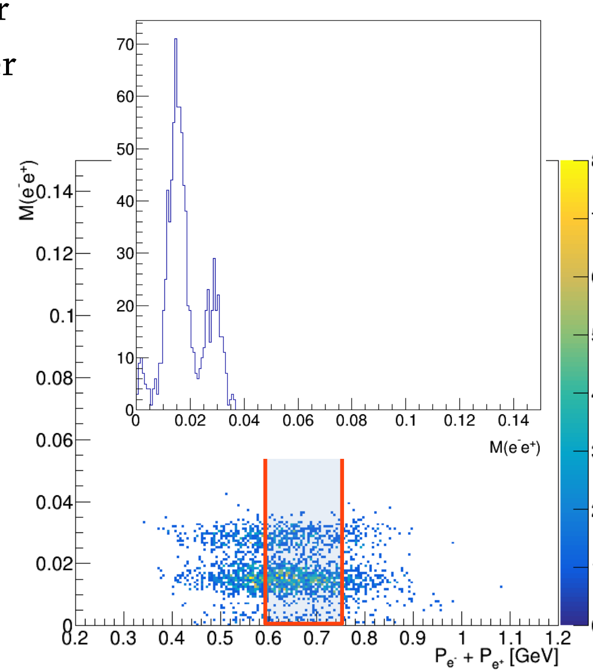


Three different peaks correspond to the photon conversion
In the target, 1st and 2nd SVT layer

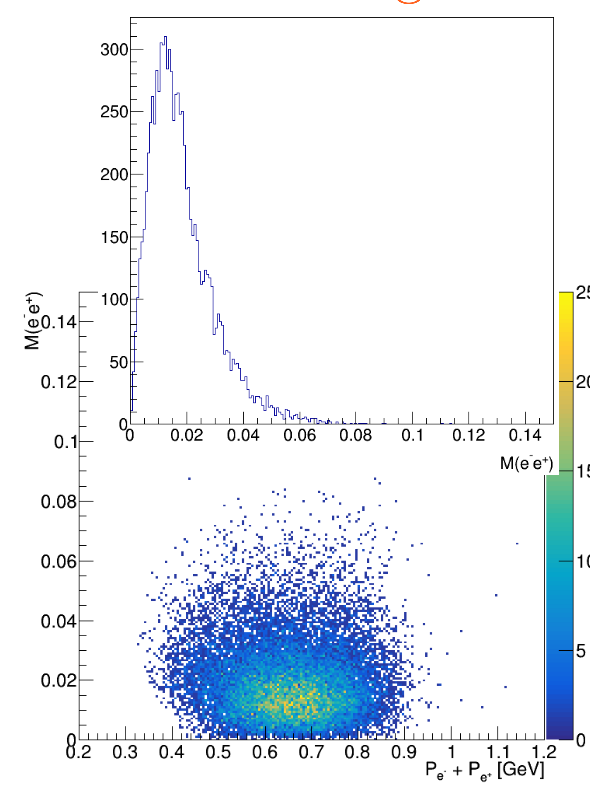
Data



WAB

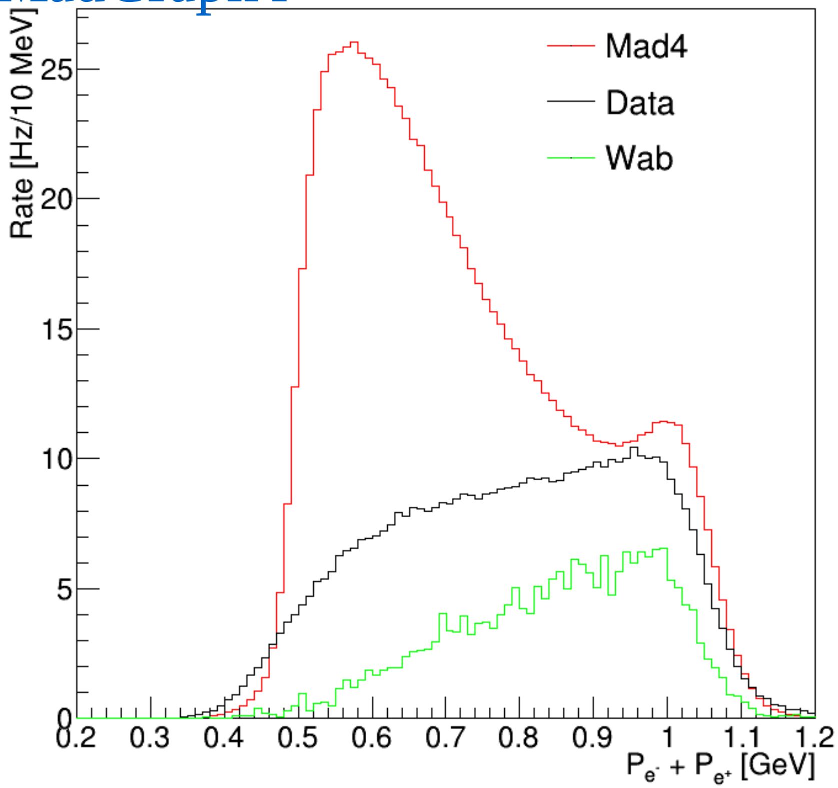


TriTrig



WABs and tridents

We generated WABs separately in MadGraph4

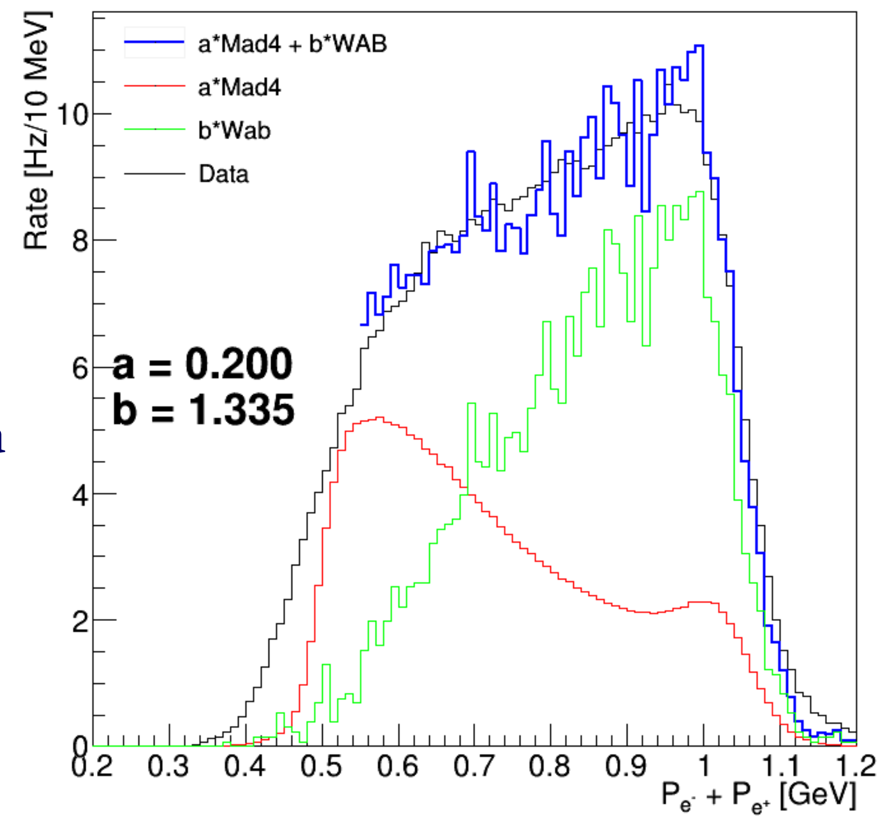


Both Tridents and WABs are generated by MadGraph4

Substantial contribution from WABs

The sum of tridents and WABs now overshoots data by significant amount

Fit data w/ a*WAB + b*Trid



Fit the sum of WAB and trident MC to the data

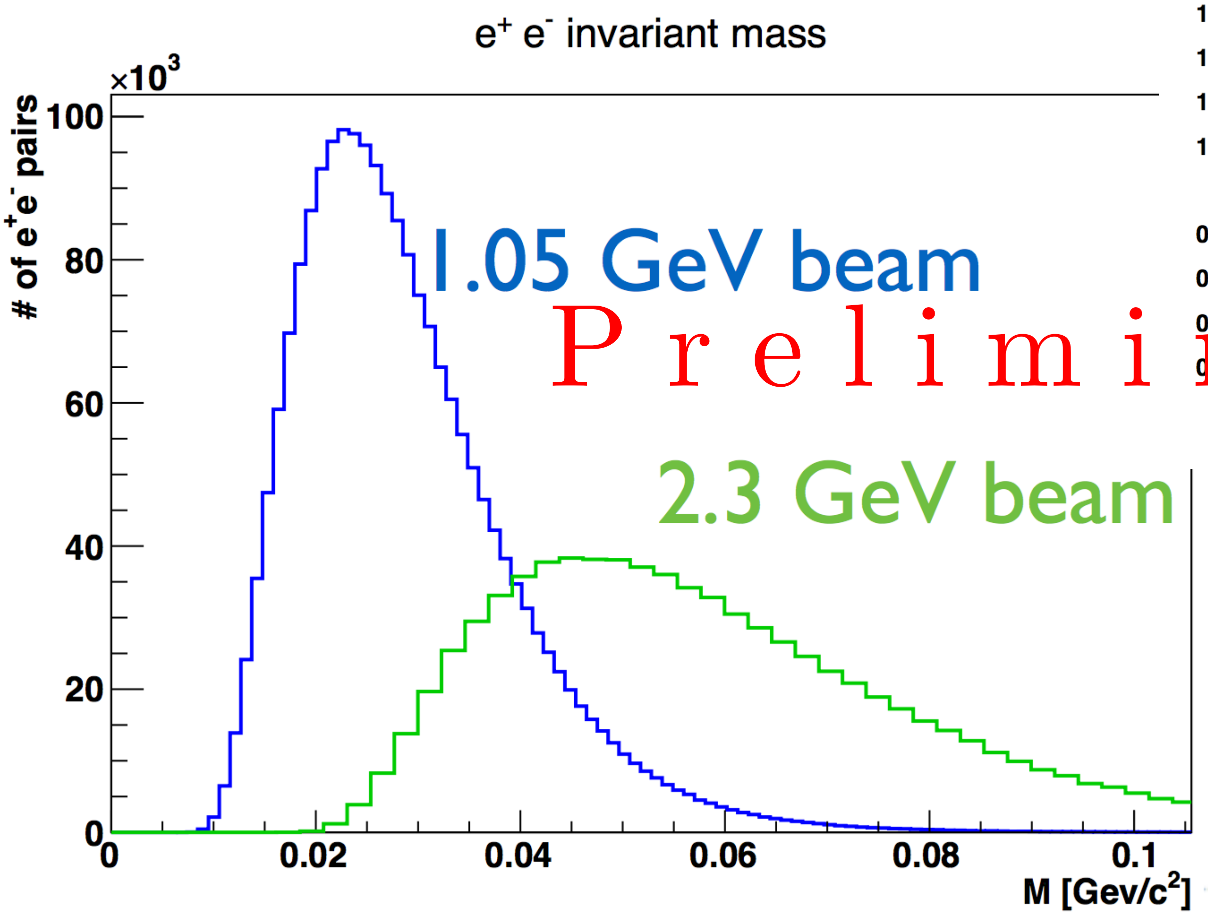
F = a*WAB + b*Trident

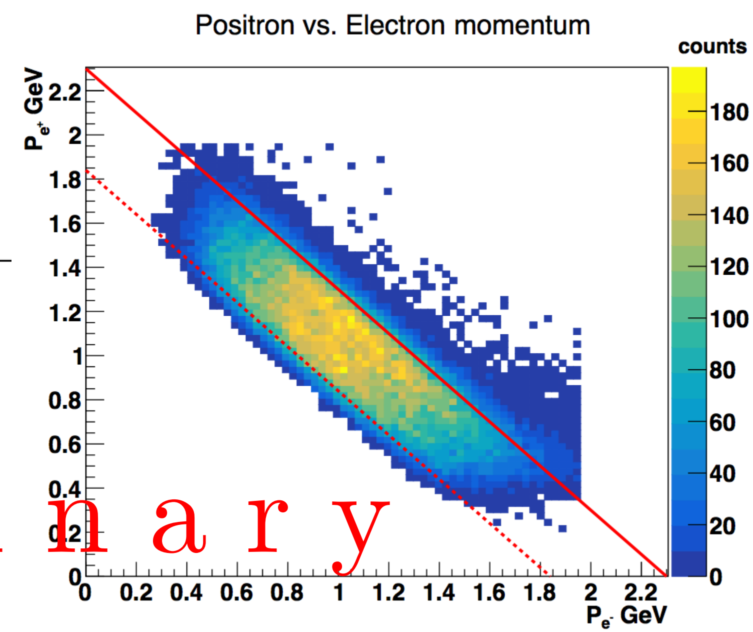
Fit is good, but coefficients “a” and “b” needs to be understood

Final selection sample

- Blinded data: only 10% of data is allowed to be looked at
- As soon analysis cuts are finalized, codes will be freezed, and the whole data will be unblinded,

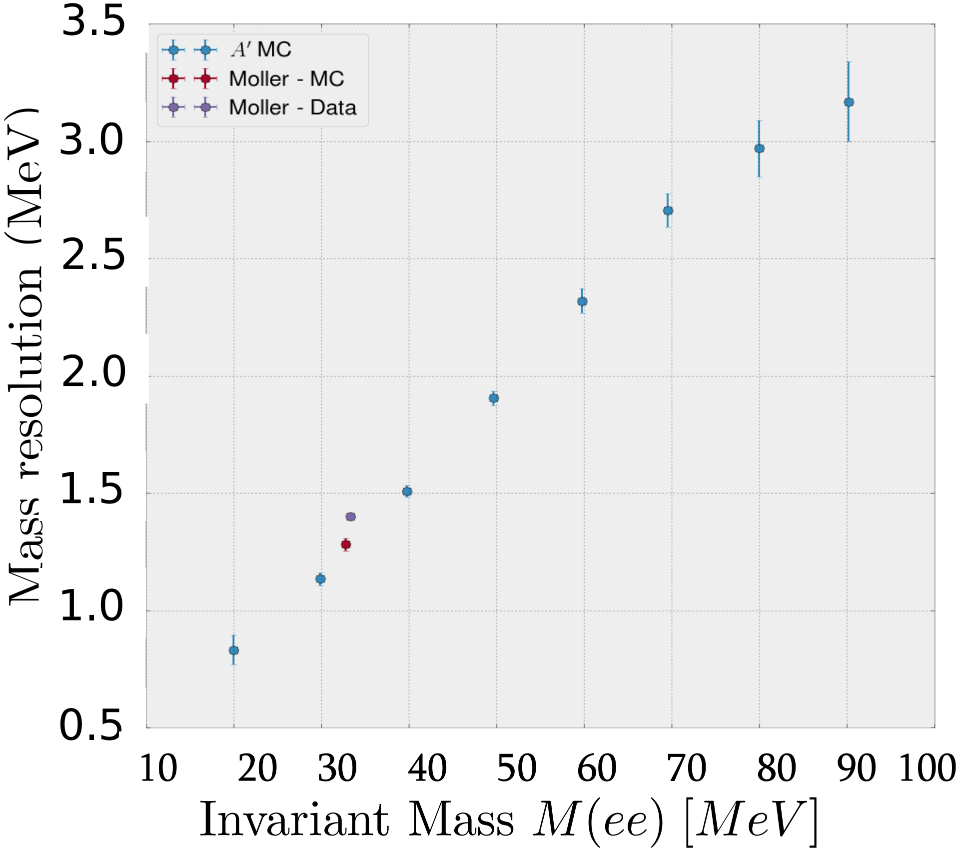
Bump hunt: search for a peak over $M(e^-e^+)$ background

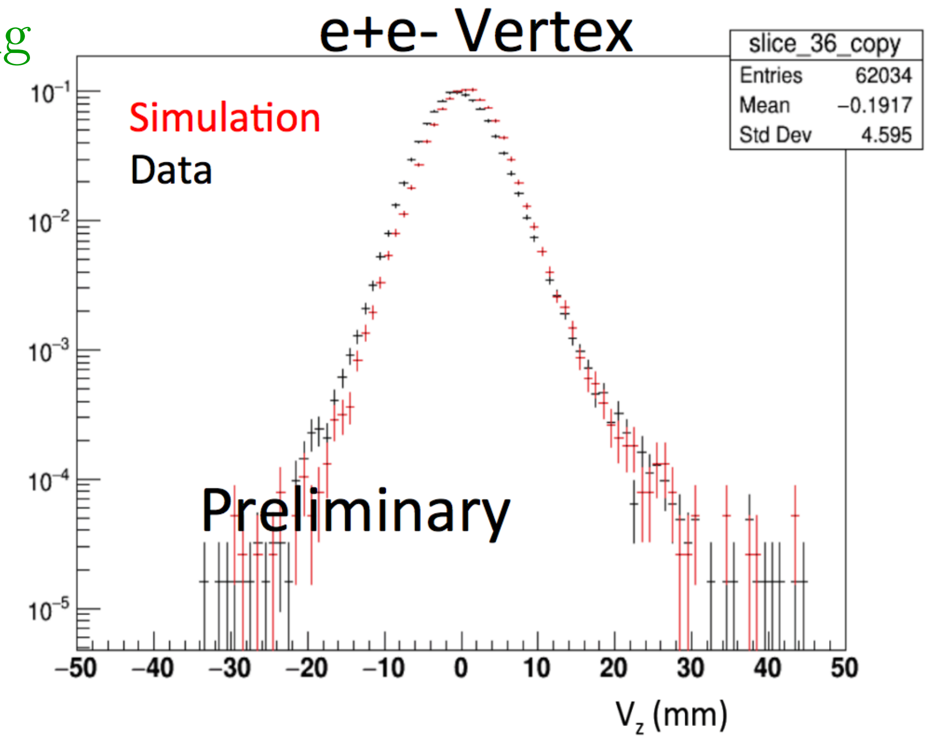




2015 Analysis

We need this for bump hunt and vertexing





Parameter	Proposal value	Measured value
Beam current	50 nA	50 nA
SVT occupancy	<1%	1.00%
Pair mass res. @ 34 MeV/c2	1.5 MeV	1.5 MeV
Pair vertex res. @ 40 MeV/c2	4.4 mm	4.6 mm

Blind analysis Bump Hunt

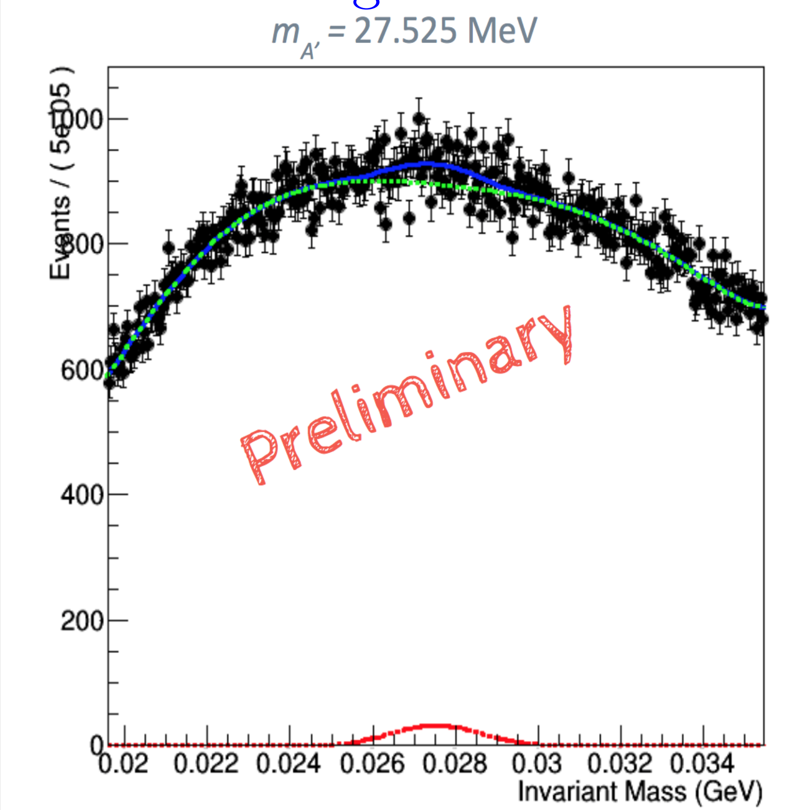
Blind analysis: 10% of the data, 74 nb^{-1}

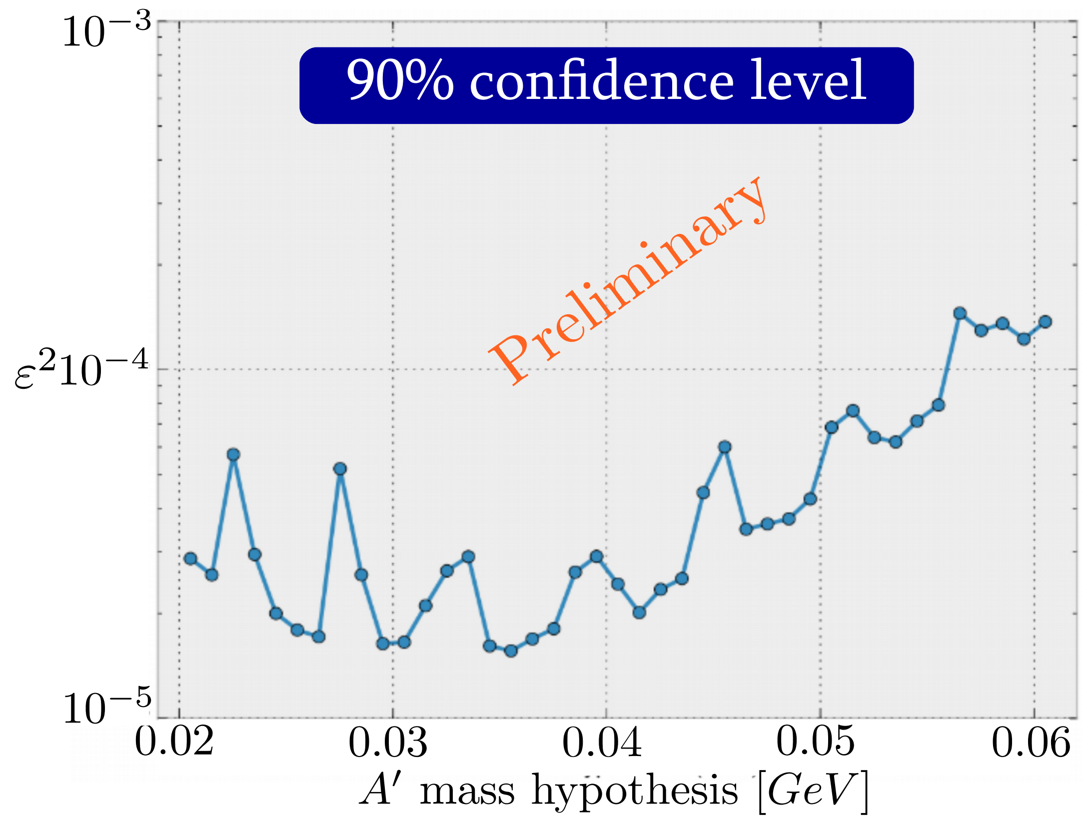
Analysis framework is developed for the extraction/exclusion of the signal

ε is calculated assuming current MC prediction for f_{Rad}

Bump hunt in the mass range 20-60 MeV

Most significant Poll





Background: 7-th order polynomial
Signal width is fixed according to the mass resolution

Blind analysis Displaced vertex search

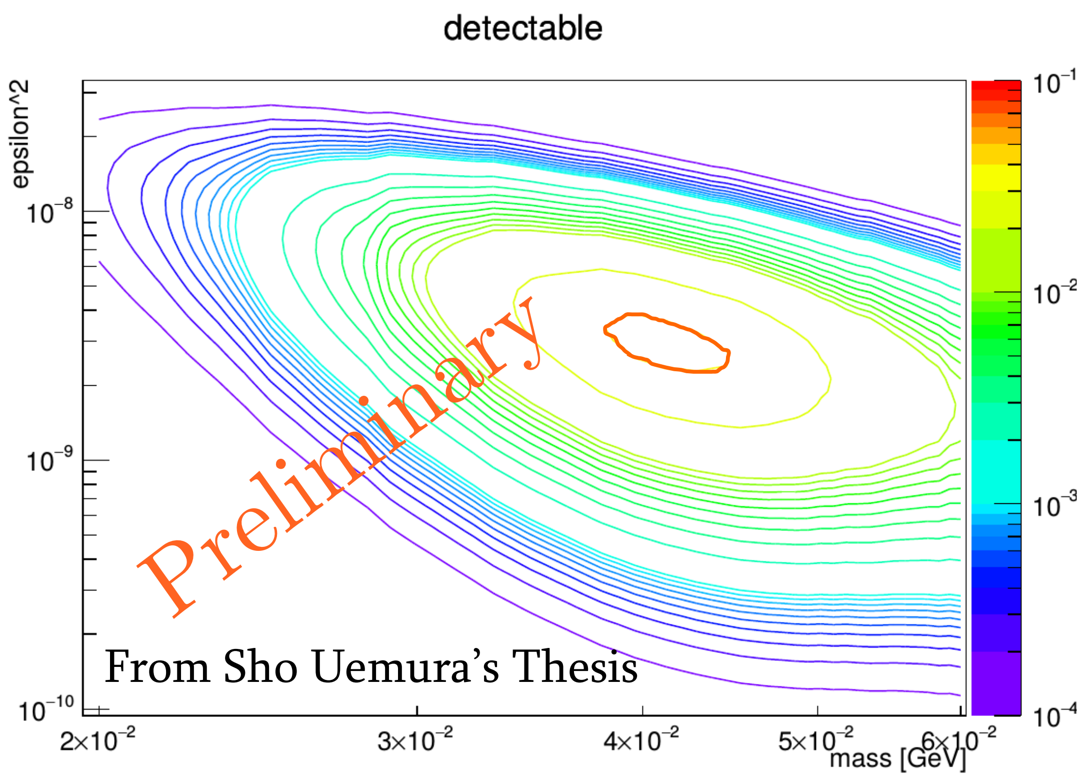
No significant excess is observed in the data, so HPS should try to set the upper limit

Unlike bump hunt, in displaced vertex search, some minimum Luminosity is needed in order to be able to exclude some of the phase space, i.e. for 90% confidence level, there should be 2.33 detectable A' events

Highest contour corresponds to 0.03 events

Factors that can help:

- Better bgr rejection $\approx \times 1.33$
- Unblinding: $\approx \times 6$
- Not requiring 1^{st} layer hit: $\approx \times 2.2$
- Using 1.5 mm data: $\approx \times 1.5$
- complete 1 Full week: $\approx \times 4.14$
- optimize trigger to go higher currents ?



Work is in progress to understand above factors

Towards publication

Completed tasks

- Detector calibrations are done

- Analysis frameworks are set up to extract, or to provide upper limit for the signal

- Full data is cooked, waiting for the green light to be unblinded

Delaying factors

- A two step process eA→ eA γ(→ e-e+) seems has a substantial contribution to our (e+e-) pair sample. This process was not in the initial MC studies of our reach
  Work is in progress to account for it properly

- We have some disagreement between different MC generators and data. Actively working on the testing it

Instrumentation papers

- ECal paper is sent to NIM

- SVT and Beamline are in a quite advanced stage

- Work on Overall HPS detector is started

Summary

- HPS experiment allows heavy photon search through bump hunt and displaced vertex search
- HPS has completed successfully data taking in 2015 and 2016
- Data analysis demonstrated good ECal and SVT performance during these runs, and one paper sent to NIM, another three are expected soon
- We have already 2 PhD dissertations and several more are in an advanced stage
- 165 days still remain: Next physics runs in 2018 and later?

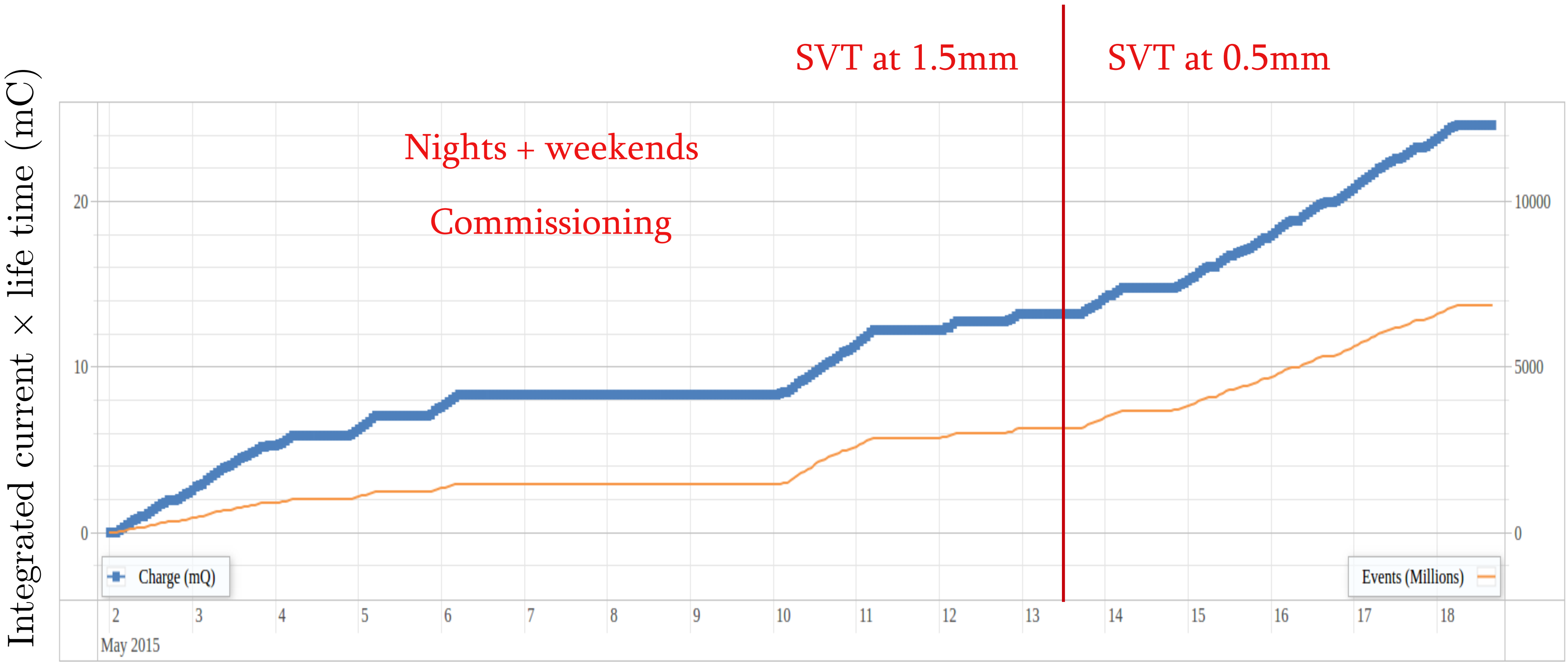
Backup

2015 run

1.05 GeV

Goal: 30 mC

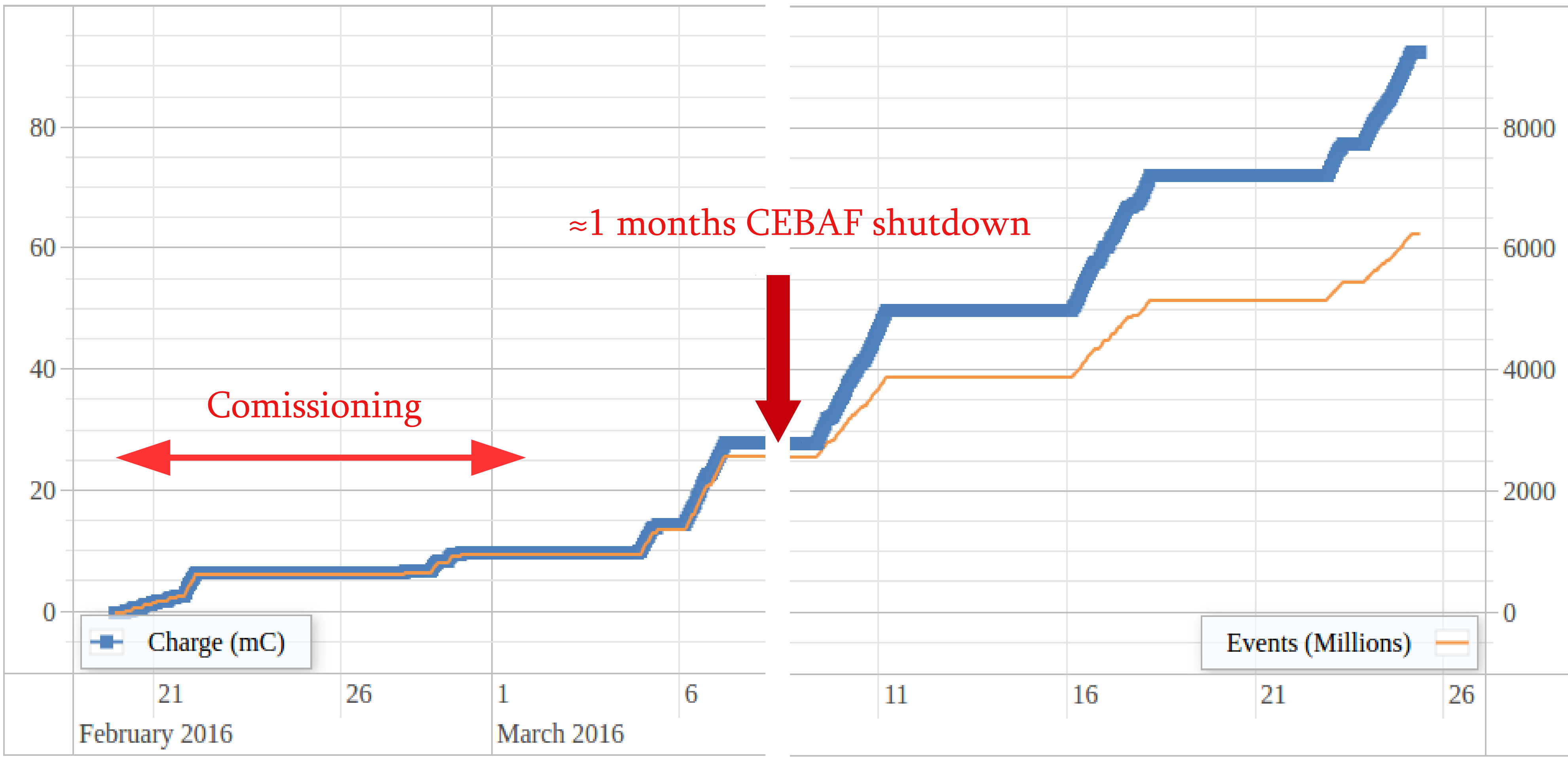
Achieved: 10 mC with SVT at 1.5 mm, 10 mC with SVT at 0.5 mm



2016 run

Goal: 120 mC 2.3 GeV Only weekends

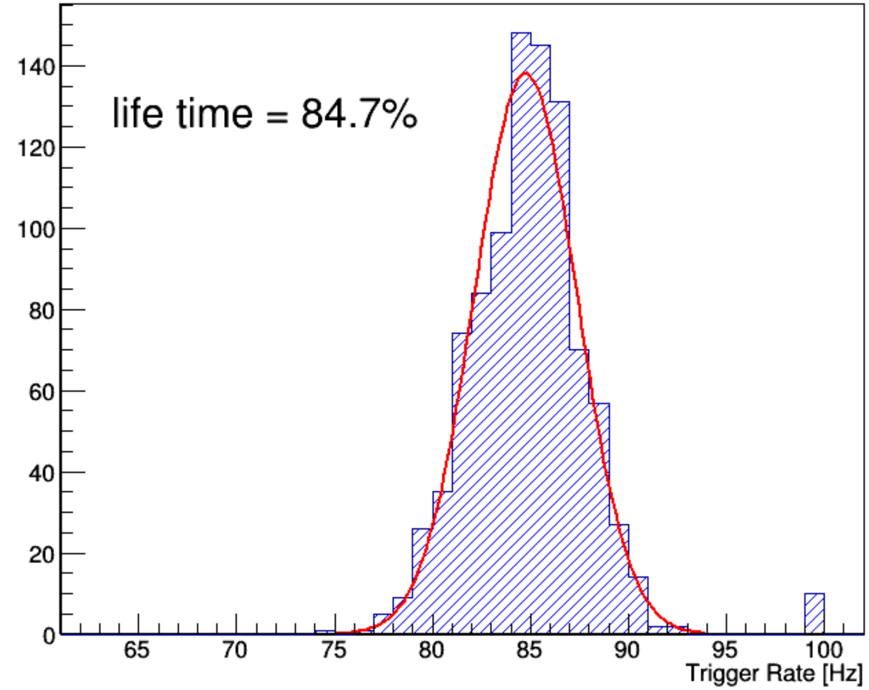
Achieved: 92.5 mC 6.3×10^9 triggers (77% of proposed running)



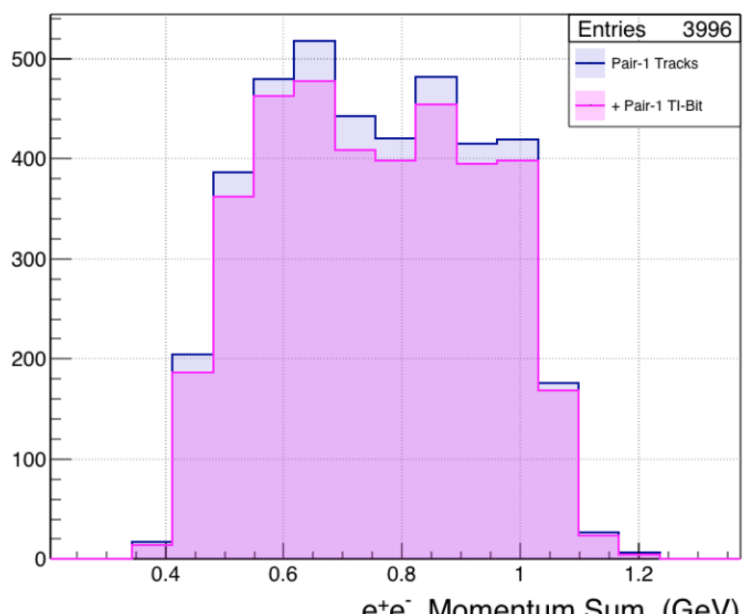
HPS efficiency

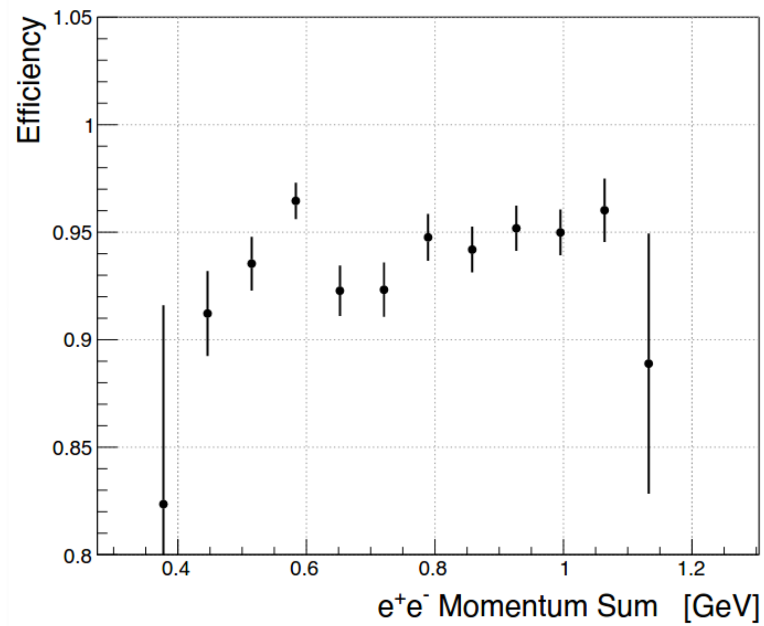
Online lifetime

Offline lifetime, from data



Trigger efficiency



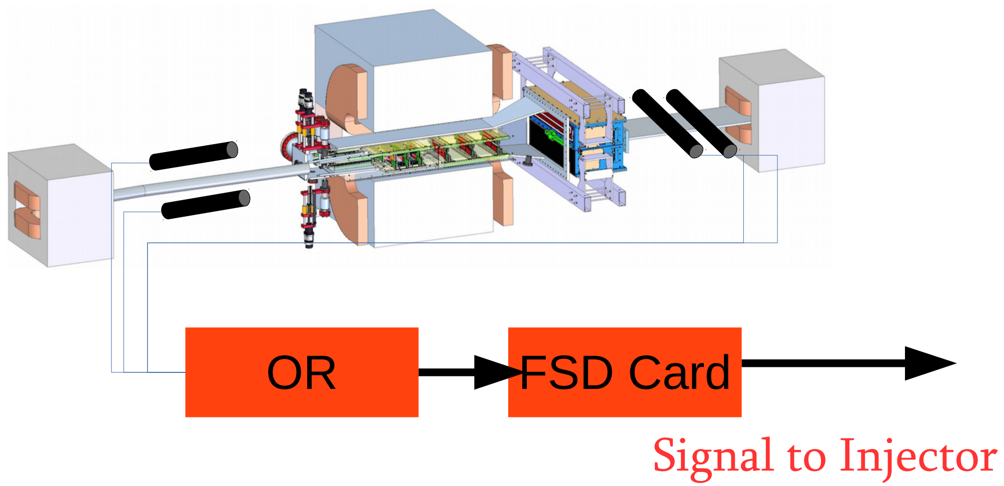


Beam motion studies

Small vertical beam motions ($\sim 0.5\ mm$) can damage silicon

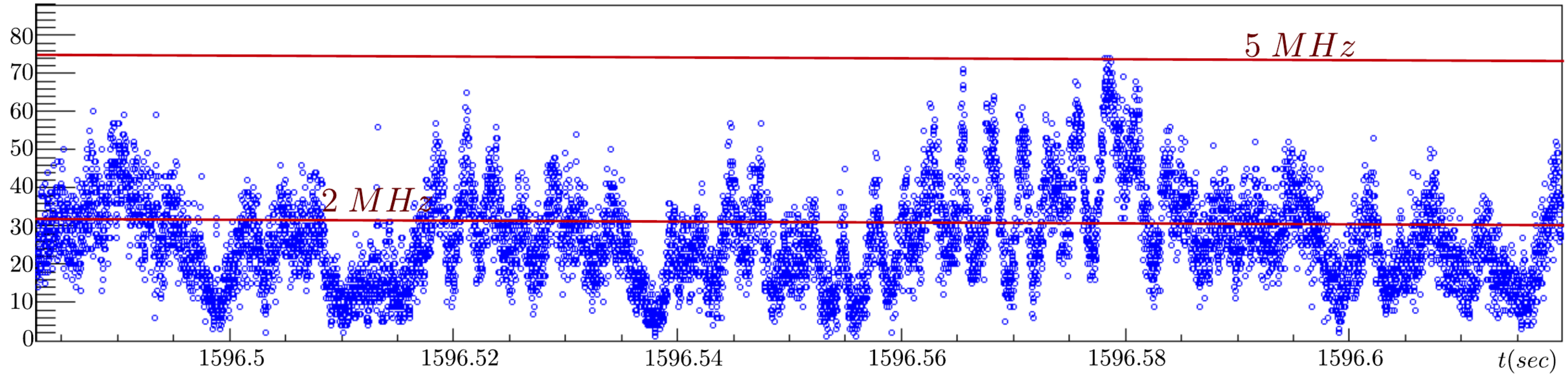
Signals from four halo counters summed up and as an input sent to Fast ShutDown card

Integration time: 1 ms



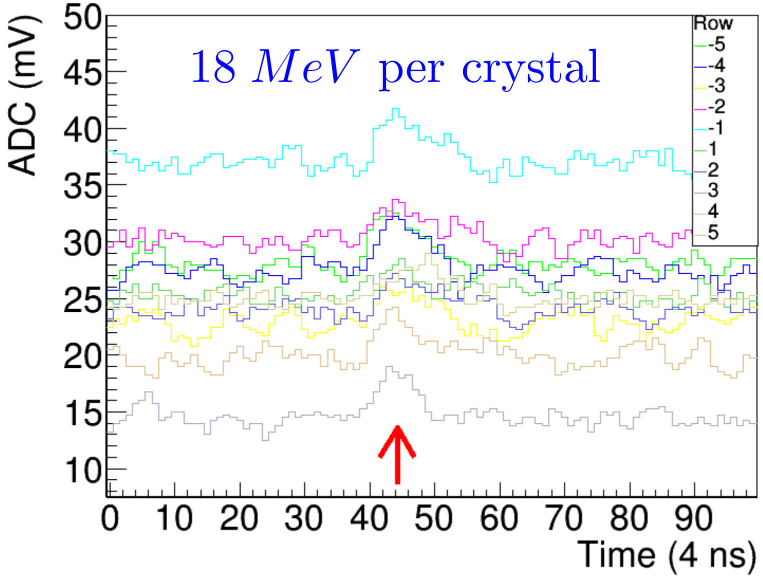
Placing harp wire close to the beam, with fast Struck scaler, we have measured fast beam motions

We have estimated the fast motion amplitude: less than 20 μm

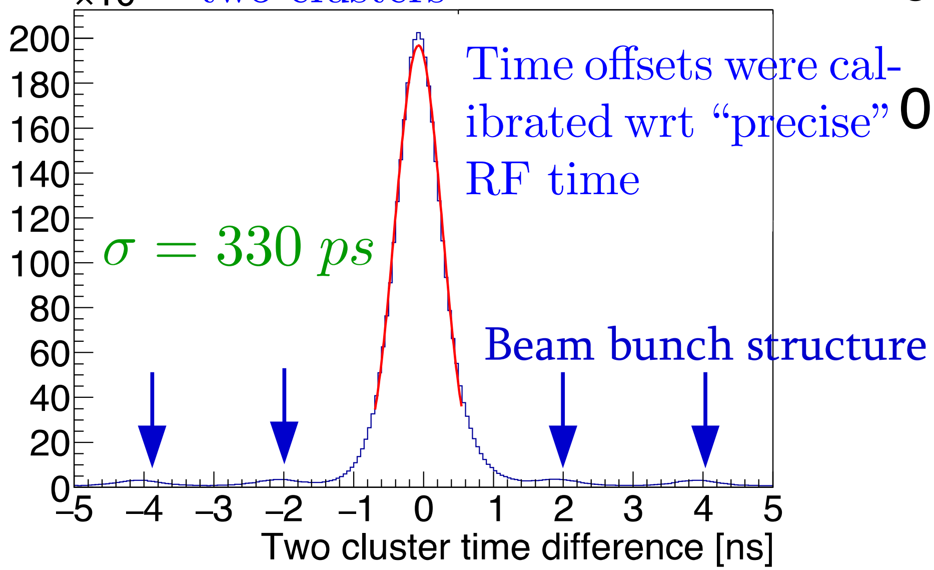


2016 Ecal performance

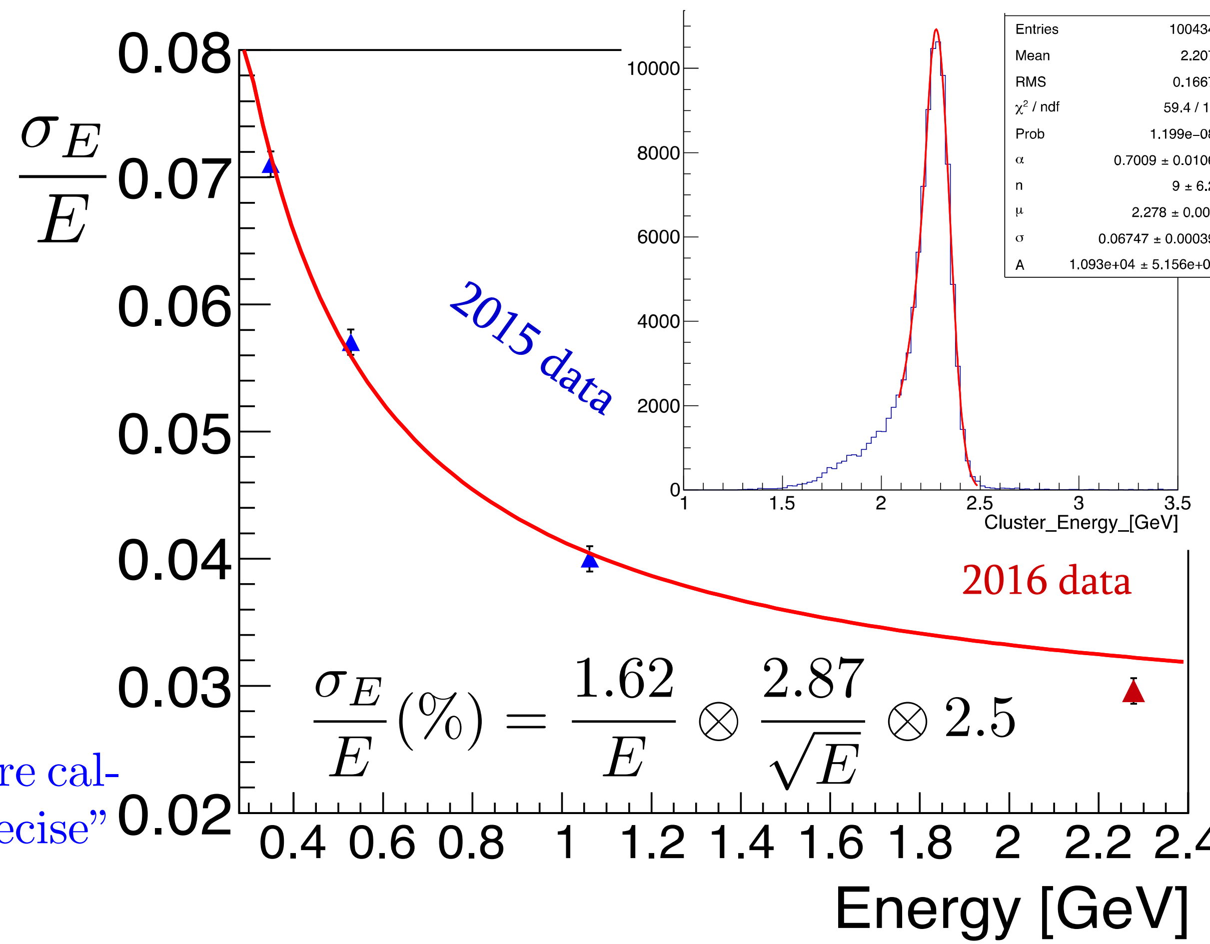
Cosmic gains for initial callibration



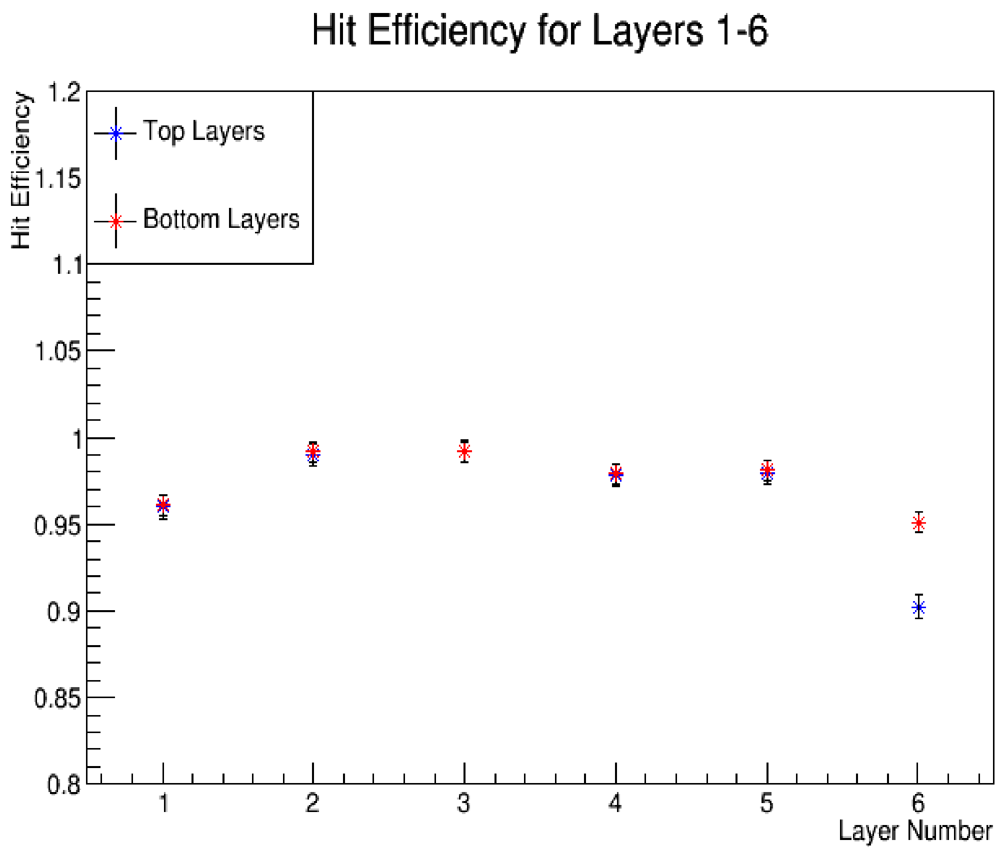
Time difference between two clusters

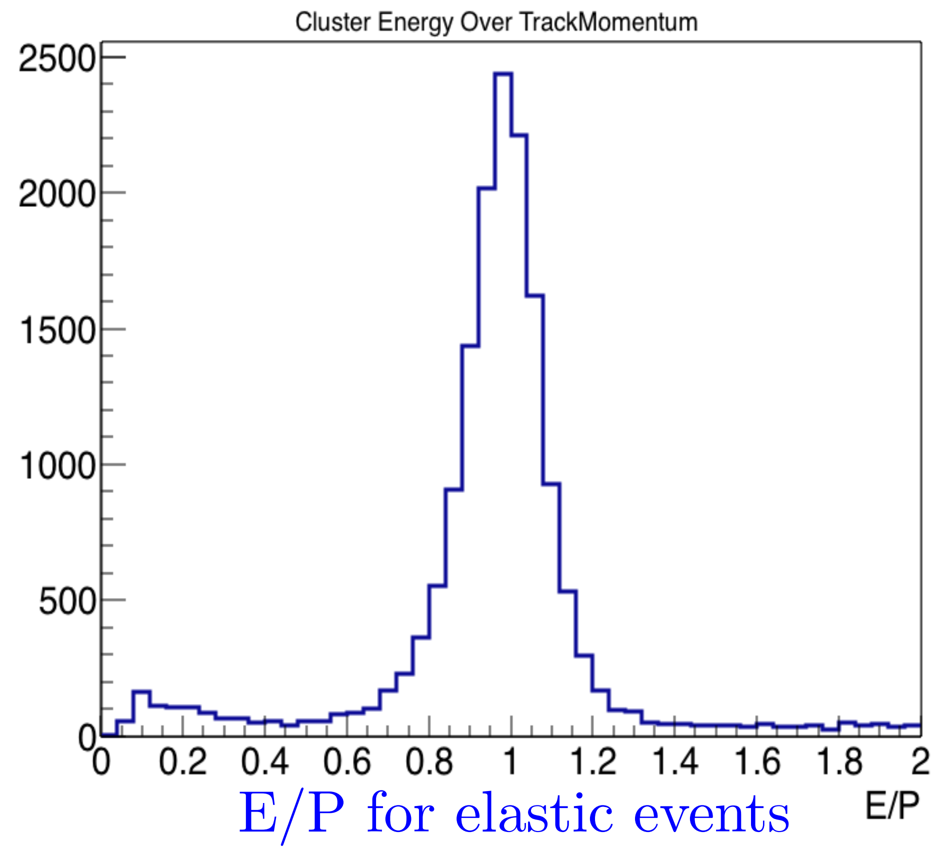


FEE peak in fiducial region



2016 SVT performance



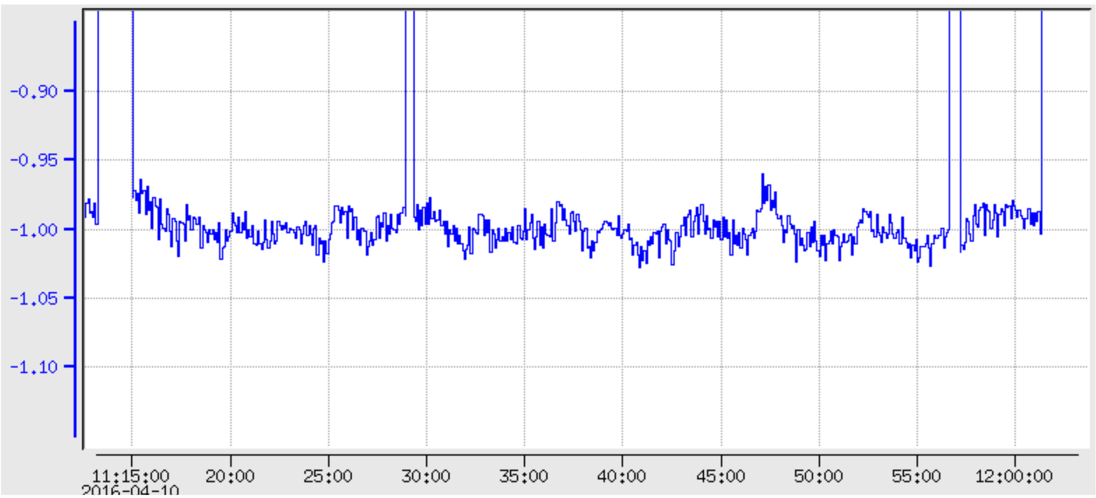


Momentum resolution is $\sim 7\%$ at 1 GeV

Beam properties

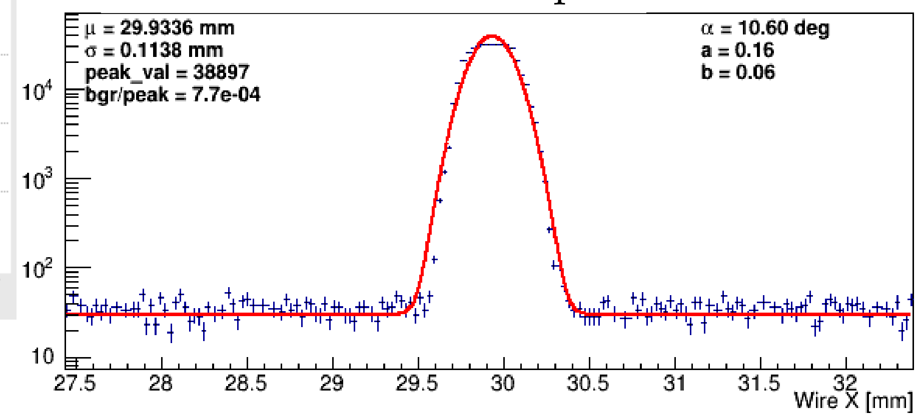
Before moving SVT to 0.5 mm beam properties were extensively studied

Good Beam position stability

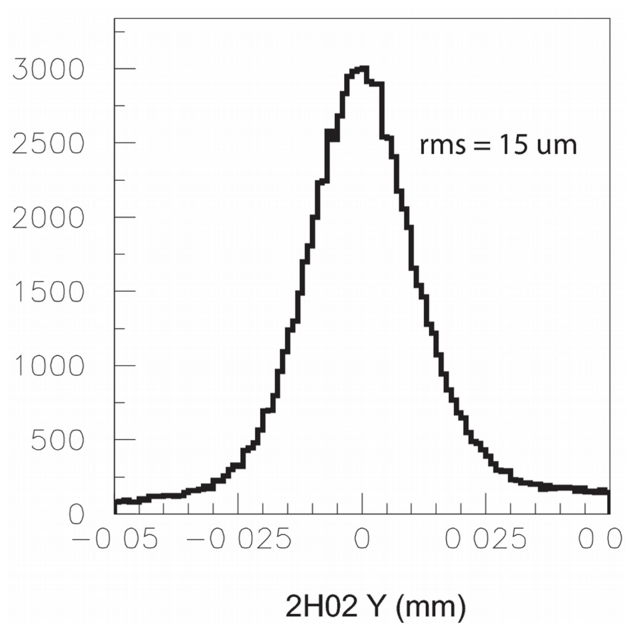


Narrow vertical beam size at the target: $\approx 50\ \mu m$

Horizontal profile



Vertical beam position distribution



Vertical profile