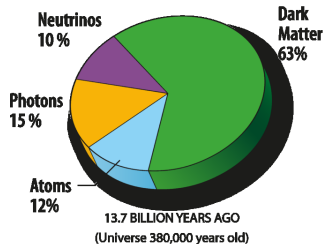
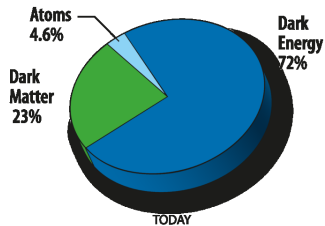


# APEX: Dark Photon Search

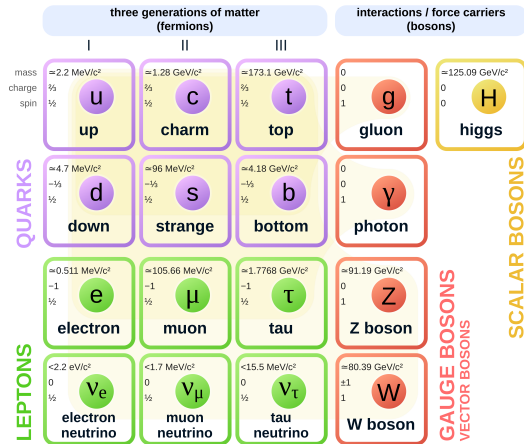
Evan McClellan

Jan 31, 2019

# What the Universe is Made of



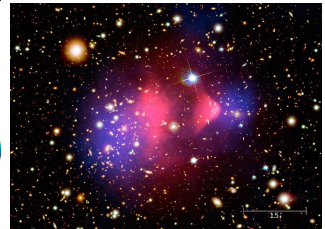
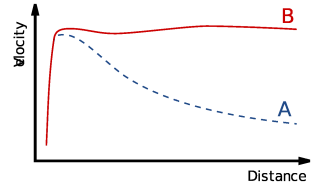
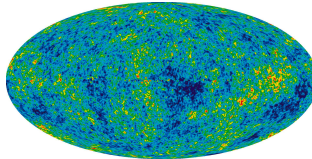
## Standard Model of Elementary Particles



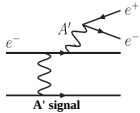
# Evidence for Dark Matter

## 3 Observational evidence

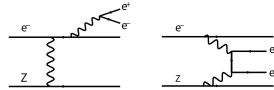
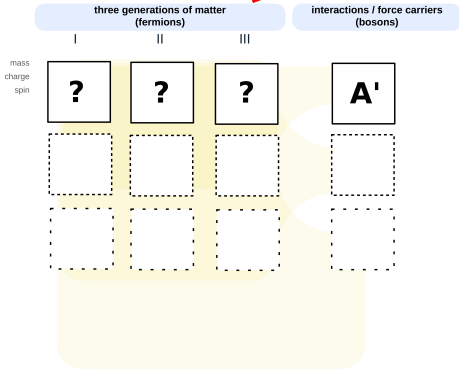
- 3.1 Galaxy rotation curves
- 3.2 Velocity dispersions
- 3.3 Galaxy clusters
- 3.4 Gravitational lensing
- 3.5 Cosmic microwave background
- 3.6 Structure formation
- 3.7 Bullet Cluster
- 3.8 Type Ia supernova distance measurements
- 3.9 Sky surveys and baryon acoustic oscillations
- 3.10 Redshift-space distortions
- 3.11 Lyman-alpha forest



# From Dark Matter to Dark Photons

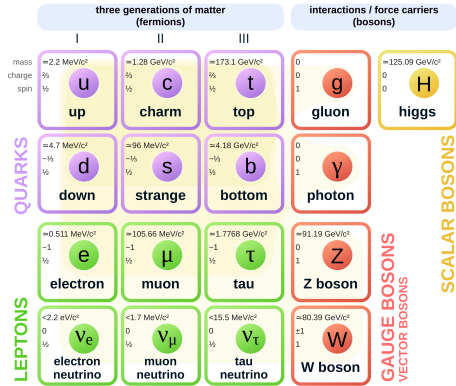


## Standard Model of Elementary Particles



Backgrounds

## Standard Model of Elementary Particles





# Dark Photon Experiments

## Summary of dark photon experiments. (Dark Sectors 2016 Workshop: Community Report, 1608.08632)

| Experiment | Lab      | Production | Detection      | Vertex | Mass (MeV)                | Mass Res. (MeV) | Beam     | Ebeam (GeV)  | Ibeam or Lumi                                     | Machine    | 1st Run | Next Run |
|------------|----------|------------|----------------|--------|---------------------------|-----------------|----------|--------------|---------------------------------------------------|------------|---------|----------|
| APEX       | JLab     | e-brems    | $\ell^+\ell^-$ | no     | 65 – 600                  | 0.5%            | $e^-$    | 1.1–4.5      | 150 $\mu$ A                                       | CEBAF(A)   | 2010    | 2018     |
| A1         | Mainz    | e-brems    | $e^+e^-$       | no     | 40 – 300                  | ?               | $e^-$    | 0.2–0.9      | 140 $\mu$ A                                       | MAMI       | 2011    | –        |
| HPS        | JLab     | e-brems    | $e^+e^-$       | yes    | 20 – 200                  | 1–2             | $e^-$    | 1–6          | 50–500 nA                                         | CEBAF(B)   | 2013    | 2018     |
| DarkLight  | JLab     | e-brems    | $e^+e^-$       | no     | < 80                      | ?               | $e^-$    | 0.1          | 10 mA                                             | LERF       | 2016    | 2018     |
| MAGIX      | Mainz    | e-brems    | $e^+e^-$       | no     | 10 – 60                   | ?               | $e^-$    | 0.155        | 1 mA                                              | MESA       | –       | 2020     |
| NA64       | CERN     | e-brems    | $e^+e^-$       | no     | 1 – 50                    | ?               | $e^-$    | 100          | $2 \times 10^{11}$ EOT/yr                         | SPS        | 2016    | 2022     |
| Super-HPS  | SLAC     | e-brems    | vis            | yes    | < 500                     | ?               | $e^-$    | 4 – 8        | 1 $\mu$ A                                         | DASEL      | ?       | ?        |
| (TBD)      | Cornell  | e-brems    | $e^+e^-$       | ?      | < 100                     | ?               | $e^-$    | 0.1–0.3      | 100 mA                                            | CBETA      | ?       | ?        |
| VEPP3      | Budker   | annih      | invis          | no     | 5 – 22                    | 1               | $e^+$    | 0.500        | $10^{33} \text{ cm}^{-2} \text{ s}^{-1}$          | VEPP3      | –       | 2019?    |
| PADME      | Frascati | annih      | invis          | no     | 1 – 24                    | 2 – 5           | $e^+$    | 0.550        | $\leq 10^{14} e^+ \text{ OT/y}$                   | Linac      | –       | 2018     |
| MMAPS      | Cornell  | annih      | invis          | no     | 20 – 78                   | 1 – 6           | $e^+$    | 6.0          | $10^{34} \text{ cm}^{-2} \text{ s}^{-1}$          | Synchr     | ?       | ?        |
| KLOE 2     | Frascati | several    | vis/invis      | no     | < 1.1 GeV                 | 1.5             | $e^+e^-$ | 0.51         | $2 \times 10^{32} \text{ cm}^{-2} \text{ s}^{-1}$ | DAΦNE      | 2014    | –        |
| Belle II   | KEK      | several    | vis/invis      | no     | $\lesssim 10 \text{ GeV}$ | 1 – 5           | $e^+e^-$ | $4 \times 7$ | $1 \sim 10 \text{ ab}^{-1} \text{ /y}$            | Super-KEKB | –       | 2018     |
| SeaQuest   | FNAL     | several    | $\mu^+\mu^-$   | yes    | $\gtrsim 10 \text{ GeV}$  | 3 – 6%          | p        | 120          | $10^{18} \text{ POT/y}$                           | MI         | 2017    | 2020     |
| SHIP       | CERN     | several    | vis            | yes    | $\gtrsim 10 \text{ GeV}$  | 1 – 2           | p        | 400          | $2 \times 10^{20} \text{ POT/5y}$                 | SPS        | –       | 2026     |
| LHCb       | CERN     | several    | $\ell^+\ell^-$ | yes    | $\gtrsim 40 \text{ GeV}$  | $\sim 4$        | pp       | 6500         | $\sim 10 \text{ fb}^{-1} \text{ /y}$              | LHC        | 2010    | 2015     |

## **The A' Experiment (APEX) Collaboration:**

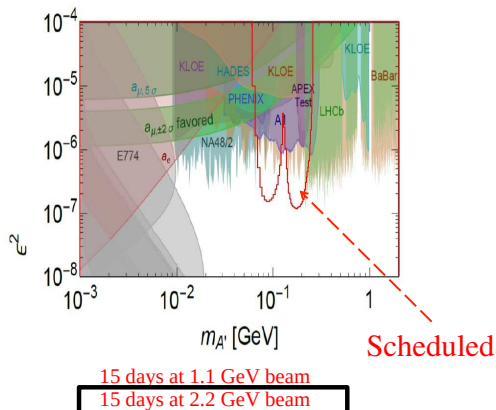
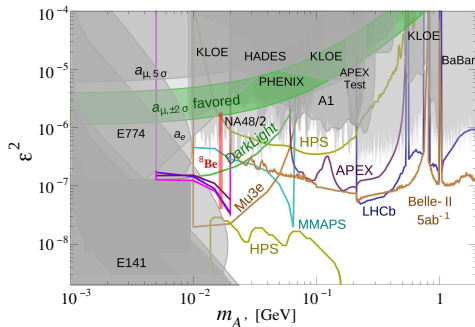
### **APEX Spokespeople:**

**Rouven Essig  
Philip Schuster  
Natalia Toro  
Bogdan Wojtsekhowski**

Yerevan Physics Institute, Yerevan 0036, Armenia  
Syracuse University, Syracuse, New York 13244, USA  
University of Kentucky, Lexington, Kentucky 40506, USA  
Saint Mary's University, Halifax, Nova Scotia B3H 3C3, Canada  
College of William and Mary, Williamsburg, Virginia 23187, USA  
**University of Virginia, Charlottesville, Virginia 22903, USA**  
University of New Hampshire, Durham, New Hampshire 03824, USA  
New York University, New York, New York 10012, USA  
Florida International University, Miami, Florida 33199, USA  
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**C. N. Yang Institute for Theoretical Physics, Stony Brook University,  
Stony Brook, NY 11794-3840, USA**  
Theory Group, SLAC National Accelerator Laboratory, Menlo Park, CA 94025  
North Carolina Agricultural and Technical State University, Greensboro,  
North Carolina 27411, USA  
**Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA**  
Longwood University, Farmville, Virginia 23909, USA  
Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA  
**California State University at Los Angeles, Los Angeles, California 90032, USA**  
Norfolk State University, Norfolk, Virginia 23504, USA  
Kent State University, Kent, Ohio 44242, USA  
University of Massachusetts, Amherst, Massachusetts 01003, USA  
University of South Carolina, Columbia, South Carolina 29225, USA  
Tel Aviv University, Tel Aviv, 69978 Israel  
**Perimeter Institute for Theoretical Physics, Waterloo, Ontario N2L 2Y5, Canada**  
George Washington University, Washington D.C. 20052, USA  
Theory Group, Stanford University, Stanford, CA 94305, USA  
**Old Dominion University, Norfolk, VA 23529, USA**  
**INFN Sezione di Catania, Italy**  
**North Carolina Central University, North Carolina 27707, USA**  
**Rutgers University, The State University of New Jersey, New Jersey 08901, USA**  
**Hebrew University of Jerusalem, Jerusalem, Israel**

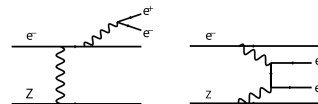
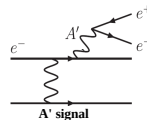
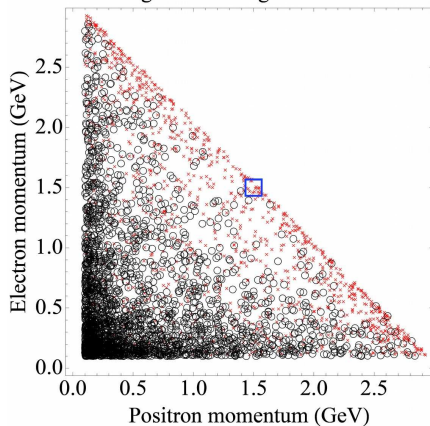
### **Hall A Collaboration**

# APEX Phase Space Coverage

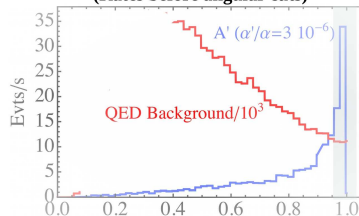


# Signal vs Background

Background vs. Signal Kinematics

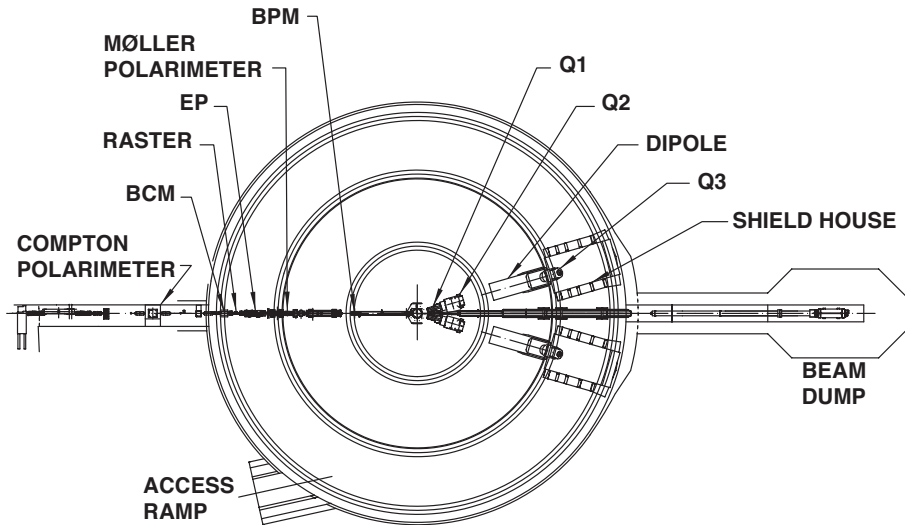


(Rates before angular cuts)



$A'$  products carry (almost) full beam energy

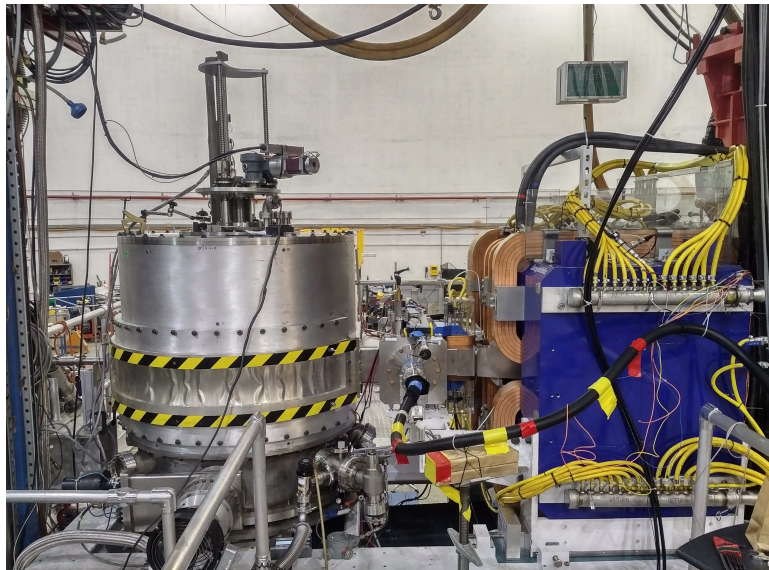
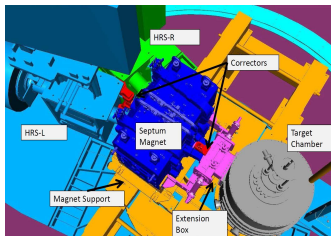
# APEX Equipment: HRSes



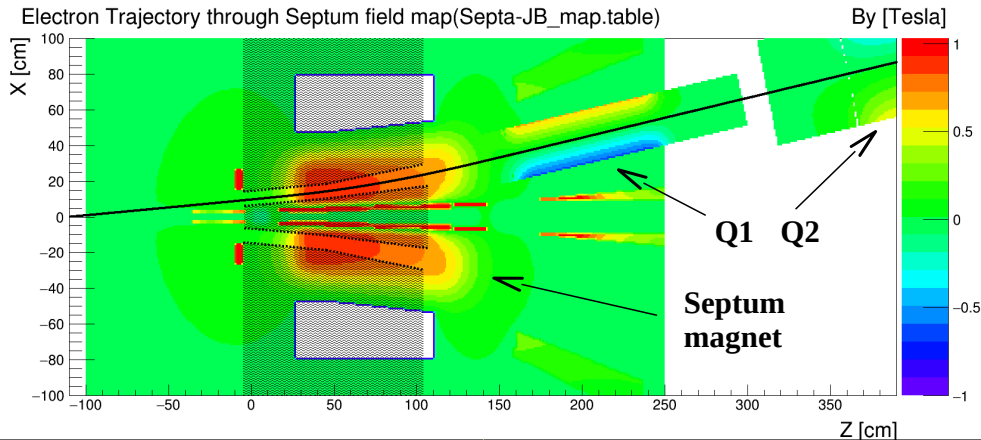
# APEX Equipment: HRSeS



# APEX Equipment: Septum Magnets

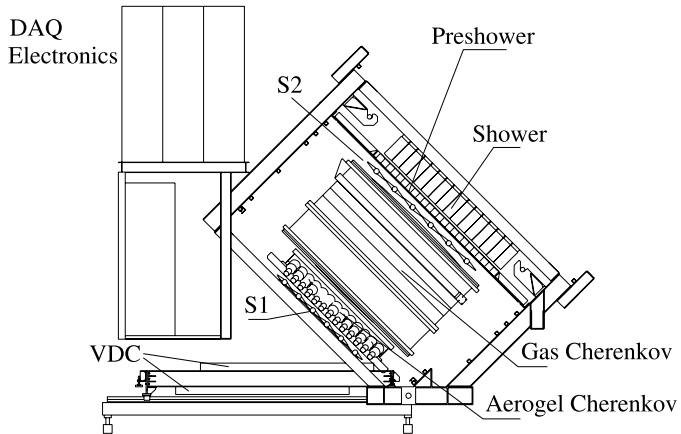


# APEX Equipment: Septum Magnets

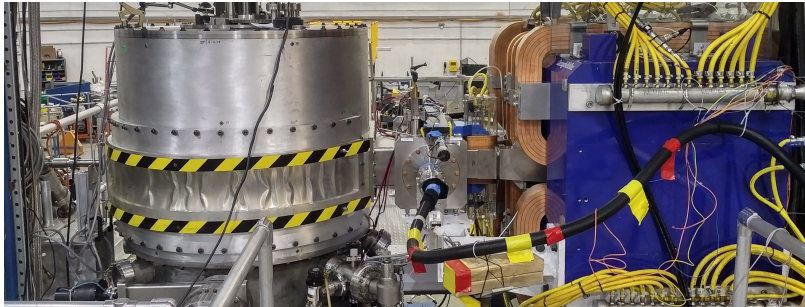
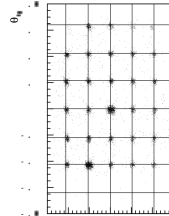
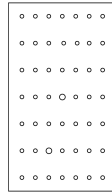
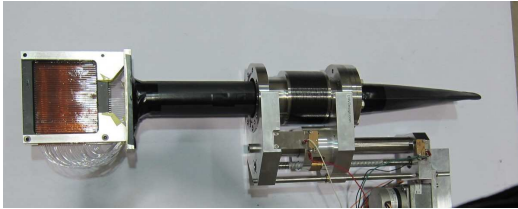




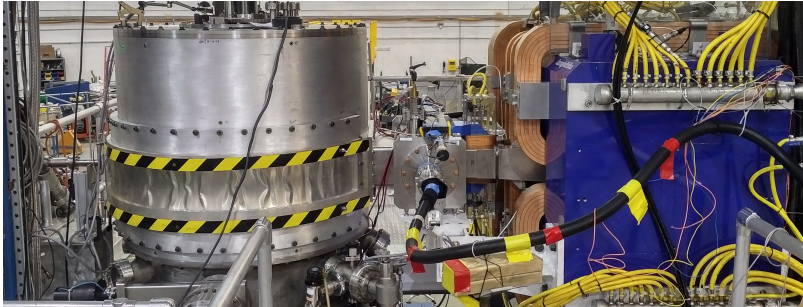
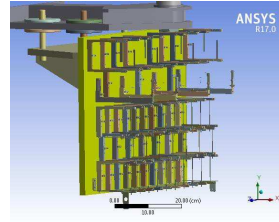
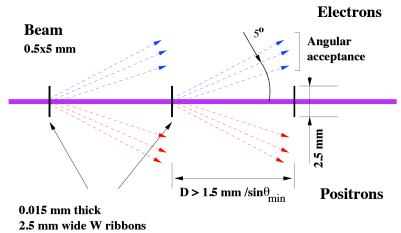
# APEX Equipment: Detector Stack

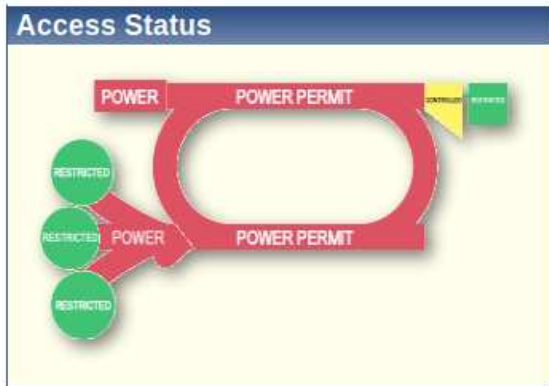


# APEX Equipment: SciFi



# APEX Equipment: Target



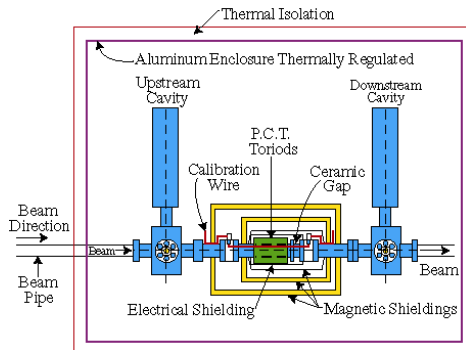


Expected APEX Physics Beam  
February 7th ..... March 15th

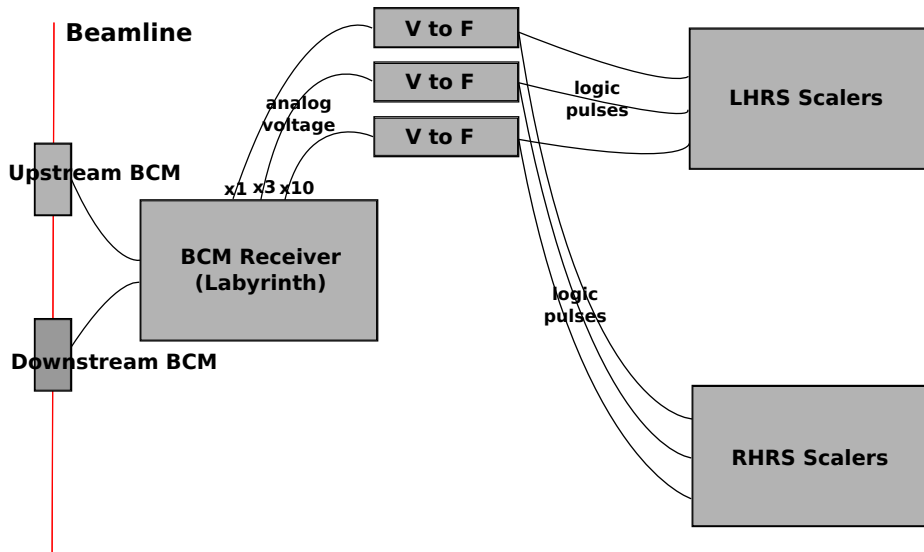
- Detectors.....Operational
- Trigger/DAQ.....Setup, Running Cosmics
- Septum.....Installed, Testing
- SciFi.....Installed, Cosmics Testing
- Target.....Installed, Aligned, Vacuum
- Shifts.....Nearly Full!
- Beam.....Imminent

# Hall A BCM Readout

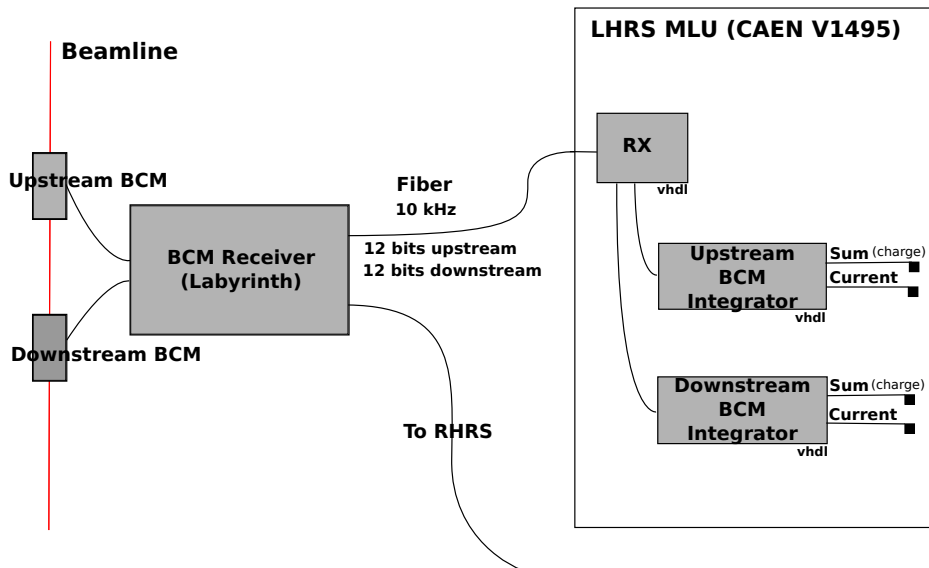
- Two cavities, up/down stream
- Calibrated to the 'unser' (PCT)
- measures current/charge



# Hall A BCM Analog Readout



# New Hall A BCM Digital Readout





# Thanks!