Heavy Photon Search update

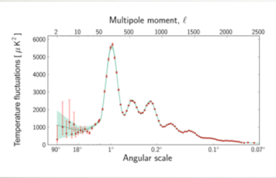
F.-X. Girod

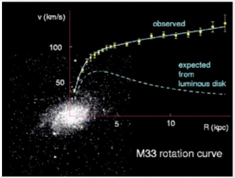
JLab Hall-B

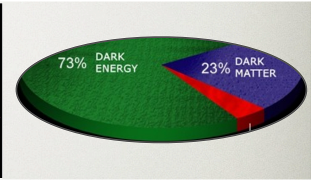
Hall-A collaboration meeting

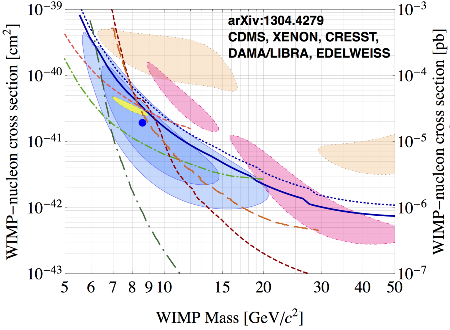
Outline

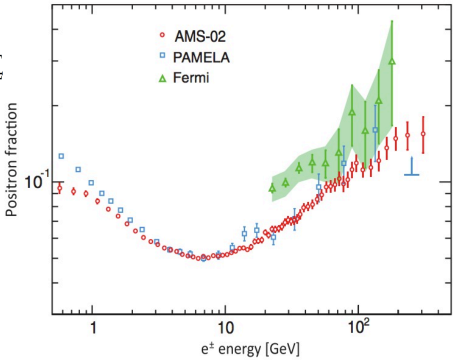
Dark matter


Multipole moment, ℓ
Temperature fluctuations [μK²]
Angular scale

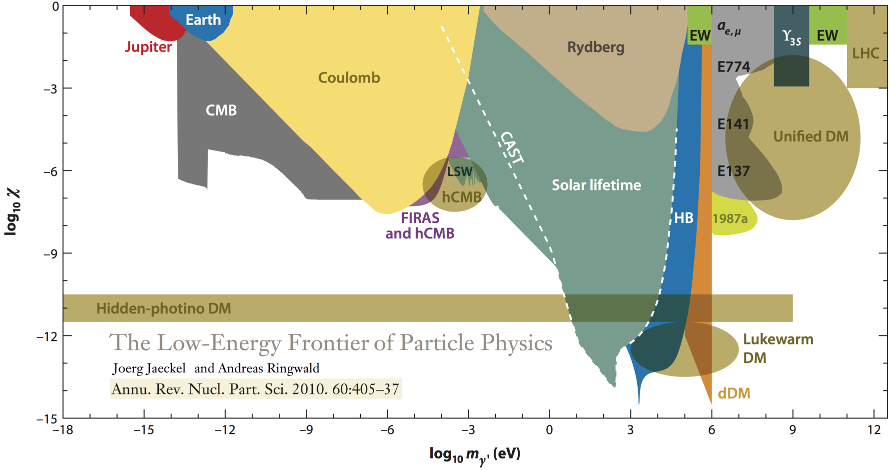

v (km/s)
observed
expected from luminous disk
R (kpc)
M33 rotation curve


73% DARK ENERGY
23% DARK MATTER

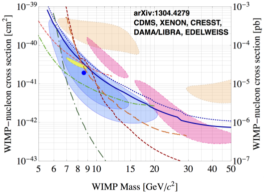

arXiv:1304.4279
CDMS, XENON, CRESST,
DAMA/LIBRA, EDELWEISS
WIMP−nucleon cross section [cm²]
WIMP−nucleon cross section [pb]
WIMP Mass [GeV/c²]

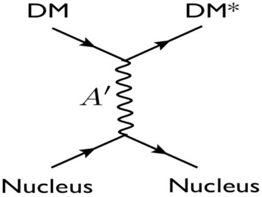

AMS-02
PAMELA
Fermi
Positron fraction
e± energy [GeV]

Hidden photon constraints

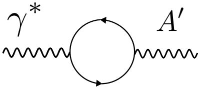


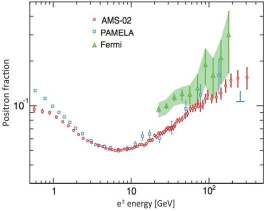
Unified DM

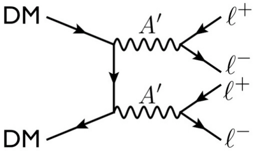


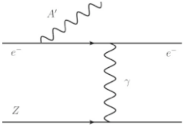


$$\Delta\mathcal{L}_{kin.mix} = \frac{\epsilon}{2} F'_{\mu\nu} F^{\mu\nu}_{Y}$$









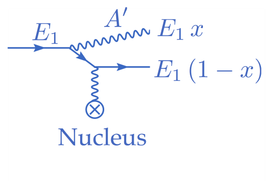
Can also explain muon g-2 anomaly

Fixed Target searches

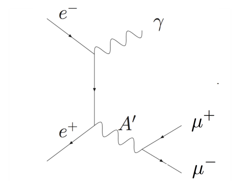
	Fixed-Target	e^+e^-
LUMINOSITY	10^{11} e⁻ → ; $\sim 10^{23}$ atoms in target	10^{11} e⁻ → ; ← 10^{11} e⁺
	N(hard scatter) ~ 0.01 – 1 *per electron*	N(hard scatter) ~ 1 *per crossing*
	O(few) ab^{-1} per day	O(few) ab^{-1} per decade

CROSS-SECTION

- Scales as A′ mass, not beam energy
- Coherent scattering from nucleus

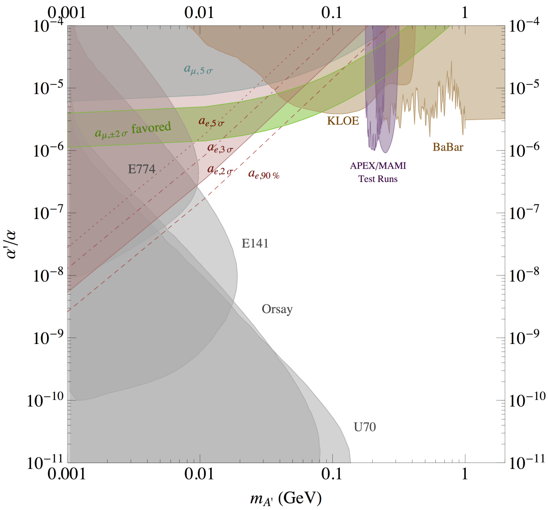


$$\sigma \sim \frac{\alpha^3 Z^2 \epsilon^2}{m^2} \sim O(10\ pb)$$

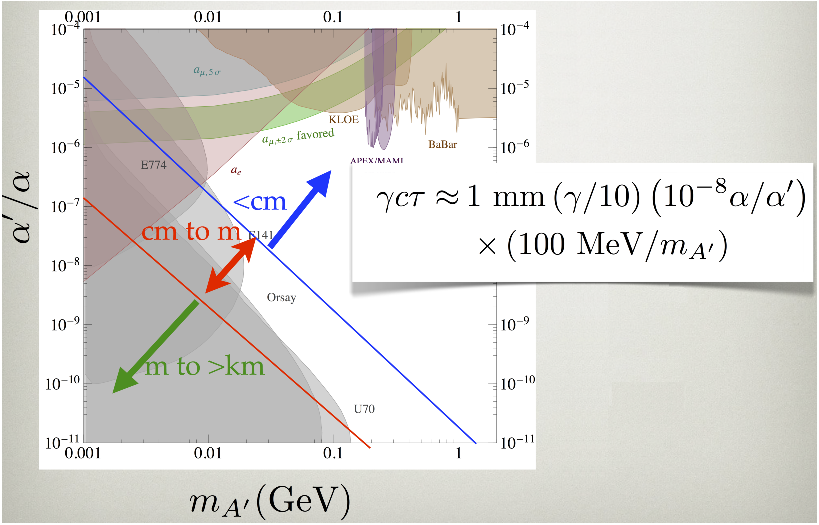


$$\sigma \sim \frac{\alpha^2 \epsilon^2}{E^2} \sim O(10\ fb)$$

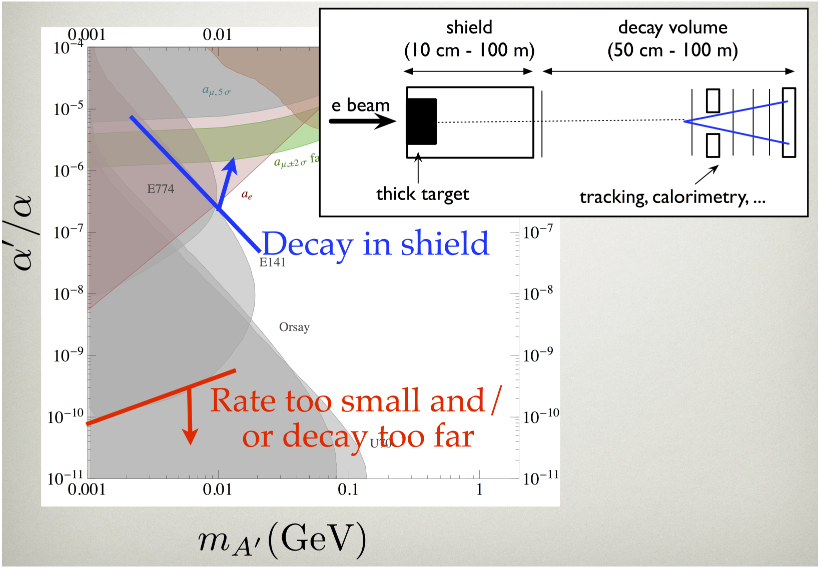
Fixed Target searches



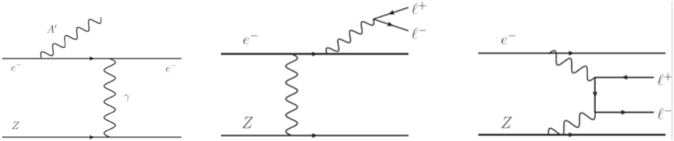
Fixed Target searches



Beam dump search limitations



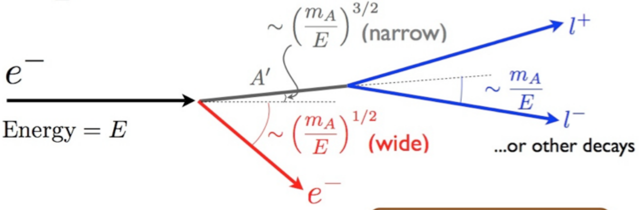
Heavy Photon Search kinematics



$$\frac{d\sigma}{dx} \propto \frac{\alpha^3}{\pi} \frac{\epsilon^2}{m_e^2 \cdot x + m_A^2(1-x)/x}$$

$$x = \frac{E_A}{E}$$

Kinematics **very different** from massless photon bremsstrahlung

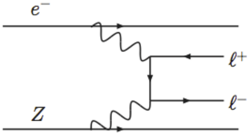


Heavier product (here A') takes most of beam energy

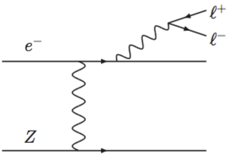
$E_A \sim E - m_A$

$E_e \sim m_A$

Heavy Photon Search backgrounds



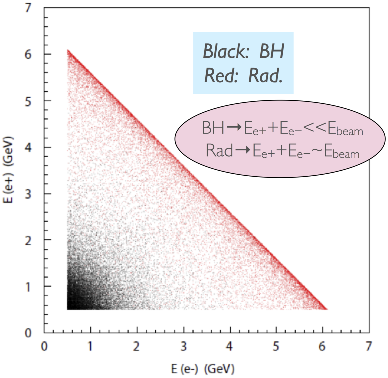
Bethe-Heitler



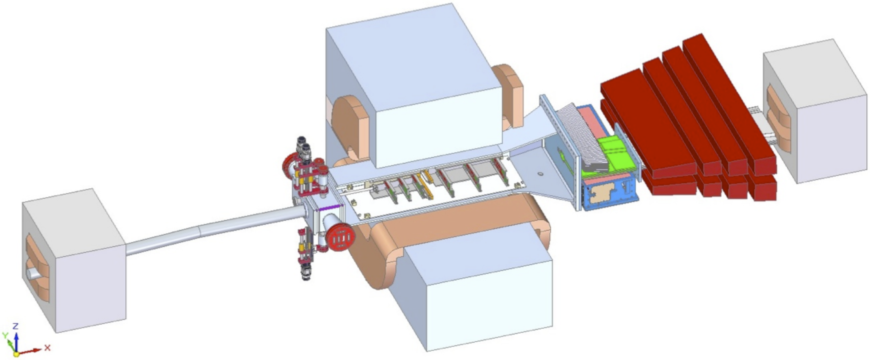
Radiative

Radiative process is kinematically indistinguishable from signal, except ...

$\sigma_{\text{B-H}}$ very large ≫ σ_{Rad}.
But kinematically distinct ➔
Use clever trigger to separate.

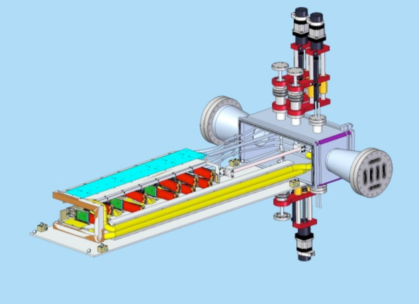


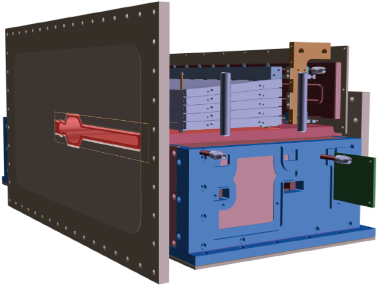
HPS detector



HPS split design

- Both the Silicon Vertex Tracker (SVT) and the Ecal are split vertically, to avoid the "sheet of flame".

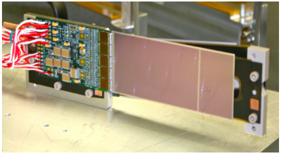


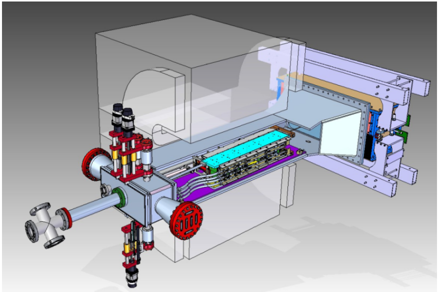


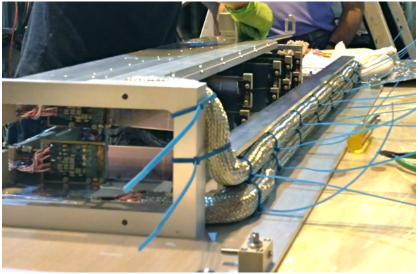
- The first layer of the SVT comes within 0.5 mm of the beam to allow acceptance at 15 mrad, so precision movers, working in vacuum, are needed to position it accurately w.r.t. the beam
- The beam passes between the upper and lower halves of the Ecal through the Ecal vacuum chamber, which accommodates the photons radiated at the target, the multiple scattered electron beam, and the "sheet of flame".

SVT design

- **Si microstrip sensors readout by CMS APV25's**
  40 MHz readout
  $\sigma_x \approx 6\ \mu m$; $\sigma_t \approx 2\text{-}3$ ns
- **Tracker has 6 (5 for test run) layers, each axial + stereo**
  Measures track momentum and trajectory
  Placed inside Hall B pair spectrometer magnet
  Resides in vacuum to minimize beam backgrounds
  Split top and bottom to avoid beam and "wall of flame"

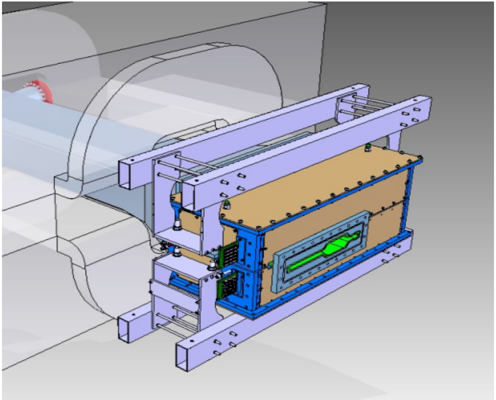
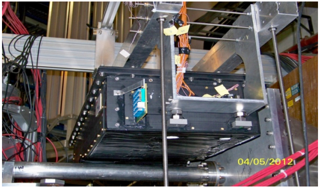


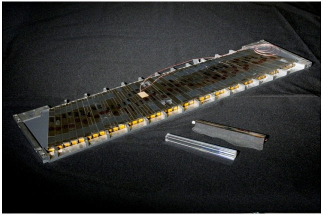




ECal design

- Ecal consists of top and bottom modules, each arranged in 5 layers , with 442 lead-tungstate ($PbWO_4$) crystals in all.
- Crystals are readout with APDs and preamplifier boards
- Data is recorded in 250 MHz JLAB FADC
- Thermal enclosure holds temperature constant to ~1° F to stabilize gains



DAQ design

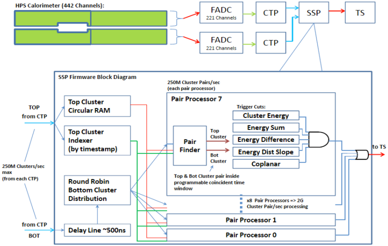
- **SVT DAQ uses SLAC ATCA-based architecture**
  * Sensor hybrids pipeline data at 40 MHz and send trigger-selected data to COB for digitization, thresholds, and formatting. COB transfers formatted data to JLAB DAQ.
  * Record data up to 16kHz in pipeline mode. Will push this up to 50 kHz with upgrades.

.
  * One ATCA crate with 2 COBs handled the full HPS Test Run SVT (20 modules, ~10k channels).

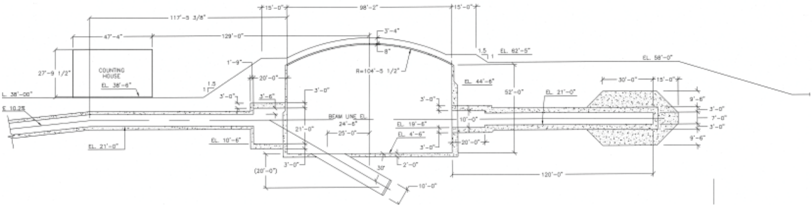
Cluster on Board (COB)

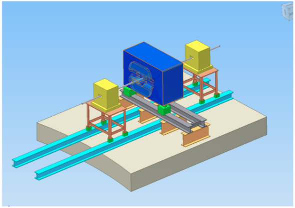
- **Ecal DAQ and Trigger**
  * Data recorded in 250 MHz JLAB FADC. PH and time transferred every 8ns to Trigger Processors.
  * Trigger sent to SVT DAQ and FADC for data transfer.
  * Ecal FADC and DAQ can trigger and record data up to 50 kHz.

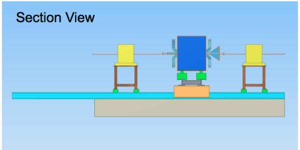
Ecal DAQ/Trigger

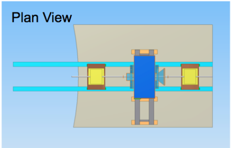


HPS location









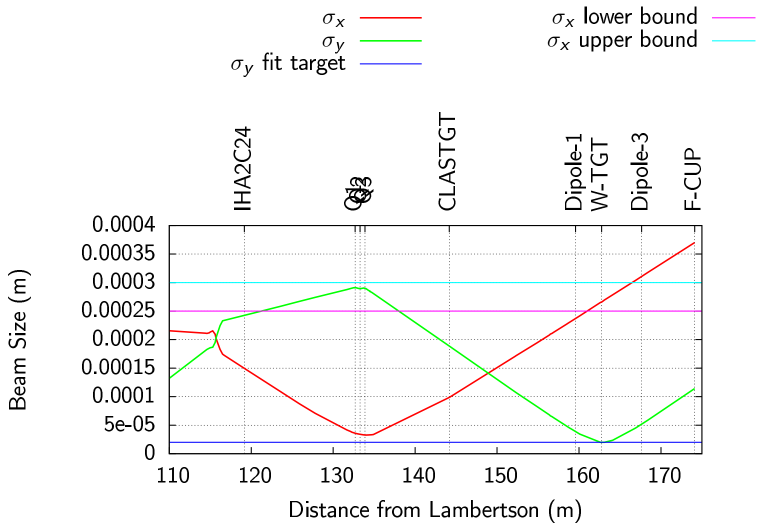
Beam optics

What	MyName	Distance to first HPS dipole	Provenance
		(m)	
Vertical Corrector	MBC2H08V	2.5	New
Horizontal Corrector	MBC2H08H	2.35	New
Beam Position Monitor	IPM2H08	2.075	New
Drift			
Beam Viewer	ITV2H09	0.89	ITV2H01?
Wire Scanner	IHA2H09	0.69	IHA2H00
Beam Position Monitor	IPM2H09	0.5	New
Center of HPS 1^{st} Dipole	MBX2H90	0	Frascati

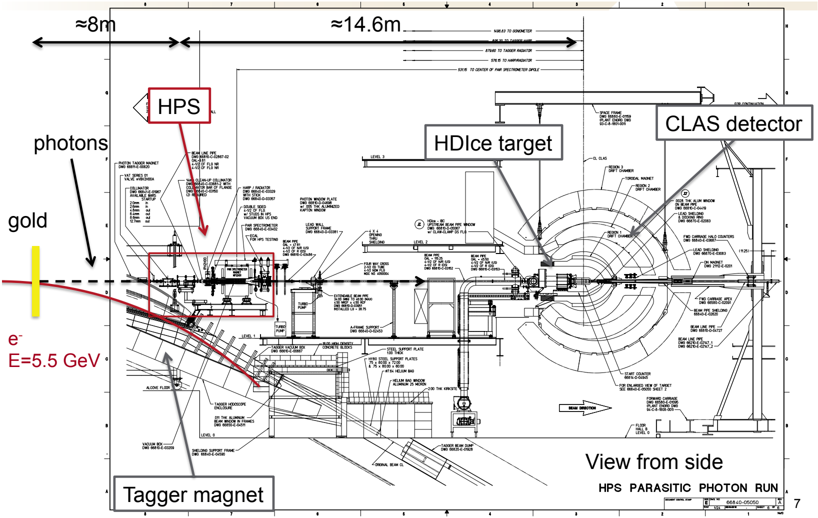
Beam optics

What	MyName	Distance to first HPS dipole (m)	Distance to Tagger harp (m)
nA Beam Position Monitor	IPM2H01	27.505	12.914
Beam Position Monitor?	IPM2H02	27.255	13.164
Quadrupole	MQA2H02	26.905	13.514
Quadrupole	MQR2H03	26.305	14.114
Quadrupole	MQA2H04	25.705	14.714
Vertical Corrector	MBC2H04V	25.180	15.239
Horizontal Corrector	MBC2H04H	24.98	15.439
Beam Position Monitor	IPM2H04	24.905	15.514
CLAS Target	ETACLAS	15.415	25.004
Center of HPS 1^{st} Dipole	MBX2H90	0	40.419

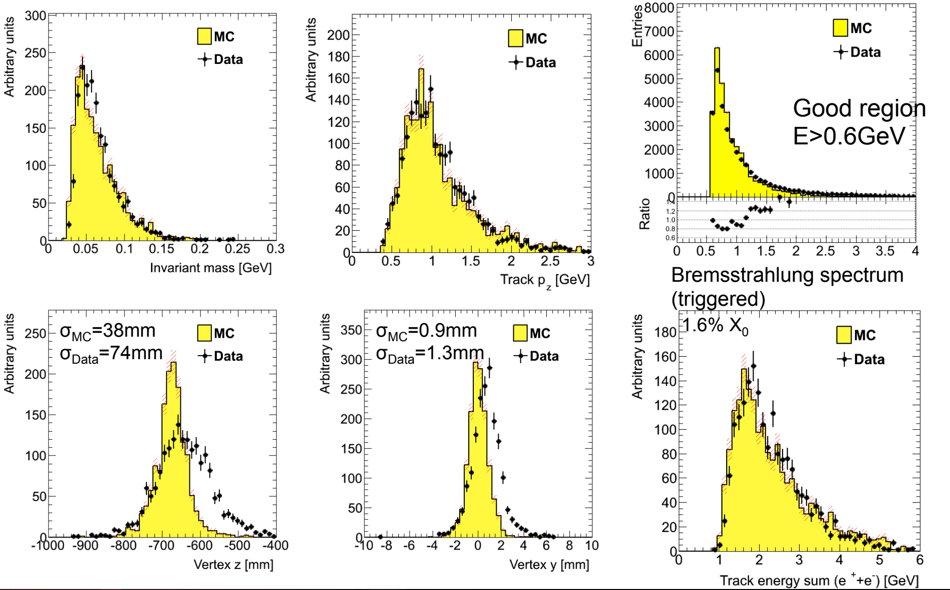
Beam optics


σx
σy
σy fit target
σx lower bound
σx upper bound
IHA2C24
CLASTGT
Dipole-1
W-TGT
Dipole-3
F-CUP
Beam Size (m)
0.0004
0.00035
0.0003
0.00025
0.0002
0.00015
0.0001
5e-05
0
110
120
130
140
150
160
170
Distance from Lambertson (m)

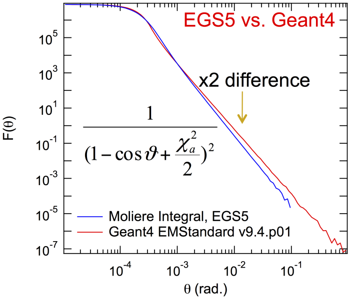
HPS test run configuration



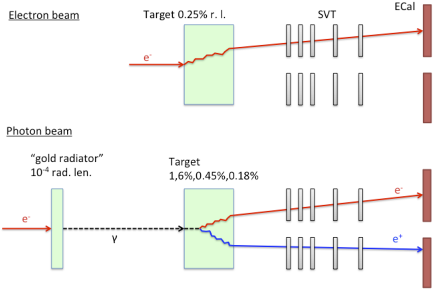
HPS test run vs MC



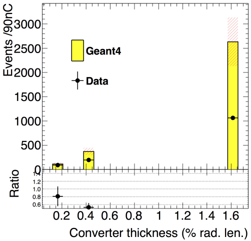
HPS test run



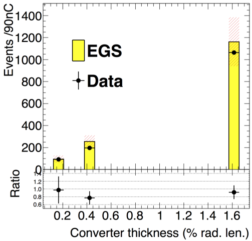
EGS5 vs. Geant4
x2 difference
$$\frac{1}{(1-\cos\vartheta+\frac{\chi_a^2}{2})^2}$$
F(θ)
θ (rad.)
Moliere Integral, EGS5
Geant4 EMStandard v9.4.p01



Electron beam
Target 0.25% r. l.
SVT
ECal
e-
Photon beam
"gold radiator"
10^{-4} rad. len.
Target
1,6%,0.45%,0.18%
e-
γ
e-
e+



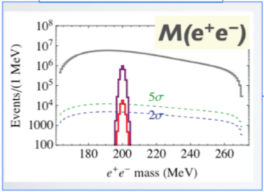
Events /90nC
Geant4
Data
Ratio
Converter thickness (% rad. len.)



Events /90nC
EGS
Data
Ratio
Converter thickness (% rad. len.)

HPS reach

Bump hunt region



Displaced decay vertex search