HPS Test Run 2012
Overview

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Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Introduction

Overview: try to cover many aspects - more details in the following talks!

Outline

- Test run apparatus
- System performance
- Analysis results

HPS Test Run Apparatus

Test Run was 1st phase of HPS

- Jan 11': Endorsed by JLab PAC 37
- Mar 11': Funded by DOE
- Apr. 12': Installation on beam line
- Only photon beam ☹

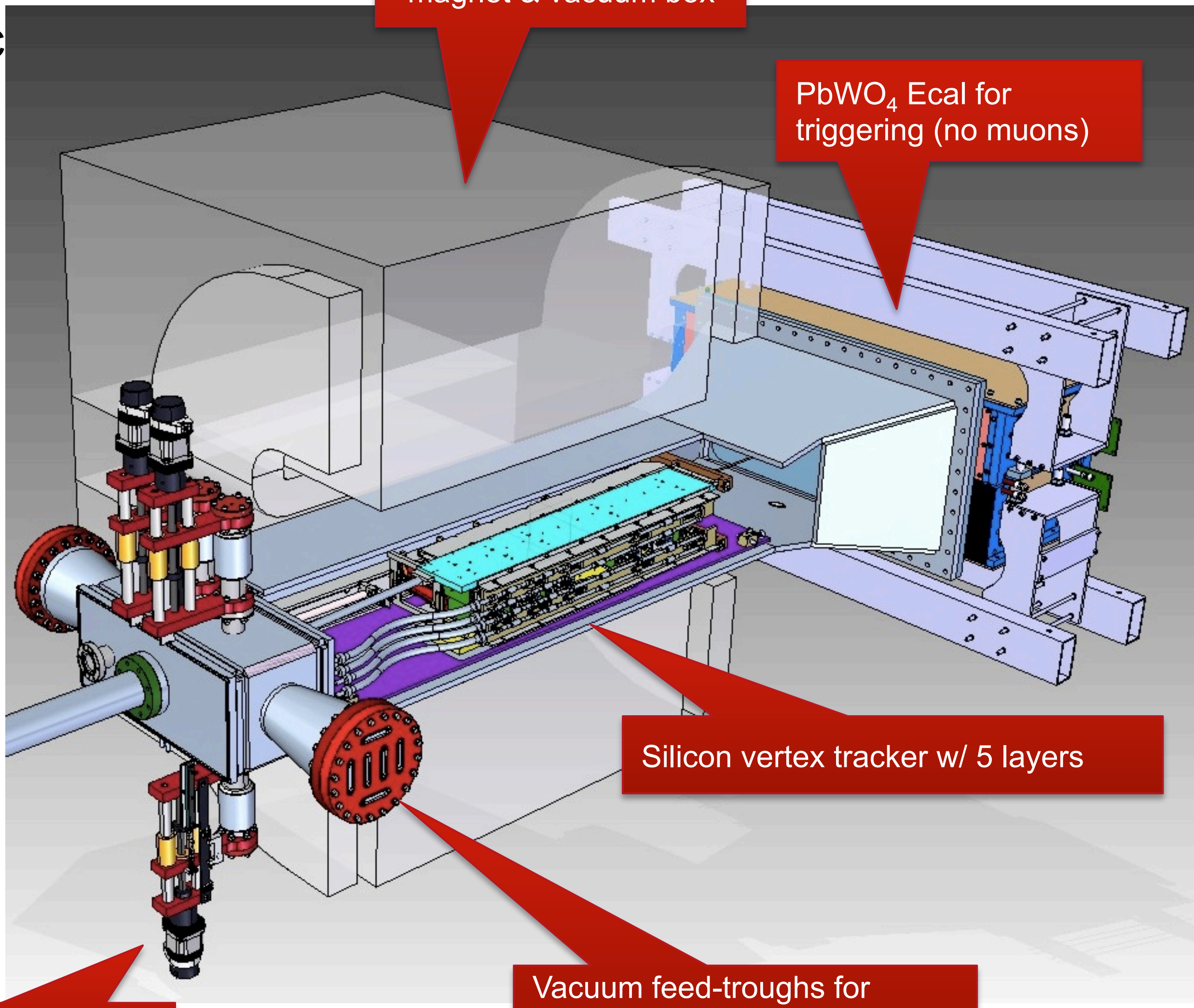
Test Run designed to

- Develop technical solutions
- Demonstrate operational principles
- Capable of A' physics

⇒ Build a smaller version of HPS…

⇒ Same challenges

…do it in 13 months…



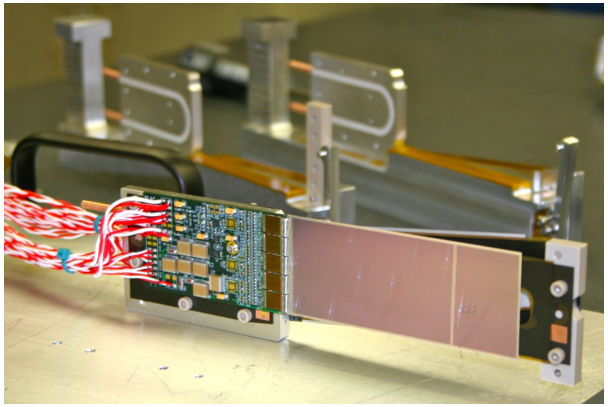
Silicon Vertex Tracker (SVT)

Silicon microstrip sensors readout by APV25 (CMS dev.) chips

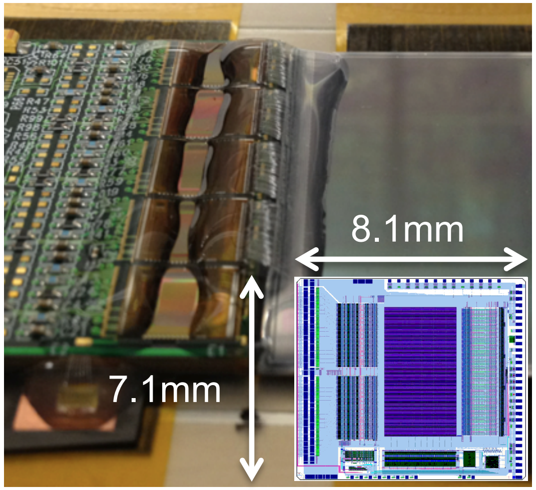
- Single hit spatial resolution: ~6μm
- 40MHz readout of up to 6 samplings of pulse shape (35ns shaping time)
- Individual hit time resolution: ~2-3ns

Five tracking layers

- Axial and stereo half-modules (re-used for 2014) sandwiched around cooling block; removes heat and improves radiation hardness
- Resides in vacuum (existing spectrometer magnet)
- Split in half to avoid dead zone; retractable for safety
- 0.7% X_0 in tracking volume



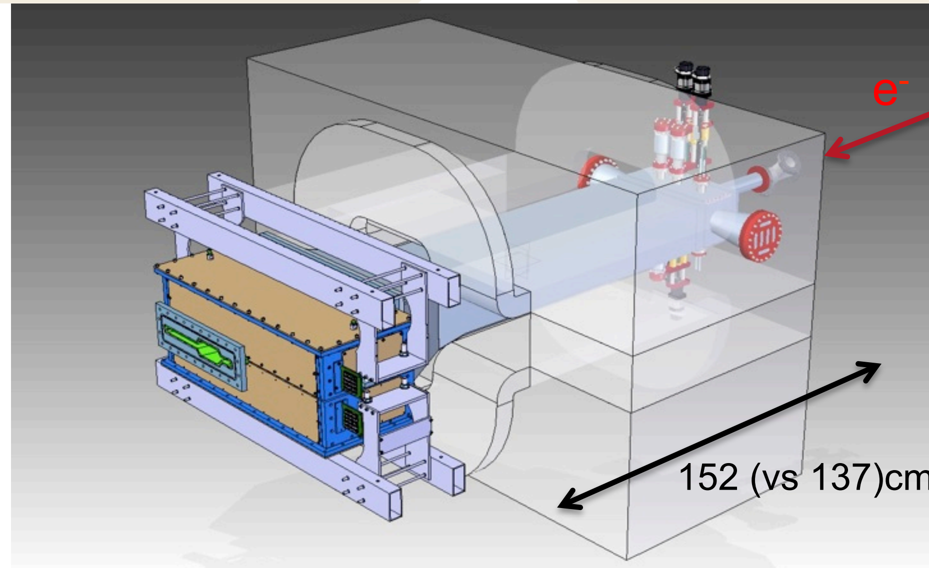
D0 RunII sensors
4x10cm, 320um thick
30(60)μm (readout) pitch



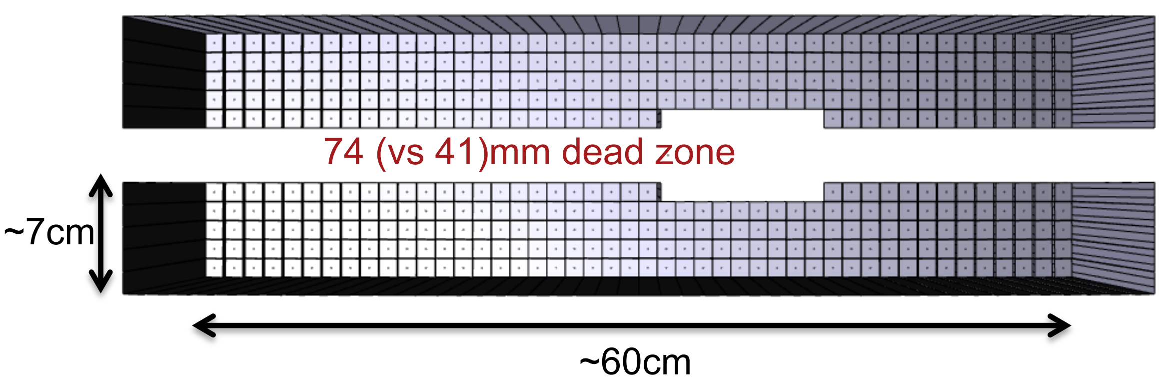
Electromagnetic Calorimeter (ECal) Trigger

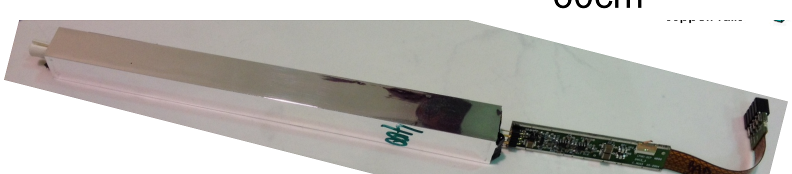
ECal consists of top and bottom modules

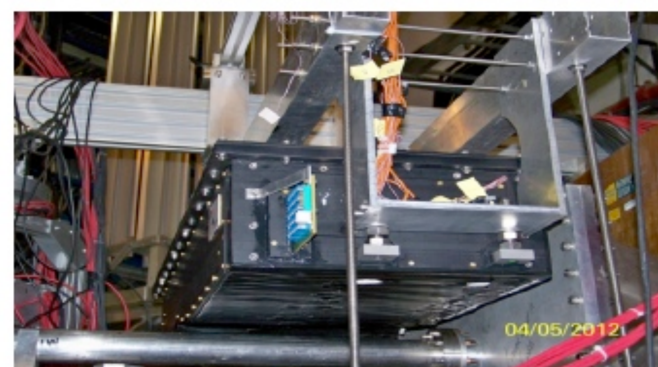
- Readout by APDs and preamplifier boards; data recorded by 250MHz Flash ADC boards
- Crystals and readout in hand from CLAS Inner Calorimeter
- Thermal enclosure ΔT~1C to keep gains stable
- No vacuum chamber for test run



442 $PbWO_4$ crystals: 13×13mm^2 (R_M~10mm), 160mm long (18X_0)







Test run installation (top half)

High Rate DAQ

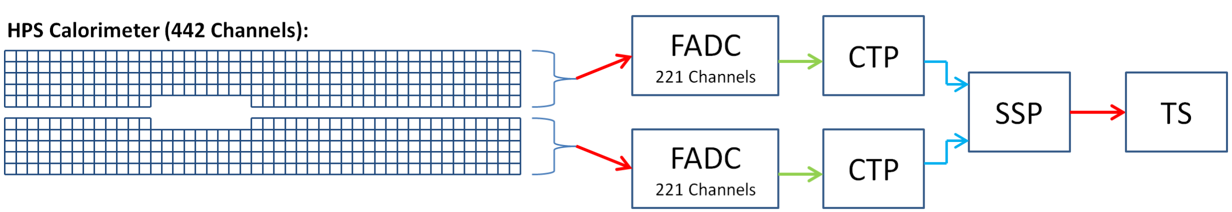
ATCA main board (COB)

SVT DAQ based on SLAC-based ATCA architecture

- APV25 chips transfer trigger-selected samples from 40MHz analog pipeline to ATCA crate
- Signal amplification and digitization on custom ATCA interface board; FPGA's on COB handle data processing (thresholds, filtering), trigger and event frame generation
- JLab DAQ communication through readout crate controller in external Linux PC
- Single ATCA crate; 2 COB's, handled test run SVT

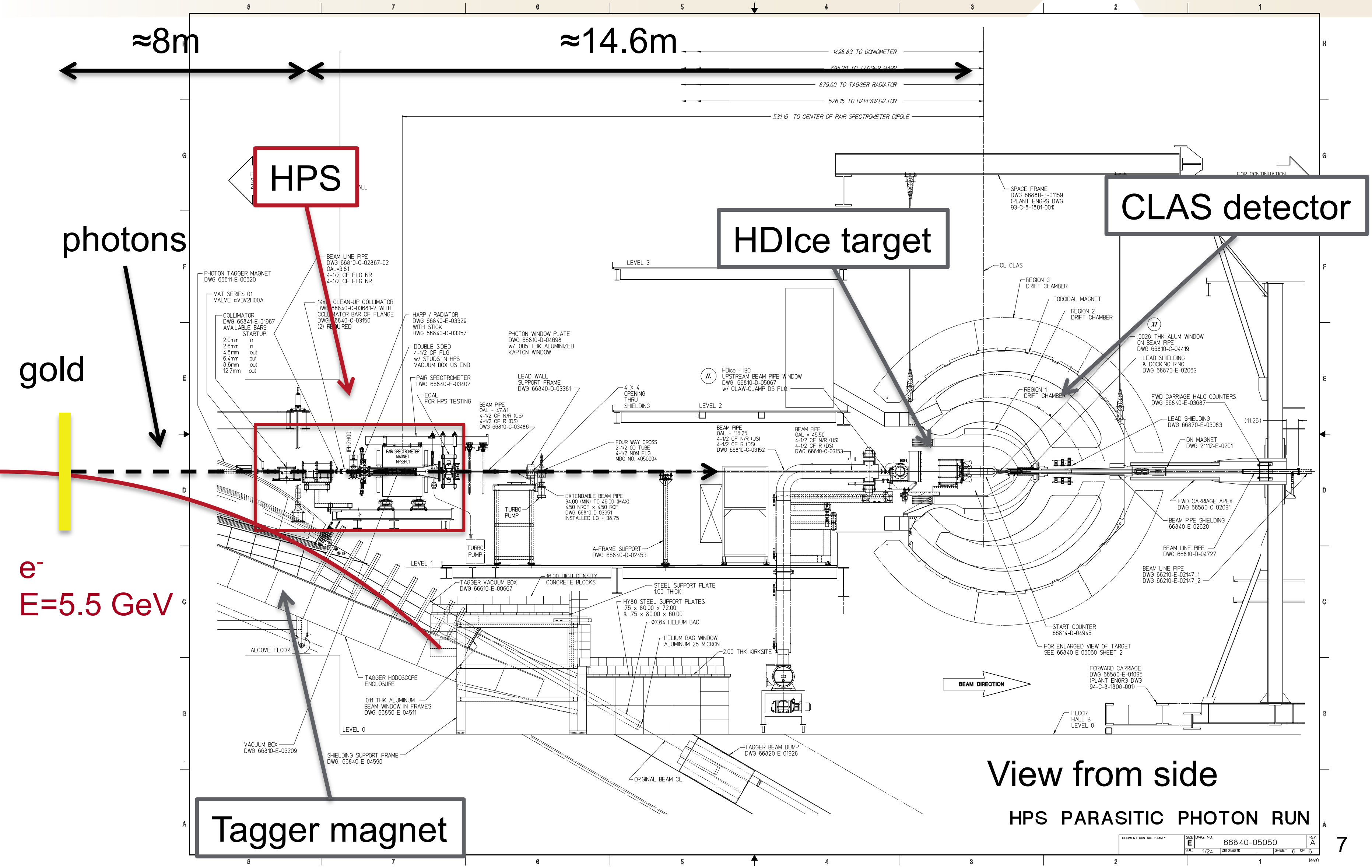
ECal DAQ and trigger based on JLab Flash ADC

- Free-running 250MHz 12-bit ADC w/ 8μs pipeline
- Can transfer hit time w/ 4ns resolution every 32ns
- Two 20-slot VXS crates handled top and bottom half of the ECal

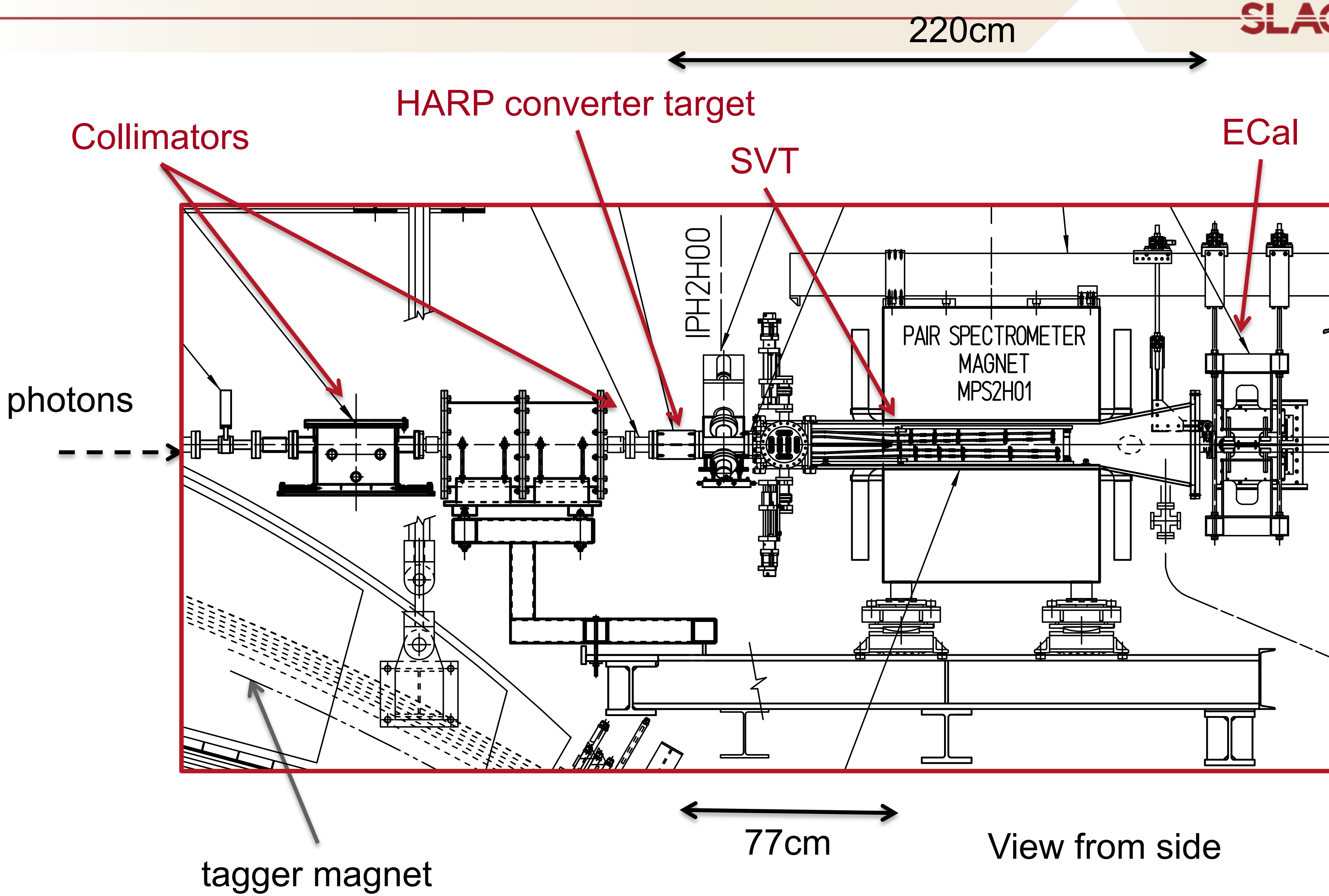


16 channel FADC

Parasitic Run – Photon beam



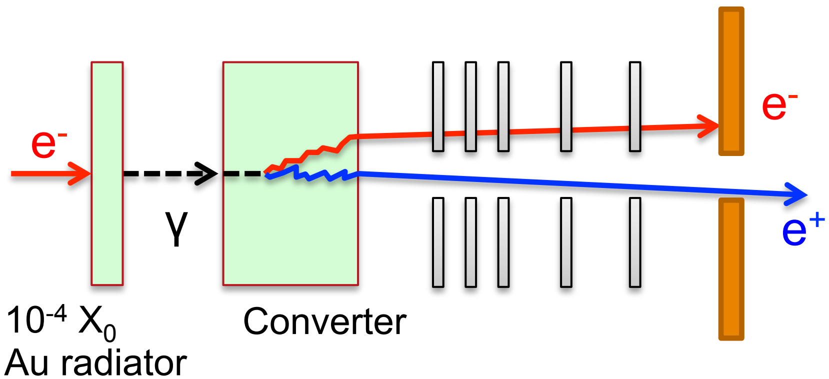
Dedicated Run – Photon beam



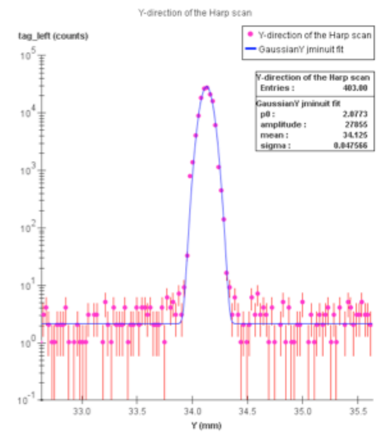
Dedicated Run – Photon beam

Beam characteristics:

- E_{beam}=5GeV, 30-90nA
- Beam envelope <1mm

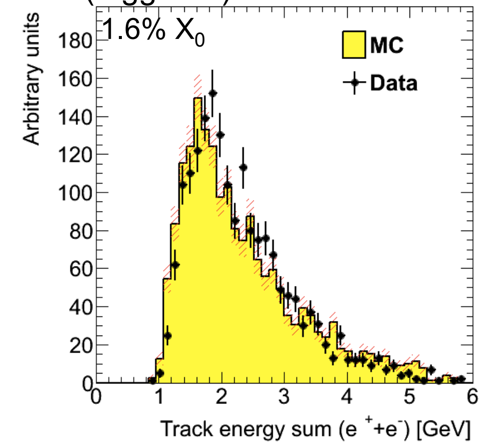


σ~0.7×0.36mm+0.3×1.1mm



HARP scan y [mm]

Bremsstrahlung spectrum (triggered)



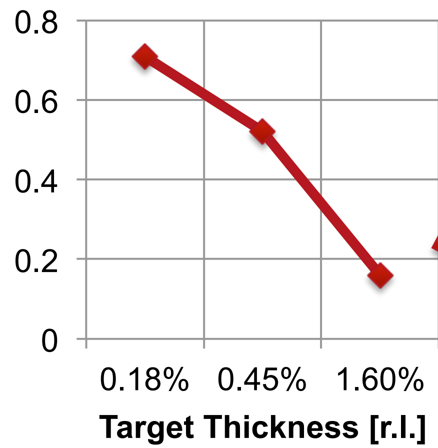
Two categories of events

- Pair production from HARP converter
- Upstream background (junk from collimators?)

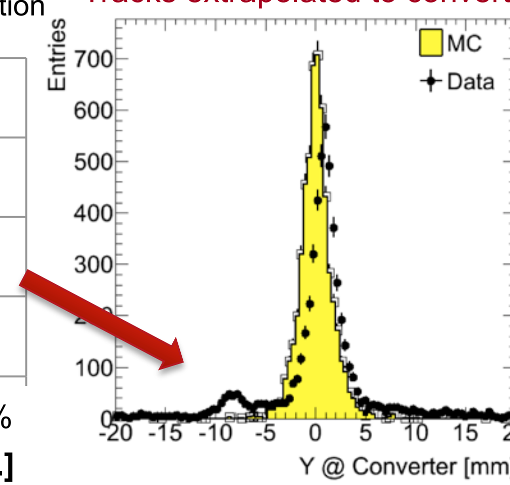
93% of triggers are single cluster events

- ECal at θ_y>17mrad;tracker fully opened θ_y>21mrad; (16mm@L1)

Rough background trigger fraction



Tracks extrapolated to converter



Dedicated Run – Photon Beam

About 8 hours of dedicated beam (1am-6am May 18th)

- Currents between 30-90nA
- Converter thicknesses: 1.6%, 0.45% and 0.18% R.L.
- Upstream background measured in dedicated runs

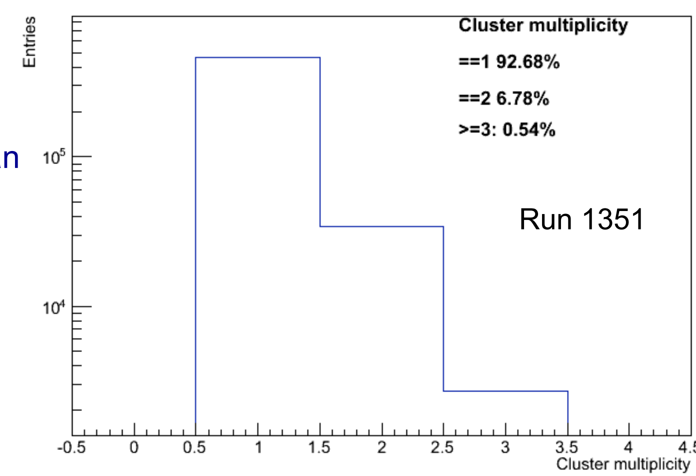
Run #	Run length (s)	Average current (nA)	Integrated beam current (nC)	Target thickness (%r.l.)	Rate (Hz)	Magnet Polarity
1349	911	60.2	54879.7	1.60	1262.12	-1
1351	306	88.0	26928.0	1.60	1933.48	-1
1353	2640	77.4	204325.1	0.18	436.90	-1
1354	2149	69.3	148839.1	0.45	596.06	-1
1358	1279	72.3	92523.9	0.00	309.79	-1
1359	1399	65.6	91761.5	0.00	318.64	1
1360	2762	76.0	209884.0	0.18	451.07	1
1362	1449	76.1	110298.6	1.60	1864.09	1
1363	278	30.8	8556.8	1.60	1864.09	1

Simulation and analysis tools

- EGS5/MadGraph/Geant4 for event generation
- SLIC (Geant4) framework for detector simulation
- LCsim (w/ hps-java package) used for reconstruction and simulation
- "DST's" (root tree's) for final analysis

Maurik, Jeremy, Norman

Omar



ECal Performance

Found 385 (87%) ECal channels useful offline

- 39 were disabled or not readout during the run (no FADC channel, had no APD HV bias, masked out due to noise); 18 found offline
- Trigger (RO) threshold was ~270MeV (~73MeV readout)

Gain calibration using E/p from SVT track matching

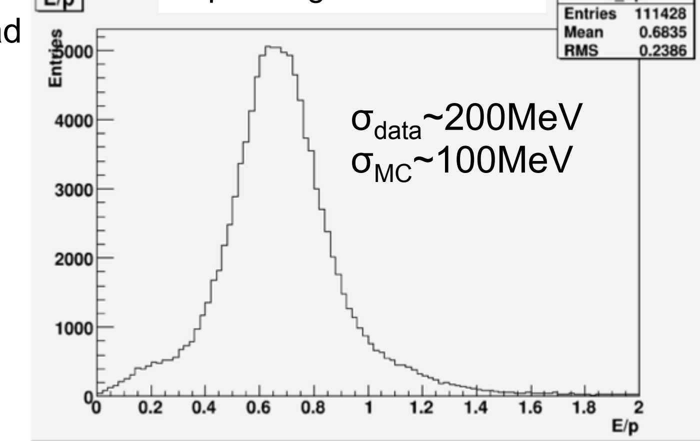
- Central part or crystals with (very) low gain hard to calibrate (no hits)
- No sampling fraction correction yet

Crude back-of-envelope resolution estimate (width of E/p)

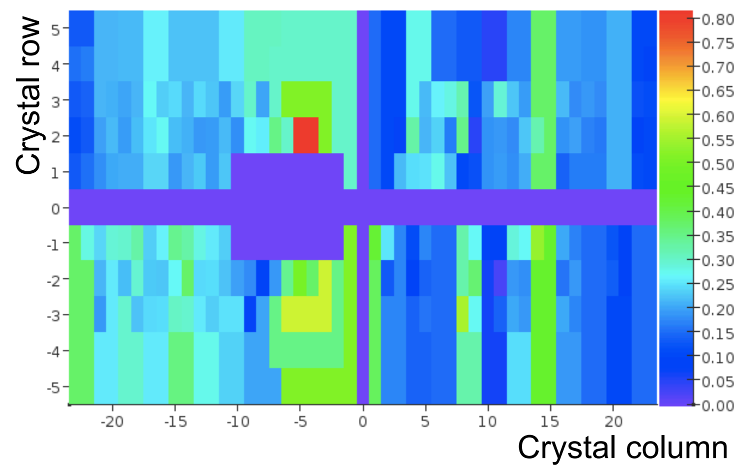
- σ/E~20% (10%) for data (MC)
- Discrepancy from un-calibrated crystals: changes across regions

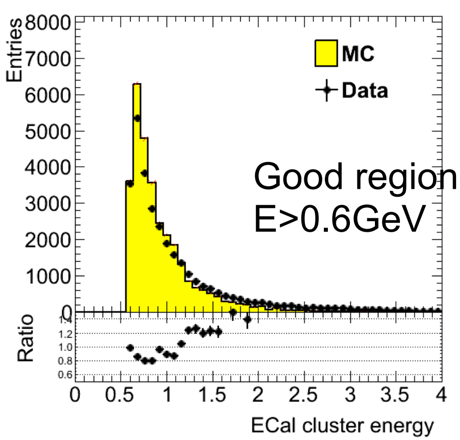
Relatively poor data/MC agreement (rate in "good region" ok)

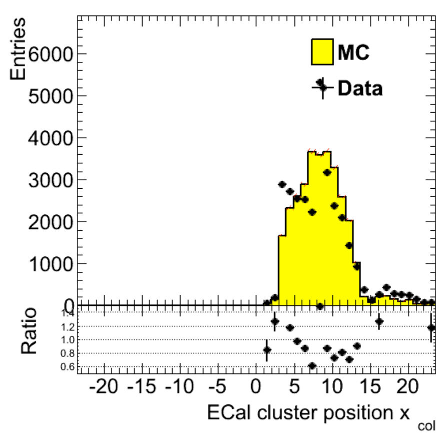
E/p after gain calibration



Crystal gain after calibration





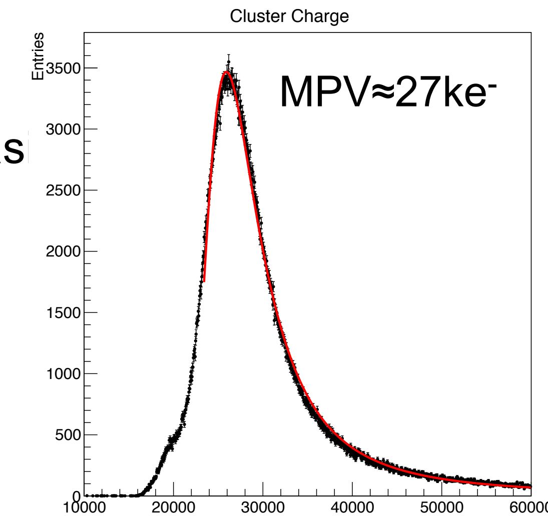


SVT Performance

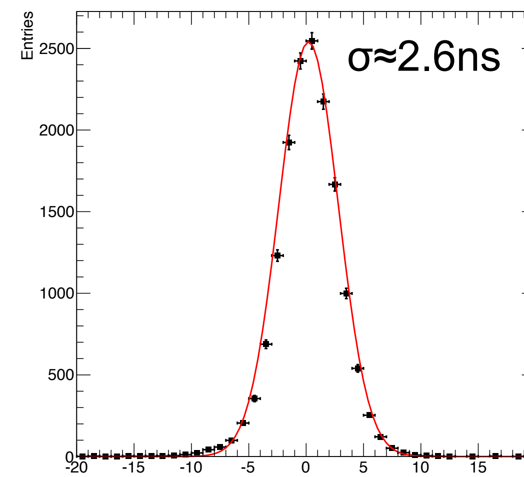
See Omar's talk

97% of SVT channels was found to be operational
- 85% of bad channels was from misconfigured APV25 chips
- Variation between 2-4%: taken into account on a per run bas

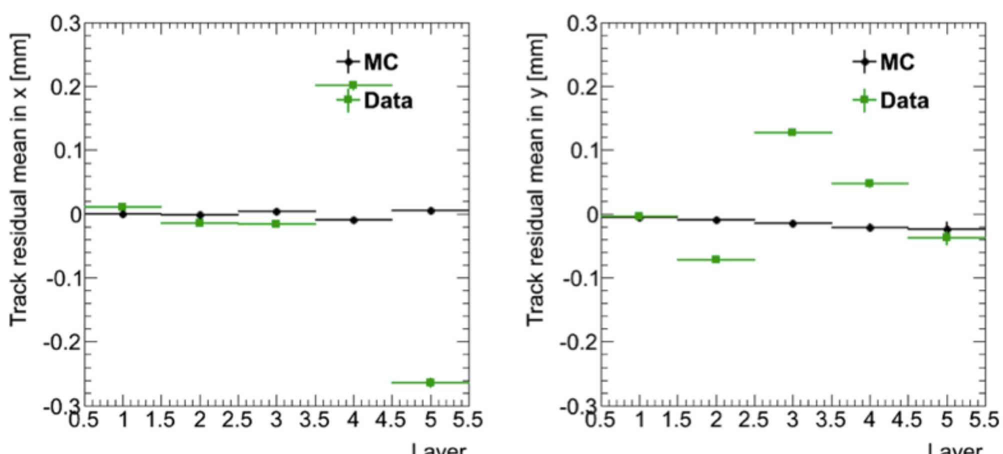
Principal tracker performance goals met
- S/N~25: sufficient to ensure ~6μm spatial resolution
- Hit time resolution ≈2.5ns
- Hit efficiency >98%
- Survey-based alignment to <300um



Cluster charge [e-]



Track time – hit time [ns]



Mean of biased track residuals vs tracker layer

Tracking Performance

See Matt's talk

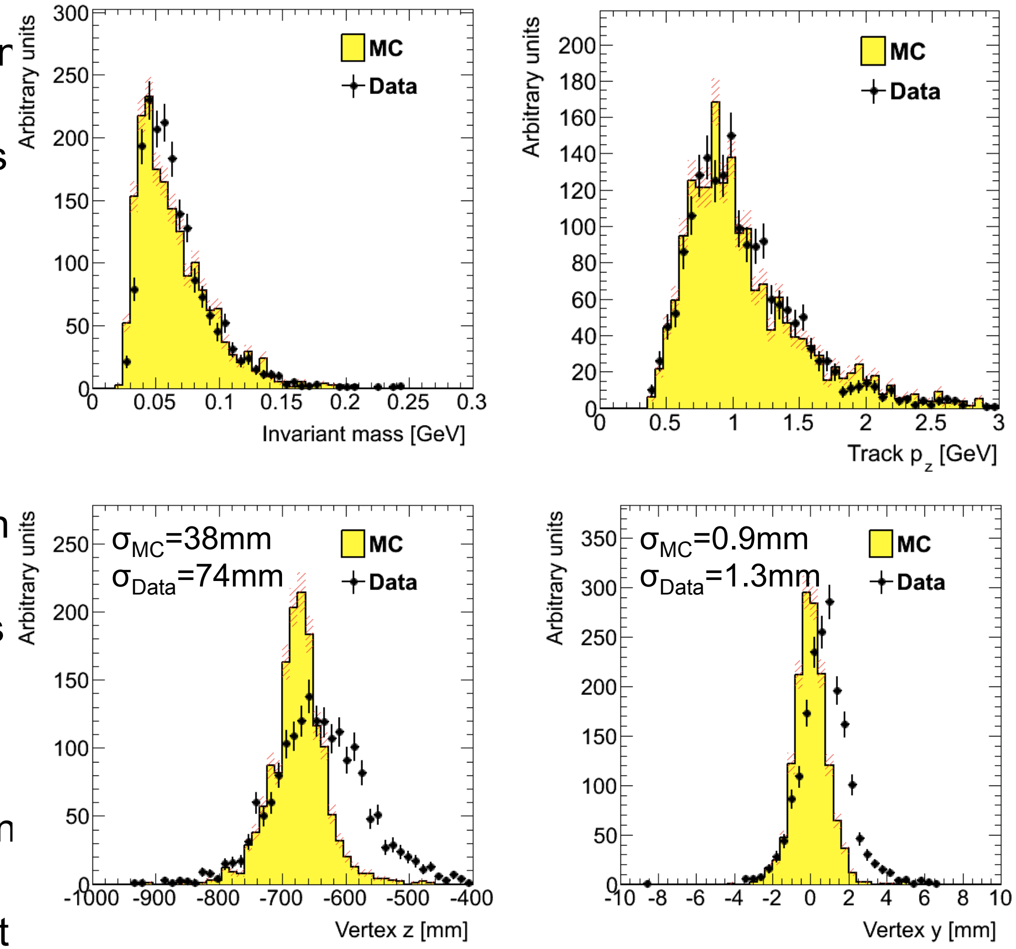
Relatively good data/MC agreement

- Bad/dead channels applied to simulation (condition per run)
- Magnet field map used in extrapolations (but not in tracking)

=> track-based alignment is limiting us now in most studies: plenty of room to help

Electron run performance fundamentals

- Momentum & mass resolution hard to extract (endpoints?): good agreement in key distributions
- Crude tracking efficiency estimate gives lower limit of 95% (ongoing work)
- Working on translating vertex resolution in test run to electron run (extrapolation suggest good agreement with simulation
- Mis-alignments gets exacerbated with lever arm; need to quantify size of effect



Worse agreement in z. Alignment effect?
Possible to toy model these effects?

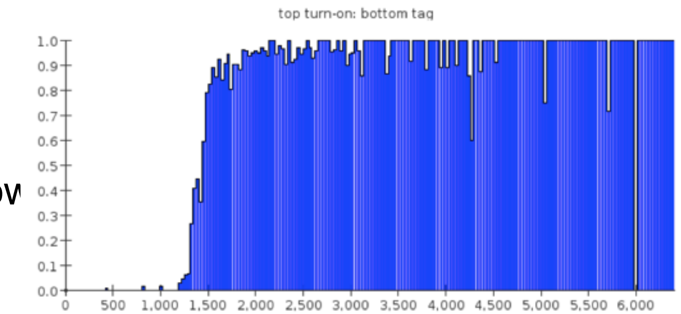
Trigger and DAQ Performance

See Sho's and Omar's talk

Trigger performance

- First time exercising new 12GeV-era system: FADC boards, cluster finding algorithms and hardware
- Trigger time and efficiency verified offline
- Trigger on top or bottom clusters
- Achieved stand-alone trigger rates >120kHz in trigger tests (low ECal thresholds)

Tag & probe trigger turn-on

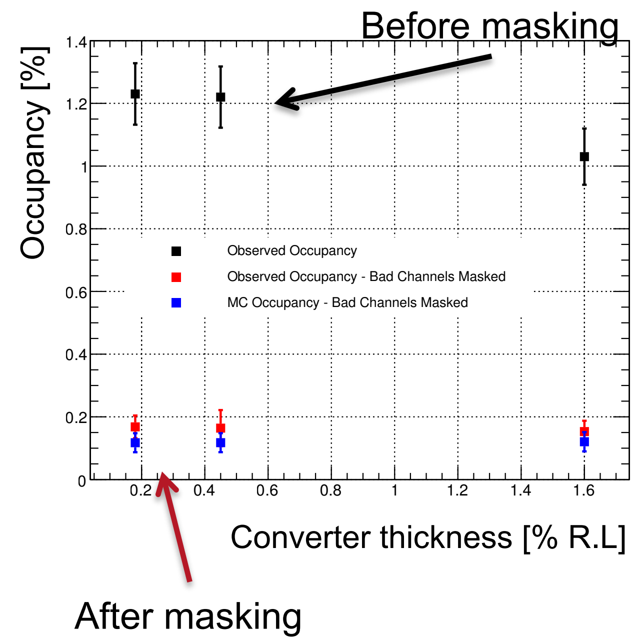


DAQ performance

- 12GeV-CODA development version integrated with SVT DAQ
- Data taken in "roc loc" mode at ~2kHz
- Achieved 11.5kHz full system rates in pipeline mode; limitation from SVT DAQ PC

SVT DAQ

- Completely new system in 12 months (1^{st} full system test after installation)
- All channels were functional; occupancy higher than expected (noisy/misconfigured chips -> fixed offline)
- Workaround w/ external PC limited test run rate (35kHz stand-alone); clear path to ultimate APV25 rate limit ~50kHz

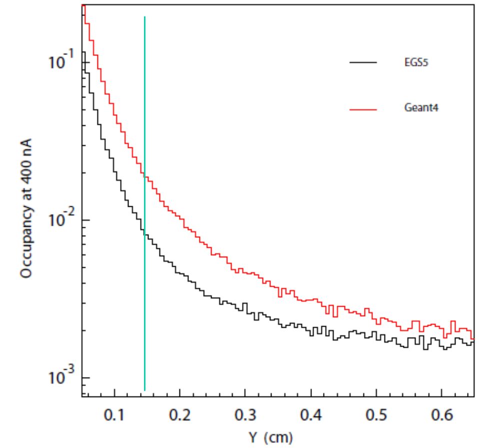


Multiple Coulomb Scattering

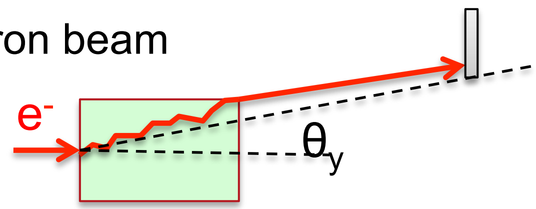
See Matt's talk

Test beam data can be used to test models of multiple scattering

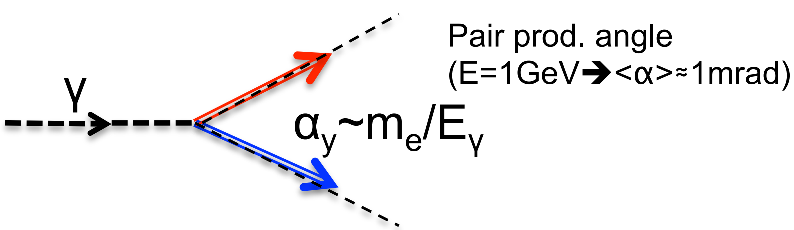
- Dominating source of occupancy in electron beam running
- Original proposal showed large discrepancies in prediction

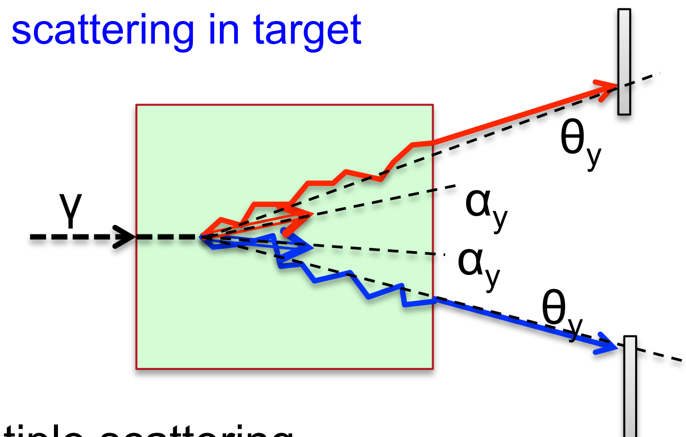


Multiple scattering in electron beam



With photon beam e^+e^- is produced at angle α before scattering in target





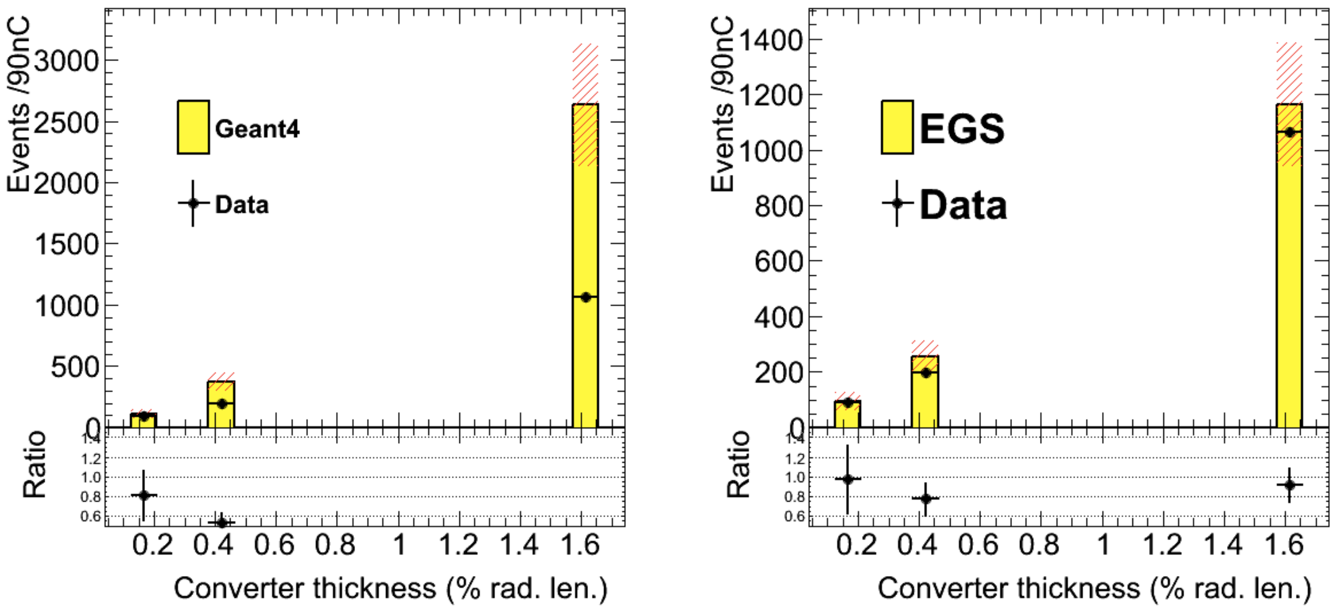
Measure a convolution of pair prod. angle and multiple scattering

- Comparable in size; only interested in multiple scattering contribution!
- Different target thicknesses change multiple scattering contribution

Absolute Trigger Rates With ECal

See Matt's talk

Check agreement vs. target thickness (increasing scattering)



Stat.+sys. uncertainties
- Bkg. Norm.
- Current norm.
- Beam gap

- Verify Geant4 overestimation at large angles
- EGS5 agree with data to within 10%

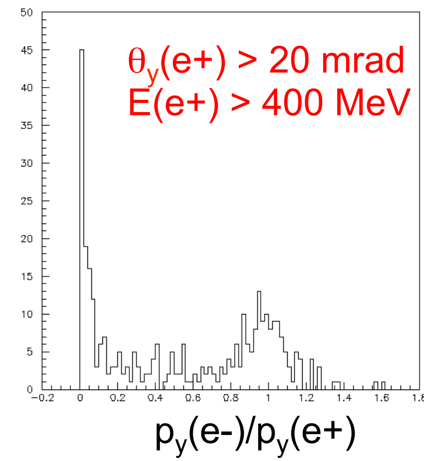
⇒ Further confidence in estimating the multiple Coulomb scattering background that dominates the HPS occupancy

e^+e^- Pair Reconstruction

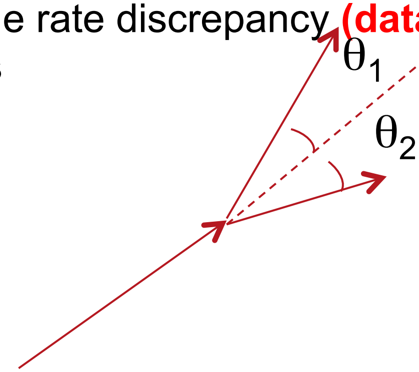
See Matt's talk

Events dominated by single triggers/ tracks (<0.5% 2trks/trigger):

- Both e+e- need "large" vertical momentum for acceptance
- Single rates agrees with EGS5 prediction!



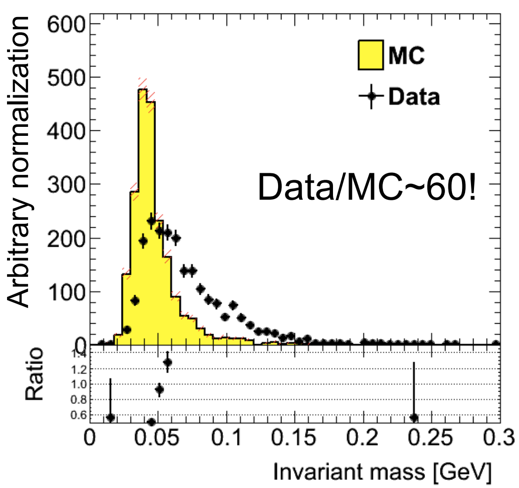
Initially reconstructed e+e- pairs showed huge rate discrepancy **(data/ MC~60!)**; also poor description of kinematics



EGS5 pair production issues

- Recoil nucleus momentum ignored
- Assumes: 180° azimuthal angle
- Decouples sampling of θ_1 and θ_2

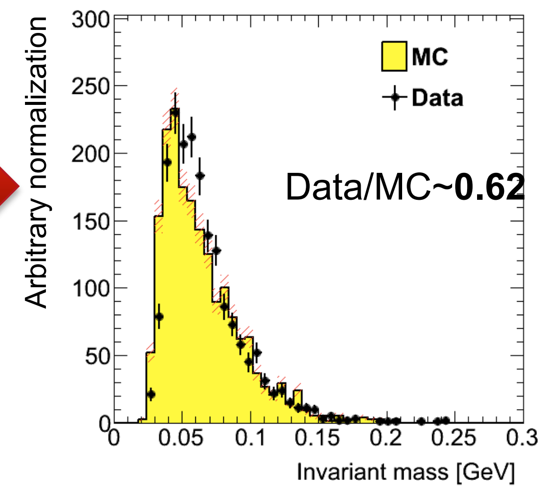
EGS5



Use MadGraph to correct EGS5 kinematics

Kinematics and rates agree much better

Corrected EGS5



Summary

HPS test run with photon beam (scheduling conflicts disallowed electron beam)

- Thin conversion target upstream of HPS allowed for detector commissioning
- An 8h dedicated run with thin conversion target ~70cm from HPS gave good quality data for performance studies

The test run demonstrated

- Trigger rates in HPS are as expected; multiple Coulomb scattering model was verified for electron beam running
- Design and technical feasibility of the detector design
- Tracker performance fundamentals where met (where possible to test)
- Viable trigger and DAQ system design with planned upgrades to reach expected rates
- Collaborations ability to meet schedule deadlines

The test run data is still very useful!

- The detector is very similar to 2014 version – practice/learn on real data
- Most developments: algorithms, condition DB, calibrations, etc. can be validated with Test Run data

More in the coming talks!

Test Run Analysis Topics

ECal performance

- Improved calibrations (sampling fraction; improved E/p algorithm?)
- Data/MC discrepancies
- Angular distributions
- Resolution
- …

Tracking performance

- Alignment: track-based and improved detector geometry model
- New tracking algorithm
- Momentum (and mass) resolution
- …

Analysis topics

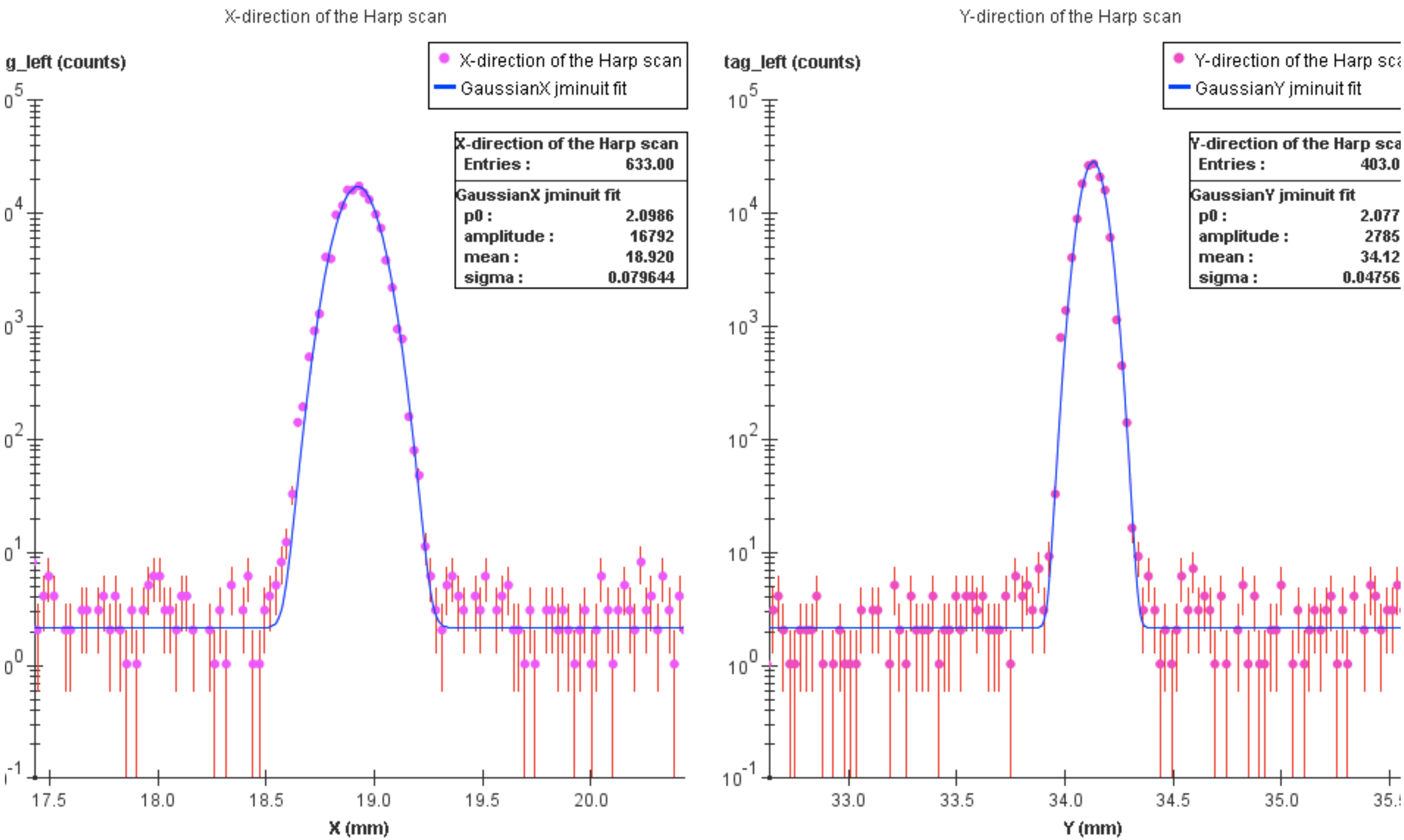
- Pair production cross-section
- Angular distributions with the tracker
- …

Conditions DB, monitoring and other software

- Use real data to fill conditions DB (where applicable) for testing
- New monitoring software would have real outliers to find
- …

Backup

HARP Scan HPS Test Run May 17 2012



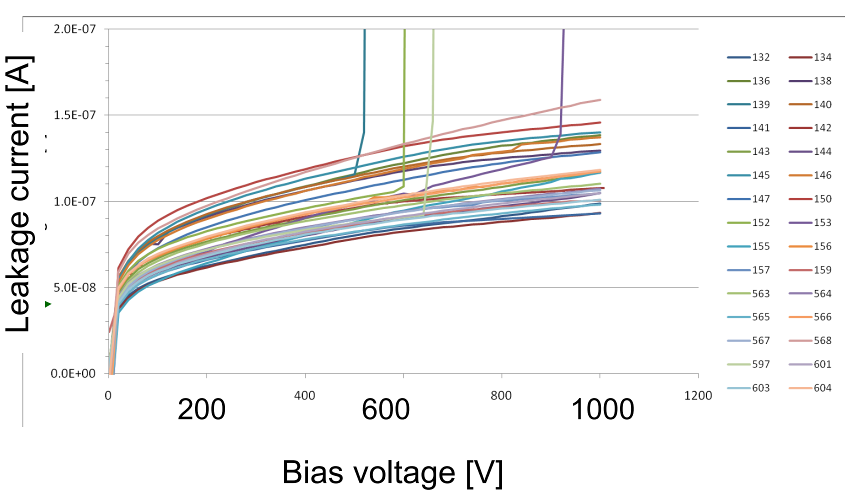
Sensor Selection

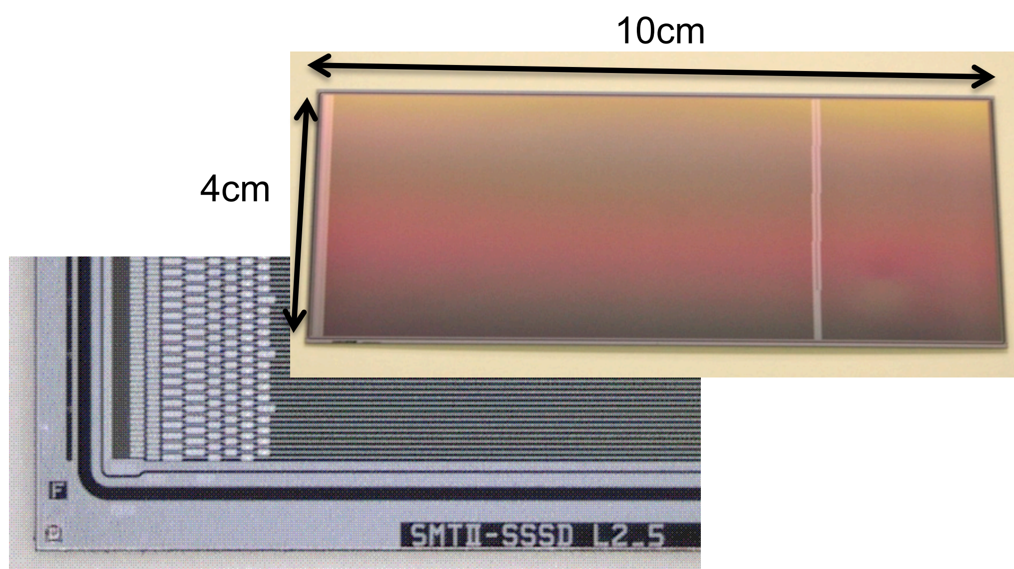
D0 RunIIb upgrade sensors

- High readout granularity
- Readily available and cheap (contribution from FNAL)
- Acceptable radiation tolerance

Technology	<100>, p-in-n, polysilicon bias
# channels	639
Active area (mm^2)	98.33x38.34
Readout (sense) pitch	60(30)μm
Thickness	320μm
Breakdown voltage	>350 V

I-V (bias) curves





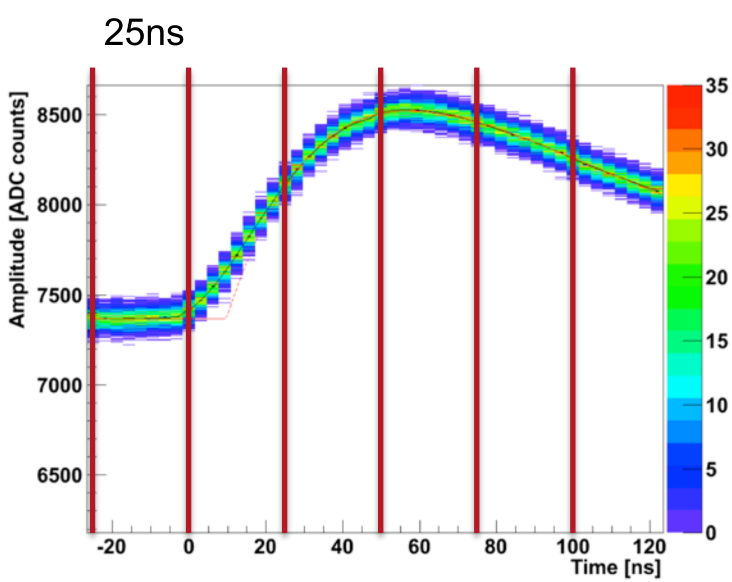
Silicon Front-End Readout Technology

APV25 chip (originally dev. for CMS)

- Low noise (S/N>25)
- Fast front-end (35ns shaping time) w/ overlapping trigger and readout
- Analog output
- Robust and proven (used in CMS tracker)
- Readily available; 28CHF/chip

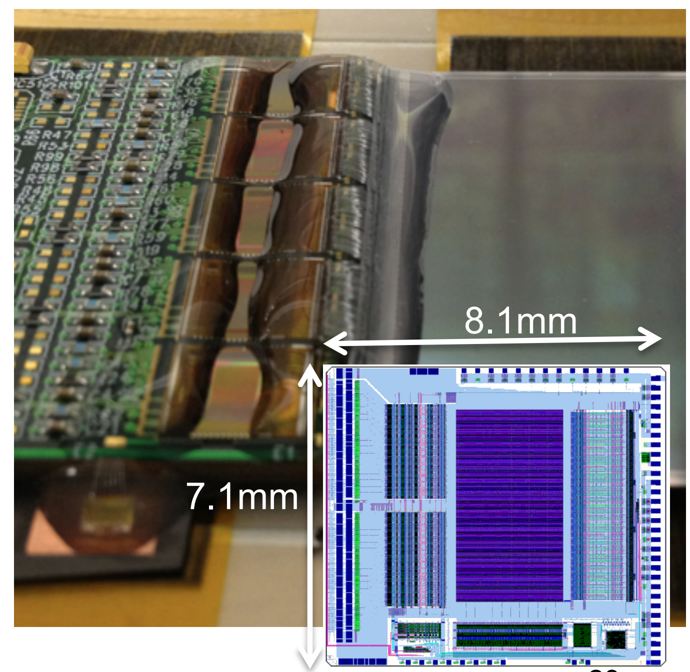
Technology	0.25μm
# channels	128
Input pitch [μm]	44
Noise [ENC e^-]	270+36×C(pF)
Power consumption	350mW

Multi-peak mode: sample pulse shape 6 times (40MSPS)



~2ns hit time resolution!

Fit CR-RC pulse shape to determine t_0



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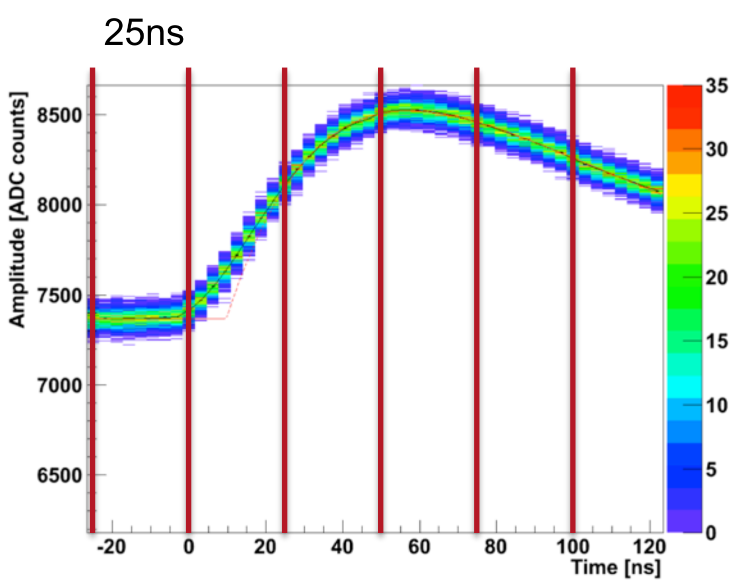
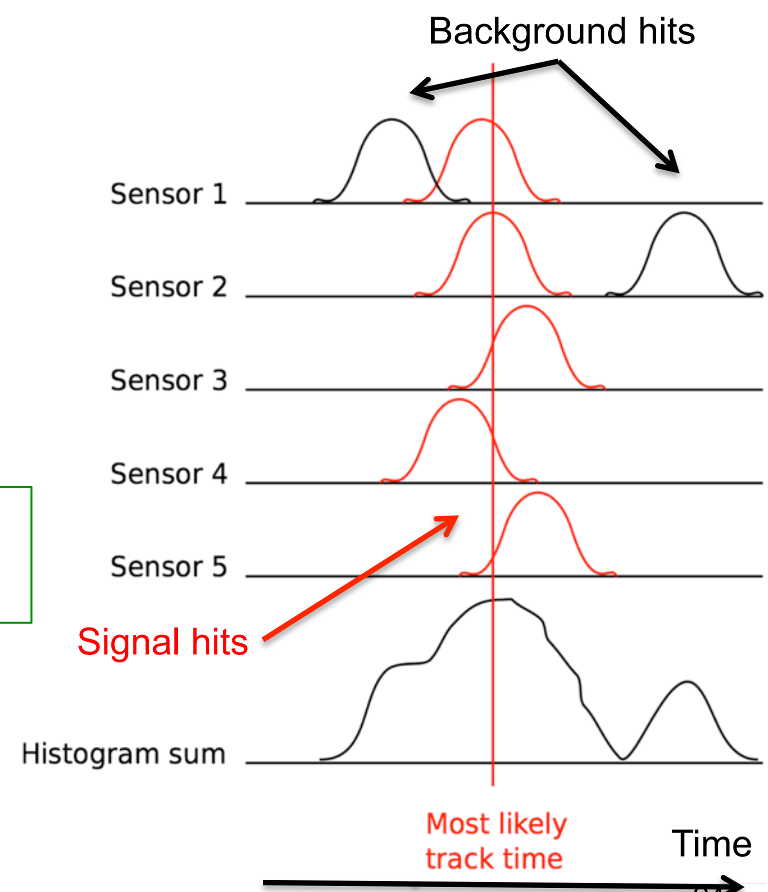


Fit CR-RC pulse shape to determine t_0

~2ns hit time resolution!

Use timing to reject background hits

⇒ Fundamental to success of HPS



Low Mass Silicon Modules

Half-module

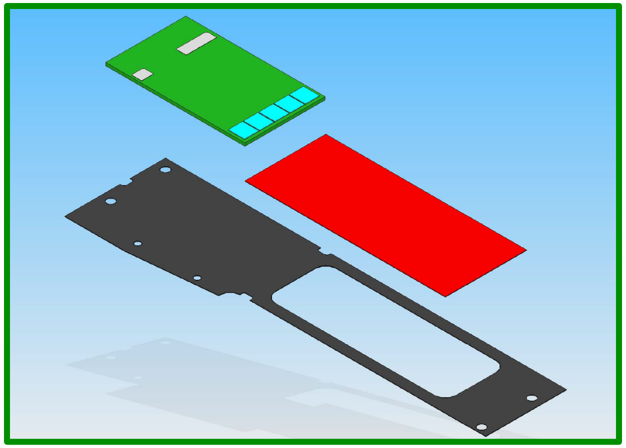
- Laminated CF frame (50+170μm)
- Hybrid w/ 5 APV25 chips; pigtail cable (twisted pair)
- Single sensor

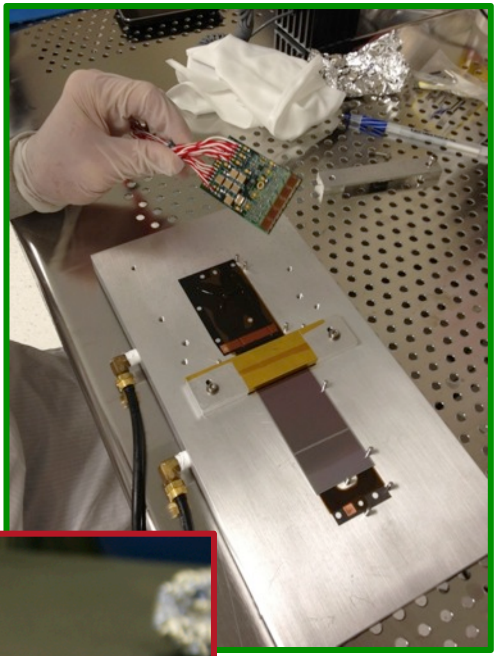
Module

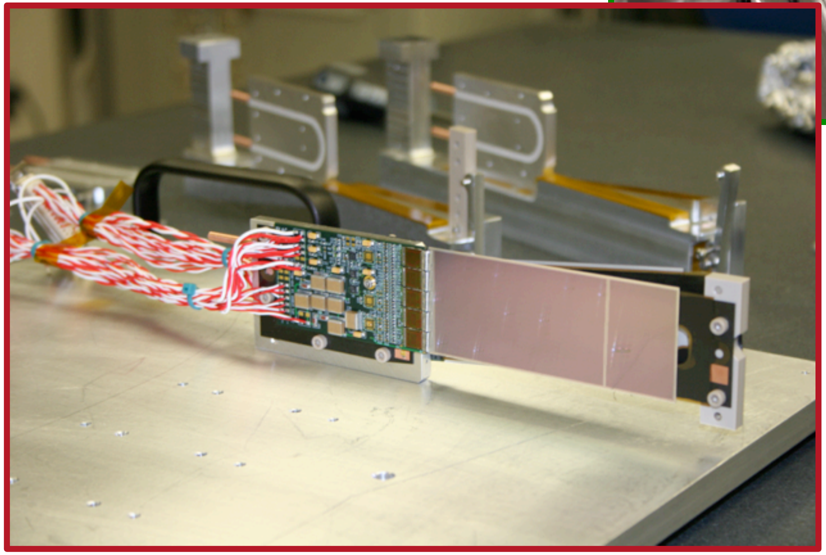
- Half-modules screwed back-to-back on Al cooling block (Cu tubing)
- Glue-less assembly

⇒ 0.7% X_0 average per layer/module (<0.1% from support)

Keep readout/cooling outside tracking volume





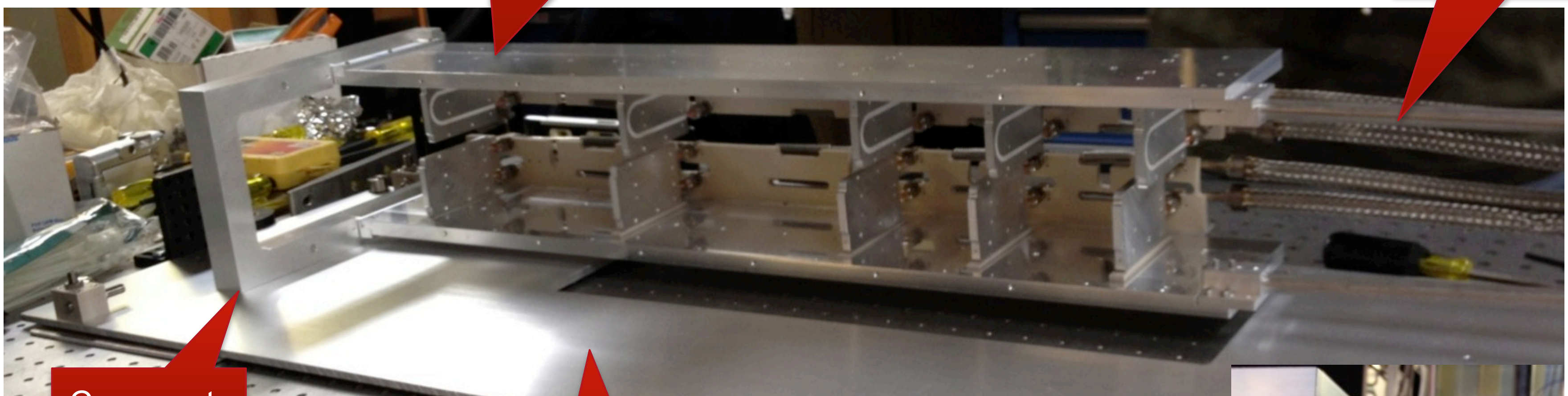


Low Mass Support & Cooling

½” Al support plate w/ precision machined pockets for Si module levelling

Keep readout/cooling outside tracking volume

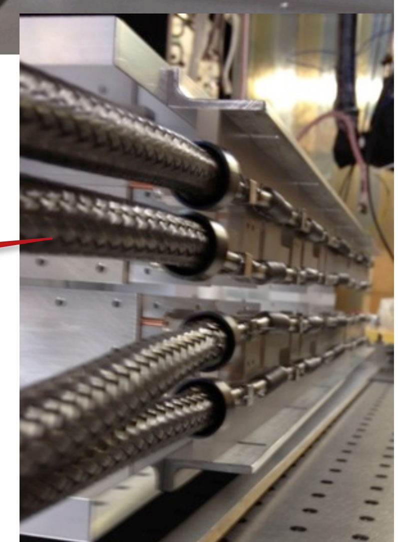
Al support rods for motion lever



C-support

Base plate

¼” braided flex links to complicated cooling manifold with 24 press fittings - inside vacuum



Silicon Vertex Tracker (SVT) Layout

Acceptance limitations

- Small $m_{A'}$: limited by dead zone
- High $m_{A'}$: magnet bore size

Mass and vertex resolution

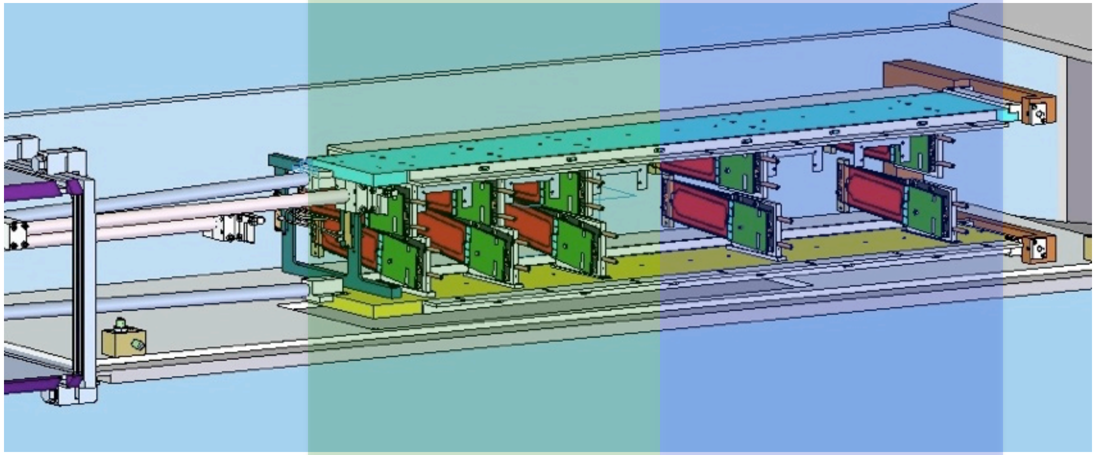
- Layer 1-3: vertexing
- Layer 4-5: pattern recognition w/ adequate pointing to Layer 1-3

- Bend plane hit resolution of same order as multiple scattering

20 sensors/hybrids
100 APV25 front-end chips
12'800 channels

Layer->	1	2	3	4	5
z position [cm]	10	20	30	50	70
Stereo angle [mrad]	**100**	**100**	**100**	**50**	**50**
Bend plane res. [μm]	≈70	≈70	≈70	≈130	≈130
Stereo res. [μm]	≈6	≈6	≈6	≈6	≈6
Dead Zone [mm]	±1.5	±3.0	±4.5	±7.5	±10.5

Vertexing (Layers 1-3) **Pattern recognition** (Layers 4-5)



M o m e n t u m

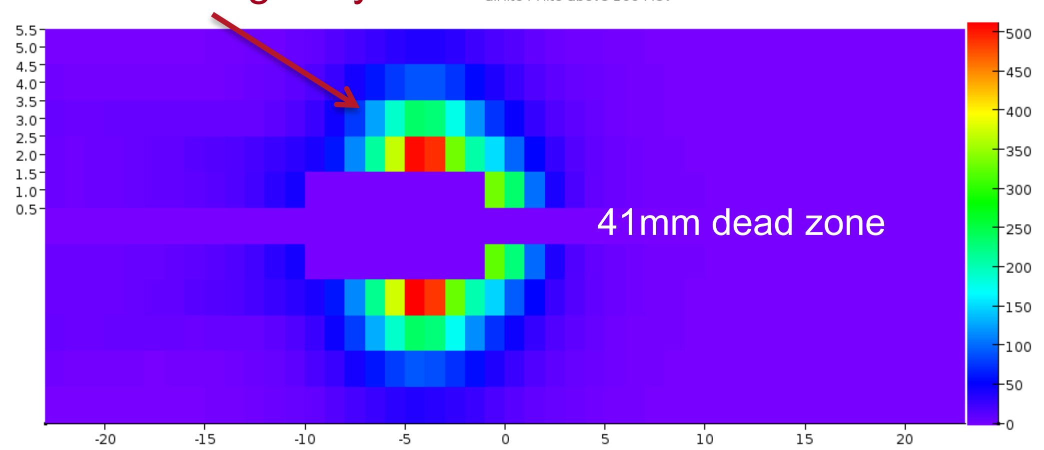
ECal Occupancy & Performance

Highly asymmetric occupancy

- Dominated by beam backgrounds in innermost crystals: ~500kHz

⇒ Need fast everything: crystals, readout and trigger

500kHz in single crystals



Signals processed by JLab 250MHz Flash ADC

- Free-running 14-bit ADC

⇒ 8ns trigger time resolution

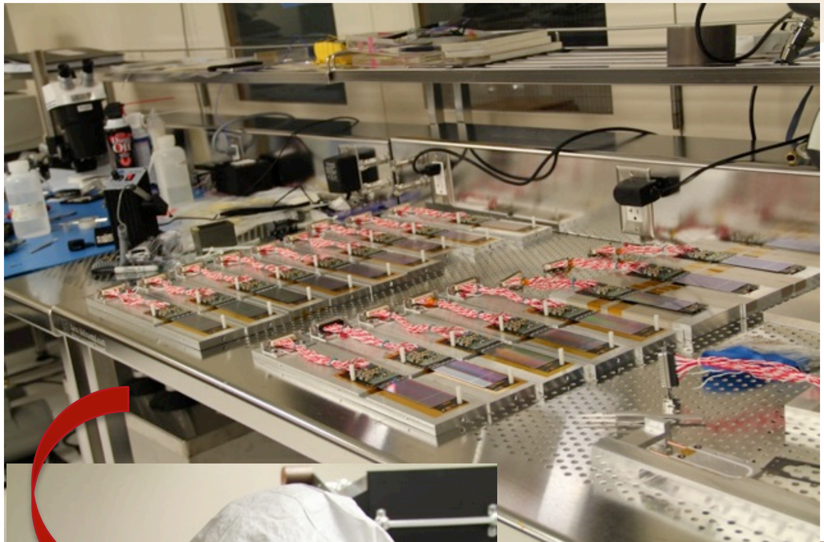
⇒ >50kHz trigger rate capability

Sample rate	250Msps
# channels (/crate)	16 (20)
Technology	VXS-based
Fixed time-window Integration time	140ns

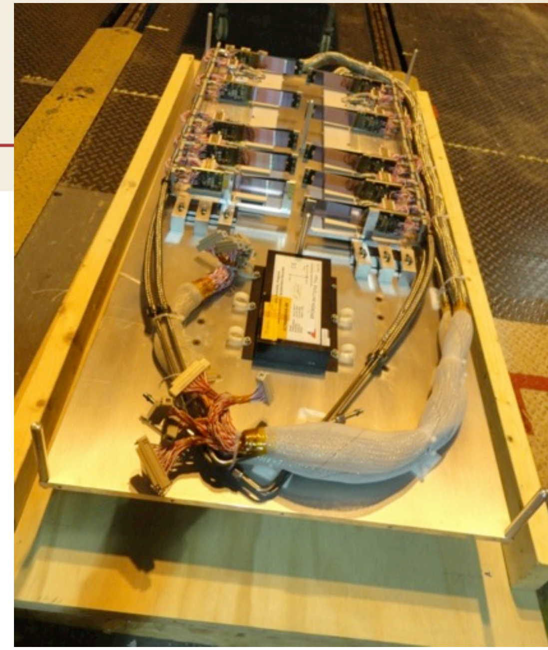
(expect ~25kHz & total rates <100Mb/s)

Test SVT Assembly (Bldg. 84 clean-room)

SLAC

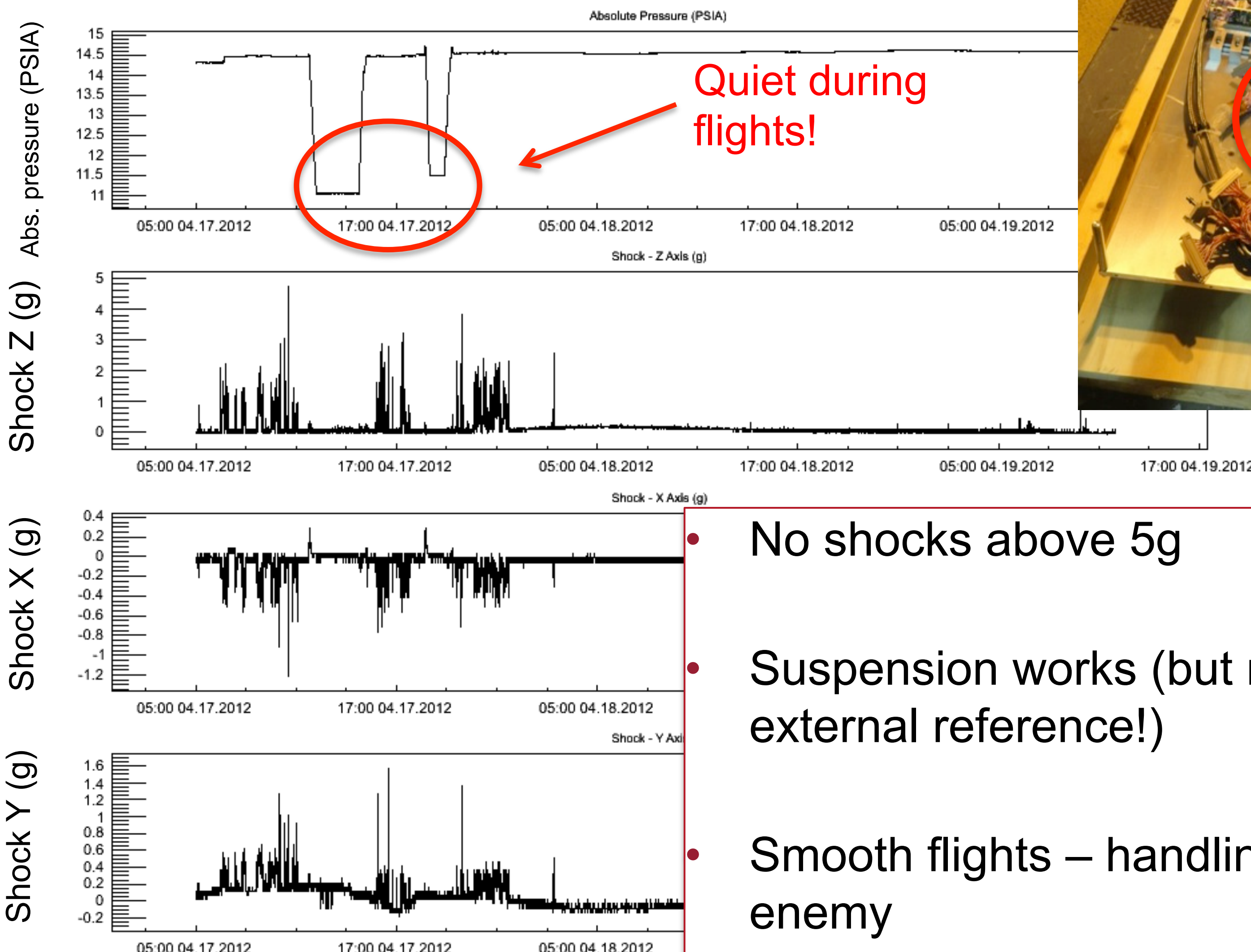


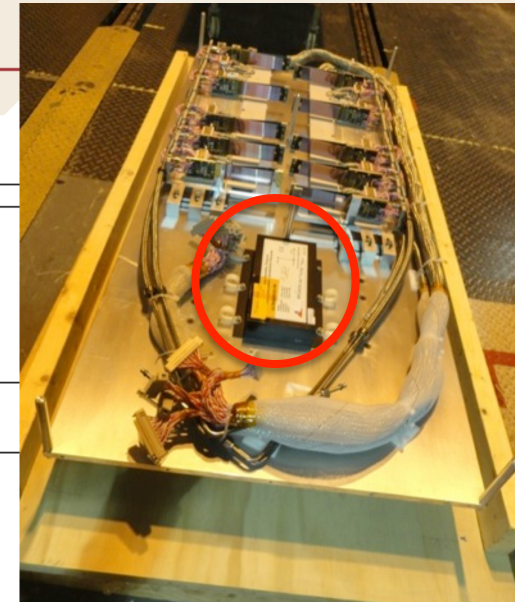
Test SVT Shipping



Custom designed two-crate shipping container with wire-rope insulators

Shipping Environment



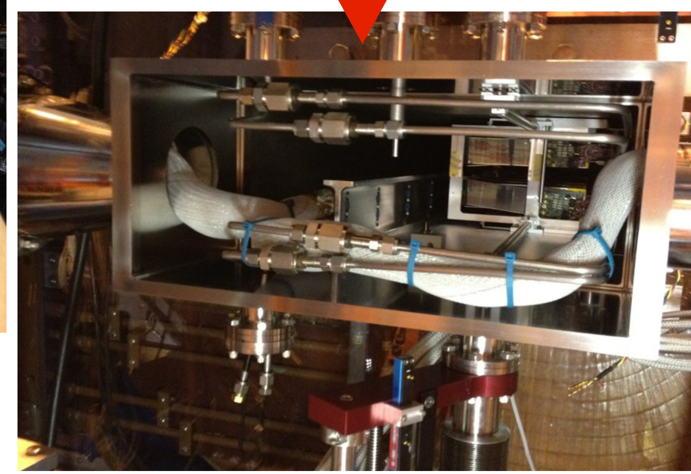


- No shocks above 5g
- Suspension works (but no external reference!)
- Smooth flights – handling is the enemy

Test SVT Installation

Arrived 4/13/2012

Clean-room @ JLab



Installed 4/19/2012

⇒ Thankful for great tech support at SLAC & Hall-B!