Charm meson studies at CLEOc and VELO commissioning at LHCb

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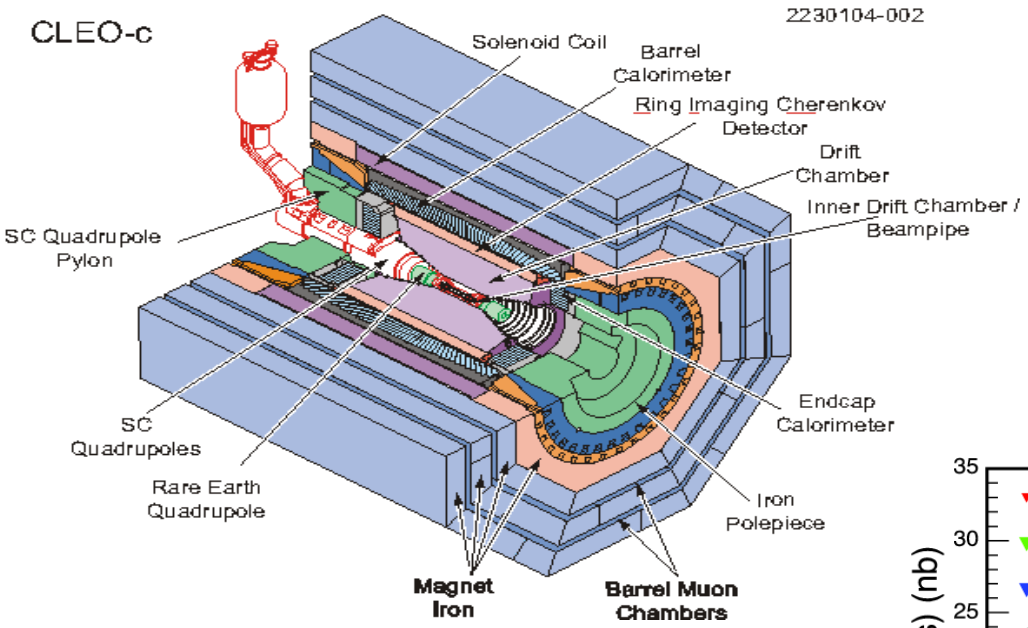
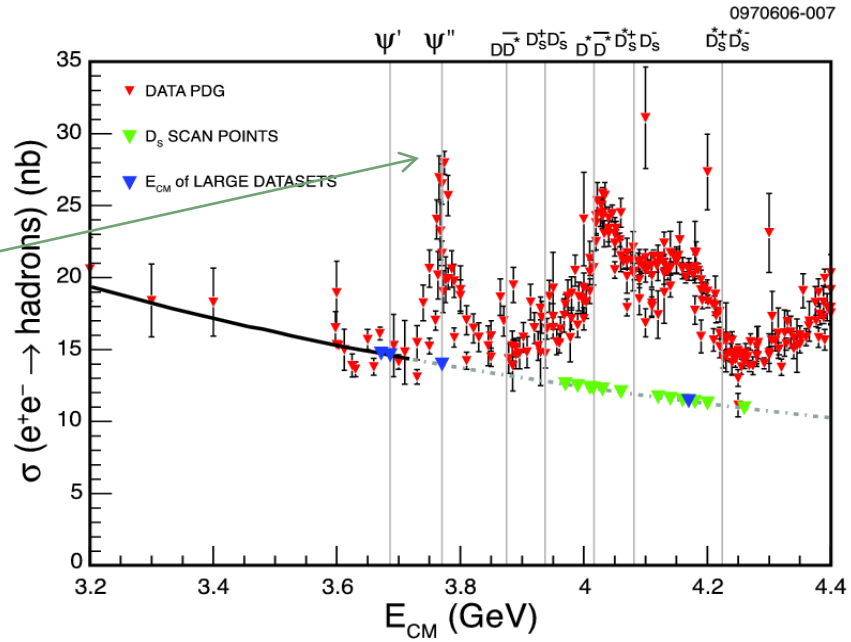
Research Overview

- Physics Analysis (CLEO-c Collaboration)
  - Measurement of branching fraction of $D^+ \rightarrow \mu^+\nu$ and determination of the pseudoscalar decay constant f_{D+} using the full data sample of 818 pb^{-1} at $\psi(3770)$ resonance . (Phys. Rev. D 78, 052003 (2008))
  - Search for $D^0 \rightarrow \bar{p}\, e^+$, $\bar{D}^0 \rightarrow \bar{p}\, e^+$, $D^0 \rightarrow p\, e^-$ and $\bar{D}^0 \rightarrow p\, e^-$ using 281 pb^{-1} CLEO-c $\psi(3770)$ data sample. (Phys. Rev. D 79, 097101 (2009))

- VELO Detector Commissioning (LHCb Collaboration)
  - Vertex Locator(VELO) Track Monitoring algorithm. (2008-2009)
  - ADC sampling time strategies and verification procedure in VELO. (2008-2009)
  - Study of radiation hardness of pixel sensors for the LHCb VELO upgrade.(2007)

CLEO-c





Was operated at

$\psi(3770) \rightarrow \gamma^* \rightarrow D\,\overline{D}$

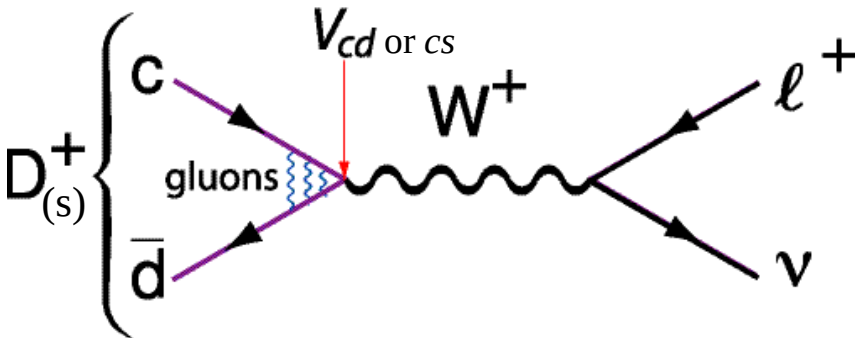
- ❑ No additional particles
- ❑ Coherent 1– state
- ❑ Ideal for absolute BF measurements

$\psi(4170) \rightarrow D^*\,\overline{D}^*$, $D^*\,\overline{D}$, $D\,\overline{D}$ and $\overline{D}_s^*\,D_s$

f_{D^+} Using the Full 818 pb^{-1} $\psi(3770)$ Sample

Introduction: In leptonic decays such as $D \rightarrow \ell^+\nu$, pseudoscalar decay constants f_D describes the hadronic vertex, and is proportional to the wave-function overlap (Prob $\propto$ cd(s)→W annihilation)

Example :

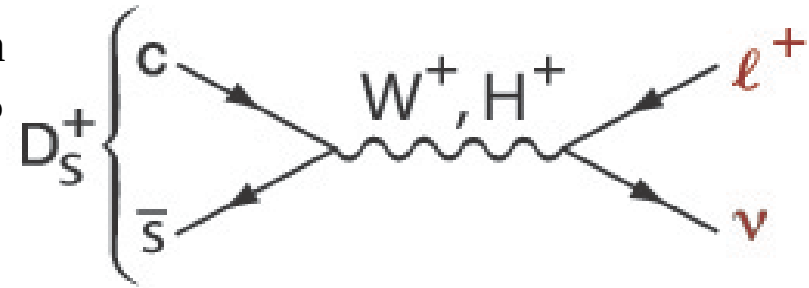


In general for all pseudoscalars:

$$\Gamma(P^+ \rightarrow \ell^+\nu) = \frac{1}{8\pi} G_F^2 f_P^2 m_\ell^2 M_P \left(1 - \frac{m_\ell^2}{M_P^2}\right)^2 |V_{Qq}|^2$$

Calculate, or measure if V_{Qq} is known, here take $V_{cd} = V_{us} = 0.2256$

New Physics Possibilities



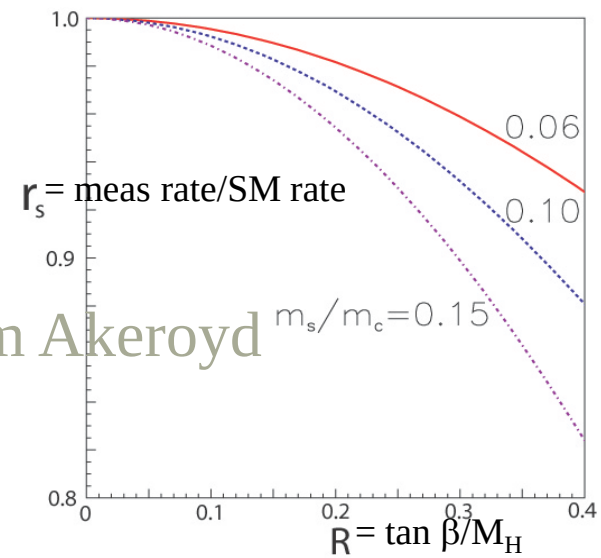
- Besides the obvious interest in comparing with Lattice & other calculations of f_P there are NP possibilities
- Another Gauge Boson could mediate decay
- Or leptoquarks (Dobresqu & Kronfeld, hep-ph/0803.0512)
- Ratio of leptonic decays could be modified e.g. in Standard Model (Hewett, hep-ph/9505246 & Hou, PRD 48, 2342 (1993)).

$$\frac{\Gamma(P^+ \to \tau^+\nu)}{\Gamma(P^+ \to \mu^+\nu)} = m_\tau^2\left(1-\frac{m_\tau^2}{M_P^2}\right)^2 \Big/ m_\mu^2\left(1-\frac{m_\mu^2}{M_P^2}\right)^2$$

- In 2HDM, predicted decay width is x by

$$r_q = \left[1 - M_D^2\left(\frac{\tan\beta}{M_{H^\pm}}\right)^2\left(\frac{m_q}{m_c+m_q}\right)\right]^2$$

- Interference between H and $W^\pm$ suppresses $D_s \to \ell\nu$, but NOT $D \to \ell\nu$ (Akeroyd, hep-ph/0308260)



From Akeroyd

Analysis Techniques

- Fully reconstruct a D^-, and count total # of tags from m_{BC} distributions.

$$m_{BC} = \sqrt{E_{beam}^2 - \left(\sum_i \vec{p}_i\right)^2}$$

- Seek events with only one additional oppositely charged track , veto events with charged tracks arising from the event vertex or with extra neutral energy that do not match a charged track within a connected region (additional photons > 250 MeV to veto $D^+ \rightarrow \pi^+\pi^o$).
- Require angle that the track subtend with beam axis to $|\cos\theta|<0.9$ (+11%)
- Charged track must deposit only minimum ionization in calorimeter (< 300 MeV case 1, ε = 99.2%).
- Compute MM^2 . If close to zero then almost certainly we have a $\mu^+\nu$ decay.

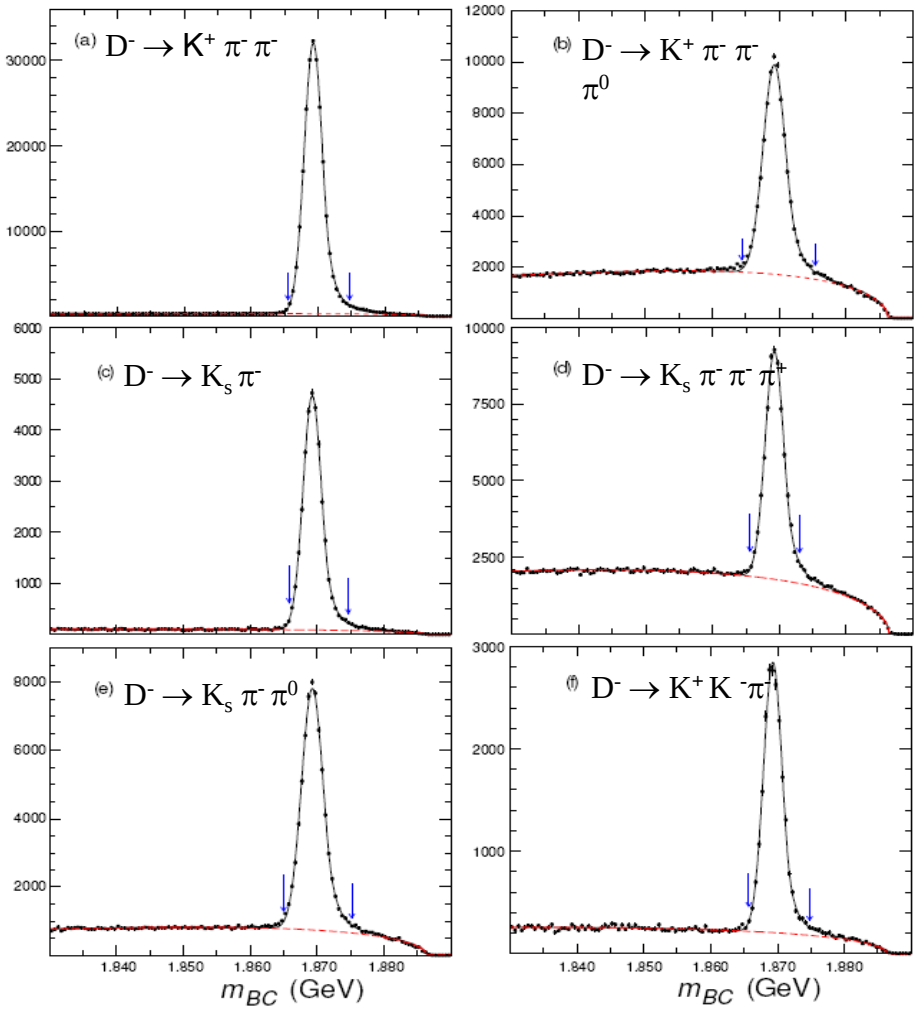
$$MM^2 = (E_{D^+} - E_{\ell^+})^2 - (\vec{p}_{D^+} - \vec{p}_{\ell^+})^2$$

where, $E_{D^+} = E_{beam}$, $p_{D^+} = - p_{D^-}$

- We fit the muon candidate distribution to extract $\mu^+\nu$ & $\tau^+\nu$, to extract yield, improves efficiency by ~5%, & also allows us to quote a B independent of assuming SM $\tau^+\nu/\mu^+\nu$ ratio.

Tags

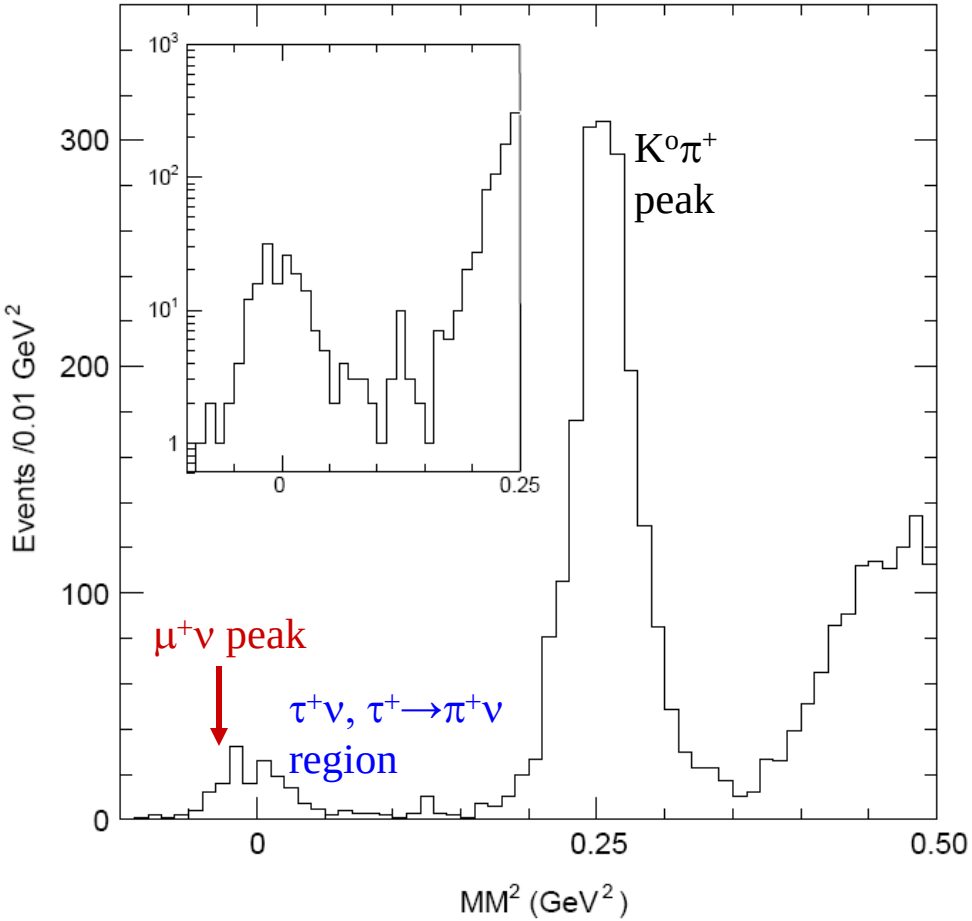
- Total of 460,000
- Background 89,400
- Luminosity 818 pb^{-1}



The MM^2 Distribution (E>300 MeV)

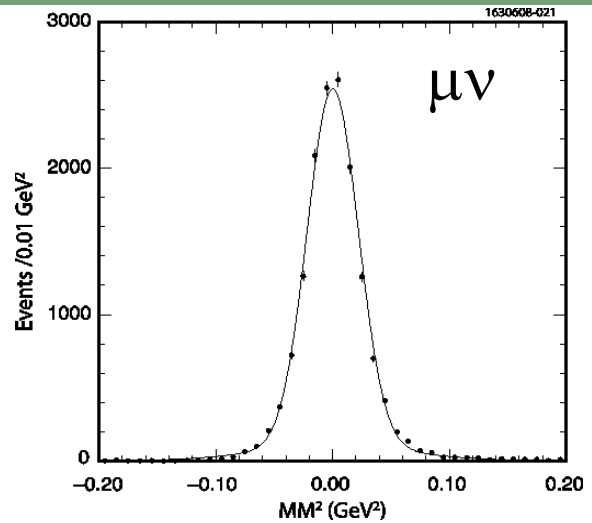
Fit Requirements

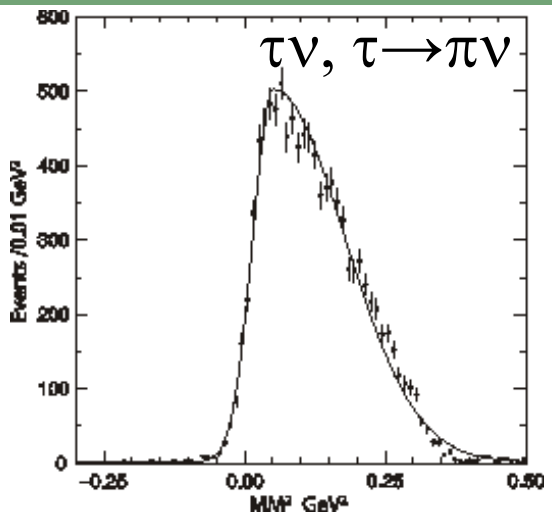
- Signal shapes for $\mu^+\nu$ & $\tau^+\nu$
- Background shapes for $K^o\pi^+$ low MM^2 tail, $\pi^+\pi^o$ & residual 3 body modes, e.g. $\tau^+\rightarrow\mu^+\nu\nu$, $\rho^+\nu$, $\pi^o\mu^+\nu$.
- Requires small residual background subtraction from continuum, etc...



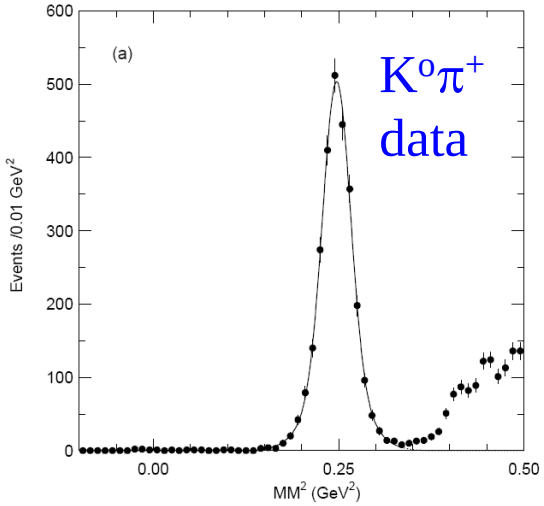
The Missing Mass Squared

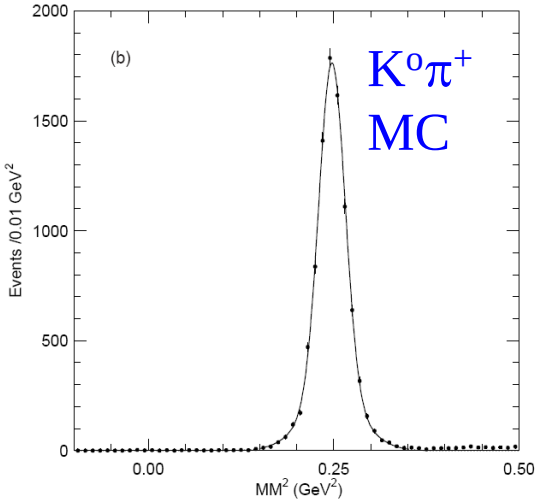
- From Monte Carlo Signal





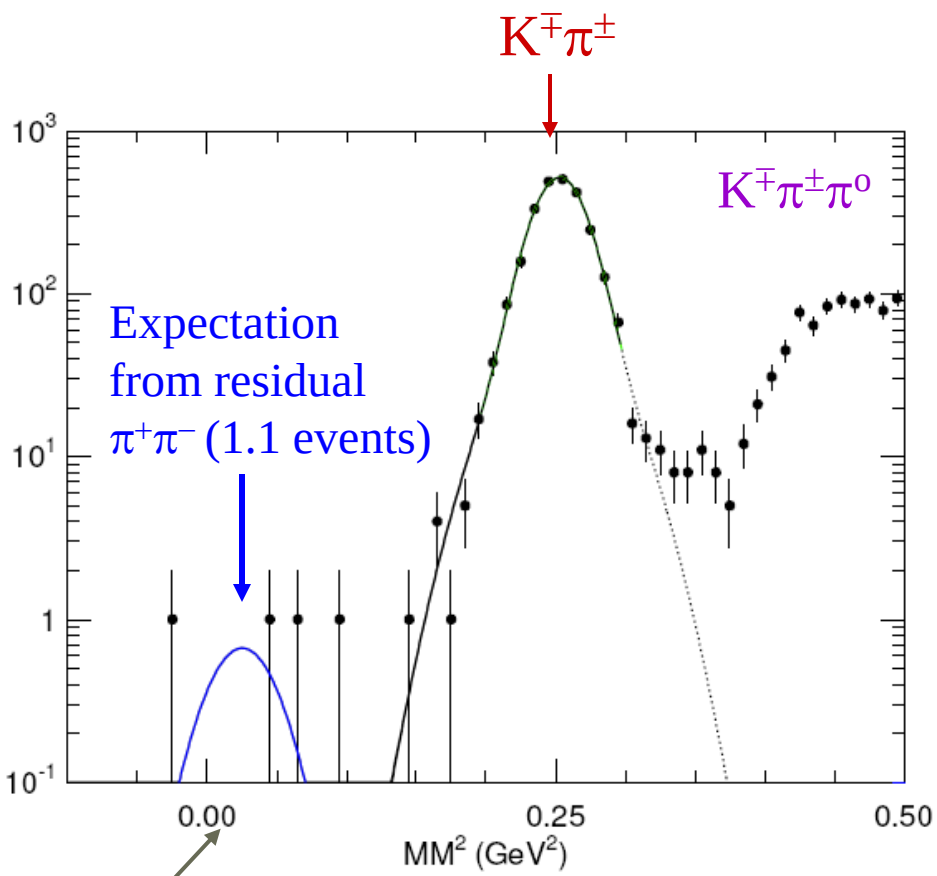
- μν signal shape is checked with shape of $K^o\pi^+$ peak
  - Data: $\sigma=0.0247\pm0.0012$ GeV^2
  - MC $\sigma=0.0235\pm0.0007$ GeV^2
  - Both average of double Gaussians





Model of $K^o\pi^+$ Tail

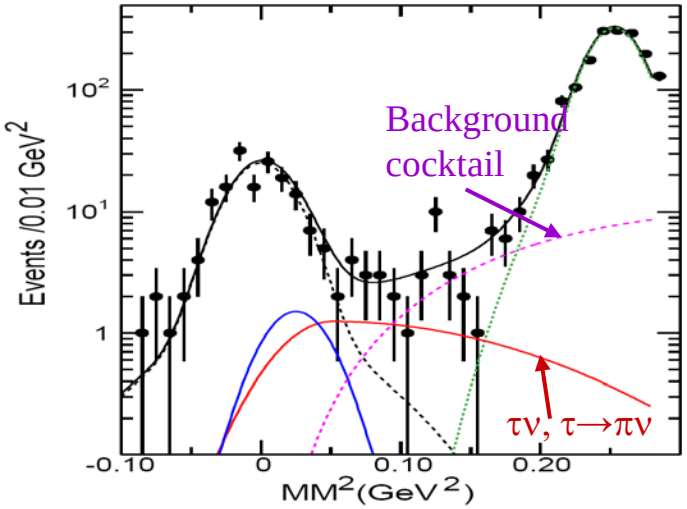
- Use double tag $D^0\,\overline{D}^0$ events, where both $D^0 \rightarrow K^{\mp}\pi^{\pm}$
- Make loose cuts on 2nd D^0 so as not to bias distribution: require only two charged tracks in the event and compute MM^2 while ignoring the charged kaon



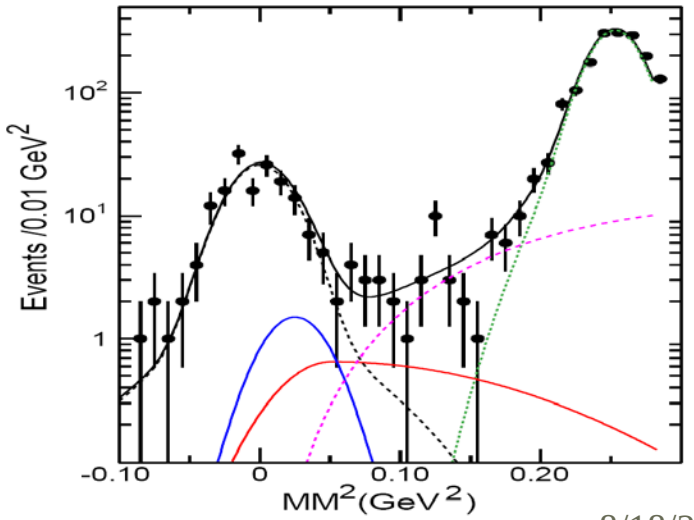
Gives an excellent description of shape of low mass tail
"Extra" 1.3 event background in signal region

Fits to case(i)

- $\tau^+\nu/\mu^+\nu$ is **fixed** to SM ratio
  - 149.7±12.0 $\mu\nu$
  - 28.5 $\tau\nu$



- $\tau^+\nu/\mu^+\nu$ is **floated**
  - 153.9±13.5 $\mu\nu$
  - 13.5±15.3 $\tau\nu$

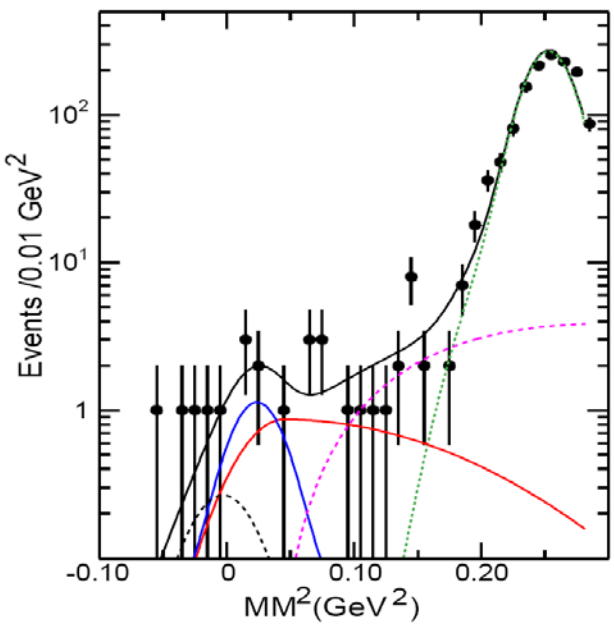


Residual Backgrounds for $\mu^+\nu$ and it's verification

- Monte Carlo of Continuum, D^o, radiative return and other D^+ modes, in $\mu^+\nu$ signal region
- This we subtract off the fitted yields

Mode	# of events
Continuum	0.8±0.4
$\overline{K}^0\pi^+$	1.3±0.9
D^0 modes	0.3±0.3
Sum	2.4±1.0

- Use case(ii) E>300 MeV
- Fix $\tau\nu$ from case(i) $\mu\nu$.
- Consider signal region $|MM^2|<0.05$ GeV^2
- Expect 1.7 $\mu\nu$ + 5.4 $\pi^+\pi^o$ + 4.0 $\tau\nu$ = 11.1
- Find 11 events
- Extra bkgrnd=-0.1±3.3 events



Efficiencies & Systematic Errors

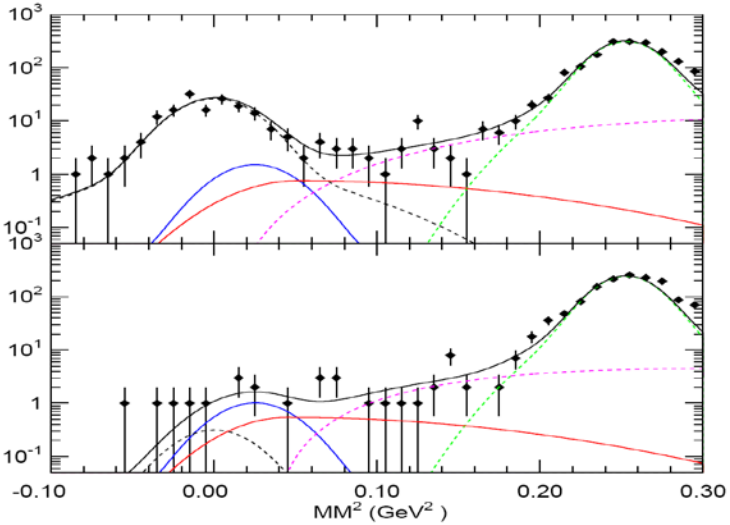
- Tracking, particle id, E<300 MeV (determined from μ-pairs) = 85.3%
- Not having an unmatched shower > 250 MeV = 95.9%, determined from double tag, tag samples
- Easier to find a μν event in a tag then a generic decay (tag bias due to low multiplicity) (1.53%), this is corrected in total # of tags.

Source of Systematic Error	%
Finding the μ^+ track	0.7
Minimum ionization of μ^+ in EM cal	1.0
Particle identification of μ^+	1.0
MM^2 width	0.2
Extra showers in event > 250 MeV	0.4
Background	0.7
Number of single tag D^+	0.6
Total	**2.2**

Branching Fractions & f_{D^+}

- Fix $\tau\nu/\mu\nu$
  - $B(D^+ \to \mu^+\nu) = (3.86 \pm 0.32 \pm 0.09) \times 10^{-4}$
  - $f_{D^+} = (206.7 \pm 8.5 \pm 2.5)$ MeV
  - This is best number in context of SM
- Float $\tau\nu/\mu\nu$
  - $B(D^+ \to \mu^+\nu) = (3.96 \pm 0.35 \pm 0.10) \times 10^{-4}$
  - $f_{D^+} = (208.5 \pm 9.3 \pm 2.5)$ MeV
  - This is best number for use with Non-SM models

Upper limits on $\tau\nu$ & $e\nu$ and CP Violation



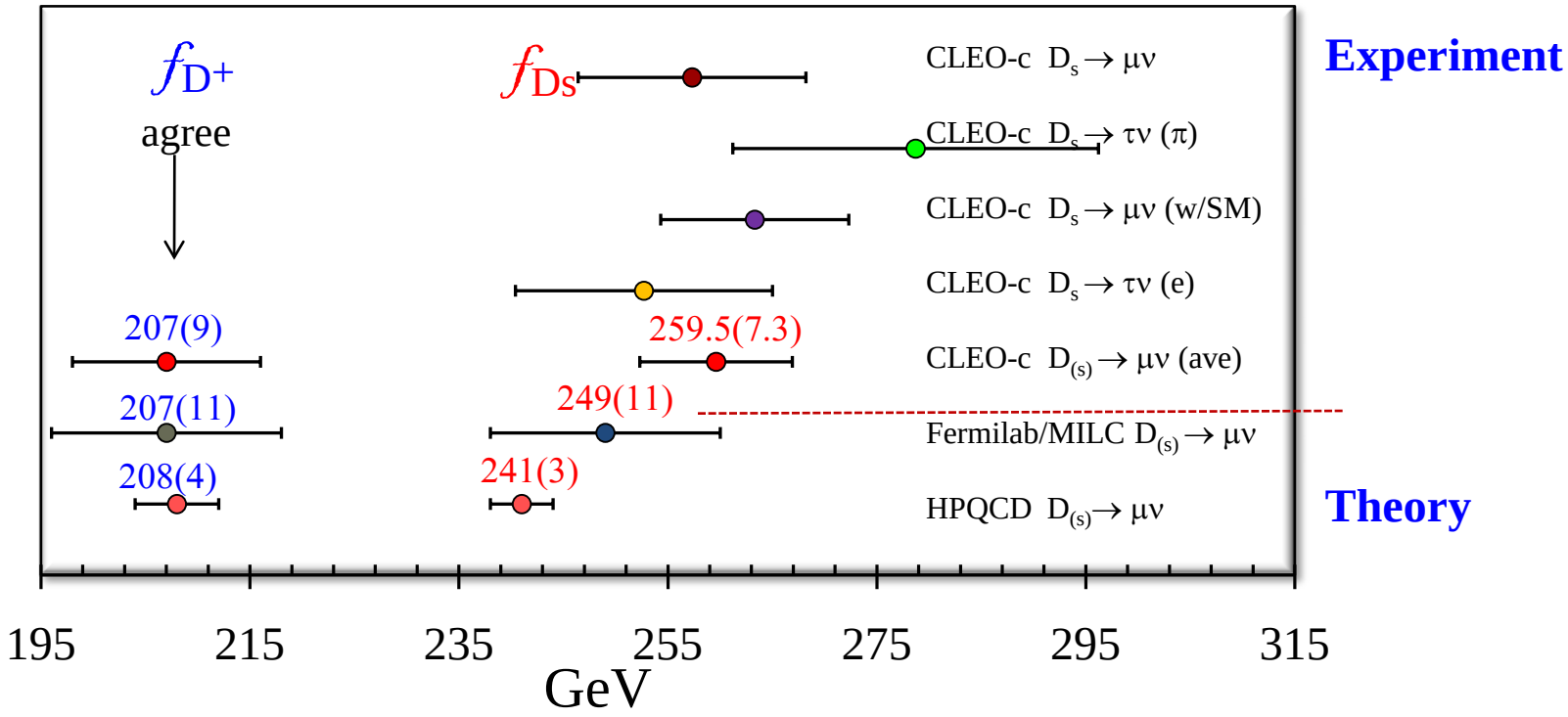
- Here we fit both case(i) & case(ii) constraining the relative $\tau\nu$ yield to the pion acceptance, 55/45.
- Find
  - $B(D^+ \to \tau^+\nu)$ $< 1.2\times10^{-3}$, @ 90% c.l.
  - $B(D^+ \to \tau^+\nu)/2.65B(D^+ \to \mu^+\nu) < 1.3$ @ 90% c. l.
- Also $B(D^+ \to e^+\nu) < 8.8 \times 10^{-6}$, @ 90% c.l.

$$A_{CP} \equiv \frac{\Gamma(D^+ \to \mu^+\nu) - \Gamma(D^- \to \mu^-\nu)}{\Gamma(D^+ \to \mu^+\nu) + \Gamma(D^- \to \mu^-\nu)} = 0.08 \pm 0.08$$

- $-0.05 < A_{CP} < 0.21$ @ 90% c. l.

Conclusions

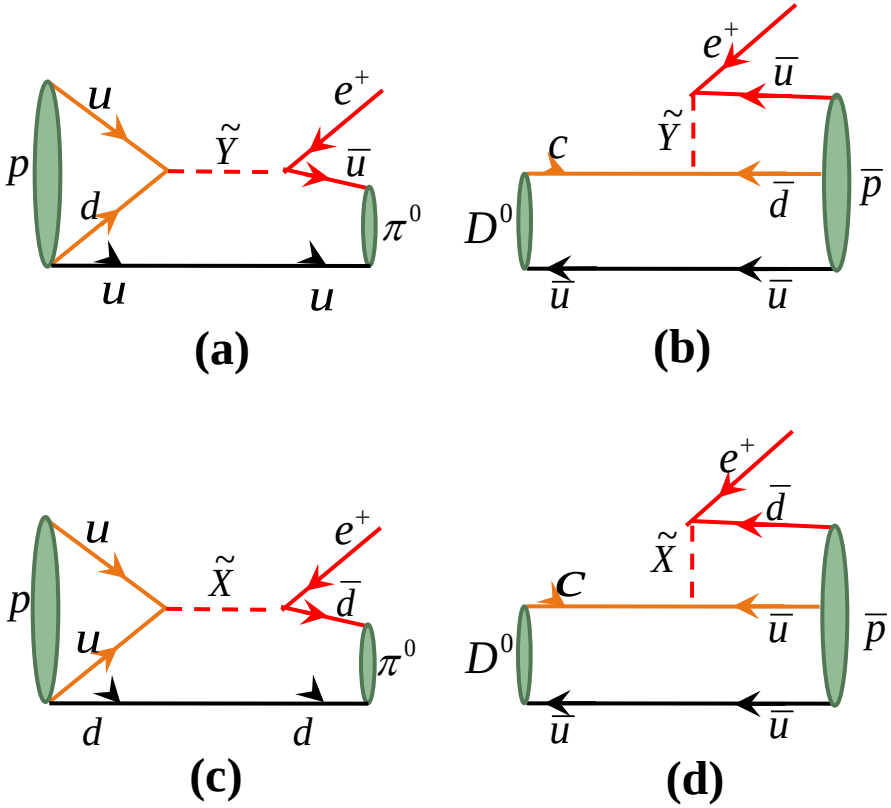
- We are in close agreement with the Follana et al calculation for f_{D^+}. This not only gives credence to their methods, but also makes the disagreement with f_{Ds} really stand out.



Search for $D^0 \to p\, e^-$ and $D^0 \to \bar{p}\, e^+$

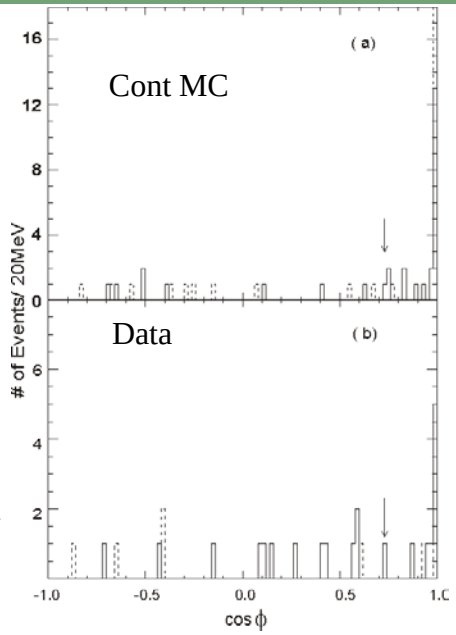
- Various BSM physics could lead to baryon# or lepton # violation.
- Earlier searches for LFV or baryon# violation in τ decays
- First search in meson decays
- One example of such B and L violating decays in SU(5) GUT shown here.
  - Interaction mediated by heavy X, Y gauge bosons
  - No tree-level $D^0 \to p\, e^-$

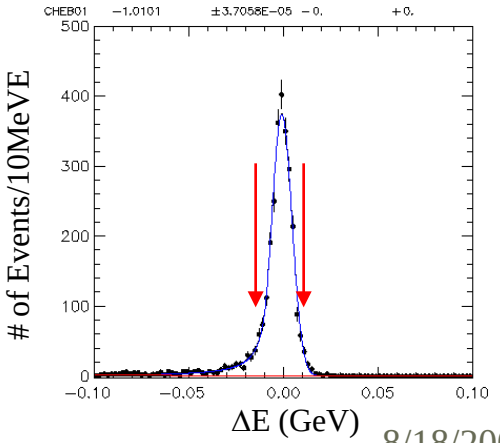
$p \to \pi^0 e^+$ $\qquad$ $D^0 \to \bar{p}\, e^+$



Data Sample & Selection

- 281 pb^{-1}at $\psi(3770)$
- Proton selection
  - $|\cos\theta_{track}|<0.9$
  - dE/dx only: $|\sigma_p|<2.5$, $|\sigma_\pi|>3$, $|\sigma_K|>3$, $|\sigma^2_p - \sigma^2_\pi|$ [$\sigma = (I_{expected} - I_{meaured})/$ Err]
- Electron selection:
  - $|\cos\theta_{track}|<0.9$, p > 200 MeV, $F_{with\text{-}RICH}>0.8$ (relative weighted likelihood ratio of electron hypothesis)
  - Antiproton veto
- Backgrounds:
  - Continuum: $p^+ e^-$ from conversion
  - Suppressed by requiring $\cos\varphi_{e\text{-}e+}<0.73$
- Cut on $|\Delta E| < 11$ MeV
- $\rightarrow$ Fit m_{BC}



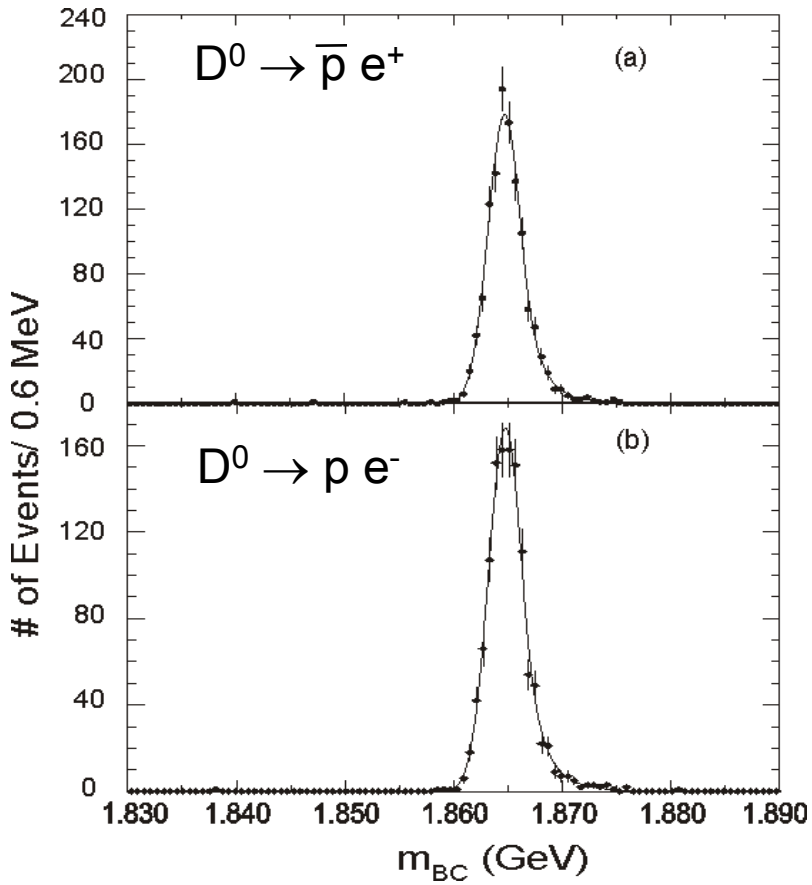


Signal MC Simulations

- Crystal Ball Line Shape

$\varepsilon = (60 \quad 1)\%$

$\varepsilon = (58 \quad 1)\%$

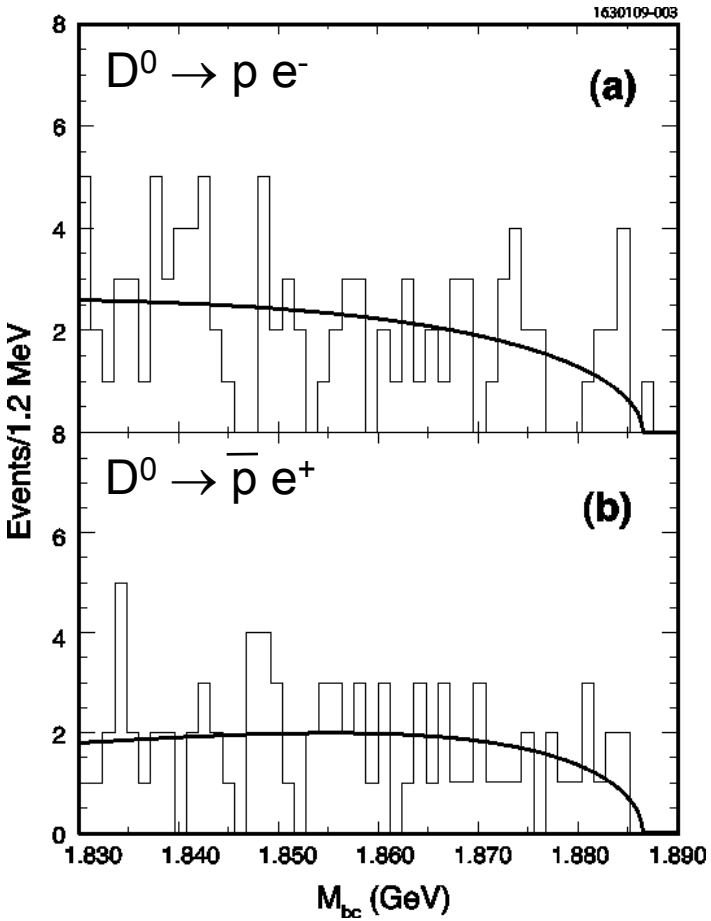


Data

- Fit to Argus background + CBAL line shape (a) and (b).
- In Argus function, we fix the E_{beam} = 1.8865 GeV and float other parameters.
- Plot the likelihood fits to find 90% CL upper limits

N < 5.9 @ 90% CL

N < 6.7 @ 90% CL



Systematics / Results

$$B = \frac{N}{N_{D^0\bar{D}^0}\varepsilon}$$

$$N_{D^0\bar{D}^0} = (1.031 \pm 0.008 \pm 0.013) \times 10^6$$

90% confidence level limits

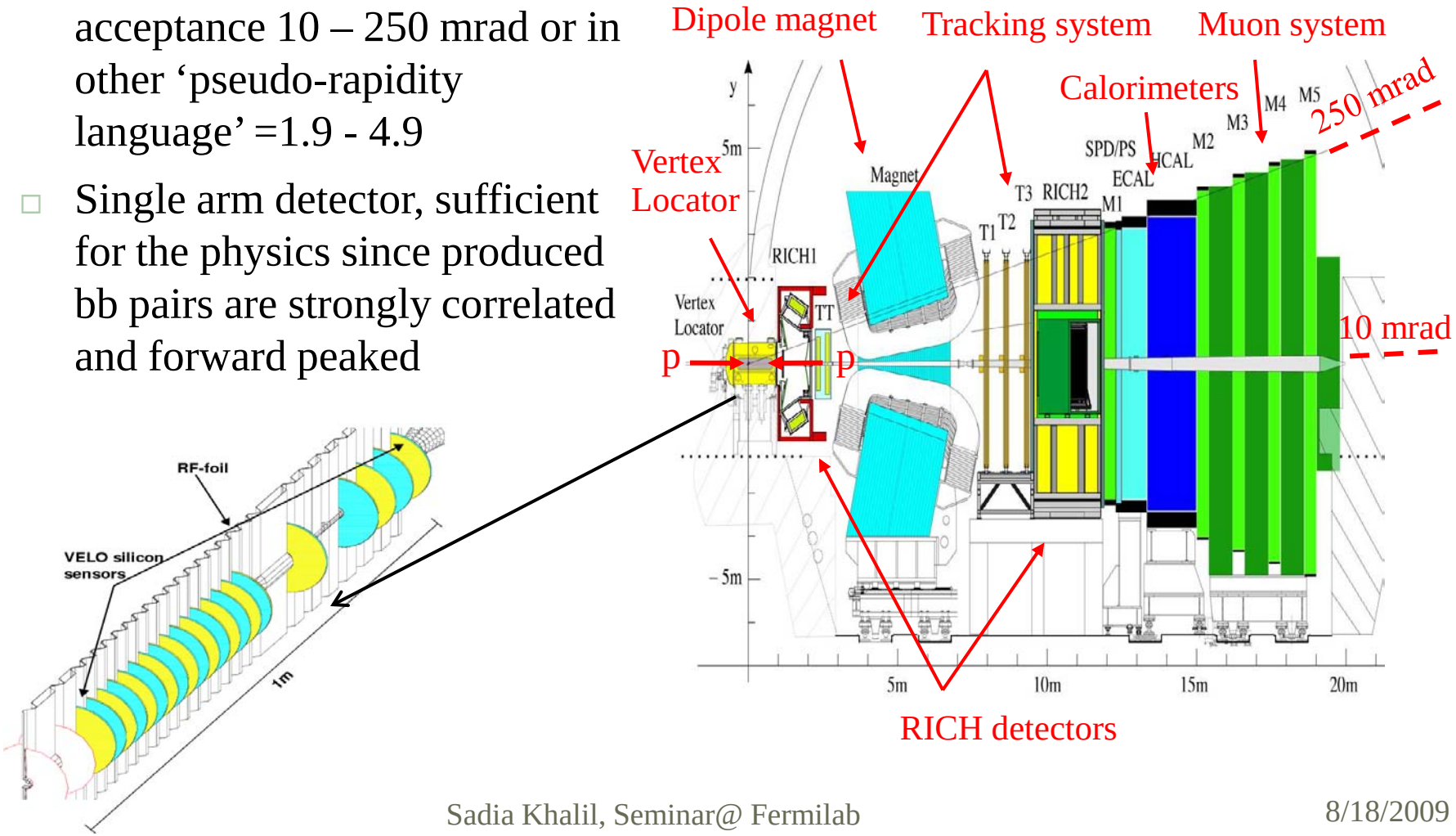
$$\mathrm{B}(\mathrm{D}^0 \to \bar{p}e^+) = 1.1 \times 10^{-5}$$

$$\mathrm{B}(\mathrm{D}^0 \to pe^-) = 1.0 \times 10^{-5}$$

Sources of errors	± % error
Tracking	1.4
PID	2
ΔE cut	0.4
$\cos\varphi_{ee}$ cut	1
Background shape	1
Relative MC Statistical error	0.8
Total in quadrature	3.0

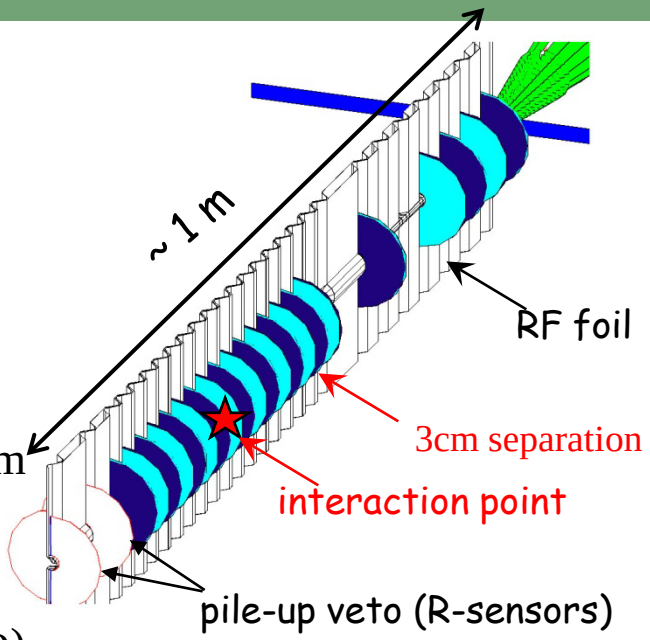
LHCb

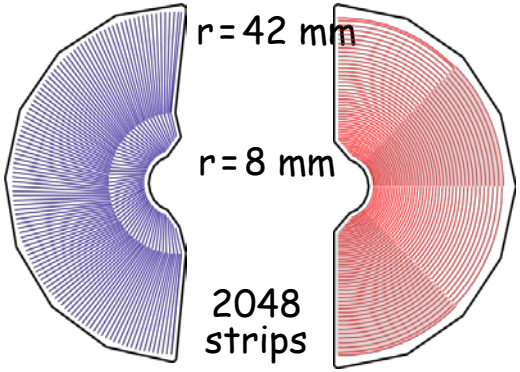
- A forward spectrometer, angular acceptance 10 – 250 mrad or in other ‘pseudo-rapidity language’ =1.9 - 4.9
- Single arm detector, sufficient for the physics since produced bb pairs are strongly correlated and forward peaked



VErtex LOcator (VELO)

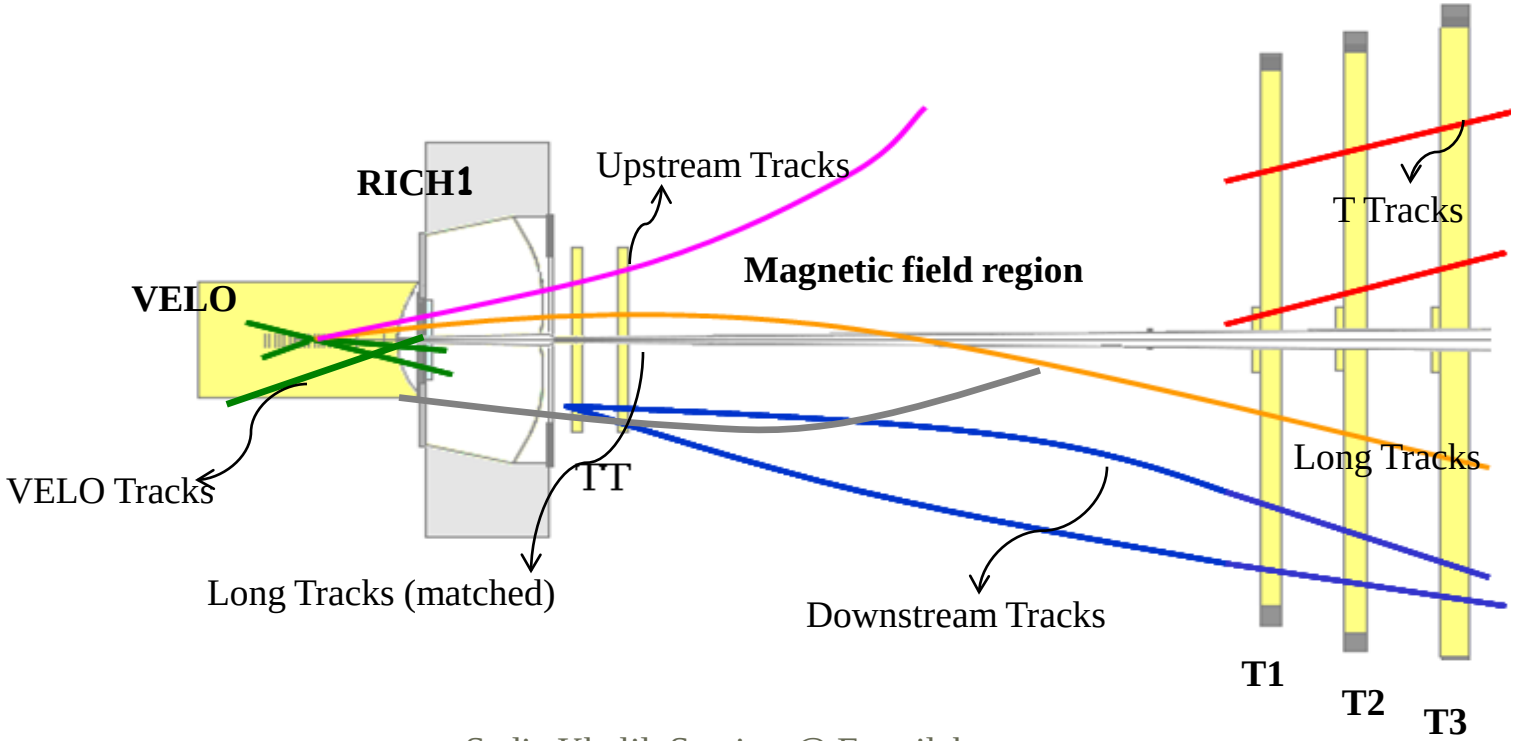
- Silicon micro-strip, n^+ in n-bulk sensors.
- Detector halves retractable (by 30μm) for injection, where LHC beam pipe has radius 27μm
- 21 tracking stations per side.
- R-Φ geometry, 40–100μm pitch, 300μm thick
- Optimized for
  - tracking of particles originating from beam-beam interactions.
  - fast online 2D (R-z) tracking.
  - fast offline 3D tracking in two steps (R-z then Φ).





LHCb Tracking

- VELO tracks: → Used to find primary vertex (36/106).
- Long tracks: → Used for most physics studies: B decay products (33/106).
- T tracks:→ Improve RICH2 performance (19/106)
- Upstream tracks: →Improve RICH1 performance, moderate *p* estimate (6/106).
- Downstream tracks: → Enhance K_S finding (14/106).



VELO Track Monitoring

- Identify plots based on VELO track information that flag:
  - Sensor problem
  - Pattern recognition problem
  - Fit quality of tracks
  - Alignment of VELO halves
  - Multiple Scattering at low p
- The algorithm works both for online and offline monitoring

Plots

Biased♥ / Unbiased Residuals* weighted by binary resolution♦ vs sensor
Biased / Unbiased Residuals vs momentum
Azimuth, theta and pseudo-rapidity = η♣ of the track
Pseudo-efficiency = Measured VELO hits/Expected hits
Number of R and R+Φ clusters per event
Number of R and R+Φ clusters vs θ
Number of times a sensor is used in tracking (Hits)
Primary Vertex position(L-R Δx, x, y, z)
Number of measurements on tracks vs momentum
XY and XZ hitmaps

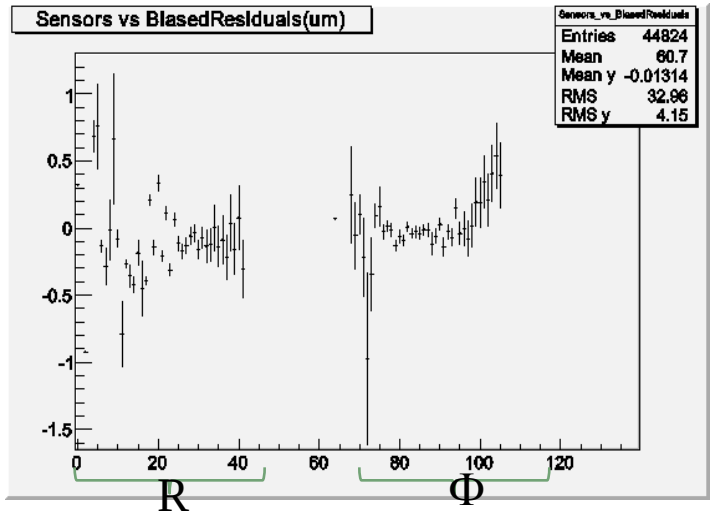
* Residual is the difference b/w reconstructed and true track position

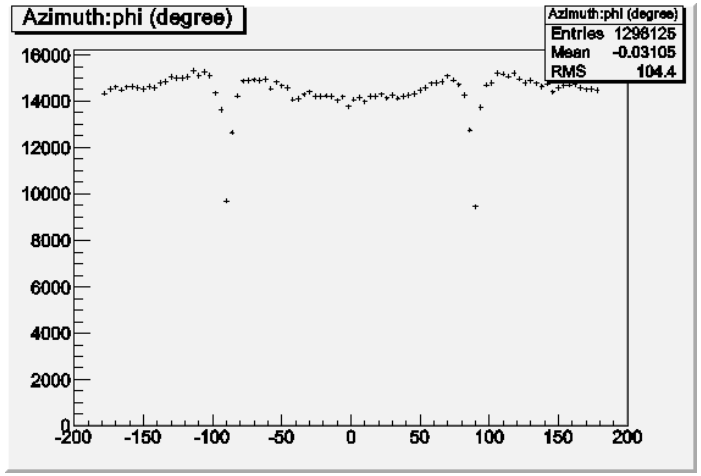
♥Biased = when the reference track is included in the fit

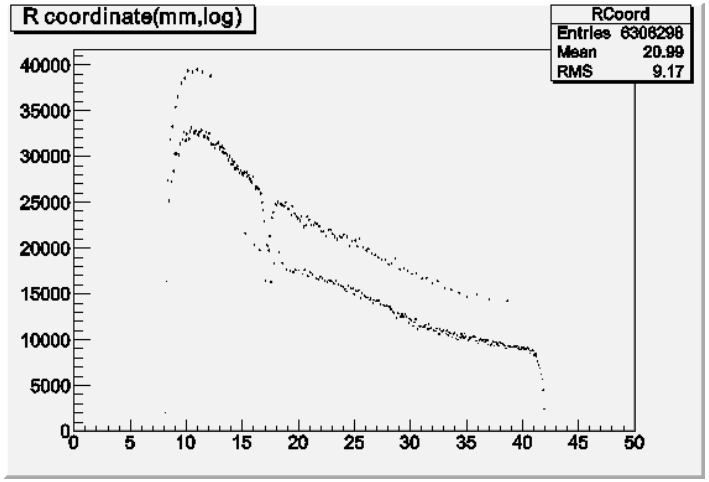
♦Binary resolution = pitch/$\sqrt{12}$

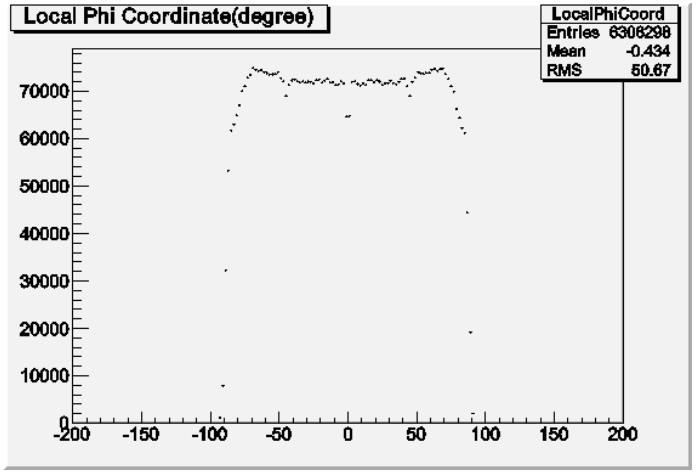
♣Pseudo-rapidity = $-\ln(\tan(\theta/2))$

Example: BiasedResiduals, Azimuth, local R-Φ coord of sensor

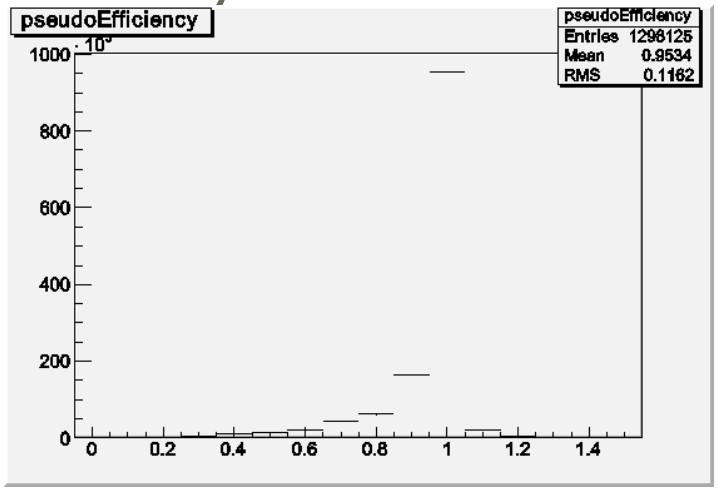


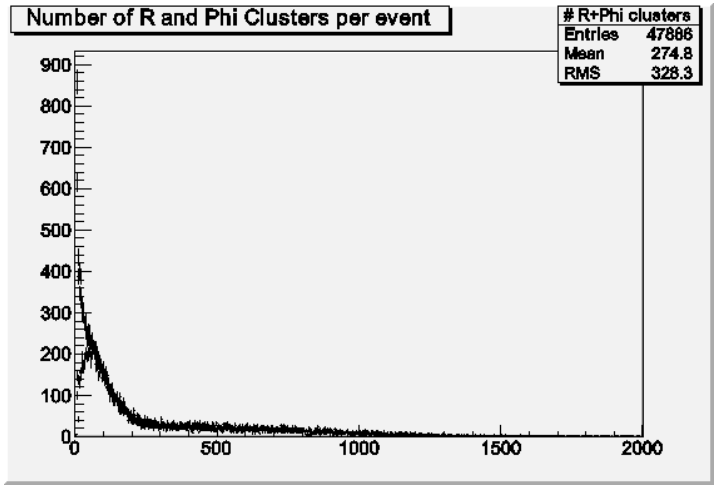


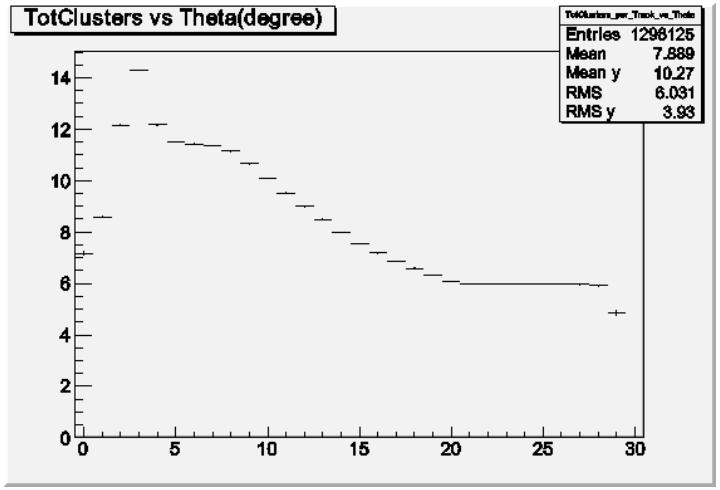


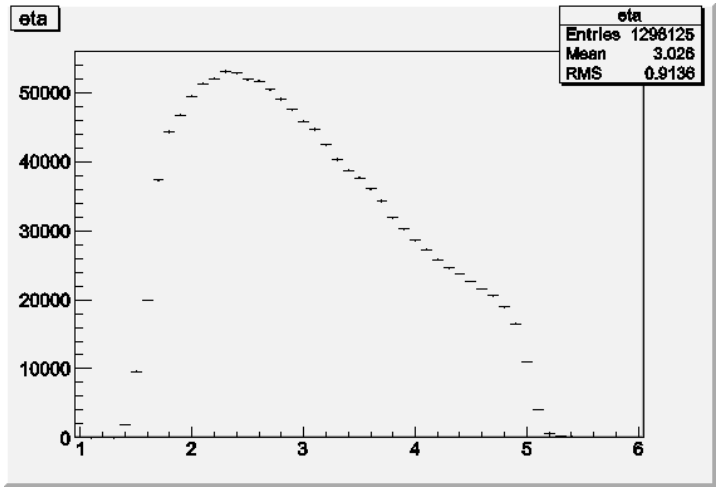


Pseudo-
Eff, Clusters/Event, Clusters vs Theta, Eta

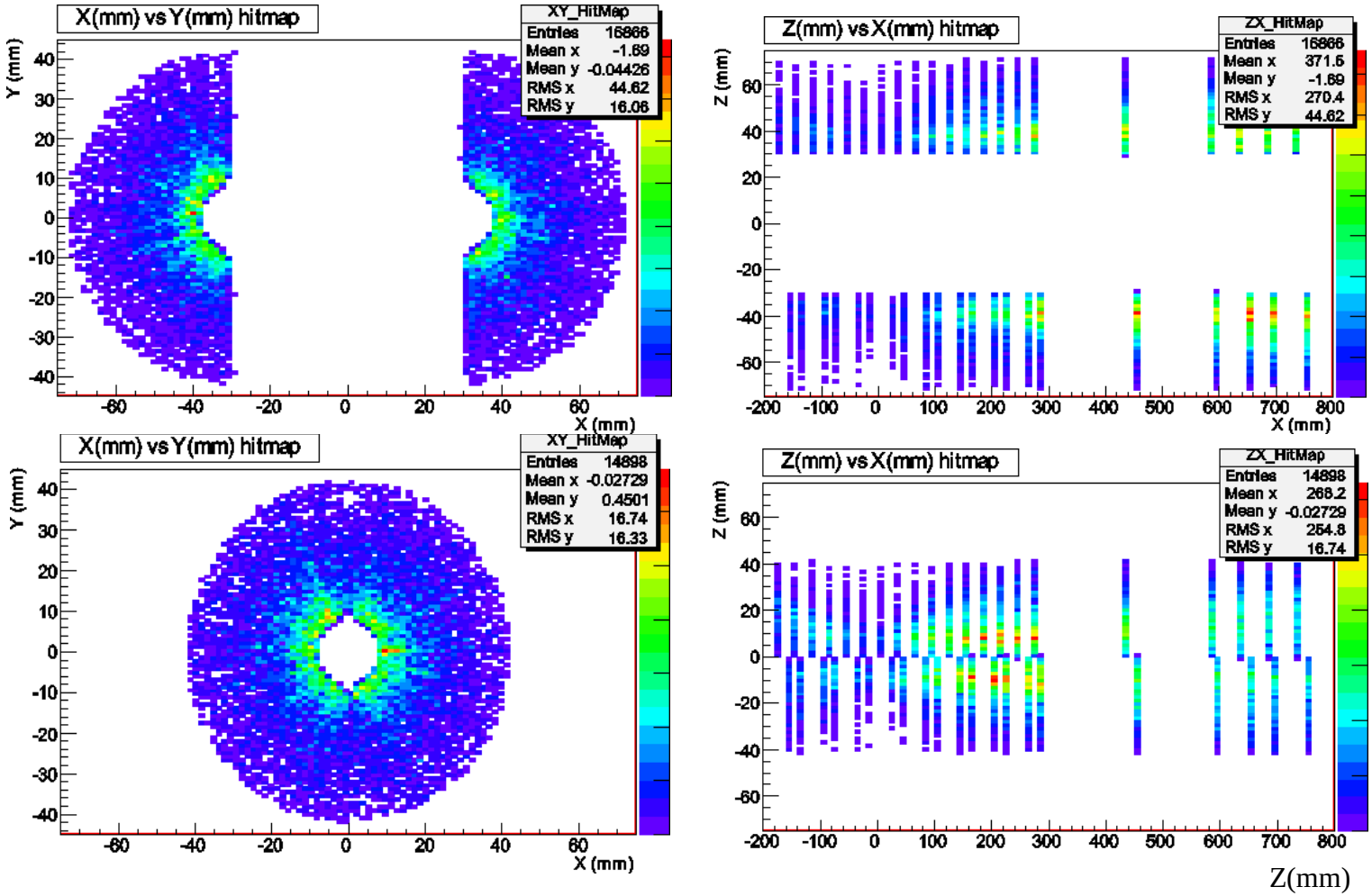








Hit Maps in XY, XZ planes



VELO Readout System

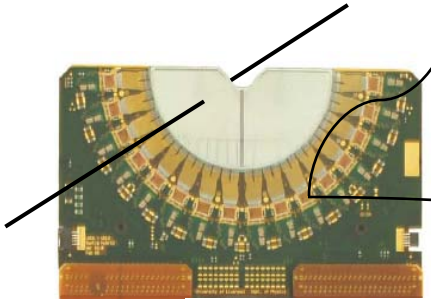
Beetle Chips at VELO front-end @ 40 MHz (25ns)

↓

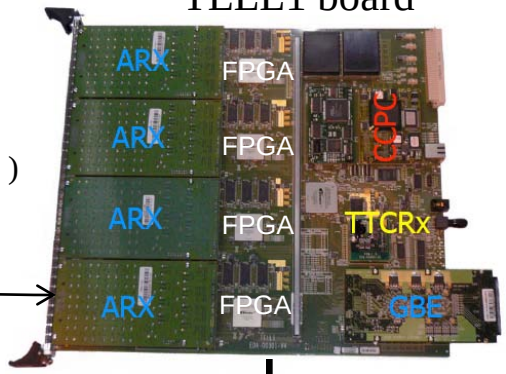
L0 trigger

↓

1.1MHz (900ns = (32+4)channels×25ns/channel)



TELL1 board

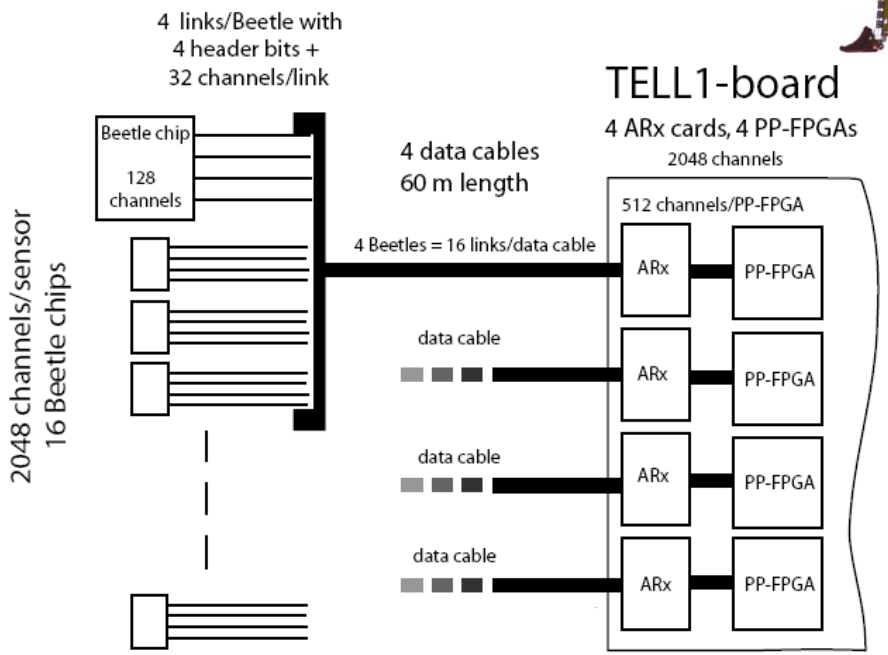


↓

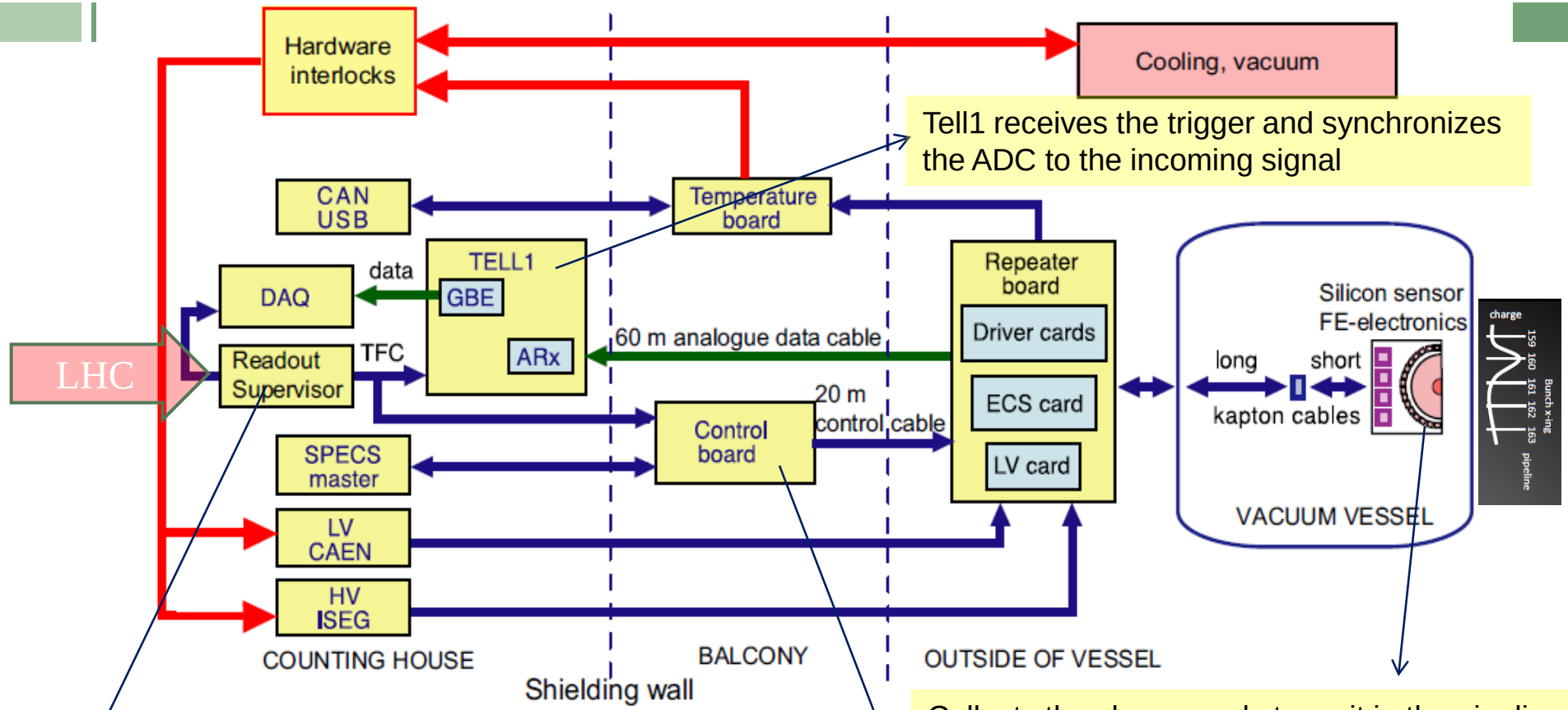
Raw cluster buffer

↓

Zero Suppressed data
(compression ~200)



VELO Readout Full Picture



Tell1 receives the trigger and synchronizes the ADC to the incoming signal

Collects the charge and stores it in the pipeline

Provides Fast Signals (L0A, Test Pulse) to Tell1 and CB

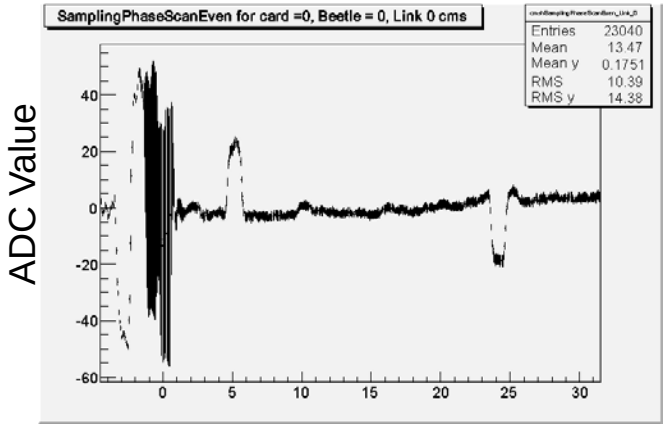
Tunes the Fast Signals and send it to module.
It also configure the Beetles

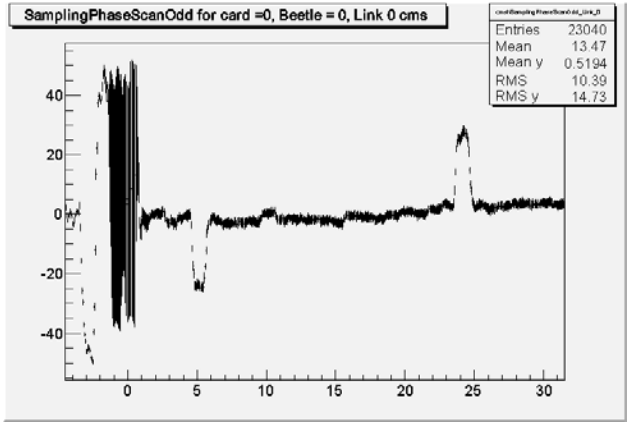
ADC Sampling Time

- To time-align the readout of the VELO with respect to the LHC clock, adjustment of the sampling points in the Beetle FE-chips and ARx cards is required.
- TELL1 setting per link. > 10,000 parameters.
- Independent of the beam: adjusted with test pulses.
- A scan procedure runs over all the possible time settings and the optimal value is chosen.

ADC Digitization Delay Scan

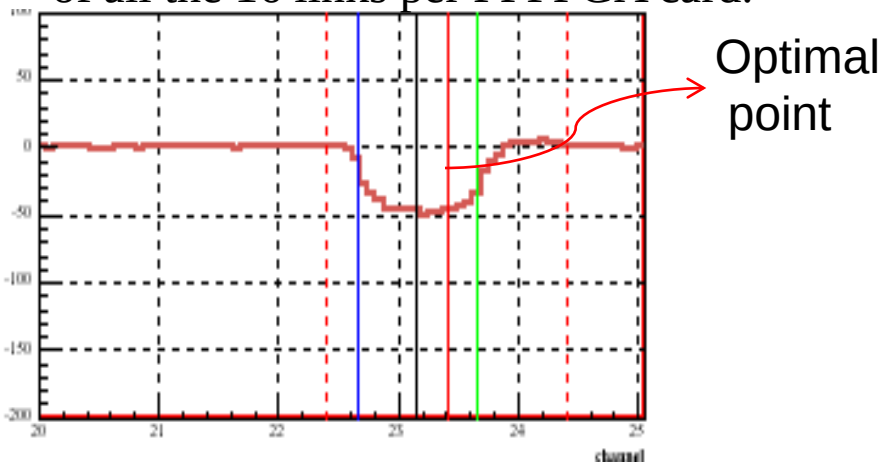
- The pulse height of the channels in one link are transmitted serially from the detector to a TELL1, with 25 ns time spacing between the channels. A delay on the TELL1 controls the ADC digitisation in coarse steps of clock cycles (25 ns) and fine steps, phases, of 1/16th of a clock cycle.
- Even and odd test pulses are injected into a given channel for the 16 possible phase settings, and the pulse height is determined at each setting.

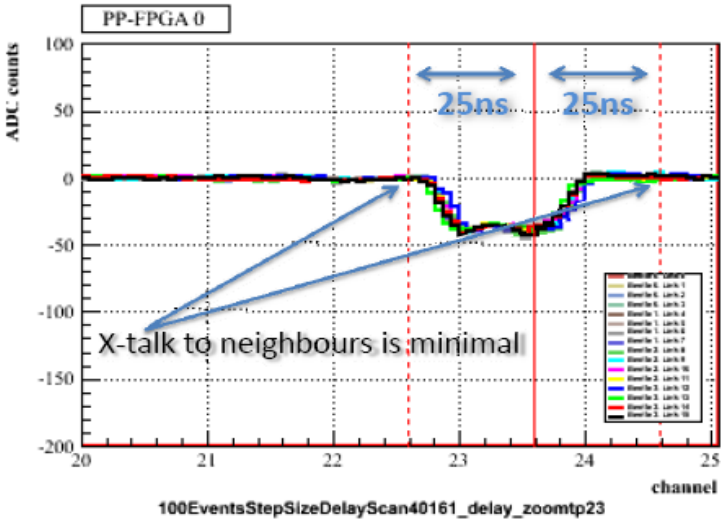




Optimization Procedure

- Sum the even and odd pulse for each link together to get rid of pedestals.
- Look for rising and falling edges and hence the plateau centre. Starting from the centre bin on plateau, require the difference of the optimal bin value (ADC) and centre value is less than 20% of the centre value. This is to makes sure to be close to the centre. Second, the difference of the optimal bin value and next bin value is required to be less than 15% of the current bin value. This prevents the optimal point to be too close to the falling edge.
- If for any link, we failed to find a rising or falling edge, we use the average value of all the 16 links per PPFPGA card.





Checking Procedure

- The TP data is composed of even and odd pulses.

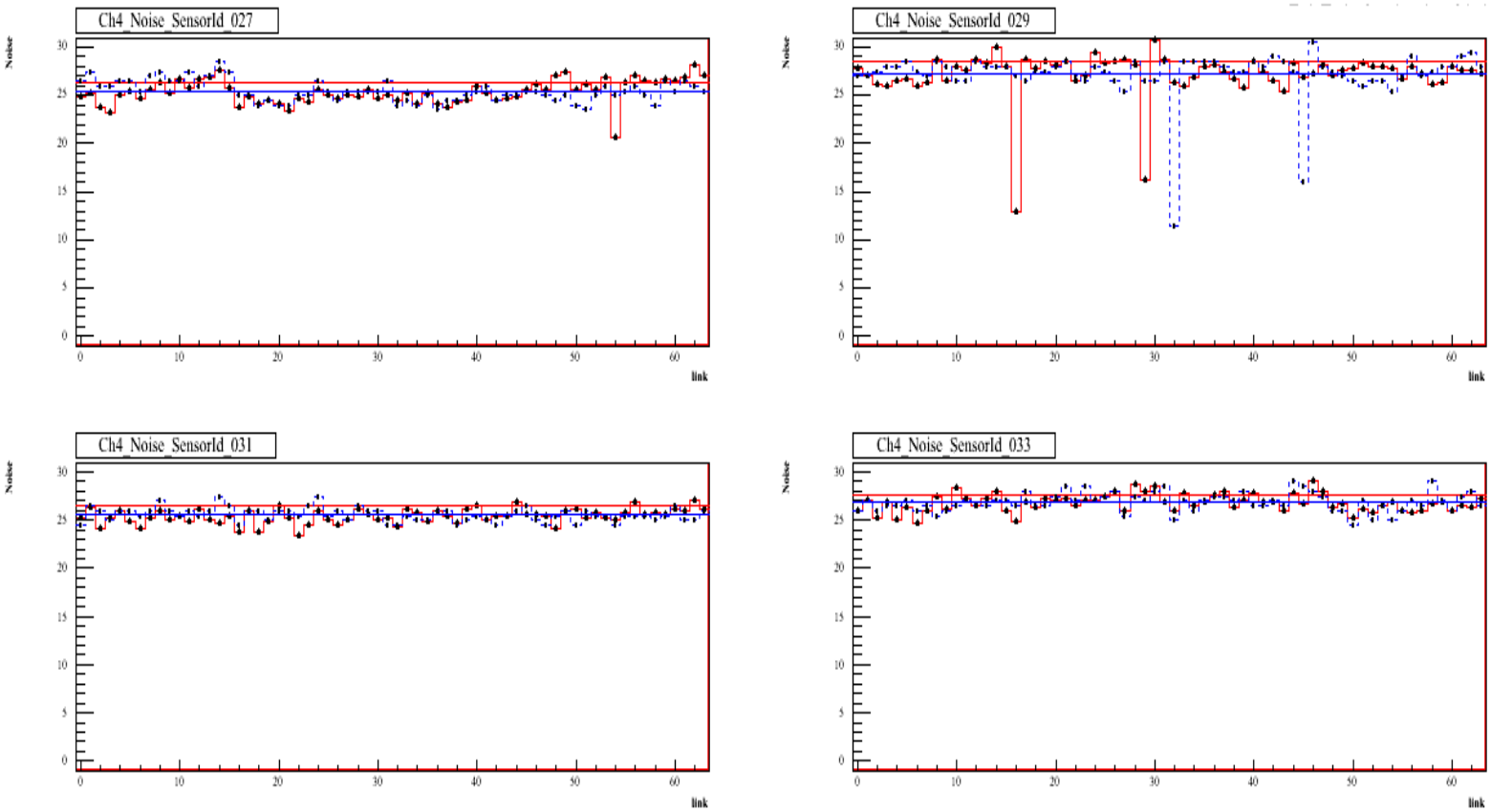
- Addition of the two plots $\Rightarrow$
  - average TP height, $\overline{x} = 0$ and

$$\text{rms} = \sqrt{\frac{\sum_i (x_i - \overline{x})^2}{n}} = \sqrt{\frac{\sum_i x_i^2}{n}} \approx x$$

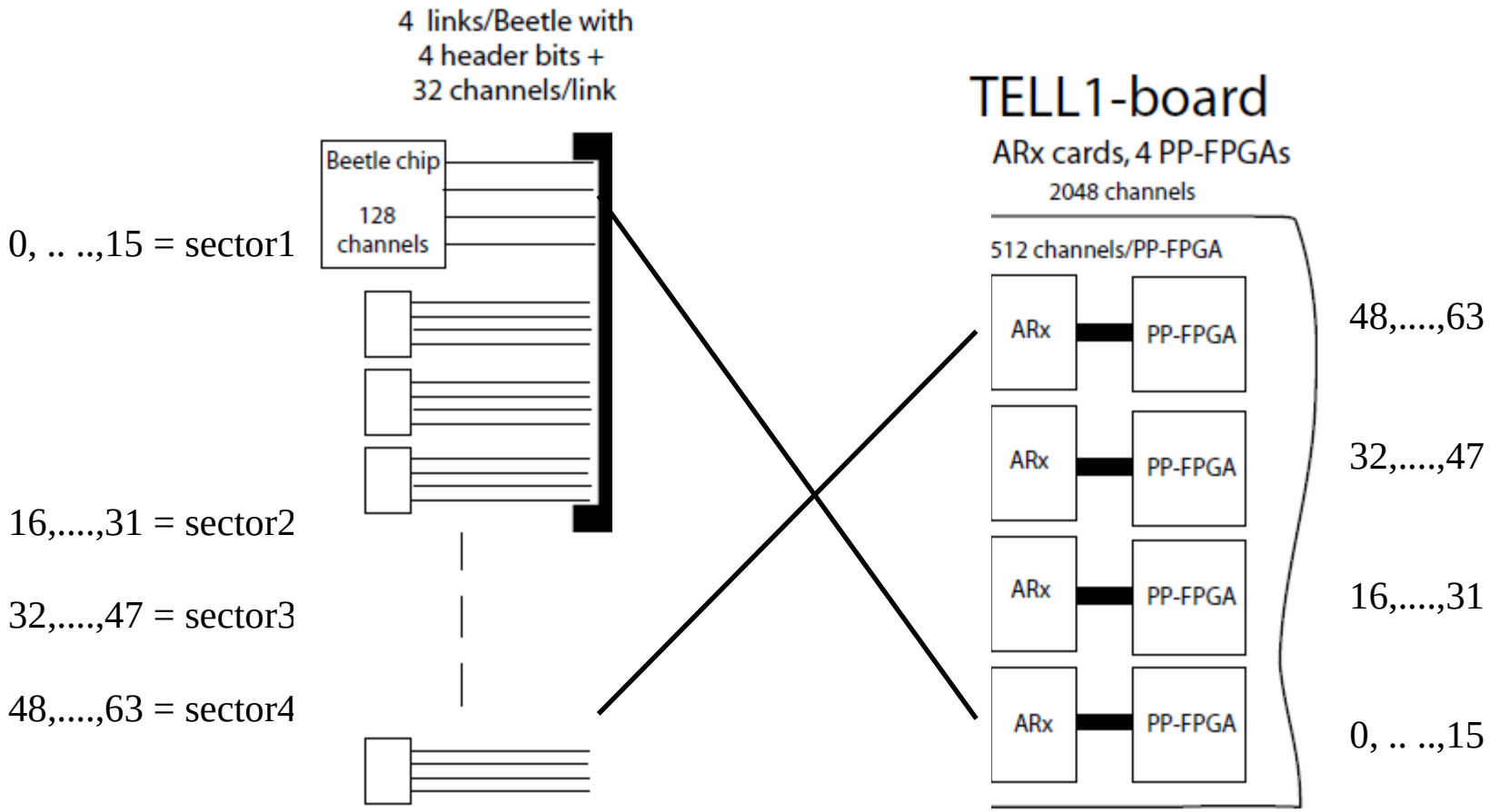
- Comparison the noise for Ch4 and Ch23, from the NZS noise data with the TP height should be same.

Checking Procedure Cont...

- Channel 4 of sensor 27, ..33(C-Side)



Cable Reordering of links



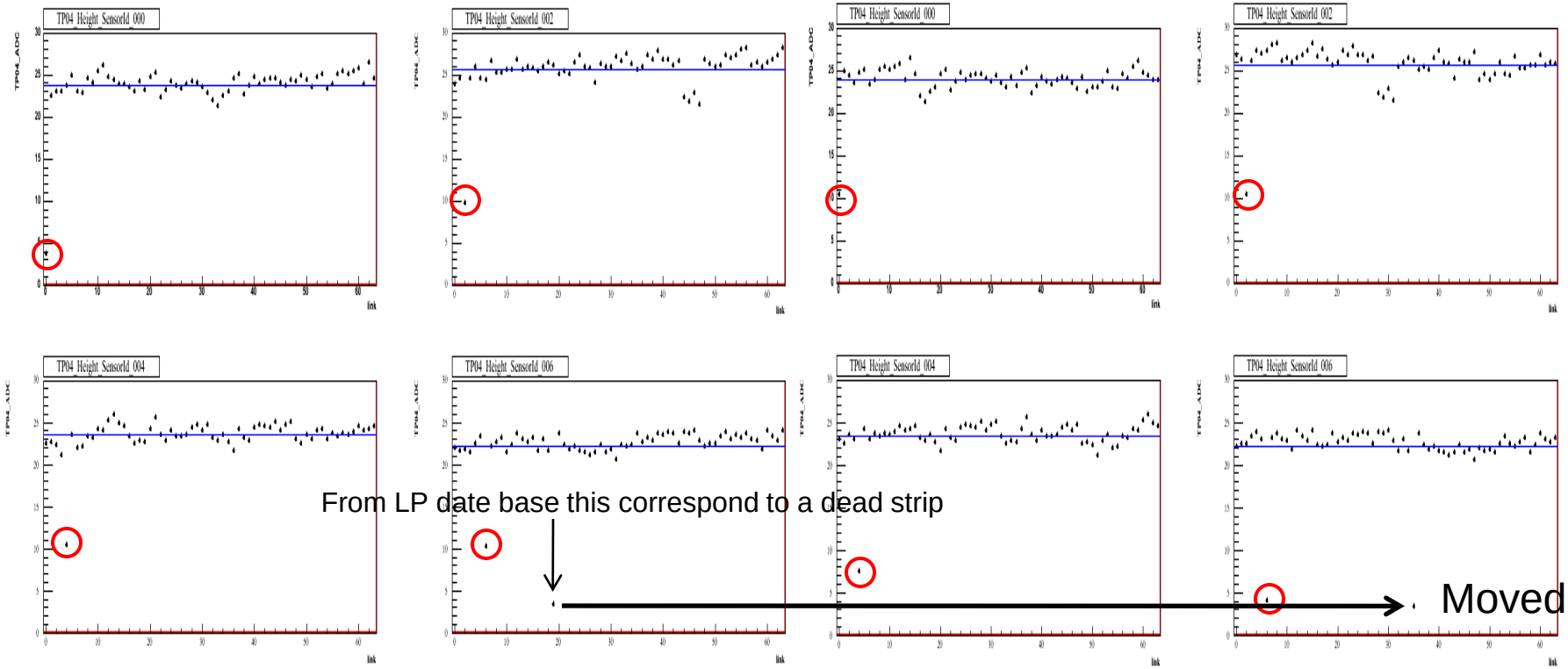
This was corrected during the emulation process but was forgotten in the ADC sampling digitization process

Investigation

- To check the right cable order, we set link#0 of sensor#0 at rising edge, link#1 of sensor#1 on rising edge and so on (Asymmetric pattern) and run a delay scan job with and without the cable order correction for A-side.

With the software corrections

Without the software corrections

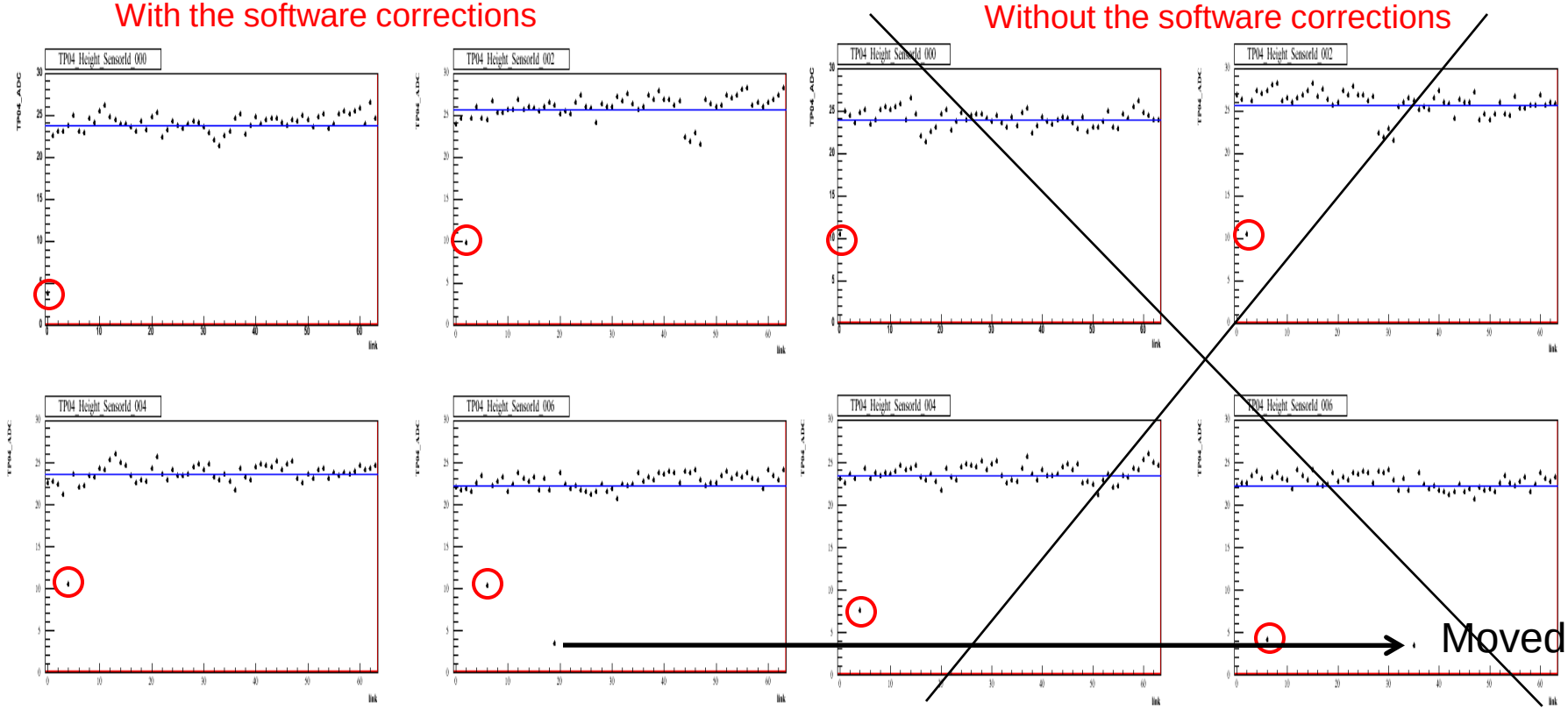


Investigation Continue....

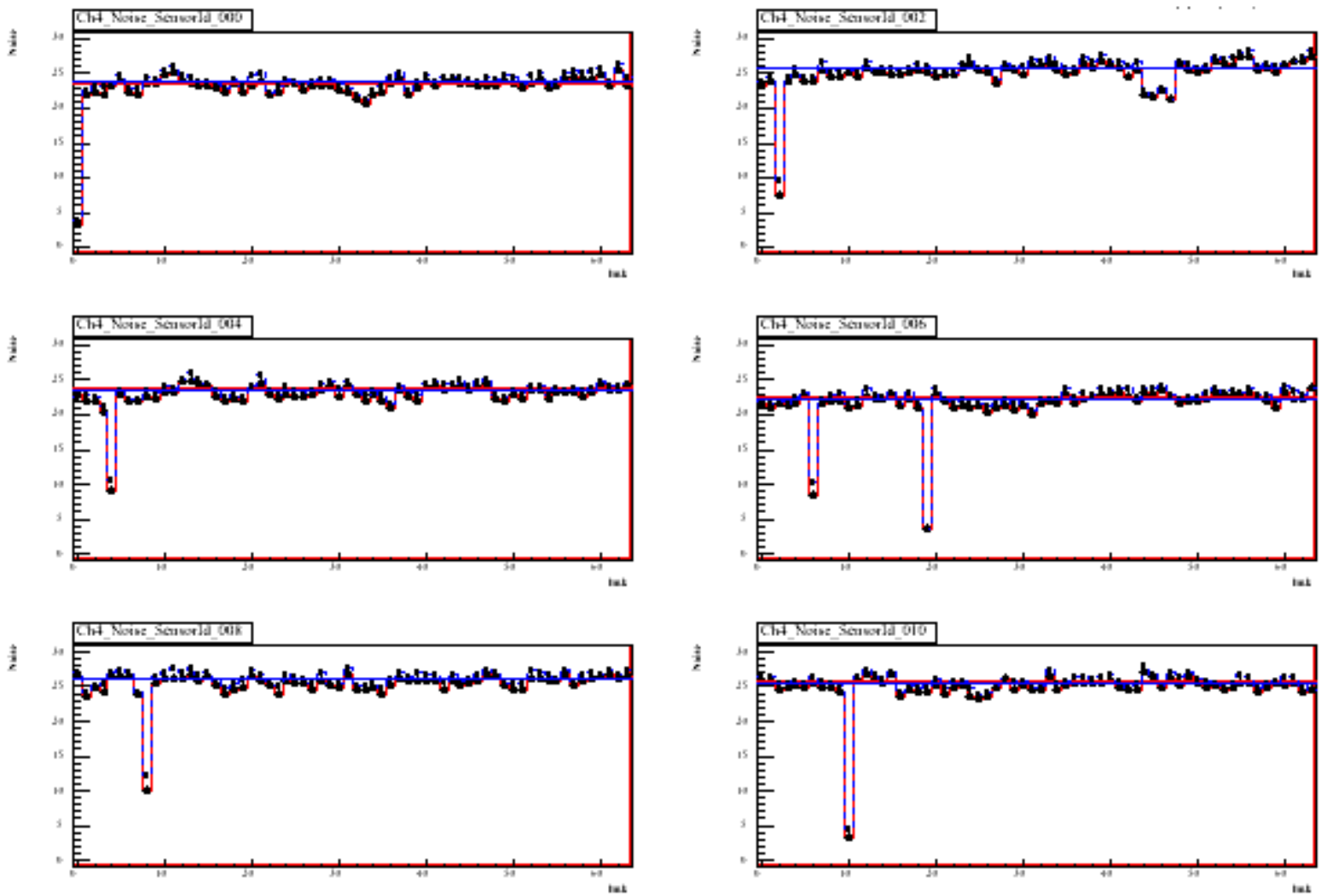
- To check the right cable order, we set link#0 of sensor#0 at rising edge, link#1 of sensor#1 on rising edge and so on (Asymmetric pattern) and run a delay scan job with and without the cable order correction .

With the software corrections

Without the software corrections

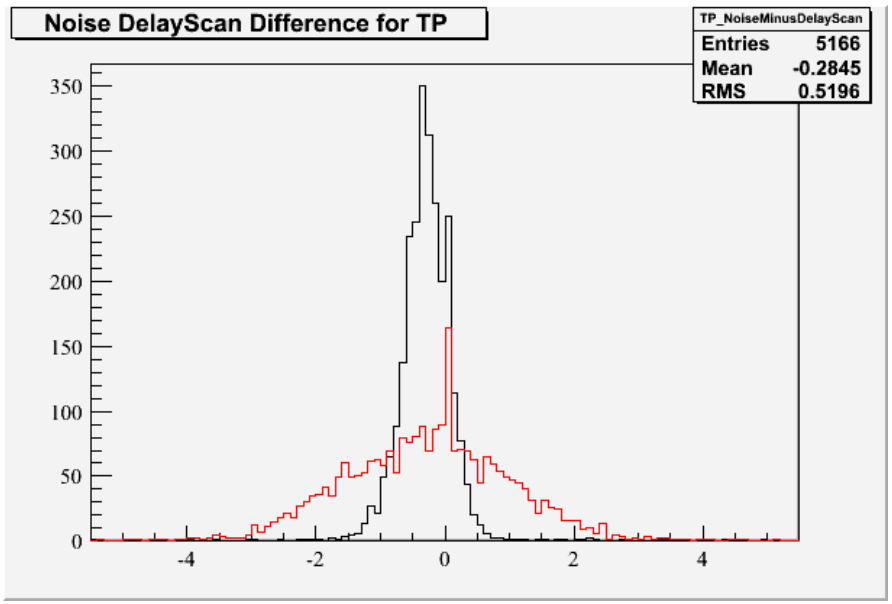


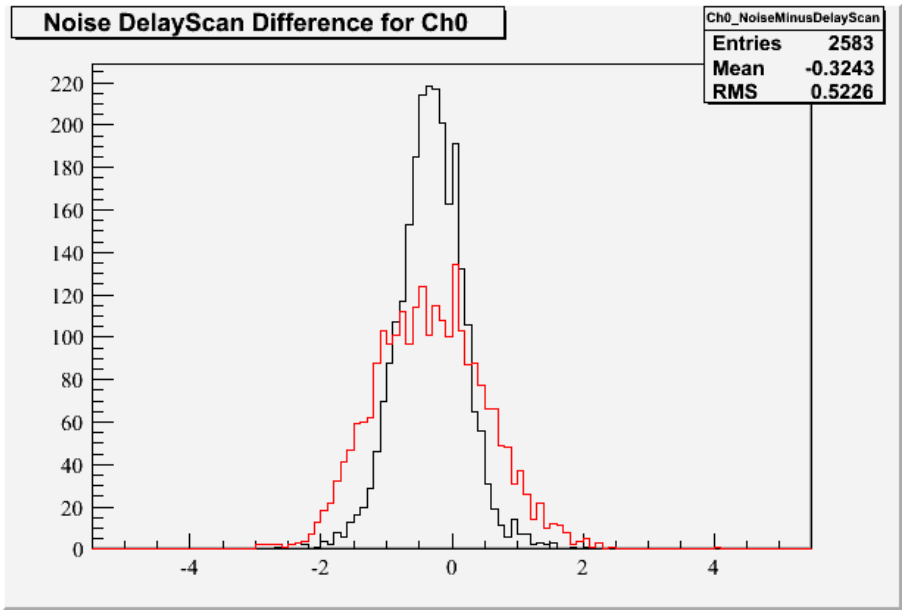
Comparison of TP height from delay scan (blue) and noise from NZS data(red) for ch4



A quick comparision

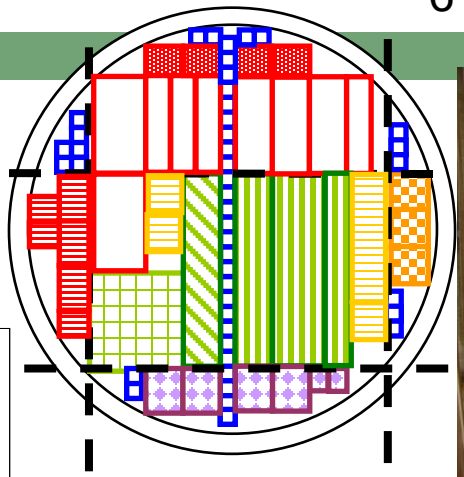
Wrong order
Right order



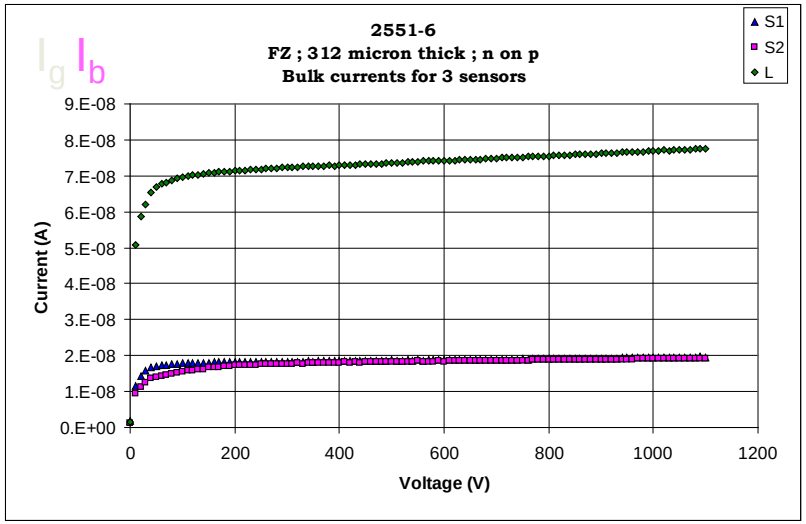


n-on-p pixels

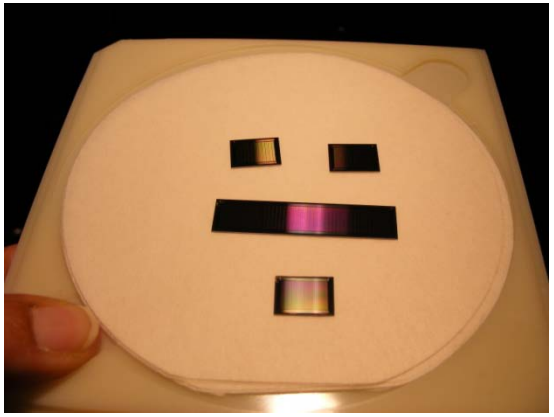
6” Micron



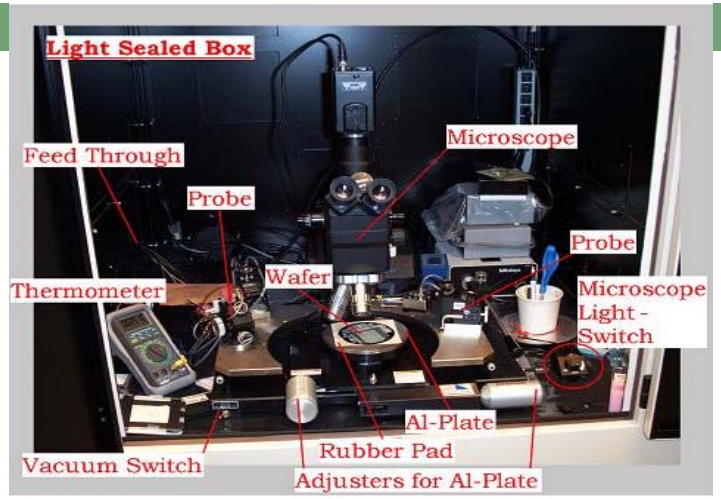
Syracuse/RD50 p-type “BTeV style” single chip pixel devices fabricated by Micron Semiconductor

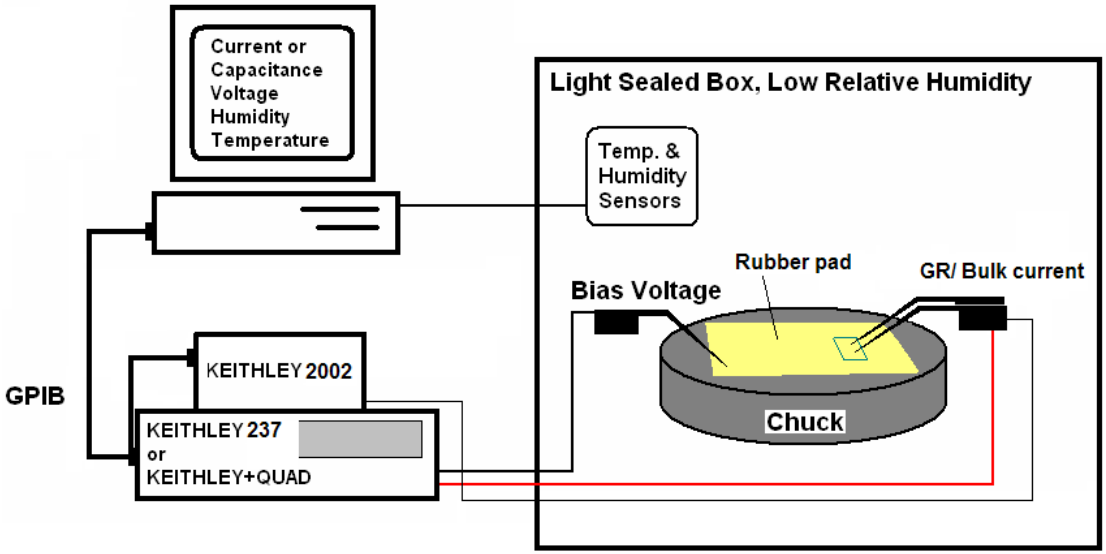


Depletion voltage 20-80 V unirradiated



Experimental Setup





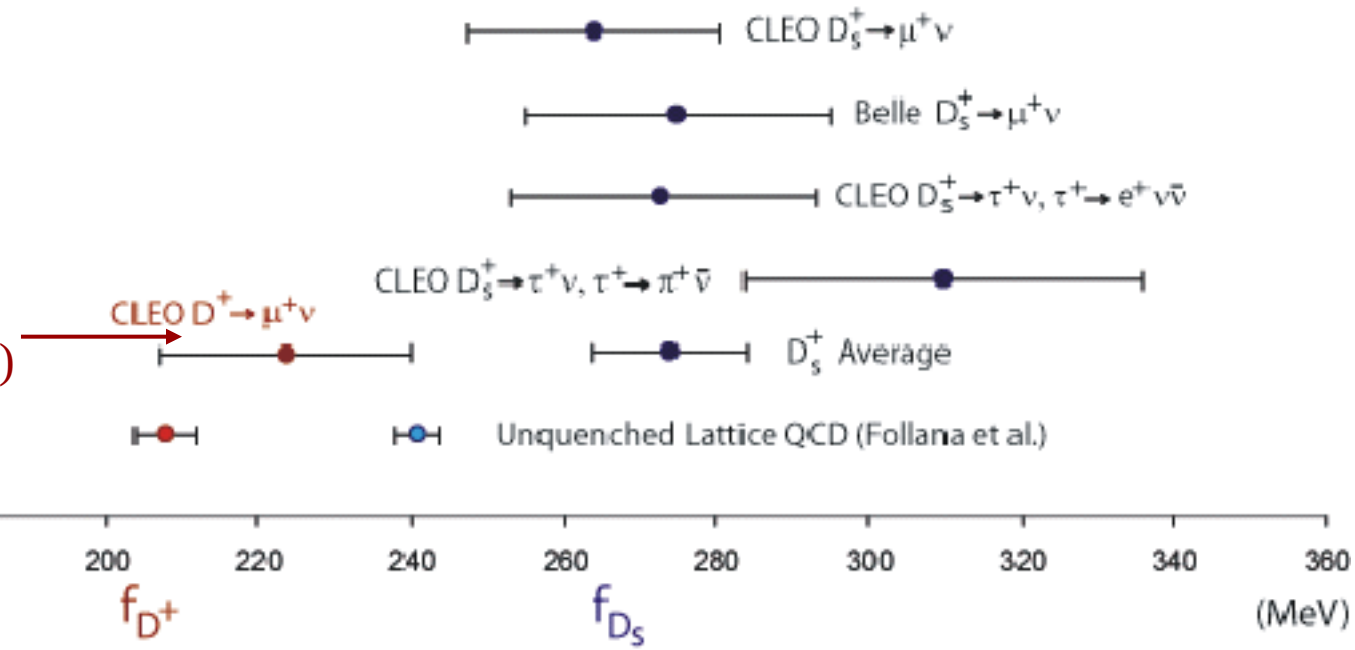
Backup slides

Previous Studies

- The previous measurement of f_{D^+} was too inaccurate to challenge Follana et al., theory

207±4 vs 223±17 MeV (CLEO)

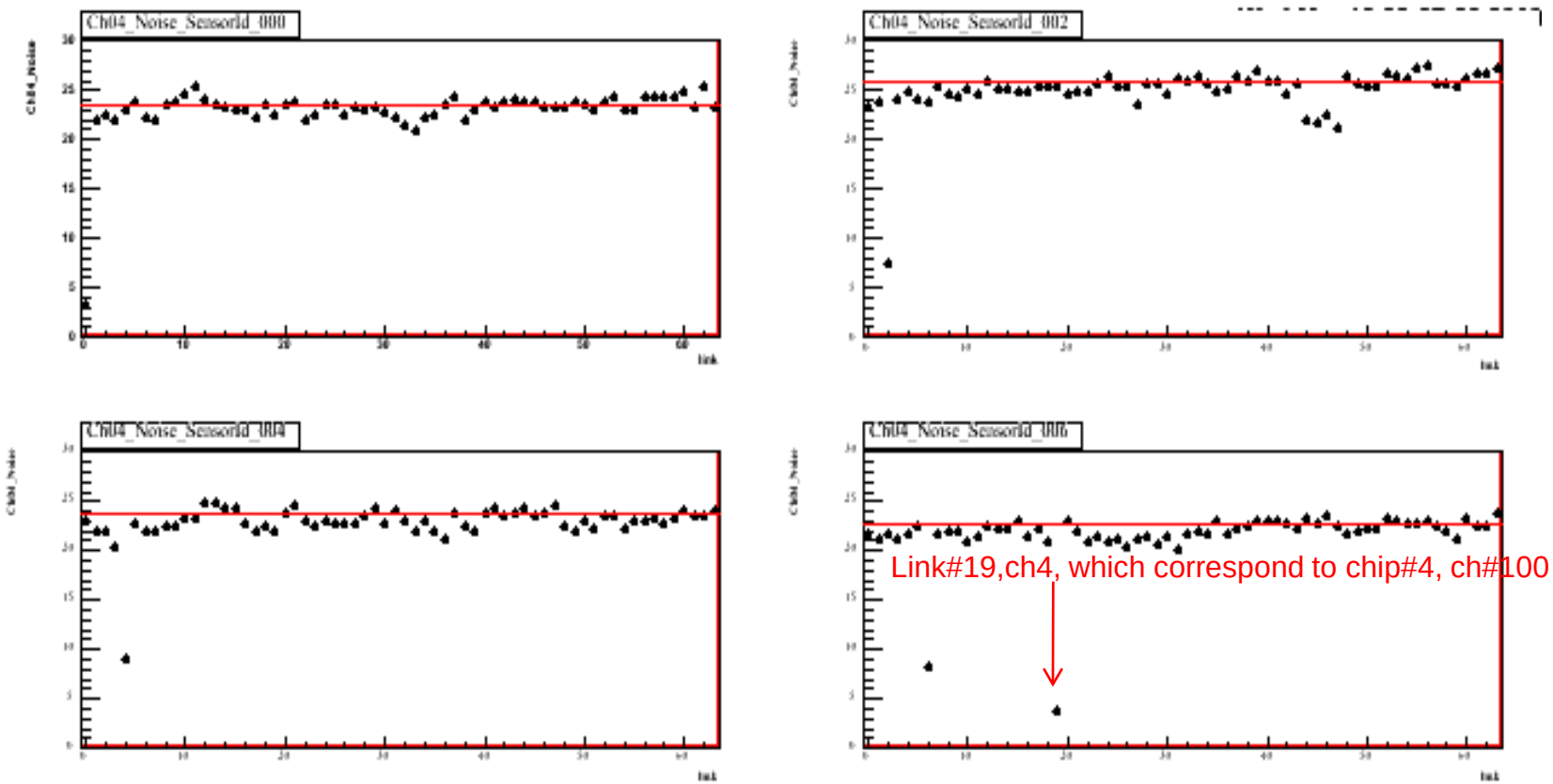
D^+ too inaccurate to say anything (3.3 σ)



TELL1 Processing

- The processing on the TELL1 board can be emulated bit perfectly in a offline software called VETRA, which follows the chain of algorithms as
  - Pedestal Subtraction: The Arx cards convert the analogue signal from the Beetle to a range of 0→1023 ADC counts. The pedestal of digitized output is 512 ADC, but fluctuates under external conditions as temperature etc. A pedestal following algorithm subtracts the pedestals.
  - Header Cross-talk correction: The last two bits of each analogue link are used to encode the beetle pipeline column number causing a x-talk to the every 1st channel of each analogue link. Correction is applied using the information of the x-talk level and pulse height of the header bit.
  - Finite Impulse Response (FIR) filter: Corrects signal distortion in the 60 m data cables of the analogue links.
  - Channel Reordering: Due to scheme with which sensor strips are bonded to the FE-electronics, scrambling occurs such that consecutive Beetle channels are not connected to the adjacent strips. The algorithm reorders the Beetle channels to the strip channels.
  - Common Mode Suppression: The sensors can pick a noise (e.g, RF). The algorithm is a linear fit to the strip charge in groups of 32 channels, performing on each event. Noise is the rms of the ADC value of a channel.
  - Clustering: Seed a strip by passing a signal threshold. Up to three adjacent strips are added.
- The processed data is send to HLT which further reduces the rate to 2kHz.

Investigation Continue....

- The Answer is University of Liverpool data base http://hep.ph.liv.ac.uk/velodb/VELO/noise_data.php

With the software corrections