LHCb Upgrade Status

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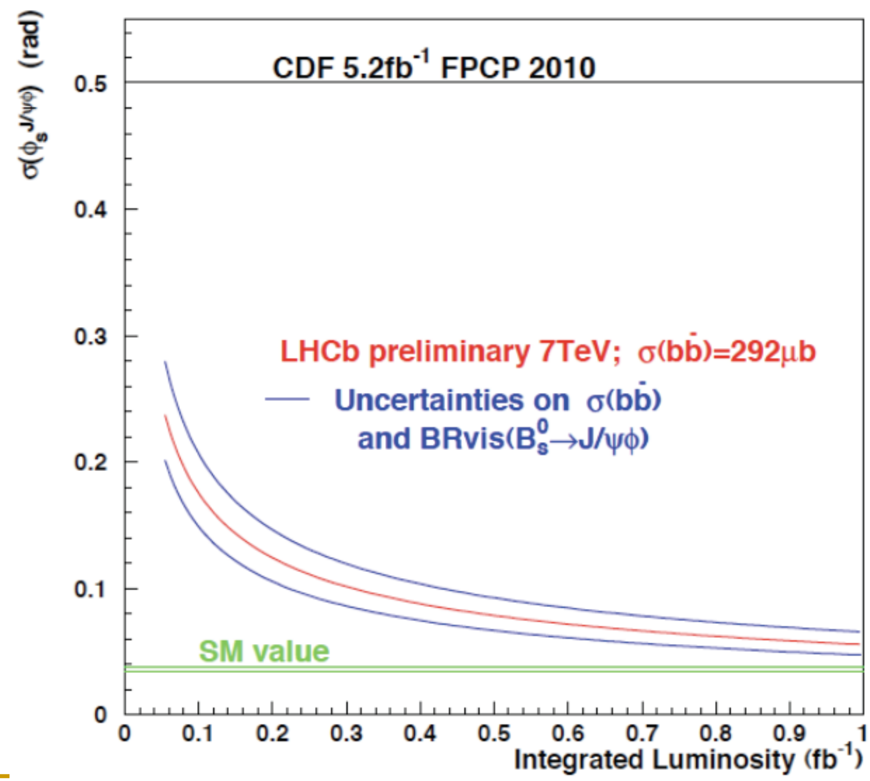
General Justification for Flavor Physics

- Expect New Physics will be seen at LHC
  - Standard Model is violated by the Baryon Asymmetry of Universe & by Dark Matter
  - Hierarchy problem (why $M_{Higgs} << M_{Planck}$)
- However, it will be difficult to characterize this physics
- How the new particles interfere virtually in the decays of b's (& c's) with W's & Z's can tell us a great deal about their nature, especially their phases

Key physics modes (as of today)

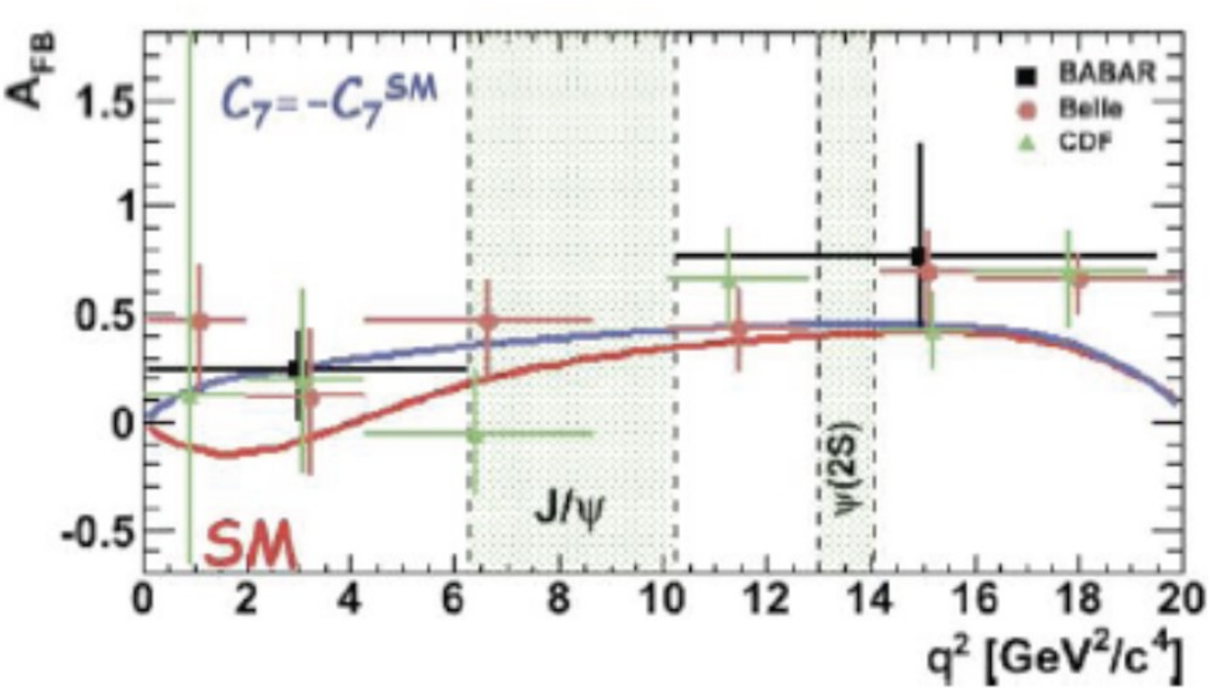
- Finding the CP violating phase ($-2\beta_s$) in $B_s \rightarrow J/\psi\ \phi$ mixing. SM prediction is 0.036±0.002 from other measurements constraining the CKM matrix. LHCb can make a measurement with an error equal to the SM value in about 2 fb^{-1}
  - A precision measurement will take 50 fb^{-1}



$B^o \rightarrow K^{*o}\ \mu^+\mu^-$

- Measuring the angular asymmetries in $B^o \rightarrow K^{*o}\ \mu^+\mu^-$. Sensitive to the presence of new particles
- Hint of NP, but lots more luminosity needed

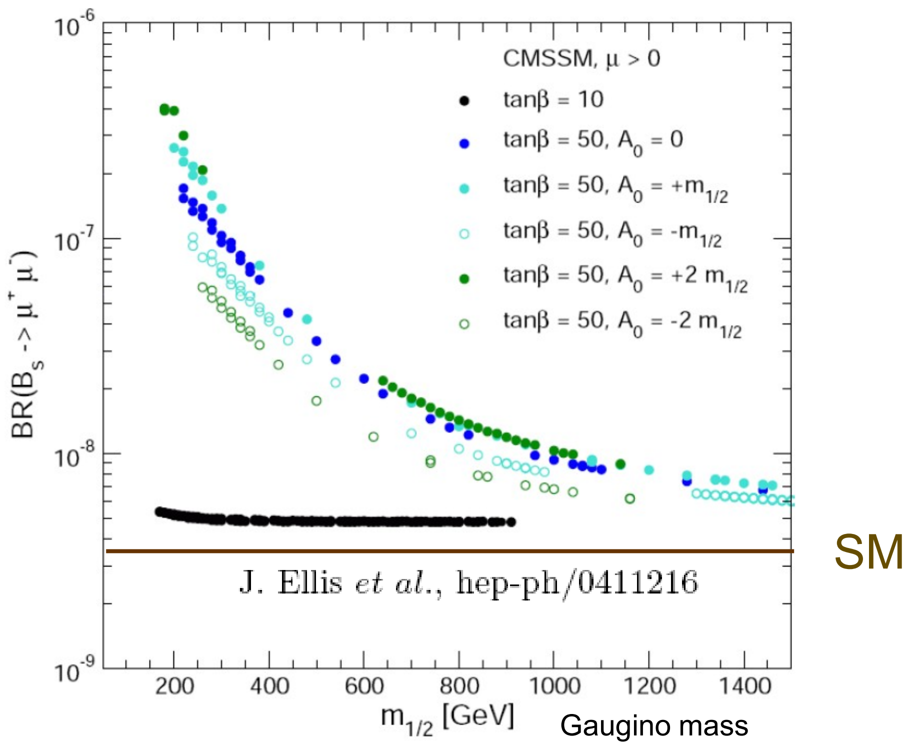
Forward-backward asymmetry

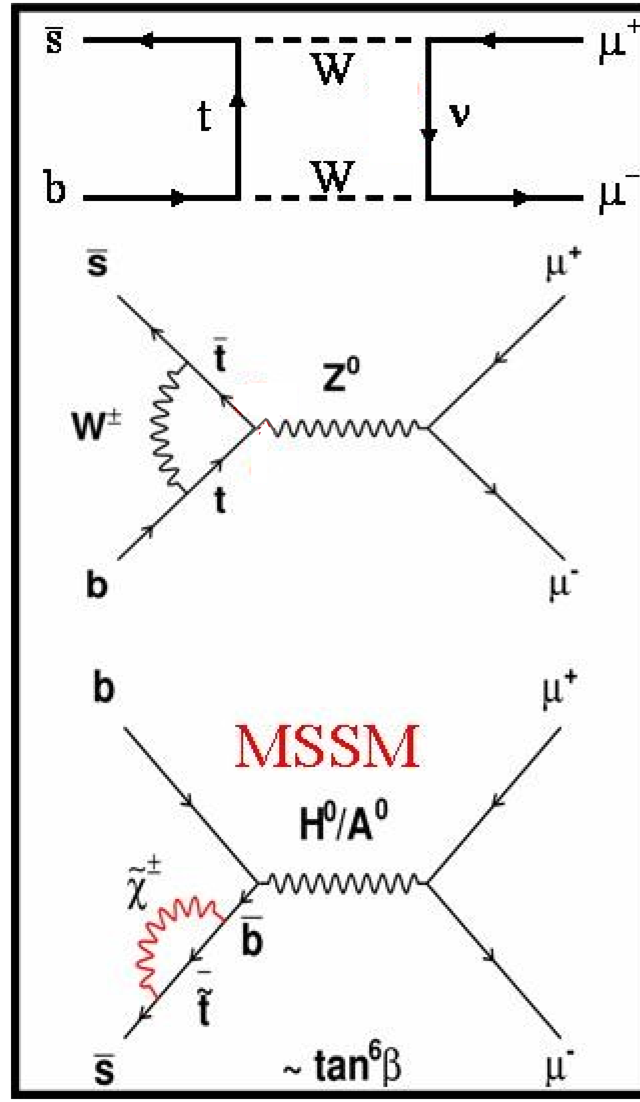


We expect 1100 in 1 fb^{-1}
Belle has 250 events in 605 fb-1

$B_S \rightarrow \mu^+\mu^-$ & Supersymmetry

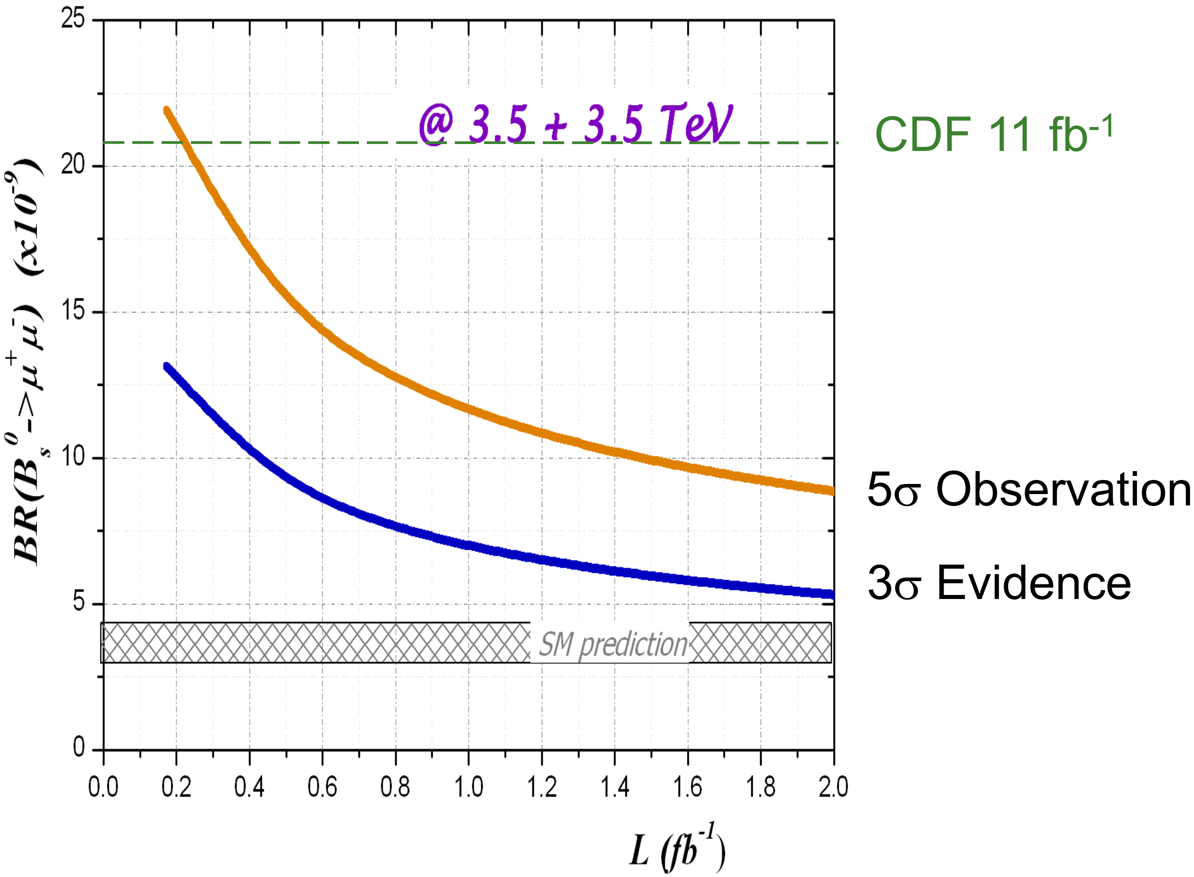
- Branching Ratio very sensitive to SUSY
- In MSSM goes as $\tan^6\beta$





$B_S \rightarrow \mu^+\mu^-$ Sensitivity

- Takes more than 2 fb^{-1} to get 3σ evidence, 50 fb^{-1} needed for accurate measurement

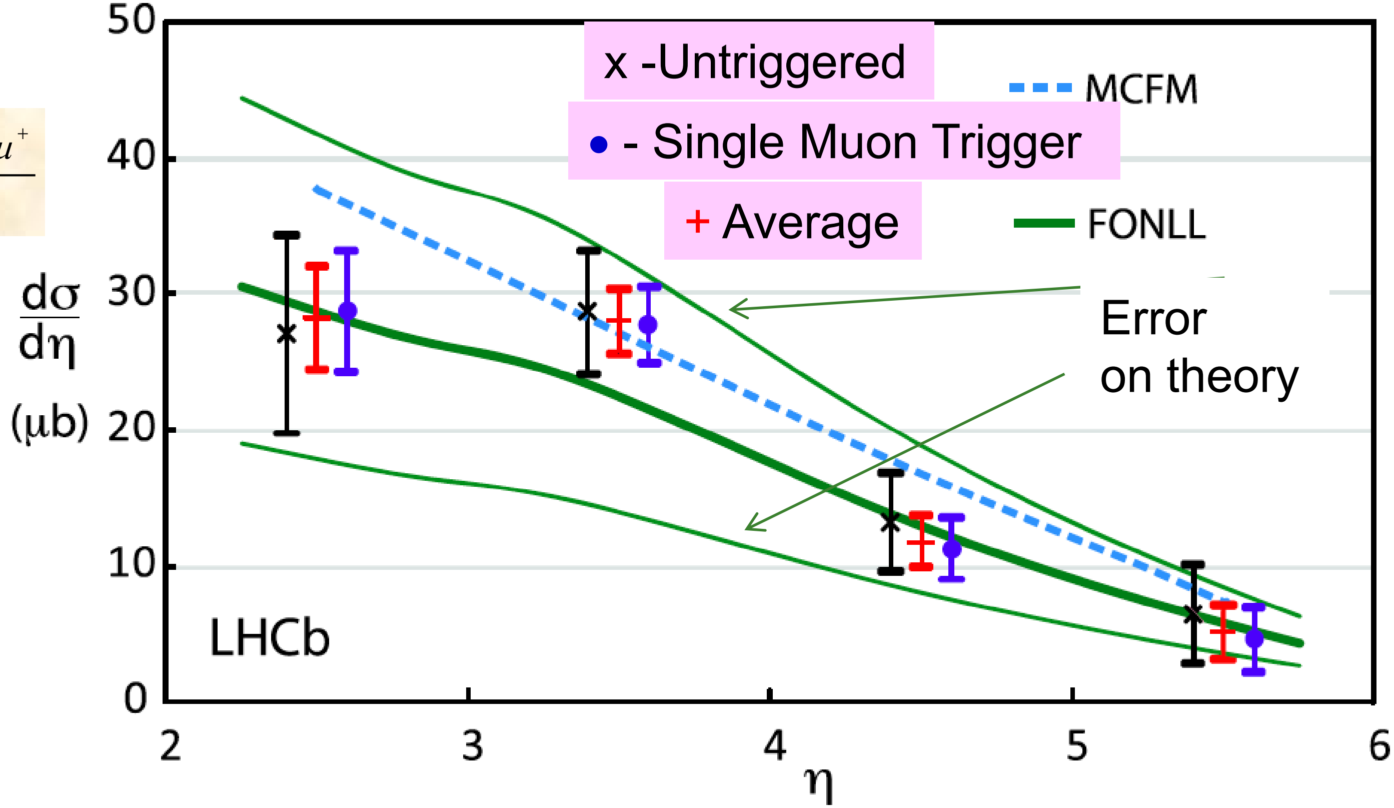


Other Physics with LHCb

- Unique coverage in $2<\eta<6$ for high energy pp collisions
- Electroweak measurements: W's & Z
- 1 m long VELO enhances possibilities for new particles with long lifetimes
- Cross-section measurements of beauty & charm
- Exotic particle searches
  - Non-SM Higgs decays
  - Stau's
  - ????

$\sigma(pp \to b\bar{b}X)$

$$\sigma = \frac{\#\text{ of detected } D^0\mu^- \ \&\ \bar{D}^0\mu^+}{L \text{ x efficiency x } 2}$$



- In 2<η<6, (75.3±5.4±13.0) μb LEP frag
- In 2<η<6, 89.6 μb Tevatron frag

Exotic Searches

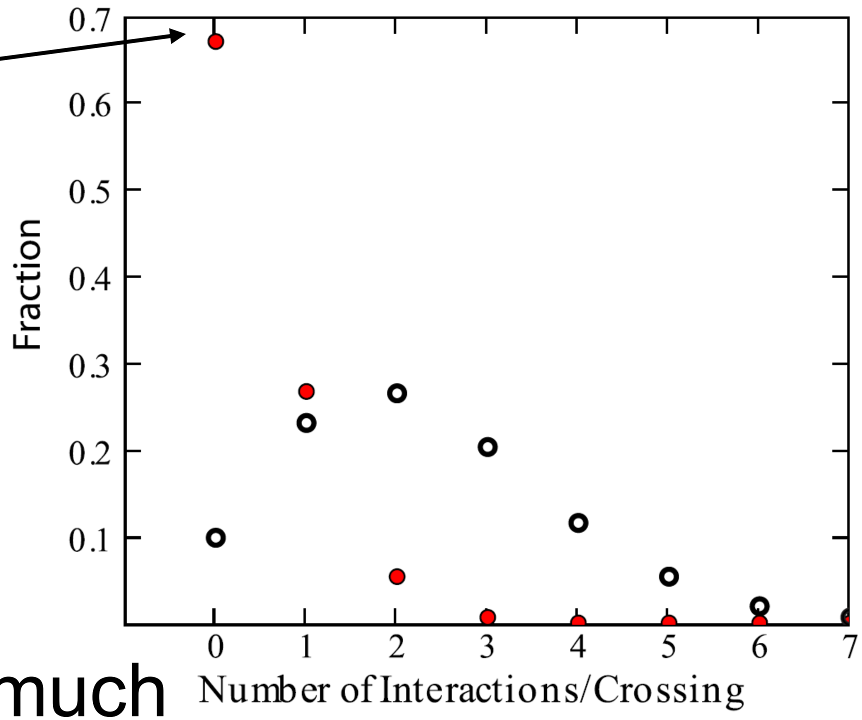
- LHCb complements the ATLAS/CMS solid angle by concentrating at large η and low p_t
- Sensitive to "Exotic" particles decaying into lepton or quark jets, especially with lifetimes in the range of $500>\tau>1$ ps.
- We will show one example, that of "Hidden Valley" Higgs decay, $H^o \rightarrow \Pi_v \Pi_v$, $\Pi_v \rightarrow bb$

Upgrade Luminosity Goal

- Accumulate minimally 50 fb^{-1} of *useable* data
- Means running for 5 years at 10fb^{-1} /year
- Requirements (general)
  - Trigger efficiencies on roadmap channels no worse than in roadmap document
  - Detector efficiencies no worse than in roadmap
  - S/B not deteriorating as a function of increased # of interactions/crossing

Running Conditions

- Nominal: luminosity $2x10^{32}$ cm^{-2}/s at beginning of run
- Take σ = 60 mb, [σ(total) - σ(elastic) - σ(diffractive)]
- Account for only 29.5 MHz of two filled bunches
- Most xings don't have an interaction
- At $L=10^{33}$ have int. in most crossings
- Recent running with <int>=~2 allowed by 10x fewer bunches. Learned much

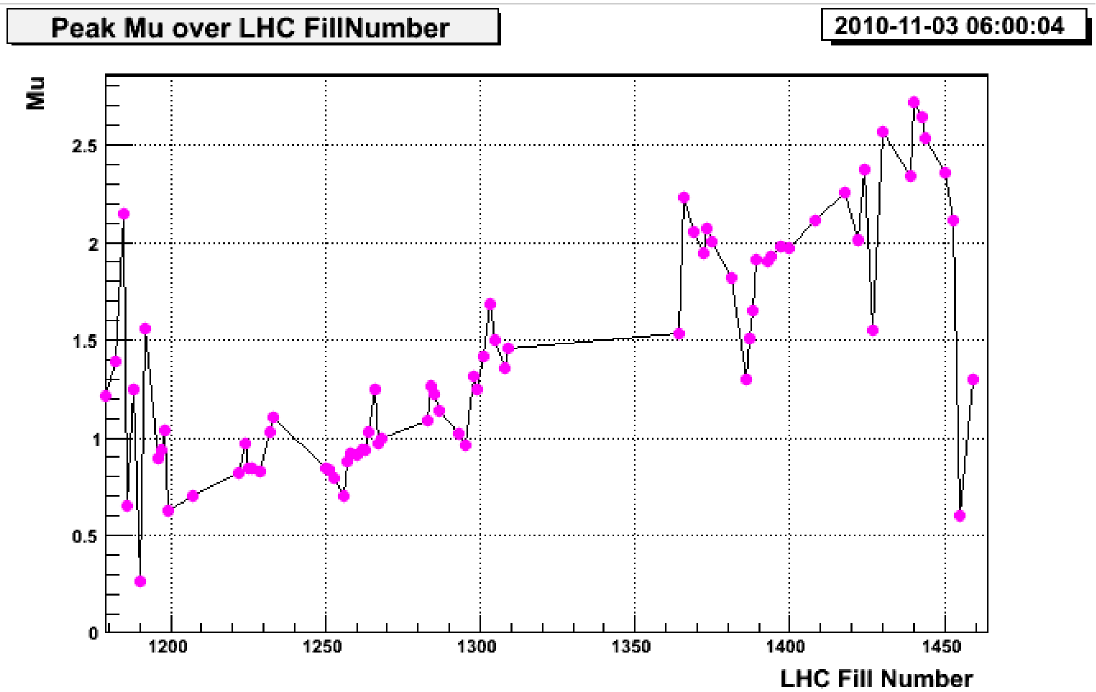


Current Running Conditions

- We are running with μ above 2 at beginning of run

μ

interactions/crossing



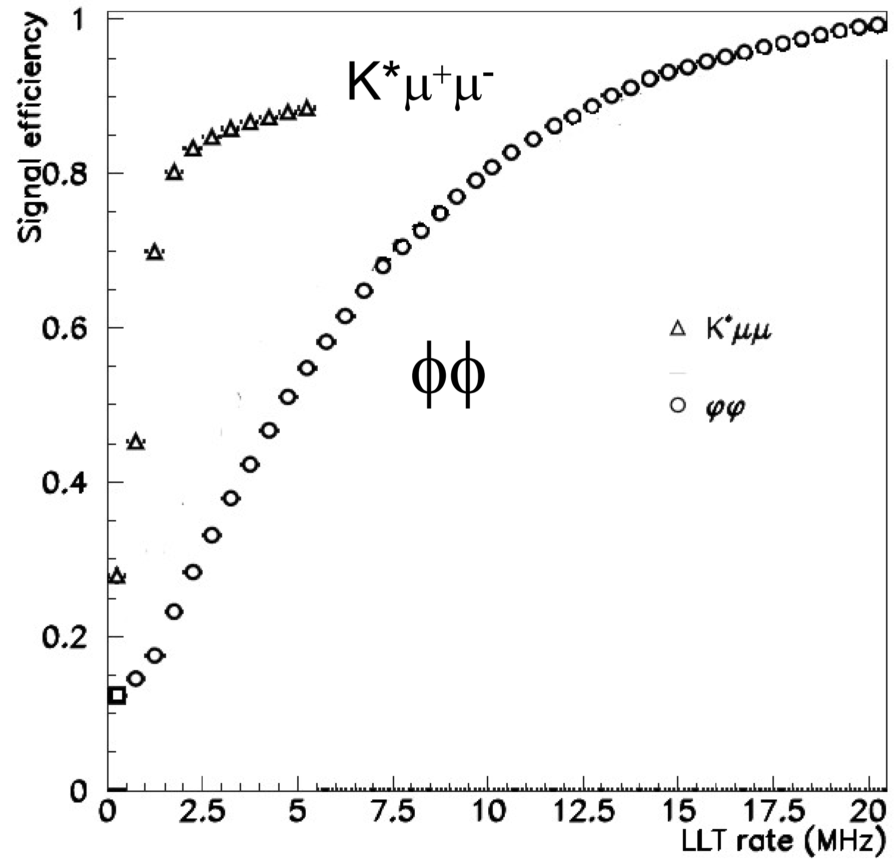
- Possible because we have only 344 crossings to look at, 3.5 MHz rate, "easy" to use trigger to get to 1 MHz. Then software to reduce to 2kHz

Current Trigger

- L0: Hardware based on muons or single tracks or photons with E_t>threshold
- Then readout detector at <1 MHz & use next
- Software based triggers
  - HLT1: finds primary vertices in VELO & tracks with large impact parameters then matches with downstream tracker to get momentum. For acceptable (IP, P_t, P) tracks pass to HLT2
  - HLT2: reconstructs all downstream tracks & accepts events based on secondary vertices, decay length and mass hypotheses at 2 kHz maximum output rate

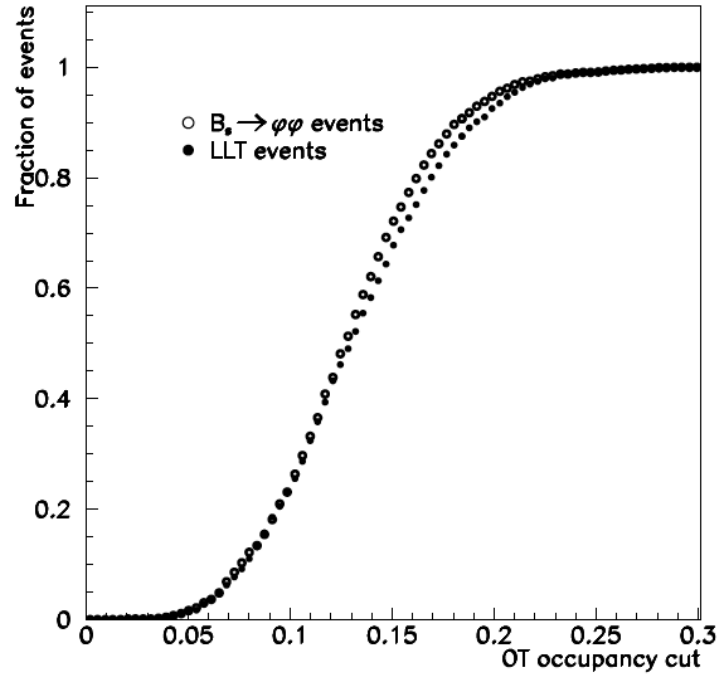
Limitation

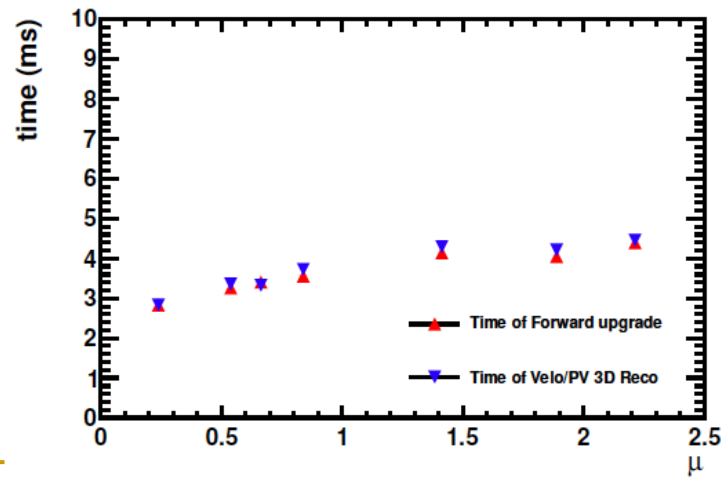
- Cannot satisfy the 1 MHz requirement without deeply cutting into the efficiency for hadronic final states
- The worse state is $B_s \rightarrow \phi\phi$, but all hadronic modes are affected
- Can ameliorate this by by reading out detector & then finding vertices



Upgrade Trigger

- Detector capable of ~40 MHz readout
  - Keep Low Level Trigger (LLT) as a crutch if HLT cannot keep up with rate, i.e. not sufficient computing. Similar to current L0
  - Cut OT occupancy >20% to preserve timing
  - Timing requirement < 20 ms, vertexing & tracking now is <10 ms, leaving time for HLT2





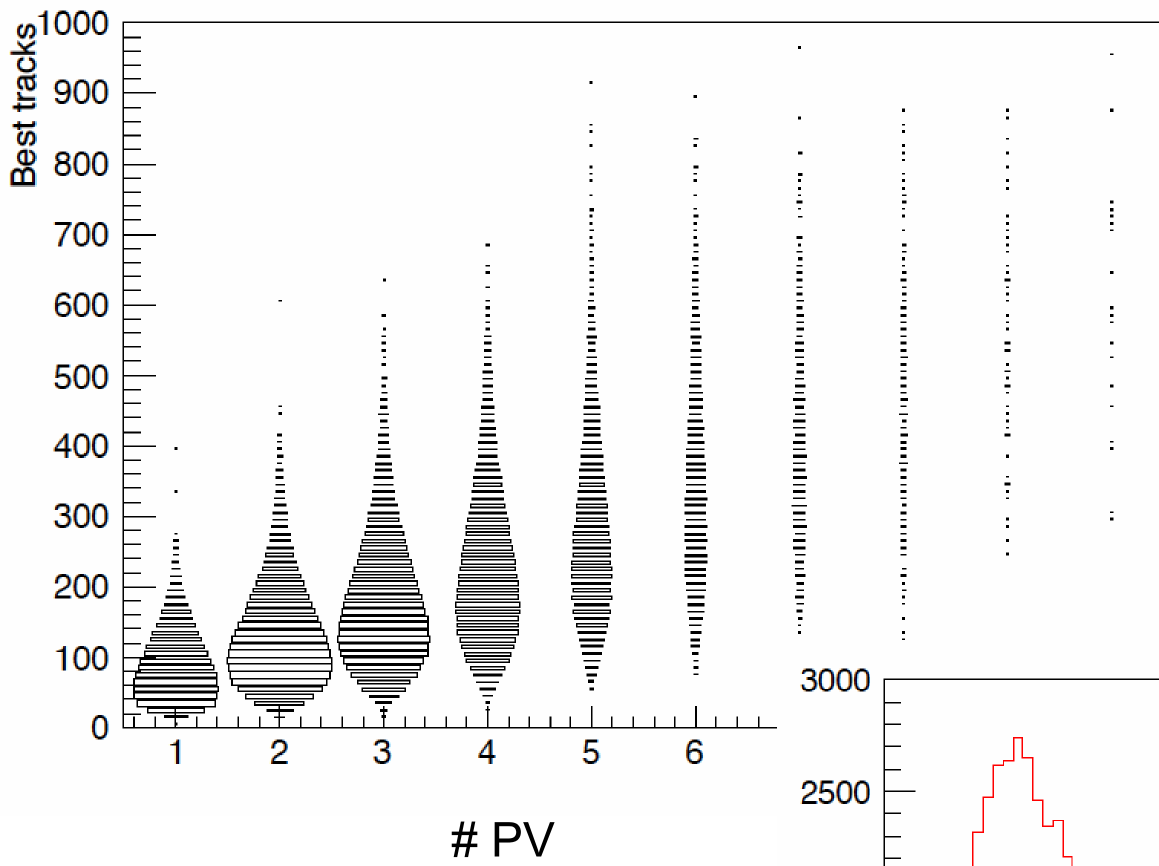
HLT

- HLT1 similar to current, but pixels speed up reconstruction due to lack of ambiguities & eliminate ghosts
- HLT2 also similar but increase to 20 kHz output rate

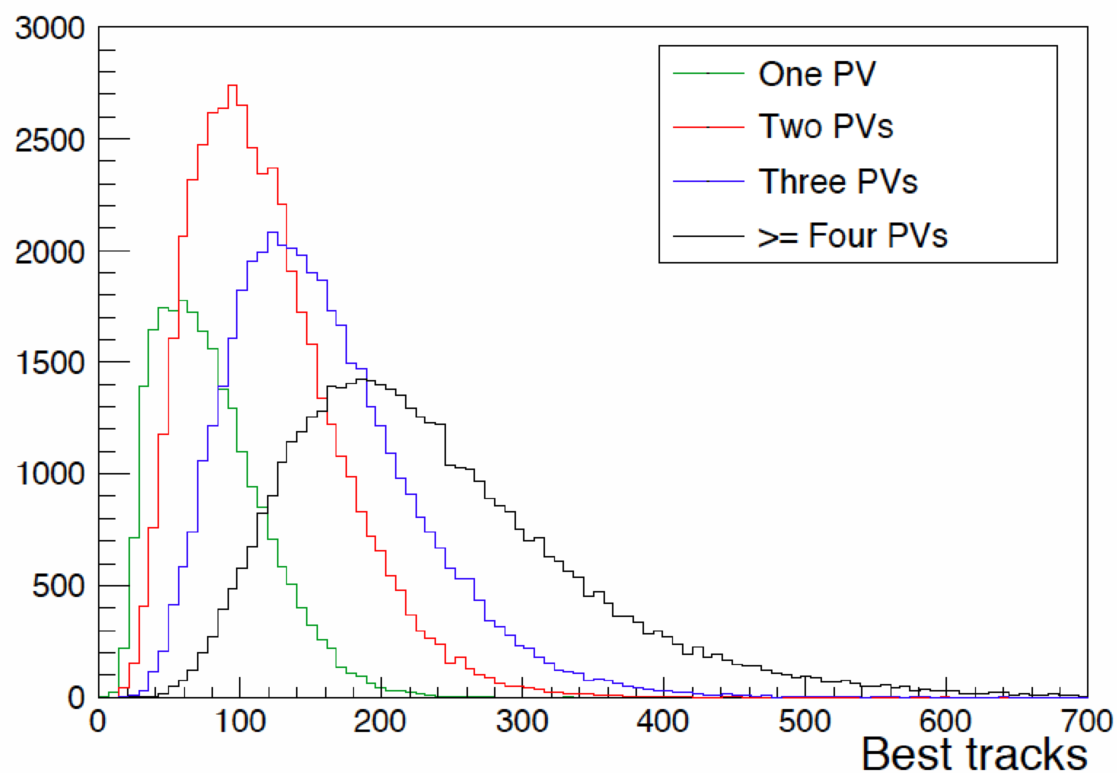
Problems encountered at high μ

First some technicalities

#PV vs. Tracks



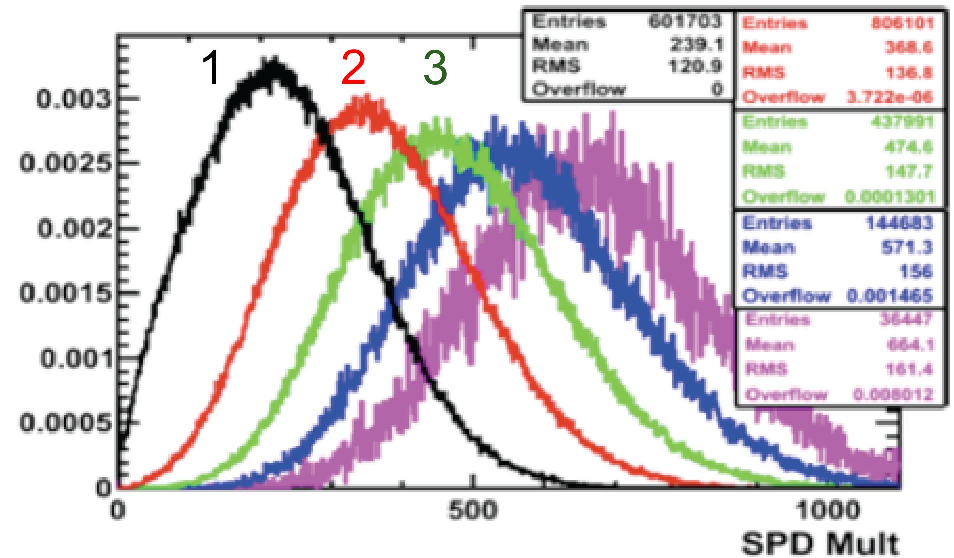
Best tracks
1000
900
800
700
600
500
400
300
200
100
0
1
2
3
4
5
6
PV

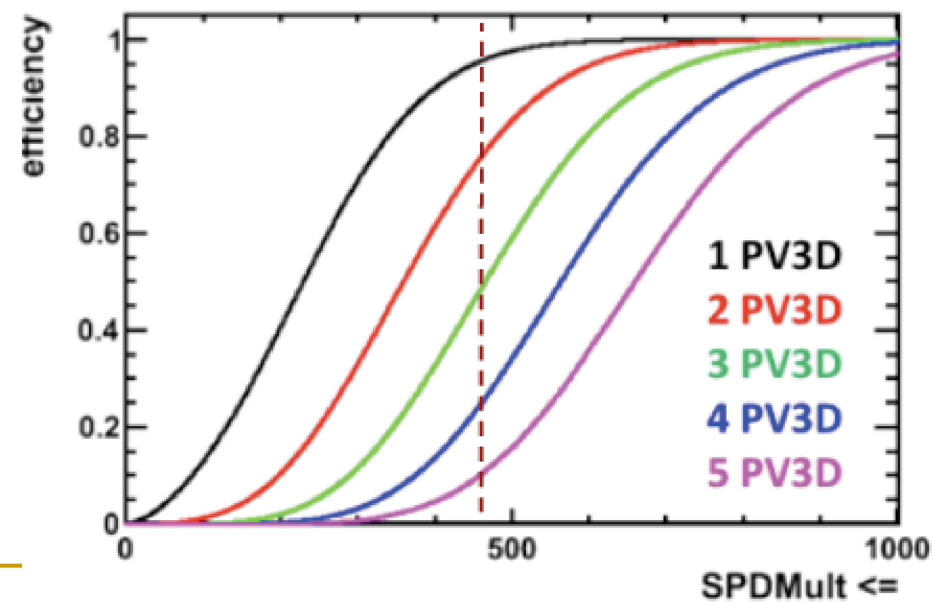


One PV
Two PVs
Three PVs
>= Four PVs
3000
2500
2000
1500
1000
500
0
100
200
300
400
500
600
700
Best tracks

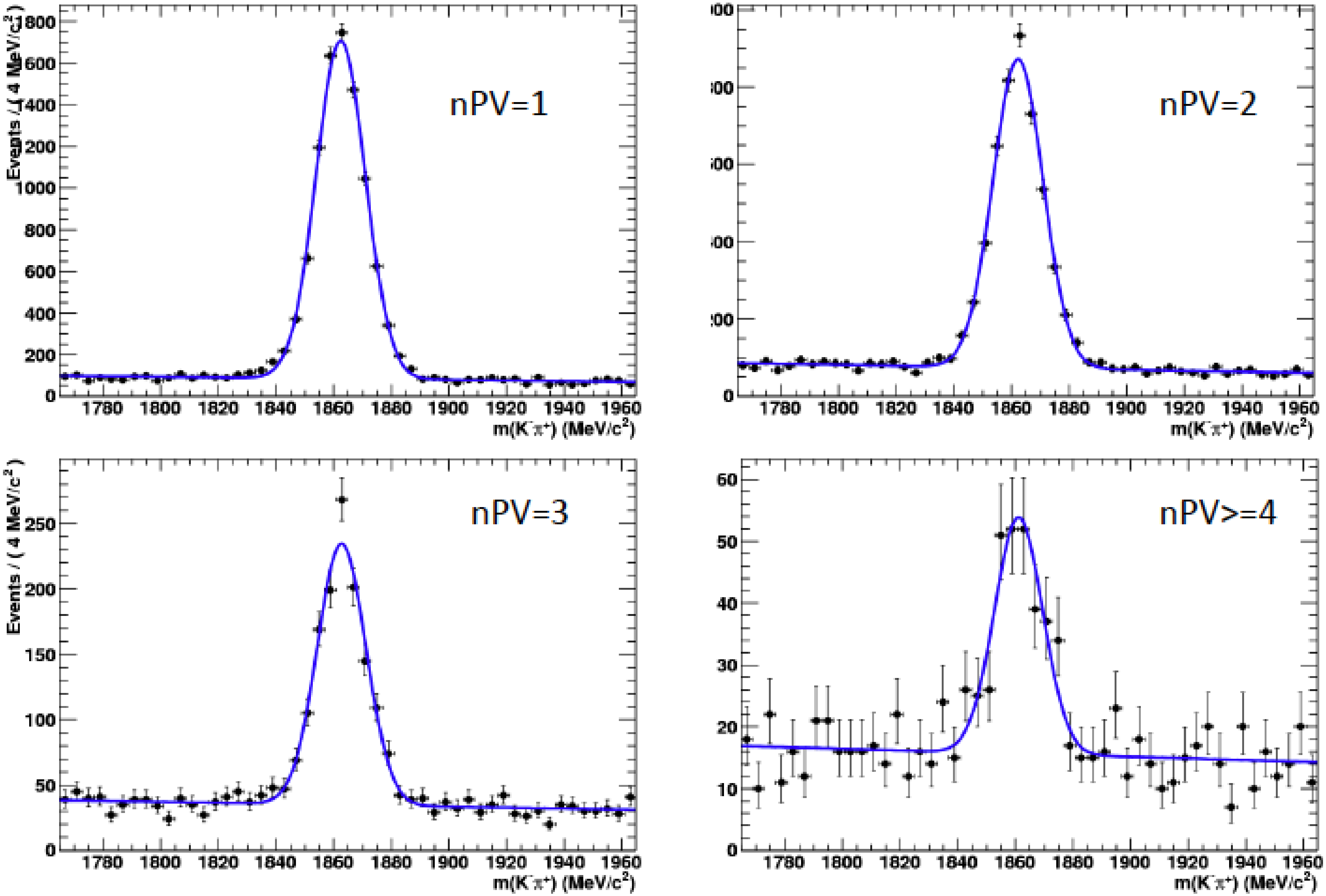
Current Limitation

- L0 trigger strategy involves cutting on SPD multiplicity: 450-900

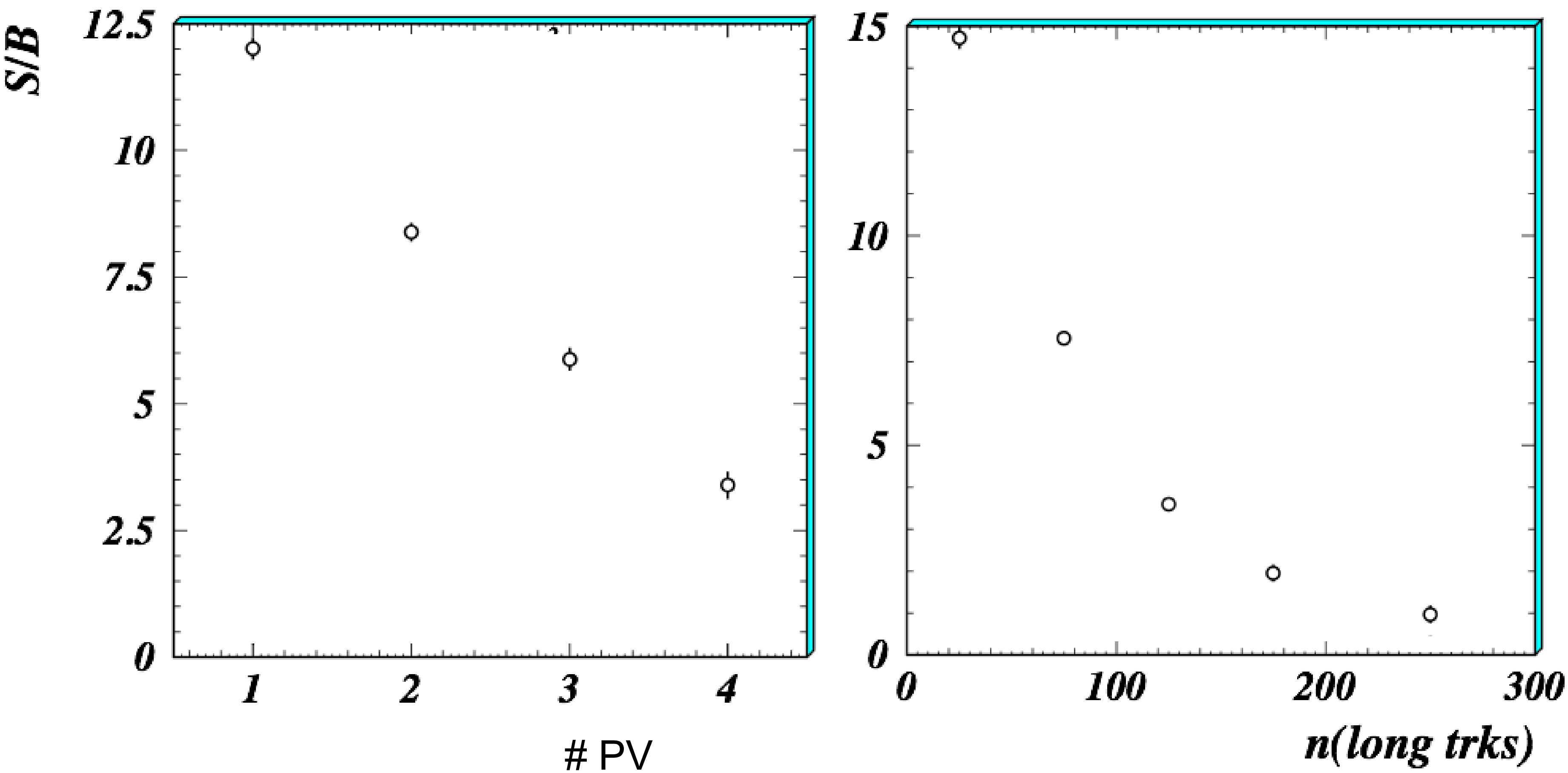




m(K⁻π⁺) for Kπμ events (1.1/pb)

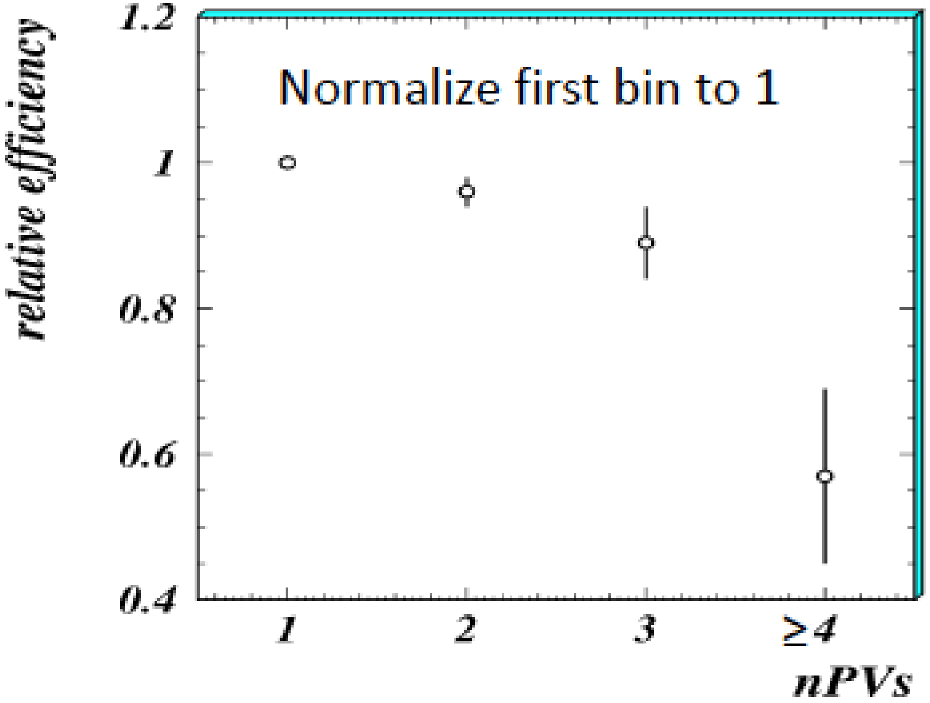


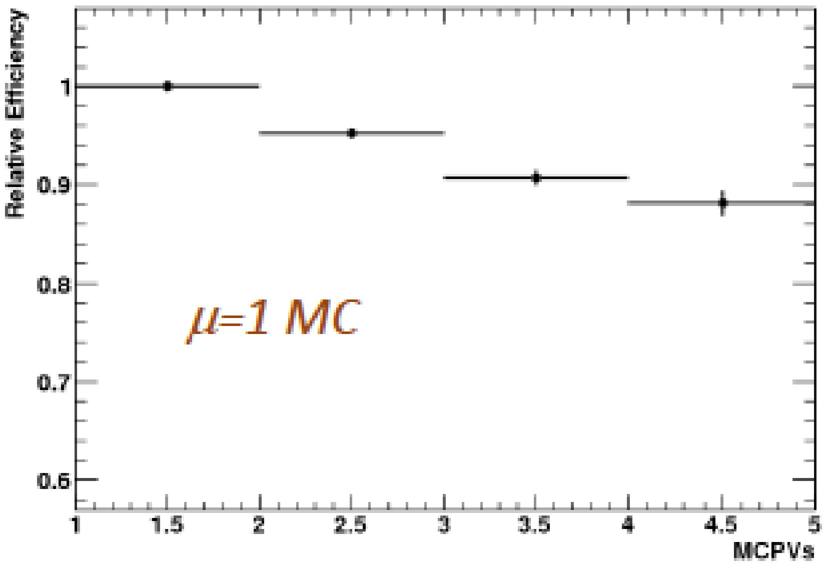
S/B



- Need to fix this

Overall efficiency is OK

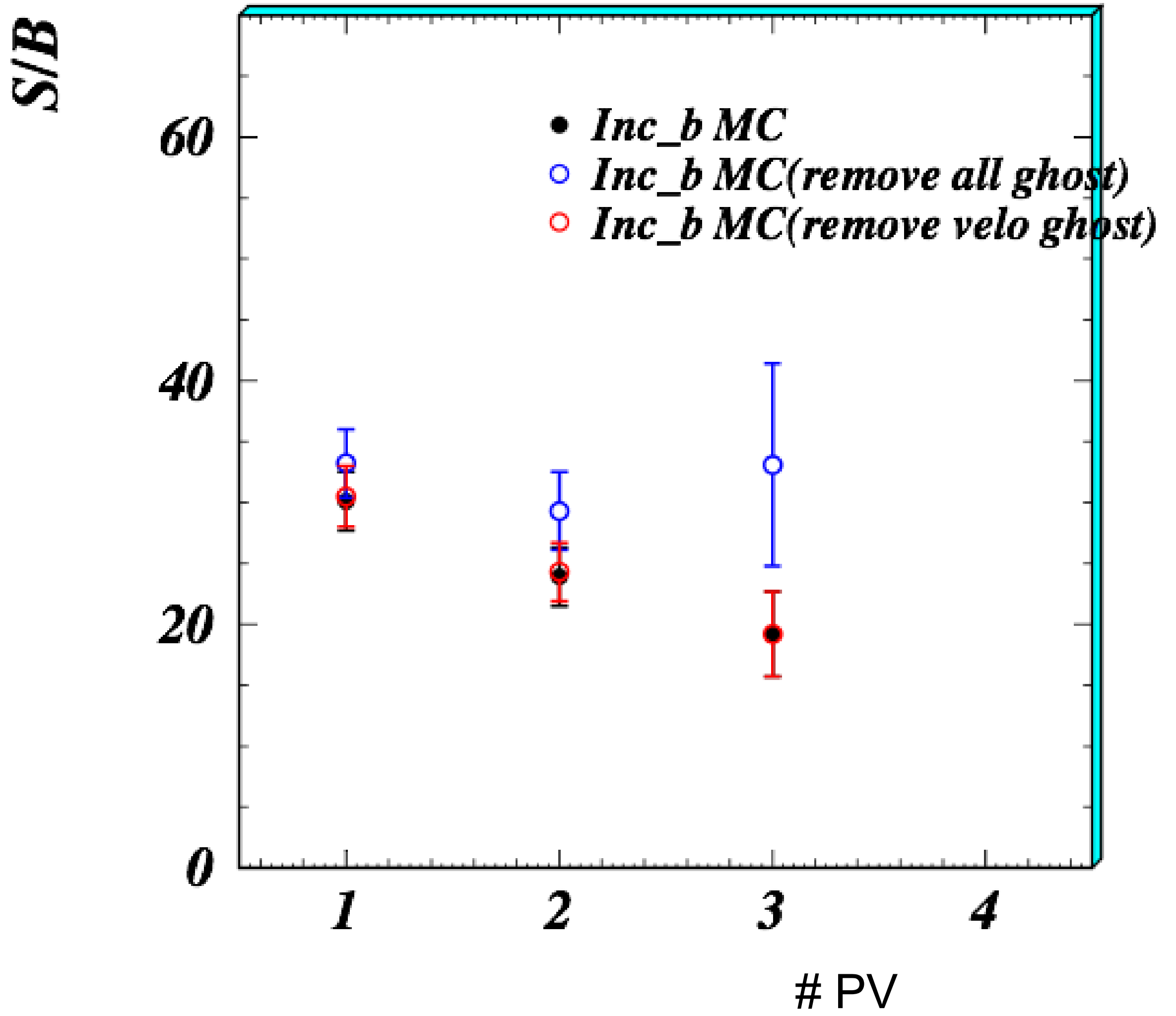




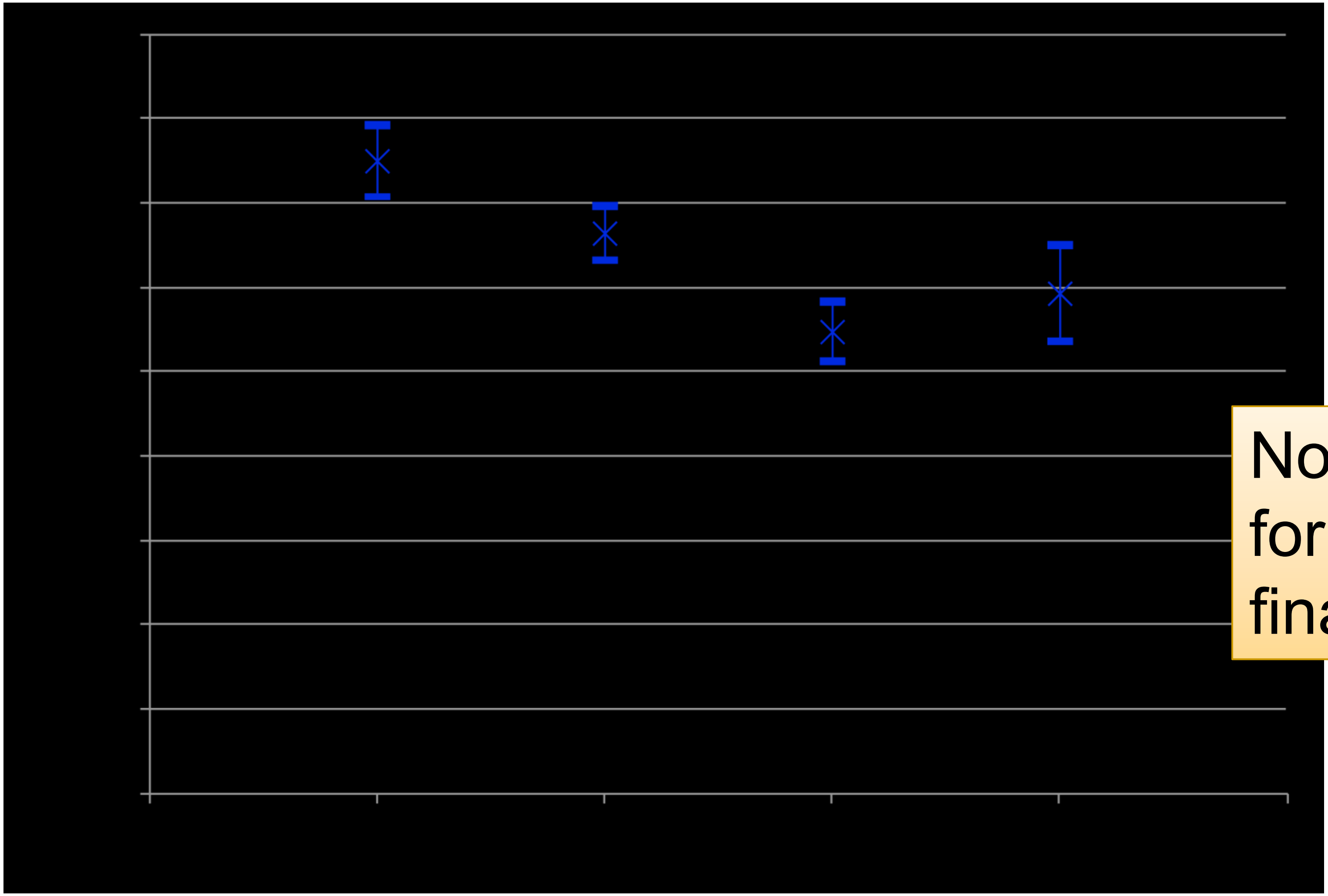
Good agreement for nPV<4, data for nPV=4 includes 5, 6 etc...

Detective Work: Ghosts found

- Can get good VELO track, but we don't know its momentum, so when we match it to T-stations we can get the wrong match (a ghost)



$J/\psi \rightarrow \mu^+\mu^-$



No problem for dimuon final states

Summary

- S/B Degrades by ~10x for large portion of upgrade data, much less for $\mu^+\mu^-$
- Ghosts are likely to be the problem. Large part could be good VELO tracks matched with good T-station track, but wrong tracks segments are matched
- This must be fixed for Upgrade

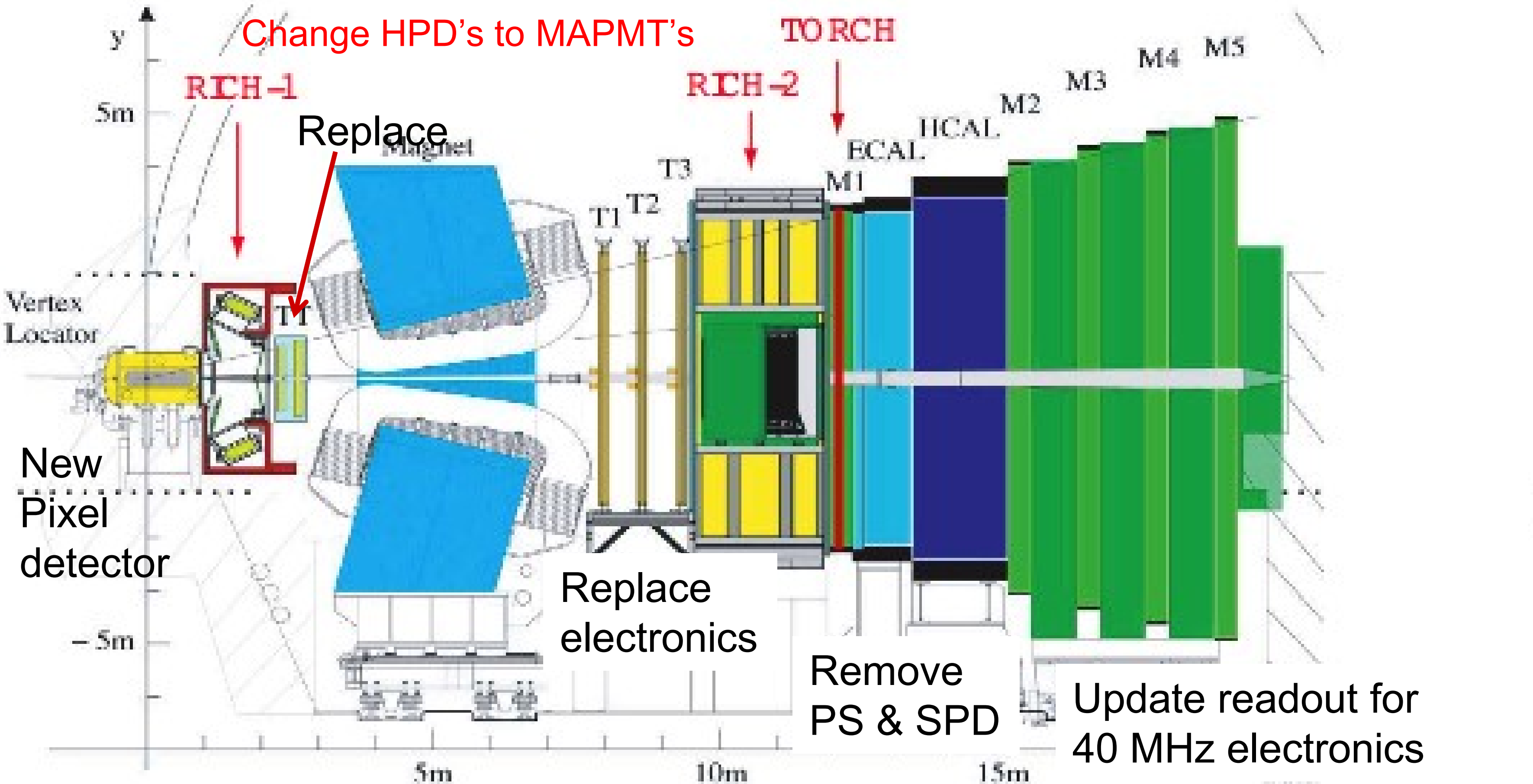
Solution

- Problem may be solved by having better tracking
- Pixel VELO will virtually eliminate ghosts in upstream tracking. For intermediate tracking we are studying replacing the TT with a device that has much better “y” segmentation (now only 2 “x” layers & 2 “x±5^{o}” stereo layers), and gets closer to the beam to increase the η coverage. Might also need to revise location in the magnet
- More simulations needed to optimize solution

Upgraded Detector

- Change all electronics to 40 MHz
- Replace current VELO with pixel device, for better segmentation, faster tracking for trigger & reduced sensitivity to radiation
- Replace TT, needed anyway to go 40 MHz
- Replace IT (possibly as a fiber detector)
- Replace HPD's in RICH with multianode photomutiplier tubes
- Remove: Aerogel, PS, SPD & M1 stations
- Add "TORCH" in M1 location for low p ID

Upgrades

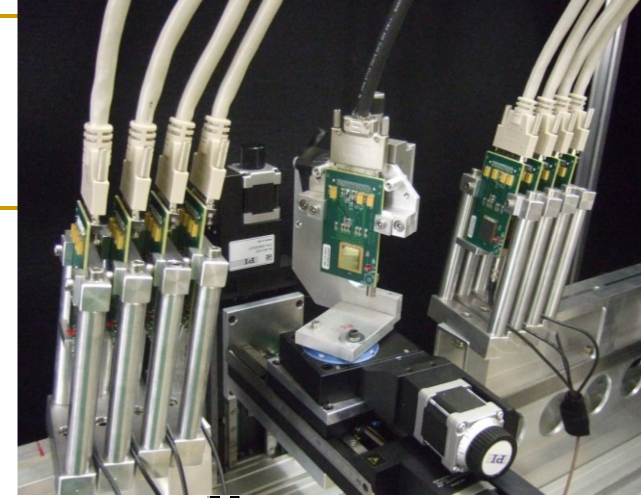


y
5m
−5m
5m
10m
15m
Change HPD's to MAPMT's
RICH-1
RICH-2
TORCH
Replace
Magnet
T1
T2
T3
T1
M1
ECAL
HCAL
M2
M3
M4
M5
Vertex
Locator
New
Pixel
detector
Replace
electronics
Remove
PS & SPD
Update readout for
40 MHz electronics

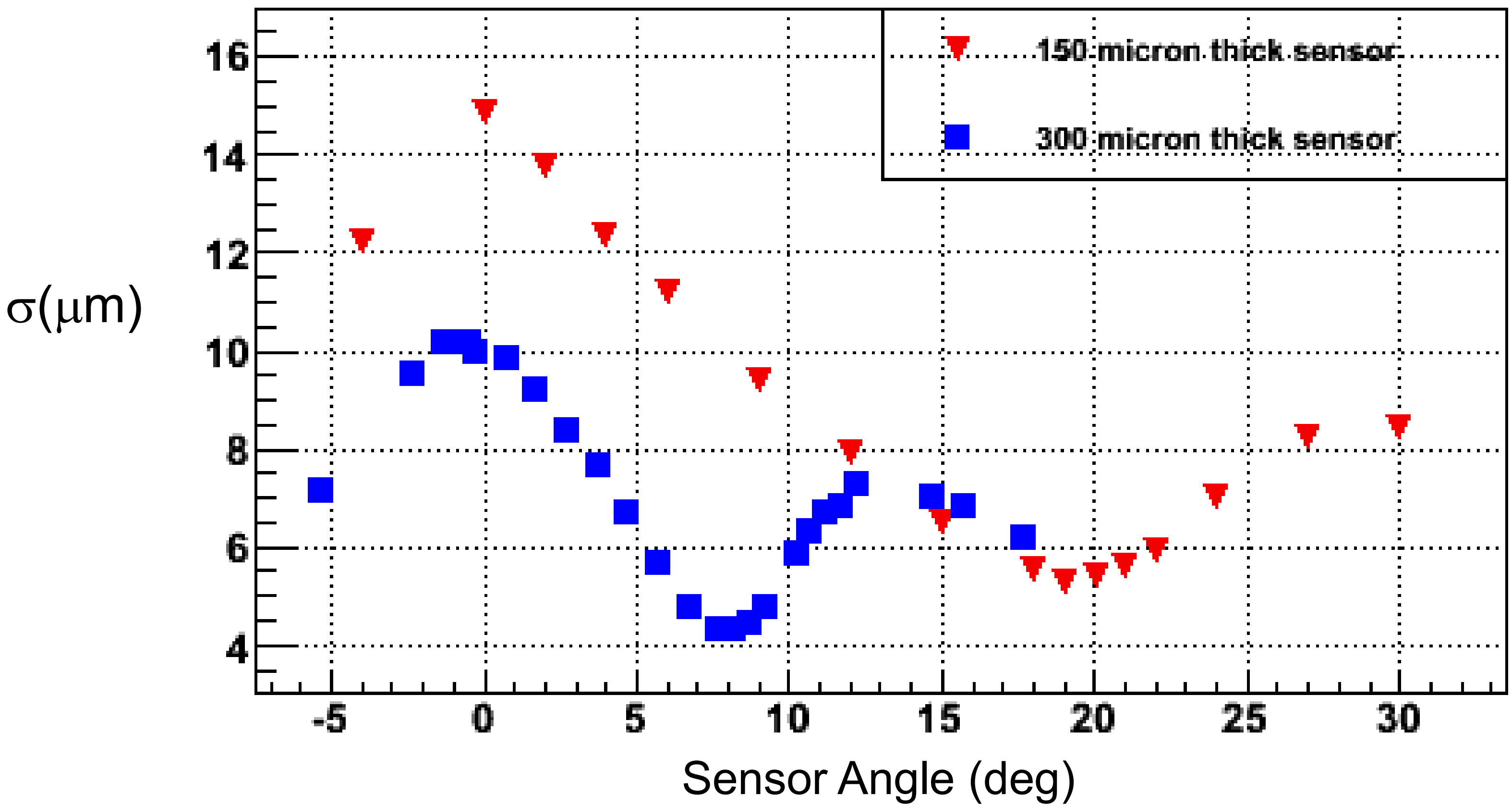
VELO-pixel R&D

- Use further development of Medipix/Timepix chip bonded to 55 μm x 55 μm square pixels

VELO-pixel R&D

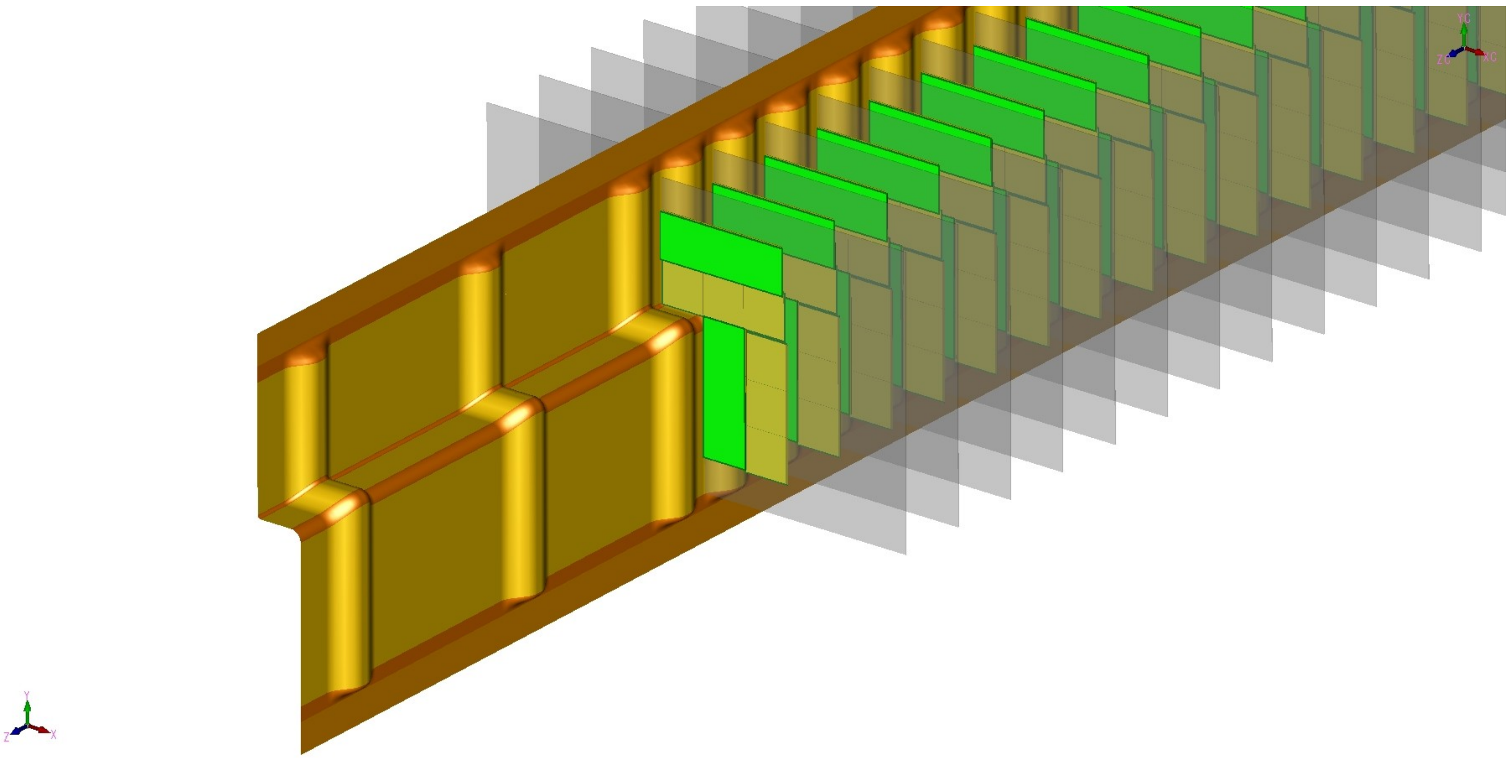


- Test beam timepix telescope
- Results



VELO –RF Foil

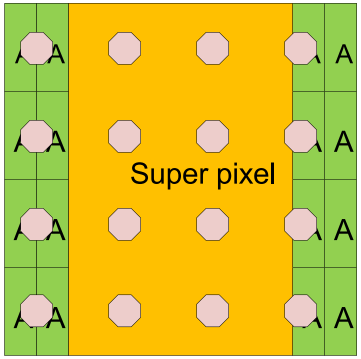
- Minimize foil radiation length – try composite



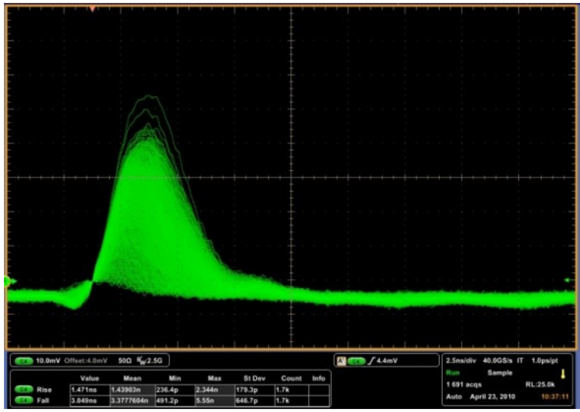
Sub-detector Electronics

VELO	Velopix ASIC architecture defined Timepix2 design started ("prototype" of Velopix)
RICH	New ASIC design started Investigating existing MAROC chip
IT/TT	Defining front-end for SciFi and Si options
OT	ASIC unchanged TDC implemented in FPGA & tested
CALO	New ASIC + FE-board prototypes under test
MUON	Front-end unchanged Back-end processing (TELL40) under study

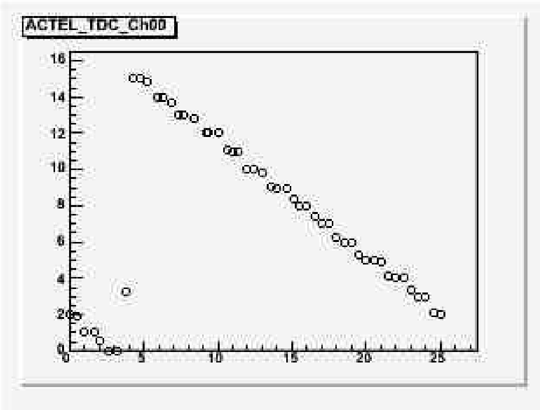
Velopix super-pixel



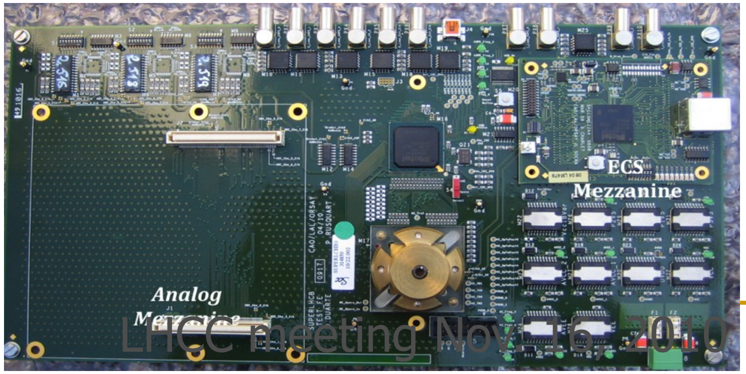
RICH shaper output



OT TDC response

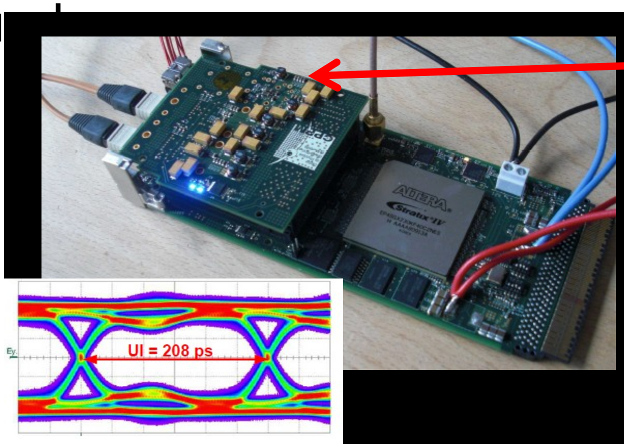


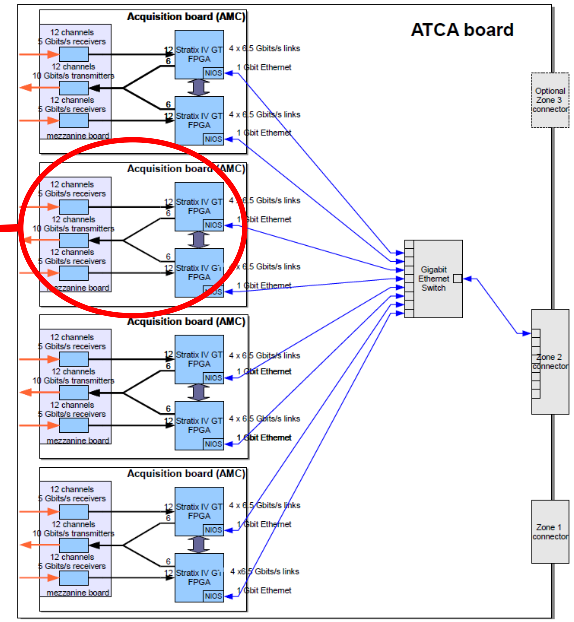
CALO FE-board



Common Electronics

TELL40 readout board
1st prototype working successfully
-> specs of high density board
u



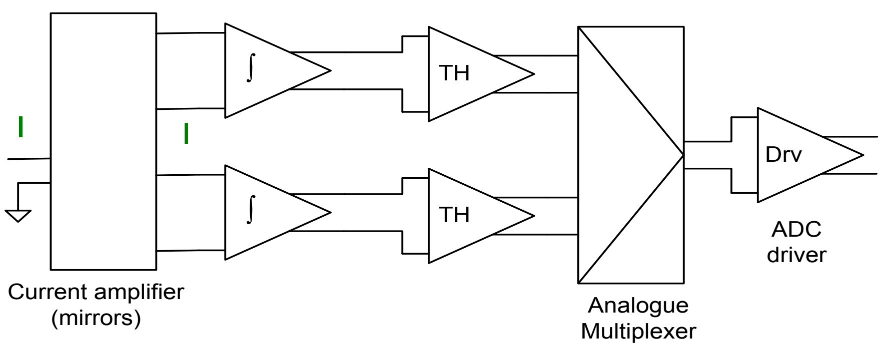


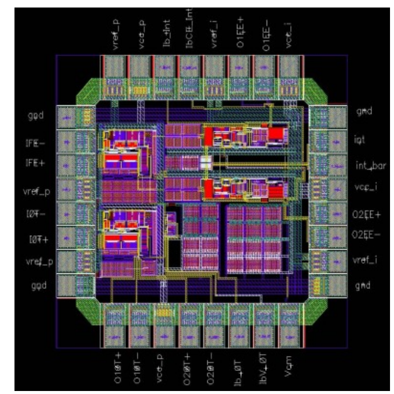
ACTEL FPGA irradiation campaign started: encouraging results, continue in 2011

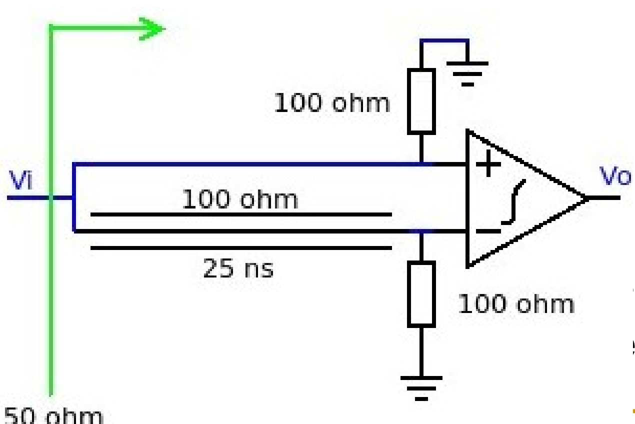
Data links based on GBT + Versatile link:
Good results from prototypes, on schedule for upgrade

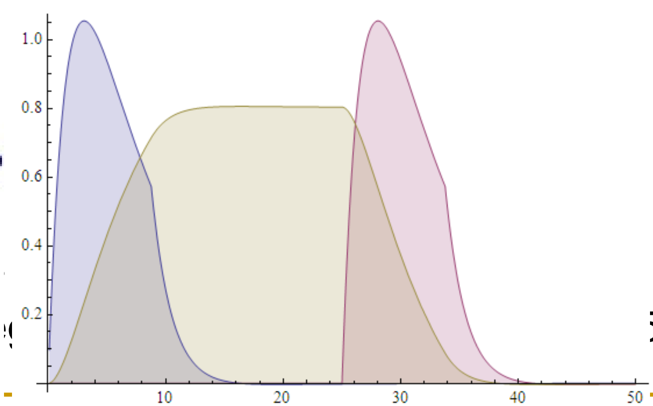
Calo electronics : Analog Part

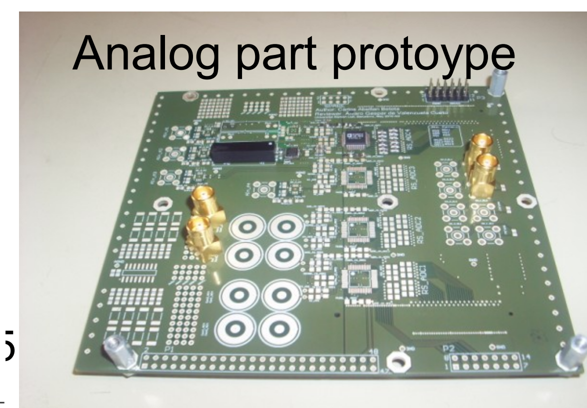
- Two paths are followed
  - ASIC : the first version was produced this summer
    - Two alternated switched signal paths
    - The signal is swallowed by an integrator while the other is readout and reset







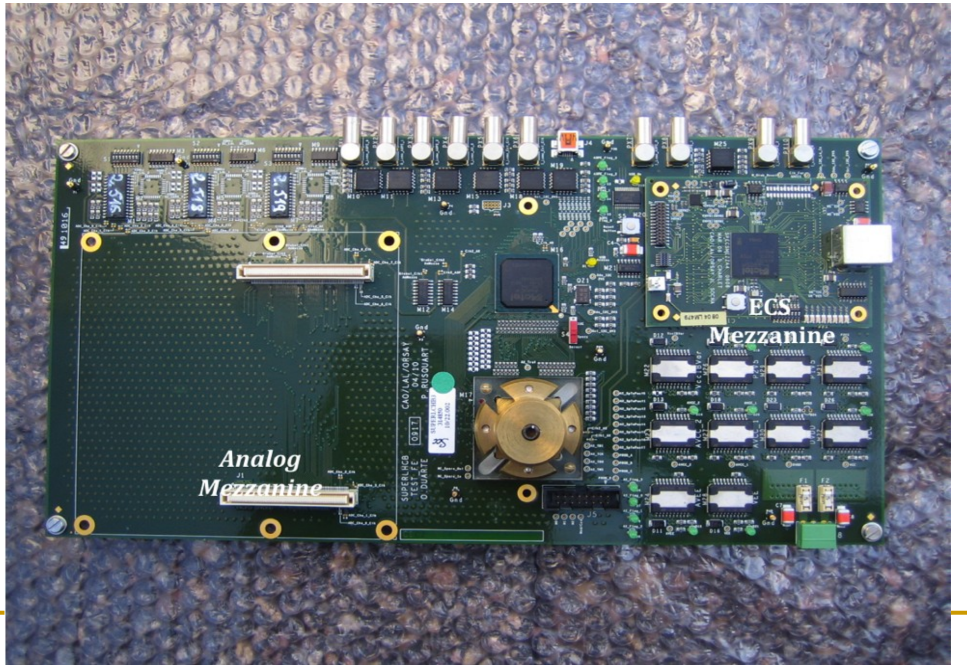




Digital prototype

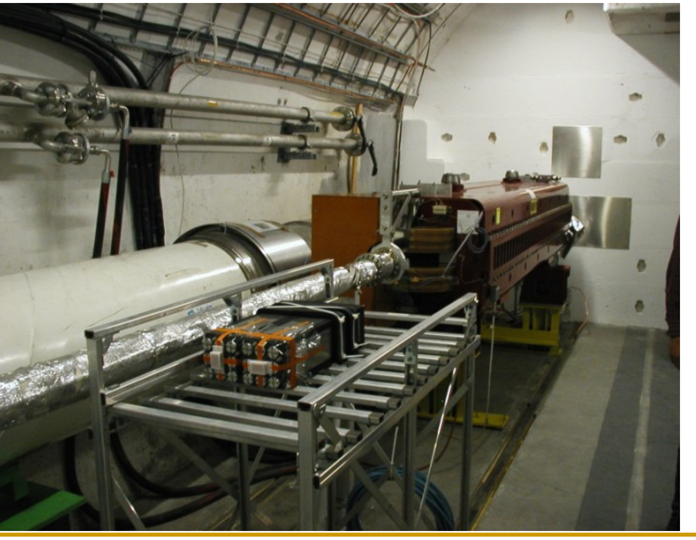
- The first prototype exists
  - It supports the analog prototype (see previous slide)
  - Test the FE feasibility
  - Can be used for irradiation tests

Digital part protoype



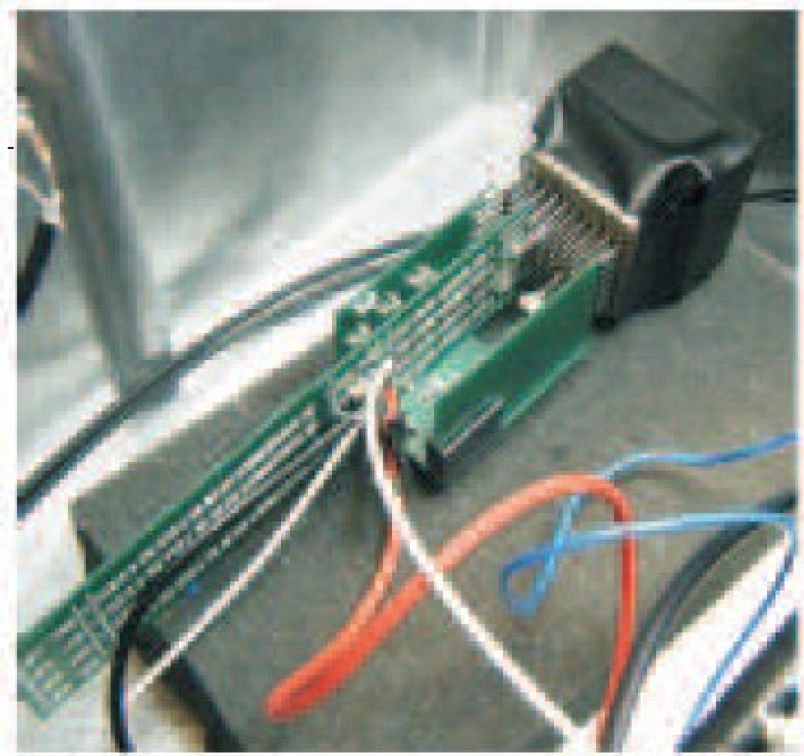
Calorimeter Module Irradiation

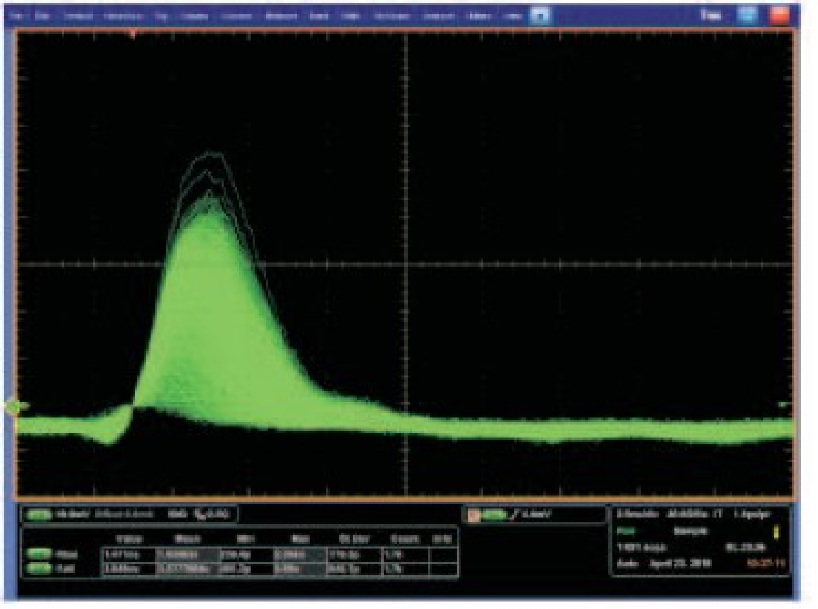
- Expected maximum dose at $2x10^{32}$ $cm^{-2}s^{-1}$:0.25 Mrad/year (1 year=10^7s) in the inner region
- Calorimeter built to cope with this radiation level for 10 years. No reliable information for higher doses. The problem mainly concerns the inner modules. Tests in LHC tunnel



RICH R&D

- Tests of R11265 Hamamatsu MAPMT
- Discreet Component front end





- Developing custom asic

The Torch

- Idea: measure time-of-flight using a 1 cm thick quartz plate.

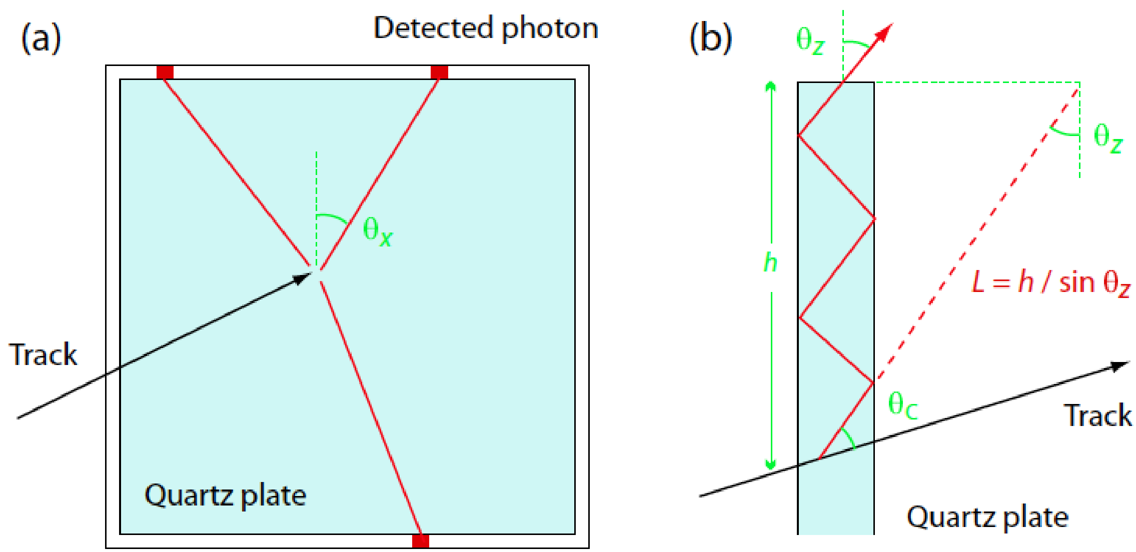
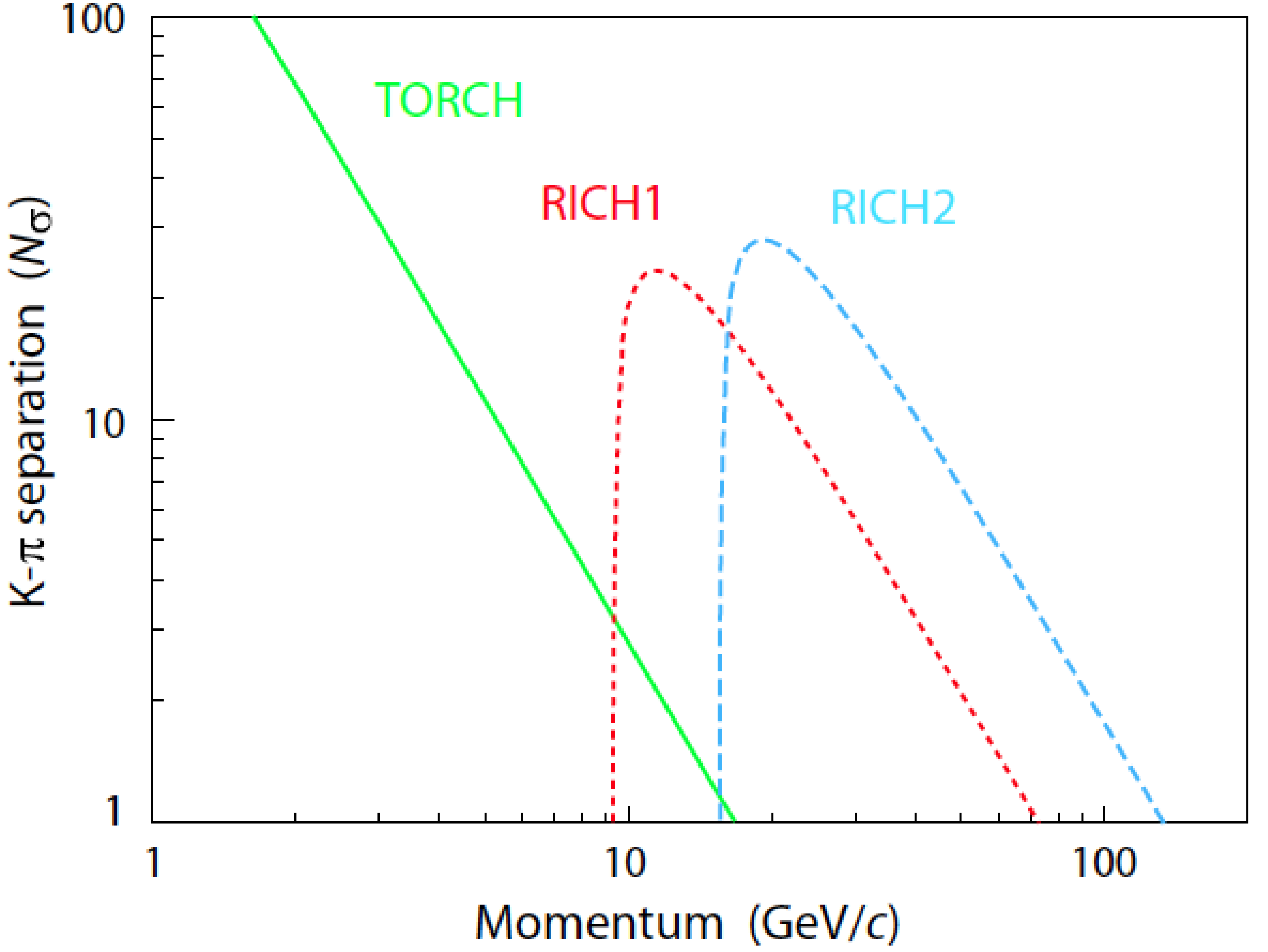


FIG. 52. Schematic view of the reconstruction of photon trajectories (a) in the transverse (x, y) projection, where the filled squares indicate detected photon hits, (b) in the (y, z) projection.

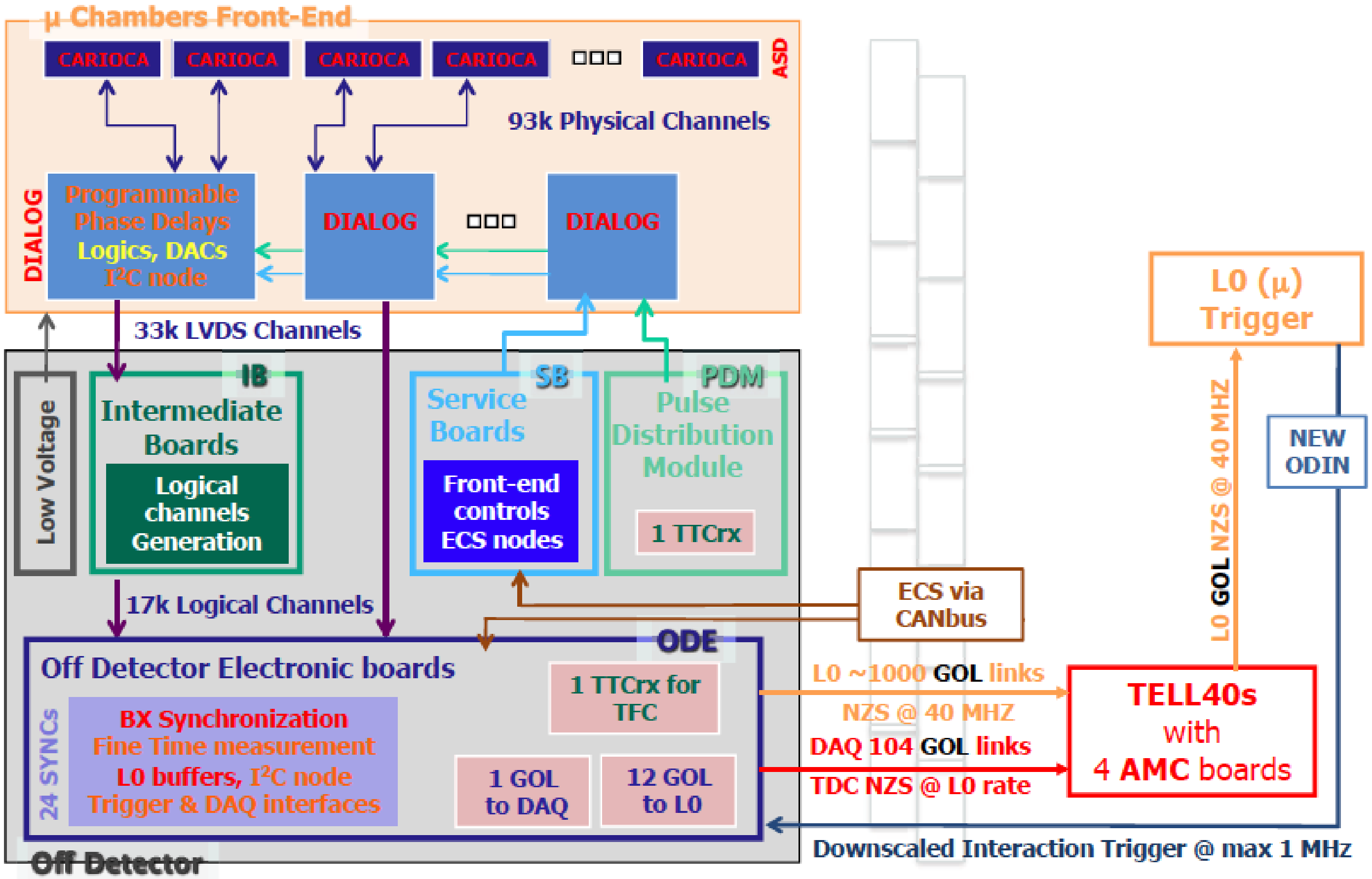
- Measure Cherenkov angle to find time propagation in the quartz

Overall System Performance



Muon

- Basically a 40 MHz already. Changes are limited to one board. Overall system:



LOI

- Submission in Jan. to LHCC
- Sections
  - Introduction
  - Physics goals
  - VELOPiX
  - Tracking: General layout (Si & fibers), TT (Si & fibers)
  - RICH
  - Calorimeters
  - Muon
  - Online
  - Trigger
  - Electronics
  - Simulations & Software

Conclusions

- LHCb is off to a great start
- Have learned much from current running at high μ. (Trigger upgrade R&D is being done using real data)
- There is a great deal of physics to be done in the forward region that compliments the GDE's
- Discoveries of new particles via quantum loops in b & c decays, or classifying the effects of such particles found at the GDE's will be of utmost importance

The End

How the Torch works

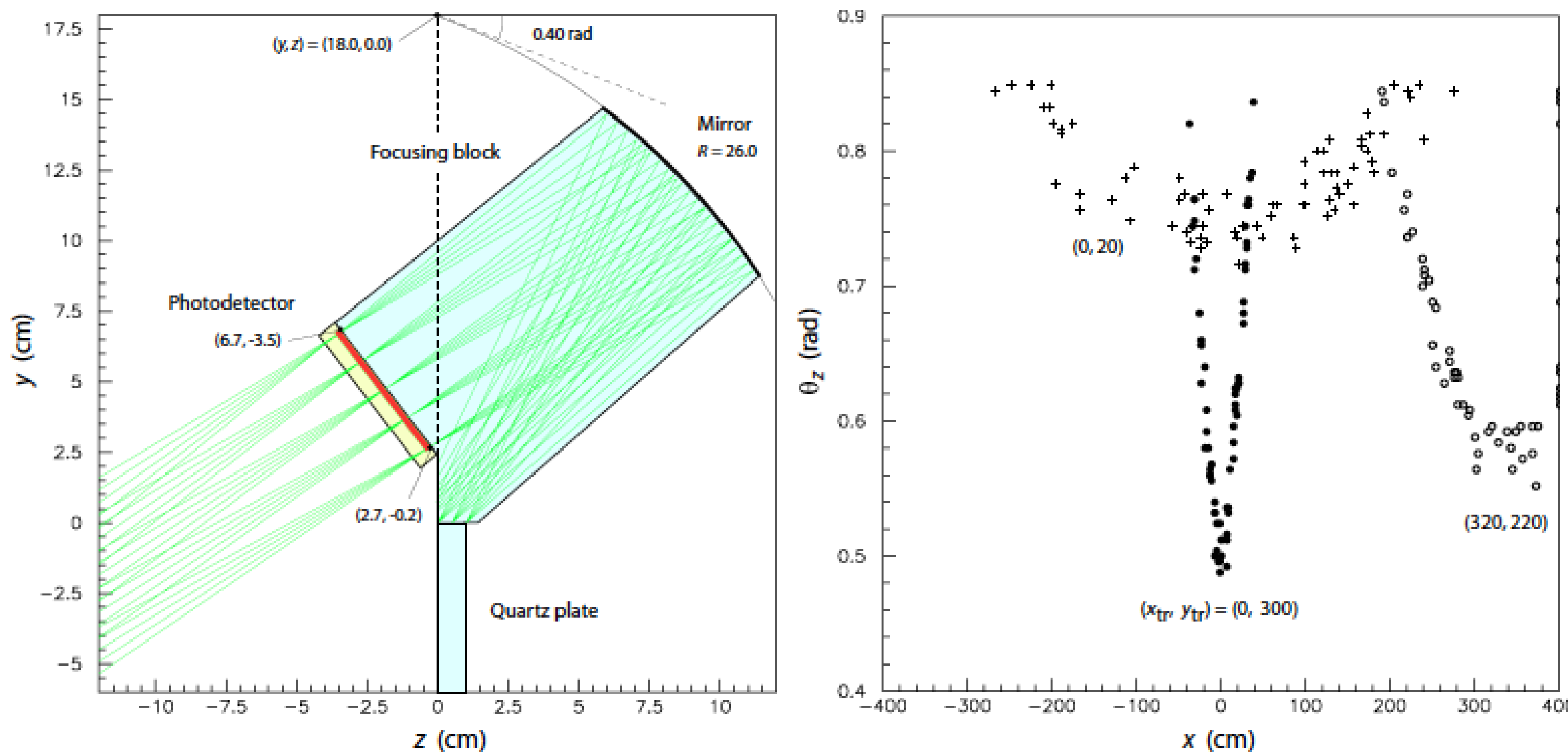
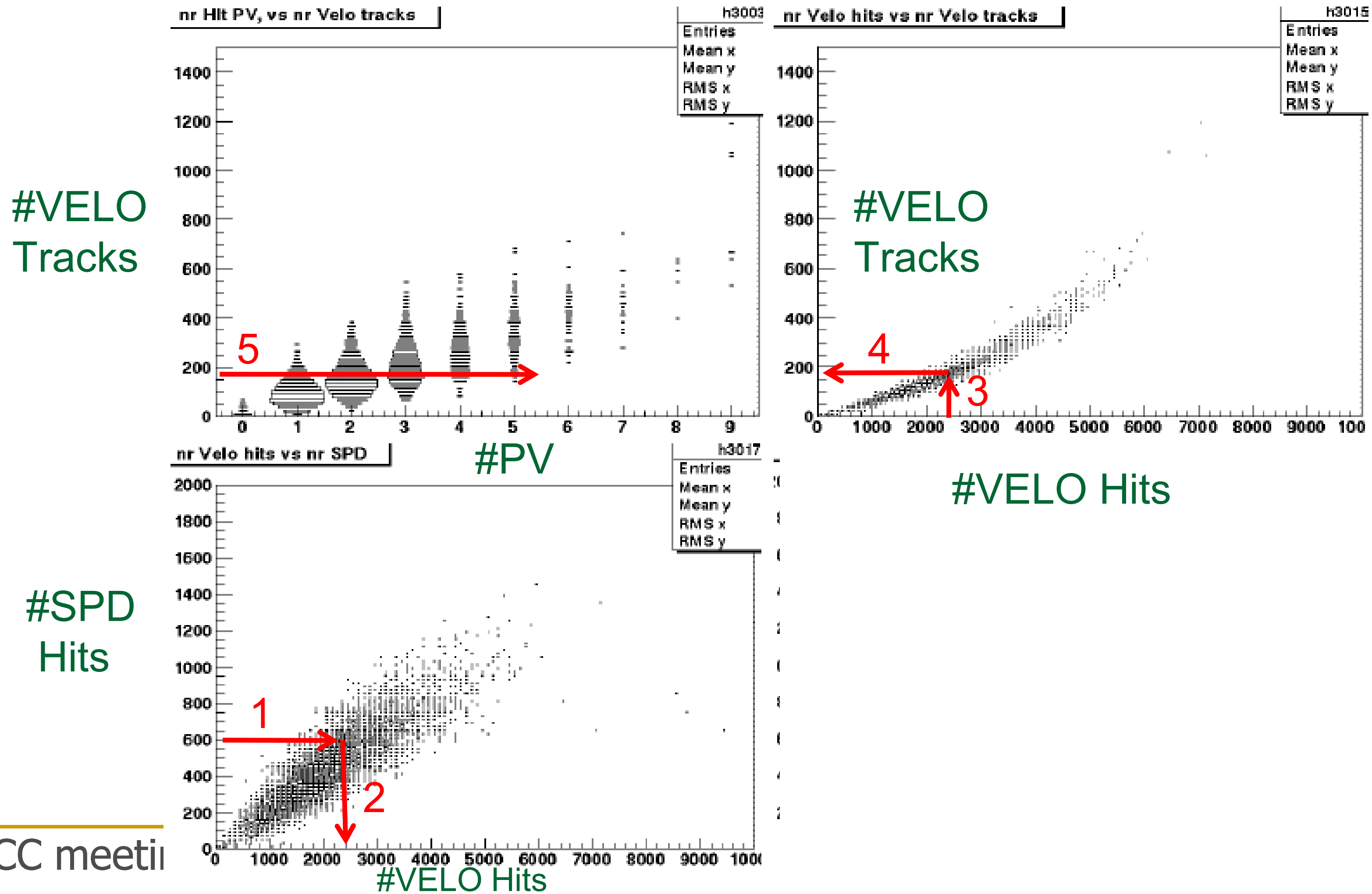


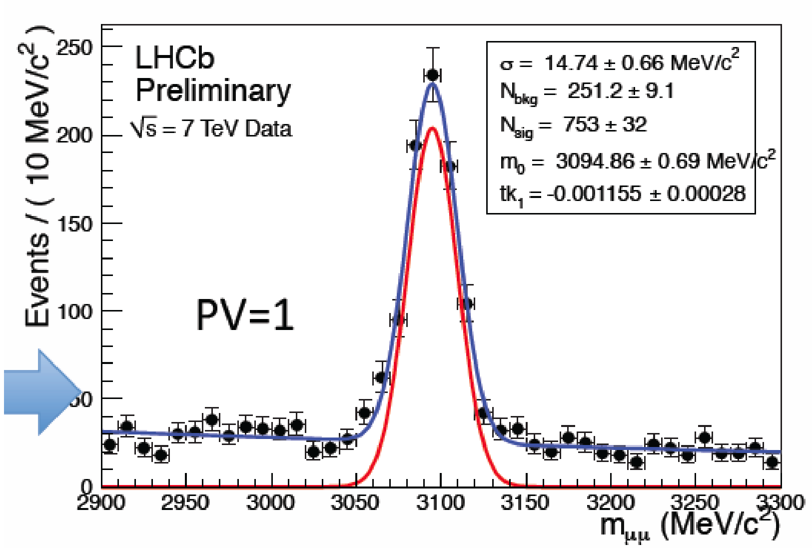
FIG. 53. (Left) Cross-section through the focusing element, attached to the edge of the quartz plate. The focusing of photons is indicated for five illustrative angles between 450 and 850 mrad, emerging at different points across the edge of the plate. (Right) Event display of detected photons from simulated tracks passing through the TORCH detector, showing their angle θ_z at the edge of the plate versus their position along one edge of the plate. Different symbols are used for the photons from three tracks, hitting the plate at different positions.

Current Limitation

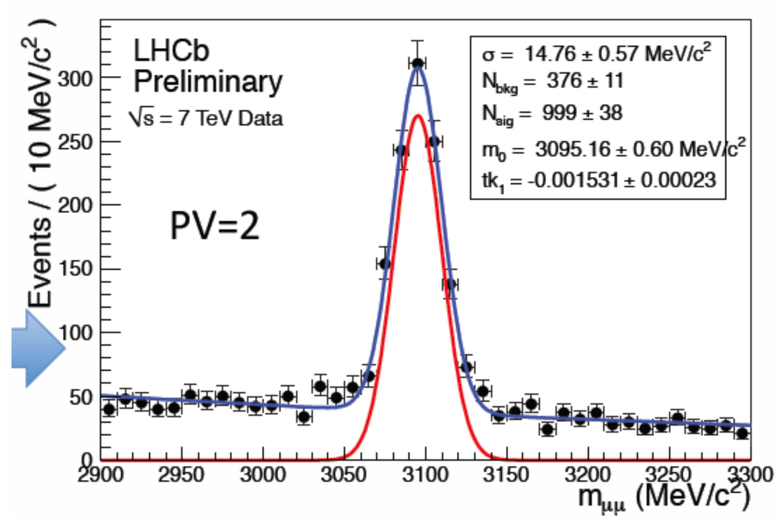
- L0 trigger strategy involves cutting on SPD multiplicity: 450-900



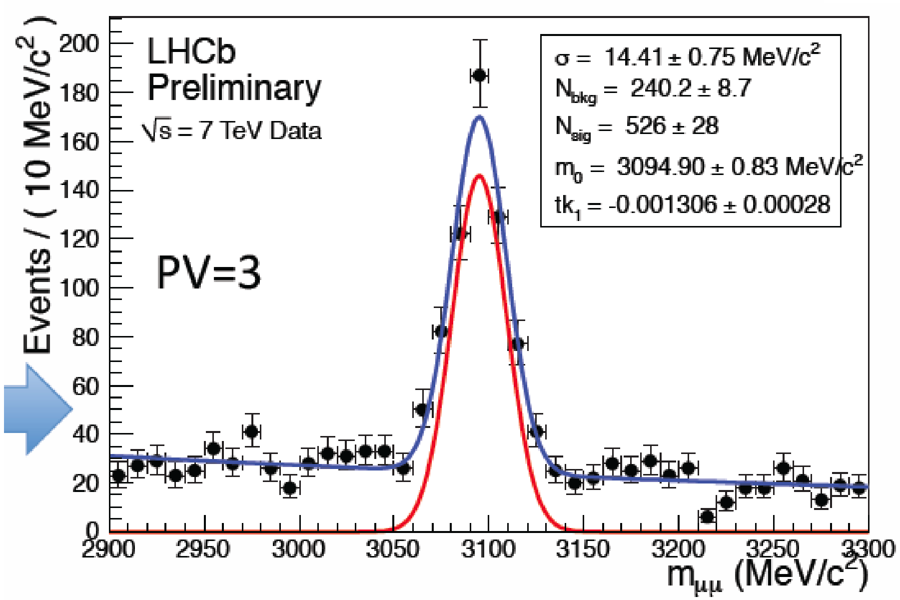
$J/\psi \to \mu^+\mu^-$



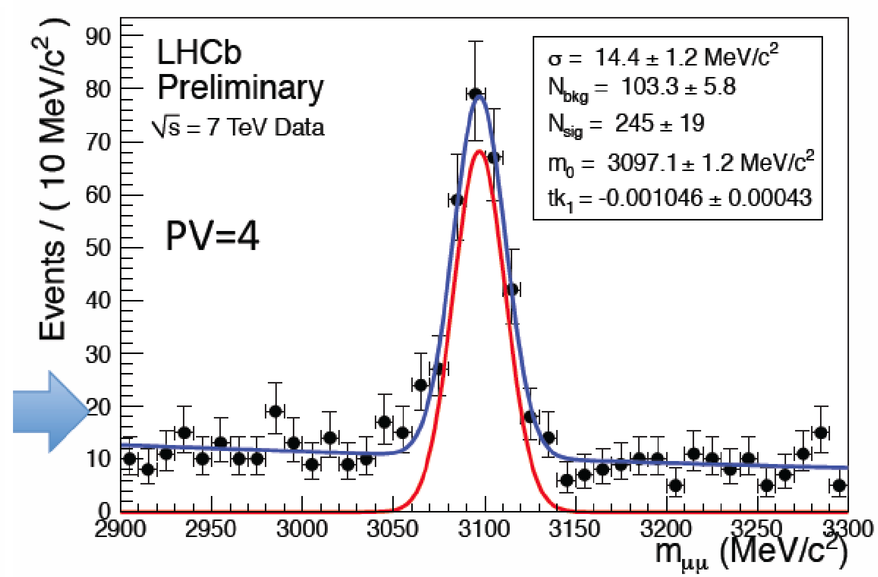
LHCb
Preliminary
√s = 7 TeV Data
PV=1
σ = 14.74 ± 0.66 MeV/c²
N_bkg = 251.2 ± 9.1
N_sig = 753 ± 32
m_0 = 3094.86 ± 0.69 MeV/c²
tk_1 = -0.001155 ± 0.00028
Events / (10 MeV/c²)
m_μμ (MeV/c²)



LHCb
Preliminary
√s = 7 TeV Data
PV=2
σ = 14.76 ± 0.57 MeV/c²
N_bkg = 376 ± 11
N_sig = 999 ± 38
m_0 = 3095.16 ± 0.60 MeV/c²
tk_1 = -0.001531 ± 0.00023
Events / (10 MeV/c²)
m_μμ (MeV/c²)

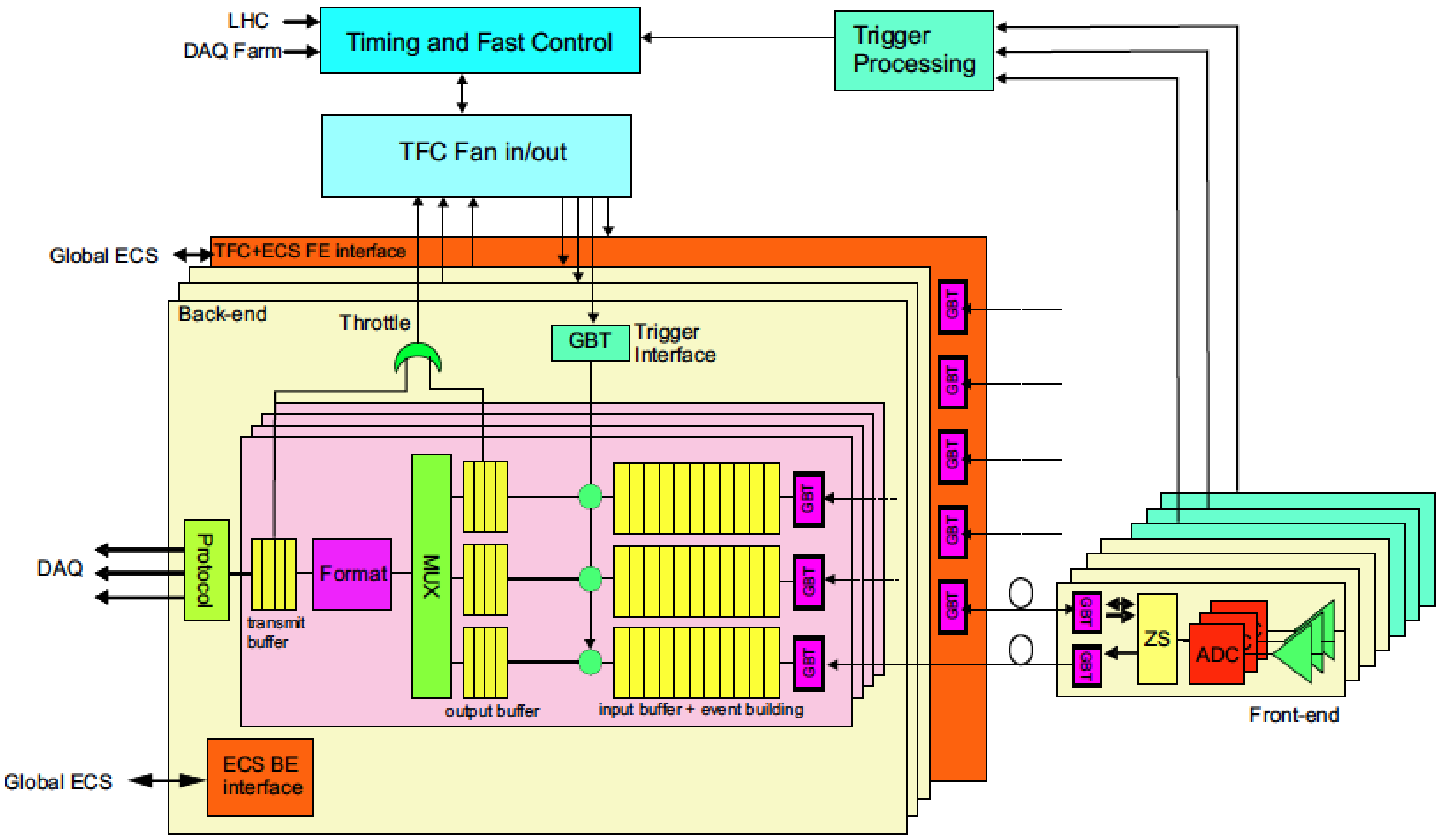


LHCb
Preliminary
√s = 7 TeV Data
PV=3
σ = 14.41 ± 0.75 MeV/c²
N_bkg = 240.2 ± 8.7
N_sig = 526 ± 28
m_0 = 3094.90 ± 0.83 MeV/c²
tk_1 = -0.001306 ± 0.00028
Events / (10 MeV/c²)
m_μμ (MeV/c²)



LHCb
Preliminary
√s = 7 TeV Data
PV=4
σ = 14.4 ± 1.2 MeV/c²
N_bkg = 103.3 ± 5.8
N_sig = 245 ± 19
m_0 = 3097.1 ± 1.2 MeV/c²
tk_1 = -0.001046 ± 0.00043
Events / (10 MeV/c²)
m_μμ (MeV/c²)

Electronics: readout architecture



Calo electronics : Digital Part

- A FE board will have 32 channels in 4 blocks of 8 channels
  - A GBT output line will have the bandwidth to send the data of 8 channels
  - A single A3PE FPGA per block
  - An extra FPGA to perform equivalent calculations as the present trigger
    - For the the throttling mechanism
    - To provide seeds to the high level trigger PC farm
- The data will be sent at 40MHz
  - Compression technique per group of 8 channels
  - 12 bits sent for large amplitudes
  - Otherwise, 5 bits are transmitted
  - An extra word permits to now the pattern used for the data words

Ongoing R&D

- VELO-pixel
- Electronics
- Trigger
- RICH &TORCH
- Calorimeters
- Muon
- Online
- Tracking: IT & OT
- TT

Other examples of interesting B modes

- Tree level determination of γ. This is the phase of the CKM element V_{ub} & is the most poorly measured angle accessible at B-factories. Can measure to 4-5^{o} with 2 fb^{-1}. Important to improve to the 1^{o} level with 50 fb^{-1}
- Find or limit right-handed currents using the radiative decay $B_s \rightarrow \phi\, \gamma$