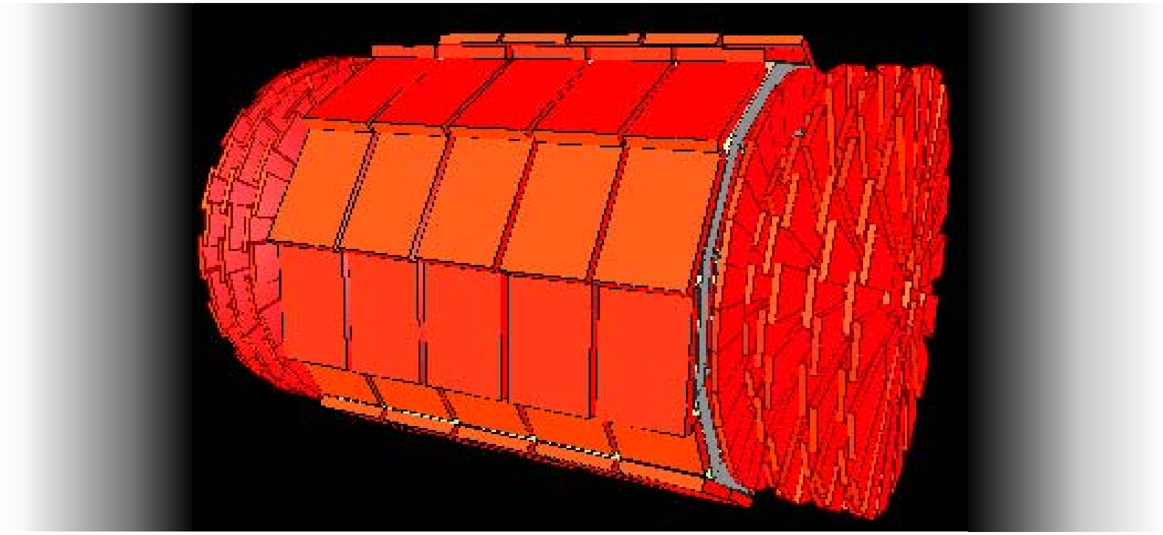
PRS/Muon Status & Plans



Darin Acosta, for the PRS/Muon Group

Results made possible by:

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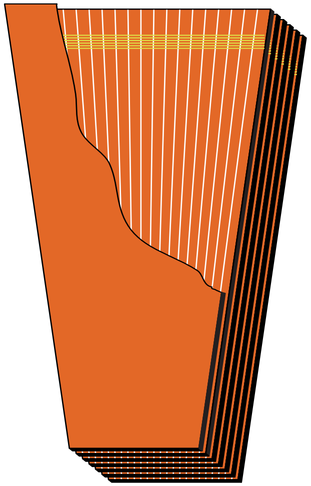
Outline

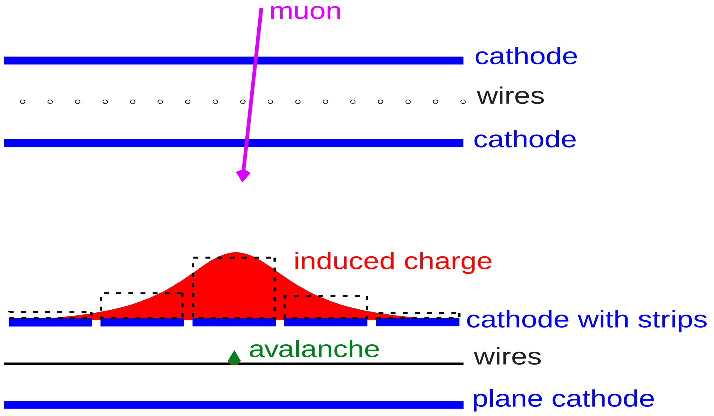
A summary of the Muon HLT material that is in the DAQ TDR (or soon will be):

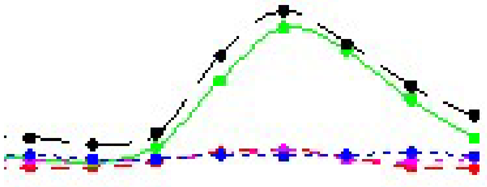
- Raw data formats and volume: CSC, DT, RPC
- Calibration procedures
- Software status
- Track segment creation
- HLT reconstruction
- Isolation
- Level-1 working point
- HLT rates and efficiencies
- CPU analysis

Overview of CSC Raw Data

- 540 chambers, 0.5 million channels
- The pulses from the cathode strips are sampled and stored in an analog memory **every 50 ns**
- The pulses from the anode wire groups (and strips) are discriminated for the trigger, and read out
- Digitization occurs when there is a L1 accept *and* if there was a local charged track (LCT) segment in the chamber
  - "Region of interest" reduces the DAQ bandwidth
  - Digitized with 12-bit ADC (2 bytes)
- 8 or 16 time samples are read out over a region 16 strips wide by 6 layers deep (3 kB or 5.4 kB per segment, or ≈20 kB/muon)







CSC Calibration Methods

Cathodes

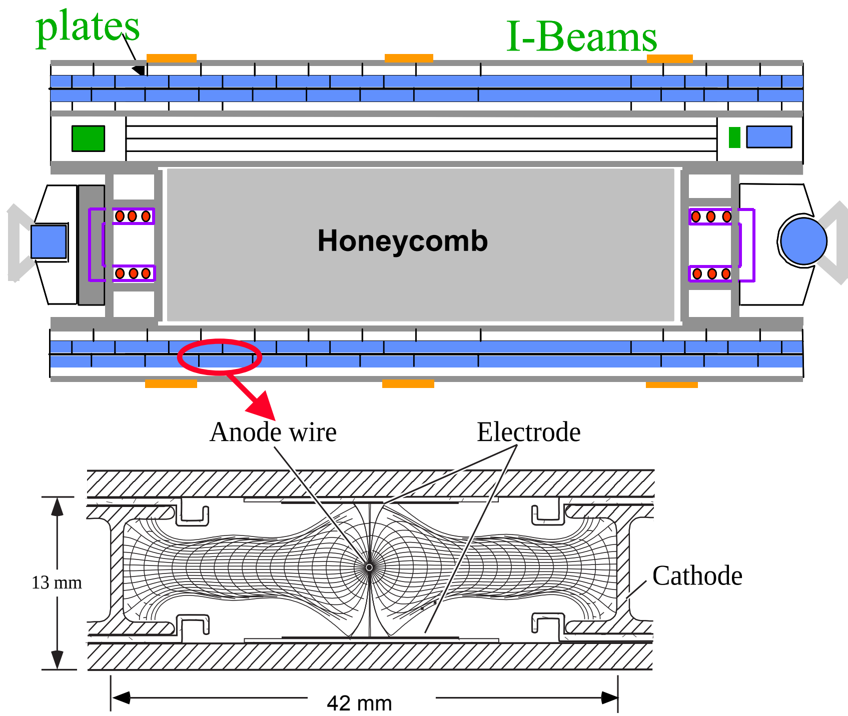
- Inject charge into one channel of every FE board simultaneously, read out all 96 channels of each board
  - Determine fC-to-ADC calibration, measure cross-talk
- Data volume per pulse: 3.5 MB
- Data volume for full calibration: ~300 GB
- Expect a full calibration to take 10–20 minutes
- Can use standalone DAQ system to collect data
- Full calibration constants checked periodically (monthly)
- Tests require no beams

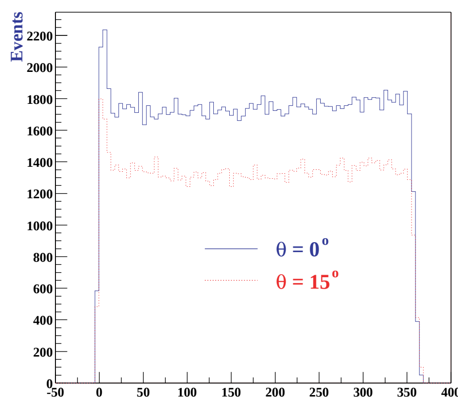
Anodes

- Pulse wire group channels
- Smaller amount of data than cathodes
  - 1 bit versus 2 bytes, since only have discriminator data

Overview of DT Raw Data

- **250 chambers, 172K channels**
- **Drift-tubes organized into 2 superlayers in ϕ and one in θ**
- **Field-shaping yields nearly uniform drift velocity along cell**
  - **But sensitive to radial magnetic field**
- **Threshold applied to signals from wires**
- **Drift time for signal to arrive on wire is measured**
  - **21-bit TDC used for each channel (4 bytes)**
  - **Programmable trigger window ~400 ns**





Drift time (ns)

DT Calibration Methods

Calibrations currently foreseen:

- Threshold run
  - Pulse channels and scan/set discriminator levels for optimum t_0 measurement
- t_0 calibration
  - Determine time-of-arrival of calibration pulse for each channel
- Rates
  - Run without beam, determine noisy channels
- Extraction gap test
  - Monitor dead channels & misalignment in trigger electronics continuously *during the run* by pulsing channels during LHC gaps

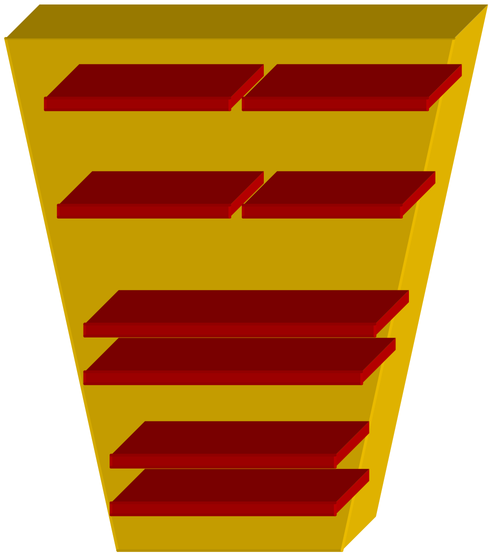
Event size not expected to exceed normal event size

Each calibration should take just several minutes during fill (or taken during run)

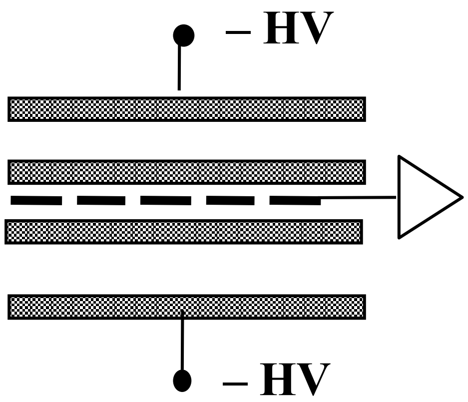
Overview of RPC Raw Data

- ➔ 612 chambers, 160K strip channels
- ➔ Double-gap design with common pickup
- ➔ Pulses from strips are discriminated
- ➔ Used by Pattern Comparator Logic, and read out by DAQ

Barrel sector



- ➔ Calibration Methods:
  - ◻ Threshold scan and set
  - ◻ Time window scan and set
  - ◻ Test pattern injection (between fills or in gaps)
  - ◻ Monitoring during physics runs



Muon Data Volume

Consider high luminosity ($L=10^{34}$) with 100 kHz DAQ

- ➔ Raw data format is well specified by hardware designs
- ➔ Rates include neutron background estimate and overhead for headers and empty events

CSC:

- ➔ 8 time samples and tight LCT coincidence
- ➔ 1100 MB/s (1300 MB/s with 3× safety factor on neutrons)
- ➔ Average occupancy is 3.4 segments ⇒ 10kB / L1A

DT:

- ➔ ~1% channel occupancy from muons, punch-through, neutrons
- ➔ Event size: 9 kB/event
- ➔ Data volume: 900 MB/s

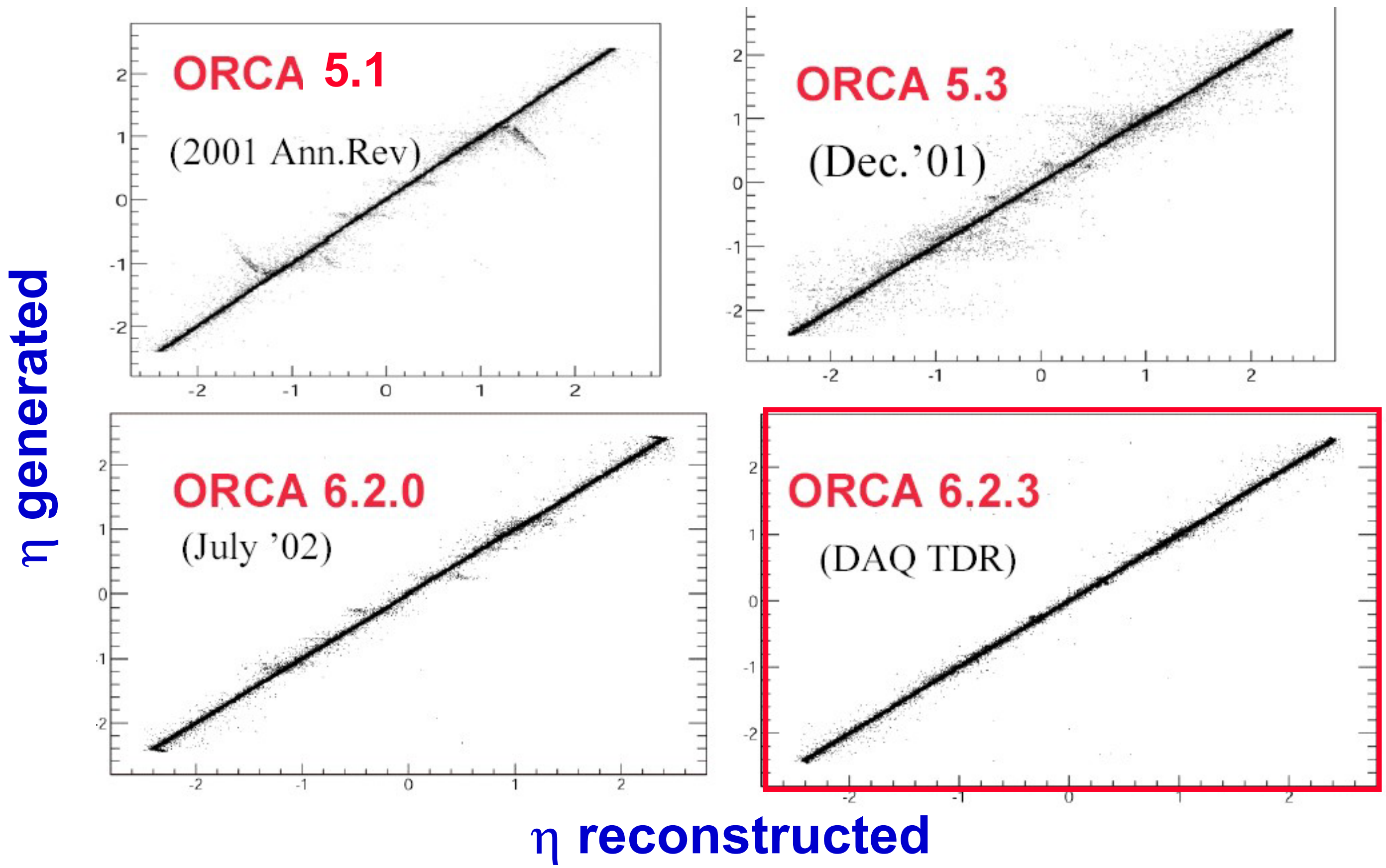
RPC:

- ➔ ~0.6 kB event size (3% of CSC+DT) mostly from noise hits

Overall: 2 GB/s at high luminosity (20kB / L1A)

HLT Results: Software Status

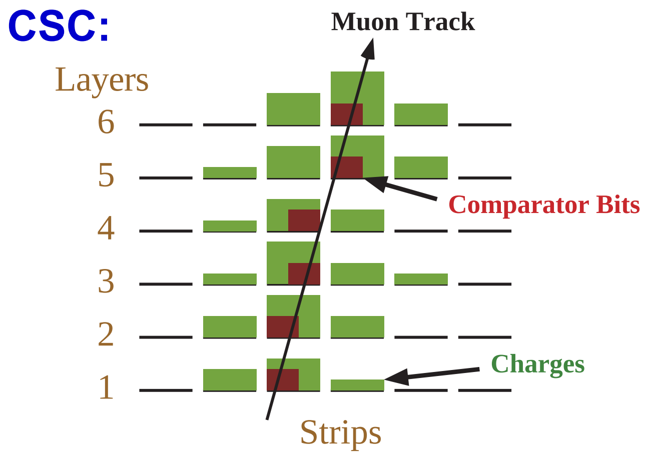
- ➔ **Many improvements to the software over the last year**
- ➔ **In addition to the development/refinement of HLT algorithms, the code runs much faster, track segment reconstruction improved, overall efficiency increased, and the code is more robust and user friendly**

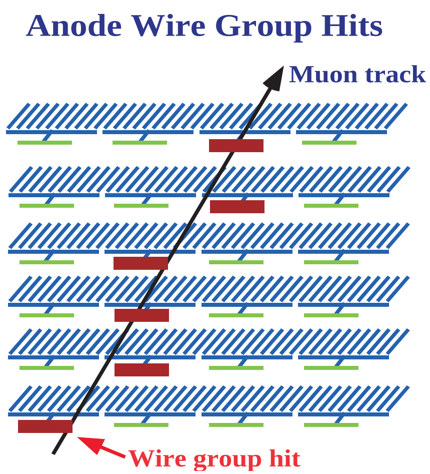


HLT Input: Track Segment Creation

CSC:

- ➔ Fit "Gatti" function to the spatial shape of 3-strip charge distribution to determine centroid of cluster in layer
  - Resolution: 120–250 μm
- ➔ Fit lines in 3-D through the collection of wire and strip clusters in chamber
- ➔ Use positions of constituent hits for HLT tracking





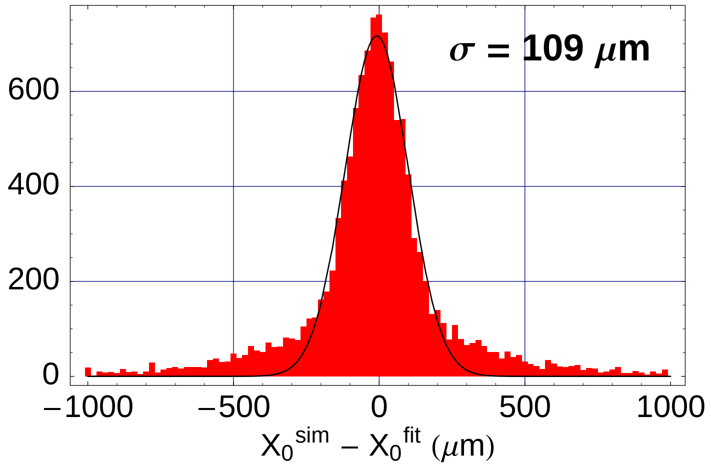
DT:

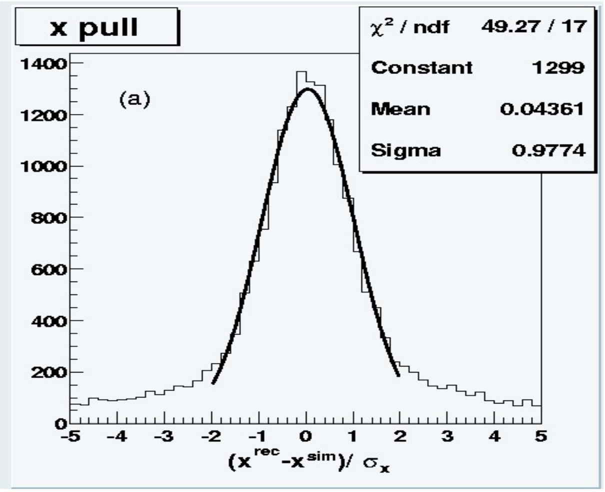
- ➔ Reconstruct position of each channel above threshold using effective drift velocity
  - Resolution: 250 μm in ϕ view
- ➔ Fit 2-D lines separately in r-ϕ and r-z through the 8+4 layers of chamber
  - L/R ambiguities solved by best χ^2
- ➔ Combine into 3-D segments, use segment position and direction for HLT tracking
  - Resolution: 100 μm in ϕ view

Residuals and Pulls in r-ϕ

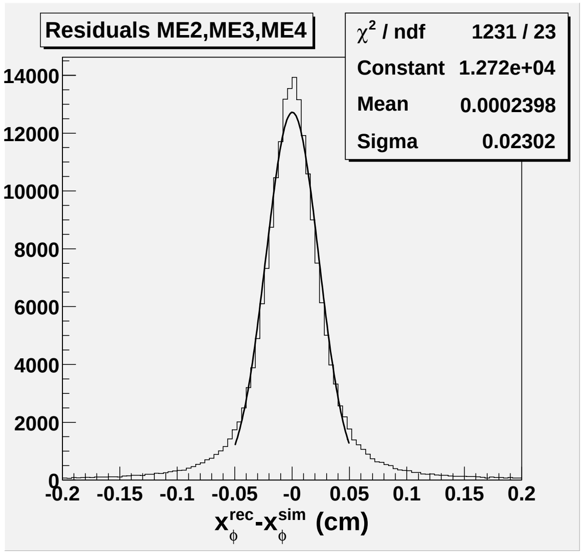
residual | **pull**

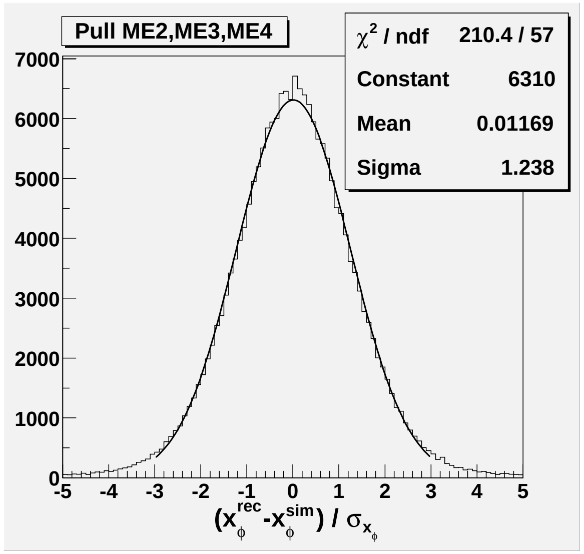
DT





CSC





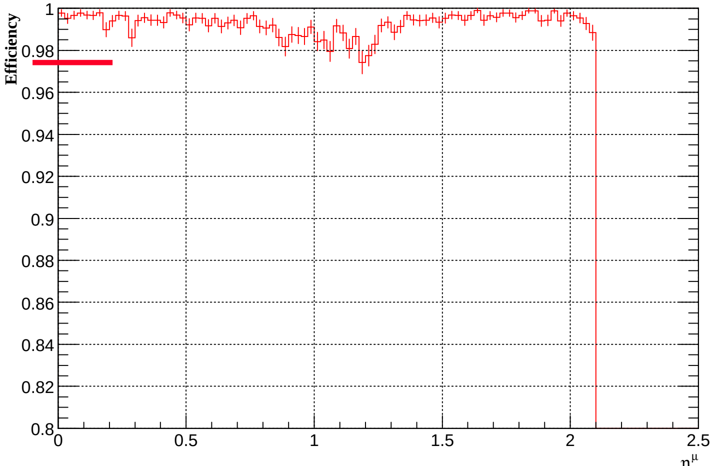
HLT Track Reconstruction

Standalone Muon Reconstruction: “Level-2”

- Seeded by Level-1 muons
- Kalman filtering technique applied to DT/CSC/RPC track segments
  - Segment positions for DT, individual hits for CSC (B-field)
- GEANE used for propagation through iron
- Trajectory building works from inside out
- Track fitting works from outside in
- Fit track with beam constraint

Inclusion of Tracker Hits: “Level-3”

- Define a region of interest through tracker based on L2 track with parameters at vertex
- Find pixel seeds, and propagate from innermost layers out, including muon
- High algorithmic efficiency →



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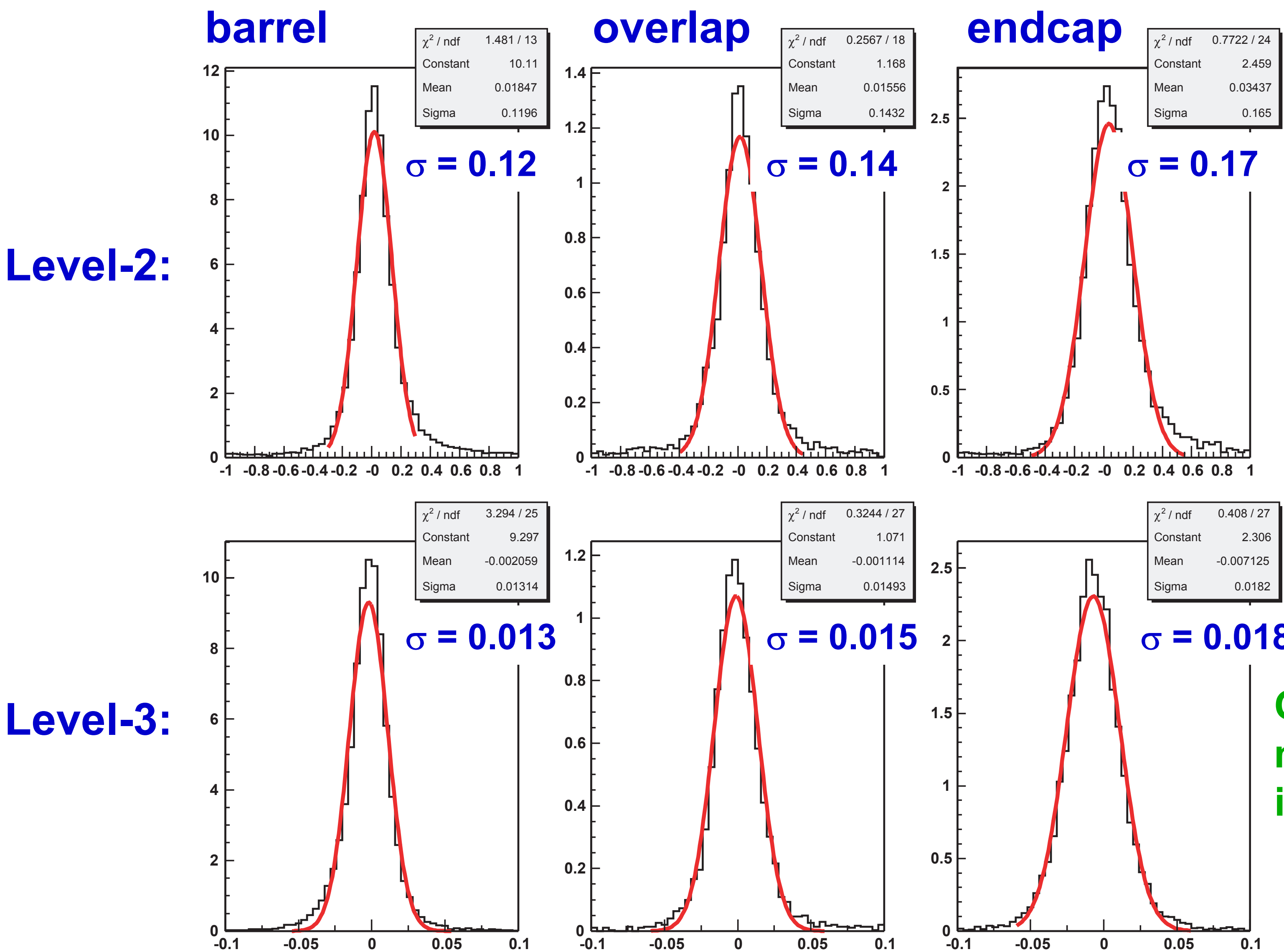
P_T Resolution

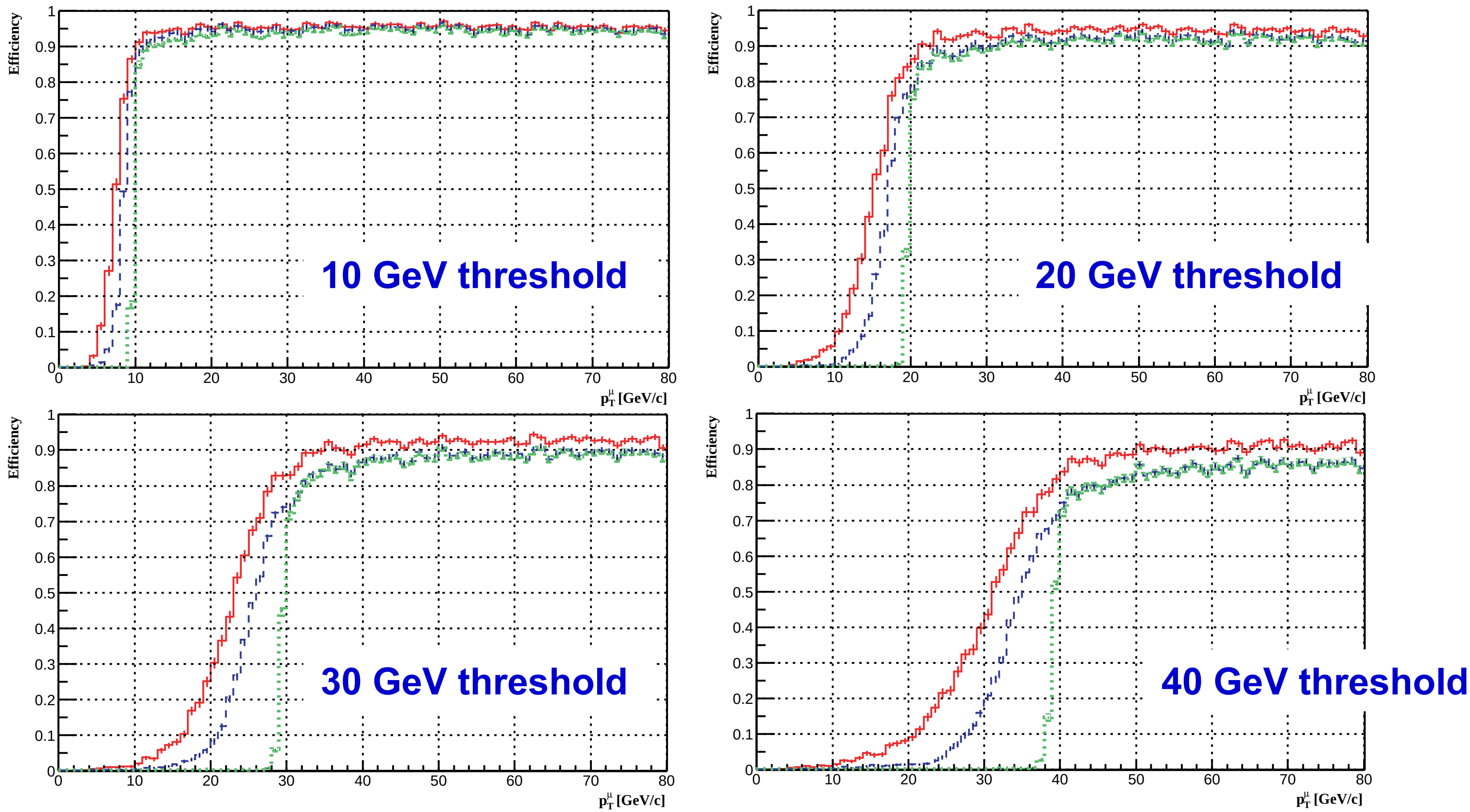


Order of magnitude improvement

Efficiency vs. P_T Threshold

Level-1, Level-2, Level-3

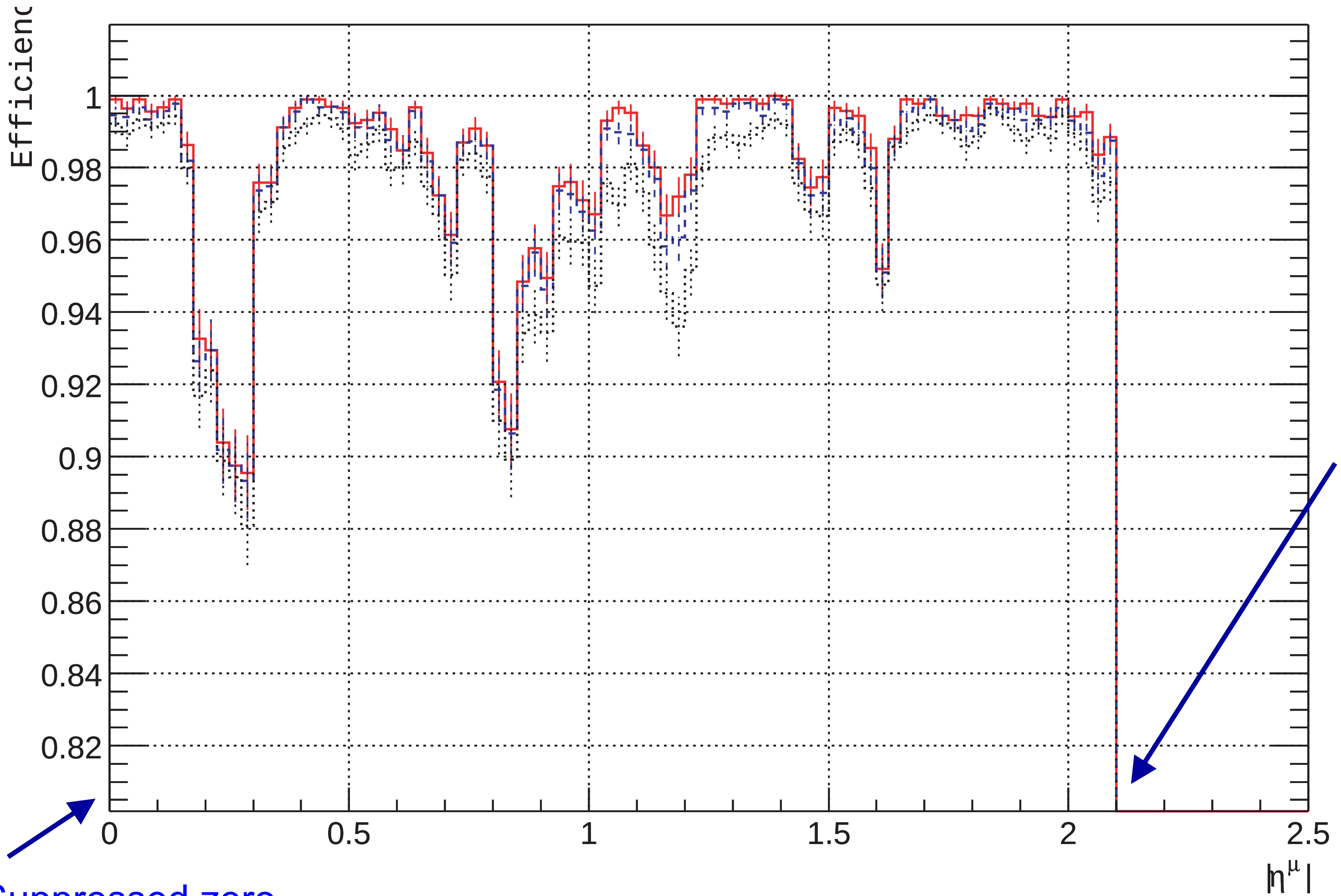
Single muons with $|\eta|<2.1$



Thresholds defined at 90% efficiency

Cumulative Efficiency vs. Eta

Level-1, Level-2, Level-3 Single muons, no threshold, no pile-up



Eta coverage limited to 2.1 (Limit of RPC, and ME1/1a of CSC does not participate @ L1)

Suppressed zero

Muon Isolation

General framework for isolation released since ORCA 6

- Based on ΣE_T or ΣP_T measurements in cones around the muon
- Cone sizes and thresholds are optimized
  - To get maximal rejection on "reference background" (Minimum Bias muons with P_T above the trigger threshold) for a given nominal efficiency on reference signal ($W \to \mu\nu$)
  - Optimization provides flat $\varepsilon(\eta)$ on signal by construction

Calorimeter Isolation

- ΣE_T from calorimeter towers in a cone around muon (sensitive to pile-up)

Pixel Isolation

- ΣP_T of 3-hit tracks in the pixel detector in cone around muon
- Studies done for full pixel detector (no staging)
- Requires that contributing tracks come from the same primary vertex as the Level-3 muon (to reduce pile-up contamination)

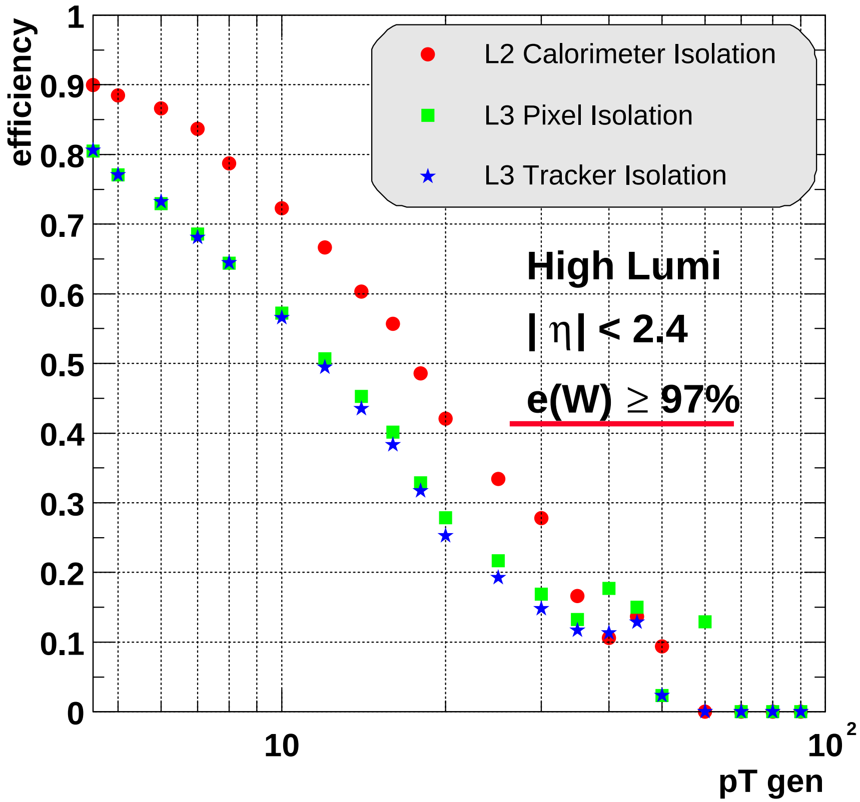
Tracker Isolation

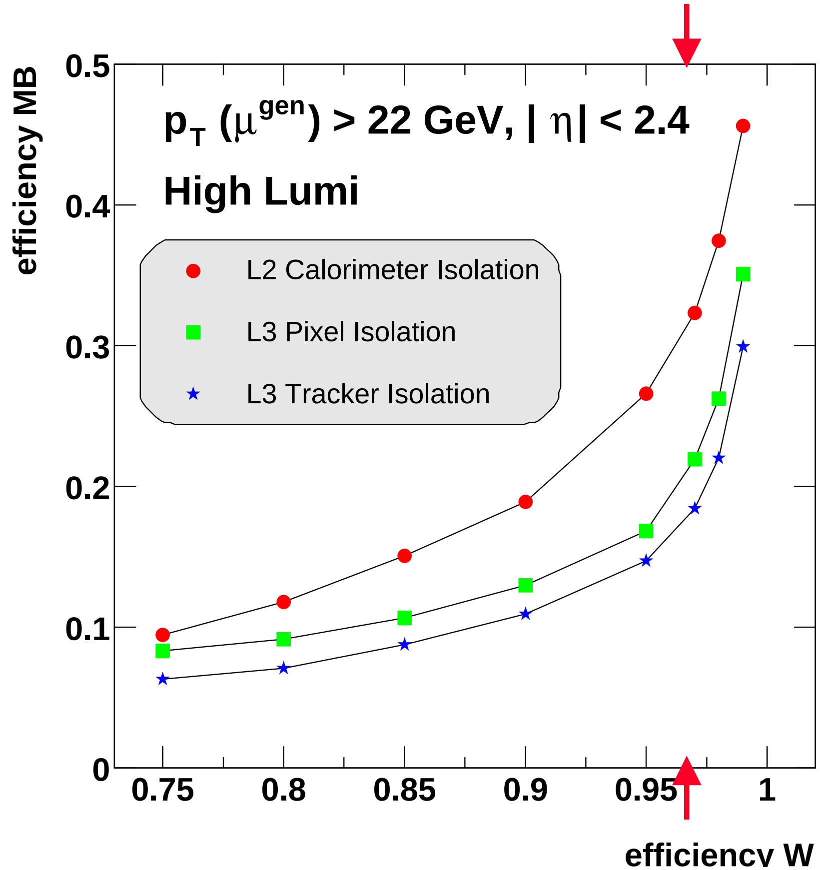
- ΣP_T of tracks in the tracker (regional reconstruction around Level-3 muon)

Isolation Performance

Efficiency on minbias events as a function of P_T^{gen} for 97% efficiency on signal

Efficiency on minbias events as a function of efficiency on W signal



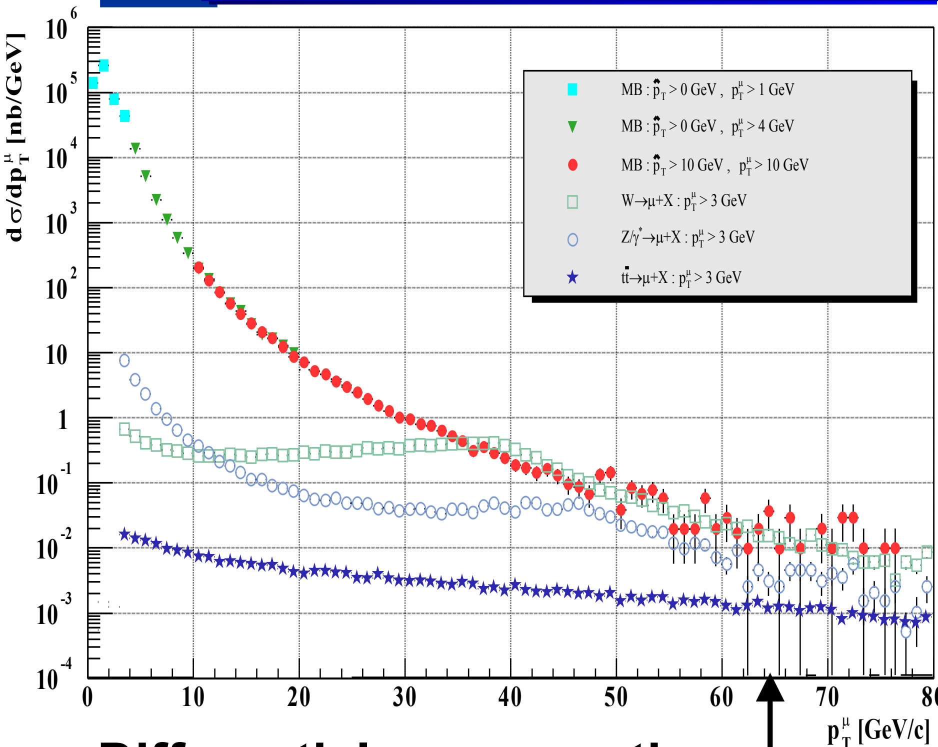


“reference background”

“reference signal”

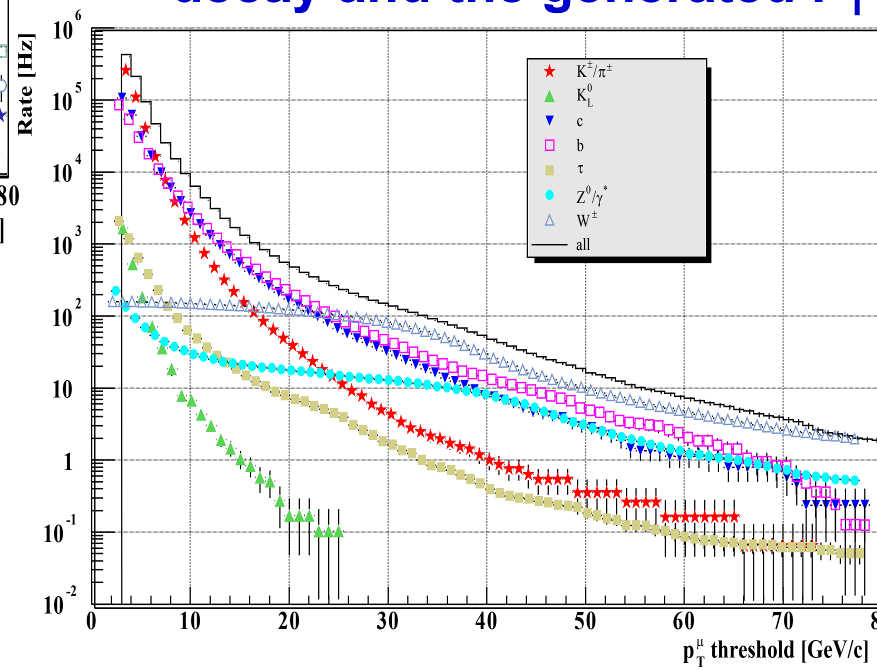
Muon Samples for HLT Rate Estimates

- ➔ Sensitive to entire inelastic cross section at LHC, since every π/K/b/c can decay into a muon and multiple-scatter to appear as high P_T
- ➔ Procedure applied to force muon decays and assign event weight based on the decay and the generated P_T



Differential cross-section

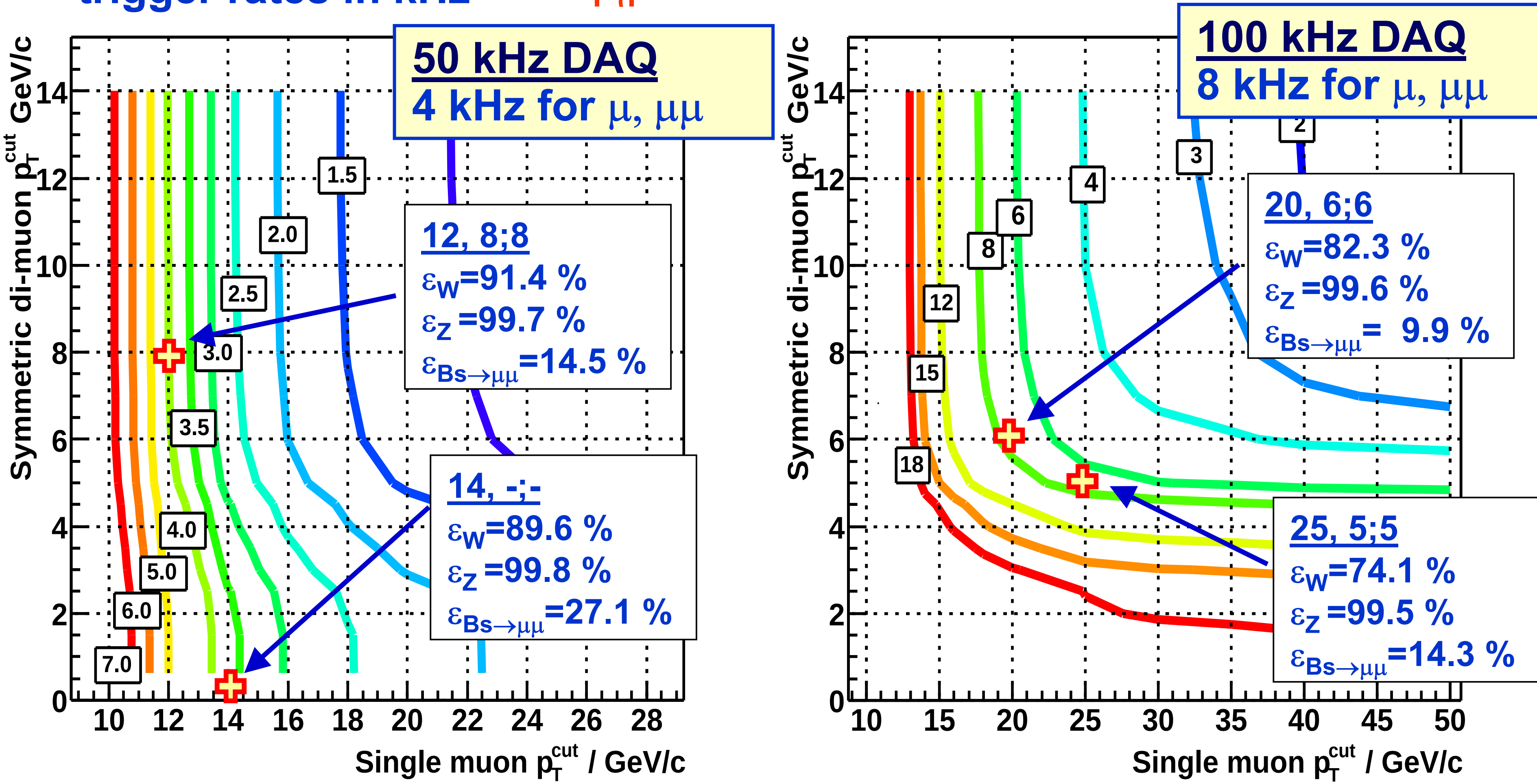
Integrated muon rates vs. P_T threshold, $L=10^{34}$, $|\eta|<2.1$ ⟶



Neutron background not included in simulations

Possible Level-1 Working Points

trigger rates in kHz $|\eta| < 2.1$



$L = 2 \times 10^{33} cm^{-2}s^{-1}$ $L = 10^{34} cm^{-2}s^{-1}$

Thresholds similar to those listed in Level-1 Trigger TDR, but acceptance limited

HLT Analysis

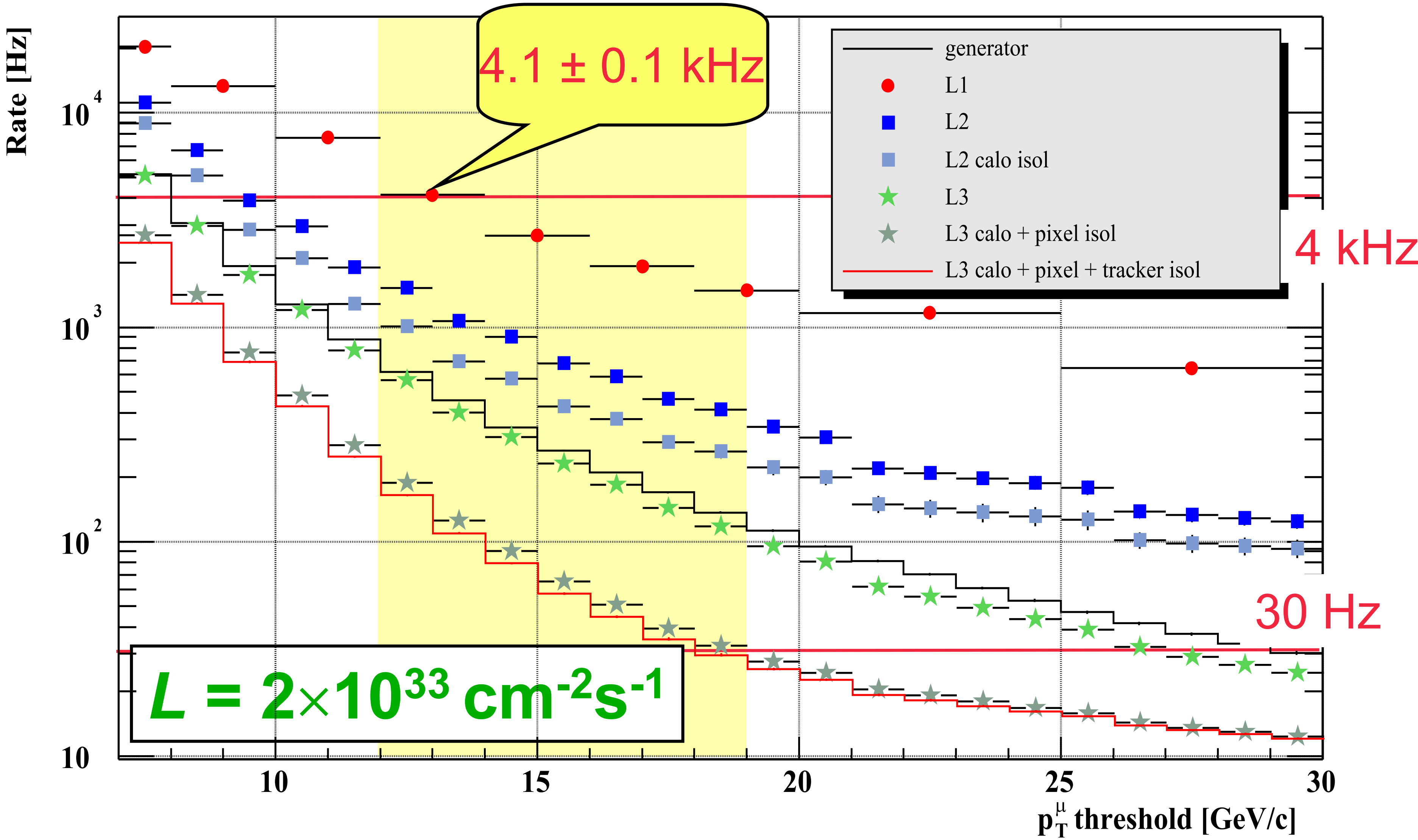
Level-2

- P_T (@vertex) > 0 (valid extrapolation to vertex)
- Number of used RecHits > 3
- Convert P_T (@vertex) to 90% efficiency scale
- Apply calorimeter isolation at 97% efficiency point
- Di-muons:
  - Require isolation of either of the two candidates

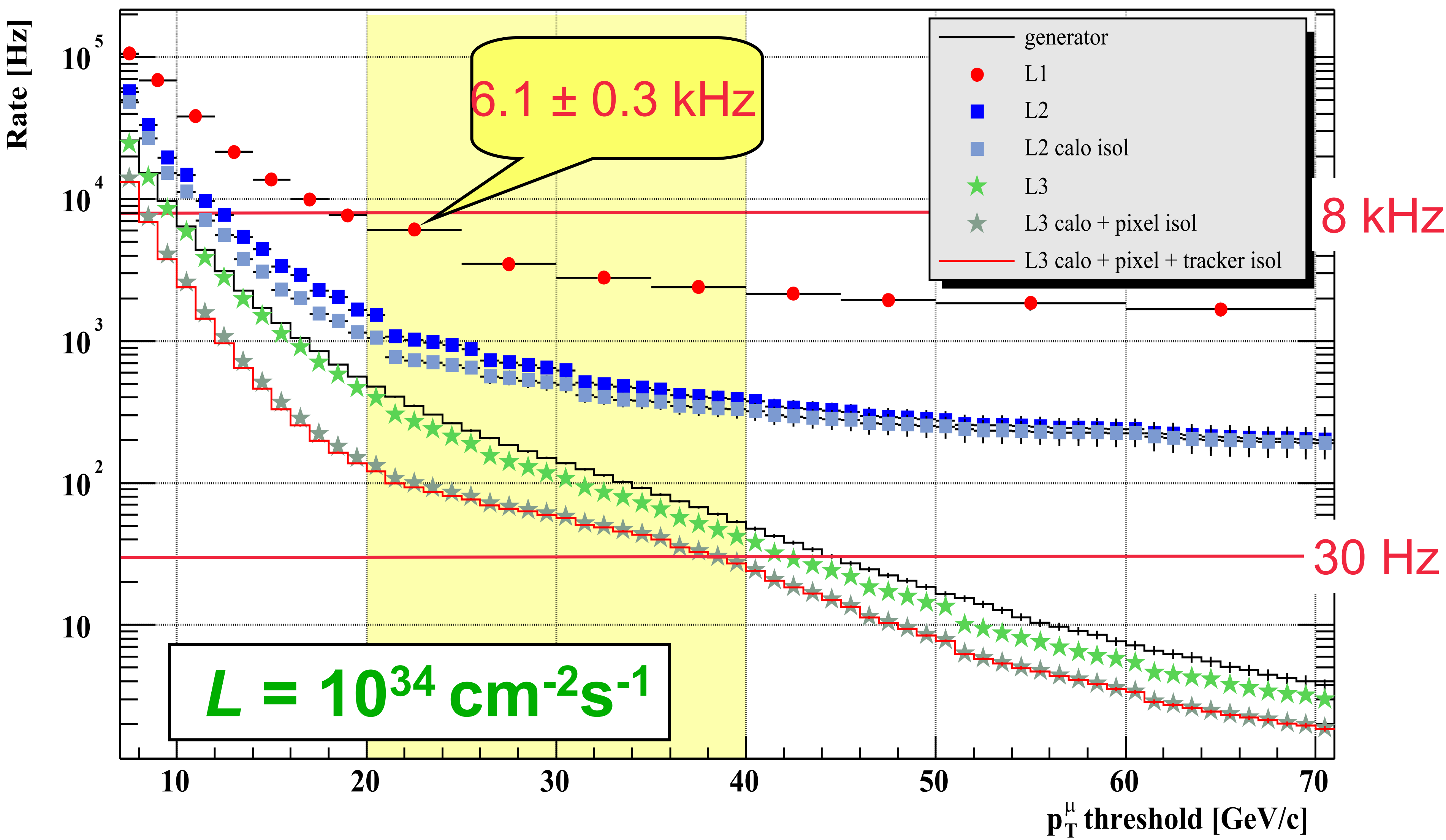
Level-3

- Number of silicon hits > 5 (pixel + strips)
- Convert P_T (@IP) to 90% efficiency scale
- Apply pixel isolation at 97% efficiency point
- Apply tracker isolation at 97% efficiency point
- Di-muons:
  - Reject ghosts ($\Delta P_T < 0.1$ and $\Delta\eta < 0.01$ and $\Delta\varphi < 0.05$)
  - $(Z_{\mu 1} - Z_{\mu 2}) < 2$mm @ IP
  - Require isolation of either of the two candidates

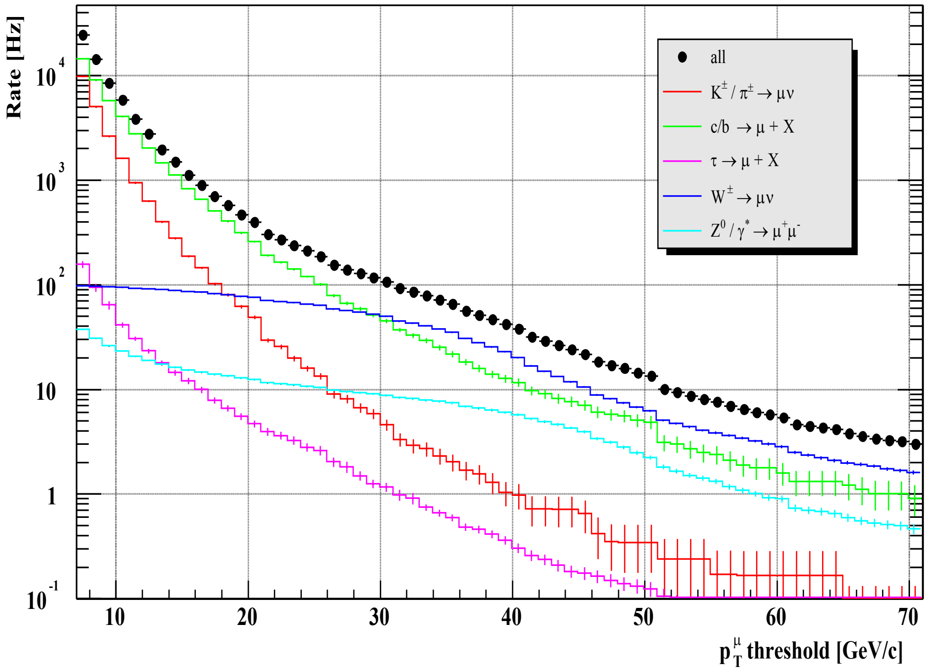
L1, L2, L3 Trigger Rates @ Low Lumi



L1, L2, L3 Trigger Rates @ High Lumi

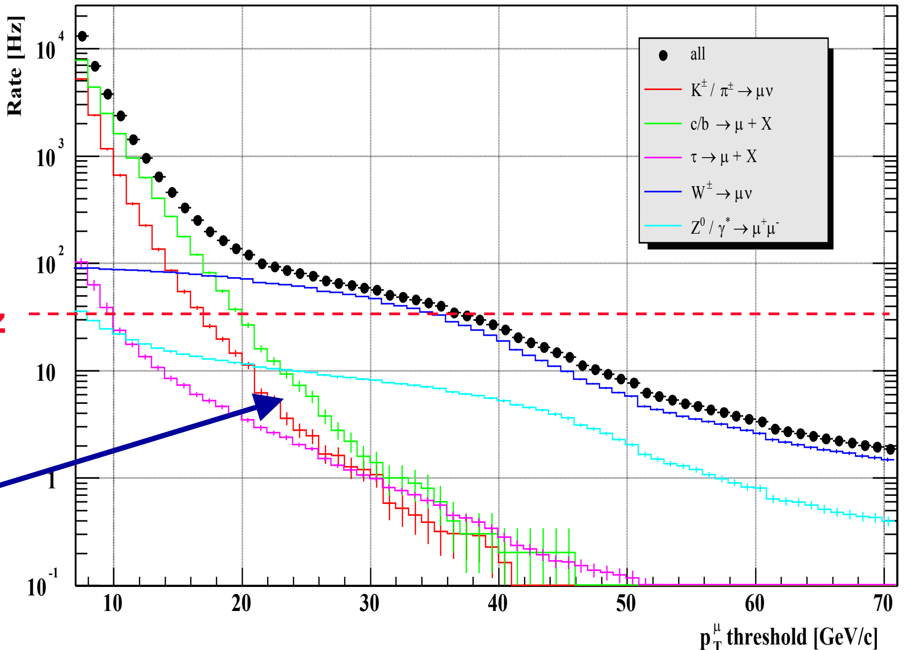


Physics Content after Level-3



Before isolation,

and after



$L = 10^{34}\ \mathrm{cm^{-2}s^{-1}}$

π/K/b/c strongly suppressed

L3 Single μ Rates with Isolation (Hz)

Low lumi

	total	K/π	b/c	tau	W → μν	Z → μμ
12 GeV	**166.1**	38.1	104.9	2.5	**16.9**	**3.5**
14 GeV	**79.8**	15.2	43.5	1.7	**16.4**	**3.0**
16 GeV	**45.0**	6.8	18.5	1.3	**15.7**	**2.7**
18 GeV	**29.9**	3.5	8.0	1.0	**14.9**	**2.5**
20 GeV	**23.0**	2.1	3.7	0.7	**14.1**	**2.3**
22 GeV	**18.4**	1.0	1.8	0.5	**13.0**	**2.1**

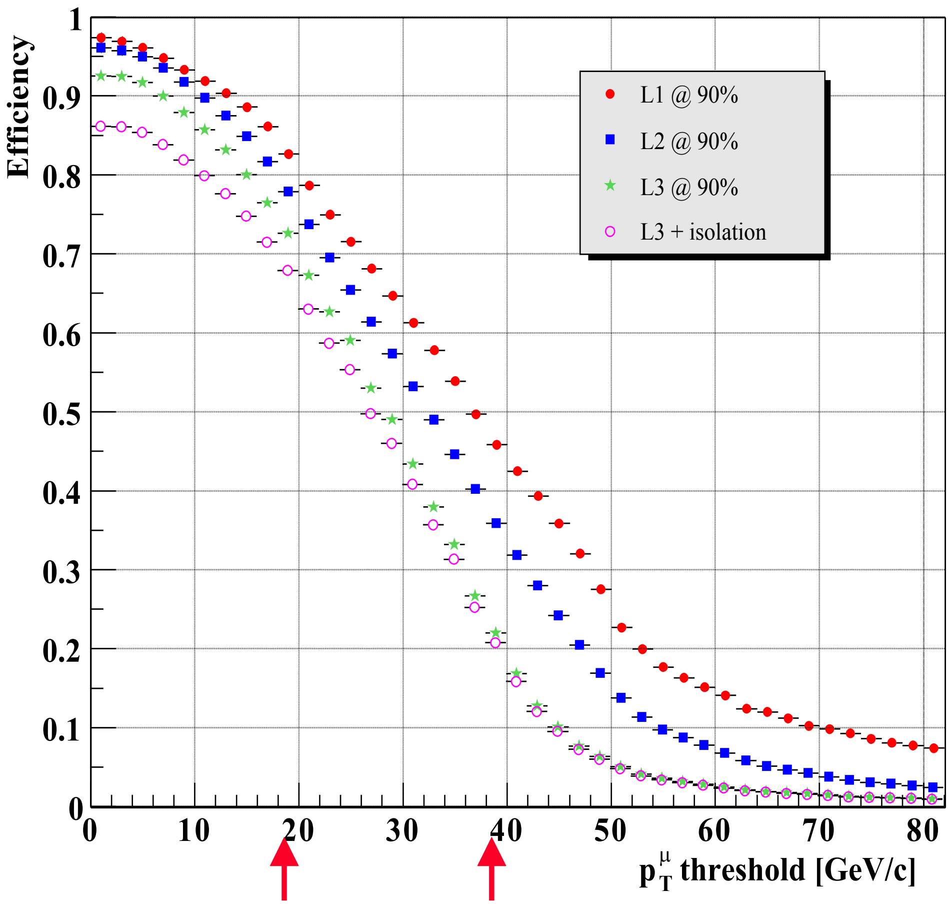
High luminosity

	total	K/π	b/c	tau	W → μν	Z → μμ
20 GeV	**121.4**	11.2	26.4	3.4	**69.1**	**11.3**
22 GeV	**93.3**	5.3	12.2	2.6	**62.9**	**10.3**
24 GeV	**81.2**	2.8	7.2	2.0	**59.5**	**9.7**
26 GeV	**69.3**	1.7	3.7	1.5	**53.5**	**8.9**
28 GeV	**62.9**	1.3	2.2	1.2	**49.8**	**8.4**
30 GeV	**56.9**	1.1	1.4	1.0	**45.5**	**8.0**
32 GeV	**48.5**	0.5	1.0	0.8	**38.9**	**7.4**
34 GeV	**43.1**	0.4	0.8	0.6	**34.3**	**7.0**
36 GeV	**35.1**	0.3	0.4	0.4	**27.8**	**6.2**
38 GeV	**29.9**	0.3	0.3	0.4	**23.2**	**5.7**

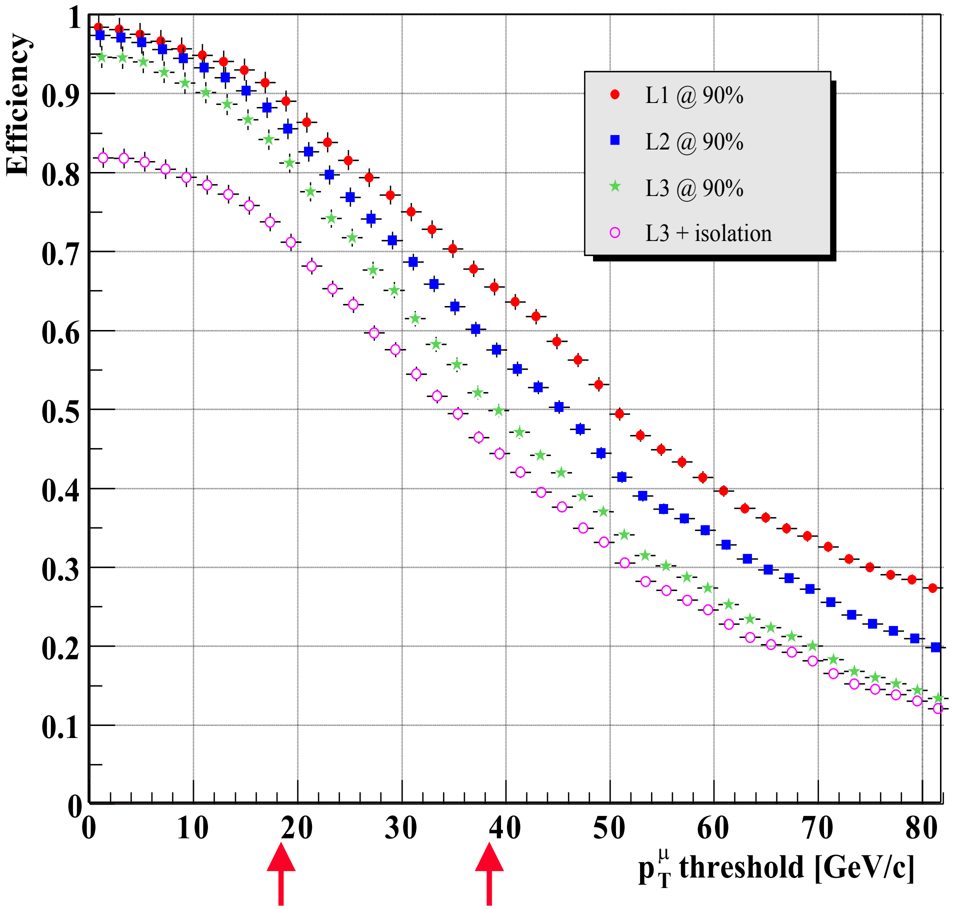
Efficiency for W, top

Effic @ high lumi

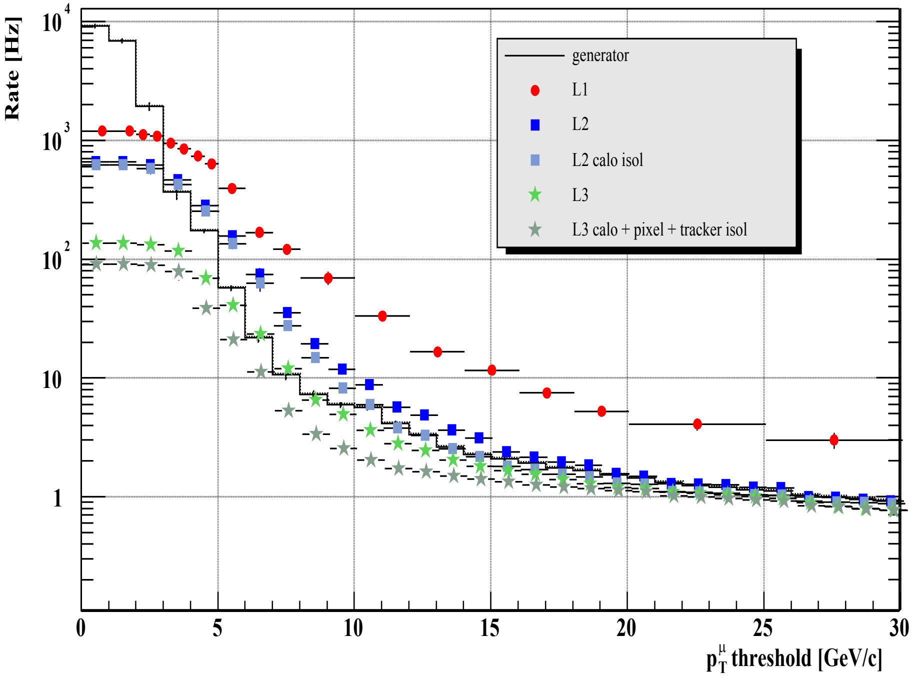
$W \to \mu\nu$



$t\bar{t} \to 1\mu + X$ ($W \to \mu\nu$)



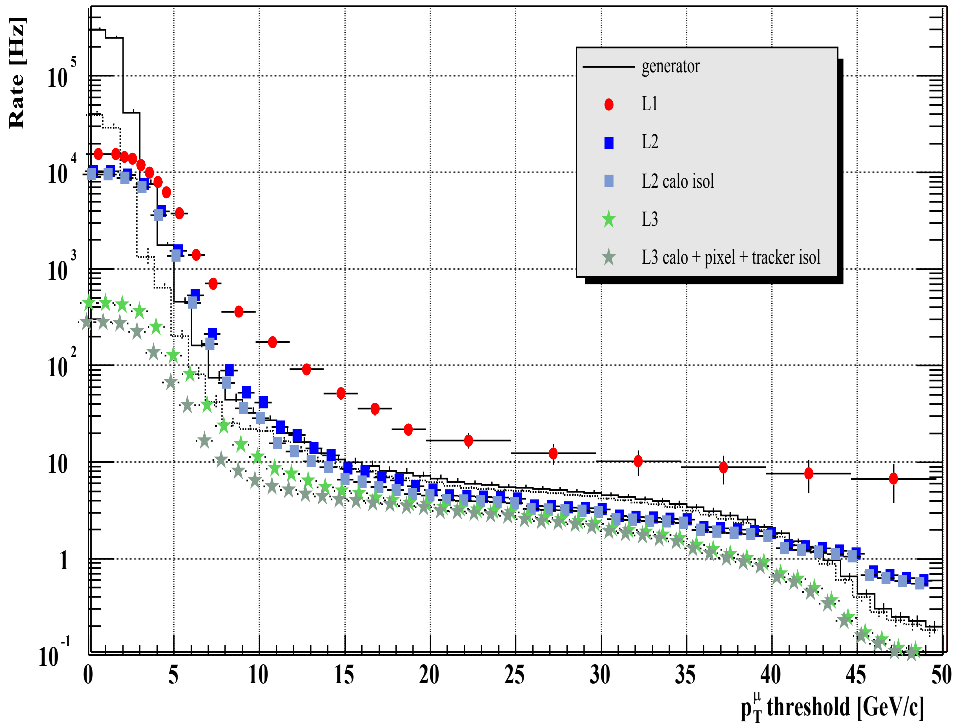
L1, L2, L3 Di-muon Trigger Rates



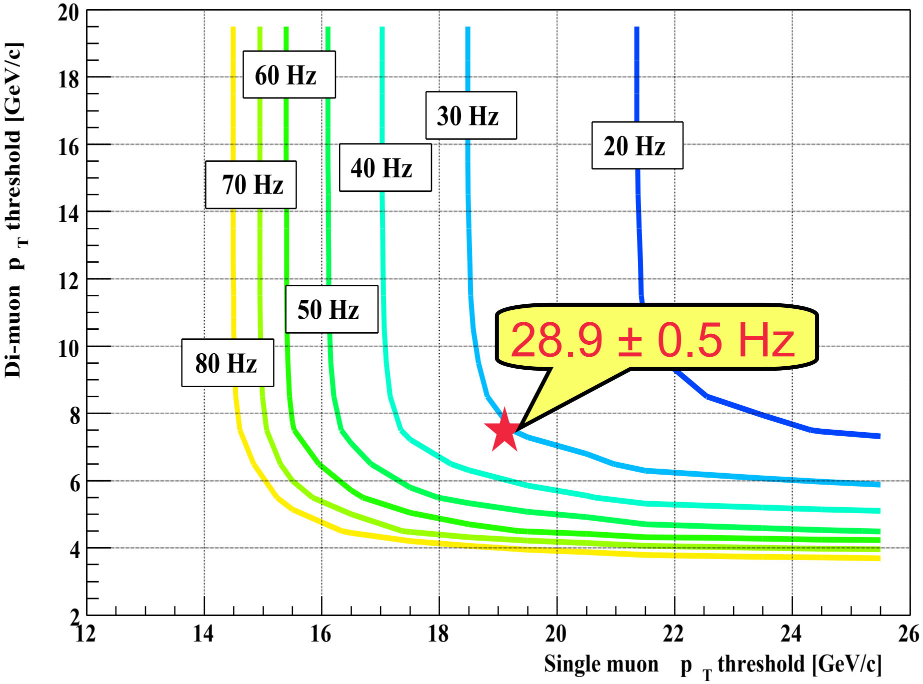
$L = 2\times10^{33}\ cm^{-2}s^{-1}$

Inclusive rates

$L = 10^{34}\ cm^{-2}s^{-1}$

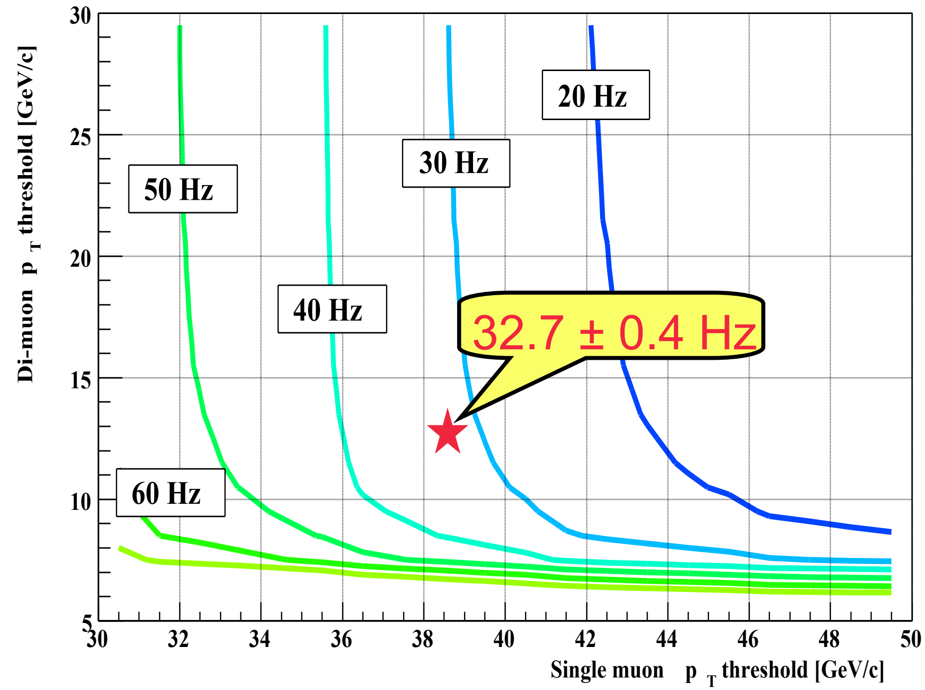


L3 Single and Di-μ Rate with Isolation



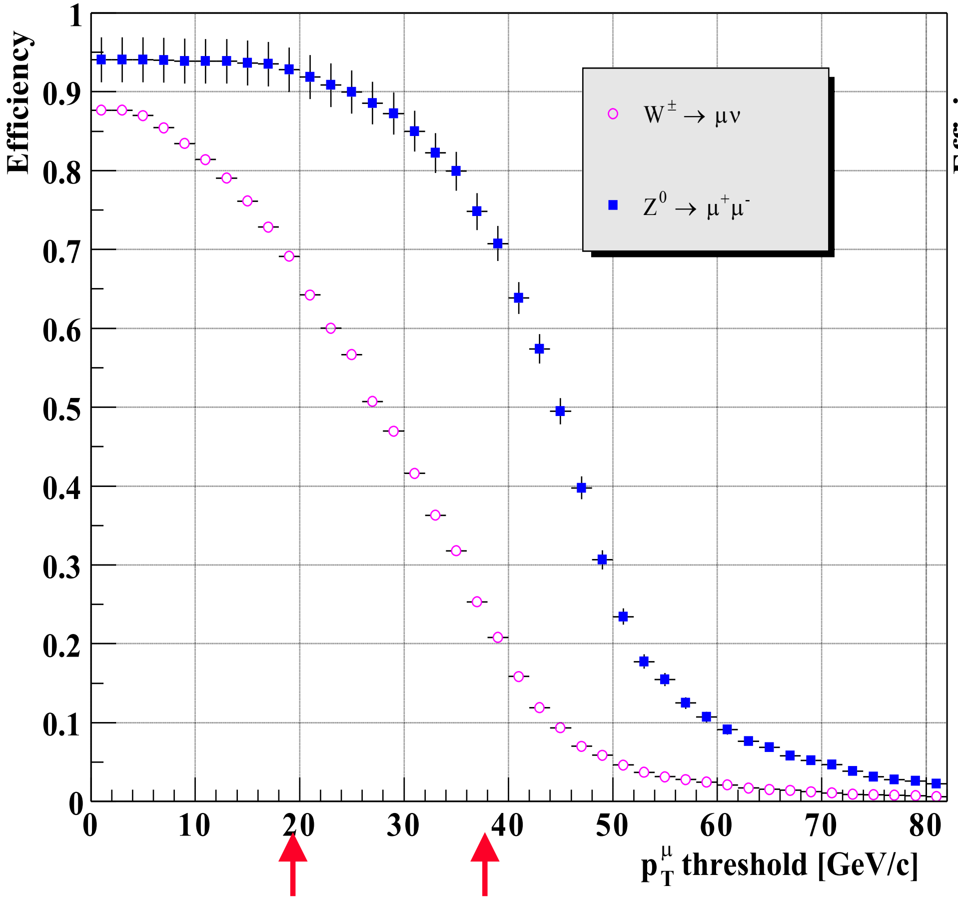
$L = 2\times10^{33}\ \mathrm{cm^{-2}s^{-1}}$

$L = 10^{34}\ \mathrm{cm^{-2}s^{-1}}$



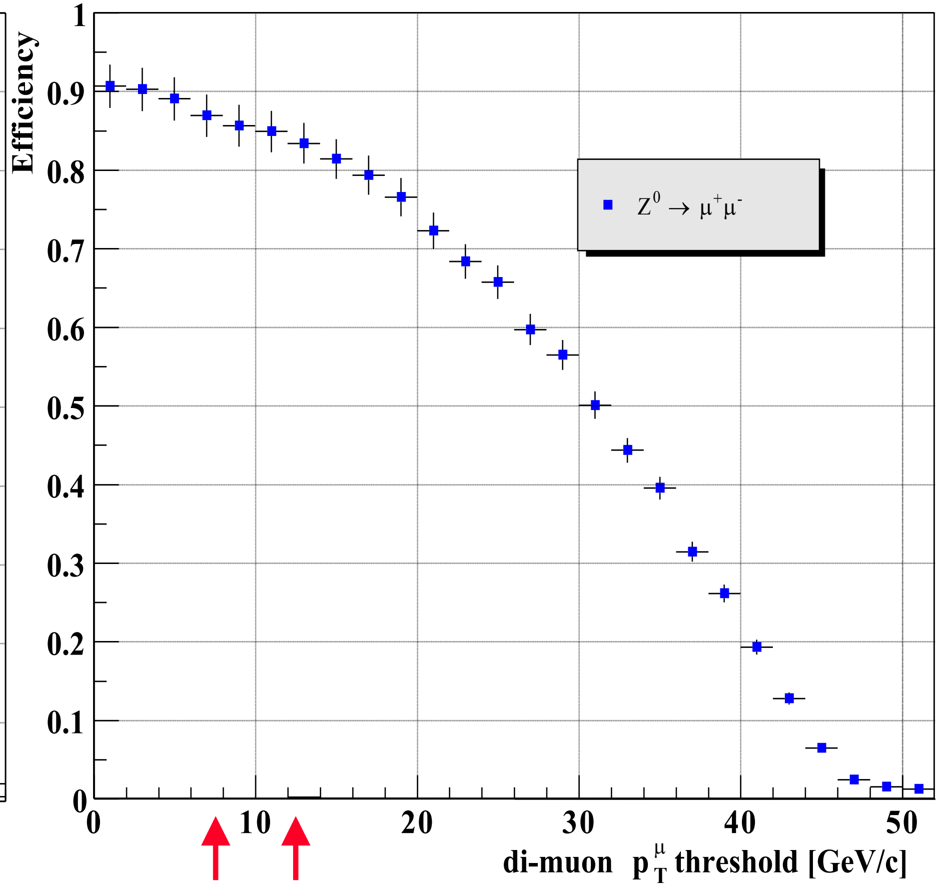
W and Z Efficiency

Single muon



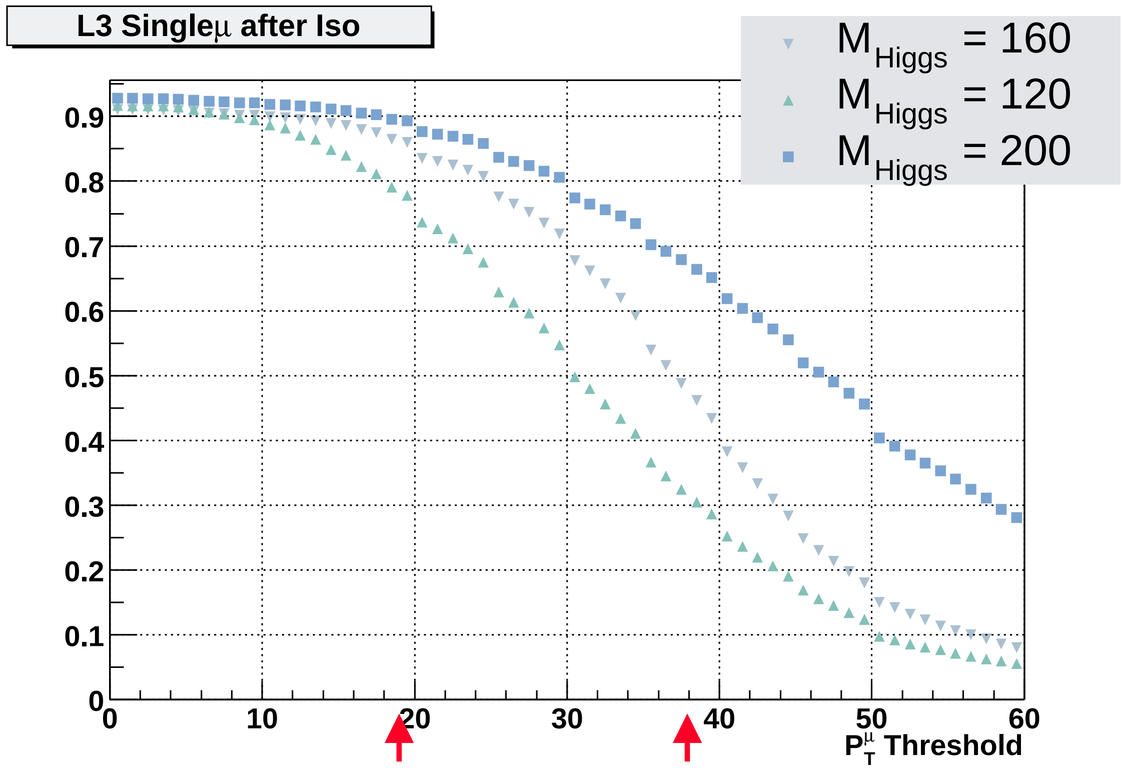
Di-muon

Effic @ low lumi



Combined Z efficiency is 98% (88%) for low (high) lumi

Efficiency of Higgs →WW → 2μ 2ν



Efficiency at low lumi:

- ➔ M_H = 120: Single μ = 73% Di-μ exclusive: 14% Combined: 87%
- ➔ M_H = 160: Single μ = 87% Di-μ exclusive: 5% Combined: 92%

Efficiency at high lumi:

- ➔ M_H = 120: Single μ = 30% Di-μ exclusive: 34% Combined: 64%
- ➔ M_H = 160: Single μ = 45% Di-μ exclusive: 32% Combined: 77%

CPU Usage

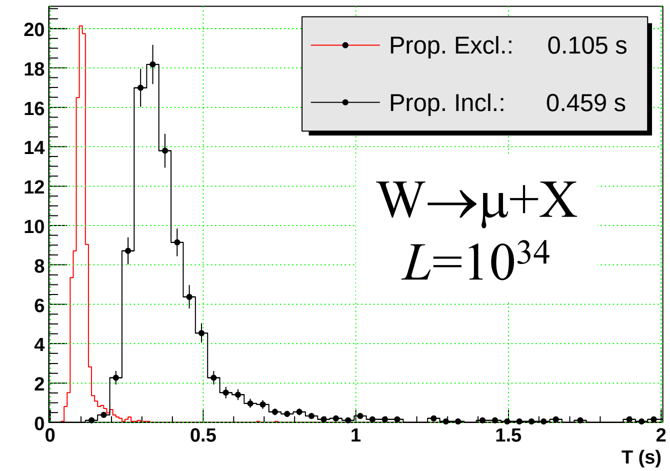
W sample Single muon trigger	$2x10^{33}$ $cm^{-2}s^{-1}$ Treshold = 10 GeV ms/(event passing previous steps)		10^{34} $cm^{-2}s^{-1}$ Treshold =18 GeV ms/(event passing previous steps)	
	Total	GEANE excl.	Total	GEANE excl.
Level-2	430	100	460	105
Calorim. Isolation	95	25	110	40
Level-3	330	160	560	336
Pixel Isolation	75	75	340	340
Tracker Isolation	70	70	220	220

CPU time on PIII 1GHz

W→μ+X events

"Signal"

L2 time/L1 event



CPU Usage: Realistic Muon Spectrum

Realistic Spectrum Single muon trigger	$2x10^{33}$ $cm^{-2}s^{-1}$ Treshold 10 GeV ms/(event passing previous steps)		10^{34} $cm^{-2}s^{-1}$ Treshold 18 GeV ms/(event passing previous steps)	
	Total	GEANE excl.	Total	GEANE excl.
Level-2			840	100
Calorim. Isolation			120	40
Level-3			735	425
Pixel Isolation			340	340
Tracker Isolation			370	370
Total/L1 muon			*1020*	*200*

CPU time on PIII 1GHz

Conclusions & Beyond the TDR

- **Muon data volume ≈2GB/s**
- **Possible HLT working point at high luminosity**
  - Single P_T threshold = 38 GeV : 29.9 ± 0.4 Hz
  - Di-muon symmetric P_T threshold = 12 GeV : 2.7 ± 0.2 Hz
  - Combined rate : 32.7 ± 0.4 Hz
  - Nearly all W/Z after isolation
- **Further studies/solutions of problematic regions needed**
  - Inefficiency in DT/CSC overlap region and showering "TeV" muons
  - Fast track propagator and replacement for GEANE
- **Further optimize L1→HLT→offline for physics**
  - Disparity between L1 and L3 inclusive muon thresholds leaves room for more exclusive HLT triggers (correlations) at lower thresholds
  - Some cuts should be relaxed at high P_T (e.g. isolation)
- **Refine/distinguish HLT tools and offline reconstruction**
  - HLT should be fast and robust. Just need to get event to tape, which means reconstructing just one or two muons
  - Offline you want all muons reconstructed (e.g. $H \to 4\mu$)

Backup Slides

Low Lumi Working Points

Low Lumi:

P1:

- Single P_T threshold = 19 GeV : 25.7 ± 0.4 Hz
- Di-muon symmetric P_T threshold = 7 GeV : 3.2 ± 0.2 Hz
- Combined rate = 28.9 ± 0.5 Hz

P2:

- Single P_T threshold = 19 GeV : 25.7 ± 0.4 Hz
- Di-muon symmetric pT threshold = 6 GeV : 8.5 ± 0.7 Hz
- Combined rate = 34.2 ± 1.0 Hz

P3:

- Single P_T threshold = 20 GeV : 23.0 ± 0.3 Hz
- Di-muon symmetric P_T threshold = 6 GeV : 8.6 ± 0.7 Hz
- Combined rate = 31.6 ± 1.0 Hz

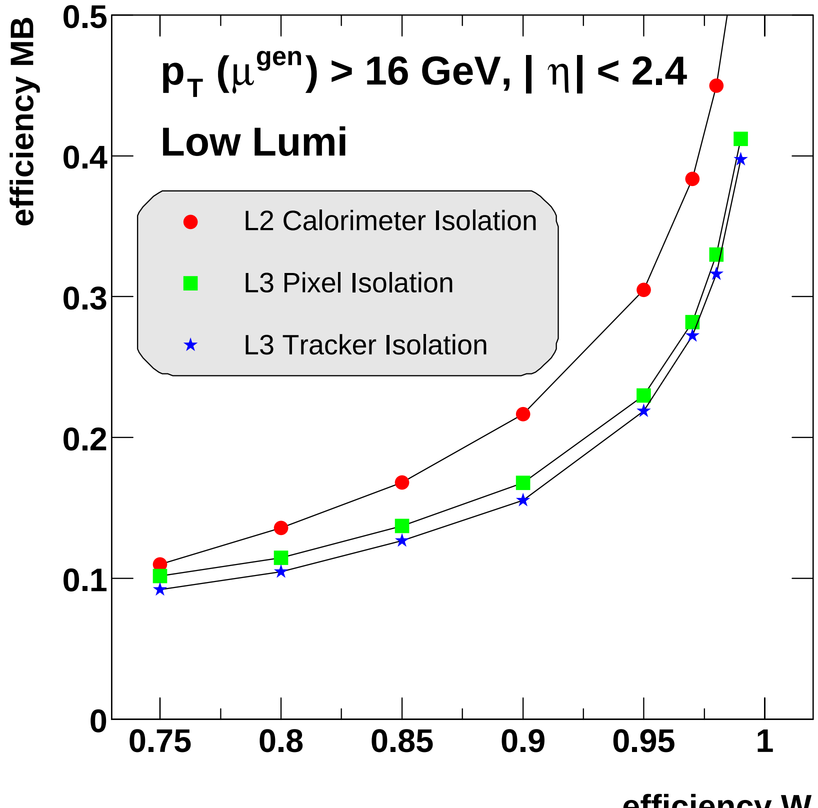
Low Luminosity Rates Comparison

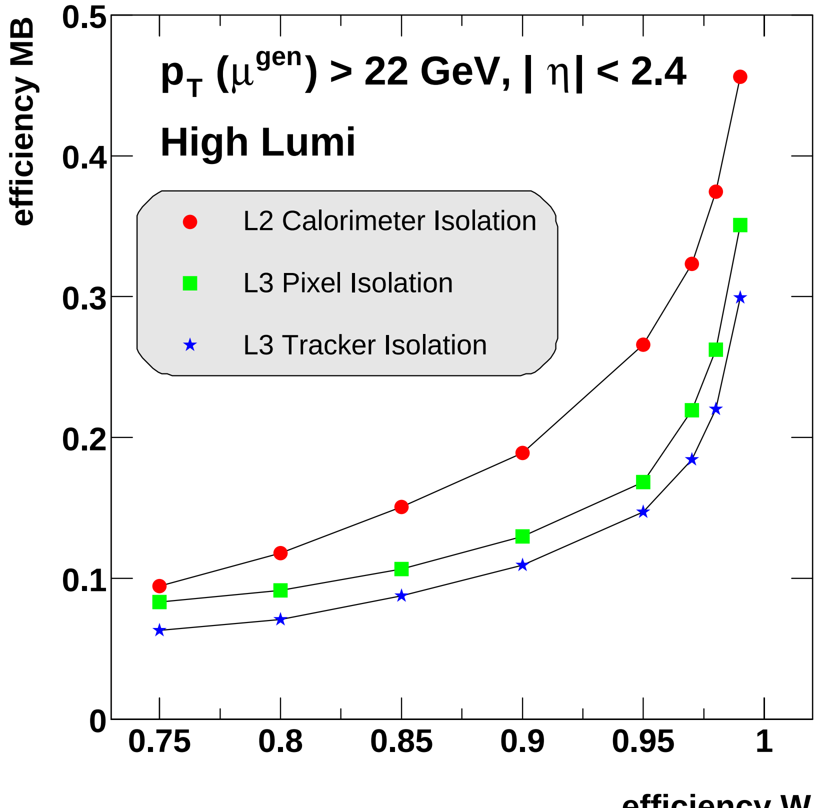
97% isolation cut (upper) and 90% isolation cut (lower)

	total	**K/π**	**b/c**	**tau**	$W \to \mu\nu$	$Z \to \mu\mu$
12 GeV	166.1 *92.2*	**38.1** ***23.1***	**104.9** ***49.3***	**2.5** ***1.8***	16.9 *14.8*	3.5 *3.1*
14 GeV	79.8 *45.0*	**15.2** ***8.9***	**43.5** ***17.8***	**1.7** ***1.3***	16.4 *14.3*	3.0 *2.6*
16 GeV	45.0 *28.0*	**6.8** ***4.1***	**18.5** ***6.8***	**1.3** ***1.0***	15.7 *13.7*	2.7 *2.4*
18 GeV	29.9 *21.5*	**3.5** ***2.3***	**8.0** ***3.2***	**1.0** ***0.8***	14.9 *13.1*	2.5 *2.2*
20 GeV	23.0 *17.8*	**2.1** ***1.3***	**3.7** ***1.5***	**0.7** ***0.6***	14.1 *12.4*	2.3 *2.0*
22 GeV	18.4 *14.8*	**1.0** ***0.6***	**1.8** ***0.6***	**0.5** ***0.5***	13.0 *11.3*	2.1 *1.8*

Isolation: performance

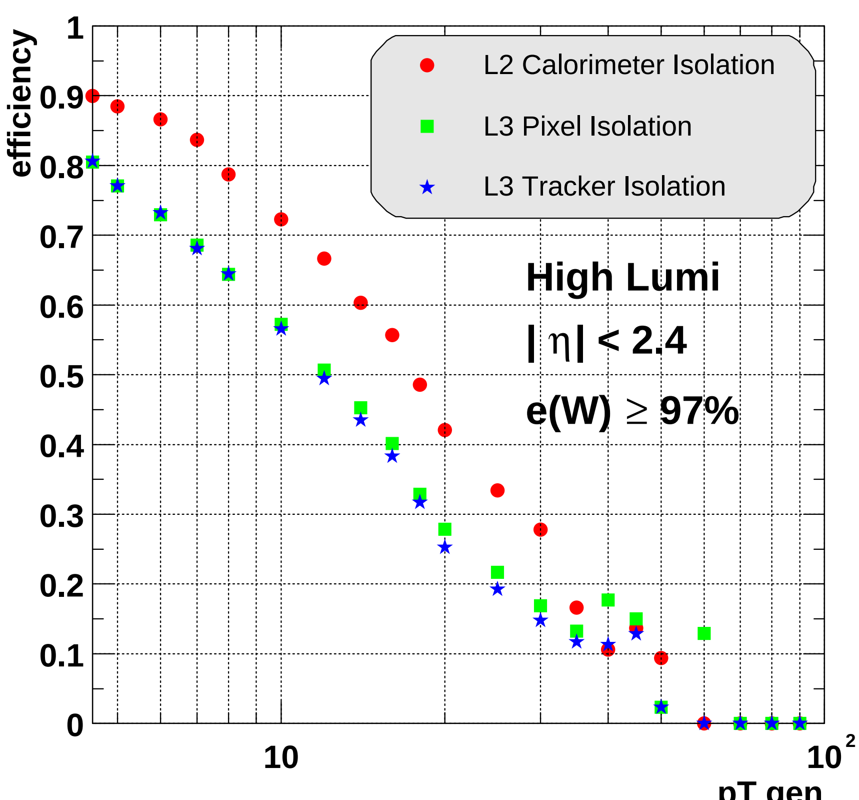
Efficiency on Minimum Bias events as a function of nominal efficiency on signal

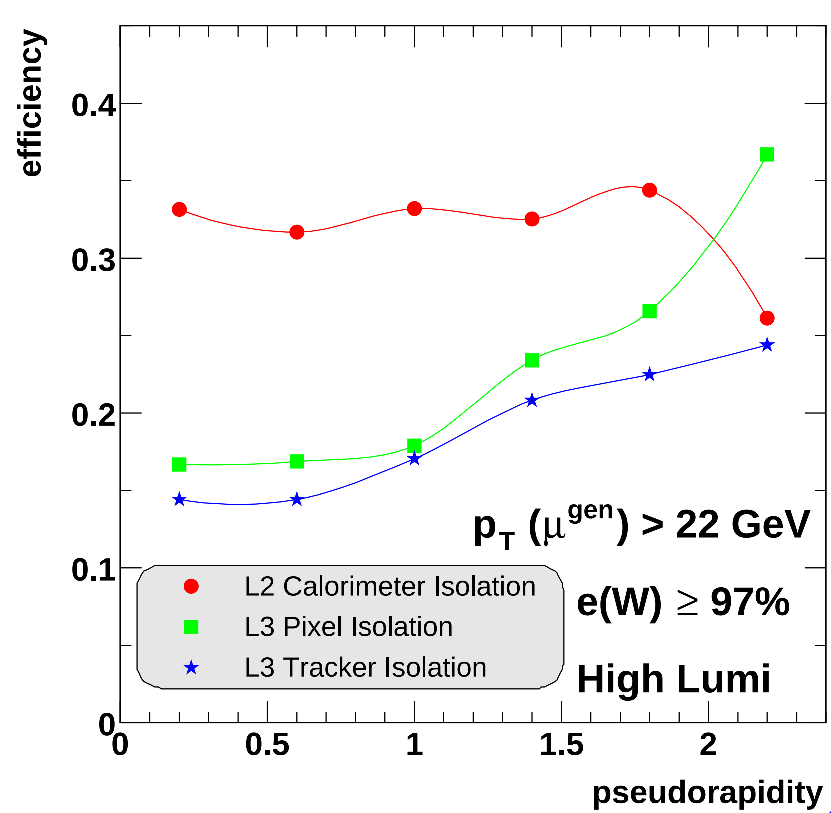




Isolation

Efficiency on Minimum Bias events as a function of P_T^{gen} and η
for 97% nominal efficiency on signal





Alignment using Muons

- Use prompt collision muons with P_T>50 GeV/c from GMT
  - ➔ 0.2–1 Hz muon/sector
- Require ~4 days @ L= 2×10^{33} to reach 200 μm precision
  - ➔ ~ 1 TB dedicated data stored offline for alignment analysis
  - ➔ Must have sufficient precision on $\Delta B/B$
    - ◻ See F.Matorras et al., CMS-TN 96-005

- For the endcaps, might make use of a special accelerator muon trigger implemented in the CSC Track-Finder and GMT
  - ➔ Triggers on halo muons traveling parallel to beam axis
  - ➔ Expect a halo muon to trigger just one endcap or the other
  - ➔ Needs investigation

Misalignment Effects on HLT Trigger

Study degradation of the muon identification and Pt resolution after applying different misalignments

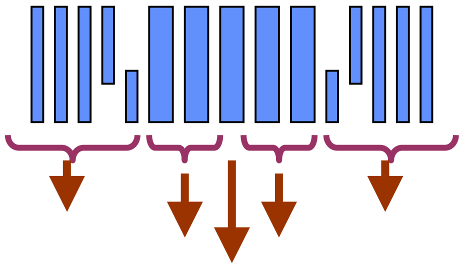
Use modified ORCA package to perform misalignments

- ➔ Great advantage: Already existing MC is used, without being necessary to simulate distorted geometries.

Based on existing Tracker 'misalignment tools':

Basic concept: displace chambers hosting the reconstructed segments while leaving its local position unchanged

Example: Vertical displacement due to gravity. Units in cm.



— $\Delta y = 0$

— $\Delta y = 1$ cm

ORCA study: CMS IN 2002/049

Calderon et al.