A Search For Charged Massive Long-lived Particles Using the DØ Detector

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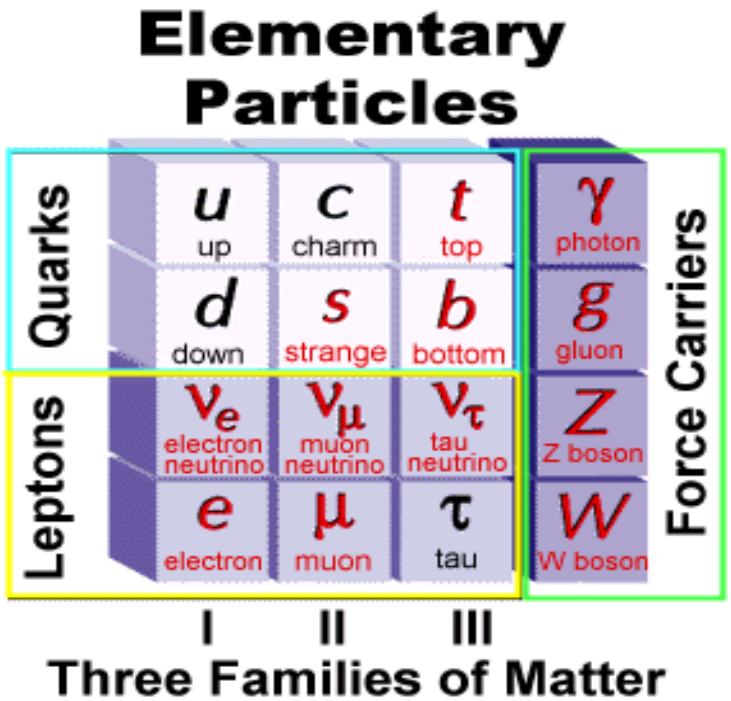
Outline

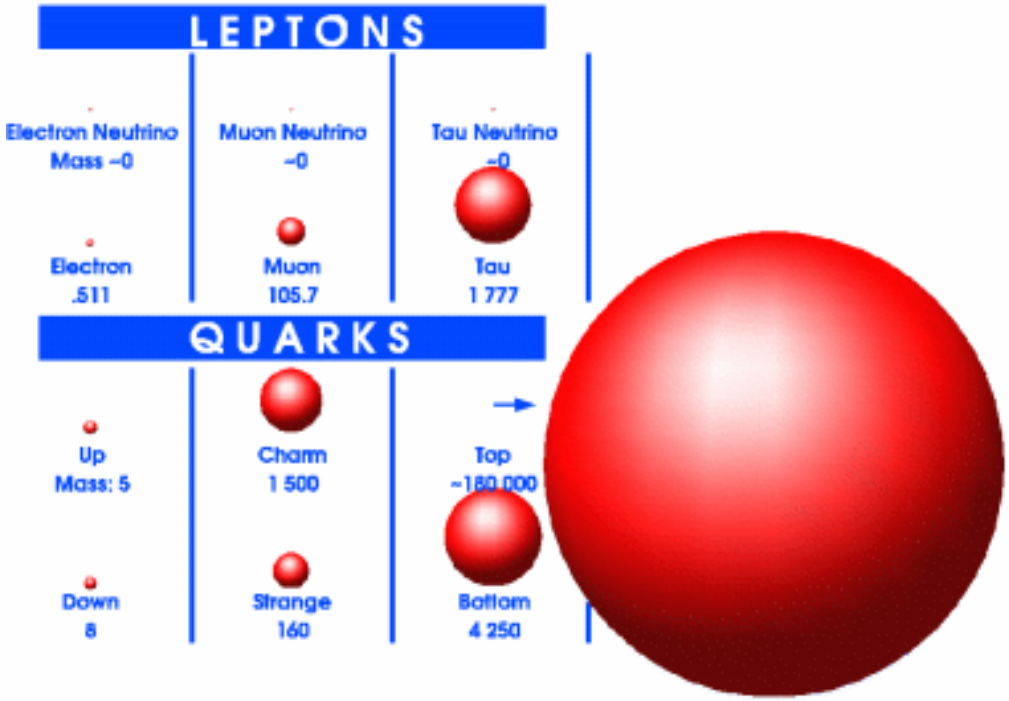
- ***Physics Motivation***
- ***Experimental Apparatus***
- ***Search Strategy***
- ***Event Selection***
- ***Analysis***
- ***Results***
- ***Summary***

The Standard Model

- Successful but incomplete theory
- Puzzles exist

Why three generations? How do particles gain their masses?





19 parameters

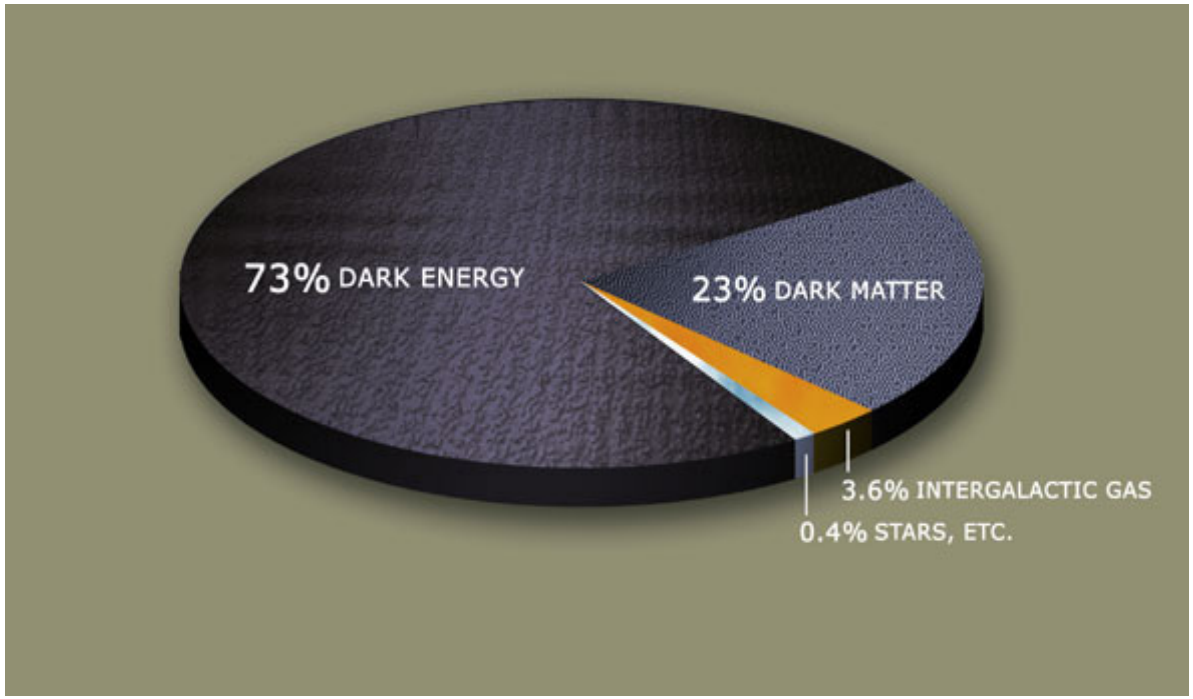
further mysteries …

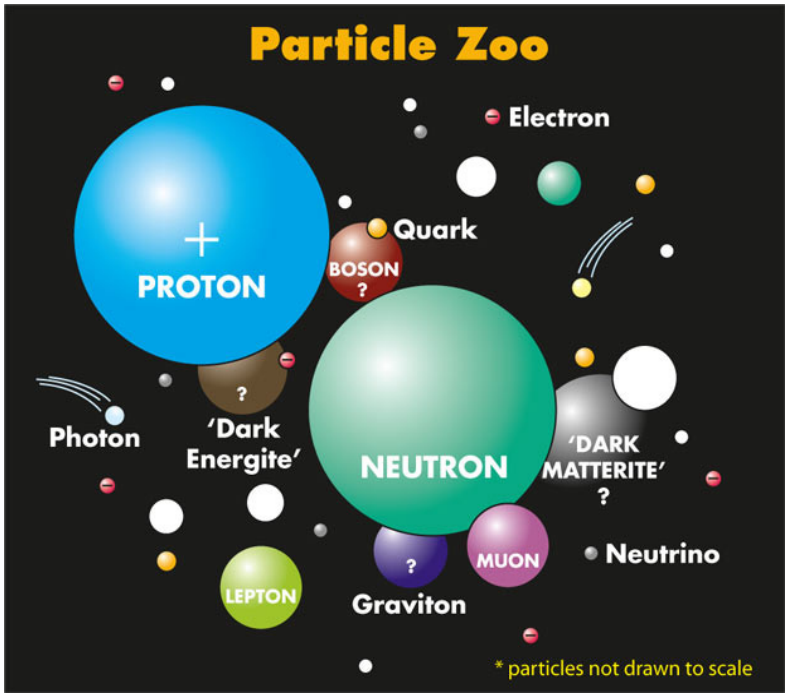
What is in the Universe?

What does the Universe consist of?

What is dark matter?

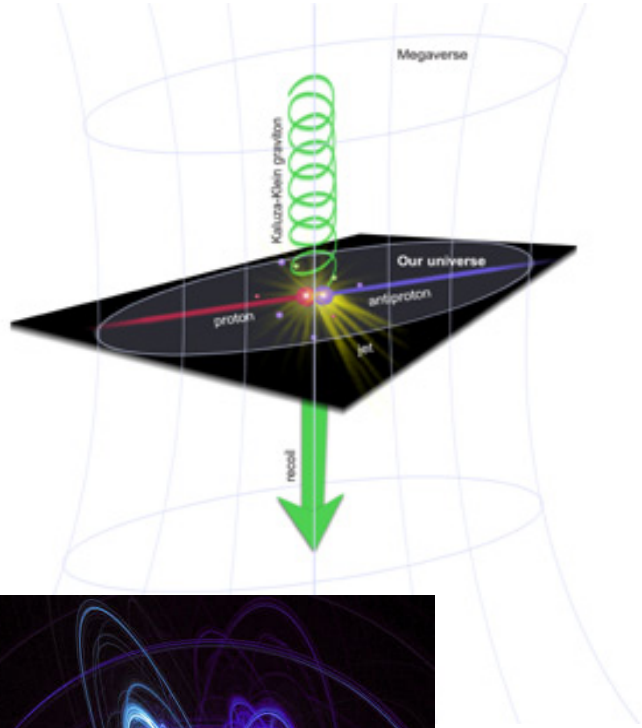
What is dark energy?



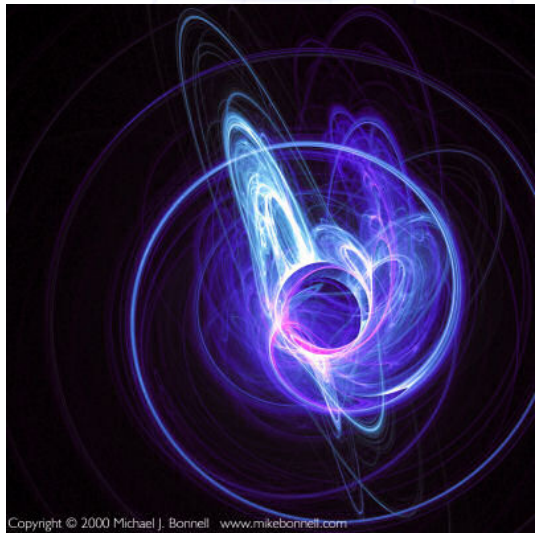


Potential Answers

- ***Many theories beyond the Standard Model***
  - Extra Dimensions
  - Grand Unified Theory (GUT)
  - String Theory
  - Strong Dynamics
  - Supersymmetry (SUSY)
  - more …



- ***New massive particles are predicted in many BSM theories***
  some predict charged massive particles with long lifetimes at experimental scale (> 100 ns)



Potential Answers – II

- ***Supersymmetry (SUSY) model***
  - New symmetry between fermions and bosons

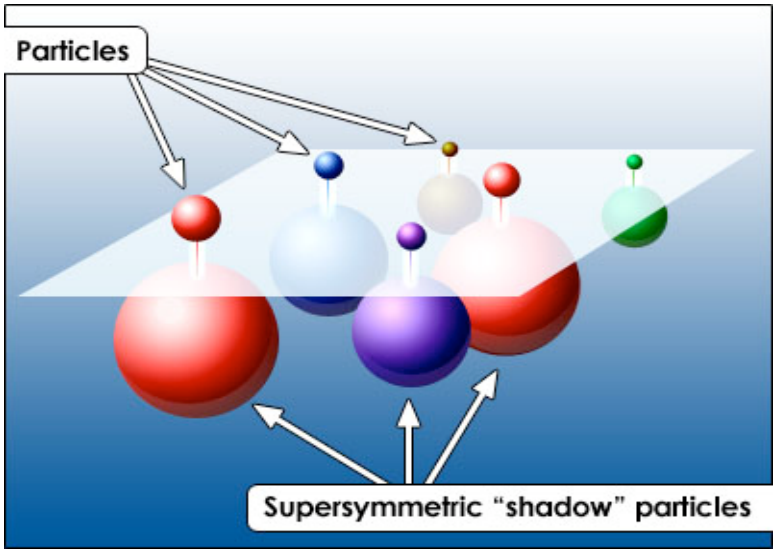
    fermion ⟷ boson

    leptons → sleptons, quarks → squarks,

    gauge bosons → gauginos, higgs boson → higgsinos

    neutralino: mix of neutral gauginos and higgsinos

    chargino: mix of charged gauginos and higgsinos



- solved the hierarchy problem free from quadratic divergences
- also a broken symmetry

  – no super-partners have been observed so far

Motivation

- ***Undertook a signature-based search***

  sensitive to any physics predicting charged massive long-lived particles

  interpreted the results with two SUSY models

- ***Gauge-Mediated Supersymmetry Breaking (GMSB) model***

  gauge interactions introduce the soft symmetry breaking

Lightest Supersymmetry Particle (LSP): gravitino

Next to LSP (NLSP): lightest neutralino or lightest tau slepton (stau)

Use "Model Line D" from the Snowmass 2001 eConf C010630, 346(2001)

heavy SUSY particles decay to stau before decaying to gravitino - Small coupling to the gravitino leads to long lifetime of stau

Motivation -- II

- ***Anomaly-Mediated SUSY Breaking (AMSB) models or SUSY models without gaugino mass unification***

symmetry breaking arises from the violation of the local super-symmetry

If the mass difference between the lightest chargino and lightest neutralino is small enough (<150 MeV), phase space suppression results in long-lived charginos.

Two extreme cases are explored:

a) the chargino is mostly gaugino

b) the chargino is mostly higgsino

Model parameters are described in Eur. Phys. J.C. **11**, 1(1999)

LEP II limits:

stau: 97.5 GeV chargino: 102.5 GeV

Detector Signature

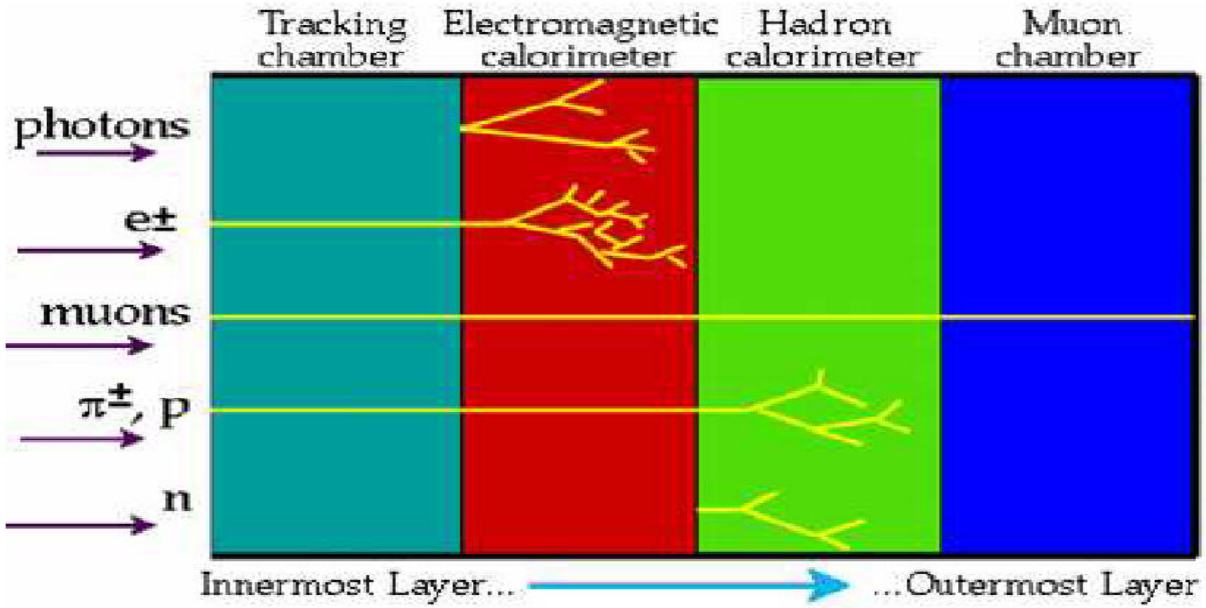
Unique signature in the collider detectors:

Charged: leaves track in the detector

Massive: moves slowly (small β)
has large time-of-flight
deposits more energy (dE/dx)

Stable: has a long lifetime, doesn't decay in the detector

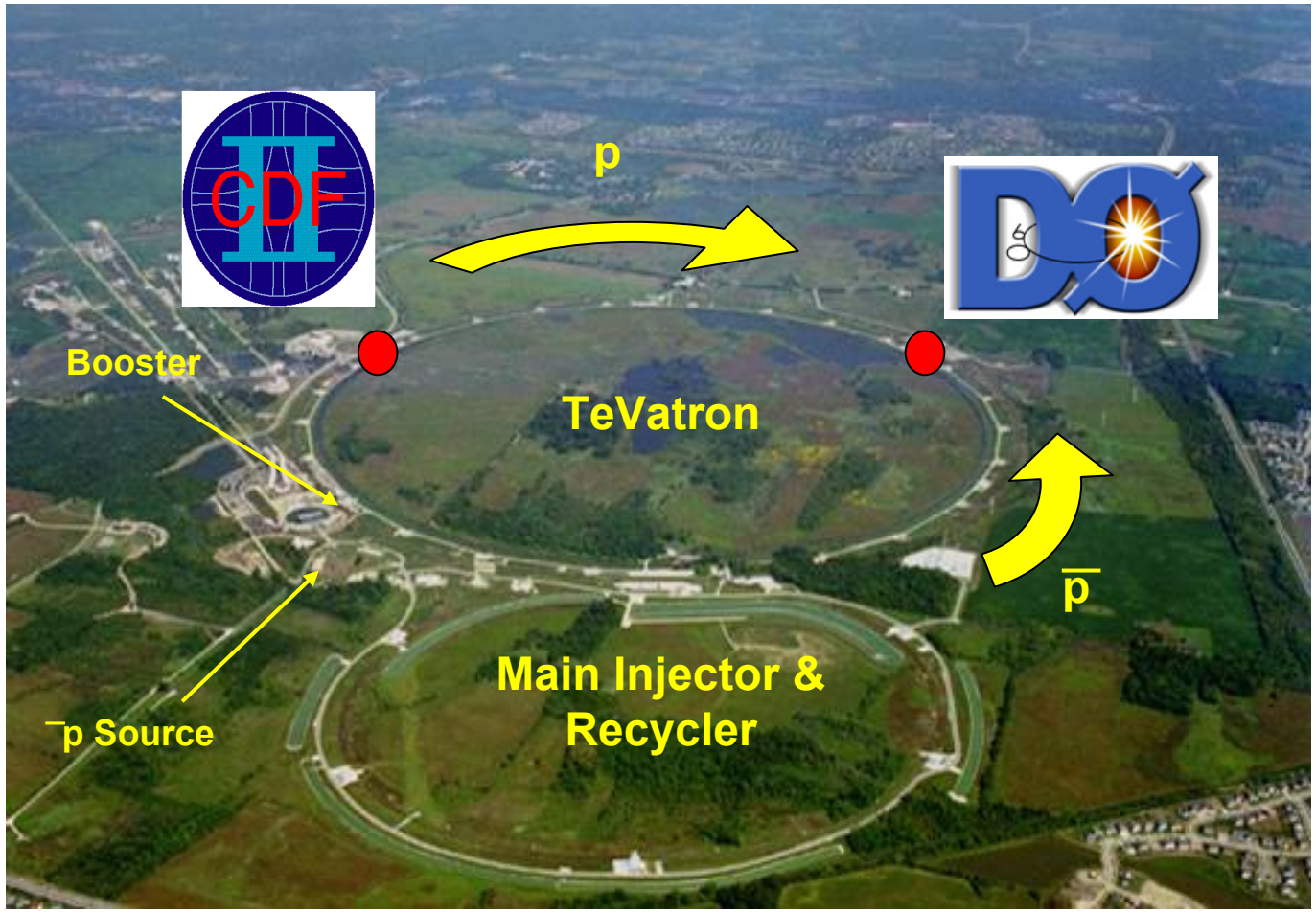
Looks like a massive slow moving muon



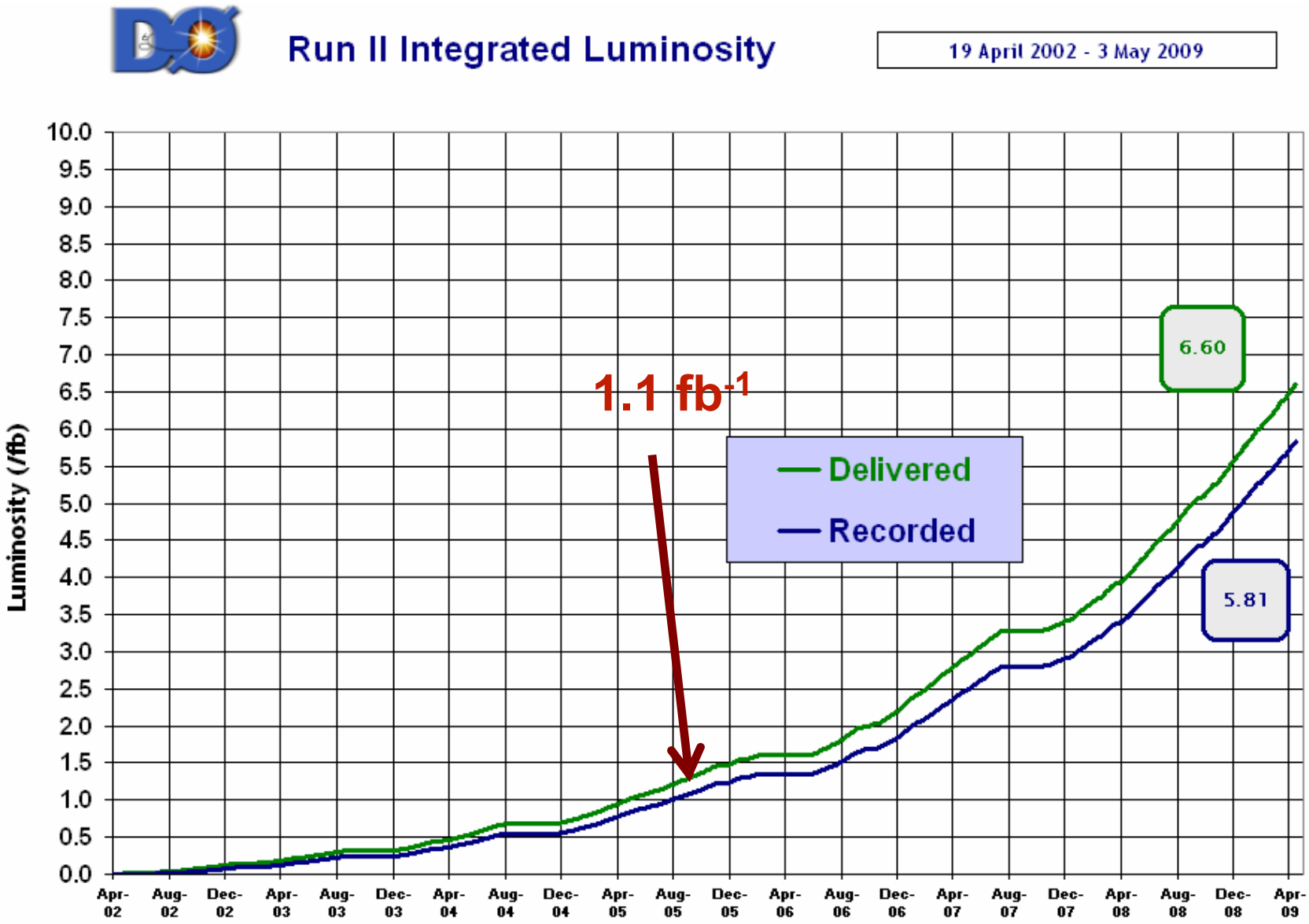
Glance at Fermilab

1993-96 Run I: 100 pb^{-1}, 1.8 TeV

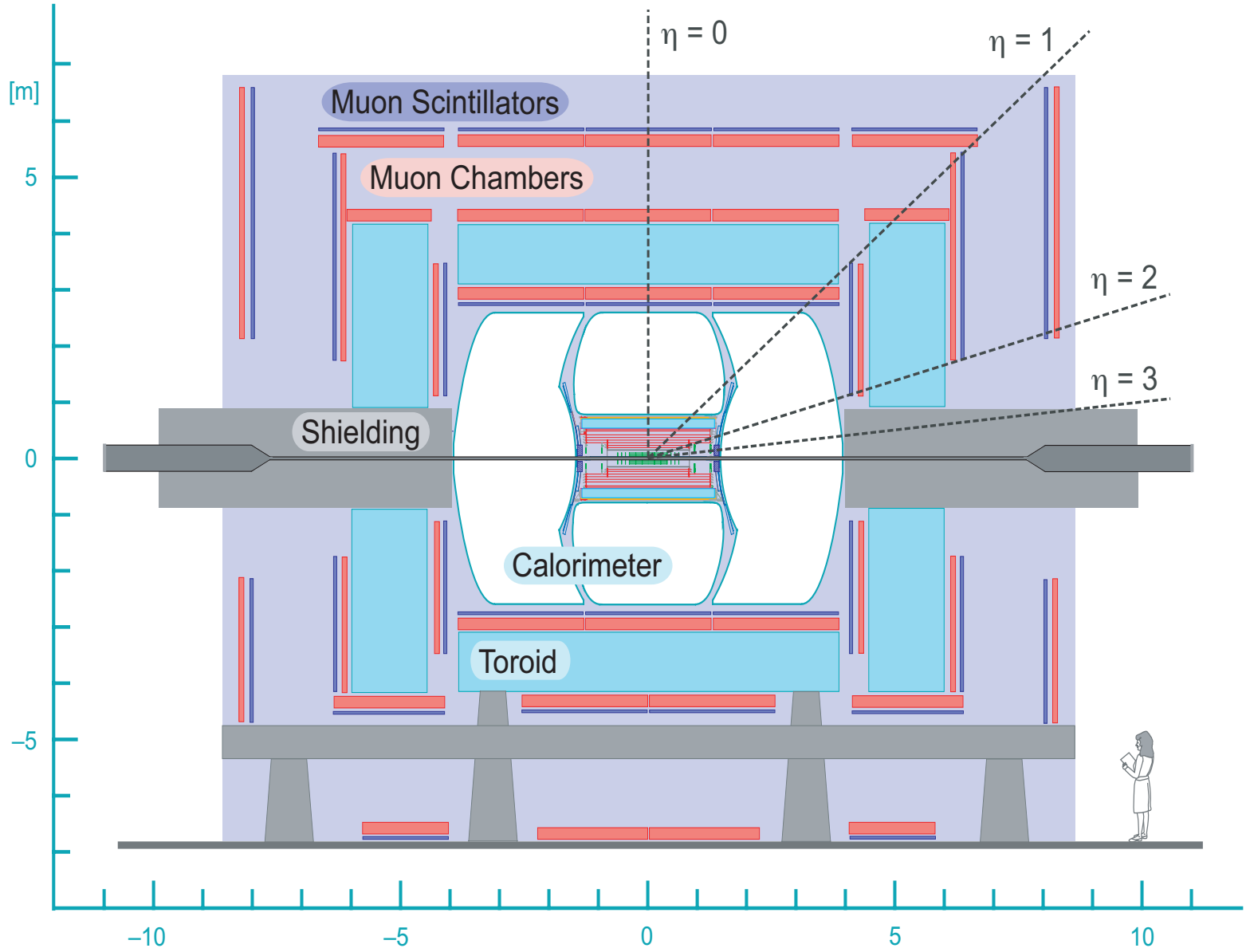
2001-? Run II: E_{cm} = 1.96 TeV



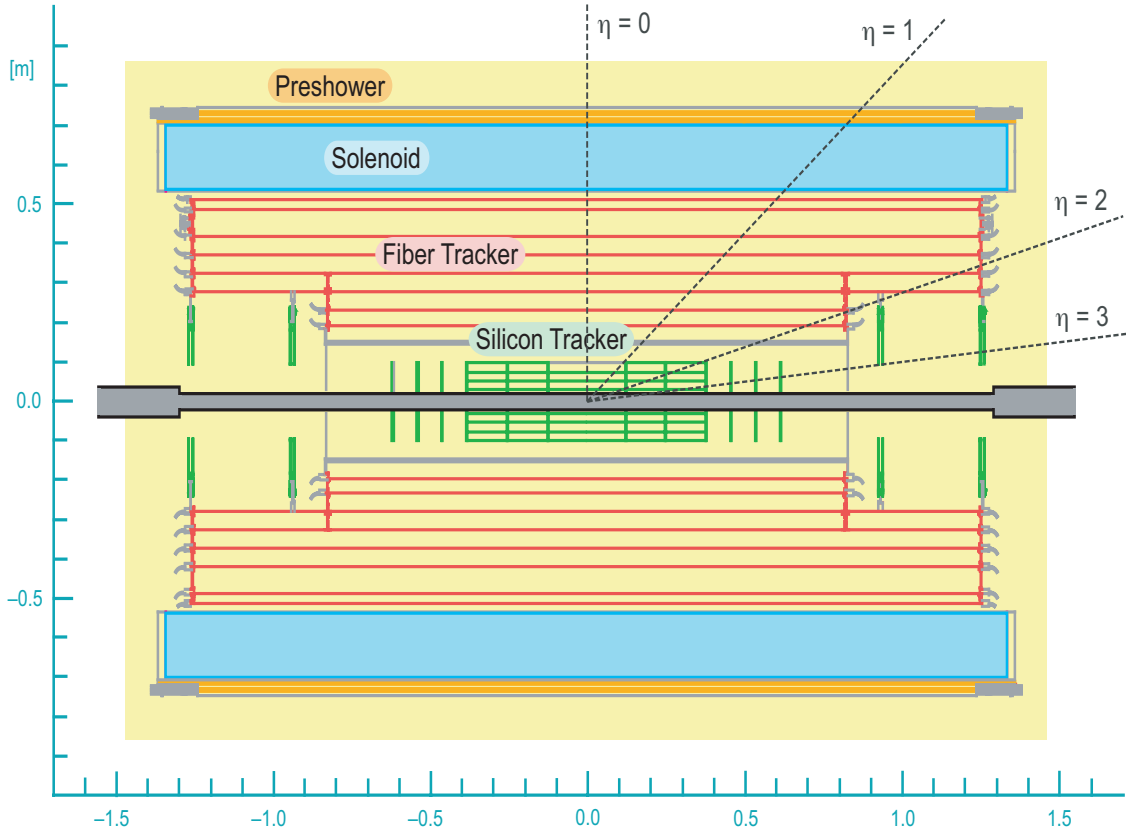
Data Recorded @ DØ



DØ Detector


η = 0
η = 1
η = 2
η = 3
[m]
5
0
–5
Muon Scintillators
Muon Chambers
Shielding
Calorimeter
Toroid
–10
–5
0
5
10

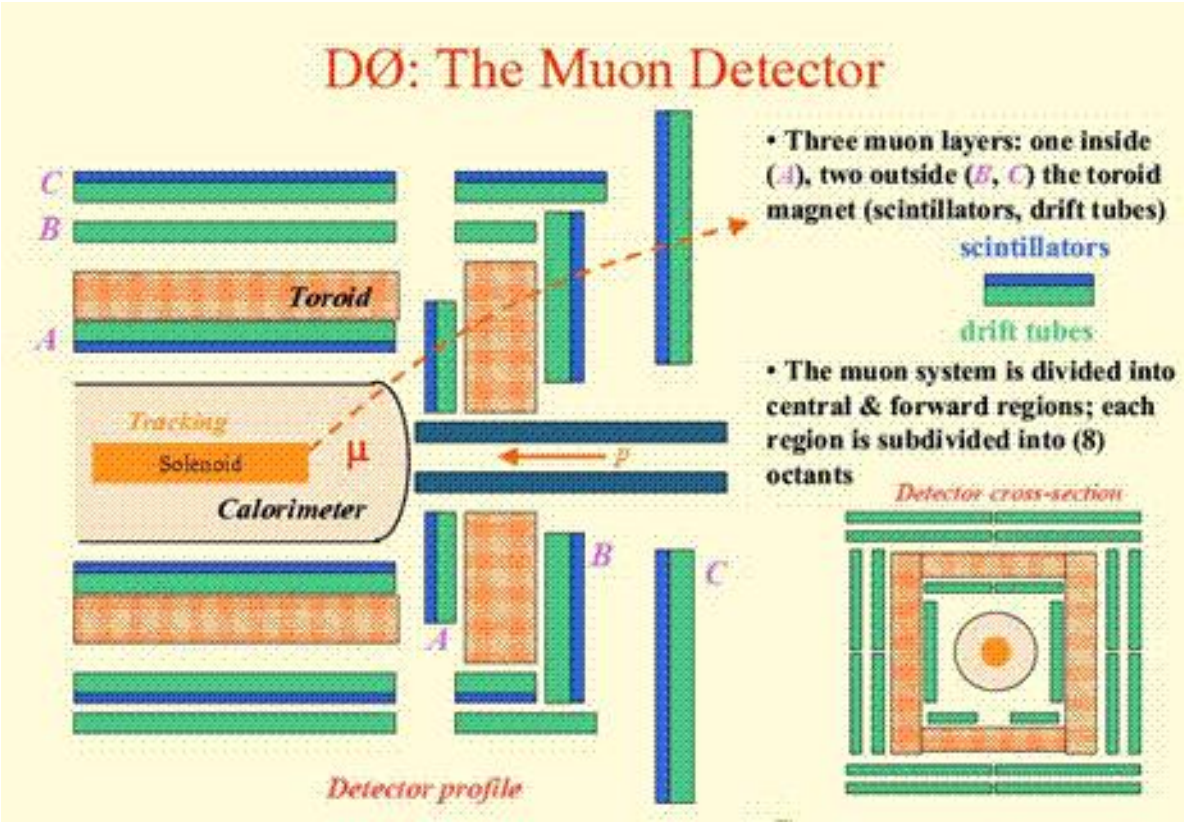
The Central Tracker



- Determines collision point, vertices
- Provides accurate p_T measurement
- Helps the particle identification

The Muon System

- The outmost tracking system provides time-of-flight (TOF) information and particle trajectory
- Three layers (A/B/C) form a cubic geometry
- A 1.8 T toroid magnet between A and B layer

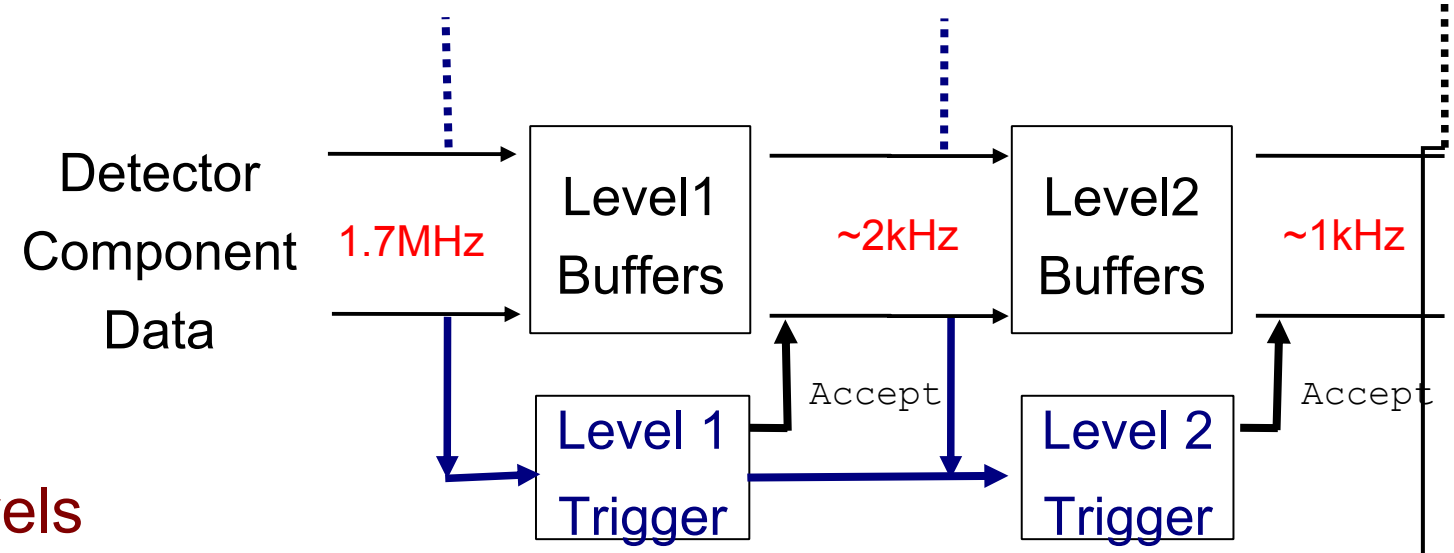


- Measures p_T
- Light speed particles arrive at zero ns
- CMSPs arrive out-of-time
- Timing resolutions :

  2—4 ns

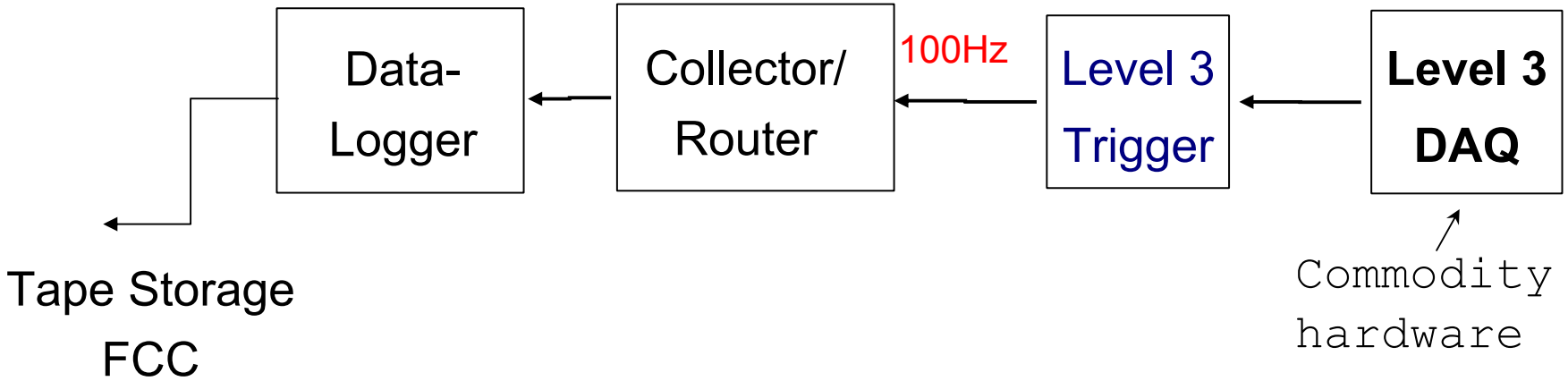
  in different counters

Trigger and Data Acquisition System (DAQ)

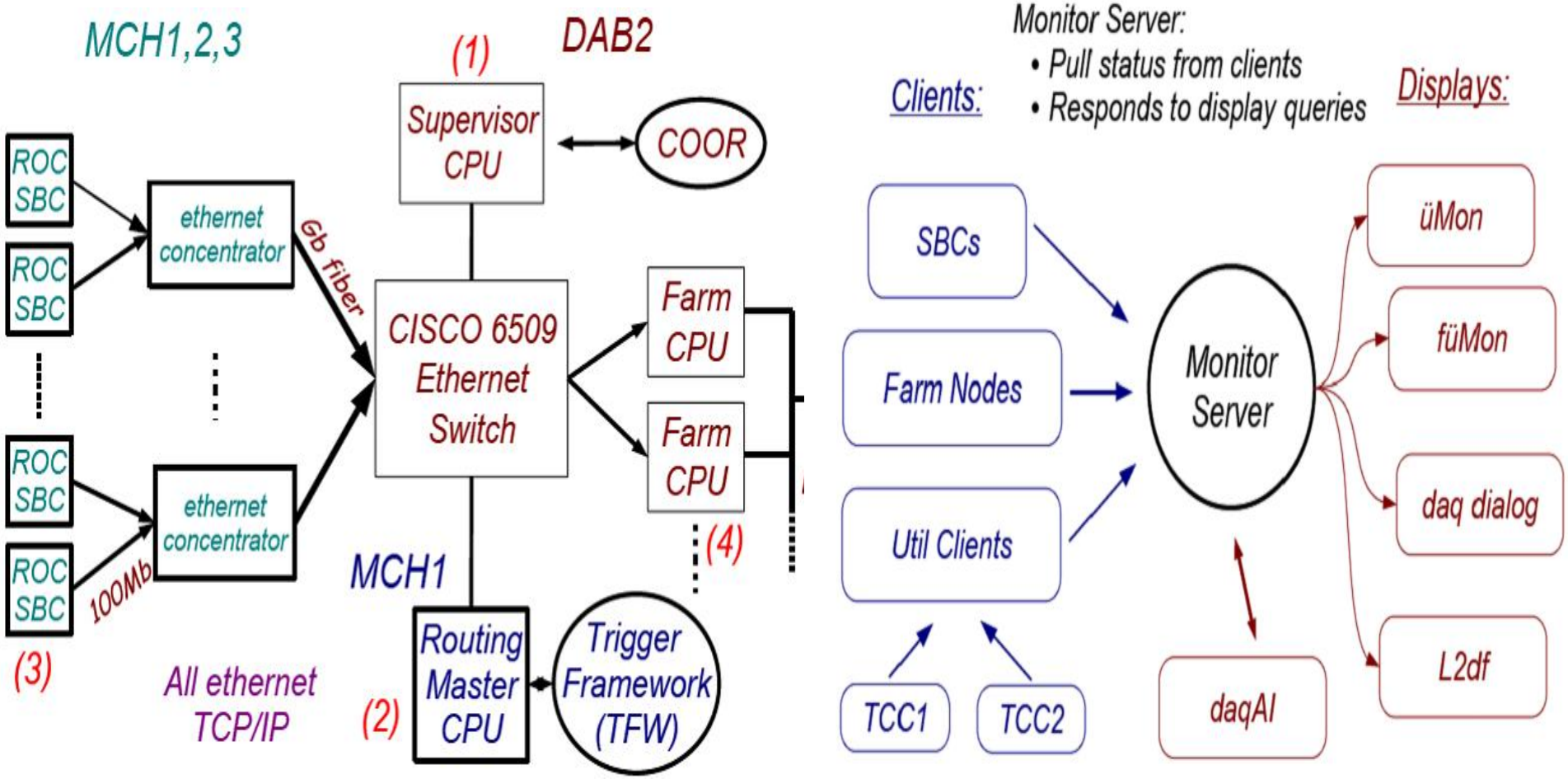


- 3 Trigger levels
- Full event read out after L2 accept
- Write 12~30 MB/s data to tape

250kB/event

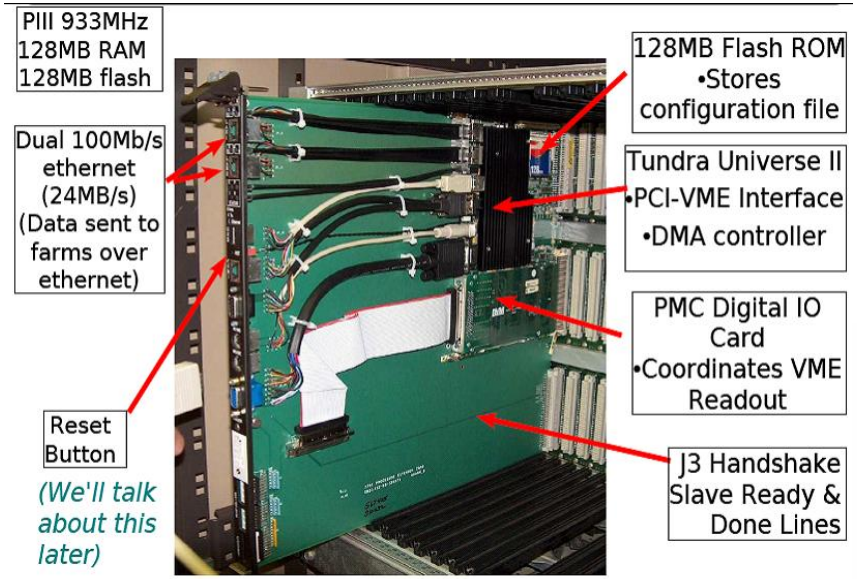


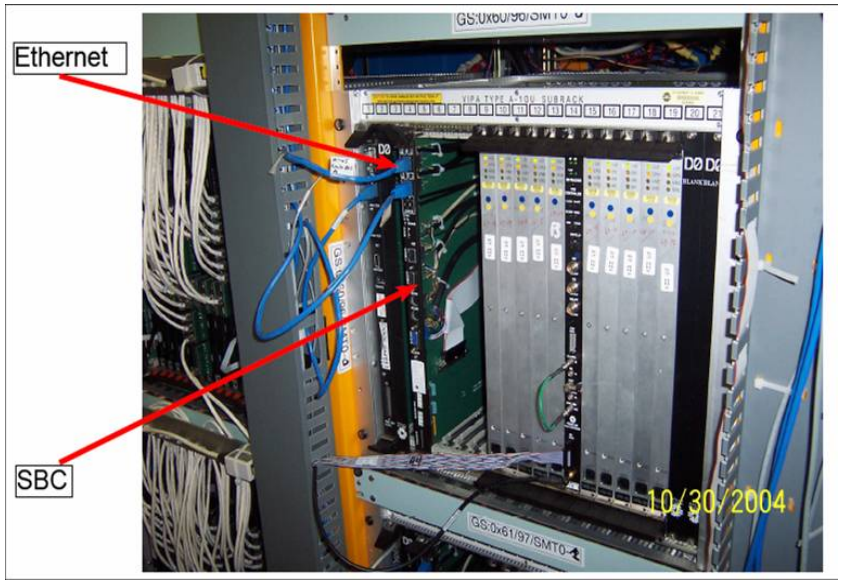
L3DAQ System



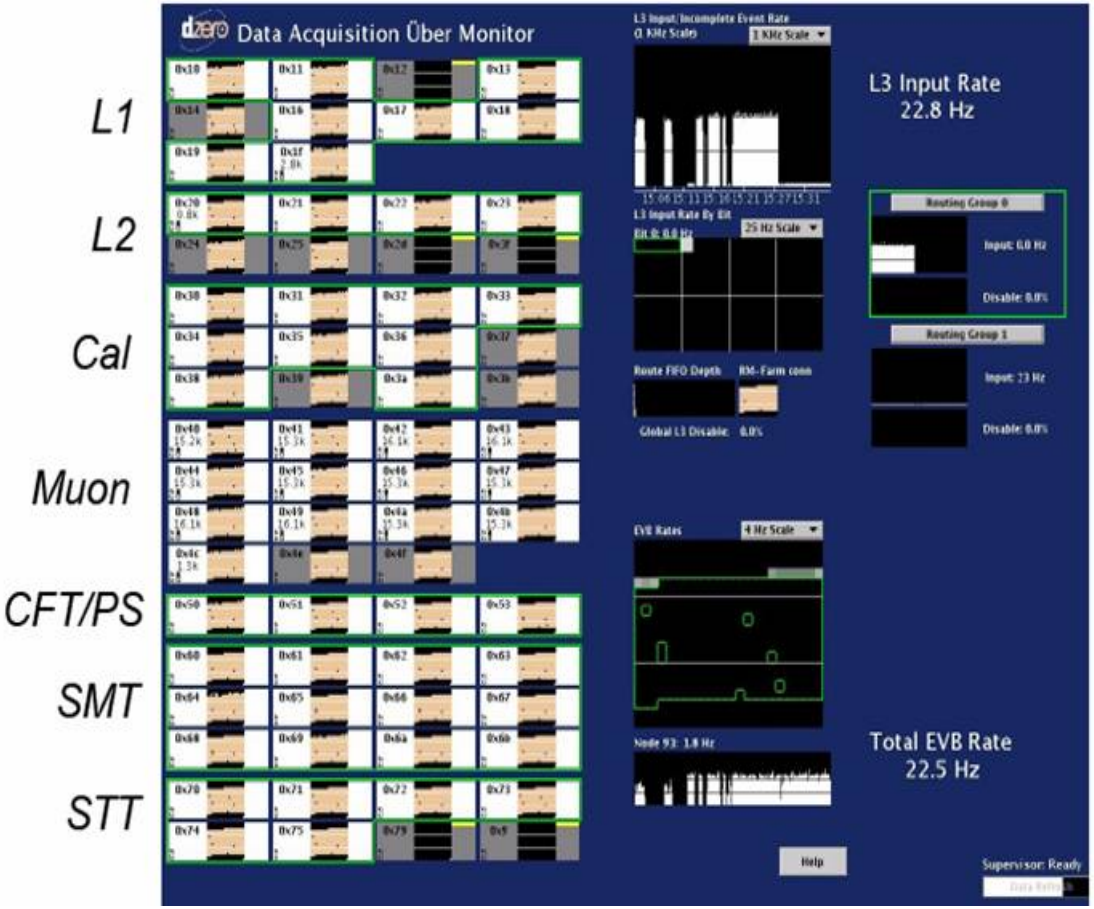
- Joined the L3DAQ team
- Maintained and upgraded the L3DAQ system
- Served as an on-call expert providing 24/7 support with our team

L3DAQ System -- II



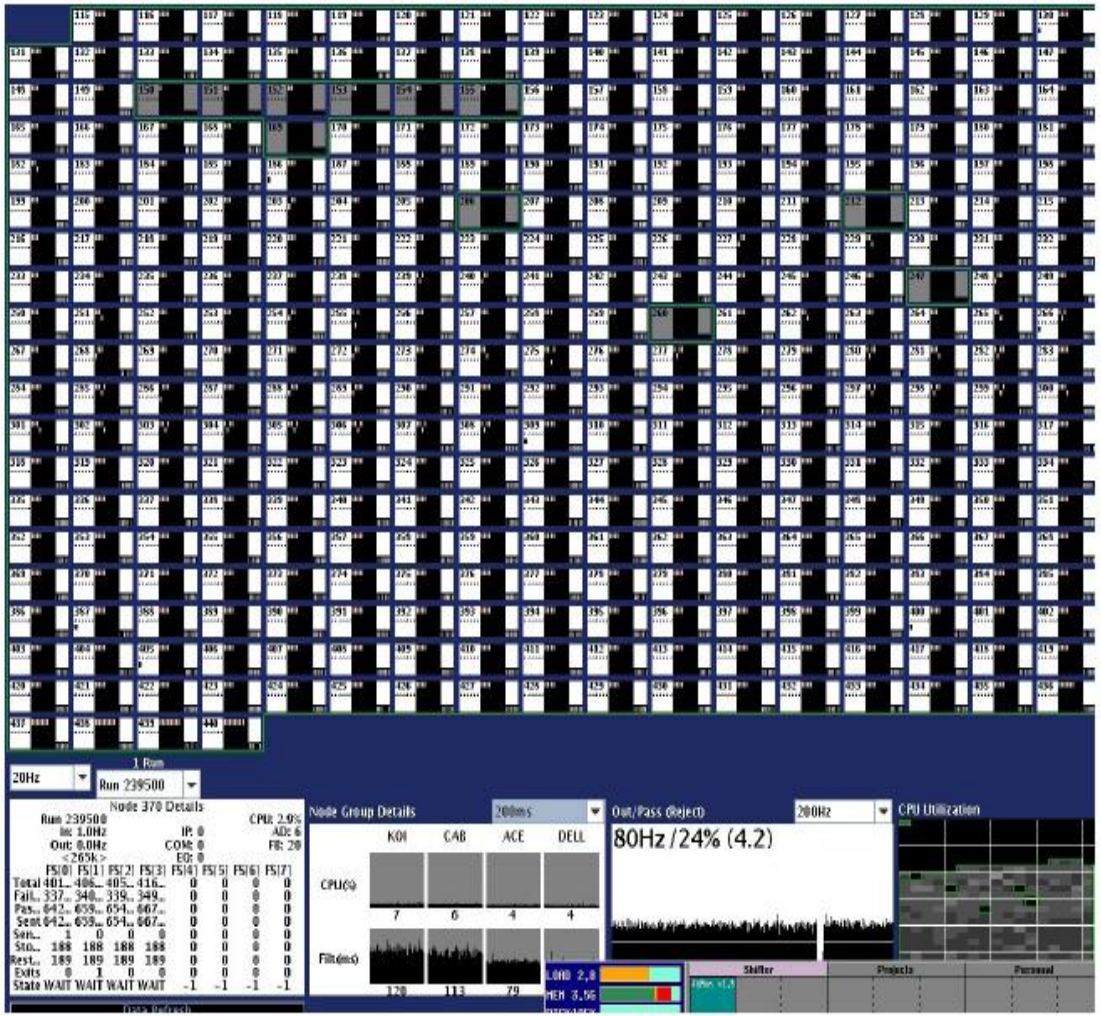


- 66 Single Board Computers (SBCs)
- Three Ethernet configurations optimized for data transfer
- Monitoring GUI: uMon



L3DAQ System -- III

- 288 Farm nodes
- Four compute types
- Optimized configuration for operations
- Monitoring GUI: fuMon



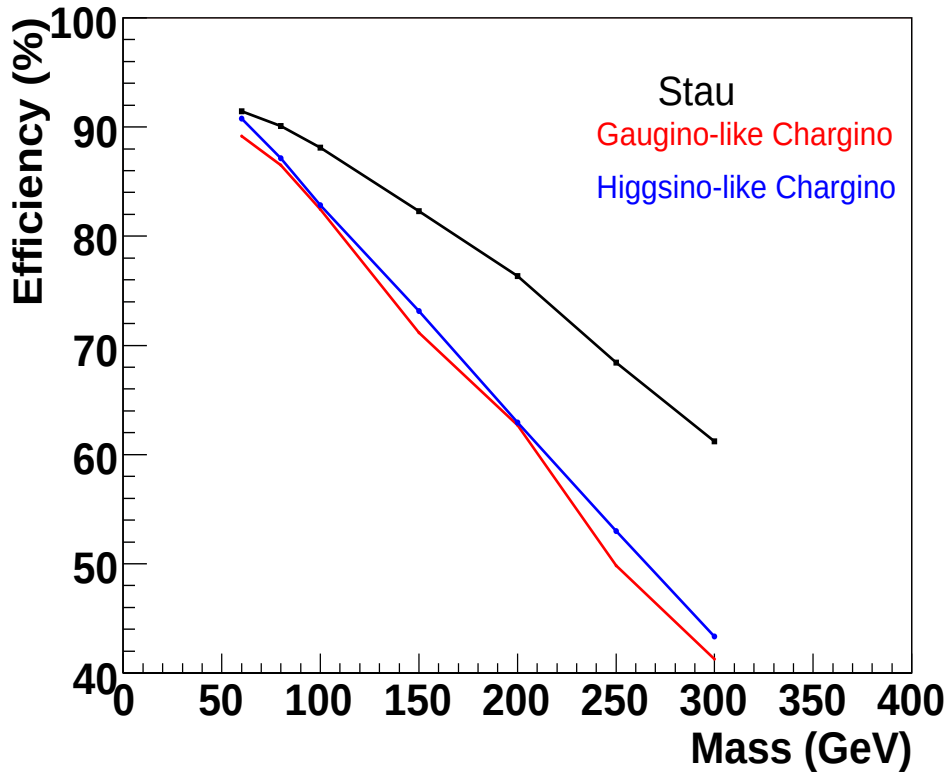
Experimental Strategy

- ***Search for CMSPs by measuring TOF***

DØ Muon Trigger gates are adjusted so that light-speed muons from the collision point will arrive at the gate center of zero ns.

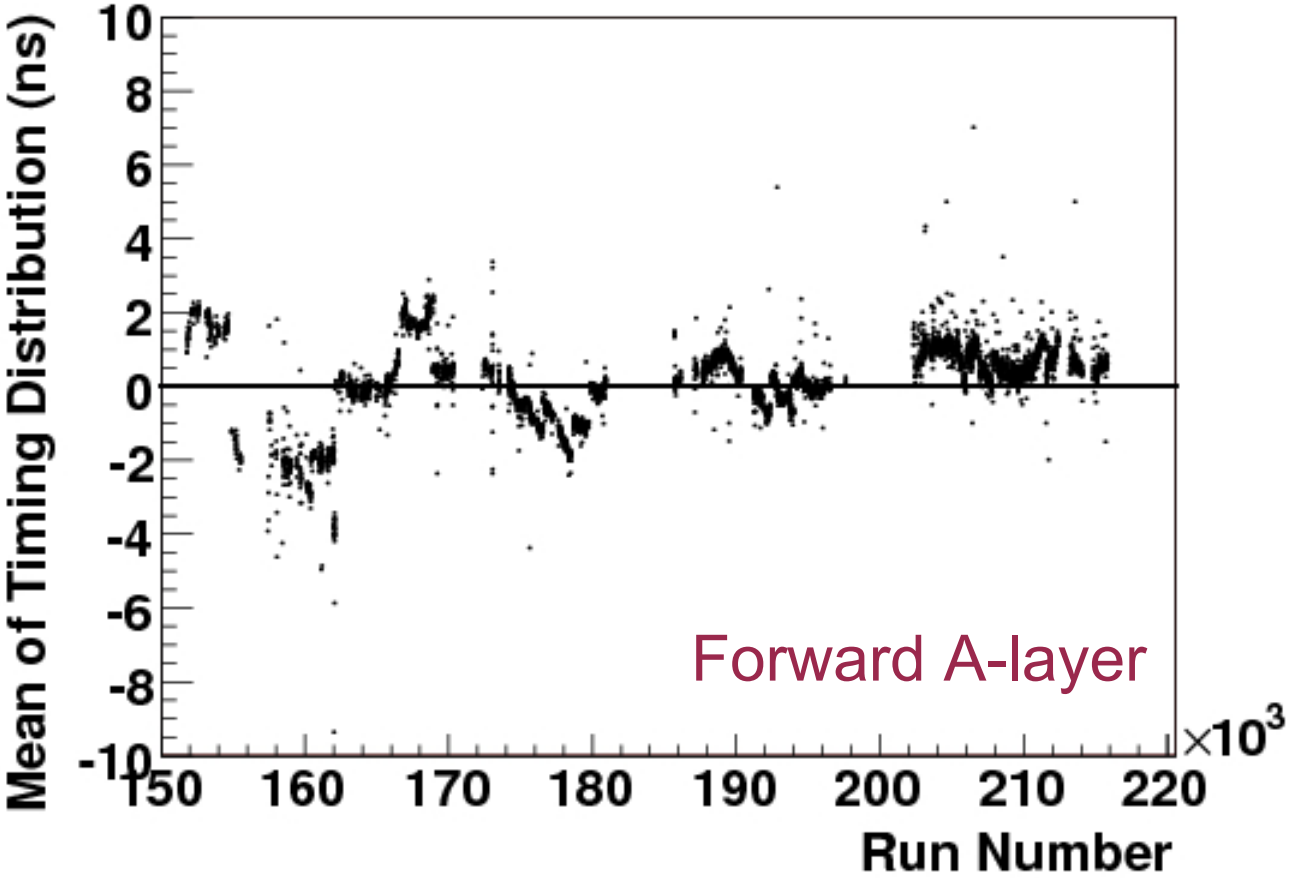
- Reject cosmic rays
- Affect the signal acceptance

layer	D_{min} (m)	Tμ (ns)	gate (ns)
A	2.97	9.9	24
Side B	4.45	14.8	84
Bottom B	4.45	14.8	50
Side C	5.70	19.0	46
Bottom C	7.50	25.0	60



TOF Corrections

The DØ master clock is adjusted to synchronize with the accelerator clock seasonally



The timing shifts are corrected run-to-run for each region in every scintillator plane:

Forward:

A, B, C

Central:

A, B-side, B-bottom, C-top/side, C-bottom

Data and Monte Carlo Simulation

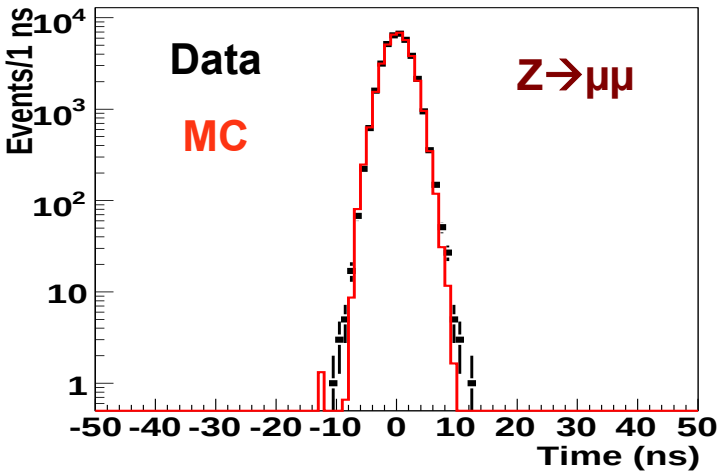
- ***Data with integrated luminosity of 1.1 fb^{-1}***
  - Use DØ standard tools in DØ framework to select events
  - Modify the standard DØ data format to store the TOF and position information of the muon scintillator hits for speed calculation

- ***Full Monte Carlo (MC) simulation for signals***
  - PYTHIA 3.23 as event generator
  - Modified GEANT-based D0 package to simulate the detector responses to the CMSPs
    - Added timing smearing for muon scintillation counter hits
    - Calculated the data/MC scale factor for the scintillation counter efficiency

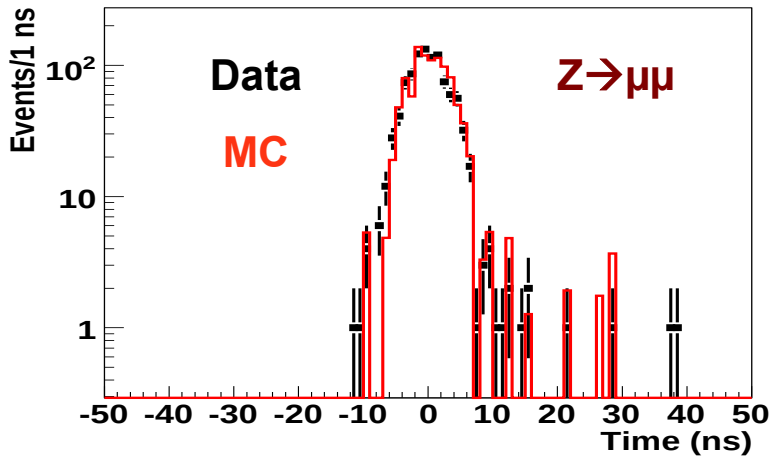
Studies with DØ GEANT Simulation

Standard packages were developed to apply p_T smearing, ID efficiencies and trigger efficiencies, as well as the data/MC scale factors

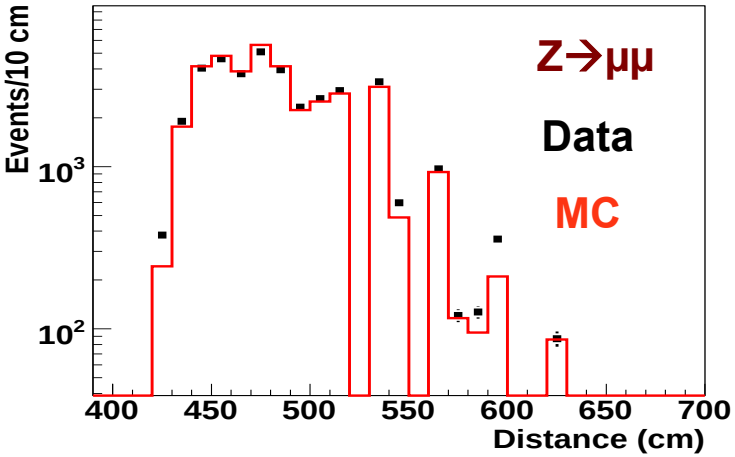
Forward A-layer time



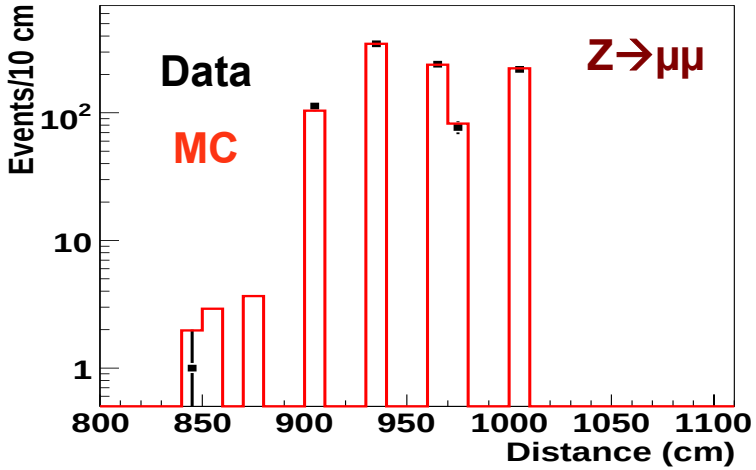
Central bottom C-layer Time



Forward A-layer distance

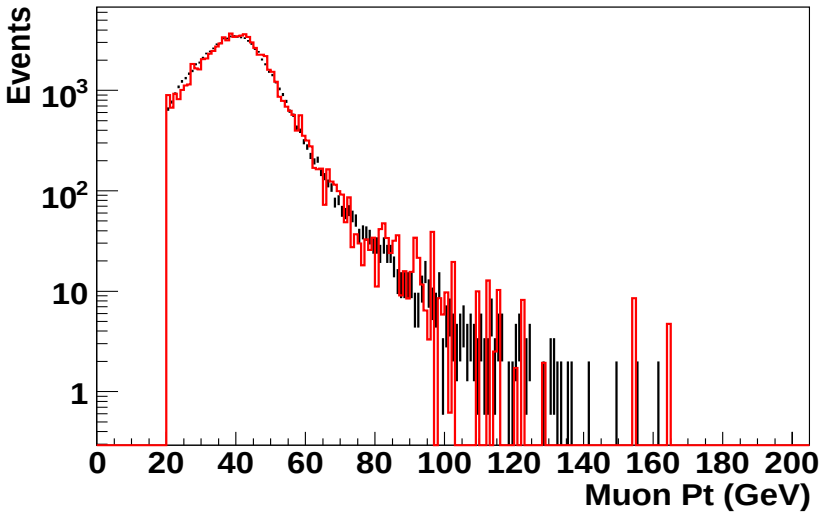


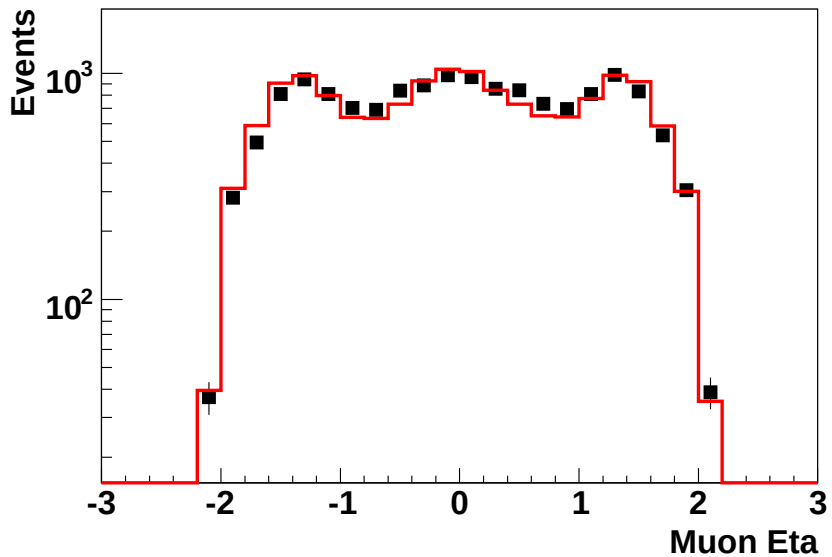
Central bottom C-layer distance

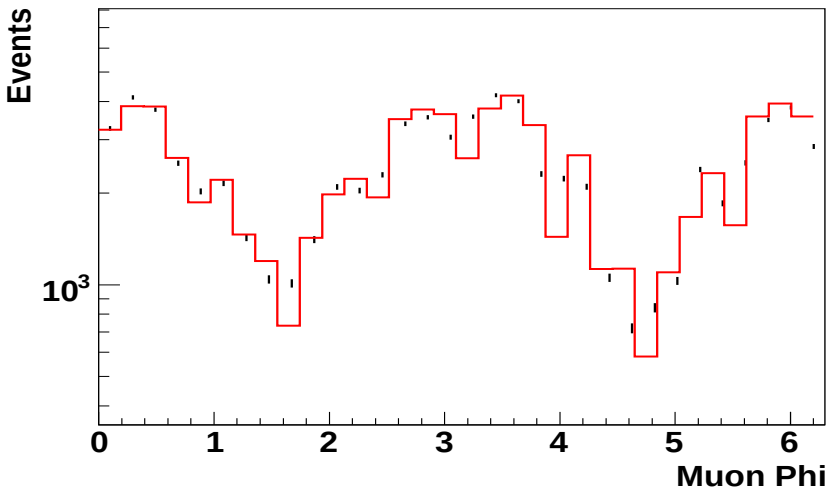


Studies with DØ GEANT Simulation -- II

P_T, η, φ plots of Z→μ μ events, data (dot) and MC (red)



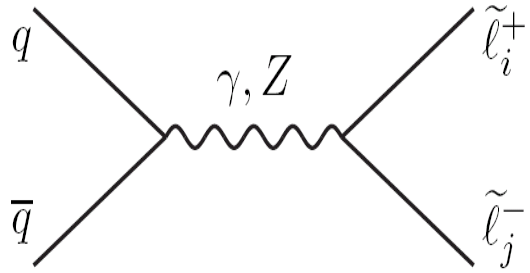




Good agreement between data and MC.

Event Selection

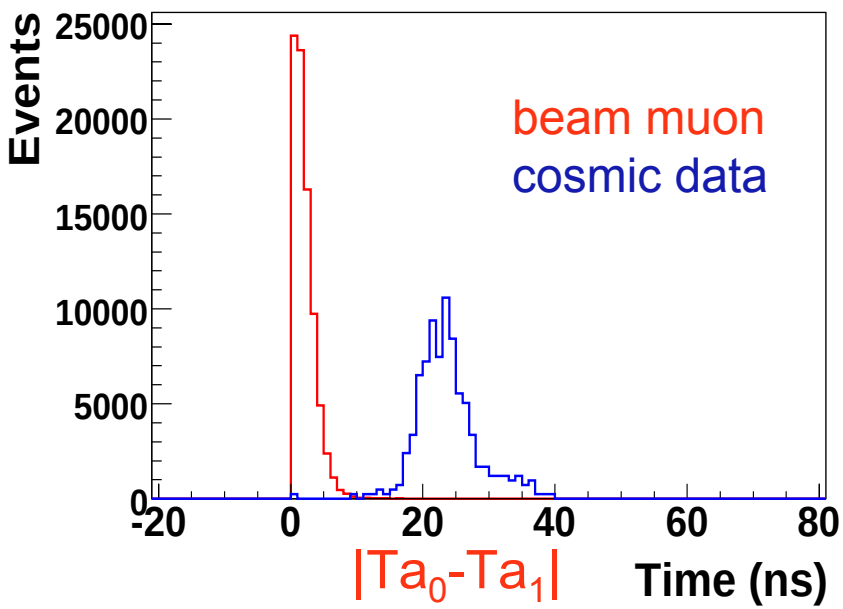
- ***Pair produced CMSPs***
  - only direct pair-production is considered
  - cascade decays are not included

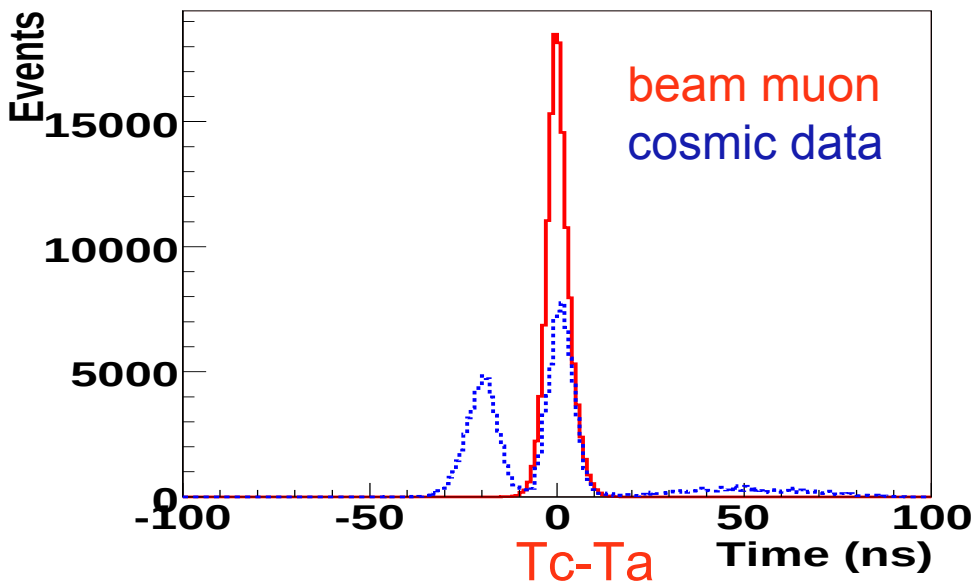


- ***Select events with two good "muons"***
  - only muons in the detector geometry
  - muons with a matched central track
  - muons with good quality, based on the muon system information, scintillator hits in both A- and B-/C- layer
  - muons with high transverse momenta $p_T > 20.$ GeV
  - muons with good isolations:
    - $\Sigma(p_T) < 2.5$ GeV (for cone of radius $R < 0.5$)
    - $\Sigma(E_T) < 2.5$ GeV (for hollow cone of radius $0.1 < R < 0.4$)

Cosmic Ray Rejection

- ***Cosmic rays will be reconstructed as two collinear muons***
  - may be mis-identified as slow muons
- ***Event is rejected if one of the following is true:***
  - Time difference between A-layer hit of two muons, $|T_{a0}-T_{a1}| \geq 10$ns
  - C-layer time minus A-layer time for either muon, Tc-Ta < -10ns
  - Psuedo-acolinearity is $\Delta\alpha = \left|\Delta\phi_{\mu\mu} + \Delta\theta_{\mu\mu} - 2\pi\right| < 0.05$



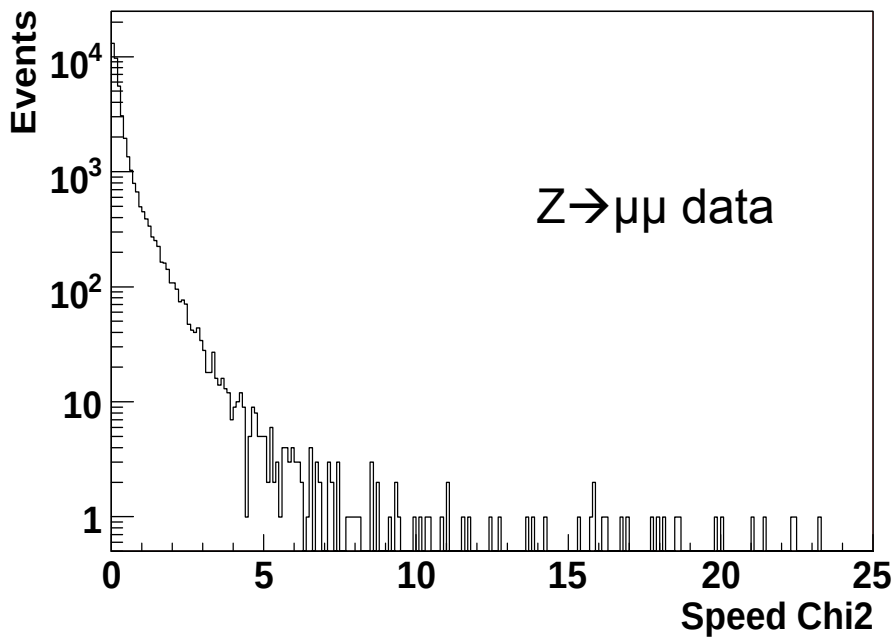


Speed and χ^2/d.o.f. cut

- ***Calculate the speed of muons at each layer***
  - v = d/t (v in units of c)
  - σ_v from timing error
- ***Calculate the average speed v_{avg} for each muon by taking the weighted average of the individual layer speeds***
- ***Speed χ^2/d.o.f. cut***
  - remove muons which have hits mis-reconstructed

$$\frac{\chi^2}{d.o.f.} = \sum_{layer} \frac{\left(v_{avg} - v_{layer}\right)^2}{\sigma_{layer}^2} < 4.7$$

  - cut value is optimized on the Z events

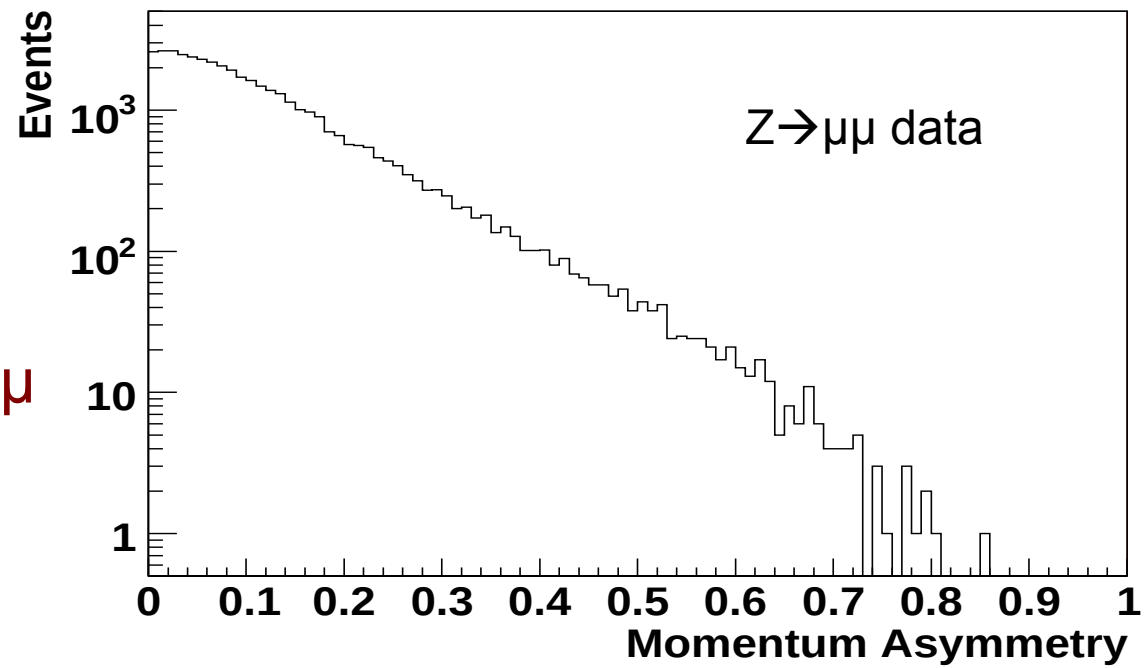


Transverse Momentum Asymmetry

- ***p_T balance***
  - the transverse momenta of the two particles should be equal or close in the pair-production events
  - measurement uncertainty is large for high momentum particles
- ***Reject events which have p_T mis-measured***
  - p_T asymmetry is defined as:

$$p_T^{asym} = \frac{\left| p_T^1 - p_T^2 \right|}{p_T^1 + p_T^2}$$

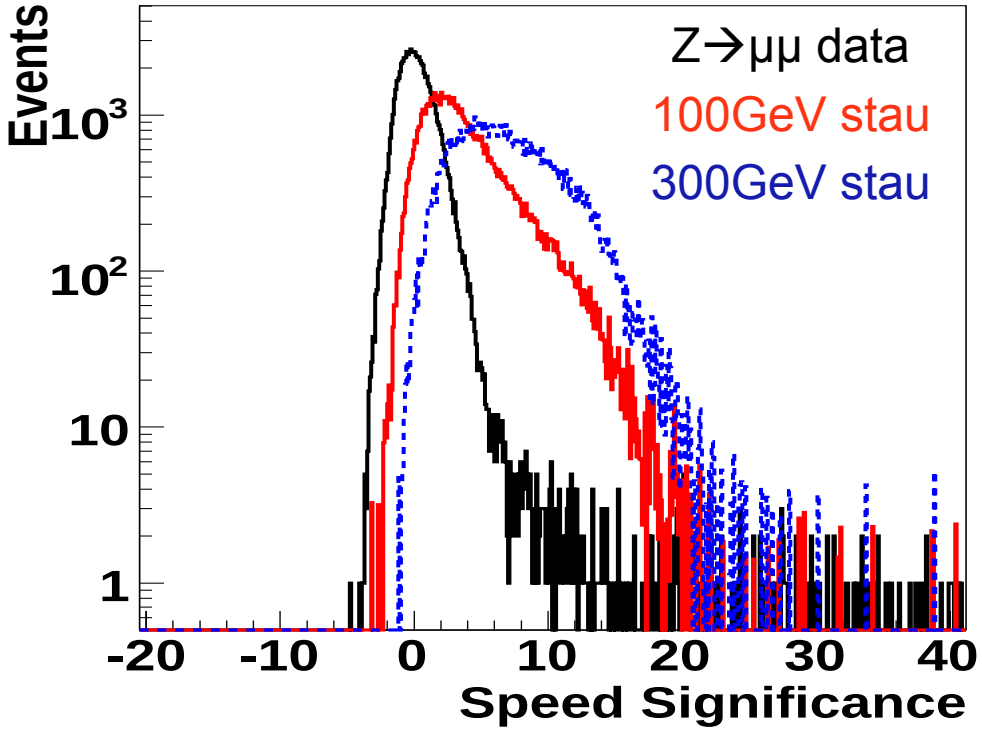
- optimized on the Z->μμ events in real data sample



New Variables

- ***New variables needed to classify the signal and backgrounds***
  - **Speed significance of the muon:** $(1-v_{avg}) / \sigma_{speed}$
  - **Speed significance product of the muon pair**
  - **Invariant mass of the muon pair**

- ***Require both particles with a positive speed significance***
  - light-speed muons will center at zero
  - CMSPs will have positive values



Speed Significance Product

- ***Three types of signals:***

  same data

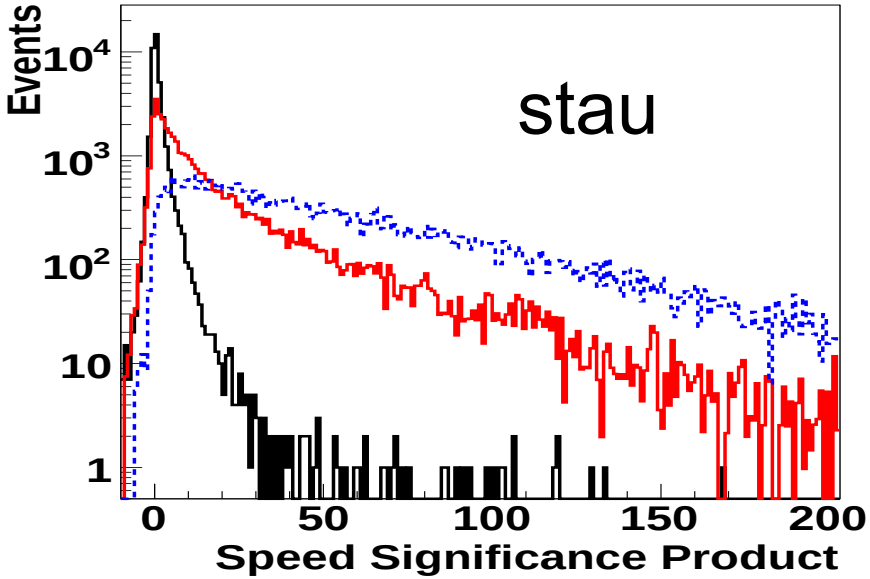
  same analysis code

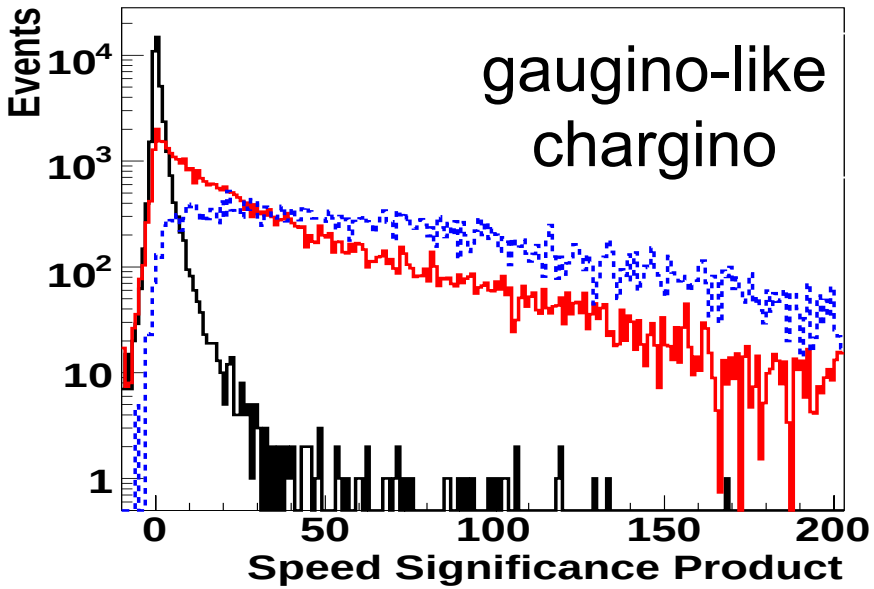
  different MC signals

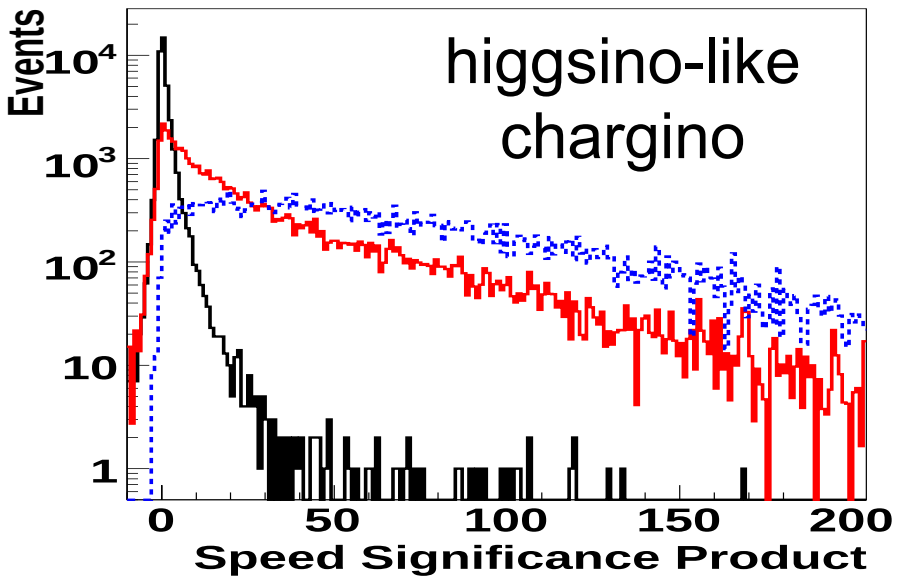
  Data

  CMSP (100 GeV)

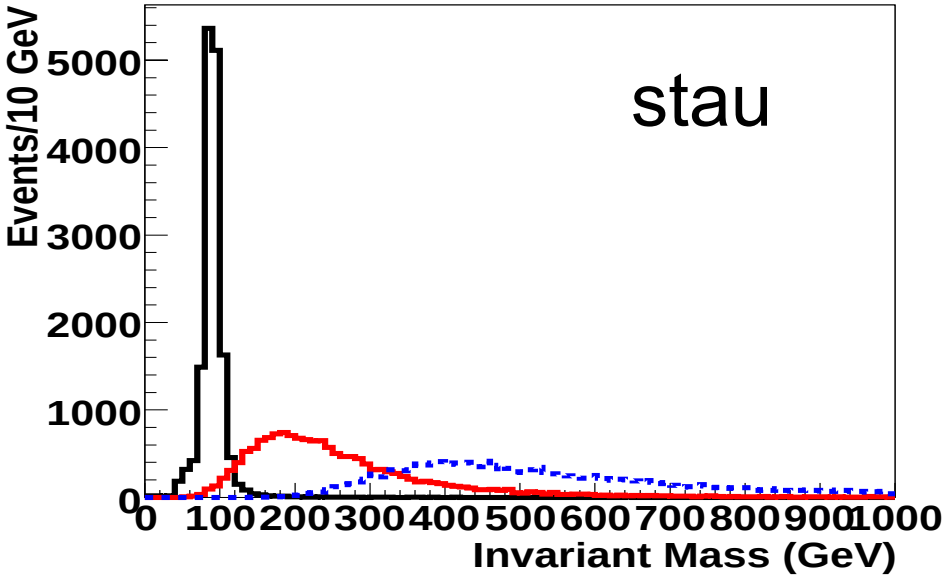
  CMSP (300 GeV)



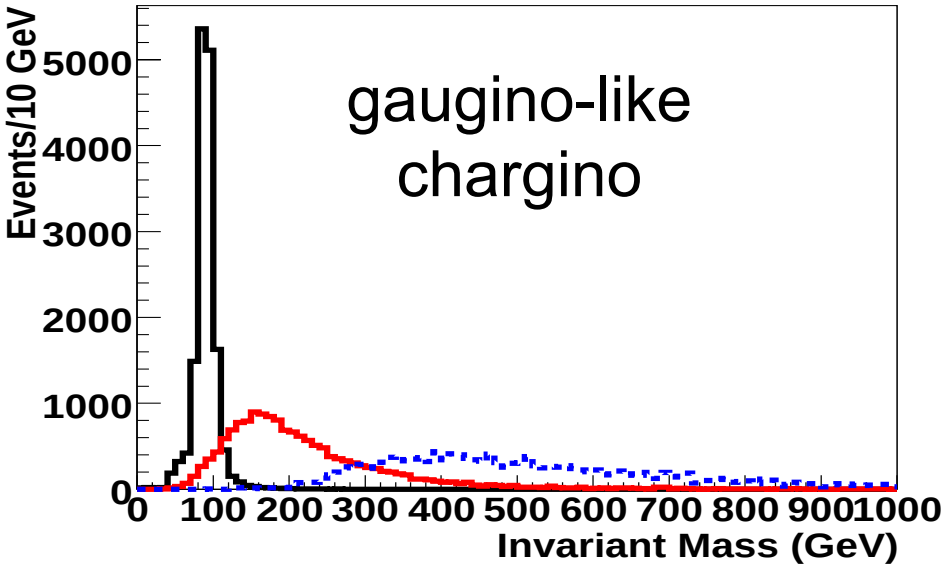


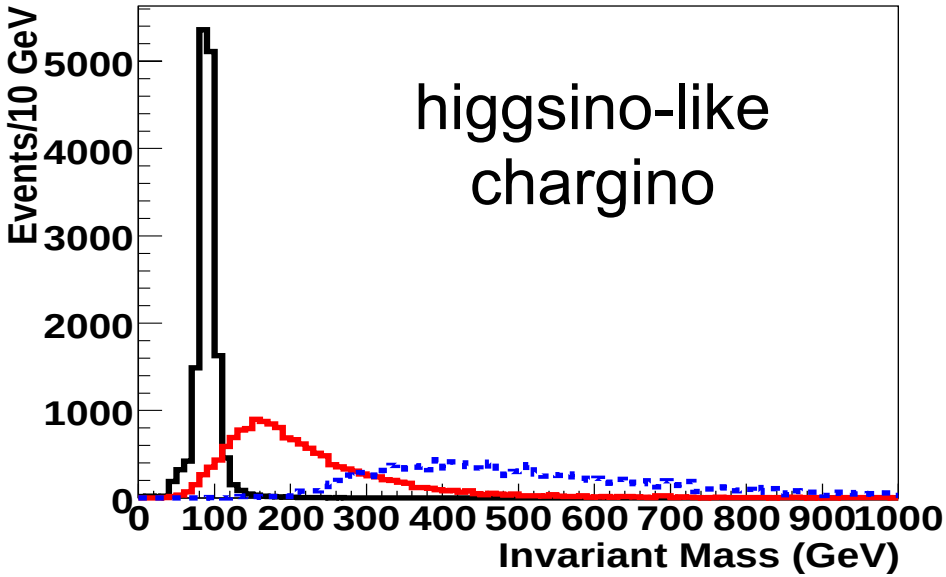


Invariant Mass



Data
CMSP (100 GeV)
CMSP (300 GeV)

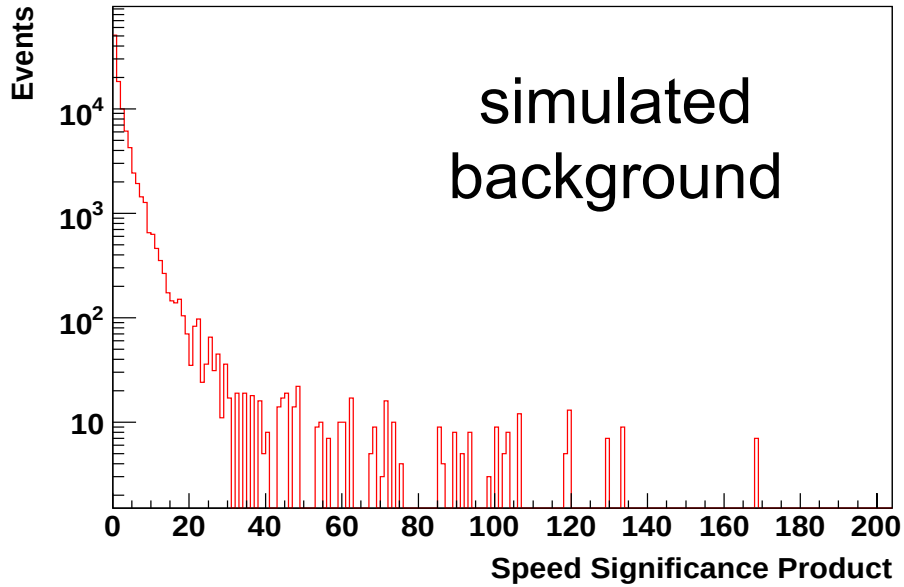




Background Estimation

- ***Clean physics channel:*** No SM physics background with high-p_T massive long-lived particles
- ***Concern of the limitations of the detector performance***
  - Mis-measured TOF of muons leads to small speed and positive speed significance
  - Mis-measured p_T of particles leads to large invariant mass
- ***Estimation done with real data***
  - The speed significance product of the muon pair of the background is simulated by the events with the invariant mass in Z peak region

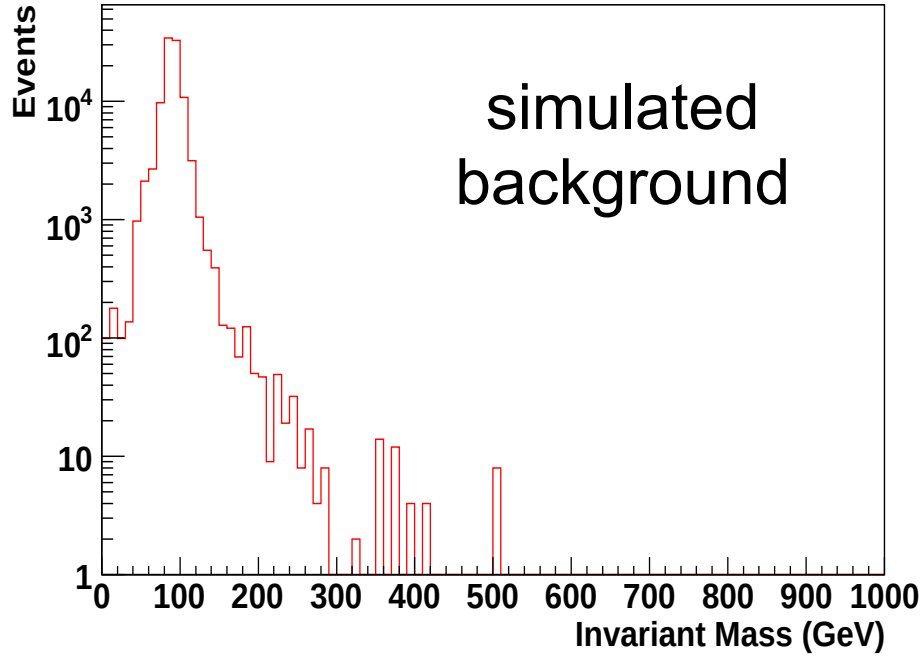
    -- the signal contamination is negligible



Background Estimation -- II

- The invariant mass of the background is simulated by the invariant mass of data events with two negative speed significance muons

-- No signal contamination



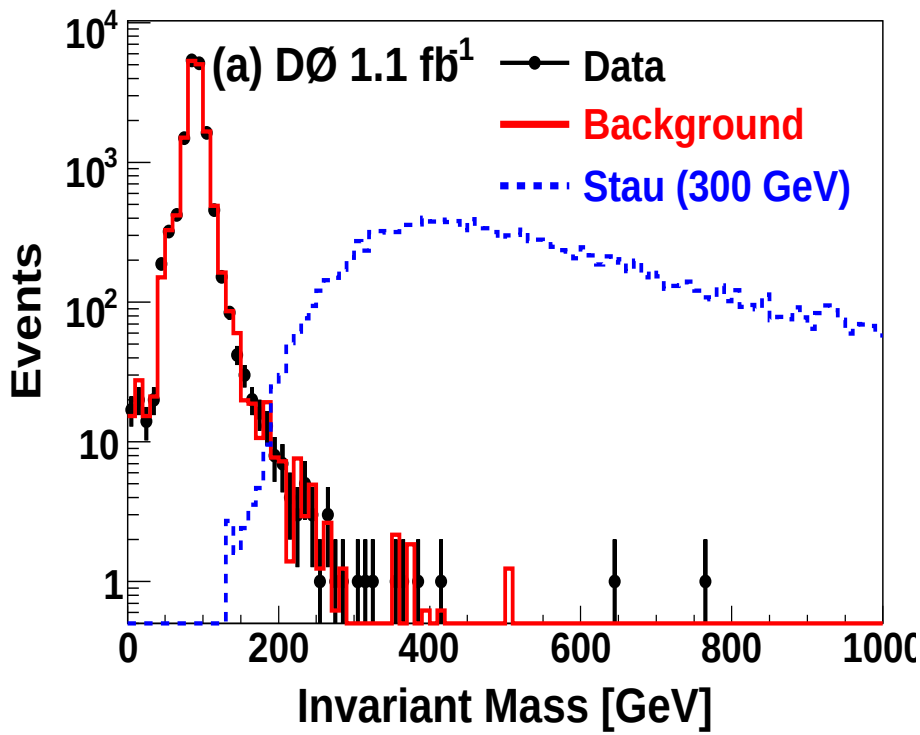
- 100 K simulated background events are generated by getting random values from these two distributions
- The number of background events is normalized to the Z/Drell-Yan events passing all the selection criteria

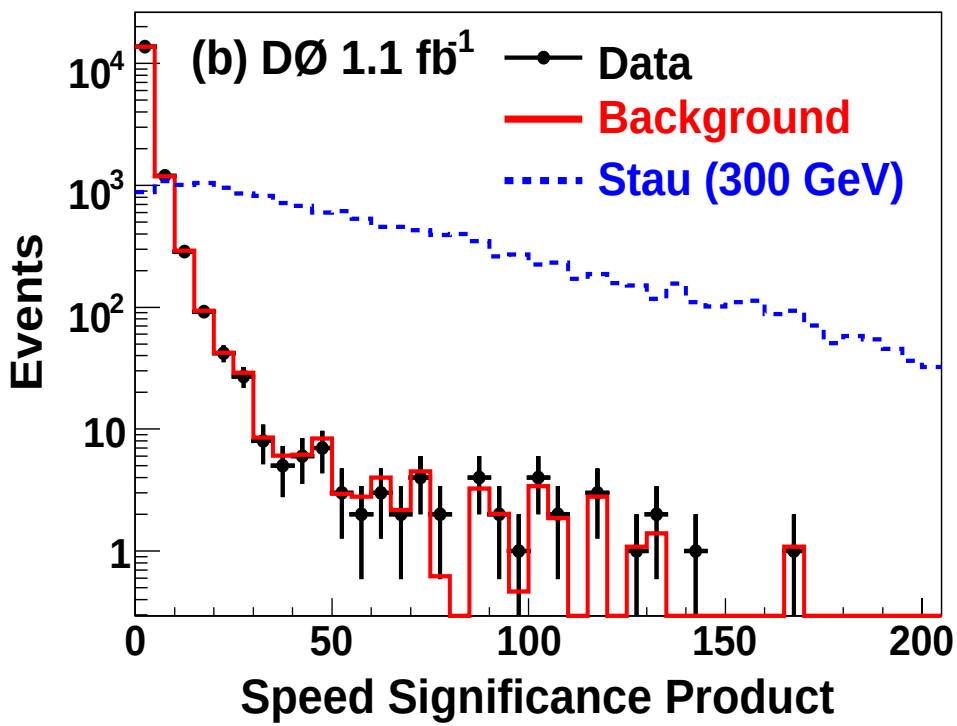
Likelihood Function

Using Bayesian decision theory with joint likelihood function

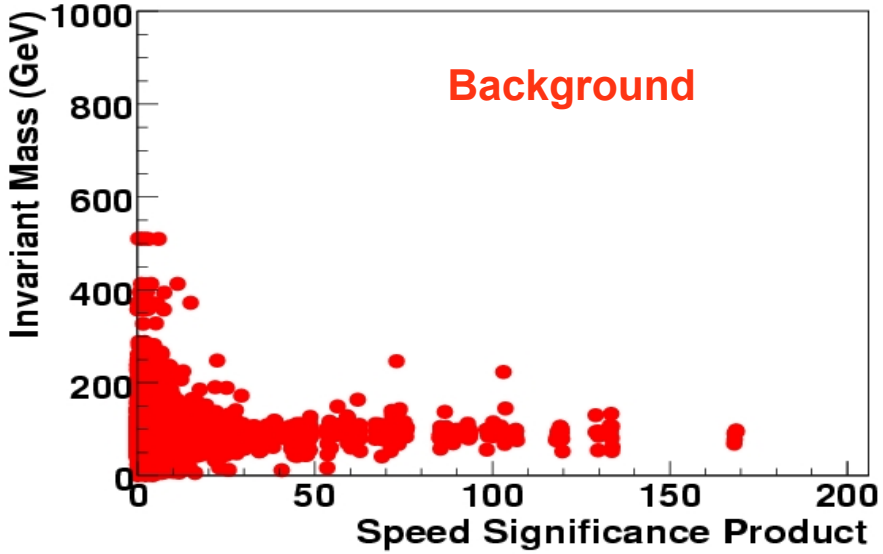
$$p(x \mid i) = p(m \mid i) \times p(sig \mid i)$$

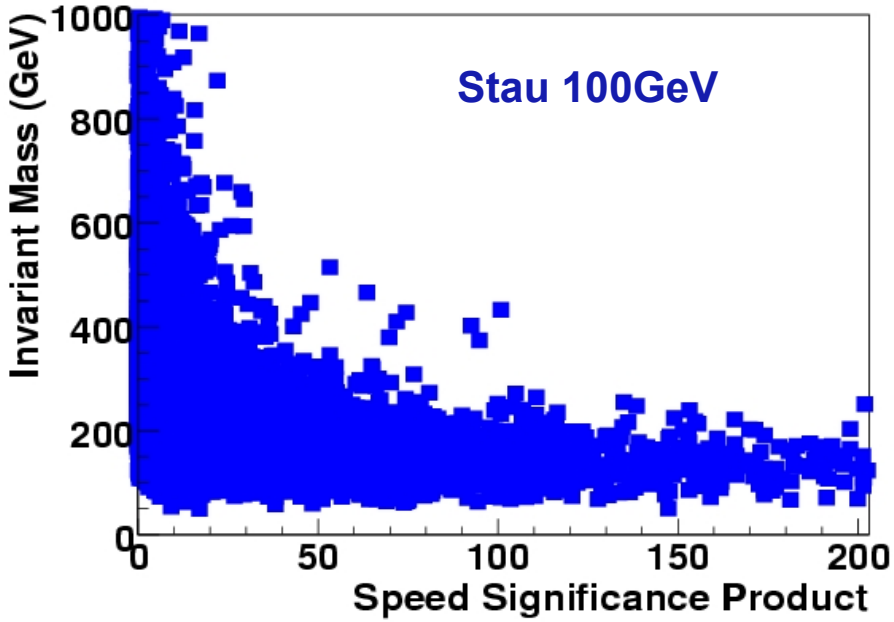
where x is the feature vector (m, sig), m is the invariant mass, sig is the speed significance product of the muons, p(x|i) is the probability of observing x given background(i=0) or signal(i=1).



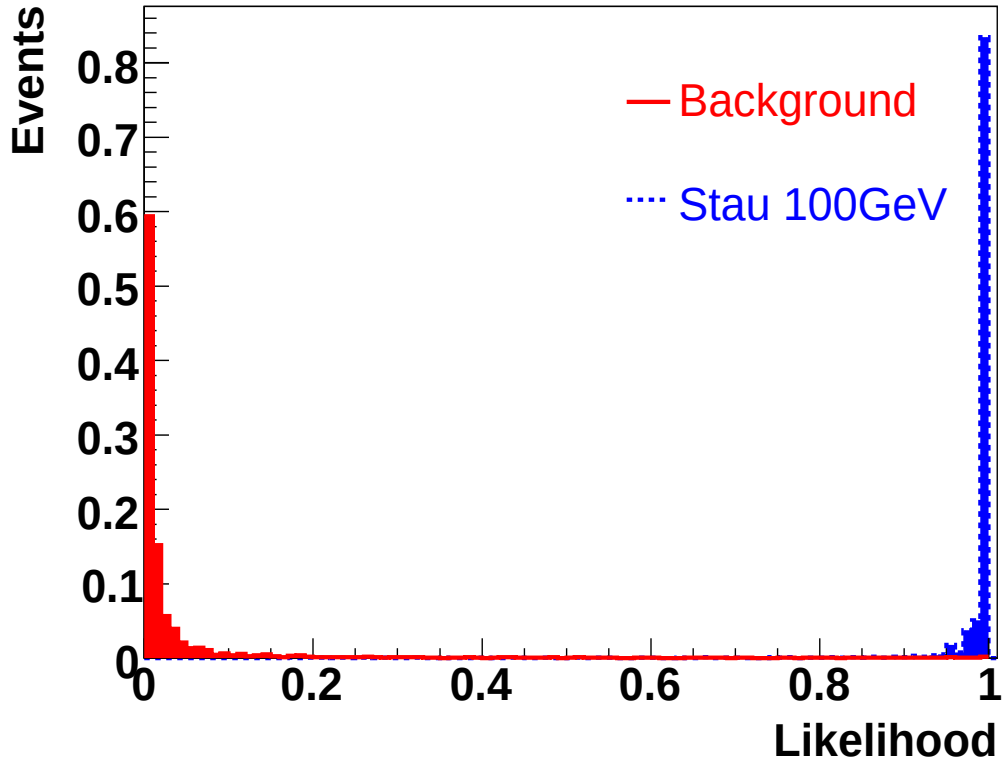


Discriminant Function





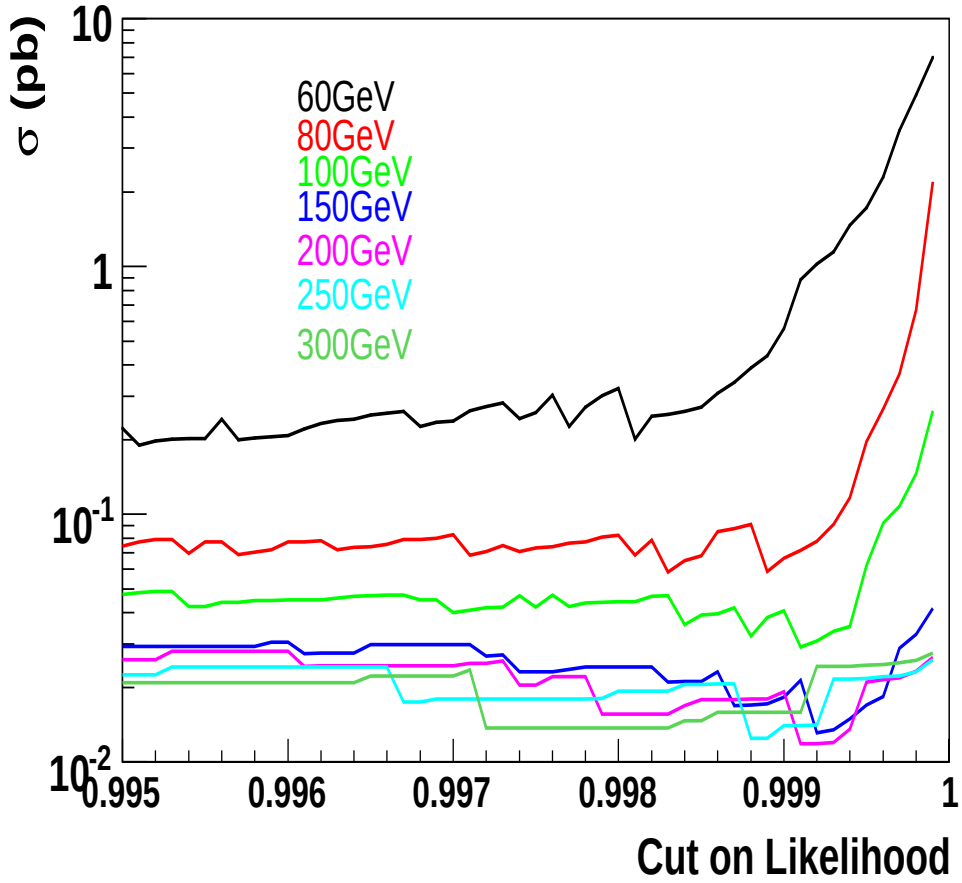
Discriminant function:
$g(x)=S(x)/(S(x)+B(x))$
in range [0, 1]



Optimization

Optimize cut on likelihood method

- Set cut value from 0 to 1 with step 0.0001
- Derive the background rejection and signal acceptance for each cut
- Calculate the expected limit for each cut with statistical uncertainties
- Find the cut with the minimum expected limit



Systematic Studies

- ***Background estimation:***

  Vary the criteria for selecting the events to simulate the background.
- ***Signal acceptance:***
  - Time-of-flight smearing
  - L1 Muon trigger gate accuracy
  - Muon ID and data/MC scale factor
  - Uncertainty in PDFs
  - Zero bias events over-lay
- ***Luminosity uncertainty***
- ***Predicted signal cross section:***

  PDFs and scale uncertainty (very small, shown in figures)

Analysis Details -- I

Stau

Mass (GeV)	Signal Acc. ($x10^{-3}$)	Exp. Signal Events	Predicted Background	# of Obs. Events
60	64 ± 1 ± 5	4.7	30.9 ± 2.2 ± 1.9	38
80	38 ± 1 ± 5	1.1	2.6 ± 0.6 ± 0.4	1
100	56 ± 1 ± 4	0.7	1.6 ± 0.5 ± 0.3	1
150	123 ± 2 ± 13	0.3	1.7 ± 0.5 ± 0.2	1
200	139 ± 2 ± 11	0.1	1.7 ± 0.5 ± 0.2	1
250	133 ± 2 ± 13	0.01	1.7 ± 0.5 ± 0.3	1
300	117 ± 2 ± 13	0.004	1.9 ± 0.5 ± 0.2	2

Analysis Details -- II

Gaugino-like Chargino

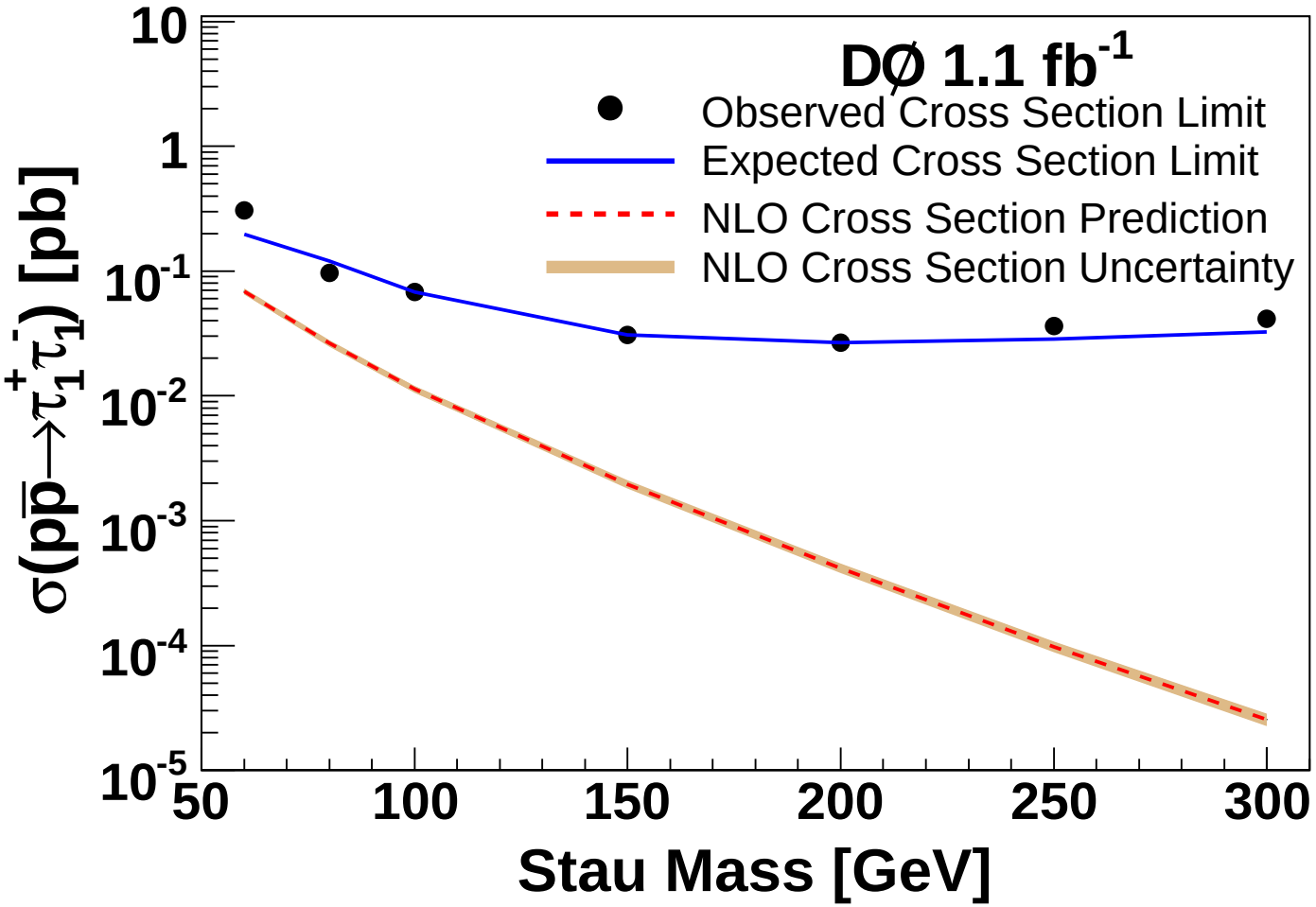
Mass (GeV)	Signal Acc. ($x10^{-3}$)	Exp. Signal Events	Predicted Background	# of Obs. Events
60	32 ± 1 ± 3	445	23.6 ± 1.9 ± 1.4	24
80	24 ± 1 ± 3	85	1.9 ± 0.5 ± 0.3	1
100	46 ± 1 ± 4	65	1.6 ± 0.5 ± 0.3	1
150	85 ± 1 ± 9	20	1.2 ± 0.4 ± 0.1	1
200	89 ± 1 ± 7	5	1.9 ± 0.5 ± 0.0	1
250	74 ± 1 ± 7	1	1.7 ± 0.5 ± 0.3	1
300	59 ± 1 ± 7	0.2	1.7 ± 0.5 ± 0.1	2

Analysis Details -- III

Higgsino-like Chargino

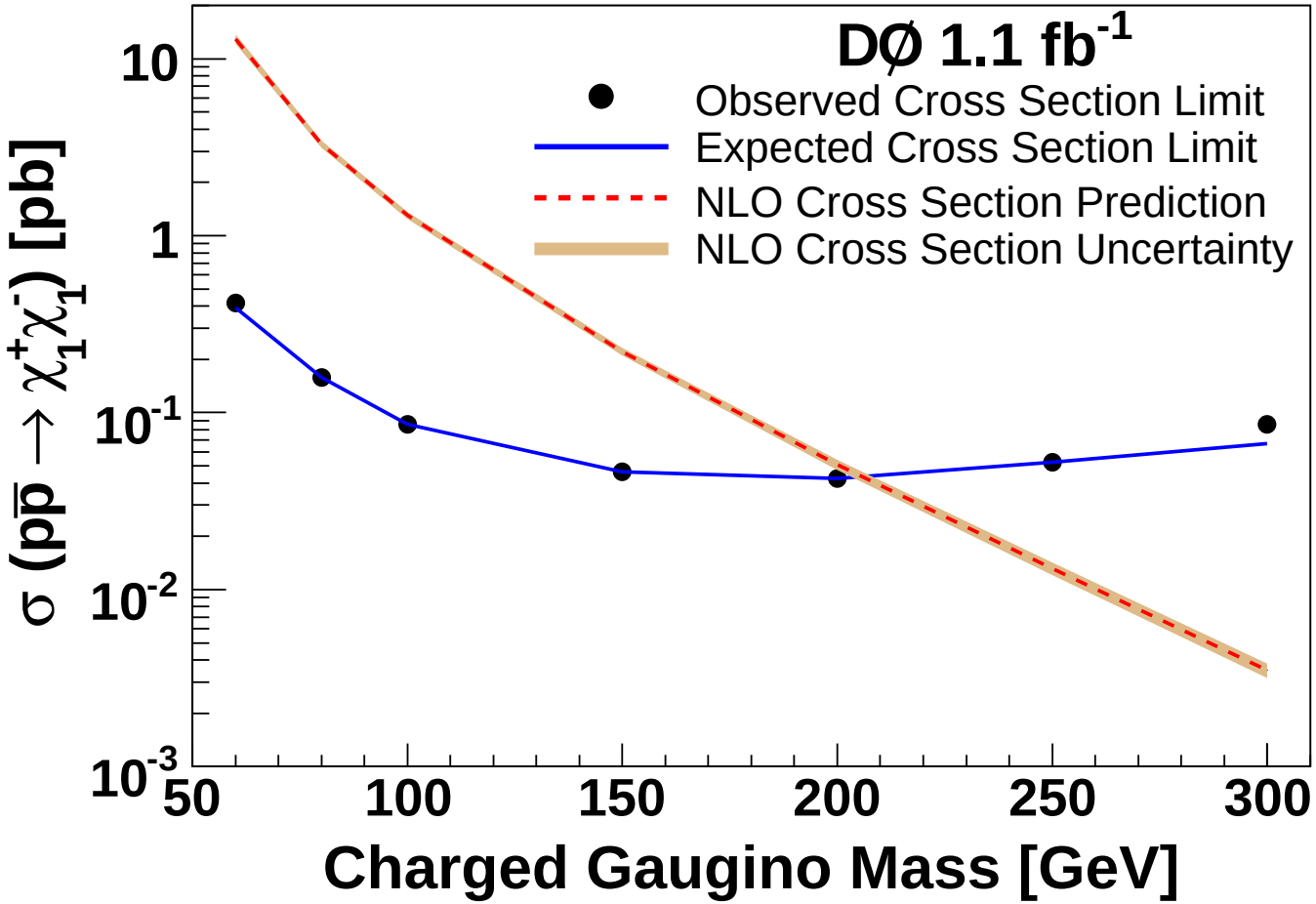
Mass (GeV)	Signal Acc. ($x10^{-3}$)	Exp. Signal Events	Predicted Background	# of Obs. Events
60	29 ± 1 ± 2	94	17.9 ± 1.7 ± 1.1	21
80	24 ± 1 ± 3	23	1.6 ± 0.5 ± 0.3	1
100	49 ± 1 ± 4	20	1.6 ± 0.5 ± 0.3	1
150	89 ± 1 ± 9	7	1.4 ± 0.5 ± 0.1	1
200	96 ± 1 ± 8	2	1.9 ± 0.5 ± 0.0	1
250	81 ± 1 ± 8	0.5	1.7 ± 0.5 ± 0.3	1
300	64 ± 1 ± 7	0.1	1.7 ± 0.5 ± 0.1	1

Final Results -- I



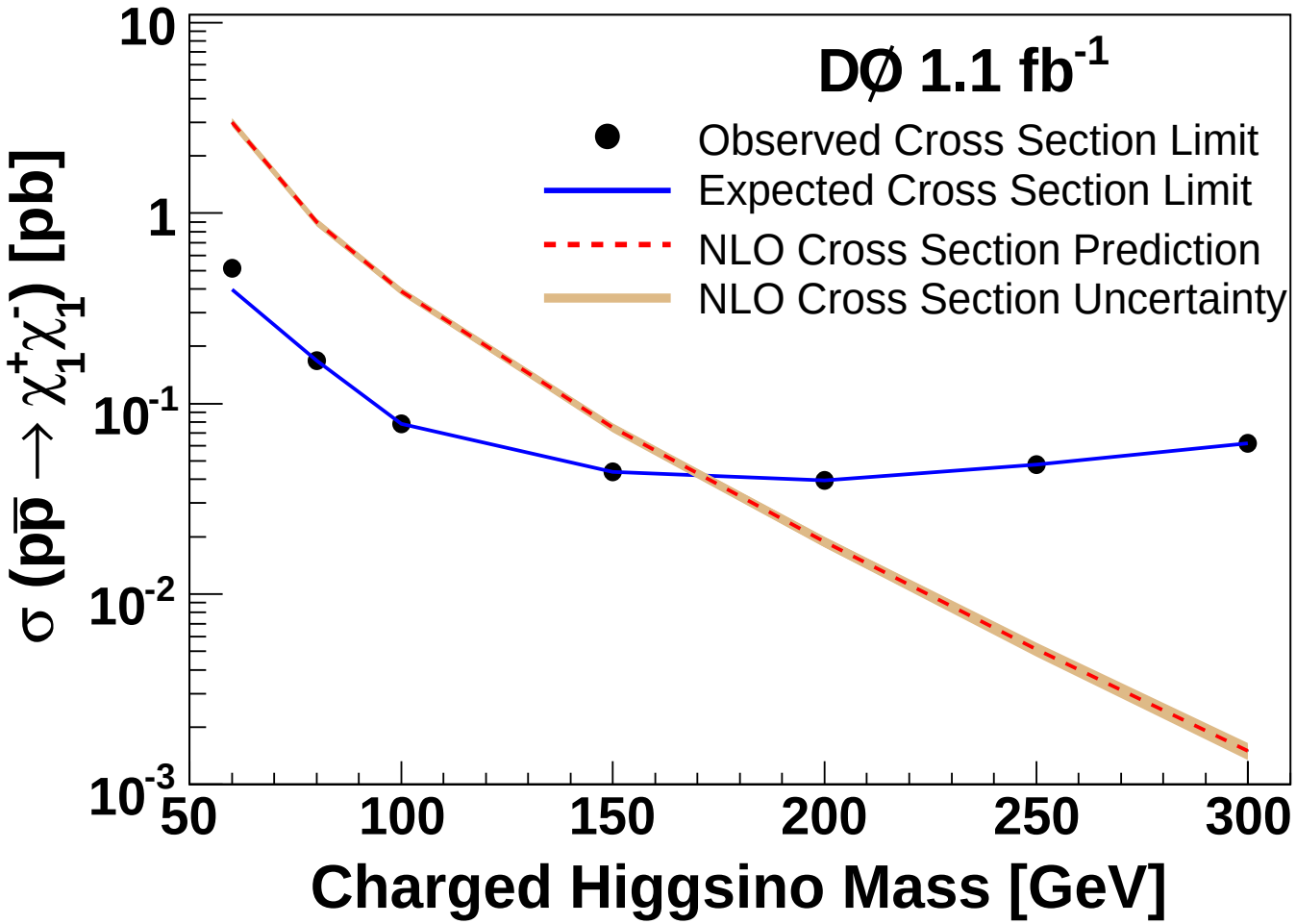
We put a 95 % C.L. cross section upper limit on the production of stable staus, from 0.31 pb to 0.04 pb, for stau masses in the range 60--300 GeV.

Final Results -- II



Using the nominal values of the NLO cross section, we obtain mass limits of 206 GeV for gaugino-like charginos.

Final Results -- III



Using the nominal values of the NLO cross section, we obtain mass limits of 171 GeV for higgsino-like charginos.

Summary

- ***Results with 1.1 fb $^{-1}$ data:***
  - We found no evidence of the signal
  - We set cross section limits which vary from 0.31 pb to 0.04 pb, for staus between 60 GeV and 300 GeV.
  - We exclude gaugino-like charginos with mass < 206 GeV
  - We exclude higgsino-like charginos with mass < 171 GeV
- ***Paper:***
  - PRL 102, 161802 (on arXiv: 0809.4472)
  - Already used in models by theorists (J.A. Hewitt, arXiv: 0812.0980 and 0903.4409)
- ***Possible improvments:***

  Extend to larger data set and include dE/dx information

Backup Slides

19 Parameters in SM

m_e, m_μ, m_τ, lepton masses

m_u, m_d, m_s, m_c, m_b, m_t, quark masses

θ_{12}, θ_{23}, θ_{13}, CKM mixing angles

δ, CKM CP-violating phase

g_1, g_2, g_3, gauge coupling

Θ, QCD vacuum angle

μ, Higgs quadratic coupling

λ, Higgs self-coupling strength

Model Parameters

Stau

Parameter	Description	Value
Λ_m	Scale of SUSY breaking	19 to 100 TeV
M_m	Messenger mass scale	$2\Lambda_m$
N_5	Number of messenger fields	3
$tan\beta$	Ratio of Higgs VEVs	15
$sgn\mu$	Sign of Higgsino mass term	+1
C_{grav}	Factor multiplying effective mass of gravitino	1

Charginos

Model	μ(GeV)	M_1(GeV)	M_2(GeV)	M_3(GeV)	$tan\beta$	Squark Mass (GeV)
gaugino-like chargino	10,000	$3M_2$	varied from 60 to 300	500	15	800
higgsino-like chargino	varied from 60 to 300	100,000	100,000	500	15	800

Talk by Jo Ann Hewett, LISHEP 2009.

Tevatron: D0 Stable Particle (= Chargino) Search

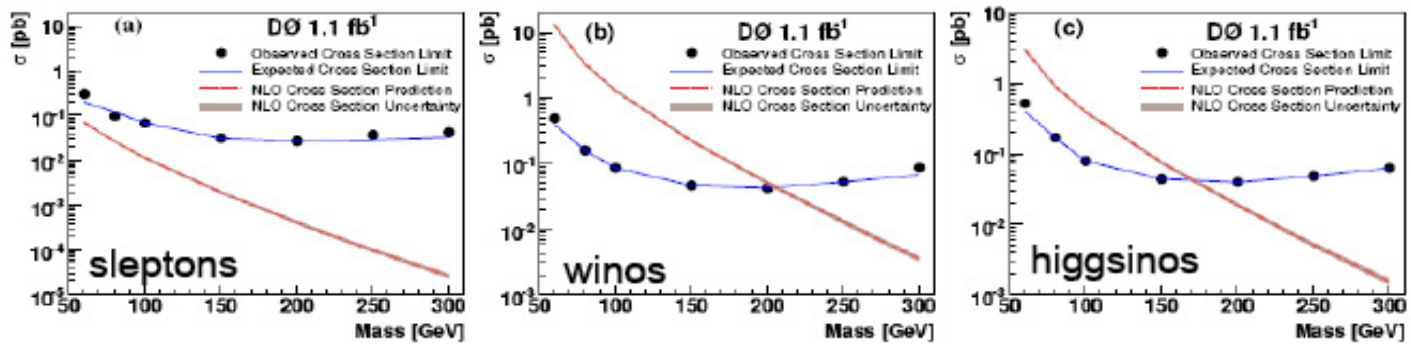


FIG. 2: The observed (dots) and expected (solid line) 95% cross section limits, the NLO production cross section (dashed line), and NLO cross section uncertainty (barely visible shaded band) as a function of (a) stau mass for stau pair production, (b) chargino mass for pair produced gaugino-like charginos, and (c) chargino mass for pair produced higgsino-like charginos.

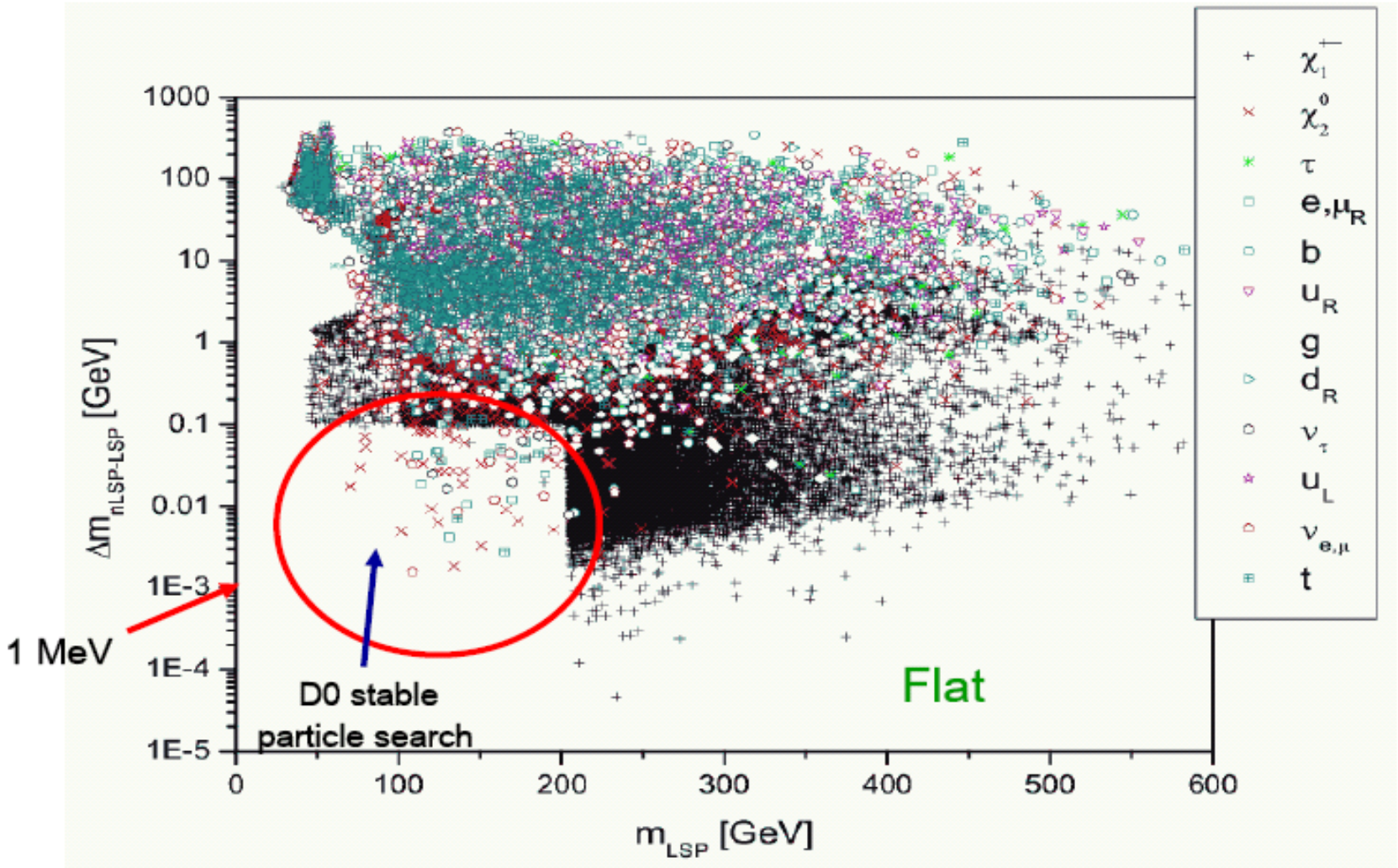
Interpolation: $M_\chi > 206\ |U_{1w}|^2 + 171\ |U_{1h}|^2$ GeV

- This is an *incredibly* powerful constraint on our model set!
- No applicable bounds on charged sleptons..the cross sections are too small.

- Cited by arXiv: 0812.0980 and 0903.4409

Tom Rizzo at the LHC2FC workshop

nLSP-LSP Mass Difference



http://indico.cern.ch/getFile.py/access?contribId=42&resId=0&materialId=slides&confId=40437

Triggers

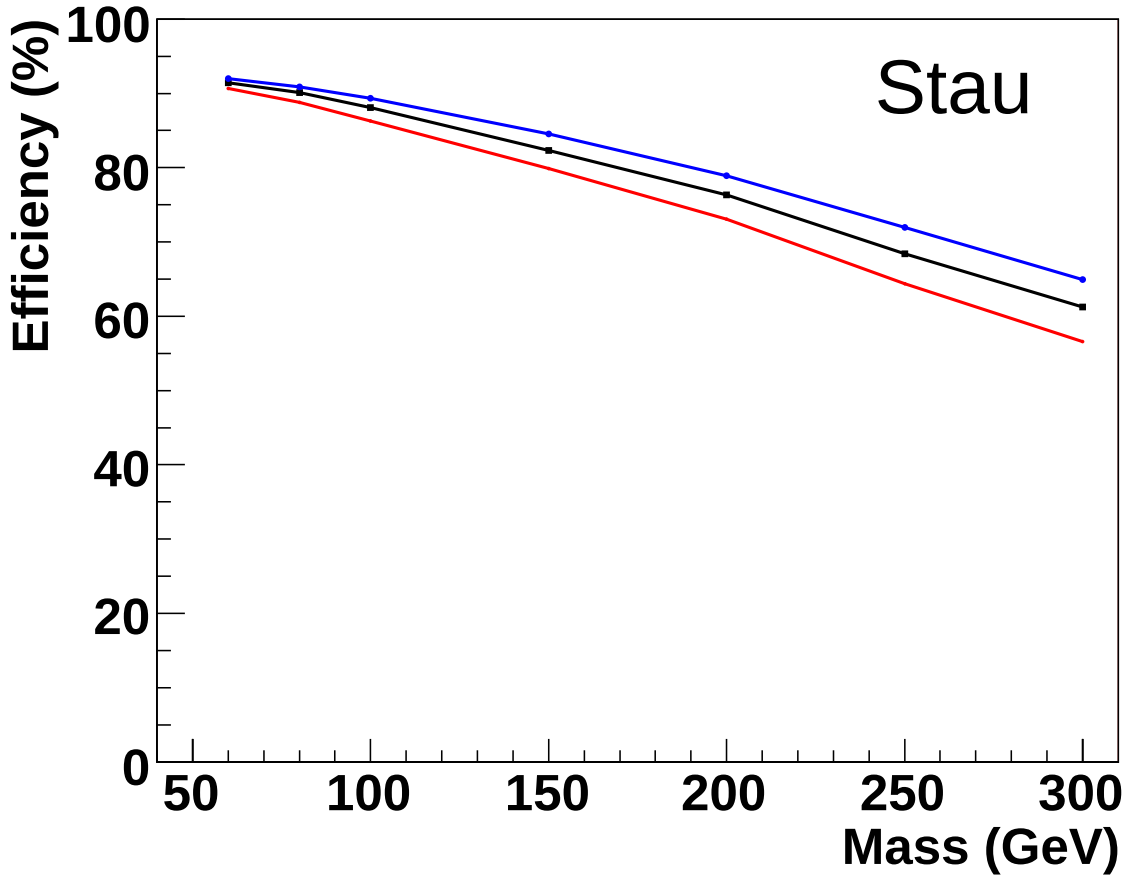
Triggers were used for event selection:

Run Start	Run Stop	Version	Trigger	Luminosity(pb^{-1})
160582	167015	v8	2MU_A_L2M0	5.91323
167019	170246	v9	2MU_A_L2M0	39.4677
170247	174802	v10	2MU_A_L2M0	17.3911
174896	178721	v11	2MU_A_L2M0_TRK10	69.9599
178722	180956	v12a	2MU_A_L2M0_TRK5	47.3961
184951	190370	v12b	2MU_A_L2M0_TRK5	88.5615
191266	194597	v12c	2MU_A_L2M0_TRK5	105.848
194567	196584	v13a	DMU1_LM6	59.1665
201485	201936	v13b	DMU1_LM6	4.61323
202152	204805	v13c	DMU1_TK8	127.539
204807	206161	v13d	DMU1_TK8	82.1435
206162	208144	v13e	DMU1_TK8	110.448
207728	211213	v14a	DMU1_LM6_TK12	172.449
211214	212107	v14b	DMU1_LM6_TK12	69.635
212804	215670	v14c	DMU1_LM6_TK12	90.0956
				1090.627

L1 Muon Trigger Gate Study

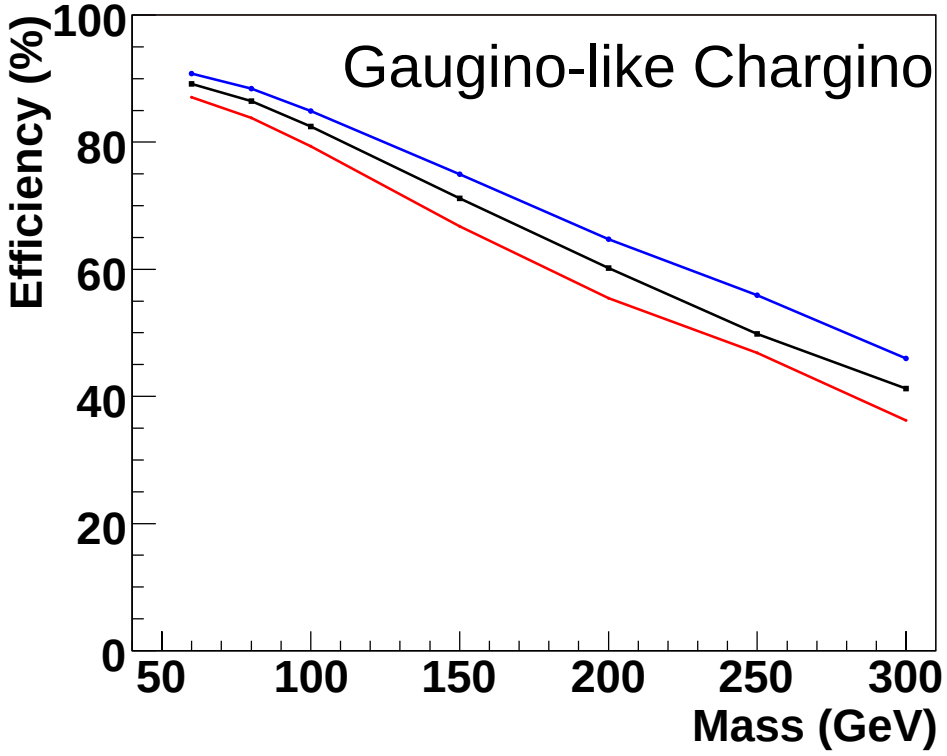
Systematic studies on the L1 muon trigger gate:

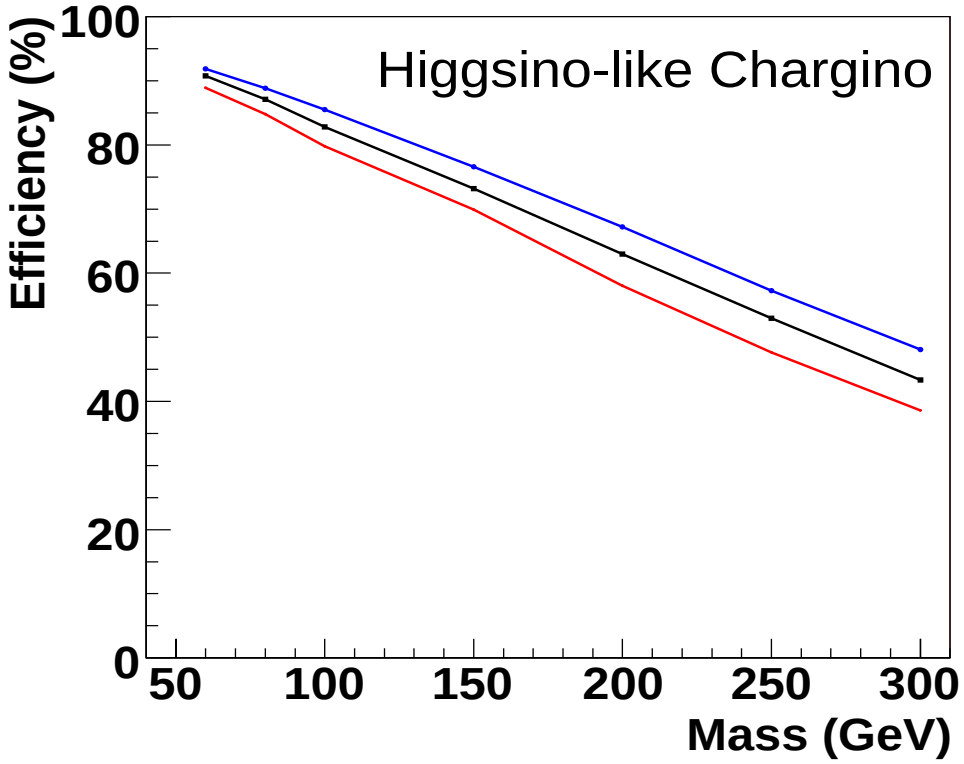
The accuracy on the gate width is in the order of 1 ns. We studied the worst scenario of changing the gate width by 2 ns and recalculated the signal acceptance in three models.



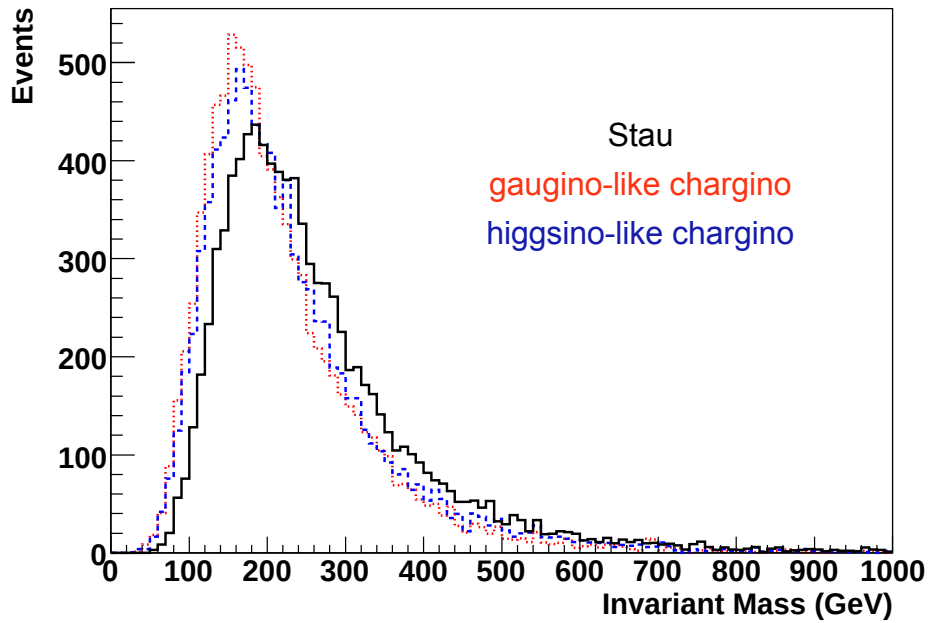
L1 Muon Trigger Gate Study -- II

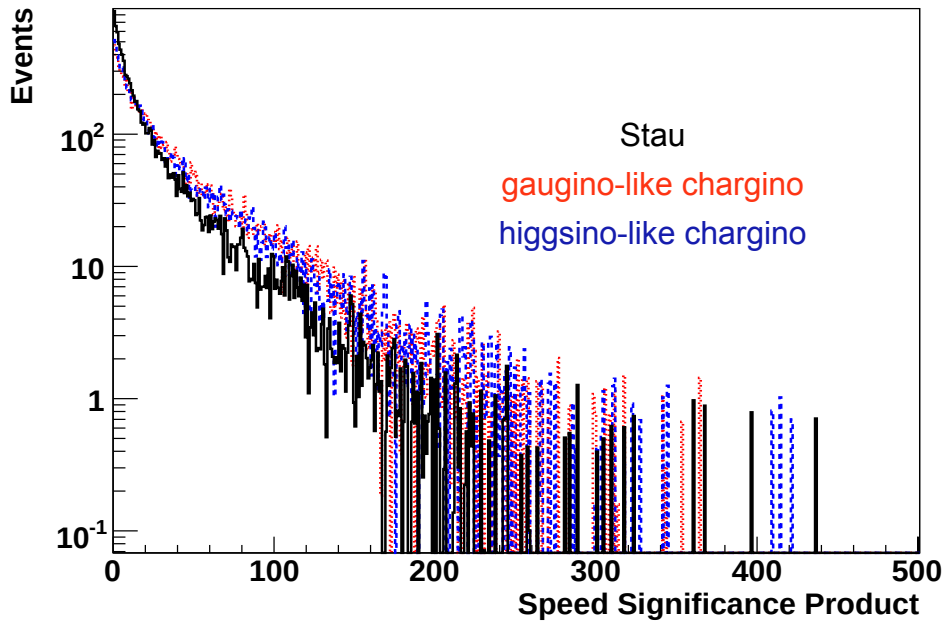
Efficiency is defined as the number of events with both two muons inside the trigger gate divided by the number of all events.

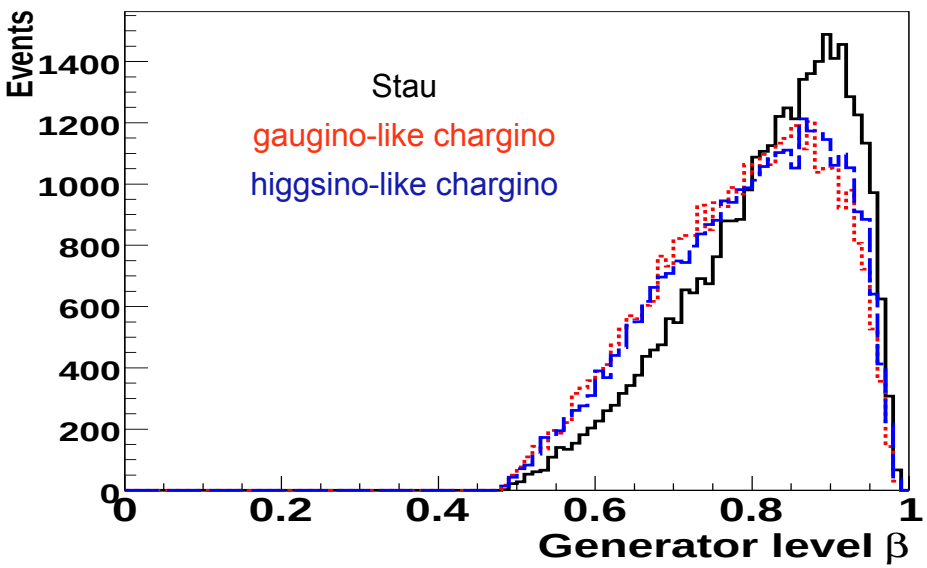


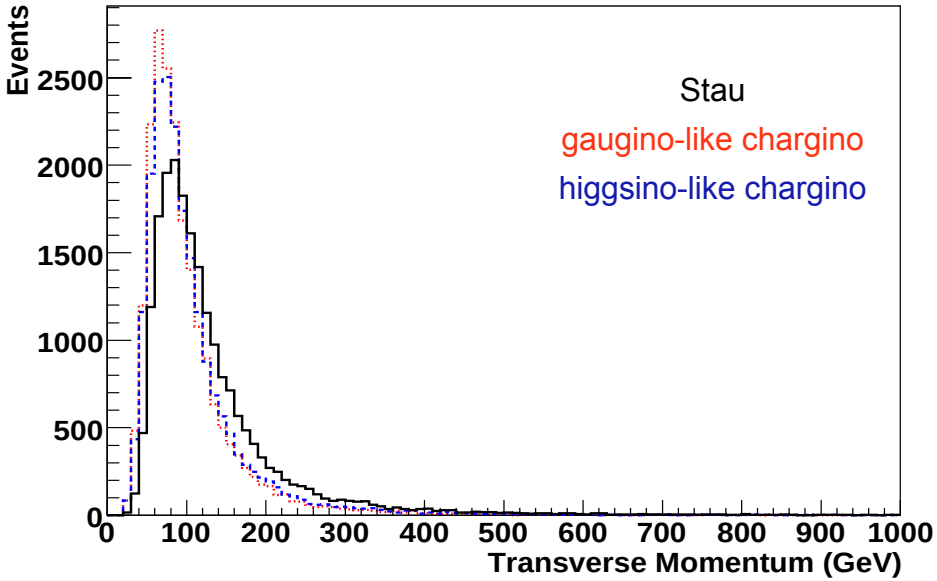


CMSP Signals (100 GeV)

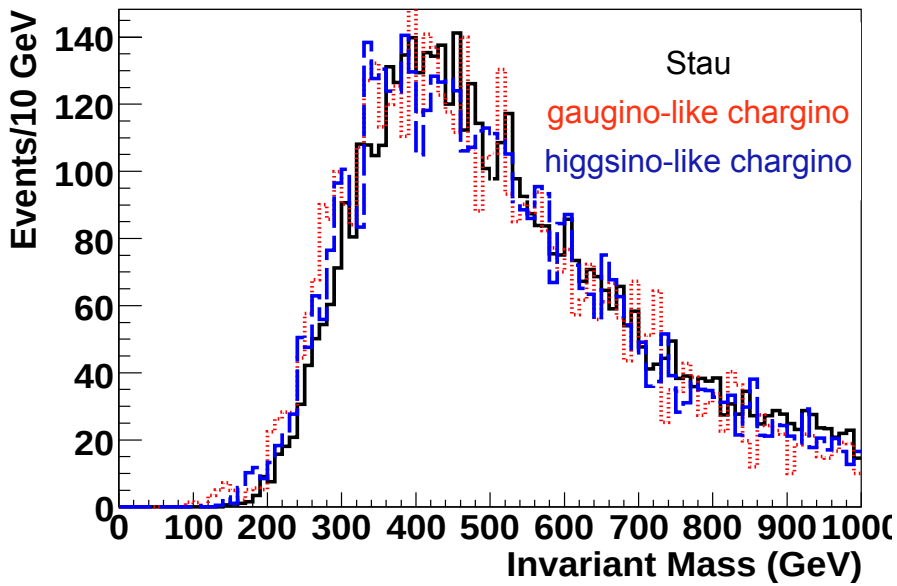


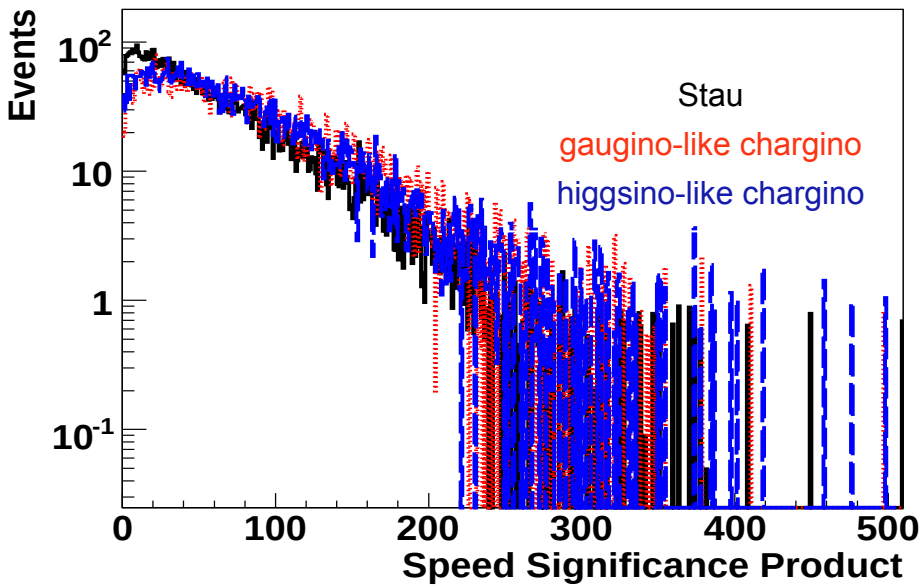


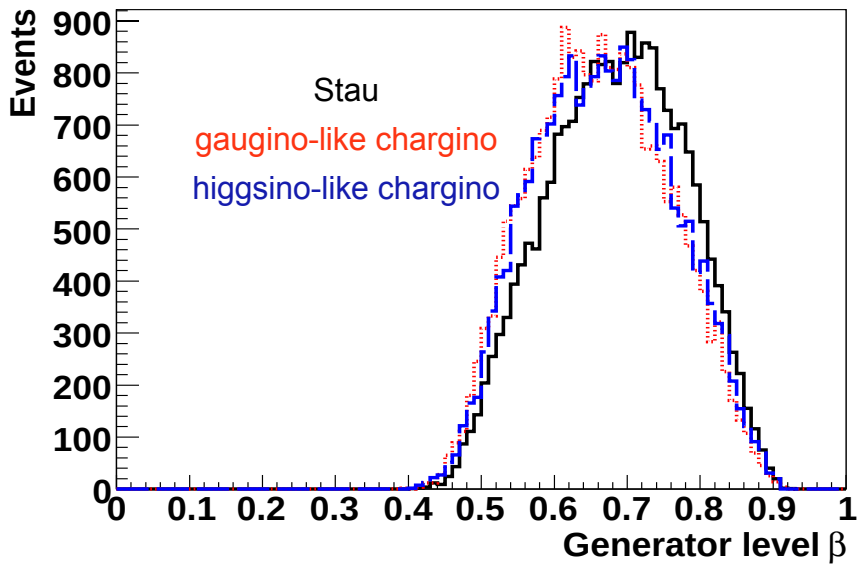


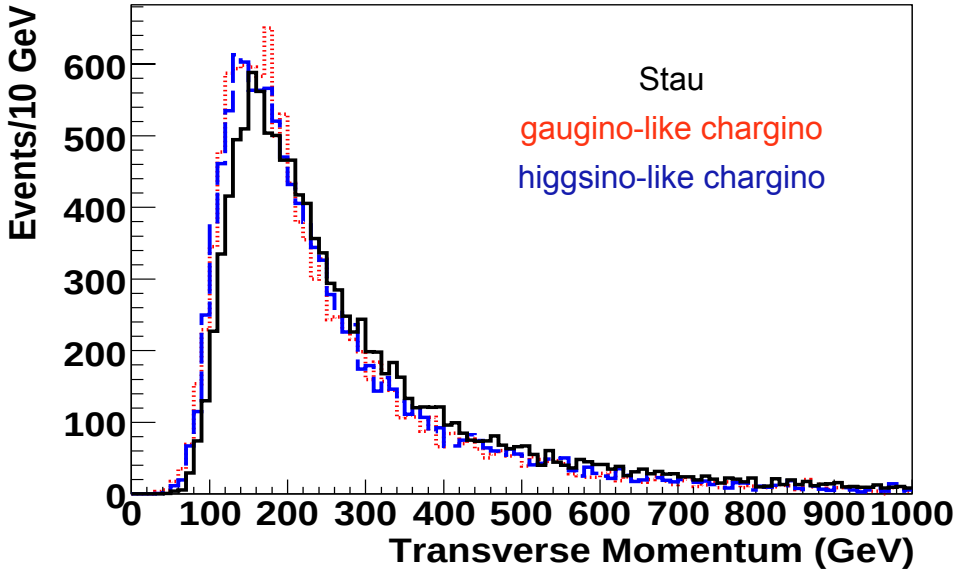


CMSP Signals (300 GeV)









Selection efficiencies -- I

Selection cut efficiencies for stau samples

Mass (GeV)	60	80	100	150	200	250	300
Bottom	98.04%	98.23%	99.32%	99.63%	99.73%	99.78%	99.8%
Medium	85.52%	87.44%	89.26%	90.54%	90.53%	90.03%	89.7%
Nseg3	84.13%	85.98%	87.84%	89.14%	89.03%	88.59%	88.14%
Track	81.65%	83.74%	85.84%	87.49%	87.59%	87.24%	86.76%
χ^2_μ	81.27%	83.4%	85.58%	87.27%	87.38%	87.06%	86.56%
DCA	81.22%	83.36%	85.54%	87.23%	87.35%	87.02%	86.53%
P_T	80.74%	83.13%	85.42%	87.14%	87.26%	86.95%	86.46%
Number	37.36%	39.13%	40.65%	42.22%	41.8%	41.87%	40.76%
Trigger	24.33%	25.39%	26.34%	27.02%	26.49%	26.44%	25.61%
MUID	24.22%	25.24%	26.14%	26.81%	26.26%	26.14%	25.34%
MUTRK	22.72%	23.63%	24.4%	24.96%	24.37%	24.24%	23.43%
L1MU	20.77%	21.29%	21.5%	20.54%	18.61%	16.59%	14.34%
Isolation	20.65%	21.18%	21.39%	20.44%	18.53%	16.52%	14.3%
Δ	20.53%	21%	21.2%	20.2%	18.16%	16.12%	13.89%
Cosmic	20.32%	20.78%	21.01%	20.01%	17.98%	15.99%	13.82%
χ^2	20.25%	20.72%	20.59%	19.94%	17.92%	15.94%	13.76%
P_T^{asym}	20.06%	20.34%	20.43%	19.04%	16.63%	14.34%	12.06%
Significance	16.64%	17.73%	18.31%	18.05%	16.21%	14.13%	11.96%

Selection efficiencies -- II

Selection cut efficiencies for gaugino-like chargino samples

Mass (GeV)	60	80	100	150	200	250	300
Bottom	90.27%	93.4%	95.09%	96.52%	97.12%	97.31%	97.57%
Medium	62.49%	69.71%	72.24%	74.55%	74.79%	73.65%	73.43%
Nseg3	60.59%	67.74%	70.32%	72.53%	72.77%	71.53%	71.11%
Track	57.63%	64.83%	67.47%	70.09%	70.38%	69.27%	68.97%
χ^2_μ	57.18%	64.43%	67.11%	69.77%	70.08%	68.96%	68.69%
DCA	57.14%	64.39%	67.07%	69.74%	70.05%	68.92%	68.67%
P_T	54.73%	63.565	66.72%	69.61%	69.97%	68.84%	68.59%
Number	19.99%	24.76%	26.62%	29.06%	29.13%	28.44%	27.98%
Trigger	13.29%	16.35%	17.55%	19.03%	19%	18.41%	18.08%
MUID	13.27%	16.34%	17.5%	18.94%	18.91%	18.29%	17.96%
MUTRK	12.52%	15.35%	16.46%	17.78%	17.71%	17.11%	16.78%
L1MU	11.16%	13.28%	13.58%	12.65%	10.66%	8.53%	6.92%
Isolation	11.13%	13.24%	13.53%	12.60%	10.63%	8.51%	6.9%
Δ	11.08%	13.14%	13.44%	12.42%	10.49%	8.29%	6.72%
Cosmic	10.95%	12.98%	13.26%	12.29%	10.39%	8.22%	6.67%
χ^2	10.92%	12.95%	13.23%	12.26%	10.36%	8.2%	6.64%
P_T^{asym}	10.87%	12.86%	13.09%	11.95%	9.87%	7.68%	5.97%
Significance	9.83%	11.8%	12.29%	11.63%	9.76%	7.63%	5.95%

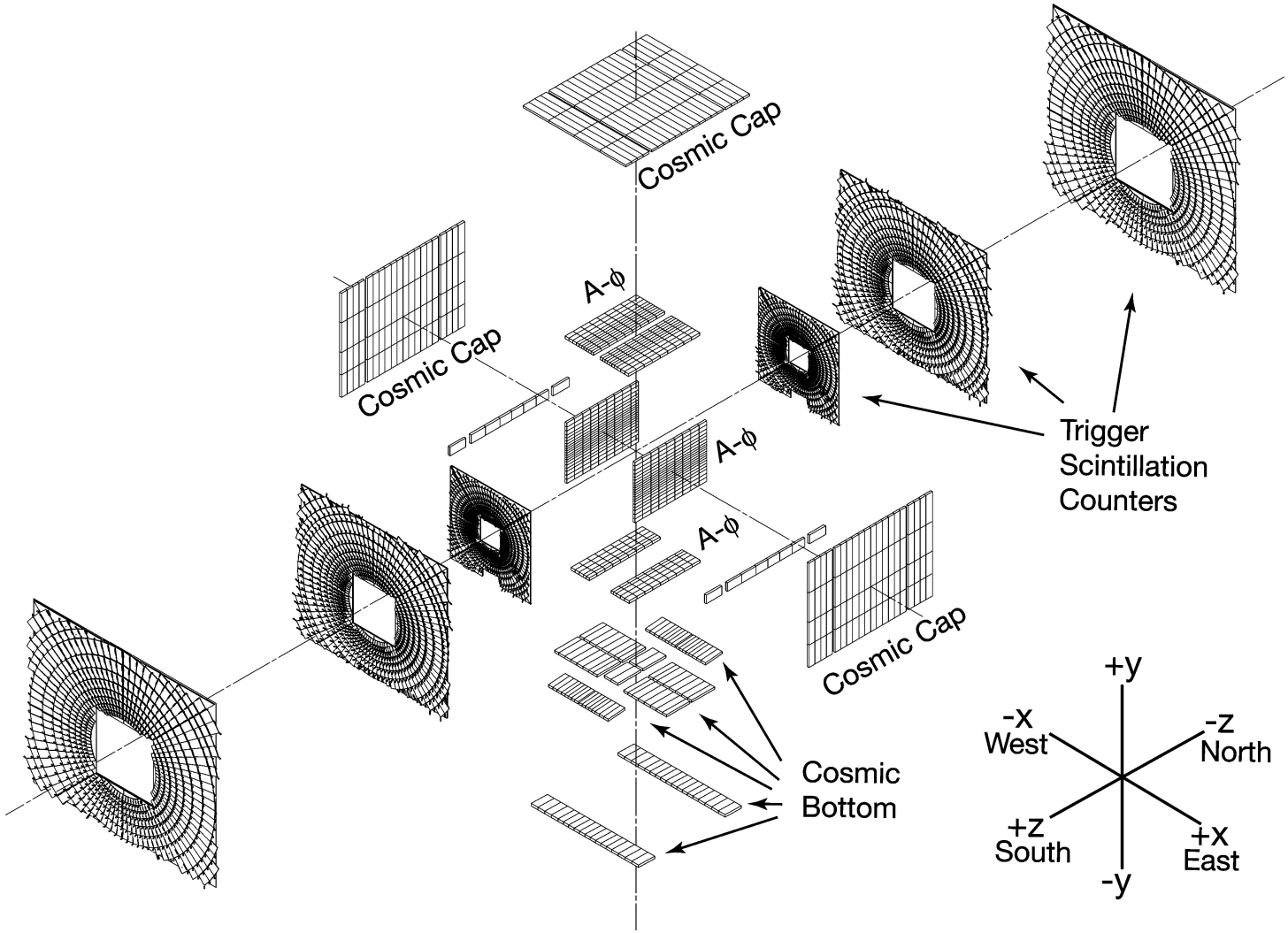
Selection efficiencies -- III

Selection cut efficiencies for higgsino-like chargino samples

Mass (GeV)	60	80	100	150	200	250	300
Bottom	91.42%	93.85%	95.3%	96.8%	97.41%	97.58%	97.83%
Medium	65.23%	71.54%	73.61%	76.12%	76.86%	75.61%	74.71%
Nseg3	63.41%	69.63%	71.82%	74.22%	74.8%	73.59%	72.57%
Track	60.49%	66.79%	69.11%	71.63%	72.5%	71.35%	70.42%
χ^2_μ	59.95%	66.26%	68.68%	71.3%	72.18%	71.06%	70.16%
DCA	59.9%	66.32%	68.65%	71.26%	72.15%	71.03%	70.13%
P_T	57.7%	65.62%	68.34%	71.16%	72.06%	70.96%	70.08%
Number	21.59%	25.9%	27.84%	30.13%	30.44%	29.94%	29.16%
Trigger	14.29%	17.08%	18.27%	19.71%	19.74%	19.3%	18.76%
MUID	14.27%	17.05%	18.2%	19.63%	19.62%	19.18%	18.64%
MUTRK	13.44%	16.02%	17.08%	18.41%	18.35%	17.93%	17.41%
L1MU	12.2%	13.96%	14.15%	13.47%	11.56%	9.5%	7.55%
Isolation	12.16%	13.92%	14.1%	13.42%	11.52%	9.48%	7.53%
Δ	12.08%	13.81%	13.98%	13.25%	11.32%	9.27%	7.33%
Cosmic	11.94%	13.64%	13.79%	13.11%	11.21%	9.19%	7.27%
χ^2	11.91%	13.6%	13.77%	13.06%	11.17%	9.16%	7.25%
P_T^{asym}	11.86%	13.47%	13.55%	12.68%	10.62%	8.48%	6.5%
Significance	10.47%	12.3%	12.62%	12.3%	10.45%	8.42%	6.48%

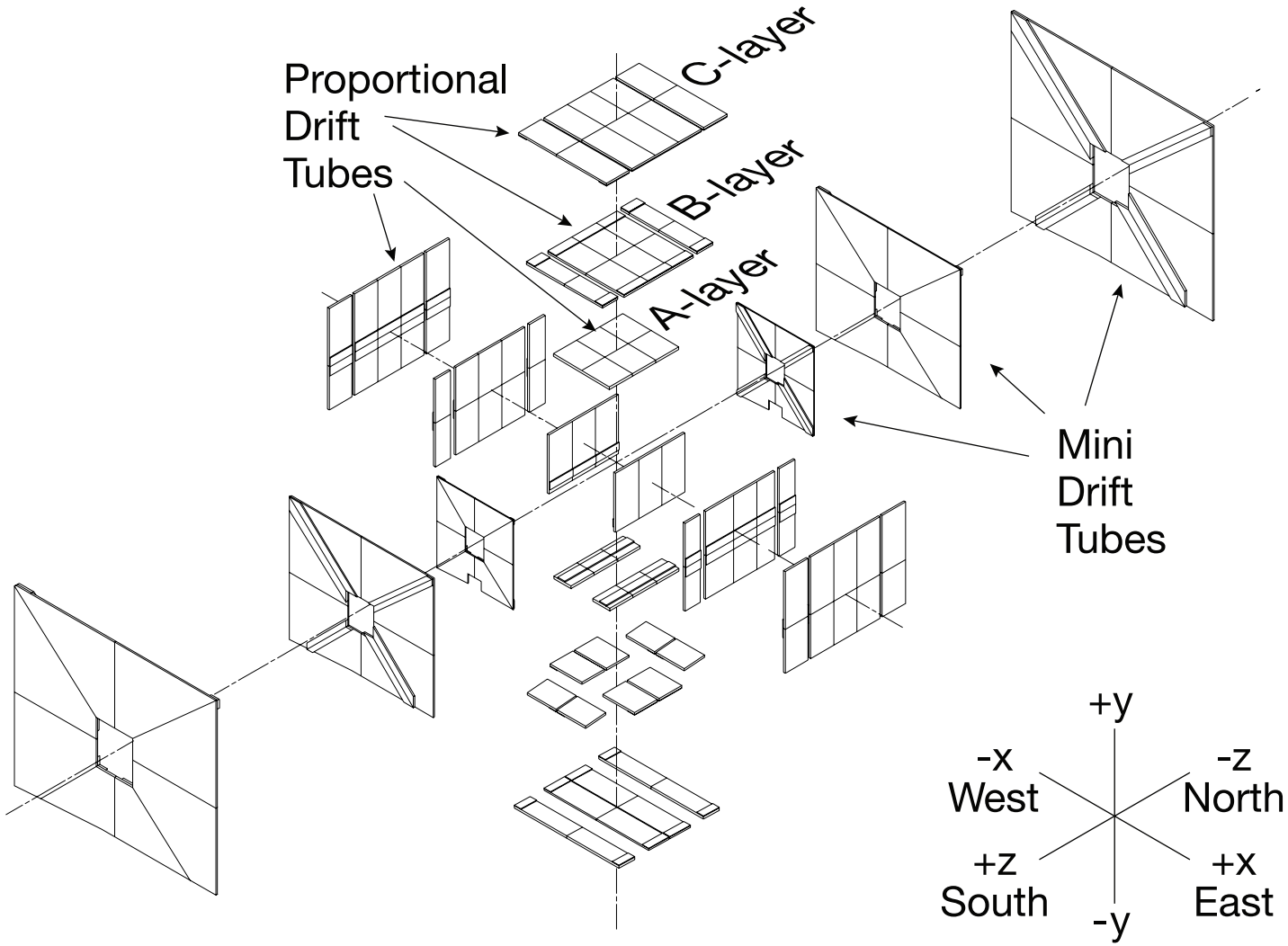
Muon Detector -- I

Muon Scintillation Counter

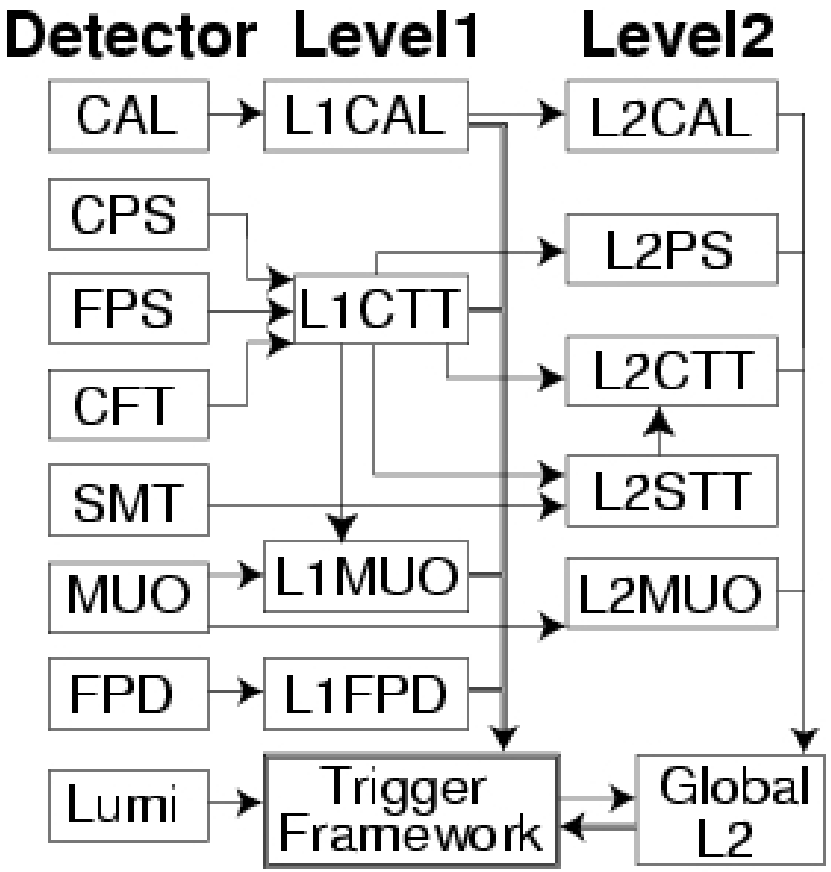


Muon Detector -- II

Muon Wire Drift Chamber



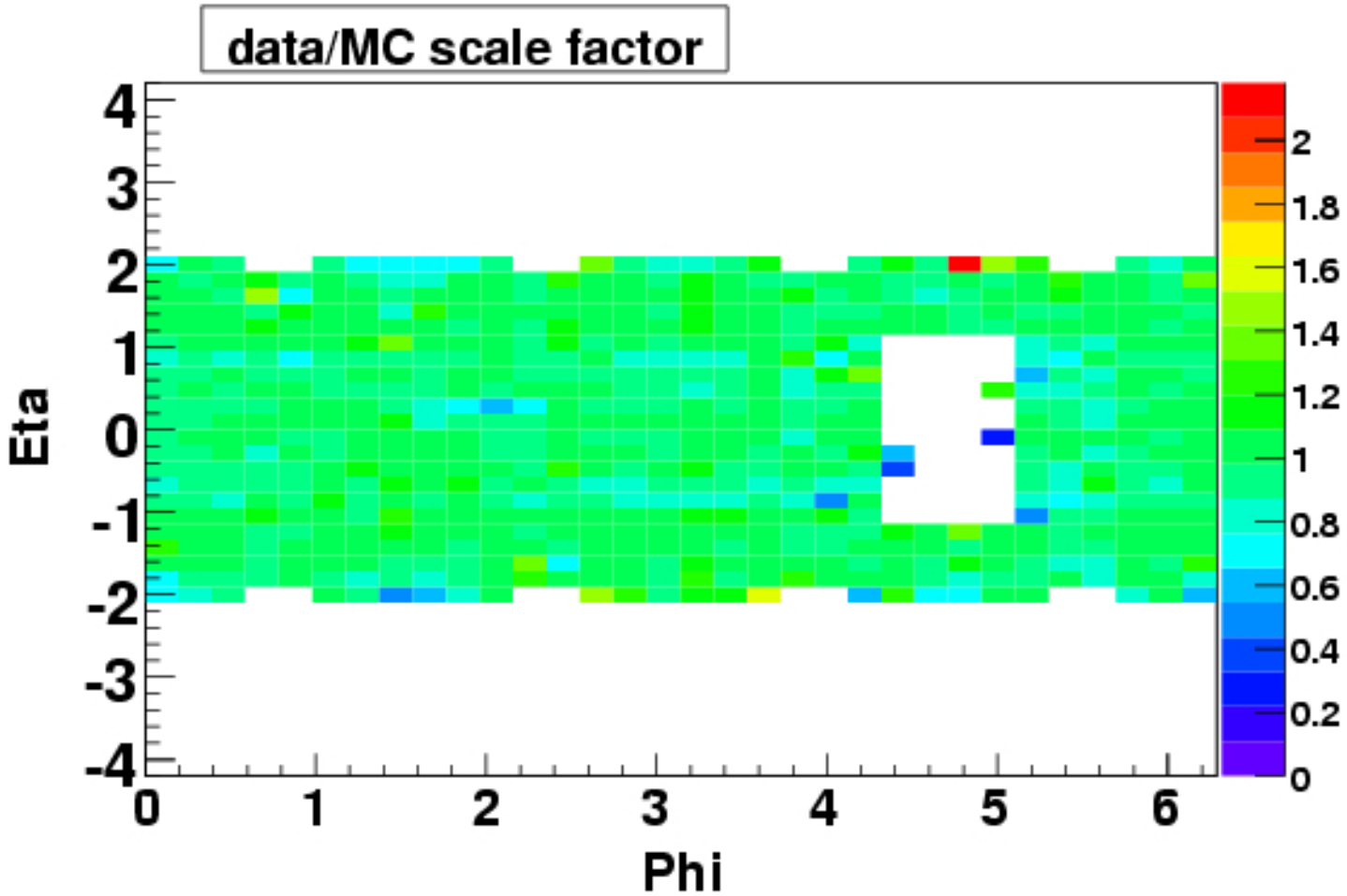
L1 and L2 Trigger System



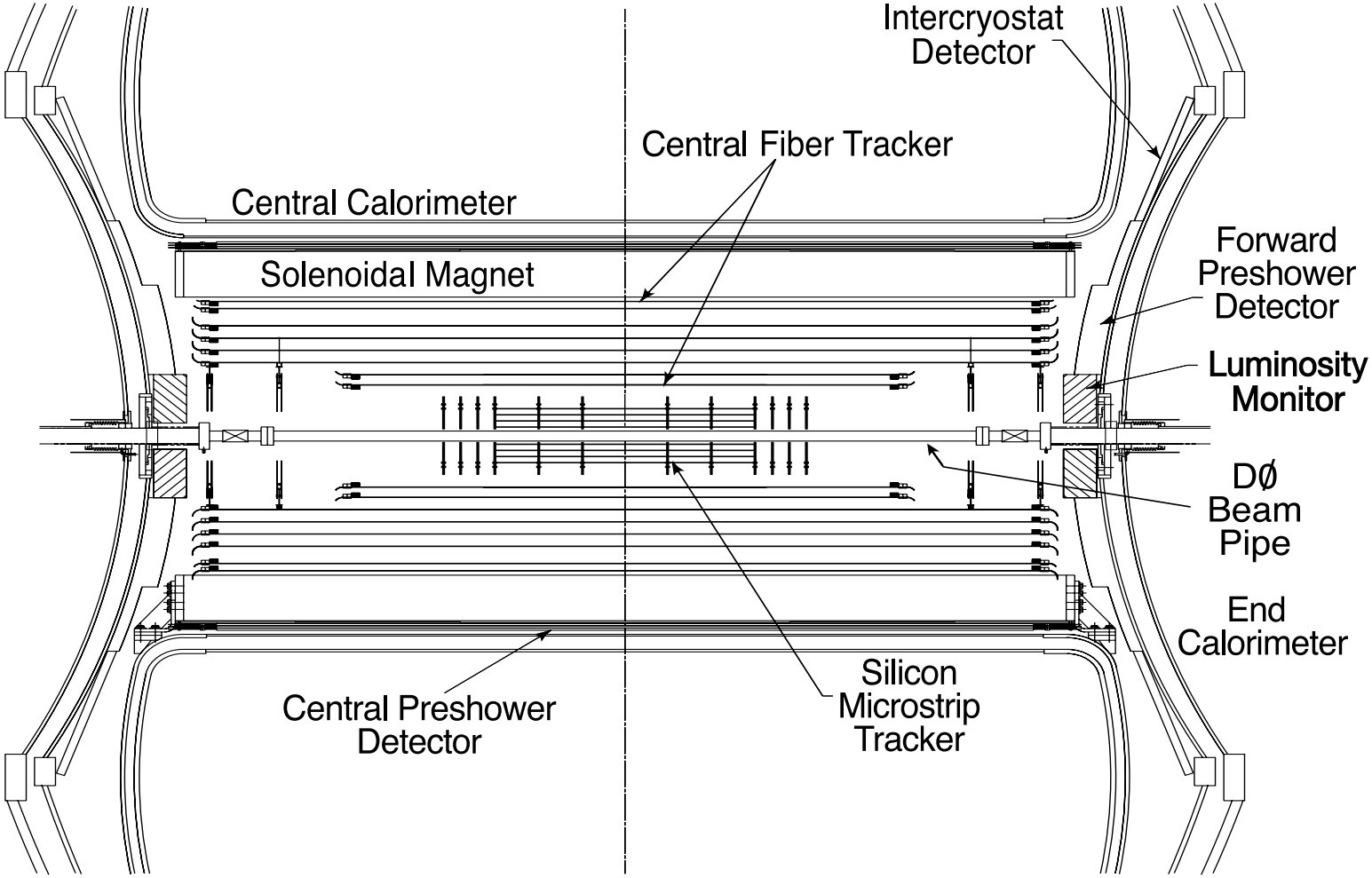
Relationship between detector components and L1/L2 trigger system

Scale factor of Scintillatior Efficiency

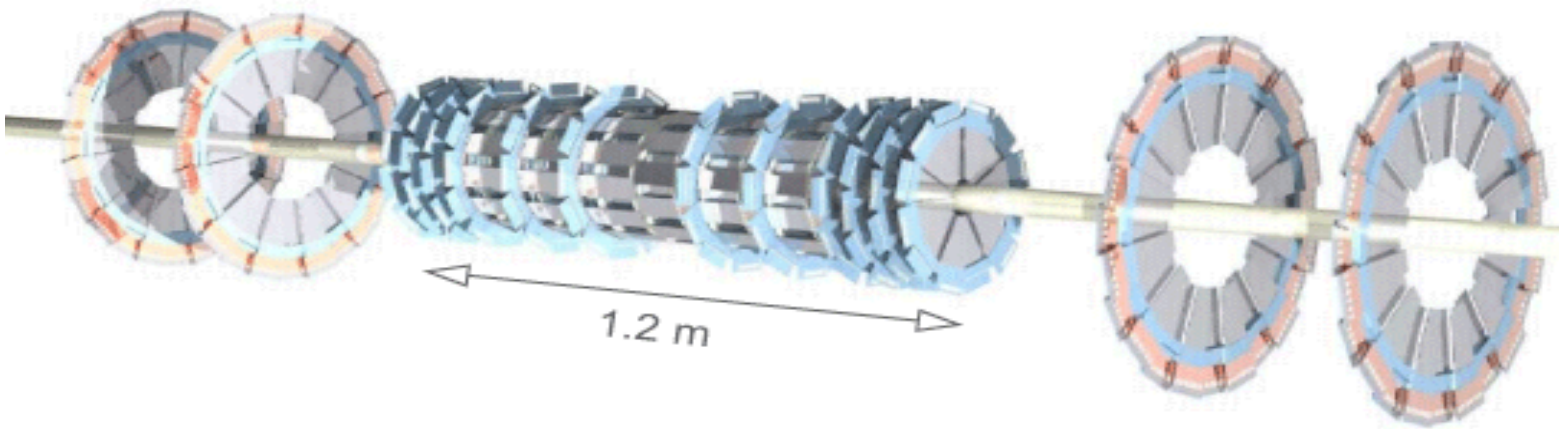
"Tag and probe" method for measuring the muonID plus at least two scintillator hits efficiencies for the data and MC.



Central Tracking System

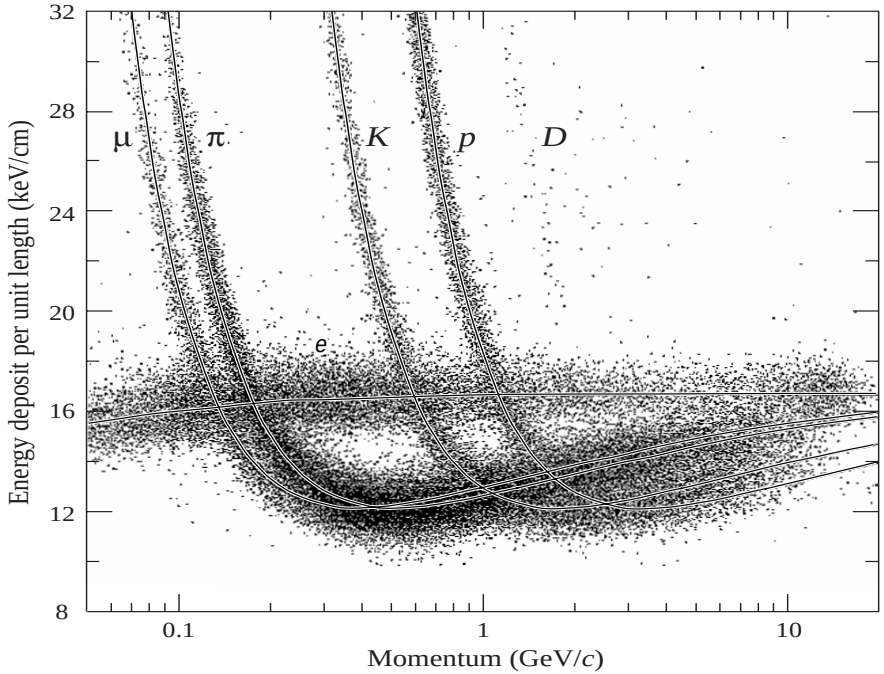


Central Tracking System -- II



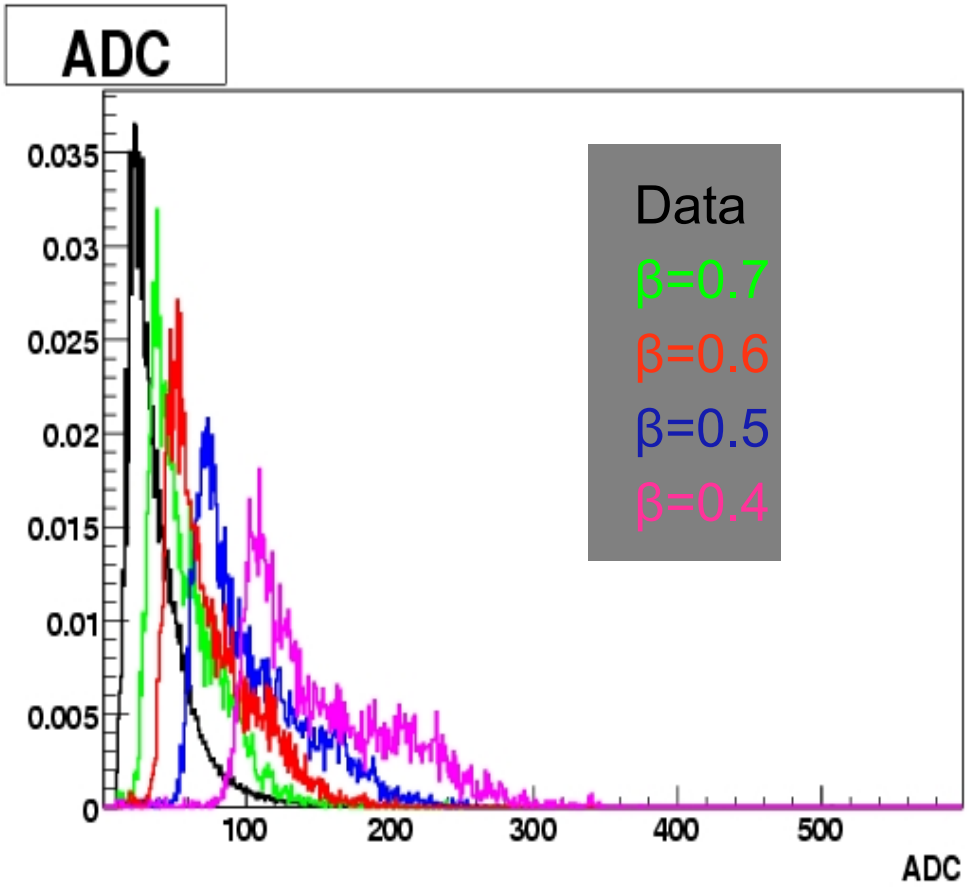
Bethe-Block formula:

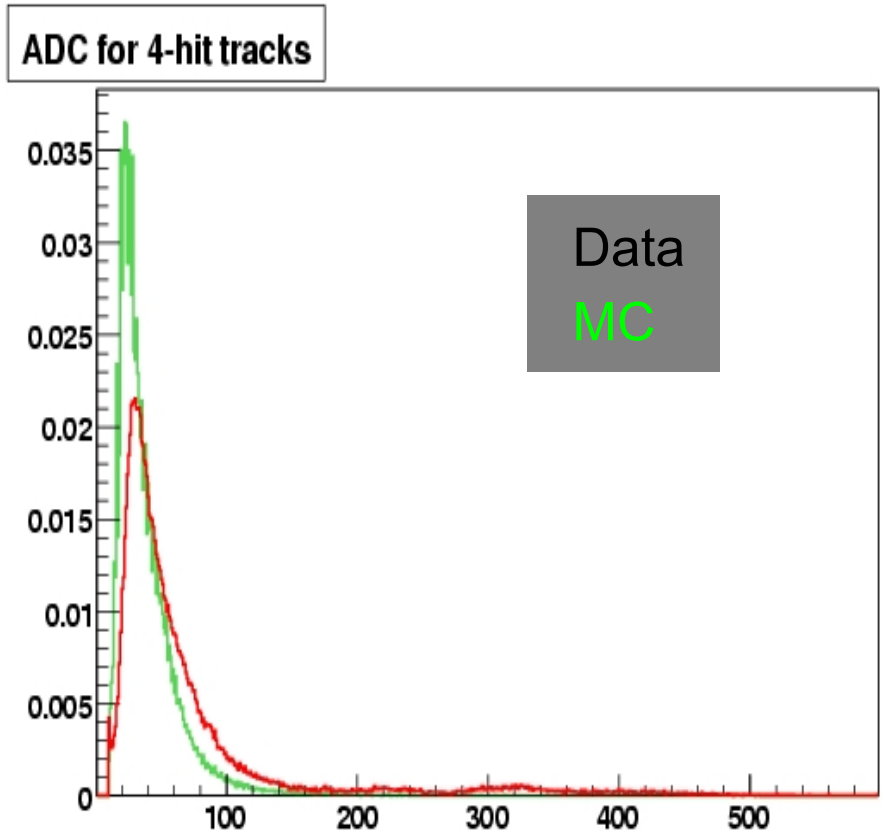
$$\frac{dE}{dx} = \frac{4\pi N_0 z^2 e^4}{mv^2}\frac{Z}{A}\left[\ln\left(\frac{2mv^2}{I\left(1-\beta^2\right)}\right)-\beta^2\right]$$



Stopping power study

- Energy deposit in the SMT studied with “sttsim”
- Comparison between real data and 100 GeV stau
- Smearing needed for MC samples

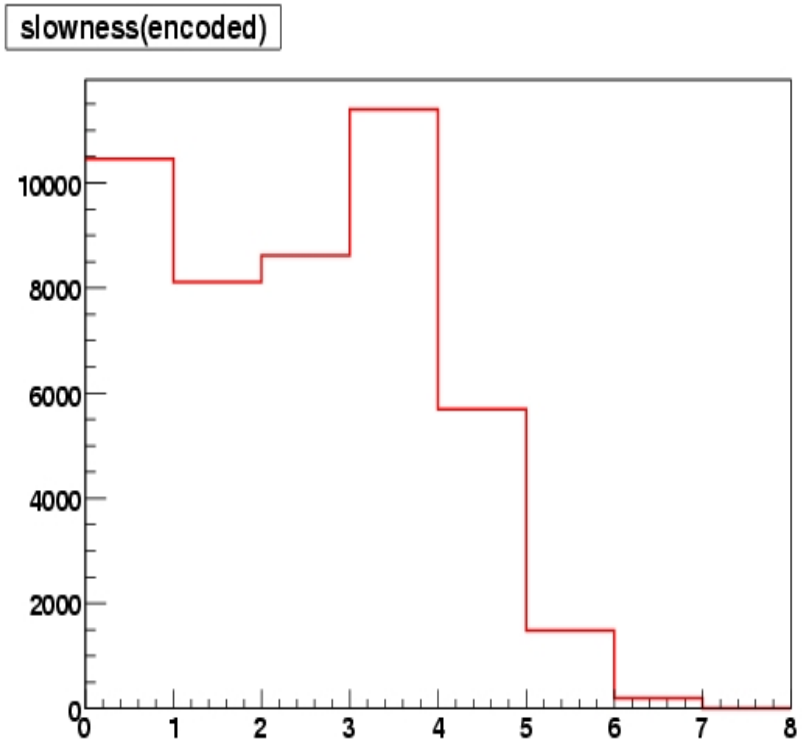


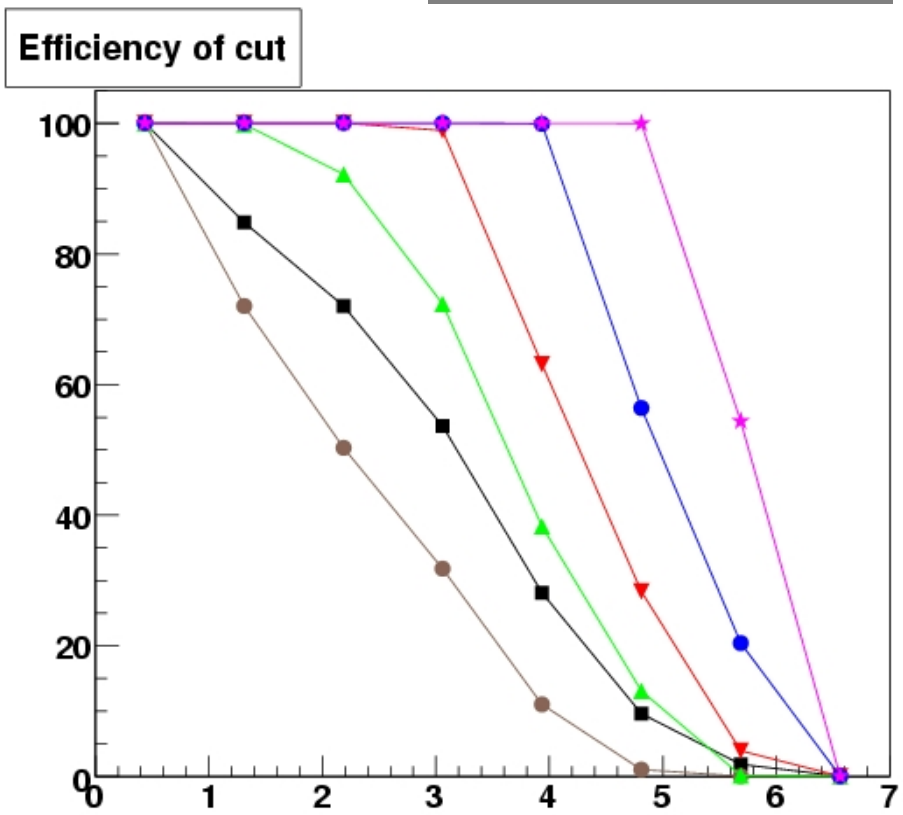


New trigger bit at STT

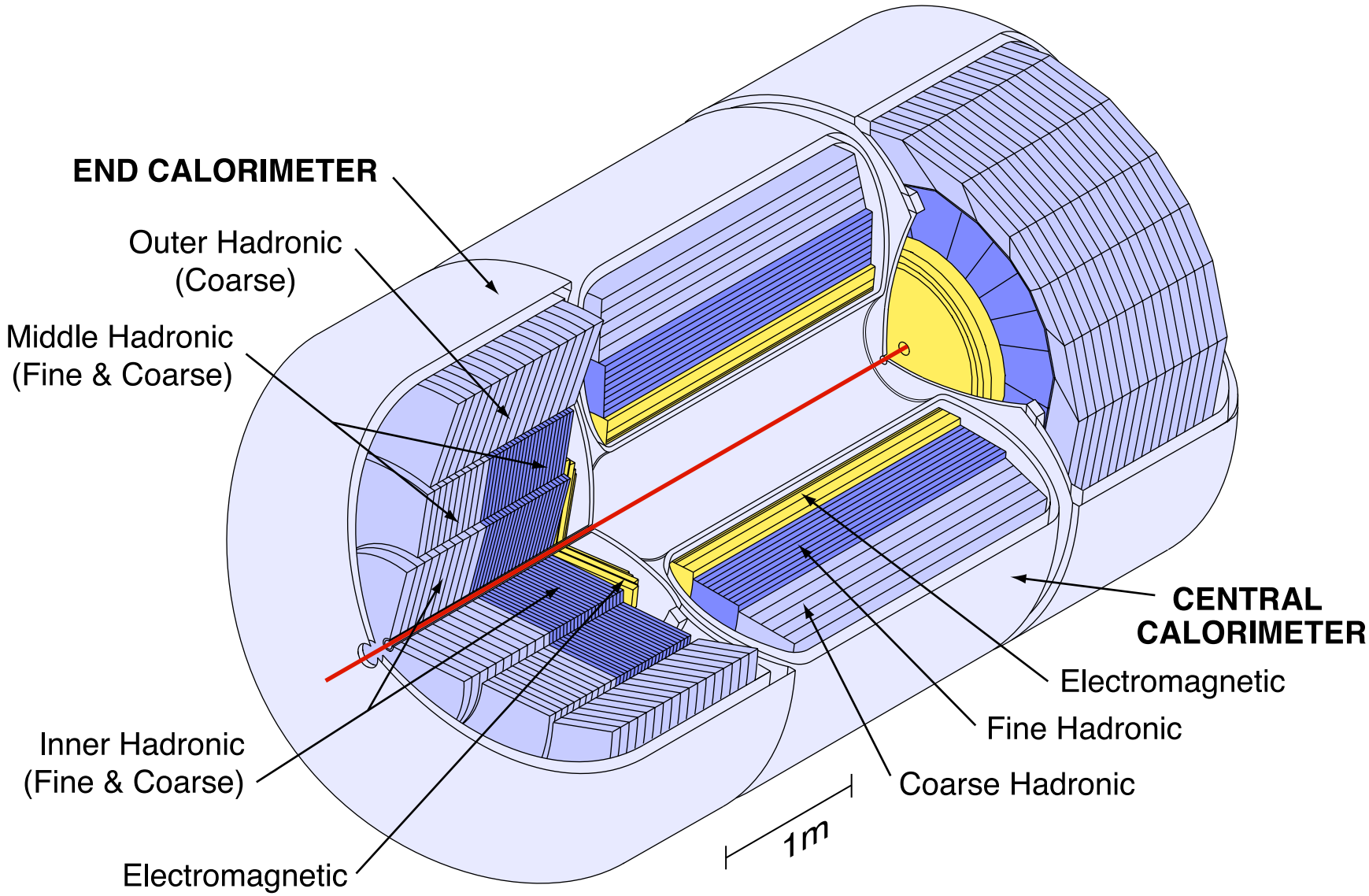
- Energy deposit in the SMT is accessible at STT
- 3 bits in trigger still free
- Studied on the raw data in “sttsim”
- Encoding in two steps to a 3-bit integer

MC	Data
β=0.7	β=0.6
β=0.5	β=0.4

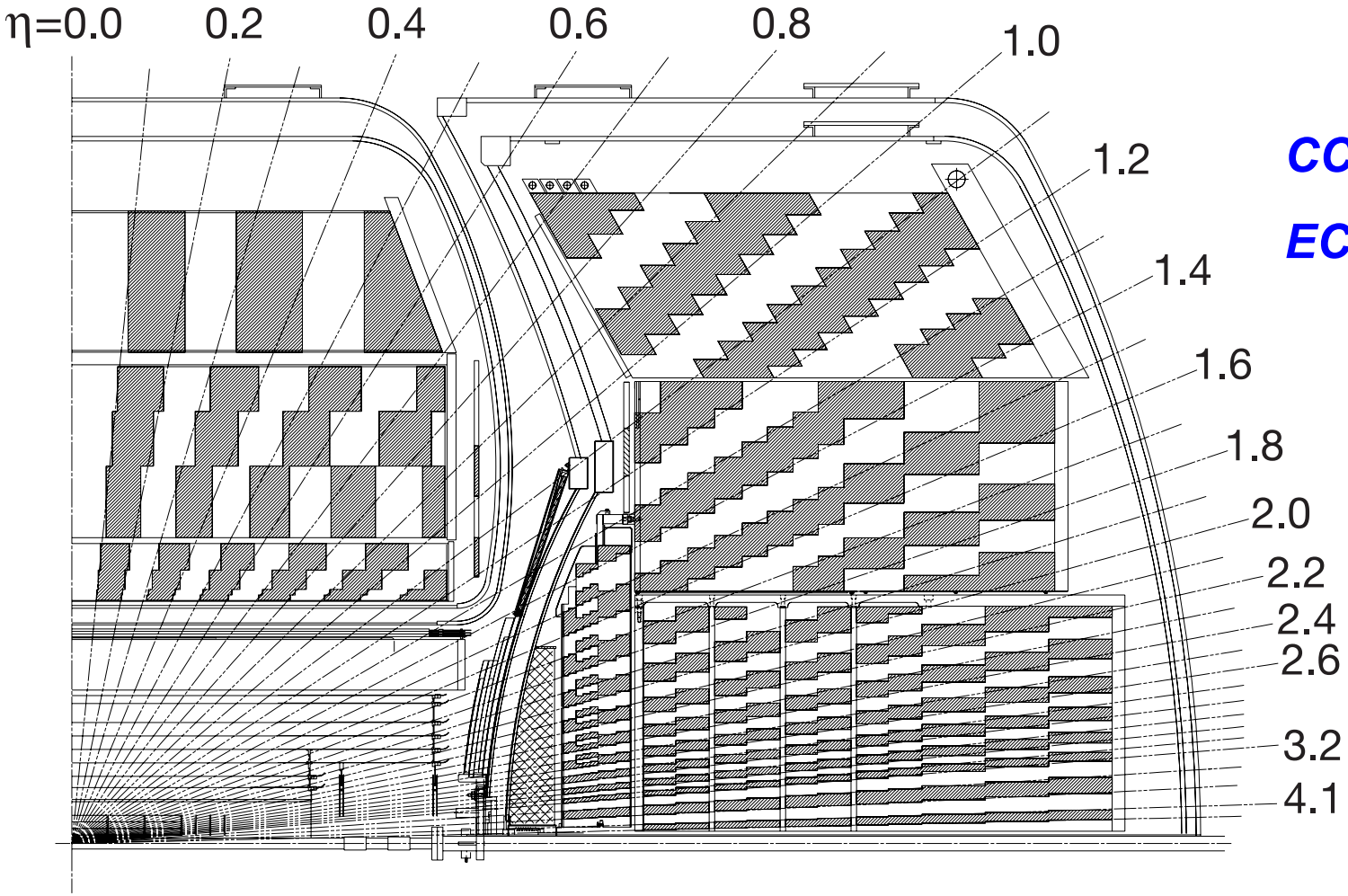




Calorimeter -- I



Calorimeter -- II



EM:

CC: 1.4; 2.0; 6.8; 9.8

EC: 1.6; 2.6; 7.9; 9.3

HC:

CC:

1.3; 1.0; 0.76; 3.2

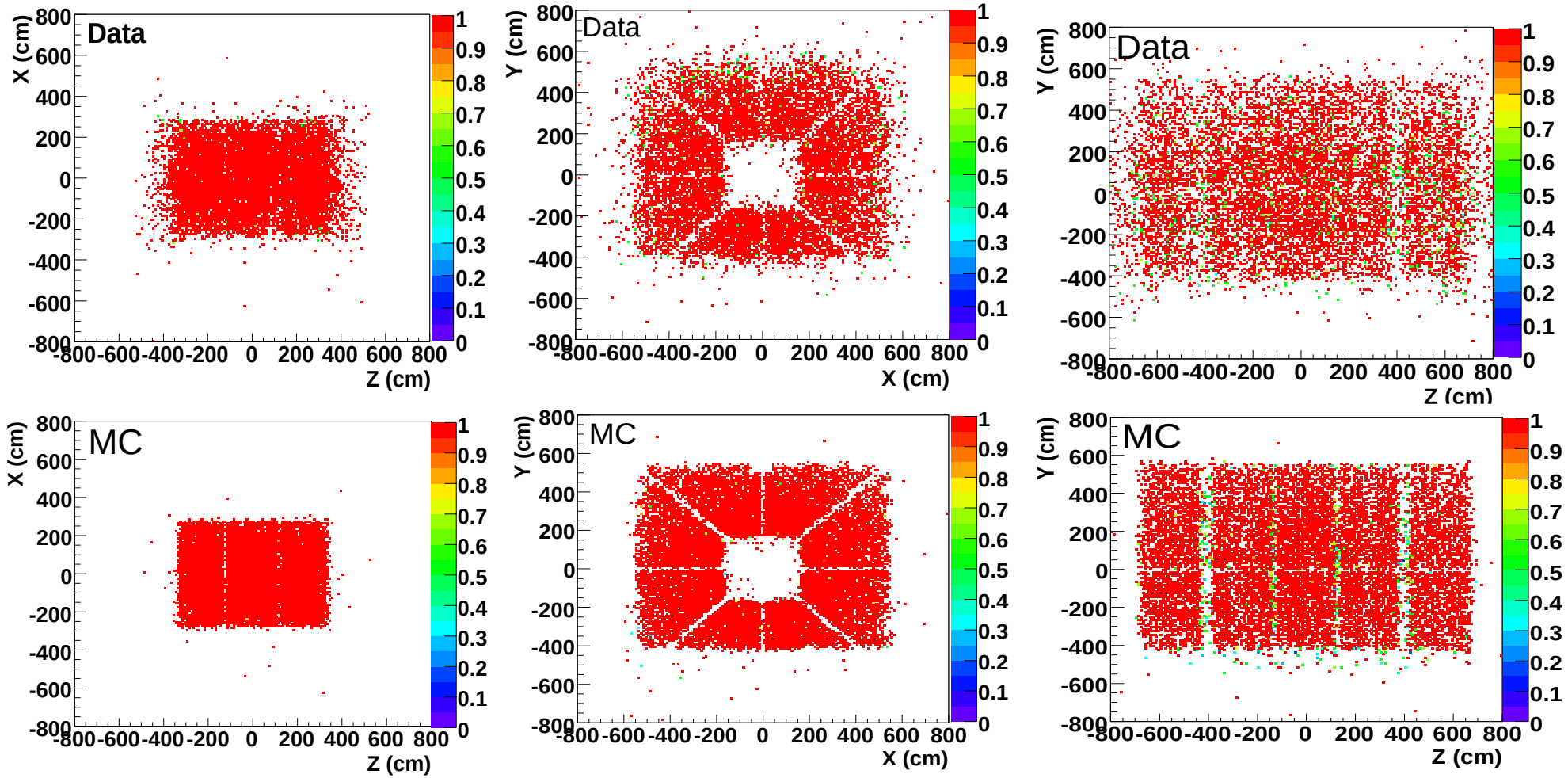
EC:

More complicated

Scintillation Counter Efficiency Maps

Scintillator geometry description already included in MC, proving that applying data/MC scale factor to re-weight scintillator counter efficiencies is possible

Top A–layer | South B-layer | East C-layer



Bayesian Decision Theory

$$P(\omega_j \mid x) = \frac{p(x \mid \omega_j) P(\omega_j)}{P(x)}$$

$$P(x) = \sum_{i=1}^{c} p(x \mid \omega_i) P(\omega_i)$$

Posterior =

likelihood*prior/evidence

Mininum-error-rate classification:

decide ω_i if $P(\omega_i|x) > P(\omega_j|x)$ for all $j \neq i$

Discriminant function $g_i(x)$

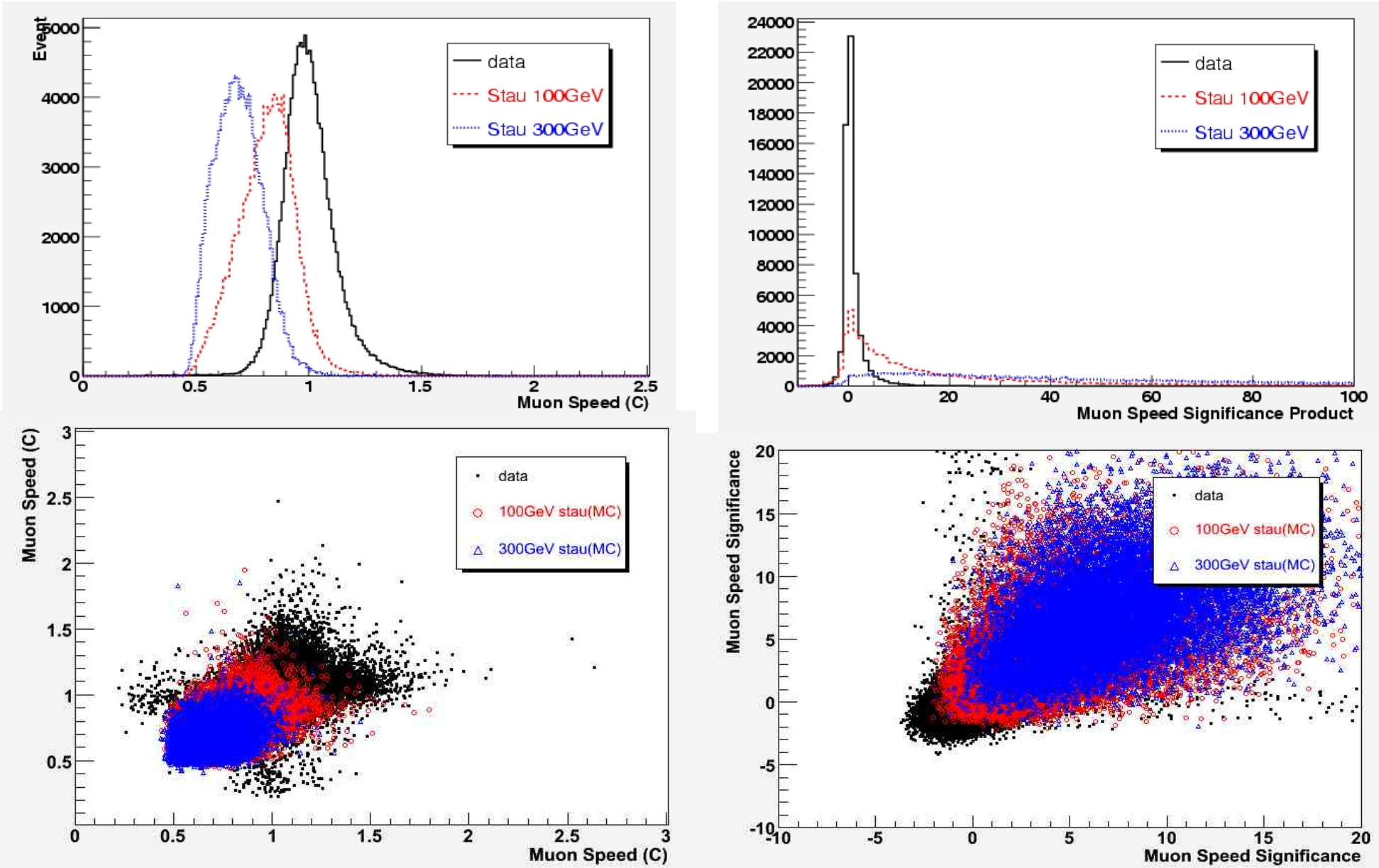
assign a feature vector x to class ω_i,

if $g_i(x) > g_j(x)$ for all $j \neq i$

Ref: 1. Richard Duda, Peter Hart and David Stork, ***Pattern Classification.***

2. Jerzy Neyman and Egon Pearson, ***On the problem of the most efficient tests of statisitical hypotheses.***

3. Abraham Wald, ***Contributions to the theory of statistical estimation and testing of hypotheses.***


Event
data
Stau 100GeV
Stau 300GeV
Muon Speed (C)
Muon Speed Significance Product
Muon Speed (C)
100GeV stau(MC)
300GeV stau(MC)
Muon Speed Significance

Previous DØ results

Short summary of earlier results based on old data

- ***Luminosity: 390 pb^{-1}***
- ***Stau cross section limit: 0.06 pb to 0.62 pb depending on stau mass***
- ***Chargino mass limit:***
  - ***140 GeV for higgsino-like chargino***
  - ***174 GeV for gaugino-like chargino***