Recent Results in Rare Heavy Flavor Decays at CDF

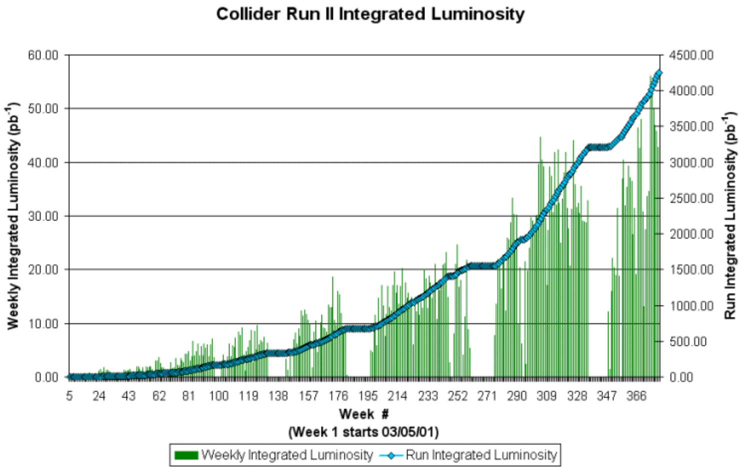
Hans Wenzel for the CDF Collaboration

(Fermilab)

- **Motivation:**
  - **The decays $B_{s,d} \rightarrow e\mu$, $B_{sd} \rightarrow e^+e^-$ and $D^0 \rightarrow \mu^+\mu^-$**
- **The Measurements:**
  - **$B_{sd} \rightarrow e^+\mu^-$ Measurement**
  - **$B_{sd} \rightarrow e^+e^-$ Measurement**
  - **$D^0 \rightarrow \mu^+ \mu^-$ Measurement**
- **Summary**

Thanks

- **Thanks to the accelerator division for keeping the data coming!**
- **Thanks to the CDF collaboration for operating such a complex detector and providing many excellent studies to build upon.**



Motivation

Why do we search for rare decays?

Rare particle decays could provide a unique glimpse of subatomic processes that elude the direct reach of even the most powerful particle colliders on Earth. Their observation could answer questions about the nature of matter and energy, shine light on the evolution of the early universe, and explain the subtle differences between matter and antimatter.

……..

Robert Tschirrhart

Symmetry mar/apr 08

Sounds pretty exciting → Let's do it

The decays $B_{s,d} \to e^+\mu^-$

- $B_{s,d} \to e^+\mu^-$ decays are forbidden within the "original" SM^{org}. But the observation of neutrino oscillations has shown that lepton flavour changes actually occur in nature →standard model needed to be modified to incorporate this. Still SM^{NG} prediction very small < 1.0×10^{-15}.
- The decays are possible in some theoretic models containing lepton-flavour violating tree-level couplings mediated by leptoquarks.
- R-parity violating SUSY or ED models can give contributions.

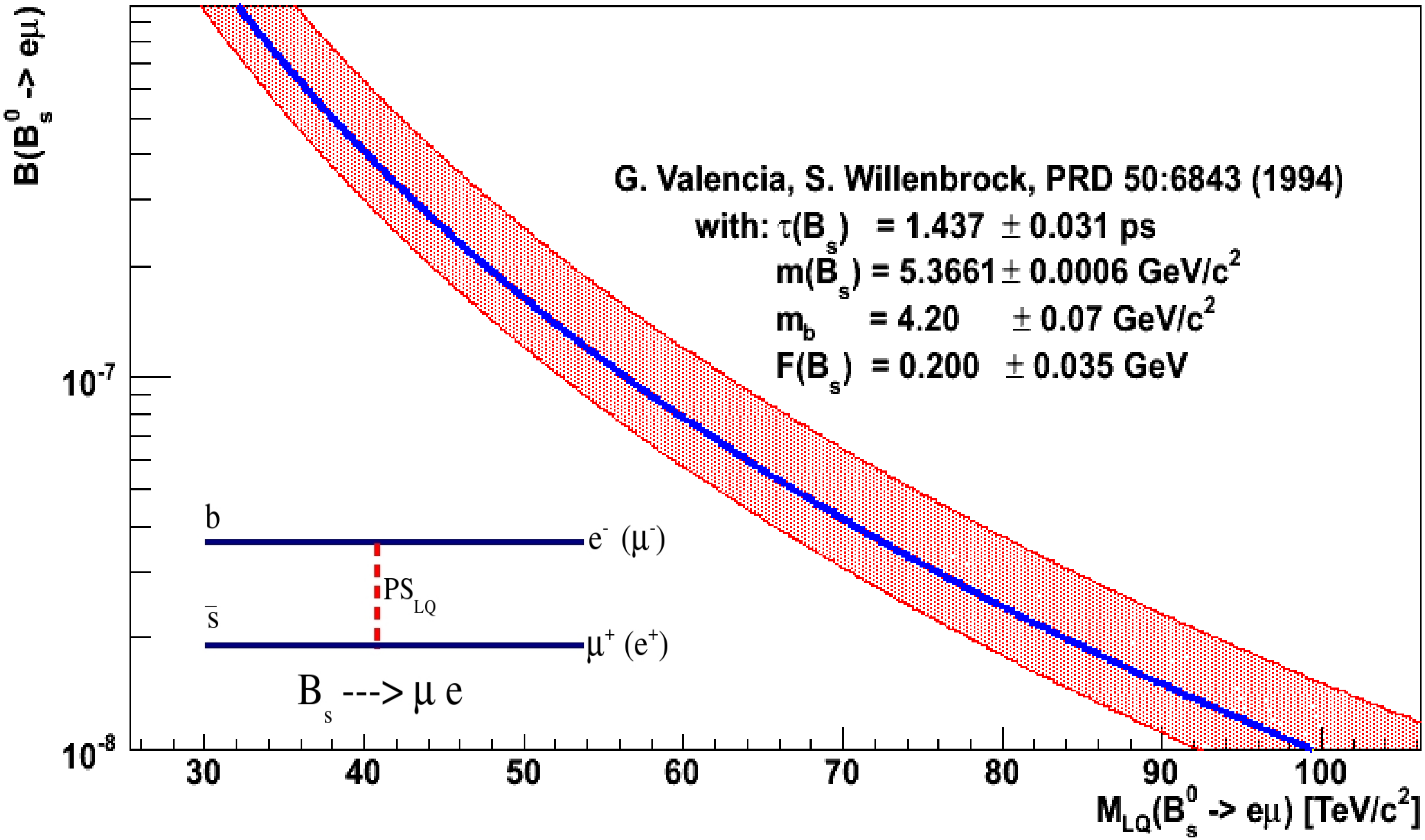
One example model: Pati-Salam Leptoquarks

- Grand Unification Theory (GUT) by J. Pati and A. Salam predicts spin 1 gauge bosons the so called "Pati Salam Leptoquarks", $PS_{LQ,}$ that carry both colour and lepton quantum numbers

  [PRD 10,275 (1974)]

- It is the simplest model based on $SU(4)_c$ where the lepton number is the fourth "colour"

Br($B_s \to e^+\mu^-$) and LQ Mass



Current Status

- **CDF Run I published limits @ 90 (95) % C.L. [PRL (81) 1998]**

$$\mathcal{B}(B_s^0 \to e^\pm\mu^\mp) < 6.1(8.2) \times 10^{-6}$$
$$\mathcal{B}(B_d^0 \to e^\pm\mu^\mp) < 3.5(4.5) \times 10^{-6}$$

$$\mathrm{M_{LQ}}(B_s^0) > 20.7(19.3)\ \mathrm{TeV}/c^2$$
$$\mathrm{M_{LQ}}(B_d^0) > 21.7(20.4)\ \mathrm{TeV}/c^2$$

- **B-factories (90% CL):**

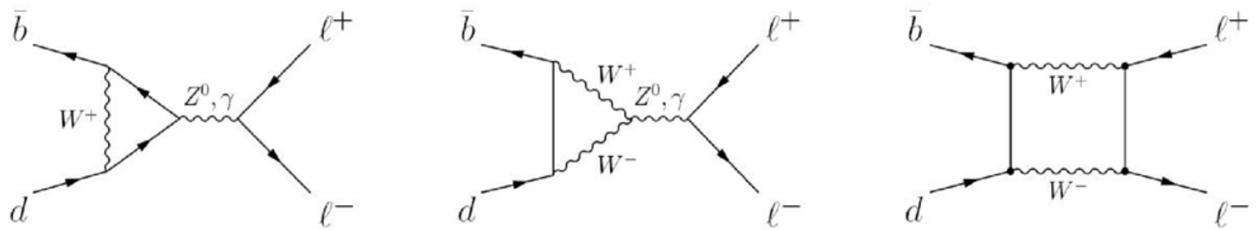
$$Br(B_d^0 \to e^+\mu^-) < 9.2 \times 10^{-8} \text{ at 90 \% C.L. (BABAR)}$$
$$Br(B_d^0 \to e^+\mu^-) < 1.7 \times 10^{-7} \text{ at 90 \% C.L. (BELLE)}$$
$$Br(B_d^0 \to e^+\mu^-) < 1.5 \times 10^{-6} \text{ at 90 \% C.L. (CLEO2)}$$

MLQ (Bd) > 53.1 TeV/c2 (BABAR 2007)

- **LQ from Kaon decays:** $Br(K_L \to \mu e) < 4.7 \times 10^{-12}$ with $M_{LQ} > 100\ \mathrm{TeV}/c^2$

Most of direct searches for LQ (different properties) set limits in the order of : M_{LQ} > 200-300GeV/c^2

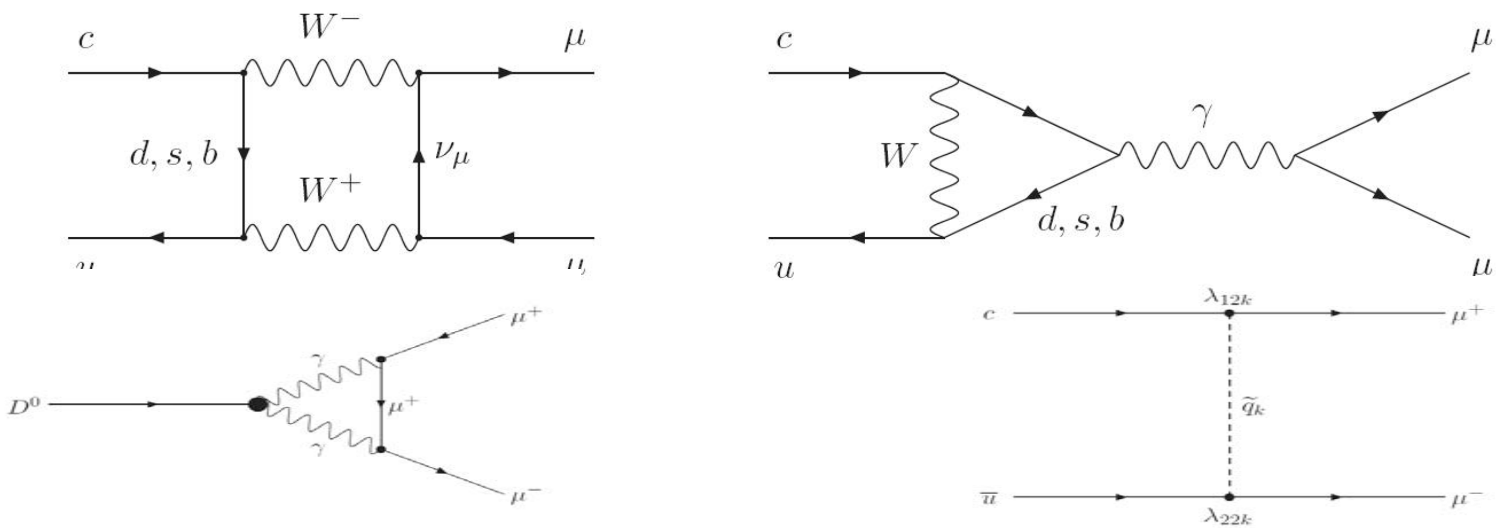
The decays $B_{s,d} \to e^+e^-$



Channel	SM prediction	CDF Run II ($2 fb^{-1}$) (@ 90(95)% C.L.)	BaBar ($347 fb^{-1}$) (@ 90% C.L.)
$Br(B_s^0 \to \mu^+\mu^-)$	$(3.42 \pm 0.54) \times 10^{-9}$	$< 4.7(5.8) \times 10^{-8}$	-
$Br(B_d^0 \to \mu^+\mu^-)$	$(1.00 \pm 0.14) \times 10^{-10}$	$< 1.5(1.8) \times 10^{-8}$	$< 5.2 \times 10^{-8}$
$Br(B_s^0 \to e^+e^-)$	-	this talk	-
$Br(B_d^0 \to e^+e^-)$	1.9×10^{-15}	this talk	$< 1.13 \times 10^{-7}$

While $B_{s,d} \to \mu^+\mu^-$ starts to put serious constraints on various models there is plenty of wiggle room left in case of $B_{s,d} \to e^+e^-$

The FCNC decay $D^0 \rightarrow \mu^+\mu^-$



Previous CDF run II measurement based on 69 pb^{-1}:
$Br(D^0 \rightarrow \mu^+\mu^-) < 2.1(3.1) \times 10^{-6}$ @ 90(95) % C.L.

Channel	SM prediction	CDF Run II preliminary ($360pb^{-1}$) (@ 90(95)% C.L.)	BaBar (@ 90% C.L.)
$Br(D^0 \rightarrow \mu^+\mu^-)$	$\leq 4. \times 10^{-13}$	this talk	$< 1.3 \times 10^{-6}$

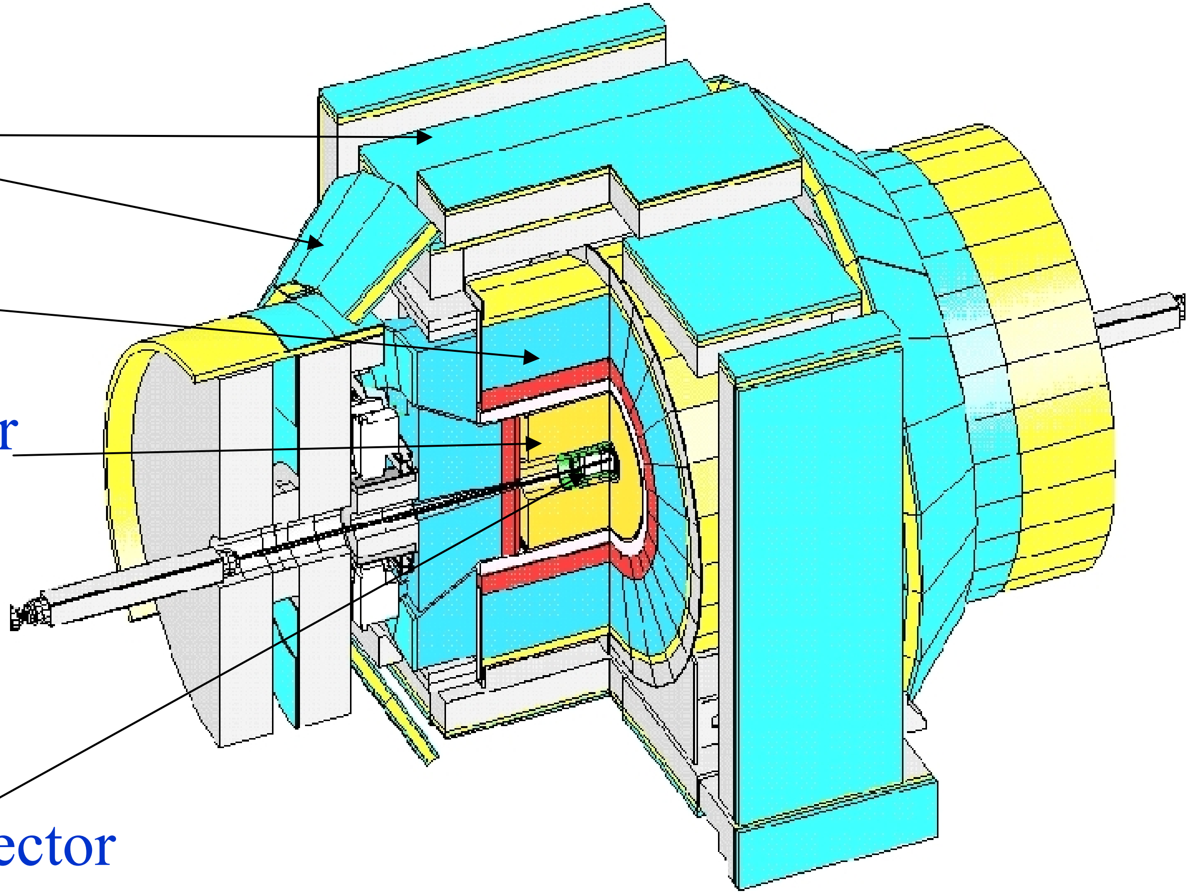
R-parity violating SUSY allows enhancements up to 3.5×10^{-6}

The CDF detector

Muon Chambers

Calorimeters

Central Drift Chamber
dE/dx, XFT Trigger



Silicon Vertex Detector
SVT: Silicon Vertex Trigger

Things in Common

All searches presented here have the following in common:

- **Based on two track data samples triggered by the Silicon Vertex Trigger, using the long lifetimes of B and D–mesons to reject prompt events.**
- **Leptonic final states (e μ).**
- **All measurements are relative measurements normalizing to a well known similar hadronic decay mode.**

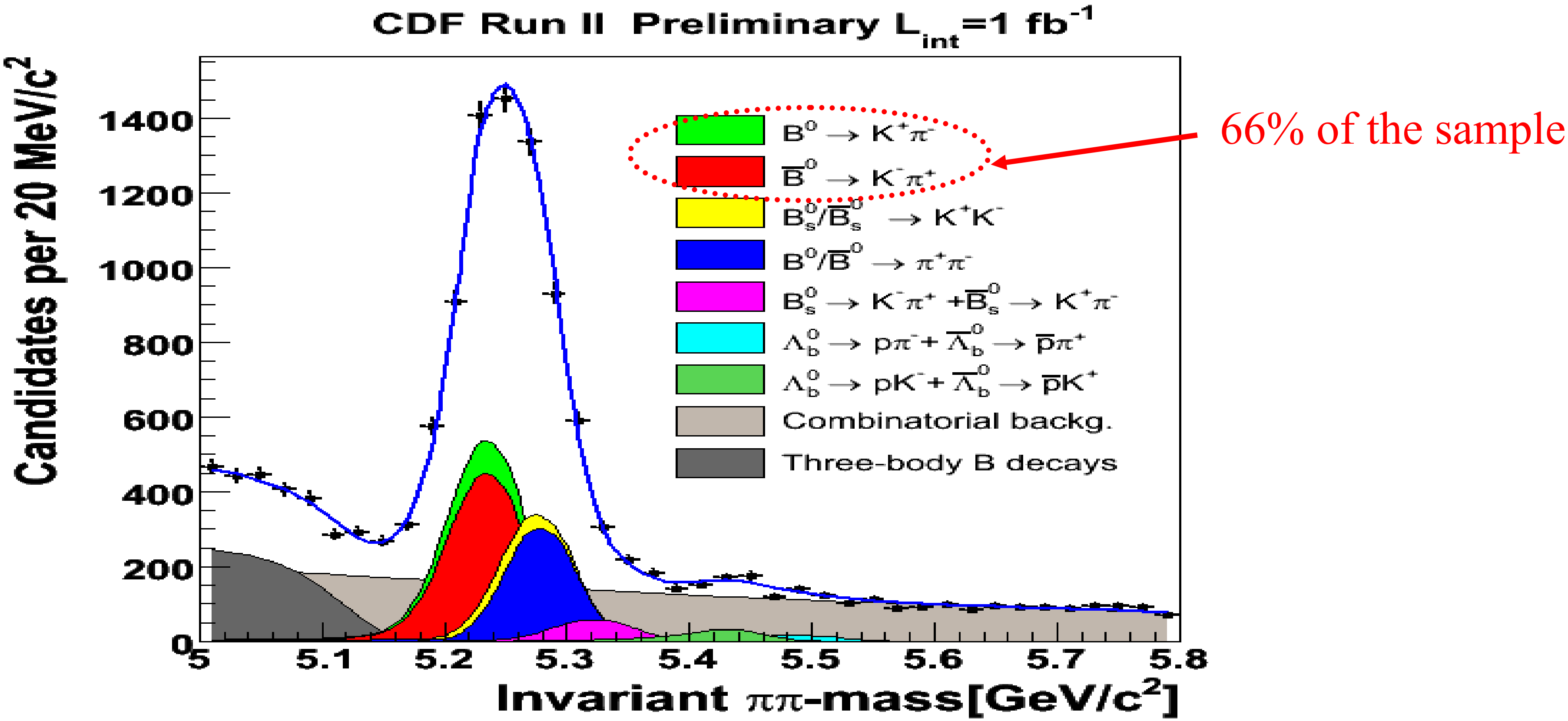
The decay $B_{sd} \to e^{+}\mu^{-}$

Who is looking for an emu?

Kaori Maeshima,
Ting Miao,
Hans Wenzel

Run-II Search Strategy

- **SVT two-track-trigger (TTT sample)**
- **Relative to B→hh: $B^0 \to K\pi$ / Bs → K K**



http://www-cdf.fnal.gov/physics/new/bottom/060921.blessed-bhh_1fb/

Run-II Search Strategy (ingredients)

Events (or Events @ limit)
surviving all selection criteria (incl. Lepton ID)

World average

$$Br(B_s^0 \to e^+\mu^-) = \frac{N(B_s^0 \to e^+\mu^-) \cdot Br(B_d^0 \to K^+\pi^-) \cdot f_{B_d^0}/f_{B_s^0}}{\epsilon^{rel}_{B_s^0 \to e^+\mu^-} \cdot N(B_d^0 \to K^+\pi^-)}.$$

The Result

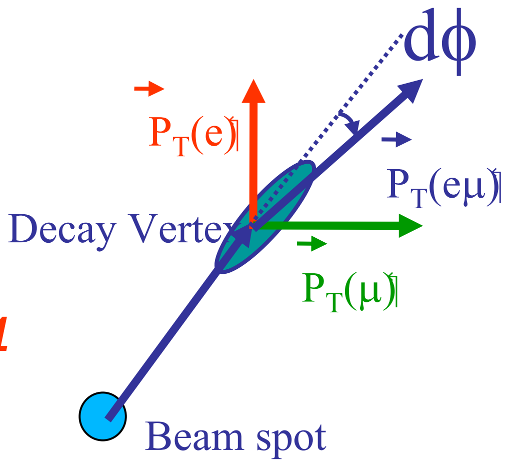
Fit to B->hh spectrum of
evts. surviving all but
lepton ID selection

Bs only:
biggest contribution
to systematic uncertainty

Relative efficiency:
MC for kinematics and mass window efficiency
CDF measurements (J/Psi,photon conversions)
for lepton ID efficiency and acceptance

Event Selection

- **SVT Trigger sample**
  - Use only tracks which actually fired the trigger
- **Standard selections as B→hh analysis**
  - *Two good tracks with pT>2GeV*
  - *100μm<d0<1mm*
  - *d0_B<140μm,* χ^2_{3D} *(B vertex)<5*
  - $L_{xy}(B)>200\mu m$
  - *Isolation = pT_B/ (pT_B+∑pT_i in R<1) > 0.4*
  - *Pointing angle d*φ *< 0.2*



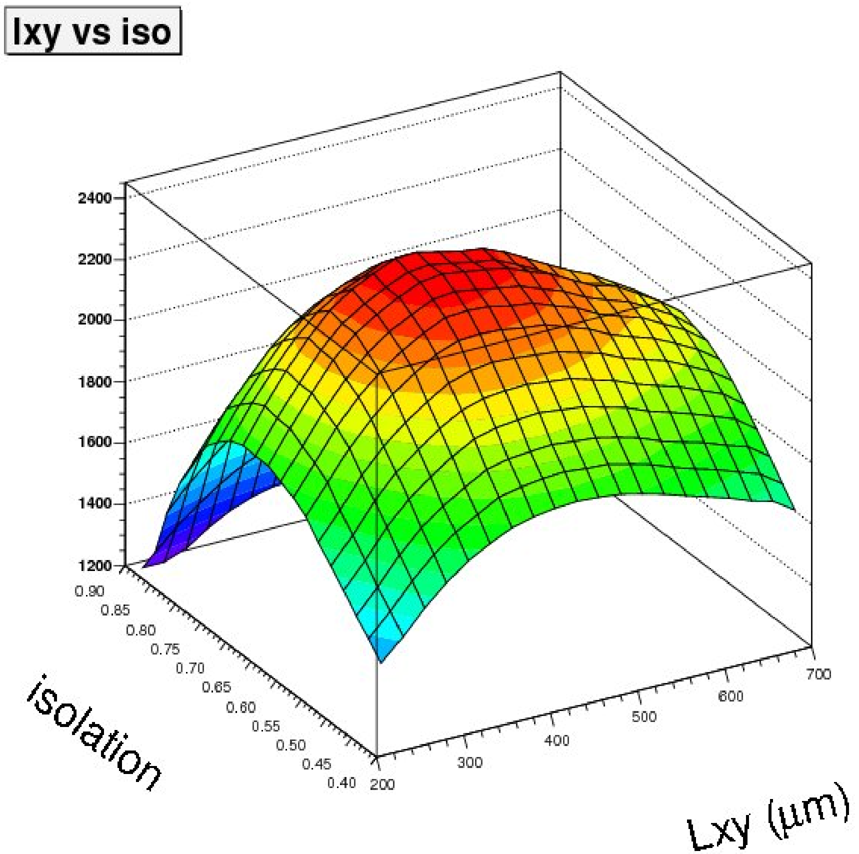
- **The last three are optimized for this analysis**

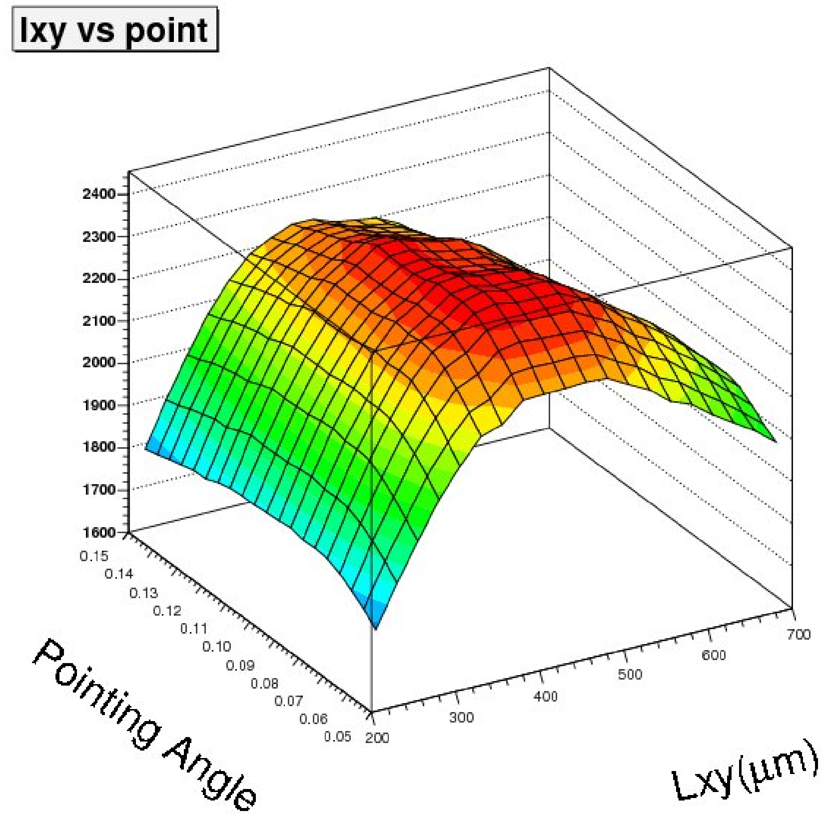
Cut Optimization

$$FOM = \frac{S}{\alpha/2 + \sqrt{B}} = \frac{S}{1.5 + \sqrt{B}} \quad (with \;\; \alpha = 3)$$

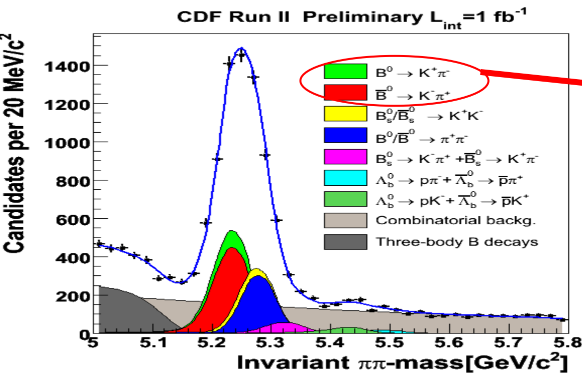
Giovanni Punzi: physics/0308063

(***FOM*** :Figure of Merit)



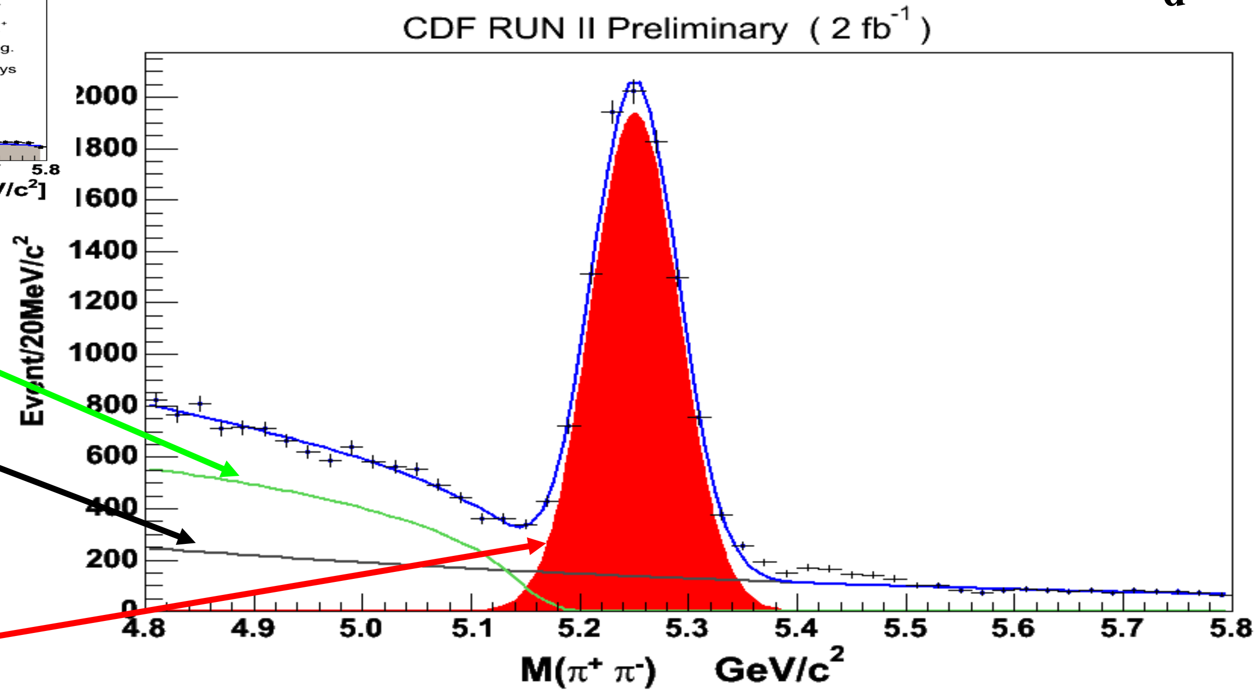


B→hh with Optimized Cuts



9648.4+/- 224.7 B->hh

~66% → 6387.0+/-214.4 B_d->$K^+\pi^-$



Three body B decays

Combinatorial backg.

B → hh

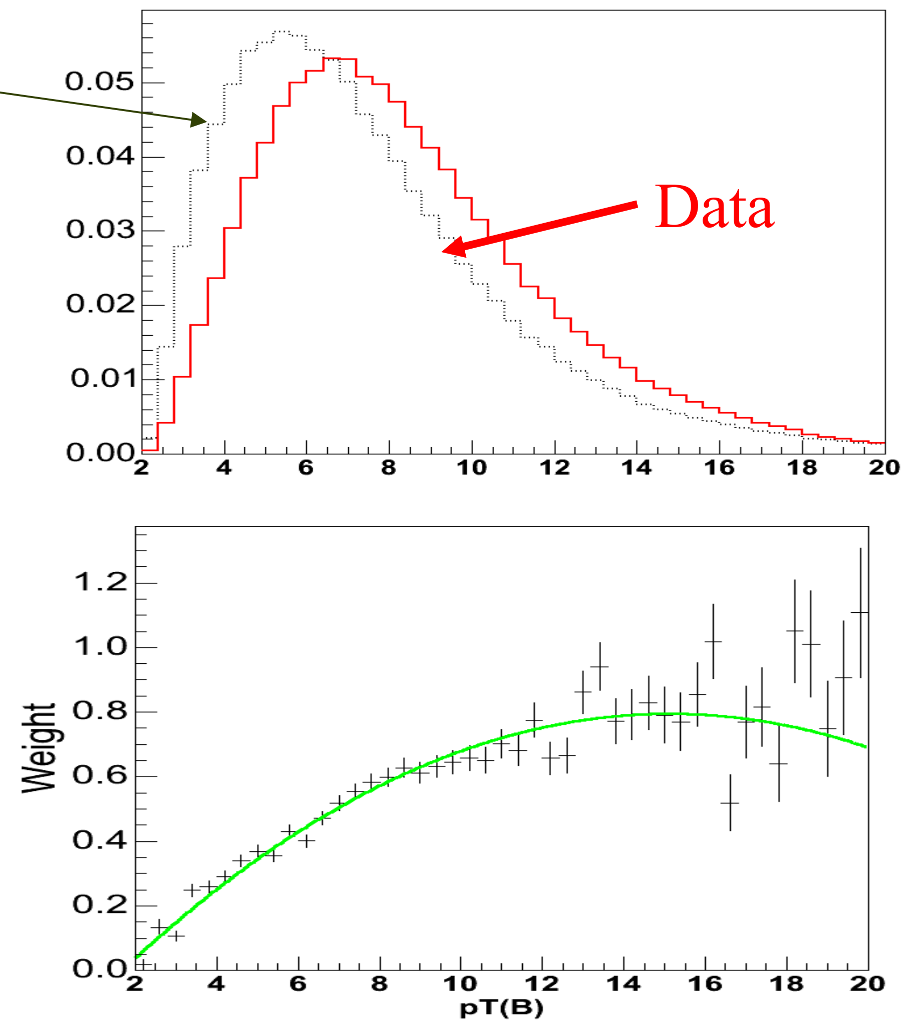
(Lxy>375μm, Iso>0.675 and dφ<0.11)

Monte Carlo

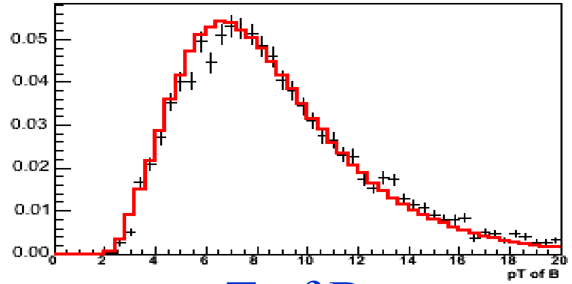
Detailed Simulation of the CDF detector including:

- Trigger simulation
- Detector response
- Event reconstruction

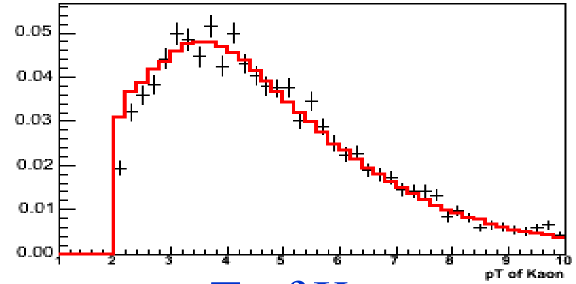
Used to model kinematics and mass window efficiency.
B → hh Signal only!



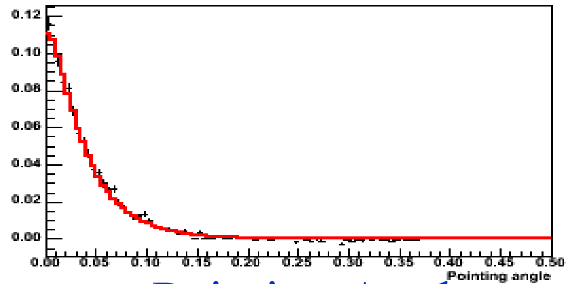
Monte Carlo (kinematical variables)



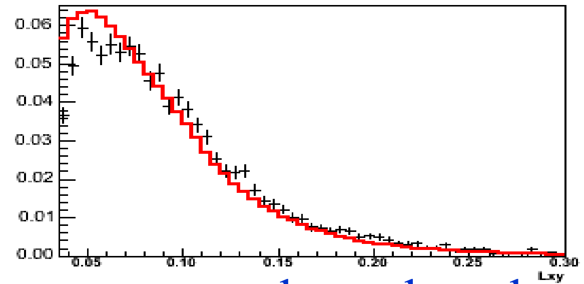
pT of B



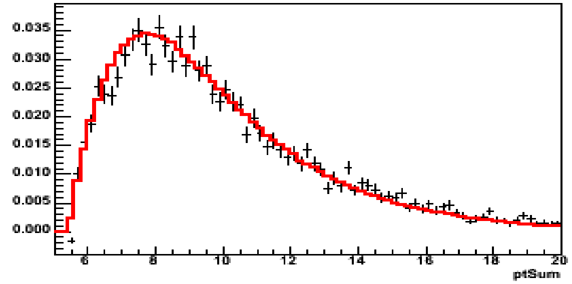
pT of Kaon

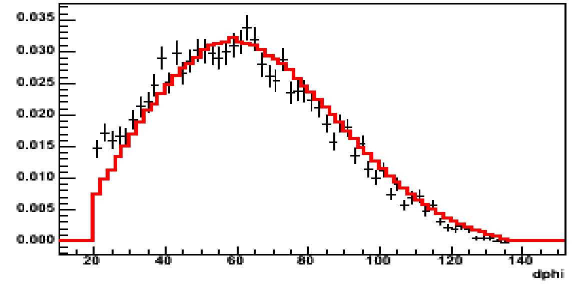


Pointing Angle

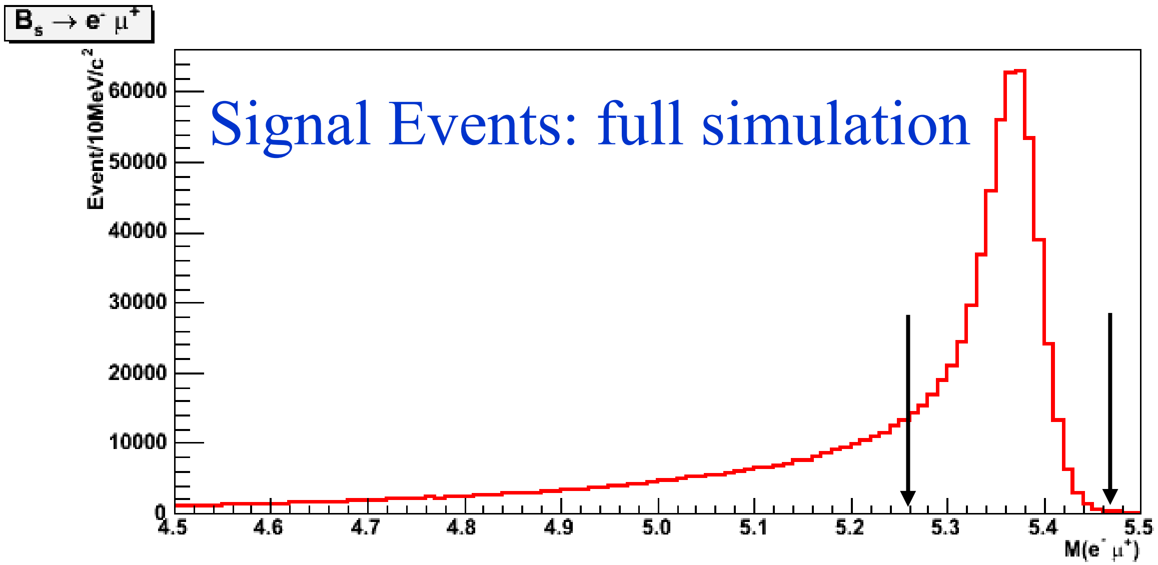


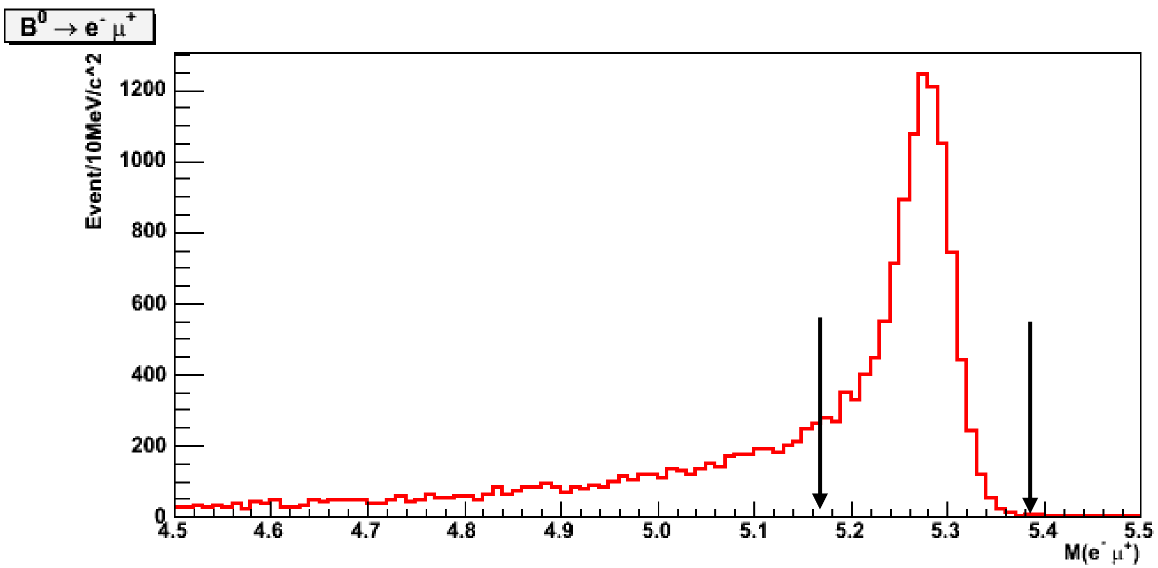
transverse decay length





Signature of B→eμ





- *Long tail due to Bremsstrahlung*
- *Search window for $B_s^{(0)} \to e\mu$ as 3σ around $B_s^{(0)}$ mass*

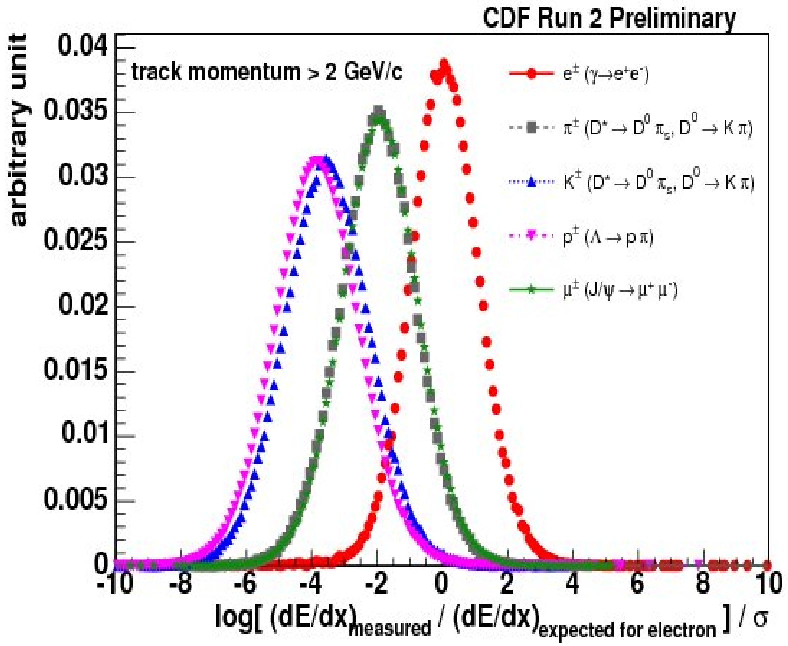
Muon Identification

- **Used the standard algorithm:**
  - Extrapolate track into the muon chambers select on matching
  - Energy deposit in calorimeter required to be consistent with minimum ionizing particle
- **Acceptance and efficiency estimated with J/Psi- events.**

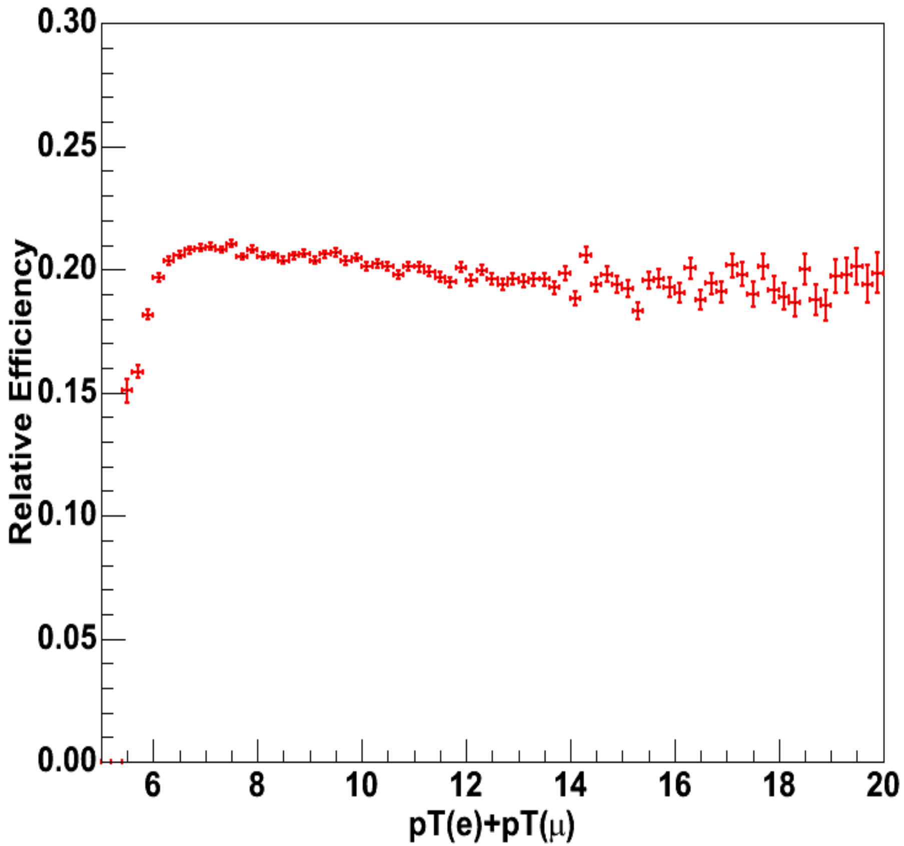
Electron Identification

- Electron ID combines Tracker (dE/dx and momentum) and calorimeter Information
- Requires match of track with shower in calorimeter.
- E/P > 0.7.
- $E_{had}/E_{em} < 0.05$.
- Requires shower profile is consistent with electron.

- dE/dx and calorimeter efficiency from photon conversions: $\gamma \rightarrow e^+e^-$

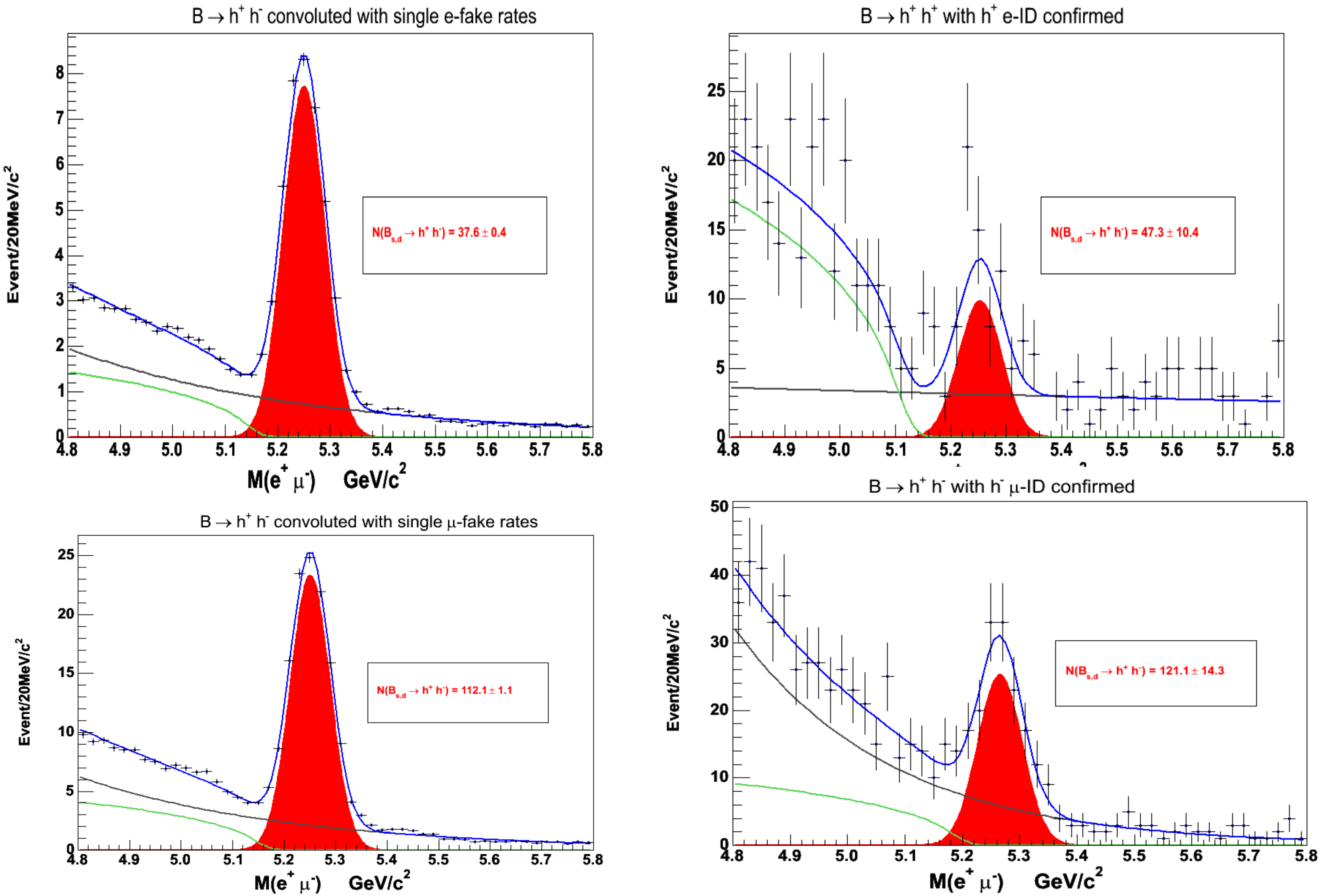


Relative efficiency: $\varepsilon(B \rightarrow e\mu)/e(B \rightarrow K\pi)$



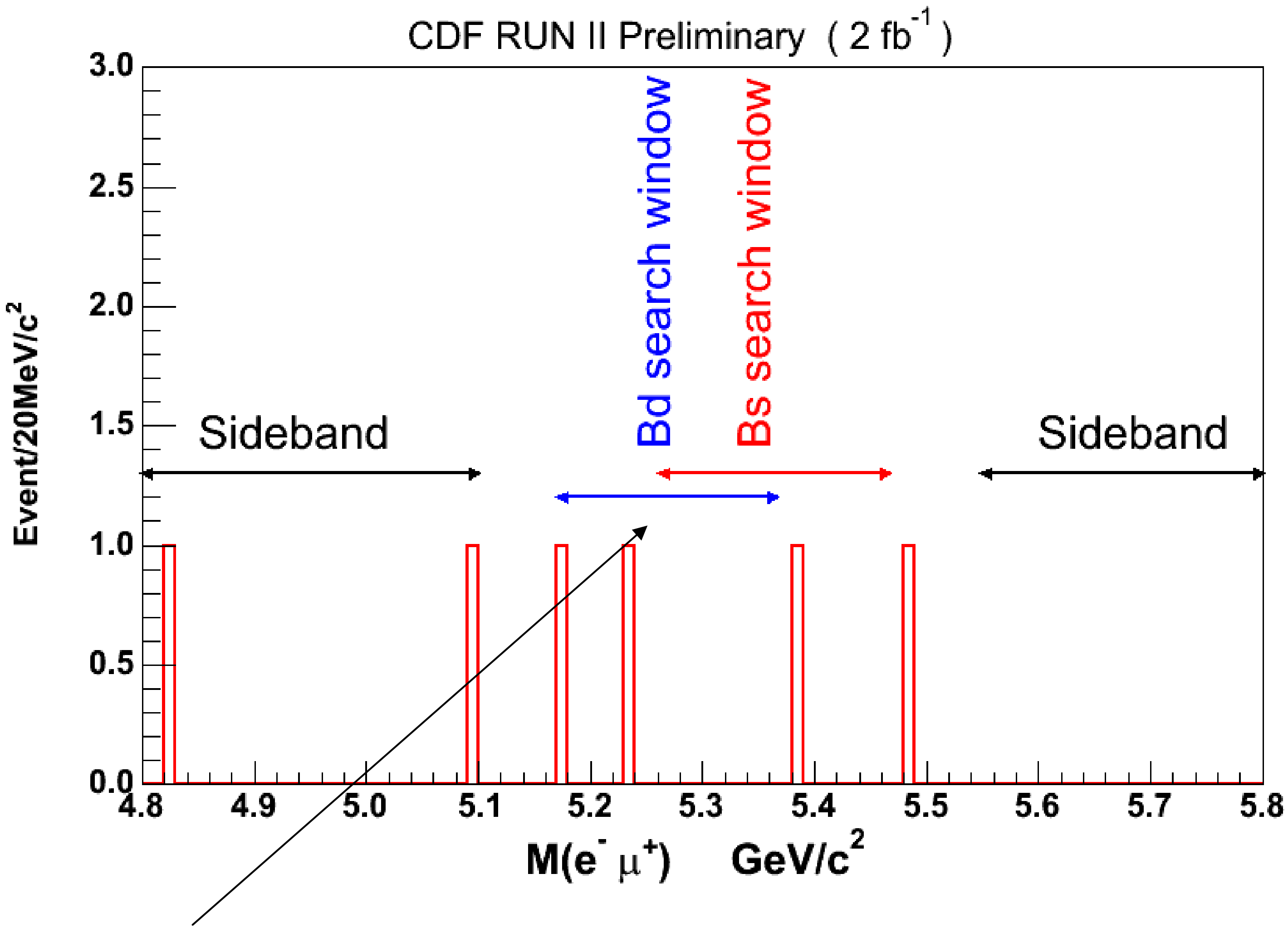
Includes:

- Muon acceptance and identification efficiency
- Electron acceptance and identification efficiency
- dE/dx efficiency
- Mass window selection efficiency
- Kinematics
- ….



Background from double fakes expected: 0.229 +/- 0.046

M(e-μ): after all selections



Excellent mass resolution
allows for tight search windows

Systematic Uncertainties

CDF Run II preliminary ($2fb^{-1}$)

Source	values	$\Delta\text{Br}(B_s^0 \to e^+\mu^-)$	$\Delta\text{Br}(B_d^0 \to e^+\mu^-)$
$N(B^0 \to K^+\pi^-)$	6387.0 ± 214.4	3.4%	3.4%
$BR(B^0 \to K\pi)$	$(19.4 \pm 0.6) \times 10^{-6}$	3.1%	3.1%
$f_{B_d^0}/f_{B_1^0}$	3.86 ± 0.59	15.3%	-
$\epsilon^{Rel}_{B_s^0 \to e^+\mu^-}$	0.2071 ± 0.0158	7.6%	-
$\epsilon^{Rel}_{B_d^0 \to e^+\mu^-}$	0.2097 ± 0.0123	-	5.9%
Total		17.7%	7.5%

Limit Calculation for Br(Bsd→eμ)

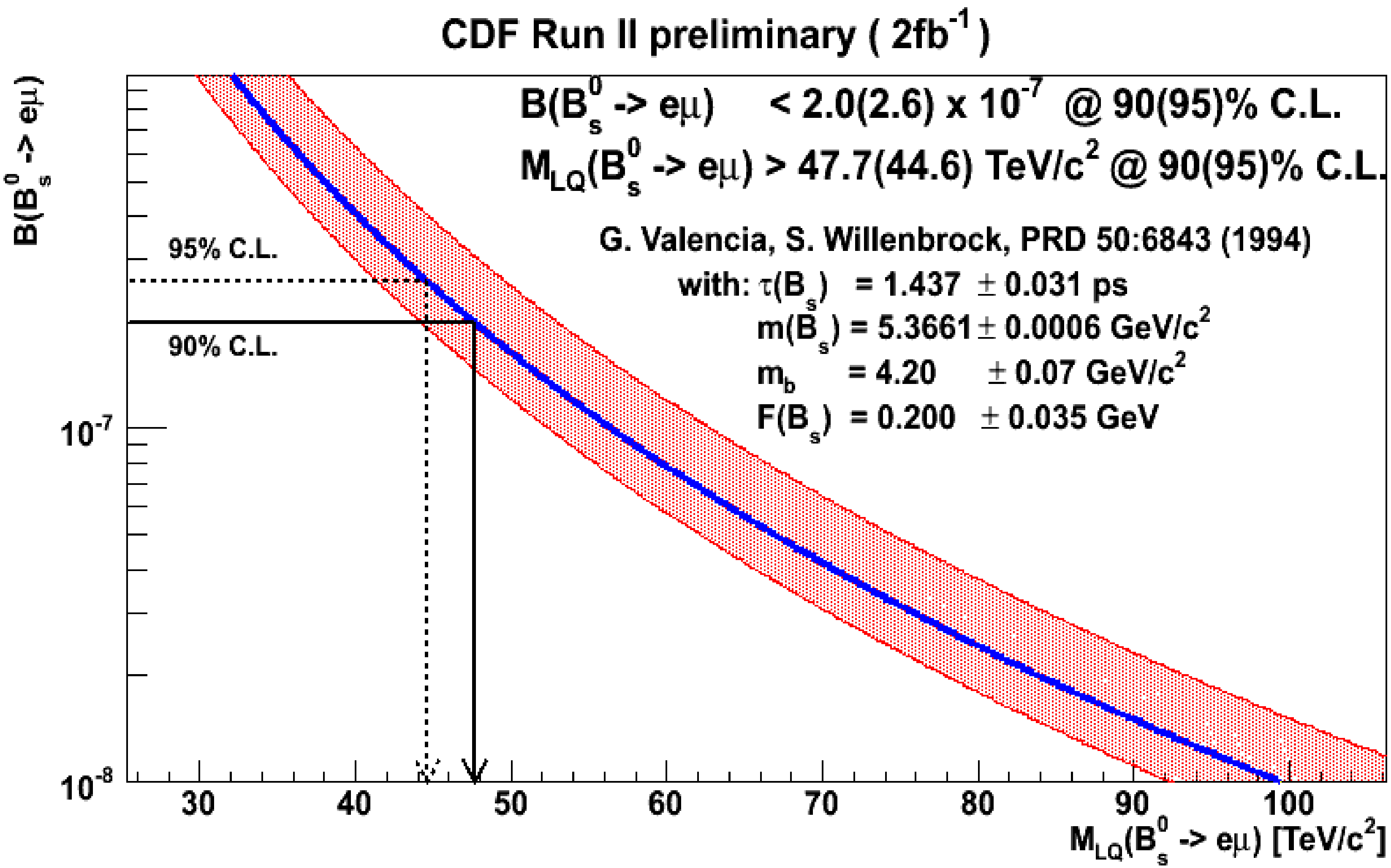
$$Br(B_s^0 \to e^+\mu^-) = \frac{N(B_s^0 \to e^+\mu^-) \cdot Br(B_d^0 \to K^+\pi^-) \cdot f_{B_d^0}/f_{B_s^0}}{\epsilon^{rel}_{B_s^0 \to e^+\mu^-} \cdot N(B_d^0 \to K^+\pi^-)}.$$

- **$Br(B^0 \to K\pi) = (19.4 \pm 0.6) \times 10^{-6}$** (world average)
- **$N(B^0 \to K\pi) = 6387.0 +/- 214.4$**
- **$\varepsilon_{Rel}(B_s)$ = 0.2071±0.0003±0.0158**
- **f_{Bd}/f_{Bs} = (39.8±1.2)%/(10.3±1.4)% =3.86 ±0.59**
- **$N_{limit}(B_s \to e\mu)$ = 3.60 (4.57) @ 90(95) % C.L.**
- **$N_{Bgr}(B_s \to e\mu)$ = 0.81 +/- 0.63**
- **$\varepsilon_{Rel}(B_d)$ = 0.2097±0.0023±0.0123**
- **$N_{Bgr}(Bd \to e\mu)$ = 0.94 +/- 0.63**
- **$N_{limit}(B_d \to e\mu)$ = 4.44 (5.44) @ 90(95) % C.L.**
-

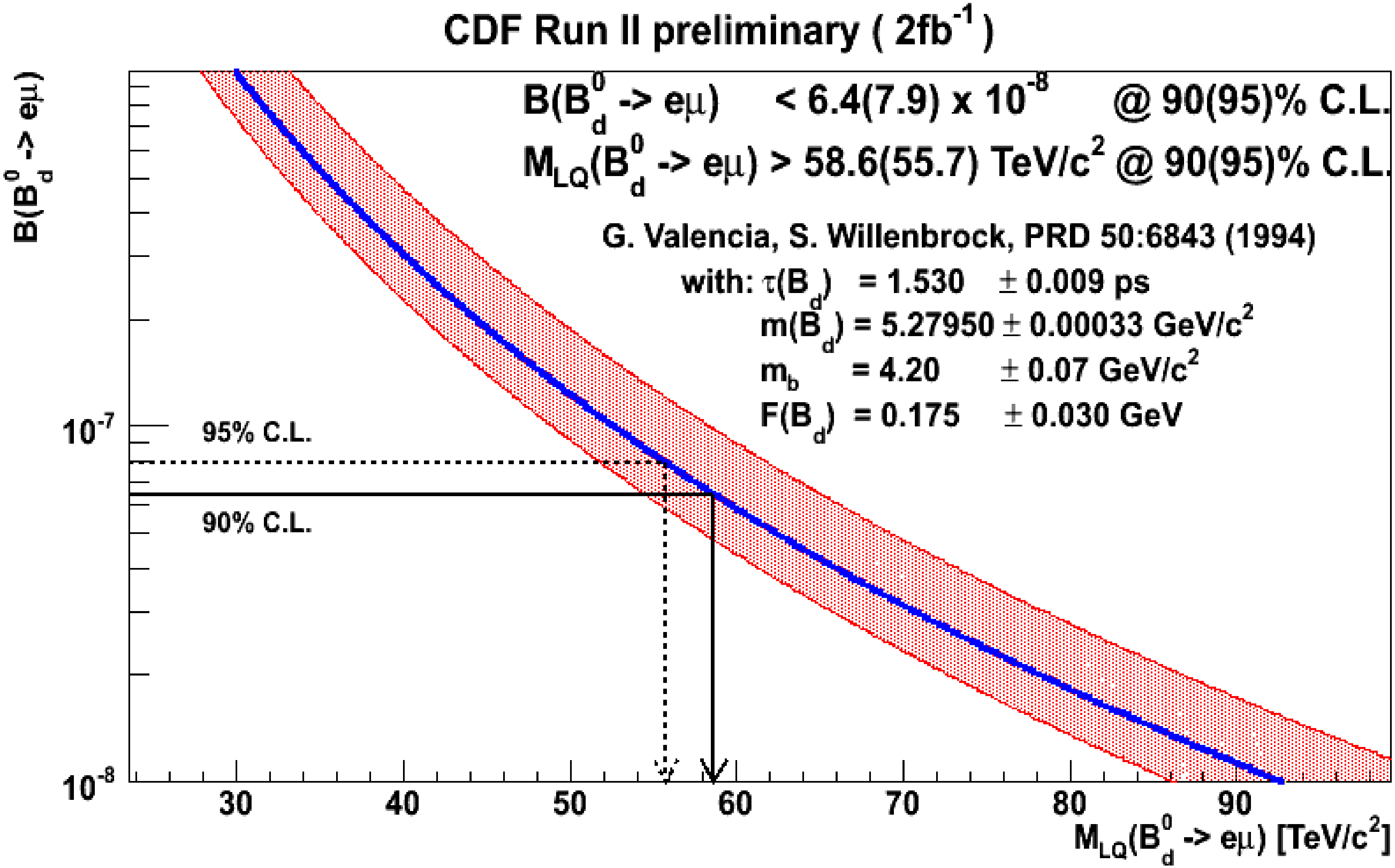
Limits for different scenarios

Search Channel	N_{obs}	N_{bgr}	Systematic uncertainty (%)	(BAYES) $N_{C.L.}^{90\%}$	(BAYES) $N_{C.L.}^{95\%}$	(POILIM) $N_{C.L.}^{90\%}$	(POILIM) $N_{C.L.}^{95\%}$
	no systematics, no background subtraction						
B_s	1	0±0	0	3.89	4.74	3.89	4.74
B_d	2	0±0	0	5.32	6.30	5.32	6.30
	systematics only						
B_s	1	0±0	17.7	4.21	5.20	4.08	5.05
B_d	2	0±0	7.5	5.40	6.41	5.37	6.37
	systematics and background subtraction						
B_s	1	0.81±0.63	17.7	3.60	4.57	3.55	4.5
B_d	2	0.94±0.63	7.5	4.44	5.44	4.59	5.58

$B_s \to e^+\mu^-$ with $2fb^{-1}$

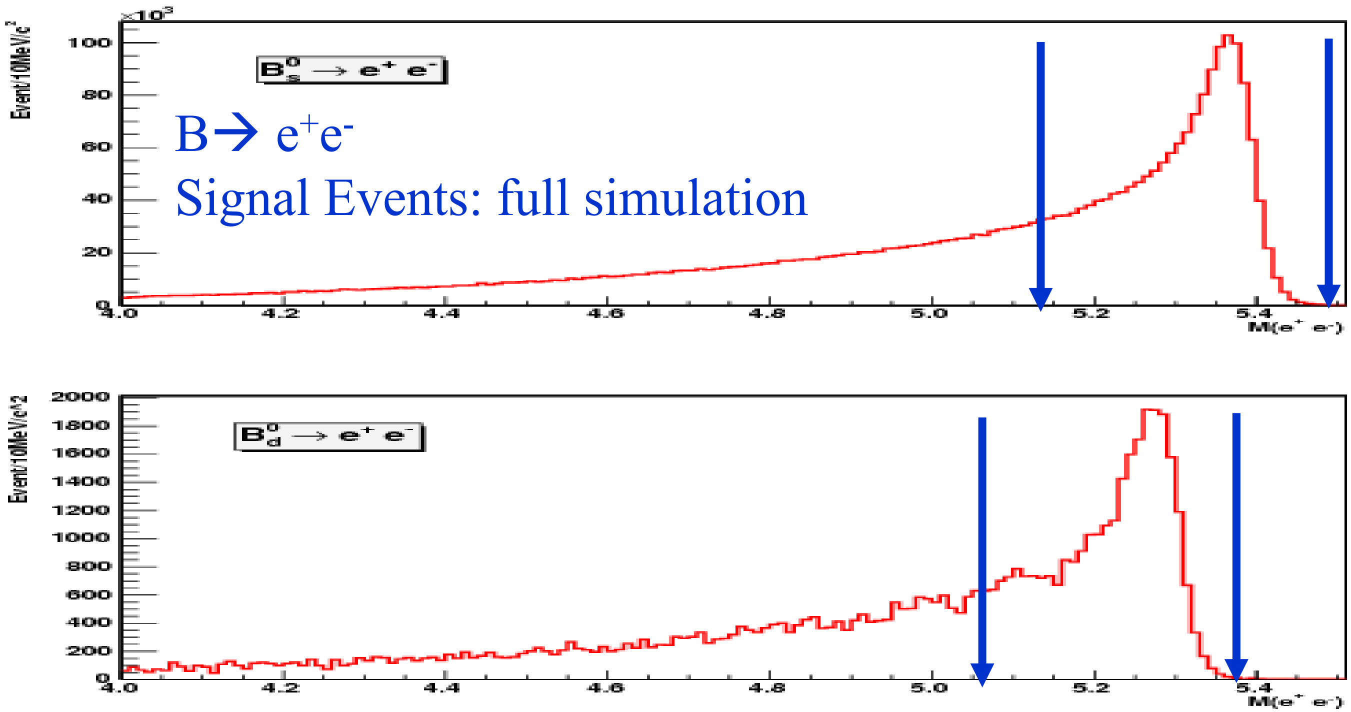


$B^0 \rightarrow e^+\mu^-$ with 2 fb^{-1}

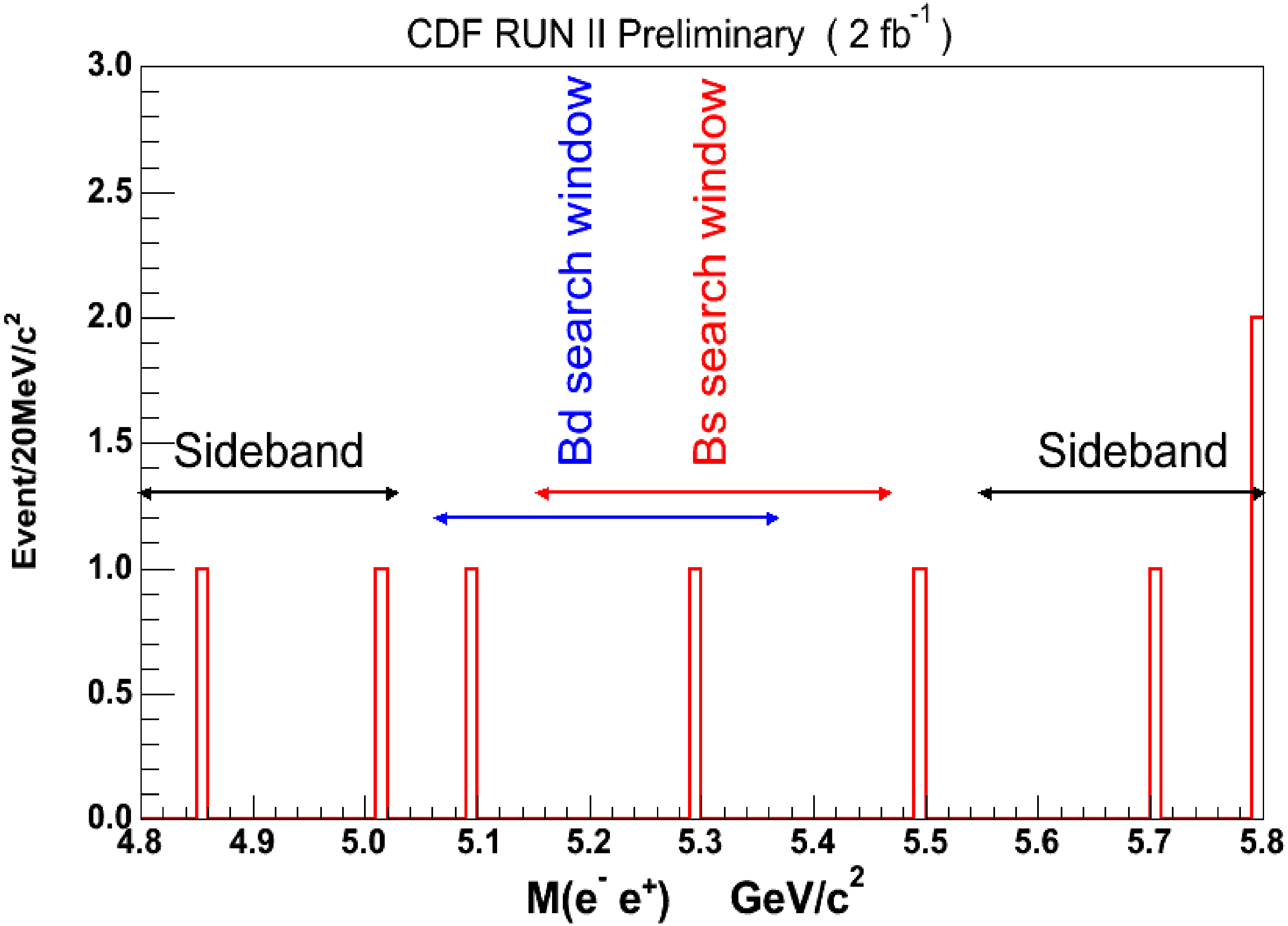


$B_{sd} \rightarrow e^+e^-$ with 2 fb^{-1}

- Identical to $B_{sd} \rightarrow e^+\mu^-$ now both tracks have to be identified as electron candidates.
- To compensate for the large Bremstrahlungs tail we use asymmetric mass windows $(-6\sigma, 3\sigma)$



$B_{sd} \rightarrow e^+e^-$ with 2 fb^{-1}



Systematic uncertainties

CDF Run II preliminary ($2fb^{-1}$)

Source	values	$\Delta Br(B_s^0 \to e^+e^-)$	$\Delta Br(B_d^0 \to e^+e^-)$
$N(B^0 \to K^+\pi^-)$	6387.0 ± 214.4	3.4%	3.4%
$BR(B^0 \to K\pi)$	$(19.4 \pm 0.6) \times 10^{-6}$	3.1%	3.1%
$f_{B_d^0}/f_{B_1^0}$	3.86 ± 0.59	15.3%	-
$\epsilon^{Rel}_{B_s^0 \to e^+e^-}$	0.1290 ± 0.011	8.9%	-
$\epsilon^{Rel}_{B_d^0 \to e^+e^-}$	0.1278 ± 0.011	-	8.9%
Total		18.3%	10.0%

Limit Calculation for Br($B_{sd} \to e^+e^-$)

- **Br($B^0 \to K\pi$)=(19.4±0.6) x 10^{-6}** (world average)
- **N($B^0 \to K\pi$)= 6387.0+/-214.4**
- **$\varepsilon_{Rel}(B_s)$ = 0.1290±0.0002±0.011**
- **f_{Bd}/f_{Bs} = (39.8±1.2)%/(10.3±1.4)% =3.86 ±0.59**
- **$N_{limit}(B_s \to ee)$ = 3.11 (4.03) @ 90(95) % C.L.**
- **$N_{Bgr}(B_s \to ee)$ = 2.66 +/- 1.80**
- **$\varepsilon_{Rel}(B_d)$ =** 0.1278±0.0017±0.011 for B0
- **$N_{Bgr}(Bd \to ee)$ = 2.66 +/- 1.80**
- **$N_{limit}(B_d \to ee)$ = 3.51 (4.47) @ 90(95) % C.L.**

Run II Preliminary (L= 2fb^{-1}):
Br($B_s \to e^+e^-$) < 2.8 (3.7) x 10^{-7}
Br($B_d \to e^+e^-$) < 8.3(10.6) x 10^{-8}

Search for the decay $D^0 \rightarrow \mu^+\mu^-$

E. Berry, I.K. Furic, R.F. Harr, Y.K. Kim

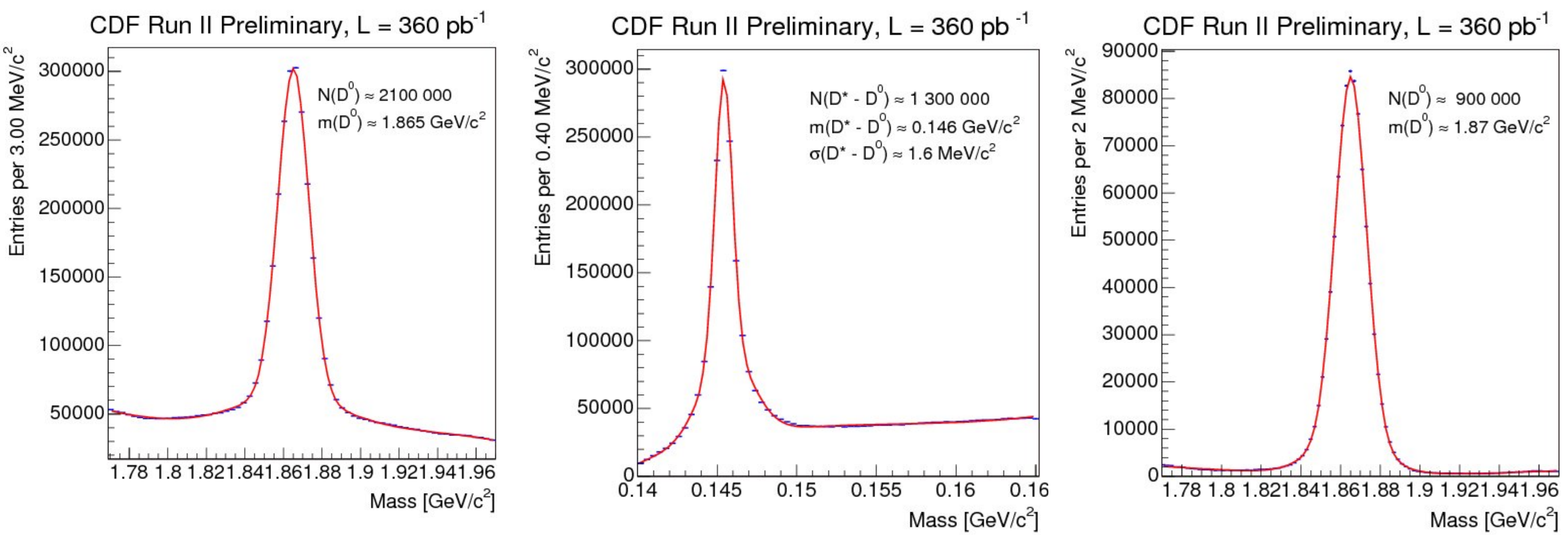
http://www-cdf.fnal.gov/physics/new/bottom/080228.blessed-d0-mumu/

Search for the decay $D^0 \rightarrow \mu^+\mu^-$

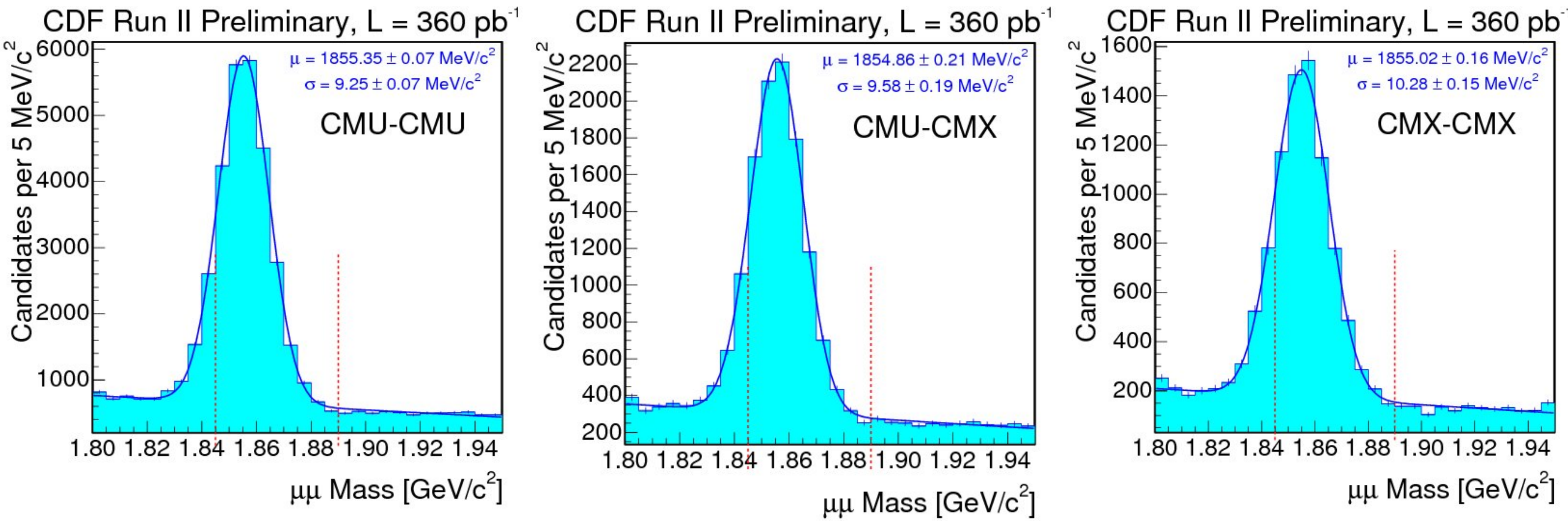
$$\mathcal{B}(D^0 \rightarrow \mu^+\mu^-) = \frac{N(\mu^+\mu^-)}{N(\pi^+\pi^-)} \cdot \frac{\epsilon(\pi^+\pi^-)}{\epsilon(\mu^+\mu^-)} \cdot \mathcal{B}(D^0 \rightarrow \pi^+\pi^-)$$

$B(D^0 \rightarrow \pi^+\pi^-) = (1.364 \pm 0.032) \times 10^{-3}$ (world average)

$D^0 \rightarrow K^+\pi^-$: Control sample



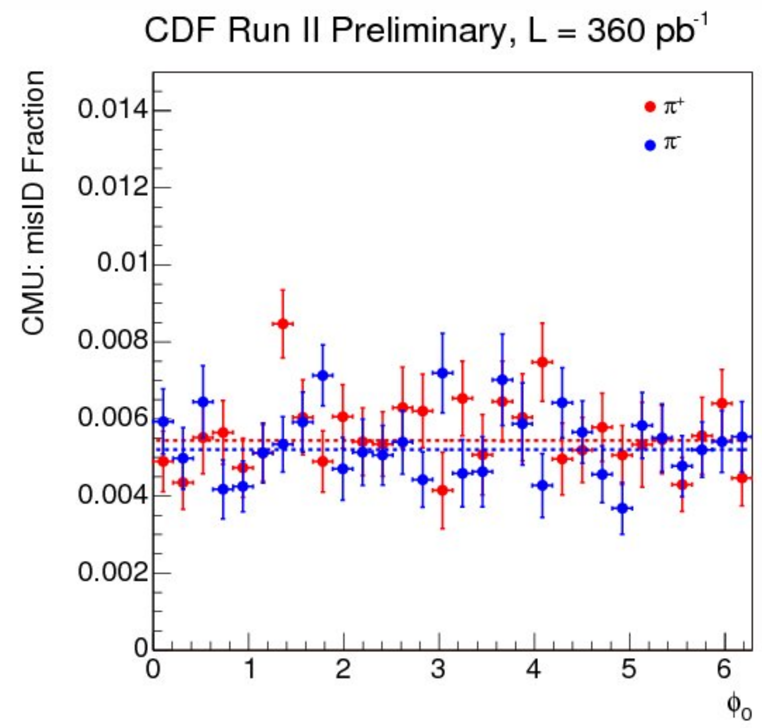
Search for the decay $D^0 \rightarrow \mu^+\mu^-$



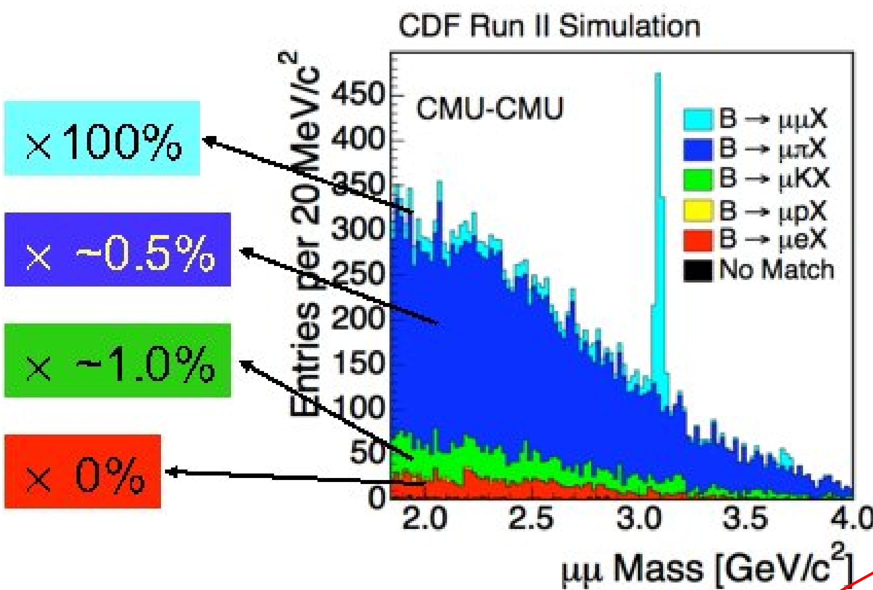
~ 45000 Events, $D^0 \rightarrow \pi^+\pi^-$ is the reference mode but can also fake $D^0 \rightarrow \mu^+\mu^-$ if both π's are misidentified as μ's.
To minimize the misidentification rate a likelihood function is used to identify μ's:
The function combines: dE/dx (tracker), calorimeter information (EM and Had) and μ–detector information. Maintains high efficiency and achieves additional hadron suppression!!

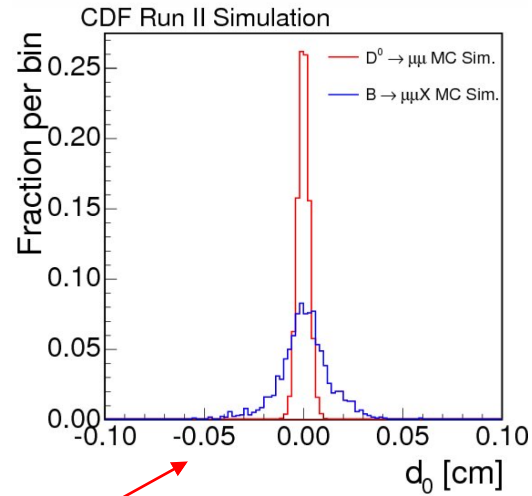
Fake Rate

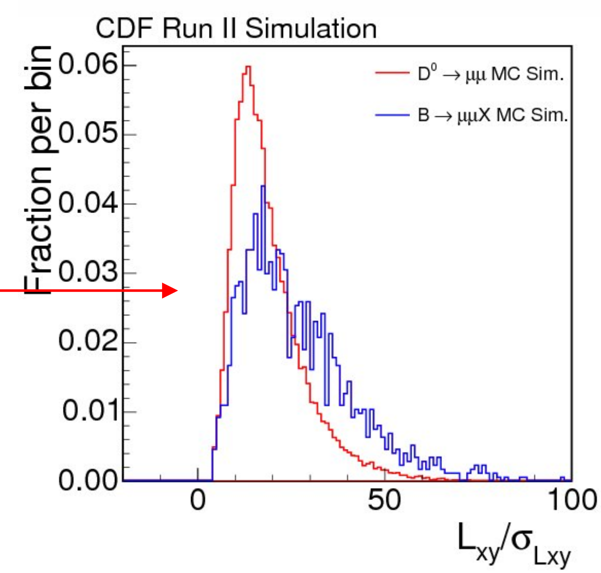
The probabilities for pions and kaons to be misidentified as muons is estimated for the D^* tagged $D0 \rightarrow K^+\pi^-$: control sample



Background from B-decays







Background is dominated by cascade semimuonic B-decays.To reduce this Bgr.:

Use Probability ratio:

- maintains 85 % of signal
- reduces Background by 60%,.

Observed events and expected Bgr.

Source	CMU-CMU	CMU-CMX	CMX-CMX
Combinatorial Background	0.040 ± 0.007	0.008 ± 0.001	0.0007 ± 0.0001
$D^0 \rightarrow \pi\pi$ double fakes	0.53 ± 0.005	0.057 ± 0.001	0.012 ± 0.002
$D^0 \rightarrow K\pi$ double fakes	< 0.01	< 0.01	< 0.01
Semimuonic D^0 decays	< 0.36	< 0.20	< 0.10
Semimuonic B Decays	0.54 ± 0.06	0.13 ± 0.03	0.07 ± 0.02
Cascade semimuonic B decays	3.8 ± 1.3	2.5 ± 1.0	1.0 ± 0.5
Total	4.9 ± 1.3	2.7 ± 1.0	1.0 ± 0.5
N_{obs}	3	0	1

dominant Background

$D^0 \to \mu^+\mu^-$ Result

	CMU-CMU	CMU-CMX	CMX-CMX
$N_{\pi\pi}$	24400 ± 200	9260 ± 130	6940 ± 110
$\epsilon_{\mu\mu}$	0.437 ± 0.003	0.257 ± 0.004	0.161 ± 0.003
$\Omega_{\pi\pi}/\Omega_{\mu\mu}$		0.872 ± 0.005	
$\mathcal{B}(D^0 \to \pi^+\pi^-)$		$(1.364 \pm 0.032) \times 10^{-3}$	
e $(\times 10^{-4})$	896.5 ± 23.7	200.1 ± 11.7	93.9 ± 3.2
N_{bkg}	4.93 ± 1.33	2.74 ± 0.96	1.04 ± 0.48
N_{obs}	3	0	1

This limit is a multichannel, Bayesian calculation.

Credibility level

Frequentist: Confidence level

Channel	SM prediction	CDF Run II preliminary ($360pb^{-1}$) (@ 90(95)% C.L.)	BaBar (@ 90% C.L.)
$Br(D^0 \to \mu^+\mu^-)$	$\leq 4. \times 10^{-13}$	$< 4.3(5.3) \times 10^{-7}$	$< 1.3 \times 10^{-6}$

this translates into a limit on the R parity violating couplings

$$\lambda_{21k}\lambda_{22k} = 1.5 \sqrt{B(D^0 \to \mu^+\mu^-)} < 9.8 \times 10^{-4}$$

Summary & Conclusion

Channel	CDF Run II preliminary ($2fb^{-1}$) (@ 90(95)% C.L.)	CDF Run I ($102pb^{-1}$) (@ 90(95)% C.L.)	BaBar (@ 90% C.L.)
$Br(B_s^0 \to e^+\mu^-)$	$< 2.0(2.6) \times 10^{-7}$	$< 6.1(8.2) \times 10^{-6}$	-
$M_{LQ}(B_s^0)$	$> 47.7(44.6)$ TeV/c^2	$> 20.7(19.3)$ TeV/c^2	-
$Br(B_d^0 \to e^+\mu^-)$	$< 6.4(7.9) \times 10^{-8}$	$< 3.5(4.5) \times 10^{-6}$	$< 9.2 \times 10^{-8}$
$M_{LQ}(B_d^0)$	$> 58.6(55.7)$ TeV/c^2	$> 21.7(20.4)$ TeV/c^2	> 53.1 TeV/c^2
$Br(B_s^0 \to e^+e^-)$	$< 2.8(3.7) \times 10^{-7}$	-	-
$Br(B_d^0 \to e^+e^-)$	$< 8.3(10.6) \times 10^{-8}$	-	$< 1.13 \times 10^{-7}$

Channel	SM prediction	CDF Run II preliminary ($360pb^{-1}$) (@ 90(95)% C.L.)	BaBar (@ 90% C.L.)
$Br(D^0 \to \mu^+\mu^-)$	$\leq 4. \times 10^{-13}$	$< 4.3(5.3) \times 10^{-7}$	$< 1.3 \times 10^{-6}$

All measurements represent the current world best limits!

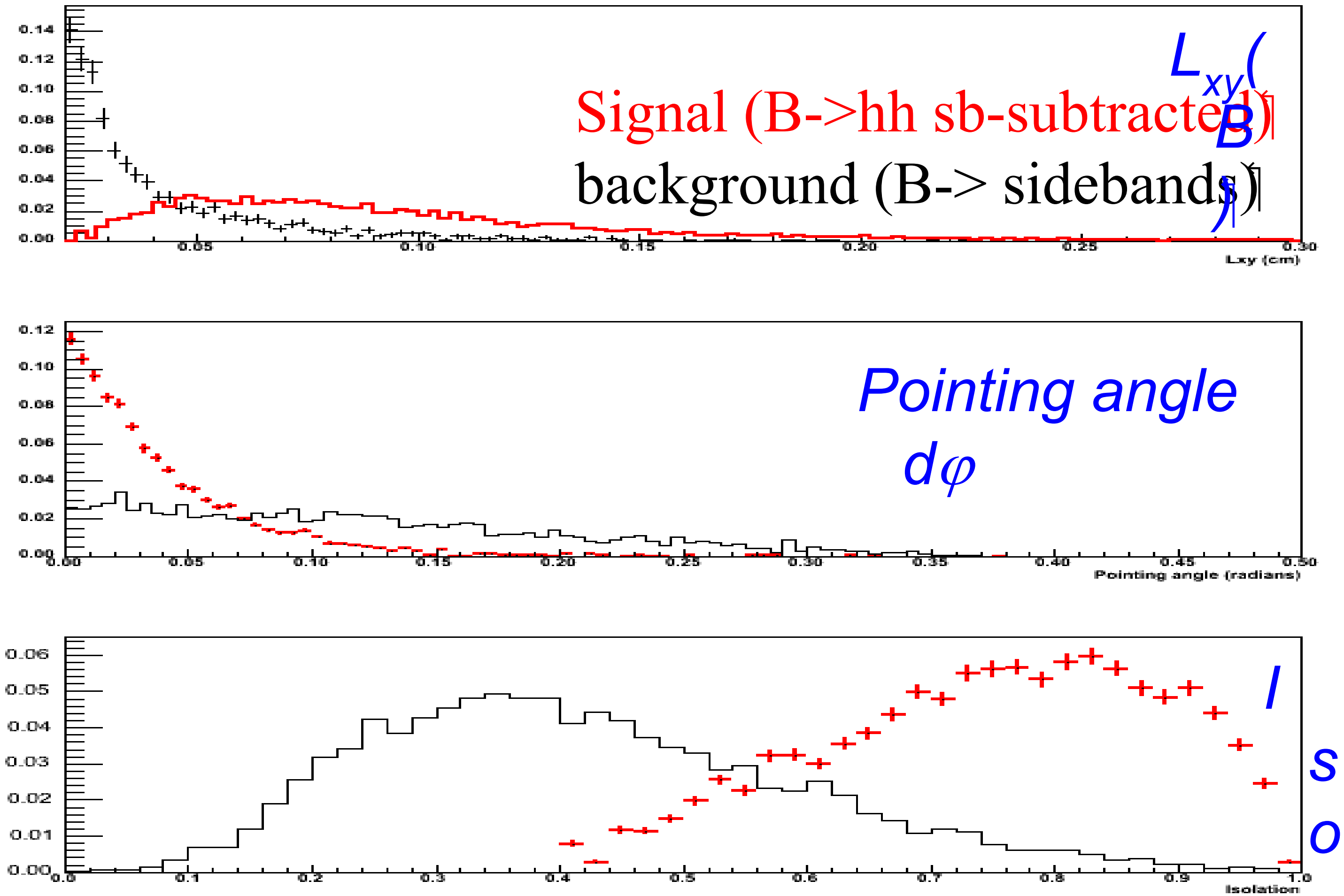
Backup slides

Limit Calculation for Br(D0→eμ)

$$\mathcal{B}(D^0 \to \mu^+\mu^-) = \frac{N(\mu^+\mu^-)}{N(\pi^+\pi^-)} \cdot \frac{\epsilon(\pi^+\pi^-)}{\epsilon(\mu^+\mu^-)} \cdot \mathcal{B}(D^0 \to \pi^+\pi^-)$$

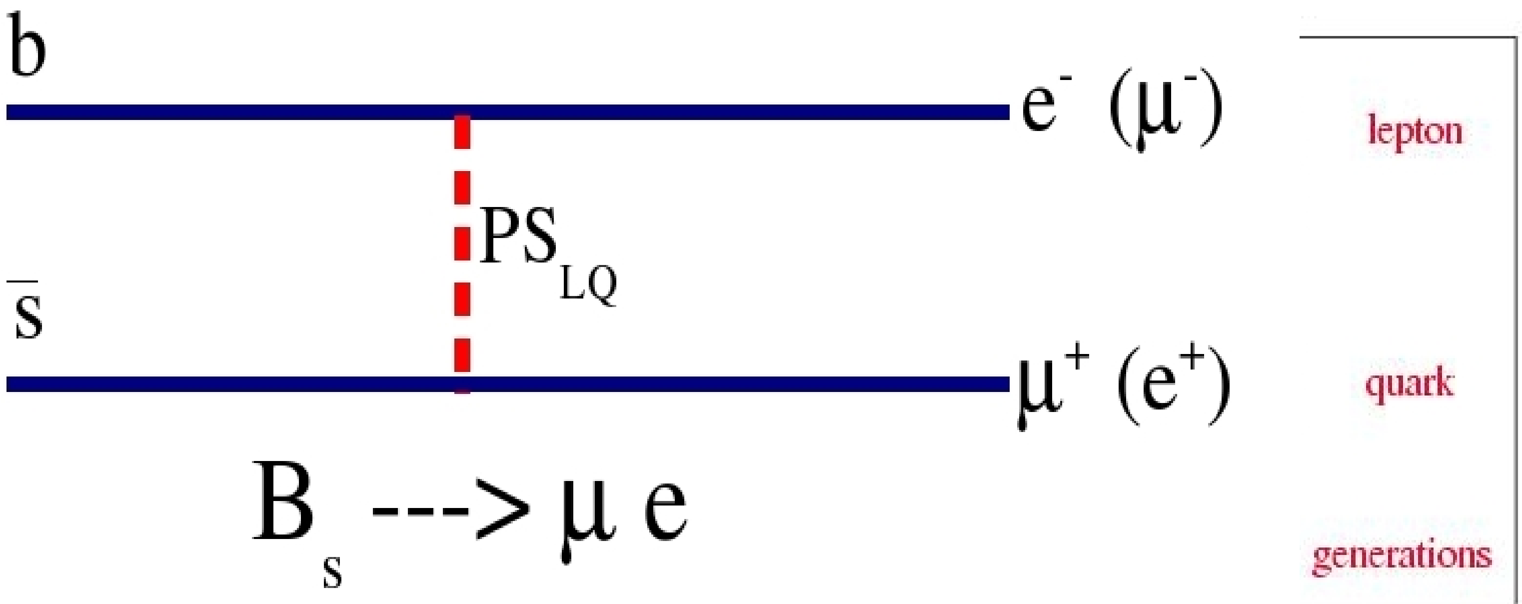
- **$Br(D^0 \to \pi^+\pi^-) = (1.364 \pm 0.032) \times 10^{-3}$** (world average)
- **$N(D^0 \to \pi^+\pi^-) = 6387.0 +/- 214.4$**
- **$\varepsilon_{Rel}(B_s)$ = 0.2071±0.0003±0.0158**
- **f_{Bd}/f_{Bs} =(39.8±1.2)%/(10.3±1.4)% =3.86 ±0.59**
- **$N_{limit}(B_s \to e\mu)$ = 3.60 (4.57) @ 90(95) % C.L.**
- **$N_{Bgr}(B_s \to e\mu)$ = 0.81 +/- 0.63**
- **$\varepsilon_{Rel}(B_d)$ = 0.2097±0.0023±0.0123**
- **$N_{Bgr}(Bd \to e\mu)$ = 0.94 +/- 0.63**
- **$N_{limit}(B_d \to e\mu)$ = 4.44 (5.44) @ 90(95) % C.L.**
-

Selection Variables

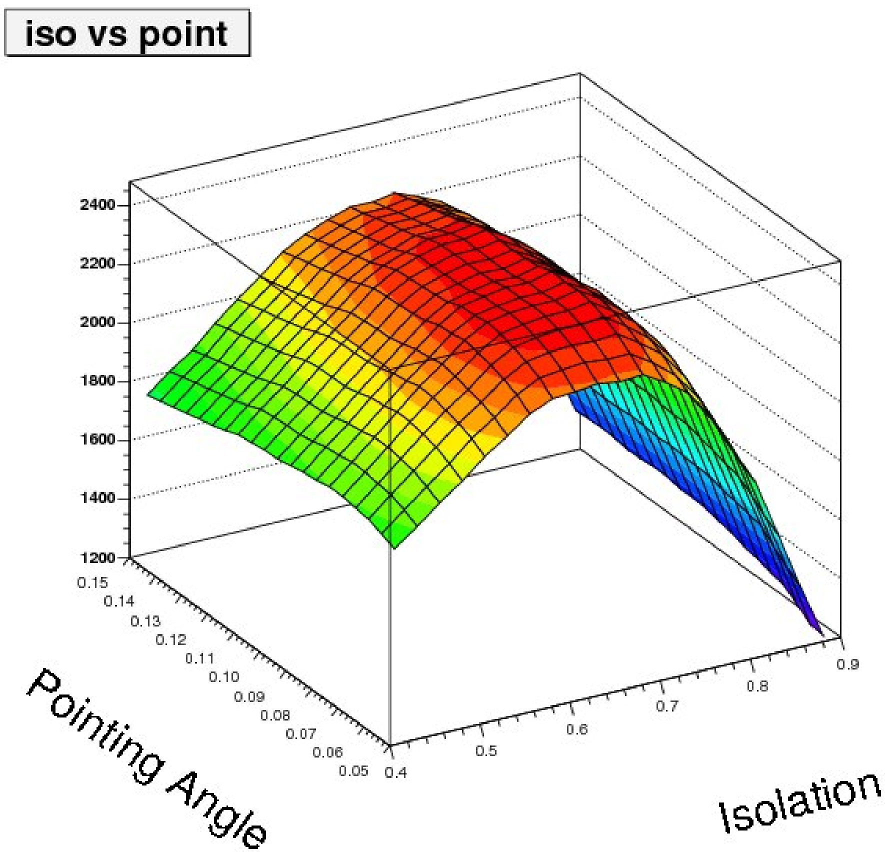


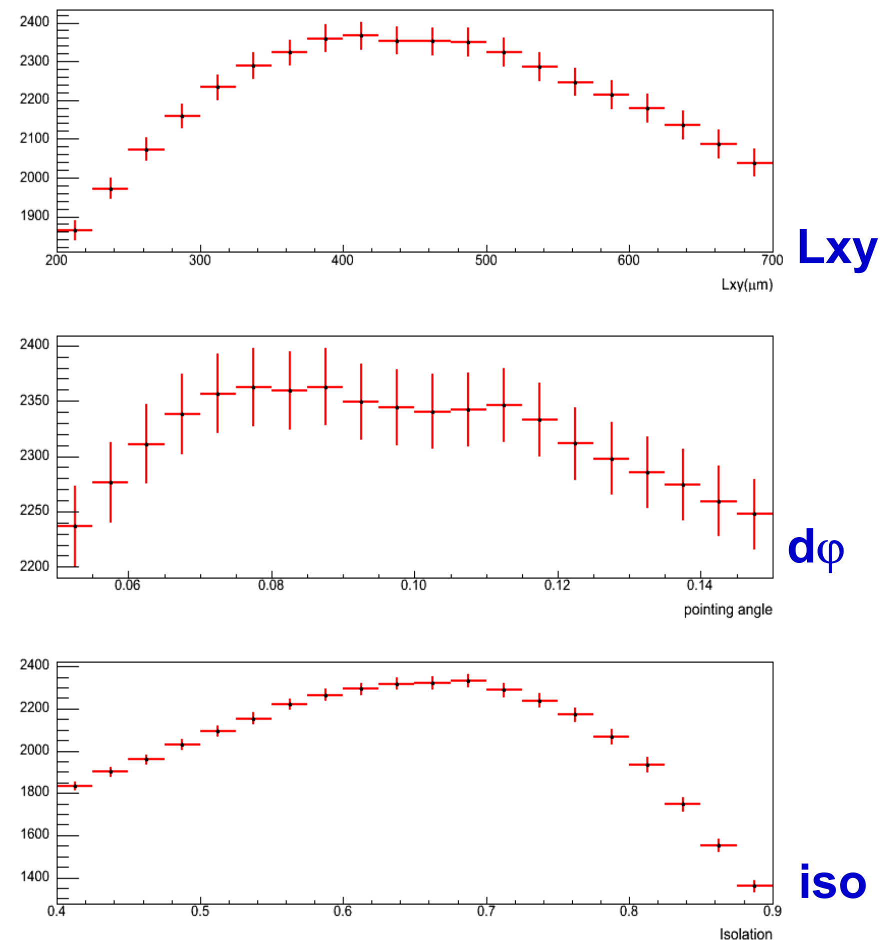
Pati-Salam Leptoquarks (cont.)

- The Pati-Salam model allows for cross-generation couplings
- Bs →e μ decay probes two Ty
  - –
  - –
- Bc
  - –



Cut Optimization (cont.)





Summary

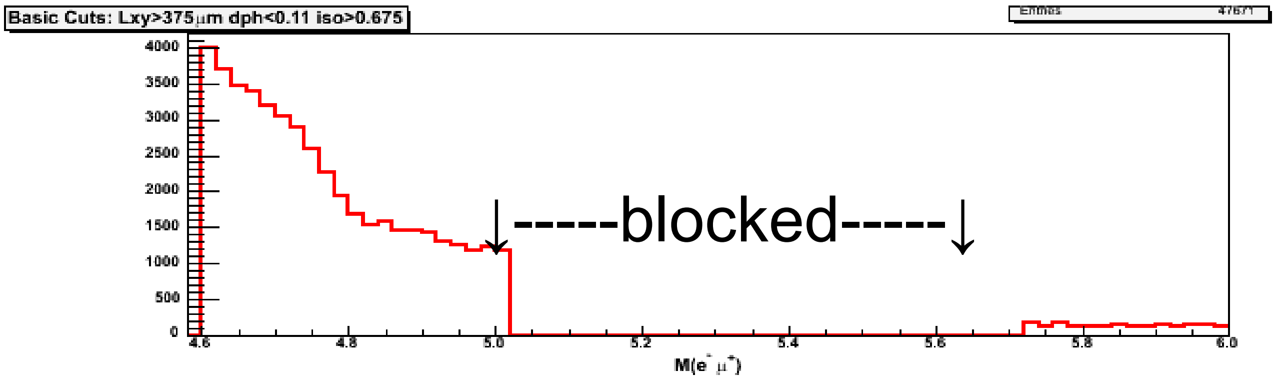
- **With 2fb^{-1} CDF data (@90(95) % C.L.)**
  - **Br($B_s \to e\mu$) < 2.0 (2.6) x 10^{-7}**
  - **M_{LQ}(Bs) > 47.7(44.6) TeV**
  - **Br($B^0 \to e\mu$) < 6.4(7.9) x 10^{-8}**
  - **M_{LQ}(B^0) > 58.6 TeV**
  - **Br($B_s \to ee$) < 2.77x 10^{-7}**
  - **Br($B^0 \to ee$) < 8.32x 10^{-8}**

- **Improvements over current limits**
  - Br($B_s \to e\mu$) < 6.1 x 10^{-6} (CDF Run I)
  - M_{LQ}(Bs) > 21.7 TeV (CDF Run I)
  - Br($B^0 \to e\mu$) < 9.2 x 10^{-8} (BABAR 2007)
  - M_{LQ}(B^0) > 53.1TeV (BABAR 2007)
  - Br($B^0 \to ee$) <1.13 x 10^{-7} (BABAR 2007)

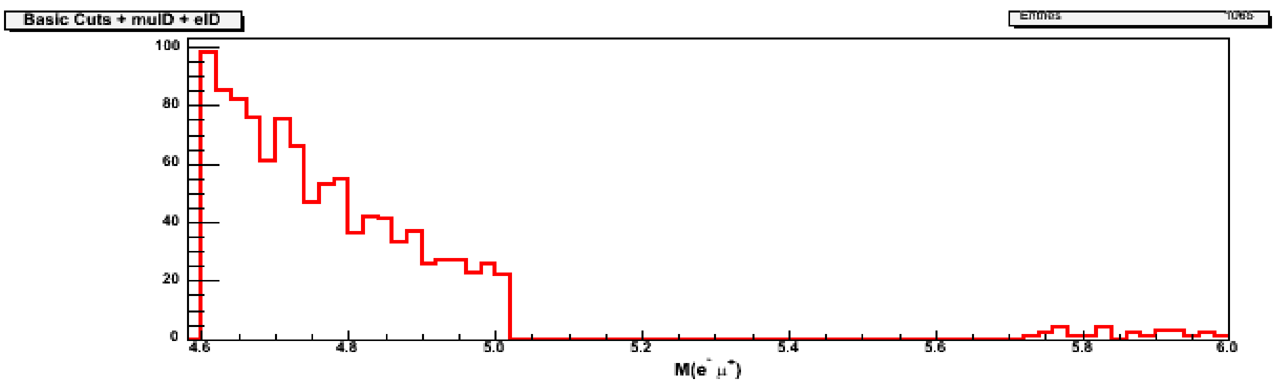
ϵ_{Rel} Systematic uncertainties

Source	Change [%]
CMU fiducial	0.74
CMU Matching	0.024
CMX fiducial	0.63
CMX Matching	0.01
dE/dx	3.3
CEM fiducial	0.97
CES/CPR Cuts	2.1
Detector Material	3.9
p_T threshold	1
$p_T(Bs)$ Spectrum	4
$c\tau(B_s)$	3
ϵ_{Rel} Total	7.62

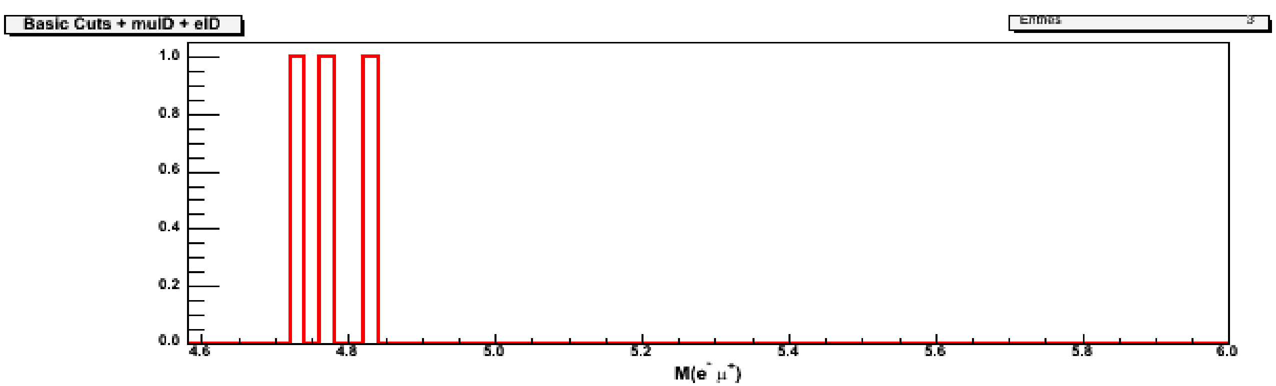
M(e-μ): Closed Box



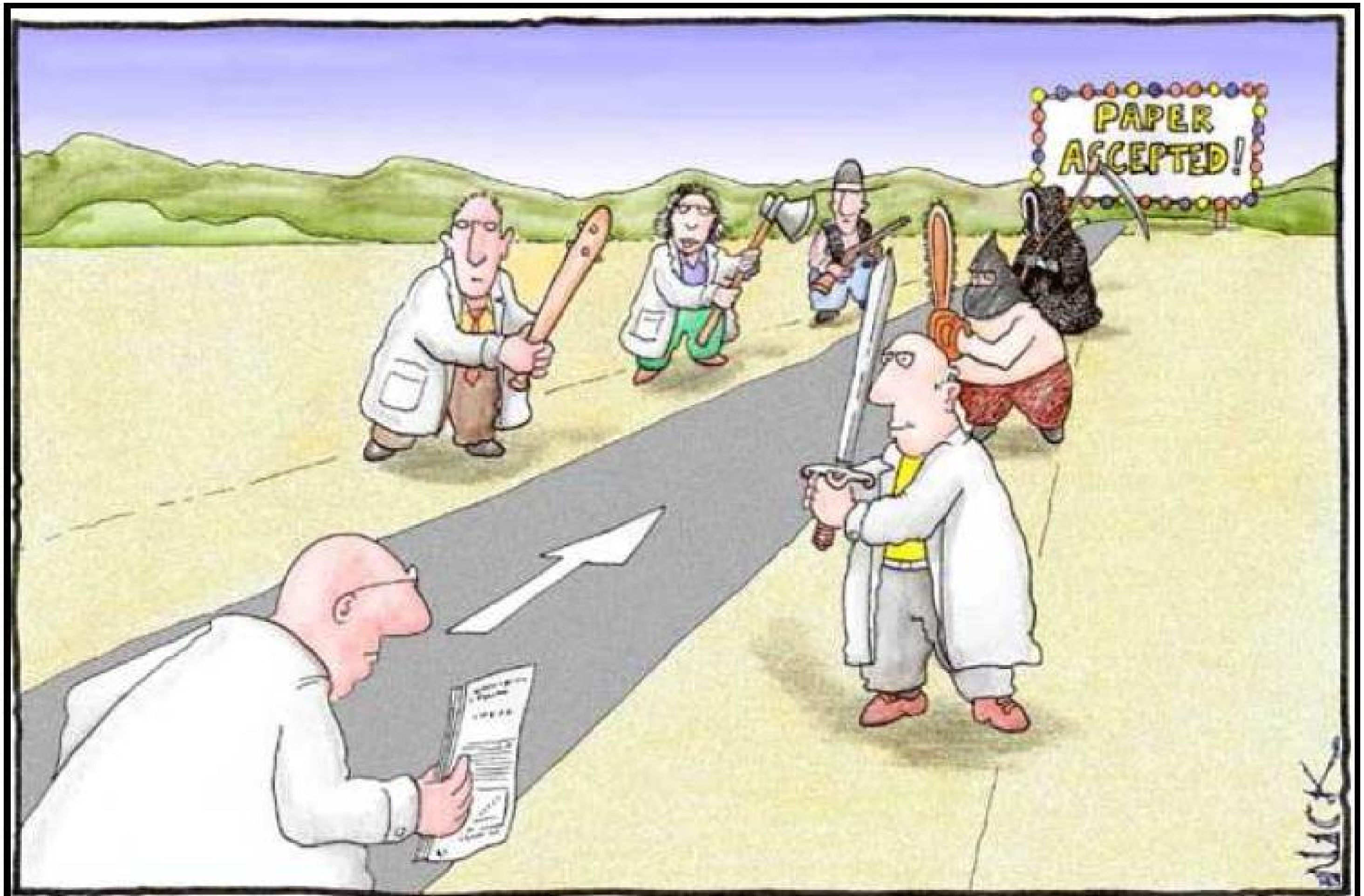
⇐ **Lxy > 375μm, iso>0.675,dφ<0.11 but before e/μ ID**



⇐ **After μ-ID**



⇐ **After e/μ ID**

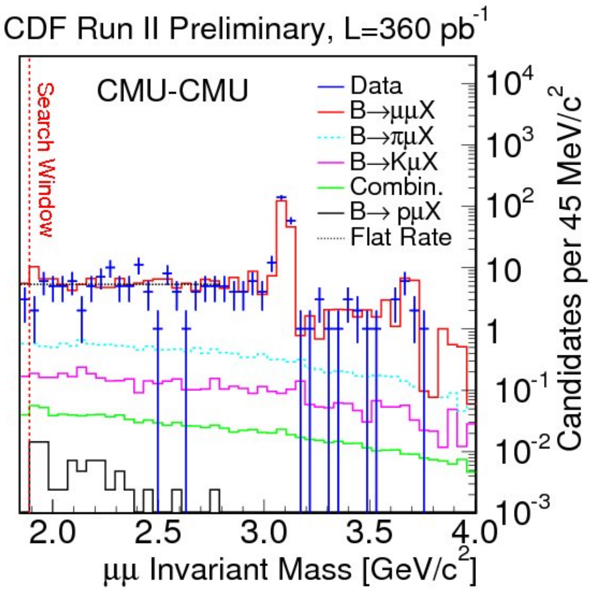


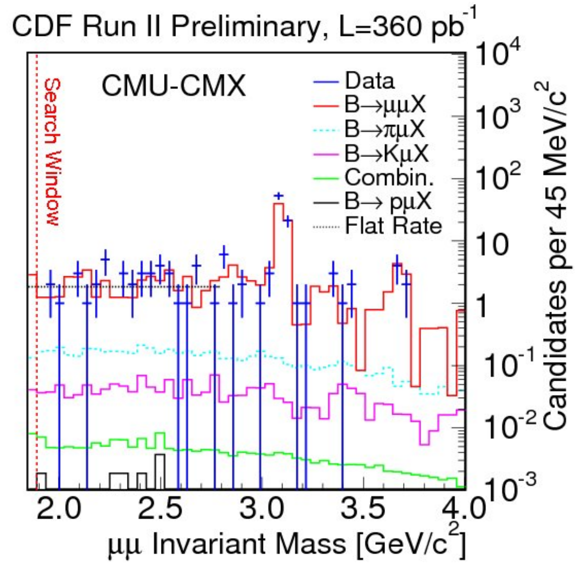
Most scientists regarded the new streamlined peer-review process as 'quite an improvement.'

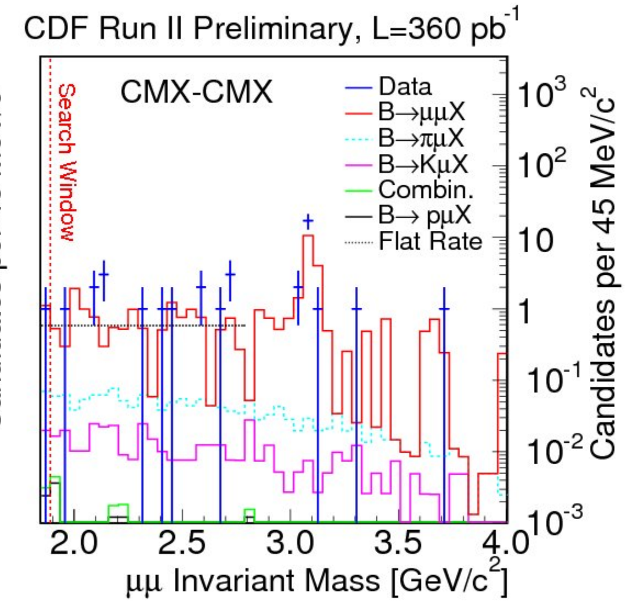
I wish we were so lucky!
Some things never change!

ee - Limits for different scenarios

Search Channel	N_{obs}	N_{bgr}	Systematic uncertainty (%)	(BAYES) $N^{90\%}_{C.L.}$	(BAYES) $N^{95\%}_{C.L.}$	(POILIM) $N^{90\%}_{C.L.}$	(POILIM) $N^{95\%}_{C.L.}$
	no systematics, no background subtraction						
B_s	1	0±0	0	3.89	4.74	3.89	4.74
B_d	2	0±0	0	5.32	6.30	5.32	6.30
	systematics only						
B_s	1	0±0	18.3	4.23	5.24	4.10	5.08
B_d	2	0±0	10.0	5.47	6.50	5.41	6.43
	systematics and background subtraction						
B_s	1	2.66±1.80	18.3	3.11	4.03	3.33	4.27
B_d	2	2.66±1.80	10.0	3.51	4.47	4.15	5.16


CDF Run II Preliminary, L=360 pb-1
CMU-CMU
Search Window
Data
B→μμX
B→πμX
B→KμX
Combin.
B→ pμX
Flat Rate
Candidates per 45 MeV/c2
μμ Invariant Mass [GeV/c2]


CDF Run II Preliminary, L=360 pb-1
CMU-CMX
Search Window
Data
B→μμX
B→πμX
B→KμX
Combin.
B→ pμX
Flat Rate
Candidates per 45 MeV/c2
μμ Invariant Mass [GeV/c2]


CDF Run II Preliminary, L=360 pb-1
CMX-CMX
Search Window
Data
B→μμX
B→πμX
B→KμX
Combin.
B→ pμX
Flat Rate
Candidates per 45 MeV/c2
μμ Invariant Mass [GeV/c2]

Electron Identification

- **Electron ID uses dE/dx and CEM/CES/CPR**
  - CEM/CES coverage: *80.28±0.78 %*
  - Track-based algorithm for low pT electrons
  - pT>2GeV, $|\eta|<1.0$
- **dE/dx and calorimeter efficiency from $\gamma \rightarrow e^+e^-$**
  - dE/dx: ~90% →
  - CEM/CES/CPR: ~70%