

Propects for Discovery of Neutral Higgs Bosons in RunII Data

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LBNL

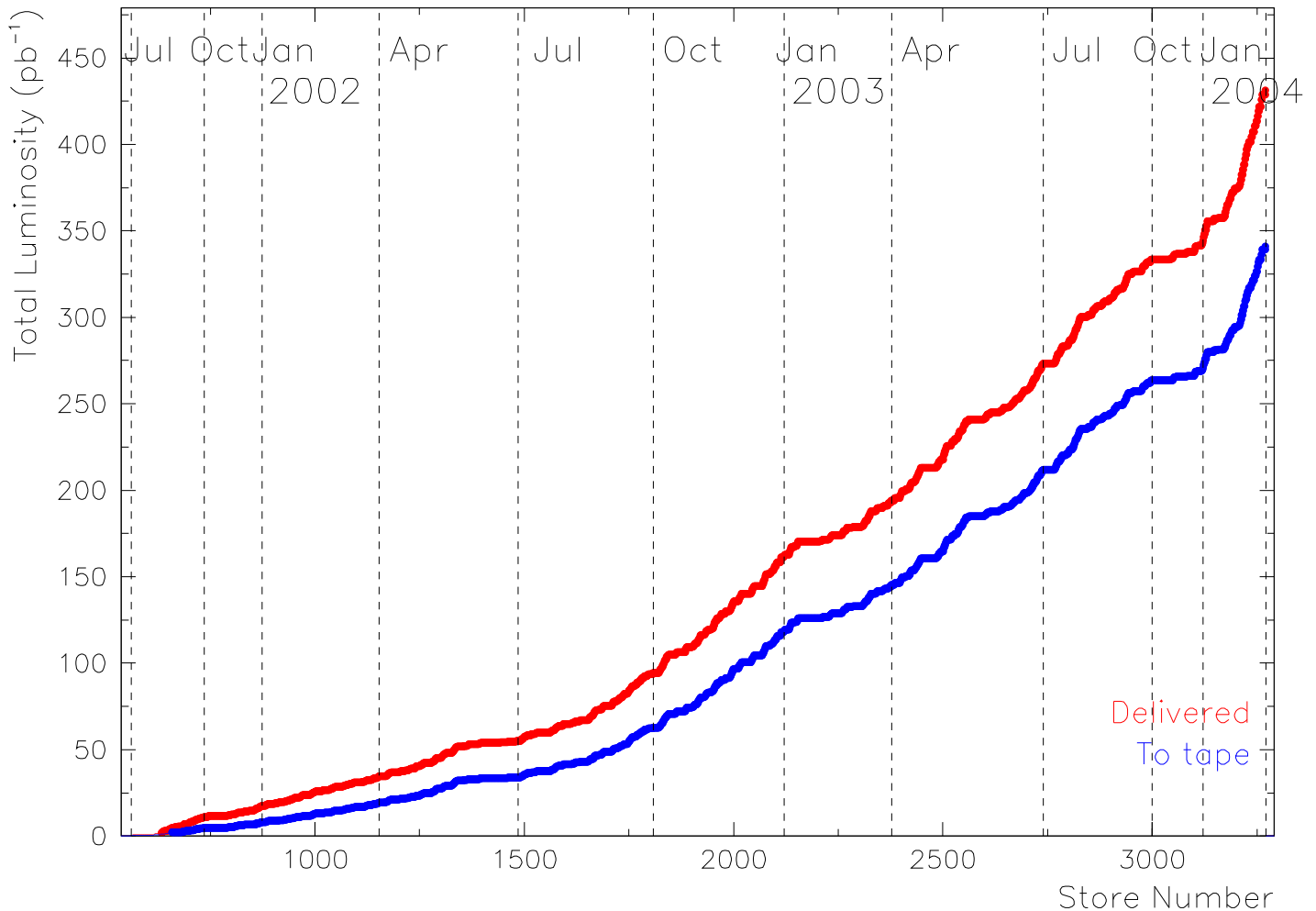
FNAL Wilson Fellow Interview, March 2004

- Motivation
- SM Higgs: Mission Improbable
- MSSM Higgs: Mission Quite Possible
- Silicon detector is key
- B-Tagging
- Re-measuring the top gives us confidence
- Trigger and the SVT
- Analysis: 4b search
- Outlook

Motivation

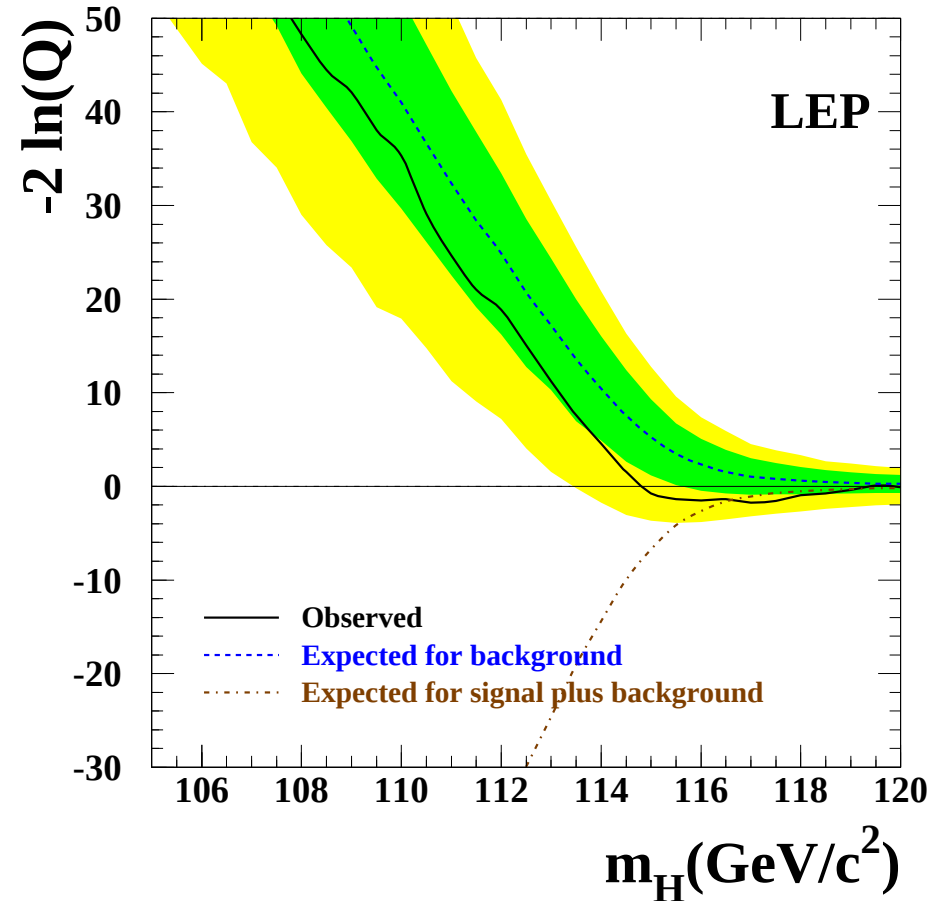
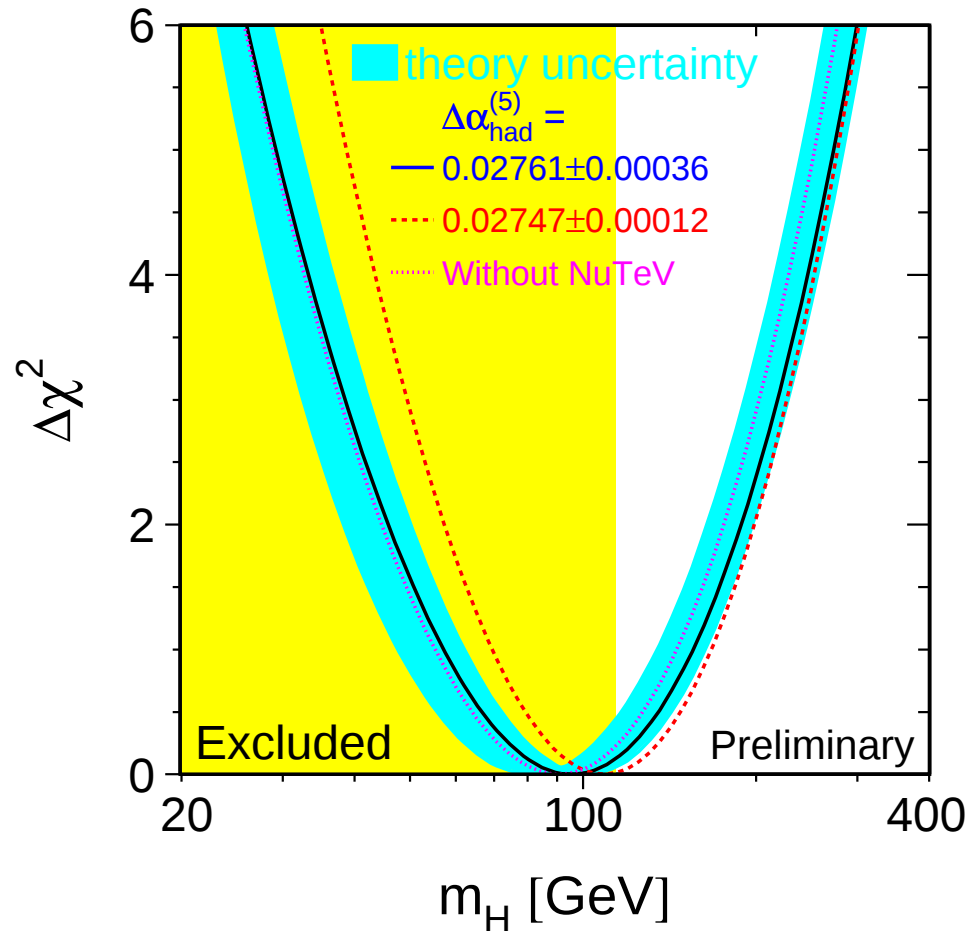
- LEP was best chance to find SM Higgs (until LHC)
- SM Higgs search is notoriously difficult at Tevatron
- SM needs some kind of help to stabilize Higgs mass (hierarchy prob)
- MSSM one candidate that has held up well to experimental scrutiny
- Introduces 5 physical Higgses
- But production cross sections at Tev can be quite large

RunII Well Under Way!



- Now have **more data than RunI**
- Can do **precision measurements** and **searches**
- What can we do to understand **neutral Higgs Sector** with our **new data and detector**?

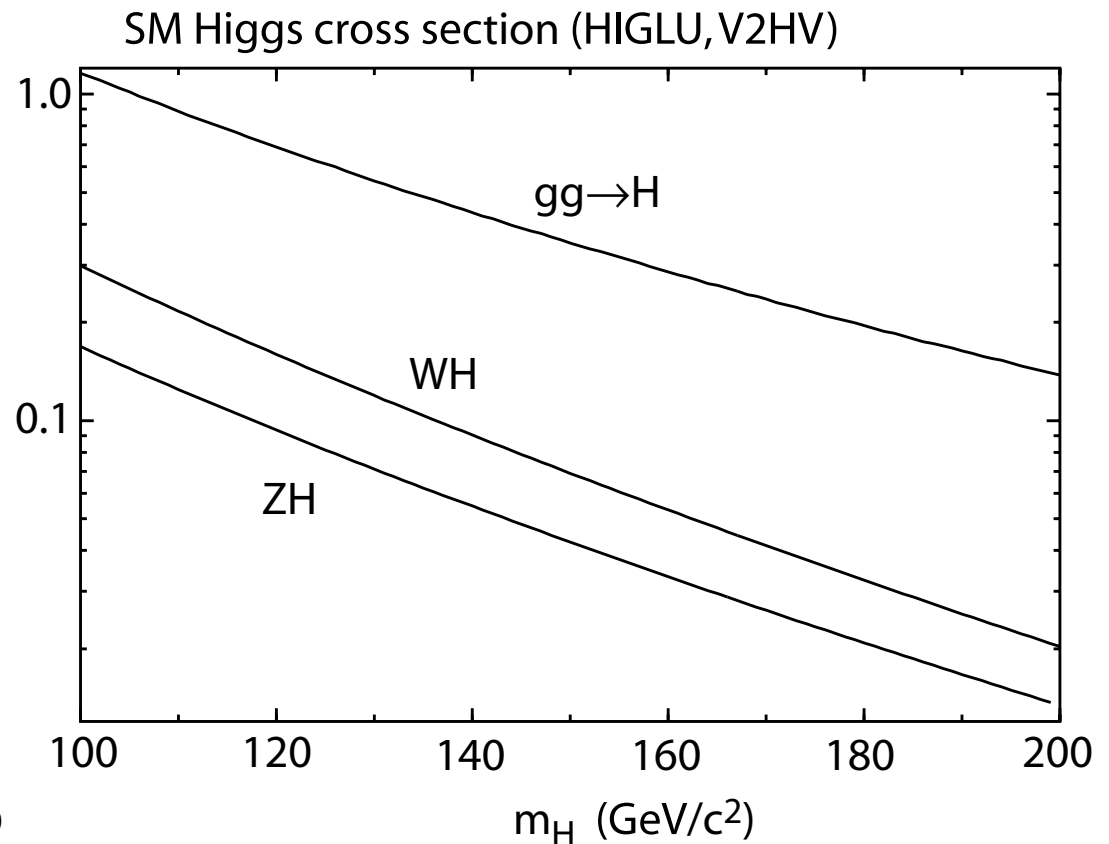
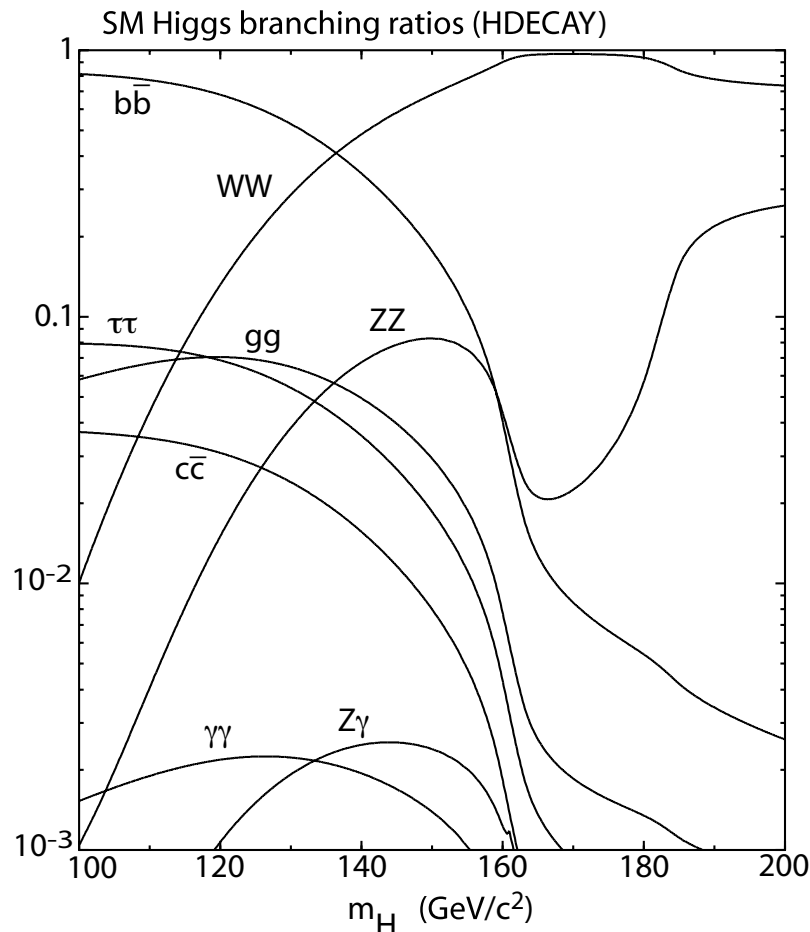
SM Higgs: Current State of Affairs



- EW Precision fits “predict”
 $m_H < 219$ GeV, 95%CL

- LEP Combined search limits
 $m_H > 114$ GeV, 95%CL

SM Higgs: Mission Improbable



- Most promising SM discovery modes:
 - Associated production with Z/W
 - Followed by $W \rightarrow \ell\nu$ or $Z \rightarrow \nu\bar{\nu}$, with $H \rightarrow b\bar{b}$
- Cross sections mostly $\lesssim 0.3$ pb! at Tevatron, and that's before branching ratio

SM Higgs: Reevaluated Sensitivity

- **Last summer**, CDF & D0 reconsidered work of **RunII Higgs Workshop** (hep-ph/0010338) taking into account knowledge of new detector
- Dominant background from physics, not detectors:
 - **W+jets**: $p\bar{p} \rightarrow W + gg, g \rightarrow b\bar{b}/c\bar{c}$.
 ~ 10 's pb
 - **$t\bar{t}$** : $p\bar{p} \rightarrow t\bar{t} \rightarrow W^+bW^-\bar{b}$. ~ 7 pb
 - **Single top**: $p\bar{p} \rightarrow t\bar{b} \rightarrow W^+b\bar{b}$. ~ 2 pb
 - **WZ**: $p\bar{p} \rightarrow WZ \rightarrow \ell\nu b\bar{b}$. ~ 3 pb.

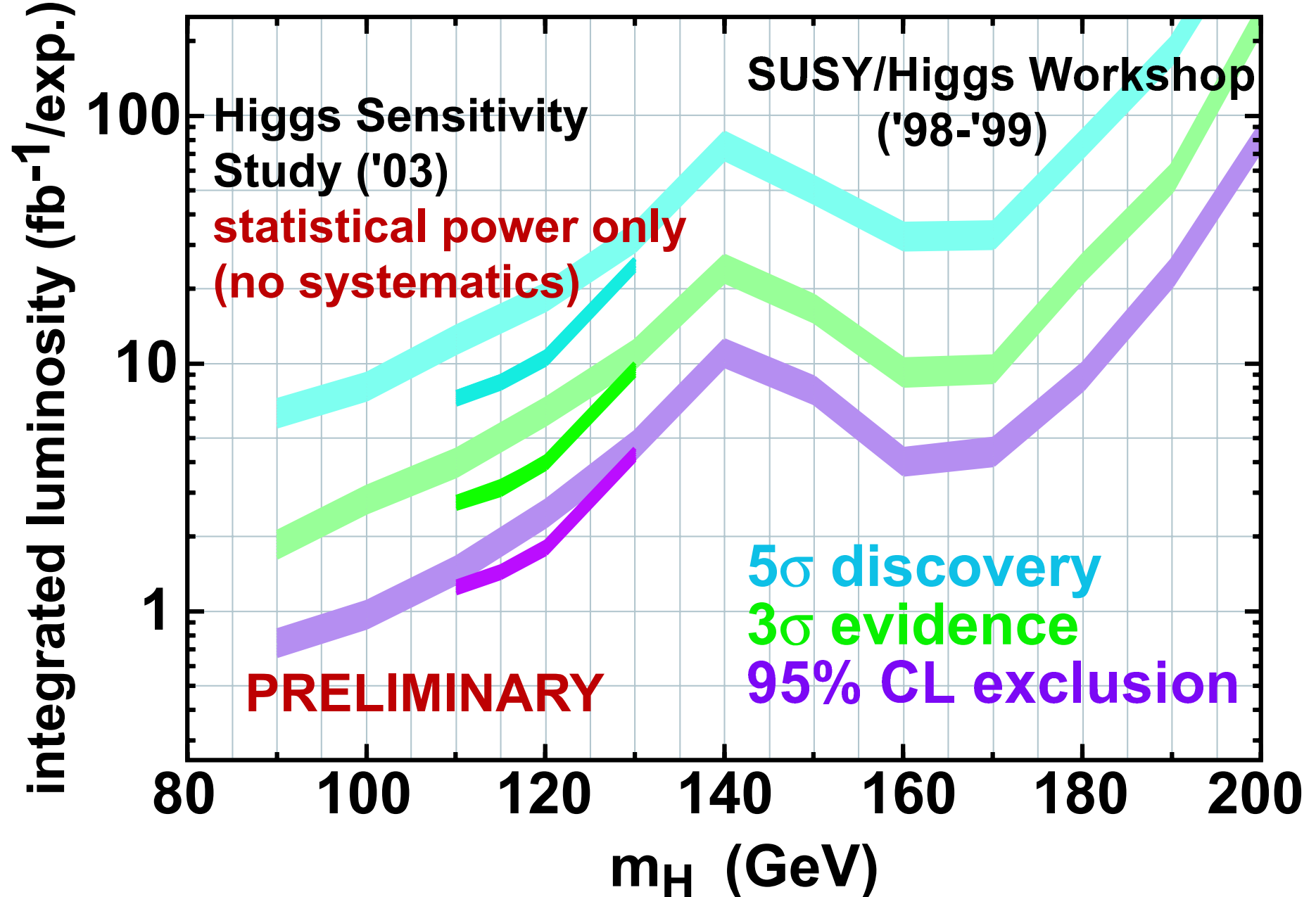
HSC vs SHW at 115 GeV

	WH (lnbb)		ZH (nnbb)	
	HSC	SHW	HSC	SHW
signal	3.7	4.6	3.5	5.5
tt	12.3	7.8	1.9	3.0
tqb/tb	6.9	5.3	1.0	5.0
Wbb/Zbb	20.9	7.7	2.9	13.8
WZ/ZZ	1.6	1.4	2.6	3.3
QCD	-	-	8.1	25.1
bkgd	42	22	16.5	50
S/B	0.57	0.98	0.86	0.78

mass window: 100-130 GeV

- “HSC” is new estimate with current algorithms for 1 fb^{-1} per Experiment
- Will be *very challenging*

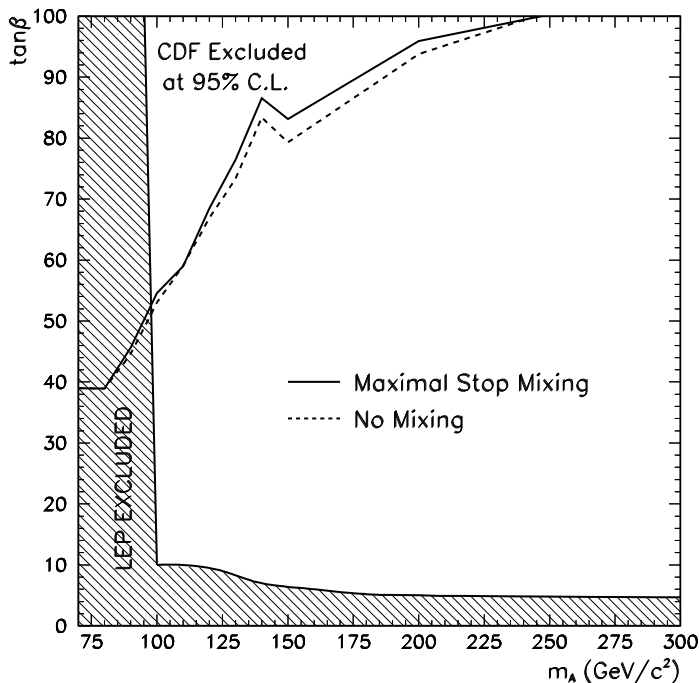
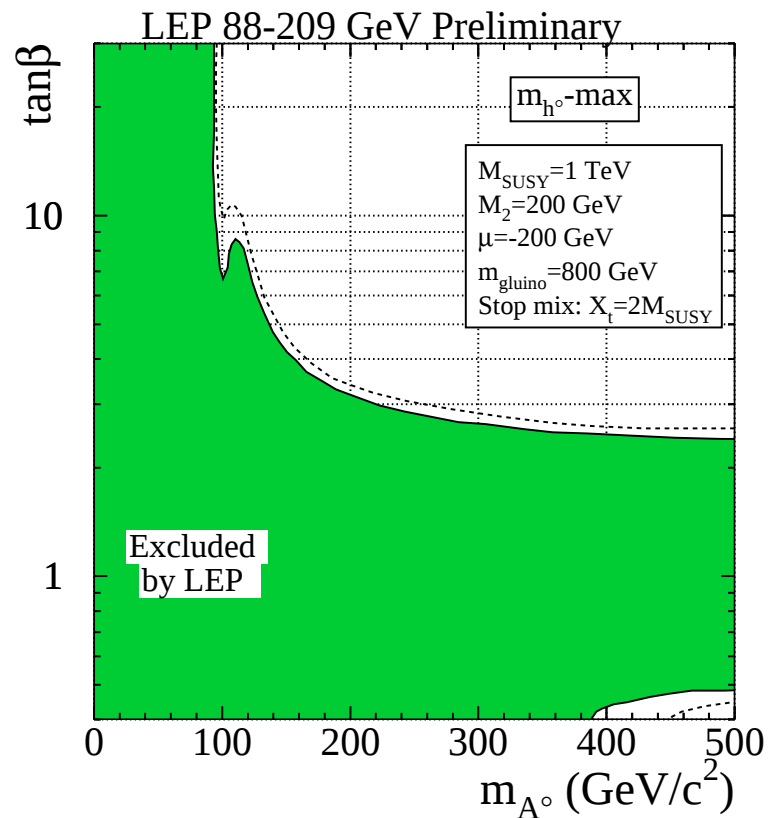
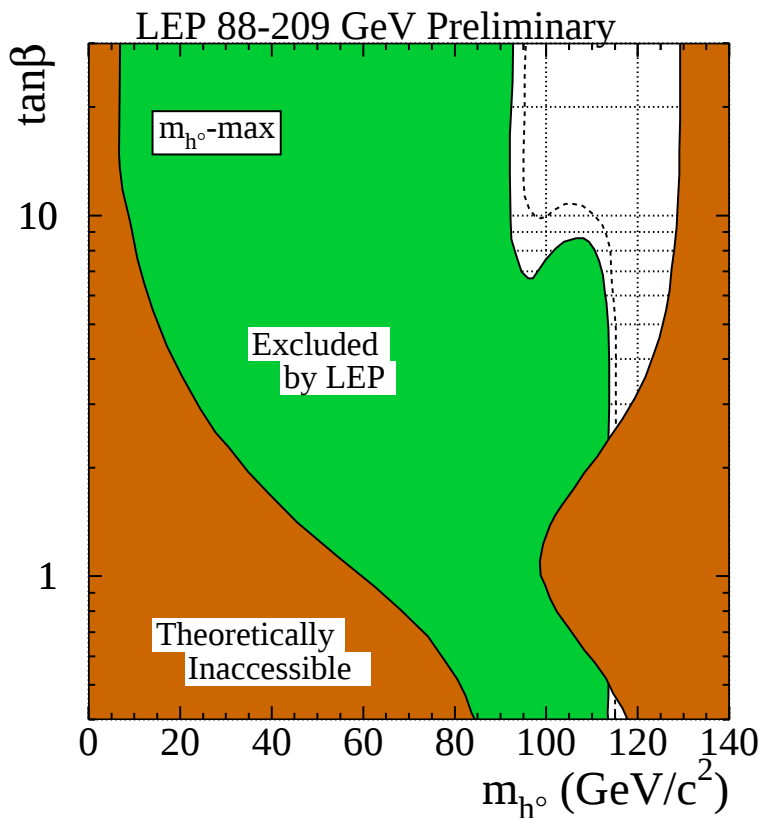
SM Higgs: Sensitivity vs Luminosity



MSSM Higgs: Mission Quite Possible

- The MSSM is well known to predict at least one **light neutral Higgs**
- Large regions of parameter space currently **consistent with SM measurements and EW predictions**.
- The price to pay is more free parameters, making the final conclusion of searches somewhat less stringent
- At **LEP**, production **cross sections** of neutral Higgses were generally **smaller** than the SM cross section
- At Tevatron, production cross section grows with $\tan\beta$

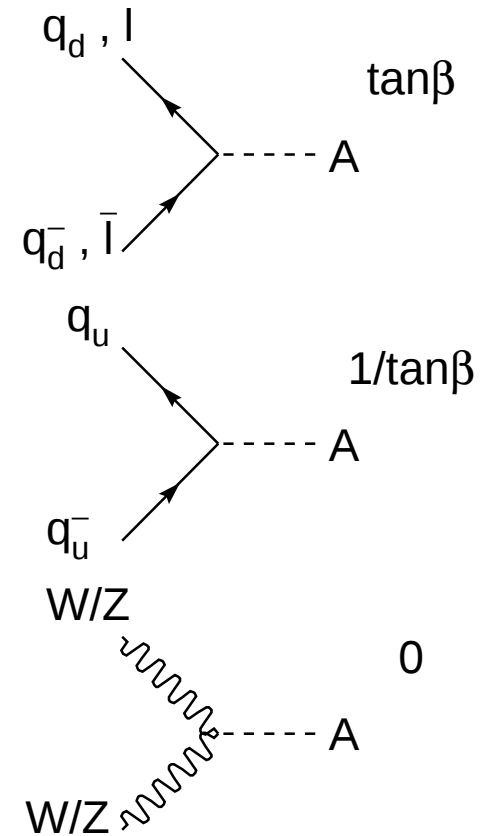
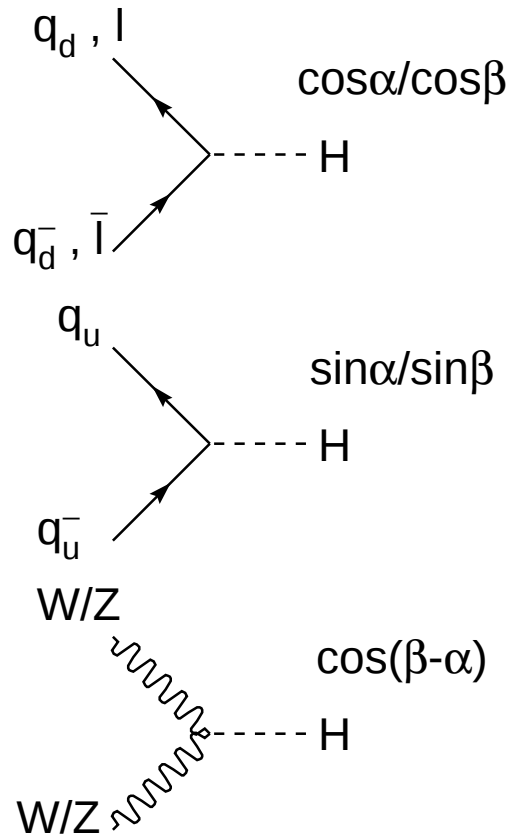
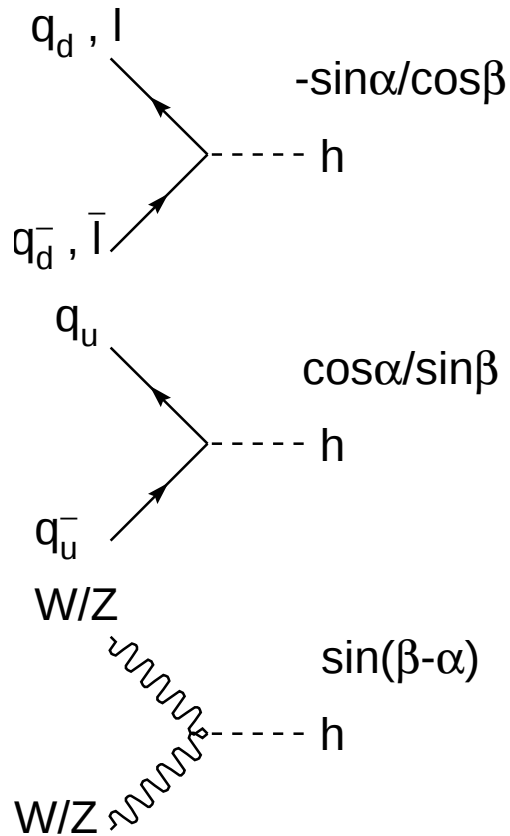
MSSM Higgs: Current State of Affairs



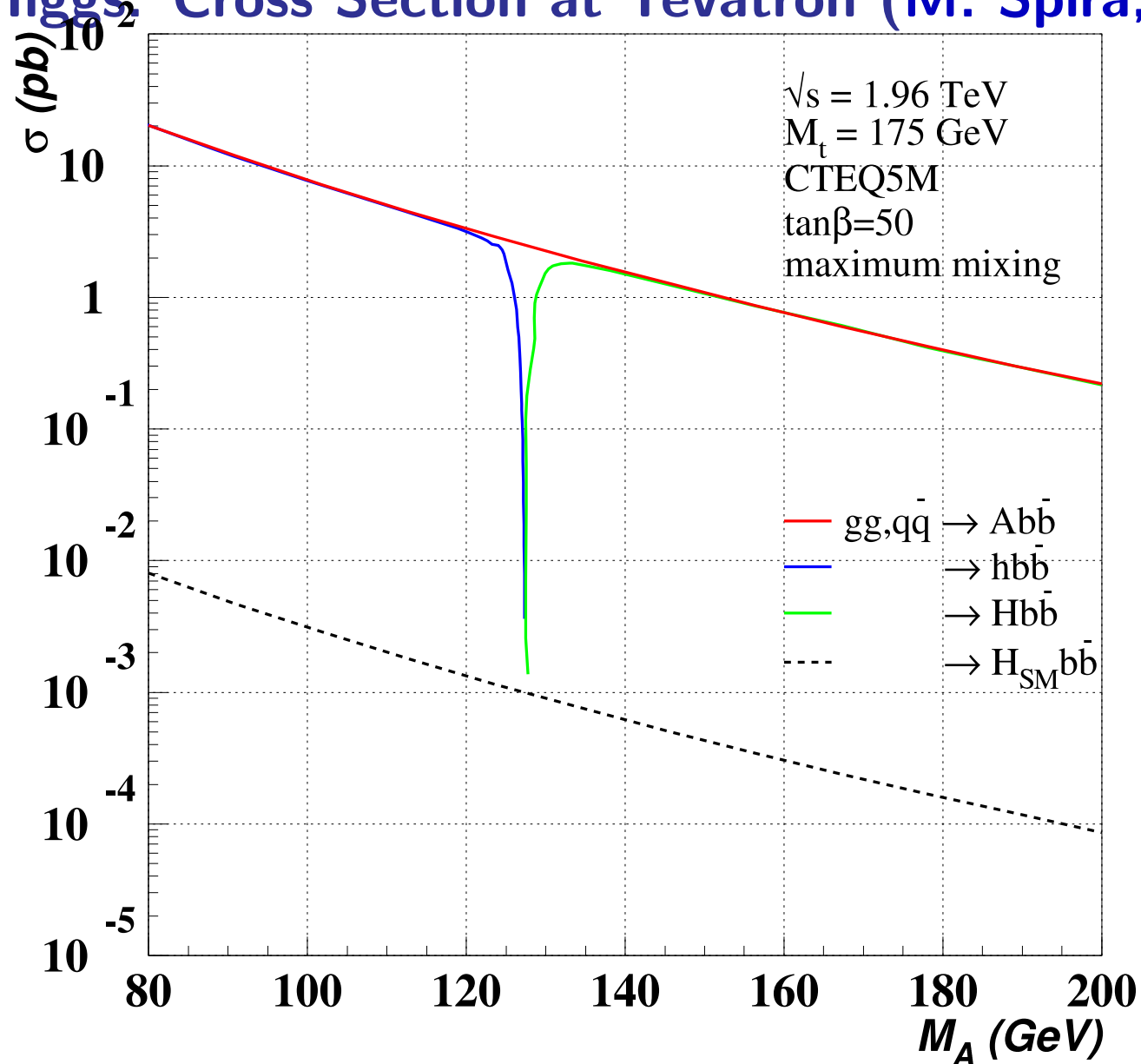
- $\sim$ Final LEP limits:
 $m_h > 91.0 \text{ GeV}$,
 $m_A > 91.9 \text{ GeV at } 95\%CL$
- CDF Run1 limits m_h and m_A for values of $\tan\beta \gtrsim 50$

MSSM Higgs: Production Modes at Tevatron

Why look at bbbb channel? MSSM couplings to down-type quarks enhanced like $\tan\beta$ relative to SM



MSSM Higgs: Cross Section at Tevatron (M. Spira, HIGLU)



Need less int. lumi for discovery compared to SM Higgs

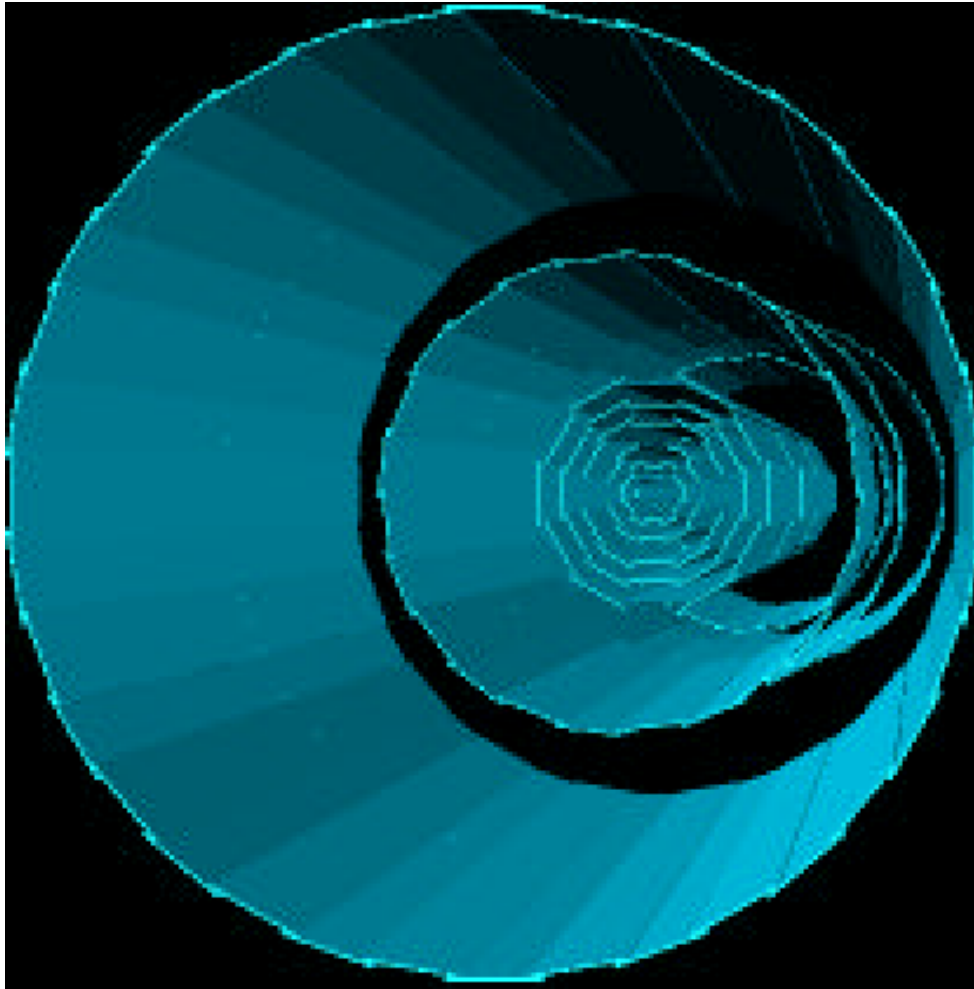
Game On

- Enhancement of $b\bar{b}A$ vertex of $\tan\beta$, compared to SM
- MSSM Higgs production at TeV is complimentary to LEP
 $\Rightarrow$ orthogonal sensitivity in $(\tan\beta, m_A)$ plane
- Branching into b's remains large: $A/h \rightarrow b\bar{b} \sim 85 - 90\%$,
 $A/h \rightarrow \tau^+\tau^- \sim 8 - 10\%$
- Game is to trigger on and reconstruct multijet events containing multiple b-jets
- Understanding and using the silicon detector is crucial for trigger and reconstruction

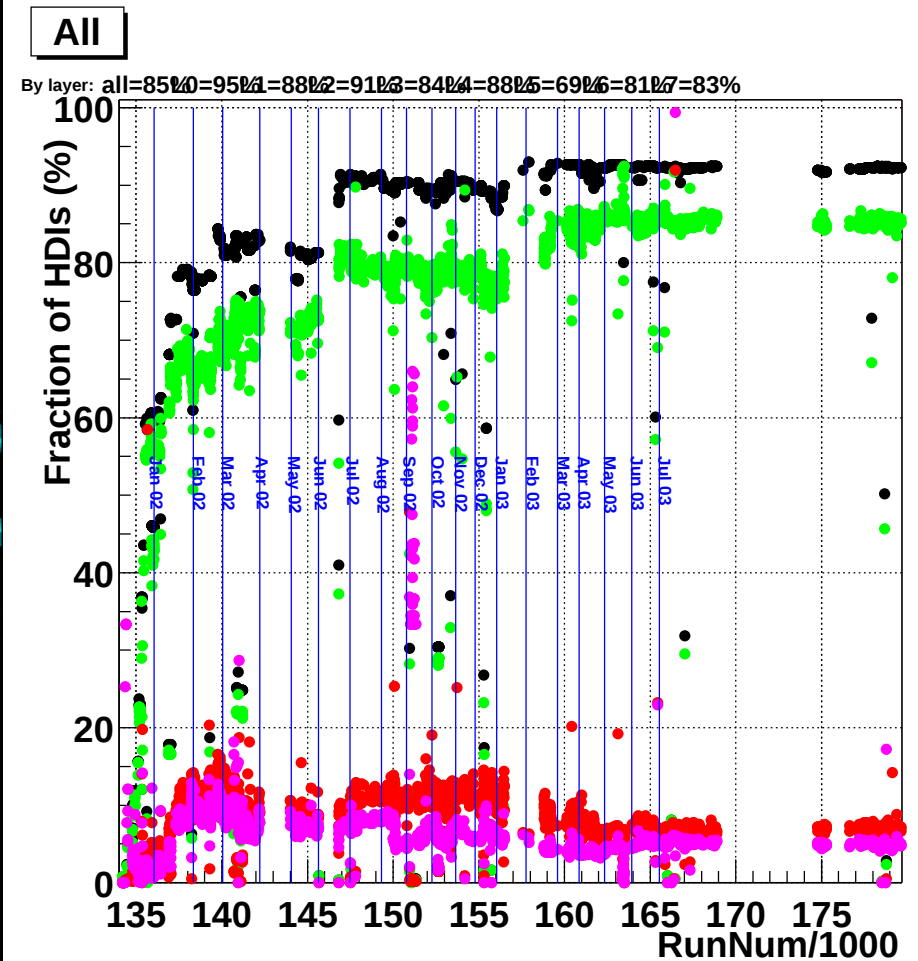
Silicon Detector is Key

- Si detector used **online & offline** to ID b's.
- Many different ways to tag b-jets, but **Si detector** best at **lifetime** reconstruction
- Need to measure in data and model in simulation:
 - Coverage
 - Efficiency
 - Resolution
 - Alignment
 - Material
 - Tracking efficiency
- **Then we can b-tag!**

Silicon Detector is Key



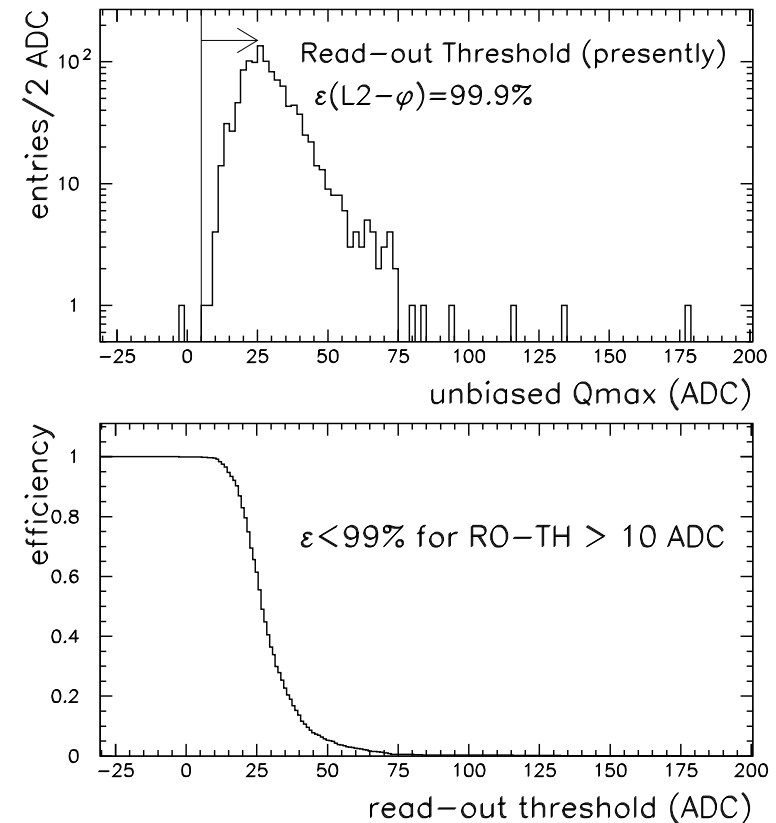
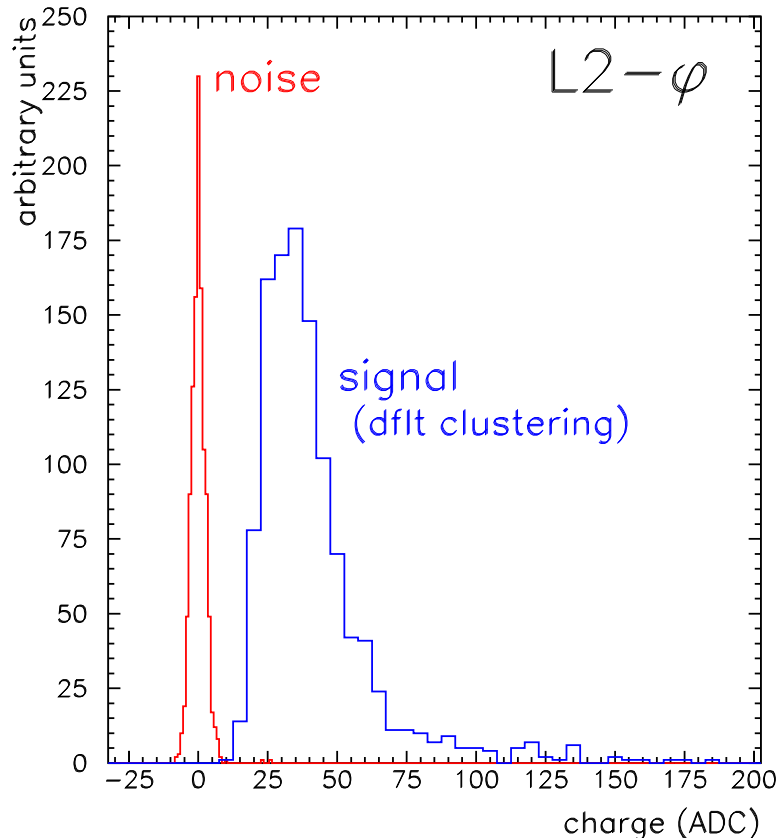
- Detector stable after commissioning period
- Coverage increased due to repairs
- 7 double sided layers (3 at 90° , 4 at 1.2°).



- Inner layer on beampipe ($\sim$ commissioned)
- Axial strip pitch $50 \mu\text{m} - 112 \mu\text{m}$, inner to outer

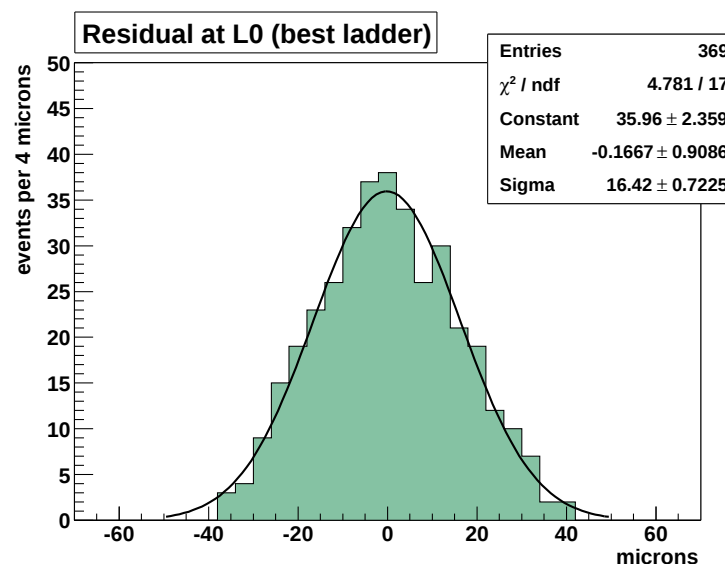
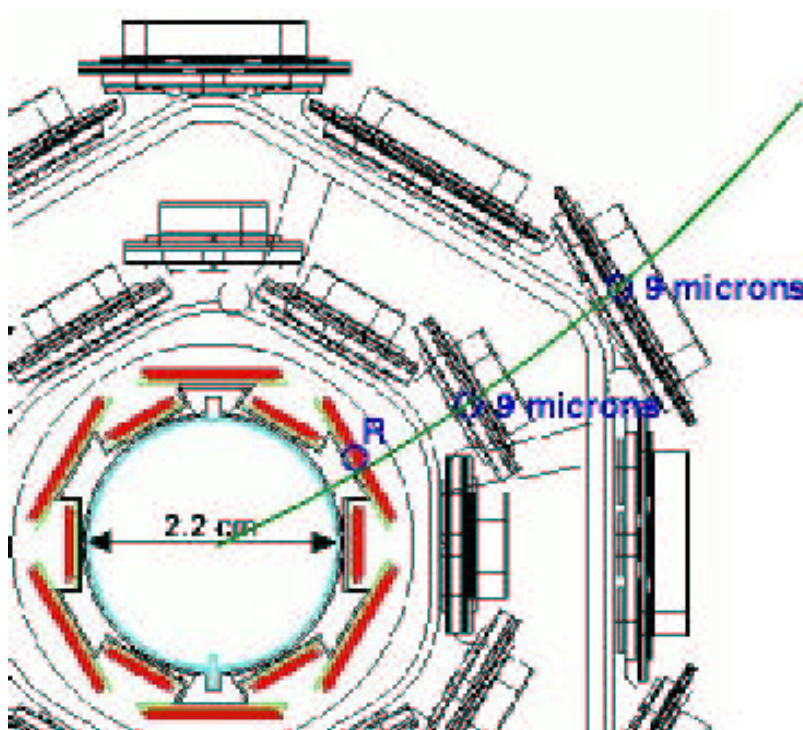
High Signal-to-Noise Device

read-out efficiency for physics



- Operation optimized for high S/N & eff • $> 99\%$ signal readout eff
- S/N of SVX axial 12:1, stereo 10:1 • With $< 1\%$ noise occupancy

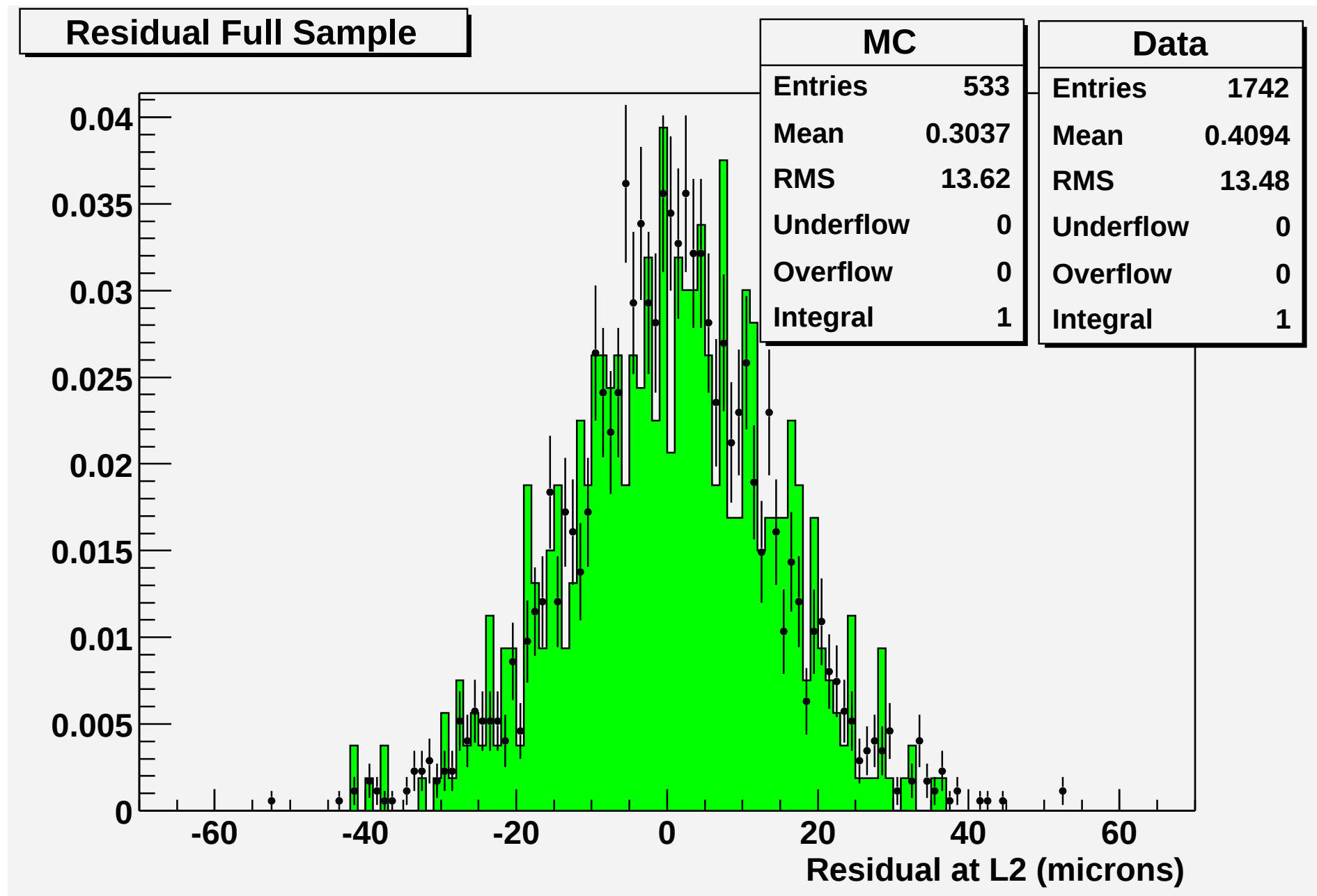
Silicon Tracking Resolution From High $P_T \mu$



Cluster Width	Measured resolution in μm		
	L00	SVX Axial L1-L5	SVX 90° L1,4
1 strip	18.4 ± 0.3	13.6 ± 0.3	29.5 ± 0.5
2 strips	10.1 ± 1.9	9.5 ± 0.1	23.0 ± 0.3
3 strips	17.2 ± 1.8	13.4 ± 0.2	34.3 ± 0.8
4+ strips	23.5 ± 2.8	18.7 ± 0.4	64.3 ± 1.8

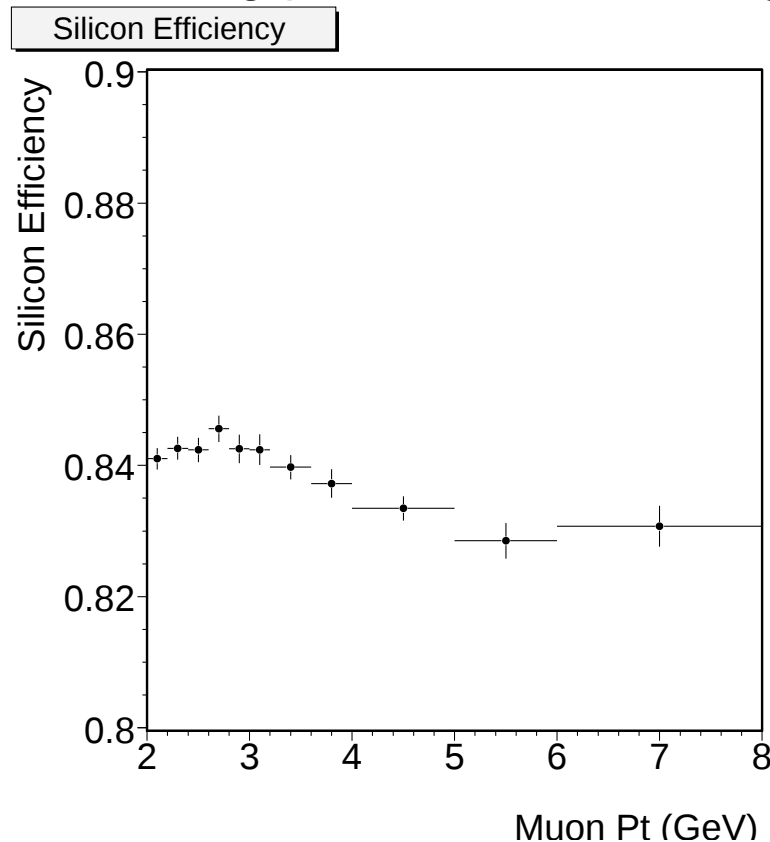
L00 resolutions are new result & will improve with alignment/study

Silicon Tracking Resolution Data vs MC

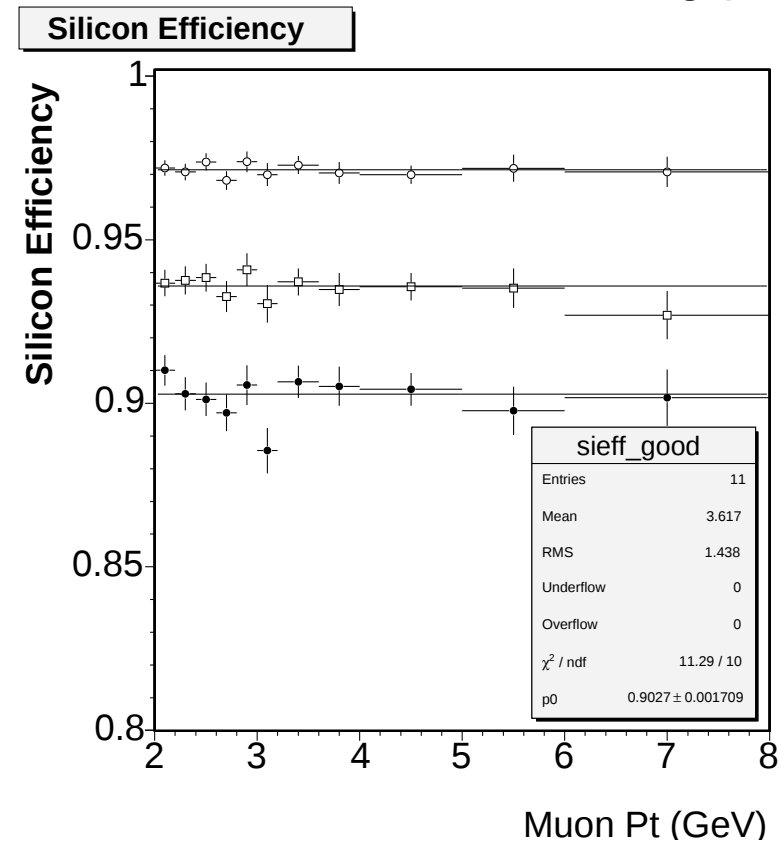


Silicon Tracking Performance

Including pre-stable-data-taking period

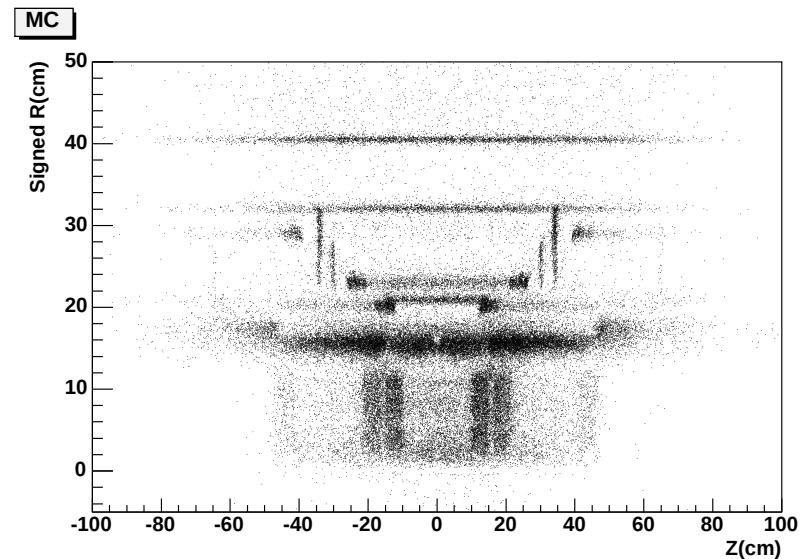
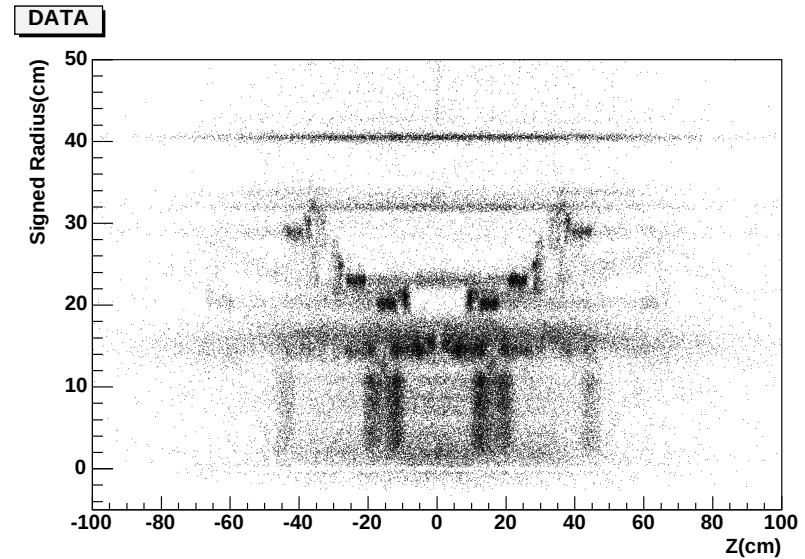
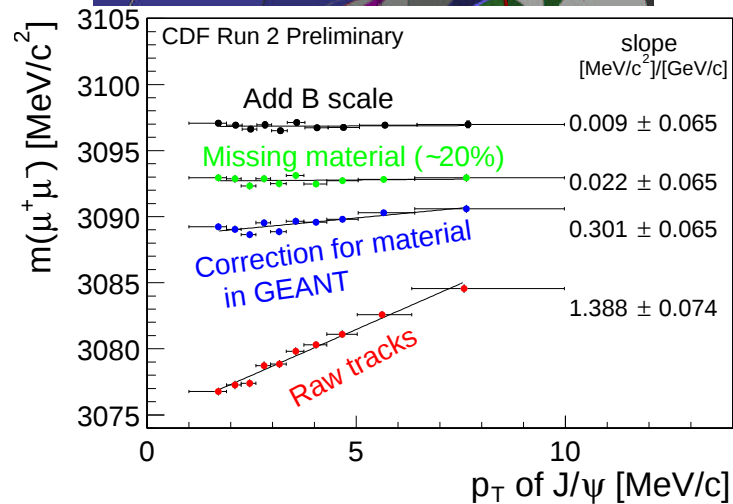
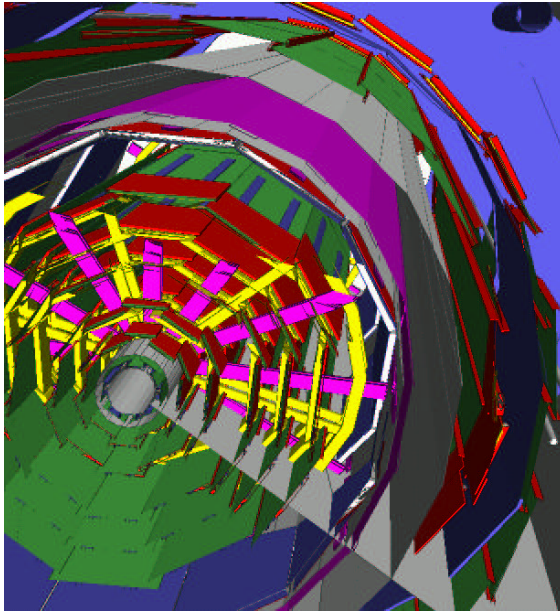


After stable-data-taking period



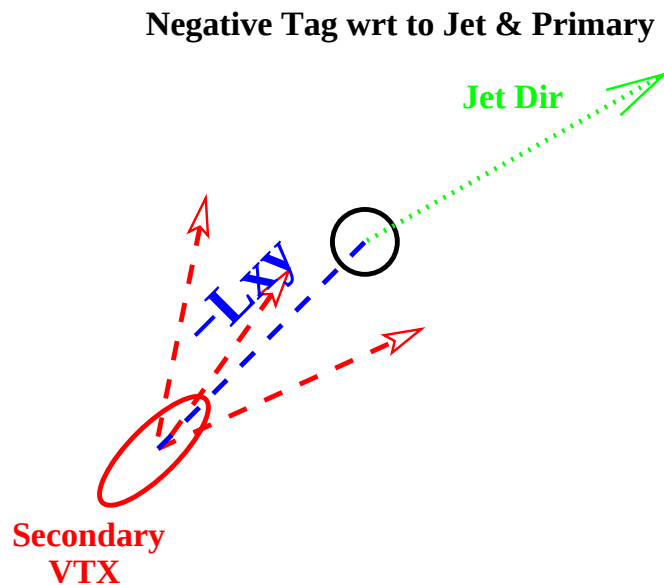
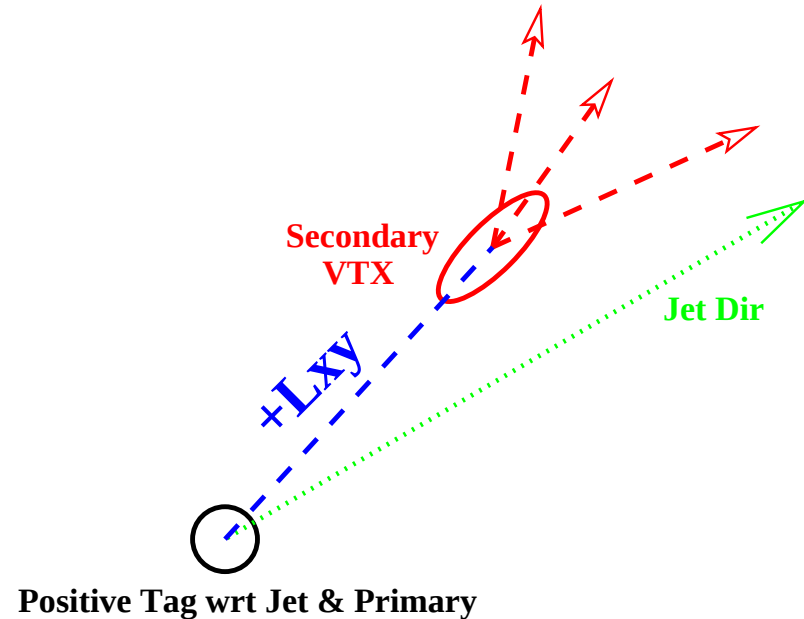
- Eff to attach $\frac{N-1}{N}$ $R\Phi$ -Si hits to good COT tracks from $J/\psi \rightarrow \mu^+ \mu^-$ events
- 5% **readout errors** (have reduced some)
- 4% **bad strips** (irreducible)
- 5% **dead wedges** (have recovered some)
- Have improved tracking/alignment

Silicon Material Map



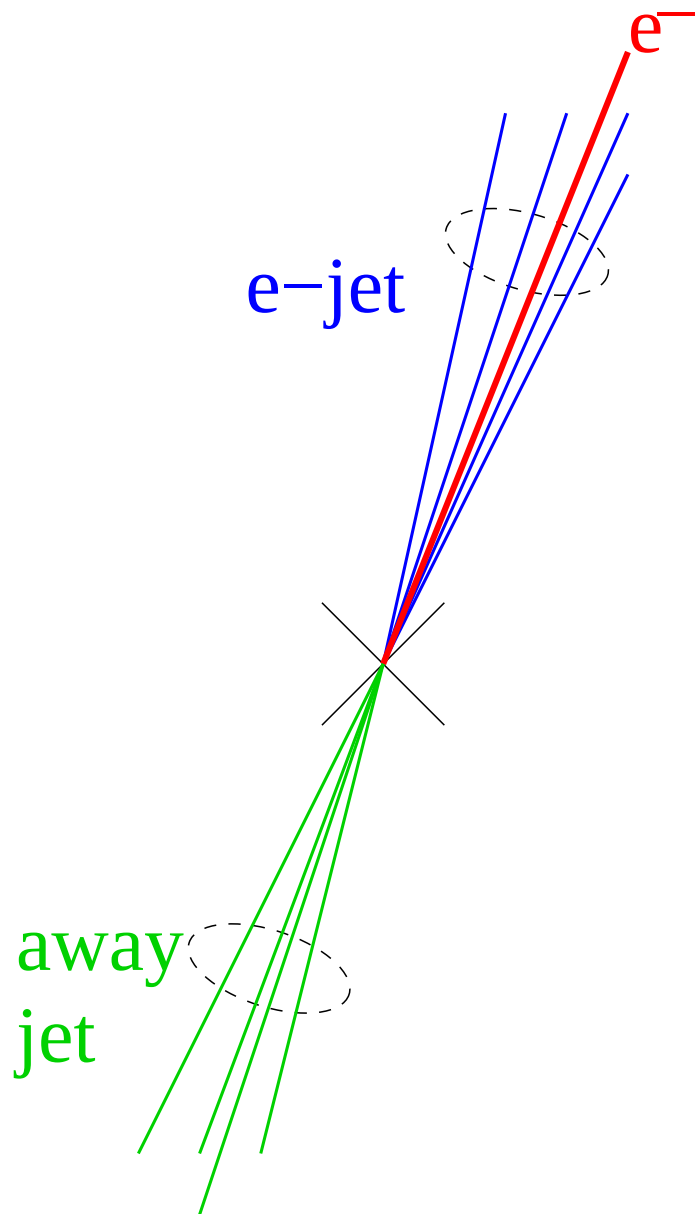
- Accounting for all material allows precise knowledge of energy loss and **mass reconstruction**
- Helps simulation get false lifetime from conversions correct

B-Tagging



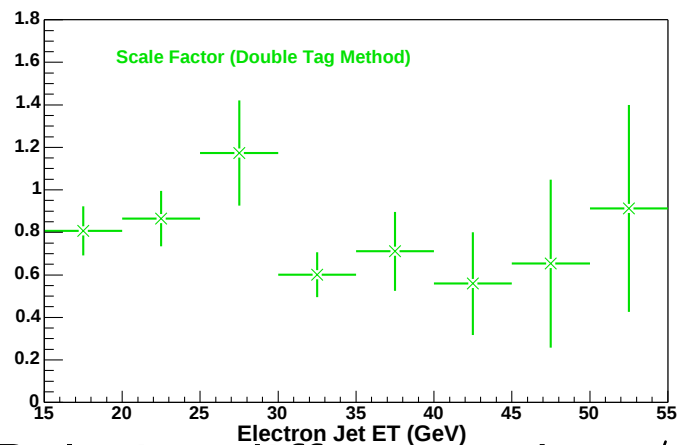
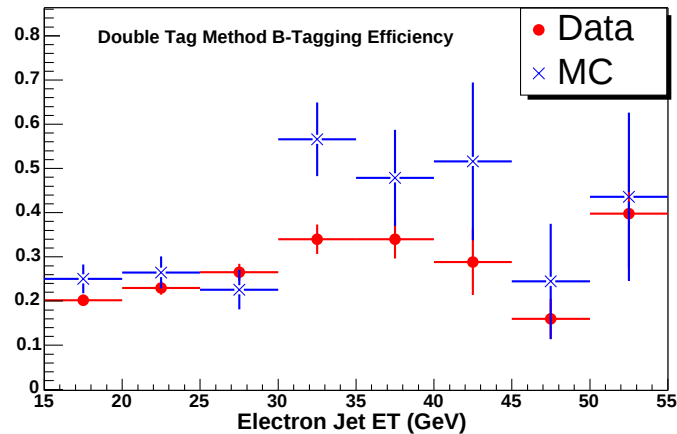
- **Displaced vertexes:** All combinations of at least 2 good tracks
- Jet is tagged as b-jet if $L_{xy}/\sigma_{xy} > 3$ (typical $\sigma_{xy} \sim 150 \mu\text{m}$)
- Measure eff and fake rate in incl lepton & generic jet data
- (Looser tagger used in Higgs analysis: SecVtx falling back to 1% CL of impact parameters in jet to be consistent with zero)

Measuring B-Tag Efficiency



- Knowing eff to tag b-jet key to any analysis using b-tag for cross section
- **Double-tag technique** to measure b-tag eff
- Start with sample enhanced in heavy flavor: **8 GeV inclusive electrons** in data/MC
- Enrich b-content by requiring **away-jet to be tagged**
- **Eff of b-tagging e-jet** determined by ratio of double-to-single tagged events
- Method less sensitive to knowledge of heavy-flavor fraction of e-jet

High- P_t B-Tagging: Efficiency

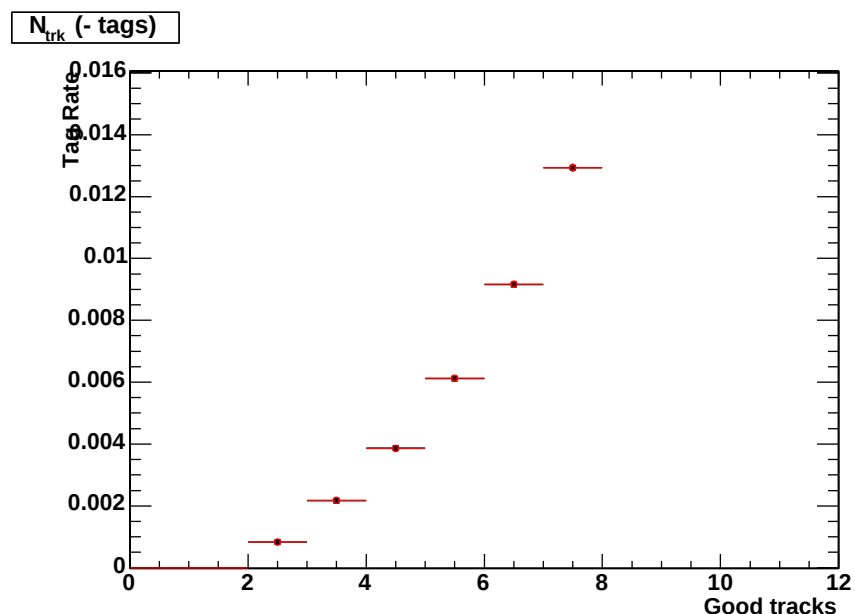
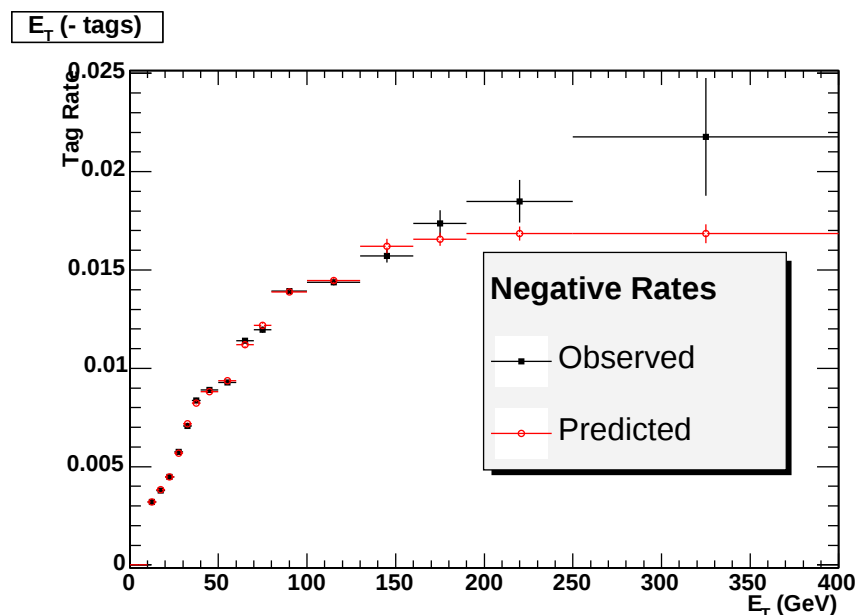


- Need 2 things about sample of jets to measure eff:
 1. Net tag rate, $r = (N_{\text{pos}} - N_{\text{neg}})/N_{\text{tot}}$
 2. Frac of jets containing HF, F_B
- Eff is then $\varepsilon = r/F_B$
- Measure r^a and F_B^a in e-jets when away jet is tagged
- Account for away-jets tagged **but e-jet is light-flavor**
- This QCD contribution measured in sample when e-jet identified as photon-conversion
- Assumes **heavy flavor** production in away-jet **independent** of e coming from **conversions/fakes**

$$\varepsilon = \frac{(N_{a+}^{e+} - N_{a+}^{e-}) - (N_{a-}^{e+} - N_{a-}^{e-})}{(N_{a+} - N_{a-})} \cdot \frac{1}{F_B^a}$$

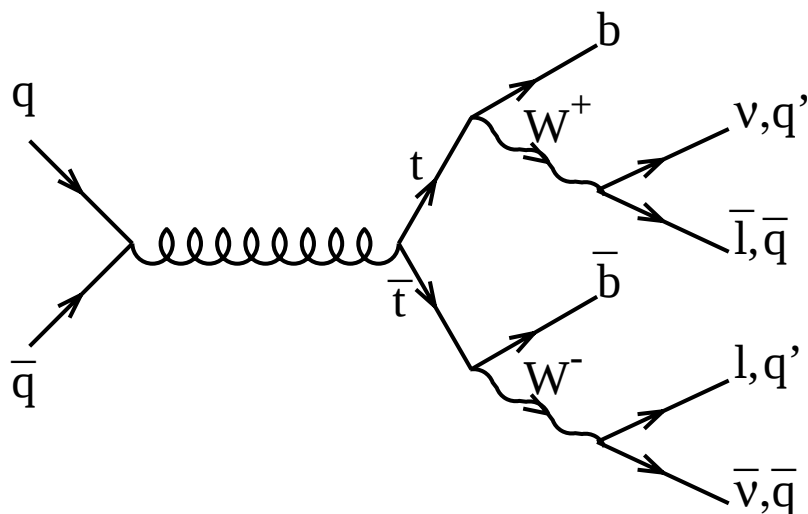
- Relative difference data/MC for tagging b-jets $81\% \pm 7\%$
- Eff to tag a $t\bar{t}$ event $52.9\% \pm 0.3\% \pm 4.6\%$
- Now measure prob to tag *light-flavor jet* as b-jet (fake tag)

High- P_t B-Tagging: Fake Rate

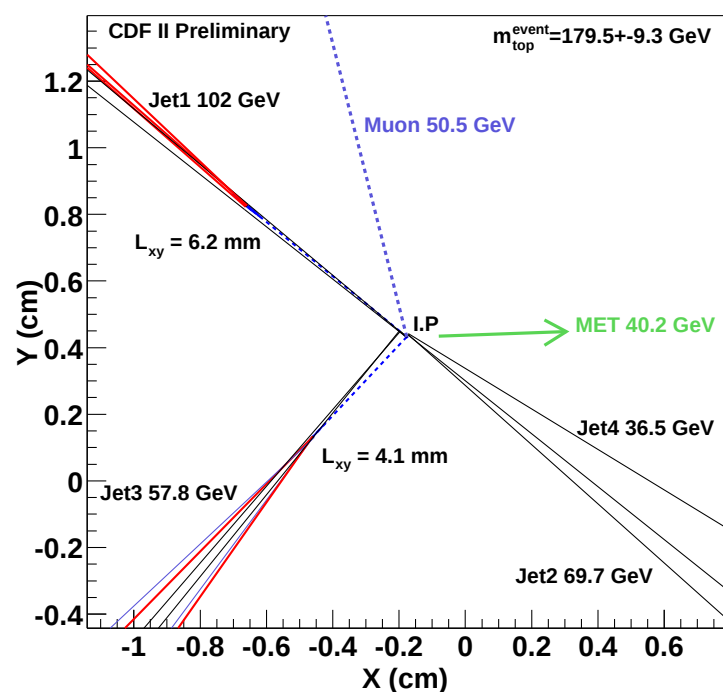


- Can't rely on absolute MC rate for tagging light partons
- Use negative tag rate in inclusive jet sample to determine “fake rate”
- Parameterize rate as function of 5 observables
 - E_T : Vtx method better for large E_T
 - $\sum E_T^{\text{jets}}$: Removes some sample dependence
 - $N_{\text{good}}^{\text{trk}}$: Tracking eff
 - ϕ, η : Detector coverage
- Use parameterization to predict negative tag rates in different samples
- Fake rate 1 – 1.5% for top-candidates

Re-Measuring the Top Cross Section



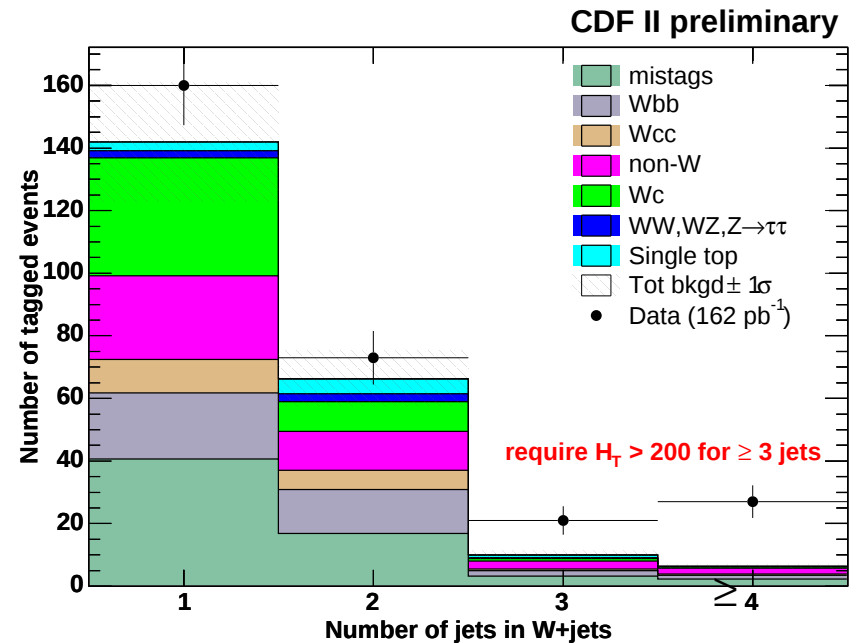
- For the purposes of the **Higgs search**, the top quark presents a known **high P_T** physical process involving **b-jets**



- Reestablishing lepton+jets top cross section give us confidence that the **b-tag is working**

Top: Lepton+Jets Cross Section

- Signature:
 - 1 high- P_t isolated lepton
 - Veto conversions, Z's, cosmuics
 - Large missing E_t
 - At least 3 high- E_t jets
 - $H_t > 200$ GeV
 - At least 1 b-tag
- B-tag improves S/B from 1/6 to 3/1



- Find 48 candidate events in 162 pb $^{-1}$
- Expect 13.8 ± 2.0 bkg events
- $\sigma_{t\bar{t}} = 5.6 \pm 1.2(\text{stat}) \pm 0.8(\text{syst})\text{pb}$
- $\sigma_{t\bar{t}}(\text{NLO}) = 6.7^{+0.71}_{-0.88} \text{ pb}$ (Cacciari *et al.*)

Now on towards the Higgs

- Si detector tuned up
- B-Tag implemented
- Jets+Lepton top cross section reestablished
- *Now let's see what has to be done for MSSM Higgs search*

4b Search: Roadmap

- Online

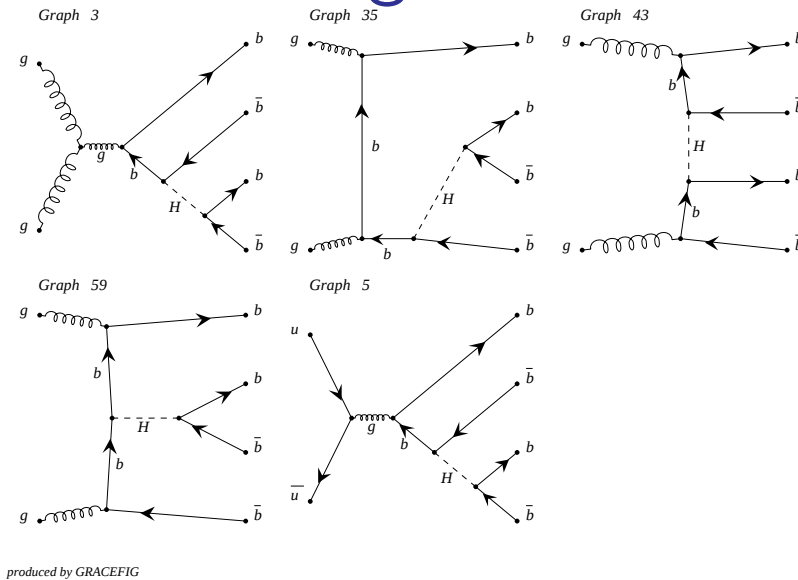
- Trigger is crucial.
- High bkg rates, this will always be somewhat low eff

- Offline

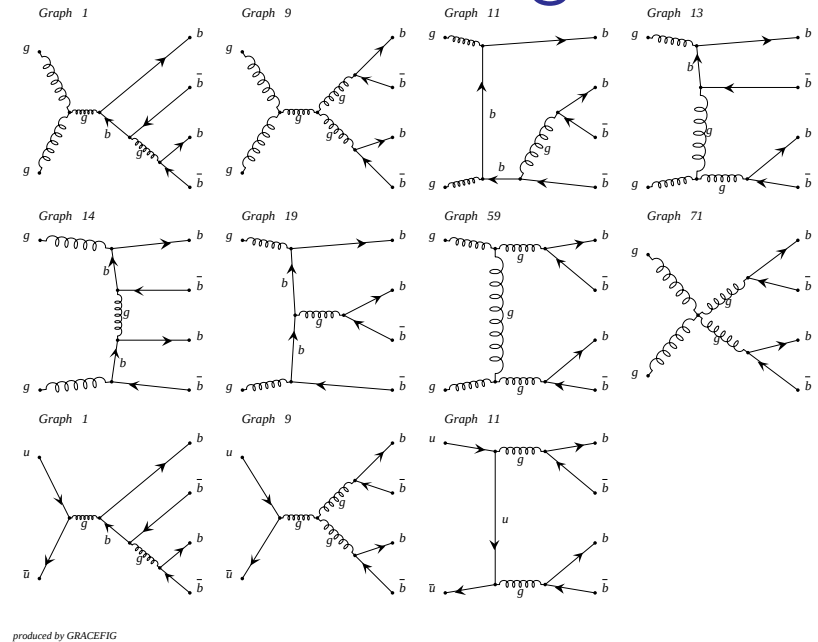
- Veto isolated high- P_T leptons from Z & W
- Require 4 jets, with $E_T > 10$ GeV
- Estimate “fake tags” from mistag matrix, like top analysis
- Estimate QCD from fit to 2-tag spectrum in data
- Harsh b-tag requirement: 3 or more positive tags!
- Dijet pairing $\Rightarrow$ mass window cuts
- Dijet mass isn't great, essentially counting exp

Triggering on 4b Events with CAL+SVT

Signal

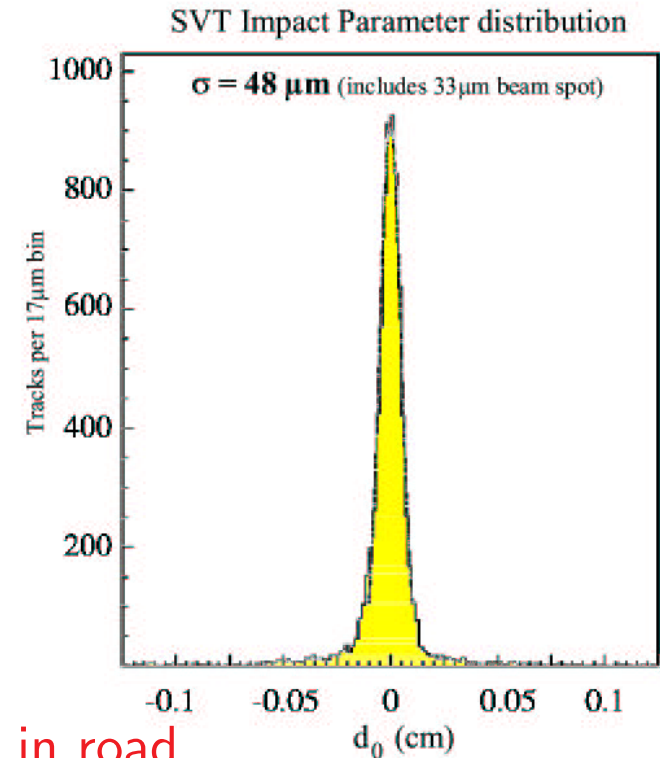
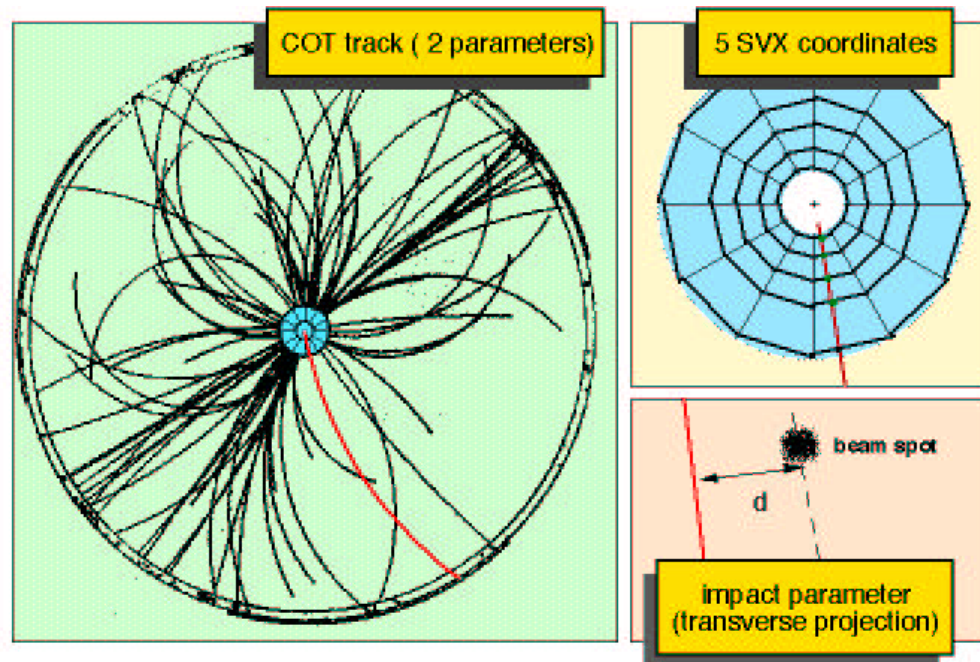


QCD 4b Background



- Signature: 4 b-jets in final state with lots of visible energy
- Dominant background: QCD processes giving 4 real b-jets in final state
- Trigger:
 - 3 jets with $E_T > 10$ GeV
 - $\sum E_T > 100$ GeV
 - Heavy flavor present (use SVT)

Triggering on Heavy Flavor with SVT



- Takes L1 tracking info from COT and finds Si hits in road
- Fits beamline position online, for IP reference
- IP resolution = $35 \mu\text{m} \oplus 33 \mu\text{m}(\text{beam})$ compares to offline resolution quite well
- System is $\sim$ deadtimeless: 25 μsec /event for silicon readout, clustering, track fitting
- 70% eff for 4/4, 80% eff for 4/5

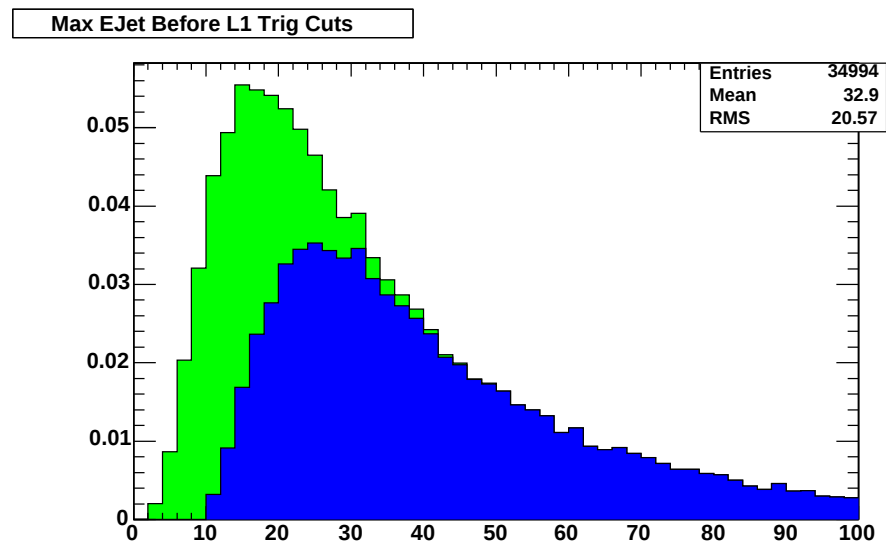
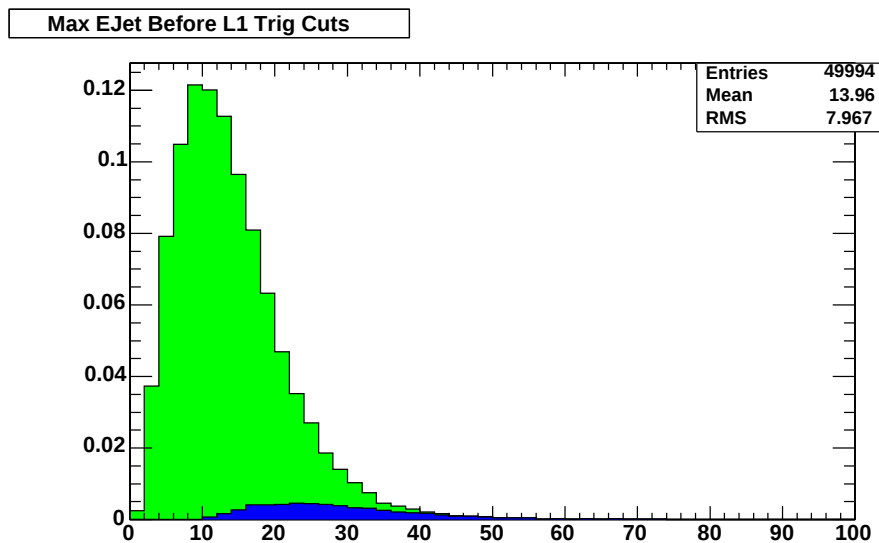
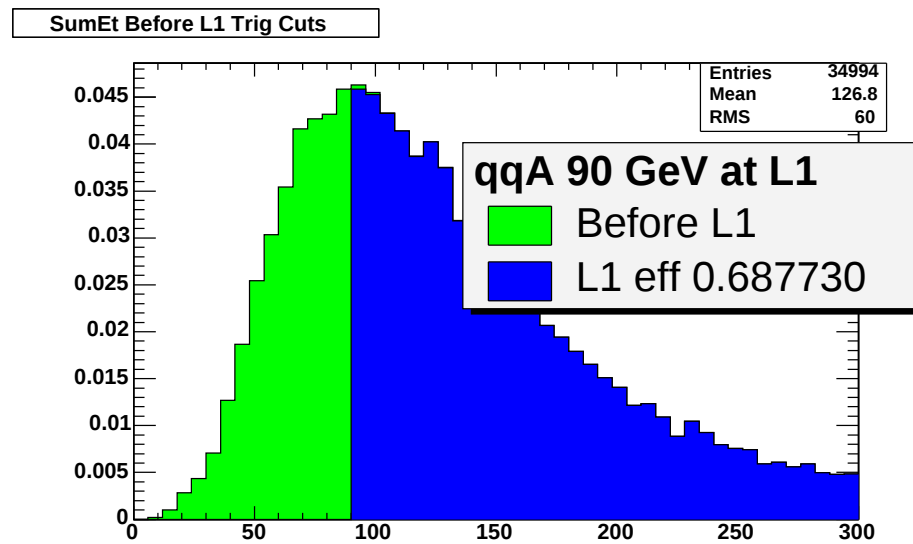
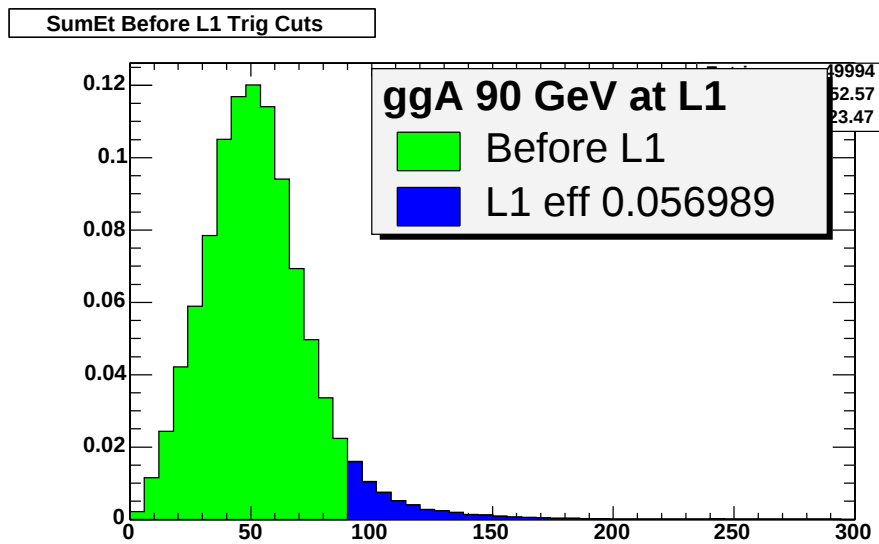
3-Level Higgs Trigger

- **L1_JET10_&_SUMET90_v-1**: Requires one 10 GeV E_T trigger jet from central or plug in coincidence with 90 GeV $\sum E_T$
- **L2_TWO_TRK2_D100_L1_JET10_&_SUMET90_v-1**: Two tracks each with $100 \mu\text{m} < d_0 < 1 \text{ mm}$, $\chi^2 < 25$ and $P_t > 2 \text{ GeV}$ from SVT.
- **L3_THREE_JET10_SUMET100_TWO_SVT_v-1**: Using cone size of 0.4, require three jets of 10 GeV E_T with total jet $\sum E_t > 100 \text{ GeV}$
- Trigger was designed before data taking began.
- Collected 200 pb^{-1} with this trigger. Looking at implementing more efficient trigger for next data taking period.
- **Run1 trigger used for MSSM Higgs was 1.7% efficient on signal**

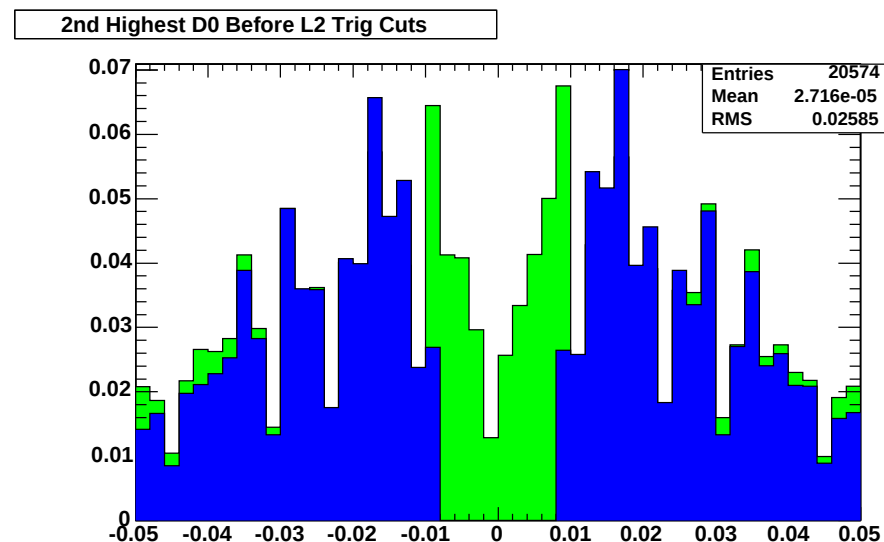
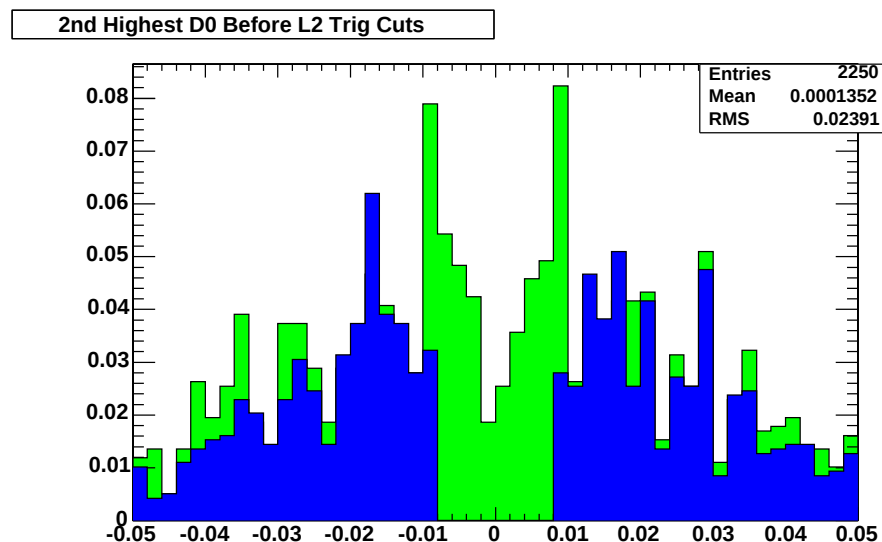
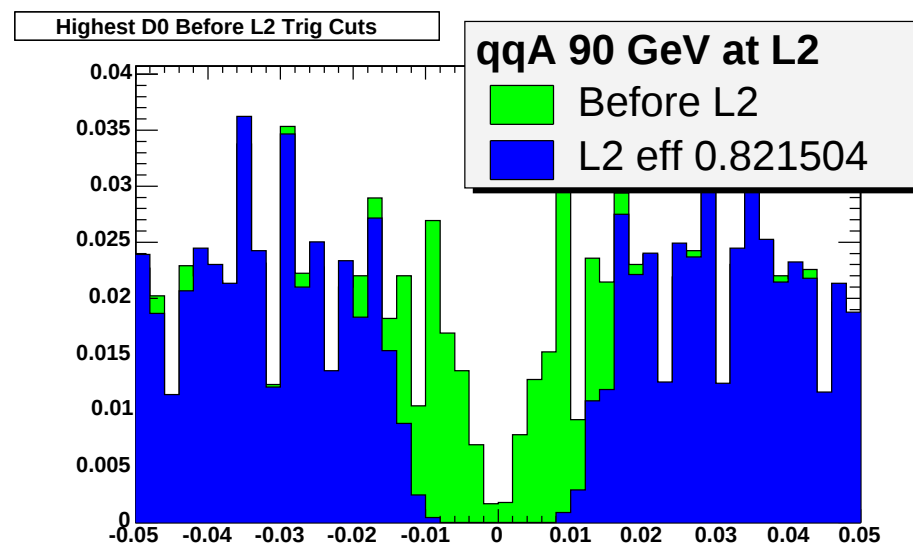
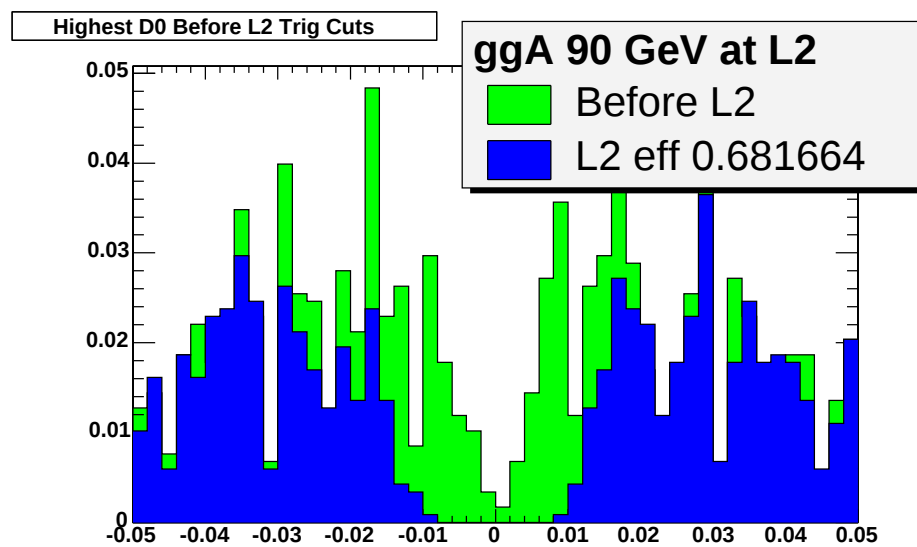
Beginning Studies with MC and Blinded Data

- We've begun MC-level studies of 4b signals in m_A range 90 GeV to 130 GeV
- Using background dominated data to study fake tags
- Currently a blinded analysis, but we've made a first estimate of expected signal and background rates
- Comparable to **previous study** (J. Valls) of expected rates
⇒ **Use as baseline** for expected sensitivity
- Everything is very preliminary

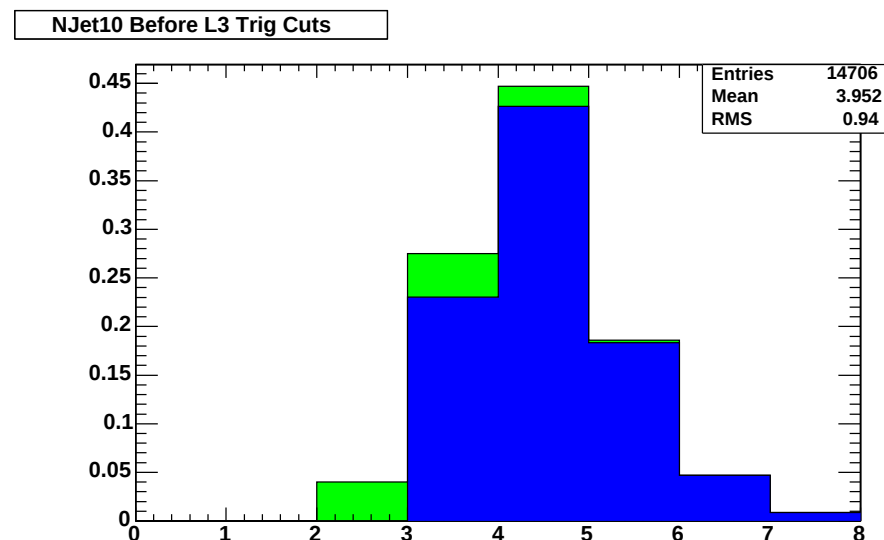
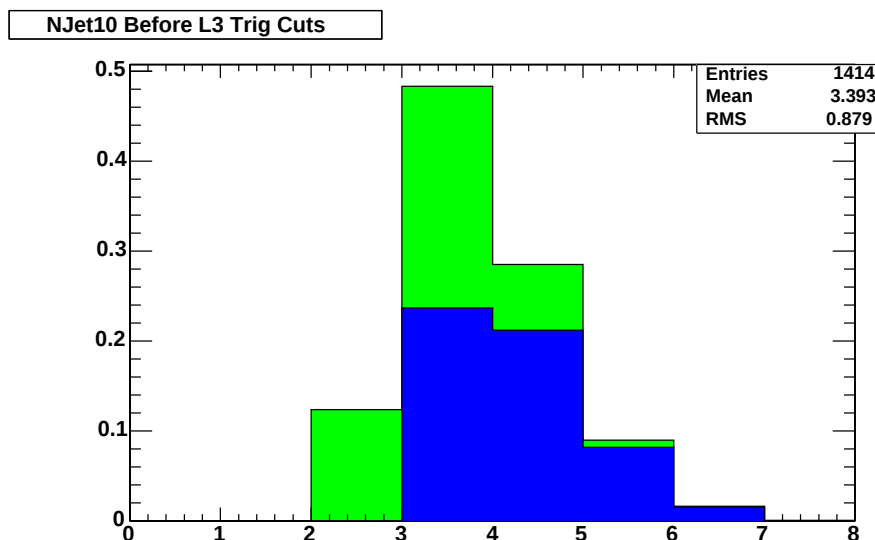
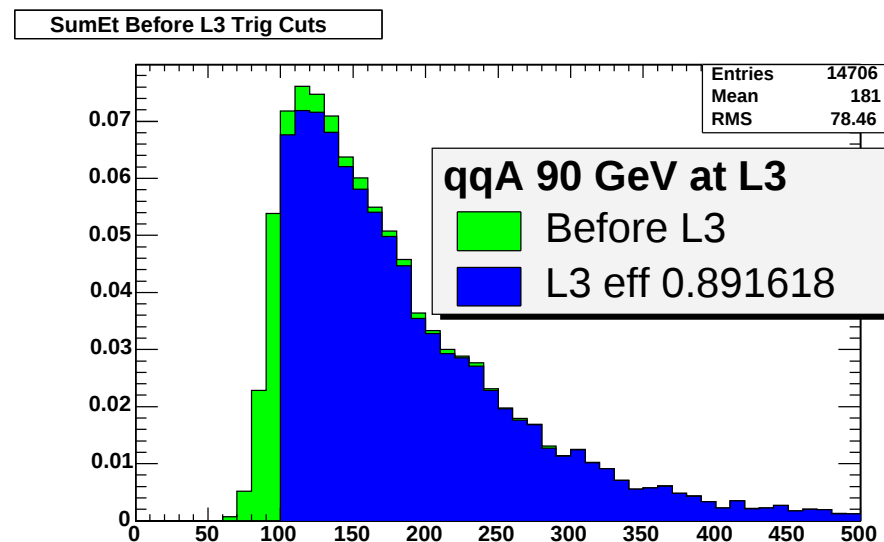
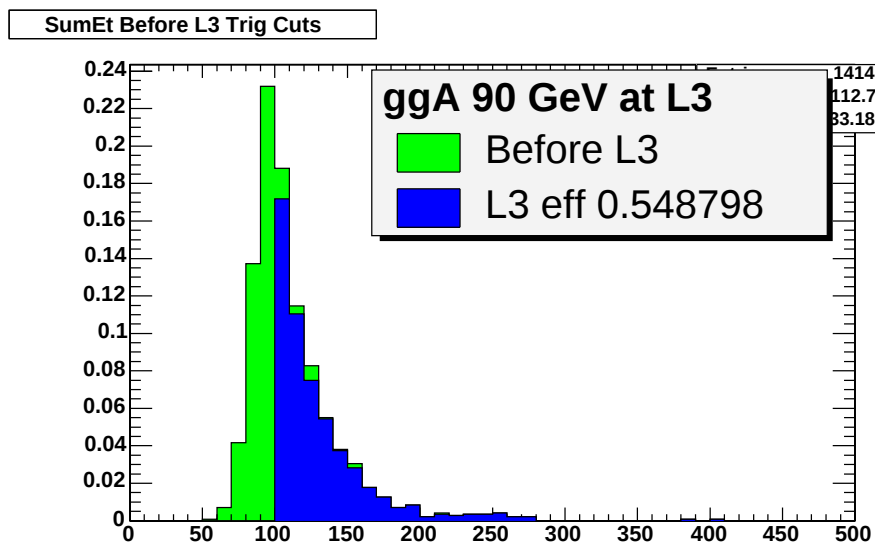
L1 Trigger Efficiency on Signal



L2 Trigger Efficiency on Signal



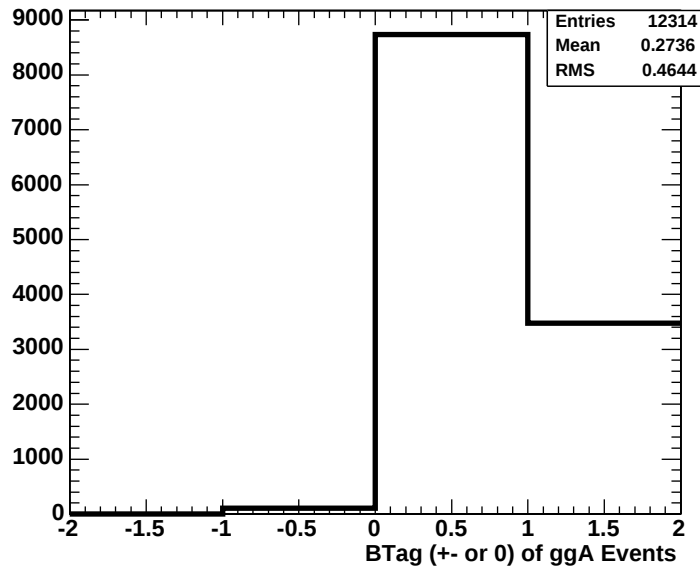
L3 Trigger Efficiency on Signal



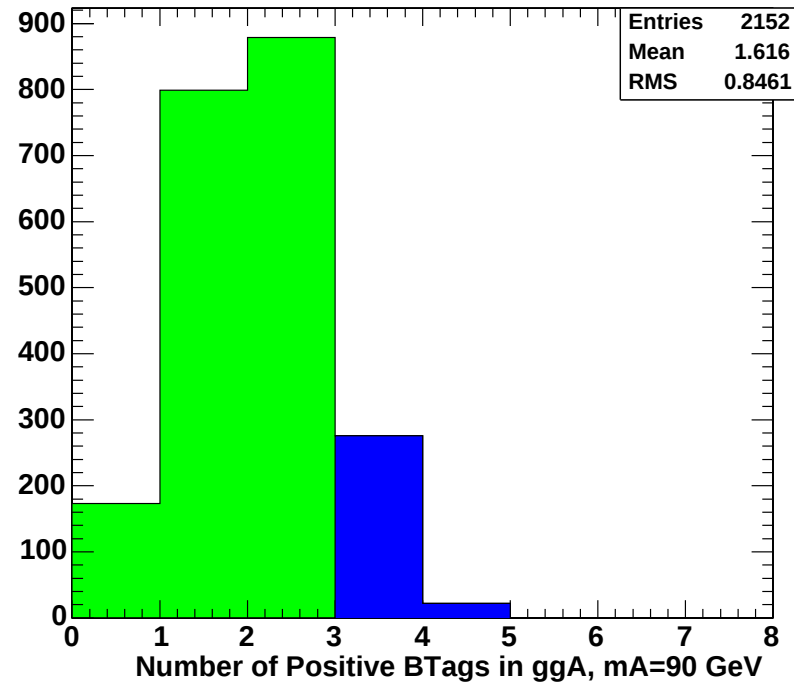
Full trigger $\sim 1.6\%$ eff on 90 GeV signal

Estimated Efficiencies on Signal

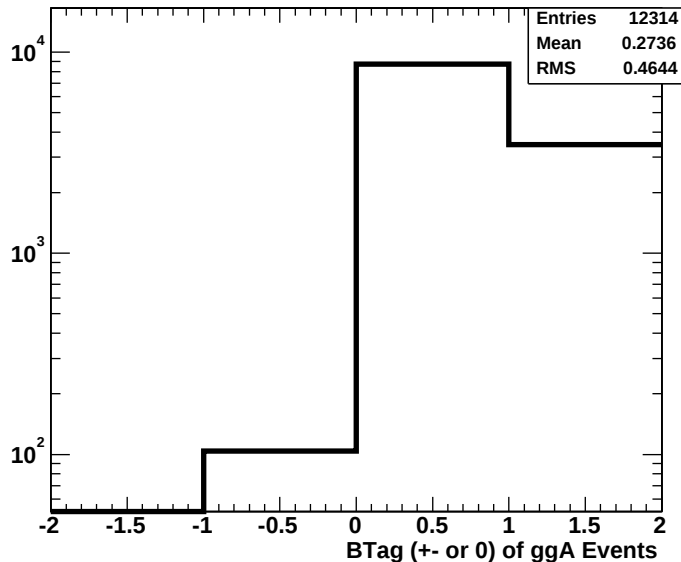
Jet Tags After L3 Trig Cuts



NPos tags After L3 Trig Cuts

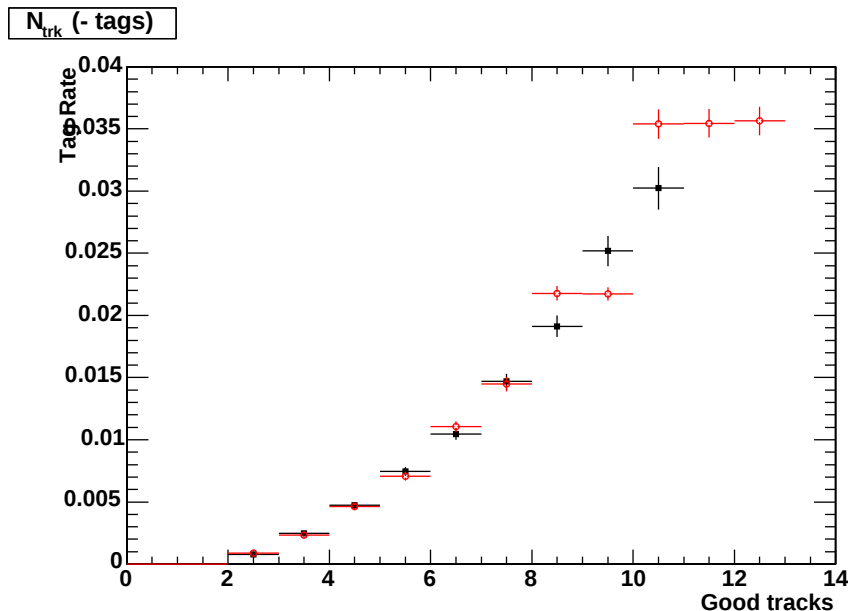
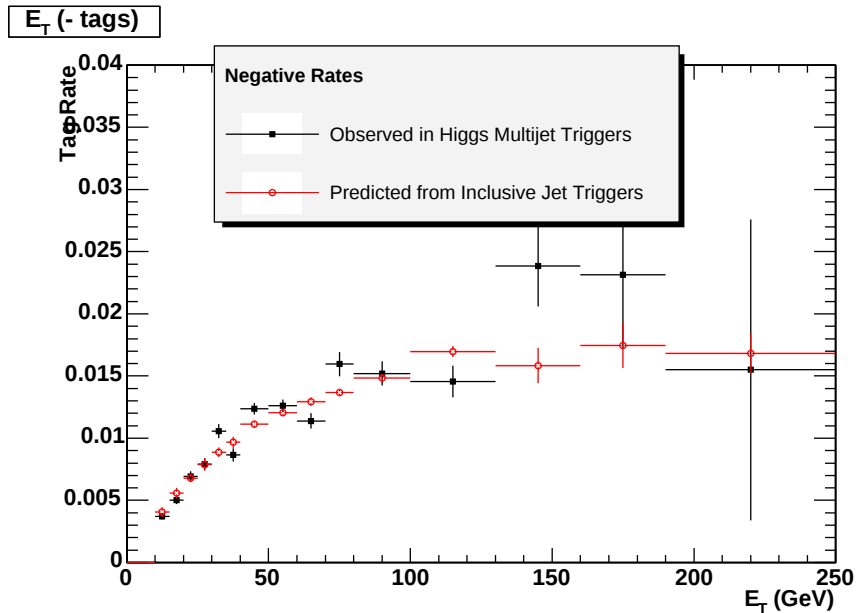


Jet Tags After L3 Trig Cuts



Requirement	$m_A = 90 \text{ GeV}, \tan\beta = 50$	
	$gg \rightarrow bbA$	$qq \rightarrow bbA$
Passes L1&L2&L3	1.5%	37.7%
2+ offline b-tags	32%	47.5%
3+ offline b-tags	9.5%	18.5%
Total eff	0.14%	7.0%
gg+qq eff	0.2%	

Fake Double-Tag Rate Prediction in Data



- Negative single-tag rate in incl. jet sample to determine fake multi-tag rate in data ($\text{QCD}_{\text{fakes}}$ in following)
- Fake double-tag is double-positive-tag with at least one light flavored jet

– Consider light-light Neg = Pos = ϵ :

$$P_{--} = \epsilon^2$$

$$P_{+-} = 2\epsilon^2$$

$$P_{++}^{\text{fake}} = \epsilon^2 = P_{+-} - P_{--}$$

– Light-heavy Neg = ϵ , Pos = η :

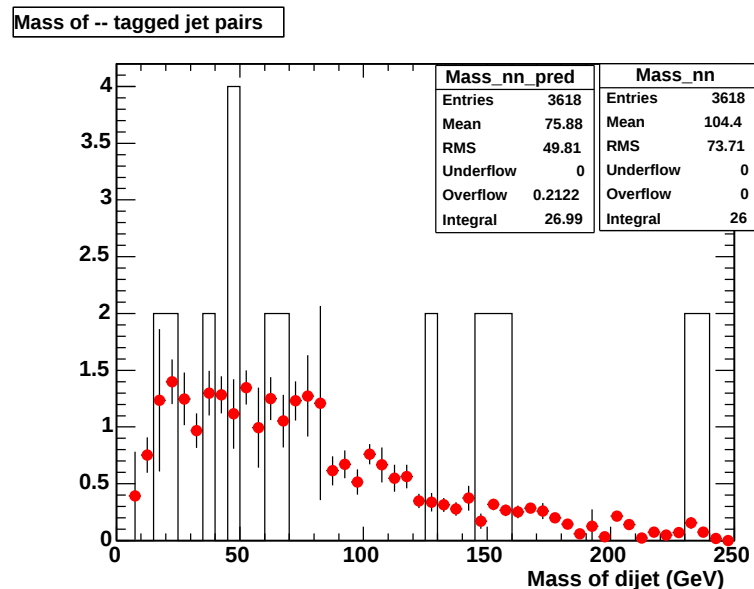
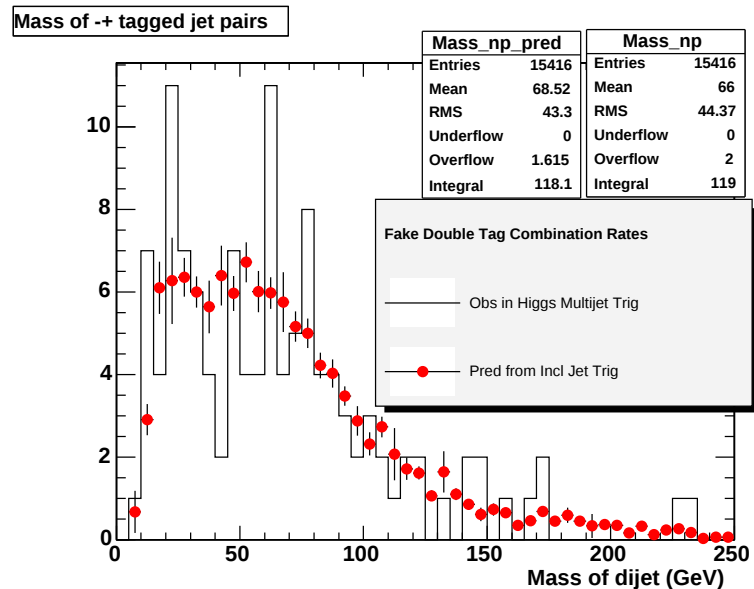
$$P_{--} = \epsilon\eta$$

$$P_{+-} = 2\epsilon\eta$$

$$P_{++}^{\text{fake}} = \epsilon\eta = P_{+-} - P_{--}$$

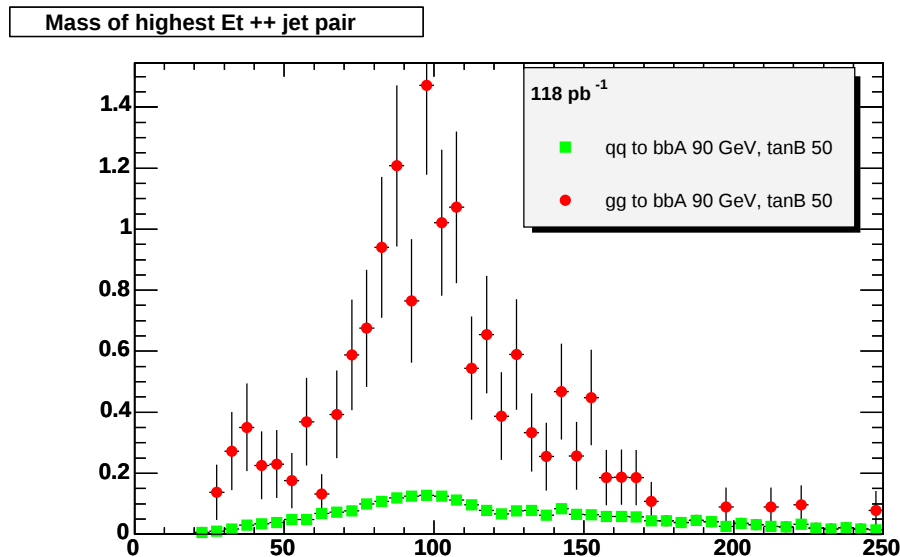
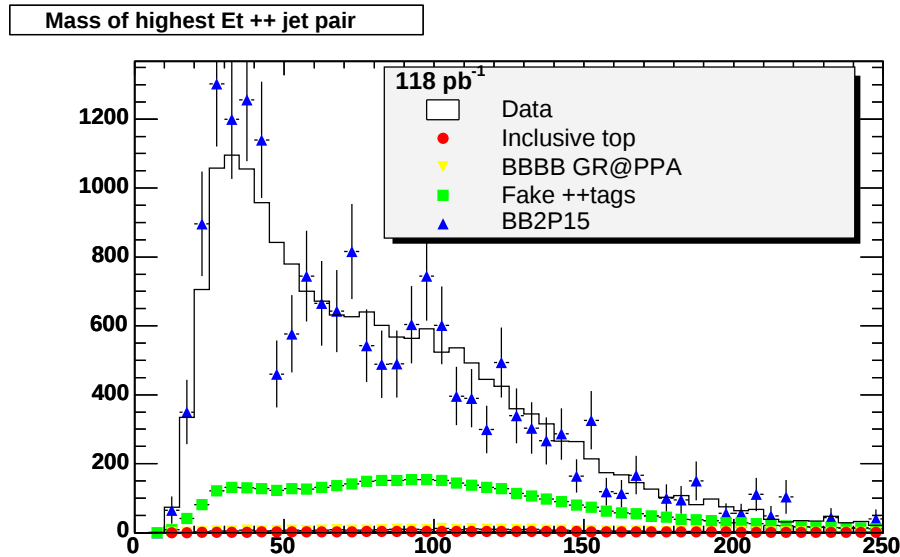
- $P_{+++}^{\text{fake}} = P_{++-} - P_{+--} + P_{---}$

Example of Fake Double Tags in HIGGS_MULTI_JET 8 pb⁻¹ Data



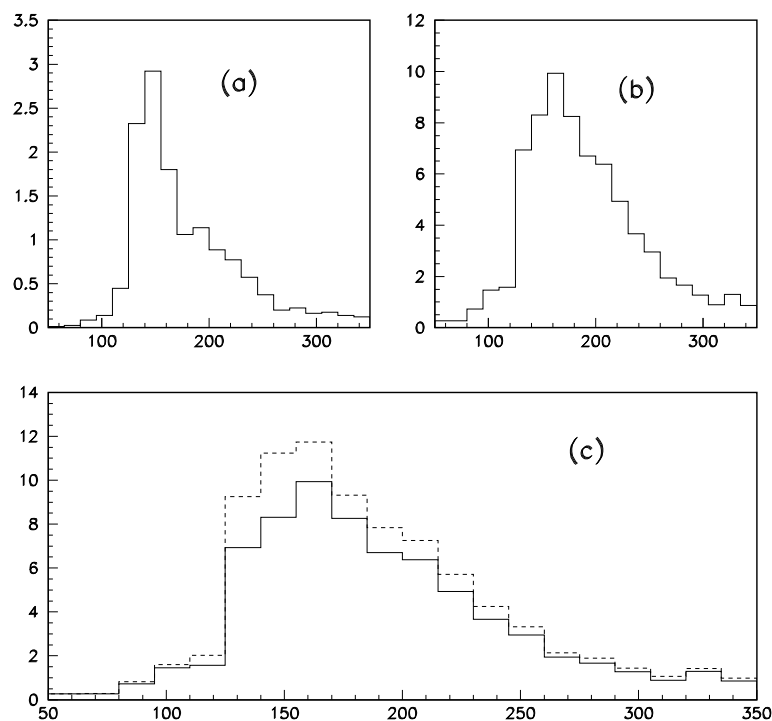
- n_{+-} :
 - Obs 121
 - Pred 119.7 ± 3.6
 - Ratio: 1.01 ± 0.09
- n_{--} :
 - Obs (26)/2
 - Pred $(27.2 \pm 1.6)/2$
 - Ratio: 0.96 ± 0.19
- Fake multitag prediction seems to work (for dijet masses above ~ 50 GeV)

Example of Fitting QCD Bkg from Data



- Use LO ME generators (ALPGEN, GR@PPA) for QCD b events (bbjj for double-tag, bbbb for triple-tag)
- Absolute cross section must come from data
- Fit double-tag data dijet mass spectrum, with known normalizations for fakes, top, smaller bkg, but let QCD float

Use Results of Analysis of 4b Events from RunII Study

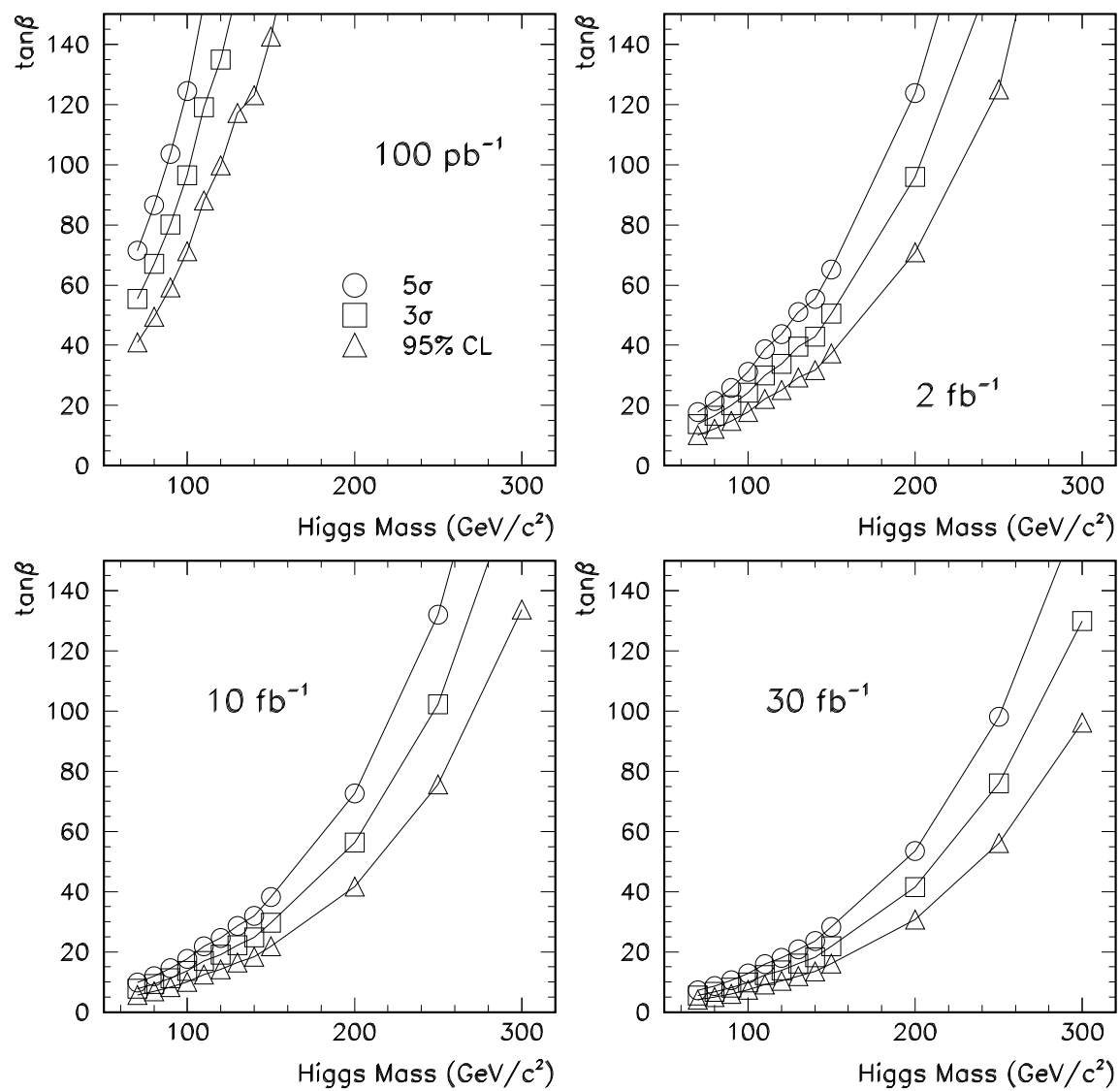


- After the trigger, require triple b-tag
- Reconstruct double-tagged dijet mass: $\sim 15\%$ resolution on signal
- Very little difference between signal (a) and bkg (b) in dijet spectrum, essentially a counting experiment
- (c) signal+bkg for $m_A = 130$, $\tan\beta = 40$ for 1 fb^{-1}

Expected Signal+Background in 1 fb^{-1}

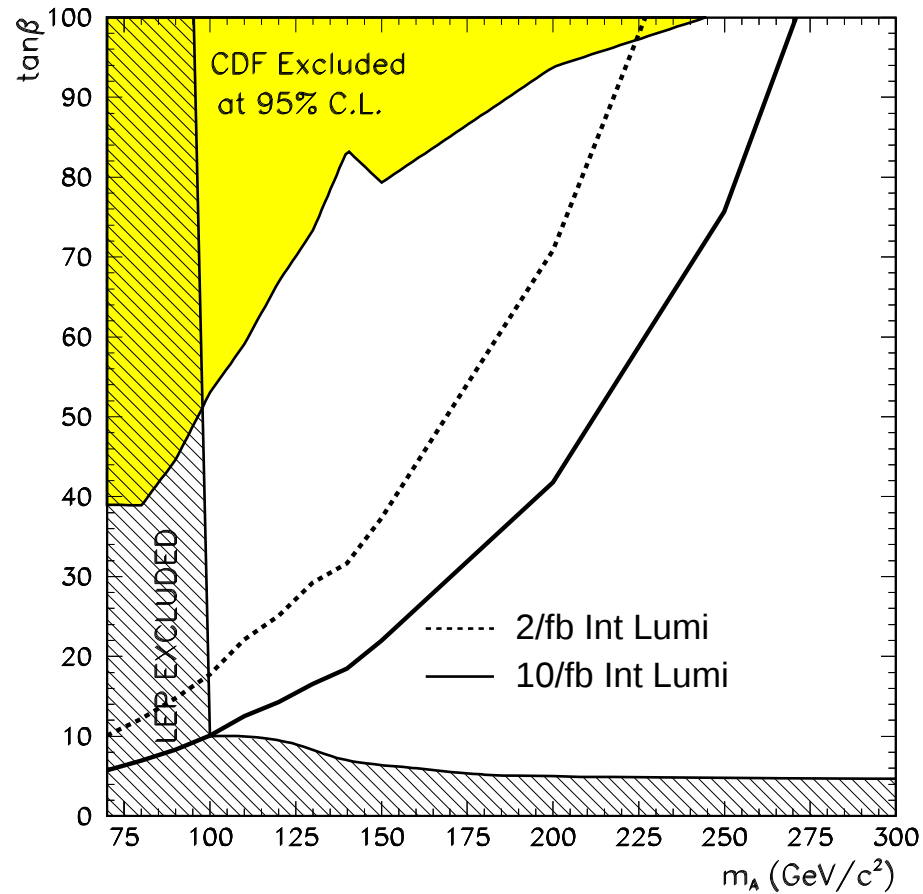
m_A GeV	signal at $\tan\beta = 40$	$\text{QCD}_{\text{heavy}}$	$\text{QCD}_{\text{fakes}}$	top	other	total
90	62.4 ± 1.5	56 ± 12	12 ± 10	13.4 ± 3.4	6.6 ± 1.7	88 ± 16
130	13.7 ± 0.5	45 ± 11	7 ± 5	12.2 ± 3.2	3.4 ± 1.4	68 ± 13

Outlook

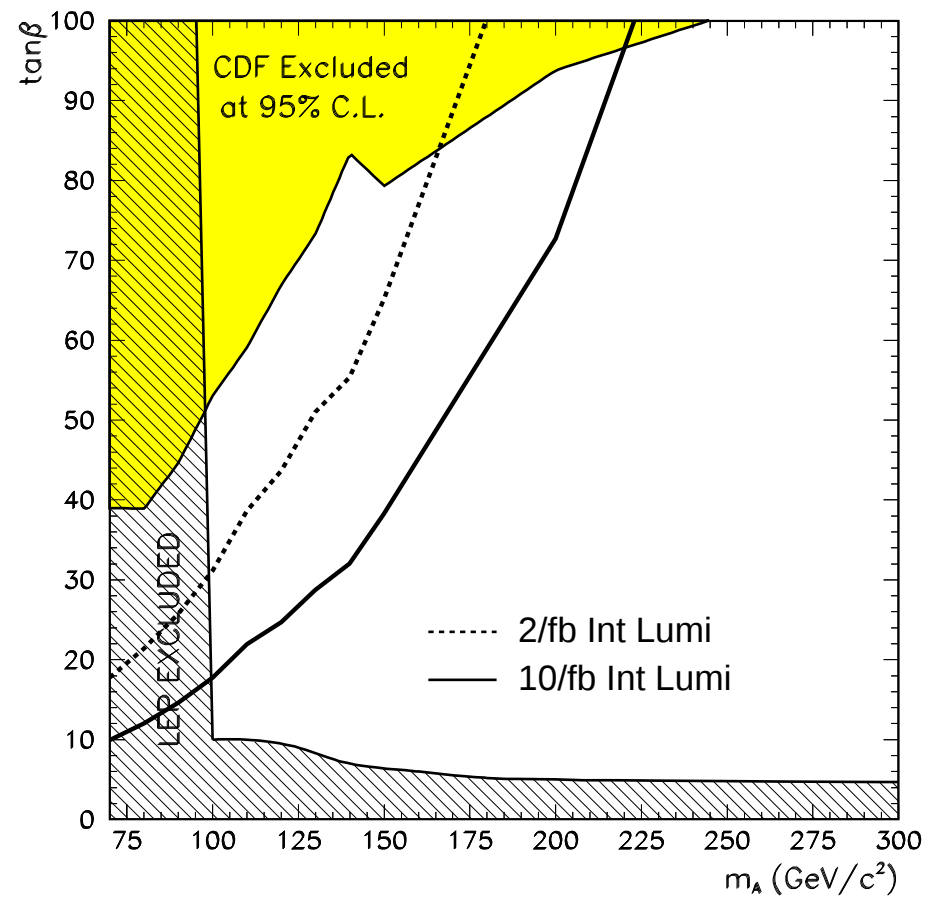


Outlook

95% CL Exclusion



5σ Discovery



Outlook

- Currently have $\sim 200 \text{ pb}^{-1}$ data on tape
- Making systematic progress in understanding b-tagging in RunII
- Higgs multijet trigger performing adequately, room for improvement
- Expect to have new exclusion potential down to $\tan\beta \sim 40$ for $m_A = 90 \text{ GeV}$ with data in hand
- Large region of parameter space with potential for discovery

Proposal Part I: MSSM Higgs Search at CDF

- Finish first round of search for $gg \rightarrow b\bar{b}A/h \rightarrow b\bar{b}b\bar{b}$
- Implement more efficient trigger
- Combined search
 - Willinbrock predicts $gg \rightarrow bA \rightarrow b\bar{b}\bar{b}$ is ~ 10 times bigger than $4b$ final state. Measure similar process $p\bar{p} \rightarrow Zb$ first.
 - $b\bar{b}\tau\tau$ channel is 10 times smaller, but still helpful at high $\tan\beta$.
 - Also combine $gg \rightarrow A \rightarrow \tau^+\tau^-$
 - Confirmation in τ -channel would be key!
 - Can combine results with D0 a'la LEPHWG for more sensitivity
- MSSM Higgs search seems quite promising

BEST (Bilingual English/Spanish Tutors)



- BEST is an outreach program that pairs up high achieving bilingual high school students with elementary school children to help them with their homework after school
- I founded the program in 2001
- Now serves three schools in Aurora's Near East Side: 30+ tutors, 75+ students
- Raised \$17k from the city, alderman, charities, and federal "No Child Left Behind"

Proposal Part II: Mentorship



- *Mentorship* is what makes the program work
 - Older students gain sense of responsibility for successful education of younger peers
 - Younger students see positive role models with similar backgrounds
- Propose to implement a mentorship program at FNAL between scientists (staff, postdocs, visitors, grad students) and underrepresented high school students