Propects for Discovery of Neutral Higgs Bosons in RunII Data

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LBNL

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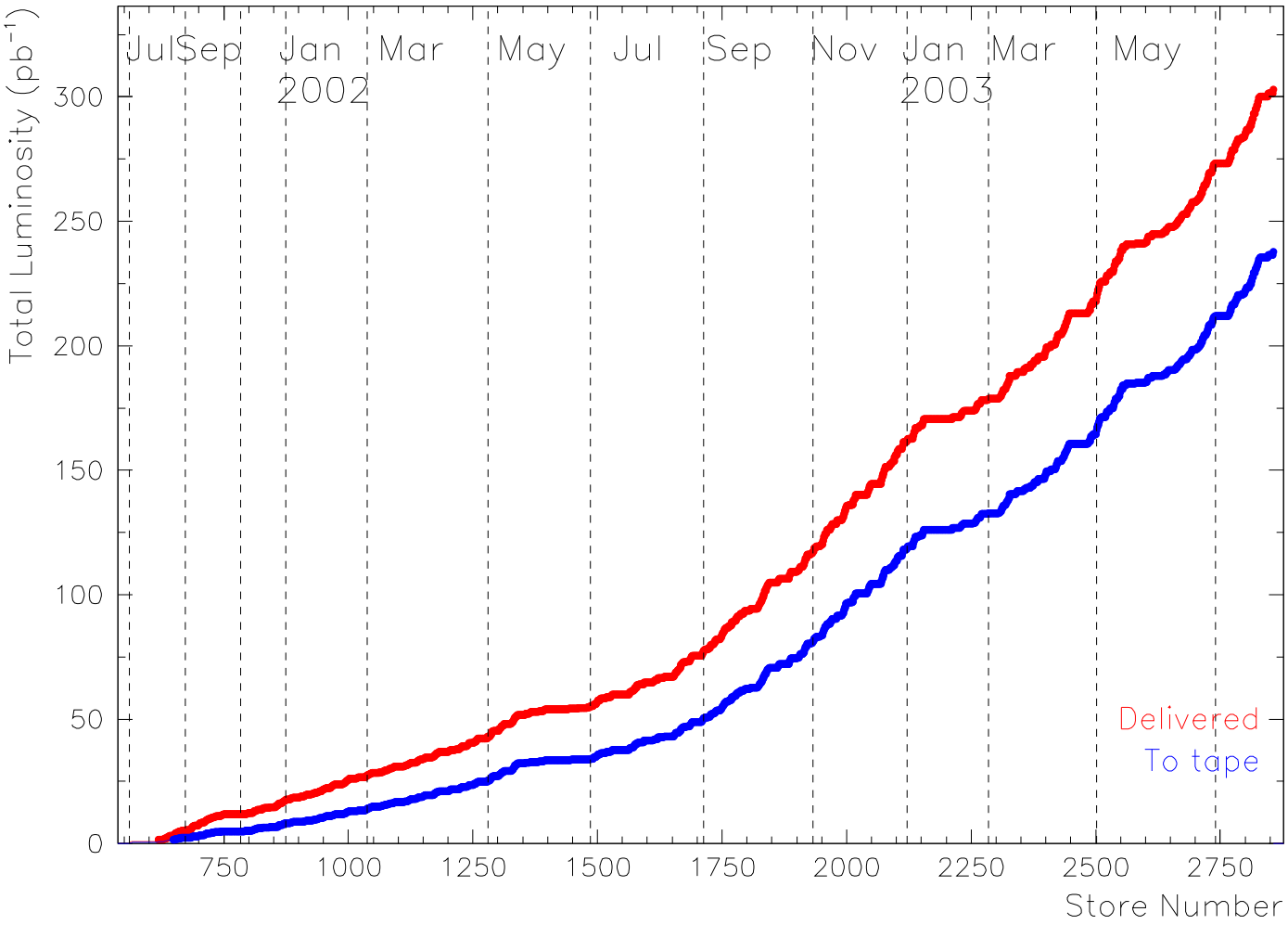
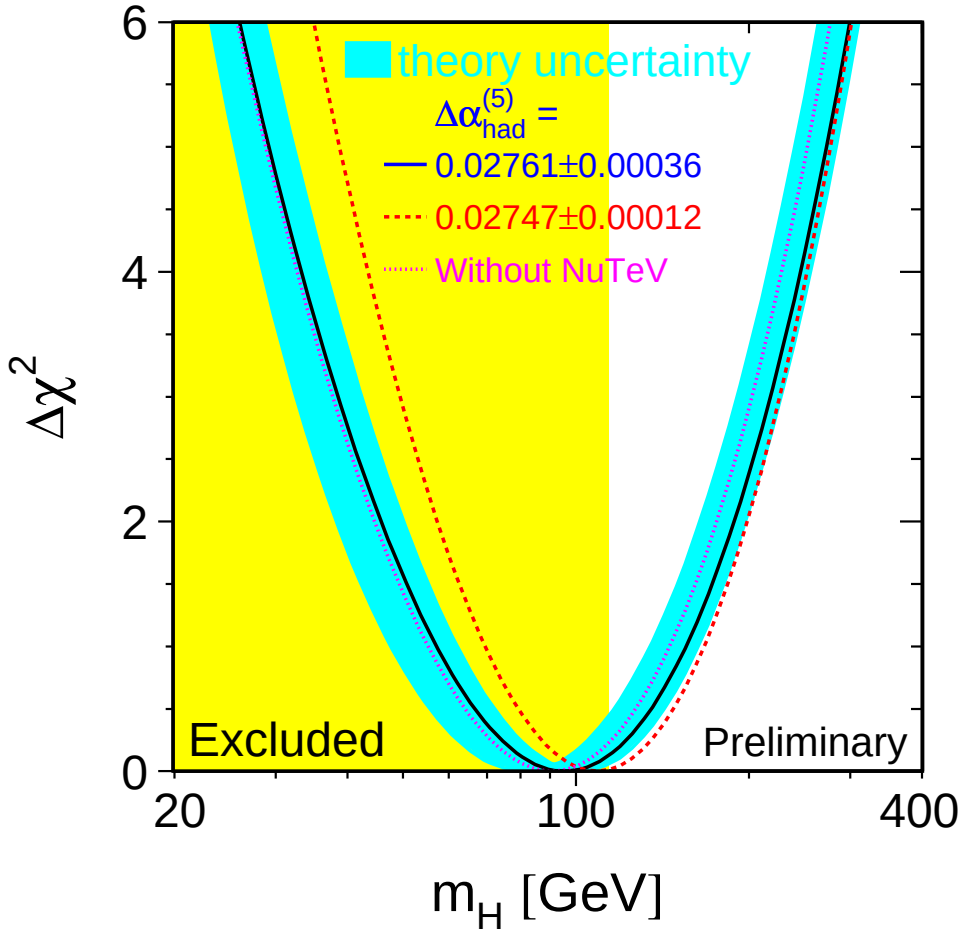
- SM Higgs: Mission Improbable
- MSSM Higgs: Mission Quite Possible
- Silicon detector is key
- B-Tagging
- Re-measuring the top gives us confidence
- Trigger and the SVT
- Analysis: 4b search
- Outlook

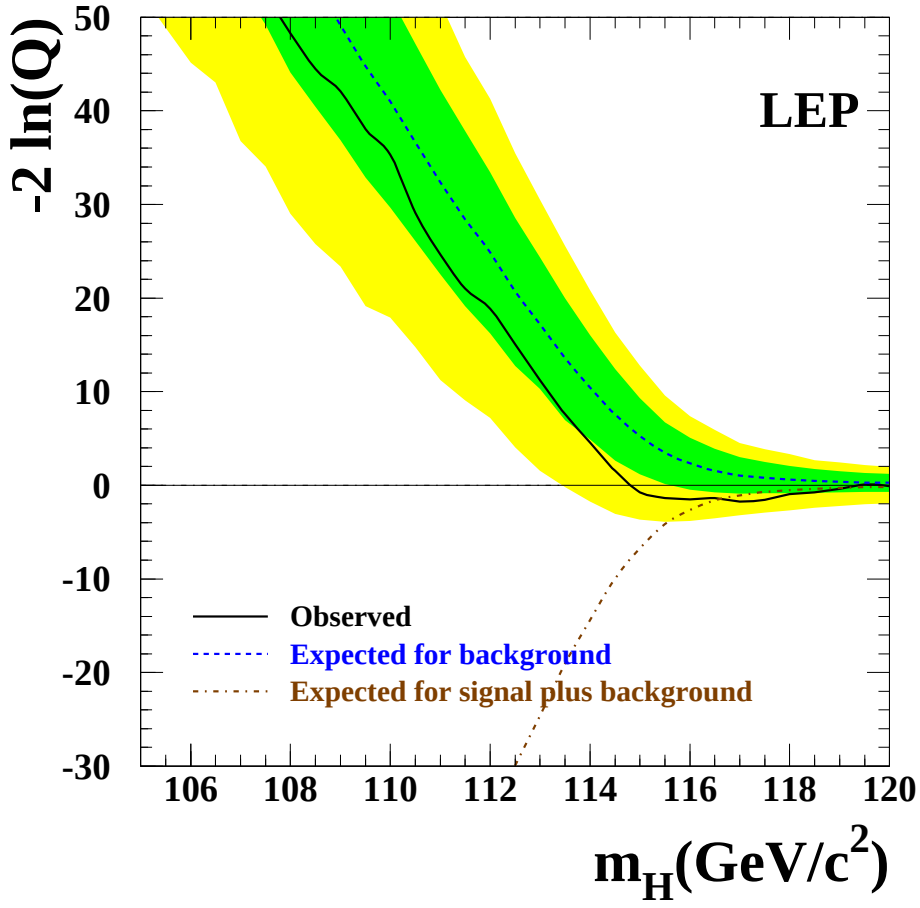
RunII Well Under Way!



- 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?

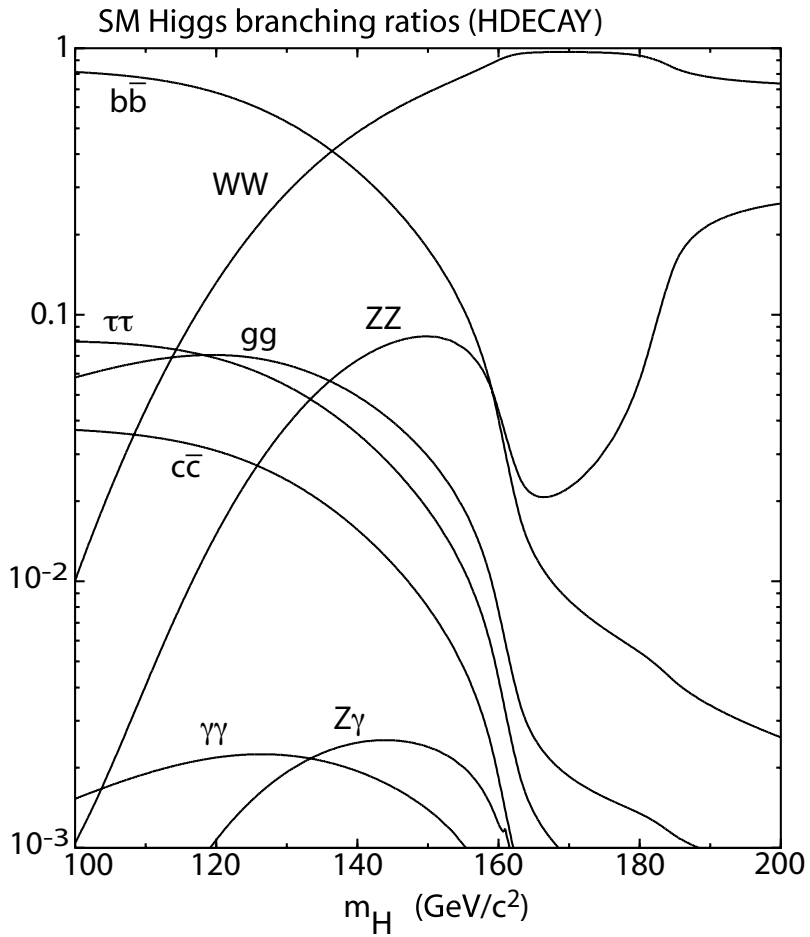
SM Higgs: Current State of Affairs

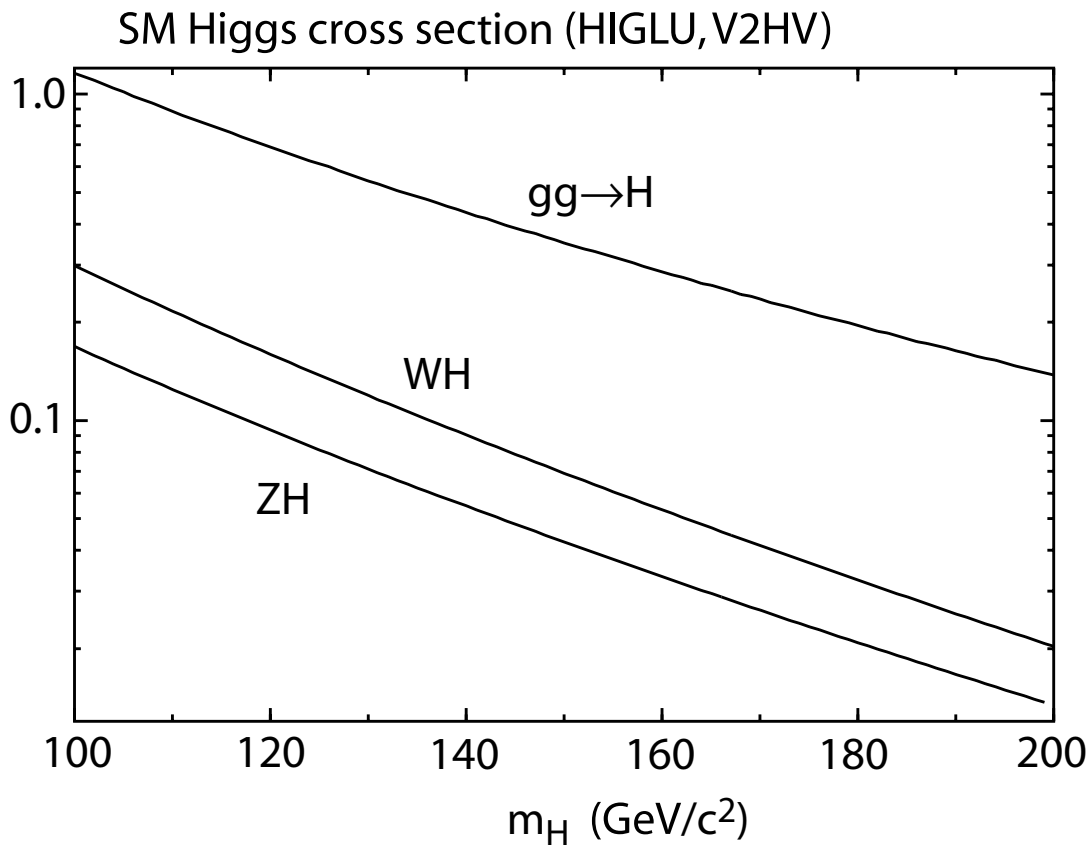




- EW Precision fits "predict"
  $m_{\mathrm{H}} < 219\ \mathrm{GeV},\ 95\%CL$
- LEP Combined search limits
  $m_{\mathrm{H}} > 115\ \mathrm{GeV},\ 95\%CL$

SM Higgs: Mission Improbable





- Most promising SM discovery modes:
  - Associated production with Z/W
  - Followed by $W \to \ell\nu$ or $\mathrm{Z} \to \nu\bar{\nu}$, with $\mathrm{H} \to \mathrm{b\bar{b}}$
- Cross sections mostly $\lesssim$ 0.3 pb! at Tevatron

SM Higgs: Reevaluated Sensitivity

- This 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: $p\bar{p} \to W + gg,\ g \to b\bar{b}/c\bar{c}$. ~ 10's pb
  - $t\bar{t}$: $p\bar{p} \to t\bar{t} \to W^+bW^-\bar{b}$. ~ 7 pb
  - Single top: $p\bar{p} \to t\bar{b} \to W^+b\bar{b}$. ~ 2 pb
  - WZ: $p\bar{p} \to WZ \to \ell\nu b\bar{b}$. ~ 3 pb.

HSC vs SHW at 115 GeV

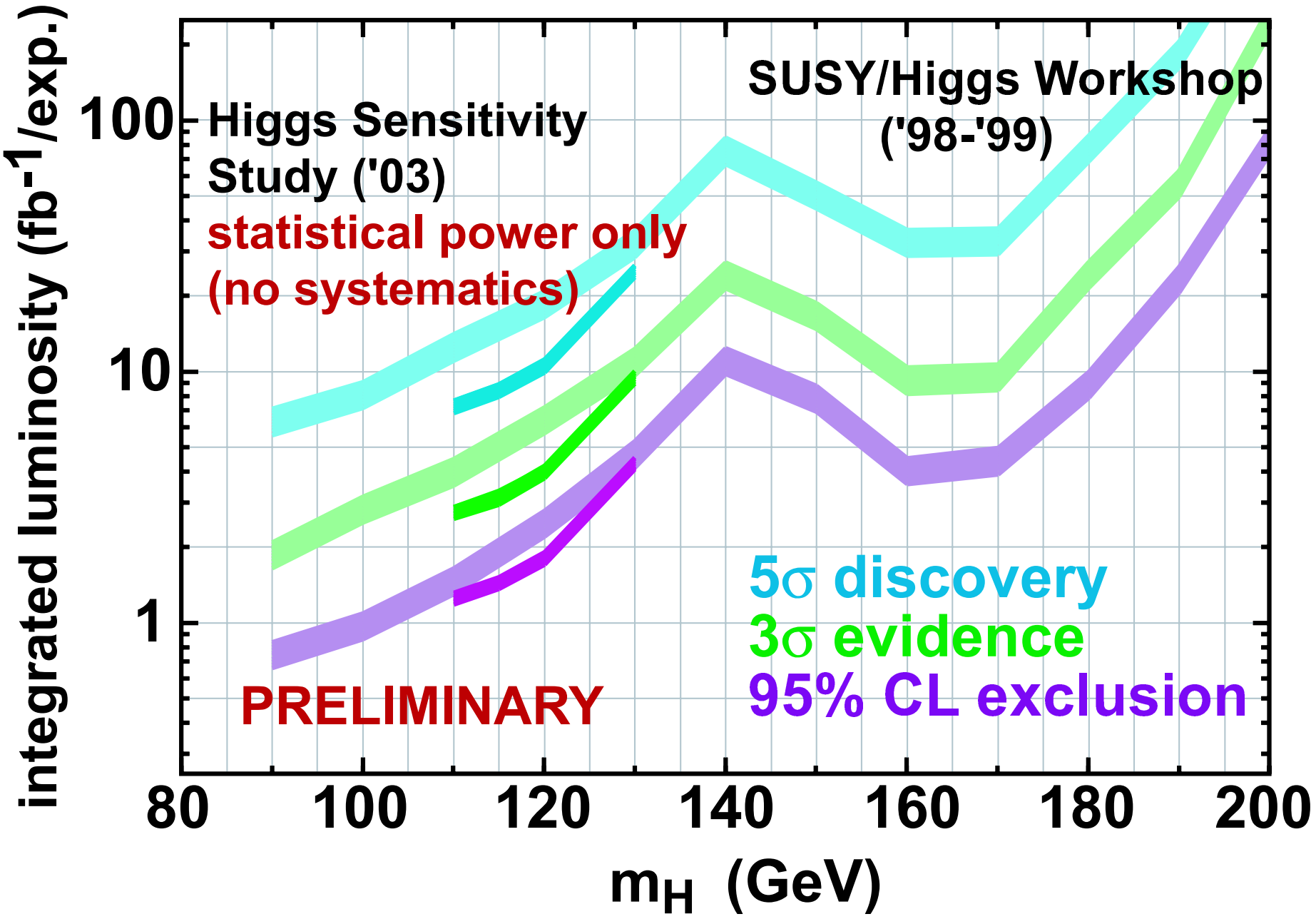
	WH ($\ell\nu bb$)		ZH ($\nu\nu bb$)	
	HSC	SHW	HSC	SHW
signal	3.7	4.6	3.5	5.5
tt	12.3	7.8	1.9	3.0
tqb/tb	6.9	5.3	1.0	5.0
Wbb/Zbb	20.9	7.7	2.9	13.8
WZ/ZZ	1.6	1.4	2.6	3.3
QCD	-	-	8.1	25.1
bkgd	42	22	16.5	50
S/$\sqrt{}$B	0.57	0.98	0.86	0.78

mass window: 100-130 GeV

- "HSC" is new estimate with current algorithms for 1 fb^{-1} per Experiment

- Will be *very challenging*

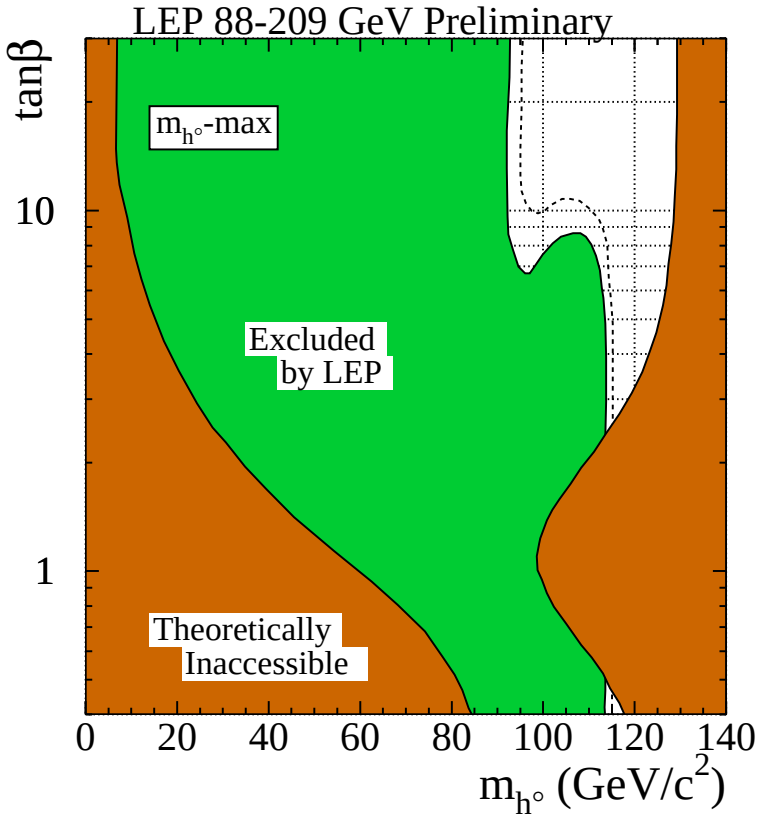
SM Higgs: Sensitivity vs Luminosity

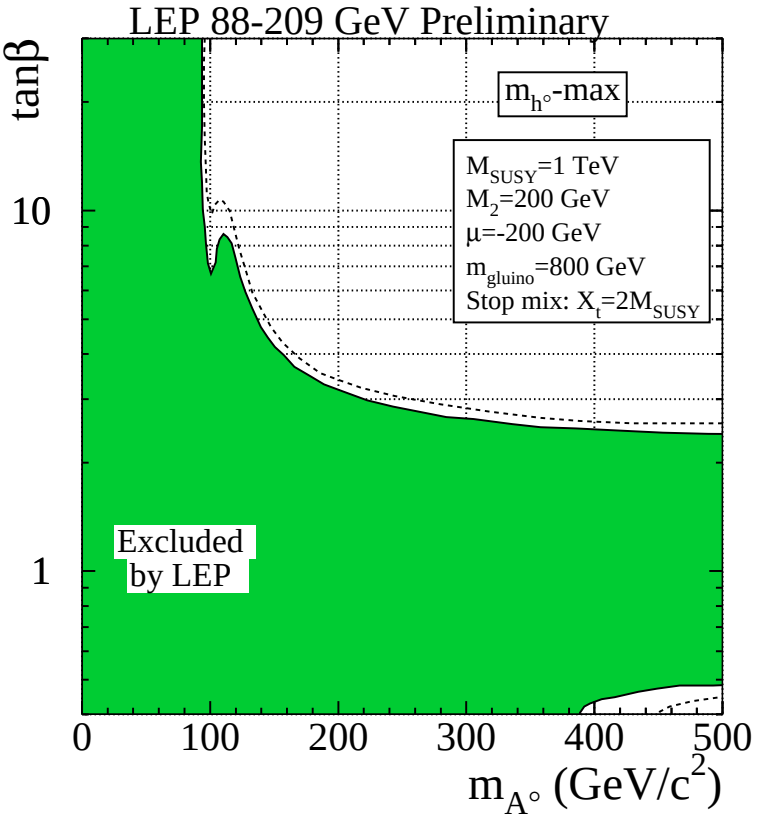


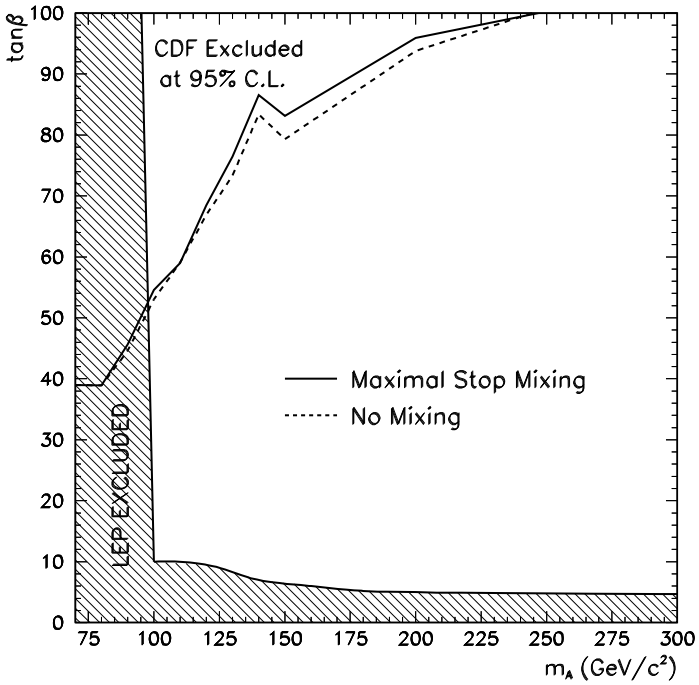
MSSM Higgs: Mission Quite Possible

- 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 Higges were generally smaller than the SM cross section
- At Tevatron, production cross section grows with $\tan\beta$

MSSM Higgs: Current State of Affairs



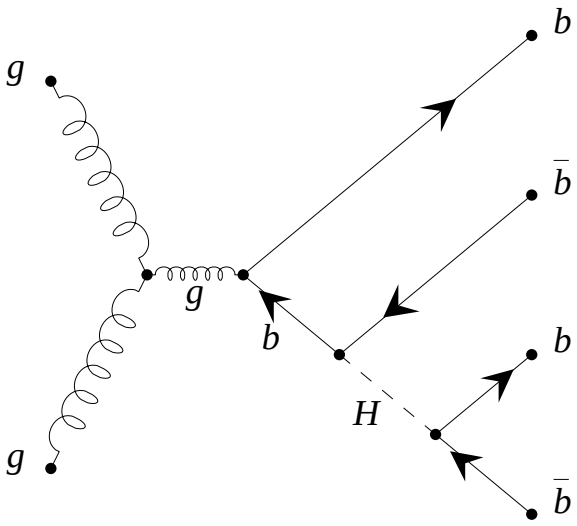




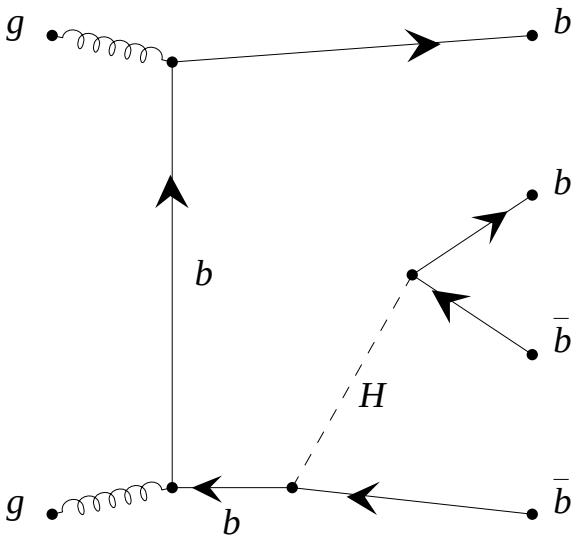
- ∼Final LEP limits:
  $m_{\mathrm{h}} > 91.0$ GeV,
  $m_{\mathrm{A}} > 91.9$ GeV at $95\% CL$
- CDF RunI limits m_{h} and m_{A} for values of $\tan\beta \gtrsim 50$

MSSM Higgs: Production Modes at Tevatron

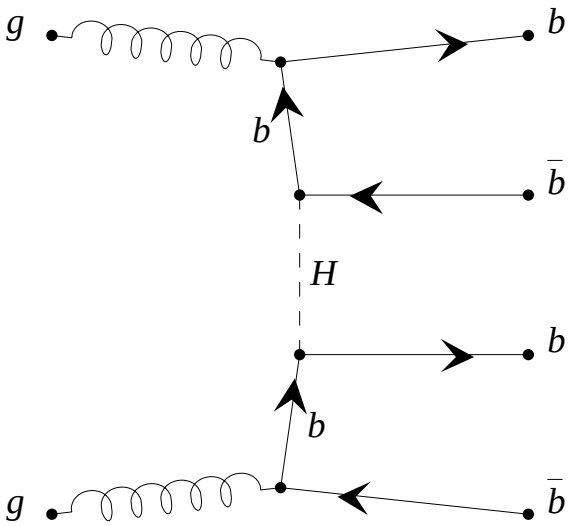
Graph 3



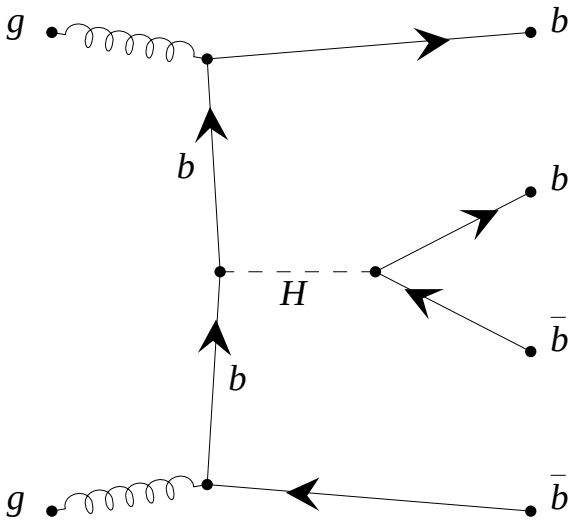
Graph 35



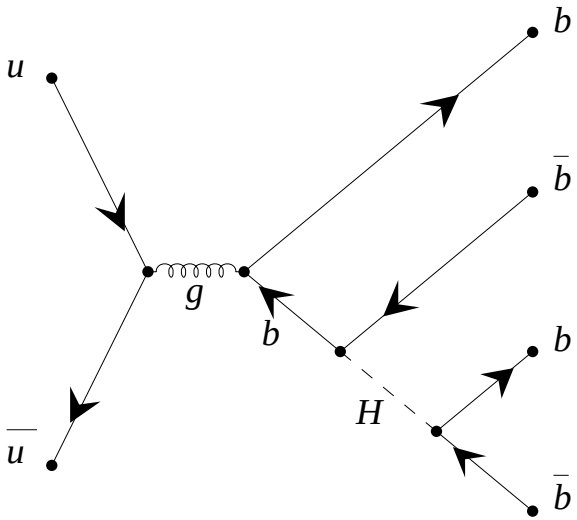
Graph 43



Graph 59

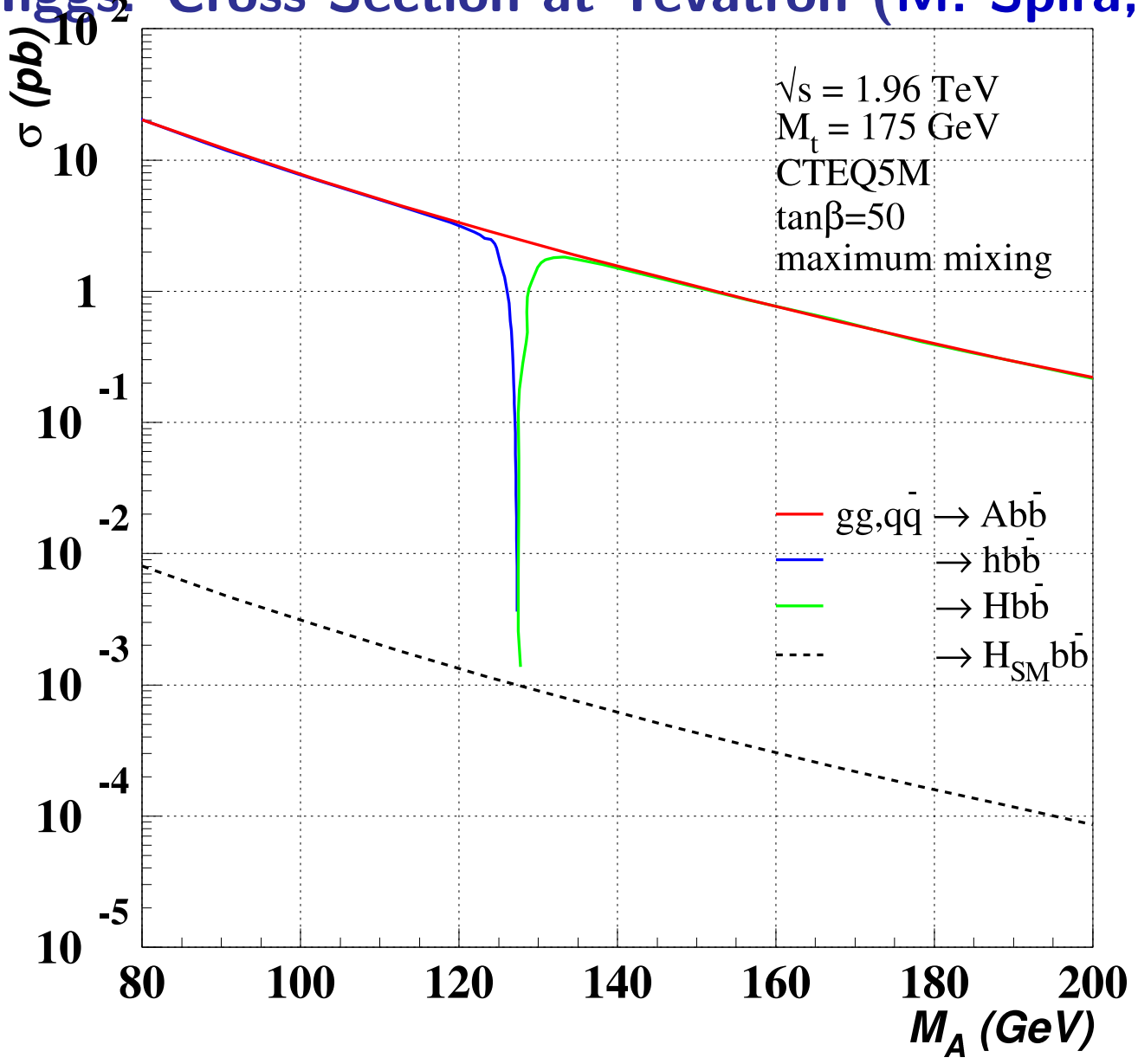


Graph 5



produced by GRACEFIG

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

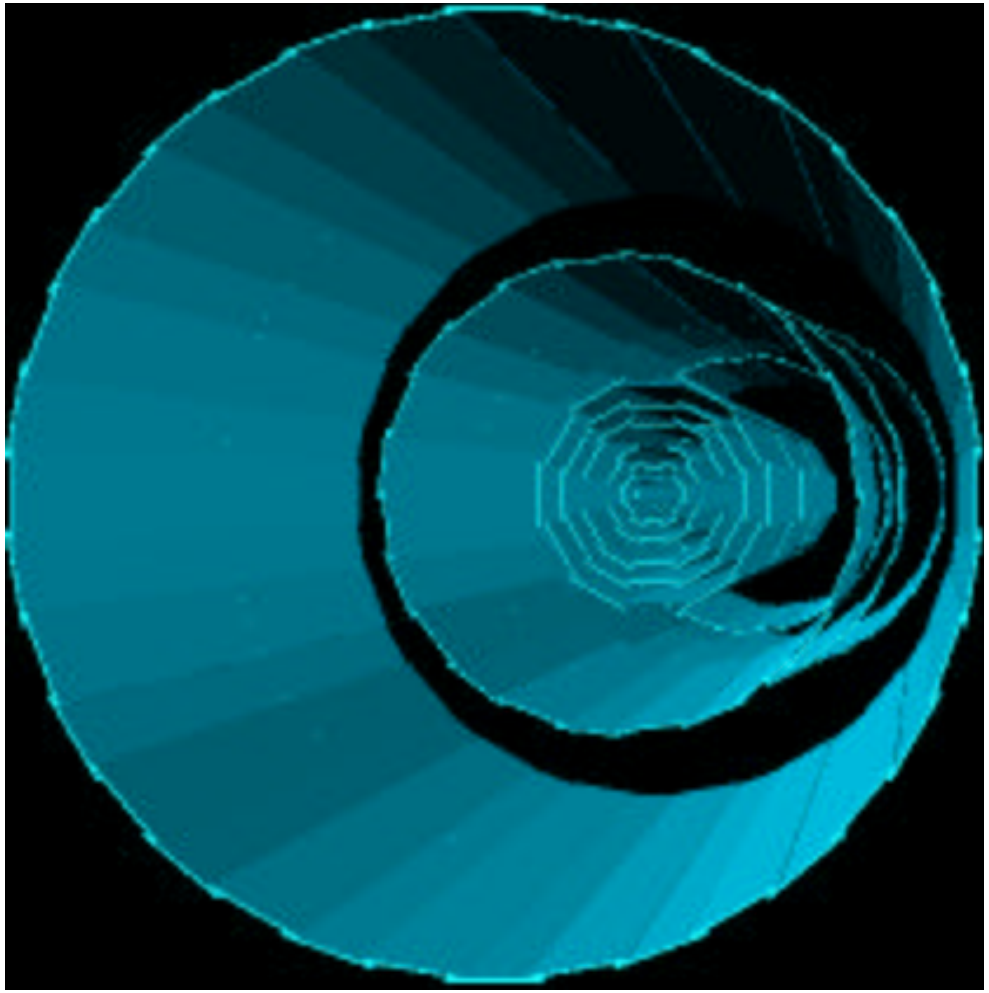


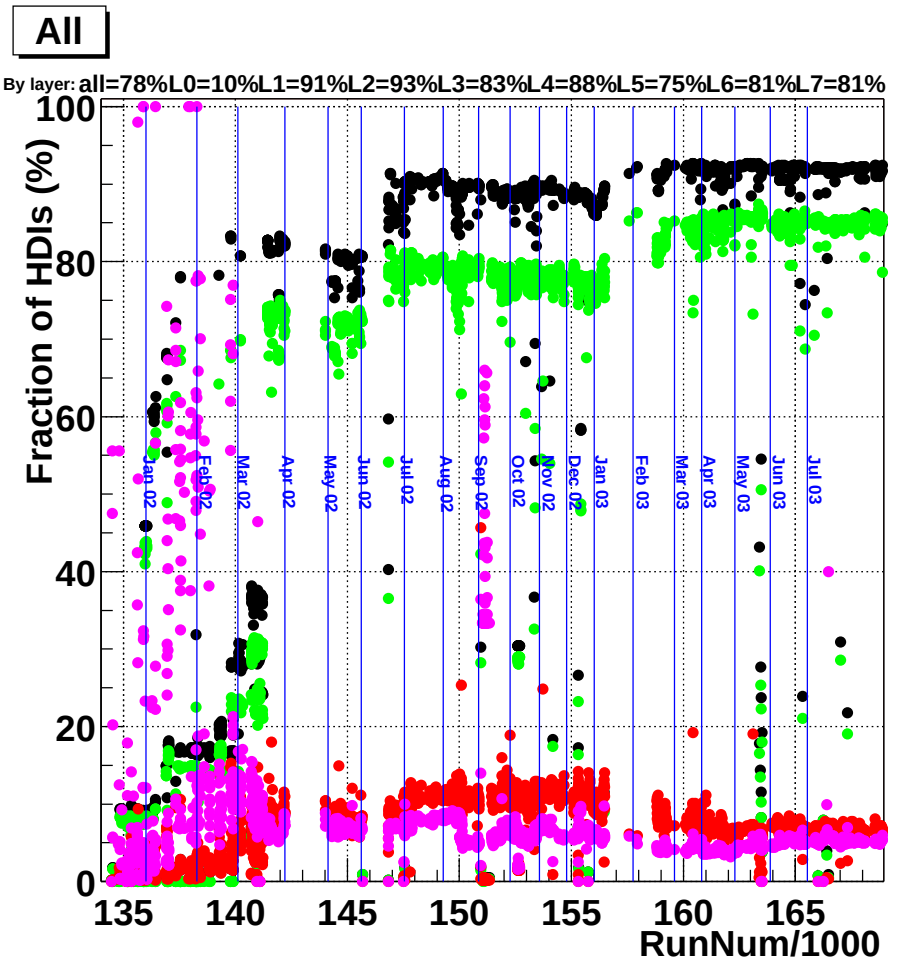
Need orders of magnitude less int. lumi for discovery compared to SM Higgs

Game On

- Due to enhancement of $\mathrm{b\bar{b}A}$ vertex of $\tan\beta$, compared to SM
- MSSM Higgs production at TeV is complimentary to LEP $\Rightarrow$ orthogonal sensitivity in $(\tan\beta, m_{\mathrm{A}})$ plane
- Branching into b's remains large: $\mathrm{A/h} \rightarrow \mathrm{b\bar{b}} \sim 85 - 90\%$, $\mathrm{A/h} \rightarrow \tau^{+}\tau^{-} \sim 8 - 10\%$
- Game is to trigger on and reconstruct multijet events containing at least 3 b-jets
- Understanding and using the silicon detector is crucial for trigger and reconstruction

Silicon Detector is Key

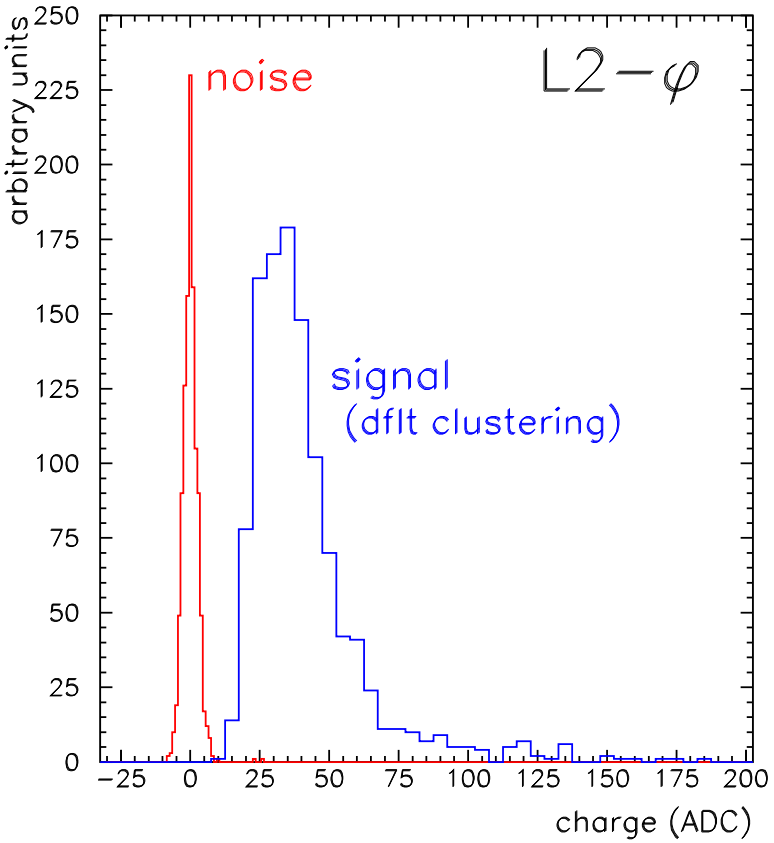


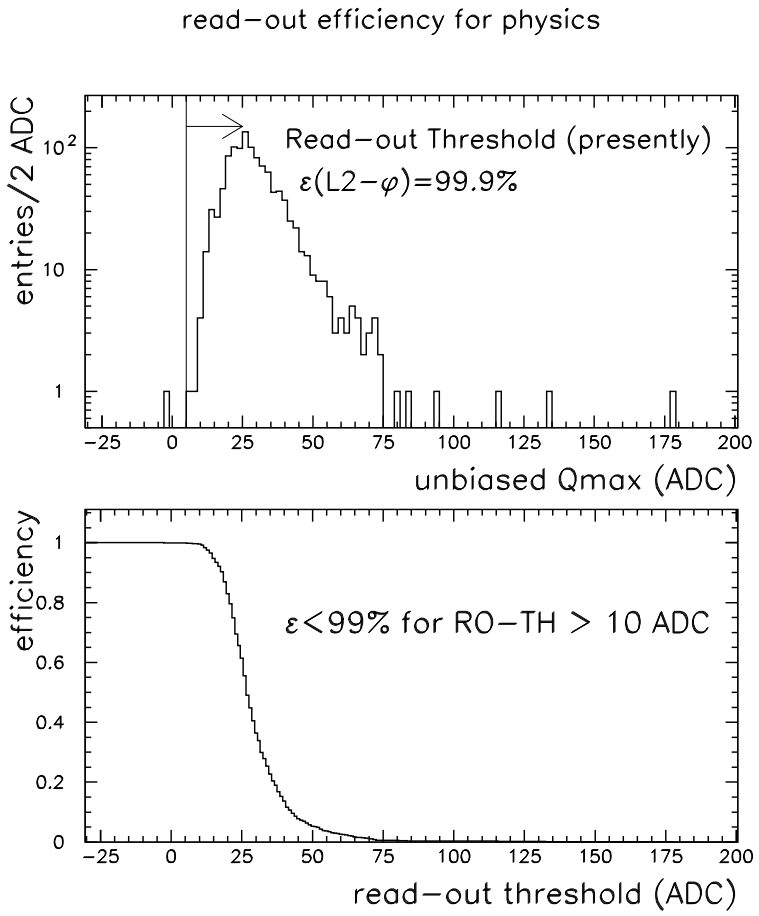


- Detector stable after commissioning period
- Coverage increased due to repairs
- 7 double sided layers (3 90°).

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

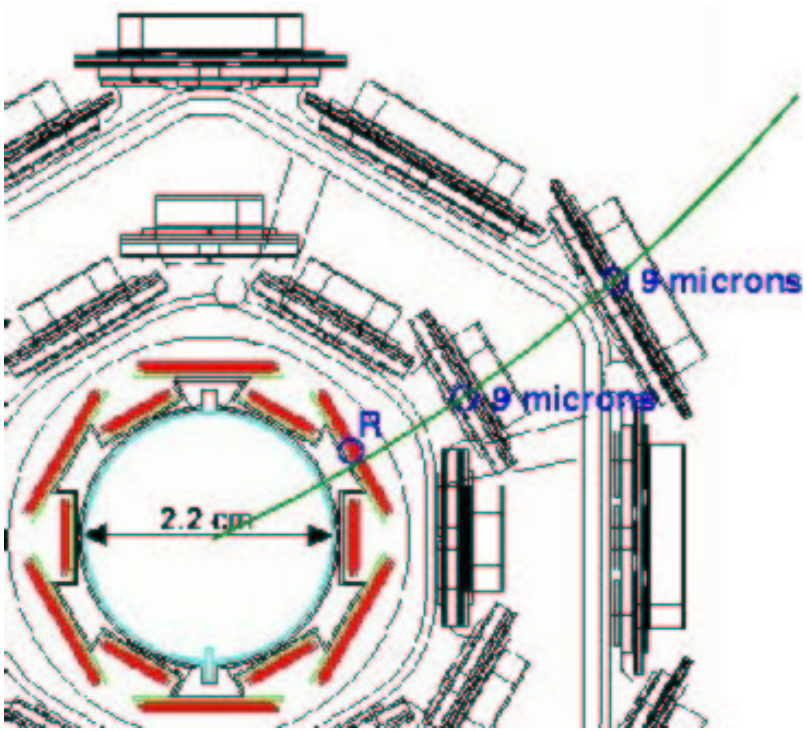
High Signal-to-Noise Device

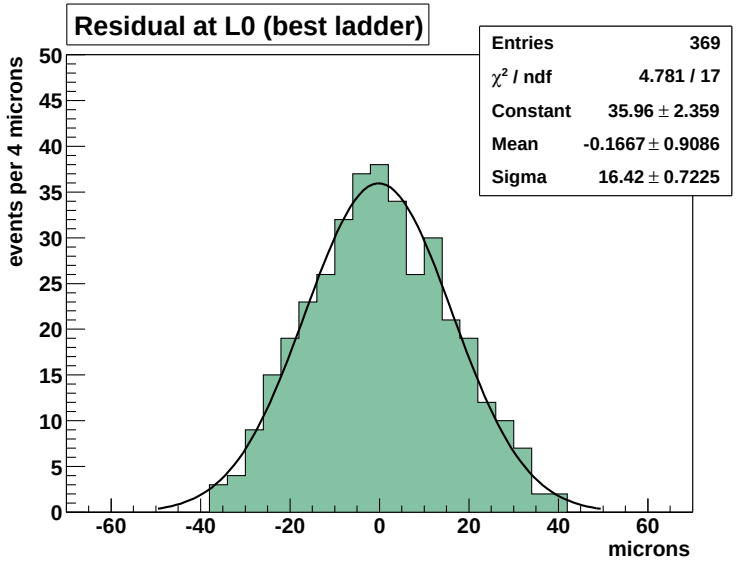




- Operation optimized for high S/N & eff
- S/N of SVX axial 12:1, stereo 10:1
- $> 99\%$ signal readout eff
- With $< 1\%$ noise occupancy

Silicon Tracking Resolution From High P_T μ

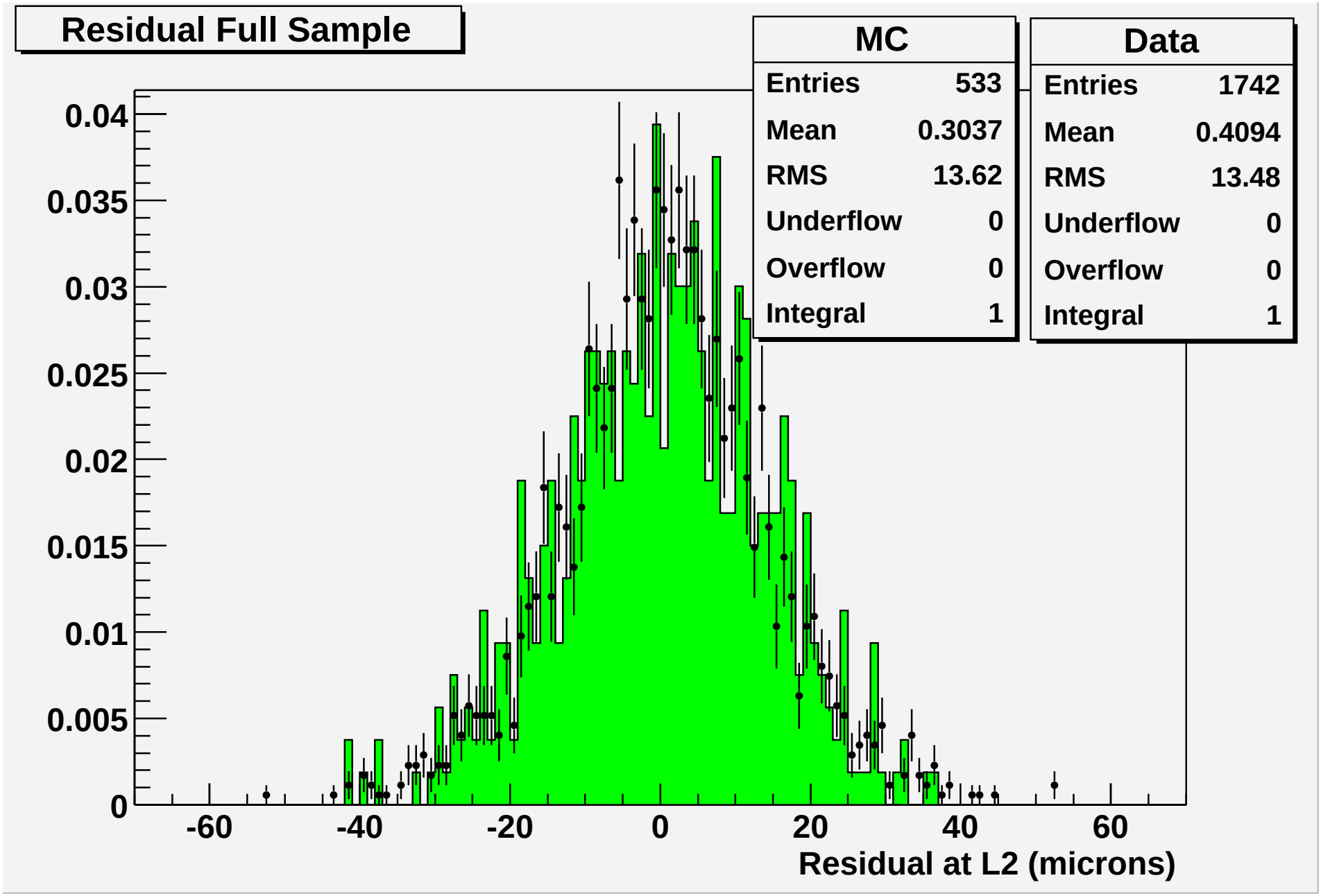




Cluster Width	Measured resolution in μm L00	SVX Axial L1-L5	SVX 90° L1,4
1 strip	18.4 ± 0.3	13.6 ± 0.3	29.5 ± 0.5
2 strips	10.1 ± 1.9	9.5 ± 0.1	23.0 ± 0.3
3 strips	17.2 ± 1.8	13.4 ± 0.2	34.3 ± 0.8
4+ strips	23.5 ± 2.8	18.7 ± 0.4	64.3 ± 1.8

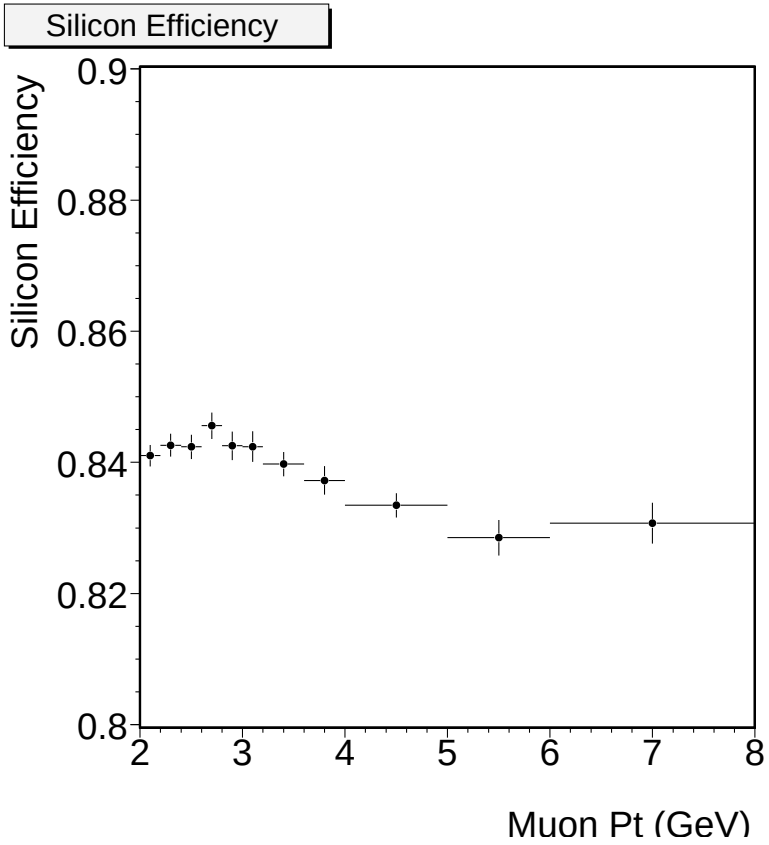
L00 resolutions are new result & will improve with alignment/study

Silicon Tracking Resolution Data vs MC

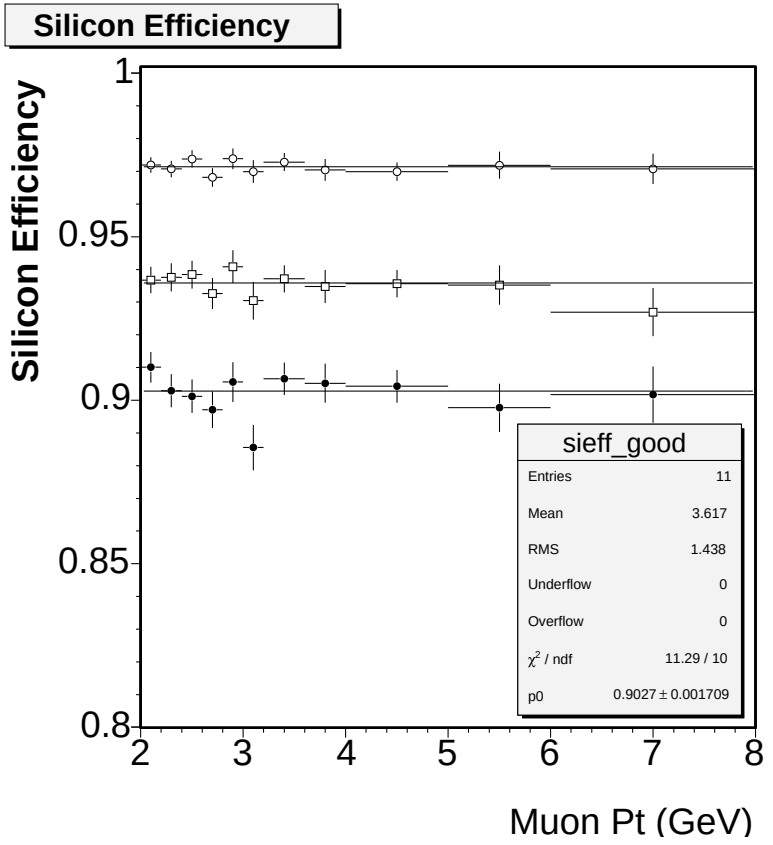


Silicon Tracking Performance

Including pre-stable-data-taking period

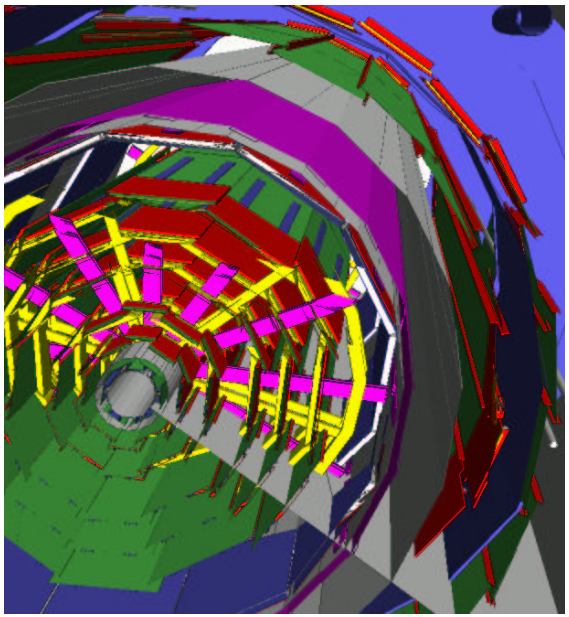


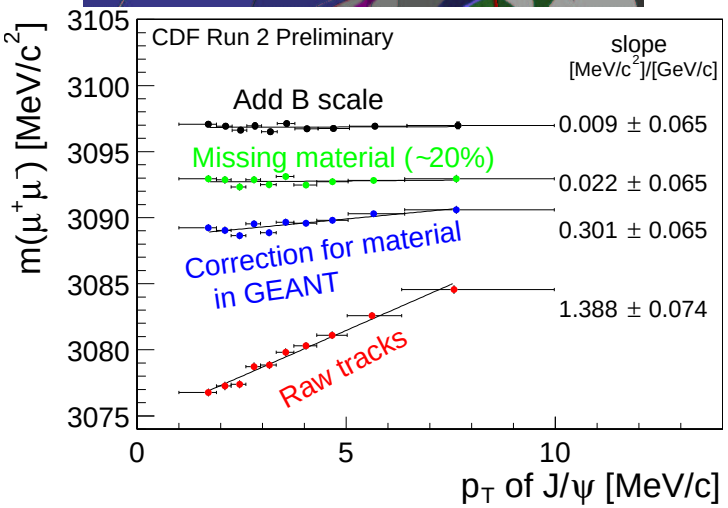
After stable-data-taking period

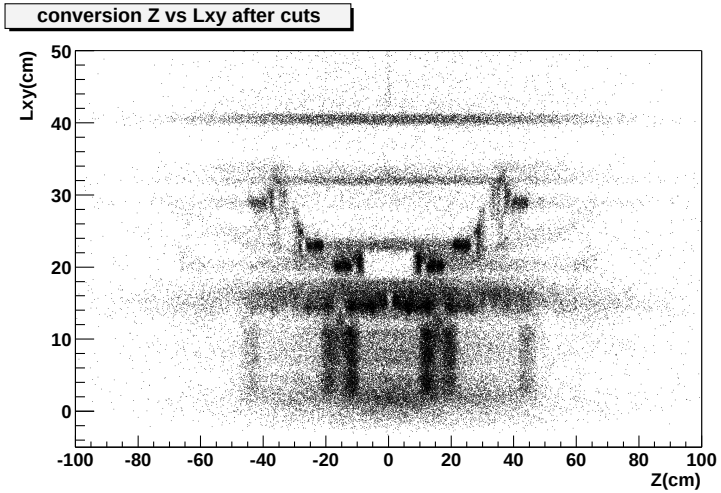


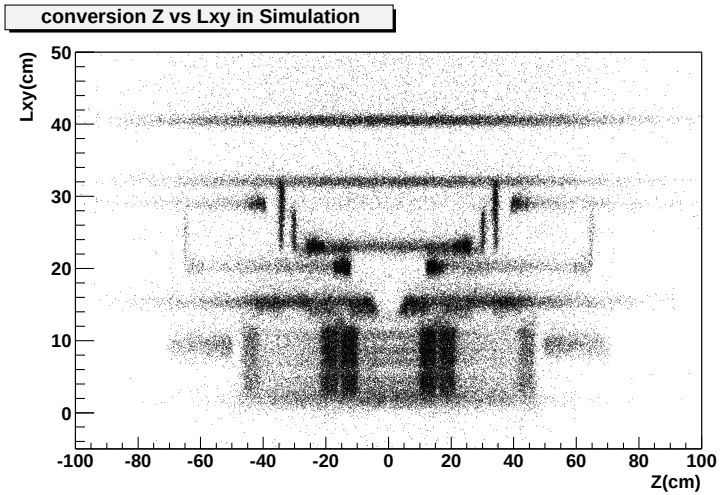
- Eff to attach $\frac{N-1}{N}$ $R\Phi$-Si hits to good COT tracks from $J/\psi \rightarrow \mu^+\mu^-$ events
- 5% dead wedges (have recovered some)
- 5% readout errors (have reduced some)
- 4% bad strips (irreducible)
- Have improved tracking/alignment

Silicon Material Map



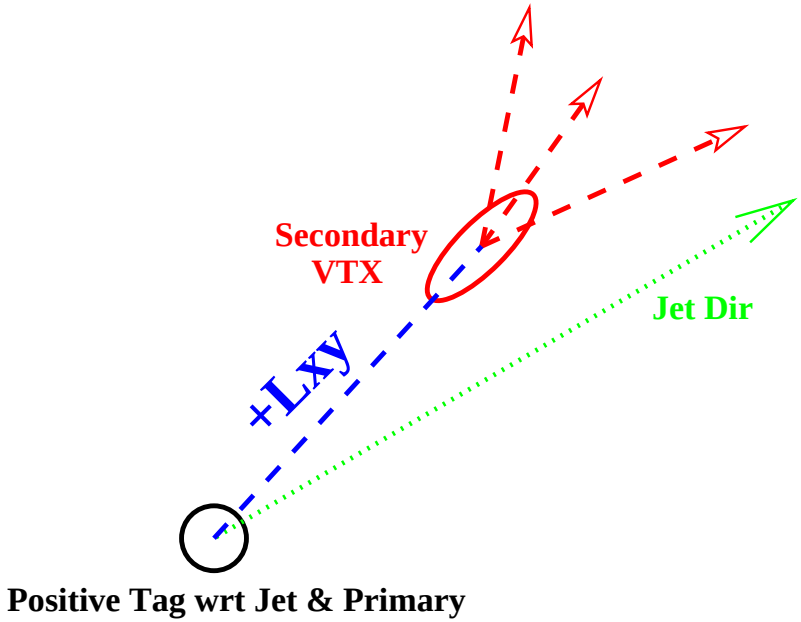


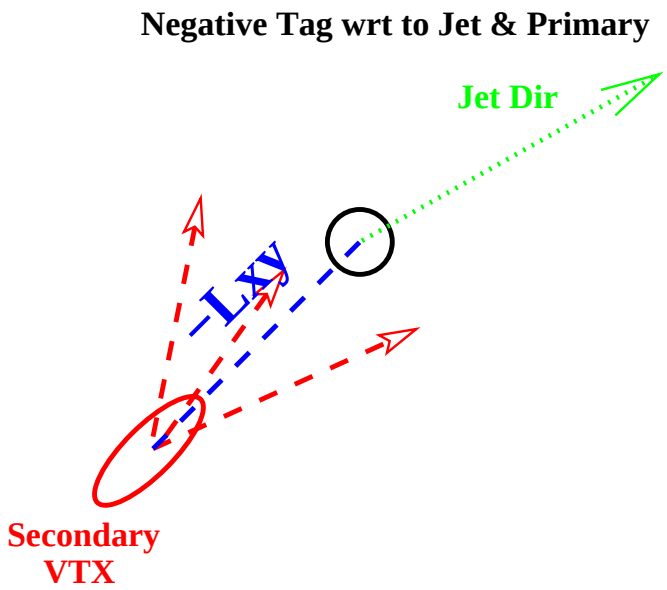




- Accounting for all material allows precise knowledge of energy loss and mass reconstruction
- Helps simulation get false lifetime from conversions correct

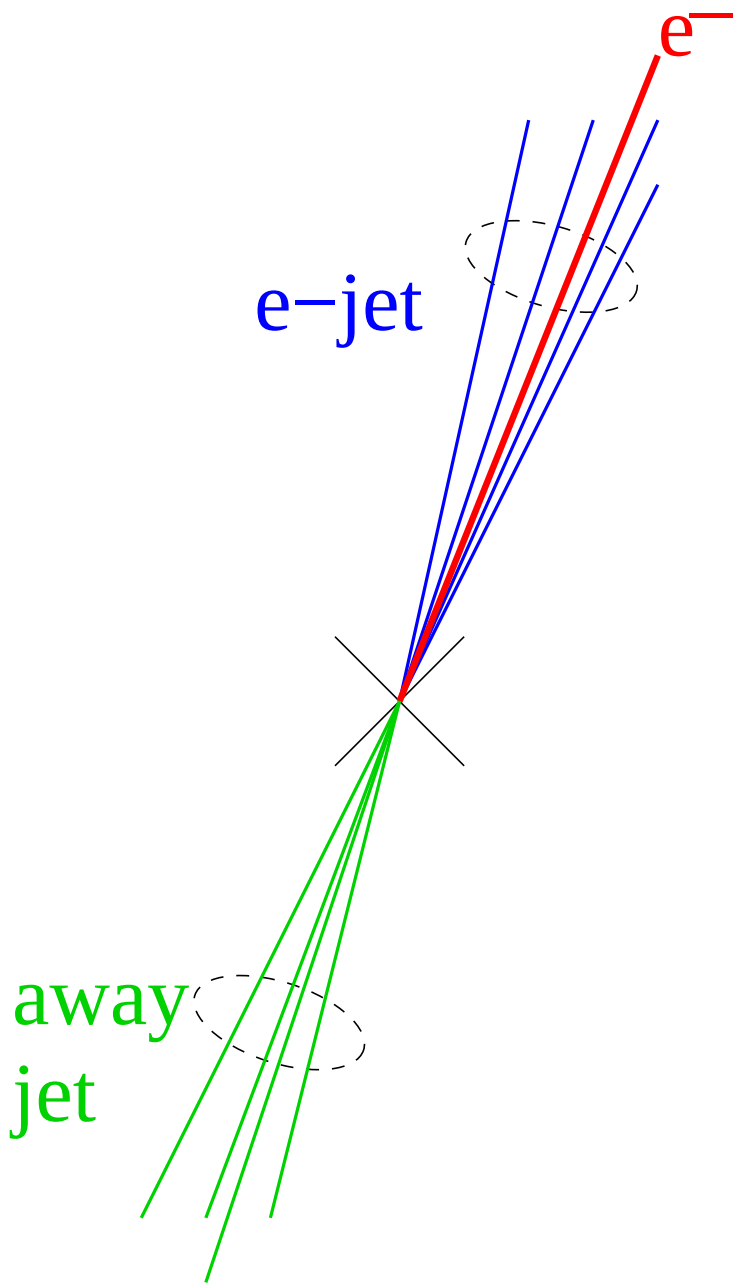
B-Tagging





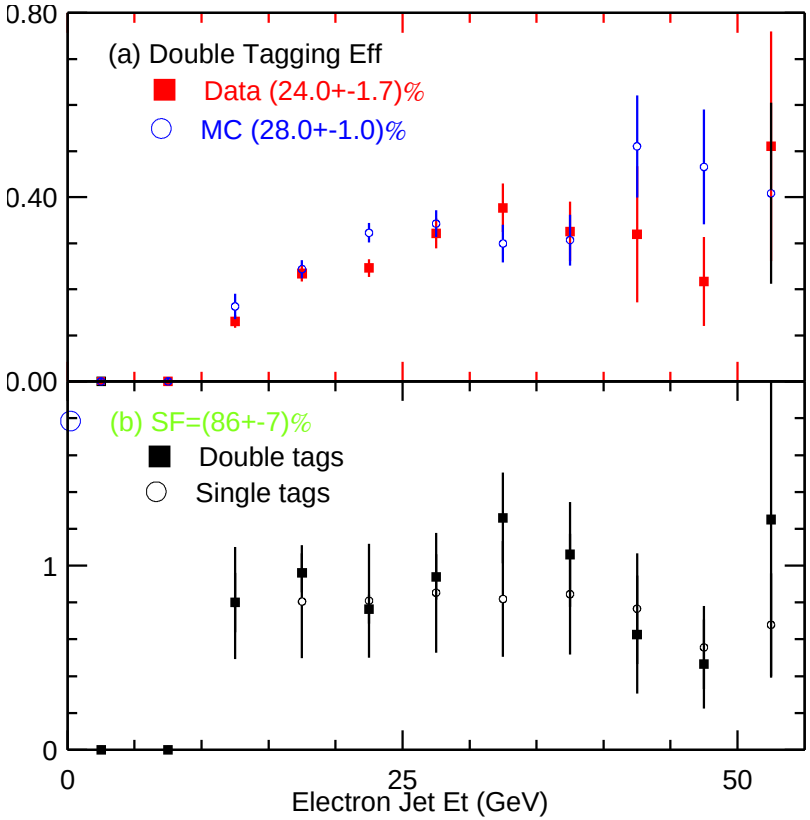
- Displaced vertexes: All combinations of at least 2 good tracks
- Jet is tagged as b-jet if $L_{xy}/\sigma_{xy} > 3$ (typical $\sigma_{xy} \sim 150\ \mu\mathrm{m}$)
- Performance/alignment/understanding of Si detectors neccessary precondition
- Measure eff and fake rate in incl lepton & generic jet data

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

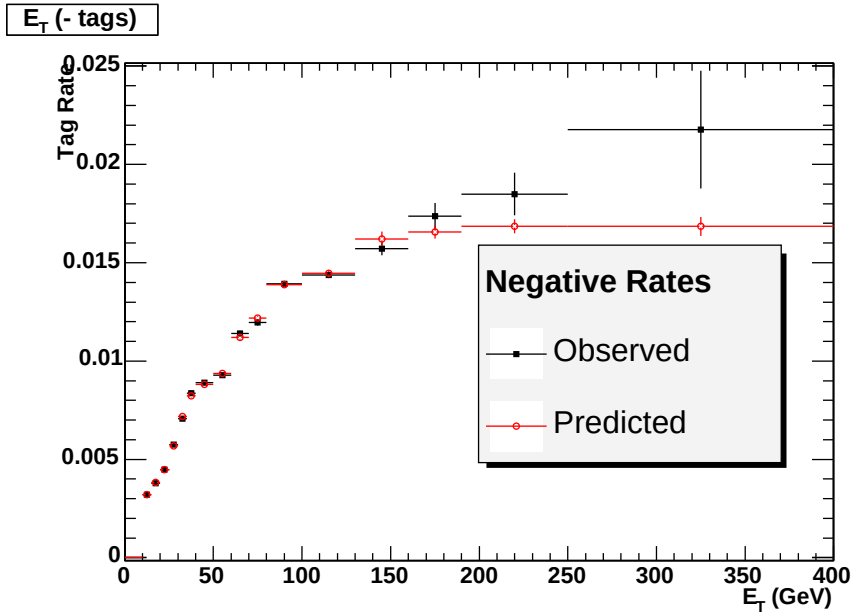


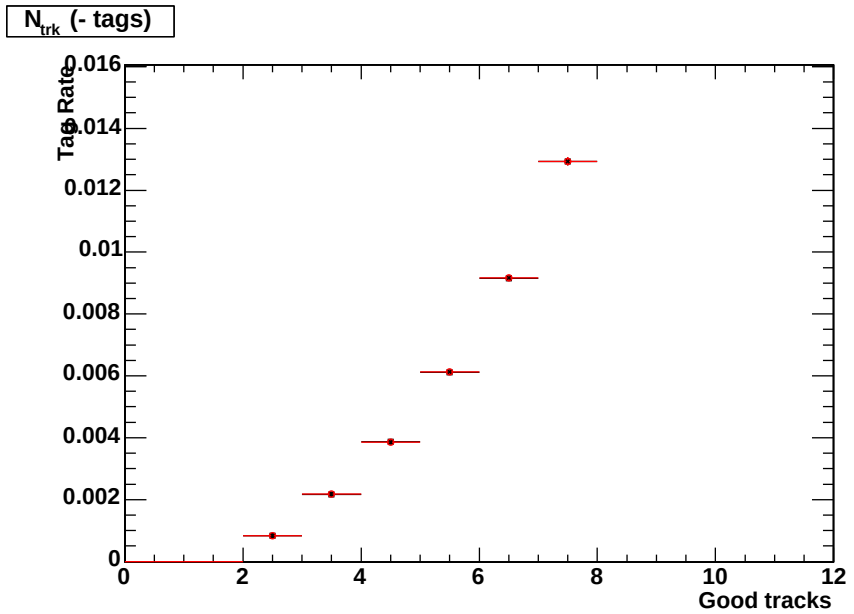
- Account for away-jets tagged but e-jet is light-flavor
- This QCD contribution measured in sample when e-jet identified as photon-conversion
- Assumes heavy flavor production in away-jet independent of e coming from conversions/fakes
- Measure conversion eff and number of fakes $\Rightarrow$ heavy flavor contribution associated with fake electrons $\Rightarrow$ $F_{\mathrm{B}}^{\mathrm{a}}$, ratio of heavy flavor in away-tagged events

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

- Relative difference between data/MC $86\% \pm 7\%$
- Eff to tag a $\mathrm{t\bar{t}}$ event $55\% \pm 1\% \pm 5\%$
- Now measure prob to tag light-flavor jet as b-jet (fake tag)

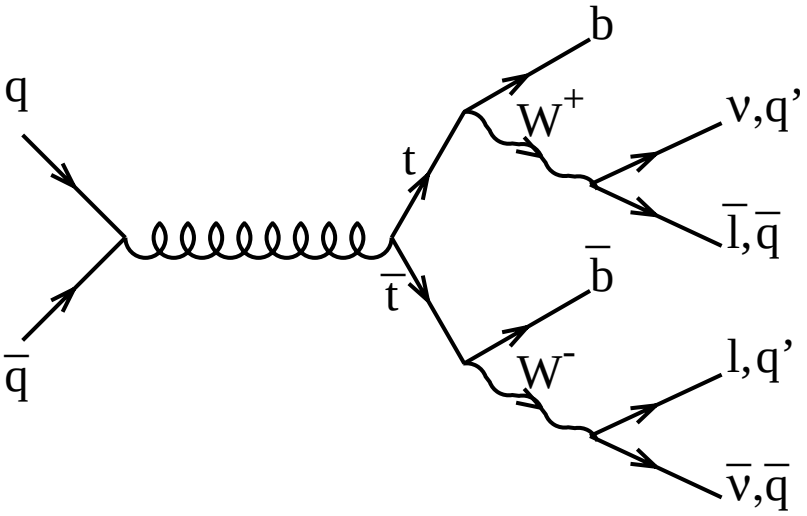
High-P_t B-Tagging: Fake Rate

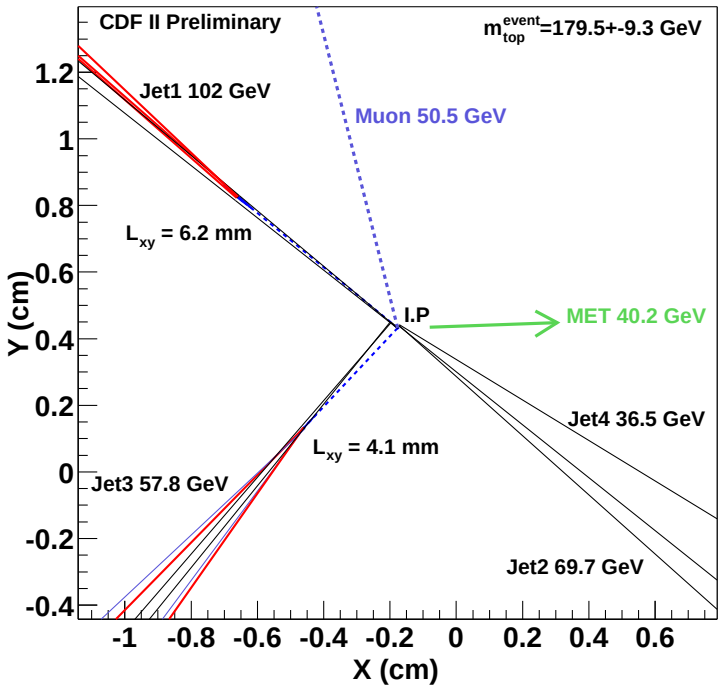




- Use negative tag rate in inclusive jet sample to determine "fake rate"
- Parameterize rate as function of 5 observables
  - E_T: Vtx method better for large E_T
  - $\sum E_T^{\text{jets}}$: Removes some sample dependence
  - $N_{\text{good}}^{\text{trk}}$: Tracking eff
  - ϕ, η: Detector coverage
- Use parameterization to predict negative tag rates in different samples
- Fake rate $1 - 1.5\%$ for top-candidates

Re-Measuring the Top Cross Section

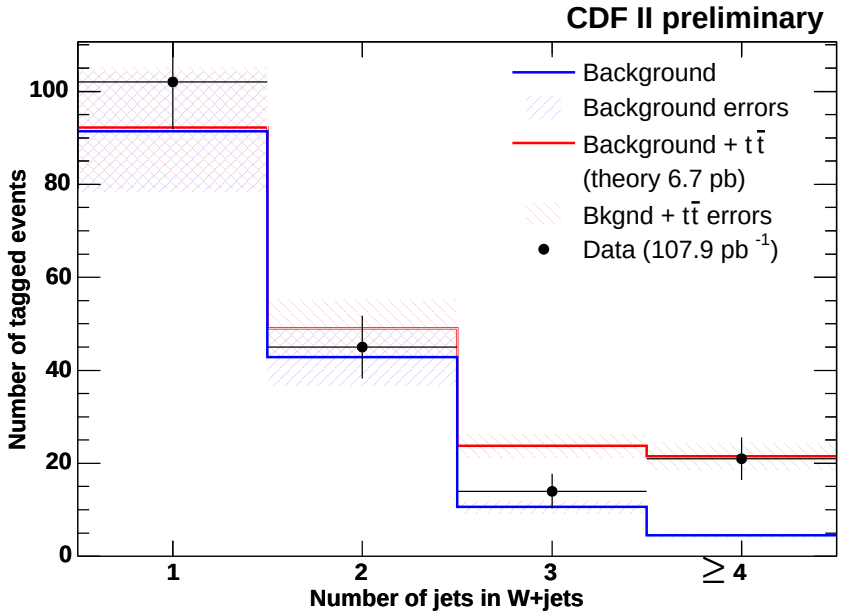




- For the purposes of the Higgs search, the top quark presents a known high P_T physical process involving b-jets
- Reestablishing the lepton+jets top cross section give us confidence that the b-tag is working

Top: Lepton+Jets Cross Section

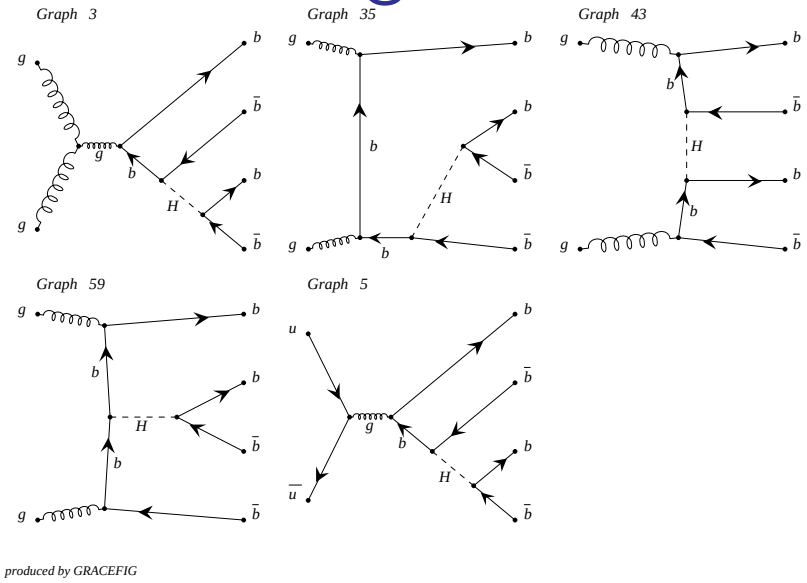
- Signature:
  - One high-P_t isolated lepton
  - Veto Z's, cosmics, conversions
  - Large missing E_t
  - At least 3 high E_t jets
  - At least 1 b-tag
- B-tag improves S/B from $1/6$ to $3/1$



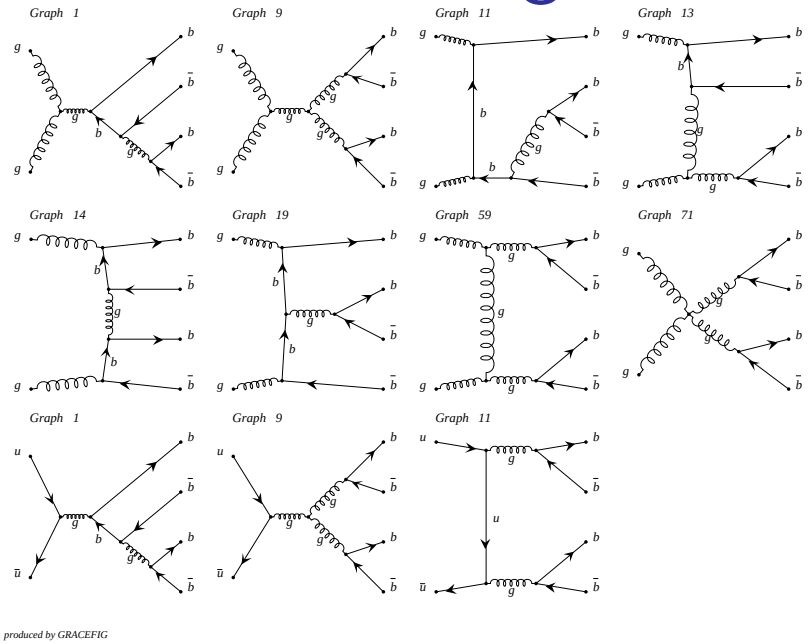
- Find 35 candidate events in 107.9 pb^{-1}
- Expect 15.1 ± 2.0 bkg events
- $\sigma_{t\bar{t}} = 4.5 \pm 1.4(\mathrm{stat}) \pm 0.8(\mathrm{syst})\mathrm{pb}$
- $\sigma_{t\bar{t}}(\mathrm{NLO}) = 6.7^{+0.71}_{-0.88}$ pb (Mangano et al)

Triggering on 4b Events with CAL+SVT

Signal

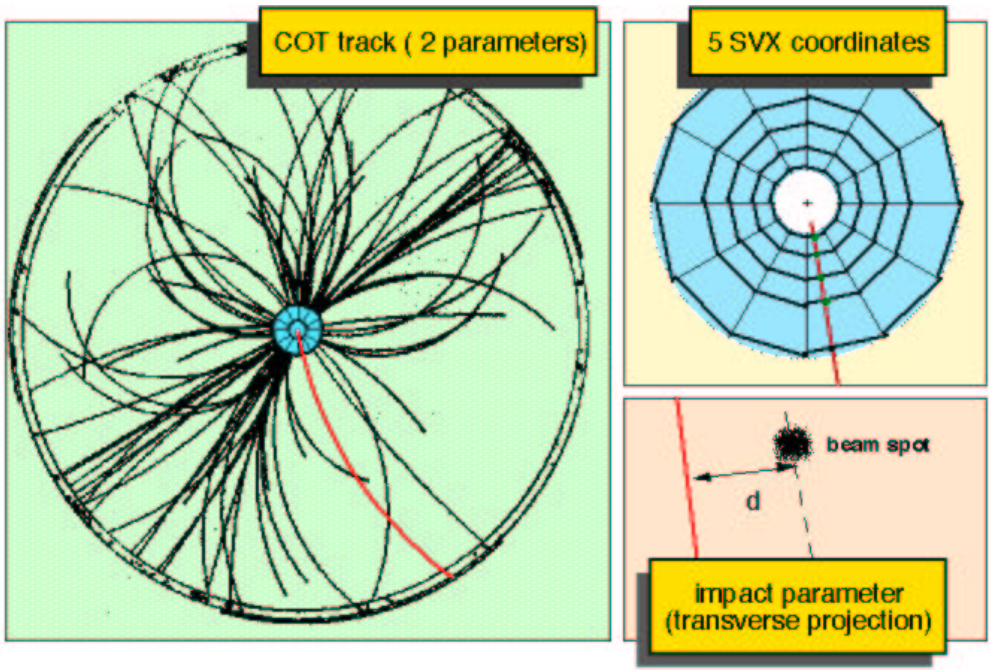


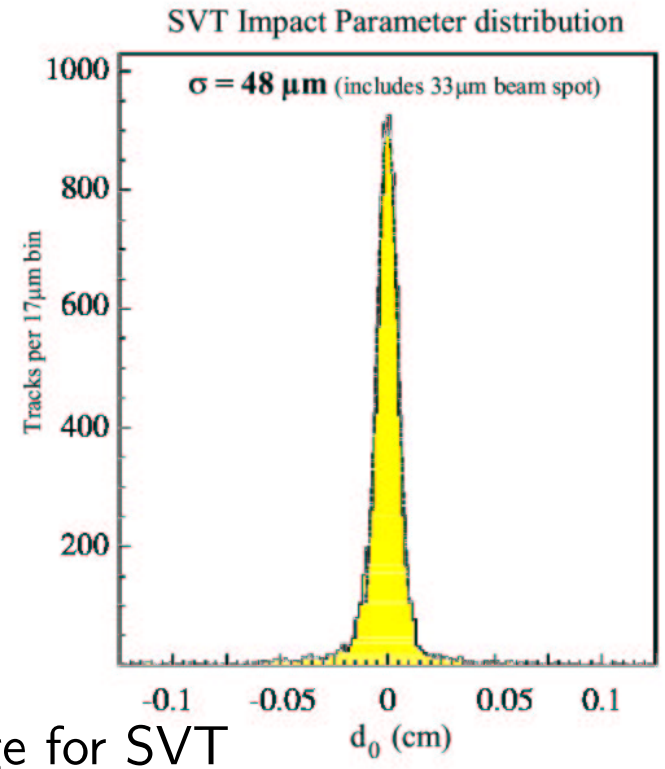
QCD 4b Background



- 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





- Hardware improvements to SVX $\Rightarrow$ 97.2% coverage for SVT
- Dynamically chooses which 4 out of 5 layers to use
- IP resolution $= 35\ \mu\mathrm{m} \oplus 33\ \mu\mathrm{m}(\mathrm{beam})$
- System is ~deadtimeless: $25\mu\mathrm{sec/event}$ for silicon readout, clustering, track fitting
- 70% eff for $4/4$, 80% eff for $4/5$

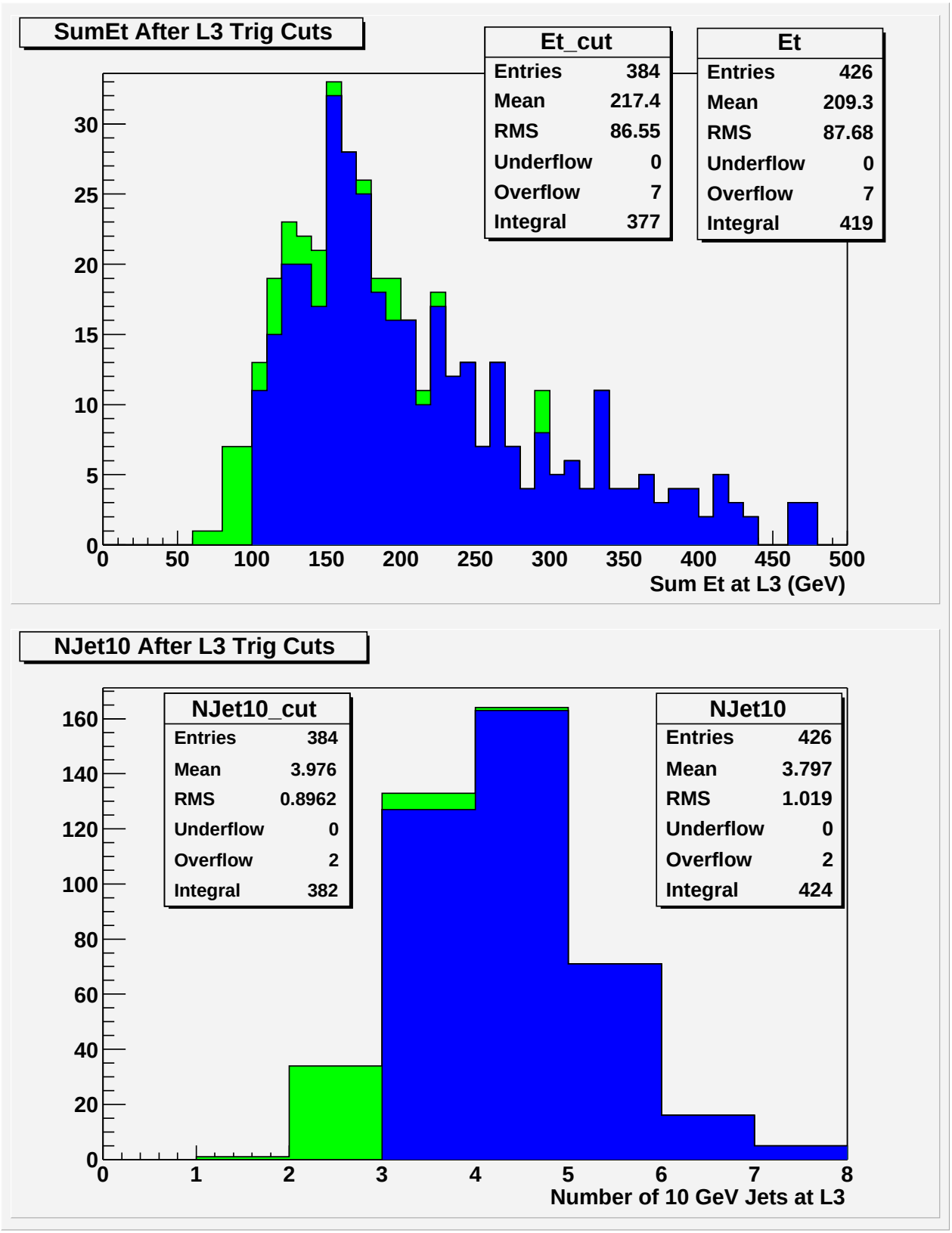
3-Level Higgs Trigger

- 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 $25\ \mu\mathrm{m} < d_0 < 1\ \mathrm{mm}$, $\chi^2 < 25$ and $P_t > 2\ \mathrm{GeV}$ 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 $E_t > 100\ \mathrm{GeV}$
- 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.
- RunI trigger used for MSSM Higgs was 0.2% efficient on signal!

Beginning Studies with MC and Blinded Data

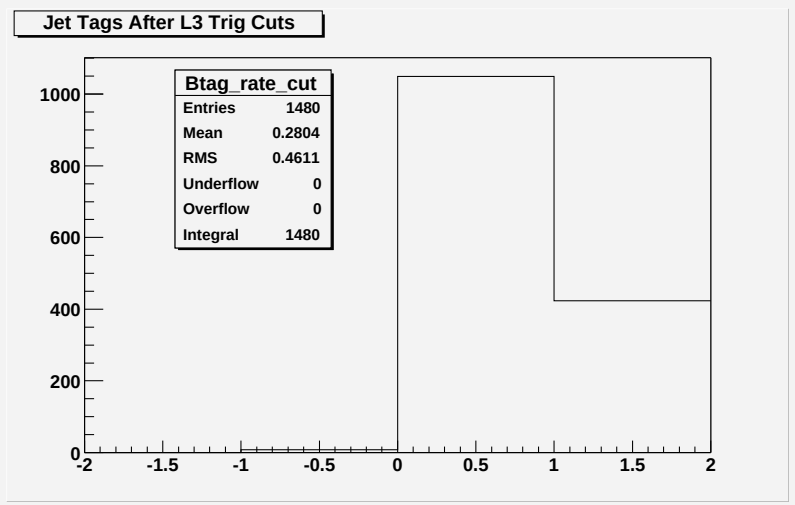
- We've begun MC-level studies of 4b signals in m_{A} range 90 GeV to 130 GeV
- Using background dominated data to study fake tags
- Currently a blinded analysis, but we've made a first estimate of expected signal and background rates
- They compare well to previous study (J. Valls) of expected rates $\Rightarrow$ Use as baseline for expected sensitivity
- Everything is very preliminary

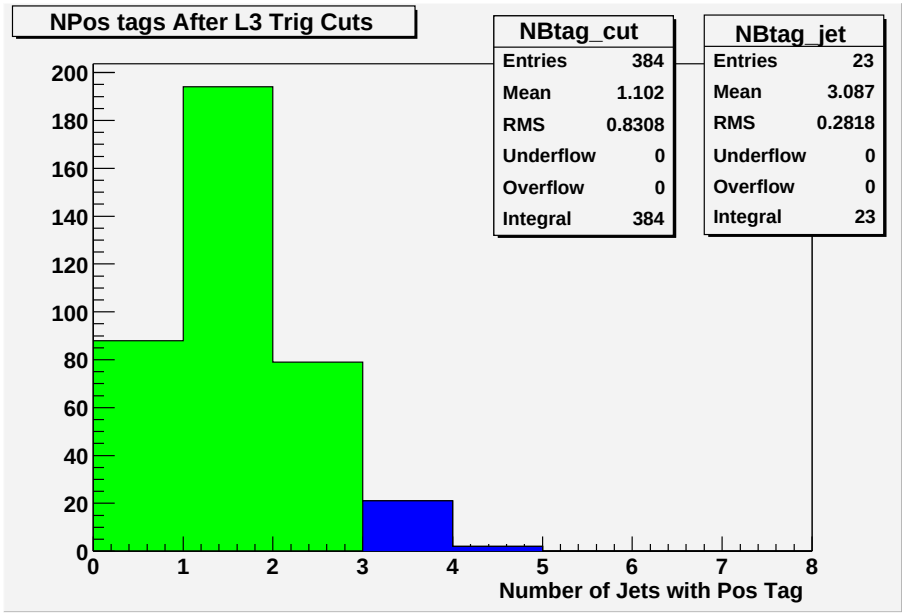
Trigger Efficiency on Signal



$\sim 35\%$ eff on 90 GeV signal

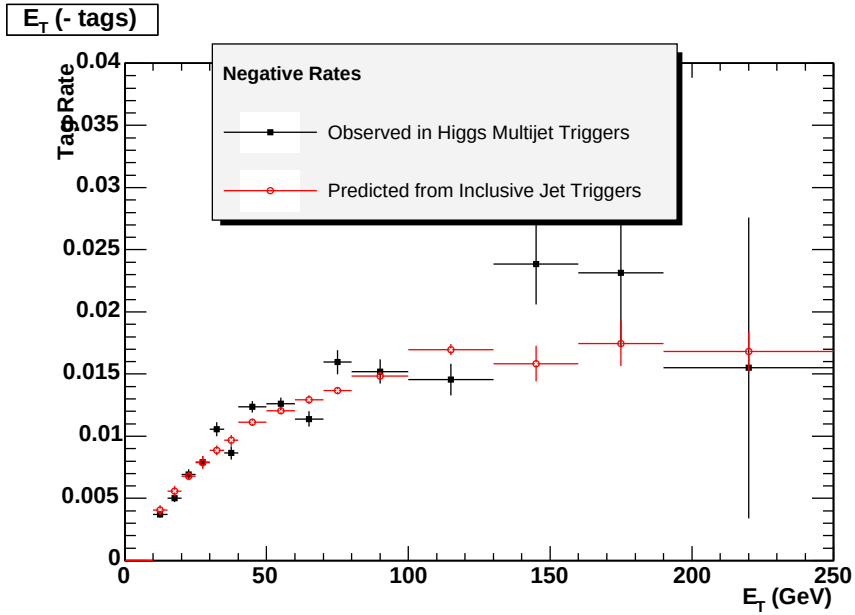
Estimated Efficiencies on Signal

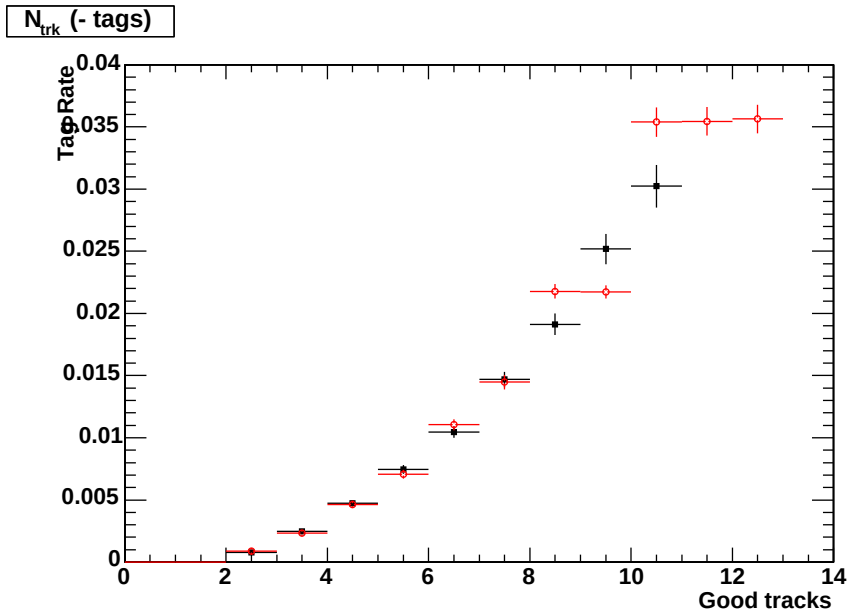




Requirement	90 GeV	120 GeV
Passes L1&L2&L3	8%	10%
3 offline b-tags	5.7%	5.7%
Total eff	0.45%	0.57%
RunII study	0.42%	0.52%

Fake Double-Tag Rate Prediction in Data





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

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

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

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

  - Light-heavy $\mathrm{Neg} = \epsilon$, $\mathrm{Pos} = \eta$:

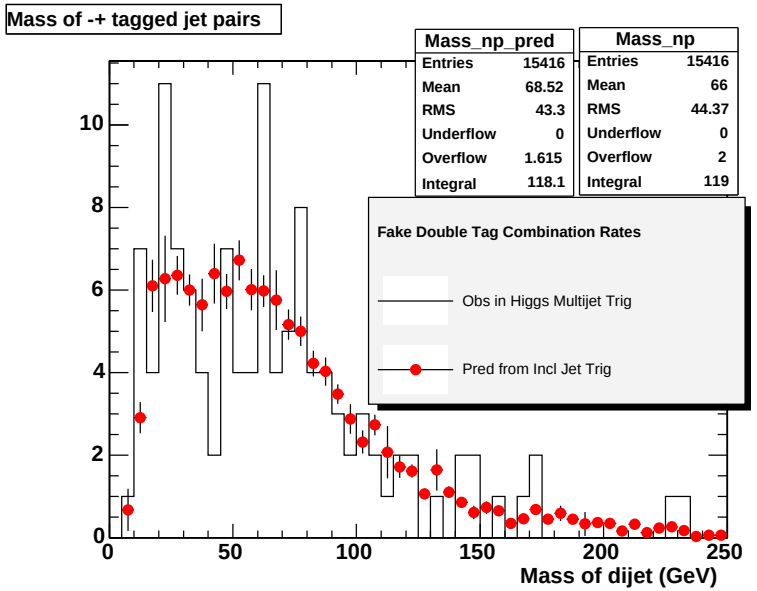
$$P_{--} = \epsilon\eta$$

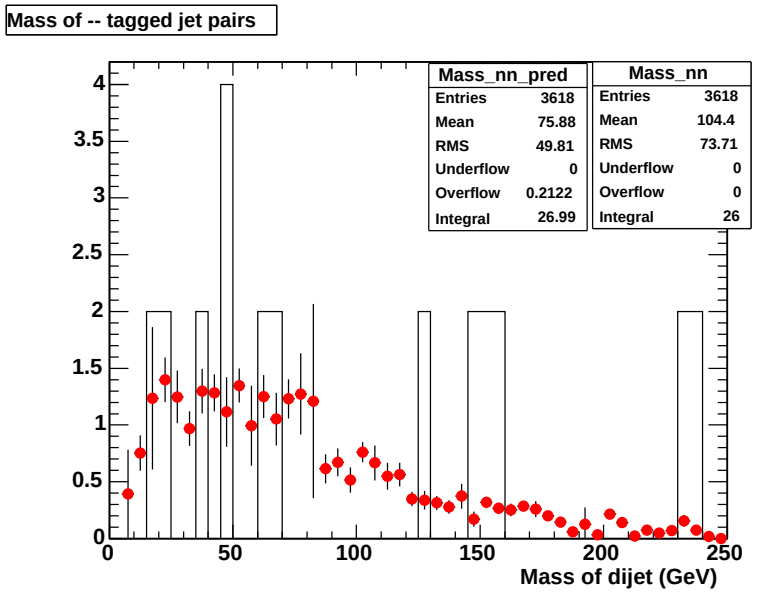
$$P_{+-} = 2\epsilon\eta$$

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

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

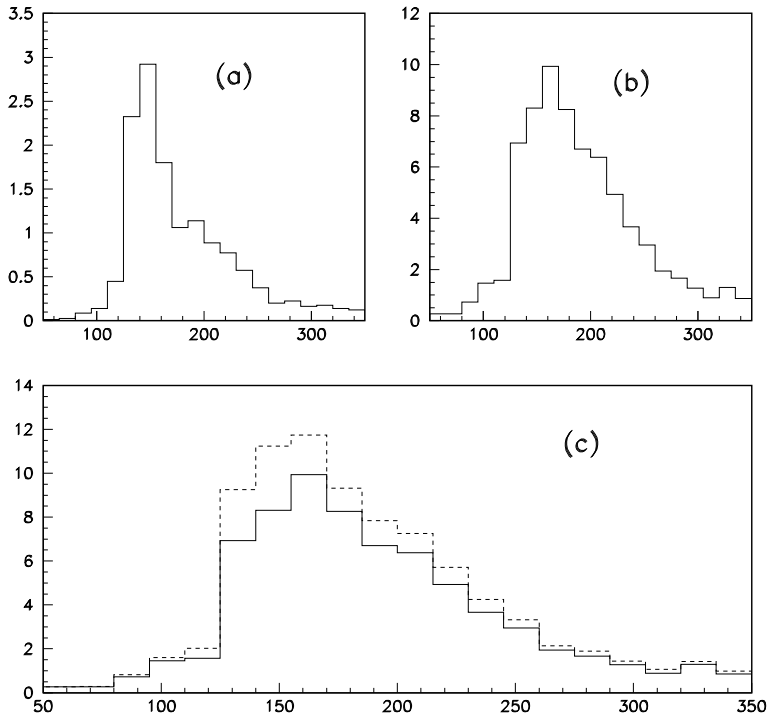
Fake Double Tags in HIGGS_MULTI_JET 8 pb^{-1} Data





- 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

Use Results of Analysis of 4b Events from RunII Study

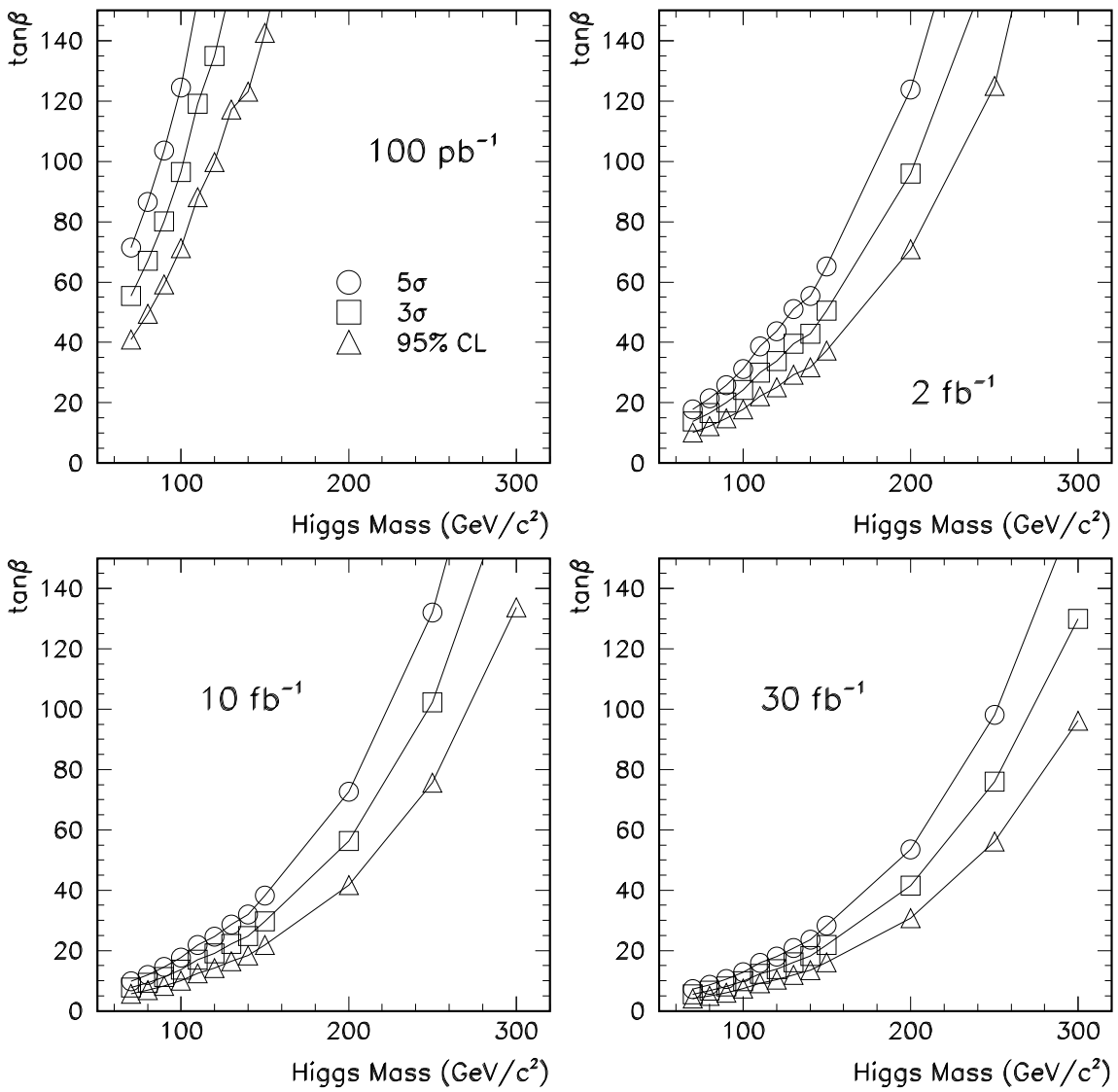


- After the trigger, require triple b-tag
- Reconstruct double-tagged dijet mass: $\sim 15\%$ resolution on signal
- Very little difference between signal and bkg in dijet spectrum, essentially a counting experiment
- (c) signal+bkg for $m_{\mathrm{A}} = 130$, $\tan\beta = 40$ for 1 fb^{-1}

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

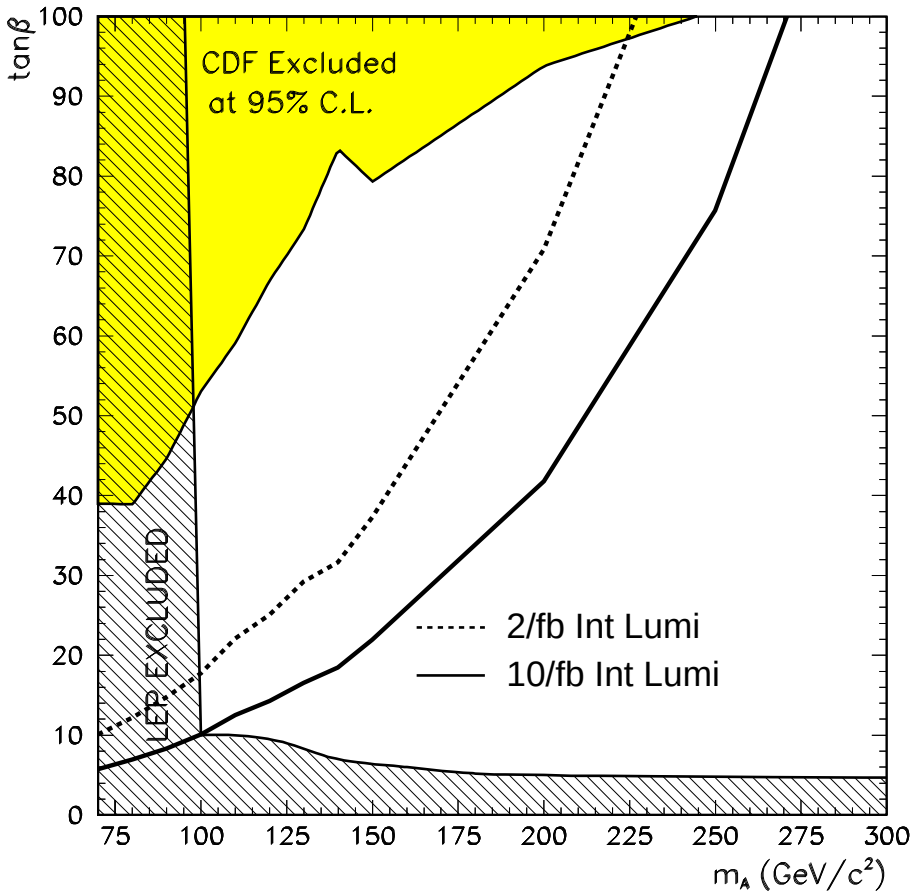
m_{A} GeV	signal at $\tan\beta = 40$	$\mathrm{QCD}_{\mathrm{heavy}}$	$\mathrm{QCD}_{\mathrm{fakes}}$	top	other	total
90	62.4 ± 1.5	56 ± 12	12 ± 10	13.4 ± 3.4	6.6 ± 1.7	88 ± 16
120	19.1 ± 0.5	48 ± 11	7 ± 5	12.6 ± 4.4	5.0 ± 1.4	73 ± 13

Outlook

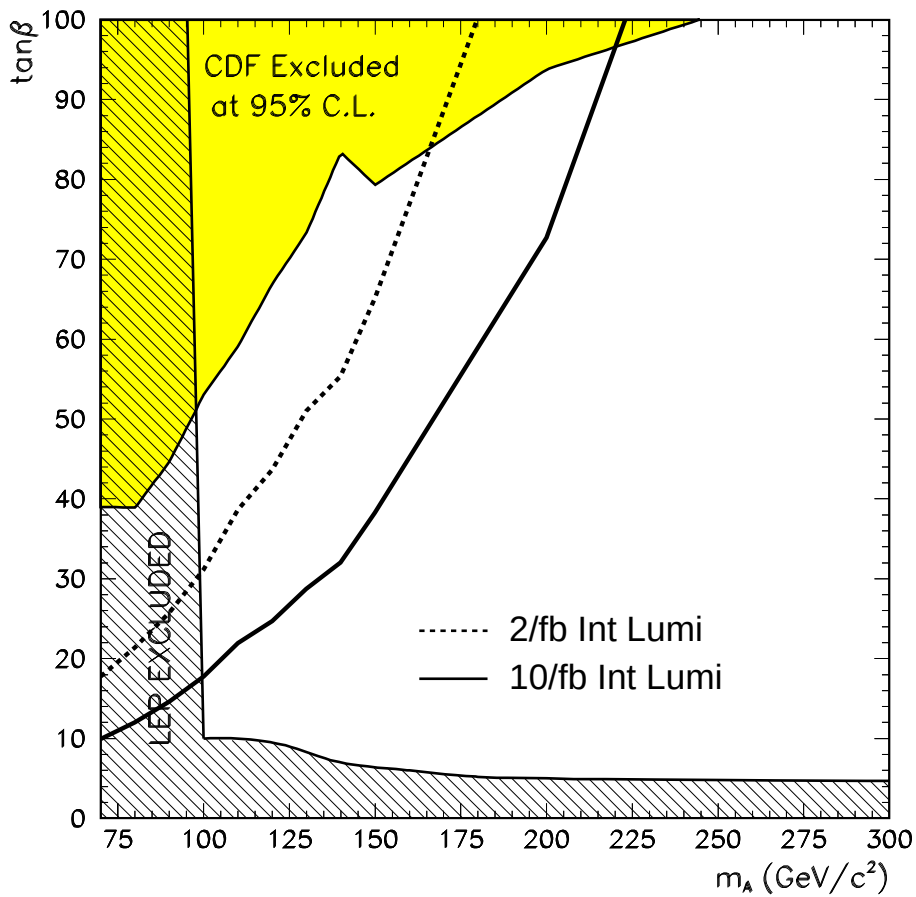


Outlook

95% CL Exclusion



5σ Discovery



Outlook

- Currently have $\sim 200\ \mathrm{pb}^{-1}$ 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 $m_{\mathrm{A}} = 90\ \mathrm{GeV}$ with data in hand
- Large region of parameter space with potential for discovery

Other Search Channels

- I covered only $gg \to b\bar{b}A/h \to b\bar{b}b\bar{b}$
  - $gg \to A/h \to \tau^+\tau^- \sim 7pb$ for $(\tan\beta, m_A) = (30, 90)$
  - Willinbrock predicts $gg \to bA \to bb\bar{b}$ is ~ 10 times bigger than 4b final state. Looking at bkg MC now!
- $b\bar{b}\tau\tau$ channel is 10 times smaller, but still helpful at high $\tan\beta$. Confirmation in τ-channel would be key!
- Can combine results with D0 a'la LEPHWG for more sensistivity
- MSSM Higgs search seems quite promising