Analisi Higgs con i Primi Dati

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Higgs Searches

Standard Model Higgs

- **SM Parameter fit** : $M_H < 182$ GeV/c^2 @ 95% CL (including LEP2 direct limit)
- **Direct searches at LEP2** : SM Higgs < 114.4 GeV/c^2 excluded at 95% CL
- **TeVatron** : SM Higgs boson with $160 < M_H < 170$ GeV excluded at 95% CL

    - **Italian contributions** : $H\rightarrow\gamma\gamma$ (Milano), VBF $H\rightarrow\tau\tau$ (Pisa), $H\rightarrow ZZ^{(*)}\rightarrow 4l$ (Frascati, Pavia, Roma1, Roma2)

Minimal Supersymmetric Higgs

- **LEP exclusion:** low $\tan\beta$ and M_A region of the parameter space

    - **Italian contributions :** (bb)A/H/h $\rightarrow \mu\mu$ (Frascati, Roma1), (bb)A/H $\rightarrow \tau\tau$ (Milano, Roma1)

Higgs convener: A. Nisati

Higgs with the First Data

[D. Charlton, T. LeCompte, Special PhCoord Meeting, 26/05/2009 - A. Nisati, K. A. Assamagan for the Higgs plans]

Small amount of 900 GeV data, bulk at 10 TeV (some perhaps at 8 TeV)

few pb^{-1} **"Spring 2010" results for conferences**

- Mainly calibrations and understanding of the detector performance: Collaborations with Trigger and CP Groups will be important
- Contribute to first physics analyses (minimum bias, lepton spectrum, jet spectrum..)

10 pb^{-1} **"Summer 2010" results for conferences**

- Expect somewhat improved detector/trigger performance
- Data-driven background estimation

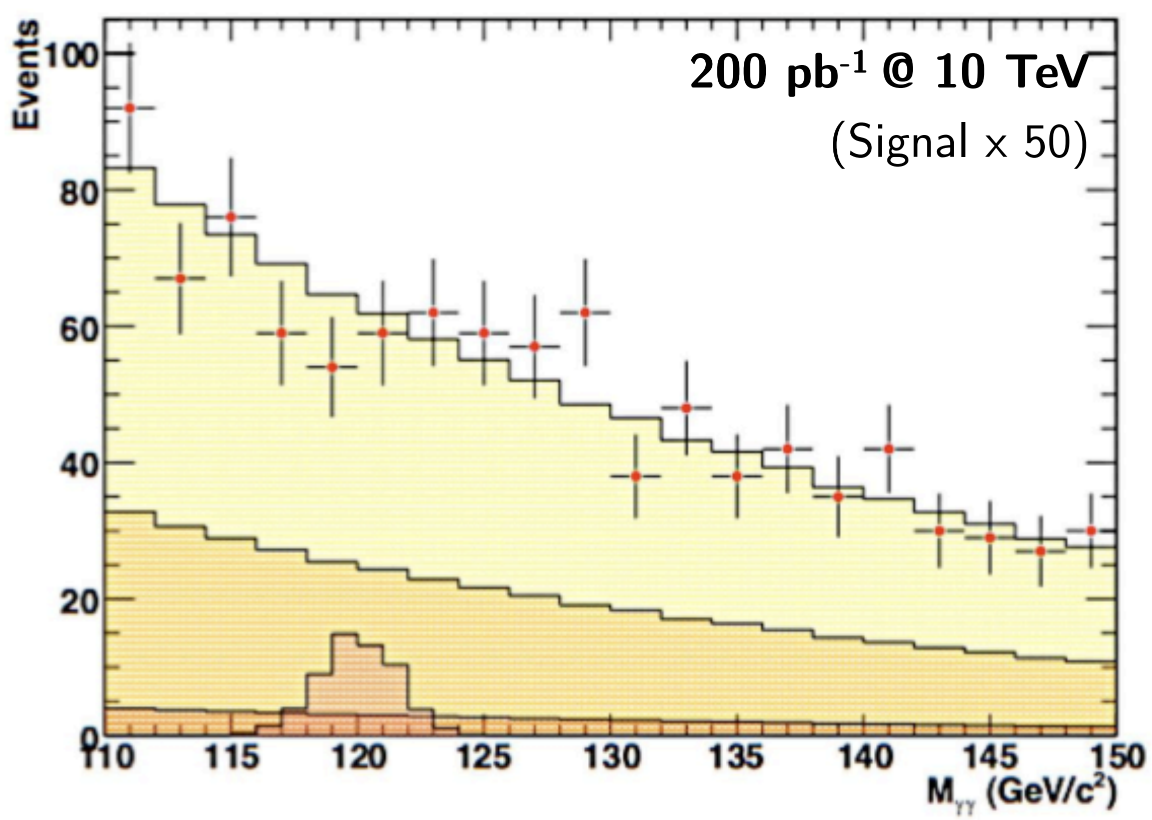
200 pb^{-1} **Full sample**

- Expect somewhat further improved detector performance
- Tight connection with SM and top groups (background cross section measurements, signal selection efficiencies and impact of systematic uncertainties, systematic error propagation)
- **Exclusion limits for $H \to WW$ - First Higgs Paper on 2009/2010 data**

SM $H \to \gamma\gamma$: Analysis Issues

- **Benchmark:** 200 pb^{-1} of data - 10 TeV - 10^{32} cm^{-2} s^{-1} - Bunch spacing 450-75 ns (0.4-4 minimum bias events added to the hard scattering process)

Number of events expected for 200 pb^{-1} of data at 10 TeV



Signal	**120 GeV $\pm$ 1.4 σ**
gg fusion	12.1 fb
VBF	1.5 fb
WH, ZH	0.8 fb
$t\bar{t}H$	0.1 fb
Total	**14.5 fb**

Background	**120 GeV $\pm$ 1.4 σ**
$\gamma\gamma$ irreducible	401 fb
γj reducible	209 fb
jj reducible	29 fb
Total	**639 fb**

only ~**3 signal** events expected - ~**128 background** events

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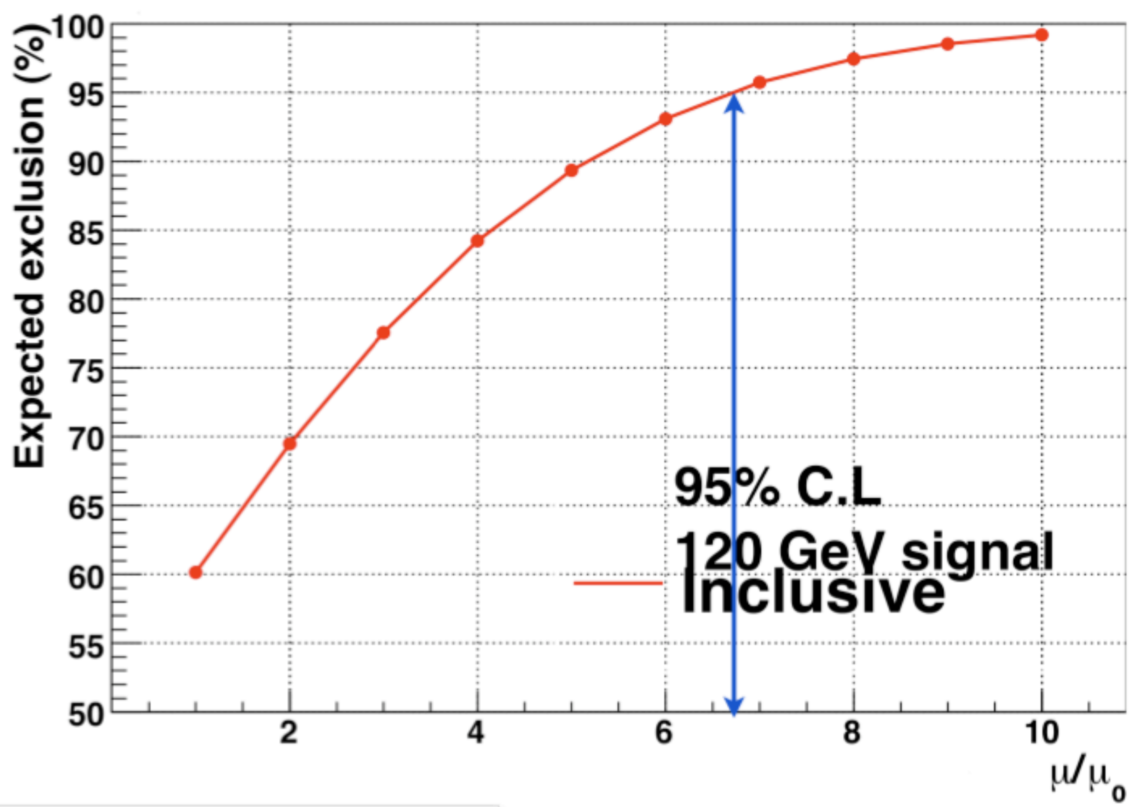
$H\to\gamma\gamma$: Exclusion Sensitivity

- Effect of pileup neglected for the moment (CSC Notes: degradation of $\sigma_M/M \approx 4\%$ when pileup 10^{33} cm^{-2} s^{-1} - bunch spacing 25ns is added)
- Exclusion with 200 pb^{-1} and 10 TeV $\rightarrow$ event counting method based on Poisson distribution gives a **95% CL exclusion range of 6.7 times the SM result**



- 8.2 fb^{-1} needed to exclude a SM Higgs
- **DØ observed (expected) limits** : 13.1 (17.5) times the SM with 95% C.L. for M_H = 120 GeV/c^2 [http://www-d0.fnal.gov/Run2Physics/WWW/results/prelim/HIGGS/H66/H66.pdf]

$\rightarrow$ Competitive with TeVatron with early data

SM $H\to\gamma\gamma$: γ Purity from First Data

[D. Banfi, L. Carminati, C. Costa, M. Fanti, L. Mandelli, F. Tartarelli]

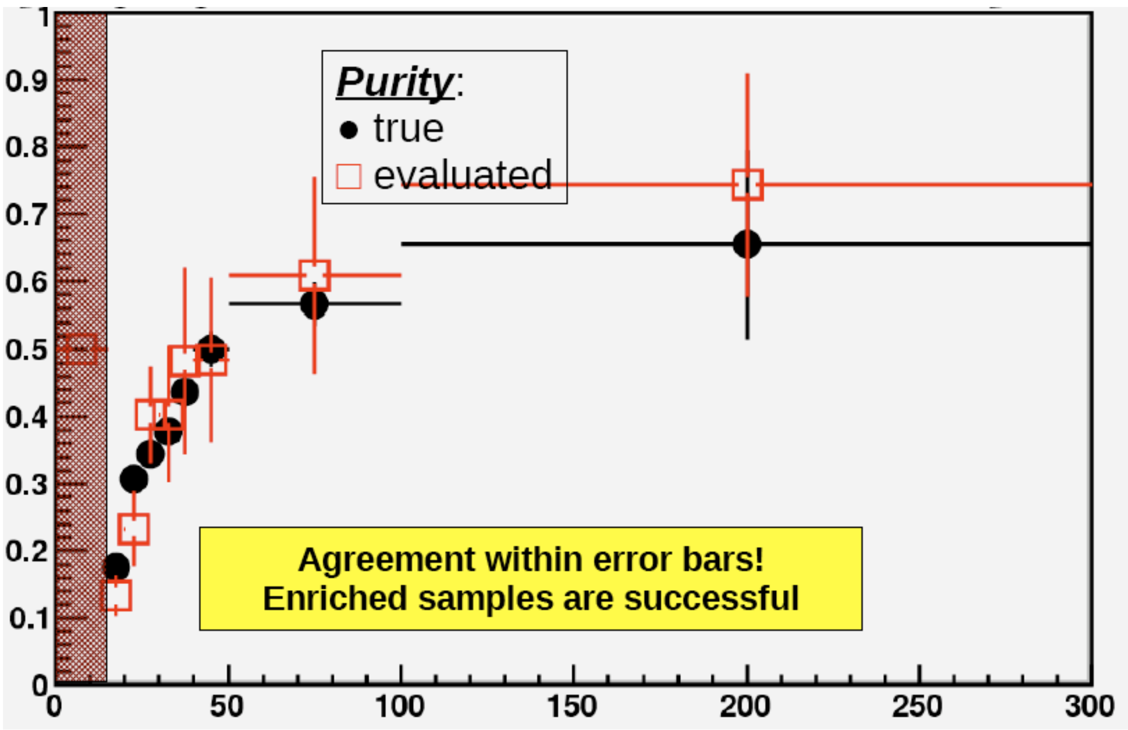
Inclusive photon and di-photon cross sections estimation: calibration and **photon purity knowledge** crucial

- Evaluation of the *photon purity P* in a sample of photon candidates
  - **Signal:** γ from hard scattering (prompt) and from fragmentation (q/g bremsstrahlung)
  - **Background:** the rest (secondary γ from hadron decays and other calo clusters not coming from γ)
- JF17 + JF35 9.2 M events analyzed (corresponding to 0.1 pb^{-1}) - photon identification via `isEM` (PhotonTight) and track isolation
  - Results checked also on *background- and signal- enriched* samples
- **Strategy for purity evaluation**:
  - Choose a separation variable, ξ, having pdf's sensibly different for signal and background: $\Pi_S(\xi)$ and $\Pi_B(\xi)$
  - Get the pdf from observed candidates sample: $\Pi_{OBS}(\xi)$
  - Find value of P that best fits $\Pi_{OBS}(\xi) = P\,\Pi_S(\xi) + (1\text{-}P)\,\Pi_B(\xi)$
- Choices of ξ: E_{PS}, P_T^{conv} (p_T of the detected conversion)/E_T

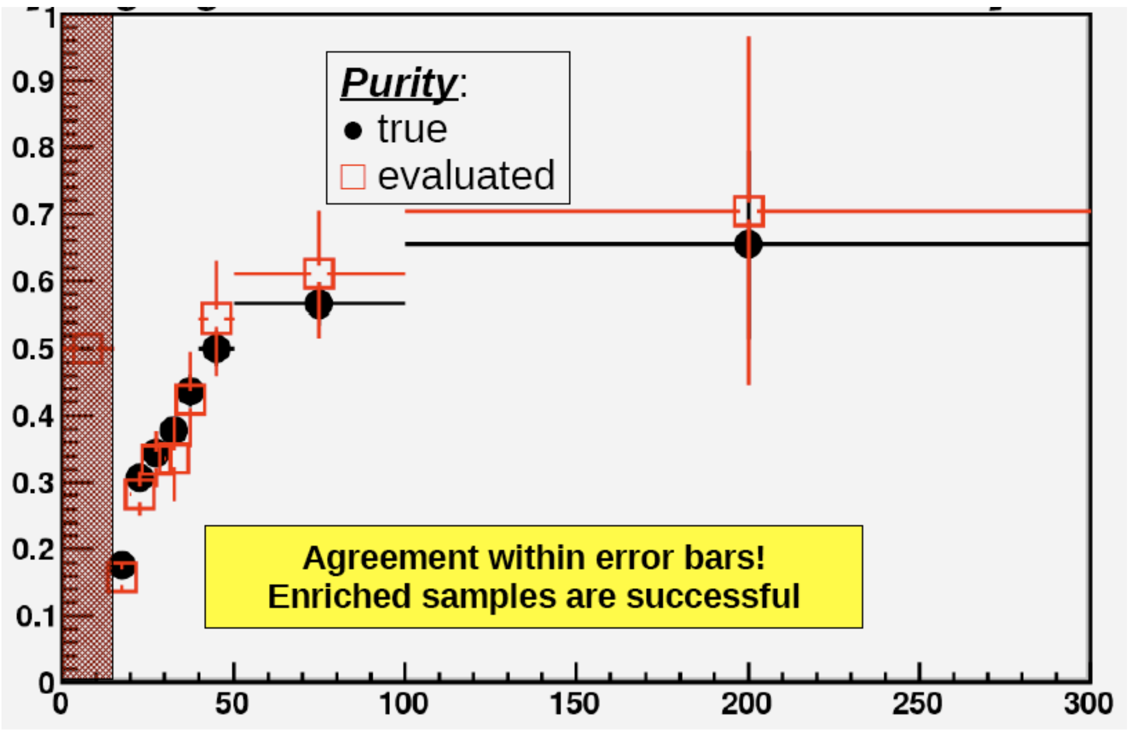
SM $H \to \gamma\gamma$: γ Purity from First Data

[D. Banfi, L. Carminati, C. Costa, M. Fanti, L. Mandelli, F. Tartarelli]

purity using E_{PS} on *enriched* samples



purity using p_T^{conv}/E_T on *enriched* samples



- **Caveats**: do we trust background and signal pdf's?
  - The first depend on fragmentation/hadronization model
  - The second are probably good for prompt γ, more model-dependent for q/g bremsstrahlung
- **Solution**: extract pdf's from real data (*enriched* samples for the moment, i.e. samples with additional selections to further reject background -*signal enriched*- or signal -*background enriched*-)

$\rightarrow$ more information in Marcello's talk

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SM H→ZZ$^{(*)}$→4l: Analysis Issues

- **Selection criteria:**
  - trigger, 4l–preselection → strongly relies on lepton reconstruction
  - m_{Z1} and m_{Z2} reconstruction
  - lepton isolation, impact parameter (IP) cut

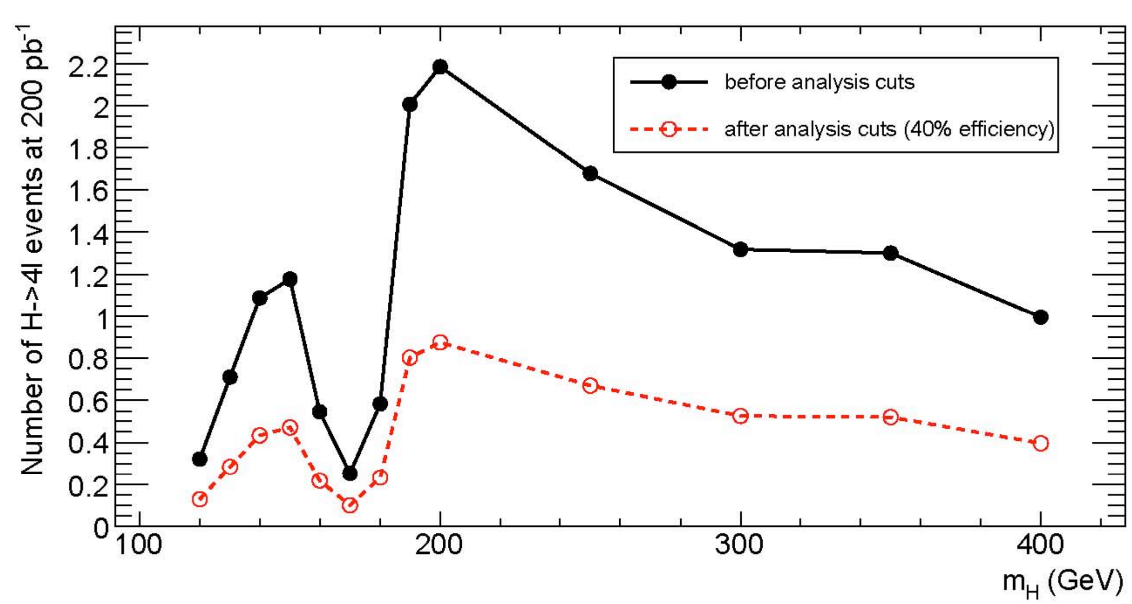
Number of events expected for 200 pb^{-1} of data at 10 TeV

Process	$\sigma\times$BR (pb)	Events	4 leptons no p_T, η-cut	4 leptons with p_T, η-cut
Signal (200 GeV)	**10.9** $\cdot 10^{-3}$	**2.1**	**2.1**	**0.9**
$ZZ \rightarrow 4l$	$\sim$16	3200	20	**3**
$t\bar{t}$ (1-l filter)	220	44000	650	**25**
$Z(\rightarrow ll)b\bar{b}$	40	8000	80	**7**
$Z \rightarrow ll$	$2 \cdot 1349$	$2 \cdot 270000$		$\sim$ **20**

selection efficiencies taken from the CSC Note

- Very small number of events remaining after the 4l-preselection, even before applying any additional analysis cuts → **not enough for an exclusion limit**
- At 10 TeV exclusion possible from ~1 fb^{-1} (provided detector and backgrounds are well understood)

Signal @ 200 pb^{-1}



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SM H→ZZ$^{(*)}$→4l with First Data

[F. Cerutti, R. Di Nardo, A. Di Simone, D. Rebuzzi, S. Rosati]

Work topics focused on **detector performance** (from data) and **understanding of background processes**

Final states with <4l

(within the Performance and SM Working Groups)

- Measurement of the SM cross-sections
  - *Z→ll inclusive, Z→ll+n(=light,c,b)-jets, tt, WZ, ZZ*
- Lepton trigger and reconstruction efficiency
  - *Tag&Probe with Z→ll and J/ψ→ll*
- Study of fake and secondary leptons, fake τ-jets
- Lepton isolation and impact parameter distributions
- Charge distributions in multilepton (3l) final states
  - *relevant for the lepton pairing needed for the Z-mass reconstruction*

Final states with ≥4l

- Increasing and understanding the signal selection efficiency
  - *Looser lepton quality criteria, improved lepton reconstruction*
  - *Optimization of the lepton isolation and IP cuts w&w/o pile-up*
- Evaluating the contribution of the Z-background
  - *Starting from the* MC *studies on large Z→ll samples, preparing extrapolation methods for measurements with data*
- Data driven evaluation of the contribution of the ZZ-background (main background)
- Evaluating separate contributions of tt, Zbb and ZZ backgrounds
  - *global fit approach*

SM H→ZZ$^{(*)}$→4l: Z Background

[R. Di Nardo, A. Di Simone, S. Rosati]

Expected events in acceptance - 200 pb^{-1} at 10 TeV	
$ZZ^{(\star)}/\gamma^{\star}$	~10 events with 4l from 100 to 500 GeV
$Zb\bar{b}$	~ 100 events with 4l
	~ 1000 events with 3l
$t\bar{t}$	~ 100 events with 4l
	~ 20k events with 1l
$Z \to ll$ incl	~ 400k events

Z inclusive potentially dangerous to Higgs searches

- **Z selections** implemented as **AOD-based analyses** in athena, benchmark analyses for the SM group (→ more information in Cesare's talk)
- Event selections and analysis problematics are different, but possibility to access the Z benchmark selection from within the H → 4l analysis very useful, in particular during understanding of the first data
  - Z+X background studies for different selections configurations : study Z→ll events + additional leptons
  - Cross checks on selection variable
  - Exercise in a measurement on real data all the corrections that will be used for the Higgs search (and exclusion) as well → advantage of developing common tools

SM $H\rightarrow ZZ^{(*)}\rightarrow 4l$: ZZ Background

[D. Rebuzzi, *et al.*]

- Very small number of ZZ events available at 200 pb^{-1} → *fit to data not feasible*

Overall idea to reduce uncertainties with the first data: reabsorb (or reduce) theoretical uncertainties arising from **pdf and QCD scales** and factorize the larger uncertainties from the **luminosity measurement** through **normalization to higher rate processes like DY** (normalization to "side-bands" not feasible with 200 pb^{-1})

  - This is an asset especially at the very beginning of data taking, when global pdf fits will not be available

- Normalization to **Drell-Yan $pp\rightarrow Z^{(*)}(\rightarrow\mu\mu)$**

$$\rho_{DY} = \frac{\sigma(q\bar{q}, qg \rightarrow ZZ \rightarrow 4l) + \sigma(gg \rightarrow ZZ \rightarrow 4l)}{\sigma(q\bar{q}, qg \rightarrow Z^{(\star)} \rightarrow 2l)}$$

- **Estimation of the ZZ events**

$$\boxed{\underbrace{N_{extr}(ZZ)}_{\text{prediction}} = \underbrace{\rho_{DY}^{MC}}_{\text{theory}} \cdot \underbrace{\varepsilon(4l)}_{\text{experimental efficiency}} \cdot \underbrace{N(q\bar{q} \rightarrow Z)_{meas}}_{\text{observed}}}$$

- **Work plan and status:**
  - Accuracy for $\sigma(ZZ \rightarrow 4l)/\sigma(Z \rightarrow ll)$ at generator level and after the PS
  - Evaluate the impact of experimental acceptance (ε) and detector-related systematic uncertainties

SM $H \to ZZ^{(*)} \to 4l$: Background Studies

[F. Cerutti]

Several other Italian activities ongoing on $H \to ZZ(*) \to 4l$ background estimation:

- Study improvements on **ZZ irreducible background rejection** with additional variables: e.g. 4 leptons p_T
- Study **systematics due to irreducible background shape** around $M_H \approx 2M_Z$
- Study of the **lepton isolation variables** trough measurements on data lepton from heavy flavor rejection:
  - Select tt events with:
    - $t_1 \to l\nu b$ (l trigger)
    - $t_2 \to jjb$ with $M_{jj} = M_W$
  - Look for 3rd J jet such that $M_{jjJ} = M_{top}$
  - Tag this 3rd jet J as b and study isolation variables

→ Preliminary studies on fast simulation showed reasonable purity and statistics

SM VBF H→ττ (hh): Analysis Issues

- **Benchmark:** 200 pb^{-1} of data - 10 TeV - Luminosity from 5 x 10^{31} cm^{-2} s^{-1} to 2 x 10^{32} cm^{-2} s^{-1} - 2 to 8 overlaying minimum bias events

Number of events expected for 200 pb^{-1} of data at 10 TeV

Signal	**σ x BR** [fb]	**presel** [fb]	**all cuts** [fb]	**events for 200 pb $^{-1}$**
VBF H(120) $\to \tau\tau$, ll	175 x 0.124	3.1	0.25	**0.050**
VBF H(120) $\to \tau\tau$, lh	175 x 0.456	4.5	0.37	**0.074**
VBF H(120) $\to \tau\tau$, hh	175 x 0.420	6.5	0.19	**0.038**

selection efficiencies taken from the CSC Note

Very small expected event yield in SM → no sensitivity

(at least three expected signal events needed to obtain exclusion at 95% CL)

- Could gain some sensitivity when re-optimizing cuts for limit setting

SM VBF H→ττ (hh): Analysis Issues

- **Dominant background sources** identified during the CSC effort → high priority is development of methods to estimate these backgrounds from data

Number of events expected at 14 TeV (CSC estimation)

Background $VBF, H \to \tau\tau \to hh2\nu$	**all cuts**(*) [fb]	**120 GeV window** [fb]
$Z \to \tau\tau$ + QCD jets	0.7	0.08
$Z \to \tau\tau$ + EW jets	0.37	0.03
$t\bar{t}$	0.16	0.03
$Z \to ll$ + jets	0.47	0.008
$W \to l\nu$ + jets	0.3	0.1
dijet prod	4	1 ± 1

(*) excluded the final window mass cut

- Estimation of the **contribution of QCD multijet** production of particular importance for the hh final state (important also for VBF H→ττ (lh) and for MSSM H→ττ)
- CSC Note estimate with Atlfast di-jet samples : uncertainty of 5 to account from the difference between: PS/ME MC, fast/full simulation)

The large uncertainty on multijet QCD background can be removed with data

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SM VBF $H \to \tau\tau$ (hh): Multi-jet from Data

[V. Cavasinni, F. Sarri, Z. Zenonos]

- Multi-jet QCD background can be estimated using the first data $\to$ with the unprescaled triggers `2j42_xe30` and `j70_xe30` for luminosity $= 10^{31}$ cm^{-2} s^{-1}, in 10 pb^{-1} of data we could have *few thousands events*
  - from Atlfast ALPGEN multijet events samples at 14 TeV (no trigger decision available being fast simulation, trigger signatures checked offline)

	3 jets (DS006916)	**4 jets (DS006917)**	**5 jets (DS006918)**
Cross sec [pb]	17000000	2295000	2000000
Events (in pb $^{-1}$)	1255000 (0.073)	2295000 (0.87)	521000 (3.84)
E_T^{miss} > 40 GeV	820	2626	5053
4 jets	385	2145	4999
2j42_xe30	3	19	147
1j70_xe30	2	18	133
2j42_xe30 OR 1j70_xe30		20	157

- Also pre-scaled jet triggers will be used - unprescaled ones have too high thresholds
- Study of the **shape and the normalization of multi-jet QCD background**

MSSM bbh/A/H→ττ (ll4ν): Analysis Issues

- **Benchmark:** 200 pb^{-1} of data - 10 TeV - Luminosity from 5 x 10^{31} cm^{-2} s^{-1} to 2 x 10^{32} cm^{-2} s^{-1} - 2 to 8 overlaying minimum bias events

Number of events expected for 200 pb^{-1} of data at 10 TeV

Signal - $\tan\beta$ = 20	σ **x BR** [fb]	**presel** [fb]	**all cuts** [fb]	**events for 200 pb $^{-1}$**
$b\bar{b}h/A(120) \to \tau\tau$, ll ($\geq$ 1 b-jet)	19900 x 0.124	98	16	**3.2**
$b\bar{b}H/A(200) \to \tau\tau$, ll ($\geq$ 1 b-jet)	3800 x 0.124	27	4.7	**0.94**

Number of events expected at 14 TeV (CSC estimation)

Background $b\bar{b}H, H \to \tau\tau \to ll4\nu$	**130 GeV window** [fb]	**200 GeV window** [fb]
$Z \to \tau\tau$ + jets	22	6
$t\bar{t}$	28	18
$Z \to ll$ + jets	4	4
$W \to l\nu$ + jets	12	4

Some sensitivity in the large tanβ region

→ Could gain additional sensitivity when re-optimizing cuts for limit setting

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MSSM bbh/A/H→ττ (lh): Backgrounds

[D. Cavalli, *et al.*]

- Milano involved in the study of A→ττ (lh) since a long time
  - Channel not included in the CSC Book due to lack of statistics for background
  - Scientific Note in preparation on 14 TeV data (by July 15)

- **QCD and W background estimation** for this channel
  - Separate events where the lepton and the tau-jet are of Opposite Sign (OS) or Same Sign (SS) → signal events are OS only - backgrounds can be OS or SS

$$N_{OS} = N_{OS}^{SIG} + \boxed{N_{OS}^{QCD} + N_{OS}^{Z} + N_{OS}^{W} + N_{OS}^{t\bar{t}}}$$ ***must be determined***

$$N_{SS} = \cancel{N_{SS}^{SIG}} + N_{SS}^{QCD} + \cancel{N_{SS}^{Z}} + N_{SS}^{W} + N_{SS}^{t\bar{t}}$$

- **Procedure** to determine each OS contribution in the OS selected sample :
  - Z (mainly Z → ττ): ${N_{OS}}^{Z}$ → Measured from data
  - tt: $N_{OS} >> N_{SS}$ → Measured from data
  - W: ${N_{OS}}^{W} = c \cdot {N_{SS}}^{W}$ → Calculate c and N_{SS} from data - c~1.5 (two production channels in pp: qq' → SS/OS, qg → OS)
  - QCD: ${N_{OS}}^{QCD} = {N_{SS}}^{QCD}$

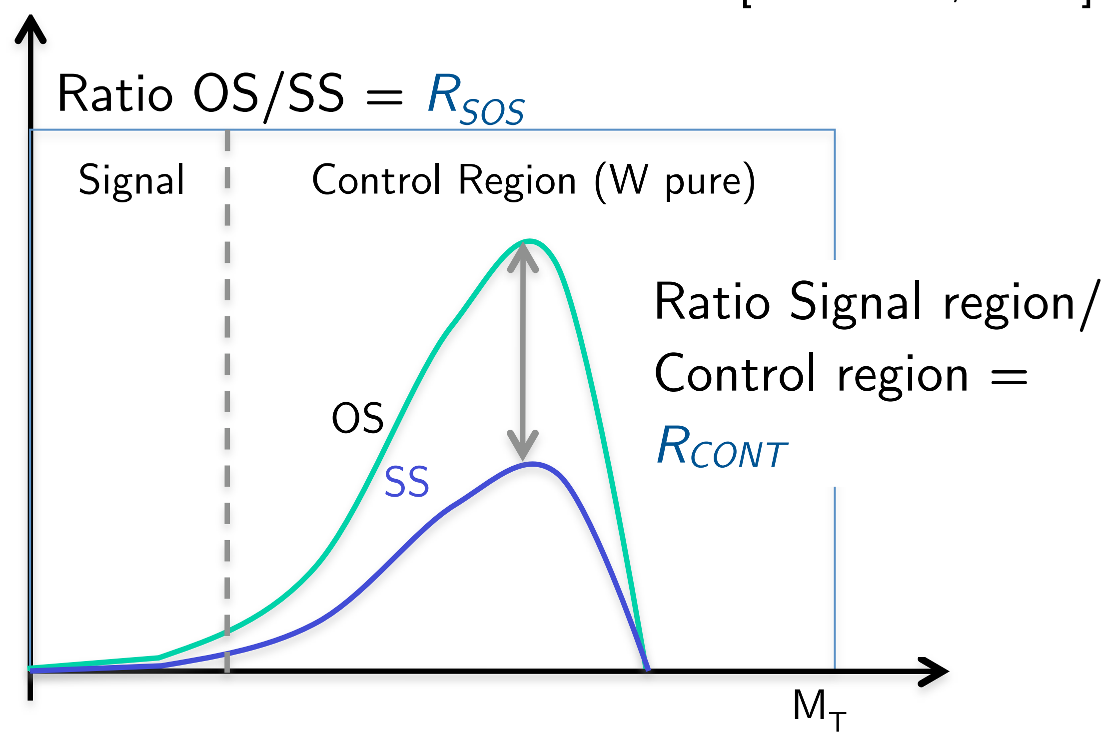
MSSM bbh/A/H→ττ (lh): Backgrounds

[D. Cavalli, *et al.*]

◉ Define the W control region

- Define a 'Control' region that is pure in W's
- Calculate OS/SS Ratio in Control Region (from data)
- Calculate Ratio Signal/Control region from MC

$$N^{W}_{OS} = \underbrace{R_{CONT}}_{\text{from MC}} \cdot \underbrace{R_{SOS} \cdot N^{CONT}_{SS}}_{\text{from data}}$$

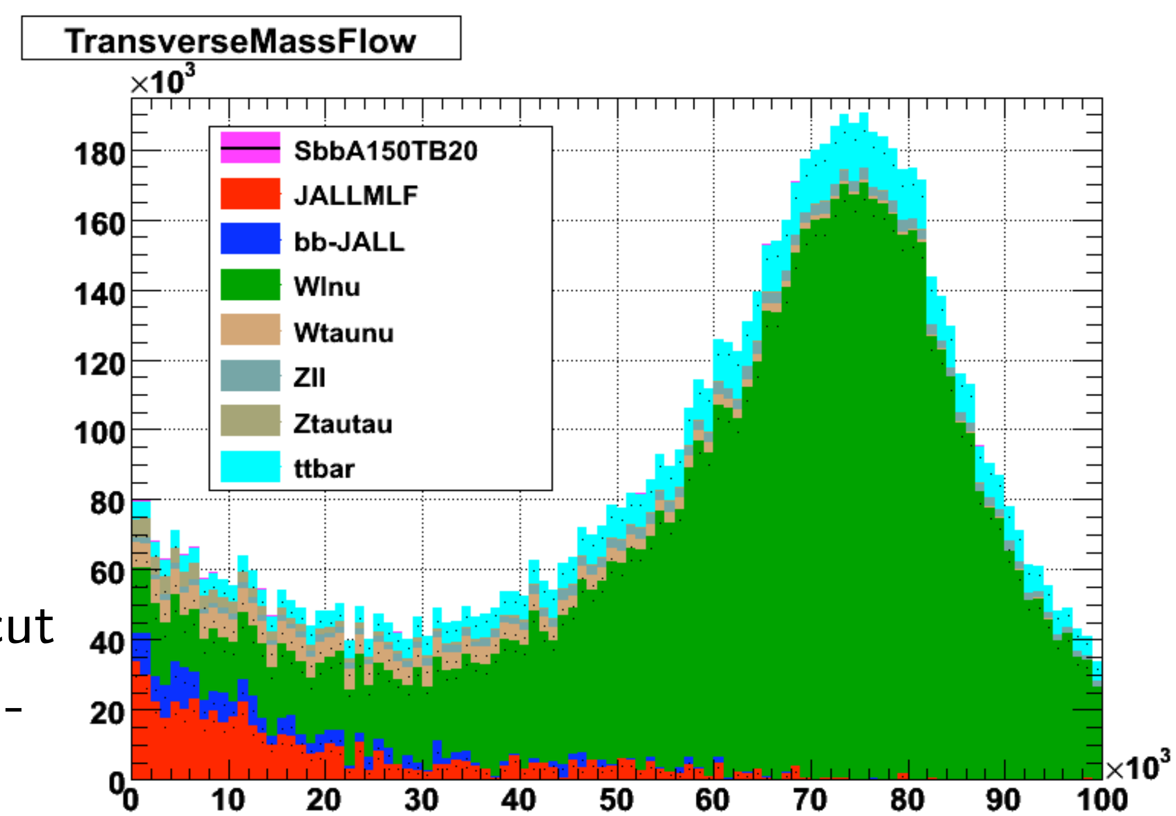


◉ Check the method

- No transverse mass cut at the beginning
- Find a suitable place in the cut flow to look into the control region (the closer to the final cut the better)

◉ Next Steps:

- Define Control Region before invariant mass cut
- Measure R_{SOS} and N_{SS}^{W} accurately from data - Efficiency of the mass cut for W's from MC



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MSSM bbh/A/H→μμ: Analysis Issues

- **Benchmark:** 200 pb^{-1} of data - 10 TeV - Luminosity from 5 x 10^{31} cm^{-2} s^{-1} to 2 x 10^{32} cm^{-2} s^{-1} - 2 to 8 overlaying minimum bias events

Number of events expected for 200 pb^{-1} of data at 10 TeV

Signal - $\tan\beta = 20$	σ **x BR** [fb]	**presel** [fb]	**all cuts** [fb]	**events for 200 pb** $^{-1}$
$b\bar{b}h/A(120) \to \mu\mu$ (0 b-jet)	70	46	29	**5.8**
$b\bar{b}h/A(120) \to \mu\mu$ (≥ 1 b-jet)	70	46	4.3	**0.86**
$b\bar{b}H/A(200) \to \mu\mu$ (0 b-jet)	13	9.2	5.3	**1.06**
$b\bar{b}H/A(200) \to \mu\mu$ (≥ 1 b-jet)	13	9.2	0.99	**0.198**

Some sensitivity in the large tanβ region

- Could gain some sensitivity when re-optimizing cuts, depending on instantaneous and integrated luminosity (S/√B for discovery and S/√(S+B) for exclusion)

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MSSM bbh/A/H→μμ: Z→μμ Estimation

[S. Gentile, H. Bilokon, V. Chiarella, G. Nicoletti]

Number of events expected at 14 TeV (CSC estimation)

Background $b\bar{b}, H \to \mu\mu$ (+b-tagging)	**all cuts**(*) [fb]	**120 GeV window** [fb]	**200 GeV window** [fb]
Z+light jets	711000 (4430)	3540 (31)	589 (7)
Z+b-jets	24200 (3300)	882 (15)	8 (2)
$t\bar{t}$	256 (89)	20 (8)	12 (6)

(*) excluded the final window mass cut

- **Estimation of the (bb)Z→μμ background** based on combined use of MC and experimental data [ATL-PHYS-PUB-2006-019, study under updates]
- Exploits two points:
  - BR(h/A/H→ee)~0 → suppressed as $(M_\mu/M_e)^2$
  - BR(Z→μμ) = BR(Z→ee) → lepton-Z coupling universality

  → use (bb)Z→ee events from data as a *control sample*
- **Caveats:** *at gen level*→inner bremsstrahlung (IB) - *at reco level*→ bremsstrahlung in detector material, e/μ different reco efficiencies and momentum resolutions

bbh/A/H→μμ: Z→μμ Estimation

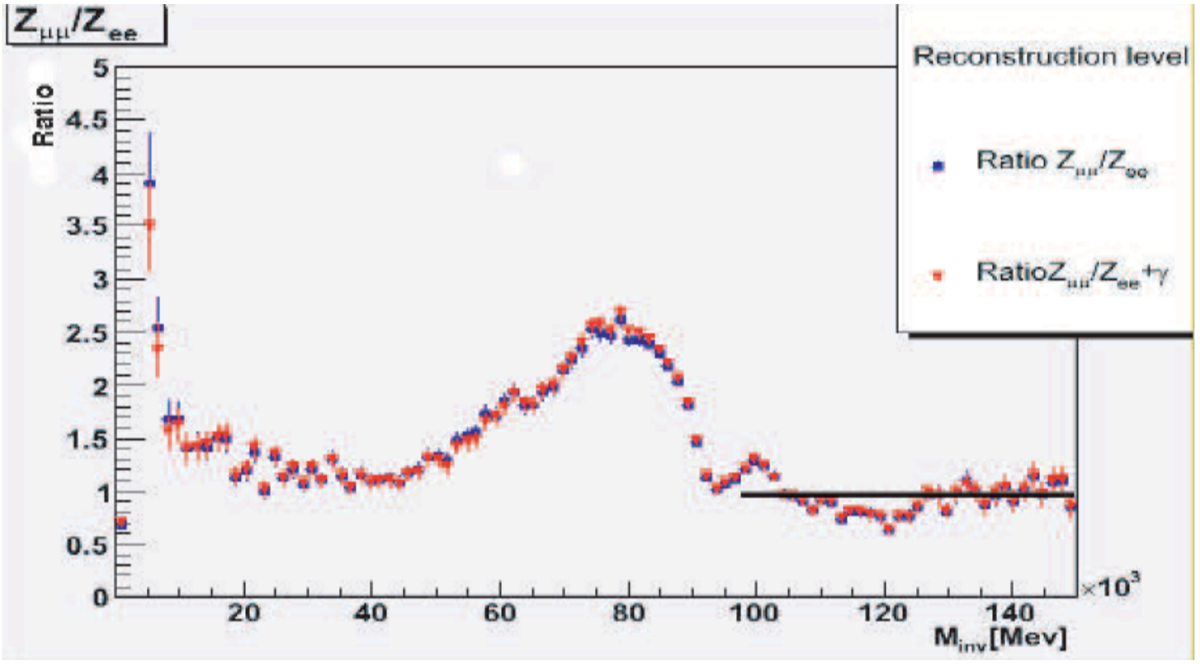
[S. Gentile, H. Bilokon, V. Chiarella, E. Kuznetsova, G. Nicoletti]

- Study done on AcerMC bbZ→$\mu^+\mu^-$ and bbZ→e^+e^- samples - 600k events, corresponding to an integrated luminosity of 30 fb^{-1} (σ = 22.8 pb)

	Generated		**Reconstructed**	
	$b\bar{b}Z \to \mu\mu$	$b\bar{b}Z \to ee$	$b\bar{b}Z \to \mu\mu$	$b\bar{b}Z \to ee$
Tot events	590575	586382	364756(*)	273780(*)
$\gamma_{brem} = 0$	541425 (91.6%)	499939 (85.2%)	362372 (99.3%)	271535 (99.2%)
$\gamma_{brem} = 1$	47413 (8%)	80679 (13.5%)	2378 (0.6%)	2228 (0.8%)
$\gamma_{brem} = 2$	1698 (0.2%)	5544 (0.94%)	6	17
$\gamma_{brem} = 3$	37	211	0	0

(*) events with two lepton reconstructed with p_T>10 GeV and $|\eta|$< 2.5

- IB more important in the electron sample → already at generation level, emphasized by the detector effects (in the muon sample 7% of IB photons recovered from mis-identification as electrons, only 1% in the electron sample)
- after application of IB photon recovery→ **$Z_{\mu\mu}/Z_{ee}$ regular in the interesting region**



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Summary and Plans: up to 200 pb^{-1}

Exclusion limits

- SM Higgs: 95% exclusion only possible in the WW channel
  - $H \rightarrow \gamma\gamma$ exclusion for 6.7 x SM - no exclusion limit for $H \rightarrow ZZ^{(*)}$ and $H \rightarrow \tau\tau$
- There is an opportunity for exclusion limits in the MSSM

Preliminary results of exclusion limits based on simulated data presented during June Cluster Week

Three main areas of activities for any Higgs sub-group

- Optimizing analysis strategies for early data for exclusion and discovery potential (for few channels)
- Understanding of the dominant backgrounds and data-driven estimation of the dominant background sources
- Contribution to Combined Performance and Trigger Groups

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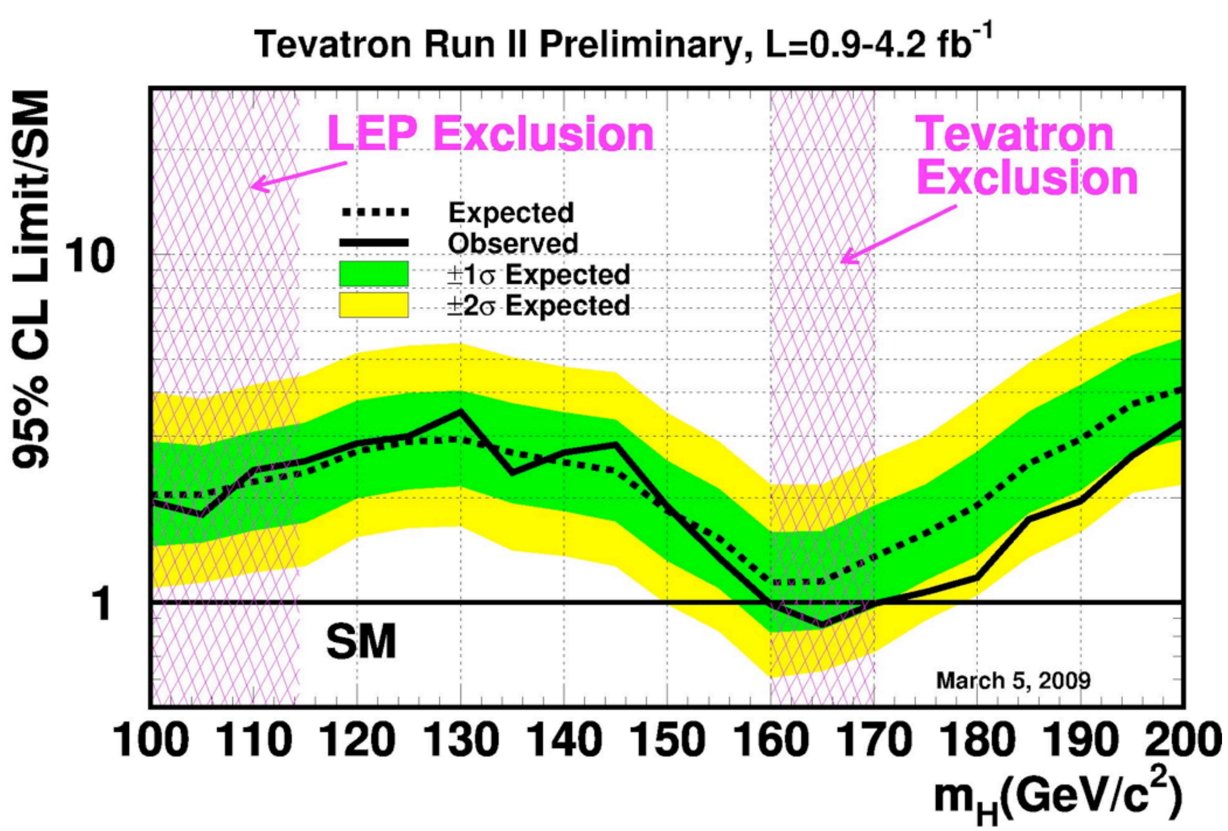
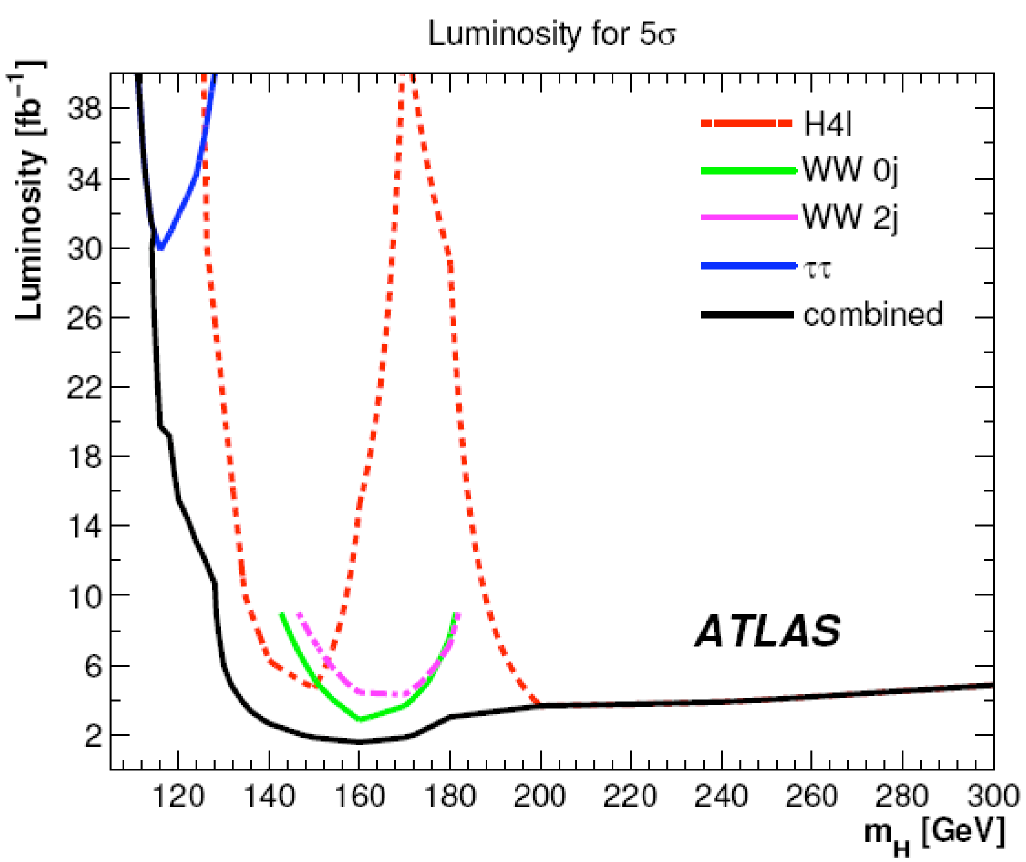
Backup Slides

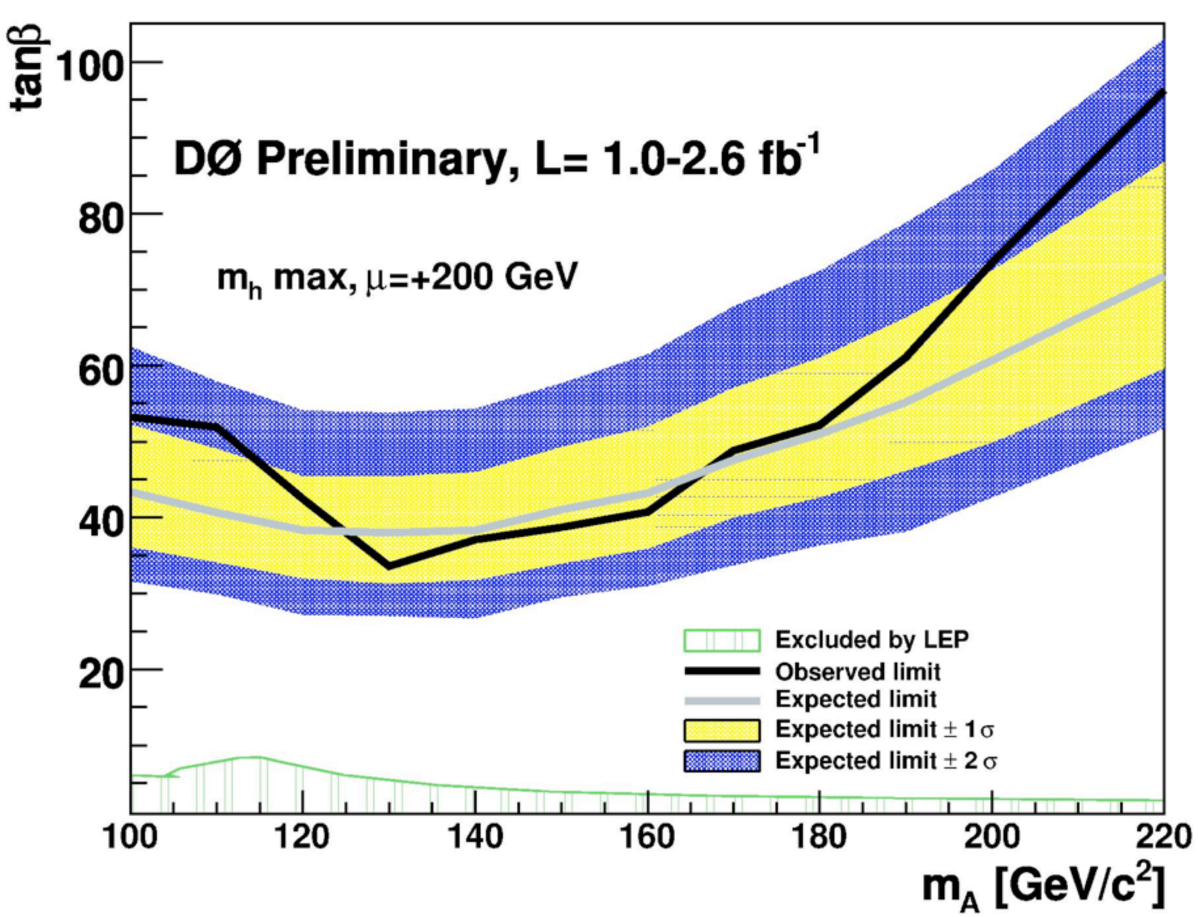
- **Standard Model fit** : $M_H < 182$ GeV/c^2 @ 95% CL (including the LEP-2 direct limit)
- **Direct searches at LEP-2** : SM Higgs lighter than 114.4 GeV/c^2 excluded at 95% CL
- **Tevatron** : SM Higgs boson with $160 < M_H < 170$ GeV excluded at 95% CL

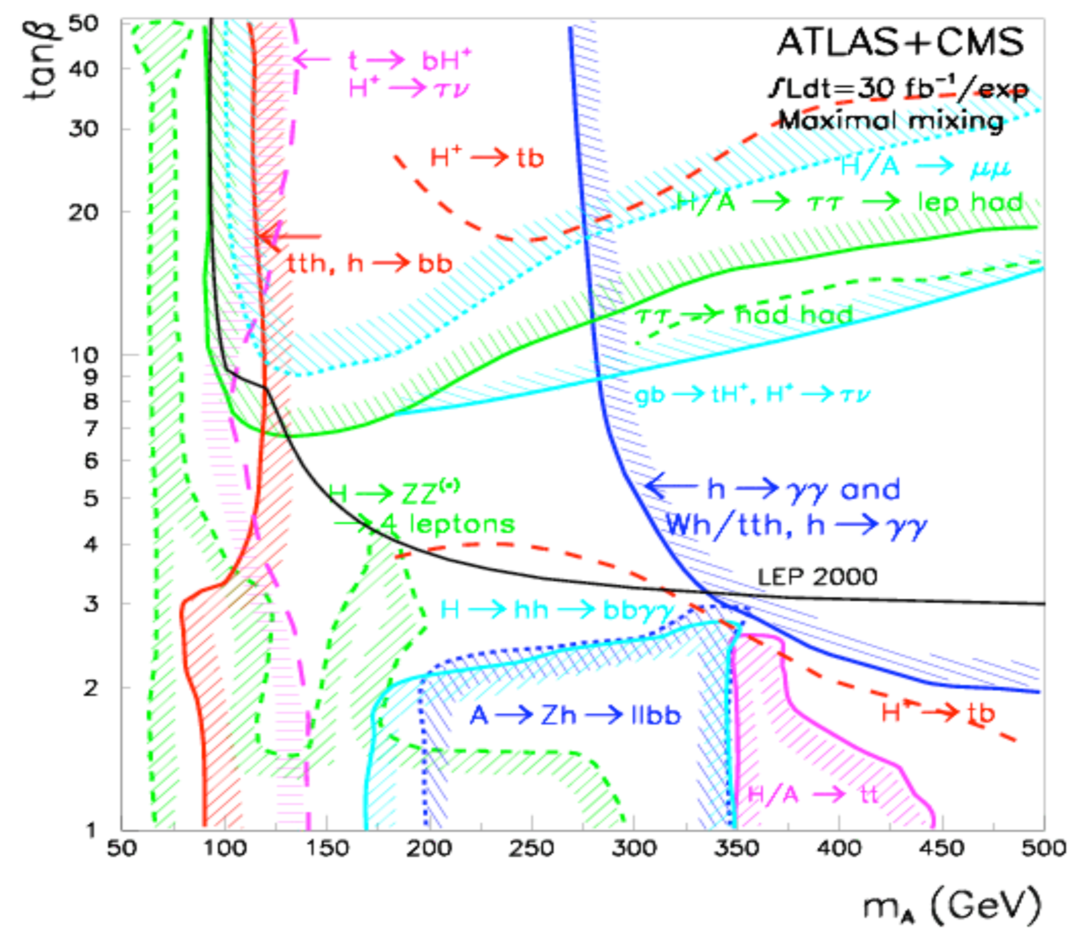




- **LEP exclusion:** low tanβ and M_A region of the parameter space
- $M_A \approx M_h$ for $M_h < 135$ GeV/c^2 - $M_A \approx M_H \approx M_{H\pm}$ at large M_A

[Conference Note 5935-CONF, 04/06/09]





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ZZ Estimation from Z: Tools and Status

- For **qq→Z$^{(*)}$** and **qq→ZZ$^{(*)}$** use MCFM v5.3 (NLO) with bug fixes provided by J.Campbell
  - caveat: if we are using MCFM for this estimation, *no EW corrections included!* (affecting Born level predictions by more than 10% for $m_{4l} > 500$ GeV/c^2)
  - Cross-checks with Pythia for the LO cross section and Sherpa

- Cross section for **qq→Z$^{(*)}$** available at NNLO (FEWZ - under study)

- For **gg→ZZ** use `gg2ZZ` - cross-sections and the scale error uncertainties made by N. Kauer -recent evaluation indicates ~10% of the qq σ_{LO}
  - evaluation through version `gg2ZZ` 1.0.0 = ~24%$\cdot\sigma_{LO}$ (30% in the CSC Note)
  - Comparison with ALPGEN and MC@NLO
  - NLO corrections can also be significant (from studies on high mass gg→γγ)

- Analysis done at parton level - theoretical errors decoupled from experimental errors
- **Status:**
  - undergoing studies for $M_Z > 2m_Z$ (see next slides)
  - to be extended also to low mass region

Event Selection and σ Estimation

- **Event Selection:**
  - Four (two) leptons with $p_T > 20$ GeV, $|\eta| < 2.5$
  - Requirement of 71 GeV $< M_{ll} <$ 111 GeV on lepton pairs
  - $\Delta R_{ll} > 0.2$ and $\Delta_{lj} > 0.7$
  - EW settings as default in MCFM taken by `gg2ZZ`
  - Set static scales to $\mu_R = \mu_F = M_V$ (V=Z,W) (results available also with dynamic scales)

Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$	$\sigma^{NLO}_{q\bar{q}\to ZZ}$	$\sigma^{LO}_{gg\to ZZ}$	$\frac{\sigma_{ZZ}}{\sigma_{Z^*}} \times 10^3$
200 - 250	1773.7	7.99	1.182	5.17
250 - 300	753.2	3.65	0.530	5.54
300 - 350	372.4	1.86	0.246	5.66
350 - 400	205.7	1.07	0.131	5.83
400 - 450	121.0	0.64	0.082	5.94
450 - 500	76.0	0.40	0.055	6.01
500 - 750	143.9	0.74	0.114	5.92
750 - 1000	27.4	0.16	0.033	6.88

cross sections in fb

- contribution from gg increases the ZZ cross section by 13%
- the $\rho_{DY} = \sigma_{ZZ}/\sigma_{Z^*}$ depends weakly with mass - nice surprise!

Scale Errors of ZZ/Z*

- Treating qq→ZZ and gg→ZZ independently (this somewhat could overestimate the errors on factorization scale due to expected anti-correlation for qq and gg)

cross sections in fb

Mass Range	$\sigma^{NLO}_{q\bar{q}\to Z^*}$		$\sigma^{NLO}_{q\bar{q}\to ZZ}$		$\sigma^{LO}_{gg\to ZZ}$		$\frac{\sigma_{ZZ}}{\sigma_{Z^*}}\times 10^3$		$\frac{\sigma_{ZZ}}{\sigma_{Z^*}}\times 10^3$	
200 - 250	1858.8	4.8	8.34	4.3	1.92	62.0	5.52	6.6	6.55	12.1
	1586.8	-10.5	7.14	-10.6	0.75	-36.4	4.98	-3.8	5.45	-6.7
250 - 300	792.0	5.2	3.86	5.9	0.83	57.3	5.93	6.9	6.98	11.7
	683.8	-9.2	3.32	-9.0	0.35	-33.9	5.36	-3.3	5.88	-6.0
300 - 350	390.5	4.9	1.94	4.2	0.38	53.6	5.94	4.9	6.91	9.2
	340.7	-8.5	1.70	-8.5	0.17	-31.5	5.50	-2.9	5.99	-5.3
350 - 400	214.7	4.4	1.10	3.3	0.20	49.3	6.05	3.8	6.97	7.7
	195.3	-5.0	0.96	-10.0	0.09	-29.8	5.40	-7.5	5.87	-9.3
400 - 450	125.8	4.0	0.67	5.8	0.12	46.0	6.31	6.2	7.26	9.7
	114.8	-5.1	0.60	-6.4	0.06	-28.5	5.70	-4.1	6.22	-6.2
450 - 500	79.5	4.5	0.43	6.5	0.08	44.3	6.38	6.3	7.37	9.7
	72.4	-4.8	0.38	-6.0	0.04	-26.7	5.78	-3.8	6.33	-5.9
500 - 750	147.6	2.6	0.78	5.9	0.16	40.9	6.39	7.8	7.47	11.3
	140.4	-2.5	0.70	-4.8	0.09	-22.0	5.64	-4.7	6.27	-6.5
750 - 1000	28.1	2.6	0.16	2.0	0.04	30.1	7.17	4.2	8.68	7.5
	28.2	2.9	0.15	-4.9	0.03	-17.8	6.21	-9.8	7.16	-11.3

- scale variation of a factor 4, 1/4
- highlighted columns indicates percentage variations
- last column obtained by correcting the scale contribution on gg with a potential QCD NLO k-factor of 2 (keeping relative errors at LO)

- The ratio ZZ/Z* seems also to be *flat as a function of the mass ranges and also of* $\sqrt{s}$ (table not shown here - calculation including only qq contribution for ZZ, so far)
  - Flatness of ratio indicates reduction of pdf uncertainties

$\sqrt{s}$ Dependence

- The contribution off the gg→ZZ to the table is not added yet
- The ratio ZZ/Z* seems to be flat as a function of $\sqrt{s}$ and different mass ranges
- The ratio ZZ/Z is less flat

$\sqrt{s}$	$200-250$	$250-300$	$300-500$	>500
14	4.51	4.87	5.18	5.06
12	4.52	4.88	5.07	4.98
10	4.45	4.88	4.96	4.98
8	4.47	4.82	4.97	4.98
6	4.44	4.73	4.93	5.04

- Flatness of ratio indicates reduction of pdf uncertainties

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Higgs Selection Criteria

SM $H \rightarrow \gamma\gamma$ Selection criteria:

- $|\eta| < 1.37$ $1.52 < |\eta| < 2.37$
- $p_T^1 > 40$ GeV and $p_T^2 > 25$ GeV

SM VBF Selection criteria: (CSC studies)

- $p_T(\tau) \geq 30/35$ GeV with opposite charge - $E_T^{miss} \geq 40$ GeV - collinear approx, $M_T(hh) \leq 80$ GeV
- total $p_T \leq 60$ GeV - CJV - M_H - 15 GeV $\leq M\tau\tau \leq M_H + 20$ GeV

MSSM bbh/A/$H \rightarrow \tau\tau$ ($ll4\nu$) Selection criteria: (CSC studies)

- Preselection: b-tagging, lepton selection ($p_T \geq 10$ GeV, $|\eta| < 2.5$, muon isolation), lepton pairing, coll approx
- Selection: $n_{jet} < 3$, $M_{ll} < 70$ GeV, $p_T^{miss} > 20/15$ GeV, $p_T^{bjet} < 70$ GeV, $p_T^{ll} < 45/60$ GeV, $2/2.24 < |\Delta\varphi^{ll}| < 3$, mass cut

MSSM bbh/A/$H \rightarrow \mu\mu$ Selection criteria: (CSC studies)

- Preselection: two isolated muons OC $p_T > 20$ GeV, $|\eta| < 2.7$
- Selection: $E_T^{miss} < 40$ GeV, $|\sin \Delta\varphi^{\mu\mu}| < 0.75$, mass window
- two selection: w/ or w/o *b*-tagging