Central Exclusive Higgs Production

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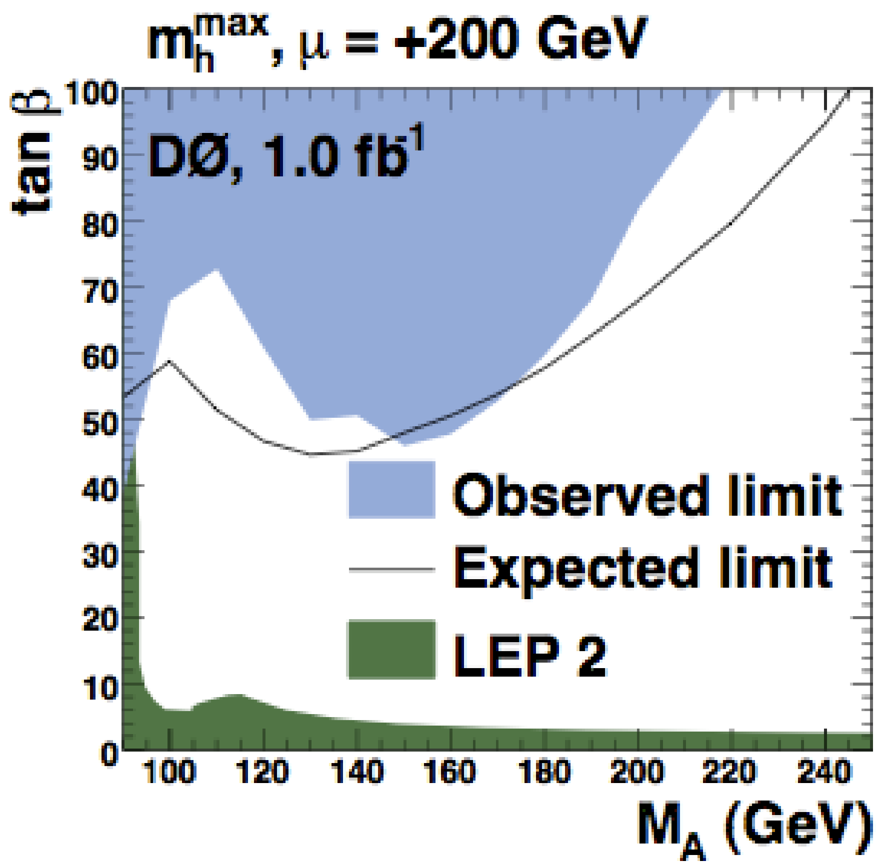
Overview

1) The MSSM and NMSSM.
2) Central exclusive production at the LHC.
3) Experimental exclusivity variables.
4) Results for $\mathrm{h} \rightarrow \mathrm{b}\bar{\mathrm{b}}$ and $\mathrm{h} \rightarrow 4\tau$.

Low-x 2008, Kolympari, Crete, 9th July 2008.

The MSSM Higgs sector

- 2 neutral scalars (h,H), 1 neutral pseudo-scalar (A) and a charged Higgs ($H^{\pm}$).
- At tree level, completely specified by 2 parameters - tanβ and m_A.
- At high tanβ, neutral Higgs coupling to down-type quarks and charged leptons is enhanced. Dominant decay is $\mathrm{h} \rightarrow \mathrm{b}\bar{\mathrm{b}}$
- High tanβ MSSM sector likely to be discovered at LHC, if not the Tevatron.



Latest limits on $h,H \rightarrow \tau^+\tau^-$ in m_h^{max} scenario of MSSM. (D0 collaboration, arXiv:0805.2491)

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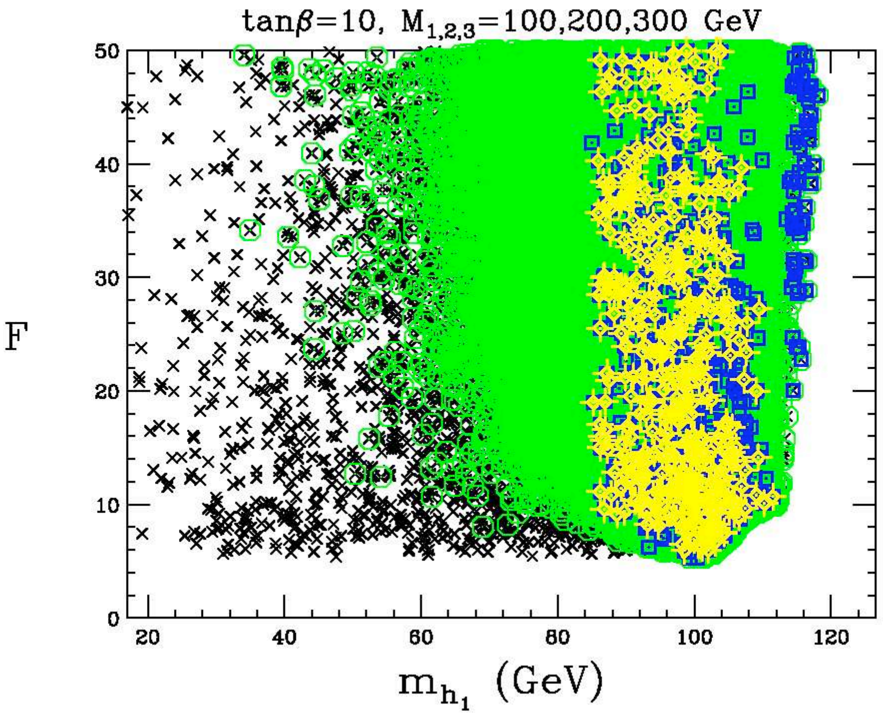
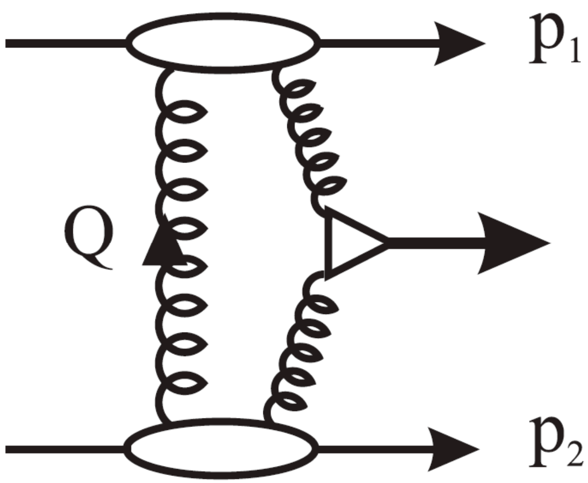
The NMSSM Higgs sector

- Extends the MSSM by inclusion of a singlet superfield, S ($\mu \mathbf{H_u H_d} \rightarrow \lambda \mathbf{S H_u H_d}$).
- 3 scalars (h_1, h_2, h_3), 2 pseudo-scalars (a,A) and the charged Higgs ($H^{\pm}$).
- Preferred mass of lightest scalar is m_h~100GeV.
- Preferred mass of lightest pseudo-scalar is $2m_\tau < m_a < 2m_b$.
- Standard search channels at LHC could fail to discover any of the NMSSM Higgs bosons [Phys.Rev.Lett.95, 041801(2005)]. Lightest Higgs dominant decay chain is $\mathrm{h} \rightarrow \mathrm{aa} \rightarrow 4\tau$.



Yellow indicates the constraints on the lightest scalar Higgs mass given stop and chargino limits and that $m_a < 2m_b$ (which avoids LEP limits by suppressing $\mathrm{h} \rightarrow \mathrm{b\bar{b}}$ decays).

Central Exclusive Production



- Defined as the process $\mathbf{pp \rightarrow p + \phi + p}$.
- Protons remain intact, scatter through small angles.
- All of momentum lost by protons goes into the production of the central system, ϕ.
- ϕ obeys a J_z=0, C-even, P-even selection rule

Kinematics

The mass, M, of the central system is given by $\mathbf{M^2 = \xi_1 \xi_2 s}$.
where ξ_i is the fractional longitudinal momentum loss of proton i.

Similarly the rapidity, y, of the central system is $\mathbf{y = \frac{1}{2} Ln \left(\frac{\xi_1}{\xi_2} \right)}$.

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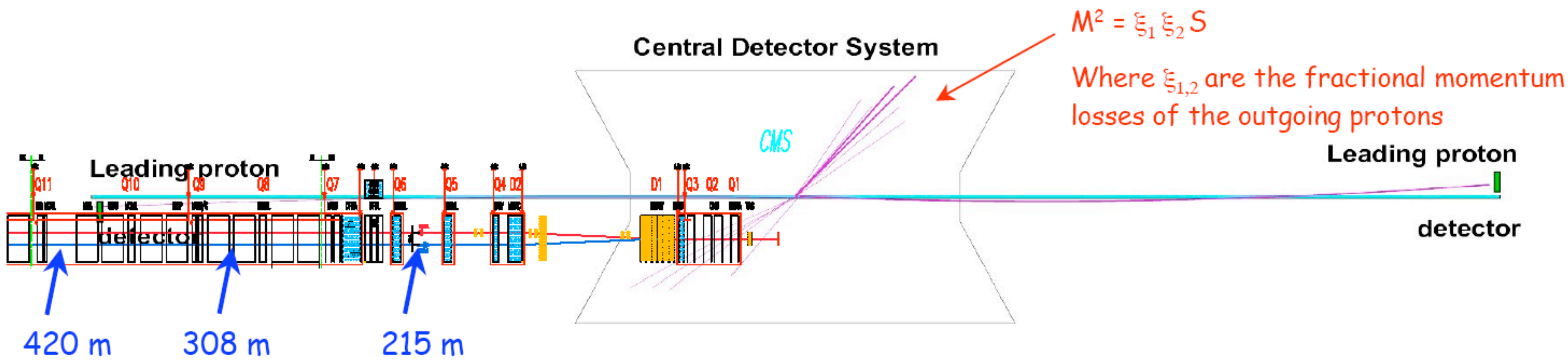
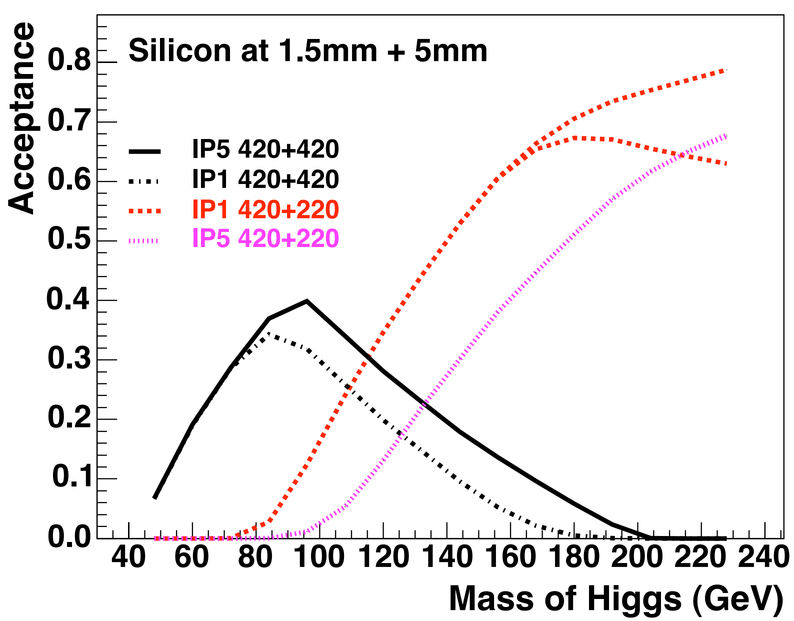
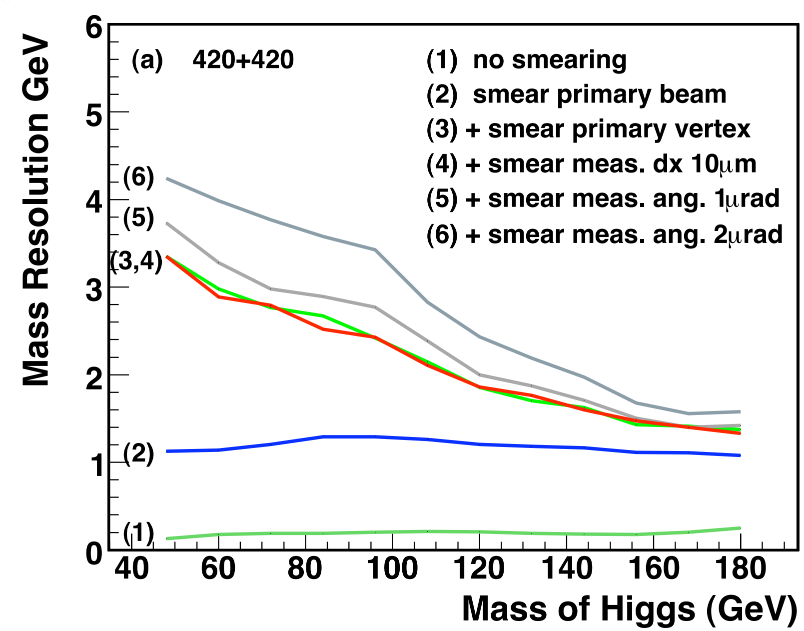
Forward proton tagging at LHC







See talk by M.Tasevsky for more details

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Higgs studies with leptons and jets

MSSM $h \to b\bar{b}$.

- m_h^{max} scenario with $\tan\beta$=40, m_A=120GeV and μ=200GeV.
- m_h=119.5GeV and Γ_h=3.3GeV; JHEP 0710:090,2007
- σ (pp→p+h+p)* BR($h \to b\bar{b}$) = 20fb.

NMSSM $h \to 4\tau$.

- m_h=92.9GeV and m_a=9.7GeV;
- BR(h→aa)=0.92; BR(a→ττ)=0.81. JHEP 0804:090,2008
- σ (pp→p+h+p)* BR(h→aa)*BR(a→ττ) = 4.8fb.

CEP trigger strategies

Forward detector information

- Level 1 (L1): Information from detectors at 220m from IP is available
- Level 2 (L2): Full forward proton tagging information available

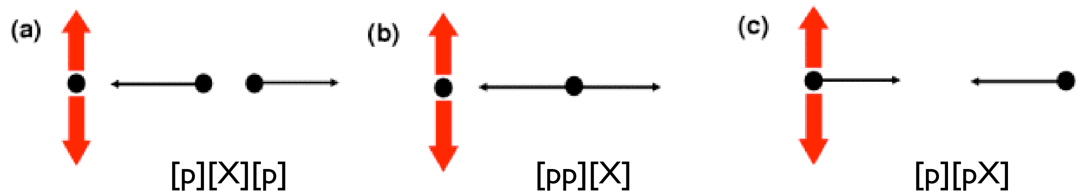
Lepton L1 triggers for CEP

- Easiest final state, use standard lepton triggers at ATLAS/CMS
- i.e If require 1 muon with p_T>6GeV, save 25% of NMSSM signal.

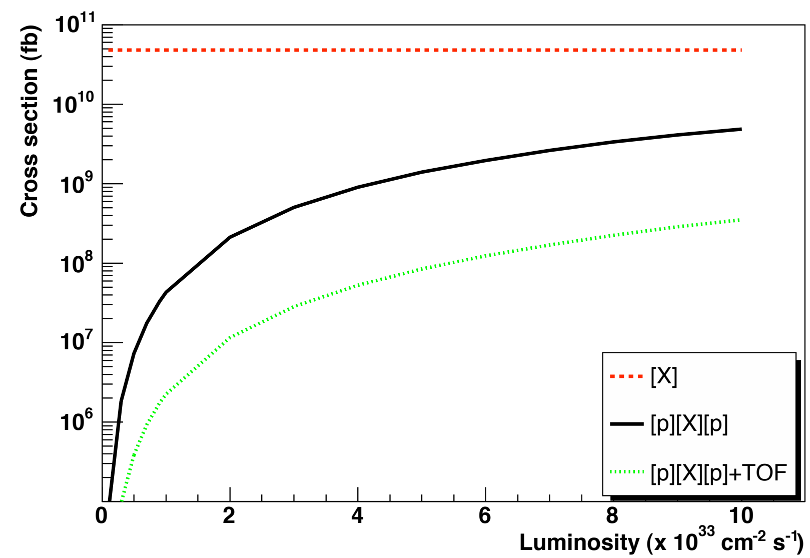
Jet L1 triggers for CEP

- Use final state muon if final state has b-jets. (10% efficient for MSSM signal if muon p_T>6GeV).
- 1 jet (E_T>40GeV) and 1 proton tagged at 220m. Rate<1kHz up to L~$3\times10^{33}cm^{-2}s^{-1}$.
- 2 jets at L1 with high rate. Reduced at L2 by full proton tagging information. Rejection ~20000 (140) for L=10^{33} (10^{34}) $cm^{-2}s^{-1}$.

Overlap backgrounds



- Coincidence between one (or more) soft SD/DPE events in the same bunch crossing as a hard scatter that has the same central topology as the signal.
- Luminosity dependent: probability of these events occurring in the same bunch crossing increases with the number of interactions in the crossing.
- [p][X][p] dominant and rate scales (roughly) as L^3.
- Rejected (initially) by measuring vertex of interaction by proton-time-of flight, $z=c(t_2-t_1)/2$, and comparing it to hard scatter vertex.
- Overlap dominates over all other backgrounds at high luminosity.



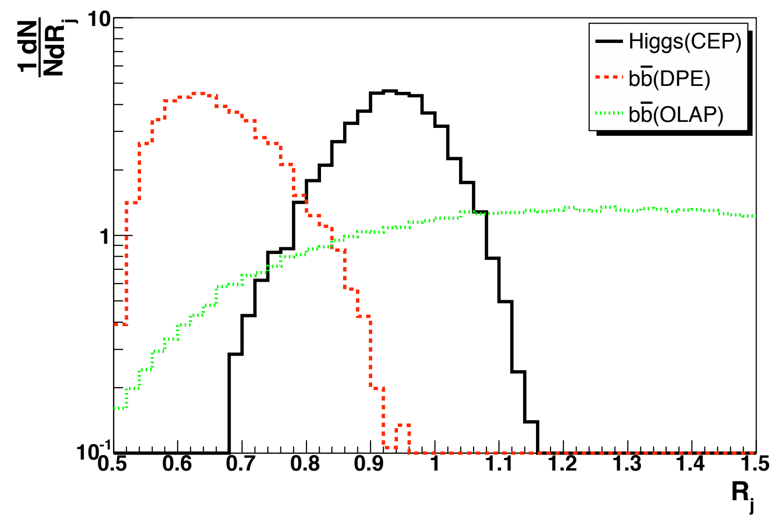
Kinematic matching

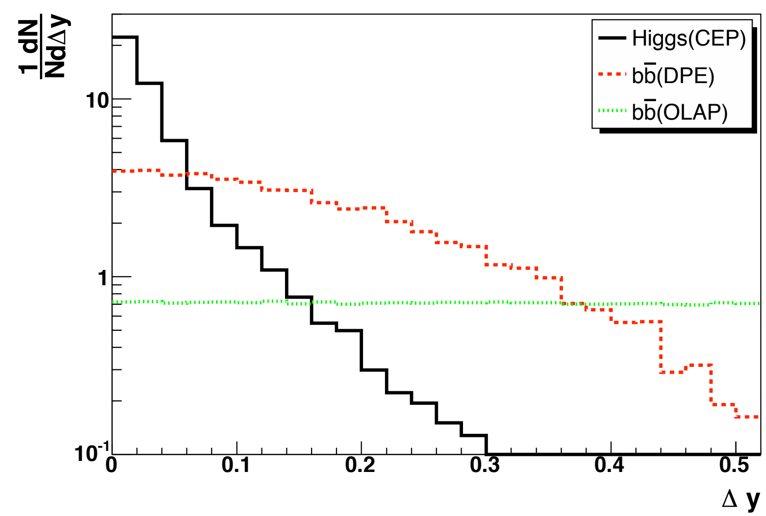
- Compare mass and rapidity, measured by forward detectors, to mass and rapidity measured in central detector.
- For jets:

$$\mathbf{R_j} = \frac{\mathbf{2E_T}}{\mathbf{M}} \cosh(\eta - \mathrm{y}) \qquad \text{(Mass Fraction)}$$

$$\mathbf{\Delta y} = \mathbf{y} - \frac{\mathbf{1}}{\mathbf{2}}(\eta_{\mathbf{1}} + \eta_{\mathbf{2}}) \qquad \text{(Rapidity difference)}$$

- Measurement of mass from leading jet $(\mathbf{E_T}, \eta)$.
- Measurement of rapidity from jet directions

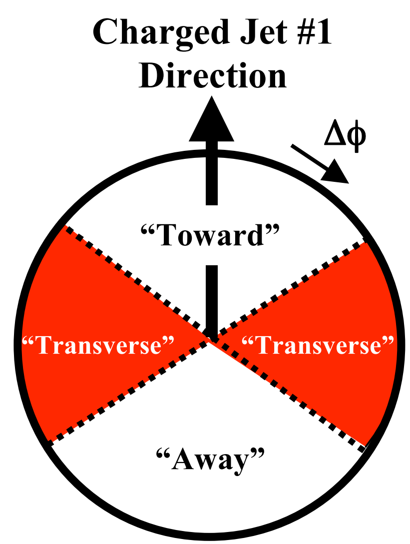




See also talk by V. Juranek.

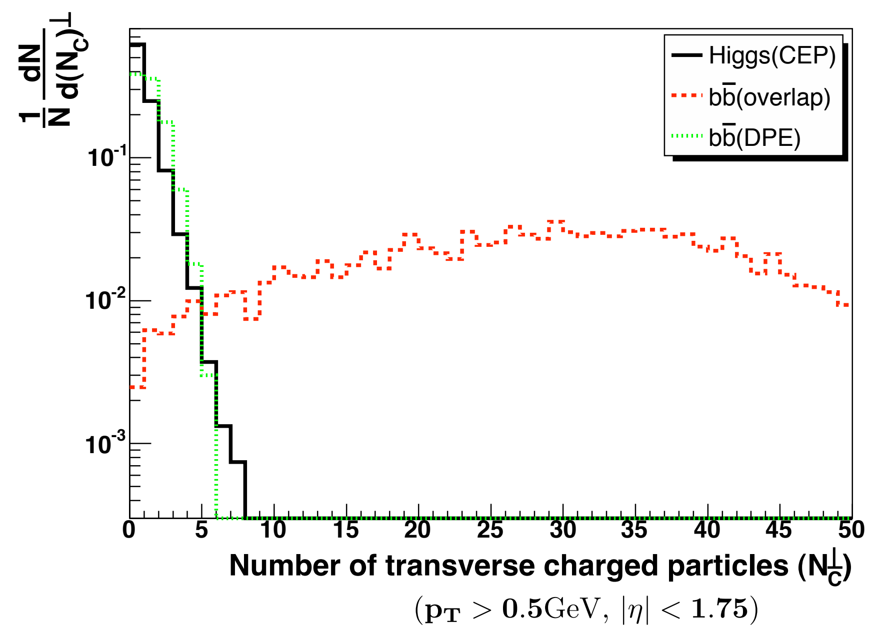
Charged tracking variables: for jets

- Tagged protons imply no multiple parton-parton interactions in CEP/DPE events.
- However, [p][X][p] events have a pp→X interaction as the primary vertex.
    - Increased track multiplicity at main vertex.



<u>Di-jet events</u>

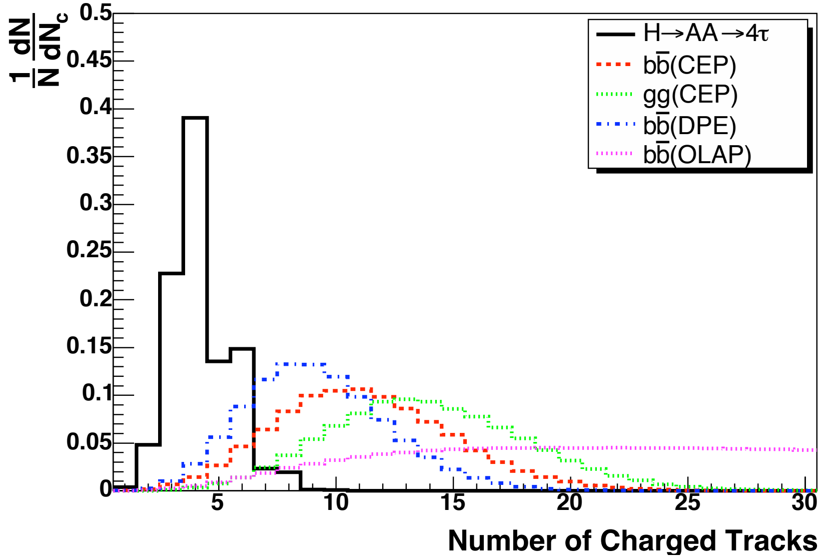
1) Construct back-to-back jets: $\pi - \Delta\phi < 0.1$
2) Require few tracks in the transverse region (perpendicular to jets).



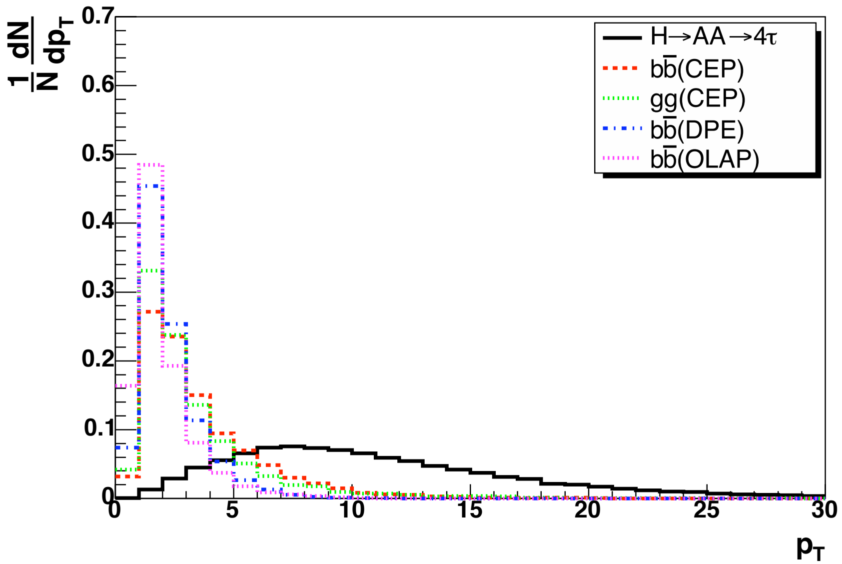
Can also look for total number of tracks outside of jet cones.

Charged tracking variables: leptonic final states

- Electrons, muons: 1 track.
- Hadronic tau decay: 1,3 tracks.
- Count tracks on vertex to reject jets and inclusive events (overlap) with multiple parton-parton interactions.



- Tracks also harder in leptonic final states than in jet final states: again cut on tracking information.
- NMSSM study only used calorimeter for isolation criteria around triggered muon.



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MSSM study results

Time-of-flight vertexing

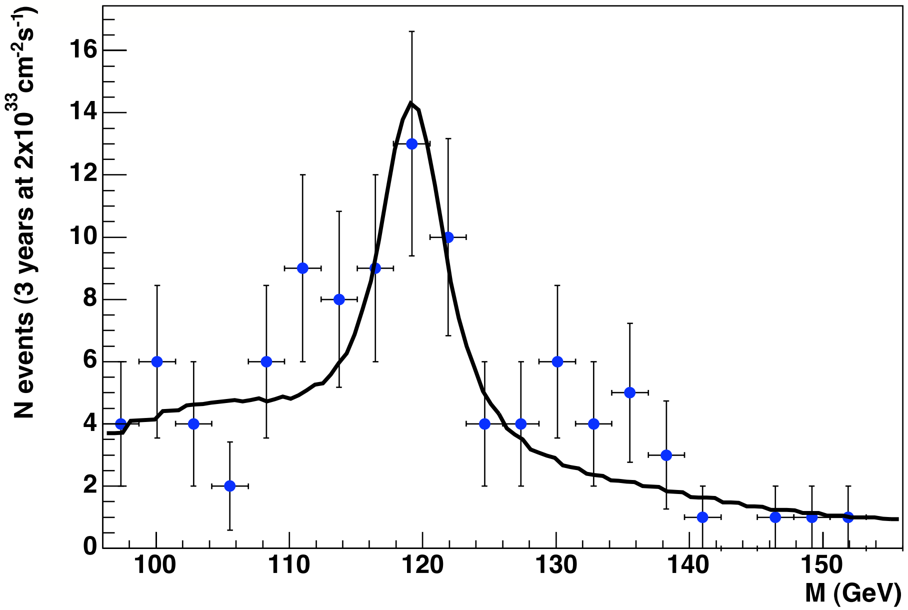
Kinematic matching

Charged track multiplicity

Cut	Cross section (fb)						
	CEP			DPE	[p][X][p]	[p][pX]	[pp][X]
	$h \to b\bar{b}$	$b\bar{b}$	gg	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$	$b\bar{b}$
E_T, ξ_1, ξ_2, M	1.011	1.390	2.145	0.666	5.42×10^6	8.98×10^3	1.16×10^6
TOF (2σ,10 ps)	0.960	1.320	2.038	0.633	3.91×10^5	7.33×10^2	6.29×10^4
R_j	0.919	1.182	1.905	0.218	4.73×10^4	85.2	7.59×10^3
Δy	0.774	1.036	1.397	0.063	2.16×10^3	1.38	3.50×10^2
$\Delta\Phi$	0.724	0.996	1.229	0.058	6.66×10^2	0.77	1.07×10^2
N_C, $N_C^\perp$	0.652	0.923	0.932	0.044	6.49	0.45	1.35
ΔM	0.539	0.152	0.191	0.009	1.28	0.06	0.28

Table 8: Cross section (fb) for the CEP Higgs boson signal and associated backgrounds after applying each one of the cuts in the text. The first cut requires that both protons are tagged at 420 m, the mass measured by the forward detectors is between 80 and 160 GeV/c^2 and the transverse energy of the leading jet is greater than 40 GeV. The second cut is the requirement that the di-jet vertex is within ±4.2 mm of the vertex predicted by proton TOF. The overlap backgrounds are defined at high luminosity (10^{34} cm^{-2} s^{-1}).

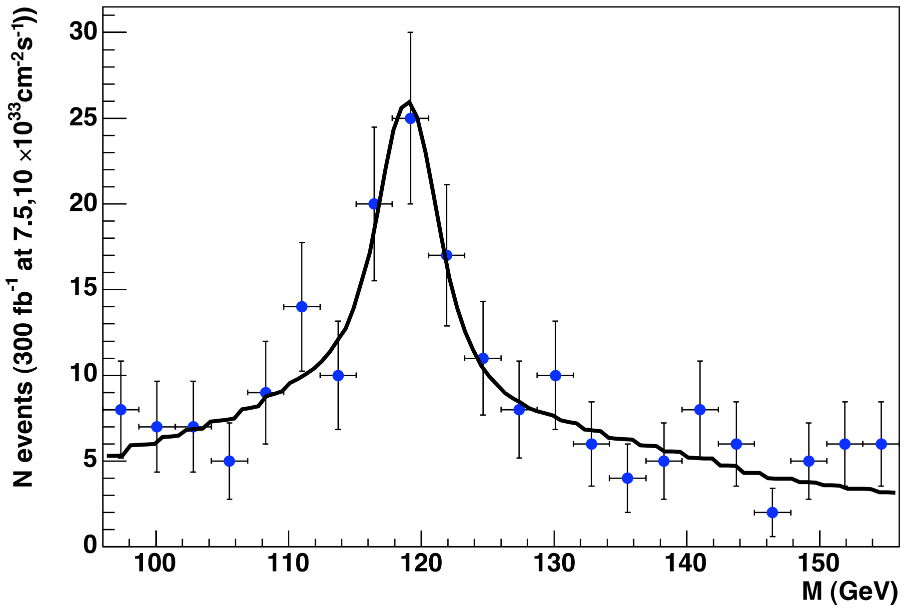
Expected mass distributions



$60fb^{-1}$, collected at $2x10^{33}cm^{-2}s^{-1}$

1) Protons tagged at 420m from IP.
2) TOF resolution: 10ps,
3) Trigger: Muon (p_T>6GeV) and high L1 jet rate (25kHz).
4) Significance = 3.5σ

JHEP 0710:090,2007.

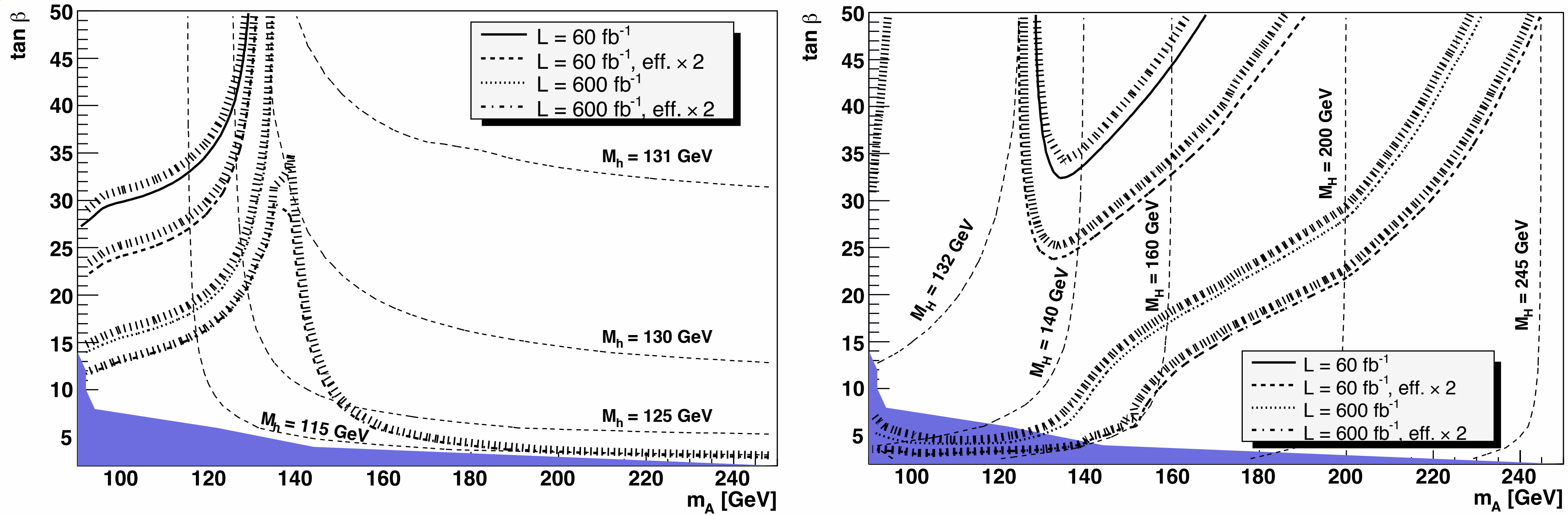


$150fb^{-1}$ collected at $7.5x10^{33}cm^{-2}s^{-1}$ plus
$150fb^{-1}$ collected at $10^{34}cm^{-2}s^{-1}$

1) Protons tagged at 420m from IP.
2) TOF resolution=5ps
2) Trigger: Muon (p_T>6GeV) and high L1 jet rate (25kHz).
3) Significance = 4.5σ

arXiv:0806.0302

MSSM expected significance



- Coverage of tanβ-m_A plane studied in Eur.Phys.J.C53:231-256,2008.
- Similar experimental efficiency to that assumed in previous slides (signal: 2.5% vs 2.7% for comparable mass windows). Trigger: (i) low p_T muon, (ii) jet + proton tag at 220m.
- Plots show 3σ contours for different integrated luminosity scenarios for h (left) and H (right) for detectors at 220m and 420m from the IP.

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NMSSM Results

Luminosity ($\times 10^{33}$ cm^{-2} s^{-1})	MU10 S	MU10 B	MU15 S	MU15 B	MU10 (2 ps) S	MU10 (2 ps) B
1	1.3	0.02	1.0	0.01	1.3	0.02
5	3.7	0.14	2.9	0.08	3.7	0.07
10	3.3	0.36	2.5	0.20	3.3	0.11

Table 2: Expected number of signal (S) and background (B) events for the three trigger scenarios assuming that the data are collected at a fixed instantaneous luminosity over a three year period. We assume the integrated luminosity acquired each year is 10 fb^{-1}, 50 fb^{-1} and 100 fb^{-1} at an instantaneous luminosity of 1×10^{33} cm^{-2} s^{-1}, 5×10^{33} cm^{-2} s^{-1} and 10 $\times10^{33}$ cm^{-2} s^{-1}.

- Trigger on muon with p_T>10GeV (MU10) or p_T>15GeV (MU15).
- Event rates double if trigger on electrons or electron/muon combinations (arXiv:0806.0302).
- S/B is greater than 10 in most cases.

The collinearity approximation

- Assume that $p_i^{vis} = f_i \, p_i^a$, i.e. the visible decay products of each pseudo-scalar are collinear with the pseudo-scalar. ($1-f_i$) is the fraction of 4-momentum carried by the neutrals.

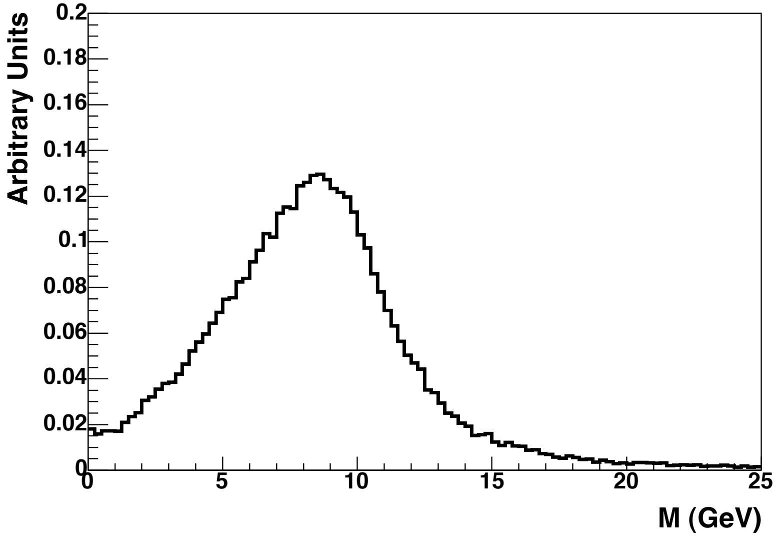
- Only charged tracks used as 'visible' particles.

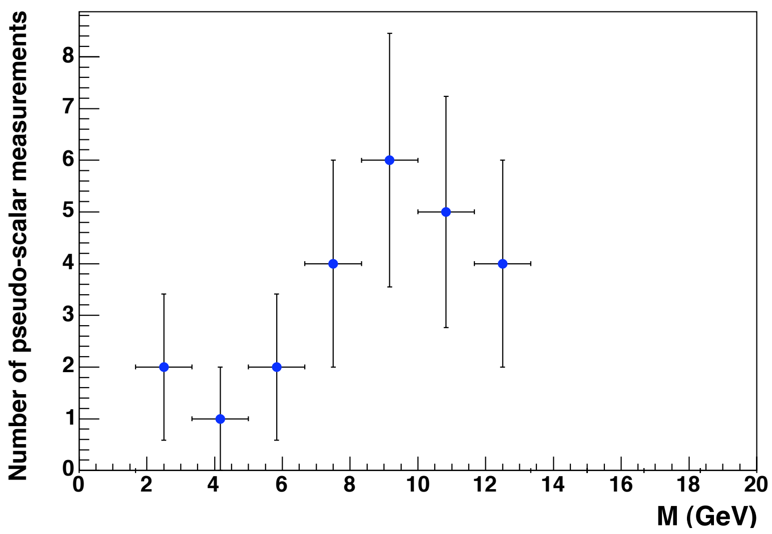
- 4-momentum of Higgs measured by forward detectors. If set transverse component to zero, obtain:

$$\frac{(p_1^{vis})_{x,y}}{f_1} + \frac{(p_2^{vis})_{x,y}}{f_2} = 0$$

$$\frac{(p_1^{vis})_{z}}{f_1} + \frac{(p_2^{vis})_{z}}{f_2} = (\xi_1 - \xi_2)\,\frac{\sqrt{s}}{2}$$

- Obtain 4 pseudo-scalar mass measurements per event.

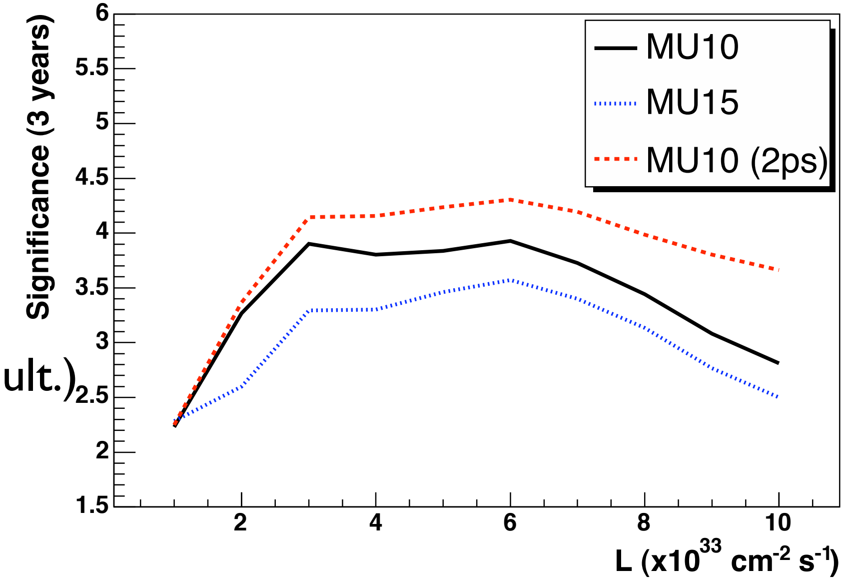




NMSSM significance

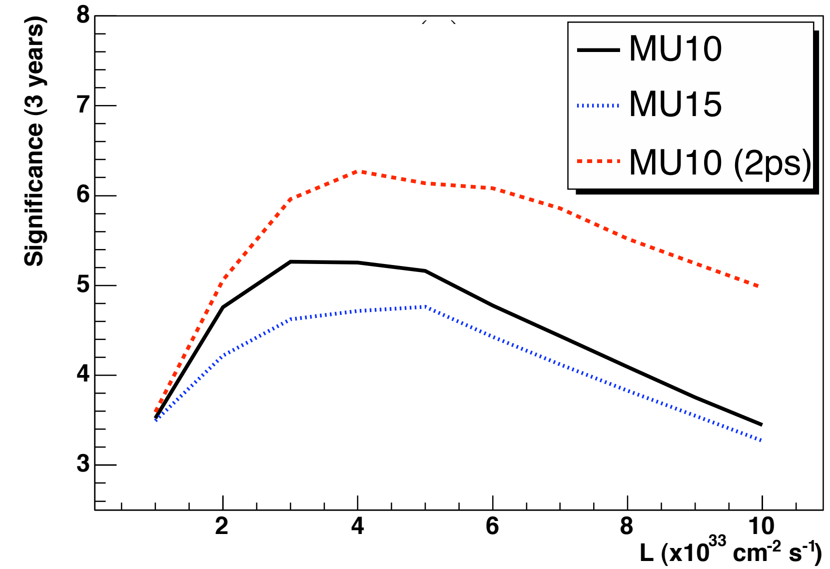
<u>Standard Results</u>

Corresponds to table shown on slide 15.
Turn-over at large luminosity due to:
a) overlap background (event no. proportional to L^3).
b) Experimental cuts (muon isolation, charged track mult.) affected by pile-up.



<u>Improved Efficiency Results</u>

Significance improved if event number is doubled.
Achieved by either
a) ATLAS+CMS combined
b) Use muon, electron, other di-lepton triggers.



Summary

Central Exclusive Production

1) CEP plus forward proton tagging offers both discovery and precision physics.
2) Experimentally the process should be well defined by 'exclusivity' requirements.

MSSM Higgs production - Precision physics

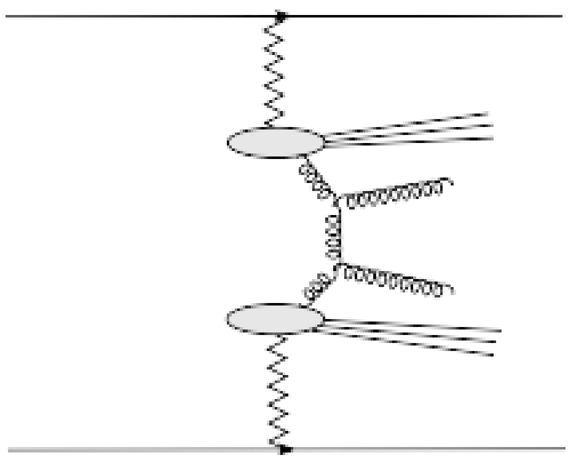
1) Mass measurement to an accuracy of ~2-3GeV.
2) Determination of quantum numbers of observed resonance.

NMSSM Higgs production - Discovery physics

1) CEP has restored a 'no-lose' theorem for the NMSSM Higgs sector.
2) Determination of both h and a masses from just a few events.

Backgrounds to CEP

DPE



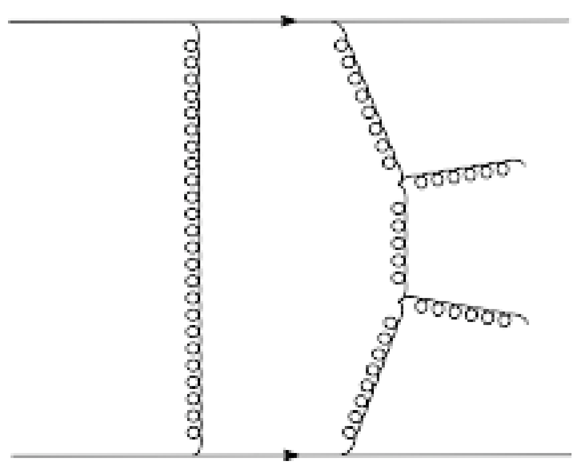
DPE backgrounds

- Production by 'pomeron' fusion. Final state contains hard scatter plus pomeron remnants.
- Mainly interested in di-jet production.

CEP backgrounds

- gg→gg dominant
- gg→bb suppressed by J_z=0 spin selection rule.

CEP



γγ fusion backgrounds

- Important source of exclusive leptonic backgrounds (i.e 4τ).
- Also jet production (but less than CEP)