Measurement of the Z+bb cross-section at CMS

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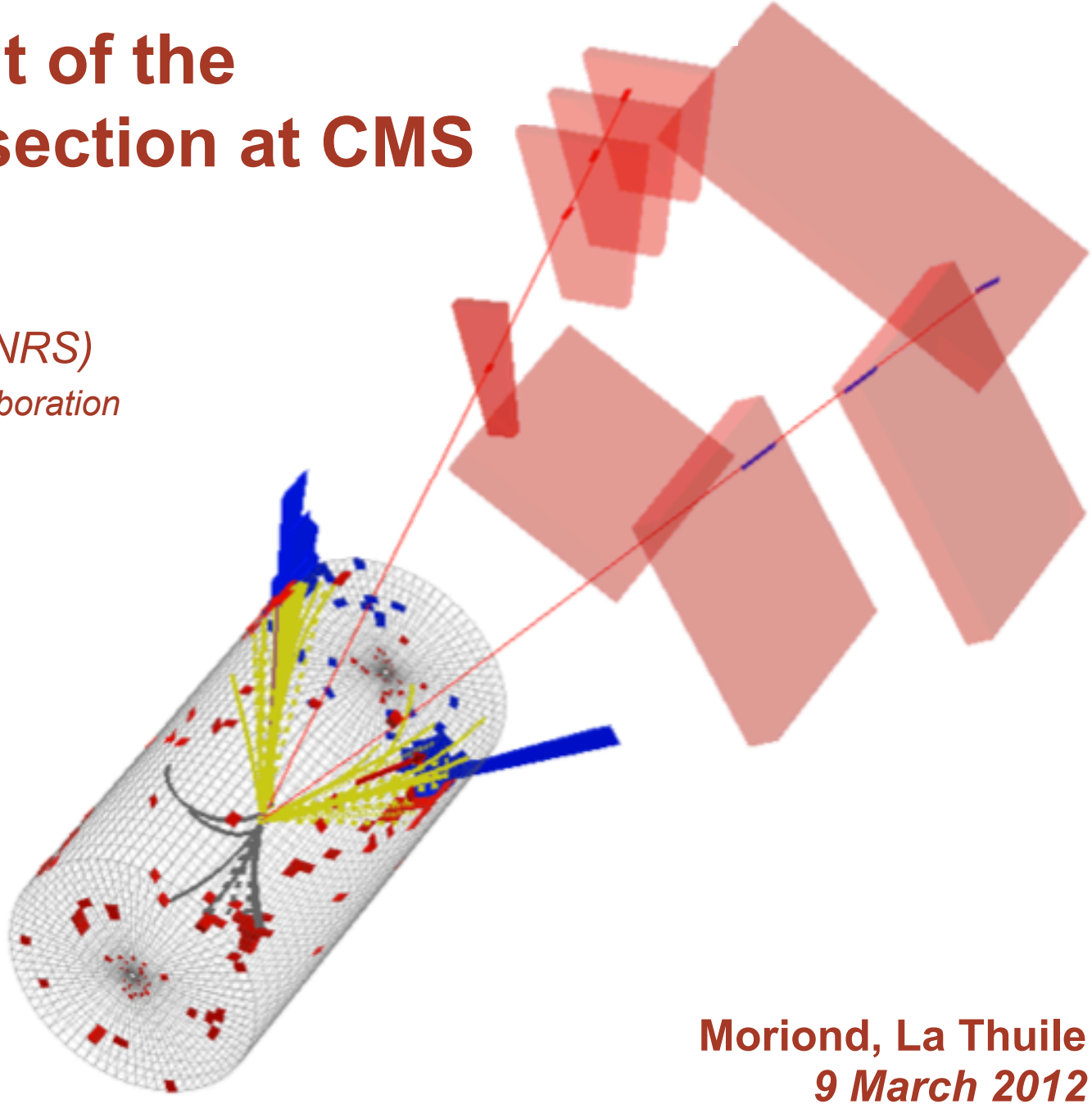
(*CP3-UCLouvain & FNRS*)
On behalf of the CMS collaboration

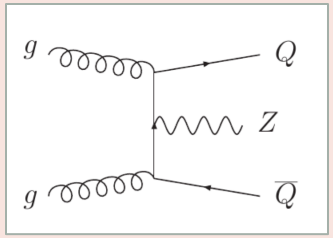


Moriond, La Thuile
9 March 2012

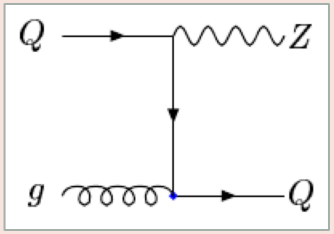
Z+b motivation

Z+1b: test QCD predictions

Fixed flavor scheme
(arXiv:hep-ph/1106.6019)
Massive b
Full event description
➢ aMC@NLO

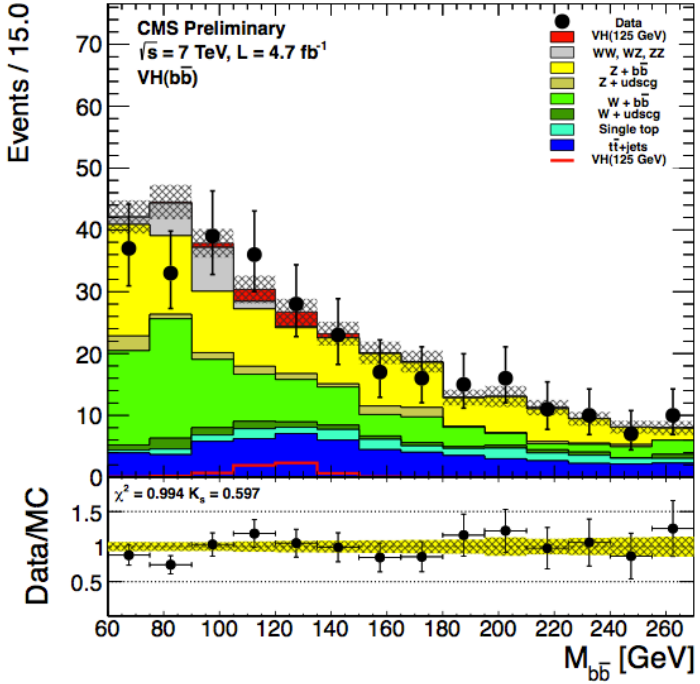


Variable flavor scheme
(arXiv:hep-ph/0312024)
Splitting inside PDF
Massless b
➢ Collinear approach



Z+2b: background and candle

- **Exotics**
  - e.g. b' search
- **MSSM** with large tanβ
  - bb+Φ(μμ,ττ,bb)
- **BSM Higgs**
  - e.g. H→Z+A(bb)
- **SM Higgs**
  - e.g. Z+H(bb)



Selection

Reconstruct **$Z \rightarrow l^+l^-$**…

- $l = e/\mu$
  - $p_T(e/\mu) > 25/20$ GeV
  - $|\eta(e/\mu)| < 2.5/2.1$
- **$76 < m(ll) < 106$** (GeV)

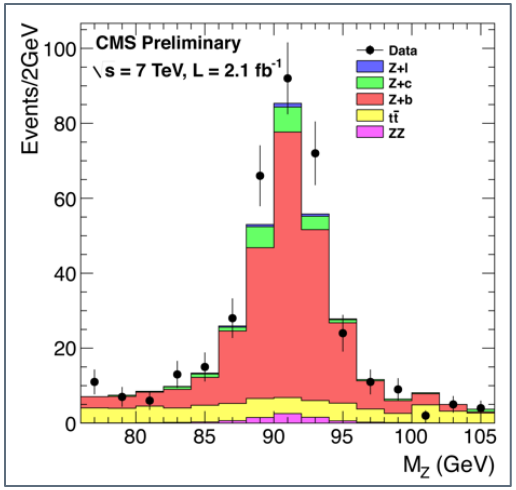
…and **two jets**…

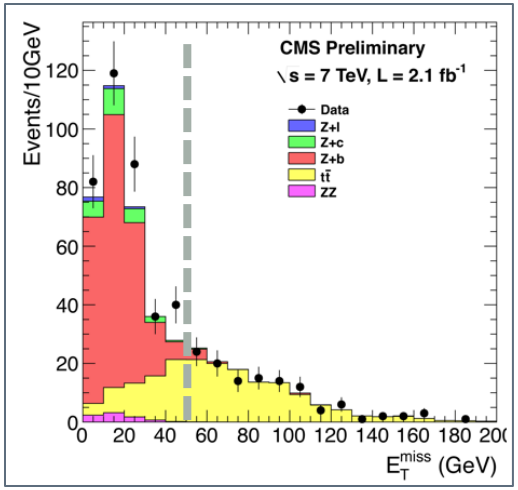
- PF, anti-k_T, $\Delta R=0.5$
  - $p_T > 25$ GeV
  - $|\eta| < 2.1$
- Reduce tt with PFMet
  - ➢ **$ME_T < 50$** GeV

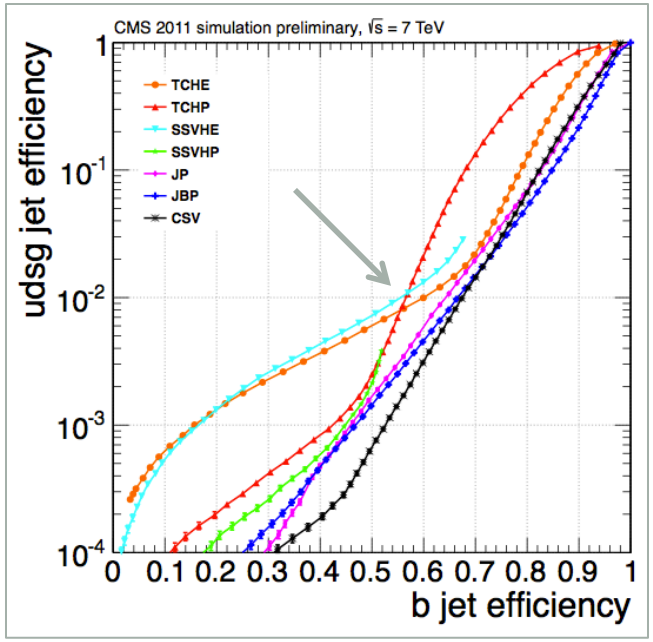
...with **b-tagging** ('SSVHE')

- Detached secondary vertex
  - High efficiency selection
    - Efficiency ~55%
    - udsg-mistag ~1%

➢ Select **Z(ll)+2b**



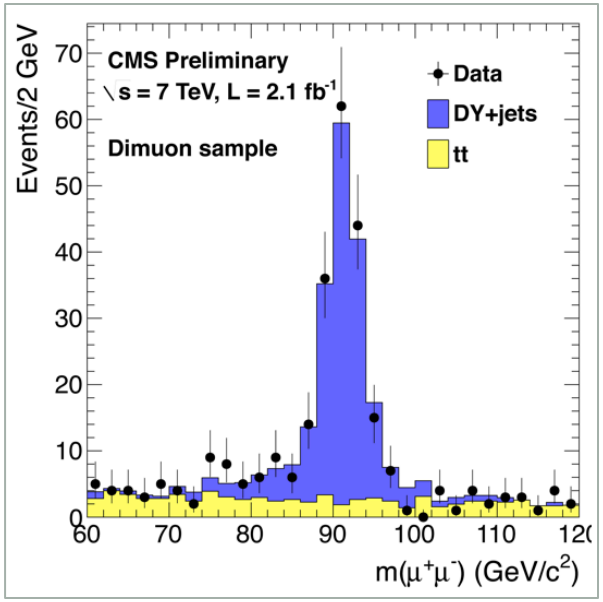


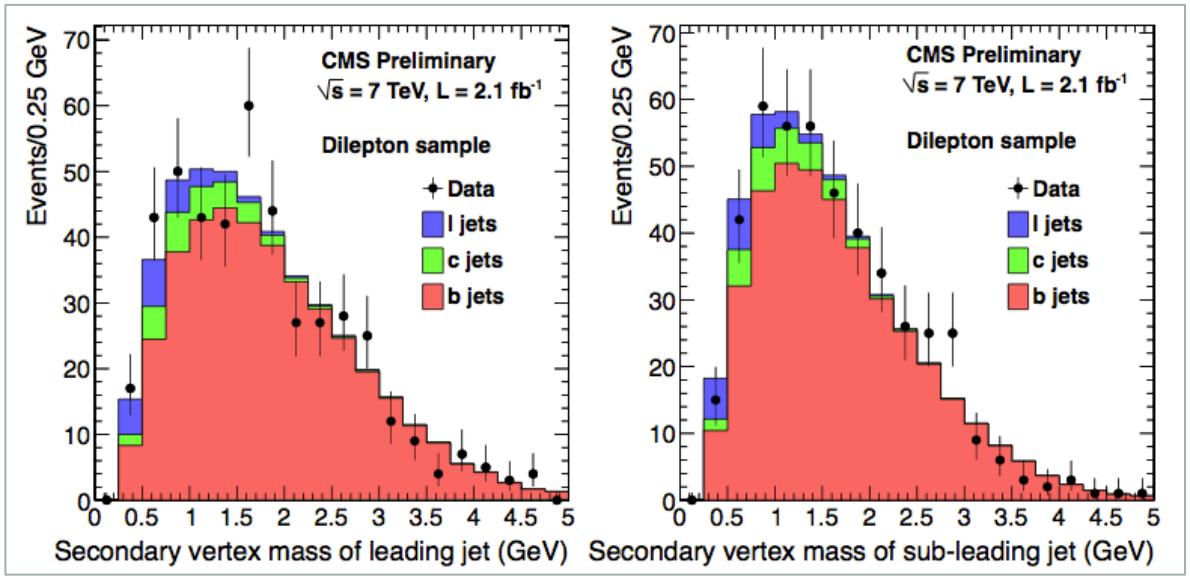


Backgrounds

To convert yields into cross-section

- **Backgrounds** estimated from data
  - **ttbar**: fit to m(ll)
  - **ZZ**
    - From MC, scaled to CMS cross-section measurement
  - **Z+ucdsg**: b-jet purity
    - Template fit to secondary vertex mass distributions





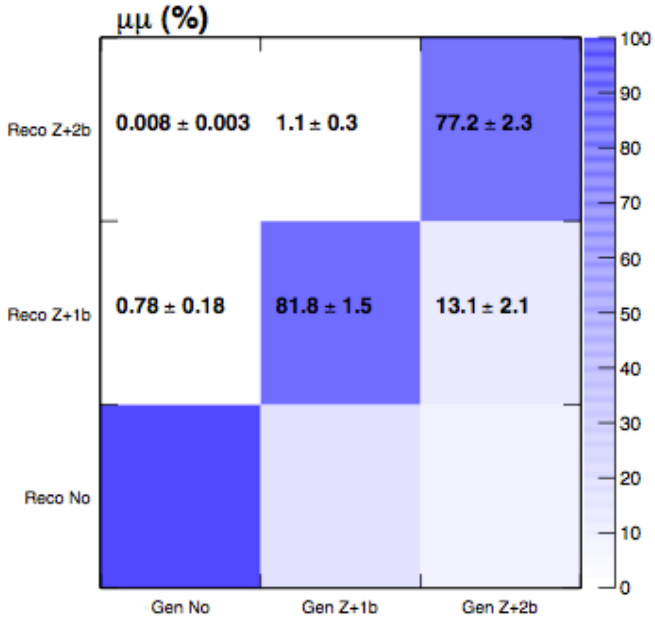
	μμ+bb	ee+bb
Yields	**219**	**148**
bb-purity	**(83 ± 6)%**	**(83 ± 6)%**
ttbar frac.	**(20 ± 5)%**	**(17 ± 5)%**
$N_{Z(ll)Z(bb)}$	**5.2 ± 0.2**	**3.0 ± 0.2**

Efficiencies

- **Z+1b and Z+2b** yields at hadron level: **unfold b-jet multiplicity**
- **# b-tagged** jets → **# reconstructed** b-jets → **# hadron-level** b-jets

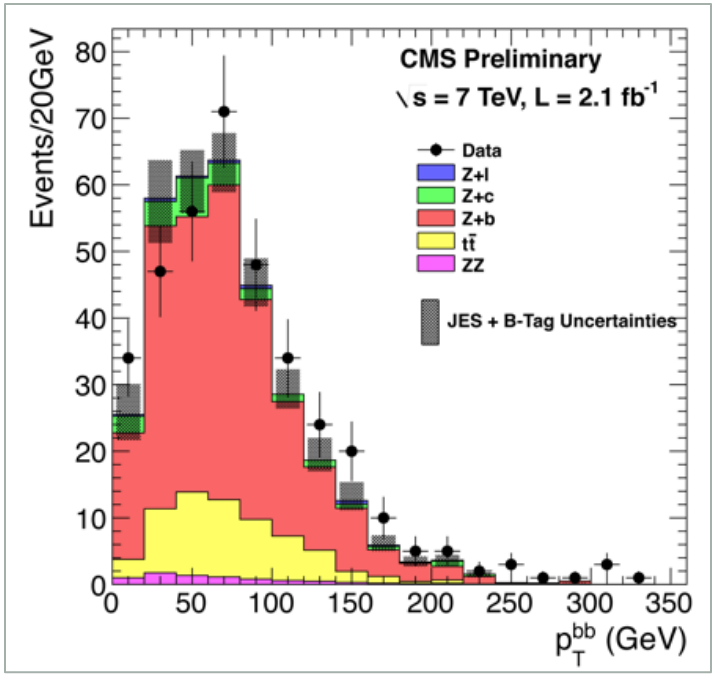
$$\begin{pmatrix} N^{gen}_{Z+1b} \\ N^{gen}_{Z+2b} \end{pmatrix} = \underbrace{\begin{pmatrix} \frac{1}{A_l^1} & 0 \\ 0 & \frac{1}{A_l^2} \end{pmatrix}}_{A_l} \underbrace{\begin{pmatrix} \epsilon_r^{11} + R\epsilon_r^{01} & \epsilon_r^{21} + R\epsilon_r^{01} \\ \epsilon_r^{12} + R\epsilon_r^{02} & \epsilon_r^{22} + R\epsilon_r^{02} \end{pmatrix}^{-1}}_{\varepsilon_r} \underbrace{\begin{pmatrix} \frac{1}{\epsilon_l^1} & 0 \\ 0 & \frac{1}{\epsilon_l^2} \end{pmatrix}}_{\varepsilon_l} \underbrace{\begin{pmatrix} \frac{1}{\epsilon_b^{11}} & -\frac{\epsilon_b^{21}}{\epsilon_b^{22}\epsilon_b^{11}} \\ 0 & \frac{1}{\epsilon_b^{22}} \end{pmatrix}}_{\varepsilon_b} \begin{pmatrix} N^{tag}_{Z_{sel}+1b} \\ N^{tag}_{Z_{sel}+2b} \end{pmatrix}$$

- **ε_b: b-tagging efficiency**
  - Scale MC to data expectations, using a.o $p_T$rel
- **ε_l: lepton selection efficiency**
  - Scale MC to data expectations, using tag&probe
- **ε_r: detector resolution**
  - Correct yields to generator level in acceptance
- **A_l: lepton acceptance**
  - Correct to full lepton acceptance



Results

- Estimated **cross section**
  - Unfold b-multiplicity
- MadGraph expectation:
- ➢ **σ(Z(ll)+2b) = 0.33 ± 0.01**(stat.) **pb**



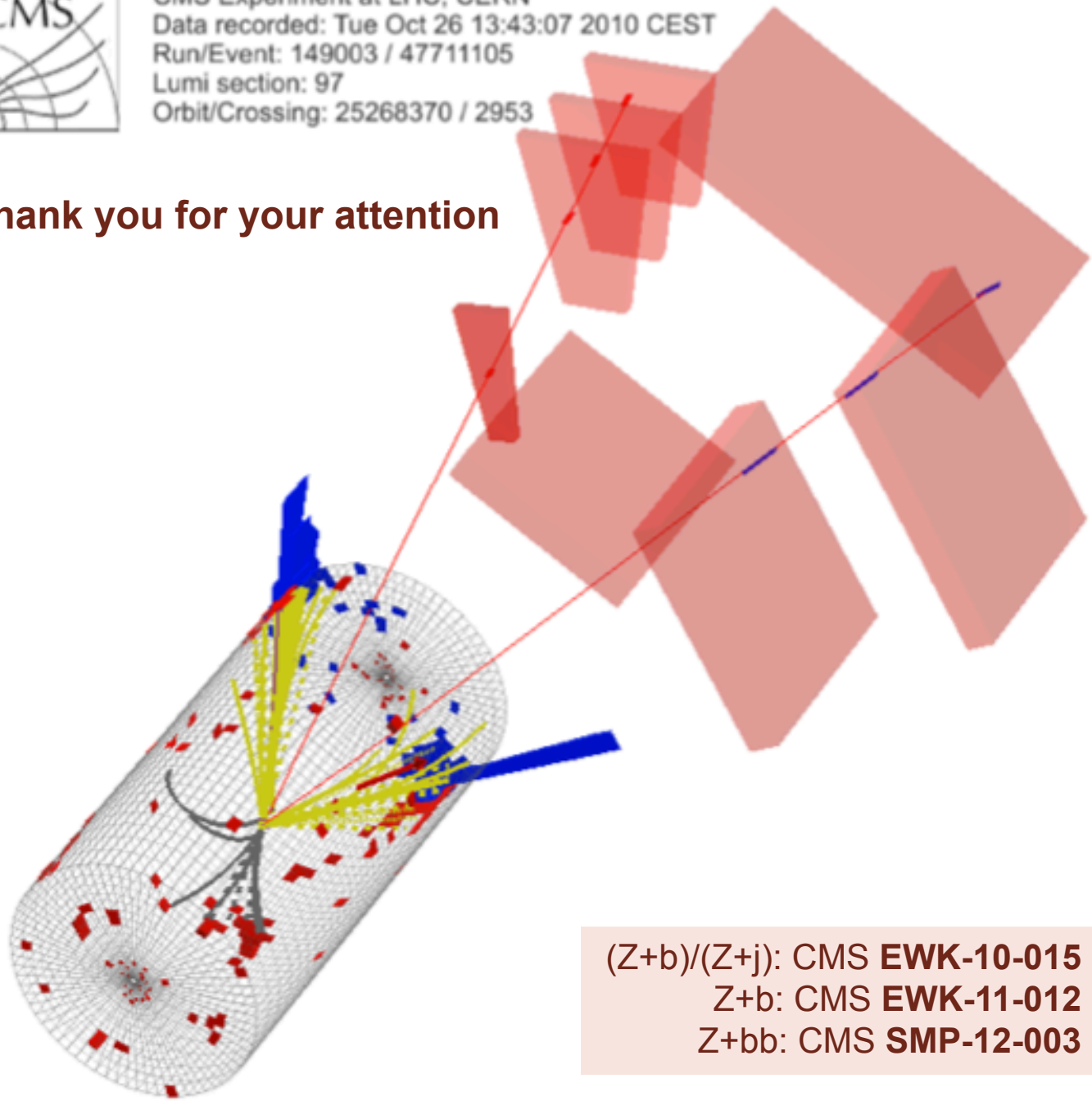
Z(ll)+nb	Cross section σ_{hadron} $p_T(l)>20$ GeV and $\lvert\eta(l)\rvert<2.5$ (acc. = 84%(e)-89%(μ), full acc.: acc. = 56%(e)-59%(μ))
Z(ll)+2b	**0.37** ± **0.02** (stat.) ± **0.07** (syst.) ± **0.02** (theory) **pb**
Z(ll)+1b	3.41 ± 0.05 (stat.) ± 0.27 (syst.) ± 0.09 (theory) pb
Z(ll)+b	3.78 ± 0.05 (stat.) ± 0.31 (syst.) ± 0.11 (theory) pb

Studied differential cross sections

- **Data/MC comparisons of kinematics**
  - ➢ Not fully in agreement
  - ➢ $p_T(bb)$, $\Delta\Phi(Z,bb)$
- **More MC comparisons required**
  - ➢ NLO MC
  - ➢ Massive b
- ➢ **Relevant for multiple searches!**

CMS Experiment at LHC, CERN
Data recorded: Tue Oct 26 13:43:07 2010 CEST
Run/Event: 149003 / 47711105
Lumi section: 97
Orbit/Crossing: 25268370 / 2953

Thank you for your attention



(Z+b)/(Z+j): CMS **EWK-10-015**
Z+b: CMS **EWK-11-012**
Z+bb: CMS **SMP-12-003**

BACKUP

References

Z+bb results

Z+b results

Selection, yields, systematics

References

- **Z+b(b)**
  - (Z+b)/(Z+j): PAS **EWK-10-015**
  - Z+b: paper **EWK-11-012**
  - Z+bb: PAS **SMP-12-003**
- **H→bb**
  - PAS **HIG-11-012**
- **B-tagging**
  - PAS **BTV-11-004**

Selection

Two electrons

Trigger	DoubleEle_17_8 CaloIdL_CaloIsoVL
p_T	> 25 GeV
$\|\eta\|$	< 2.5
η_{SC}	$\|\eta_{SC}\| < 1.4442$ or $\|\eta_{SC}\| > 1.566$
ID	WP85
Isolation	WP85 relative
Non-prompt rejection	$dB < 200\mu$m
Trigger match	Two $\Delta R < 0.3$, $\Delta p_T/p_T < 0.5$
Pair	opposite signs
Invariant mass	$76 < M_{ll} < 106$ GeV

Two muons

Trigger	DoubleMu_7, DoubleMu_13_8
p_T	> 20 GeV
$\|\eta\|$	< 2.1
ID	$n_{trk} + n_{pix} > 10$, $\chi^2 < 10$
	$n_{trk} > 0$, $n_{pix} > 0$
	$> 1\mu$ seg matched
isolation	$\Sigma(I_{combined})/p_T < 0.15$
Non-prompt rejection	$dB < 200\mu$m
Trigger match	Two $\Delta R < 0.3$, $\Delta p_T/p_T < 0.5$
Pair	opposite signs
Invariant mass	$76 < M_{ll} < 106$ GeV

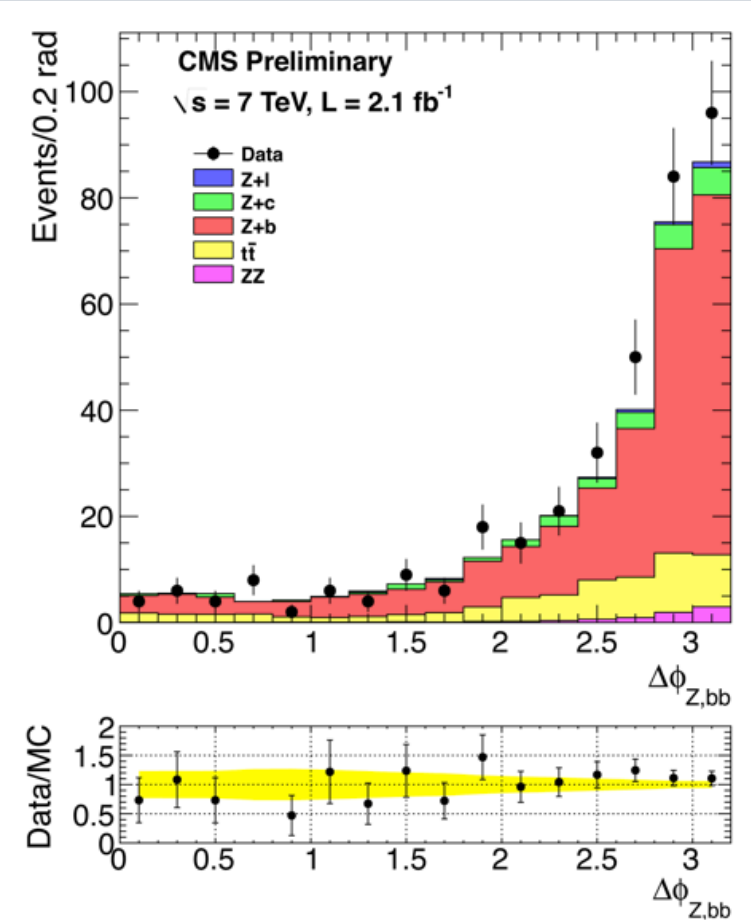
B-jet selection

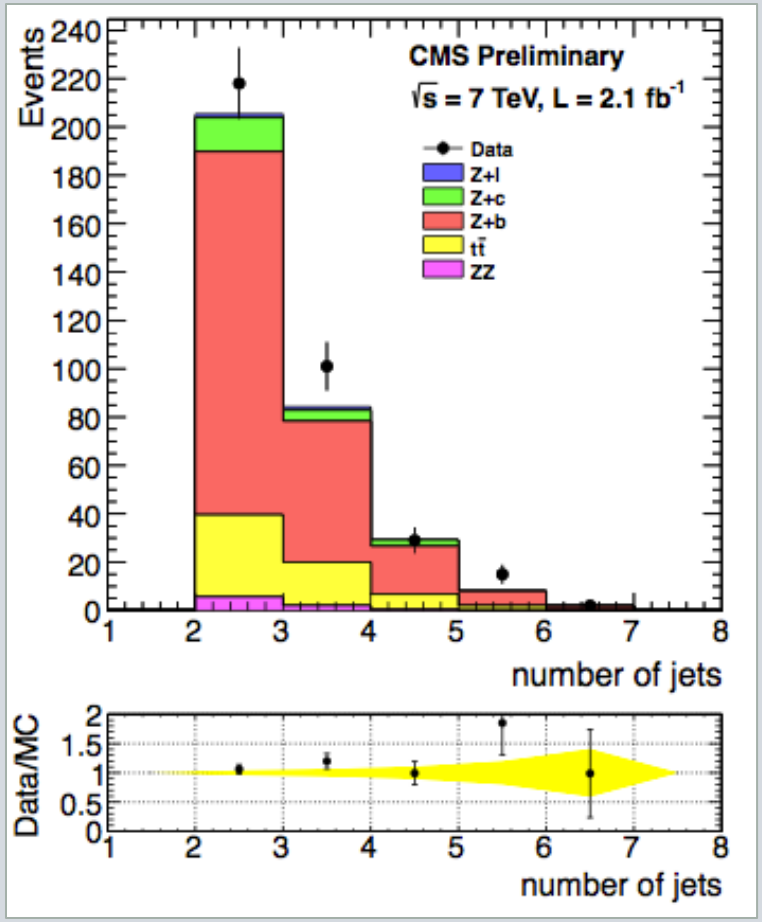
p_T	> 25 GeV
$\|\eta\|$	< 2.1
id	loose PF ID
ΔR(leptons)	> 0.5
btag High Efficiency	$SSVHE > 1.74$
(btag High Purity)	$SSVHP > 2.0$)

Vertex selection

$\|z\|$	< 24 cm
ρ	< 2 cm
n_{dof}	> 4

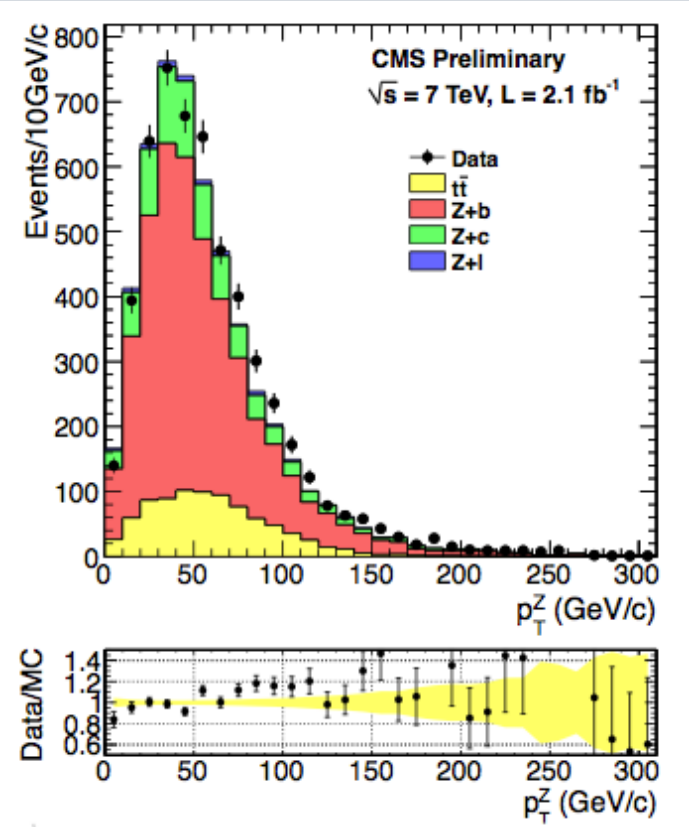
Z+2b

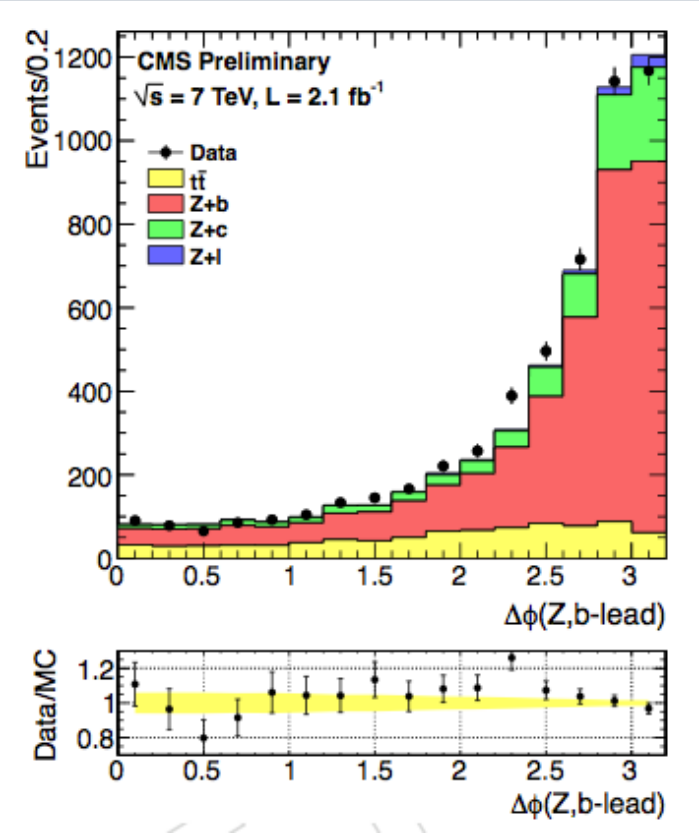

CMS Preliminary
√s = 7 TeV, L = 2.1 fb-1
Data
Z+l
Z+c
Z+b
tt̄
ZZ
Events/0.2 rad
Δφ Z,bb
Data/MC
Δφ Z,bb


CMS Preliminary
√s = 7 TeV, L = 2.1 fb-1
Data
Z+l
Z+c
Z+b
tt̄
ZZ
Events
number of jets
Data/MC
number of jets

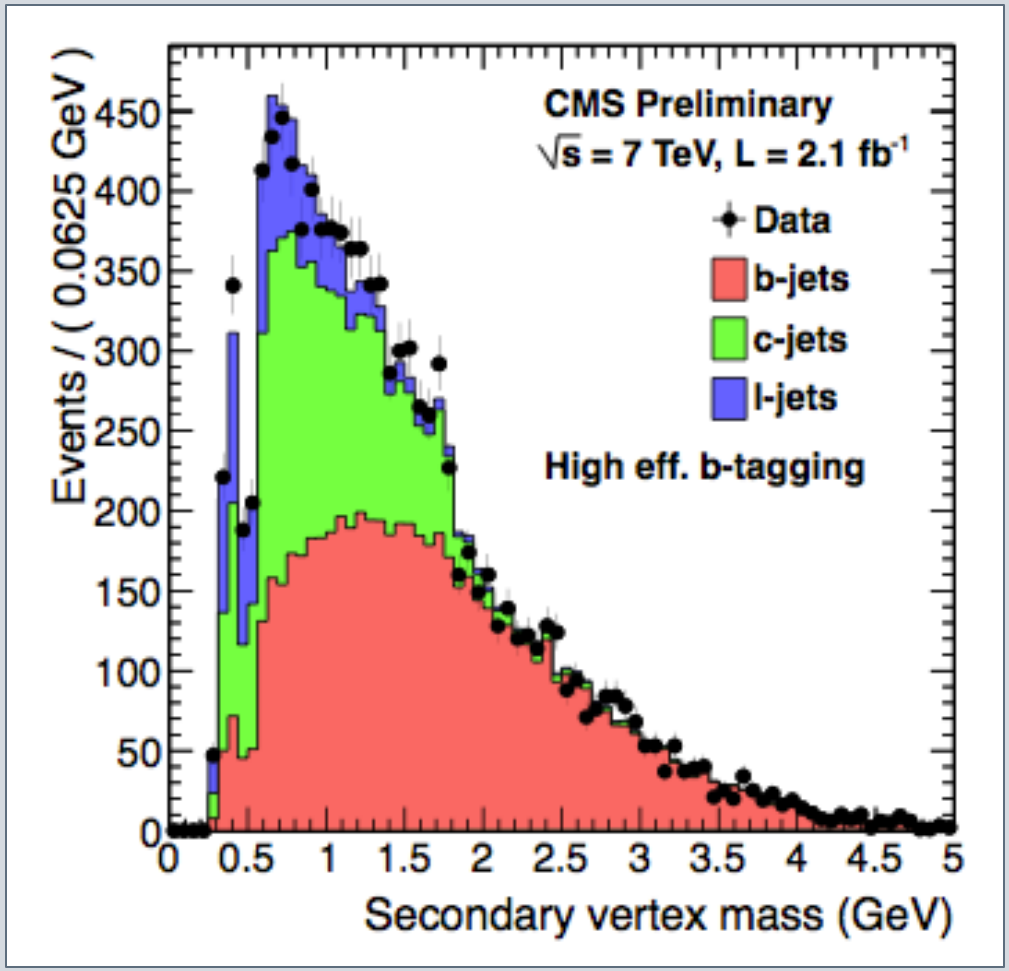
$p_T(ll)$ & $\Delta\Phi(Z,b)$
Z+1b

- **pT(ll)**



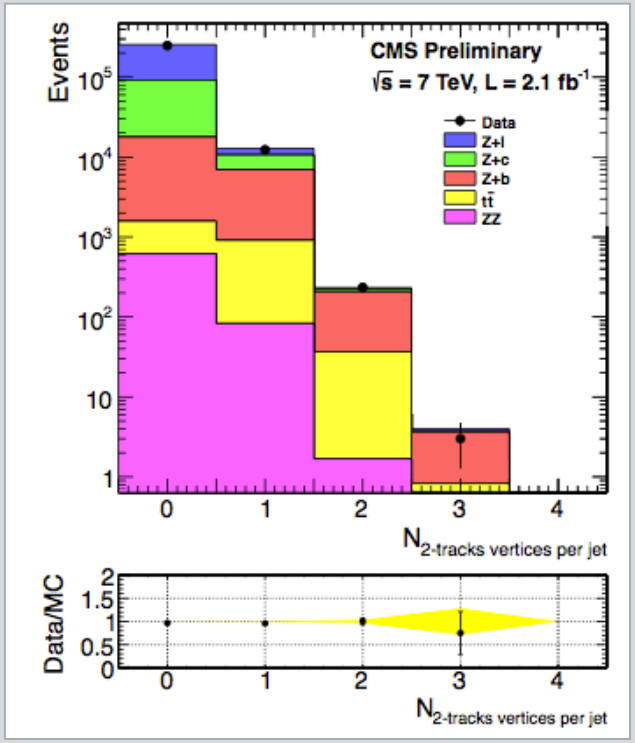


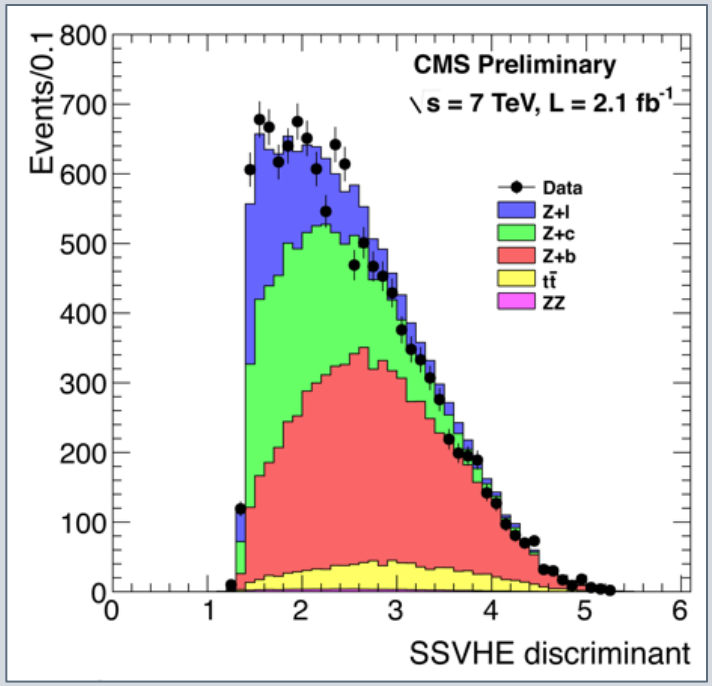
Z+1b: m(SV)


CMS Preliminary
√s = 7 TeV, L = 2.1 fb⁻¹
Data
b-jets
c-jets
l-jets
High eff. b-tagging
Events / (0.0625 GeV)
0
50
100
150
200
250
300
350
400
450
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Secondary vertex mass (GeV)

B-tagging
Z+2b

- **B-tag control plots**

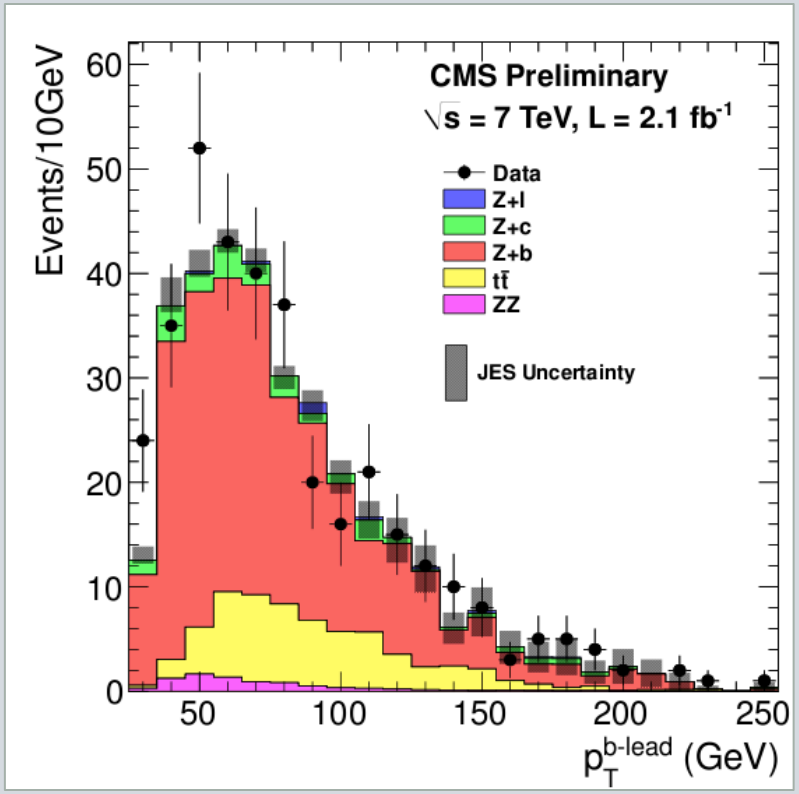


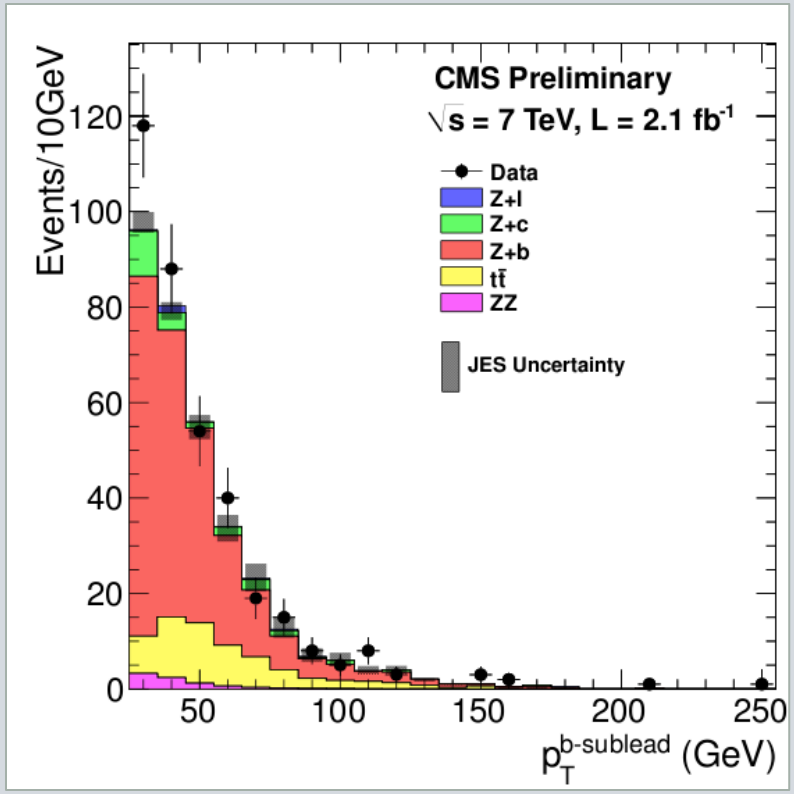


- **b/c/l fraction not fitted**
- b/c/l fractions and eff/mistag from MC

Kinematics comparison
Z+2b

- **Leading & sub-leading b-p_T**





Yields

- **Data & MC comparison after Z+bb selection**

Table 1: The data and MC yields for the different selection steps. Uncertainties are statistical only.

	data	ZZ	$t\bar{t}$	Z+b	Z+c	Z+l	Total MC	Ratio	Deviation	S/B	S/sqrt(S+B)
$Z+b\bar{b}$ [HE*HE]	484 ± 22.0	8.4 ± 0.2	175.4 ± 4.0	240.7 ± 6.6	21.9 ± 2.0	3.0 ± 0.7	449.4 ± 8.0	1.08	1.48σ	1.2	11.4
$Z+b\bar{b}$ [HE*HE]+$\not{E}_T^{miss}$	365 ± 19.1	8.3 ± 0.2	60.3 ± 2.3	235.8 ± 6.5	21.6 ± 2.0	3.0 ± 0.7	329.0 ± 7.2	1.11	1.76σ	2.5	13.0
$Z+b\bar{b}$ [HP*HP]	204 ± 14.3	3.6 ± 0.1	87.3 ± 2.8	105.5 ± 4.3	1.7 ± 0.6	0.0 ± 0.0	198.1 ± 5.2	1.03	0.39σ	1.1	7.5
$Z+b\bar{b}$ [HP*HP]+$\not{E}_T^{miss}$	142 ± 11.9	3.5 ± 0.1	28.7 ± 1.6	103.7 ± 4.3	1.7 ± 0.6	0.0 ± 0.0	137.6 ± 4.6	1.03	0.34σ	3.1	8.8

- **Choose HEHE working point**
  - Z+b: HP
  - Better significance in HEHE when requiring 2 b jets

Systematics table

- **Systematics on cross section**

Table 5: Fractional uncertainties on the measured cross sections.

	ee(%)		$\mu\mu$(%)	
Correlated sources	Z+1b	Z+2b	Z+1b	Z+2b
b-tagging efficiency	4.0	7.4	3.9	7.5
b-jet purity	3.5	10.1	2.4	10.7
$t\bar{t}$ contribution	0.9	8.7	0.6	9.2
Jet energy scale	3.9	6.8	3.8	6.3
Luminosity	4.5	4.5	4.5	4.5
MET selection	0.3	2.4	0.3	2.4
Pileup	1.7	1.8	0.3	0.3
ZZ contribution	0.2	0.6	0.1	0.8
Jet energy resolution	0.1	0.2	0.1	0.1
Mistagging rate	0.02	0.08	0.02	0.07
Theory (via $\mathcal{A}_l$)	1.8	6.7	3.0	6.4
Uncorrelated sources	Z+1b	Z+2b	Z+1b	Z+2b
MC sample stat.	1.2	5.1	0.9	4.2
Dilepton selection	4.0	4.0	1.9	1.9
Statistical	2.4	9.9	1.8	8.0
Experimental systematic	9.1	18.4	7.7	18.5
Theoretical systematic	1.8	6.7	3.0	6.4