



Risonanze ad alta massa ed analisi Beyond 2 Generations

CMS Italia

30 Novembre 2017

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Overview:

- Fisica e topologie nel B2G
- Stato delle analisi attuali
- Nuove idee e analisi possibili
- Prospettive per i dati 2017-18

Il gruppo B2G: alla ricerca di risonanze ad alta massa

Tipologia di nuova fisica nel gruppo Beyond 2 Generations:

- interagisce in maniera privilegiata con la **terza famiglia di quark** (t/b) e con i in **bosoni SM** (W/Z/H)
- stati **risonanti** in nuove particelle, o particelle pesanti in produzione associata

Risonanze ad alta massa: → particelle pesanti SM “**boosted**”

Regioni estreme dello spazio delle fasi per fondi SM → tecniche **data driven**

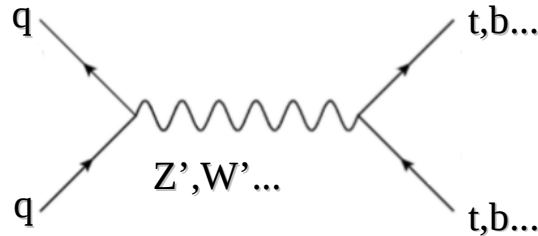
Topics di fisica del B2G e organizzazione

Processi

Un esempio

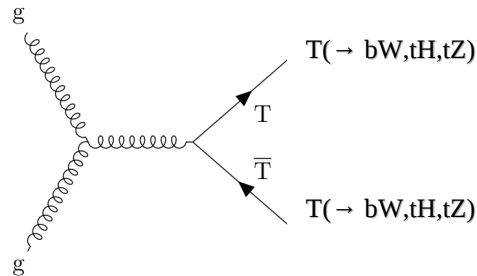
Gruppo

Risonanze **W'/Z'**
 Stati eccitati **t^*/g^***
Lepto Quarks \rightarrow quarks



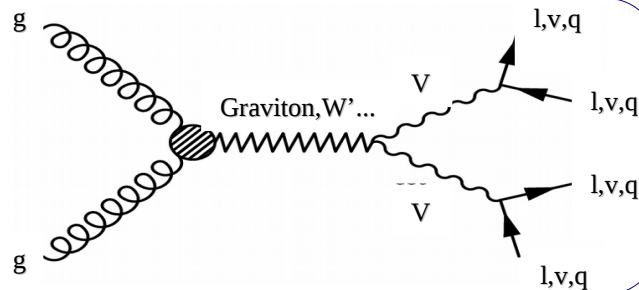
“Resonances” (RES)

Vector-Like-Quarks (T, B):
 produzione doppia e singola



“Very Heavy Fermions” (VHF)

Stati risonanti in **coppie di bosoni VV/VH/HH**

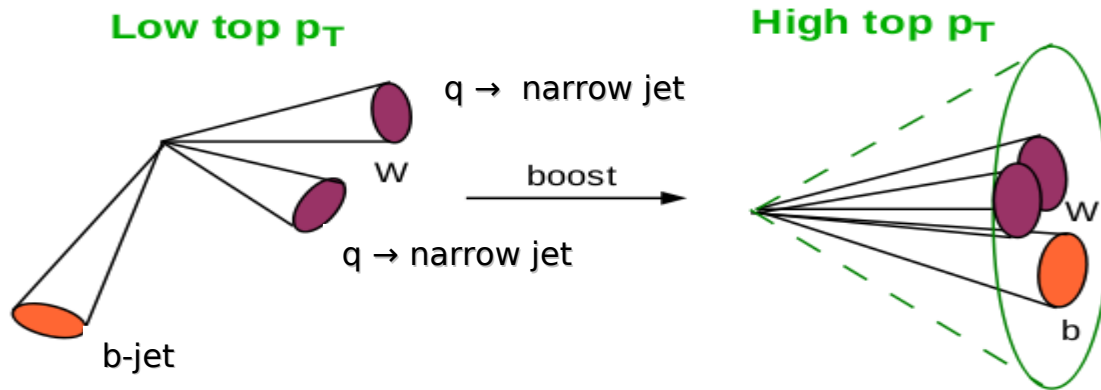


“Dibosons” (DIB)

“Strumenti” del B2G: particelle SM boosted

Risonanze ad energie di \sim TeV:

- top quarks prodotti con forte boost
- decadimenti adronici: un unico jet nello stato finale.



Decadimenti “merged” in un fat jet

- si identificano i componenti “sub-jet”

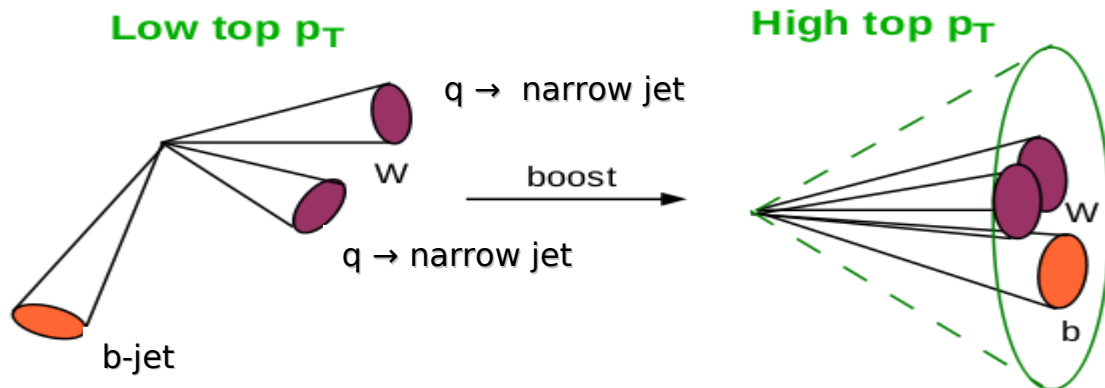
- potenzialmente si usa il b-tagging per i sub-jet

“Strumenti” del B2G: particelle SM boosted

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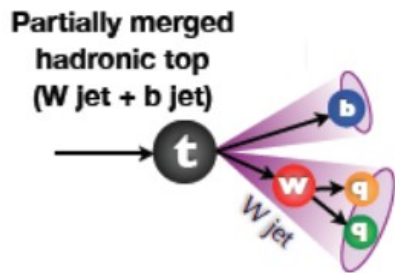


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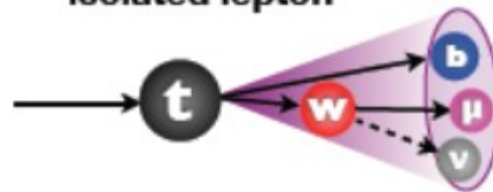
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Altri casi (per il top): decadimenti del bosone W separati dal top o decadimenti leptonici:



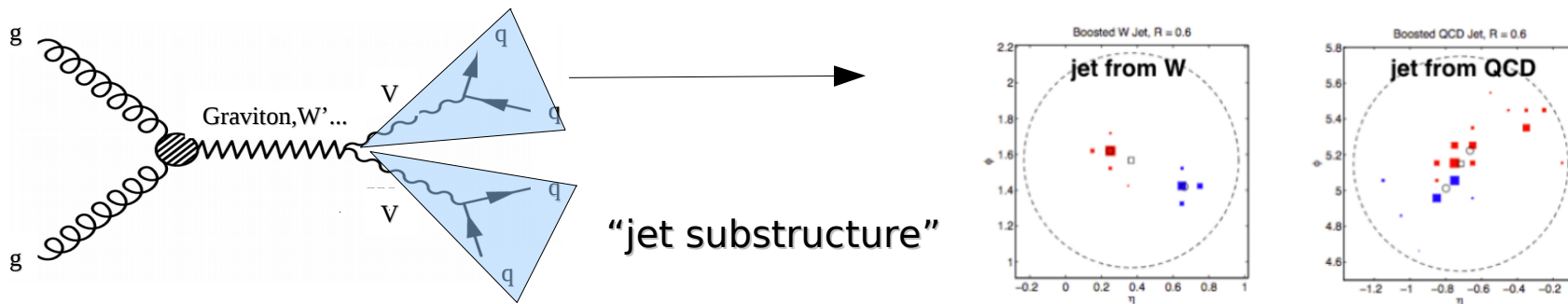
Albo

Leptonic top with non-isolated lepton



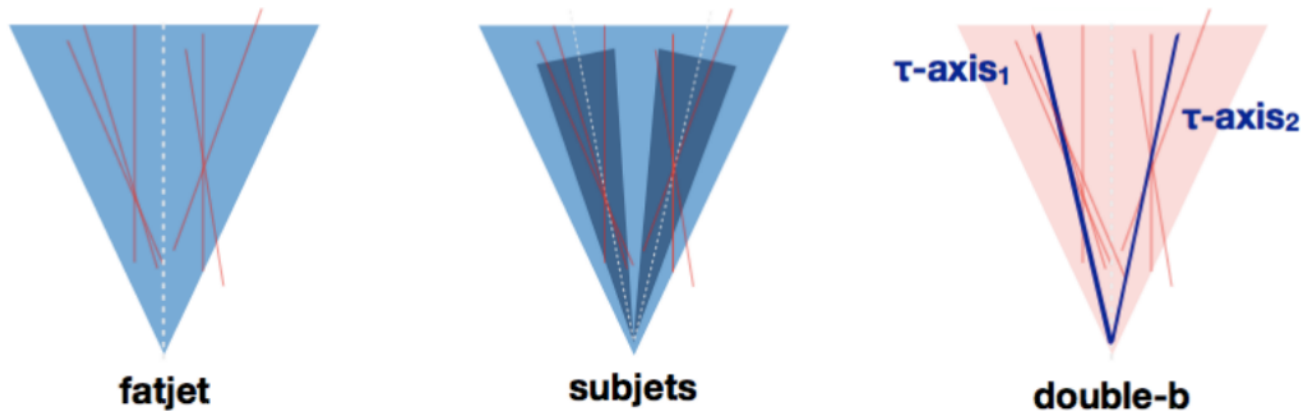
“Strumenti” del B2G: particelle SM boosted

Bosoni W e Z:



Bosoni H/Z \rightarrow bb

b-tagging dei subjet oppure un approccio **“inclusivo”** (double tagger:



B2G connections in CMS



- Stretti legami, di natura diversa, con gli altri PAG

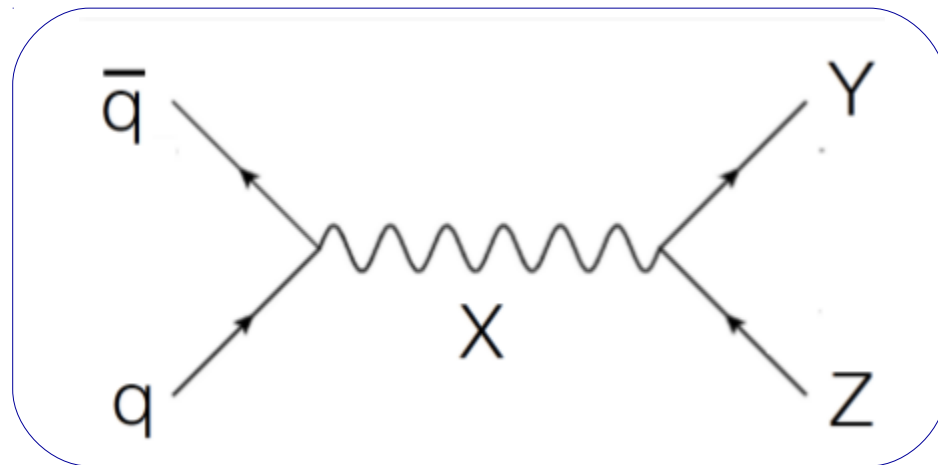
- Legame anche con i POG, specie JME per sugli oggetti boosted

Searches gruppo per gruppo

Risonanze in quark pesanti (RES)

Nuove risonanze (processi nel canale s) che decadono in quark di terza generazione ed oltre:

- $X = Z', W', gKK, t^*, b^* \dots$
- $Y, Z = t, b, T, B \dots$

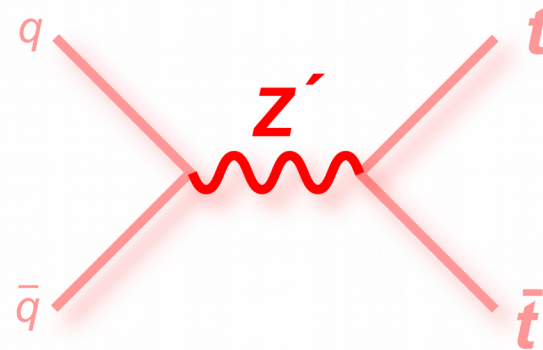


Risonanze in $Z' \rightarrow tt$

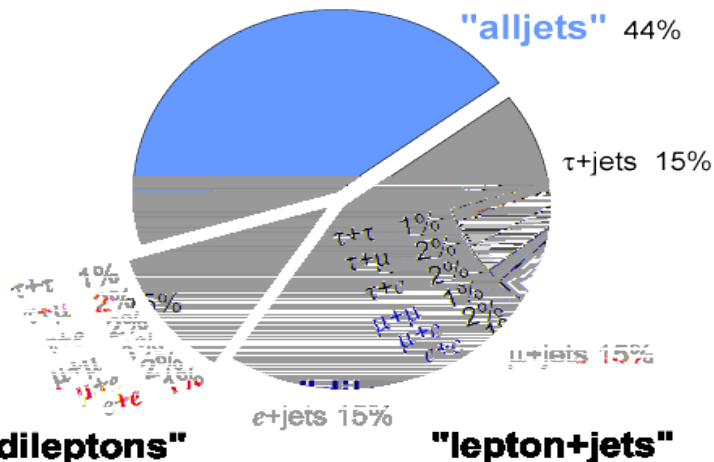
“Benchmark analyses”: stati finali comune a diversi modelli, relativamente semplice

Tipi di decadimento delle coppie tt :

Dileptonici, semi-leptonici, all-hadronic,



Top Pair Branching Fractions



Rispetto allo SM tt :

- Massa dello $Z' > \text{TeV} \rightarrow$ tutti i top boosted
- per ora nessuna

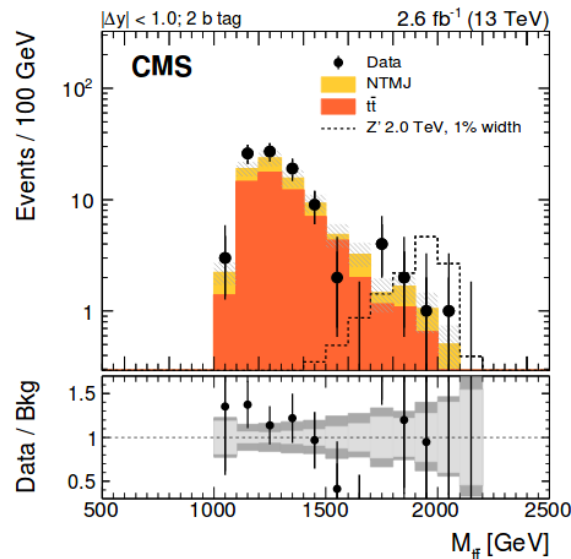
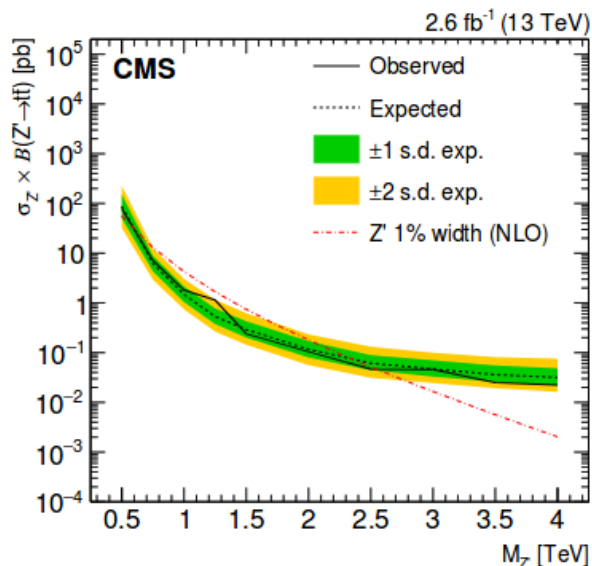
Risonanze in $Z' \rightarrow tt$

Misura attualmente pubblicata con dati 2015 - combina canali semileptonico e adronico

→ In fase avanzata di lavorazione la misura con i dati 2016.

→ Estende la sensibilità a masse molto più elevate

<https://arxiv.org/abs/1704.03366>

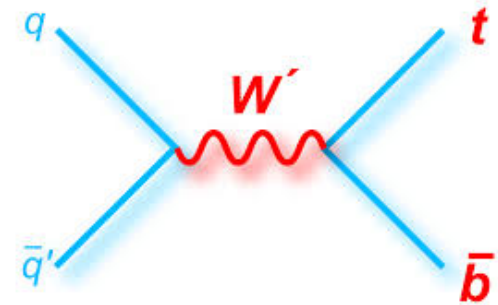


Con 36/fb ci si aspetta 0.5-1 TeV di miglioramento:

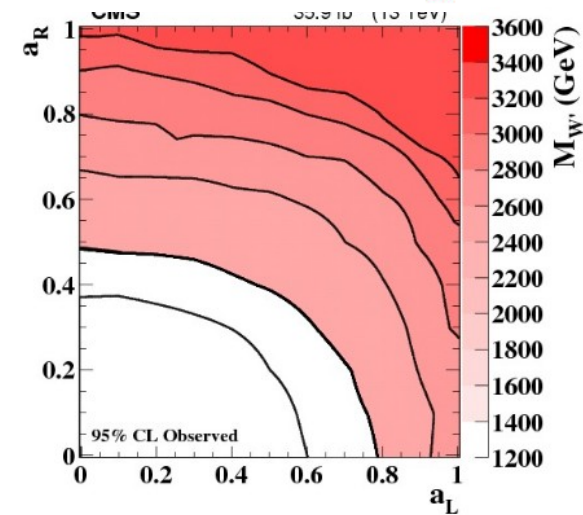
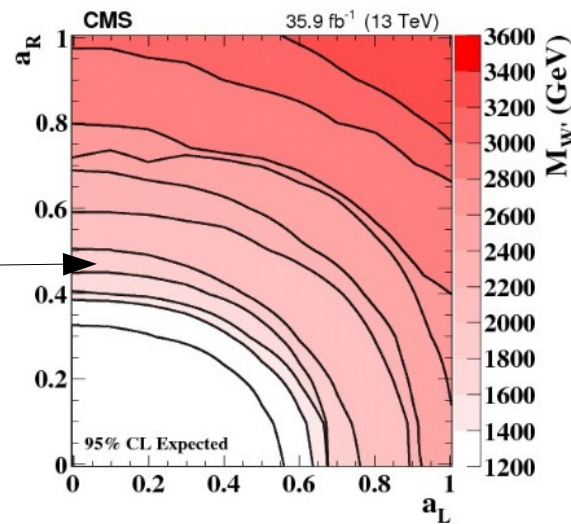
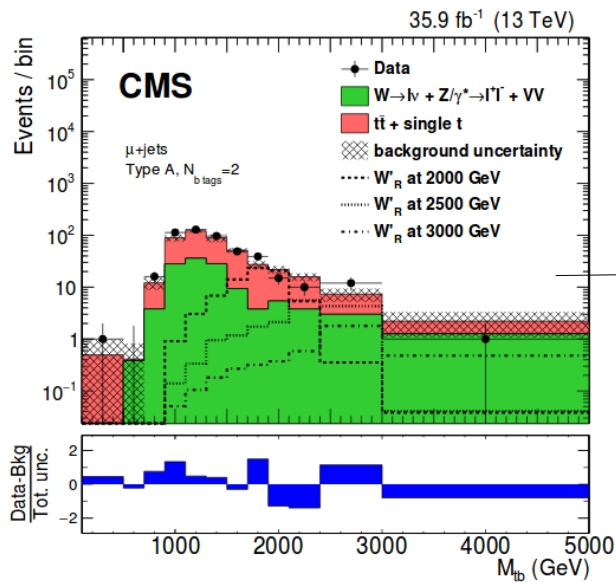
Mass Exclusion Limits	
Signal Model	Expected Exclusion Range (TeV)
Z' (1% Width)	1.0 – 3.5
Z' (10% Width)	1.0 – 4.3
Z' (30% Width)	1.0 – 5.0
RS Gluon	1.0 –

Risonanze in $W' \rightarrow tb$

Misura con i dati del 2016: limiti più stringenti disponibili nel canale semi-leptonico!



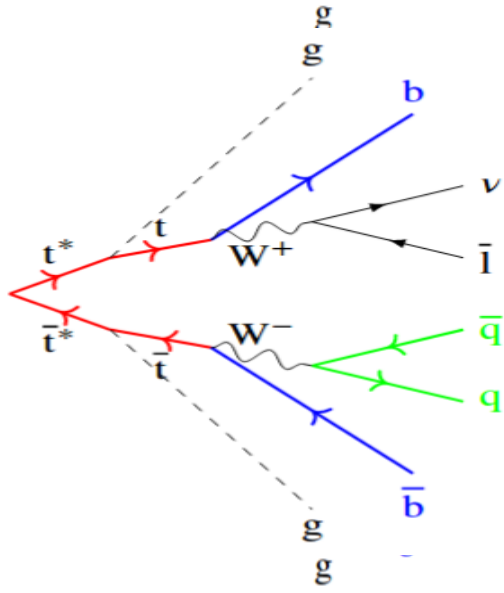
→ Limiti su accoppiamenti left e right



<https://arxiv.org/abs/1708.08539>

→ Canale adronico al momento **non coperto!** Ultima misura con i **dati 2015**

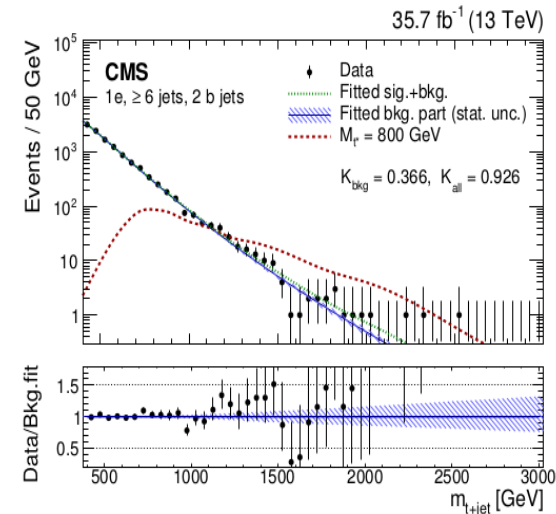
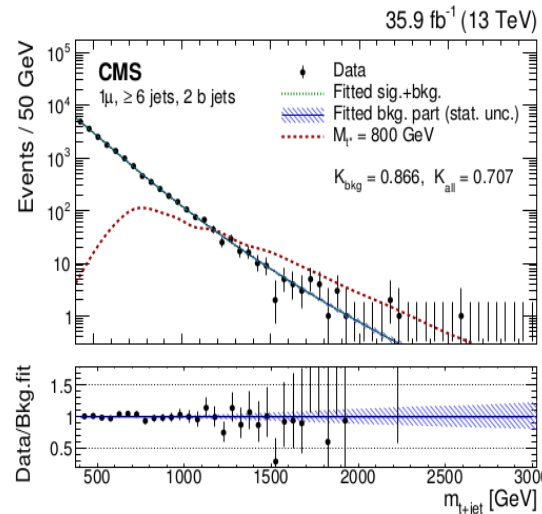
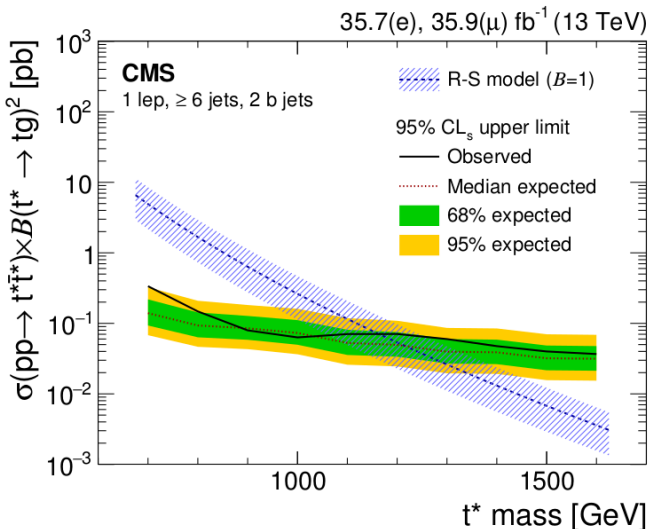
Risonanze in stati eccitati



Risonanze in stati eccitati **t*t*** a spin 3/2:

→ limiti migliori al momento a 13 TeV

→ possibili miglioramenti per il Full-Run II esplorando topologie boosted

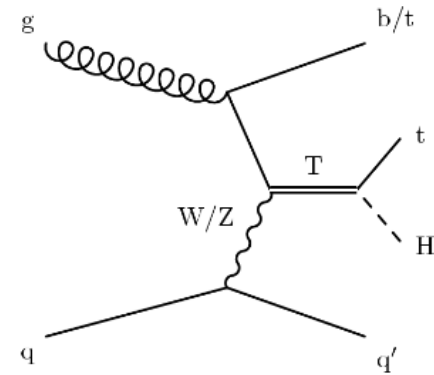
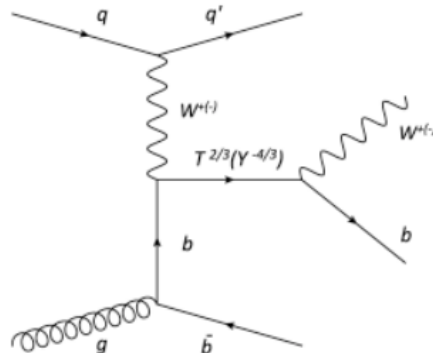
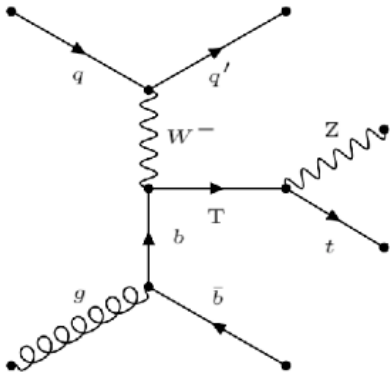
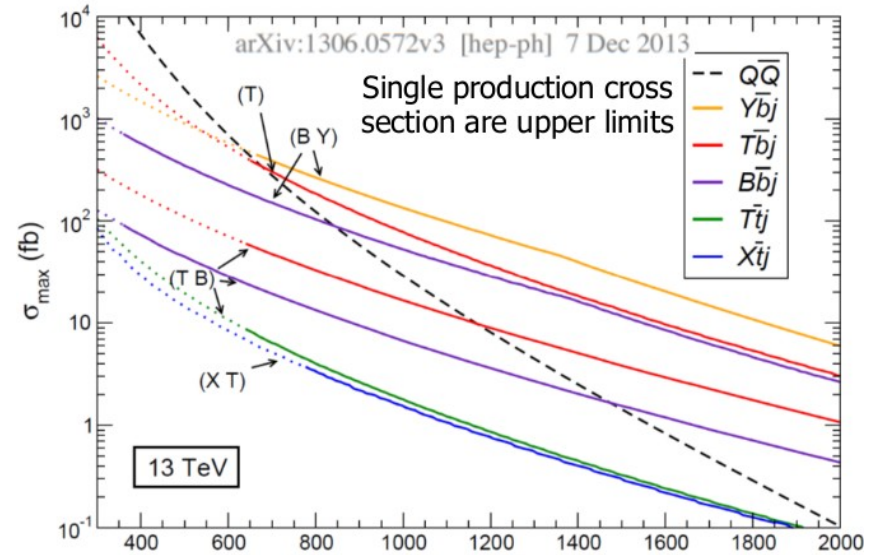
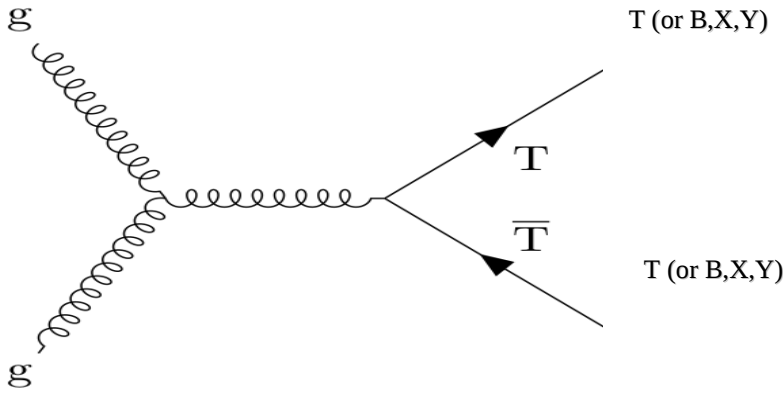


Sottomesso ad arXiv ieri, vedi anche PAS B2G-16-025

Produzione diretta di quark oltre la terza generazione

Produzione di Vector Like T, B quark e X (carica 5/3), Y carica (4/3):

→ **Produzione doppia**

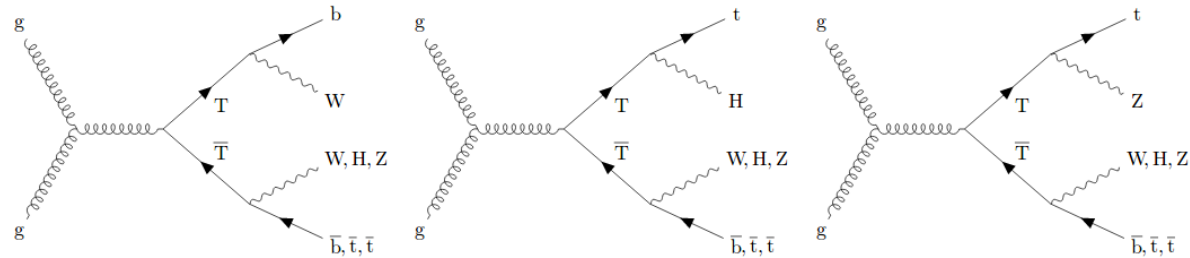


Coppie di Vector Like Quarks (VLQ)

Numerosi canali di decadimento:

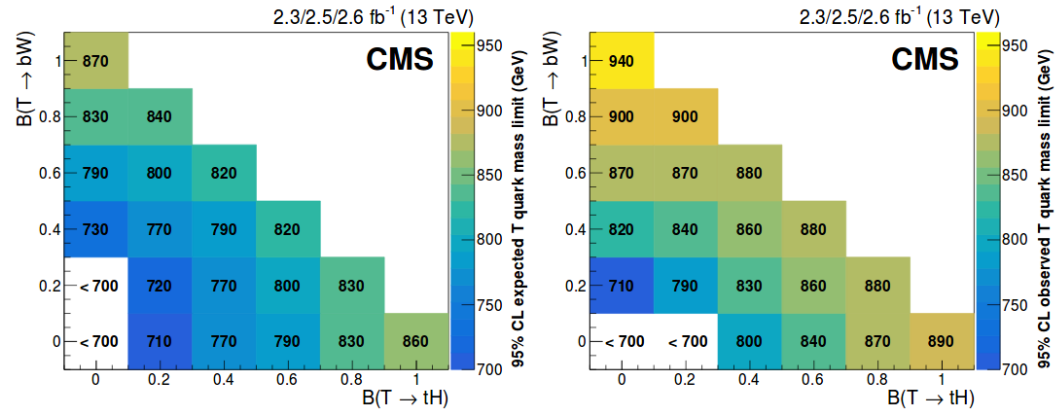
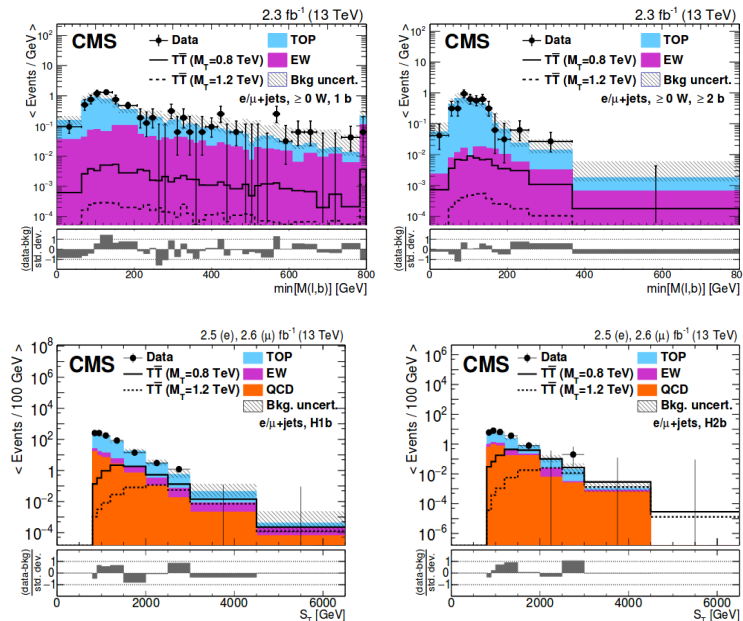
- T/Y \rightarrow tH, tZ, Wb
- B \rightarrow bH, bZ
- X \rightarrow Wt

Single lepton final state :
 Selezioni diverse per estrarre
 limiti a BR simultaneamente



<http://arxiv.org/abs/1706.03408>

Analisi con dati 2015 - 2016 in progress!



Coppie di Vector Like Quarks (VLQ)

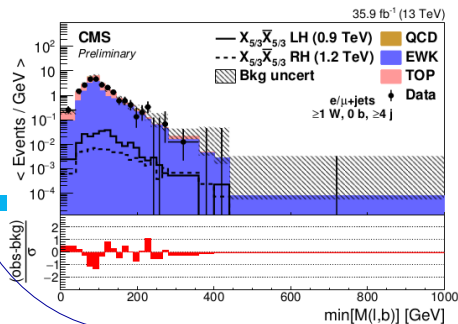
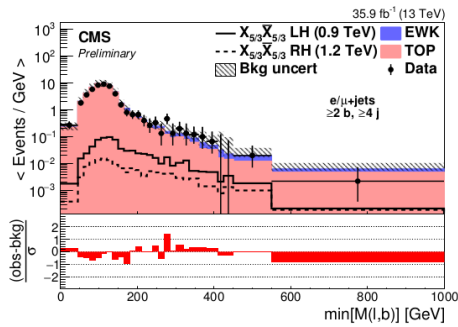
Numerosi canali di decadimento:

T/Y → WbWb
 XX → WtWt

TT → WbWb
 fit cinematico

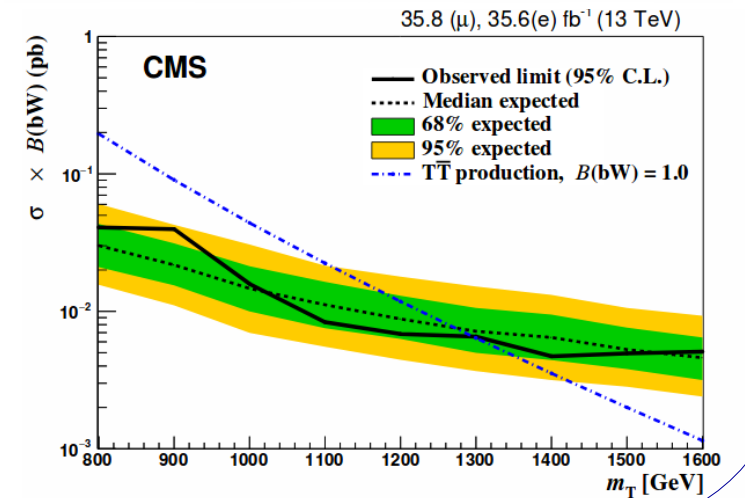
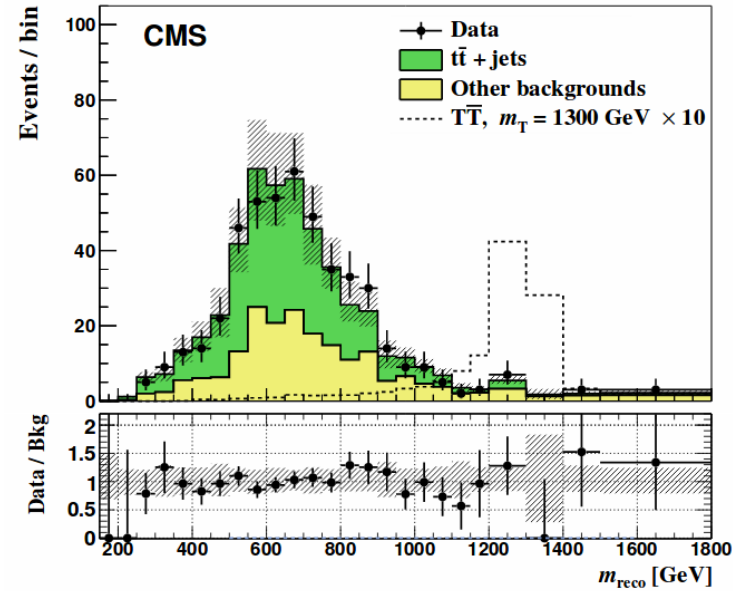
Molteplici leptoni nello stato finale: leptoni con lo stesso segno per ridurre il fondo SM

PAS B2G-17-008
 combinazione con Opposite-sign leptons in corso



<https://arxiv.org/abs/1710.01539>

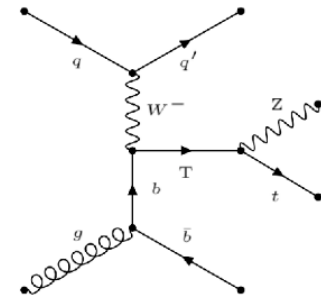
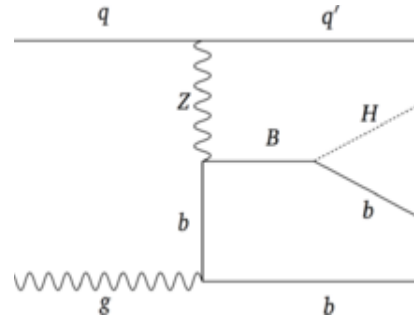
35.8 (μ), 35.6(e) fb⁻¹ (13 TeV)



Single VLQ e accoppiamenti allo SM

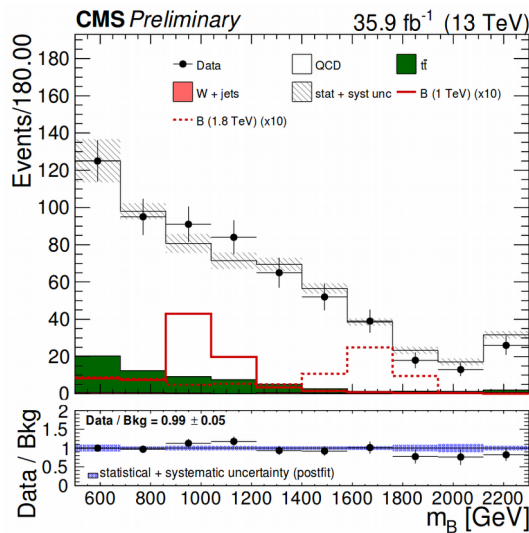
Canali a produzione singola:

→ Accoppiamento elettrodebole con SM quarks tramite vertice $T(B)Wq$



$B \rightarrow bH$ ($H \rightarrow bb$):

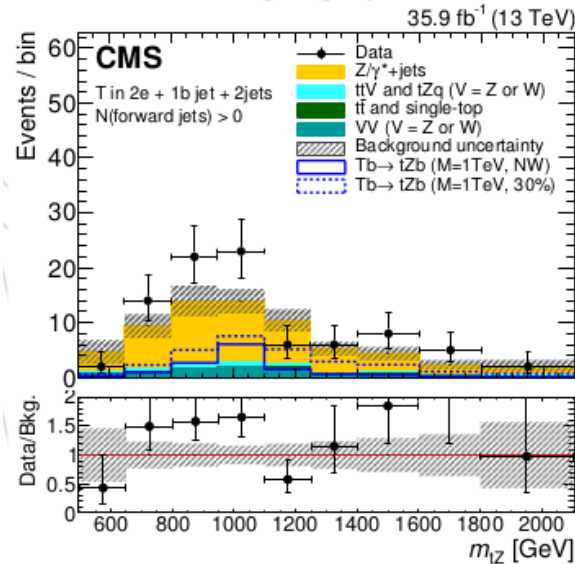
Prima misura di quest tipo!



PAS B2G-17-009 – paper after CWR

$T \rightarrow tZ$ ($Z \rightarrow ll$):

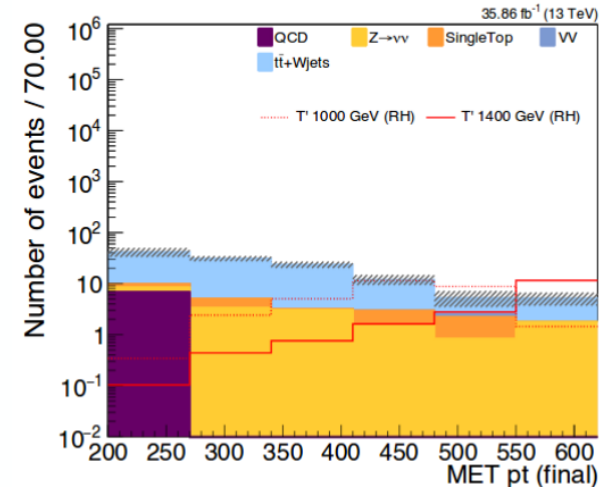
si può ricostruire in maniera diretta m_T



<http://arxiv.org/abs/1708.01062>

$T \rightarrow tZ$ ($Z \rightarrow \nu\nu$):

Nuovo canale (WIP)
collaborazione Napoli-UZH



Risonanze in VLQ: nuovi canali "CMS only"

$W' \rightarrow bT/B e t$ $Z' \rightarrow tT$: new benchmarks!

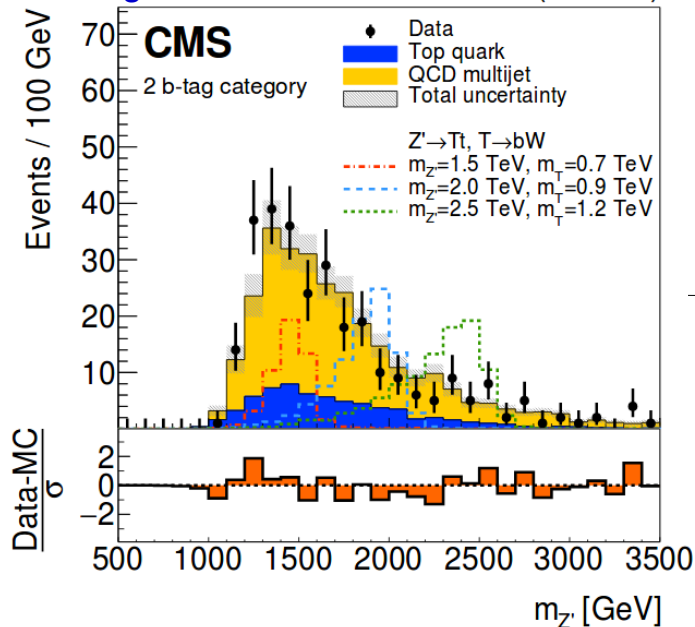
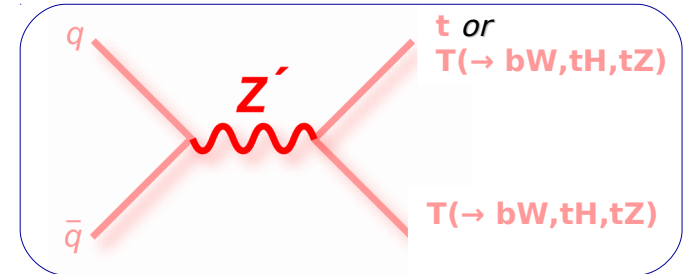
- canali in cui ci sono VLQ nella catena di decadimento (**T,B**)

- nuovi modelli che abbiamo iniziato ad esplorare nel
→ references: W' : 10.1103/PhysRevD.89.095027

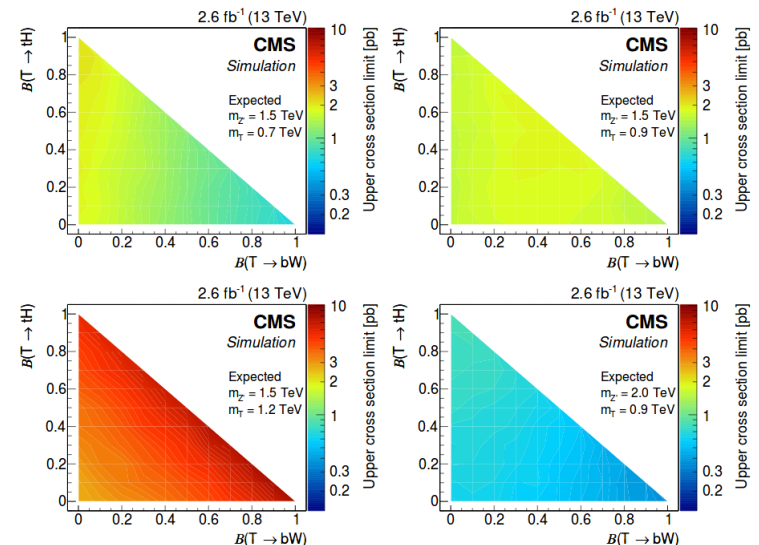
Z' : 10.1007/JHEP01(2012)157; arXiv:1611.03433

- Prima misura con dati 2015, misure 2016 in progress:

<https://arxiv.org/abs/1703.06352> 2.6 fb⁻¹ (13 TeV)

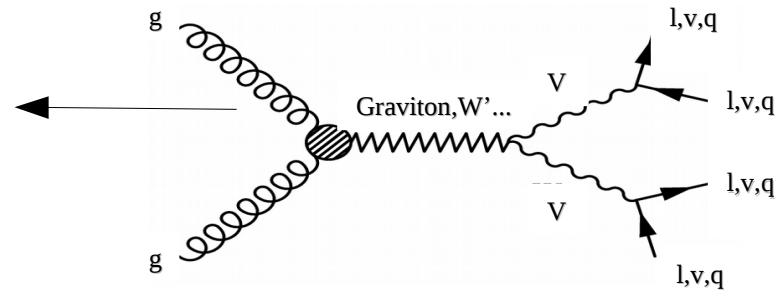


to Orso Maria



Risonanze in coppie di bosoni

Numerosi possibili stati finali da studiare



	W/Z(qq)	Z(vv)	W(lv)	Z(ll)	H(bb)	H(ττ)
W/Z(qq)	17-001					
Z(vv)	17-005					
W(lv)	16-029					
Z(ll)	17-013	16-023				
H(bb)	17-002	17-004	17-004	17-004	16-026	
H(ττ)	17-006		17-016		17-006	

- Categorizzati in base a decadimento, massa del jet etc.
- Coinvolgimento italiano di Padova in molte di queste analisi

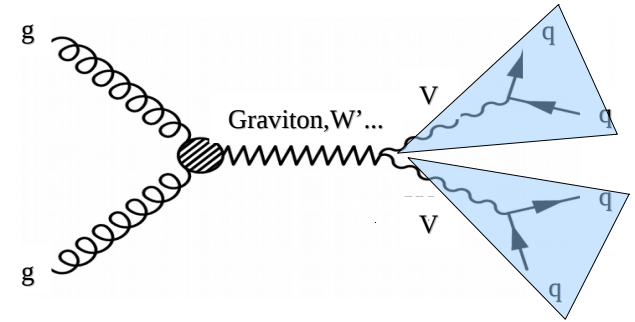
Risonanze in coppie di bosoni: canali adronici

Analisi con 2 Jet (ak8) nello stato finale:

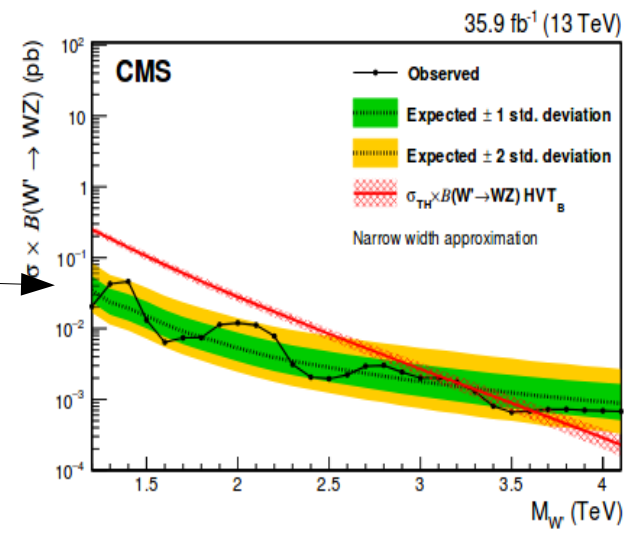
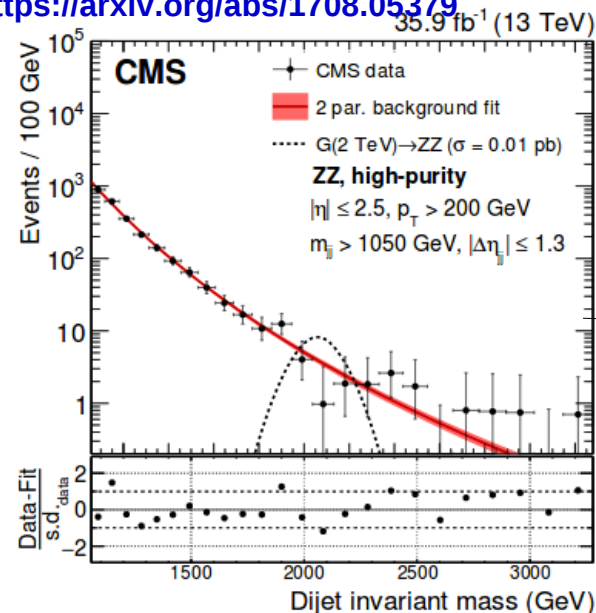
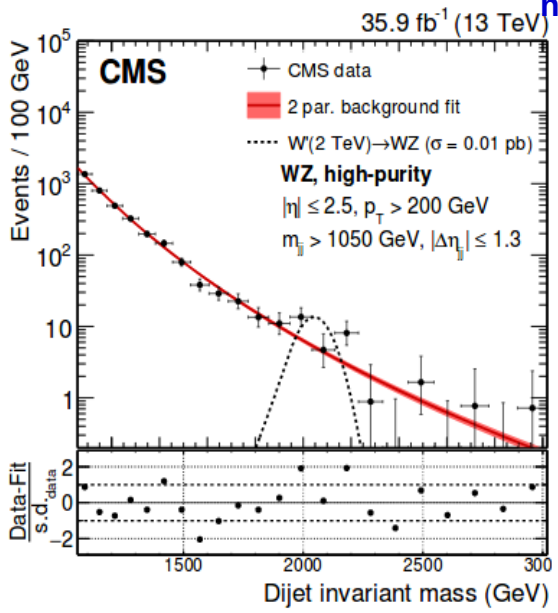
→ limiti su VV e su $q^* \rightarrow qW$

Massa del jet usata per discriminare i tipi di bosone

Fit ad m_{JJ} in categorie a diversa purezza usando
l' n -subjettiness



<https://arxiv.org/abs/1708.05379>

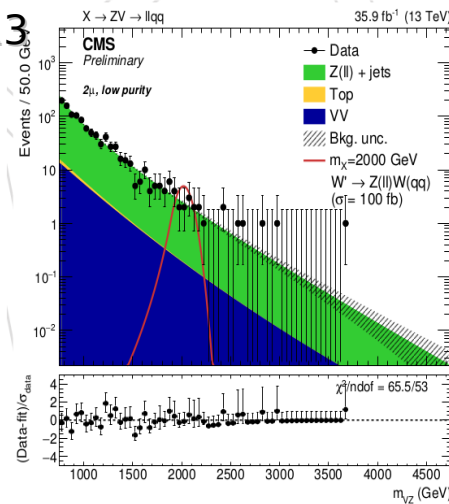
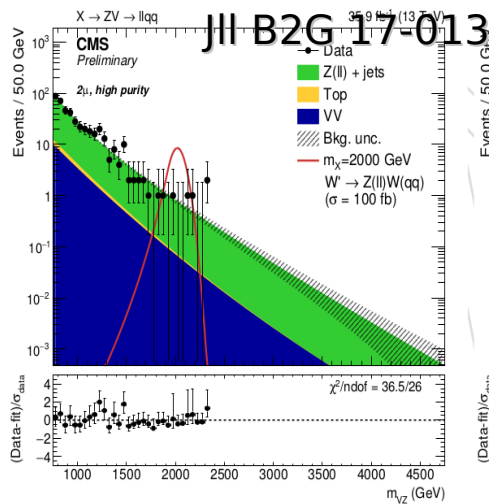


Risonanze in coppie di bosoni: canali leptonici

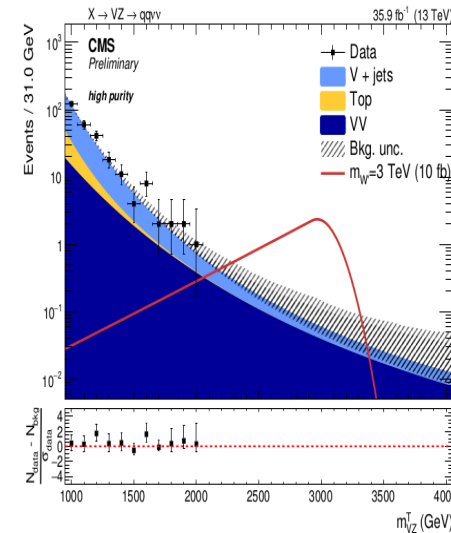
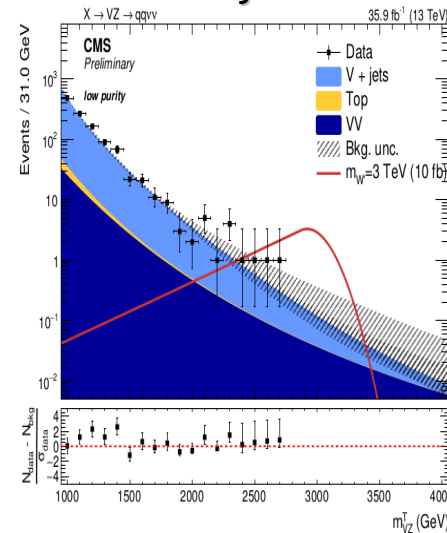
Canali complementari in cui:

- $VV \rightarrow 1 \text{ Jet} + (\ell\ell/l\nu/v\nu)$

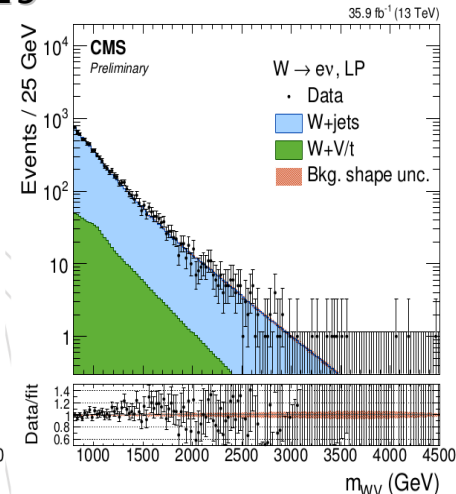
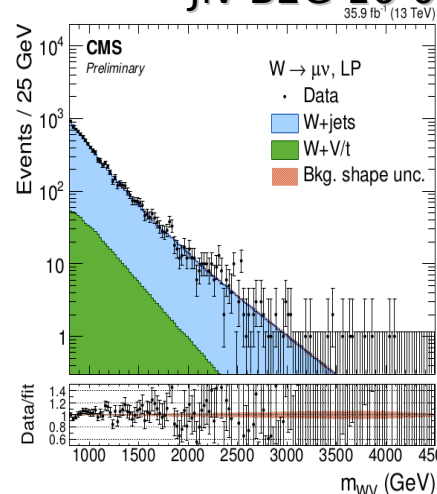
- Contributo di Padova (Lisa Benato, Jacopo Pazzini - currently Brown)



Jvv PAS B2G 17-005



Jlv B2G 16-029



HH → 4b resonances

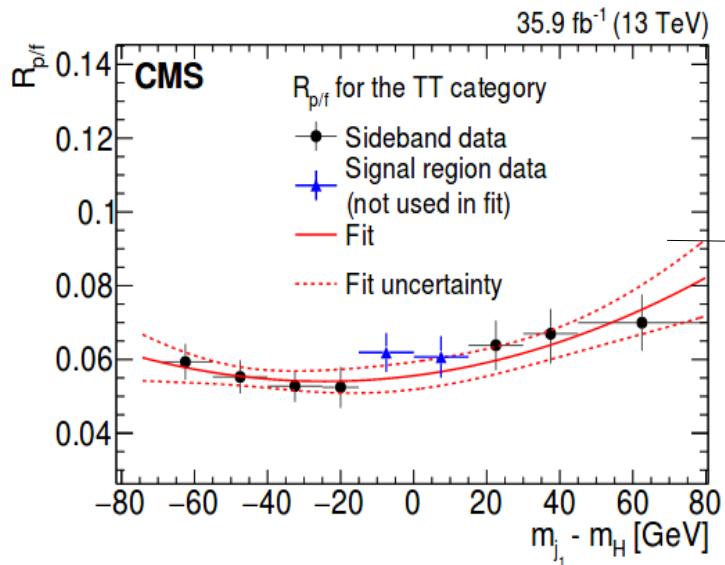
Risonanze in **HH**:

→ Canale principale con HH→ 4b, identificati con il double b-tagger

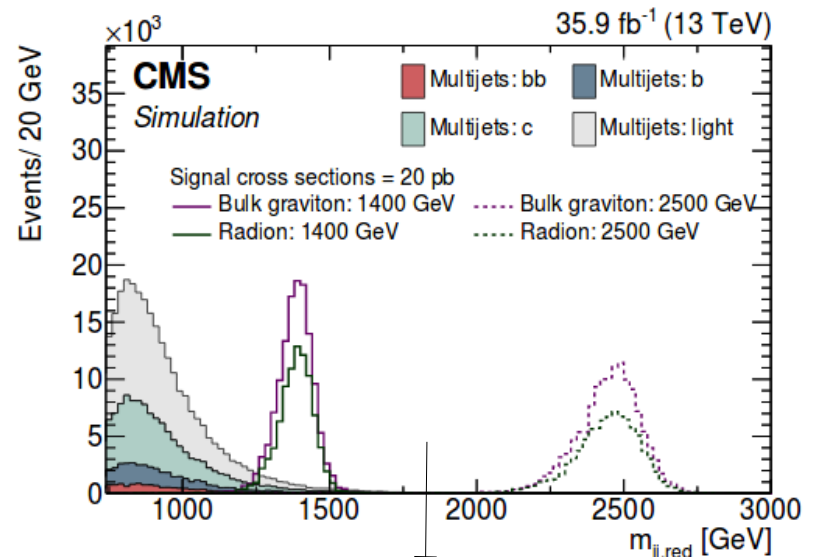
→ variabile discriminante: massa ridotta

$$M_{jj}^{\text{red}} = M(jj) - (M_{\text{jet1}} - M_H) - (M_{\text{jet2}} - M_H)$$

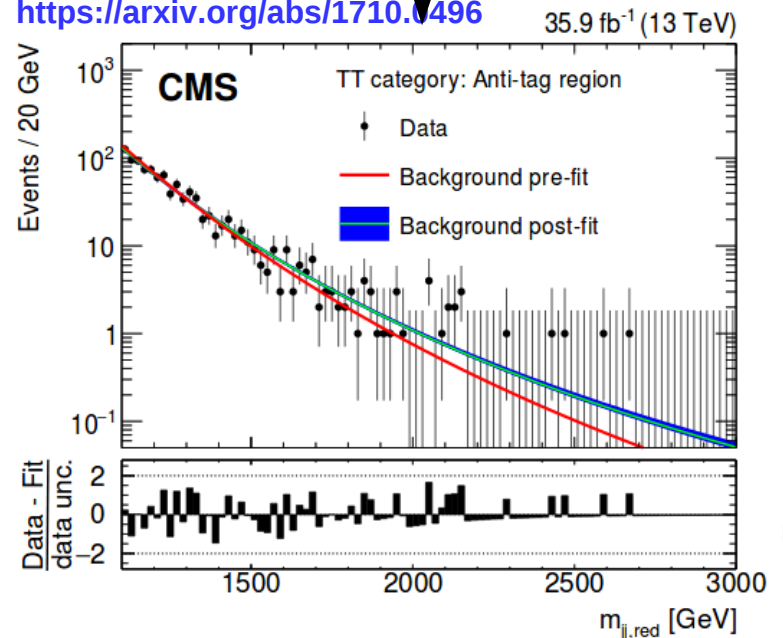
→ Si estrae il contributo del fondo dalla sideband in $m_{j1} - m_H$



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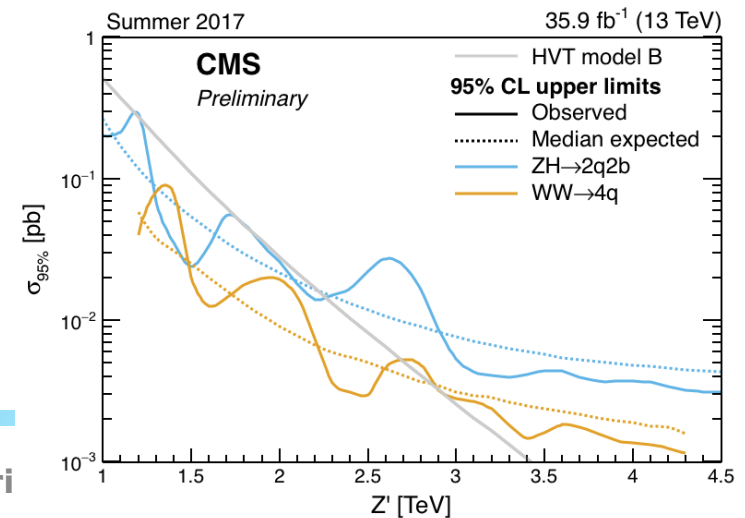
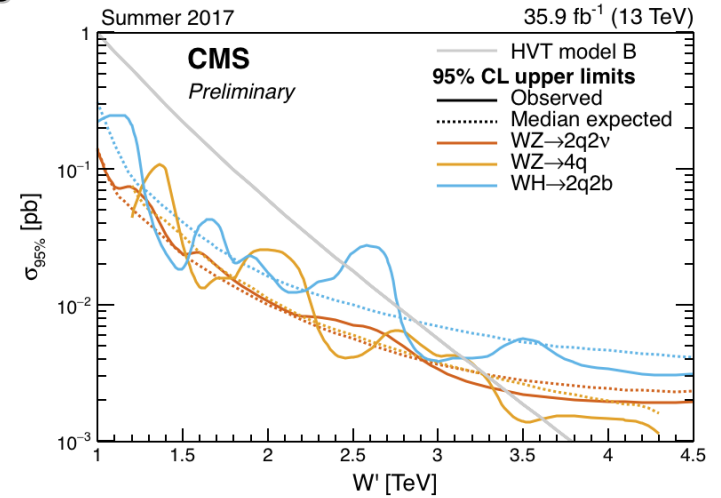
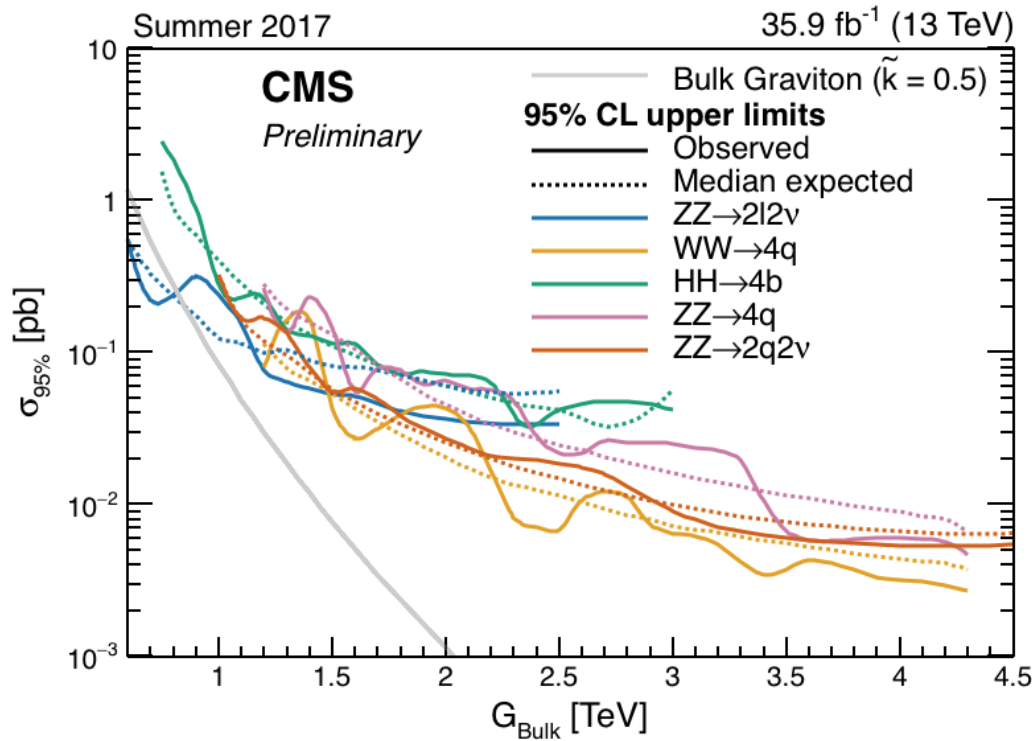
<https://arxiv.org/abs/1710.0496>



DIB summary plots

- Limiti per Bulk Graviton model o HVT triplet model comuni a molti/ tutti i canali!

- Primo passo verso una combinazione - work in progress!



Nuove idee per il Run-II

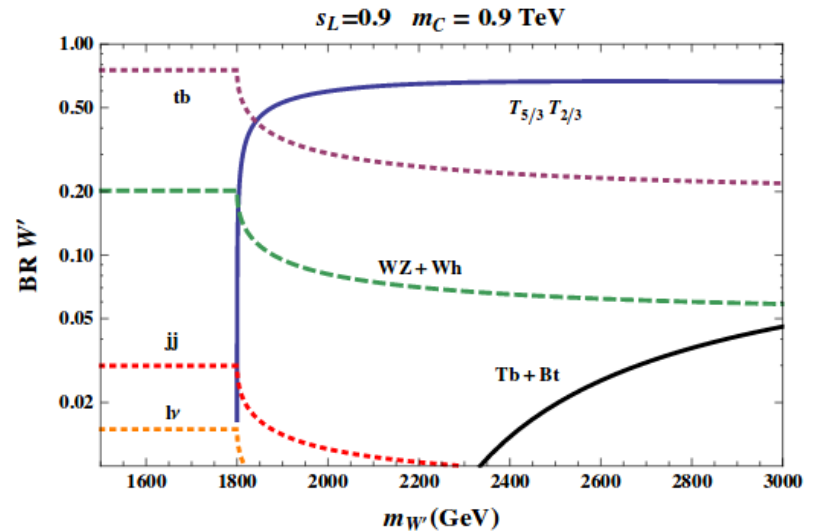
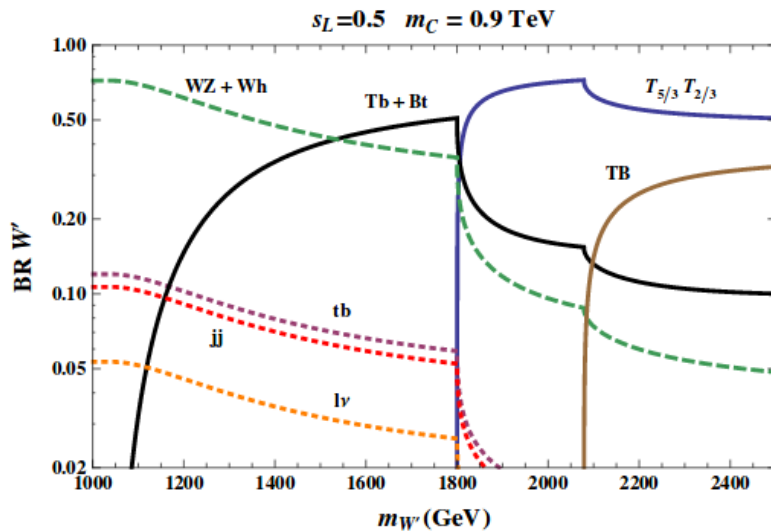
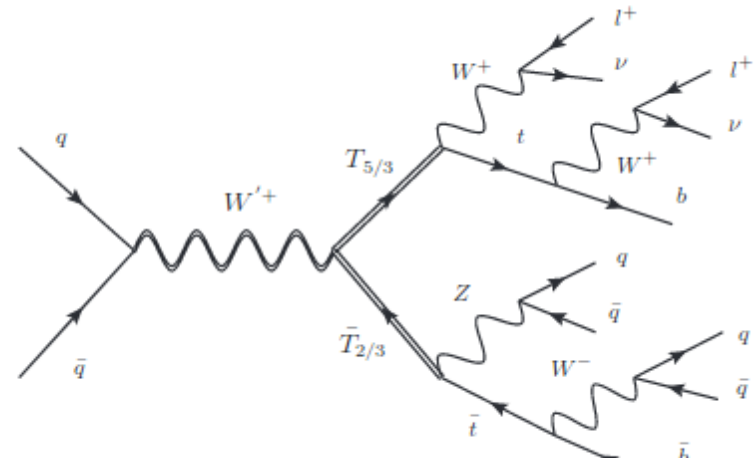
New ideas for resonant searches (I)

Così come per $Z' \rightarrow \tau\tau$, numerosi modelli prevedono risonanze in VLQ:

$W' \rightarrow TZ$
 $W' \rightarrow TX_{5/3}$
 $g^* \rightarrow XX$

Stati finali simili alle searches VLQ
 \rightarrow cinematica diversa

See also: [10.1103/PhysRevD.89.095027](https://arxiv.org/abs/10.1103/PhysRevD.89.095027)

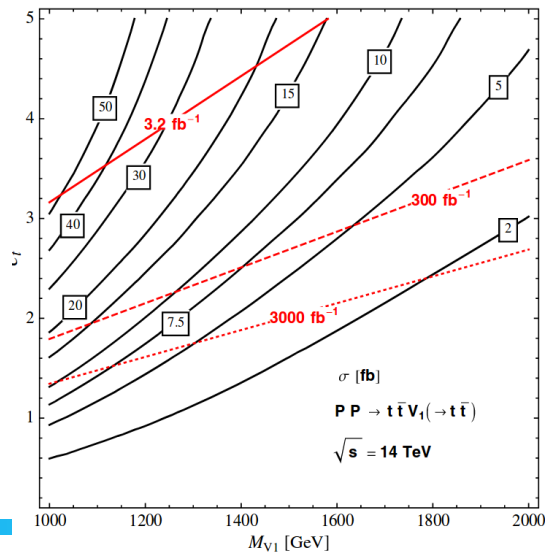
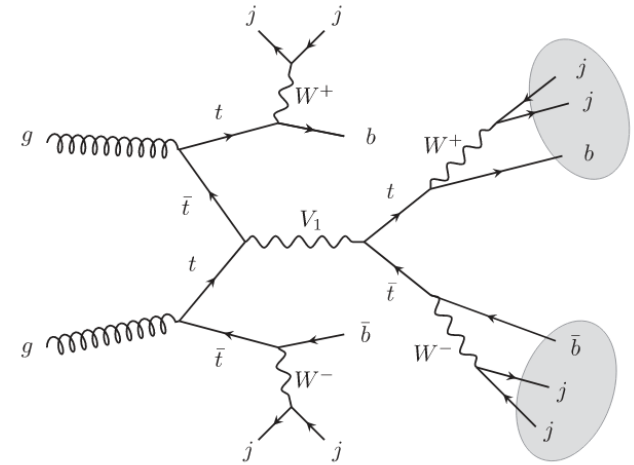


New ideas for resonant searches (II)

4 top resonant production

Vedi anche [10.1103/PhysRevD.94.035023](https://arxiv.org/abs/10.1103/PhysRevD.94.035023) →

- Diverse topologie possono essere sfruttate
- all-hadronic, leptoni + MET etc.



VHF: New search avenues (I)

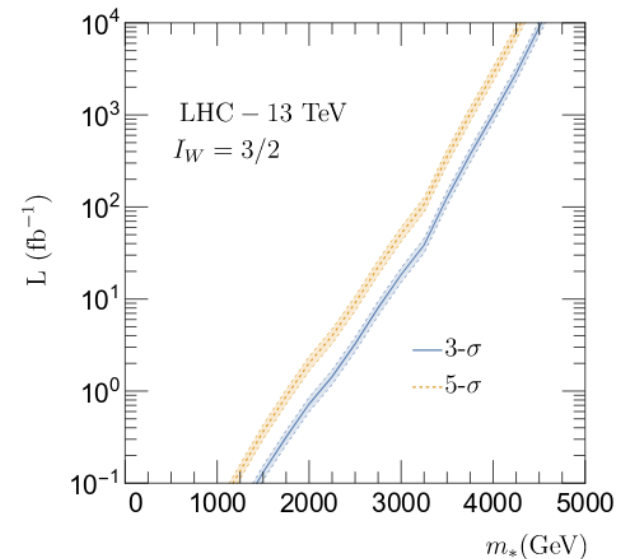
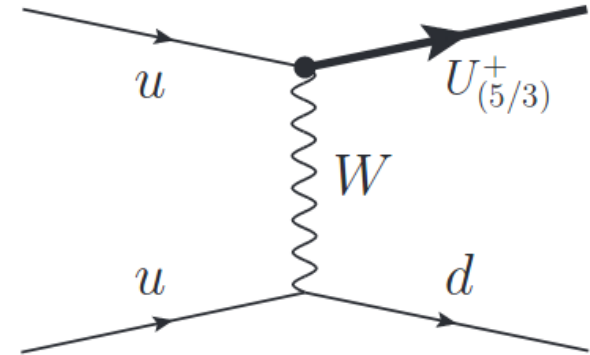
Single U/D quarks da extended isospin models: nuova idea mostrata anche in questo talk

Vedere anche: arXiv:1703:06913

→ Segnatura semplice (Wq decays)

→ Autori in CMS (Orlando Panella, Roberto Leonardi)

Proiezioni basate su B2G-12-016



VHF: New search avenues (II)

Nuovi modi di avere VLQ in particelle SM → Vedere anche questo talk!

T → at

Prodotti in coppie (QCD) singolarmente (EWK)

- T ha mixing con il top quark SM
- la massa di a dipende da T mass
- Numerosi canali sotto la massa di T:
T→at, con a→ gg, WW, γZ , ZZ, tt etc.

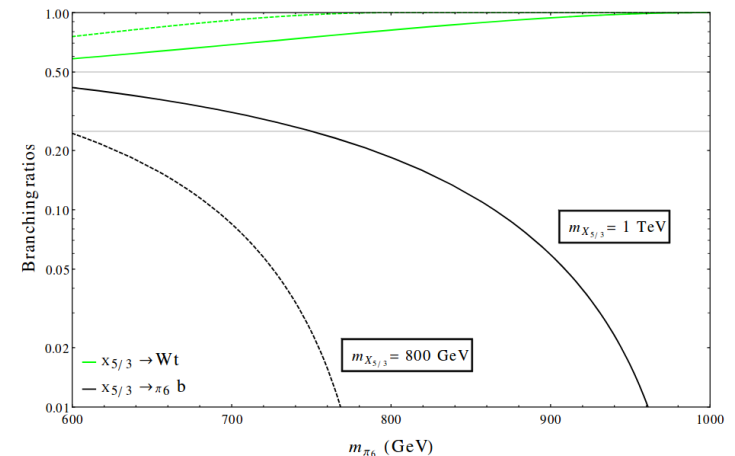
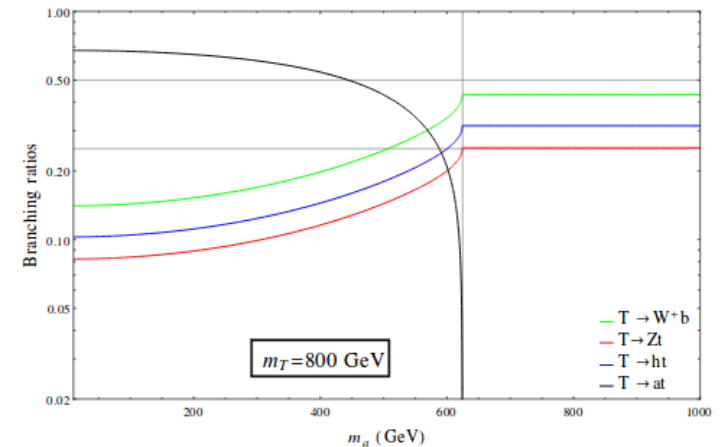
Pair QQ → t/b + X

$\mathbb{T}\mathbb{T} \rightarrow \eta t \eta t$, con $\eta \rightarrow WW, \gamma Z, ZZ$

$X_{5/3} \rightarrow \pi_6 b$, con $\eta \rightarrow WW, \gamma Z, ZZ$

$X_{5/3} \rightarrow \phi + t$, con $\eta \rightarrow WW, \gamma Z, ZZ$

Assieme a $\mathbb{T}\mathbb{T} \rightarrow at$

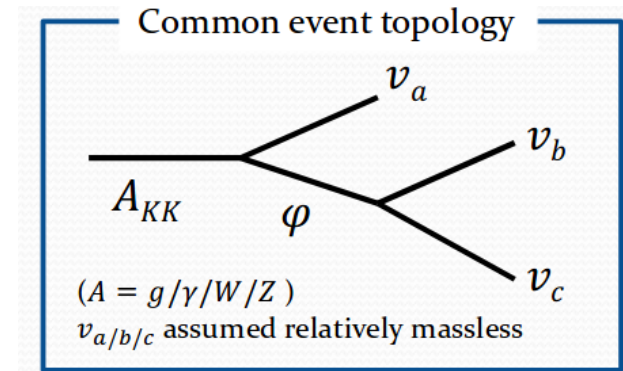
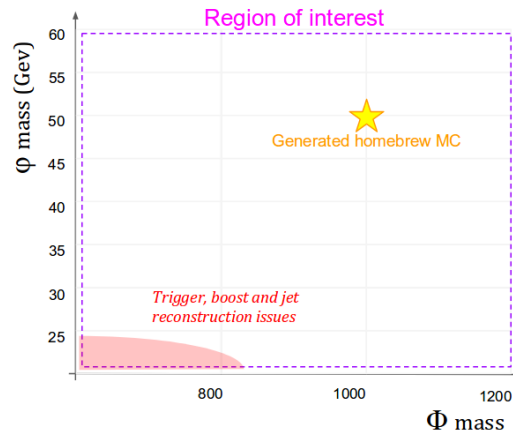
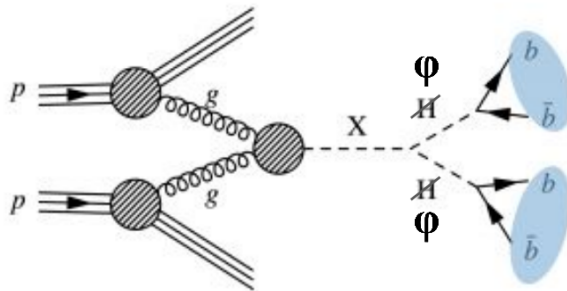


Other new DIB ideas:

Numerose nuove idee proposte negli scorsi mesi:

Tri-boson **WWW**: vedere anche [questo talk](#)

X \rightarrow $\phi\phi$ \rightarrow **4b**: new model: theory paper soon to be completed



Piani per le analisi 2017-18

A breve termine: analisi con dati 2017 per Moriond

Going for Moriond with 2017 data:

→ Analisi robuste con risultati interessanti

VHF: Single $T \rightarrow tZ$:

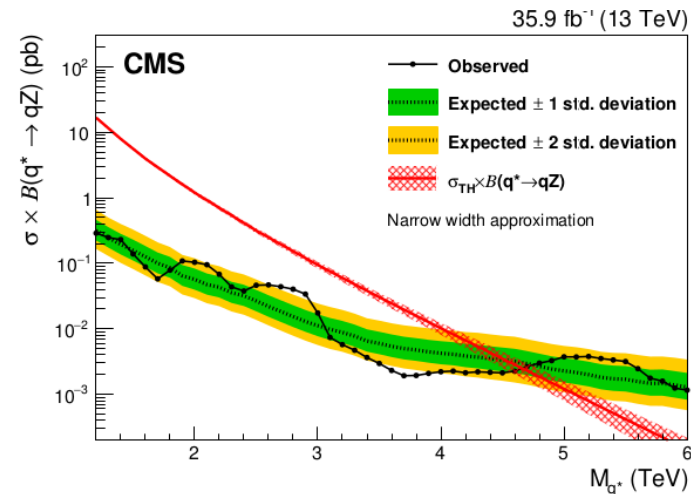
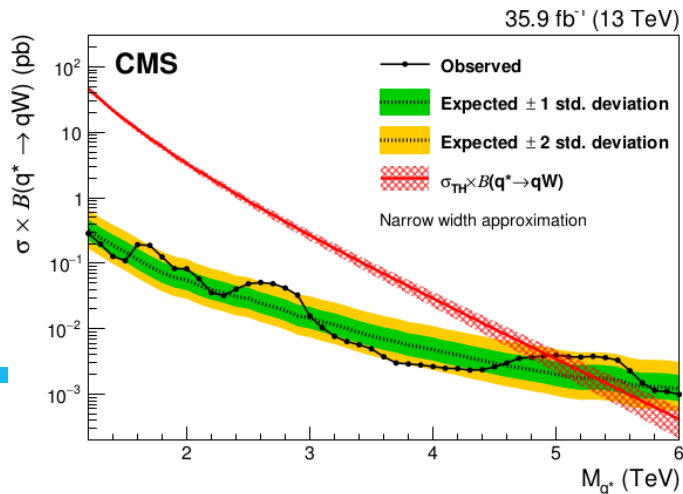
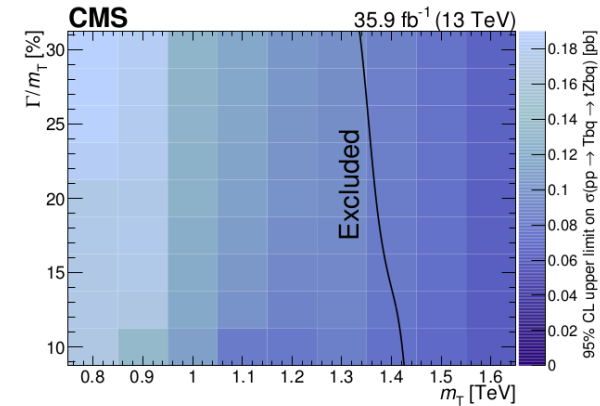
→ strategia già pubblicata in B2G-17-007.

→ diverse larghezze del segnale,

DIB: $VV \rightarrow JJ$

→ strategia come in B2G-17-001, con potenziali update

→ risultati incoraggianti con il dataset 2016



Piani a medio-lungo termine per il 2017-18

Canali Z'/W' :

- interesse nei decadimenti “standard” tt/tb + le coppie $tT/TT/tB$ (probabilmente a lungo termine)
- altri canali di decadimento ancora aperti, e.g. $W' \rightarrow tb$ adronico, $W' \rightarrow TB$ (VLQ), etc.
- Alcuni canali di $Z' \rightarrow tT$ e $W' \rightarrow Tb$ potrebbero includere i dati 2017 - possibilità sul tavolo.

Produzione diretta VLQ (no resonance):

- Alcuni canali di single-production potrebbero includere 2016-17
- Numerose nuove tecniche (BEST, Xcone) sotto studio per i legacy papers.
- Nuovi canali proposti per diverse topologie VLQ

Risonanze in dibosoni:

- Misure 2016 stanno volgendo al termine
- Misure 2017: nuove strade con fit 2-3D sono sotto studio.
- Le nuove misure includeranno produzione VBF
- Nuovi canali (e.g. $3V$) possibili oggetti di studio per il full Run-II

Conclusioni

Il B2G è al momento attivo per raggiungere importanti **milestones del Run-II:**

- Risonanze Z'/W' in prodotti SM e VLQ.
- Searches dirette di VLQ in pair e single-production
- Completamento del quadro della produzione di dibosoni.

Alcune analisi sono avviate verso l'uso dei dati 2017:

- Includono alcune analisi “guida” che sonderanno i dati per Moriond 2018
- Altre mirano al top-up di tecniche già rodiate.

Ci si prepara anche per il 2018 e il Full Run-II:

- Si sono stabiliti i canali di “benchmark” che è imperativo avere come legacy
- Si sono aggiunte numerose interessanti proposte per nuove analisi future.
- Ampie opportunità per collaborare con gruppi esistenti o iniziare nuove attività!

... so stay tuned!

Thanks!

RES new ideas: new families of searches!

W'/Z'/g* to other T/B decays: an entire new family of analyses: similarly to Z'→TT, several models consider potential resonances to other BSM final states, e.g.:

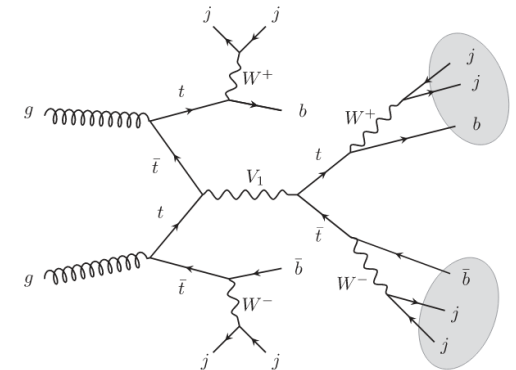
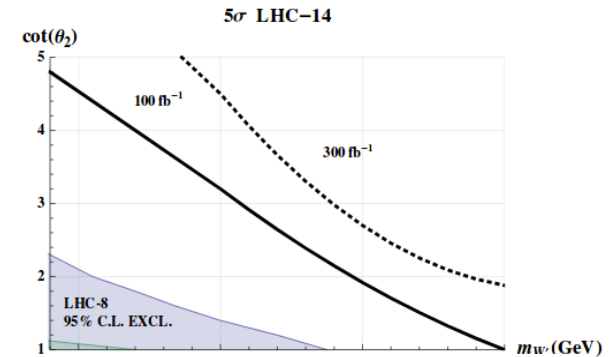
W' → TZ; g* → X5/3X5/3; W' → TX5/3;

→ Similar final states to VLQ analyses, different kinematics!
See also: [10.1103/PhysRevD.89.095027](https://arxiv.org/abs/10.1103/PhysRevD.89.095027)

4 top resonant production

→ Several topologies can be exploited
→ fully hadronic, one or multiple leptons.

See also [10.1103/PhysRevD.94.035023](https://arxiv.org/abs/10.1103/PhysRevD.94.035023)

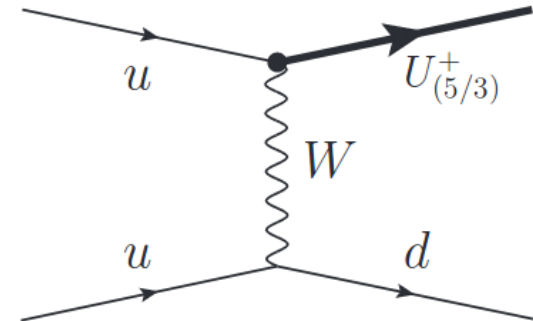


Channel	Foreseen dataset / timeline	Priority	Groups interested	Prev. dataset	Triggers
New physics in γ +jet	2016-17/Run-II	Medium	yes	NEW!	HT/Jet + substructure
W'/Z'/g* to other VLQ	2016-17/Run-II	Medium	not yet	NEW!	Depending on the final state
4 top resonant	2016-17/Run-II	Low	yes - pls join	NEW!	Depending on the final state

VHF: New search avenues

Single U/D quarks from extended isospin model: new idea showcased also during [this talk](#)

See also: arXiv:1703:06913
 → Simple signature (Wq decays)
 → Authors of the theory model in CMS Projections done based on an existing analysis (B2G-12-016).



New VLQ to SM particles

→ See also [this talk at the vhf meeting](#)

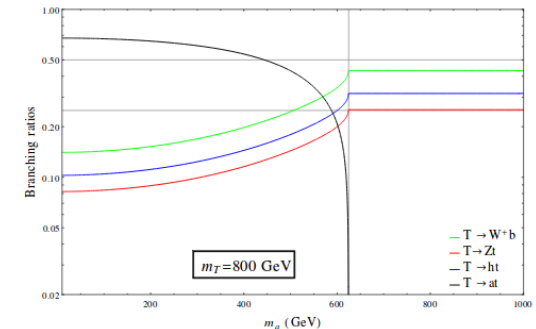
T → at: Pair-produced (QCD) or single-produced (EWK)

→ T mixes with SM top quark

T → at, with a → gg, WW, γZ , ZZ, tt etc.

Other pair QQ → t/b + X

TT → $\eta t \eta t$, X5/3 → $\pi_6 b$, X5/3 → $\phi + t$.



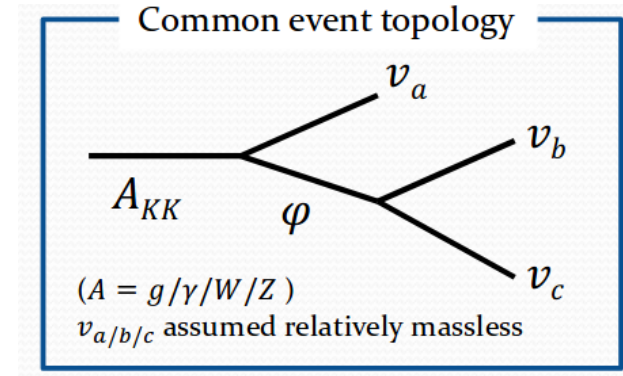
Channel	Foreseen dataset	Priority	Groups interested	Prev. dataset	Triggers
bbHH	2016-17/Run-II	Medium	yes	NEW!	HT/Jet + substructure
Single U/D	2016-17/Run-II	Medium	Not yet	NEW!	Single lepton / MET
Pair TT/XX to ϕ/π	2016-17/Run-II	Medium	Not yet		Depending on signature (multiple)
Single T → ta	2016-17/Run-II	Medium	Not yet	NEW!	Depending on signature (multiple)

Other new DIB ideas:

Several new interesting channels proposed to be investigated:

Tri-boson **WWW**: see [this talk](#)

X → $\phi\phi$ → **4b**: new model: theory paper soon to be completed



Channel	Foreseen dataset / timescale	Priority	Groups interested	Prev. dataset	Triggers
WWW	2016-17/Run-II	Medium	yes - pls join!		Single lep
VVV / other	2016-17/Run-II	Medium	Not yet		TBD
X → $\phi\phi$ → 4b	2016-17/Run-II	Medium	yes		HT/Jet / btag
New gauge bosons	Run-II	Low	under study		TBD

Hot topics for Moriond:

Going for Moriond with 2017 data:

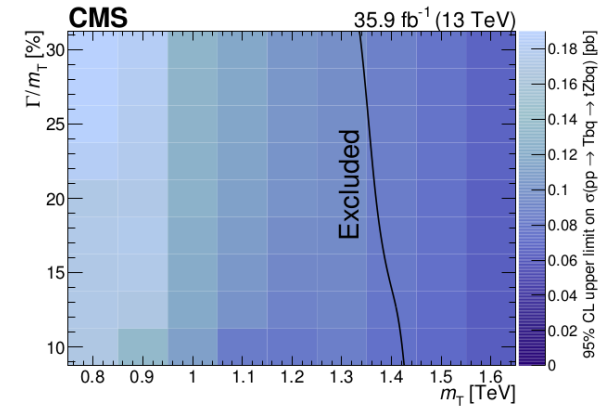
→ Identifying robust analyses with interesting final states!

VHF: Single $T \rightarrow tZ$:

→ strategy as in B2G-17-007, recently published.

→ search for different width signals,

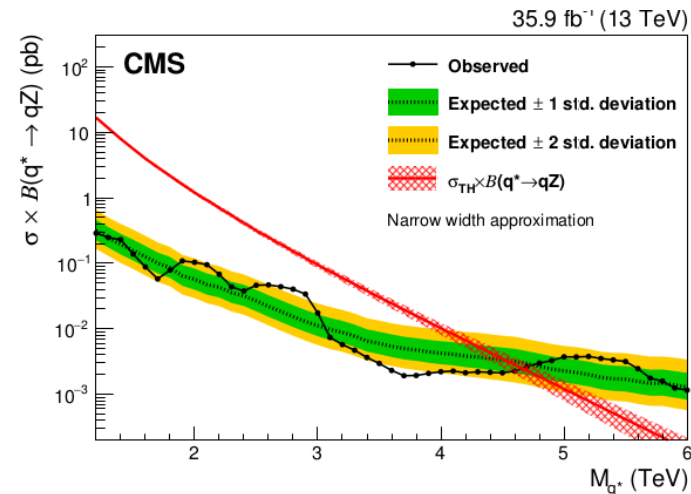
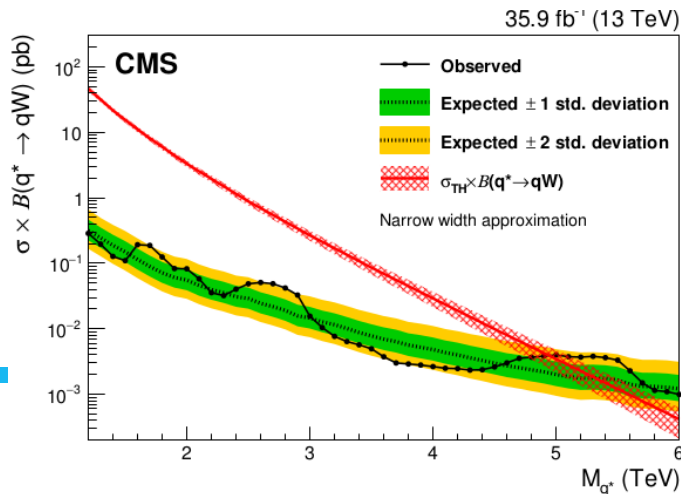
→ possibility for probes of resonant production



DIB: $VV \rightarrow JJ$

→ strategy as in B2G-17-001: one or two boson-tag analysis

→ encouraging results with the 2016 dataset



Plan highlights for the three groups:

RES Subgroup:

- Several new searches with final states similar current VHF searches but involving a resonant mass!
- **Z',W' to heavy T-B** → new family of models that will allow for a wide variety of searches!
- Z',W' decaying directly to standard model final states are “traditional” benchmark channels.

VHF Subgroup:

- pair production are benchmarks sought for for the legacy measurements, new techniques being sought after
- Several single-production channels of interest still to be exploited
- New families of searches (e.g. from **T→at**) are open for investigation!

DIB Subgroup:

- **VBF** production: high priority for 2016/17, never probed in Run-II!
- VH being studied as potentially sharing categories with VV, new techniques being applied.
- New decay and production channels (**Tri-boson, $\phi\phi \rightarrow 4b$ etc**)

Summary: far ahead the road has gone!

- Different profiles of analyses identified:
 - impact **without the full dataset** - shorter timescale, many new models/ideas!
 - **analyses that go for Run-II**- longer timescales, work on improvements while looking at new data!
- **Baseline strategy for benchmark analyses**
 - potential intermediate “stepping-stones” with new techniques or channels explored.
- **Trigger strategy** roughly identified. Available triggers will be maintained and monitored, new triggers will come with new analyses!
- **Groups involvement in Run-II** probed, still plenty of open topics and chance to join!
 - all efforts are in the making and getting defined!
 - discussion also at the B2G workshop next month!

Opportunities and ample room for new groups to get involved on B2G topics and give impactful contributions: both on **benchmark analyses** and **entirely new studies**, with possibilities for different timescales and profiles of analysts!



...and we pursue it with eager feet!

Ricerche di LeptoQuarks

1) Several analyses are considered as **benchmark analyses**:

- model-independent searches in important topologies - seen through all channels.
- specific models of high interest

Analyses we consider as a **must-have** and **legacy Run-II** analyses. Longer timescale: full Run-II dataset.

2) Some of the previous analyses might get **impactful results before the end of Run-II**:

- New techniques developed / not yet applied
- Original decay channels / topologies never explored
- Significant improvement in dataset size/energy wrt previous measurement

The above are typical motivations for a new publication on a **shorter timescale**/ with a 2016+17 dataset!

3) **Ideas for new compelling models / signatures**: great to probe on an immediate timescale!

We'll try to focus on 1-2, including new ideas that can be addressed in the next year