

BARD: B-Resonance Algorithm using Rare Decays

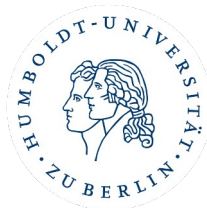
Hagen Möbius

57.Herbstschule HEP

10.09.2026

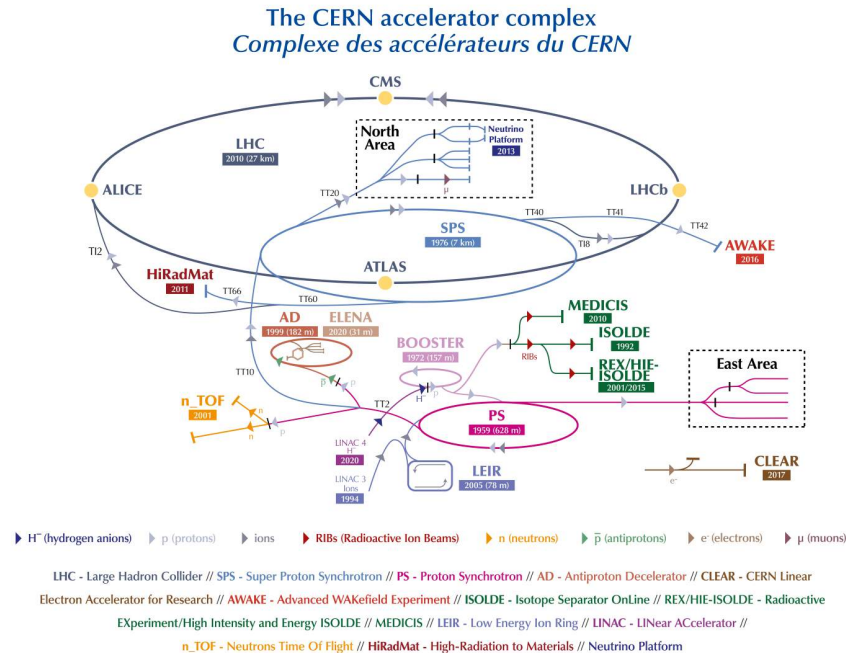


Funded by the European Union. This work is supported by an ERC Grant (BARD, 101116429). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority ERCEA can be held responsible for them.



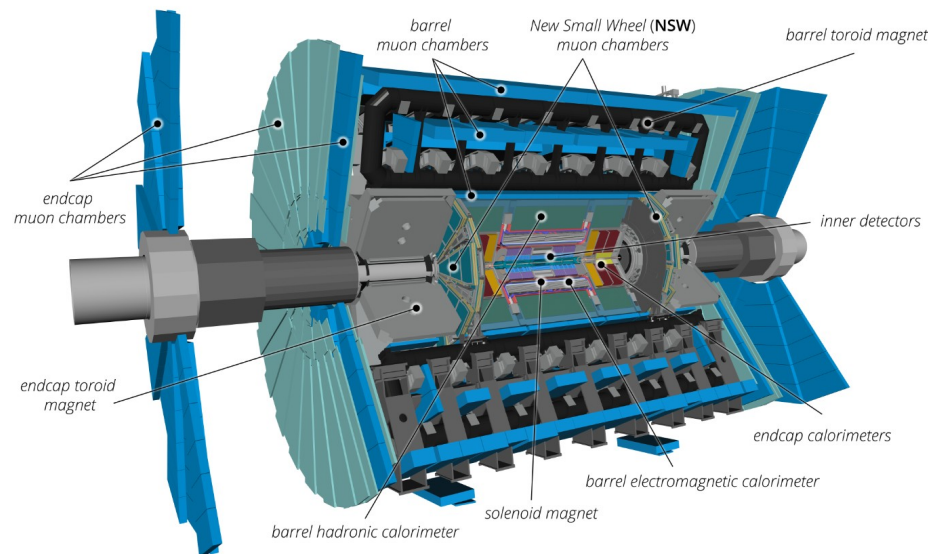
Large Hadron Collider

- Large Hadron Collider (LHC) is a proton-proton collider at CERN with currently a center of mass energy of $\sqrt{s}=13.6\text{ TeV}$
- Four main experiments: ATLAS, CMS, ALICE, LHCb



ATLAS

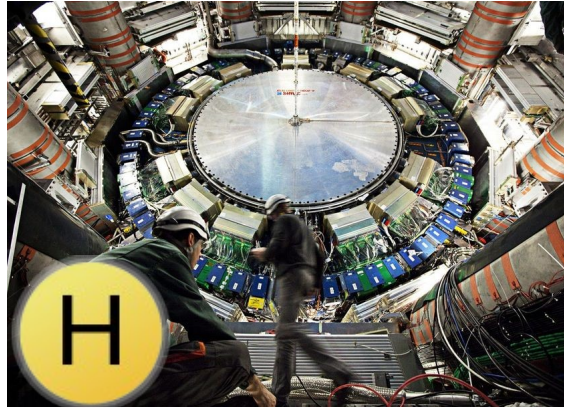
- General purpose detector at the LHC
- Multiple subdetector systems
 - Inner Detector:
 - tracking of charged particles
 - Calorimetry:
 - measure energy of particles
 - Muon spectrometer
 - measure minimal ionizing particles
 - Magnet system
 - momentum measurement and charged particle identification
- Trigger system: Use reduced detector information to decide which events should be recorded and fully reconstructed



<https://cds.cern.ch/record/2859916?ln=de>

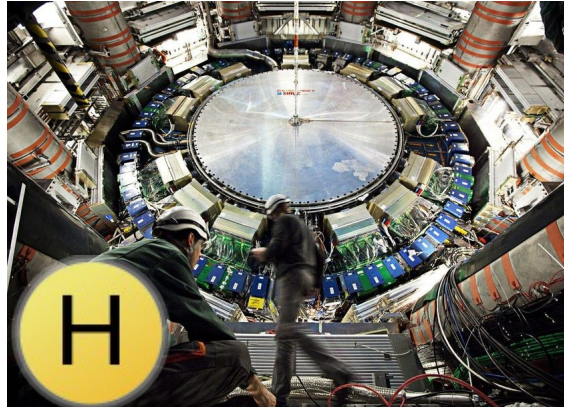
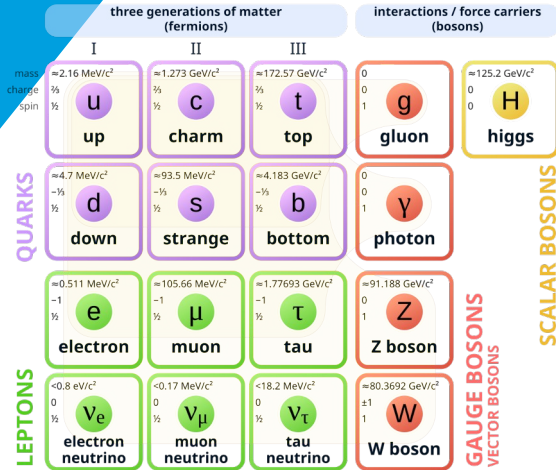
Standard Model of Elementary Particles

three generations of matter (fermions)						interactions / force carriers (bosons)	
I		II		III			
mass charge spin	$\approx 2.16 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$	$\approx 1.273 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$	$\approx 172.57 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$	0 1 1	$\approx 125.2 \text{ GeV}/c^2$ 0 0		
	u up	c charm	t top	g gluon	H higgs		
QUARKS	$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$	$\approx 93.5 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$	$\approx 4.183 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$	0 0 1			
	d down	s strange	b bottom	γ photon			
	$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$	$\approx 1.77693 \text{ GeV}/c^2$ -1 $\frac{1}{2}$	0 0 1			
LEPTONS	e electron	μ muon	τ tau	Z Z boson			
	$< 0.8 \text{ eV}/c^2$ 0 $\frac{1}{2}$	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$	$\approx 91.188 \text{ GeV}/c^2$ 0 1			
	ν_e electron neutrino	ν_μ muon neutrino	ν_τ tau neutrino	± 1 1			
				W W boson			

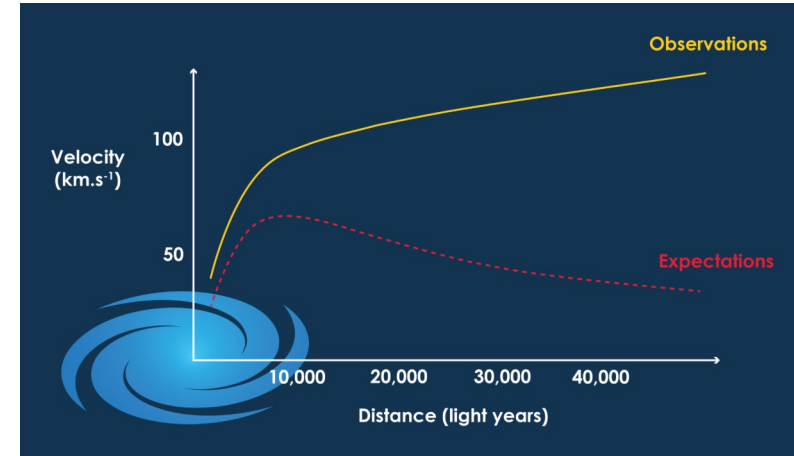


higgs

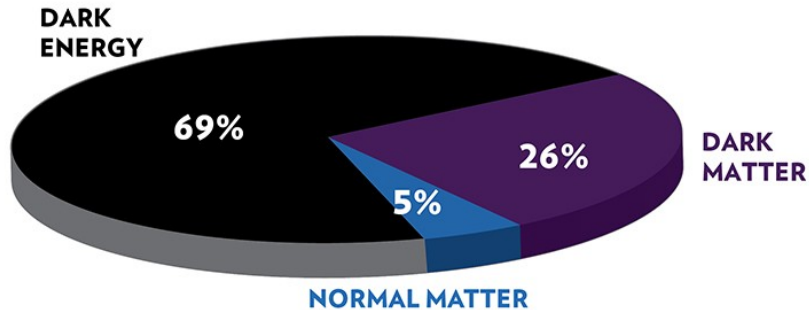
Standard Model of Elementary Particles



higgs

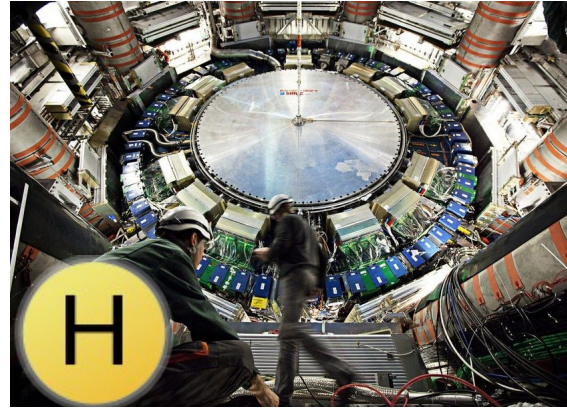


ENERGY DISTRIBUTION OF THE UNIVERSE

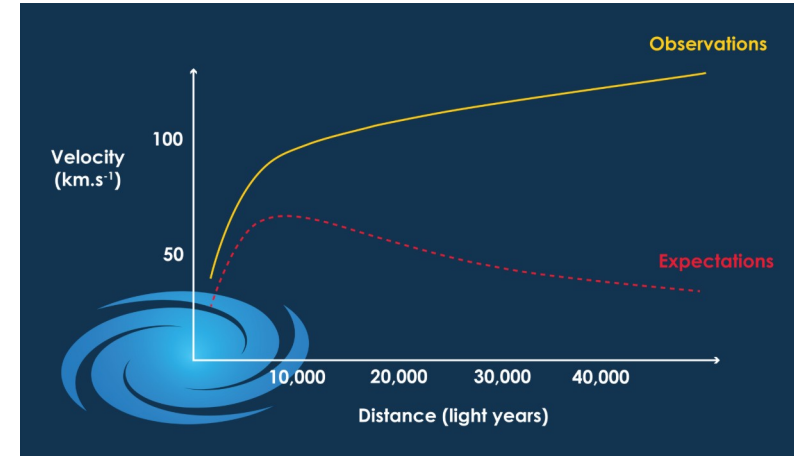


Standard Model of Elementary Particles

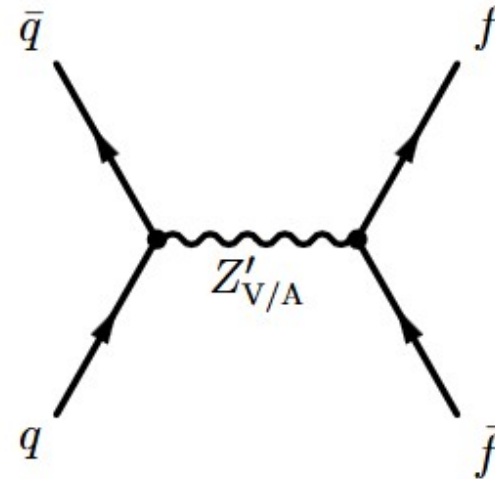
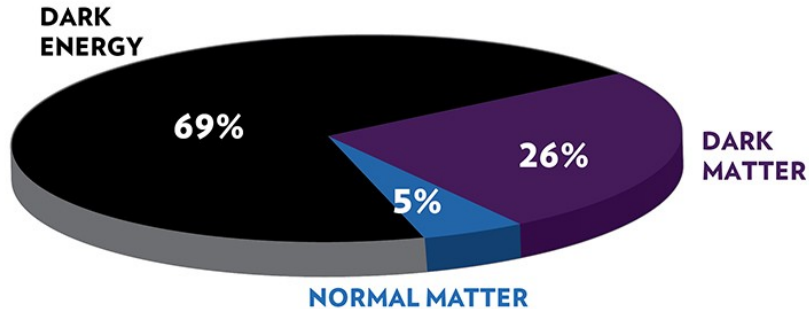
three generations of matter (fermions)			interactions / force carriers (bosons)	
I	II	III		
$\approx 2.16 \text{ MeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ u up	$\approx 1.273 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ c charm	$\approx 172.57 \text{ GeV}/c^2$ $\frac{2}{3}$ $\frac{1}{2}$ t top	0 0 1 g gluon	$\approx 125.2 \text{ GeV}/c^2$ 0 0 H higgs
$\approx 4.7 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ d down	$\approx 93.5 \text{ MeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ s strange	$\approx 4.183 \text{ GeV}/c^2$ $-\frac{1}{3}$ $\frac{1}{2}$ b bottom	0 0 1 γ photon	
$\approx 0.511 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ e electron	$\approx 105.66 \text{ MeV}/c^2$ -1 $\frac{1}{2}$ μ muon	$\approx 1.77693 \text{ GeV}/c^2$ -1 $\frac{1}{2}$ τ tau	0 0 1 Z Z boson	
$< 0.8 \text{ eV}/c^2$ 0 $\frac{1}{2}$ ν_e electron neutrino	$< 0.17 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_μ muon neutrino	$< 18.2 \text{ MeV}/c^2$ 0 $\frac{1}{2}$ ν_τ tau neutrino	$\approx 80.3692 \text{ GeV}/c^2$ ± 1 1 W W boson	



higgs

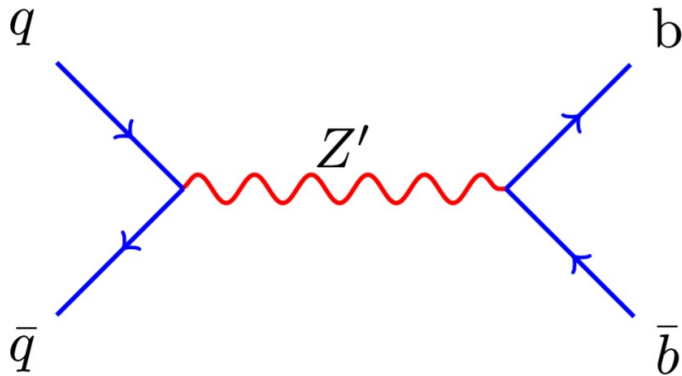


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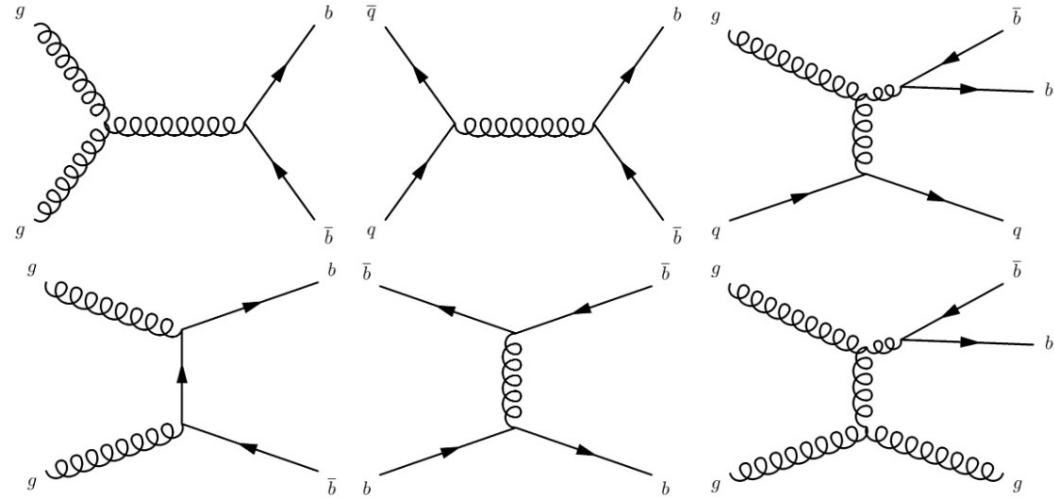
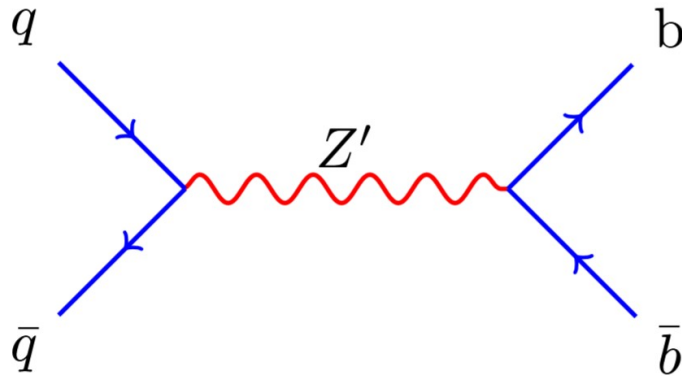
di-bjet searches

- B-resonance searches look for new particles decaying into a $b\bar{b}$ -pair



di-bjet searches

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- Challenging:
 1. Huge amount of QCD background



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 2. SM di-bjet events are very common ≈ 50000 events per second

di-bjet searches

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- Challenging:
 1. Huge amount of QCD background
 2. SM di-bjet events are very common ≈ 50000 events per second (50kHz)
→ exceeds the disk rate available at ATLAS

LHC collision rate & event size

40 MHz | **3.0 MB**

Level-1 accept rate

100 kHz | **300 GB/s**

HLT output to storage

3 kHz | **6 GB/s**

di-bjet searches

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- Challenging:
 1. Huge amount of QCD background
 2. SM di-bjet events are very common ≈ 50000 events per second (50kHz)
→ exceeds the disk rate available at ATLAS
- HLT output rate is 3kHz → Impossible to store all these events
→ You have to bring down the event rate

LHC collision rate & event size

40 MHz | **3.0 MB**

Level-1 accept rate

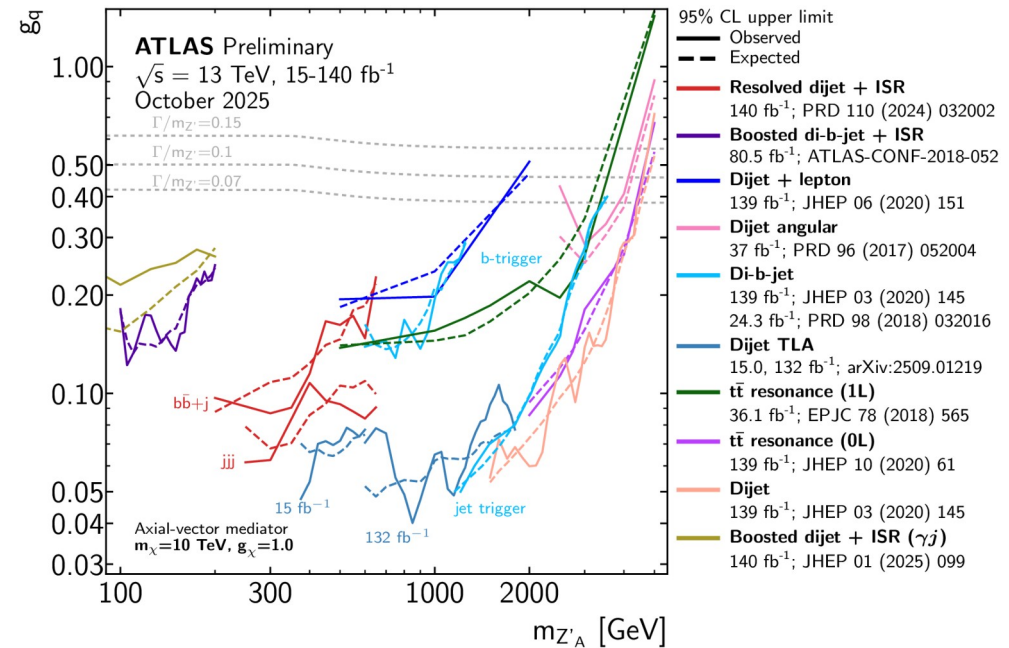
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HLT output to storage

3 kHz | **6 GB/s**

State of the art di-bjet searches

- Common procedures to reduce QCD background and event rate:



<https://cds.cern.ch/record/2946408/files/ATL-PHYS-PUB-2025-041.pdf>

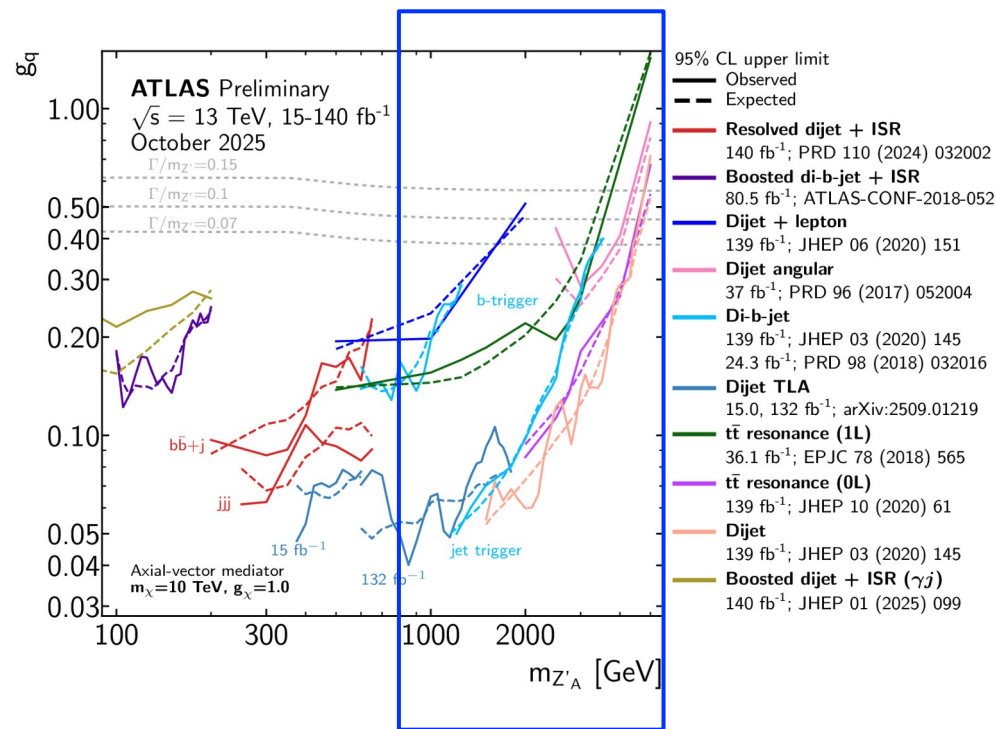
State of the art di-bjet searches

Common procedures to reduce QCD background

and event rate:

1. Use the lowest single jet trigger possible

→ jet at HLT with a $p_T > 400\text{GeV}$



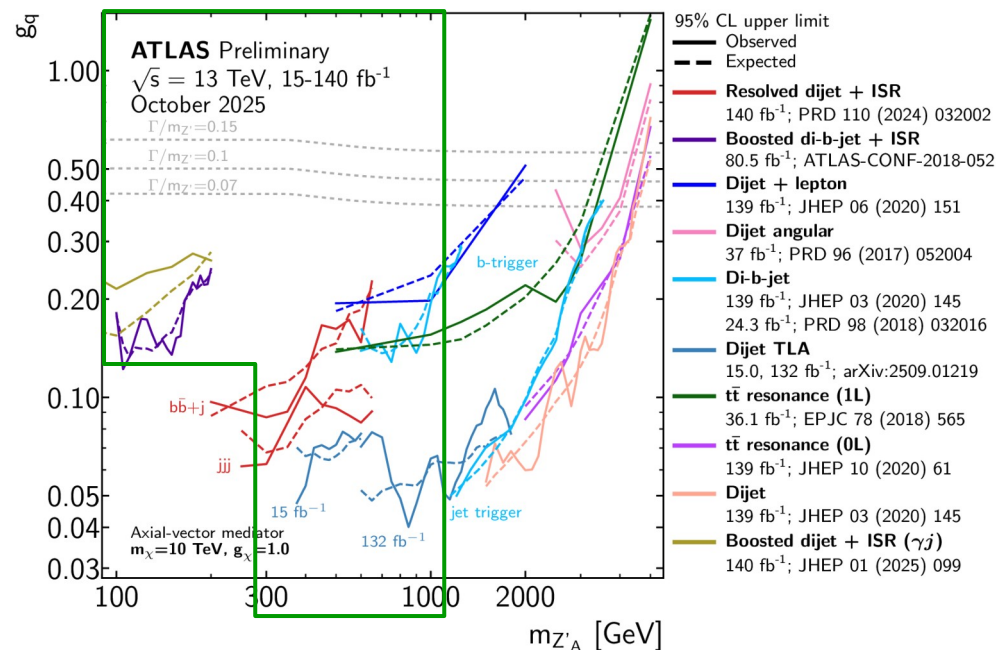
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State of the art di-bjet searches

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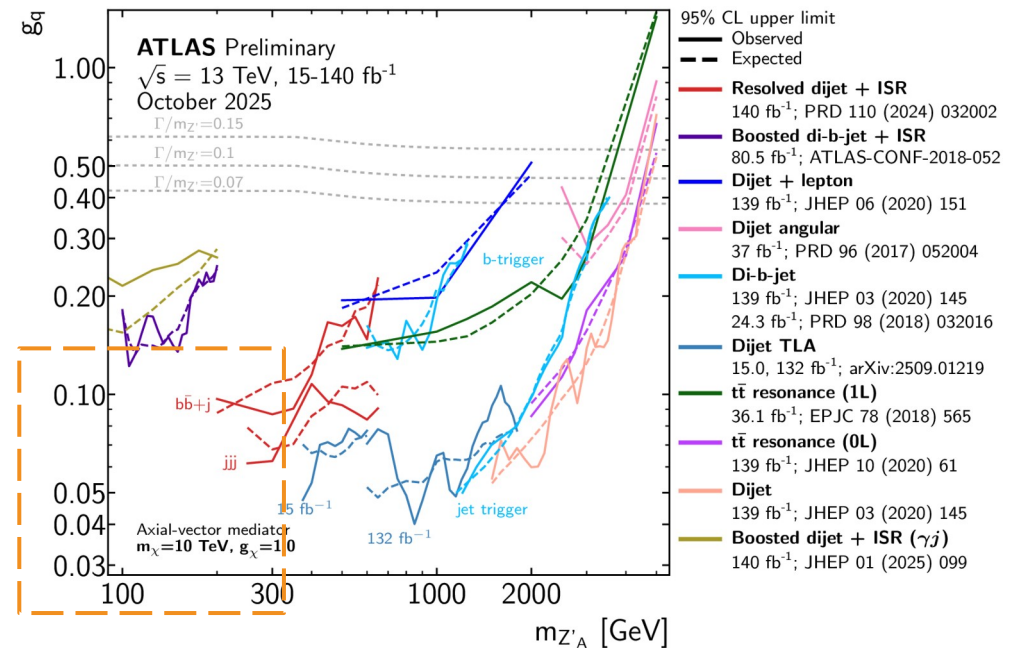
1. Use the lowest single jet trigger possible
→ jet at HLT with a $p_T > 400\text{GeV}$
2. Use ISR photon or ISR jet in association with dijet production (photon $p_T > 150\text{GeV}$)



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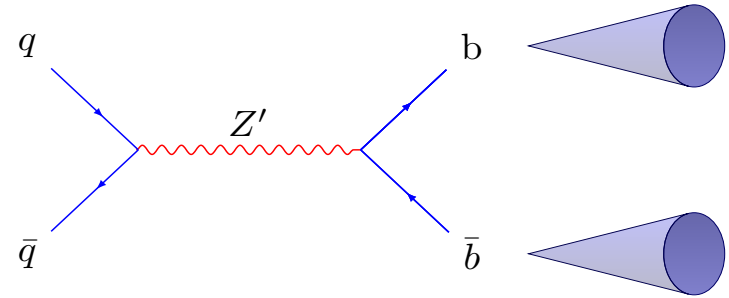
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 1. Use the lowest single jet trigger possible
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- **BARD idea:** Can something other than p_T requirements achieve similar results?
 If yes: The low mass regime becomes more accessible



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The idea of BARD

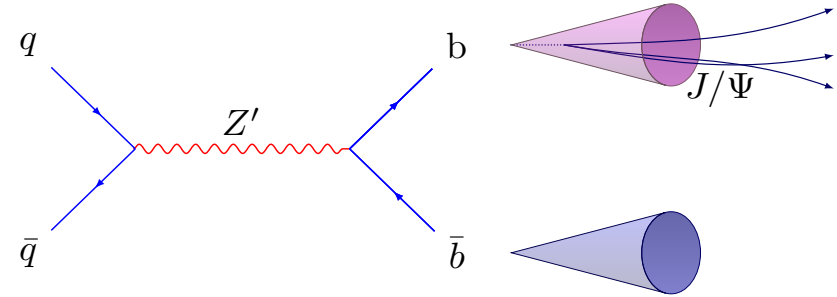
- Can a rare decay trigger suppress QCD while retaining enough signal to observe a resonance?



The idea of BARD

- Can a rare decay trigger suppress QCD while retaining enough signal to observe a resonance?
- $\approx 1\%$ of b-meson decays contain a J/ψ

	Channel	Branching Ratio		Channel	Branching Ratio
1	$B^\pm \rightarrow J/\psi K^\pm$	$(1.020 \pm 0.019) \cdot 10^{-3}$	7	$B^0 \rightarrow J/\psi K^+ \pi^-$	$(1.15 \pm 0.05) \cdot 10^{-3}$
2	$B^\pm \rightarrow J/\psi K^0 \pi^\pm$	$(1.14 \pm 0.11) \cdot 10^{-3}$	8	$B^0 \rightarrow J/\psi K^*(892)^0$	$(1.27 \pm 0.05) \cdot 10^{-3}$
3	$B^\pm \rightarrow J/\psi K^+ \pi^- \pi^\pm$	$(8.1 \pm 1.3) \cdot 10^{-4}$	9	$B^0 \rightarrow J/\psi K^*(1270)^0$	$(1.3 \pm 0.5) \cdot 10^{-3}$
4	$B^\pm \rightarrow J/\psi K^*(892)^\pm$	$(1.43 \pm 0.08) \cdot 10^{-3}$	10	$B_s \rightarrow J/\psi \phi$	$(1.08 \pm 0.08) \cdot 10^{-3}$
5	$B^\pm \rightarrow J/\psi K^*(1270)^\pm$	$(1.8 \pm 0.5) \cdot 10^{-3}$	11	$B_s \rightarrow J/\psi K^+ K^-$	$(7.9 \pm 0.7) \cdot 10^{-4}$
6	$B^0 \rightarrow J/\psi K^0$	$(8.91 \pm 0.21) \cdot 10^{-4}$	12	$B_s \rightarrow J/\psi K^0 K^- \pi^+ + cc$	$(9.5 \pm 1.3) \cdot 10^{-4}$

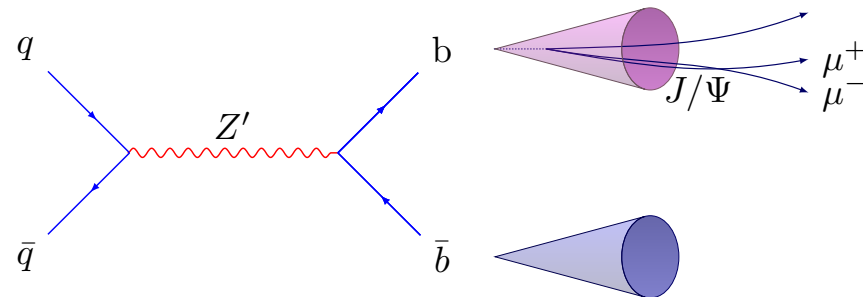


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- J/ψ decays to $\mu\text{-}\mu^+$ pair with 6% branching fraction each
→ rare but easy-to-tag signal
- suppression of $0.01 * 0.06 \approx 10^{-4} \rightarrow$ event rate reduced within acceptable levels



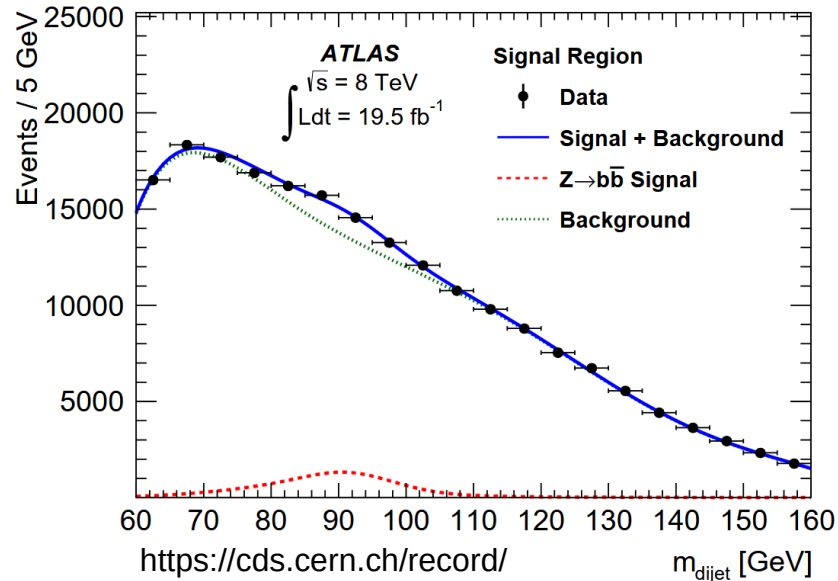
Proof of principle

- Can we find a known resonance?
- Proof-of-principle: Identify the SM Z above QCD background

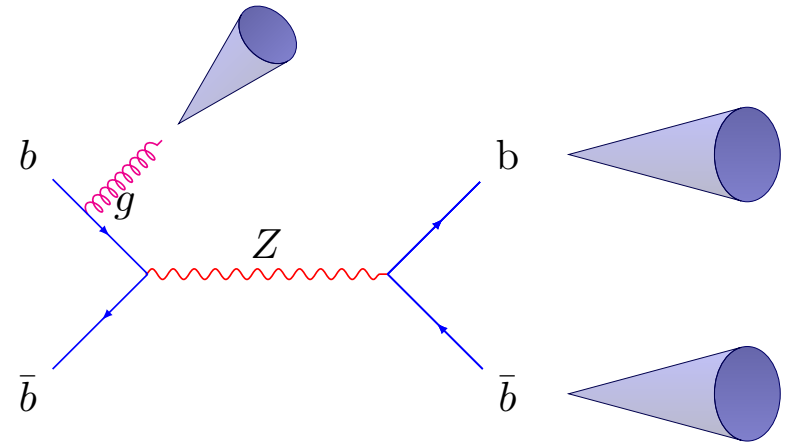
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Boosted $Z \rightarrow b\bar{b}$ analysis from 2014

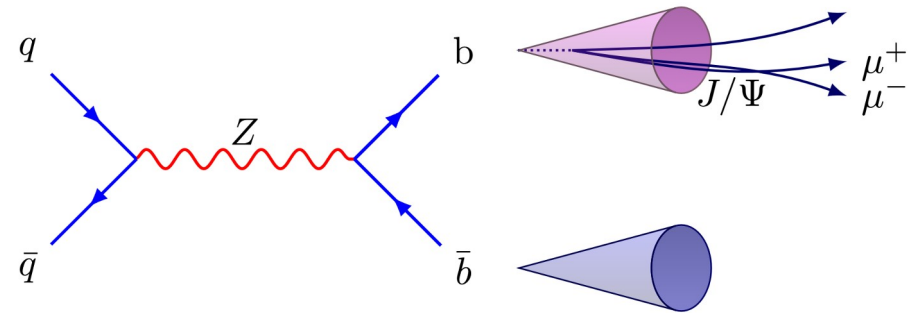
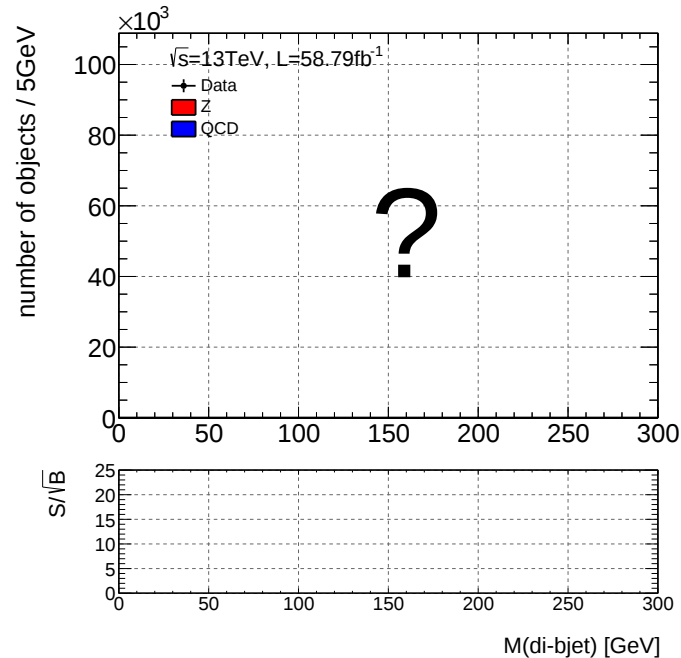


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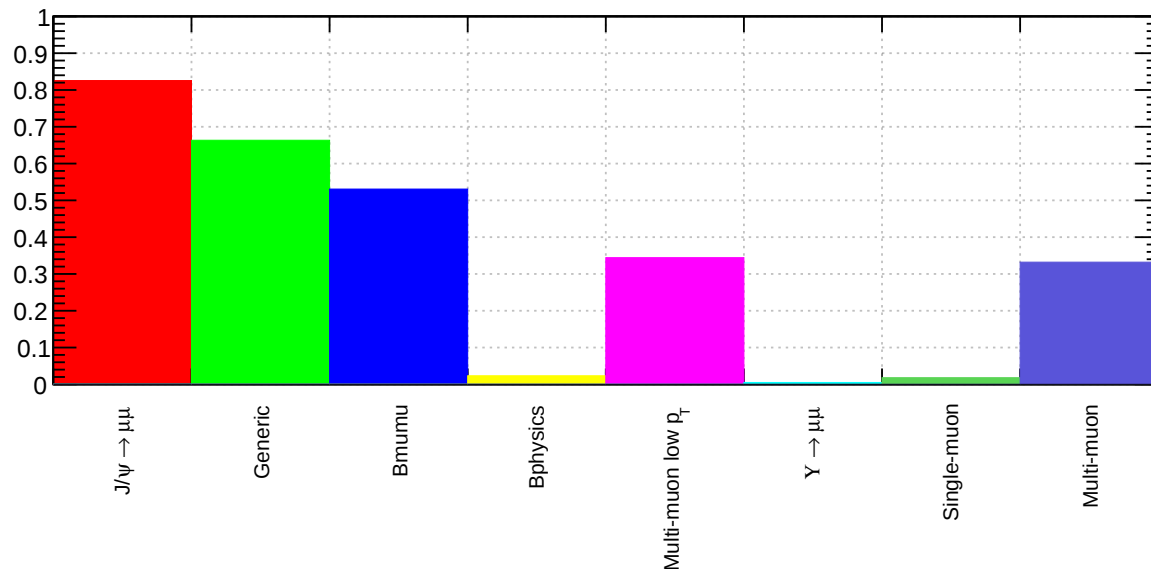
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BARD triggers

- First step: Identify optimal trigger list
- Many different triggers already exist that target dimuon topology
- Trigger acceptance has been studied



Trigger

$J/\psi \rightarrow \mu\mu$

```
HLT_2mu6.bJpsimumu.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_2mu6.bJpsimumu.Lxy0.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_mu11.mu6.bJpsimumu.L1LFV_MU11
HLT_mu11.mu6.bJpsimumu
HLT_mu11.mu6.bJpsimumu.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bJpsimumu.Lxy0
HLT_2mu10.bJpsimumu
```

Generic

```
HLT_mu11.mu6.bDimu.L1LFV_MU11
HLT_mu11.mu6.bDimu
HLT_mu11.mu6.bDimu.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bDimu.Lxy0
HLT_mu11.mu6.bDimu2700.L1LFV_MU11
HLT_mu11.mu6.bDimu2700
HLT_mu11.mu6.bDimu2700.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bDimu2700.Lxy0
```

Bmu mu

```
HLT_mu11.mu6.bBmumu.L1LFV_MU11
HLT_mu11.mu6.bBmumu
HLT_mu11.mu6.bBmumuxv2.L1LFV_MU11
HLT_mu11.mu6.bBmumuxv2
HLT_2mu6.bBmumux.BpmumuKp.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_mu11.mu6.bBmumux.BpmumuKp.L1LFV_MU11
HLT_mu11.mu6.bBmumux.BpmumuKp
```

Bphysics

```
HLT_2mu6.bBmumu.Lxy0.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_2mu6.bBmumux.BsmumuPhi.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
```

Multi-muon low p_T

```
HLT_mu6.2mu4.bJpsi
HLT_3mu4.bJpsi
HLT_3mu6.bJpsi
```

$\Upsilon \rightarrow \mu\mu$

```
HLT_2mu6.bUpsimumu.L1BPH_8M15_2MU6.BPH_0DR22_2MU6
HLT_mu11.mu6.bUpsimumu.L1LFV_MU11
HLT_mu11.mu6.bUpsimumu
```

Single-muon

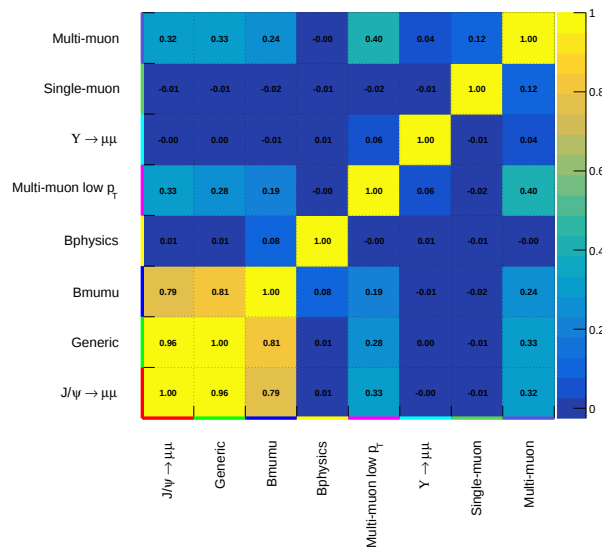
```
HLT_mu26.iavarmedium
HLT_mu50
HLT_mu60.0eta105_msonly 2
```

Multi-muon

```
HLT_2mu14
HLT_mu22.mu8noL1
HLT_mu20.2mu4noL1
HLT_3mu6
```

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- First step: Identify optimal trigger list
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- Trigger acceptance has been studied
- correlations between trigger families were analysed



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HLT_2mu6.bJpsimumu.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_2mu6.bJpsimumu.Lxy0.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_mu11.mu6.bJpsimumu.L1LFV_MU11
HLT_mu11.mu6.bJpsimumu
HLT_mu11.mu6.bJpsimumu.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bJpsimumu.Lxy0
HLT_2mu10.bJpsimumu
```

Generic

```
HLT_mu11.mu6.bDimu.L1LFV_MU11
HLT_mu11.mu6.bDimu
HLT_mu11.mu6.bDimu.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bDimu.Lxy0
HLT_mu11.mu6.bDimu2700.L1LFV_MU11
HLT_mu11.mu6.bDimu2700
HLT_mu11.mu6.bDimu2700.Lxy0.L1LFV_MU11
HLT_mu11.mu6.bDimu2700.Lxy0
```

Bmumu

```
HLT_mu11.mu6.bBmumu.L1LFV_MU11
HLT_mu11.mu6.bBmumu
HLT_mu11.mu6.bBmumuxv2.L1LFV_MU11
HLT_mu11.mu6.bBmumuxv2
HLT_2mu6.bBmumux.BpmumuKp.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_mu11.mu6.bBmumux.BpmumuKp.L1LFV_MU11
HLT_mu11.mu6.bBmumux.BpmumuKp
```

Bphysics

```
HLT_2mu6.bBmumu.Lxy0.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
HLT_2mu6.bBmumux.BsmumuPhi.L1BPH_2M9_2MU6.BPH_2DR15_2MU6
```

Multi-muon low p_T

```
HLT_mu6.2mu4.bJpsi
HLT_3mu4.bJpsi
HLT_3mu6.bJpsi
```

$\gamma \rightarrow \mu\mu$

```
HLT_2mu6.bUpsimumu.L1BPH_8M15_2MU6.BPH_0DR22_2MU6
HLT_mu11.mu6.bUpsimumu.L1LFV_MU11
HLT_mu11.mu6.bUpsimumu
```

Single-muon

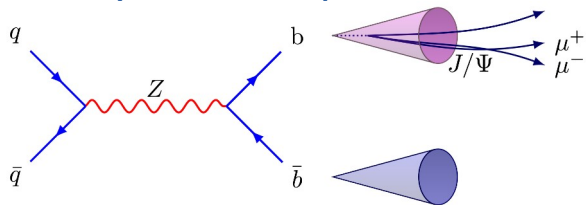
```
HLT_mu26.ivarmedium
HLT_mu50
HLT_mu60.0eta105_msonly
```

Multi-muon

```
HLT_2mu14
HLT_mu22.mu8noL1
HLT_mu20_2mu4noL1
HLT_3mu6
```

Monte Carlo samples

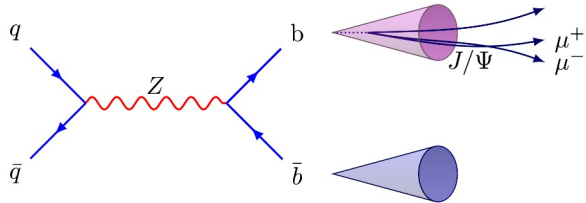
- Created **Pythia Z sample** to simulate $Z \rightarrow b\bar{b} \rightarrow [J/\psi \rightarrow \mu\mu] + X$



→ Pythia only LO generator → Madgraph sample work in progress to account for higher orders

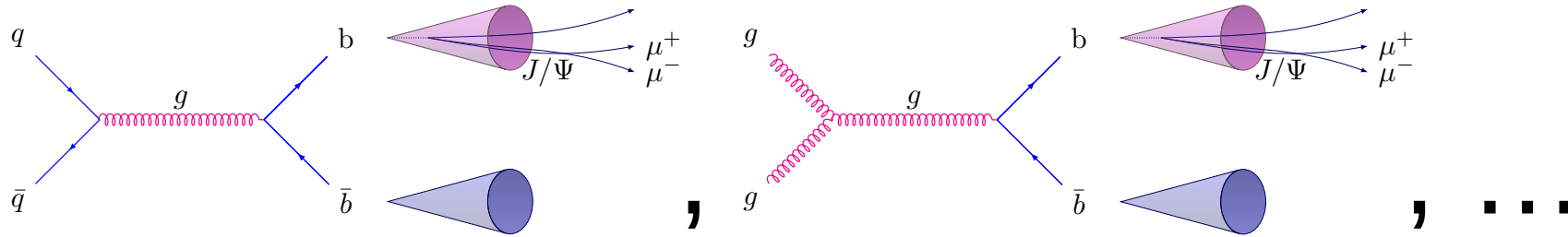
Monte Carlo samples

- Created **Pythia Z sample** to simulate $Z \rightarrow b\bar{b} \rightarrow [J/\psi \rightarrow \mu\mu] + X$



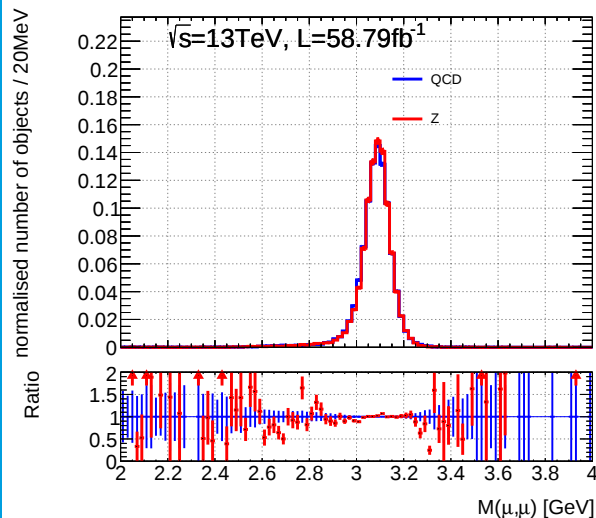
→ Pythia only LO generator → Madgraph sample work in progress to account for higher orders

- Pythia QCD sample** to simulate $QCD \rightarrow b\bar{b} \rightarrow [J/\psi \rightarrow \mu\mu] + X$



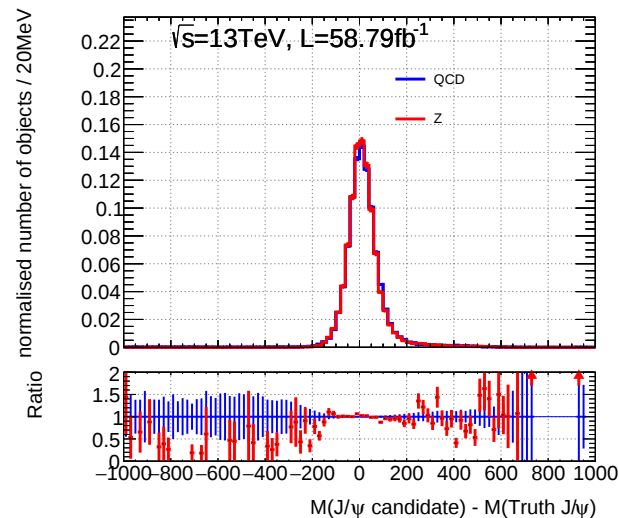
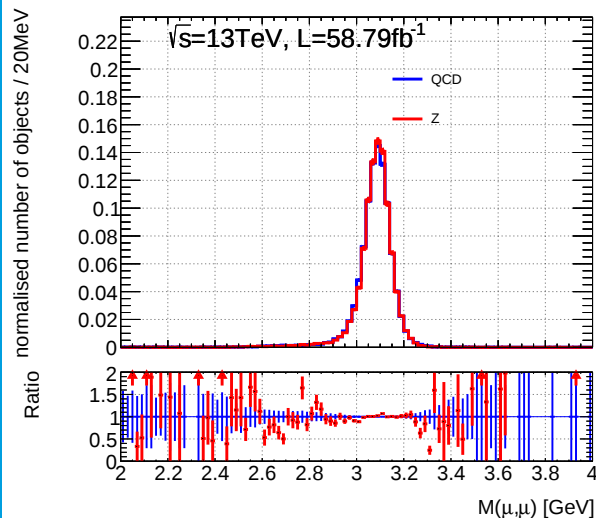
Reconstruction of J/ψ

- Muons with $p_T \geq 4\text{GeV}$ and $|\eta| \leq 2.7$, Identification WP: Loose, Isolation WP: NonIso
- ΔR -method: - Find the muon-pair with the smallest ΔR and $d_0^{\text{sig}} > 3$
 - calculate the sum of their 4-vectors to get J/ψ 4-vector



Reconstruction of J/ψ

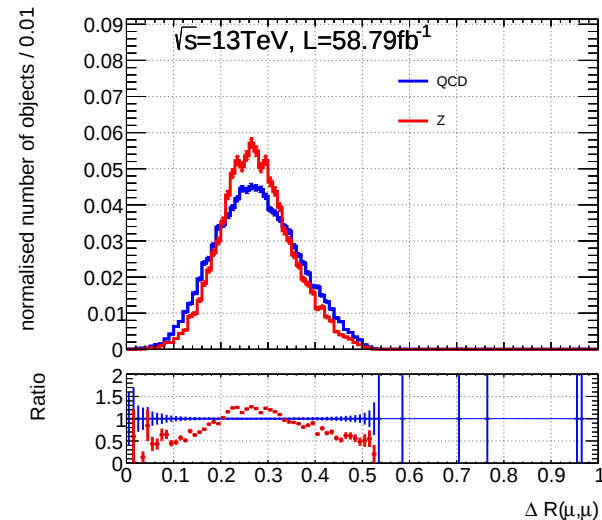
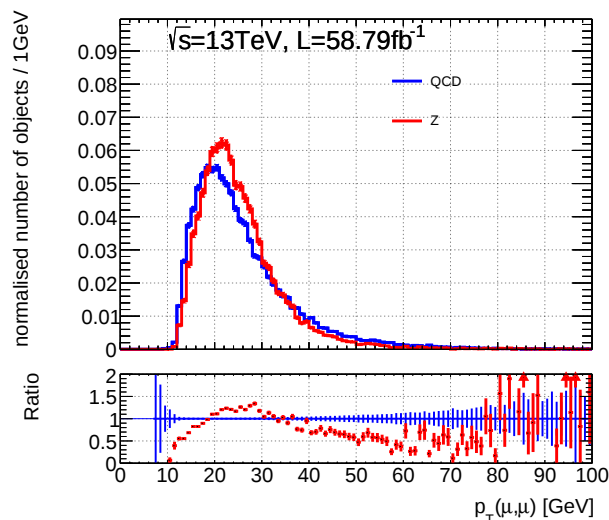
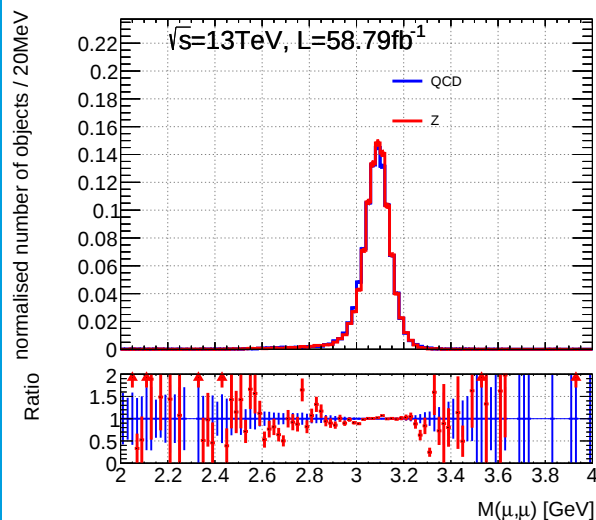
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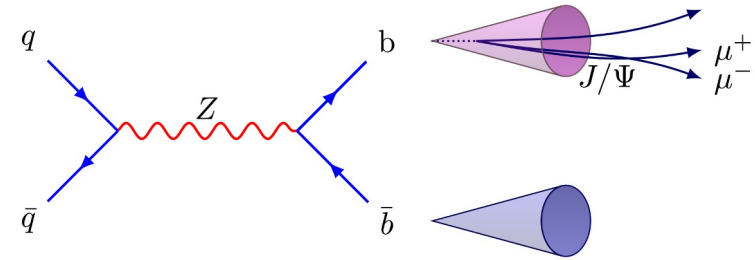
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- calculate the sum of their 4-vectors to get J/ψ 4-vector

$$\Delta R = \sqrt{(\eta_1 - \eta_2)^2 + (\phi_1 - \phi_2)^2}$$



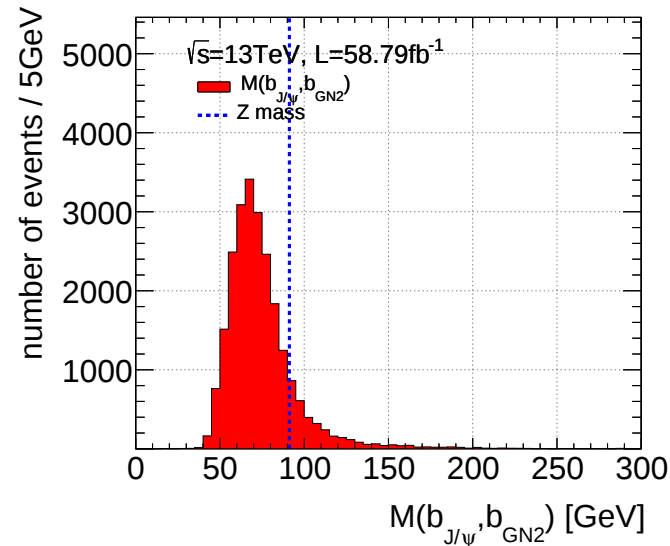
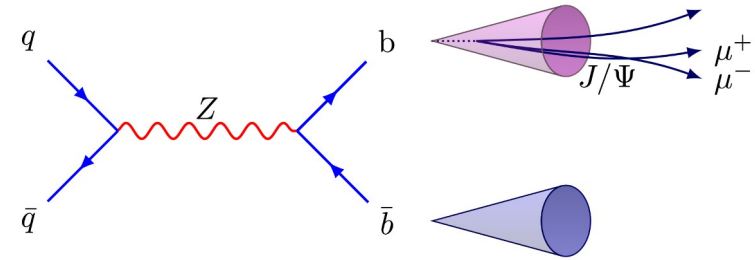
Reconstruction of the Z

- Jets with $p_T \geq 20 \text{ GeV}$ and $|\eta| \leq 2.5$
- Jet with $\Delta R(J/\psi \text{ candidate}, \text{jet}) < 0.4$ gets assigned as $b_{J/\psi}$ - jet
- Check that there is a second non-overlapping GN2 b-tagged jet in the event $\rightarrow b_{\text{GN2}}$ - jet



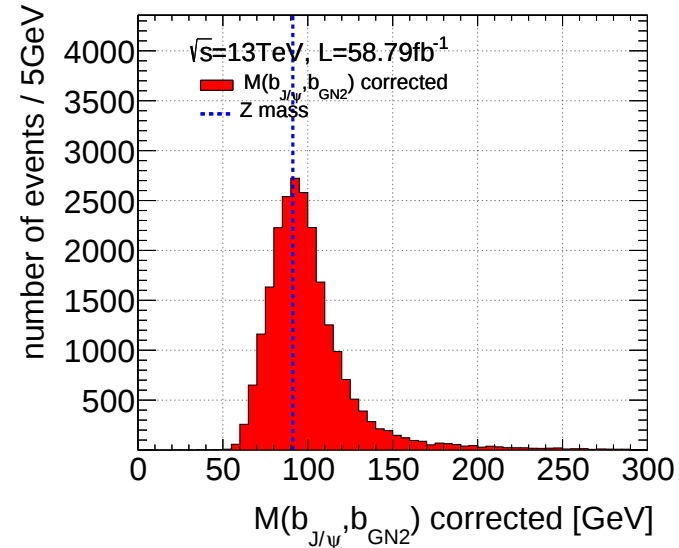
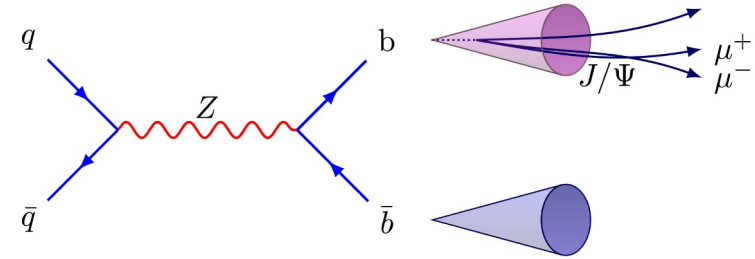
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- $M(b_{J/\psi}, b_{\text{GN2}})$ not at the position of the Z peak $\rightarrow$ standard jet reconstruction does not add the muons to the jet
- $M(b_{J/\psi}, b_{\text{GN2}})$ corrected $\rightarrow$ Add 4-vector of the J/ψ -candidate (di-muon-system) to $b_{J/\psi}$ -jet and recalculate $M(b_{J/\psi}, b_{\text{GN2}})$



Preliminary sensitivity studies

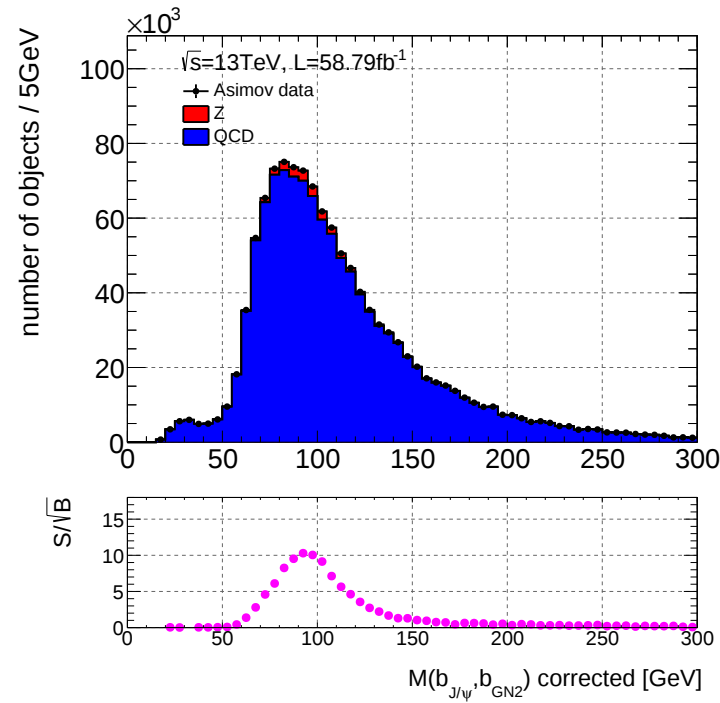
- Selection:

- Event triggered by the $J/\psi \rightarrow \mu\mu$ trigger family
- A J/ψ candidate with $3.0\text{GeV} < M(J/\psi \text{ candidate}) < 3.2\text{GeV}$
- 1 jet with $\Delta R(\text{jet}, J/\psi \text{ candidate}) < 0.4$
- An additional GN2 b-tagged jet
- Number of jets = 2

Preliminary sensitivity studies

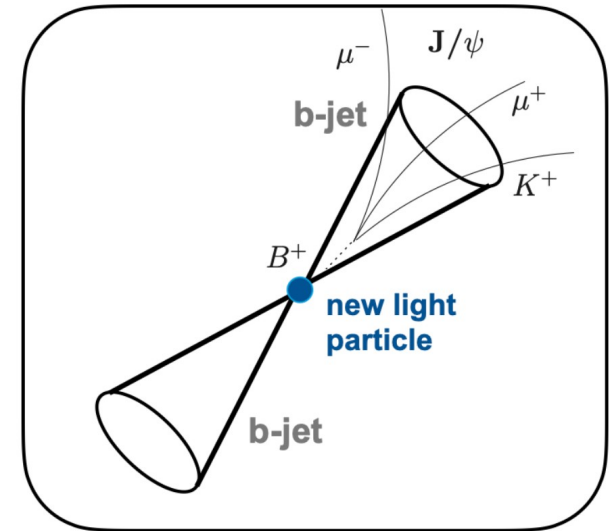
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- 1 jet with $\Delta R(\text{jet}, J/\psi \text{ candidate}) < 0.4$
- An additional GN2 b-tagged jet
- Number of jets = 2
- Very preliminary stat-only sensitivity looks promising
→ modelling uncertainties need to be considered



Conclusion

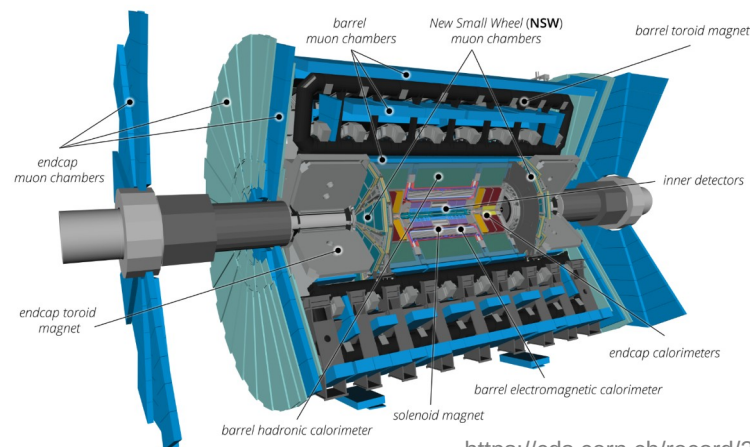
- BARD: B-Resonance Algorithm using rare decays
- Current B-resonances searches limited to high masses because high energetic objects are needed to trigger the event
- BARD is a new approach to trigger these events using a rare but clean $B\text{-hadron} \rightarrow J/\psi \rightarrow \mu\mu$ decay
- Ongoing proof of principle to identify the Z
 - Trigger acceptance and correlations studied
 - Z signal and QCD background samples created
 - Construction of J/ψ candidate and $b\bar{b}$ -system set up
 - First sensitivity studies on mass spectrum look promising



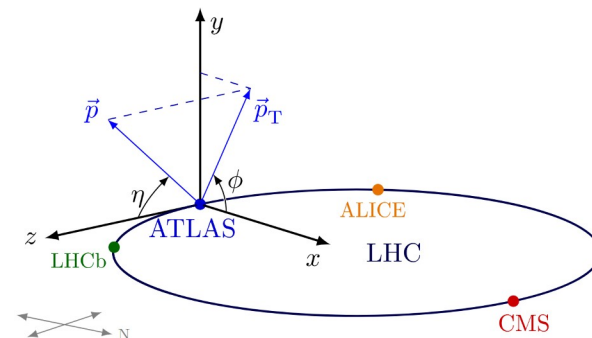
Backup

ATLAS

- General purpose detector at the LHC
- Multiple subdetector systems
 - Inner Detector:
 - tracking of charged particles
 - Calorimetry:
 - measure energy of particles
 - Muon spectrometer
 - measure minimal ionizing particles
- Magnet system
 - momentum measurement and charged particle identification

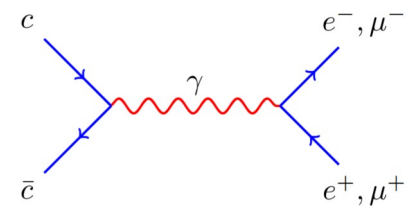
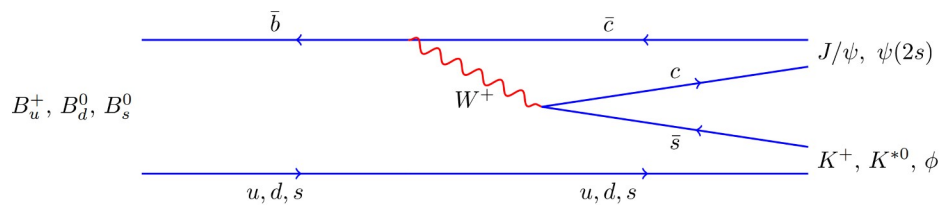
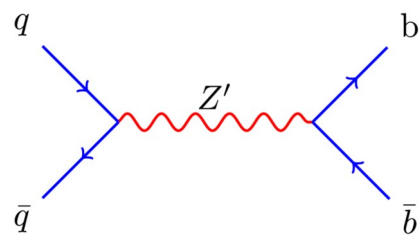


<https://cds.cern.ch/record/2859916?ln=de>



BARD

- Idea of BARD: Instead of requiring high pT objects at trigger level require a rare but clean b-hadron decay to trigger the event



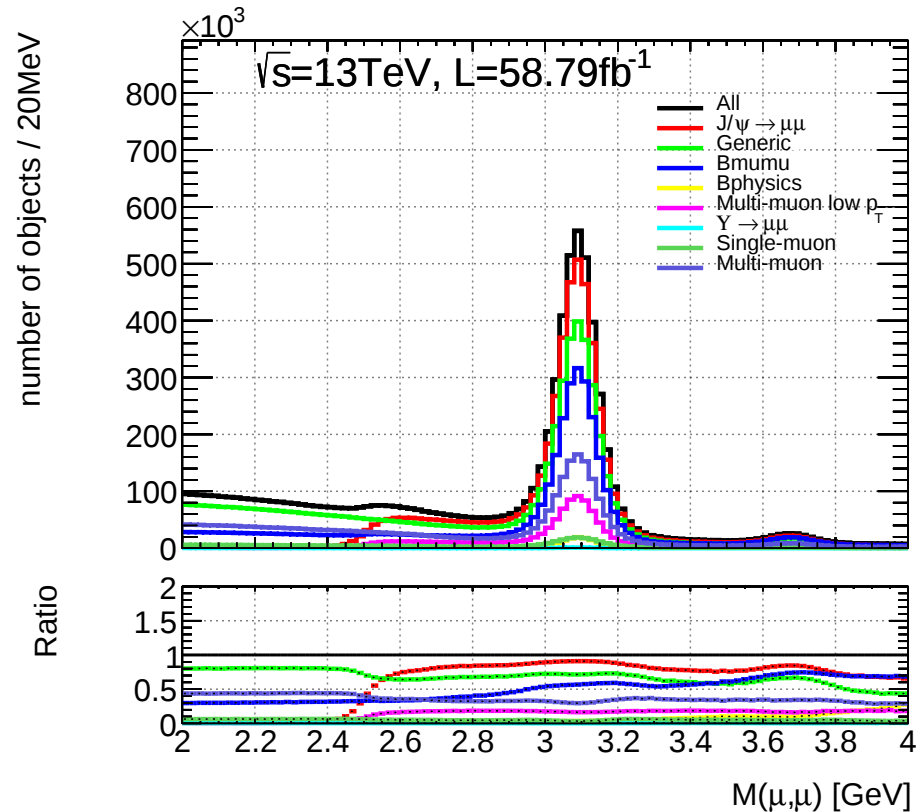
- B-meson to Jpsi decay has branching fraction of order 10^{-3}

- Jpsi $\rightarrow \mu\mu$ has branching fraction of 6%
 $\rightarrow$ Signal of two muons is easy to identify

	Channel	Branching Ratio		Channel	Branching Ratio
1	$B^\pm \rightarrow J/\psi K^\pm$	$(1.020 \pm 0.019) \cdot 10^{-3}$	7	$B^0 \rightarrow J/\psi K^+ \pi^-$	$(1.15 \pm 0.05) \cdot 10^{-3}$
2	$B^\pm \rightarrow J/\psi K^0 \pi^\pm$	$(1.14 \pm 0.11) \cdot 10^{-3}$	8	$B^0 \rightarrow J/\psi K^*(892)^0$	$(1.27 \pm 0.05) \cdot 10^{-3}$
3	$B^\pm \rightarrow J/\psi K^+ \pi^- \pi^\pm$	$(8.1 \pm 1.3) \cdot 10^{-4}$	9	$B^0 \rightarrow J/\psi K^*(1270)^0$	$(1.3 \pm 0.5) \cdot 10^{-3}$
4	$B^\pm \rightarrow J/\psi K^*(892)^\pm$	$(1.43 \pm 0.08) \cdot 10^{-3}$	10	$B_s \rightarrow J/\psi \phi$	$(1.08 \pm 0.08) \cdot 10^{-3}$
5	$B^\pm \rightarrow J/\psi K^*(1270)^\pm$	$(1.8 \pm 0.5) \cdot 10^{-3}$	11	$B_s \rightarrow J/\psi K^* K^-$	$(7.9 \pm 0.7) \cdot 10^{-4}$
6	$B^0 \rightarrow J/\psi K^0$	$(8.91 \pm 0.21) \cdot 10^{-4}$	12	$B_s \rightarrow J/\psi K^0 K^+ \pi^- + cc$	$(9.5 \pm 1.3) \cdot 10^{-4}$

- Rare B-meson to Jpsi decay reduces the event rate within acceptable levels

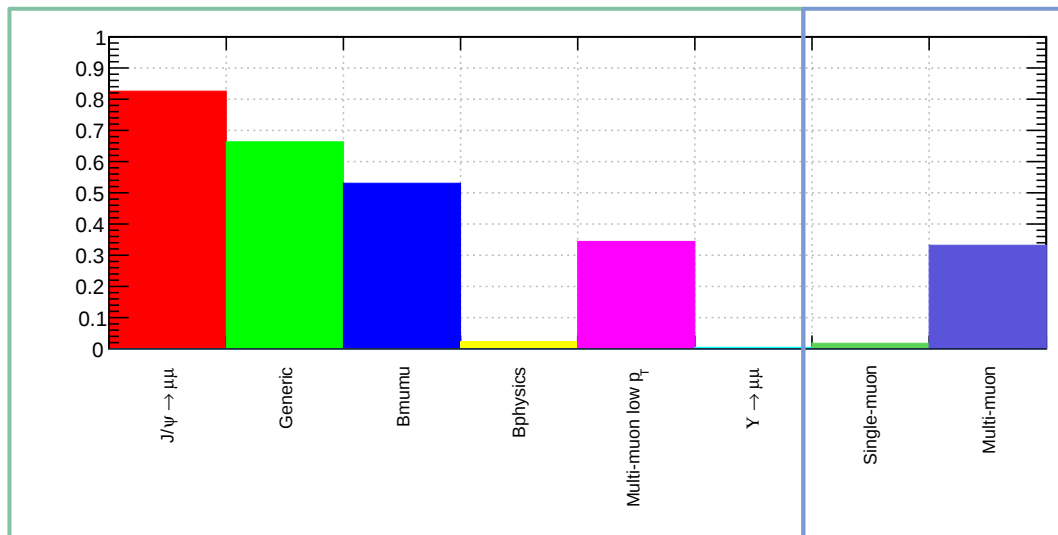
BARD triggers



Data streams in ATLAS

- Trigger system routes accepted events into multiple data streams:
Main stream, Express stream, delayed streams, calibration streams, ...
- Main stream: standard physics analyses and data quality → event is written to disk and full reconstruction starts basically immediately
- Delayed stream: specialized data stream (for example for B-physics) → event is written to disk but full reconstruction is done later when computing resources are free

Delayed stream

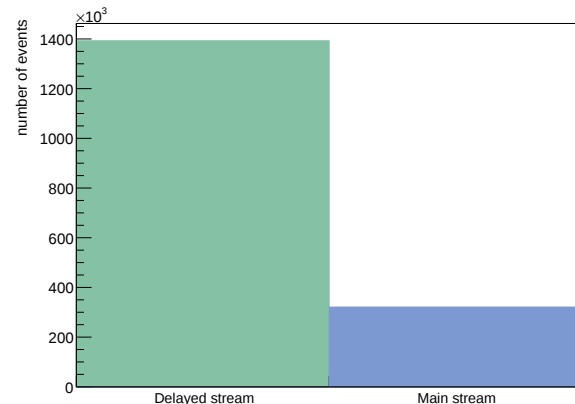


Main stream

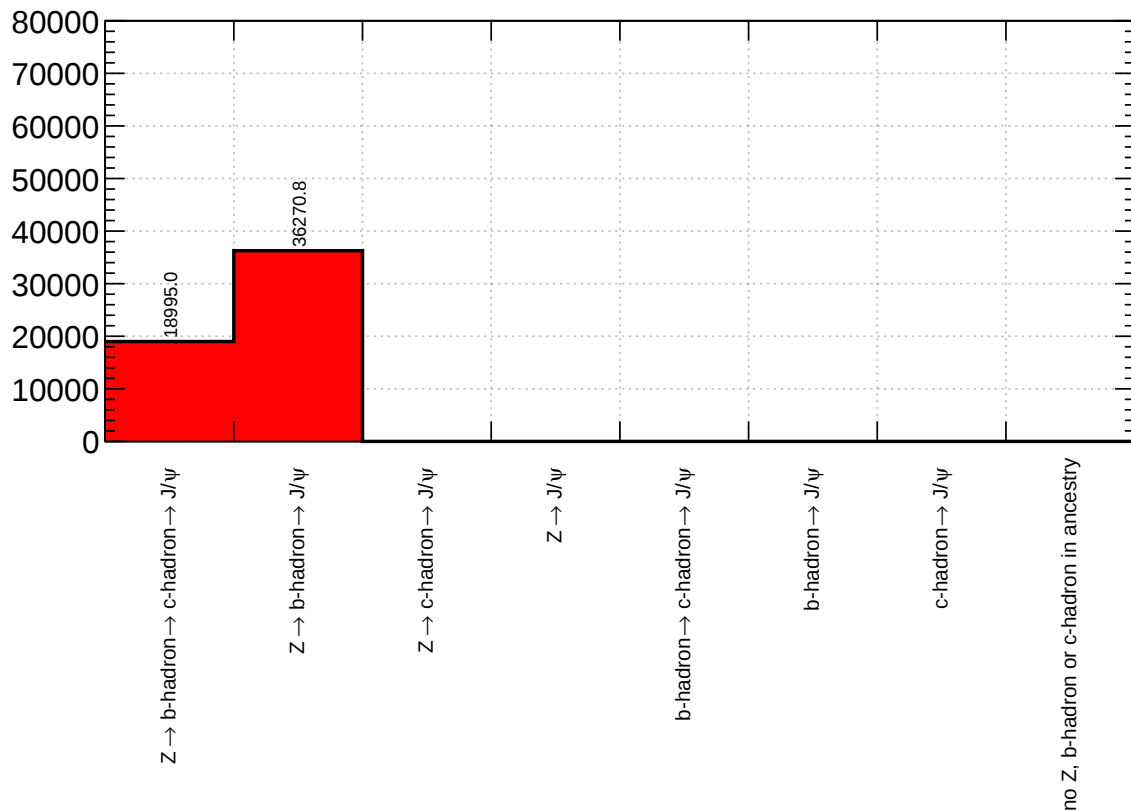
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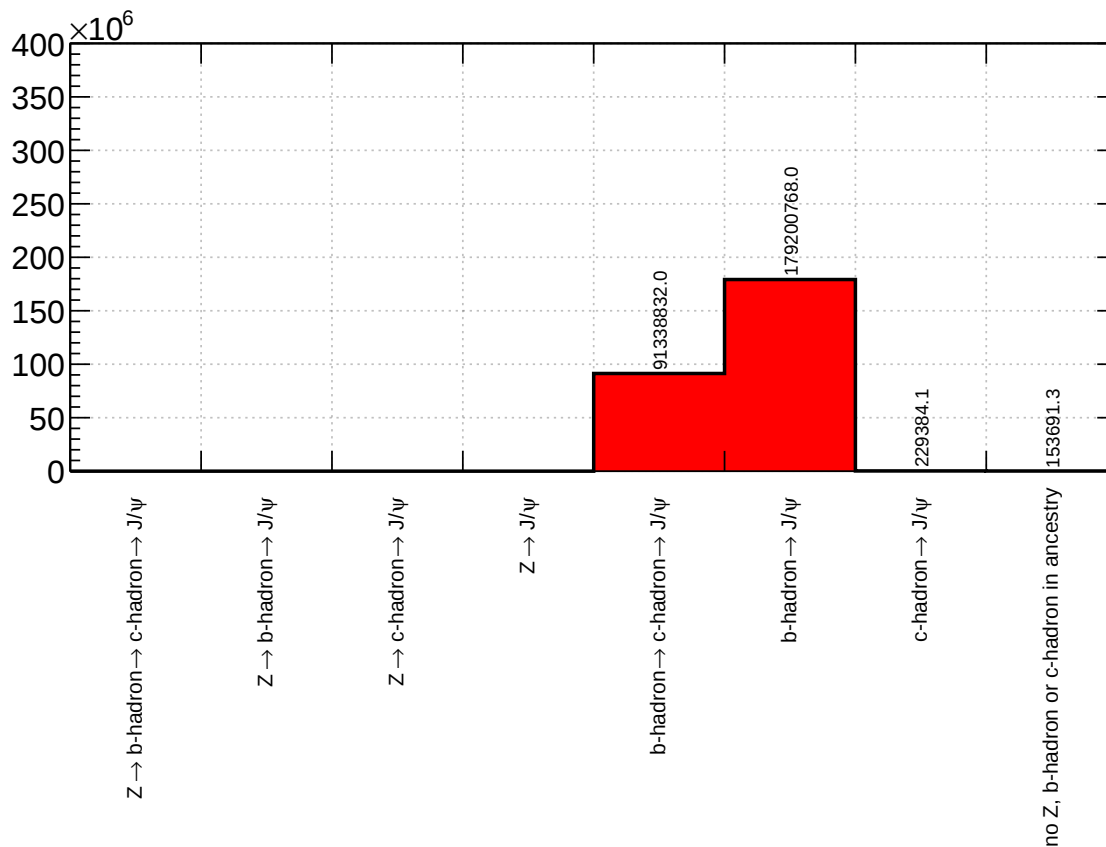
Important for BARD: Relevant $J/\psi \rightarrow \mu\mu$ triggers are writing to B-physics delayed stream, much more events



TruthJpsi origin in Z sample

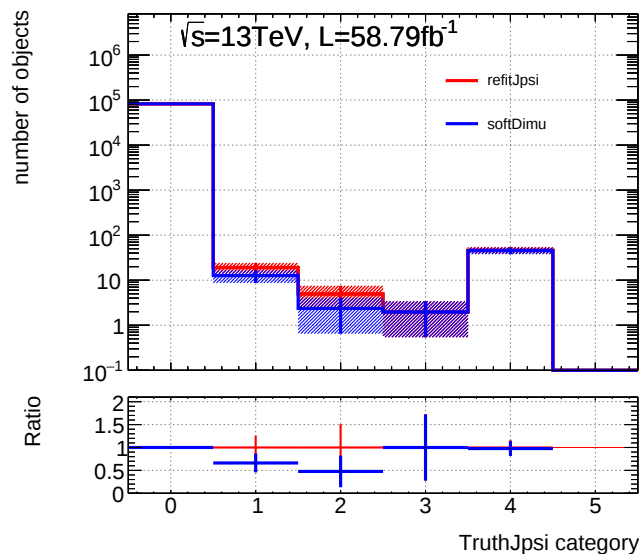


TruthJpsi origin in QCD sample



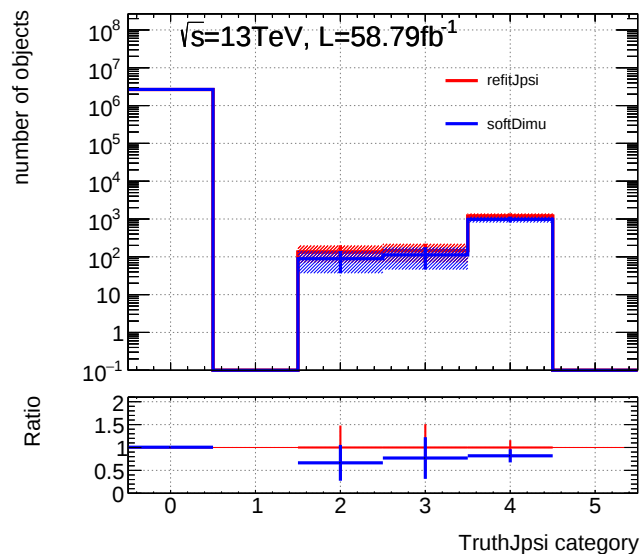
TruthJpsi categories in Z sample

- 0: both muons have the same TruthJpsi parent
- 1: both muons have a TruthJpsi parent but they are actually different TruthJpsi
- 2: one of the muons has a parent that is not a TruthJpsi
- 3: both muons have parents that are not TruthJpsi
- 4: one of the muons does not have a truthmatched Truthparticle
- 5: both muons do not have a truthmatched Truthparticle



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QCD vs Z

- Z difficult to see above QCD background
→ Find selections to improve signal to background ratio
- Useful to quantify discrimination power: Separation

$$\langle S^2 \rangle = \frac{1}{2} \int \frac{(y_S(x) - y_B(x))^2}{(y_S(x) + y_B(x))} dx$$

y_S = signal pdf (Z)

y_B = background pdf (QCD)

- separation = 0 means signal and background are identical
- separation = 1 means signal and background have no overlap

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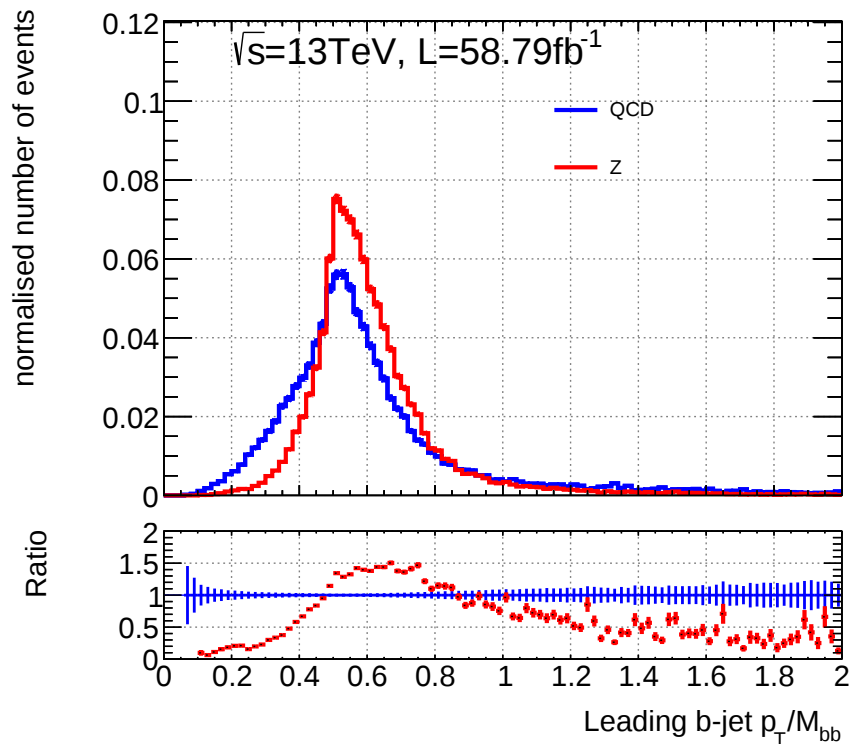
- separation = 0 means signal and background are identical
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→ Investigated many different variables

Variable	Separation
Mbb_corrected_softDimu_R	0.1218
Mbb_softDimu	0.0881
leading_bjet_pt_Mbb_ratio	0.0568
jpsi_tagged_jet_cos_theta_Collins_Soper	0.0564
btagged_jet_cos_theta_Collins_Soper	0.0564
cos_theta_collins_soper_from_function	0.0544
DeltaEta_bb_softDimu	0.0521
dibjet_centrality	0.0518
sorted_passed_leading_bjet_pt	0.0245
btagged_jet_cos_theta_Collins_Soper_2D	0.0216
jpsi_tagged_jet_cos_theta_Collins_Soper_2D	0.0216
Is_leading_jet_btagged	0.0204
etabb_softDimu_asymmetry	0.0201
leading_jet_that_is_not_bbsystem_tlv_pt	0.0173
pTbb_softDimu	0.0142
pT_mumu	0.0139
A_ZBB	0.0064
Jpsi_jet_fragmentation_pt	0.0053
dibjet_rapidity	0.0052
DR_between_jet_and_jpsi_softDimu	0.0046
pTbb_softDimu_asymmetry	0.0043
Jpsi_jet_fragmentation_pt_2	0.0039
JPSI_softDimu_tau	0.0035
number_of_jets	0.0034
JPSI_softDimu_d0sig2	0.0021
JPSI_softDimu_d0sig1	0.0020
massbb_softDimu_asymmetry	0.0019
JPSI_softDimu_simpleLxy	0.0016

Discriminating variables

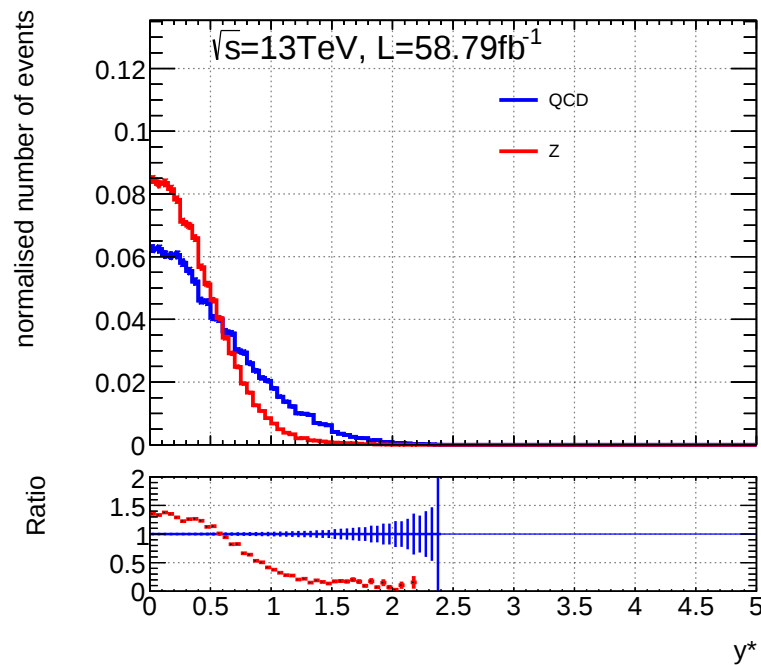
- Leading bjet p_T/M_{bb} currently has the best separation of 0.0568



Discriminating variables

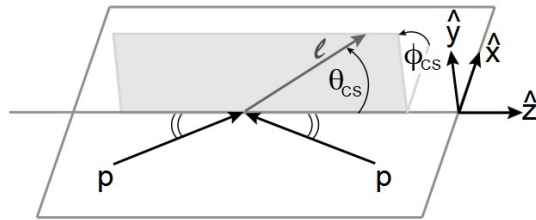
- Leading bjet pT/Mbb currently has the best separation of 0.0568

- Centrality defined as $|y^*| = \frac{|y_{jet,0} - y_{jet,1}|}{2}$



$\cos(\theta^*)$ in Collins-Soper frame

- Collins Soper frame is for example defined here: <https://arxiv.org/pdf/1606.00689>
- z-axis defined as the bisector of the incoming proton beams in the Z-mass restframe
- calculate $\cos(\theta^*)$ of boosted b-jet and boosted jpsi-jet with respect to this z-axis

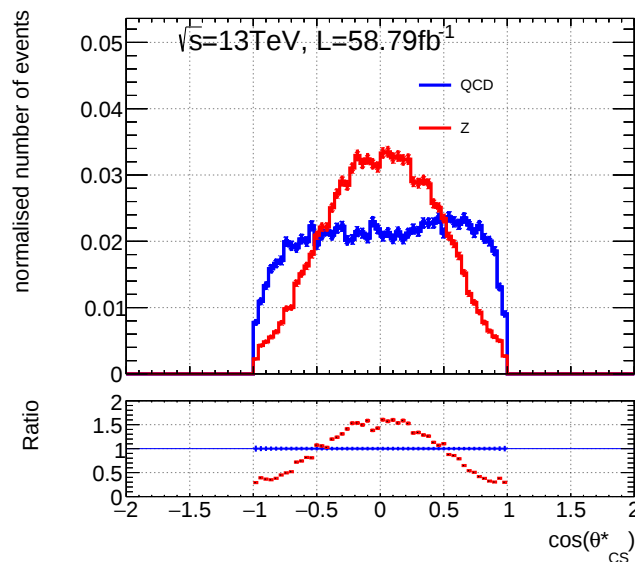


$$\cos \theta^* = \frac{p_{z,\ell\ell}}{m_{\ell\ell}|p_{z,\ell\ell}|} \frac{p_1^+ p_2^- - p_1^- p_2^+}{\sqrt{m_{\ell\ell}^2 + p_{T,\ell\ell}^2}}$$

- <https://arxiv.org/pdf/1710.05167> has a direct formula to calculate $\cos(\theta^*)$
- Usually used for leptons where the charge of the lepton is known
→ Charge not known for jets but can still apply the formula

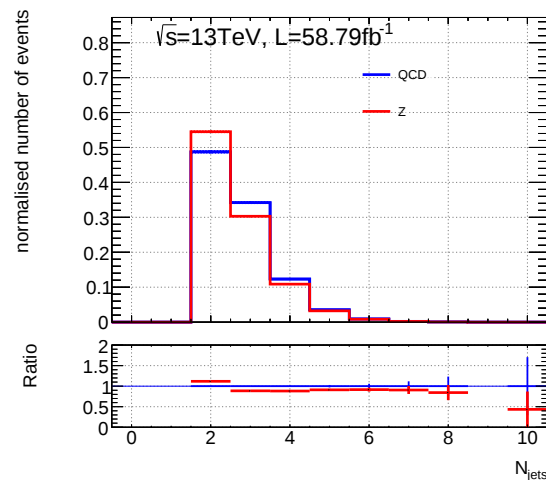
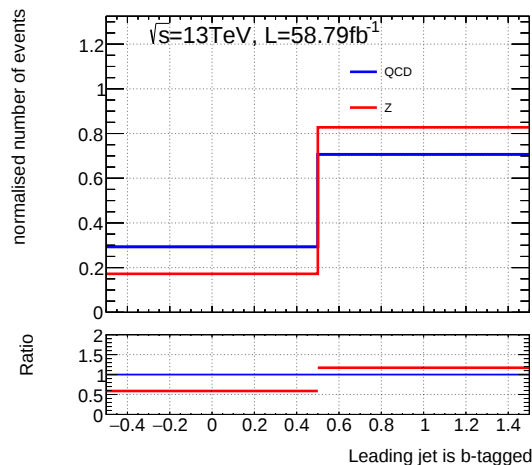
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- Centrality defined as $|y^*| = \frac{|y_{jet,0} - y_{jet,1}|}{2}$
- $\cos(\theta^*)$ usually used for $Z \rightarrow ll$ measurements but could also be applied here
- Requiring number of jets equal to 2 or that the leading jet in the events is b-tagged reduces the low Mbb contribution $\rightarrow$ Mbb turn on can be fitted easier



Trigger naming for L1 Muon

Naming for L1Muons

- MUxx + "V", "F", "C", "H", "R", "BO", "EC", "M"
 - xx : measured-pT value (**Different definition from Run-2.**). E.g. The pT distribution of muons which fire MU10, but not MU11, peaks at 10 GeV. The plateau starts around 12.5 GeV for endcap. See slide 10 onwards of [these slides](#) for details.
 - "V" : Variable thresholds with eta (e.g. different between barrel and endcap). TGC pT value is used for **xx** by definition.
 - "F" : require **F**ull-station (three-station) big-wheel coincidence for endcap
 - "C" : require inner-**C**oincidence for endcap (additional coincidence between Big Wheel TGC and one of the inner muon detectors — TGC-EI, [TileCal](#), NSW, or RPC-BIS78* if available; *RPC-BIS78 is currently under integration and not yet used for coincidence)
 - "H" : **H**ot-Rol mask (taken only events satisfied the good magnetic field flag) for endcap
 - "R" : **R**estricted region. available to exclude the RPC feet.
 - "BO": central (**B**arrel **O**nly) muons (only candidates from RPC, not from BIS78)
 - "EO": **E**ndcap **O**nly muons (everything from EC Sector Logic, so BIS78, TGC EC and FWD)
 - "M": **M**ultiple muon candidates by a flag which indicates two or more candidates in a RPC pad. (only available in barrel to mitigate inefficiencies of close-by muons, i.e. set with B)

Baseline L1 muon menu proposal:

Run2	Run3
MU4	MU3V
MU6	MU5VF
MU10	MU8F
MU11	MU8VF
MU20	MU14FCH
MU21	MU14FCHR

Muon trigger signatures

Muon

[Hide](#)

Field	Key description	Default	Allowed values	Value description
etaRange	Pseudorapidity cuts	0eta250	0eta105	barrel region only, $0 < \text{fabs}(\eta) < 1.05$
extra		""	noL1	full scan (only runs precision algos, no seed)
			lateMu	aka mgonly in Run-2. Runs late muon reconstruction
			muoncalib	muon calibration
			noL2Comb	aka nomucomb in Run-2
l2AlgInfo		""	l2io	L2MuonSA inside-out
			l2mt	L2MuonSA Multi-Track
isolInfo	isolation cut	""	ivarloose	ptvarcone30/pt < 0.16
			ivarmedium	ptvarcone30/pt < 0.07
			ivarperf	runs isolation, but no cut on output
			iloosems	isolation for MOnly legs ptcone30 < 3 GeV
lrlInfo	Muons with large d0	[]	d0loose	d0>2 mm
			d0medium	d0>3 mm
			d0tight	d0>5 mm
invMassInfo	Invariant mass range	""	10invm70	$10 < M(\text{mumu}) < 70 \text{ GeV}$
		""	invmJPsiOS	$2.5 < M(\text{mumu}) < 4.3 \text{ GeV}$ with opposite charge cut
		""	invmDimu	$1.5 < M(\text{mumu}) < 14 \text{ GeV}$
msonlyInfo	MS only, not running combination between ID and MS tracks	[]	msonly	
addInfo		[]	idperf	fast and precision combined muon steps in passthrough
			LRT	Large radius tracking
			3layersEC	3 layer hits in MS EC
			cosmic	naming for cosmic triggers, no actual difference in configuration
			muonqual	muon passes: $\chi^2 < 8.0$ && ! isBadMuon && qOverPsignif<7.0 && MuidCo
			nscan	muons with dR of 0.5

BLS trigger signatures

BLS

As BphysicsChainConfiguration inherits from MuonChainConfiguration, the fields defined in the Muon slice are still relevant for BLS chain configuration. B-physics part adds `topo` values responsible for configuration of multi-muon/track handling described below.

▼ Hide

topo[0]	topo[-1]	trigger type	mass selection	chi2 selection	notes
bJpsimumu		di-muon	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}$	< 20	
bJpsi		di-muon	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}$	< 20	
bJpsimumu		di-muon	$8 < m(\mu^+\mu^-) < 12 \text{ GeV}$	< 20	
bJpsi		di-muon	$8 < m(\mu^+\mu^-) < 12 \text{ GeV}$	< 20	
bBmumu		di-muon	$4 < m(\mu^+\mu^-) < 8.5 \text{ GeV}$	< 20	
bDimu		di-muon	$1.5 < m(\mu^+\mu^-) < 14 \text{ GeV}$	< 20	
bDimu2700		di-muon	$0.1 < m(\mu^+\mu^-) < 2.7 \text{ GeV}$	< 20	
bDimu6000		di-muon	$0.1 < m(\mu^+\mu^-) < 6 \text{ GeV}$	< 20	
bPhi		di-muon	$940 < m(\mu^+\mu^-) < 1100 \text{ MeV}$	< 10	
bTau		di-muon	$0 < m(\mu^+\mu^-) < 2.7 \text{ GeV}$	< 50	
bBeeM6000		di-electron	$0.1 < m(e^+e^-) < 6 \text{ GeV}$	< 20	
bJpsimutrk		muon+track	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}$	< 20	to use with PEB
bBmumux		dimuon+{1,2,3} tracks		< 20	general cut on dimuon vertex
bBmumux	BpmumuKp	dimuon+1 track	$0.1 < m(\mu^+\mu^-) < 5.5 \text{ GeV}, 4.5 < m(\mu^+\mu^-K^+) < 5.9 \text{ GeV}$	< 50	$B^+ \rightarrow \mu\mu K^+$
bBmumux	BcmumuPi	dimuon+1 track	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 5.5 < m(\mu^+\mu^-p^+) < 7.3 \text{ GeV}$	< 50	$B_c^+ \rightarrow J/\psi p K^+$
bBmumux	BsmumuPhi	dimuon+2 tracks	$0.1 < m(\mu^+\mu^-) < 5.5 \text{ GeV}, 940 < m(K^+K^-) < 1100 \text{ MeV}, 4.8 < m(\mu^+\mu^-K^+K^-) < 5.8 \text{ GeV}$	< 60	$B^0_S \rightarrow J/\psi \eta$
bBmumux	BdmumuKst	dimuon+2 tracks	$0.1 < m(\mu^+\mu^-) < 5.5 \text{ GeV}, 700 < m(K^+p^+) < 1100 \text{ MeV}, 4.6 < m(\mu^+\mu^-K^+p^+) < 5.9 \text{ GeV}$	< 60	$B^0_d \rightarrow \mu\mu K^0$
bBmumux	LbPqKm	dimuon+2 tracks	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 4.8 < m(\mu^+\mu^-p^+p^+) < 6.4 \text{ GeV}$	< 60	$\Lambda^0_b \rightarrow J/\psi p K^-$ (pentaquark studies)
bBmumux	BcmumuDloose	dimuon+3 tracks	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 940 < m(K^+K^-) < 1100 \text{ MeV}, 1750 < m(K^+K^-p^+) < 2100 \text{ MeV}, 5.5 < m(\mu^+\mu^-K^+K^-p^+) < 7.3 \text{ GeV}$	< 60	$B_c^+ \rightarrow J/\psi D^+_s + (-\phi(K^+K^-)\pi^+)$, chi2 cut is on the D^+_s vertex with a requirement to point to the dimuon vertex
bBmumux	BcmumuDploose	dimuon+3 tracks	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 1750 < m(K^+p^+p^+) < 2000 \text{ MeV}, 5.5 < m(\mu^+\mu^-K^+p^+p^+) < 7.3 \text{ GeV}$	< 60	$B_c^+ \rightarrow J/\psi D^+(K^+\pi^+\pi^+)$, chi2 cut is on the D^+ vertex with a requirement to point to the dimuon vertex
bBmumux	BcmumuD0Xloose	dimuon+2 tracks	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 1750 < m(K^+\pi^+) < 2000 \text{ MeV}, 5.5 < m(\mu^+\mu^-K^+\pi^+) < 7.3 \text{ GeV}$	< 60	$B_c^+ \rightarrow J/\psi D^0(K^+\pi^+) X$, chi2 cut is on the D^0 vertex with a requirement to point to the dimuon vertex
bBmumux	BcmumuDstarloose	dimuon+3 tracks	$2.5 < m(\mu^+\mu^-) < 4.3 \text{ GeV}, 1750 < m(K^+p^+) < 2000 \text{ MeV}, m(K^+p^+s) < 2110 \text{ MeV}, 5.5 < m(\mu^+\mu^-K^+p^+) < 7.3 \text{ GeV}$	< 60	$B_c^+ \rightarrow J/\psi D^{*+}(D^0(K^+\pi^+)\pi^+)$, chi2 cut is on the D^0 vertex with a requirement to point to mumpi+ vertex, and the same on the mumpi+ vertex itself
bBmux		muon+{2,3} tracks with cascade fit		< 50	chi2 cut for the entire cascade (common for all branches)
bBmux	BsmuDsX	muon+3 tracks with cascade fit	$940 < m(K^+K^-) < 1100 \text{ MeV}, 1750 < m(K^+K^-\pi^-) < 2100 \text{ MeV}, m(\mu^+K^+K^-\pi^-) < 10 \text{ GeV}$	< 27	$B^0 \rightarrow \mu^+ D^- (\rightarrow \phi (\rightarrow K^+ K^-) \pi^-) X$, chi2 cut is on the D^- vertex, $L_{xy}(B^0) > 0.1 \text{ mm}, L_{xy}(D^-) > 0.02 \text{ mm}$
bBmux	BdmuDPX	muon+3 tracks with cascade fit	$1750 < m(K^+\pi^-\pi^-) < 2000 \text{ MeV}, m(\mu^+K^+\pi^-\pi^-) < 10 \text{ GeV}$	< 27	$B^0 \rightarrow \mu^+ D^- (\rightarrow K^+\pi^-\pi^-) X$, chi2 cut is on the D^- vertex, $L_{xy}(B^0) > 0.1 \text{ mm}, L_{xy}(D^-) > 0.05 \text{ mm}$
bBmux	BpmuDOX	muon+2 tracks with cascade fit	$1750 < m(K^+\pi^-) < 2000 \text{ MeV}, m(\mu^+K^+\pi^-) < 10 \text{ GeV}$	< 20	$B^+ \rightarrow \mu^+ D^0 (\rightarrow K^+\pi^-) X$ (also selects $B^0 \rightarrow \mu^+ D^{*-} (\rightarrow D^- (\rightarrow K^+\pi^-) \pi^-) X$), chi2 cut is on the D^0 vertex, $L_{xy}(B^+) > 0.1 \text{ mm}, L_{xy}(D^0) > 0$
bBmux	BdmuDstarX	muon+3 tracks with cascade fit	$1750 < m(K^+\pi^-) < 2000 \text{ MeV}, m(K^+\pi^-\pi^+) < 2110 \text{ MeV}, m(\mu^+K^+\pi^-) < 10 \text{ GeV}$	< 20	$B^0 \rightarrow \mu^+ D^{*-} (\rightarrow D^- (\rightarrow K^+\pi^-) \pi^-) X$, chi2 cut is on the D^0 vertex, $L_{xy}(B^0) > 0.05 \text{ mm}, L_{xy}(D^0) > 0$
bBmux	LbmLcX	muon+3 tracks with cascade fit	$2190 < m(pK^+\pi^-) < 2390 \text{ MeV}, m(\mu^+pK^+\pi^-) < 10 \text{ GeV}$	< 27	$\Lambda_b^0 \rightarrow \mu^+ \bar{\Lambda}_c^- (\rightarrow pK^+\pi^-) X$, chi2 cut is on the $\bar{\Lambda}_c^-$ vertex, $L_{xy}(\Lambda_b^0) > 0.1 \text{ mm}, L_{xy}(\bar{\Lambda}_c^-) > 0.02 \text{ mm}$

Other options affecting the selection are listed below:

topo[0]	description
nocut	for di-muon chains: no selection, AcceptAll=True
noos	for di-muon chains: no muon opposite-sign requirement
Lxy0	for di-muon chains: require Lxy of dimuon vertex > 0

ATLAS muon system

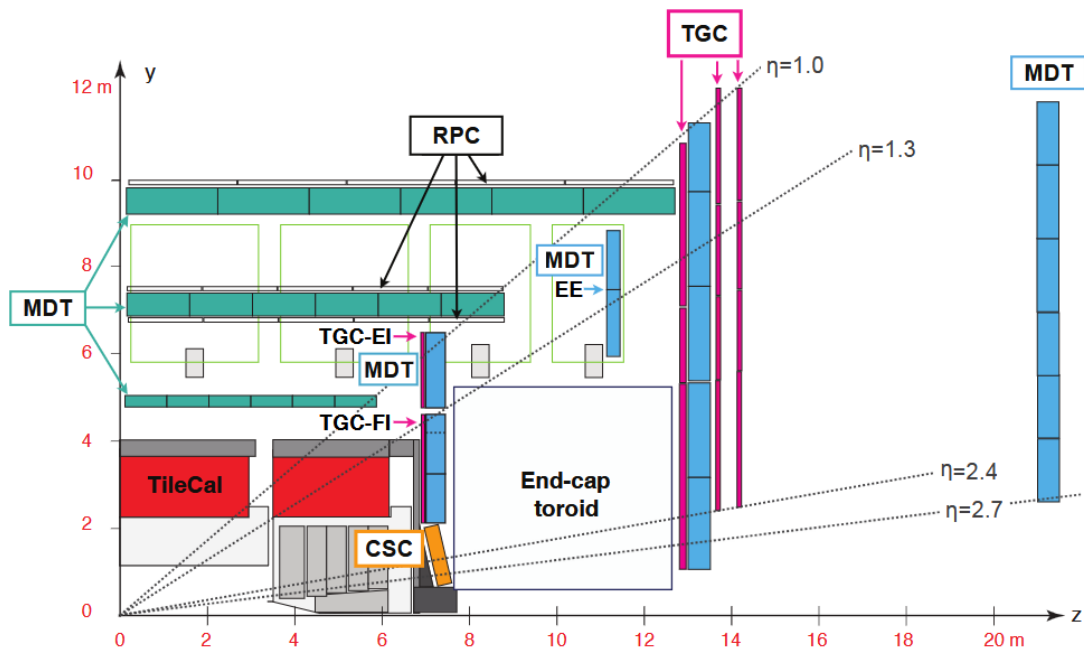
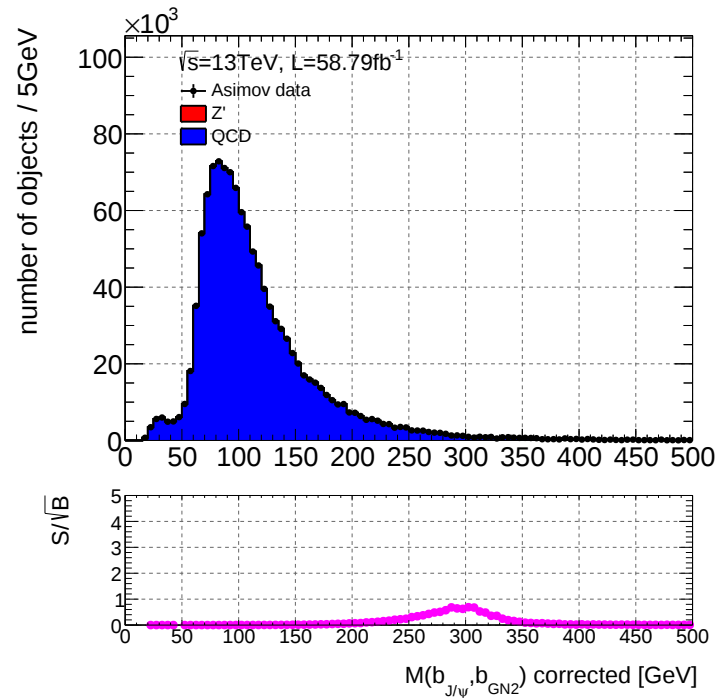


Figure 1: A schematic picture showing a quarter-section of the muon system in a plane containing the beam axis, with monitored drift tube (MDT) and cathode strip (CSC) chambers for momentum determination and resistive plate (RPC) and thin gap (TGC) chambers for triggering. The Forward Inner and Endcap Inner TGC chambers are marked as TGC-FI and TGC-EI, respectively. The Extended Endcap MDT chambers are referred to as EE.

Zprime

- Zprime with mass 300GeV
→ sensitivity much lower but peak at a better position



Higgs

- Another resonance that could decay to a pair of b-quarks is the Higgs
- Higgs cross section: 59.3pb
- Higgs→bb branching fraction: 0.53
 - $59.3\text{pb} * 0.53 \approx 31.43$
- Z cross section: 59120pb
 - $59120\text{pb} * 0.15 \approx 8868.0$
 - Higgs would have at least factor $8868.0/31.43 \approx 282$ less events