An introduction to the MCnet MOSES project
and,
Heavy KK gauge bosons search at the LHC

Given at the MC4BSM workshop

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http://projects.hepforge.org/moses

arXiv:1004.1649v1 [hep-ex], MCnet/10/05

arXiv:1004.2432v1 [hep-ex], MCnet/10/06 (submitted to JHEP)

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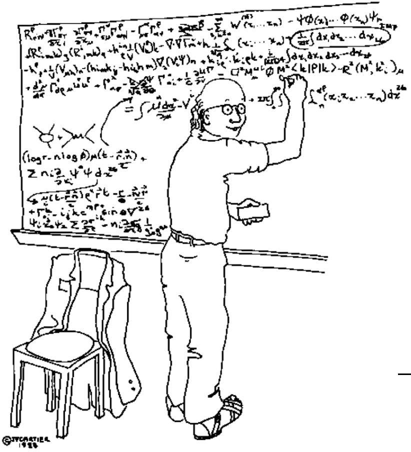
Outline

1. About the MOSES Project
2. Heavy gauge bosons search at the LHC
   - Extra dimensions (EDs)
   - The Kaluza-Klein (KK) process in the LHC
   - Kinematics study with simulated events

A (very) brief overview

- Goal: To generate events according to a certain Kaluza-Klein model, which has not yet been implemented in any generator
- Constraint: To work within an existing MC generator (Pythia8)
- The general KK process, $f\bar{f} \to \sum(\gamma^*/Z^*)_n \to F\bar{F}$, is implemented as a standard plugin to Pythia8 which allows $2 \to 1$, $2 \to 2$ and $2 \to 3$ new processes to be plugged in externally
- We also implemented it inside Pythia8 **(to be out in v8.140)**
- What is MOSES ? **(1^{st} release is available in HepForge)**
  - A C++ framework for probing and developing BSM procs'
  - Coded as a set of interfaces to common HEP tools like ROOT, LHAPDF, HepPDT and of course Pythia8 (now)
  - What's inside ? the KK process + related examples
  - The framework enables to extend for new processes
- Main feature: The classes written for probing the model phenomenology, can be used also by Pythia8

EDs frameworks



"At this point we notice that this equation is beautifully simplified if we assume that space–time has 92 dimensions."

- ADD [a] (Many) Large flat EDs upto few microns. G can propagate out, SM particles restricted to $3d$.
- RS [b] Small highly curved extra spatial ED. Gravity localized in the ED.
- TeV^{-1} [c] Bosons propagate in the bulk. Fermions localized at $3d$: KK-SM interference, e.g. the S^1/Z_2 model.
- UED All SM particles propagate in Universal ED, often embedded in LED.

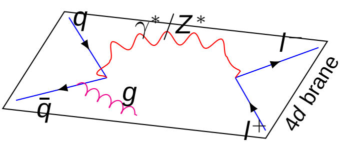
[a] Arkani-Hamed, Diamopoulos, Dvali, Phys. Rev. Lett. 83 (99)
[b] Randall, Sundrum, Phys. Lett. B429 (98)
[c] Dienes, Dudas, Gherghetta, Nucl. Phys. B537 (99)

The S^1/Z_2 TeV^{-1} ED model

- A single ED compactified on a S^1/Z_2 orbifold with radius R
- Equally spaced KK states with masses $m_n^2 = m^2 + \frac{n^2}{R^2}$
- We focus on the 1^{st} KK mode of γ and Z^0 (γ^* and Z^*)
- The KK mass is defined as $m^* = R^{-1}$
- Current (indirect) low bound: $m^* =$4 TeV
  - Assuming this is the only BSM physics
- A strong destructive interference with the SM exchanges below the resonance mass leads to a significant suppression of the cross section JHEP08(2009)082, August 21, 2009.
- In this model, a SM-KK mixing is not considered

Experimental analysis

- Production channel (for $m^* = 4$ or 3 TeV): The Drell-Yan $pp \to \gamma^*/Z^* \to l^+l^- + X$
- Signal: heavy di-muon final state, $\sqrt{\hat{s}} \sim 1$ TeV
- Background: Very low, SM di-lepton pairs
- Compare with a Z' signal from GUT breaking

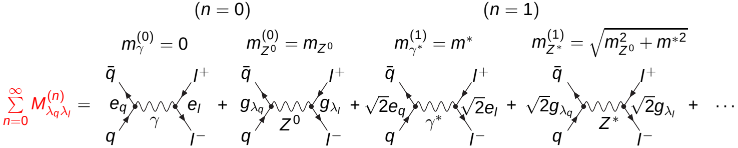


Detection & identification

- Distinguishing from similar BSM processes should be possible only at $\sqrt{s}_{\text{LHC}} = 14$ TeV and $\mathcal{L}_{\text{LHC}} = 10 - 100\ \text{fb}^{-1}$
- Hints for a remote KK peak, beyond the LHC reach, should be visible as early as 7 TeV and 10 fb^{-1} for $m^* \gtrsim 3$ TeV

Cross section and Amplitude

- The LO helicity amplitude formulation is similar to the SM (therefore the validation is trivial, see backup slides)
- The amplitude is an infinite KK tower (SM term is $n=0$)



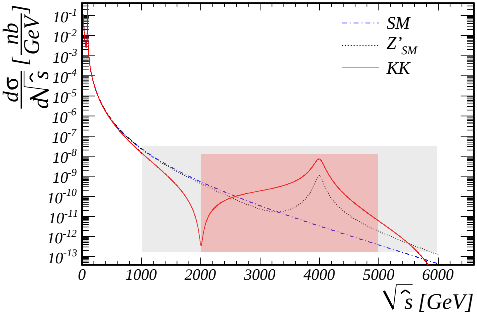
- The partonic cross section for $q\bar{q} \to \sum_{n=0}^{\infty} (\gamma^*/Z^*)_n \to l^+l^-$,

$$\frac{d\hat{\sigma}(\hat{s},\cos\theta^*)}{d\hat{t}} = \frac{\pi\alpha_{em}^2}{4N_C^q} \sum_{\lambda_q} \sum_{\lambda_l} \left| \sum_{n=0}^{\infty} M_{\lambda_q\lambda_l}^{(n)} \right|^2 (1+4\lambda_q\lambda_l\cos\theta^*)^2$$

Hadronic cross section

- The KK, Z'_{SM} and SM hadronic differential cross section

Note the unique "dip" between ~1 and 2.5 TeV



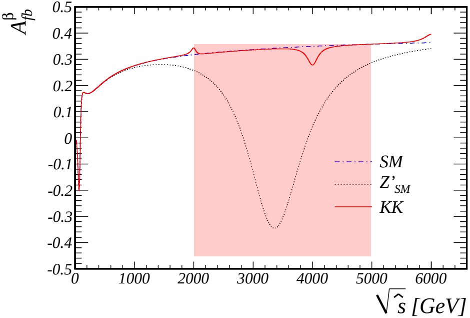
- Approximate number of events expected for $\mathcal{L}$=100 fb^{-1}

Model	Events in 1(2) $\leq \sqrt{\hat{s}} \leq$ 6(5) TeV
SM	480(15)
Z'_{SM}	460(30)
KK	400(190)

Within the *ATLAS* detector acceptance

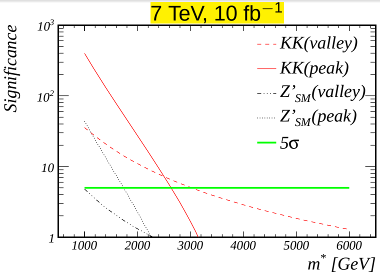
Forward-backward asymmetry

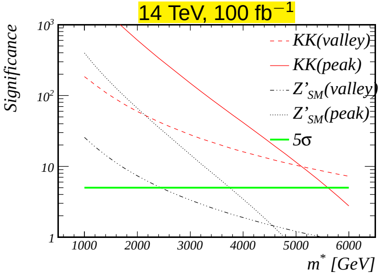
- Naively, $A_{fb} = \frac{N_f - N_b}{N_f + N_b}$
- Can be obtained from the $\cos\theta^*$ distribution (in LO): $\sim \frac{3}{8}\left(1+\cos^2\theta^* + \frac{8}{3}A_{fb}\cos\theta^*\right)$
- q direction is unknown
  - Should reclassify $\cos\theta^*$
  - Naturally, relative to $\vec{\beta} = \beta\hat{z}$
  - Redefine: $\cos\theta^*_\beta$, A^β_{fb}
- Cannot measure ON peak
  - Calculate in a wider range
  - Average on $\hat{m} \equiv \sqrt{\hat{s}}$: $\widehat{A^\beta_{fb}} \equiv \int_2^5 \frac{d\sigma}{d\hat{m}} A^\beta_{fb} d\hat{m} \div \int_2^5 \frac{d\sigma}{d\hat{m}} d\hat{m}$



Model	$\widehat{A^\beta_{fb}}$ in $2 \leq \sqrt{\hat{s}} \leq 5$ TeV
SM	0.325
Z'_{SM}	0.090
KK	0.308

Expected sensitivity around the KK peak and dip





Significance: $S(m^*) \equiv \frac{|N_{BSM}(m^*) - N_{SM}|}{\sqrt{N_{SM}}}$

where, $N = \mathcal{L} \int \sigma d\sqrt{\hat{s}}$

integrate peak in: $\frac{m^*}{2} \leq \sqrt{\hat{s}} \leq \frac{3m^*}{2}$

integrate "dip" in: $2m_{Z^0} \lesssim \sqrt{\hat{s}} \leq \frac{m^*}{2}$

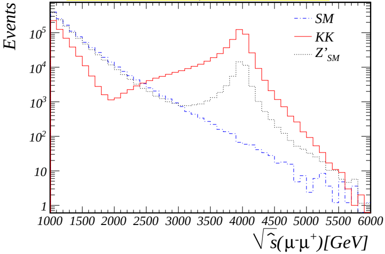
but dip **shape** is more informative than the number of events !

At the generator level

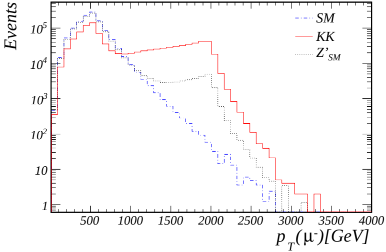
- Using the C++ framework MoSES, and Pythia8 with MRST2001lo (LHAPDF)
- Supplied hard process: $q\bar{q} \to \sum_{n=0}^{100} (\gamma^*/Z^*)_n \to \mu^+\mu^-$
- Generation range $1 \leq \sqrt{\hat{s}} \leq 6$ TeV
  - Practically, only $n = 0, 1, 2$ contribute
- Samples: Large ref', pseudo-data: 100 fb^{-1}
- Pythia8 is responsible for the complete event generation:
  - Generation of partons from the incoming protons (PDFs)
  - Effects of ISR and FSR
  - Parton showering
  - Hadronization
  - Proton remnant fragmentation
  - Particle decay etc.

Kinematic distributions - Large MC references

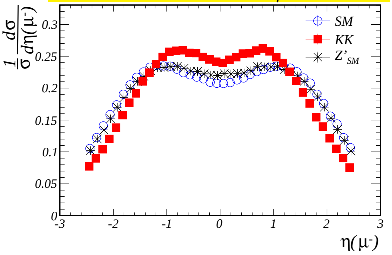
The di-muon $\sqrt{\hat{s}}$ distribution



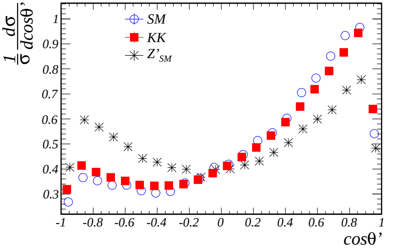
The muons p_T distribution



The muons normalized η distribution

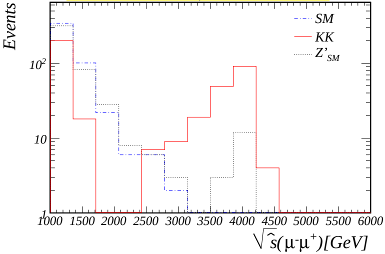


The normalized $\cos\theta'$ distribution

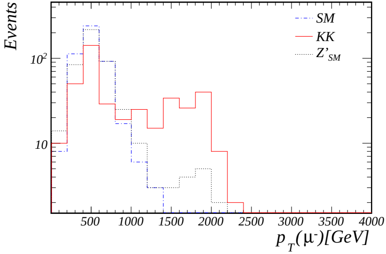


Kinematic distributions - $\mathcal{L} = 100\text{fb}^{-1}$

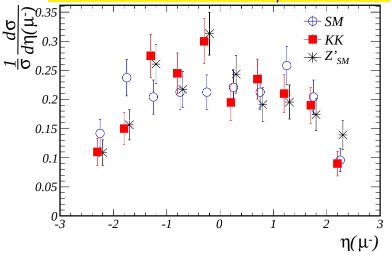
The di-muon $\sqrt{\hat{s}}$ distribution



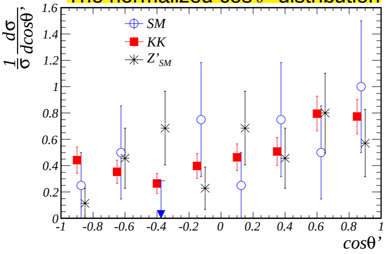
The muons p_T distribution



The muons normalized η distribution

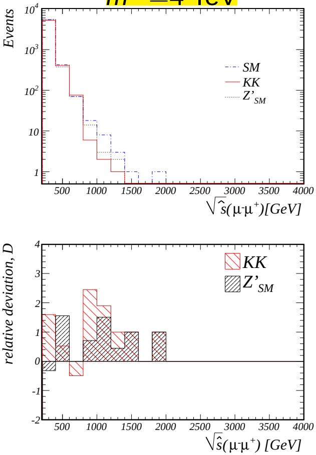


The normalized $\cos\theta'$ distribution



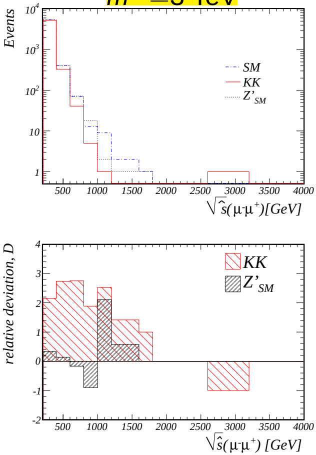
Expected sensitivity with early data: 7 TeV, 10 fb^{-1}

$m^* = 4$ TeV



	χ^2_{DOF}	*Kolmog*.prob
KK	1.8	0.26
Z'_{SM}	1.06	0.98

$m^* = 3$ TeV



	χ^2_{DOF}	*Kolmog*.prob
KK	2.74	0.005
Z'_{SM}	0.85	0.95

Relative deviation:

$$D \equiv \frac{N_{BSM} - N_{SM}}{\sqrt{N_{BSM} + N_{SM}}}$$

Look above $\sim$200 GeV: $\sqrt{\hat{s}} > 2m_{Z^0}$

Both the size & **trend** of D are important !

Outlook

- An important BSM process can now be used in a standard way
- This process is particularly interesting for the early LHC programme
  - The unique KK "dip" in the $\sqrt{\hat{s}}$ distribution
  - The enhancement in the p_T distribution
- Potential discovery of a resonance at $\sim$4 TeV
  - Only during the late LHC programme (14 TeV and 10-100 fb^{-1})
  - Can use also the $\cos\theta'$ distribution and the derived A_{fb} for discrimination with other BSM models
- All the information presented here is supported by a preliminary full simulation study within *ATLAS* (not yet official)
- The MOSES code is under continuous development and improvement
- Add more BSM processes - (flavor violating ED procs' etc.)
- Official integration of BSM procs' in PYTHIA8 is much easier

END

...a lot more can be found in the backup slides, in arXiv:1004.1649v1 [hep-ex] or, simply email me: noam.hod@cern.ch

Additional heavy boson production

- GUTs postulate that the SM symmetries have a common origin
  - A larger symmetry group – for example, E_6 and $SO(10)$
- Below some critical energy scale, it is spontaneously broken
  - At least one additional gauge boson is predicted
- The extra neutral gauge bosons are usually denoted by Z'
  - The LHC discovery potential is high and well known
  - Exclusion by Tevatron (direct): $m_{Z'} \geq 900$ GeV
- Similar (KK-like) deviations from the SM may be observed
  - Need to choose one conventional model: Z'_{SM} (why ?)
  - Need to study the differences between the 2 candidates
  - Need to build a mechanism for distinction

Couplings and Widths

- Couplings of the of the excited (Z^*) KK states to fermions

$$g^{(n)}_{\lambda_f} = \begin{cases} g_{\lambda_f} & \text{if } n = 0 \\ \sqrt{2} \cdot g_{\lambda_f} & \text{otherwise} \end{cases}$$

  - Replace g_{λ_f} with e_f for the KK photon (γ^*)

- Total γ^* and Z^* decay width to fermion-antifermion pairs

$$\Gamma^{(n)}_{Z^* \to F\bar{F}} = \Gamma_{Z^0 \to F\bar{F}} \cdot \begin{cases} 1 & \text{if } n = 0 \\ 2\frac{m^{(n)}_{Z^*}}{m_{Z^0}} & \text{otherwise} \end{cases}$$

$$\Gamma^{(n)}_{\gamma^* \to F\bar{F}} = \frac{2N^F_C \alpha_{em} e^2_F}{3} \cdot m^{(n)}_{\gamma^*} \qquad \text{if } n \neq 0$$

The origin of the $\sqrt{2}$ factor of the effective KK couplings

- The 5d action takes the form

  $S = \int_0^{2\pi R} dx^5 \int d^4x \left[\frac{1}{2}\mathcal{L}_{\text{Bulk}} + \mathcal{L}_0\delta(x^5) + \mathcal{L}_\pi\delta(x^5 - \pi R)\right]$ where, $\mathcal{L}_{\text{Bulk}} \sim \frac{1}{g^2_{\text{KK}}}$

- As the point x^5 is identified with the point $-x^5$, the S^1/Z_2 is regarded as a line segment whose length is πR, so

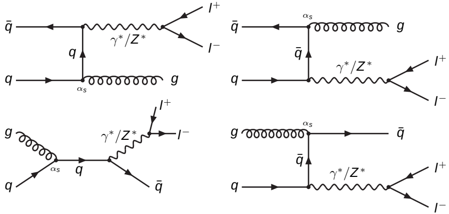
$$\int_0^{\pi R} dx^5 \mathcal{L}_{\text{Bulk}} = \frac{1}{2}\int_0^{2\pi R} dx^5 \mathcal{L}_{\text{Bulk}} \Rightarrow \mathcal{L}^{\text{Eff}}_{\text{Bulk}} = \frac{1}{2}\mathcal{L}_{\text{Bulk}}$$

- Therefore, if we postulate that $g_{\text{KK}} = g_{\text{SM}}$ then the effective couplings are,

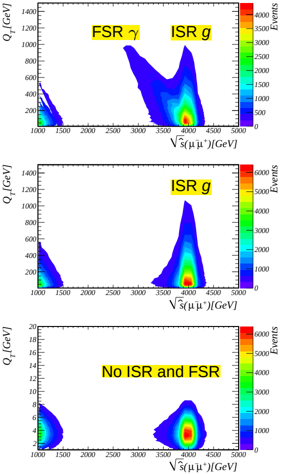
$$\frac{1}{g^2_{\text{Eff}}} = \frac{1}{2g^2_{\text{KK}}} \Rightarrow g_{\text{Eff}} = \sqrt{2}g_{\text{SM}}$$

ISR and FSR effects

- LO DY picture: $\vec{\beta} = \beta\hat{z}$
- NLO DY picture: $\vec{\beta} = \beta_z\hat{z} + \beta_T\hat{T}$
  - Original q emits an ISR g

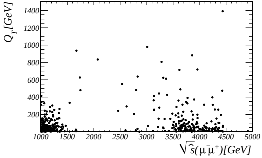


  - Outgoing ℓ^- radiates an FSR γ
- Effect on kinematics:
  - Modify LO $\cos\theta^*$ distribution
  - Shift $\sqrt{\hat{s}}$ to lower values (FSR)

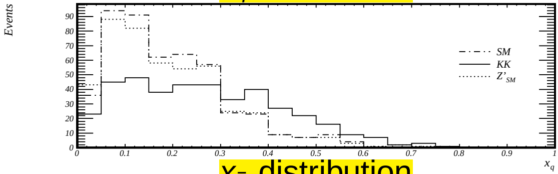


x_{Bjorken} and ISR effect for the 100 fb^{-1} samples

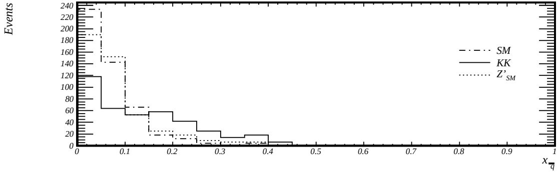
Q_T vs. $\sqrt{\hat{s}}$ distribution



x_q distribution



$x_{\bar{q}}$ distribution



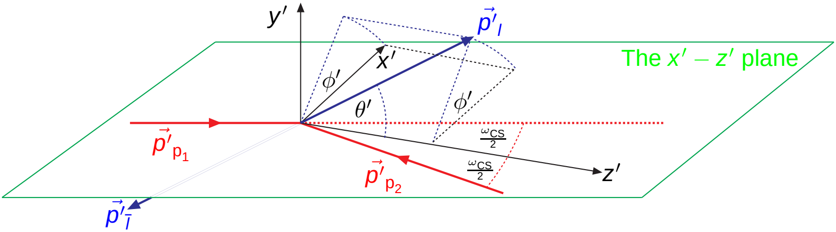
Angular distribution – in the light of ISR

- Rotate the di-lepton system to a new reference frame
- New frame can be the Collins-Soper (CS, denoted by $\mathcal{O}'$)
  - Minimizes the contribution of longitudinal polarized Z^*'s
- Calculate $\cos\theta'$ relative to the di-lepton rapidity sign
- The $\cos\theta'$ distribution to first order in α_s is,

$$\frac{1}{N}\frac{dN}{d\cos\theta'} = \frac{3}{8}\left[1 + \frac{1}{2}A_0 + \frac{8}{3}A_{fb}\cos\theta' + \left(1 - \frac{3}{2}A_0\right)\cos^2\theta'\right]$$

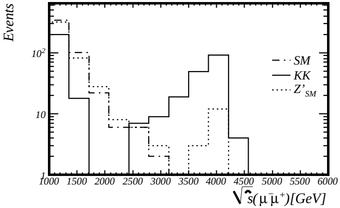
  - The A_0 coefficient is small

The Collins Soper reference frame

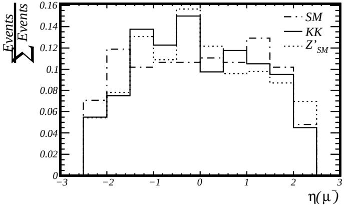


Kinematic distributions - $\mathcal{L}$=100 fb^{-1}

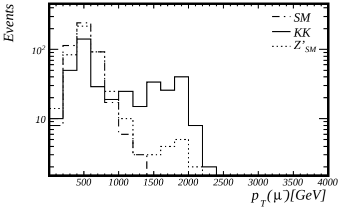
The di-muon $\sqrt{\hat{s}}$ distribution



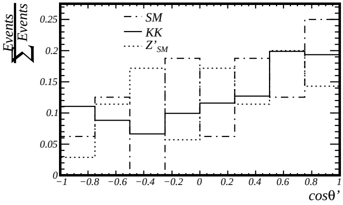
The muons normalized η distribution



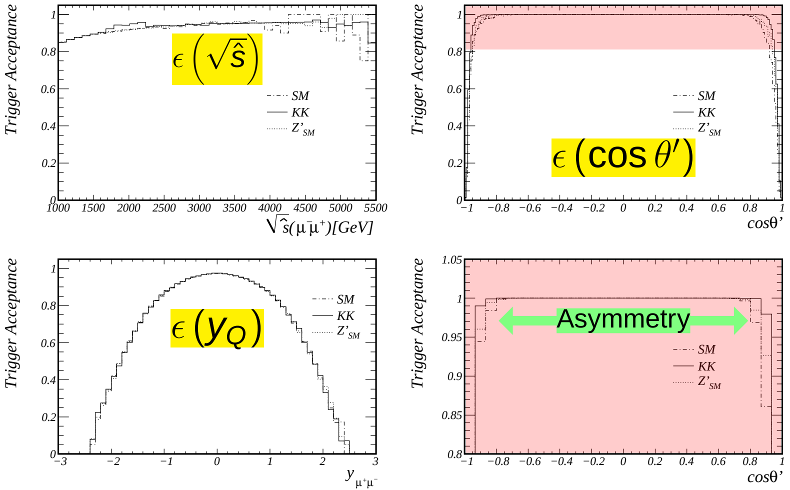
The muons p_T distribution



The normalized cos θ' distribution

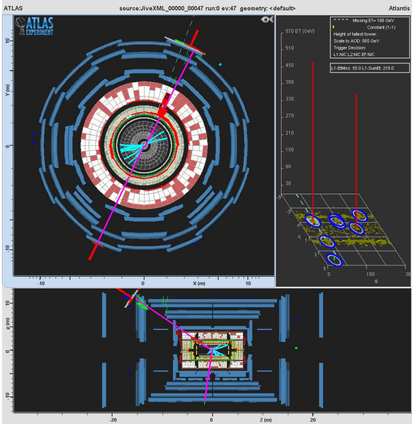


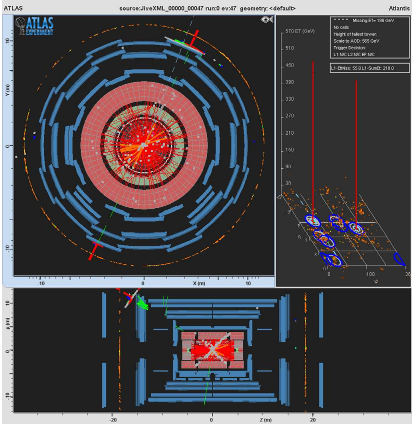
Detector and Trigger acceptance



Full ATLAS simulation - KK event display

Event's mass: $\sqrt{\hat{s}}_{\mathrm{rec}}$=3.86 TeV, $\sqrt{\hat{s}}_{\mathrm{tru}}$=3.58 TeV





Load vp1 Display...

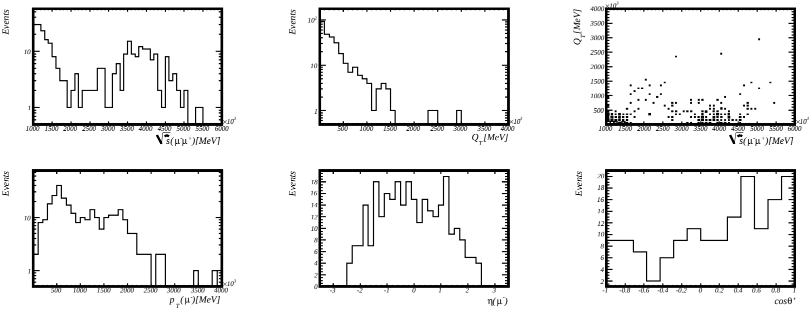
Full ATLAS simulation - KK Kinematics - $\mathcal{L}$=100 fb^{-1}

Process(KK): $pp \to \gamma/Z^0 + \sum_{n=1,...,100} (\gamma^*/Z^*) \to \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14$ TeV

Simulation: Full ATLAS chain with Athena version 15.3.0 (used for 2008 & 2009 MC), ATLAS-GEO-06-00-00

Preselection: ≥ 2 reconstructed muons with opposite charge, $\sqrt{\hat{s}} \geq 1$ TeV, $|\eta|<2.5$, $p_T>6$ GeV

Events: $N^{generated}_{full}=440$, $N^{preselected}_{full}=290$, $N^{preselected}_{peak}=151$



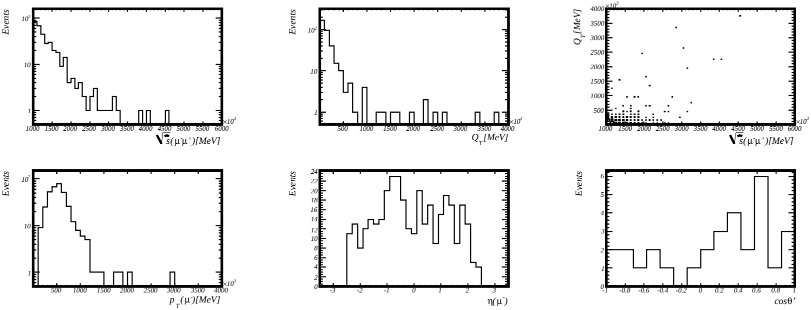
Full ATLAS simulation - SM Kinematics - $\mathcal{L}$=100 fb^{-1}

Process(SM): $pp \to \gamma/Z^0 \to \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14\ TeV$

Simulation: *Full ATLAS chain with Athena version 15.3.0 (used for 2008 & 2009 MC), ATLAS-GEO-06-00-00*

Preselection: ≥ 2 *reconstructed muons with opposite charge,* $\sqrt{\hat{s}} \geq 1\ TeV$, $|\eta|<2.5$, $p_T>6\ GeV$

Events: $N^{generated}_{full}=555$, $N^{preselected}_{full}=350$, $N^{preselected}_{peak}=30$



Full ATLAS simulation - preliminary KK resolutions

Process(KK): $pp \rightarrow \gamma/Z^0 + \sum\left(\gamma^*/Z^*\right)_{n=1,\dots,100} \rightarrow \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14\ TeV$

Simulation: *Full ATLAS chain with Athena version 15.3.0 (used for 2008 & 2009 MC), ATLAS-GEO-06-00-00*

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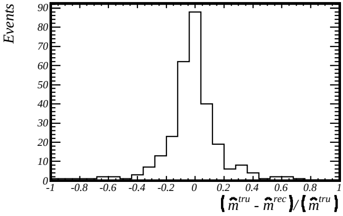
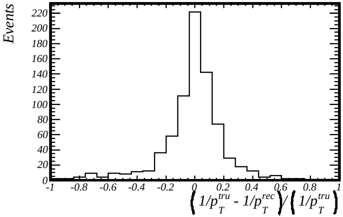




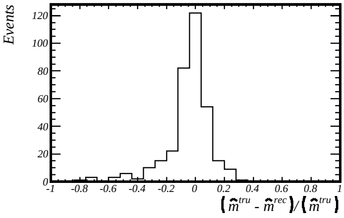
Full ATLAS simulation - preliminary SM resolutions

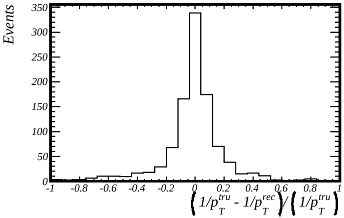
Process(SM): $pp \rightarrow \gamma/Z^0 \rightarrow \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14$ *TeV*

Simulation: *Full ATLAS chain with Athena version 15.3.0 (used for 2008 & 2009 MC), ATLAS-GEO-06-00-00*

Preselection: ≥ 2 *reconstructed muons with opposite charge,* $\sqrt{\hat{s}} \geq 1$ *TeV,* $|\eta|<2.5$, $p_T>6$ *GeV*

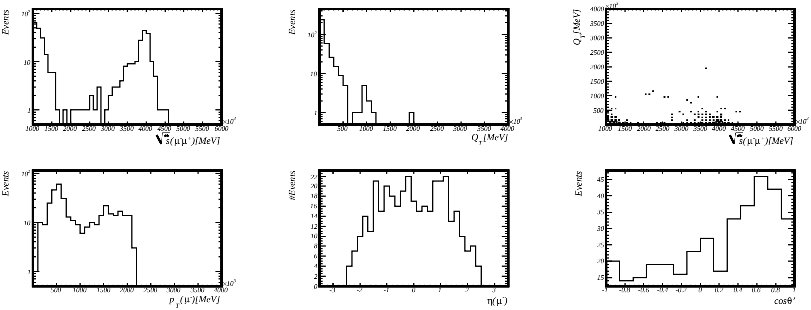
Events: $N_{full}^{generated}=555$, $N_{full}^{preselected}=350$, $N_{peak}^{preselected}=30$





Full ATLAS simulation - KK Truth kinematics

Process(KK):	$pp \to \gamma/Z^0 + \sum(\gamma^*/Z^*)_{n=1,\dots,100} \to \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14\ TeV$
Simulation:	*Truth information by Athena version 15.3.0 (Pythia8)*
Preselection:	≥ 2 *final (status>0) muons with opposite charge,* $\sqrt{\hat{s}} \geq 1\ TeV$, $\lvert\eta\rvert<2.5$, $p_T>6\ GeV$
Events:	$N^{generated}_{1\text{-}6\ TeV}=440$, $N^{preselected}_{full}=361$, $N^{preselected}_{peak}=188$



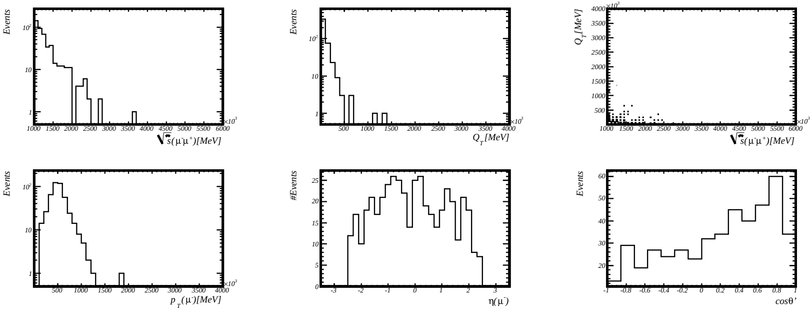
Full ATLAS simulation - SM Truth kinematics

Process(SM): $pp \to \gamma/Z^0 \to \mu^+\mu^-$ *generated by Pythia8,* $L=100\ fb^{-1}$, $\sqrt{s}=14$ *TeV*

Simulation: *Truth information by Athena version 15.3.0 (Pythia8)*

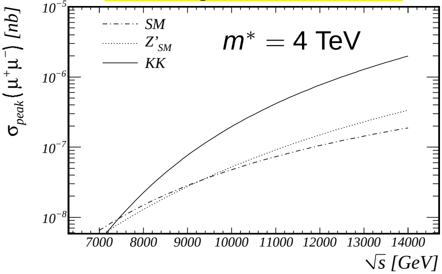
Preselection: ≥ 2 *final (status>0) muons with opposite charge,* $\sqrt{\hat{s}} \geq 1$ *TeV,* $|\eta|<2.5$, $p_T>6$ *GeV*

Events: $N^{generated}_{1\text{-}6\ TeV}=555$, $N^{preselected}_{full}=454$, $N^{preselected}_{peak}=19$

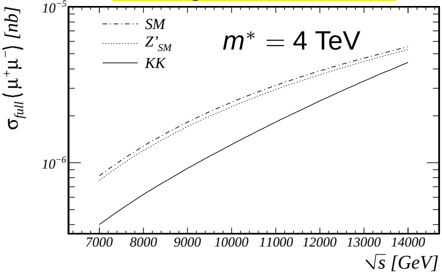


The total cross section vs. the LHC CM energy

Peak range: $2 \leq \sqrt{\hat{s}} \leq 5$ TeV



Full range: $1 \leq \sqrt{\hat{s}} \leq 6$ TeV



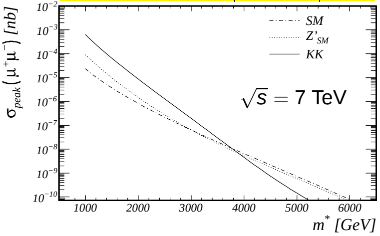
For $\mathcal{L} = 300$ pb^{-1} $\rightarrow 10$ fb^{-1}

Range	Events for $\sqrt{s} = 7$ TeV	Events for $\sqrt{s} = 10$ TeV
Peak	0	0$\rightarrow$2
Full	0$\rightarrow$4	0$\rightarrow$12

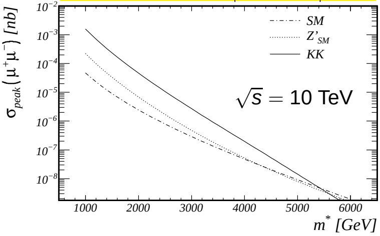
First KK events, for $m^* = 4$ TeV, should come no sooner than for $\mathcal{L} = 10$ fb^{-1}

The total cross section vs. m^*

1^{st} KK resonance: $\left|\sqrt{\hat{s}} - m^*\right| \leq \frac{m^*}{2}$



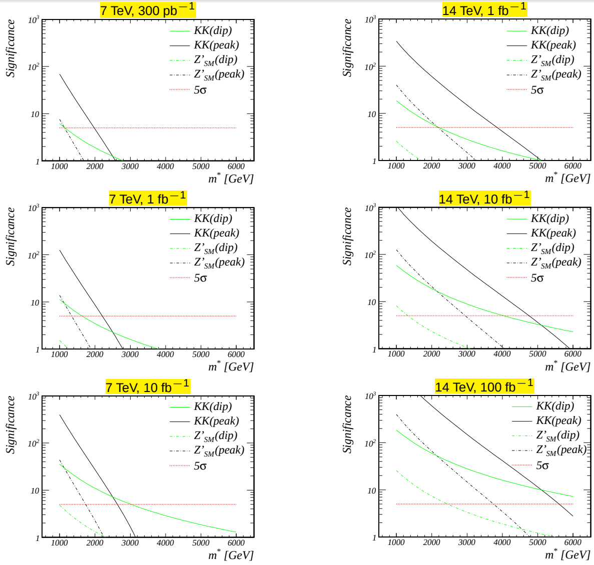
1^{st} KK resonance: $\left|\sqrt{\hat{s}} - m^*\right| \leq \frac{m^*}{2}$



m^*	$\mathcal{L}$	Events for $\sqrt{s} = 7$ TeV	Events for $\sqrt{s} = 10$ TeV
1 TeV	300 pb^{-1}	210	600
	10 fb^{-1}	$7 \cdot 10^3$	$2 \cdot 10^4$
1.5 TeV	300 pb^{-1}	24	75
	10 fb^{-1}	800	$2.5 \cdot 10^3$
2 TeV	300 pb^{-1}	3	15
	10 fb^{-1}	100	500
2.5 TeV	300 pb^{-1}	0	3
	10 fb^{-1}	15	100
3 TeV	300 pb^{-1}	0	0
	10 fb^{-1}	2	20
3.5 TeV	300 pb^{-1}	0	0
	10 fb^{-1}	0	7

- Resonance may be <4 TeV
- LHC early: 10 TeV and 300 pb^{-1}
  - Earliest obs' can be ≤ 2 TeV
- LHC Late: 10 TeV and 10 fb^{-1}
  - Earliest obs' can be ≤ 3 TeV

Expected sensitivity around the KK peak and dip



Significance:

$$z \equiv \frac{|N_{BSM} - N_{SM}|}{\sqrt{N_{SM}}}$$

where,

$$N = \mathcal{L} \int \sigma d\sqrt{\hat{s}}$$

integrate peak in:

$$\frac{m^*}{2} \leq \sqrt{\hat{s}} \leq \frac{3m^*}{2}$$

integrate dip in:

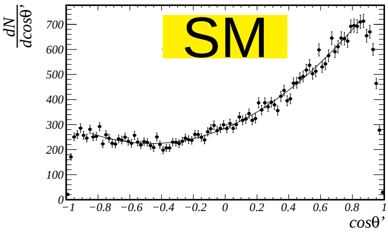
$$2m_{Z^0} \lesssim \sqrt{\hat{s}} \leq \frac{m^*}{2}$$

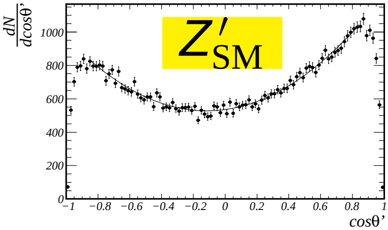
but dip shape is more informative than # of events !

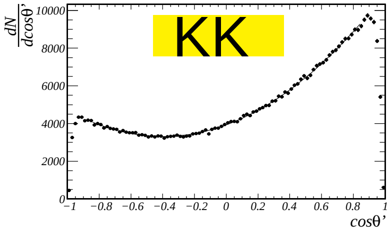
ML fit and Kolmogorov test

- Compare measured (pseudo-)signals with model expectations
  - Find A_{fb} from $\cos\theta'$ distribution using the ML fit
  - Kolmogorov test on the $\cos\theta'$ and $\sqrt{\hat{s}}$ distributions
- Because of low statistics, both comparisons are unbinned
- Perform the ML fit only in the range $|\cos\theta'| \leq 0.85$ where the acceptance is 100%

ML fit







	Model	MC reference	$\mathcal{L}$=500 fb^{-1} pseudo-data	$\mathcal{L}$=100 fb^{-1} pseudo-data
A_{fb}	SM	0.3476 ± 0.0053	0.37 ± 0.11	0.48 ± 0.25
	Z'_{SM}	0.0900 ± 0.0042	0.117 ± 0.083	0.24 ± 0.18
	KK	0.2958 ± 0.0015	0.216 ± 0.035	0.304 ± 0.078
A_0	SM	0.00 ± 0.02	0.09 ± 0.39	0.62 ± 1.40
	Z'_{SM}	-0.025 ± 0.015	-0.53 ± 0.26	1.06 ± 0.86
	KK	0.0075 ± 0.0056	0.00 ± 0.13	0.00 ± 0.28
Events	SM	30145	73	13
	Z'_{SM}	57053	142	31
	KK	413391	798	150

Fit range is unbiased: $|\cos\theta'| \leq 0.85$

Kolmogorov tests

K-test for the $\cos\theta'$ distributions

MC ref' model	Luminosity of pseudo-data	#Events of pseudo-data	SM pseudo-data	$Z'_{\rm SM}$ pseudo-data	KK pseudo-data
SM	$\mathcal{L}$=500 fb^{-1}	82	0.97	0.002	0.008
	$\mathcal{L}$=100 fb^{-1}	16	0.887	0.66	0.89
$Z'_{\rm SM}$	$\mathcal{L}$=500 fb^{-1}	160	0.018	0.811	0
	$\mathcal{L}$=100 fb^{-1}	35	0.458	0.458	0.013
KK	$\mathcal{L}$=500 fb^{-1}	971	0.724	0.011	0.18
	$\mathcal{L}$=100 fb^{-1}	181	0.933	0.822	0.999

$\cos\theta'$ distributions

- $|\cos\theta'| \leq 1$
- $2 \leq \sqrt{\hat{s}} \leq 1$ TeV

K-test for the $\sqrt{\hat{s}}$ distributions

MC ref' model	Luminosity of pseudo-data	#Events of pseudo-data	SM pseudo-data	$Z'_{\rm SM}$ pseudo-data	KK pseudo-data
SM	$\mathcal{L}$=500 fb^{-1}	2400	0.254	0.002	0
	$\mathcal{L}$=100 fb^{-1}	480	0.887	0.006	0
$Z'_{\rm SM}$	$\mathcal{L}$=500 fb^{-1}	2300	0.017	0.663	0
	$\mathcal{L}$=100 fb^{-1}	460	0.28	0.016	0
KK	$\mathcal{L}$=500 fb^{-1}	1980	0	0	0.308
	$\mathcal{L}$=100 fb^{-1}	400	0	0	0.108

$\sqrt{\hat{s}}$ distributions

- $1 \leq \sqrt{\hat{s}} \leq 6$ TeV

Combined analysis

ML fit

- A_0 coefficients are consistent with zero
- At $\mathcal{L}$=100 fb^{-1}, the A_{fb} coefficients are compatible with their MC reference estimations within less than 1σ
- The sensitivity for probing the couplings using the A_{fb} coefficients requires higher integrated luminosities.

Kolmogorov test

- Clear compatibility between all three models (pseudo-data) to the corresponding large statistics MC samples
- Clear distinction between the KK and Z'_{SM} models

SM Background processes

- Event topology: two high energetic and isolated muons
- A significant contribution of QCD-background is expected
  - The dominating contribution is $b\bar{b}$-mesons decays
- Expected BG processes are (similar to the Z^0):
  - $W^{\pm} \to \nu\mu$ and QCD-*jet* $\to \mu + X$
  - $Z^0 \to \tau^+\tau^- \to \bar{\nu}_\tau \mu^+ \nu_\mu \nu_\tau \mu^- \bar{\nu}_\mu$
  - $t\bar{t} \to W^+ b W^- \bar{b} \to \mu^+ \nu_\mu \mu^- \bar{\nu}_\mu b\bar{b}$
  - $b\bar{b} \to \mu^+\mu^-$
  - Cosmic muons

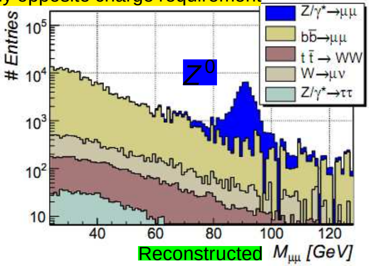
- BG processes contribution at $\sqrt{\hat{s}} \gtrsim 1$ TeV was never measured
- BG in the TeV scale can come also from BSM processes

SM Background dominance estimation relative to Z^0

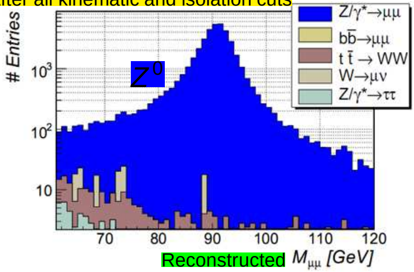
QCD and $W \to \nu\mu$ BGs - need to introduce isolation cuts

- To apply only after full detector simulation
- The dominant contribution: SM Drell-Yan (estimated here)
- At 4 TeV, $N_{SM} < N_{KK}/10$

Only opposite charge requirement

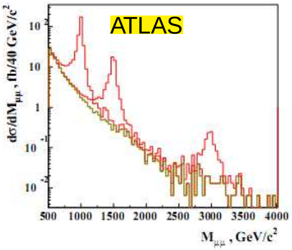


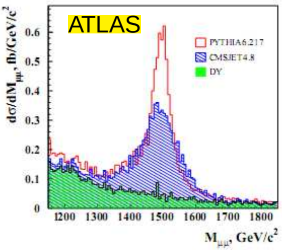
After all kinematic and isolation cuts



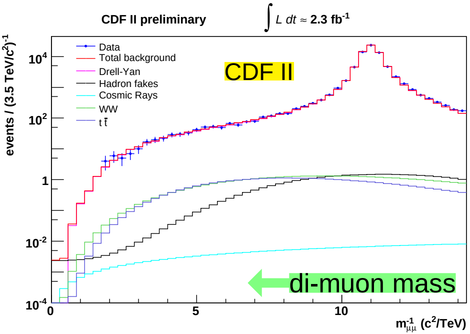
M. Schott (PhD thesis), *"Study of the Z Boson Production at the ATLAS Experiment with First Data"*, (2007)

SM Background dominance estimation relative to Z'





Note that this is not Z'_{SM}



Left: I. Golutvin *et al*. *"Search for TeV-scale bosons in the dimuon channel at the LHC"*, arXiv:hep-ph/0310336v4, (2004)

Right: The CDF collaboration *"A search for high-mass resonances decaying to dimuons at CDF"*, PHYS. REV. LETT. PRL 091805 (2009)

The hierarchy problem

- Effective 4d Plank's scale

$$M_{Pl}^2 \sim M_{Pl(4+n)}^{2+n} \times R^n$$

where if, $M_{Pl(4+n)} \sim m_{EW}$ and R is chosen to reproduce the observed M_{Pl}, then

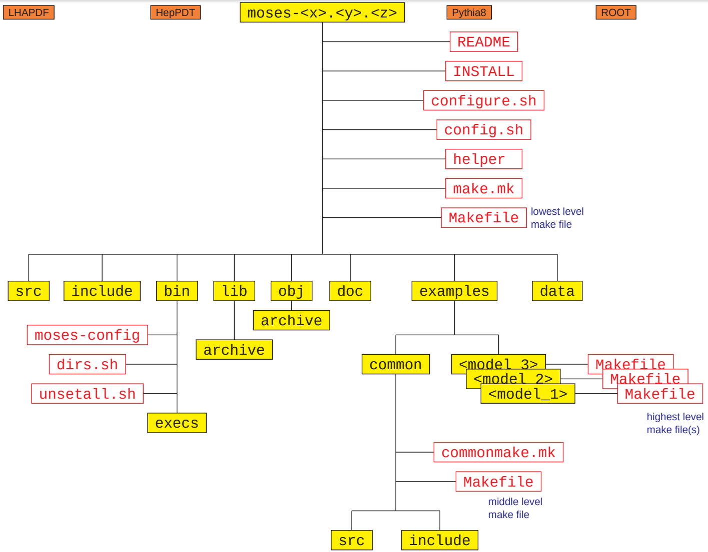
$$R \sim 10^{\frac{30}{n}-17}\ \mathrm{cm} \times \left(\frac{1\mathrm{TeV}}{\mathrm{m_{EW}}}\right)^{1+\frac{2}{\mathrm{n}}}$$

- For $n = 1$, $R \sim 10^{13}$ cm and this is unrealistic
- For $n = 2$, $R \sim 0.1 - 1$ mm
- Why can we take $n = 1$?
  - Distinguish between parallel and transverse EDs

N. Arkani-Hamed *et al.*, *"The hierarchy problem and new dimensions at a millimeter"*, Phys. Lett. B Vol. 429, (1998)

I. Antoniadis, *"Physics of Extra Dimensions"*, Journal of Physics: Conference Series 33, (2006)

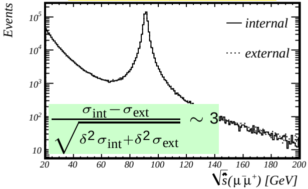
The MOSES STRUCTURE



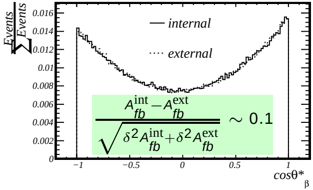
Validation

Done with $pp \to \gamma/Z^0 \to \mu^+\mu^-$ by comparing the $\sqrt{\hat{s}}$ and $\cos\theta^*_\beta$ distributions obtained with Pythia8(internal) and MOSES(external).

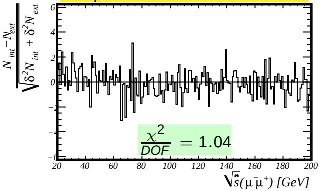
The di-muon $\sqrt{\hat{s}}$ distributions



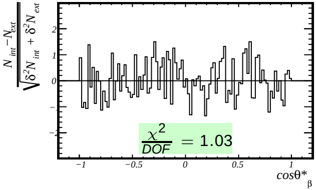
The normalized $\cos\theta'$ distributions



Comparison of the $\sqrt{\hat{s}}$ distributions



Comparison of the $\cos\theta'$ distributions



The two formalisms agree to a very good level