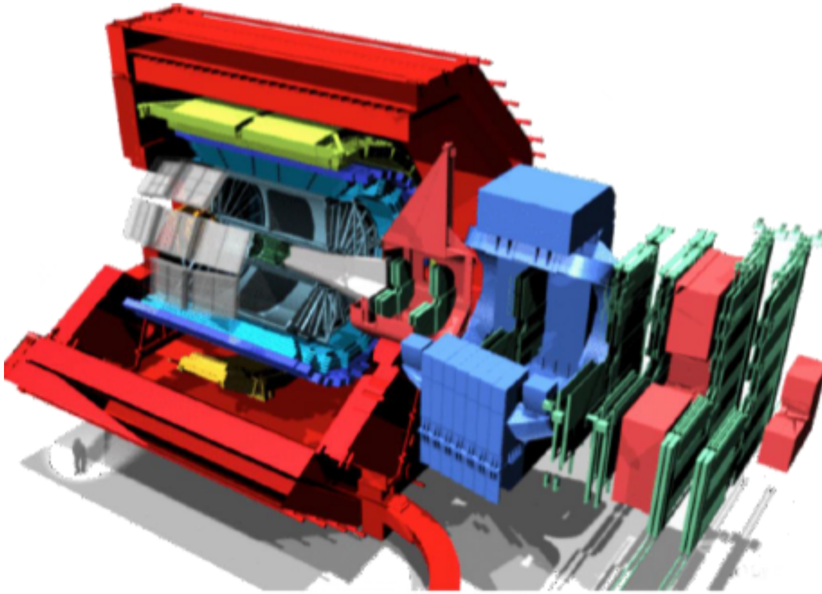
ALICE forward pp physics in runs 3-4



by Risto Orava
for the ALICE Collaboration

agenda

- alice forward physics options
- physics items for run periods 3/4
- concluding remarks

alice offers a unique platform for forward proton-proton physics at the lhc

- inclusive diffractive scattering
- central exclusive production
  - partial wave analysis of the $\pi^+\pi^-$ -system
  - glueball candidates: $J^{PC}=0^{++}, 2^{++}, 0^{-+}$
  - $\chi_{c0,1,2}$-states
  - gluon jets
  - magnetic monopoles

why alice has an edge?

- **no pile-up:** $\mu_{alice} \approx 0.05$ vs. $\mu_{atlas,\, cms} >> 1$
- **acceptance:** covers most of the available phase space for the fwd masses in η, p_T
- **particle identification** (dE/dx & TOF): $\pi^{\pm}/K^{\pm}/p^{\pm}$
- **event statistics**: *pp* collision data collected during the nominal low β^* LHC runs

by today, alice has collected about *5 pb^{-1}* of central exclusive event candidates at *13 TeV*

ALICE HAS AN EDGE:

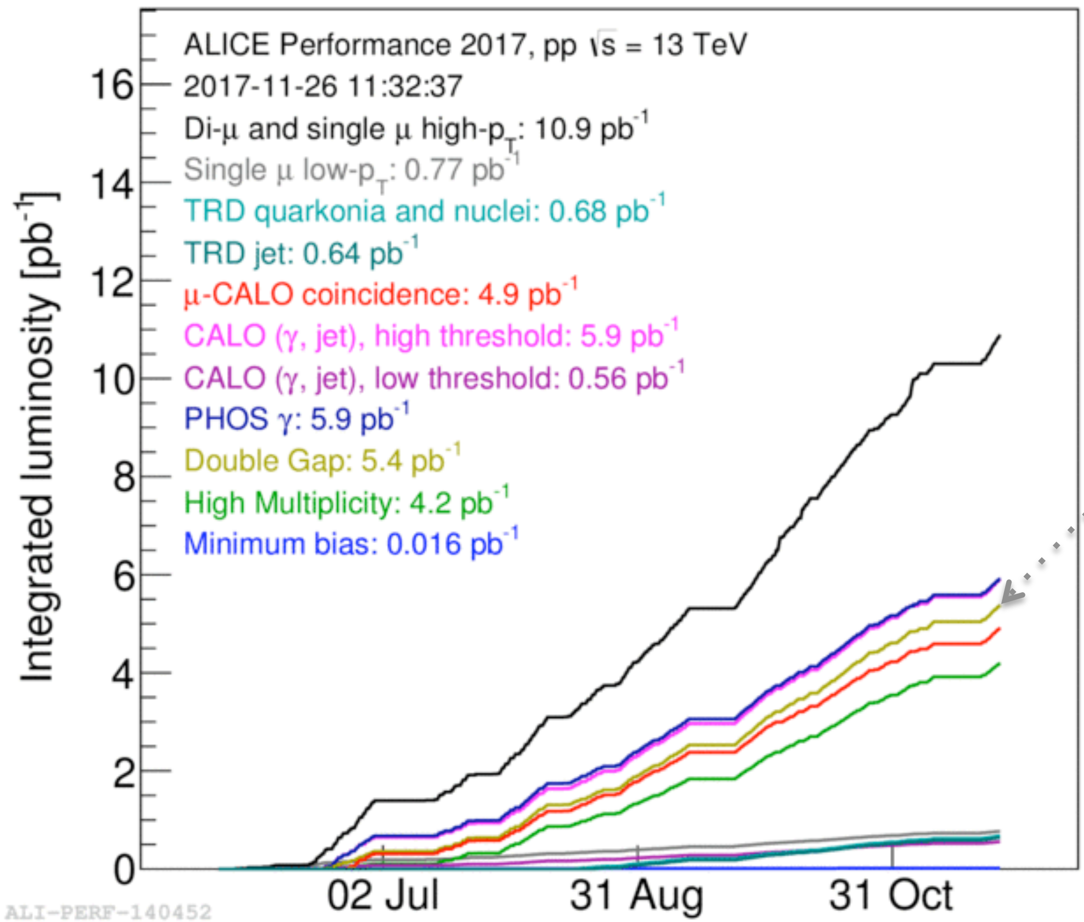
- *central tracking*, particle ID, p_T acceptance, mass resolution

- *zero degree calorimetry* (ZDC/ZDA) for leading neutron & gamma detection

- *forward muon detection* capabilities: central exclusive states decaying into $\mu^+\mu^-/\tau^+\tau^-/W^+W^-$ pairs

- *upgraded forward acceptance* of the ADC/ADA detectors have acceptance down to the *lowest diffractive masses*

Integrated luminosity pp 13 TeV 2017



Central Exclusive Event candidates

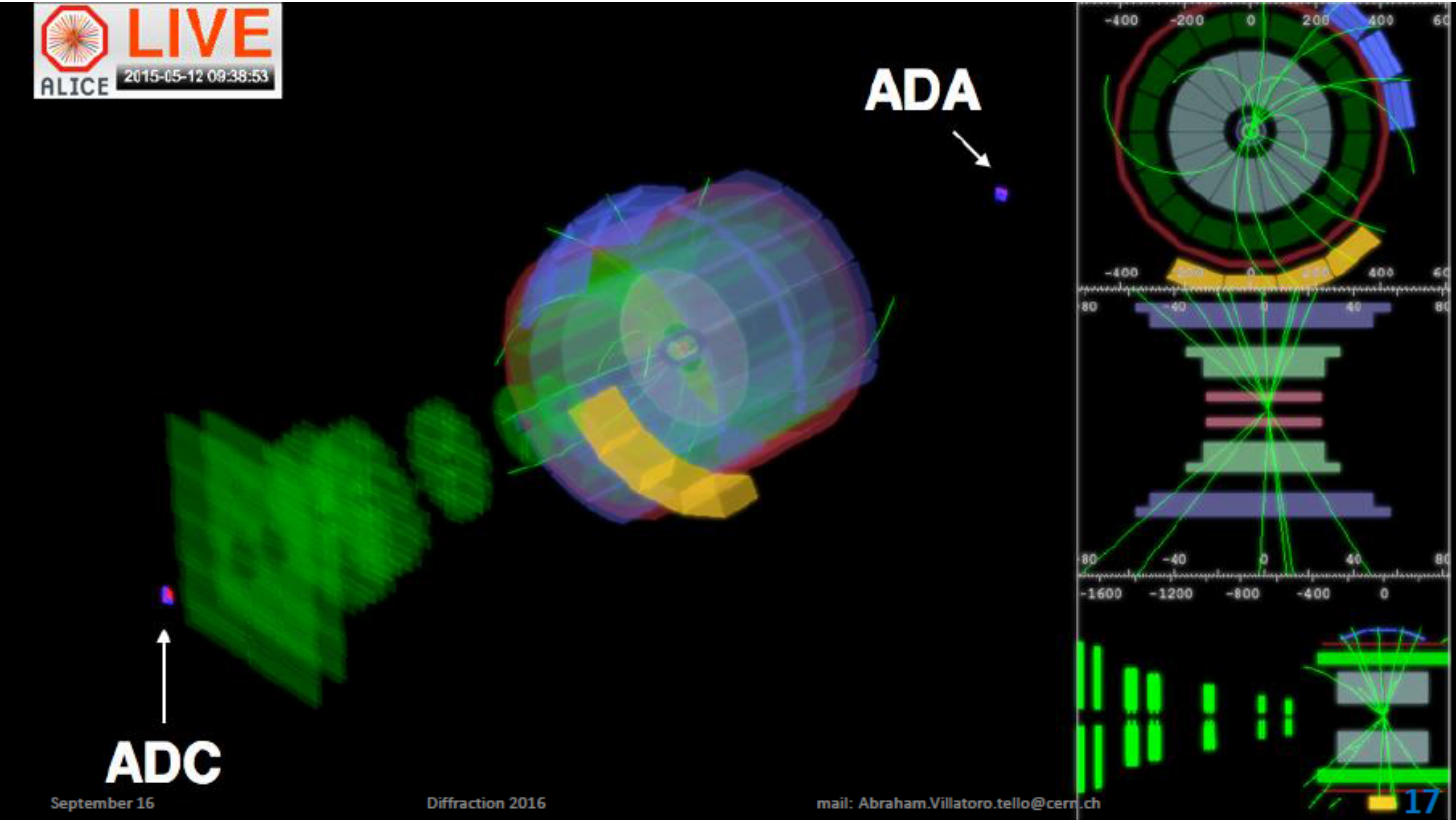
expect ≈ 15 pb^{-1}/Run2

project for:

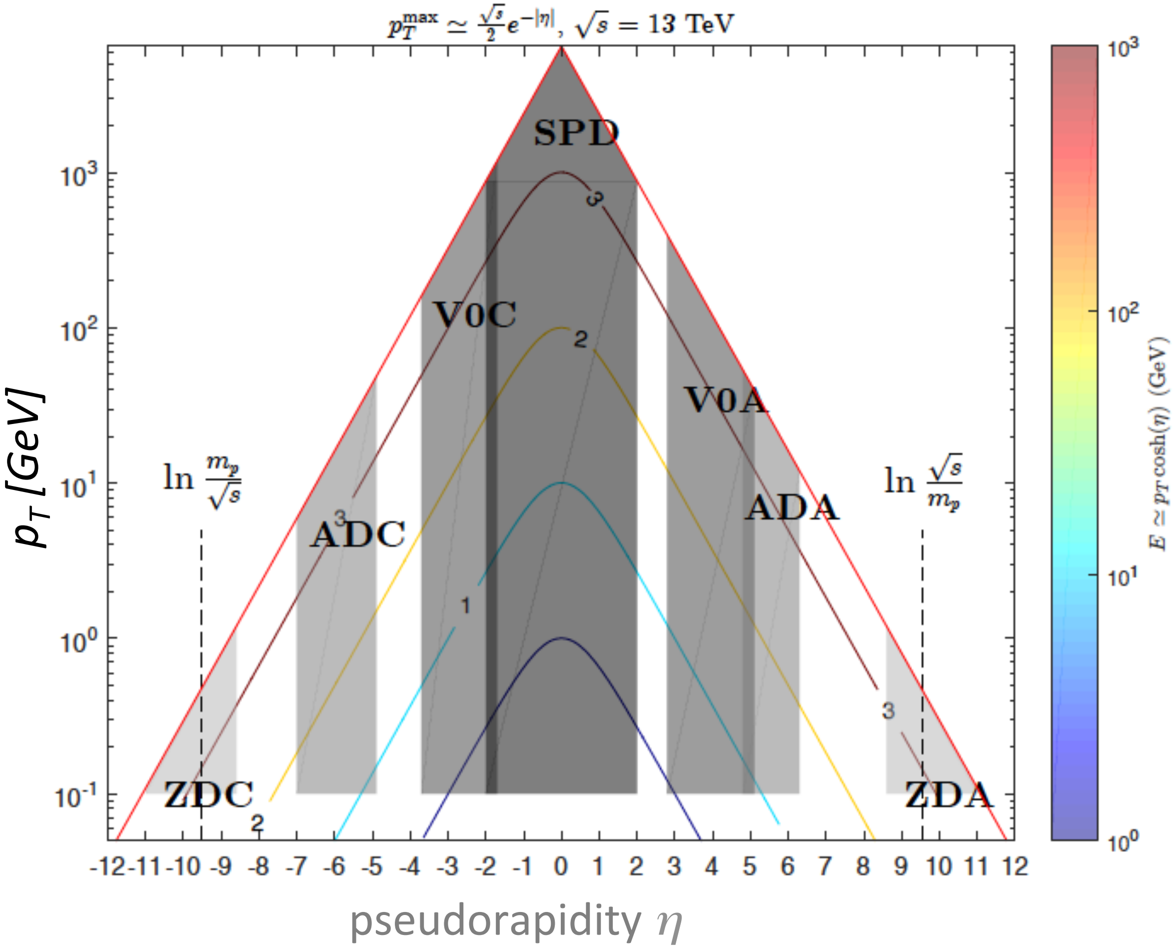
- > 6 pb^{-1} at 5.5 TeV
- ≤ 200 pb^{-1} at 14 TeV (under discussion)

inclusive forward physics

a crucial fwd upgrade: alice AD detectors installed in 2015



alice covers most of the relevant phase space in η-p_T



slices in η-p_T space:
input to multivariate analysis

detectors (or sub-detectors) define the slicing density

combinations of the slices represent different physics channels

models mapped into these combinations yield a sensitive test of models - and the least model dependent ***diffractive cross sections***

mieskolainen & ro

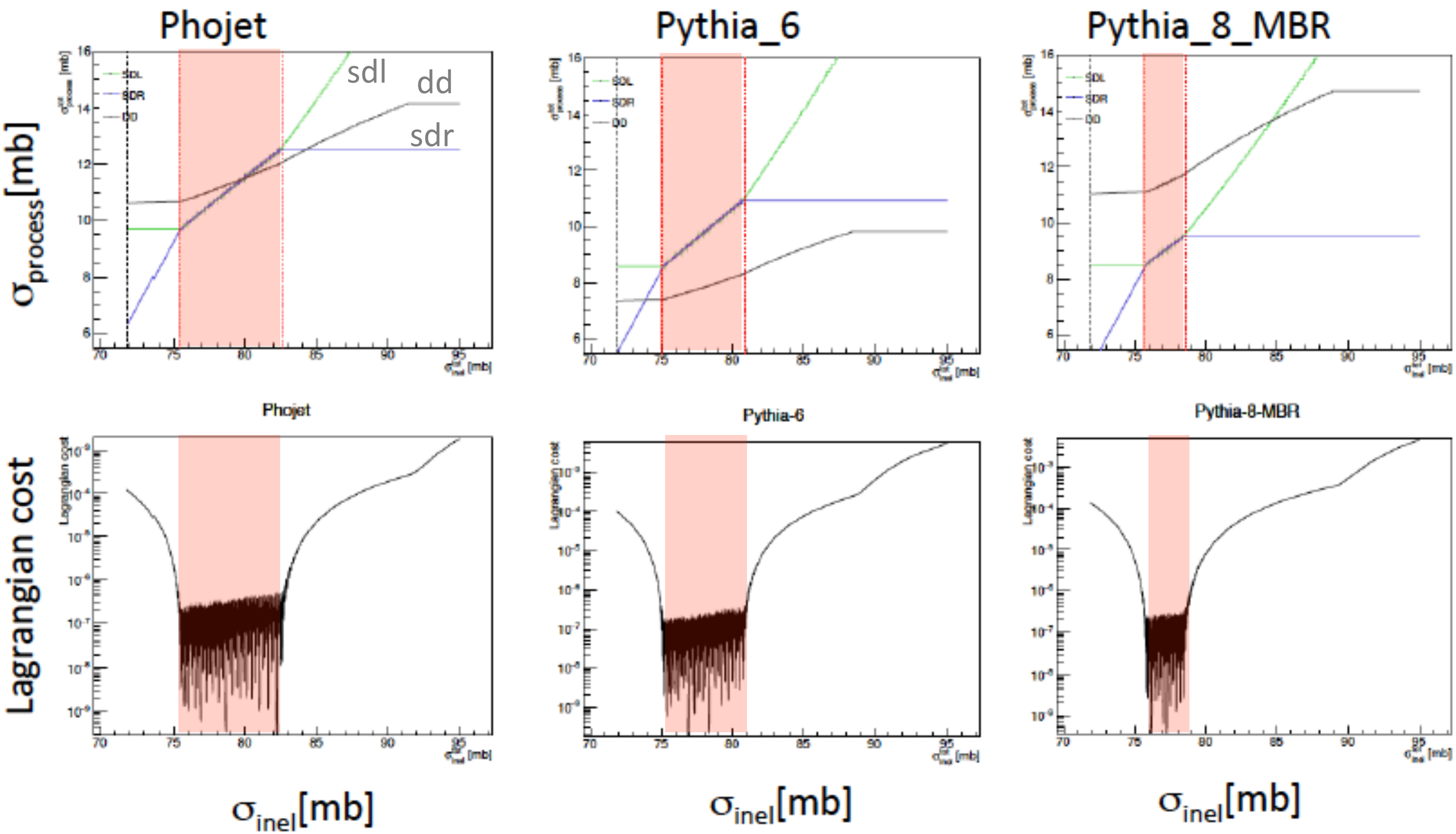
results on inclusive forward physics

- ➔inclusive diffractive cross sections
- ➔space-time structure of hadron interactions
- ➔test of mc models => asymptotic qcd

inclusive diffractive cross sections

mieskolainen & ro, diffraction 2016, arXiv:1612.00980 [hep-ph]
mieskolainen, low-x 2017, Bari, Italy, 12-18.07.2017

process cross sections defined by the models – diagnose the models & constrain the inelastic cross section

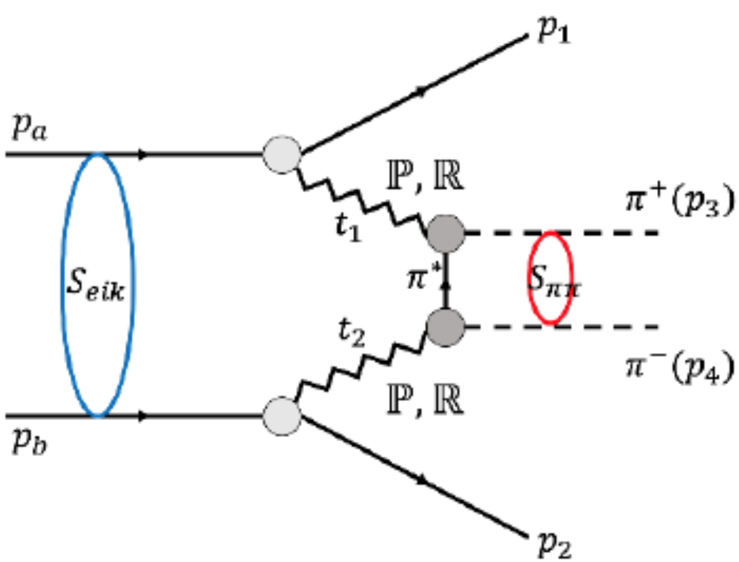


see: mieskolainen & ro, *Observables of QCD Diffraction*, diffraction 2016, Sicily, 4.9.2016, arXiv (2017)

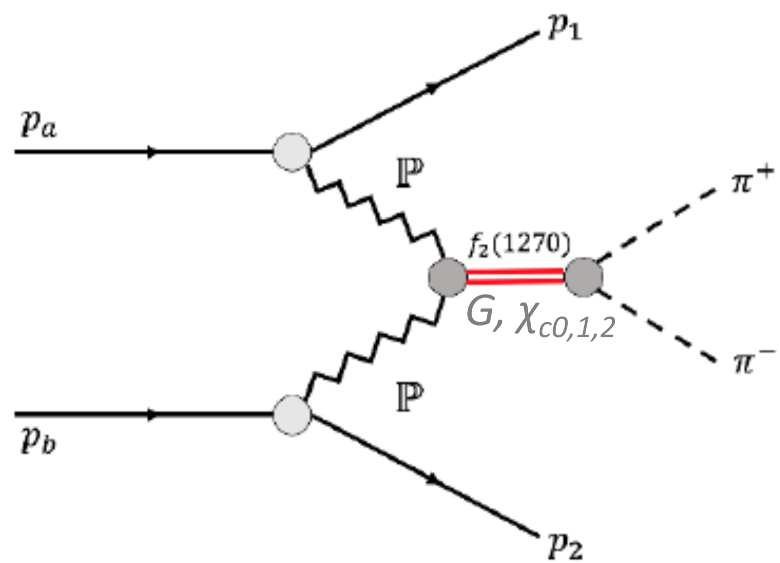
mieskolainen

central exclusive production

soft central production – dg event selection is clean!



central continuum of π -pairs



central production of the $f_2(1270)$ tensor meson, glueball (G), or $\chi_{c0,1,2}$ in a 'gluon rich' process

ATLAS: work in progress

ATLAS tags protons with RomanPots: $|t_p|>0.03\ (GeV/c)^2$: very clean sample.

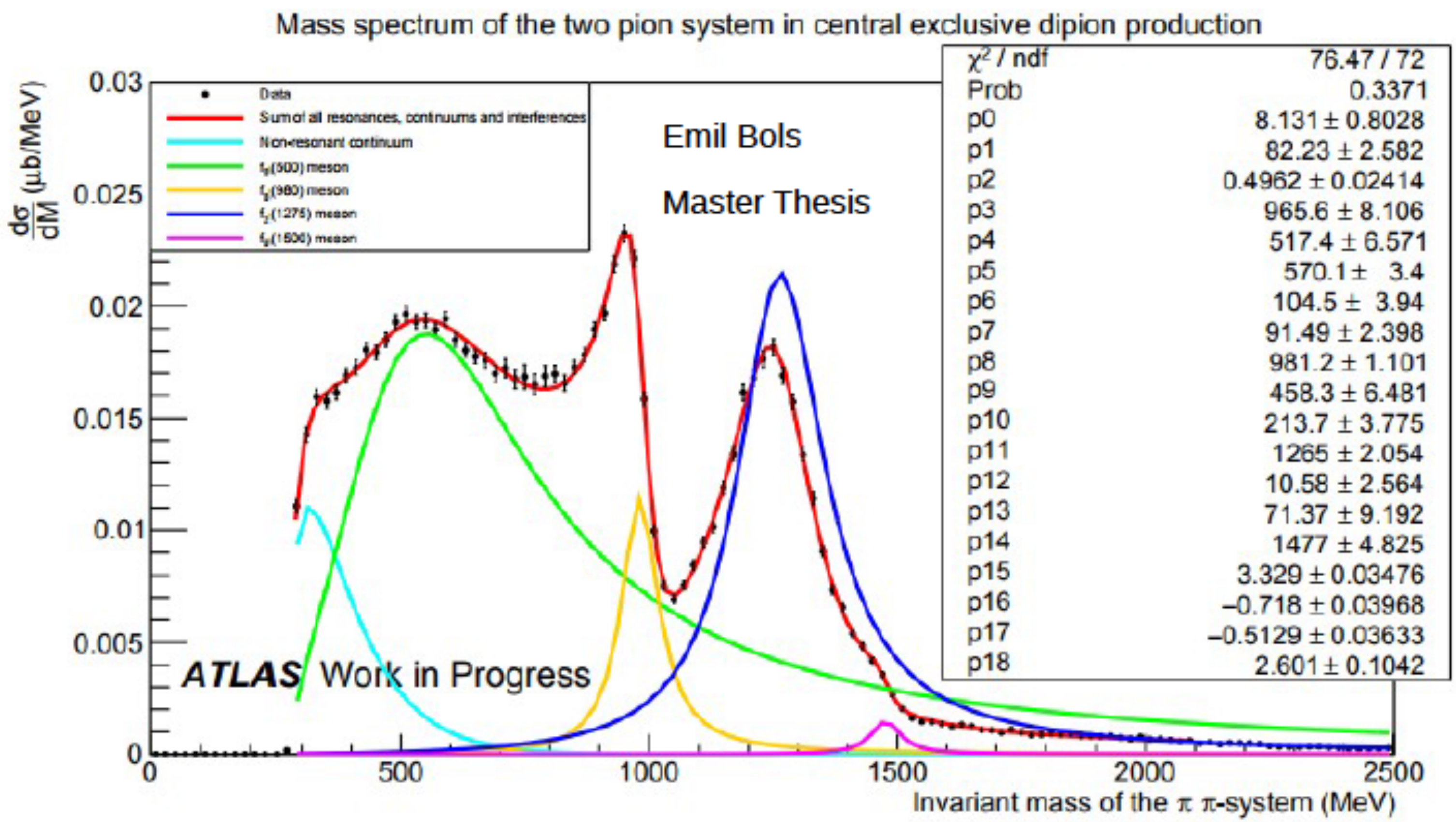
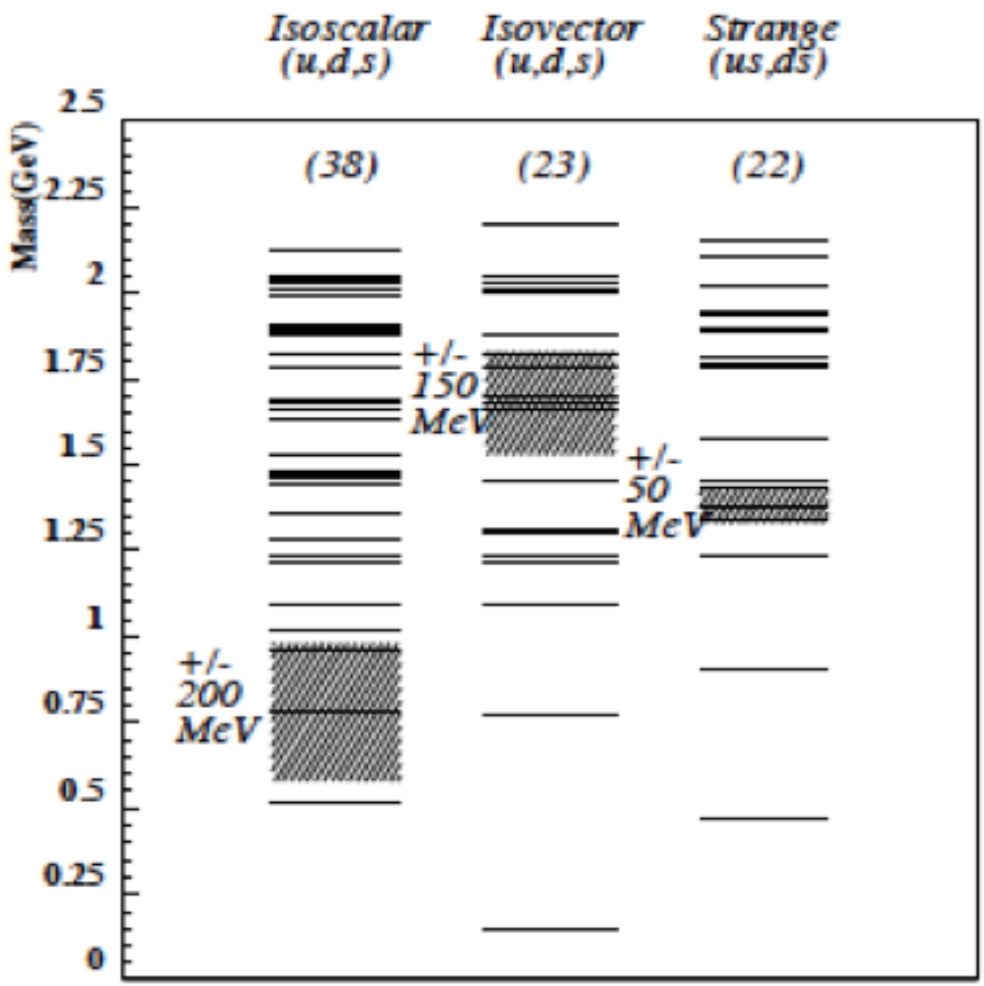


Figure 47: The differential cross section as a function of the dipion invariant mass. The total fit is shown in the red color. Bare Breit-Wigners with no interference effects has been drawn separately for the different resonances to illustrate their widths and masses.

partial wave analysis of the $\pi\pi$ system

q-qbar spectrum



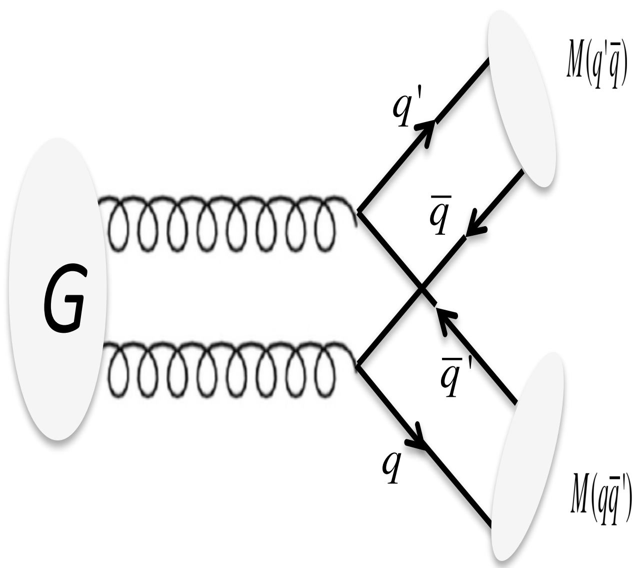
need spin-parity analysis to id different qqbar/glue-states

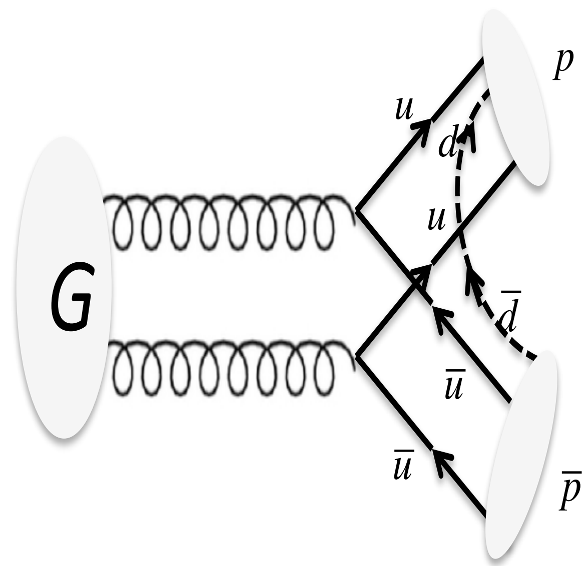
ALICE has completed $\pi^+\pi^-$ PWA for 7 TeV data

Particle Data Group

glueballs?

$J^{PC} = 0^{++}, 2^{++}, 0^{-+}$ glueballs?

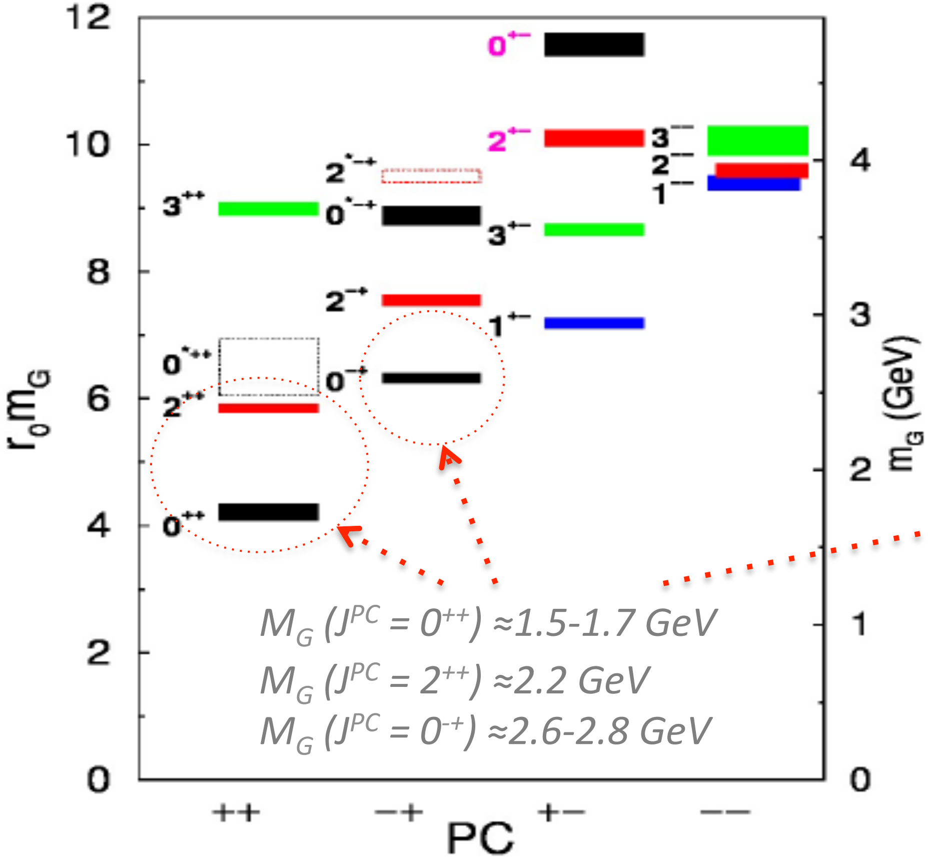




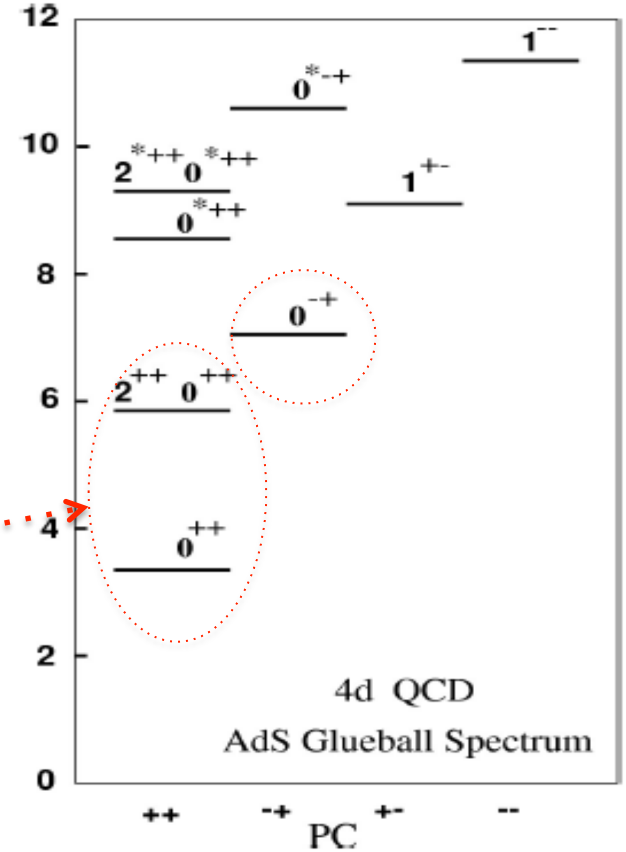
mixed *qq* and *gg* states – need to look at their *flavour* structure

orava

lattice and holography based calculations



C. Morningstar and M. Peardon (SDQCD), Nucl.Phys. B (Proc.Suppl.) 53(1997)917.



Koji Hashimoto, Chung-I Tan, Seiji Terashima *Glueball Decay in Holographic QCD*, arXiv: 0709.2208 [hep-th]

low mass $J^{PC} = 0^{++}$ glueball candidates

Resonance X	$f_0(\sigma)$	$f_0(980)$	$f_0(1370)$	$f_0(1500)$	$f_0(1710)$
M(X) [MeV]	400-550	990±20	1200-1500	1504±6	$1723\pm^{6}_{5}$
Γ(X) [MeV]	400-700	10-100	200-500	109±7	139±8
$\Gamma_{\gamma\gamma}(X)$ [keV]	seen	seen	seen	not seen	-
B(ππ) [%]	dominant	dominant	seen	34.9±2.3	seen
B(KK) [%]	-	seen	seen	8.6±1.0	seen
B(ηη) [%]	-	-	seen	5.1±0.9	seen
B(ηη') [%]	-	-	-	1.9±0.8	-
B(4π) [%]	-	-	seen	49.5±3.3	-
$B(J/\Psi \rightarrow \gamma X) \times 10^{-3}$	-	-	0.42±0.15	0.13±0.02	1.93±0.12
$B(\Upsilon \rightarrow \gamma X) \times 10^{-4}$	-	< 0.3	-	< 0.15	< 2.6

low mass $J^{PC} = 2^{++}$ glueball candidates

Resonance X	$f_2(1950)$	$f_2(2010)$	$f_2(2300)$	$f_2(2340)$
M(X) [MeV]	1944±12	$2011 \pm^{60}_{80}$	2297 ± 28	$2345 \pm^{50}_{40}$
Γ(X) [MeV]	472±18	202±60	149±40	$322 \pm^{70}_{60}$
$\Gamma_{\gamma\gamma}(X)$ [keV]	seen	-	seen	-
B(ππ) [%]	-	-	-	-
B(KK) [%]	seen	seen	-	-
$B(K^*(892)\bar{K}^*(892))$ [%]	seen	-	-	-
$\pi^+\pi^-$	seen			
$\pi^0\pi^0$	seen			
B(ηη) [%]	seen	-	-	-
B(ηη') [%]	-	-	-	-
B(4π) [%]	seen	-	-	-
B(φφ) [%]	-	seen	seen	seen
B(ωω) [%]	-	-	-	seen
$B(p\bar{p})$ [%]	seen	-	-	-
$B(J/\Psi \to \gamma X) \times 10^{-3}$	>0.7	-	-	>0.056
$B(\Upsilon \to \gamma X) \times 10^{-4}$	-	-	-	-

Charm sector

Channel	BR	A x ε	σ(5.5 TeV) pb	Y (5.5 TeV) 1 /pb	Y(5.5 TeV) 6 /pb	σ(14 TeV) pb	Y (14 TeV) 1 /pb	Y(14 TeV) 2.4 /pb	Y(14 TeV) 200 /pb
$\chi_{c0} \rightarrow \pi\pi$	0.83%	25.2%	97933	205	**1229**	118120	247	**593**	**49412**
$\chi_{c0} \rightarrow KK$	0.59%	20.5%	97933	118	**711**	118120	143	**343**	**28573**
$\chi_{c0} \rightarrow 4\pi$	2.24%	9.40%	97933	206	**1237**	118120	249	**597**	**49743**
$\chi_{c0} \rightarrow 2\pi 2K$	1.75%	1.70%	97933	29	**175**	118120	35	**84**	**7028**
$\chi_{c1} \rightarrow \pi\pi$	<0.10%	25.2%	968	0	**<1**	1009	0.3	**<1**	**<51**
$\chi_{c1} \rightarrow KK$	<0.10%	20.5%	968	0	**<1**	1009	0.2	**<0**	**<41**
$\chi_{c1} \rightarrow 4\pi$	0.76%	9.40%	968	1	**4**	1009	0.7	**2**	**144**
$\chi_{c1} \rightarrow 2\pi 2K$	0.45%	1.70%	968	0	**0**	1009	0.1	**0**	**15**
$\chi_{c2} \rightarrow \pi\pi$	0.23%	25.2%	5779	4	**22**	7634	4.4	**11**	**885**
$\chi_{c2} \rightarrow KK$	0.11%	20.5%	5779	1	**9**	7634	1.7	**4**	**344**
$\chi_{c2} \rightarrow 4\pi$	1.07%	9.40%	5779	6	**38**	7634	7.7	**18**	**1536**
$\chi_{c2} \rightarrow 2\pi 2K$	0.89%	1.70%	5779	1	**6**	7634	1.2	**3**	**231**

- σ estimated with SuperChic2 generator
  - using lowest prediction with NNPDF3.0 and model 1 for the gap survival probability)
  - caveat: Superchic2 predicts at least x3 higher cross section wrt LHCb preliminary
- A x ε, σ and Y estimates provided in |y|<0.8 fiducial regions
- A x ε for ππ and KK channels: at least one track with TOF PID + σ(TPC)+σ(TOF)<1.5
- A x ε for 4π and 2π2K channels: only TPC PID with σ(TPC) < 2

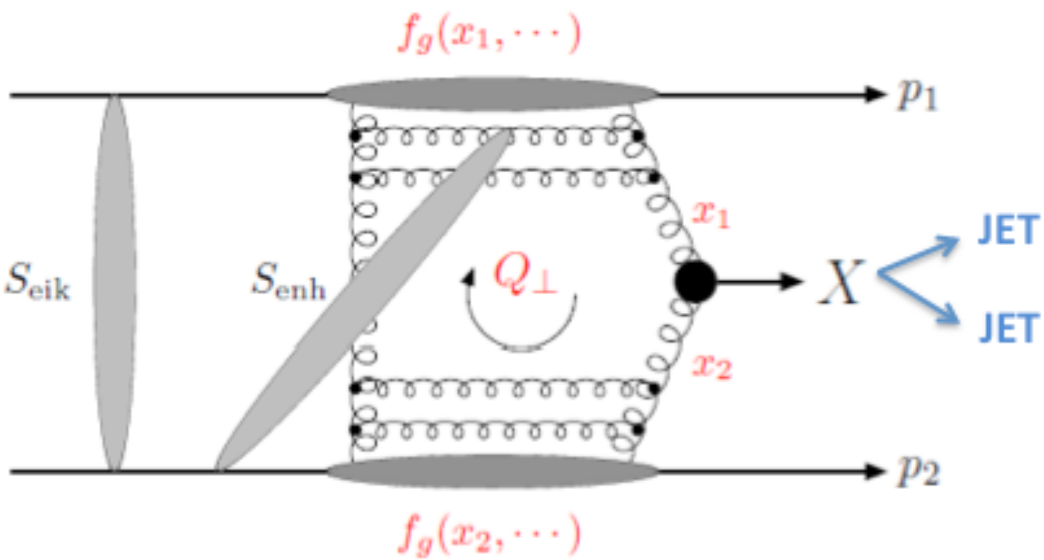
Only χ_{c0} channel is feasible in the baseline plan: O(10^3) expected.
X_{c2} might be feasible with extended 14TeV program ~200 /pb

23

hard central exclusive production

mieskolainen, mäkelä, ro & et.al.,arXiv:1604.05778 [hep-ex]
ro, low-x 2016 Workshop, Gyöngyös, Hungary, 06.-11.06.2016
ro, low-x 2017 Workshop, Bari, Italy, 12-18.06.2017

hard central exclusive production

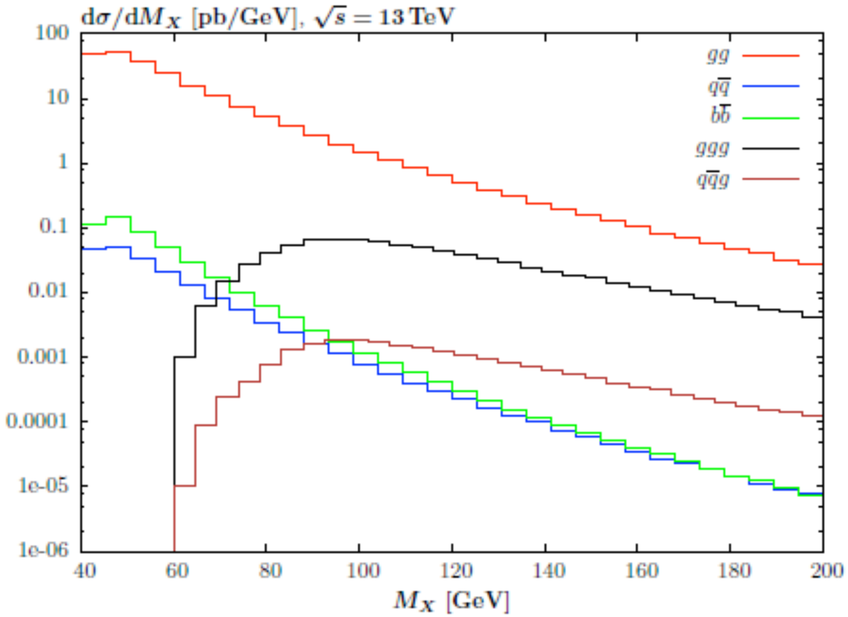


light quark production is suppressed:

$$\frac{d\sigma^{J_z=\pm 2}(q\bar{q})/dt}{d\sigma(gg)/dt} \approx \frac{N_c^2-1}{16N_c^3}\frac{\langle p_\perp^2\rangle^2}{\langle Q_\perp^2\rangle^2} \approx 10^{-4}$$

=> clean gluon jets

cep gluon jet events vs. M_X

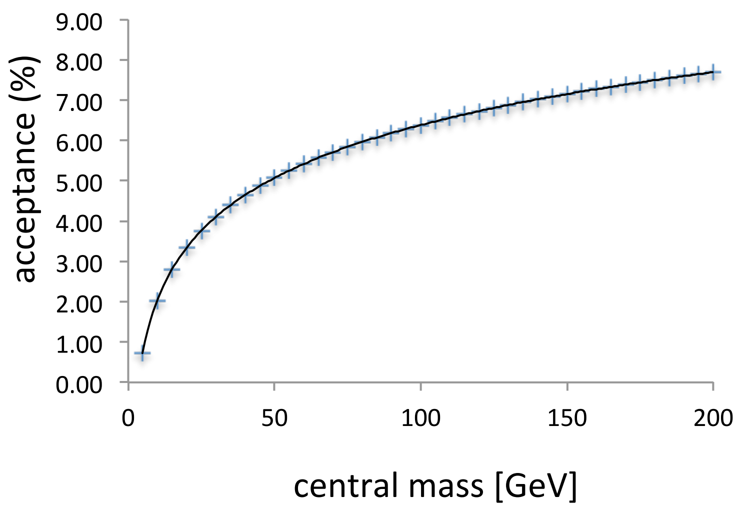


harland-lang – khoze - ryskin

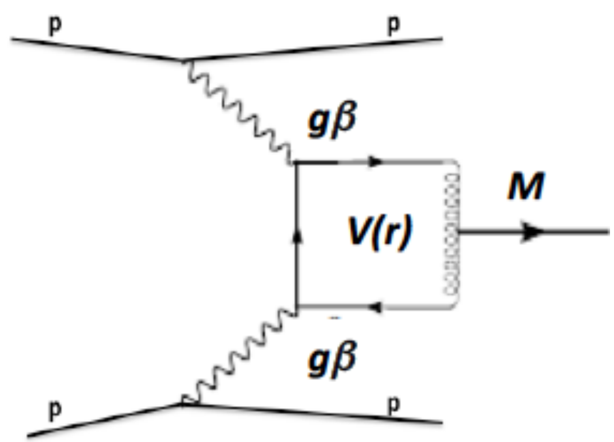
hundreds of clean

pp –> p + gg + p

events expected
at 16 pb^{-1}



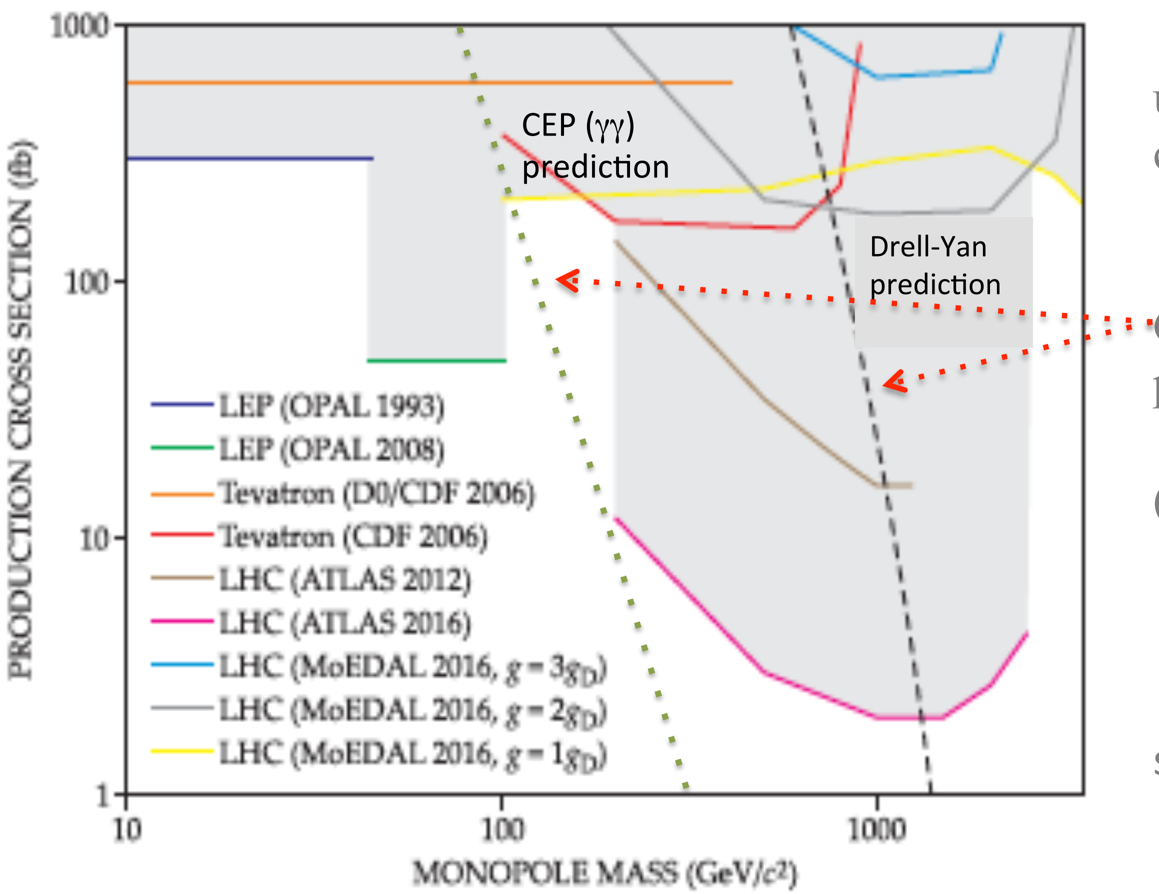
magnetic monopoles?



multiple photons!

monopolium production
in Superchic: Lucian Harland-Lang et al.

monopole mass limits



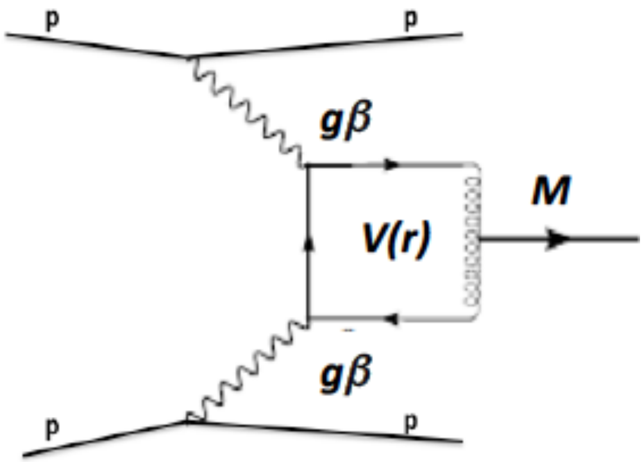
usually no production cross sections given
=> no absolute mass limits

CEP and Drell-Yan predictions

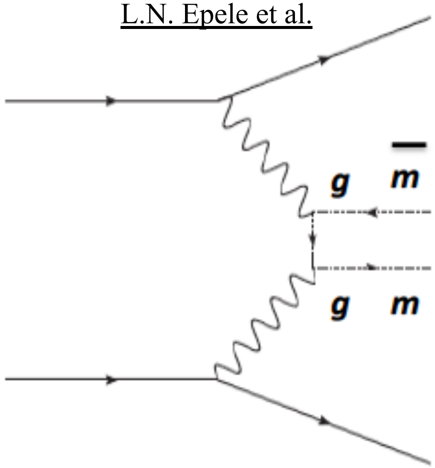
(CEP prediction by orava)

see: Gould & Rajantie

magnetic monopoles in alice?



L.N. Epele et al.



J.T. Reis and W.K. Sauter.

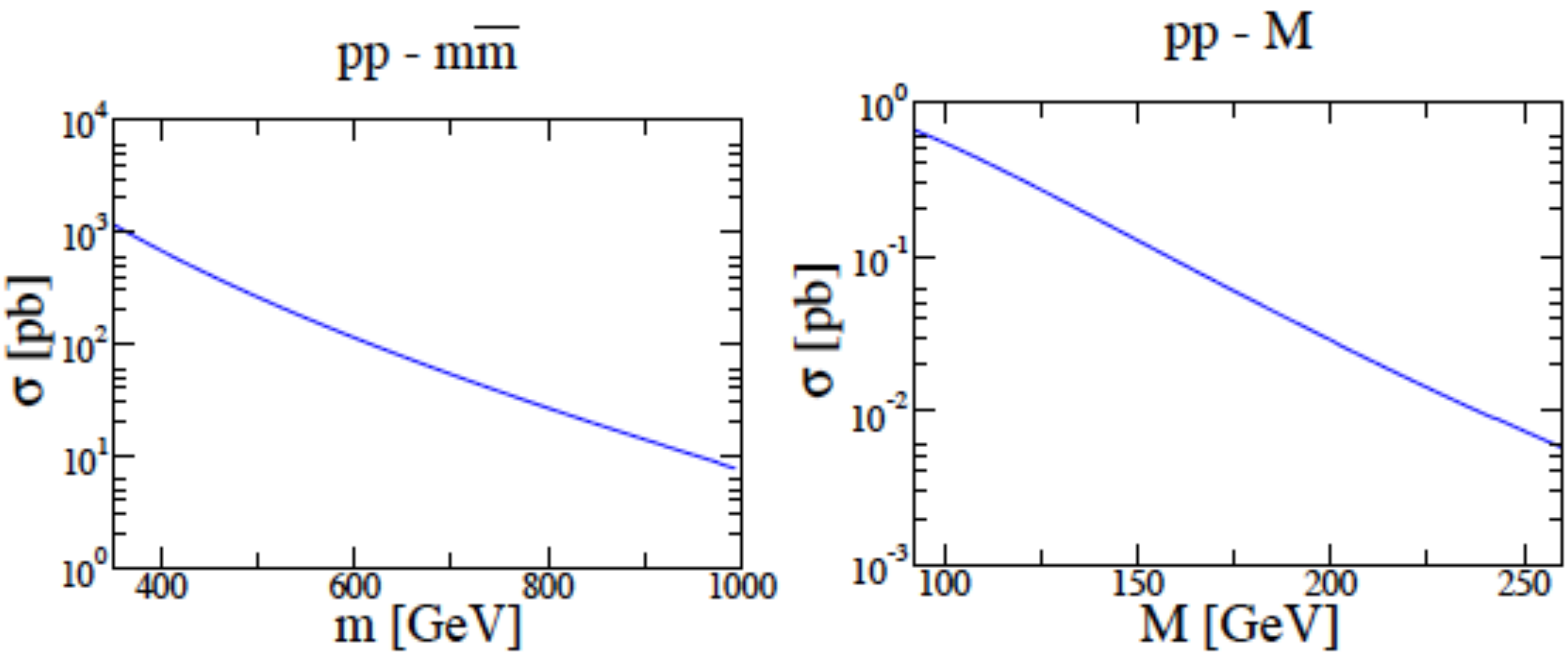
CEP monopolium: coupling to photon, α_{mag}, for a monopole moving with velocity β, is given as:

$$\alpha_{mag} = (\beta g)^2/4\pi$$

where g = magnetic charge of the monopole, and
$V(r)$: interaction between the monopole-antimonopole pair.

CEP process for monopole-antimonopole pair production[11], with the Dirac coupling $\alpha_{mag} = g^2/4\pi$.

cross section predictions



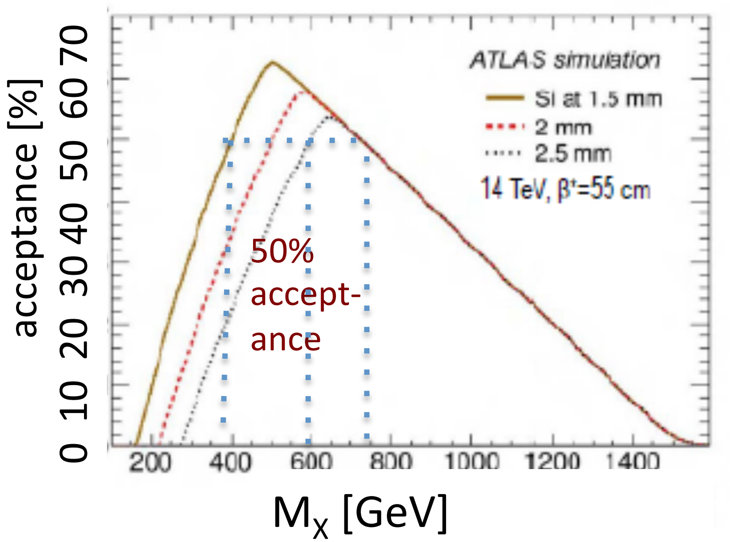
J.T. Reis and W.K. Sauter.

longitudinal roman pots

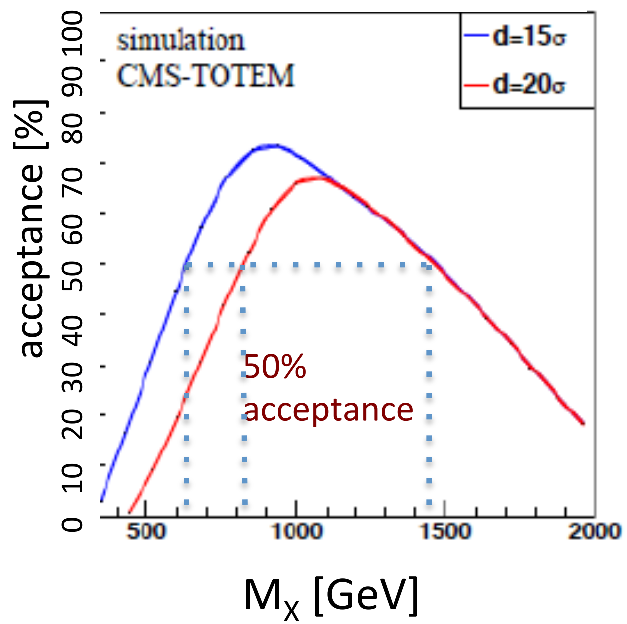
LHC Ring proto-collaboration,
invited presentations in (1) *low-x 2017*, Bari, Italy; (2) *photon 2017*, CERN

ATLAS & TOTEM ROMAN POTS HAVE LIMITED ACCEPTANCES

z = 210m + 210m



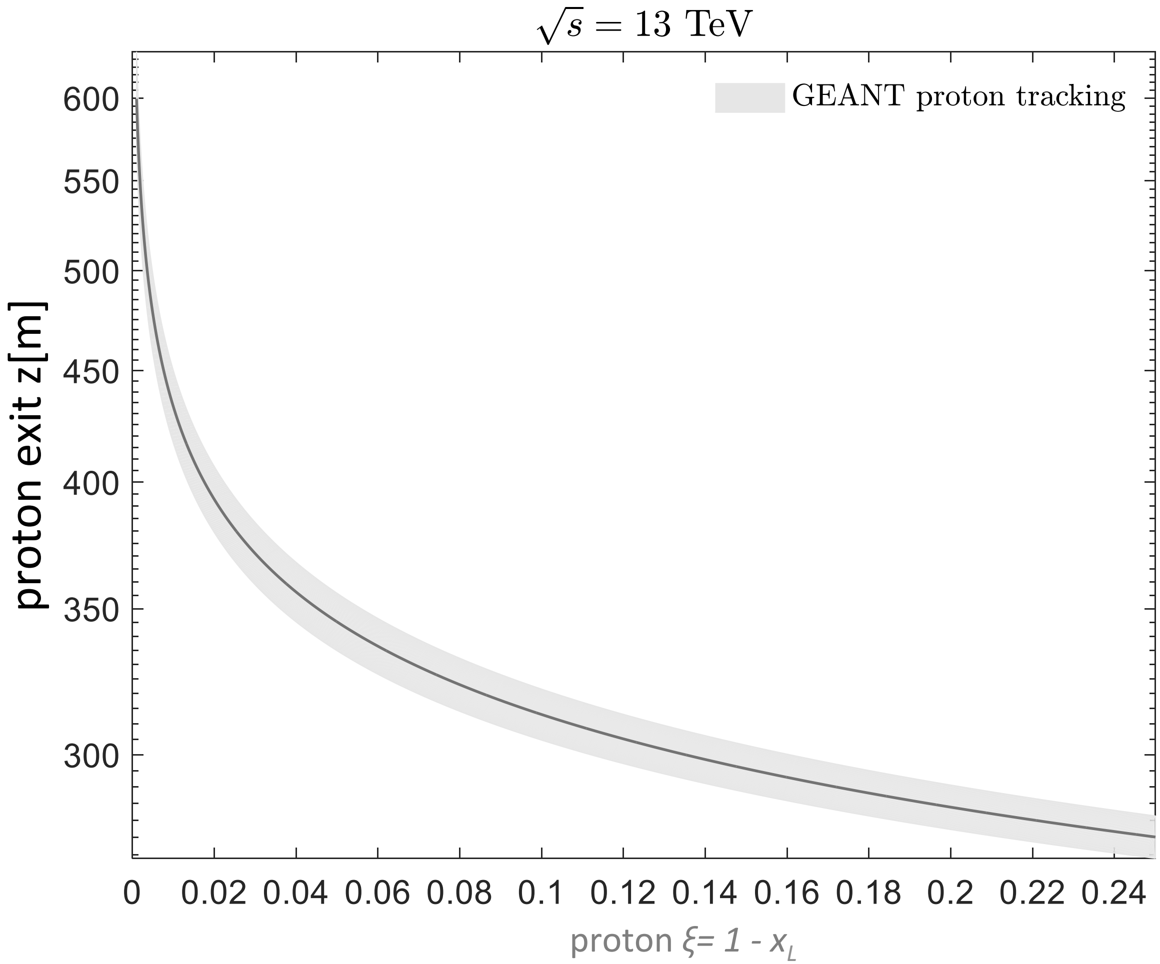
z = 204m + 215m



ATLAS: *M_X≈400/600 – 750 GeV* **CMS/TOTEM: *M_X≈650/820 – 1450 GeV***

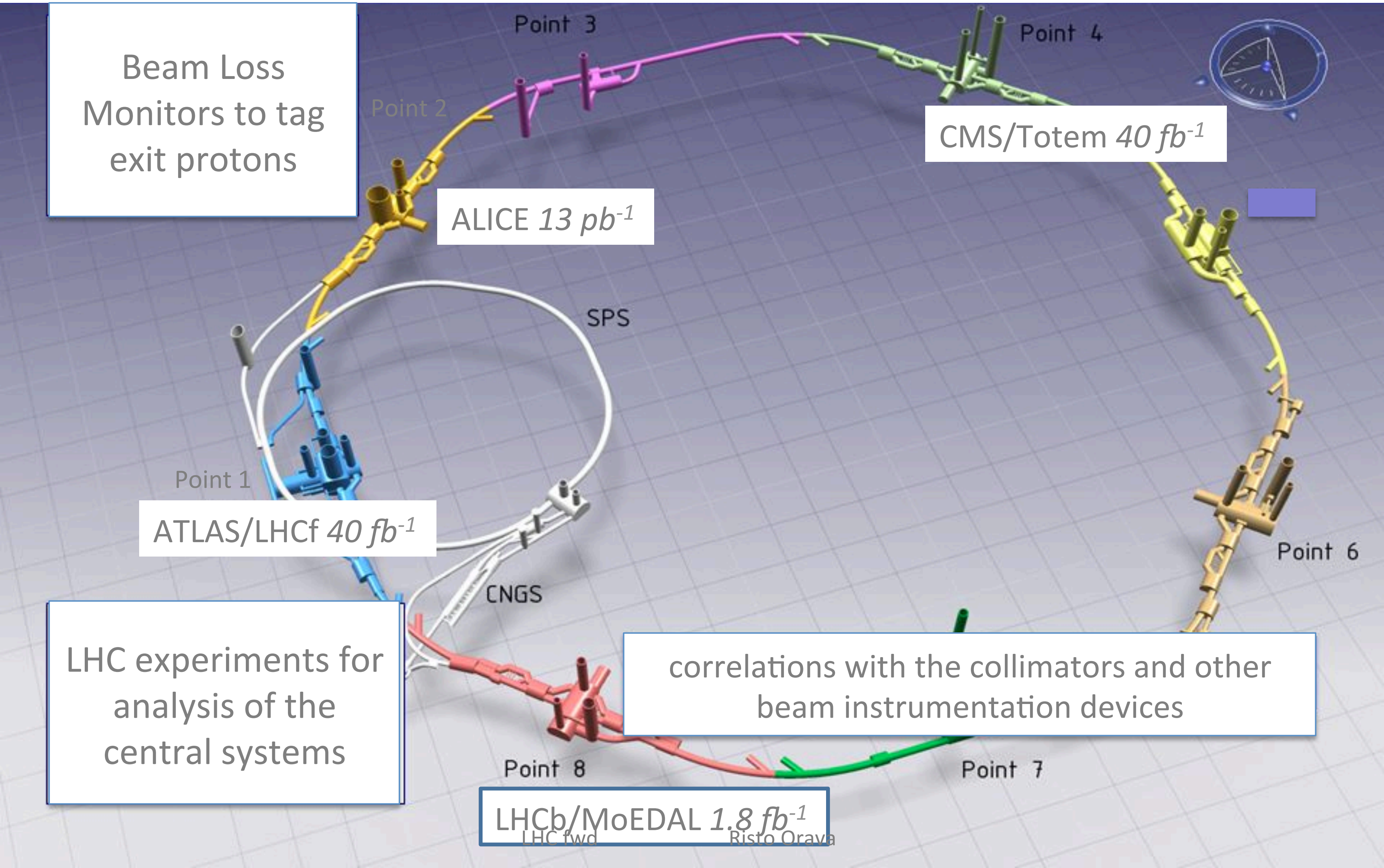
- **allowed distances to the beam?**
- **acceptance in *φ* & *t*?**
- **options via correction dipoles...**

PROTON EXIT POINTS vs. ξ



J. Aaron. *Hacking the LHC to shift trash could help find a mystery particle* – 2016.New Scientist Daily News, 25th April.

LHC RING AS A NEW PHYSICS SEARCH MACHINE

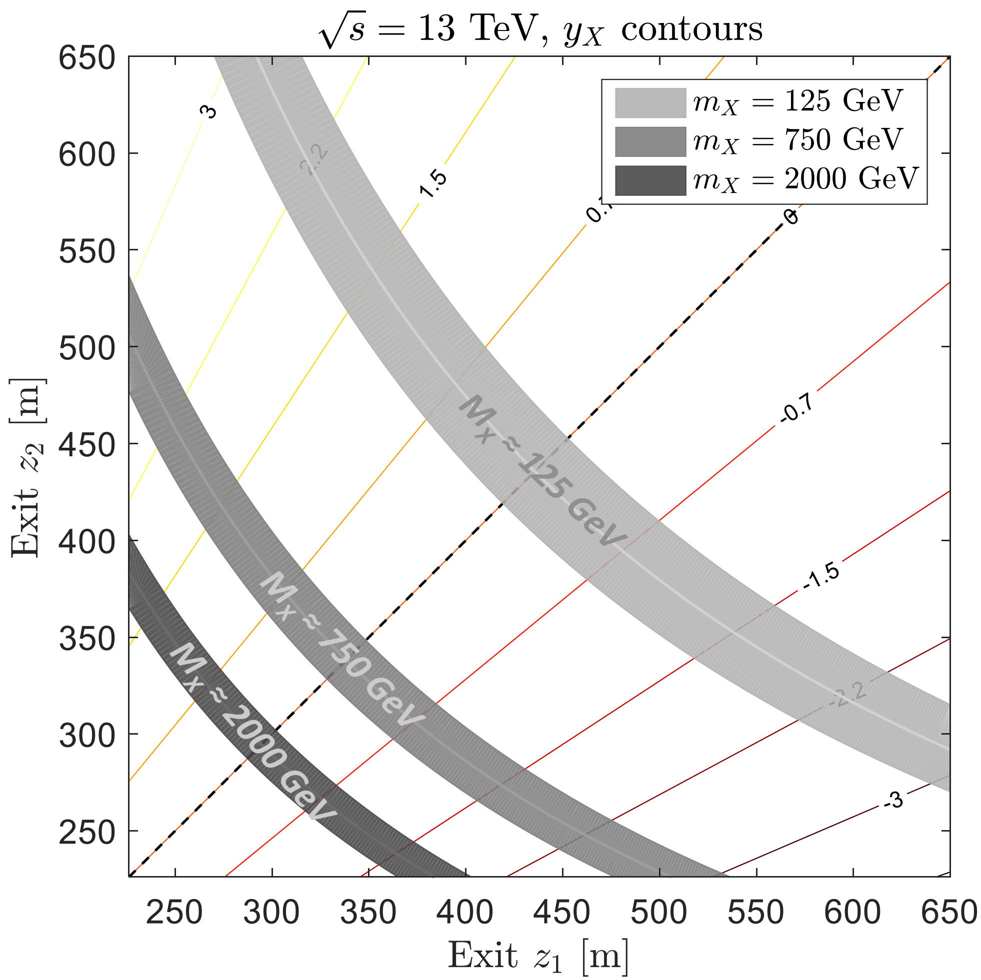


Beam Loss Monitors to tag exit protons

LHC experiments for analysis of the central systems

correlations with the collimators and other beam instrumentation devices

PAIRS OF PROTON EXIT POINTS MAP OUT THE CENTRAL MASSES



$\xi = 1 - \Delta p_z / p_{beam}$

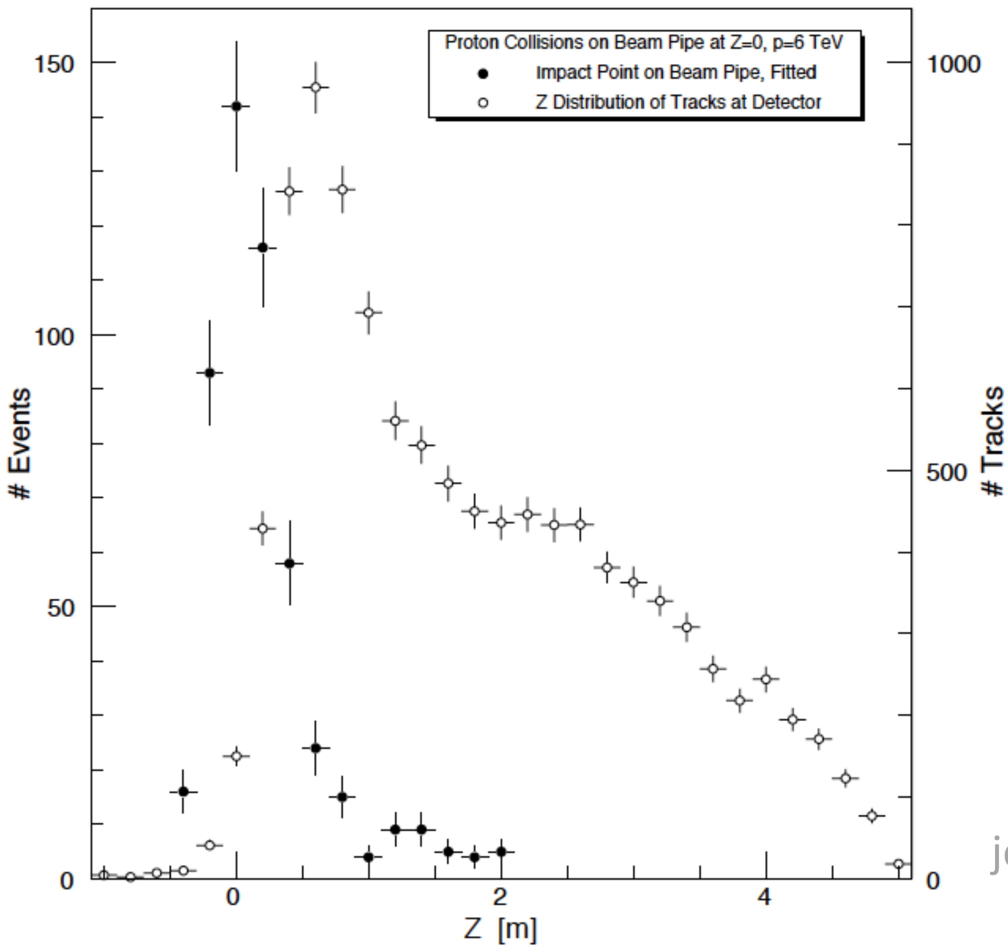
$z_{1,2} \rightarrow \xi_{1,2}$

$M_X \approx sqrt(\xi_1 \times \xi_2 \times s)$

Matti K. Kalliokoski, RO et al., arXiv:1604.5778; Diffraction 2016

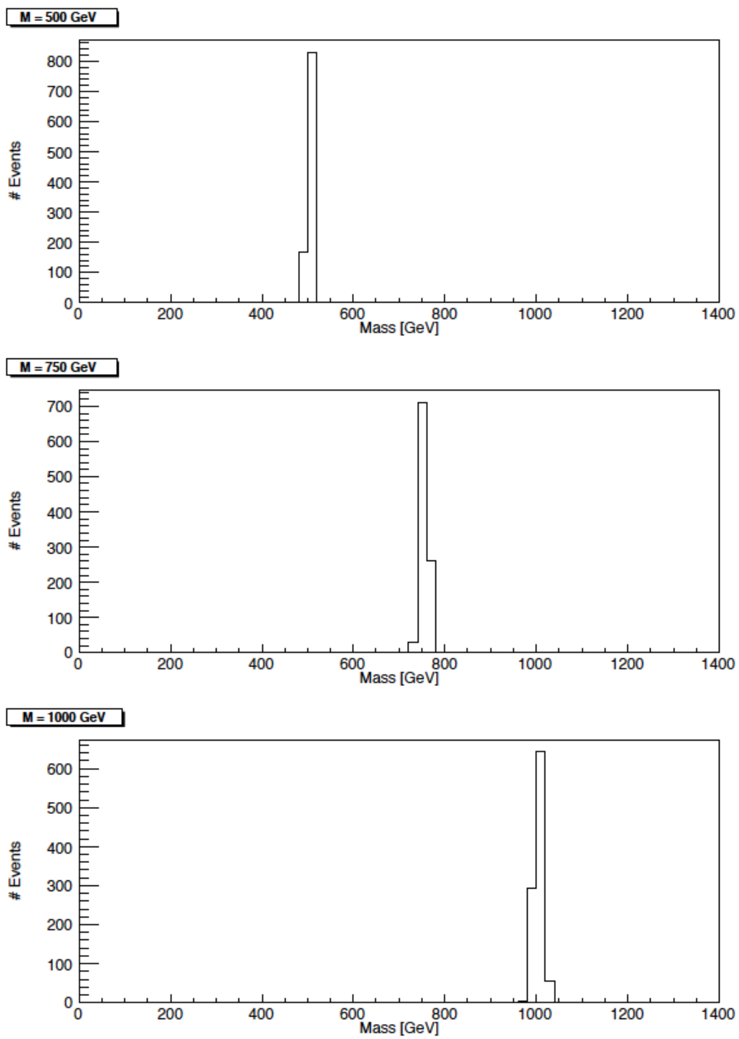
J. Aaron. *Hacking the LHC to shift trash could help find a mystery particle* – 2016.New Scientist Daily News, 25th April.

proton impact point reconstruction



jerry w lämsä

CENTRAL MASS RESOLUTION



assuming 50 cm exit point resolution
reach < 10% resolution in ξ

about ≈ 10 cm resolution fesible in
reconstructing the proton exit locations

jerry w lämsä

alice upgrade and forward physics

ALICE upgrades during LS2 (2019-20)

New Inner Tracking System (ITS)
- improved pointing precision
- less material -> thinnest tracker at the LHC

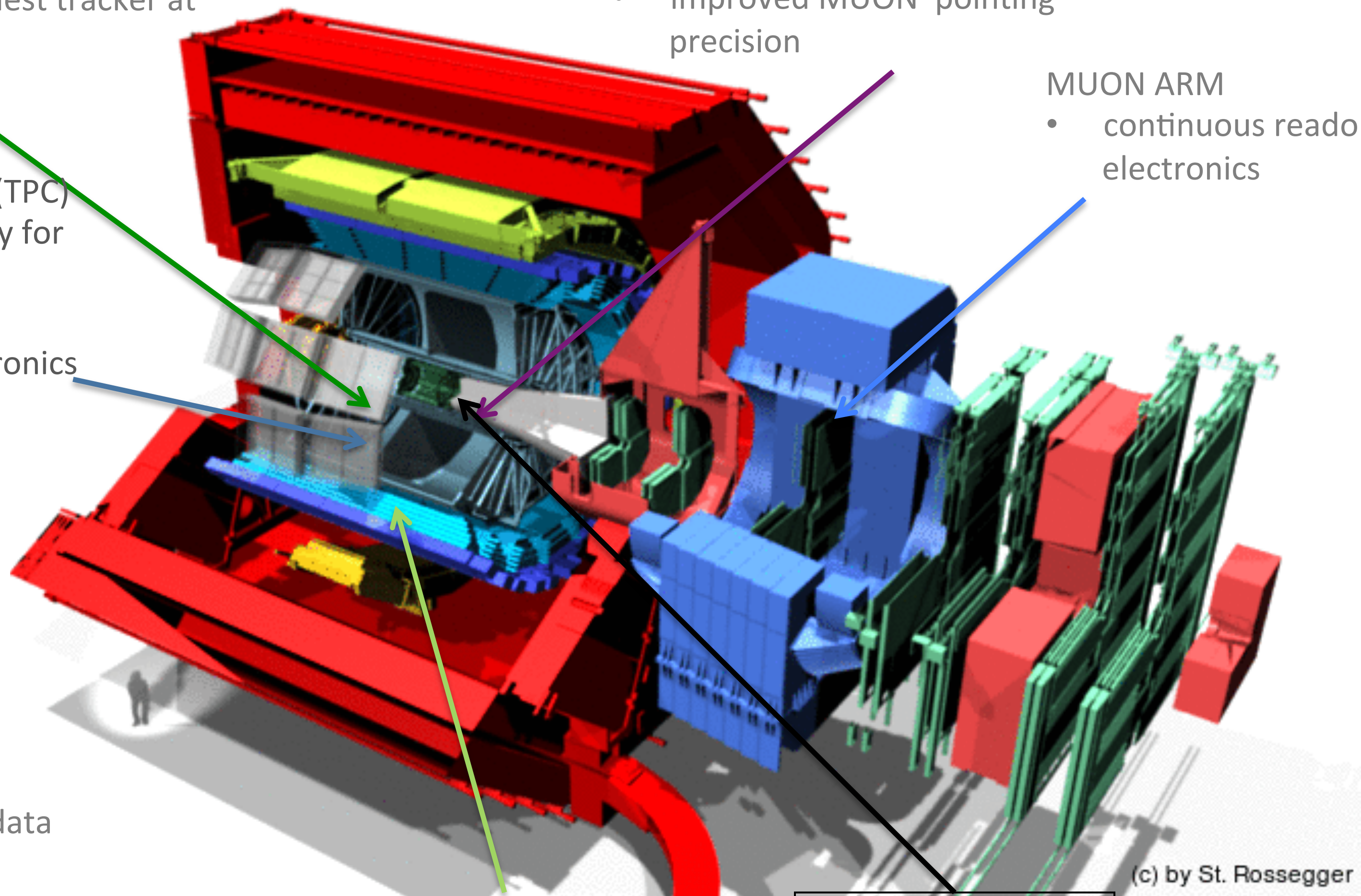
Muon Forward Tracker (MFT)
- new Si tracker
- improved MUON pointing precision

MUON ARM
- continuous readout electronics

Time Projection Chamber (TPC)
- new GEM technology for readout chambers
- continuous readout
- faster readout electronics

New Central Trigger Processor

Data Acquisition (DAQ)/ High Level Trigger (HLT)
- new architecture
- on line tracking & data compression
- 50kHz Pbb event rate



TOF, TRD, ZDC
- Faster readout

New Trigger Detectors (FIT)

UPC measurements in Run3 and Run4

- Expected integrated luminosities:
  - PbPb: 10/nb @0.5T, 3/nb @0.2T
  - pPb: 50/nb (×15 pPb 2015)
- Multi-differential studies J/ψ, Ψ(2S)
  - b-slope dependence → transverse gluon distributions (1611.05471)
  - ZDC → disentangle low-x and high-x contributions
- High-mass vector mesons:
  - Ψ(3S) -> DDbar (not measured at HERA) and ϒ
- γγ processes:
  - η_C (χ_{C0}, χ_{C2})
  - γγ → 4μ: double-VM production, e.g. γγ → J/ψ J/ψ , ρ^0 J/Ψ
  - γγ → ppbar (η_C → ppbar)
  - γγ → γγ
- Jet photoproduction: gives direct access to the gluon distribution (ATLAS-CONF-2017-011)
- coherent UPC Φ production

Expected number of events for L^{int} = 10/nb in Pb-Pb

process	central barrel	muon arm	Comments
J/ψ → l+l-	4.1M	620k	STARLIGHT
Ψ(2S)	109k	15k	STARLIGHT
ϒ	5,260	430	STARLIGHT
Ψ(3S) → DDbar	(acc×eff) × 5,900	---	Ψ(3S) -> DDbar -> $K^+\pi^- K^-\pi^+$ https://indico.cern.ch/event/347071/
η_C → 2π 2K	(acc×eff) × 49k	---	σ = 490 μb (STARLIGHT), BR(η_C -> 2π2K) ≈ 0.01
γγ → 4μ (VV)	(acc×eff) × 310	---	p_T > 0.5 GeV, |y| < 0.9: σ ≈ 31 nb (Sczcurek et al. 1708.07742)
γγ → ppbar	(acc×eff) × 350k	---	p_T > 1 GeV, |y| < 0.9: σ ≈ 35 μb (Szczurek et al. 1708.09836)
γγ → γγ	240 (E_T>3 GeV, |η|<2.4)	---	ATLAS: 0.45/nb 13 ev --> 10/nb 240 ev (DOI: 10.1038/NPHYS4208)
UPC jets	(acc×eff) × O(4M)	----	ATLAS-CONF-2017-011: 110k events with 0.3/nb in|η|<3.2 --> 3.7M events with 10/nb

concluding remarks

- **alice produces unique forward physics**:
  - space-time structure of hadron interactions
  - glue-states: ALICE has an edge!
  - central exclusive production of gluon-jets, monopoles...
- **further run periods 3-4:**
  - unique prospects for discoveries & forward analysis

  IF ALICE WAS NOT THERE, IT WOULD HAVE TO BE RE-INVENTED!