Isolation in inclusive and exclusive processes

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Quarkonia as Tools 2020
14.1.20

Why is isolation important?

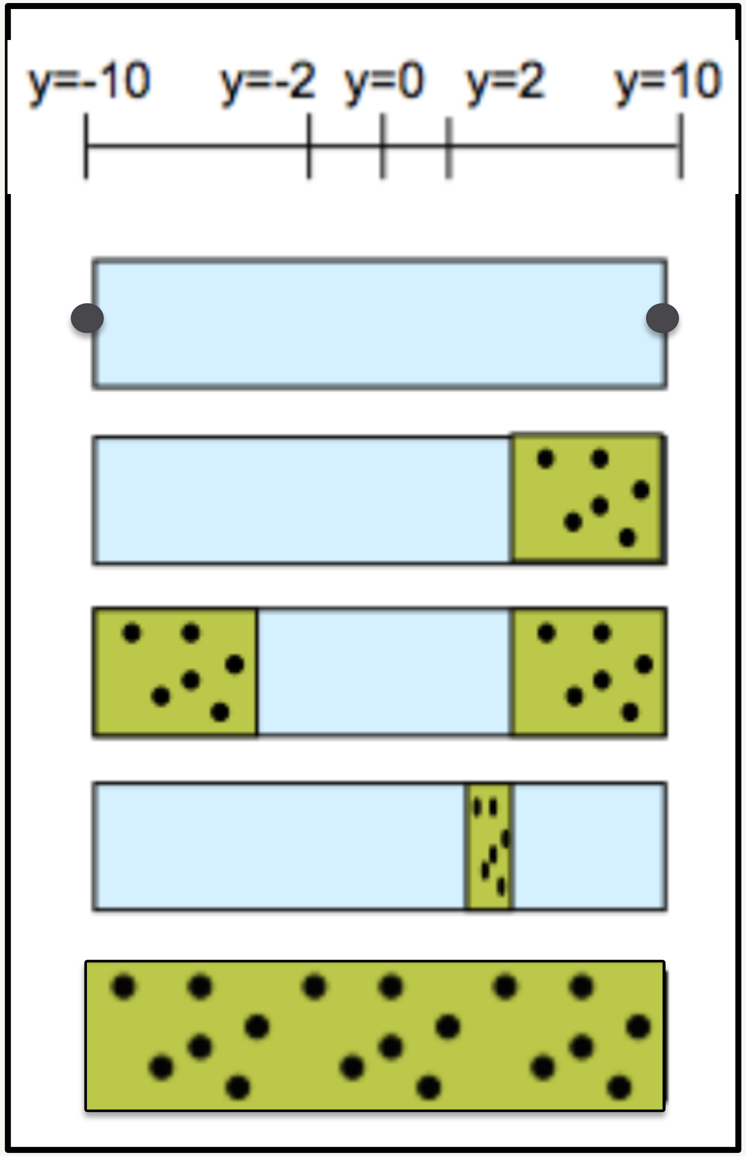
- *One definition of diffraction (Alan Martin)*

  "A diffractive process is characterized by a large rapidity gap (LRG), caused by t-channel Pomeron exchange."

Cross-section (13 TeV)	(mb)
Elastic	~40
Diffractive	~10
Inelastic	~60

Diffractive can be further divided into single (SD), double (DD) and central exclusive production (CEP) ~ 0.1mb, where the gaps are critical.

Schematic Representation



Elastic

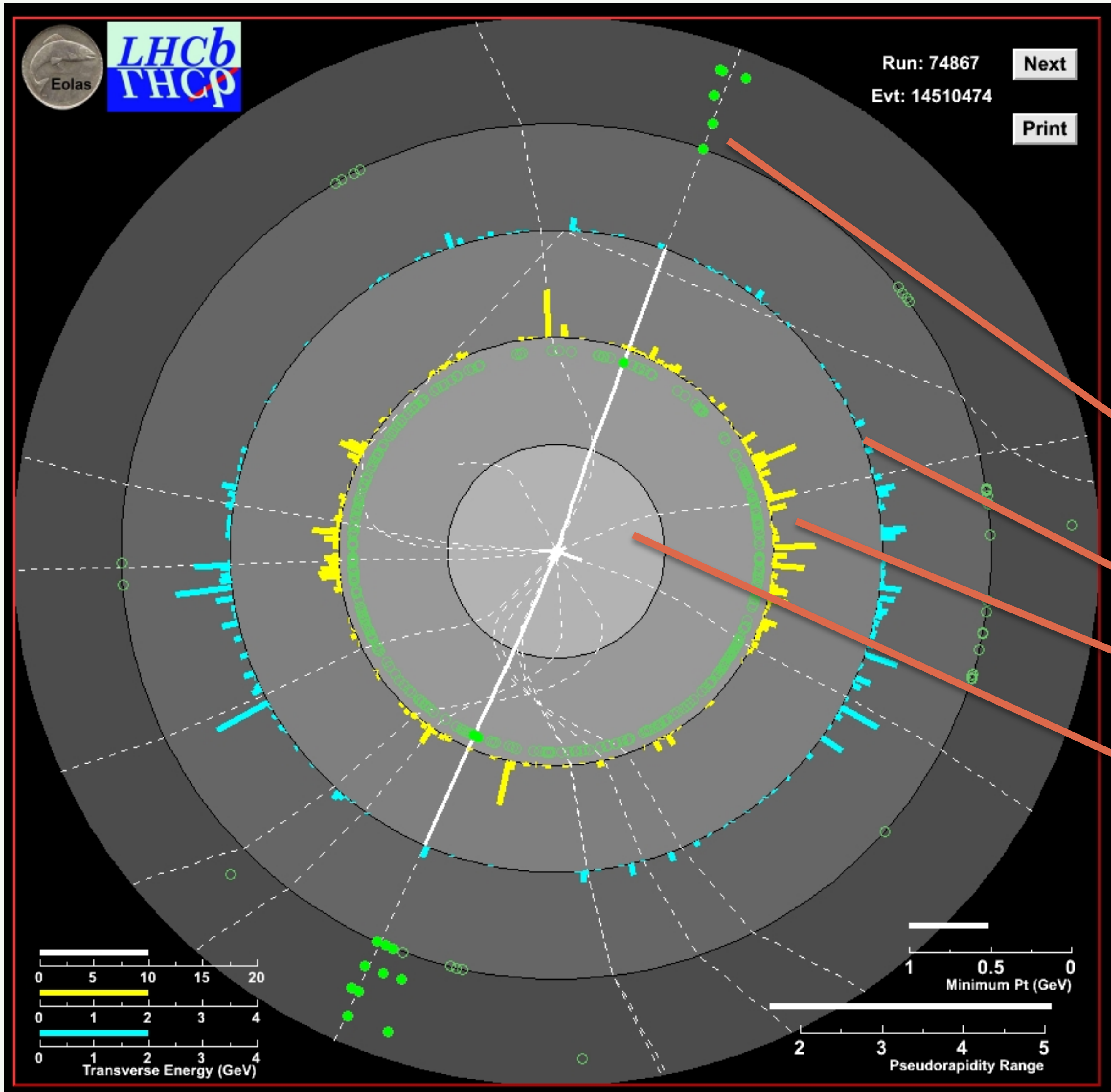
Single Diffractive

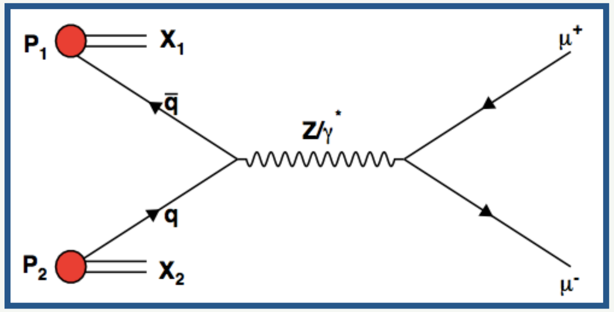
Double Diffractive

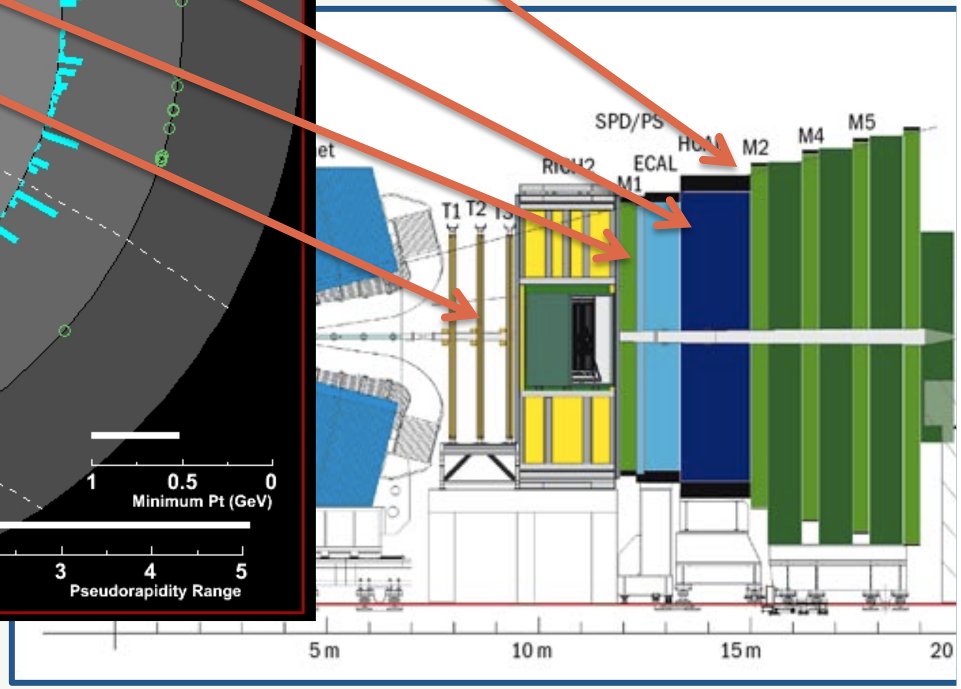
Central Exclusive Production

Inclusive

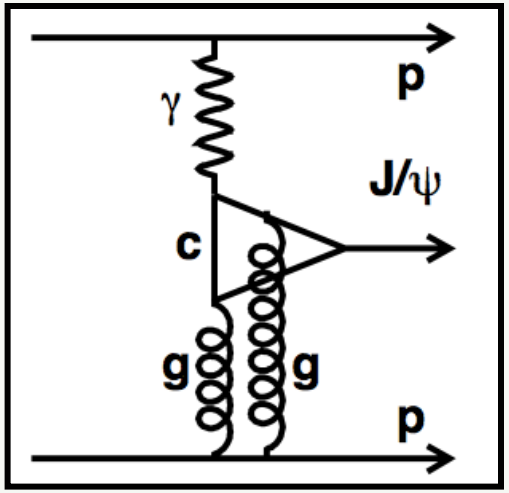
Inclusive pp->ZX

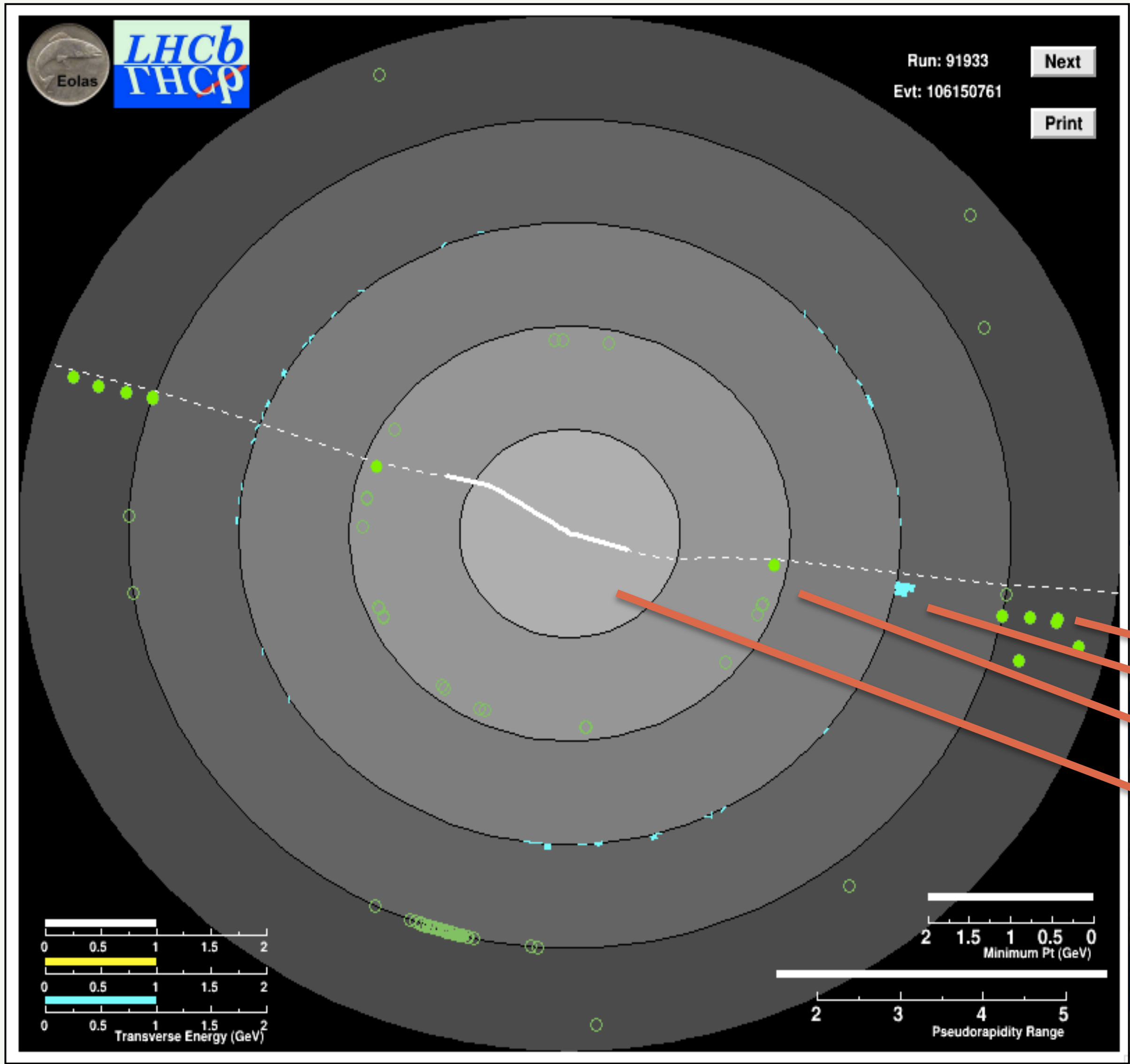


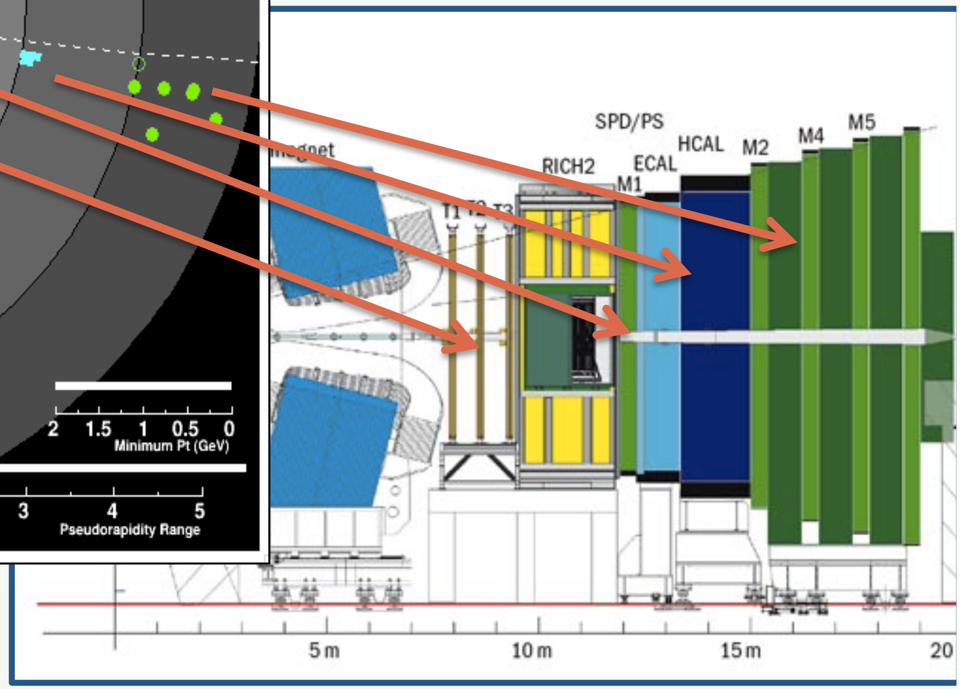




CEP

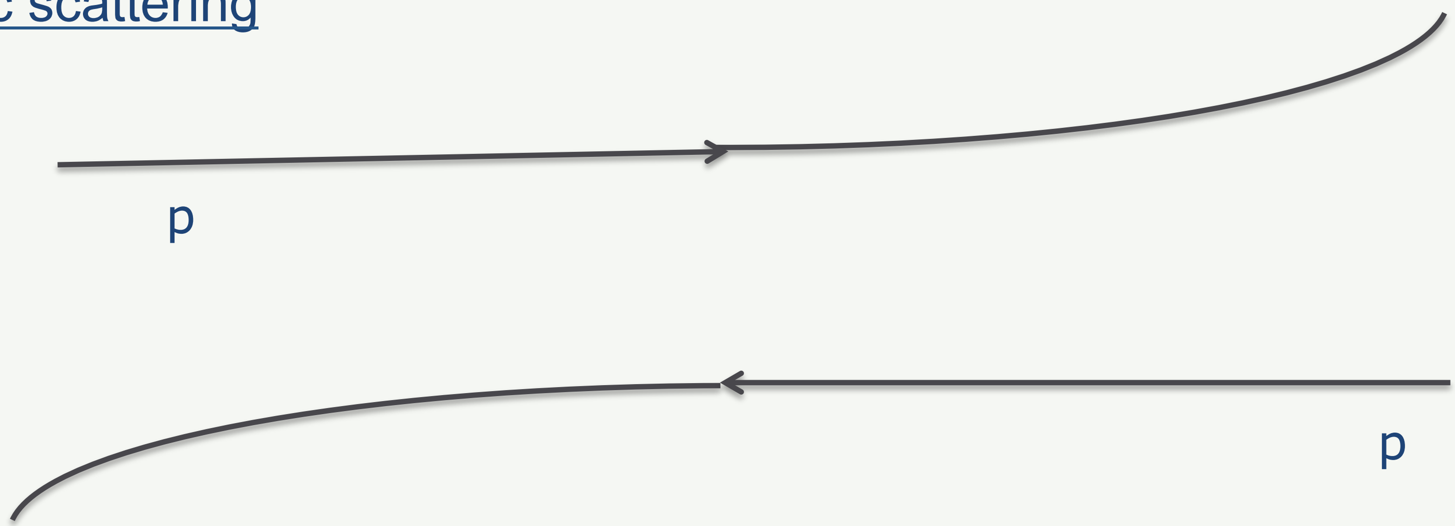

p
γ
J/ψ
c
g
g
p


Eolas
LHCb
Run: 91933
Evt: 106150761
Next
Print
0 0.5 1 1.5 2
Transverse Energy (GeV)
2 1.5 1 0.5 0
Minimum Pt (GeV)
2 3 4 5
Pseudorapidity Range


SPD/PS
HCAL
M2
M4
M5
RICH2
ECAL
M1
5 m
10 m
15 m
20

Physics of the Vacuum

Elastic scattering



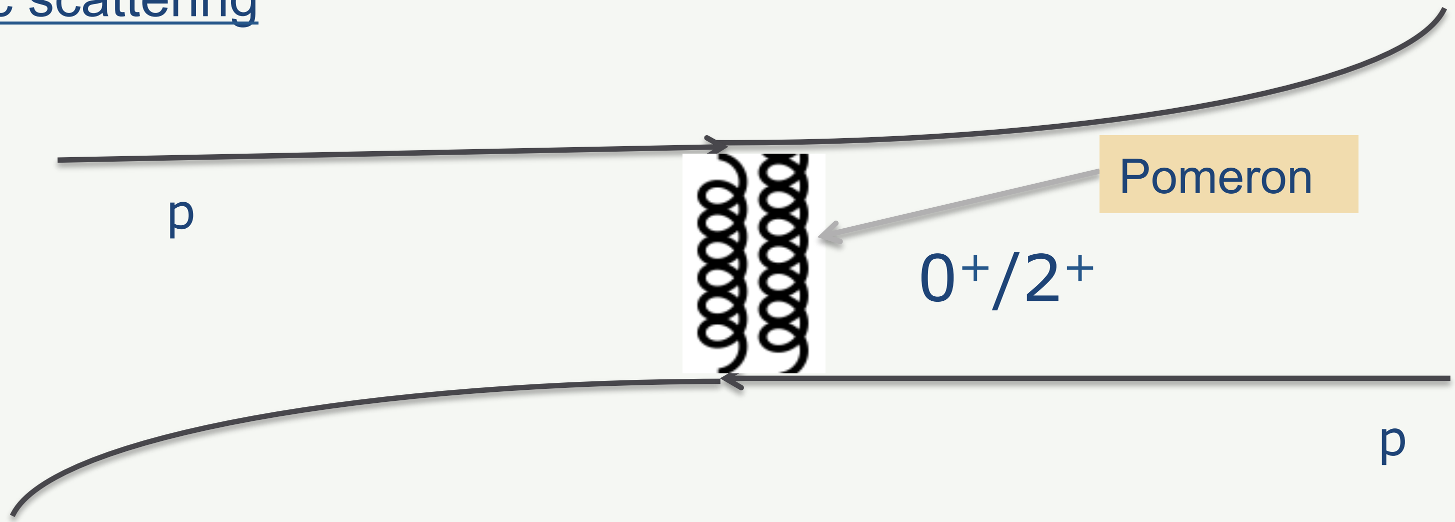
$\sigma_{elastic}$ ≈ 40mb

$\sigma_{diffractive}$ ≈ 10mb

$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

Elastic scattering

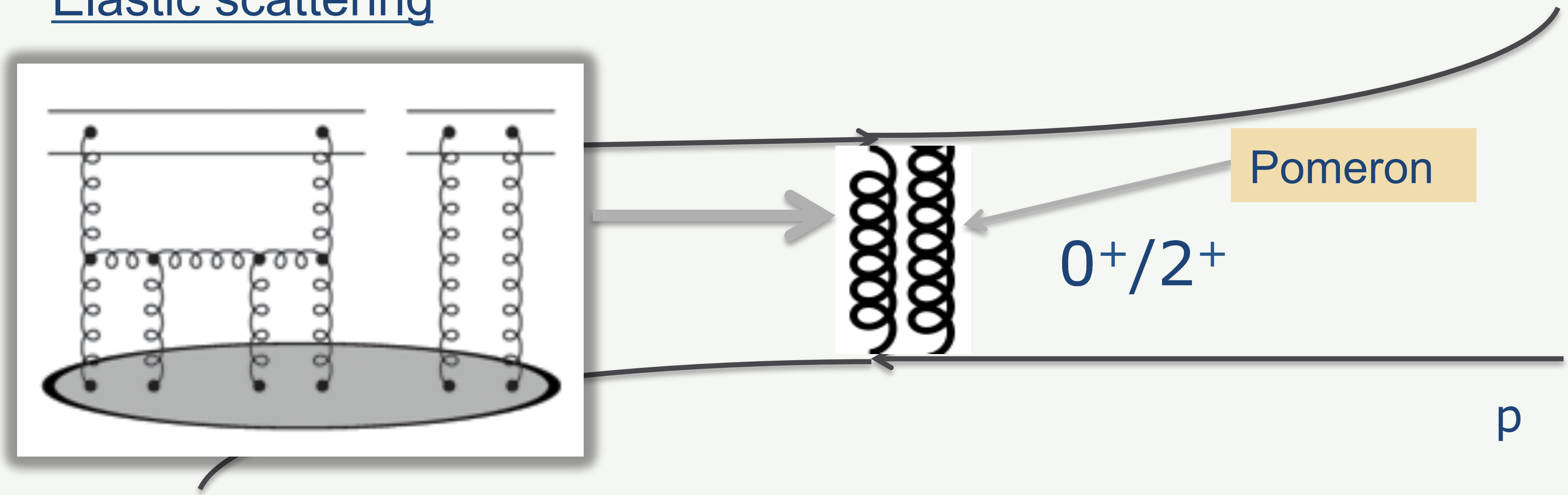


It's QCD – but not as we normally see it. It's colour-free

$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

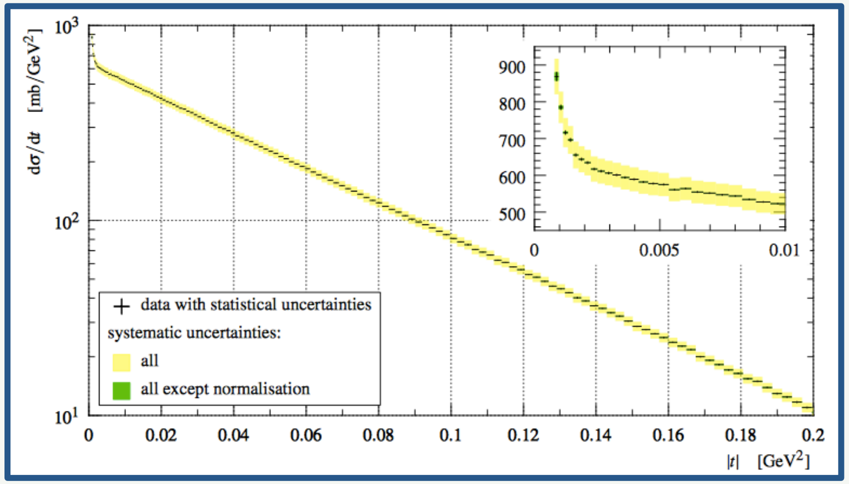
Elastic scattering



At high energy: $A(s,t)=s^{\alpha(t)}$
$\alpha_P(t)=\alpha_P(0)+\alpha' t$

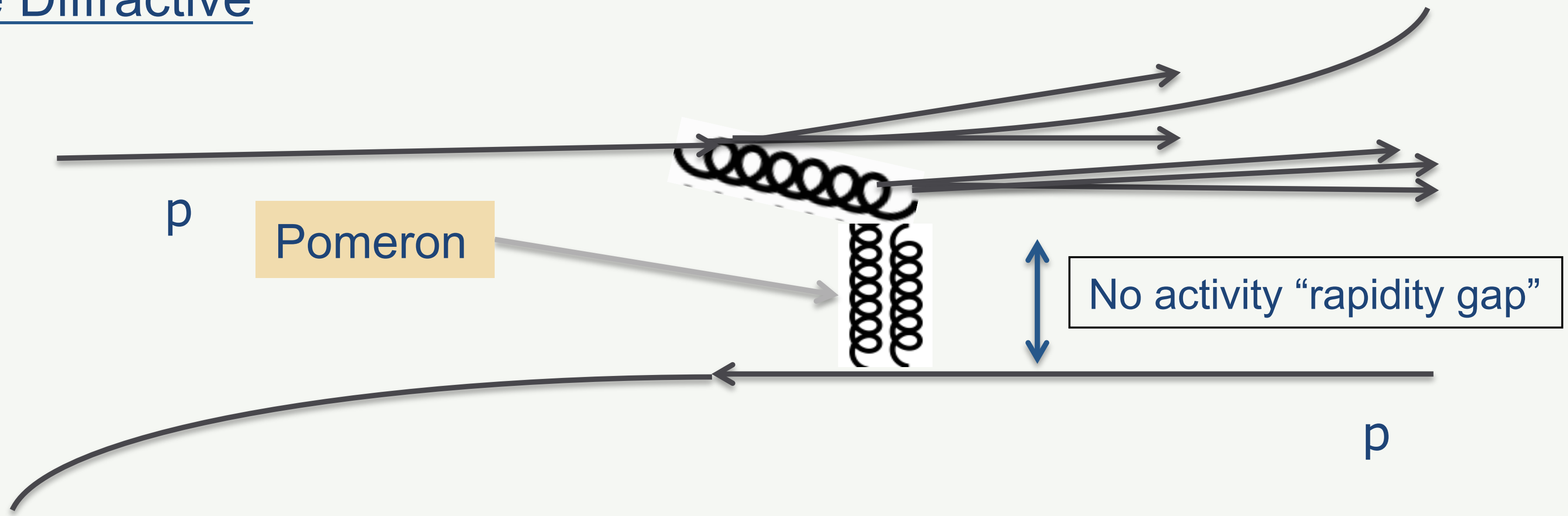
$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Totem: Eur.Phys.J. C79 (2019) no.9, 785



Physics of the Vacuum

Single Diffractive

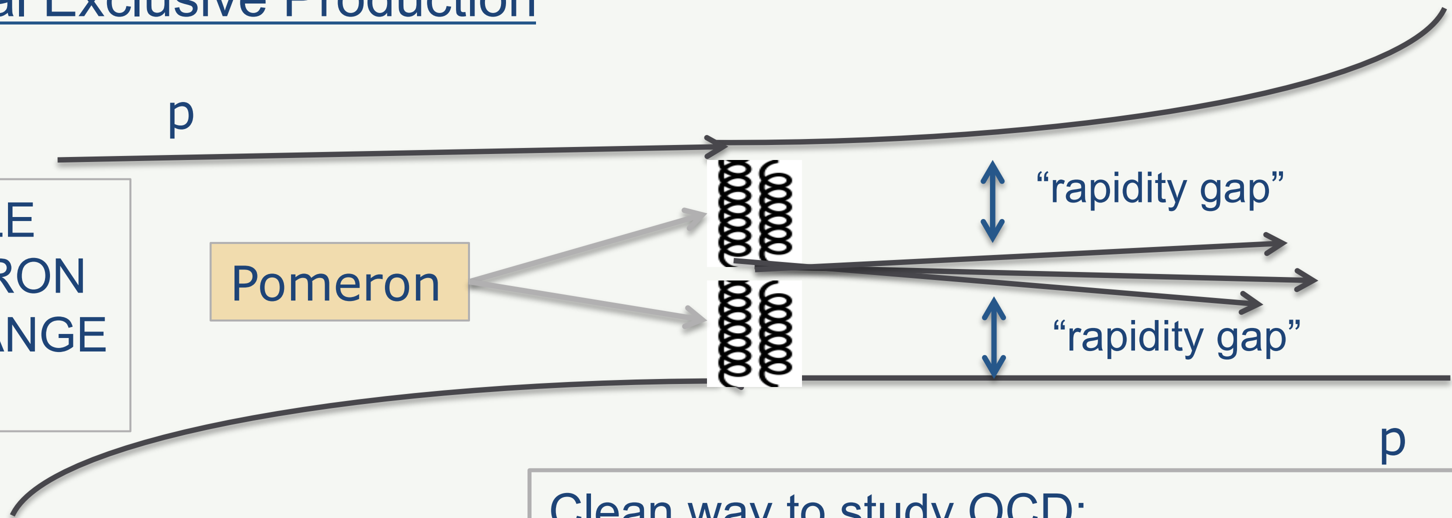


$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

Physics of the Vacuum

Central Exclusive Production

DOUBLE POMERON EXCHANGE (DPE)



Clean way to study QCD:
- structure of projectiles
- nature of colour-free propagators
- structure of what is produced out of vacuum

$\sigma_{elastic} \approx 40$mb

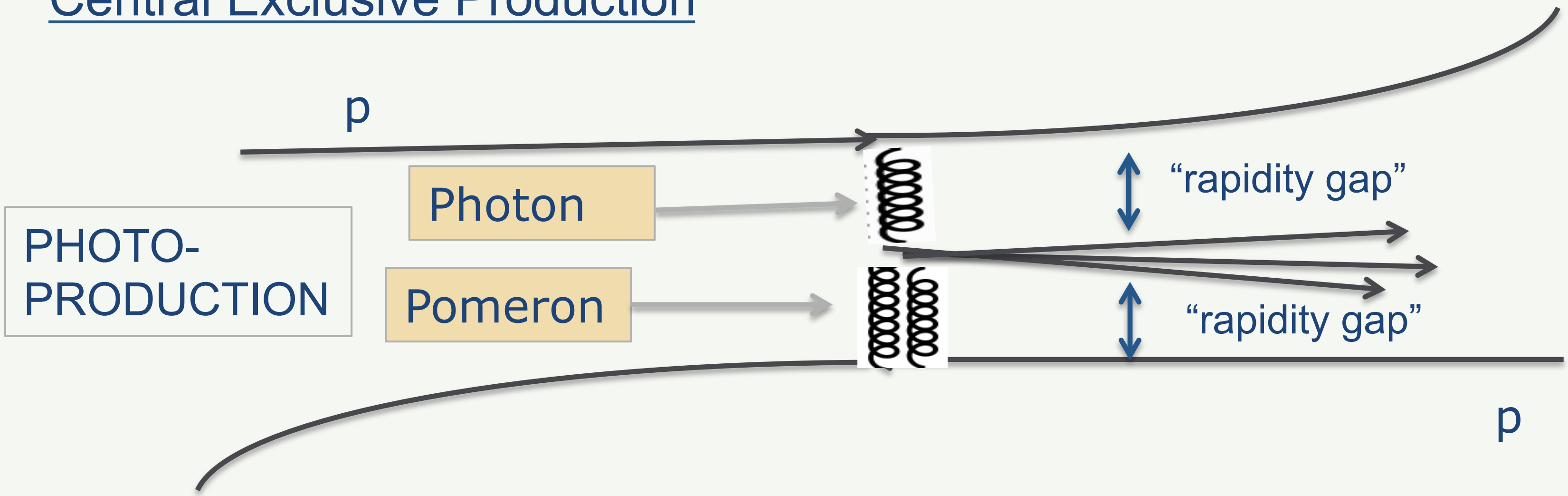
$\sigma_{diffractive} \approx 10$mb

$\sigma_{inelastic} \approx 60$mb

100 µb

Physics of the Vacuum

Central Exclusive Production



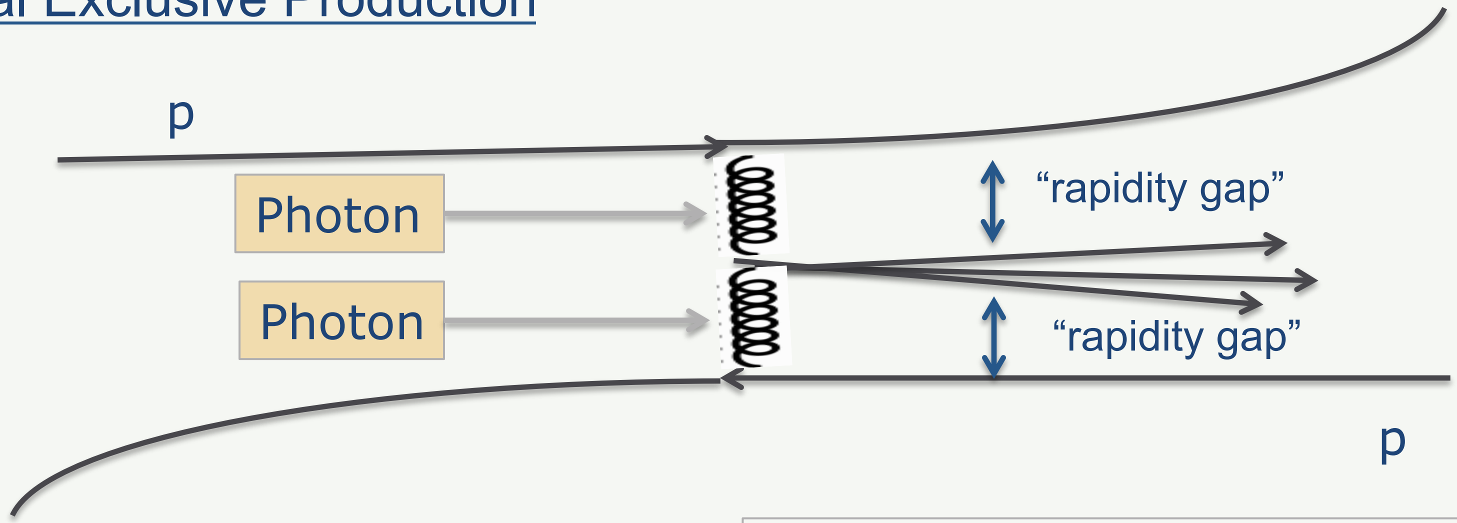
$\sigma_{elastic}$ ≈ 40mb
$\sigma_{diffractive}$ ≈ 10mb
$\sigma_{inelastic}$ ≈ 60mb

100 μb

Physics of the Vacuum

Central Exclusive Production

QED



CEP is characterised by a rapidity gap all the way to the proton

Detect as large a gap as possible...

$\sigma_{elastic} \approx 40mb$

$\sigma_{diffractive} \approx 10mb$

$\sigma_{inelastic} \approx 60mb$

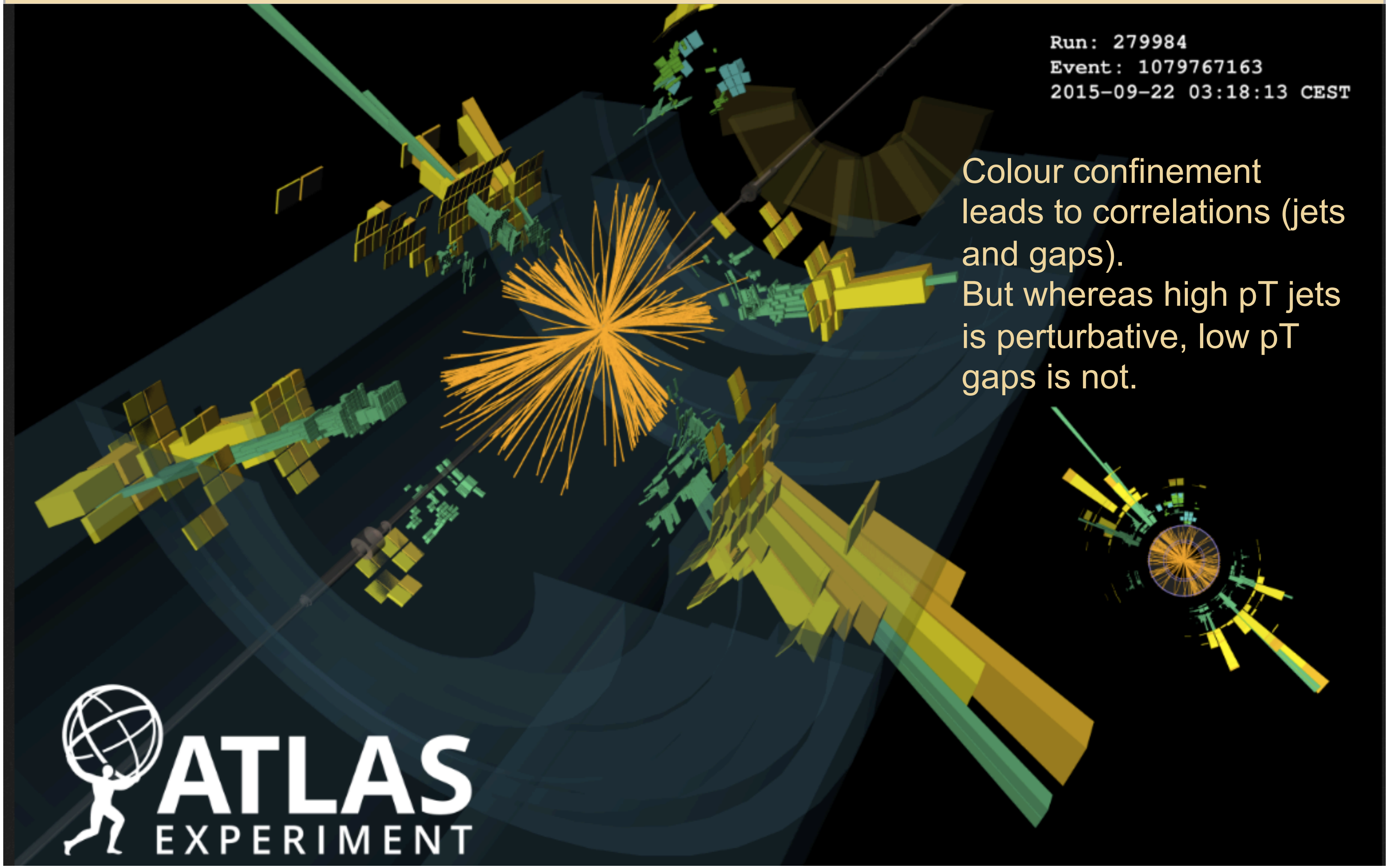
100 pb

(At least) 2 problems detecting gaps

Detectors do not have 4π coverage.

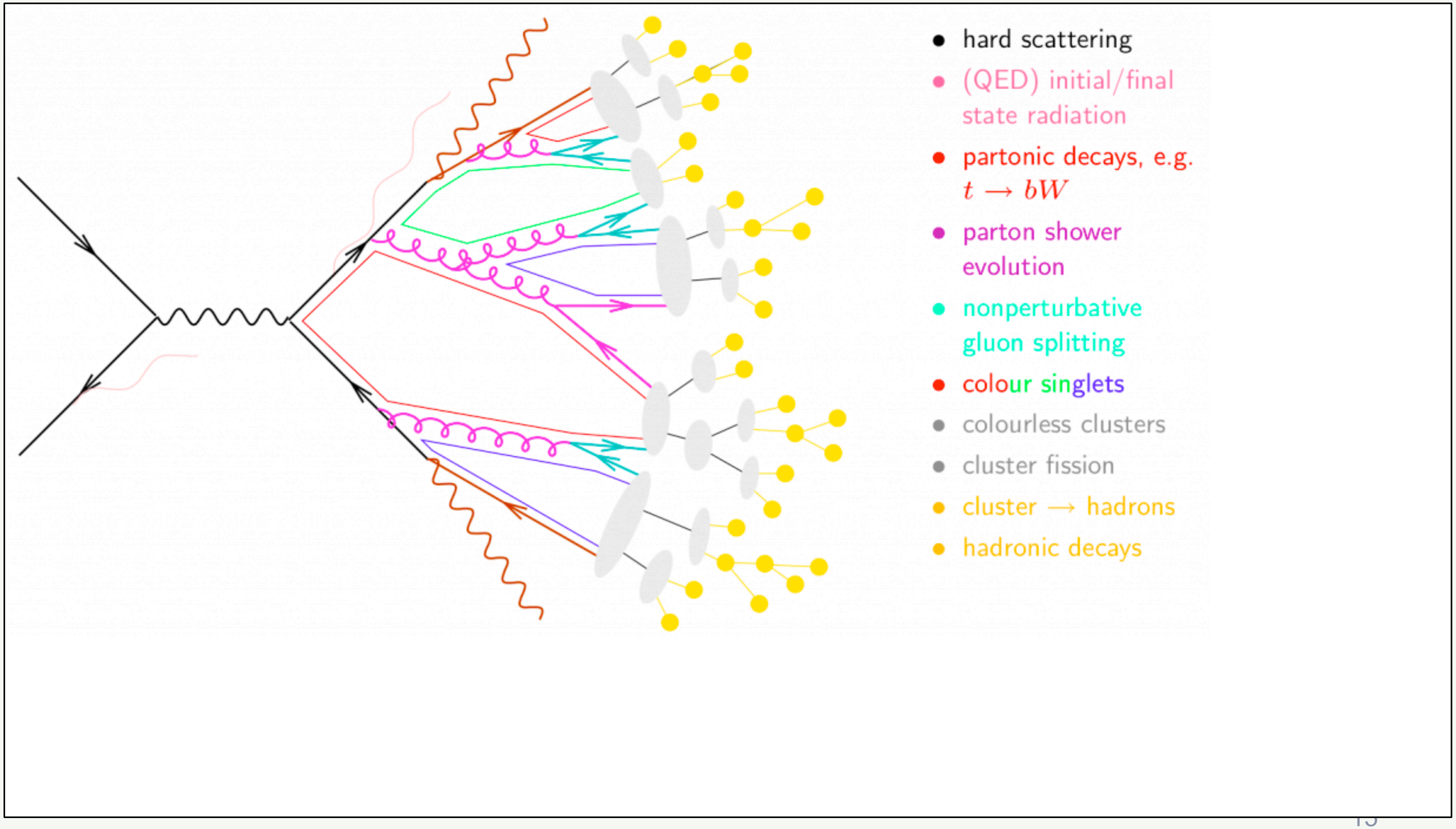
- How big a gap do you need to know it is diffractive?
- How can we deal with proton dissociation, where the break-up products are emitted at very low angles?

Isolation v Jets

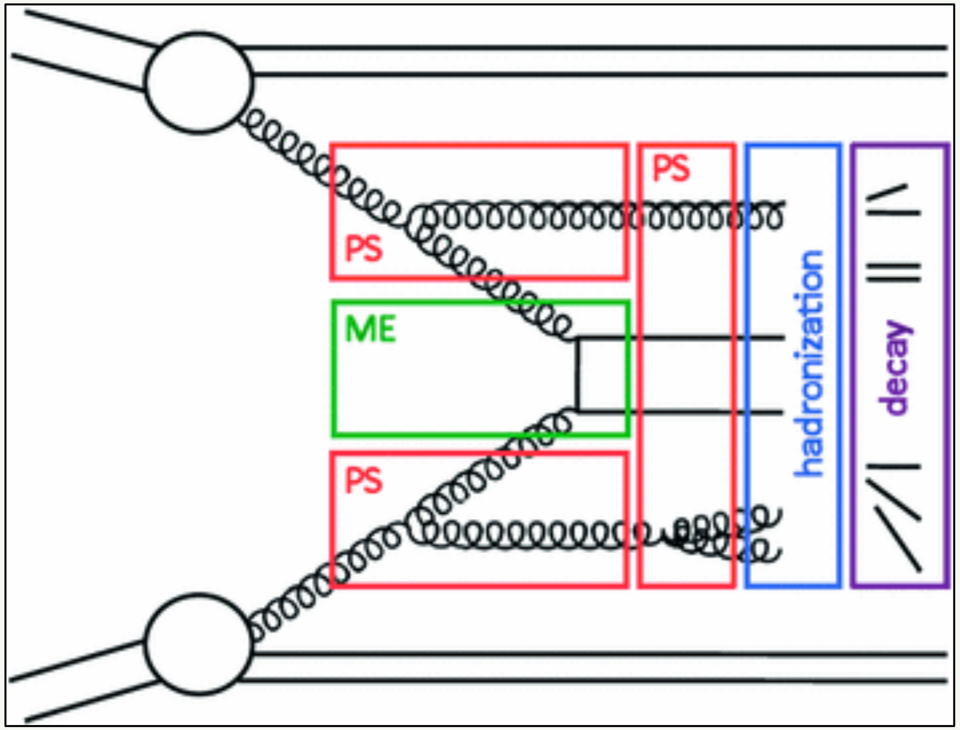


Colour confinement leads to correlations (jets and gaps).
But whereas high pT jets is perturbative, low pT gaps is not.

Determining isolation....

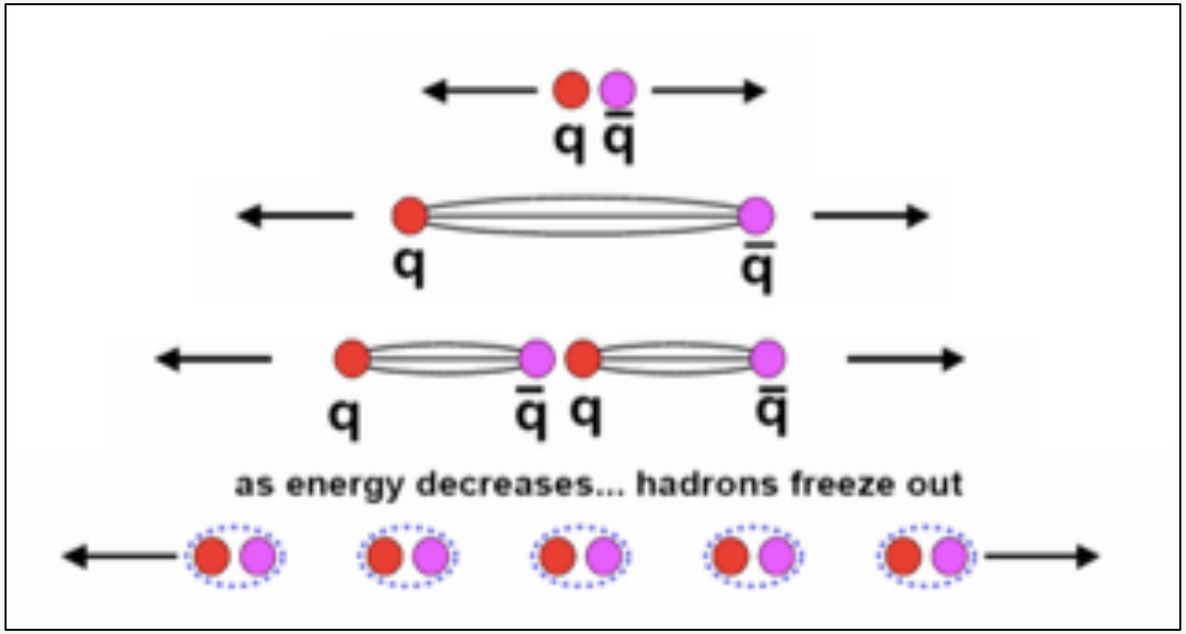


Determining isolation...



Final particle distribution depends critically on parton shower and (non-perturbative) hadronisation

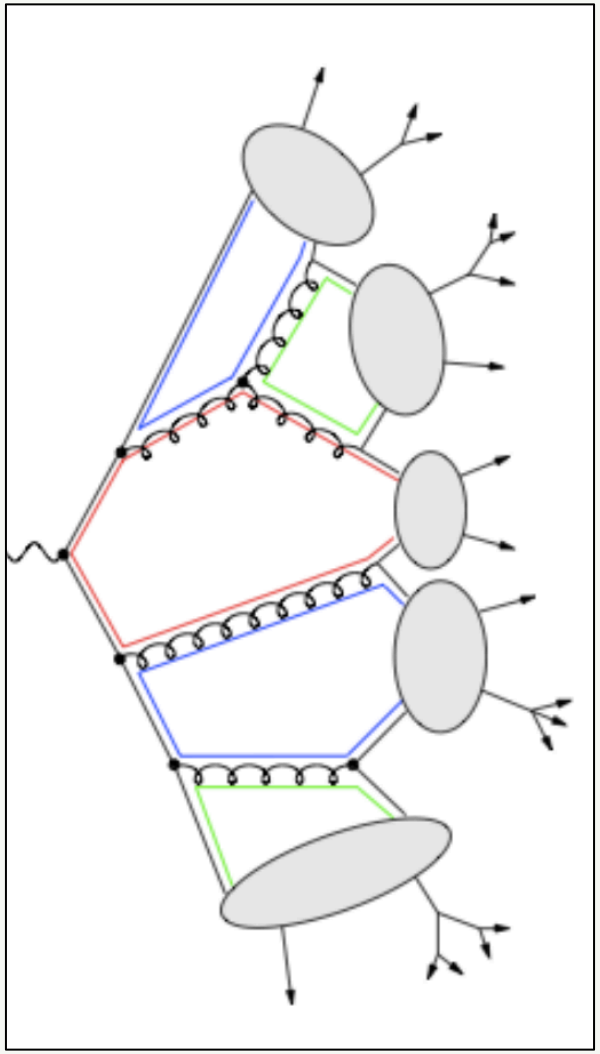
String Fragmentation (Pythia)



String tension, κ=1 GeV / fm

Cluster Hadronisation (Sherpa/Herwig)

- Force non-perturbative g->qq
- Follow colour
- Group into colour neutral **clusters**
- Clusters decay to hadrons according to phass-space

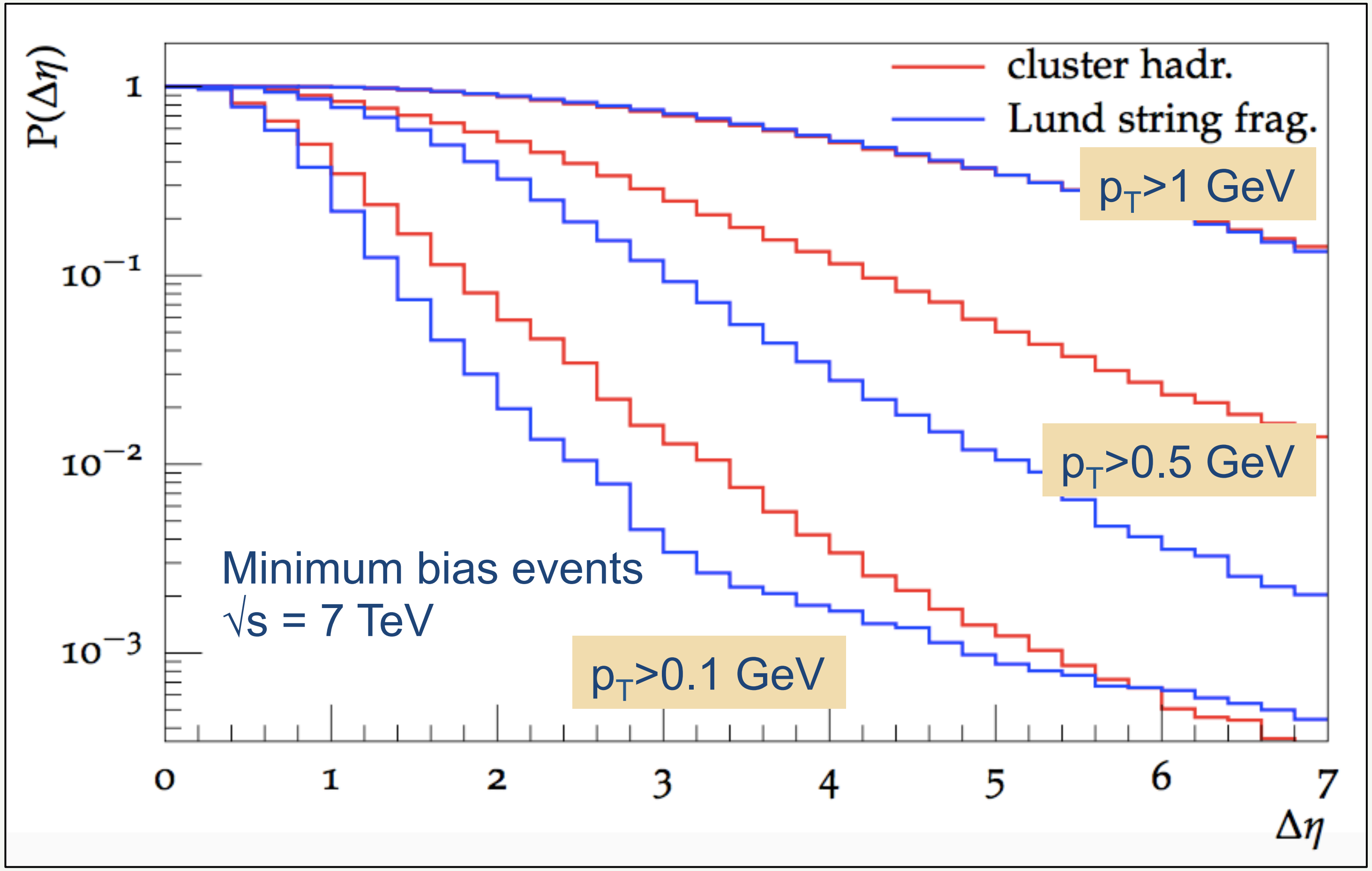


Investigate gaps with simulation

- Very sensitive to details of simulation
  - How partons become hadrons
    - parton shower (parton emissions, radiation)
    - cluster hadronisation / string fragmentation
    - Multiple parton interactions
    - Underlying event
  - Tuning

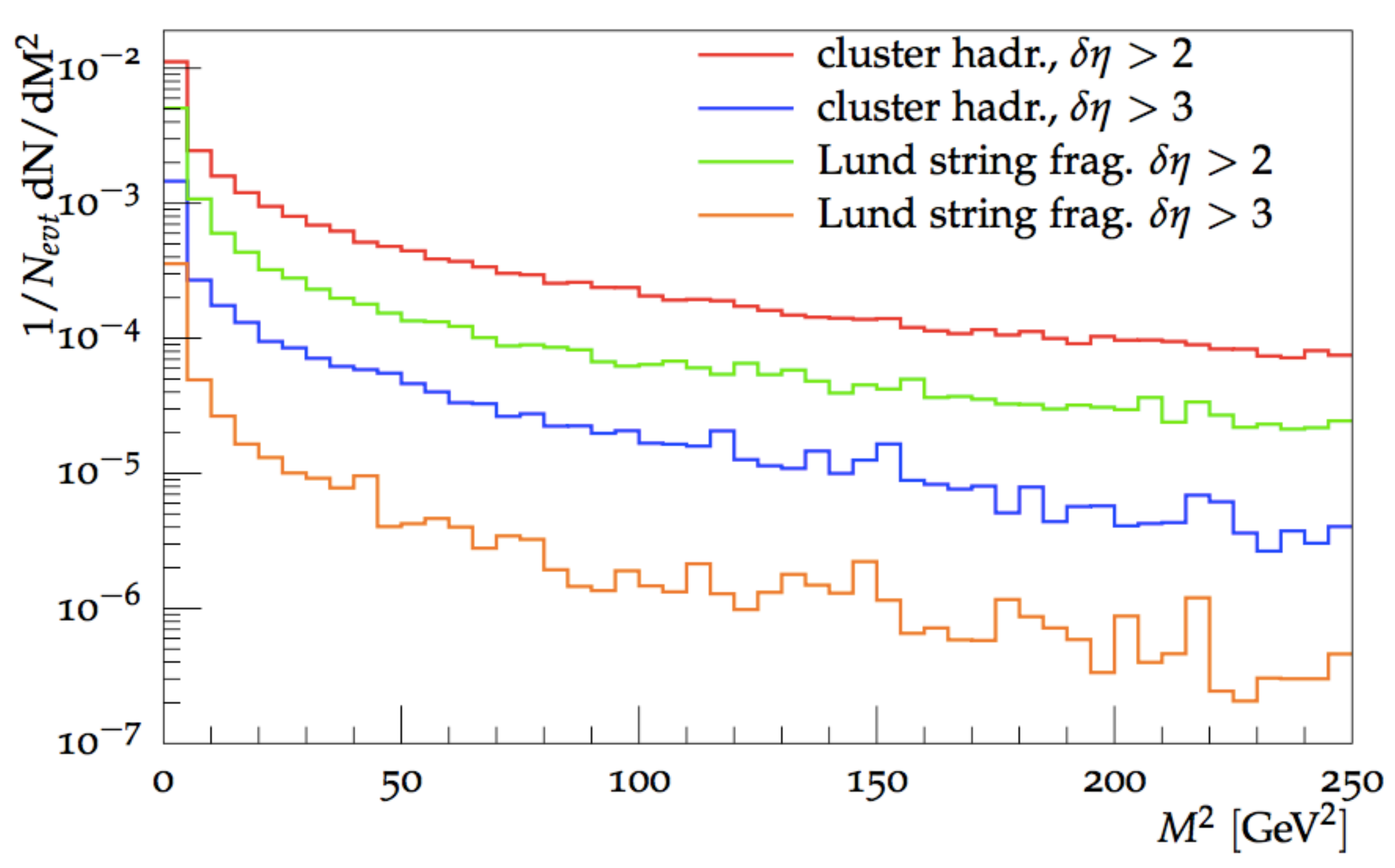
Probability of gap > Δη

Khoze, Krauss, Martin, Ryskin, Zapp, arXiv:1005.4839



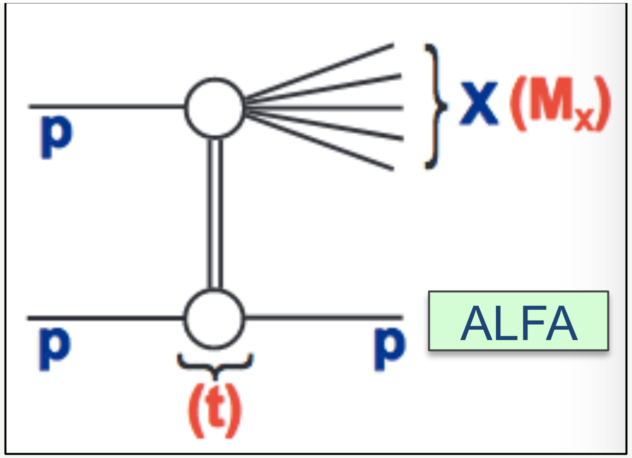
Given the large inclusive cs, you can easily get a gap and it's nothing to do with diffraction. Note also the large model dependence (order of magnitude)

Require two rapidity gaps > 2 or 3

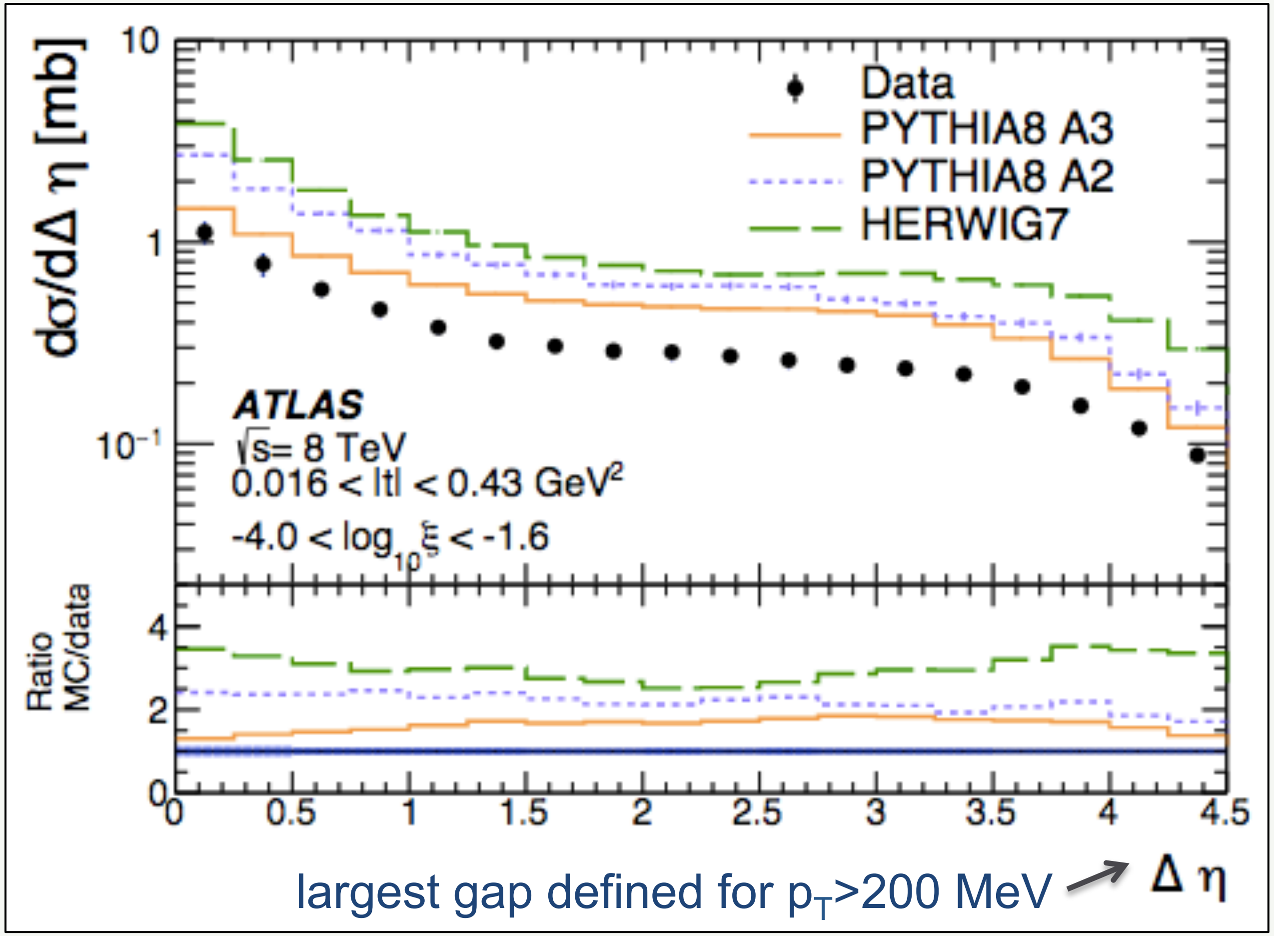


Background to CEP DPE:
Massive systems less likely to have two large rapidity gaps.
Light systems often do.

ATLAS measurement of SD



arXiv:1911.00453



Data exhibits fewer large gaps than models predict.

We are pretty rubbish at describing isolation.

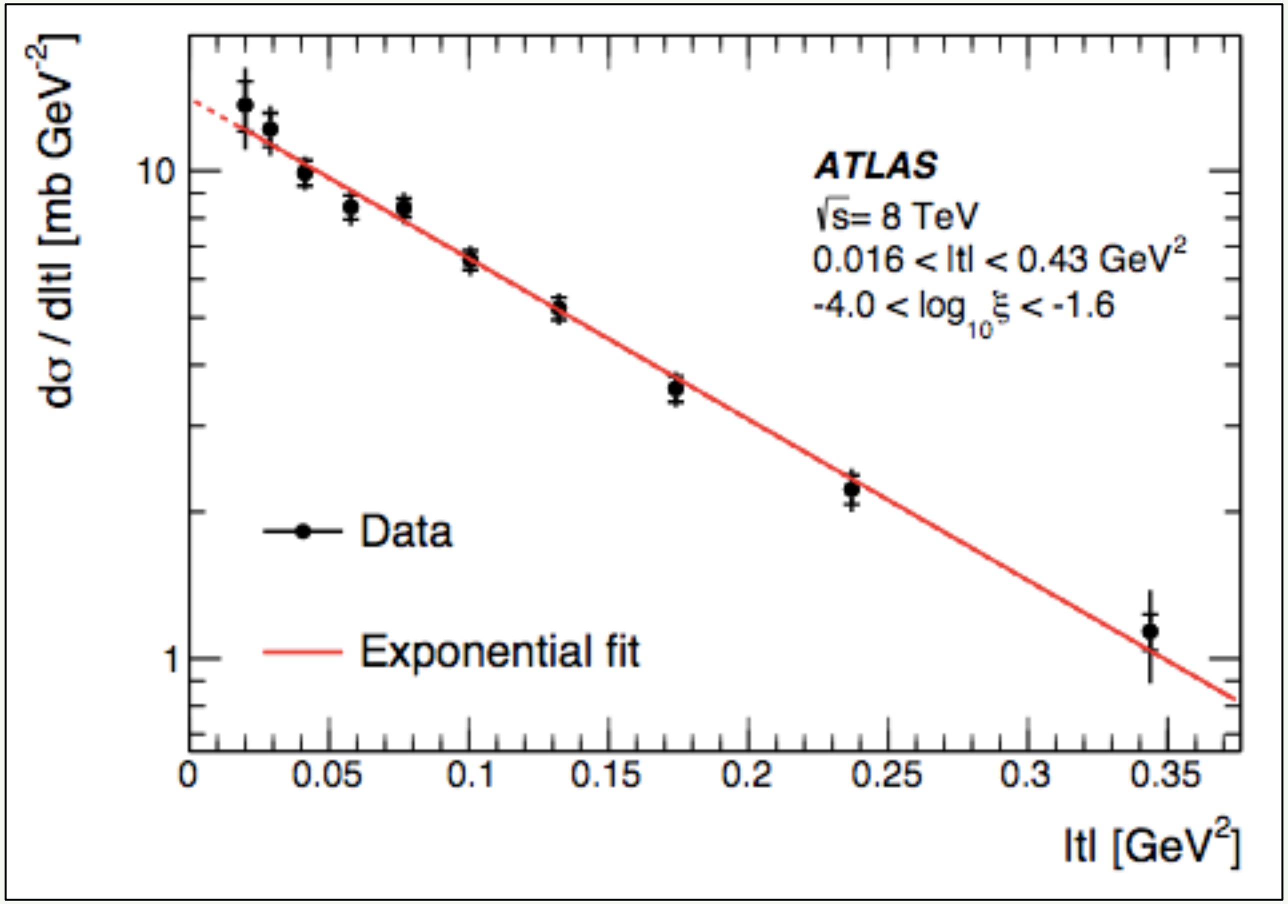
Gaps get filled in nature.....

Regge theory

For $s \gg M_X \gg t$ (where $\xi = M_X^2/s$)

$$\frac{d^2\sigma}{d\xi dt} \propto \left(\frac{1}{\xi}\right)^{2\alpha(t)-1} (M_X^2)^{\alpha(0)-1}\, e^{B_0 t}$$

Pomeron flux   Pomeron–p cs

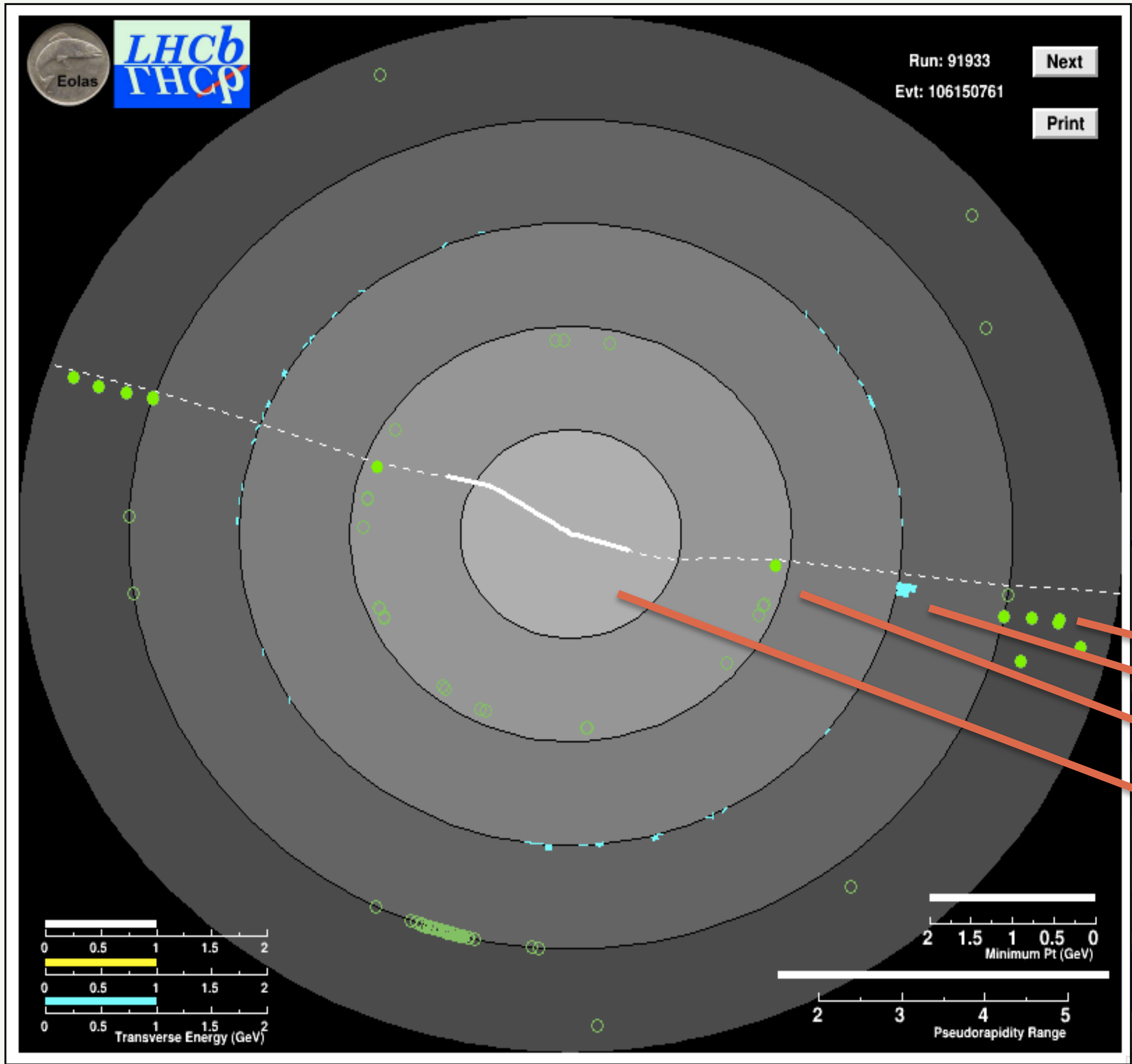


$B_0 = 7.65 \pm 0.34\ \text{GeV}^{-2}$

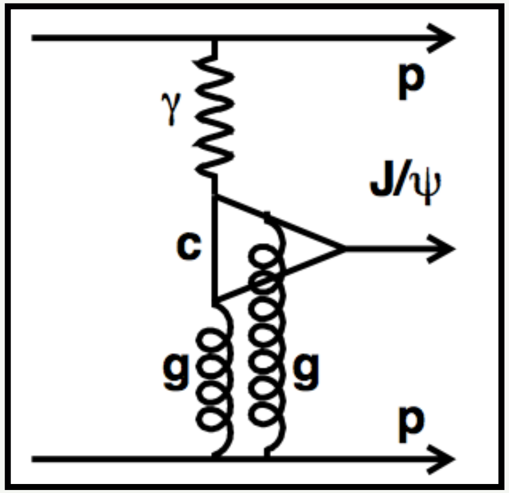
Good fit to single exponential

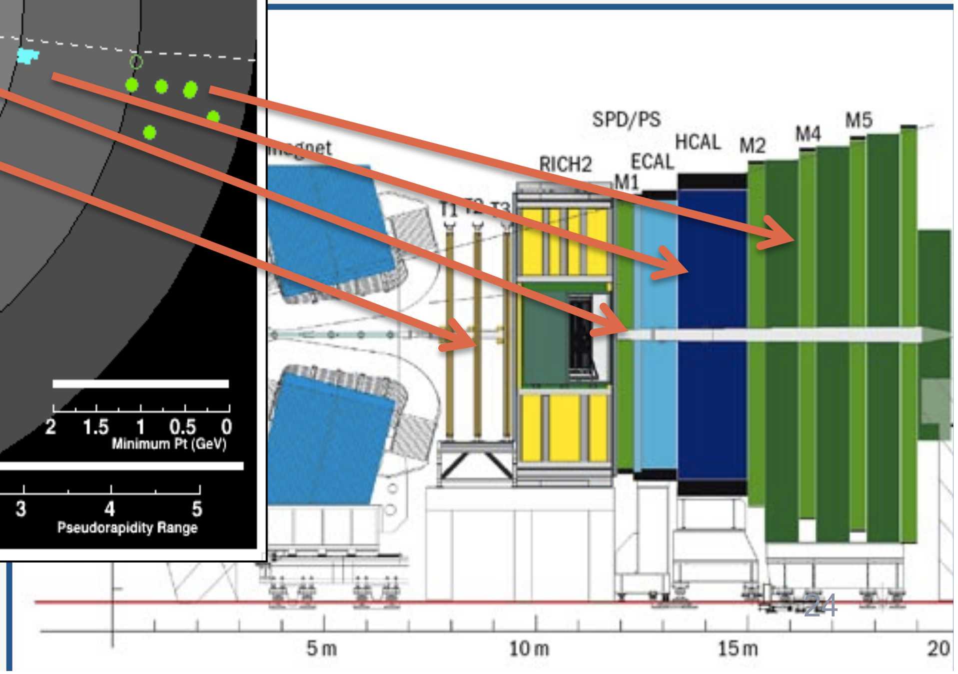
B_0 = 4-12 GeV^{-2} is typical of diffractive processes at HERA and LHC (J/ψ CEP, DPE ππ)

Is it completely isolated?

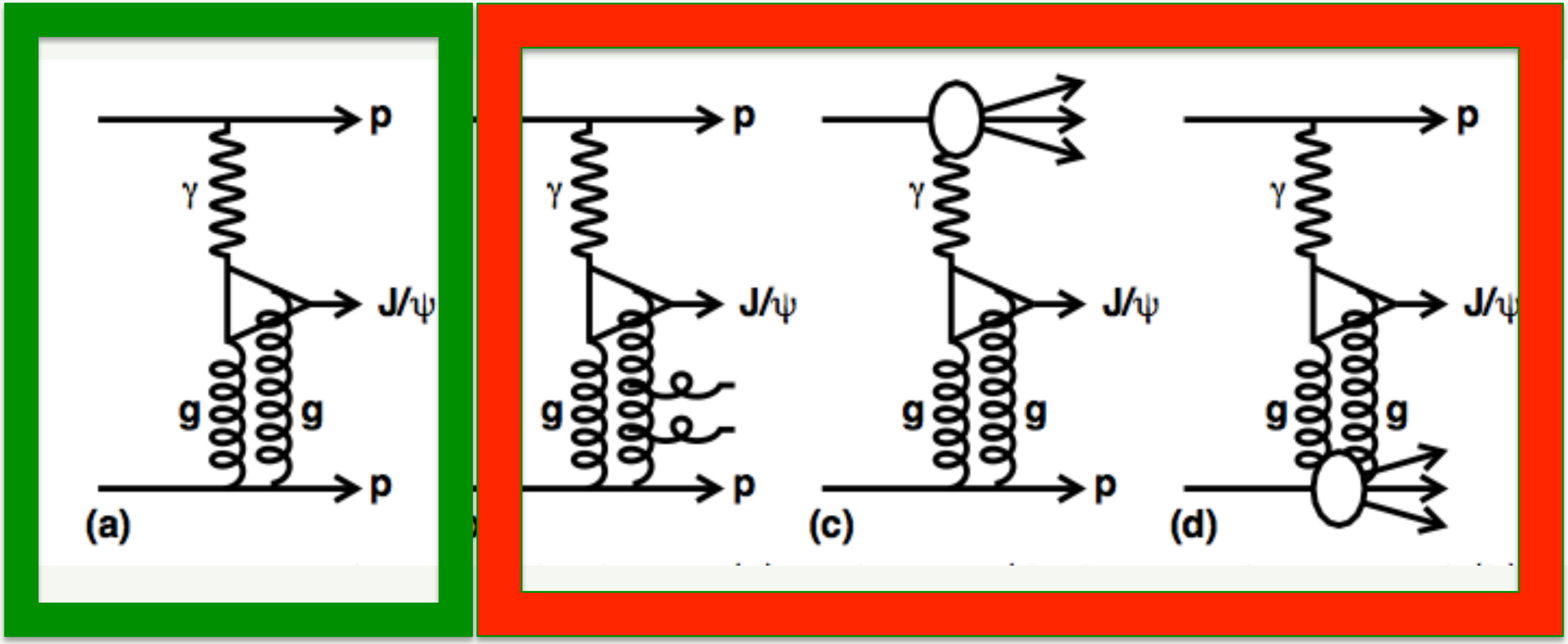


CEP





Proton dissociation

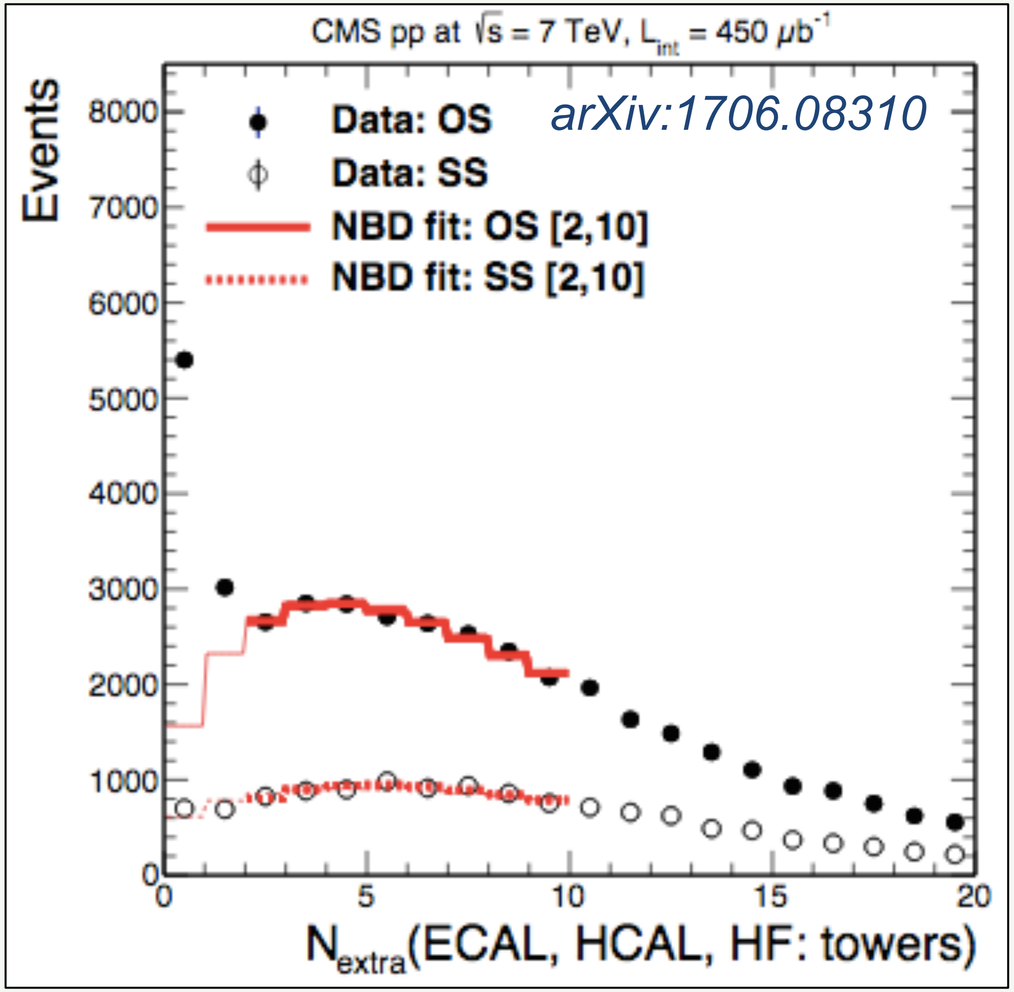


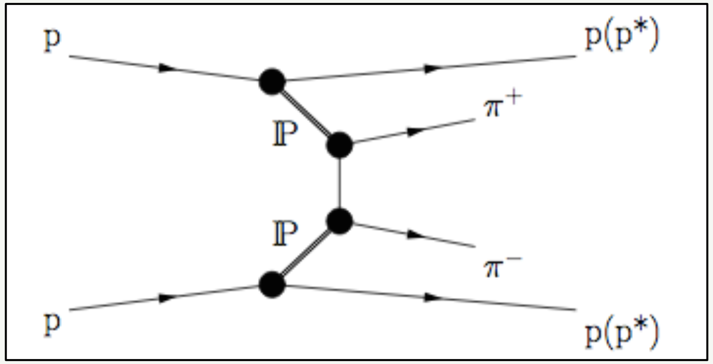
Signal

Background

We see something ‘exclusive’ in our detector. Is it?
How can we estimate what we can’t see?

1: CMS-Exclusive ππ

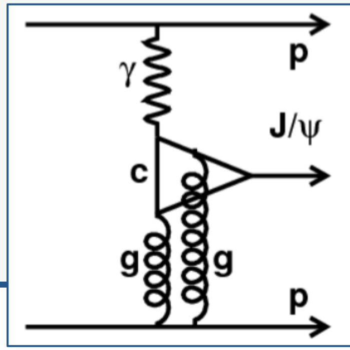


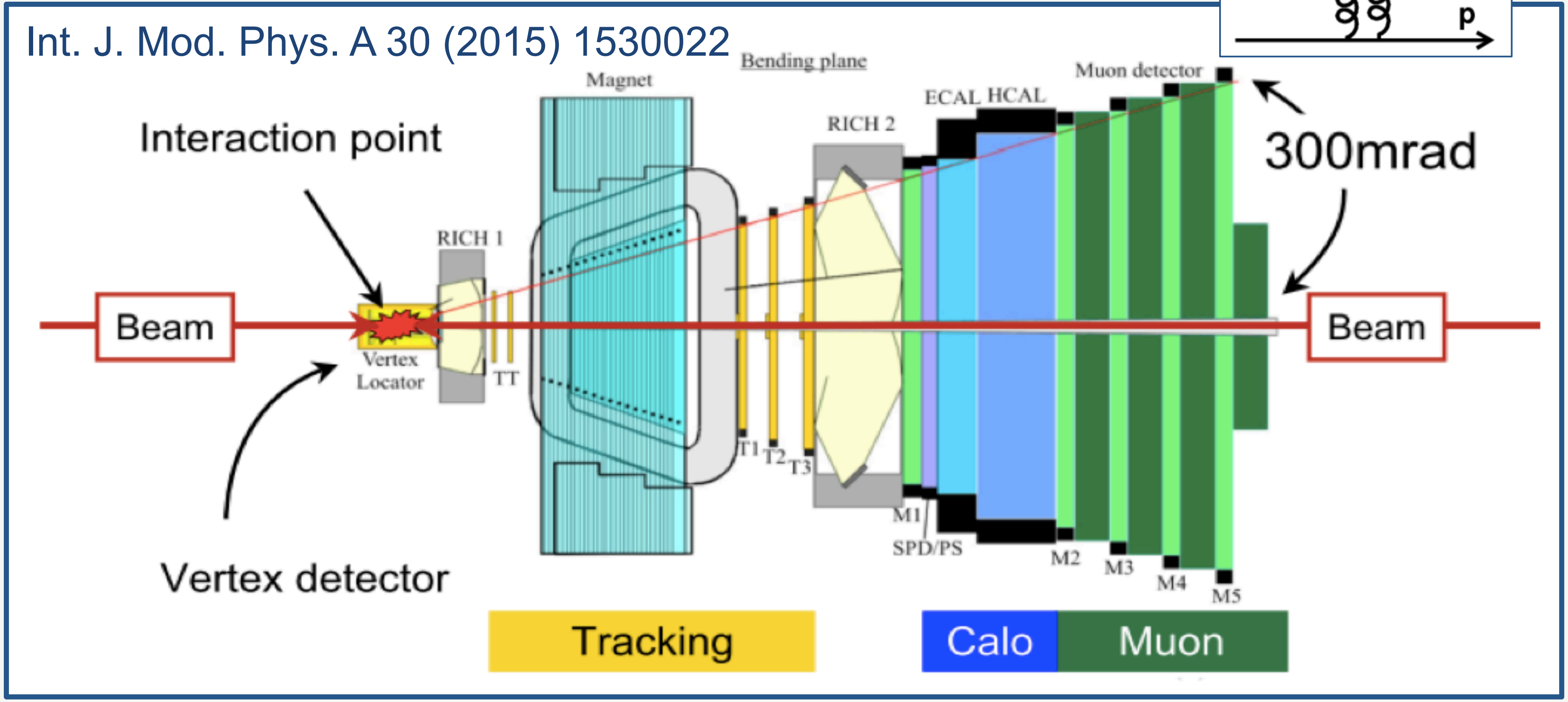


Extrapolate seen backgrounds to unseen background

Look at additional neutral energy
Assume reasonable shape
Extrapolate below exclusive signal

2: LHCb

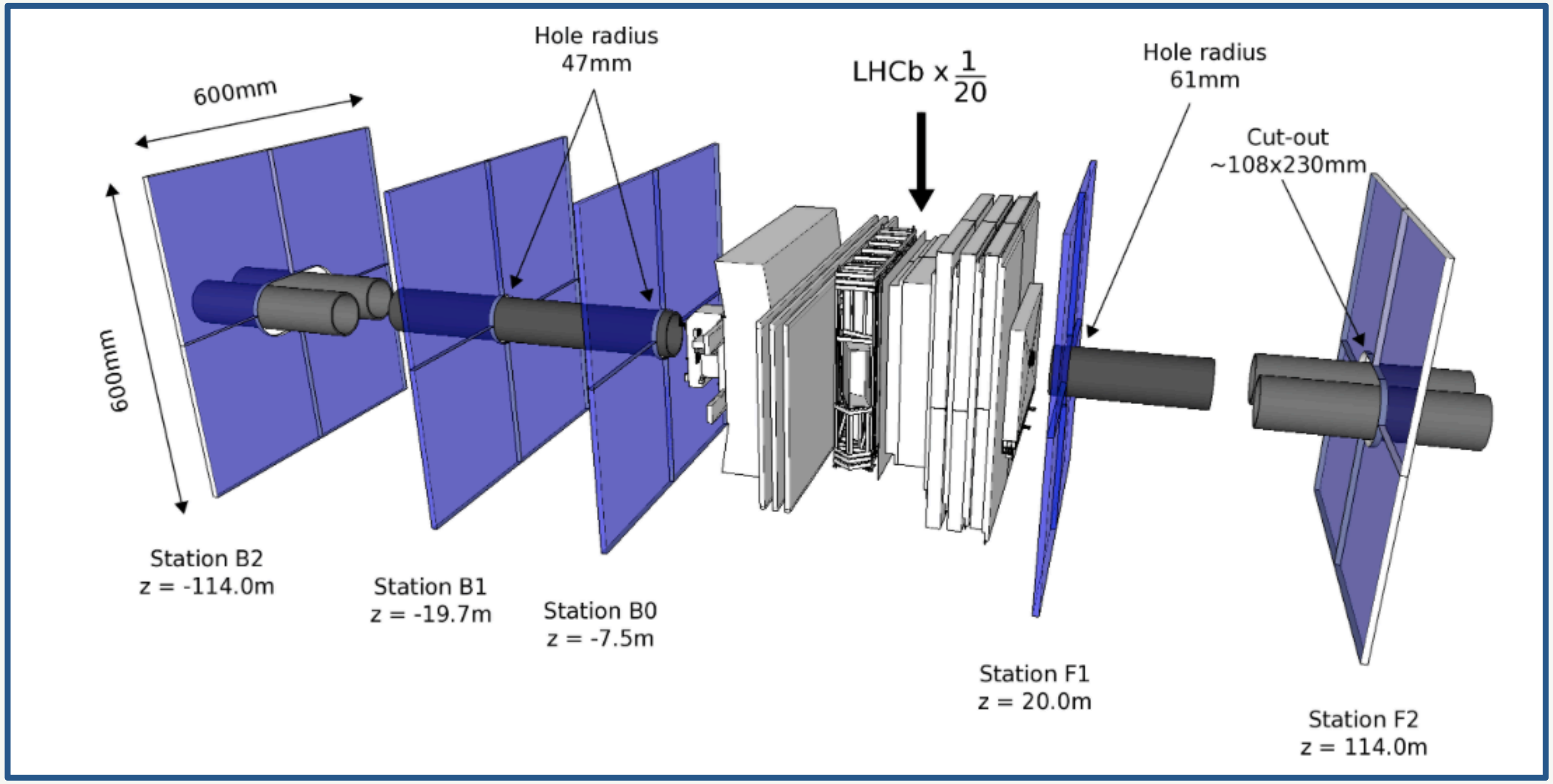




Fully instrumented: $2 < \eta < 5$
Veto region (Run 2): $-10<\eta<-5$, $5<\eta<10$

2: LHCb

JINST 13 (2018) no.04, P04017



Fully instrumented: $2 < \eta < 5$

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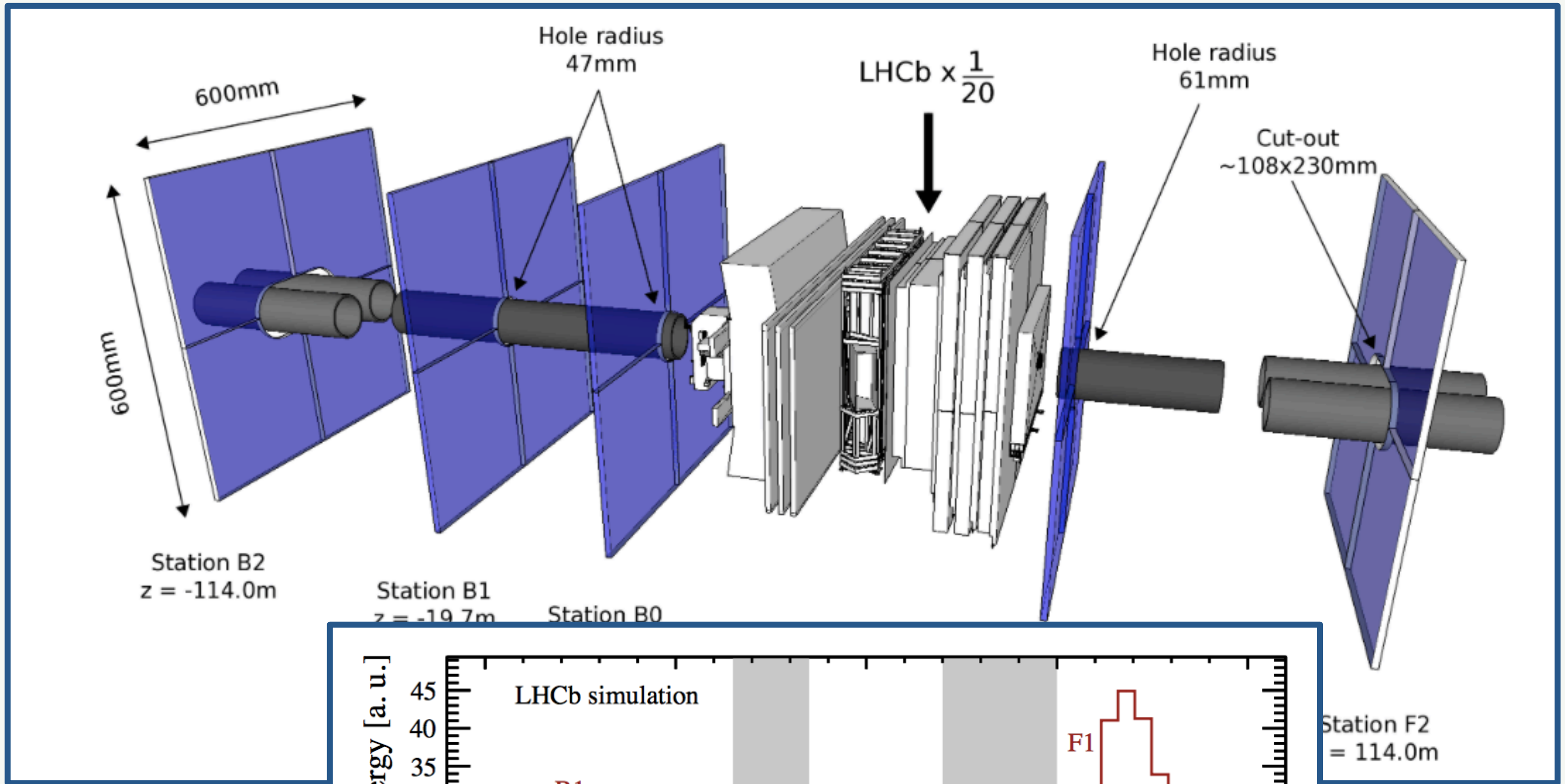
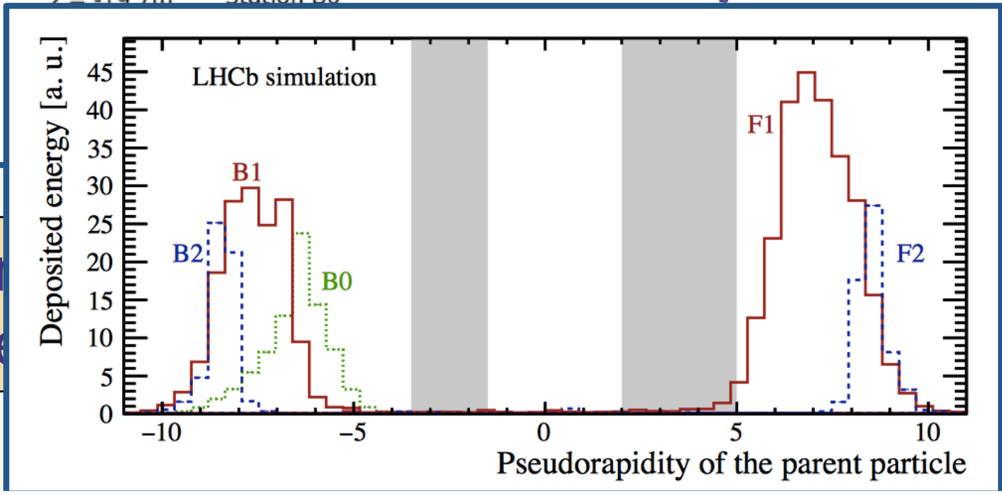
2: LHCb

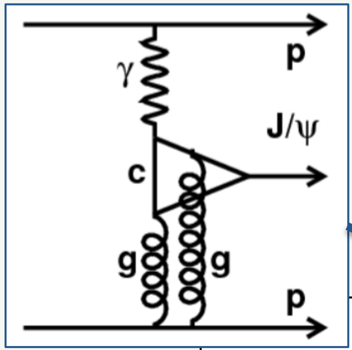
JINST 13 (2018) no.04, P04017

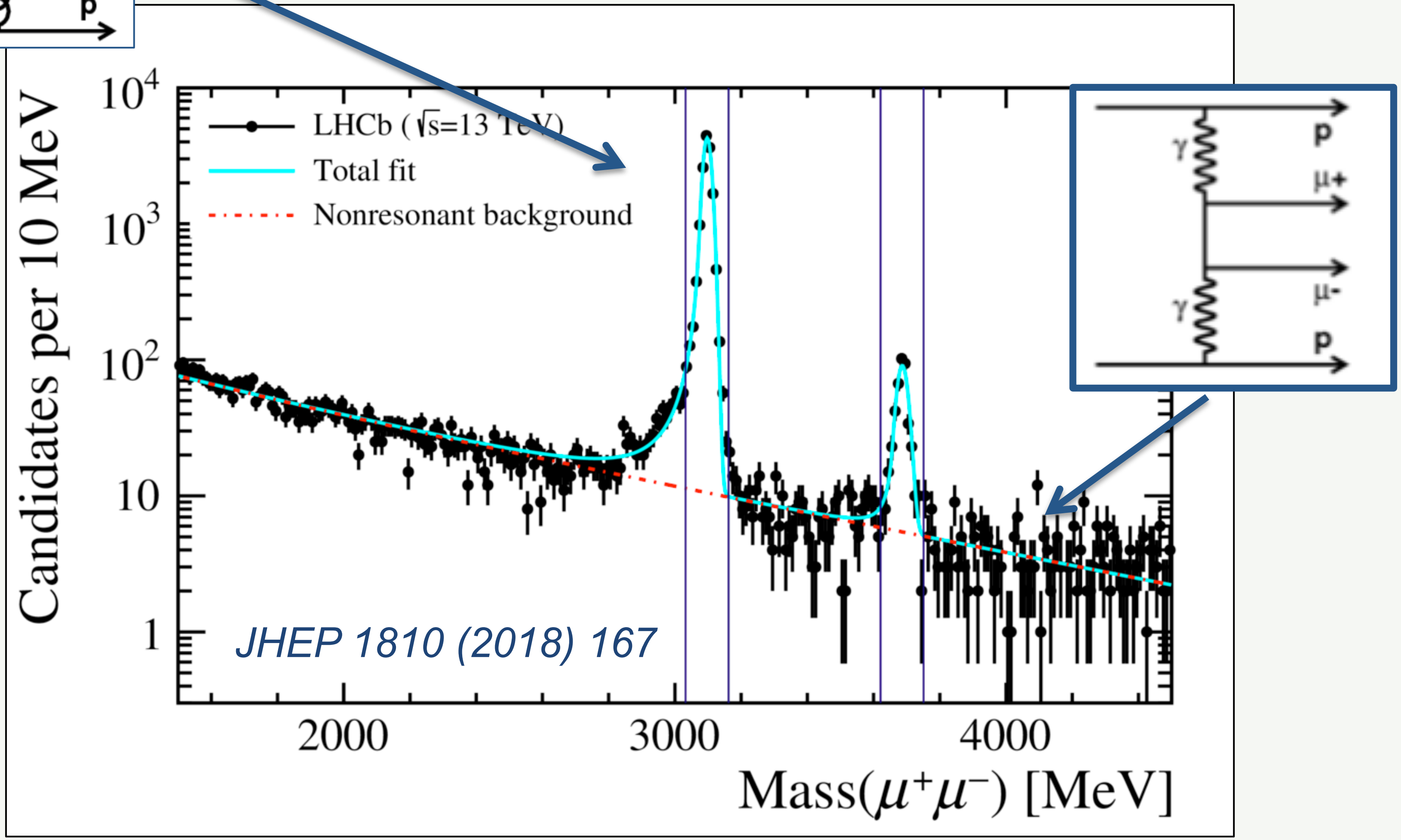




Fully i
Veto re

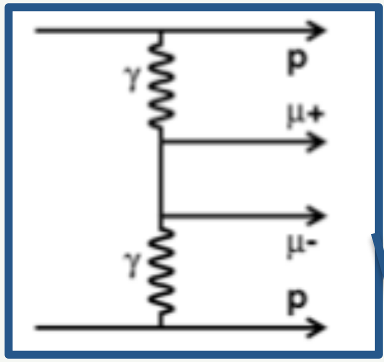
Calibration exclusive signal

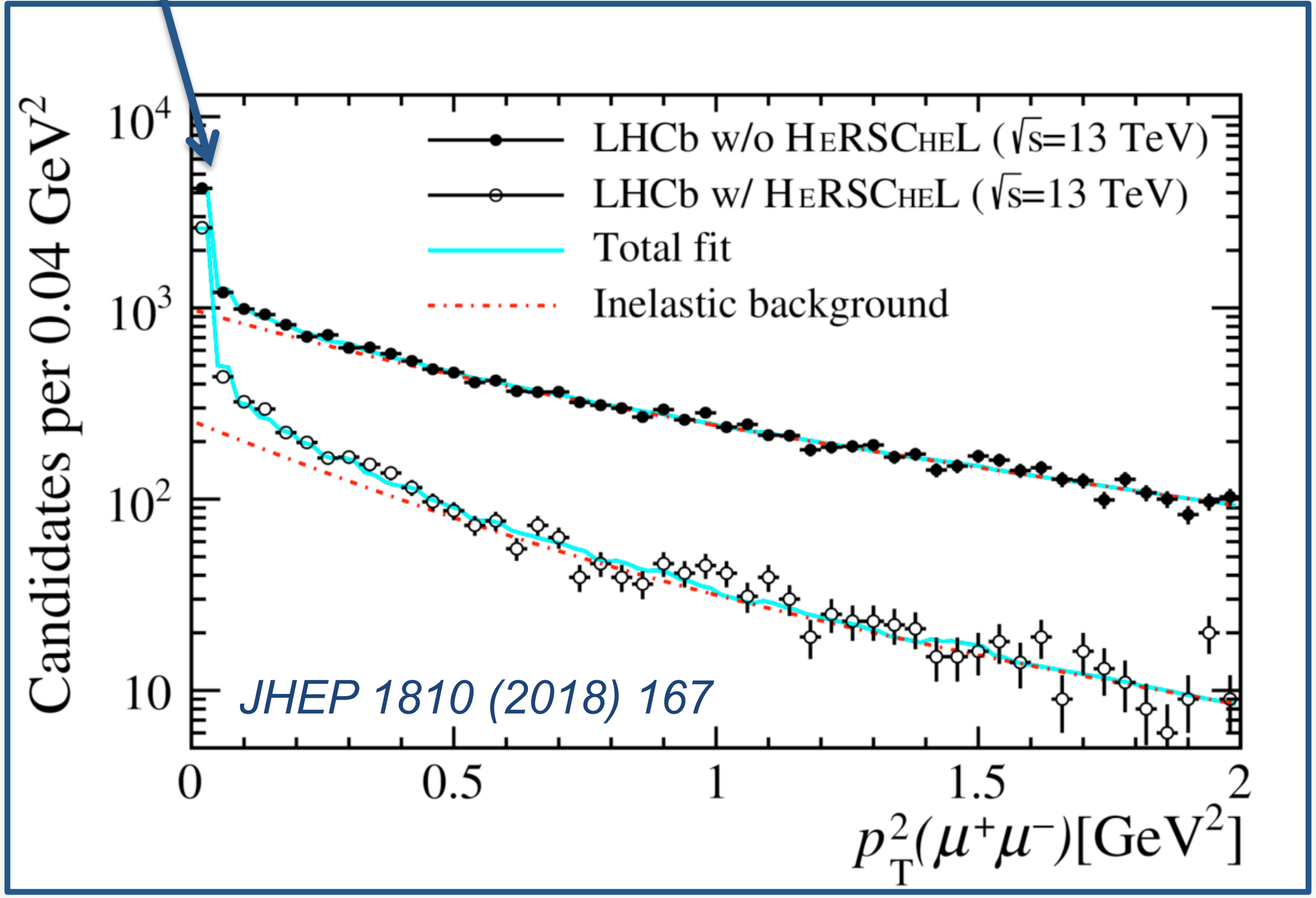




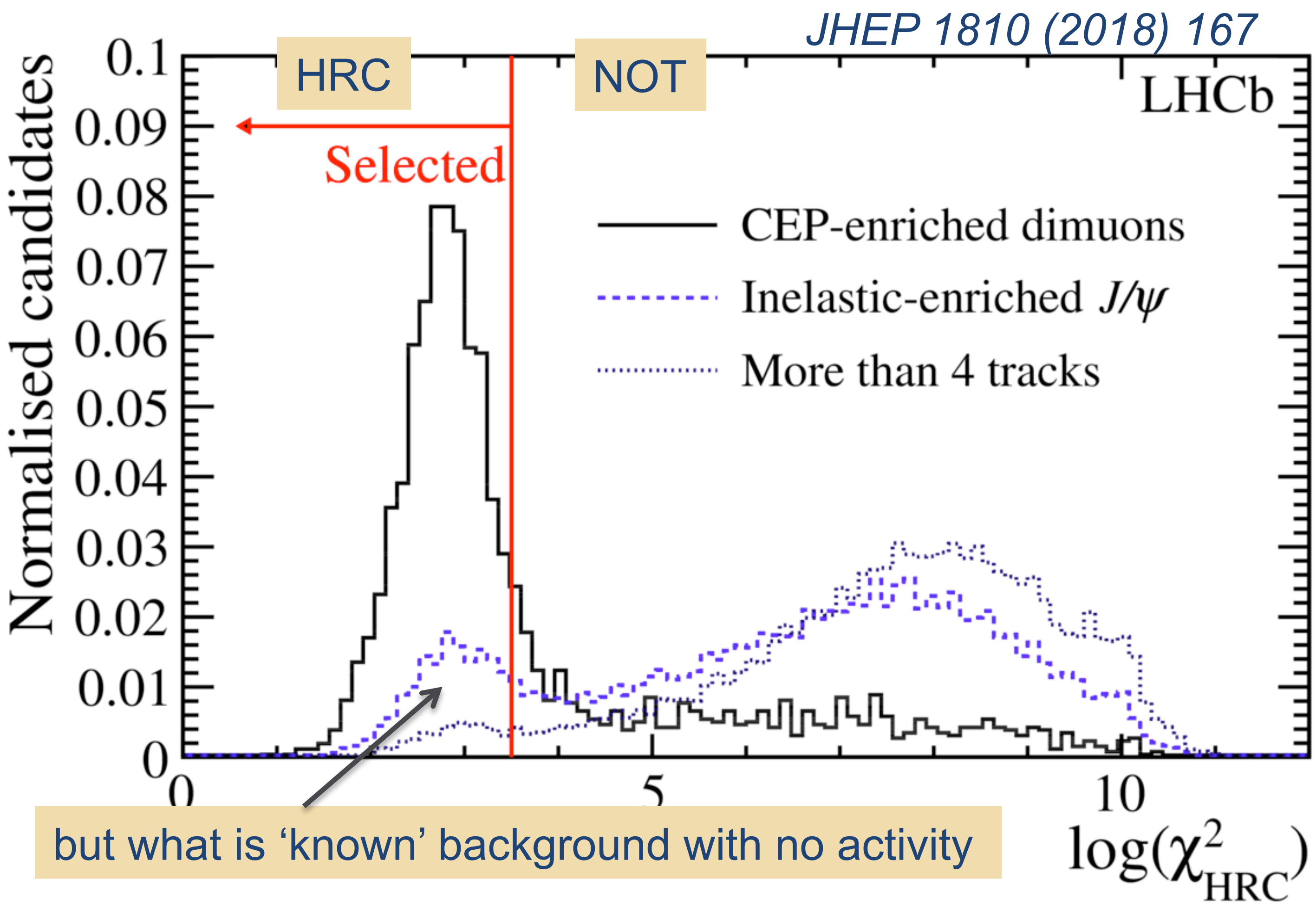
Two muons and nothing else in the LHCb detector

Calibration exclusive signal





Discrimination power of Herschel



but what is ‘known’ background with no activity

Extrapolate seen background to unseen background

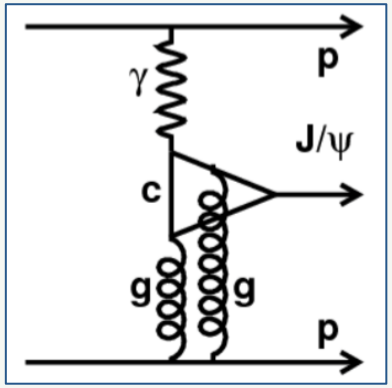
$$\begin{aligned}\tilde{N}_{\mathrm{HRC,i}} &= \epsilon S_i + b_i B_i \\ \tilde{N}_{\mathrm{NOT,i}} &= (1-\epsilon)S_i + (1-b_i)B_i\end{aligned}$$

$$\begin{aligned}\beta_i &\equiv \tilde{N}_{\mathrm{NOT,i}} - \frac{1-\epsilon}{\epsilon}\tilde{N}_{\mathrm{HRC,i}} \\ &= (1-\frac{b_i}{\epsilon})B_i\end{aligned}$$

approximately shape of proton dissociation

but caution: HRC/NOT has a pT dependence

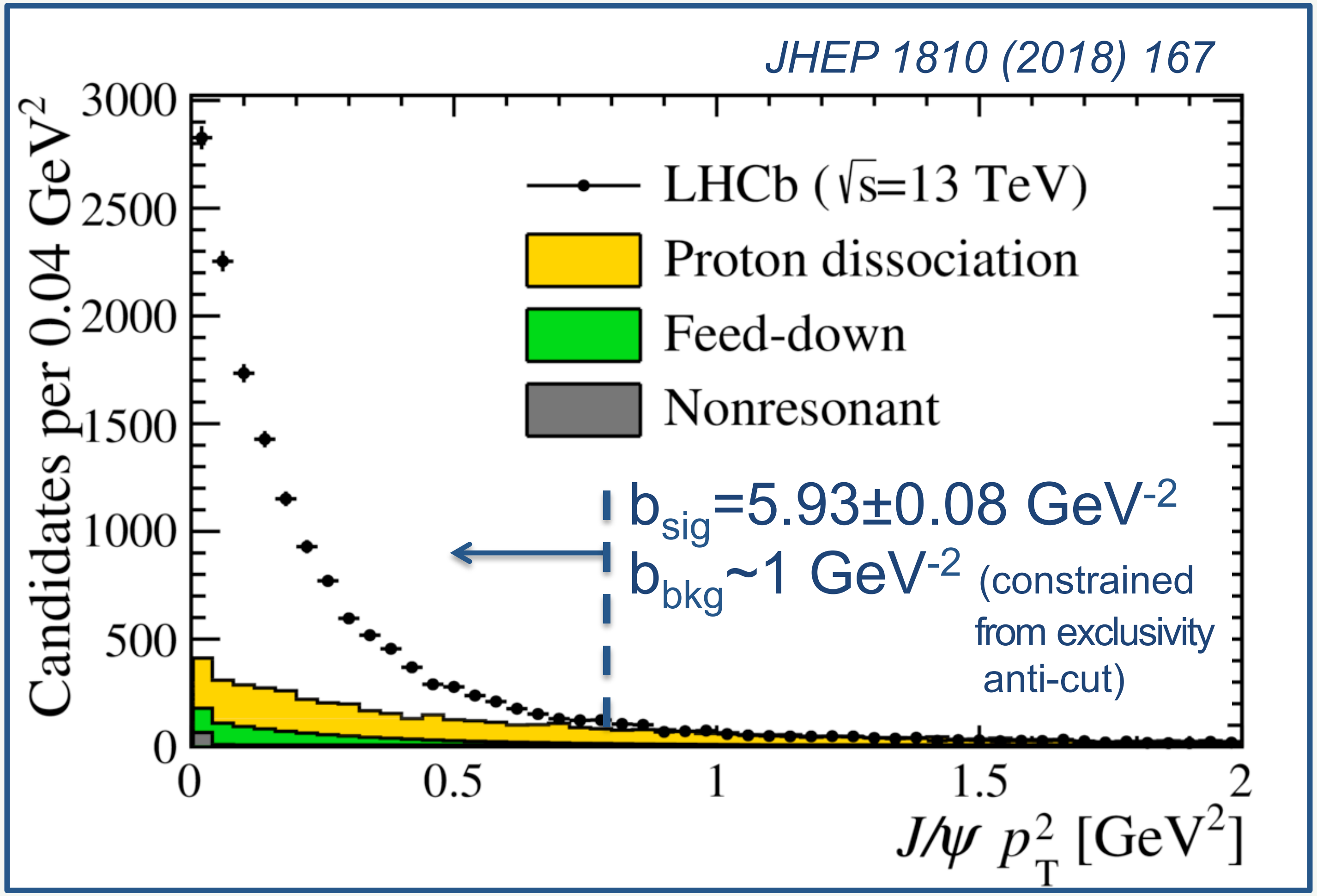
Almost flat for p_T^2>1 GeV^2, so extrapolate this below signal



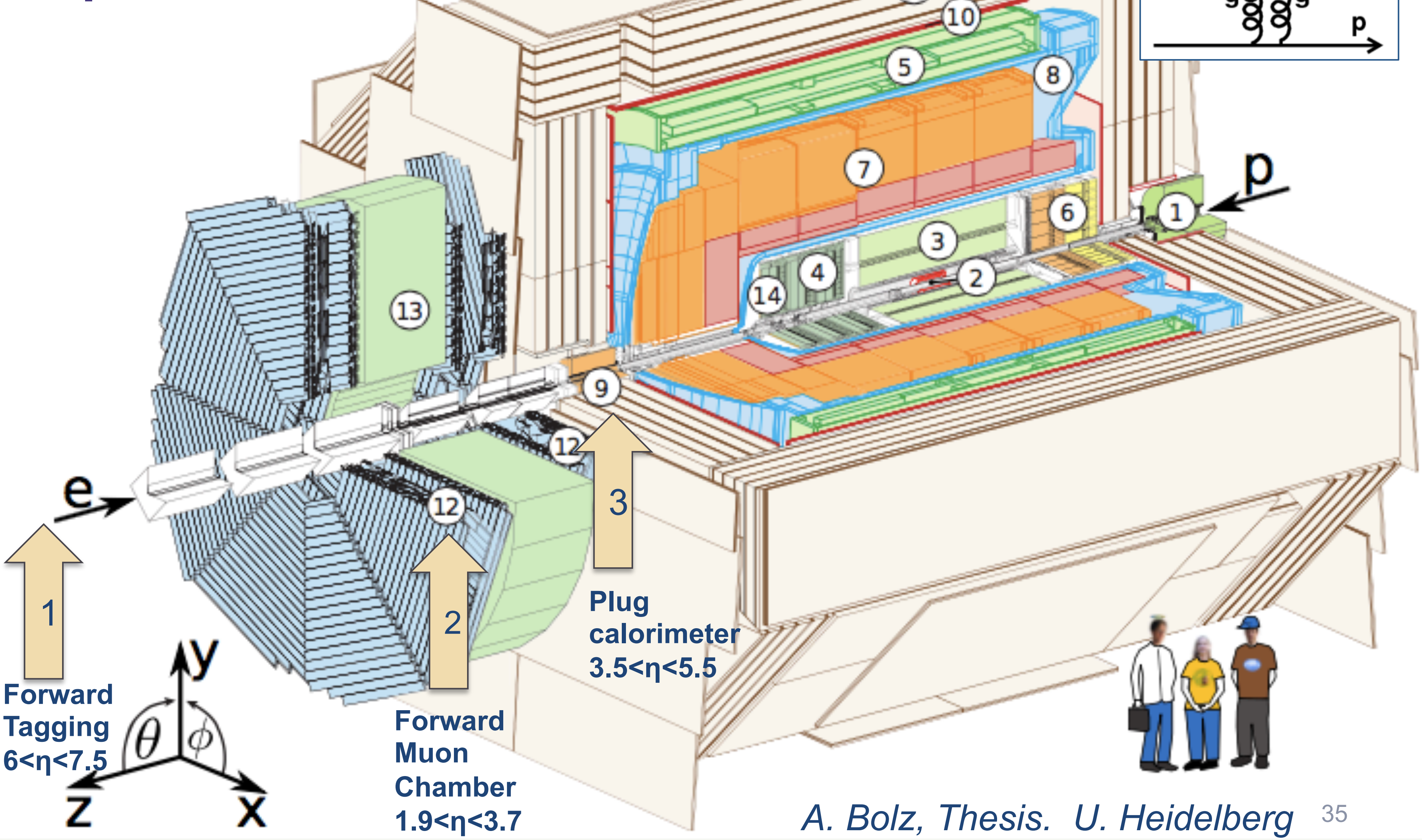
Purity for Exclusive J/ψ

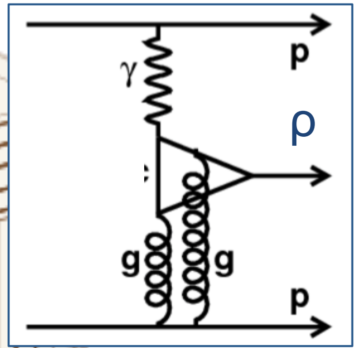
Assume Signal and Background

$$\frac{d\sigma}{dt} \sim e^{bt}$$



3: H1- ep collisions

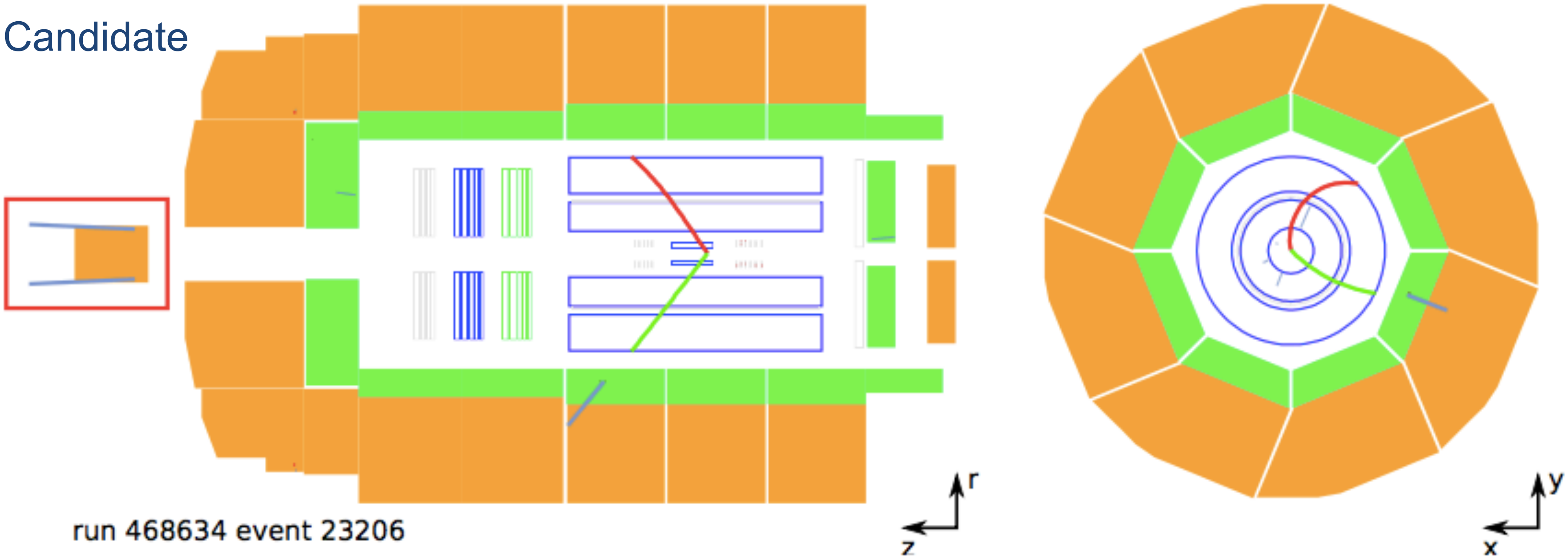




A. Bolz, Thesis. U. Heidelberg

Select proton-dissociation events

Candidate



Most dissociative products go down beam-pipe.
Not well described in detector simulation, either generator or detector.

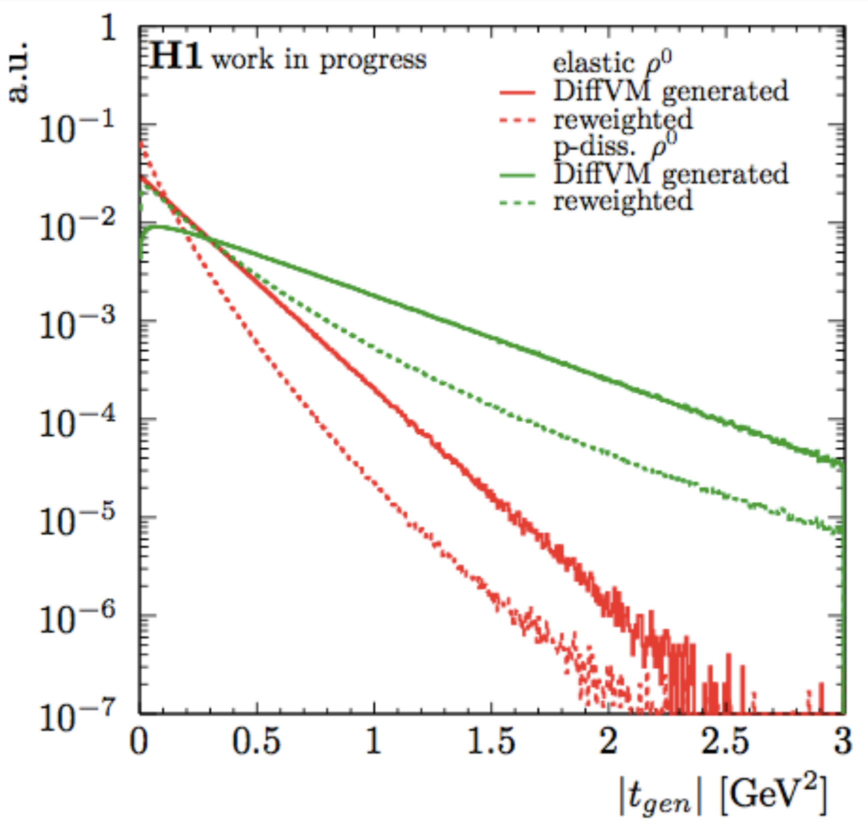
DIFVM generator

$$\frac{d\sigma}{dm_Y^2} \propto \frac{f(m_Y^2)}{(m_Y^2)^{1+\epsilon_Y}}$$

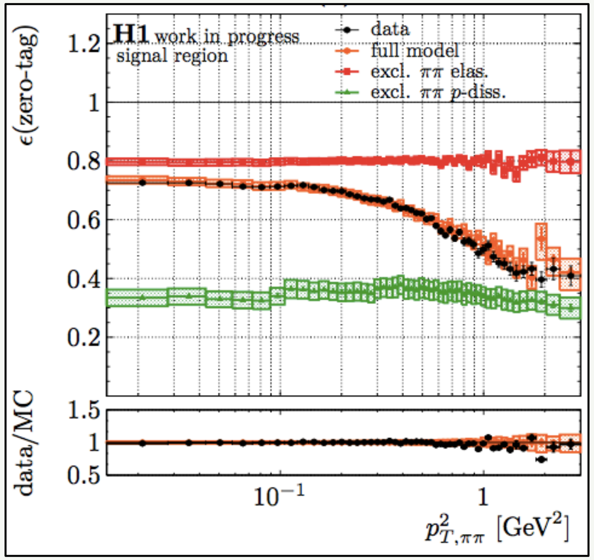
Proton dissociation in DIFVM

m_Y^2<3.6 GeV^2: ***f*** taken from proton-deuteron scattering. Includes N* resonances.

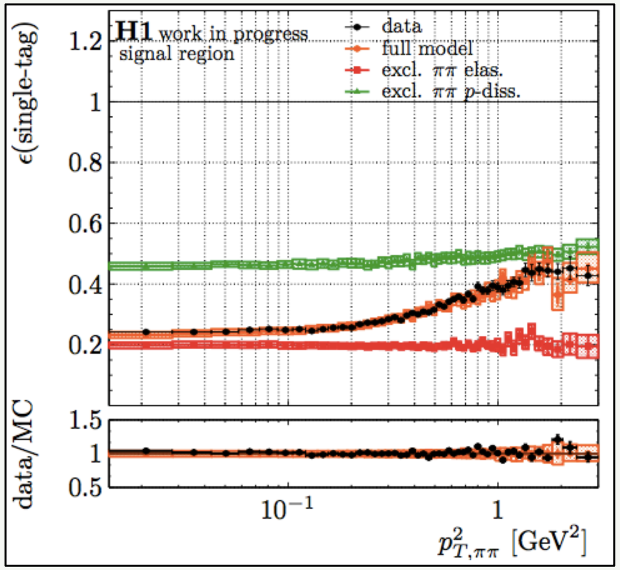
m_Y^2>3.6 GeV^2: ***f***=1. Quark set free and string fragmentation used.



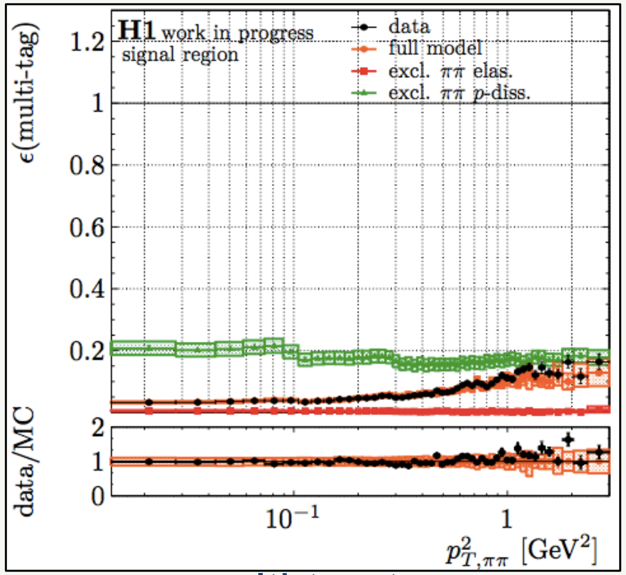
Large t-dependent reweighting necessary.



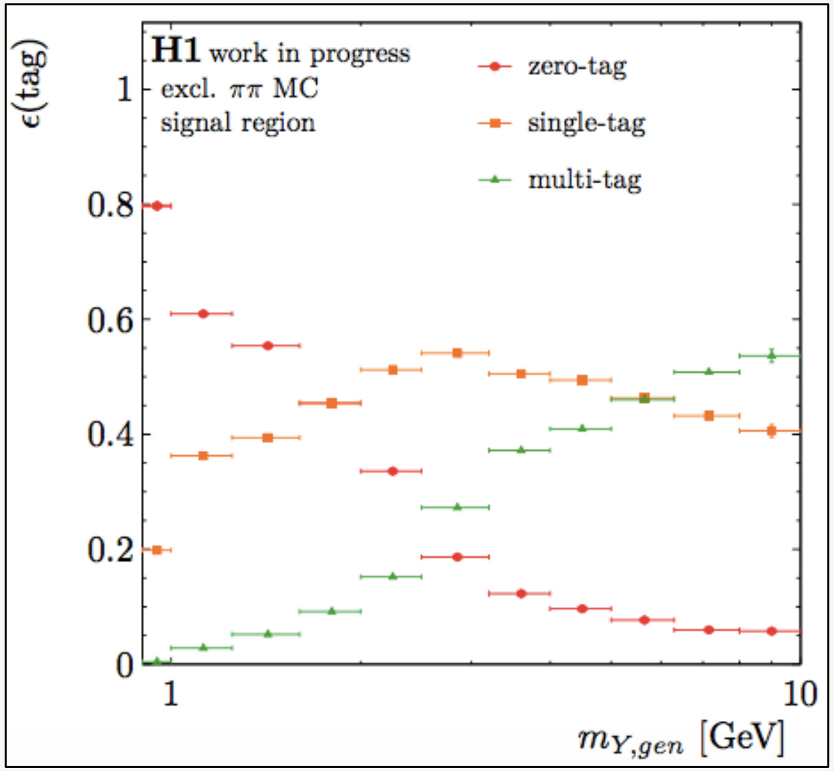
zero tag



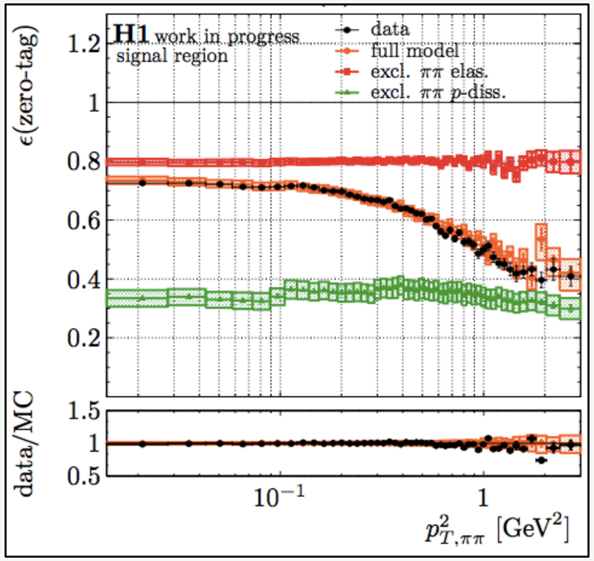
one tag

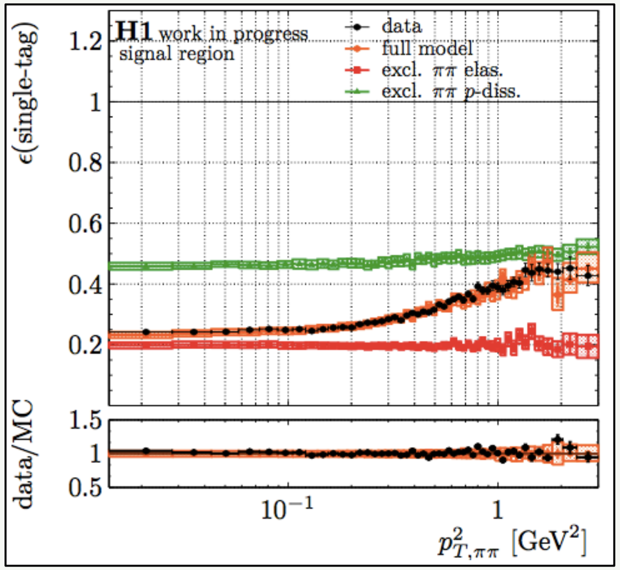


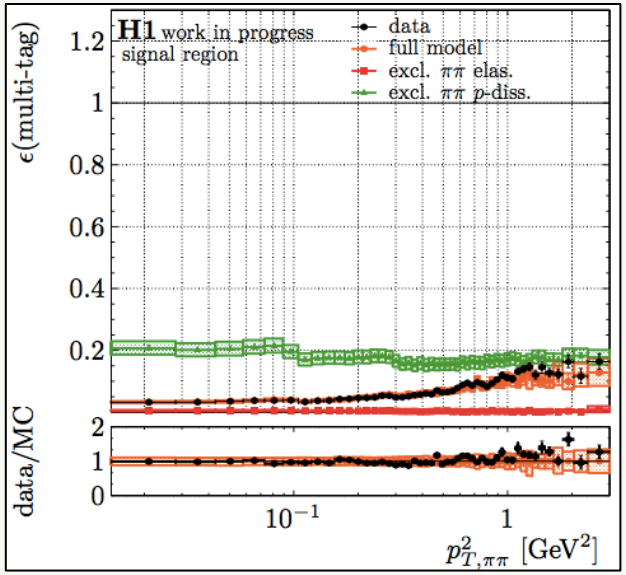
multi-tag tag



Probabilities for signal / dissociation



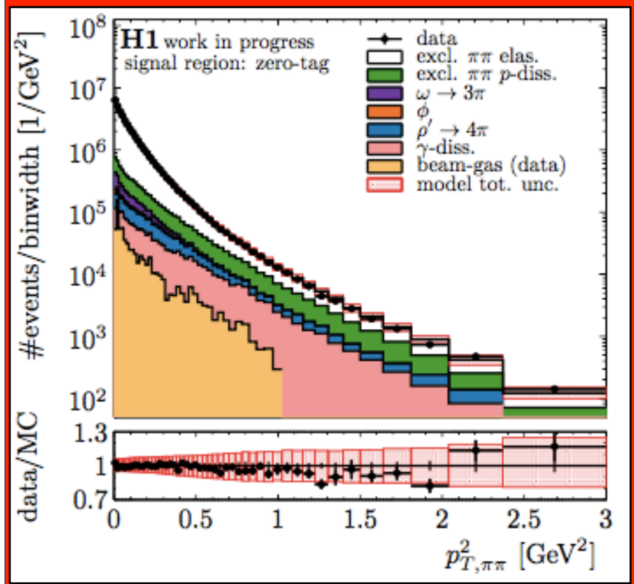


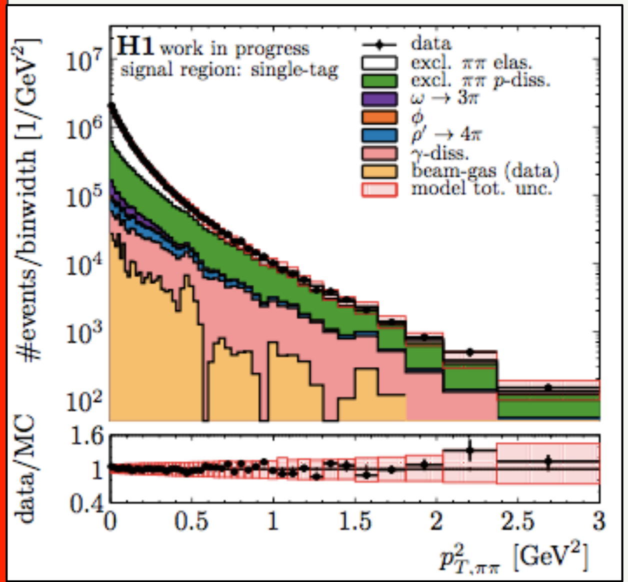


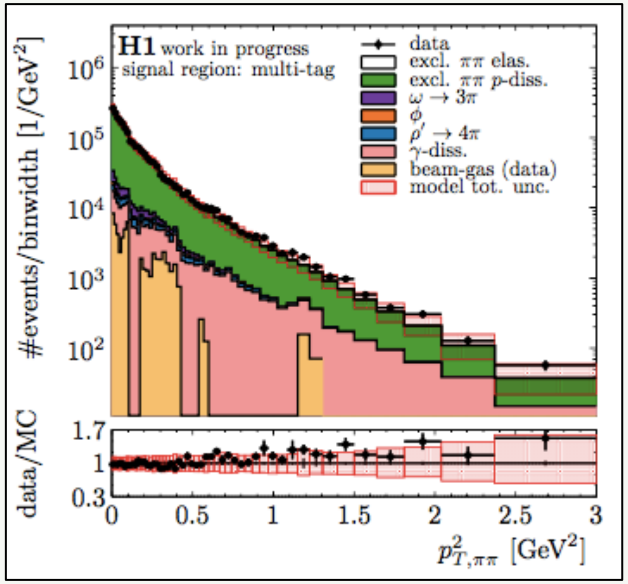
zero tag

one tag

multi-tag tag

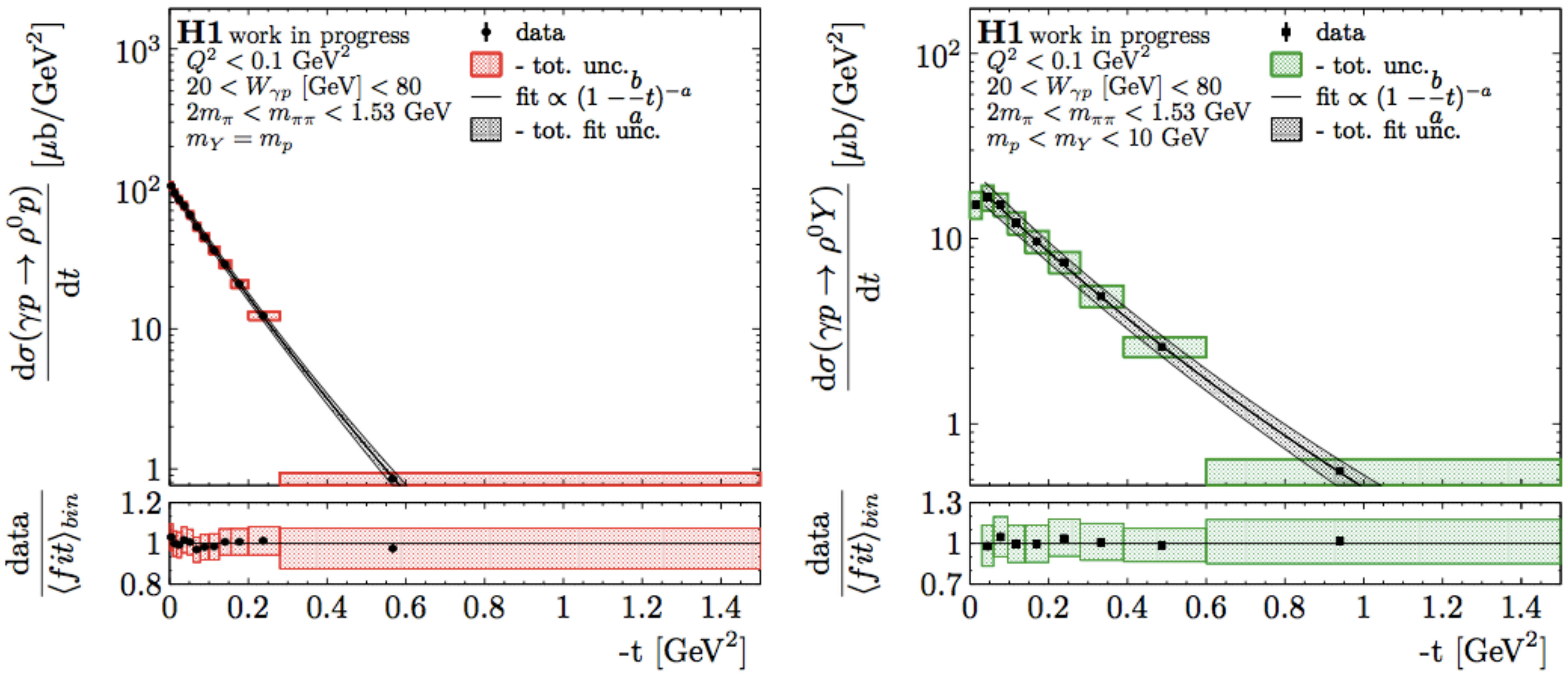






Very good agreement with simulation, (but required a lot of tuning)

t-distribution



Roughly exponential fall-off again, with steeper fall for elastic than dissociation
B_{el}=9.6+-0.2 GeV^{-2}, B_{pd}=4.8+-0.4 GeV^{-2}

Summary

- Isolation is not predictable from first principles: have to use models.
- Less isolation in inclusive SD than in MC
- Proton dissociation not (well) described in simulation.
- Various experimental techniques to correct for what is missed due to <4π coverage.
- These techniques can be (too?) simple, assume linearity, or require heavy reweighting of simulation where great care is necessary to avoid a circular argument.
- How can we improve our description of isolation?