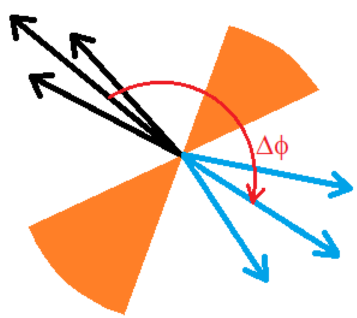
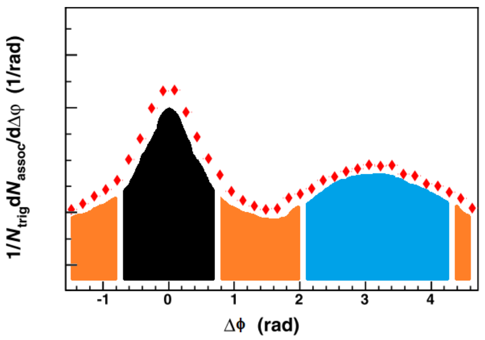
Jet-associated deuteron production in p-p collisions at 13 TeV with ALICE at the LHC





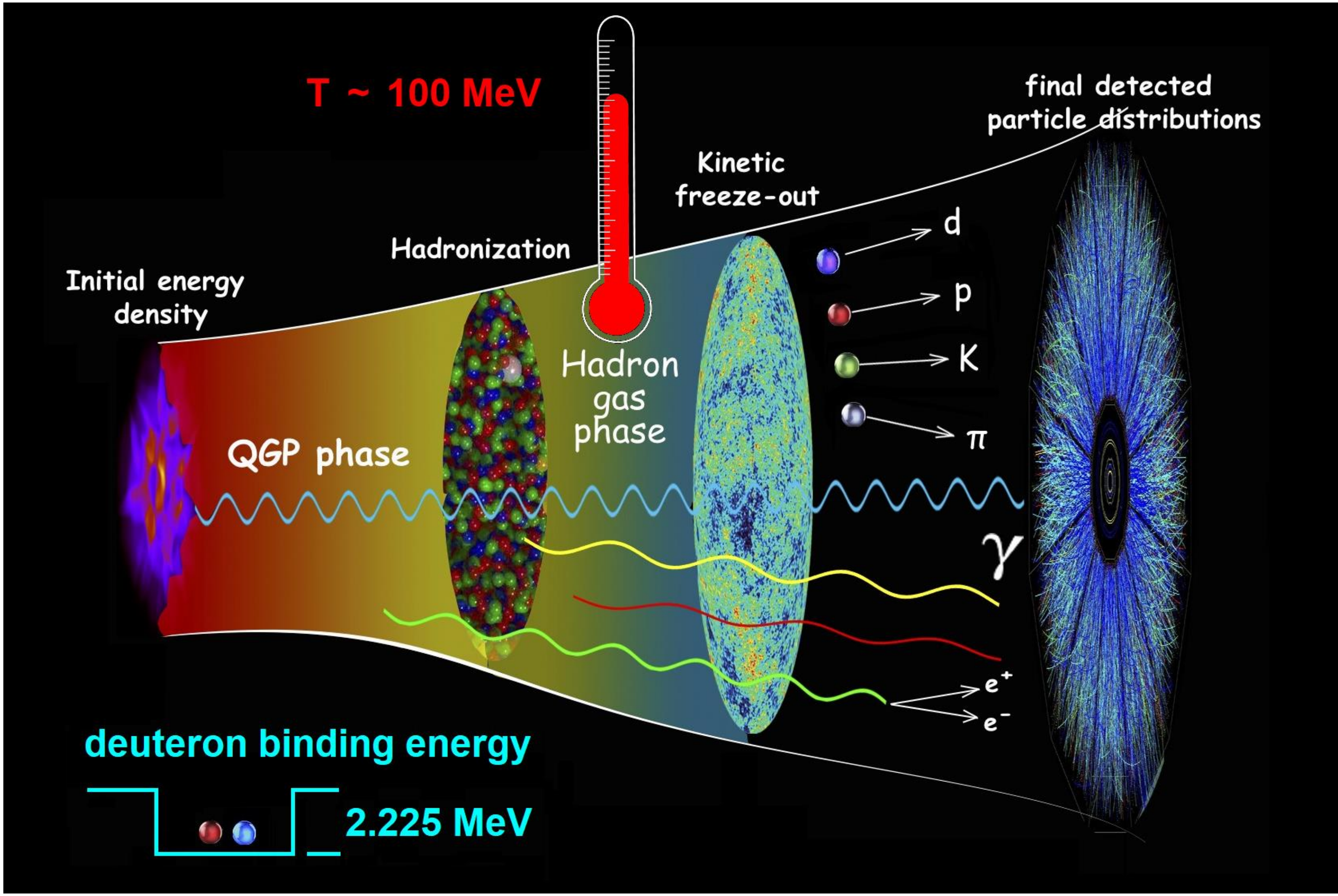
Brennan Schaefer
Oak Ridge National Laboratory

LANL Seminar - 16 Feb 2018

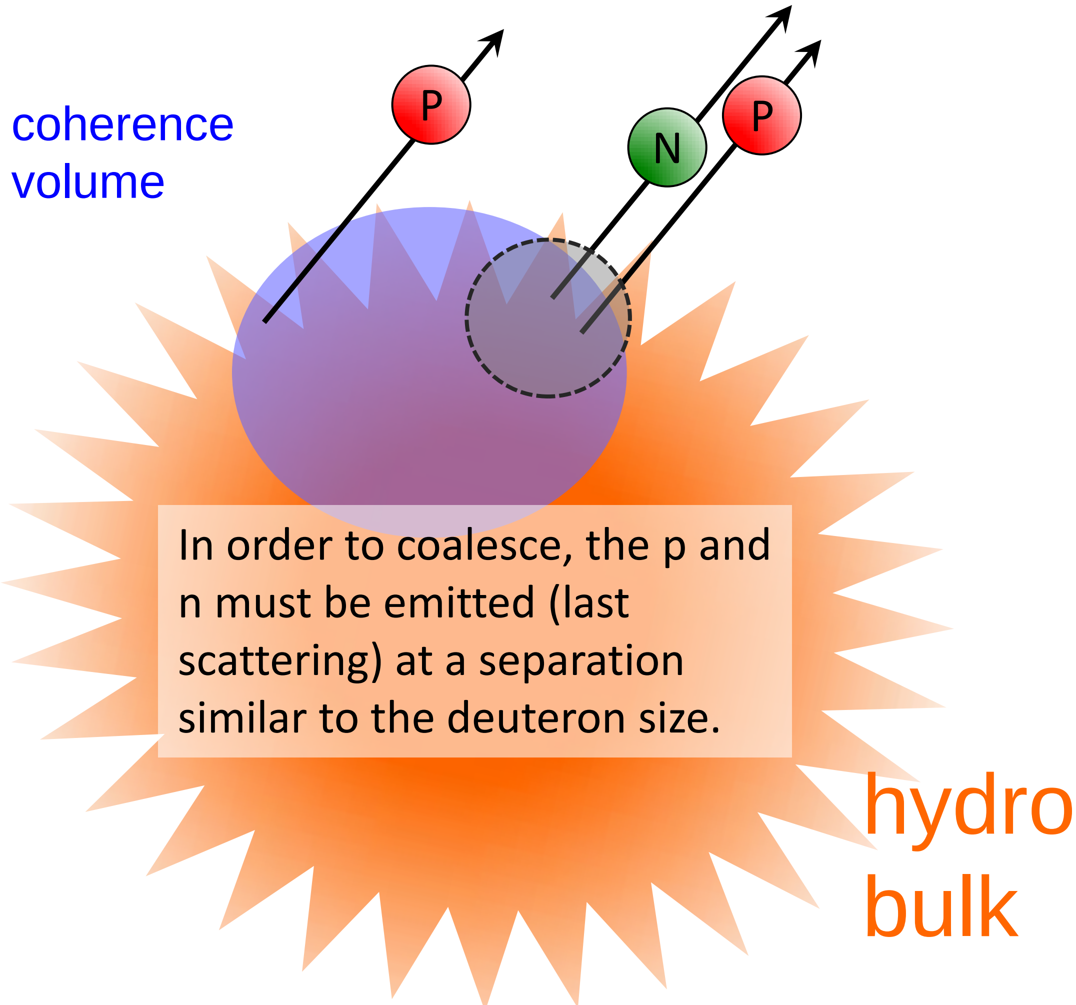
contents

- motivation – why look for deuterons in jets?
- the ALICE Detector
- analysis procedure: PID, correlations, corrections
- data and findings

the nature of deuteron production is a long standing mystery in HE physics

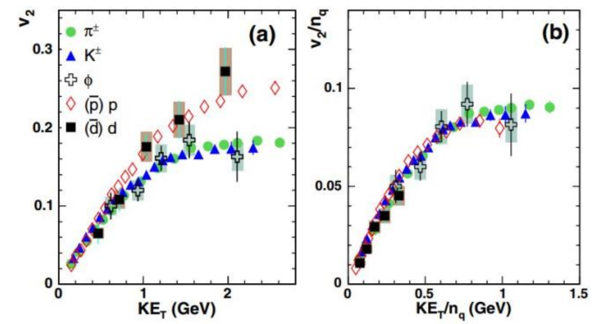


The Coalescence Model

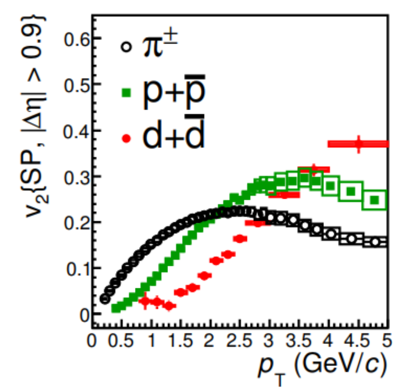


In order to coalesce, the p and n must be emitted (last scattering) at a separation similar to the deuteron size.

deuteron anisotropy measurements are consistent with coalescence picture



(PHENIX) Phys. Rev. Lett. **99**, 052301



ALICE Preliminary

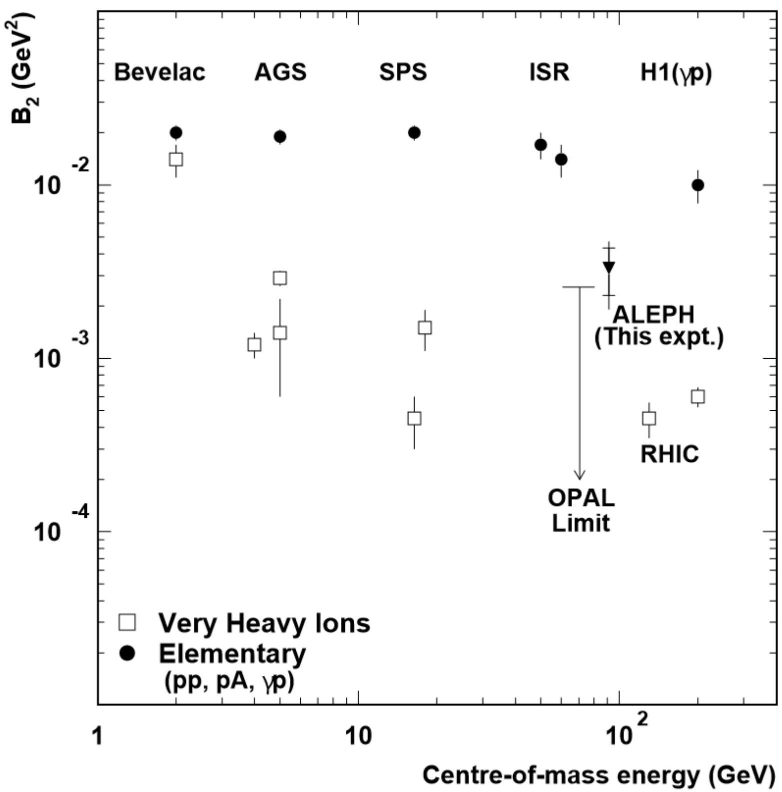
Pb-Pb $\sqrt{s_{NN}}$ = 2.76 TeV 30-40%

v_2 is approximately additive from constituents to composite particles

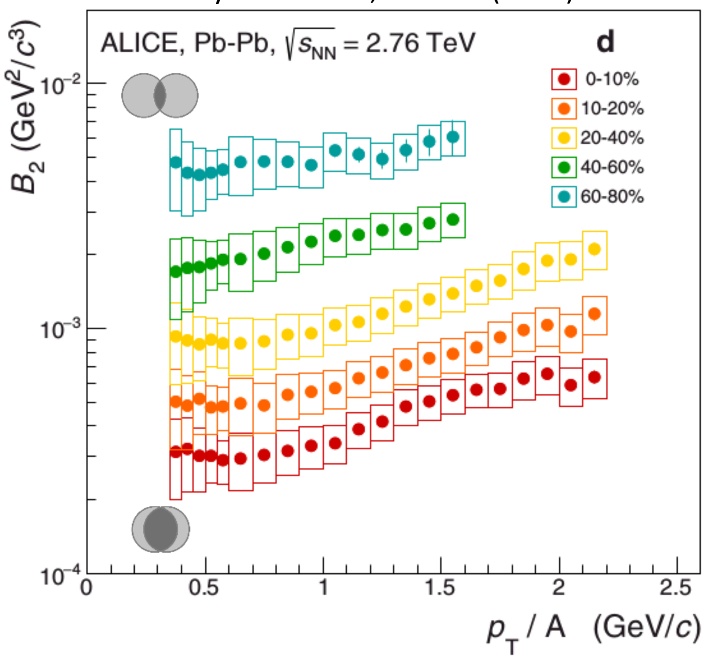
deuteron coalescence model measurements

$$B_2 = \frac{\pi}{2} \frac{\frac{dN_\mathrm{d}}{dy}}{\left(\frac{dN_\mathrm{p}}{dy}\right)^2} \frac{1}{\int_0^\infty \frac{f^2(p_\mathrm{T})}{p_\mathrm{T}} dp_\mathrm{T}}$$

Phys.Lett. B639 (2006) 192-201

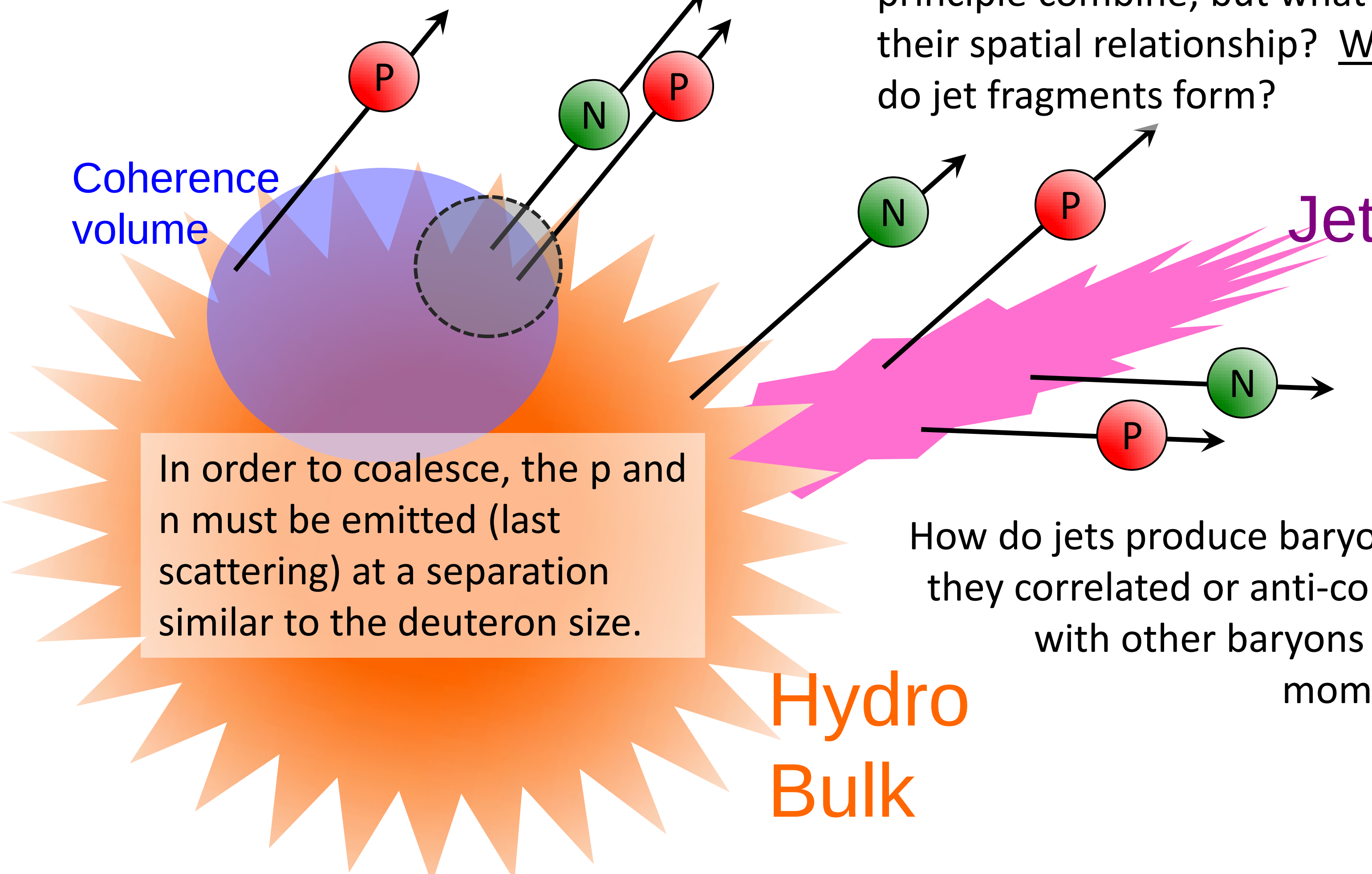


Phys. Rev. C 93, 024917 (2016)



are deuterons made in jets?

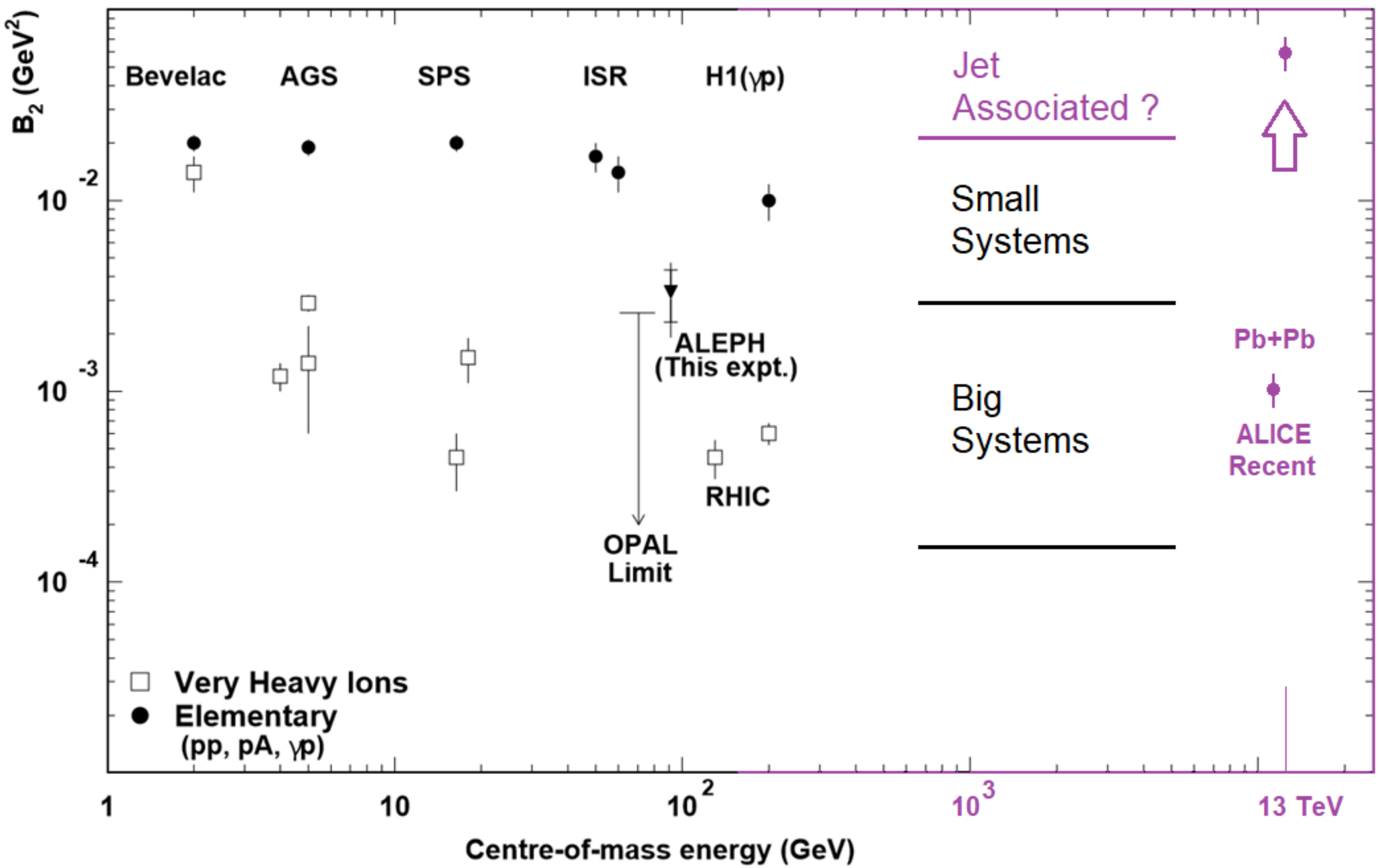
Nucleons from jet and bulk can in principle combine; but what is their spatial relationship? <u>Where</u> do jet fragments form?



In order to coalesce, the p and n must be emitted (last scattering) at a separation similar to the deuteron size.

How do jets produce baryons? Are they correlated or anti-correlated with other baryons at close momentum?

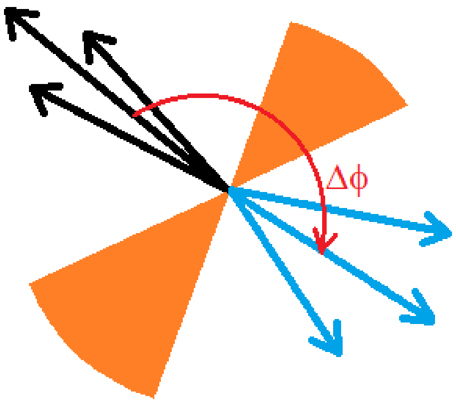
is coalescence more or less likely inside jets?



key questions include:

are deuterons made in jets?

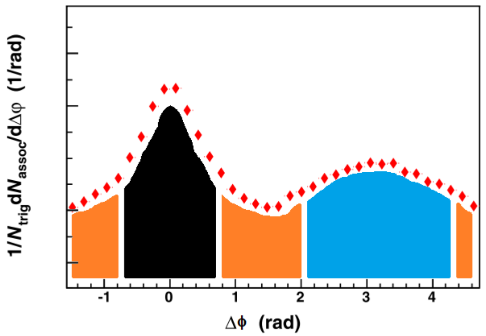
if so, what is B_2 inside jets, background?

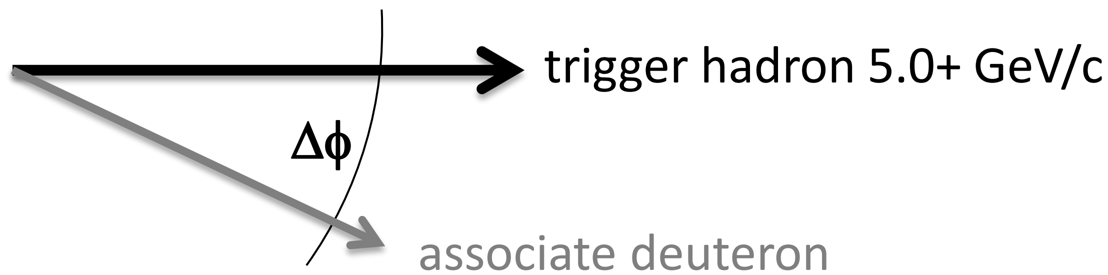


plan of attack:

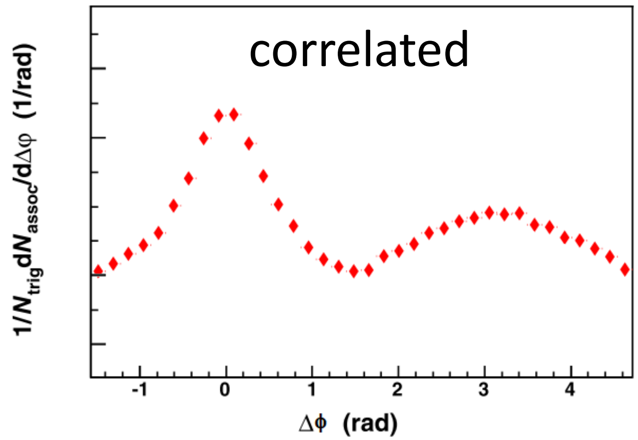
analyze 2-particle correlation with deuterons, protons in yr: 2015-17 13 TeV p-p dataset, 1B minbias events.

(p-p events minimize contribution from flow)

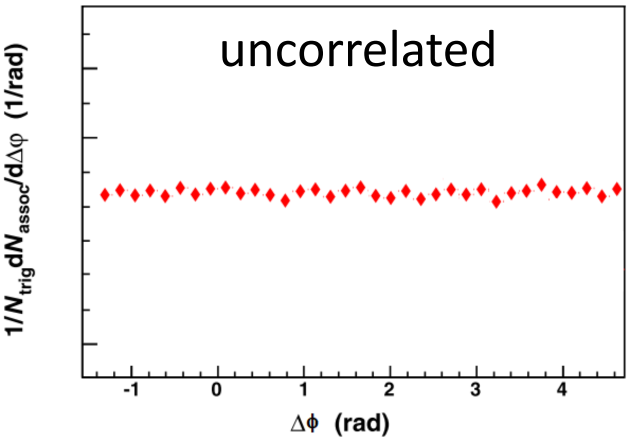




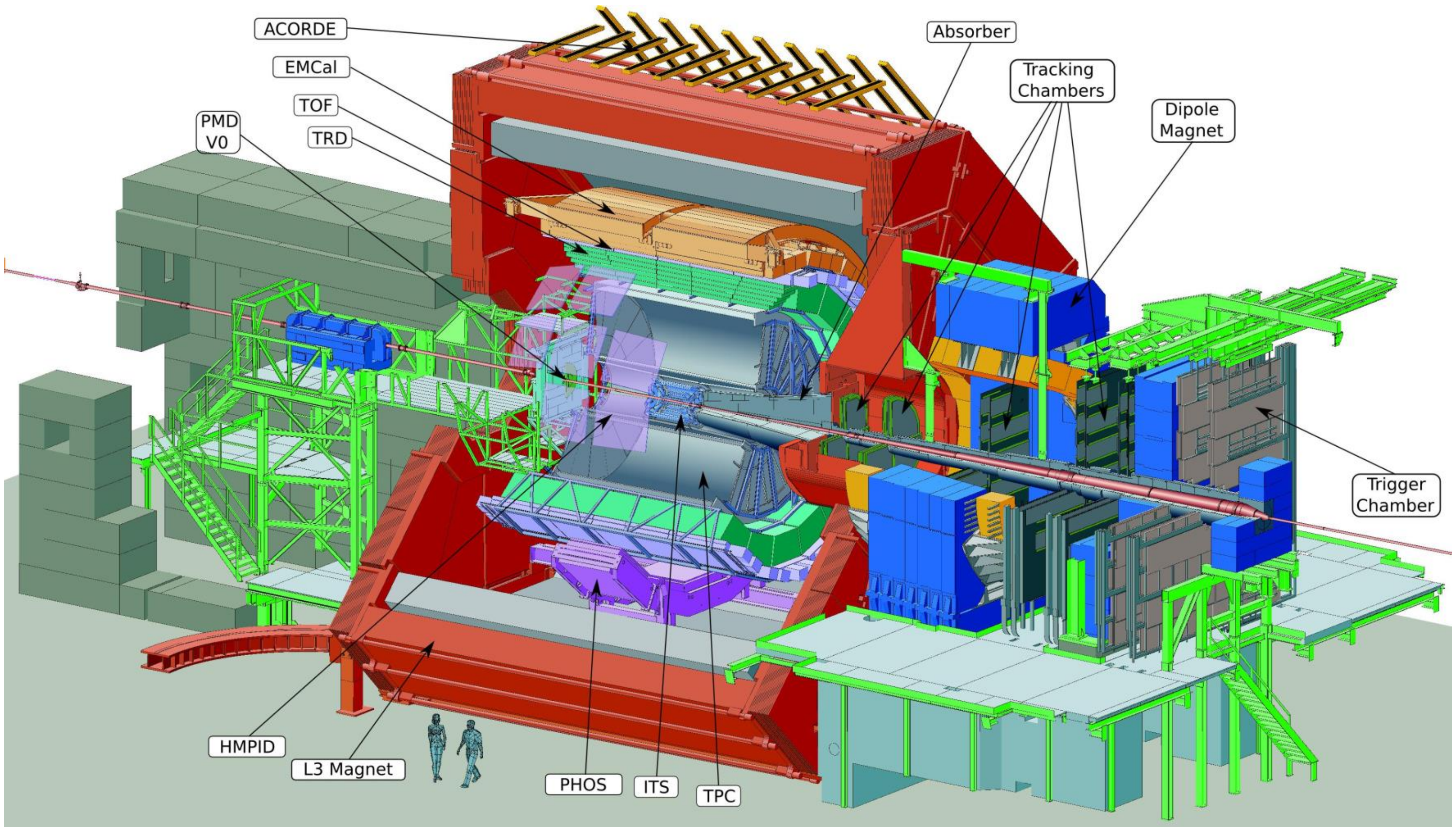
trigger hadron 5.0+ GeV/c
Δϕ
associate deuteron



correlated
$1/N_{trig} dN_{assoc}/d\Delta\varphi$ (1/rad)
-1
0
1
2
3
4
Δϕ (rad)



uncorrelated
$1/N_{trig} dN_{assoc}/d\Delta\varphi$ (1/rad)
-1
0
1
2
3
4
Δϕ (rad)



The Inner Tracking System has six layers of silicon.

The Time Projection Chamber is the world's largest (88m^3).

The Time Of Flight has 157k channels.

From a Google search, this is how you'd think we enter ALICE.

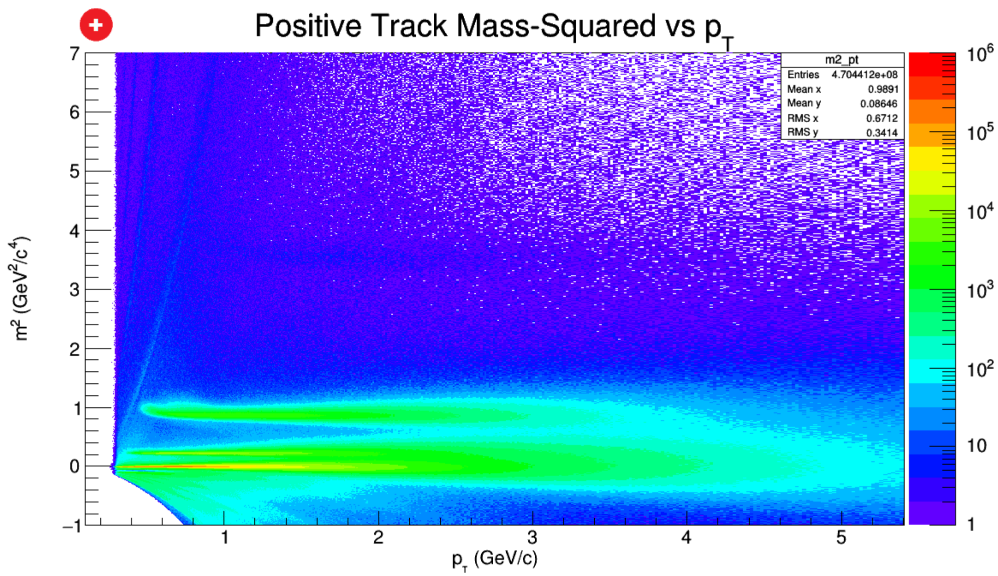
How we normally get inside the detector.

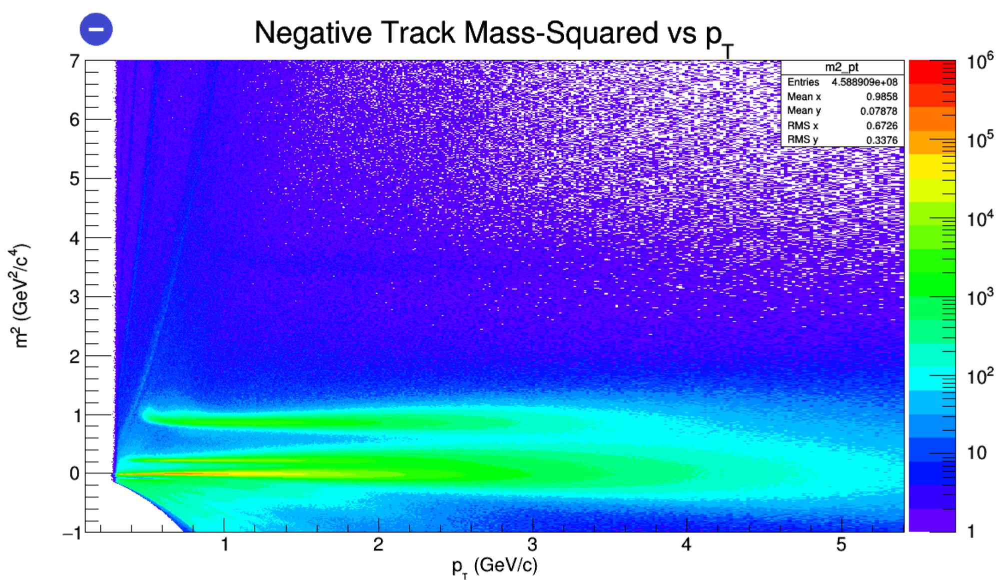
Identifying Deuterons

$T_{TOF} - T_0$

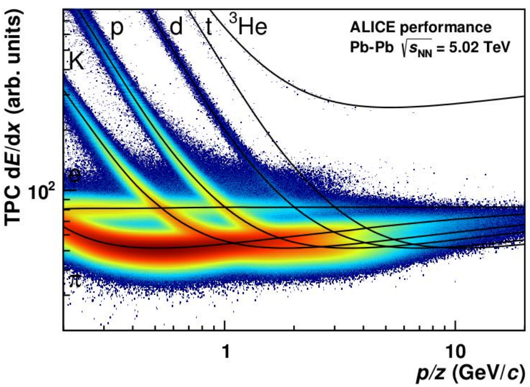
$$m^2 = \frac{p^2}{c^2}\left(\frac{t^2c^2}{L^2} - 1\right)$$

from tracking

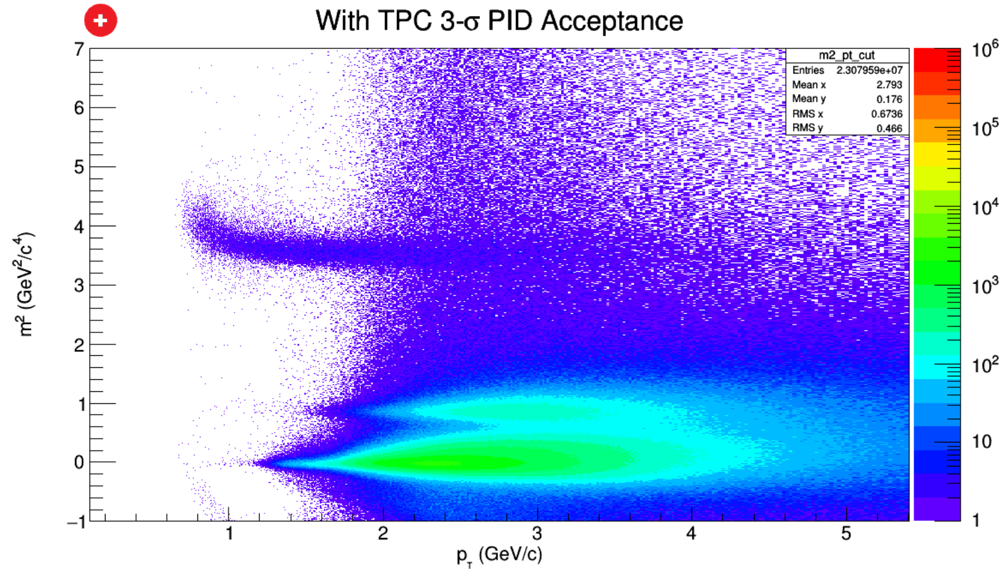


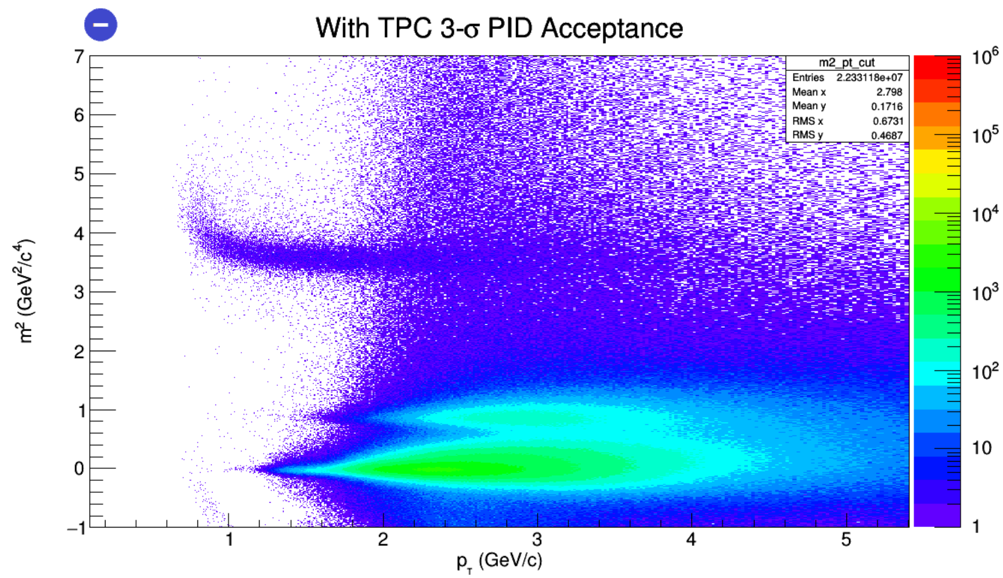


with 3σ TPC band cut



parametrization comes from Bethe-Bloch

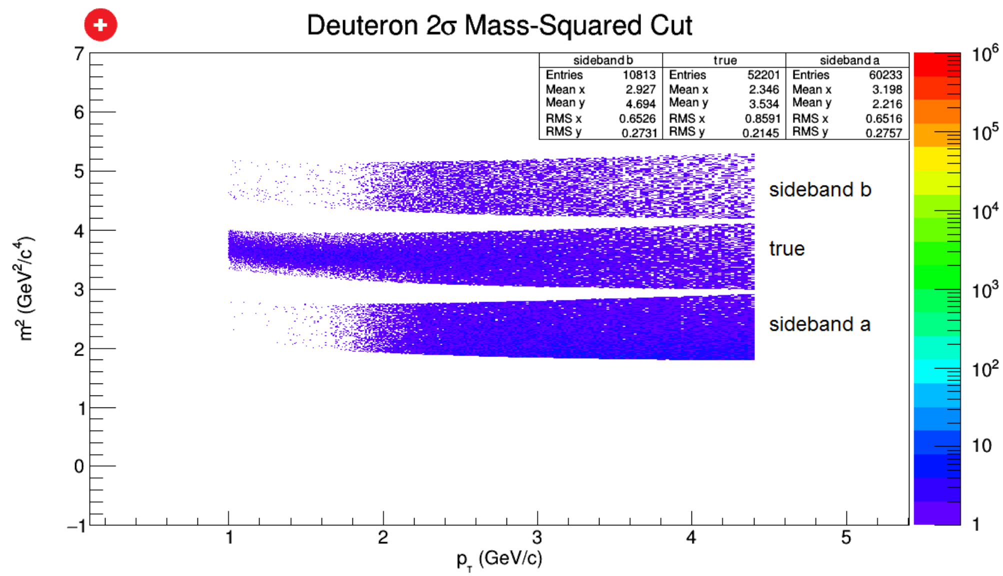


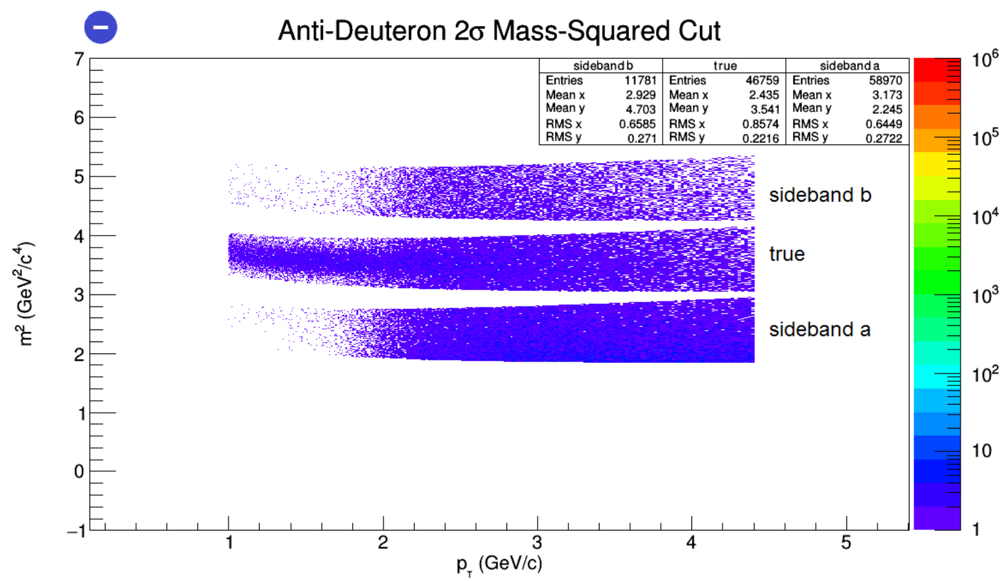


Oak Ridge National Laboratory

2σ TOF-PID cut
and sidebands

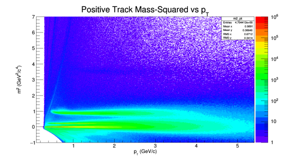
1.0 GeV/c lower limit
is used to avoid
secondary deuterons

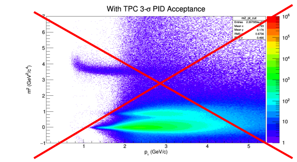


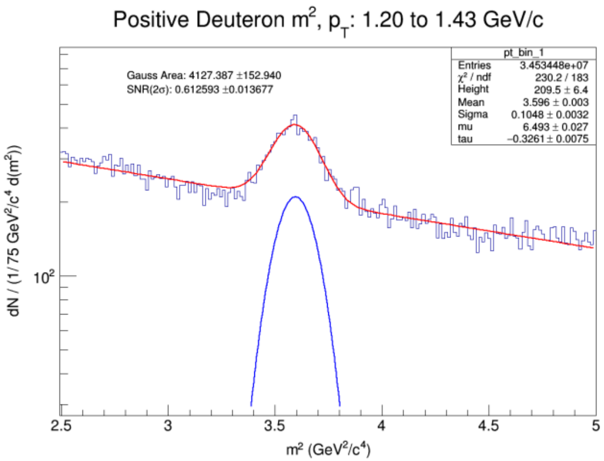


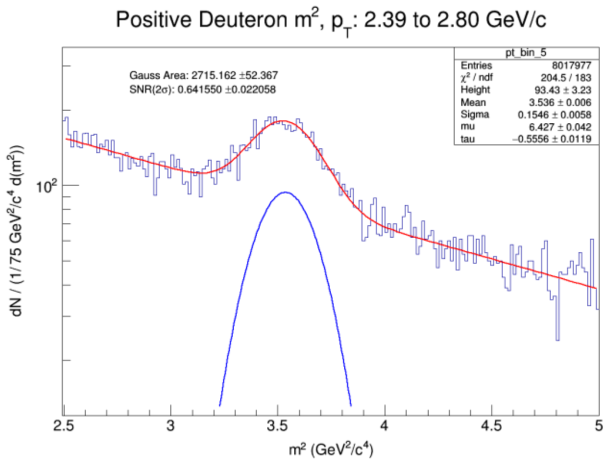
OAK RIDGE National Laboratory

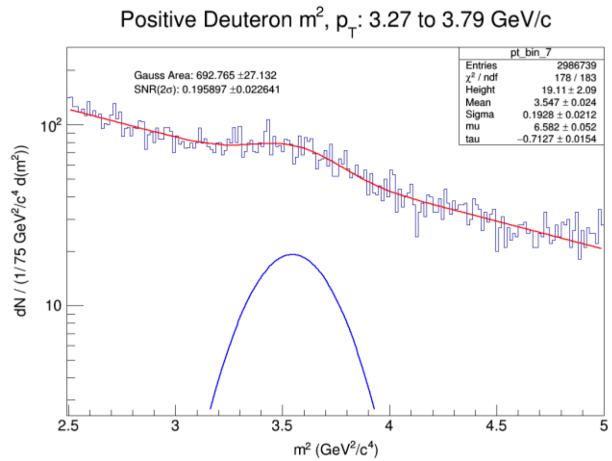
deuteron identification cuts are made using raw m^2 data

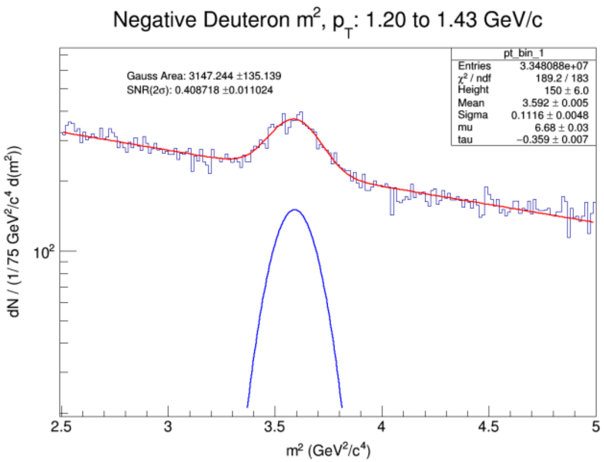


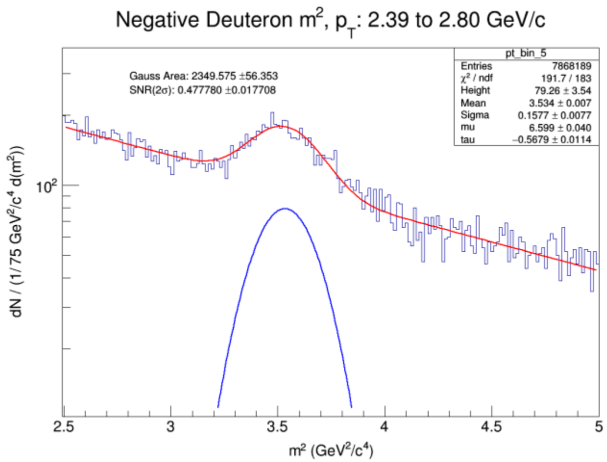


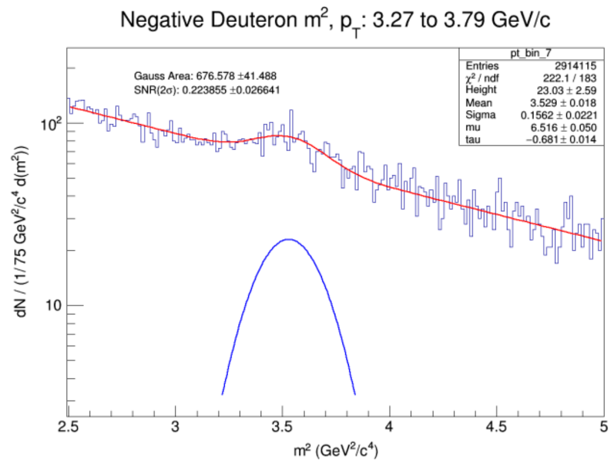




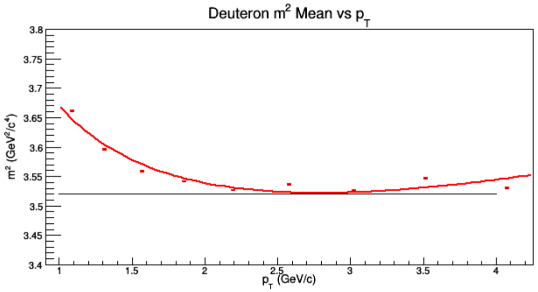


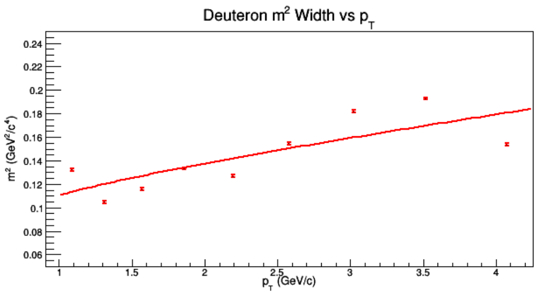


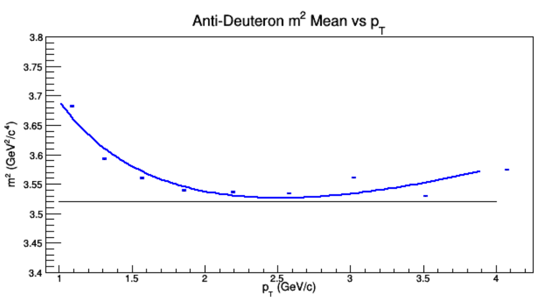


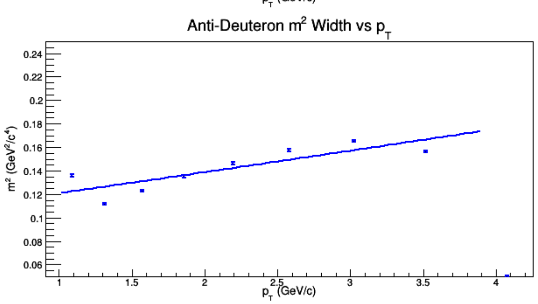


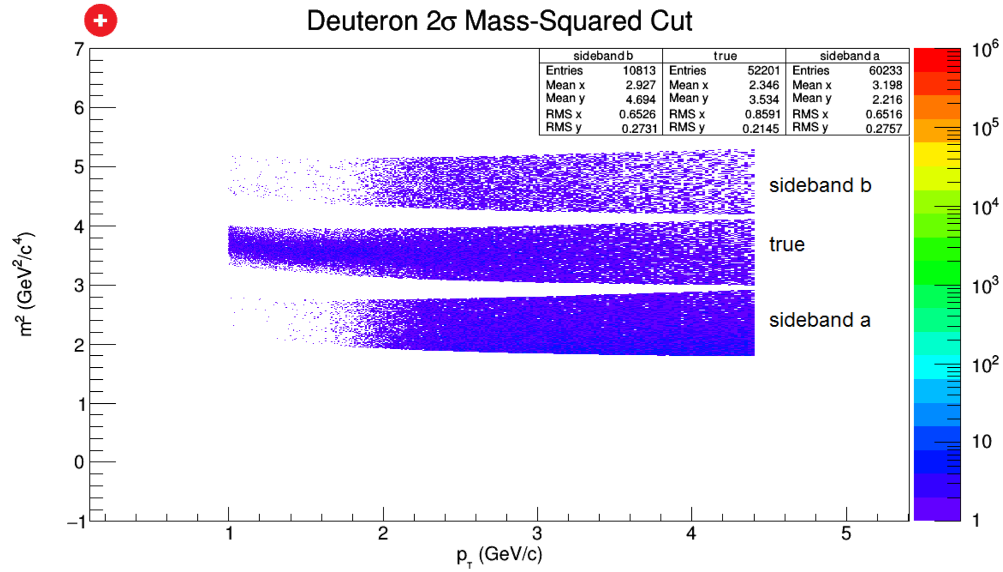
cuts use mean, width functional fittings

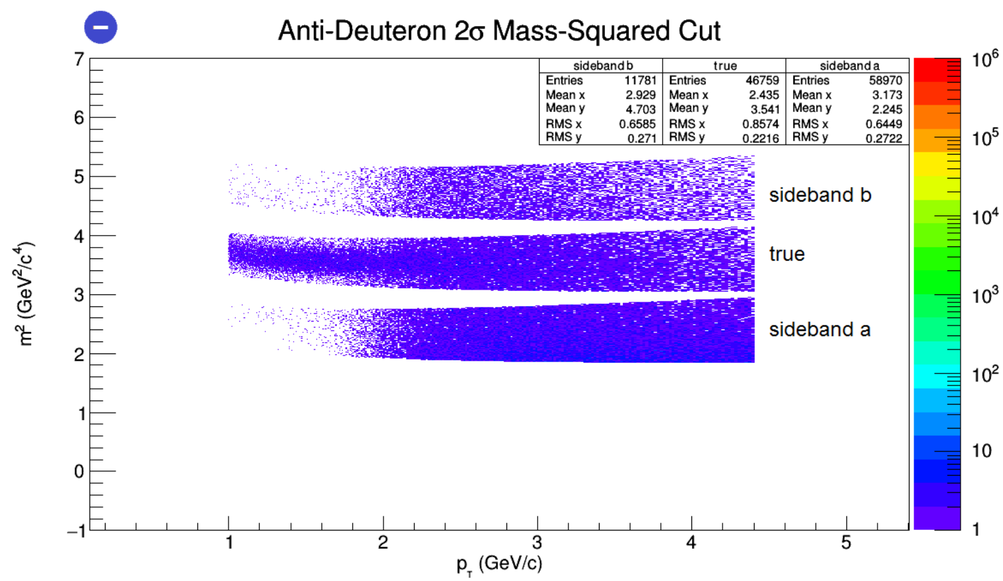




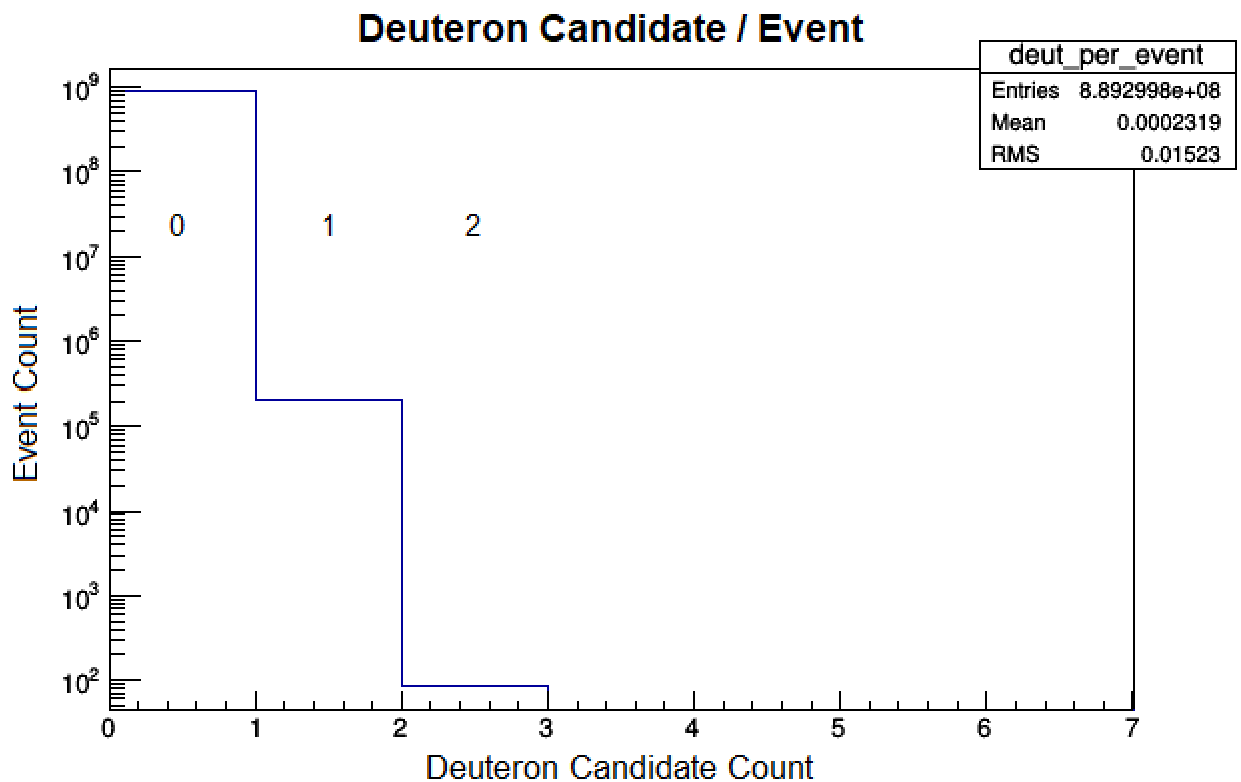




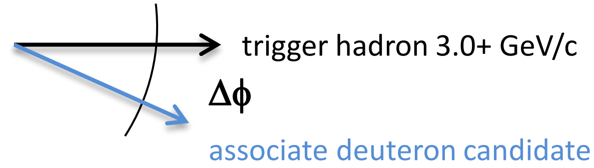


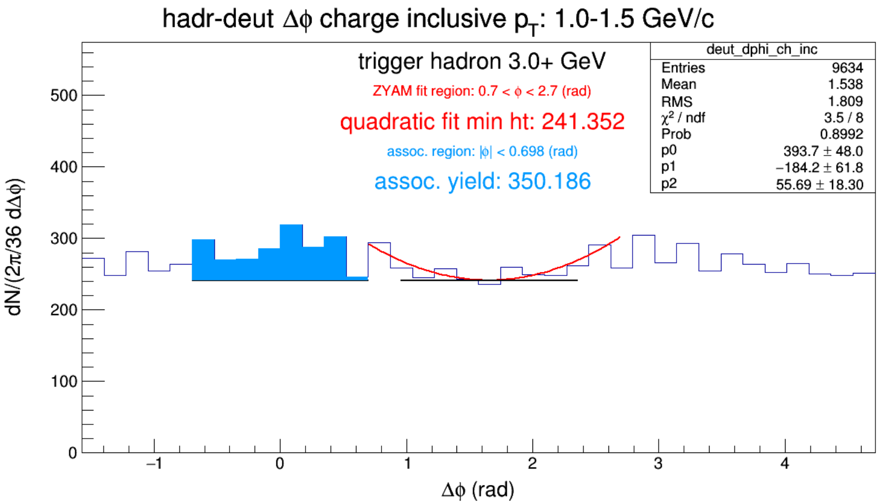


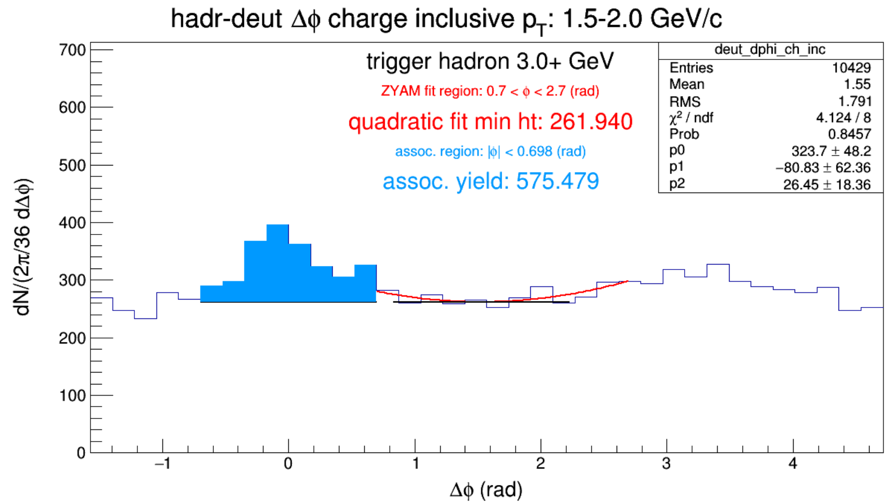
deuteron candidates with $1.0 < p_T < 4.4$ GeV/c
are in about 1/4500 p-p 13TeV events

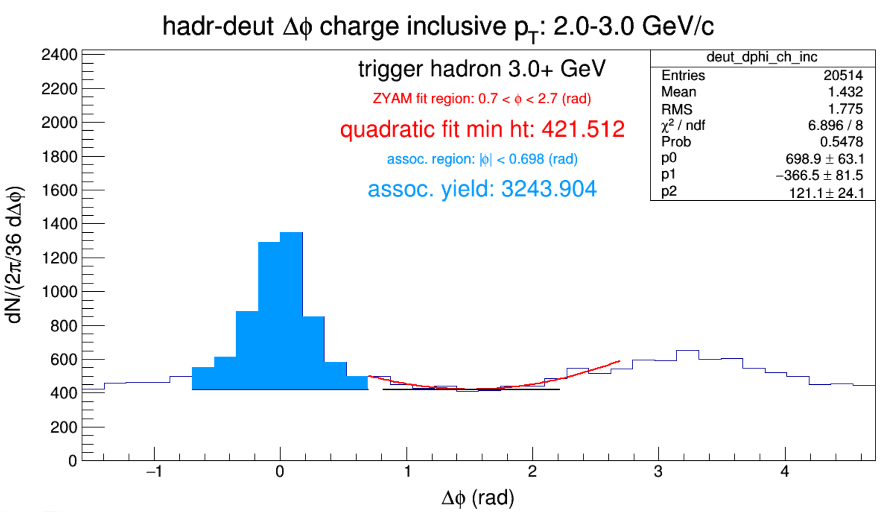


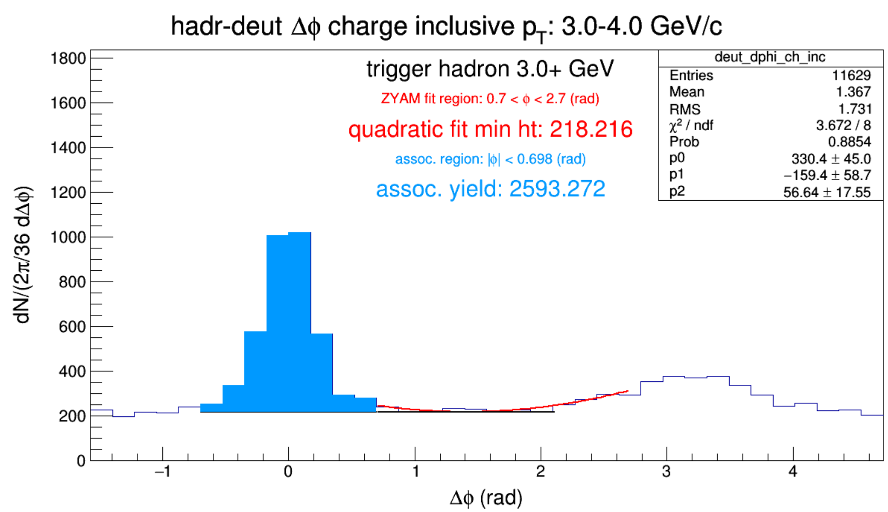
deuteron to hadron(3.0+ GeV) correlation









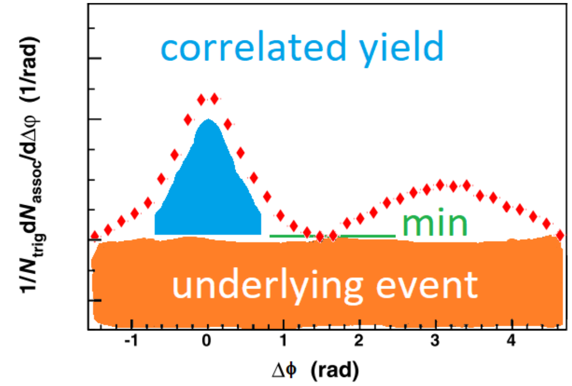


is the correlation due to impurities?

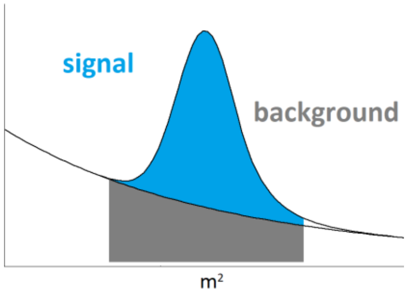
$$Y_{per-trigger}^{deuteron} = \frac{CorrelatedYield}{TriggerCount}$$

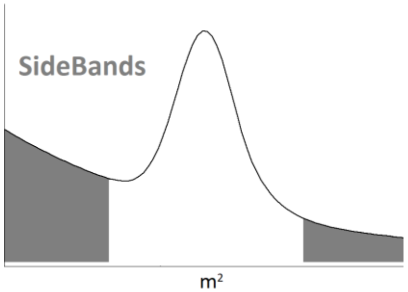
1. Subtract uncorrelated pairs "underlying event" with ZYAM method (zero yield at minimum).

2. Correlated yield is divided by the total trigger hadron count.



$$Y = Y_{per-trigger}^{deuteron} - \frac{back}{signal + back} Y_{per-trigger}^{side-band}$$

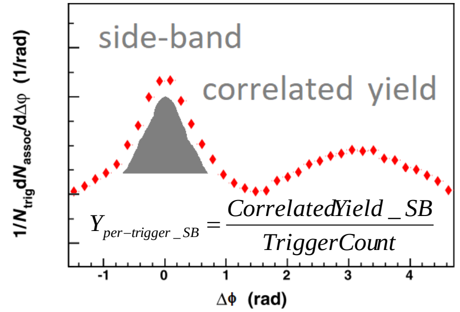




3. Find impurity ratio with mass-squared fitting.

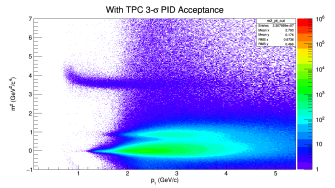
4. Select side-band regions above and below candidate region.

5. Subtract purity weighted (*side-band correlated yield / trigger*).

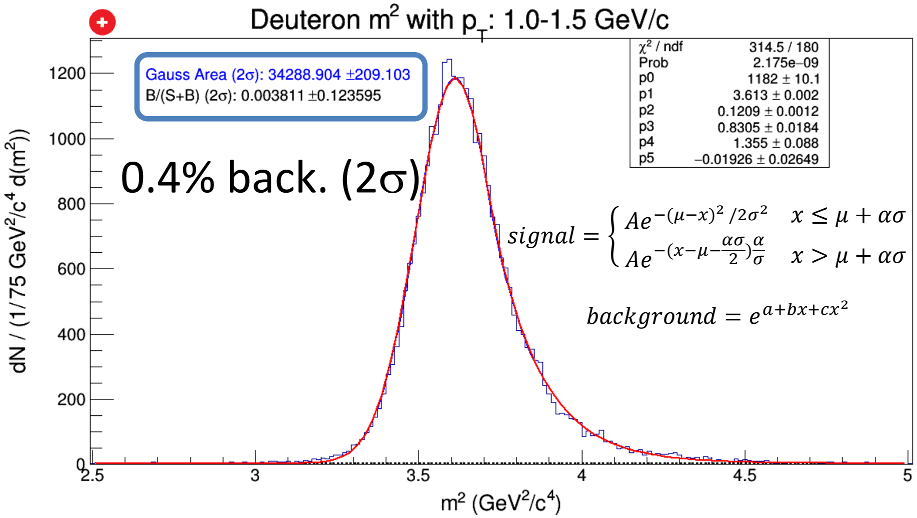


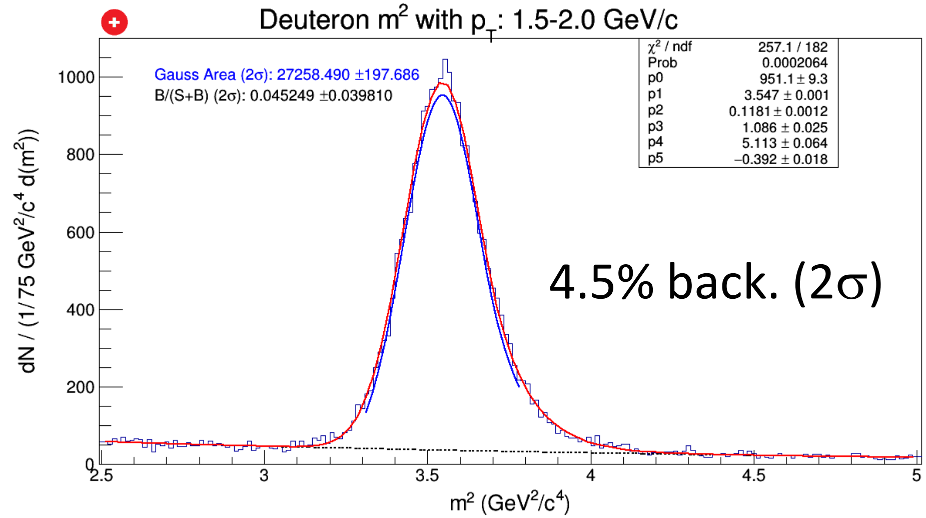
Purity

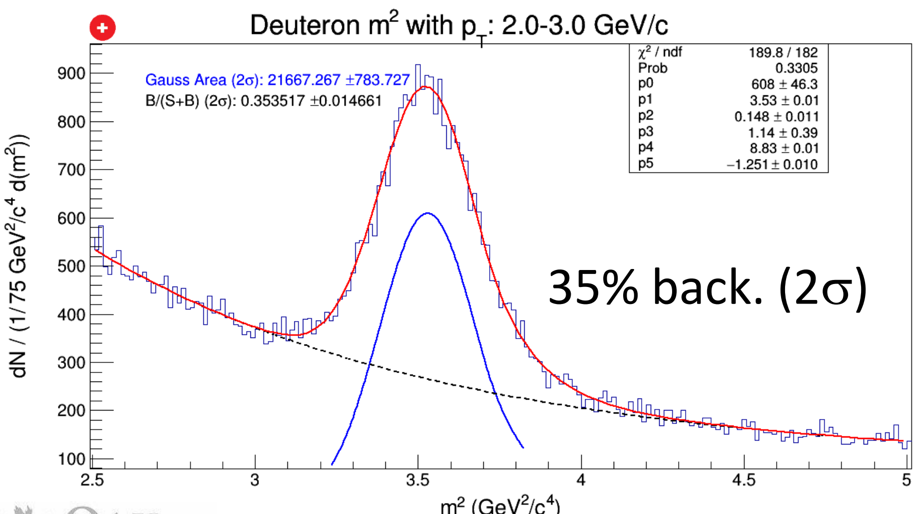
$$Y_{corrected} = \left(Y^{deuteron}_{per-trigger} - \boxed{\frac{back}{signal + back}} Y^{side-band}_{per-trigger}\right) \frac{1}{efficiency \cdot accept.}$$

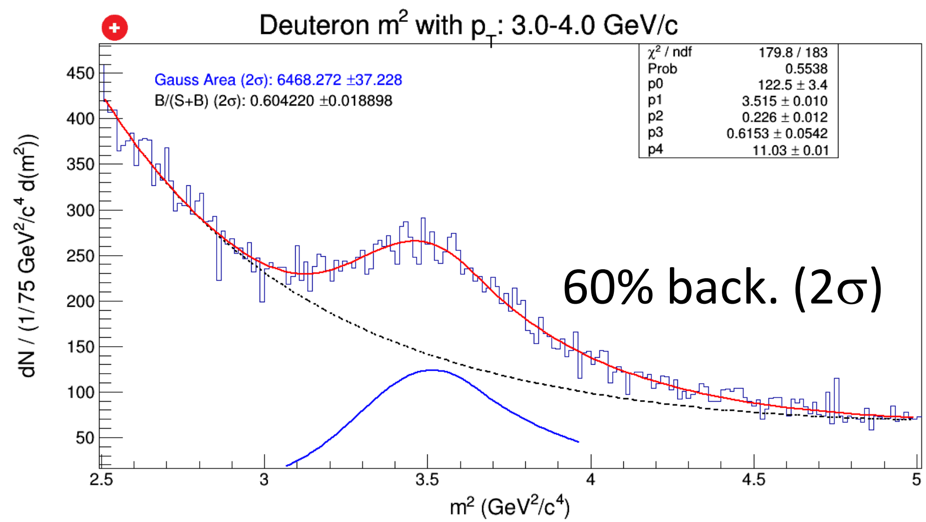


B/(B+S) of separate charges is combined using statistically weights



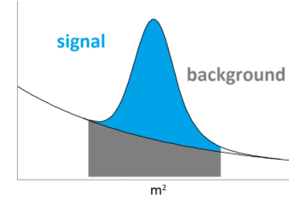




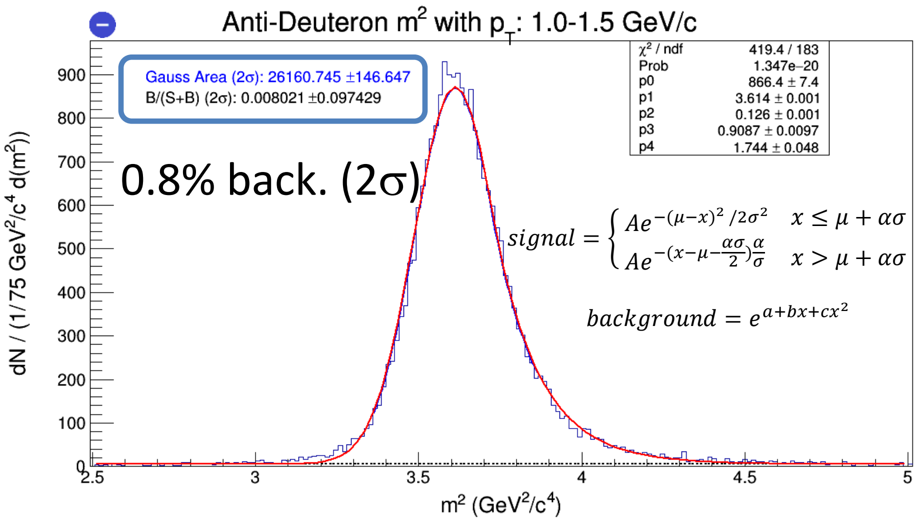


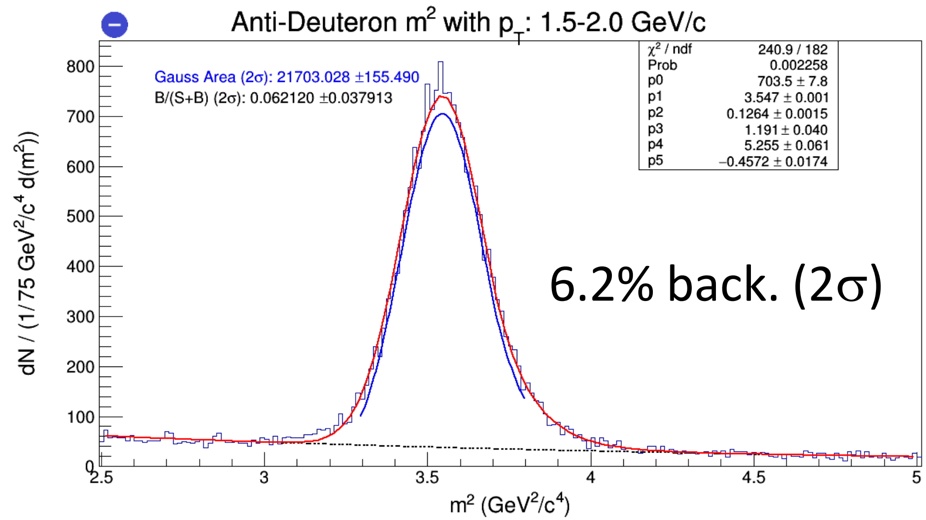
Purity

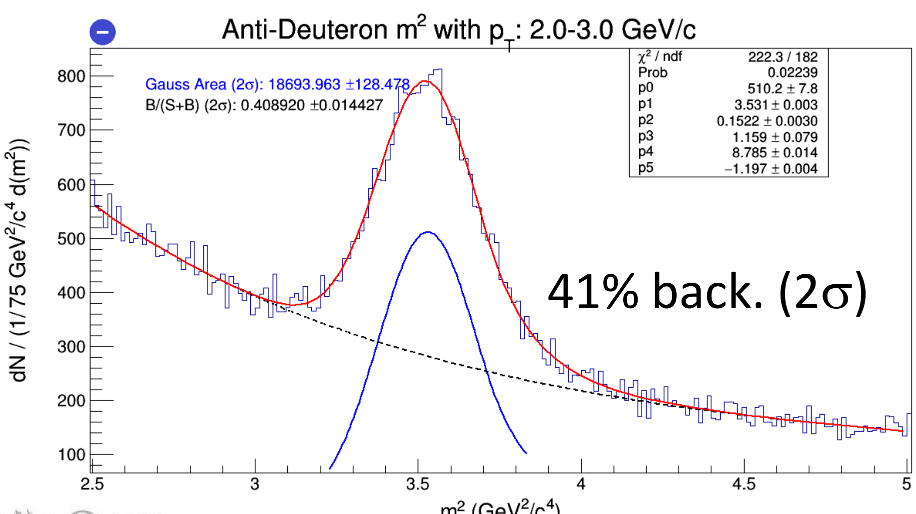
$$Y_{corrected} = (Y^{deuteron}_{per-trigger} - \boxed{\frac{back}{signal + back}} Y^{side-band}_{per-trigger}) \frac{1}{efficiency \cdot accept.}$$

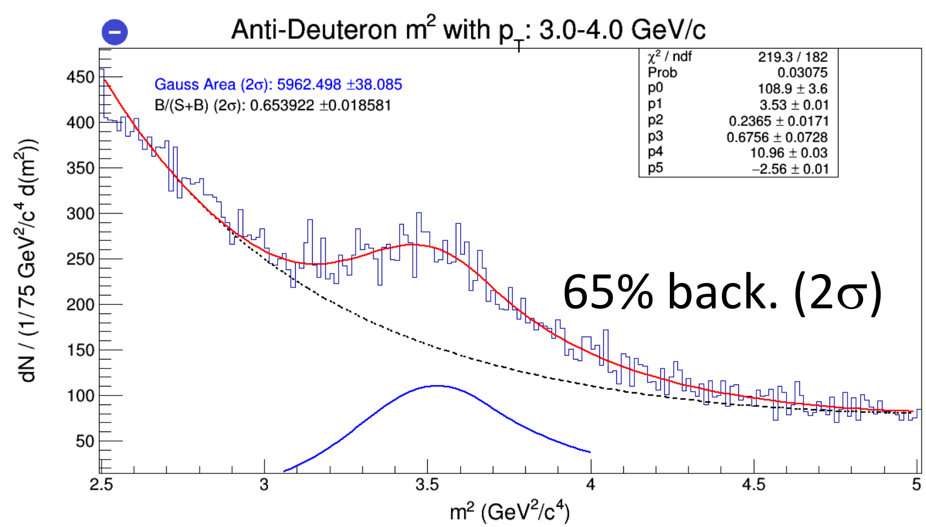


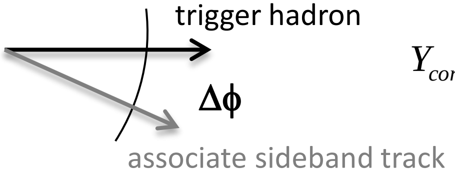
B/(B+S) of separate charges is combined using statistically weights



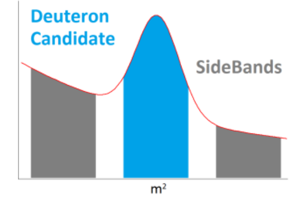


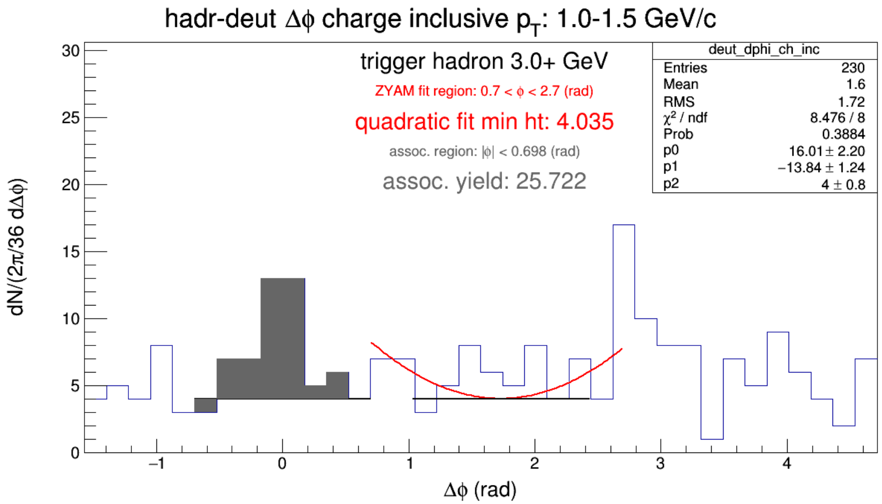


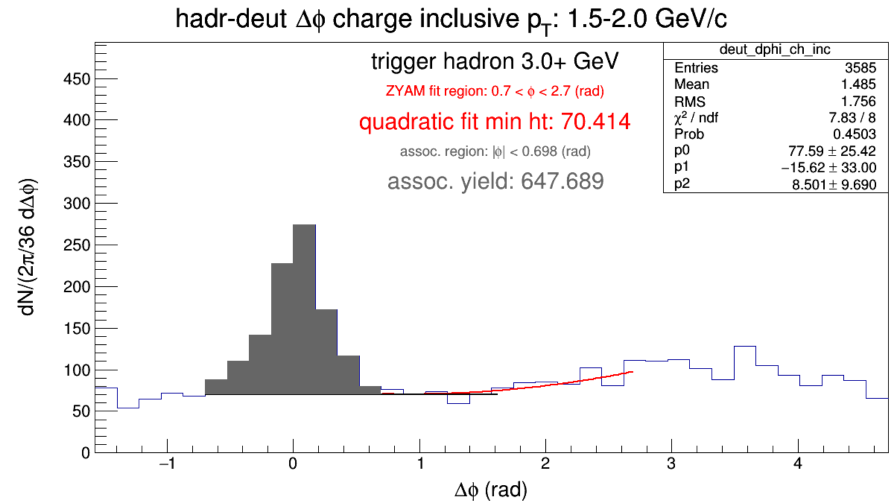


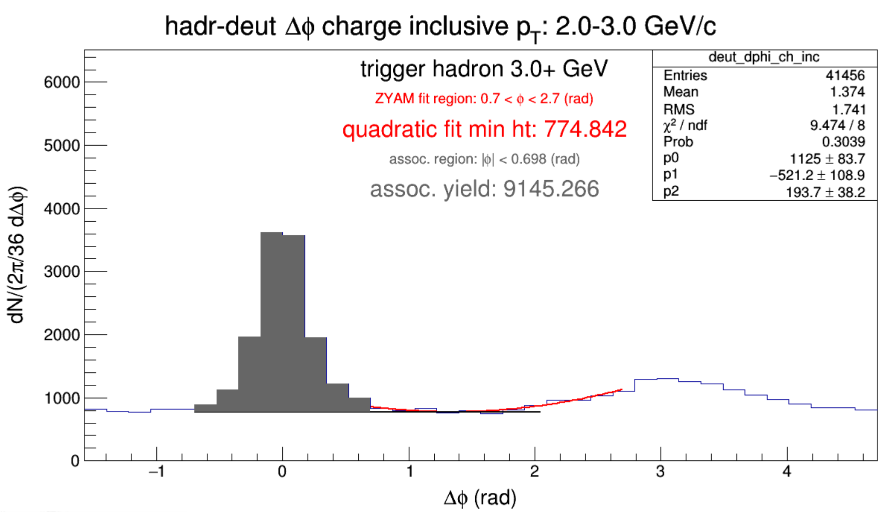


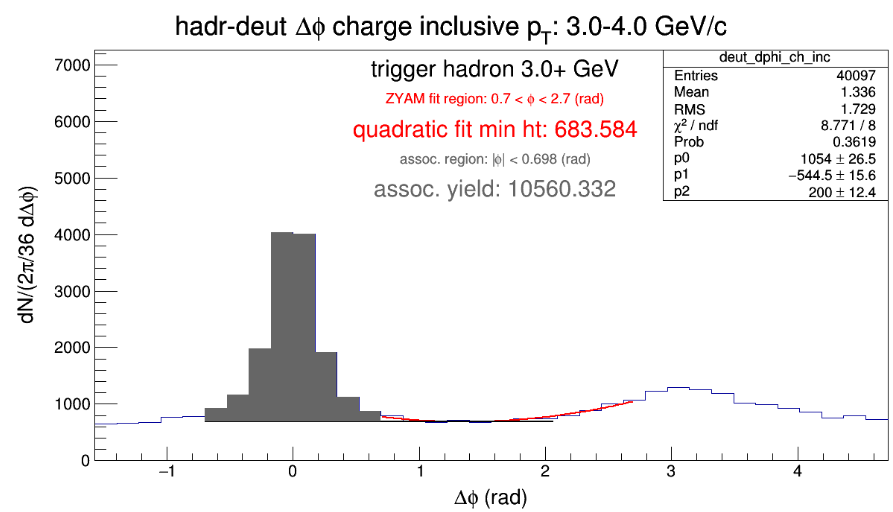
$$Y_{corrected} = (Y^{deuteron}_{per-trigger} - \frac{back}{signal+back}\boxed{Y^{side-band}_{per-trigger}})\frac{1}{efficiency\cdot accept.}$$









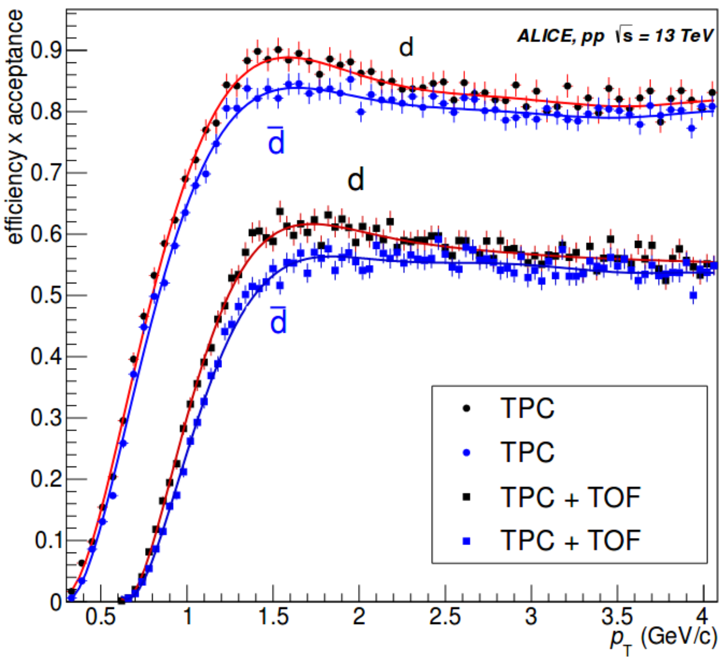


efficiency & acceptance

$$Y_{corrected} = (Y^{deuteron}_{per-trigger} - \frac{back}{signal+back} Y^{side-band}_{per-trigger}) \boxed{\frac{1}{efficiency \cdot accept.}}$$

$f(x) = a_0 + a_1 x + \ldots a_9 x^9$

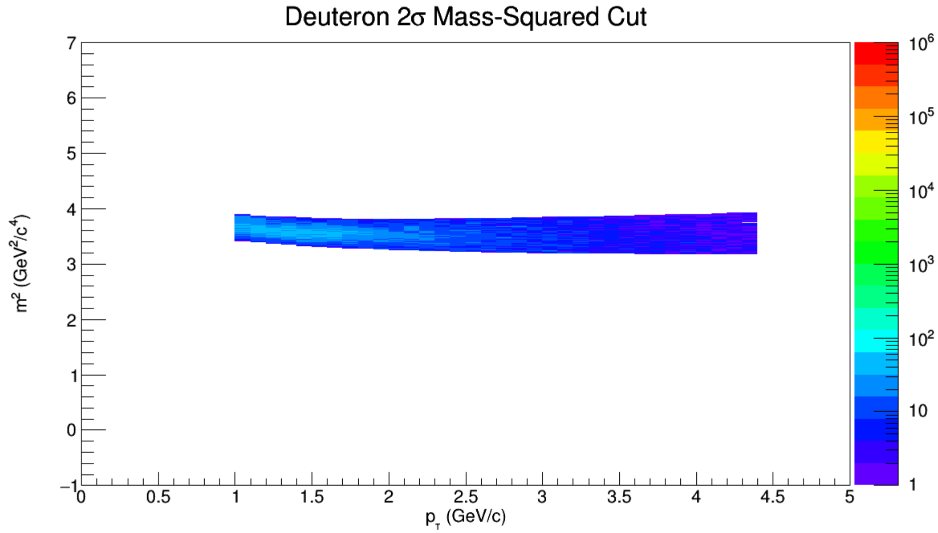
B. Krimphoff, B. Dönigus



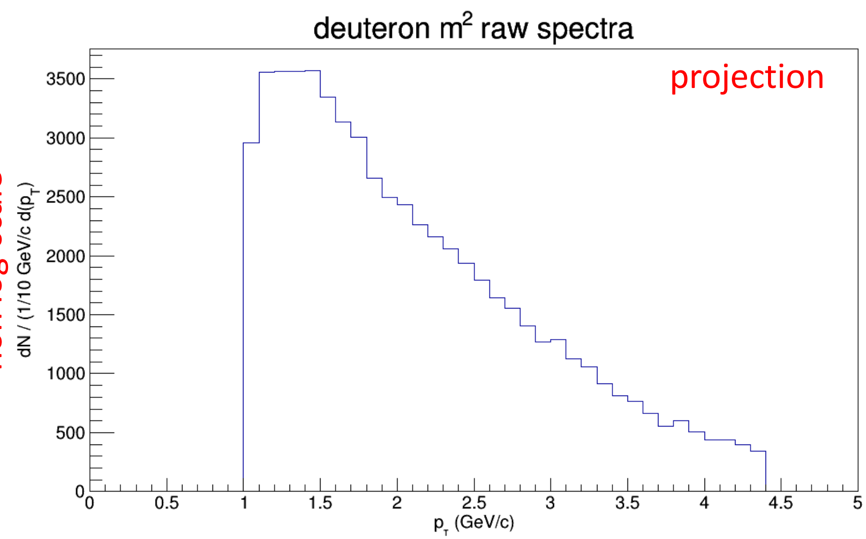
Deuteron and anti-deuteron production in pp collisions at 13 TeV

Donigus, ANA-3952

function values in 0.1 GeV/c intervals are weighted with spectra inside each bin

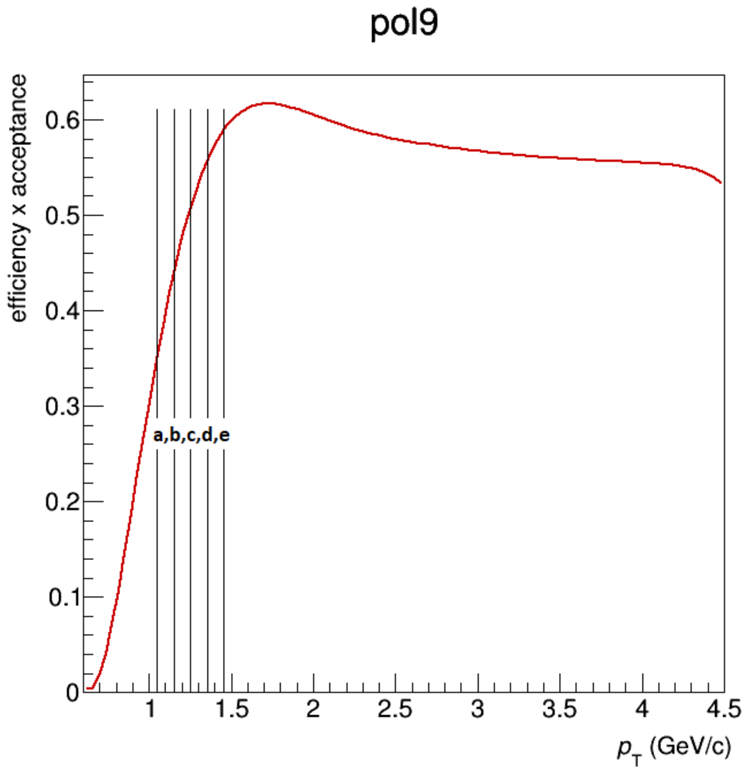


non log-scale



efficiency & acceptance

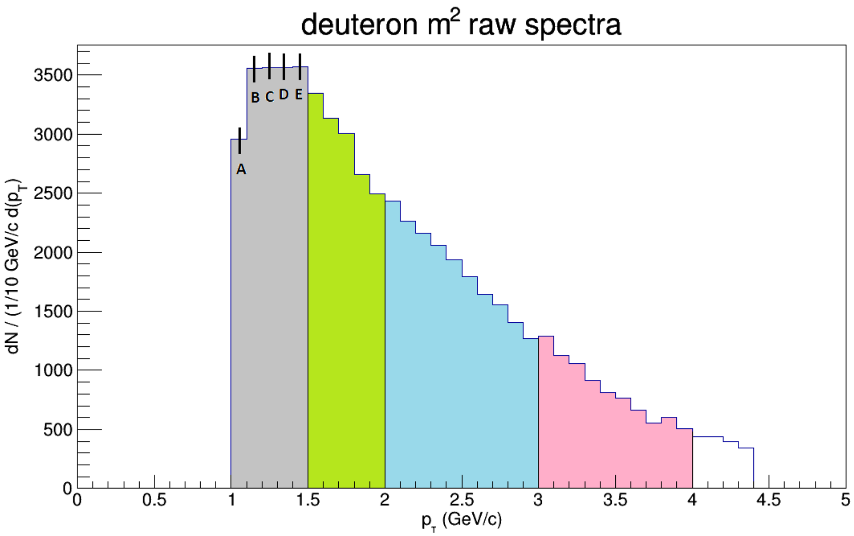
$$Y_{corrected} = (Y^{deuteron}_{per-trigger} - \frac{back}{signal+back} Y^{side-band}_{per-trigger}) \boxed{\frac{1}{efficiency \cdot accept.}}$$



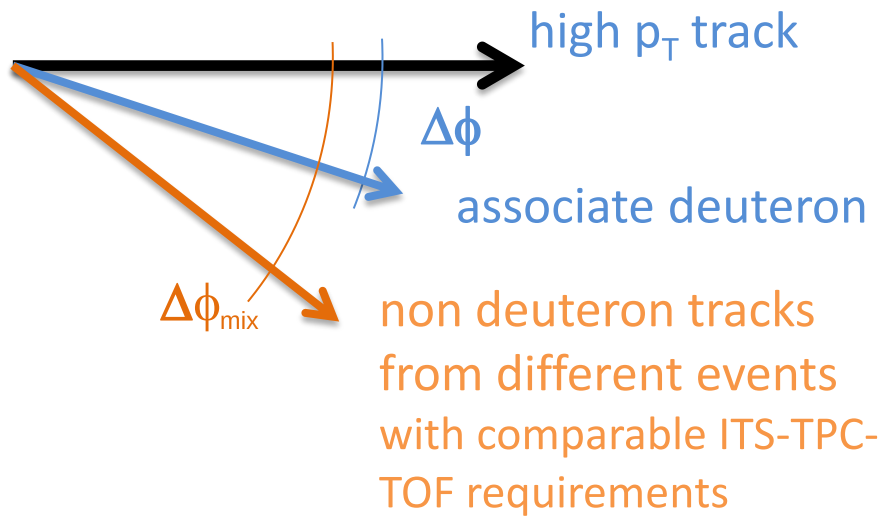
from 1.0 - 1.5 GeV/c the correction is:

$$\frac{Aa + Bb + Cc + Dd + Ee}{A+B+C+D+E}$$

function values in 0.1 GeV/c intervals are weighted with spectra inside each bin

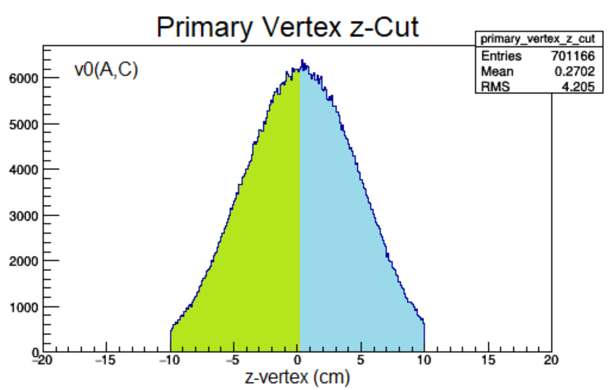


pair reconstruction efficiency is accounted for using event mixing

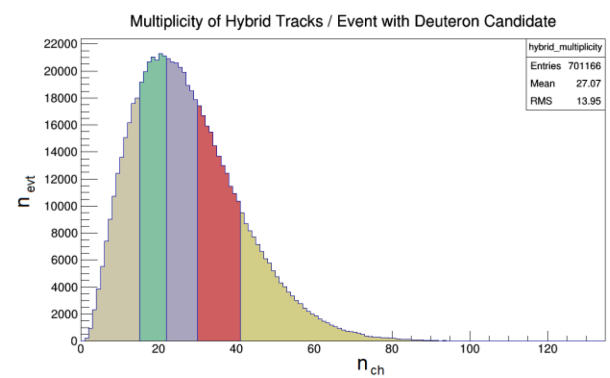


mixing tracks are selected from the same p_T interval,

z-vertex range,



and event multiplicity



Extraction of Correlated Jet Pair Signals in Relativistic Heavy Ion Collisions

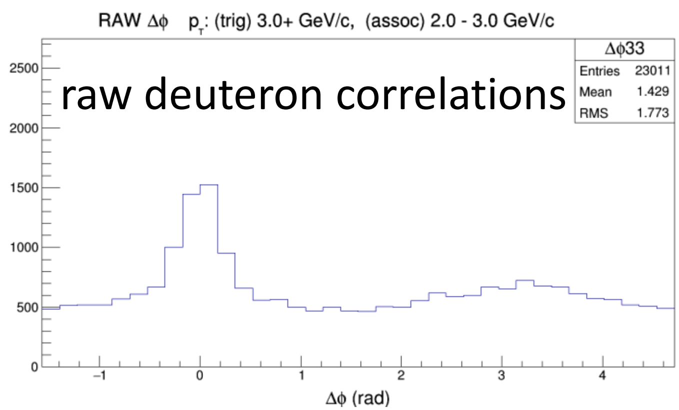
Anne Sickles*
Department of Physics Brookhaven National Laboratory Upton, NY 11973

Michael P. McCumber
Department of Physics and Astronomy SUNY Stony Brook Stony Brook, NY 11794

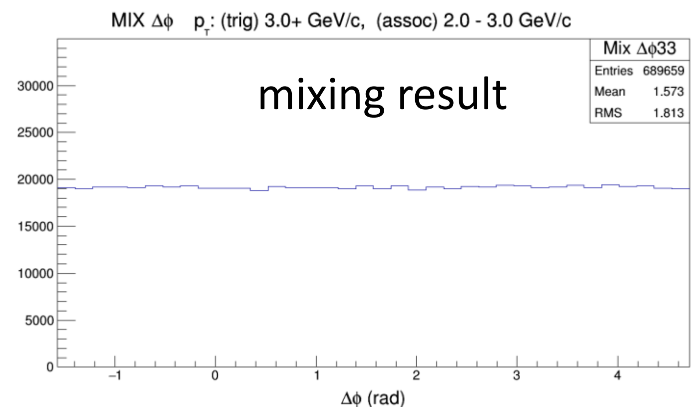
Andrew Adare
Department of Physics University of Colorado Boulder, CO 80309
(Dated: September 23, 2013)

$$C(\Delta\phi) = \frac{\dfrac{d\langle n^{AB}_{same}\rangle}{d\Delta\phi}}{\dfrac{d\langle n^{AB}_{mix}\rangle}{d\Delta\phi}} \frac{\int \dfrac{d\langle n^{AB}_{mix}\rangle}{d\Delta\phi} d\Delta\phi}{\int \dfrac{d\langle n^{AB}_{same}\rangle}{d\Delta\phi} d\Delta\phi} \tag{1}$$

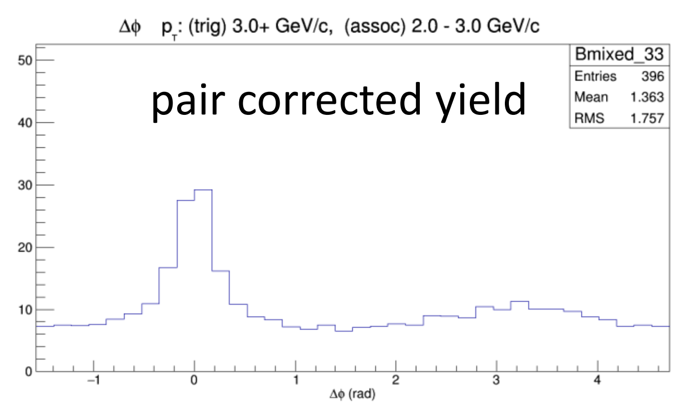
$$c = \frac{real\_bin}{mix\_bin} \cdot \frac{mix\_sum}{real\_sum}$$



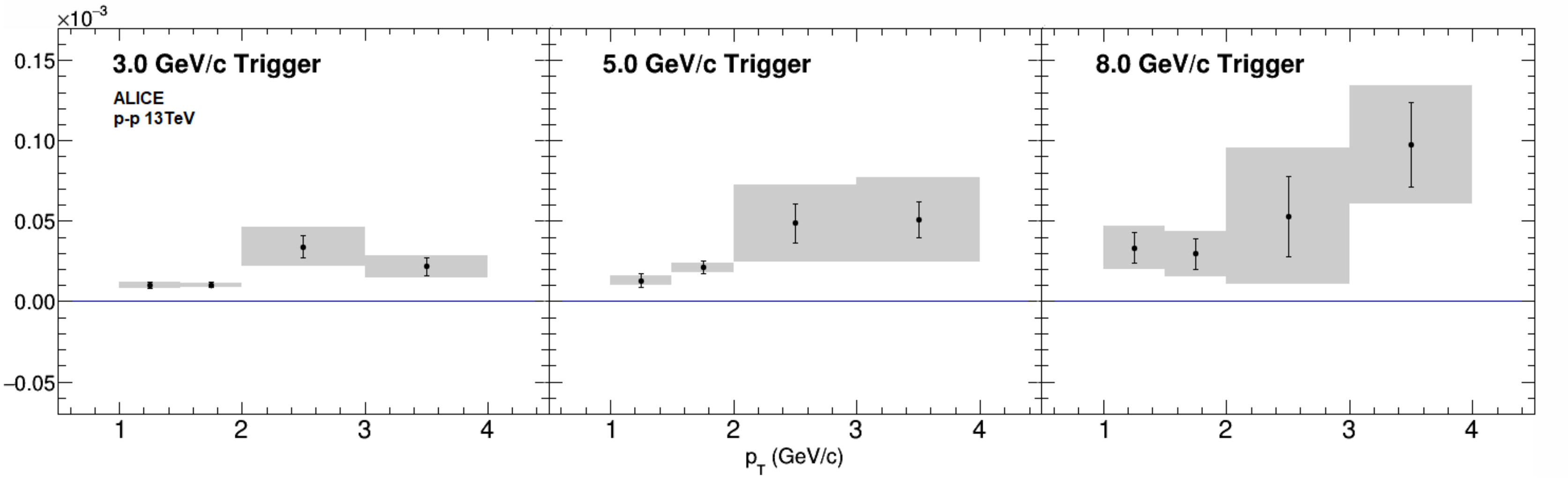
÷



=



Per-trigger deuteron yields

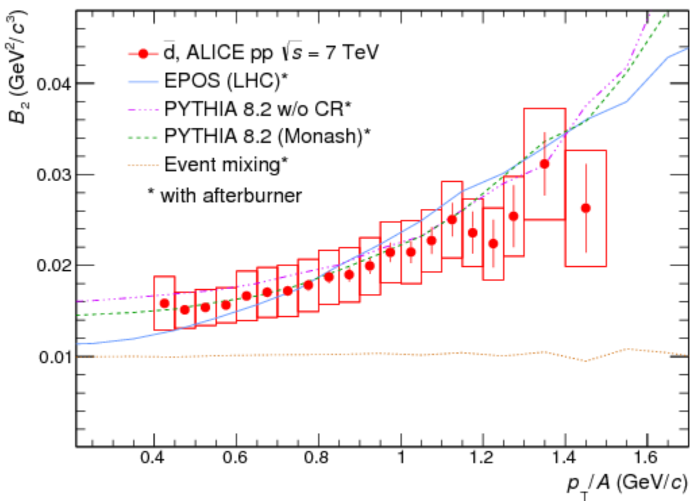


!! remaining work: duplicate per-trigger yields for protons

$$B_2 \sim \frac{deuteron\_corrected\_yields}{(proton\_corrected\_yields)^2}$$

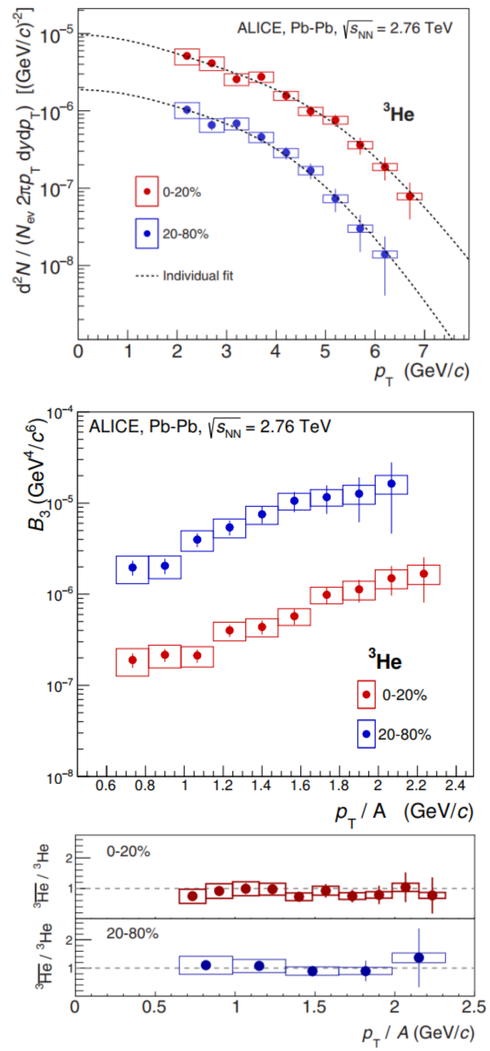
the production of light (anti)-nuclei is simulated using PYTHIA afterburners

model comparisons



arXiv:1709.08522

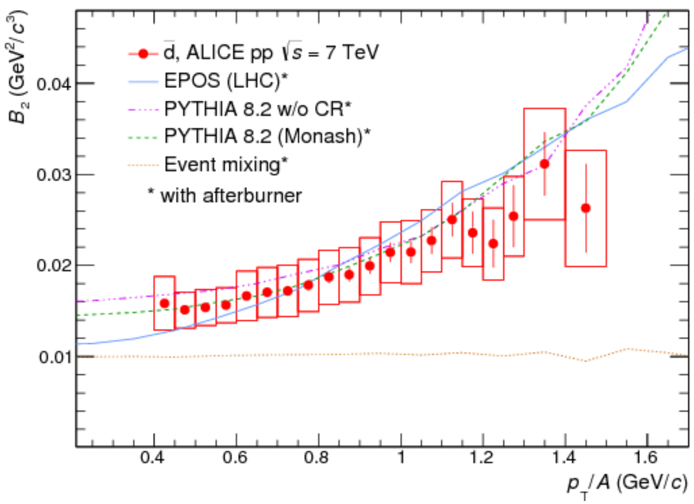
^{3}He measurements!



PHYSICAL REVIEW C 93, 024917 (2016)

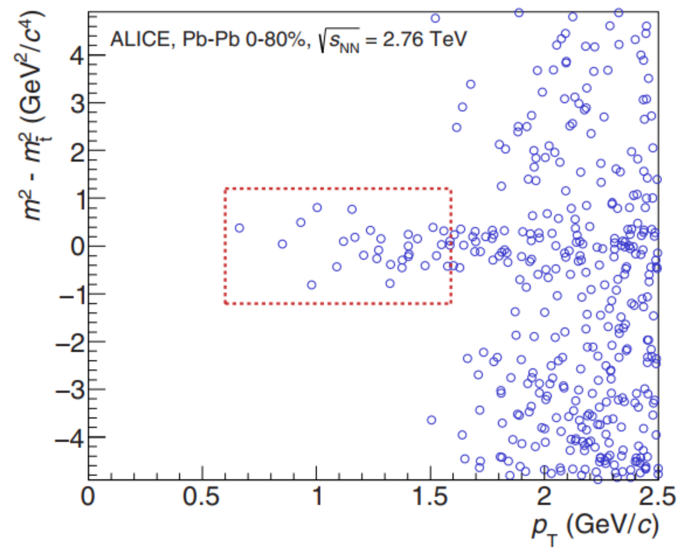
the production of light (anti)-nuclei is simulated using PYTHIA afterburners

model comparisons



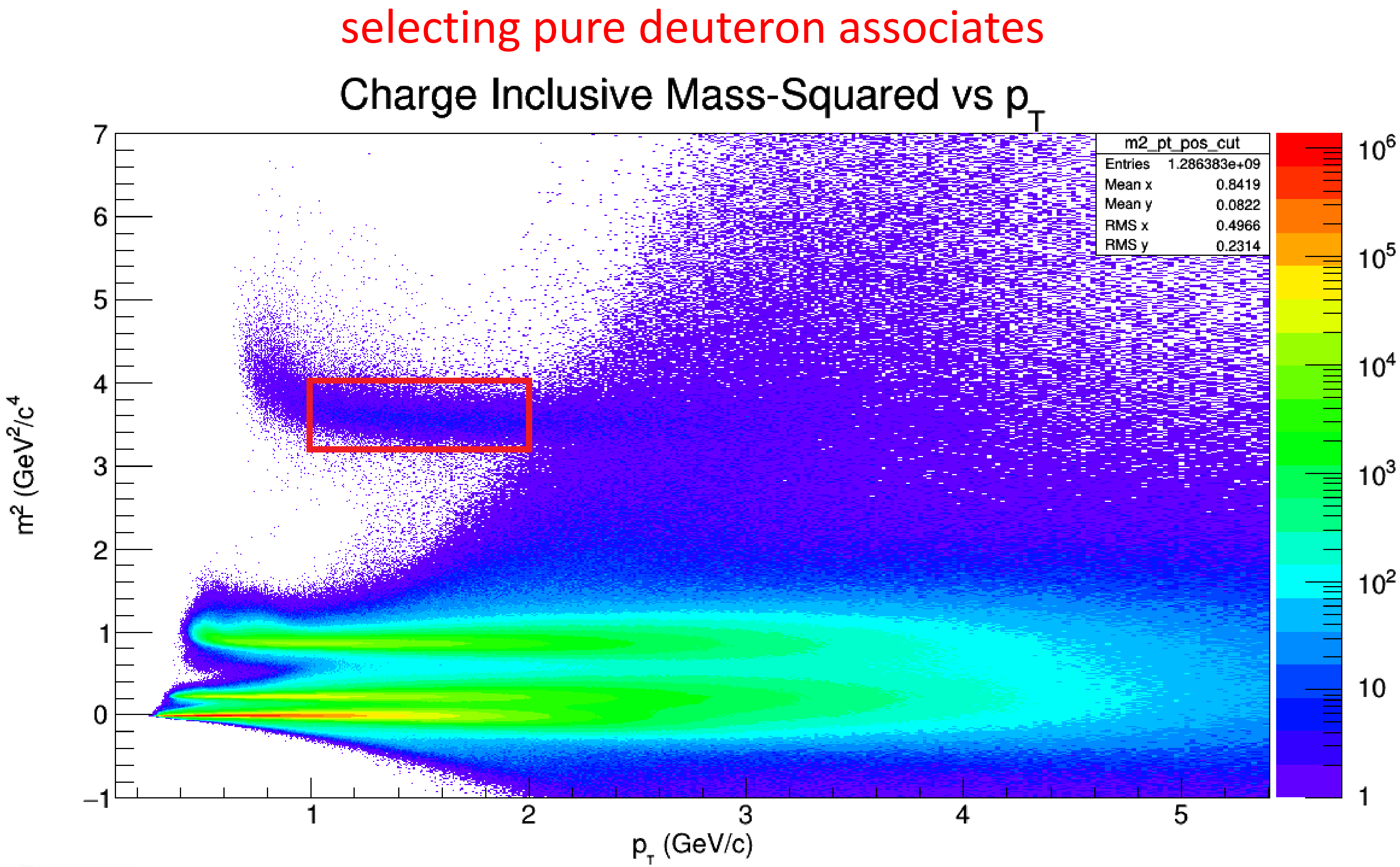
arXiv:1709.08522

also anti-triton!



PHYSICAL REVIEW C 93, 024917 (2016)

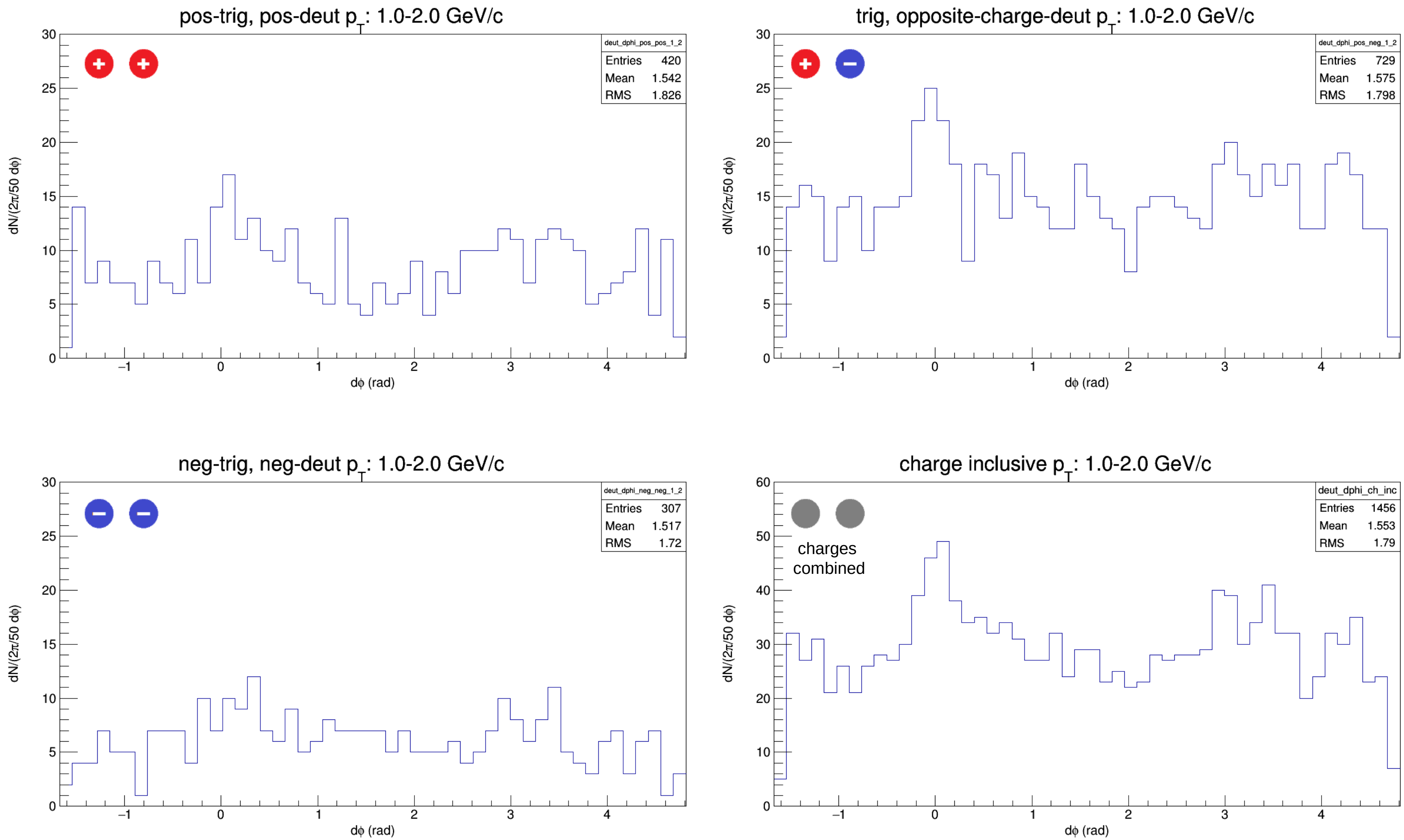
basic cross check



Brennan Schaefer

basic cross check

5.0+ GeV/c trigger hadron



backup

$$Y_{corrected} = \left(\frac{c_{deuteron}}{N_{trig}} - \frac{back}{signal+back}\frac{N_{deut\_candidate}}{N_{side-band}}\frac{c_{side-band}}{N_{trig}}\right)\frac{1}{eff.\cdot accept.}$$

$${}^{1}\sigma = \sigma_c$$

$${}^{2}\sigma = \frac{back}{signal+back}\frac{N_{deut\_candidate}}{N_{side-band}}\sigma_{c_{side-band}}$$

$${}^{3}\sigma = c_{side-band}\frac{back}{signal+back}\frac{1}{N_{side-band}}\sigma_{N_{deut\_candidate}}$$

$${}^{4}\sigma = c_{side-band}\frac{back}{signal+back}\frac{N_{deut\_candidate}}{(N_{side-band})^2}\sigma_{N_{side-band}}$$

$${}^{5}\sigma = c_{side-band}\frac{signal}{(signal+back)^2}\frac{N_{deut\_candidate}}{N_{side-band}}\sigma_{back}$$

$${}^{6}\sigma = c_{side-band}\frac{back}{(signal+back)^2}\frac{N_{deut\_candidate}}{N_{side-band}}\sigma_{signal}$$

$$\sigma_c = \sqrt{\sigma^2_{area\_|\phi|<0.7} - \sigma^2_{area\_ZYAM}}$$

statistical uncertainties are taken as Poissonian

$$\sigma_Y = \frac{1}{N_{trig}}\frac{1}{eff.\cdot accept.}\sqrt{\sum{}^{i}\sigma^2}$$

Extraction of Correlated Jet Pair Signals in Relativistic Heavy Ion Collisions

Anne Sickles*
Department of Physics Brookhaven National Laboratory Upton, NY 11973

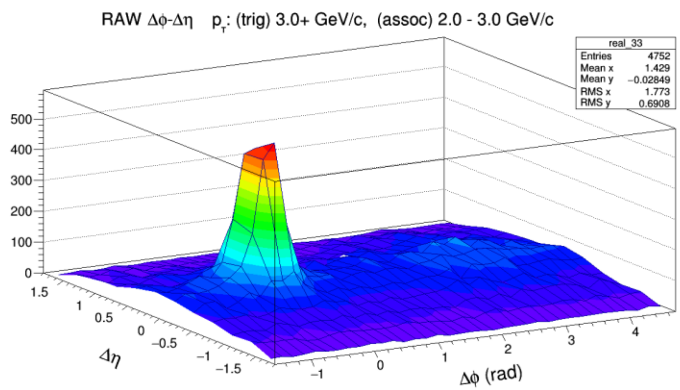
Michael P. McCumber
Department of Physics and Astronomy SUNY Stony Brook Stony Brook, NY 11794

Andrew Adare
Department of Physics University of Colorado Boulder, CO 80309
(Dated: September 23, 2013)

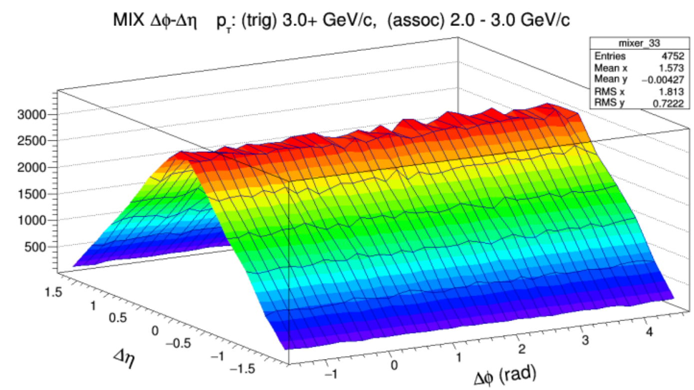
$$C(\Delta\phi) = \frac{\frac{d\langle n^{AB}_{same}\rangle}{d\Delta\phi}\int\frac{d\langle n^{AB}_{mix}\rangle}{d\Delta\phi}d\Delta\phi}{\frac{d\langle n^{AB}_{mix}\rangle}{d\Delta\phi}\int\frac{d\langle n^{AB}_{same}\rangle}{d\Delta\phi}d\Delta\phi} \quad (1)$$

raw deuteron correlations

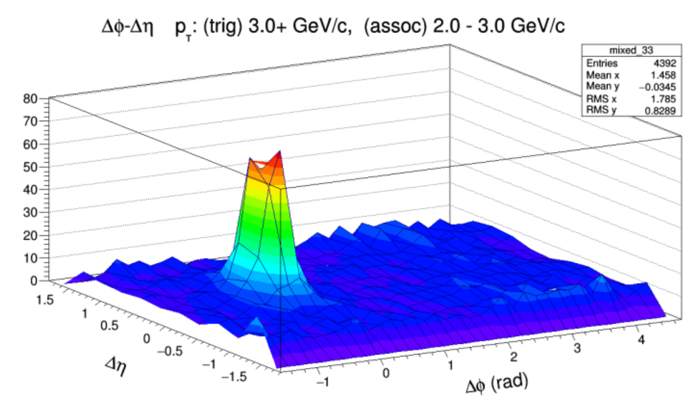
$$c = \frac{real\_bin}{mix\_bin}\cdot\frac{mix\_sum}{real\_sum}$$



÷



=




ORNL Heavy Ion Group
ALICE - Nuclear Physics at the LHC
CMS
LHCb
ALICE
ATLAS
CLRC
© Photo CERN

DEUTERON PRODUCTION IN HIGH-ENERGY COLLISIONS

R. Hagedorn
CERN, Geneva, Switzerland
(Received August 29, 1960)

finding it as small as Ω (or smaller) is given by the integral over the deuteron wave function:

$$\int_\Omega |\psi_d|^2 dV.$$

Therefore, whereas each pion and nucleon is represented in S by a factor Ω/V, the deuteron gives rise to a factor

$$\frac{\Omega_d}{V} = \frac{\Omega}{V}\int_\Omega |\psi_d|^2 dV. \qquad (3)$$

Taking a Hulthén-type wave function with hard core (the latter has little influence) gives[5] $\int_\Omega |\psi_d|^2 dV \approx \frac{1}{5} - \frac{1}{10}$. With this value for Ω_d one finds the results given in Tables I and II. They show, though they do not apply directly to the experiments (no pp collisions have so far been analyzed with respect to deuterons), that this "elementary production" yields the correct orders of magnitude. The differences may be due to the presence of nuclear matter, to an anisotropy of nucleons in the center-of-mass frame (the transformation c.m. to lab involves the simplifying assumption of isotropy), and to "peripheral" collisions.

It is satisfying that the above picture, which treats the deuteron as a quasi-elementary particle (at least makes no assumptions about how it is formed), can be supported by a kinematical consideration. It can be shown that the above formula can be made plausible also by asking the condition that a neutron and a proton leave the interaction region with a relative momentum, which

Table II. The (deuteron/proton) ratio in the lab system at 15.9° in pp collisions with 25-Gev primary energy.

Momentum of d and p in Gev/c	$\Omega_d = \frac{1}{5}$	$\Omega_d = \frac{1}{10}$	Experiment p-Al[a]
2	0.002 %	0.001 %	approximately
4	0.6 %	0.3 %	constant, 2 %,[b]
6	2.8 %	1.4 %	between 2.6 and
8	7.8 %	3.9 %	5.5 Gev/c
10	8.2 %	4.1 %	

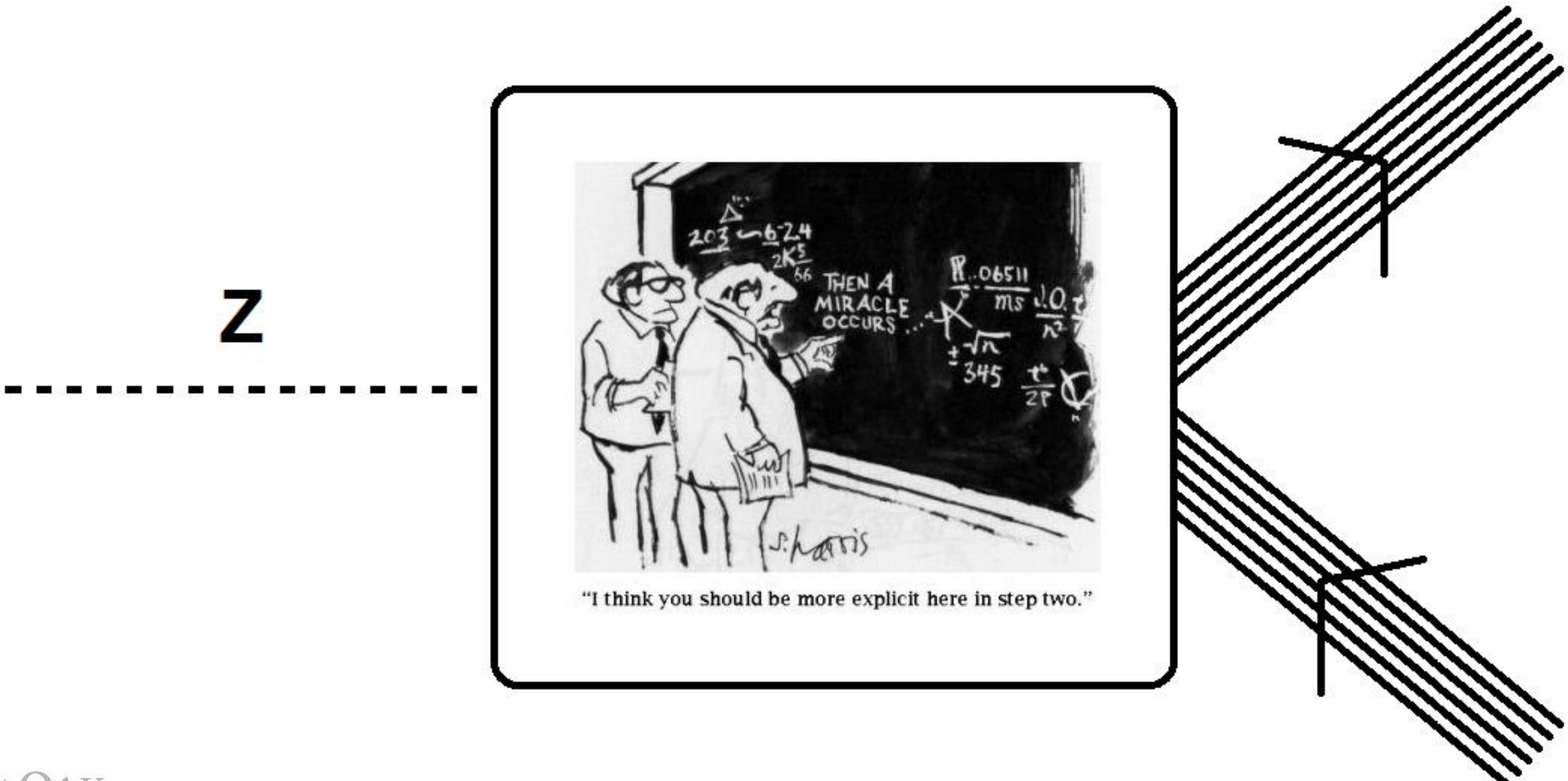
[a]See reference 1.
[b]Note that the experiment refers to p-Al collisions and the theory to pure p-p collisions.

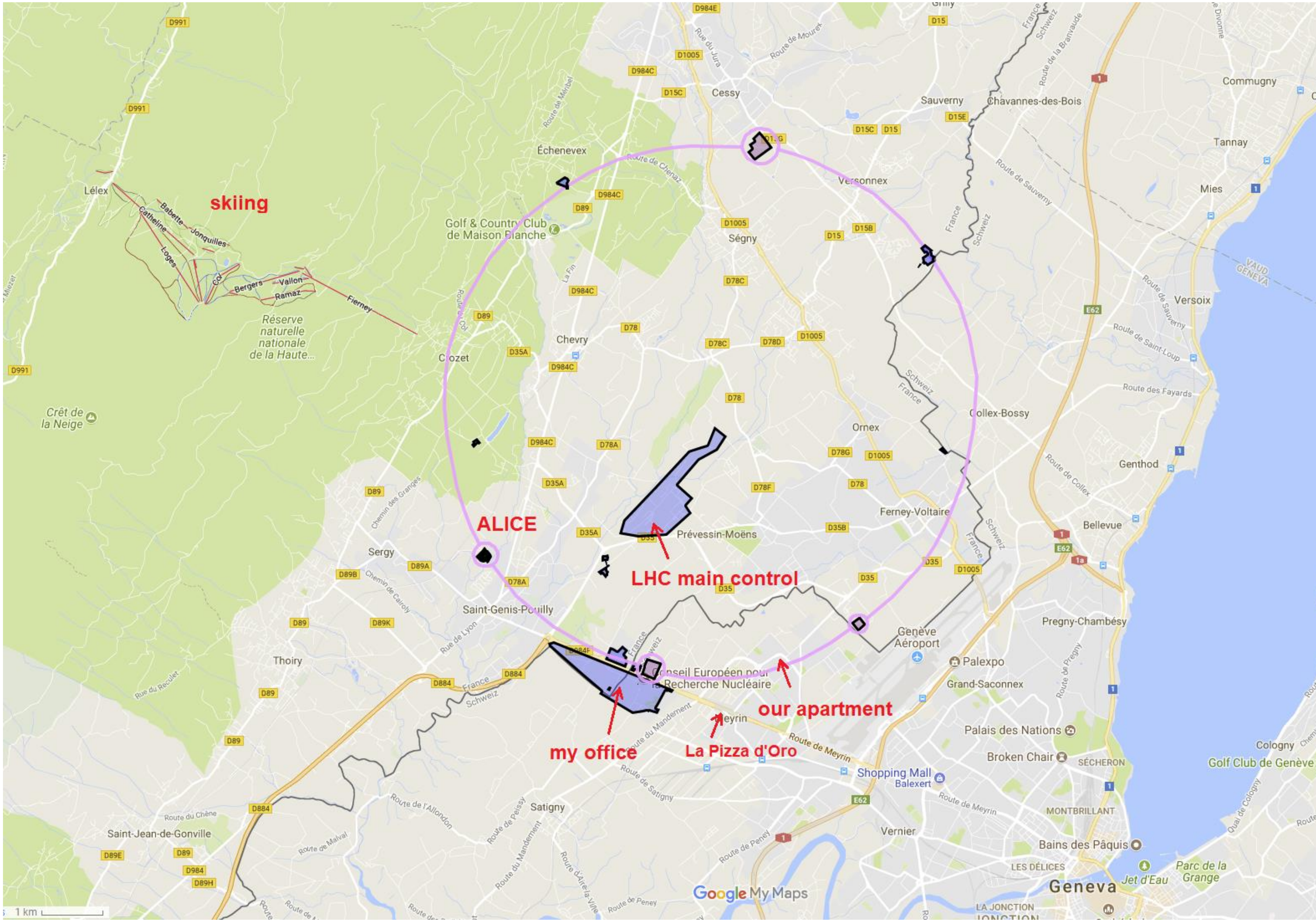
will be explained elsewhere. Even a detailed final-state interaction treatment[6] leads back to essentially the statistical formula with Ω_d as in (3). The phase-space integrals are computed rigorously (apart from the statistical errors of a Monte Carlo method[7]). All computing work was done on Ferranti-Mercury computers[8] (partly by the author but) mainly by Dr. W. Laskar, University College, London. The author is very grateful to him for not only carrying out the machine runs but also writing up all data tapes.

Many thanks are due to the University College, London, for offering computing time on their Mercury, to Dr. J. von Behr, CERN, for transforming the c.m. spectra to the lab system, and to many colleagues for discussions, in particular to J. von Behr, G. Bernardini, F. Cerulus, G.

Z -> d-d   Phys. Lett. B 639, 192 (2006).

alternatives to the coalescence model….?




skiing
ALICE
LHC main control
our apartment
my office
La Pizza d'Oro